

DEAP-3600 hardware upgrade and ^8B charged-current solar neutrino measurements

Abhijit Garai on behalf of DEAP-3600 collaboration

June 10, 2025

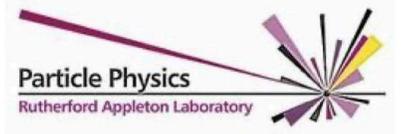
CIPANP 2025, Madison, Wisconsin



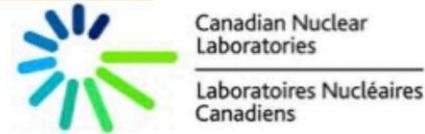
Arthur B. McDonald
Canadian Astroparticle Physics Research Institute



DEAP-3600: Hardware upgrade



DEAP-3600 collaboration

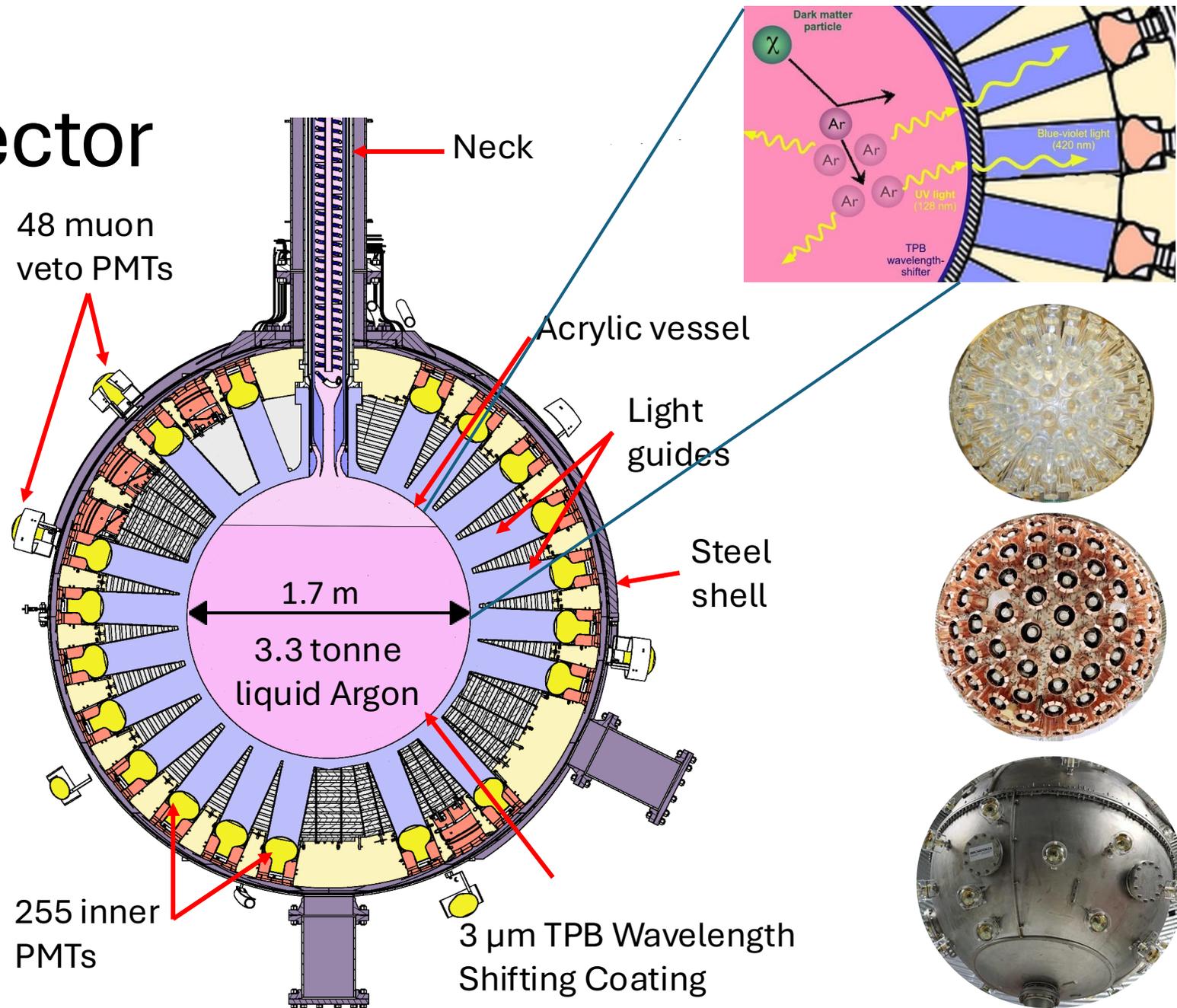


~100 researchers in Canada, Germany, Italy, Mexico, Poland, Russia, Spain, UK, USA

