Dark Matter Search with Liquid Argon (Present and near future): DEAP-3600 and DarkSide 20k

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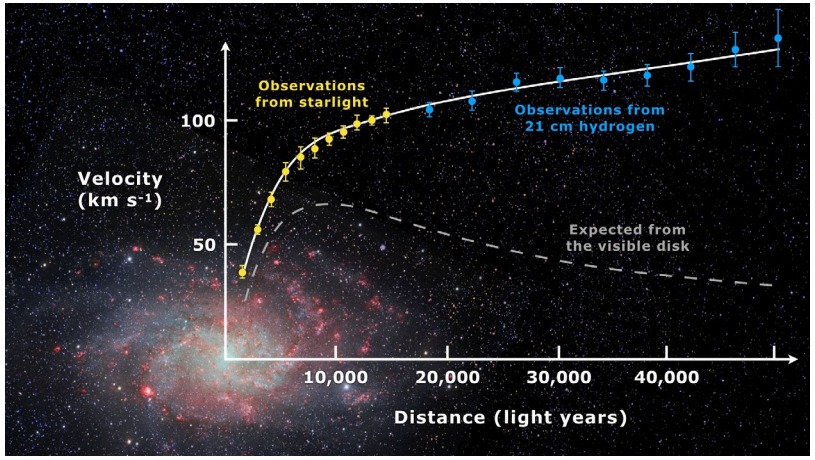
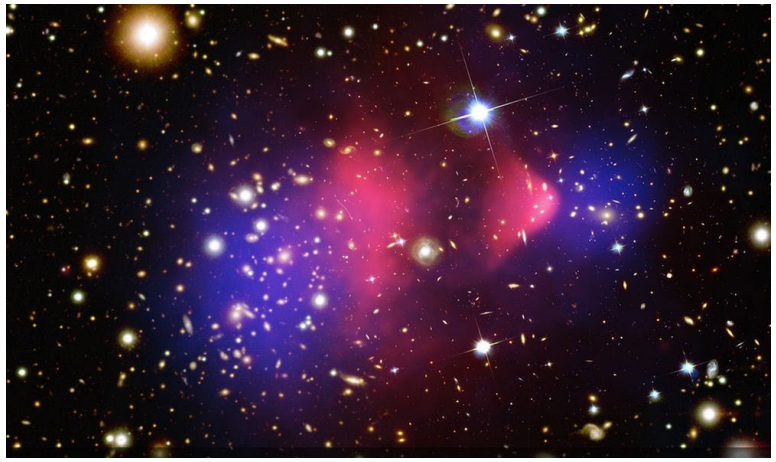
On behalf of the **Global Argon Dark Matter Collaboration**

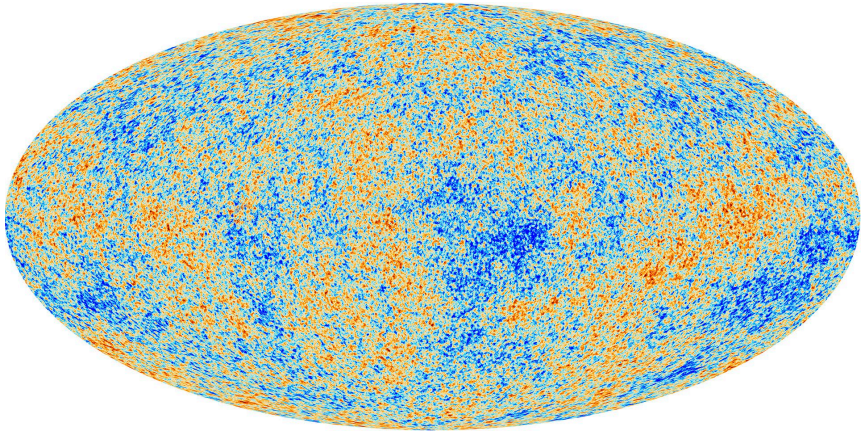
Converging evidences towards dark matter



Rotation curves of spiral galaxy (Wikipedia)

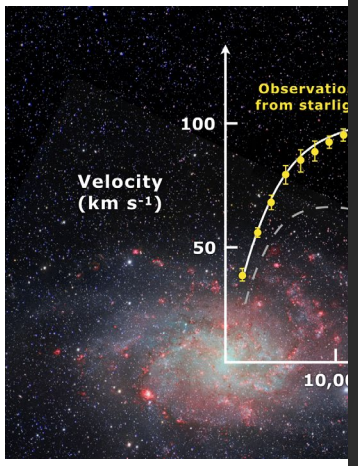


Bullet cluster (Chandra X-Ray Observatory)

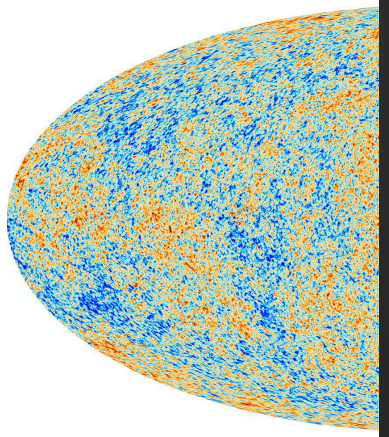


Cosmic Microwave Background (ESA–Planck)

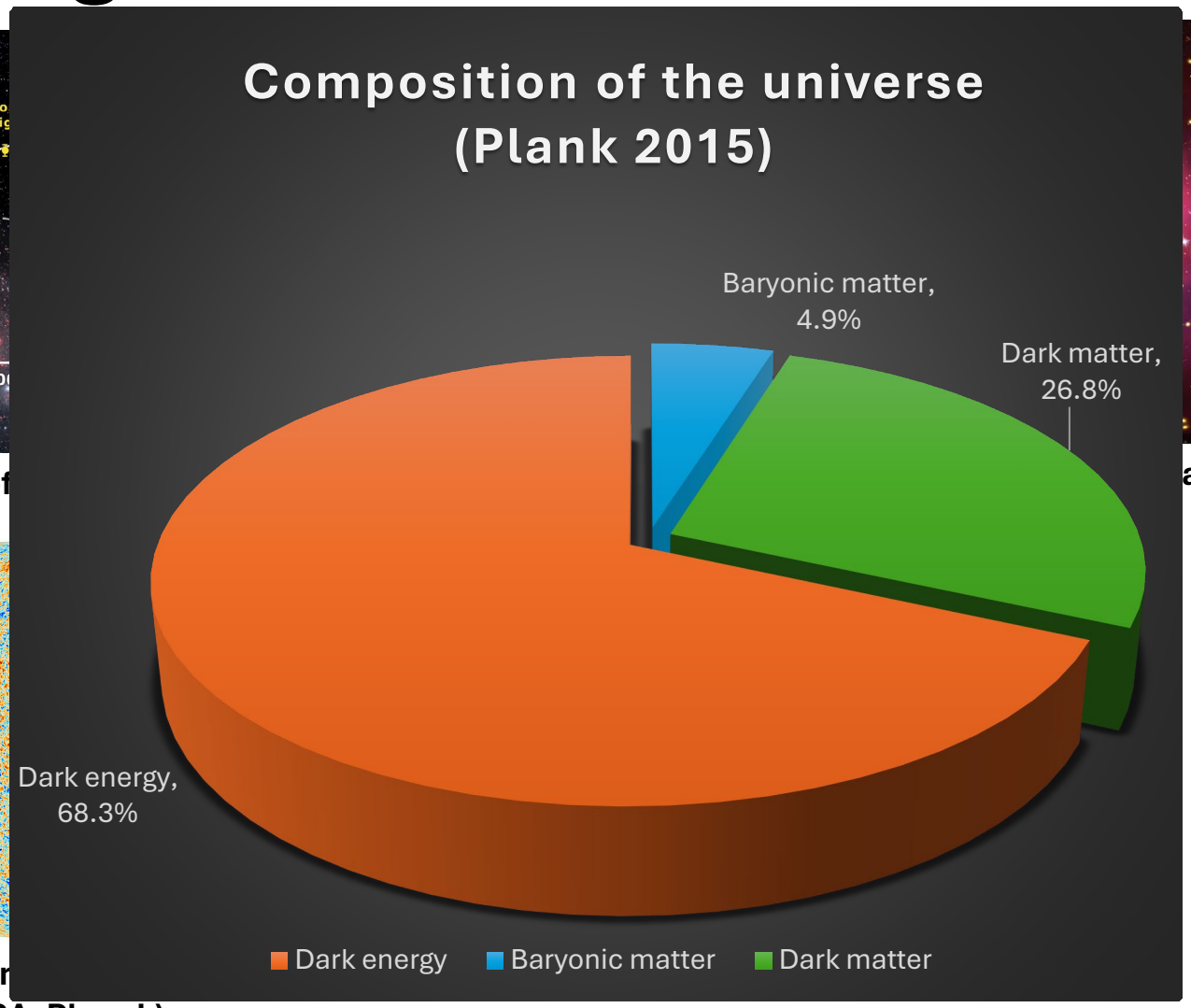
Converging evidences towards dark matter

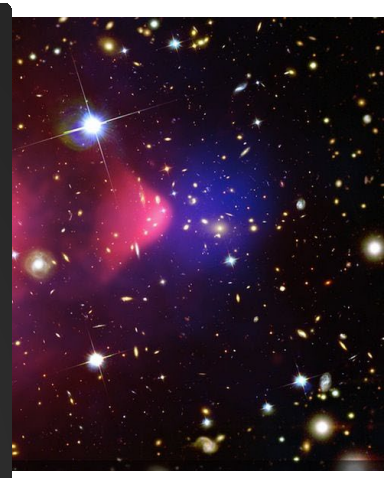


Rotation curves of



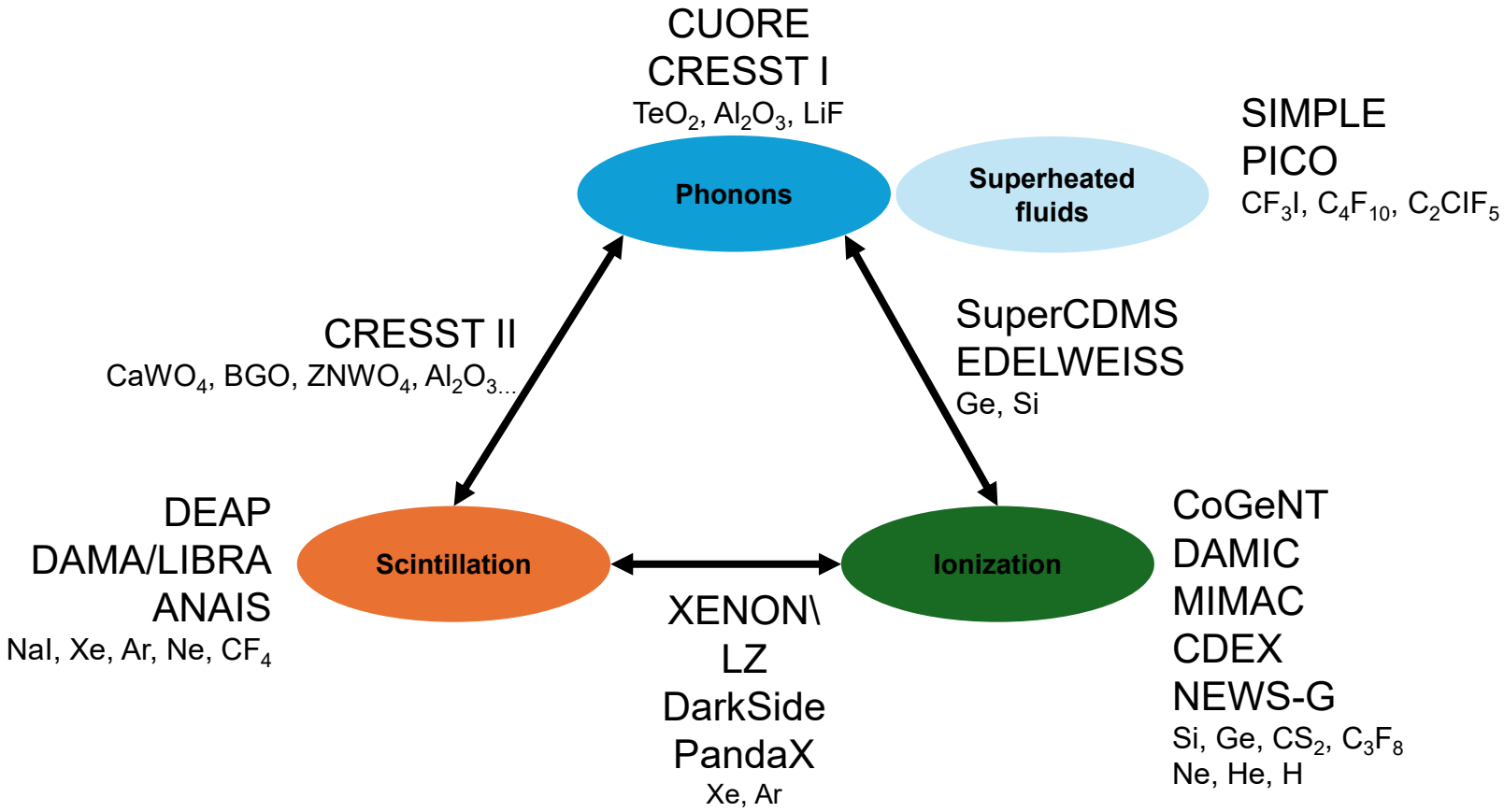
Cosmic Micr
(ESA–Planck)





a X-Ray Observatory)

