Neutron Veto Detector of DarkSide-50 Experiment

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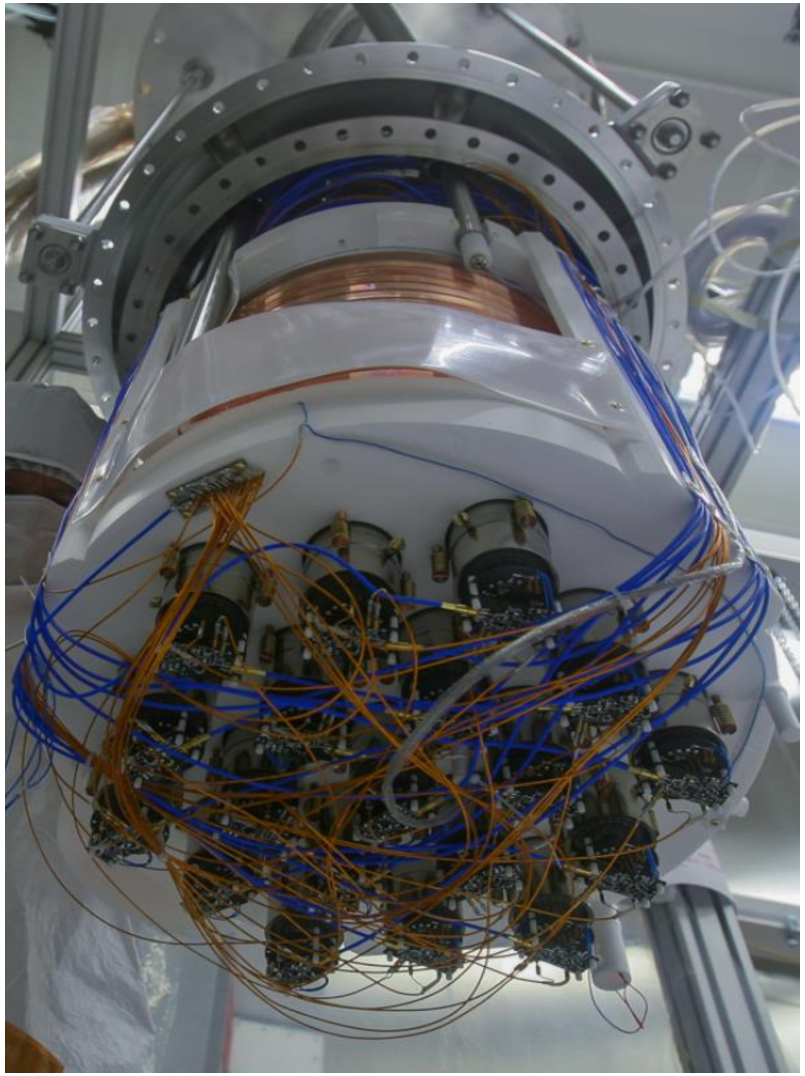
Overview of DarkSide-50 Experiment

DarkSide-50 TPC

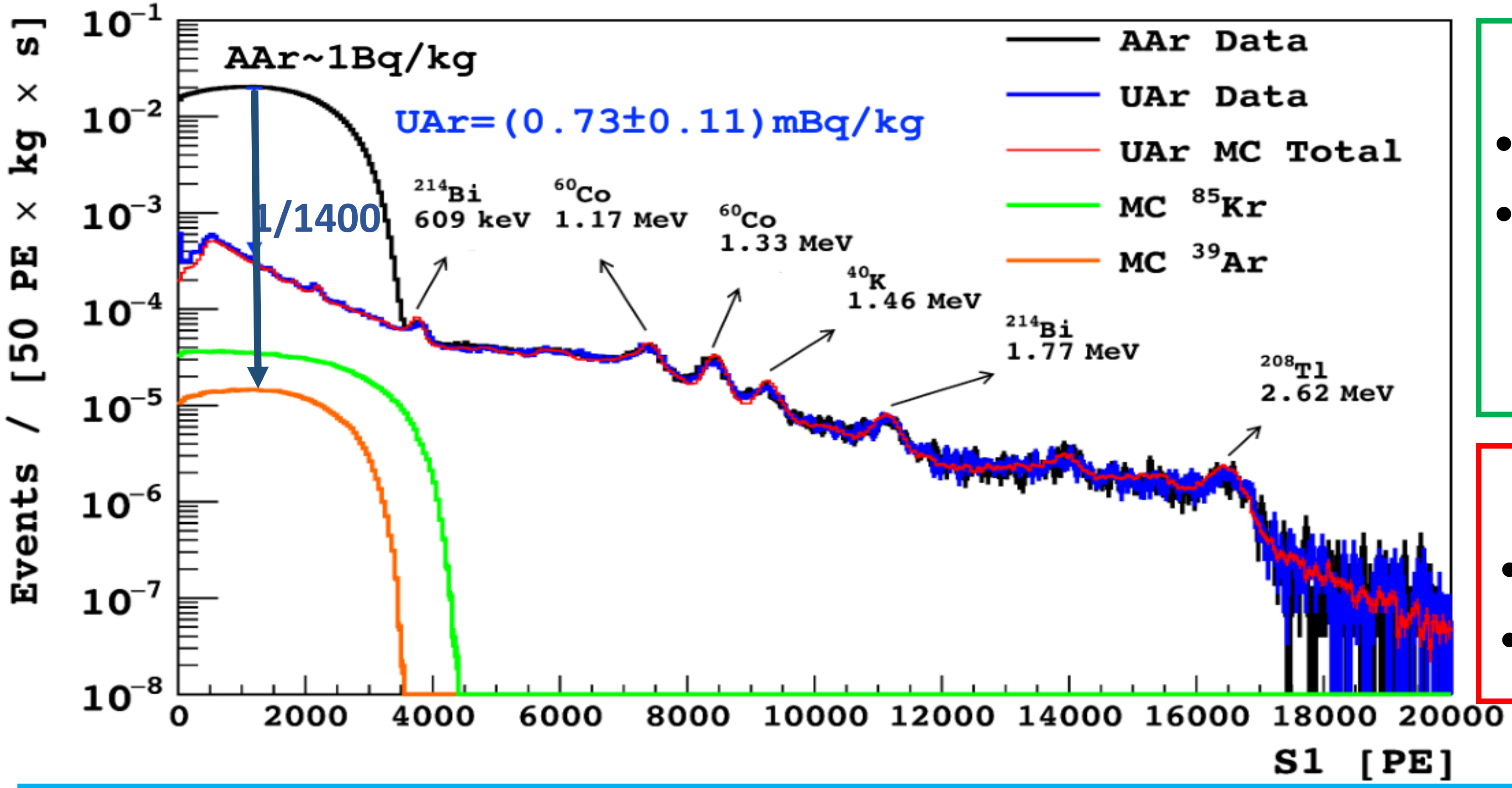


- Location: LNGS, Italy (3800m underground)
- Target: WIMP direct search with sensitivity< $10^{-44}\ cm^2$
- Operation: 2013-present

