15th International Workshop on the Identification of Dark Matter 2024
Jul 8-12 2024 L'Aquila (Italy)

Status of DEAP-3600

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On Behalf of the DEAP-3600 Collaboration

Carleton University
Canada's Capital University

DEAP collaboration

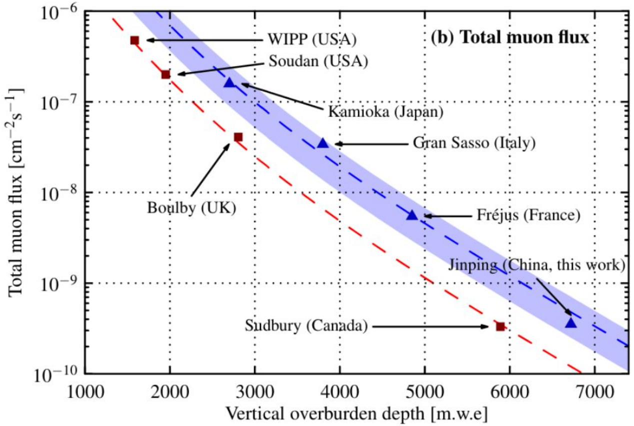
~100 researchers in Canada, Germany, Italy, Mexico, Poland, Russia, Spain, UK, USA

DEAP site

DEAP detector is located at SNOLAB in Sudbury Ontario

A deep underground laboratory which uses the 2 km of rock overburden (provides a ~6 k.m.w.e overburden)

[2007.15925] (arxiv.org)



DEAP-3600 detector

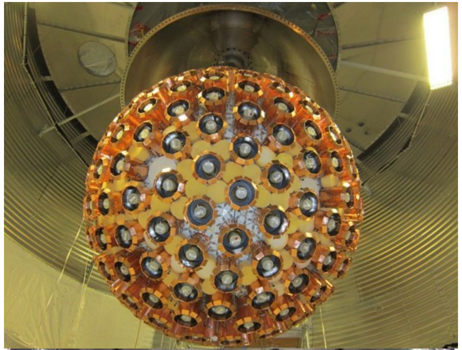
Target : 3269±24 kg of LAr in acrylic vessel

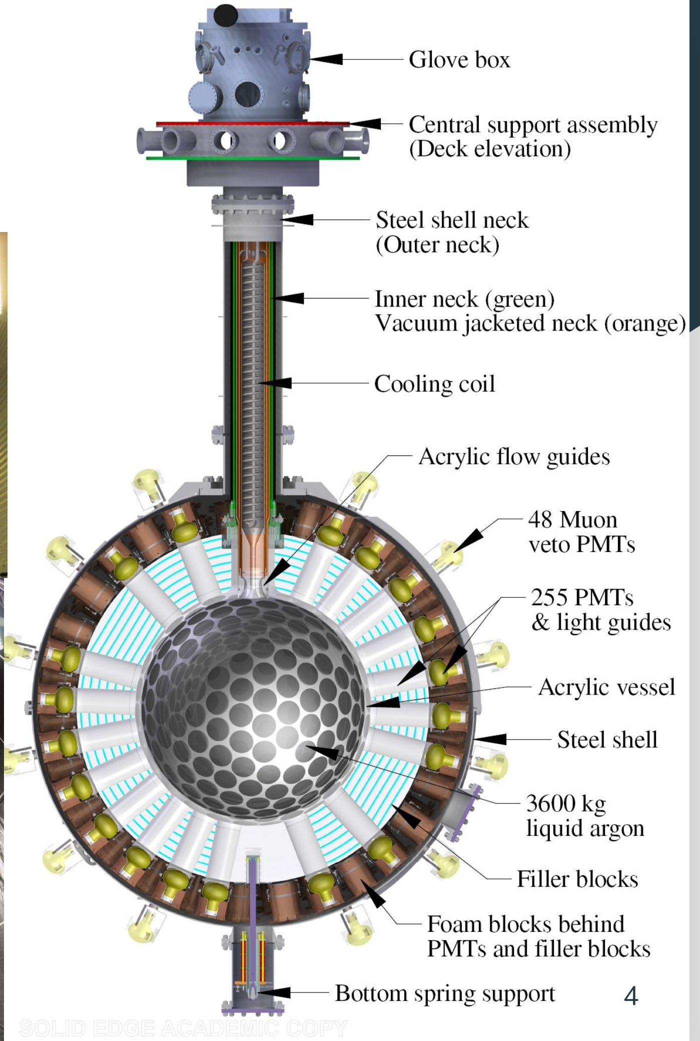
Photon detection: 255 HQE PMTs connected via acrylic light guides

Inner surface of vessel coated with TPB wavelength shifter

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

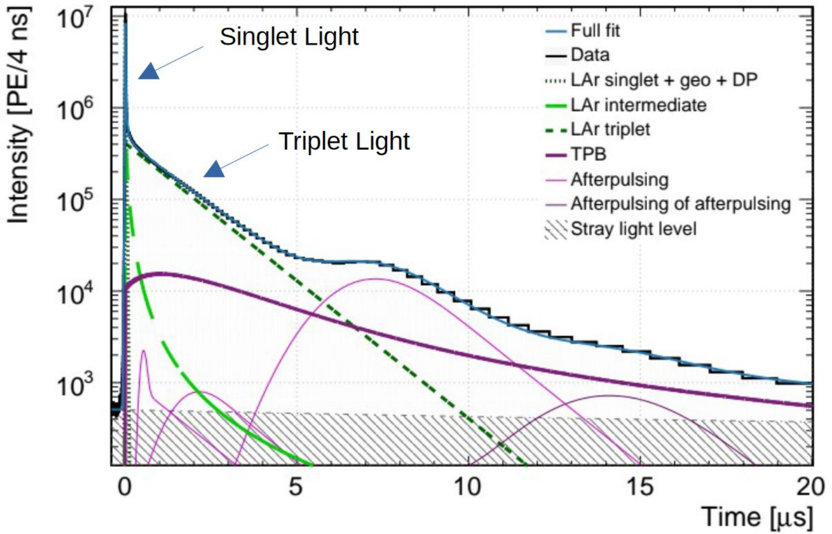
Veto: Steel shell is immersed in 300 tons of H_2O, viewed by 48 veto PMTs



