Technical University of Munich

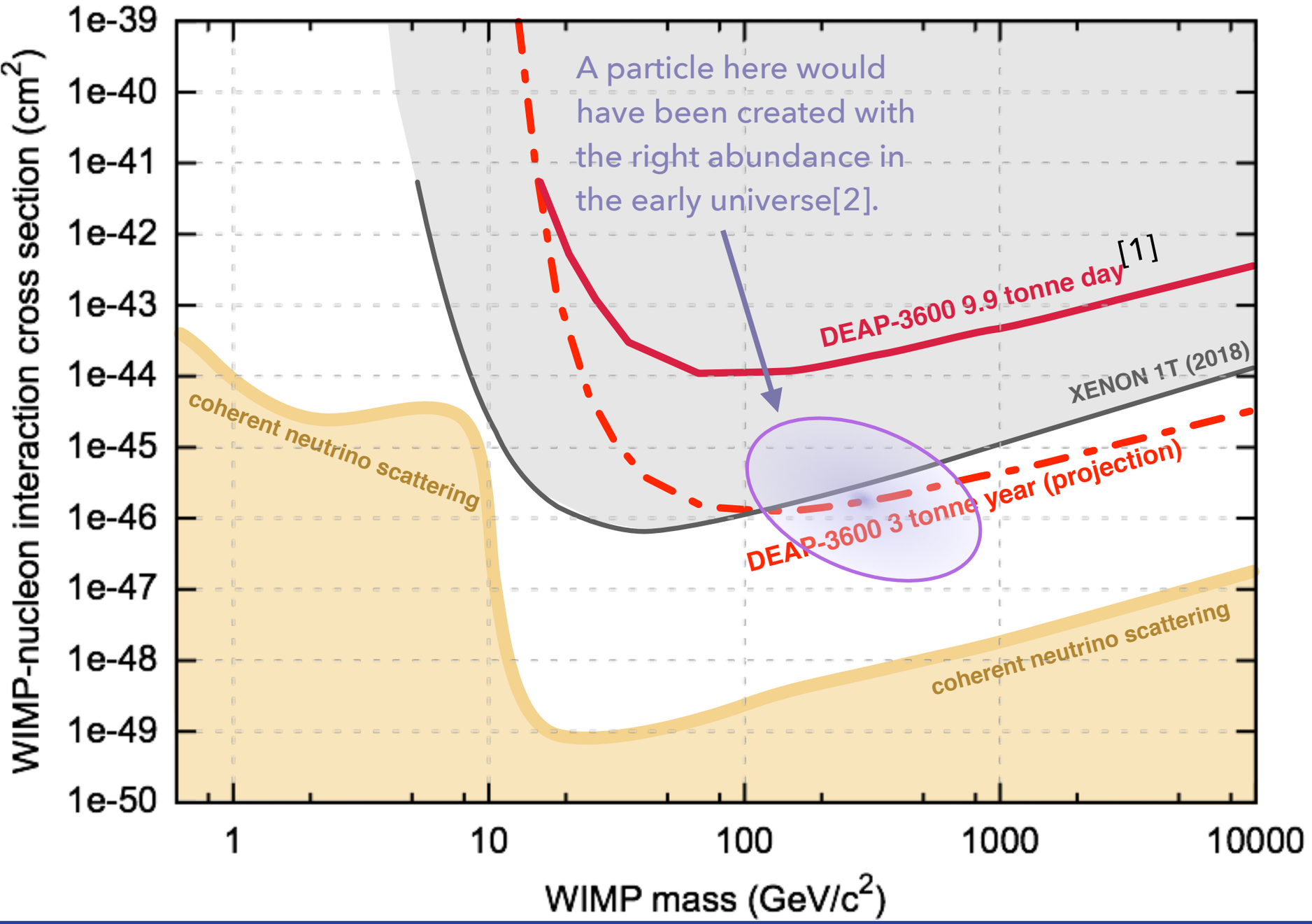
Direct dark matter search with DEAP-3600

Dr. Tina Pollmann
for the DEAP collaboration
DSU Workshop 2018, Annecy

The DEAP collaboration. 75 researchers from Canada, UK, Mexico, Germany

+ new collaborators from DarkSide

DEAP-3600 is a single-phase liquid argon direct-detection experiment, which will probe into the favoured WIMP parameter space, and test the results obtained with xenon targets.



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

[2] O. Buchmueller, et al. Supersymmetry and Dark Matter in Light of LHC 2010 and Xenon100 Data, arXiv:1106.2529 [hep-ph]

To shield against cosmic radiation, the DEAP-3600 detector is located deep underground at the SNOLAB research facility.

2 km
(6000
m.w.e.)

DEAP-3600

SNOLAB
underground laboratory.

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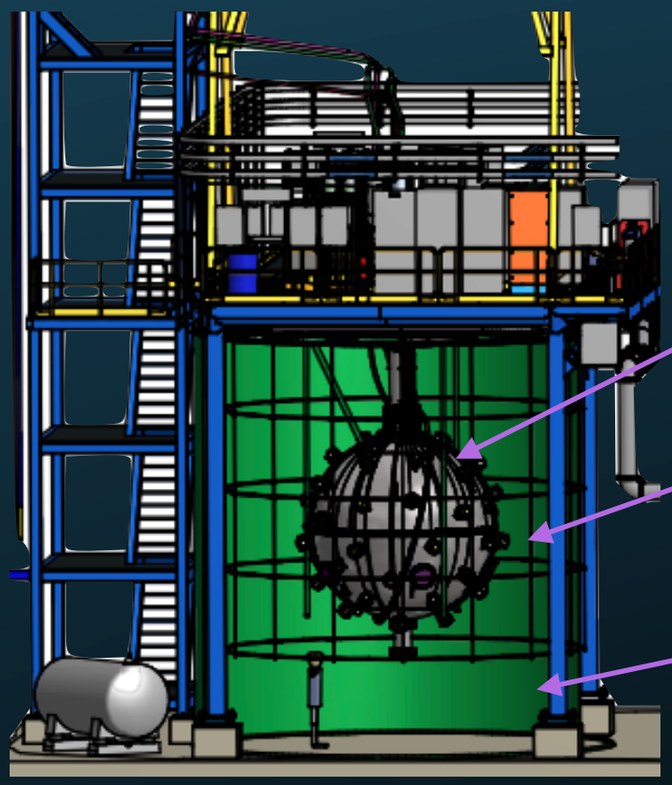


Steel shell

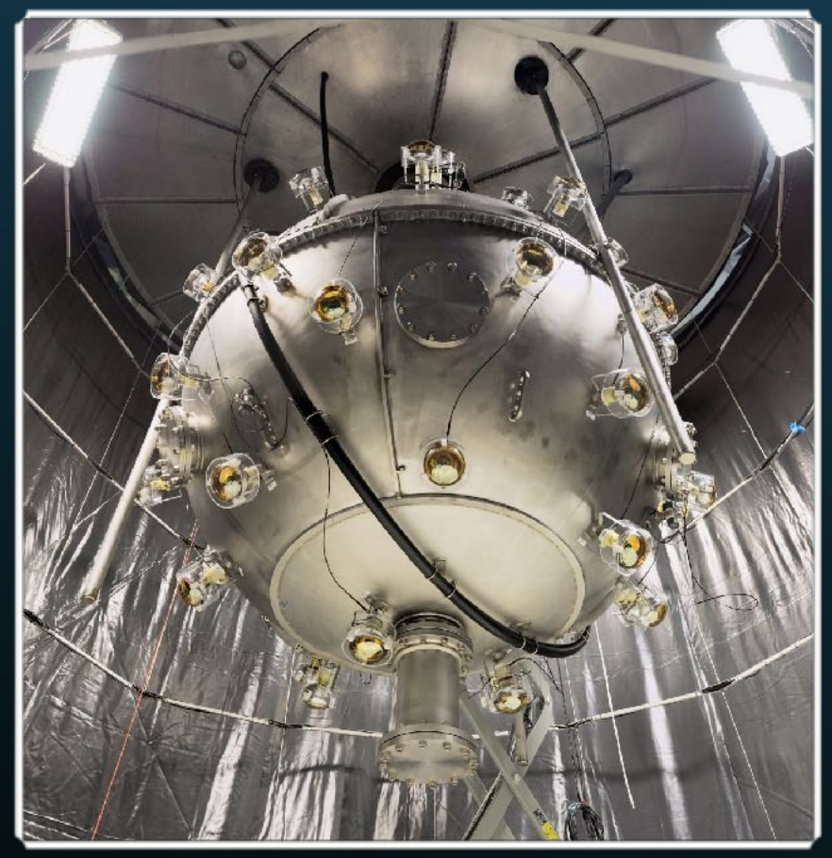
(Earth) magnetic field compensation coils

Water Cherenkov veto tank ⌀ 8m

DEAP-3600

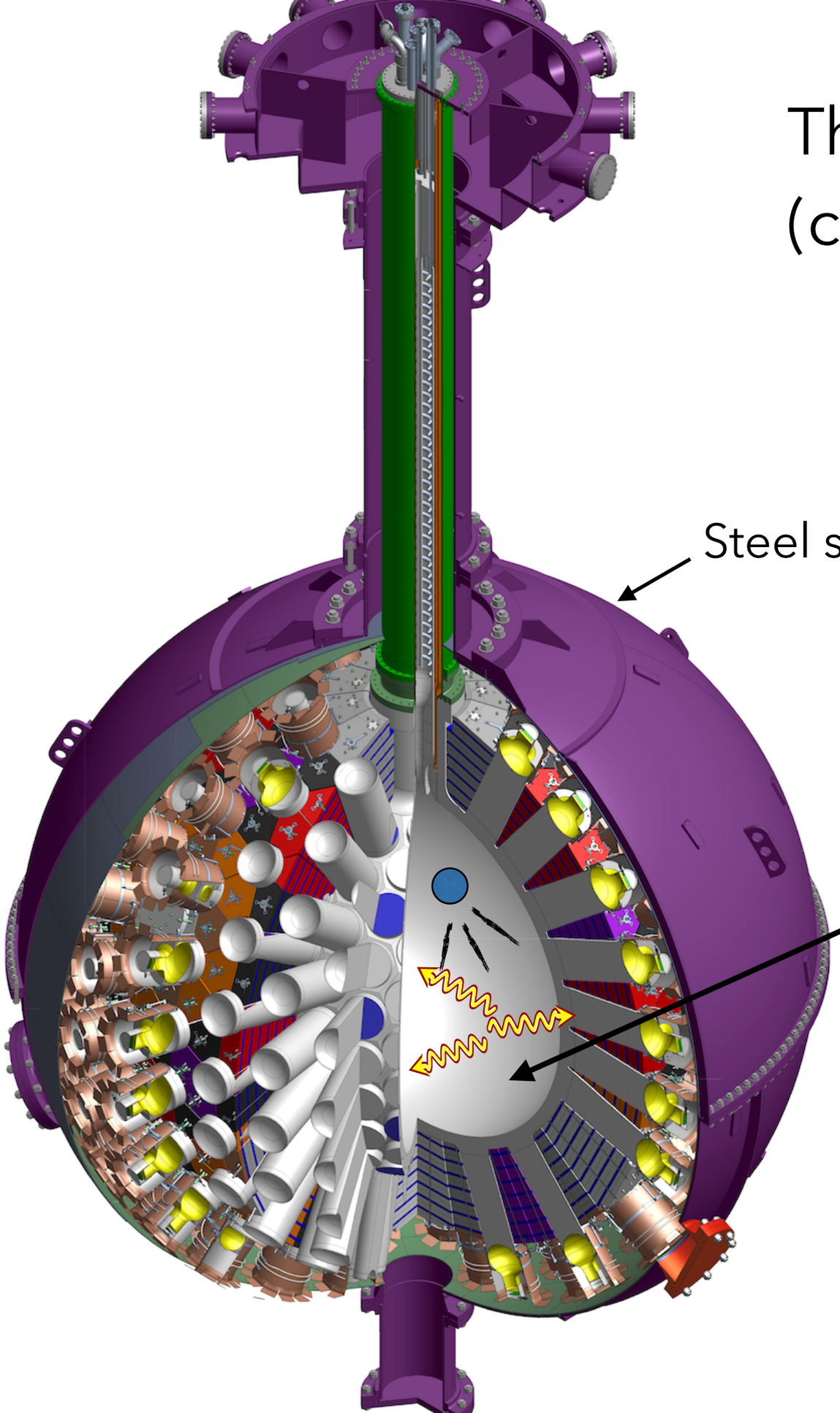
SNOLAB underground laboratory.

2 km (6000 m.w.e.)



"Design and Construction of the DEAP-3600 Dark Matter Detector" arXiv:1712.01982

The heart of the detector is a 3.6 (currently 3.3) tonne LAr volume.

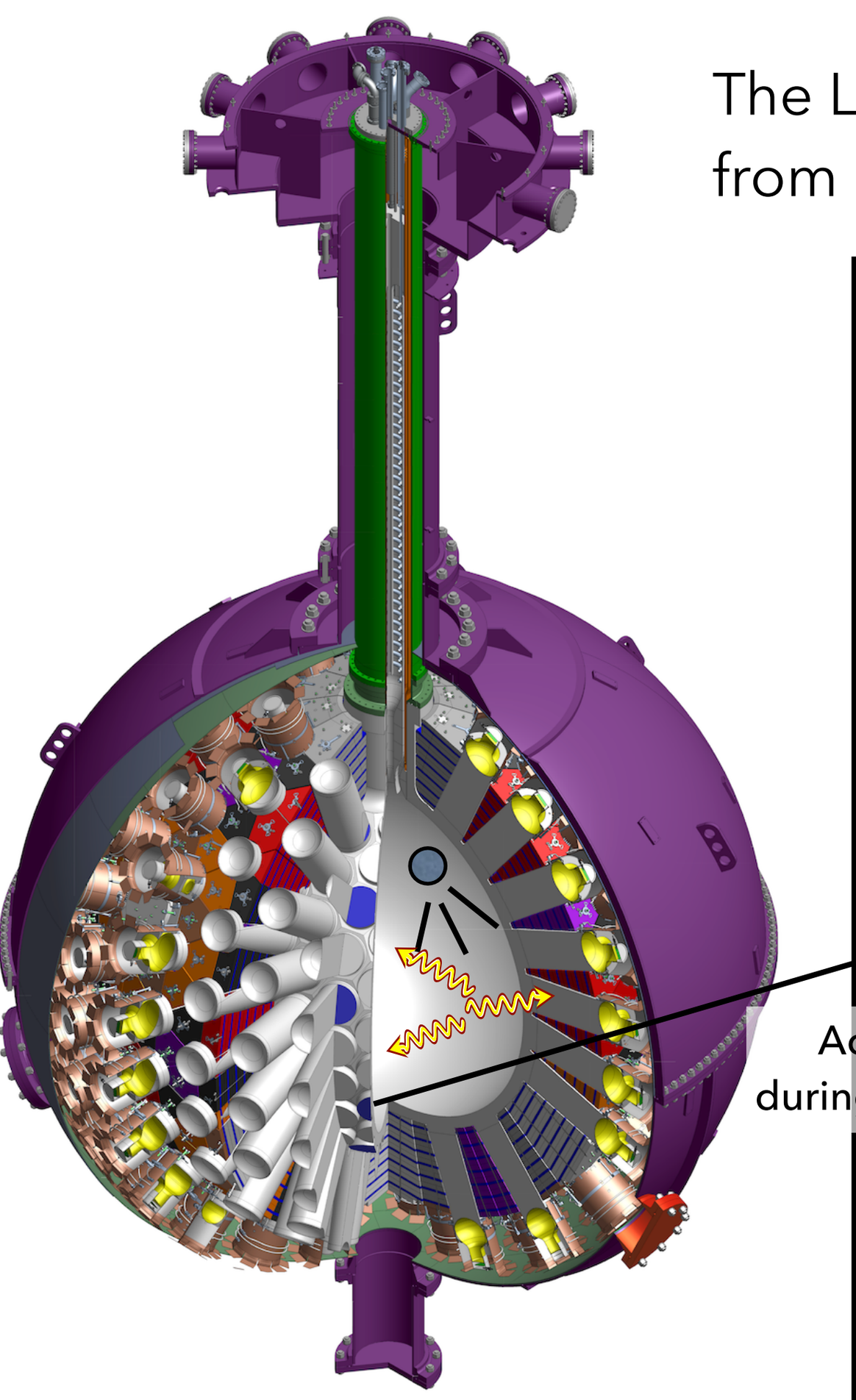


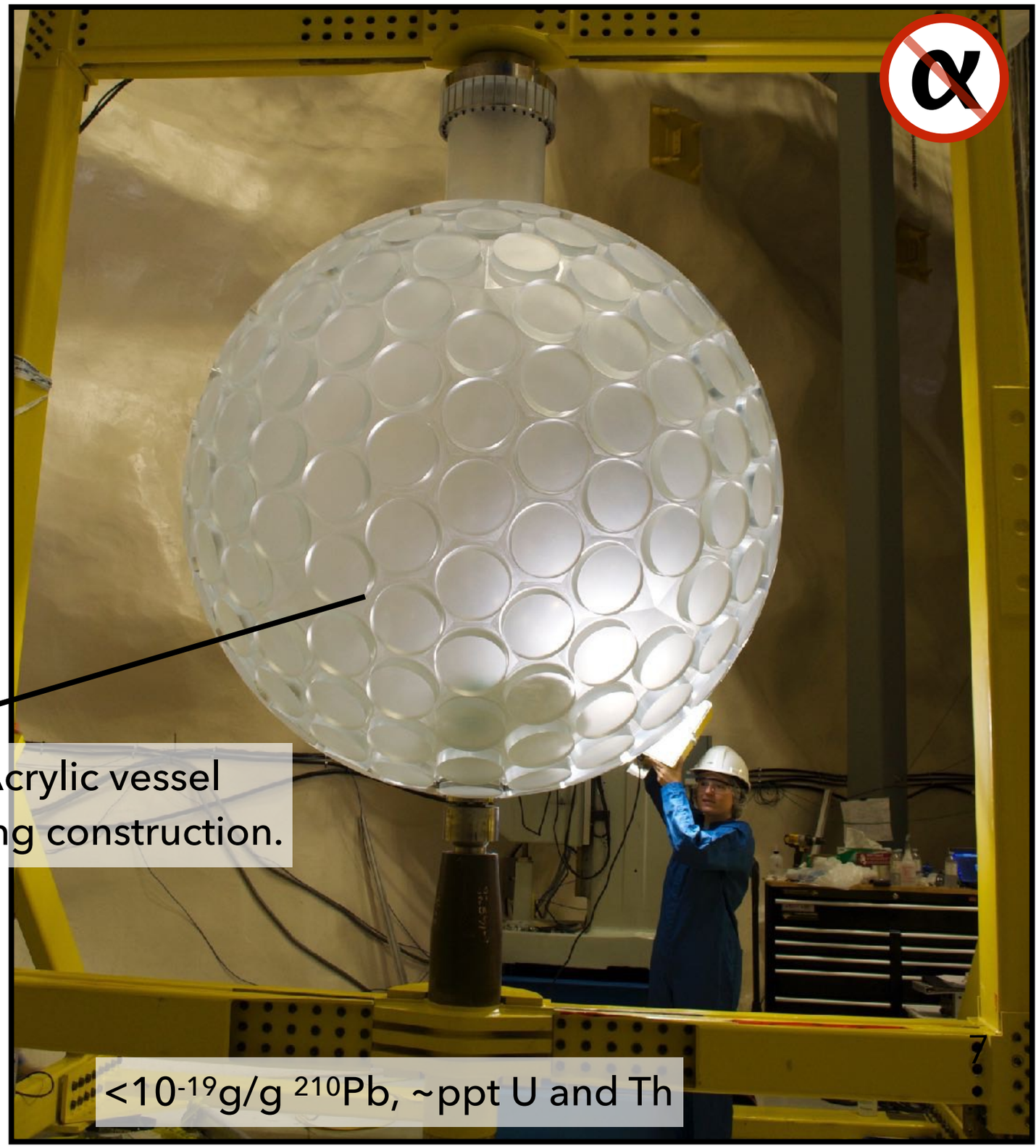
Liquid Argon (84 K, -188°C)

single-phase

A clean, affordable Dark Matter target with a bright scintillation signal and excellent background suppression capabilities.

