ELI-NP GAMMA-RAY BEAM SYSTEM - STATUS UPDATE AND FUTURE

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Abstract

The high brilliance ELI Gamma-ray Beam System (ELI-GBS) is under implementation at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) in Romania. The system uses an 800 MeV S-band accelerator driver as an Inverse Compton Scattering (ICS) source coupled to an interaction laser and in the future to a high-finesse optical cavity. The γ-ray beam will be available with energies up to 19.5 MeV to drive an ambitious scientific program which requires high spectral density (larger than 5×10^3 photons/s/eV), narrow bandwidth of 0.5%, and linear polarization higher than 95%. The ELI-GBS is foreseen to be finalized in an initial configuration in 2026. Details of the status of the LINAC commissioning, electron - laser interaction system design, and challenges for completing the system are presented.

INTRODUCTION

The ELI-GBS consists of all components necessary to create, accelerate and inject bunches of electrons into an interaction point (IP) for the collision with photon pulses from a dedicated laser system. It consists of six main parts:

- RF electron source
- Linear accelerator (LINAC)
- Electron Transfer Line (ETL)
- Interaction laser system
- Interaction chamber (IC) / optical cavity (OC)
- Electron beam removal and beam dump

The electron bunch is created in the RF electron source shown in the lower right corner in Fig. 2. The bunch is then accelerated in the linear accelerator, transported into the IP where it interacts with laser photons from the interaction laser system. After the electron-photon interaction, γ-ray photons are emitted in the forward direction along with the electrons which are deviated using magnetic fields into a beam dump. The Gamma-ray Beam System design presented in this paper is new and different from previous designs, EuroGammaS design from 2014 [1] and the VEGA design from 2019 [2, 3].

RF ELECTRON SOURCE

The RF electron source is composed of an 1.6-cell RF gun, 11-cell SW booster cavity, solenoid magnets, UV laser, and optical transport assembly. The RF power comes from the 7.5 MW klystron through the waveguide system and enters a 3 dB hybrid, which symmetrically splits the power to the RF gun and the SW booster cavity. The entire system was designed to produce low emittance (ϵ_{xy}< 5 µm), synchronized electron pulses at pulse repetition rates up to 50 Hz with an energy of 13 MeV at the exit of the booster cavity.

Electron bunches are generated in the RF electron source by illuminating the photocathode by ultraviolet picosecond pulses from the injector laser. The injector laser is a commercial industrial class laser system called PHAROS, produced by Light Conversion, comprised of oscillator, pulse stretcher, regenerative amplifier, pulse compressor, and nonlinear harmonic generation stages. Both oscillator and regenerative amplifier are based on Yb:KGW crystals that are pumped by diodes with 980 nm wavelength . UV pulses will be delivered to the photocathode via the UV transport system which directs the beam towards a pair of steering mirrors mounted near the vacuum window.

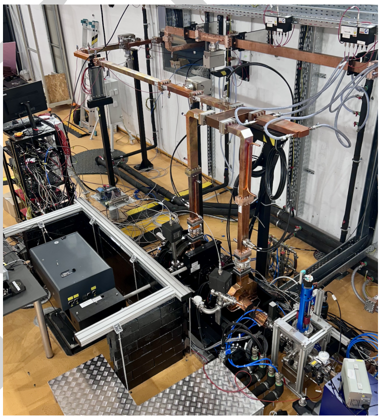

Figure 1: View of the RF electron source, waveguide system, and injector laser on position at ELI-NP.

The RF electron source is fully installed as shown in Fig. 1, connected to the klystron, and receiving RF power for ongoing RF conditioning as of April 2026. The system is under UHV of a few times 10^{-9} mbar. The UV laser and optical transport assembly are fully commissioned. Laser - RF synchronization is achieved by using a commercially available PhaseLock device from TEM Messtechnick.

LINEAR ACCELERATOR

The LINAC consists of five accelerating modules, each with four accelerating structures, with two beam diagnostics stations for beam commissioning and tune up. The main electron beam parameters are summarized in Table 1.

