DEAP-3600: Recent Results and Ongoing Work

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DEAP Collaboration

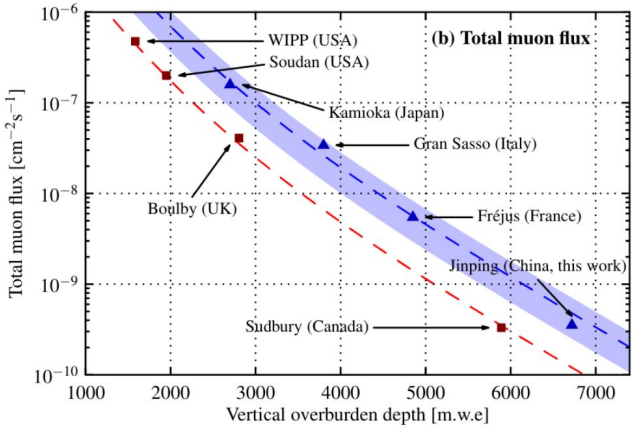
~100 researchers in Canada, Germany, Italy, Mexico, Poland, Russia, Spain, UK, USA

DEAP-3600

DEAP-3600 detector is located at SNOLAB in Sudbury Ontario

An underground laboratory located beneath 2 kilometers of rock, providing an overburden equivalent to approximately 6 kilometers of water (k.m.w.e.)

[2007.15925] (arxiv.org)



DEAP-3600

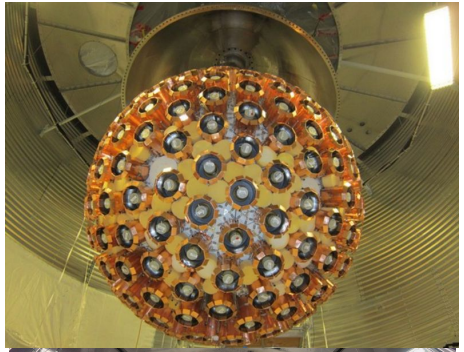
Target : 3269±24 kg of LAr in acrylic vessel

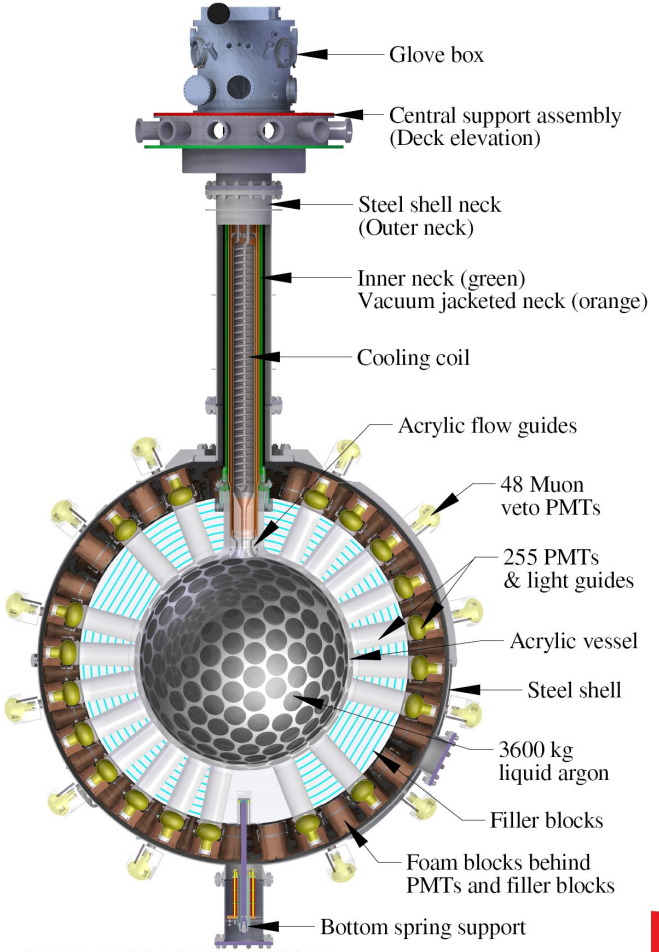
Photon detection: 255 HQE PMTs connected via acrylic light guides

Inner surface of vessel coated with TPB wavelength shifter

Shielding: Filler blocks between LGs used for thermal insulation and neutron shielding

Veto: Steel shell is immersed in 300 tons of H2O, viewed by 48 veto PMTs.



