Updates on the DEAP-3600 experiment and steps towards the ARGO experiment

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(on behalf of the Global Argon Dark Matter Collaboration and the DEAP Collaboration)

October 21, 2025

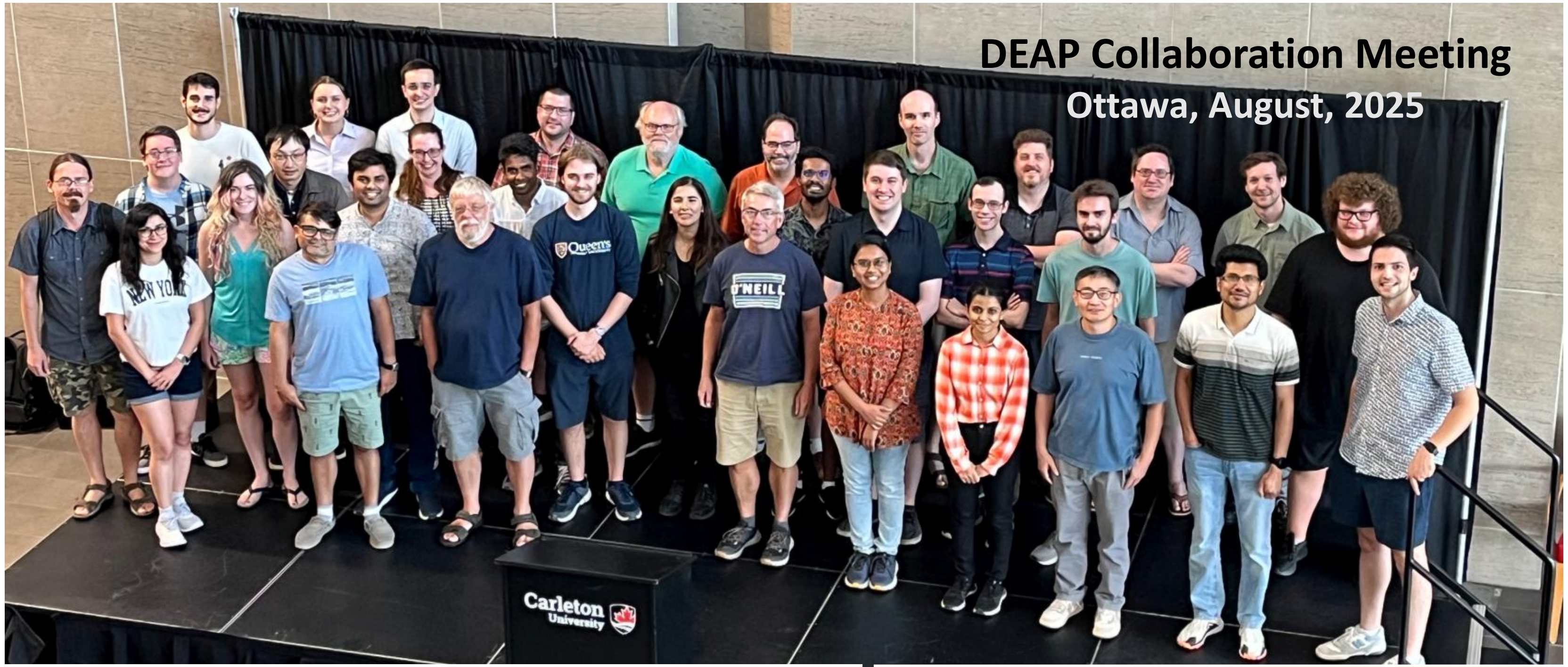
LIDINE 2025: LIght Detection In Noble Elements, Hong Kong, China, Oct. 21-24, 2025

Carleton University

Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

The DEAP Collaboration

Dark matter **E**xperiment using **A**rgon **P**ulseshape discrimination
Direct dark matter detection experiment utilizes single phase liquid argon (LAr) detector.
Operating in SNOLAB underground facility in Sudbury, Canada.



Particle Physics Rutherford Appleton Laboratory
SNOLAB
University of Sussex
Technical University of Munich
TRIUMF
Instituto de Física
PRINCETON UNIVERSITY
UNIVERSITY OF ALBERTA
ASTROCENT Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences
Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens
Carleton UNIVERSITY
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
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JOHANNES GUTENBERG UNIVERSITÄT MAINZ JG|U
LaurentianUniversity UniversitéLaurentienne
Queen's UNIVERSITY
ROYAL HOLLOWAY UNIVERSITY OF LONDON

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

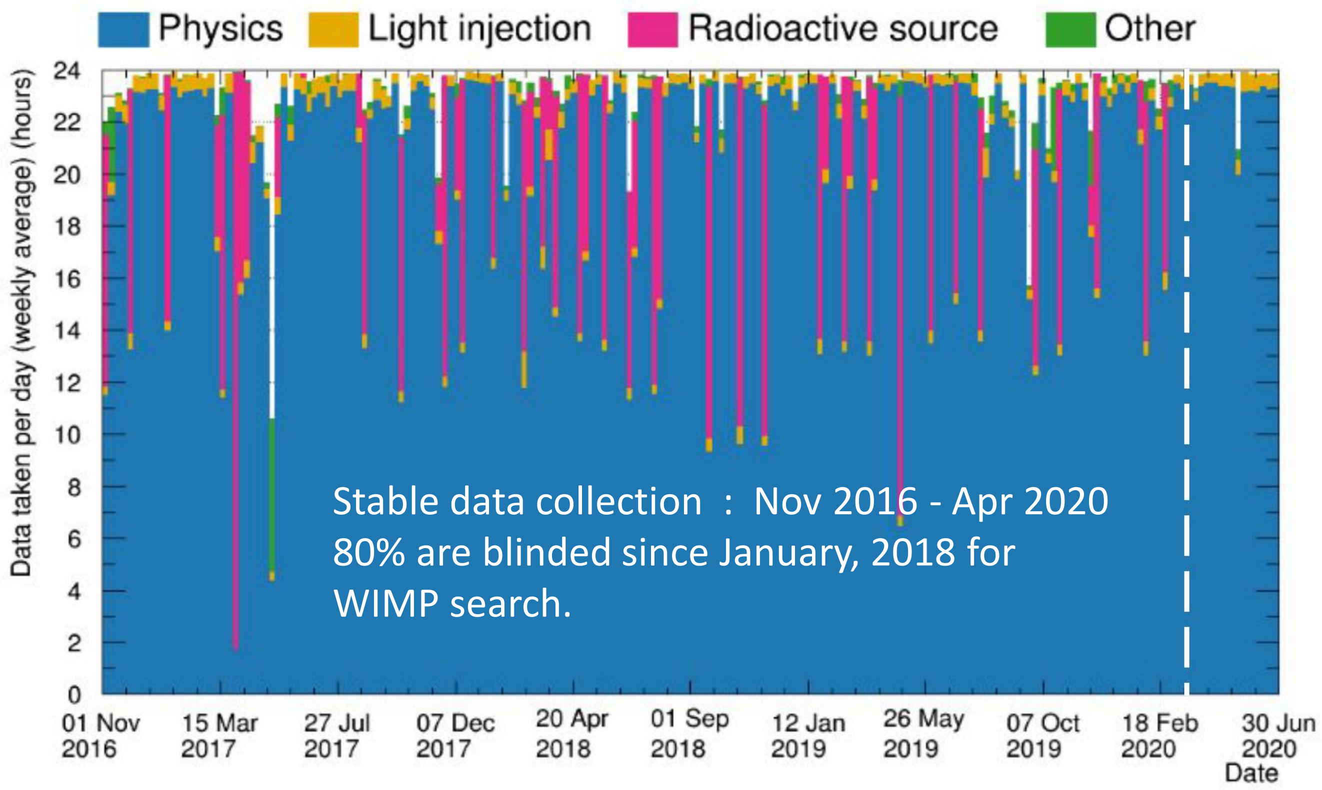
DEAP3600: Timeline and Scientific Program

Timeline

- Data collection: 2016-2020
- Detector upgrade: 2020 -2024 (completed)
- Detector Refilling : 2025 (completed)
- Final data collection: 2025 – 2026 (running)

Latest Results (2025)

- Relative measurement of alpha quenching
- Direct measurement of ^{39}Ar half-life
- Improved position-reconstruction algorithm

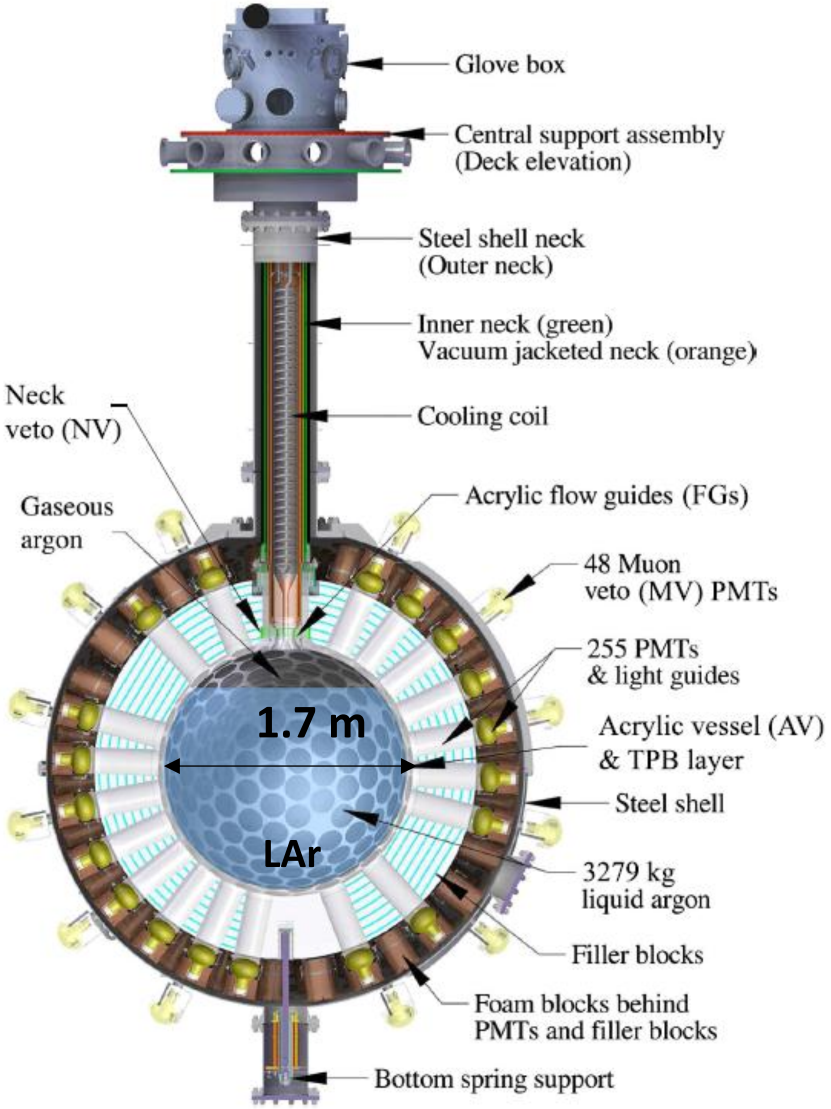


Ongoing analyses

- WIMP search using improved background model and Profile Likelihood Ratio analyses (813 live days exposure)
- Solar neutrino absorption in ^{40}Ar. (making first measurement)
- Muon flux measurement at SNOLAB.