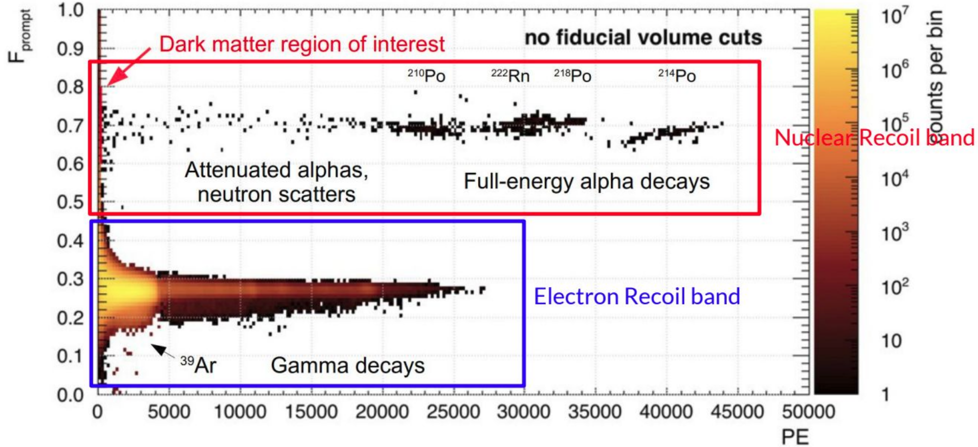


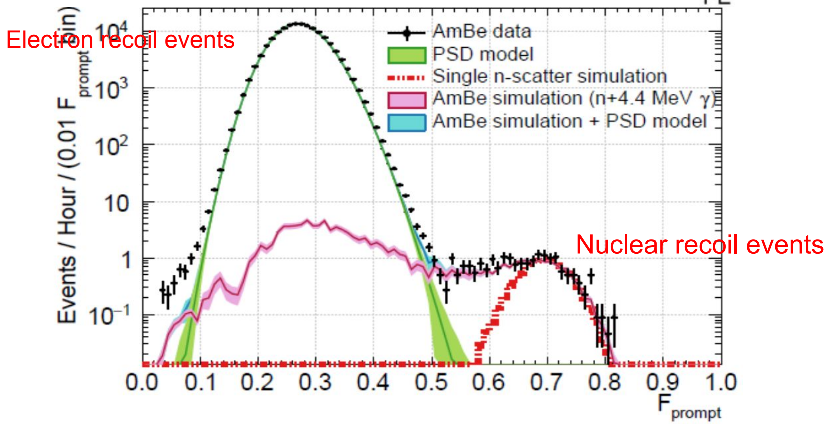
Pulse shape discrimination

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



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



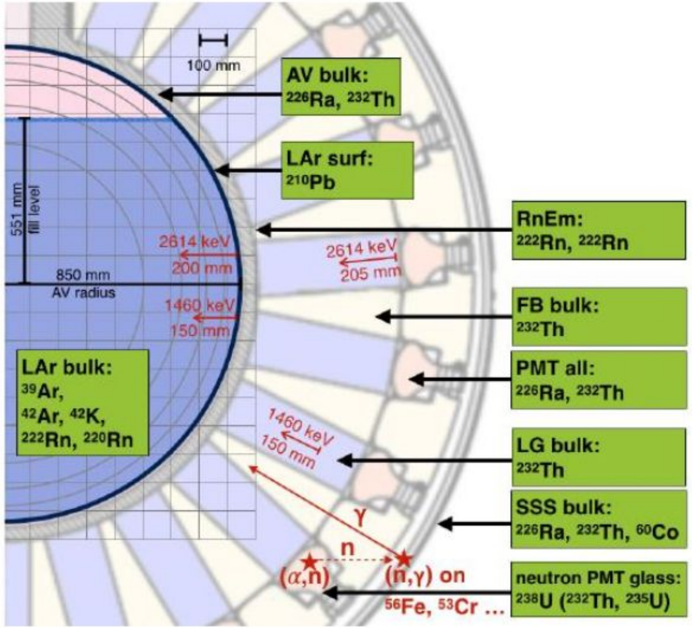


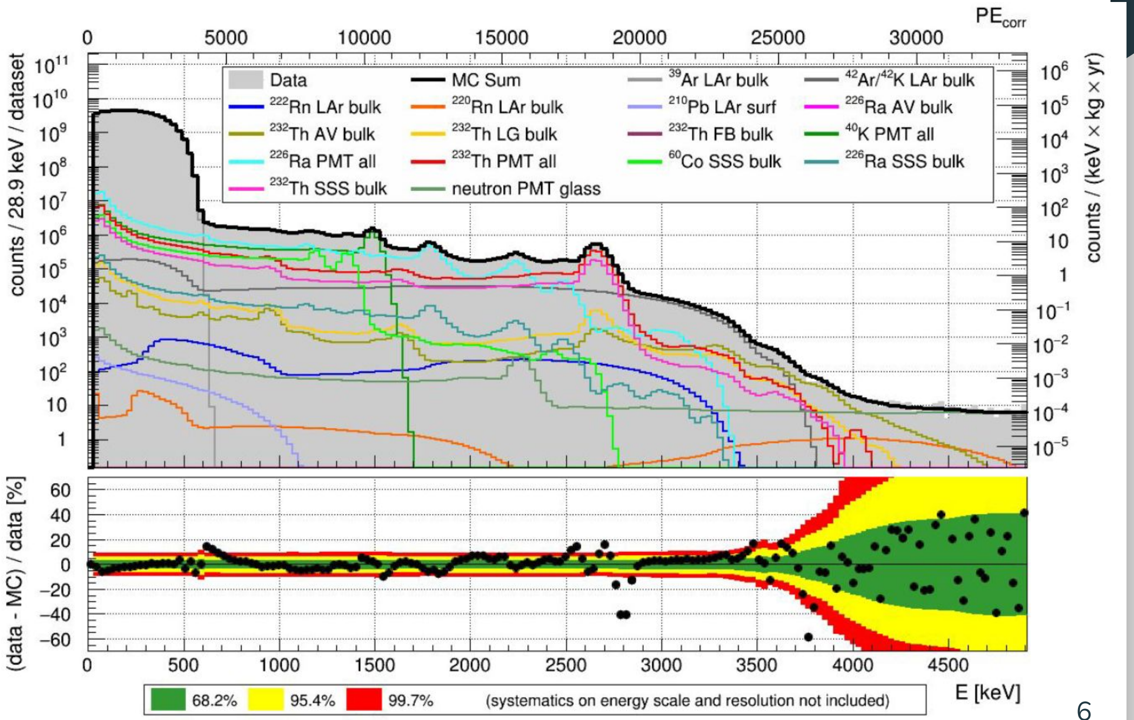
Eur. Phys. J. C 81, 823 (2021)

Electromagnetic background

