

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

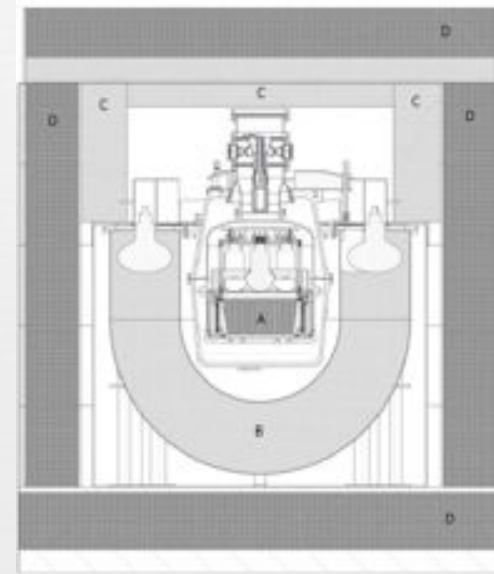


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Princeton University
LRT2010, 28 August 2010

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

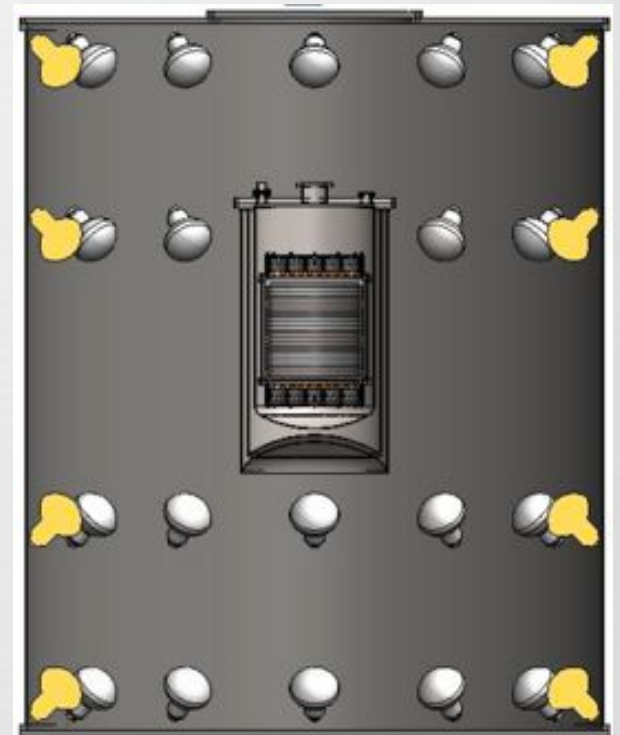


WARP,
from L. Grandi PhD.
Thesis, University of
Pavia

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