Weakly Interacting Massive Particles (WIMP) Direct detection techniques

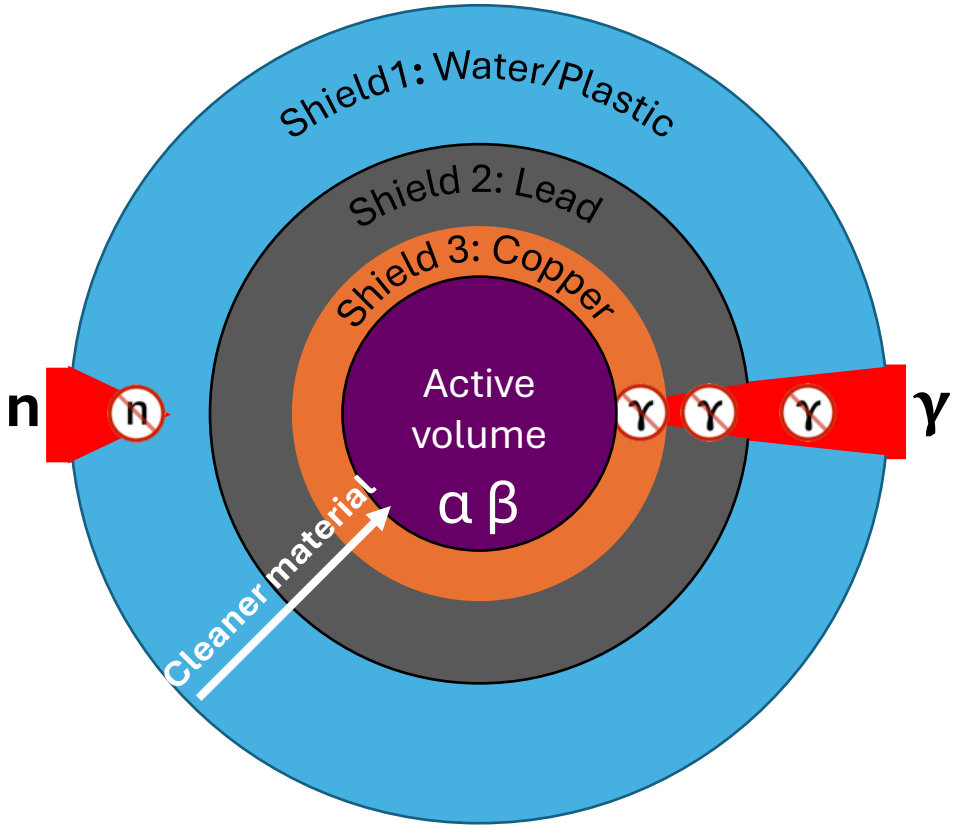


Detection of a nuclear recoil (or possibly an electronic recoil)

Depending on material, nuclear spin dependent interaction

Background suppression: onion layers

Passive shielding (external Background)



Discrimination (Internal background)

- Active veto
- Energy
- Position
- Pulse shape
- …

Neutrons mimicking WIMP signal
=> All sources need to be removed or shielded

Argon is a good dark matter target material

- Noble gas are easy to purify
- Scintillation/Ionization properties allow discrimination of nuclear recoils from electromagnetic background.
- Cheapest of the noble gas
- Good scintillator, transparent to its scintillation light

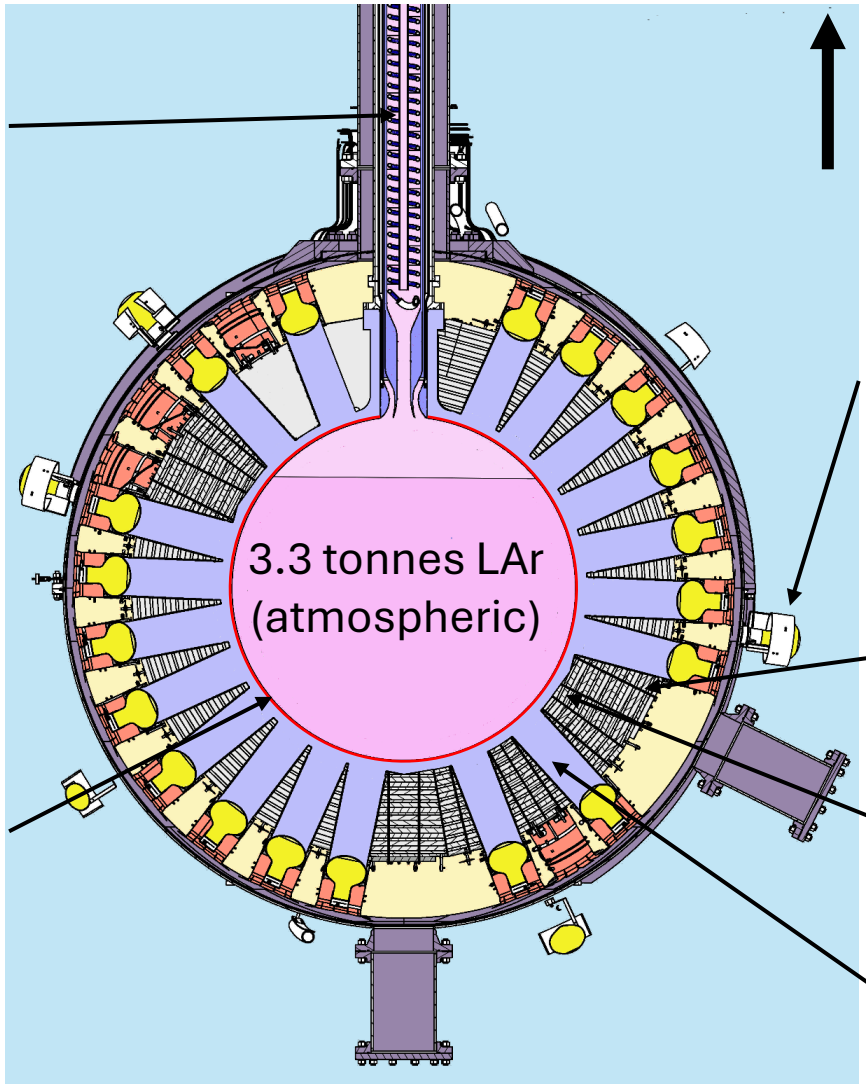
} Ideal for large detectors

DEAP-3600: Single phase dark matter detector

Cooling coil
(Liquid Nitrogen circulation)

255 8” HQE photomultipliers
(75% coverage)

Wavelength shifter:
Tetraphenylbutadiene



2070m underground (~6000 m.w.e.)
➔ Muon flux 0.27 μ/m^2/day

48 outward-looking
8” photomultipliers
+ Ø7m x H7m water tank
➔ Muon veto, neutron/gamma shield

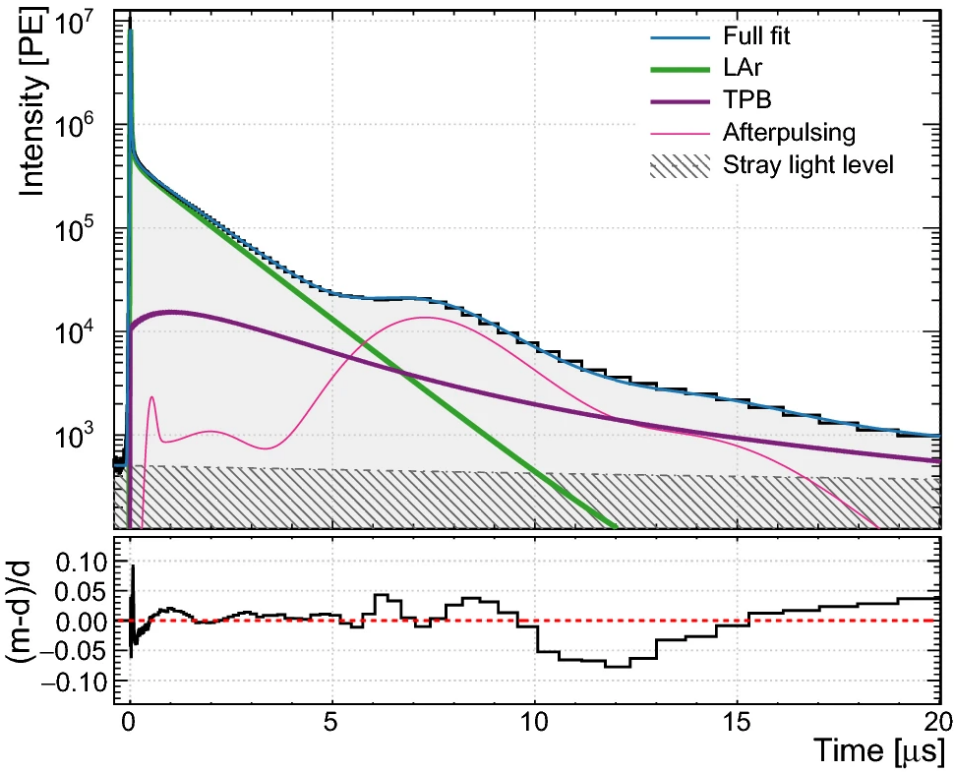
Filler blocks:
HDPE and Styrofoam

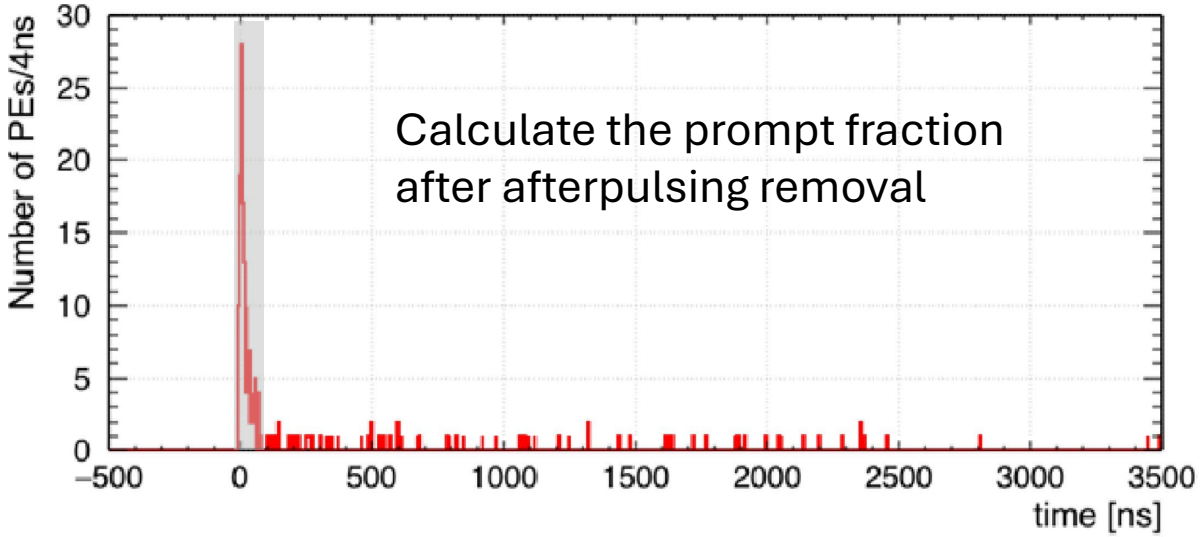
Ultra-low background
acrylic vessel

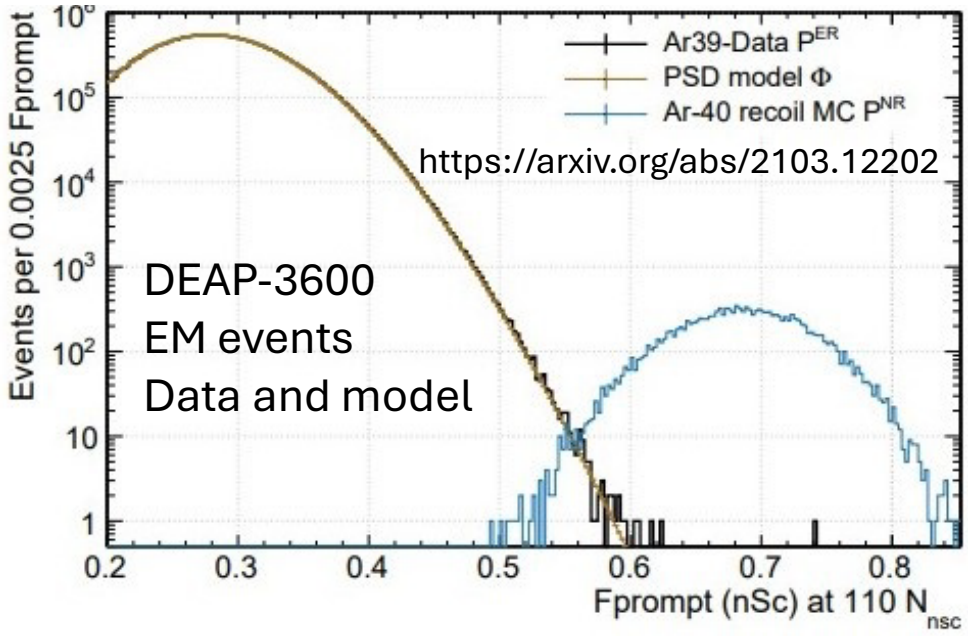
0.5m long acrylic
Light-guides

Neutron
shielding

Pulse-Shape Discrimination in Liquid Argon Works!





