

## Status of the project for a positron laboratory at ELI-NP

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**Abstract.** We report on the plans of a positron laboratory to be built at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) facility. The slow  $e^+$  source is based on  $e^-e^+$  pair production in a converter made of tungsten foils by a brilliant gamma beam ( $E_\gamma < 3.5$  MeV,  $I_\gamma = 2.4 \times 10^{10} \gamma \text{ s}^{-1}$ ) which will be generated by Compton back-scattering of photons from a high power laser on electrons from a LINAC. Numerical simulations of  $\gamma$ -ray interactions with the designed converter showed that, if the tungsten foils are used for moderation of the created fast  $e^+$ , a slow  $e^+$  beam of an intensity of  $\sim 1 \times 10^6 \text{ s}^{-1}$  can be obtained. Circular polarization of the  $\gamma$ -beam is proposed to be one of the ELI-NP's upgrades. The slow  $e^+$  will be extracted perpendicularly to the  $\gamma$ -beam and will have  $\sim 30\%$  transversal polarization degree. By using a transmission re-moderation stage and electrostatically turning the re-moderated beam by  $90^\circ$ , the transversal polarization will be changed to longitudinal. Longitudinal polarization can then be preserved in the longitudinal magnetic guiding field. The heat load to the converter was estimated at  $< 2$  mW which implies that  $e^+$  moderation by frozen neon is applicable.

### 1. Introduction

One of the methods to produce slow  $e^+$  beams of high intensity involves the  $(\gamma, e^+e^-)$  reaction in high- $Z$  materials like tungsten or platinum to obtain fast  $e^+$  which are subsequently moderated. The  $\gamma$ -rays needed for the  $e^+e^-$  pair production are obtained either from bremsstrahlung of electron beam in a target or from nuclear reactors [1-4]. Another method to produce a brilliant source of  $\gamma$ -rays is the Compton scattering of photons off a high-energy electron beam [5, 6]. This method will be realized for the Gamma Beam System (GBS) at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) (under construction in Magurele, Romania) to produce two brilliant  $\gamma$ -beams, with maximum energies of 3.5 MeV, and 19 MeV, both tunable [7]. At the very early stage of the ELI-NP project, it was considered that a  $\gamma$ -beam intensity of  $10^{13} \gamma \text{ s}^{-1}$  is achievable [8]. Based on this data and, in addition, on the presumption of a beam spot size of few tens of  $\mu\text{m}$ , Hugenschmidt *et al.* estimated that a slow positron beam at ELI-NP would have an intensity exceeding the present highest-intensity positron source ( $10^9$  slow  $e^+ \text{ s}^{-1}$ , NEPOMUC)[9]. However, according to the reported simulations of the GBS, the low-energy  $\gamma$ -beam will have an intensity of  $2.4 \times 10^{10} \gamma \text{ s}^{-1}$  [7]. Although the  $\gamma$ -beam at the photon- $e^-$  interaction point ( $\text{IP}_\gamma$ ) will have an extremely low divergence, of a few  $\mu\text{rad}$ , the design restrictions determine that the converter for  $e^+$  production can be placed only at a distance of  $\sim 4$  m away from the  $\text{IP}_\gamma$ , where the spot size of the non-collimated  $\gamma$ -beam will have a diameter of  $\sim 6$  mm (FWHM). By using these data, we have simulated the interaction of the  $\gamma$ -rays with the specially designed converter/



moderator assembly (CMA), made of tungsten foils, the moderation of fast  $e^+$ , the extraction of moderated  $e^+$  from CMA, and their focusing to form a beam [10, 11]. The optimization of the CMA sizes showed that a primary slow  $e^+$  beam can be obtained with an intensity of  $1\text{--}2 \times 10^6 \text{ e}^+ \text{ s}^{-1}$ .

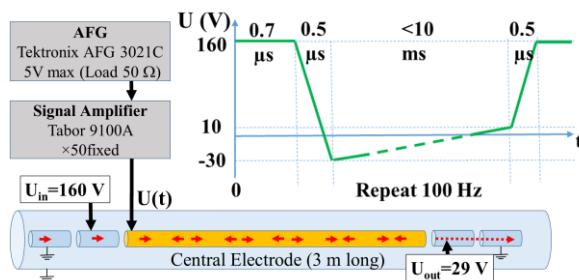
The present paper reports on the status of the project to build a slow positron beam line at ELI-NP.

