Simulations for Neutron Detection Efficiency in a Large Gd Doped WC Detector

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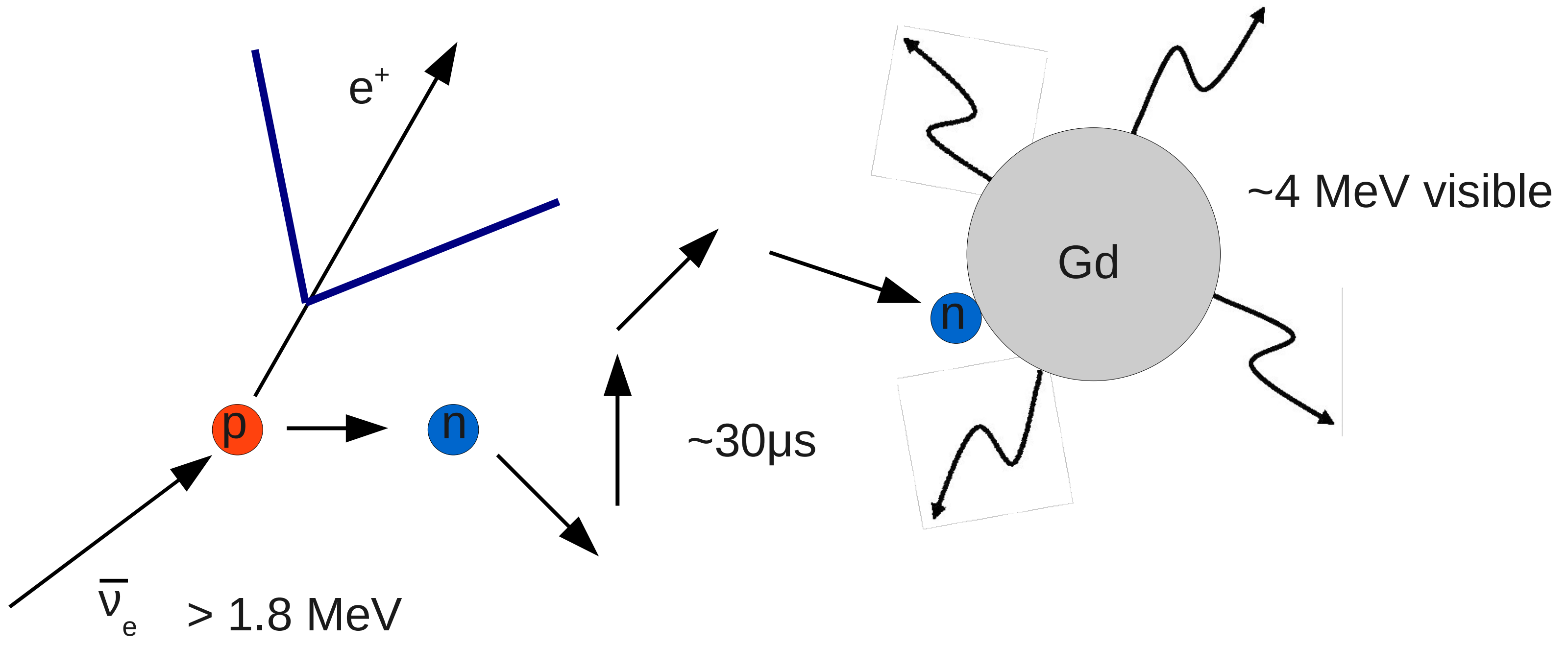
Motivation for Gd