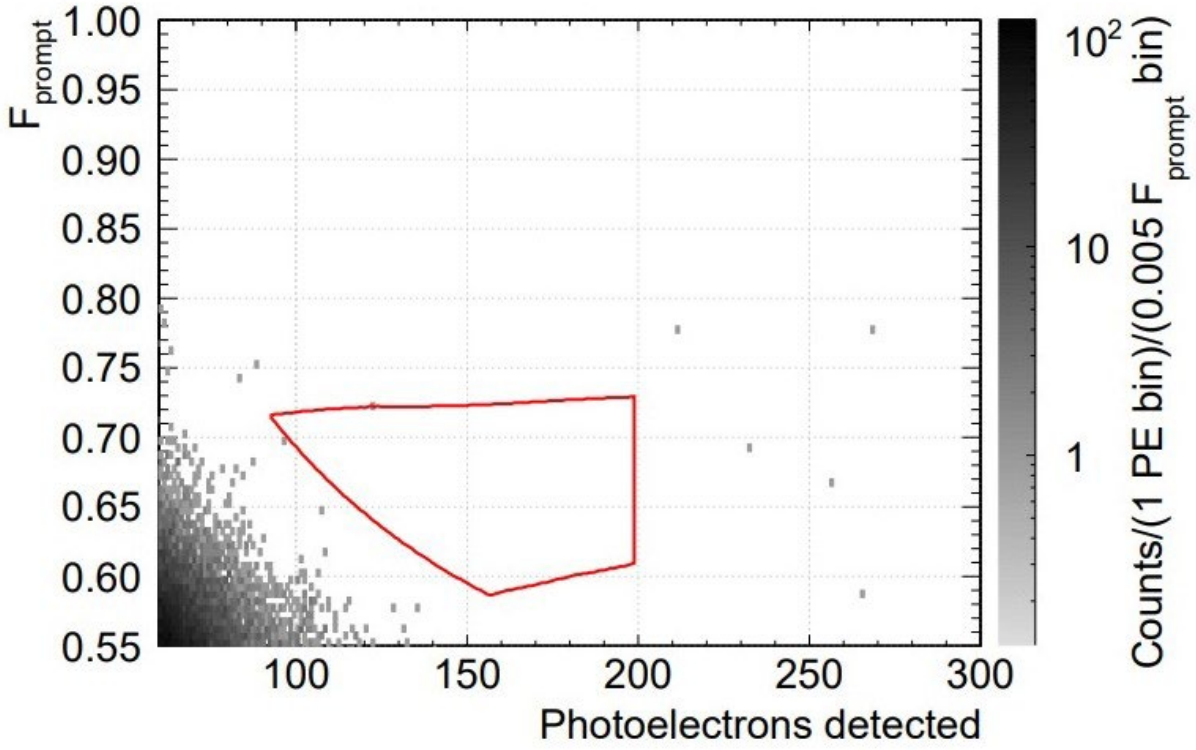


Liquid argon pulse shapes, including instrumental effects such as PMT afterpulsing and stray light are well understood.

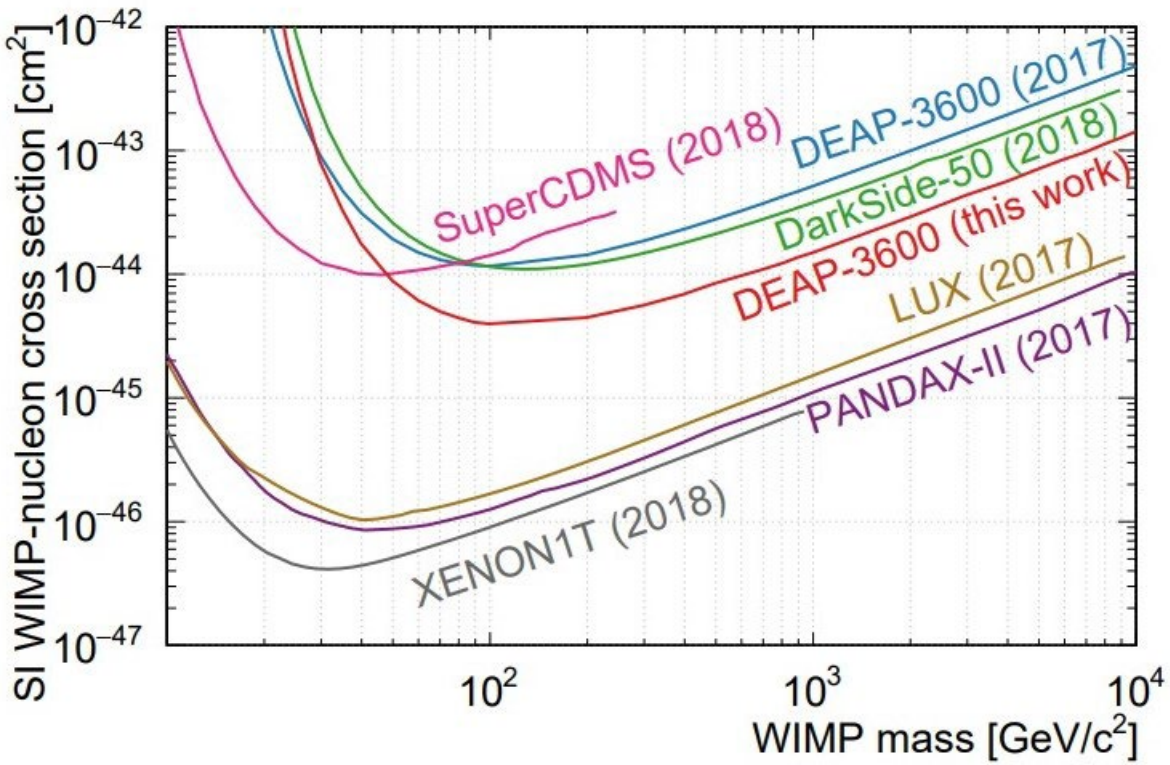
Eur. Phys. J. C 80, 303 (2020)
http://arxiv.org/abs/2001.09855

DEAP-3600 set the most stringent limit on WIMP-nucleon coupling using Argon

Zero events in ROI (with two near misses)



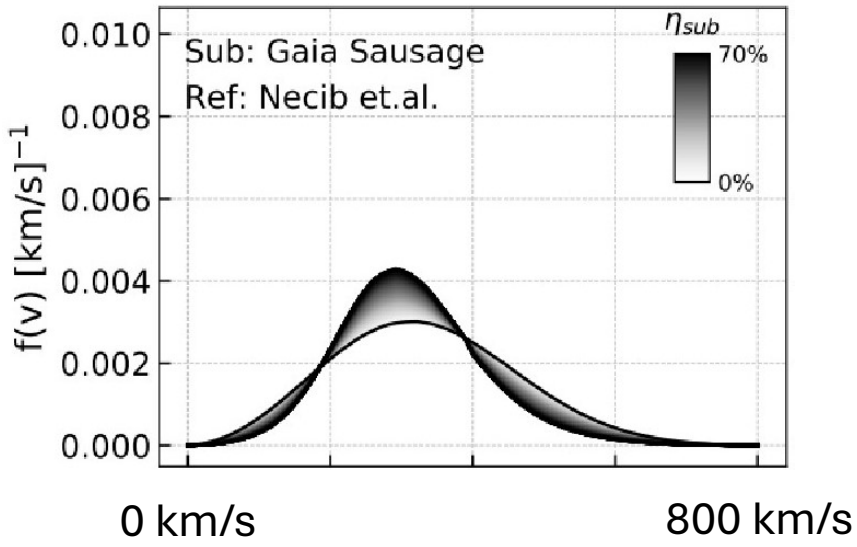
Phys. Rev. D 100, 022004 (2019)
https://arxiv.org/abs/1902.04048



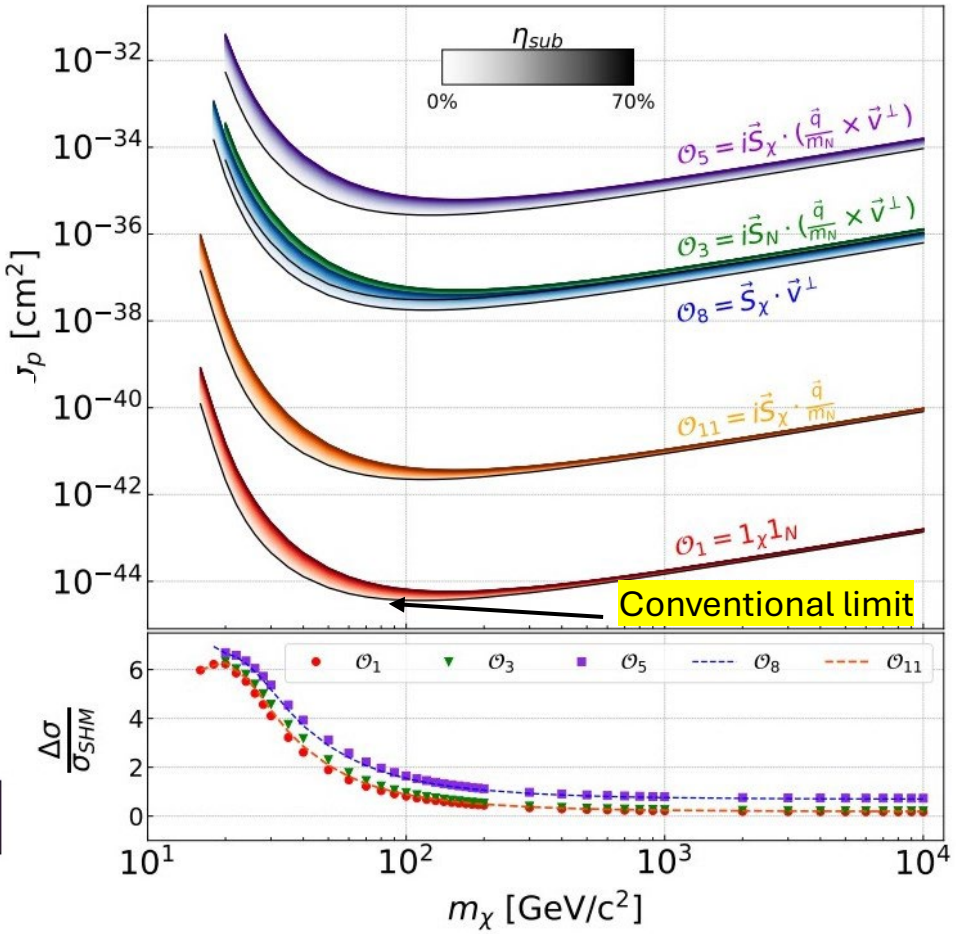
DEAP-3600 expanded that analysis taking into account Effective Field Theory and Galactic Models

Phys. Rev. D 102, 082001 (2020)
http://arxiv.org/abs/2005.14667

$$\frac{dR}{dE_R} = \frac{\rho_T}{m_T}\frac{\rho_\chi}{m_\chi}\varepsilon(E_R)\int_{v_{\min}}^{\infty} v f_\chi^{\oplus}(\vec{v})\frac{d\sigma}{dE_R}d^3\vec{v}$$



$$\mathcal{O}_1 = 1_\chi 1_N$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp\right)$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp\right)$$
$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}_\perp$$
$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_{12} = \vec{v}_\perp \cdot (\vec{S}_\chi \times \vec{S}_N)$$
$$\mathcal{O}_{15} = -\left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left[\left(\vec{S}_N \times \vec{v}_\perp\right) \cdot \frac{\vec{q}}{m_N}\right]$$

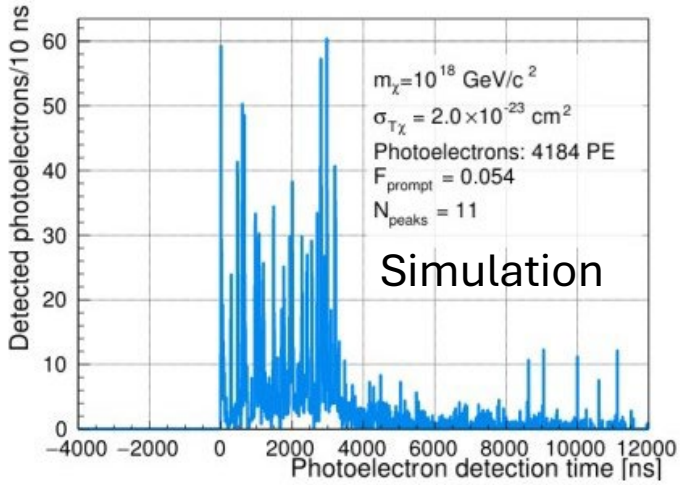


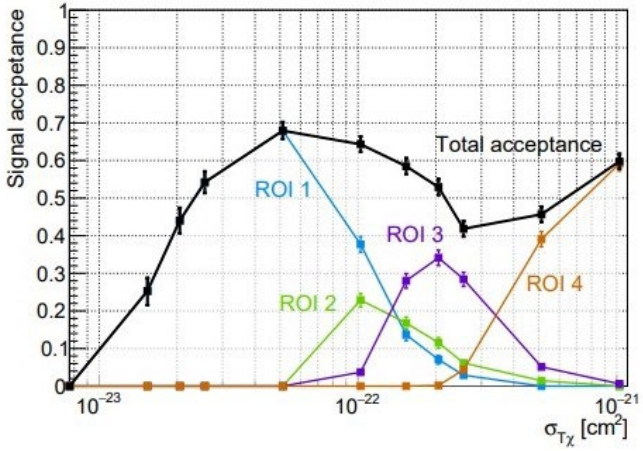
(a) *Gaia* Sausage (Necib *et al.*) [60]

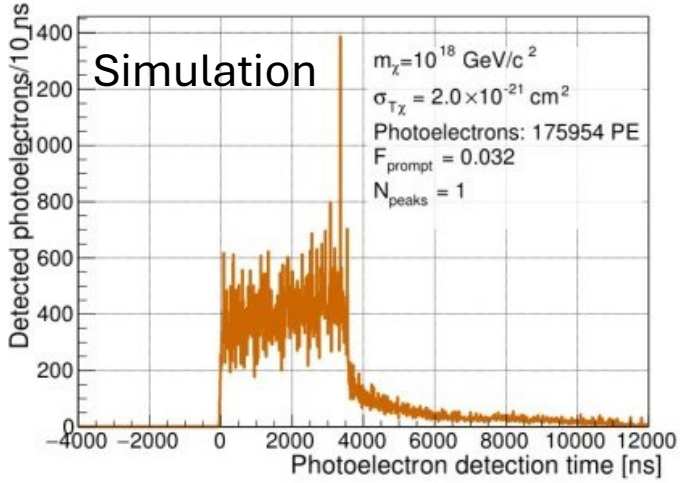
(one of 16 velocity distributions considered)

DEAP-3600 searched for Planck-scale dark matter

These interact many times traversing the detector and give large and unique signals.

