



**Dark matter search with
DEAP-3600 at SNOLAB**

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WNPPC

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DEAP Collaboration:

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





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**Thank you to funding agencies and
partners for making this research possible!**

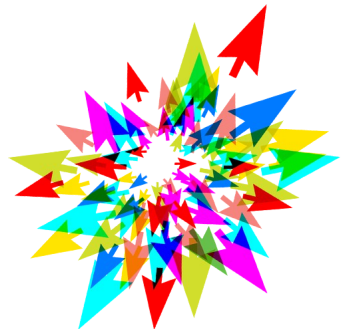
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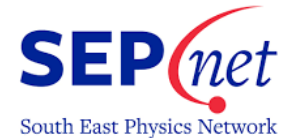
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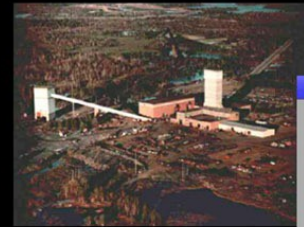


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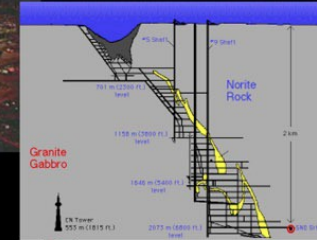


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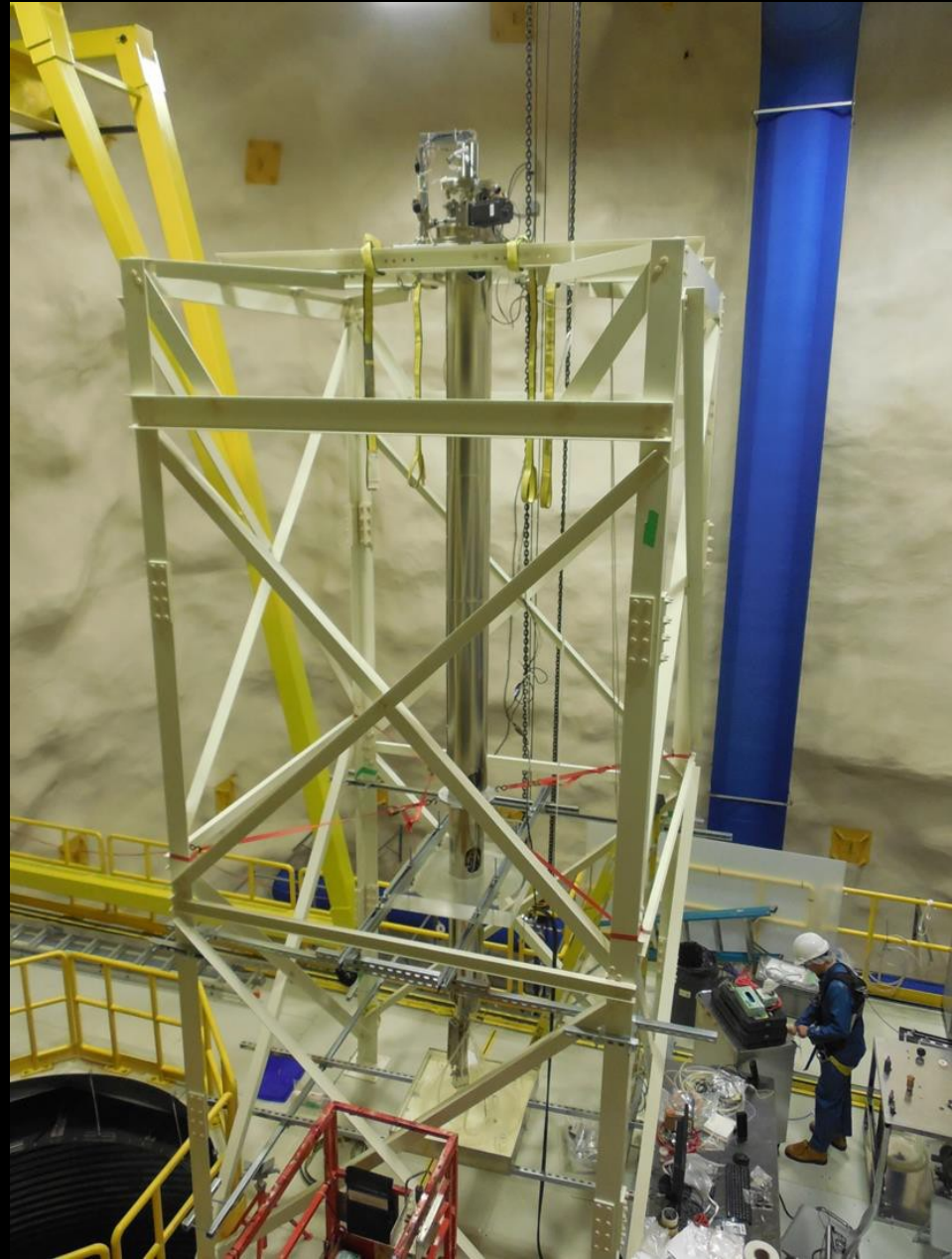
Video: A Day at SNOLAB
<https://www.snolab.ca/outreach>

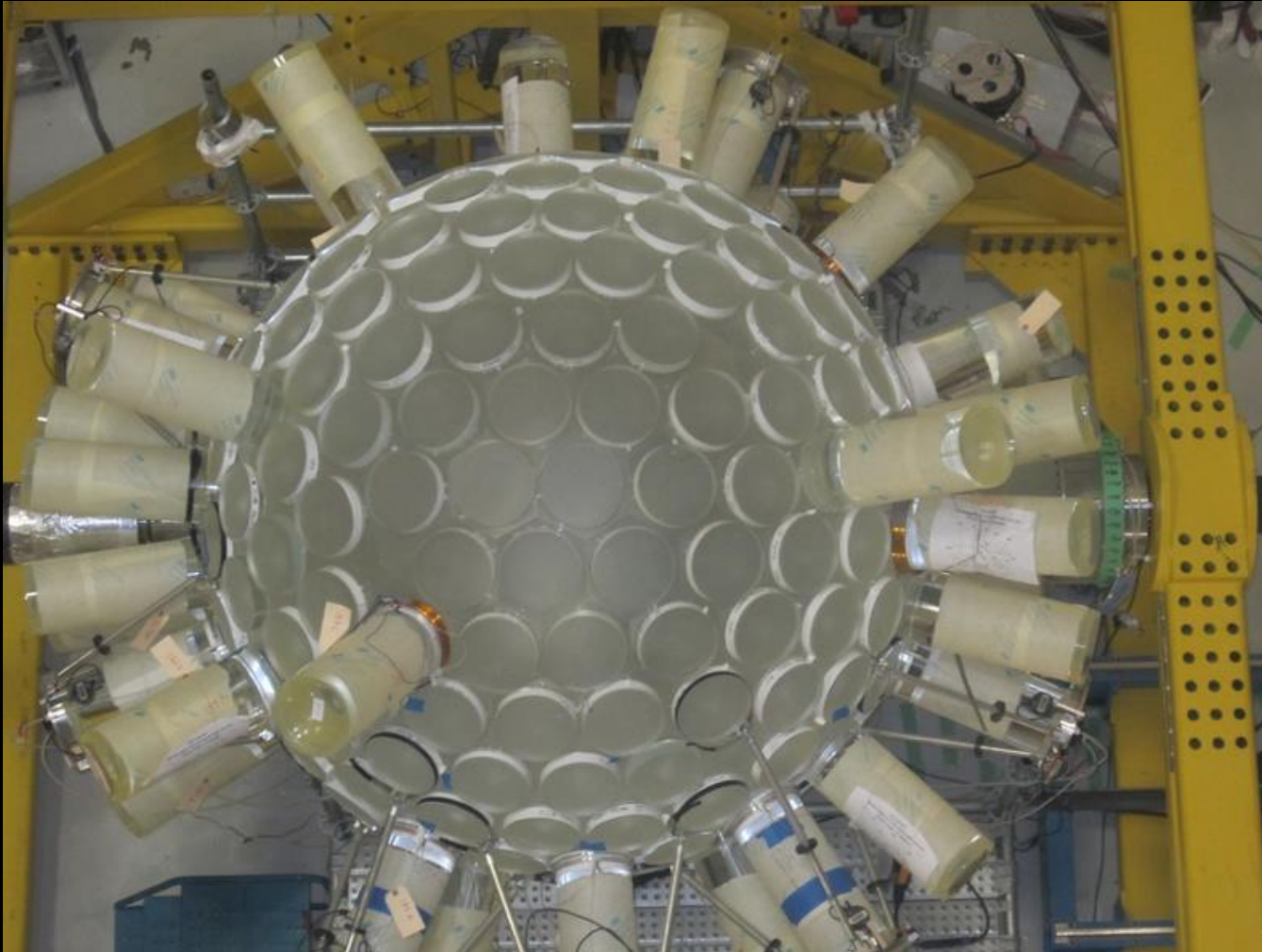
2070 m underground



Acrylic vessel underground at SNOLAB

Acrylic vessel resurfacer:
Mechanical sander to remove 0.5 mm off the inner surface



