A High Efficiency Neutron Veto Based on Boron-Loaded Liquid Scintillator

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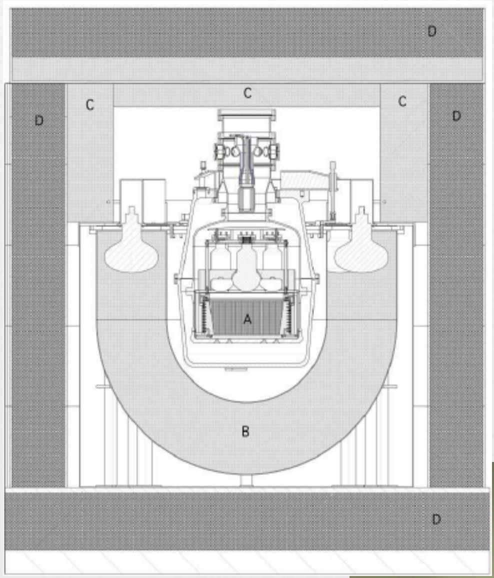
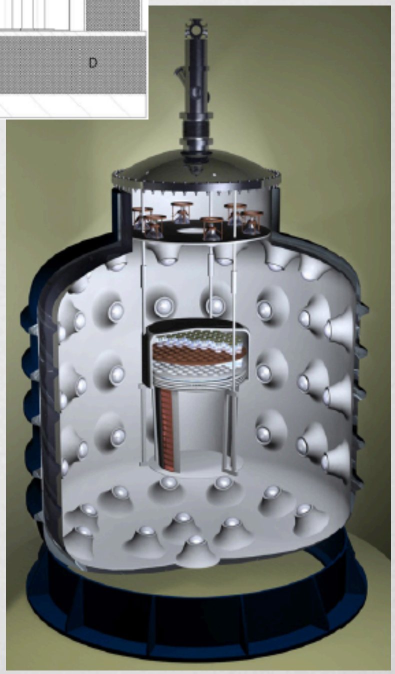
Neutron Vetoes in Dark Matter Experiments

- Single scatter neutron events are a “perfect background” for direct detection dark matter experiments
- Vetoing these events with high efficiency can significantly increase the sensitivity of an experiment
- Also provides an in-situ measurement of the neutron environment
  - Significantly strengthen any claim of a dark matter detection



