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MONITORING AND CONTROL SYSTEMS FOR EXPERIMENTS AT ELI-NP

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Abstract. The current TDR describes the requirements for the experiments taking place in areas E1-E8 of the ELI-NP facility, in terms of monitoring and control, specifying input/output signals, estimated data fluxes, storage necessity, synchronization, vacuum control and monitoring, reliability, maintenance, integration with subsystems and other transverse needs. Based on this information, follows the design and implementation details of a modular architecture that will fit the ELI-NP starting needs and will permit further development.

Key words: ELI-NP, control for experiments, data fluxes, synchronization, storage, modular architecture.

1 ELI-NP SYSTEMS GENERAL OVERVIEW

The Extreme Light Infrastructure - Nuclear Physics (ELI-NP) facility will host two major systems: the High Power Laser System (HPLS) and the Gamma Beam System (GBS). The HPLS will be able to deliver six optical laser outputs: 2 beams of 0.1 PW with repetition rate of 10 Hz, 2 beams of 1 PW with repetition rate of 1 Hz and 2 beams of 10 PW with a repetition rate of 1/minute. The GBS will deliver gamma-ray beams with energies up to 3.5 MeV (low-energy) and 19.5 MeV (high-energy), respectively [1]. These two systems will be delivered with their own control system framework, the HPLS/GBS Control Systems. They will also include their own Machine Protection System (HPLS/GBS MPS) in order to avoid any damages caused by abnormal modes of operation and safety systems. To transport the laser outputs to one of the 5 experimental areas (E1, E6, E4, E5, E7), a Laser Beam Transport System (LBTS) system including its own control system will be provided. A similar system for the transport of the gamma beam will be implemented – GBDD (Gamma

Beam Delivery and Diagnostics). The LBTS/GBDD will handle the configuration for the transport of the laser/gamma beam in function of the experiment.

Three main types of experiments are envisaged in the ELI-NP facility: laser driven experiments, gamma driven experiments and combined laser and gamma driven experiments. In order to control and monitor the experiments, dedicated Monitoring and Control Systems are mandatory (EXPs MCS). These EXPs MCS will integrate the control and monitoring of the devices (actuators, sensors and experimental detectors/instruments with their power supplies) that will allow the setting up and running of the experiments in the experimental areas. These devices require slow control signals. The acquisition of data coming from the experimental detectors will benefit of dedicated transmission lines for highest data throughput. The data acquisition systems (DAQs) will be made with specific equipment that will depend on the experiment. These DAQs require fast communication for data output.

A Personnel Safety System (PSS), dedicated to the safety of the people working in the facility shall avoid any risks in term of radiation and optical exposures. This PSS will have to supervise all the others systems and to interlock their operation. In that sense, a radioprotection system will be implemented (levels of radiation will be accessible through detectors installed in the different areas). However, the Personnel Safety System is not the subject of the current TDR that only refers to the experiments control and the interfaces with the other systems.

Machine Protections Systems (MPS) for the components part of the LBTS/GBDD/EXPs MCS will be developed in order to guarantee their integrity. This will maximize operational availability by minimizing down-time (quench, repairs) and avoid expensive repair of the equipment. A key network within the ELI-NP facility is the timing/synchronization and tag network that will be used at the identification of the laser/gamma shot number and synchronization within the experiment. This network is foreseen to be composed of the HPLS Timing System (HPLS TS) that ensures the triggering and/or synchronization of the different laser driven experiments with the HPLS and the GBS Timing System (GBS TS) that ensures the triggering and/or synchronization of the different gamma driven experiments with the GBS.

All the equipment described above will be installed within the laser building and the gamma and experiments building. Three other buildings (Office, Laboratories and Workshops, and Guest) complete the installation. The Building Management System (BMS) will manage these five buildings for general purposes. The BMS system will be interlocked with the Personnel Safety System as the first one commands the experiments doors position and state while the latter will integrate the procedures for operation and logic. The BMS will handle building specific information like: CO_2, O_2 monitoring, fire alarms, access levels, etc. Work is being done to define the access modes in the experimental areas and associated procedures. Regarding the emergency situations, an evacuation plan and the necessary procedures will be developed by the designer of the facility. In the situation of electricity blackout, the facility benefits from UPS systems and a power generator in order to handle the critical or sensitive equipment.

The scheme below summarizes the general systems in the facility:

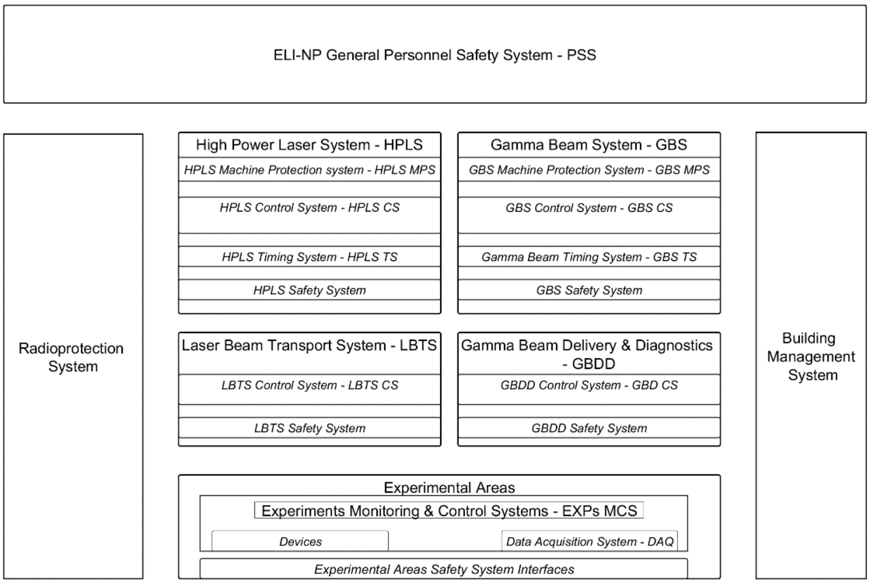

Fig. 1 – Schematic block overview of the ELI-NP systems.

The current Monitoring and Control System technical proposal describes the architecture and the design approach for the slow signals required to monitor and control the experiments, equipment synchronization with the machines and data storage. By slow signals we refer to parameters/configurations that do not need a deterministic communication. All the parameters and actions that need a fast response or feedback need to be implemented in real-time systems or with embedded logic. The synchronization between the HPLS and the GBS will be done in a later stage and the link between GBS and HPLS is envisaged to be made exclusively by hardware means for synchronization and native software TANGO - EPICS interface for system state communications.

The proposed architecture for ELI-NP experiments monitoring and control systems is based on a client – server architecture as will be detailed in the following section. A couple of software frameworks will be developed in TANGO and EPICS for the implementation of the standardized communication bus, data packet exchange and communication protocol between the devices in the experimental areas and the users which will drive the experiments.

The following sections will focus only on the EXPs MCS and their interfaces with the others systems described above. Moreover, a specific section in the “System Implementation” will describe the proposed timing/synchronization and tag network that will ensure the timing distribution within the facility. An in more detail description of the LBTS/GBDD systems and safety systems approach is also presented in the sections below.

2 INTRODUCTION

The ELI-NP facility is anticipated to have a modern implementation of a distributed monitoring and control system (MCS), as used in any research facility. The entire monitoring and control system architecture will be implemented on a standardized architecture (TANGO/EPICS) with various hardware ranging from commercially available devices (PLCs, PCs, etc.) to specific apparatus that will be designed to fit ELI-NP research purposes. Specific monitoring, control and graphical user interfaces are foreseen to be implemented in National Instruments (NI) LabVIEW and Matlab in a fast manner as they permit integration with the above mentioned standards. Also, different controls in the experiments may be developed into LabVIEW due to the easiness it provides for non-programmers and ability to develop applications in a short time. The backbone of the MCS infrastructure will be fiber optics for both slow control and large data fluxes intended for storage and for long distance communication. The network connectivity between network’s backbone and equipment will be made using Category 6 (Cat6), Category 6a (Cat6a) and fiber optic (FO) standards for network cabling. To ensure the protection and stability of the MCS network, servers and gateways will be used to provide data access between the internal network and the outside ones, as also suggested in Ref. [2]. The ELI-NP facility will have a dedicated major control system for the HPLS, developed in TANGO and a second dedicated control system for the GBS developed in EPICS. For the building management (doors access, HVAC, safety, fire, etc.) the BMS will integrate, acquire, log and control all the necessary signals (Fig. 1). In order to implement the personnel safety, the hardware controllers that will come with the BMS and will handle the door interlocks will be controlled further on by the PSS of the ELI-NP facility. Three separate control rooms will exist, each for the BMS, HPLS, and GBS where the proper equipment will be installed for monitoring and controlling the building, the HPLS and Gamma Beam system, respectively. Additional safety system access panels will be available in the HPLS control room and GBS control room to integrate the safety procedures and signals (interlocks, radiation, etc.).

The proposed experiments will have specific detection, monitoring and control equipment that will be remotely controlled, through a distributed system, from two areas of the building: the “Data Acquisition Room” (DAqR) and “Users Room” (UsR). Moreover, in the DAqR and UsR, displays are needed to provide to the user the necessary parameters of the major equipment (HPLS and GBS) and from the BMS. This architecture will be client – server based, where the monitoring and control clients together with displays will be in the DAqR and UsR.

The proposed architecture for ELI-NP experiments monitoring and control systems is based on distributed, local control of the experiment and additional client to remotely control/supervise each experiment. Each of the eight ELI-NP experimental areas may house different number of experiments, each with its own apparatus for detection, monitoring and control of the experiment. Each detector, monitoring system or other similar apparatus from the experiments will have to save necessary information and data through a very high speed data bus (*e.g.*, Gigabit Ethernet or 10 Gigabit Ethernet). For this, a storage solution offering high availability and high throughput is envisaged. Each of the experiments will have a dedicated storage quota. The experimental data storage and transmission will benefit in general from dedicated data busses, as depicted in Fig. 2, separated from the MCS bus that controls and monitors the equipment itself, in order to achieve the highest data throughput. This data will be available from the DAqR and UsR clients for various usages, as presented in Fig. 2.

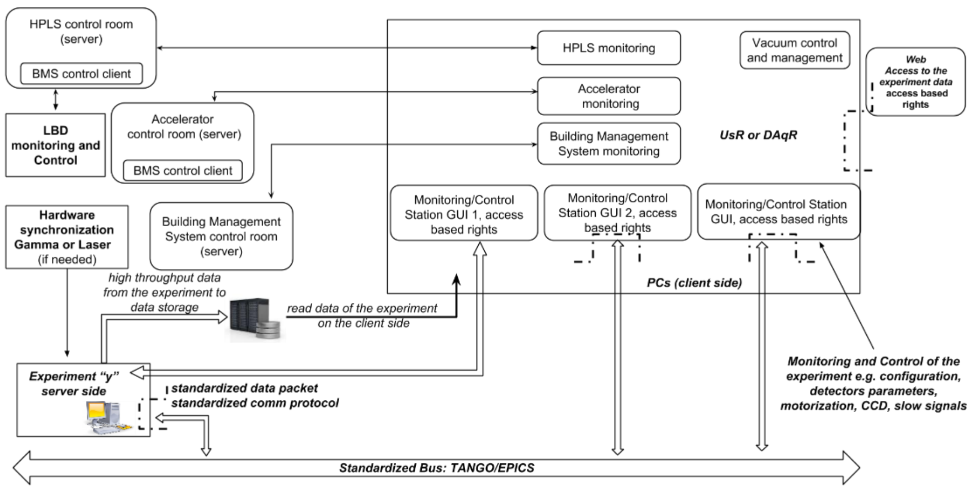

Fig. 2 – General block architecture for Monitoring and Control of experiments in the ELI-NP facility.

For each experiment, a number of detection equipment is envisaged, that needs to be monitored and controlled remotely from DAqR and UsR that both lie at more than 100 m away from the experimental area, where the experiment is taking place. For this reason, a localized control of the equipment associated with an experiment is necessary for making calibrations, adjustments, maintenance, etc. through different Human Machine Interfaces (HMI). In the case of the running experiment, due to radioprotection issues and functionality of the infrastructure, the users will control and monitor the experiment only from the DAqR or UsR. The same HMI may be used to access the equipment, however, multiple access levels will be implemented.

For each experiment, a distributed monitoring and control of the apparatus will be needed. The user, based on different security access levels (*e.g.*, SuperUser, User, Guest), must have the ability to locally configure the devices in the experiment for calibration, maintenance and any other required parameters. The local control will be in general an industrial PC connected by various interfaces (*e.g.*, Ethernet) to all the other equipment like detector electronics. Each equipment will have its own HMI that must communicate with the local control by software Application Programming Interfaces (API) or hardware means. From the software point of view, the communication implies that the API of the equipment to be available and able to communicate with the local control HMI. The MCS framework will be based on TANGO or EPICS, function of the controlled area, as described later. Depending of the chosen standard (TANGO or EPICS), the framework will afterwards be ported in all the experiments to obtain the client – server communication. This approach will allow to manage remotely each experiment from at least one client. TANGO will be the control system software for the high power laser based experiments, while for the gamma based experiments, EPICS will be used. In the HPLS based experiments, multiple TANGO frameworks will be developed, each for one experiment, for reasons related to redundancy, safety and better maintenance. In the case of the GBS based experiments, one EPICS framework will handle the entire experiments, as its native architecture has the redundancy already implemented.

The motivation for choosing this approach lies in the characteristics of the architectures:

In the TANGO architecture, a central database is needed to handle all the devices. Redundancy should therefore be implemented to be sure that if the database crashes, another one takes its place. The database must be active at the start-up of the entire system to map each device server (each device in the network). If maintenance is operated in the database, the system cannot be used (the devices cannot access the database and, at the same time, they cannot be accessed through the database).

The above mentioned ported framework has some advantages. From the safety point of view, each experiment has its own server – client communication that does not interfere with the others. In the eventuality of a failure, there is only one area under maintenance while the others can operate. The same goes for upgrade procedures. The use of the same framework for all the experiments will ease the implementation process and the maintenance ones but with increased costs.

In comparison to TANGO, in the EPICS architecture, each device has its own database and therefore redundancy is not needed. A central database can also be implemented but this will not affect the functioning of the devices that are in the network.

For each experiment, in the UsR and DAqR there will be at least one client PC and at least one display to show the information of interest to the user. The UsR and DAqR will also house clients that will show the information of interest from the BMS and from the two major equipment: HPLS and GBS. The LBTS technologies (*e.g.*, motorized mirrors, alignment, polarization control and adaptive optics) will be controlled from the HPLS control room by the operators due to the fact that these technologies affect the pulse parameters on the target. The scientists will not be allowed to directly control these parameters as improper handling can cause the malfunction of the entire system. In order to change the parameters of the laser pulse, requests will be issued to the operators, in the HPLS control room. Because the LBTS has to deliver the 10PW laser pulses of the HPLS to the experimental areas and has to be operated in correlation with the HPLS, the control and monitoring architecture is envisaged to be also based on TANGO. This is schematically shown in Fig. 3.

For the case when equipment associated with an experiment needs to be synchronized with the HPLS or GBS, the synchronization will always be hardware based, in order to ensure the speed, required deterministic operation and avoid software glitches. However, the synchronization hardware must feed in this case to the UsR or DAqR information regarding the synchronization status or whatever information is considered necessary. This will be implemented using the same adopted standard (EPICS/TANGO).

The doors system of the experimental areas, which is connected to the BMS, will be supervised by the PSS and interlocked in such way to provide a safe operation of the facility. The central supervision system of the BMS should be able to be programmed to acquire/log the information from all the sensors/door states and send audio-visual panic signals to the users or even intervene in case of necessity (*e.g.*, automatic fire extinguish).

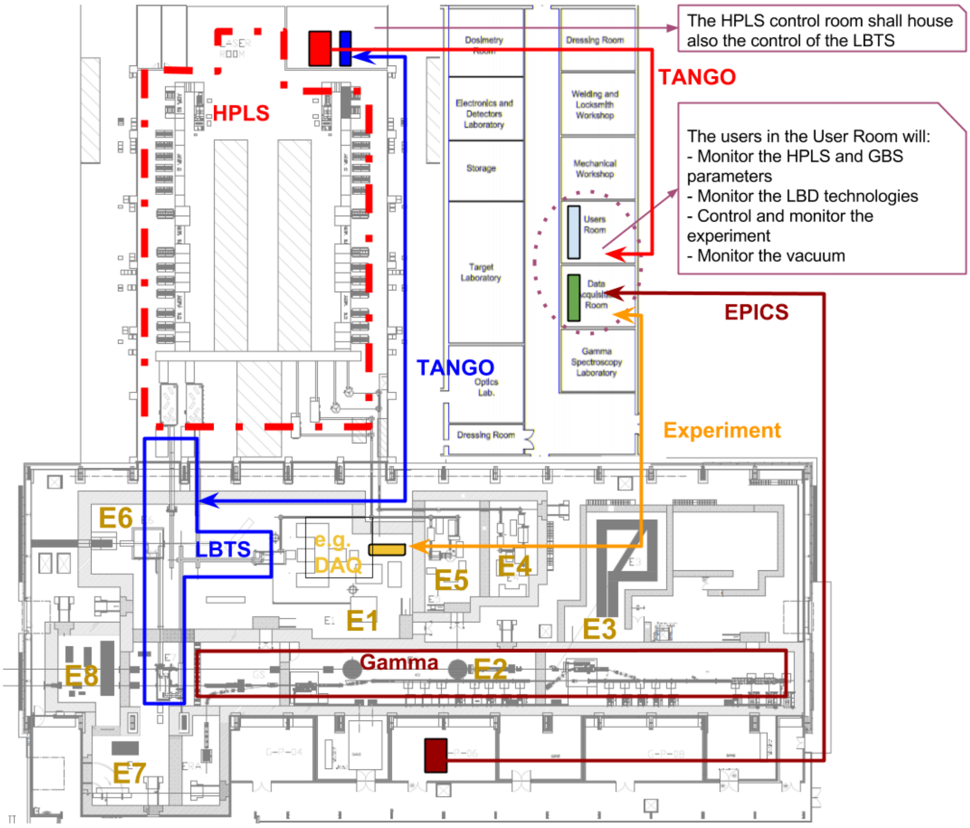

Fig. 3 – Schematic diagram of the TANGO and EPICS controlled systems: HPLS, LBTS and GBS, and connection to the UsR and DAqR.

The vacuum system for the HPLS and GBS will be in each tender's assignment. For each vacuum system, the parameters will be controlled from the corresponding control room. The vacuum system for the LBTS system will be controlled via the LBTS Control System. The central control supervision post of the LBTS will be placed inside the control room of the HPLS. The architecture for the vacuum control is based on PLCs and a master – slave connection will be used in order to ensure the supervision [3]. This will also allow the implementation of safety procedures that will not allow the users to use the pumps or vanes in a way that can damage the devices.

The contents of the paper are presented below. On the right side there is the main equipment that is linked to the experiments and with the building systems (BMS, PSS, and Radioprotection). The experiments requirements will be described, followed by the system design and implementation.

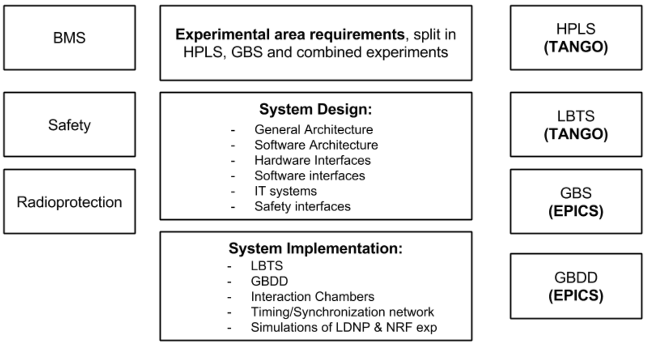

Fig. 4 – Contents organization of the TDR depicting the requirements, system design and implementation along with the additional building and main equipment systems.

3 GENERAL SYSTEM REQUIREMENTS

As presented in Ref. [4], a definite requisite of an experiment's architecture is scalability, which can be achieved through distributed computing and control. By replacing a centralized operation with a distributed one, the usual limitations for system resources (*i.e.*, computing power, hard-disk space, and memory) are eliminated. Adding more resources into the architecture becomes also less costly. However, as the experimental setups often change for a user facility like ELI-NP, on the supervision side that controls and manages the entire experiment, various centralized state machines can be implemented, that will coordinate the equipment actions in an autonomous and predefined way. The reliability is paramount for user facilities and redundancy is therefore necessary in order to ensure reliable data storage and maximum beam-time for experiments. Given these aspects, it is envisaged that for each experimental area of ELI-NP to use industrial PCs with redundant power sources. The advantages of these PCs in comparison to standard desktop computers are amongst others, better tolerances to shock/vibration, enhanced EMI filtering and gasketing, and higher grade power supply. Also, better expandability, durability and easier access to the inside make them better candidates to environments such as experimental areas. In addition, distributing the system to distinct control nodes is important for reliability as well as scalability. If a local control node for an experimental area fails, it will not be affecting the operation of the rest of the areas. For this reason, each experimental area is envisaged to have its own control system equipment for controlling/monitoring the devices, along with a distributed control system inside the experiment. Ideally, in the case of an unexpected node failure, spare resources should be available to rapidly shift the applications from the failed node. In this situation, the distributed control shows an advantage, also in correlation with virtualization servers.

The control network of the experiments and HPLS or GBS must be safe of any intrusion, as also presented in Ref. [4]. This can be achieved by separating the control network from internet. Access security needs to be provided through either code access security, VPN, using permission tables or role-based security implementations [2]. The access from the outside world to the monitoring and controlling tools for the experiments will be done through secure network connection, using solutions such as VPN or secure protocols like https, based on digital certificates.

Due to the ELI-NP environmental constraints (various pipes, radiation, EMP, etc.), some hardware might not be fitted in the desired areas. This means that the control nodes that have to be used within the experimental areas have to be compact, reliable and should fit in places that are as much as possible protected by the radiation and EMP sources. As also pointed out in Ref. [4], high energy radiation is known to deteriorate the transparency of fiber-optic cables and special shielded cables should be used in specific areas.

In order to operate in safe conditions for all personnel, a facility must have a dedicated safety system. This system must use dedicated hardware, following the safety standards and must be interfaced with the other systems and equipment in the facility. All protected areas (laser rooms, gamma rooms) and experimental areas must have a radiation protection system linked with a safety system with dedicated hardware (panic buttons, safety PLCs, checkboxes, interlocks, etc.) that is able to allow or block the access based on clear procedures. The Personnel Safety System of the facility must interface all the other subsystems in the facility that protect the personnel and the entire system must be built in a unitary way.

The control hardware or software library used in the implementation of the control system architecture should be compliant to the highest possible extent with third party tools. In this way, preexisting equipment can be easily integrated into the architecture. TANGO – EPICS – LabVIEW translators are envisaged as a multitude of equipment have drivers already implemented for one of the above mentioned control system architectures.

In order to have a good management and a low maintenance, due to the fact that the ELI-NP facility will house 8 experimental areas, each will have its own control system equipment. The hardware systems inside each experimental area (PCs for control, protection racks for experimental area equipment, data storage systems) that integrate the specific detection systems are envisaged to be standardized and similar equipment to be used, in order to provide quick replacement and shorter training periods. Moreover, having separate equipment for each experimental area, one experimental area can enter in maintenance mode, while the others can still function during the period of system upgrades.

4 HIGH POWER LASER BASED EXPERIMENTS REQUIREMENTS

In the following schematic, it is highlighted in red the building layout where the laser experiments are taking place (E1, E6, E4, E5 and E7).

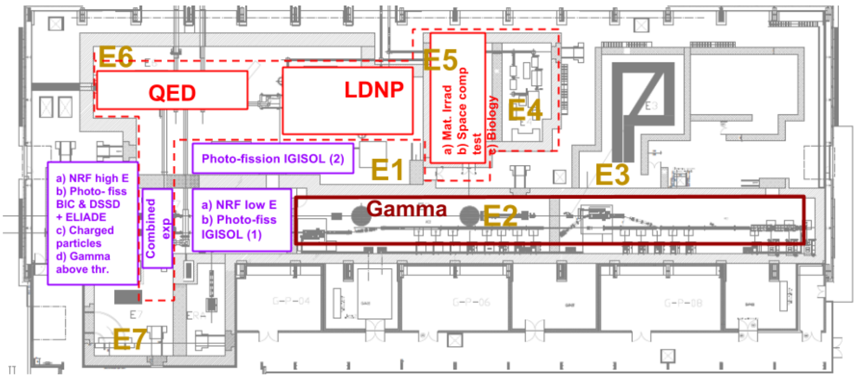

Fig. 5 – Building layout highlighting in red the laser based experimental areas (from left to right): E6, E1, E5, E4 and E7.

In the following subsections, the requirements in terms of experimental equipment are presented for each area.