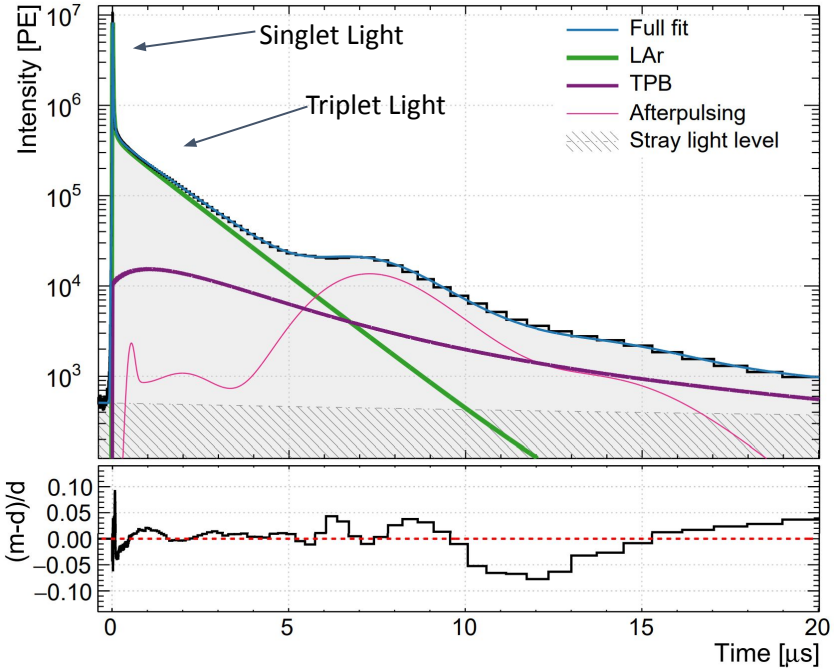


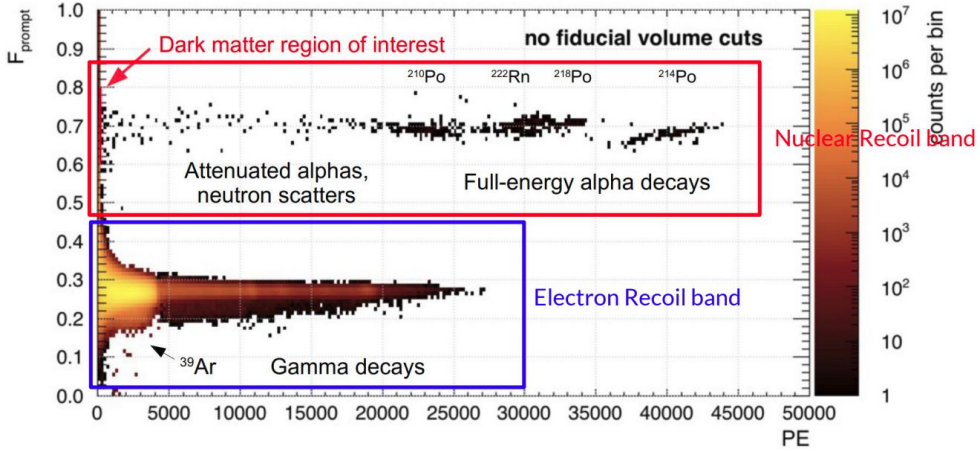
Pulse shape discrimination

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

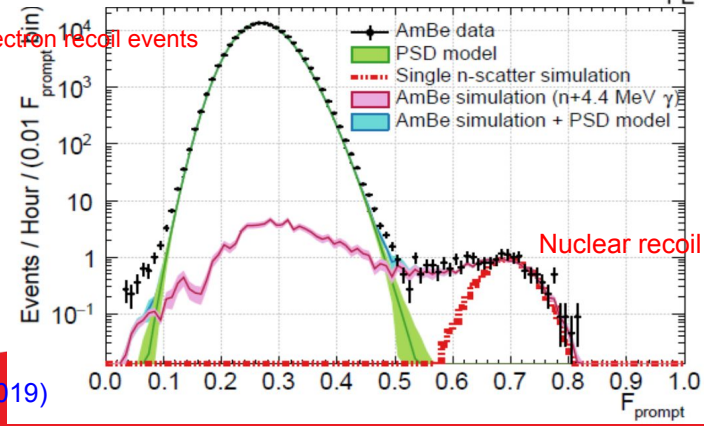
Ar39 pulse shape and model fit including detector effects i.e. TPB response and afterpulse

Eur. Phys. J. C 80, 303 (2020)





Electron recoil events



Nuclear recoil events

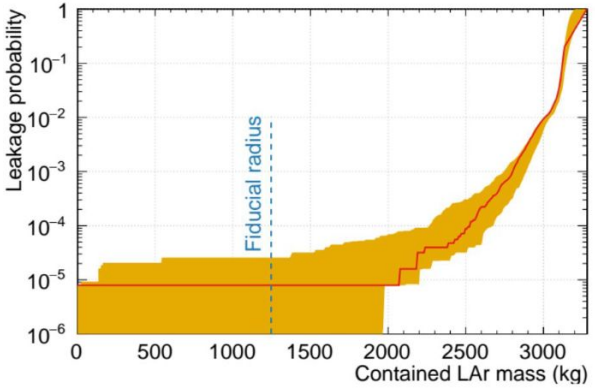
Physical Review D, 100, 022004 (2019)

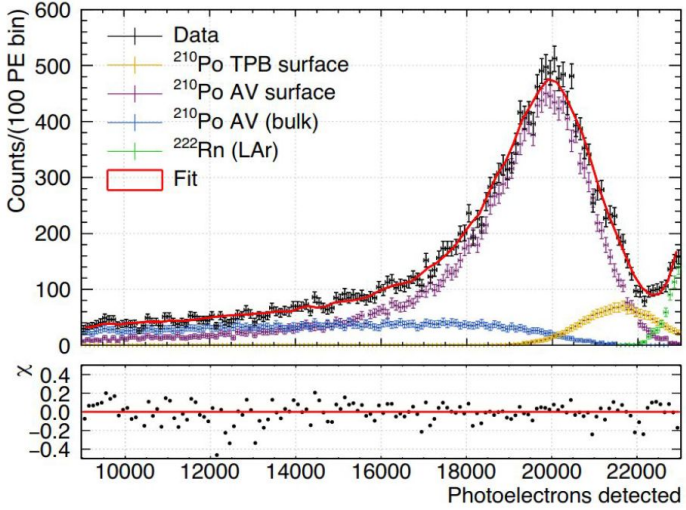
Surface background

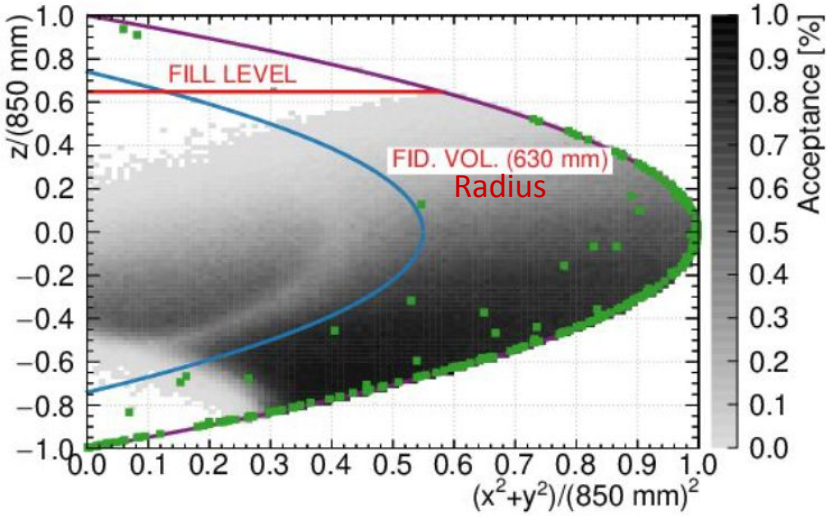
Physical Review D, 100, 022004 (2019)

