Background Control and Evaluation in DEAP-3600

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for the DEAP-3600 Collaboration

DEAP 3600

UNIVERSITY OF ALBERTA

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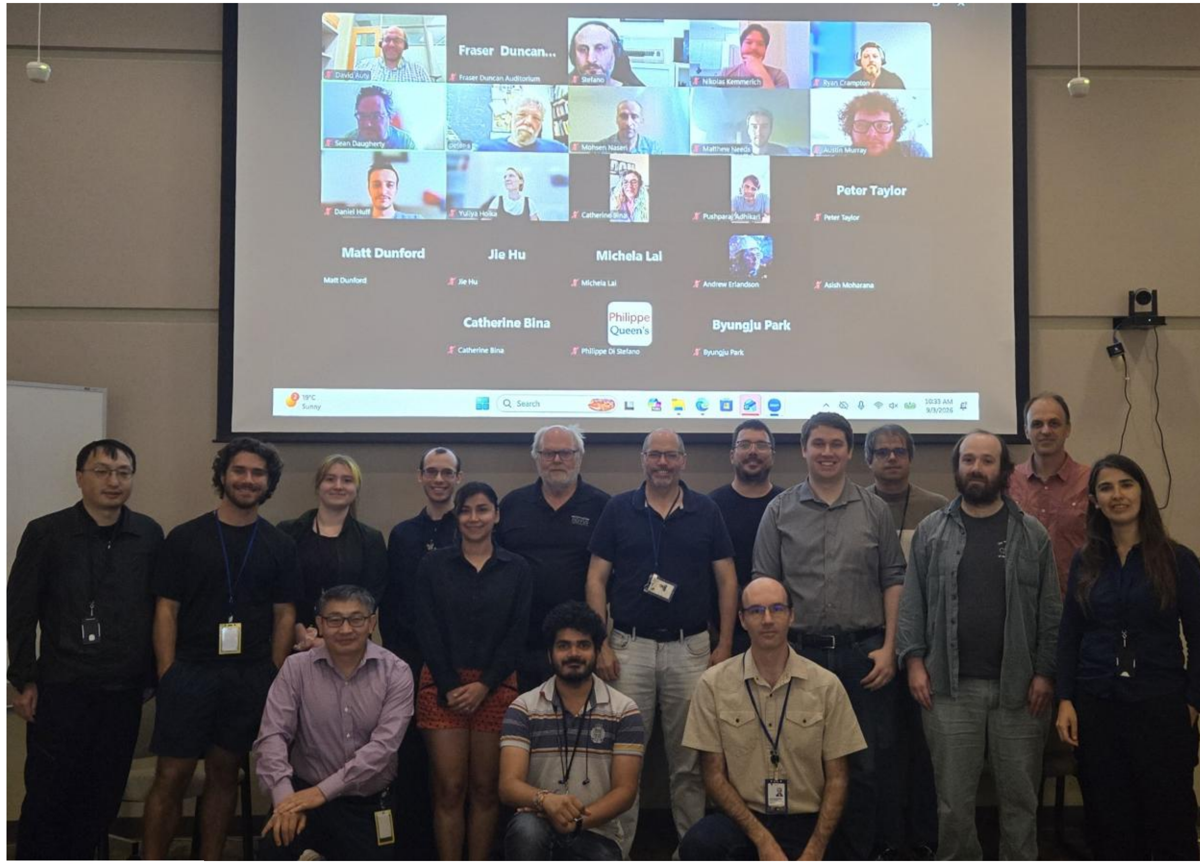

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Backgrounds at low and high energy

- B-8 solar neutrino analysis
  - (n,γ) backgrounds
  - Cosmogenic backgrounds
  - Instrumental backgrounds

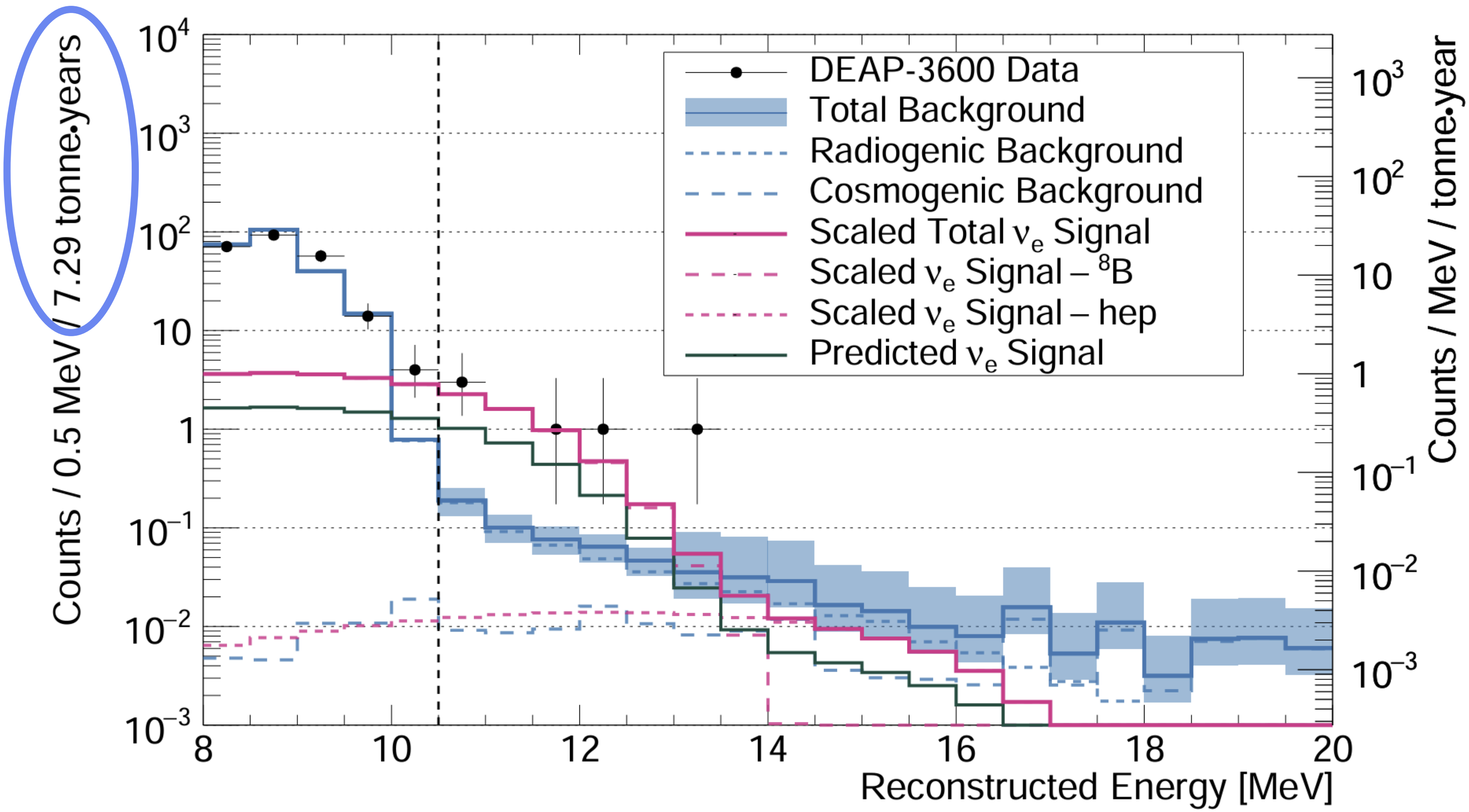
- Dark Matter analysis
  - Degraded alphas from optical shadowing: “neck events”.
  - Degraded alphas from dust suspended in the argon.