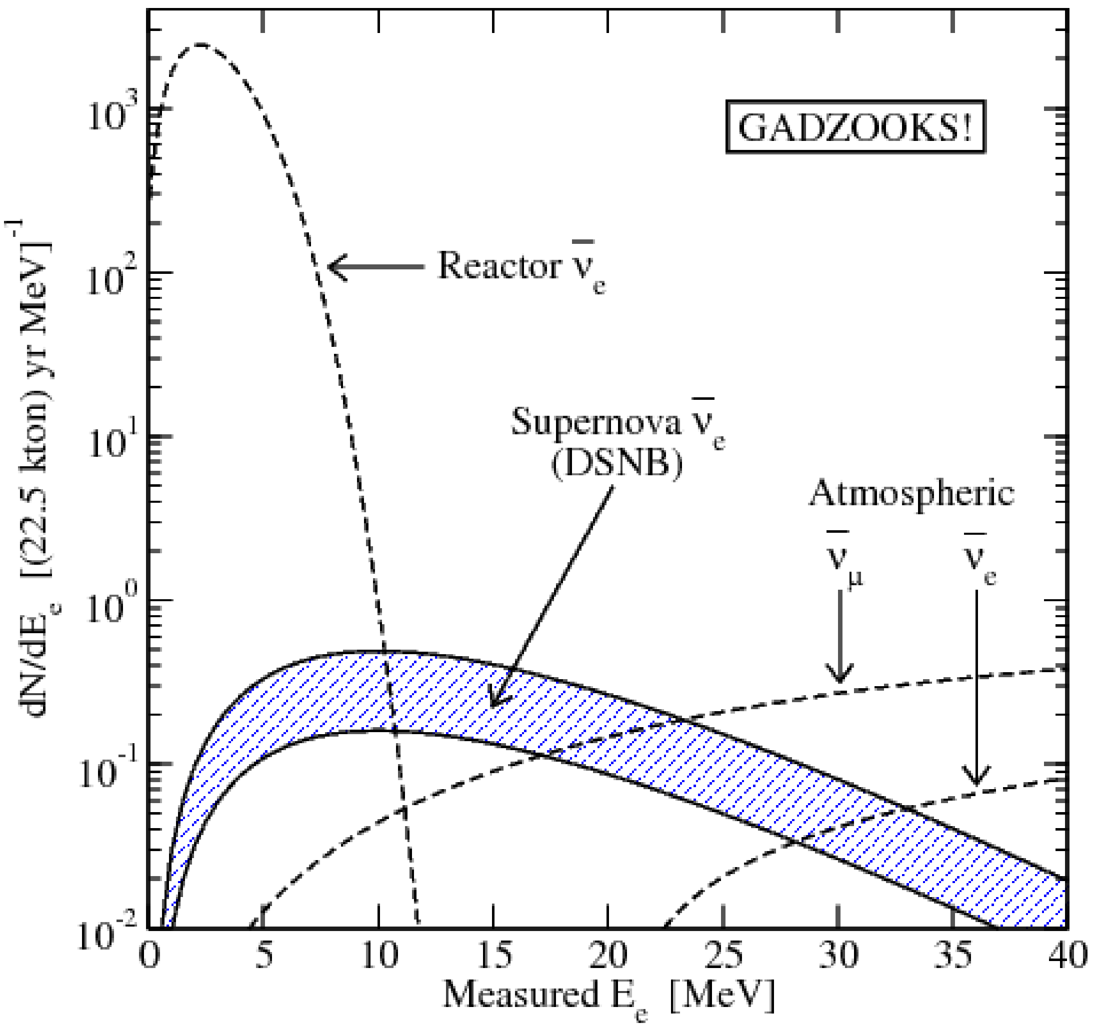
- A well known mechanism in neutrino physics for reducing accidental backgrounds by requiring coincident signals
- Gd has a large thermal neutron capture cross section.
- n capture on Gd releases ~8Mev gamma cascade.

Motivation for Gd

Diffuse Supernova Neutrino Background

Reduced background opens window to lower energy electron anti-neutrinos. Plot was made for SuperK detector.

Neutron detection could also reduce some backgrounds for proton decay searches.