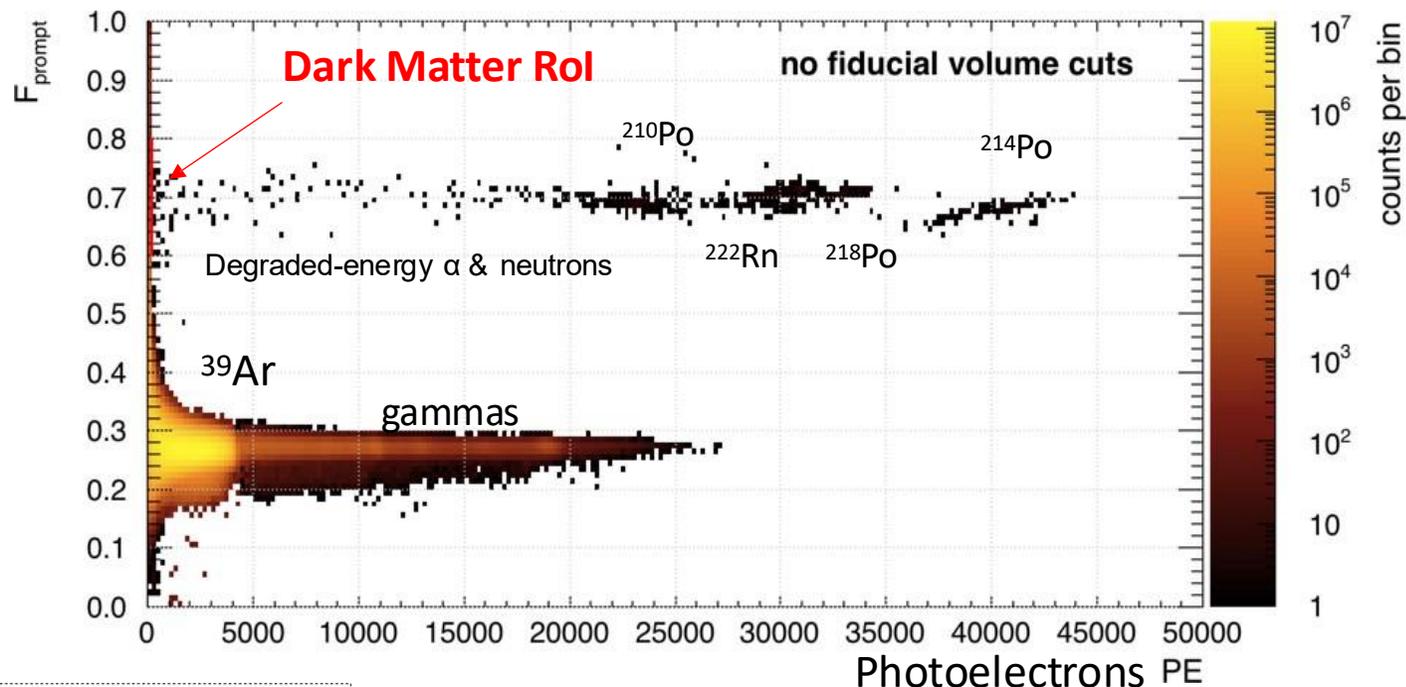
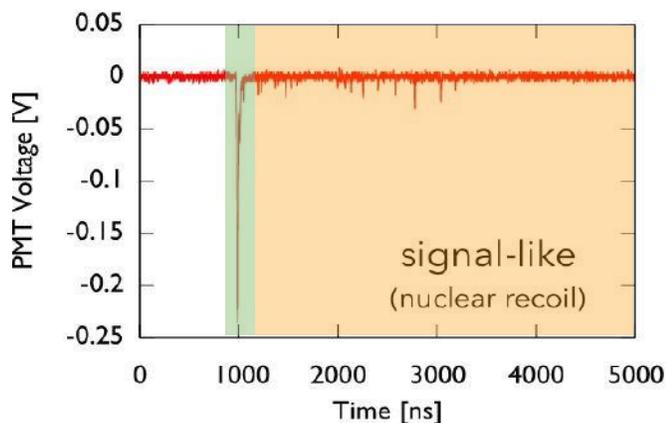
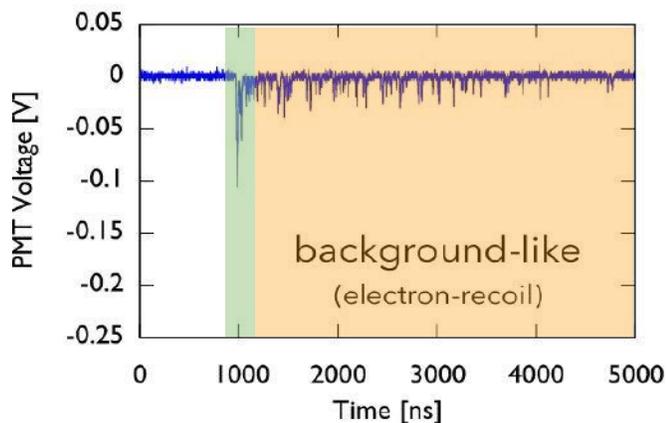
DEAP-3600 detector

Dark matter Experiment using Argon
Pulseshape discrimination

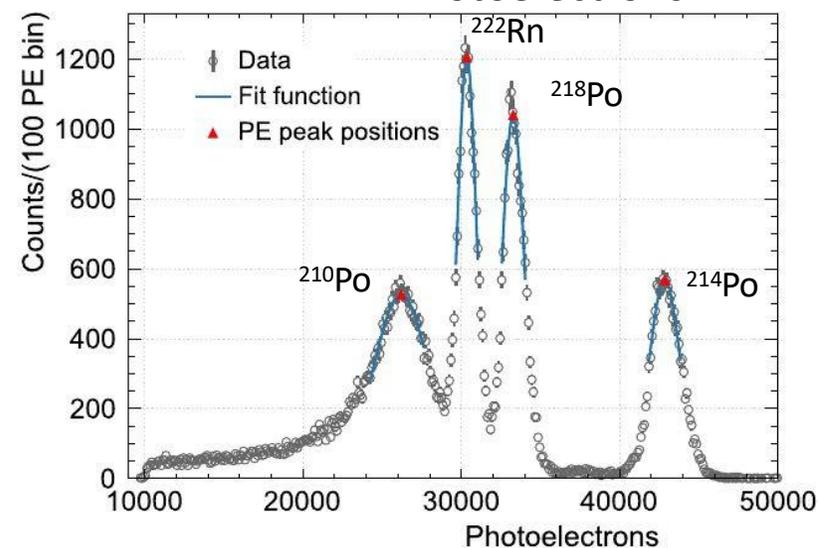
- Located ~2 km underground at SNOLAB. ~ 0.27 muons/m² per day
- Single phase liquid scintillator detector with 3.3 tonne of liquid Ar
- 255 Hamamatsu PMTs
- Water veto with 48 PMTs
- Pulse shape discrimination for background rejection
- Strongest limit on WIMP-nucleon cross-section on Ar in 2019 + ... -> **Daniel Huff's talk**



Degraded-energy alpha background



$$F_{\text{prompt}} = \frac{\sum_{t=-28 \text{ ns}}^{60 \text{ ns}} \text{PE}(t)}{\sum_{t=-28 \text{ ns}}^{10 \text{ }\mu\text{s}} \text{PE}(t)}$$



^{39}Ar leakage probability $< 10^{-8}$

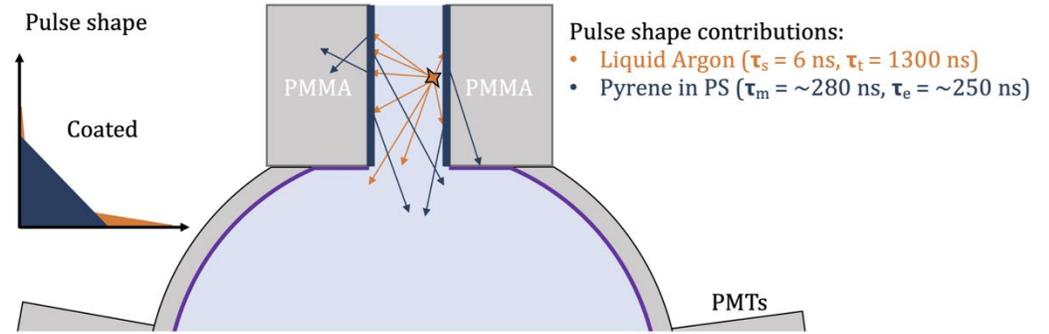
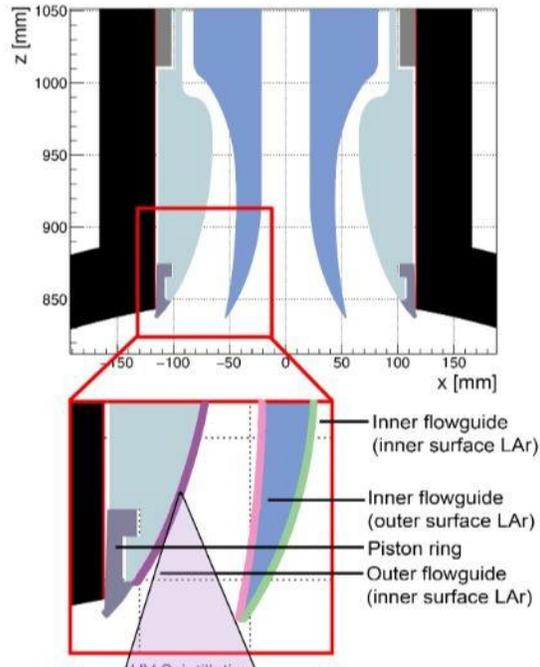
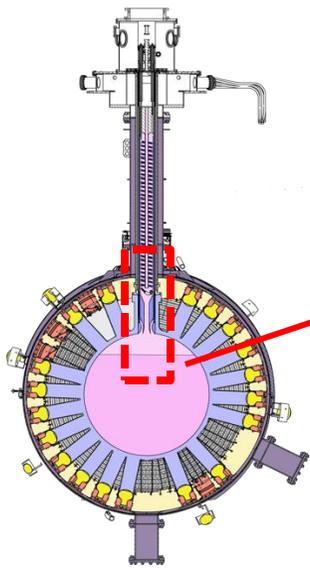
European Physical Journal C, 81, 823 (2021) [arXiv:2103.12202](https://arxiv.org/abs/2103.12202)