Shielded by water, SSS, filler blocks, light guide, acrylic vessel.

Phys. Rev. D 100, 072009 (2019)

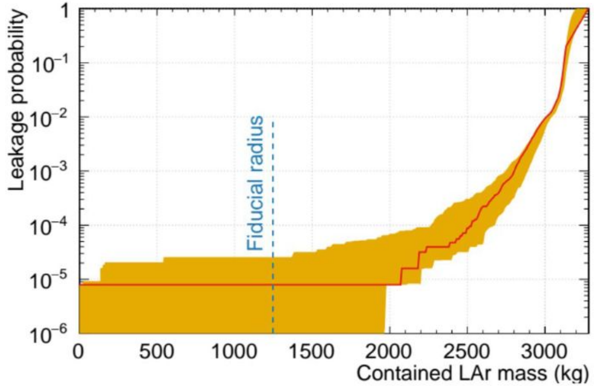




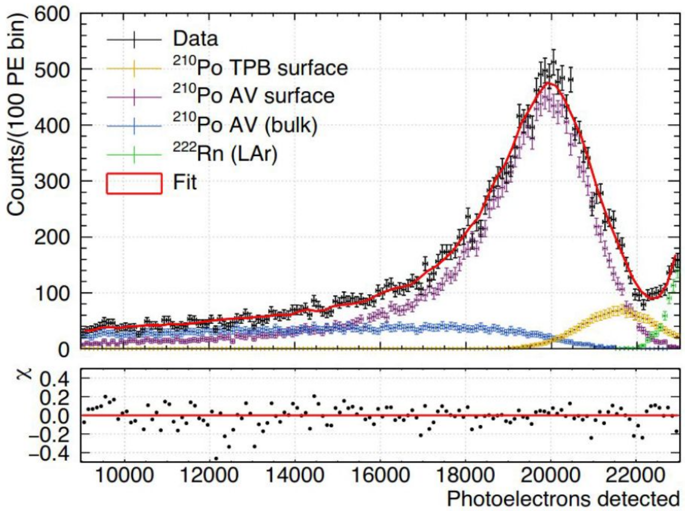
Surface background

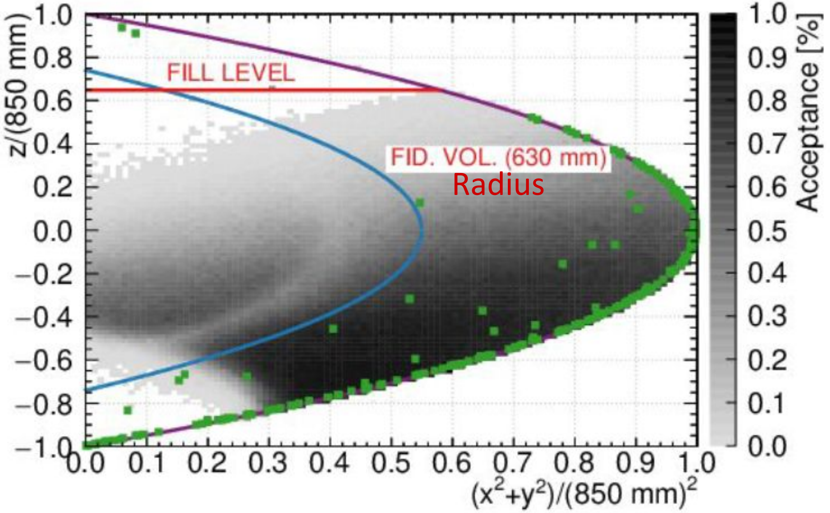
Mostly Po-210 decays on the surface of AV

Constrained by the fiducial cut



Physical Review D, 100, 022004 (2019)