Accelerator Modules

High-power RF pulses are generated by Canon klystrons with a nominal rating of 50 MW, each powered by a solid-

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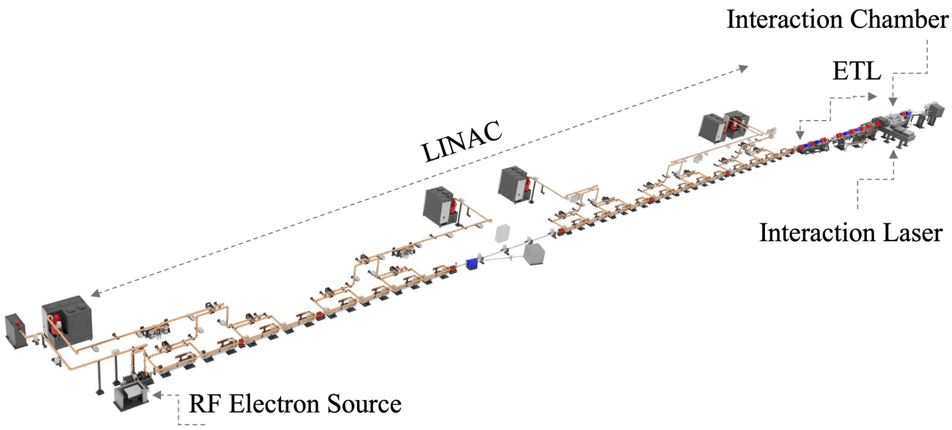

Figure 2: Layout of ELI-GBS, including main components: RF electron source, LINAC, electron transfer line (ETL), interaction chamber, and interaction laser.

Table 1: Beam Parameters at the End of the LINAC

Parameter	**Value**
E_{linac} - Energy at the end of the LINAC	150-750 MeV
ϵ_{xy} - Normalized emittance (x and y)	3.5 µm
σ_z - Bunch length rms	0.48 mm
σ_δ - Relative energy spread	$5.3{\times}10^{-4}$
$\beta_{x,y}$ - Twiss parameter β (x and y)	10 m
$\alpha_{x,y}$ - Twiss parameter α (x and y)	-0.65

state pulsed high-voltage modulator (K300 model by ScandiNova, Uppsala) The pulsed power from the klystron is conducted through a waveguide to enter the SLED system. The SLED system is a passive RF pulse compression system which, after a phase switch, delivers about 3 times more power with ¼ of the pulse length to the first hybrid. This hybrid splits the power, which is in turn split again to feed each of the four two-meter long accelerator structures. The waveguides and spacing of the structures are arranged and tuned so that a relativistic electron bunch remains at the peak of acceleration throughout the length of the module. Each module can deliver up to 160 MeV of energy, corresponding to 20 MeV/m acceleration gradient. At the end of the module a triplet magnet system focuses the beam for acceleration in the next module. At each of these triplet or quadruplet systems there is a beam position monitor to permit steering of the beam down the LINAC to maintain alignment of the electron beam near the center of the accelerator cavities.

The accelerator structures and waveguide system are fully installed, connected to the klystron, and receiving RF power for ongoing RF conditioning as of April 2026. Partial details of an installed module are shown in Fig. 3

LINAC Magnets

The LINAC contains groups of quadrupole magnets that focus the electron beam and dipole magnets at two locations that can divert the electron beam into diagnostic stations. There are a total of 23 quadrupole magnets and two dipole magnets. Magnet power supplies are based on commercially available products from CAEN ELS.

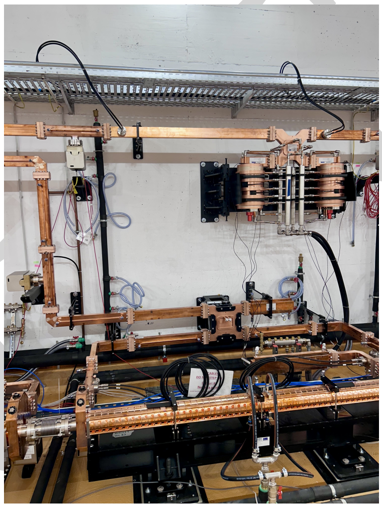

Figure 3: Partial view of installed module 5 (M5) of the linear accelerator.

Low Level RF

The Low Level RF (LLRF) and Trigger Synchronization Unit (TSU) subsystems control the RF phase and amplitude outputs as well as the global timing and synchronization. The system is based on commercial S-band Libera products from Instrumentation Technologies (i-Tech). The LLRF and TSU were successfully installed and commissioned in September 2024 [4].