- Background in nuclear recoils band, in particular **degraded-energy α**

Pulse-Shape Model: European Physical Journal C, 80, 303 (2020)

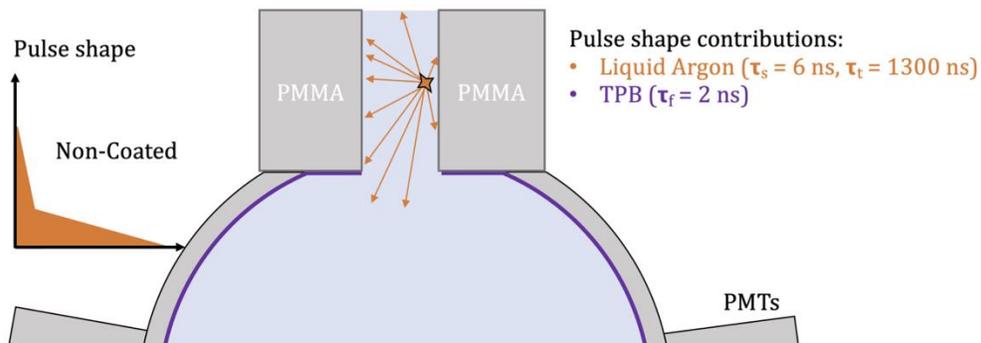
[arXiv:2001.09855](https://arxiv.org/abs/2001.09855)

Neck alpha



- Pyrene-coated (**slow** wavelength shifter): Adjust the pulse shape of shadowed events coming from the neck region to make them distinguishable from WIMP search parameter space

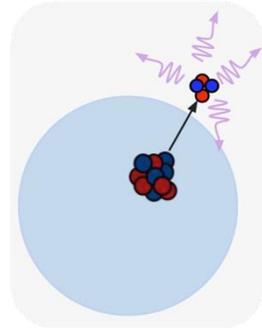
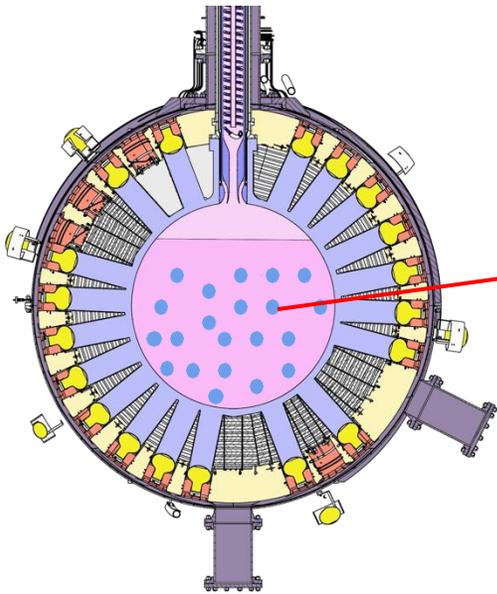
JINST 16, P12029 (2021) [arXiv:2110.08103](https://arxiv.org/abs/2110.08103)



Pyrene coated flow guide installed in the upgrade

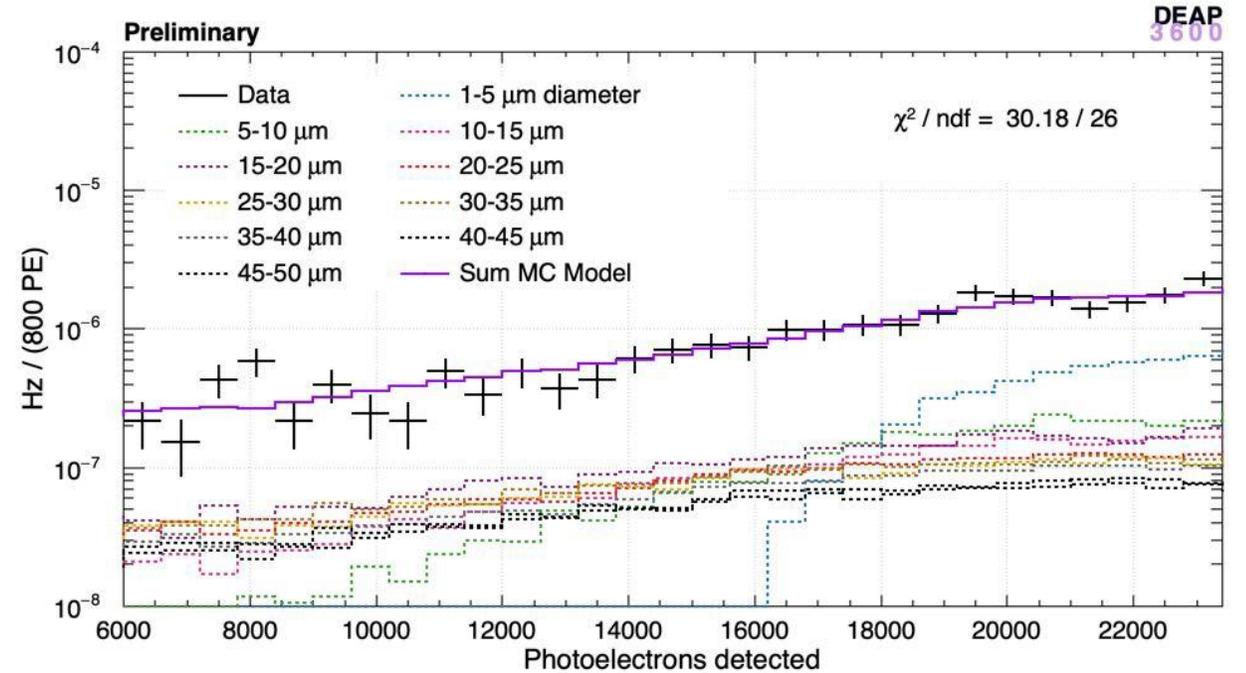
^{210}Po α -decays in the neck can result in shadowing of scintillation light
 -> **fraction of photons** are detected by the PMTs.