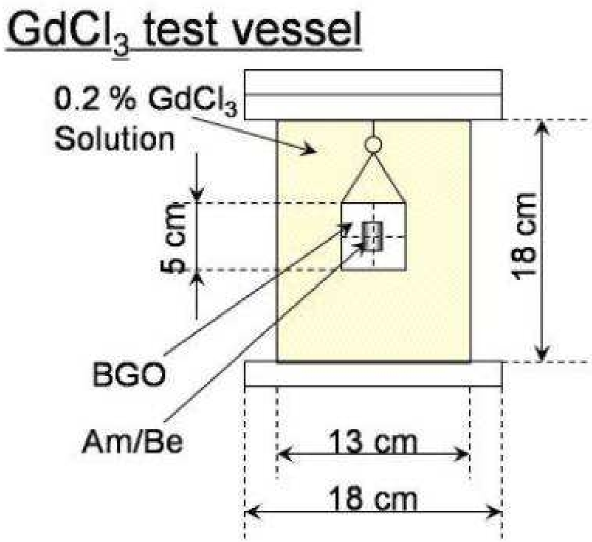


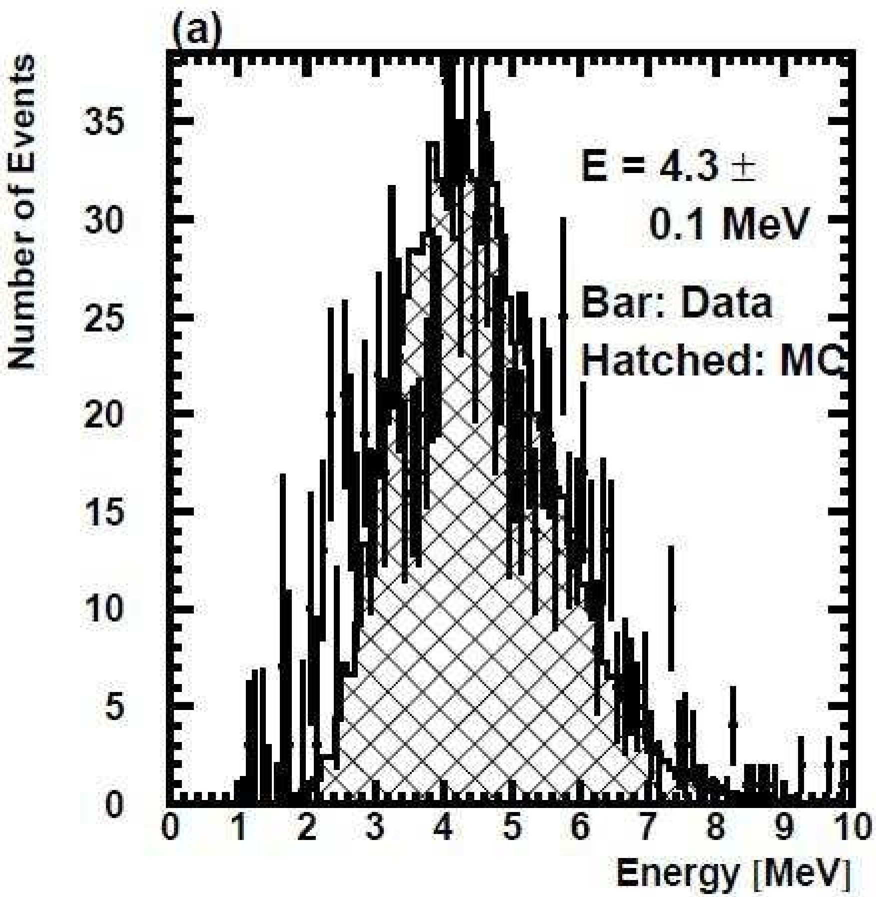
References:

J. Beacom, M Vagins. Phys.Rev.Lett. 93 (2004) 17110 arXiv:hep-ph/0309300v1
J. Beacom. Ann.Rev.Nucl.Part.Sci.60:439-462,2010 arXiv:1004.3311v1

Motivation for Gd

A neutron tagging efficiency measurement was carried out in the SuperK detector.





The authors estimate a neutron tagging efficiency of 66.7%, after a standard 80% SK event reduction.

Research is ongoing.

