Dark matter search results from 231 live-days of DEAP-3600

Dr. Tina Pollmann
for the DEAP collaboration

EPS-HEP meeting Gent 2019

The DEAP collaboration. ~90 researchers from Canada, UK, Mexico, Germany, Russia, Italy, Spain

DEAP 3600

University of Alberta

Laurentian University / Université Laurentienne

SNOLAB

INFN Istituto Nazionale di Fisica Nucleare

Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens

Queen's University

University of Sussex

National Research Center "Kurchatov Institute"

Carleton University

Royal Holloway University of London

TRIUMF

Princeton University

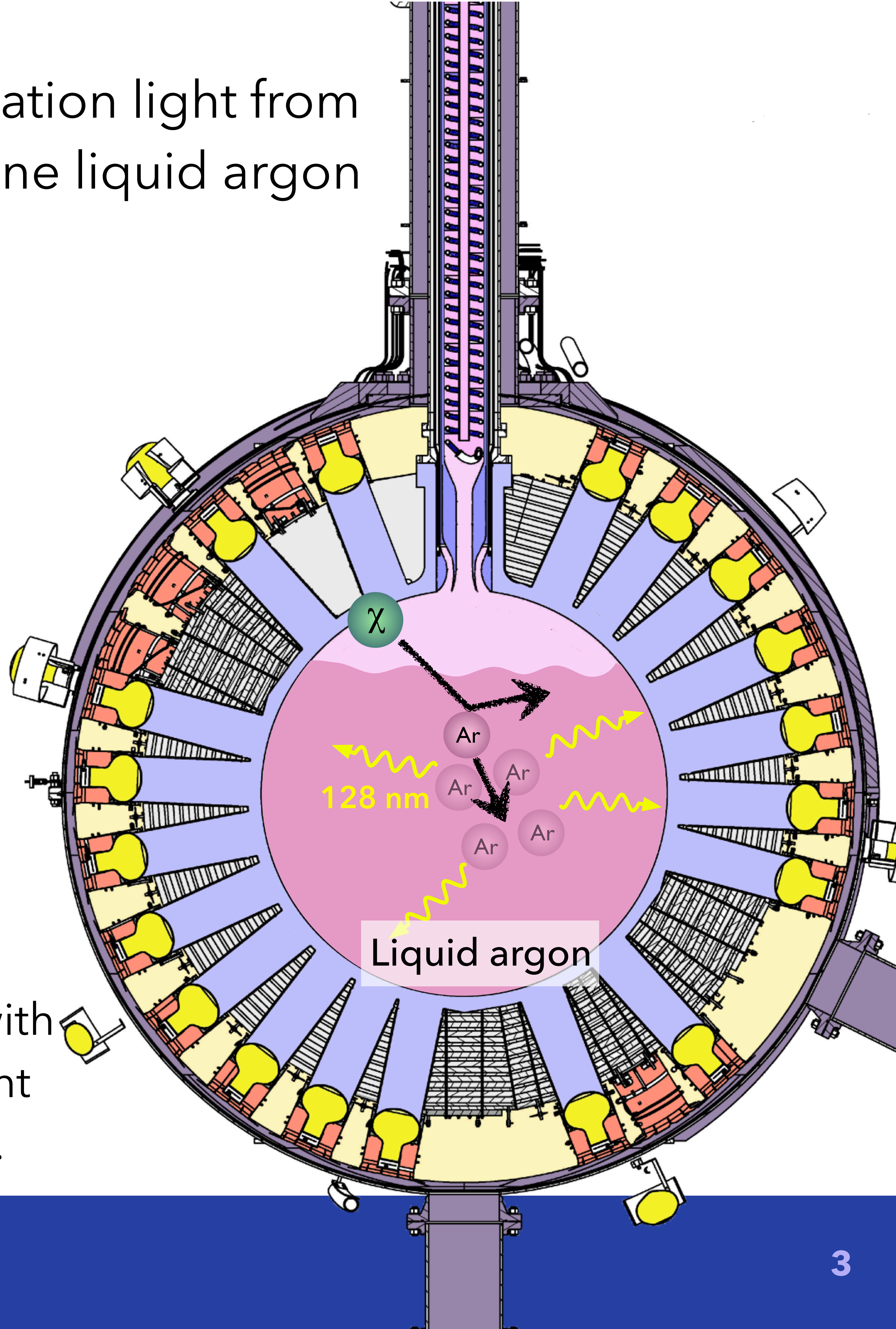
Instituto de Física

Particle Physics Rutherford Appleton Laboratory

Technical University of Munich

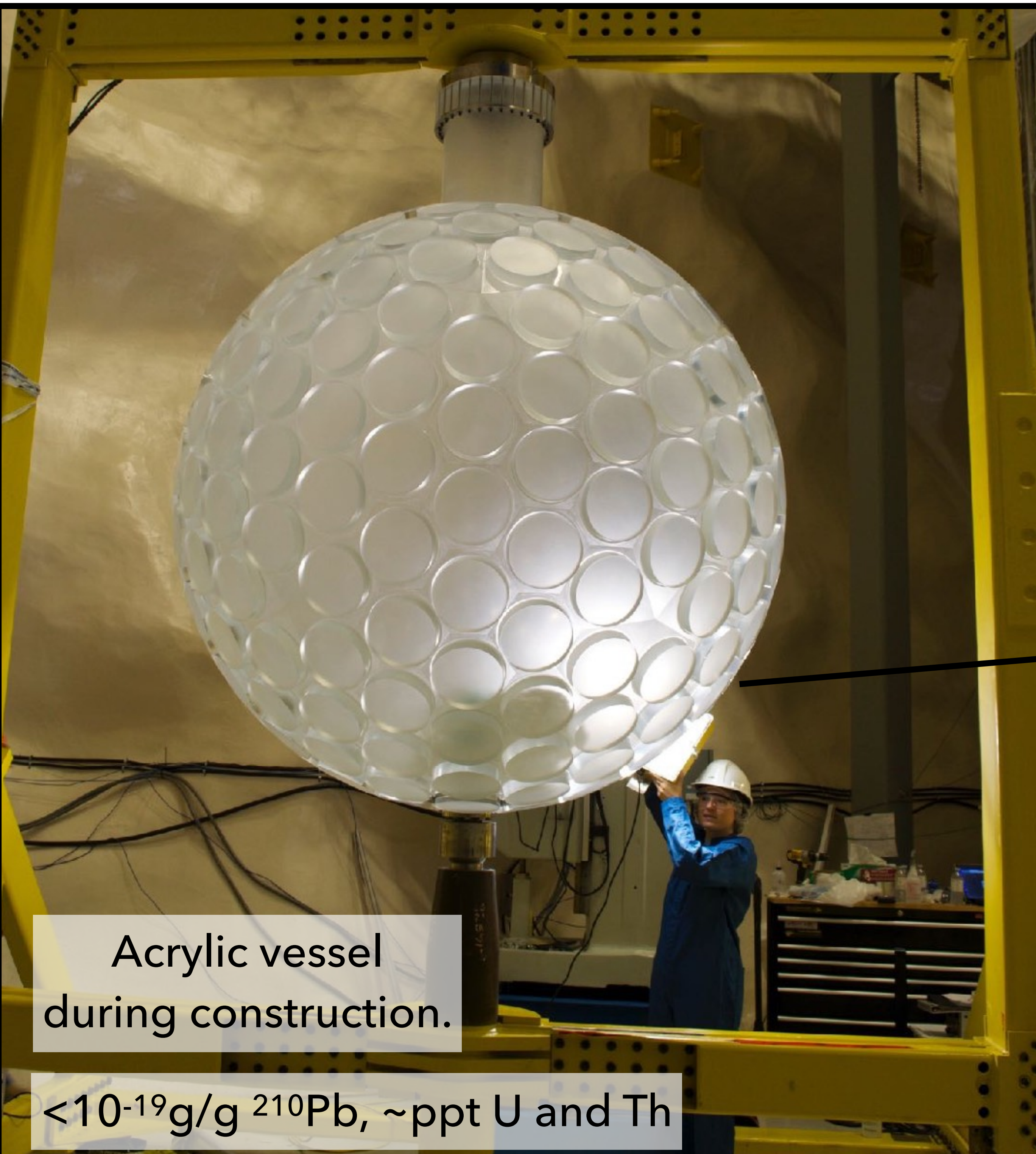
Gobierno de España, Ministerio de Ciencia, Innovación y Universidades, Ciemat

DEAP-3600 looks for the scintillation light from particle interactions in a 3.2 tonne liquid argon target.



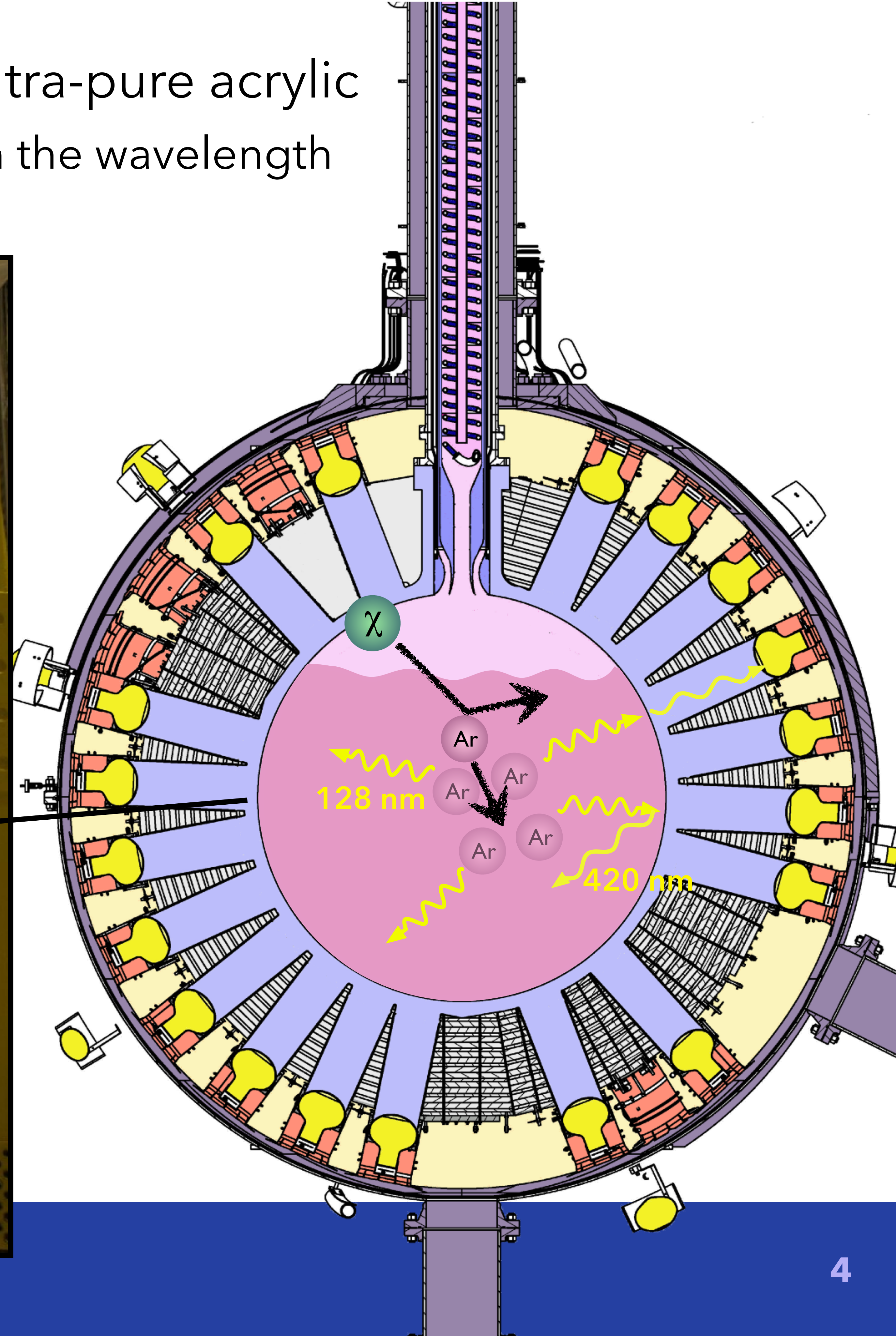
Liquid Argon (84 K, -188°C)
single-phase
A clean, affordable Dark Matter target with a bright scintillation signal and excellent background suppression capabilities.

The argon is contained in an ultra-pure acrylic cryostat, coated on the inside with the wavelength shifter TPB.



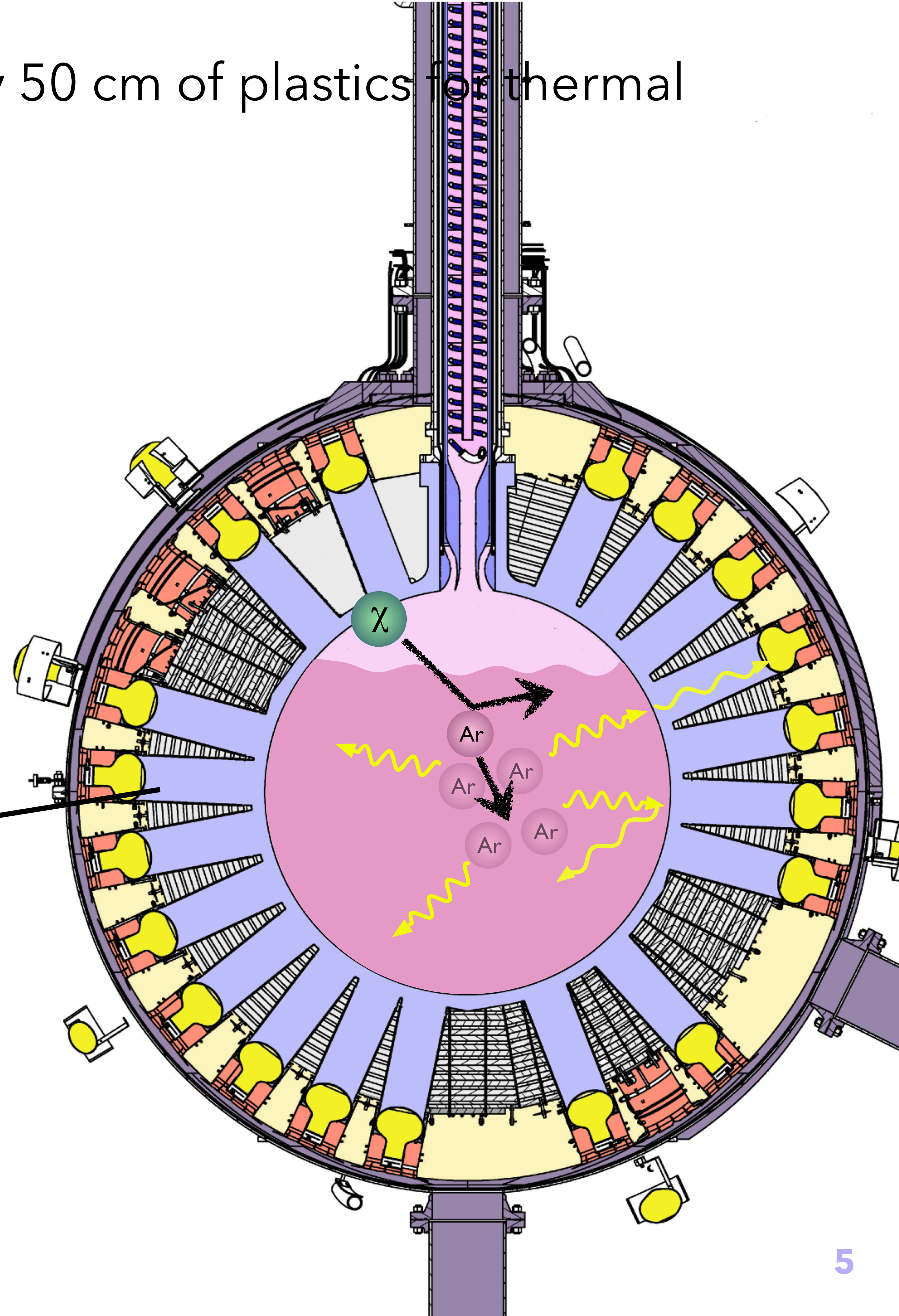
Acrylic vessel during construction.

$<10^{-19}$g/g ^{210}Pb, ~ppt U and Th



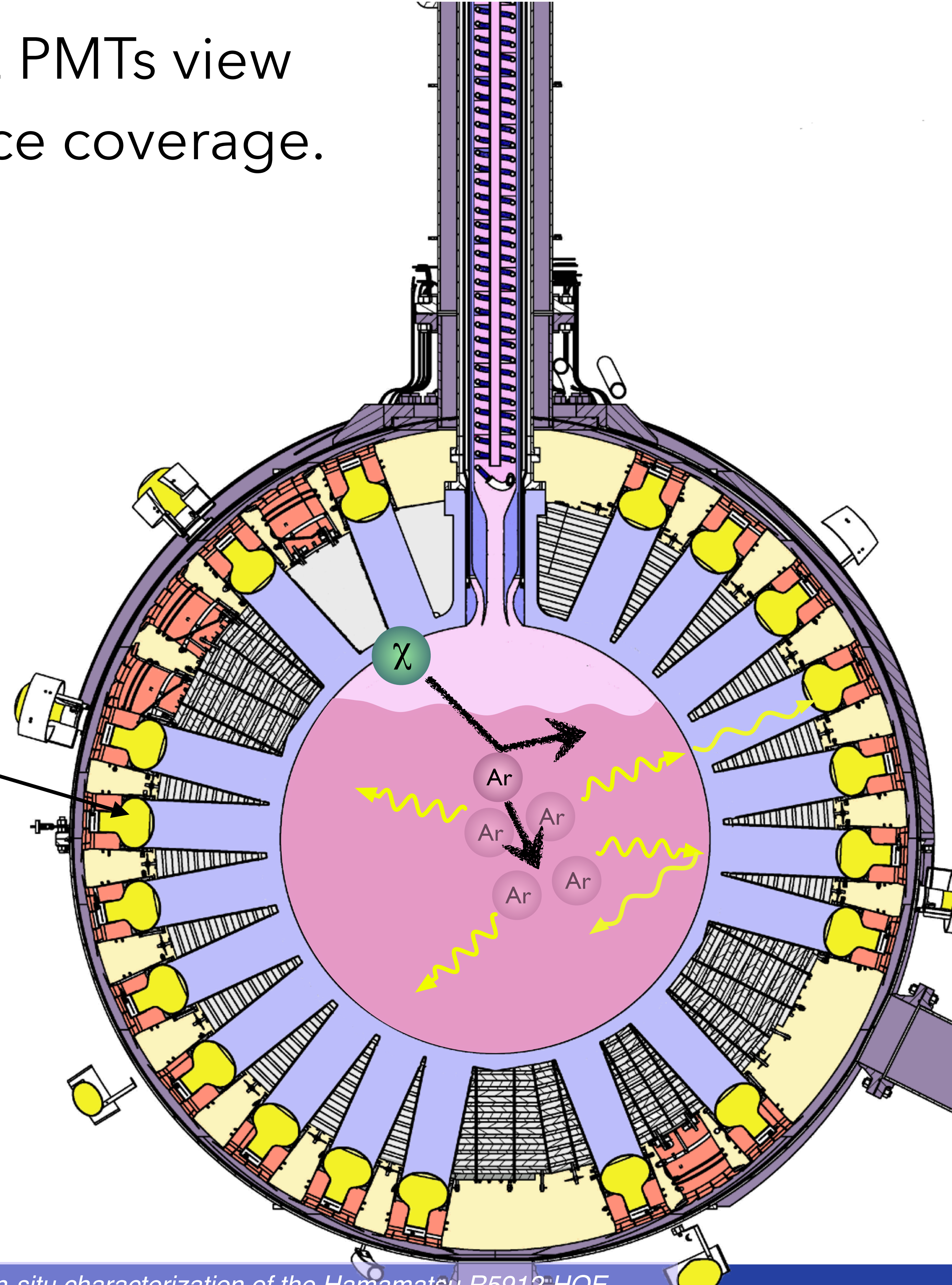
The cryostat is surrounded by 50 cm of plastics for thermal and neutron shielding.

Acrylic vessel during construction.