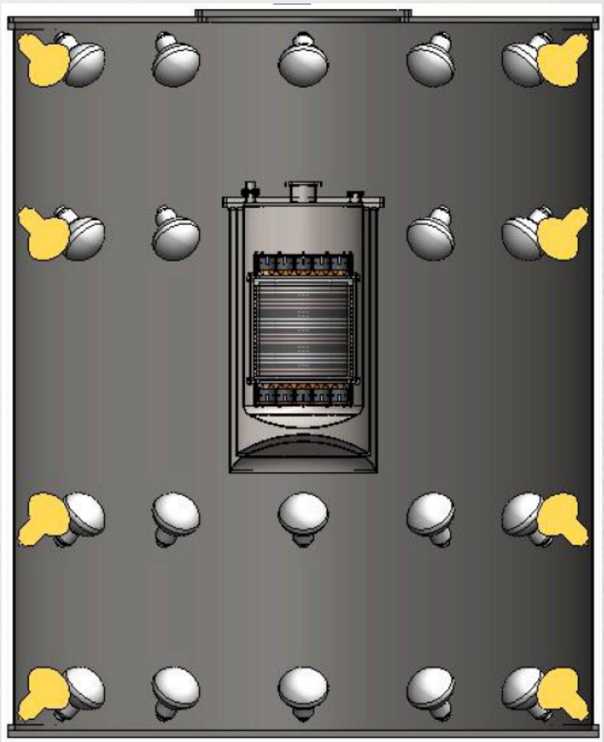
Zeplin II, from astro-ph/0701858v2



WARP, from L.Grandi PhD. Thesis, University of Pavia

A Neutron Veto Using Boron-Loaded Liquid Scintillator

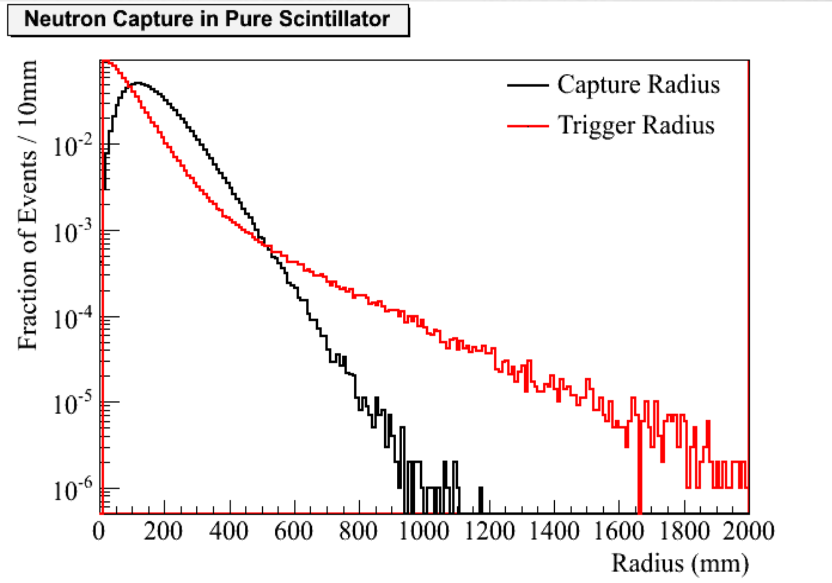
- Immerse the dark matter detector in boron-loaded liquid scintillator
  - Baseline: 1 m thick liquid scintillator loaded with 5.2% w/w natural boron
- Veto efficiency simulations with Geant4
- Practical considerations:
  - Light yield
  - Veto-induced deadtime



Pure Scintillator

- In pure scintillator, the mean neutron capture time is long (~250 μ s) so long veto windows are required to get high efficiency
  - Very low background rates are required in the veto to avoid large deadtimes
- Neutron capture on protons produces gamma rays, which can propagate some distance before interacting

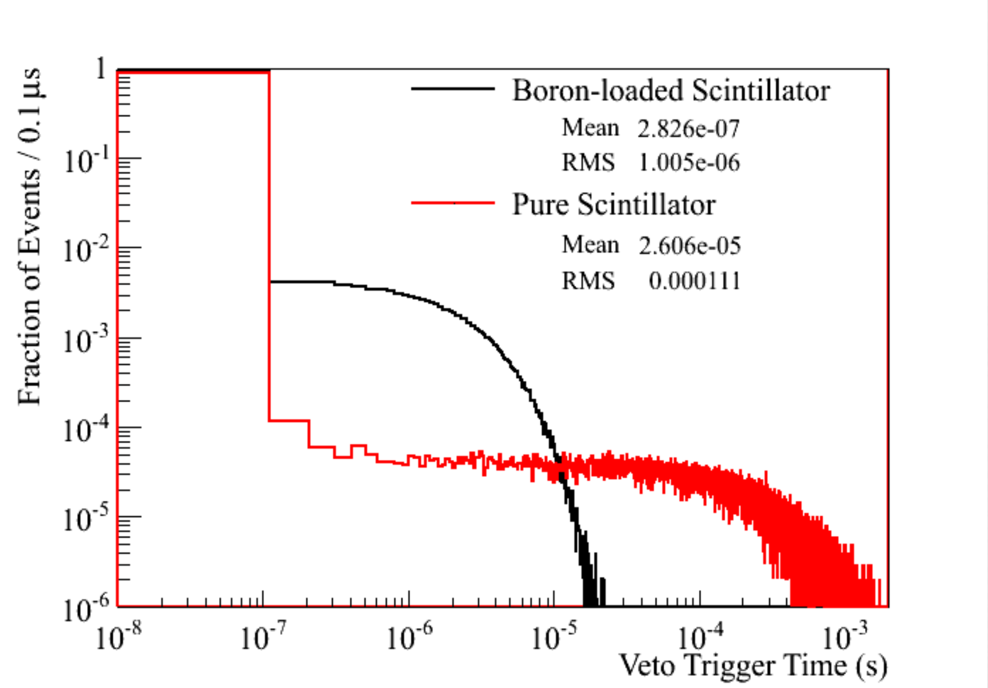
Veto Window	Veto Rate for 5% Deadtime
10 μ s	5,100 Hz
100 μ s	510Hz
1 ms	51 Hz



