SIMULATIONS ON REDUCING THE INFLUENCE OF BACKSCATTERED SLOW POSITRONS ON LIFETIME MEASUREMENTS

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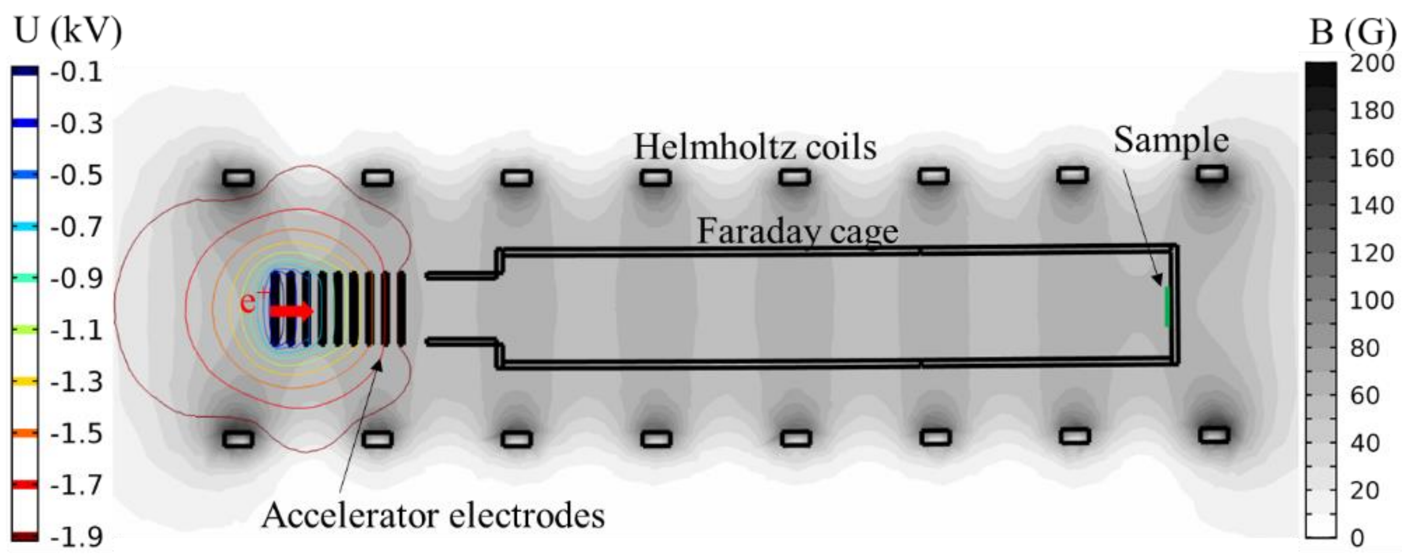
Abstract

For analyzing subsurface layers and thin films, slow e⁺ beams are necessary. At the European Light Infrastructure – Nuclear Physics (ELI-NP), a brilliant γ-beam will produce fast e⁺ by the pair production in a suitable converter made of tungsten foils, which will also act as a moderator [1]. One of the positron annihilation techniques, which over the years has become an increasingly valuable tool for study of the defect structure in materials is the Positron Annihilation Lifetime Spectroscopy (PALS). In order to perform PALS with a slow e⁺ beam a start signal is needed. For obtaining the start signal, at ELI-NP, the slow e⁺ beam will be pulsed using the chopping and bunching technique [2]. For depth profiling purposes, the slow e⁺ are accelerated by a few graded electrodes to a desirable energy up to typically 30 keV.

When incident e⁺ hit the target a fraction of them is backscattered. If the backscattered e⁺ reach back the accelerator they can be reflected by the electric field and implanted into the sample with a delay from the initial e⁺ bunch. Despite their small overall contribution, the caused satellite structures can make the spectrum analysis difficult.

