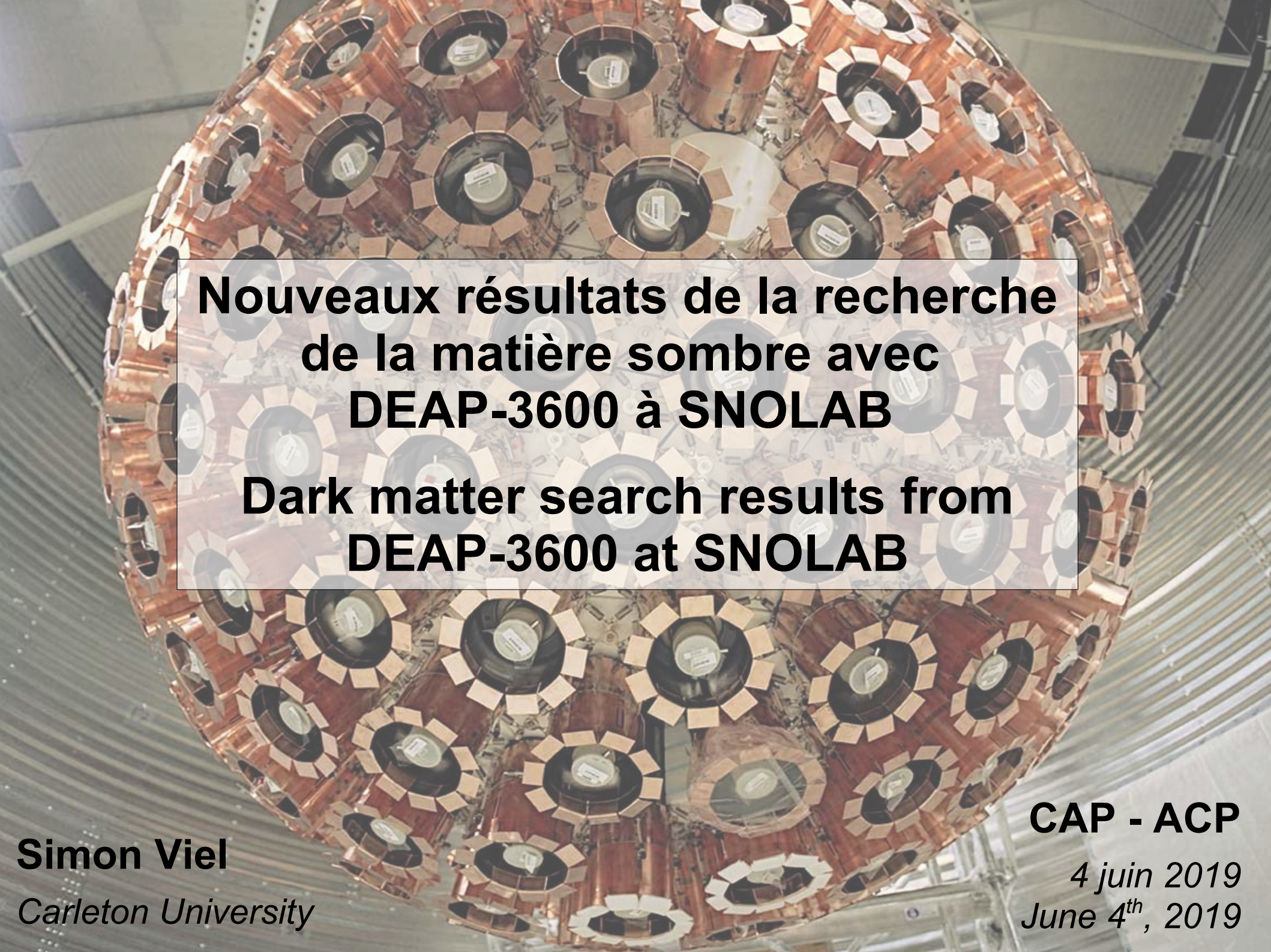


Nouveaux résultats de la recherche de la matière sombre avec DEAP-3600 à SNOLAB

Dark matter search results from DEAP-3600 at SNOLAB

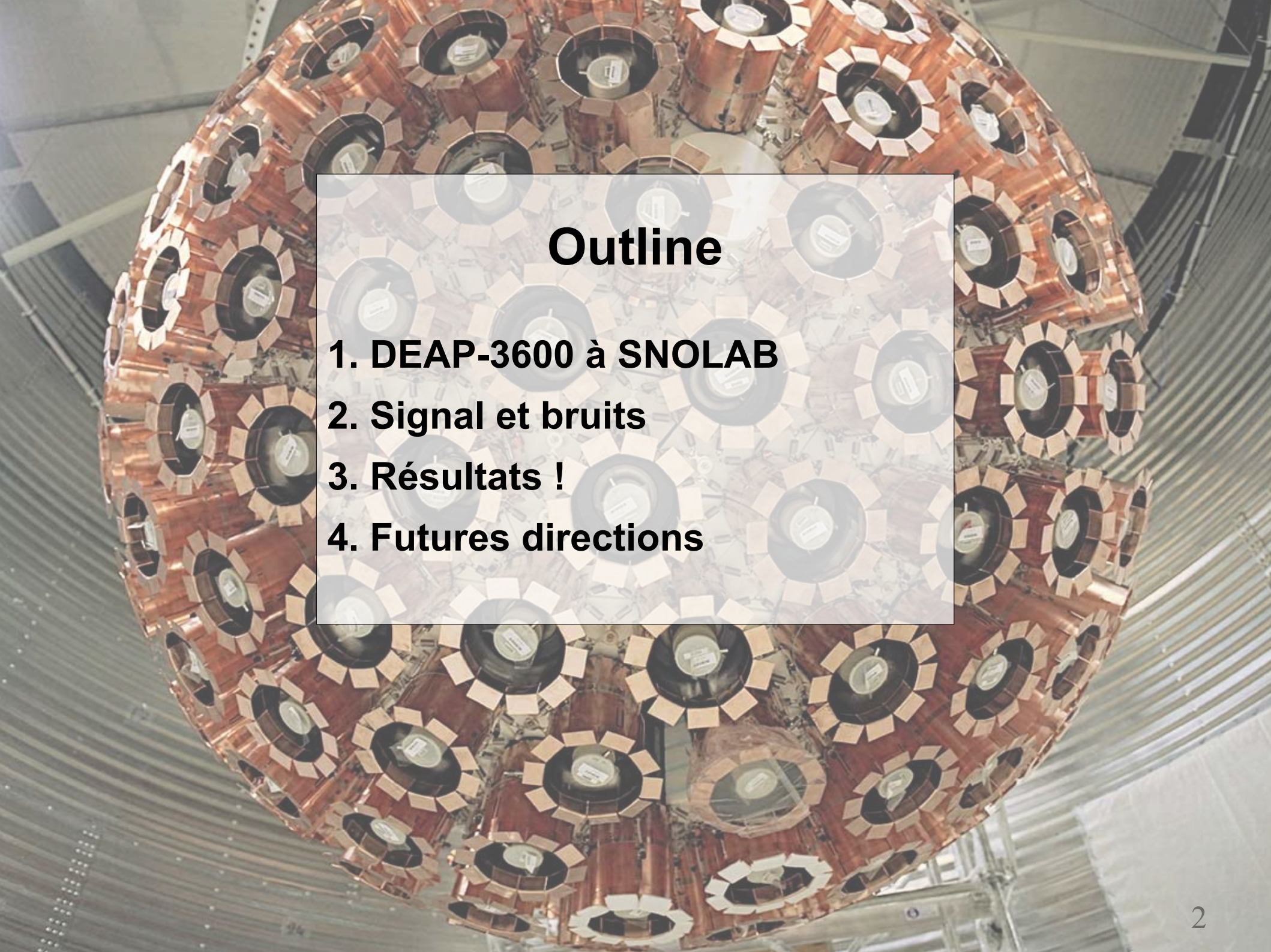
Simon Viel

Carleton University

CAP - ACP

4 juin 2019

June 4th, 2019



Outline

1. DEAP-3600 à SNOLAB
2. Signal et bruits
3. Résultats !
4. Futures directions

DEAP Collaboration:

80 researchers in **Canada**, Germany, Italy, Mexico, Russia, Spain, UK, USA

University of Alberta

Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens

Carleton University

Ciemat

Laurentian University / Université Laurentienne

Instituto de Física

INFN Istituto Nazionale di Fisica Nucleare

National Research Center "Kurchatov Institute"

Princeton University

Queen's University

Royal Holloway University of London

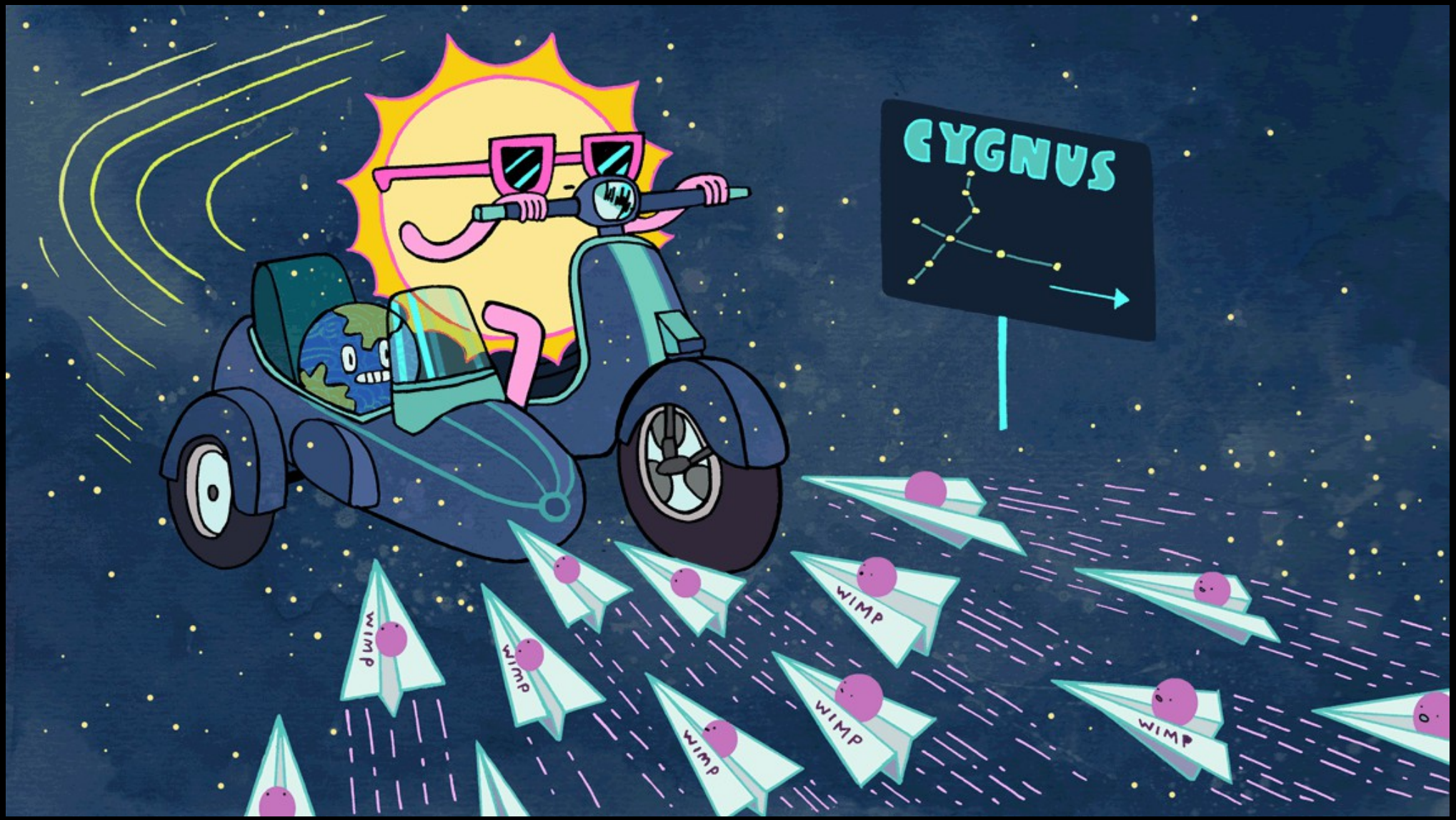
Particle Physics Rutherford Appleton Laboratory

SNOLAB

University of Sussex

Technical University of Munich

TRIUMF



Riding in the Dark Matter Wind

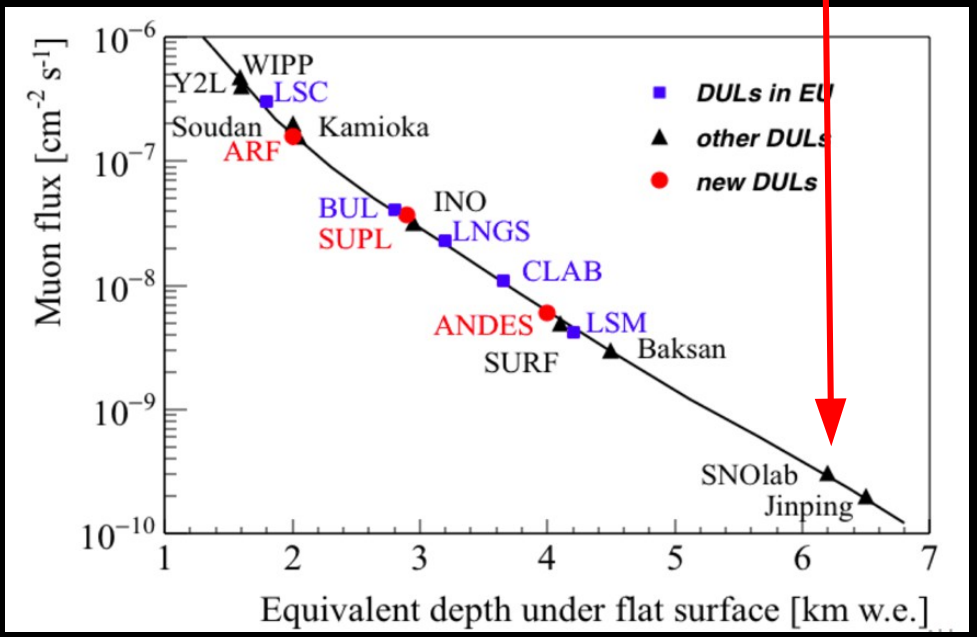
Source: Symmetry Magazine – Artwork by Sandbox Studio, Chicago with Corinne Mucha

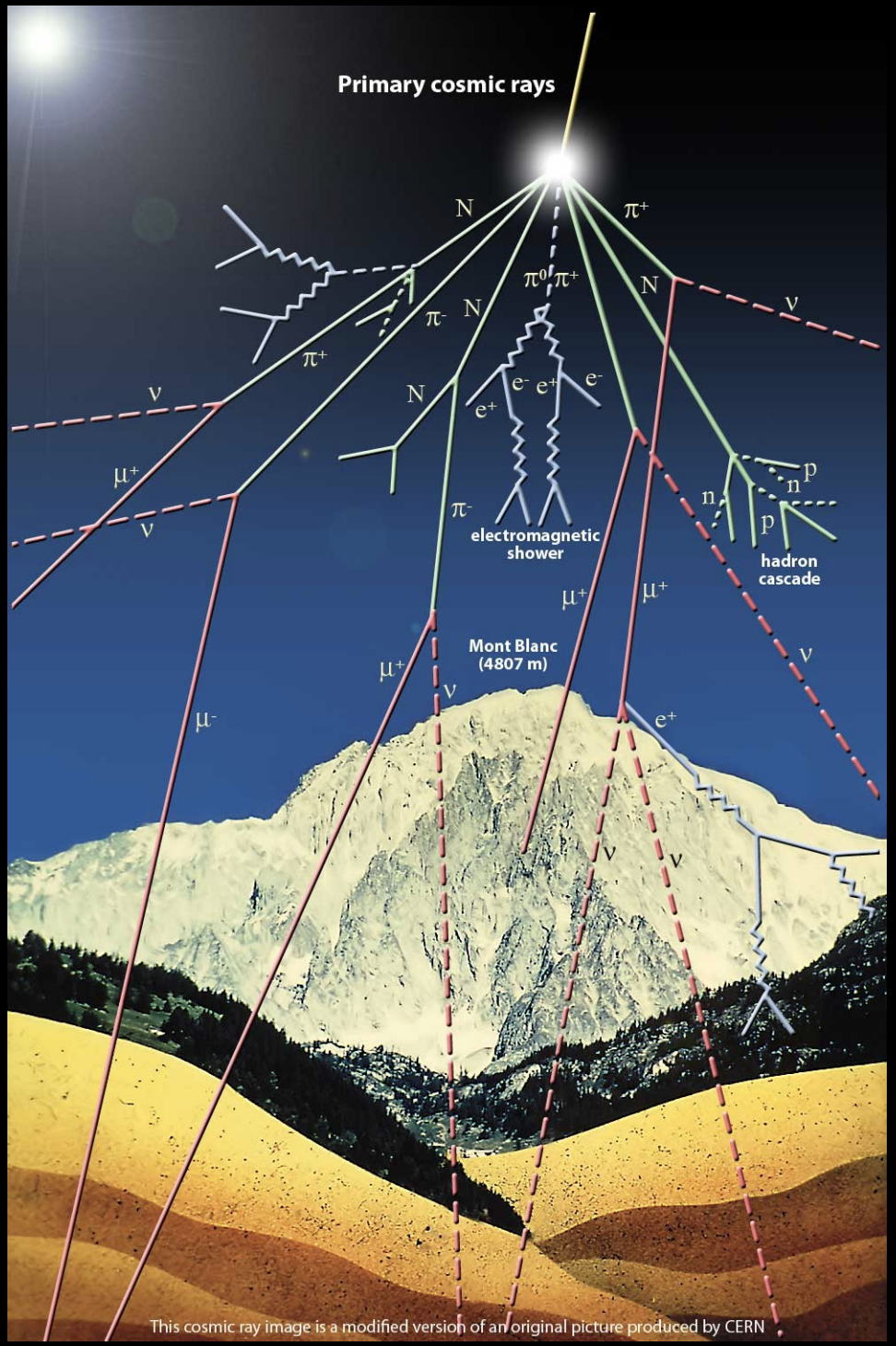
Why go underground?