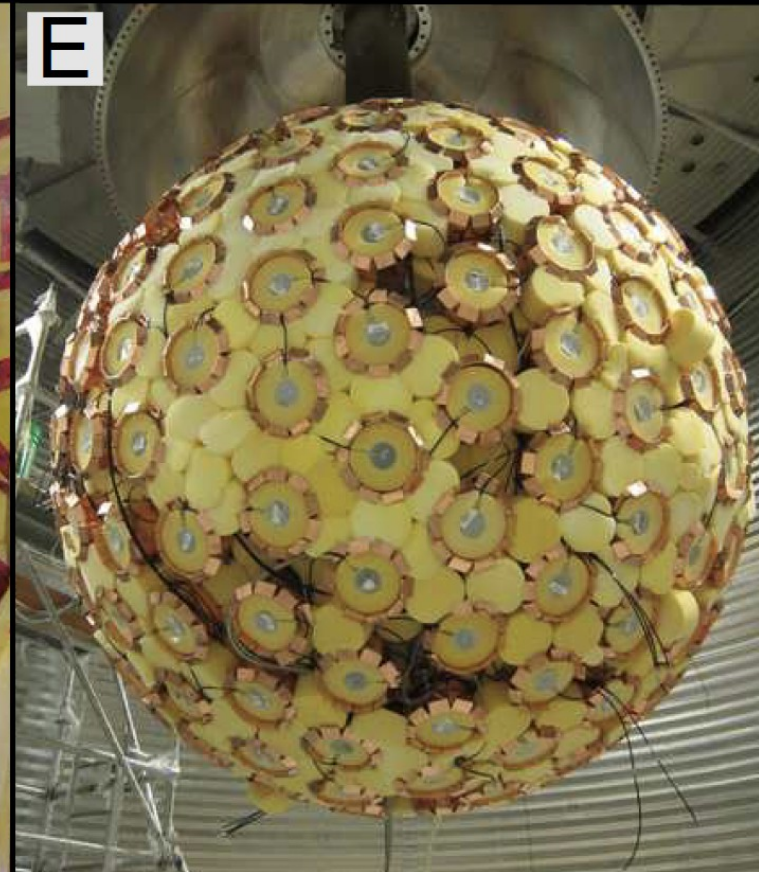
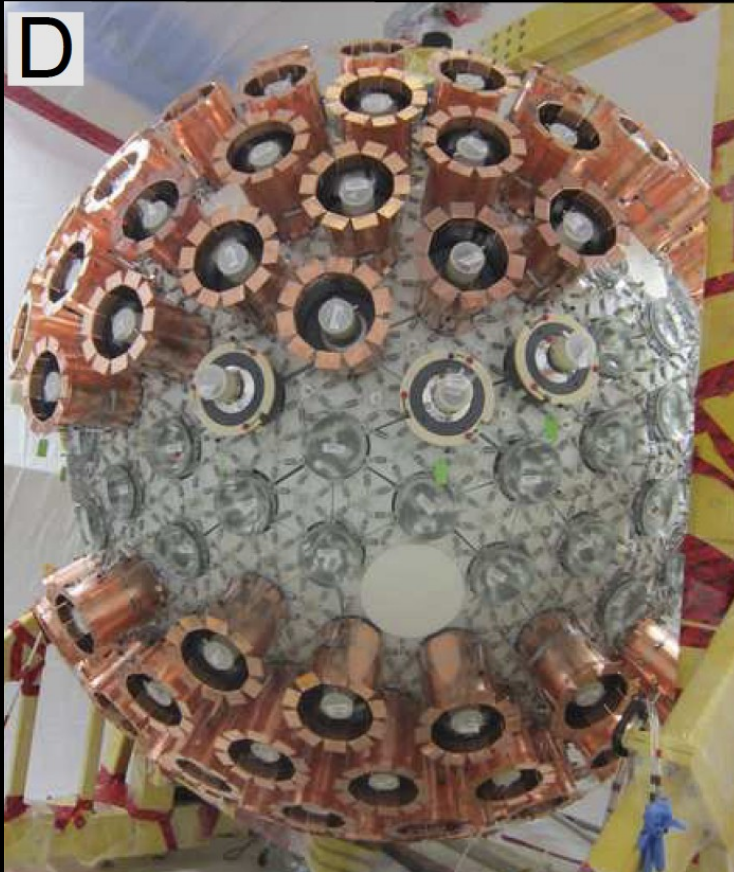
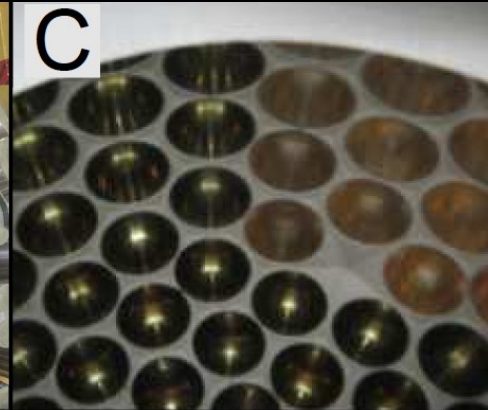


Bonding light guides underground at SNOLAB

Light guides

Reflectors

Inside view

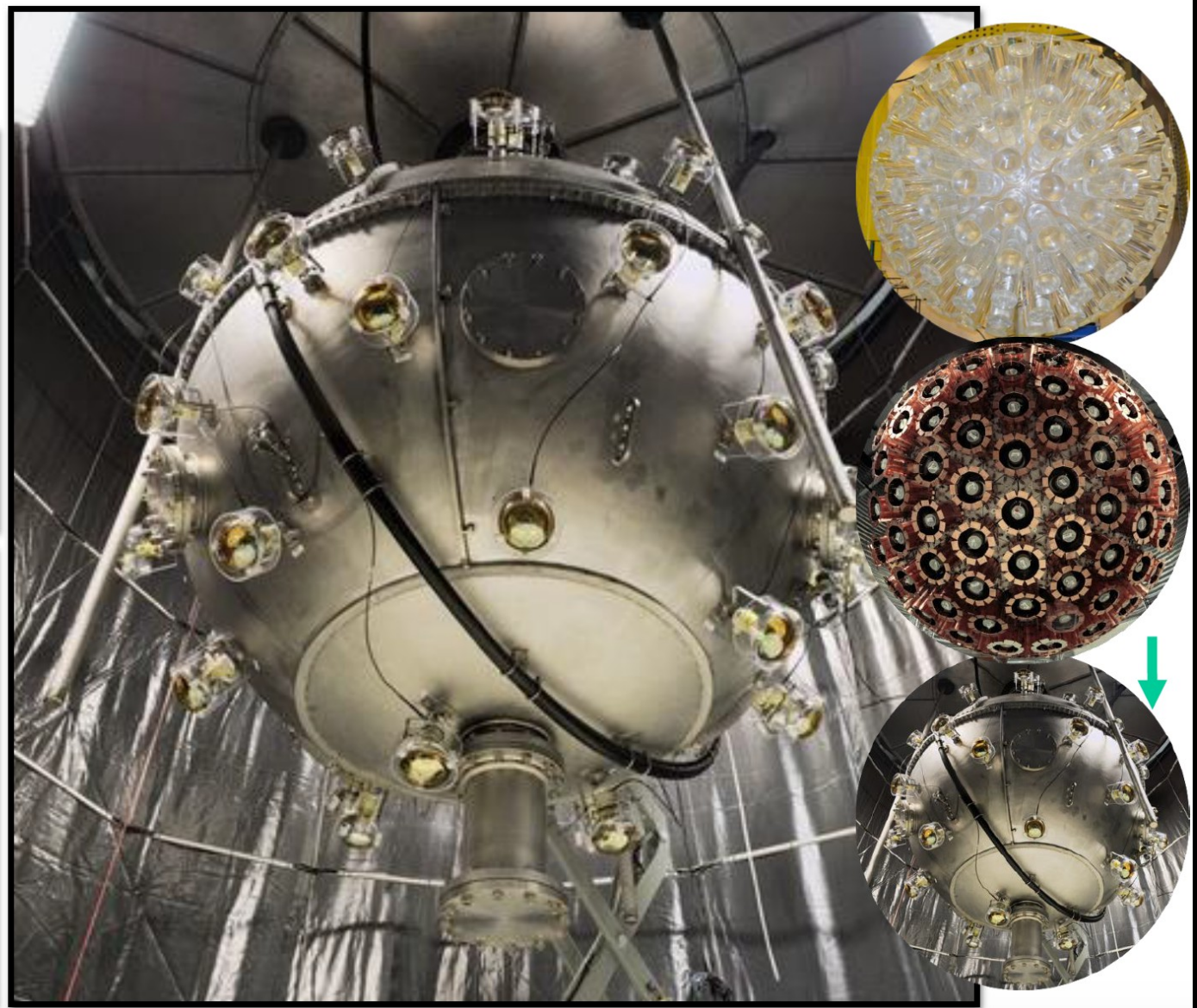
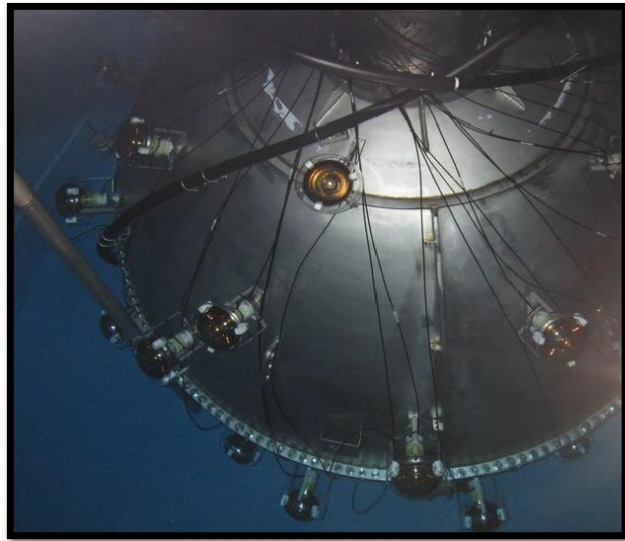
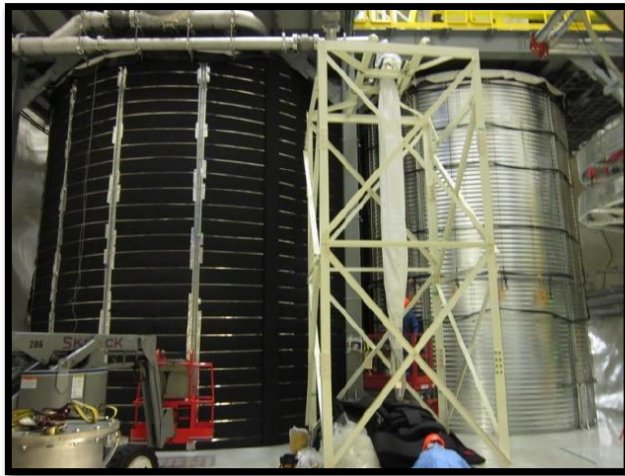