- two-phase Time Projection Chamber
- 38 PMTs in TPC (19 each at top and bottom)
- 50 kg active Underground Argon
- low ^{39}Ar to reduce β background
- TPC 3D event reconstruction

see Xin's talk

Background: ER



ER source

- β decay from ^{39}Ar
- γ rays from radioactive sources in detector materials

Rejection of ER

- PSD highly rejects ER
- S2/S1 ratio suppress ER

- ^{39}Ar (in Atmospheric Argon) has 1 Bq/kg of β decay (τ=388yr, Q=565 keV)
- AAr replaced by UAr in 2nd run of DarkSide-50
- ^{39}Ar activity in UAr is 1400 times lower than AAr

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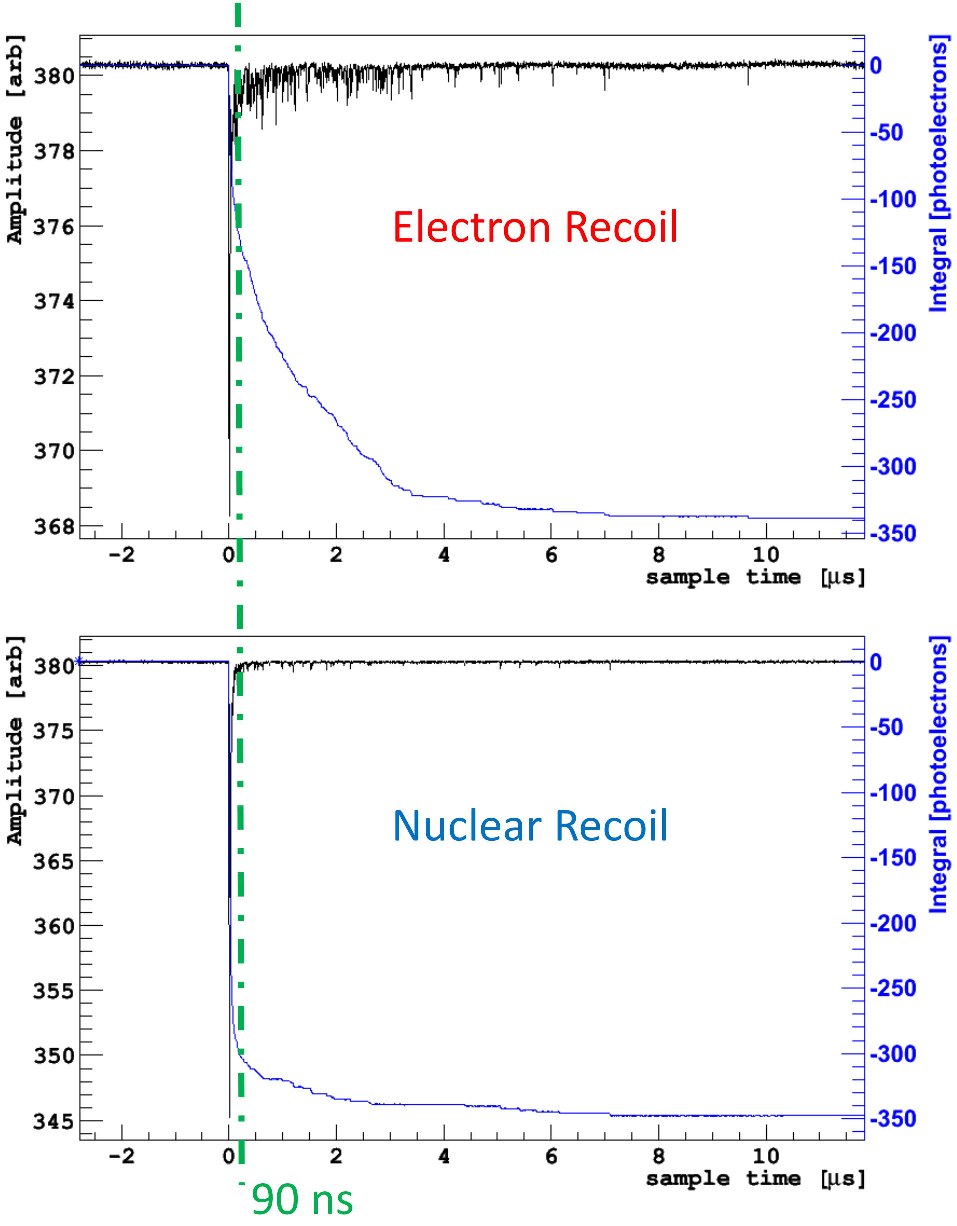
Pulse Shape Discrimination (PSD) in Liquid Argon



- LAr scintillation light (S1) has 2 components: τ_{fast}=7ns, τ_{slow}=1600ns
- $f_{prompt} = \frac{\#\, prompt\ photons}{\#\, total\ photons}$ as discrimination var
- 90ns as the optimal prompt time to optimize PSD

- Two events with ~ the same integrated S1 signal
- use f_{90} to separate ER and NR
- ER: $f_{90} \approx 0.3$
- NR: $f_{90} \approx 0.75$
- Electron rejection power > 1.5 x 10^7