Boron Loading

- High ^{10}B capture cross section (3837(9)b) reduces neutron capture time

Detection Efficiency	Time in Pure Scintillator (μs)	Time in Boron Scintillator (μs)
70%	0.08	0.08
90%	7.8	0.1
95%	185	1.7
98%	421	3.8
99%	603	5.4
99.5%	788	7.0
99.9%	1282	10.9
99.99%	–	22.0



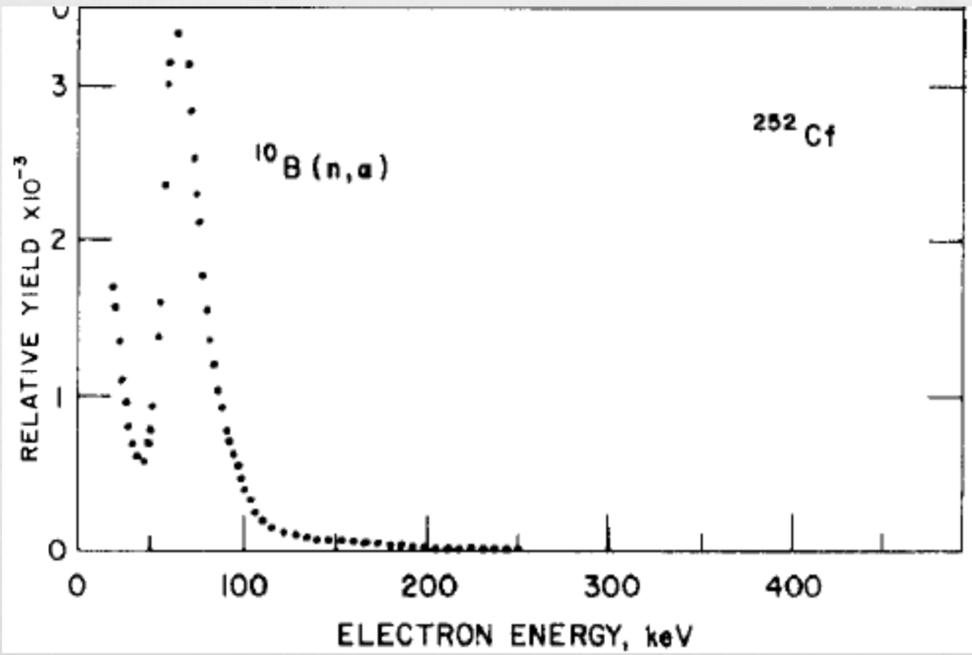
("Boron scintillator" has 5.2% w/w natural boron)

Boron Loading

$^{10}B + n \rightarrow {}^{7}Li^{*} + \alpha \rightarrow {}^{7}Li + \alpha + 478\text{ keV } \gamma$ (93.7%)

$\rightarrow {}^{7}Li + \alpha$ (6.4%)

- Recoil fragments have ~2 MeV kinetic energy, quenched to 50-65 keV_{ee}
  - Detecting the recoil particles eliminates gamma-propagation