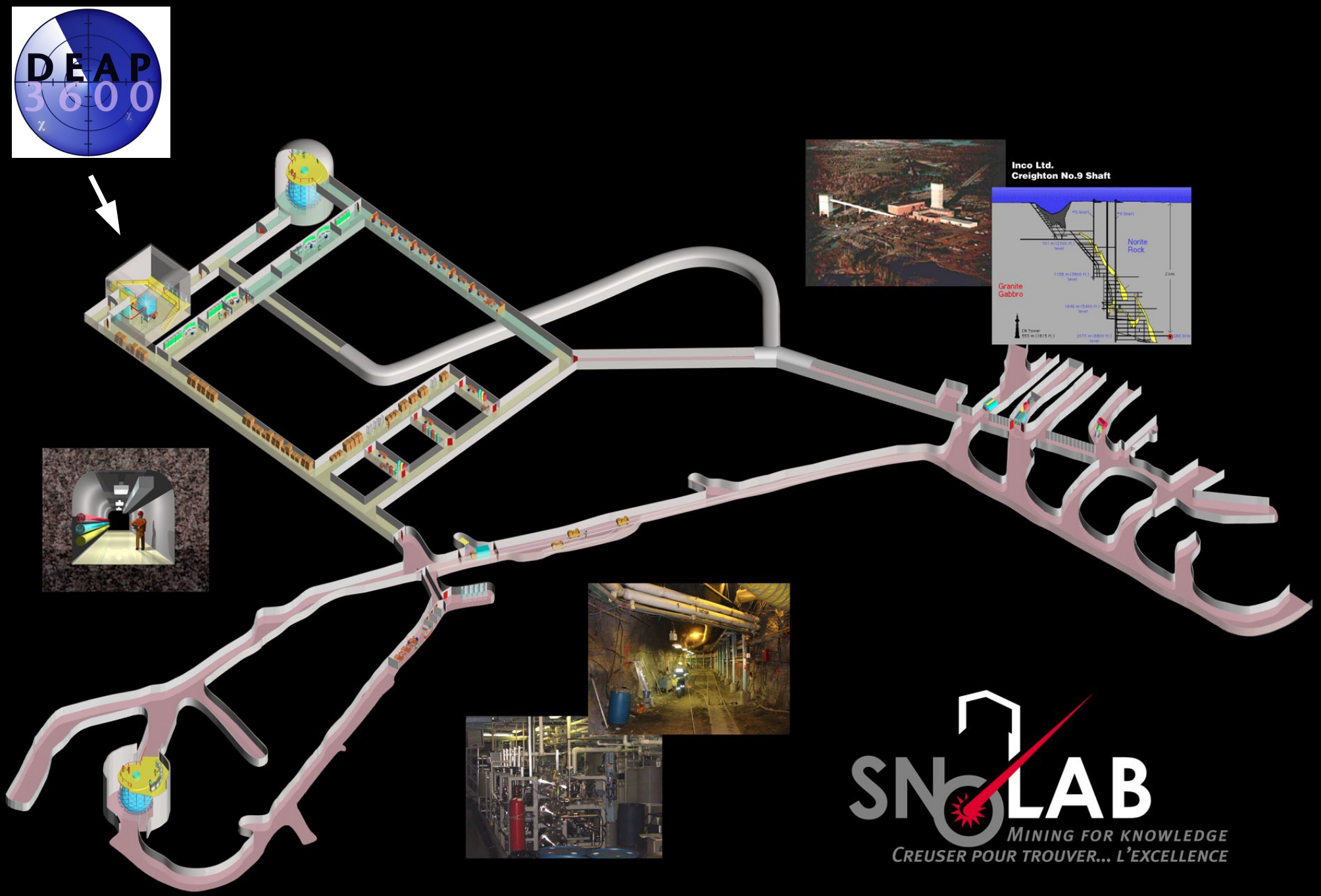
To shield detectors against cosmic rays

Surface:
~ 1 muon / cm² / minute
~ 14.4 million muons / m² / day

SNOLAB:
0.27 muons / m² / day





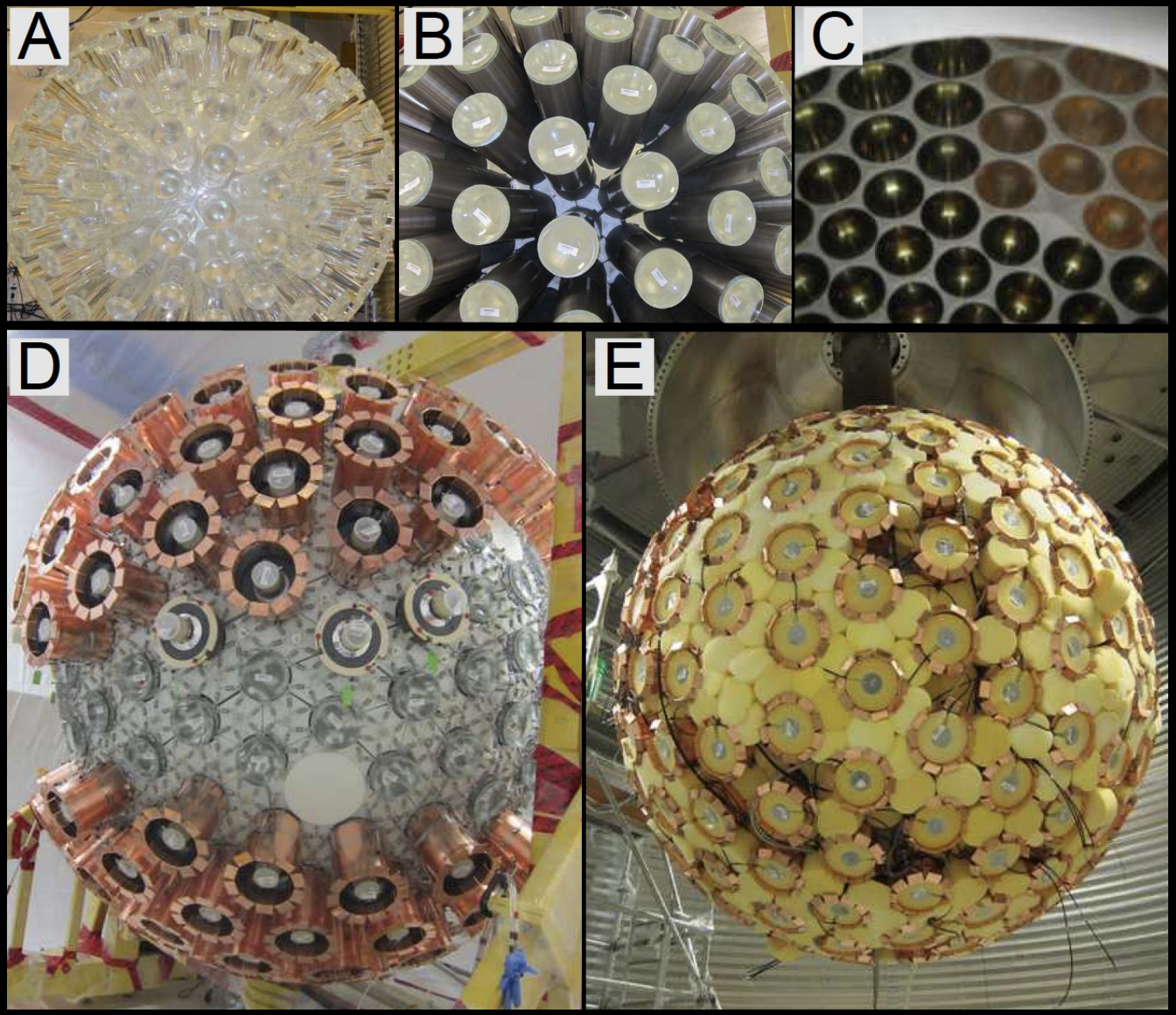


Video: A Day at SNOLAB
https://www.snolab.ca/outreach

2070 m underground

Acrylic vessel underground at SNOLAB

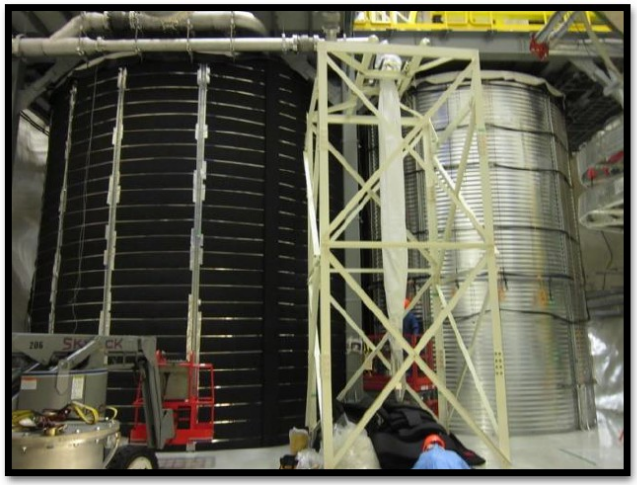
Light guides Reflectors Inside view

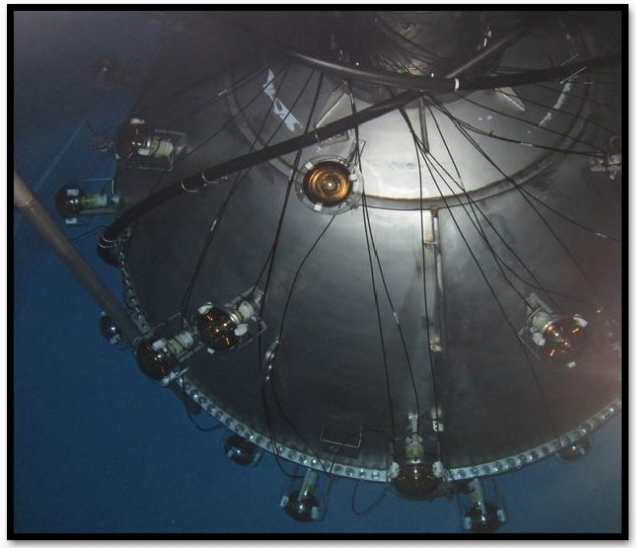


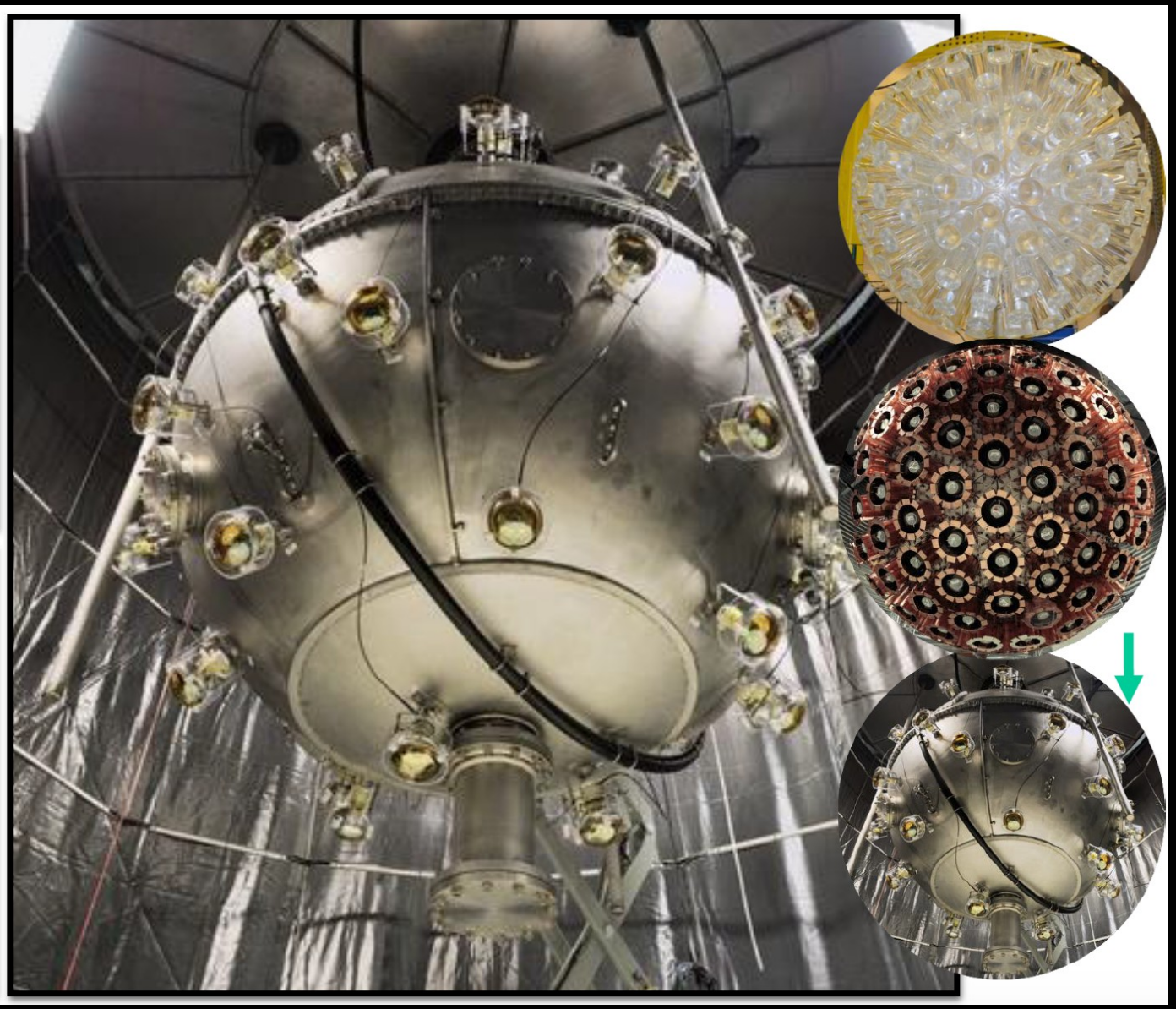
PMTs installation Backing foam installation

Steel shell, Veto PMTs

Water tanks in Cube Hall

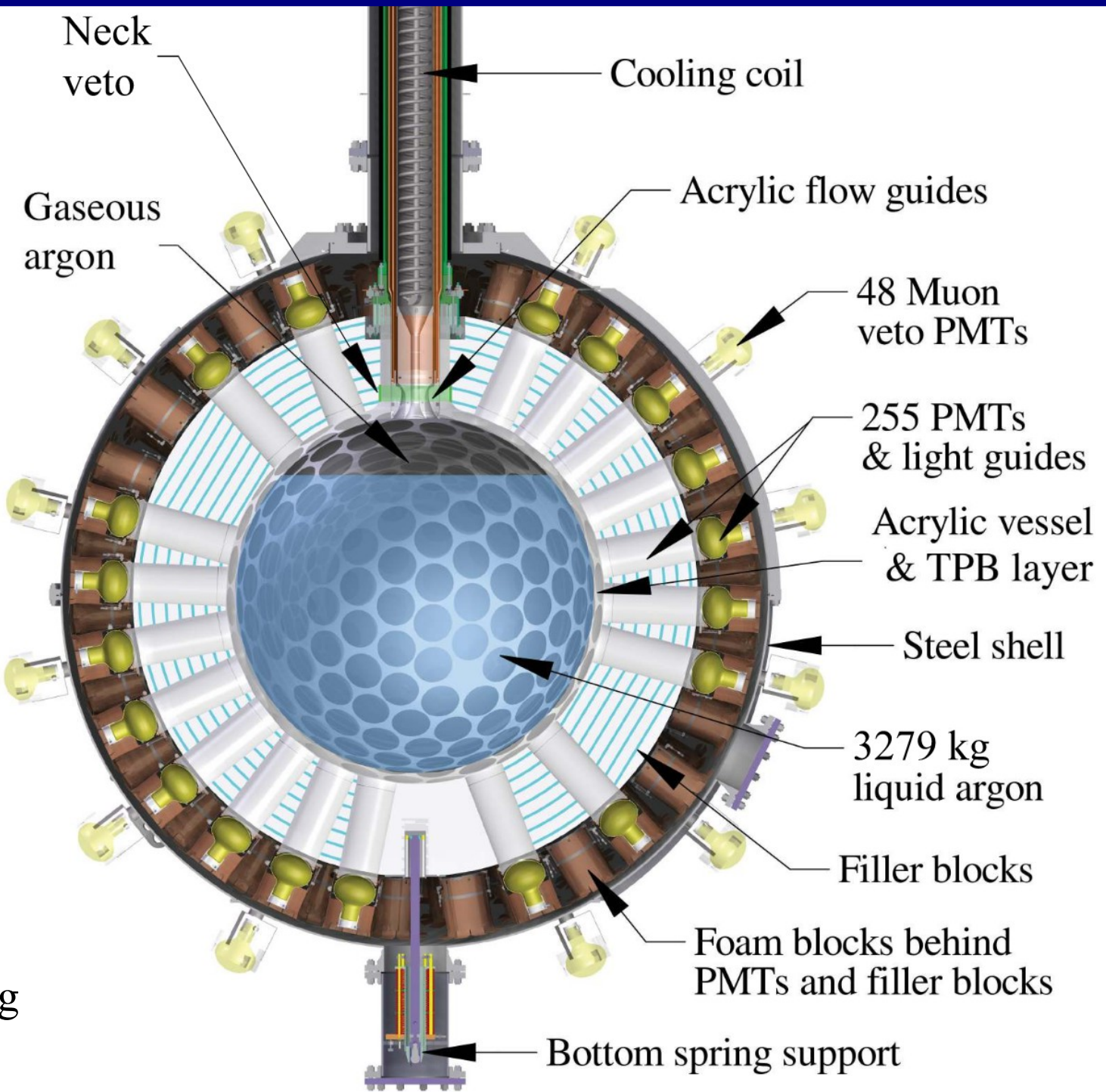






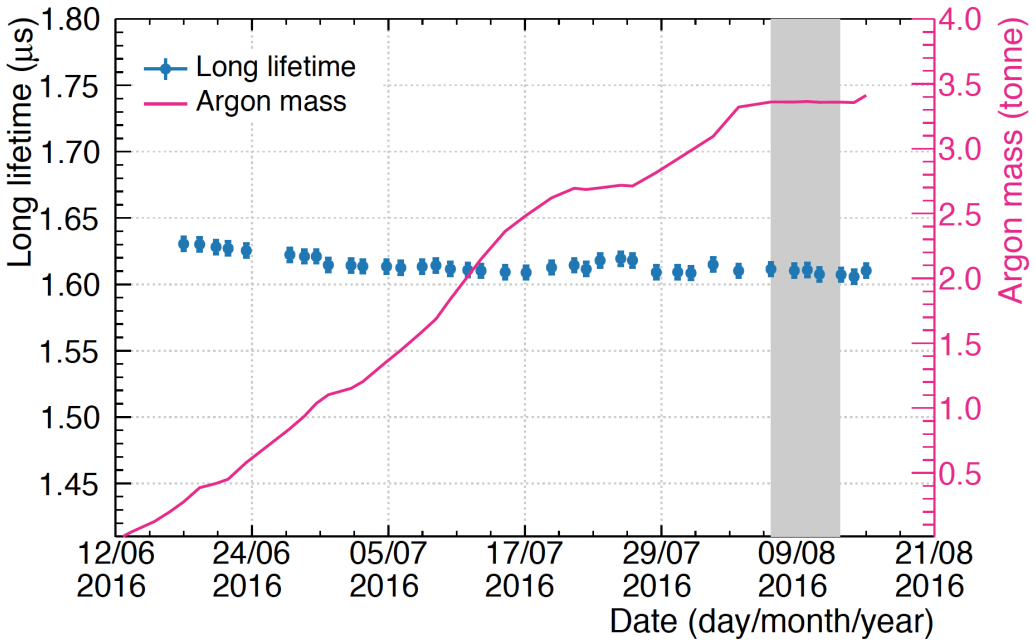
All details available in the DEAP-3600 detector publication!
Astroparticle Physics 108 (2019) 1-23. arXiv:1712.01982