- Status of hardware upgrades towards a zero-background detector

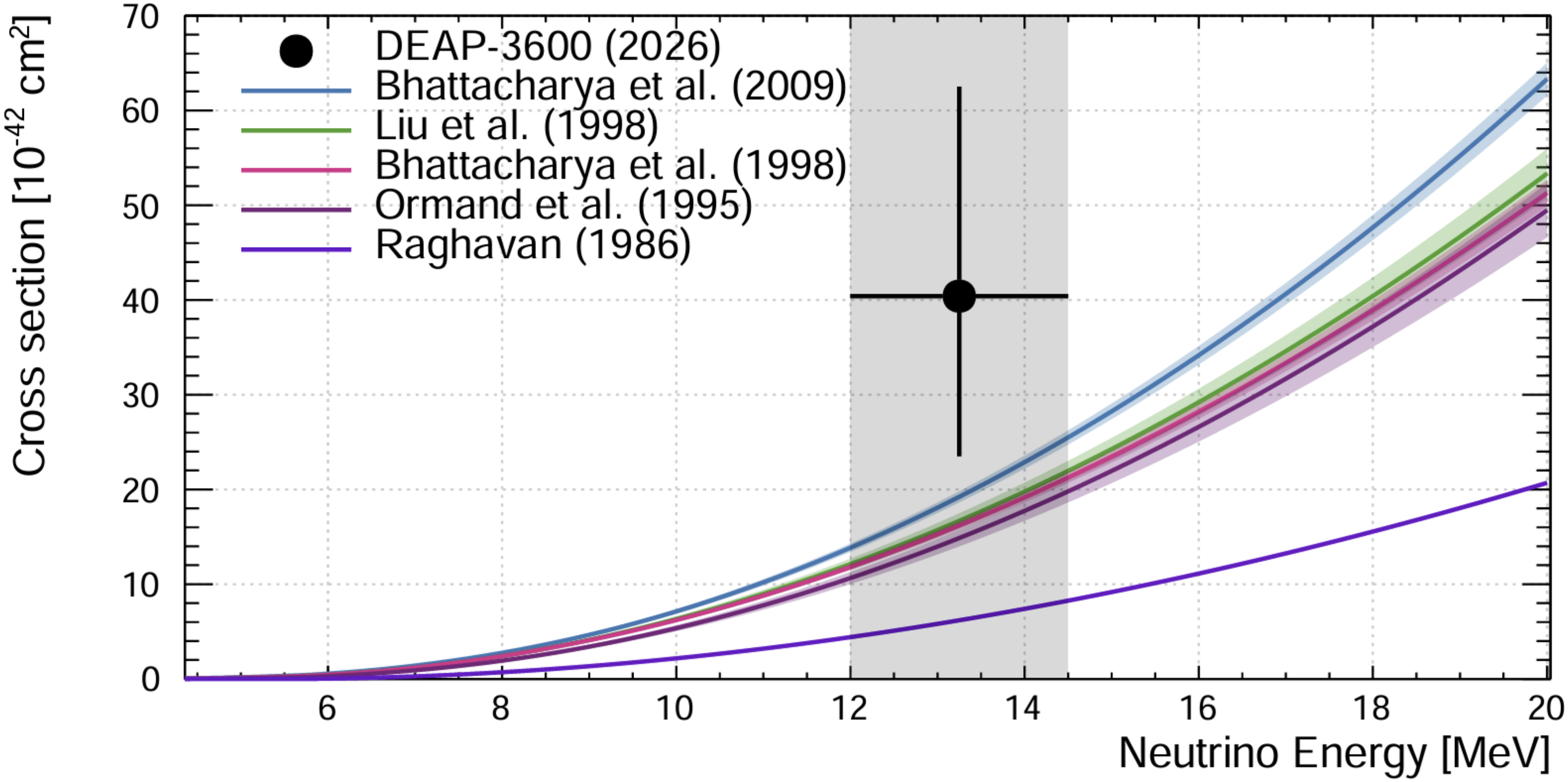
Neutrinos

We measured 6 candidate Boron-8 solar neutrino charged-current events with a background expectation of 0.48 +0.16 -0.15

https://arxiv.org/abs/2605.12769



… corresponding to a cross-section 2.4 x theoretical models



The DEAP-3600 Detector

TPB-coated acrylic vessel

Cooling coil

Acrylic neck and flowguides

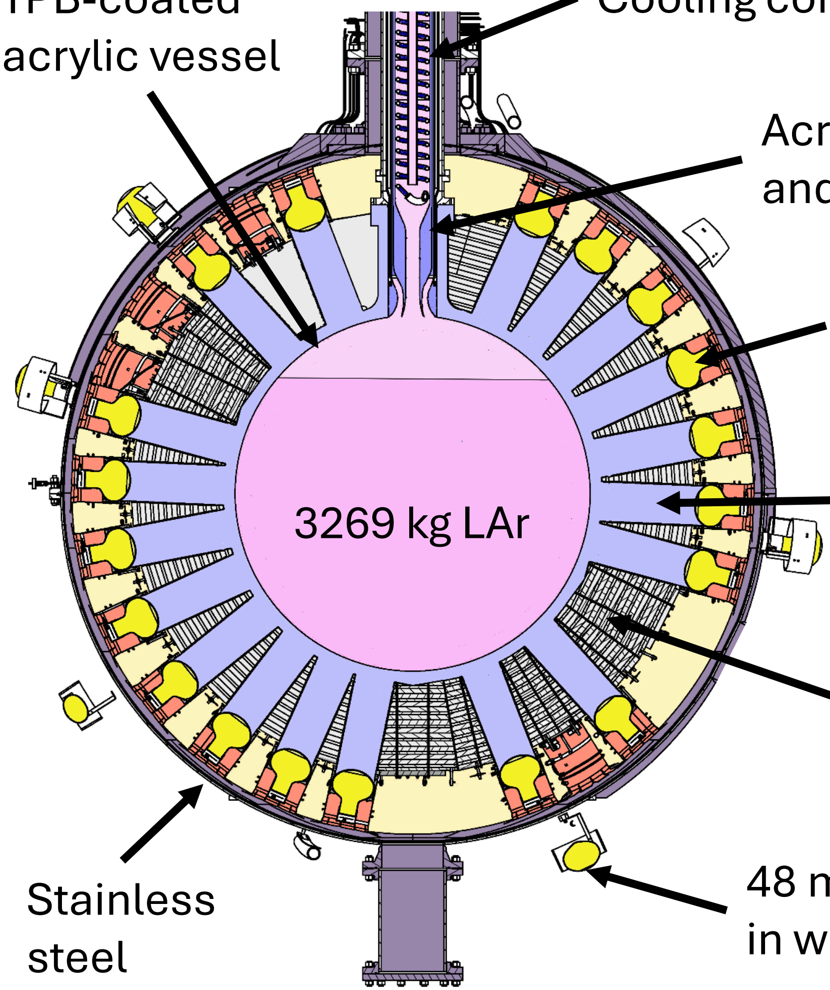
255 Hamamatsu HQE PMTs

Acrylic light guides

Neutron shielding blocks

48 muon veto PMTs in water tank

Stainless steel shell



Water tank

(before reflective liner installed)

Calibration guide tube

https://arxiv.org/abs/1712.01982

Radiogenic (α,n) followed by (n,γ) dominate our background estimate

TABLE II. Backgrounds in the neutrino search ROI.

Background Source	Events in ROI in 815 live-days
Radiogenic (n, γ)	$0.43 \pm 0.05\,(\text{stat}) \pm 0.14\,(\text{sys})$
Cosmogenic	$0.048 \pm 0.009\,(\text{stat})\ {}^{+0.070}_{-0.025}\,(\text{sys})$
Correlated $\gamma - \gamma$ pile-up	$< 10^{-3}$
Uncorrelated $\gamma - \gamma$ pile-up	$< 10^{-3}$
Correlated $\alpha - \alpha$ pile-up	$< 10^{-3}$
Uncorrelated $\alpha - \alpha$ pile-up	$< 10^{-3}$
Total Background	$0.48\ {}^{+0.16}_{-0.15}$