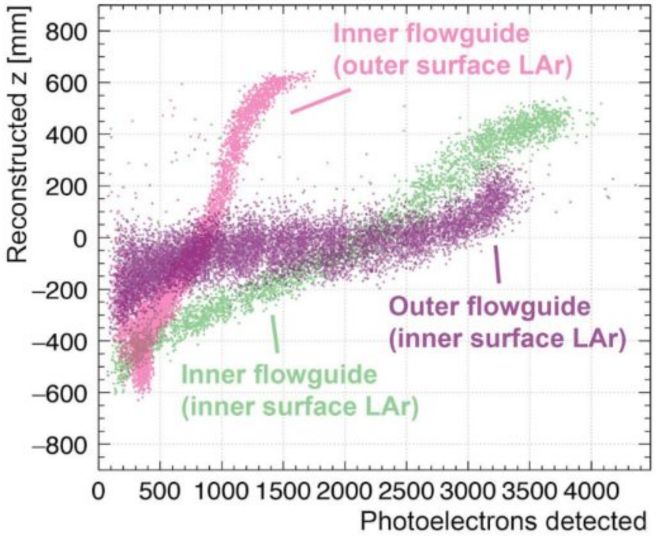


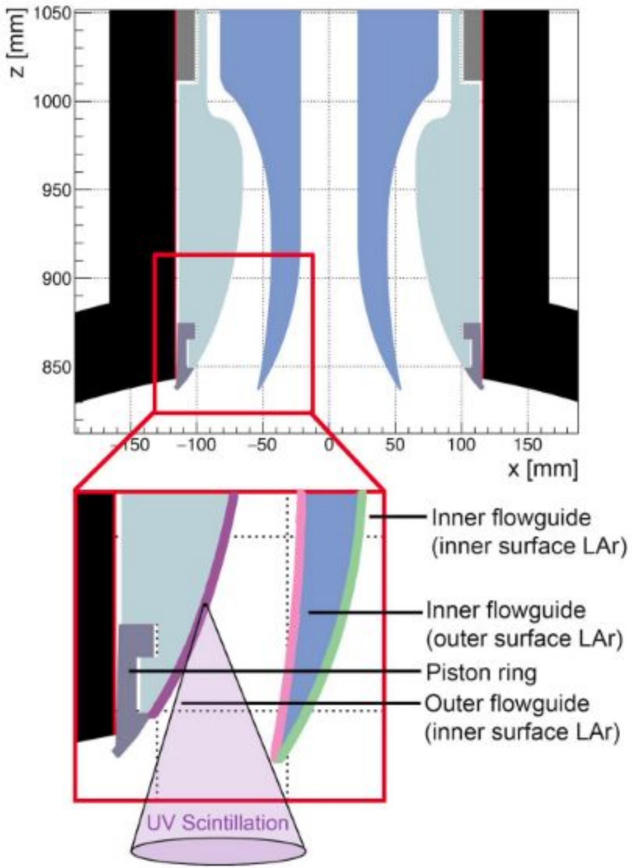


Physical Review D, 100, 022004 (2019)

Neck background

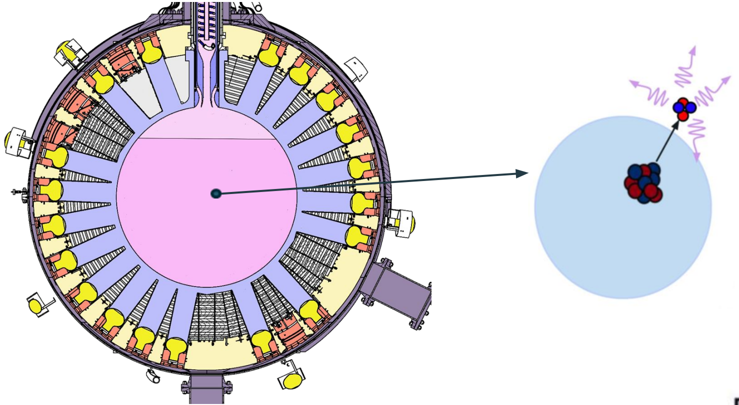
Alpha decay by the Po-210 from the surface of the acrylic flow guide located at neck of the detector





Significant backgrounds on low energy produces due to the shadowed/degraded alpha decays

