A EUROPEAN PROPOSAL FOR THE COMPTON GAMMA-RAY SOURCE OF ELI-NP*

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Abstract

A European proposal is under preparation for the Compton gamma-ray Source of ELI-NP. In the Romanian pillar of ELI (the European Extreme Light Infrastructure) an advanced gamma-ray beam is foreseen, coupled to two 10 PW laser systems. The photons will be generated by Compton back-scattering in the collision between a high quality electron beam and a high power laser. A European collaboration formed by INFN, Univ. of Roma La Sapienza, Orsay-LAL of IN2P3, Univ. de Paris Sud XI and ASTeC at Daresbury, is preparing a TDR exploring the feasibility of a machine expected to achieve the Gamma-ray beam specifications: energy tunable between 1 and 20 MeV, narrow bandwidth (0.3%) and high spectral density, 10^4 photons/sec/eV. We will describe the lay-out of the 720 MeV RF Linac and the collision laser with the associated optical cavity, as well as the optimized beam dynamics to achieve maximum phase space density at the collision. The predicted gamma-ray spectra have been evaluated for the case at 360 MeV.

INTRODUCTION

In the context of the ELI-NP Research Infrastructure, to be built at Magurele (Bucharest, Romania) an advanced Source of Gamma-ray photons is planned, capable to produce beams of mono-chromatic and high spectral density gamma photons, up to two orders of magnitude better than present state of the art.The Gamma Beam System is based on a Compton back-scattering source. Its main specifications are: photon energy tunable in the range 1-20 MeV, rms bandwidth smaller than 0.3% and spectral density lager than 10^4 photons/sec.eV, see Table 1. In order to design a machine capable to meet these quite challenging specifications, a European collaboration has been recently set up among the following Institutions: Istituto Nazionale di Fisica Nucleare, Università di Roma La Sapienza, Université Paris Sud, CNRS/IN2P3, and STFC.

Table 1: Summary of Gamma-Ray Beam Specifications

Photon energy	1-20 *MeV*
Spectral Density	$> 10^4$ *ph/sec.eV*
Bandwidth (rms)	< 0.3%
# photons/shot within bandwidth	$2\text{-}6 \cdot 10^5$
Source rms size	10 - 30 μm
Source rms divergence	25-250 μrad
Linear Polarization	> 95 %
Macro rep. rate	100 Hz
# of pulses per macropulse	< 25
Pulse-to-pulse separation	> 15 *nsec*

THE SOURCE DESIGN

The main quality factors that characterize the Compton sources are the energy, the spectral width and divergence of the X/γ radiation yield that can be expressed in terms of energy, number and momentum of the emitted photons. These quantities can be evaluated in terms of coordinates and momenta of the interacting electrons and of the laser pulse main parameters by means of a quantum-dynamical treatment of the Compton interaction [1]; in our case, the evaluation of the output X/ rays in the laboratory frame, for the case of a gaussian laser pulse it is extensively described in [2], where, under the assumption of a circular electron beam transverse section σ_x, the total number of photons per second and within the normalized acceptance angle Psi, turns out to be:

$$N = \frac{7.4\times10^{9}\, E_L Q \Psi^2 f_{RF} n_{RF}}{h\nu_L \left(w_0^2 + 2\sigma_x^2\right)\sqrt{1+\left(\sigma_z \delta/(4\sigma_x)\right)^2}} \qquad (1)$$

where E_L is the energy of the laser in Joule, Q the charge in pC, $\Psi = \gamma_0\theta$ the normalized acceptance angle for the emitted radiation, f_{RF} and n_{RF} the RF frequency and

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*http://www.e-gammas.com/

number of bunches per RF pulse respectively, $h\nu$ is expressed in eV, w_0 is the laser beam waist, σ_x and σ_z are the transverse and longitudinal electron beam size, and δ the interaction angle. The bandwidth, deduced from the Compton relation [2,3], scales with the quadratic sum of the contributions due respectively to the acceptance Ψ, to the normalized transverse emittance ε_n, to the laser natural bandwidth, diffraction and temporal profile, similar to the corresponding classical terms:

Table 2: ELI Gamma-Ray Source Parameter List for Spectrum Simulation

Charge	*Q (pC)*	250
Energy E (MeV)	*E (MeV)*	360
Energy spread	*δE/E (%)*	0.05
Hor./Ver. Emittance	*mm-mrad*	0.5
Focal spot size	*μm*	15
Laser wavelength	*μm*	0.523
Laser rms time duration	*ps*	1.5
Laser waist	*μm*	25
Laser energy	*J*	0.5

$$\frac{\Delta\nu_\gamma}{\nu_\gamma} \cong \sqrt{\Psi^4 + 4\left(\frac{\Delta\gamma}{\gamma}\right)^2 + \left(\frac{\varepsilon_n}{\sigma_x}\right)^2 + \left(\frac{\Delta\nu}{\nu}\right)^2 + \left(\frac{M^2\lambda_L}{2\pi w_0}\right)^4 + \left(\frac{a_{0p}^2/3}{1+a_{0p}^2/2}\right)^2} \tag{2}$$

