MCPEETS

MONTE CARLO POSITRON EMISSION ENTANGLEMENT TRACKING SIMULATION

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Why?

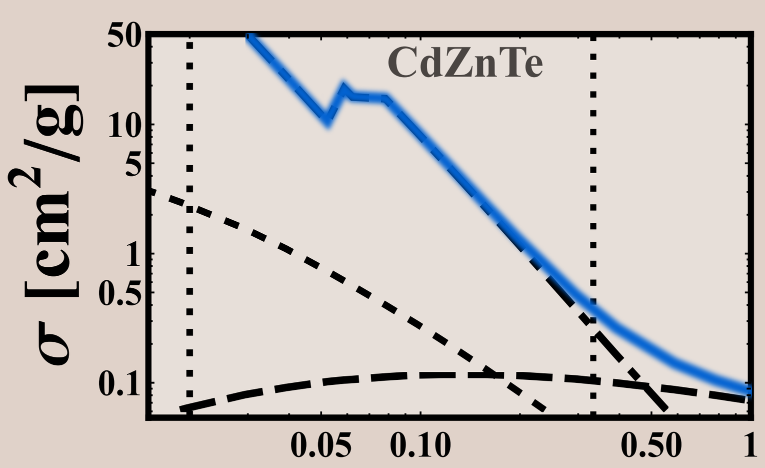
Incorporating ***photon entanglement*** into propagation simulations improves their accuracy and, in PET imaging, can help quantify signal noise from photon scatter (Hiesmayr & Moskal 2019).

What?

MCPEETS is a custom gamma-photon transport simulation built for a typical photon entanglement detection experiment using volumetric detectors.

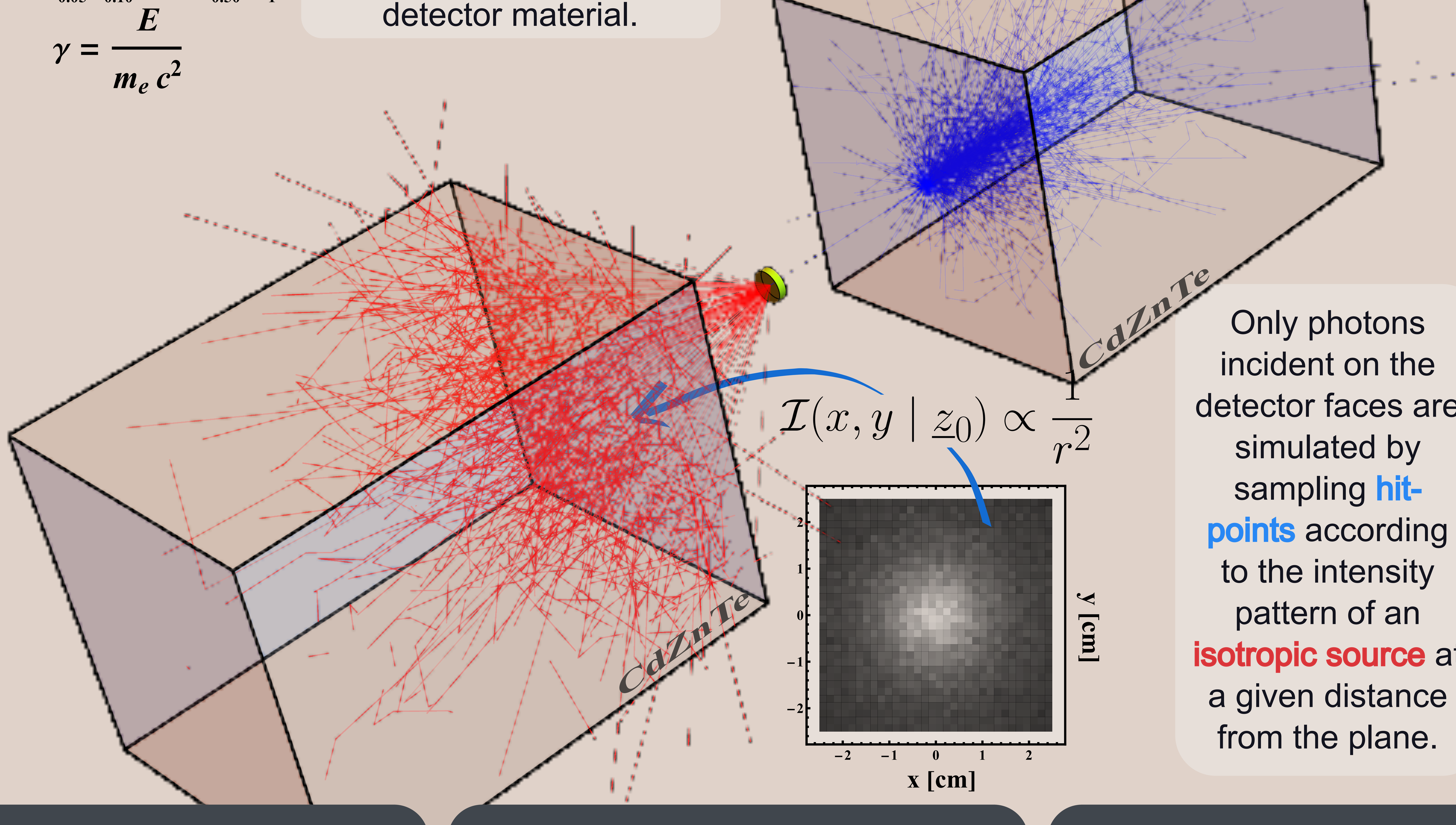
How?