Two methods to evaluate (n,γ) rates

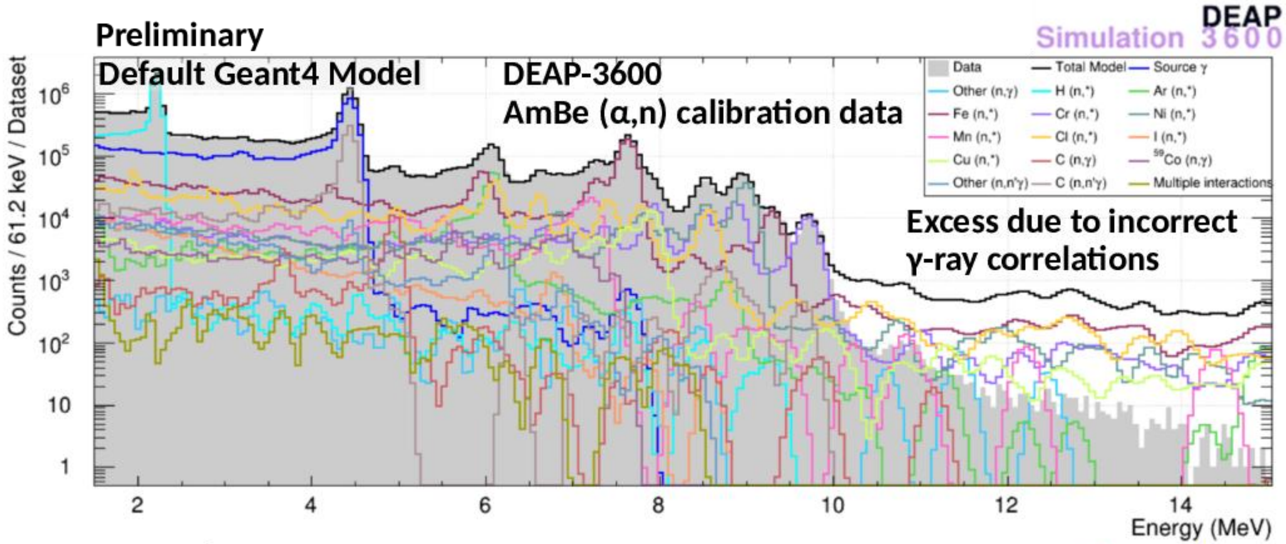
Bottom-Up Approach

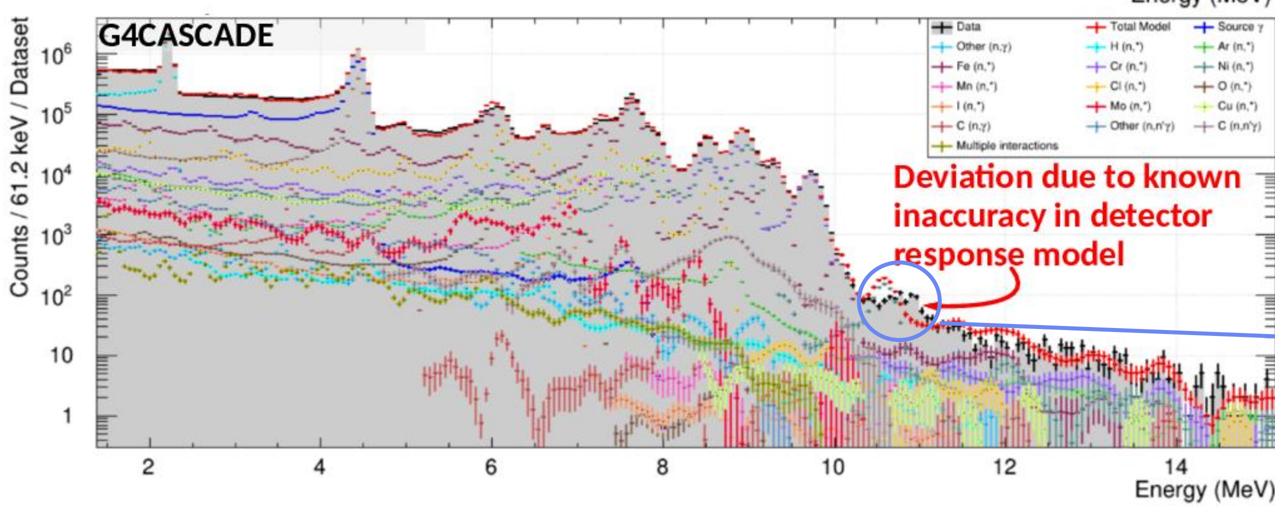
- Build a Monte Carlo model in G4 .
- Fit model to AmBe spectrum up to 10 MeV.
- Extrapolate into R.O.I.
- Improved modeling of n-capture gammas in G4. [2408.02774] G4CASCADE: A data-driven implementation of (n, γ) cascades in Geant4
- Allows for a blind analysis, in principle.
- Difficult to account for N-14

Scaled AmBe Calibration

- Use AmBe source deployments throughout run of DEAP-3600 to measure (n,γ) spectrum.
- Details to follow

AmBe calibration allows us to build a Monte Carlo model...





Ni-61 and N-14

2 MeV

10 MeV

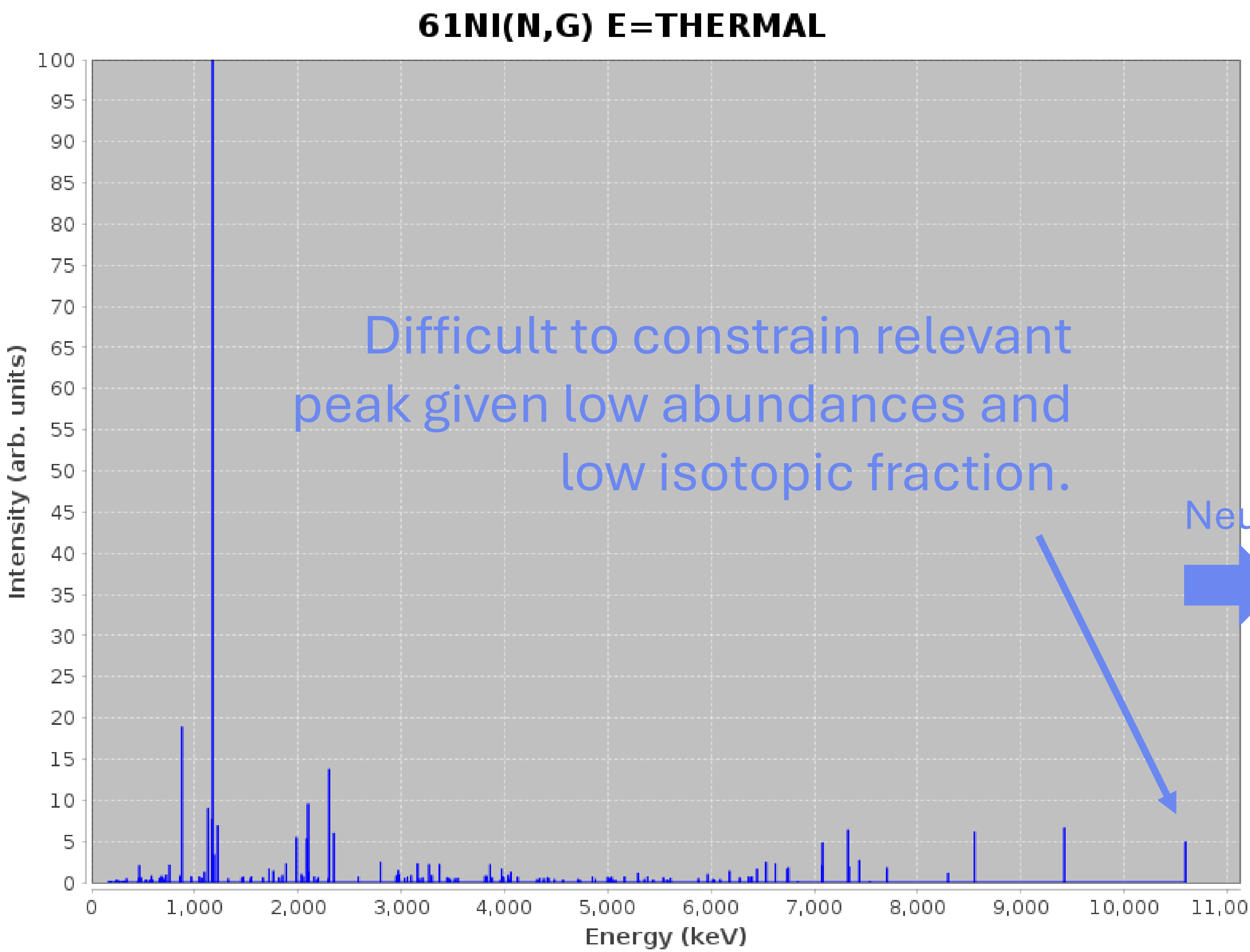
... if correct (n,γ) cascade models are used.

ArXiv: [2408.02774]

https://github.com/UCRDarkMatter/G4RiversideCASCADE

Ni-61 is only ~1% of natural nickel.

Plot from https://www.nndc.bnl.gov/capgam/

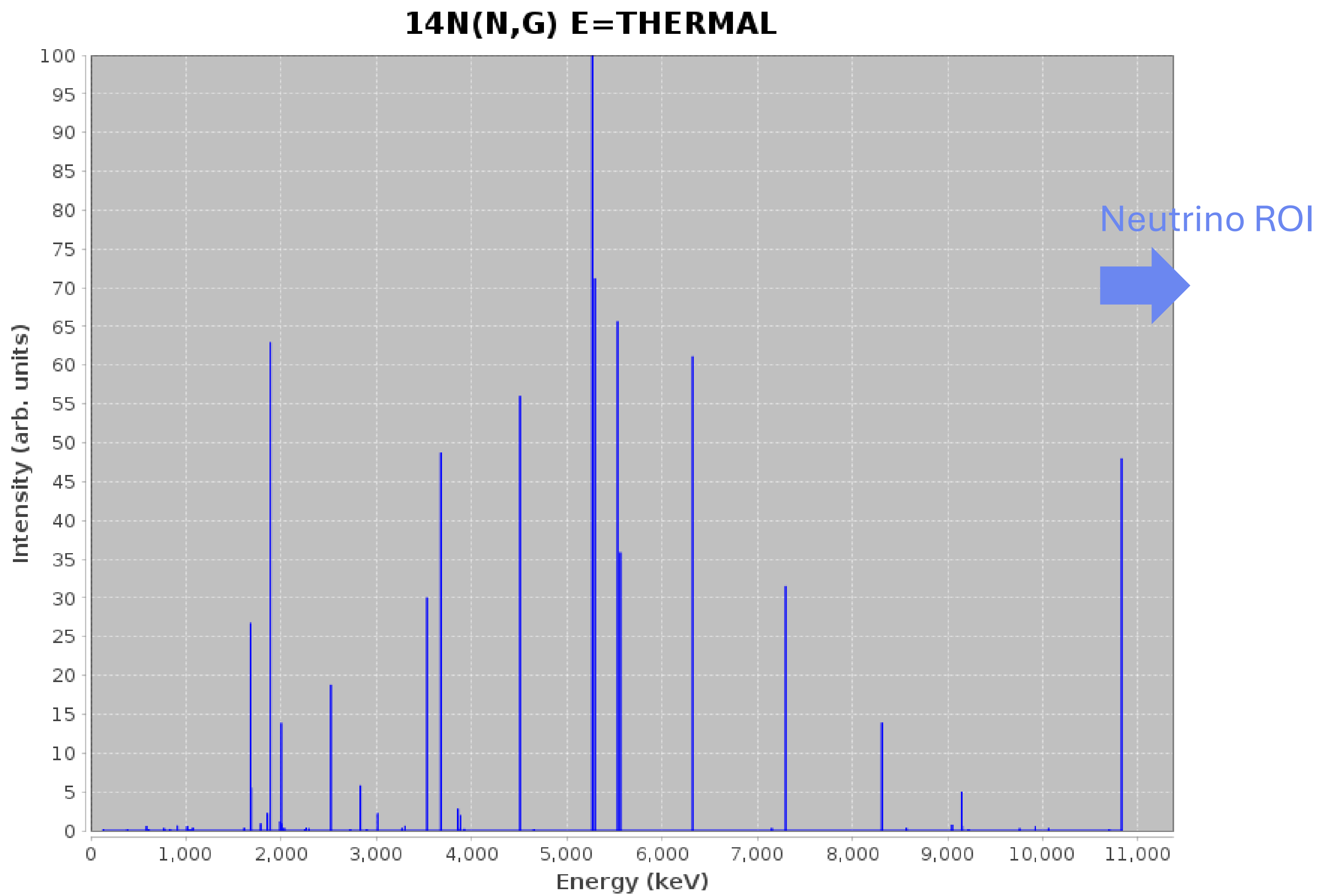


Difficult to constrain relevant peak given low abundances and low isotopic fraction.