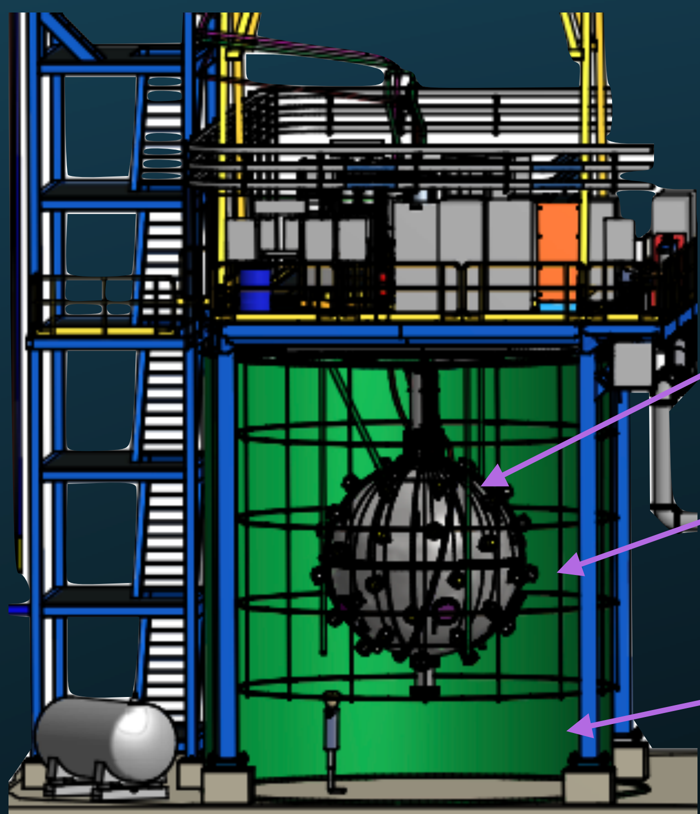
255 Hamamatsu R5912-HQE PMTs view the LAr volume at 71% surface coverage. PMTs at Temp > -40C.

Inner detector with protruding PMTs.



"In-situ characterization of the Hamamatsu R5912-HQE photomultiplier tubes used in the DEAP-3600 experiment"
EPJ **922** (2019)
arXiv:1705.10183

The DEAP-3600 detector is located 2 km deep at SNOLAB in Canada.



Steel shell

(Earth) magnetic field compensation coils

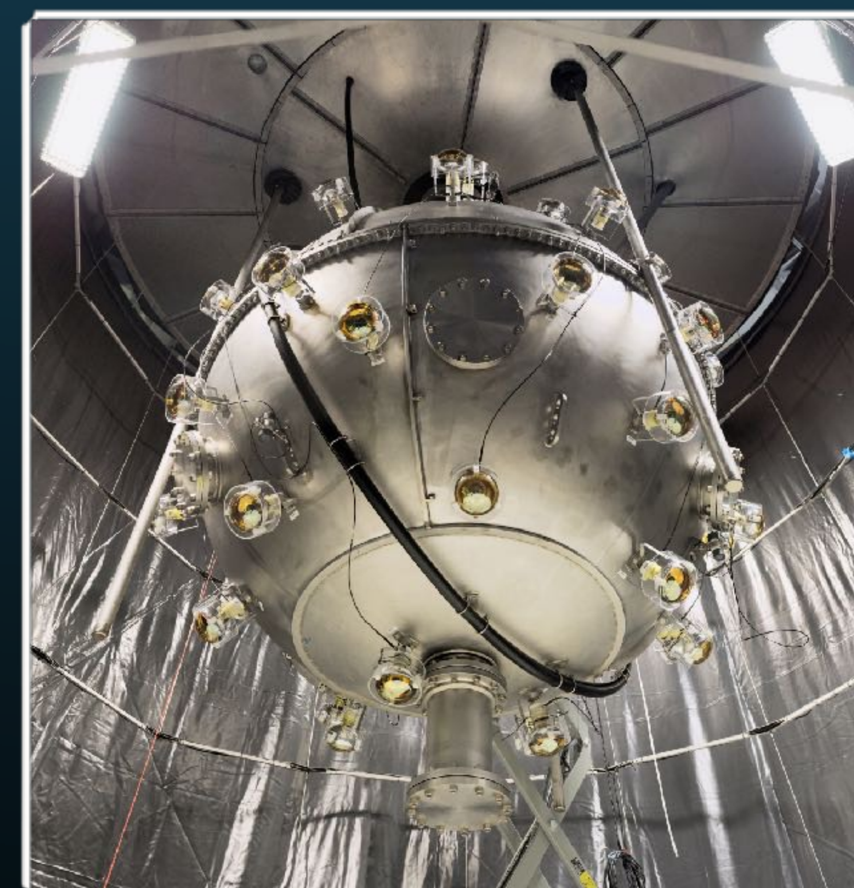
Water Cherenkov veto tank ⌀ 8m

DEAP-3600

2 km

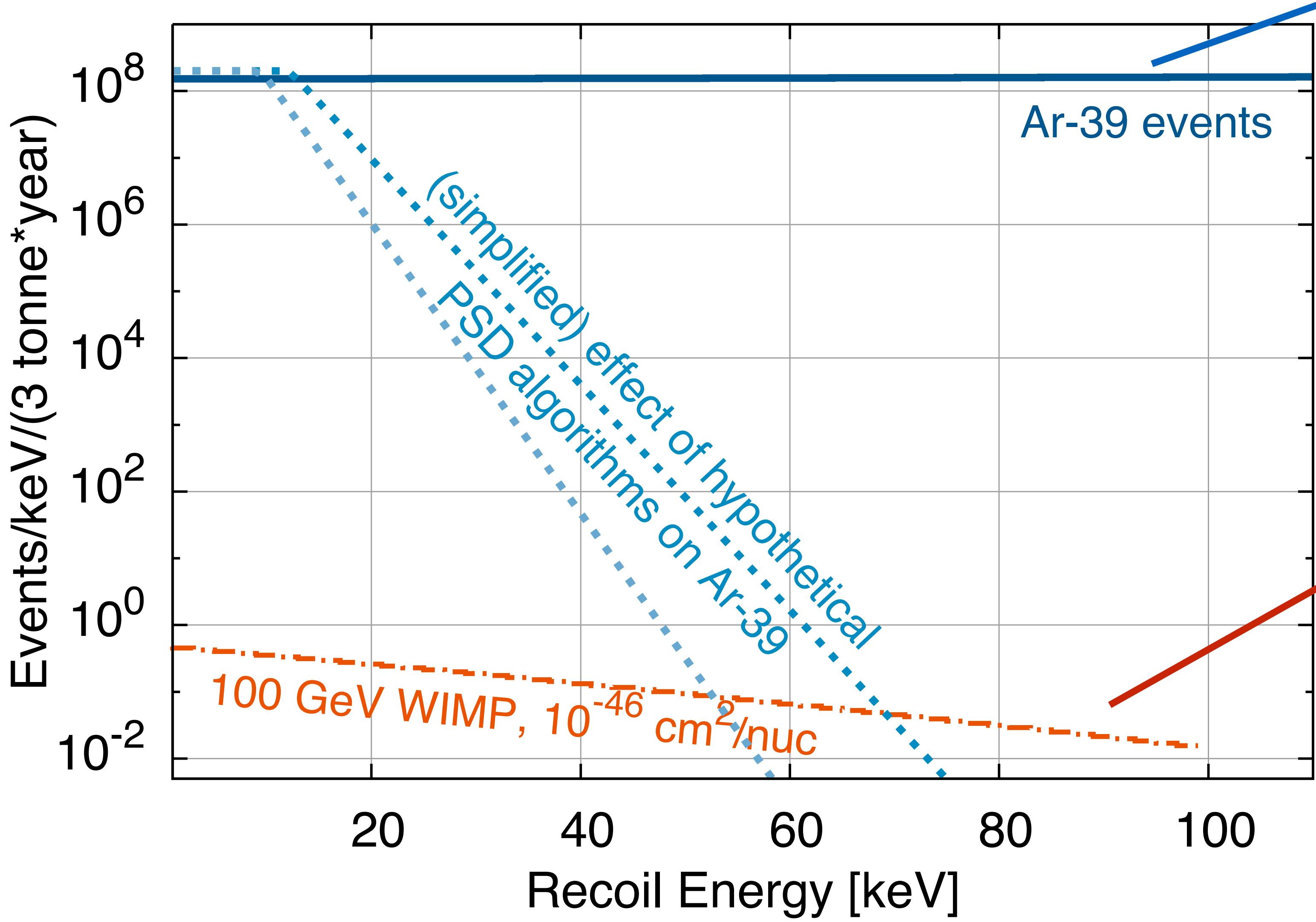
(6000 m.w.e.)

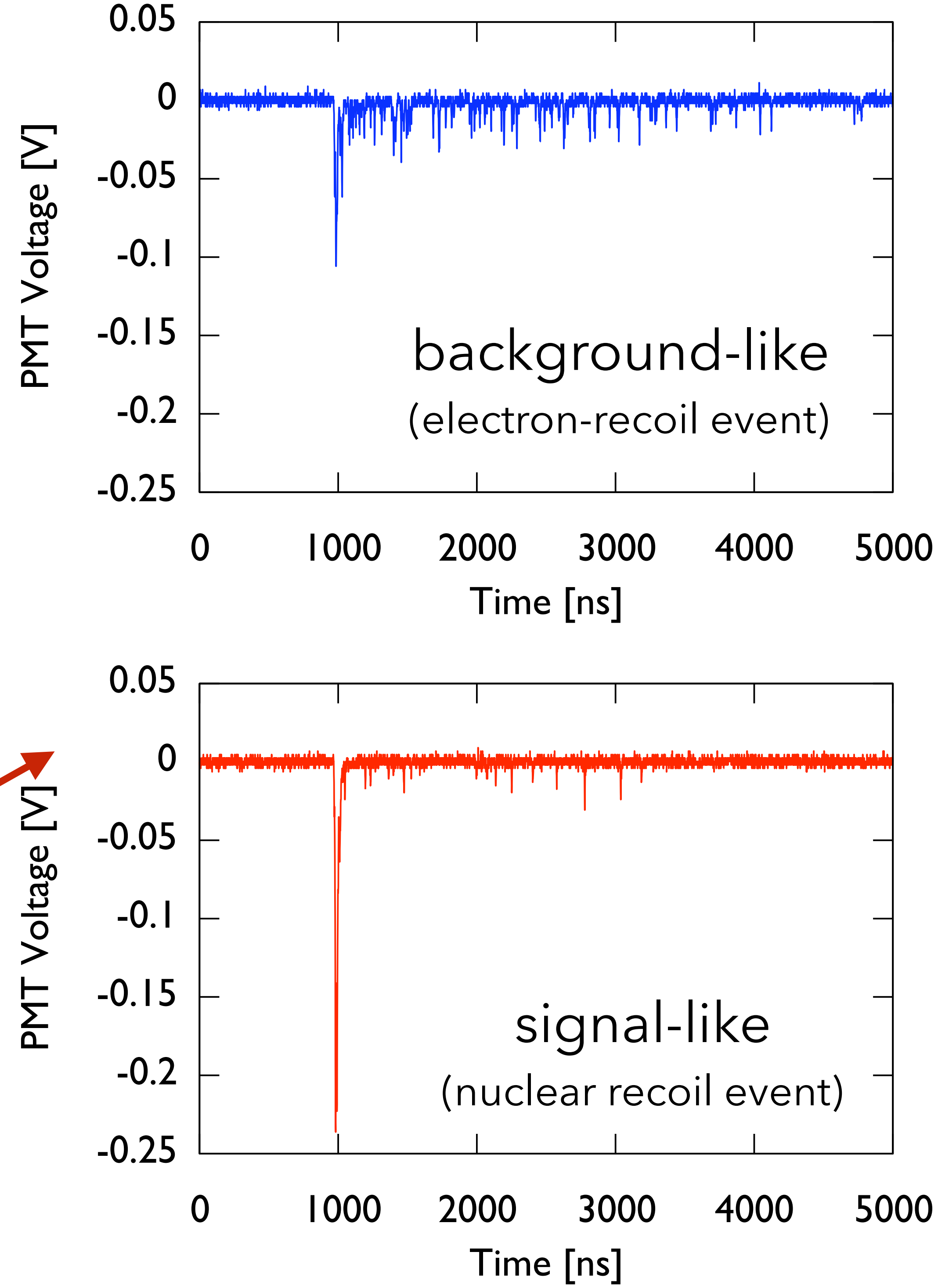
SNOLAB underground laboratory.



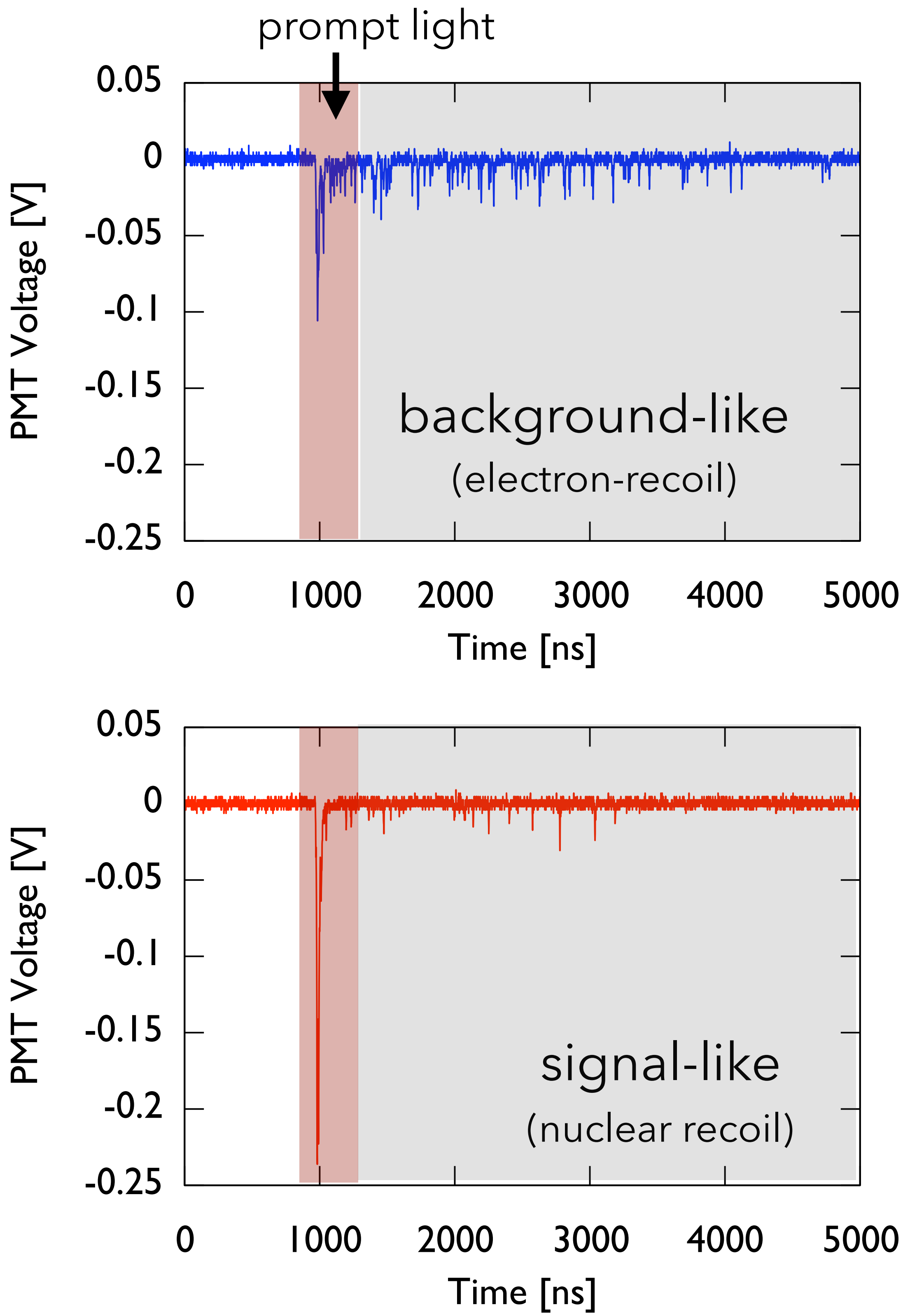
"Design and Construction of the DEAP-3600 Dark Matter Detector"
Astroparticle Physics **108** (2019)
arXiv:1712.01982

The background from Ar-39 beta decays is suppressed through pulse shape discrimination (PSD).

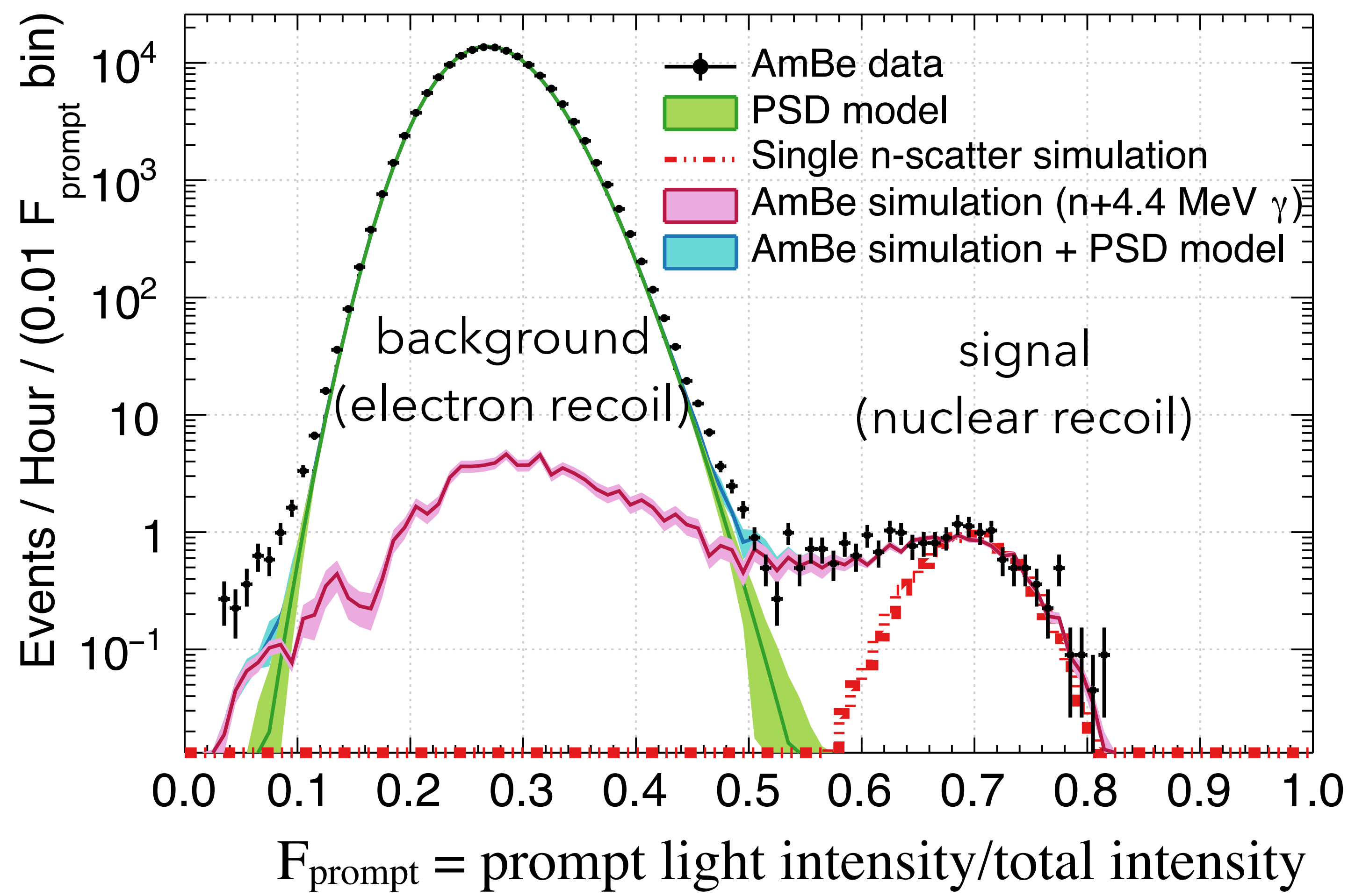




The argon scintillation pulseshape allows for effective PSD against electron-recoil background events.



