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Republic of Poland

FNP Foundation for Polish Science

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ASTROCENT

Status and recent results from the DEAP-3600 Experiment

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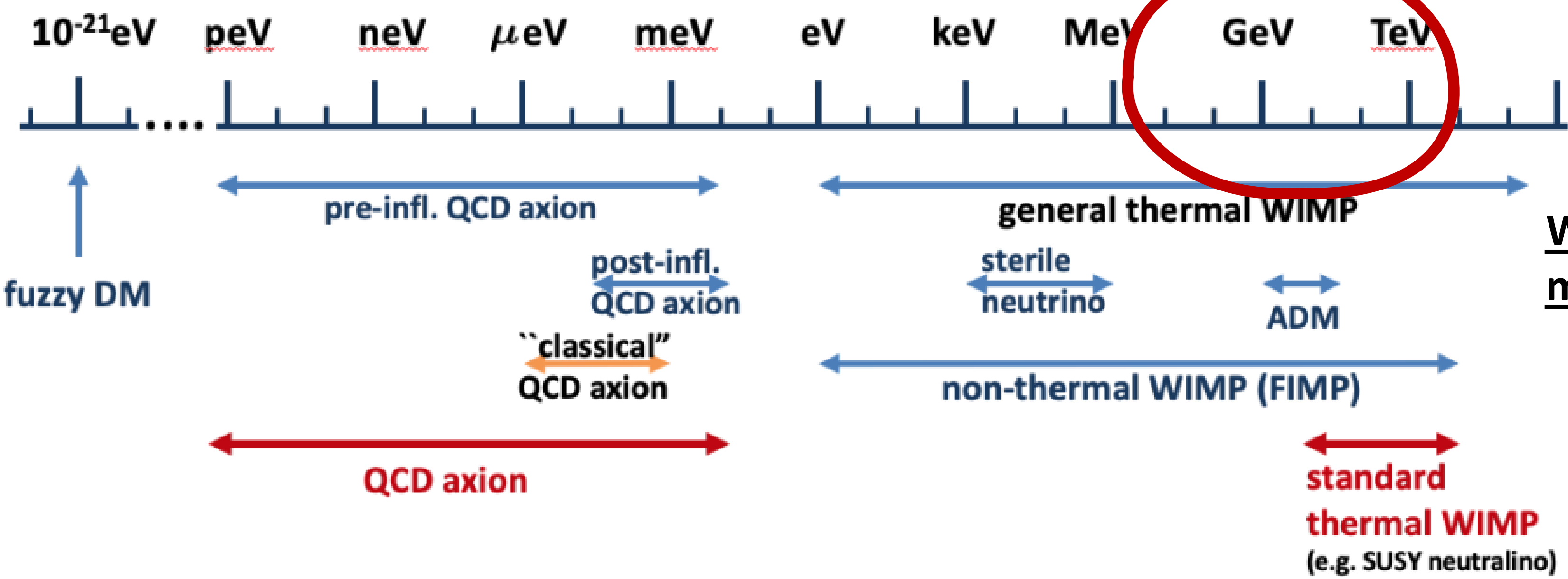
Plan

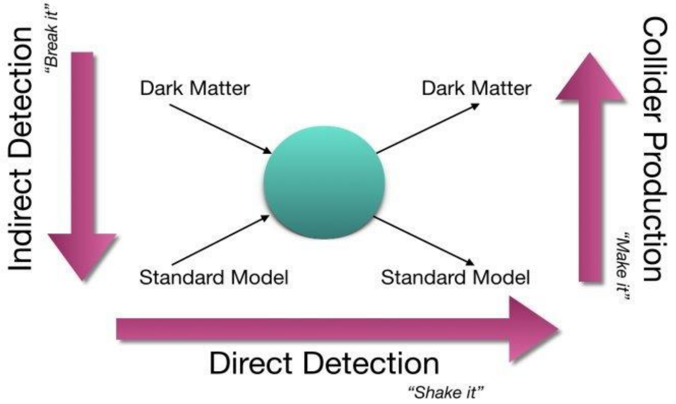
- Particle Dark Matter
- DEAP-3600 detector
- Detection with Liquid Argon
- DEAP-3600 status
- PLR WIMP analysis
- Ar39 half-life
- Boron-8 solar neutrinos analysis

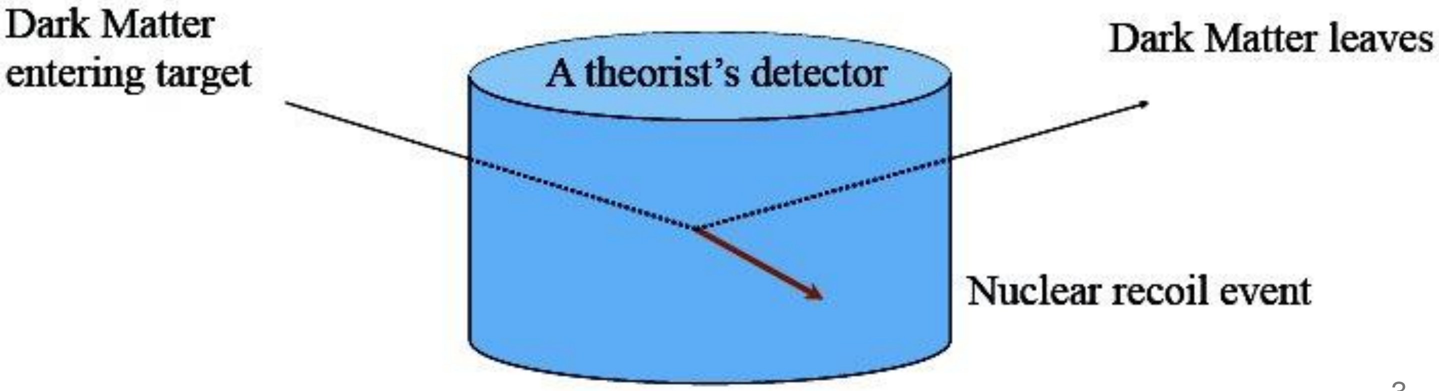
WIMP search - Particle Dark Matter



We search for WIMPs of mass in ~10-10^3 GeV range.