4.1 EXPERIMENTAL AREA E1

In the E1 area, Laser Driven Nuclear Physics (LDNP) and gamma induced experiments will be performed.

4.1.1 Beam parameters

The laser beam requirements for the experiments are: 10 PW, 1 and 2 beams configurations, short focal, circular polarized laser beams.

4.1.2 Target systems

For the targets of the LDNP, the specifications are as following [5]:

Solid targets with thicknesses of tens of nm for RPA acceleration technique, hundreds of nm for BOA and tens of μm for TNSA are needed to be used. The total dimensions of the wafer can be 100 ×100 mm^2. Gas targets will be used as secondary (plasma) target. Liquid targets are also considered, but later in the development stage. For the thin targets, the wafer technology is being considered, with the targets being manufactured from SiN in a circular wafer with 100 mm diameter. An alternative solution will be metallic depositions – *e.g.,* Au on Si or DLC foils and polymer foils. Thorium targets are to be used later in the development schedule. The holders for solid targets need to have a standardized design, in order to ease the usability of the targets in multiple target systems and experimental setups.

Manipulation drive systems are required, both in-chamber and outside, for alignment. The accuracy of these has to be 0.25 μm in positioning on the *x*, *y* and *z* axes and 1 mrad in angular rotation. High resolution microscope optics are required in-situ within the interaction chamber (IC), for accurate positioning of targets. A target alignment station with high resolution microscope optics for off-line positioning in *x, y, z* and θ is also needed. The manipulation drive system and alignment optics will be part of a Target Alignment System (TAS). In order to achieve a high repetition rate with solid targets, a Target Insertion System (TIS) with load lock is compulsory. The solid target needs to be furthermore synchronized for precise positioning before laser shot and also cleaned from impurities on surfaces.

4.1.3 Timing/Synchronization systems

For the LDNP experiments, the CCD cameras from the detectors need to be synchronized with the HPLS pulse. This requires gated signals. Delay generators are needed to tune the value of the delay. The HPLS trigger signal should come with approximately 100 ms before the laser pulse and the HPLS needs to provide the burst mode (selectable number of pulses) to run the experiments. The data generated by the detectors and stored in the data storage must be correlated with the laser shot in a unique way.

4.1.4 Detector and DAQ

The laser driven experiment requires a number of detection equipment, as described in Ref. [5] and depicted below (Table 1). $LaBr_3$, plastic scintillators and Ge detectors will need to be developed. The CCD cameras will need a fast trigger signal (correlated with the laser shot). A delay generator will be needed in this way to be synchronized with the laser pulse and to adjust the gating signal. The delay generator parameters needs to be remotely controlled in order to fine adjust the settings from the UsR/DAqR.

For the $LaBr_3$, plastic scintillators and Ge detectors, digitizers need to be triggered, while the trigger delay is not an issue (orders of ± 100 ns the jitter value are reasonable, with acquisition based on digitizers). Each shot with the HPLS will need to be correlated with the beam diagnostics data and other relevant information and this has to be available in the UsR/DAqR. Additional, a hardware signal may be necessary from the GBS, in order to determine if perturbations/background occurred and if the data must be analyzed differently. The mass spectrometer and recoils spectrometer needs to be designed (Table 1). They will employ high current sources with control, slits, diagnostics, and cooling water.

The gas needed for the gas filled recoil spectrometer needs to be monitored/controlled from the UsR/DAqR. A tape transport system from the decay station will also be available and it has to be controlled and monitored from the UsR/DAqR. Motorized stages (order of tens) will also be needed to be controlled and monitored from the UsR/DAqR.

Table 1

Status of the development of the detectors and associated requests.

Device	Stock components	Needs monitoring in UsR/DAqR	Needs control UsR/DAqR
LaBr3 detectors (PMT)	To be designed	No	No
Plastic Scintillators (PMT)	To be designed	No	No
Ge detectors – high-voltage control but local	To be designed	No	No
Gas filled recoils spectrometer (laser induced experiments) – later design full control	To be designed	Yes	Yes
Tape transport system (decay station) – full control, to decide the equipment first, dedicated equipment for control with interfaces	To be designed	Yes	Yes
Mass separator (photofission) – dedicated control equipment	To be designed	Yes	Yes
Laser Ion source (photo-fission) same as above	To be designed	Yes On/Off signal	Yes On/Off signal
Multireflection trap/Penning trap	To be designed	Yes	Yes
Delay generator (laser induced experiments)	Yes	Yes	Yes
Motorized stages (laser induced experiments)	Yes	Yes	Yes

For the photo-fission experiment that will be performed in E8/E1, a gas cell (ion guide) needs to be monitored and controlled. Moreover, differential pumping of 0.1 atm to 10^{-7} atm is needed. The multireflection trap must have a monitoring/control client in the UsR/DAqR. Regarding the beam diagnostics there will be a detector that monitors the time structure of the beam and will produce logic signals (NIM/TTL) that will be distributed to the experimental setups.

4.1.5 Interaction chamber and vacuum system

The vacuum pumps, gauges and valves will be part of the Laser Beam Transport System and separately for the interaction chamber. The interaction chamber must have a safety system to secure the access to the chamber and must be interlocked with the LBTS for the same reasons. The IC must be controlled during the operation of the laser from the HPLS control room, to prevent any accident and because of the system's complexity.

4.1.6 Storage and data flows

For the laser driven experiments in E1, the following data flows are expected:

Table 2

Data flows expected for LDNP.

Detector type	Front-end	Data size (MB/pulse/ detector)	Number of detectors	Laser Rep. Rate	Throughput (MB/second)	Trigger	Trigger jitter
1) gated CCD 4 Mpixels	USB	8	Less than 5	0.01 - 10 Hz	less than 400	External, synchronized with laser pulse	0.1 ns
2) $LaBr_3$ with PMT	Digitizer w/o PSA: more than 400 MS/s, 14 bits (trace of few ms)	1	10	0.01 - 10 Hz	less than 100	External, synchronized with laser pulse	0.1 ns

	Digitizer with PSA: >400 MS/s, 14 bits (gamma time and energy in-between laser pulses)	n/a	10	n/a	less than 0.4	Internal: threshold on amplitude, OR External: from a CFD	
3) plastic scintillator with PMT	Digitizer w/o PSA: more than 1 GS/s, 12 bits (trace of few μs)	0.01	10	0.01 - 10 Hz	less than 0.1	External, synchronized with laser pulse	0.1 ns
4) Ge or $LaBr_3$ detectors for Decay Station	Digitizer with PSA: 100 MS/s, 14 bits	n/a	8	n/a	less than 0.1	Internal: threshold on amplitude, OR External from a CFD	
	TDCs (for fast-timing experiments)	See requirements from gamma spectrometry with gamma-beam					

The data output from the detectors must either be stored on a dedicated storage server or on a PC near the experimental area. Part of the data must be sent in the UsR/DAqR for online experiment control. The requirements for the experiment, in terms of usable storage capacity, for short term period (6 months) is 70 TB.

4.1.7 EMP

For proper operation of the equipment and to prevent the malfunction of the apparatus when the experiments are running, the electronics and other sensible equipment must be electrically shielded and placed as far as possible from the EMP source. The electrical signals must be filtered to the largest possible extent and FO used to minimize the EMP background generated during the experiment.

4.1.8 HMI, clients and supervision

The users' access on the clients monitoring system (UsR/DAqR) to the experiment supervision and control (on the E1 area side) will be based on various security levels. Other clients (configuration or control) may have the right to configure in depth specific parameters. For the equipment that cannot provide interfaces with the general control system architecture, a remote desktop connection can be used to access remote the parameters of the apparatus, in the UsR.

4.1.9 Safety system interfaces

An experimental area safety system must exist to handle the access door interlocks, other interlocks, panic buttons, check boxes, shutters, etc. and this must be interfaced with the ELI-NP PSS.

4.2 EXPERIMENTAL AREA E5

In the E5 area, multiple experiments are programmed to be implemented, like materials irradiation, biology and space science research, as presented in Ref. [6].

4.2.1 Beam parameters

The beam requirements for the experiments are: 1 PW, 1 and 2 beams, linear and circular polarized laser beam, long and short focal configurations.

4.2.2 Detector and DAQ

The equipment envisaged for the materials irradiation experiments are described in the table below:

Table 3

Equipment requirements for the Materials irradiation experiments.

Device	Comments	Development for device	Local control software	Bus
Pyrometer (ns scale integration time)	Outside the inter. chamber	Custom	TANGO/LabVIEW/ RemDesktop	TANGO/RemDesktop
Streak camera	Outside the inter. chamber	Exists	Proprietary	Remote desktop
Focusing optics motorization	Inside the inter. chamber	Custom	TANGO/	TANGO/RemDesktop
VISAR	Outside the inter. Chamber.	Exists	Proprietary	Remote desktop
Ion spectrometer	Inside interaction chamber	Custom	TANGO	TANGO

Electron spectrometer (E to be defined, more than 100 MeV)	Inside interaction chamber	Custom	TANGO	TANGO
CCD cameras	For manipulators	Exists	LabVIEW/TANGO	TANGO
Cryostat, temperature 4 K	Needed for probe mount cooling	Exists	TANGO/EPICS/proprietary	TANGO/RemDesktop
Precision motorized manipulator, 1 µm steps, at least 2 degrees of freedom (rot. and translation)	Needed for probe handling.	Custom	LabVIEW/TANGO	TANGO
Gas jet system	For accelerated particles production (electrons, neutrons)	Exists	LabVIEW may be possible	TANGO
Min 10 motorized stages, 2-3 degrees of freedom	Inside the interaction chamber to move the probes inside the interaction chamber.	Custom	LabVIEW/TANGO	TANGO
Target feed system with intermediate vacuum chamber	Automatic target feeding system into the interaction chamber, with intermediate vacuum chamber not to ventilate the interaction chamber	Custom	LabVIEW/TANGO	TANGO
Radiochromic films - consumables	Offline detection	-	-	
Imaging plates - consumables	Offline detection	-	-	
Heating stages	Needed for probe heating			
Probe beam for X ray online diagnostics	The second 1PW beam can be used for this	Custom	TANGO	TANGO

The detection is accomplished with the Pyrometer, Streak camera, Visar, Ion and Electron Spectrometers and with the probe beam. The data from these devices has to be stored on a local PC with timestamp. For the devices that have their own software application that cannot be interfaced with TANGO/EPICS/LabVIEW, a remote desktop connection will be used to monitor de data and interface with the equipment. For the biology and space science related experiments, the same equipment as described above can be used. The requirements for the experiment, in terms of usable storage capacity, for short term period (6 months) is 70 TB.

4.2.3 HMI, clients and supervision

The devices that have to be controlled remotely from the UsR during the experiments are the following [6]:

a) Motorized stages;
b) Manipulator for the radiation generator target;
c) Manipulator for the irradiated target;
d) CCD camera;
e) Cryostat;
f) Heating stages;
g) Gas jet system;

For the devices a), c) and d) that are related to motion and vision, a custom application or multiple applications needs to be built to handle all the parameters on the local control of the equipment (near the experimental area). For devices e) and f) that control the target temperature, a custom application must be also built to handle the parameters on the local control of the equipment (near the experimental area). For devices b) and g) used for particle production, a custom application must be also built to handle the parameters on the local control of the equipment (near the experimental area). The application must be able to permit the selection between the two systems that generate accelerated particles (gaseous or solid) and their parameters. These parameters must be available via the TANGO/EPICS bus in the UsR/DAqR on a second GUI interface.

The applications should permit logging of the state of the selected parameters. For the detection equipment, a software trigger application must exist, to start the data acquisition procedure. Additional, hardware trigger must be implemented, function of necessities, to sync the equipment with the laser shot. For the equipment that cannot provide interfaces with the general control system architecture, a remote desktop connection will be used to access remote the parameters of the apparatus, in the UsR.

4.2.4 Other requirements

The requirements for the targets needed in the materials irradiation experiments are similar to the one of LDNP. Thin and thick solid targets are necessary as primary targets and in addition gas targets are also required [6]. The latter will need nozzles, driver, holder, positioning and alignment. Similar to the requirements described for the LDNP experiments, standardized holders and alignment systems are necessary. In order to benefit from the 1 Hz laser repetition rate, a TIS will be used to insert/extract the target holders from the IC without breaking the vacuum.

The requirements related to timing/synchronization, EMP and safety system interfaces are similar to the ones expressed for the LDNP experiments.

4.3 EXPERIMENTAL AREA E6

In the E6 area, QED experiments will be developed [7]. The requirements are as follow:

4.3.1 Beam parameters

The beam requirements for the experiments are: 10 PW, 2 beams compressed, long and short focal mirrors, circular polarized laser beam.

4.3.2 Detector and DAQ

Specifications of the required diagnostics for X-ray, electron and ion beam spectral and spatial measurements [7] are enumerated below:

- High resolution dispersion spectrometers required for multi GeV electrons and ions (spectral changes expected due to the onset of high-field QED processes).
- High energy (hundreds of MeV) γ-ray spectral measurements.
- Spatially/angularly-resolved measurement of high energy γ-rays.
- Low background detectors required for measurement of positron production.

The required diagnostics of the laser-plasma interaction are depicted below:

- Optical probing using a small portion of the main beam split off, frequency doubled and directed along the target surface to characterize density gradients.
- Measurement of the back-scatter and absorbed laser pulse energy (Optical isolation is required to prevent back reflection causing damaging of laser components upstream).
- Nuclear activation to characterize plasma temperature.

The following detectors are required by the experiments:

- Active detectors, *e.g.,* high dynamic range CCD cameras to image scintillator or phosphor radiation in the dispersion plane of the electron, ion and γ-ray spectrometers.

- All detection systems employed must be characterized for their EMP sensitivity in a high energy laser-plasma environment.
- Passive detectors based on dosimeters film, track detectors, imaging plate etc. Used in single-shot operation mode to cross reference results obtained using the active detectors.

The requirements for the data acquisition systems are as following:

- On-line/real-time analysis of data is required to guide decisions on the next laser shots to be taken.
- Data upload via a central data management system – to enable quick extraction of data over a range of laser, plasma and beam diagnostics.

4.3.3 Other requirements

The targets needed to perform the QED experiments are similar to the ones described for LDNP and materials irradiation experiments. The difference is the need of a capillary waveguide. An injector (LWFA) gas jet with possible counter propagating beam is also required together with x, y, z, θ and φ adjustments for the capillary waveguide. The users' access on the clients monitoring system (UsR/DAqR) to the experiment supervision and control (on the E1 area side) will be based on various security levels. Other clients (configuration or control) may have the right to configure in depth specific parameters. For the equipment that cannot provide interfaces with the general control system architecture, the remote desktop connection will be used to remotely access the parameters of the devices from the UsR. The requirements for the timing/synchronization, data storage, IC and vacuum systems, EMP and safety systems interfaces are similar to the ones described for the LDNP and materials irradiation experiments.

5 GAMMA BEAM BASED EXPERIMENTS REQUIREMENTS

In the following schematic, the gamma experiments areas (E1, E7, E8, E3, E7, Gamma Source Recovery area) are depicted in purple.

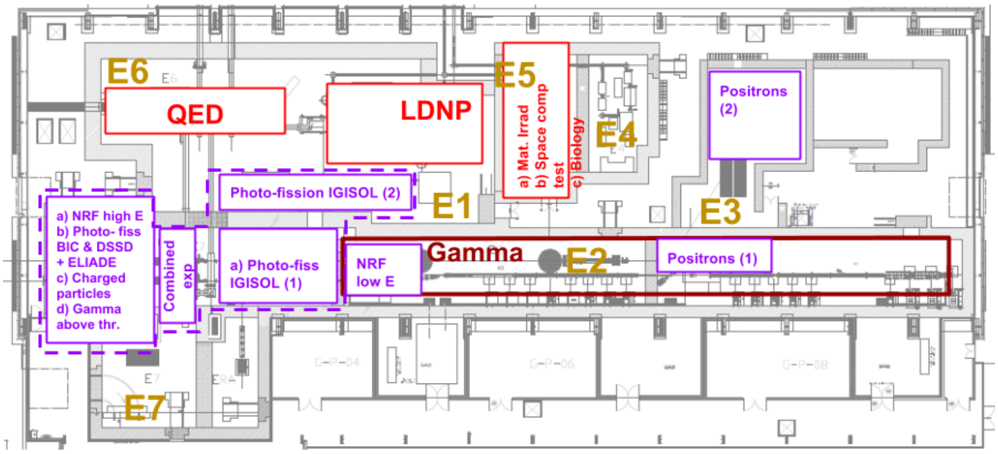

Fig. 6 – Building layout highlighting in purple gamma based experimental areas: E8 (slightly to the left of E7, covered by text), E7, Gamma Source Recovery Area, E1, E2 and E3.

In the following subsections, the requirements in terms of experimental equipment are presented for each area.

5.1 EXPERIMENTAL AREA E2

The E2 area will host the NRF experiments using the low-energy gamma beam [8]. In this case, the detectors are an array of segmented HPGe crystals and $LaBr_3$ detectors, named ELI-NP Array of DEtectors (ELIADE).

5.1.1 Beam parameters

The list of the gamma beam parameters is detailed in the following table:

Table 4

Gamma Beam parameters.

Parameter [units]	**Value**
Photon energy [MeV]	0.2 – 19.5
Spectral density [photons/s/eV]	> 0.5 10^3
Relative bandwidth [%]	< 0.5
Peak brilliance [photons/s·mm2·mrad2·0.1%bwd]	10^{20} – 10^{23}
Macropulse repetition rate [Hz]	100
# micropulses per macropulse	32
Duration of micropulses [ps]	0.7 – 1.5
Micropulse–to–micropulse separation [ns]	16
Linear polarization [%]	> 95

These specifications shall be taken into account for all the gamma based experiments. However, the experiments planned in E2 area will use the low-energy beam with the gamma rays characteristics of less or equal than 3.5 MeV, and with a relative bandwidth of less or equal than 0.5%.

5.1.2 Target systems

The Target systems regroups two main sub-systems [8].

The first module consists of a pipe, called CCD black box, and contains a scintillator, a lens and a mirror. The latter are fixed on the internal side of the pipe. The CCD black box is installed on a stage that can be moved with motors with 3 axes movement (*x*, *y*, and *z*). The CCD black box with the motors forms the target alignment system, belonging to the GBDD system.

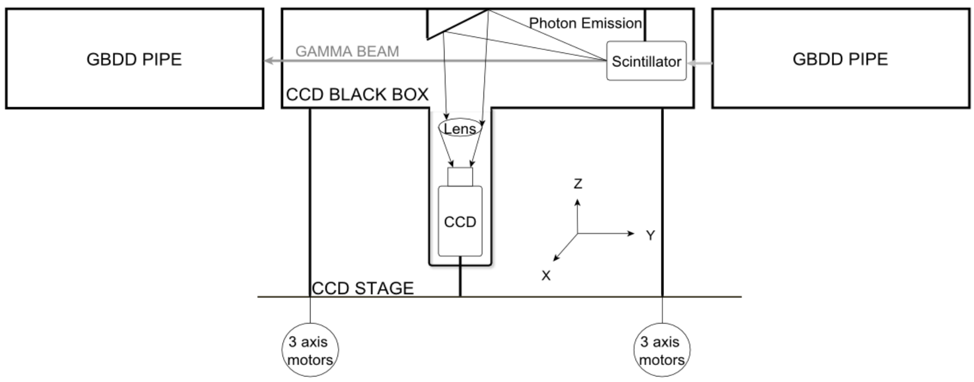

Fig. 7 – Scheme representing the target alignment system used in the GBDD system.

Regarding the CCD camera, the control system will ensure the trigger of the CCD camera, image acquisition and storage of theses image on a computer that will perform the image processing. The storage of the processed images in a dedicated data storage location has also to be taken into account. After processing, the images shall be displayed in the UsR. The control system has to provide the means to interact with the image (cursors, spatial profile of the beam, statistics, etc.). The motorized stages require to be controlled remotely in the UsR.

The second system is composed by the ELIADE Interaction Chamber (ELIADE IC) and its contents. This ELIADE IC will always contain one pipe, name collimator pipe, used for the transport of the beam. Two collimators will enable/disable the passage of the beam and the remote control of the position (open/close) of the two collimators is required. A last pipe, called target pipe, contains the target that is manually inserted. It is assumed that this target pipe will be automatically aligned with the collimator pipe.

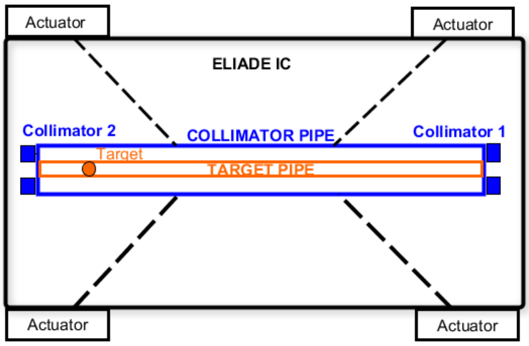

Fig. 8 – Representation of the ELIADE Interaction Chamber with its actuators, collimators, pipes and target.

5.1.3 Detector ELIADE + DAQ

The ELIADE detector is the most complex equipment involved in the experiment. It regroups two mechanical supports, one for the clover detectors and one for the $LaBr_3$ detectors. An array of 8 clover detectors is mounted on the first support and an array of 4 $LaBr_3$ detectors is mounted on the second one. Finally, the ELIADE IC will be fixed on the first support.

ELIADE detectors

A clover detector is composed by 4 High Purity Germanium crystal (HPGe), each of them having 8 segments. The crystals are installed in a common vacuum cryostat as shown in the figure below:

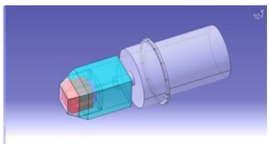

Fig. 9 – Schematic of the clover detector.

The HPGe crystals require the control of two parameters:

- Temperature through 2 Pt-100 sensors.
- Bias voltage through high-voltage power supplies.

To control the temperature of each HPGe crystal, an automated LN_2 filling system is foreseen. It has to keep the HPGe detectors at the temperature of the liquid nitrogen without any external action. The system should enable the monitoring of critical parameters, allow the users to make a minimum set of operations and give the administrator access to the configuration of the system. The crystals are assembled close together with an electric insulation between them which allow them to be operated at different bias voltages. The separate bias voltage for each crystal improves noise immunity and allows operation at lower than the operational voltage should it be needed. The high-voltage power supply shall provide a voltage up to 5000 V due to the specifications of the HPGe crystals. The current high-voltage power supplies are already delivered with their own controller. This latter provides safety interlock signals. However, the control power supply units will be ensured along with the control of the LN_2 filling system by a National Instruments compactRIO equipment.

ELIADE DAQ

The DAQ envisaged for the HPGe crystals is based on the sequence described below. Each HPGe crystal will be read–out by a charge sensitive preamplifier (front-end electronics) requiring a low-voltage power supply. After the preamplifier, a digital readout system enabling to cope the signals from Ge crystals has to be developed. The samples acquired by the digitizers will be read-out by some PCs that will process the data. The processed data will be stored in the DAqR in two separate storage disks in order to have a back-up/recovery feature. The $LaBr_3$ detectors require a similar system for acquiring data. In that case, the front-end detector is the Photomultiplier (PMT) attached to the detector while the front-end electronics is specific to this type of detectors.

Assuming that the ELIADE DAQ front-end will be based on dedicated crates (VME, PXI, CompactPCI, etc.) with digitizers boards that will be accessed by a PC, several parameters are envisaged to be measured and compared to acceptable values. These parameters can be divided between physical parameters and logical parameters. The physical parameters are the temperature, the voltage and the current of the crate. The logical parameters could consist of the status of the computer process unit (run, failure, reset, etc.), watchdog timer and of the board memory (registers and FIFO). At a first stage, the requirements in terms of control are to remotely monitor the physical parameters. In a second stage of development, the control of the logical parameters might be achieved.

5.1.4 Interaction chamber and vacuum system

The vacuum system for the ELIADE IC will fit the following requirements:

The nominal vacuum level should be better than 10^{-3} mbar. A/several vacuum gauge(s) along with its/their controller will enable to monitor the value of the pressure inside the chamber. At a first stage, the pumping will be started and stopped manually. Only a remote monitoring of the vacuum is required. A hardware interface will provide the effective value of the vacuum inside the ELIADE IC to the vacuum system of the GBDD (see section 8.3).

5.1.5 Data storage

As detailed in the technical design report for Nuclear Resonance Fluorescence experiments [8], the bandwidth is evaluated at 80 MB/s after the Event Builder (see section 7.8.). Based on this value, and making some hypothesis about the duration of the experiment and the number of experiment per month, the table below presents the space needed (including an eventual backup of the data) for the storage of experimental data during one month.

Table 5

Estimation of storage required for NRF experiment.

Experiment duration (days)	Number of Experiment / month	Storage duration (months)	Storage Space (TB)	Storage Space with data backup (TB)
10	2	1	140	280

Based on the hypothesis detailed above, a minimum storage space of 300 TB is needed for this experiment.