see Xin's talk

Neutron Veto Detector of DarkSide-50 Experiment

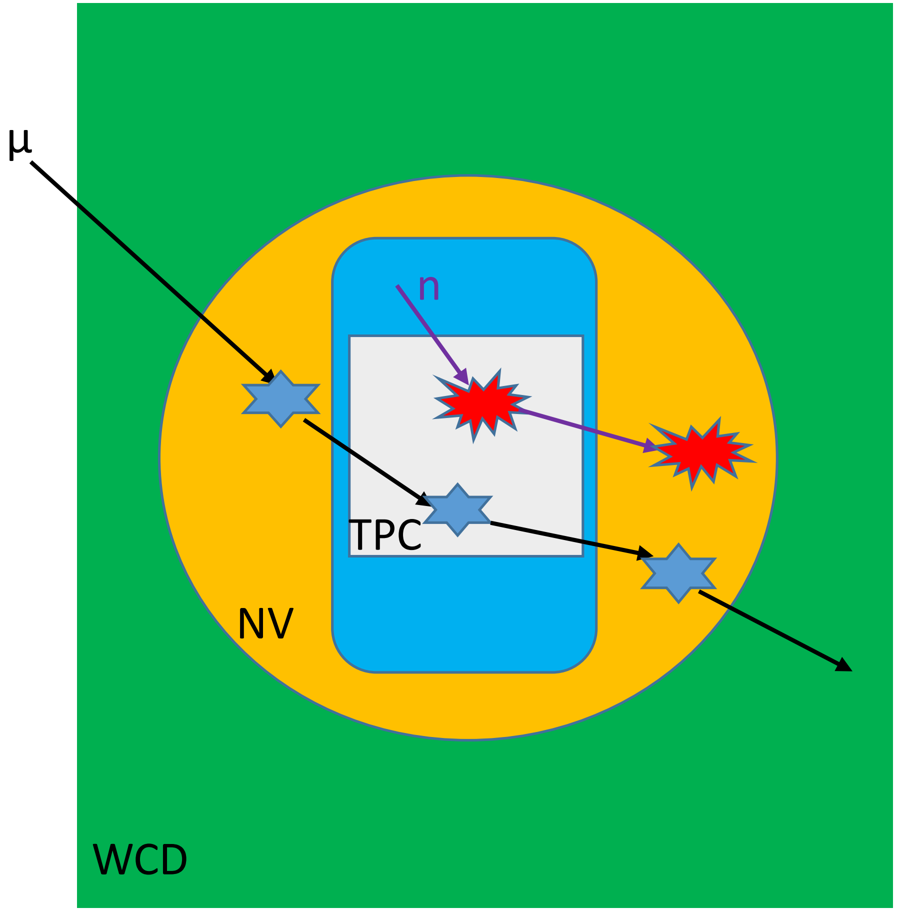
Darkside-50 Neutron Veto

- TPC inside Neutron Veto Detector
- 4 m diameter Stainless Steel Sphere
- 30 t Boron-loaded Organic Liquid Scintillator
- 5% Trimethyl borate(TMB, with natural ^{10}B)
- 110 8-inch PMTs
- Water Cherenkov Detector installed outside

1. active shielding against cosmic rays (muon, etc) by WCD
2. NV: detect neutrons and γ rays in coincidence with TPC
3. NV: neutron capture on ^{10}B, ^{1}H(~8%) , ^{12}C(~2%)

Background: NR

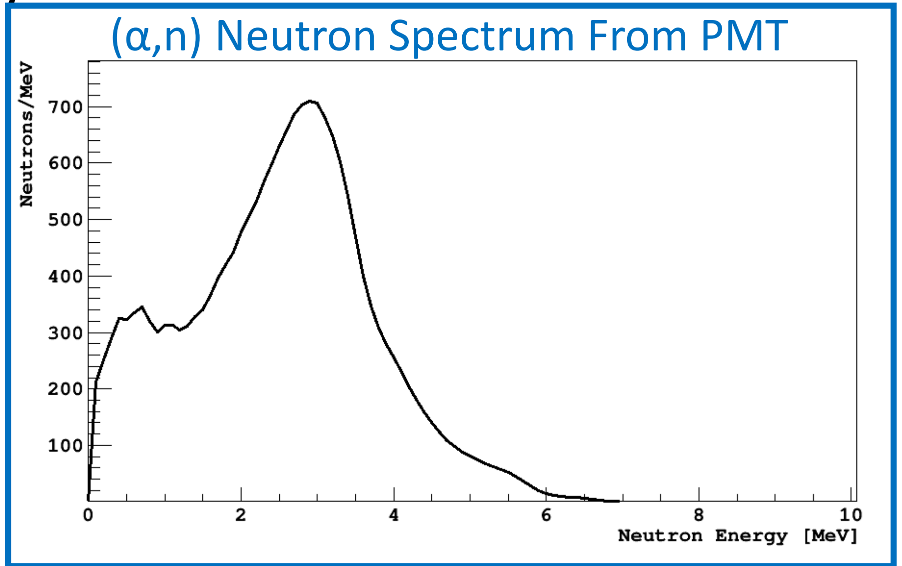
Active Shielding



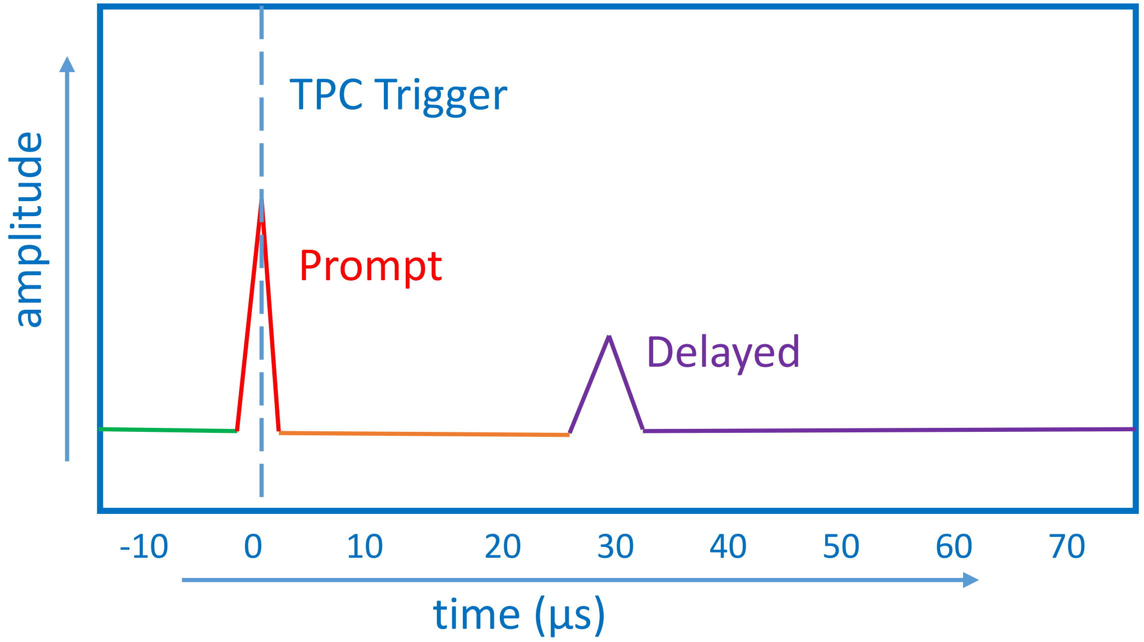
- WIMPs give NR-like signal
- NR bg cannot be rejected by PSD

✓ Cosmogenic Neutron: <3 n/yr (MC, in TPC, all easily vetoed)

- Radiogenic neutron:
  - ✓ Fission reactions: <4.4 e-3/yr (MC,after all cuts)
  - ○ (α,n) Neutron reactions:
    - mainly comes from detector materials



Neutron Detection



Time window in Neutron Veto

- total NV acquisition window: 220 μs
- Preprompt: [-10, -0.05] μs
- Prompt: [-0.05,0.25] μs
- Delayed: [0.25,190] μs

Target Veto Efficiency > 99.5%

- in coincidence with TPC
- Neutron Thermalization
- very fast (<200ns)
- Prompt cut: sum charge in ROI>1PE
- calibrate with $^{241}Am\,^{13}C$

- Thermalized Neutron Random Walk before capture
- No signal produced

- Neutron Capture
- Isotopes: ^{10}B, ^{1}H , ^{12}C
- Delayed Cut: max charge in sliding window>6PE
- calibrate with $^{241}Am\ ^{9}Be$