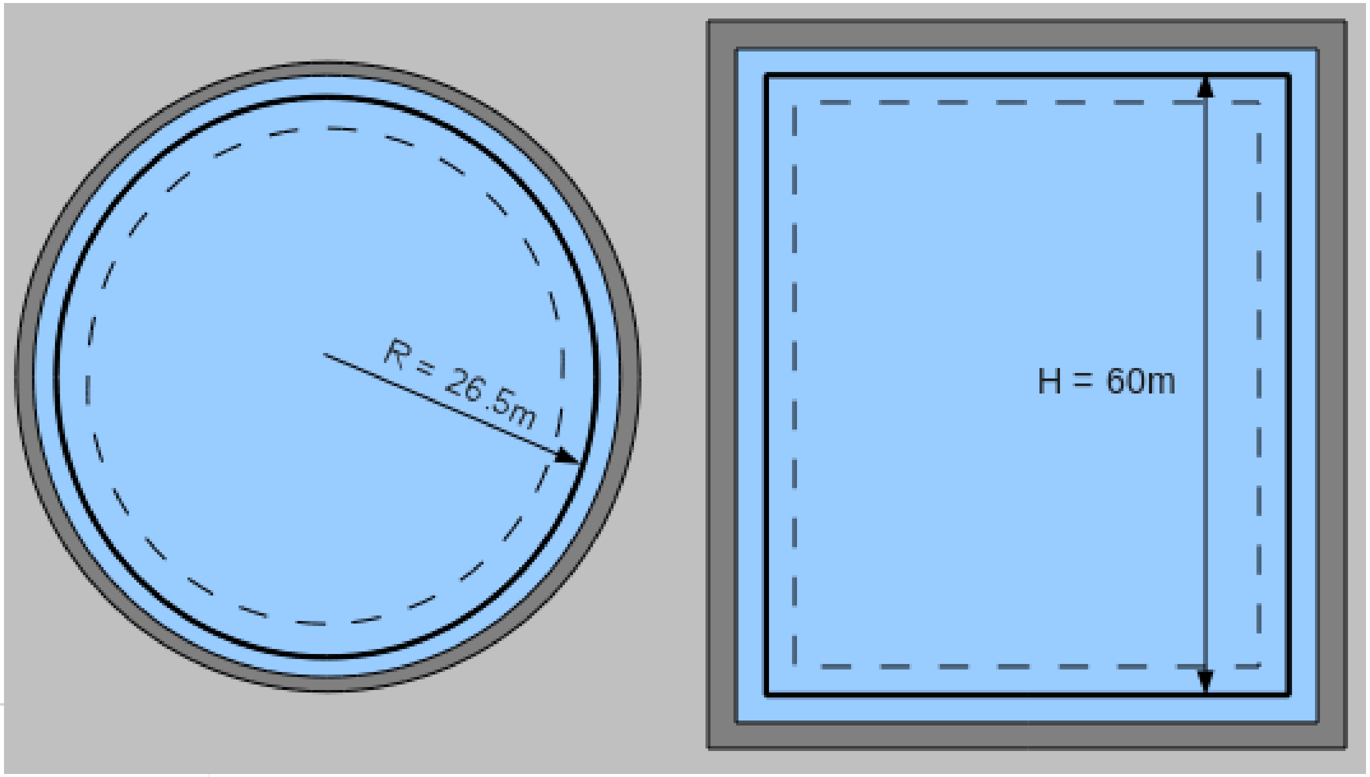
arXiv:0909.5528v1

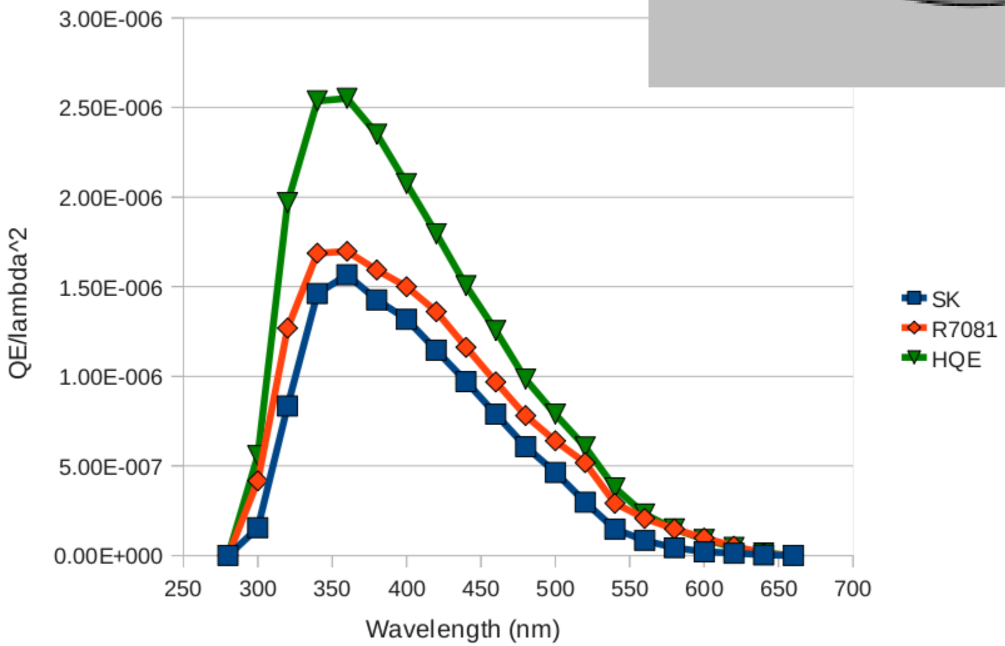
Goal of Simulation Study

- Simulate neutron captures in a large LBNE like WC detector.
- Include radioactive backgrounds.
- Analyze efficiency of neutron detection.
- Study detection efficiency as a function of PMT coverage.

Simulation Overview - Detector

- WCSim (Geant4)
- Cylindrical geometry
- 100kT FV
- 30cm concrete shell
- 80 cm water buffer
- Optical barrier “Black Sheet”
- FV is defined 2m from BS





- 10” HQE PMTs
- 30% photocoverage
  Reduced coverages by masking.

Simulation Overview - Backgrounds

Simulate radioactive backgrounds including U/Th/K in the rock, concrete, and PMT glass, Rn in the water, and PMT dark noise. (See LBNE docdb# 966)

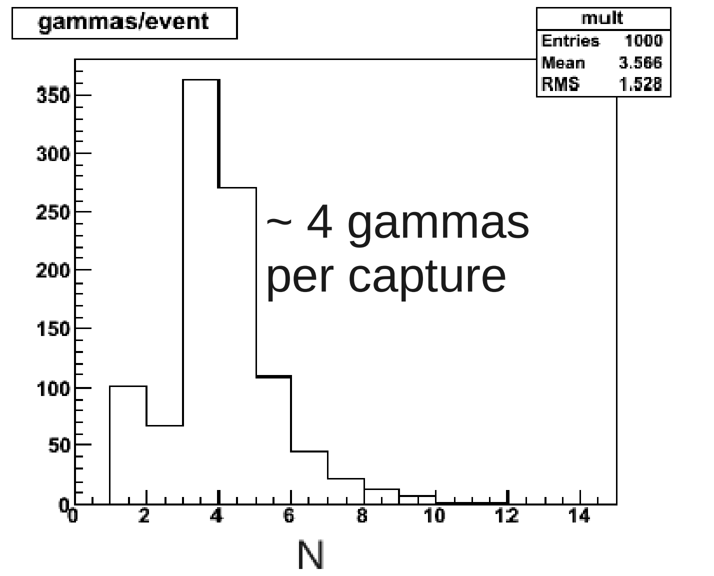
Concentrations			
Material	U	Th	K
Amphibolite	0.16 ppm	0.20 ppm	0.154%
Rhyolite	8.67 ppm	12.2 ppm	2.82%
60% - 40% Mix	3.564 ppm	5 ppm	1.22%
Concrete	2.02 ppm	1.87 ppm	0.23%
PMT Glass	67 ppb	25 ppb	16 ppm