PMT installation

Backing foam installation

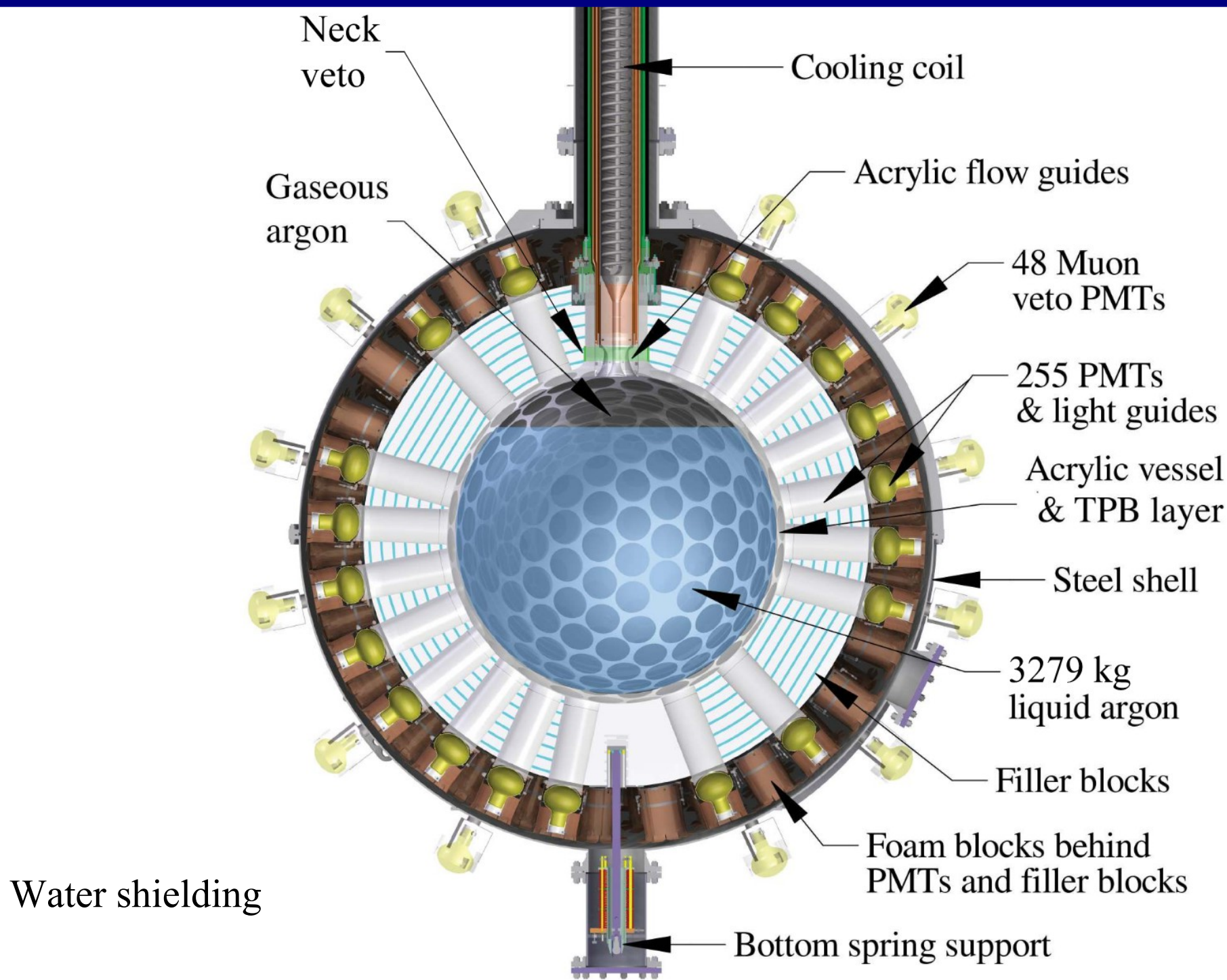
Steel shell, Veto PMTs

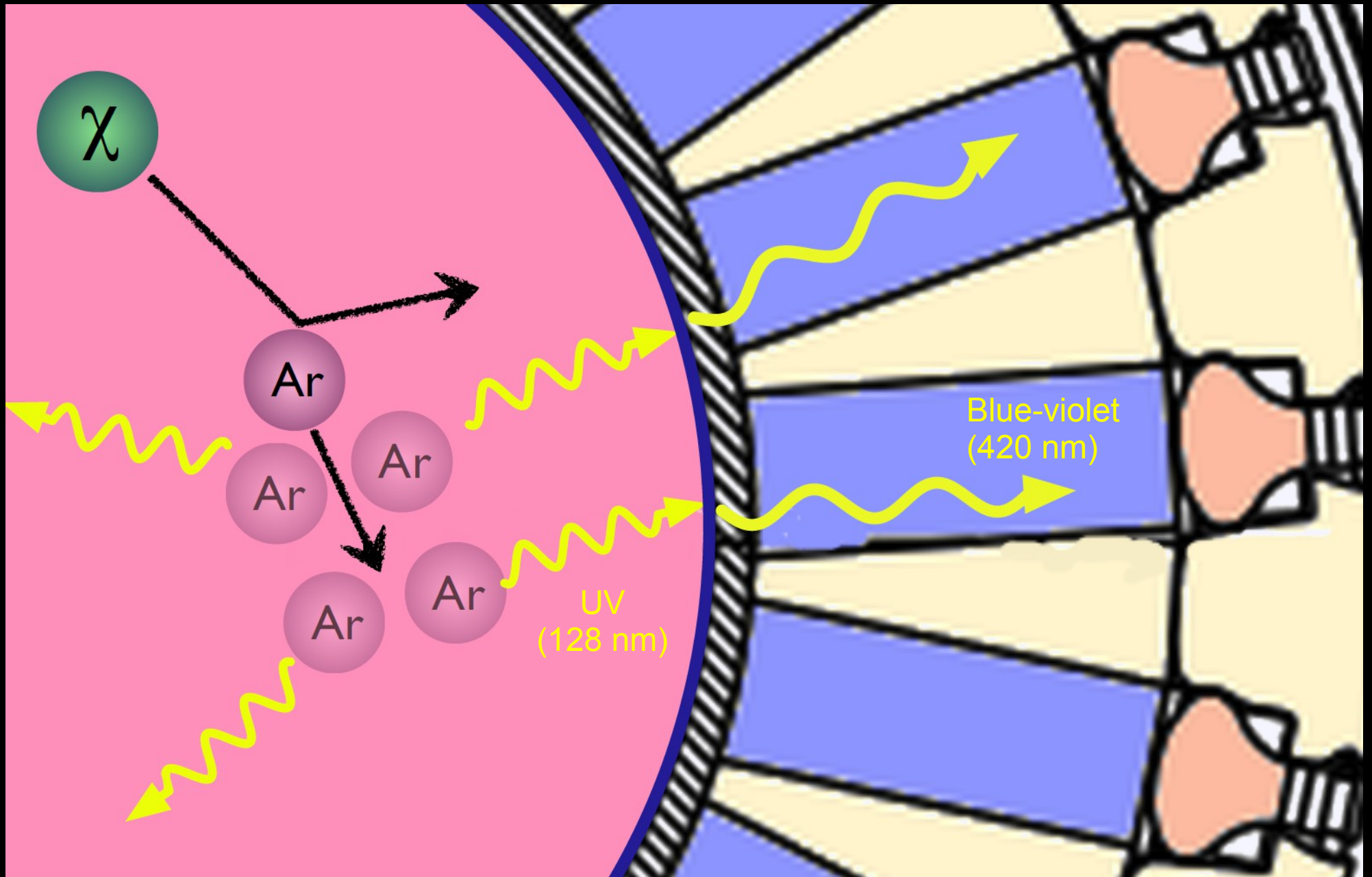
Water tanks in Cube Hall



All details available in the DEAP-3600 detector publication! [arXiv:1712.01982](https://arxiv.org/abs/1712.01982)

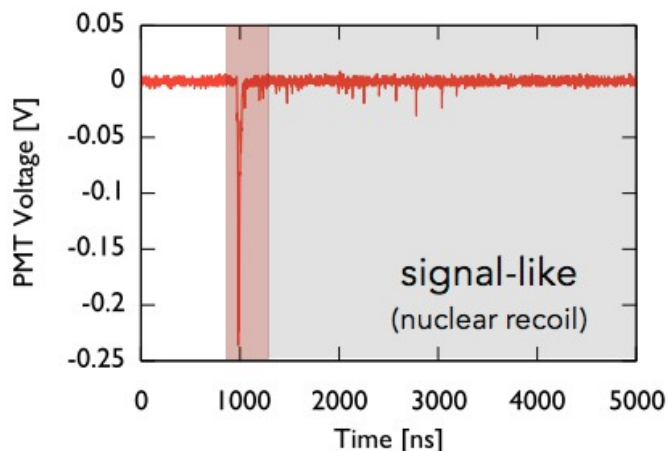
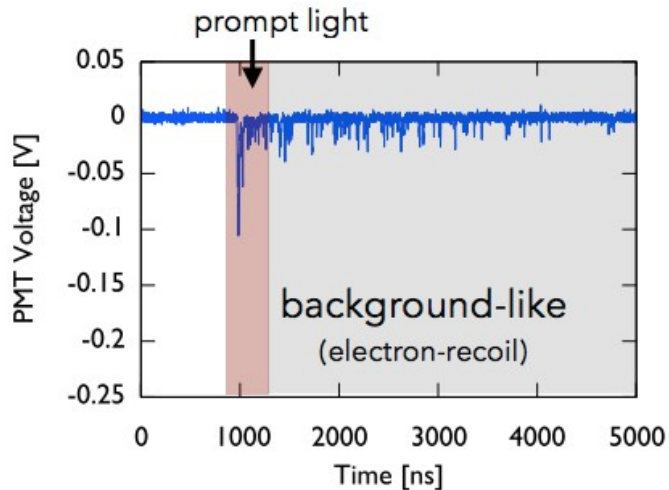
Dark matter Experiment using Argon Pulse-shape discrimination