The LAr target is held in a cryostat made from ultra-pure acrylic.

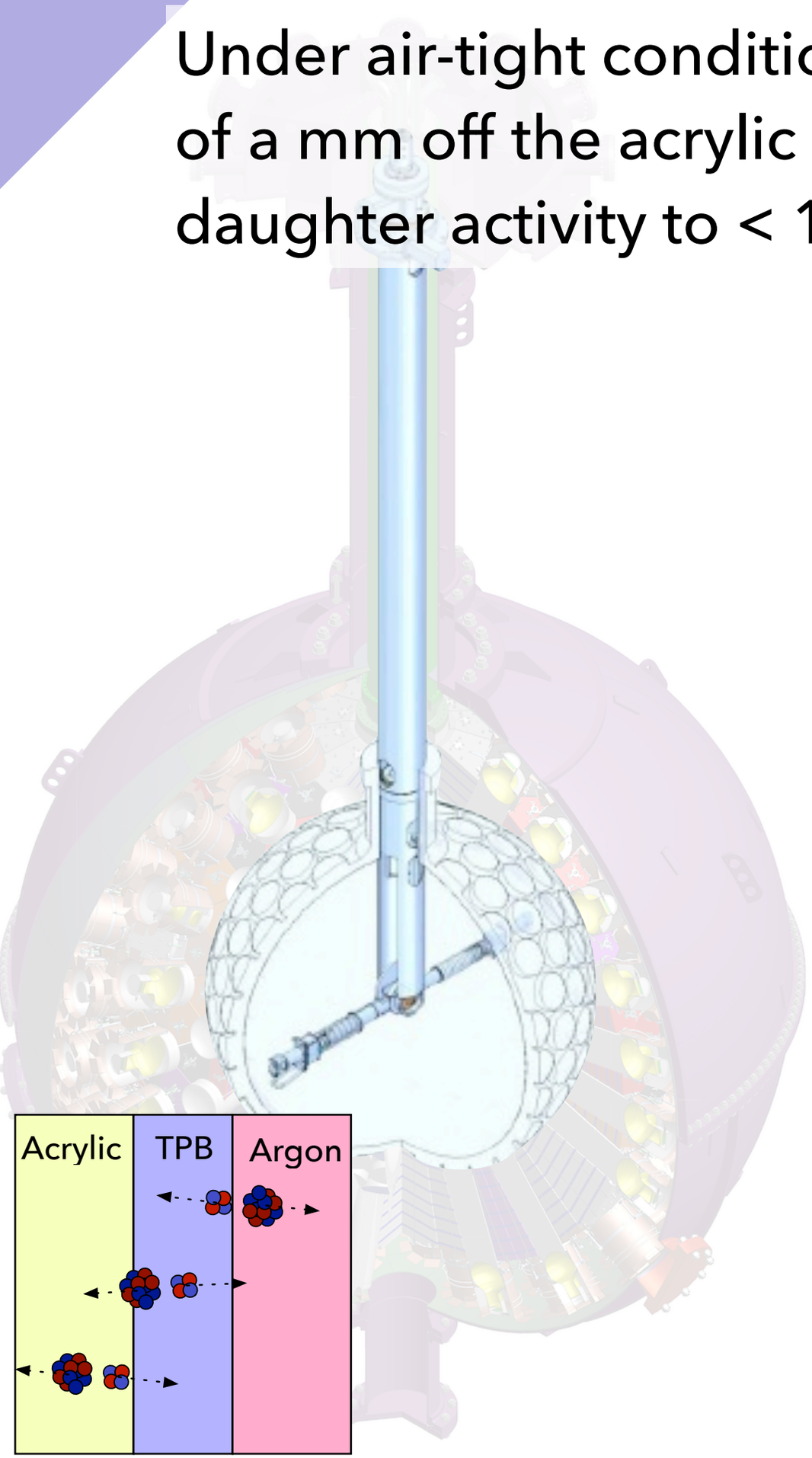




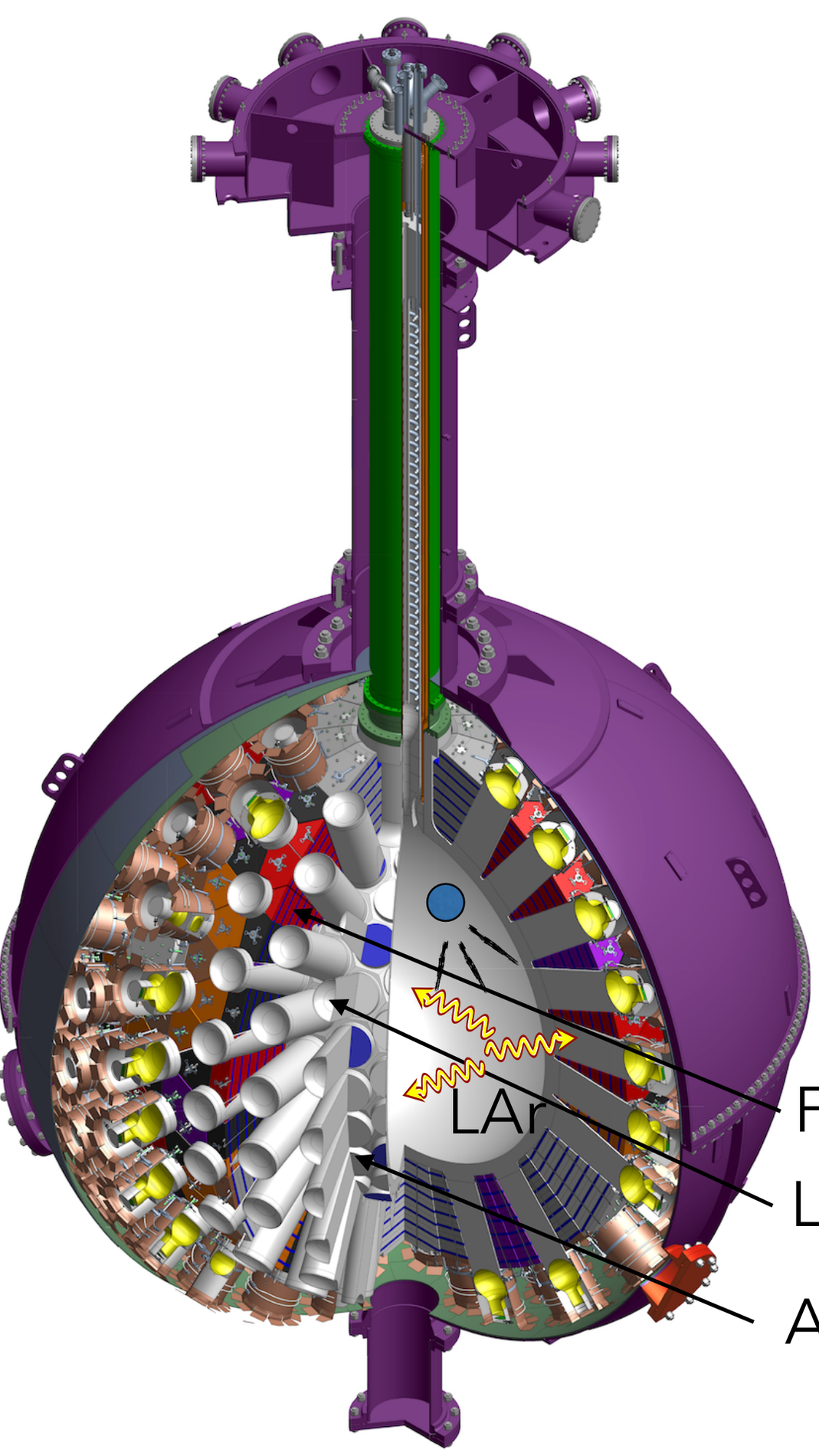
Acrylic vessel during construction.

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

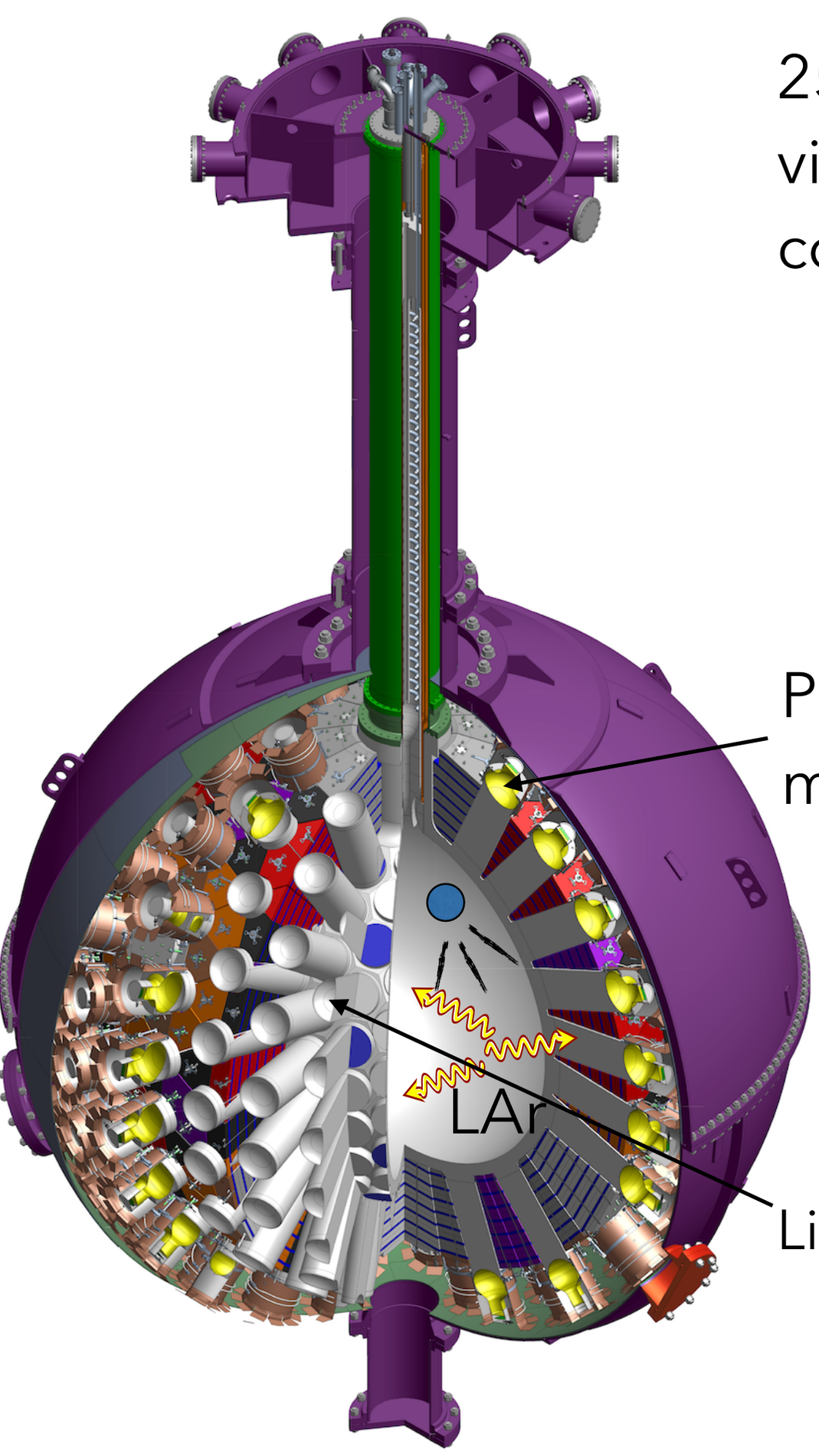
Under air-tight conditions, resurfacer removed fraction of a mm off the acrylic cryostat's inside, reducing radon daughter activity to < 10 $\alpha/m^2/day$.



50 cm of plastic provide thermal isolation and neutron shielding.