Mostly Po-210 decays on the surface of AV

Constrained by the fiducial cut



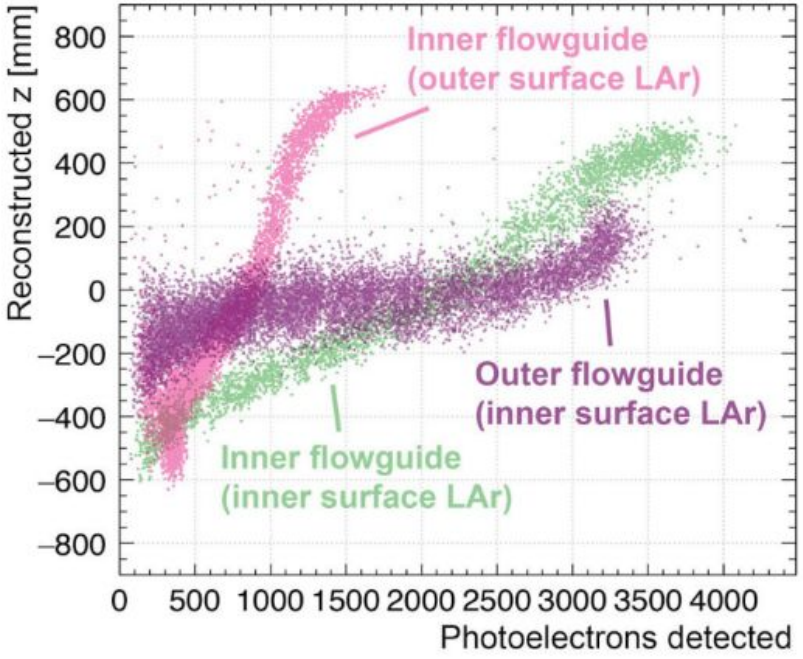


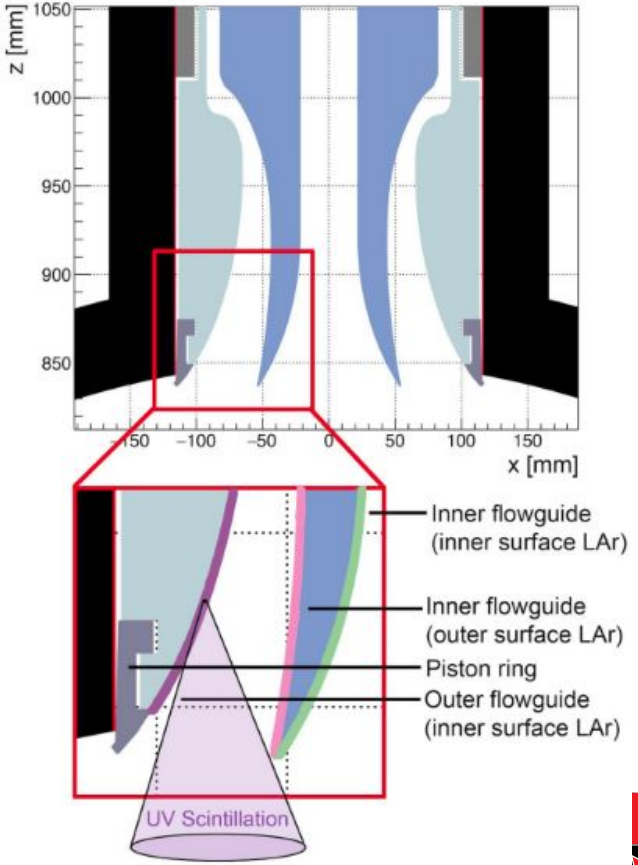


Shadowed alpha

Physical Review D, 100, 022004 (2019)

Alpha decay by the Po-210 from the surface of the acrylic flow guide located at neck of the detector





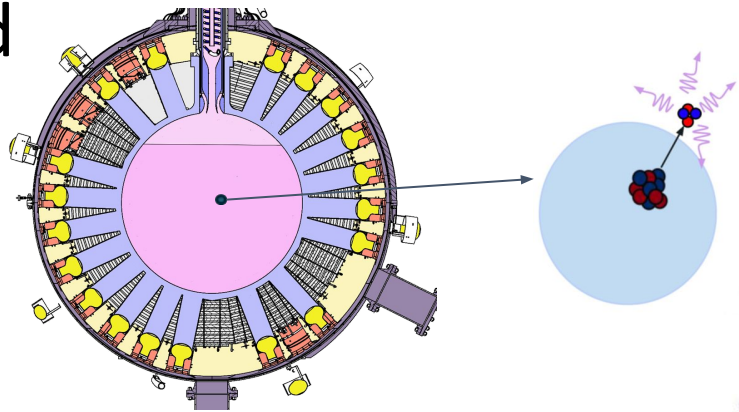
Dust-induced alpha background

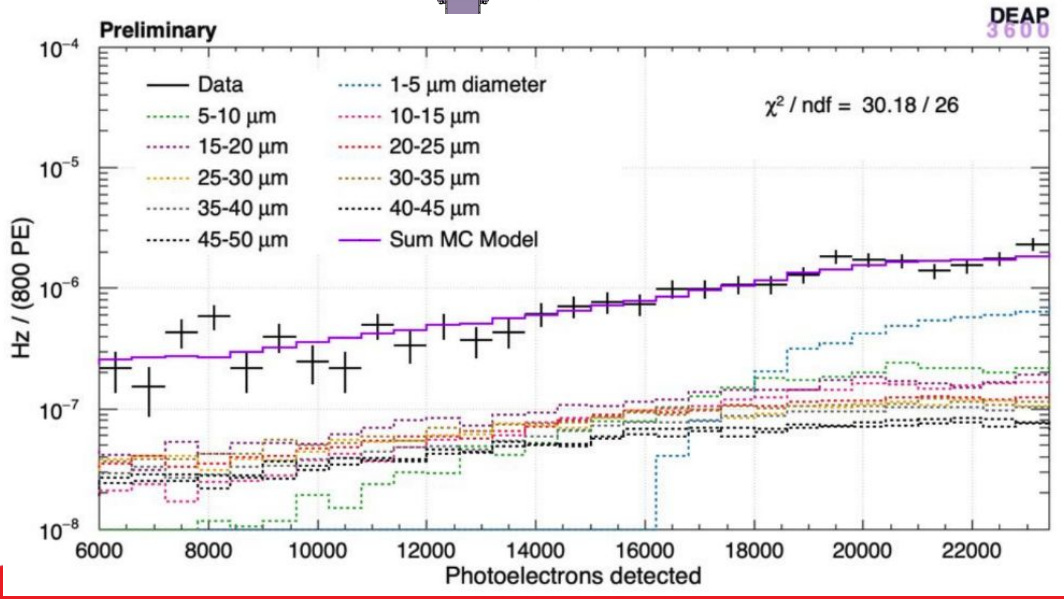
Alpha decays can occur in trace amounts of dust inside the detector and may then become attenuated within the dust itself.

The attenuated alpha may produce scintillation in the liquid argon, and the dust can also cast a shadow, affecting the light collection

Different dust sizes are simulated and modelled with the data

Ex-situ measurements of metallic dust in liquid nitrogen support this hypothesis

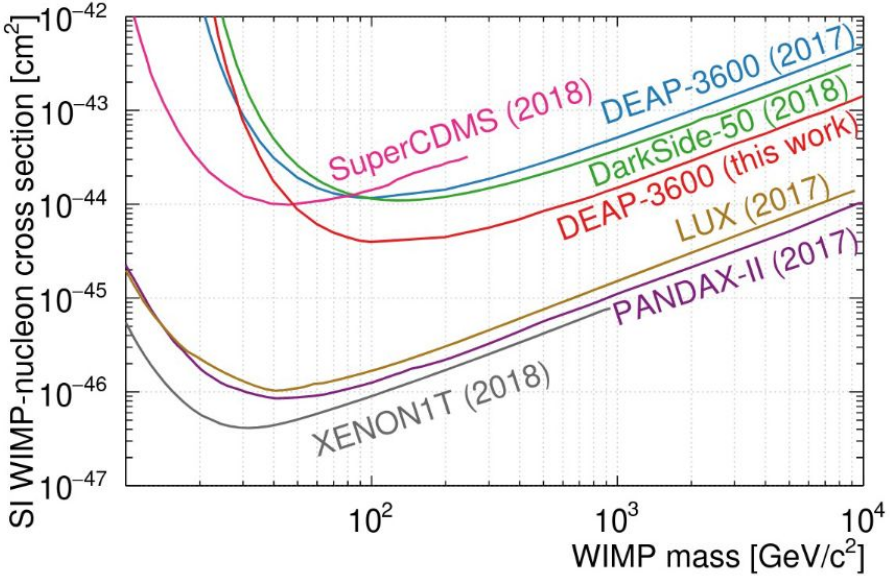




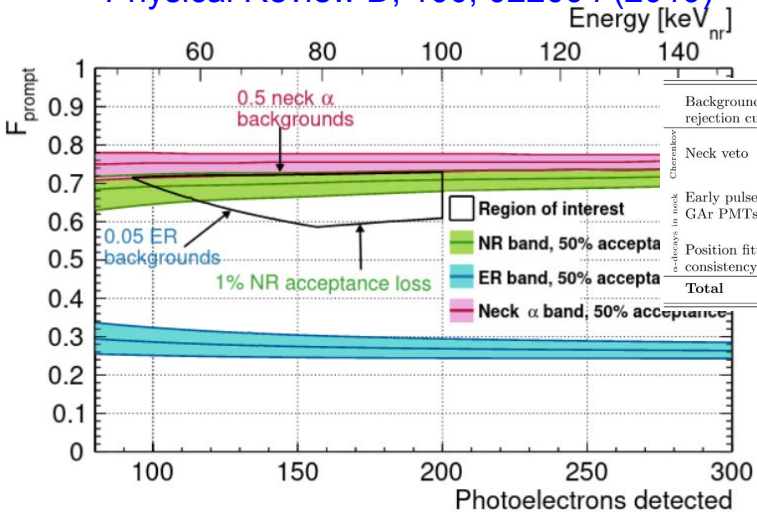
WIMP search

First year dataset (DS) : November 2016 - October 2017 (231 live days)