Rev. Sci. Instrum., Vol 50, No.4, April 1979 466-471

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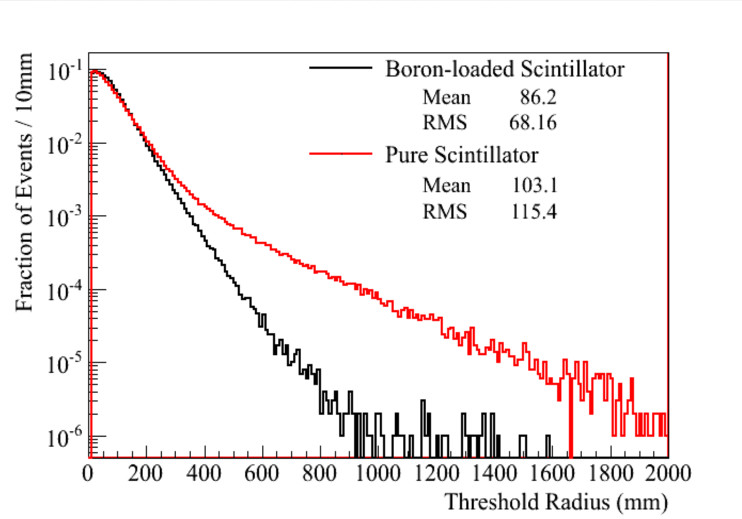
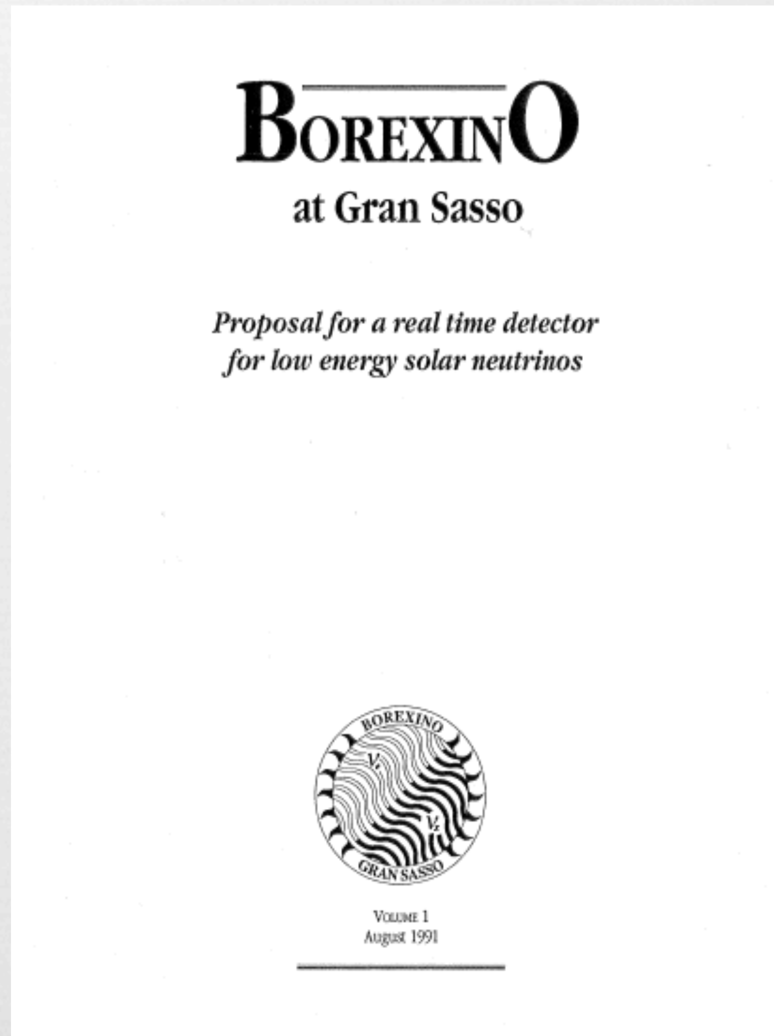