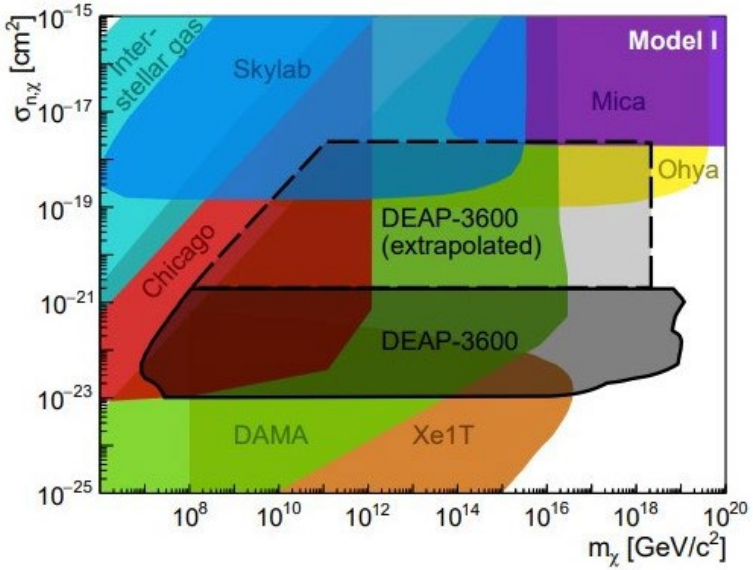


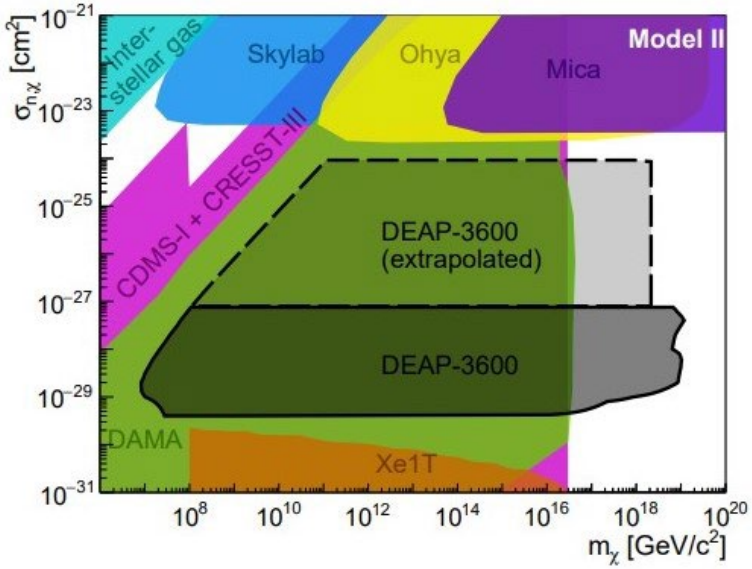




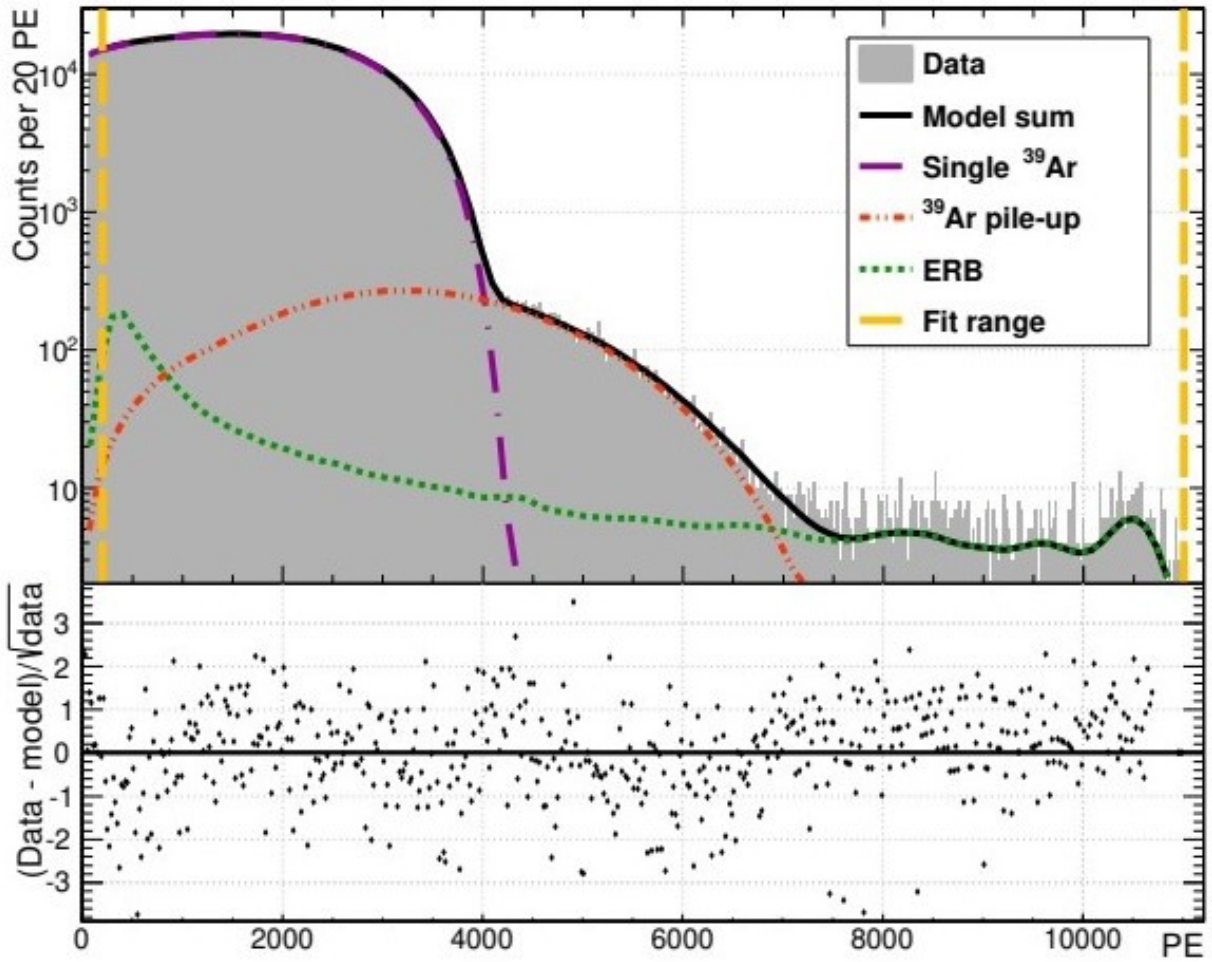
DEAP produced world-leading limits

[Phys. Rev. Lett. 128, 011801 (2022)](https://arxiv.org/abs/2108.09405)
https://arxiv.org/abs/2108.09405





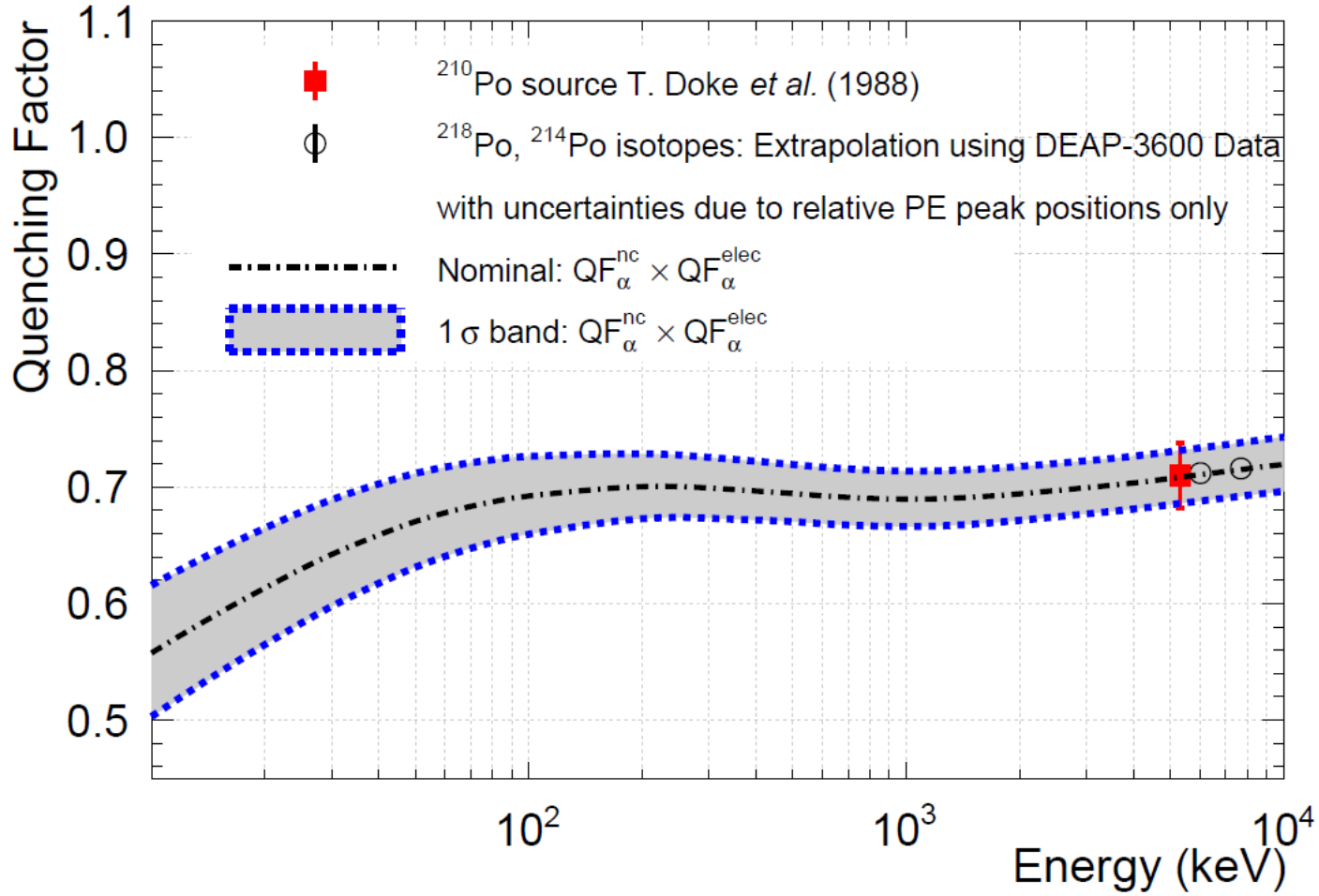
Atmospheric Argon contains 39Ar with a specific activity of 0.964 ± 0.001stat ± 0.024sys Bq/kg



- ^{39}Ar is created in the atmosphere from ^{40}Ar(n,2n)
- Half life of 268y
- Endpoint 565 ± 5 keV

Eur. Phys. J. C 83, 642 (2023)
https://arxiv.org/abs/2302.14639

Scintillation quenching factor of α particles in liquid argon critical for background understanding