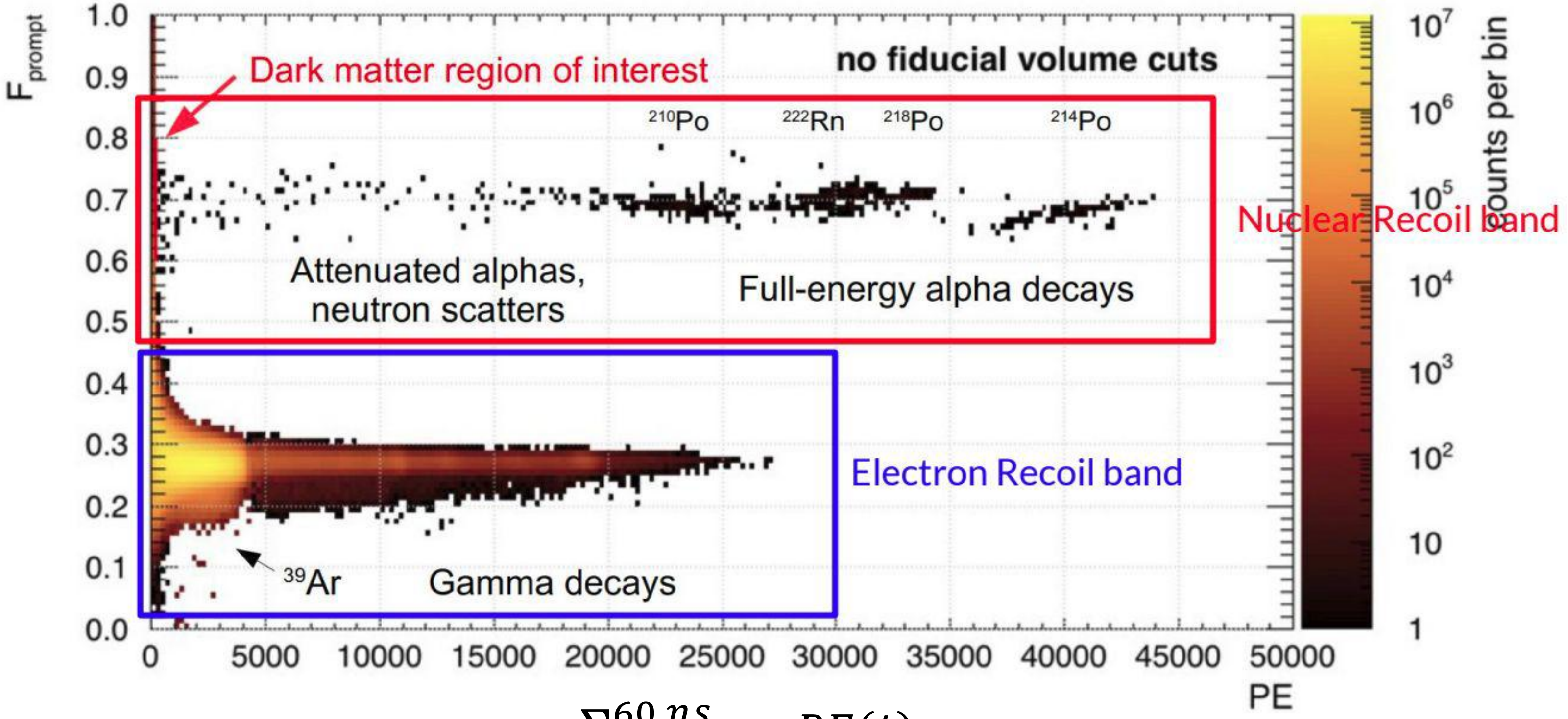
Detector Overview

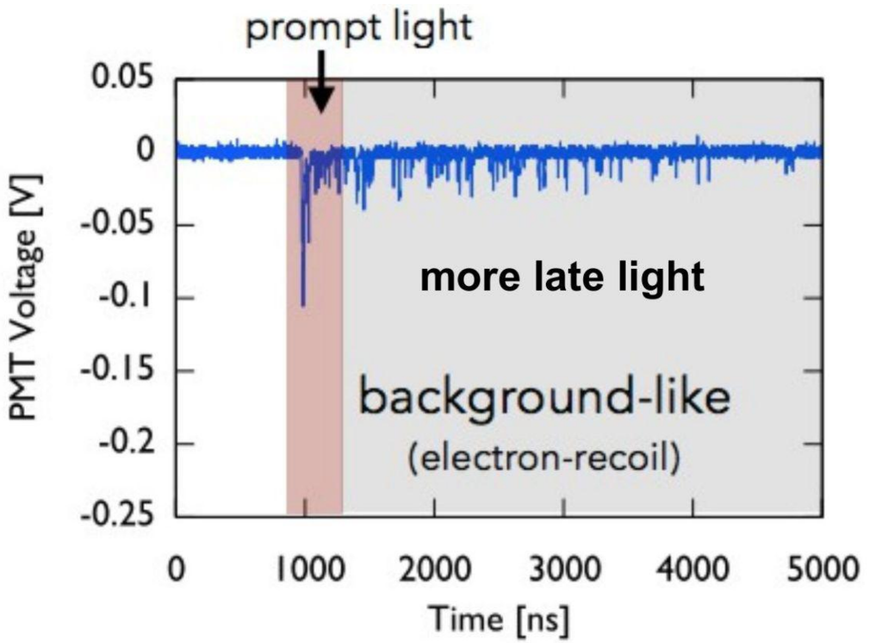
- **Liquid argon (LAr) mass:** 3269 $\pm$ 24 kg
- **Target housing:** Spherical acrylic vessel **(AV)**, 5 cm thick, inner diameter 1.7 m
- **TPB Coating:** 3 µm TPB layer on AV inner surface; shifts 128 nm to 420 nm
- **Photon detection:** 255 inward-facing low-radioactivity, high-QE PMTs.
- **Passive shielding:** spaces between light guides filled with high-density polyethylene and Styrofoam for neutron shielding and insulation between LAr and PMTs.
- **Muon veto:** Steel shell is submerged in water tank and viewed with 48 outward-facing PMTs; water suppresses external neutrons and gammas.

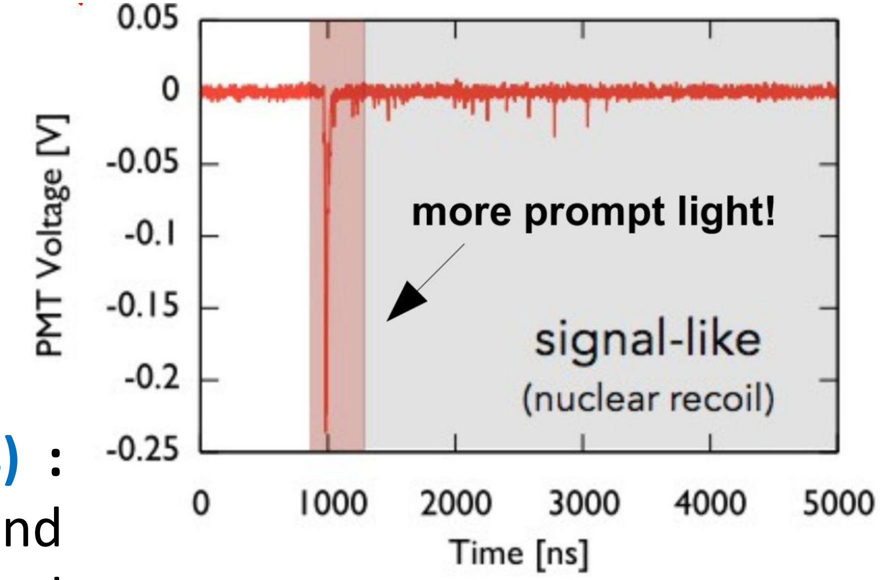


Phy. Rev. D 100, 022004 (2019)

Pulseshape Discrimination





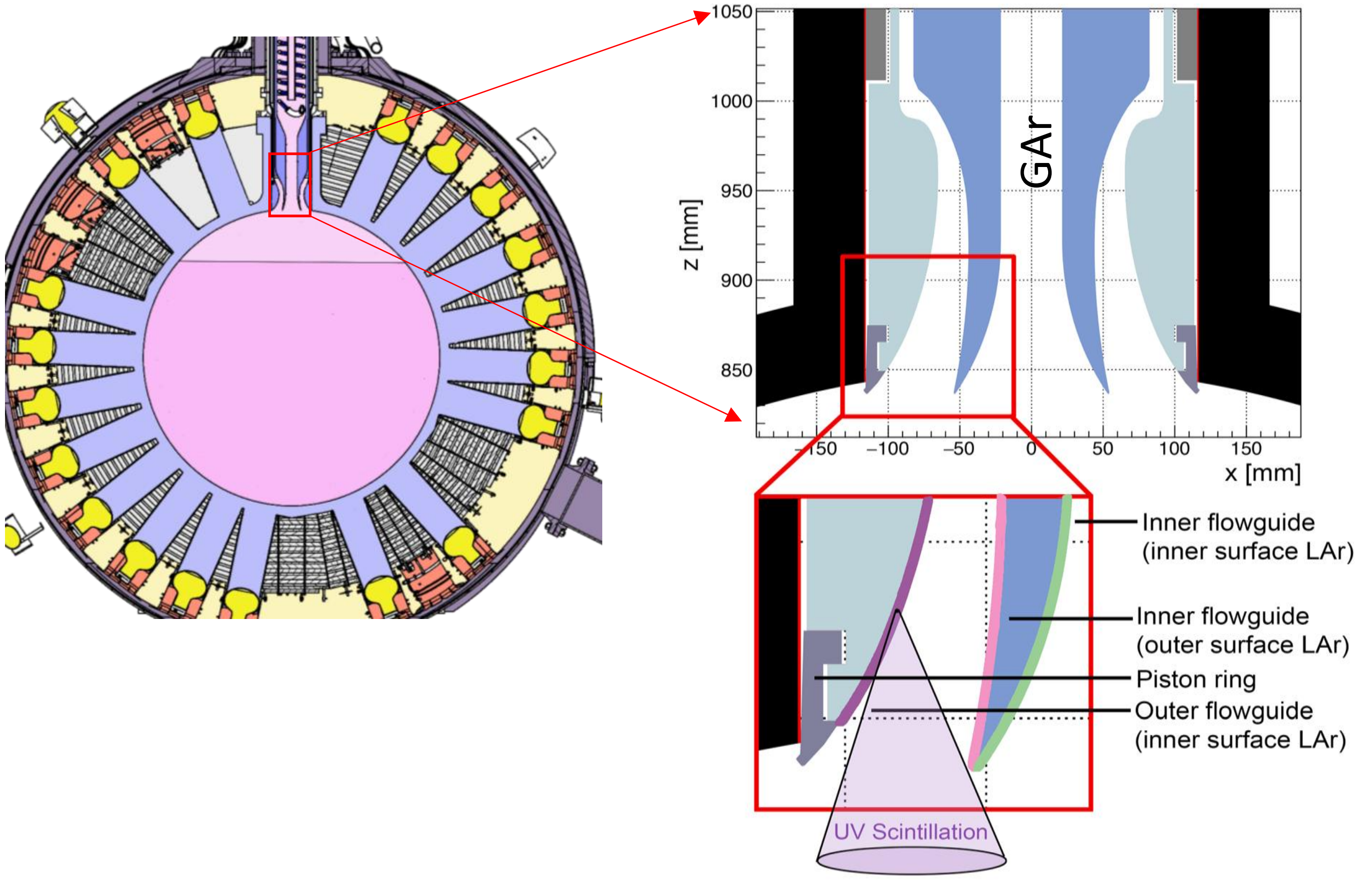


$$F_{prompt} = \frac{\sum_{t=-28\,ns}^{60\,ns} PE(t)}{\sum_{t=-28\,ns}^{10\mu s} PE(t)}$$

World leading performance for rejection of electron recoils (ERs) : Near detector threshold at 17.5 $keV_{ee,}$ the electron recoil background leakage probability is about 10^{-10} with 50% nuclear recoil signal acceptance.

