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NOVEL POSITRON BEAM GENERATION BASED ON SHANGHAI LASER ELECTRON GAMMA SOURCE*

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Abstract

The Shanghai Light Source has been operated since 2009 to provide synchrotron radiation to 40 beamlines of the electron storage ring at a fixed electron energy of 3.5 GeV. The Shanghai Laser Electron Gamma Source (SLEGS) is approved as one of 16 beamlines in the Phase II project in 2016 to produce energy-tunable gamma-ray beams in the inverse Compton slant-scattering of laser photons from a 100 W CO_2 laser on the 3.5 GeV electrons as well as in the back-scattering The SLEGS can produce gamma rays in the energy range of 0.66 – 21.7 MeV.

A positron source based on SLEGS is designed to produce positron beams in the energy range of 3 – 16 MeV with a flux of 10^5 /s with an aperture of 10 mm of the collimator system. The positron beam generated by SLEGS has been simulated using GEANT4, which uses a SLEGS gamma beam injected into positron generating target, and a dipole magnet is used to deflect the generated positrons, and the positron measurements are made at a lower background location. Based on the continuously adjustable energy of SLEGS gamma rays, the optimized parameters at each gamma energy were simulated to obtain a continuously adjustable energy positron source.

We have confirmed the generation of gamma-ray beams in the commissioning of the SLEGS beamline. We plan to construct the positron source in the summer of 2024. We present the performance of the positron source based on results of the simulation and test measurements.

INTRODUCTION

The positron beam based on SLEGS [1-3], is simulated by Geant4. In this process, the SLEGS gamma ray parameters are added to the simulation programme, where they are injected into the positron generating target. This injection initiates the electron-pairing effect, which produces the positrons. As the gamma ray will be scattered after hitting the target, generating a large amount of scattered gamma background, a dipolar deflecting magnetic field is subsequently added to the simulation programme to deflect the charged particles so that they drift to the lower region of the scattered gamma background for collection. Following a systematic simulation of the deflected magnetic field, it was determined that the addition of a free fly distance after the deflected magnetic field would result in a more efficient collection of positrons in the low background region. Based on the above analysis, the SLEGS-based positronic simulation procedure is modelled as shown in Fig. 1.

Given that the SLEGS gamma rays possess the property of continuously adjustable energy, systematic simulations of the positron beam are conducted at each energy point in order to obtain a continuously adjustable energy positron beam stream. Based on this rationale, a multilayer target and a focusing system have been designed to enhance the positron beam quality, which has a markedly positive impact on the positron flow intensity, particularly in the low-energy region.

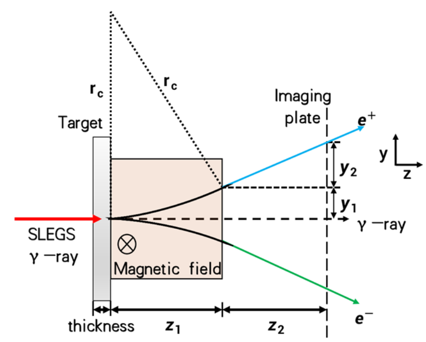

Figure 1: The setup of the positron generation system (target, magnetic field, free flight distance and image plate, not in scale).

BASIC SIMULATION SECTION

Based on the modelling in Fig. 1, the Geant4 program was used to optimise the various parts of the positron generation process.

Target

For the optimised simulation of the positron generating target, a SLEGS gamma incidence of 17 MeV is used (17 MeV gamma is used because NewSUBARU has already performed experiments at this energy and cross-checking with its experimental data ensures the reliability of the simulation program). The target has two parameters, material and thickness, which are simulated in detail as shown in Fig. 2. The signal-to-noise ratio (SNR) was defined by combining the positron yield and the background of the scattered gamma, and a 1 mm copper target was chosen as the positron generating target for the 17 MeV gamma incidence.

