# ELI-NP GBS STATUS

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*Abstract*

New generation of Compton sources are developing in different countries to take advantage of the photon energy amplification given by the Compton backscattering effect. In this framework the Eurogammas international collaboration is producing a very high brilliance gamma source for the Nuclear Physics pillar of the Extreme Light Infrastructure program (ELI-NP). At present there is a lot of effort in the mass production of all the components and in the developments and tests of the different high technology devices that will operate in the gamma beam source, like the optical recirculator and the high gradient - high average current warm C-band accelerating sections. In this paper we will provide a general overview of the GBS status and of the perspectives for the future integration phase.

## INTRODUCTION

At ELI-NP the scientific advanced potentials will be explored of a high intensity laser system (up to $10^{24}$ W/cm$^2$) joined with a high brilliance Gamma ray Beam System, in the field of Nuclear Physics and Nuclear Photonics for users, not yet addressable nowadays. Such a $\gamma$ photon beam is meant to provide a source with unprecedented quality, as already mentioned, in terms of small bandwidth (0.5 %), very high spectral density (> $10^4$ photons/sec/eV) and peak brilliance (>$10^{21}$) in the wide energy range 0.2 - 19.5 MeV. It represents a step forward in the available technologies in comparison to the present state of the art, with an expected step-up of the various beam performances by at least two orders of magnitude. Beside the ultra high quality of the electron beams the upgrade comes from the operation at 100 Hz repetition rate for the RF in the multi-bunch configuration and the circulation of the laser pulse as many times as possible at the IP that allow to increase the number of collision per second, and so the gamma flux.

In March 2014 the EuroGammas Consortium (EGS), which is led by Italy's Institute of Nuclear Physics (INFN), awarded and signed the contract to build and deliver the ELI-NP Gamma Beam System (GBS) in Romania, therefore the executive phase of the RF linac project started since then. The ELI-NP GBS is currently in its delivering phase in Magurele (Romania) with the machine divided in 36 modules each of them pre-assembled and tested before their delivery to the Magurele site as described in [1]. The completion of ELI-NP-GBS by EuroGammaS is foreseen by the end of 2018 and so a preparatory phase of the future integration of the technical plants and of the commissioning of the overall facility is already ongoing. The machine installation, that is suffering due to a certain delay in the building delivery, is scheduled by the end of 2017.

An overview status of the RF linac, the laser systems and the gamma beam characterization system will follow.

## THE RF LINAC

At ELI-NP facility the preservation of the electron beam quality is ensured adopting an hybrid scheme consisting in a SPARC-like S-band high brightness injector [2] followed by two C-band linac (low and high energy composed of four and twelve C-band cavities respectively) that trough the respective transfer lines provide the electron beam to the Low and High Energy Interaction Points (LE IP and HE IP) respectively [3, 4]. This scheme allows handling a

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bunch long enough, $\sigma_z \approx 1$mm, in the RF gun to reduce the emittance degradation due to the space charge contribution, but taking advantage of the higher accelerating gradients provided by the high gradient - high average current warm C-band accelerating sections, designed and developed at LNF [5], in the rest of the linac to compact its length.

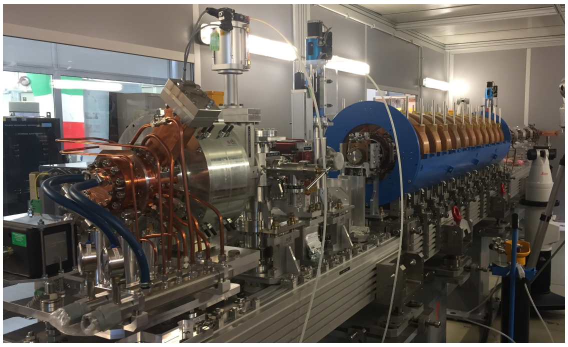

Figure 1: The photoinjector have been already assembled and aligned at INFN-LNF laboratories and is hosted on three independent modules: the RF gun and the gun solenoid are on the first module (M1), while the S-band structures on the following ones (M2 and M3).

The RF linac delivery to IFIN-HH started in 2015 and the phase II conclusion is now approaching. The photoinjector has been already assembled, aligned at INFN-LNF laboratories (see Fig. 1) and delivered at the Magurele site. It is hosted on first three of thirty-six independent modules: the RF gun and the gun solenoid are on the first module (M1), while the S-band structures on the following ones (M2 and M3). The modules from M4 to M8, hosting the first four C-band damped cavities and the relative magnets and the low energy dogleg transport line, have been also assembled and aligned at STFC and LNF-INFN and delivered to IFIN-HH.

