$0\nu\beta\beta$-decay Event Topology Reconstruction

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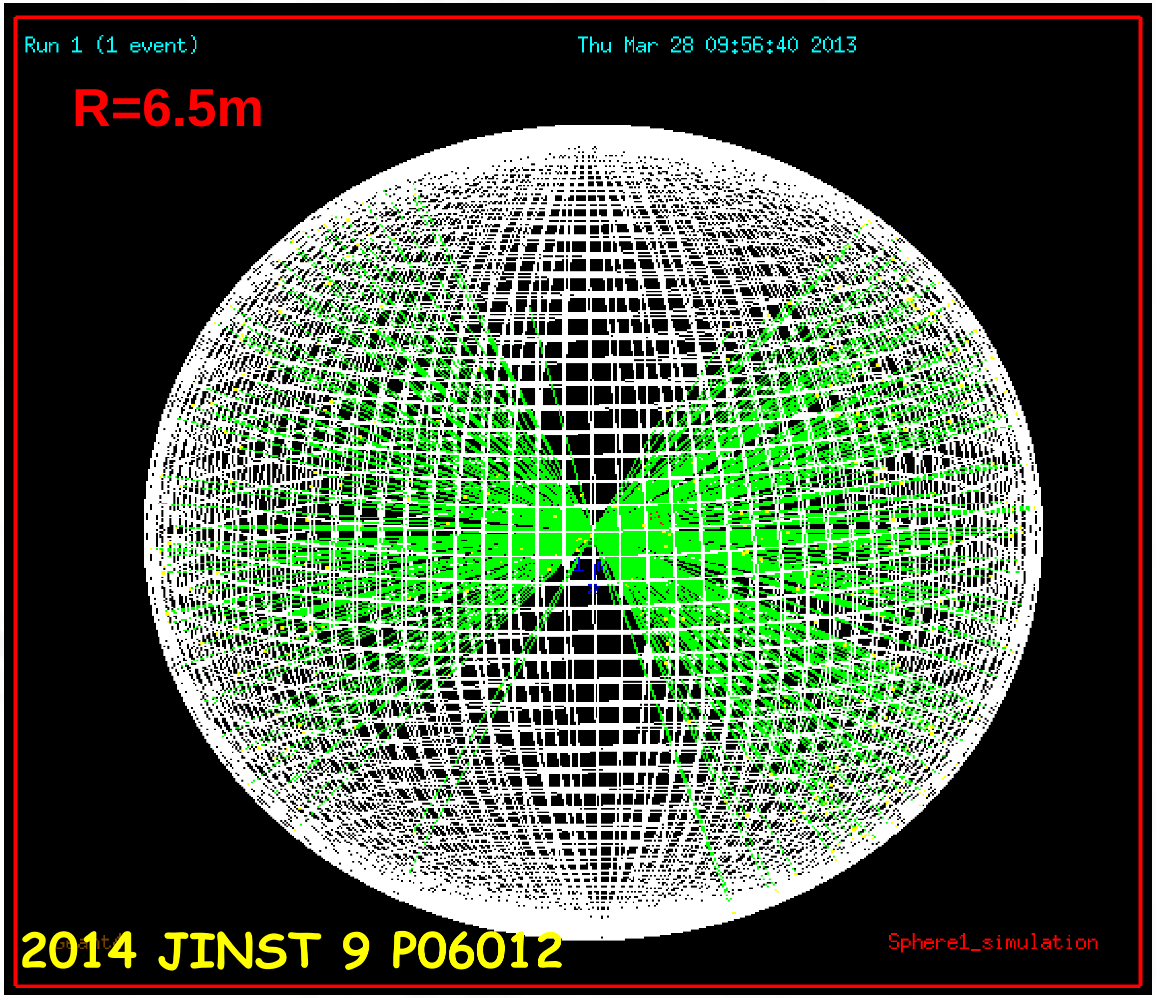
Can We See This?

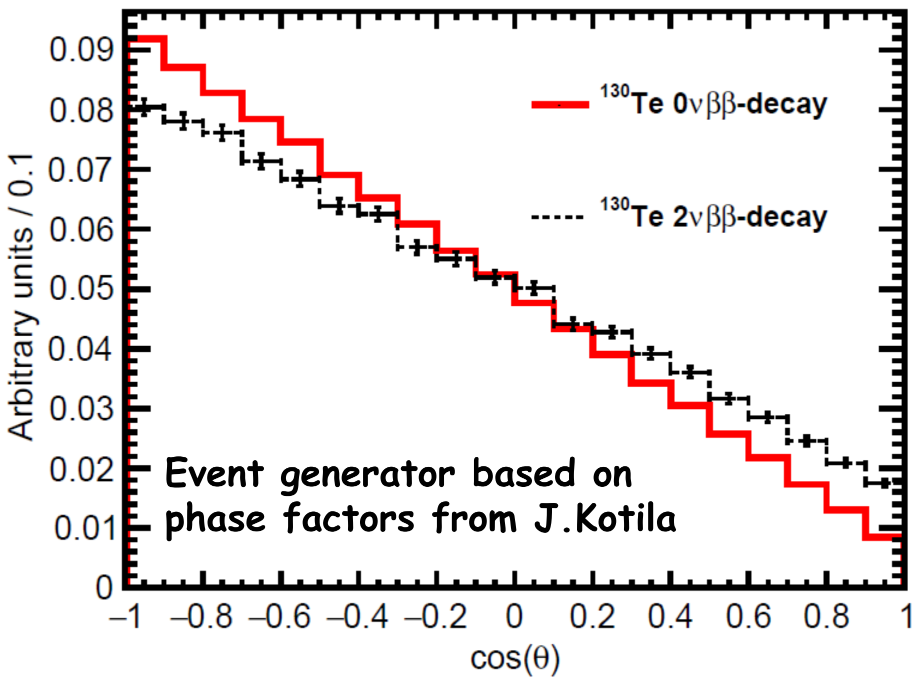
Simulation of a back-to-back $0\nu\beta\beta$ event