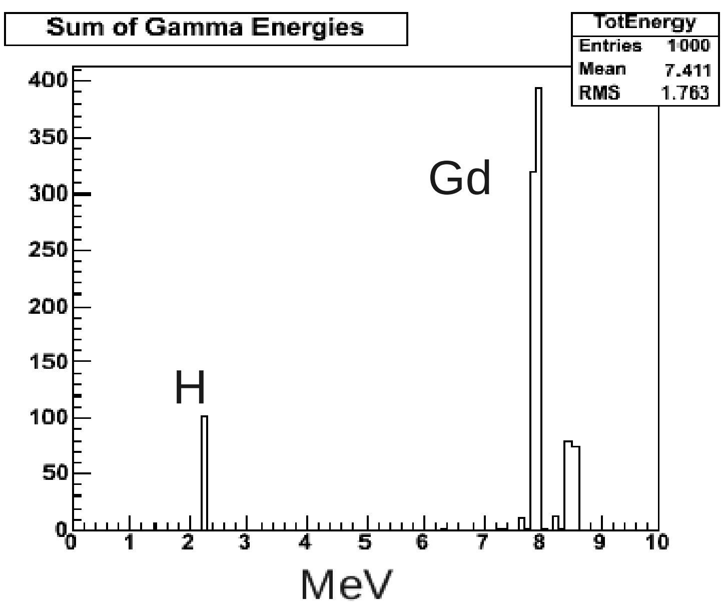
← Identified as an average concrete, not a low radioactivity one.

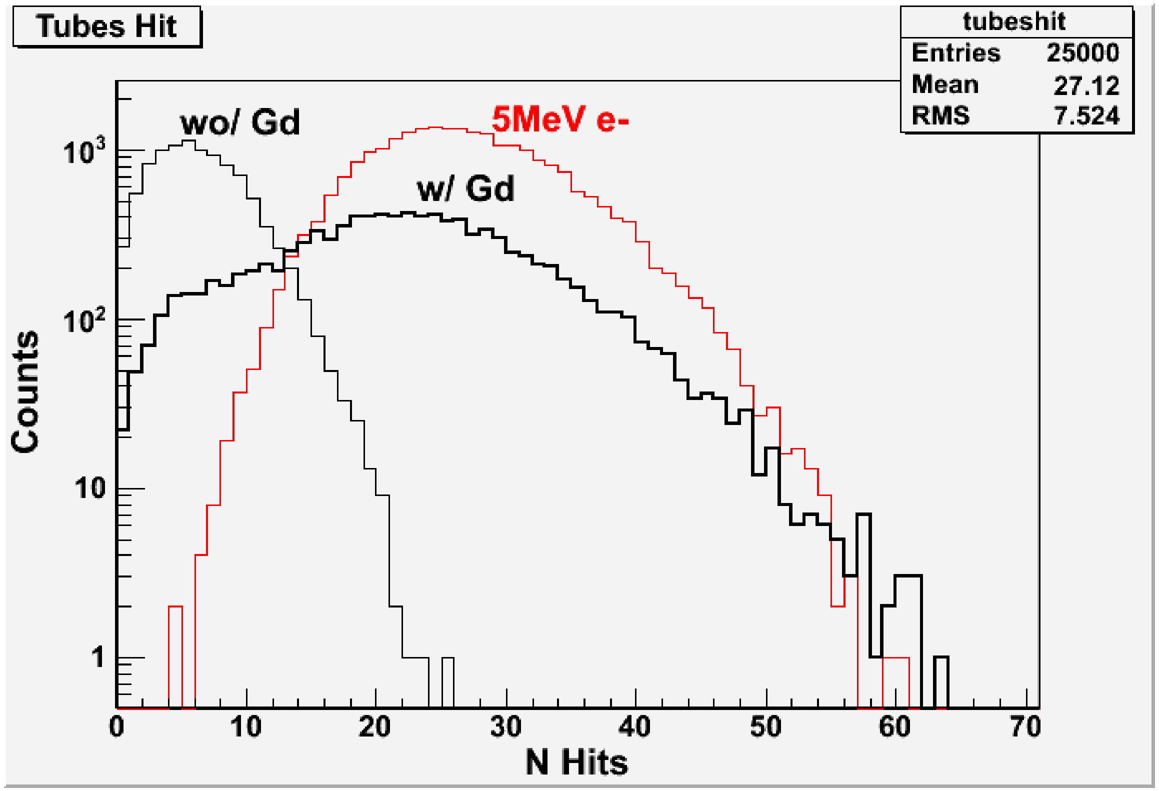
Radon rate is set to SK levels, 2 mBq/m^3 --> 280 Bq for 100kT detector