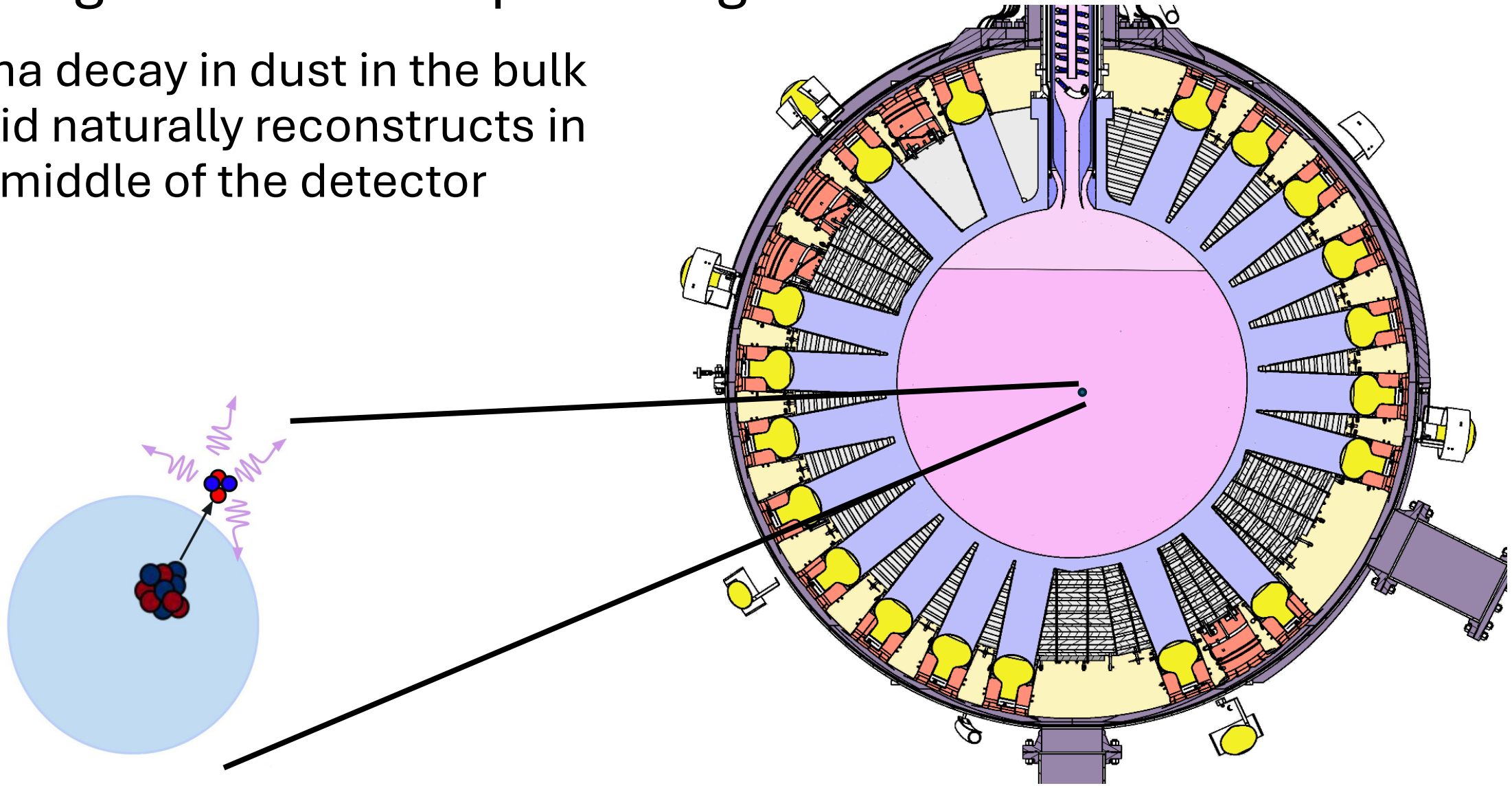
Submitted to EPJC
https://arxiv.org/abs/2406.18597

Five analyses to complete this year

- A Profile-Likelihood Ratio dark matter search using the entire second-fill data set.
- A measurement of the lifetime of ^{39}Ar.
- A search for ^{8}B solar neutrinos.
- A search for a 5.5 MeV solar axion.
- A muon-flux measurement.

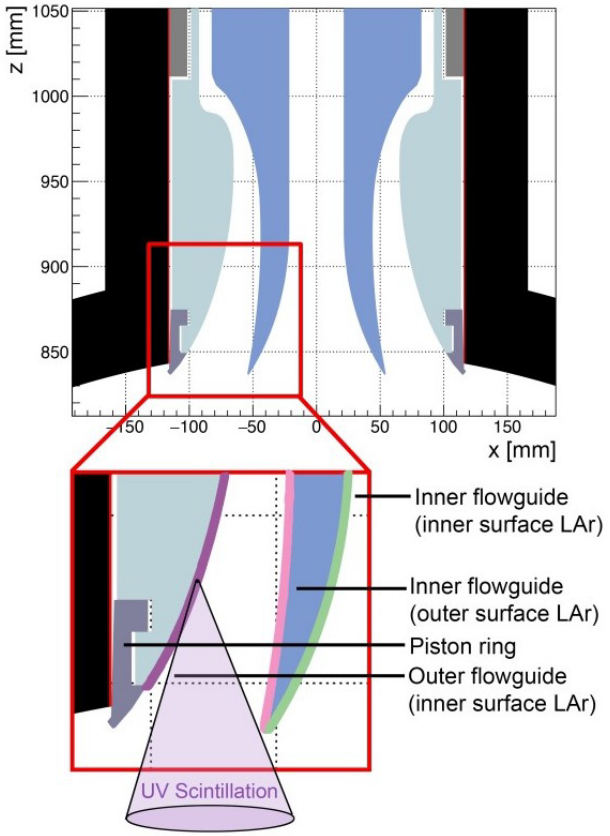
DEAP-3600 background model contains two alpha backgrounds that require mitigation

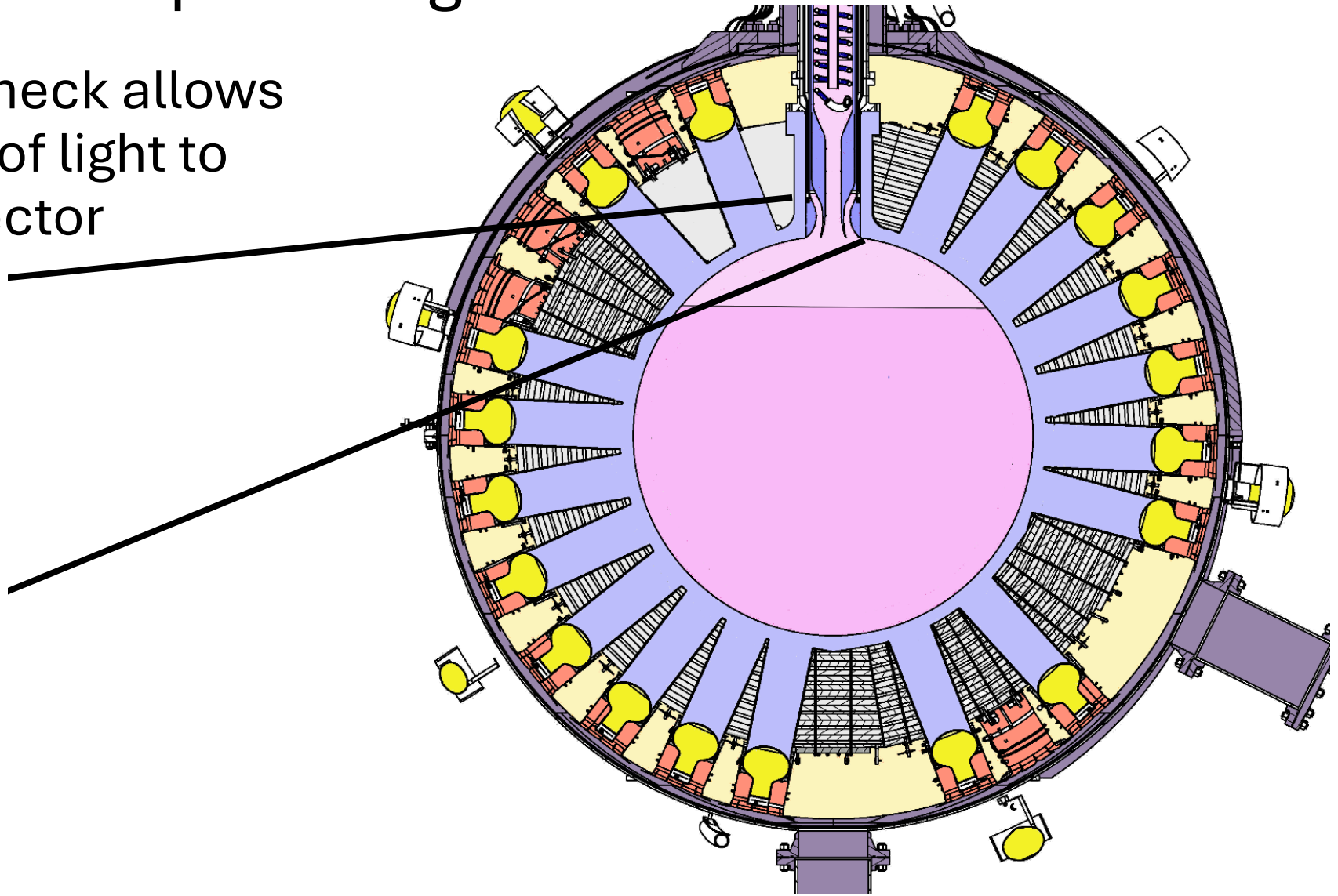
Alpha decay in dust in the bulk liquid naturally reconstructs in the middle of the detector



DEAP-3600 background model contains two alpha backgrounds that require mitigation

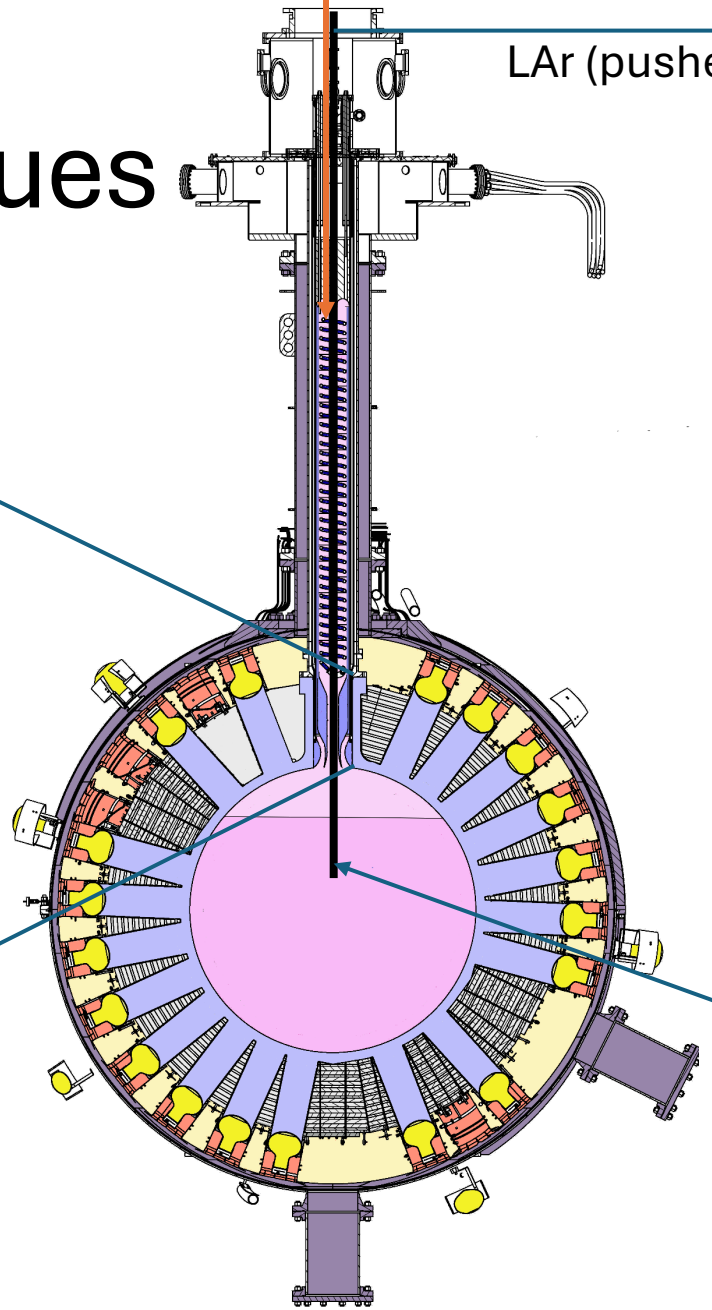
Alpha decay in the neck allows for a small fraction of light to enter the main detector

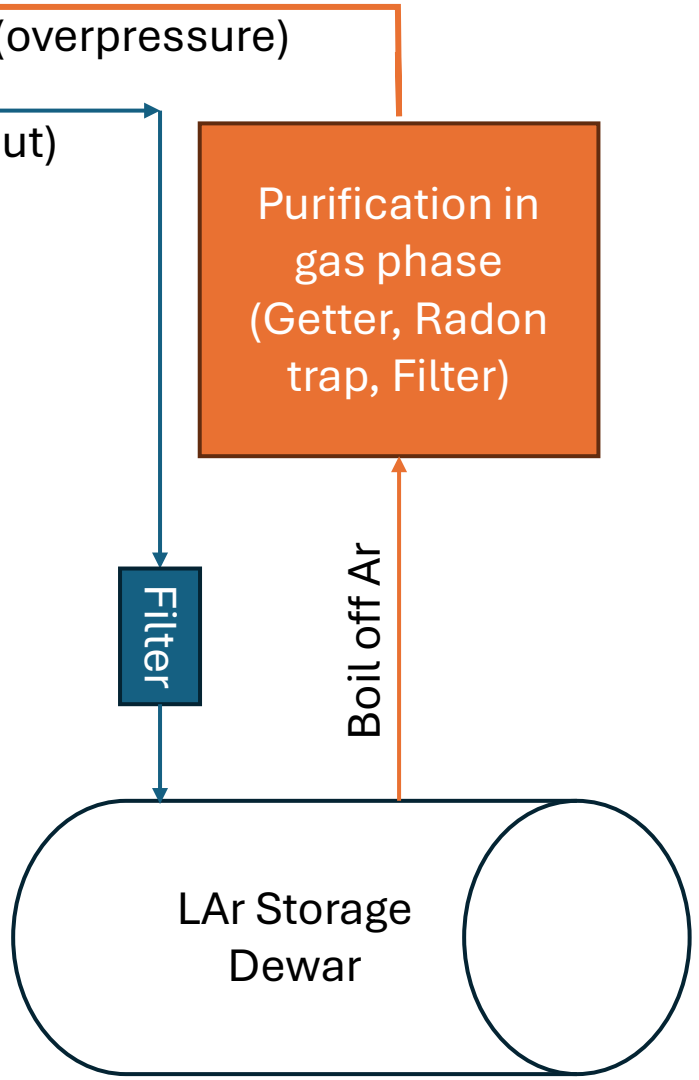




New background mitigation techniques

Replacement acrylic flowguides assembly made in Rn-clean room and coated with pyrene-doped polystyrene