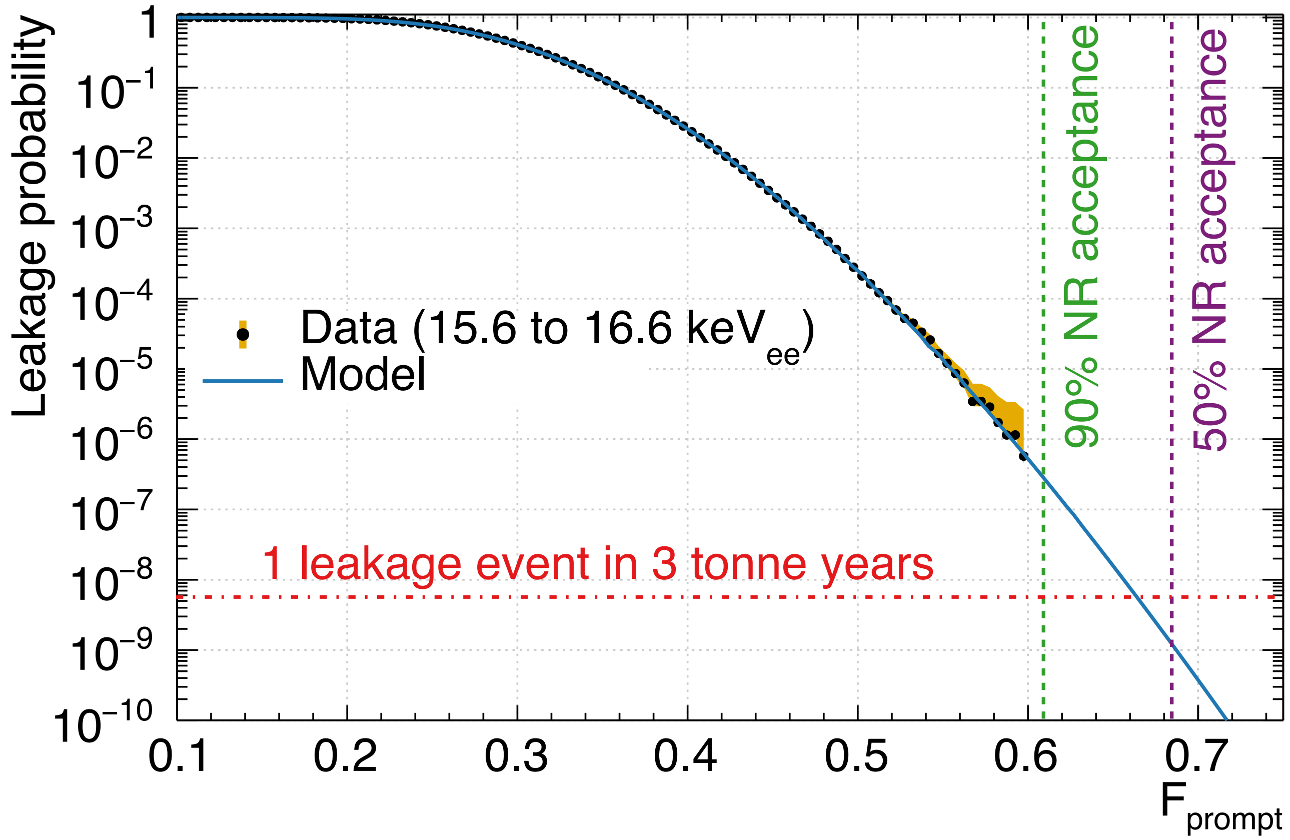
AmBe calibration data



Exploiting the singlet (6 ns) and triplet (1.5 μs) lifetime difference.

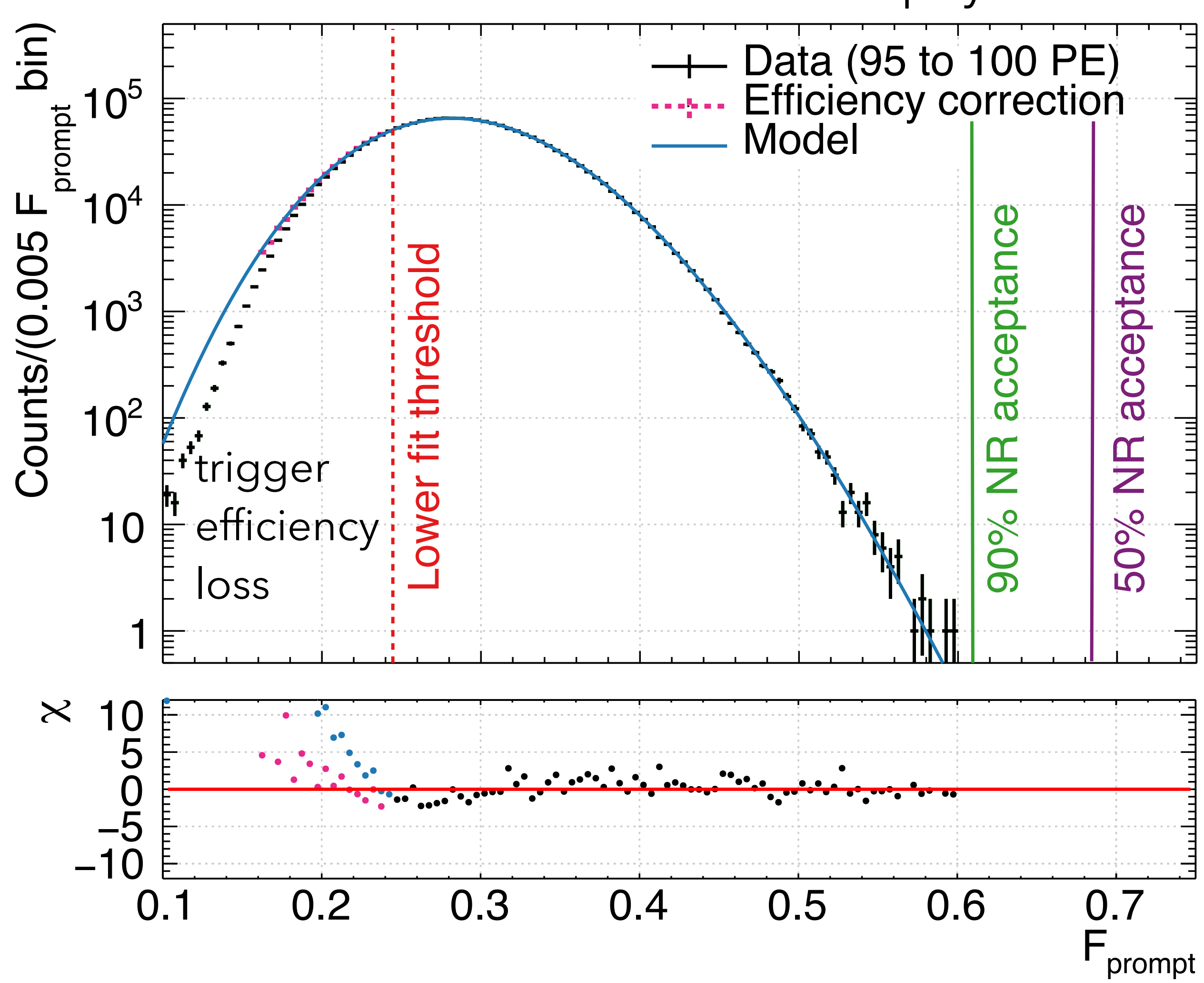
Leakage prediction for ER background @ 90% signal acceptance:
3e-7 in lowest keV
4.1e-9 in full energy ROI (~50 to 100 keVnr)

With a factor 1000 reduction in Ar-39 activity when using underground argon, a 20 kT detector can easily reach similar discrimination power, given similar light yield.

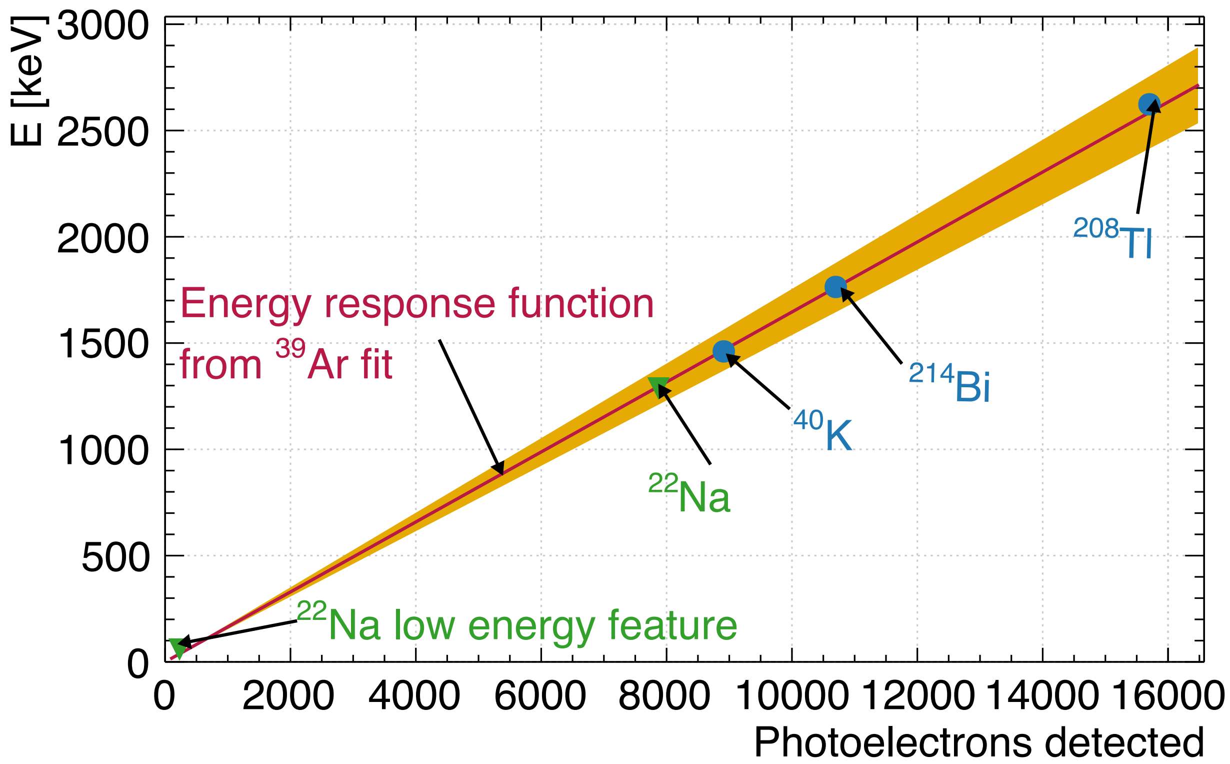


1 keV slice near low edge of energy ROI.

physics data



The energy response is calibrated using beta decays from the internal Ar-39 and gammas from an external Na-22 source.



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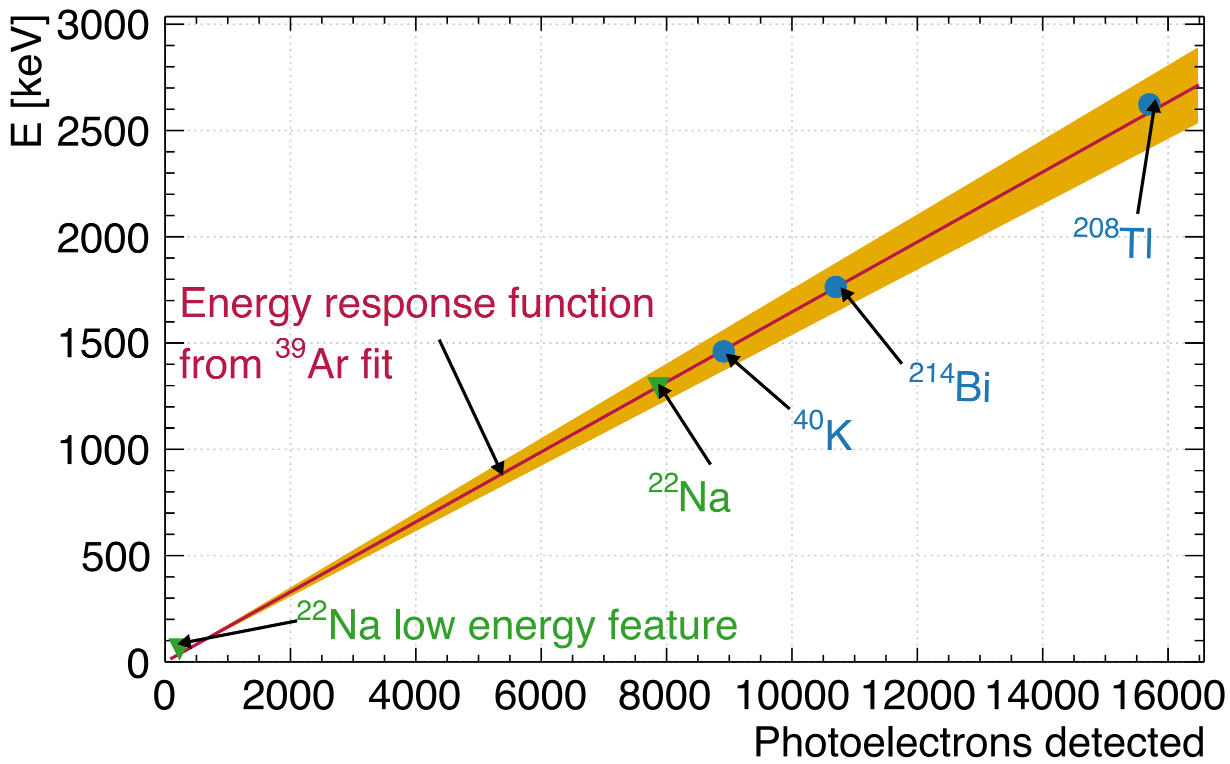
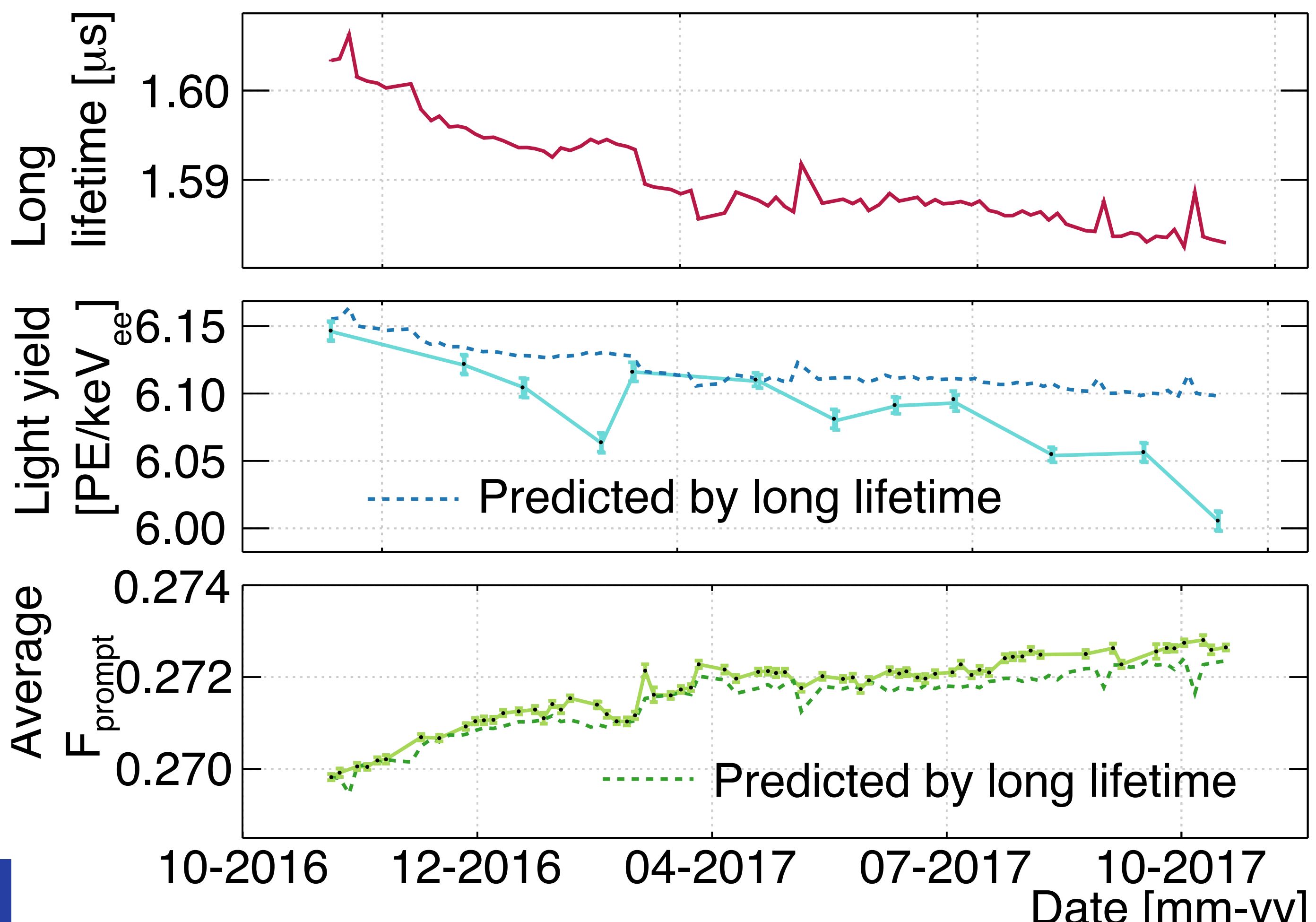
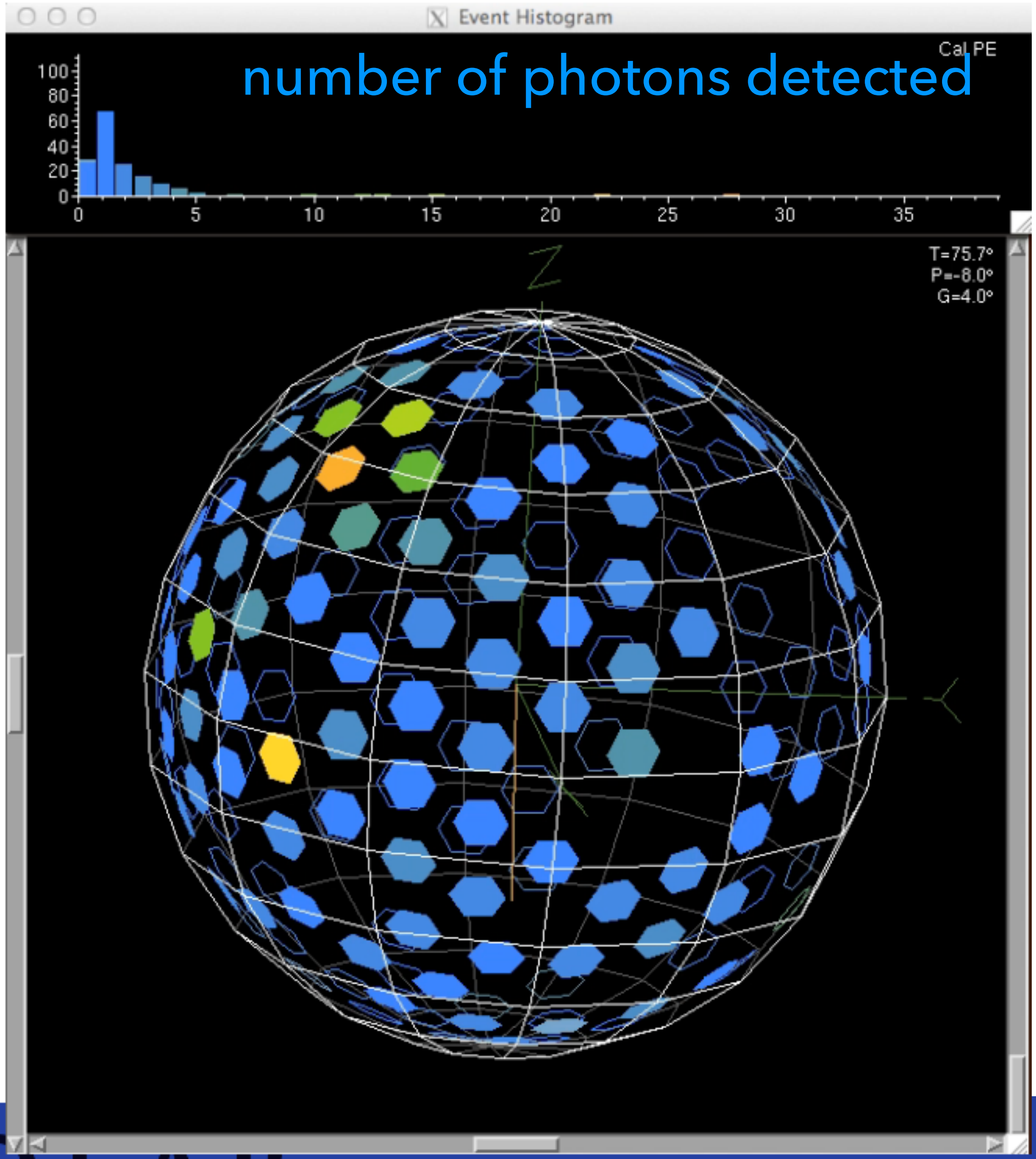


The lifetime of the LAr triplet state, the light yield, and the signal and background-regions in the PSD parameter were stable to better than 5% over a year of data taking.

