Antineutrinos sensitivity at Theia

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Experimental detection of geo- and reactor antineutrinos

- Low energy geo- and reactor $\bar{\nu}_e$ between [1, 10] MeV are detected using the Inverse-Beta Decay (IBD) interaction: $\bar{\nu}_e + p \rightarrow e^+ + n$
- IBD threshold: $E_{\text{IBD}} = 1.806$ MeV
  - Prompt signal from $e^+ \Rightarrow$ Reconstruction of $\bar{\nu}_e$ energy
  - Delayed signal (+200 μs) by a 2.2 MeV gamma from n-H capture.

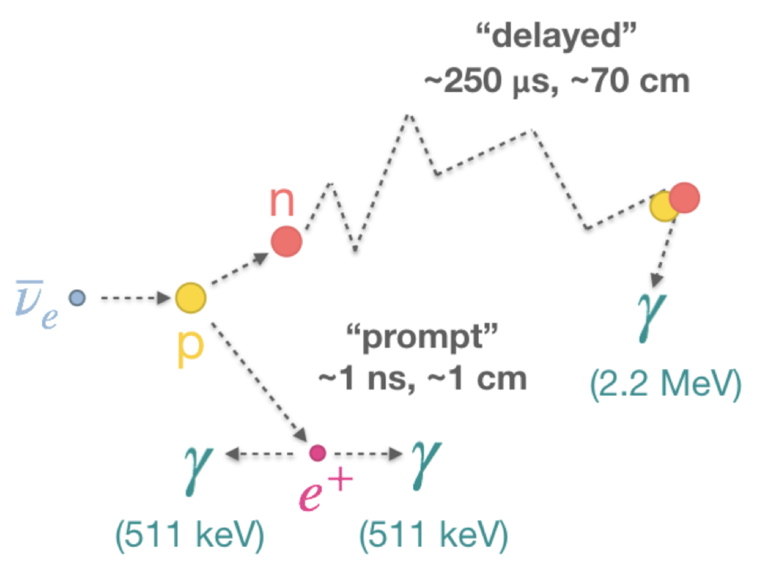

Figure 1: IBD interaction on a free proton of a water target

- Currently, geo- and reactor $\bar{\nu}_e$ have exclusively been detected in liquid scintillator (LS) detectors such as KamLAND[1] and Borexino[2].

Theia: An Advanced Optical Neutrino Detector

- Theia[3]: proposed large-scale novel neutrino detector designed with the ability to discriminate between Cherenkov and scintillation signals.
  - Cylindrical tank viewed by inward-looking PMTs and filled with 100 kT of water-based liquid scintillator (WbLS).
  - We are considering here a **25 kT geometry filled with 3% WbLS** which could be deployed at Sanford Underground Research Facility (SURF).

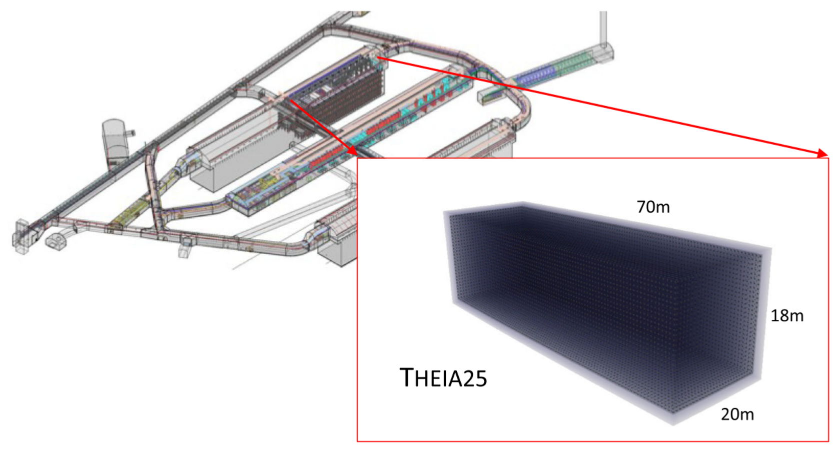

Figure 2: Potential 25 kt detector configuration

- Long attenuation length from water + high light yield of LS:
  - Increased detection efficiency from pure water detector
  - Separating Cherenkov and Scintillation photons $\Rightarrow$ PID

Analysis Strategy

- Use Geant4-based framework RAT-PAC [https://github.com/rat-pac/rat-pac] for MC production of both signal and background sources:
  - IBD generator based on spectra from geoneutrinos.org [4]
  - Accidentals background from PMTs glass and water contaminants
- Position and time reconstruction based on time residuals fitter, including both early (Cherenkov) and late (Scintillation) photons.