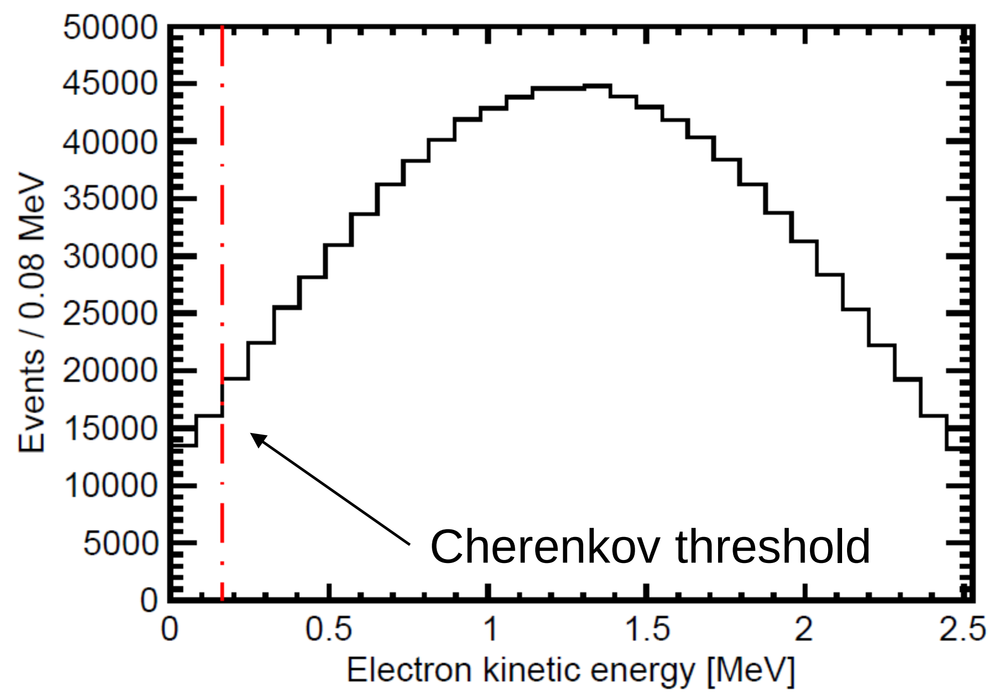
Double beta decay kinematics

- Distinct two track topology with preference to be "back-to-back" (~120°)
- Electrons are above Cherenkov threshold

Angle (cosΘ) between two electrons



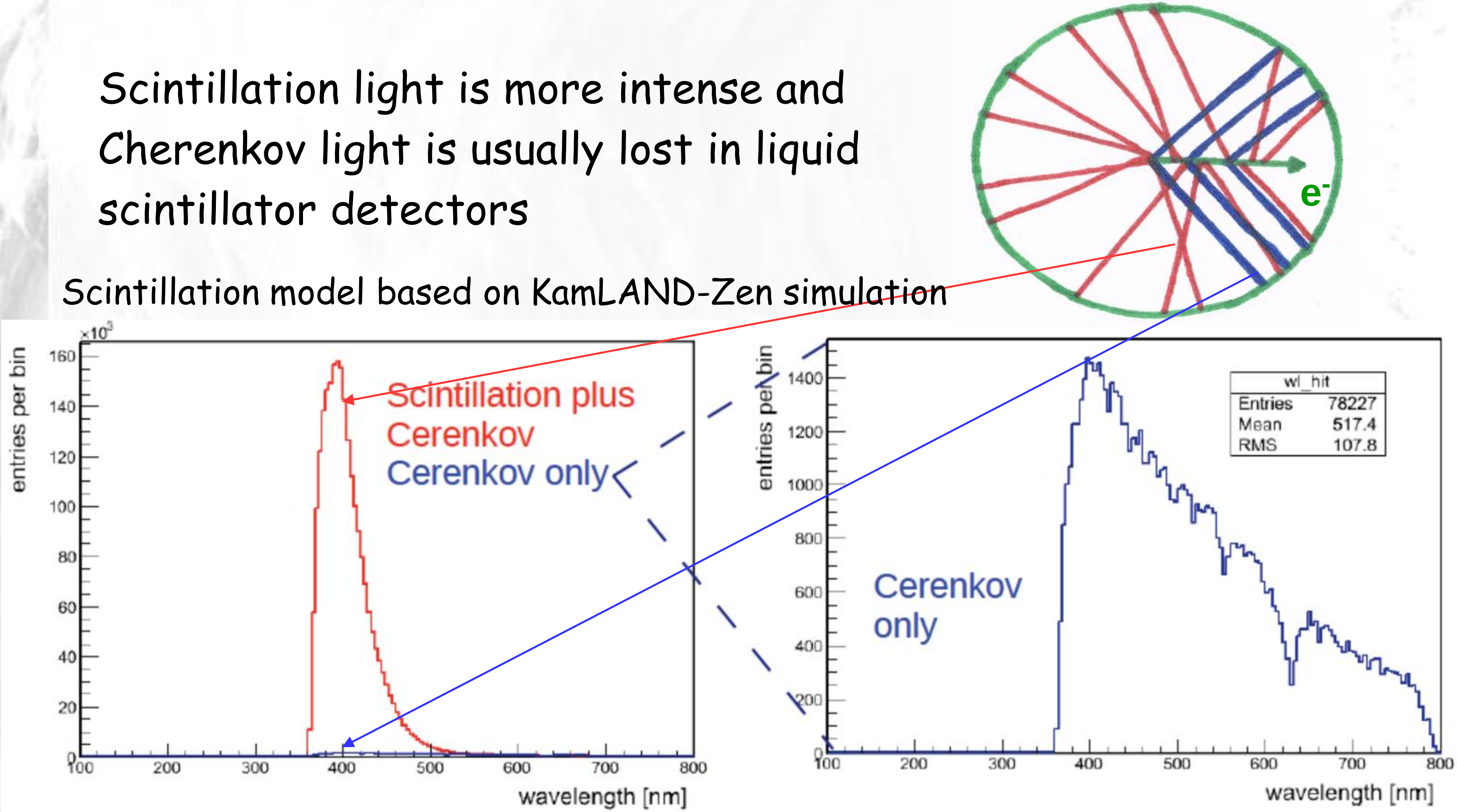
Kinetic energy of each electron



Can We Detect Cherenkov Light?