Containment Probability	Pure Scintillator Radius (cm)	Boron Scintillator Radius (cm)
70%	11.1	10.2
90%	21.0	17.2
95%	29.1	21.7
98%	44.8	28.0
99%	60.4	32.9
99.5%	78.0	38.1
99.9%	129.7	51.6
99.99%	–	136.5

Boron Loaded Scintillator

- Trimethyl borate (TMB) is miscible in pseudocumene
  - 50% w/w TMB gives 5.2% boron
- TMB loading investigated in the context of BOREX (and, for small detectors, elsewhere)
  - After distillation, TMB radiopurity and optical transmission as good or better than PC
  - Light output of 6000 photons/MeV achieved at 80% v/v TMB

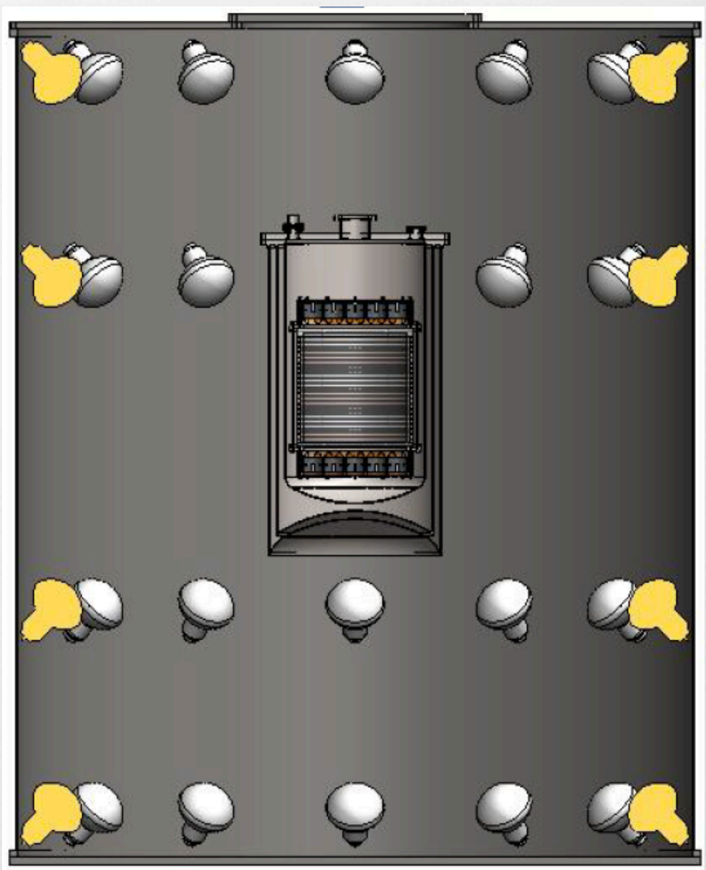

BOREXINO
at Gran Sasso

Proposal for a real time detector for low energy solar neutrinos

Volume 1
August 1991

Efficiency Studies

- Study veto efficiency using Geant4
  - 1 m 50% (w/w) TMB scintillator around the DarkSide-50 dewar
  - Simplified cylindrical geometry
  - 10 cm diameter air-filled feed-through with dogleg penetrates the veto
  - Radiogenic neutron energy spectrum from SOURCES4A