Pulse-Shape Discrimination

Objective: **select dark matter signal events**, and reject background events



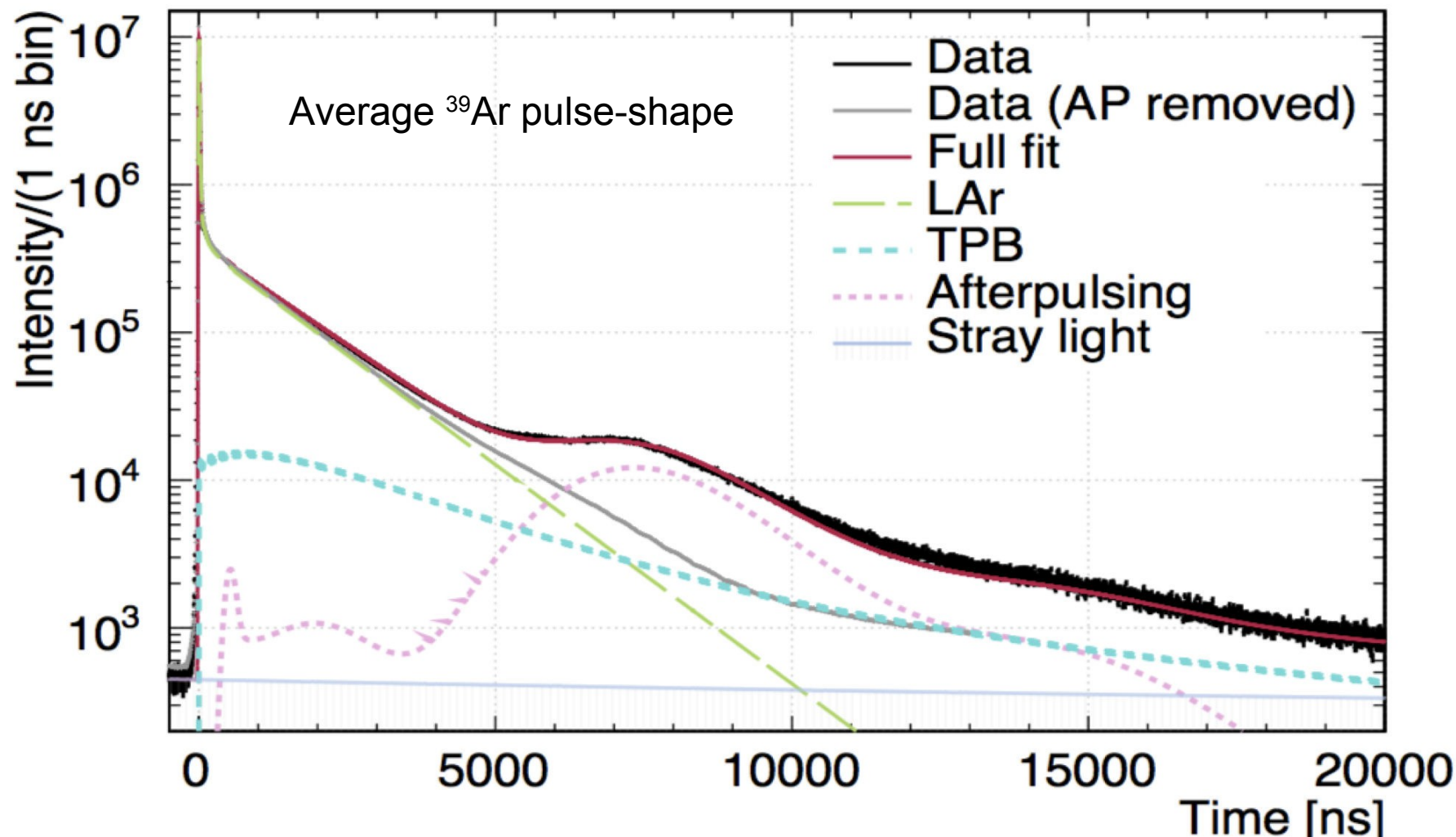
- Liquid argon is suitable for very large targets
 - Transparent to its own scintillation light
 - Easy to purify
 - Much lower cost compared to xenon

