THE TURN-KEY CONTROL SYSTEM FOR THE ELI-NP GAMMA BEAM SYSTEM

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Abstract

The new Gamma Beam System (GBS) [1] under construction in Magurele (RO) by the consortium EuroGammas is led by INFN, as part of the ELI-NP project, can provide gamma rays that open new possibilities for nuclear photonics and nuclear physics. In the ELI-GBS, gamma rays are produced by means of Compton back-scattering to get monochromaticity (0,1% bandwidth), a high flux ($10^{13}\ \frac{photon}{s}$ the highest in the world), tunable directions and energies up to 19 MeV. Such gamma beam characteristic is obtained when a high-intensity laser collides a high-brightness electron-beam with energies up to 720 MeV. In order to increase the gamma beam flux, the electron beam operates at a repetition rate of 100 Hz in a multi-bunch mode: trains of 32 bunches, 16 ns apart, interact with the laser pulse recirculated 32 times through the interaction point. The EPICS Control System collects data from all sub-systems, constantly monitoring to ensure the safety of the ELI-GBS facility. This paper describes all the aspects of the ELI-GBS turn-key Control System, such as hardware integration, micro-bunches diagnostics, high level applications, the data network and the pico-second timing system.

ARCHITECTURE

Control systems for large experimental physics facilities usually have a 3-tier structure.

1. User interface. These are graphical and non-graphical user interfaces.
2. Central services. Services that need to run continuously irrespective of user activities, e.g., for archiving process variables' values, monitoring alarm states, etc.
3. Equipment interfaces. This tier is responsible for interaction with equipment and devices. It provides an abstract representation of equipment to higher layers through which the equipment can be monitored and controlled.

The control system (CS) of the ELI-GBS is based on EPICS, which is a distributed control system framework based on a client-server architecture. It defines a communication protocol, the Channel Access (CA) protocol and messages are transferred via Ethernet. The Equipment interfaces tier is represented by the EPICS servers - Input/Output controllers (IOCs). EPICS IOCs communicate with hardware devices and expose their parameters through CA. Central services (Archiver, Alarm handler, Logger) and user interfaces (GUIs) are EPICS clients that use CA to access device parameters. The EPICS framework has a long history and it is a common standard for many scientific facilities around the world.

Devices in the control system are grouped by subsystems:

- Diagnostic sub-system: Beam Position Monitors (BPM), Fast Current Transformers (FCT), CCD cameras, screen motion control, gated camera.
- Laser sub-system: photo-cathode laser, power lasers and laser transport lines.
- Radio Frequency (RF) systems: modulators, Low Level RF (LLRF) and RF motion (attenuator and phase-shifters).
- Timing system at 100 Hz.
- Vacuum sub-systems.
- Magnet sub-systems.
- Conventional facilities sub-system.

Each subsystem includes a number of device types, which repeat along the beam path. A properly designed control system simplifies scalability of the system. To integrate a device of a specific type into the control system, an abstraction called a "vertical column" (VC) was introduced. The VC specifies the whole stack of HW-SW for particular device type, starting with the device sensors and progresses up to the GUI. In this way, CS development is split into chunks of work which simplifies requirements elicitation, development, testing and integration and which in turn simplifies management of the overall CS development.

A vertical column approach, see Fig. 1, helped to identify and standardize the required equipment along the entire ELI-GBS machine. Furthermore, having similar types of equipment in each VC reduces the number of required spare parts and simplifies maintenance of the machine.

A set of development guidelines and conventions, based on the CODAC Control System guidelines, was produced to standardize CS development. The development process reused the EPICS modular system, packaging and continuous integration process from CODAC. This ensures that any custom, ELI-GBS specific, development, is done in a standardized and coherent manner.

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ISBN 978-3-95450-147-2

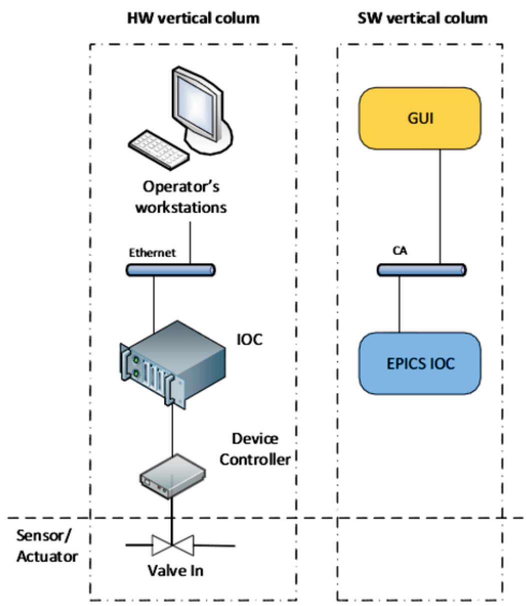

Figure 1: Vertical Column concept. Hardware and Software models comparison on the left.