Scintillation light is more intense and Cherenkov light is usually lost in liquid scintillator detectors

Scintillation model based on KamLAND-Zen simulation



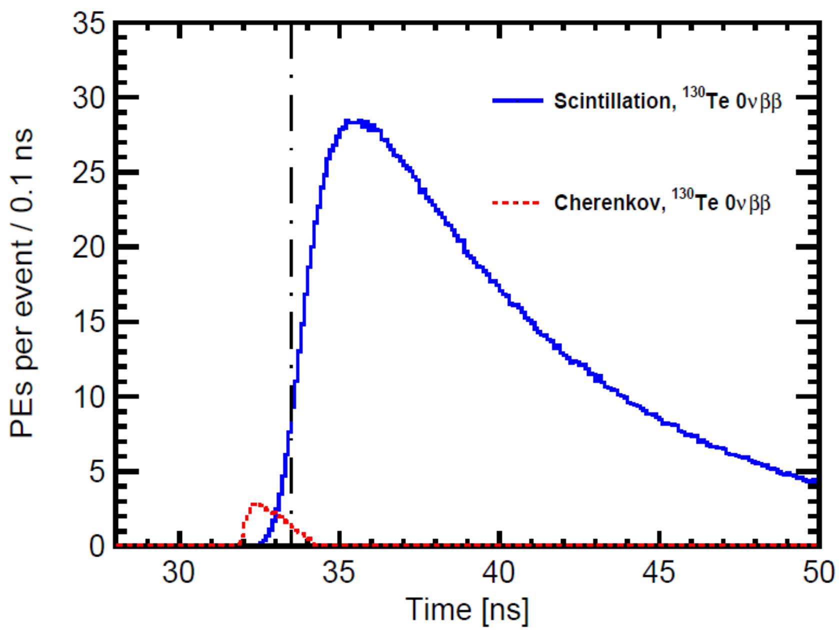
- Scintillation emission is slower
- Longer wavelengths travel faster
- Cherenkov light arrives earlier

370 nm → 0.191 m/ns
600 nm → 0.203 m/ns
~2 ns difference over 6.5m distance

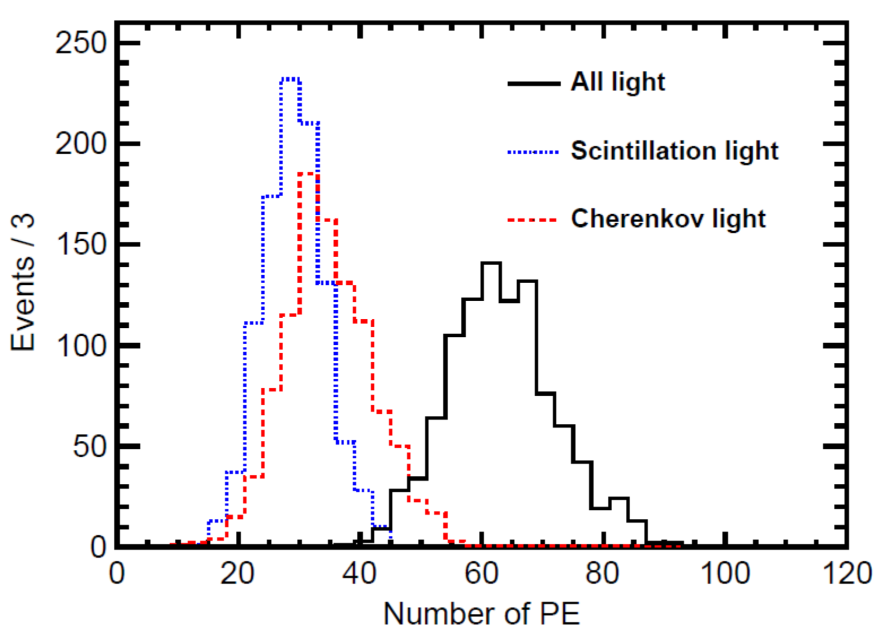
What about scintillation light?

- Scintillation is "slow" compared to Cherenkov
  - Cherenkov emission is prompt
  - red tail of Cherenkov photons travels faster
- Early light is directional due to Cherenkov component