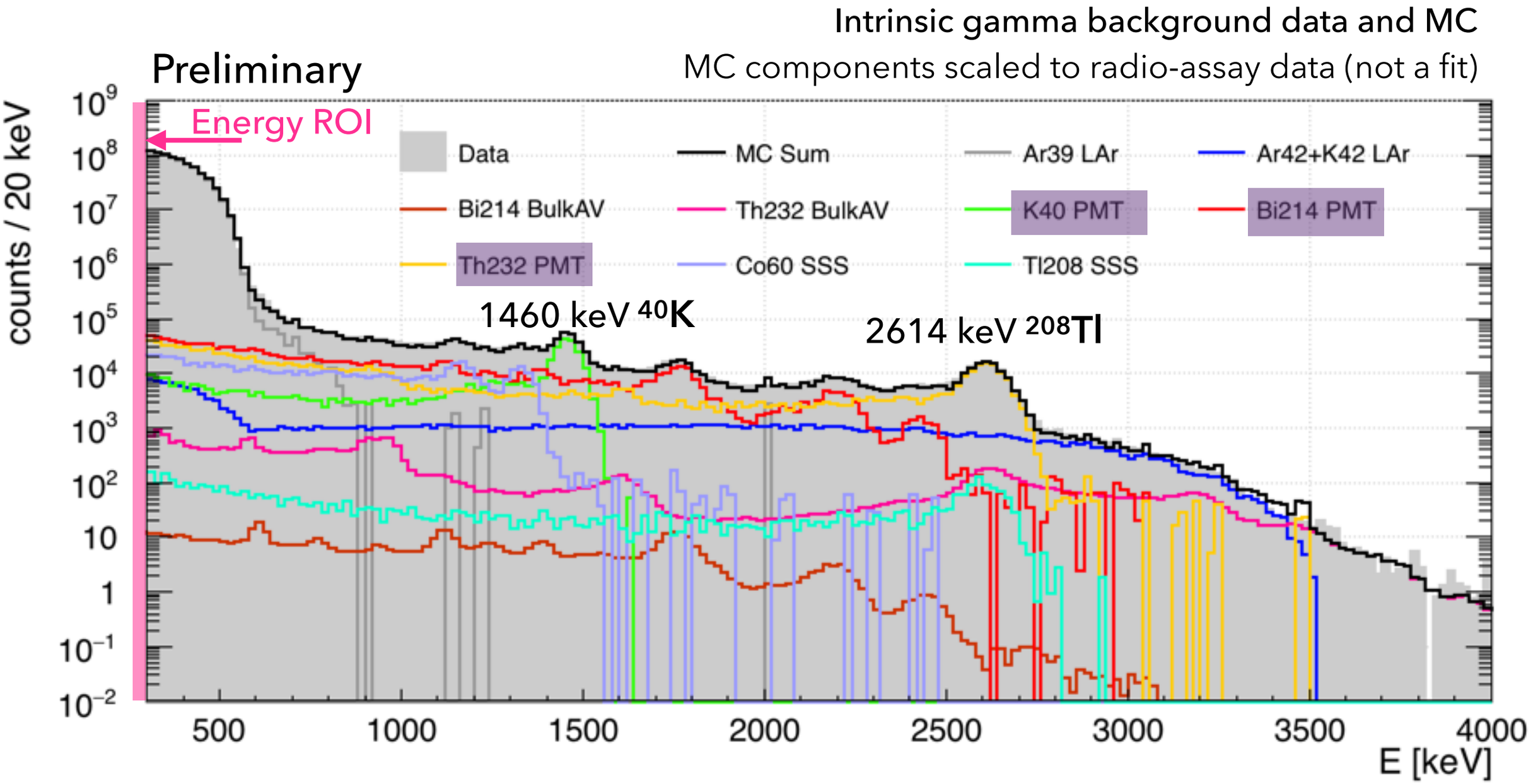


255 Hamamatsu R5912-HQE PMTs view the LAr volume at 71% surface coverage. PMTs at Temp > -40C.

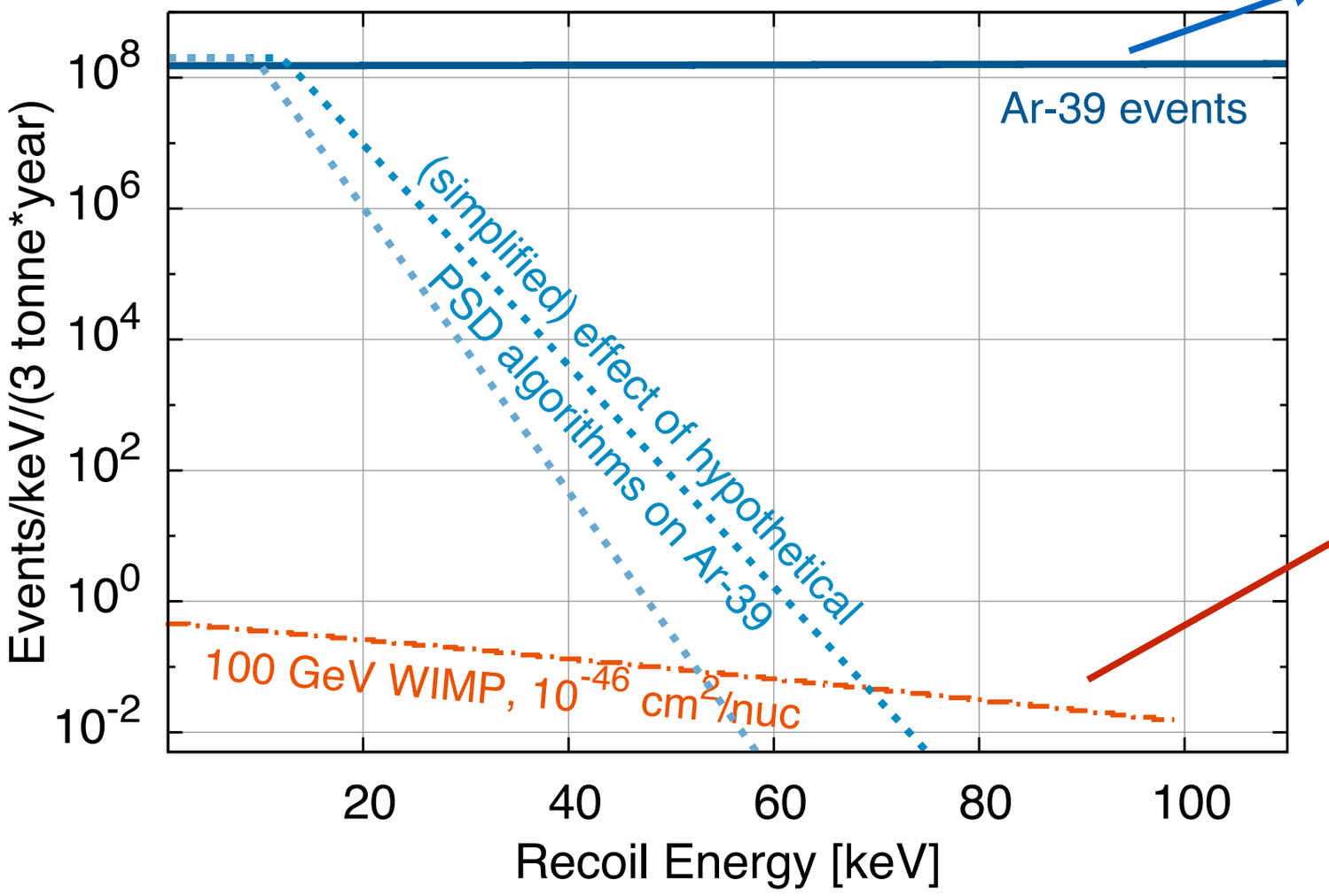


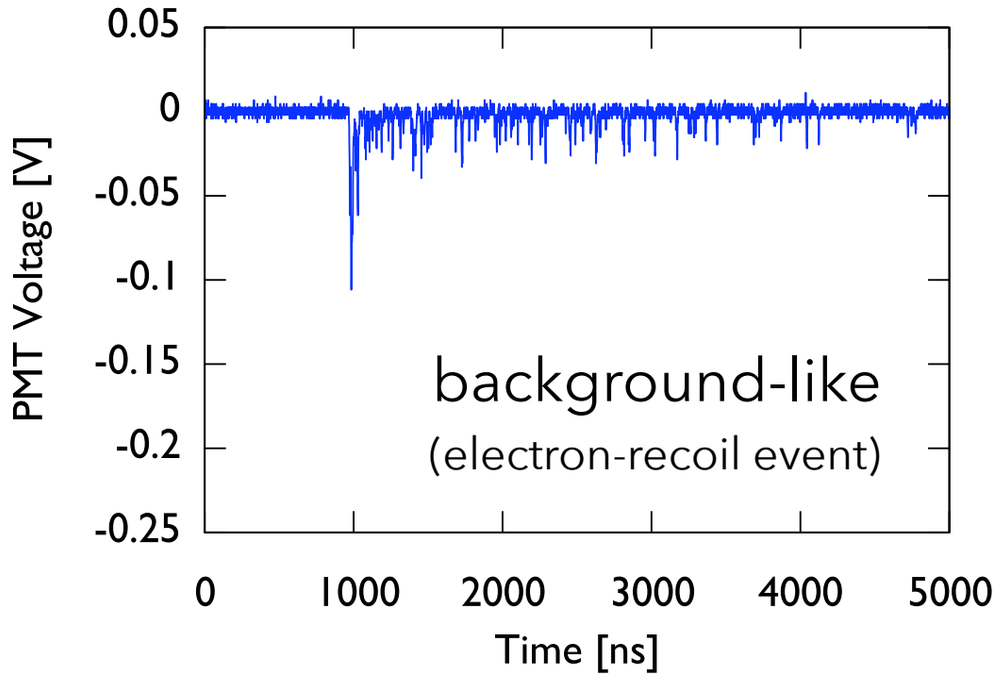
Intrinsic and external radiation sources are used for

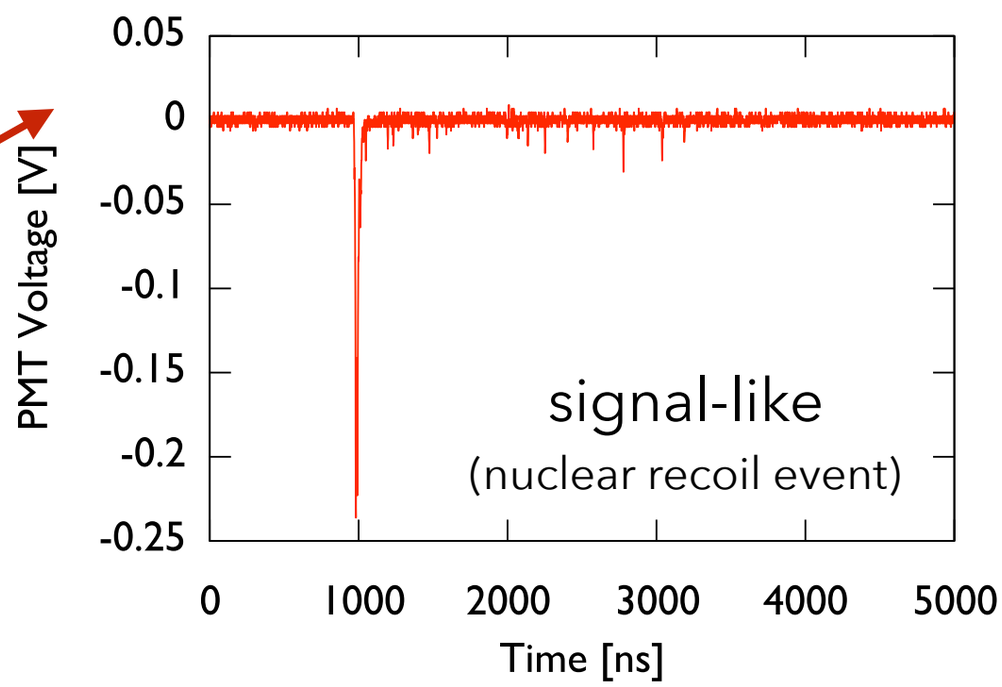
- energy calibration
- position reconstruction calibration
- constraints on α,γ, n background rates (e.g. find ~0.2 μBq/kg ^{222}Rn in LAr)



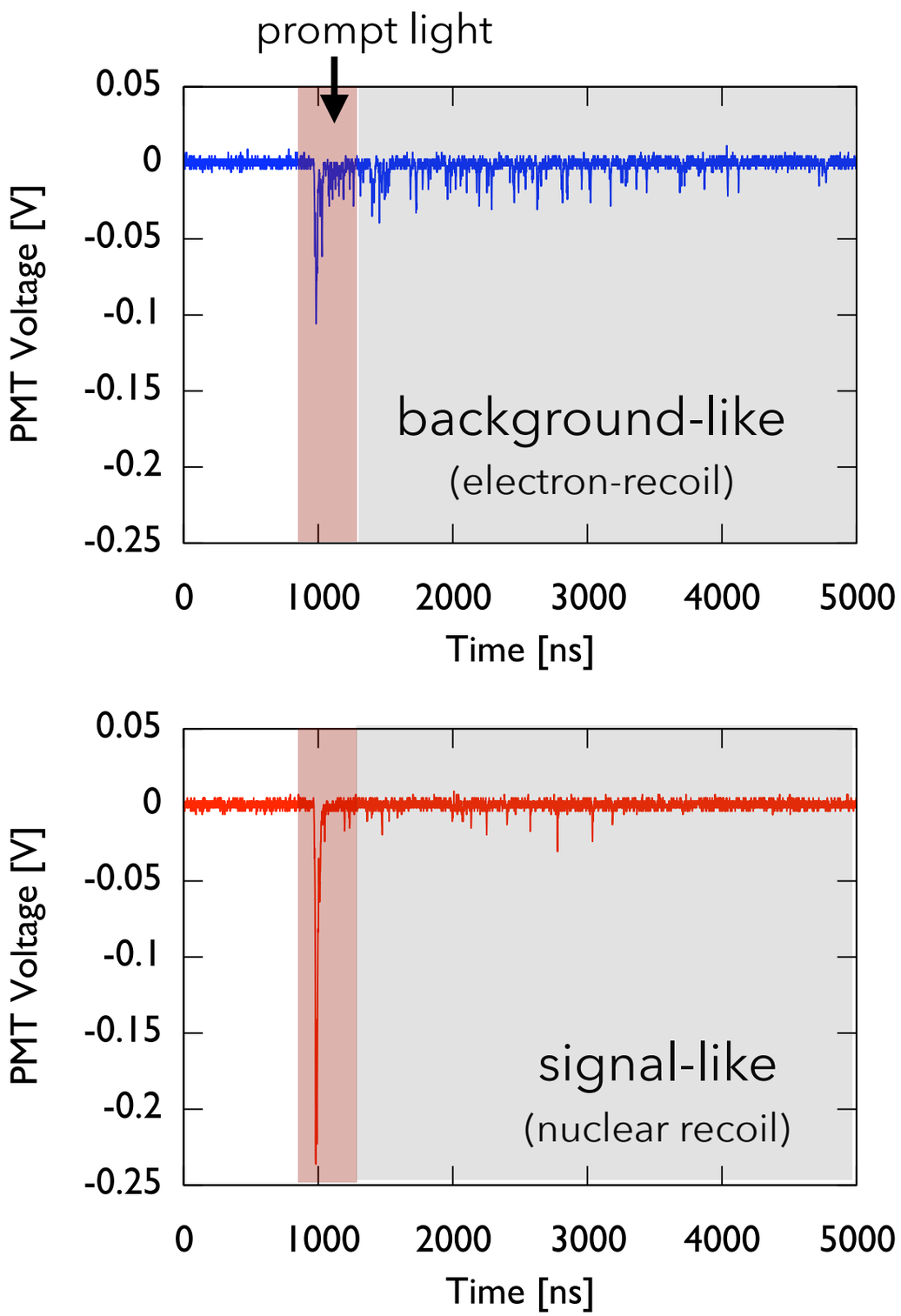
The background from Ar-39 beta decays is suppressed through pulse shape discrimination (PSD).

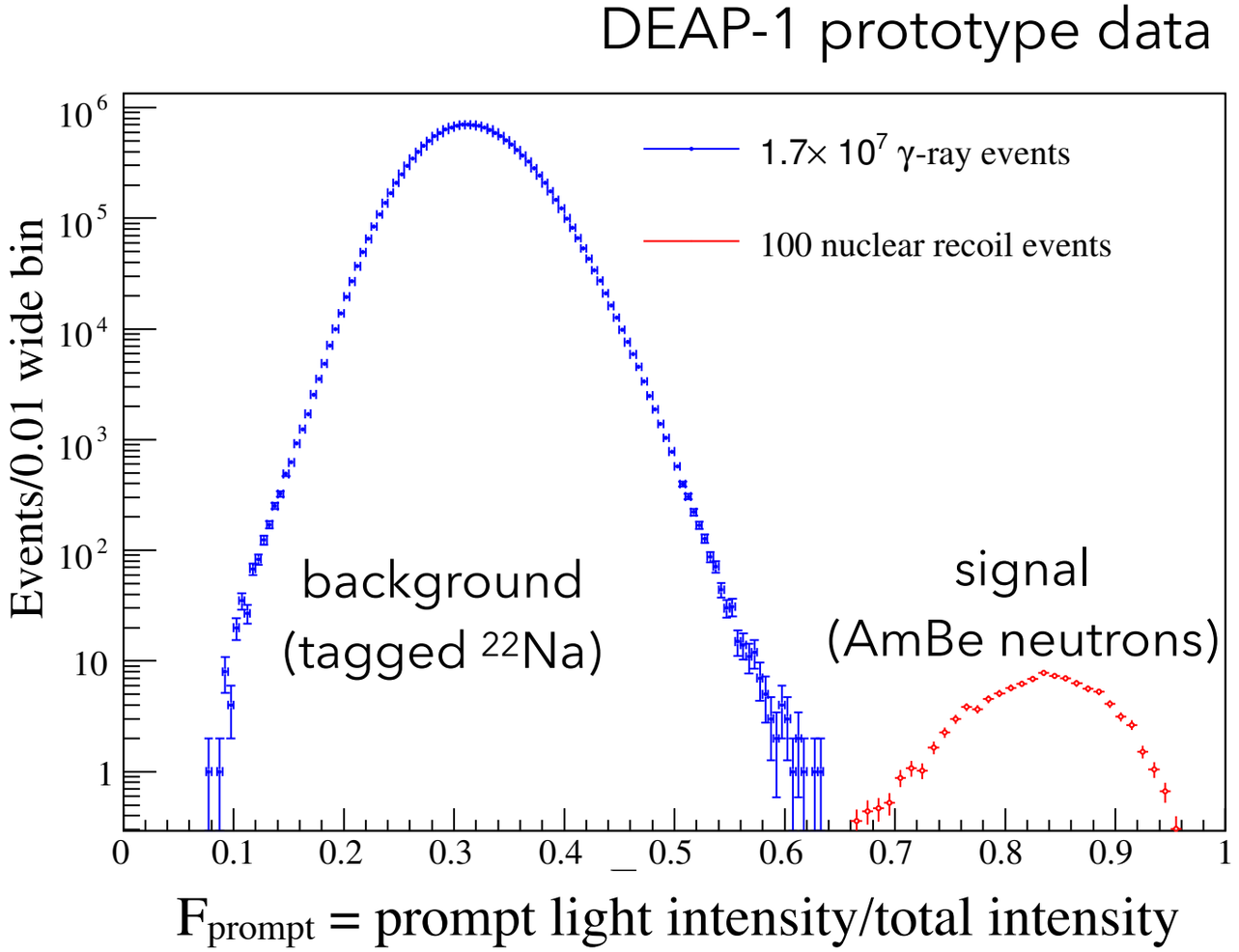






The argon scintillation pulseshape allows for effective PSD against electron-recoil background events.





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

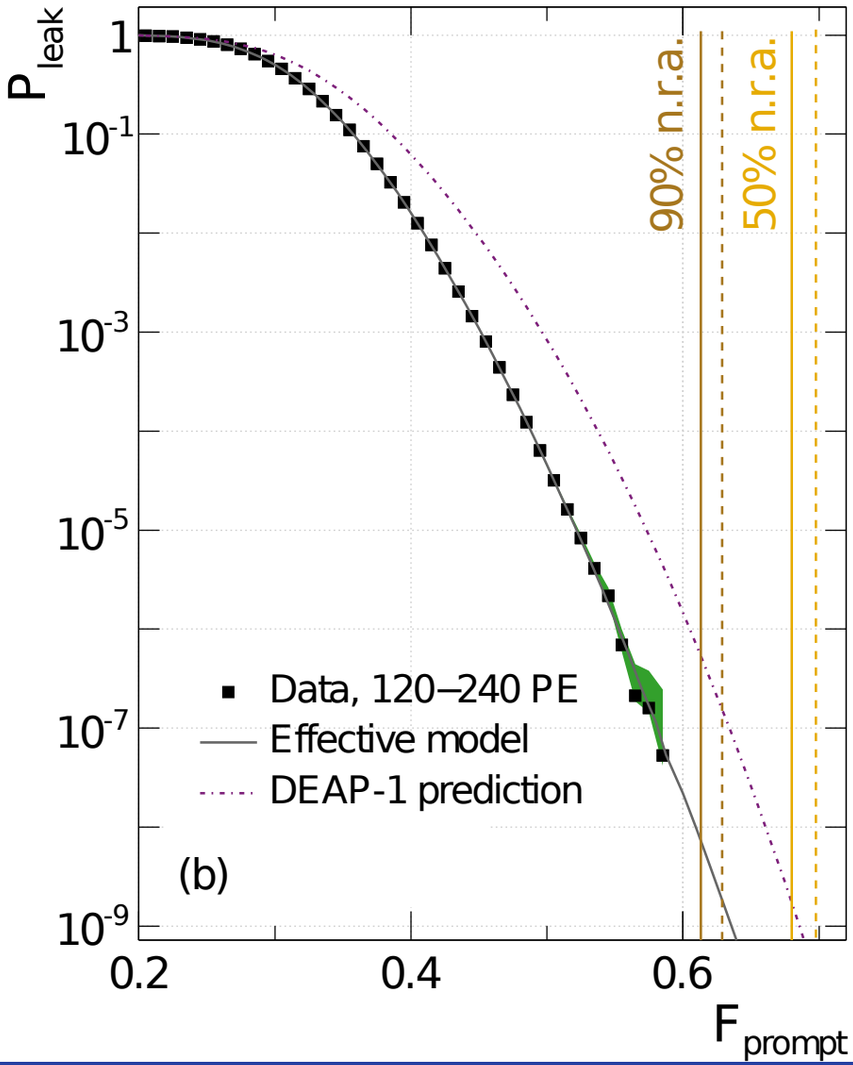
Boulay, M G, et al.
Astroparticle Physics 85 (2016).