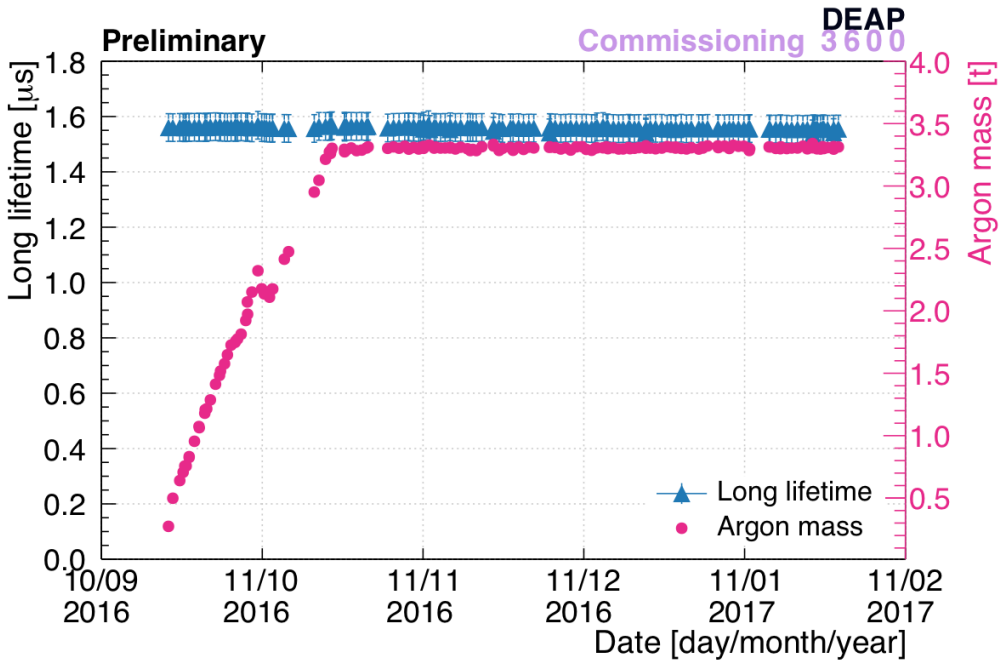
Dark matter Experiment using Argon Pulse-shape discrimination



Water shielding

DEAP-3600: Datasets





First fill dataset
August 2016

3322 kg LAr
4.4 live-days passing data quality

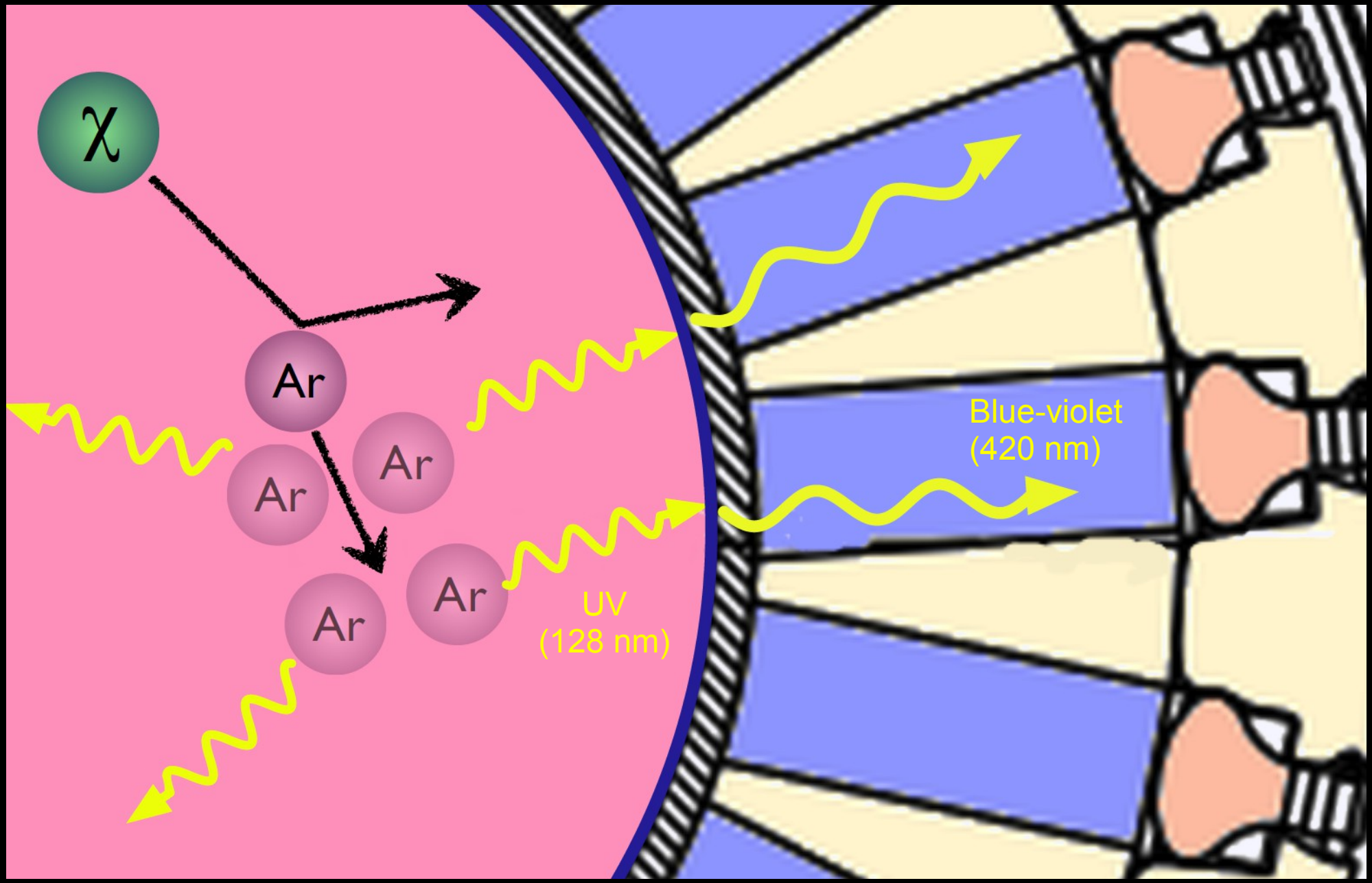
Phys. Rev. Lett. 121, 071801 (2018)
arXiv:1707.08042

Second fill: **First year dataset**
November 2016 – October 2017

3279 kg LAr
231 live-days passing data quality

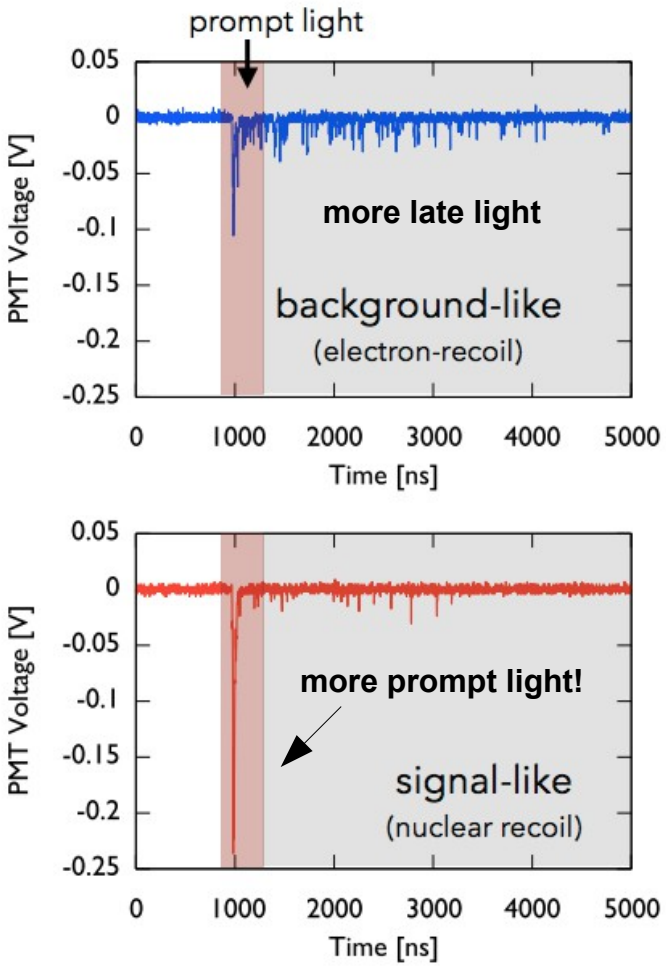
arXiv:1902.04048, submitted to PRD
arXiv:1905.05811, submitted to PRD

- DEAP-3600 stable data collection with 3279 kg of LAr since November 1st, 2016
  - Working on DM search with full second-fill data (80% blind since January 2018)


χ
Ar
Ar
Ar
Ar
Ar
UV
(128 nm)
Blue-violet
(420 nm)

Pulse-Shape Discrimination

Dark matter search objective: **select signal events**, and <u>reject background events</u>



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

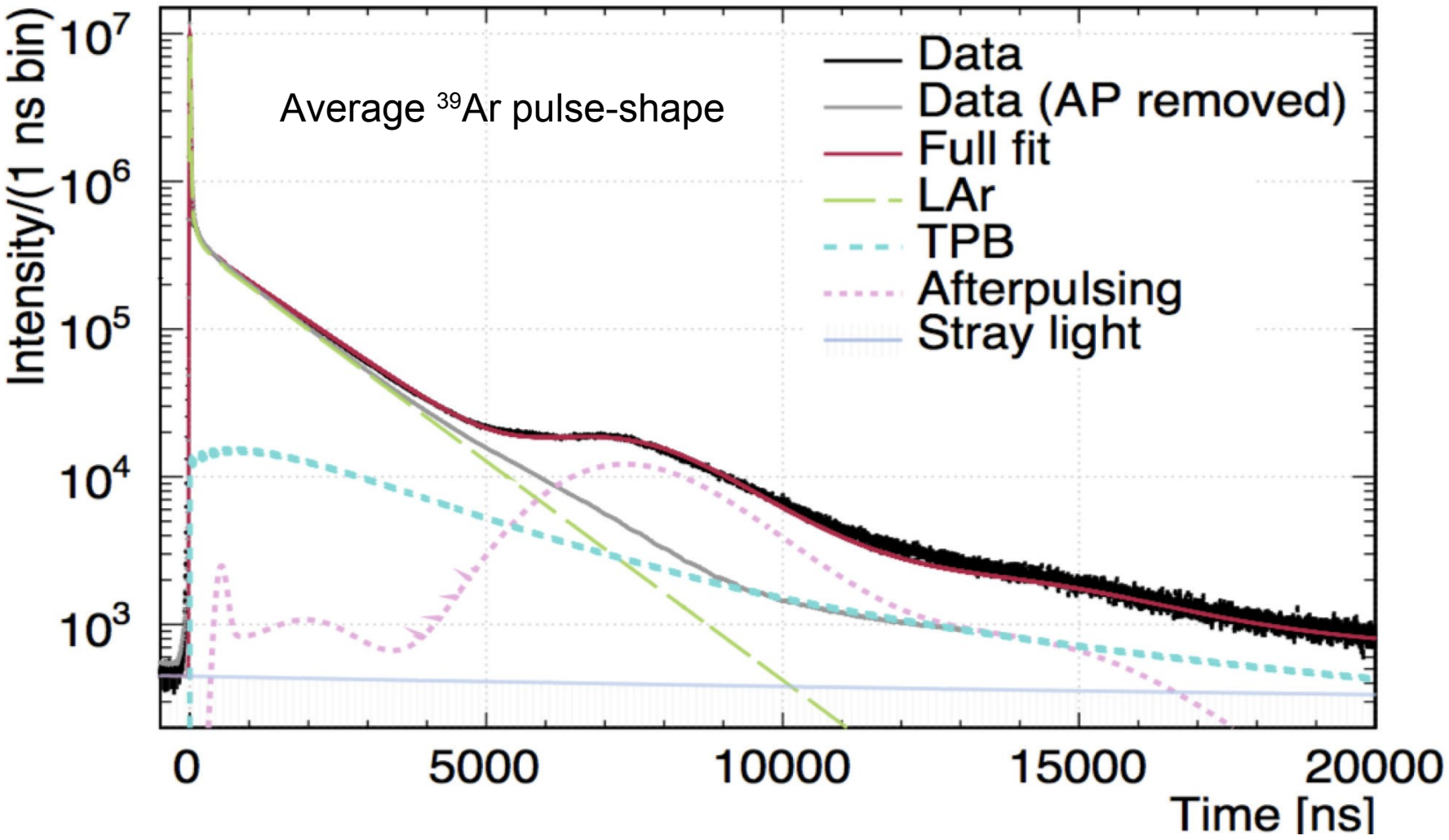
- Liquid argon is suitable for very large targets
  - Transparent to its own scintillation light
  - Easy to purify
  - Much lower cost compared to xenon

... but there is **^{39}Ar**: β decays with $t_{1/2}$ = 269 years, around 1 Bq/kg in natural argon

- Solution: **Pulse-shape discrimination** (PSD)
  - Scintillation via two lowest excited states, with very different lifetimes
    - Singlet state: **6 ns** (“prompt light”)
    - Triplet state: **1.3 µs** (“late light”)
  - Nuclear recoils excite predominantly the singlet state: **signal events have more prompt light** !

[Also see Astroparticle Physics 85 (2016) 1-23]

Pulse-Shape Discrimination

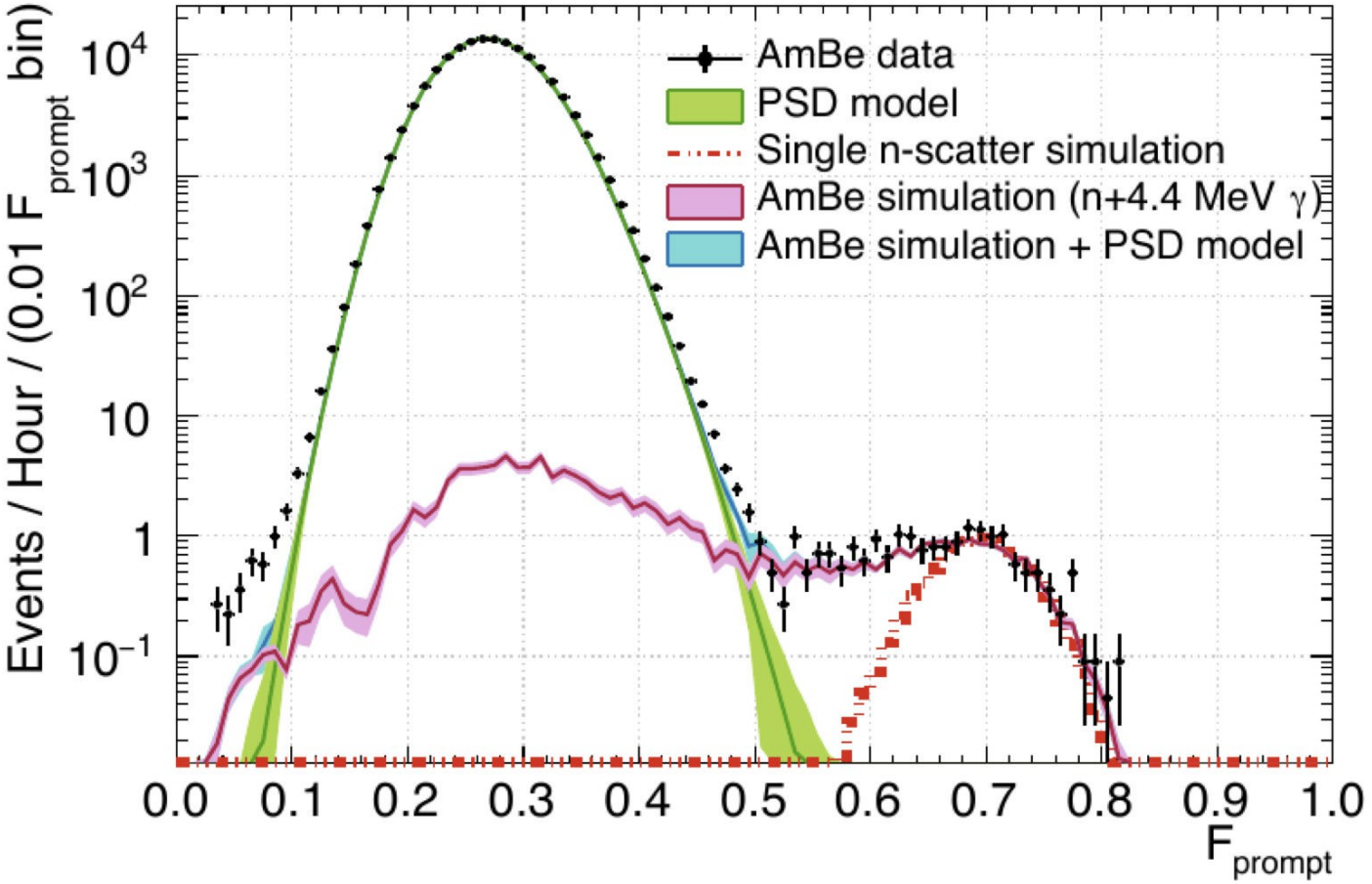


Visible photons → Photoelectrons at PMT cathode → PMT pulses

New Bayesian algorithm to remove instrumental PMT afterpulsing ("AP removal") results in improved PSD, energy reconstruction, and position reconstruction