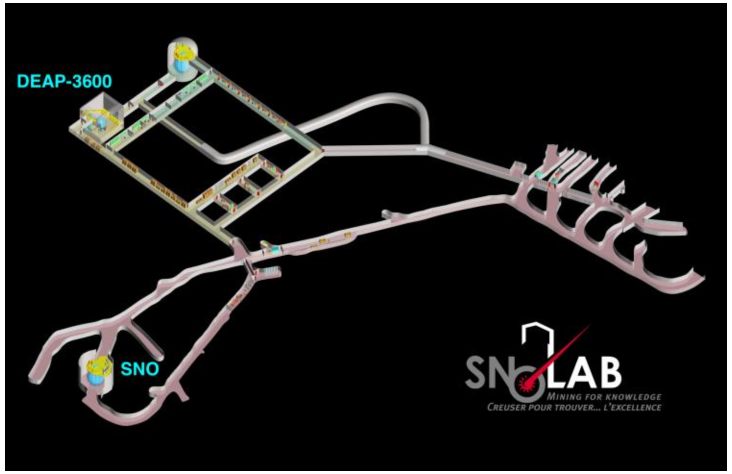
Direct Detection search



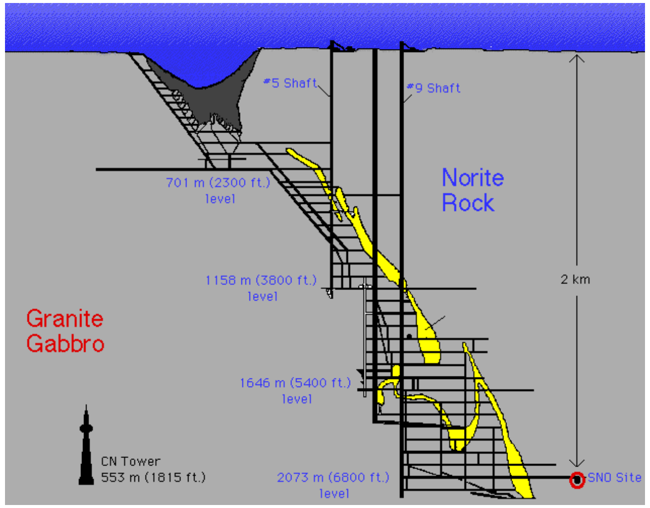


DEAP-3600

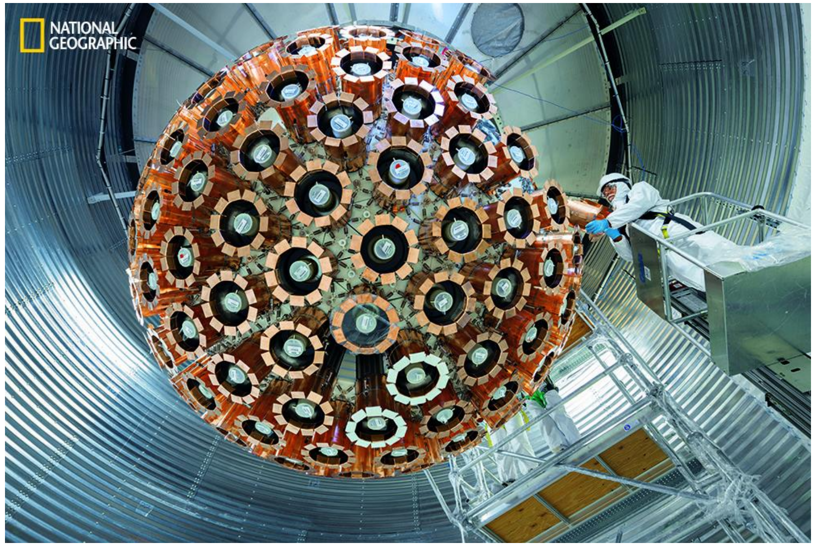
ONTARIO
QUEBEC
SNOLAB
Québec City
Ottawa
Montreal
WISCONSIN
MAINE
VERMONT
MICHIGAN
Toronto
NEW HAMPSHIRE
NEW YORK
Chicago
MASSACHUSETTS
PENNSYLVANIA
New York
ILLINOIS
INDIANA
OHIO
Philadelphia
Indianapolis
MARYLAND
St. Louis
WEST VIRGINIA
Washington
MISSOURI