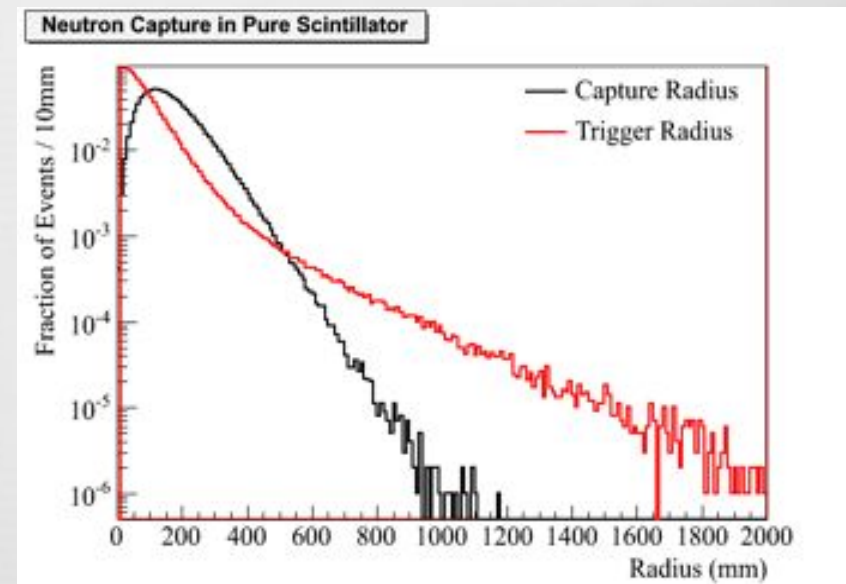


Pure Scintillator



- ∞ In pure scintillator, the mean neutron capture time is long ($\sim 250 \mu\text{s}$) 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
$10 \mu\text{s}$	5,100 Hz
$100 \mu\text{s}$	510 Hz
1 ms	51 Hz

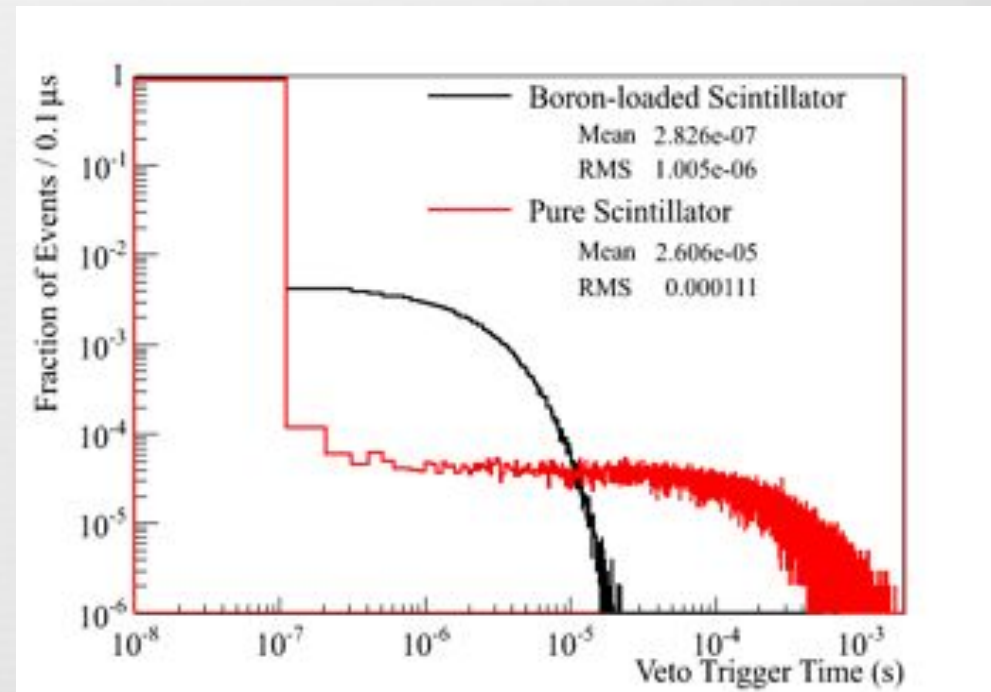


Boron Loading



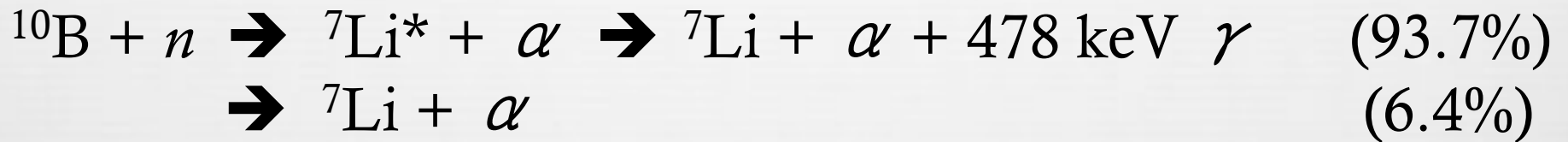
∞ High ^{10}B capture cross section (3837(9)b) reduces neutron capture time

