Machine Learning to Constrain Optical Parameters at Liquid Scintillator Detectors

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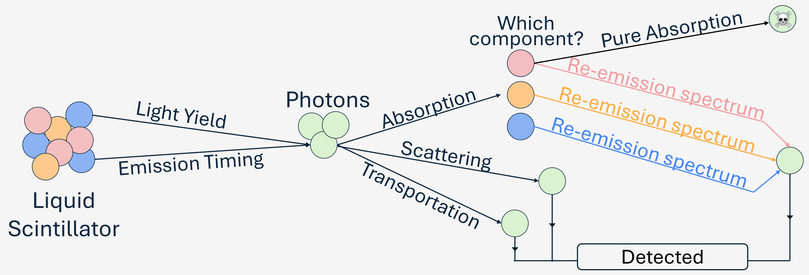
Liquid Scintillator and Optical Modeling

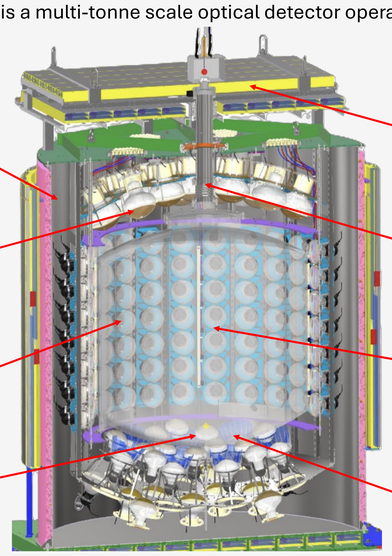
Liquid scintillator is a target material used by many neutrino detectors. It is often a mixture of different components: a primary solvent and a combination of wavelength shifters.



The production and propagation of photons in liquid scintillator depends on optical properties that must be characterized for accurate simulations.

Eos Experiment

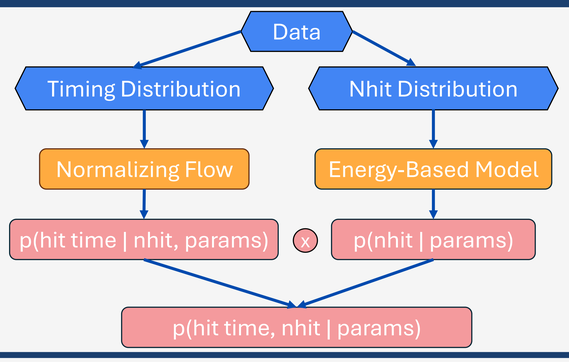
The Eos Experiment is a multi-tonne scale optical detector operating at UC Berkeley.



Eos uses novel liquid scintillators to detect Cherenkov and Scintillation light.

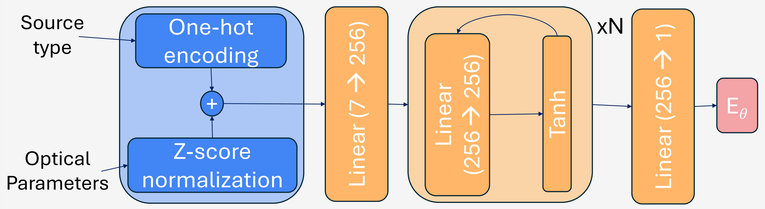
Simulation-Based Inference

Training ML model on simulations to learn relationship between optical parameters and detector signal, then apply that model to data to extract true optical parameters.

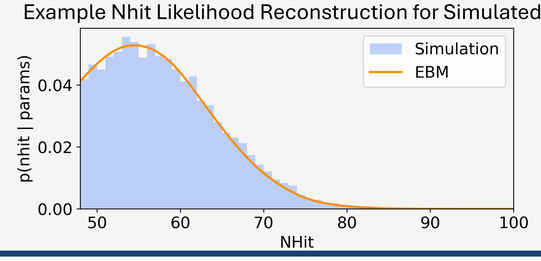


Energy-Based Model (EBM)

$$p_\theta(\text{nhit} = k \mid \text{params}) = \frac{\exp\big(E_\theta(k, \text{params})\big)}{\sum_j^{\max \text{nhit}} \exp\big(E_\theta(j, \text{params})\big)}$$

