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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

Development of innovative detectors for dosimetry and diagnostic

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PhD Physics XXXiX Cycle

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DIPARTIMENTO INTERATENEO DI FISICA

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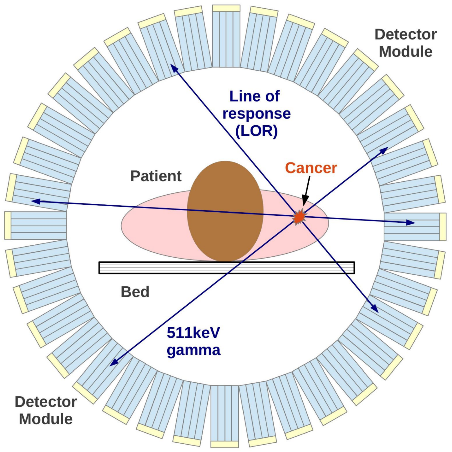
Positron Emission Tomography (PET)



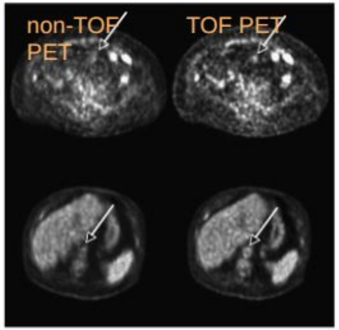
- Positron emission tomography (PET) relies on β^+-decay and positron-electron annihilation.
- **Positron Emission:** The radioactive tracer attached to the biomarker undergoes β^+ decay and emits a positron.
- This positron annihilates with the surrounding electrons and produces two collinear 511 keV gamma rays.

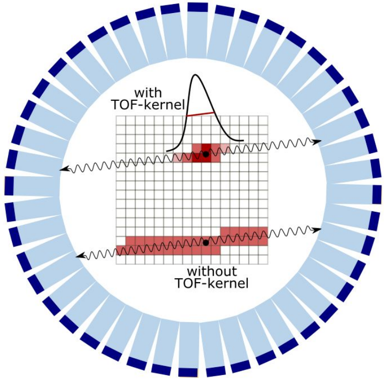
Time of Flight in PET (TOF-PET)

Using time of flight (TOF) information to estimate the emission position can drastically improve the image quality.

Factor Limiting PET Detector Performance:

- ❖ Poor localization along the line of response (LOR).
- ❖ Low signal-to-noise ratio (SNR).
- ❖ Limited sensitivity
- ❖ High random and coincidence contribution.

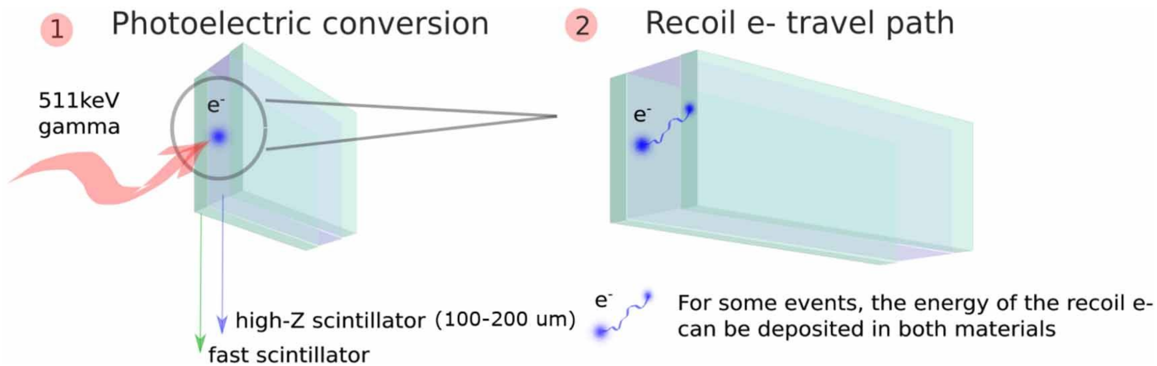




Standard PET: Equal probability along LOR
TOF-PET: Weighted by most likely annihilation point