Pulse-Shape Discrimination

Neutron source calibration data

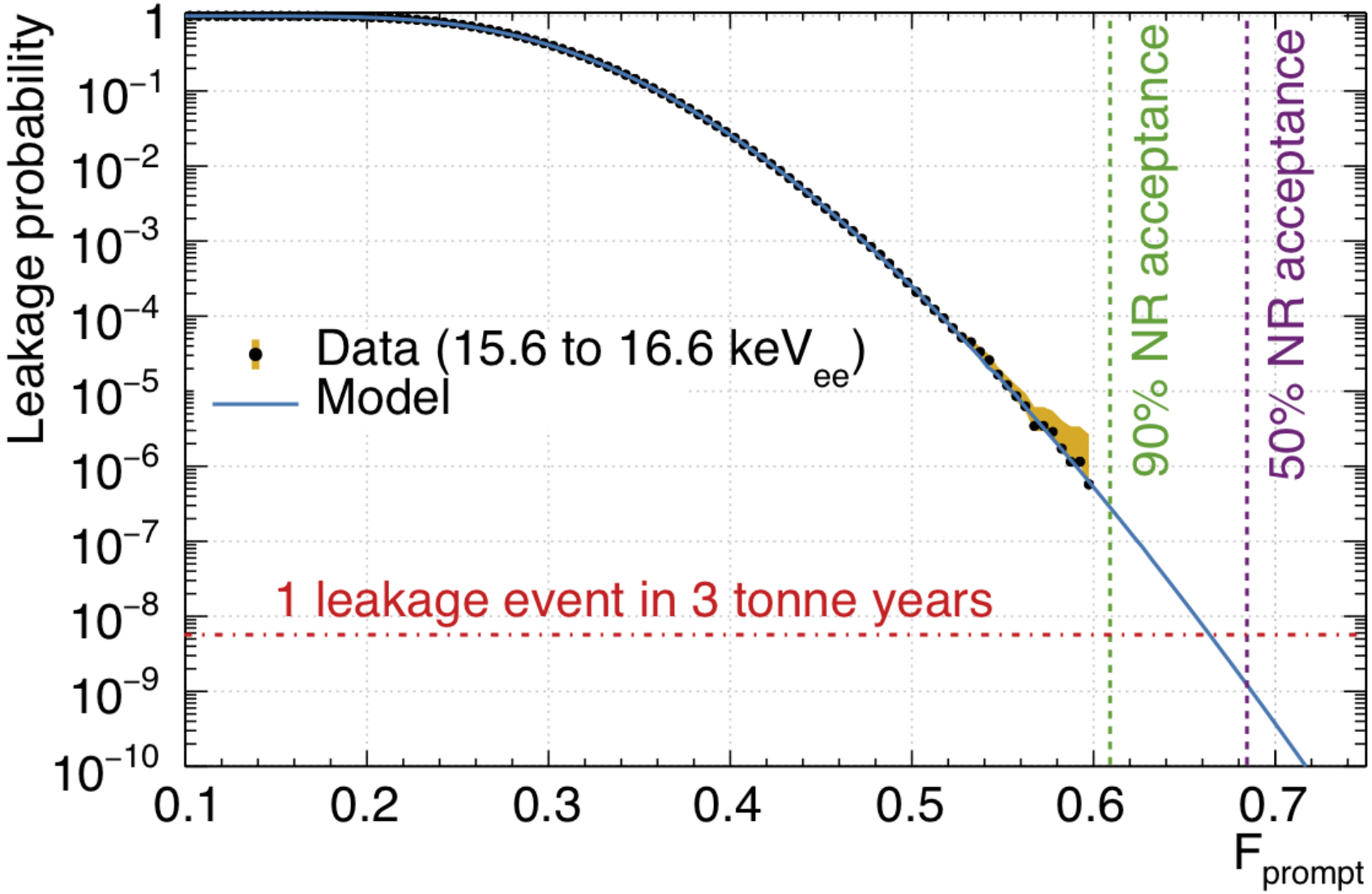


Background-like
(electron recoils, ^{39}Ar)

Signal-like
(nuclear recoils)

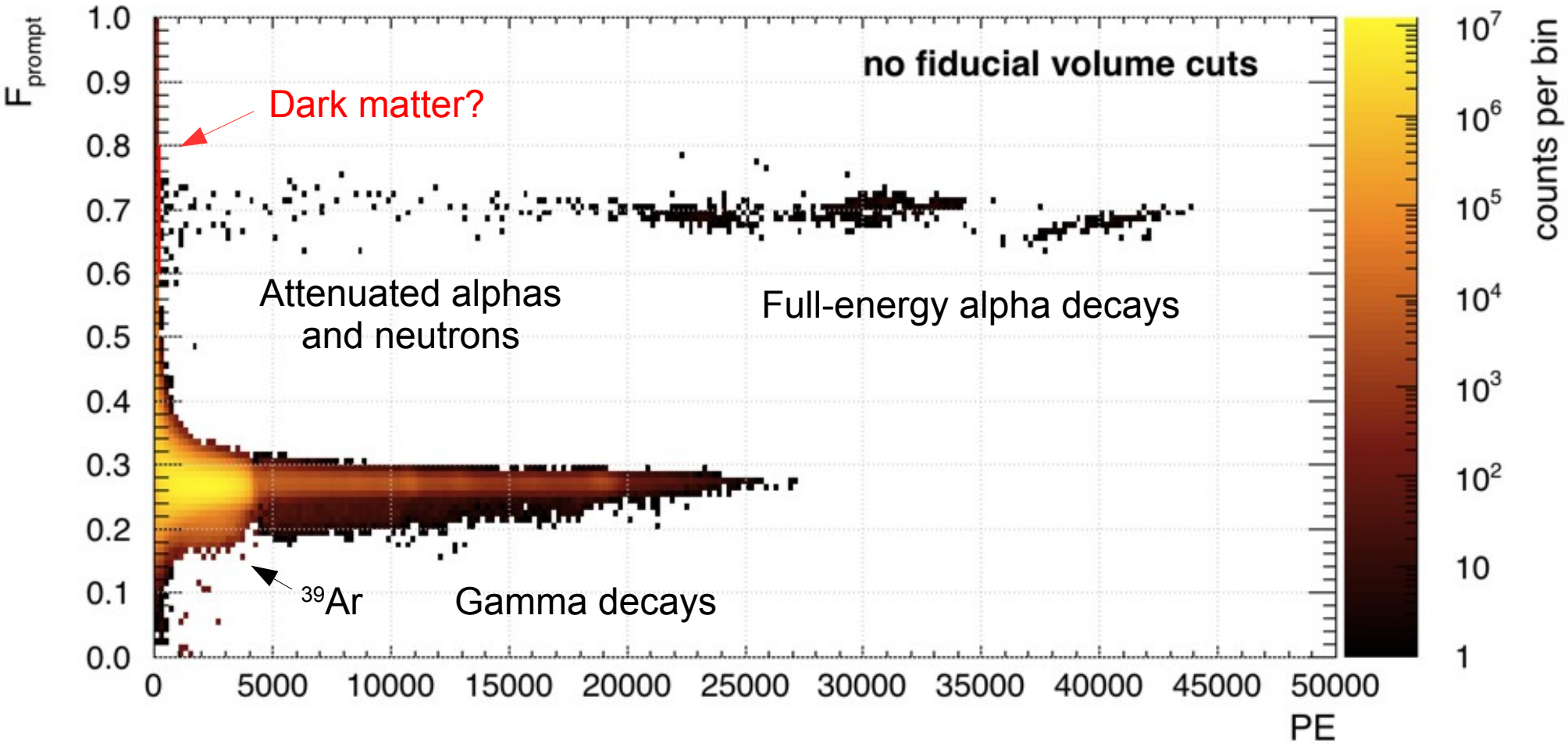
Pulse-Shape Discrimination

World-leading PSD performance!

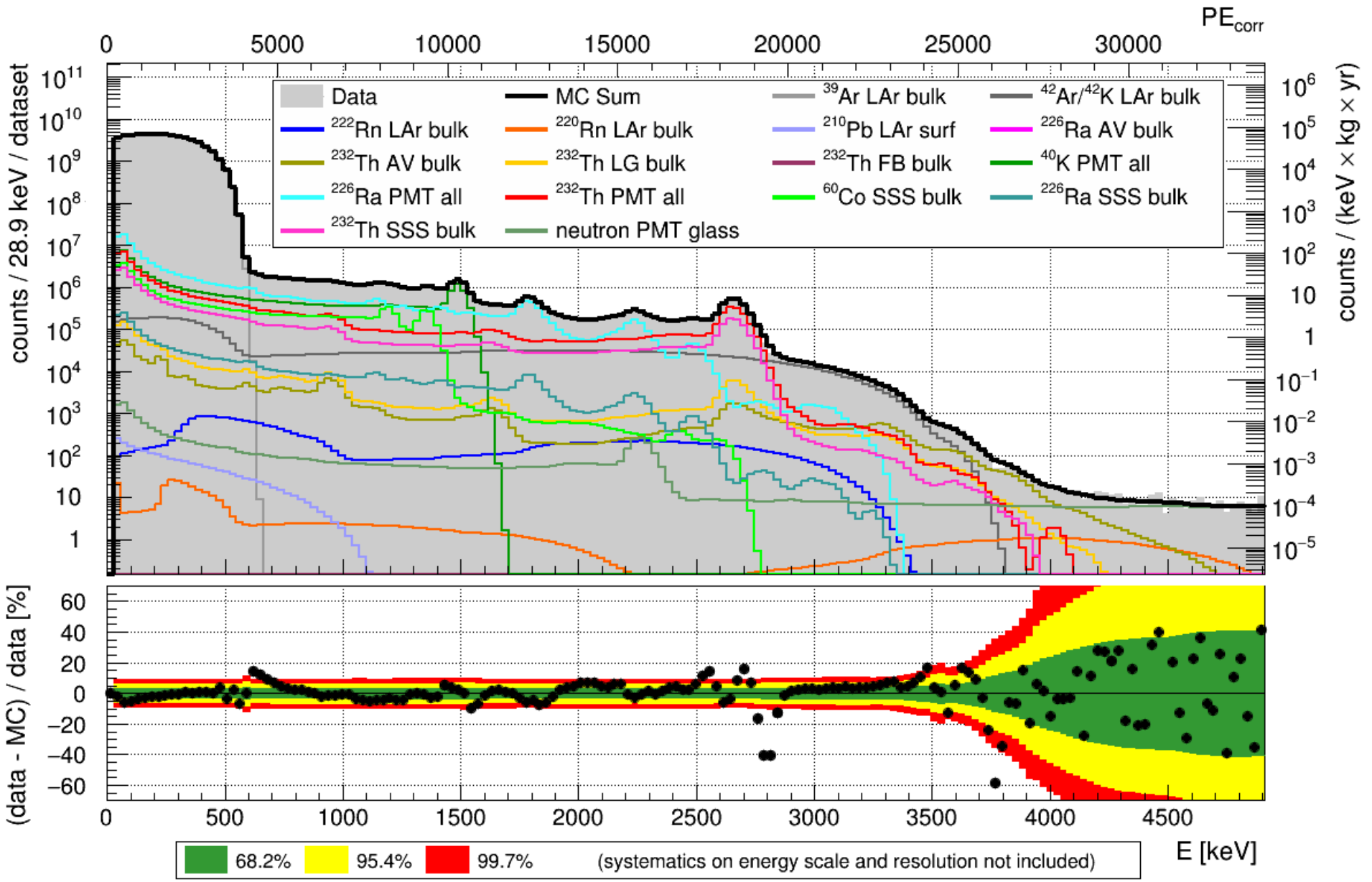


DEAP-3600 Physics Data

First fill dataset, 4.4 live-days



Electromagnetic Backgrounds in First-Year Dataset



Submitted for publication! arXiv:1905.05811

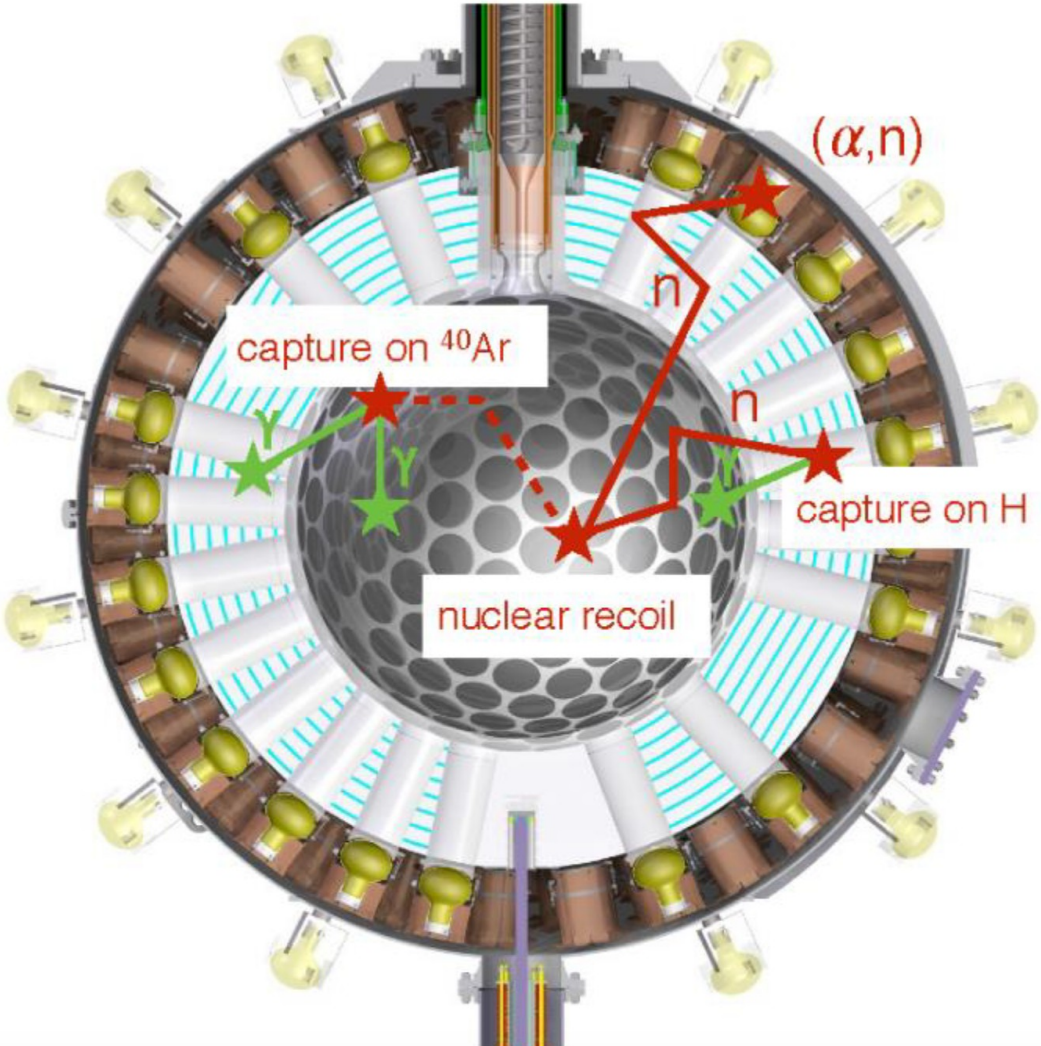
Neutron Backgrounds

Neutrons can cause multiple nuclear recoils in close succession, or result in γ-ray emission

→ Reject events consistent with multiple interactions

→ Estimate remaining neutron backgrounds dedicated **control region**

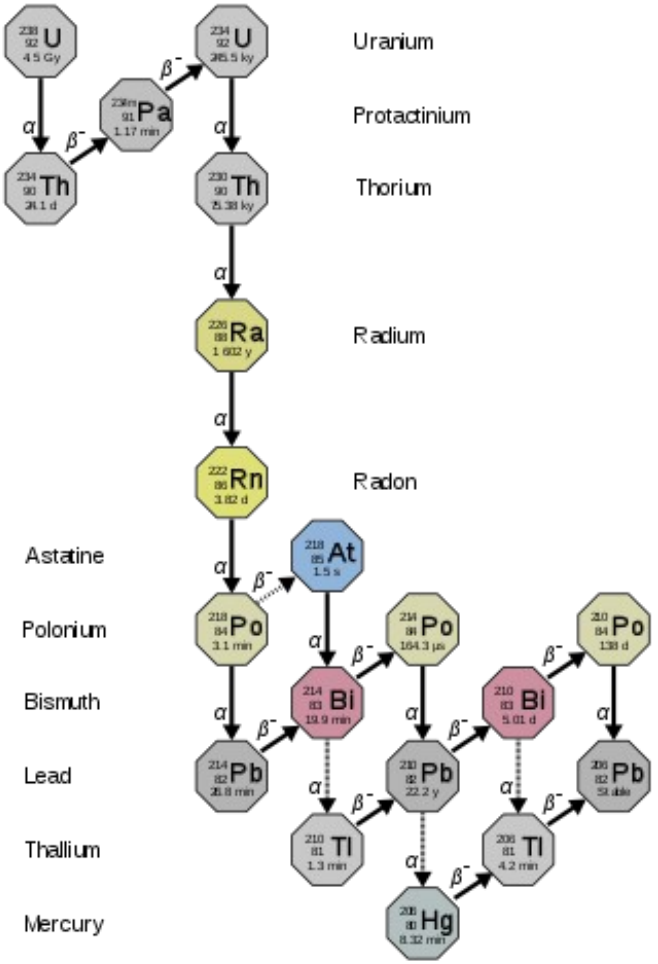
result in agreement with simulations taking material assays as input