5.1.6 Requirements summary for area E2

The devices that have to be controlled during the experiments [8] are the following:

a) CCD camera and motorized stages (target alignment system, part of the GBDD).
b) Motorized stages for the collimator pipes.
c) Bias voltage of the HPGe crystals.
d) Temperature of the HPGe crystals (LN_2 filling system).
e) Low-voltage power supply units for the $LaBr_3$ detectors.
f) ELIADE DAQ crates.
g) Vacuum of the ELIADE IC.

For the devices a), a common application will be used for the experiments using the target alignment system. This application will ensure a remote control and monitoring of the devices during the alignment phase. For the devices b), e) and f) multiple custom applications needs to be built to handle all the parameters for a local control of the equipment (near the experimental area). For the devices c), d) and g), dedicated computers running applications based on commercial solutions will be used for a local control.

The remote monitoring and/or control of all these devices will be provided to the user in the UsR. Moreover, these requirements are completed with the ones listed in the section 5 of this document.

5.2 EXPERIMENTAL AREA E3 AND ACCELERATOR BAY 1

Accelerator Bay 1 and E3 areas will be used for positron production experiments [9]. Two types of positron sources will be available. The first source is a converter chamber, the second one is based on isotope (^{22}Na). Each of them will produced positrons beams that will be transported to three experimental setups in E3:

- Coincidence Doppler Broadening Spectroscopy (CDBS).
- Positron Annihilation Lifetime Spectroscopy (PALS).
- Positron induced Auger Electron Spectroscopy (PAES).

The Accelerator Bay 1 will host the gamma-induced positron spectroscopy (GIPS) experiments.

5.2.1 Target systems

The converter chamber has no specific requirements in addition to vacuum systems that are compulsory.

Two types of target manipulators under vacuum are envisaged for the isotope source:
- Two 1 m long linear manipulator for the isotope source.
- Two 5 cm short linear and rotation manipulator for the moderator.

In total, 4 manipulators are foreseen because two chambers will be used (see section 5.2.2). The position (1 axis and rotation) of the isotope source and the position of the moderator (1 axis) has to be controlled.

No specific requirements have been expressed for the CDBS, PALS and PAES.

5.2.2 Positron source interaction chambers and vacuum

No specific control requirements have been expressed for the converter chamber. Two 5-way cross, DN200CF type, are foreseen as vacuum chambers for the experiments using the isotope source. The 1st chamber will contain the isotope source, whereas the moderator will be either in the first or in the second chamber depending on the working mode. An electron gun system will be placed in the 2nd chamber. This system require the usage of power supply that shall be monitored by the user.

5.2.3 Positron beam transport technologies and vacuum

The beam transport can be divided between sections in Accelerator Bay 1 and in E3.

Accelerator Bay 1: focus lens system

This system focuses the positron beams via six electrostatic lenses. The voltage of each lens has to be controlled.

E3: Magnetic switches

Two magnetic adiabatic switches are foreseen. The current approach is the superposition of the longitudinal main field generated by a solenoidal coil with a transverse switching field by a magnetic dipole. The magnetic field of the solenoid coils and dipole magnets has to be controlled.

E3: Beam Profile

A beam profile will be achieved by MCP coupled with phosphor screen. The reflection will be recorded through a view port by CCD camera by the help of 45^{o} mirror. The CCD needs to be triggered. The images acquired by the CCD camera have to be stored on a computer that will perform the image processing. The processed image has to be displayed on a computer in the E3 area and in the UsR. Finally, these images must be stored in a dedicated data storage area.

Vacuum

Fore vacuum and ultra-high vacuum pumps and gauges will ensure the vacuum in the different section of the beam transport. Five pneumatic gate valves (GV) are envisaged:

- 1 after the focus lens system in Accelerator Bay 1, called GV1.
- 1 before the Isotope IC in E3, called GV 2.
- 1 before the CDBS IC in E3, called GV3.

- 1 before the PALS IC in E3, called GV4.
- 1 before the PAES ICs in E3, called GV5.

The vacuum inside the different sections will be controlled by a vacuum control system. At a first stage, these systems will provide a control of the vacuum pump units associated with one section of the beam transport and a control of the valves (open/close) separating these sections. This system shall avoid any differential pressure between effective vacuum and nominal vacuum and the opening/closing of the valves in unsafe vacuum conditions. The vacuum system will provide software and hardware interfaces to the ELI-NP PSS.

5.2.4 Detectors

The table below summarizes the detectors used for each of the 4 experiments.

Table 6

List of detectors for E3 and Accelerator Bay 1 areas.

Area	Experiment	Detectors
E3	CDBS	2 HPGe crystals
E3	PALS	1 BaF_2 with photo-multiplier (PMT)
E3	PAES	No detectors (chambers assembly)
Accelerator Bay 1	GIPS	4 HPGe crystals and 1 BaF_2 with photo-multiplier (PMT)

The control requirements for the HPGe crystals are the same as the ones expressed for the HPGe crystals used in ELIADE. The system used for ELIADE (LN_2 gas filling system and high-voltage power supply, both controlled by a National Instruments compactRIO) could be shared with the GIPS experiment. This is motivated by the fact that only one experiment can be performed at the same time and the rack that will host the National Instruments compactRIO will be movable. The BaF_2 require high-voltage power supplies (3 kV) that shall be monitored.

5.2.5 Interaction chambers and vacuum systems

The experimental interaction chambers are located only in E3. The following tables presents them.

Table 7

List of interactions chambers in E3 and Accelerator Bay 1 areas.

Experiment	Interaction chambers
CDBS	1 IC: 6-way cross, DN160CF
PALS	1 IC: 6-way cross, DN160CF
PAES	4 ICs : - IC no.1: load lock and plasma ion-milling cleaning - IC no.2: sample preparation by e-beam deposition (metals deposition) - IC no. 3: sample preparation by DC/RF sputtering (oxides deposition) - IC no. 4: analysis chamber

For the CDBS IC and PALS IC, the vacuum will be performed by different pump units. A/several vacuum gauge(s) along with its/their controller will enable to monitor the value of the pressure inside the chambers. At a first stage of development, the starting and stopping of the pumps will be manual. A remote monitoring of the CDBS/PALS IC vacuum in the UsR is required.

For the PAES assembly, the vacuum system should have a nominal level of 10^{-9} mbar. The vacuum inside the ICs will be performed by 4 dry backing pumps; 4 turbo pumps (2 of 400 l/s, for the deposition chambers, one of approximately 685 l/s for the analyzing chamber, one of approximately 265 l/s for the load lock chamber), one ion gate pump might be required for the analyzing chamber to reach background pressure of around 5×10^{-10} mbar. A/several vacuum gauge(s) along with its/their controller will enable to monitor the value of the pressure inside the chambers. Because of the complexity of the assembly, a specific vacuum system should be implemented.

For the 6 chambers, hardware interfaces will provide the effective value of the vacuum inside the chambers to the vacuum control system of the positron beam transport.

5.2.6 Requirements summary for Accelerator Bay 1 and E3 areas

The devices that have to be controlled during the experiments [9] are the following:

a) Target manipulator systems for the isotope source chambers.
b) Power supply for the electro gun system placed in one of the isotope source chamber.

c) Power supply units required in the positron beam transport (lens system, magnetic switch).
d) CCD camera for beam-profile, part of the position beam transport.
e) Bias voltage of the HPGe crystals.
f) Temperature of the HPGe crystals (LN_2 filling system).
g) High-voltage of the BaF_2 detectors.
h) Vacuum systems for the 6 experimental chambers.

For the devices a), b), c), d) and g), multiple custom applications are needed to be built to handle all the parameters for a local control of the equipment (near the experimental area). For the devices e) and f) the solution used for the NRF low-energy experiment detailed in the section 5.1.3 of this document could be used. For the devices h), dedicated computers running applications based on commercial solutions will be used for a local control. The remote monitoring and/or control of all these devices shall be provided to the user in the UsR. Moreover, these requirements are completed with the ones listed in the section 5 of this document.

5.3 EXPERIMENTAL AREA E7

Only one gamma driven experiment is envisaged at this moment in the E7 area, a gamma above threshold experiment using the ELIGANT arrays of detectors [10]. The first array is composed by a detection system consisting of 30 – 60 $LaBr_3$ detectors for gamma rays and the second one contains 60 liquid scintillators for neutrons detection.

5.3.1 Target systems

The target should be aligned with the ELIGANT detector. The system that will implement this feature is not designed. The TAS described in the section 5.1.2 of this document is considered also for this alignment.

5.3.2 Detector and DAQ

The NE213 and $LaBr_3$ detectors array requires high-voltage (6 – 10 kV for NE213 type and 0.5 – 1 kV for $LaBr_3$ type). The main requirement is the control of voltage of each detector.

Regarding the DAQ system, a remote monitoring of the crates, similar with the one proposed for the ELIADE DAQ system (see section 5.1.3), is required.

5.3.3 Interaction chamber and vacuum system

No specific interaction chamber exist, but the common vacuum beam-line of the GBDD will be used.

5.3.4 Requirements summary for E7 area

The main requirements for the target alignment system have been already detailed (see section 5.1.6 of this document).

The additional devices that have to be controlled during the experiments [10] are the following:

a) High-voltage power supply units for the NE213 and $LaBr_3$ detectors.
b) ELIGANT DAQ crates.

For these devices multiple custom applications needs to be built to handle all the parameters for a local control of the equipment (near the experimental area). The remote monitoring and/or control of all these devices will have to be provided to the user in the UsR. Moreover, these requirements are completed with the ones listed in the section 5 of this document.

5.4 EXPERIMENTAL AREA E8

In the E8 area, four types of experiments are foreseen [8, 10-12]:

- Photo-fission experiments based on the following type of detectors
  - High efficiency ionization chamber (BIC) and Si DSSD detector system (BIC array and DSSDs).
  - Thick Gas Electron Multiplier (THGEM).
  - ELIADE.
- Gamma above threshold experiments with a 4π neutron detector.
- Nuclear Resonance Fluorescence (NRF).
- Charged Particles experiments based on the following type of detectors.
  - Large area of Silicon Strip Detectors (SSDs).
  - Gas time projection chamber read by an electronic readout (eTPC).

5.4.1 Target systems

For the photo-fission experiments, no specific requirements have been addressed regarding targets. The target must be mounted and fixed in laboratories. For the NRF high-energy experiments, the requirements are the same as the ones expressed for the NRF low-energy experiments.

For the eTPC detector used in the charged particles experiments, the target is the active medium (gas) inside the chamber. The control of this medium is addressed below. For the SSDs, the target has to be placed inside a reaction chamber with a target ladder. In addition, it is foreseen that the vertical position (height) and the rotation of the target can be set before and during the experiment.

5.4.2 Detectors and DAQ

The table below summarizes all the detectors used for the experiments [8, 10-12].

Table 8

List of detectors for gamma based experiments in E8 area

Detector	Experiment	Detectors number
BIC array and DSSDs	Photo-fission	Up to 5 BIC, each coupled with 8 DSSDs
THGEM array		Up to 12 THGEMs
ELIADE	Photo-fission and NRF high-energy	Up to 32 HPGe crystals and 4 $LaBr_3$ scintillators
4π neutron detectors	Gamma above threshold	From 20 to 30 neutrons counters (^3He, BF_3 or ^{10}B type)
SSDs	Charged particles	36 Super X3 silicon-strip detectors (4 strips detector) and 8 QQ3 segmented silicon detectors
eTPC		-

BIC array and DSSDs detectors

The BIC is an ionization chamber containing an active medium (gas). The characteristics foreseen are a mixture of 90% Ar and 10% CH_4 at gas pressure of 1 bar. A local system for gas-recycling is envisaged. This will ensure local control of the flow, temperature and pressure of the gas in the chamber. The filling command along with the temperature and pressure sensors values will form a close loop in order to keep a very high purity degree of the gas. The high-voltage applied between the cathode and the anode of the chamber will also be controlled locally. A remote control must be available for the user in the UsR.

THGEM array detector

This type of detector is also an ionization chamber containing an active medium (gas). The active gas flow envisaged is 5 mbar isobutene. A similar system as the one described for the BIC array will be used.

4π neutron detectors:

The neutrons detectors requires high-voltage (approximately 2 kV). The power supply units delivering this voltage shall be locally controlled and remotely monitored in the UsR.

ELIADE detector

The requirements are the same as the ones for NRF low-energy experiments.

SSDs

Silicon detectors requires bias supply locally controlled and remotely monitored in the UsR.

eTPC detector

This chamber works at low pressure (approximately 100 mbar), the target being a special TPC-compatible gas. A local system for gas-recycling is envisaged, with local feedback and the possibility to monitor the key values and control the functioning remotely from the control room. The gas system with the temperature and pressure monitor will form a close loop in order to keep a very high purity degree of the TPC gas. Moreover the drift-velocity has to be monitored. Finally, the generation of the drift field in the eTPC requires high-voltage power supplies (tens or hundreds of kV). This system has to be controlled remotely. The temperature and pressure monitor is envisaged to be implemented into the DAQ system by the use of a local controller. The gas control system with gas recycling feature for both non-rare and rare gases will be locally controlled. The high-voltage power supply will be controlled with a local controller. Each of the above mentioned devices is envisaged to be remotely monitored and/or controlled in the UsR.

5.4.3 Interaction chambers and vacuum systems

No specific requirements exist besides the control of the gas medium in each of the THGEM and BIC detectors. For the 4π neutron detectors, no specific interaction chamber exist and the common vacuum beam-line of the GBDD will be used. The requirements for the ELIADE detector are the same as the ones expressed for the NRF Low Energy.

The SSDs based experiments require a target located inside an interaction chamber under vacuum. A/several vacuum gauge(s) will enable to monitor the value of the pressure inside the IC. At a first stage, the pumping-down will be started and stopped manually. A hardware interface will provide the effective value of the vacuum inside the chamber to the vacuum system of the GBDD (see section 8.3).

For the eTPC detector, the vacuum is integrated in the gas control system previously mentioned.

5.4.4 Requirements summary for E8 area

The main requirements for the ELIADE detectors, the ELIADE IC and the target alignment system have been already detailed (see section 5.1.6 of this document).

The additional devices that have to be controlled during the experiments [8, 10-12] are the following:

a) Target system for the experiments using SSDs detectors.
b) 3 Gas-recycling systems for the BIC array, THGEM array and eTPC.
c) Power supply units for the 4π neutron detectors, and the SSDs detectors.
d) Vacuum of the ELIADE IC and vacuum of the chamber for SSDs based experiments.

For the devices a), b) and d) dedicated computers running applications based on commercial solutions will be used for a local control. For the devices c), custom applications will be built for a local control. The remote monitoring and/or control of all these devices shall be provided to the user in the UsR. Moreover, these requirements are completed with the ones listed in the section 5 of this document.

5.5 COMMON REQUIREMENTS FOR THE EXPERIMENTAL AREAS

Here are the requirements shared by all the gamma based experiments.

5.5.1 Gamma beam parameters

The beam parameters as defined in section 5.5.1, set or measured in the gamma beam system will be accessible in the UsR. This transmission of data from the GBS network to the EXPs MCS network should be easily because both control system frameworks are EPICS based.

5.5.2 Diagnostics

The diagnostics part of the GBDD system will provide measurement for low and high-energies. These diagnostics are detailed in the section 8 of this document. Data acquired by the diagnostics instruments will be displayed in the UsR.

5.5.3 Timing/Synchronization system

The time structure of the gamma beam is as follows:

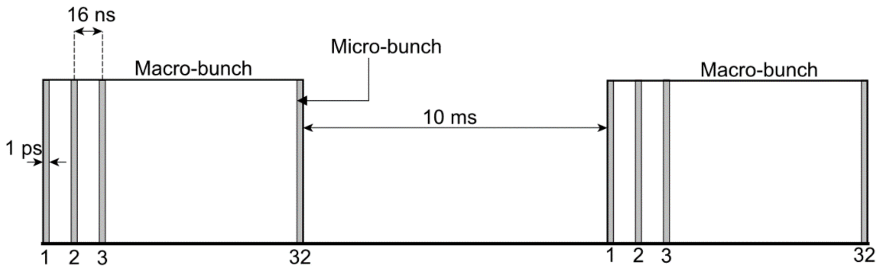

Fig. 10 – Illustration of the gamma beam time structure at ELI-NP.

Thirty-two micro-bunches of 1 ps each, separated from each other by 16 ns, form one macro-bunch. These macro-bunches are generated with a frequency of 100 Hz. Because the sampling rates of the digitizers used for the experiment are of the order of 100 MS/s, a continuous data sampling and read-out is impossible. Most of the digitizers used for nuclear experiments involving gamma rays have a lot of features in terms of trigger and data analysis (threshold trigger, waveform/pulse analysis, zero suppression, etc.).

Besides, these internal features, a timing system must be implemented. It must deliver several global triggers to the DAQ system in order to decide when the data should be read-out. The basic requirements, using as example the ELIADE DAQ involved in the NRF experiments, are summarized by the two following figures.

All the data acquired for one macro-bunch by the digitizers will be read-out only during an "Acquisition Time Frame" fixed by the type of detectors.

Another requirement is an absolute timestamp for the macro-bunches generated in the GBS, to be correlated with the machine parameters and afterwards to correlate the parameters with the experimental data.

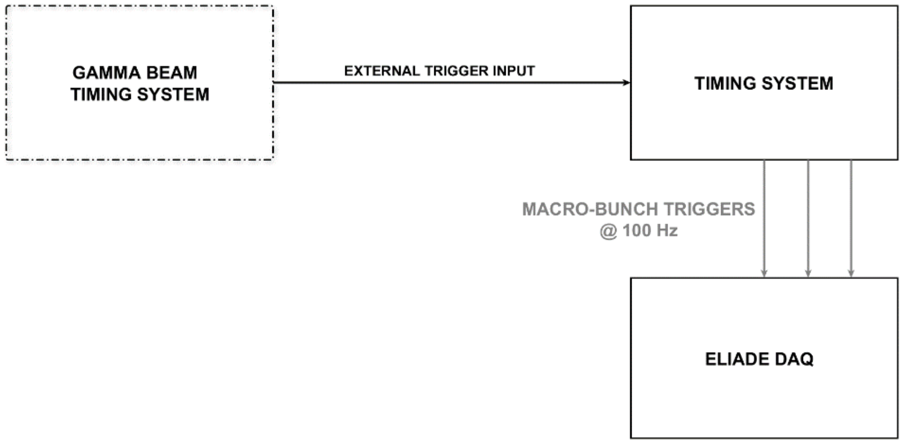

Fig. 11 – ELIADE DAQ triggering system sketch.

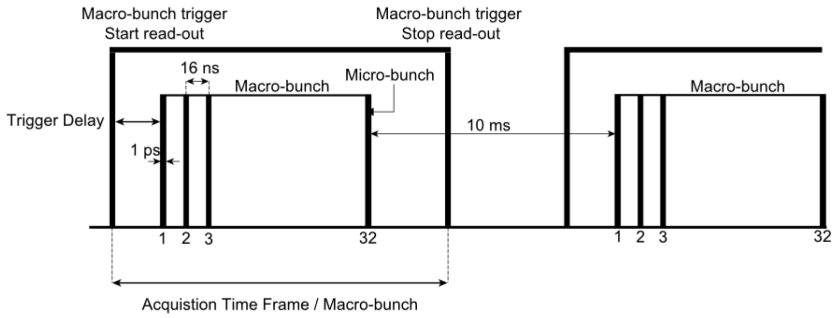

Fig. 12 – Representation of one possible trigger solution for based on the gamma beam macro-bunches.

5.5.4 Security and authentication

Access to the local (near the experimental areas) or the remote (in UsR and DAqR) applications parts of the control and monitoring systems for the gamma based experiments shall be based on various security levels. The authentication of the users will be required (using login and password) and the privileges (full-control, partial-control, read-only, etc.) will depends on the user type (*e.g.*, SuperUser, User, Guest).

5.5.5 Safety system interfaces

Experimental area safety systems must exist to handle the access door interlocks, other interlocks, panic buttons, check boxes, shutters, etc. These local safety systems must be interfaced with the ELI-NP PSS.

6 COMBINED LASER AND GAMMA BASED EXPERIMENTS REQUIREMENTS

6.1 EXPERIMENTAL AREA E7

6.1.1 Target systems

The experiments in this area will either focus the laser beams in vacuum, or use a primary gas target for electron acceleration to two energy ranges: 50-100 MeV and 2-2.5 GeV [12].

6.1.2 Timing/Synchronization systems

In order to perform combined experiments, with HPLS 10 PW pulses and GBS gamma/electron bunches, the experiments will need a way of correlating the experimental data with the parameters of the beams themselves, which are measured by the large equipment or by additional setups. For this, a unique way of identifying the parameters of the pulses, or other parameters in the large machines that are important for the experiment is necessary.

6.1.3 Detectors and DAQ

For the experiments diagnosis, the following are necessary [13]:

- Electron spectrometer for energies of hundreds MeV-GeV.
- Gamma radiation detector for high energy gammas (hundreds MeV) – using convertors for pair creation.
- Gamma radiation detectors for up to tens of MeV.

7 SYSTEM DESIGN

7.1 GENERAL ARCHITECTURE MODEL

The EXPs MCS will be based on three layers: Supervision layer, Control layer and Equipment layer, as illustrate in Fig. 13.

The Supervision layer is composed by the Human Machine Interface and Central Services sub-layers. The Human Machine Interfaces sub-layer regroups general purpose PCs and Monitors that will be used in the UsR/DAqR. These HMI will provide high-level supervision to the equipment and state machines inside the experiment.

The Central Services sub-layer will include several type of services: archiving, logging, alarm handling systems, common network services (domain name system, etc.) or eventually specific services for Distributed Control System (DCS) needs. In general, they must run continuously during the experiment that is why they are referred as "central". From the hardware point of view, industrial PCs or high performance virtualization servers are the solutions taken into account.

The Control layer includes the Local Control Unit and the Local Human Machine Interface sub-layers. The Local Control Unit sub-layer consists of local rack-mounted industrial PCs. If required, some PLC or others dedicated computers (*e.g.,* National Instruments) will be used as local controller for specific purposes (vacuum, machine protection, delay, etc.). All these control units will manage the hardware equipment or its interfaces. The Local Human Machine Interface sub-layer will provide a local access to the equipment for monitoring, maintenance and configuration purposes. This feature will be possible through dedicated Keyboard Video Mouse (KVM) switches and consoles in the case of industrial PCs. In other cases, specific HMI or others solutions will be provided.

The Equipment Layer is composed by hardware and equipment interfaces. The Equipment Hardware sub-layer consist of sensors, detectors, and actuators used during the experiment. The Equipment Interface sub-layer, when the experiment requires it (I/O specific controller, switches, etc.) refers to intermediary equipment that can be controlled by the Control layer.

The hardware architecture can be seen as three-tier layers structure. The connection between the different modules containing in each of these layers will be done by the use of several type of networks/connections (*e.g.,* equipment connections and control system network). The equipment connections will handle the equipment – control unit connections. The type of connection depends on the equipment. It can be a dedicated network for PLCs, a single cable between the equipment and the control unit using Ethernet, RS-232, GPIB, etc. The control system network will handle control unit – supervision connections. An Ethernet Bus network will be used based on fiber optics link to the largest possible extent. Moreover, dedicated networks physically separated from the others such as a Video Network are envisaged if the amount of data transmitting by specific equipment, such as cameras, over the control system network is too large.

Finally, electromagnetic perturbations/constraints like Electromagnetic Pulse (EMP) that will occur in the areas used for laser experiments will be taken into consideration for the choice of the cables (Cat6, Cat6a, fiber optic, etc.). The protection/isolation of electrical hardware modules is necessary to be done.

