Simulations of absorption in the brain of gamma quanta from positronium atoms

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Introduction

Positronium imaging [1] is a new imaging method that allows to determine not only the location of the tumor, but also the degree of its malignancy [2]. It is the multi-photon imaging, which uses annihilation into not only 2γ, but also into 3γ. Number of detected photons from decay into $2\boldsymbol{\gamma}$ or $3\boldsymbol{\gamma}$ give information about tissue structure. Moreover, the $3\boldsymbol{\gamma}/2\boldsymbol{\gamma}$ ratio allows the description of neoplastic changes [3]. Hence, the purpose of this work was to determine how many gamma quanta from positronium atoms are not absorbed in the brain and skull and can reach the detector and, in the end, can be used for determination of the $3\boldsymbol{\gamma}/2\boldsymbol{\gamma}$ ratio.

Assumptions

- Positronium decay (for $3\boldsymbol{\gamma}$ and $2\boldsymbol{\gamma}$) is in the head.
- Brain is a sphere with water, because values of attenuation coefficient for brain are similar to attenuation coefficient for water [4].
- Radius of the brain d_B = 7 cm for men and women [5].
- Thickness of the skull d_S = 6.5 mm for men and women [6].
- Number of simulated events: 1,000,000 p-Ps->2γ, 1,000,000 o-Ps->3γ.

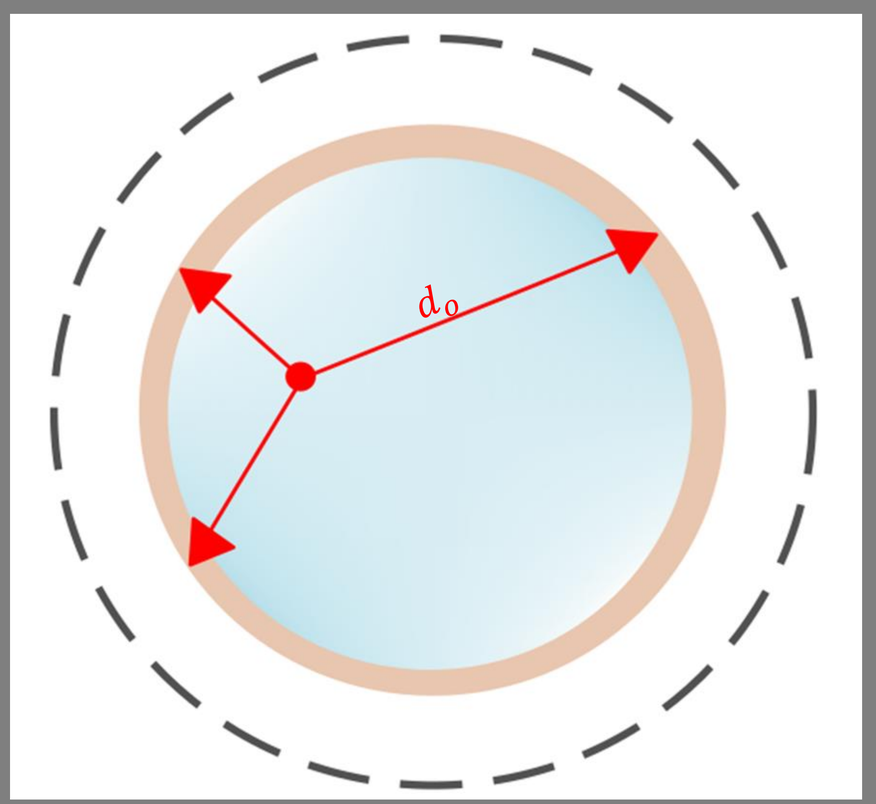

Figure 1: Scheme of annihilation in the brain, blue circle denotes brain, beige ring denotes skull, red point is a place of decay, arrows denote photons, grey, dashed circle denotes detector.

Absorption probability

Probability that gamma quantum with energy E is not absorbed and pass through the head is equal to:

$$P_i = e^{-\mu_B(E)d_B} e^{-\mu_S(E)d_S}, \quad (1)$$

where $\mu_B(E)$, $\mu_S(E)$ are attenuation coefficients for brain (water) and skull (bone). Atennuation coefficiens depend on photon energy, this dependence is shown in the plots on the right. The simplest case of gamma quanta absorption is decay in the center of the brain. Due to the assumption that the brain is spherical, a distance of each gamma quanta in the brain is the same and is equal to radius of the brain. For each Monte Carlo simulated event a probability for a given quantum to pass outside the head is calculated according to equation 1. Finally, number of events when all annihilation gamma quanta had not been absorbed are counted.