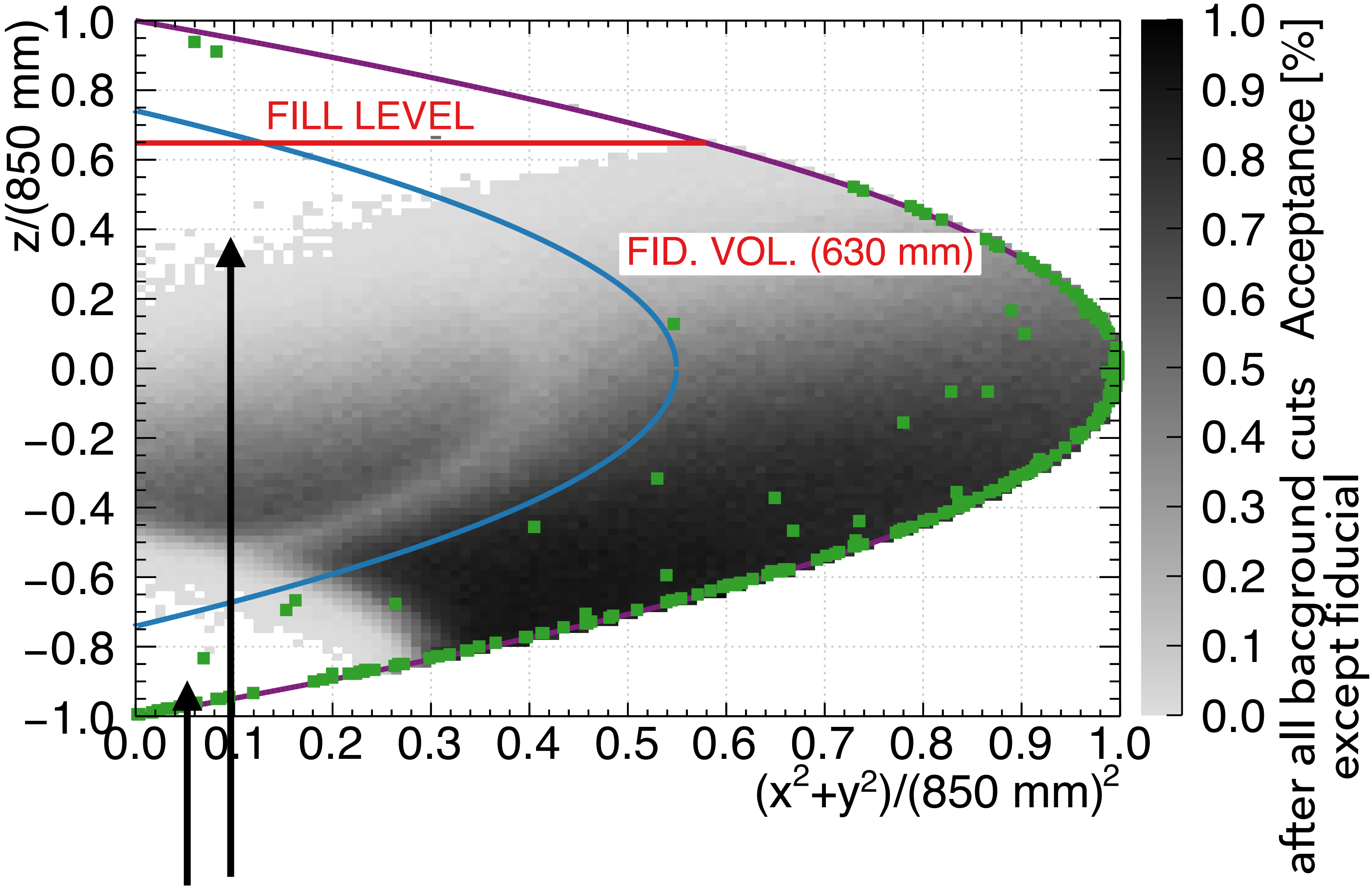


Surface backgrounds are removed by fiducialization.

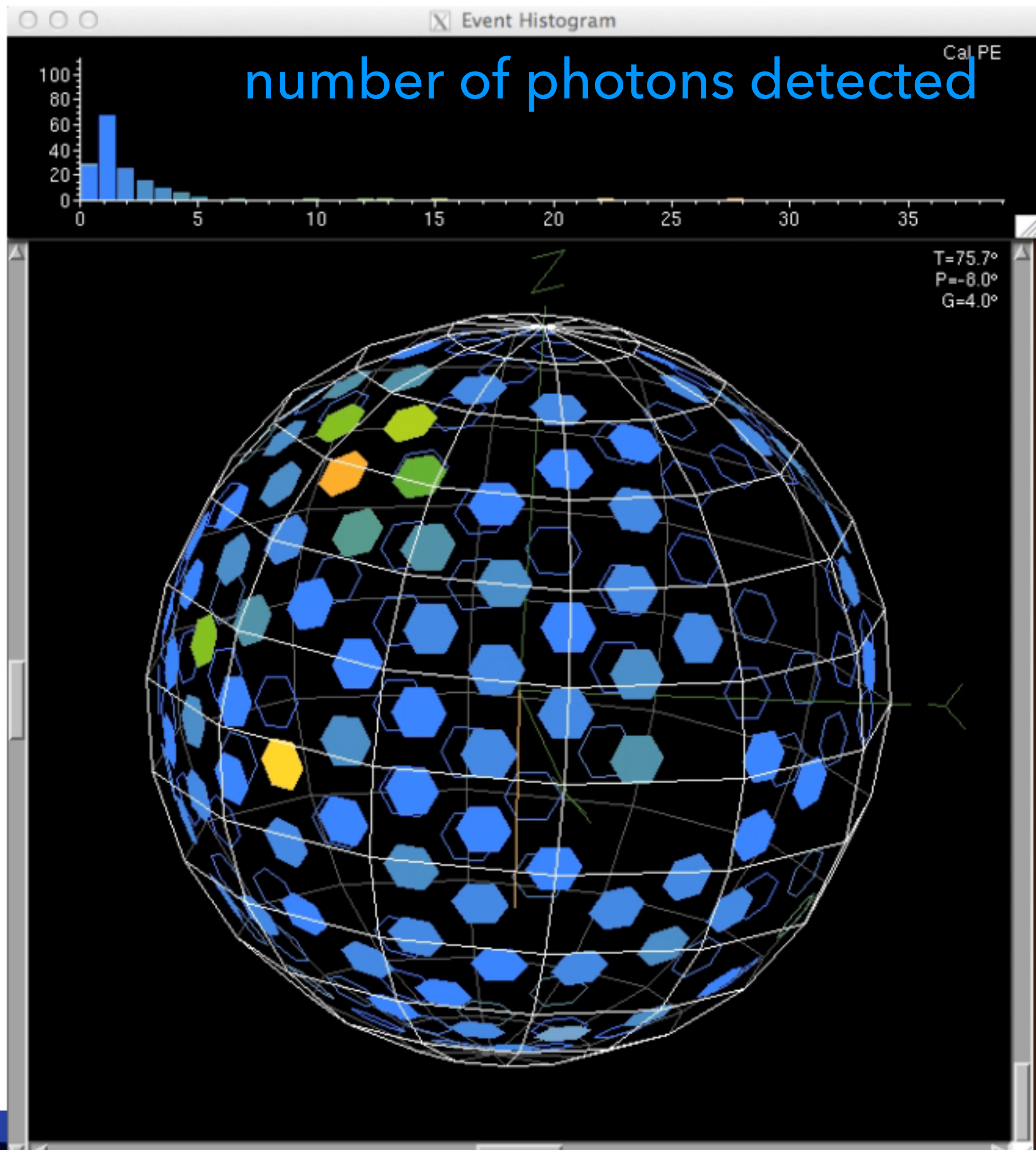


Event position is reconstructed from hit pattern across the PMT array, and photon arrival times. ~2cm resolution at border of ROI.

Surface backgrounds are removed by fiducialization.



Loss of fiducial volume due to alpha decays in the detector neck. Expected to recover partially using more elaborate cuts.



Event position is reconstructed from hit pattern across the PMT array, and photon arrival times. ~2cm resolution at border of ROI.

Background rates

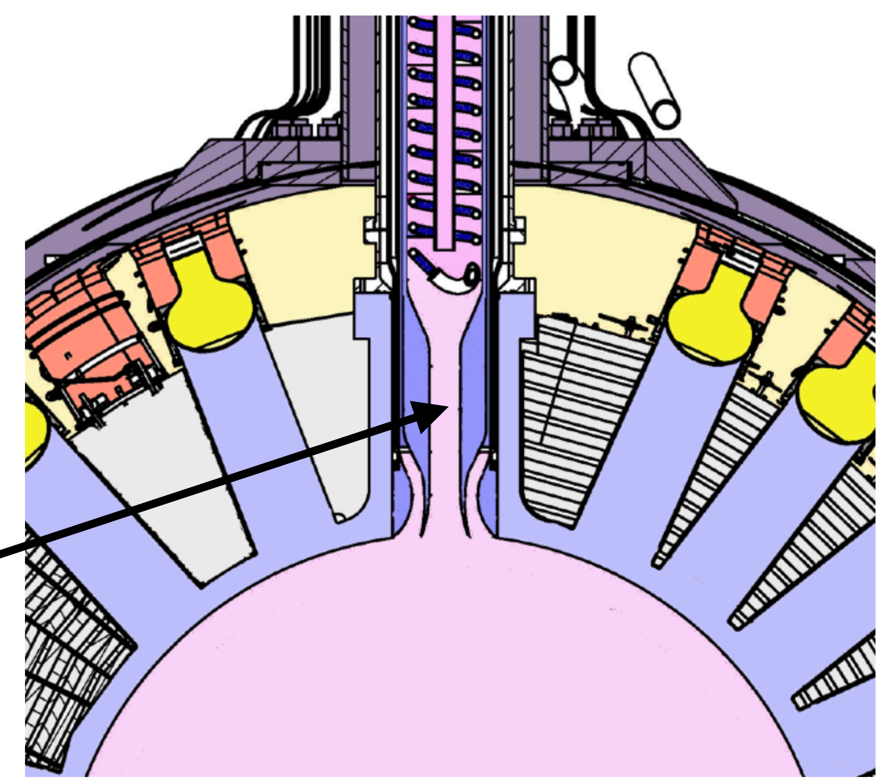
Rn-222 in the bulk target material (measured)

	^{222}Rn activity
DEAP-3600	0.15 μBq/kg
PandaX-II	6.6 μBq/kg
LUX	66 μHz/kg
XENON1T	10 μBq/kg

- PandaX-II: PHYSICAL REVIEW D 93, 122009 (2016)
- LUX: Physics Procedia 61 (2015) 658 – 665
- XENON1T: XeSAT 2017 talk

Background predictions in ROI

	Source	N^{CR}	N^{ROI}
β/γ's	ERs	2.44×10^9	0.03 ± 0.01
	Cherenkov	$< 3.3 \times 10^5$	< 0.14
n's	Radiogenic	6 ± 4	$0.10^{+0.10}_{-0.09}$
	Cosmogenic	<0.2	<0.11
α's	AV surface	<3600	< 0.08
	Neck FG	28^{+13}_{-10}	$0.49^{+0.27}_{-0.26}$
	Total	N/A	$0.62^{+0.31}_{-0.28}$

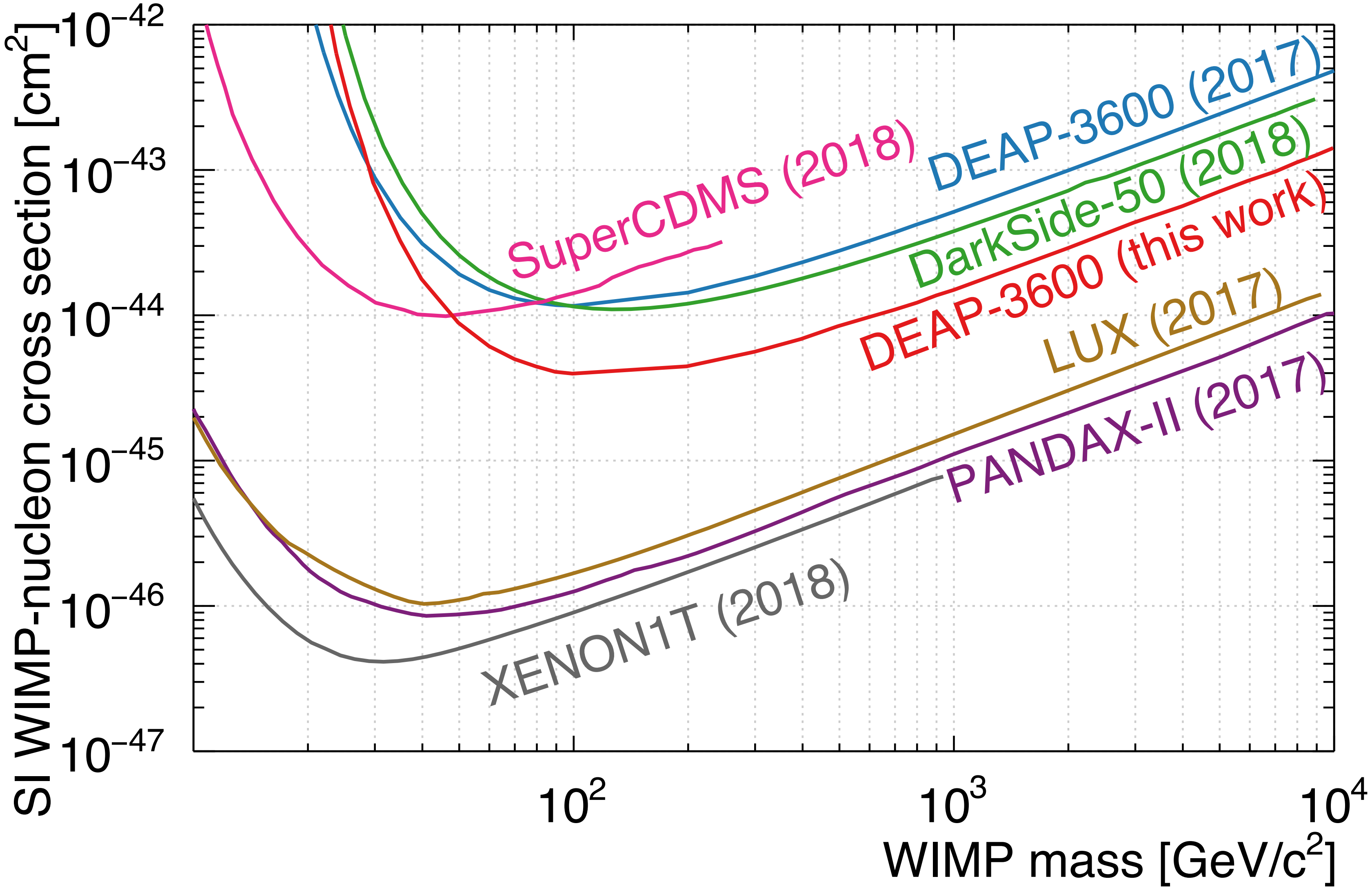


Flow guides (FG)

"Search for dark matter with a 231-day exposure of liquid argon using DEAP-' at SNOLAB"
arXiv:1902.04048

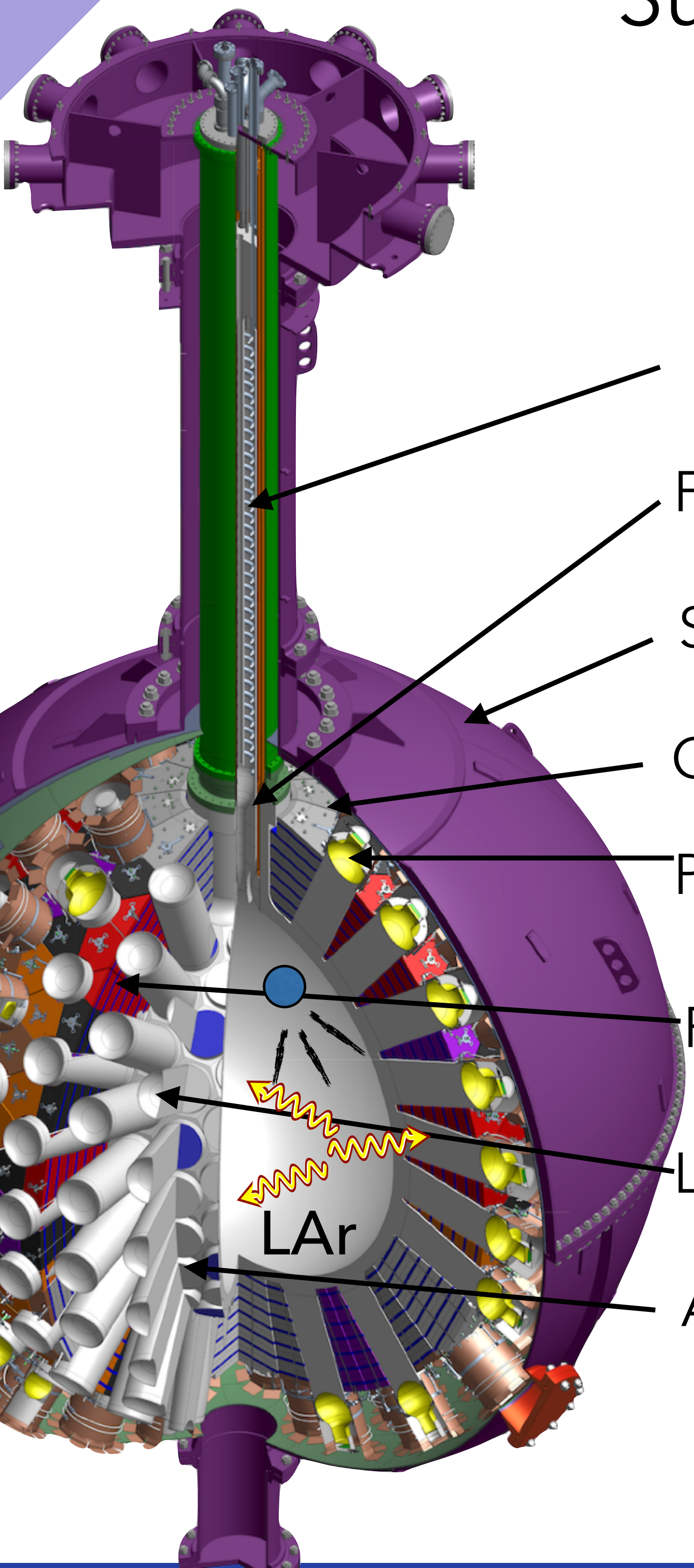
DEAP 3600

Background-free (0.62 background events expected in ROI) search with 758 tonne-days (231 live days) exposure.
Most sensitive limit on LAr above 30 GeV.



"Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB"
arXiv:1902.04048

Summary and Outlook



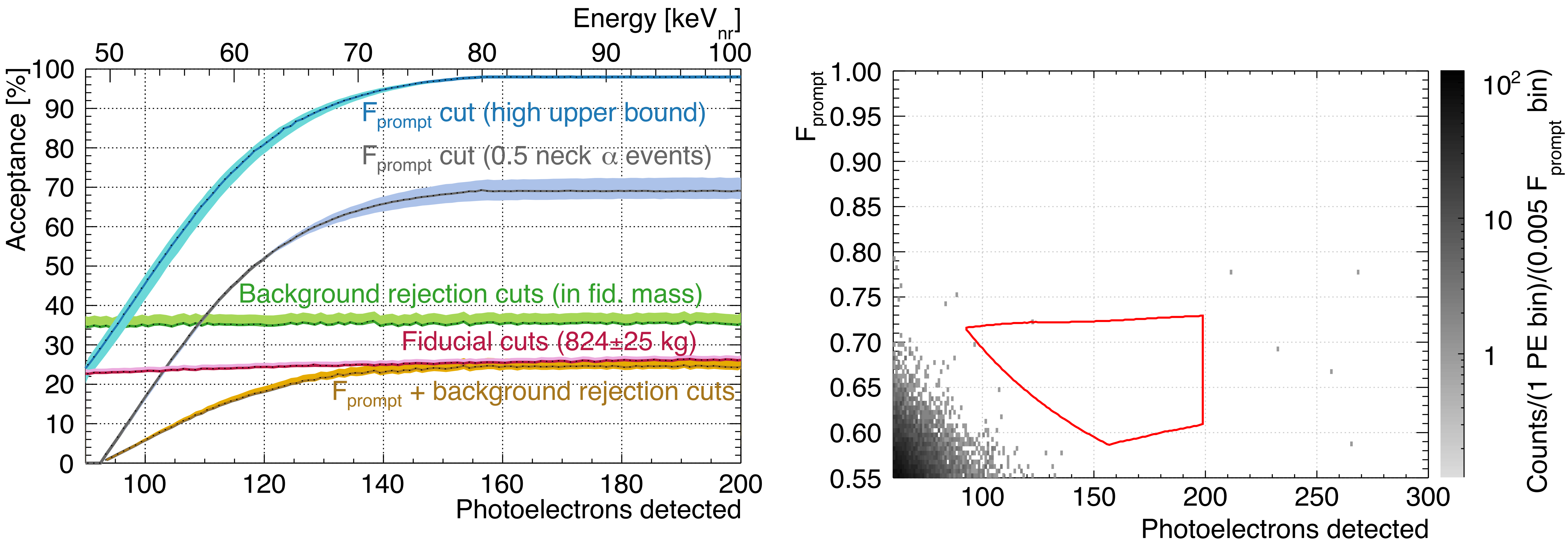
- Largest LAr-based DM detector ever built, with stable operation for over 2.5 years
- **1 year open dataset published** (Nov 2016 - Oct 2017)
  - Best PSD on LAr ever demonstrated
  - Background-free search for WIMP-nucleon cross section limit $<4\times10^{-45}$ cm^2 @100 GeV/c^2 (90% CL)
- Blind data since Jan 2018
  - Current being analyzed
- New global LAr collaboration
  - DarkSide + DEAP + CLEAN + ArDM
  - 20 tonne (DS-20k) and then 300 tonne detector (Argo)

see following talk by Alessio Caminata

DEAP 3600

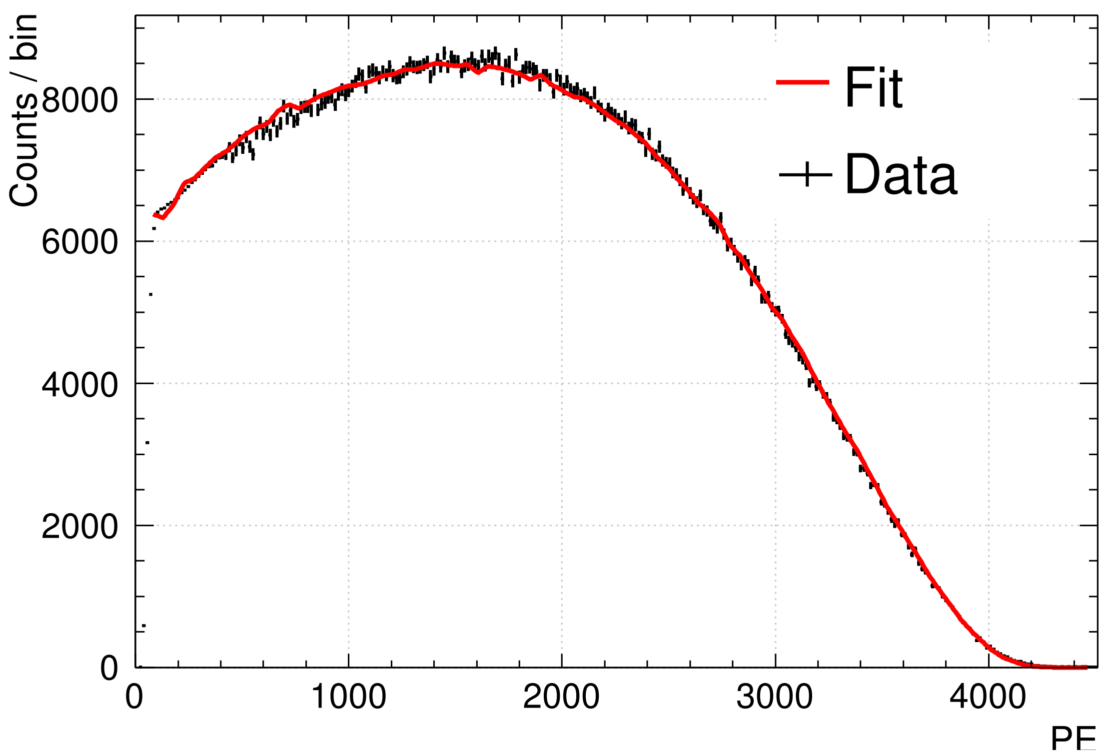
Backup

ROI and acceptance.

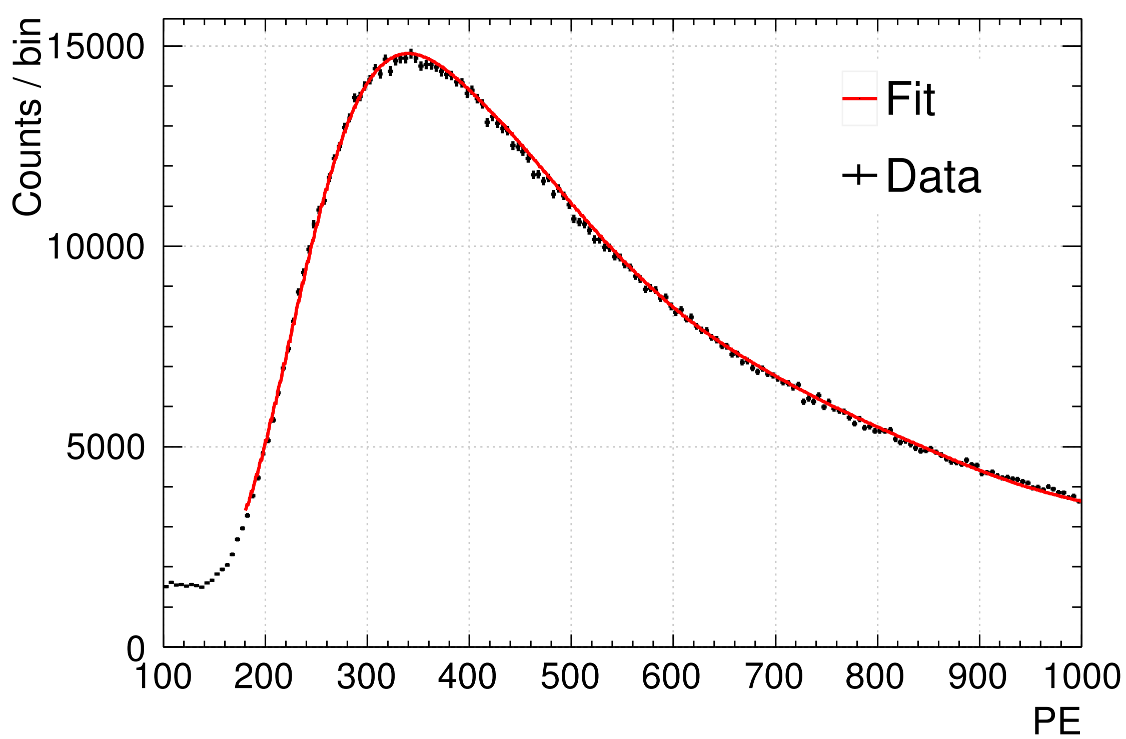


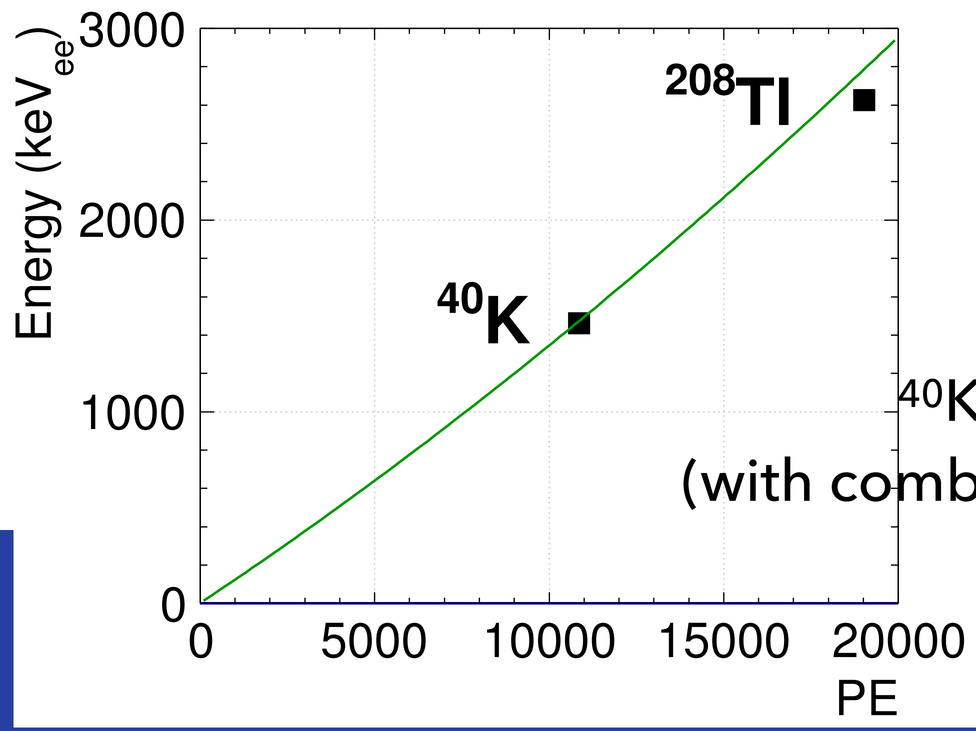
Energy calibration from intrinsic and external beta/gamma sources

^{39}Ar beta spectrum (intrinsic)



^{22}Na (external)

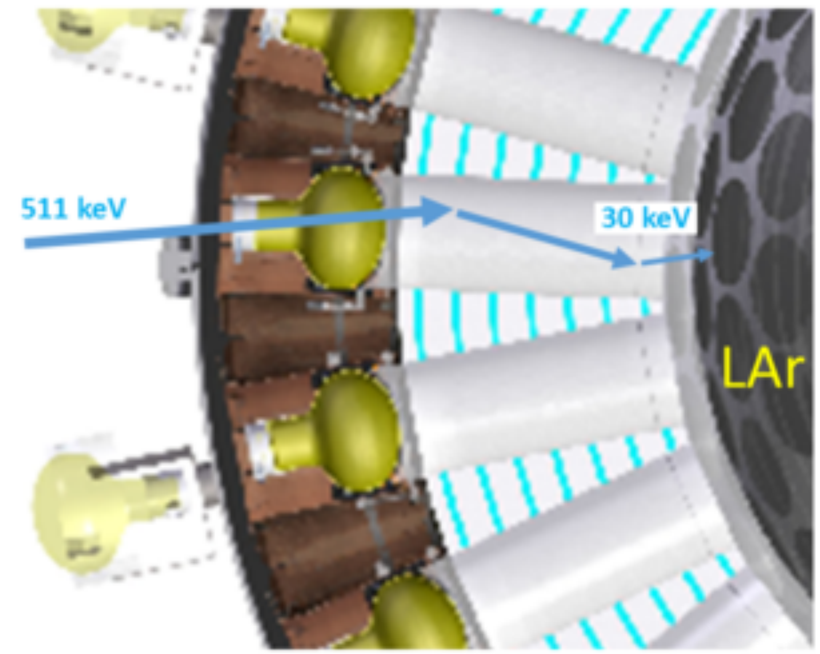


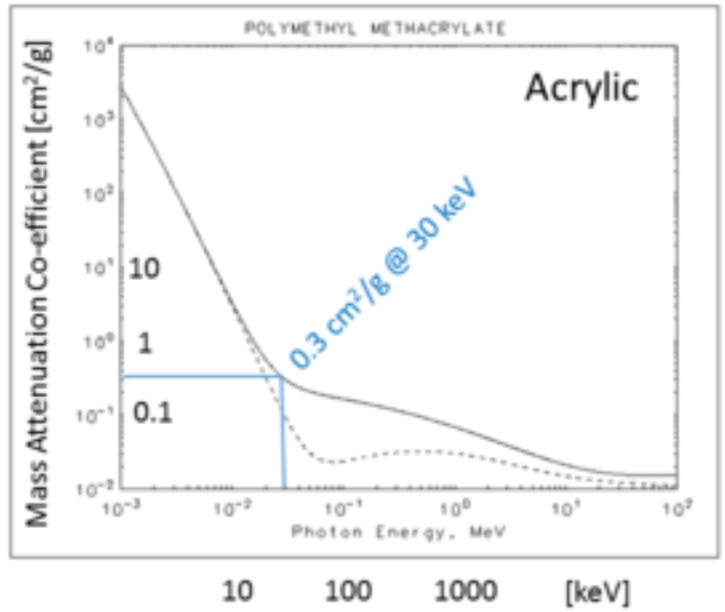


^{40}K and ^{208}Tl (intrinsic)

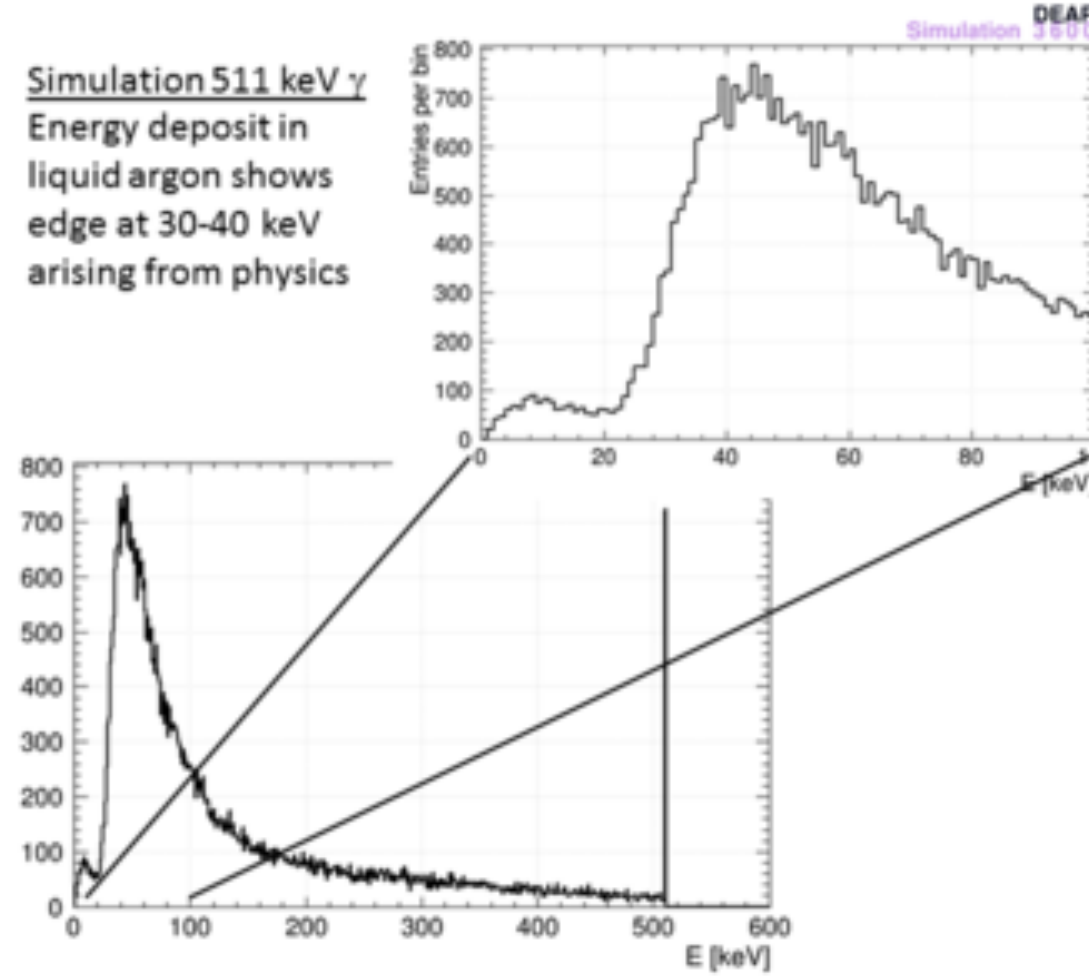
(with combined fit from ^{39}Ar and ^{22}Na)

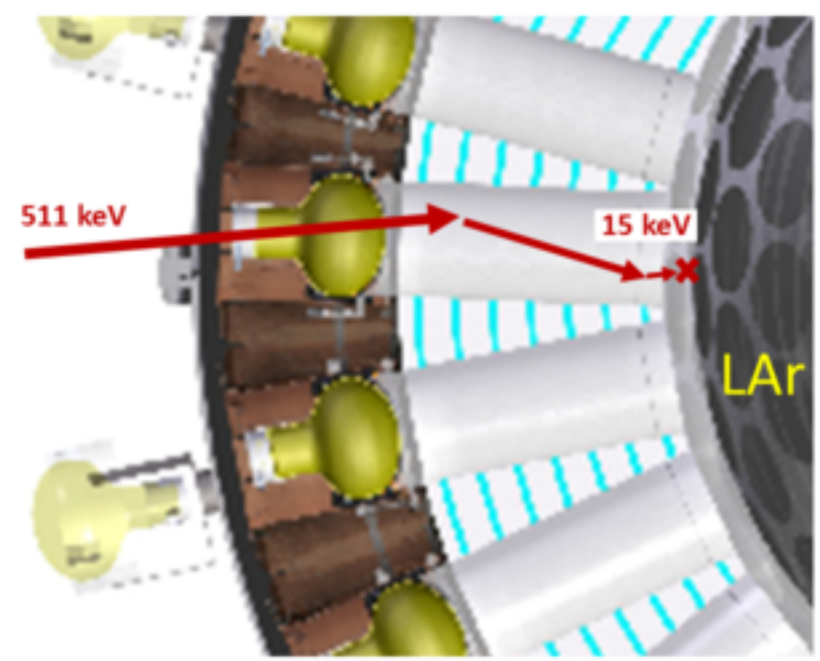
The Na-22 feature

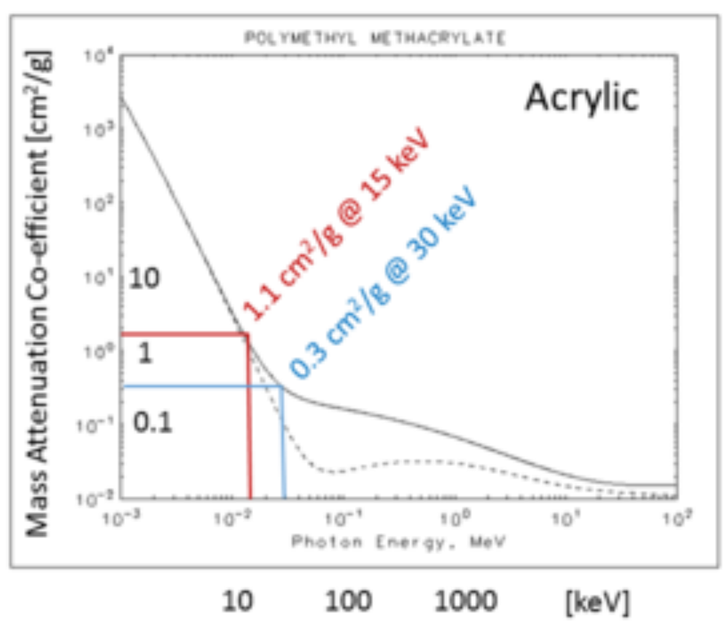




Simulation 511 keV γ
Energy deposit in liquid argon shows edge at 30-40 keV arising from physics