Neutron Calibration: $^{241}Am\ ^{9}Be$

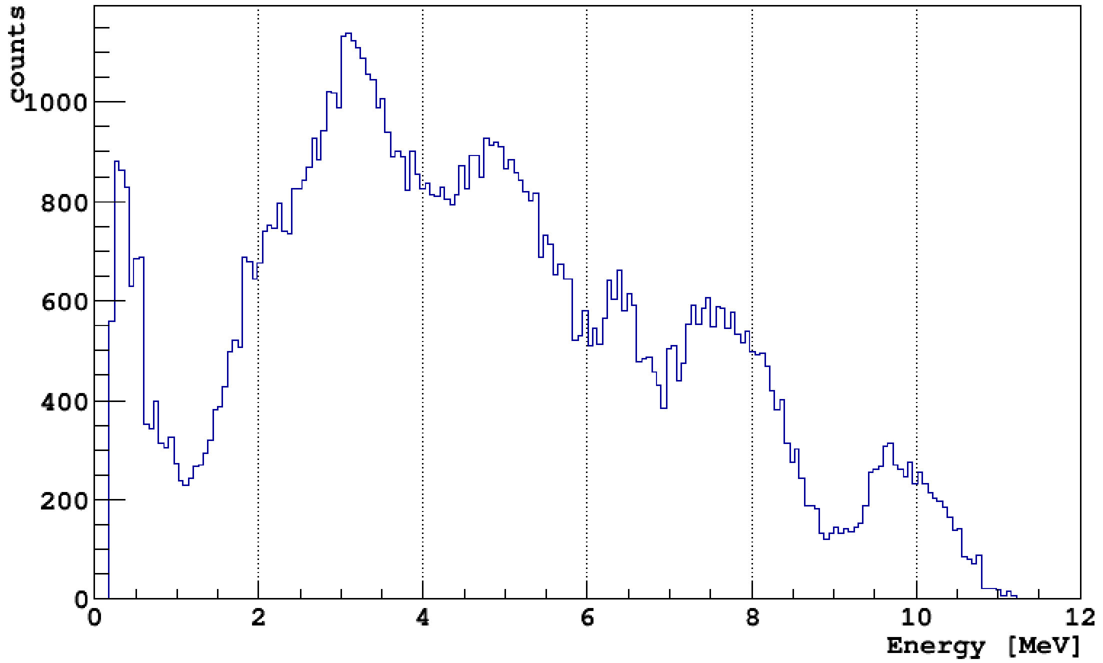
Goal

- quantify the NV response to neutron signals
- study the neutron capture signal in delayed window

$^{241}Am\ ^{9}Be$ decay mechanism

- Br = 36%: neutron only channel
- Br = 61%: neutron + γ (4.4 MeV)
- Br = 3%: neutron + γ (4.4 MeV) + γ (3.2 MeV)

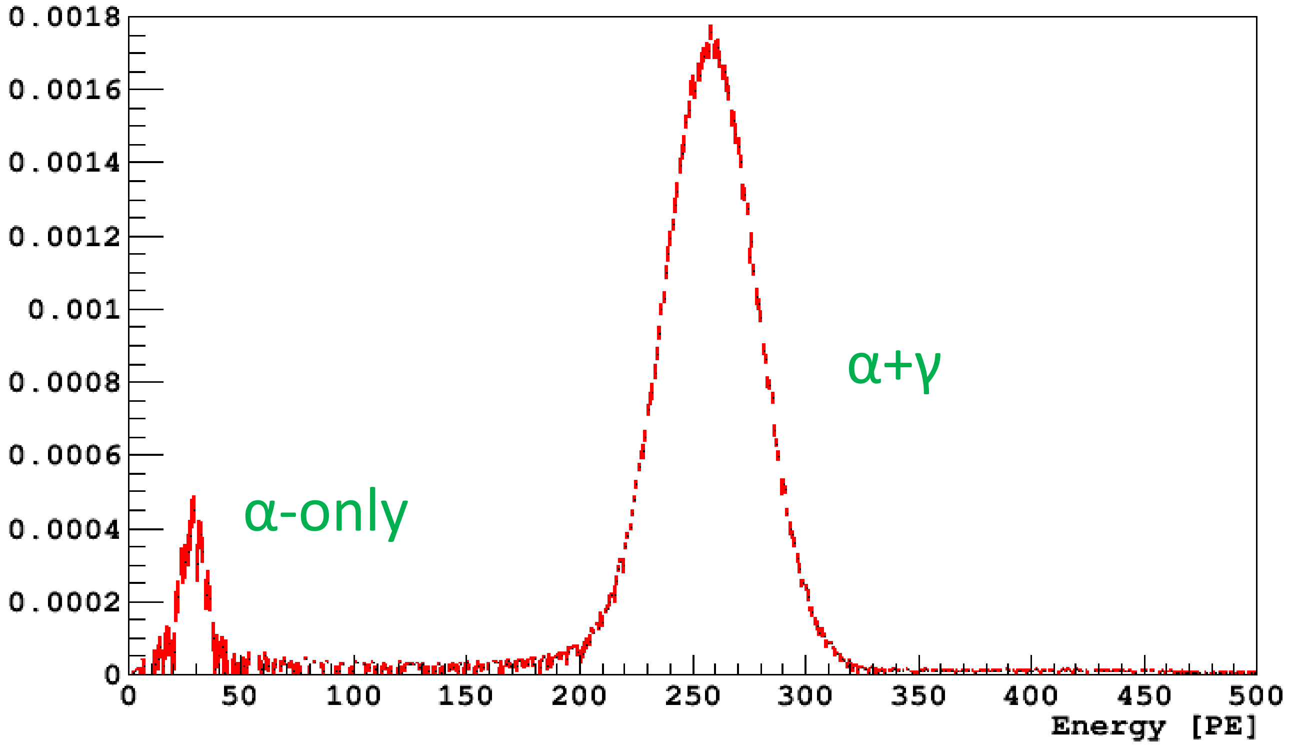
$^{241}Am\ ^{9}Be$ neutron only spectrum (MC)



source placed ~1cm outside TPC cryostat

Neutron Calibration: $^{241}Am\ ^{9}Be$

spectrum from neutron capture on ^{10}Be



- $^{10}B + n \rightarrow\ ^{7}Li(1015keV) + \alpha(1775keV)$ (6.4%)
- $^{10}B + n \rightarrow\ ^{7}Li + \alpha(1471keV)$ (93.6%)
  $^{7}Li \rightarrow\ ^{7}Li\ (839keV) + \gamma(478keV)$

Feature

- ^{10}B isotope in TMB
- neutron capture cross section on ^{10}B: 3838 b
- neutron capture time: τ = 21.81$\pm$0.20 μs (5% TMB)
- delayed neutron capture threshold set at 6PE (below α-only peak) to get high veto efficiency