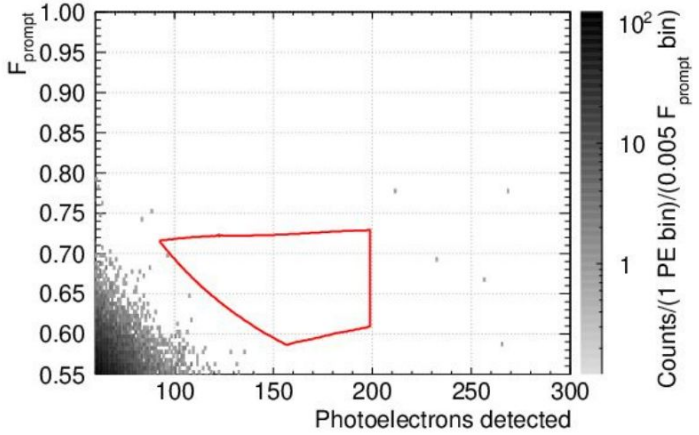
No WIMP-like signals: 0 events in ROI



Physical Review D, 100, 022004 (2019)



	Background rejection cut	WIMP accept. [%]	N_{bkg}^{ROI}	N_{obs}^{ROI}
Cherenkov	Neck veto	$92.0^{+1.0}_{-0.1}$	$9.2^{+4.4}_{-3.5}$	29
α-decays in neck	Early pulses in GAr PMTs	$45.4^{+1.5}_{-0.1}$	$2.3^{+1.1}_{-0.9}$	2
	Position fitter consistency	$35.4^{+2.5}_{-0.1}$	$0.62^{+0.31}_{-0.28}$	0
	Total	$35.4^{+2.5}_{-0.1}$	$0.62^{+0.31}_{-0.28}$	0

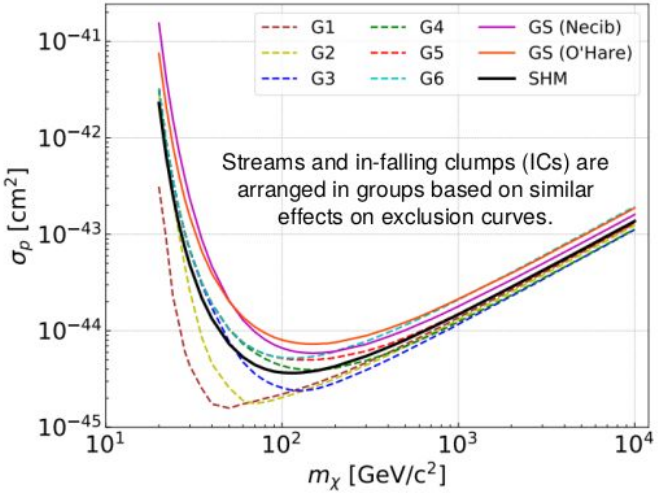


Constraints on dark matter-nucleon effective coupling

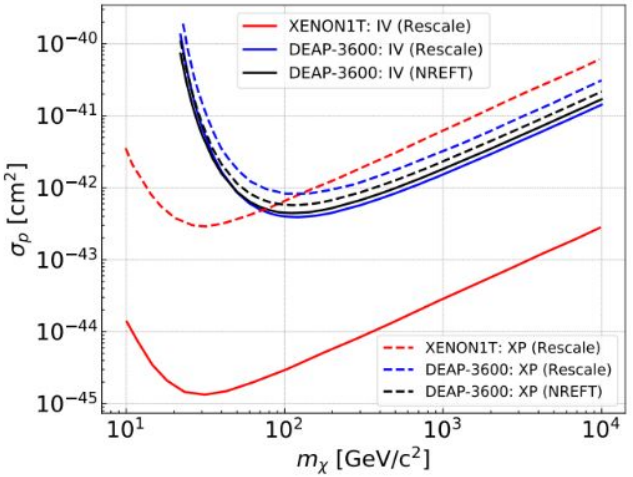
Phys. Rev. D 102, 082001 (2020)

Results are interpreted with a Non-Relativistic Effective Field Theory framework.

Examines how various substructures in the local dark matter halo may affect these constraints.



Upper limits (90 % C.L.) on the effective operator Q1 for substructures.



Constraints on the Q1 interaction, for IV (isovector; solid) and XP (xenonphobic; dashed) scenarios.

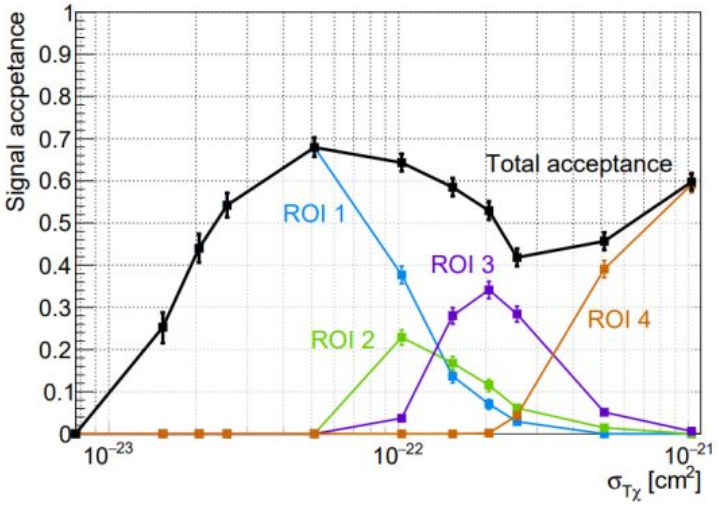
Planck-scale mass dark matter

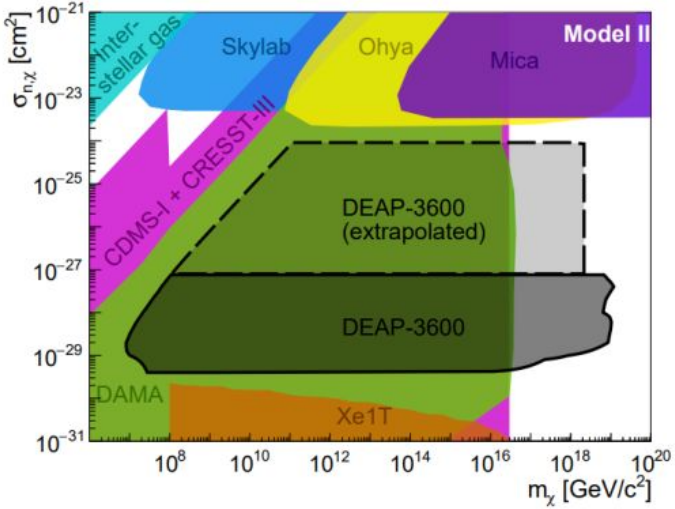
A search for multi-scatter signals from supermassive dark matter was performed.