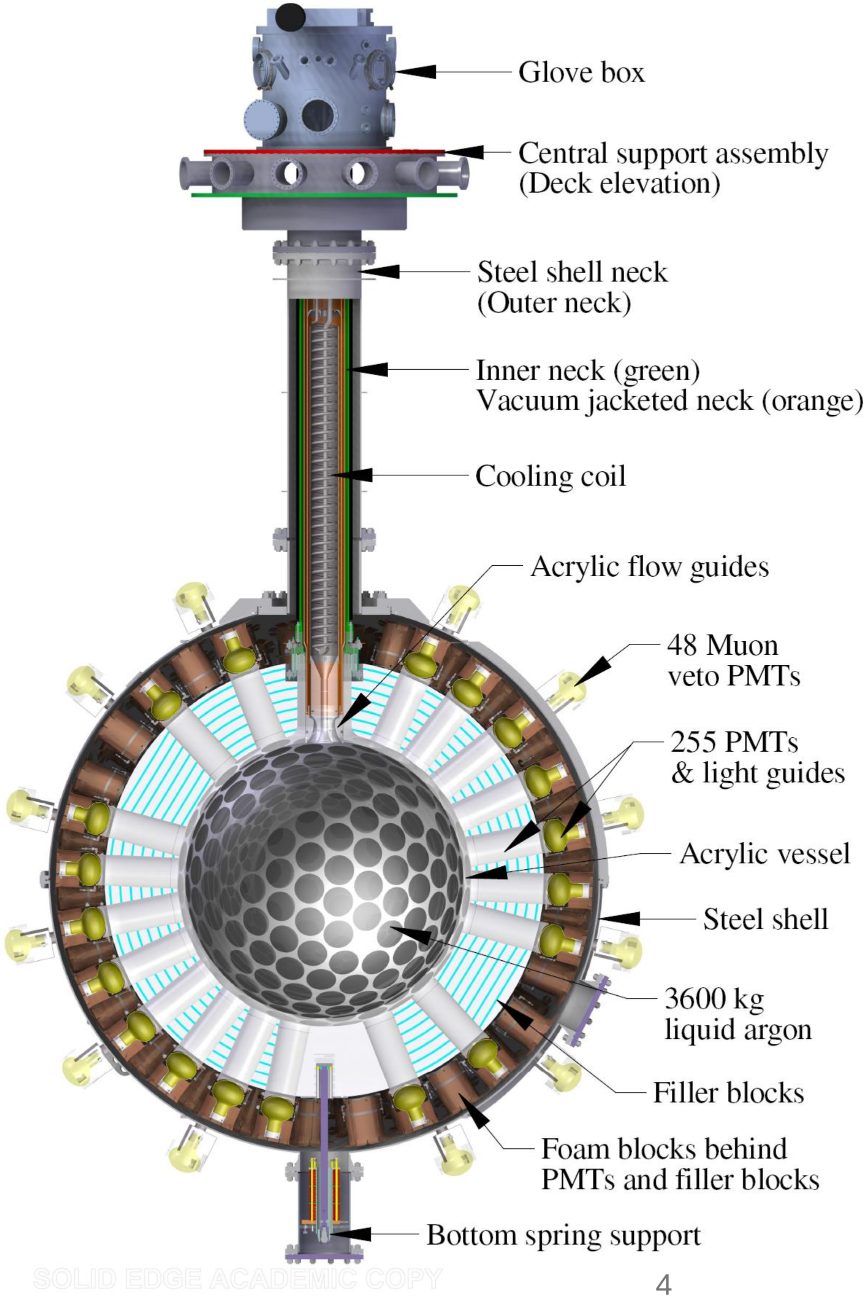
DEAP-3600
SNO
SNOLAB



#5 Shaft
#9 Shaft
Norite Rock
701 m (2300 ft.) level
1158 m (3800 ft.) level
2 km
Granite Gabbro
1646 m (5400 ft.) level
CN Tower 553 m (1815 ft.)
2073 m (6800 ft.) level
SNO Site

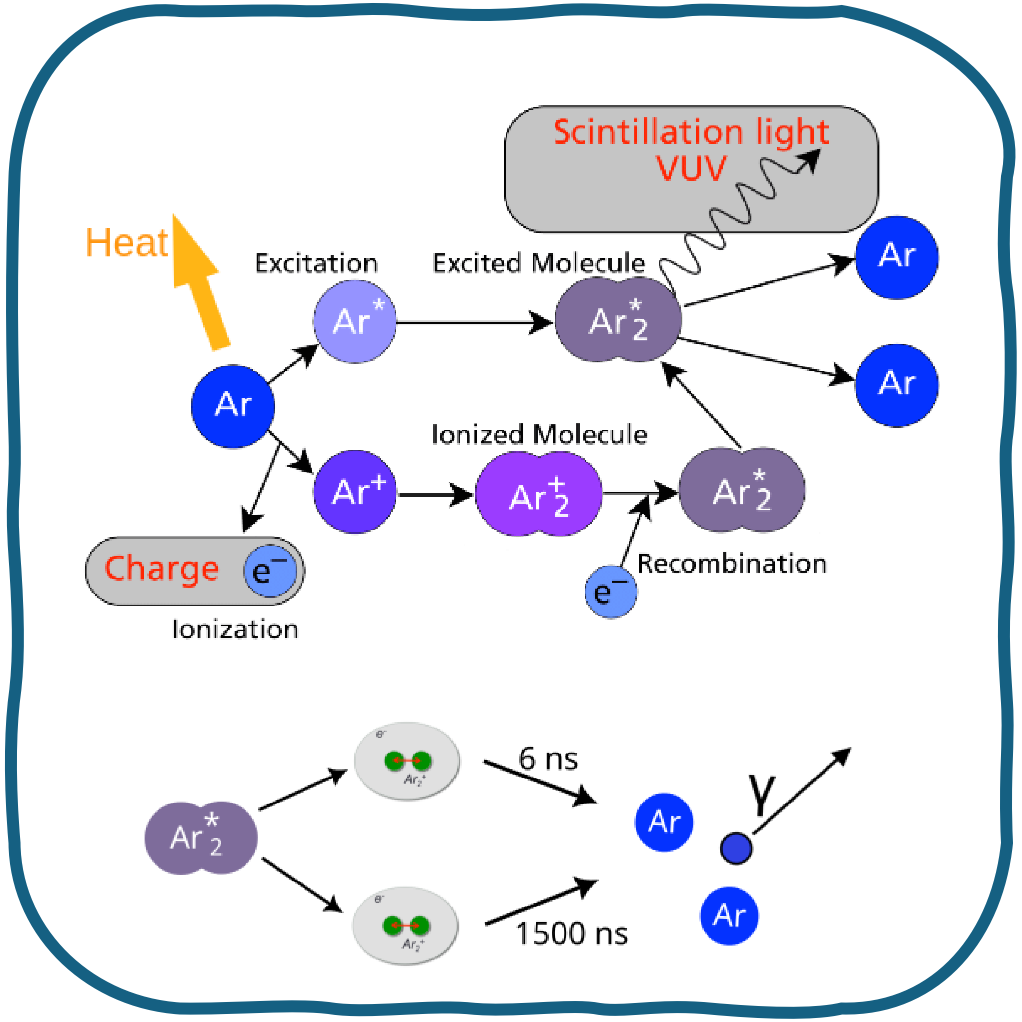


NATIONAL GEOGRAPHIC



Glove box
Central support assembly (Deck elevation)
Steel shell neck (Outer neck)
Inner neck (green)
Vacuum jacketed neck (orange)
Cooling coil
Acrylic flow guides
48 Muon veto PMTs
255 PMTs & light guides
Acrylic vessel
Steel shell
3600 kg liquid argon
Filler blocks
Foam blocks behind PMTs and filler blocks
Bottom spring support

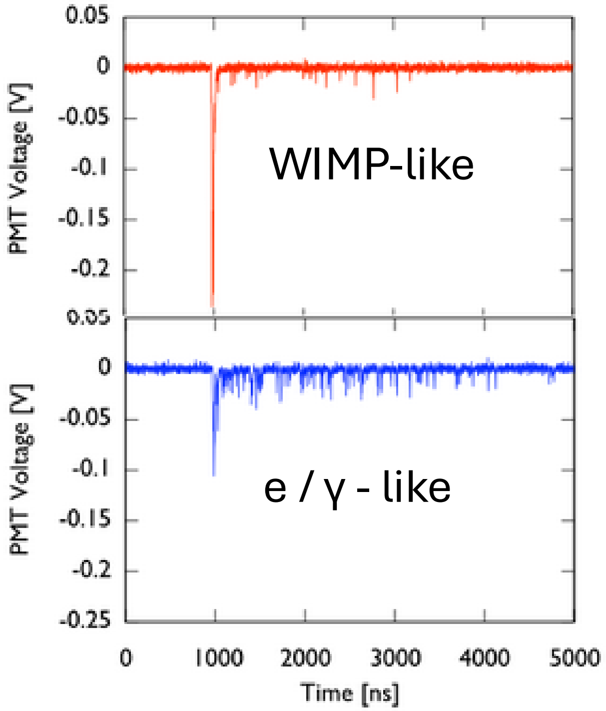
Scintillation in Liquid Argon (LAr) and Pulse shape discrimination (PSD) method