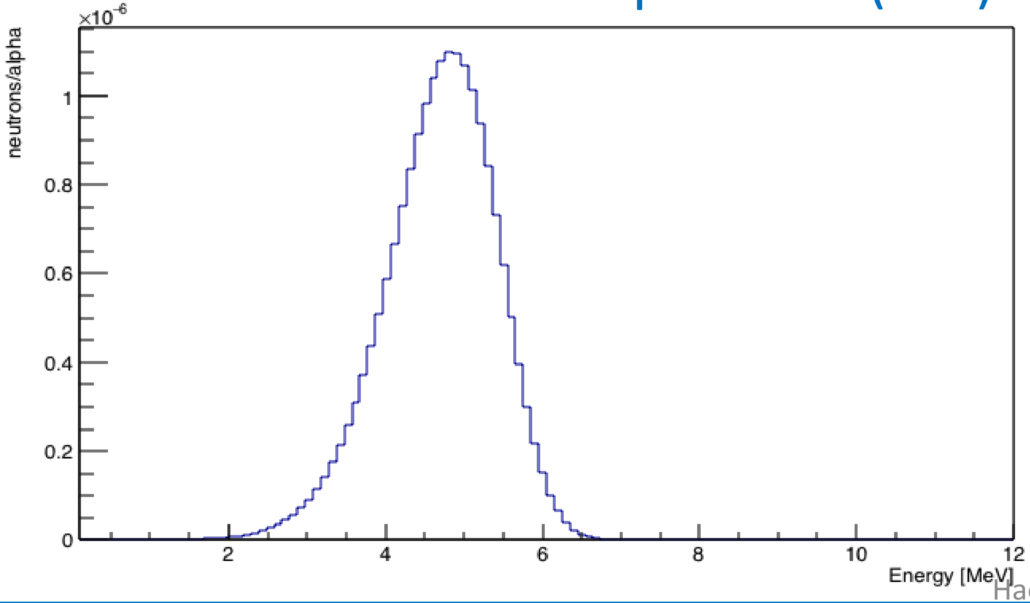
JINST, 11 (2016): P03016

Neutron Calibration: $^{241}Am^{13}C$

Goal

- negligible γ coincident with neutron
- measure neutron thermalization signal
- tune NR quenching model
- study the prompt neutron efficiency

$^{241}Am^{13}C$ neutron spectrum (MC)



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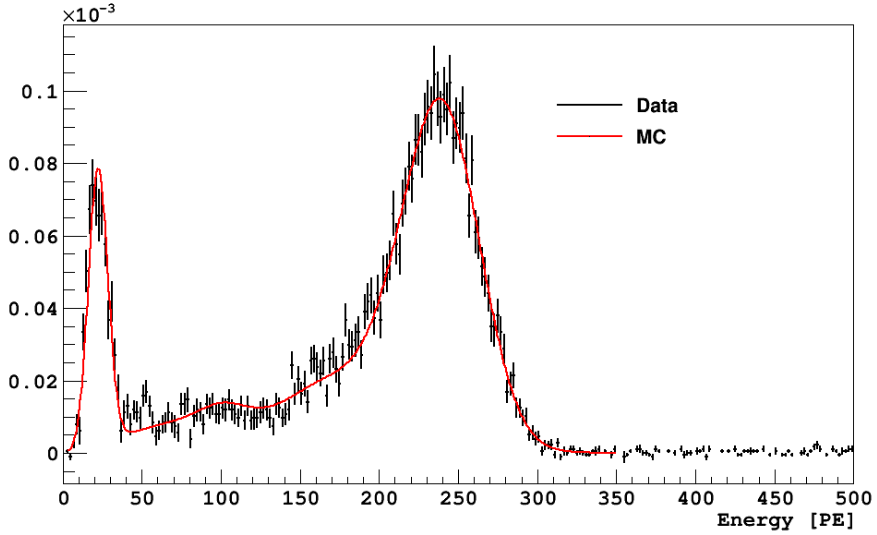
- α from ^{241}Am decay:
  - 99.5% has E_{α}>5.39MeV
- α + $^{13}C \rightarrow {}^{16}O$ + n
- threshold of ^{16}O first excited state: 5.048MeV
- gold foil wrap around ^{241}Am, degrades α to below excited state threshold
- source surround by ~2mm thick lead to block 60 keV ^{241}Am x-rays

$^{241}Am^{13}C$ source

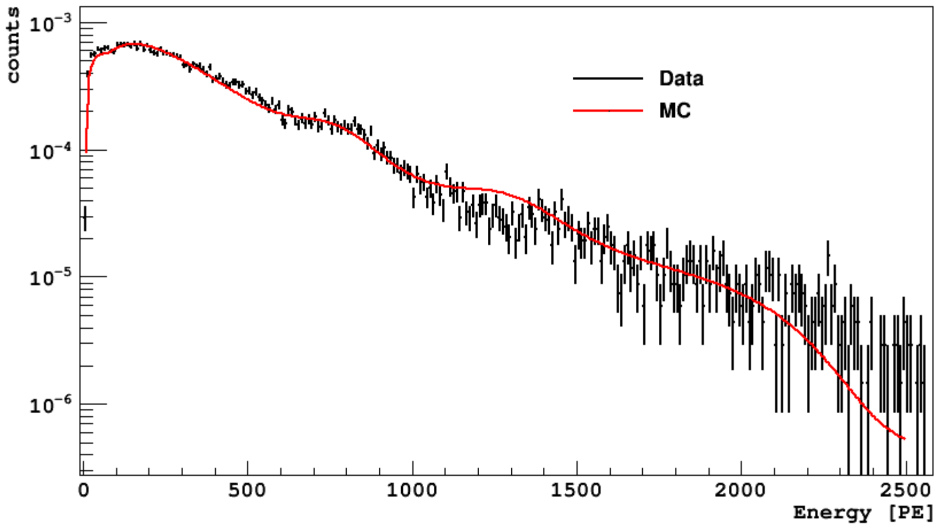
source is placed ~1cm outside TPC cryostat

Neutron Calibration: $^{241}Am^{13}C$

$^{241}Am^{13}C$ delayed neutron capture signal



$^{241}Am^{13}C$ Prompt Neutron Thermalization signal



- Quenching Model (Craun et al):