... 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 !**

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

Pulse-Shape Discrimination

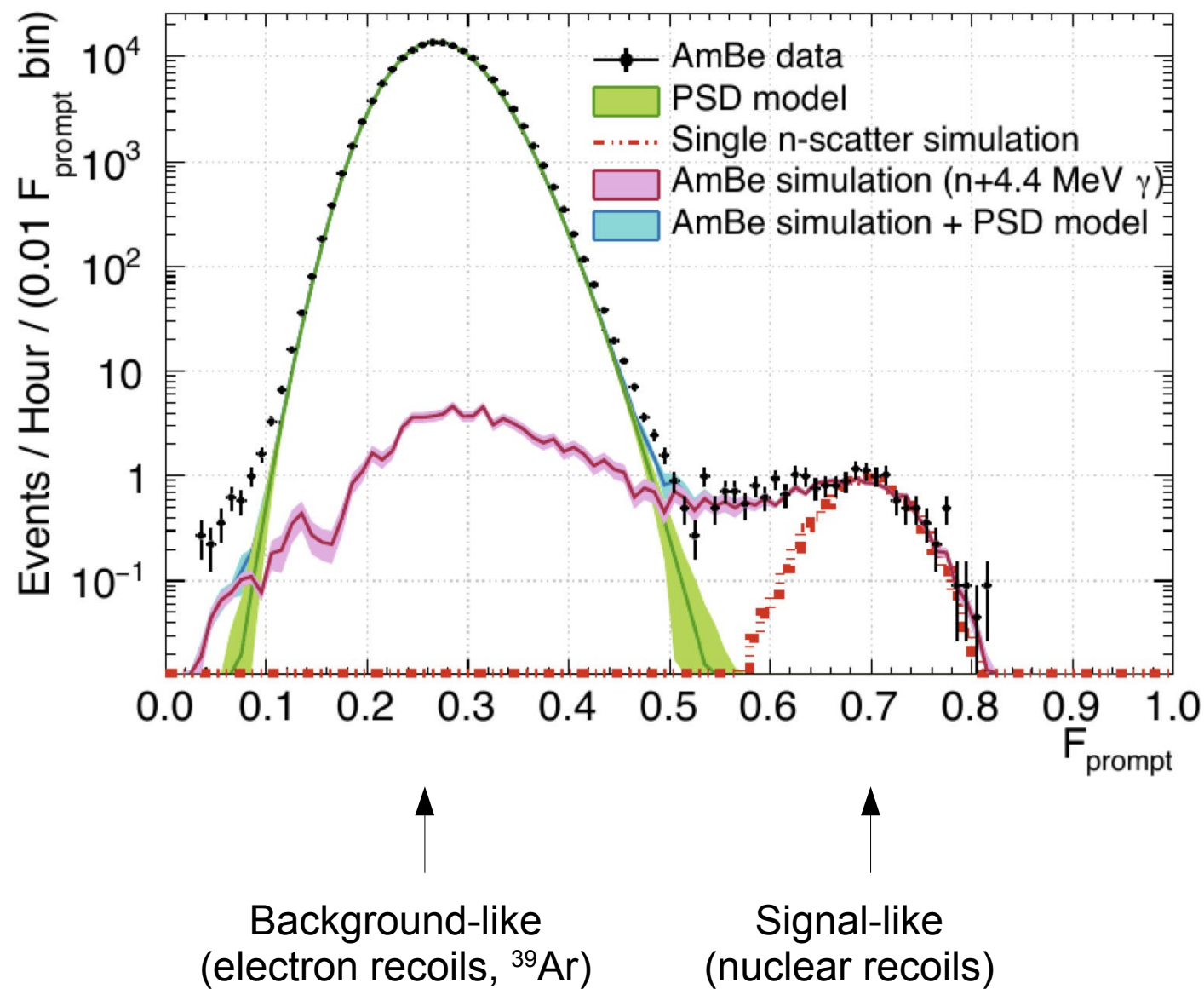


Visible photons → Photoelectrons at PMT cathode → PMT pulses

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

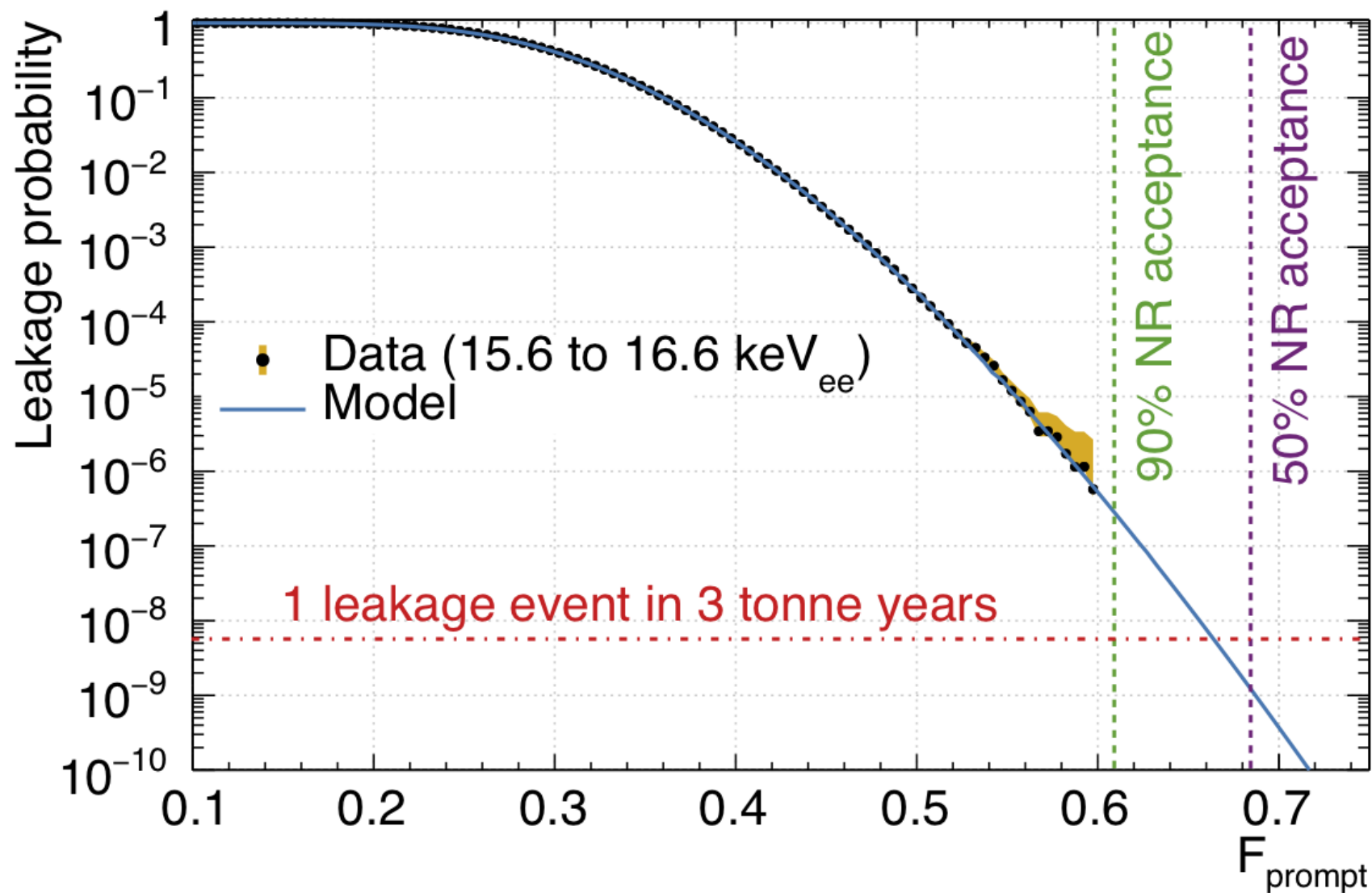
Pulse-Shape Discrimination

Neutron source calibration data



Pulse-Shape Discrimination

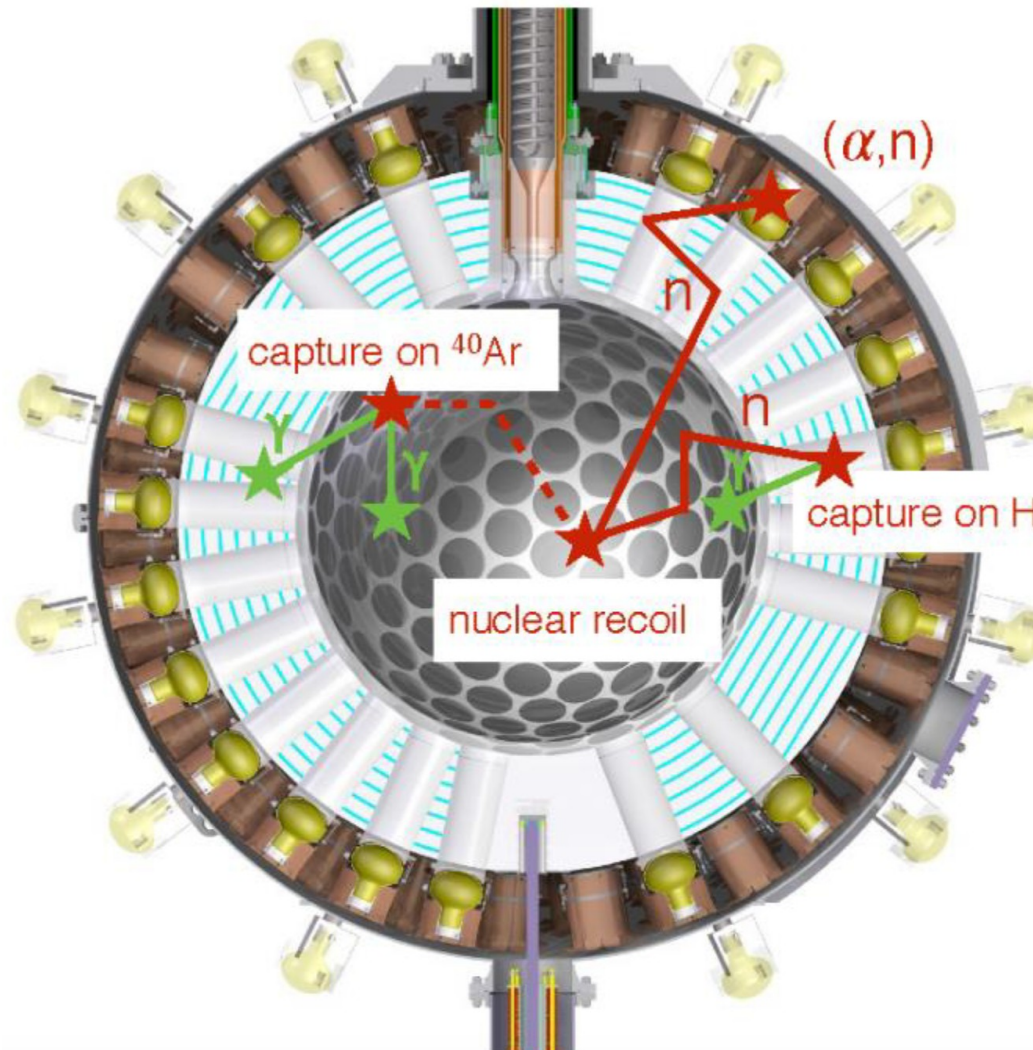
World-leading PSD performance!



Nuclear recoil backgrounds: Neutrons

Signal-like events can be produced by **neutrons** wandering into the detector

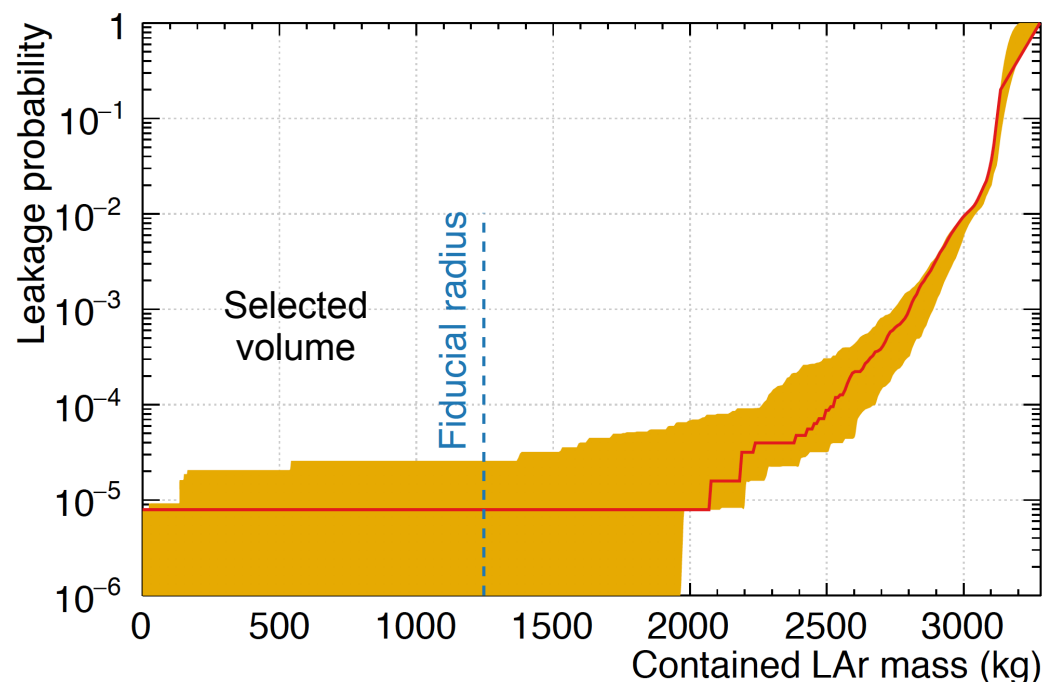
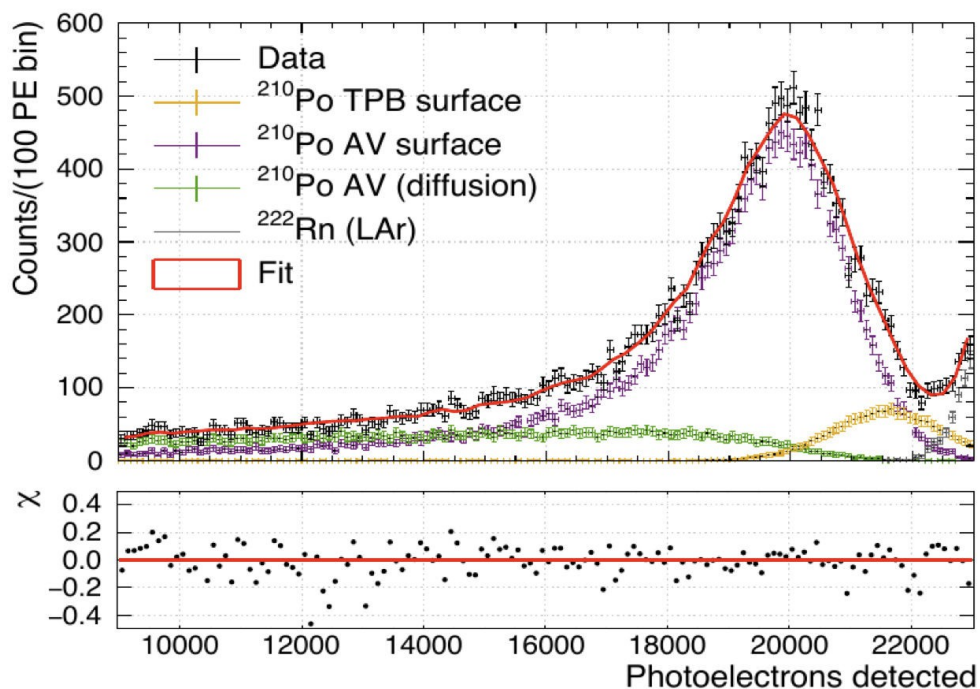
Neutron events can cause multiple nuclear recoils in close succession,
or result in gamma-ray emission → **Reject** events observed with these properties



Nuclear recoil backgrounds: Alphas from detector surface

Signal-like events can be produced by **alpha** decays at the **detector surface**

Position reconstruction algorithms are able to reject these backgrounds effectively



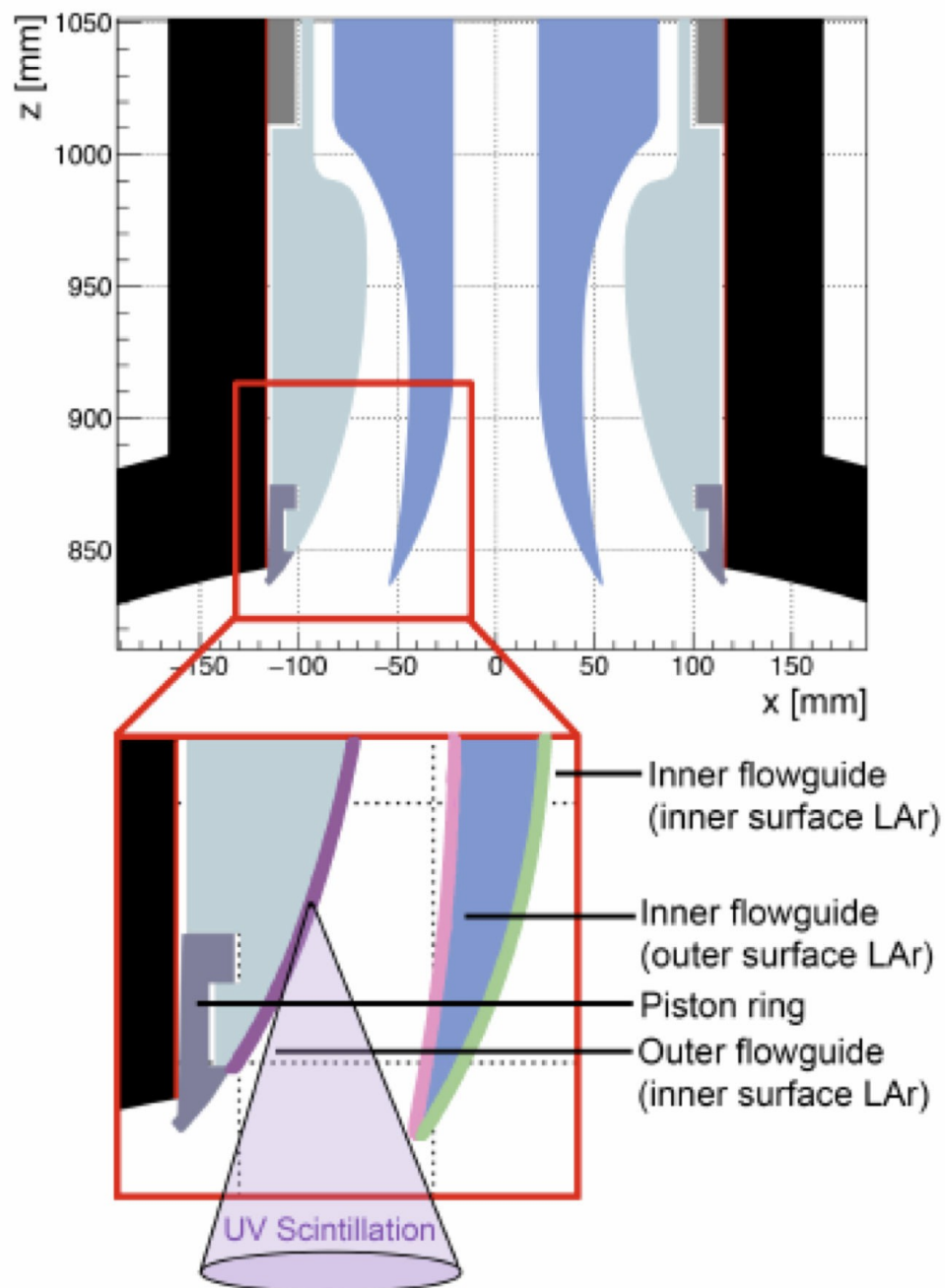
High-energy events observed from the detector surface are well-explained by our model