Beam Instrumentation

Each LINAC module contains one Beam Position Monitor (BPM) which measures both the horizontal and vertical position of the electron beam as it passes through the set of 3 or 4 magnets in each accelerator module. The BPMs are button-type manufactured by BEVATECH GmbH with Single Pass E electronics provided by Instrumentation Technologies.

Two charge monitors will be installed to monitor the individual bunch charge. The charge monitors are commercially available from Bergoz Instrumentation, Turbo-ICT current sensor and BCM-RF-E electronics.

Five beam screens are used to detect beam size as well as the centroid. There is one right after the electron source, and one each at the start and the end of the two diagnostic stations. The front screen at the diagnostic station is used to measure emittance, and the second one is used for momentum spread measurement. The beam screens will be manufactured by Research Instruments GmbH.

Cooling Water System

The Cooling Water System (CWS), includes connections to the end devices (modulators, chillers, electronic racks, accelerator structures, waveguides, SLED's, magnets, RF loads, and RF electron source components), aims to ensure the necessary infrastructure for the operation of the equipment at optimal parameters. The main components of the CWS are: the heat exchanger, 6 Mydax precision chillers, 2 main pumps (variable speed) of 140 m^3/h each, and distribution piping network.

Control System

The ELI-GBS control system is an EPICS-based distributed system that coordinates multiple subsystems, including RF, vacuum, magnets, cooling, interlock, and diagnostics, to support beam commissioning and operation. The complete engineering-level control system architecture consists of OPI, IOC, and PLC layers, all interconnected via a high-speed local area network. This full PLC/EPICS-based engineering-level control system will be delivered by the Research Instrument GmbH in July 2026.

ELECTRON TRANSFER LINE

The electron transfer line (ETL) transports the beam from the LINAC to the interaction point as shown in Fig. 4. The beam is bent both vertically upwards and horizontally to the right to change the original LINAC electron trajectory so that it can be aligned with the position of the γ-ray beam dump which was already built and installed in one of the downstream experimental rooms.

The transport line contains dipole magnets that bend the electron beam along its path and quadrupole magnets for beam focusing. The electron beam position will be measured throughout the transport line using 20 BPMs so that the beam can be steered to be near the nominal trajectory. There will also be 5 beam screens which measure the local beam size at certain points throughout the transport line. The ETL will be designed and delivered by Research Instruments GmbH.

INTERACTION LASER

Generating high-brilliance gamma beams via Inverse Compton Scattering (ICS) requires a specialized interaction laser system as the maximum achievable energy, the energy spread, and flux of the resulting gamma rays are directly correlated with the laser parameters. The interaction laser chosen for the ELI-GBS is a custom made laser, manufactured by AMPHOS GmbH and has the following main specifications: spectral wavelength - 515nm, pulse energy - 12mJ, pulse duration between 8-16ps, beam diameter - 5mm.

LASER - ELECTRON INTERACTION

The Interaction Chamber receives the laser beam from the interaction laser and focuses it onto the Interaction Point (IP), where it intersects the electron beam at an angle of 2°. The electron beam and laser pulse interact to produce γ-rays. The γ-rays exit the chamber along the electron beam direction, downstream of the focusing mirror. The transmitted laser beam is absorbed in a beam dump or partially directed to a photodiode for diagnostic purposes. The IC will be designed and delivered by Research Instruments GmbH.

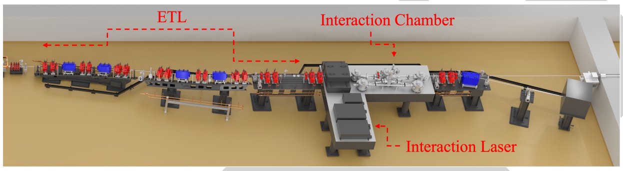

Figure 4: Overview of the ETL, interaction laser, and IC.

CONCLUSION

A new design of the ELI-GBS is under implementation with installation of the electron transfer line, interaction laser, and interaction chamber foreseen for Q4 2026. The LINAC is fully installed and undergoing RF conditioning with electron beam commissioning in the second part of 2026.

ACKNOWLEDGEMENTS

We would like to acknowledge the strong contribution of all colleagues from the Gamma System Department and support from the Technical Division at ELI-NP.

This work was carried out in part under the contract PN 23 21 01 06 sponsored by the Romanian Ministry of Research, Innovation and Digitalization.

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