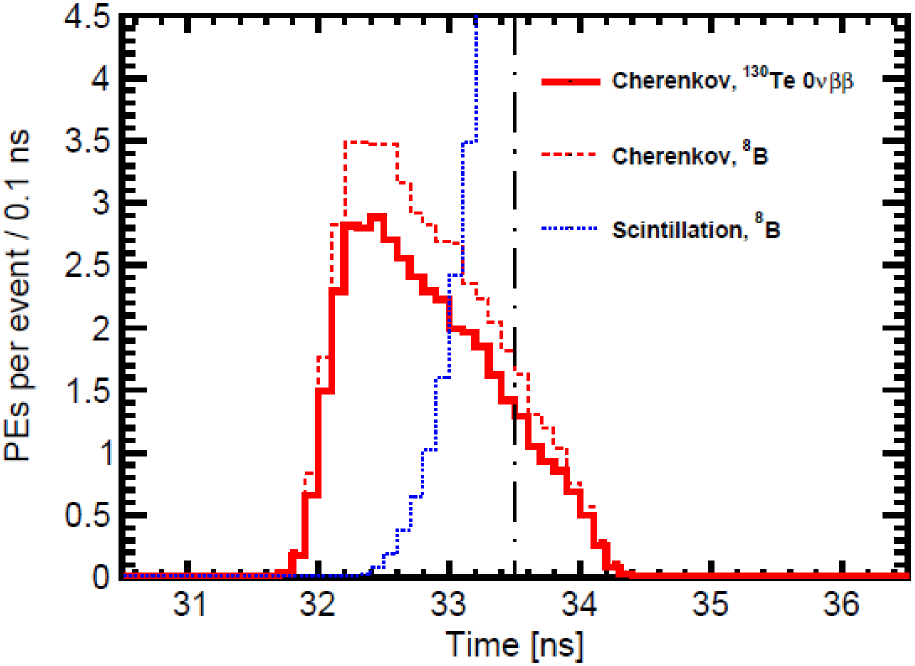
PE arrival times

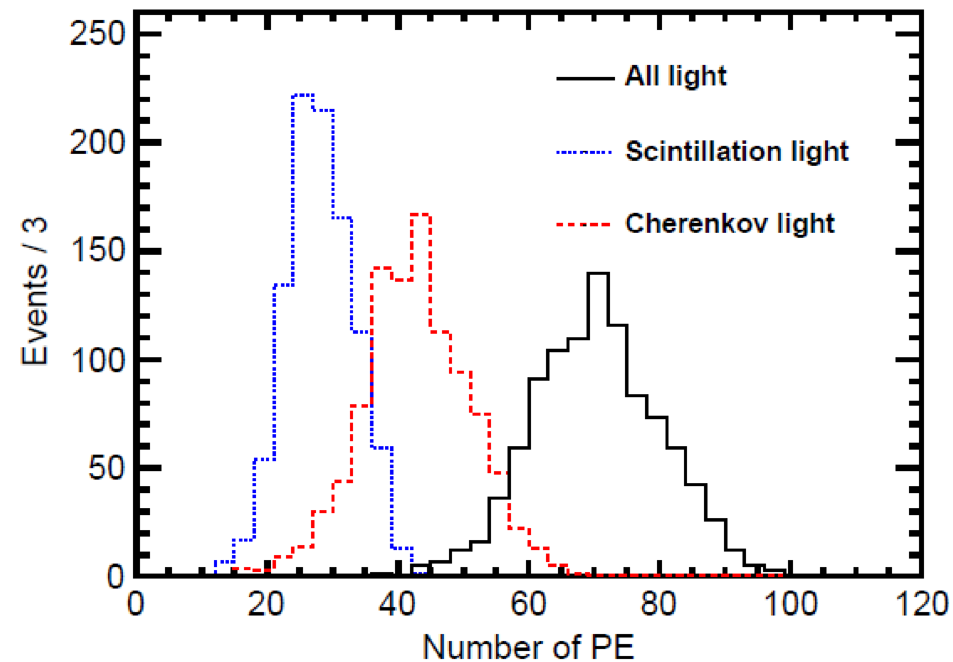


Early PE sample



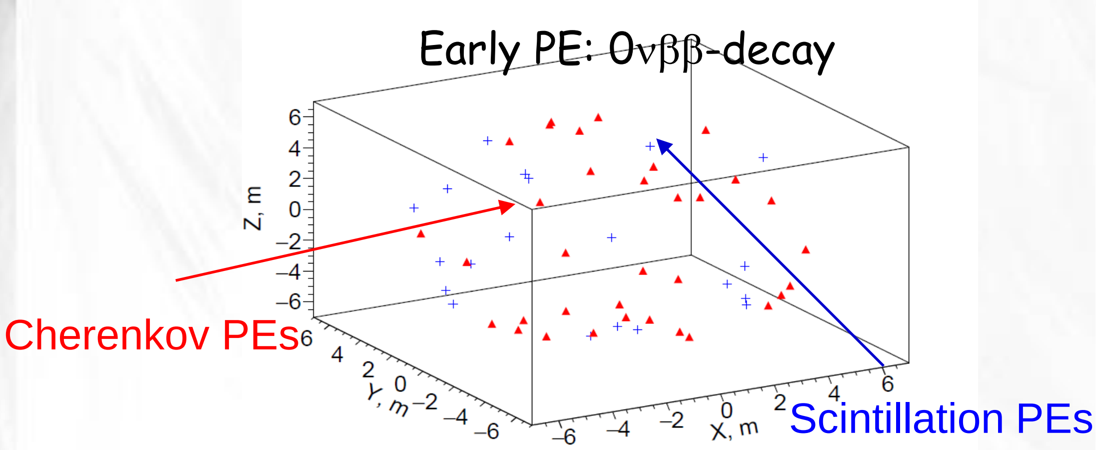
Early light: 8B vs 0vbb

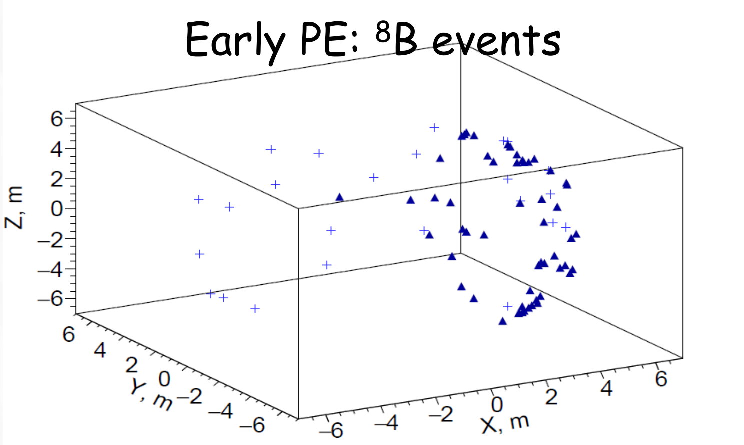




Early Light Topology

- A good pattern recognition algorithm should pick up the difference between two track and one track topologies
- E.g., a spherical harmonics analysis can separate signal and background on a statistical basis
  - see arXiv:1609.09865 for details (submitted to NIM)