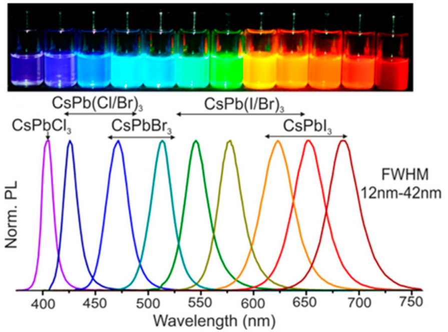
Heterostructured Scintillators For Fast Timing

During my PhD project, hybrid structures will be considered in which high-Z inorganic scintillator is combined with scintillating nano-crystals (NC) for time tagging.

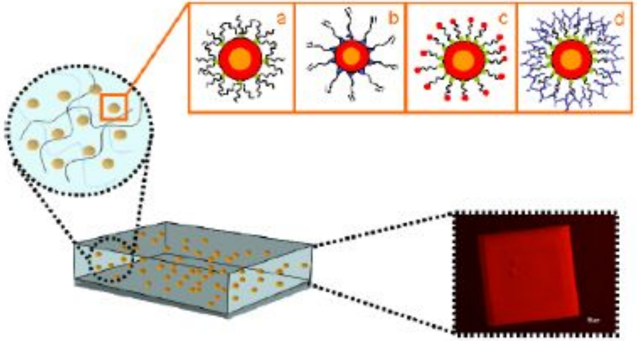


P. Lecoq et al 2020 Phys. Med. Biol. 65 21RM01

- The simplest approach is stacking alternating layers of both materials.
- The more energy is deposited in the fast material, the more fast photons are produced.



Perovskite-polymer 3D composite

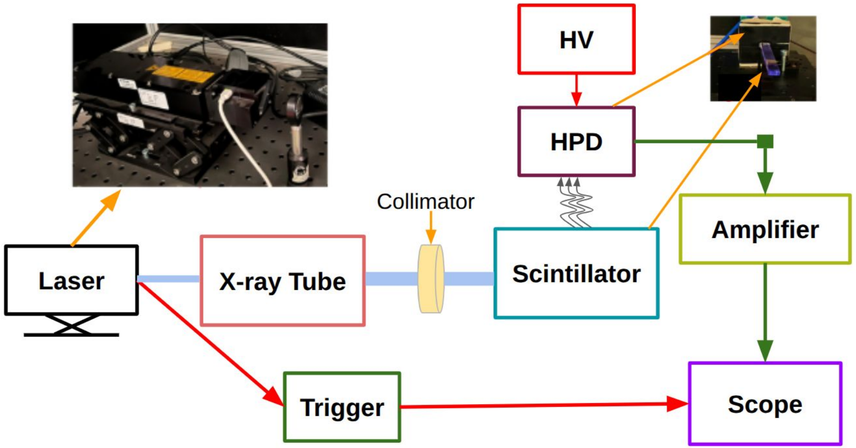


Striccoli et al Materials **2010**, 3, 1316-1352

Experimental Setup for Timing Characterisation

An experimental setup is currently under validation in the Physics Department (UNIBA), funded by the Quasimodo project. The aim is to characterize the timing performance of scintillators using a pulsed soft X-ray source (40 keV).

- Steady-state light yield
- Time resolution
- Time-Correlated Single-Photon Counting



Experimental Setup Under Validation

Towards Advanced Scintillating Materials: Experiment & Simulation

Experimental Work: Developed a Python-based data analysis framework; performed preliminary measurements with a hybrid photodetector during setup validation.

Simulation Studies: Built and validated the Geant4 model; investigated heterostructured scintillators, including Pb-doped plastics, as potential alternatives to inorganic crystals.

Monte Carlo Simulations

Detector model: Geant4-based heterostructure (3 × 3 × 15 mm³).