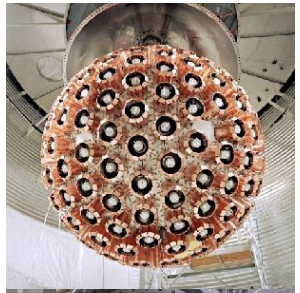
"dust pipe": LAr pushed in

Filtering of the liquid argon to remove particulates

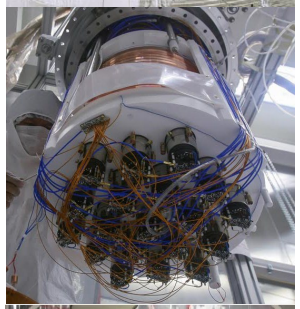
The hardware upgrades will allow us:

- to verify the DEAP background model
- to have a “zero background” data set
- to reach DEAP-3600 design sensitivity

The Global Argon Dark Matter Collaboration

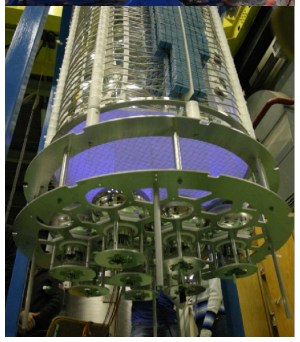


DEAP



DarkSide-50

MiniCLEAN



ArDM

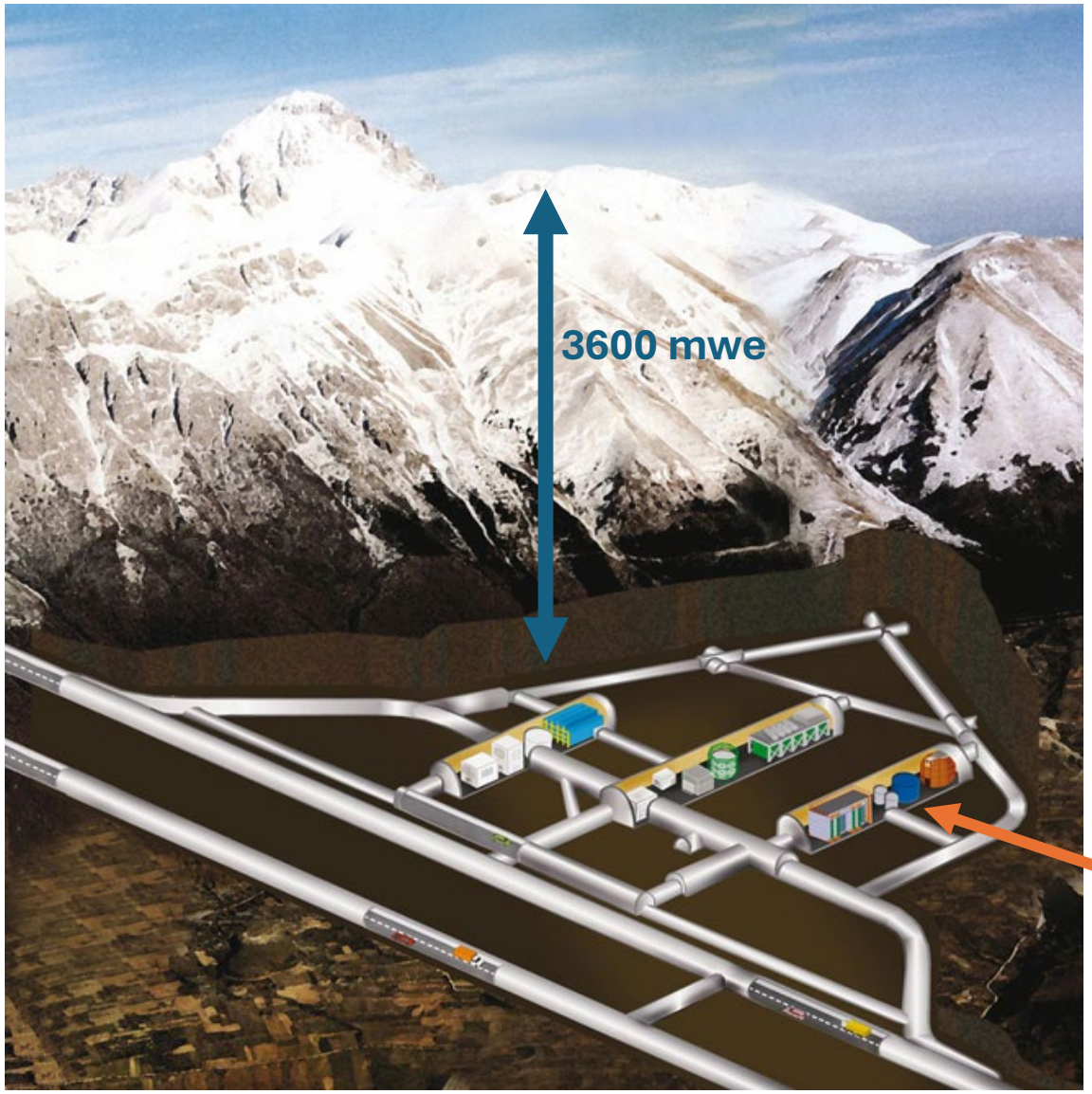
The GADMC

First priority:
Finish DEAP-3600

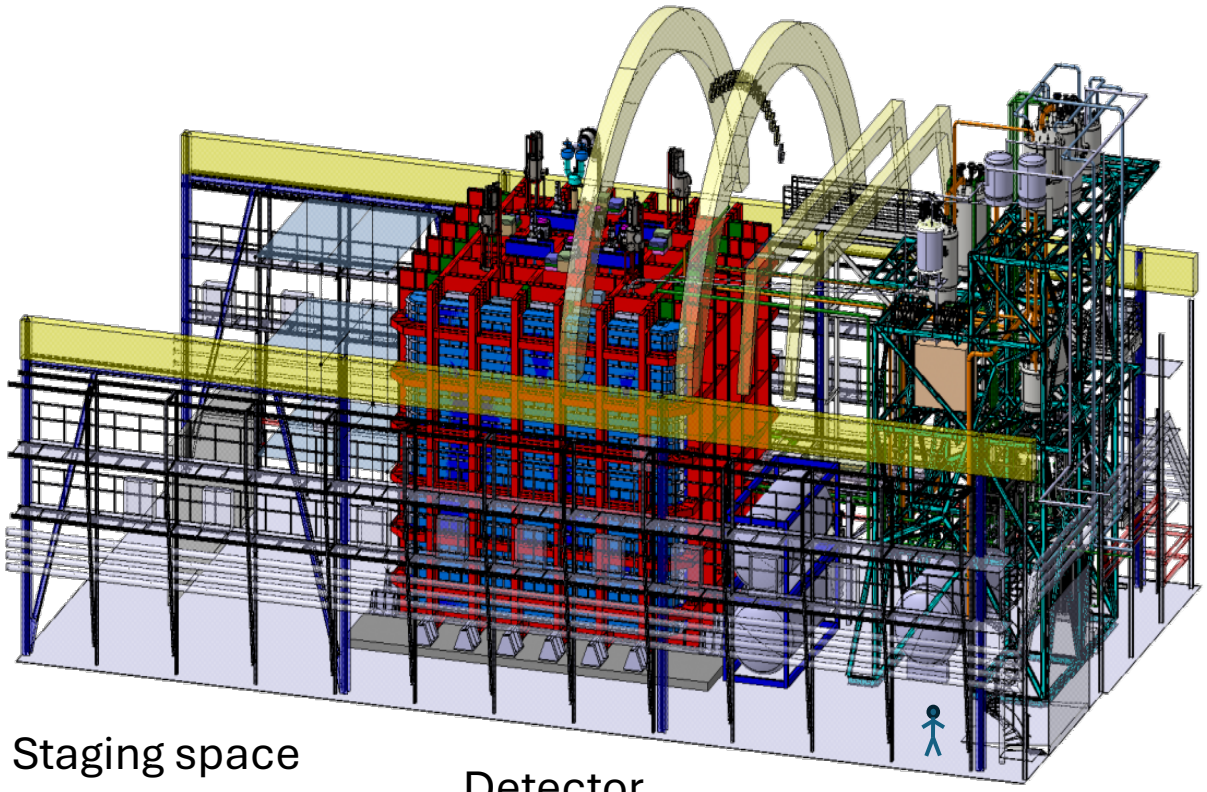
DarkSide-20k under construction at LNGS

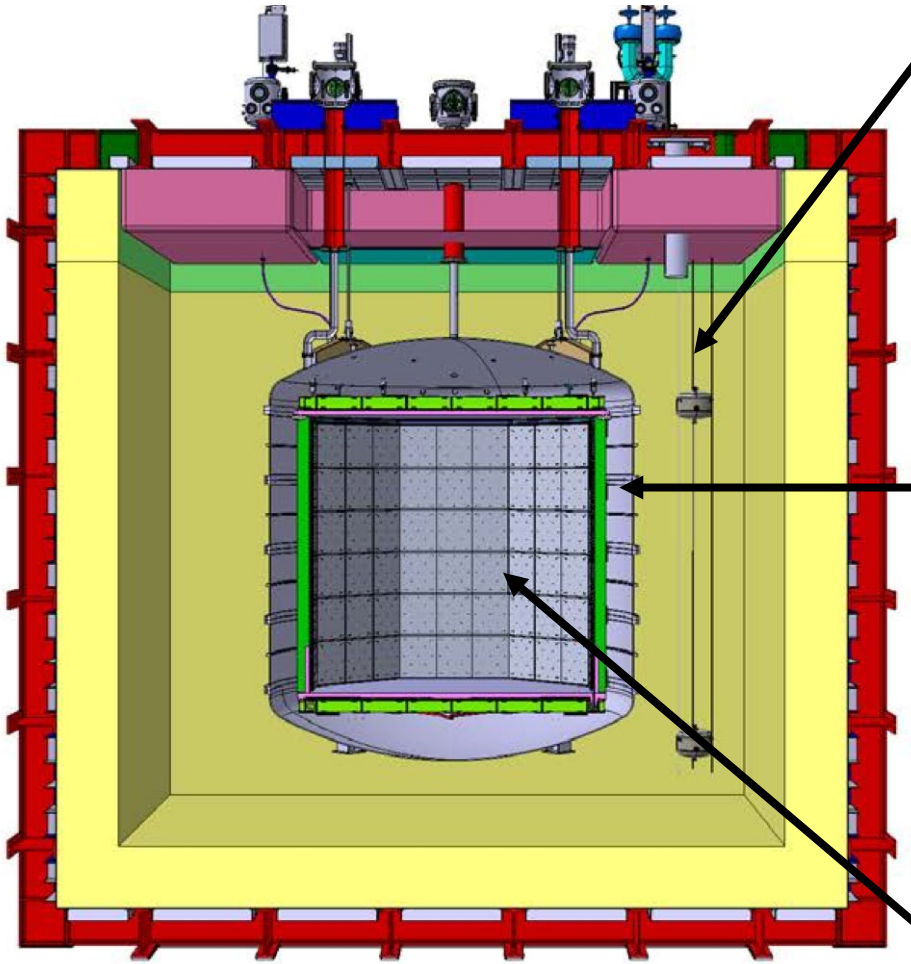
Next: ARGO

DarkSide-20k is under construction at LNGS



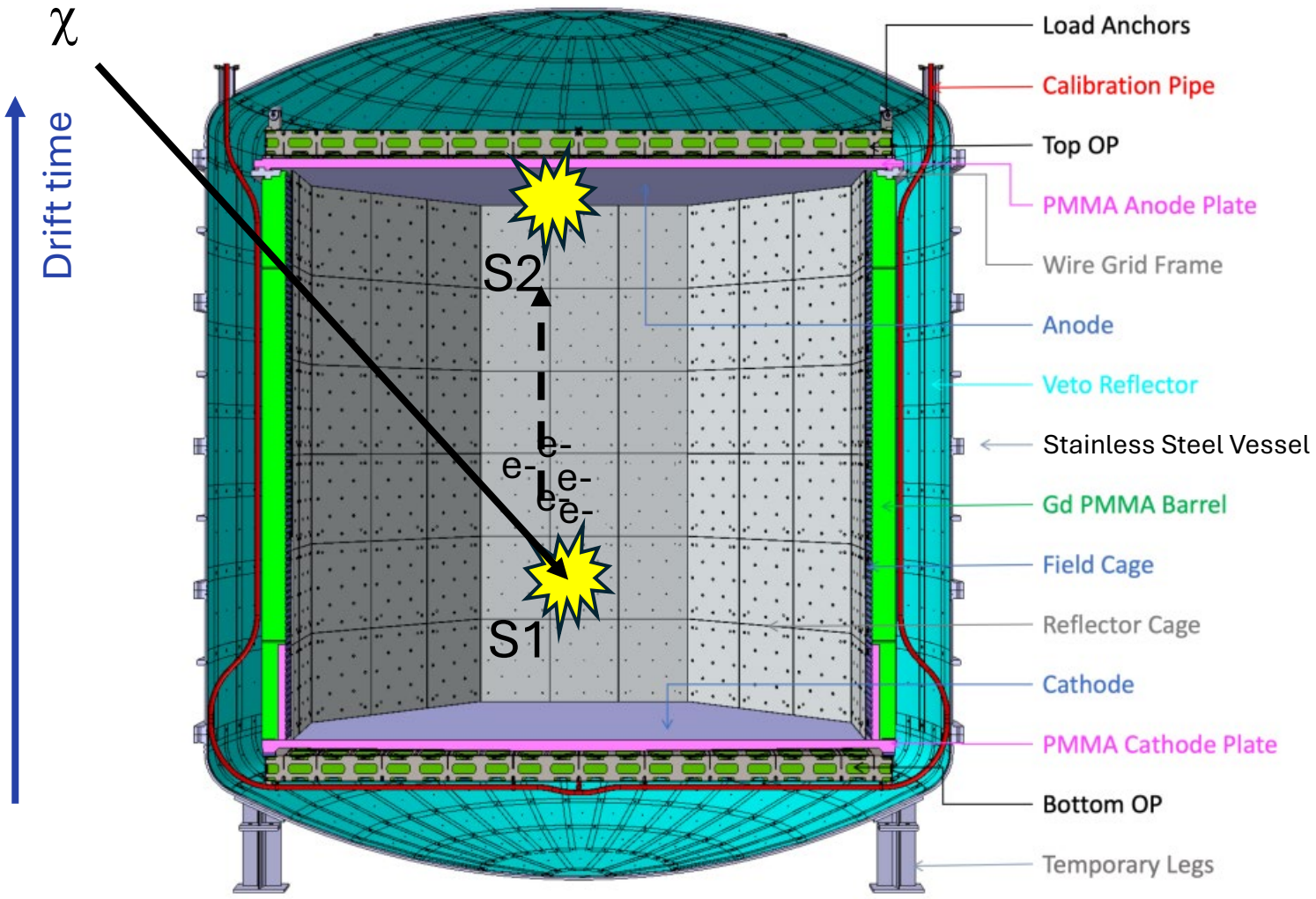
DarkSide-20k is under construction at LNGS

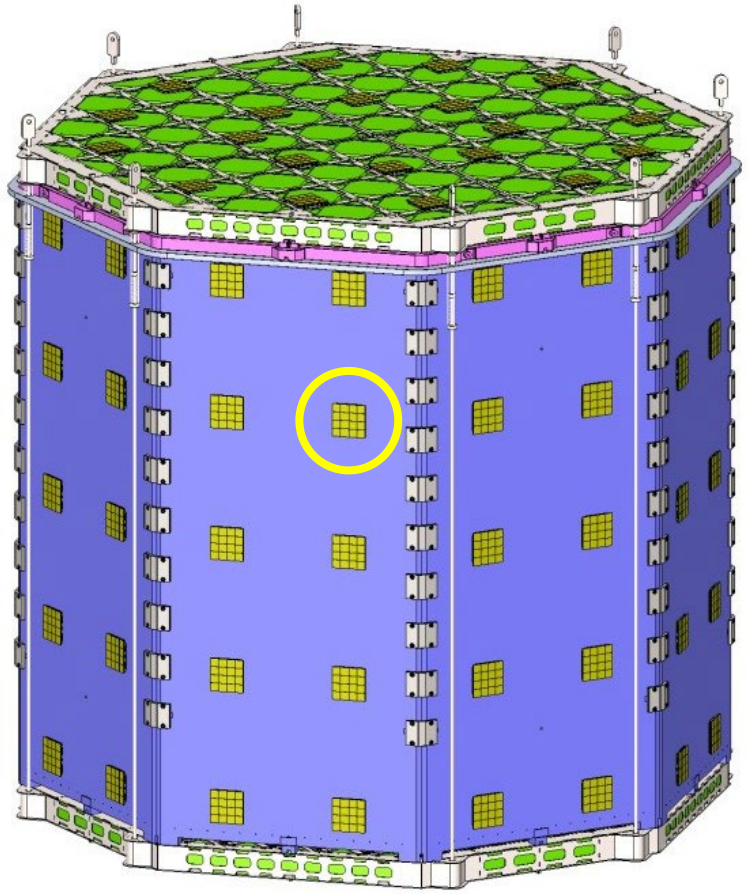




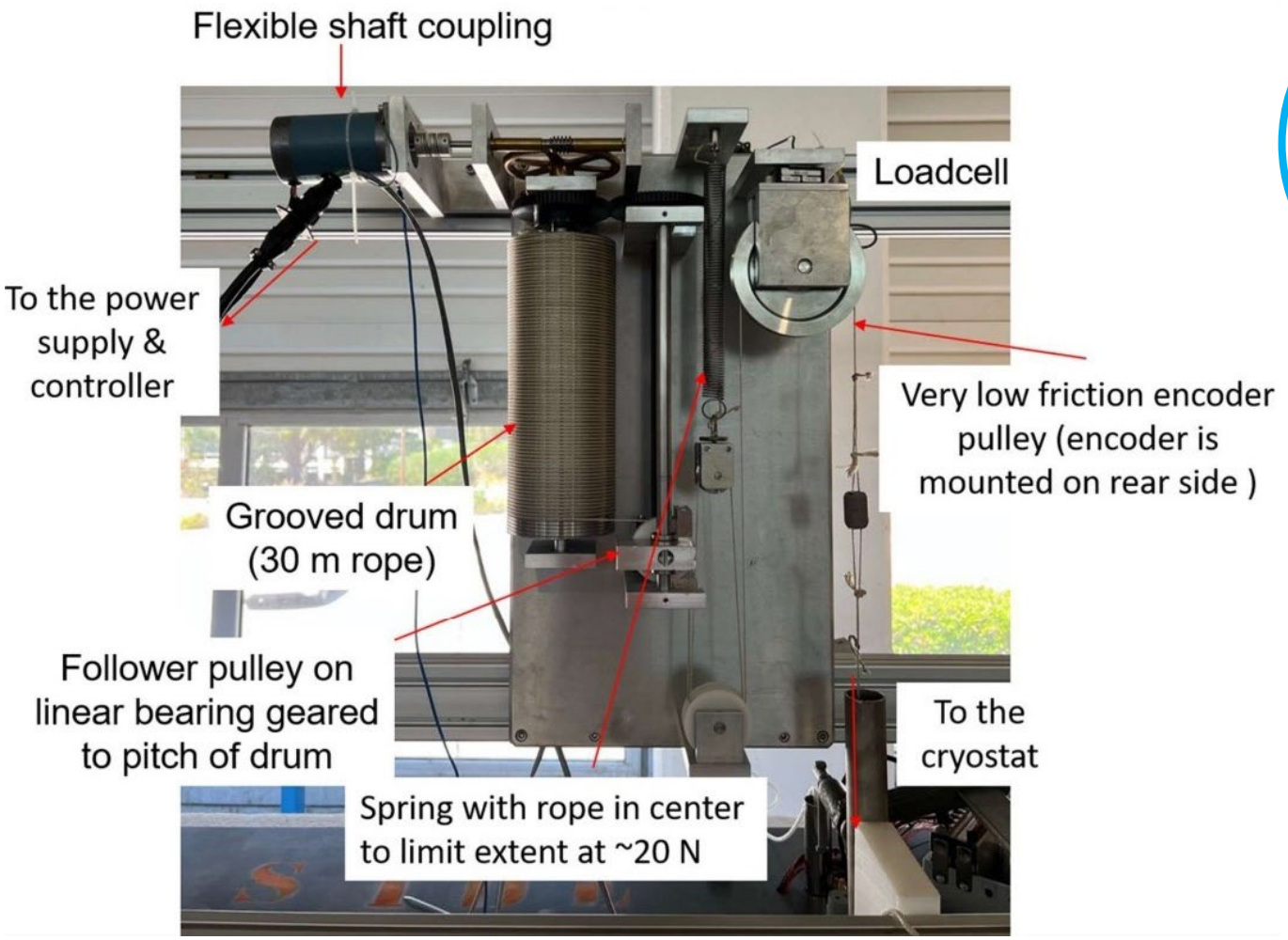