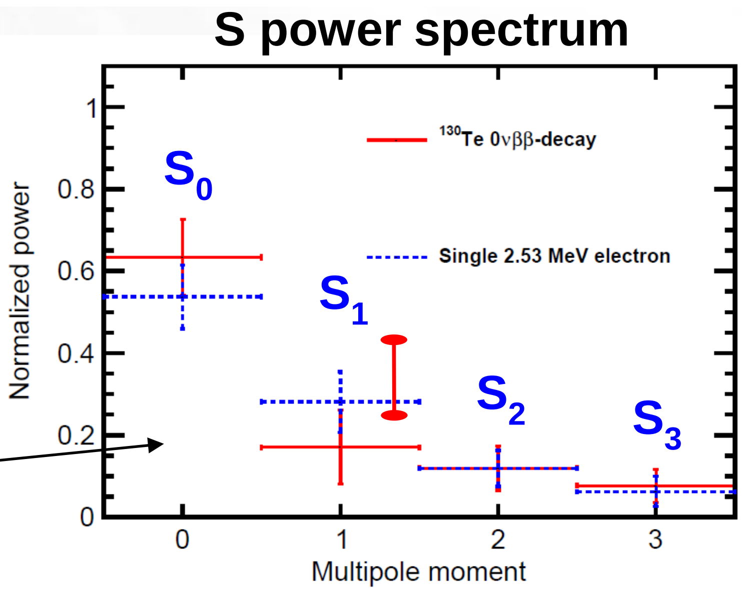


Spherical harmonics analysis

$$f(\theta,\varphi) = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} f_{\ell m} Y_{\ell m}(\theta,\varphi).$$

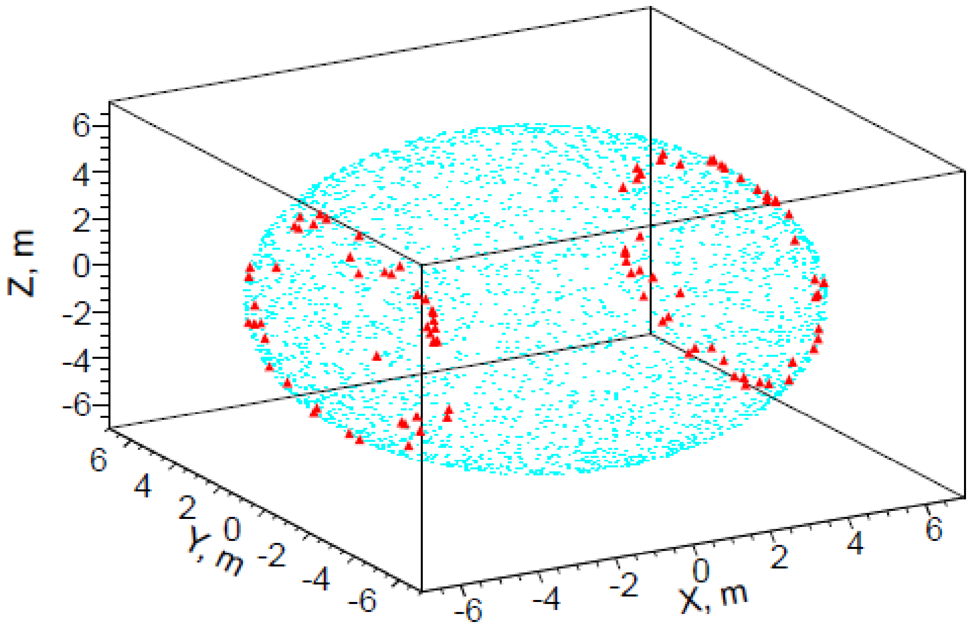
Rotation invariant power spectrum

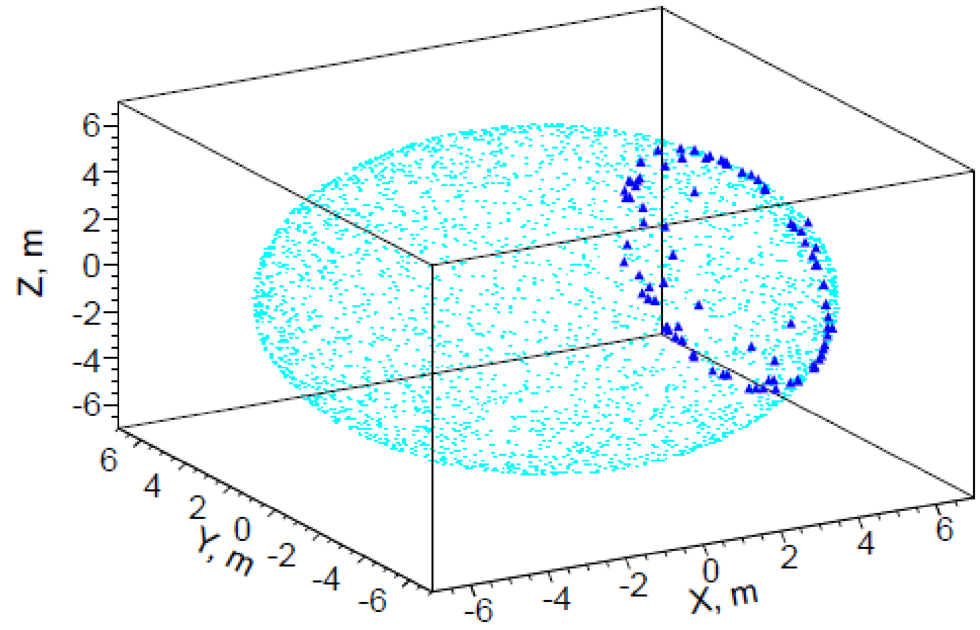
$$S_{ff}(\ell) = \sum_{m=-\ell}^{\ell} |f_{\ell m}|^2$$