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

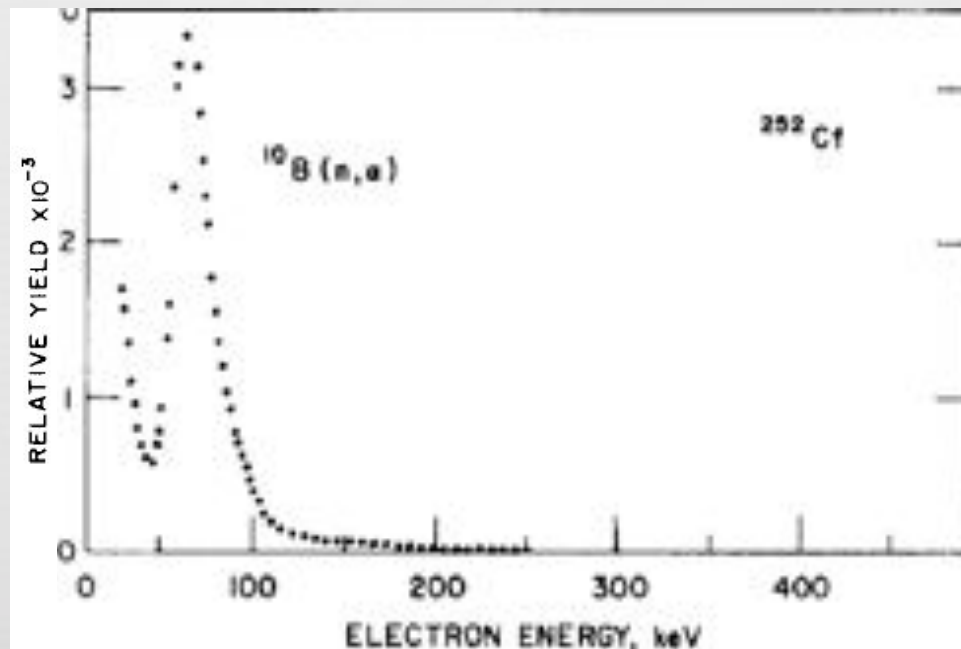


(“Boron scintillator” has 5.2% w/w natural boron)

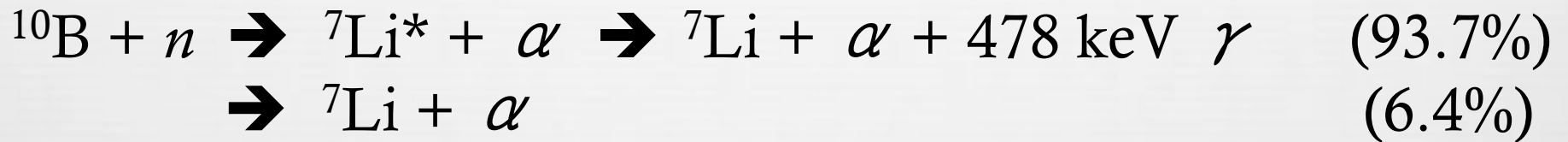
Boron Loading



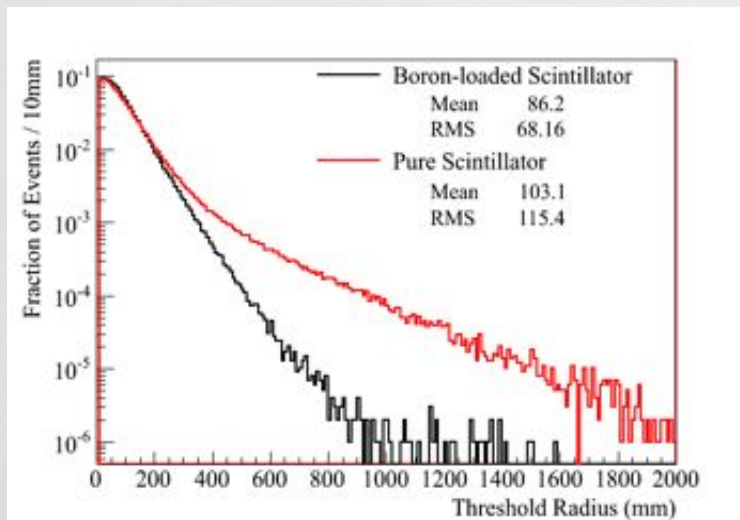
- Recoil fragments have ~ 2 MeV kinetic energy, quenched to 50-65 keV_{ee}
- Detecting the recoil particles eliminates gamma-propagation