Dust alpha



dust particle

- **α -decays** from trace amount of **dust particulate** contamination within liquid argon.
 - Attenuation of energy and scintillation light shadowed by dust particulates itself
- > **Fewer scintillation photons.**



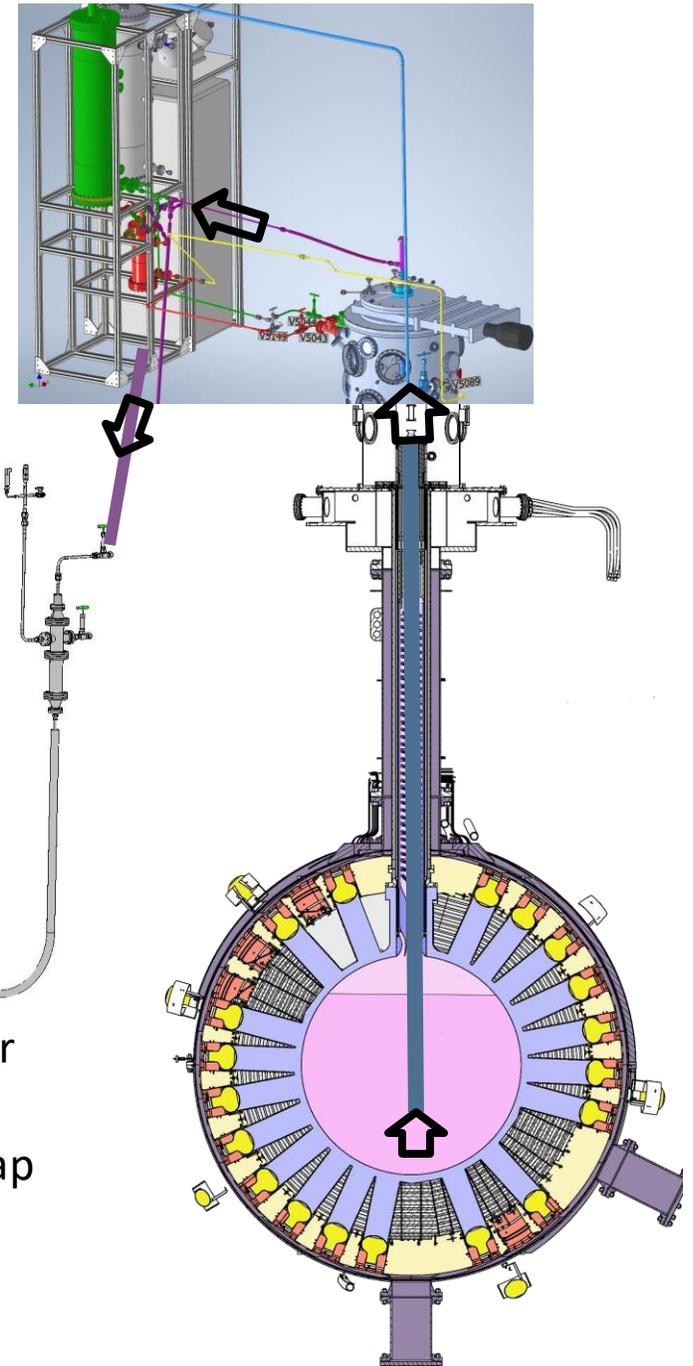
- Dust particles modeled with uniform distribution in the LAr with ^{210}Po contamination
- Different dust sizes are simulated and the size distribution is modelled by a power law
- Fit performed in photoelectron spectrum at higher (photo electrons) PE and extrapolated to lower energy region

Dust removal pipe

- Vacuum deployment system used to insert pipes through the existing neck/glove box
- Vessel cooled and then filled with ~500 kg of LAr
- Extract argon in a liquid state and ability to filter liquid argon through existing purification system
- Current Status:
 - Installed dust removal pipe
 - Cooling started
 - Liquid Ar filling to start next month
 - Physics data runs starts Oct/Nov 2025
 - End of data taking and starting of decommissioning : early 2027 -> ARGOLite start

To argon storage tank

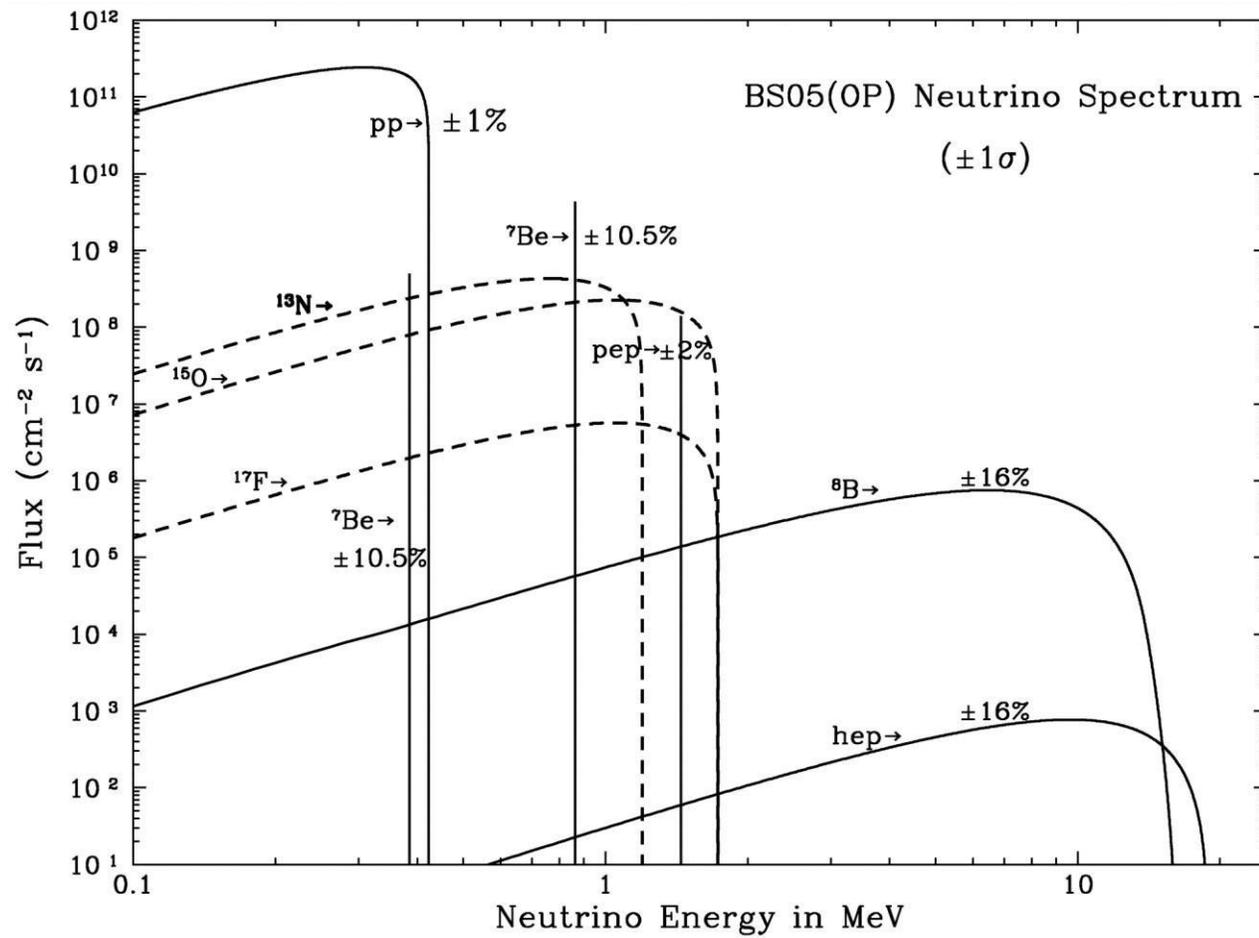
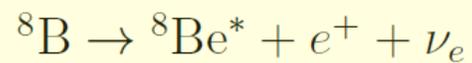
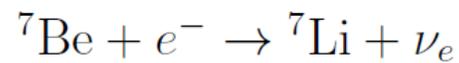
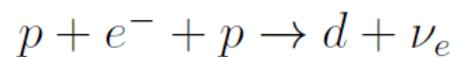
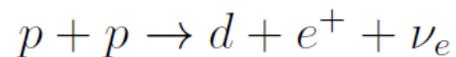
Filter
and
P-trap