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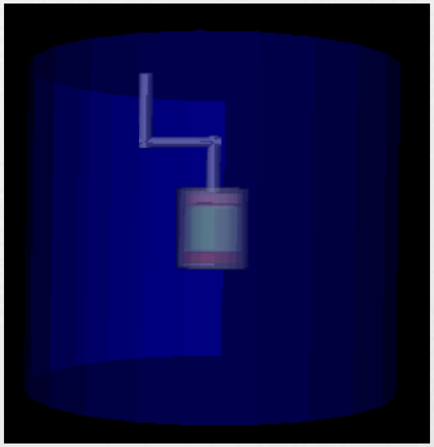
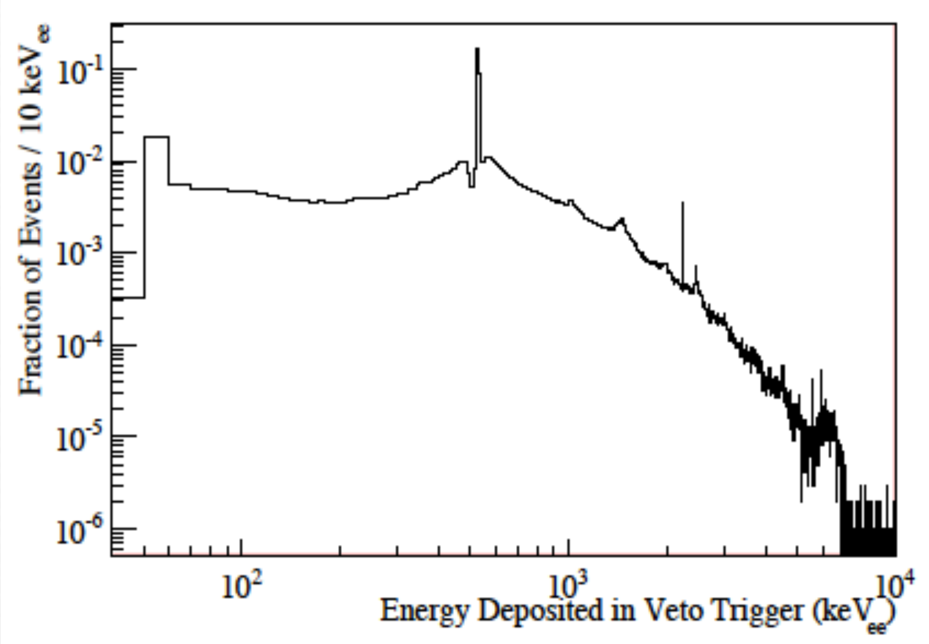


Component	Material	Mass (kg)
Active Volume	Liquid Argon	52.7
Inner vessel + photo-sensors	Fused Silica	25.4
Passive Buffer	Liquid Argon	74.1
Dewar + Internal Mechanics	Titanium	78.6
Neutron Veto	Boron-Loaded Scintillator	11,500

Internal Radiogenic Neutrons

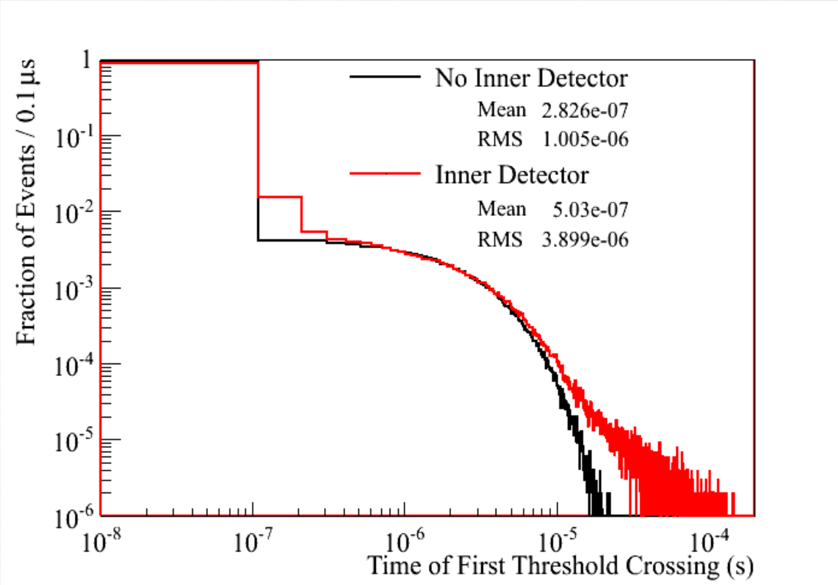
- 99.8% of internal radiogenic neutrons produced a "veto trigger" (>40 keV_{ee} deposited in the veto within 1 μ s)