Boron Loading



- ∞ Recoil fragments have ~ 2 MeV kinetic energy, quenched to $50\text{-}65 \text{ keV}_{ee}$
- ∞ Detecting the recoil particles eliminates gamma-propagation



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*

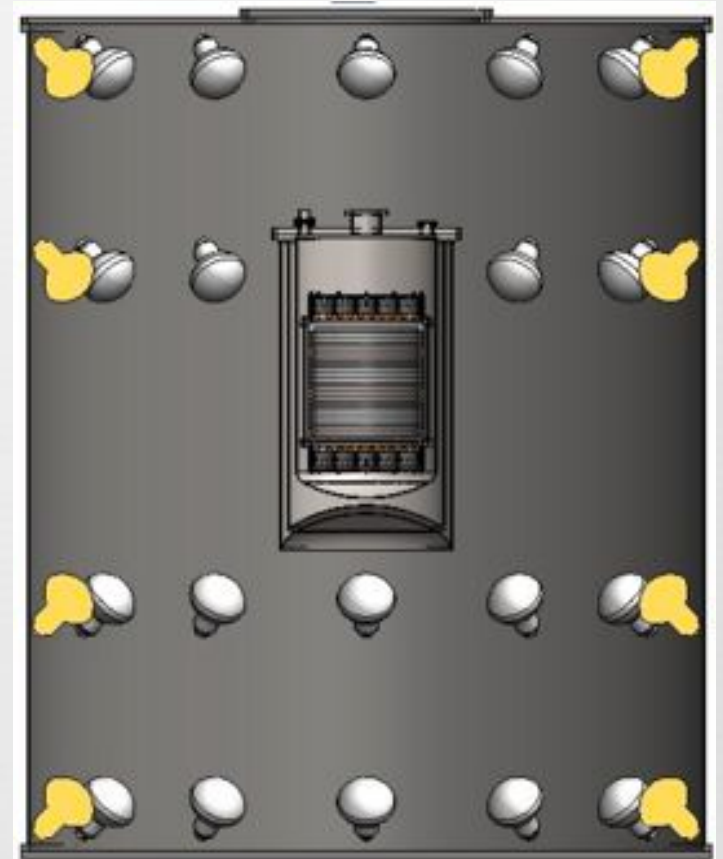


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Efficiency Studies



- 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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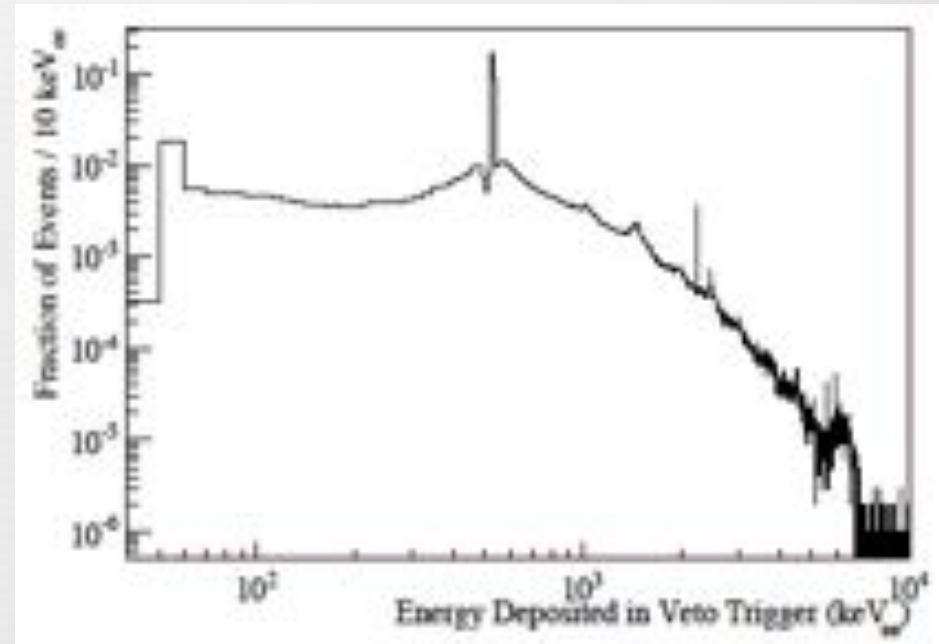