The dark noise rate is 1 kHz per pmt. Which assumes a cooled detector at 13^{o}C

Simulation Overview – Neutron Captures





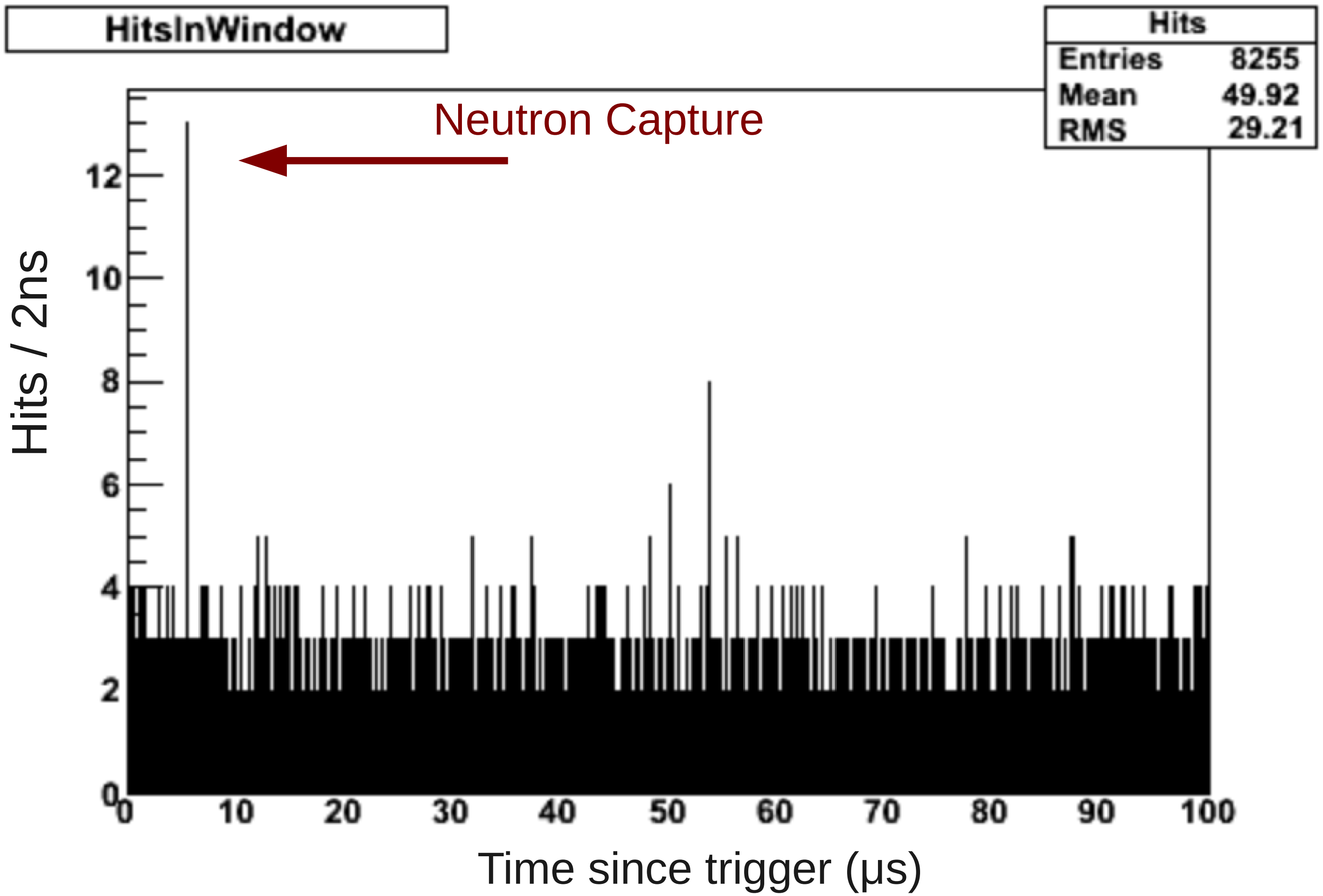


As expected, Gd captures give ~4 MeV visible energy

~90% captures on Gd

Analysis Techniques

- Assume an IBD event producing a ~10MeV positron.
- Assume the positron vertex is reconstructed with resolution ~50cm.
- Correct the PMT hit times for TOF from this vertex.
- Capture event should arrive in time within ~100 μs.