^8B charged-current solar neutrino
measurements

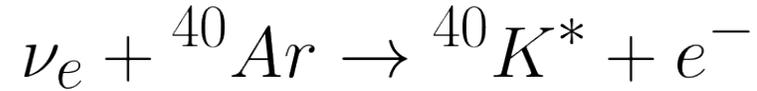
Solar Neutrinos

p-p chain

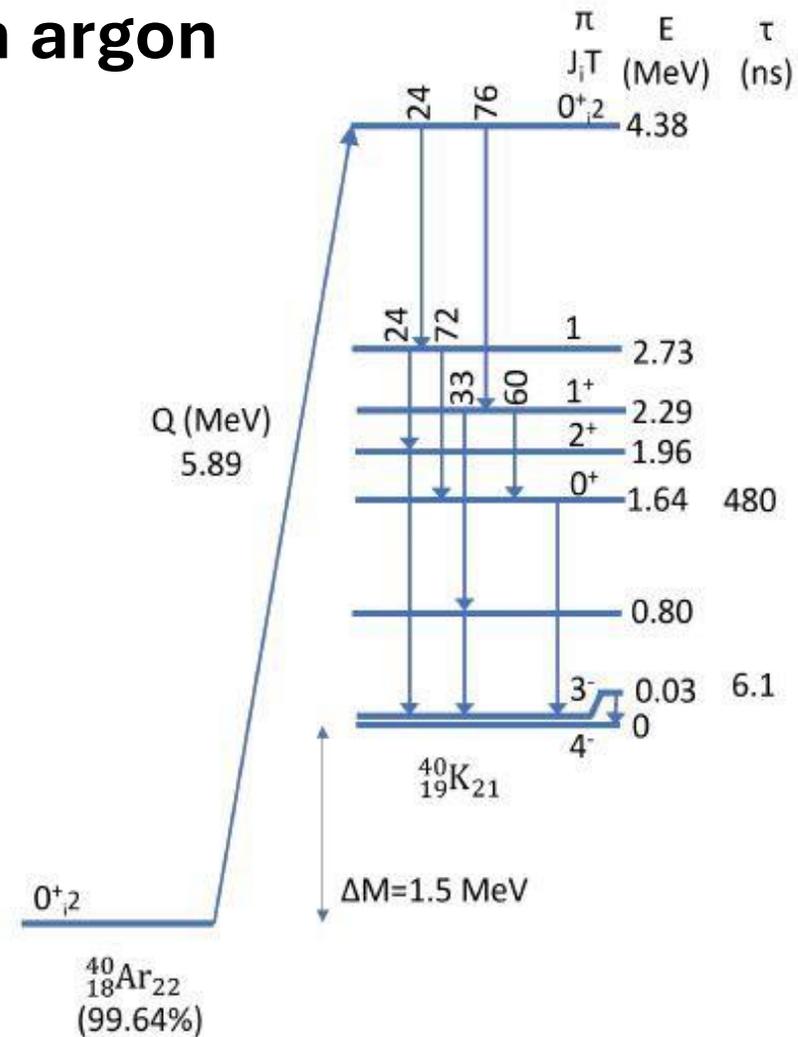
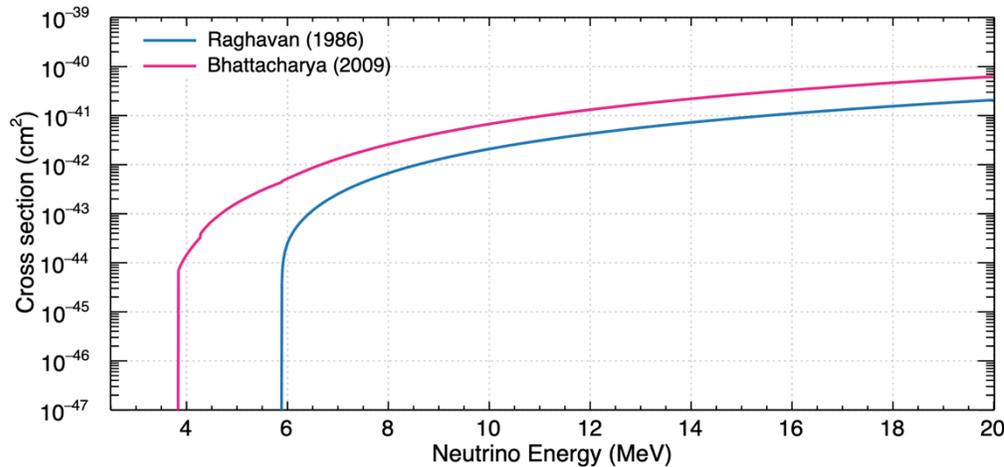


[38] J. N. Bahcall, A. M. Serenelli, and S. Basu. New Solar Opacities, Abundances, Helioseismology, and Neutrino Fluxes. *ApJL*, 621(1):L85–L88, 2005.

Neutrino charge-current interaction in argon



- First proposed by R. S. Raghavan (1986)
- Not yet observed
- Would be first observation of charged-current neutrino interactions in a dark matter detector
- **Fundamental process for future multi-tonnes liquid Argon dark matter and neutrino detectors!**



M. Bhattacharya et al. measured Gamow-Teller (GT) strengths for transitions from ${}^{40}\text{Ar}$ to ${}^{40}\text{K}^*$

- Energy threshold decreased from 5.885 MeV (Fermi) to 3.9 MeV (GT)

R. S. Raghavan Phys. Rev. D 34, 2088 (1986)

Bhattacharya, et al., Phys.Rev. C 80, 055501 (2009)

Expected Neutrino Signal

- Expected neutrino rate :

$$\Gamma = N_{nuclei} \int_{E_{min}}^{E_{max}} \frac{d\phi(E)}{dE} \sigma_{tot} dE$$