Component	Material	Mass (kg)
Active Volume	Liquid Argon	52.7
Inner vessel + photo-sensors	Fused Silica	25.4
Passive Buffer	Liquid Argon	74.1
Dewar + Internal Mechanics	Titanium	78.6
Neutron Veto	Boron-Loaded Scintillator	11,500

Internal Radiogenic Neutrons



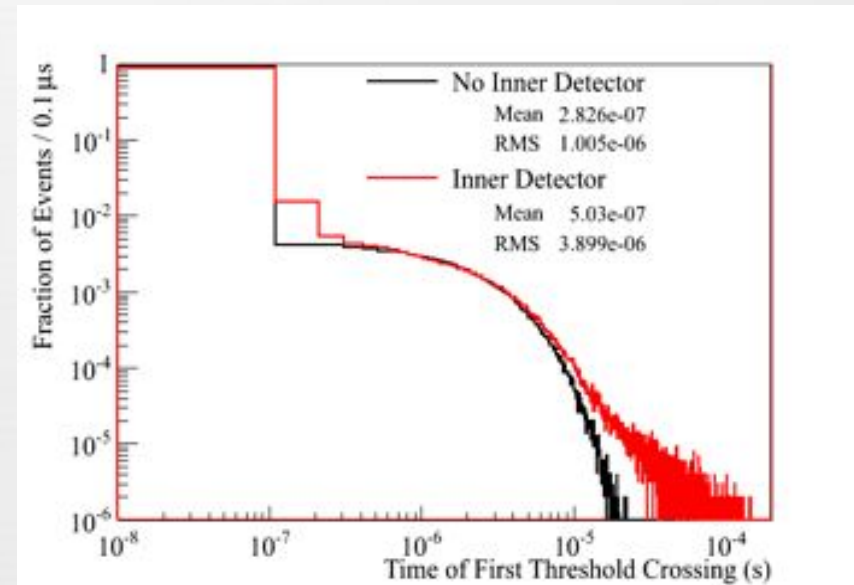
- 99.8% of internal radiogenic neutrons produced a “veto trigger” ($>40 \text{ keV}_{ee}$ deposited in the veto within $1 \mu\text{s}$)
- $\sim 20\%$ of the neutrons were captured by inner vessel components
 - Detected in the veto either through proton recoils or gamma rays from the capture
 - To have 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