DarkSide-20k is a two-phase Underground Argon TPC with 20t fiducial volume

… surrounded by an instrumented LAr veto

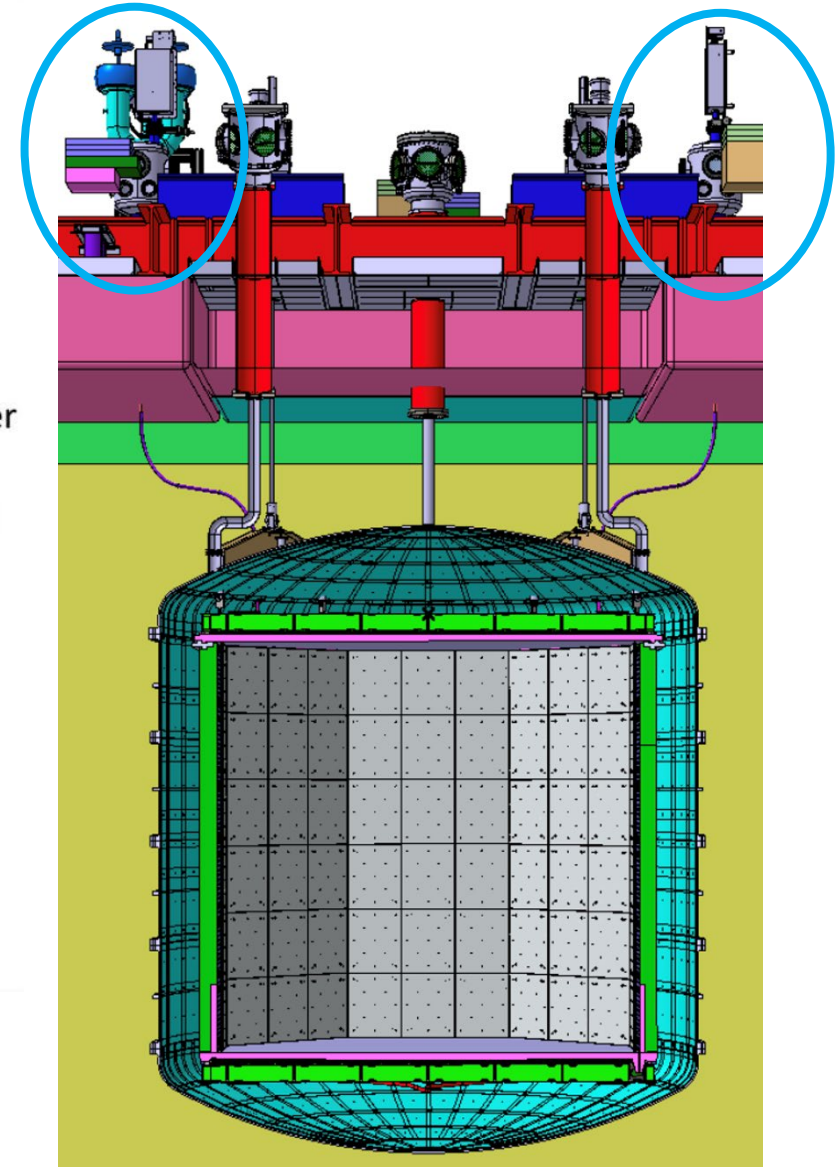




SNO-style motor & pulley for calibration deployment



Two SNO-style motor control units



Low-radioactivity, Low-noise, High Efficiency SiPM Arrays

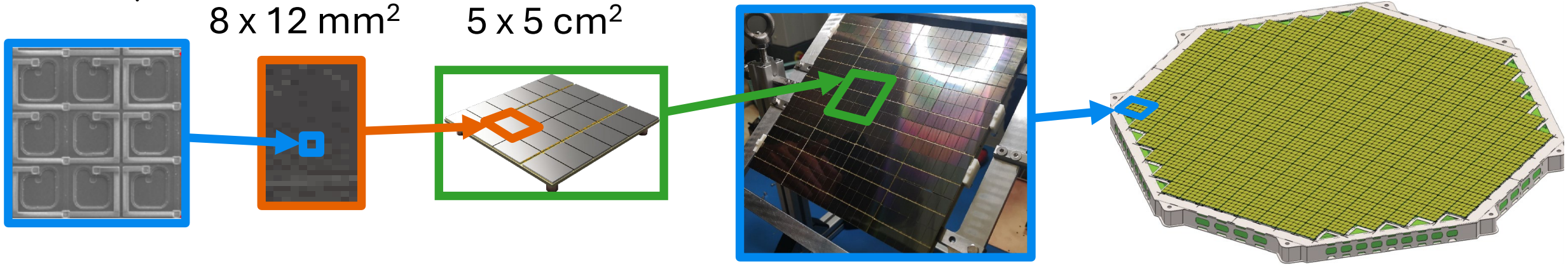
SPAD
30 x 30 μm²

SiPM
8 x 12 mm²

Tile (24 SiPM)
5 x 5 cm²

PDU
20 x 20 cm²

Optical Plane (264 PDUs)
21 m² in TPC; 5 m² in veto



PDU packaging and assembly at Nuova Officina Assergi (NOA) at LNGS

C. E. Aalseth et al 2017 JINST 12 P09030

NUV-HD-CRYO meet all requirements:

Photon detection efficiency: **>40%** at 77 K

Dark count rate: **<0.01 Hz/mm²** at 77 K

SNR: **>8** for 10×10 cm² TPC PDU)

All individual components and whole assemblies pass radiopurity requirements for DarkSide-20k