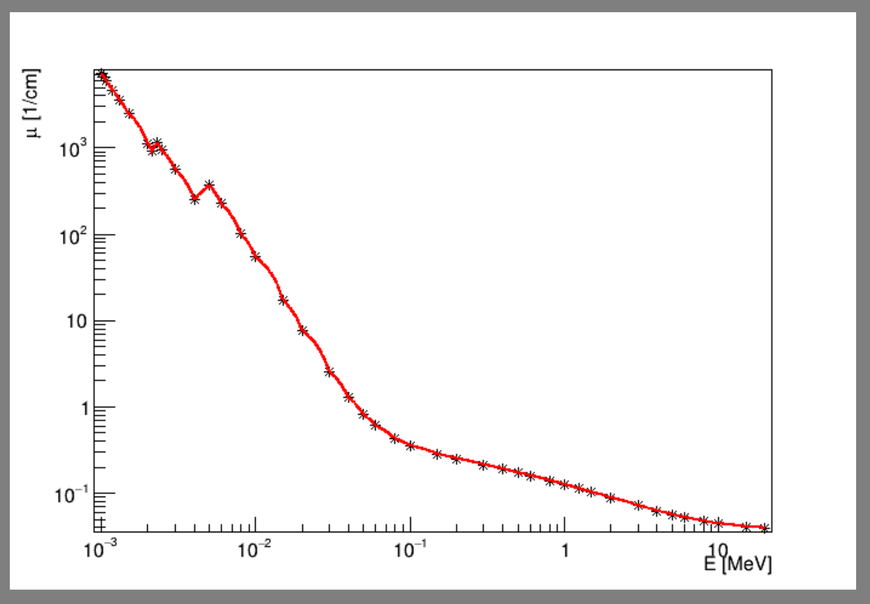

Figure 2: Linear attenuation coefficient for water [4] with cubic interpolation.

Results

Fraction of events for which all gamma quanta were not absorbed in the brain and skull are as follows:

- 20.84±0.05 %for para-positronium,
- 5.46±0.02 %for ortho-positronium.

Fraction of $3\boldsymbol{\gamma}$ /$2\boldsymbol{\gamma}$ events for which none of the gammas is absorbed in the brain

$$f_{3\gamma 2\gamma} = 0.262 \pm 0.002.$$

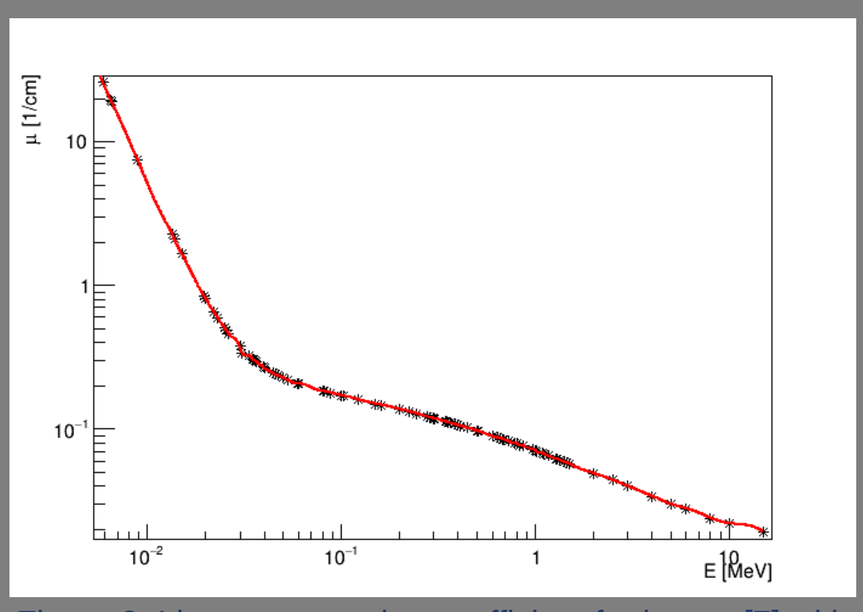

Figure 3: Linear attenuation coefficient for bones [7] with linear interpolation.