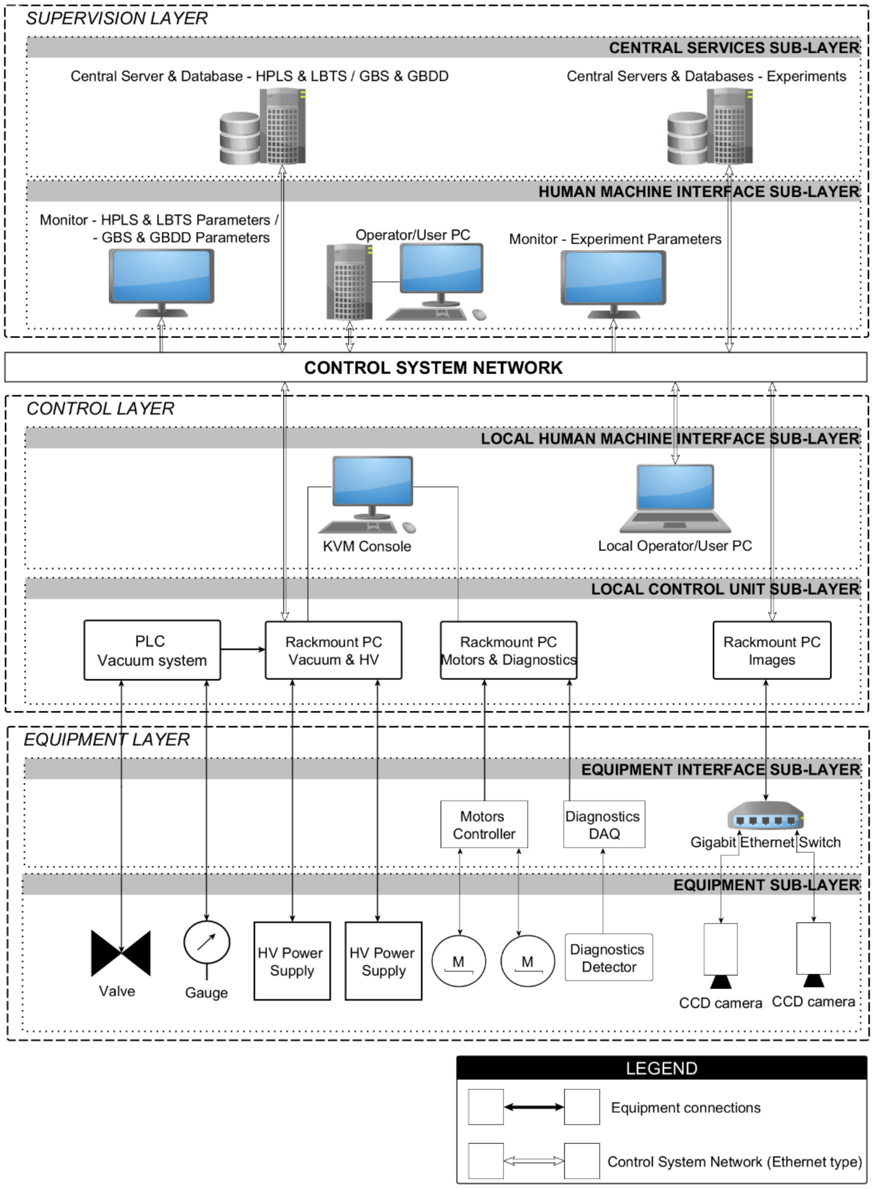

Fig. 13 – General Architecture Model with three-tier layer depicting the Equipment layer, Control layer and Supervision layer.

7.2 SOFTWARE ARCHITECTURE MODEL

As stated at the beginning of this document, the EXPs MCS are split in two categories: the EXPs MCS for laser driven experiments, referred as Laser EXPs MCS and the one for the gamma driven experiment, Gamma EXPs MCS. This distinction is clear from a software point of view: the Laser EXPs MCS will use TANGO whereas the Gamma EXPs MCS will be developed on EPICS. For the combined experiments, a decision will be taken based on the equipment involved and on synchronization level needed.

EPICS and TANGO are DCS that have been first developed by the research community in the 1990's in USA for EPICS [14] and in the years 2000 in France for TANGO [15]. Both systems have been used in research facilities all over the world and they have the goal to allow the control and the monitoring of a variety of devices that are mandatory in a research facility. The following sections contain a brief description of each software. Their differences and their similarities are also presented.

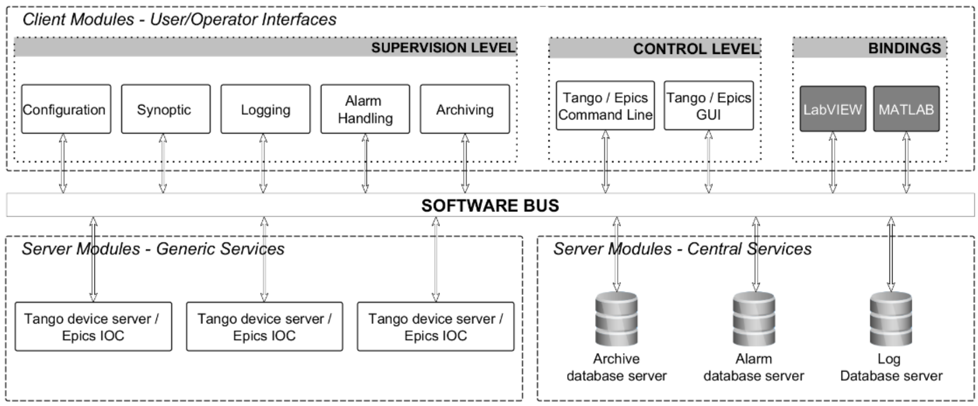

Fig. 14 – General Software architecture model depicting the TANGO/EPICS bus and client and server modules.

7.2.1 EPICS

The Experimental Physics and Industrial Control System (EPICS) is a DCS "hardware-oriented" enabling data exchange between different components of a system through a client-server model communication. EPICS is based on a hardware hierarchy composed by three main component:

- An Operator Interface (OPI): workstation which can run various EPICS clients tools.

- An Input Ouput Controller (IOC): any platform that can support EPICS run time databases (iocCore) together with the other software components included into an IOC. It can be a VME crate, a desktop, an embedded-controller, etc. The IOC interfacing one equipment enables its control.
- A Local Area Network (LAN): network that allows the communication between the IOCs and OPIs.

The following part will describe each EPICS software component associated to this hardware architecture.

EPICS servers

From a software point of view, the key component of EPICS is the Process Variable (PV). A PV represents a physical quantity that is measured by a sensor or controlled by an actuator. A PV is modeled as a record in the EPICS real-time database running on one IOC. This IOC acts generally as an EPICS server, even if it can also be an EPICS client. IOC encapsulates specific state machine database (Sequencer) which describes PV’s owned by it and device support modules for interfacing the hardware. The scheme below summarizes these ideas.

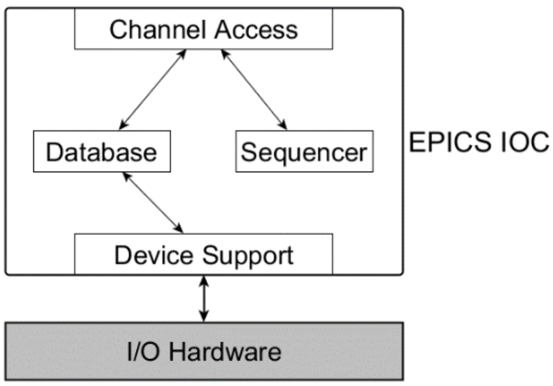

Fig. 15 – Schematic representation of one EPICS IOC.

The concept of EPICS IOC was strongly related to the I/O hardware (*e.g.*, VME, VXI) on which it should run. You could perfectly control one hardware device and even define its state machine with real-time operating system (*e.g.*, vxWorks). However it was not possible to run this IOC on machines using more "conventional" operating systems (*e.g.*, Linux, Windows, and Mac OS). This issue has been solved with the development of soft IOCs.

EPICS communication protocol

The Channel Access (CA) part depicted in Fig. 16 is related to the communication between the EPICS OPIs (clients) and the EPICS IOCs (servers). Each clients, respectively server, using Channel Access will be referred as Channel Access Client (CAC), respectively Channel Access Server (CAS). The Channel Access is the protocol enabling the transmission of the data related to PVs [16]. In order to avoid network conflicts, each PV must have a unique name. A CAC can set (write), get (read) or monitor the data of PVs via the Channel Access protocol. This protocol is based on an UDP request broadcasted to the servers that are listed in an EPICS environment variable. Then the CAS handling the PV requested will reply and a TCP connection will start between the CAC and the CAS selected.

Figure 16 exemplifies three PVs: "SA1:T1:temp" reading a temperature value, "SB1:V1:voltage" reading a voltage value and "SC1:G1:pressure" reading the value of the pressure in vacuum. These PVs are implemented inside the IOC database. CAC are able to display the values of these PVs by the use of different type of Graphical User Interfaces (GUIs) provided with the EPICS software.

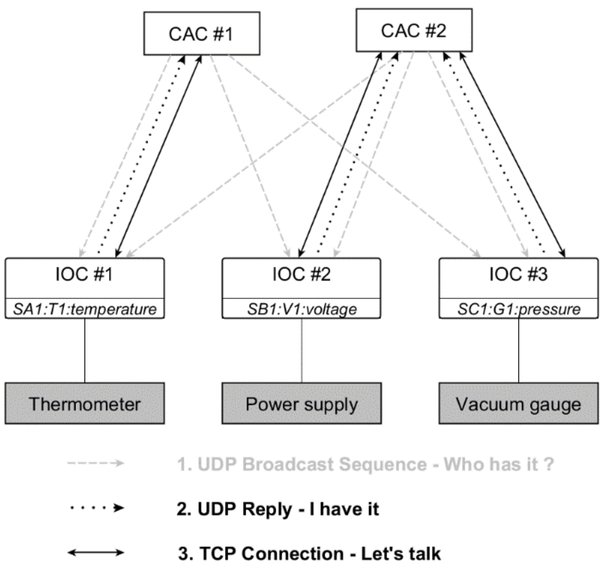

Fig. 16 – Channel Access overview: communication between EPICS clients and server.

EPICS clients

The EPICS clients consist in Graphical User Interfaces (GUI) displayed on the OPIs. These GUIs are based on EPICS client extensions that have been developed for more than 30 years. Some of them are using Channel Access as described below:

- Operator display manager (MEDM [17]): different display managers for monitoring purposes have been developed.
- Sequencer system (Sequencer [18]): tool for running an IOC sequencer that consists on the execution of state programs running on the I/O controller.
- Alarm handling system (ALH [19]): interactive graphical applications displaying and monitoring EPICS database alarm states. It serves as an interface between an operator and the EPICS database and communicates with the database using channel access function calls. The user interface for the alarm handler contains a hierarchical display of an alarm configuration structure allowing both high level and detailed views of the alarm configuration structure.
- Archiving system (CA Archiver): archiving toolsets for EPICS that can archive the values of PVs via the EPICS CA. The CA archiver is however no longer supported.
- Logging system (ioCLog): a system wide error logger supplied with the EPICS base. It writes all messages to a system wide file. iocLogServer is provided with the EPICS base software whereas iocLogClient ensures the configuration of the system.

Other tools are based on other environment, the best example being the Database Management tools (VDCT). This refers to an IOC database configuration tool, based on Java, developed and maintained by Cosylab [20]. It must be noticed that some of these tools can be used with other central servers or databases for achieving their goals (archiving, alarm handling, etc.) that can be integrated into the EPICS environment. Nowadays, Control System Studio [21] is widely used for the integration of these central services. Moreover, a lot of users prefers to develop and use other software or programming languages. This is the reason why bindings between EPICS and LabVIEW, C/C++, Java, Matlab, Perl, or Python have been created and maintained. Finally, EPICS provides an access security system that limits access from CAC to IOC database.

EPICS software architecture model

To summarize the ideas detailed above, the following scheme presents the EPICS backbone software architecture:

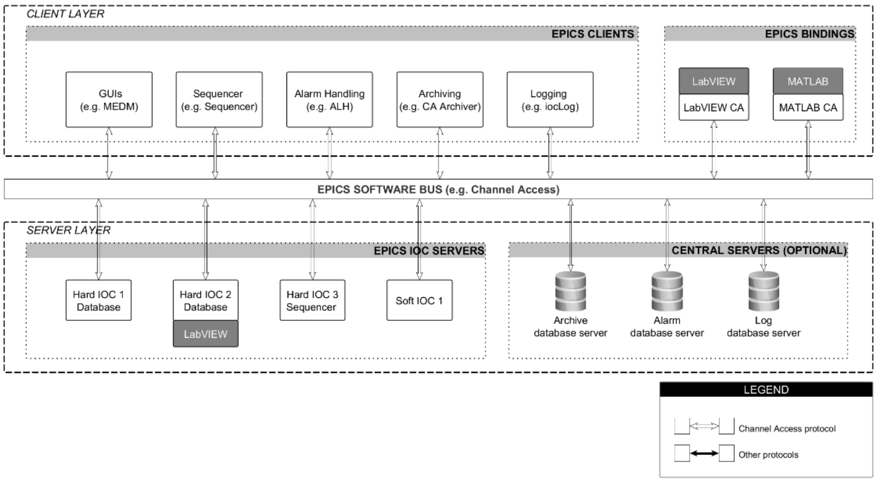

Fig. 17 – EPICS Architecture: communication bus, servers, clients and central services.

The IOCs provide generic services for the control of the system. They can be divided into two categories: hard IOCs and soft IOCs, as previously explained in this section. The generic services delivered by the IOCs servers are accessed by several EPICS clients using Channel Access. Each Channel Access Client can be implemented with the access security system. The majority of CAC clients are used for "generic monitoring". The CAC sequencer client is specially used for IOC Sequencer. Others CAC manages the central services and can be used in conjunction with additional central servers. EPICS provides bindings with other software such as LabVIEW and Matlab. LabVIEW bindings exist on both client and server sides.

7.2.1 TANGO

TANGO is an object oriented distributed control system based on CORBA (Common Object Request Broker Architecture) [22]. The main goal of CORBA is to provide a network communication between the TANGO clients and servers through a common Interface Description Language (IDL). To facilitate the implementation of the control system, TANGO hides all the details concerning CORBA. TANGO can run on Linux and Windows.

The following parts describe the major concepts related to the TANGO servers, the communication protocol and the TANGO clients.

TANGO Device Server model

The philosophy of TANGO is that all TANGO servers components can be seen as an object within a model, named TANGO Device Server Model (TDSM). This model includes three basic concepts [23]: TANGO Class, TANGO Device and TANGO Device Server.

The key object is the TANGO Device. It can be an equipment (*e.g.,* a motor), a set of equipment (*e.g.,* several motors driven by the same controller), a software processes (data processing) or a group of devices representing a subsystem. Each Device is an instance of a TANGO Class and give access to the services of this class. The TANGO Device has also a unique name that identifies it in network name space. A CORBA type interface permits the possibility to execute commands that perform some actions. The CORBA interface allows also the reading/writing of attributes that describe a physical unit produced or administrated by the device. The TANGO Device has additional one state/status (ON/OFF, STANDBY, INIT, etc.), defining a state machine. If the Device is a real hardware, a hardware control code has to be written.

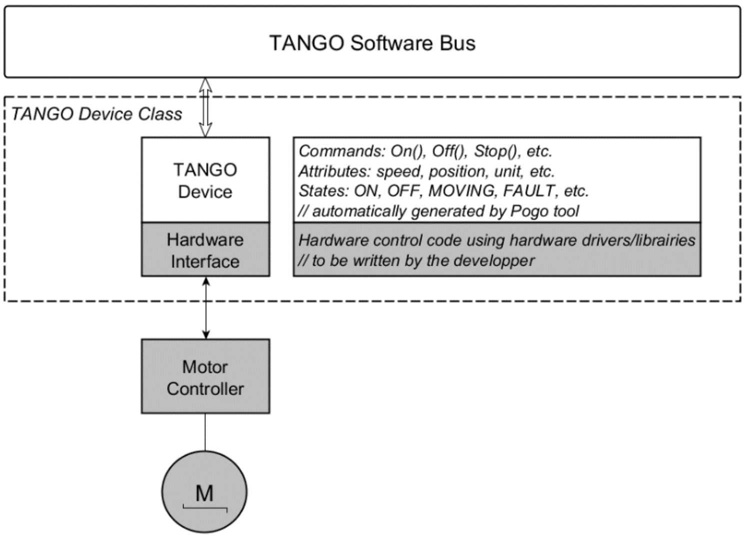

Fig. 18 – TANGO Device showing attributes, command and state connected to the TANGO Bus.

TANGO Classes define the interface and implements the device control or the implementation of a software treatment. All the code related to the interface can be automatically generated with POGO [24]. All classes are derived from one root class thus allowing some common behavior for all devices.

Finally, each Device are hosted within a server process named TANGO Device Server whose main task is to offer one or more services to one or more clients.

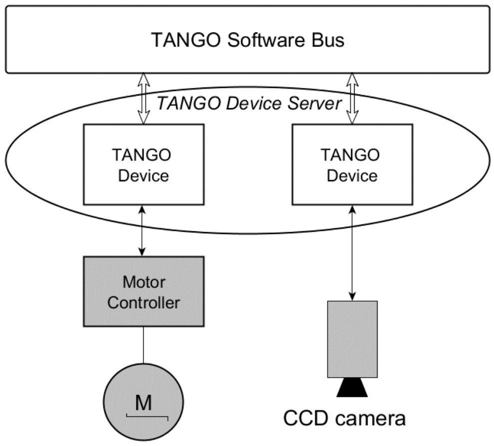

Fig. 19 – TANGO Device Server connected to the TANGO bus.

TANGO Database

In order to define and parametrize the Devices inside the system, TANGO uses the concept of Properties. The Properties permit the configuration of one Device without changing the TANGO Class code. To facilitate the configuration of an entire system composed by several devices, a MySQL relational database, named TANGO Database or TANGO Property Database stores all these Properties. Moreover, the TANGO Database is also used for the network communication (see TANGO Communication Protocol).

TANGO communication protocol

TANGO Device Servers and TANGO clients can use synchronous, asynchronous and events communication mode with CORBA and events communication mode with ZeroMQ [25]. In synchronous mode, a client send a request and wait until it receipts the answer sent by a server or until a pre-defined timeout. When waiting, the client is blocked. In asynchronous mode, a client sends a request and is not blocked until the response arrives. The response sent by a server can be retrieved by calling an API specific call or by requesting the execution of a call-back method when the answer from the server arrives. The event mode is now based on the ZeroMQ library that implements several well-known communication pattern including the publish/subscribe pattern which is the basic of the new TANGO event system. The TANGO Database is also used for the network configuration. In that sense, all client and servers have to access it at startup. Moreover, the Database ensure the uniqueness of device name. The two schemes below give an overview of the TANGO communication protocols:

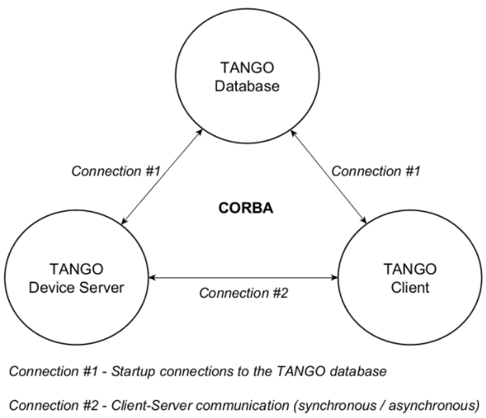

Fig. 20 – TANGO synchronous/asynchronous communication mode between TANGO Database, TANGO client and TANGO Device Server.

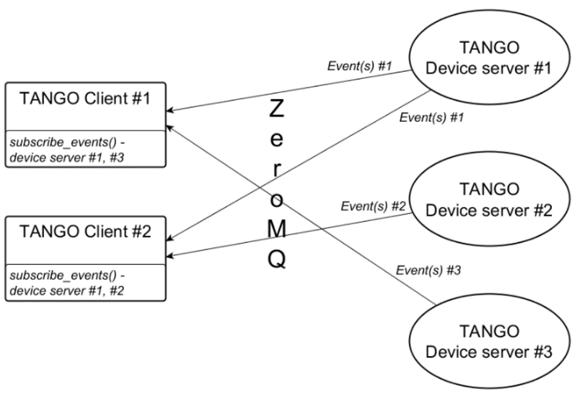

Fig. 21 – TANGO events communication mode between TANGO Device Server and clients.

TANGO clients

The client applications consists in GUIs that requires different services. Here are some of them:

- Configuration tool (Jive, [26]): client for browsing and editing the TANGO Database.

- Display management tool (Java ATK Panel, [27]): generic application which displays panels allowing to execute any Device commands or read/write any Device attributes.

- Global administration tool (Astor/Starter, [28]): On each host to be controlled, a Device Server (called Starter) takes care of all Device Servers running (or supposed to) on this computer. The controlled server list is read from the TANGO Database. A graphical client (called Astor) is connected to all Starter servers and is able to display the control system status and component status using colored icons, execute actions on components (*e.g.*, start, stop, test, configure, display information), etc.

- Logging system (LogViewer): TANGO implements a TANGO logging service enabling the display of messages related to the control system status. The LogViewer client enables the control over how much information coming from the Devices is actually generated and to where it goes. It can be used in conjunction with a database for the storage of the messages.

- Archiving system (Mambo): TANGO includes in itself some methods for archiving values of Devices attributes. Mambo allows the user to define configurations that describe archiving and data exploitation for a group of attributes. It requires two databases, one Historical Database (HDB) for the "infinite" storage and one Temporary Database (TDB) that erases from time to time the oldest attributes values [29].

- Alarm System (PANIC [30], Elettra Alarm System [31]): several clients have been developed for the configuration, management and display of the alarms of the different devices composing the system. It requires also in general the use of a database dedicated to this central services.

It must be noticed that some of these clients' tools can be used along with dedicated central servers and databases for achieving their goals (Logging system, Archiving system, Alarm system, etc.). They can be integrated into the TANGO environment.

Similarly to EPICS, bindings between TANGO and other software (LabVIEW, Matlab, etc.) has been created and maintained. Finally, TANGO provides a Control Access service that allows an access with different rights, *(e.g.*, defines which users can execute some commands (or write attributes) on a device and from which host). Fig. 22 summarizes the ideas presented above.

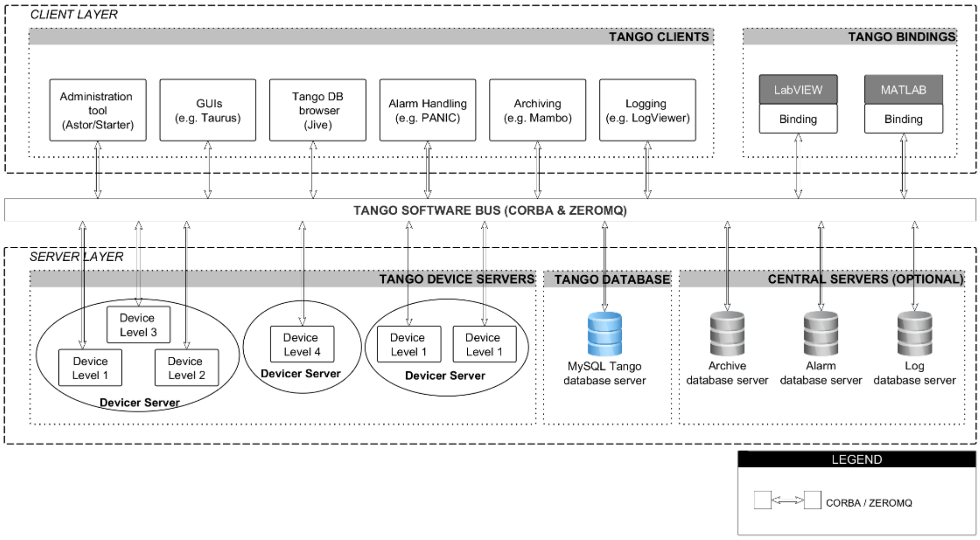

Fig. 22 – TANGO Software Architecture: central servers, central database, TANGO Device Servers, TANGO clients and TANGO – IDE bindings running on the TANGO bus.

The main servers components are the Device Servers distributed within the system. They can be implemented for the control of one hardware device (level 1), the control of a set of hardware devices (level 2), implementation of software processes (level 3) or representation of an entire subsystem (level 4). One central database server, the TANGO Database, is the key component making possible the communication between the Devices Servers and the clients. These clients are used for general monitoring/administration purposes, the configuration of the TANGO Database, or for managing central services. These latter can require additional central servers and databases. Client bindings exist between TANGO and other software such as LabVIEW and Matlab.

7.2.2 Remote desktop

For the equipment that cannot be interfaced with the EPICS or TANGO architectures, the remote desktop connection will be used to remotely control the devices from the UsR.

7.3 LASER BASED EXPERIMENTS ARCHITECTURE MODEL

The HPLS based experiments architecture is presented below.