Eur. Phys. J. C 81 (2021) 823, **Eur. Phys. J. C. 80 (2020) 303**

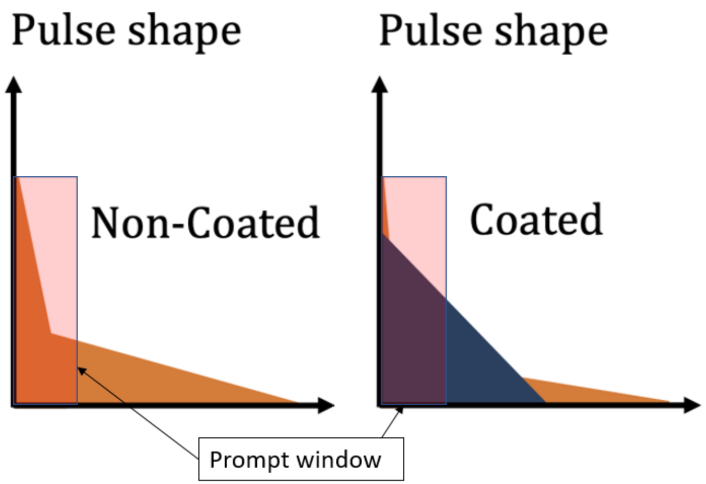
Shadowed Alpha Background

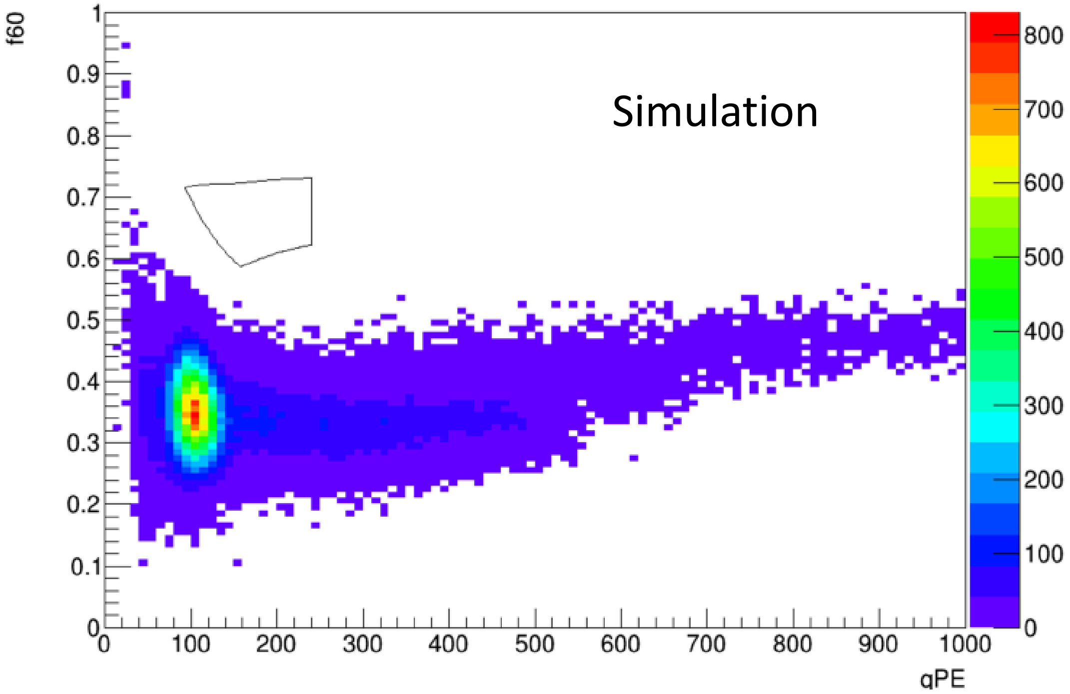


- Originates from ^{210}Po α-decays on the acrylic surfaces of flowguides located at the neck of the detector.
- No-coating on flowguides surfaces.
- UV light is **absorbed by the acrylic flowguides** .
    - significant backgrounds at low energy due to shadowed scintillation light.
- Modeled with a 50-micron liquid argon layer on the flowguide surfaces.
    - F_{prompt} from simulation is consistent with data.

Phys. Rev. D 100, 022004 (2019)

Hardware Upgrades: Shadowed α-Background Mitigation





Pyrene-doped polystrene coated new flowguides have been installed

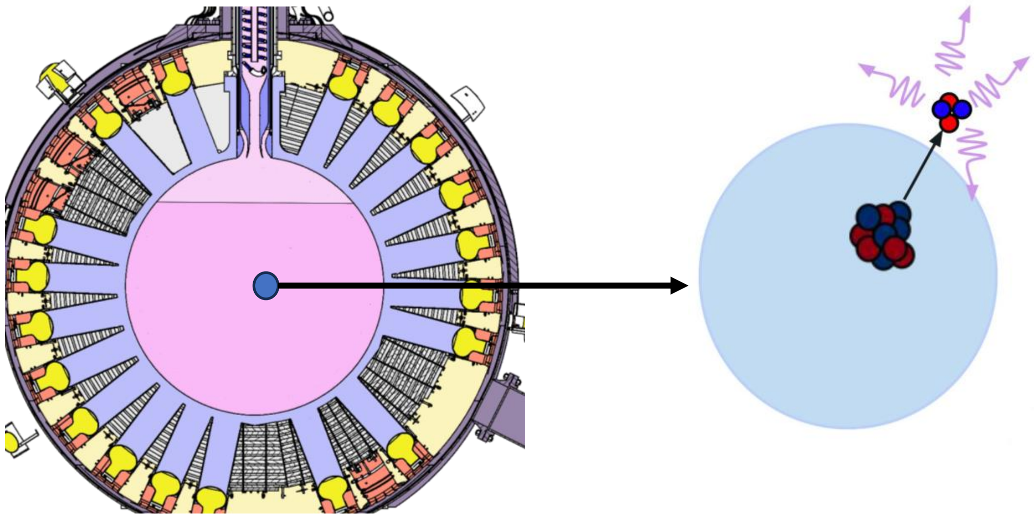
- The long decay time of pyrene reduces the F_{prompt} value for alpha scintillation.
- Pyrene shifts UV photons to visible light--produces higher photoelectrons.
- Removal possible by PSD supported by simulation study.

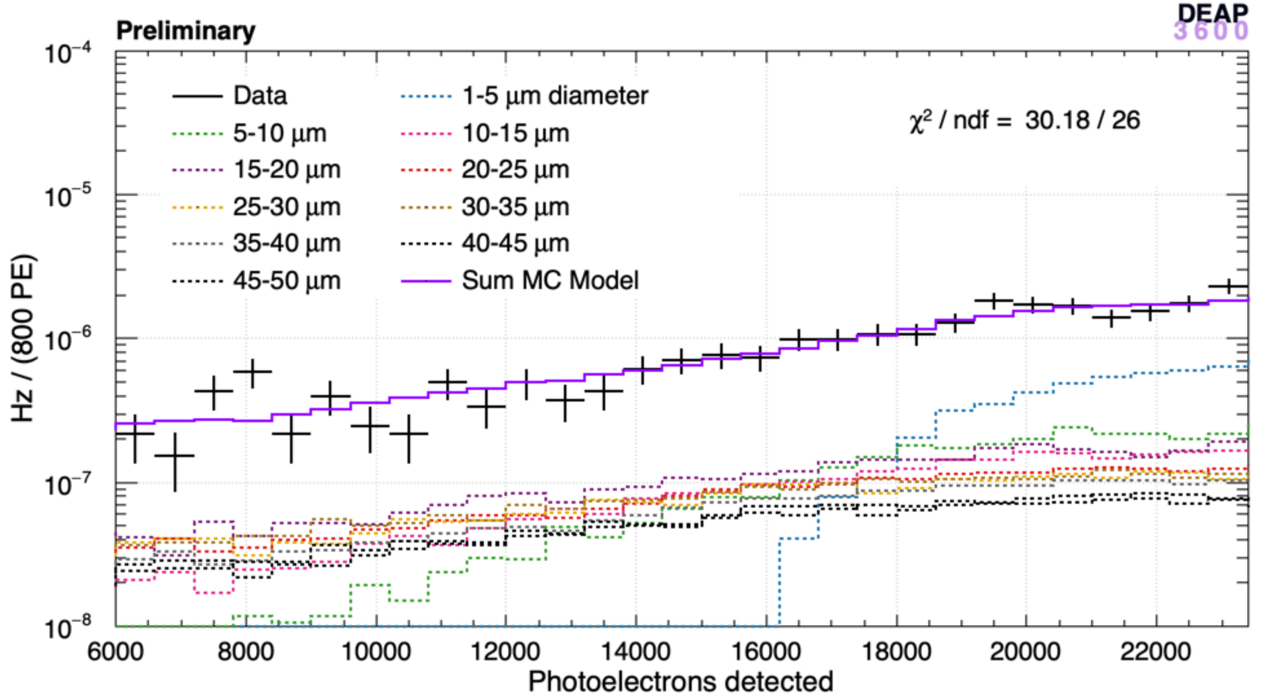
External cooling system

- Prevent formation of liquid argon layer on flowguide surfaces.

Nucl. Instr. and Meth. A 1034 (2022) 166683 , Garg PhD thesis 2023

Alpha-Induced Background from Dust





- α-decays **from trace amount of dust particulate suspended** within liquid argon.
  - Attenuation of α-energy before entering in liquid argon and scintillation light is shadowed by dust particulates itself.
  - Causes fewer scintillation photons.

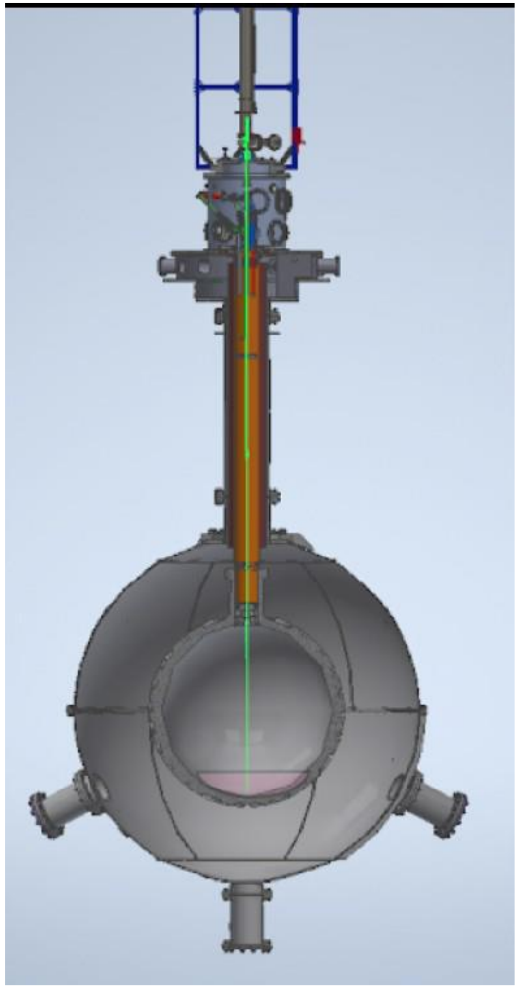
- Background is modelled with a uniform distribution of different size dust in LAr with ^{210}Po contamination.

- Fit performed in high photoelectron spectrum and extrapolated to lower energy region.