$$T^i_{Res} = \int_{Bin(i)}^{Bin(i+1)} \sum_{Hit} T_{Hit} - T_{Guess} - \frac{\vec{x}_{Hit} - \vec{x}_{Guess}}{c} \, dt \qquad (1)$$

- Energy reconstruction based on max likelihood from number of PMT hits VS E_{True} and Charge VS E_{True} 2D distributions, from e^+ uniformly distributed and isotropic.

$$E_{Rec} = \max_{E} \left(e^{-\frac{1}{2}\frac{(Q-\mu_Q(E))^2}{\sigma_Q(E)}} \times e^{-\frac{1}{2}\frac{(Q-\mu_{NHits}(E))^2}{\sigma_{NHits}(E)}} \right) \qquad (2)$$

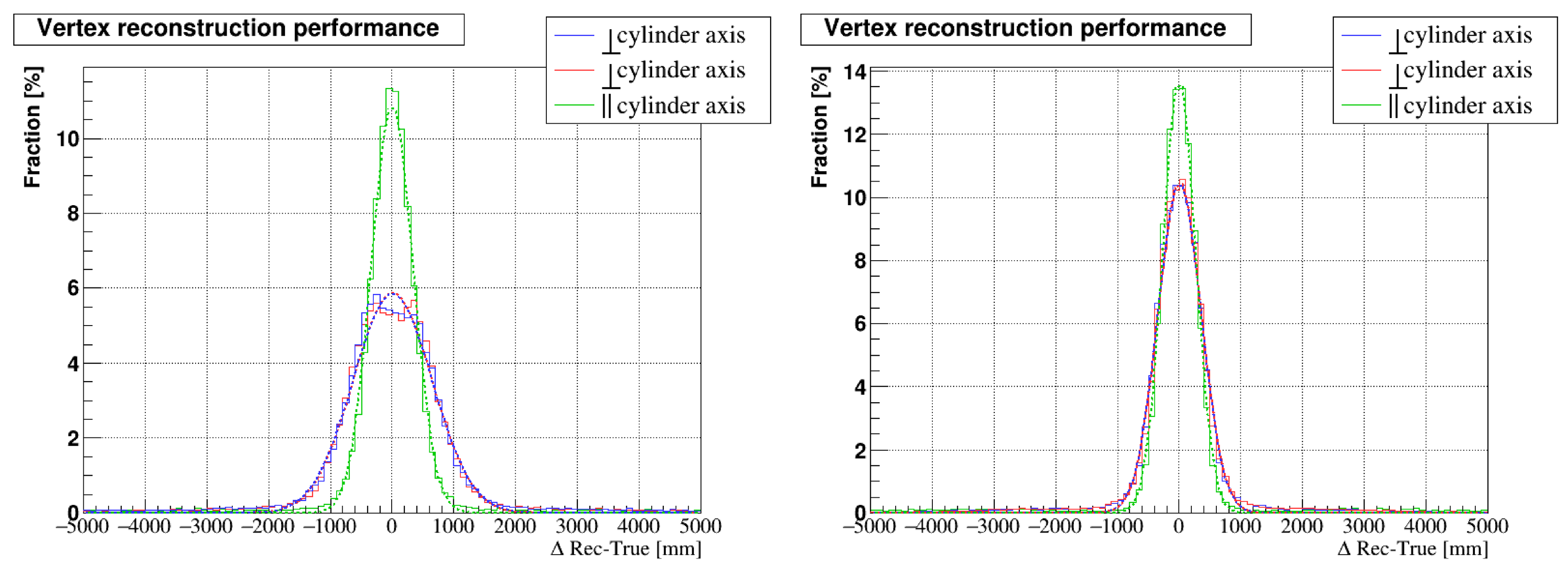

Figure 3: Reconstruction performance with respect to positron true energy, for geo- (left) and reactor $\bar{\nu}_e$, integrated throughout the whole detector and energy spectrum.

- Vertex resolution:
  - Geoneutrinos:
    - 58.0 ± 0.3 cm $\perp$ axis
    - 32.8 ± 0.2 cm $\parallel$ axis
  - Reactor:
    - 34.3 ± 0.2 cm $\perp$ axis
    - 26.6 ± 0.1 cm $\parallel$ axis
- Energy resolution:
  - WbLS 3%:
    - $14\% \cdot \frac{1}{\sqrt{E}}$