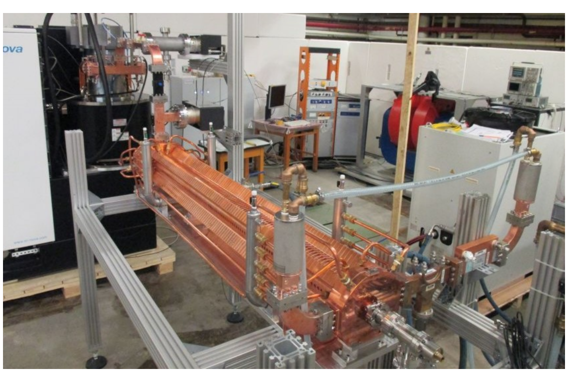

Figure 2: A C-band structure under high power test at ELSA facility (Bonn).

The RF gun and the C-band structures have been machined by the COMEB Company while the S-band structures by the Research Instrument (RI) Company. Prior to this delivery the RF gun [6], one S band structure and one full scale prototype of the C-band structures [7,9] have been tested at high power at the Bonn University under the RI responsibility reaching the nominal performances in term of gradient, repetition rate and pulse length. A C band structure under high power test is shown in Fig. 2. The production of the remaining 8 C-band structures is in progress.

As reported in [8], the RF system of the ELI-NP GBS Linac comprises 13 RF power sources: 3 S-band and 10 C-band. The RF Gun and the deflectors are powered by a dedicated 45 MW S-band unit, while two 60 MW S-band units feed the S band accelerating structures and ten 50 MW C-band sources feed individually a TW structure, except for the last 2 that feed two structures each. Every unit is composed by a Toshiba klystron powered with high voltage pulses by a ScandiNova solid state Modulator. Nowadays, all the power sources have been realized and tested successfully in factory, the first seven have already been delivered on site and are ready to be installed. The Low Level RF (LL RF) system, consisting of 13 temperature stabilized digital boards (one for each power unit) and manufactured by Instrumentation Technologies (SI), and the synchronization system, reference for the RF and the two high power lasers and fabricated by Menlo System, have been successfully tested in factory. The installation of the synchronization and LL RF systems at the Magurele site is scheduled to begin in July 2017 and next year respectively.

The magnets have been machined, assembled and measured by the Danfysik Company, except for the ones of the low energy dump line whose manufacturing is ongoing. The magnet power supplies have been fabricated by the Sigmaphi (solenoids, quadrupoles, dipoles) and the iTest (steerers) companies and the factory acceptance tests for each power supply model have been successfully performed. Further tests followed at STFC laboratories feeding the magnets of modules M4 and M8 with their respective power supplies confirming the expected magnet system requirements.

The beam diagnostics can be divided in intercepting and non intercepting devices as done in modern high brightness photo-injectors. The first category includes striplings or cavity beam position monitors and current transformers for charge measurement [10]; all such devices will be tested in properly designed bench set-ups at LNF and Alba laboratories. The second class relies on Optical Transition Radiation screen [11] or scintillating ones (YAG screens); it is used to measure the beam transverse spot size allowing also measurement of energy and energy spread (with a dipole or corrector magnet), bunch length (with a RF deflector), Twiss parameters (by means of quadrupole scan) or in general 6D characterization on bunch phase space. Most of the diagnostics devices have been produced and tested.In view of the commissioning phase high level applications to provide routine measurements and stability feedbacks are currently being developed. The framework chosen to develop such applications is the Matlab Middle Layer one, a widespread set of tools for operating light sources in a manner closer to running simulations. Applications for beam energy and bunch length measurements have been written and tested on a virtual EPICS control system environment.




ISBN 978-3-95450-182-3

Intense electron beam dynamics studies have been performed regarding the aspects that are mostly involved in the robustness, operational reliability and active and passive element constraint specifications of such a demanding machine and on the challenge introduced by the multi-bunch operation [12]. More in details start to end simulations for the RF linac have been performed to optimise the 6D phase space of the electron beam at the interaction point for the wide set of working points required by the user community together with machine sensitivity studies aiming to check the robustness of the source in terms of jitter and misalignments in the linac [13].The insertion of measured field maps in the tracking codes is ongoing for accelerating cavities (including RF couplers) and magnets as well. Results from beam dynamics studies are being also used to test the high level application tools such as the one dedicated to the beam based alignment [14].