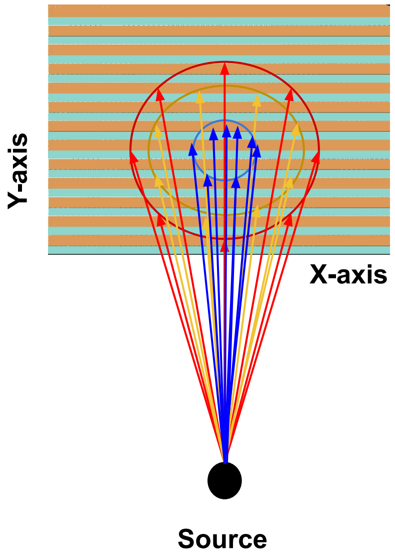
Layer design: Alternating bulk scintillator (100 μm) and fast scintillator (10–220 μm, step 10 μm).

Air gaps: 1 μm separation between layers to account for interfaces.

Study goal: Assess effect of fast-layer thickness on interaction and signal properties

Analysis metrics:

- Photoelectric interaction probability
- Event sharing between layers
- Energy deposited in fast scintillator



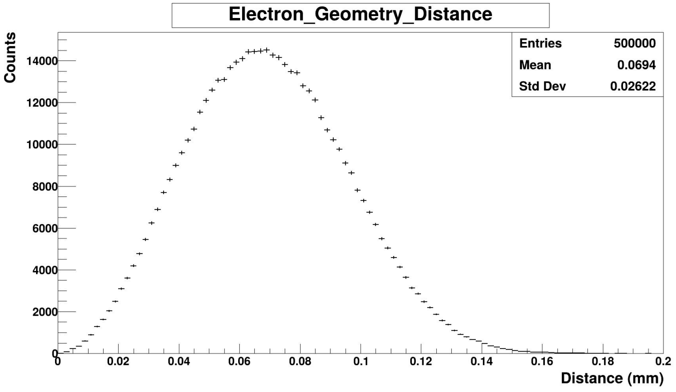
$$\text{Photoelectric Probability (PE)} = \frac{\text{Events Depositing} > 400\ \text{keV}}{\text{Events Depositing} > 0\ \text{keV}} \times 100 \quad (1)$$

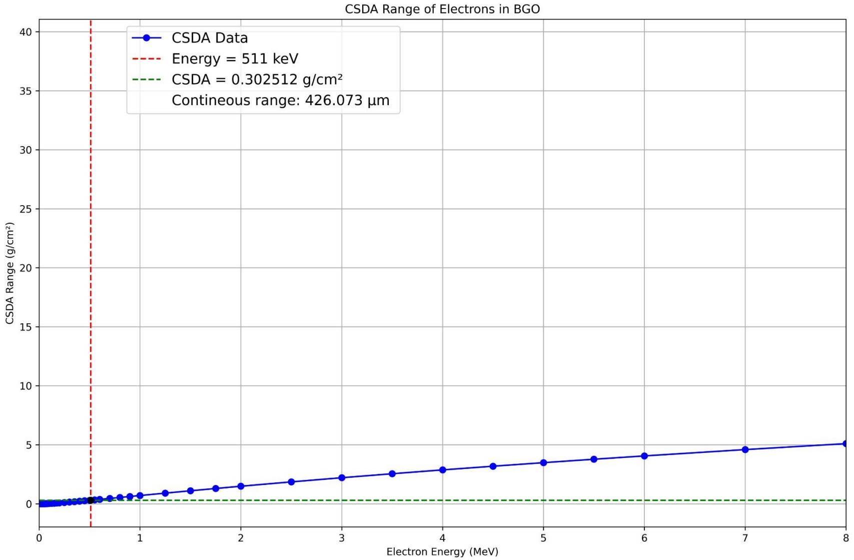
$$\text{Shared PE} = \frac{\text{PE Events with } E_{n,\text{fast}} > 50\ \text{keV}}{\text{Total PE Events}} \times 100 \quad (2)$$