MICRO-BUNCHES DIAGNOSTICS

ELI-GBS Beam Diagnostics includes common hardware to monitor electron bunch trains like 28 strip-lines BPM read from Libera Single-pass system with integrated IOC or 22 OTR beam screen monitors in which several IOCs acquire signal from Basler Scout GigE CCD cameras and related Technosoft screen motor driver.

Beam Diagnostics is equipped also with some dedicated hardware to investigate micro-bunches properties.

Fast Current Transformer

Along the LINAC 4 Fast Current Transformer toroids are acquired through Keysight M9210A 10-bit 4 $\frac{GS}{s}$ digitizers to monitor not only the train charge but also the charge of each one of the 32 pulses.

Cavity Beam Position Monitor

2 Cavity BPMs, acquired with a Libera systems with IOCs, are placed before and after each interaction point to monitor the 32 electron beam pulses trajectory at the Compton sources with a sub-micron resolution to make possible a fine tuning of the electron beam and then control properties of the produced gamma beam.

High Efficiency Gated Camera

An Hamamatsu high efficiency gated camera ORCA – flash 4.0 with intensifier able to run with high quantum efficiency over 70% a rise time of 5 ns and high-speed readout up to 100 $\frac{frame}{s}$ thanks to camera link protocol it's used to photograph each one of the 32 pulses and compute the transverse emittance of each pulse. Due to the constraint of the camera link cable maximum length, a dedicated industrial PC is placed near the Hamamatsu camera inside the radiation area (shielded to avoid radiation damage). Such camera is provided with its own camera link acquisition software, based on Windows OS and able to stream data over TCP protocol, that runs with a LabVIEW wrapper collecting data from the TCP socket to the EPICS channel access.

HIGH LEVEL APPLICATION

Over the hardware integration on the EPICS CA there is another layer devoted to the slow-control and elaboration of data to compute several analysis to monitor the accelerator working status.

We define two groups of tools: one for general purpose and one for beam diagnostics, see Fig. 2 and 3. In both cases PVs are acquired from the channel access, processed by a dedicated IOC, designed for intensive workload, and then results became available again on the CA to be achieved by the CS and ready for additional analysis.

With this solution data produced on this layer are easily available on the CA, these information with all other PVs from hardware IOCs are used from Matlab Middle Layer, to optimize accelerator's working point, or used from accelerator users to run their own analysis tools through available CA interfaces in C/C++, LabVIEW or Matlab.

DATA AND TIMING NETWORK

The ELI-GBS data network is a star-center architecture based on a CISCO 4500-X, with throughput of 10 GBit on single-mode fiber connections, that opens on 7 CISCO 2960 switches distributed in the whole facility where FTP connections, with 1 GBit throughput, are available for different purpose.

The data network manages different VLANs to encapsulate traffic from different user, there are a dedicated VLAN for EPICS channel access, laser and gamma beam diagnostics control system that are partially out of the EPICS CS, personnel and machine safety, and a VLAN for utility (oscilloscope, probes, etc…) for general purpose use and easily extendible with a dynamic DHCP.

The timing system is based on the MRF platform, available with mrfioc2 EPICS support. The timing sequence is repeated at a rate of 100 Hz, controlled by an external trigger synchronized to the mains. An event clock of 62.08 MHz, which sets the resolution of the timing system, is derived from an externally provided OMO (optical master oscillator).

The ELI-GBS timing network is star-center architecture based on a central optical fan-out streaming the 100 Hz signal from the Event Generator (EVG) to 8 fan-outs distributed in the whole building where the signal could be converted from optical to electrical from Event Receivers (EVRs).