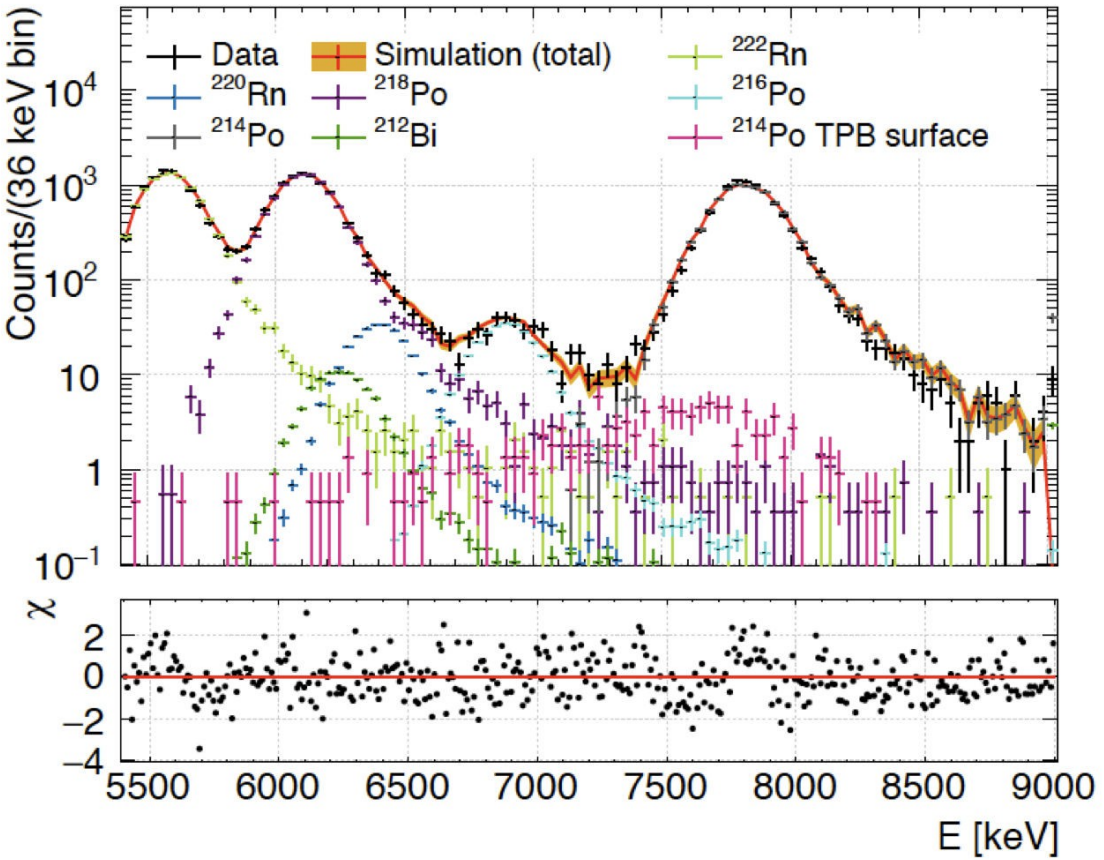


Liquid Argon Bulk Alpha Backgrounds

Alpha decays in the liquid argon bulk deposit **much more energy** compared to dark matter interactions (< 100 keVnr)

→ Much more light detected → **No impact** on the dark matter search



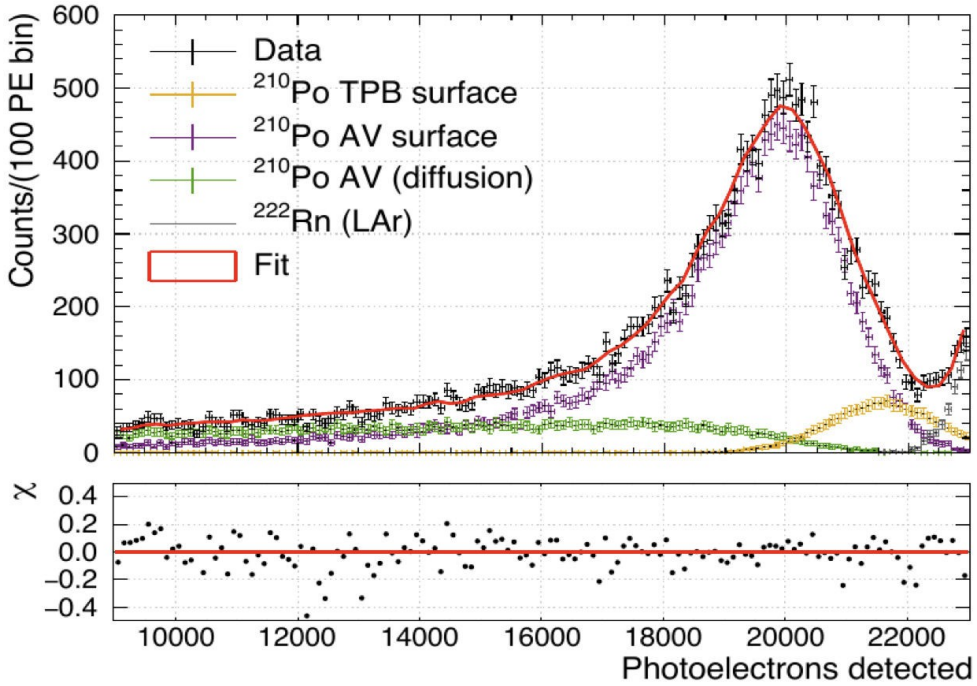


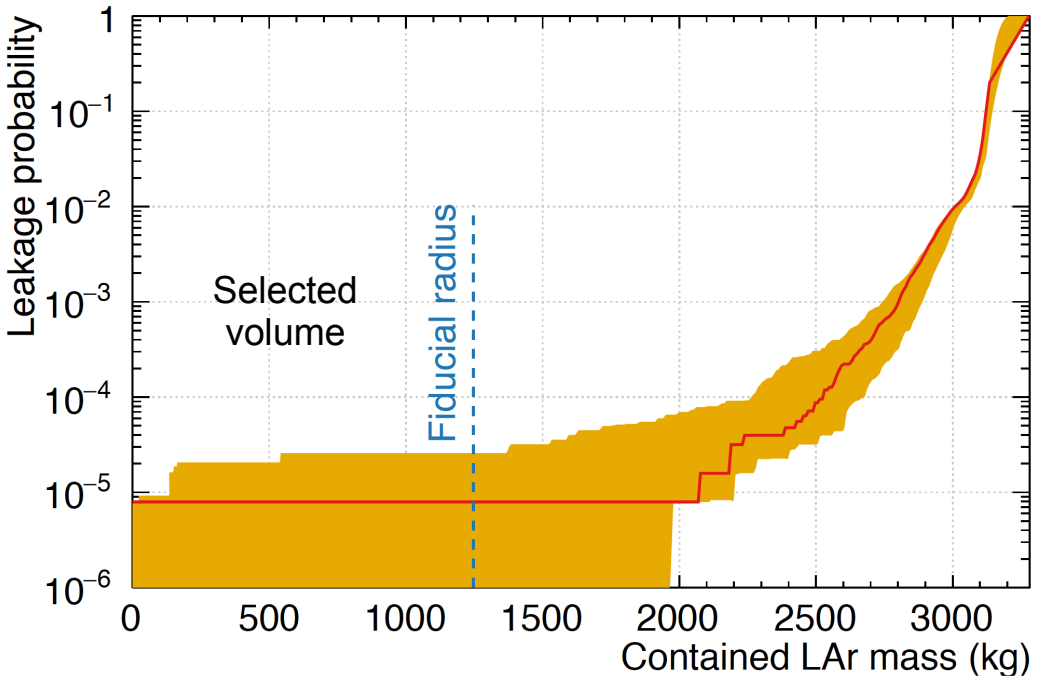
Well-explained by our background model

Surface Alpha Backgrounds

Alpha decays from the inner surface of the acrylic vessel may be attenuated

→ Some reconstruct at intermediate energy → **Rejected** with position reconstruction





Well-explained by our background model

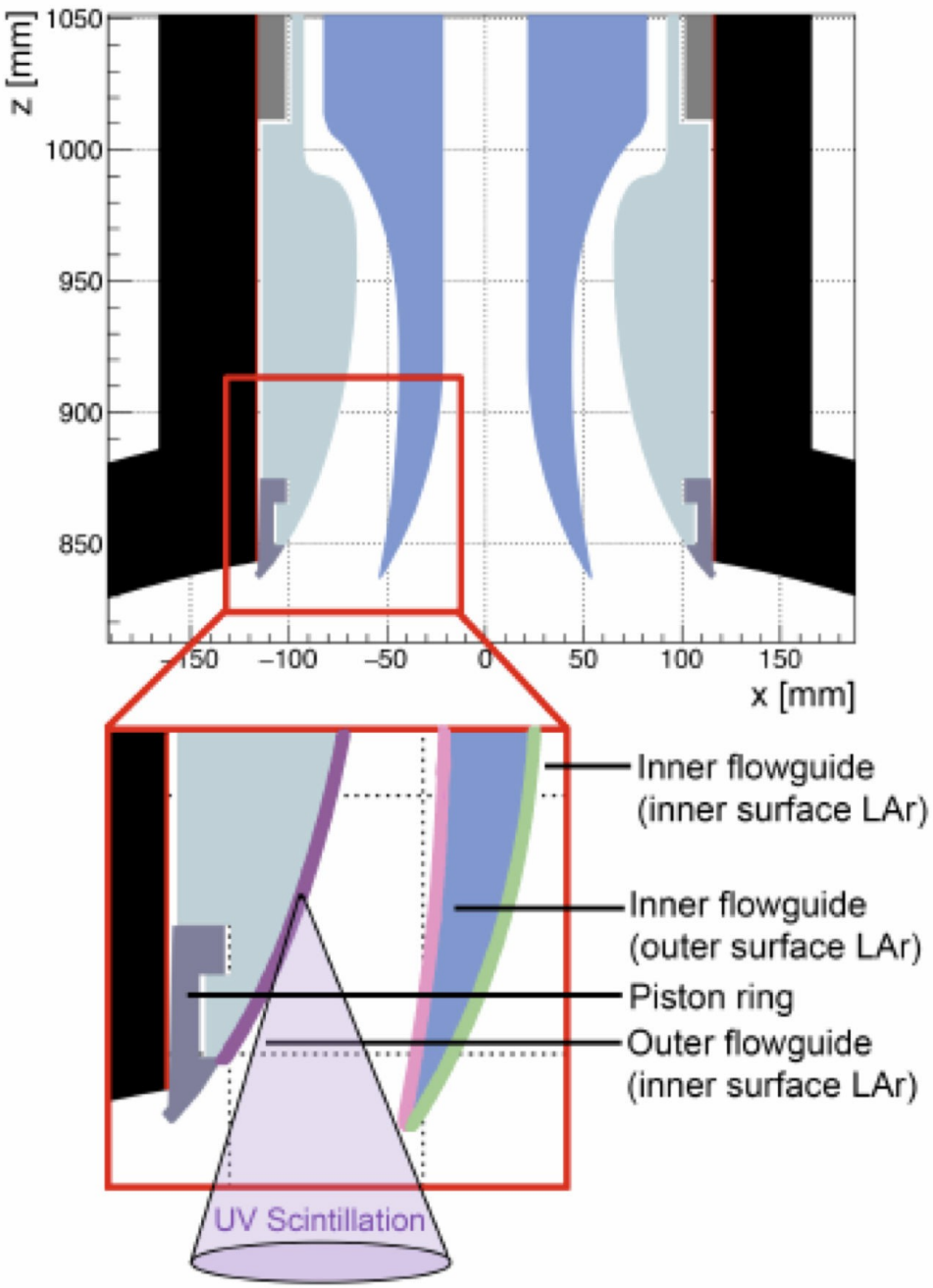
More alpha activity detected at the bottom of the detector:

Reject events with high fraction of total PE from bottom rows of PMTs

Position reconstruction algorithms: Charge-based, Time-based

Fiducial region: Select events from the innermost part of the liquid argon vessel

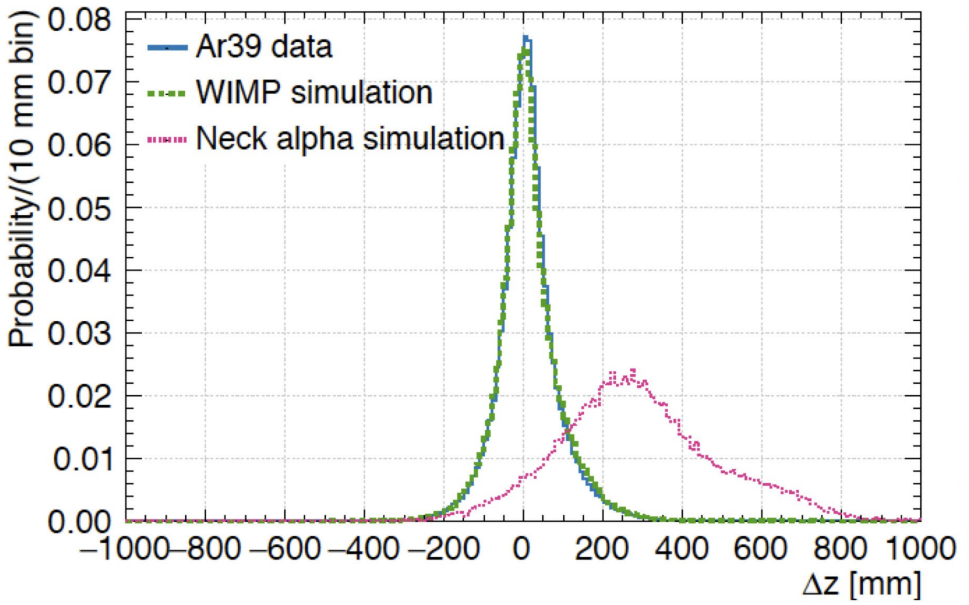
Neck Alpha Backgrounds



Alpha decays from the **detector neck** are particularly challenging

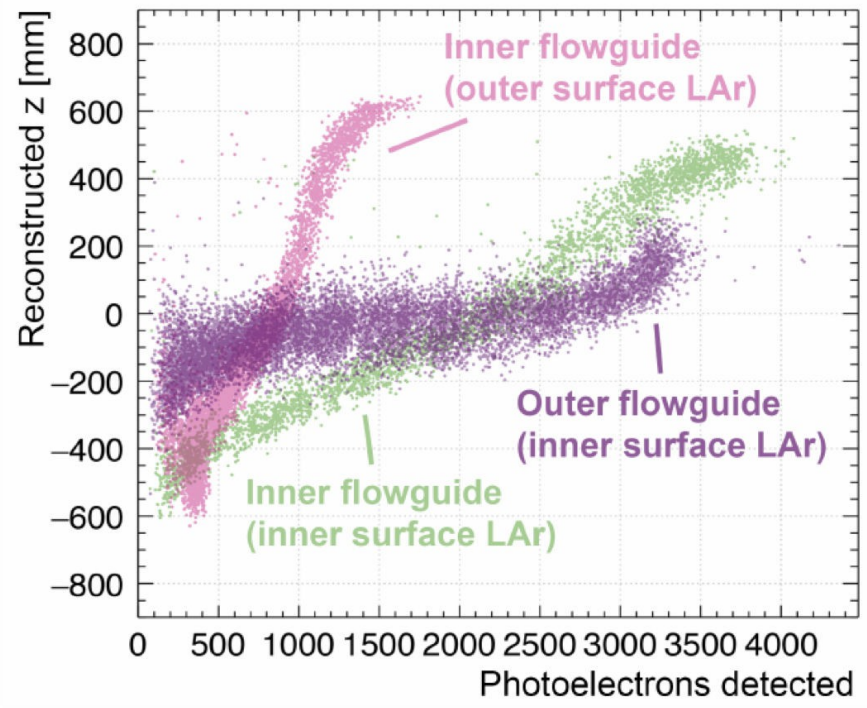
Scintillation light is shadowed
→ Low PE → Signal-like!

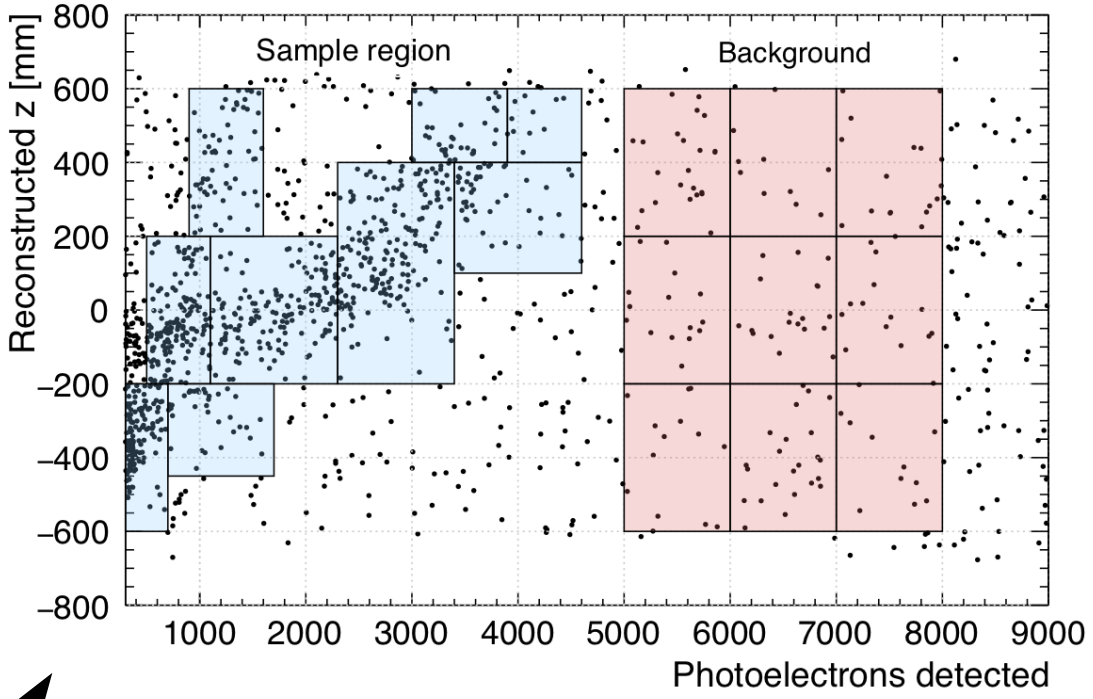
Dedicated event selection rejects events:
... with light in the neck veto fibres
... with *excess* light in the top rows of PMTs
... with *early* light in the top rows of PMTs
... where our main two position reconstruction algorithms disagree