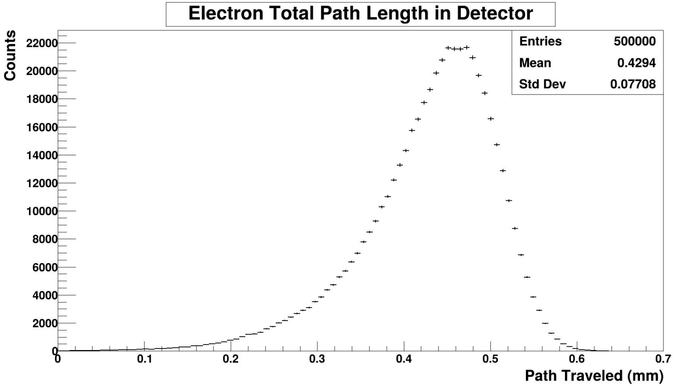
$$\langle E_{n,\text{fast}} \rangle = \frac{\sum_{i=1}^{N_{\text{shared}}} E_{n,\text{fast},i}\ [\text{keV}]}{N_{\text{shared}}} \quad (3)$$

Figure Of Merit For Choosing The Thickness Of Bulk Layers

Geometric Distance $= \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$



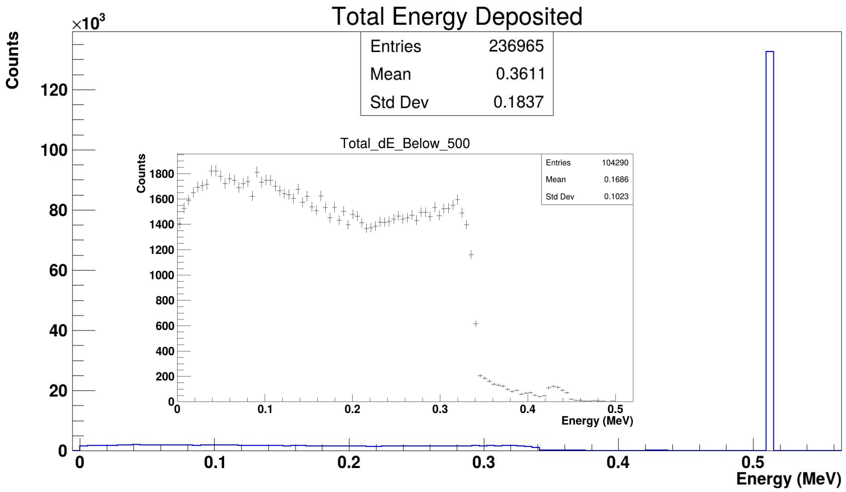


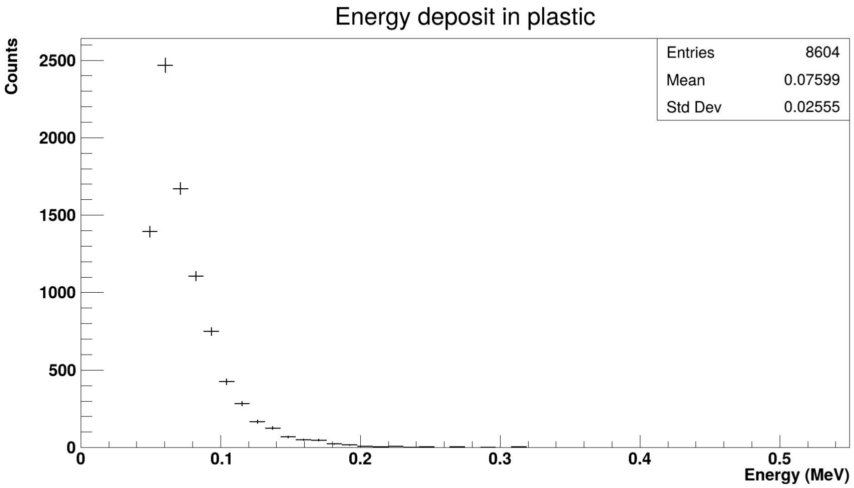


The Continuous Slowing Down Approximation (CSDA) range of electrons in Bismuth Germanate (BGO) is presented as a function of electron kinetic energy, based on data derived from the NIST ESTAR database.