Multiple recoils - very high-energy, low F_{prompt} event

Blind analysis of data collected over a 813 days live time - no event was found in the region of interest.

Phys. Rev. Lett. 128, 011801 (2022)





Probability of DM with m = 10^{18} GeV/c^2 populating each ROI and surviving all cuts at varying $\sigma_{T\chi}$

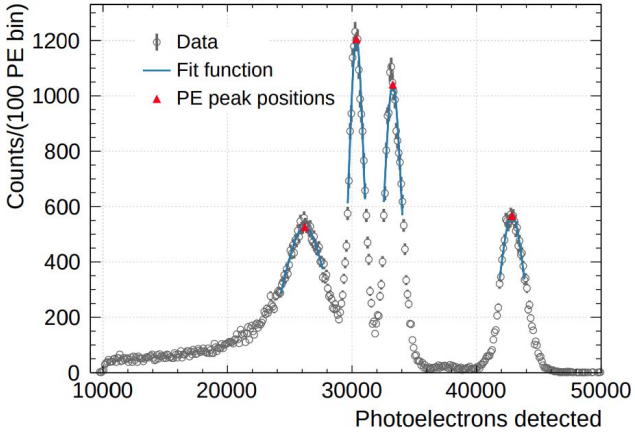
Alpha quenching factor in liquid argon

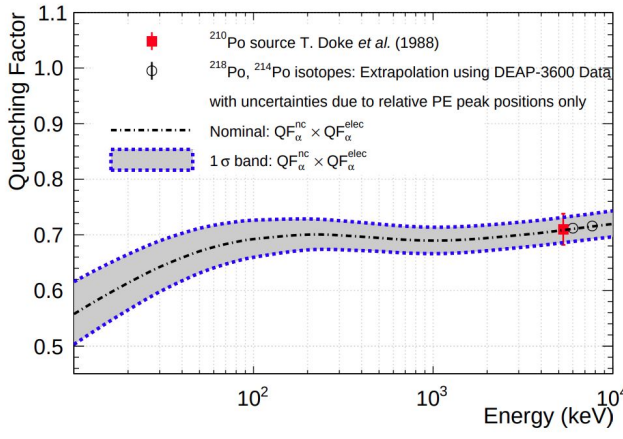
Eur.Phys.J.C 85 (2025) 1, 87

Performed a relative measurement of the QF at energies between 5.489 and 7.686 MeV - full-energy α peak

Extrapolated the QF values into the low-energy region down to 10 keV

The energy-dependent QF: product of the best-fit electronic QF curve and the nuclear QF curve from TRIM

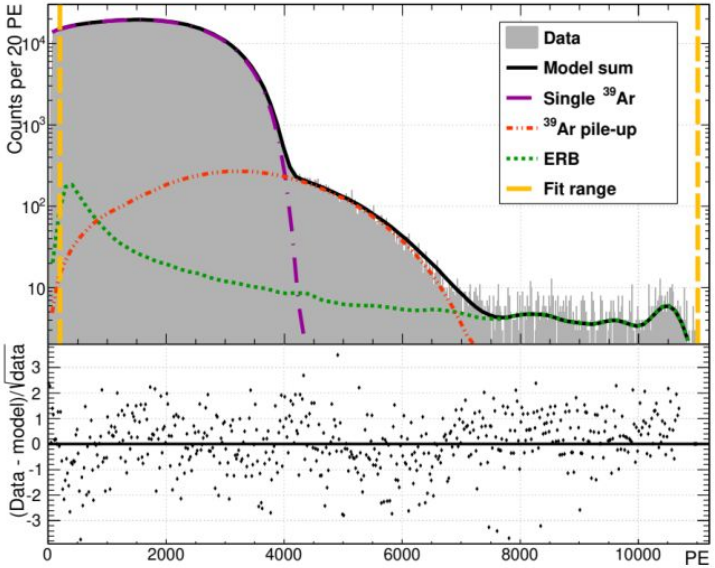




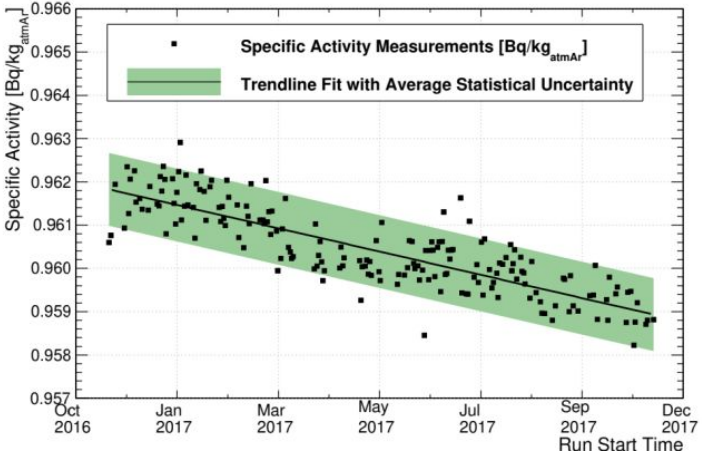
Specific activity of ^{39}Ar

Eur. Phys. J. C 83, 642 (2023)

Most precise measurement of the specific activity of ^{39}Ar in atmospheric argon to date and agrees with existing measurements.



An example fit on one run including the ^{39}Ar, electron recoil backgrounds (ERB), and ^{39}Ar pile-up components.