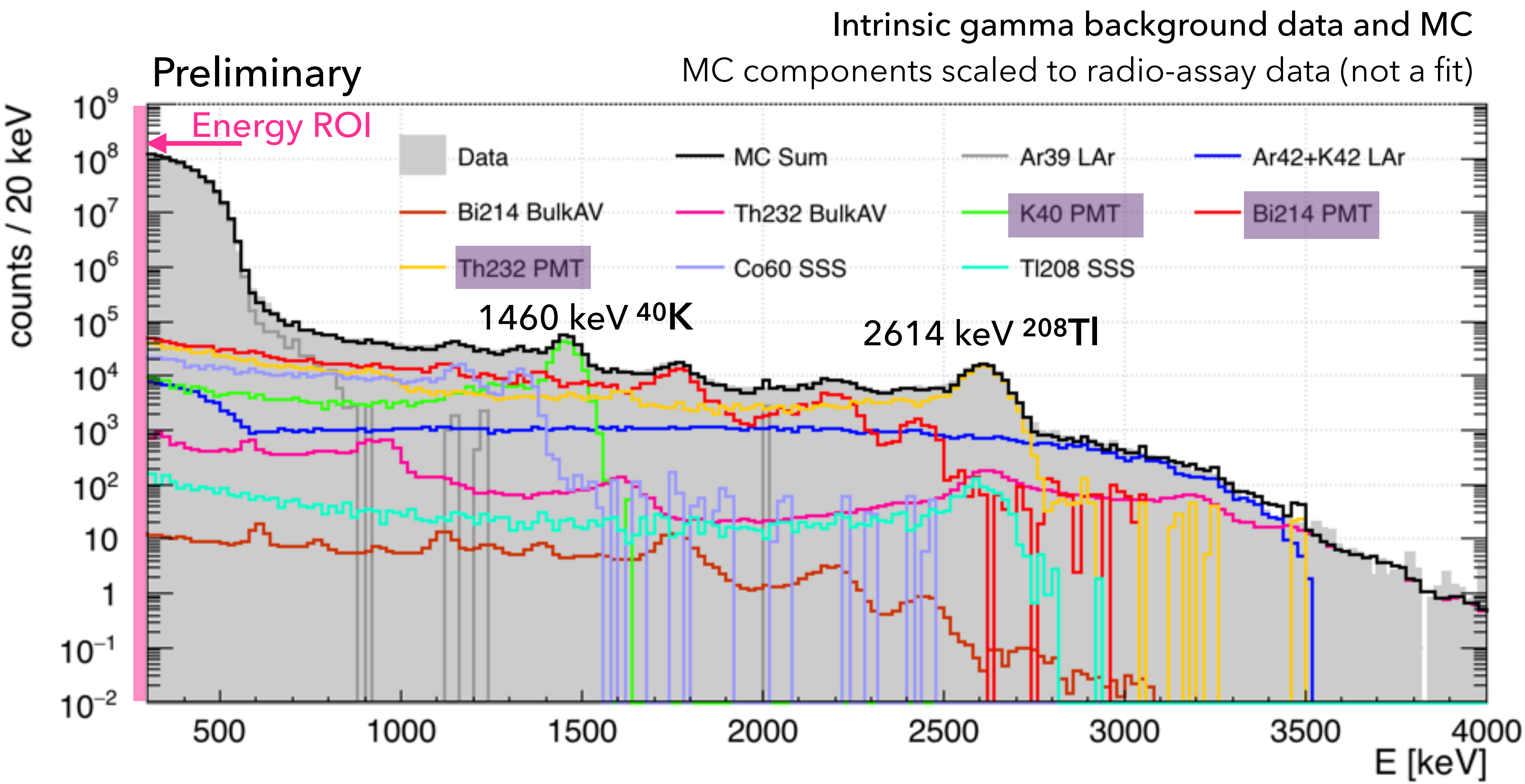




Plot and data from NIST.gov X-ray mass attenuation coefficients

Intrinsic and external radiation sources are used for

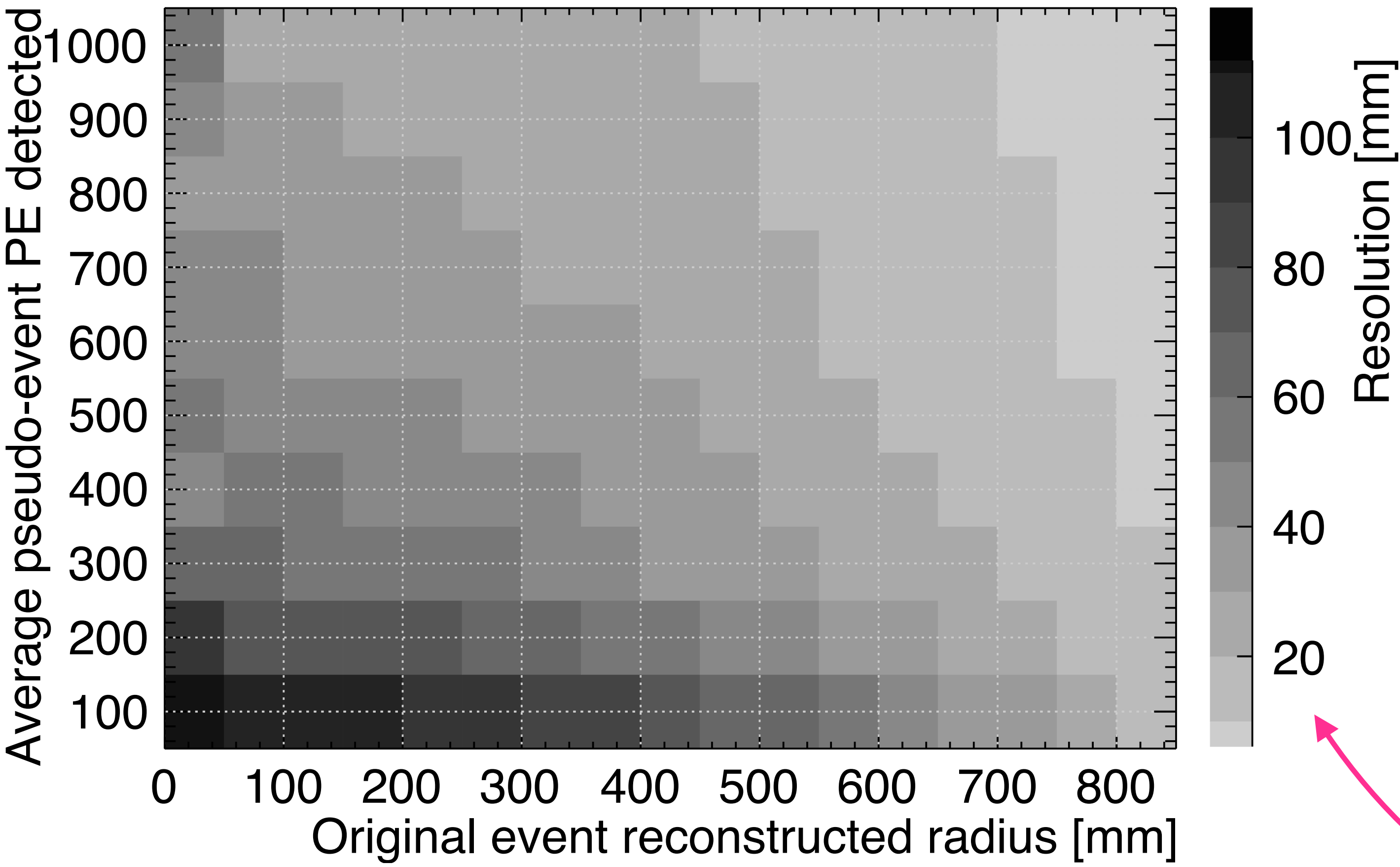
- energy calibration
- position reconstruction calibration
- constraints on α,γ, n background rates (e.g. find ~0.2 μBq/kg ^{222}Rn in LAr)



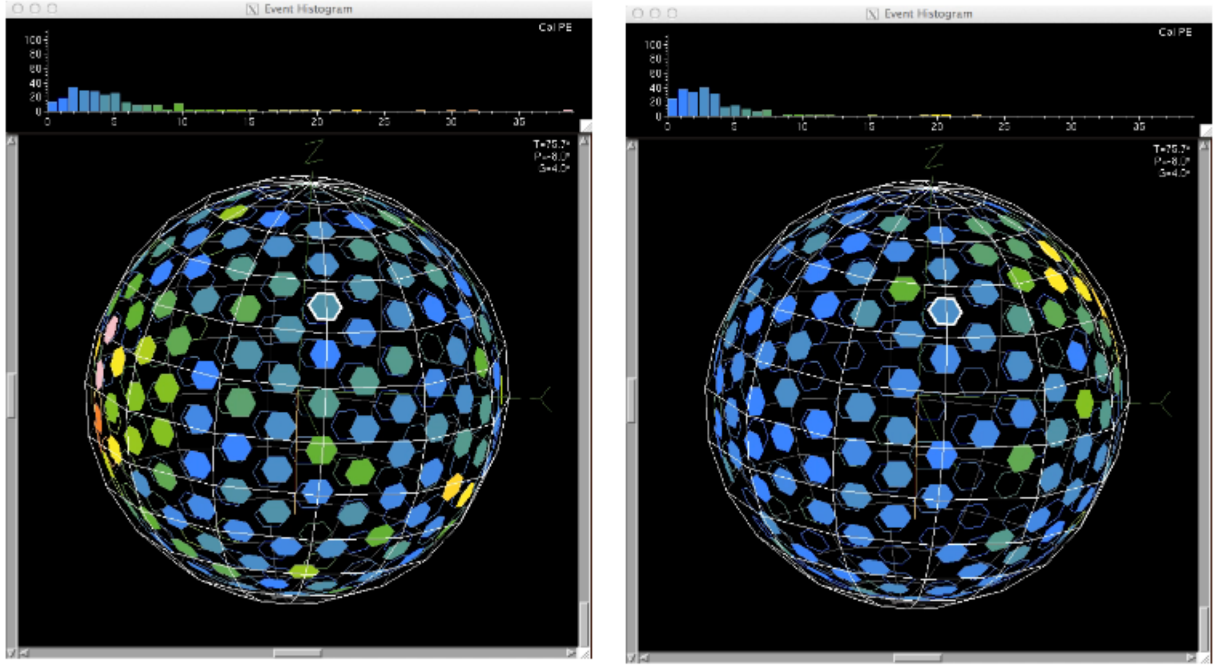
Where did the interaction occur?

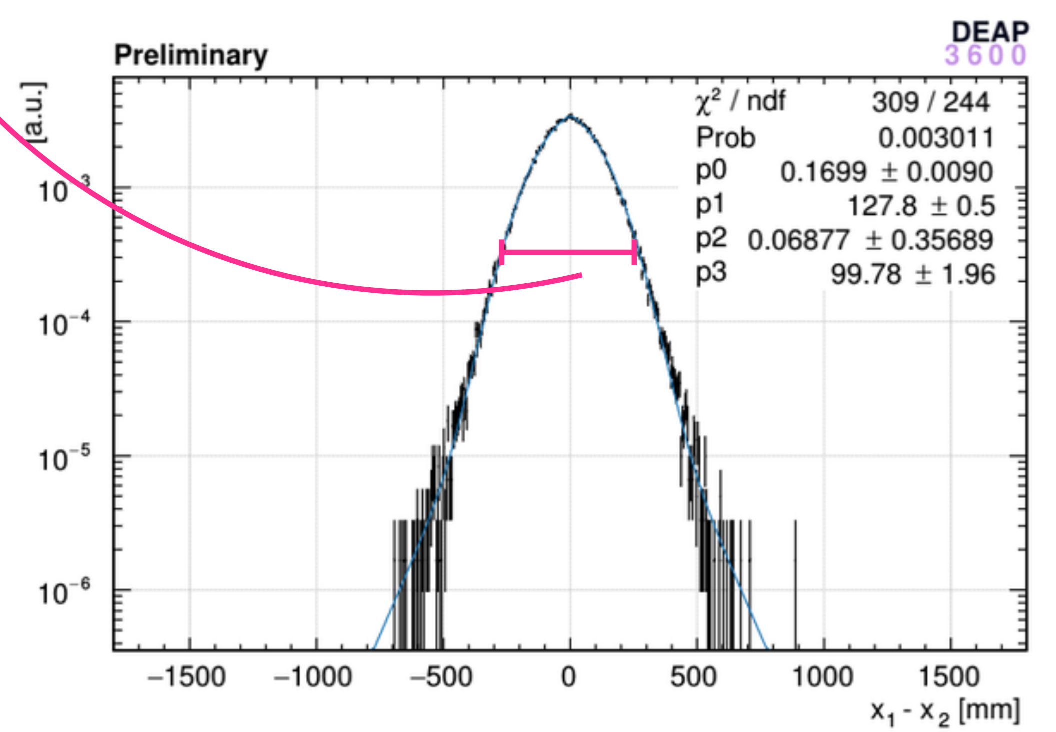
1) Compare the light pattern across the PMT array to simulated expected light patterns and find most likely event position.

Position revolution achieved as a function of radius and energy.



Example light patterns (real events).

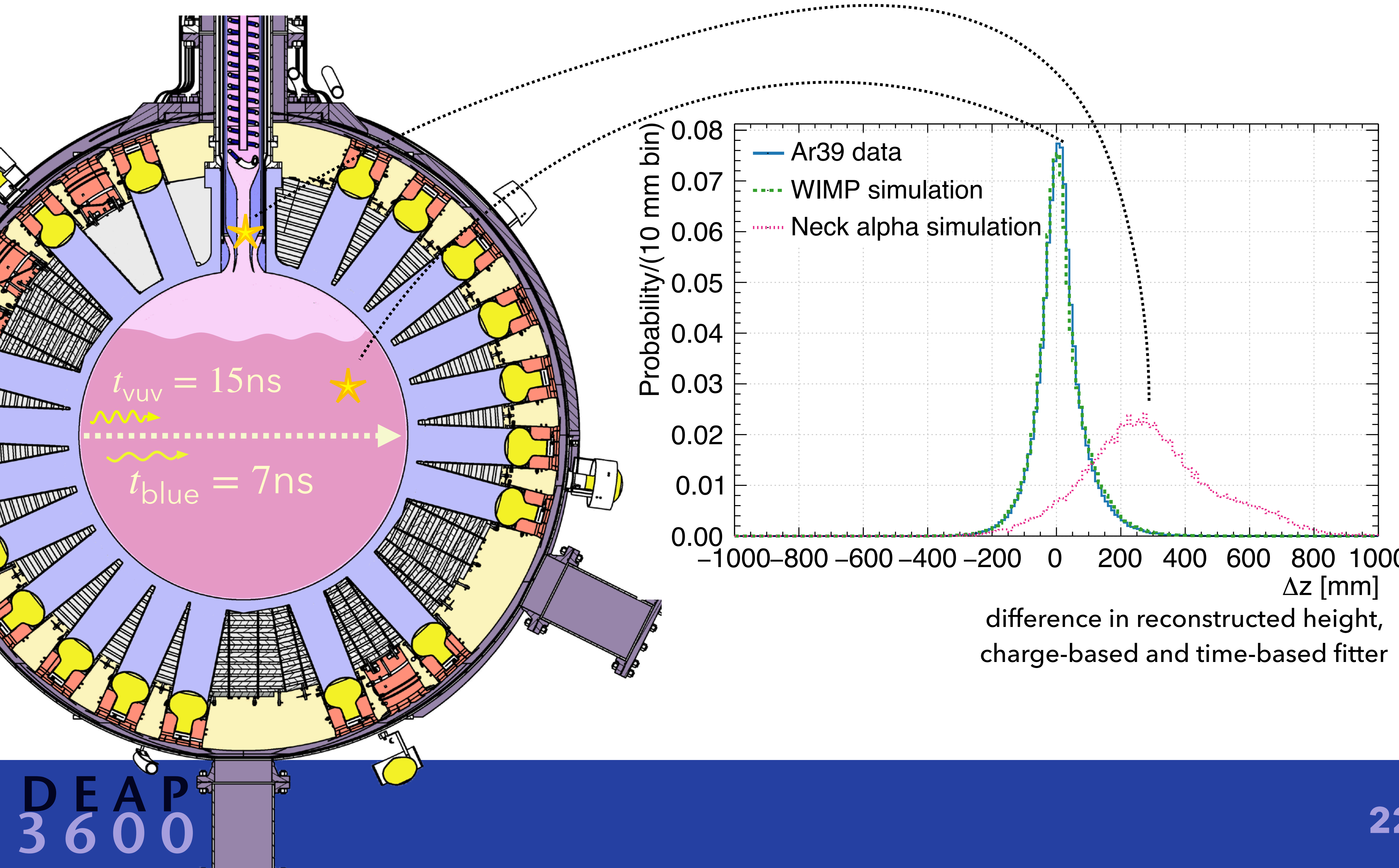




Resolution determined by randomly dividing the photons from an event into two new events and looking at difference in their reconstructed position.

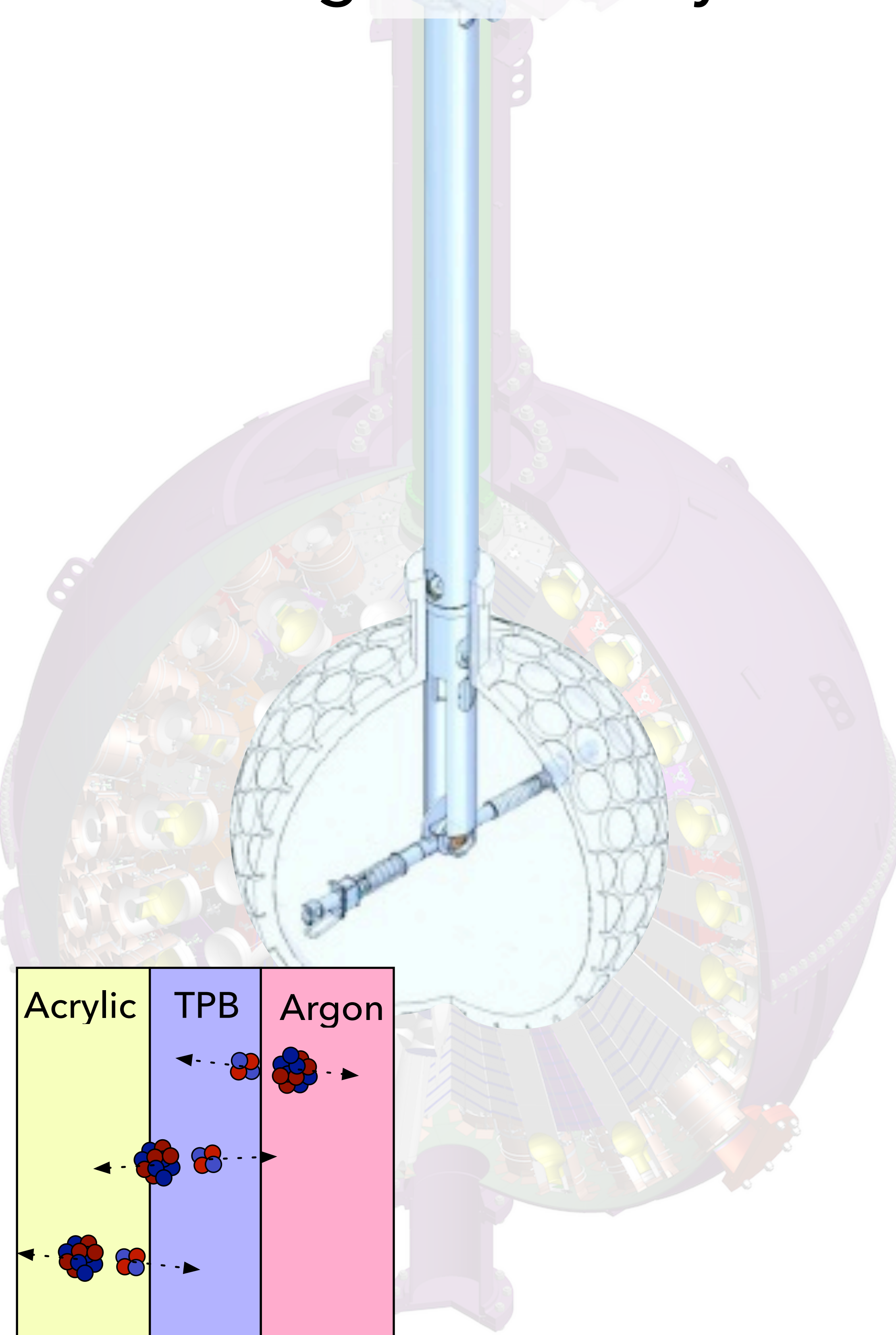
Where did the interaction occur?

2) Compare photon arrival times at each PMT with simulated arrival times from each point of the LAr volume.