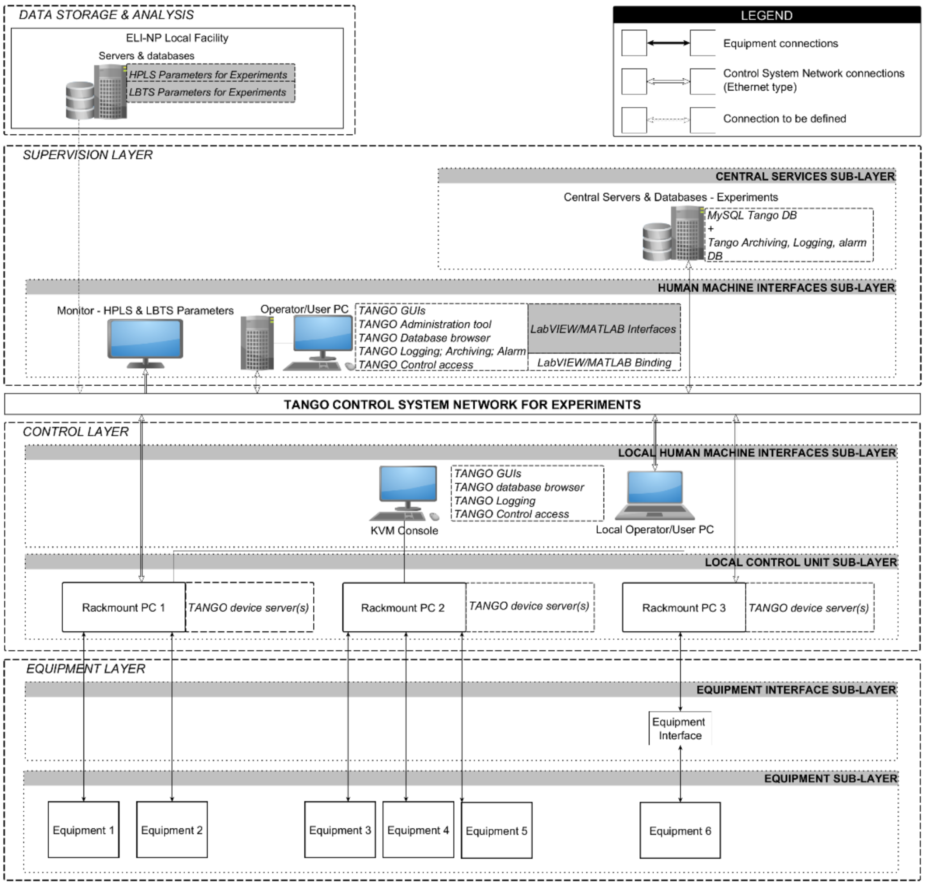

Fig. 23 – Laser based experiments architecture with the three layers: Equipment layer (cameras, delay generator, etc.), Control layer (Hardware: PCs, controllers; Software: TANGO Device Servers) and Supervision layer (Hardware: PCs; Software: TANGO clients).

Inside the experimental areas, local HMIs will exist to control the equipment of the experiment and make all necessary configurations when preparing the experimental set-up. The associated hardware for the local HMIs will be based on industrial PC racks placed inside EMP protected cages. The industrial PCs will be connected to the TANGO bus and will run the TANGO Device Servers enabling a distributed control of the equipment. These PCs will also hold the drivers for the equipment controlled or linked to them.

On the Supervision layer, inside the control room of the experiment (UsR and DAqR), desktop PCs will be used when the experiment is running. These PCs will hold the HMI supervision that will control the experiment remotely. At a first stage, the HMI supervision will be based on native TANGO clients or on commercial software (*e.g.,* LabVIEW). A dedicated PC will be used for the TANGO database and others central services. The HPLS and LBTS parameters required for the experiments will be displayed in the UsR/DAqR. These parameters will be stored on servers belonging to the ELI-NP local facility (see section 7.8) and will be connected to the TANGO control system network.

For each experiment, a separate TANGO client-server architecture will be implemented, each with its own database, physical or logical network, clients and servers. This is due to maintenance reasons and maximum operational time of the experiments (if one experimental area is in upgrade/maintenance mode the others can still function).

7.4 GAMMA BASED EXPERIMENTS ARCHITECTURE MODEL

The GBS based experiments architecture is presented in Fig. 24. Inside the experimental areas, local HMIs will exist to control the equipment of the experiment and make all necessary configurations when preparing the experimental set-up. The associated hardware for the local HMIs will be based on industrial PC racks. The industrial PCs will be connected to the EPICS bus and will run the EPICS IOCs/Sequencers enabling a distributed control of the equipment. These PCs will also hold the drivers for the equipment controlled or linked to them. On the Supervision layer, inside the control room of the experiment (UsR and DAqR), desktop PCs will be used when the experiment is running. These PCs shall hold the HMI supervision that will control the experiment remotely. At a first stage, the HMI supervision will be based on native EPICS clients and later on Control System Studio. The GBS and GBDD Parameters required for the experiments will be displayed in the UsR/DAqR. These parameters will be stored on servers belonging to the ELI-NP local facility (see section 7.8) and will be connected to the EPICS control system network. For the experiments, the EPICS client - server architecture will be implemented.

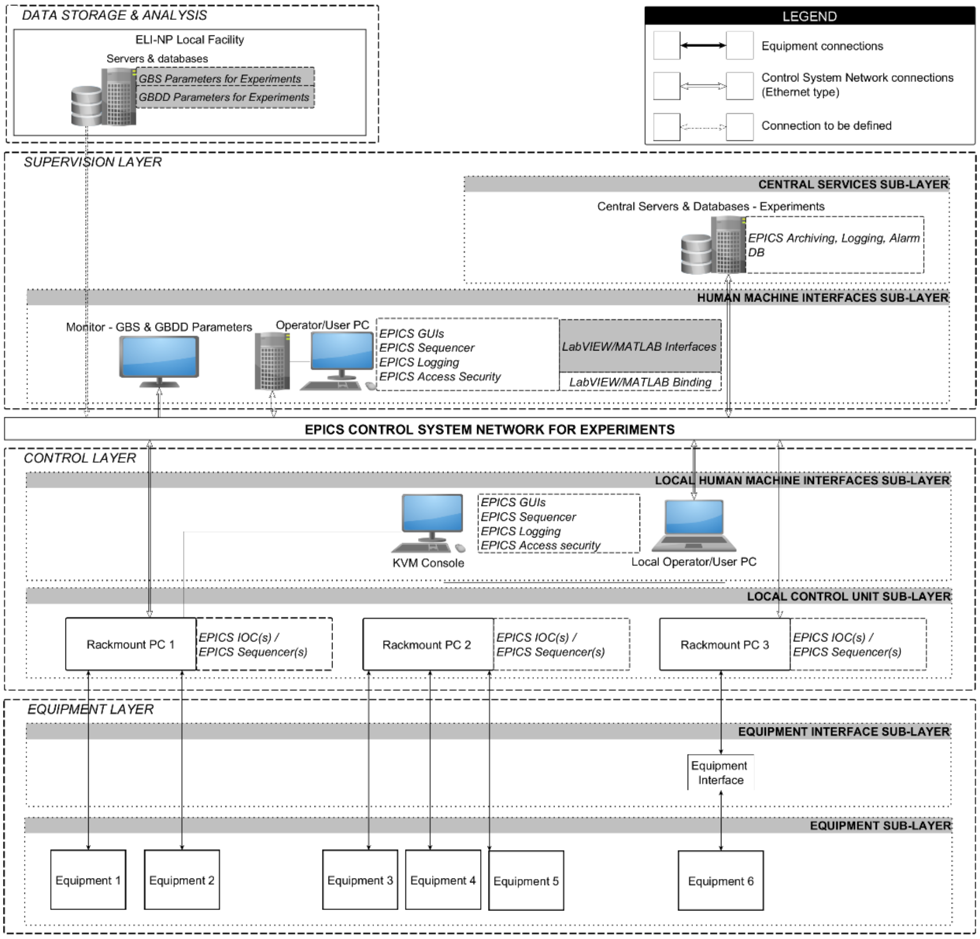

Fig. 24 – Gamma based experiments architecture with the three layers: Equipment layer (cameras, delay generator, etc.), Control layer (Hardware: PCs, controllers; Software: TANGO Device Servers) and Supervision layer (Hardware: PCs; Software: TANGO clients).

7.5 HARDWARE INTERFACES

The hardware interfaces between systems will use standardized communication as much as possible (*e.g.*, Ethernet, RS 232, RS 485, Modbus, and USB). The link between the experimental areas equipment (industrial PCs) and the UsR/DAqR will be made using fiber optics. If in some cases this is not possible, Cat6 or Cat6a cable will be the alternative.

7.6 SOFTWARE INTERFACES

The software interfaces between equipment will be made using the TANGO and EPICS native means as much as possible. TANGO and EPICS bindings to Matlab and LabVIEW will be also used in order to achieve the best performance in the shortest time and to take advantage of the mathematical and processing packages already existent in Matlab and LabVIEW applications.

A TANGO – LabVIEW binding that will allow any LabVIEW application behave like a TANGO Device Server represents an opportunity, as it will ease the integration of already existent equipment in the TANGO bus.

A TANGO – EPICS bidirectional binding that will allow any EPICS IOC to be used as a TANGO Device Server (and vice-versa) represents an opportunity, as it will ease the interfaces between the two control architectures and reduce code rewriting.

7.7 IT SYSTEMS

The implementation of the EXPs MCS will be made using industrial PCs and any other equipment that solely permits the integration into the EPICS or TANGO architectures (*e.g.,* NI CompactPCI devices with intrinsic integration to the EPICS architecture via LabVIEW core).

Inside the experimental area, a crate will be used to store a number of industrial PCs with EMP housing protection. The physical output of the crate will be fiber optics and this link will be passed through the penetrations in the antivibration floor and afterwards to the control rooms of the experiment – UsR/DAqR

Additional crates will be installed on the corridors, connected to the fiber optics network that will store the Database of the TANGO control system and its services. In these crates, one database handles one experimental area, yielding 5 industrial PC units for the HPLS based experiments (E1, E6, E7, E4 and E5). An additional solution is to use virtualization servers inside the UsR/DAqR. The two solutions shall be analyzed based on costs estimates, space, performance, maintainability and function of the other equipment in the building. In the UsR/DAqR, at least a supervision unit will be available for each experimental area.

7.8 DATA STORAGE AND DATA PROCESSING/ANALYSIS

In ELI-NP, the data storage and data analysis infrastructure will be developed in order to offer scalability and reliability for the experiments. The infrastructure will serve as a research tool for data transfer and data processing and the system will be designed as a hub between the user and the data sets that will need to be analyzed.

The data flow architecture is presented for two cases:

- Experiment side – related to the experiment itself, user dependent.
- Local facility side – related to the facility and the features available to the user.

The experiment side data flow presents the data flux from the front-end electronics (digitizers, camera, etc.) through real time preprocessing (if necessary) up to the event builder and to the data management. The real time processing will be made using FPGA or DSP in order to reduce the data where high fluxes are generated by the detectors (*e.g.*, ELIADE array). An event builder will merge the byte streams with the desired conditions and the timestamp into a single data structure passed to the data management system that will make the metadata for each file.

The local facility side depicts the data flow for storage (short term – disk and long term – tape storage), online/offline processing and analysis and simulation. This architecture is under development and various solutions are being evaluated.

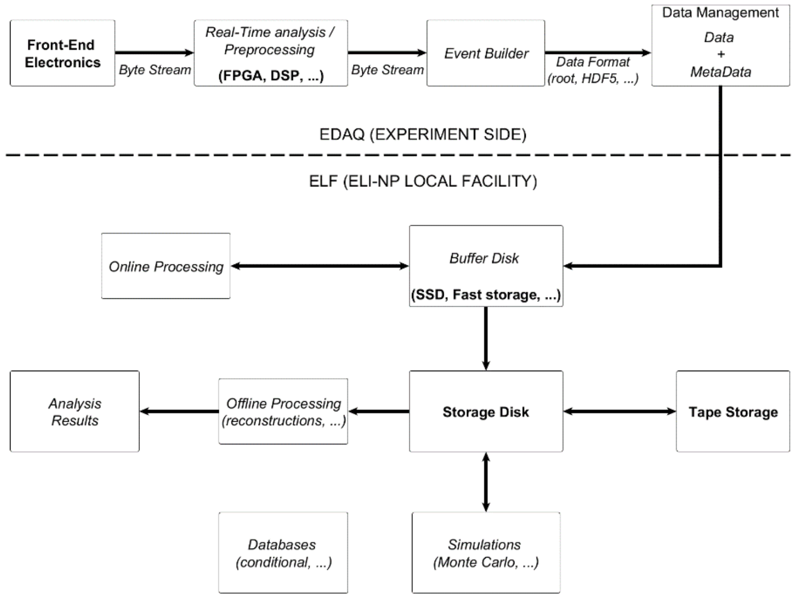

Fig. 25 – Data flow for ELI-NP experimental data.

A place will be dedicated in the UsR/DAqR for the short term data storage center (no more than 6 months), dedicated to the experiments data. An amount of 1 PB is considered sufficient for the first stage experiments (from the implementation phase). Redundancy will be implemented in order to protect the data and special care will be taken for protection against power failures.

7.9 SAFETY SYSTEM INTERFACES

For the experimental areas, it is required to have a safety system that is linked to the BMS of the building in order to command the doors access and interlocks and connected to panic buttons, shutters, check boxes, etc. This safety system is supposed to be interfaced with the general ELI-NP Personnel Safety System. The HPLS, GBS, LBTS and GBDD will have dedicated safety systems that will also be interfaced with the general ELI-NP PSS. The 10 PW interaction chambers will have dedicated safety systems in order to protect the personnel when in operating with the chamber and the system will be interfaced with the general ELI-NP PSS.

The general architecture overview for the laser related safety systems is presented below:

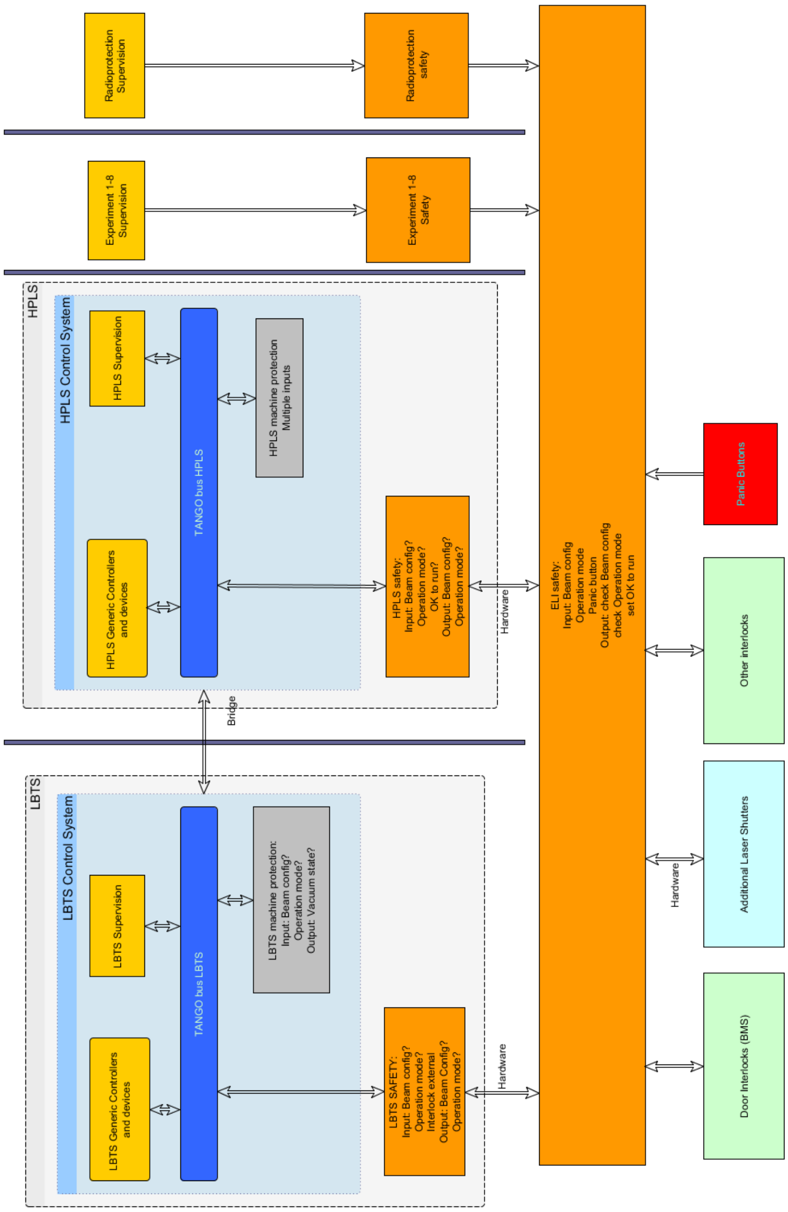

Fig. 26 – General block architecture of the safety and control system of LBTS in connection with the rest of the ELI-NP facility.

The general overview of the E1 interaction chamber control system and safety system is presented below.

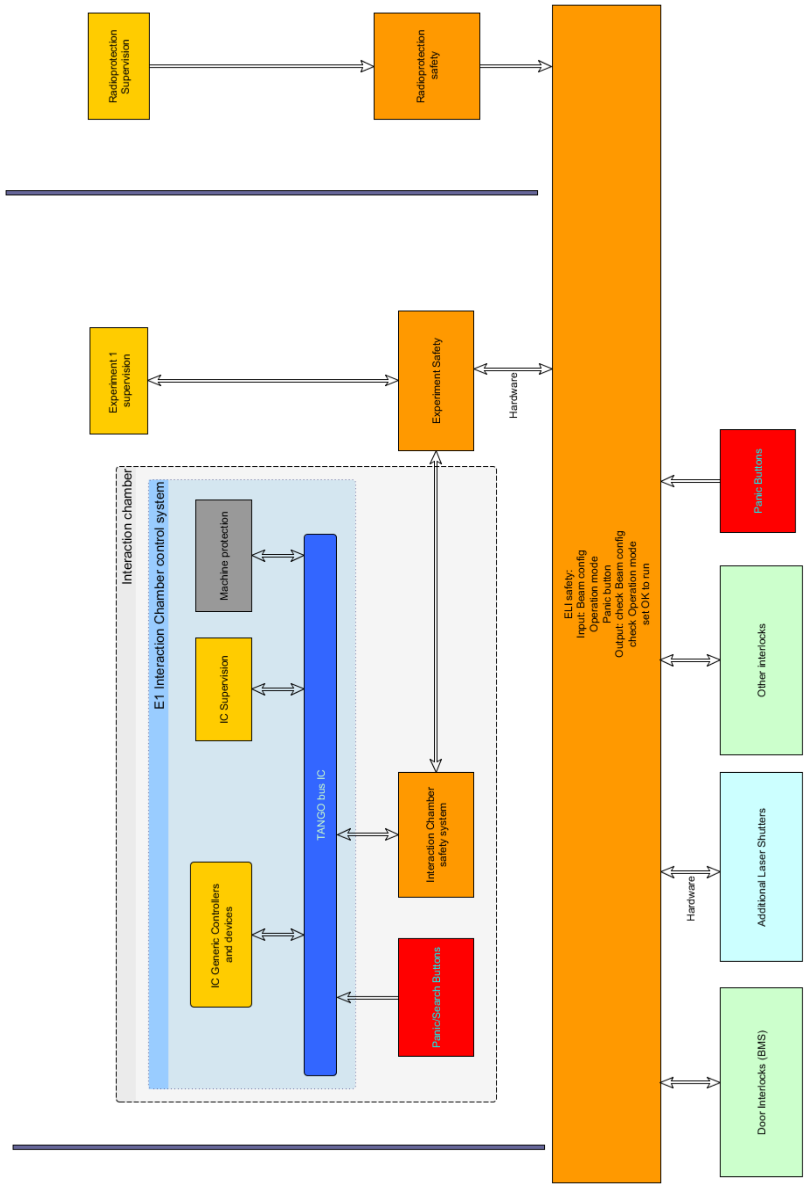

Fig. 27 – General overview of the E1 interaction chamber safety system and control system in connection with the rest of the ELI-NP Personnel Safety System.

8 SYSTEM IMPLEMENTATION

8.1 BUILDING INTERFACES

For the experiments control systems equipment and their interfaces with the users there will be space provided for positioning the equipment inside the experimental areas, hallways and UsR/DAqR. Power outlets will be available to connect the equipment in the areas where they are placed. FO cables and copper cables between experimental areas and UsR/DAqR, HPLS room, GBS room will be available.

8.2 LBTS TECHNOLOGIES AND VACUUM

The LBTS will have two systems for controlling its functionality, one being the safety system and the other the control system. The safety system is a dedicated part of the LBTS that deals with the human safety when working in the areas where the LBTS operates. The LBTS Safety System will exchange with the ELI-NP PSS information regarding the state of the LBTS that will be used in the general ELI-NP PSS to properly operate the facility (experimental areas personnel clearance, laser interlocks, radiation safety, etc.). The control system of LBTS is a dedicated part of the LBTS that will control the alignment, diagnostics, focusing and the routing of the two 10 PW laser beams, to the seven outputs corresponding to the possible experimental areas (E1, E6, E7), in their associated specific configurations required by the experiments. It will also provide monitoring, control, alarms management and logging of the status of all the subsystems of LBTS via hardware and software means. As currently envisaged, the control system of LBTS should provide through the supervision software the following functionality:

- Laser beam configuration routing (for each arm).
- Local (inside of the E1, E6, E7 area) and remote control (outside of the E1, E6, E7 area).
- Gate valves and vacuum control via hardware and software from the control system application.
- Beam alignment and associated procedures control and monitoring.
- Status reporting with history, logging and alarm signaling.
- Beam diagnosis.
- Unitary control and status feedback for all the LBTS subsystems:
    - LBTS configuration - routing mirrors.
    - Alignment system.
    - Gate valves and vacuum system.
    - Machine protection system.

The control system of the LBTS will provide a supervision software. The supervision of the LBTS is envisaged to ensure the following features and functionality:

- Sequence and configure the LBTS system (vacuum configuration, mirrors configuration, beam alignment, diagnosis).
- Human Machine Interface.
- Synoptic display.
- Alarm management.
- History of configurations management.
- Logging management.
- User profiles configuration.
- For each subsystem at least one dedicated HMI will exist in the supervision software.

The HMI of the supervision for LBTS and the associated HMI of the LBTS Safety System will be located in the HPLS control room. Additional clients with HMIs will exist to individually access the parameters of the LBTS subsystems that will be described below. The access to the client will be made such to avoid concurrent access to the same parameter. A separate client and HMI will display only the video from the cameras, which will be implemented with a dedicated network due to bandwidth issues. For the clients and supervision software implementation, TANGO based applications are considered for compatibility issues and maintenance. The routing of the laser beams will be made in manual and automatic modes. The convention for the gate valves (VR and VB) refer to the red beam 1 and blue beam 2. The red beam 1 denotes the left arm of the HPLS, from the West side of the building while the blue beam to the right arm of the HPLS from the East side.

8.3 GBDD TECHNOLOGIES AND VACUUM

8.3.1 GBDD overview

The Gamma Beam Delivery and Diagnostics (GBDD) system consists of two "lines" (GBDD low-energy and GBDD high-energy) that cross the ELI-Building. The line starts at low-energy interaction point, respectively at high-energy interaction point, and goes until the E8 experimental area. These lines are not continuous due to the fact that a lot of equipment have to be inserted/removed from the beam for experimental purposes.

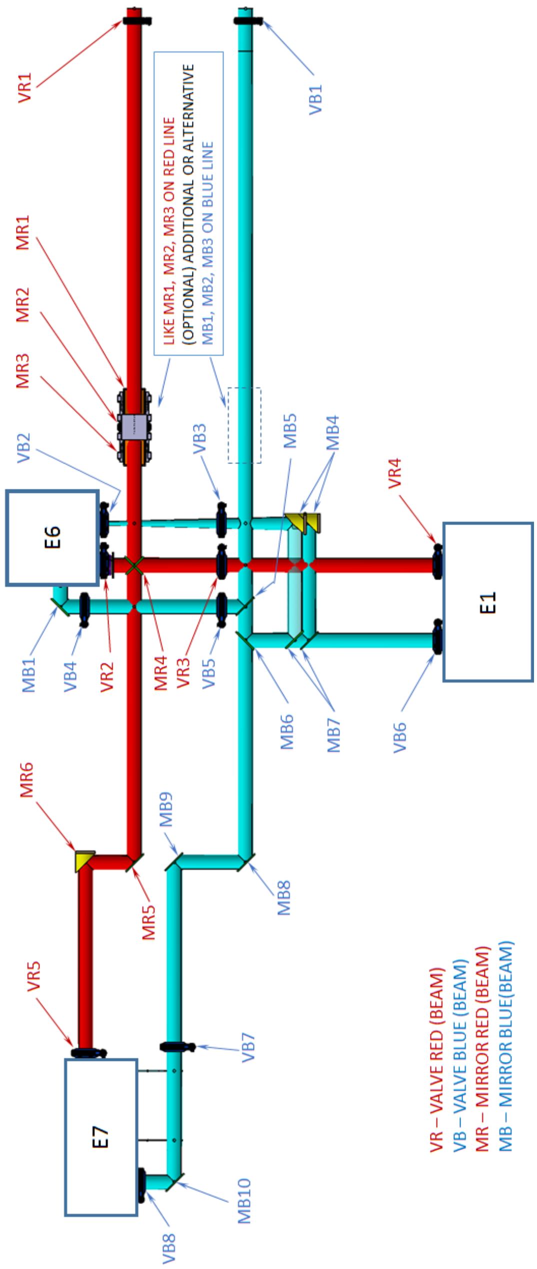

Fig. 28 – Preliminary LBTS configuration from the 10 PW output compressors to E1, E6 and E7 interaction chambers.