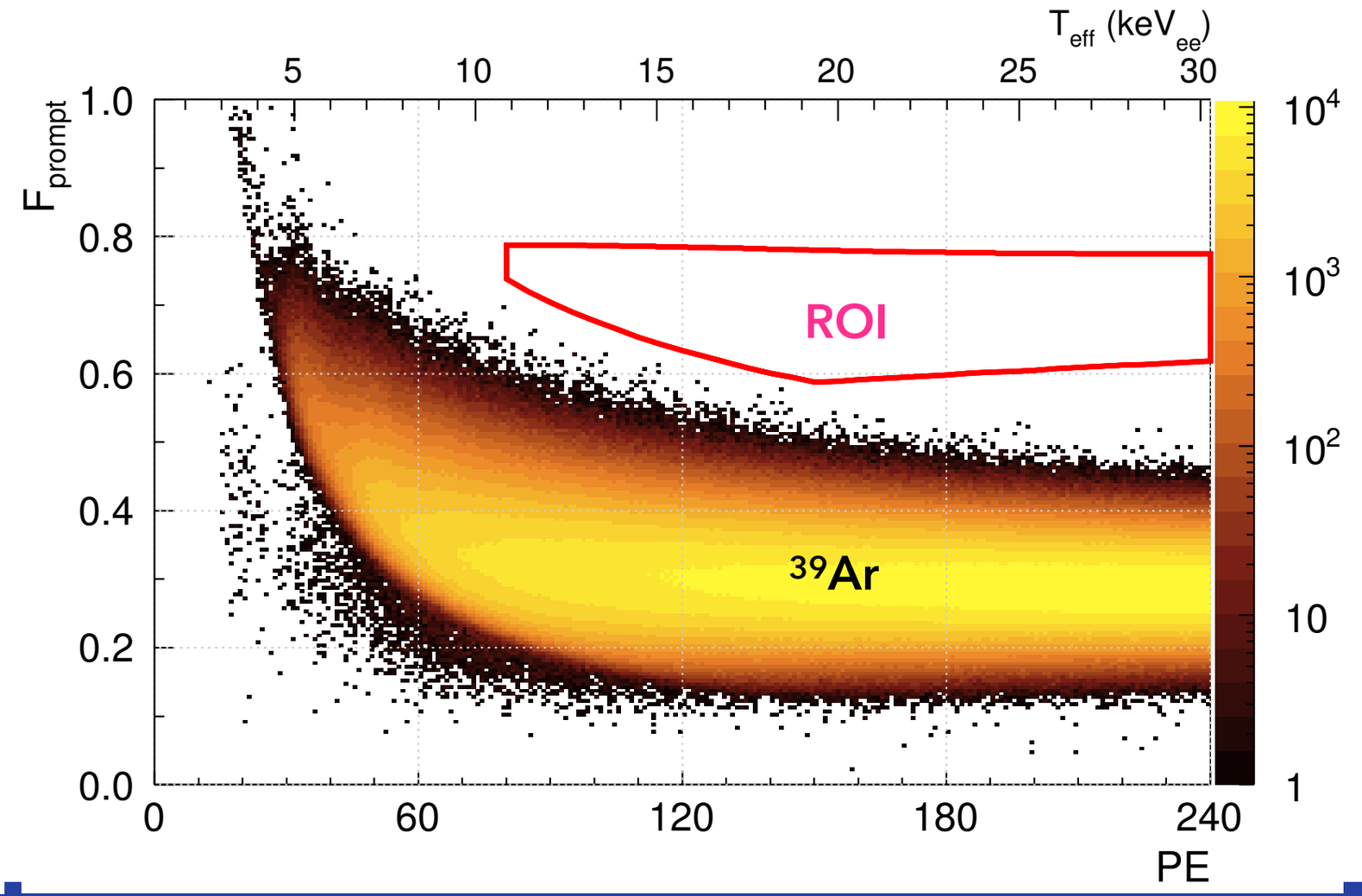
The PSD power in DEAP-3600 is better than predicted from the DEAP-1 prototype (thanks to less electronic noise than predicted).

9.87 tonne × days (Aug 2016)

1.87×10^7 events

Approx. 15.4 -- 30.9 keV

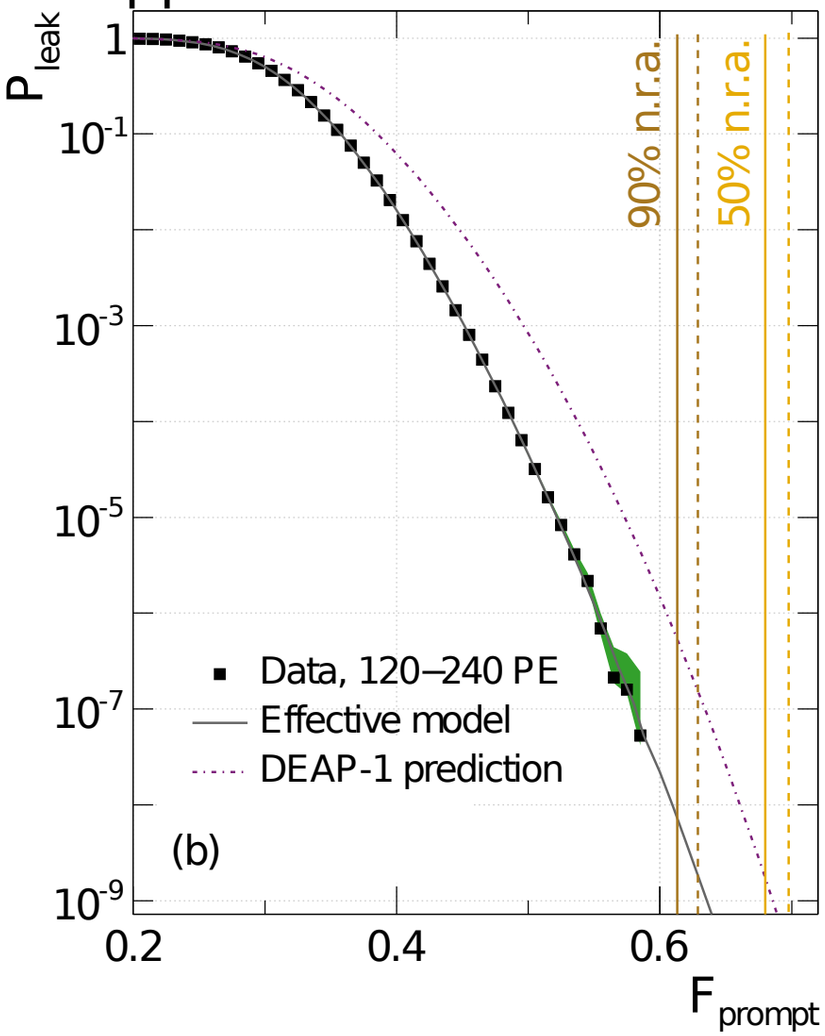




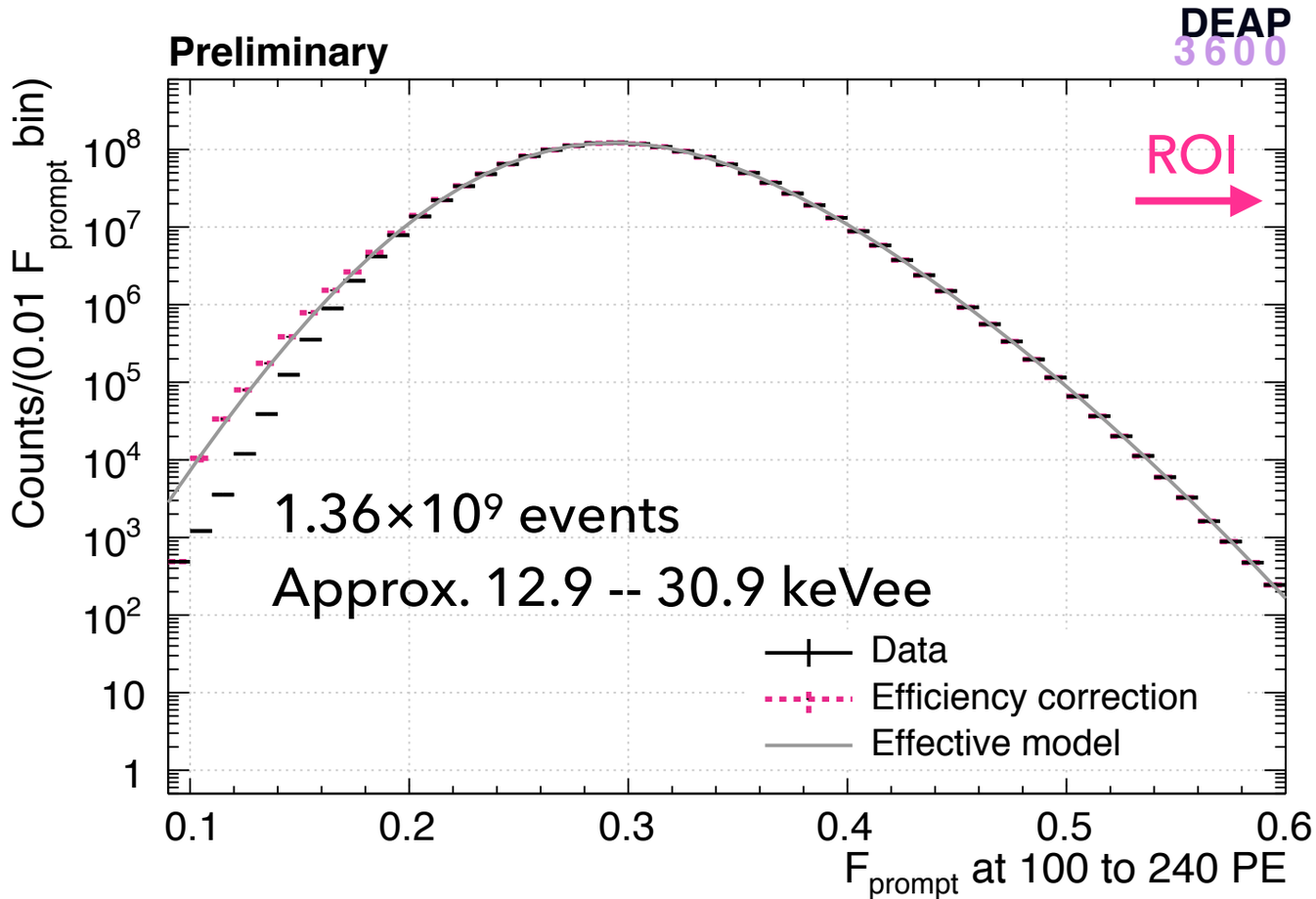
"First results from the DEAP-3600 dark matter search with argon at SNOLAB" arXiv:1707.08042

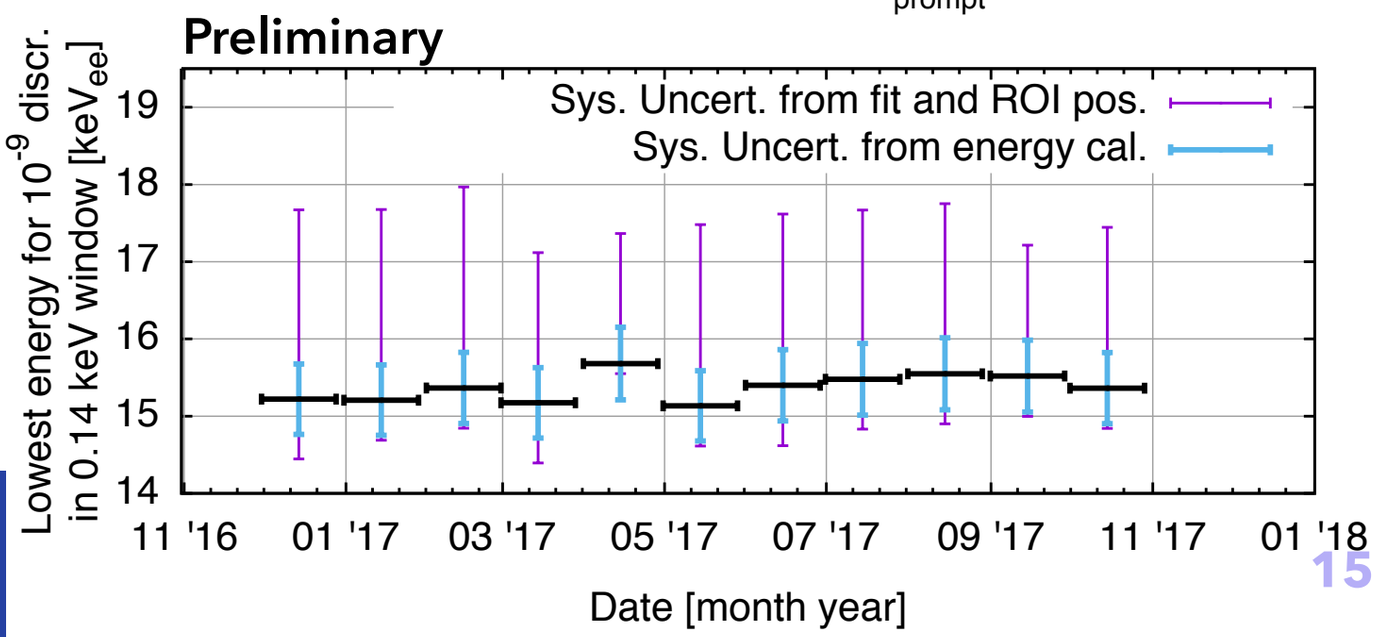
PSD power has remained excellent over a year of data collection.

9.87 tonne × days
(4.4 live days Aug 2016)
1.87×10⁷ events
Approx. 15.4 -- 30.9 keV