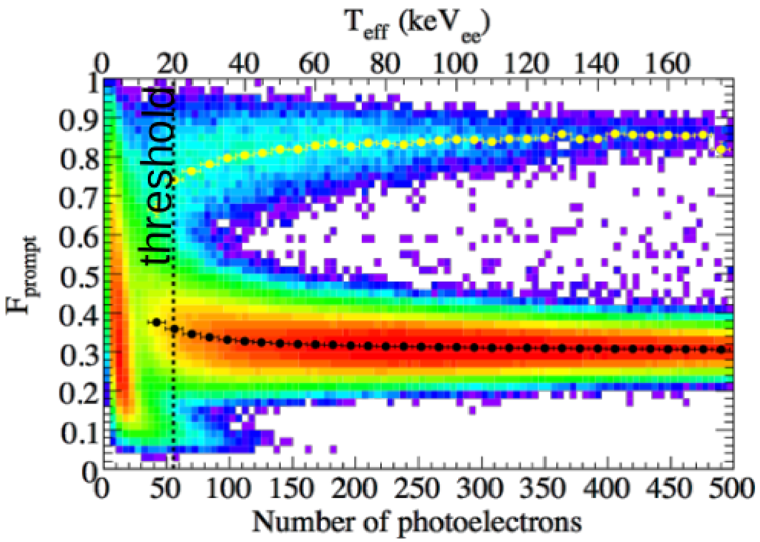


Signal dependence on:

- E field
- **Particle type (or dE/dx)**
- Purity

$$\text{FPrompt} = \frac{N_{prompt}}{N_{prompt} + N_{late}}$$





Electron-induced recoils (ER) are dominated by scintillation light slow component (triplet -> S1 slow).

Highly ionizing Nuclear recoils (NR) are dominated by the fast component (singlet -> S1 fast)

Timeline / Status

02.2015
Construction was completed, taking calibration data with nitrogen gas purge in the detector

08.2016
Data-taking with LAr was started

08.2017
The first dark matter search results with an exposure of 4.44 live days

02.2019
The second dark matter search with over 231 live days from the second fill in 2016-2017

03.2020
End of second run data-taking with LAr

2020
Detector maintenance started

2021-2022
Upgrade:
- PMT DEAP Tank Replacement
- Veto PMT replacement
- High-flow particulate filter
- Flow Guides Assembled @ Carleton

01.2022
Results based on 813 live-days setting constraints for dark matter with Planck-scale mass with mass between 8.3×10^{6} GeV/c^{2} and 1.2×10^{19} GeV/c^{2} and cross section from 1×10^{-23} cm^{2} to 2.4×10^{-18} cm^{2}.

01.2025
DEAP-3600 has completed the hardware upgrades and final commissioning

02.2025
Formal cooldown approval from SNOLAB

Upgrade – Physics Goals

Eliminate Neck events

What:

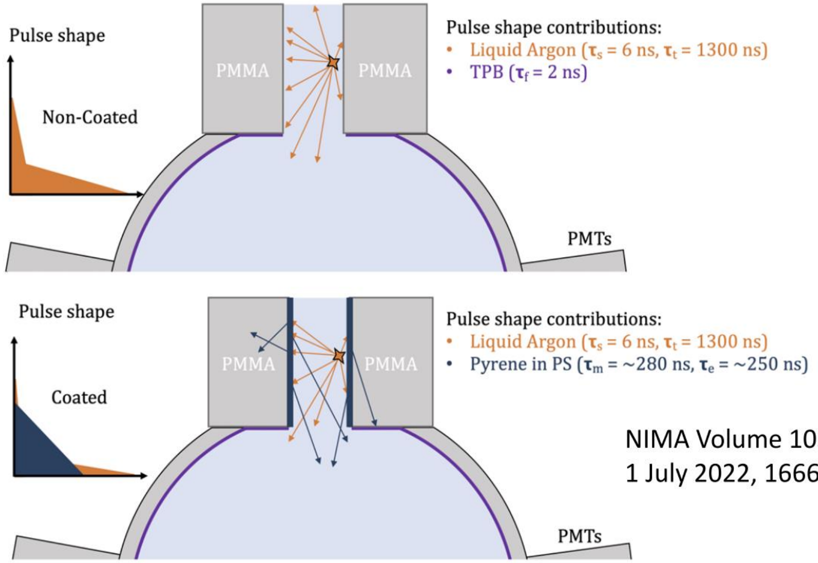
- Alpha scintillation in LAr film/mist covering the flowguides
- Shadowing effect from the flowguides limiting the solid angle

Why:

- Apparent low-energy nuclear recoil events, i.e. high FPrompt bkg. events in WIMP ROI

How:

- Rebuild the neck with WLS (pyrene) coatings on the flowguide. WLS coating produces a significantly different PSD that can be tagged very effectively



NIMA Volume 1034,
1 July 2022, 166683

Filter particulates from LAr

What:

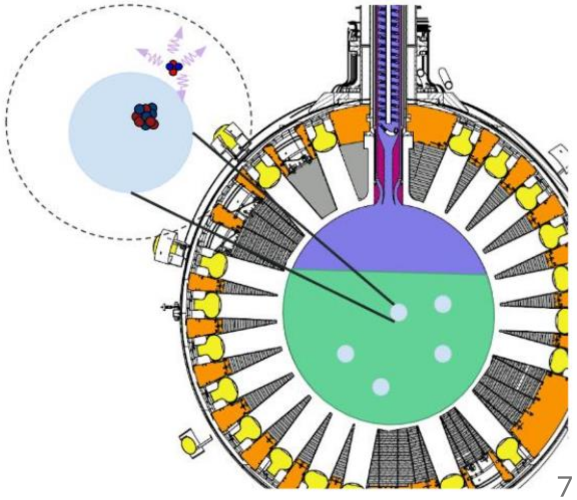
- Evidence for presence of dust particulates in LAr in the detector.