The diagnostics modules of the GBDD system will provide the measures of 5 key beam parameters: energy spread, polarization, flux (intensity), time structure, spatial profile. The used system depends on the energy of the beam. Here is the list of the ones envisaged:

- Low-energy beam ($E\gamma$ is less than 3.5 MeV)
    - Attenuator system using HPGe detectors for energy spread measurements and $LaBr_3$ for flux monitoring and time structure.
    - CCD black box for spatial profile.
    - NRF polarimeter based on ELIADE with the use of four HPGe crystals mounted at 90 degrees.

- High-energy beam ($E\gamma$ is less than 19.5 MeV)
    - D_2O system composed of a deuterium target and four neutrons detectors for Flux monitoring and Polarization measures (for this last parameter, the energy of the beam has to be above 3 MeV).
    - CCD black box for spatial profile (the same as the precedent one).
    - Fission chamber for Flux monitoring with beam energy below 3 MeV.
    - Stand-alone $LaBr_3$ detector for time structure.

The energy spread system used for high-energy is not yet defined.

Two others features are achieved through the GBDD:
- Collimation of the beam via several collimators that are located in the walls between the Gamma Source Recovery and E8, and between E7 and E8 areas (2 collimators per beam).
- Vacuum inside each GBDD section: the effective level of vacuum should be the same in all the sections of the low-energy line, respectively high-energy line.

The GBDD Control System will implement the control of all the modules listed above. Moreover, a dedicated GBDD Safety System interfaced with the ELI-NP PSS will handle the safety of the people working in the areas.

8.3.2 GBDD Control System

The GBDD Control System will provide the following functionalities:

- Local monitoring (in E2, E7, E8 areas) of the low-energy and high-energy diagnostics parameters.

- Local control (in E2, E7, E8 areas) of the beam collimators and vacuum inside each GBDD line section.
- Remote supervision of the items previously listed via an HMI located in the UsR.

8.3.3 GBDD Safety System

The GBDD Safety System is a dedicated part of the GBDD that deals with the human safety when working in the areas where the GBDD operates. The GBDD Safety System will exchange information with ELI-NP PSS regarding the state of the GBDD (collimators position, vacuum level, etc.). This information will be used to properly operate the facility (experimental areas personnel clearance, gamma interlocks, radiation safety, etc.) and the experiments.

8.4 INTERACTION CHAMBERS FOR 10 PW EXPERIMENTS (E1, E6)

The interaction chambers for E1 and E6 areas used for the 10 PW laser based experiments will have two systems for controlling their functionality, one being the safety system and the other the control system. The safety system is a dedicated part of the interaction chamber that deals with the human safety when working with the IC. The IC Safety System will exchange with ELI-NP Personnel Safety System and experimental area information regarding the state of the IC, that will be used in the general ELI-NP PSS to properly operate the facility (experimental areas personnel clearance, laser interlocks, radiation safety, etc.) and the experiments. The Control System of the IC will control and monitor the vacuum state in the chamber, monitor the CCD cameras attached to the interaction chamber and will be interfaced with the LBTS control system for exchanging information regarding the gate valves status and vacuum level status from the LBTS. The HMI of the supervision for IC and the associated HMI of the IC Safety System will be located in the HPLS control room and UsR. Additional clients with Human Machine Interfaces will permit to individually access the parameters of the IC (vacuum parameters, CCD, etc.). Concurrent access from multiple users will be avoided. Dedicated clients and HMIs will display only the video from the cameras and vacuum status for the users when they are in the interaction area. The information will also be available in the UsR. For the clients and supervision software implementation, TANGO based applications will be considered for compatibility and maintenance reasons.

8.5 TIMING/SYNCHRONIZATION NETWORK FOR HPLS EXPERIMENTS

Two solutions are taken into account for the implementation of the timing/synchronization network:

A system that generates a tag, synchronized with the beam shot can be implemented [32]. The solution must correlate the HPLS pulse by pulse beam properties (*e.g.*, energy, pulse duration, spectrum, spatial profile, contrast) with the diagnostics data. The tag will be hardware transmitted to all the experimental areas/unprotected areas where it will be read by the equipment required to perform the data encapsulation "timestamp/tag, data" (*e.g.*, a PC). This PC should be able to run in real time the tag reading and to perform the tag association with the data acquired from other equipment (*e.g.*, CCD camera). The TTL trigger for the camera will also be sent to these computers in order to know when the acquisition was triggered. The idea of tag identifier correlation is presented below:

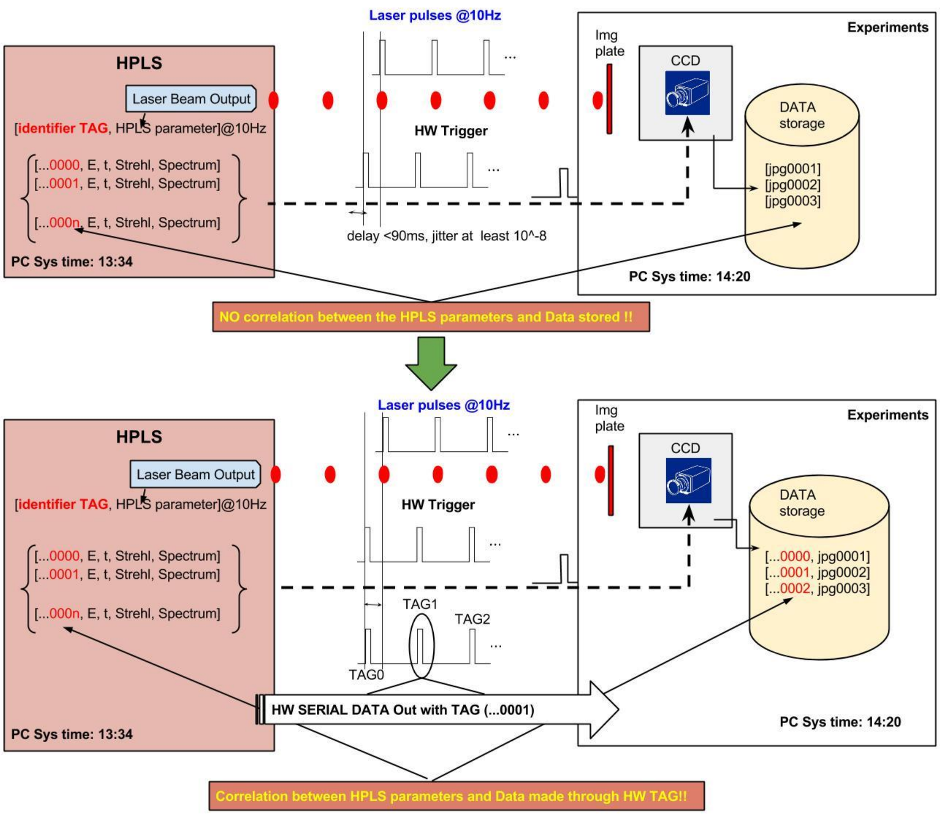

Fig. 29 – Laser – experiments correlation approach.

For the DAQ data correlation with the tag, the serial tag data can be sampled with one of the analog inputs and reconverted to the 32 bit identifier, in this way both data and tag will be extracted at the same time. Together with the acquired data, these signals should be enough to determine what data corresponds to what timestamp/tag. A requirement is that the tag generation system and the HPLS database that logs the beam parameters to be able to run and log in real time (frequency of 10 Hz) the unique tag and the diagnostics data. An example of machine-experiment correlation is provided below:

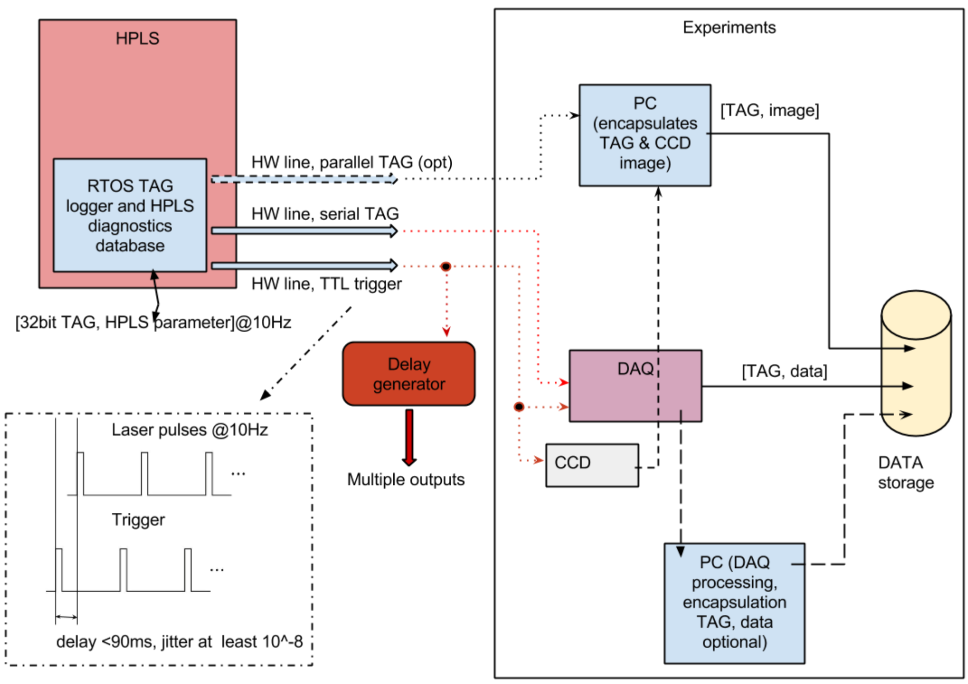

Fig. 30 – Proposed solution for HPLS beam properties – data experiment correlation.

The second solution is to have all computers synchronized with the same Network Time Protocol (NTP) server, linked to a GPS. The synchronization will allow that all PCs (of the HPLS and on the experiment side) to have the same timestamp, allowing an easy correlation but not deterministic. This solution is able to provide the correlation if the experiments are made with low repetition rate pulses (less than 1 shot/s) and if the applications are carefully treated.

8.6 TIMING/SYNCHRONIZATION NETWORK FOR GBS EXPERIMENTS

The requirements of the experiments are that a global trigger is correlated with the macro-bunches for reading-out the data acquired by the digitizers. If possible, a global timestamp is necessary for all the data produced and acquired during the experiments or at least for the ones that will be used in the same processing after one experiment. A system that generates a tag, synchronized with the beam that identifies some GBS parameters at a certain moment can be implemented. The solution could exist to correlate the gamma beam macro-bunch diagnostics data with the gamma beam machine parameters and with experimental data. The tag can be hardware transmitted to all the experimental areas/unprotected areas where it will be read by the equipment required to perform the data encapsulation (fast read-out PC in this case). Two proposed solutions are presented, both based on the GBS TS [1].

For the synchronization of the devices part of the GBS Control System, the GBS TS is using a system based on the Micro Research Finland timing system [33], referred as Gamma Picosecond Timing System. This system distributes a timing sequence composed by several data packets transmitted at a frequency referred as Event Clock. Each data packet is composed by one Event Code, 1 Byte, along with 1 Byte of data (Distributed Bus, DBus). The transmission (Tx) uses the 8b10b protocol and is physically achieved by optical fiber.

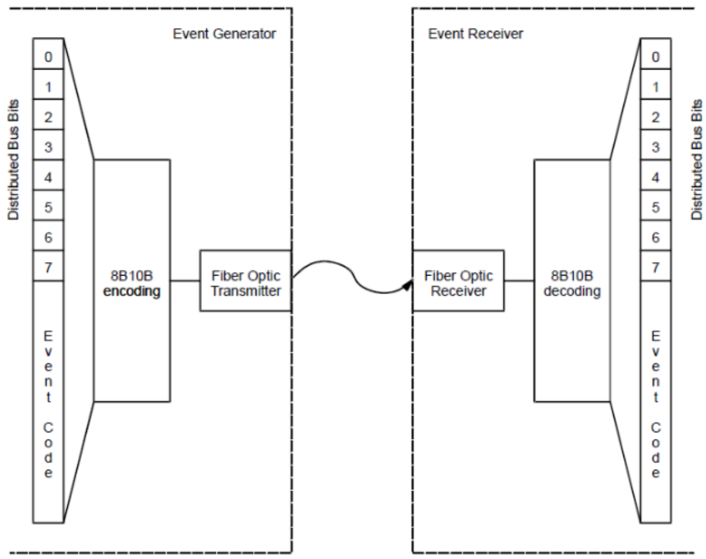

Fig. 31 – GBS synchronization system based on event generators.

The generation of the events is ensured by the Event Generator (EVG) that is phase locked with an external clock (in this case the RF clock of the GBS runs at 62.08 MHz) that is therefore the Event Clock. The timing sequence of events is generally up streamed with fan outs. In the gamma beam machine one timing sequence will broadcast its events to Event Receivers (EVR) at a frequency referred as repetition frequency equal to 100 Hz (macro-bunch frequency).

The EVR can be configured to perform some actions when it receives a specific event code: generation of signals (*e.g.*, TTL) with/without delays, possibility to choose the width of the signal, etc. Moreover, a global time stamp, a "second counter" using 32 un-signed bits, is generated by the EVG and distributed over the timing network. Each EVR implements also an "event counter" using 32 un-signed bits. This counter allows a high precision timestamp, up to 16.1 ns (the reciprocal value 1/Event Clock). Since all the EVR are phase locked with the same EVG, this means that the relative time offset between events that are generated by different EVRs can only be a multiple of 16.1 ns. The jitter between two outputs located on different EVRs is assumed to be less than 25 ps rms with a 125 MHz reference clock [34]. Some EVRs could be used in the timing network for gamma experiments being connected to the Event Generator of the Gamma Picosecond Timing System. Two solutions are proposed. In each solution, EVRs receive an Event Code associated to a macro-bunch generation. Then the EVRs generates macro-bunch trigger signals for starting the acquisition of data (*e.g.*, with digitizers). The delay and width of each macro-bunch trigger can be programmed on the EVR. Moreover, each EVR generates a tag that identifies the trigger sent (*i.e.*, the macro-bunch). The tag can consist of an event counter, (*e.g.*, on 24 bits) sent by the GBS machine when an event is generated. Then, this tag is sent to the fast-read out PC connected to the digitizers by optical link, parallel lines (*e.g.*, 24 bit – 24 lines) on copper cable or serial over copper cable. This PC makes the data processing and its output will consist of the encapsulated data with the format “tag, data”. The only differences between the two architectures proposed is that in the first approach, one EVR is located on each DAQ crate (Fig. 32) while in the second, all the EVRs are mounted on the same crate (Fig. 33), referred as Timing System. The second solution reduces the number of EVR because each EVR can send several triggers to different crates (*e.g.*, the EVR – EXP on the figures could generate another macro-bunch trigger that could be sent to another crate). However, if a problem occurs on the Timing System crate, the entire timing network could be down.

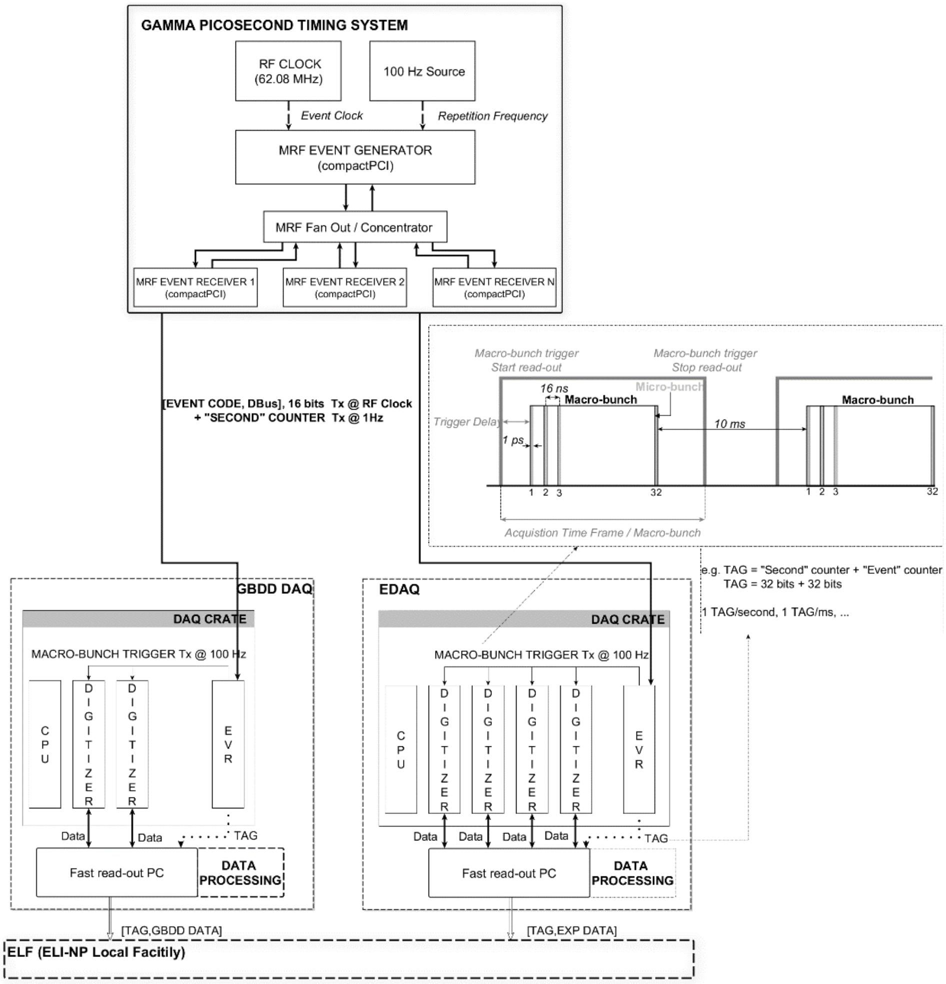

Fig. 32 – Proposed solution for synchronization and tag signals, EVR on each DAQ. See the high resolution version as Supplemental Web Material.

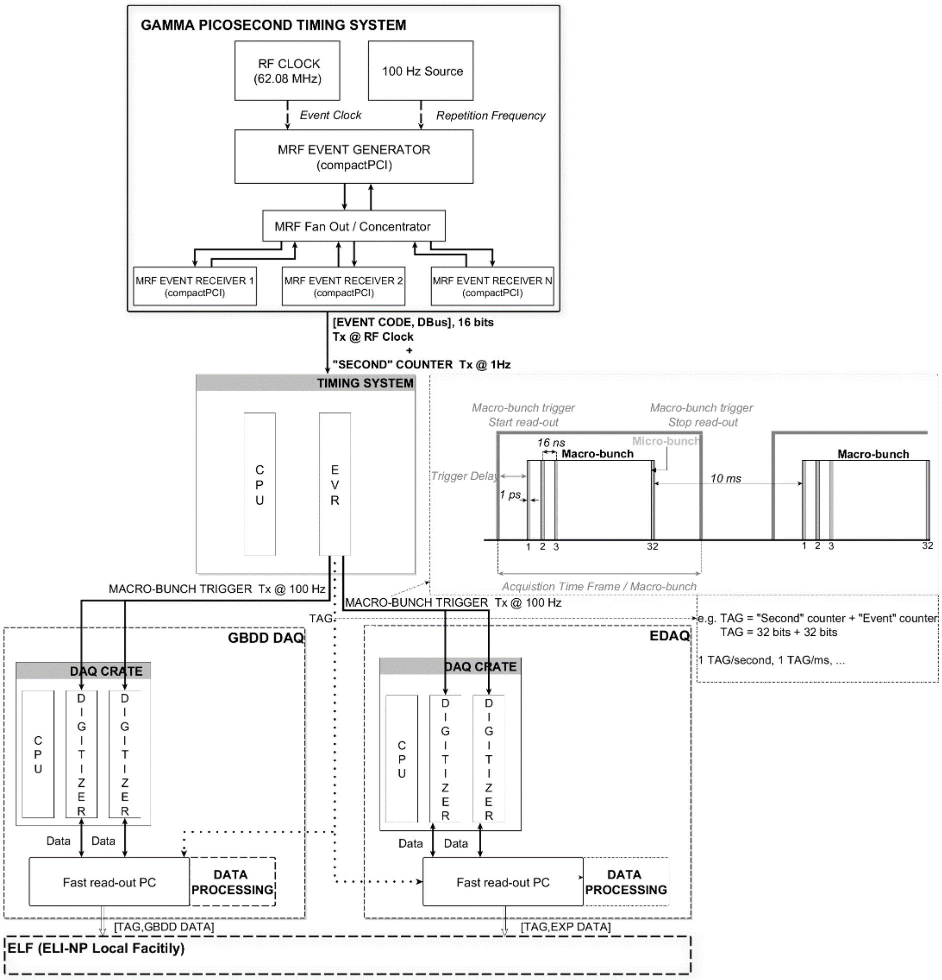

Fig. 33 – Proposed solution for synchronization and tag signals, 1 timing unit and afterwards tag and trigger signals distributed to all equipment. See the high resolution version as Supplemental Web Material.

The third solution is to use an NTP server synchronized with a GPS, and all PCs to be synchronized with the NTP server. In this way, all systems will have the same timestamp. This solution can be implemented only if the requirements do not request deterministic correlation. Moreover, this solution will be based only on the clock of each PC and the tasks running on it under various operating systems, which have to be carefully treated in order to achieve a reliable correlation.

8.7 TOOLSET EVALUATION AND COORDINATION BETWEEN SIMILAR FACILITIES

Various tests have been performed in ELI-NP in order to determine the best choice for the toolset to be used for the development of the described architecture. Ideally the choice will be to have as few programming languages and similar GUIs development both for EPICS and TANGO. These aspects are under evaluation:

8.7.1 TANGO DCS toolset evaluation

The selection of software tools that will be used to develop, test and deploy the integrated control system for HPLS and related experiments is based on the constraints and assumptions presented below.

The TANGO framework is already mature and comes with a large toolsets (see section 7.2.2). The HPLS equipment will use Device Servers written mostly in C++ and Python. The local human machine interface will use the Comete package developed at SOLEIL [35]. The HPLS is also using a commercial high-level supervision software, name Panorama [36]. In terms of programming languages, this solution implies to master C++, Java and Python.

The first idea is to reduce the number of programming languages. In that sense, the Devices Servers that will be developed for the laser driven experiments shall be written in C++. The usage of existing device servers is encouraged, even if they are written in a different language (*e.g.,* LIMA [37]) written in both C++ and Python.

A first TANGO control system prototype has been demonstrated in ELI-NP by:

- Developing several Tango Device Servers for a target manipulation system (based on translation and rotation motorized stages), and a delay generator running on Windows 7.
- Integrating CCD cameras on both Windows and Ubuntu with the LIMA library.
- Developing a LabVIEW interface for controlling the target manipulation system, using the Tango – LabVIEW binding and running on Windows 7.

The choice of the end-user GUI package is challenging. The ATK panels developed at ESRF [27] are included by default in the TANGO binary. This is a very good interface for test purposes. However for the end-user, other type of interfaces are evaluated: the Taurus package part of Sardana [38] developed at ALBA, and the Comete framework are the candidates for the both local and supervision clients. Only one of them will be implemented at a first stage of development. The advantages of Taurus over Comete are its simplicity and the development time for a GUI. The advantages of Comete over Taurus are its existing implementation within the HPLS and the possibility to aggregate and visualize a lot of data using different formats.

Rapid client application prototyping will be done using the TANGO – LabVIEW binding which allows the creation of client GUIs. Control loops on Windows PCs will also be tested. The development or usage of a common error handling system is envisaged. This topic has been presented by ELI-ALPS [39] and is of interest to ELI-NP. As an advantage, this eases the debugging of errors and impose some rules in the development of new device servers.

A repository tool will be used for hardware and software management. The CCDB tool [40], developed at ALBA is a candidate as it eases the management of all the equipment integrated into the control system and is possible to benefit from external resources.

8.7.2 EPICS DCS toolset evaluation

The selection of software tools that will be used to develop, test and deploy the integrated control system for GBS and related experiments is based on the constraints and assumptions presented below.

The GBS machine will be delivered by an external supplier with its own control system software and hardware, which includes the CODAC software suite [41] version 4.1. CODAC is a mature package, with wide usage in the scientific community, including EPICS version: 3.14.12.3, an extensive list of EPICS hardware and software support packages and Control System Studio. The latter represents a tool for creating EPICS client interfaces, which contains: a GUI design tool (BOY), an archiving system (BEAUTY) and an alarm handling system (BEAST). The GBS machine will also use Compact PCI hardware platforms for running the IOC servers and desktop PCs having Scientific Linux (release 6.3) operating system for running EPICS clients.

EPICS and its extensions are open source, supported by a large scientific community and are flexible enough to be installed on different range of hardware platforms and operating systems (*e.g.*, vxWorks, RTEMS, Linux and Windows). They are able to interoperate by means of the EPICS Channel Access network protocol.