Time-based vs. charge-based reconstructed position

Neck Alpha Backgrounds

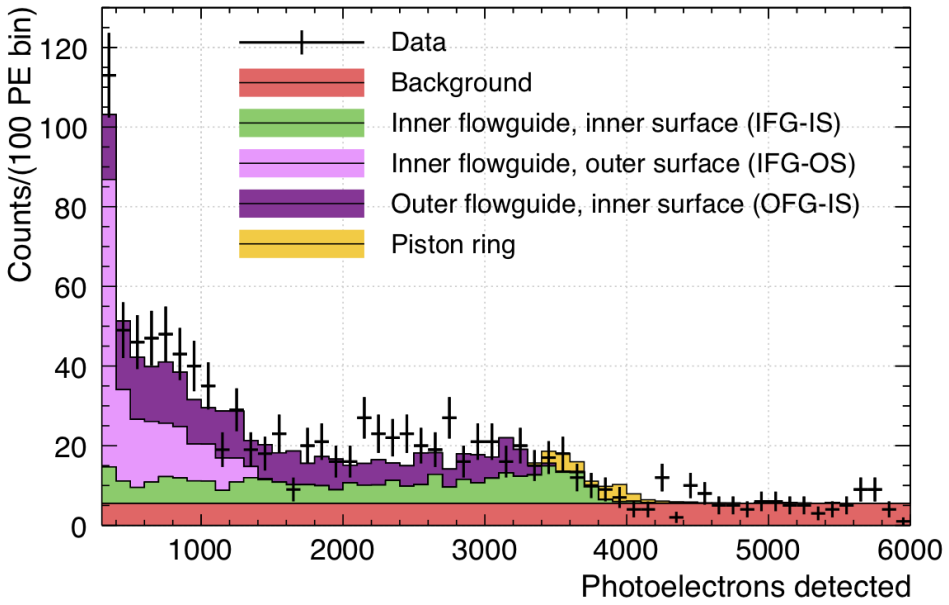




Identification of features
from Monte Carlo **simulation**

... matching features seen in **data**

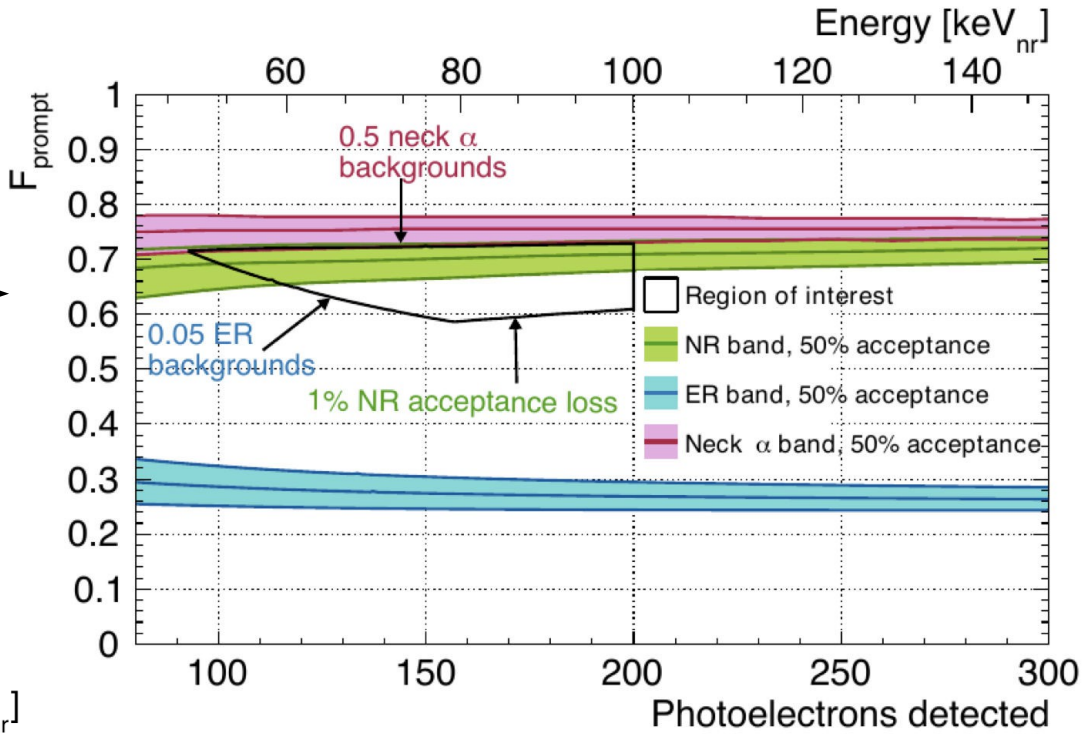
... allows a **template fit** using multiple control regions, to figure out rates of neck alpha events from all sources



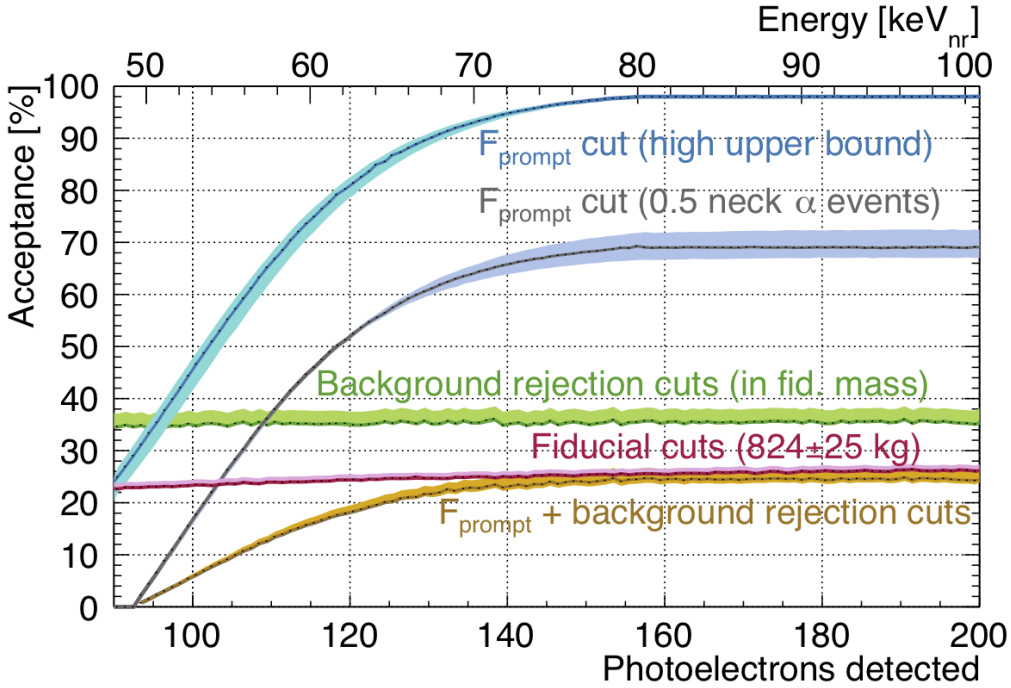
Signal Region

Pulse-shape discrimination is also applied against neck alpha backgrounds

Final event selection in F_{prompt} and PE such that the total background expectation is **< 1 event**



WIMP signal acceptance

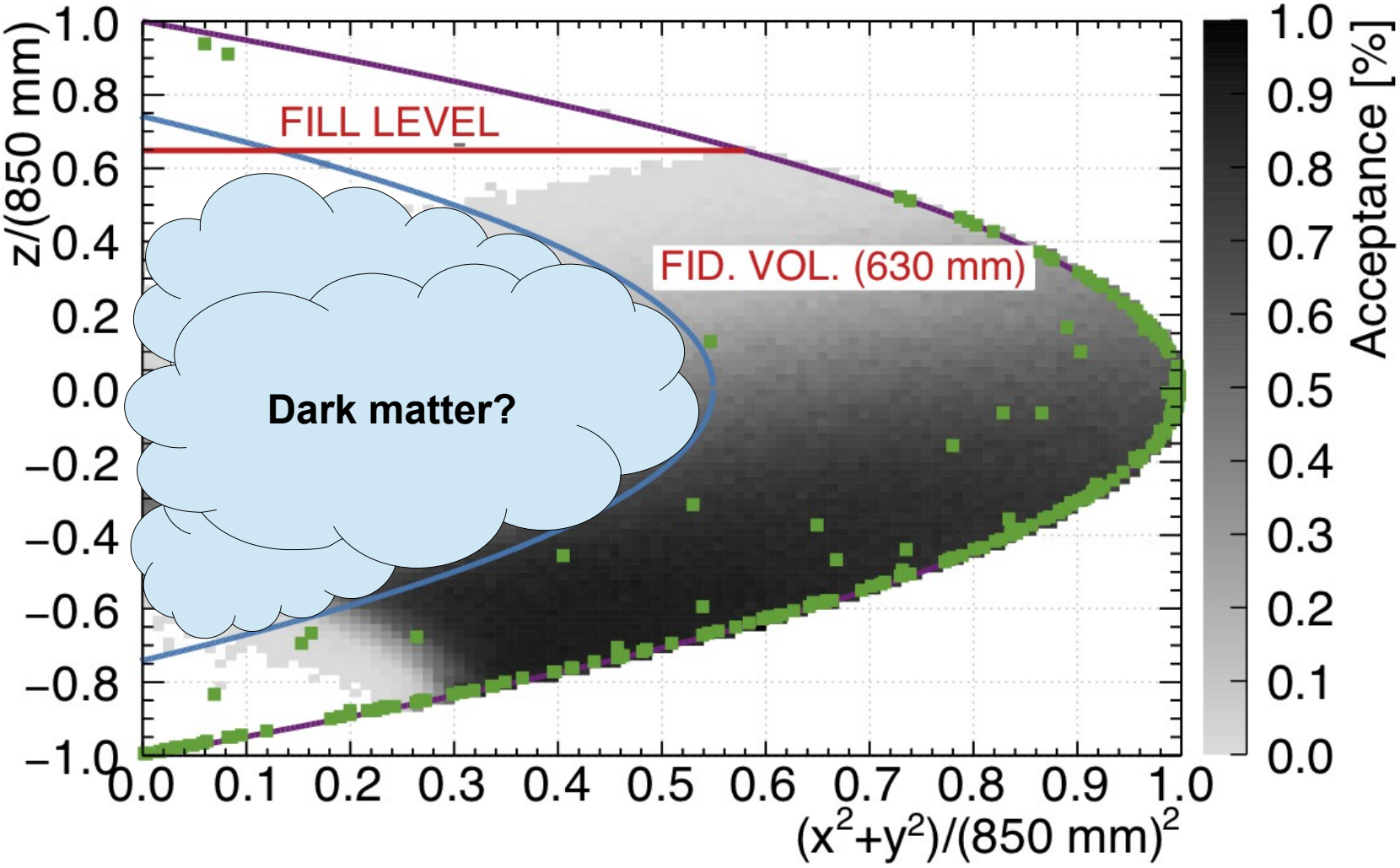


Expected backgrounds

	Source	N^{ROI}
β/γ's	ERs	0.03 ± 0.01
	Cherenkov	< 0.14
n's	Radiogenic	$0.10^{+0.10}_{-0.09}$
	Cosmogenic	< 0.11
α's	AV surface	< 0.08
	Neck FG	$0.49^{+0.27}_{-0.26}$
	Total	$0.62^{+0.31}_{-0.28}$

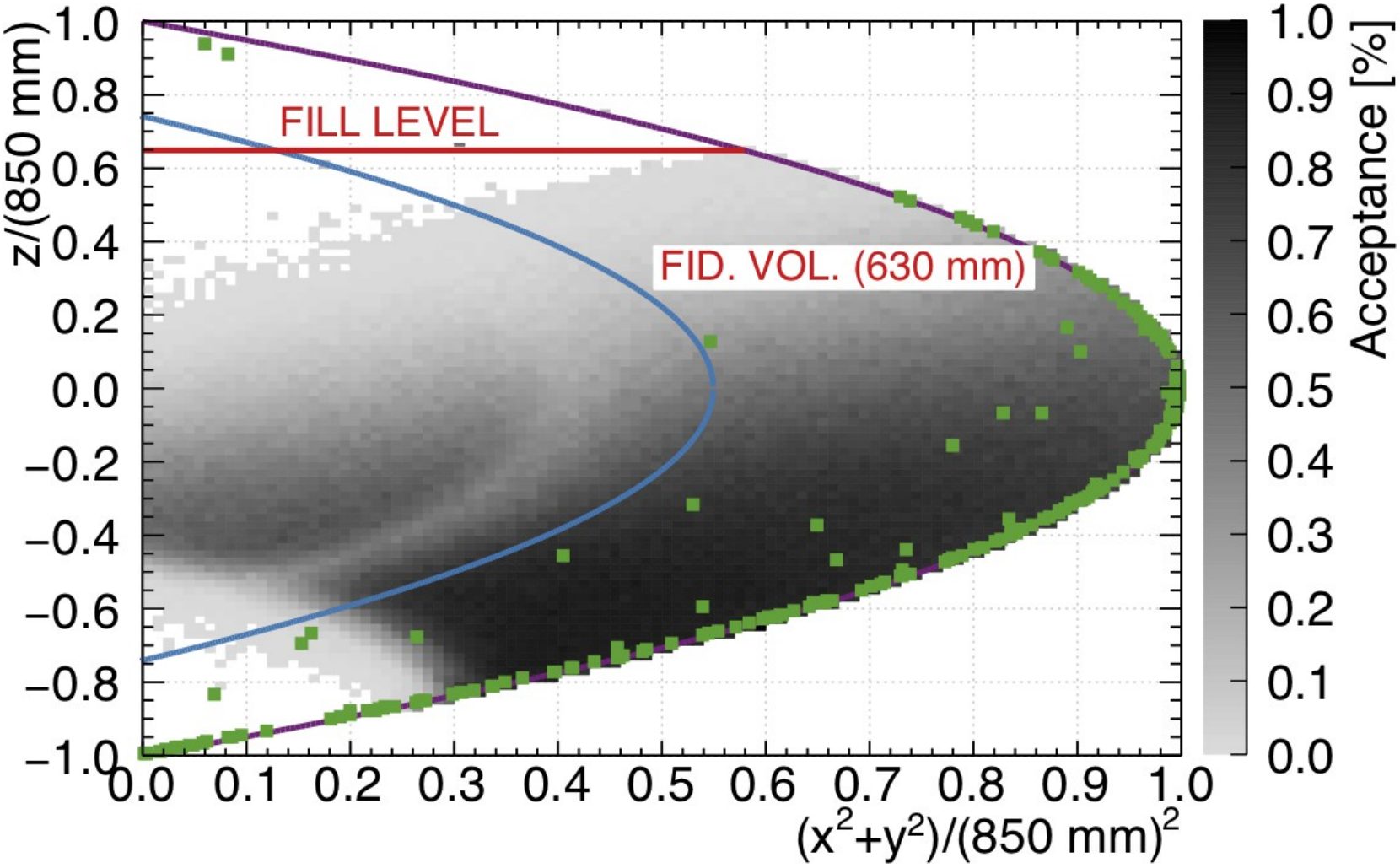
Dark Matter Search Results

Was dark matter observed in the first year of DEAP-3600 data?



Dark Matter Search Results

The detector is sensitive to dark matter, but no signal event was observed

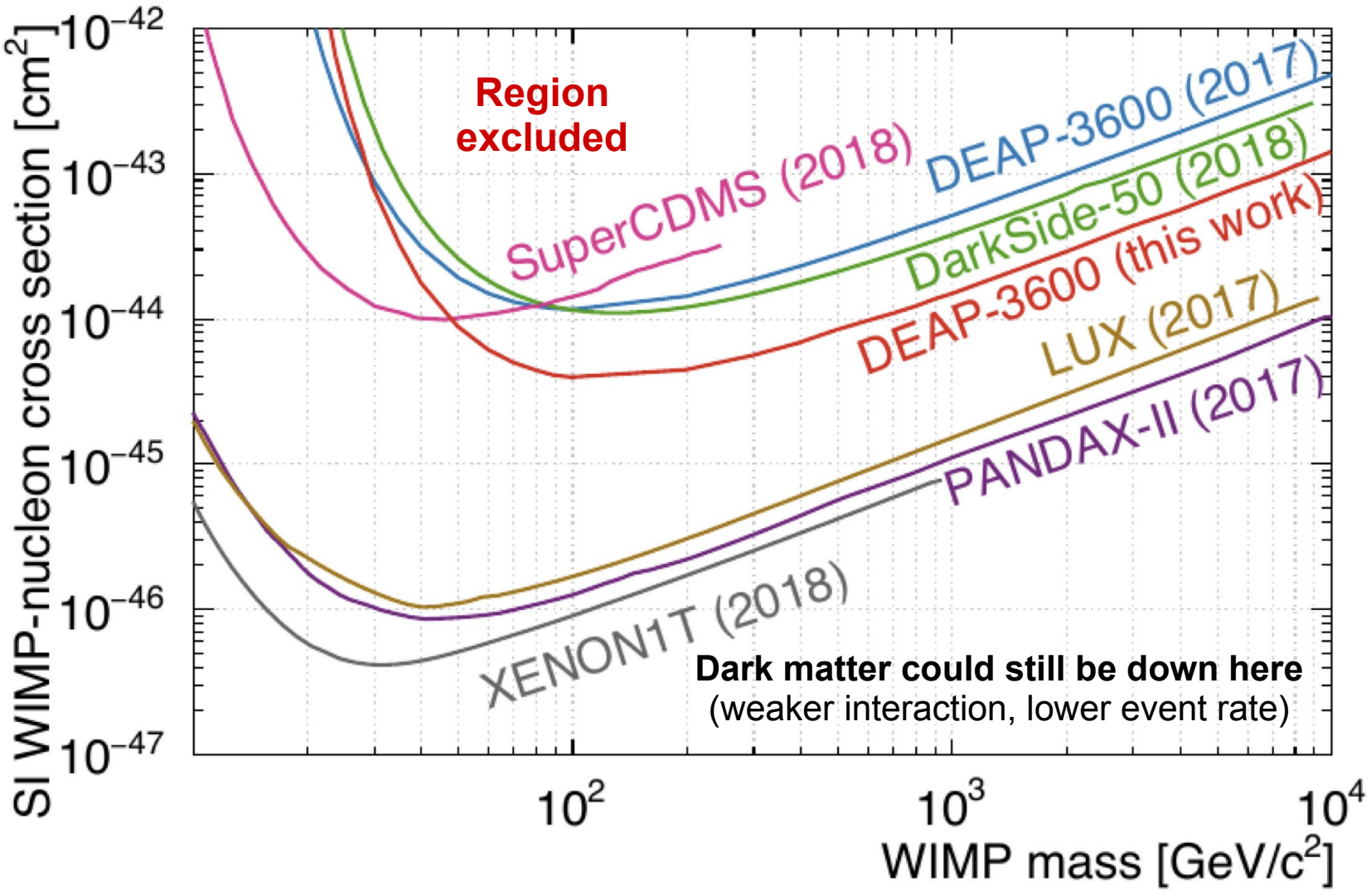


Submitted for publication! arXiv:1902.04048

Dark Matter Search Results

The detector is sensitive to dark matter, but no signal event was observed

Therefore we **exclude** certain dark matter hypotheses



Future Dark Matter Searches

- How to maximize sensitivity with next-generation experiments? **Think BIG!**
- **Global Argon Dark Matter Collaboration** formed!
  - Objective: to reach ultimate sensitivity to spin-independent nuclear interactions with high-mass dark matter, with a **multi-hundred tonnes** liquid argon detector