$$Q = E * LY * \frac{1}{1+kB*\frac{dE}{dx}+C*(\frac{dE}{dx})^2}$$

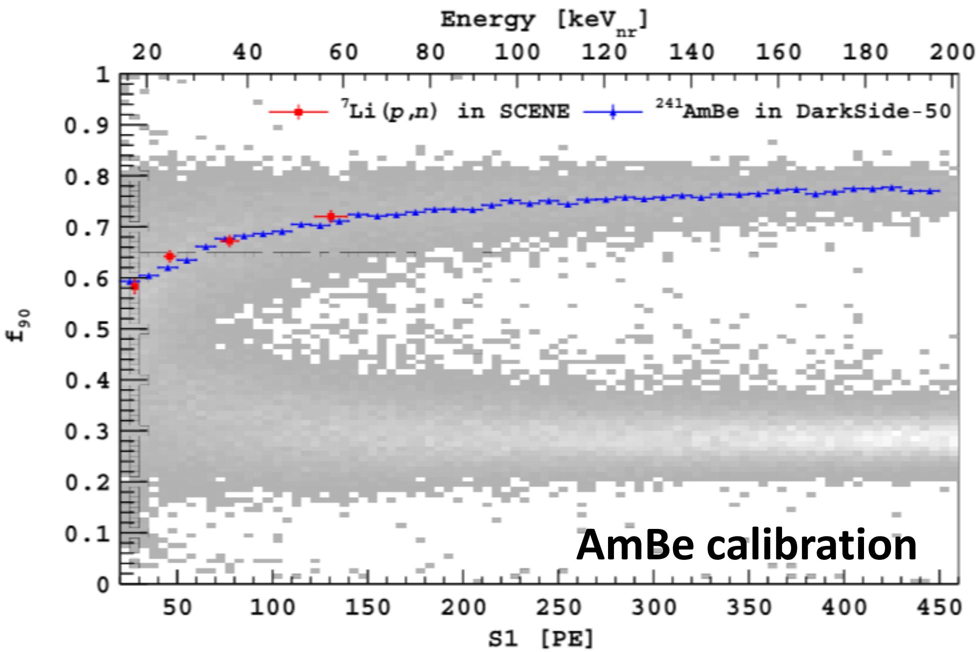
- add non-linearity for NR

Radiogenic Neutron: MC

- Use $^{241}Am^{13}C$ data to measure veto efficiency for events with WIMP-like TPC signals
- Use $^{241}Am^{13}C$ and $^{241}Am\ ^{9}Be$ data to tune detector (TPC + NV) response in MC
- generate $^{241}Am^{13}C$ and radiogenic neutrons in MC
  - simulate 0-10MeV neutrons uniformly at each position of detector
  - calculate probability of neutrons passing cuts
- correct measured $^{241}Am^{13}C$ efficiency for different position and spectrum of radiogenic neutron

Radiogenic Neutron: MC

- generate flat neutron spectrum
- calculate probability of neutron passing TPC Cuts:
  - TPC fiducial volume
  - Single NR
  - NR energy range



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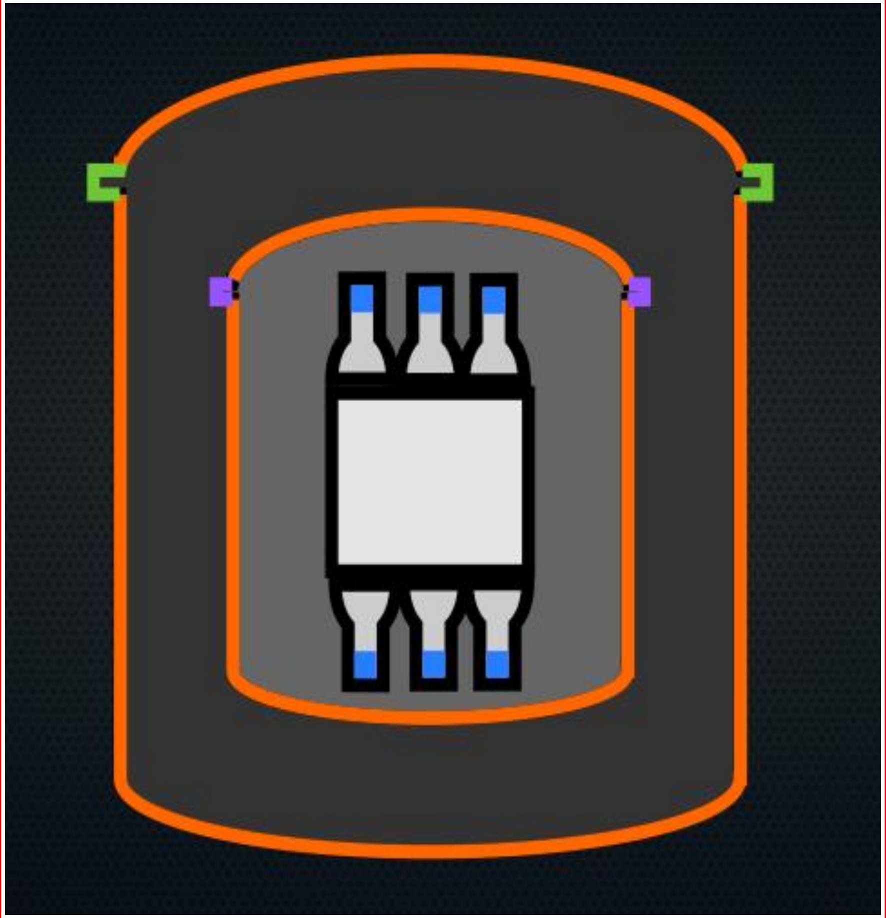
- calculate probability of neutron passing veto cuts
- use NeuCBOT software (based on TALYS and SRIM database, available at https://github.com/shawest/neucbot)
  - calculate (α,n) yield
  - get neutron spectra for one year

Radiogenic Neutron: Positions

Positions to generate radiogenic neutron

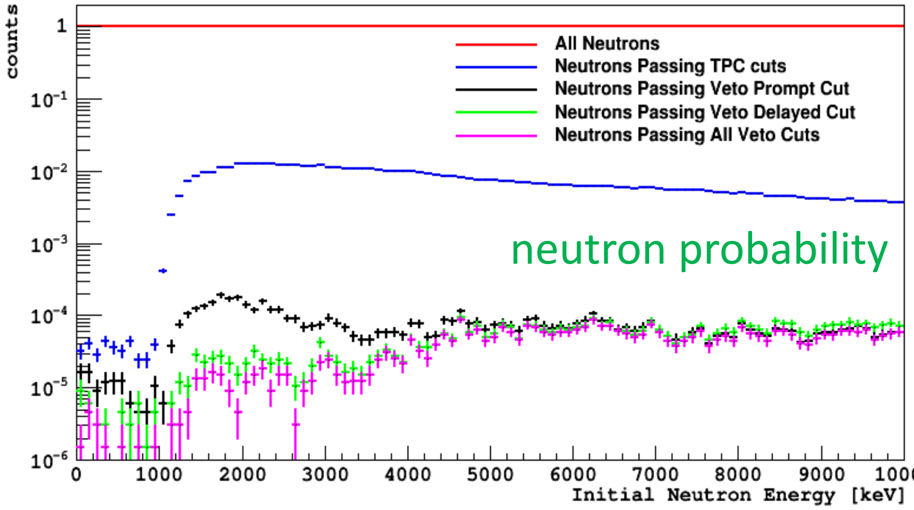


arXiv: 1702.02465

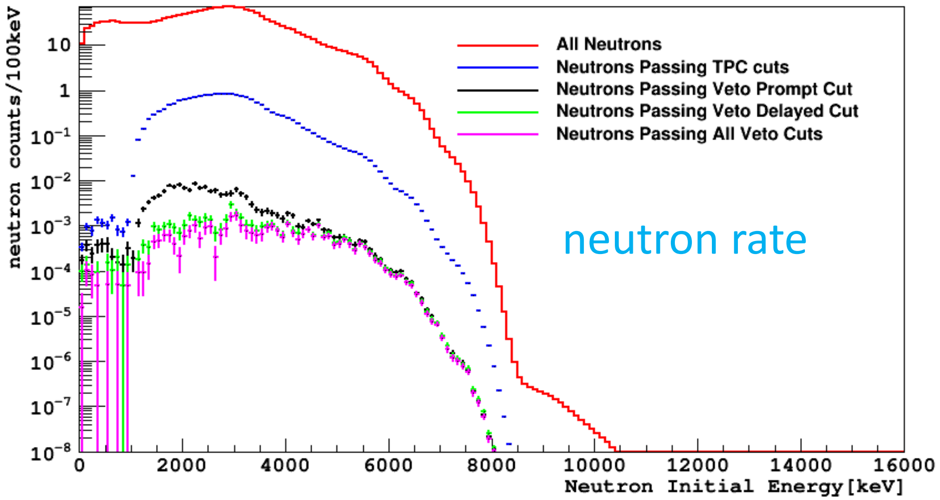
Neutron Positions	Material
PMT Stem	Borosilicate glass
PMT Electronics	Be-Cu alloy connectors
Cryostat Walls	Stainless Steel
Multilayer Insulation	Aluminized mylar foils
Inner Flange	Stainless Steel
Outer Flange	Viton O-ring, Stainless Steel