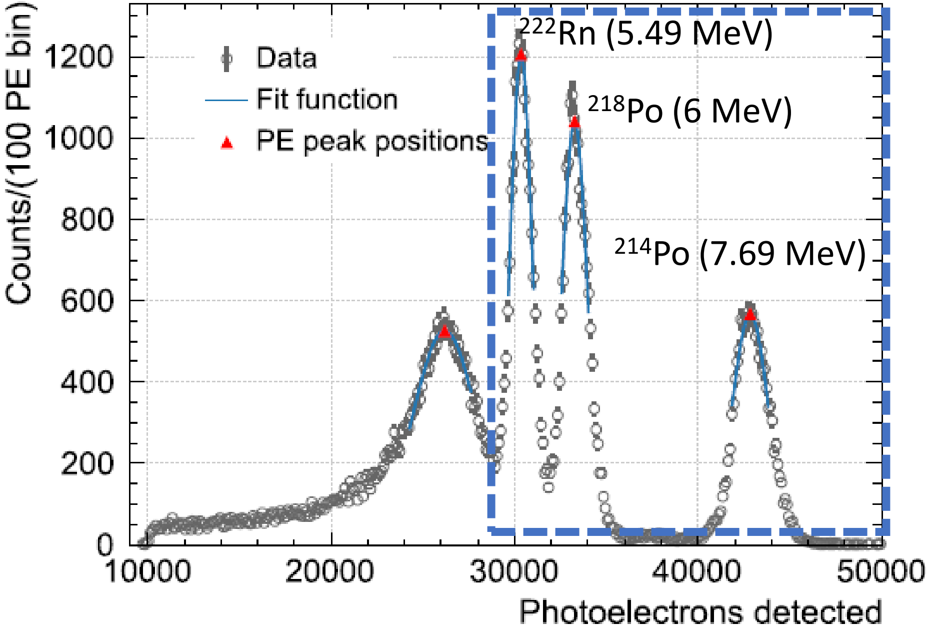
Dust Removal and Detector Current Status

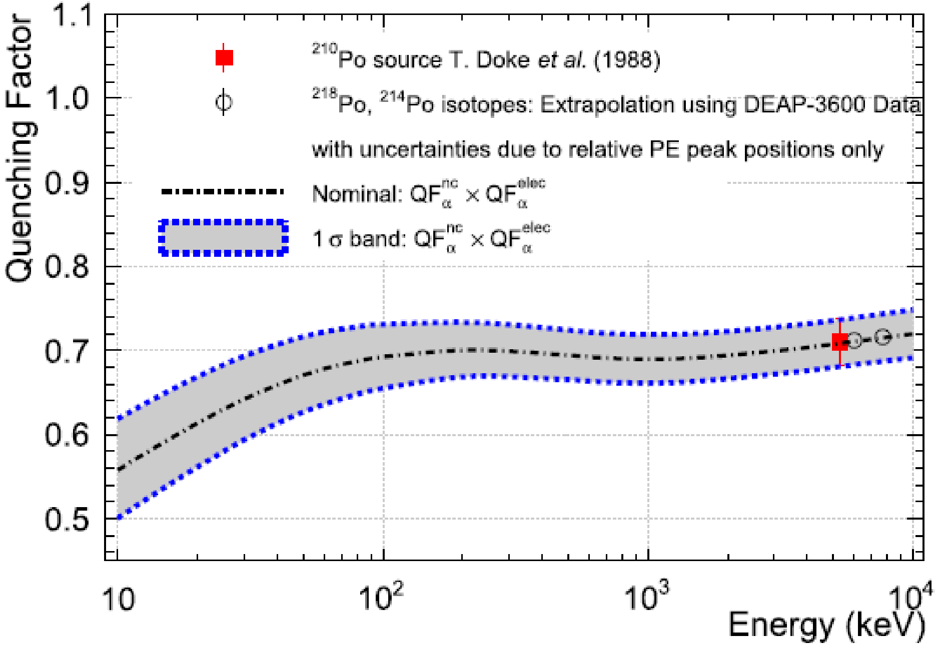
- **Dust filtration :**
  - **Dust filtration pipe installation completed.**
  - Dust pipe deployed to the bottom of acrylic vessel to filter out dust and recirculate LAr in a few cycles.
  - Vessel has been cooled and then refilled with LAr.

- **Current status :**
  - Data collection ongoing.
  - Dust removal procedure will start soon.
  - Data taking will end ~ summer – 2026



Energy-dependent Alpha Quenching Model Eur. Phys. J. C. 85 (2025) 87

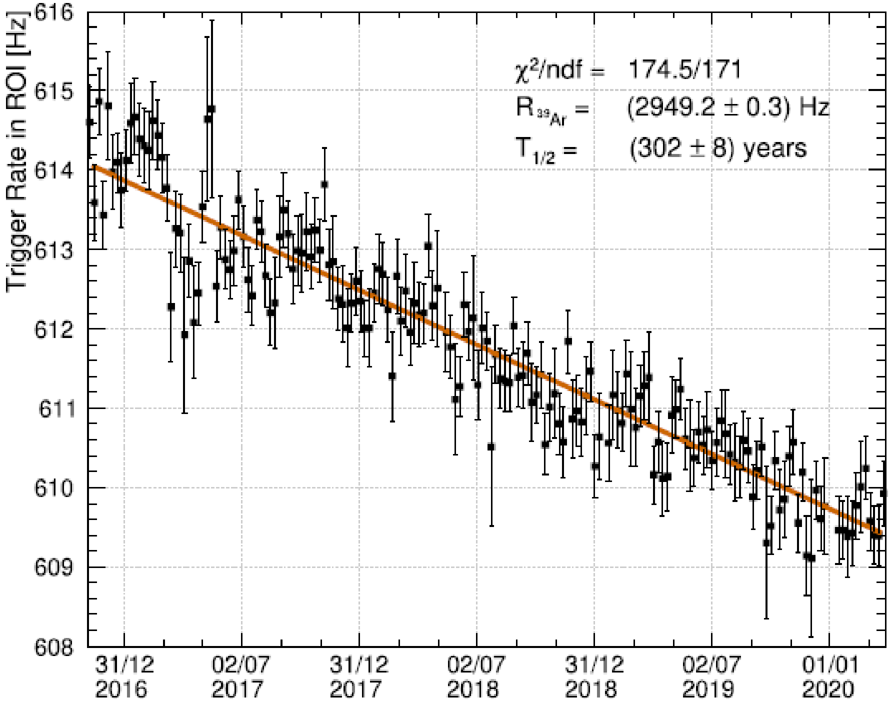


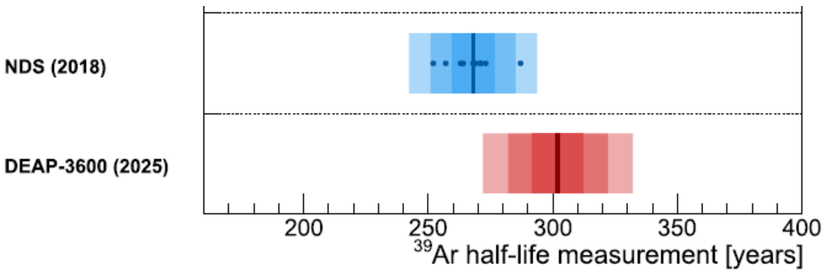


- Contributions from energy transfer to nuclei (nuclear QF) and atomic electrons (electronic QF).
- The quenching model is the product of nuclear and electronic quenching.
- **Nuclear quenching :** Ratio of energy loss in ionization over incident α-energy, calculated by TRIM.
- **Electronic quenching:** Follows Birks's formalism. Parameters of best fit curve and uncertainty bands are constrained by three data points:
  - Absolute QF from a ^{210}Po source. (5.305 MeV) [T. Doke et al. , NIM A 269 (1988) 291]
  - Relative QF for α-energies 6.0 MeV and 7.69 MeV, measured w.r.t. 5.49 MeV. [DEAP-3600 data]

Half-life of ^{39}Ar Measurement

[Eur. Phys. J. C. 85 (2025) 728](#)





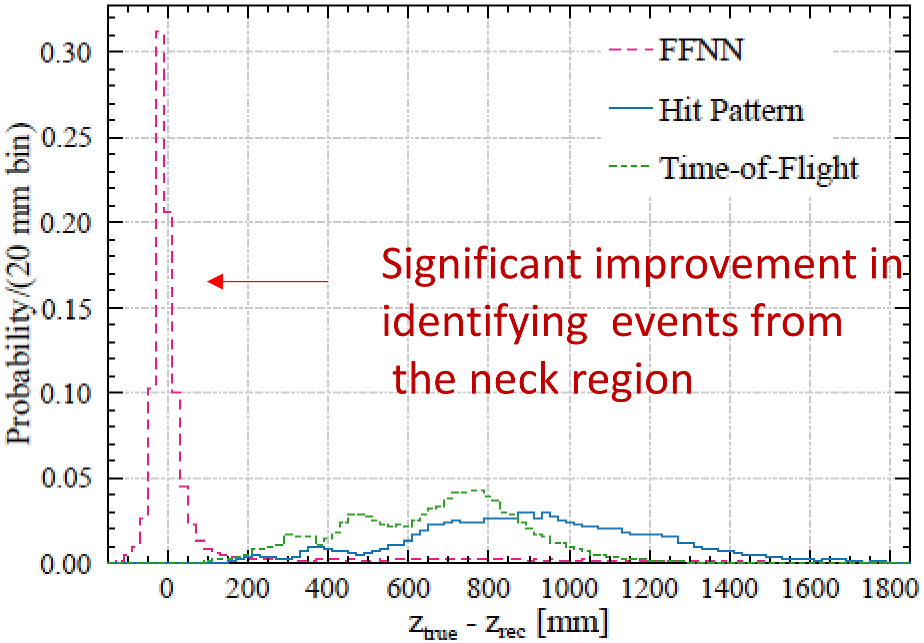
First direct measurement of ^{39}Ar half-life by continuously observing its decay curve. $T_{1/2} = (302 \pm 8_{stat} \pm 6_{sys})$ years .
(longer than usually accepted values)

Position Reconstruction

[JINST 20 P07012 (2025)](#)

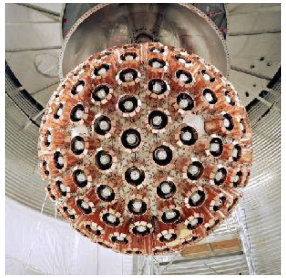
Developed three position reconstruction algorithms:

- **Hit-pattern algorithm:** Likelihood algorithm based on PMT charge pattern .
- **Time-of-flight algorithm:** Likelihood algorithm based on photon arrival time to at each PMT.
- **Machine-learning algorithm:** Feed-forward neural network with hit-pattern as input. [newest algorithm]

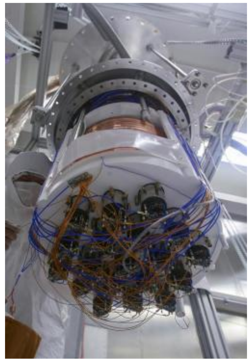


Future Prospects of Dark Matter Search with Liquid Argon

The Global Argon Dark Matter Collaboration formed in 2017



DEAP-3600



DarkSide-50

MiniCLEAN

ARDM

DarkSide20K

Brings together over 400 scientists from 100 institutes in 14 countries, working on liquid argon detectors.

Timeline

Currently running experiment:

DEAP-3600

First planned new experiment:

- DarkSide20K at LNGS, Italy
- 20 tonnes of fiducial mass

Final planned new experiment:

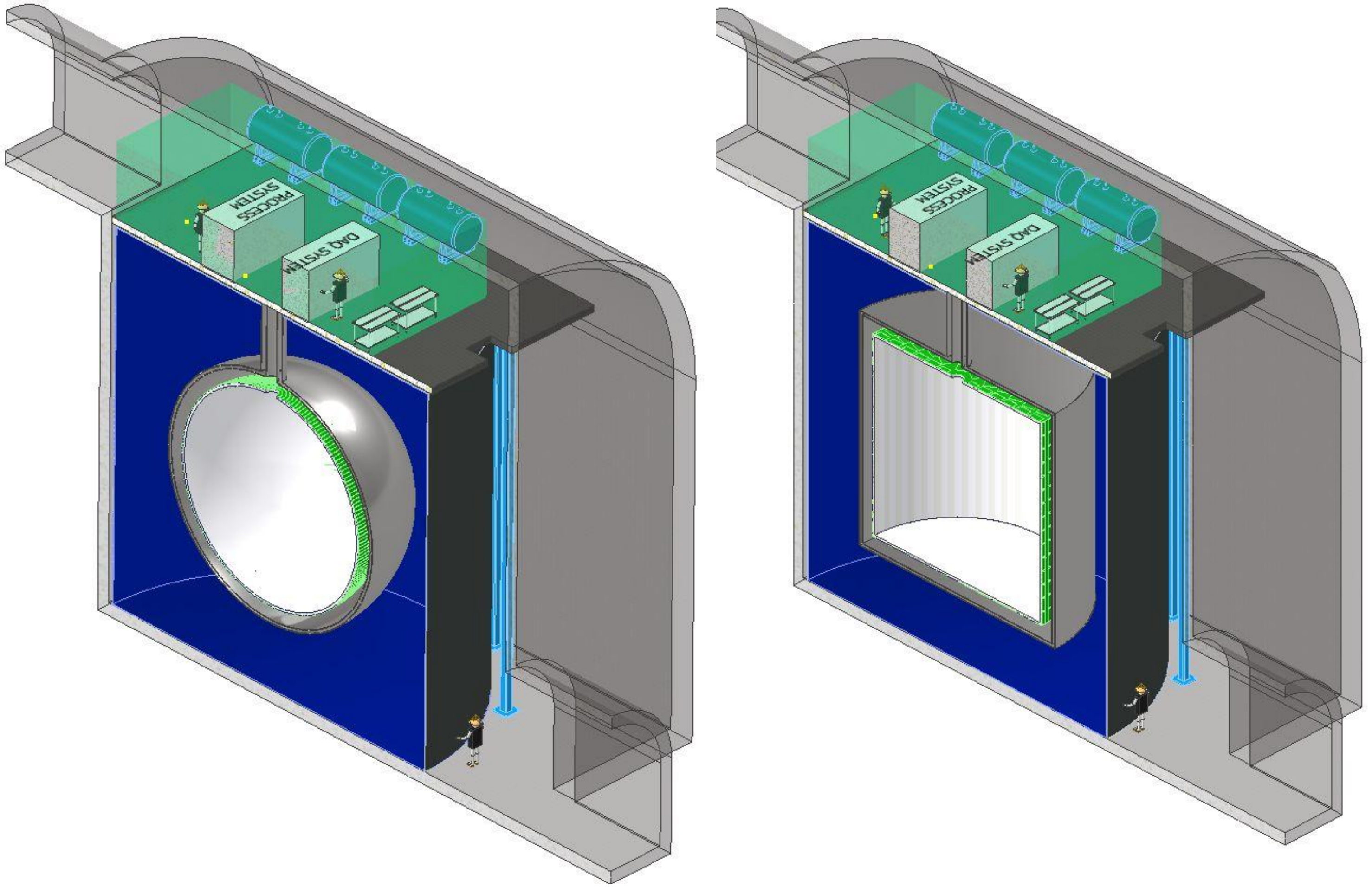
ARGO

ARGO Conceptual Design

- Concept is being developed for the SNOLAB Cube Hall ; Carrying two options for scintillation-only / TPC-style.