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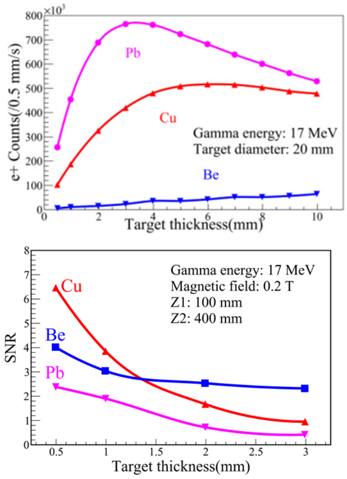

Figure 2: The normal positron yield and SNR with Be, Cu and Pb target.

Deflecting Magnet and Free Flight Distance

The deflecting magnetic field has two main parameters: the magnetic induction intensety and the extent of the field range (Z_1). In the simulation procedure 17 MeV gamma is injected into a 1 mm copper target and add a deflecting magnetic field to deflect the secondary charged particles, the detailed simulation results are shown in Fig. 3. It can be concluded that the deflection effect on positrons is the same for low field strength and larger magnetic field range and high field strength and smaller magnetic field range, and 0.3 T and 90 mm are selected as the parameters of the deflecting magnetic field for comprehensive consideration. After the magnetic field, a free fligh distance is added to make the positron drift along the region with lower scattering gamma background, and it can be concluded from Fig. 3 that the maximum SNR is reached when the drift distance is 400 mm, and the quality of the positron beam is the best at this time.

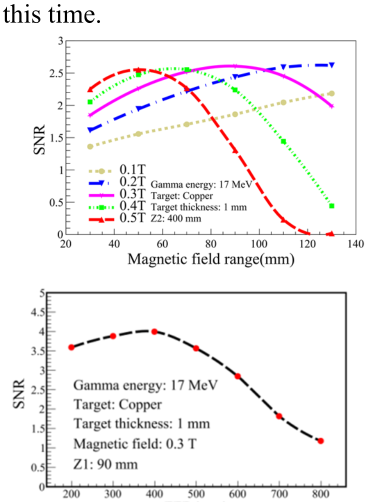

Figure 3: The relationship between SNR, magnetic inductiontion intensety and Free Flight Distance(FFD).

Summary of the Basic Simulation Section

Based on the simulation method above, set SLEGS gamma incidence of 2 MeV-21.7 MeV, and a set of parameters is simulated at each energy point to produce the best quality positron beam flow at this point. In Fig. 4 the positron energy spectra of several points are given, and it can be seen that the positron mean energy varies correspondingly with the incident gamma energy.

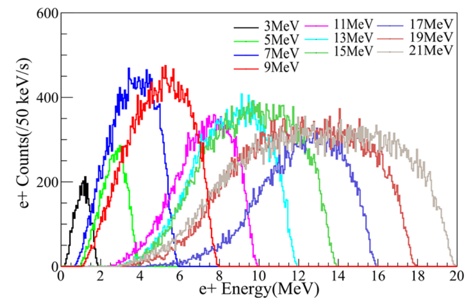

Figure 4: Positron energy spectrum at varying incident gamma energy.

EXTENDED SIMULATION SECTION

It's shown that the positron flow intensity is not particularly high, especially in the low-energy region range in Fig. 4. Based on this problem, a way to collect positrons in the vertical direction is proposed, and the simulation schematic is shown in Fig. 5.

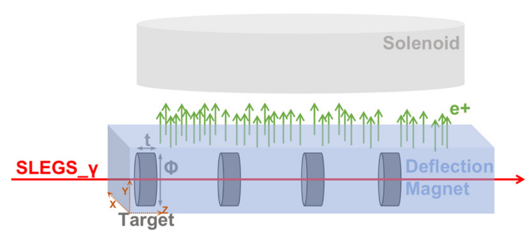

Figure 5: The schematic of extended simulation.

The main changes made are:

- Selecting thinner targets and increasing the number of targets
- Increasing the strength of the deflecting magnetic field to ensure positrons leave field in vertical direction
- Addition of a focusing system, with the energised solenoid chosen as the focusing mechanism for the positron beam cluster

In order to enhance the positron flux intensity, the initial step is to augment the positron yield, which is multiplied by increasing the number of targets. However, this method is unable to collect positrons in the horizontal direction and deflects the positrons to the vertical direction by deflecting the magnetic field. As a consequence of the larger number of targets and the larger gap, the radius of the deflected positron beam cluster is also larger, shown in Fig. 6.