## 2. Positron beam line setup

Details on the planned positron spectroscopy techniques: Positron Annihilation Lifetime Spectroscopy (PALS), Coincidence Doppler Broadening Spectroscopy (CDBS), Age MOmentum Correlation spectroscopy (AMOC), and Positron annihilation initiated Auger Electron Spectroscopy (PAES) to be used at the positron laboratory at ELI-NP can be found in [11]. One of the disadvantages to generate  $e^+$  by using a warm (non-superconducting) LINAC is the low duty cycle. In order to avoid detectors pile-up and to assure high count rates for PALS, CDBS and AMOC, application of a  $e^+$  pulse stretcher is required [2]. The GBS machine includes a warm LINAC that will provide trains of 32  $e^-$  bunches separated by gaps of 16 ns in a micro pulse of 0.5  $\mu\text{s}$  with a repetition rate of 100 Hz [7]. By reflections in a recirculator, one and the same laser pulse will interact with all the  $e^-$  bunches in a micro pulse. Back scattered photons forms a high energy  $\gamma$ -beam through inverse Compton scattering with the  $e^-$  beam. When the  $\gamma$ -beam interacts with the CMA the created fast  $e^+$  will have almost the same timing structure as the  $e^-$  from the LINAC. Due to different trajectory lengths of the moderated  $e^+$  at the extraction and formation points of the primary slow  $e^+$  beam, the fine timing structure will be smeared and the slow  $e^+$  will feed the stretcher with  $\sim 0.6 \mu\text{s}$  pulses of 100 Hz repetition.

### 2.1. Stretcher

The  $e^+$  pulse stretching technique is well-known and successfully applied. The simplest one is a low-field Penning-Malmberg trap with the entrance gate synchronized with the LINAC, central electrode at ground, and exit gate with potential barrier gradually decreasing between the pulses [12]. Another version of the stretcher can be realized with fixed potential for the entrance and exit electrodes, and a central electrode which potential suddenly drops when the  $e^+$  pulse enters and is then gradually increased in each repetition cycle [13]. The advantage of the last version is that the  $e^+$  energy can be controlled by the output electrode potential. A schematic drawing of the designed stretcher for the ELI-NP positron laboratory is shown in Figure 1.



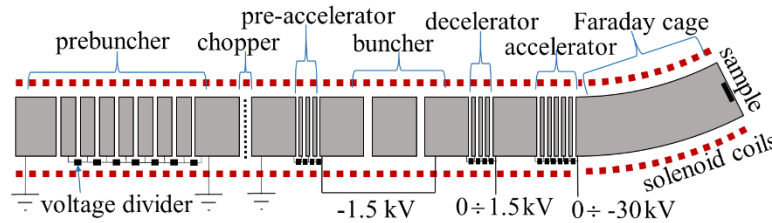
**Figure 1.** The designed stretcher section with a central electrode of time-varying potential and gate electrodes at fixed potentials.

The incoming  $e^+$  come in short pulses ( $\sim 0.6 \mu\text{s}$ ) with an energy of 200 eV. The potential of 160 V of the entrance electrode will slow them down to 40 eV within the central electrode. The 3-m-long central electrode will be able to accommodate a whole pulse before the potential of the central electrode ( $U$ ) drops to make a trap for  $e^+$  between the entrance and exit potential barriers. By slowly increasing the potential  $U$ , at a maximum rate of  $4 \text{ V ms}^{-1}$ , the trapped  $e^+$  which have enough energy to pass the decreasing potential barrier of the exit gate and will form a quasi-continuous slow  $e^+$  beam made up of stretched pulses with length up to 10 ms. It was proven that a stretched  $e^+$  pulse duration of 1-2 ms is enough to avoid detector pile-up problems [13].

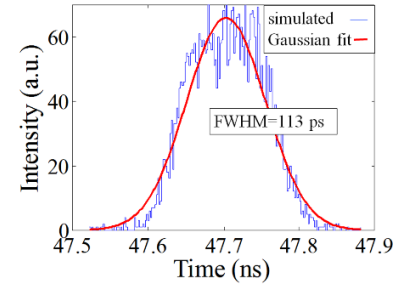
### 2.2. Pulsing

Application of the PALS and AMOC techniques in combination with a continuous or quasi-continuous beam of slow  $e^+$  requires a signal to start the electronics to measure the  $e^+$  lifetime. One solution is the

pulsing technique by which continuous beam is chopped and bunched at MHz frequency to obtain short pulses of about 100 ps at the sample position. We have designed a pulsing part consisting of multi-electrode prebuncher, retarding potential chopper, pre-accelerator, buncher, decelerator and accelerator with bent drift tube (see Figure 2).



**Figure 2.** Scheme of the pulsing part consisting of prebuncher, chopper, pre-accelerator, buncher, decelerator, and accelerator with bent drift.