The method implemented at the EPOS beam line of guiding the e⁺ through a 45˚ bent tube equipped with steering coils after they pass the accelerator will not allow the e⁺ backscattered from the target to reach the acceleration field [3]. The same method will be implemented at the ELI-NP e⁺ line. To understand the origin of these satellite structures and to further improve the performance of the system, comprehensive simulations were performed in Comsol Multiphysics and Geant4. The aim of the study conducted in the present poster is to determine the optimum parameters of the designed system in order to obtain PALS spectra with minimum distortions caused by the backscattered e⁺.

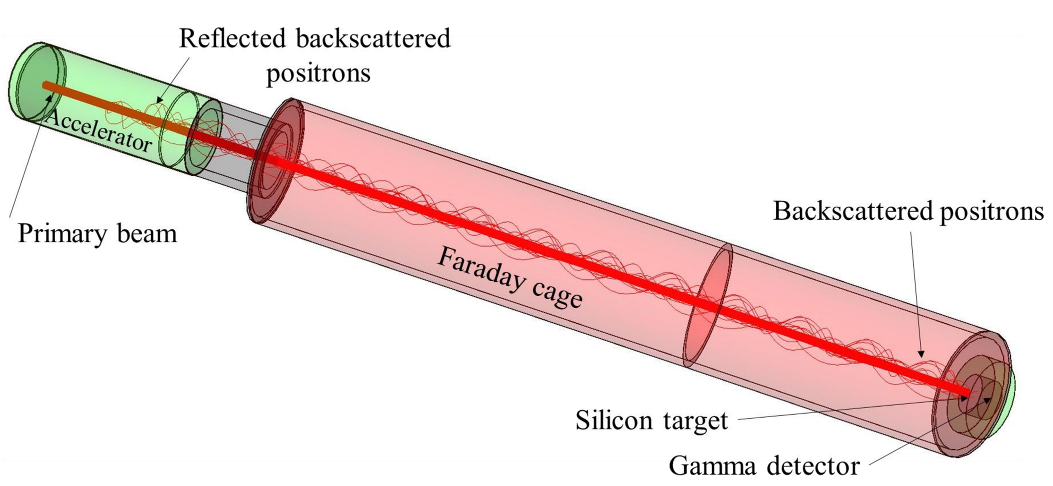
COMSOL Multiphysics Simulations



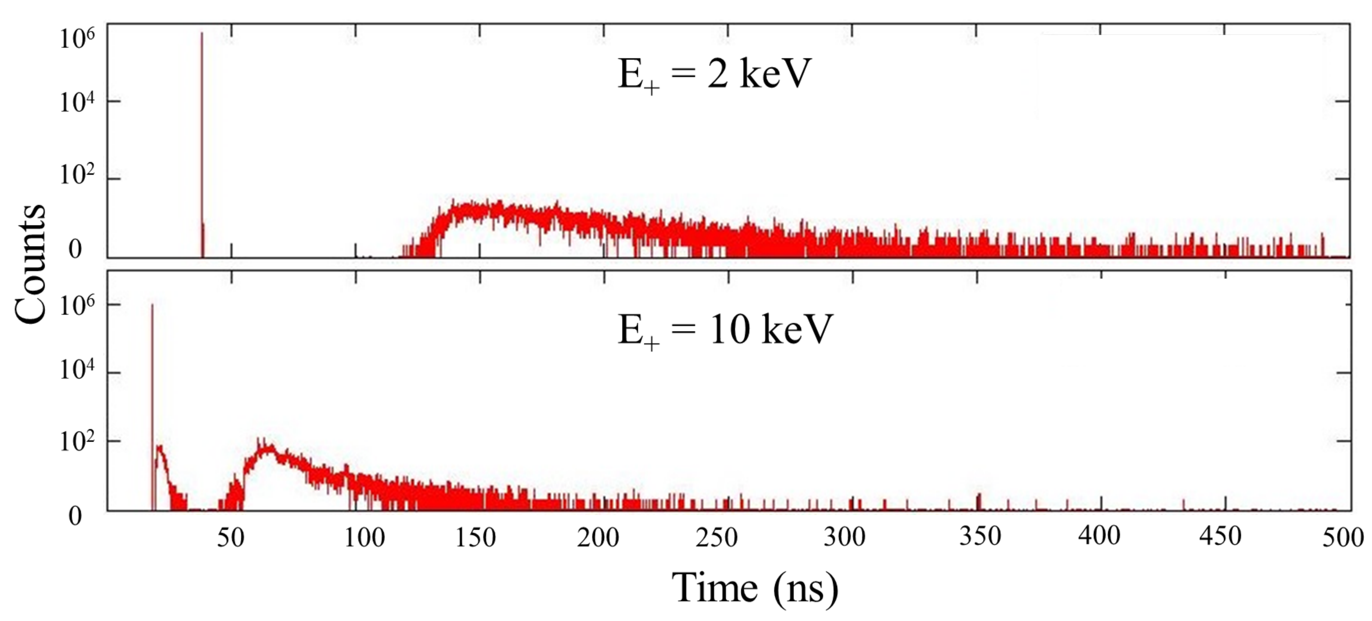
Comsol Multiphysics was used for simulating the magnetic field that will guide the e⁺ beam from the accelerator to the center of the sample, and for the generation of the electric field of the accelerator.