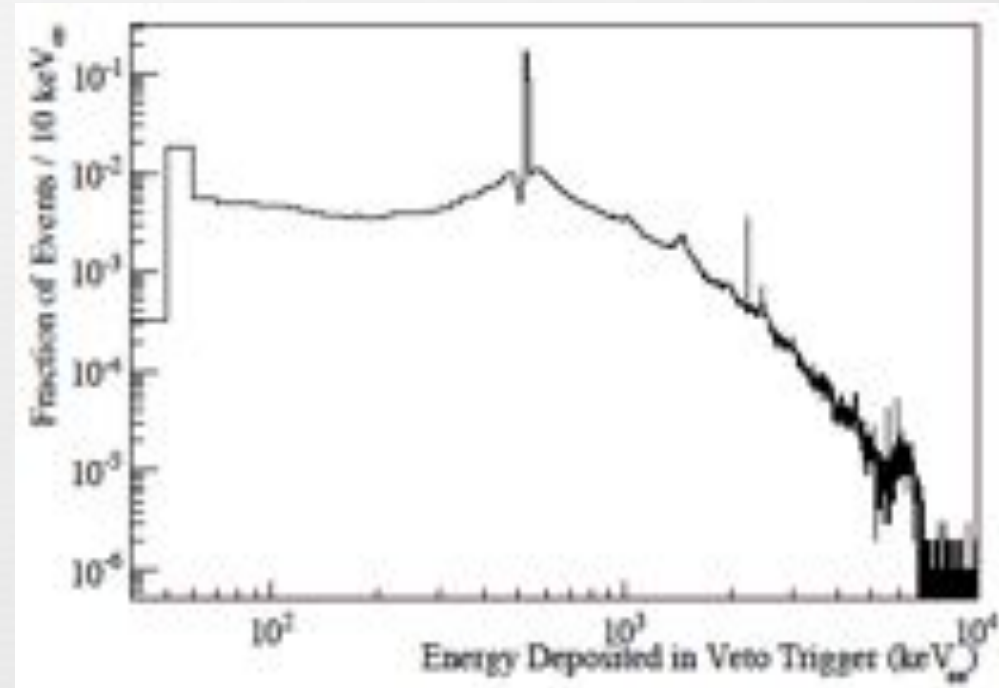
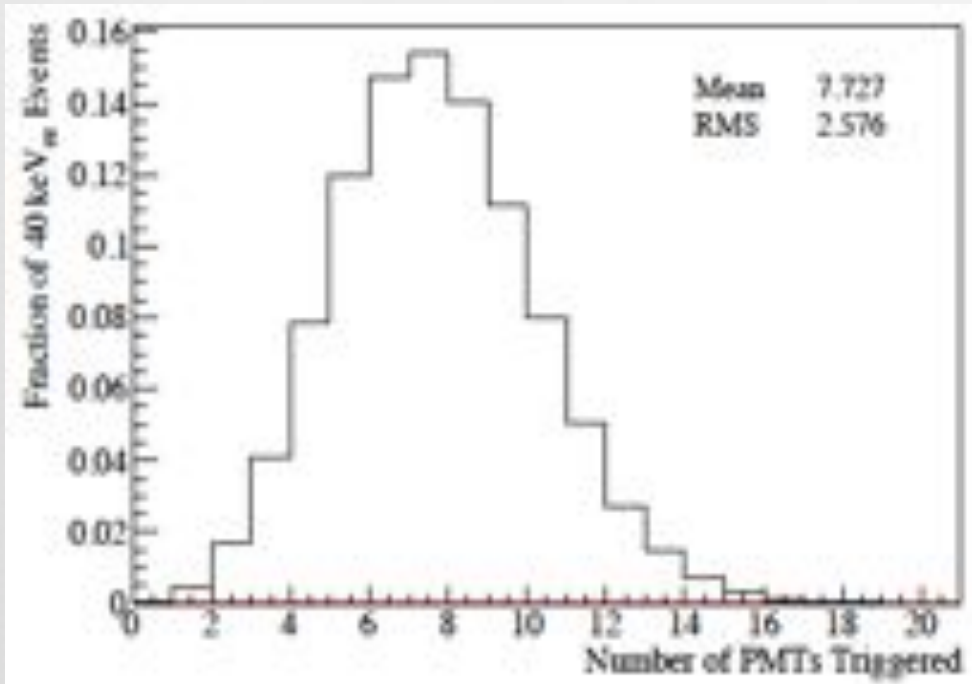
Is a 40 keV_{ee} Veto Threshold Achievable?



- ∞ 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 $\sim 3\%$ deadtime with a $60 \mu\text{s}$ 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