To obtain a spectral bandwidth value of $\frac{\Delta\nu_\gamma}{\nu_\gamma} \cong 0.3\%$ and a spectral density:

$$\mathrm{SPD} \equiv \frac{N_\gamma^{bw}}{\sqrt{2\pi}\,h\Delta\nu_\gamma} \geq 10^4\ (photons/s/eV) \tag{3}$$

as required for the source applications, the working point parameters have been set as reported in table 2 for the case at 360 MeV, with interaction angle of 4 degrees. The total number of photons and relative bandwidth has been calculated by means of a code developed by Petrillo et al [2] and in Fig. 2 the obtained result is plotted vs the rms acceptance angle for the working point reported in Table 2.

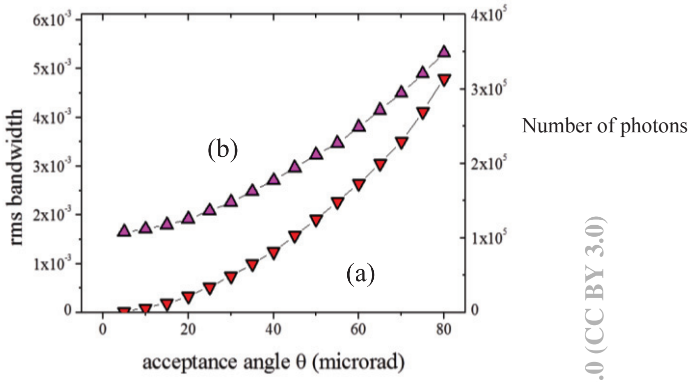

Figure 1: The total number of photons (a) and relative bandwidth (b) vs the rms acceptance angle of the data obtained by adopting the parametrs reported in Table 2.

THE MACHINE LAYOUT

The machine is based on a RF Linac operated at C-band (5.7 GHz) with an S-band photoinjector similar to SPARC [5], delivering a high phase space density electron beam in the 250-720 MeV energy range, colliding with a high power laser to produce via Compton back-scattering the gamma-ray photon beam. The repetition rate of the machine is 100 Hz, however within the RF pulse, whose duration is about 450 nsec, up to 30 electron bunches will be accelerated, each one carrying 250 pC of charge, separated by 15 nsec. In this way the effective repetition rate of the electron bunches can reach 3 kHz.

In Fig. 2 the schematic layout is shown where two beamlines are foreseen to deliver the beam for the Compton interaction at two different energies: 360 and 720 MeV. The SPARC-like S-band photoinjector consists of a 1.6 cell RF gun with a Copper photocathode and an emittance compensating solenoid followed by two 3-meters long SLAC-type TW sections operating at 2856 MHz reaching electron energies up to 130 eV on crest.

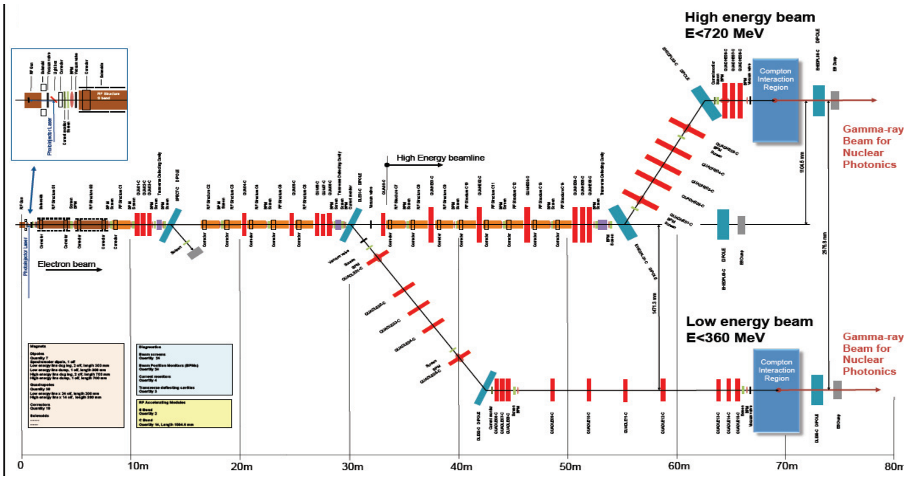

Figure 2: Schematic layout of the Gamma-ray source.