Why:

- Originally installed LAr filtration loop could not be used for technical reasons
- Alpha decays in dust particles can create high Fprompt and shadowed events, mimicking WIMP events

How:

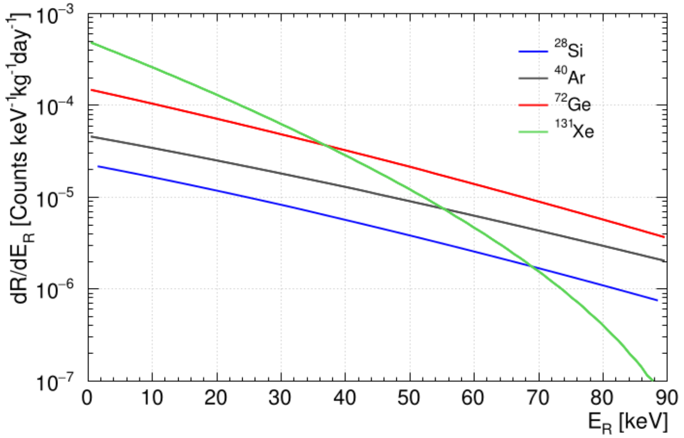
- Improvements to the Ar process system to filter particulates and accommodate the external cooling.
- Reduction in dust background via LAr removal and filtration



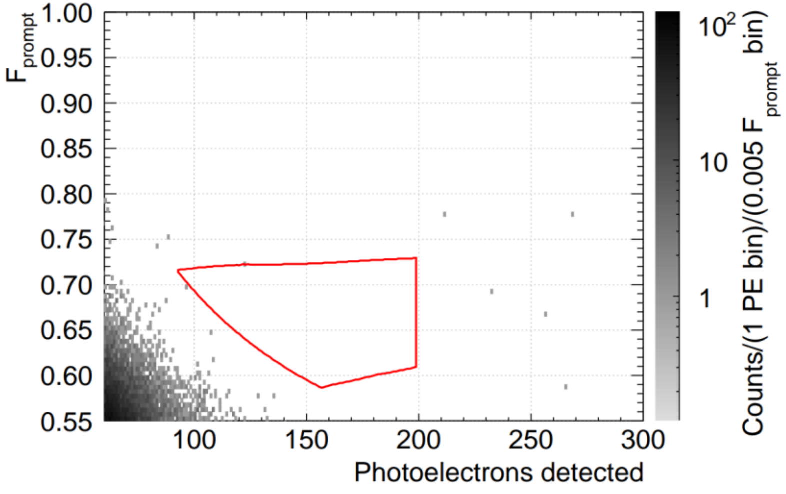
PLR WIMP DM search - overview

Goal: set up new upper limit on the WIMP-nucleon spin-independent cross section as a function of WIMP mass for LAr detectors

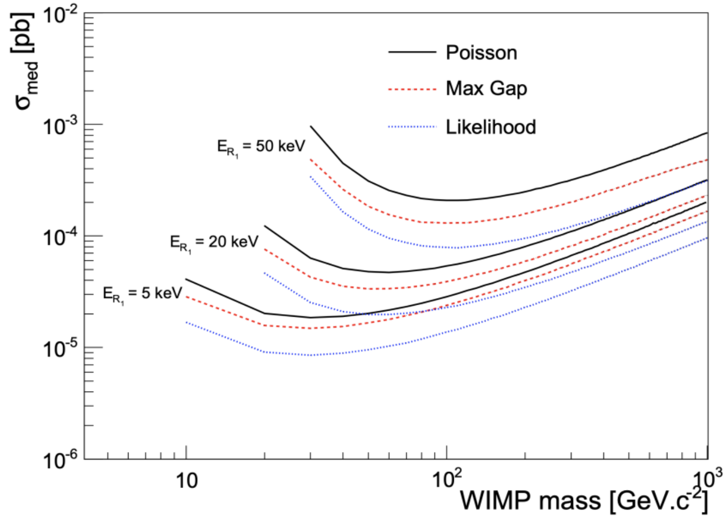
Expected energy distribution of WIMPs as a function of their recoil energy (i.e. differential nuclear recoil rate) for MC of 100 GeV DM and cross section of 10^{-44} cm^2 we can calculate



The WIMP ROI is defined in the two-dimensional PE-Fprompt (i.e. Energy vs Pulse Share Discriminator / PSD) plane. Since the PLR analysis is not a zero-background approach, the ROI bounds can be relaxed compared to a cut-and-count analysis, to enhance sensitivity.



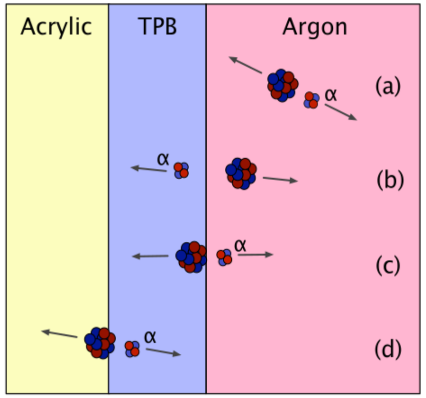
To boost sensitivity Profile Likelihood Ratio (PLR) approach is used. In PLR signal p-value can by calculated from PDF of the test statistics defined by ratio of likelihoods of the alternate hypothesis (there is DM) to the likelihood of the null hypothesis (there is no DM).



Pictures by Ashlea Kemp, PhD Thesis (left & right) and 10.1103/PhysRevD.100.022004 (center)