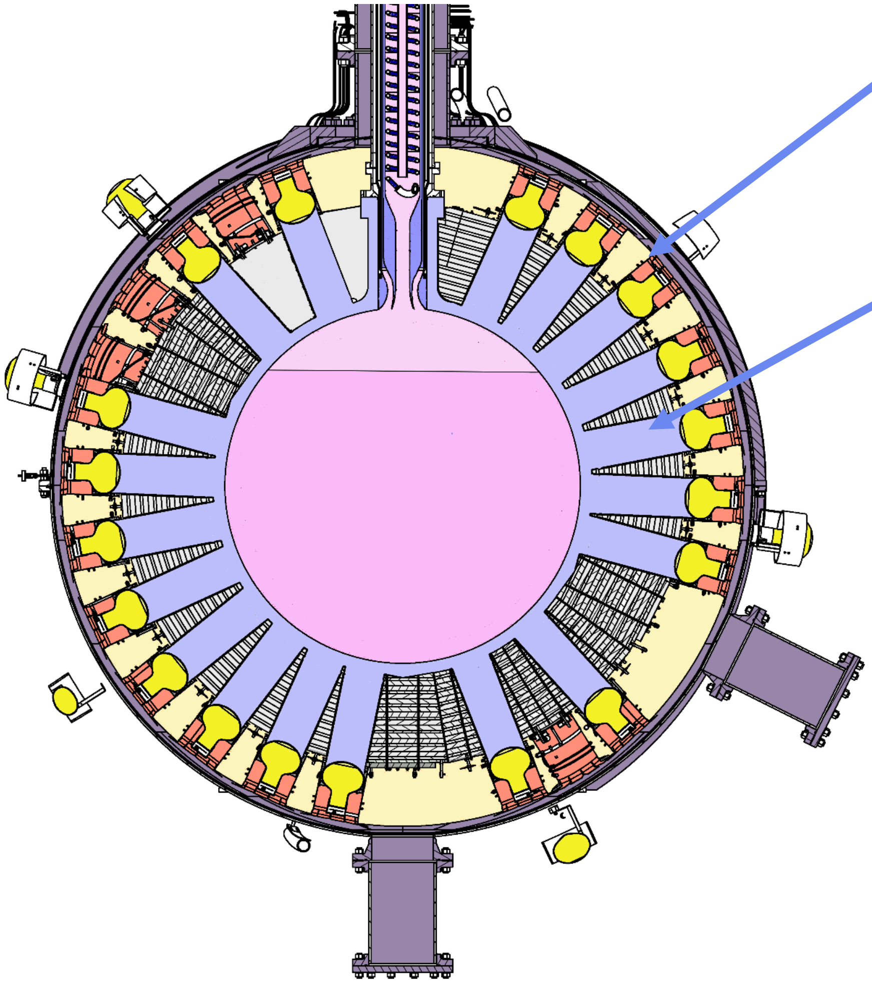
Neutrino ROI

N-14 is used as a purge gas in the steel shell and is dissolved in the water shielding tank.

Plot from https://www.nndc.bnl.gov/capgam/



The amount of N2 in DEAP-3600 is tricky to estimate.



Purge flow around PMTs:
Density = $\rho(T(\mathbf{x}))$

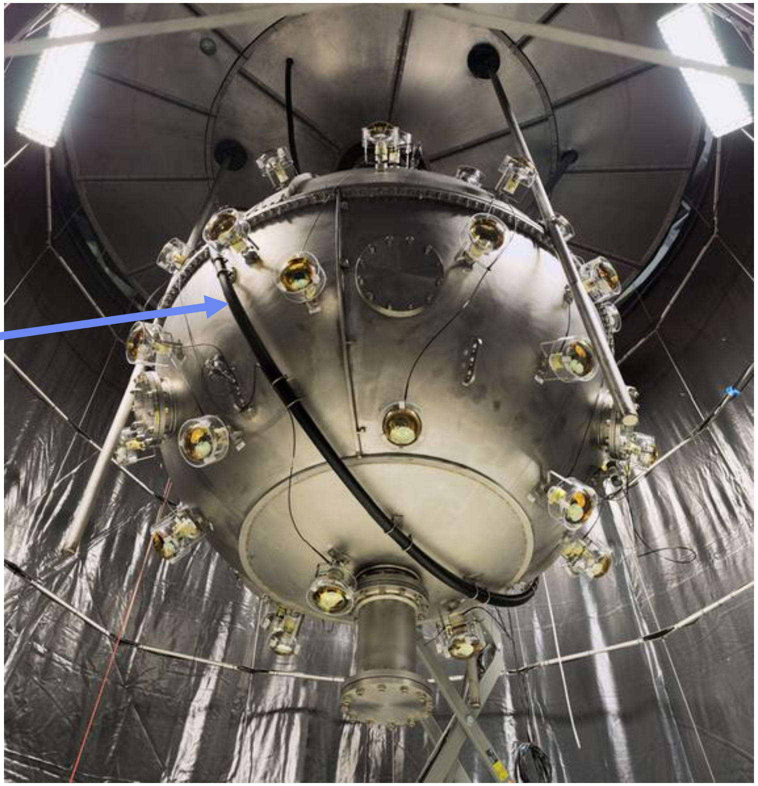
Unknown quantity dissolved in plastic lightguides or filler blocks

Amount dissolved in water varies with de-oxygenation and replacement with nitrogen

Detailed modeling above 10 MeV difficult

➔ Use all the AmBe calibration as a direct model after some important corrections.

Calibrations carried out at several locations around this guide tube.



Equivalent to ~10^7 days of physics data

The AmBe recipe

- → Pile-up corrections: AmBe calibration at much higher rate.
- Normalize the AmBe calibration such that the number of events from 8 to 10 MeV matches data.
- Integrate in the neutrino region of interest.
- → Use the Monte Carlo model, in ratio, to scale the AmBe estimate due to the difference in initial neutron location and the neutron energy spectrum.

Pile-up removal and the AmBe scaling by Monte Carlo ratio drive the uncertainly in the radiogenic background estimate

Systematic Unc.	Value	Bkg	CC ν_e
Energy Scale Bias	$0 \pm 1.5\%$	10.1%	11.7%
Energy Resolution	96 keV $\pm$ 17 keV	0.5%	0.1%
Int./Ext. γ LY Bias	$0 \pm 1.3\%$	0.2%	12.6%
AmBe Bkg Scaling	0.8 ± 0.2	18.4%	–
AmBe Pile-up Est.	0.28 ± 0.09 events	21.9%	–
MV Cut Efficiency	$99.6\%^{+0.4\%}_{-1.0\%}$	$^{+14\%}_{-4.4\%}$	–
^{8}B solar ν_e flux	$(5.2\pm0.2)\times10^{6}$ cm^{-2} s^{-1}	–	3.9%
hep solar ν_e flux	$(0.8\pm0.2)\times10^{4}$ cm^{-2} s^{-1}	–	0.4%
Expected $\langle\sigma_{\mathrm{model}}\rangle$	$(1.67\pm0.05)\times10^{-41}$ cm^{2}	–	3.0%
Total	–	$^{+33\%}_{-31\%}$	18%

Cosmogenic Background

Note: a reflective Tyvek liner was added after this picture was taken.

Water tank:

7m diameter

7m high

Cosmogenic backgrounds are sub-dominant

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Total Background	$0.48\ {}^{+0.16}_{-0.15}$