A basic EPICS control system has been demonstrated in ELI-NP using out-of-the-box open-source code:

- EPICS IOC running on Linux (Ubuntu 14.04) to control a delay generator.
- EPICS client represented by CSS instance running a BOY *.opi interface on a Windows 8 machine.

There are also bindings available between EPICS and commercial applications (*e.g.*, LabVIEW, Matlab), which will allow rapid prototyping of control system clients.

Additional control software will need to be developed in-house to control the gamma beam experiments and correlate the data acquisition with the beam parameters. This control software will need to be interoperable with the one installed on the GBS machine, but also with legacy 3rd party control interfaces. Finally, it may also need to be compatible with the HPLS control system, (which is built on TANGO). The control software will need to support additional hardware devices (*e.g.*, sensors, motors, power sources, cameras, etc.) which may function on different operating systems as Windows or Linux. Moreover, the implementation of specialized control algorithms and loops are required.

Based on the above, a heterogeneous solution is foreseen. This solution will have EPICS framework at its core, but with the following particularities:

- Different types of computing platforms (desktop/industrial) and operating systems (Windows, Linux or real-time OS).
- Different types of clients. The CSS IDE has only a limited capability of integrating complex control algorithms in the client side, so in the first stages of development Matlab or LabVIEW are envisaged. A staged approach is intended to be adopted as it will be described in section 8.9.

In terms of software engineering, this solution would require the following skill set:

- Linux and Windows operating knowledge for installing IOCs already available in the community.
- C and C++ programming for development of new or modified IOCs.
- Matlab or LabVIEW for prototyping of new control client interfaces.

Information exchange with the other ELI pillars has been performed, with respect to the common issues/problems and the common control system tools shared by the facilities. The common issues faced by the ELI sites should obviously require common solutions. However, each facility has its particularity and own experimental program and some solutions will be specific driven by the experimental request.

8.8 CONFIGURATION AND SIMULATION FOR LASER DRIVEN NUCLEAR PHYSICS EXPERIMENT (E1)

In the following, it is presented a simulation for the equipment and procedures involved in the LDNP experiment and the hardware and software architecture for performing the experiment together with the system design and implementation. In the architecture, TANGO will be used for compatibility with the HPLS and LBTS, maintenance reasons, development effort and scalability of the solutions.

8.8.1 Equipment involved in the experiment

The following equipment will be used in the experiment:

- Target Insertion System with load lock– used to insert a target wafer or RCF place inside the interaction chamber, without breaking the vacuum inside the IC.
- Target manipulation system – inside the IC, at least 5 axis of movement, used to position the target in the required focal spot of the HPLS.
- Target alignment based on CCDs – inside the IC, multiple CCDs placed such to monitor the position of the target and align it correspondingly with the target manipulation system.
- Delay generators for synchronization and tag network.
- High Power Laser System (HPLS).
- Laser Beams Transport System (LBTS).
- Interaction chamber (IC).
- Data storage system.

- Detection specific for LDNP:
    - Thomson parabola:
        - High-voltage ctrl (offline).
        - CCD camera gated.
        - MCP – high-voltage control (offline).
    - Scintillators
        - Gated high-voltage.
    - DAQ

8.8.2 General experiment systems, machine setup and running steps

In the following subsections there will be described the envisaged setups for the synchronization and tag system, the Target Insertion System and the Target Alignment System. The experimental flow takes into account the safety systems involved in the HPLS based experiments, the LBTS and HPLS configurations for experiment run, the data storage setting up and the experiment itself (in the interaction area).

The Synchronization and tag system

The solution, as presented in the sections before will be able to synchronize the information from the detectors with the beam parameters given by the HPLS system.

Target insertion system

A possible implementation for the TIS is presented below. The insertion of the target will be made from above the IC, using the combination of the motion controllers of the TIS itself (2 axes) and the Target manipulator inside the IC. The systems are depicted below. The TIS shall have a load-lock system and separate vacuum pumps. A prototype for a TIS with three holder positions is under development.

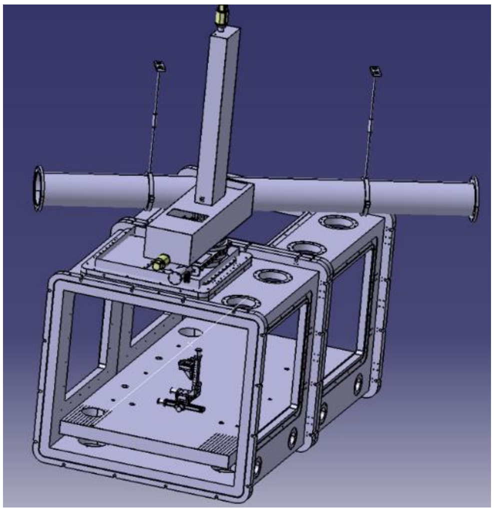

Fig. 34 – Example of the Target Insertion System placed on top of the IC and target manipulation system inside the IC.

Target alignment system description

In the following we shall refer to the Target Alignment System as composed by a target manipulator and CCD cameras for alignment. The system is suited for solid target wafers but can be adapted to gaseous targets also.

The target wafers are envisaged to have a couple of markers used to identify the wafer and determine the wafer plane in the holder. Before its insertion in the interaction chamber, the wafer will be characterized and a predefined format file will contain the x, y and z position of each target in respect to the alignment markers.

The laser focus and the wafer planes can be overlapped roughly using a short depth of view microscope installed in the interaction chamber. In addition, an interferometer can be used to apply fine alignment corrections. Together with the target coordinates previously acquired, all the targets can be positioned in the laser focal spot.

The alignment of each target is considered to be maintained from one target to the other, based on the mechanical setup and flatness of the wafer. In the case the wafer has irregularities induced by the frame in the vacuum or from other reasons, the interferometric setup can be used as an online monitor of the target position in focus.

Another possibility assumes that the joints of the mechanical system have wears which may lead to movements of the alignment system that are not reproducible on large strokes. This implies an online correction of the system that may involve multiple axis.

The proposed solution is an online heuristic control algorithm that monitors the wafer position for each target before the laser shot and control the alignment system motors position to correct any misalignment. A possibility is to have a mirror on the side of the alignment system of the wafer, or even using the substrate surface as a mirror. When the wafer is moved to another target position, the far field measurement will show if the wafer is moving on the correct axis or if some compensation has to be made.

The heuristic algorithm can be a genetic algorithm that has to control the motorized stages of the alignment system in order to perform the alignment of the wafer plane with respect to the laser beam axis or afterwards, to adjust the wafer for each of the targets in order to maintain the correct focal spot on the target and angle of incidence. The benefit of the algorithm is that it will automatically find through iterative steps the minimum error between the chosen criteria and the actual solution, not having to deal with individual control of several motorized axes.

However, different other approaches are taken into account depending on target type and manipulation stages that will be finally used.

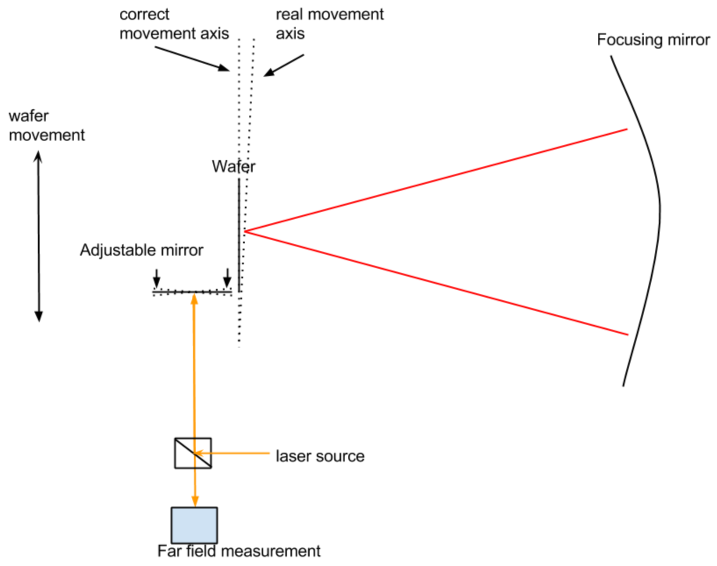

Fig. 35 – Proposed alignment system based on heuristic algorithm.

Experiment flow

In general, for each experiment, the Safety system, the LBTS and HPLS have to be prepared to run the experiment. In the following it is presented the design for the general ELI-NP Safety system and how the user will interact with the LBTS and HPLS to reach the desired beam parameters configuration for the experiment.

Safety setup (interaction area)

In the ELI-NP facility, the LBTS and HPLS will each have their own safety systems. Each of them will provide the personnel safety when operating in the interaction area and in the HPLS area, respectively. In the interaction area, the interaction chambers will have their own safety system, as depicted in subsection 7.9. This safety system of the IC will act on the IC doors state, search boxes and panic buttons. Due to its size, the IC access doors will have hardware locking systems, search boxes and panic buttons, to protect the personnel from accidents.

LBTS setup for experiment run

Users will be able to extract the beam information of the machine in their predefined storage area. A server will be present and all the software interfaces available to extract the necessary information of the machine.

The user will not be allowed to modify the parameters of the beam transport system. The beam transport system will have its control room in the HPLS control room. Its operation will be interlocked with the HPLS operation and with the ELI-NP safety system. In order to modify the laser beam transportation parameters – deviate beam, change polarization level, adjust wave front with adaptive optics, a request will be made to the LBTS operator to change the desired parameters.

HPLS setup for experiment run

A server will be present and the software interfaces available to extract the information from the HPLS database to the user's database. The HPLS database accessible to the user will generally have only information regarding the output beam properties of the HPLS. The HPLS database will provide also a unique shot number identifier, to correlate the parameters with the laser shot. The user will not be allowed to modify any of the beam parameters or fire shots but only request this to the HPLS operators.

Data storage setup

The data storage system will exist in the DAqR in a dedicated space. A virtualization system will be implemented, where each experiment will have an allocated slot inside the data storage system where the user will be allowed to store the data from the experiment. The parameters from the HPLS can be available on the same system. The amount of space for the experiment will be function of the users request and can vary from experiment to experiment. The data storage from the DAqR will be used for short term storage of the experimental data. The data storage system from the DAqR architecture is presented below:

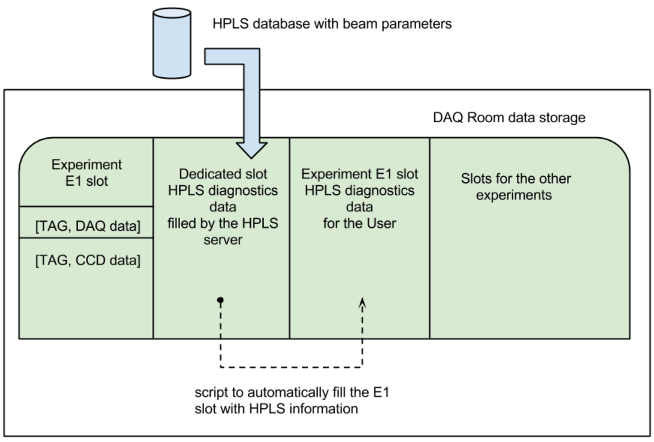

Fig. 36 – Data storage solution with dynamic slot assignment for each experiment

Experiment run

The setup is first prepared inside the interaction area. Before exiting the experimental area, an assigned person will use the search box buttons and the search procedure is being made inside the area, before exiting. After the search is completed, the radioprotection door is closed. The user will control afterwards the entire setup from the UsR and DAqR. Within the experiment flow, the user will control the TIS and the TAS remote during full power shots. The delay generators that trigger the equipment for acquisition will also be available to the user for setting the correct gating signals. The user will request to the HPLS and LBTS operators the correct configuration before the experiment run and then during the experiment they will request for laser shots.

A pre-configuration will be needed to be made by the user when he is in the experimental area, consisting of laser configuration in experimental chamber (mirrors positions, etc.), diagnostics assembly installation, target system placing, TIS alignment, offline equipment setting up, request for allocation of data storage space, adjustments of the remote controlled equipment, pre-alignment and testing of the target, TIS testing, optimizing the focus, IC closing and pumping, realignment in vacuum, high-voltage setup. During the closing of the interaction area, a procedure has to be followed, after which the control will be made from outside the experimental area. The user will be able to request beam in order to test the equipment and test online the DAQ and CCDs. After all equipment was adjusted, the user can start the experiment by requesting beam and visualizing online the data and exchange targets.

8.8.3 Experiment IT systems

Figure 37 presents the E1 area and the possible locations for the IT systems. The place outside the interaction area will be assigned to equipment that can be placed at large distance from the experiment (*e.g.,* motor drivers, TANGO services). However, for the motor drivers' position, a solution will be chosen based on the interfaces with the LBTS equipment, vacuum related equipment, cost effectiveness and performance.

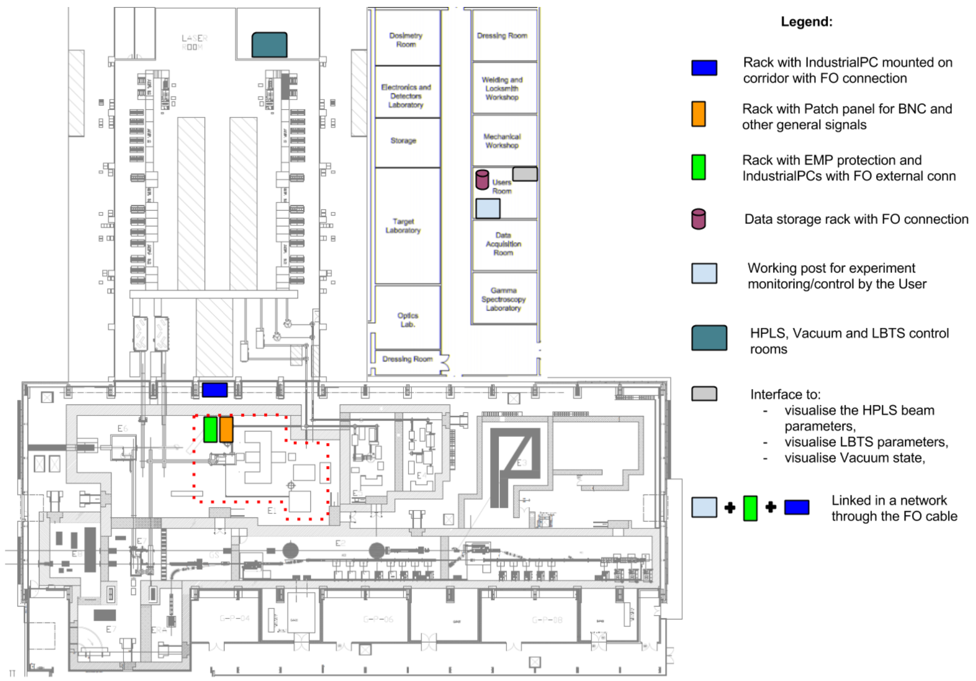

Fig. 37 – Example of E1 experimental area IT systems layout together with the UsR equipment and HPLS control room equipment.

Two solutions are considered and will be tested for best performance and cost effectiveness regarding the TANGO architecture:

- 1 PC rack with 2 industrial PCs to run the TANGO based services and database.
- Virtualization server inside the DAqR, with separate quota for each experimental area.

Inside the interaction/experimental area, the following equipment are considered:

- PC rack with EMP protection with industrial PCs and fiber optics output to minimize the penetration holes for cables.
- PC rack with EMP protection with 5 industrial PCs for E1.
- 1 PC for Target Insertion System control.
- 1 PC for target manipulation system control and delay generator control.
- 1 PC for alignment (CCD cameras).
- 2 PC for DAQ and CCD diagnostics.

The rack units can be split into two categories: one unit for digitizers, oscilloscopes, EMP sensitive equipment that will output the data via fiber optics. The rack will be EMP protected and one unit for analog signals and other signals for equipment (motor drivers connection to the motor itself, triggers, etc.). The rack will be EMP protected. The rack for digitizers will have one patch panel with general purpose connectors, 50 connectors to be available for each experimental area. Additional, the tag HW signal and TTL signal will be available in the racks. The rack for the analog signals will have one patch panel with BNC connectors – general purpose, and 50 wires are considered to be available for each experimental area. Additional, the tag HW signal and TTL trigger signal will be available in the rack. The digital I/O communication will be fiber optics over Ethernet, to prevent the data corruption and equipment malfunction due to EMP. The proposed solution is using one industrial PC rack system, with slots filled with industrial PCs for general purpose that will convert the data passed through fiber optics intro serial/parallel communication as needed. For the signal filtering and EMP protection of the sensible equipment, the solution complexity should be decided after the first tests, when a real estimation of the EMP value will be available and measured progressively. In this sense, the first approach will be to use EMP protection crates and EMP filters at the entrance of the cables into the crates (if this is permitted by the bandwidth/frequency of the signals needed to be transmitted). As the signals usually come from the detection, a high EMP is however not accepted as it would mean the detection was already affected by the pulse.

The proposed approach is depicted below:

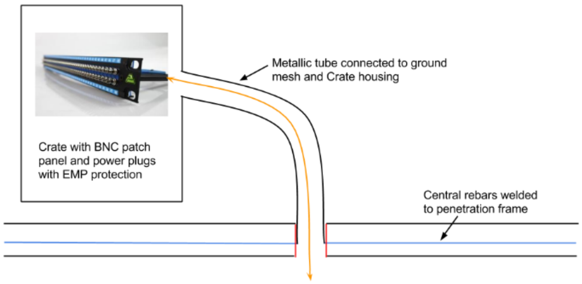

Fig. 38 – Proposed solution for E1 experimental area EMP protected rack and output signals from the interaction area.

For the fiber optics pass through the experimental area floor, a similar solution exists. The fiber optics will come also from a crate like the one described above.

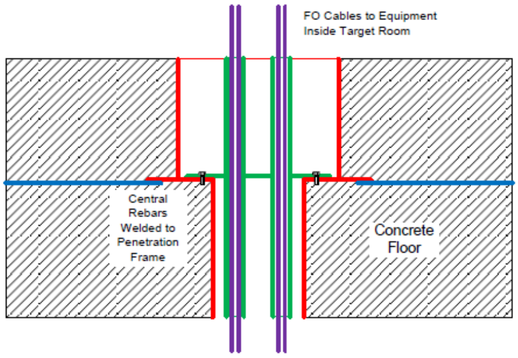

Fig. 39 – E1 experimental area EMP solution for fiber optics cable passing through the concrete floor of the interaction areas.

All cables from the experimental room will go into the racks where the equipment for detection and the IT systems that will be part of the control systems will be placed. The industrial PCs will have a fiber uplink in the switch that will provide fiber optics links between the experimental room's racks or from them to the non-protected area. Multimode fiber optic (62.5 nm core) will be used and it is mandatory that each industrial PC has a fiber optic interface (at least 1Gbps) in order to transmit real-time data without the need to stop data acquisition. In the proposed topology, the computers in the racks can communicate horizontally or vertically according to the requirements.

8.8.4 Experiment Design

The alarm, services and database in the TANGO architecture will be placed on separate computers. Two solutions are considered and will be tested for best performance and cost effectiveness as presented in section 3. One solution will be to place the services and TANGO related database on industrial PCs placed in protected racks on the corridors. The second choice is to have a virtualization server inside the DAQ room.

For each experimental area, a separate slot will be dedicated in the virtualization server and the necessary software will be installed accordingly. The solution shall be chosen based on price estimation, scalability, maintenance and occupied space also in conjunction with the experimental apparatus and other equipment for the LBTS, vacuum, etc. For the experiment, the IT systems from the interaction area will house the TANGO device servers for the equipment. In the first stage of the development, the TANGO device serves will only implement the access to the parameters of the

HW device and not the logic (*e.g.*, only the means to send commands and receive the status from a motor and not the logic to perform an automatic alignment). Because a long period of testing, development and adjustments will be needed for the implementation of the logic, this will be made at the HMI layer and not inside the device server. LabVIEW and Matlab are envisaged to implement the GUI and the logic at the Users level. The machines housing the TANGO drivers (device servers) for equipment will also have additional clients where the user will be able to control the hardware device in particular.

In the following we will refer to the client as being the hardware and the HMI inside the interaction area, where the user have access to setup his experiment. The client will have an HMI where all the parameters of a device that can be controlled or monitored are available. The supervision will be the hardware and software that allows the user to remotely access the parameters of the devices. Usually, the supervision will allow less access to the parameters of the devices than the client, for security reasons. In the current configuration, the user will also be available to access the supervision software from the interaction area.

The devices and their associated implementation are as follow:

- Target manipulation system – Device Servers for motor drivers API in TANGO, supervision software and logic in LabVIEW and afterwards in TANGO specific application.
- Alignment based on CCD cameras – drivers for camera in TANGO, supervision software and mathematics for image recognition, etc. in LabVIEW and Matlab.
- Target Insertion System (2 possibilities to be tested for the best performance)
  - Complete control in LabVIEW and integration with TANGO as a Device Server. This requires a TANGO-LabVIEW translator. Useful to see any LabVIEW application as a device server.
  - TANGO Device Server for motor drivers API, logic and supervision software in LabVIEW or TANGO specific application.
- Delay generator – drivers in TANGO, supervision software in TANGO or LabVIEW.
- Controls and drivers for DAQ system in LabVIEW, remote desktop to be used in the beginning.
- CCD from the detection – (2 possibilities)
  - Driver in TANGO; supervision software and image processing, logic in LabVIEW and Matlab.
  - Driver and logic in TANGO; supervision software in LabVIEW.

As the development will advance and satisfactory working solutions that do not need any longer development will be obtained, the mathematics and logic from the supervision HMI and client HMI can be progressively shifted from LabVIEW and Matlab to the device servers themselves as presented below.

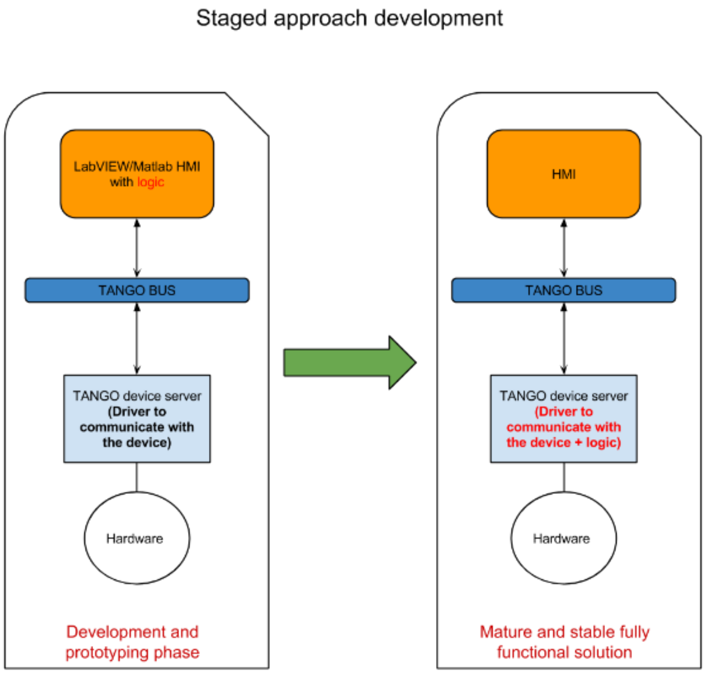

Fig. 40 – Staged approached development for TANGO drivers and logic/mathematics for experiment control.

The other specific detection equipment, will first be implemented with remote desktop access control if no TANGO interface already exist implemented for the device. For the data output from the detection system (CCDs, DAQs, etc.) no specific file format exists. Dedicated high throughput links will exist either connected directly to the data storage system, either intermediate PCs will be added by the user to encapsulate, manipulate or process the data and put it in the correct format for storage in the ELI-NP data storage system, as presented in Fig 1. For the web access to the data from the experiment, the figure below presents the proposed solution. A VPN connection will be used to secure the PC that access the data. The VPN will be installed a priori to the PC of the user that is granted the access to see the data of interest.

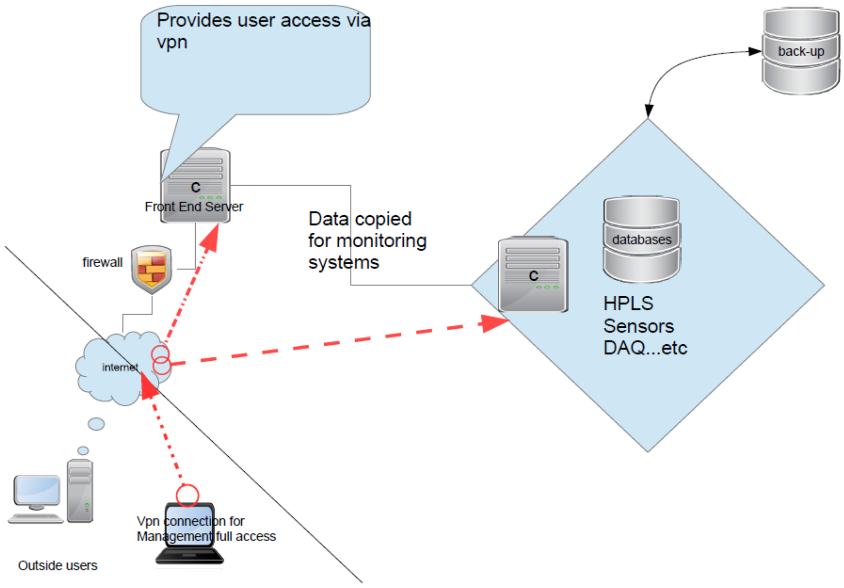

Fig. 41 – Proposed external access to the data of the experiment.