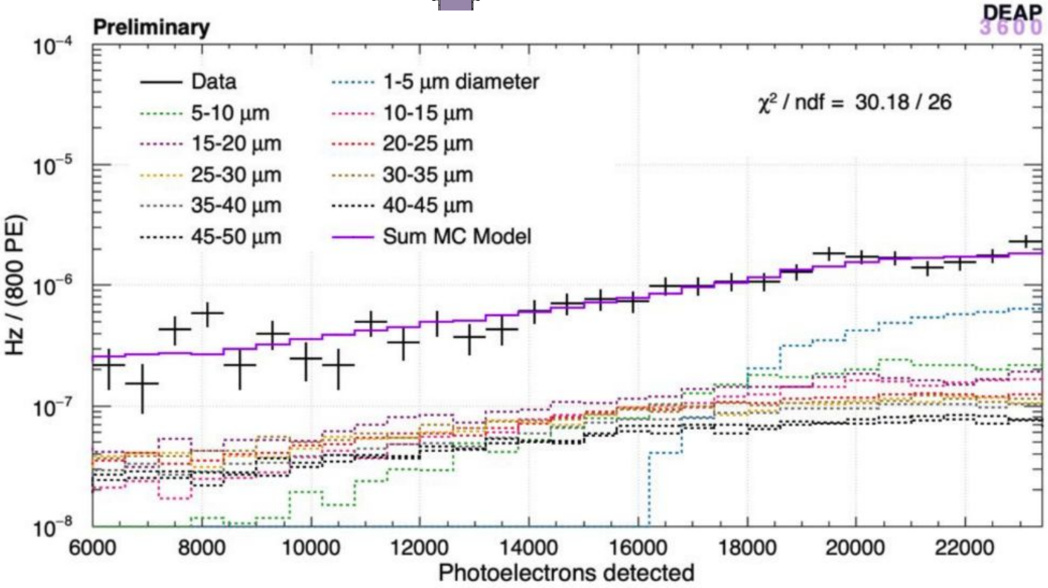
Dust background



Attenuation before entering liquid argon, and scintillation light shadowed

Different dust sizes are simulated and modelled with the data

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



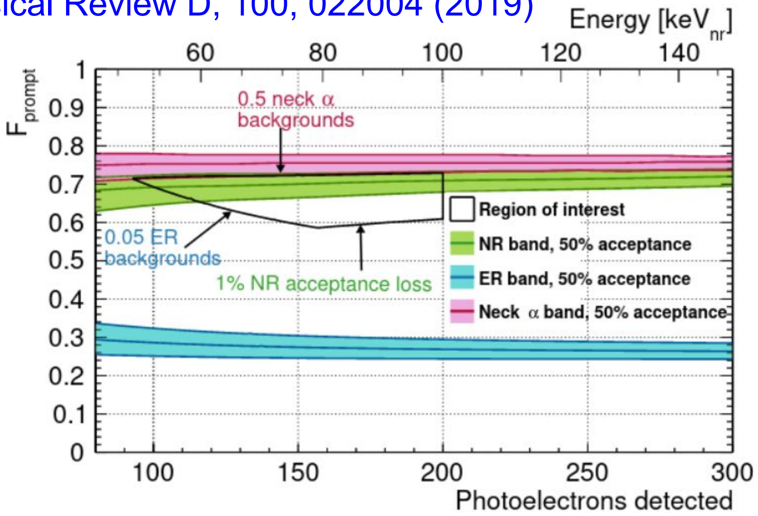
Physical Review D, 100, 022004 (2019)

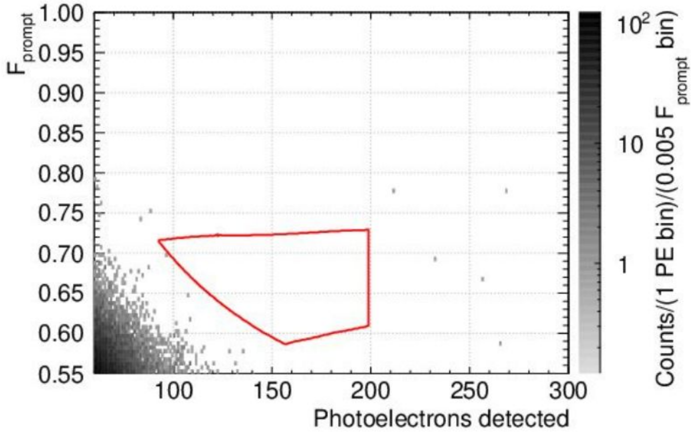
WIMP search

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

No WIMP-like signals: 0 events in ROI

	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
α-decays in neck	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

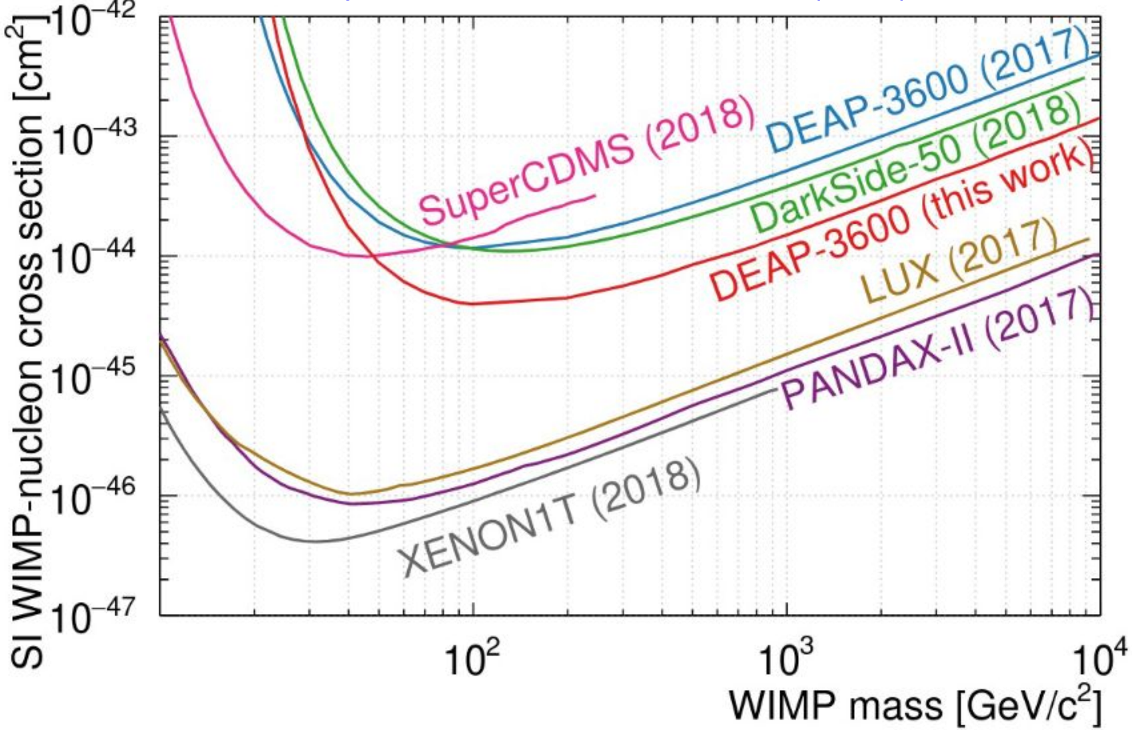




Sensitivity

Exclude S.I WIMP-nucleon cross sections above $3.9x10^{-45}$ cm² for 100 GeV/c² WIMP mass (90% C.L.)