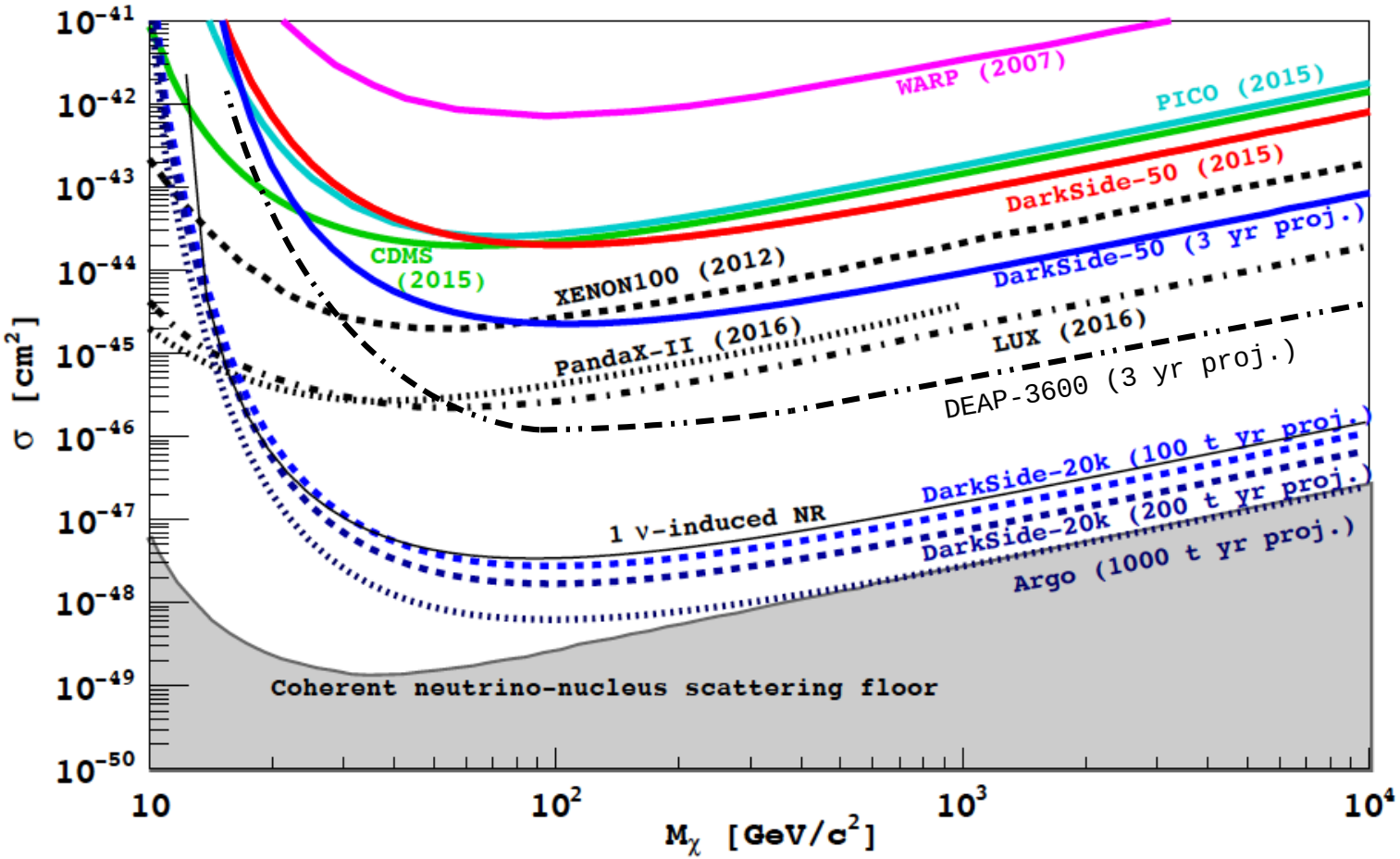
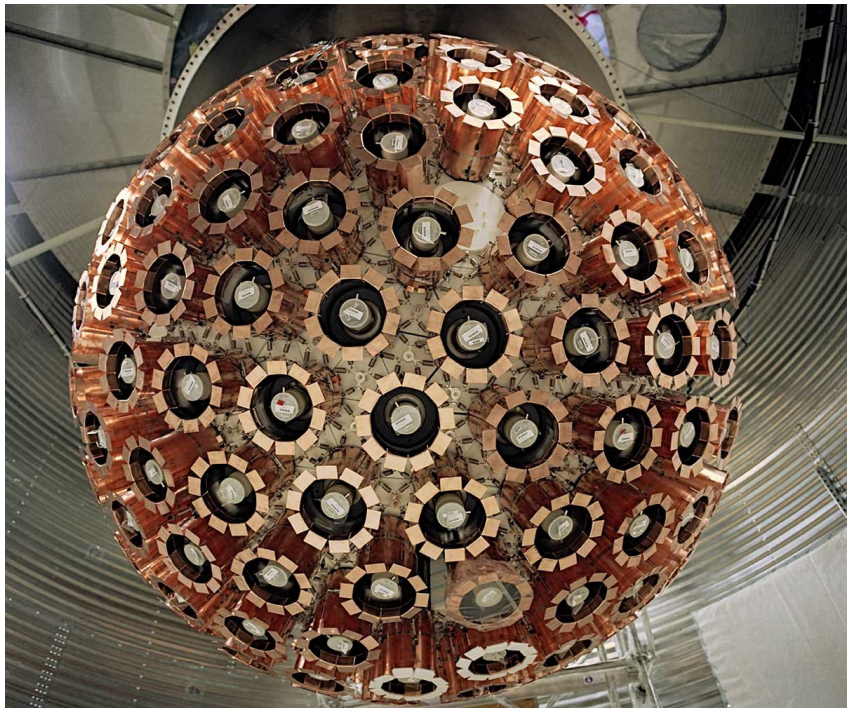


Figure credit: DarkSide-20k, arXiv:1707.08145 (DEAP-3600 expected limit added by hand)

Conclusions and Future Directions

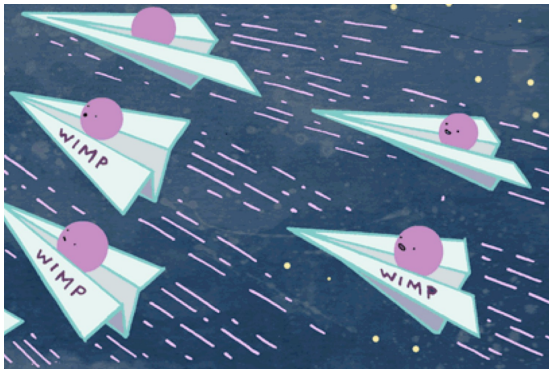
- **Looking for dark matter** with **DEAP-3600**
  - Excellent detector performance!
    - Pulse-shape discrimination
    - Event reconstruction
    - Background rejection
    - Sensitivity to new physics
  - Stable data-taking continues
    - 80% blind since January 1st, 2018
  - Work in progress
    - Multivariate analysis to improve signal acceptance
    - New searches and measurements
    - Hardware improvements



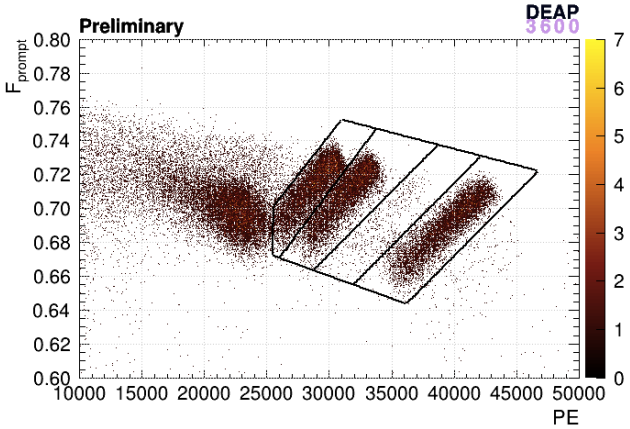
- **Instrumentation** research and development for future particle detectors
  - Design and simulation for DarkSide-20k and ARGO
  - Silicon photomultipliers

For more details, see other DEAP-3600 presentations at CAP!

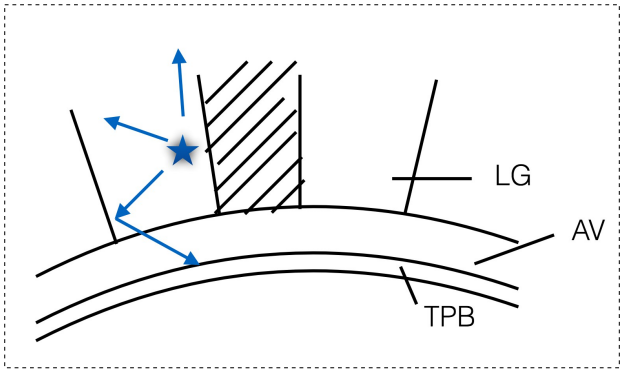
Ashlea Kemp
Profile-likelihood to search for dark matter in DEAP-3600



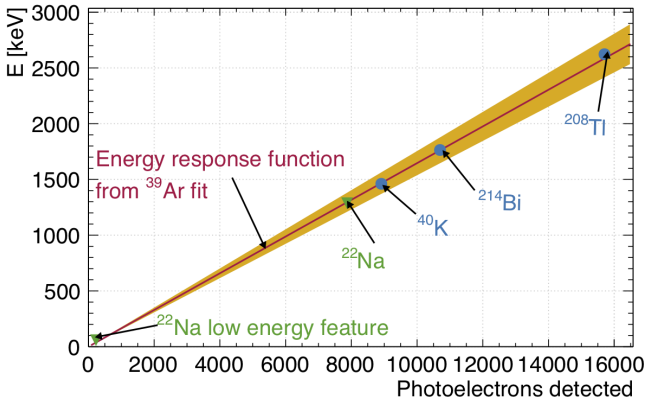
Carl Rethmeier
Alpha backgrounds in DEAP-3600



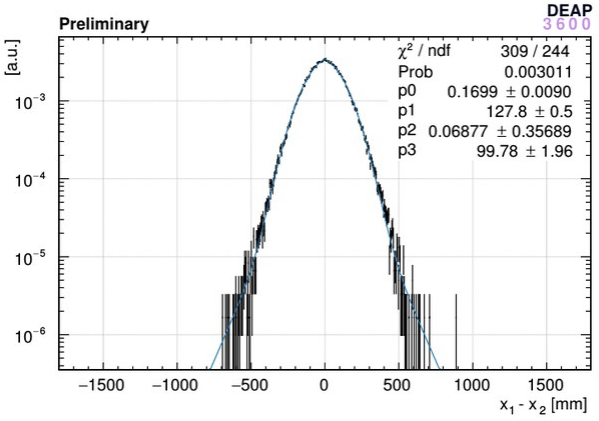
Courtney Mielnichuk
Cherenkov backgrounds in DEAP-3600

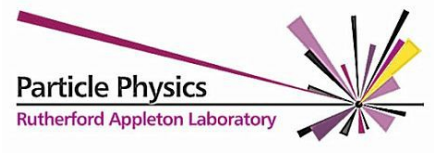


Pierre Gorel
Calibrating an ultra-low background detector: DEAP-3600

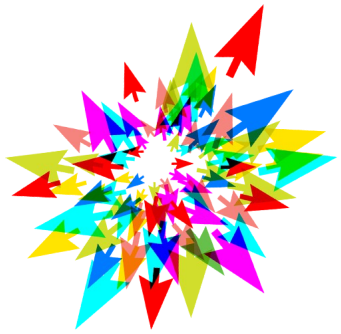


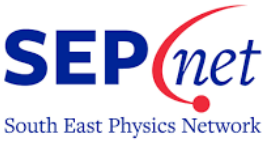
Joseph Willis
Position resolution in DEAP-3600





Thank you! Merci !

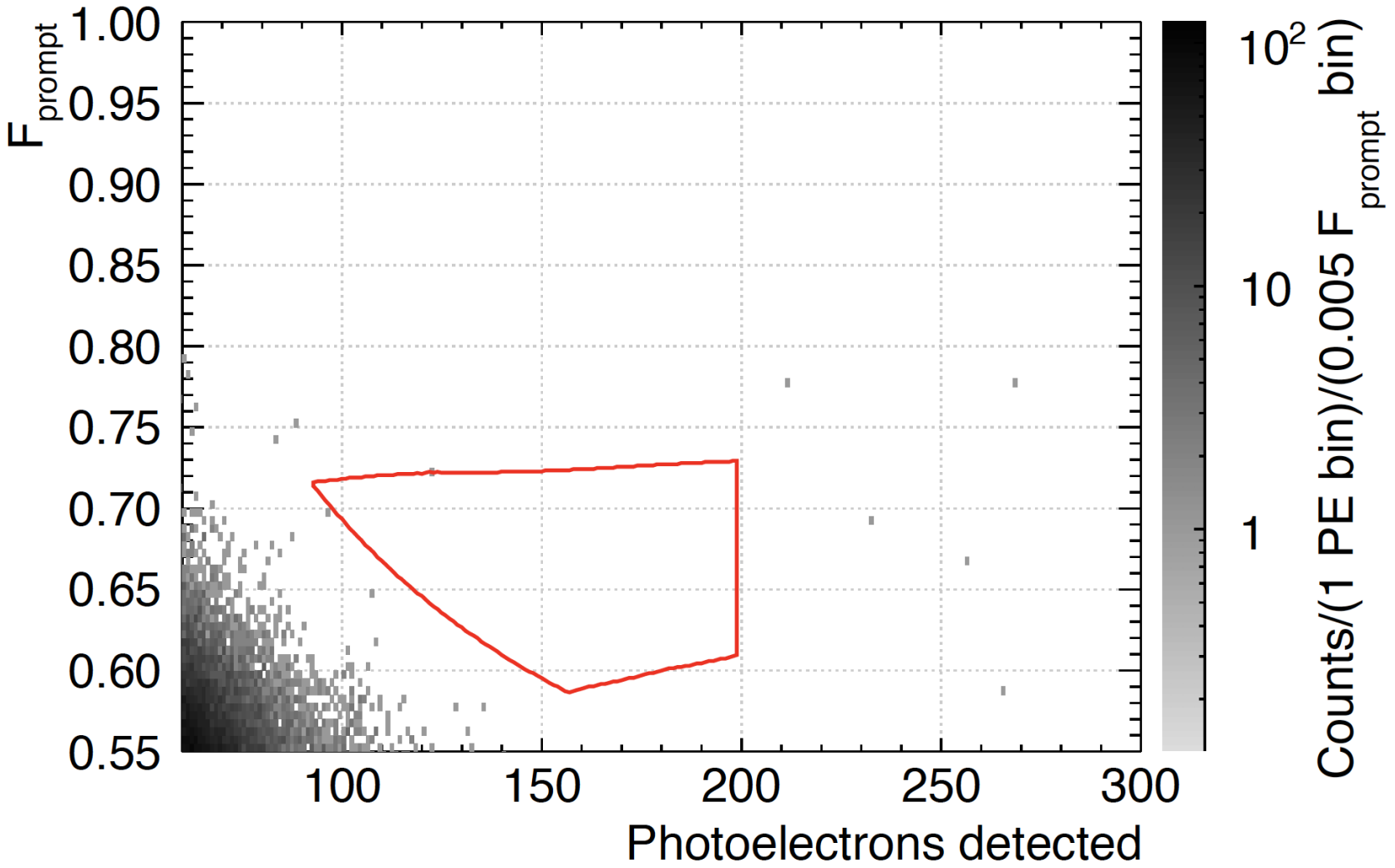




Bonus slides

Dark matter search results after event selection

The detector is sensitive to dark matter, but no signal event was observed

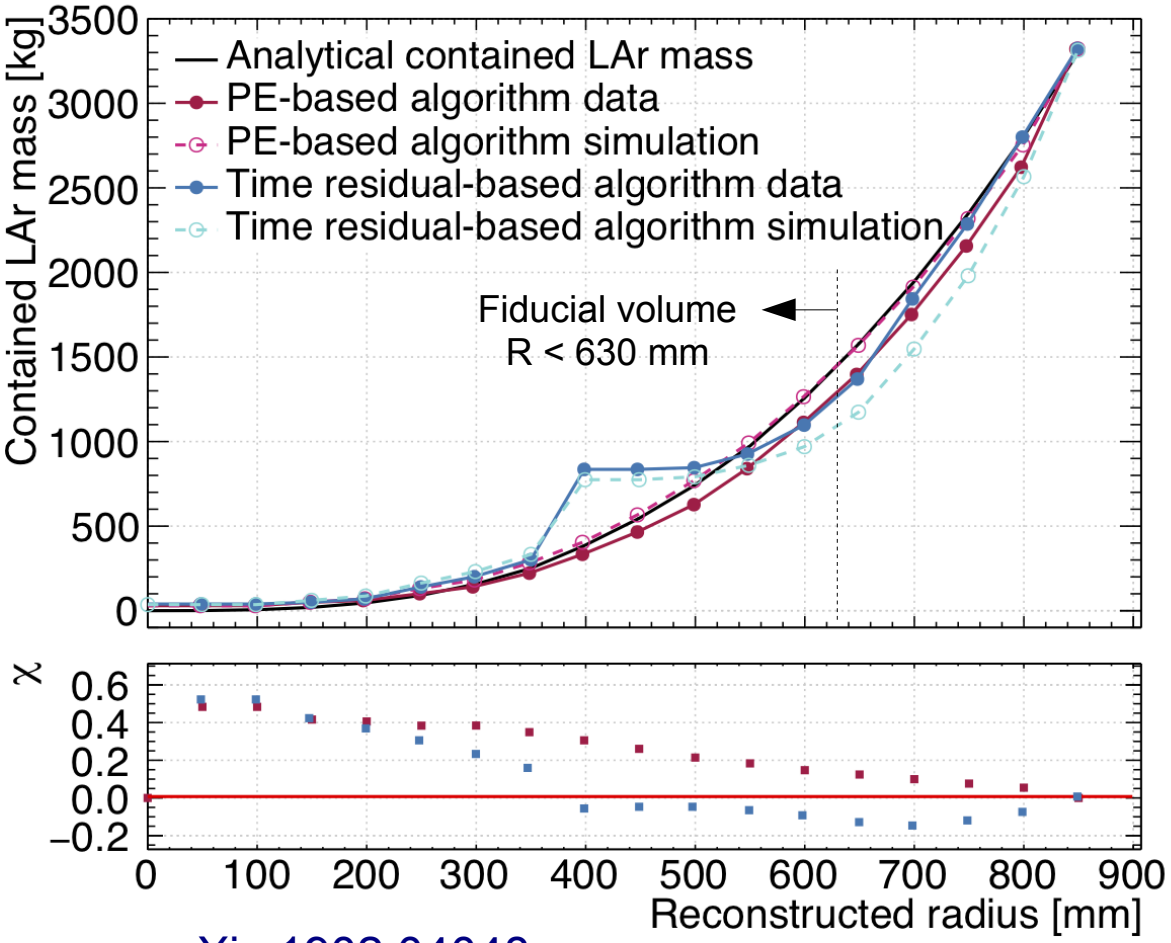


Submitted for publication! arXiv:1902.04048

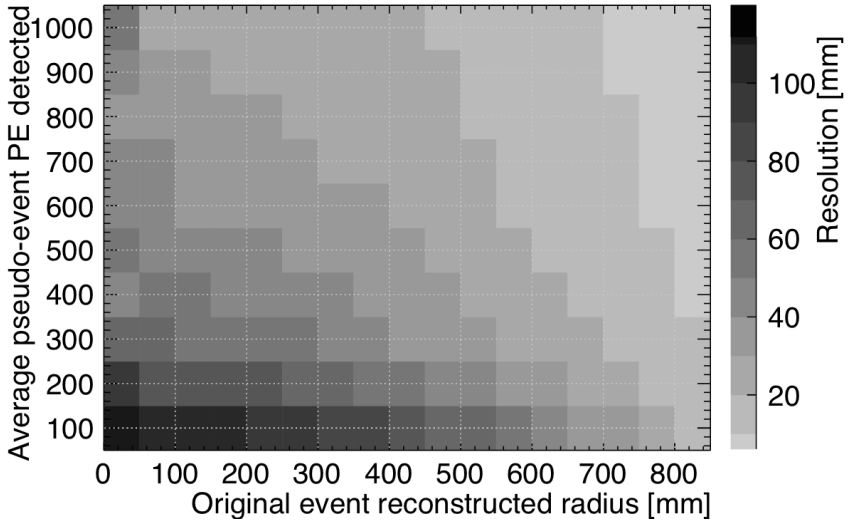
Position reconstruction in DEAP-3600

Two main algorithms for position reconstruction

- "PE-based": **more PE are detected** closer to the event (use full 10 μs event window)
- "Time-based": **PE are detected earlier** closer to the event (use first 40 ns of event)



arXiv:1902.04048



SplitEvent: data-driven measure of position resolution

Resolution = **30-45 mm** at the fiducial volume boundary for low-energy events (better at high-energy)