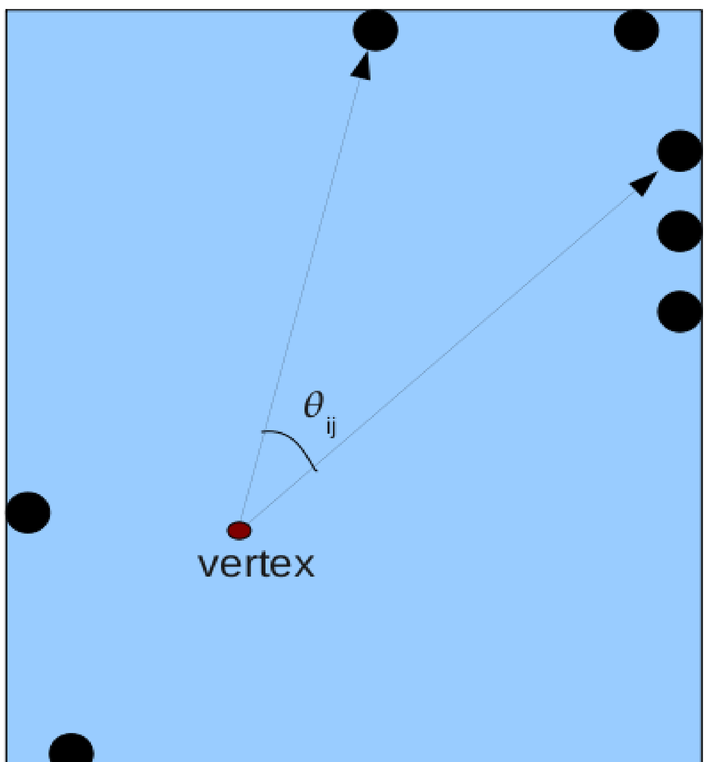


Analysis Techniques

Inside a 20 ns sliding window, maximize the following Likelihood ratio:

$$\frac{L(N,t;\mu_s,\tau)}{L(N;\mu_b,R_b)} = \frac{\frac{1}{N!}\mu_s^N e^{-\mu_s}\frac{1}{\tau}e^{\frac{-t}{\tau}}}{\frac{1}{N!}\mu_b^N e^{-\mu_b}R_b}$$

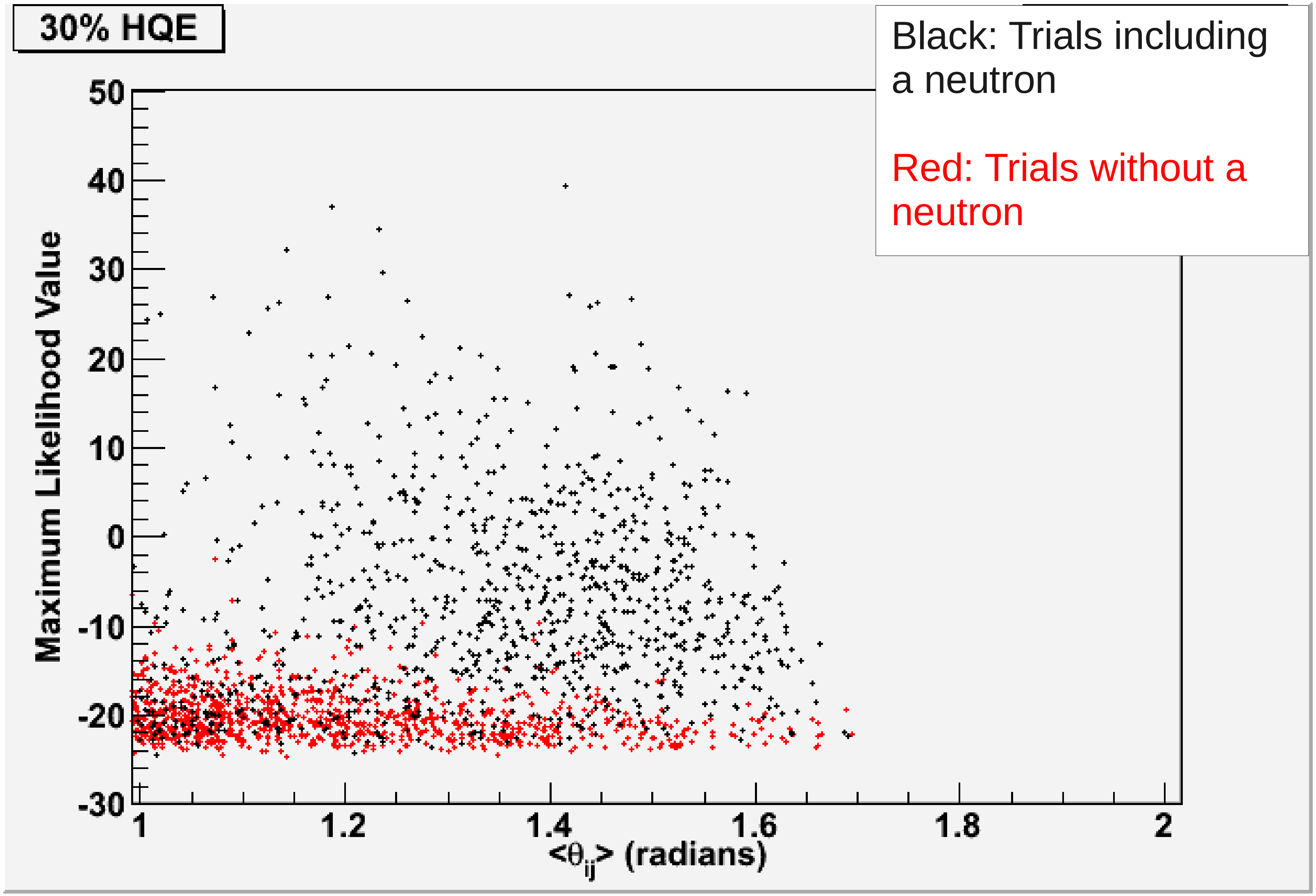
μ_s = average # hits including a n capture
μ_b = average # hits without a n capture
τ = neutron capture time
R_b = rate of background events.