The velocity bunching scheme is adopted to produce a beam sufficiently short (280 μm) to get an energy spread around 0.05% at high energy, with low emittance $\varepsilon_n \approx 0.4\,\mu rad$ and charge $Q = 250\ pC$. Due to the compression (off crest operation) at the photoinjector exit the energy is reduced to 80 MeV and the induced energy spread is $\sigma_\delta \approx 1.7\,\%$ (that is recovered during the acceleration in the C-band booster). The evolution of beam emittance, transverse envelope and length inside the photoinjector are plotted in Fig. 3 along the longitudinal coordinate as obtained with Tstep code [6], an updated version of the well known PARMELA code[7].

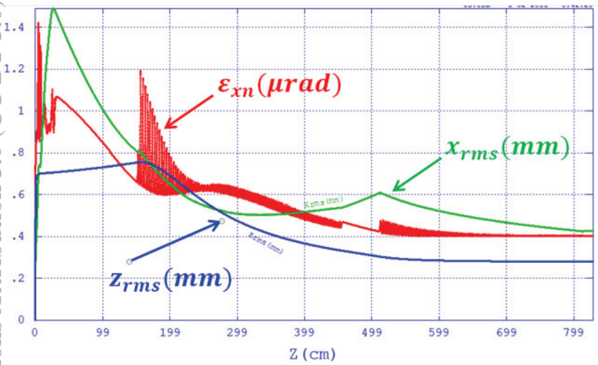

Figure 3: Electron beam emittance, envelope and bunch length evolution in the photoinjector.

Downstream the photoinjector six C-band accelerating sections follow and raise the energy up to 360 MeV for the low energy interaction, seven more accelerating sections bring the electron beam energy up to 720 MeV for the high energy Compton scattering. In Fig. 4 the energy spread histogram and its distribution along the bunch length, together with the bunch current are reported as obtained from simulation with Elegant [8] for 40 k particles.

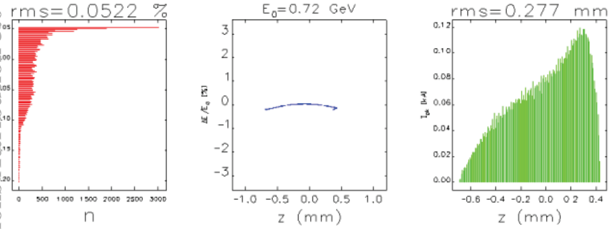

Figure 4: Energy spread histogram (left), longitudinal distribution (center), together with the current along the bunch longitudinal coordinate (right) for the 720 MeV beam at the linac exit.

THE LASER SYSTEMS

Two different laser.systems are required for the source: one to drive the copper photocatode with λ= 263 *nm* and one for the interaction with λ= 515, see Table 3 for more details. A common oscillator is foreseen for best synchronization able to lock to a reference clock at the requested stability and drive the two subsystems amplifiers. A laser beam recirculator made of individual spherical mirrors is foreseen at the Interaction Point, see Fig.5 : the focusing mirrors are located on 2 rings centred on the electron beam axis, with a 13 ns round-trip period in order to provide around 25 passes in the interaction point, in Fig. 5 a schematic layout of the optical recirculator is reported.

Table 3: Laser System Parameter List

Photocatode laser	Pulse energy (μJ) in UV	10-250
	Pulse length (flat-top, psec)	5-12
	Pulse rise-time (psec)	< 1
	# pulses in the train	20-30
	Focal spot size (μm) uniform	100-400
	pulses separation (nsec)	10-20
Interaction laser	Pulse energy (mJ)	500
	Wavelength (*eV*)	2.4
	Pulse length (FWHM psec)	2-4
	Focal spot size (μm) uniform	25-40
	Repetition Rate (Hz)	100

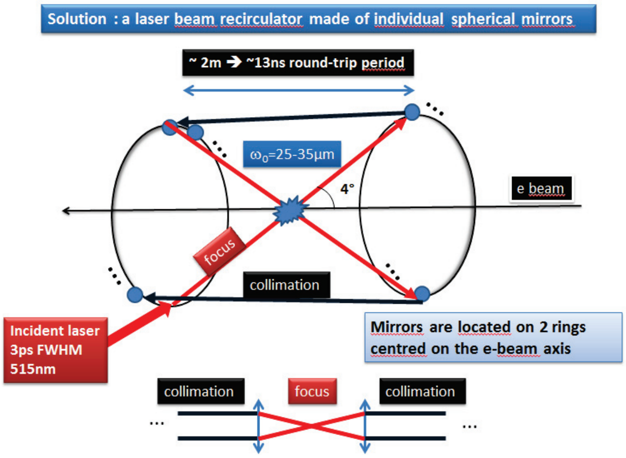

Figure 5: Optical recirculator schematic layout.

CONCLUSIONS

The European proposal for the Compton gamma-ray Source of ELI-NP has been briefly presented in some of its main aspects. The source optimization with the respect of the multibunch operation requirements, tolerances an so on, has been addressed and is part of the TDR presently under preparation.

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