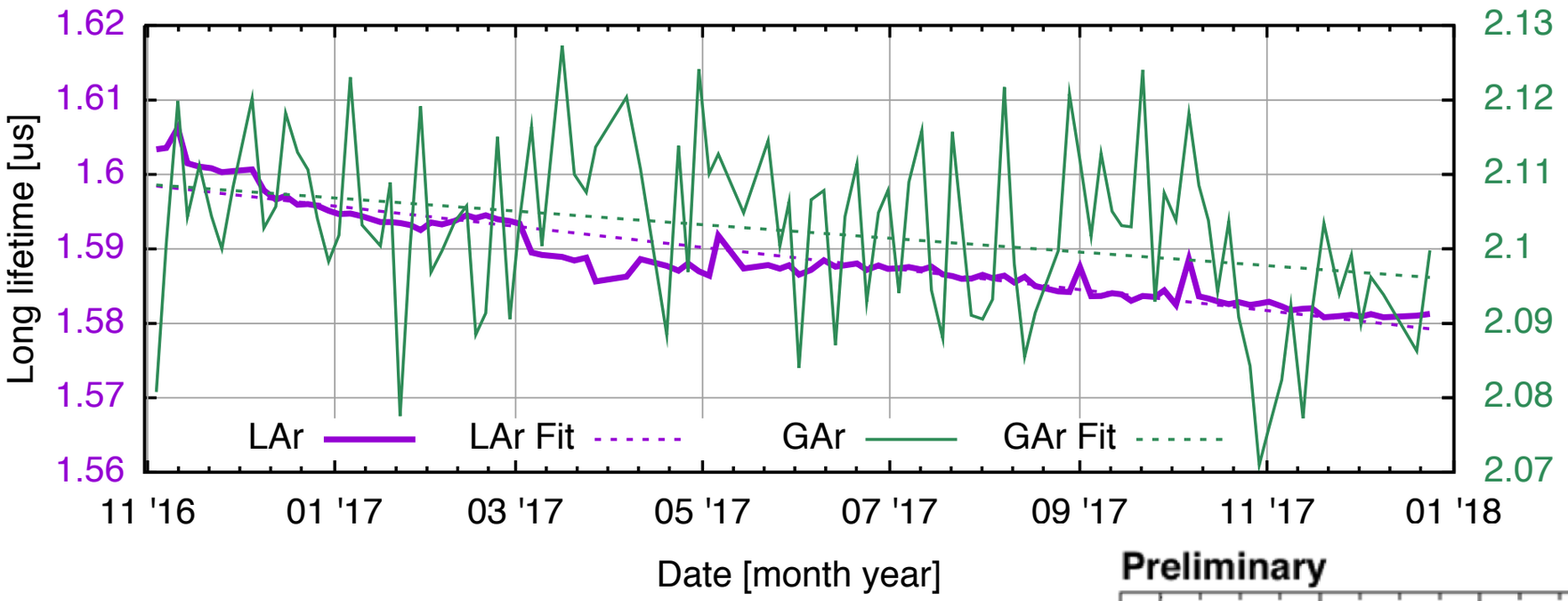


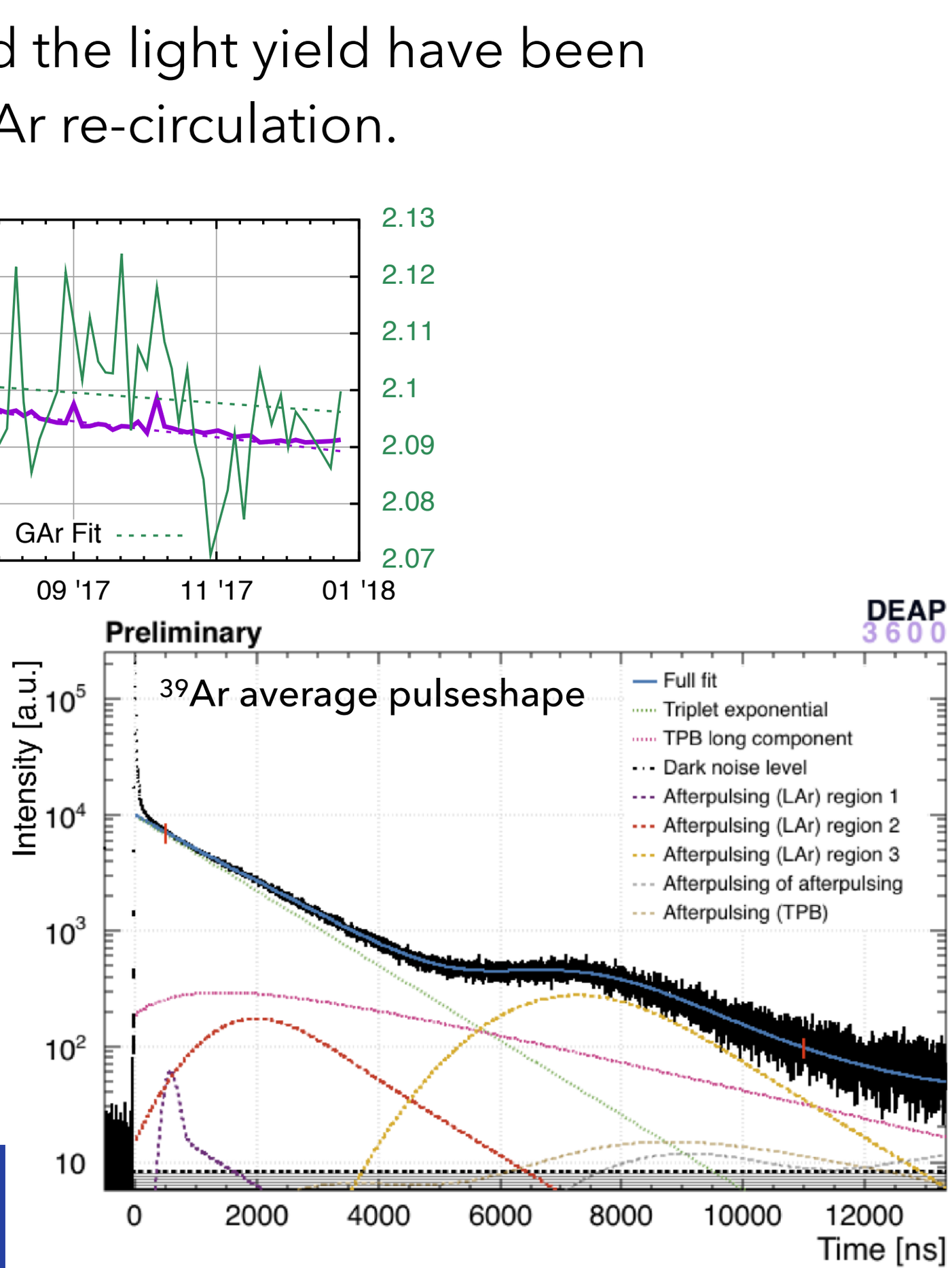
~ 250 live days (Nov 2016 - Oct 2017)





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





DEAP 3600

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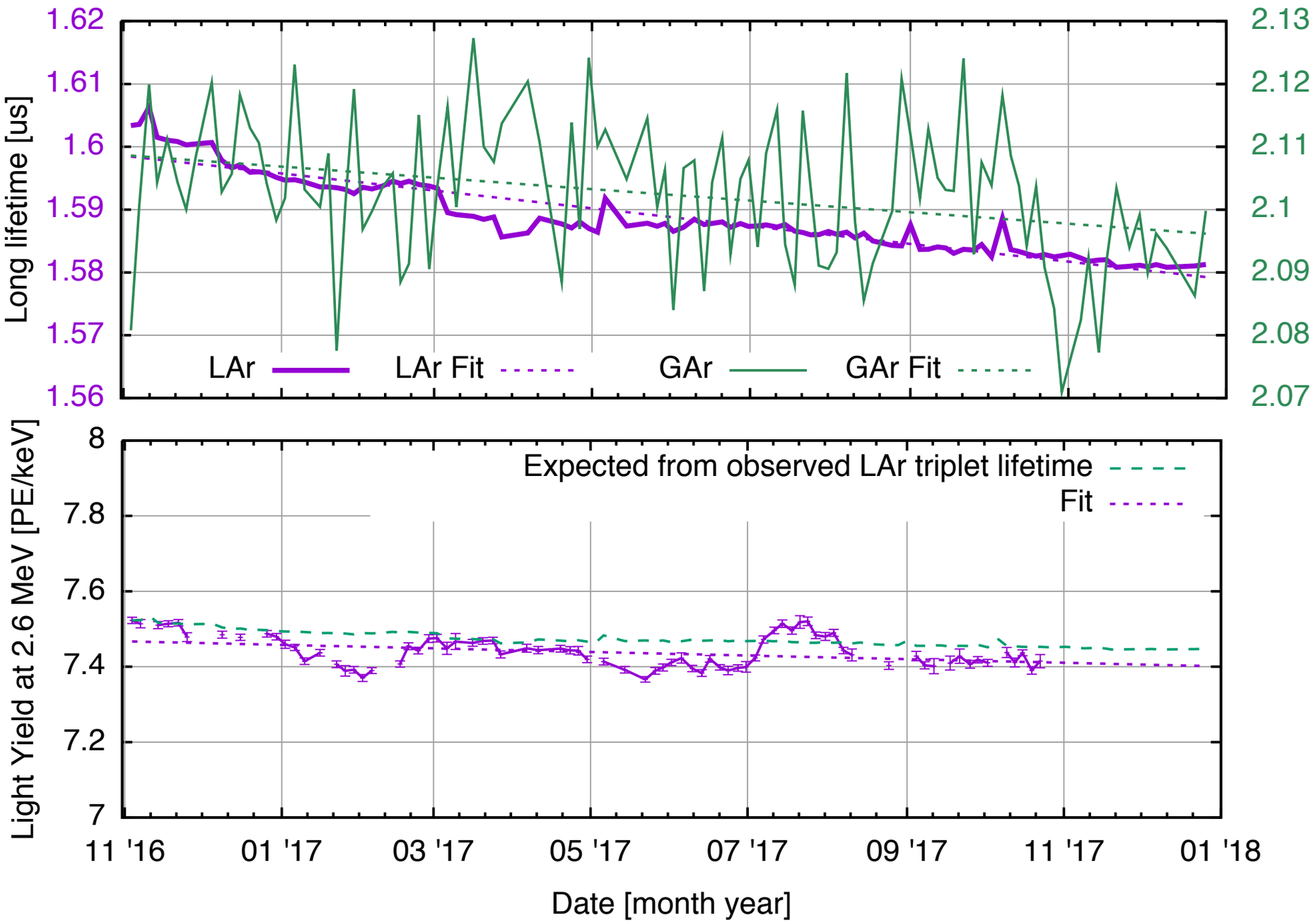
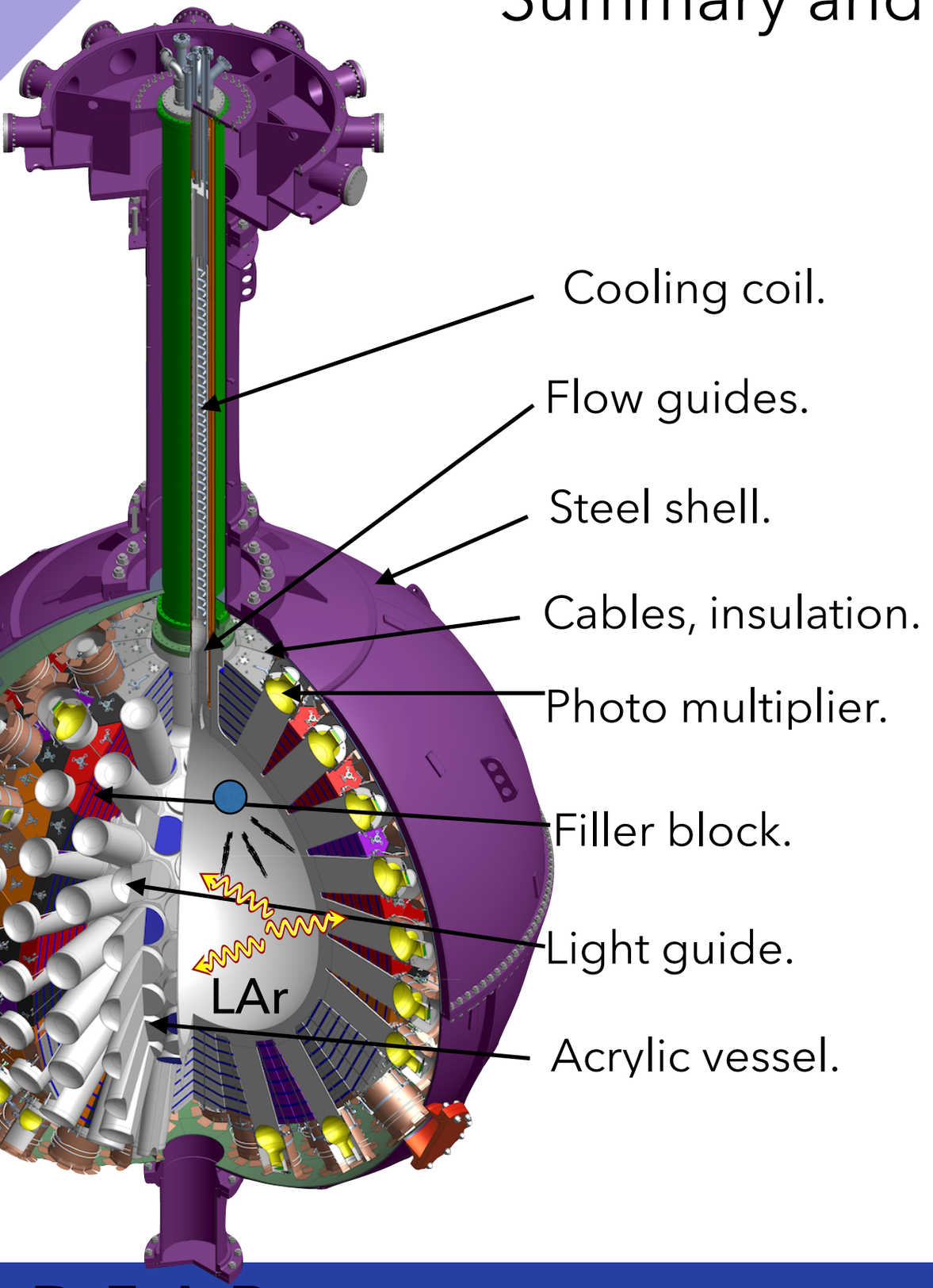


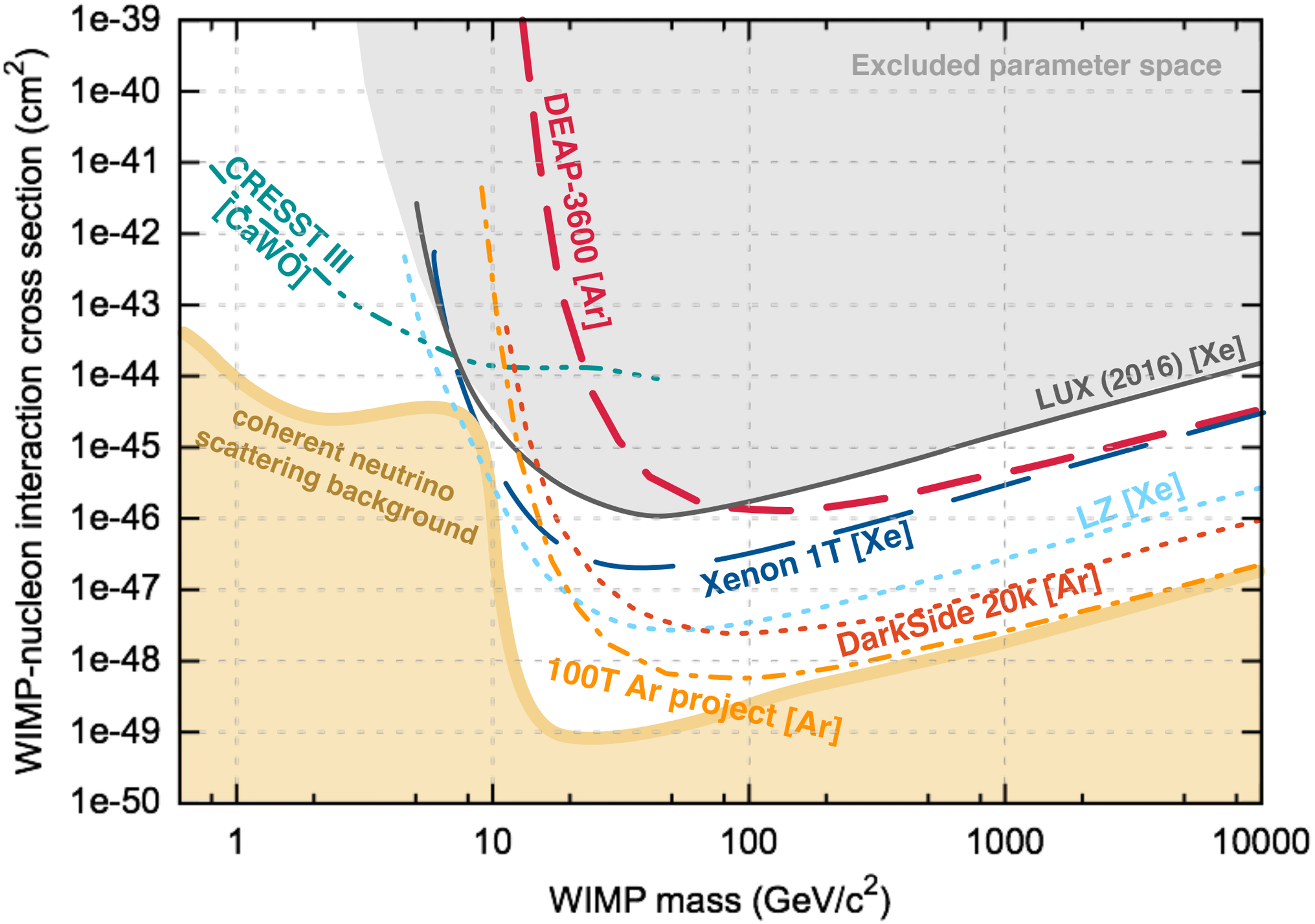
Summary and Outlook



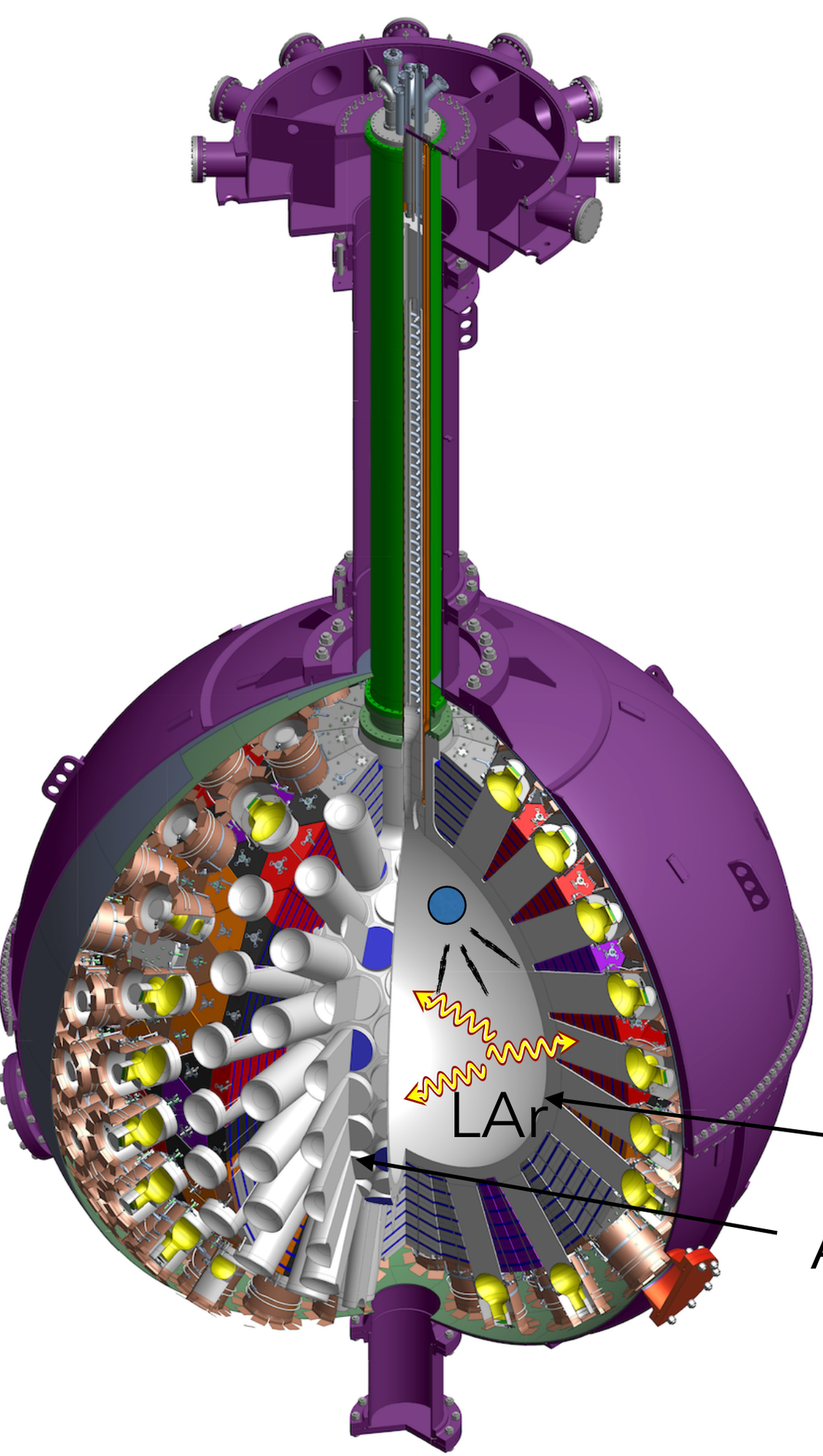
- First 4 days of physics data (Aug 2016)[1]
  - Largest LAr-based DM detector ever built achieved stable operation
  - Best PSD on LAr ever demonstrated
  - Background-free search for WIMP-nucleon cross section limit
    $<1.2\times10^{-44}$ cm^2 @100 GeV/c^2 (90% CL)
- 1 year open dataset collected
  - ~250 live days (Nov 2016 - Oct 2017) (after prelim. data quality cuts) with stable detector conditions
- Blind data since Jan 2018
- New global LAr collaboration
  - DarkSide + DEAP + CLEAN + ArDM
  - 20 tonne (DS-20k) and then 300 tonne detector