- **Total 400 tonnes of underground argon with 300 tonnes fiducial mass.**

- Pixelated digital photodetector read-out.

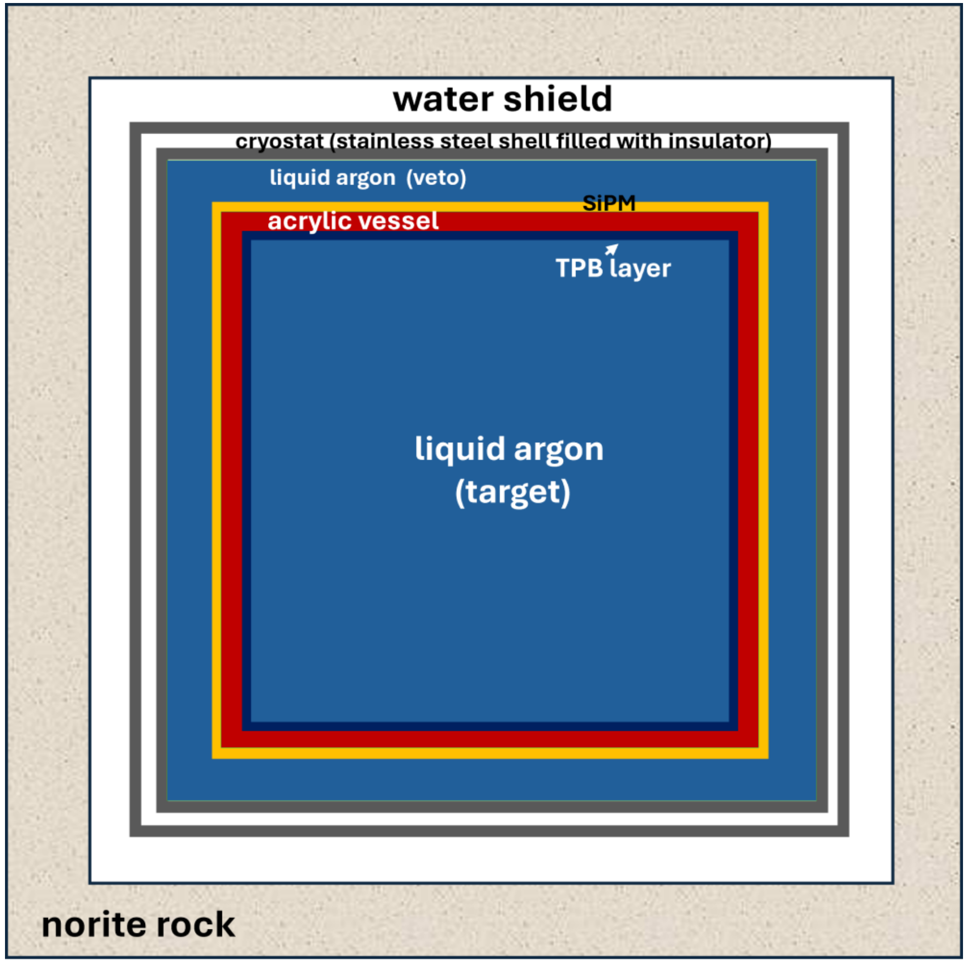


Physics goal, ongoing R&D and development of optical model will be discussed in **Asish Moharana's talk on Oct 23, 2025 at 10:40 am.**

Neutron Background Simulation

Goal: To achieve fewer than one neutron leaking into the ROI over 3000 tonne-year fiducial mass exposure.

- Monte Carlo simulation with RAT software build upon Geant4.
- No optical simulation since it's too CPU intensive; the effect of PSD cuts is estimated by tagging events with sufficient electron-recoil energy.
- Estimated leakage of radiogenic neutron background within (15 -35) keV_{ee}.



Key elements in ARGO Geometry used in simulation
https://rat.readthedocs.io/en/latest/overview.html

Radiogenic Neutron Background Simulation Results

Geometry A

- 3 m thick water shield.
- 1.5 m thick LAr Veto within **protoDune-style cryostat (foam insulated steel)**
- AV Cylinder (ID Ø 7 m, height 7 m, 15 cm thick).

Geometry B

- 2 m thick water shield
- 1 m thick LAr Veto within **vacuum cryostat**
- AV Sphere (ID Ø 8 m, 10 cm thick).

Source of radiogenic neutron	Neutron leakage over a 10-year period within WIMP ROI	
	Geometry A	**Geometry B**
Norite Rock	< 0.13 (95% C.L.)	< 0.2 (95% C.L.)
Cryostat	42 ± 17.6	0.78 ± 0.09
SiPM (Si only)	0.06 ± 0.03	0.105 ± 0.002
Acrylic Vessel	0.72 ± 0.32	0.58 ± 0.02
Total	**43 ± 18**	**1.5 ± 0.3**

- In the cube hall, with Geometry B detector design radiogenic neutron background is low enough.
- Additional discrimination from multiple scattered events is in progress.

Summary and Outlook

DEAP-3600: Largest operating LAr dark matter detector with excellent PSD; **leading sensitivity for high WIMP masses above 30 GeV/c^2 in argon.**

- Leading sensitivity to superheavy, multi-scattering dark matter.
- **Upcoming:** WIMP sensitivity result (3-years dataset, improved background models, PLR analysis)
- Completed hardware upgrades; **targeting a background-free sensitivity at the 10^{-46} cm^2 level — a first for liquid argon.**
- Detector refilled with LAr and currently collecting data.

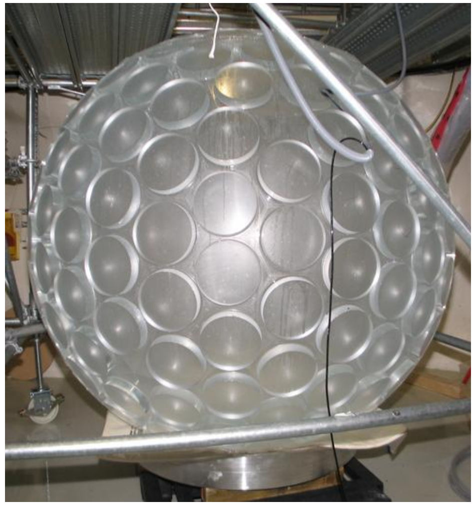
ARGO: Third-generation 400-tonne underground LAr detector planned at SNOLAB, Canada.

- **Detector design is nearing completion, targeting** < 1 radiogenic neutron background for 3000 tonne-year exposure.
- **Best discovery sensitivity to high mass dark matter** and **excellent sensitivity to neutrinos through several channels**. [see Asish Moharana's talk]

Thank You

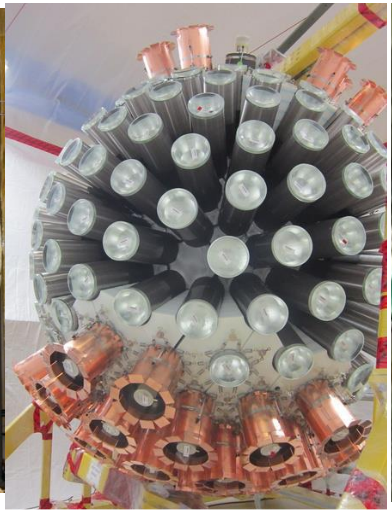
Extra Slides

DEAP-3600 detector at SNOLAB



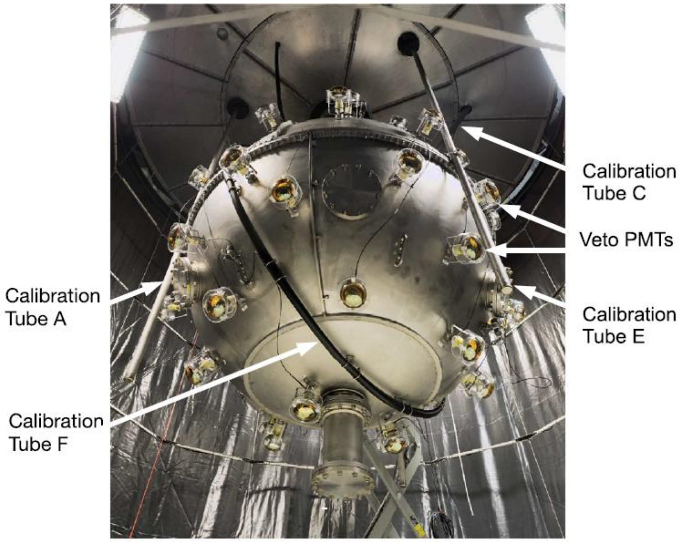
Acrylic vessel of diameter 1.7 m which contains ~ 3.3 tons of liquid argon.

Acrylic vessel after bonding on 45 cm long light guides.