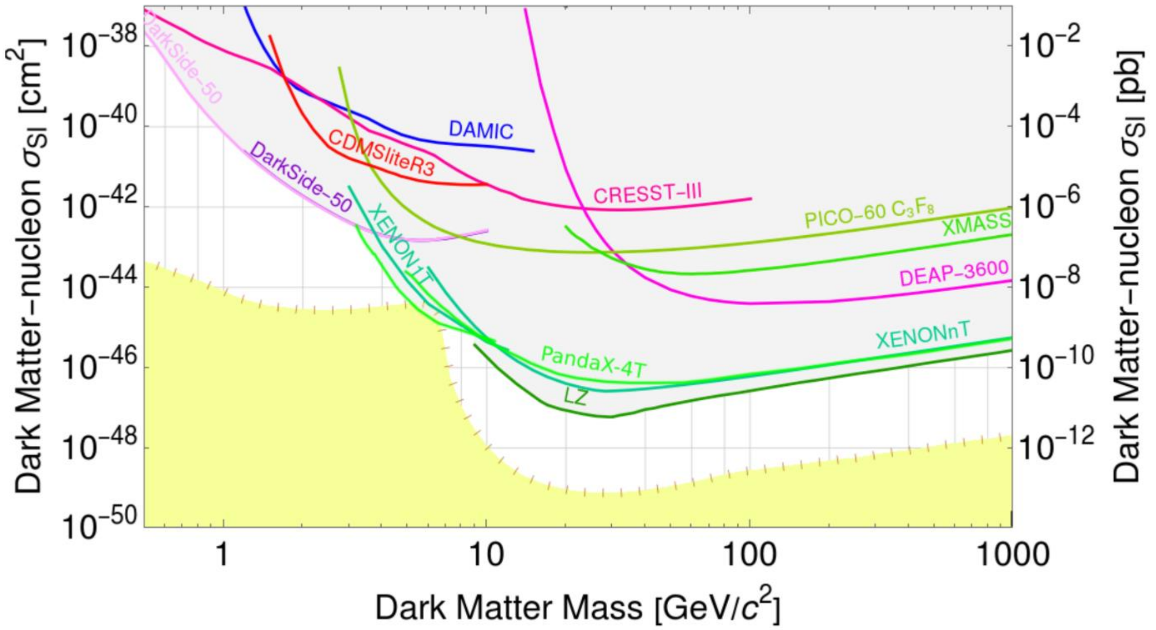
WIMP - Backgrounds and signal variables / Region of Interest (ROI)

- ^{39}Ar β-decays – long-lived isotope present in target volume, highest trigger rate at DEAP-3600, used for detector energy response calibration;
- Surface α-decays – radioactive isotopes (mainly ^{222}Rn, ^{238}U, ^{232}Th, ^{210}Pb) from acrylic vessel and TPB coating;



- Neck α-decays – like above but coming from surfaces of the flow guides in the neck. Put separately as fiducialisation not efficient here.
- Dust α-decays – metallic/residual acrylic/rock dust circulating within the LAr target
- Radiogenic background – neutrons coming from the rock around the laboratory

Observed 90% CL upper limit on the WIMP-nucleon spin-independent cross section [cm2] as a function of WIMP mass [GeV/c2]



We are finalizing a profile-likelihood ratio search analysis on the 2016-2020 dataset. Sensitivity improvements will come from a larger fiducial volume and a more detailed background model.

Ar-39 half-life

- Direct observation of the decay curve

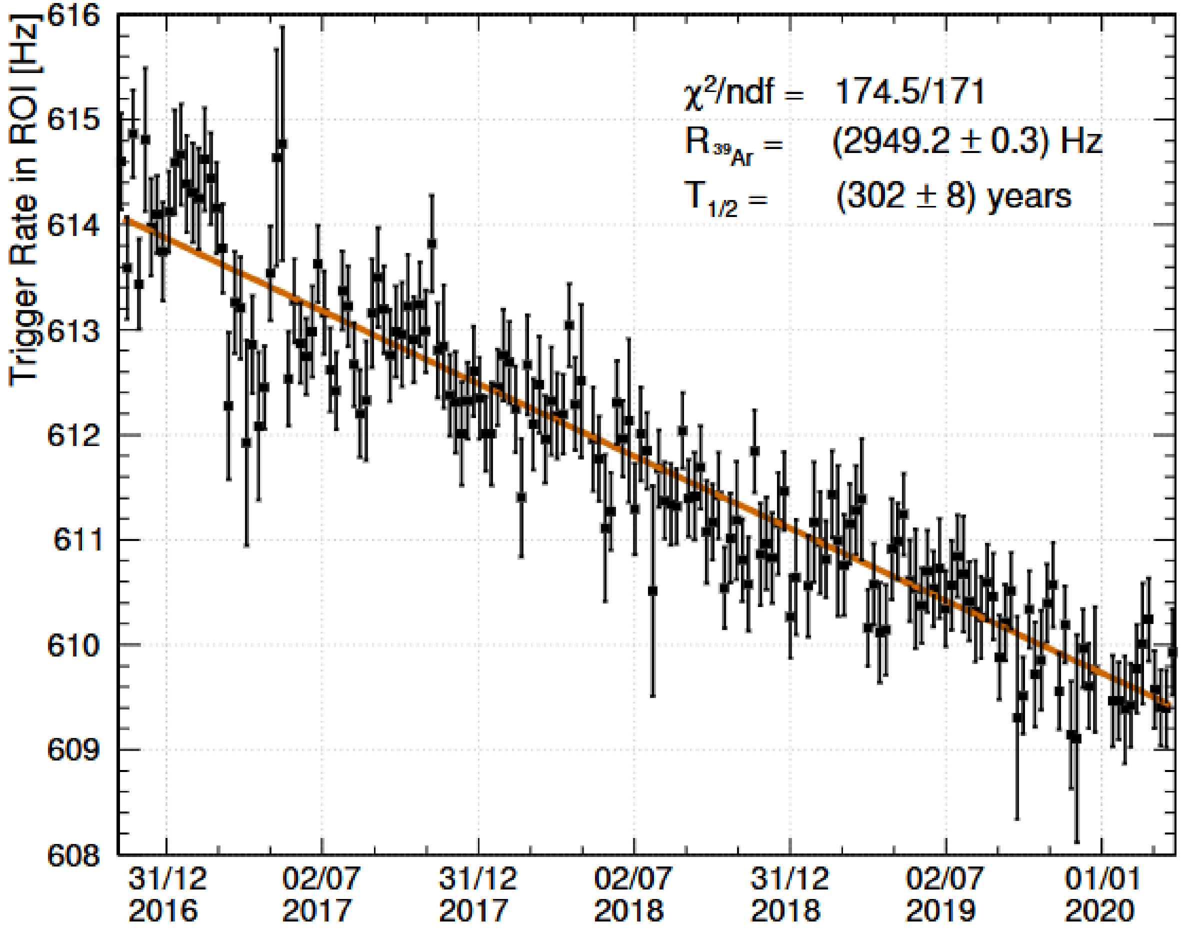


Fig. 7 The trigger rate fit for the full dataset. Each point here represents the rates averaged over a one week period. The best-fit values of R_{39Ar} and $T_{1/2}$ are shown with statistical uncertainties only.