DEAP-3600 the largest detector you can make with atmospheric argon

Argon signal is about 10 microseconds long

At 1 Bq/kg and 3300kg in DEAP-3600,

~3.3% of events contain random Ar^{39} pile-up

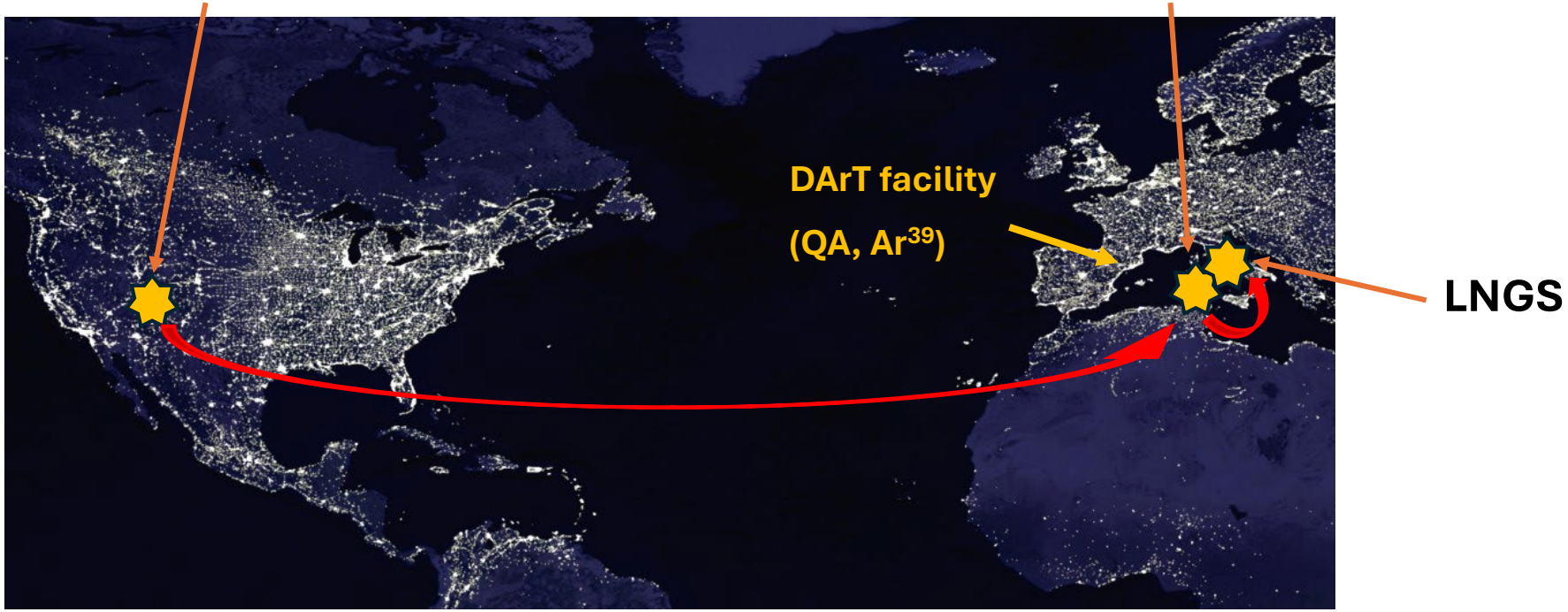
^{39}Ar created by cosmic rays on $^{40}Ar(n,2n)$

➔ **Argon trapped underground has a lower activity**

Industrial Scale Underground Argon Production

- **Urania (Cortez, CO)**
- Industrial scale extraction plant
- Extraction rate: 250-330 kg/day
- Production capability ≈ 120 t over two years
- UAr purity: 99.9-99.99%

- **Aria (Sardinia, Italy)**
- 350 m cryogenic distillation column
- O(1 tonne)/day capability
- UAr purity: better than 99.9999%
- Ultimate goal: isotopic separation



The ARIA Prototype runs were successful

- The prototype tower is 26m tall
- Isotopic separation of Ar-36, Ar-38, and Ar-40 has been demonstrated.

https://doi.org/10.1140/epjc/s10052-021-09121-9

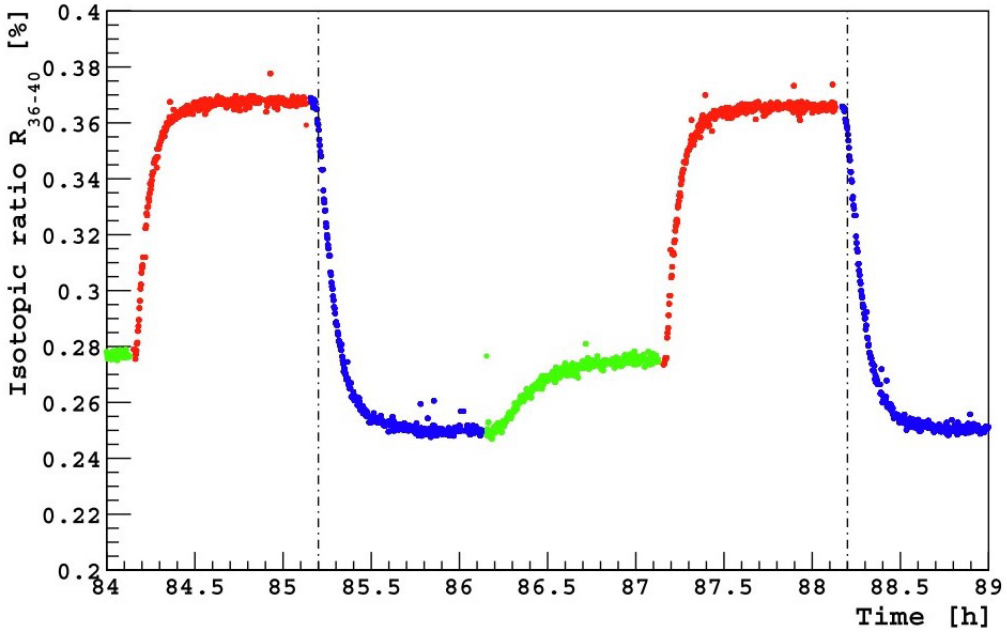
https://doi.org/10.1140/epjc/s10052-023-11430-0

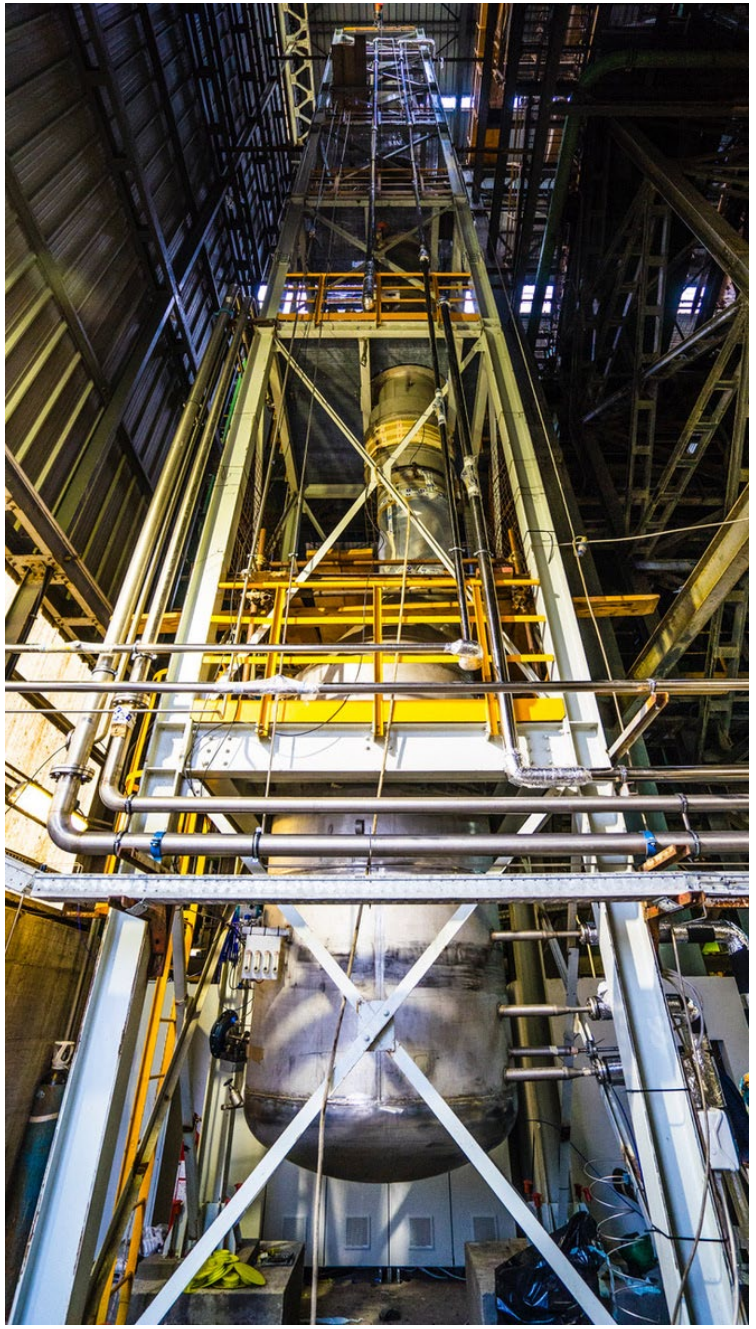
0.36% top of tower

Ratio Ar-36/Ar-40

0.28% feed

0.25% bottom

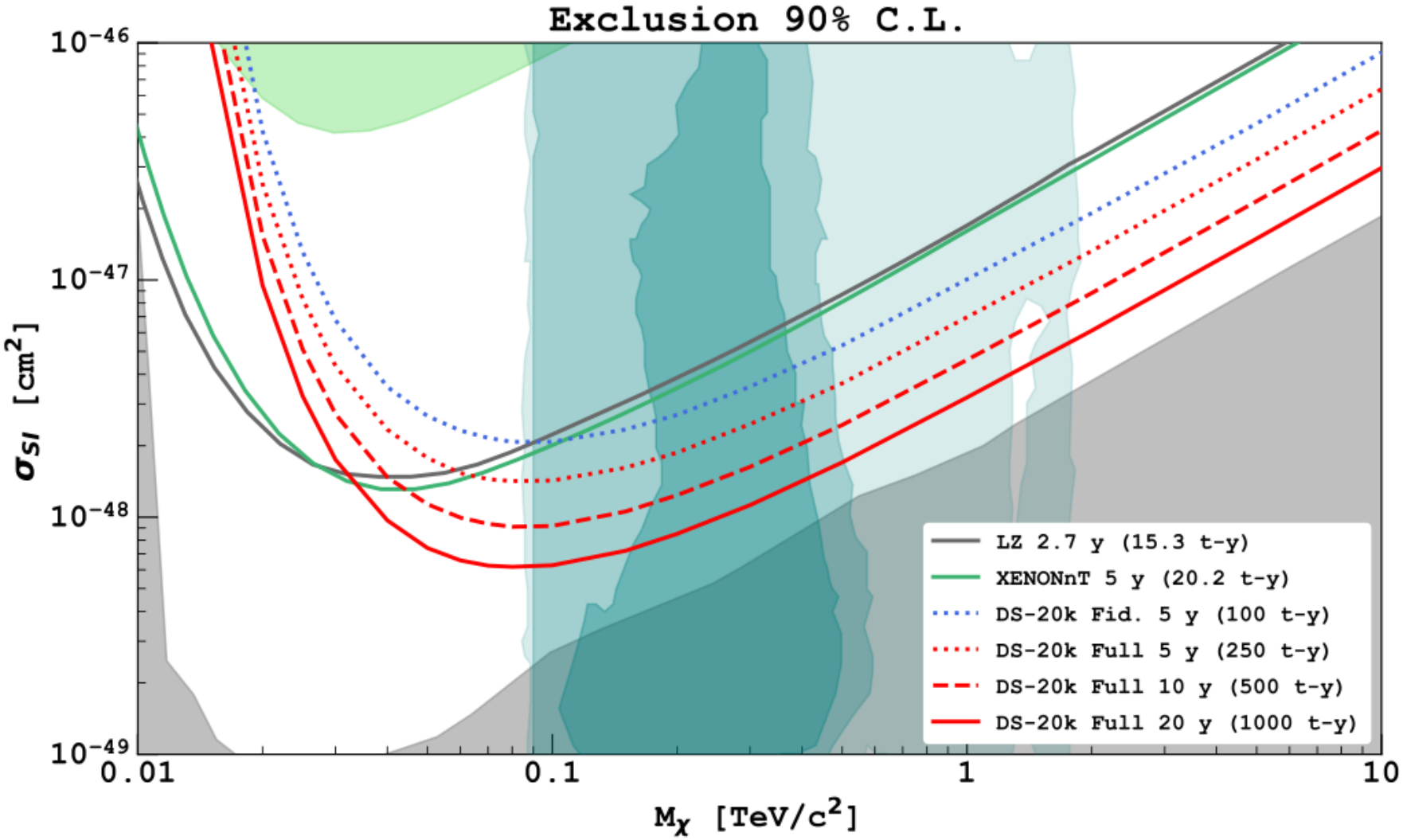




Projected Sensitivity of DarkSide-20k

Expected 3 events in 200 tonnes-year from neutrino coherent scattering

Underground Argon target, excellent PSD, and neutron veto allow zero instrumental background



Exciting times ahead !

- DEAP-3600 expected to restart taking data end of 2024, for two years. Quick turn-around analysis prepared to test the effect of the dust removal.
- DarkSide-20k expected to come online in 2027
- And then… stay tuned for Asish’s talk !