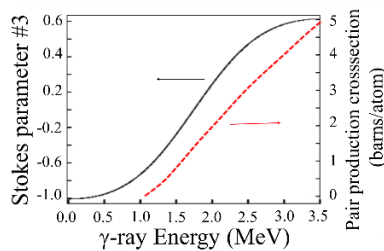


**Figure 3.** Simulated distribution of  $e^+$  at the sample position.

The  $e^+$  will enter the prebuncher with an energy of 29 eV. The  $e^+$  will be subjected to energy modulation due to applied potential ( $\sim t^2$ , 40 MHz) at the first electrode of the prebuncher. The retarding potential will have 2 ns transmission window. The chopped  $e^+$  will be pre-accelerated to 1.5 keV before entering the double gap buncher which operates with a 120 MHz sine wave applied to the central electrode. By adjusting the potentials of the decelerator and accelerator the bunched  $e^+$  will drift to the sample position at the desired focus time independently on their adjustable final energy (0-30 keV). The bent drift tube will be equipped with dipole coils to generate a transversal magnetic field in order to keep the incident  $e^+$  on axis. The same magnetic field will force the backscattered  $e^+$  from the sample to deviate from the axis and they will annihilate at the tube walls far from the sample. This method was already successfully applied to minimize the spectrum distortion due to backscattered positrons [14]. Our simplified simulation considers only chromatic aberrations and showed that the described pulsing part can compress a continuous  $e^+$  beam to pulses of  $\sim 100$  ps FWHM (Figure 3) with an efficiency of  $\sim 65\%$ .

### 3. Positron polarization

The international scientific and advisory board of the ELI-NP project recommended circular polarization of the  $\gamma$ -beam to be the first update of the GBS. Our previous simulations showed that if  $\gamma$ -rays are 100% circularly polarized the slow  $e^+$  beam may have 33% degree of spin polarization for CMA sizes optimized for best  $e^+$  beam intensity [10]. However, close to 100% circular polarization  $\gamma$ -rays can be achieved only for a narrow bandwidth  $\gamma$ -beam. For  $e^+$  production, we will use a wide bandwidth  $\gamma$ -beam (1-3.5 MeV). Simulations of the interaction of circularly polarized photons with a relativistic  $e^-$  beam have shown a strong correlation of the Stokes #3 parameter with the energy of the resulting  $\gamma$ -rays (see the supplementary online material of [15]). This correlation together with the cross section for  $e^-e^+$  pair production is shown in Figure 4.



**Figure 4.** Circular polarization, represented by the Stokes parameter #3, of the  $\gamma$ -rays obtained by inverse scattering of 100% circularly polarized photons of relativistic  $e^-$  beam and the  $e^-e^+$  pair production cross section in tungsten as a function of the  $\gamma$ -ray energy.

Using the correlation of the Stokes parameter #3 on the  $\gamma$ -ray energy we found that the  $e^+$  spin polarization degree was previously overestimated and the new value is 30%. Actually, this

overestimation was not huge due to the fact that more energetic  $\gamma$ -rays carry higher circular polarization and produce more  $e^+$  (see Figure 4). The slow  $e^+$  will be extracted perpendicularly to the  $\gamma$ -beam and the primary  $e^+$  beam will have  $\sim 30\%$  transversal polarization degree. By using a transmission re-moderation stage and electrostatically turning the re-moderated beam by  $90^\circ$ , the transversal polarization will be changed to longitudinal. Longitudinal polarization can be preserved in the longitudinal magnetic guiding field.

#### 4. Neon moderation

Moderation of fast  $e^+$  by a frozen neon layer due to its high efficiency is widely used in the last decade. Simulation of the interaction of the  $\gamma$ -ray with the CMA (with optimized sizes) showed that the heat load to the converter will be less than 2 mW [11]. This implies that  $e^+$  moderation by frozen neon is applicable. Our plans are to freeze a layer of neon directly on the surface of the foils of the CMA. We have estimated that a commercially available cryocooler with a cooling power of 3 W at 6 K can be used. The design challenge is to modify the cold finger of the cryocooler, with a sapphire interface, in order to have an electrically insulated cold finger to be able to sustain a few kV potential difference. The high efficiency of neon moderator will compensate the intensity lost due to re-moderation.

#### 5. Summary

We have reported on the proposed updates of the positron laboratory to be built at ELI-NP. We have re-estimated the  $e^+$  spin polarization degree using a more realistic estimate for the circular polarization of the  $\gamma$ -rays from the GBS. The designs of a pulse stretcher and a pulsing part have been completed. We have proposed that the fast  $e^+$  created in the CMA to be moderated by a neon layer, directly frozen on the CMA foils. The expected slow  $e^+$  beam intensity, with this modification, is greater than  $10^7 \text{ s}^{-1}$  for non-polarized  $e^+$  and greater than  $10^6 \text{ s}^{-1}$  in the case of polarized  $e^+$ .

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