Energy Deposition Spectra

- Simulation records **total deposited energy** from all particles (primary + secondary).
- Distribution reflects **full and partial energy deposition events.**
- Events with **Edep < 500 keV** indicate partial absorption (e.g., Compton scattering with photon escape)
- Spectrum analysis is used to **separate complete vs. incomplete absorption processes.**



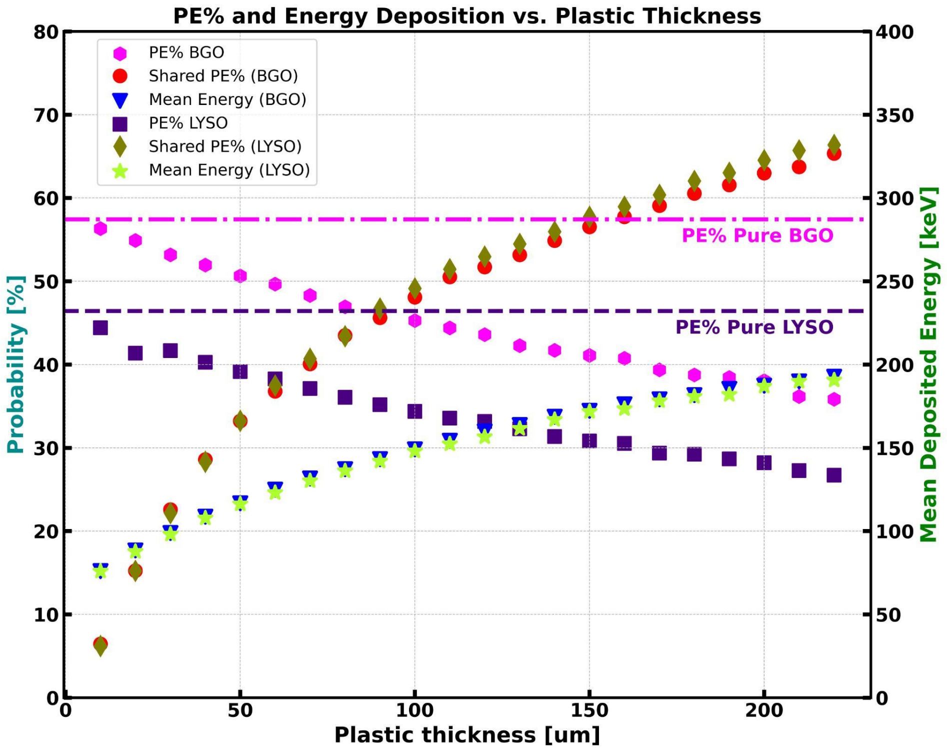


Shared Energy Distribution

- A **threshold of 50 keV** is applied to select events depositing significant energy in the plastic layer.
- This filtered distribution reveals how energy is shared between the **bulk** and **fast** layers during photoelectric interactions.

Comparison of BGO/EJ-232 and LYSO/EJ-232 Heterostructures

- **Photoelectric probability:** The BGO-based heterostructure demonstrates a higher overall photoelectric interaction probability compared with its LYSO-based counterpart.
- **Shared photoelectric fraction:** Despite the higher total PE probability in BGO, the fraction of shared photoelectric events is slightly greater in the LYSO-based configuration.
- **Energy deposition in the fast material (EJ-232):** The mean deposited energy within the fast scintillator is nearly equivalent between both heterostructures, with the BGO/EJ-232 case exhibiting an increase of approximately 2 keV.



Conclusions and Future Work

- **Model validation:** GEANT4 simulations were carried out and validated against the published results, confirming the reliability of the implemented model.
- **Interaction mechanism:** At 511 keV, γ-rays are primarily absorbed in the high-Z bulk scintillators, with partial energy transfer to the coupled fast scintillator layer.
- **Timing performance:** Enhanced energy deposition within the fast scintillator is directly correlated with improved coincidence time resolution (CTR).
- **Future directions:** Ongoing work will extend the simulations to heterostructures incorporating perovskite nanocrystals (NCs), with subsequent experimental fabrication and comprehensive timing characterization planned.

Thank You