⁸B neutrino flux spectrum

Cross-section model

Number of ⁴⁰Ar nuclei in the detector

- Depends on detector mass, ⁴⁰Ar abundance

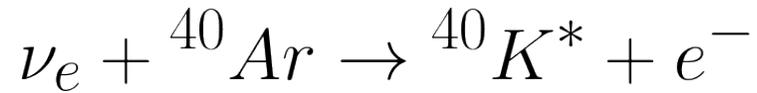
Expected neutrino rate :

$$\Gamma = (2.21 \pm 0.21_{sys.}) \text{ events}/(\text{tonne-year})$$

Total expected neutrinos :

$$N_{\nu,exp} = 16.1 \pm 1.5 \text{ events in 7.292 tonne-years}$$

Expected Signals



Single-Pulse Events

- De-excitation does not go through metastable state
- Event only has one pulse

$$E_{single} = E_e + \sum E_\gamma$$

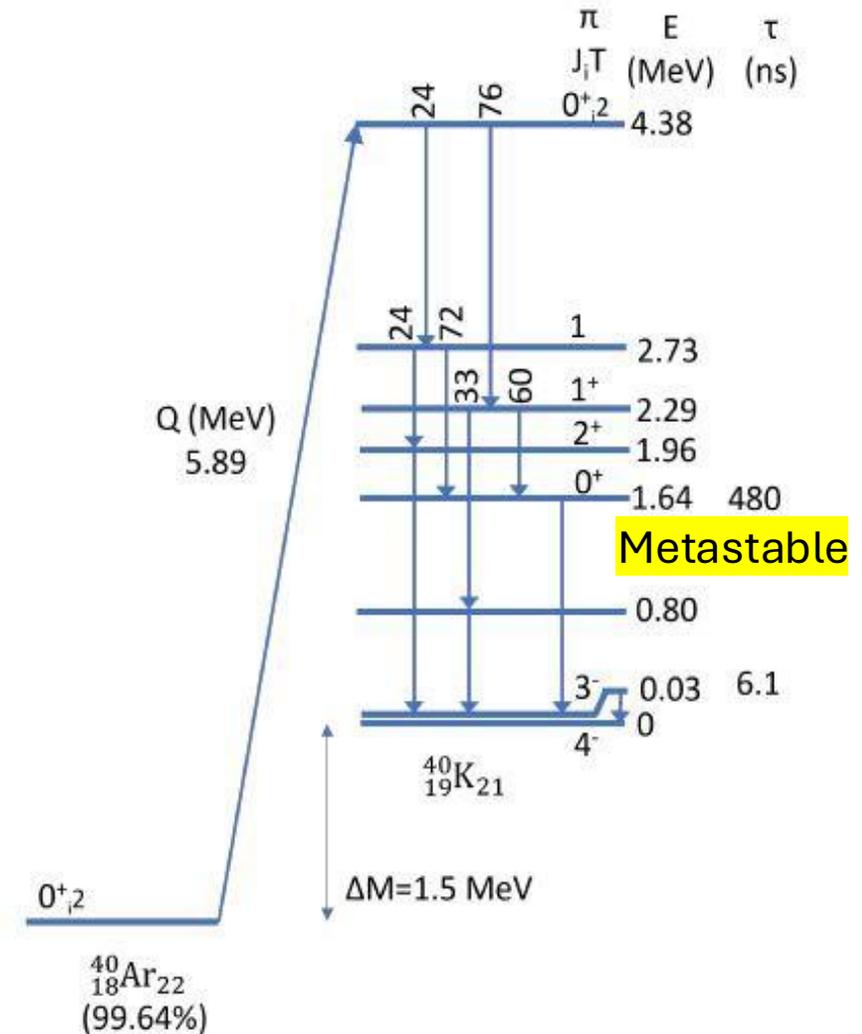
Delayed Coincidence Events

- De-excitation goes through the metastable state
- Event has two pulses

$$E_{prompt} = E_e + \sum E_{\gamma,1}$$

From excitation level to 1.64 MeV metastable state

$$E_{delayed} = \sum E_{\gamma,2} = 1.64 \text{ MeV}$$



65% of de-excitations through **metastable** state

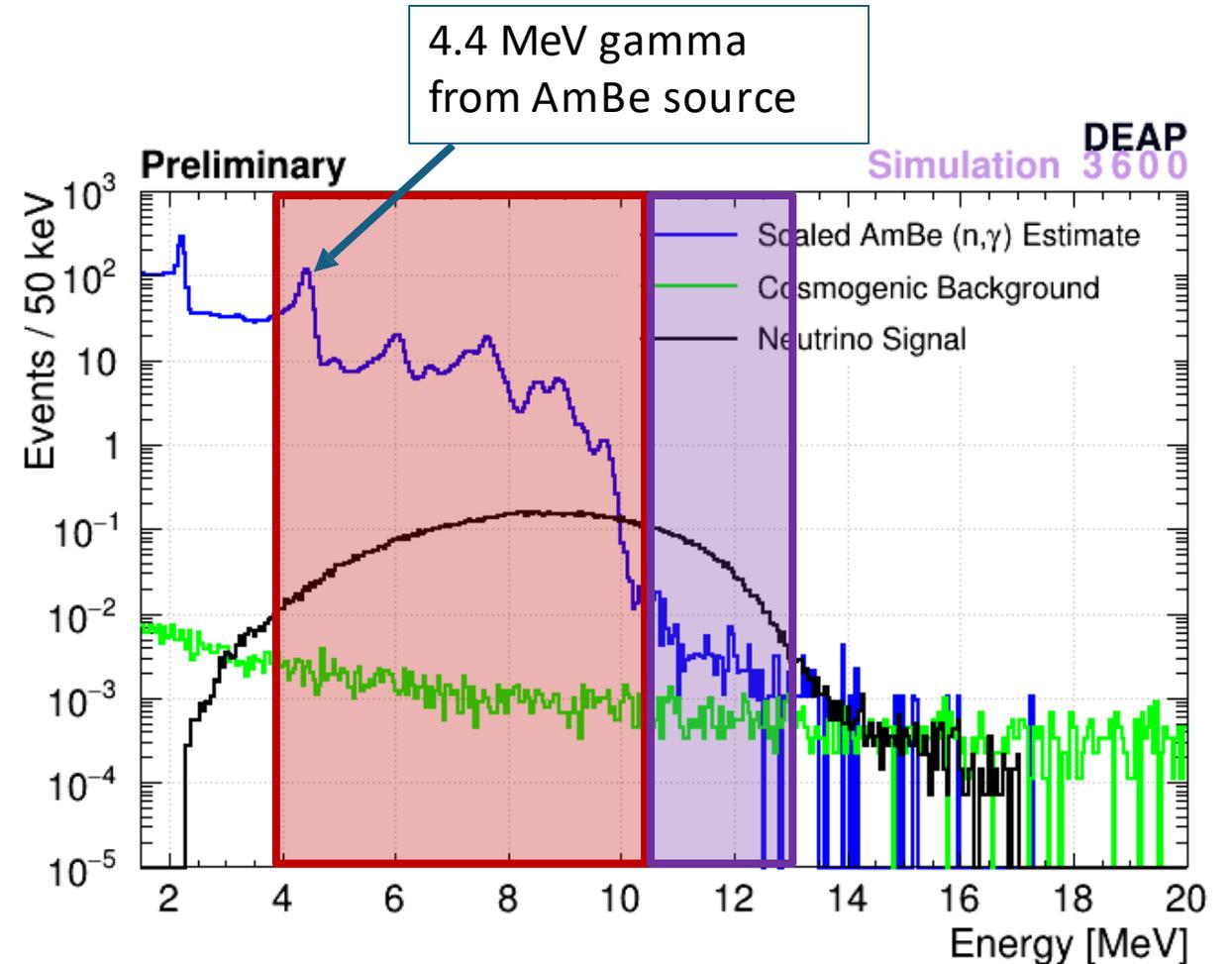
Search Regions

Delayed Coincidence

- Unique neutrino signature
- Neutrino signal \ll background

High-Energy Region

- Counting experiment
- Neutrino signal $>$ background
- Accurate background model