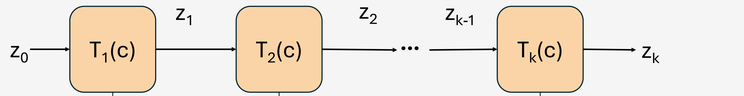


Example Nhit Likelihood Reconstruction for Simulated ^{208}Tl



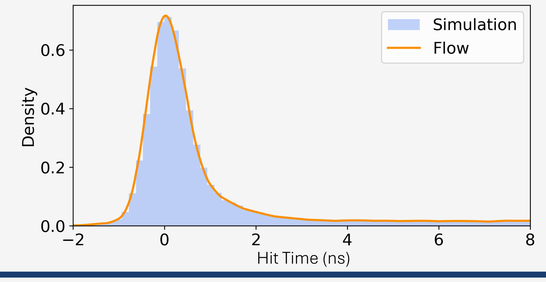
Normalizing Flow

Start with a simple distribution.
Apply a series of invertible conditional transformations to model the likelihood.



$$\log \pi(z_0) + \log\left|\det J_{T_1^{-1}}(z_1; c)\right| + \log\left|\det J_{T_K^{-1}}(z_K; c)\right| = \log p(z|c)$$

Example Timing Likelihood Reconstruction for Simulated Laserball



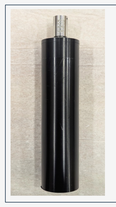
Calibration Sources

Sources used in this analysis

Laserball

Isotropic light using 515 nm laser

Sensitive to scattering from timing



Thorium

2.6 MeV gamma rays from thoriated tungsten rods

Sensitive to light yield, scattering and absorption

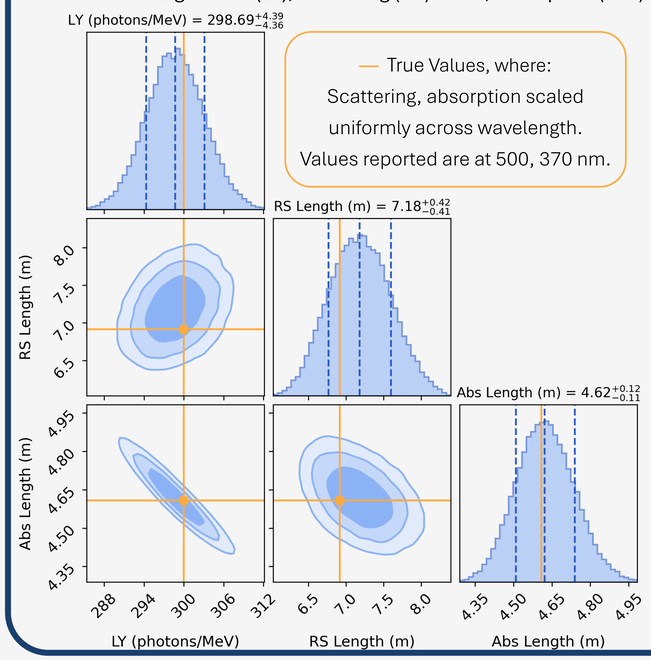
Cherenkov

^{90}Sr button source in a UVT acrylic

Sensitive to scattering and absorption

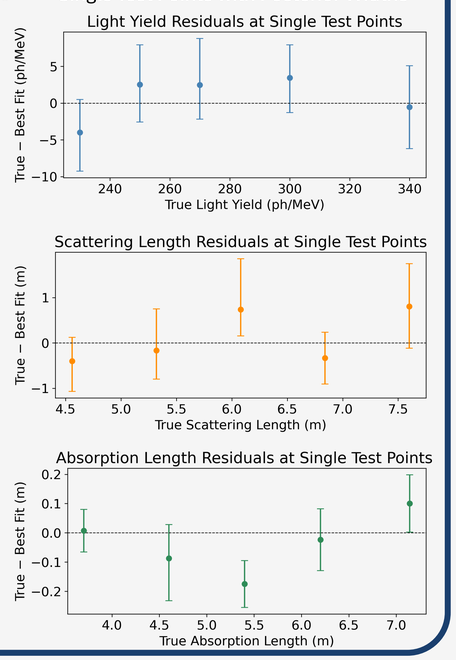
Results

3D Posterior in Light Yield (LY), Scattering (RS) Scale, Absorption (Abs) Scale



— True Values, where:
Scattering, absorption scaled uniformly across wavelength.
Values reported are at 500, 370 nm.

Single Test Points with Posterior Widths



References and Acknowledgements

[1] Askins, M., et al. Theia: an advanced optical neutrino detector. Eur. Phys. J. C 80, 416 (2020).
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