Require capture events to be isotropic. Calculate the average PMT pair angle, ignore events which are too localized (usually from external gammas)

$$\langle\theta_{ij}\rangle = \frac{2}{N(N-1)}\left[\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\theta_{ij}\right] > 1 \text{ rad}$$

Analysis Techniques



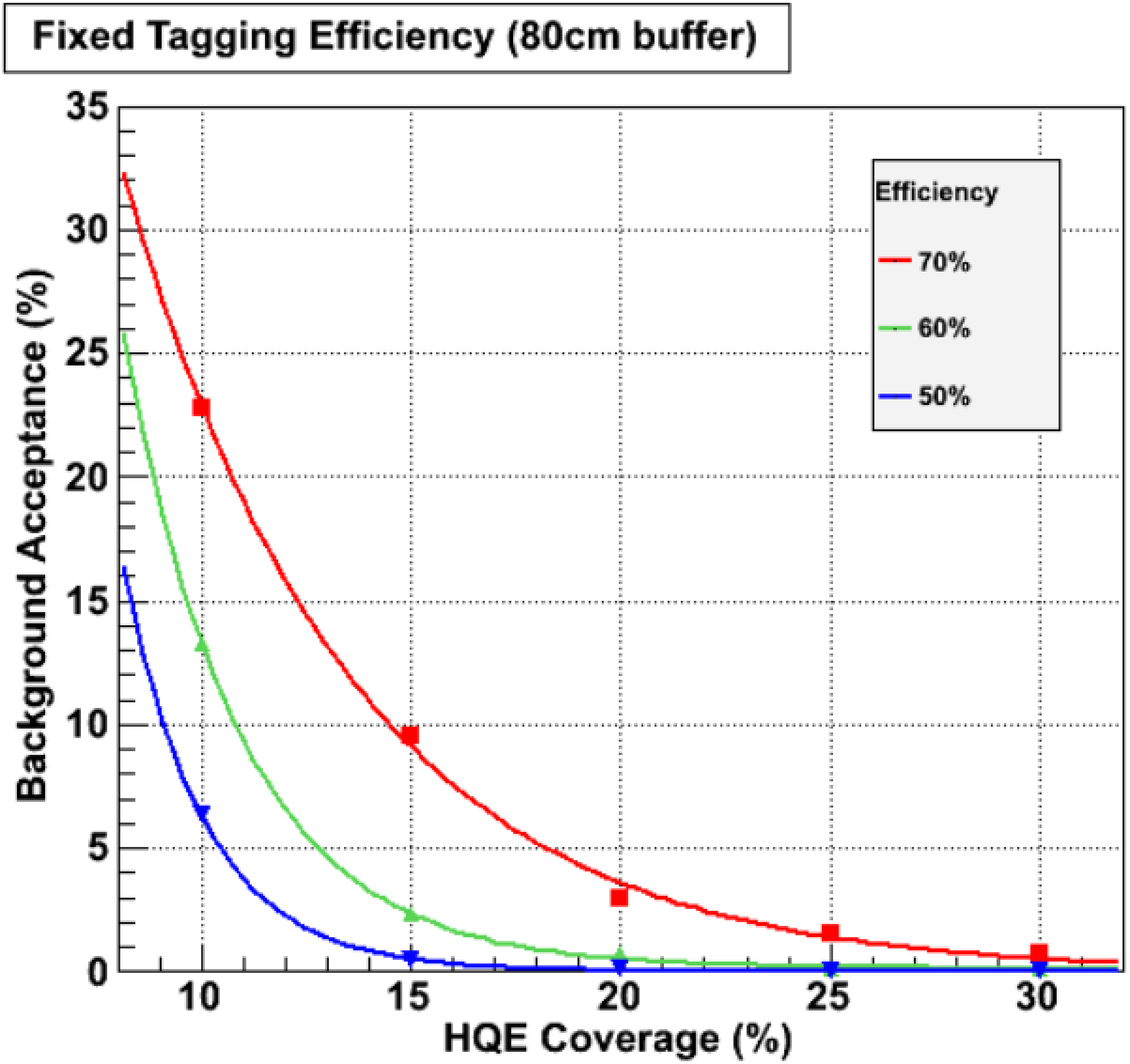
Make a simple (flat) cut on Likelihood and angle to isolate neutron captures.
Can then evaluate tagging efficiency and background mis-ID.

Results and Conclusion

For a chosen neutron detection efficiency, how much background will be mis-ID'd?

Answer will depend on number of PMTs.

Less than 15% photo coverage starts to look very difficult.



Results and Conclusion

Where does the background come from?

Of 100 events @15% HQE coverage, and an 80 cm buffer, the contribution of hits in the chosen 20 ns window was:

75.2% from Gd
22.3% from Dark Noise
2.3% from gammas from Concrete
0.9% from gammas from Rock
0.0% from Radon
0.0% from gammas from PMT glass

Dominant remaining background is from dark noise, and there is not a whole lot one can do about that. The simulation assumes a cooled (13^{o} C) detector with 1kHz/PMT dark noise.