Radiogenic Neutron: Probability and Rate

- simulate 0-10MeV neutrons uniformly at each position
- calculate probability of neutrons passing cuts



- simulate radioactive decay chains: ^{238}U, ^{235}U, ^{232}Th
- break ^{238}U decay chain at , ^{226}Ra and ^{210}Pb (when data available)
- sum over neutron spectra from each source for each position to get neutrons produced per year
- scale the neutron production rate per year by cut-survival probability to get estimated surviving bg per year

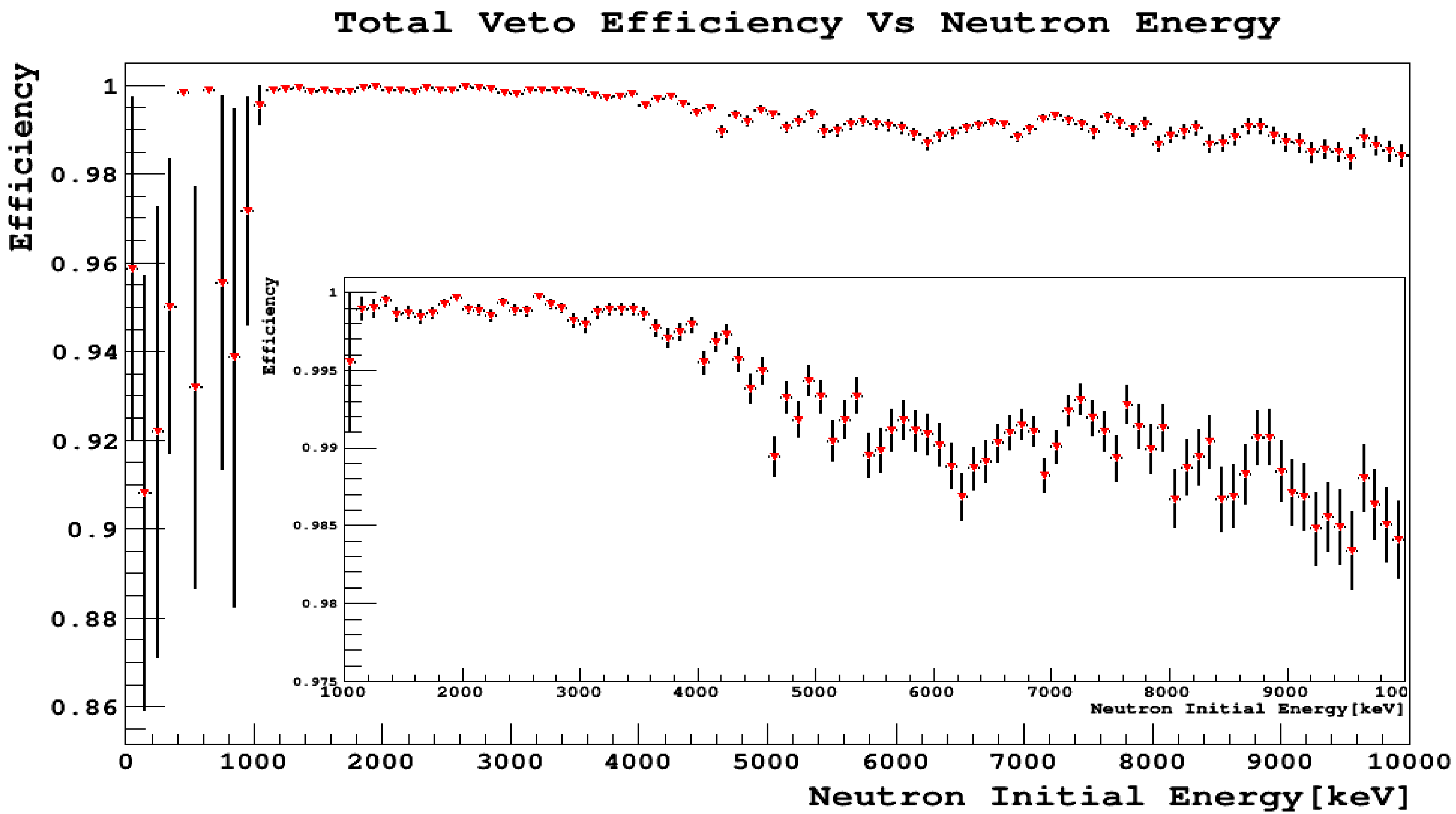


Radiogenic Neutron: Prediction for one year

Preliminary

Position	Total	TPC cuts	Preprompt	Prompt	Delayed	All
PMT Stem	1948.64	17.3893	14.2135	0.1637	0.0433	0.0304
PMT Electronics	33.84	0.2287	0.1852	0.0023	1.e-3	7.8e-4
Cryostat Walls	8.48	0.0218	0.0191	2.3e-4	8e-5	3e-5
Multilayer Insulation	5.34	0.017	0.0125	1.6e-4	1e-4	7.3e-5
Inner Flange	14.27	0.0134	0.0093	2e-4	7.3e-5	2.45e-5
Outer Flange	794.15	0.3935	0.2621	5.2e-3	2.8e-3	6.3e-4
Total	2804.72	18.0637	11.4004	0.1334	0.0366	0.0320 ± 0.0014