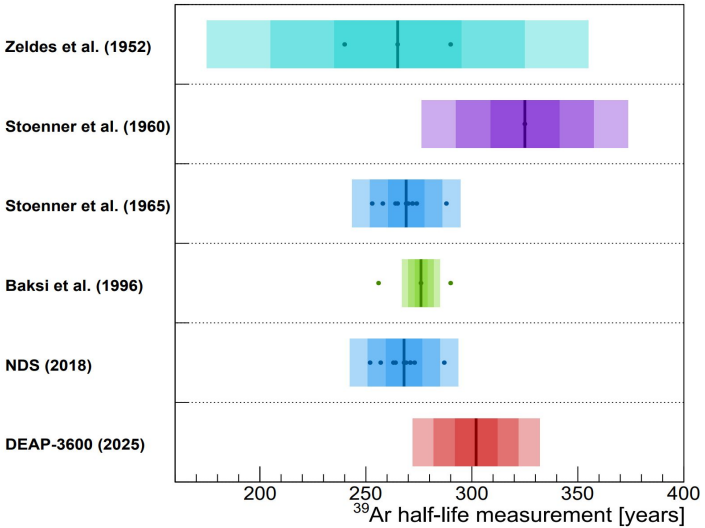


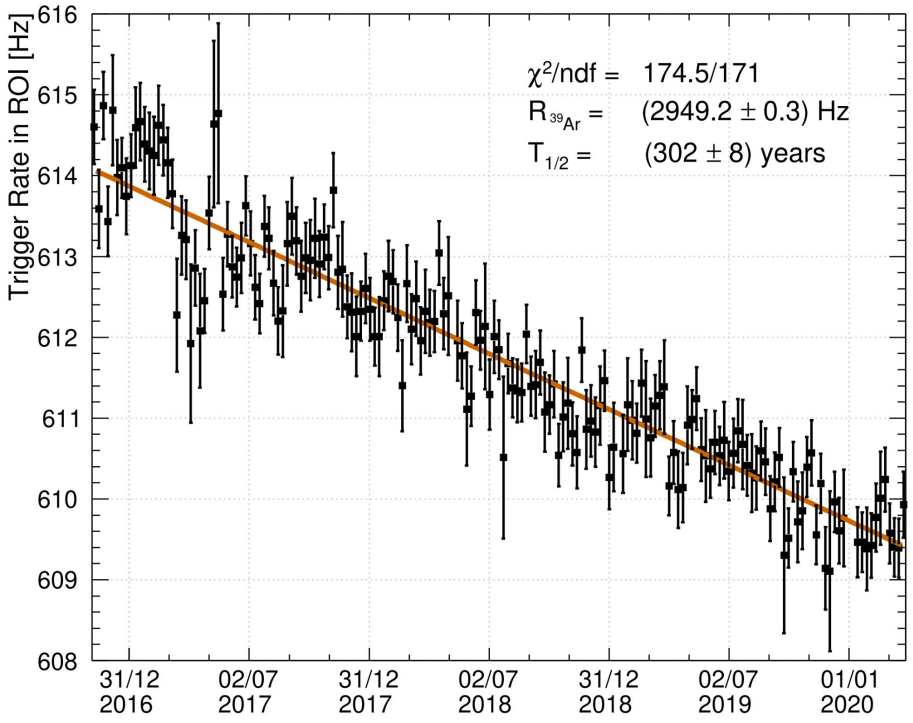
Measurement	Specific activity [Bq/kg$_{atmAr}$]
WARP [15]	$1.01 \pm 0.02_{stat} \pm 0.08_{sys}$
ArDM [16]	0.95 ± 0.05
DEAP-3600 (this work)	$0.964 \pm 0.001_{stat} \pm 0.024_{sys}$

Argon-39 Half Life Measurement

Eur.Phys.J.C 85 (2025) 7, 728

First Direct Measurement of Ar-39 decay curve and its half life



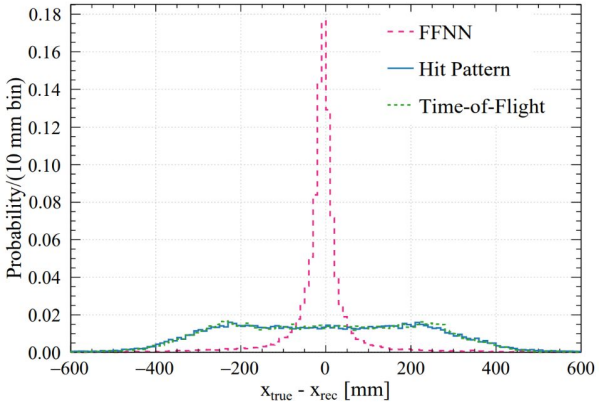


Position reconstruction

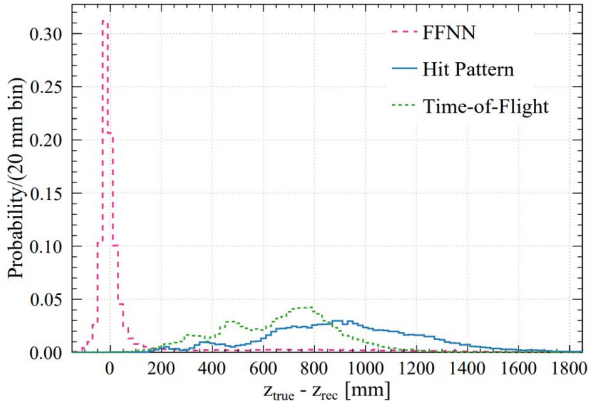
Development of three position reconstruction algorithms

- A likelihood method using photon time-of-flight (TF2)
- A likelihood method based on PMT hit patterns (MBL)
- A feed-forward neural network (FFNN)

2025 JINST 20 P07012



(c) Error in x for events originating in the neck.



(d) Error in z for events originating in the neck.

These approaches show significant improvement in the reliability of position reconstruction, particularly for events occurring near the neck region.

Coming up

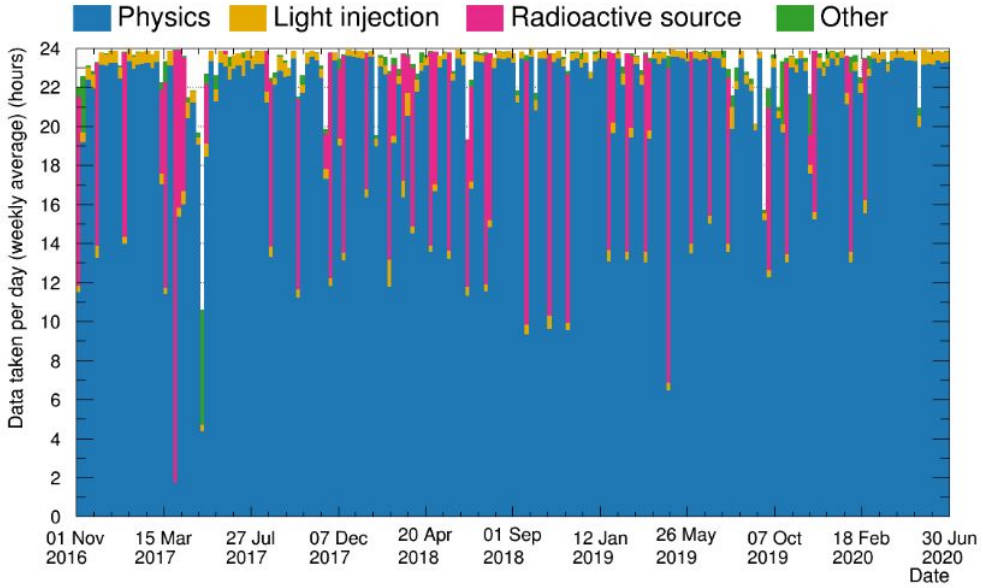
3 Year Dataset (Nov 2016 to March 2020) expect ~800 days of lifetime instead of 231 days

An improved background model

Extended fiducial volume and relaxed cuts for increased WIMP acceptance

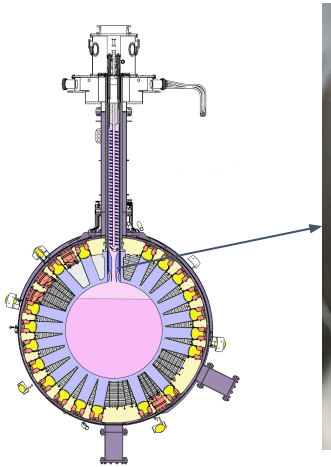
A profile-likelihood ratio analysis to achieve the best sensitivity to WIMPs in this dataset

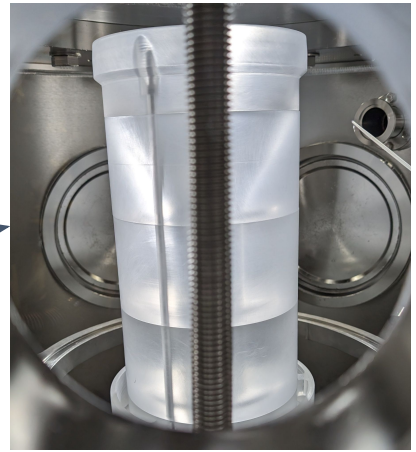
Analysis is nearly completion



Detector upgrade

The hardware upgrades will allow us to reach DEAP-3600 design sensitivity - zero background





Neck flow guide replacement:

Coat the flow guide surfaces with a “slow” WLS - Pyrene is selected.