The uncertainty comes mostly from the muon veto tagging efficiency

Three systematics most affect muon veto capability

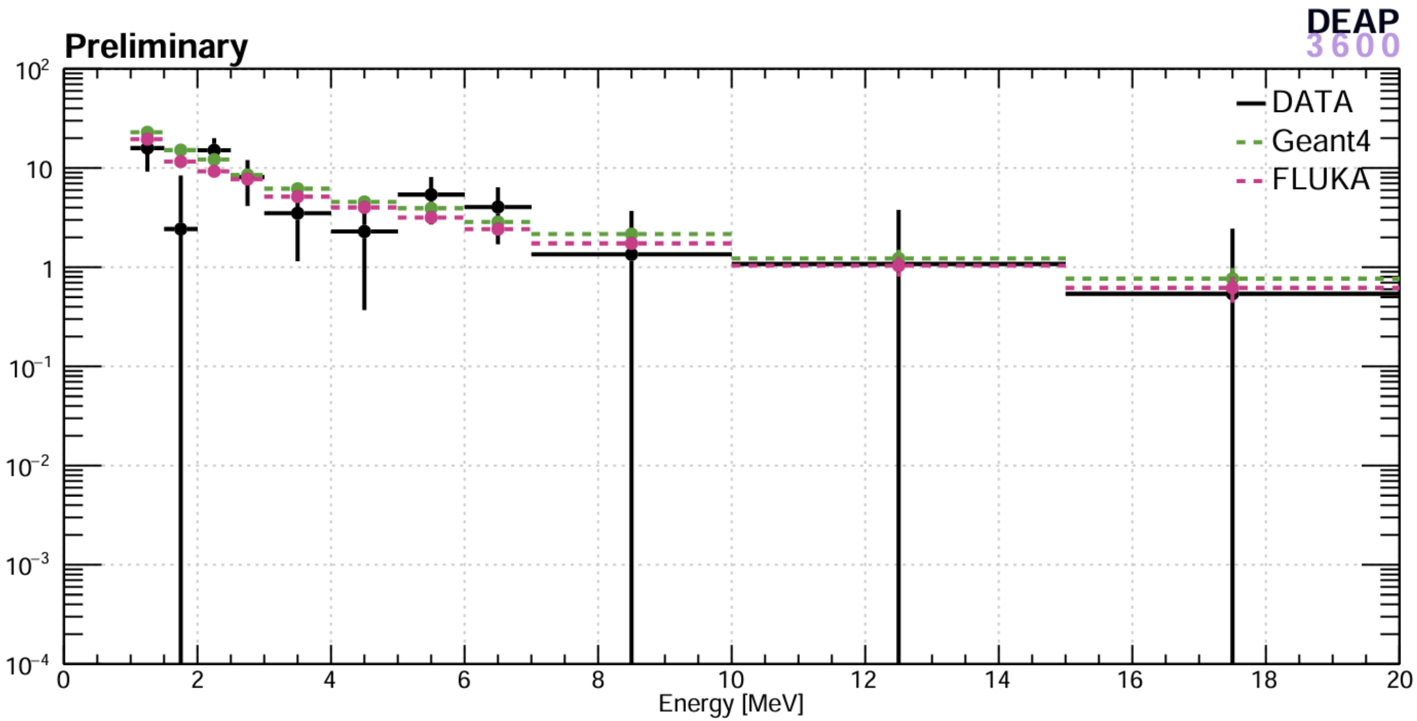
1. Reflectivity of the Tyvek liner.
2. Quantum Efficiency x Collection Efficiency of Hamamatsu R1477 PMTs
3. Water absorption length (smaller systematic effect because the water tank is 7m.)

Geant4 simulations with detailed optical modeling explored the tagging efficiency with these three parameters varied by **±30%**.

→ Results converted to a possible # of events

Energy spectrum of data in time with muon veto matches Fluka and Geant4 predictions for rate and shape

Events / bin / year



0 MeV 10 MeV 20 MeV

From the dissertation of Andrew Erlandson, Carleton University, 2024
https://carleton.scholaris.ca/items/7b3a8fd6-e4a2-4694-a2af-26b0152c57ce

Instrumental effects are removed with small effect on signal acceptance

Event selection cut	Live time	ROI Events
Low-level cuts	817.9 d	12
Muon veto cut	814.7 d	12
Event selection cut	**Acceptance**	**ROI Events**
Neck veto cut	1.00	6
Reconstructed height cut	0.99	6
Event timing cut	0.98	6
Early pulse suppression cut	0.97	6
PMT charge distribution cut	0.97	6
Pile-up cut	0.95	6
Scintillation waveform cut	0.92	6

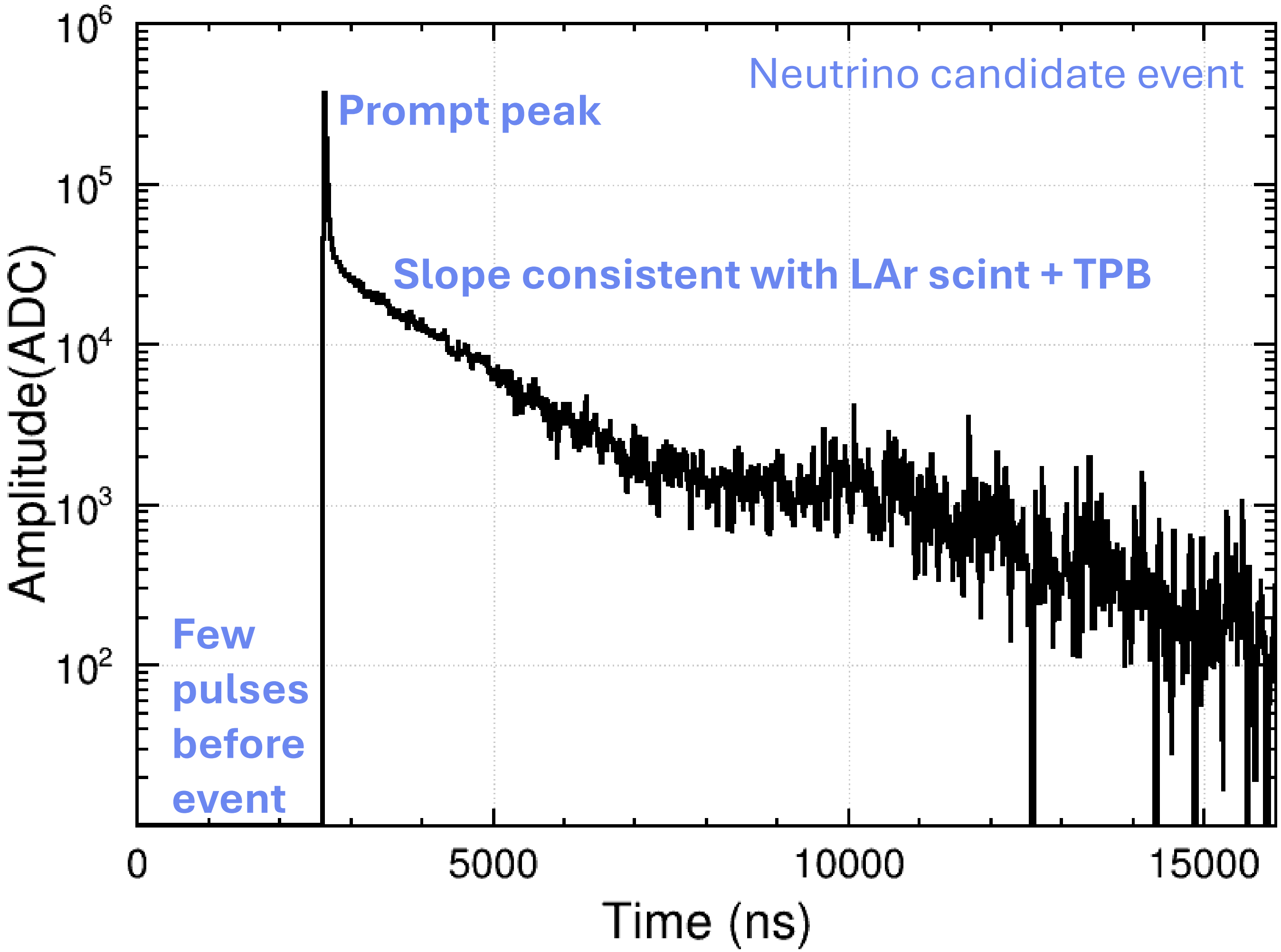
Light from the neck, above the liquid argon