Physical Review D, 100, 022004 (2019)

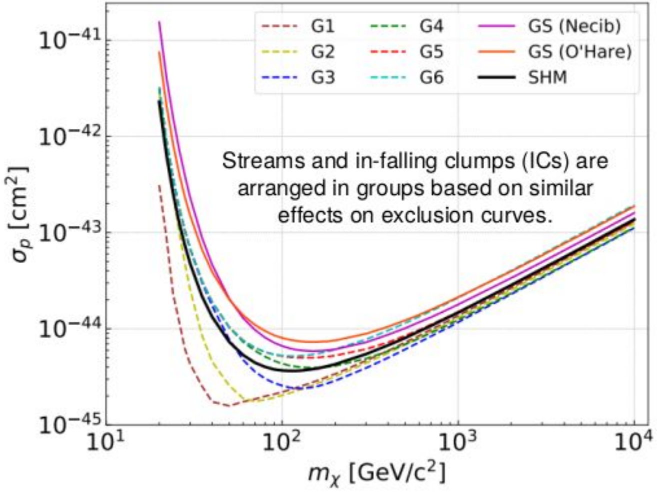


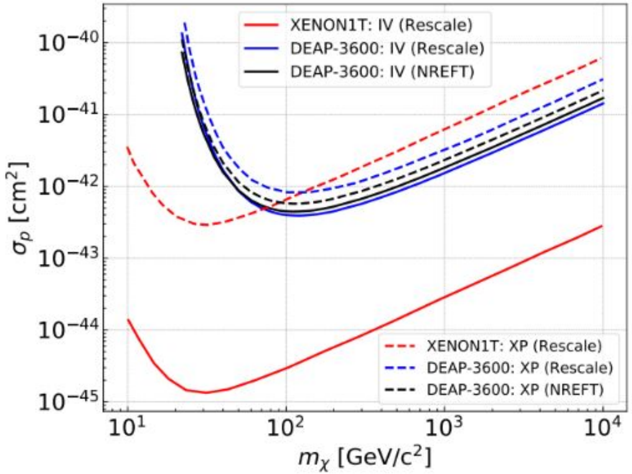
Constraints on dark matter-nucleon effective coupling

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.

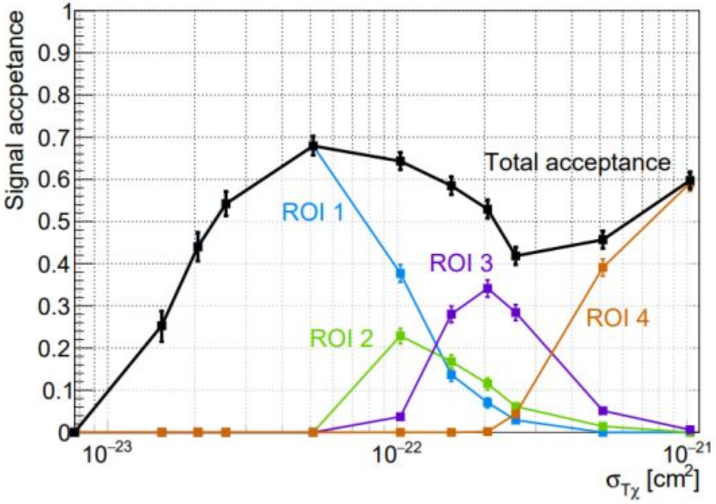
Constraints on the Q1 interaction, for
IV (isovector; solid) and
XP (xenonphobic; dashed) scenarios.

Planck-scale mass dark matter

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

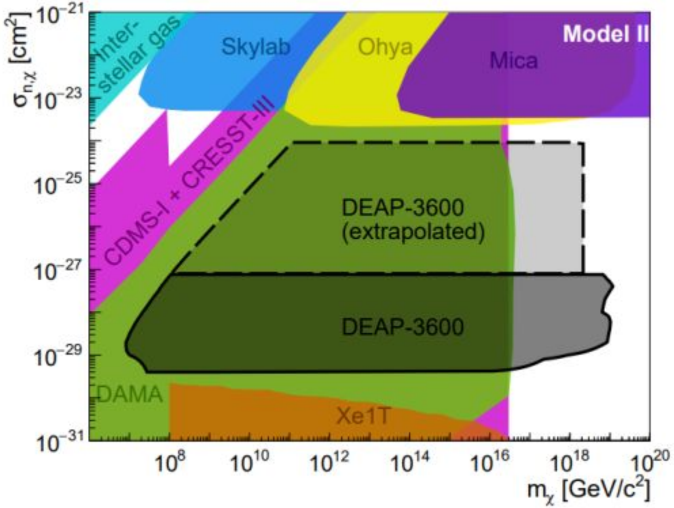
Multiple recoils - very high-energy, low F_{prompt} event

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



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

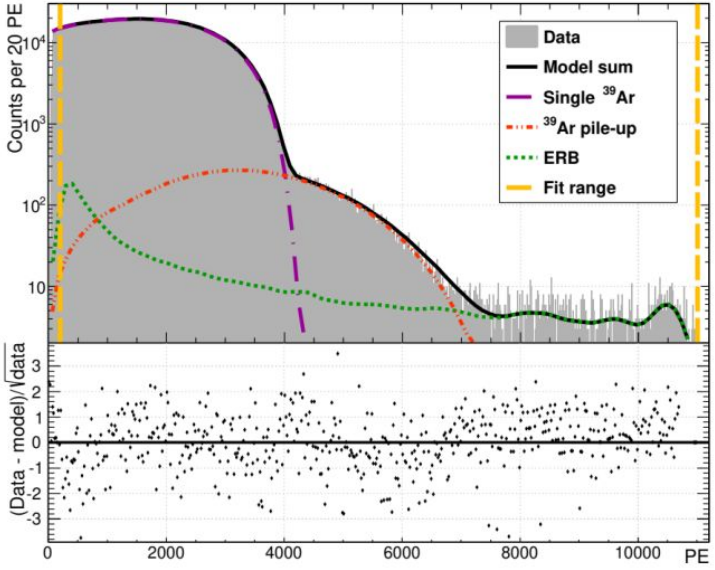
Phys. Rev. Lett. 128, 011801 (2022)