- ~20% of the neutrons were captured by inner vessel components
  - Detected in the veto either through proton recoils or gamma rays from the capture
  - To have high veto efficiency avoid gamma shielding around the inner detector



Internal Radiogenic Neutrons

- The distribution of veto times is lengthened by the presence of the inner detector



Detection Efficiency	Time Required (μs) Inner Det.	No Inner Det.
70%	0.08	0.08
90%	0.37	0.1
95%	2.3	1.7
98%	5.5	3.8
99%	9.3	5.4
99.5%	21.5	7.0
99.8%	57.7	10.9

Internal Radiogenic Neutrons

- Veto efficiency is degraded (and the timing further worsened) by hydrogenous material in the inner detector
  - Changing the fused silica vessel to acrylic reduced the veto efficiency to ~98%
  - The increase in veto efficiency from removing neutron shielding more than offsets the increase in neutron rate

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Cosmogenic Neutrons

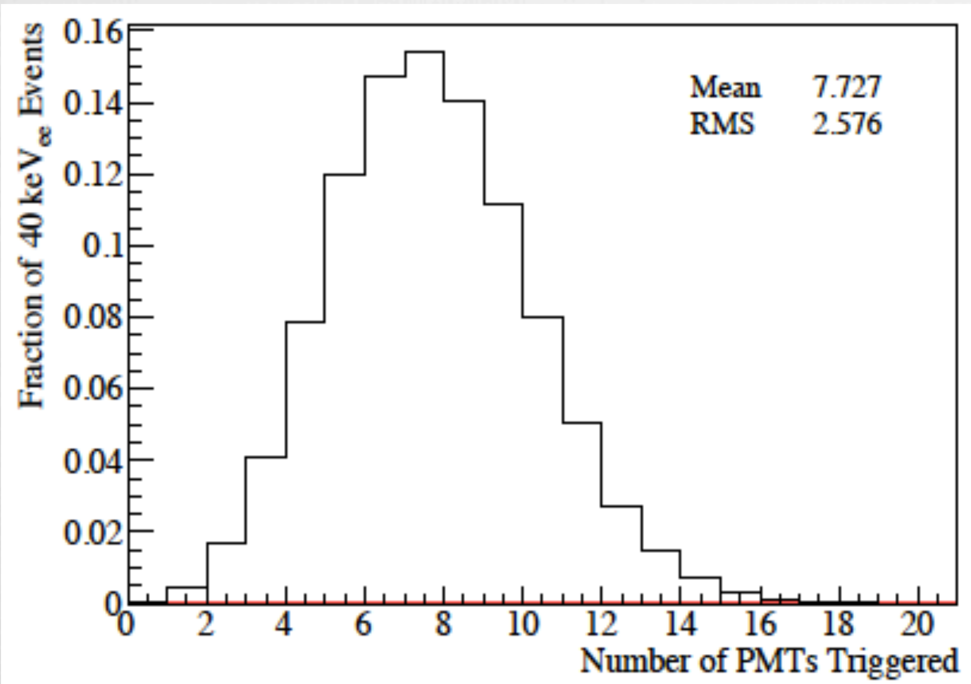
- Simulate external cosmogenic neutrons individually, using the energy spectrum from Mei & Hime (PRD 73, 053004, 2006)
  - Should underestimate veto efficiency
- With 1 m scintillator, recoil backgrounds from external cosmogenic neutrons are reduced by a factor of 40
- Internal cosmogenics are tiny due to very high efficiency of detecting primary muon