8.8.5 Experiment implementation

The system implementation is presented below. The Supervision layer refers to the equipment and services placed inside the DAqR and UsR. For the data storage, a virtualization server will be used to assign a data slot for the experiment needs. This data storage will only accommodate the short term data storage of the experiment (*e.g.*, 6 months), following that after this period the data to be placed in a larger data center, proprietary to IFIN-HH. A tape system is envisaged as a solution for long term backup.

In the UsR and DAqR, the user will have multiple computing stations (general PC) with multiple monitors. A total of 5 monitors is considered sufficiently to display the information related to the LDNP experiment, as detailed in the first stage of development. A number of three computers is considered sufficiently to perform the logic and mathematics in the HMI (LabVIEW or Matlab at this stage).

For the TIS, a PC with a supervision HMI that holds also the logic is considered sufficiently to perform all the required tasks. For the TAS, an industrial PC will hold the drivers to control the manipulator, CCDs and the delay generator used in the experiments. The PC will also have the clients HMI to access the parameters of the above mentioned devices.

Two solutions will be tested for the best performance:

- The logic for the manipulation system and the logic for the CCD cameras processing can be implemented each in separate HMI LabVIEW or Matlab clients, on the local Control layer, and the processed parameters accessed in the supervision of the TAS, another HMI LabVIEW or Matlab, at the remote operator level. The approach will be tested for processing speed and reliability. Additional development is needed to interface a LabVIEW application as a TANGO device server.
- The entire control is implemented directly in the supervision HMI, at the remote operator level. This solution can burden the CPU of the supervision HMI at the remote operator level.

Figure 42 represents the experimental setup and associated detection and control. The Hardware architecture and equipment is presented in Fig. 43.

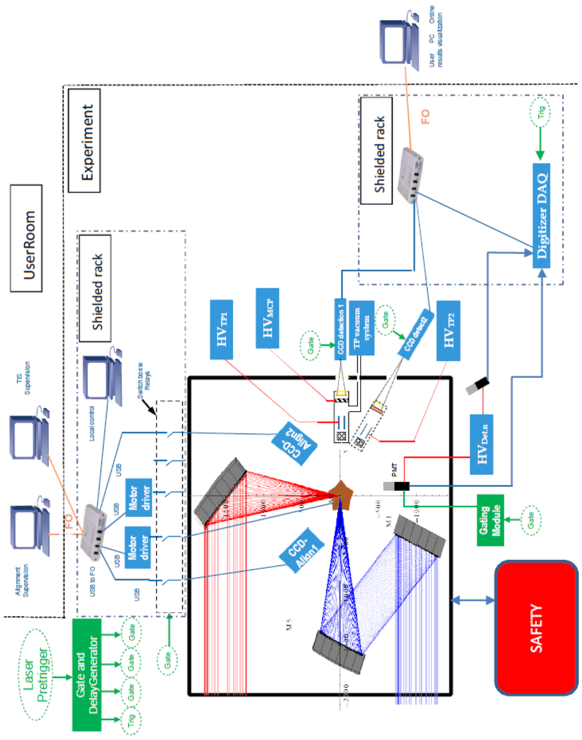

Fig. 42 – Schematic of E1 experimental setup systems and connections with the experimental area racks and UsR.

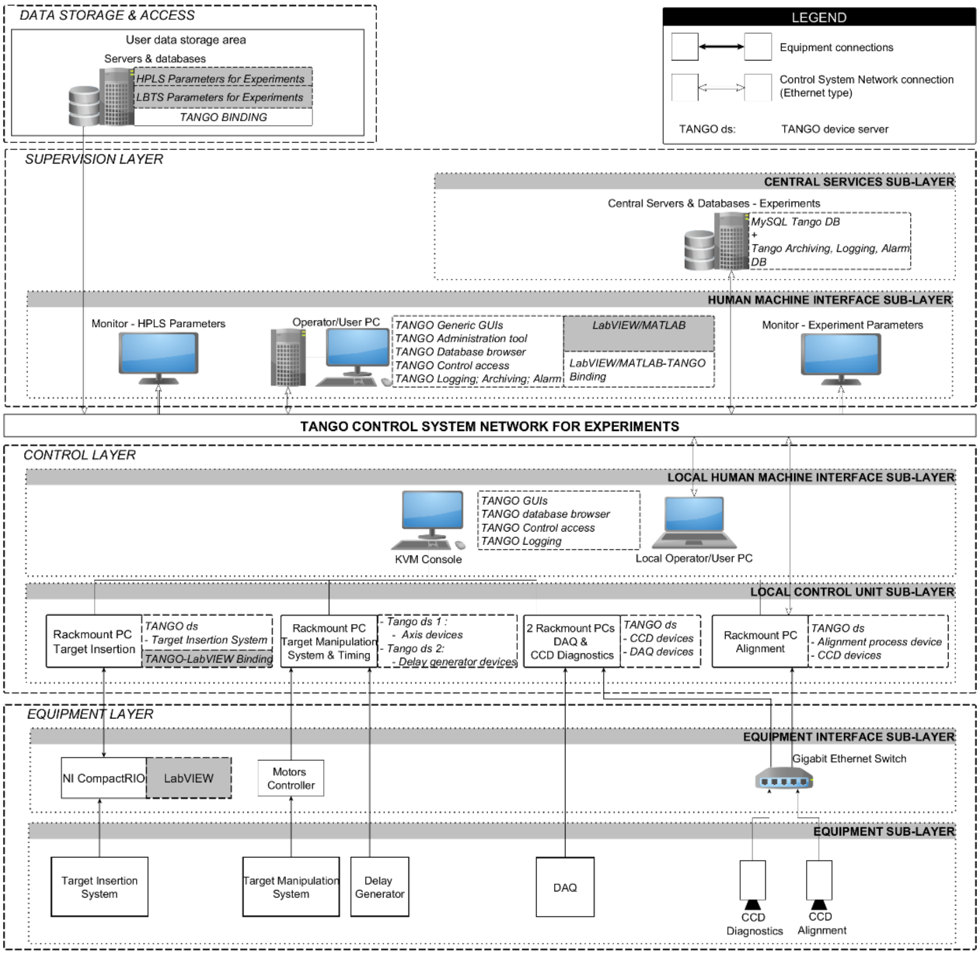

Fig. 43 – Example of E1 experiment Hardware Architecture Model with CCDs, motors and delay generator.

8.8.6 Equipment estimates

In order to implement the setups, equipment will be considered for:

- Control remotely the TIS.
- Control remotely the TAS.
- Provide a short term storage (6 months) to save the experimental data.
- Control remotely the delay generators for various equipment that needs to be triggered at a defined moment in respect to the HPLS pulses.

- Control the parameters of the detection: acquisition boards, CCDs and view the results in the DAqR and UsR.

8.9 CONFIGURATION AND SIMULATION FOR NUCLEAR RESONANCE FLUORESCENCE EXPERIMENT (E8)

The general layout of the experiment is the following:

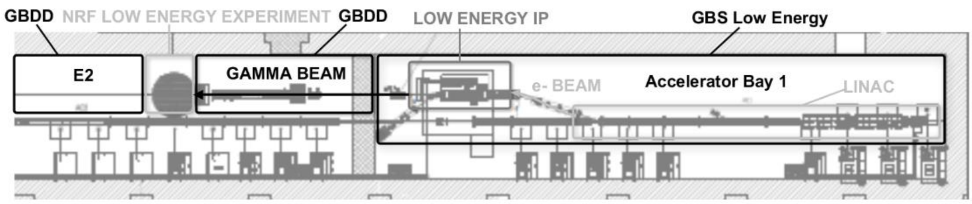

Fig. 44 – NRF low-energy experiment position map.

The GBS in Accelerator Bay 1 is composed by one linear accelerator that will provide an electron beam. This beam interacts with lasers at the low-energy interaction point at 100 Hz frequency. This interaction produces a gamma beam with an energy of 3.5 MeV. The gamma beam is transported to the E2 experimental area via the Gamma Beam Delivery and Diagnostics system. Finally the ELIADE detector and its associated systems (Target systems, ELIADE detectors, ELIADE DAQ and timing system) form the setup used during a Nuclear Resonance Fluorescence experiment.

A simulation for the equipment and running procedures involved in the NRF experiment is presented in the following sections.

8.9.1 Equipment involved in the experiment description

Besides, the GBS and the GBDD systems, one NRF experiment with a low-energy beam will include the target systems, the ELIADE detectors, the ELIADE DAQ and the timing system.

The target alignment system will consist of the CCD black box, the collimator pipe, and the target pipe as depicted in subsection 5.1.2. The ELIADE detector will be the one presented in subsection 5.1.4.1, consisting of clover and LaBr3 array detectors. The detector will need vacuum and temperature control using the National Instruments compactRIO integrating and managing the LN_2 filling system and high-voltage power supply units.

As explained in the section 5.1.3, the ELIADE DAQ crates will be monitored. The monitoring of the DAQ crates physical parameters are nowadays achievable by the use of power supply units and fan tray containing a microcontroller and providing CAN, Ethernet or RS-232 ports. This enables the remote monitoring of the power supply parameters (voltage, current, limits set-up, etc.) and fan tray parameters (voltage, current, power, temperature, speed, etc.). Regarding the logical parameters, two major solutions have been developed:

- Local control of the single board with another one: the VME System Monitor Board developed in the Argonne National Laboratory [42] is one example.
- Remote control of the boards of the crate by the use of a PC running a server that maps the memory location of any board installed on crate. This enables the access to the registers and the FIFO's of each board. This system has been developed in the Canadian Light Source [43].

The two solutions detailed for the logical parameters can also be used for the physical ones. At a first stage, the requirements are to remotely control the physical parameters, via a HMI in the UsR.

The solution for timing system, as presented before (see section 8.6), will be based on a system that outputs a trigger signal and a tag identifier. Inside the GBS machine, each tag identifier will be logged with the correspondent machine beam diagnosis data or other data of importance (*e.g.,* flash lamp pulse number). The second solution is to use the NTP server and synchronize all PCs with a GPS in order to have the same timestamp.

8.9.2 General experiment systems, machine setup and running steps

In this section, the setups and the experimental flow for NRF experiment are detailed.

GBS

The beam parameters set or measured in the gamma beam system will be accessible for the user in the UsR.

Experiment Safety

The safety of the persons working in the facility will be handled by the ELI Personal Safety System. The scope of the ELI PSS is:

- The control access in the areas where a risk exists (this supposes that all the risks have been evaluated).
- The monitoring and alarm of the radiations level in the facility areas.
- The respect of safety procedures related to the use of dedicated components/systems for the experiment (liquid nitrogen, high-voltage, vacuum, etc.).

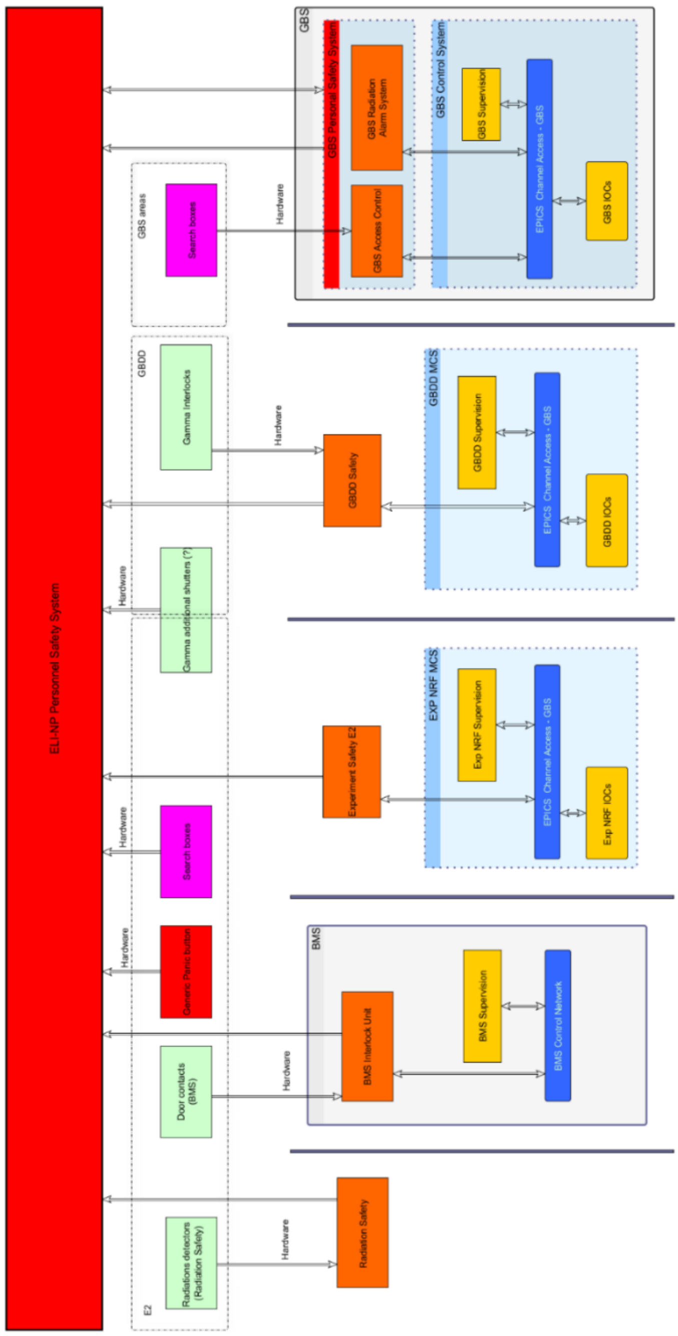

Fig. 45 – GBS Safety system in correlation with other ELI-NP safety systems.

The ELI-PSS has to handle all the risks induced directly by the different phases of all the experiments (Set-up, Start, Run, and Maintenance).

The ELI-PSS will supervise several safety sub-systems distributed in the facility. The GBS Safety System will handle the access control to the GBS machine areas and implement a radiation alarm system in these areas [1]. The interfaces with the other systems is schematically presented in Fig. 45.

The GBDD Safety System will collect interlock signals in order to avoid any vacuum risks. An experimental area Safety System will cover all the risks that could happened during the different phases of one experiment (calibration, set-up, run, and maintenance). The access in the experimental area will be provided through the BMS Door Interlock system and the Radiation Monitoring System will monitor the radiations level in the entire facility.

Experimental Flow

The steps of the experimental setup for the NRF experiment taking place in E2 are the following:

Safety

The setup involves the presence of the users in the experimental area. An "access safety procedure" will be followed each time the user want to enter in this area. This procedure shall ensure that:

- The level of radiations in E2 has to be under the threshold given by the radiation safety sub-system.
- The access to the E2 area is impossible if the accelerator is ON.
- The presence of one person in E2 will be continuously indicated to the ELI-PSS.

A "safety experiment request" should be followed each time a user ask for running an experiment using the gamma beam. It will consists of a search procedure inside the experimental area by an assigned person. After the search is completed, the radioprotection door is closed. All the different safety systems will give their status to their master, the ELI-NP PSS. This latter will then enable or disable the start of the experiment and will provide this information to the user.

GBS set-up

A server will be present and the software interfaces available to extract the information from the GBS database to the user’s database. The GBS database accessible to the user will generally have only information regarding the output beam properties of the system. The user will not be allowed to modify any of the beam parameters or fire shots but only request this to the GBS operators.

GBDD set-up

Users will be able to extract the beam information of the diagnostics installed in the GBDD in their predefined storage area. A server will be present and all the software interfaces available to extract the necessary information of the machine.

Experimental equipment setup

The user with the help of operators and technicians will first mount the ELIADE target pipe and CCD black box in E2 area. Afterwards, the alignment of the collimator pipe with the beam will be done. This alignment must be performed in the UsR using an attenuated gamma-ray beam. Once this step is completed, the target is manually inserted inside the target pipe. The vacuum in the ELIADE IC is also manually started. For the ELIADE HPGe crystals set-up (temperature and bias voltage), each dewar has to be connected to the transfer lines of the LN_2 filling system. All the temperature channels of the HPGe crystals must be connected to the controller (NI compactRIO). The high-voltage power supply units have also to be connected to this latter. The final adjustment will be made locally by the usage of the rackmount PCs along with the local human machine interface. Once the configuration is done, this latter shall be save in the User database.

Data storage setup

The data storage depends strongly on the DAQ and timing systems implemented. The following features are envisaged:

- Processing of the raw data by the use of fast read-out PC (*e.g.,* one read-out PC with several fiber ports or with a PCI-express card linked to one/several digitizers).
- Replication of raw data on dedicated storage disks for backup/recovery.
- Storage of the processed data in a data storage system similar to the one designed for the laser experiments, see Fig. 36.

If the user wants to integrate new equipment for the experiment, he will use local EPICS clients or by using other IDEs (bindings with EPICS/TANGO will be provided). Moreover, he will decide what kind of values of interest must be archived, what the settings of the alarms are and what errors logs have to be taken into account. To summarize he will set the central services. He should also configure a part of the timing system (trigger delay, width, etc.).

Experiment run
Before starting the safety process, the user will start the EPICS supervision clients located in the UsR. The "safety start experiment request" will be launched. If this request ends with an "OK signal" by the ELI-NP PSS, the experiment can start. During the experiment, the users will visualize on a dedicated monitor the diagnostics parameters provided by the GBDD and the beam parameters of the GBS.

The user will monitor the controller that performs the auto-filling system. This monitoring includes the surveillance of both the hardware status and crystals critical parameters: temperature and voltage. The low-voltage power supply for $LaBr_3$ detectors and the vacuum level inside the ELIADE IC have also to be monitored. Further on, the timing system will be controlled together with the physical parameters of the ELIADE DAQ front-ends (the control of the logical parameters will not be achieved in a first phase). The alarms status, error logs and archiving values of interest will be also provided. These features are referred as central services.

During the experiment, the user can request new beam parameters (*e.g.*, energy, as in the gamma driven experiments, and in particular NRF requires the use of different energy of the beam). When the user wants to modify this parameter, he has to send the request to the GBS operator via the Control System Network (EPICS CA) or by phone. In both cases, this request has to be logged and archived in the central services. As previously detailed, the ELI-NP facility will host several sub-safety systems that will be interconnected through the ELI-PSS. All the workflow presented in this section must be done according to safety procedures and configurations allowed by the ELI-PSS and its subsystems.

8.9.3 Experiment Implementation

The following describes the hardware and software implementation associated to the NRF experiment. However, hardware and software from the GBDD Control System will also be used. The central services implementation is common to all the Gamma based experiments and will be also used for the GBDD Control System.

Hardware
The goal is to purchase the same type of hardware in the entire facility, to the largest possible extent. One rack is envisaged inside or outside E2/E8, movable from E2 to E8. The NRF rack should contain:

- Control Units
    - 1 industrial PC for the motors used for the collimator pipe & ELIADE IC vacuum.
    - 1 compactRIO used for the control of the LN_2 filling system and the high-voltage power supplies.

    - 1 industrial PC for the control of ELIADE DAQ front-ends and timing system.
- Local HMI:
    - 1 KVM switch with 4 ports and 1 KVM console or 1 HMI Touch Panel
- 1 Power Distribution Unit (PDU).
- Control Unit – Equipment interface: 1 Switch 48 Ethernet ports and 1 patch panel.

One desktop PC with several monitors inside the UsR is considered as the supervision computer that will ensure the monitoring of the ELIADE IC vacuum, the control of the ELIADE DAQ and timing, the monitoring of the temperature and voltage of HPGe crystals.

For data processing computers, the solution envisaged is the usage of real-time industrial PCs for DAQ front-end read-out, with 4 industrial multi-cores PC with four 1/10 Gb ports (optical link). These PCs will have also the possibility to integrate PCI-e cards. These data will be then sent to the data storage area (ELF) located in the DAqR.

Software

The Operating system is envisaged to be Scientific Linux except for the platforms that require real-time operating system (*e.g.*, timing platform or NI compactRIO). On all the computers described above, the EPICS base will be installed. Others EPICS extensions and modules will be added. They will depend on the IOC implemented.

A number of EPICS IOCs are being considered for:

- Target alignment system:
    - One software IOC for the motors moving for the collimator pipe
    - One software IOC for controlling the CCD camera and the images acquisition
- ELIADE detectors:
    - One software IOC will be used for interfacing the vacuum system controlling both vacuum in GBDD and in ELIADE IC.
    - Implemented directly on the compactRIO: one hardware IOC for monitoring the LN_2 filling system, the temperature and the voltage of the HPGe crystals. It will work along with LabVIEW. This feature has already been implemented [44].
- ELIADE Timing: the implementation will depend on the solution chosen but one hardware IOC for the set-up of the timing/synchronization parameters will be implemented on the PC interfacing the timing system.
  ELIADE DAQ: one software IOC for the control of the physical parameters from the ELIADE DAQ front-ends.

A number of CSS clients are also considered: BOY, archive, alarm. All of them will used the CSS security feature. The logging will be ensured by the logging package included in Java. These clients will be installed on all the industrial PC listed above. The local clients will provide an easy access to the hardware equipment or its interface via the EPICS IOC.

The supervision software will be the software installed on supervision computers allowing the user to remotely access the parameters of the devices. Usually, the supervision will allow less access to the devices parameters than the client, for security and bandwidth reasons. The supervision software will also implement along with Central servers and databases, the central services detailed previously. An EPICS health IOC monitoring is also envisaged.

The preliminary General architecture model is presented below.

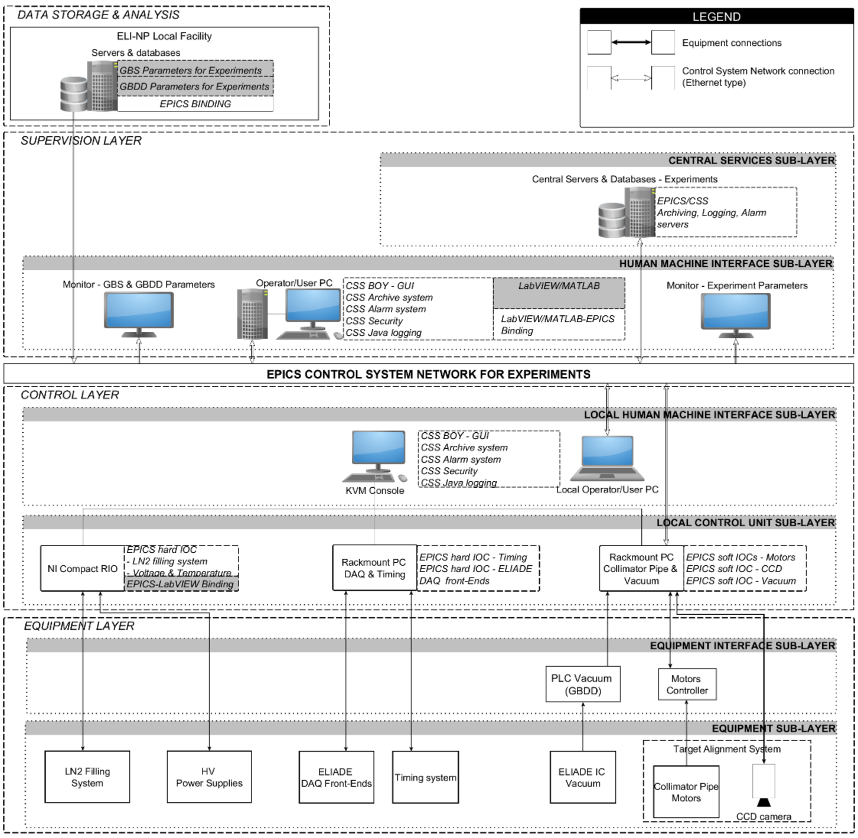

Fig. 46 – NRF experiment Hardware architecture model.

8.9.4 Equipment estimates

Each area will have one of multiple racks with the following minimum requirements:

- Each rack has its own air cooling unit.
- Each rack will provide space for BNC and connectors patch panel.
- Each rack provides minimum UPS power supply to support the Industrial PC and other equipment installed respecting ESD protection requirements.

Industrial PCs mounted in racks will have a fiber connection that will provide the link to the remote monitoring clients. The racks will be distributed near the experimental areas and will provide the slow control for the equipment. A storage server will be located in a dedicated data center which will allow the storage/processing of the data according to the needs.

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