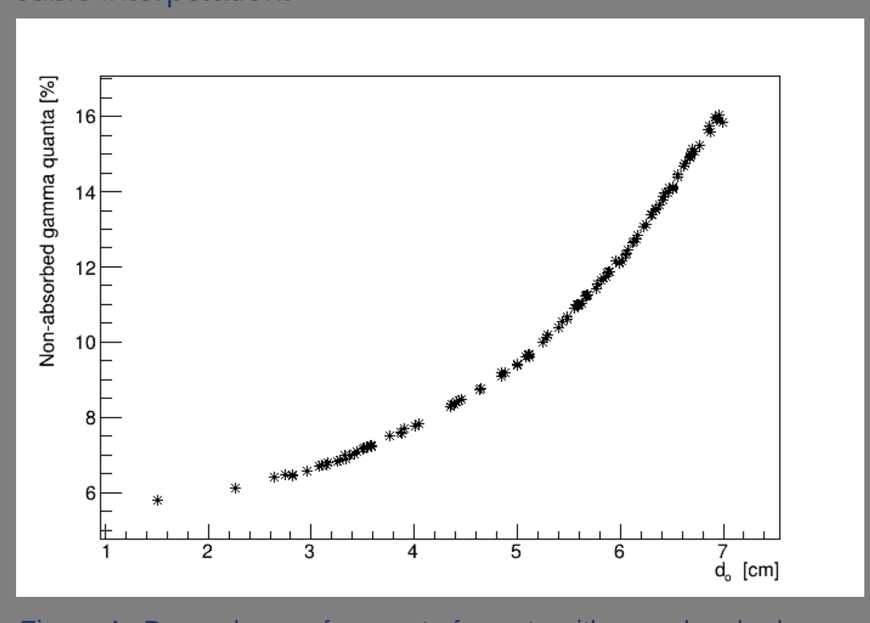

Figure 4: Dependence of percent of events with non-absorbed photons on place of annihilation (distance d_o).

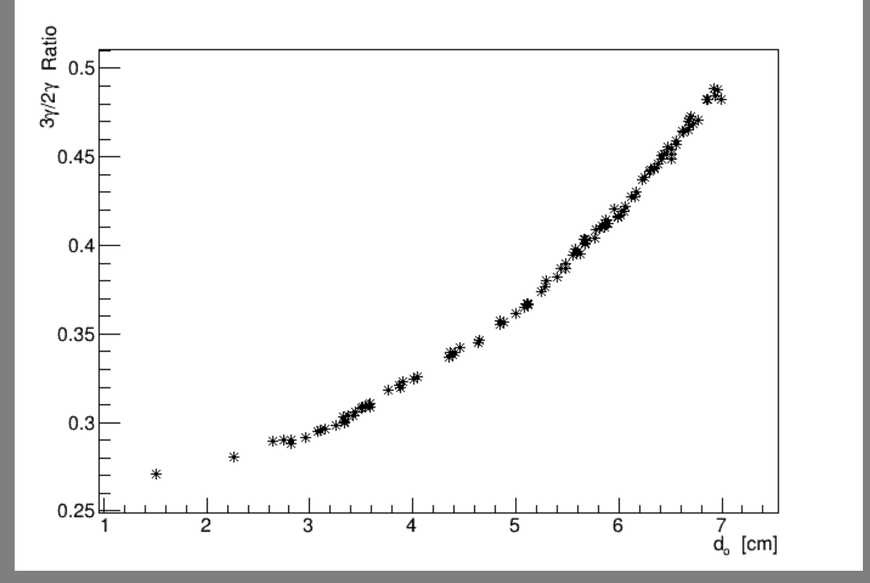

Figure 5: Dependence of the 3γ/2γ ratio on place of annihilation (distance d_o).

Summary

The brain in this study is approximated by a sphere with water. Monte Carlo simulations of positronium atom decay and gamma quantum absorption in brain and skull were performed. The absorption depends on the attenuation coefficient and the distance in the material. The coefficients depend on the energy, so for the energy from positronium decay an interpolation was made for the attenuation coefficient values from reference [4], [7]. The dependence of the absorption on the annihilation location, which is drawn in a homogeneous sphere, was also investigated. The dependence of absorption and 3γ/2γ ratio on the decay location of the positron atom in the brain was also determined.

References

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