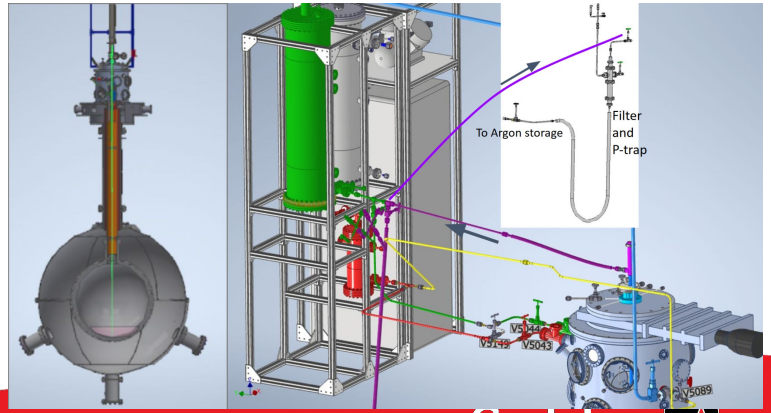
Pyrene has a long decay time : neck events will have lower fprompt.

Dust removal:

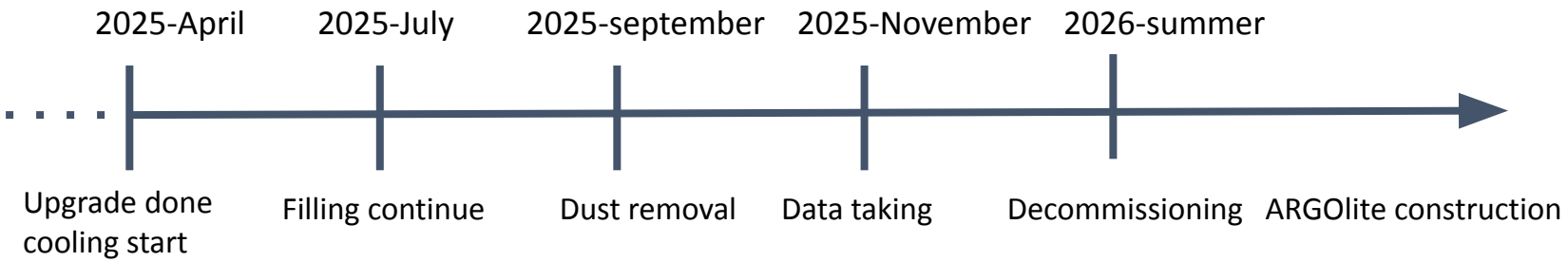
Syphon liquid argon into external storage dewar through a filter and P-trap which allows for liquid to be removed from the detector.

Removal of dust using high purity filter installed in existing gas purification system

Refill AV with clean LAr



Upgrade timeline



Upgraded neck and particulate removal system installed

Cooling of the detector began in April

Liquid argon filling is underway, with a target finish in July

Dust pipe will filter the dust in a few cycle: September-October

Data taking start after removing the dust pipe : October/november

Data taking will end ~ summer - 2026

Decommissioning the DEAP-3600 to start ARGOlite in the Cube Hall.

Next: Darkside

The Global Argon Dark Matter Collaboration (GADMC)

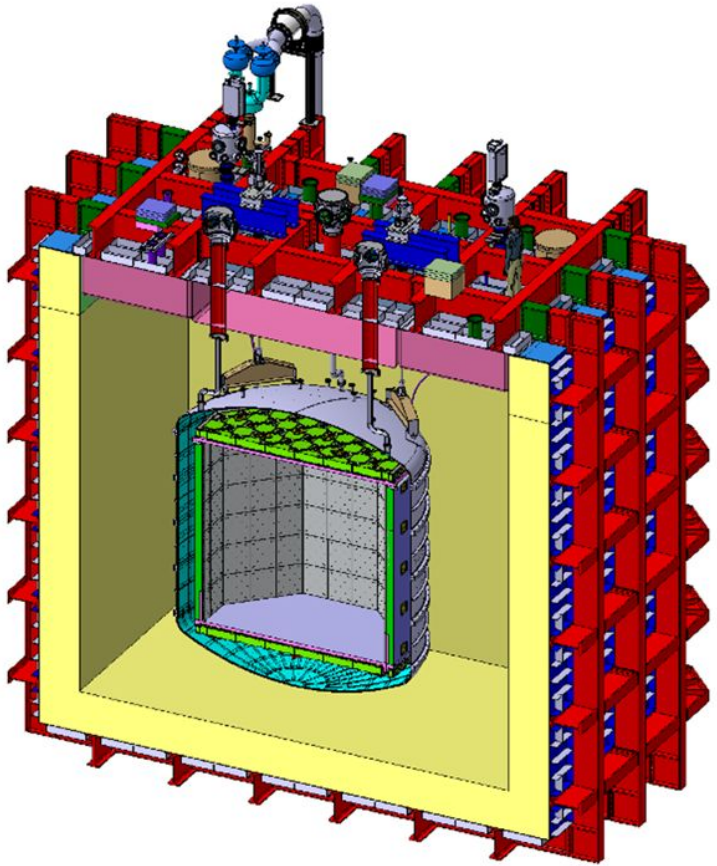
GADMC brings together more than 400 scientists committed to explore heavy (and light) dark matter to the neutrino fog and beyond

Darkside is the next step up from DEAP-3600

Dual-phase LAr detector with a 50 tonnes active target (20 tonnes fiducial vol.) of underground 40Ar (UAr)