The magnetic field was generated by a series of multi-turn Helmholtz coils. The figure presents the surface plot of the magnetic and the contour lines of the electric 3D maps on a cross section along the central axis. The magnetic field is close to uniform (60 ± 2 G) along the axis. The electric field used for the acceleration of the particles towards the sample was obtained by applying a potential U_{acc} equally spread on the graded electrodes (having holes with diameter D = 60 mm) of the accelerator. The Faraday cage with internal diameter 116 mm and length of 720 mm was kept at the potential U_{acc} to act as a e⁺ drift region.

Geant4 Simulations

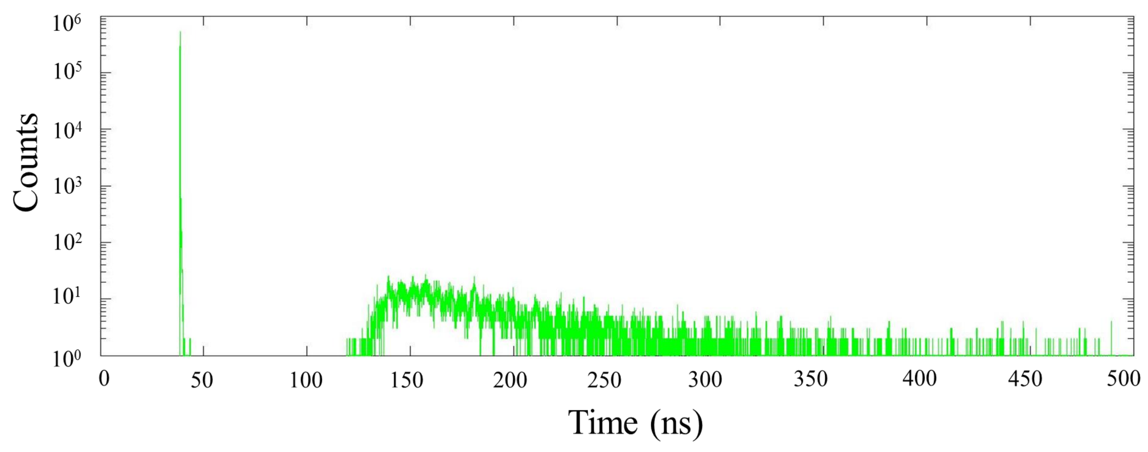


For each Geant4 simulation 1×10^6 e⁺ were shot towards the sample. The figure shows the trajectories of the primary 2 keV e⁺ beam and the event of e⁺ backscattering with 300 incident particles. Example of a straight tube obtained by Geant4.