Ar-39 half-life

- Data taken over a period of 3.4 years
- A subset of the full energy spectrum between 700 and 1200 PE (approximately 115 keV to 195 keV) is selected for analysis.
- The lower limit at 700 PE is selected to be well above the prescaling boundary at around 500 PE.
- The upper limit at 1200 PE is selected to reject any systematic effects resulting from saturation of the PMTs.
- The limit of Fprompt ≤ 0.41 is made to reject events outside of the ERB (Electron Recoil Band)

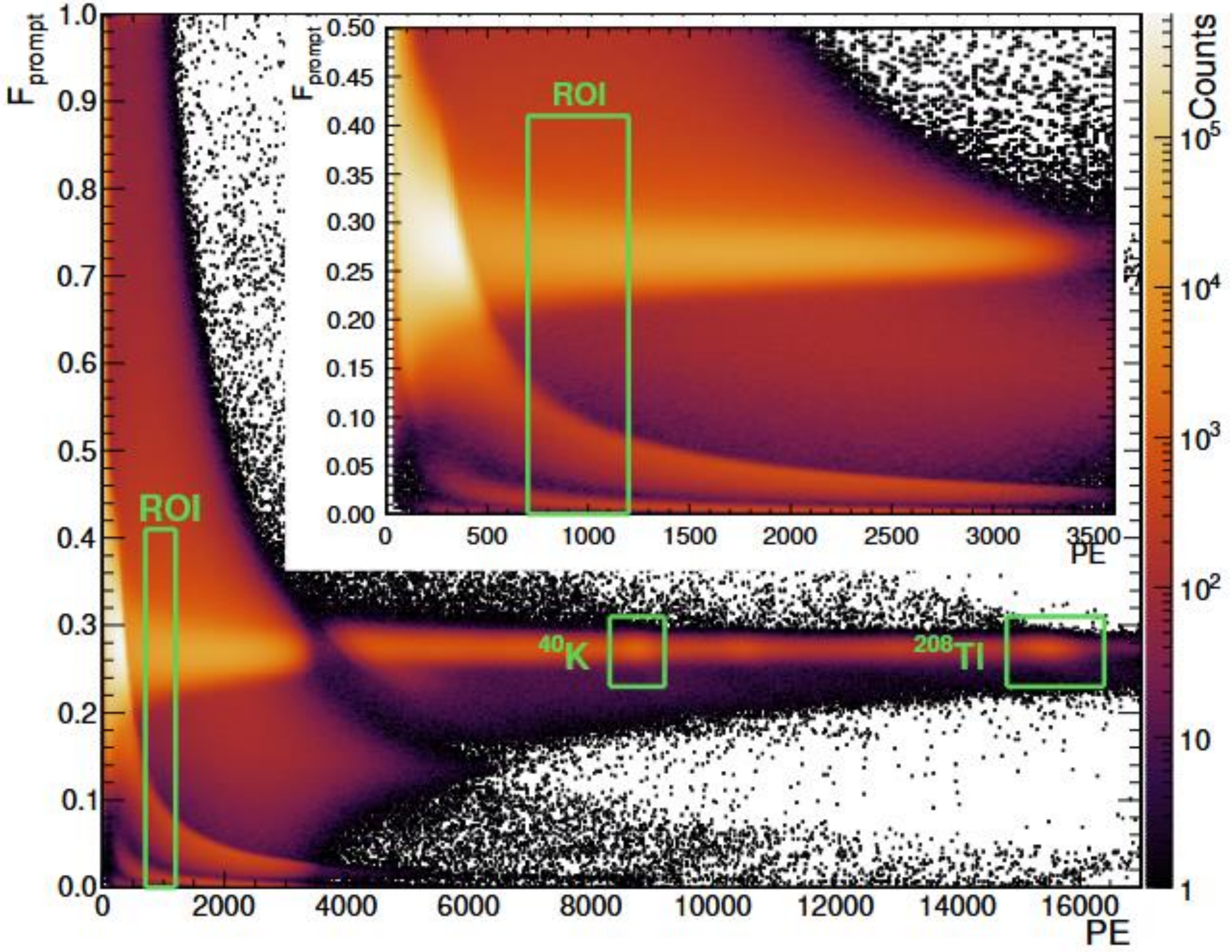


Fig. 3 Histogram of F_{prompt} versus the number of observed PE. The ROI is highlighted in the left-most box for ∼20 days of data. All the events in the ROI are within the prescaled region. The regions labeled ^{40}K and ^{208}Tl highlight the γ-peak positions of those isotopes. The events within the ROI at $F_{prompt} < 0.15$ are due to pile-up and are accounted for in the analysis.

Ar-39 half-life measurement

In addition to impacting measurements sensitive to this isotope's half-life, such as studies of meteorites, this result is relevant for future experiments using atmospheric argon.