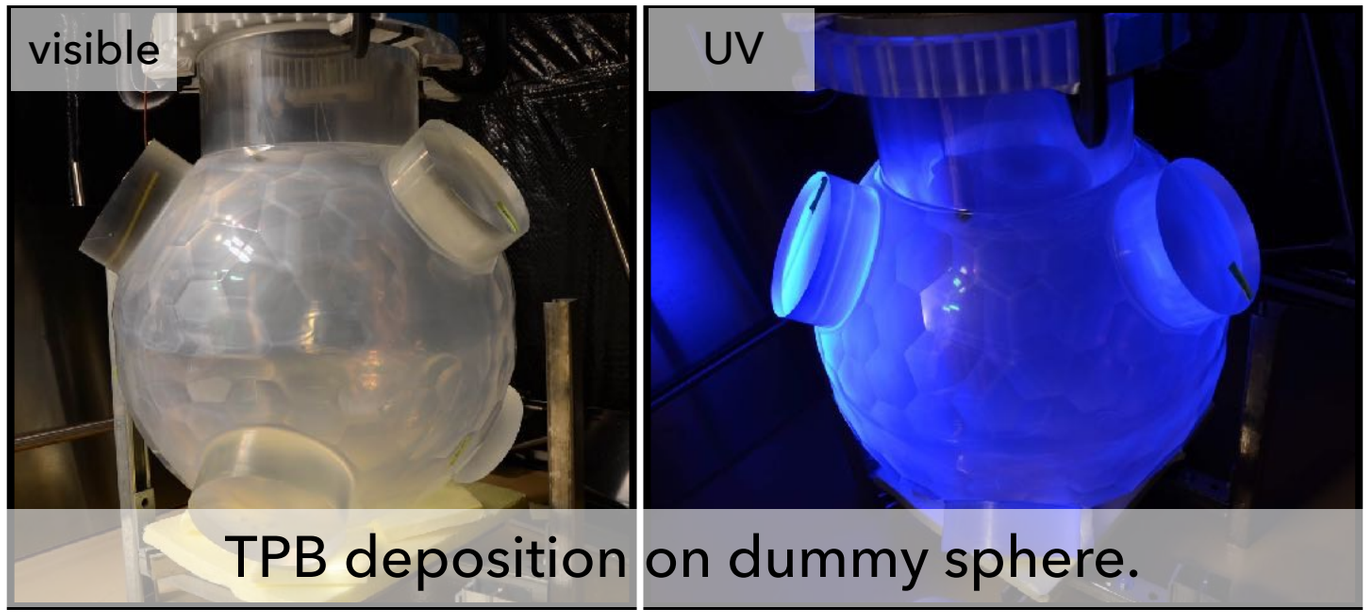
[1] "First results from the DEAP-3600 dark matter search with argon at SNOLAB" arXiv:1707.08042

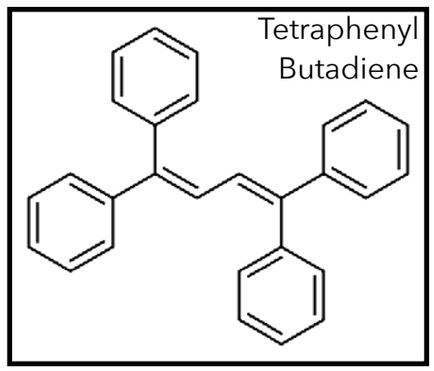
Backup


Excluded parameter space
DEAP-3600 [Ar]
CRESST III [CaWO]
LUX (2016) [Xe]
Xenon 1T [Xe]
LZ [Xe]
DarkSide 20k [Ar]
100T Ar project [Ar]
coherent neutrino scattering background
WIMP-nucleon interaction cross section (cm^2)
WIMP mass (GeV/c^2)
1e-39
1e-40
1e-41
1e-42
1e-43
1e-44
1e-45
1e-46
1e-47
1e-48
1e-49
1e-50
1
10
100
1000
10000

A coating of TPB makes the LAr scintillation visible.



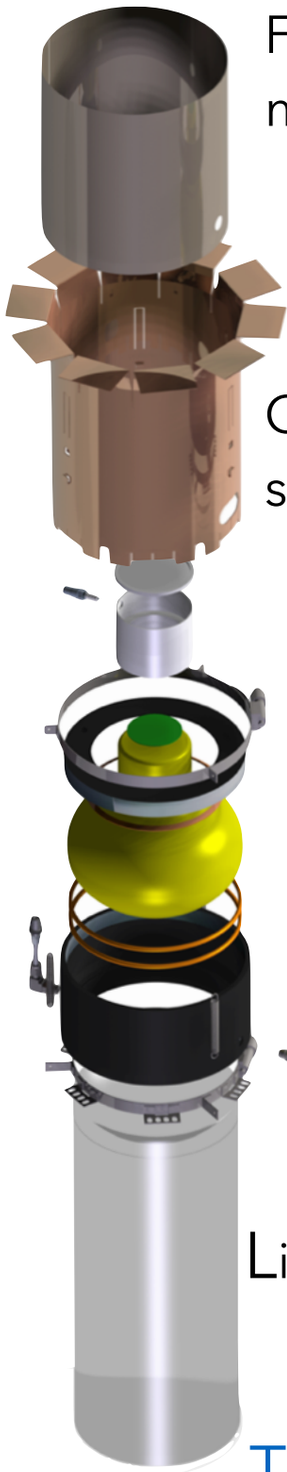


128 nm → 

→ 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

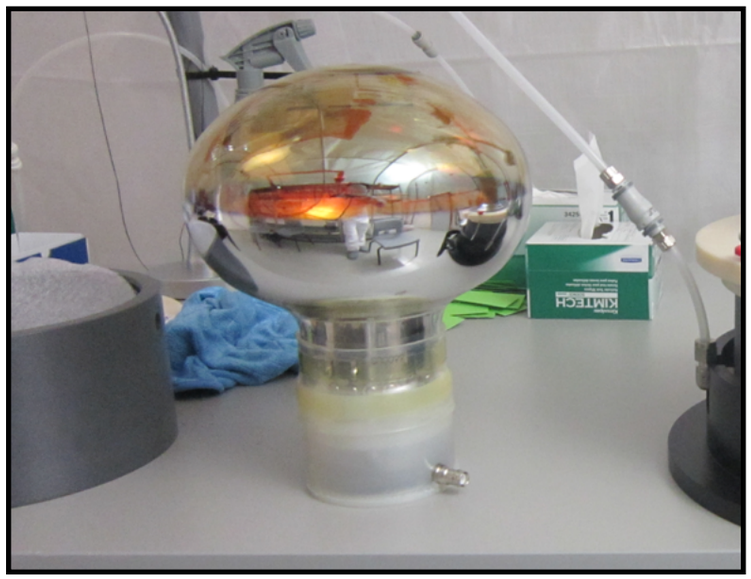
Mount

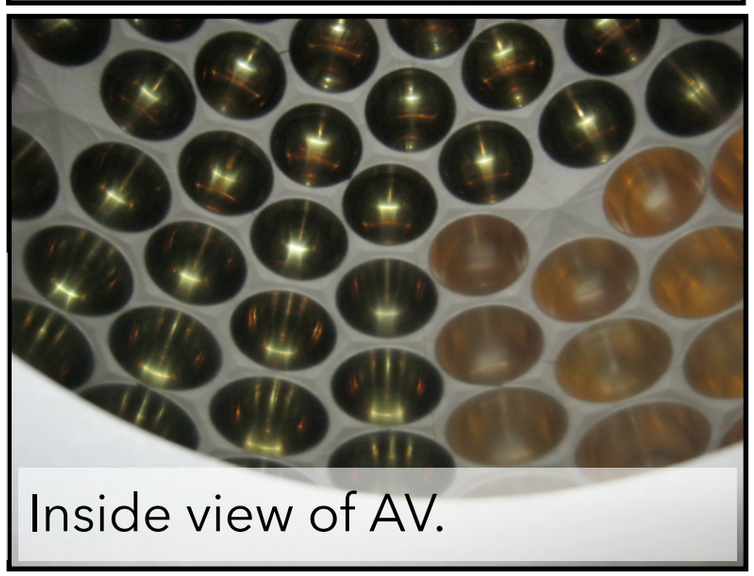
LightGuide

T ~ -184 C

255 Hamamatsu 5912 PMTs, oil coupled to LG faces. 71% coverage.

PMT being installed on LG.



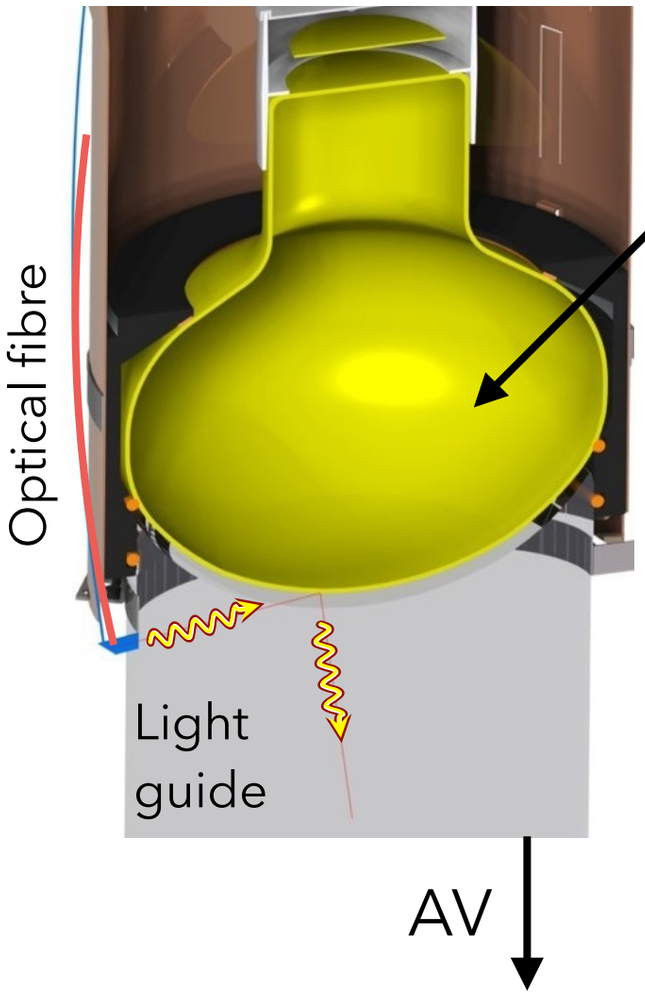


Inside view of AV.

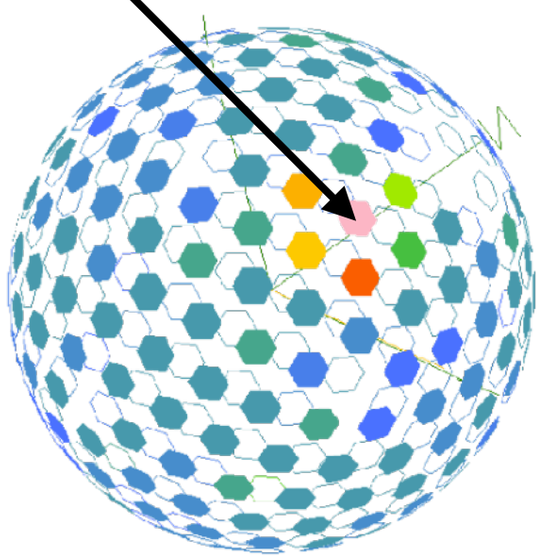
LG face
Fillerblocks
Copper short
PMT base

Optical calibration sources

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



Fibre PMT



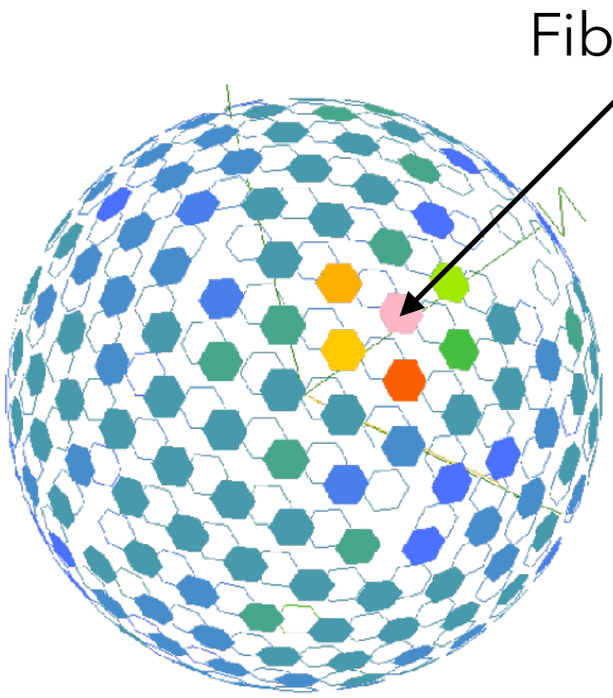
DEAP event display.
Blue: low charge,
red: higher charge,
purple: highest charge.

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,
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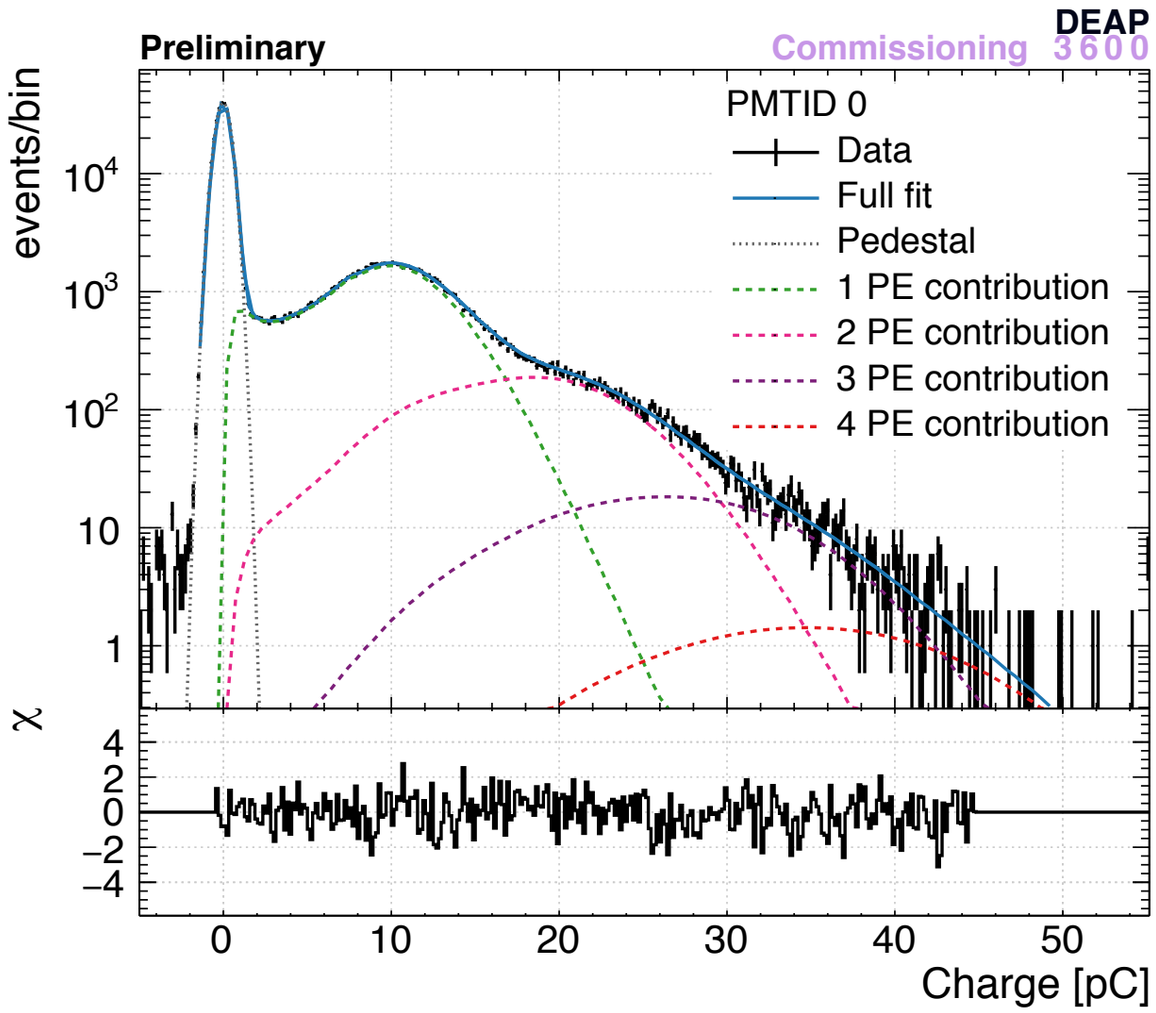
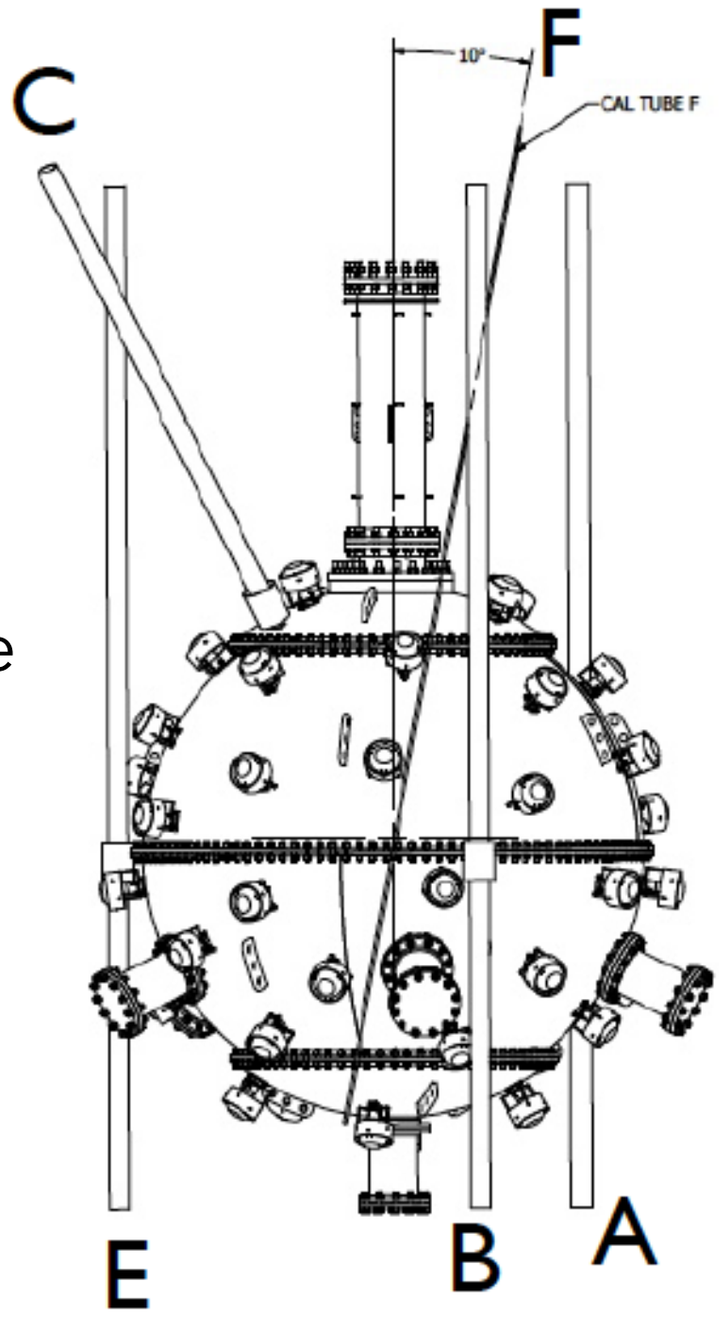
E.g. PMT gain monitoring