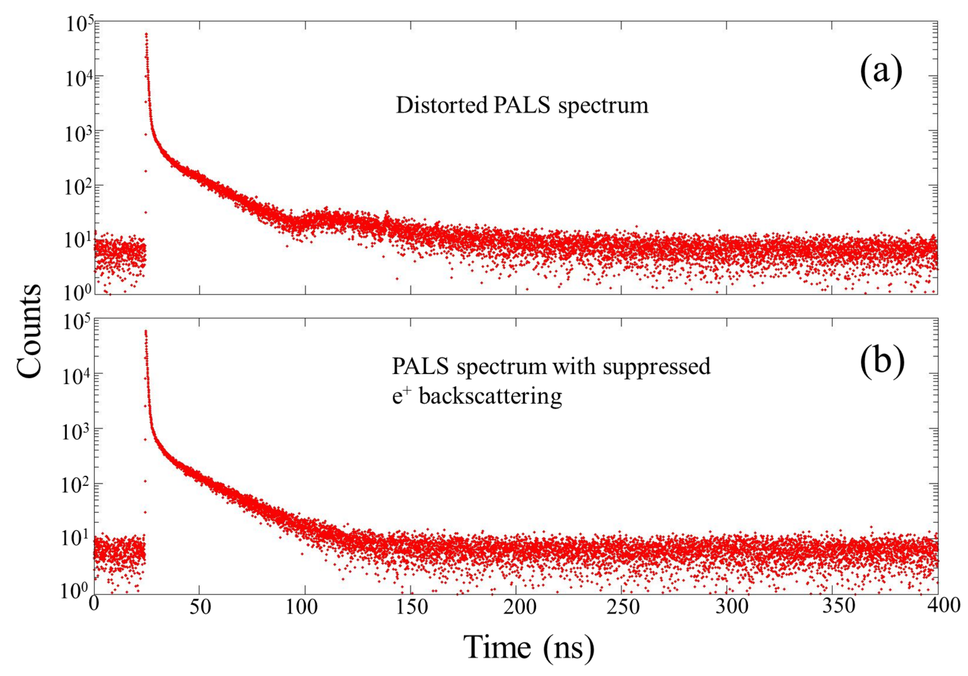
The figure shows the time of annihilation within the target for e⁺ accelerated to E_+= 2 keV and E_+= 10 keV in a straight geometry. The very sharp peak corresponds to e⁺ which are directly implanted into the target. The very broad peak is due to backscattered e⁺ reflected from the accelerator electric field and then implanted into the target. The delayed e⁺ can significantly distort the long-lived components when measuring a PALS spectrum.

Spectra Simulations



Histogram of the time of the gamma rays interaction with the BaF2 detector obtained by Geant4. Example of a straight tube and E_+= 2 keV. This signal was used as a resolution function for simulating PALS spectra

In order to study the effect of backscattered e⁺, we simulated PALS spectra convoluting the resolution function R(t) with four components with lifetimes [τ_1, τ_2, τ_3, τ_4] =[0.1, 0.5, 3, 20] ns and corresponding intensities [I_1, I_2, I_3, I_4] =[10, 60, 10, 20]%.