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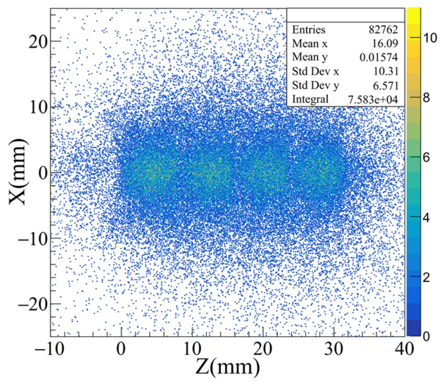

Figure 6: Positron distribution before entering solenoid.

Consequently, it is necessary to add a focusing system to focus the positron beam cluster. At this stage, the simulation uses an energised solenoid for focusing. For common sample sizes, e. g. selecting 20 mm*20 mm, the positronic flow intensity can reach $8.1*10^3$ e+/s/cm^2 (Incident gamma of 3.5 MeV, 10^7 γ/s), shown in Fig. 7.

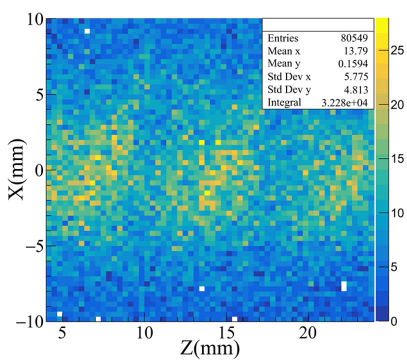

Figure 7: Selecting 20 mm*20 mm area after the solenoid.

A comparison can be made between the positron beam flow intensity in the basic method and the addition of multiple targets and a focusing system, which provides a significant improvement in the flow intensity. Since the scattering gamma is distributed in full space with a forward angle, the effect of the scattering gamma background can be eliminated by elongating the solenoid in the vertical direction, and the positron is not affected in any way, as shown in Fig. 8.

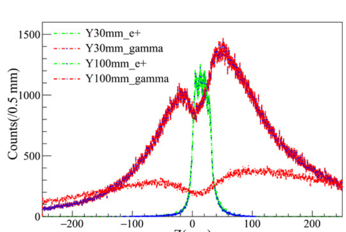

Figure 8: Positron and gamma distributions in the Z-direction for solenoids of 30 mm and 100 mm.

A series of detailed simulations of the low-energy region were conducted using this method, and the results are presented in Fig. 1. Finally, the positron beam energy, based on the SLEGS method, can be obtained with continuously adjustable energy in the range of 1.0 - 9.1 MeV, and flow intensity of $7.3*10^3$ to $2.1*10^5$ e+/s/cm^2 (Incident gamma flux of 10^7 γ/s). Specific energy and flow intensity density shown in Table 1.

Table 1: Positron Intensity Density at Various Energies

Gamma energy (MeV)	*Positron mean energy (MeV)*	*Positron intensity after selection(e+/s/cm2)*	
		10 mm 10 mm*	*20 mm* 20 mm*
3.0	1.0	7.3*103	4.4*103
3.5	1.2	1.0*104	8.1*103
4.0	1.4	1.6*104	1.2*104
21.7	9.1	2.1*105	1.32*105

CONCLUSION

This paper presents a positron beam generation method based on a Shanghai laser electron gamma source. The fundamental single-target positron generation method is initially presented, followed by an enhancement of the positron beam quality through an increase in the number of targets and the addition of solenoids in the vertical direction. This improvement is of paramount importance, as it addresses the inherent limitations of the single-target positron generation method, which has a limited positron beam yield in the low-energy region and an unavoidable gamma background. The aforementioned shortcomings of the positron generation method are addressed, namely the low positron beam yield in the low-energy region and the unavoidable gamma background. Furthermore, the possibility of larger beam spots and higher positron beam densities is opened up for the measurement of material defects.

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