PMT installation

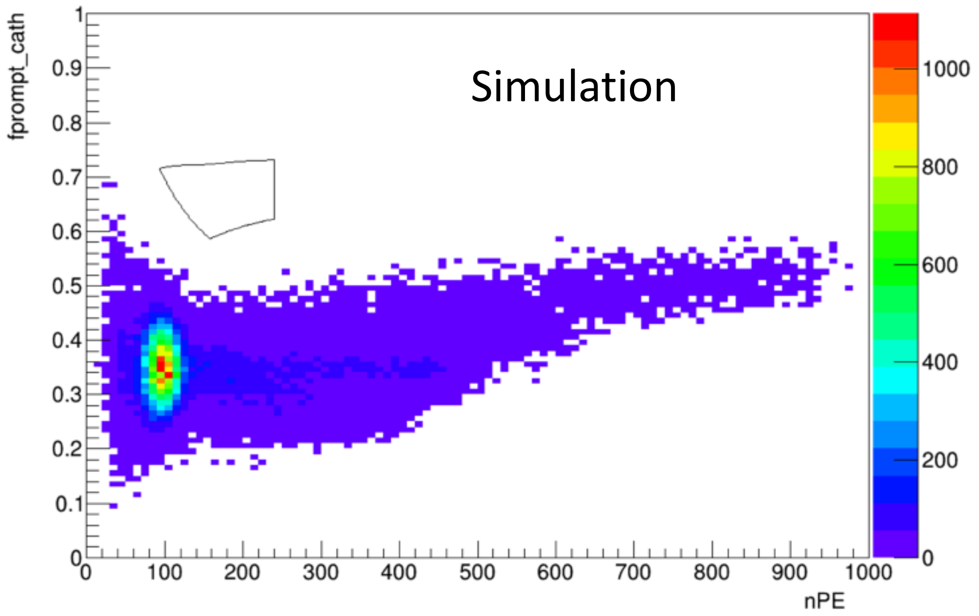
Detector with PMT installed & during backing foam (yellow) installation



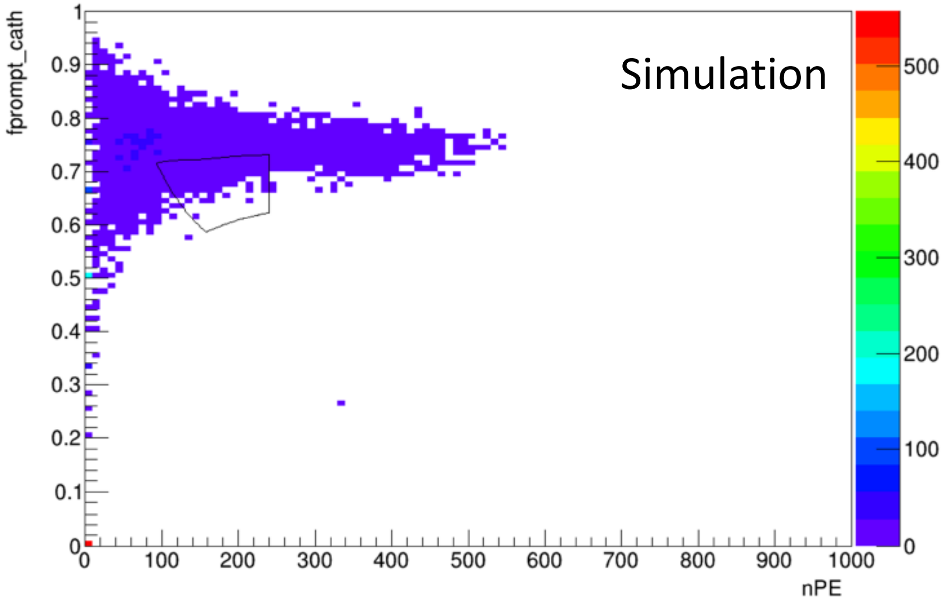
Within steel shell and muon veto PMTS

Astroparticle Physics **104, 1 (2019)**, **arXiv: 1712.01982**

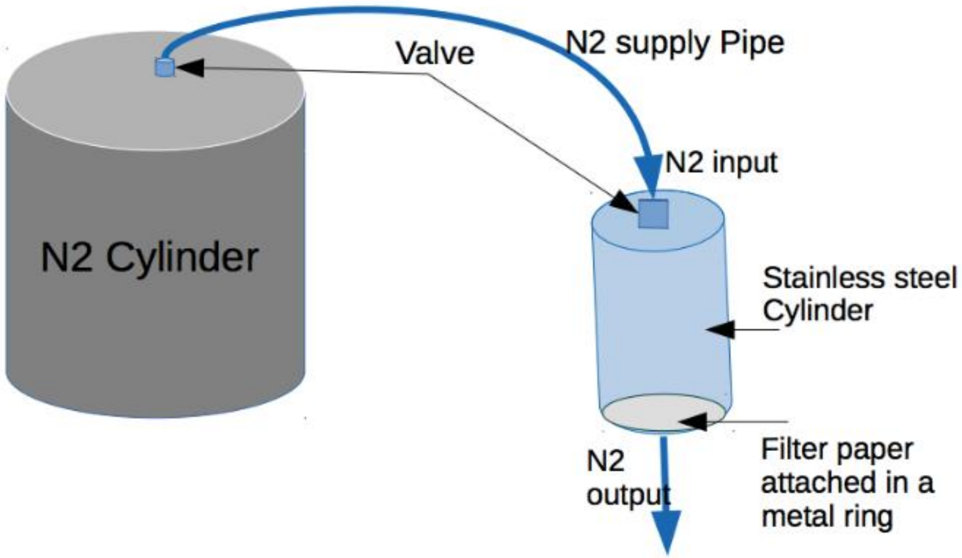
Shadowed alpha Background Rejection using pyrene



Same events without photons from pyrene

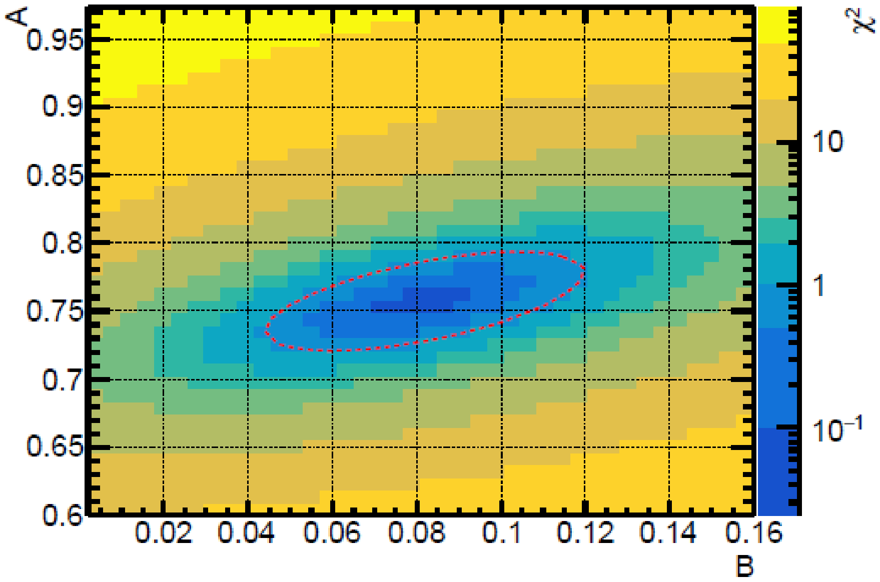


Dust Size & Component Measurements



- During installation, dust particulates could enter DEAP-3600 detector--- supported by ex-situ measurements .
- During installation, nitrogen gas were used to purge the AV, keeping it in a low radon environment.
    - a filter with a 50 µm pore size was used.
    - allows metal particulates of less than 50 µm diameter from the nitrogen cylinder to enter the AV.
- At Carleton university, an ex-situ measurements of size and component of the metallic dust has been performed by circulation nitrogen gas from a metal cylinder through filter.
    - characterized using a Scanning Electron Microscope (SEM).
    - consist of copper and zinc.

Electronic quenching factor

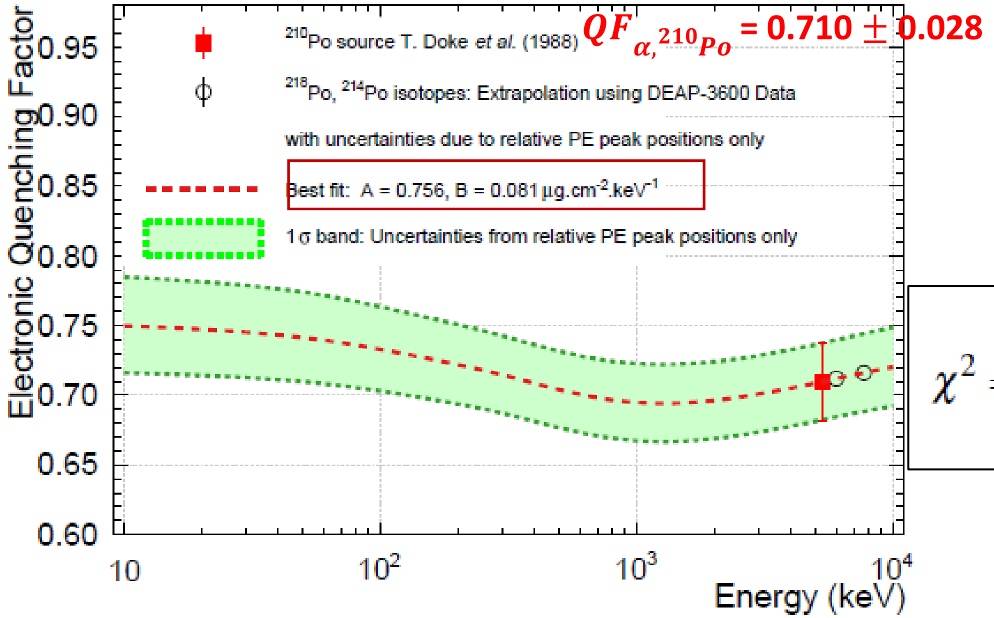


$$\frac{QF_{\alpha,{}^{218}Po}}{QF_{\alpha,{}^{222}Rn}} = \frac{PE_{\alpha,{}^{218}Po}}{PE_{\alpha,{}^{222}Rn}} \times \frac{E_{\alpha,{}^{222}Rn}}{E_{\alpha,{}^{218}Po}} \equiv R_2 \times \frac{E_{\alpha,1}}{E_{\alpha,2}},$$

$$\frac{QF_{\alpha,{}^{214}Po}}{QF_{\alpha,{}^{222}Rn}} = \frac{PE_{\alpha,{}^{214}Po}}{PE_{\alpha,{}^{222}Rn}} \times \frac{E_{\alpha,{}^{222}Rn}}{E_{\alpha,{}^{214}Po}} \equiv R_3 \times \frac{E_{\alpha,1}}{E_{\alpha,3}}.$$

Following Birks' formalism: $\boxed{\dfrac{dy}{dE} = \dfrac{A}{1+B\frac{dE}{dx}}}$

- `A' accounts for average quenching due to the density of the deposition within the track core.
- `B' accounts for the change in density with energy.
- dE/dx is the electronic stopping power at each step along the α-particle's track.



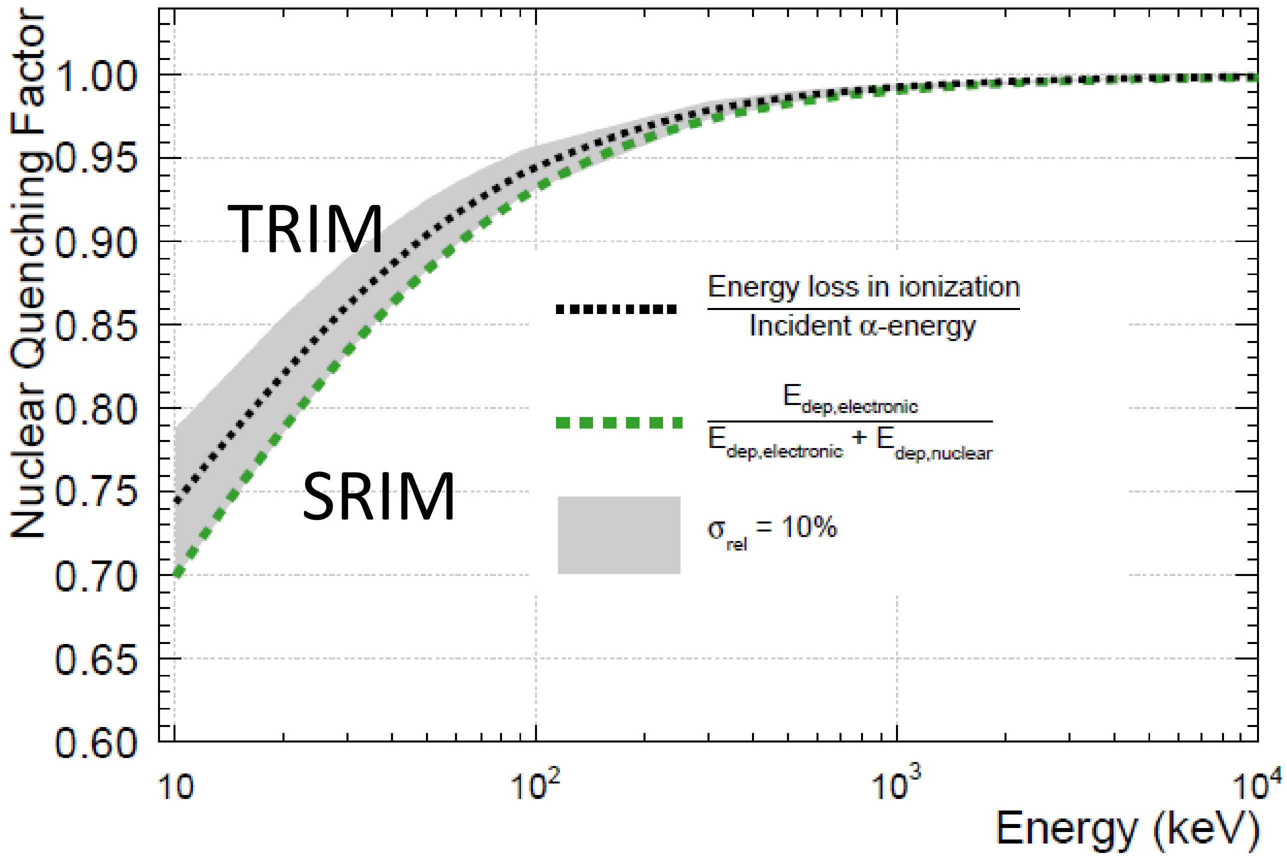
$$\boxed{\chi^2 = \frac{\left(QF_{\alpha,{}^{210}Po} - QF^M_{\alpha,{}^{210}Po}\right)^2}{\sigma_0^2} + \sum_{i=2}^{3} \frac{\left(R_i - R_i^M\right)^2}{\sigma_i^2}}$$