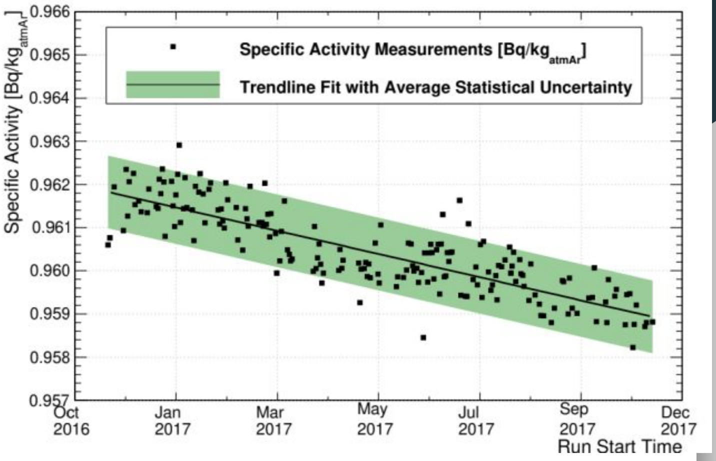
Specific activity of ^{39}Ar

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)	$0.964 \pm 0.001_{stat} \pm 0.024_{sys}$

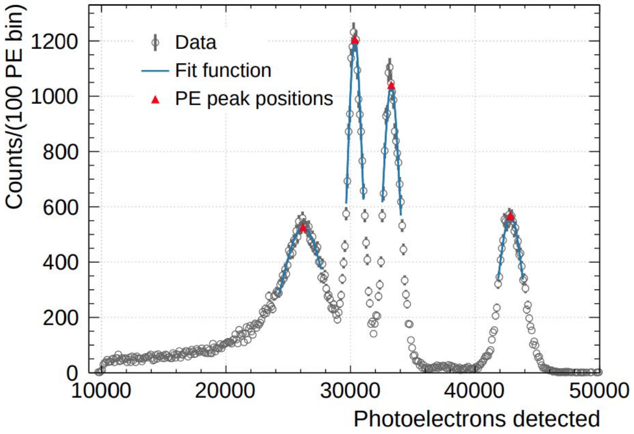
https://arxiv.org/pdf/2406.18597

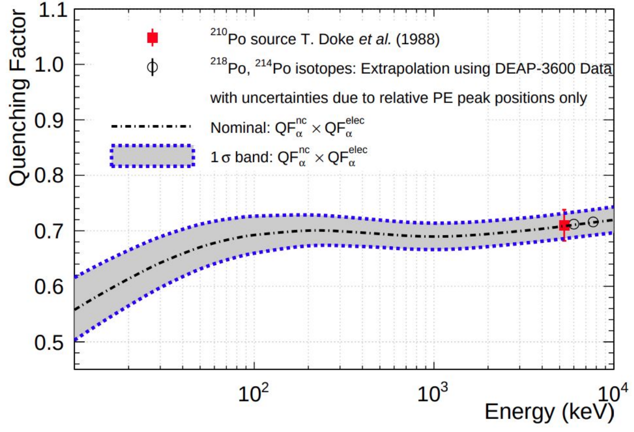
Alpha quenching factor in liquid argon

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

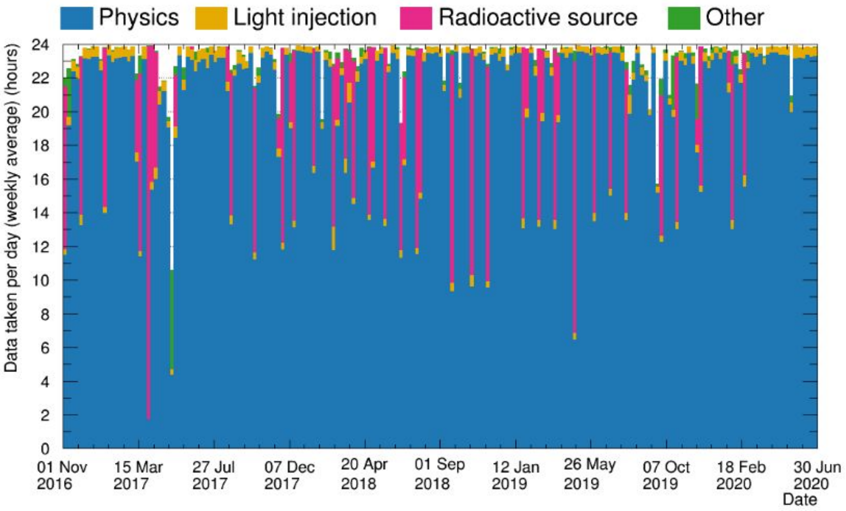
The energy-dependent QF: product of the best-fit electronic QF curve and the nuclear QF curve from TRIM



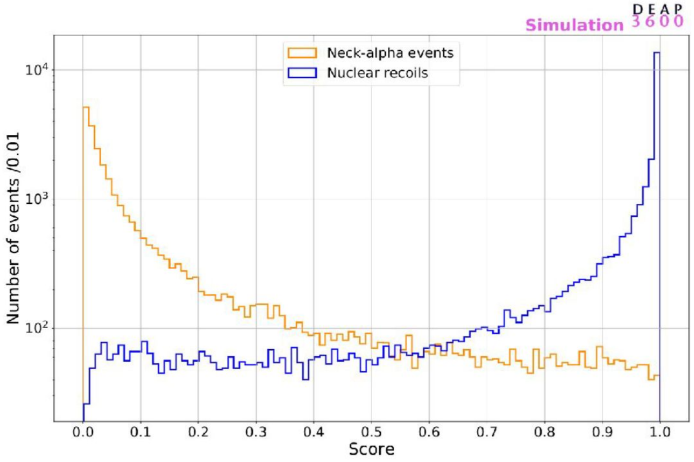


Coming up

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



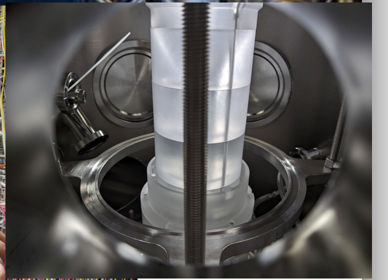
MVA algorithms (RF, BDT, NN) for background rejection (neck alpha, dust alpha for example)