Thickness of Veto (m)	Interaction Rate in DarkSide50 (after veto)
0	1.0
1	0.027
2	0.0024
3	0.0005

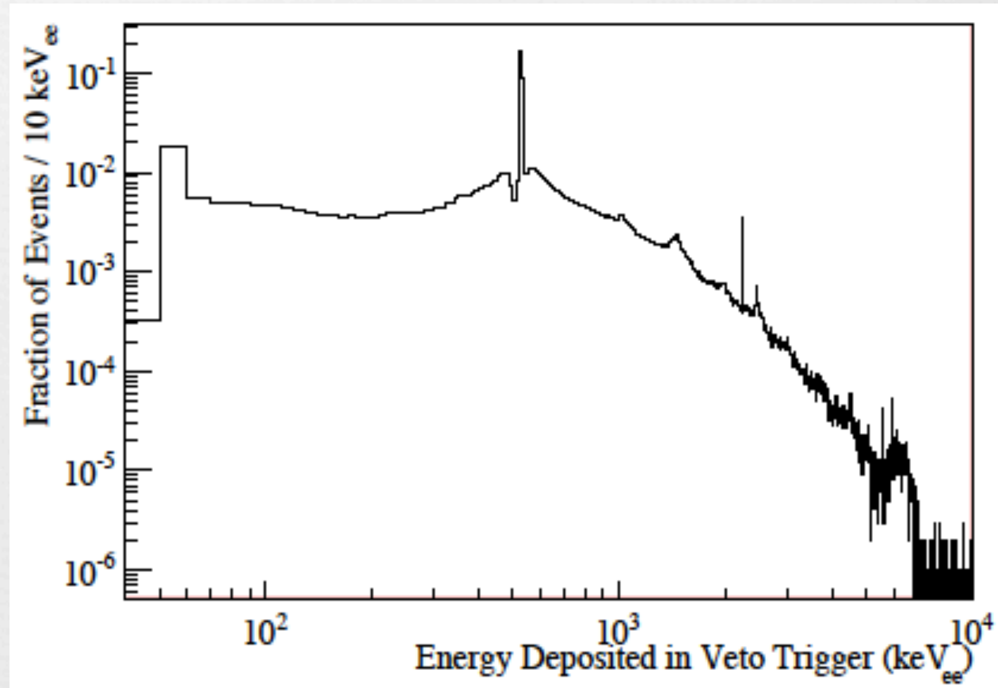
Is a 40 keV_{ee} Veto Threshold Achievable?

- Assume 80 8'' PMTs in veto
  - With 1 kHz dark rate, a 3 hit threshold gives a reasonable random rate
- Optical simulation:
  - 6000 photons/MeV
  - 20% PMT Q.E.
  - 95% reflection from walls/surfaces
  - 5m attenuation length
  - 2m scattering length

Is a 40 keV_{ee} Veto Threshold Achievable?



98% of uniformly distributed 40 keV_{ee} events in the veto give 3 or more hits



Only a small fraction of veto events fall below 100 keV_{ee}

40 keV_{ee} seems to be a feasible threshold!

Deadtime from Veto Backgrounds

- Estimate background rates (primarily γ 's) in the veto for a 'typical' underground lab

Background Source	Veto Rate (Hz)
Inner Detector	<1
Scintillator Background	<1
PMTs	200
External Backgrounds with 25 cm steel	150
Steel Backgrounds	65
Random Veto Triggers (1 kHz dark rate)	80
Total Veto Rate	495

- 500 Hz corresponds to ~3% deadtime with a 60 μ s trigger window

Conclusions

- Simulations suggest that very high efficiency for both radiogenic and cosmogenic neutrons are realizable using boron loaded liquid scintillators
  - 1 m veto gives >99.5% and >95% efficiency, respectively
- Acceptable veto light outputs and backgrounds rates seem practically realizable
- Simulations are nice but…
  - DarkSide-50 will deploy a scintillator veto and test its performance