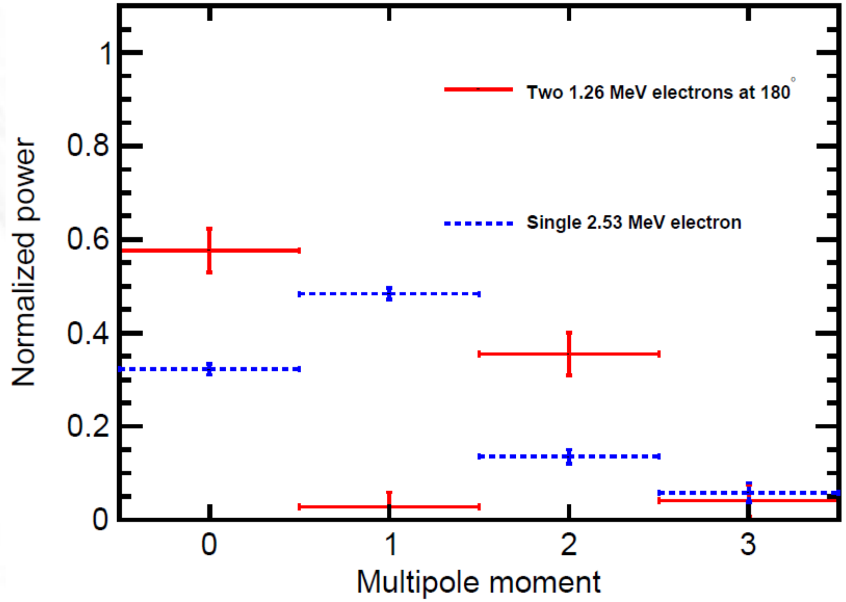


Early Light Topology

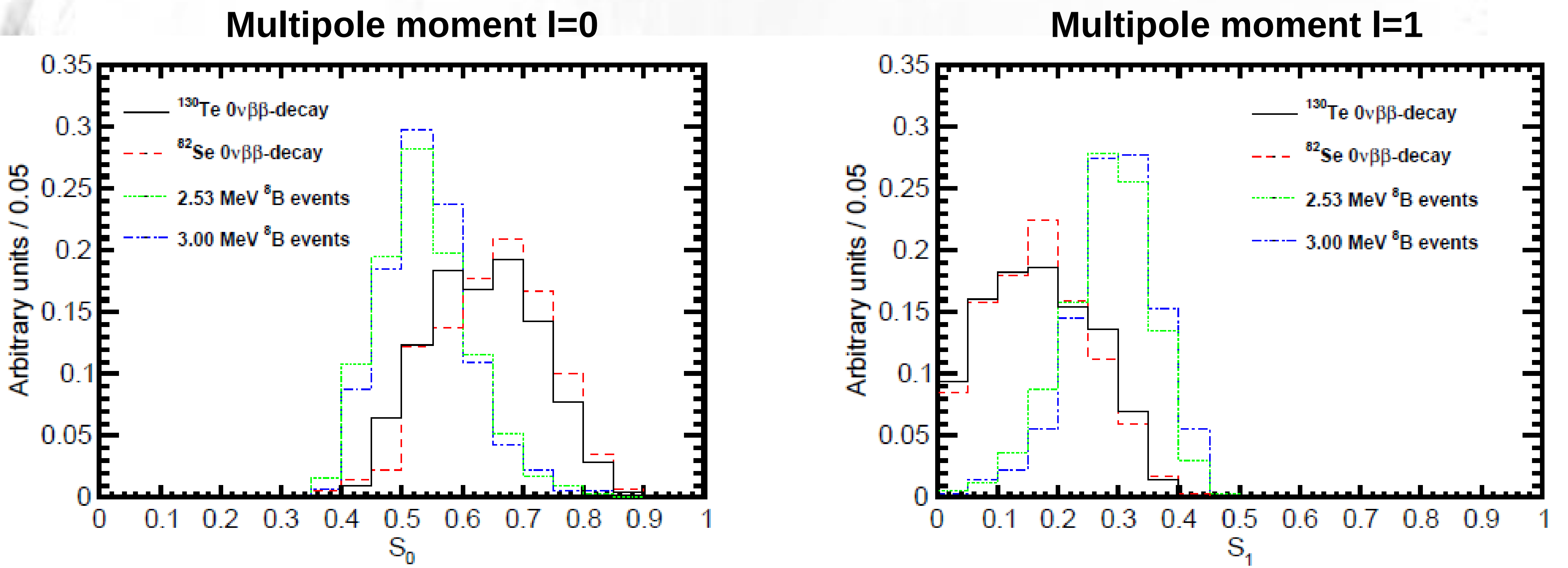
In an ideal case with no scattering it would work better







$0\nu\beta\beta$ vs ^8B



Simulation details:

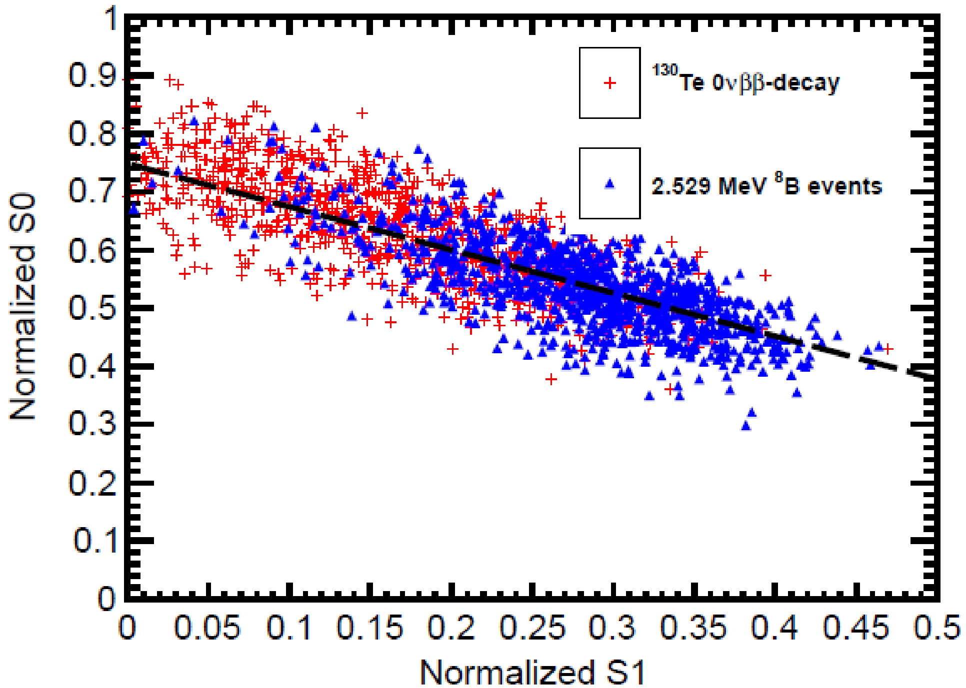
- 6.5m radius detector, scintillator model from KamLAND simulation
- TTS=100 ps, 100% area coverage, QE(che) ~12, QE(sci) ~23%