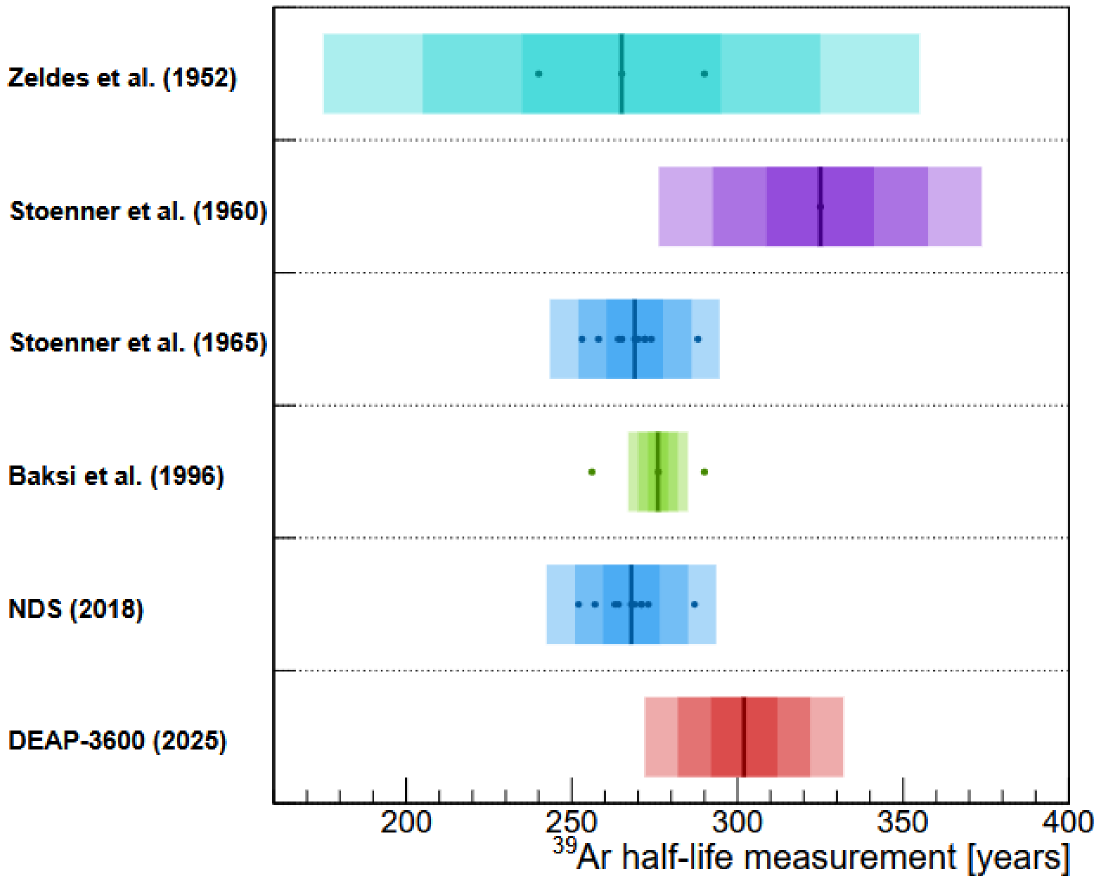


Table 1 A comparison of existing ^{39}Ar half-life measurements with this result.

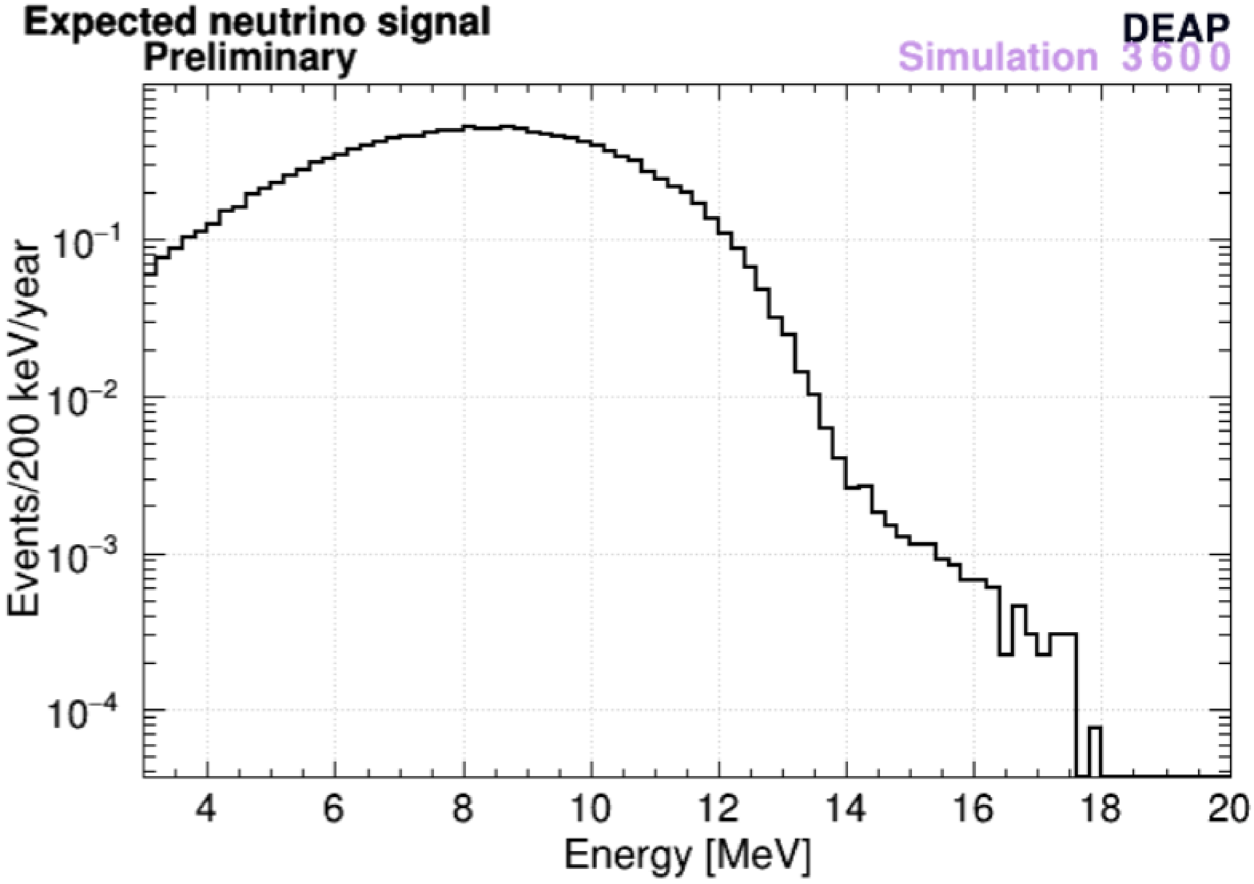
Measurement	Half-life [years]	Method
Zeldes et al. (1952)	265 ± 30	Isotopic ratios of argon samples using mass spectrometry
Stoenner et al. (1960)	$325 \pm 16^{\dagger}_{stat}$	Activity ratios of ^{39}Ar to ^{37}Ar
Stoenner et al. (1965)	$269 \pm 3_{stat} \pm 8_{sys}$	Activity ratios of ^{39}Ar to ^{37}Ar
Baksi et al. (1996)	$276 \pm 3_{sys}$	Isotopic ratios of ^{39}Ar to ^{38}Ar in a double-spike using mass spectrometry
NDS (2018)	$268 \pm 8_{sys}$	Re-evaluation of the Stoenner et al. (1965) result with an updated ^{37}Ar half-life
DEAP-3600 (2025)	$302 \pm 8_{stat} \pm 6_{sys}$	Direct observation of the decay curve

†Estimated from uncertainty on the measured count rates.

Submitted to EPJ C
arXiv 2501.13196

First direct Argon-39 measurement

Boron-8 solar neutrinos



The rare β decay of Boron-8 produces high-energetic continuous spectrum of neutrino energies that extends to 15 MeV. It's main source of solar neutrinos with energies above 2 MeV

$$^{8}\mathrm{B} \rightarrow {}^{8}\mathrm{Be} + e^{+} + \nu_e$$

<u>This reaction has never been observed.</u>
Our measurement will be the first: allows experimental constraint on the cross section.

<u>Journal publication draft is advanced</u>

Summary

- DEAP-3600 hardware upgrades completed, starting cooldown;
- PLR WIMP and Boron-8 solar neutrinos searches in final stage;
- New Ar-39 half-life result published.

Thank you!