Proper triggering

Too much charge concentrated in a single PMT

Scintillation Waveform Cut

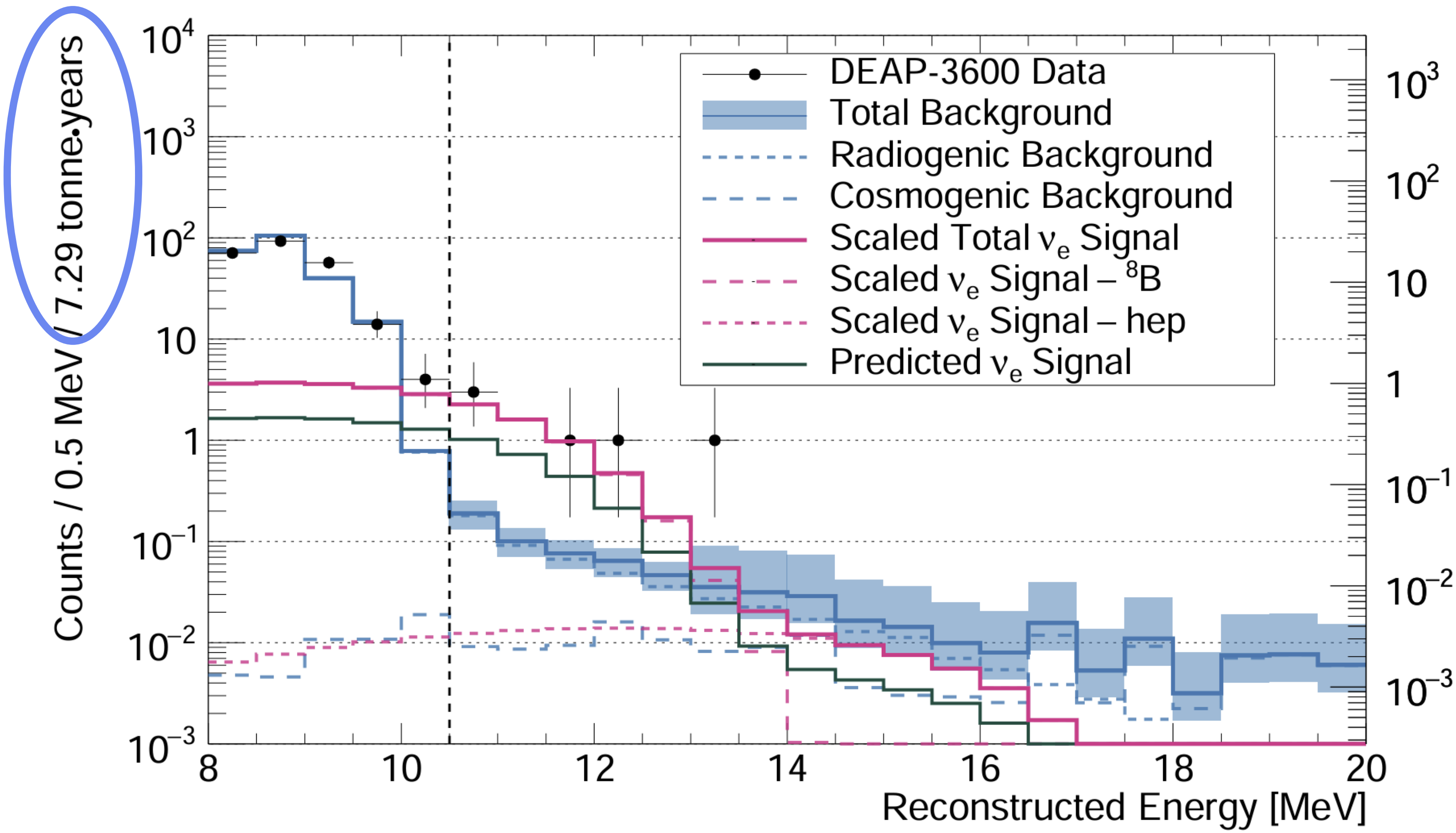
We insist upon a proper waveform



Waveform does not vary with energy except for non-linearities in the prompt peak.

Verified with gamma template using events in the 9.7 MeV n capture peak.

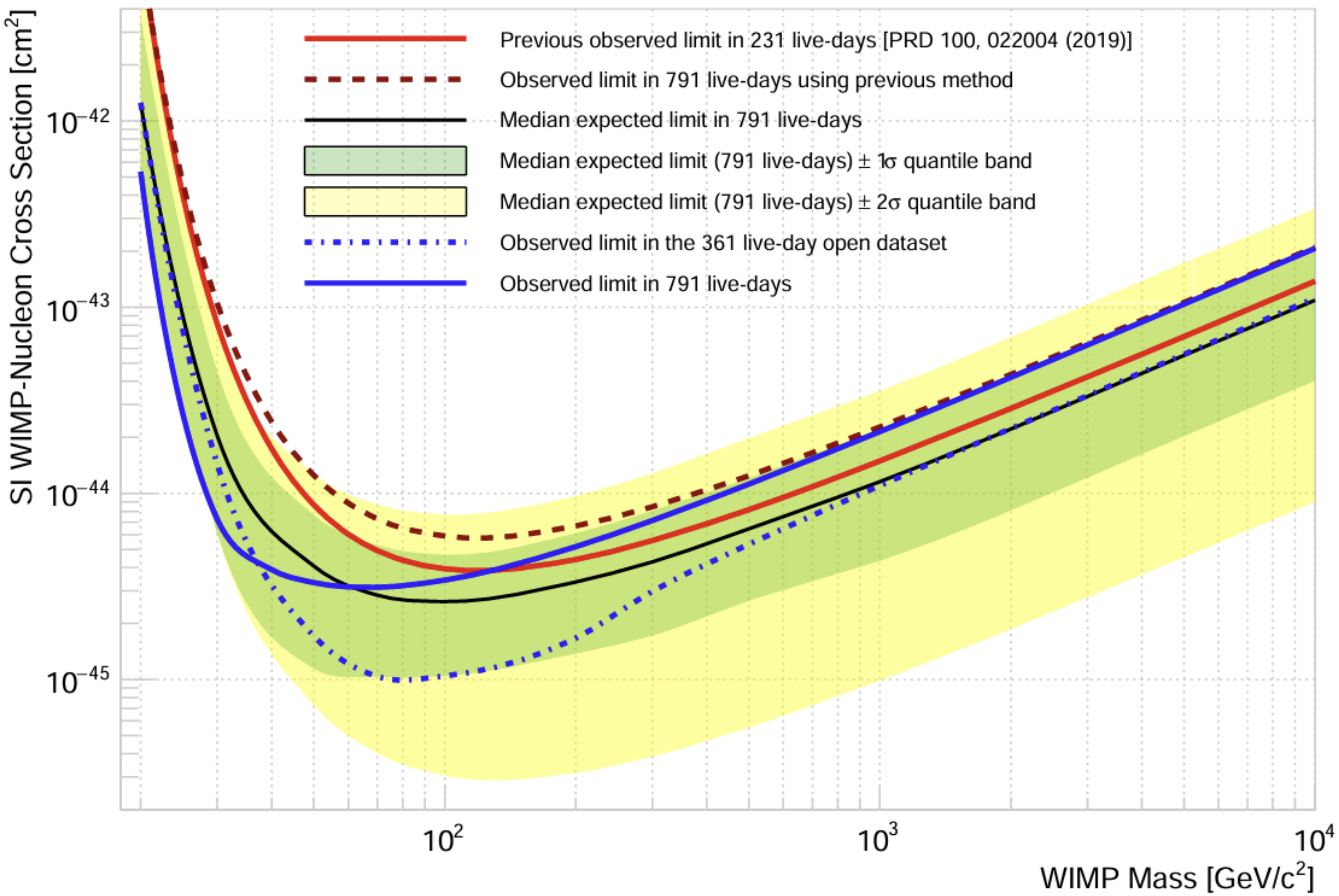
We measured 6 candidate Boron-8 solar neutrino charged-current events with a background expectation of 0.48 +0.16 -0.15