The ELI-NP timing system is configured remotely through a GUI. A configuration file in JSON format holds the sequence of timing events and their times of emission, together with additional parameters controlling the response of the multitude of available EVRs. This setup allows the operator to configure the complete timing network from one central

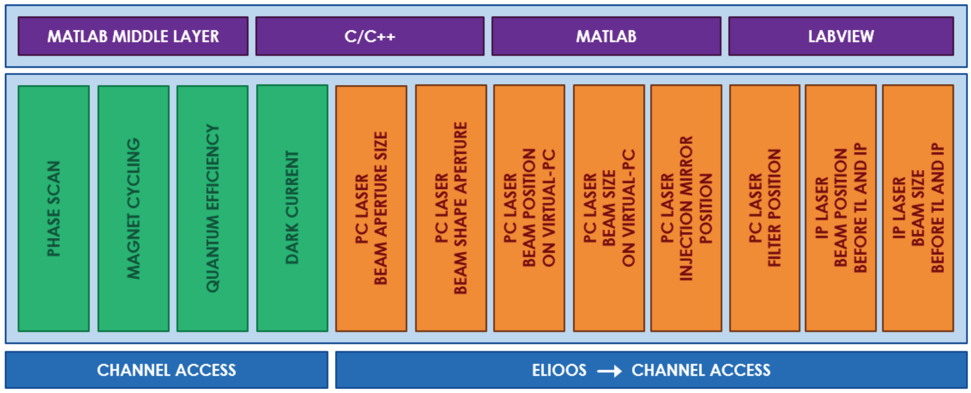

Figure 2: General purpose tools; in green electron beam tools, while in orange laser and gamma beam tools. The first bunch of tools get information directly from the EPICS CA while the second bunch uses data collected from the laser systems CS, called ELIOOS, which shares data on the EPICS CA.

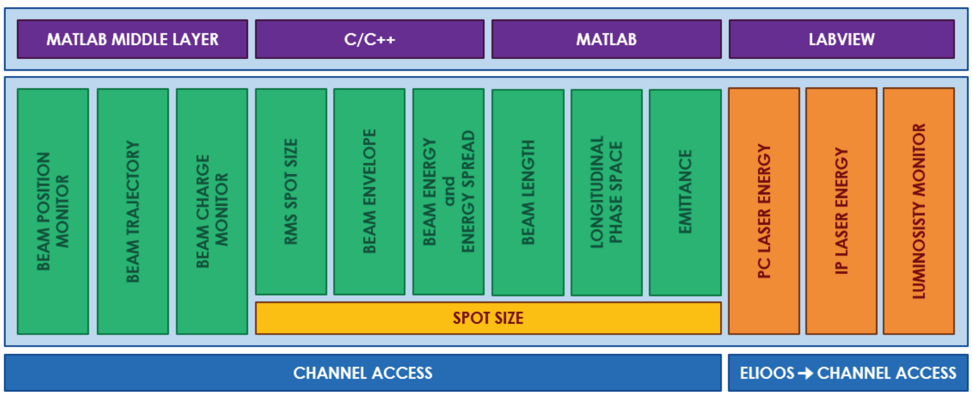

Figure 3: Beam Diagnostics tools; in green electron beam tools, while in orange laser and gamma beam tools. The first bunch of tools get information directly from the EPICS CA while the second bunch uses data collected from the laser systems CS, called ELIOOS, which shares data on the EPICS CA.

location, load the configuration and start the sequence from the GUI.

Dedicated operator screens are provided to control the triggering of EVRs to specific events, such as pulse width and polarity as well as additional delays to fine tune the EVR response on the fly. Any changes can be stored conveniently from the main screen and are logged for future reference.

Timing Reconfiguration Delay

An additional feature is the trigger delay reconfiguration functionality. It is designed to enable visual beam diagnostics by controlling the Hamamatsu high efficiency gated camera that photographs individual electron bunches. These bunches are grouped in trains of 32, repeated every 100 Hz as dictated by the external trigger.

The individual micro bunches are 16 ns apart, the resolution provided by the event clock, see Fig. 4. The operator can control the operation of the camera through the GUI by tweaking the trigger delay on a dedicated EVR. The goal is to acquire an image of each individual electron bunch. This means that it takes at least 32 RF cycles to get an image of each micro bunch, which corresponds to an array of 32 delays.

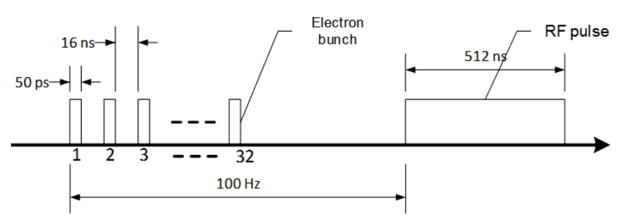

Figure 4: 32 Bunches train temporal structure.

CONCLUSION

This is the Control System architecture developed for the ELI-GBS facility to collect data from different systems and compute data analysis of the challenging electron, laser and gamma beam.

REFERENCES

[1] *L. Serafini et al.*, "Technical Design Report EuroGammaS proposal for the ELI-NP Gamma beam System", arXiv:1407.3669, 2014.

ISBN 978-3-95450-147-2