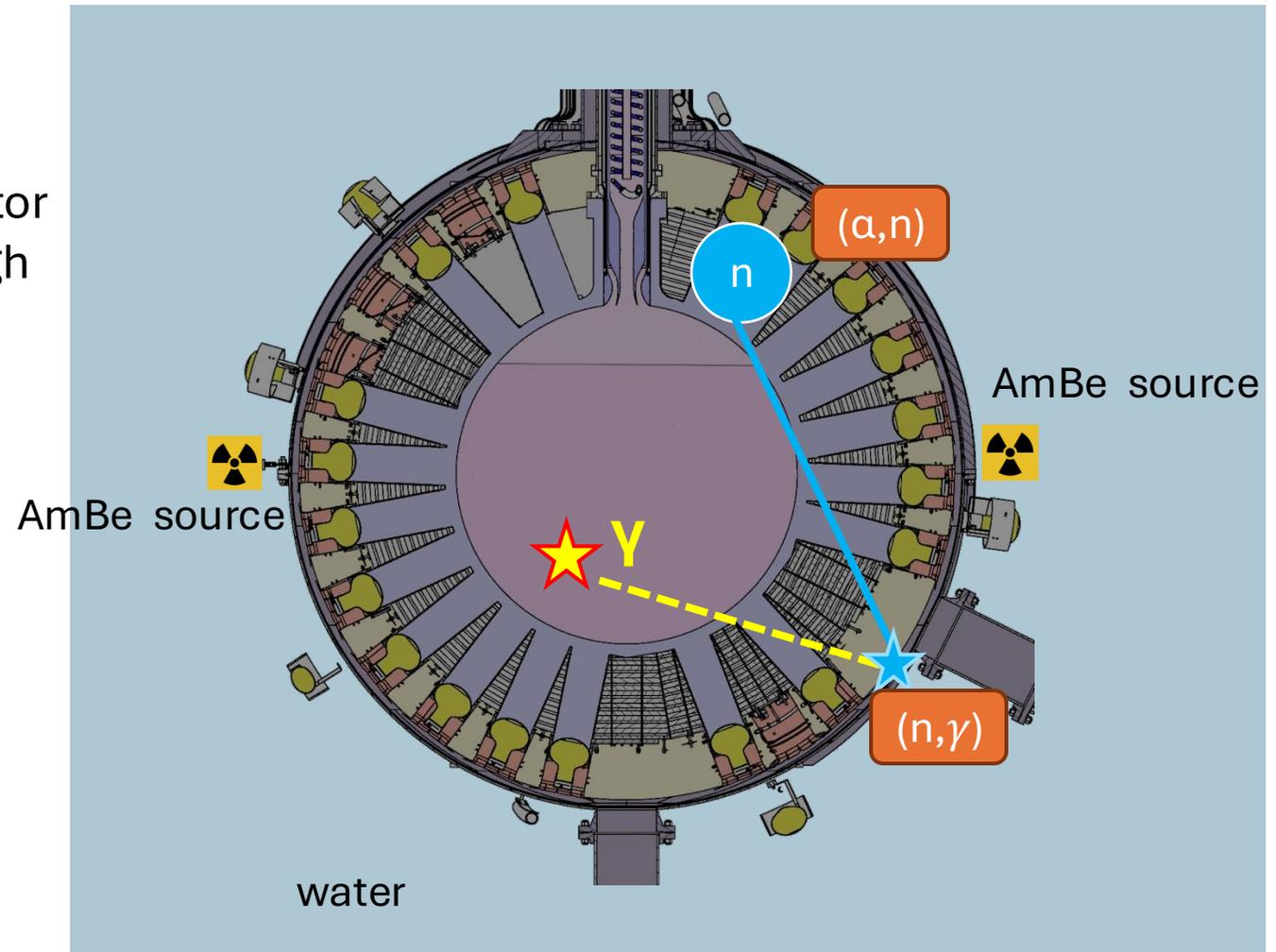


Backgrounds: Radiogenic neutrons

- Main source : ^{238}U decay in the PMT glass produces alphas
- Undergoes an (α, n) producing a neutron
- Neutron captured by material in the detector
- Neutron capture isotope de-excites through a series of gamma rays

Two independent approach

- **Fit Monte Carlo to the Data** in 5-10 MeV allowing scaling of different elements to float and extrapolate to the ROI
- **Scale the AmBe** source neutron spectra to a sideband (energy window below the ROI) in the physics dataset and calculate expected neutron background in the ROI



Backgrounds: Cosmogenics

- Cherenkov light in the water triggers veto PMTs
- Events in the LAr that are correlated with the muon veto triggers are vetoed
- Fraction of muons untagged due to finite veto-efficiency or secondaries