Under a mountain (3800 m.w.e) at LNGS

Construction is underway now



Next- Argo

Low-radioactivity argon

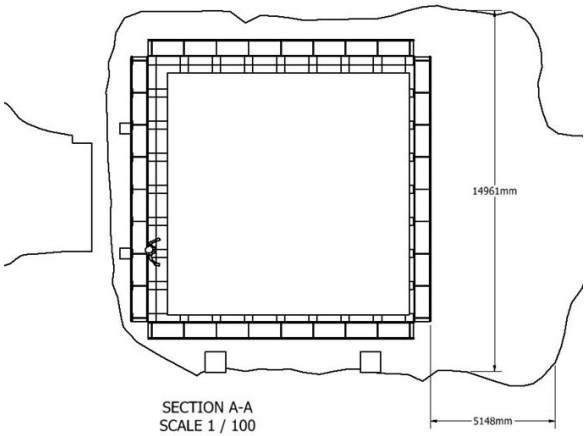
Total 400 tonnes, fiducial 300 tonnes

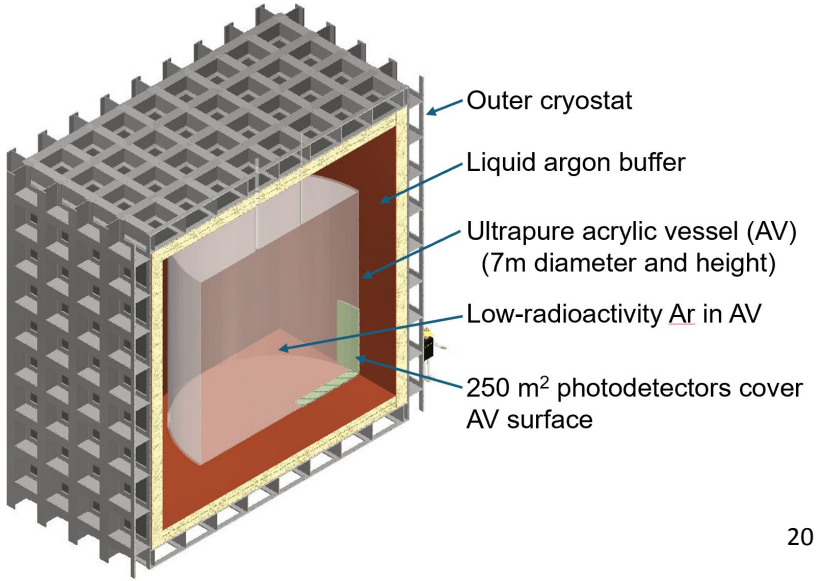
Pixelated digital photodetector readout

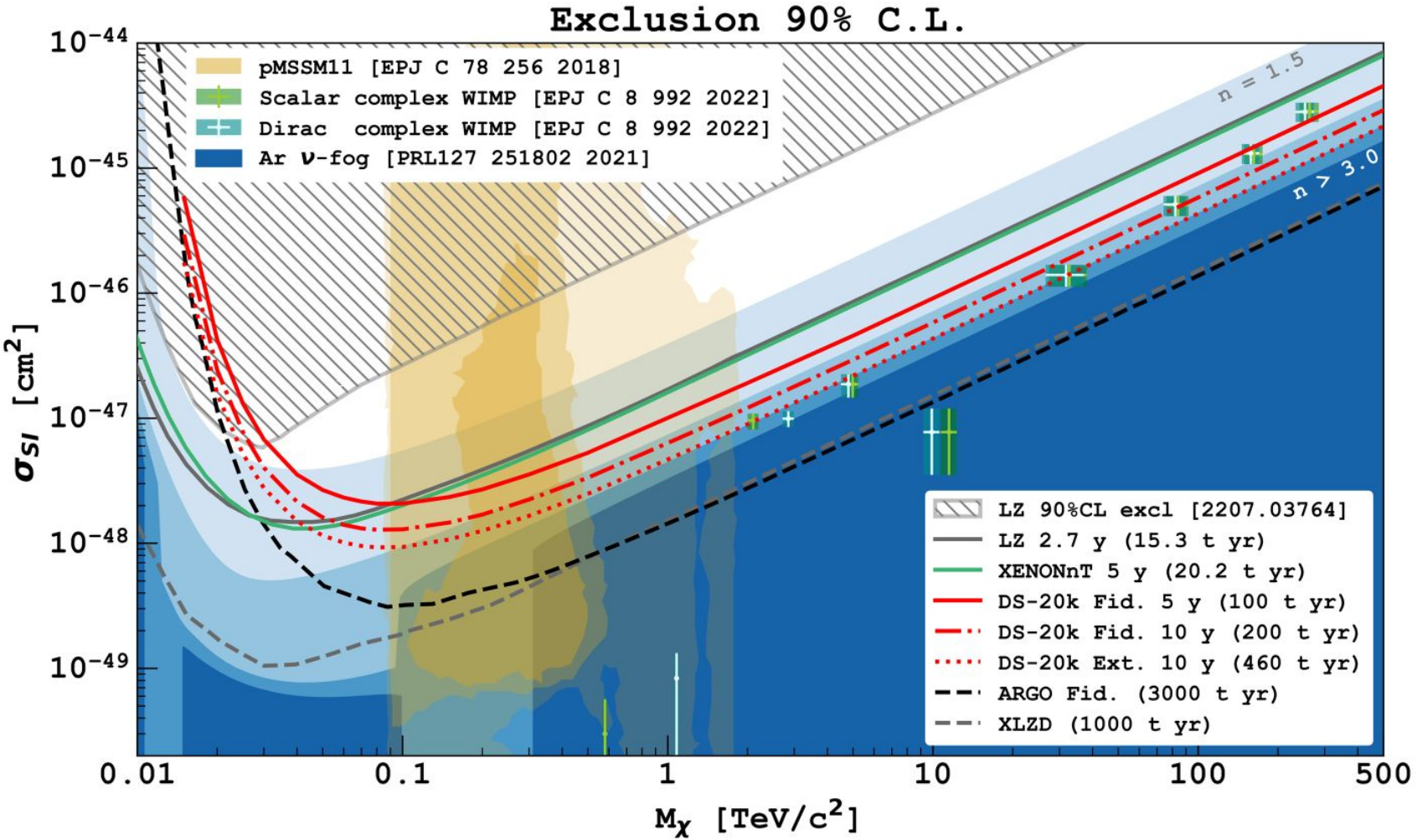
Preferred site: SNOLAB Cube Hall

Current focus in Canada is scintillation-only design, but configuration allows either this or TPC version.

Backgrounds are being calculated






Exclusion 90% C.L.
pMSSM11 [EPJ C 78 256 2018]
Scalar complex WIMP [EPJ C 8 992 2022]
Dirac complex WIMP [EPJ C 8 992 2022]
Ar ν-fog [PRL127 251802 2021]
n = 1.5
n > 3.0
LZ 90%CL excl [2207.03764]
LZ 2.7 y (15.3 t yr)
XENONnT 5 y (20.2 t yr)
DS-20k Fid. 5 y (100 t yr)
DS-20k Fid. 10 y (200 t yr)
DS-20k Ext. 10 y (460 t yr)
ARGO Fid. (3000 t yr)
XLZD (1000 t yr)
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
σ_{SI} [cm^2]
0.01
0.1
1
10
100
500
M_χ [TeV/c^2]

Summary

- World-class PSD performance in Liquid Argon.
- Exclude S.I WIMP-nucleon cross sections above 3.9×10^{-45} cm² for 100 GeV/c² WIMP mass (90% C.L.).
- Results reinterpreted using a non-relativistic EFT framework.
- World-leading sensitivity to Planck-scale mass dark matter
- Measurement and extrapolation of scintillation quenching factor of α-Particles in Liquid Argon
- Direct measurement of Ar-39 half life
- Coming up: 3 years Dataset, improved background model, PLR analysis.
- Hardware upgrades expected to reduce background significantly.
- Effort to the Global Argon Dark Matter Collaboration (GADMC) for large projects such as Darkside and Argo.

Backup

The detector