Detector Upgrade

- The hardware upgrades will allow us to reach DEAP-3600 design sensitivity
- To verify the DEAP background model
- To have a “zero background” data set
- Upgrades are designed to remove the neck and dust backgrounds.
- Replace faulty VETO PMTs
- Many maintenance/process improvements

Detector Upgrade

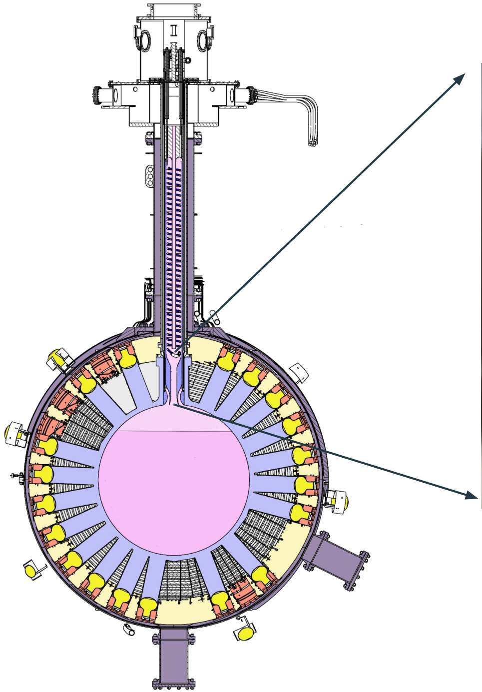


Neck flow guide replacement

Warming the neck region to remove possibility of liquid film or droplets forming

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

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



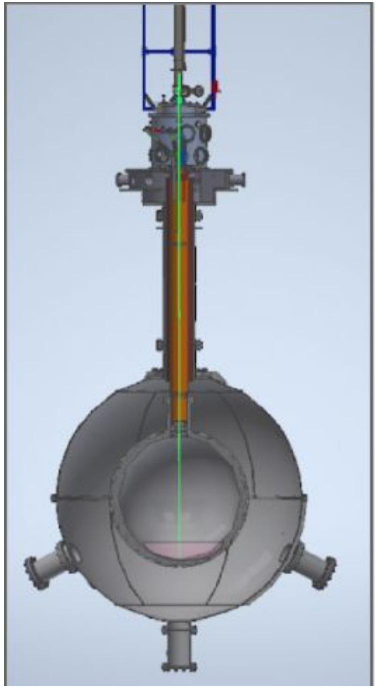
Dust removal

Deployment of stainless steel pipe through the neck of the detector

- syphon liquid argon into external storage dewar

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

Refill AV with clean LAr



Summary

- World-class PSD performance in Liquid Argon.
- Exclude S.I WIMP-nucleon cross sections above 3.9×10^{-45} cm^2 for 100 GeV/c^2 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
- Coming up: 3 years Dataset, MVA algorithms, improved background model.
- Hardware upgrades are in progress and are expected to significantly reduce degraded alpha backgrounds.

Thank you for your attention

Backup

The detector

Neutron background

Cosmogenic Neutrons:

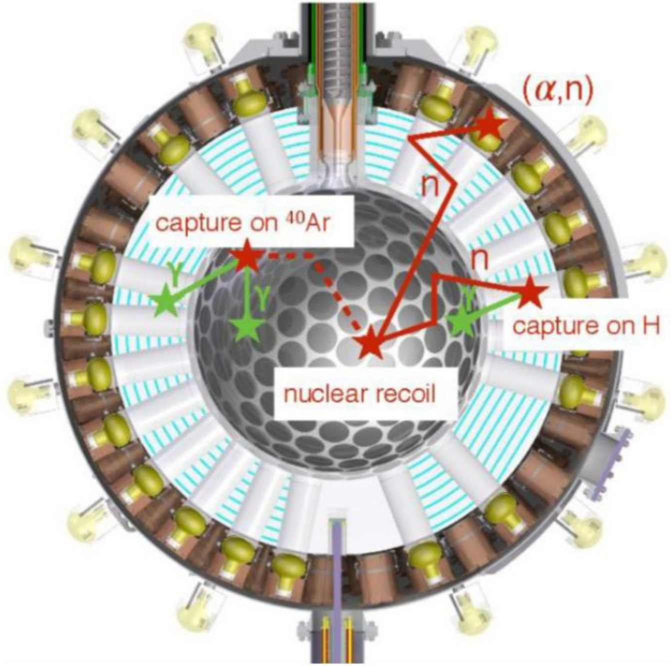
Produced by high energy atmospheric muon: are tagged when passing through muon veto

Radiogenic neutrons:

Produced in the (α,n) reaction triggered by α-decays from Uranium/Thorium chains or by the spontaneous fission of 238-U.

Mitigation process: estimation of flux with material assays

Neutron capture analysis: tagging NR event closely followed (1ms) by high energy ER event



Liquid Argon

Good scintillation light yield (40,000 photons/MeV)

Transparent to scintillation light (128 nm)

Singlet State (6 ns) → Nuclear Recoils (NR) i.e. (WIMP, α, n)

Triplet State (1.4 μs) → Electron Recoils (ER) i.e. (β, μ, γ)