Photon absorptions and scatters in each detector are modeled statistically using interaction **cross-sections** as probability distributions. ***Monte Carlo techniques*** are then used to simulate thousands of events (Arqueros & Montesinos 2003).



$$\gamma = \frac{E}{m_e c^2}$$

Interaction cross-sections for Compton scattering, p.e. absorption, (and coherent scattering) sum to the **total cross-section** in CdZnTe detector material.



$$\mathcal{I}(x, y \mid \underline{z}_0) \propto \frac{1}{r^2}$$

Only photons incident on the detector faces are simulated by sampling **hit-points** according to the intensity pattern of an **isotropic source** at a given distance from the plane.

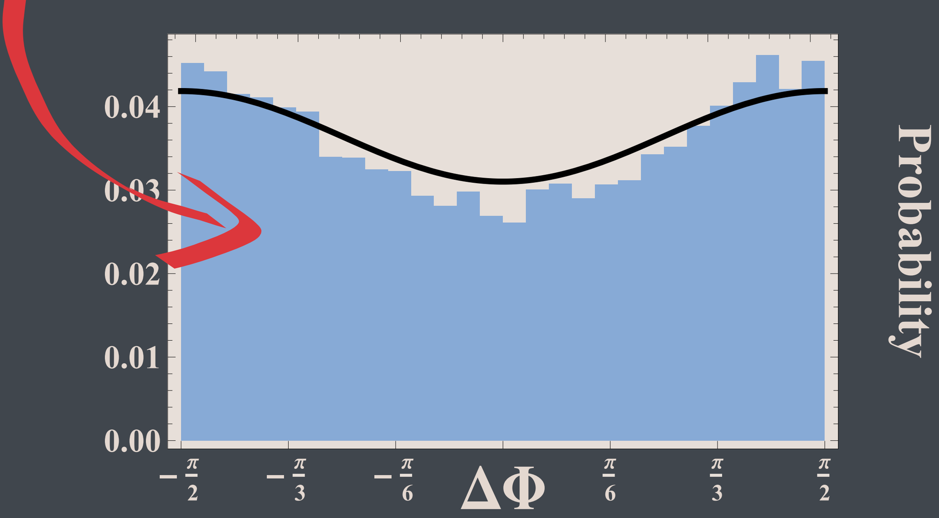
SAMPLING METHODS

$$p(s) \xrightarrow{\text{CDF}} P(s) \xrightarrow{\text{invert}} P^{-1}(\mathfrak{r}) \xrightarrow{\text{sample}} s$$

In **MCPEETS**, photons propagate through media over mean free path lengths before interacting via photoelectric absorption or Compton scattering. Simulation variables, including scattering angles in Compton scatters, are sampled from underlying distributions, handled analytically when possible and numerically otherwise. The primary sampling technique used is the Inverse CDF Method.