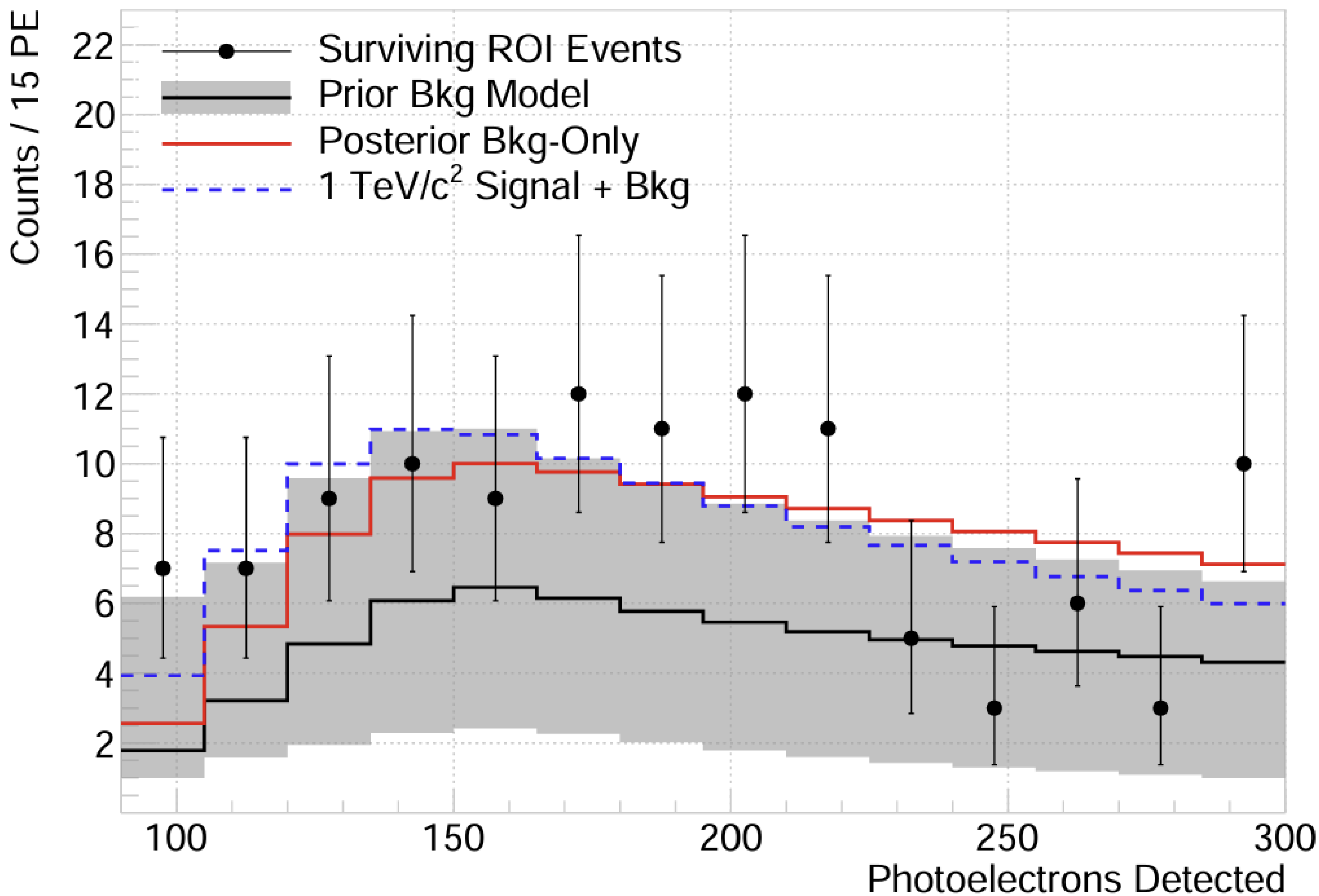
Dark Matter

Profile Likelihood Analysis

https://arxiv.org/abs/2603.13965



We are limited by backgrounds



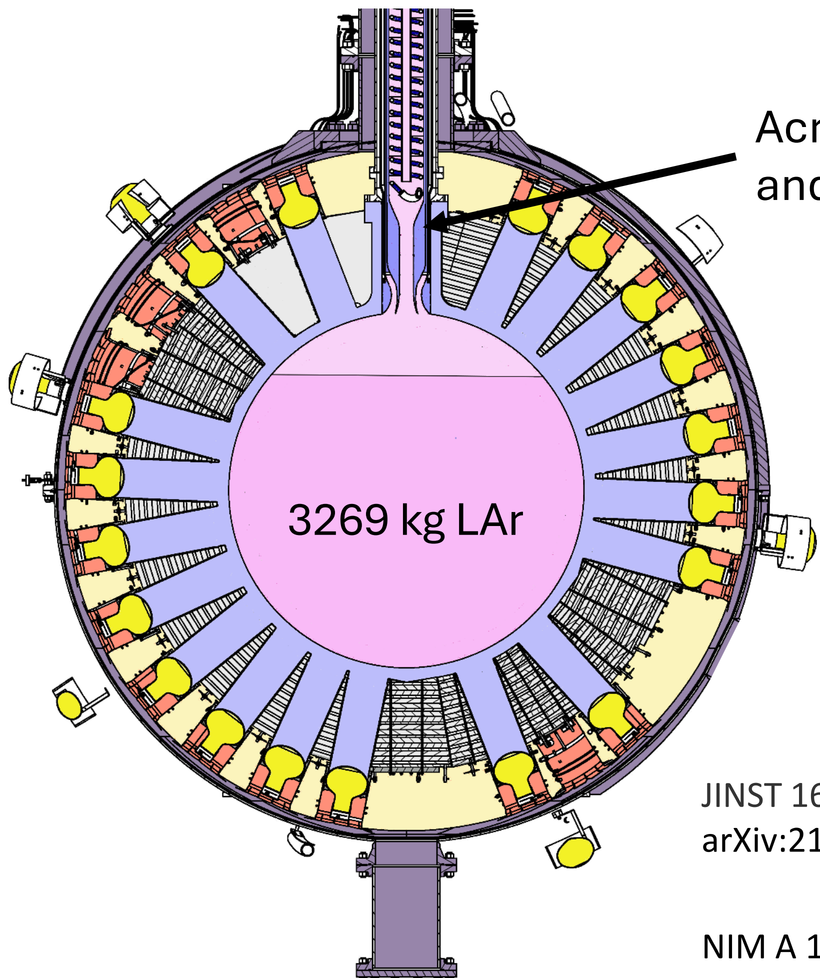
DUST and shadowed alphas dominate backgrounds

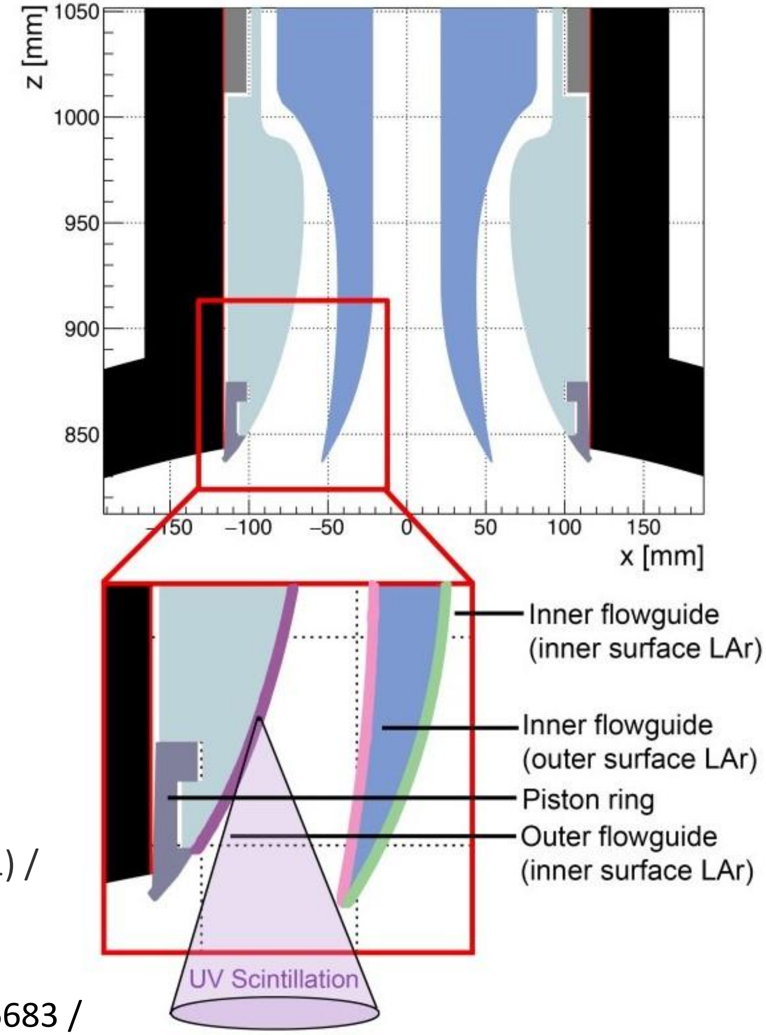
TABLE II. Summary table of the expected number of ROI events from each source in the prior background model, the posterior model in the background-only hypothesis, and the posterior model in the signal+background hypothesis with $M_\chi = 1$ TeV/c^2, $\sigma_\chi = 1.3 \times 10^{-44}$ cm^2. Shown are the systematic uncertainties. In data, 115 events are observed in the ROI.

Source	**Prior**	**Best-fit (bkg-only)**	**Best-fit (sig+bkg)**
Radiogenic n	$1.2^{+1.0}_{-1.0}$	$1.2^{+0.9}_{-0.9}$	$1.2^{+0.9}_{-0.9}$
Surface α	$7.4^{+15.2}_{-15.4}$	$0.0^{+3.1}_{-3.1}$	$0.0^{+1.8}_{-1.8}$
Shadowed α	$15.2^{+12.3}_{-10.3}$	$18.3^{+8.9}_{-7.4}$	$16.5^{+8.2}_{-6.9}$
Dust α	$44.2^{+39.9}_{-40.4}$	$91.6^{+10.6}_{-11.9}$	$64.1^{+15.9}_{-16.2}$
Total Bkg	$68.0^{+49.9}_{-45.2}$	$111.1^{+16.3}_{-15.2}$	$81.7^{+20.3}_{-18.0}$
$M_\chi = 1$ TeV/c^2	–	–	$32.0^{+23.9}_{-22.4}$