Radiogenic Neutron: Veto Efficiency Vs Energy



- at each energy bin, average the efficiency from each position

Radiogenic Neutron: Summary

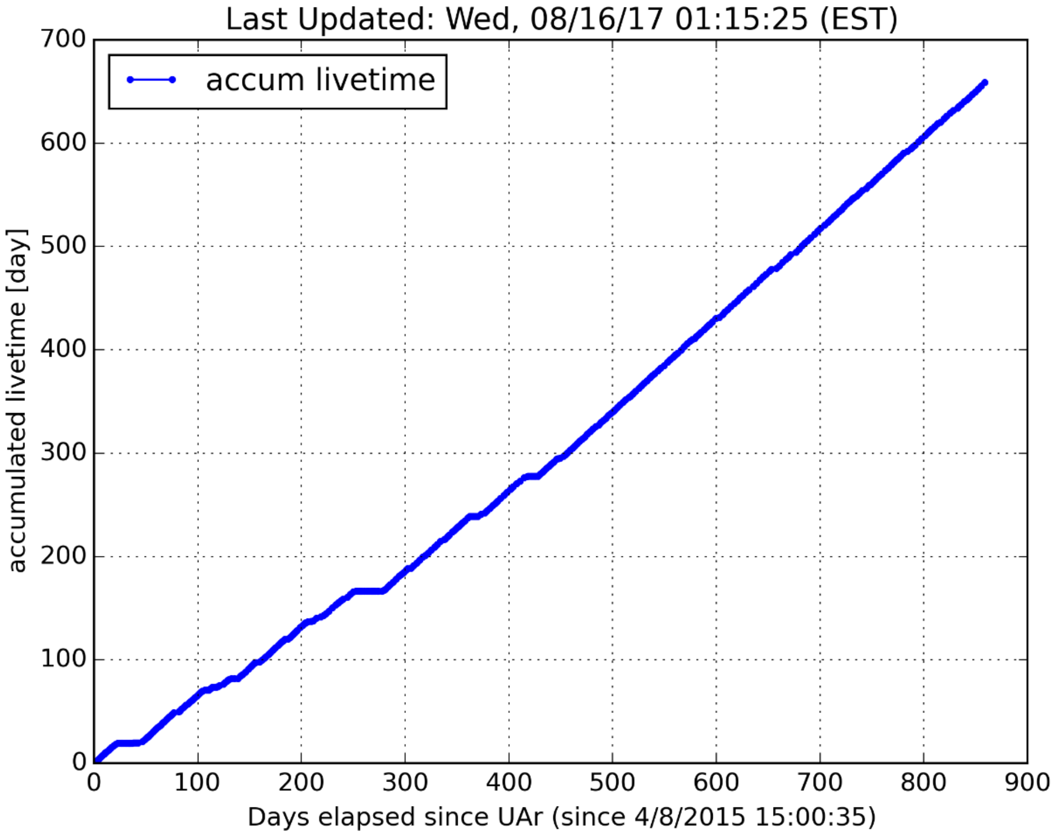
- After applying all TPC cuts, use neutron veto cuts to get the veto efficiency:

Prompt Cut Only Veto Efficiency	Delayed Cut Only Veto Efficiency	Total (all Veto Cuts) Veto Efficiency
$99.05\% \pm 0.02\%$	$99.74\% \pm 0.01\%$	$99.82\% \pm 0.01\%$

- With TPC and NV, total neutron rejection power ~500
- With TPC and NV, expect 0.0320 ± 0.0014 radiogenic neutron bg per year
- In the furture, count NR bg in 500-days data and check with MC prediction
- Stay tuned for new results coming this fall with blind data analysis

- Backup Slides

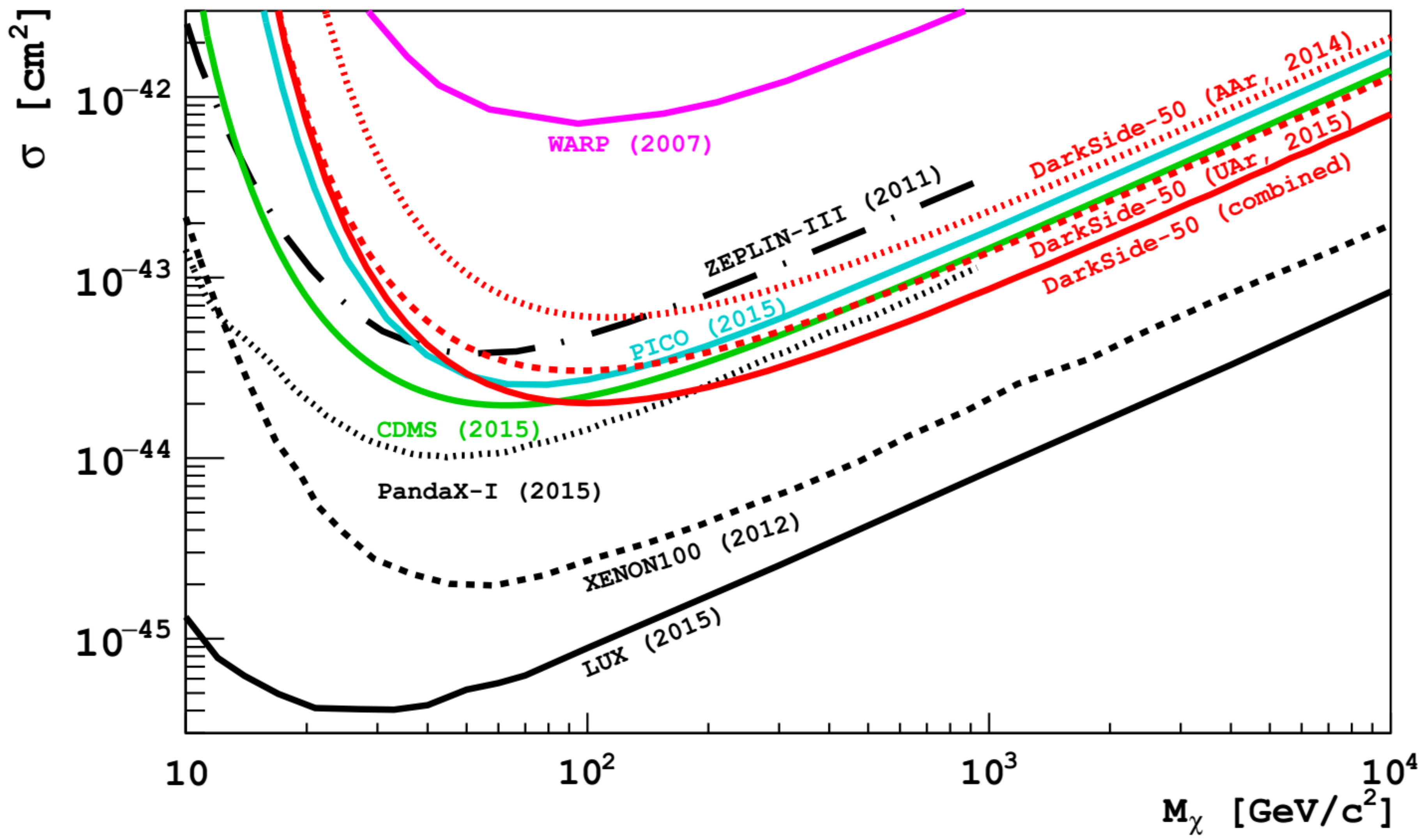
Status of DarkSide-50



Stay tuned for new results coming this fall

- ~500 live-days of usable post-70-day UAr data
- Signal region hidden for the first Blind Analysis
- Cuts and bg prediction using open data
- Most bg estimated and under control:
  - ✓ Radiogenic neutrons
  - ✓ Cosmogenic neutrons
  - ✓ Single and Multiple ERs in LAr
  - ✓ Surface bg
  - ✓ Multiple Compton scatter of γ events
- still in progress:
  - ❑ Cherenkov signal
- Prepare final tests before box opening

Current limits with DarkSide-50



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BackUp: $^{241}Am\ ^{9}Be$, $^{241}Am^{13}C$ and UAr Prompt Spectrum