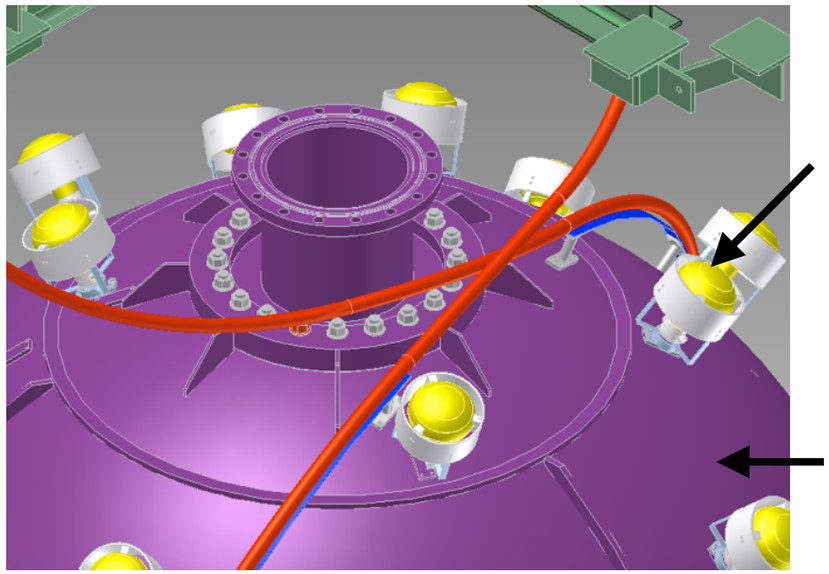


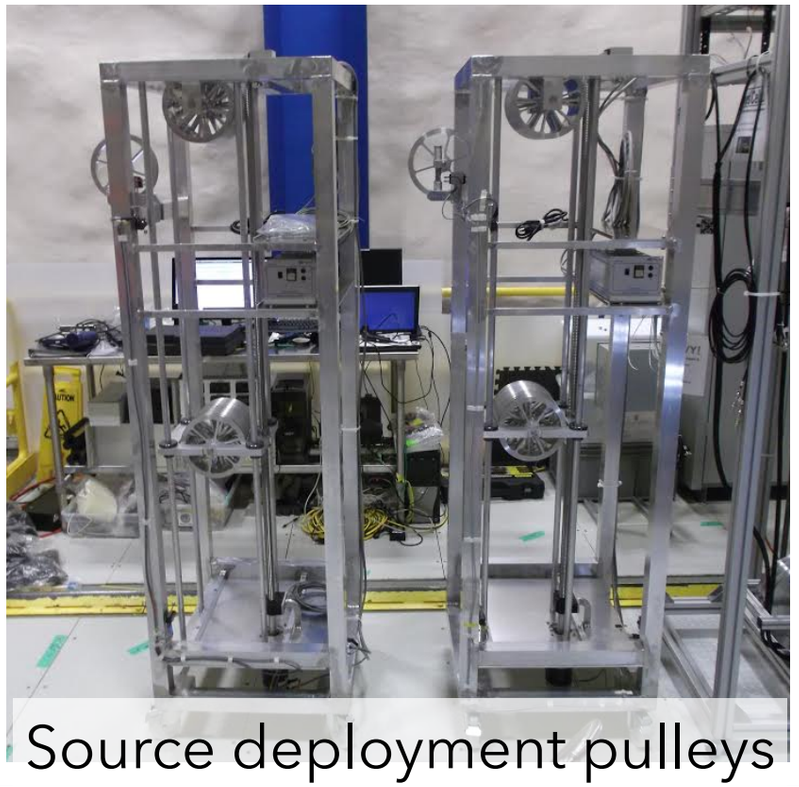
In-situ PMT characterization
arXiv:1705.10183

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

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

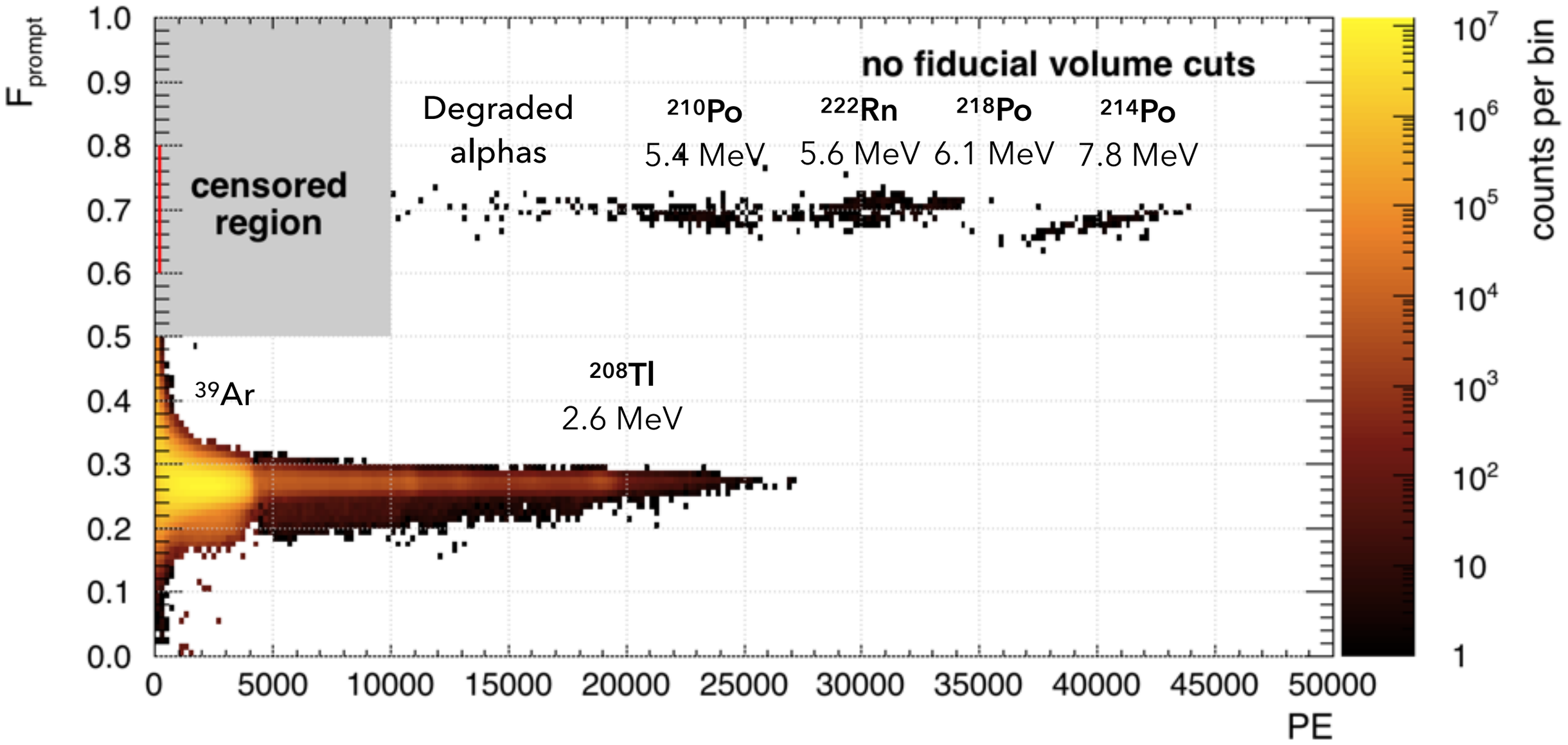






Source deployment pulleys

Electron and nuclear recoil backgrounds.



Background rates

Rn-222 in the bulk target material (measured)

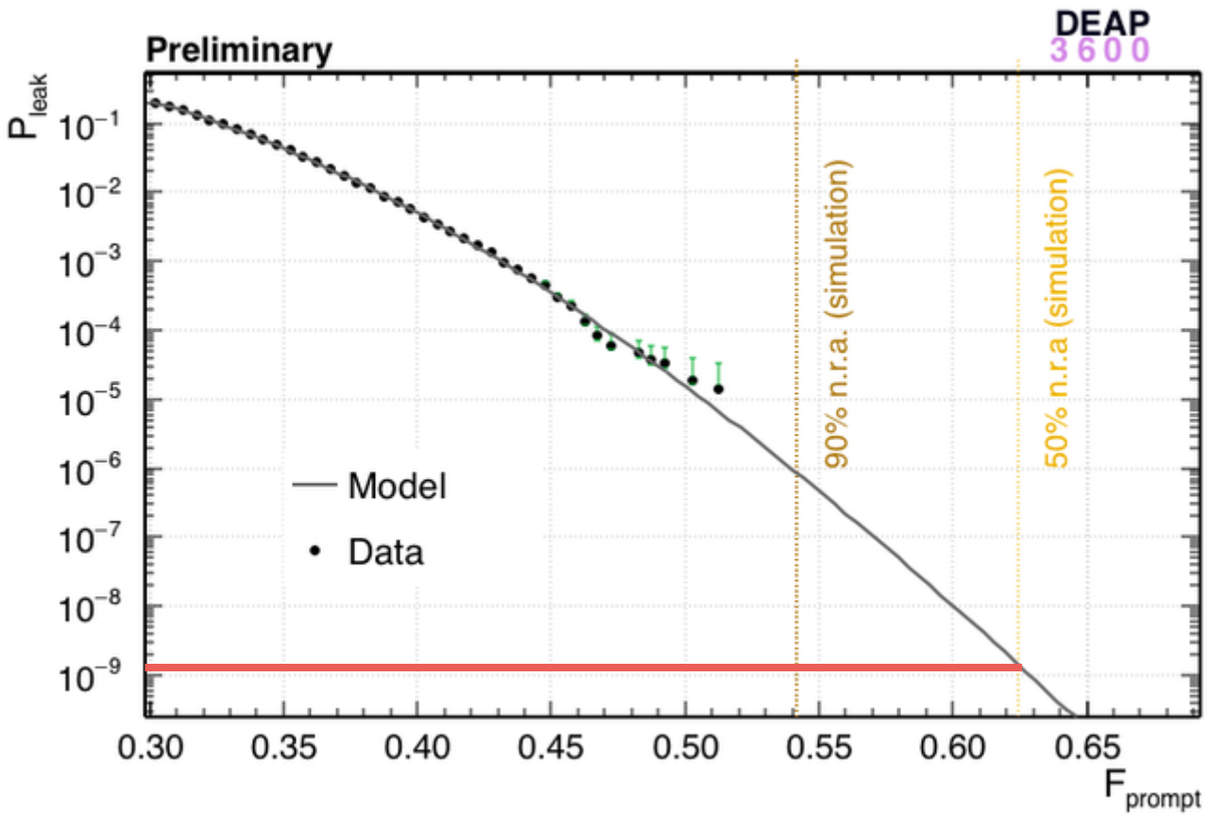
	^{222}Rn activity
DEAP-3600	~0.2 μBq/kg
PandaX-II	6.6 μBq/kg
LUX	66 μHz/kg
XENON1T	10 μBq/kg

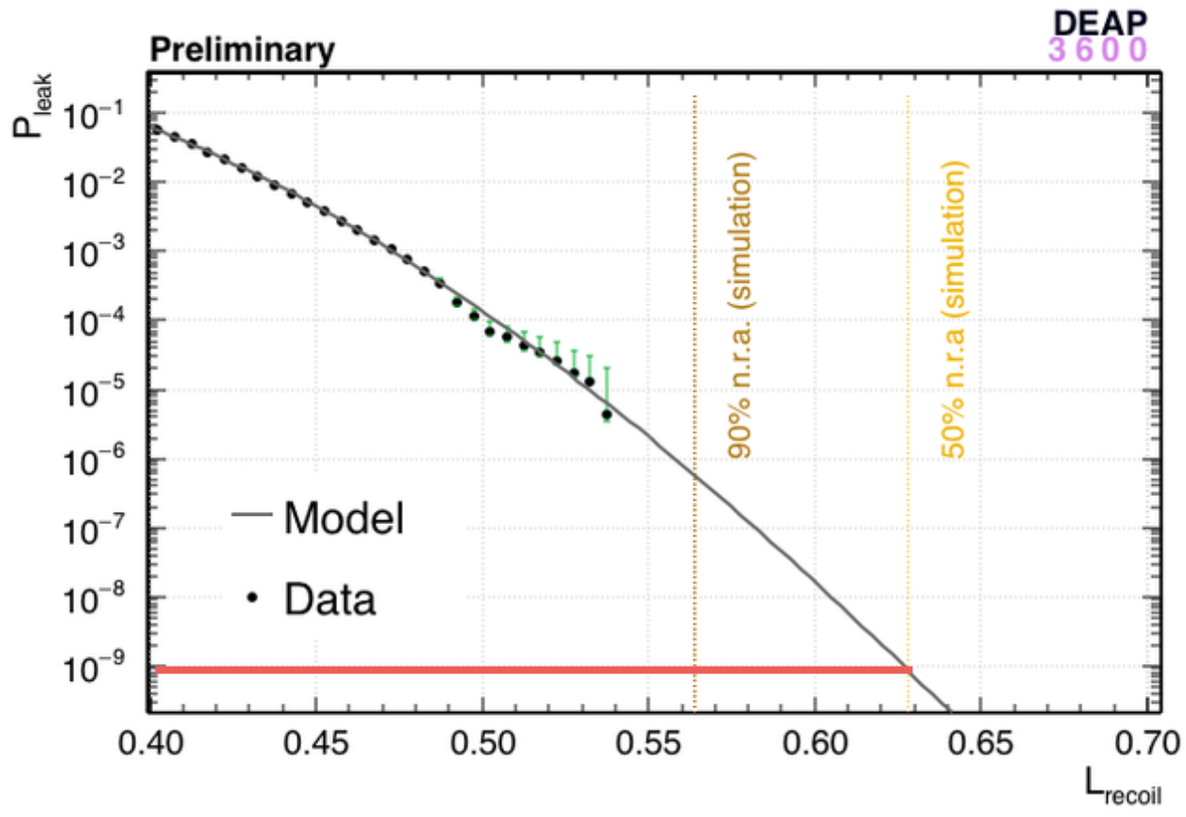
Dominant activities in DEAP-3600 from screening or literature

	Location	Aproximate activity [Bq]
39Ar	LAr	3300
232Th	PMT glass	26
238U	PMT glass	169
40K	PMT glass	100