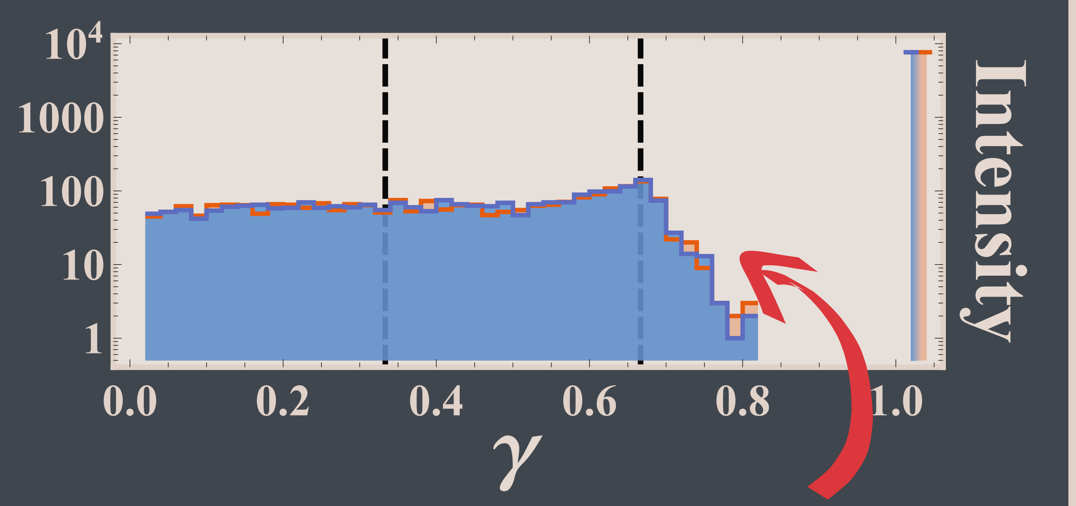
ENTANGLEMENT

$$\psi(\Delta\Phi \mid \underline{x}_1, \underline{x}_2) = \frac{r_e^4}{4\sigma_{\mathrm{KN}}^2}\left(K_a(\underline{x}_1, \underline{x}_2) - K_b(\underline{x}_1, \underline{x}_2) \cdot \cos(2\Delta\Phi)\right)$$

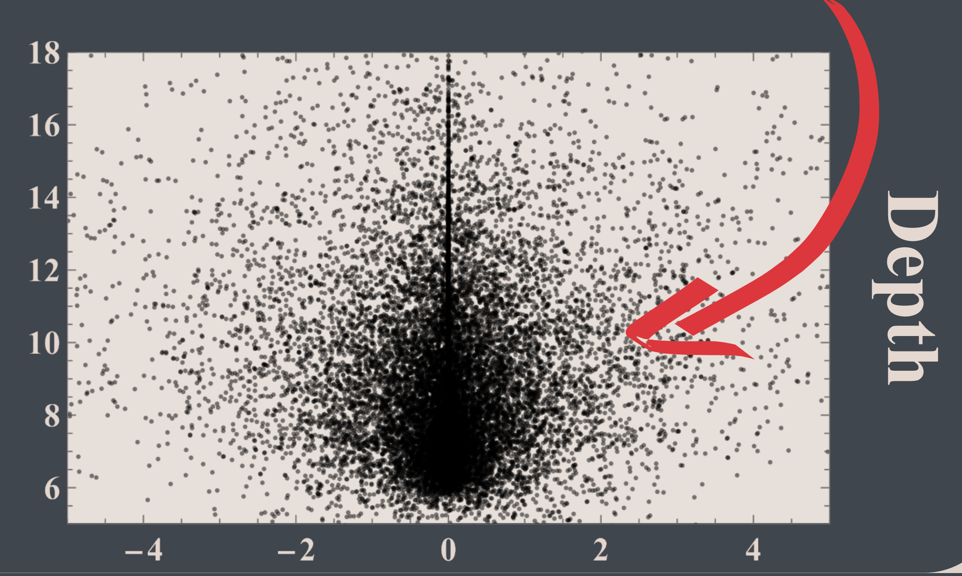


Electron-positron annihilation photon pairs have orthogonal polarizations due to entanglement, resulting in correlated azimuthal scattering angles as described by the Differential Cross Section above.

VALIDATION



Simulated gamma spectrum & xz-projected energy deposition sites.



References: Arqueros, F., & Montesinos, G. D. (2003). Am. J. Phys., 71, Hiesmayr, B. C., & Moskal, P. (2019). Sci. Rep., 9, 44570.