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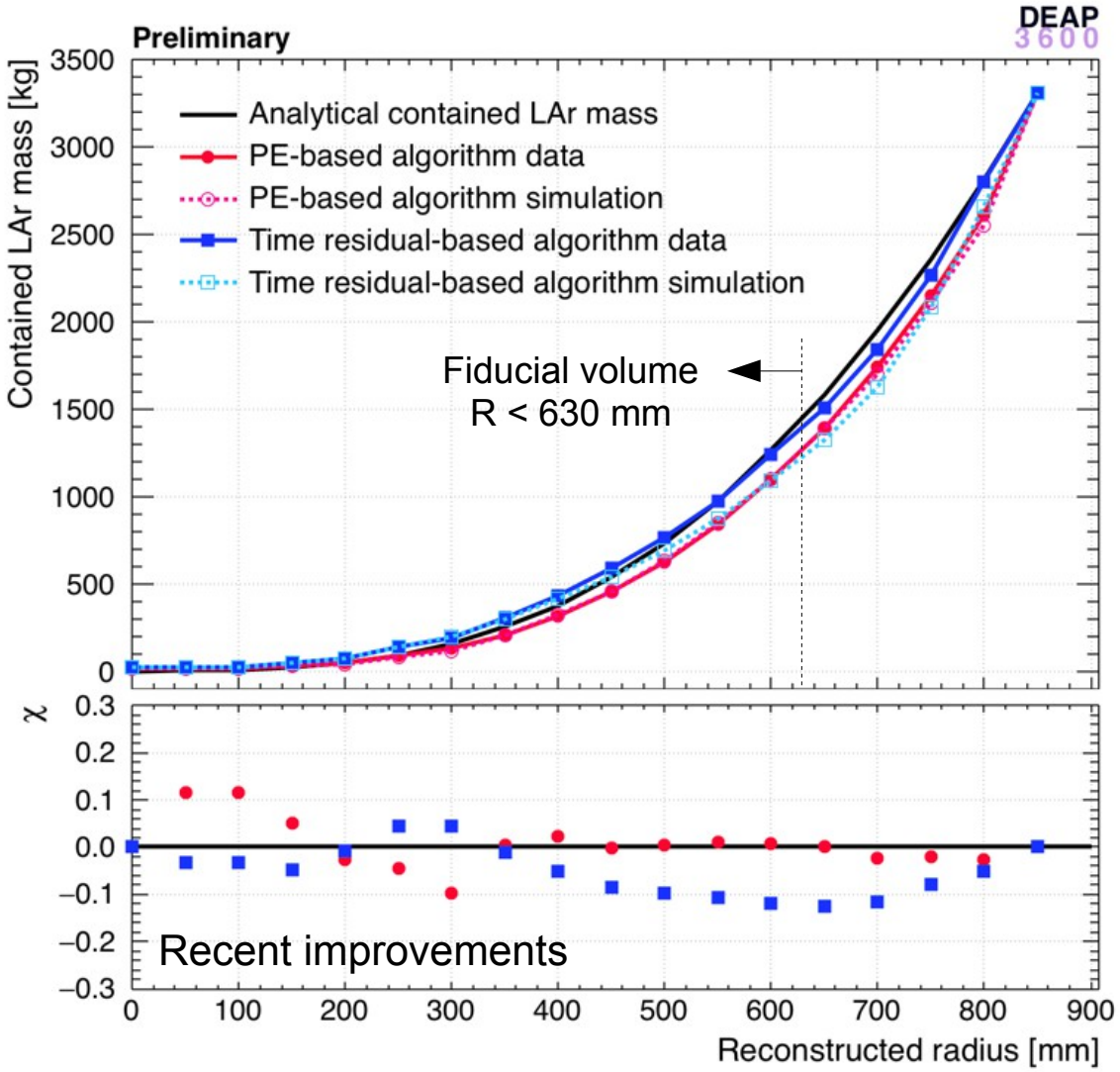

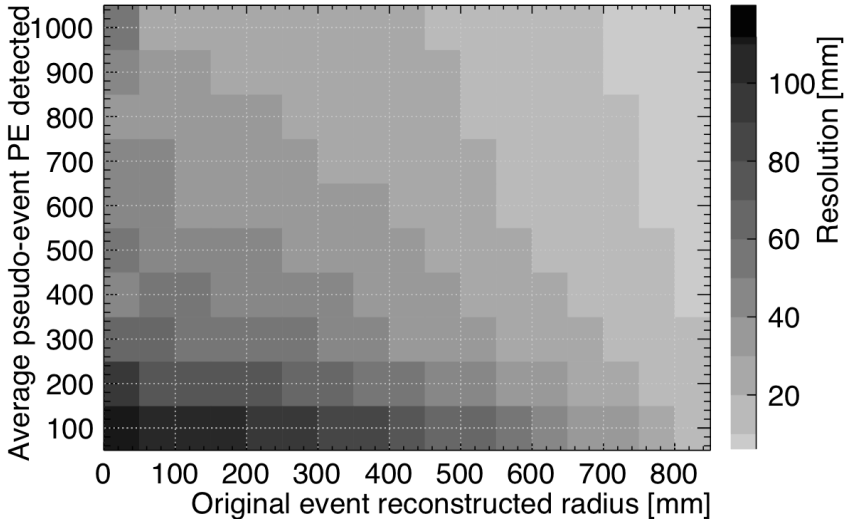

SplitEvent: data-driven measure of position resolution

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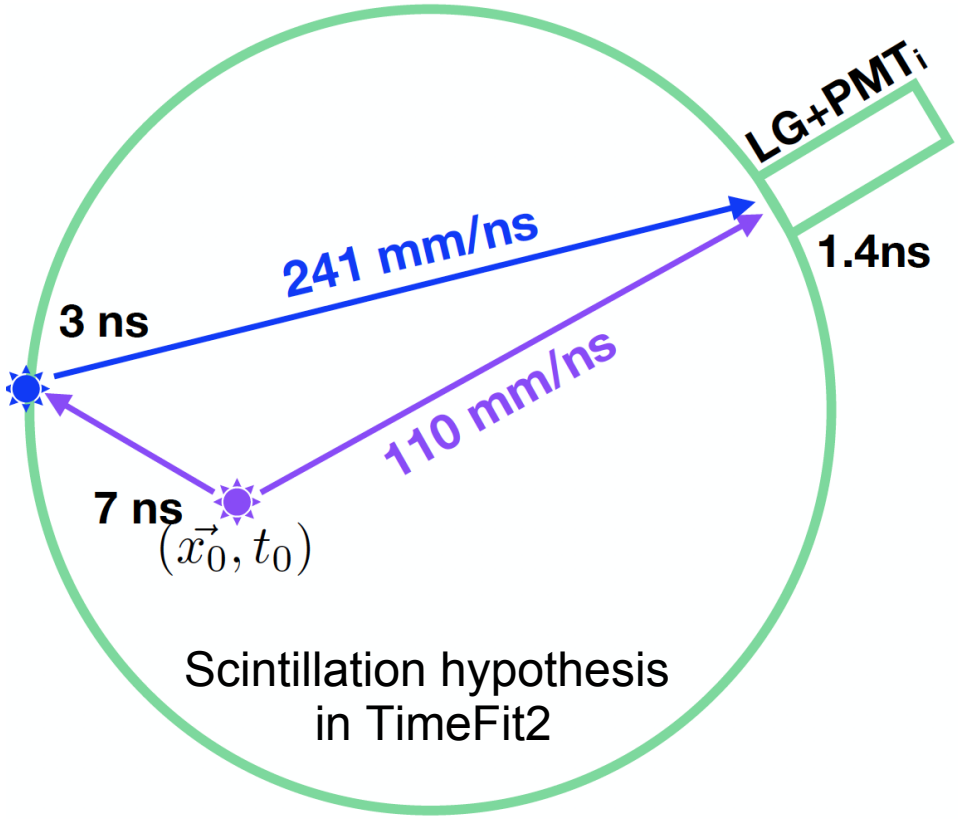
Time-based position reconstruction algorithms

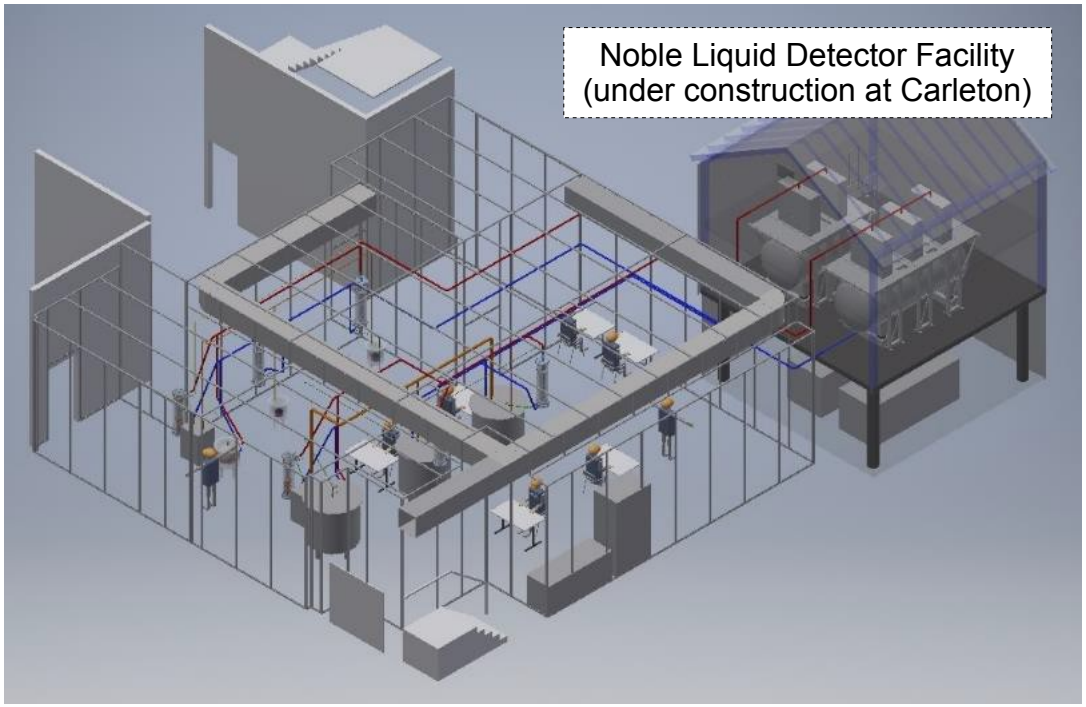
- Original TimeFit:
  - Using the **first** pulses in each PMT
  - Event position reconstruction assuming direct photon propagation to PMT
  - Provides our current estimate for scintillation **event timing** (T_0)
- New TimeFit2:
  - Takes into account secondary emission, wavelength-dependent speed of light, and TPB time constants
    - Group velocities assumed in LAr:
      - 110 mm/ns @ 128 nm
      - 241 mm/ns @ 420 nm



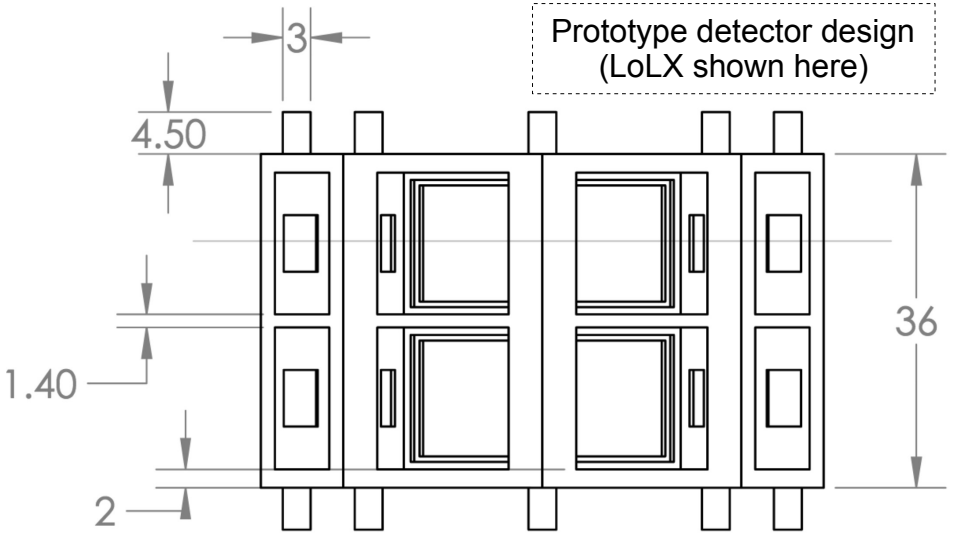
Scintillation hypothesis in TimeFit2

- Using expected time-of-arrival profiles for **prompt** visible photons (in first 40 ns), as simulated in events from different positions
- Scintillation hypothesis of TimeFit2 now available in the standard data structure
  - Cherenkov hypothesis almost ready; neck hypothesis in development

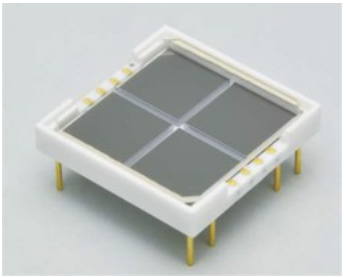
Experiment design, research and development



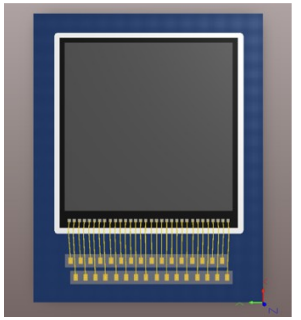
Noble Liquid Detector Facility
(under construction at Carleton)



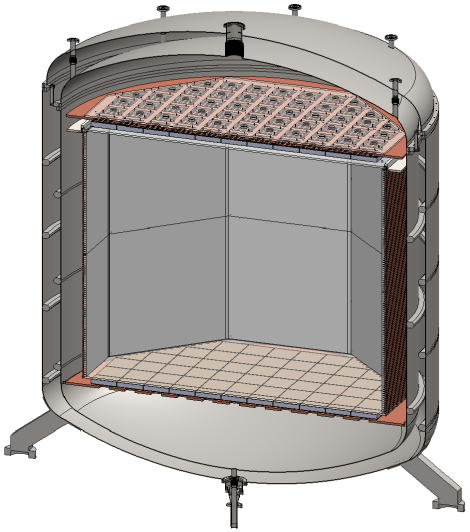
Prototype detector design
(LoLX shown here)



Hamamatsu VUV4

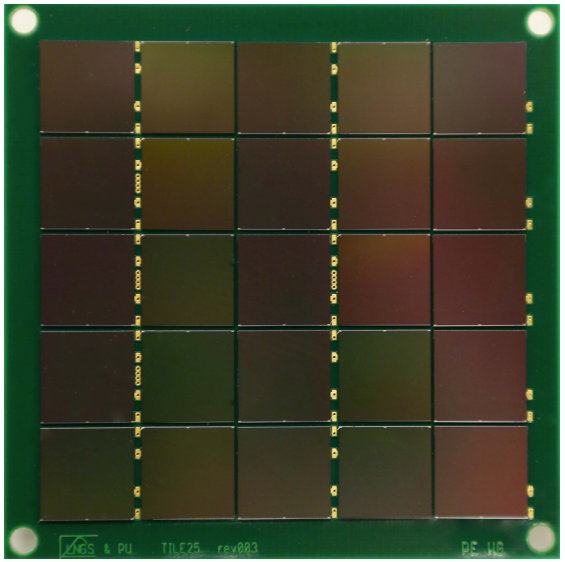


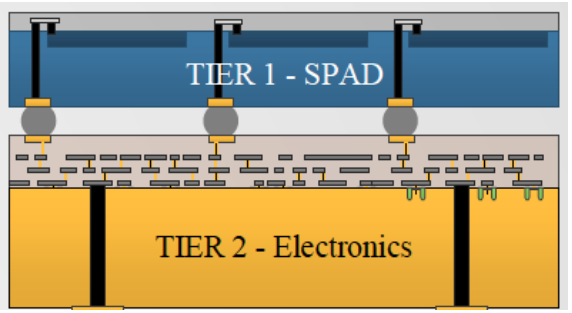
3DdSiPM, top view



DarkSide-20k simulation

DarkSide-20k prototype SiPM tile





3DdSiPM, side view