$$R_i^M = \frac{y(E_{\alpha,i})}{y(E_{\alpha,1})} = \frac{\int_0^{E_{\alpha,i}} \frac{dE}{1+B\frac{dE}{dx}}}{\int_0^{E_{\alpha,1}} \frac{dE}{1+B\frac{dE}{dx}}}$$

$$QF^M_\alpha = \frac{y(E_\alpha)}{E_\alpha} = \frac{A}{E_\alpha}\int_0^{E_\alpha} \frac{dE}{1+B\frac{dE}{dx}}$$

$$R_2 = \frac{PE_{\alpha,{}^{218}Po}}{PE_{\alpha,{}^{222}Rn}},\; R_3 = \frac{PE_{\alpha,{}^{214}Po}}{PE_{\alpha,{}^{222}Rn}}$$

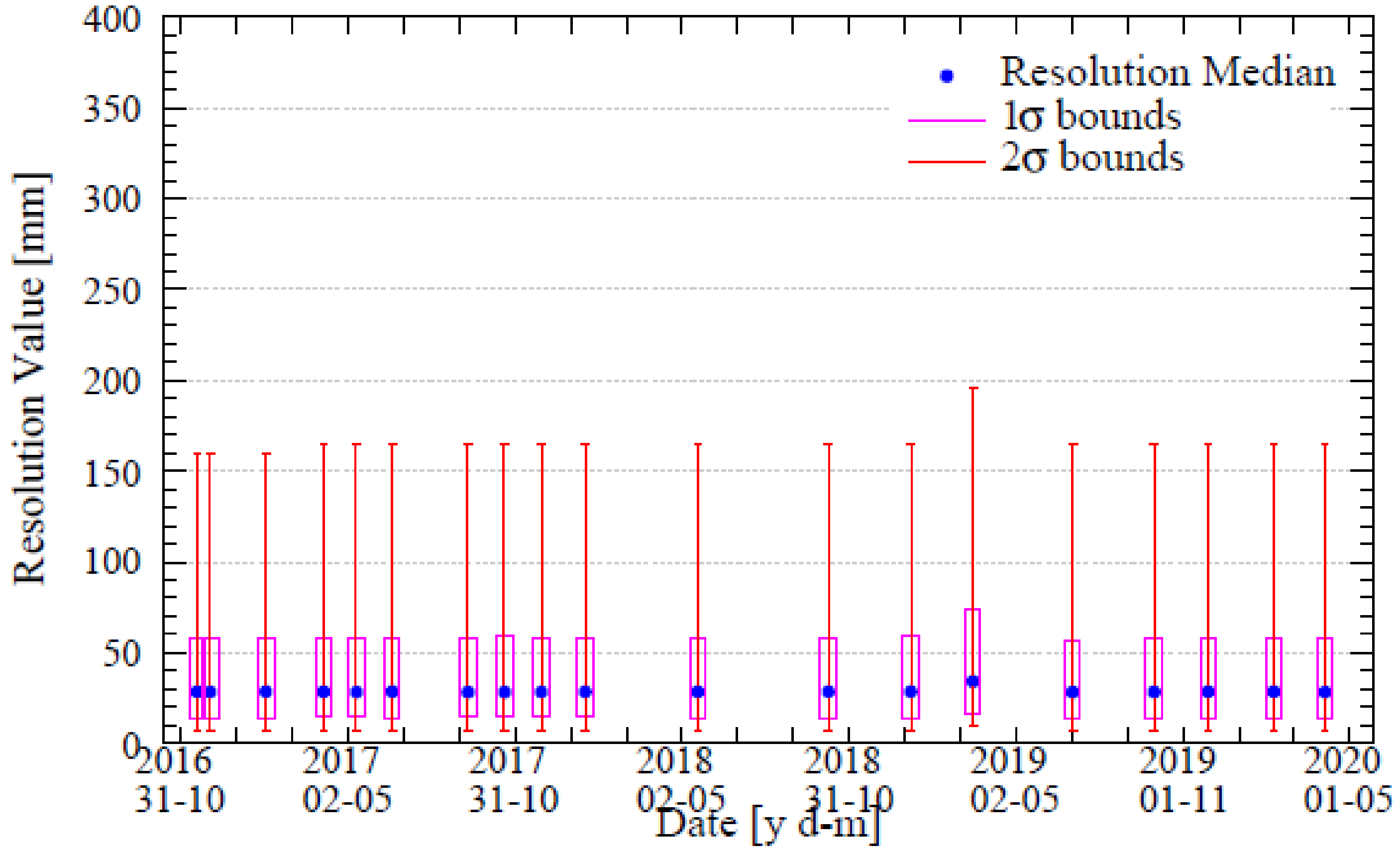
Nuclear Quenching



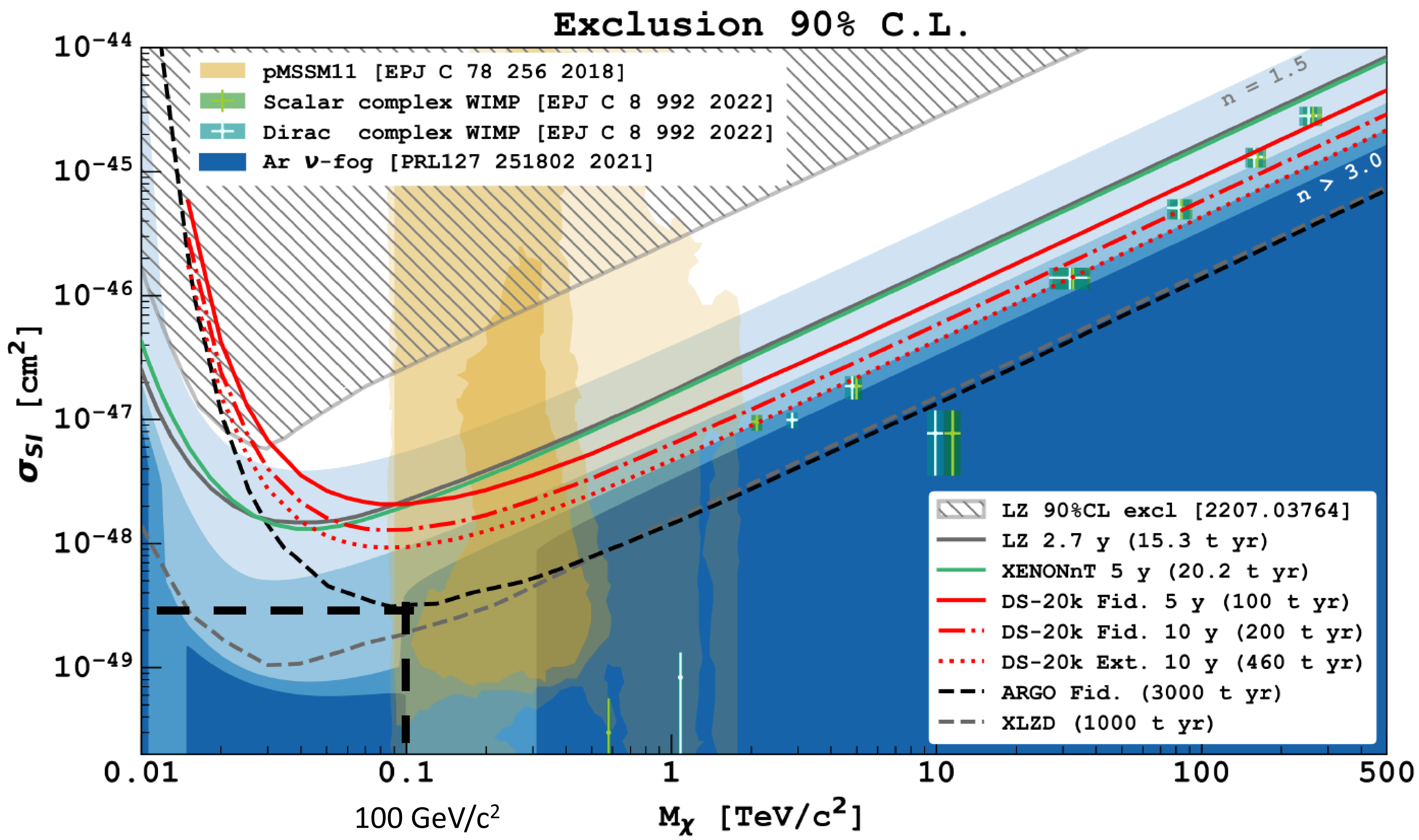
SRIM provides the amount of energy transferred to atomic electrons and nuclei directly, but does not account for the subsequent scatters and the final state distribution of the energy deposited.

$$\begin{aligned}
\Delta \mathrm{QF}_{\alpha}^{\mathrm{nucl}} &= \Bigg[\left(\frac{\partial \mathrm{QF}_{\alpha}^{\mathrm{nucl}}}{\partial E_{\mathrm{dep,elec}}} \sigma_{\mathrm{elec}} \right)^2 + \left(\frac{\partial \mathrm{QF}_{\alpha}^{\mathrm{nucl}}}{\partial E_{\mathrm{dep,nucl}}} \sigma_{\mathrm{nucl}} \right)^2 \\
&\quad + 2\rho\sigma_{\mathrm{elec}}\sigma_{\mathrm{nucl}} \left(\frac{\partial \mathrm{QF}_{\alpha}^{\mathrm{nucl}}}{\partial E_{\mathrm{dep,elec}}} \right) \left(\frac{\partial \mathrm{QF}_{\alpha}^{\mathrm{nucl}}}{\partial E_{\mathrm{dep,nucl}}} \right) \Bigg]^{1/2} \\
&= \Bigg[\left(\frac{E_{\mathrm{dep,nucl}} \cdot \sigma_{\mathrm{elec}}}{(E_{\mathrm{dep,elec}} + E_{\mathrm{dep,nucl}})^2} \right)^2 \\
&\quad + \left(\frac{-E_{\mathrm{dep,elec}} \cdot \sigma_{\mathrm{nucl}}}{(E_{\mathrm{dep,elec}} + E_{\mathrm{dep,nucl}})^2} \right)^2 \qquad (5) \\
&\quad - 2\rho \cdot \frac{E_{\mathrm{dep,nucl}} \cdot E_{\mathrm{dep,elec}} \cdot \sigma_{\mathrm{elec}} \cdot \sigma_{\mathrm{nucl}}}{(E_{\mathrm{dep,elec}} + E_{\mathrm{dep,nucl}})^4} \Bigg]^{1/2} \qquad (6) \\
&= \sqrt{2(1-\rho)} \frac{E_{\mathrm{dep,elec}} \, E_{\mathrm{dep,nucl}}}{(E_{\mathrm{dep,elec}} + E_{\mathrm{dep,nucl}})^2} \sigma_{\mathrm{rel}} \qquad (7)
\end{aligned}$$