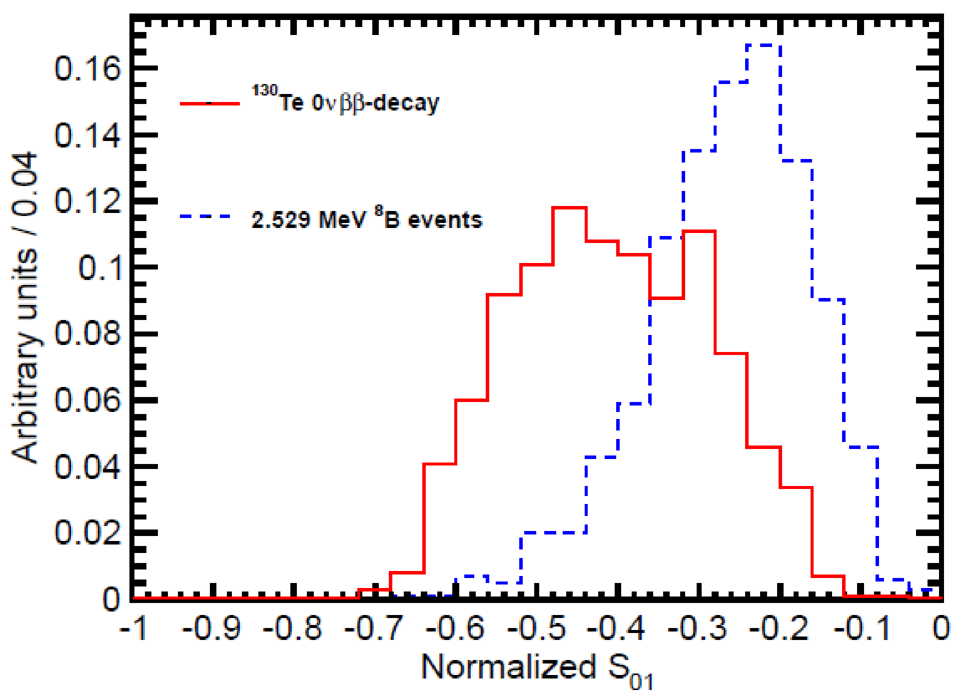
Key parameters determining separation of $0\nu\beta\beta$-decay from ^{8}B:

- Scintillator properties (narrow spectrum, slow rise time)
- Photo-detector properties (fast, large-area, high QE)
- Measuring photon color and timing with high precision would be even better…

$0\nu\beta\beta$ vs ^8B

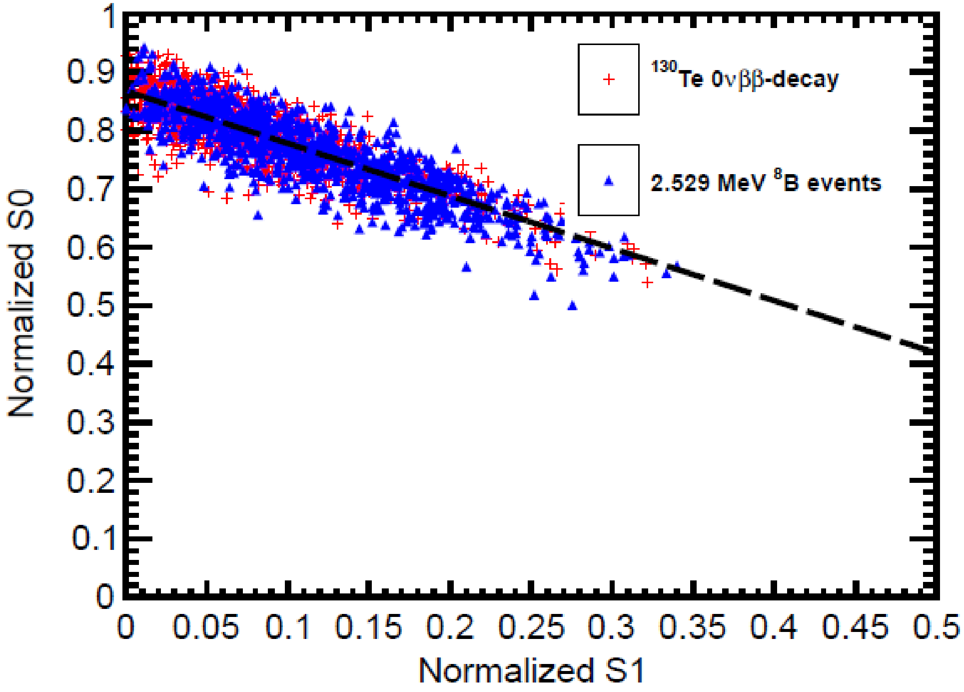
Ideal vertex, central events only
Sci rise time 1 ns