More activity detected from the top and bottom of the detector: pre-emptively **reject** events with high fraction of total PE from top rows and bottom rows of PMTs

Select events from the **innermost part** of the liquid argon vessel

Excellent performance of position reconstruction for rejecting simulated alpha decays from the detector surface

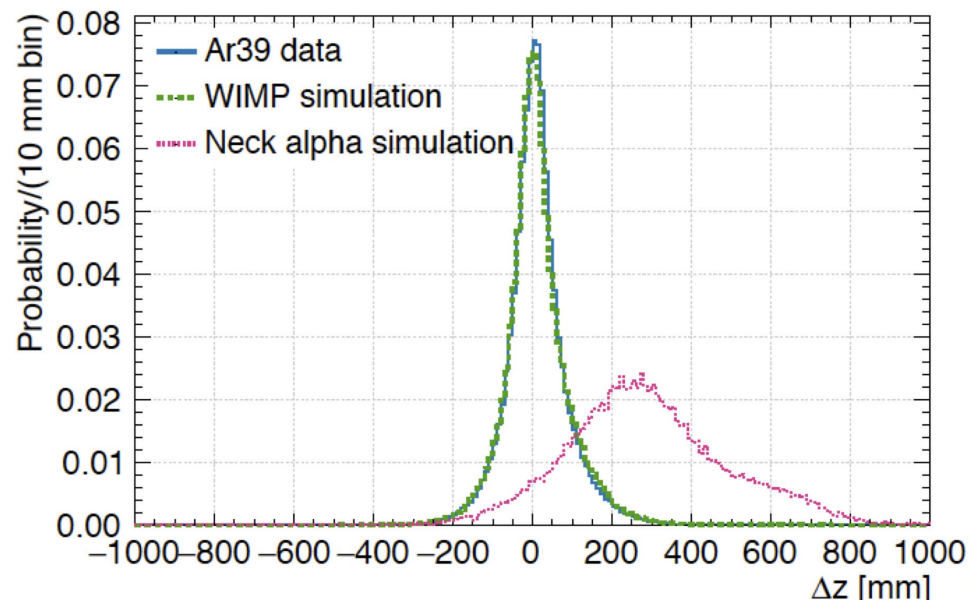
Nuclear recoil backgrounds: Alphas from detector neck



Signal-like events can be produced by **alpha decays at the detector neck**

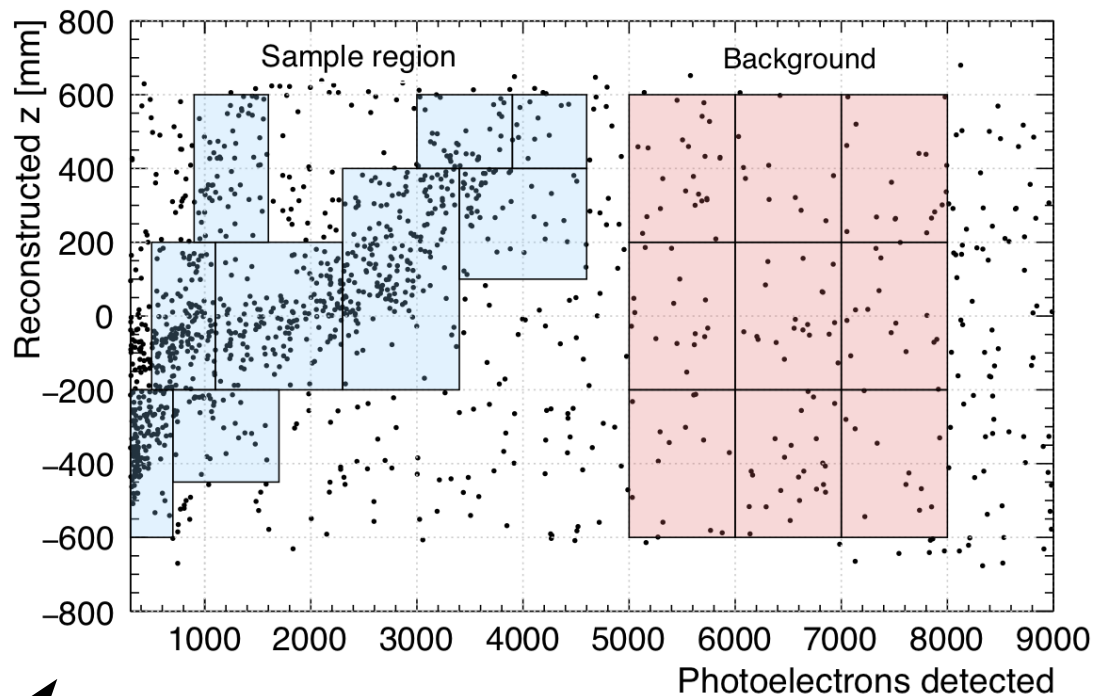
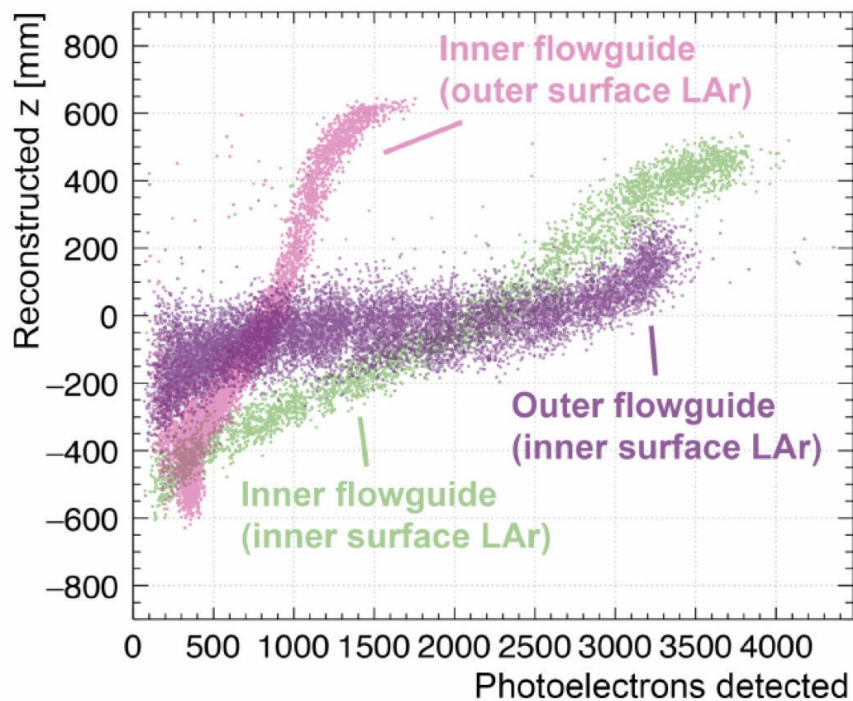
These background events can be particularly **challenging**, because the scintillation light can be blocked

Dedicated event selection and position reconstruction are able to reject these backgrounds effectively