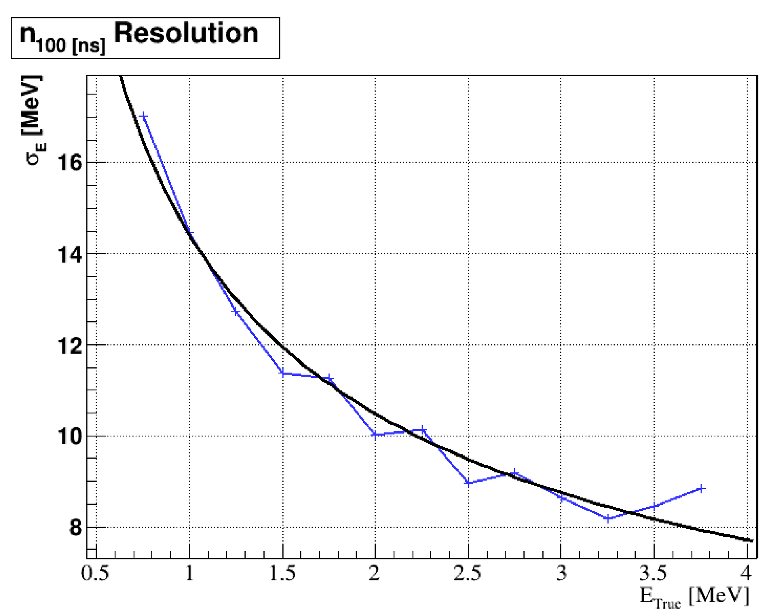

Figure 4: Energy reconstruction resolution for positrons generated throughout the whole detector volume between 0.5 MeV to 4 MeV.

Event classification

- Use a Boosted Decision Tree (BDT) trained on reconstructed variables to reject accidental-like (red) from signal-like (blue) events.

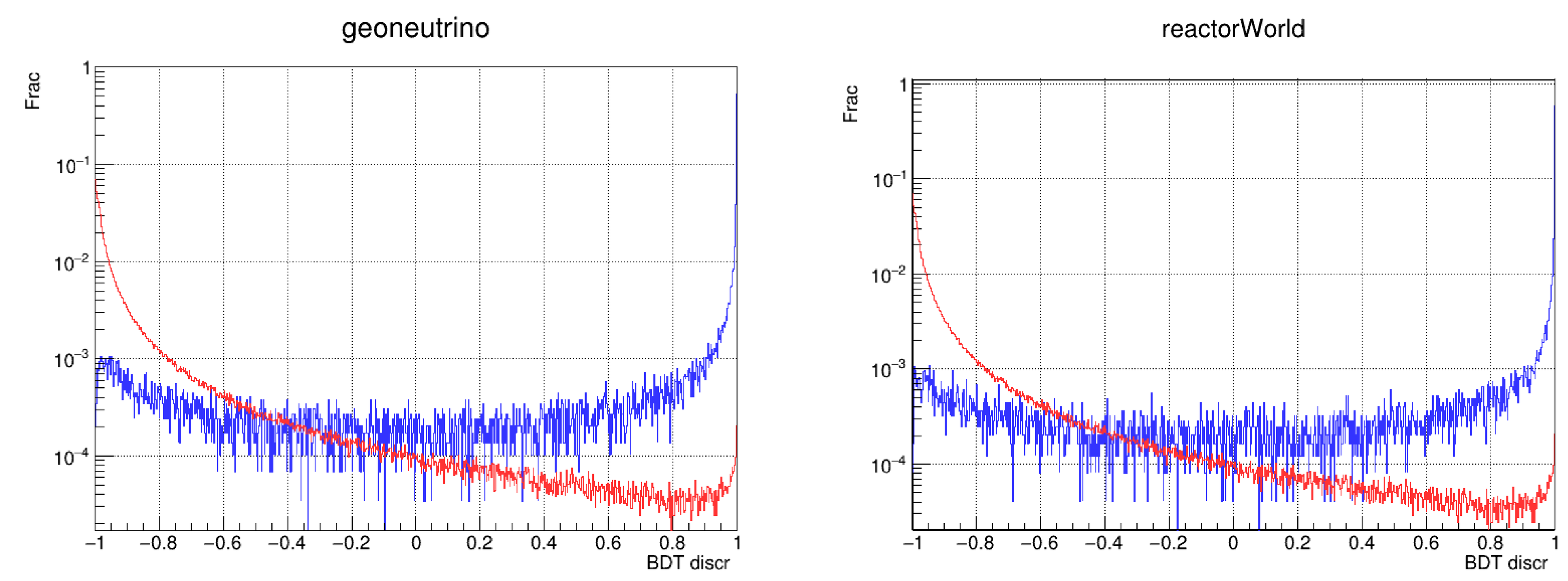

Figure 5: BDT discrimination variable, for geo- (left) and reactor (right) $\bar{\nu}_e$, integrated throughout the whole detector and energy spectrum.