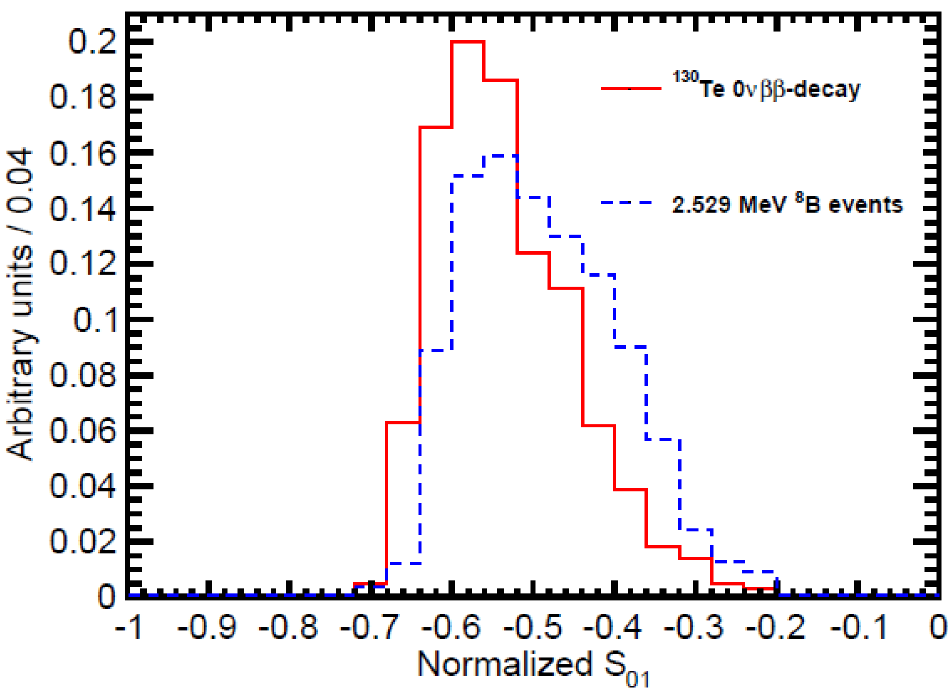




$0\nu\beta\beta$ vs ^{8}B

Vertex res 5cm, events within R<3m
Sci rise time 1 ns

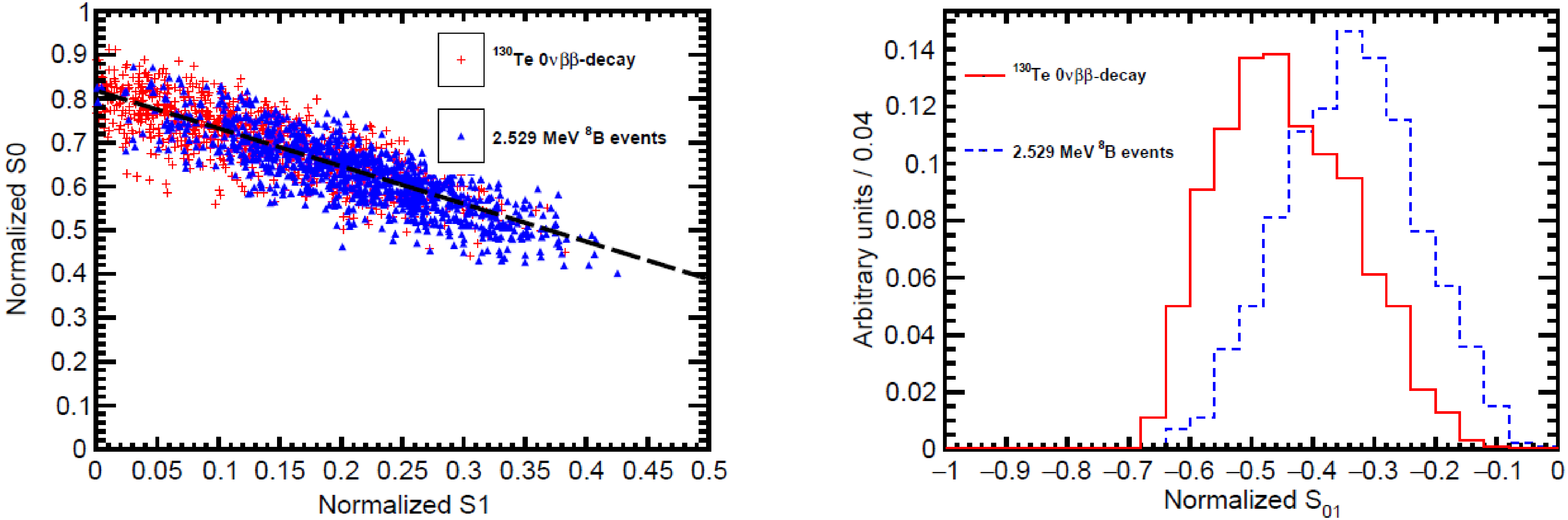




$0\nu\beta\beta$ vs ^8B

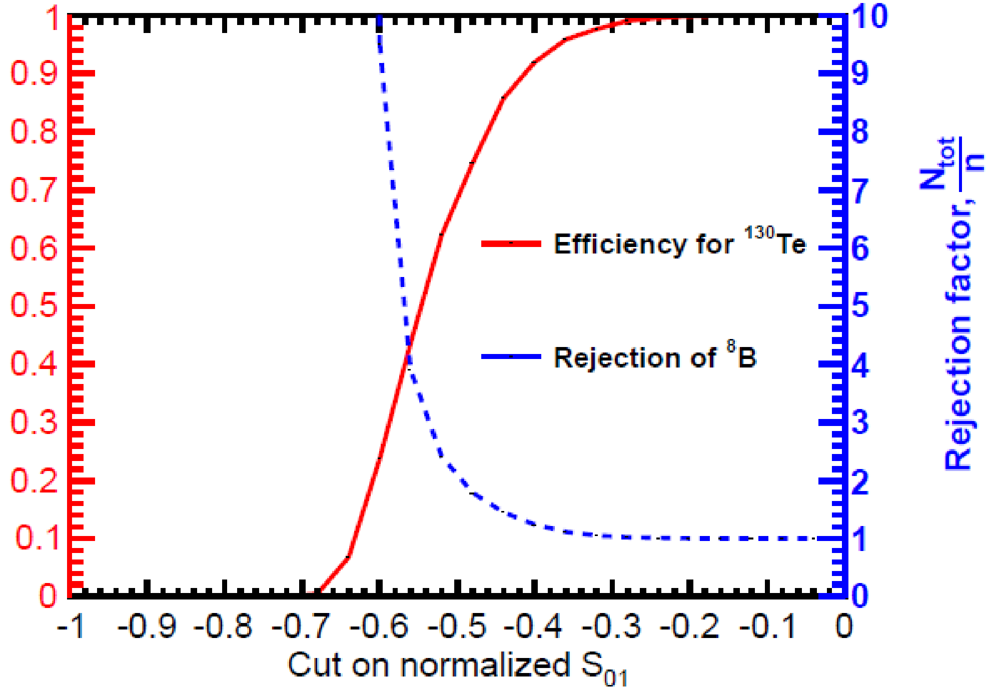
Vertex res 5cm, events within R<3m

Sci rise time **5 ns**



0νββ vs ^{8}B

Vertex res 5cm, events within R<3m
Sci rise time 1 ns



Vertex res 5cm, events within R<3m
Sci rise time **5 ns**