Time-based vs. pattern-based reconstructed position

Nuclear recoil backgrounds: Alphas from detector neck

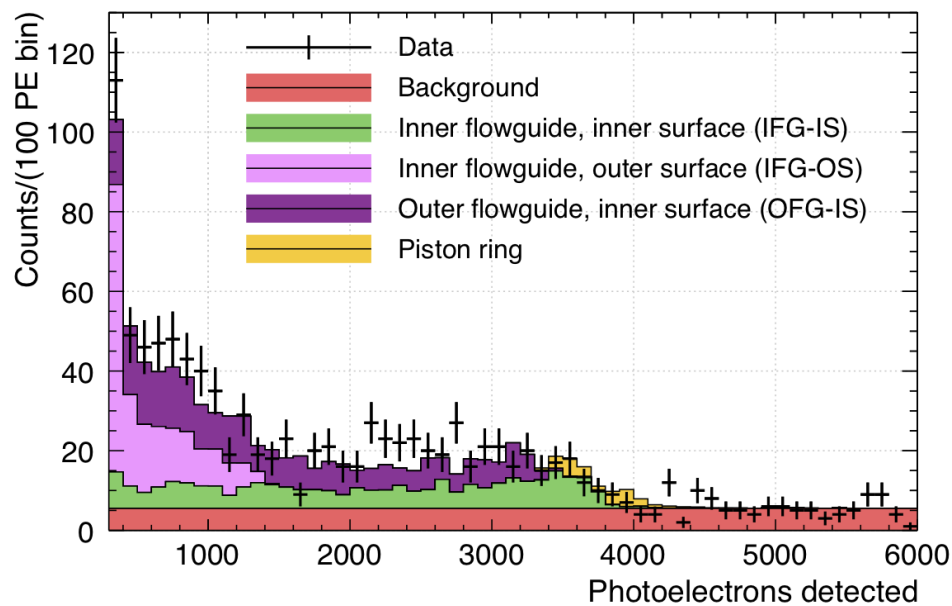


Identification of features from Monte Carlo **simulation**

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

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

Further, **reject** events with early pulses detected in top rows of PMTs

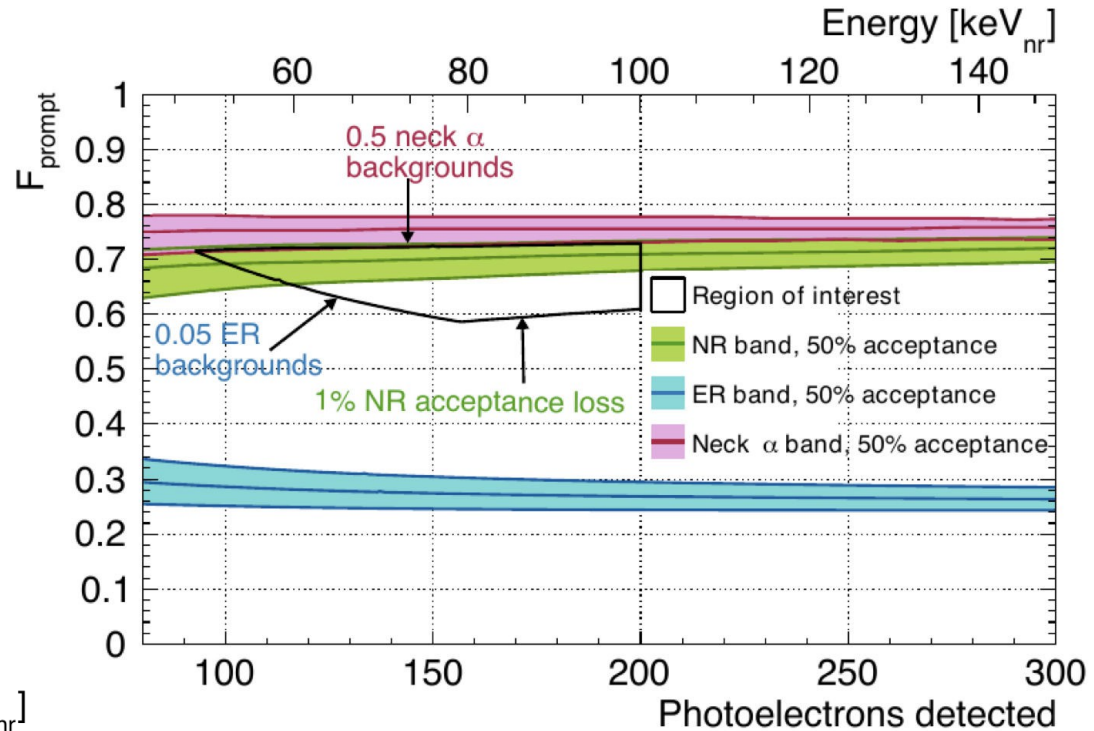
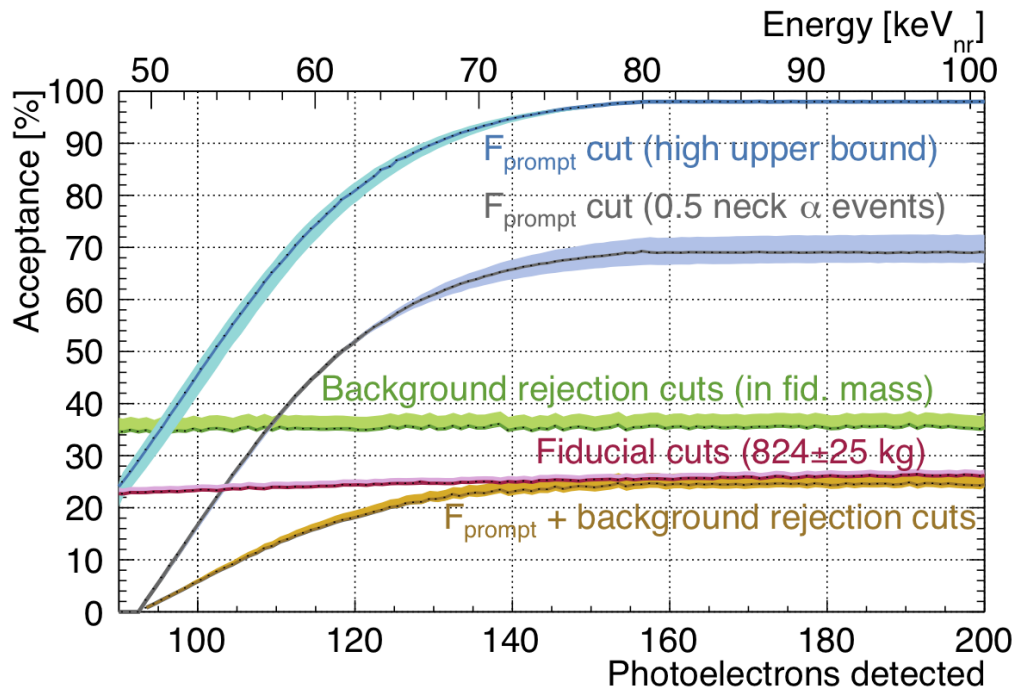


Signal region

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

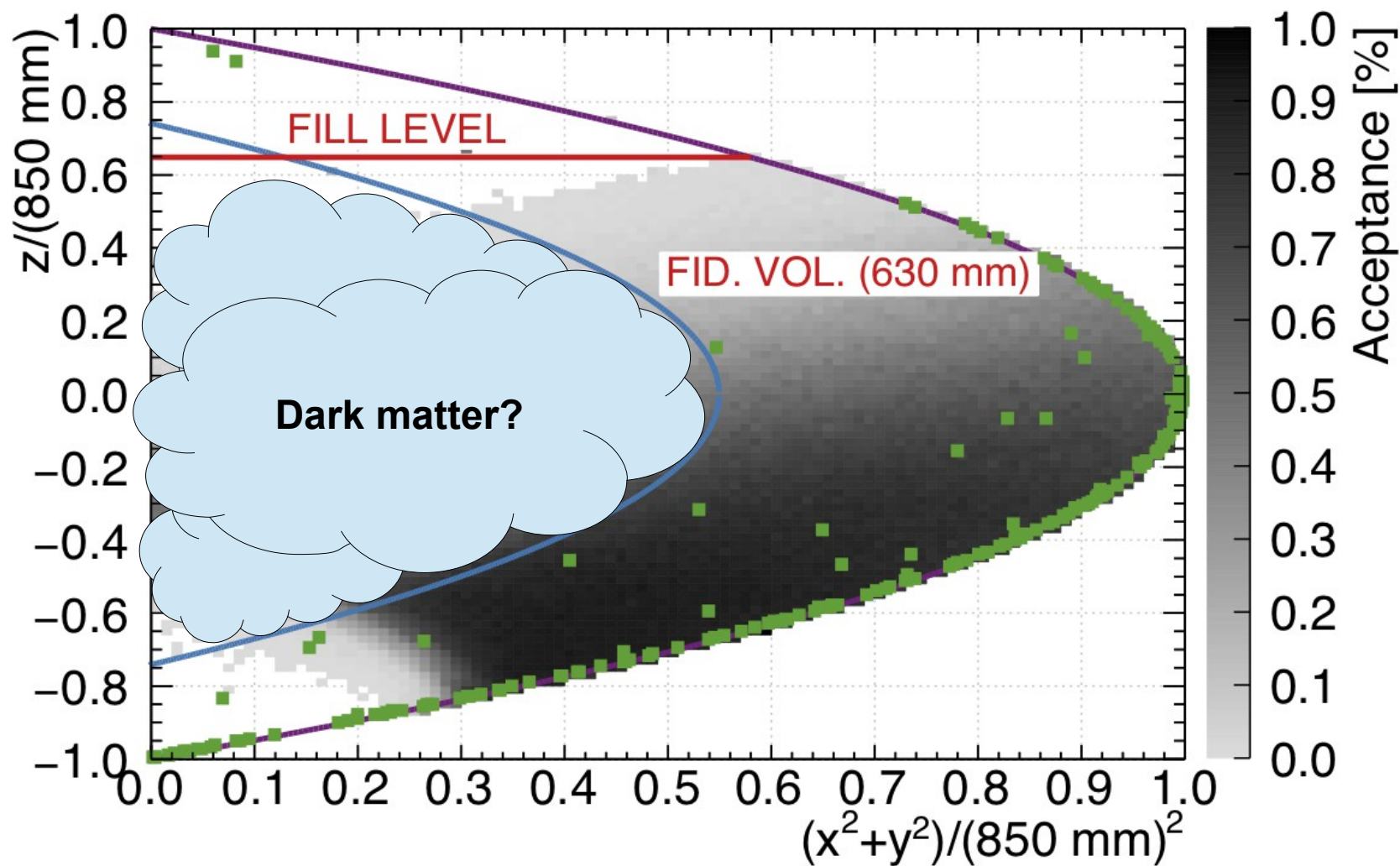


Expected backgrounds

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	$0.62^{+0.31}_{-0.28}$

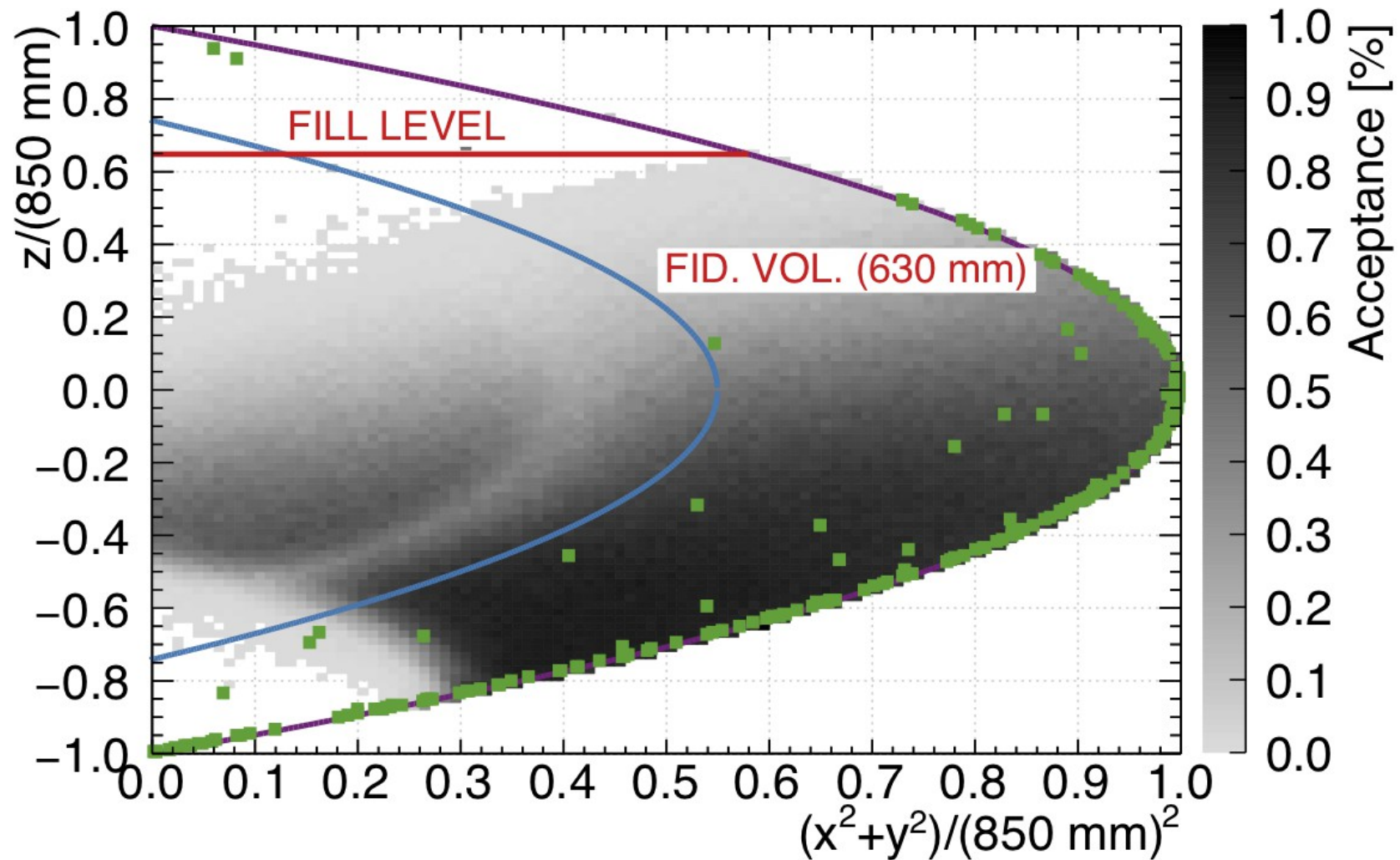
After event selection, the result is ...