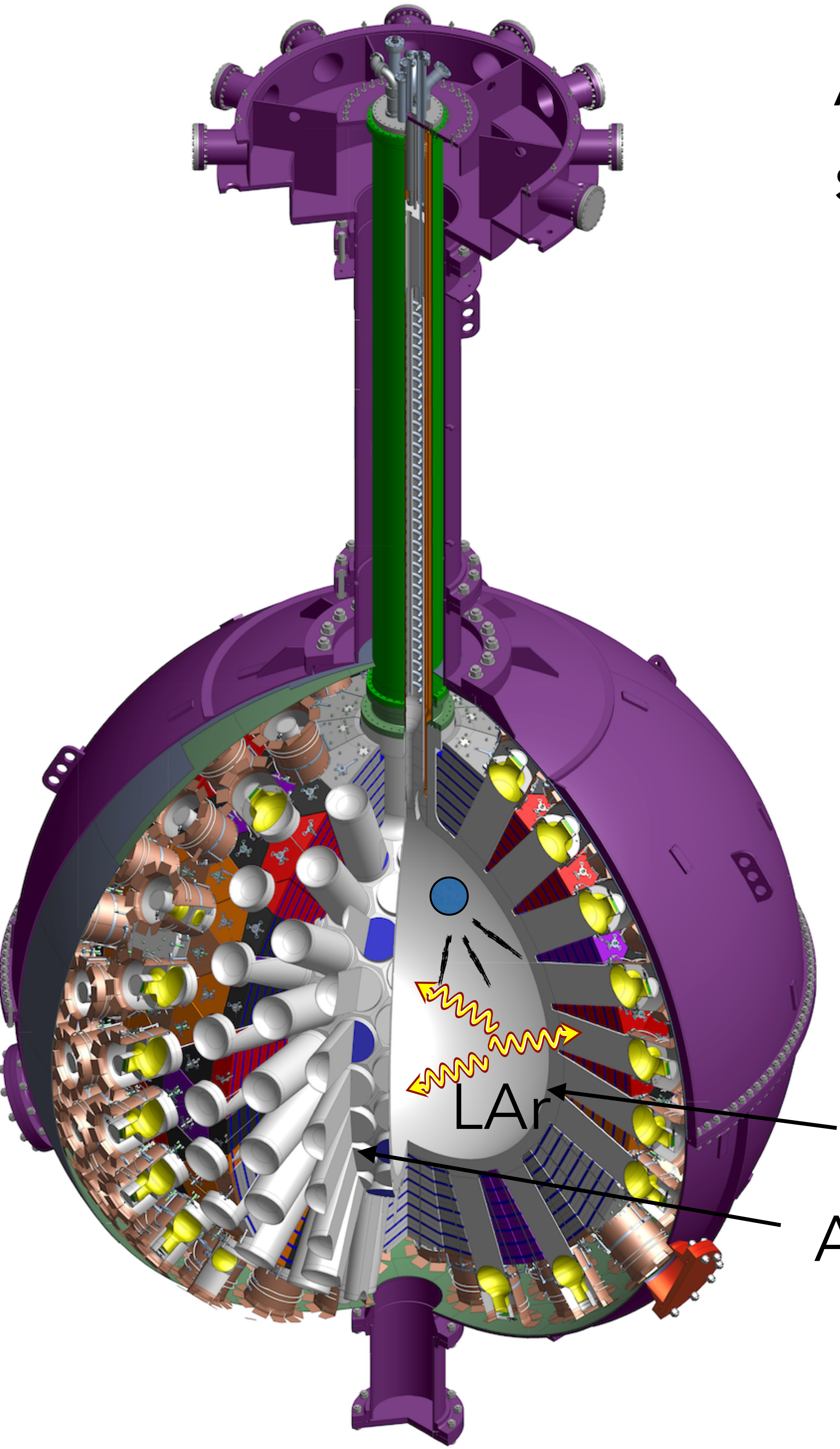


difference in reconstructed height, charge-based and time-based fitter

Under air-tight conditions, resurfacer removed fraction of a mm off the acrylic cryostat's inside, reducing radon daughter activity to < 10 α/m²/day.

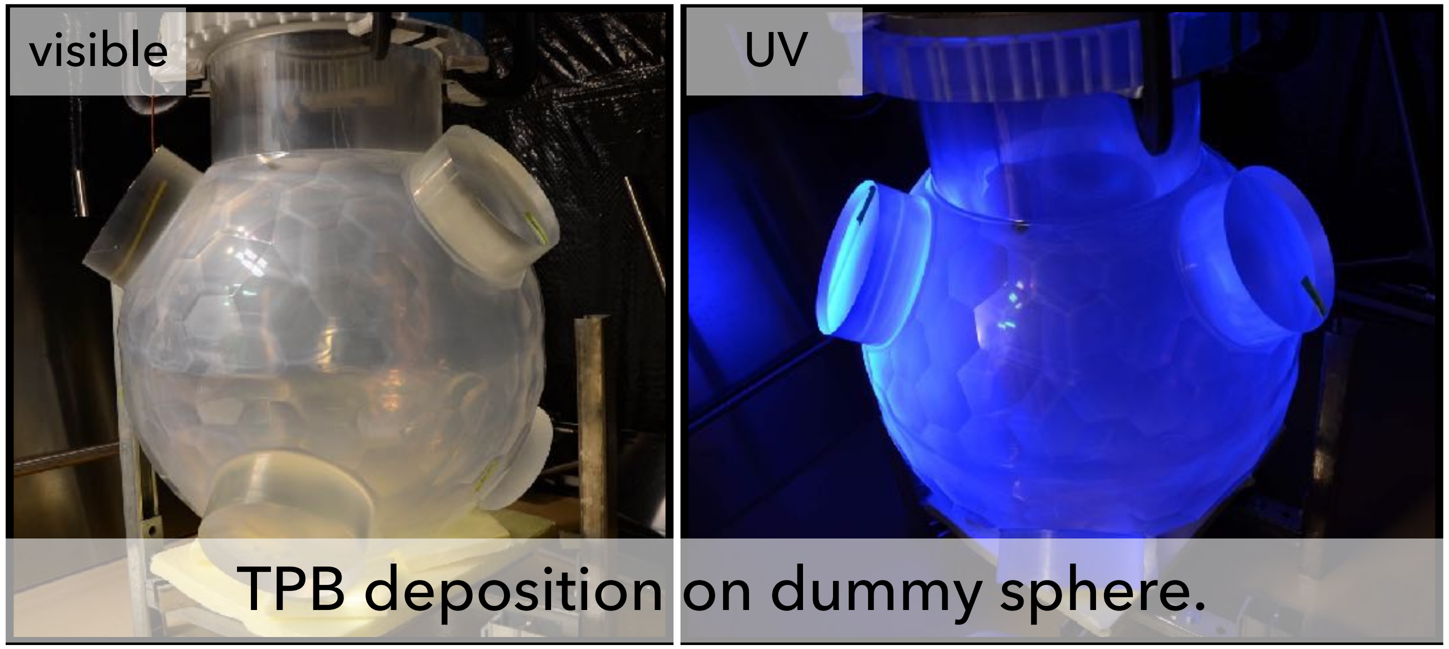


A coating of TPB makes the LAr scintillation visible.



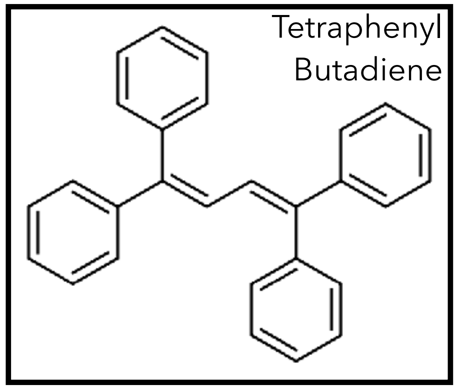
TPB wavelength shifter.

Acrylic vessel.



TPB deposition on dummy sphere.

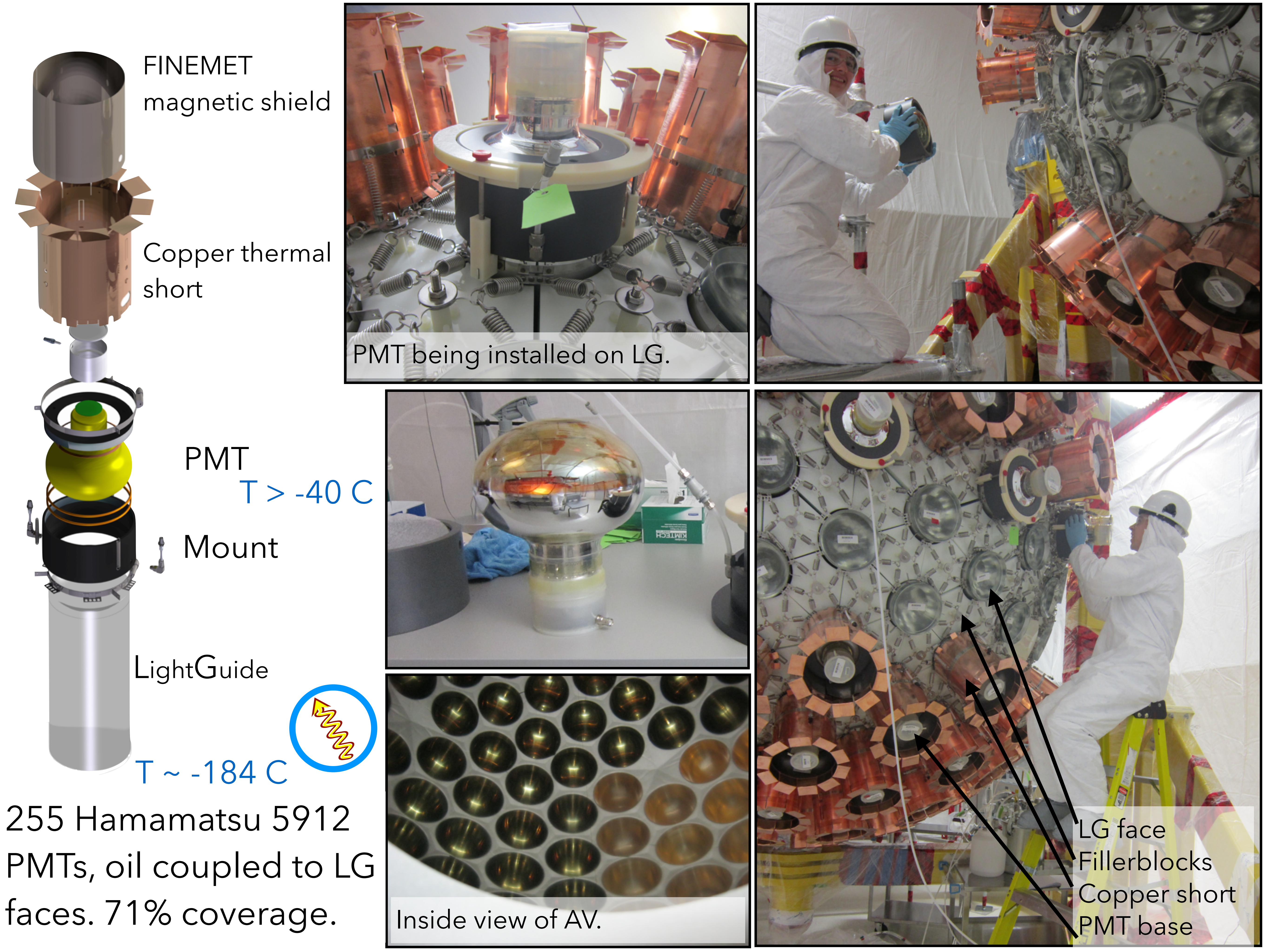
128 nm →



→ 420 nm

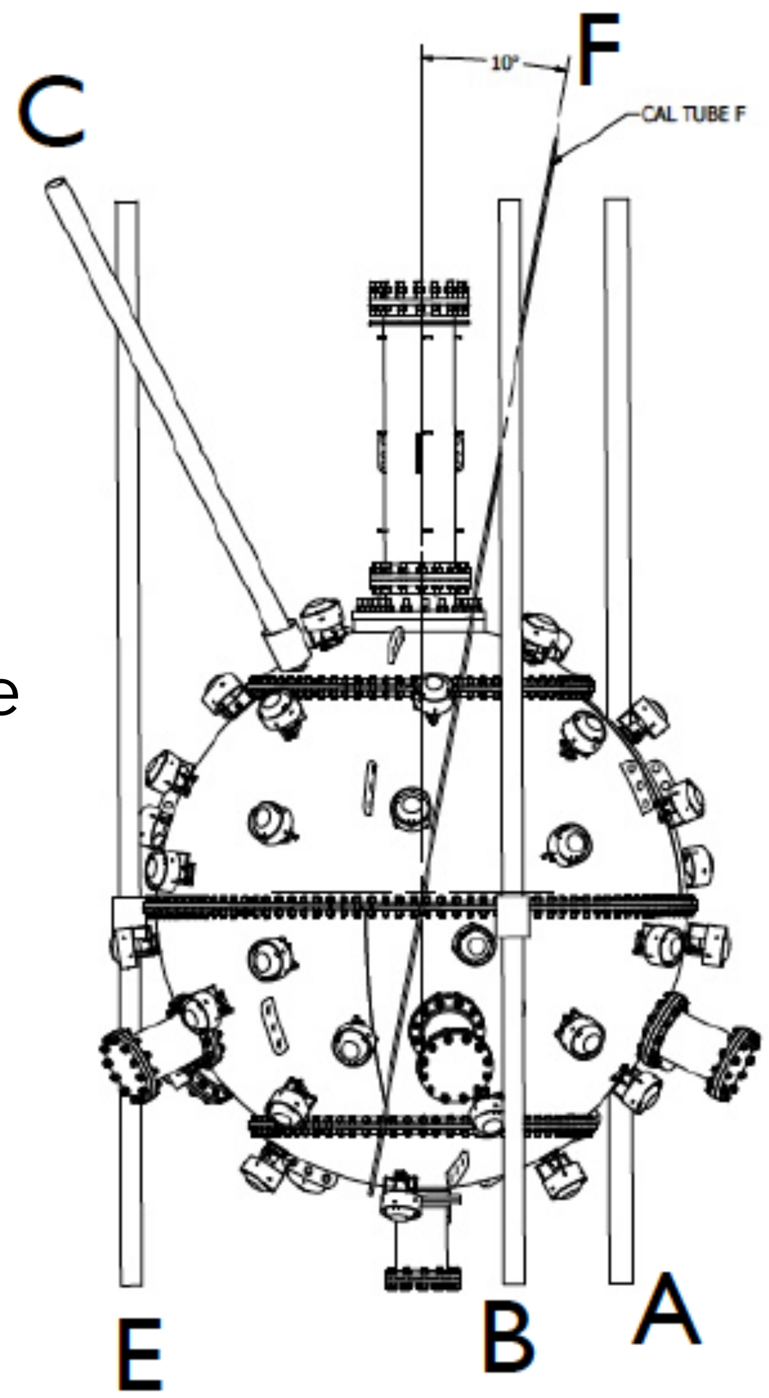
Image credit: Wikipedia

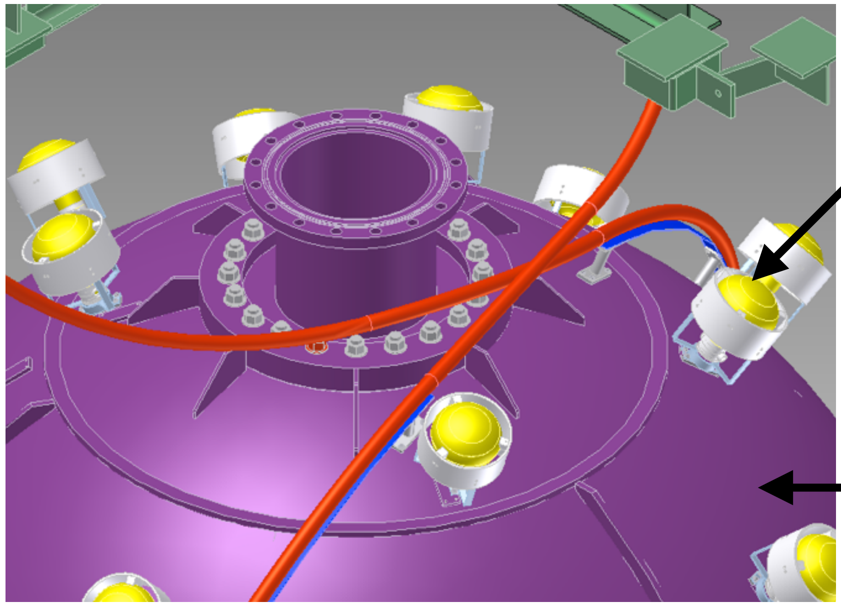
Broerman, B, et al. "Application of the TPB Wavelength Shifter to the DEAP-3600 Spherical Acrylic Vessel Inner Surface ." JINST 12 (2017)

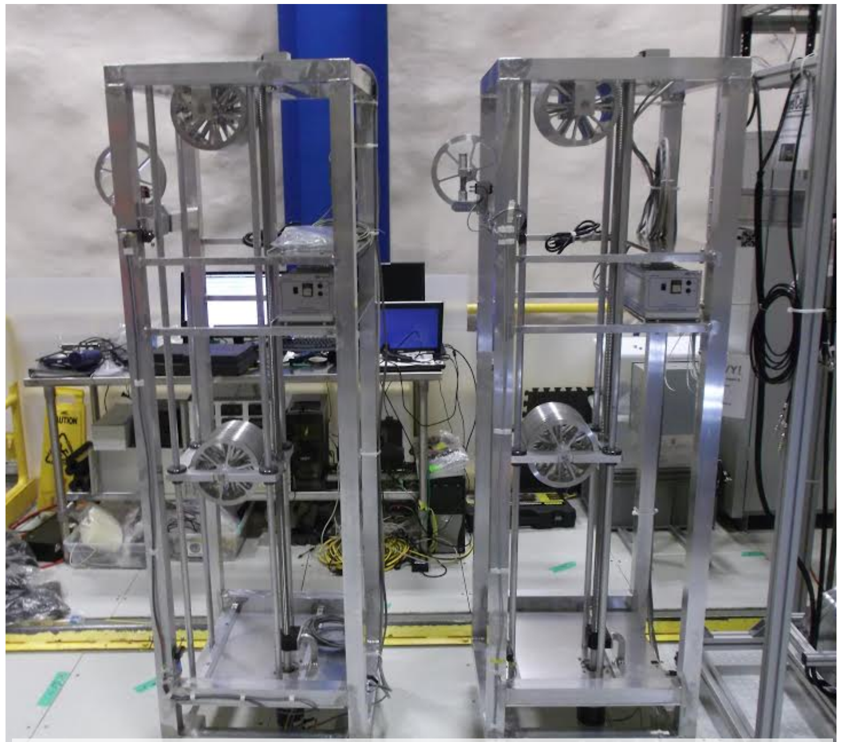

FINEMET
magnetic shield
Copper thermal
short
PMT
T > -40 C
Mount
LightGuide
T ~ -184 C
255 Hamamatsu 5912
PMTs, oil coupled to LG
faces. 71% coverage.
PMT being installed on LG.
Inside view of AV.
LG face
Fillerblocks
Copper short
PMT base

Detector response is characterized and monitored using ^{22}Na and AmBe sources.

Sources are brought near the detector using external source deployment tubes.



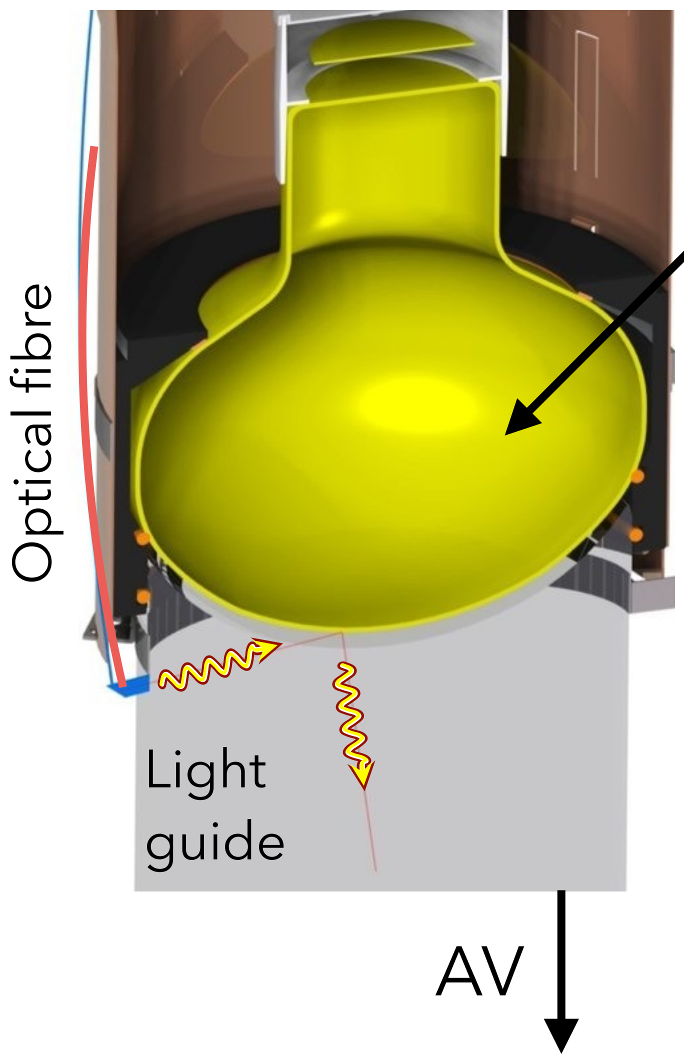


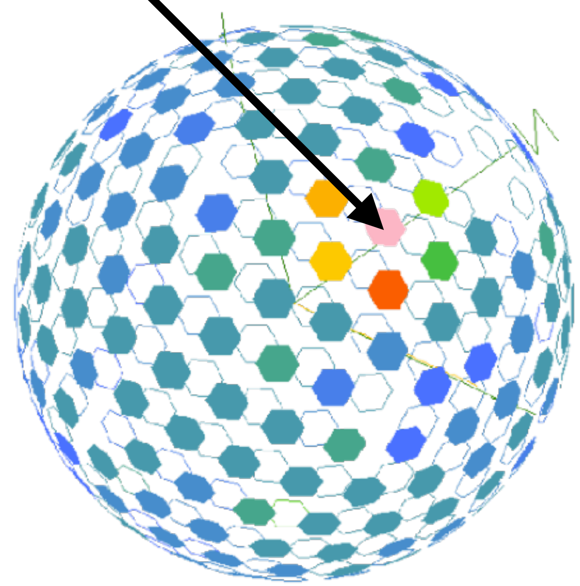


Source deployment pulleys

Optical calibration sources

LED light injection system on 20 light guides and AV neck.