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

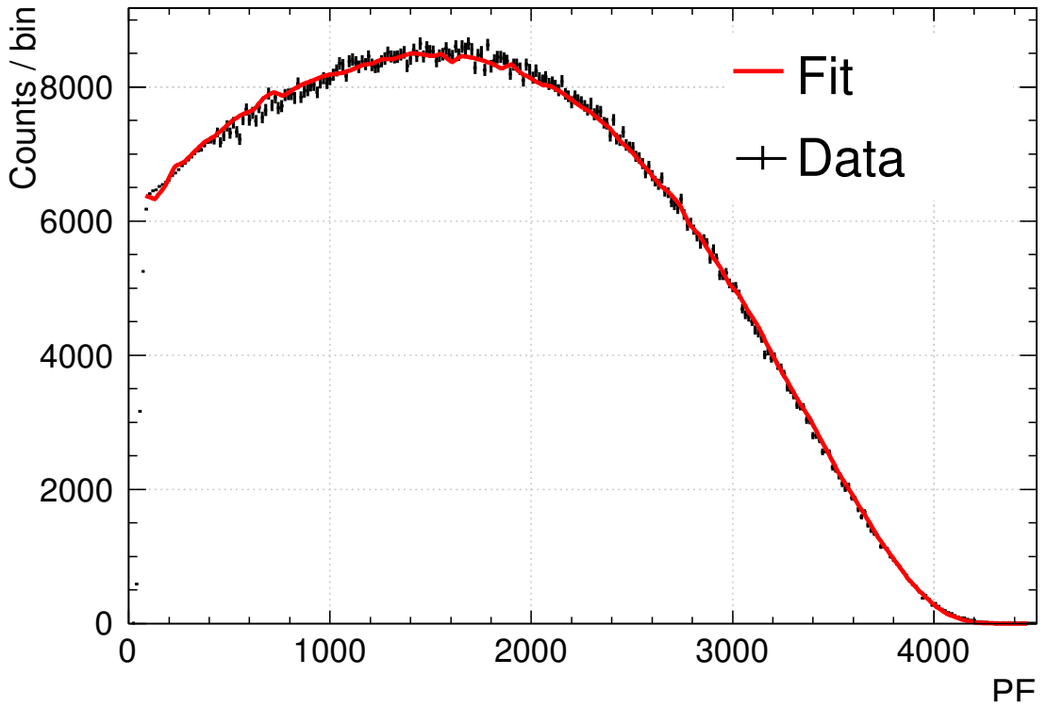
Improving the PSD parameter



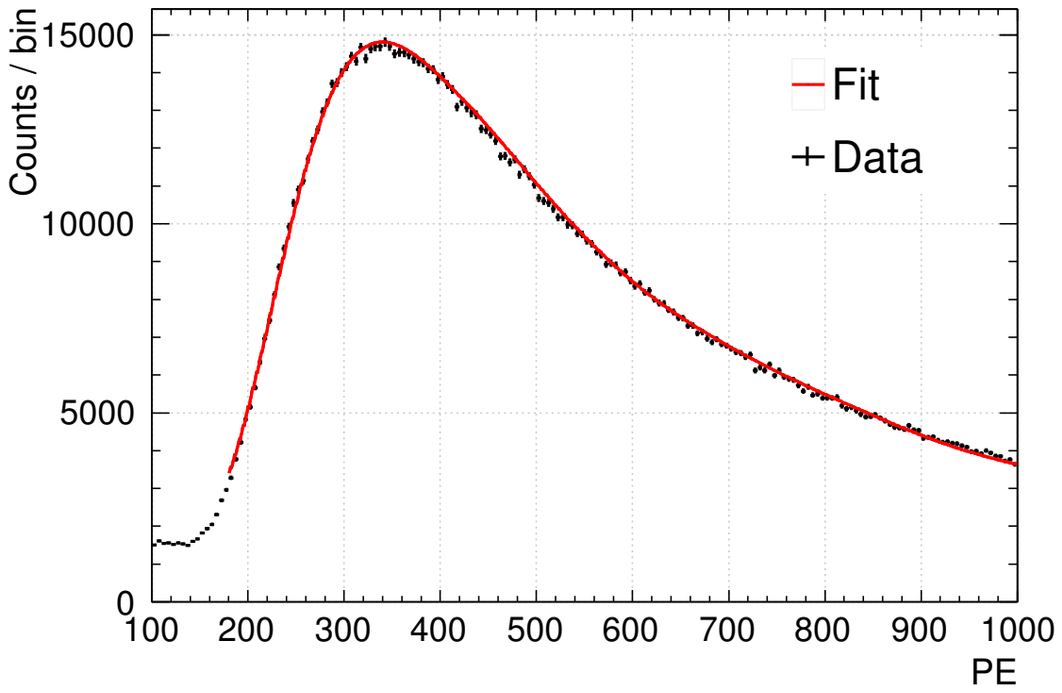


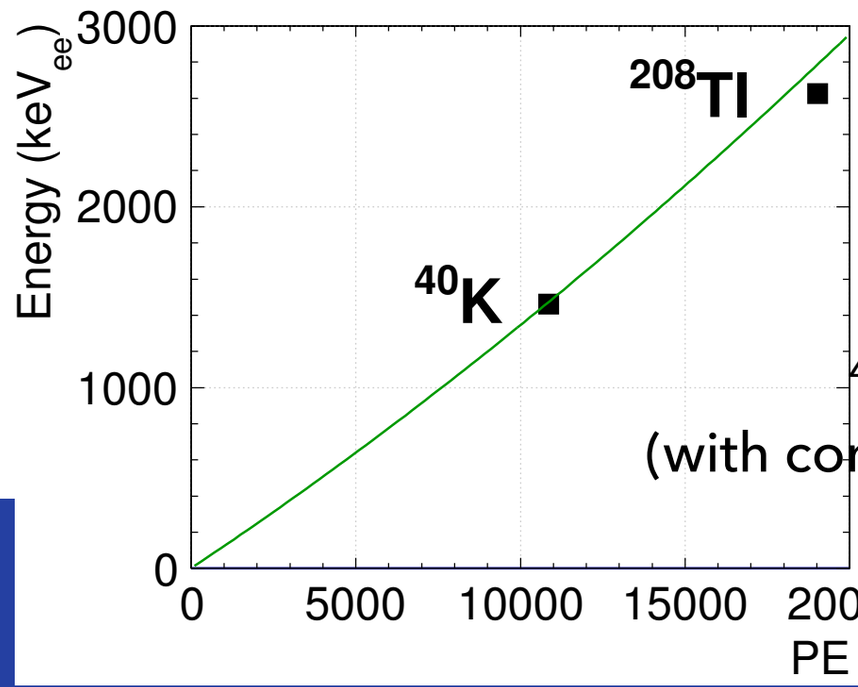
Energy calibration from intrinsic and external beta/ gamma sources

^{39}Ar beta spectrum (intrinsic)



^{22}Na (external)

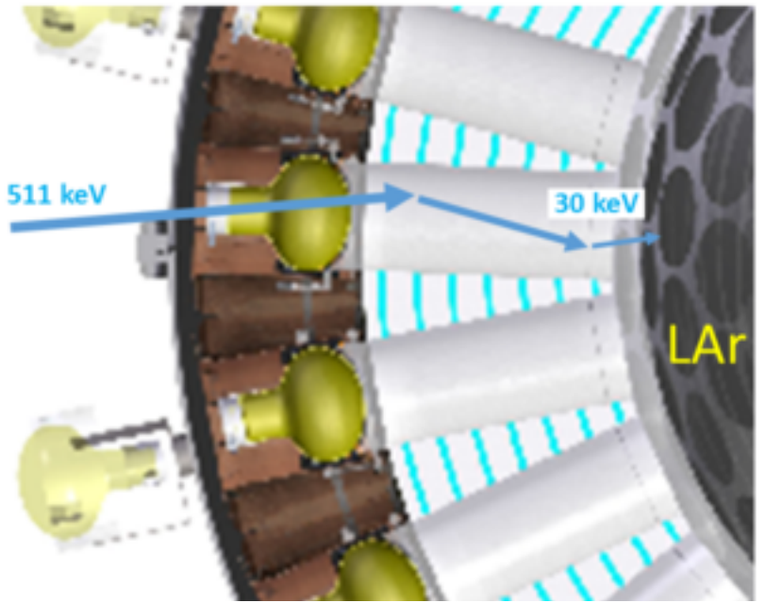


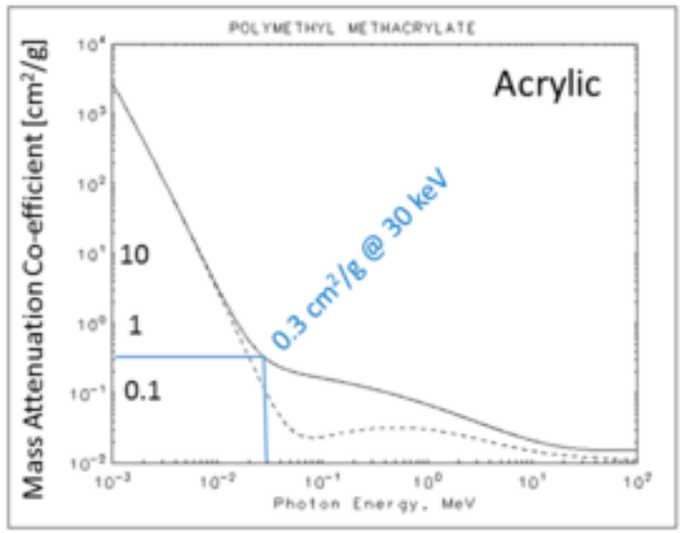


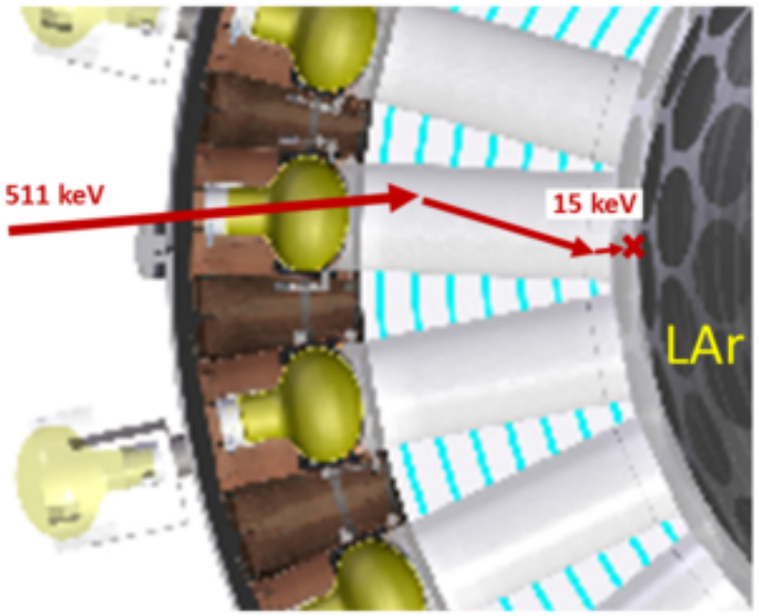
^{40}K and ^{208}Tl (intrinsic)

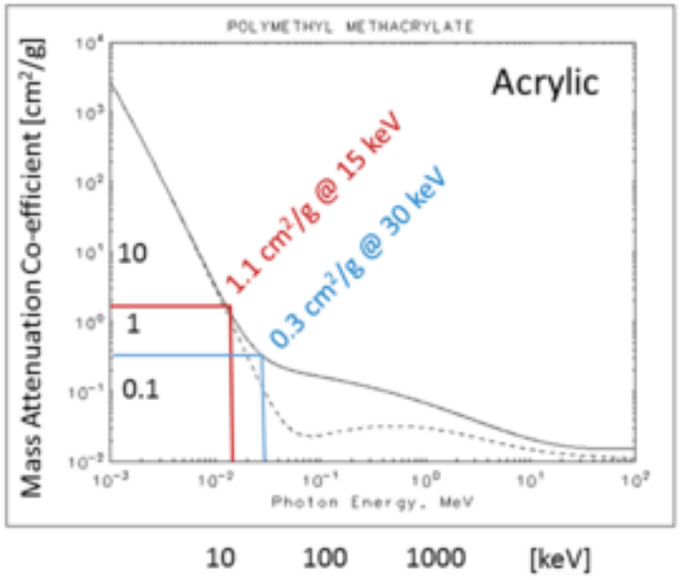
(with combined fit from ^{39}Ar and ^{22}Na)

The Na-22 feature





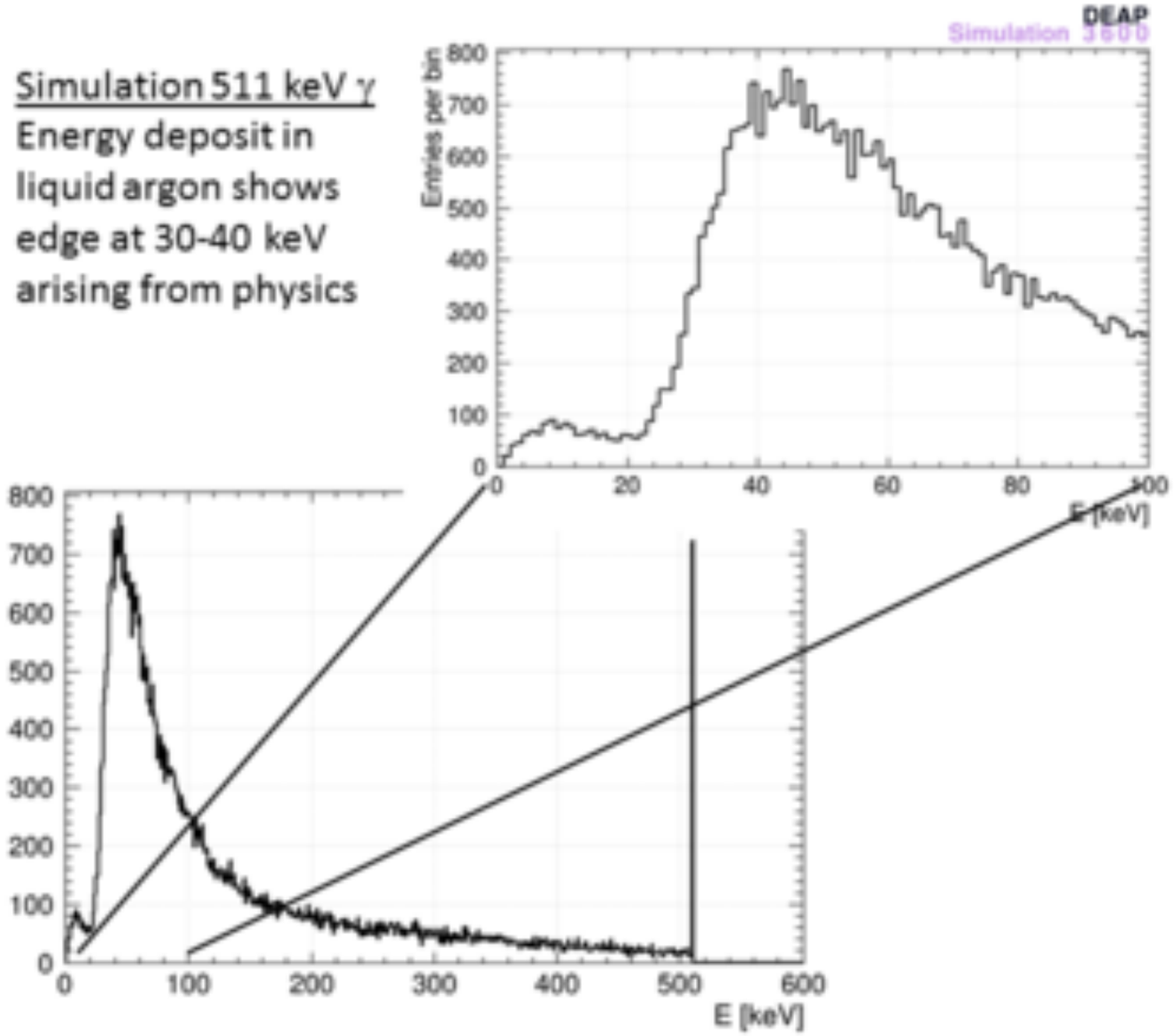


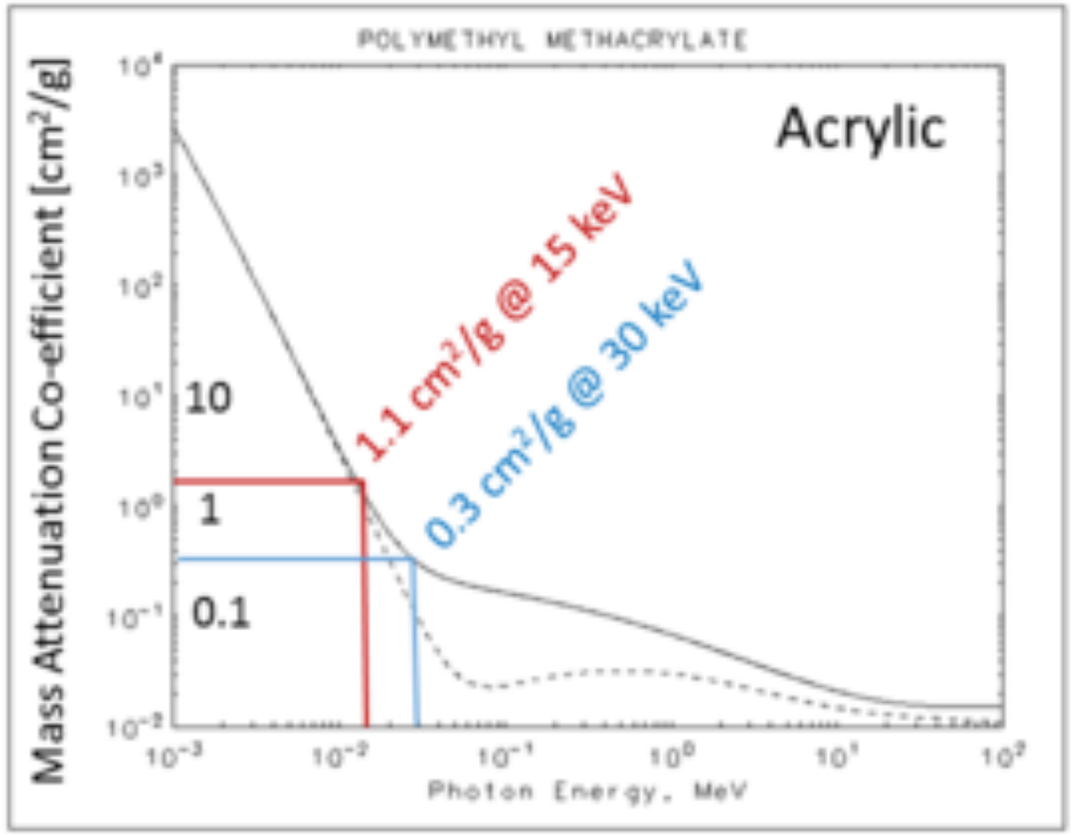


Plot and data from NIST.gov X-ray mass attenuation coefficients

The Na-22 feature

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





10 100 1000 [keV]

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