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



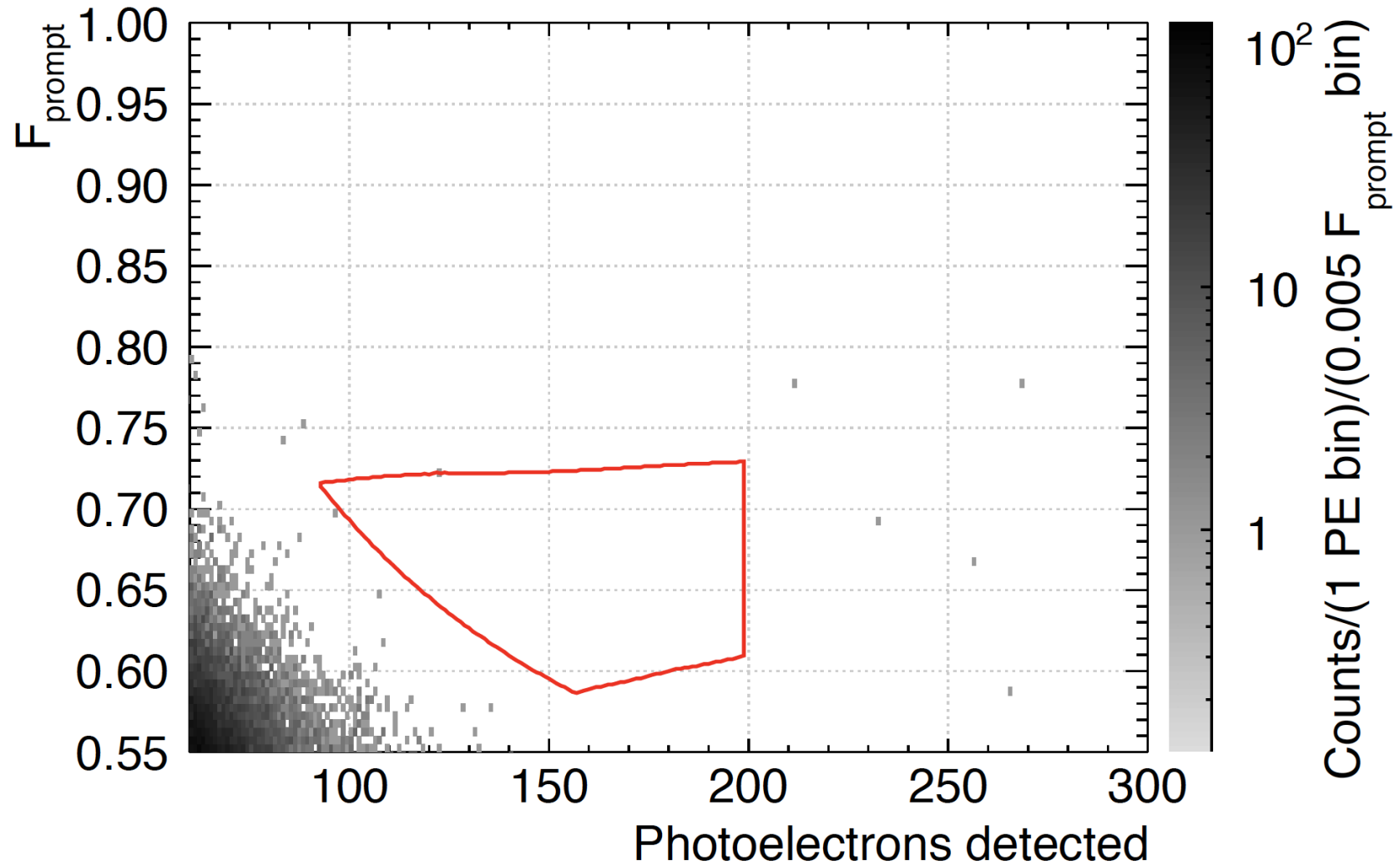
After event selection, the result is ...

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



After event selection, the result is ...

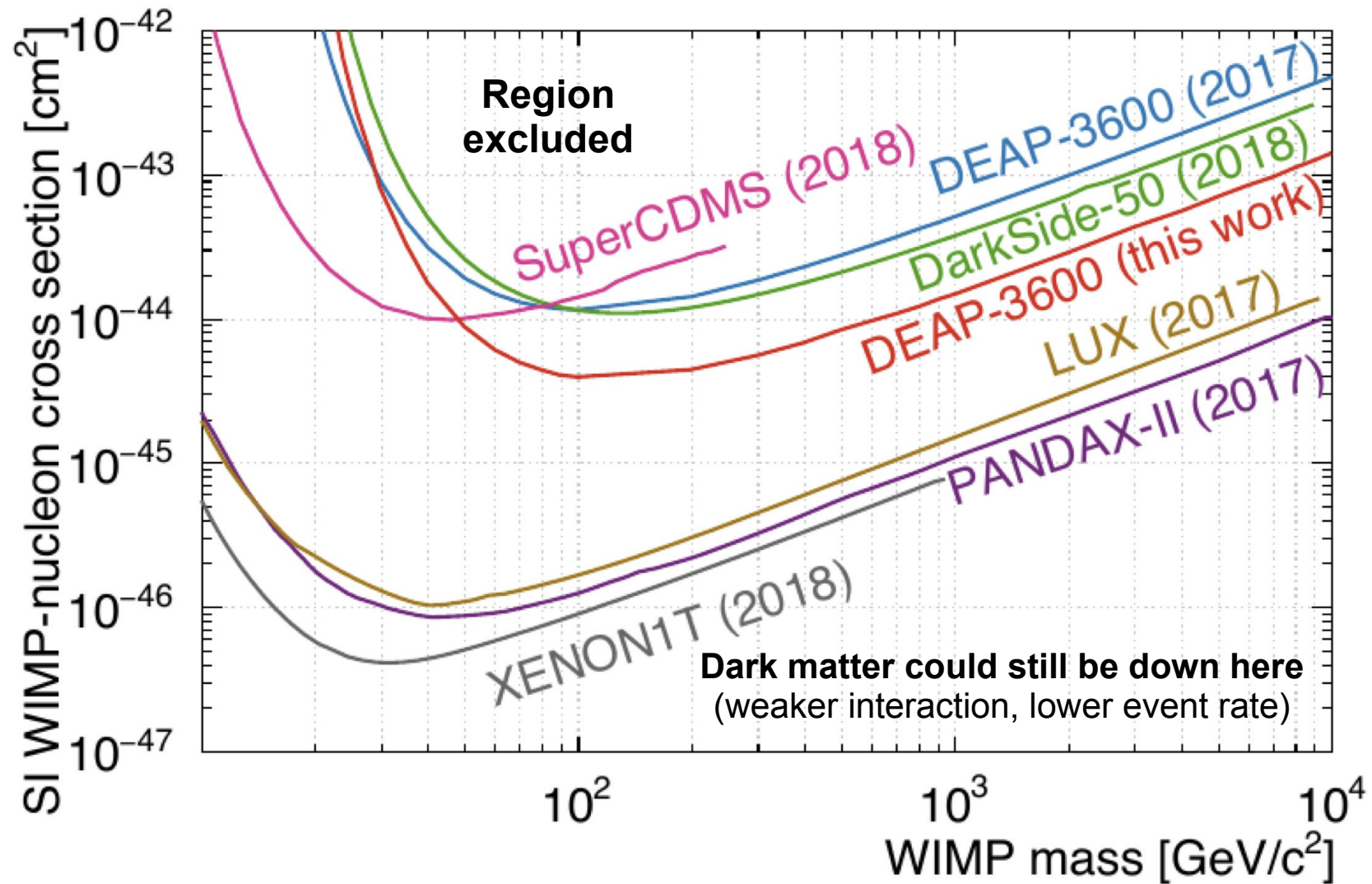
The detector is sensitive to dark matter, but no signal event was observed!



Dark matter search results

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

Therefore we **rule out** certain dark matter hypotheses



Conclusions and Outlook

- **Dark matter** is one of the most fundamental questions of our time
 - Has to exist in abundant quantities
 - Five times more dark matter, than ordinary matter!
 - Interacts so weakly with ordinary matter, that it has not been discovered yet
 - Looking for dark matter directly with the **DEAP-3600** experiment at **SNOLAB**
 - Found no dark matter signal event → Excluded some parameter space
 - Leading sensitivity for argon detectors, complementary to xenon searches
 - Experiment is still taking data!
 - More and more sensitive to very rare events in the detector
- **Instrumentation** research and development for future particle detectors
 - Design and simulation for DarkSide-20k and ARGO
 - Silicon photomultipliers, with applications within and outside particle physics (e.g. medical physics: imaging devices, positron emission tomography, etc.)
- Can we discover dark matter? **Let's find out!**

Thank you!