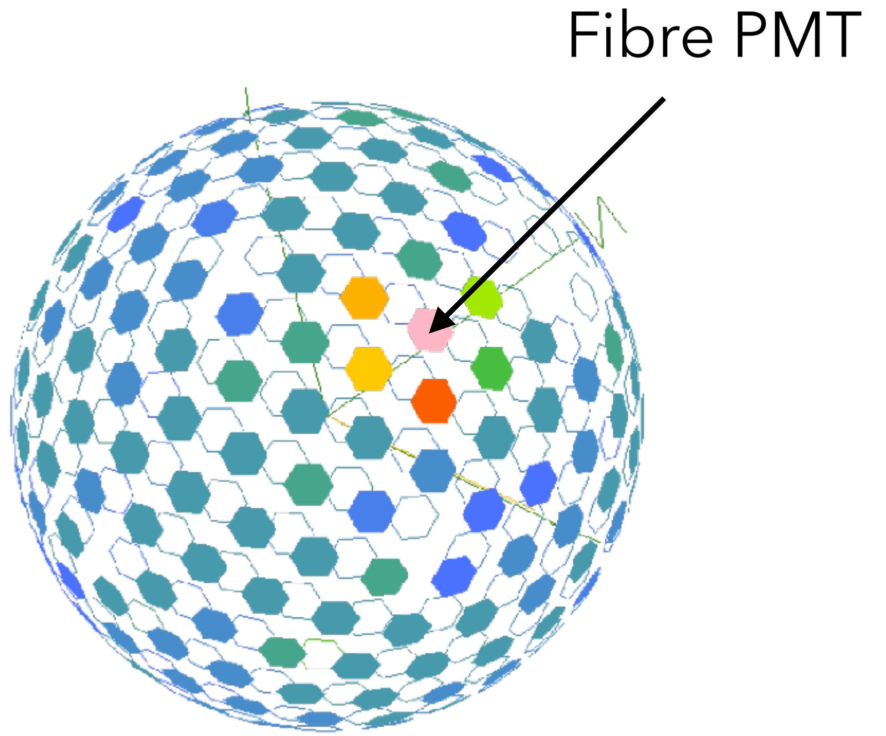
DEAP event display.
Blue: low charge,
red: higher charge,
purple: highest charge.

Laserball

Deployed at three positions inside of (warm) detector.

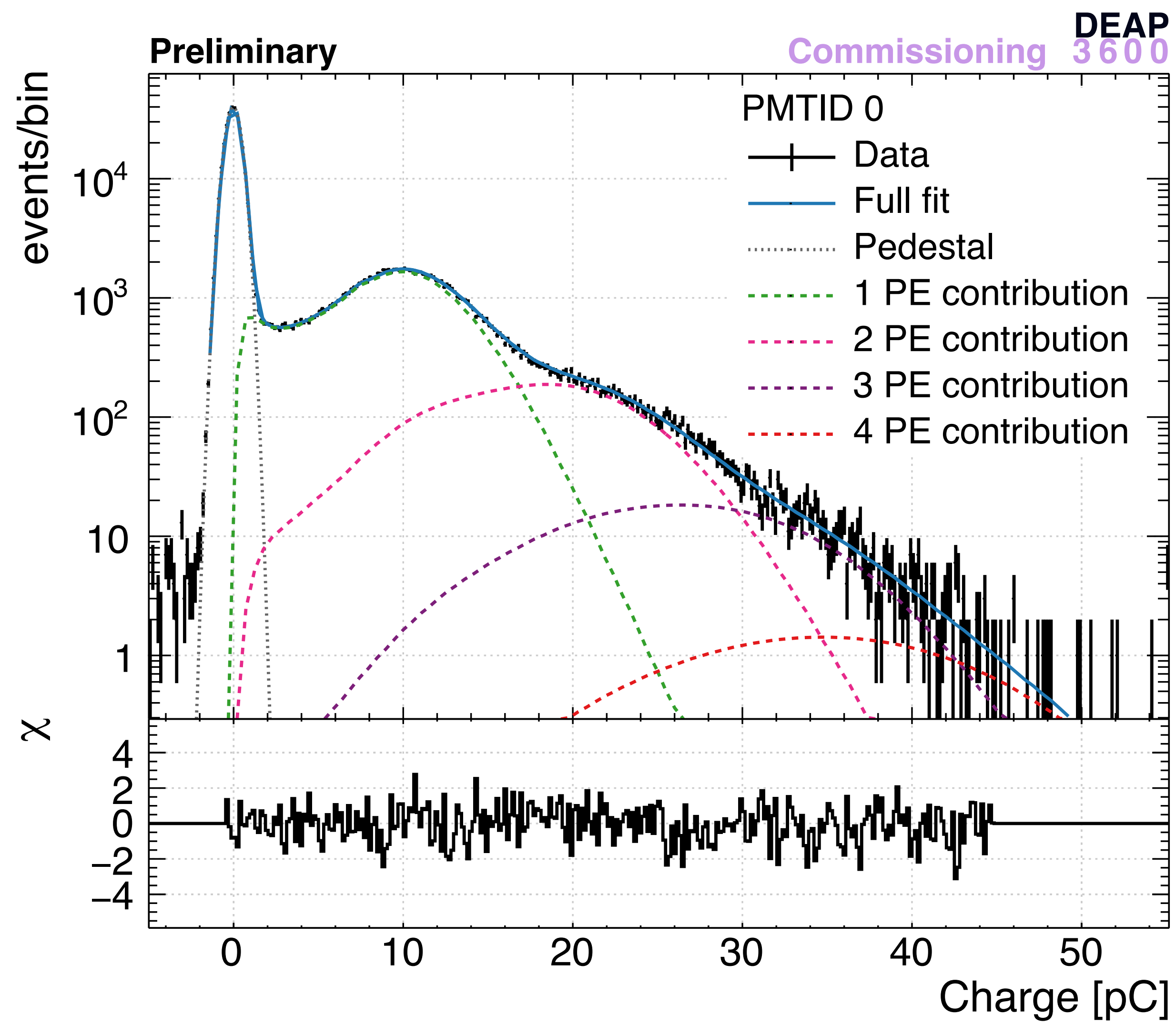
Optical properties are characterized and monitored through light injection.

LED light injection system on 20 light guides and AV neck.



DEAP event display.
blue: low charge,
red: higher charge,
purple: highest charge.

E.g. PMT gain monitoring

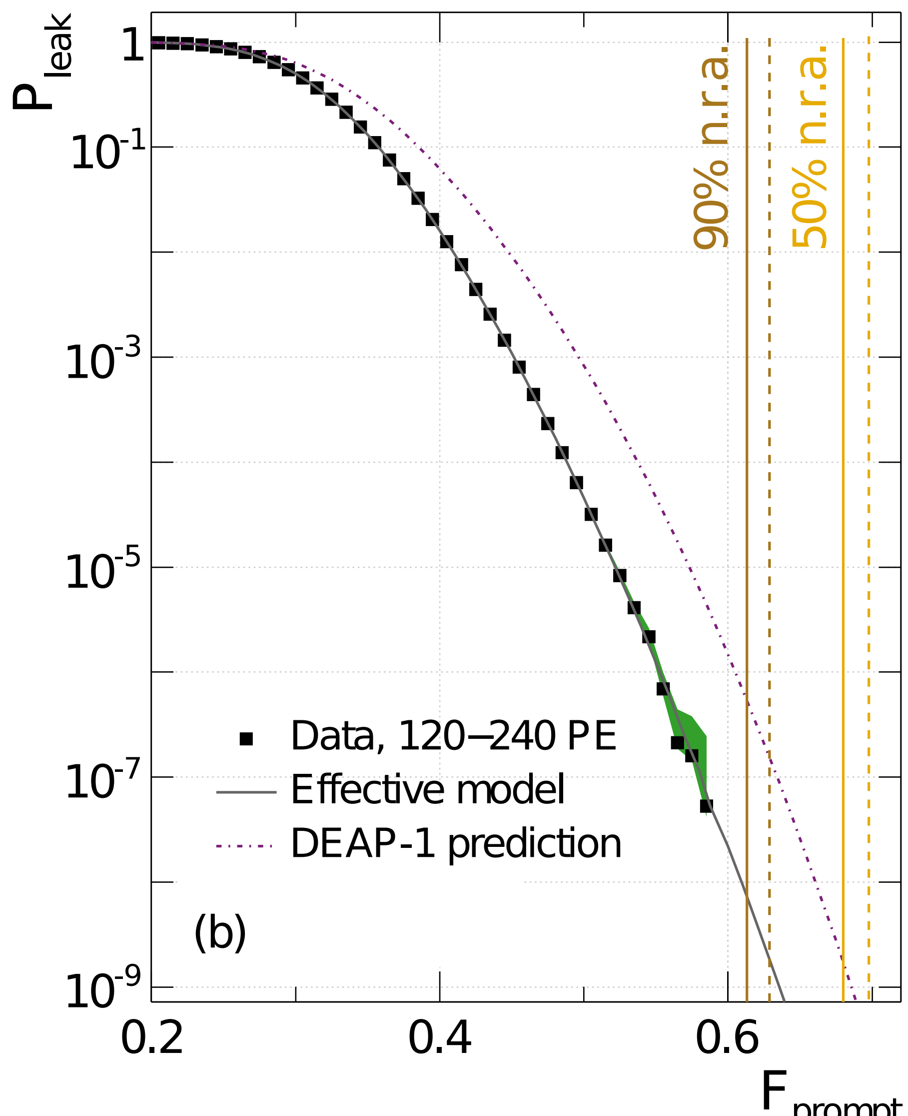


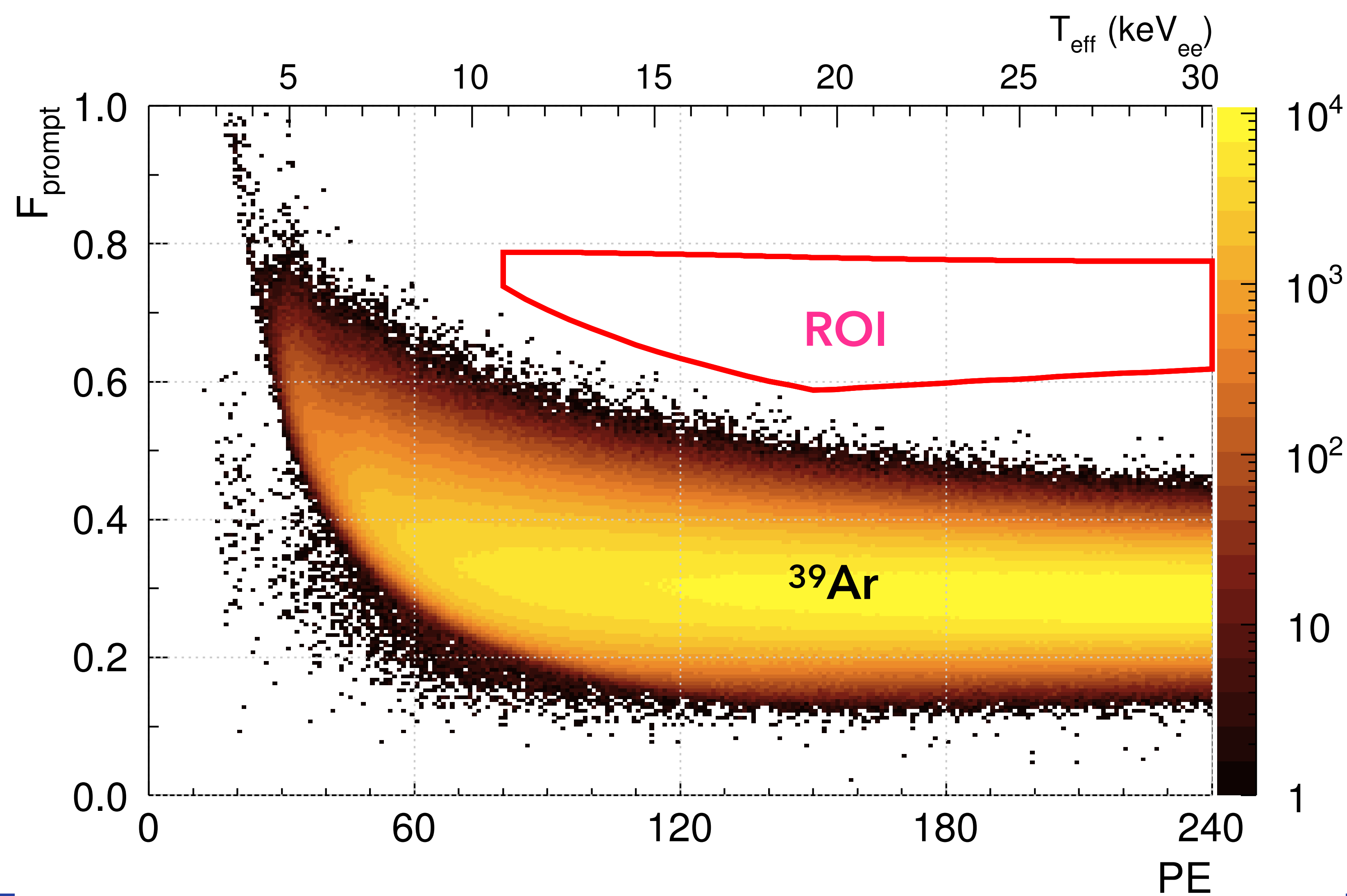
The PSD power in DEAP-3600 is better than predicted from the DEAP-1 prototype (thanks to less electronic noise than predicted).

9.87 tonne × days (Aug 2016)

1.87×10^7 events

Approx. 15.4 -- 30.9 keV

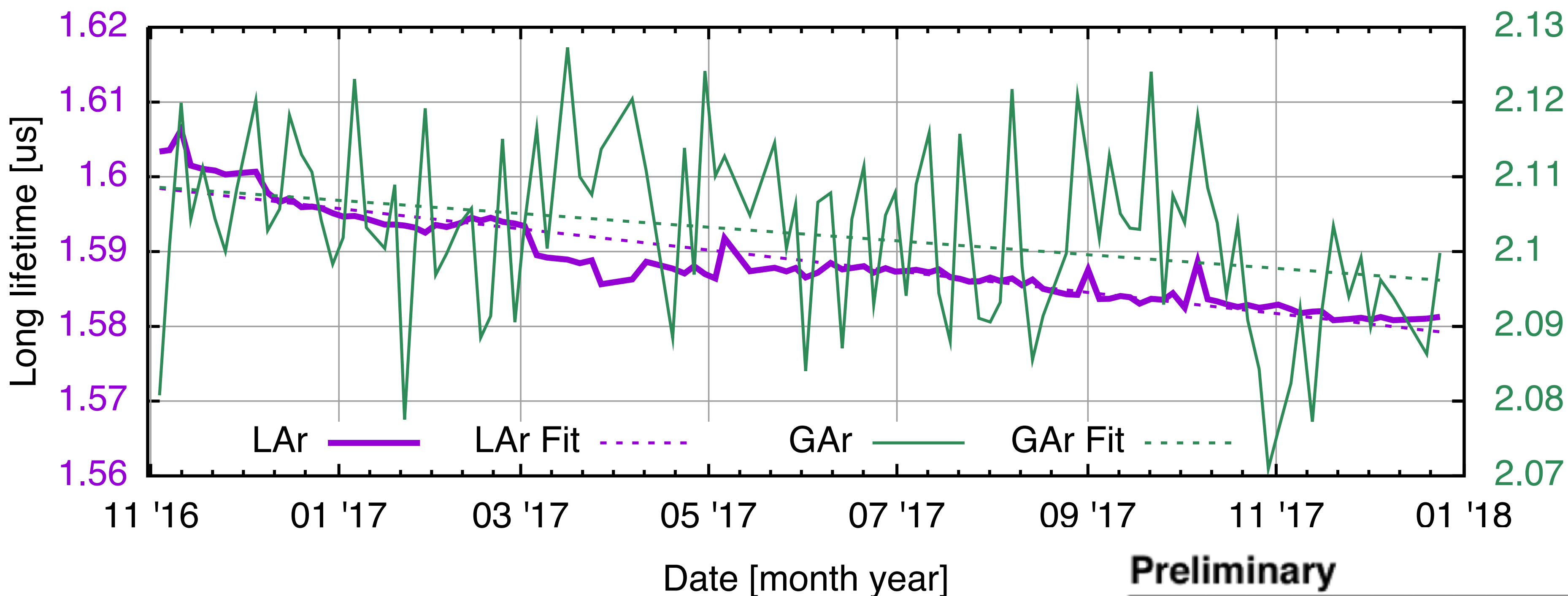


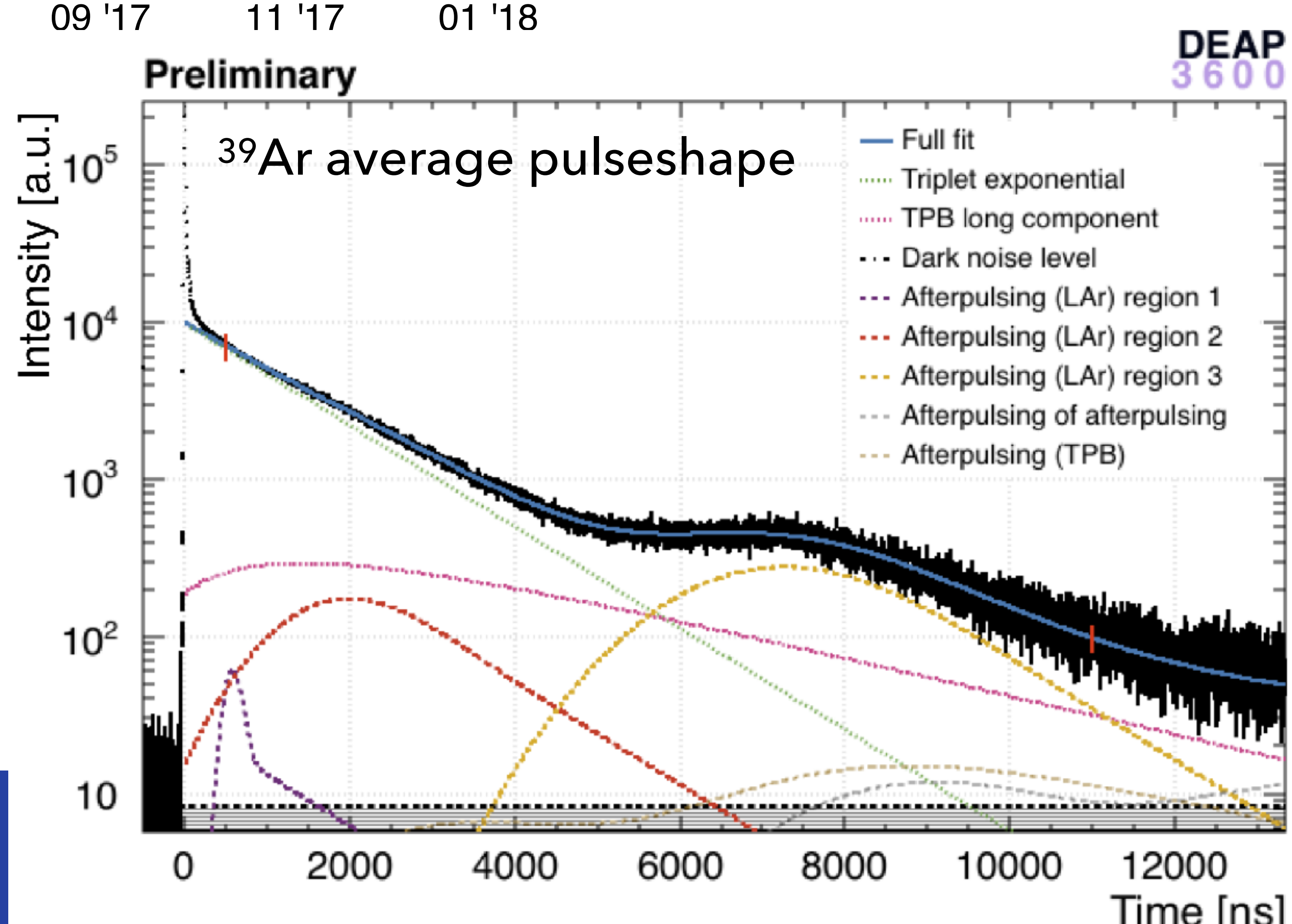


DEAP 3600

"First results from the DEAP-3600 dark matter search with argon at SNOLAB" arXiv:1707.08042

The LAr long lifetime and the light yield have been stable to < 2% without LAr re-circulation.





DEAP 3600