Event selection optimization and sensitivity

- Create realistic datasets by merging bckg and signal
- Variables to select IBD:
  - FV($\rho = \sqrt{x^2 + y^2}, z$)
  - ΔT, ΔR, E_{prompt}, E_{delay}
- Optimize selection cuts:
  - $\max \frac{S}{\sqrt{S+B}}$

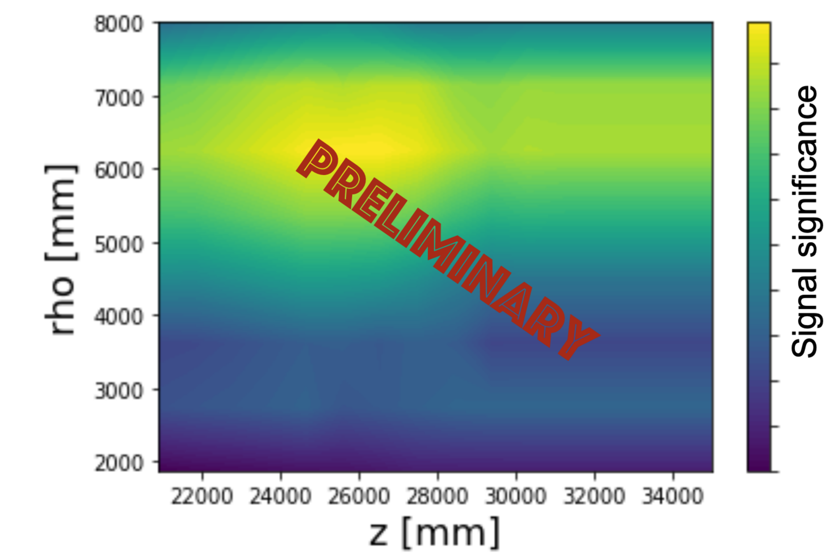

Figure 6: ρ VS z

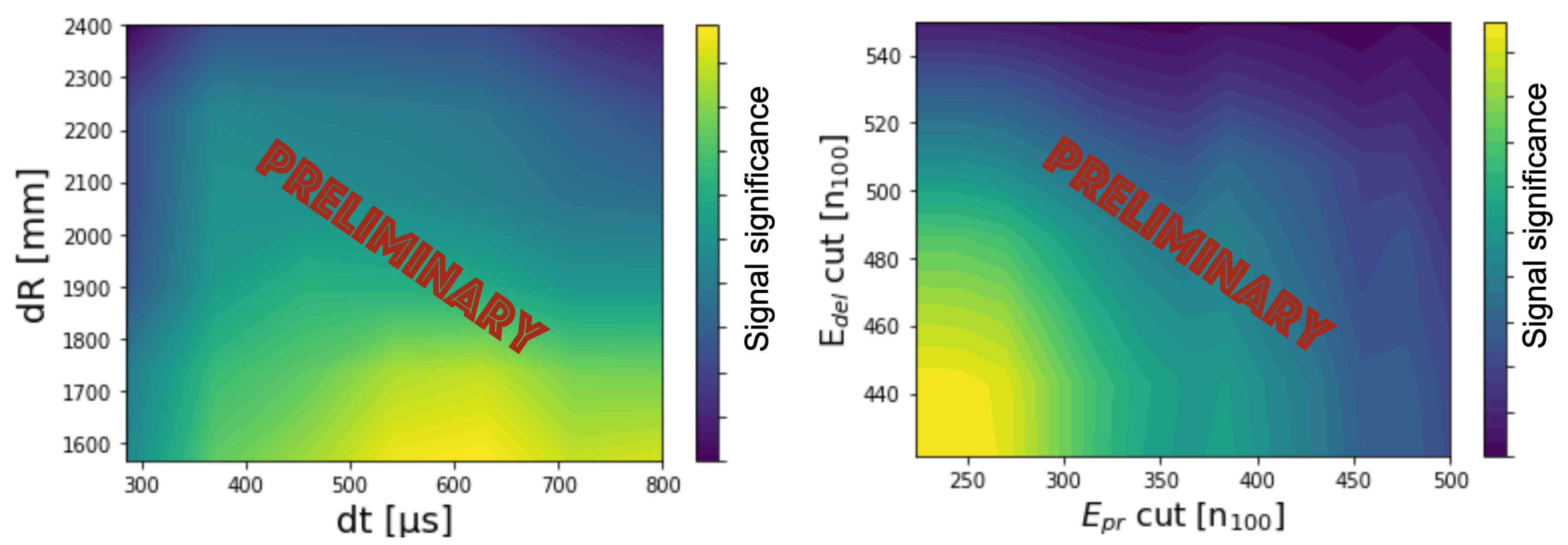

Figure 7: Left: ΔT VS ΔR. Right: E_{prompt} VS E_{delay}

References and Acknowledgments

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