Two independent analysis

- Geant-4 based MC simulation
- FLUKA based MC simulation



Summary

8B solar neutrino cc interaction in argon

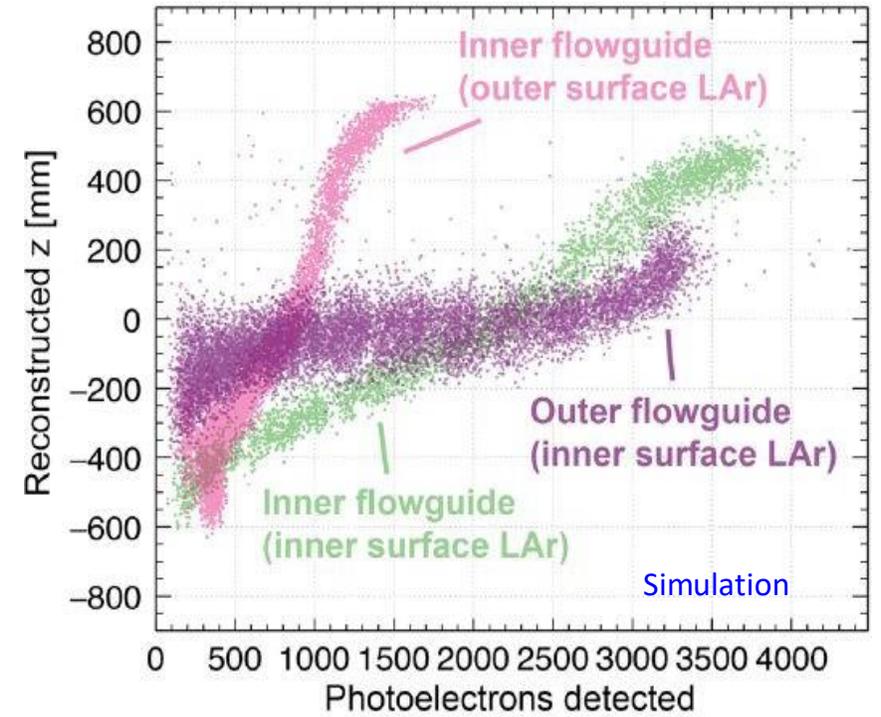
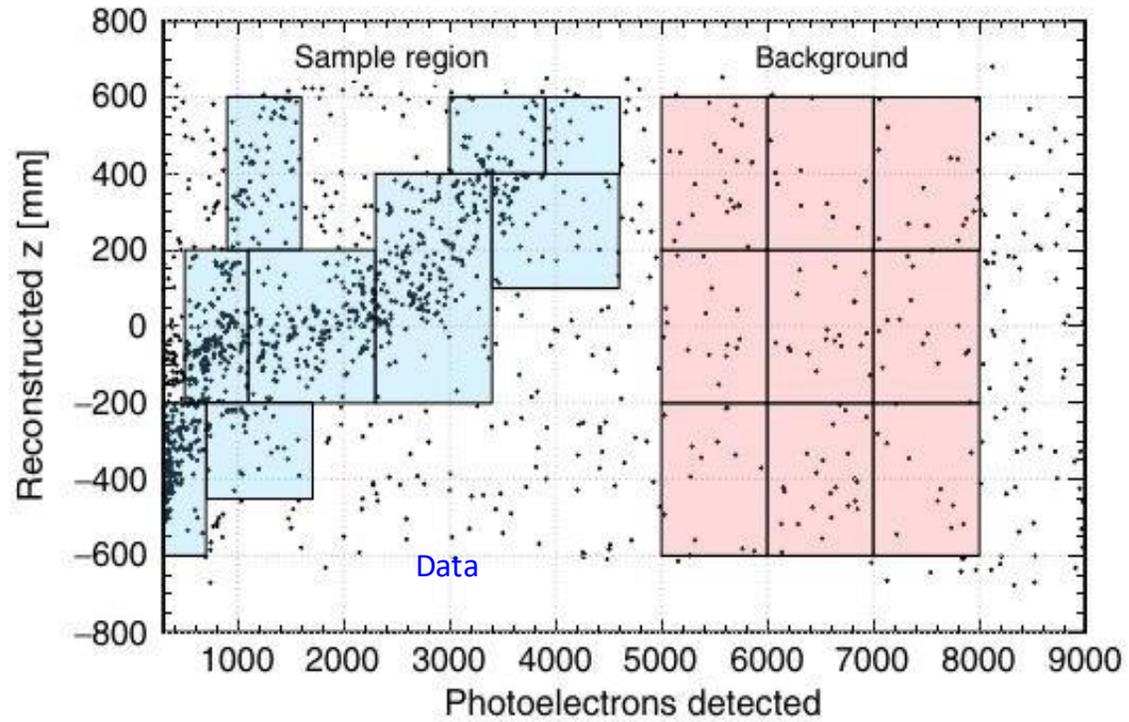
- Finalizing internal collaboration review on background estimates and systematic uncertainties
 - Fine-tuning MC model for radiogenic background and fit to the data
 - Systematics uncertainties on radiogenic background using source neutrons
 - Finalizing estimates on the cosmogenic background and uncertainties
- Manuscript under preparation

DEAP hardware upgrade

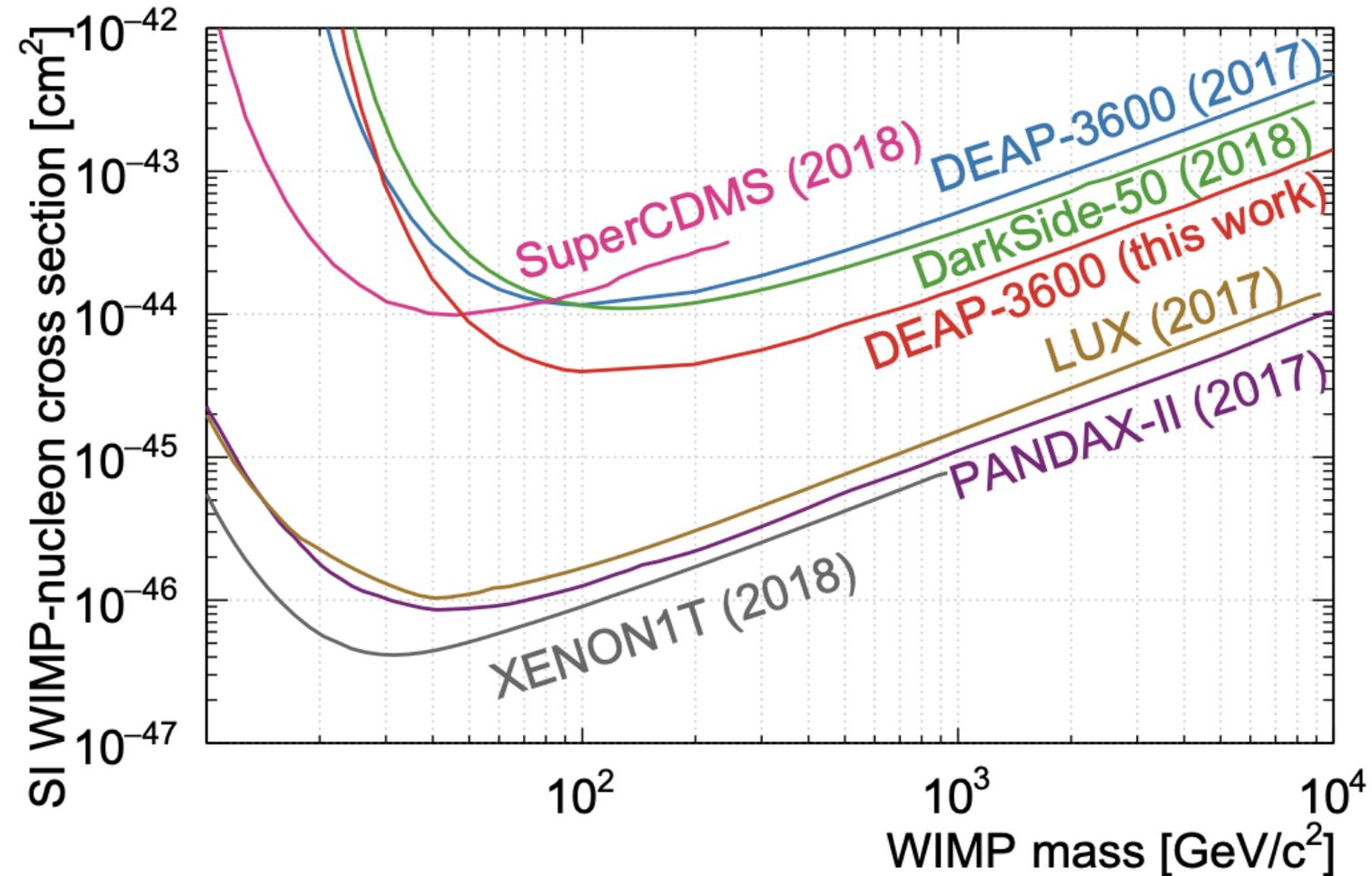
- DEAP-3600 finished installing upgrades
- Cooling and filling in progress, physics data runs starting in Fall 2025
- Will continue data taking until early 2027

Backup slides

Neck alpha simulation



DEAP-3600 cross-section limit



Sources of uncertainties

Energy scale

- Light yield correction

- Energy resolution

ROI bound on signal and background

Exposure

- Event rate

- Mass

- Live time

Cosmogenic

- Veto efficiency

Radiogenic

- AmBe source position and Energy spectrum

- Statistical uncertainty on the fitted normalization