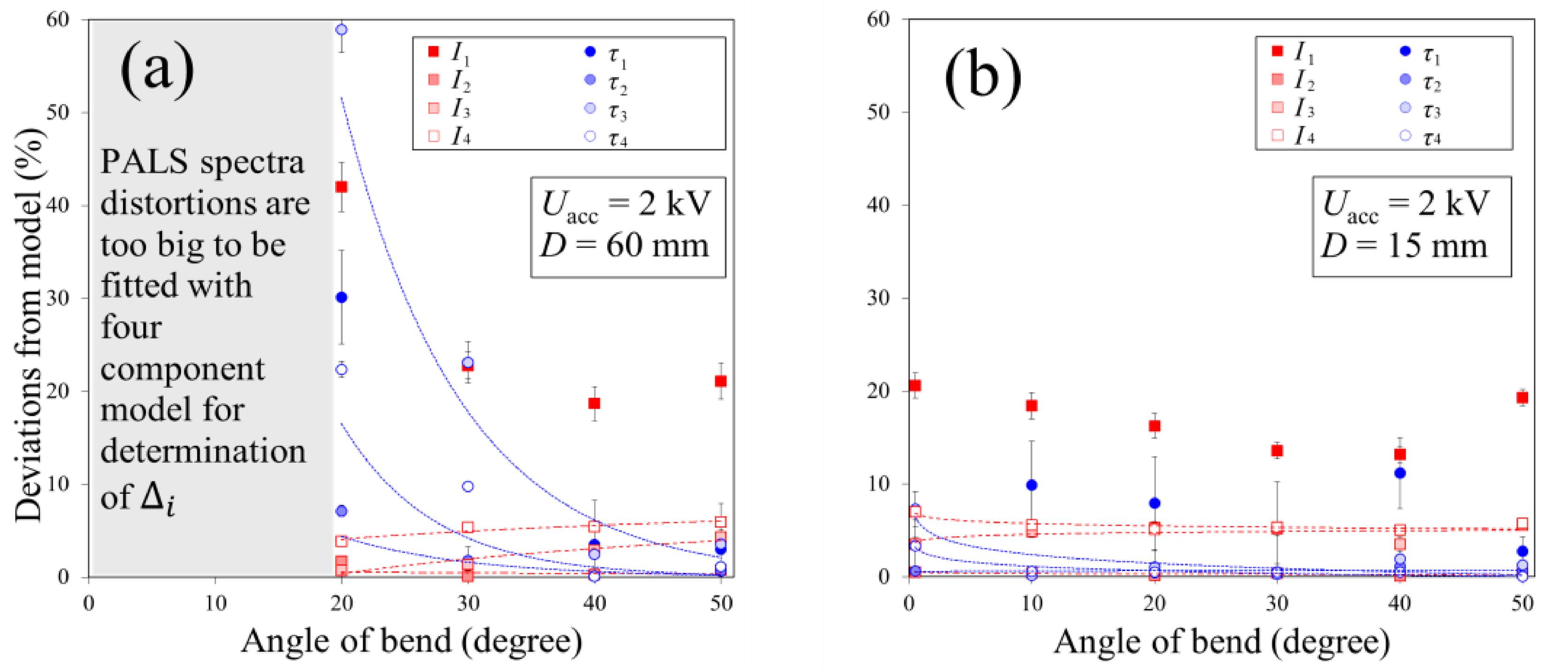


Example of a simulated spectrum is shown in the figure on the left side (a) and a simulated spectrum with suppressed backscattering is shown for comparison (b). The distortion in the PALS spectrum introduced by the backscattered e⁺ is clearly seen in figure (a). In order to quantify the distortion from the model spectrum, the spectra were analyzed by LT9 software to find the best fit parameters and the deviations:

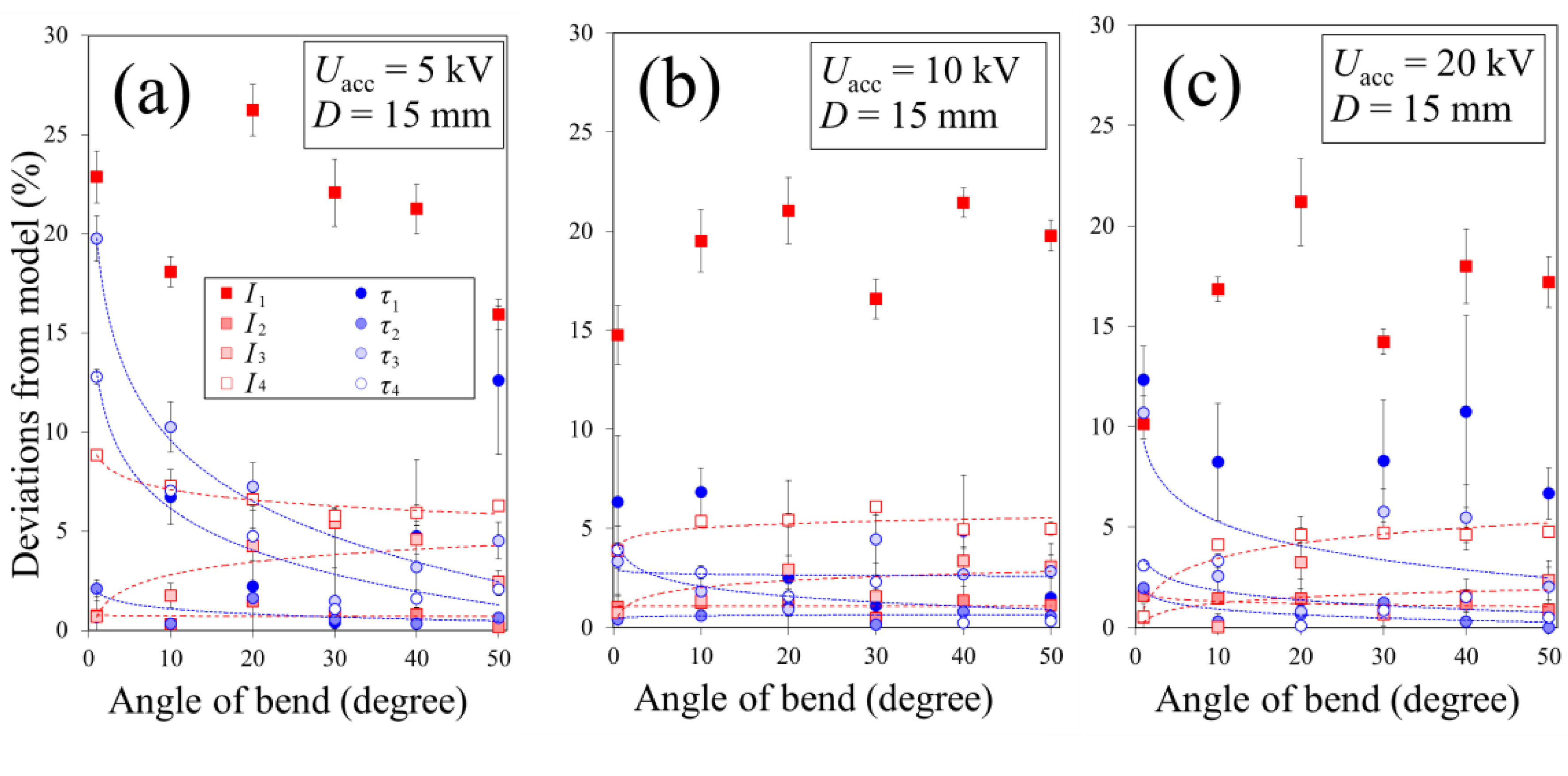
$\Delta_i = 100\times\left(P_i - P_i^{fit}\right)/P_i$ (P = τ or I, and i = 1 to 4) were calculated.

Results

For minimizing the effect of e⁺ backscattering, two possible solutions were simulated. The first solution is to add an aperture at the accelerator exit, with a diameter D, comparable with the beam spot size. The figures below show the deviations from the fit parameters for D= 60 mm (a) and D= 15 mm (b).



The second solution is to pass the accelerated e⁺ beam through a bent tube equipped with steering coils to act as a velocity filter. The study was performed for the acceleration potentials U_{acc} = 2, 5, 10 and 20 kV with angles of the bend between 0 and 50˚. The figures show the deviations from the fit parameters for U_{acc}=2kV (a), U_{acc}=5kV (b) and U_{acc}=10kV (c).



References

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[3] M. Jungmann, J. Haeberle, R. Krause-Rehberg, W. Anwand, M. Butterling, A. Wagner, J. M. Johnson and T. E. Cowan, J. Phys.: Conf. Series 443, 012088 (2013)