## THE LASER SYSTEM

The photocathode laser system has to deliver 32 UV sub picosecond pulses of 300 $\mu J$ each at 266 nm central wavelength. The EGS collaboration is in charge of the development of a lossy cavity, needed to generate the 32 pulses, and of a balanced cross correlator based on two photon absorption in a GaAsP photodiode for the synchronisation on the optical master oscillator of the timing distribution system. A jitter limited by noise on the photodetectors of 300 fs has been demonstrated with a prototype balanced cross correlator. Improvement in the setup and DAQ will ensure the EGS collaboration to provide the optimal solution for ELI-NP.

The laser beam recirculator is an optical system allowing one or several laser beam pulses to be focalized a the interaction point 32 times with a constant period and crossing angle to interact with the electron bunch train and so produce 32 gamma pulses. The laser beam circulator (LBC) [15] is mainly composed by: 2 large parabolic mirrors and 31 small mirror pairs. The parabolic mirrors focalize and collimate the beam respectively. The small mirror pairs shift the interaction plan and allow the fine adjust of the optical beam path length of each circulation. The first interaction point is under assembly by ALSYOM near Bordeaux in France and vacuum tests are ongoing on the 5 $m^3$ vacuum chamber of the laser beam circulator. A prototype has been mounted by ALSYOM and LAL to develop alignment, synchronization methods and also small mirror pairs performance, especially the parallelism crucial characteristics to ensure good enhancement factor. First circulation has been observed in the 12 passes laser beam circulator prototype shown in Fig. 3.

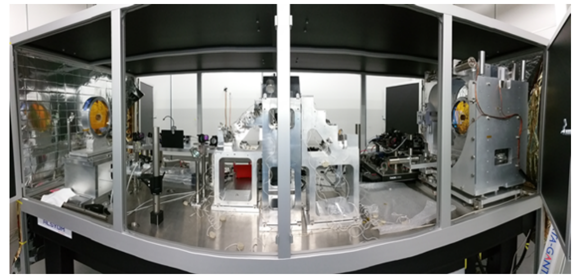

Figure 3: The 12 passes laser beam recirculator prototype has been mounted by ALSYOM and LAL.

## THE GAMMA BEAM CHARACTERIZATION SYSTEM

As a result of the inverse Compton interaction, the energy of the emitted radiation is related to the emission angle, it is maximum in the backscattering direction and decreases as the angle increase. Therefore, the required energy bandwidth can be obtained only by developing a specific collimation system of the gamma beam, i.e. filtering out the radiation emitted at larger angles. EuroGammaS collaboration will deliver this collimation system, which was designed and is currently being assembled and tested at Ferrara INFN section [16, 17]. In order to cope with such unprecedented gamma beam specifications, innovative devices and techniques have been developed to measure and monitor the gamma beam parameters to characterise the source in terms of energy distribution, beam intensity, time structure and spatial profile [18, 19]. The study, design, assembly and test of all the detectors has been carried out by INFN sections of Ferrara, Firenze and Catania. The entire collimation and characterisation system will be installed and tested at Ferrara INFN laboratories during the summer of 2017, before the shipment and installation at ELI-NP facility.

In view of the machine installation, Montecarlo simulations have been performed in order to provide alignment specifications for the collimation system [20]. The study shows that transverse misalignments of the collimation system in the range ± 200 $\mu m$ for the low energy line and ± 100 $\mu m$ for the high energy one, have negligible effects on the BW.

## CONCLUSIONS

The delivery phase of the ELI-NP GBS facility started in 2015 and is ongoing. Up to now the low energy electron beam line has been assembled and aligned at STFC and LNF-INFN and delivered to IFIN-HH for the phase II conclusion, with the photoinjector already hosted at the Magurele site. The production and development of the linac components is moving on as scheduled with the magnets, the RF power, LL RF and the synchronisation system already fabricated and successfully tested in factory and the 8 remaining accelerating cavities in their manufacturing phase. Promising results have been also obtained for high technology devices such as the S-Band gun prototype fabricated with the new clamping technology without brazing, the high gradient - high average current warm C band accelerating sections and the 12 passes laser beam circulator prototype.

The installation of all the components at the Magurele site is foreseen in the next future.

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ISBN 978-3-95450-182-3