Hardware Upgrades

Change behaviour of shadowed alphas: New pyrene coated flow guides installed

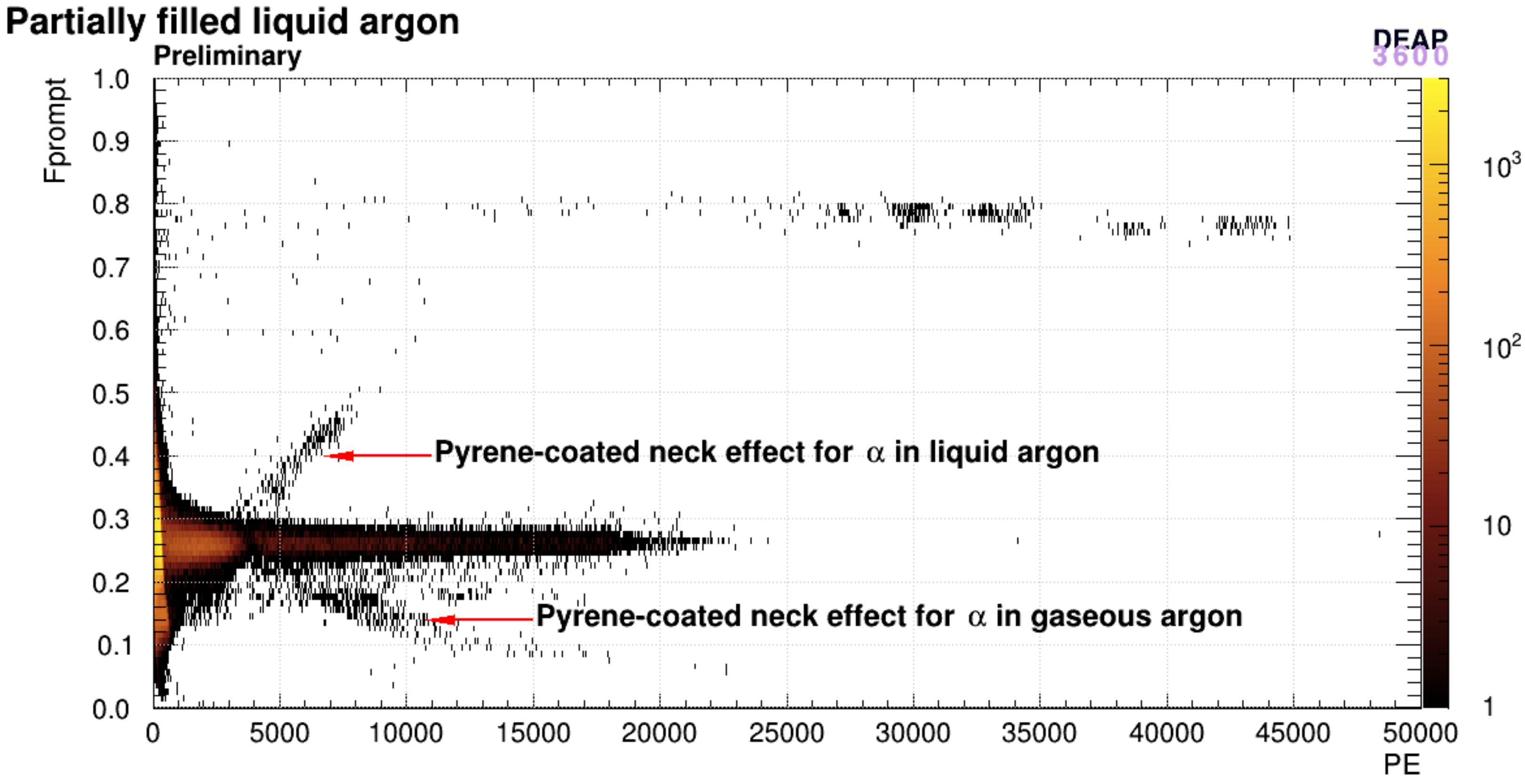




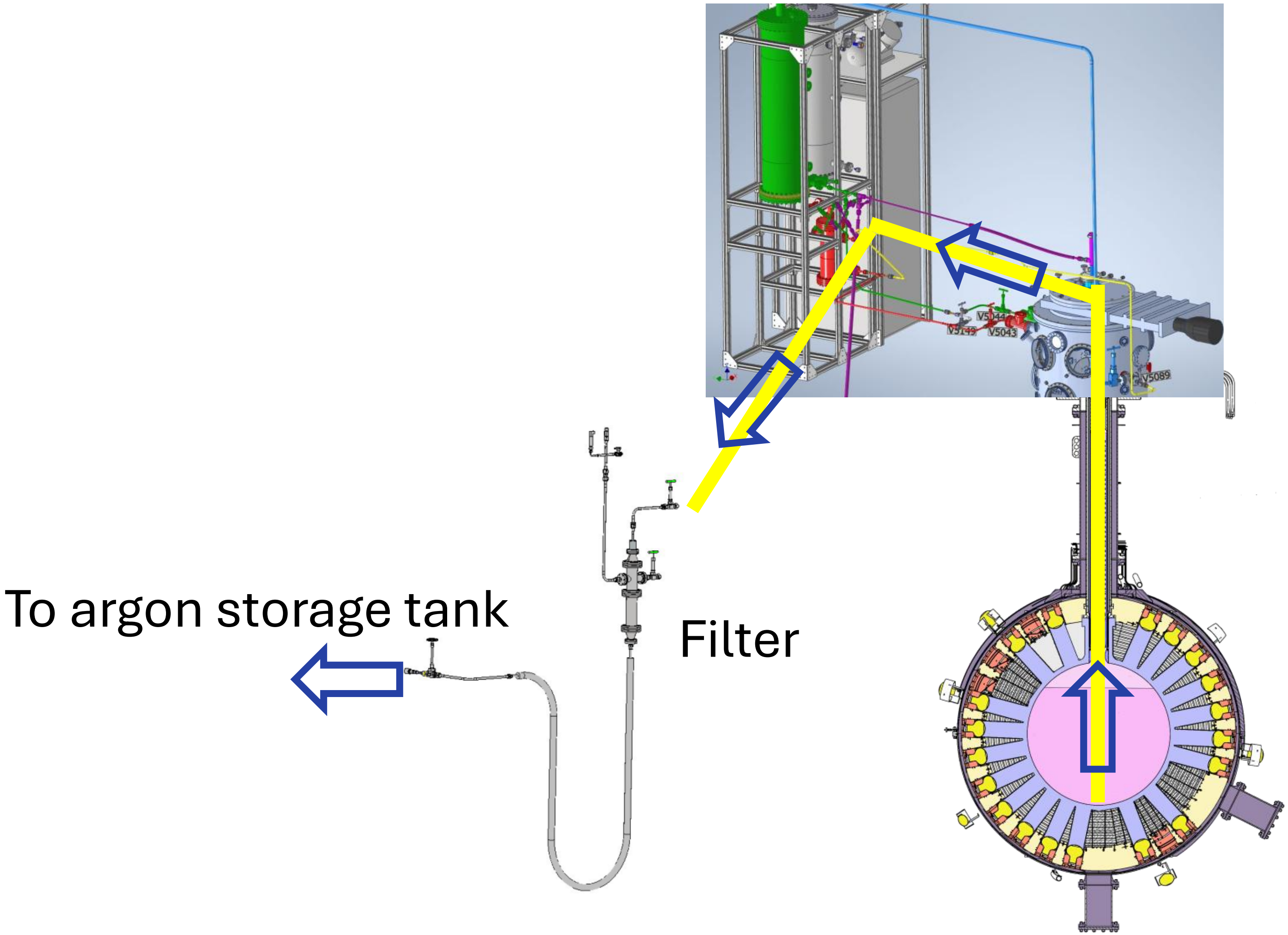
JINST 16, P12029 (2021) /
arXiv:2110.08103

NIM A 1034 (2022) 166683 /
arXiv:2109.06819

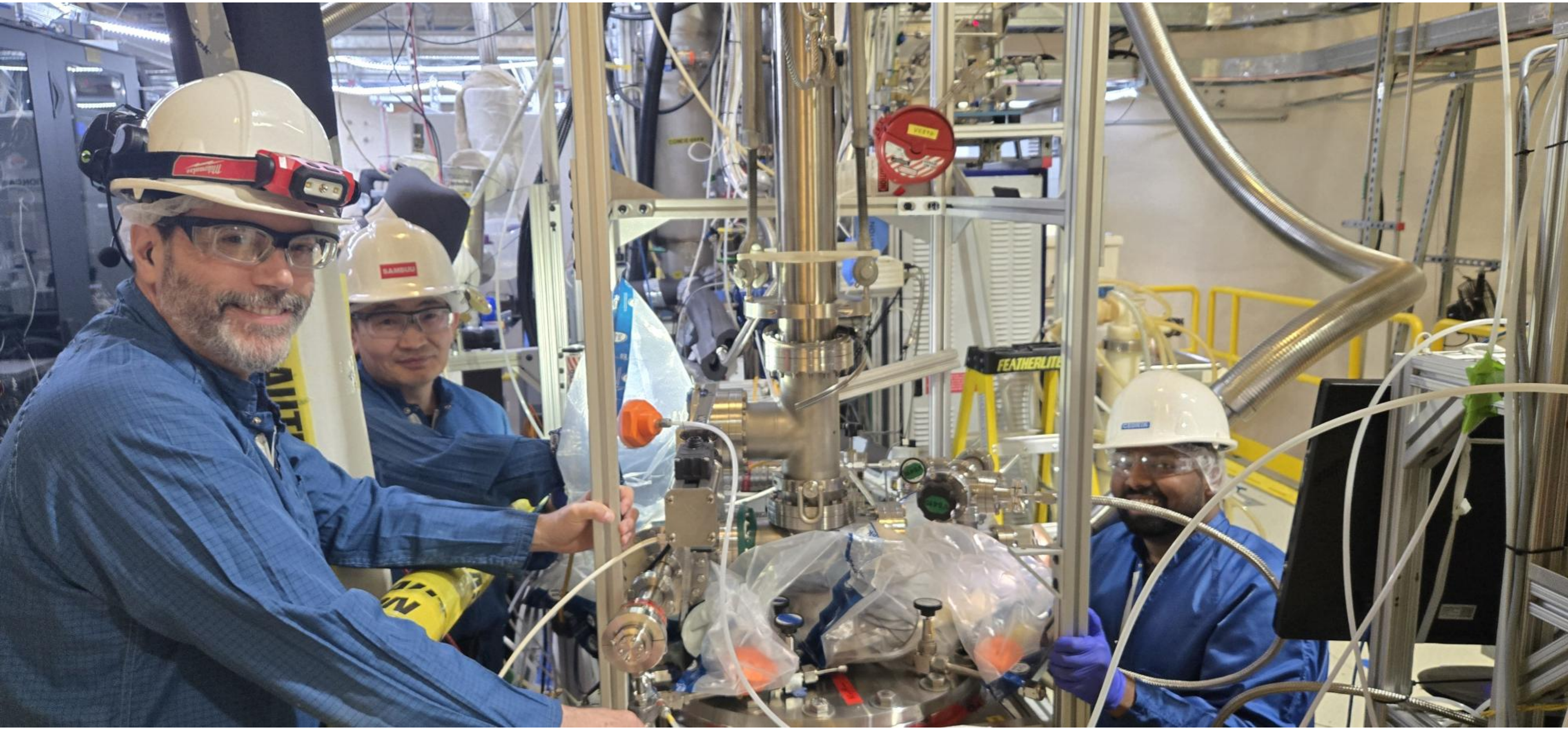
Preliminary data show effects of pyrene



Remove dust with a liquid removal pipe



The dust pipe is installed and ready



Next

- Run the dust filtration
- Take low-background data for dark matter
- Improve statistics for neutrino analysis

Thank you