Position Resolution

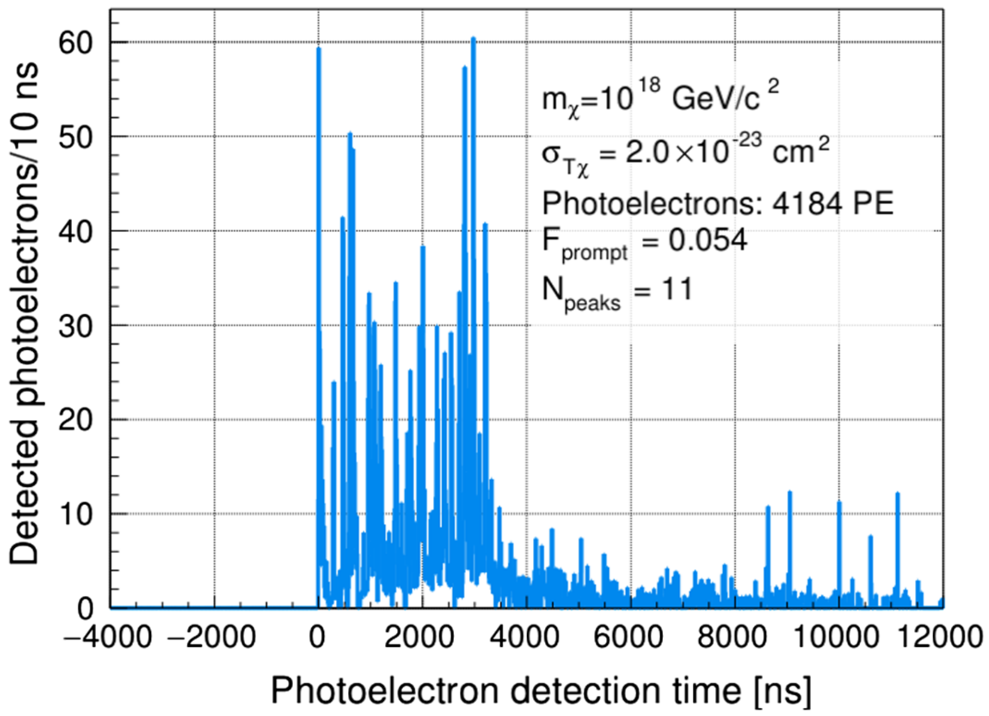


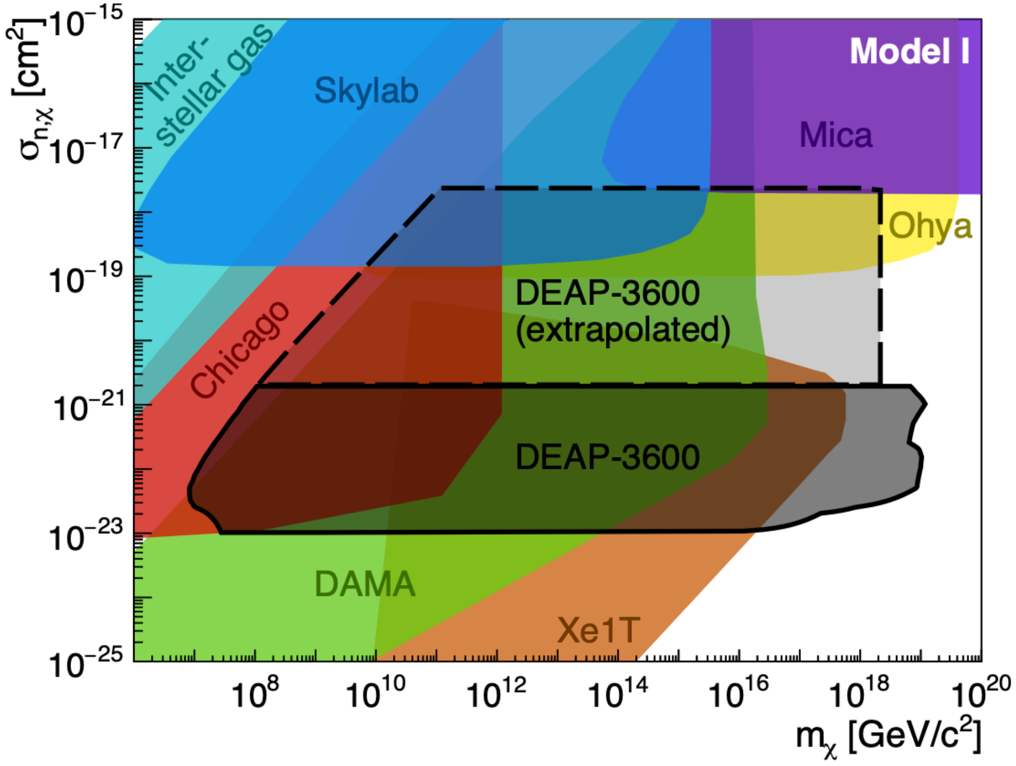
Hit pattern algorithm


Exclusion 90% C.L.
pMSSM11 [EPJ C 78 256 2018]
Scalar complex WIMP [EPJ C 8 992 2022]
Dirac complex WIMP [EPJ C 8 992 2022]
Ar ν-fog [PRL127 251802 2021]
n = 1.5
n > 3.0
LZ 90%CL excl [2207.03764]
LZ 2.7 y (15.3 t yr)
XENONnT 5 y (20.2 t yr)
DS-20k Fid. 5 y (100 t yr)
DS-20k Fid. 10 y (200 t yr)
DS-20k Ext. 10 y (460 t yr)
ARGO Fid. (3000 t yr)
XLZD (1000 t yr)
σ_{SI} [cm^2]
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
0.01
0.1
1
10
100
500
100 GeV/c^2
M_χ [TeV/c^2]

Supermassive Dark Matter Search

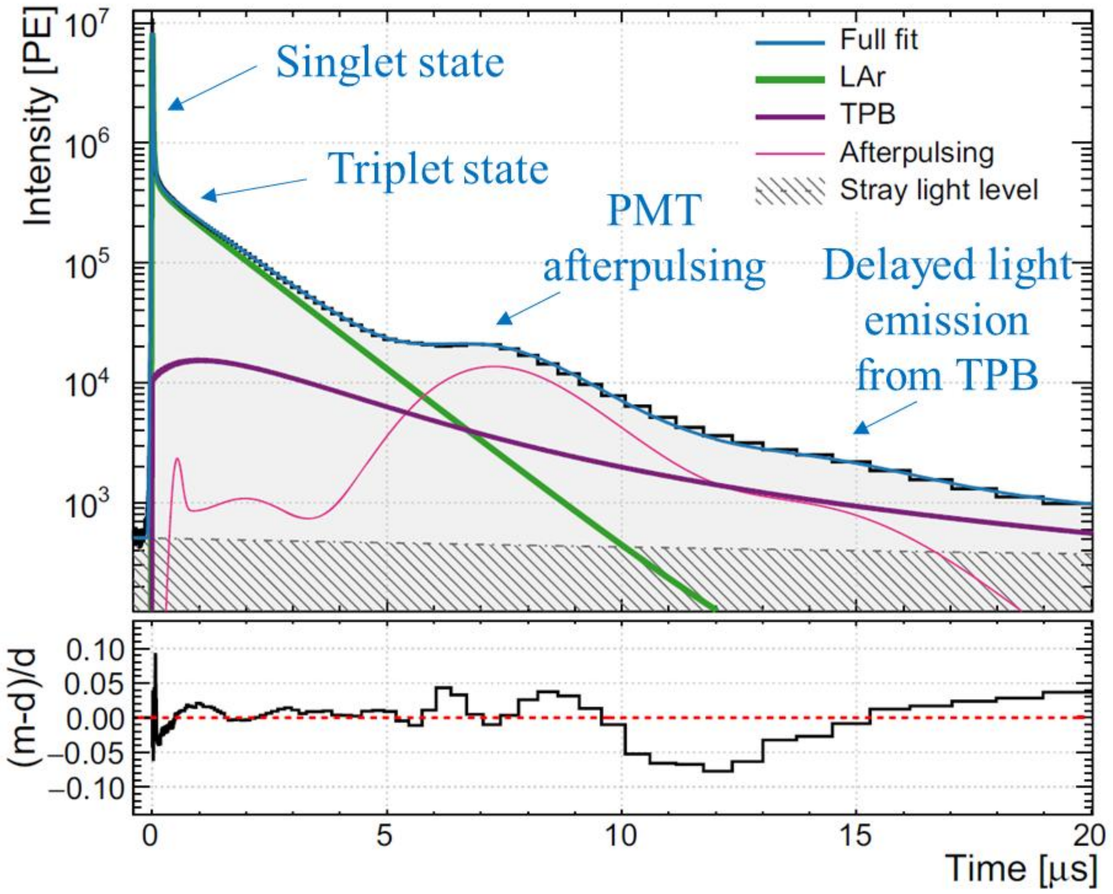
Phys. Rev. Lett. 128, 011801 (2022)

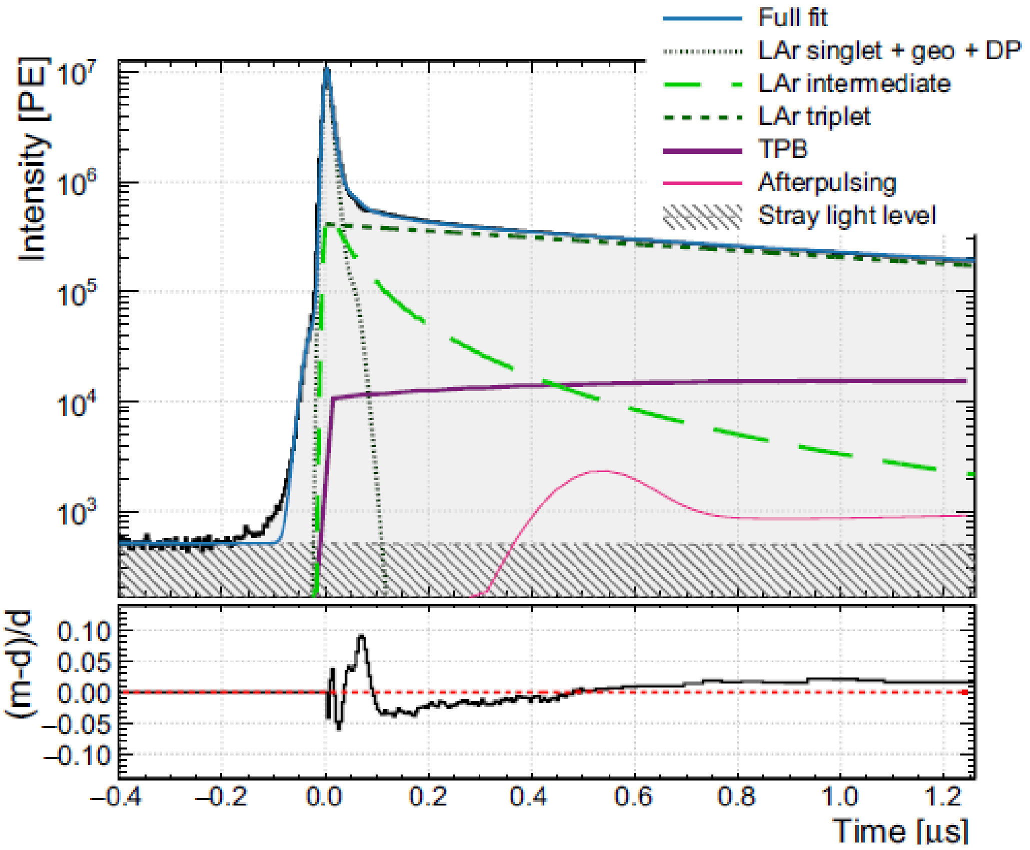




- Higher cross-section than WIMPs — generates multiple nuclear recoil scatters in LAr ; produces signals with multiple peaks and low F_{prompt}.
- No events found in the region of interest --- Constrain the DM masses and ^{40}Ar-scattering cross-sections.
- **First direct detection experiment to achieve Planck-scale sensitivity due to large detector size.**

Liquid argon scintillation pulseshape model in DEAP-3600





A pulseshape model is developed which contains: (a) liquid argon scintillation including intermediate scintillation, (b) time response of TPB wavelength shifter, (c) PMT response.

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