Dark Matter Search in DEAP-3600: Recent Results and Future Prospects

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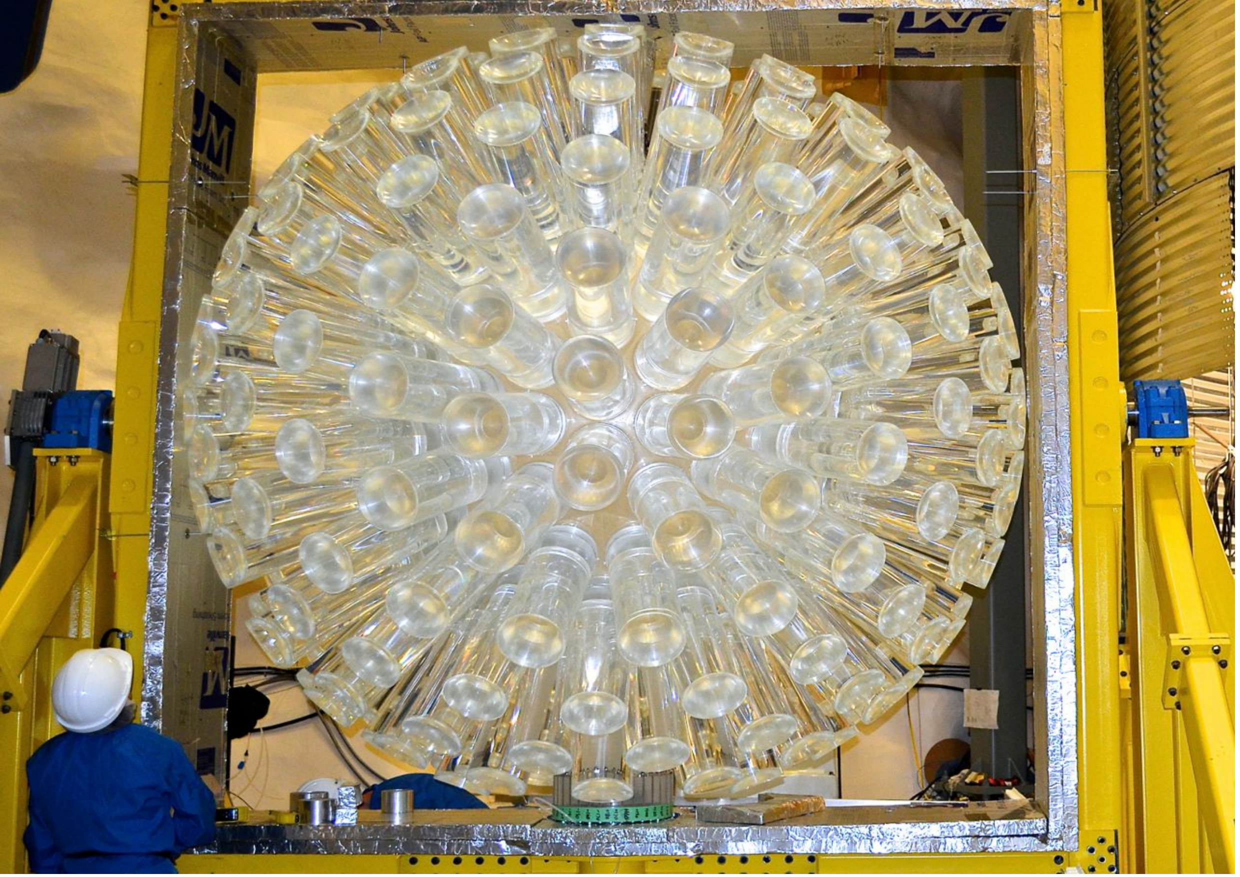
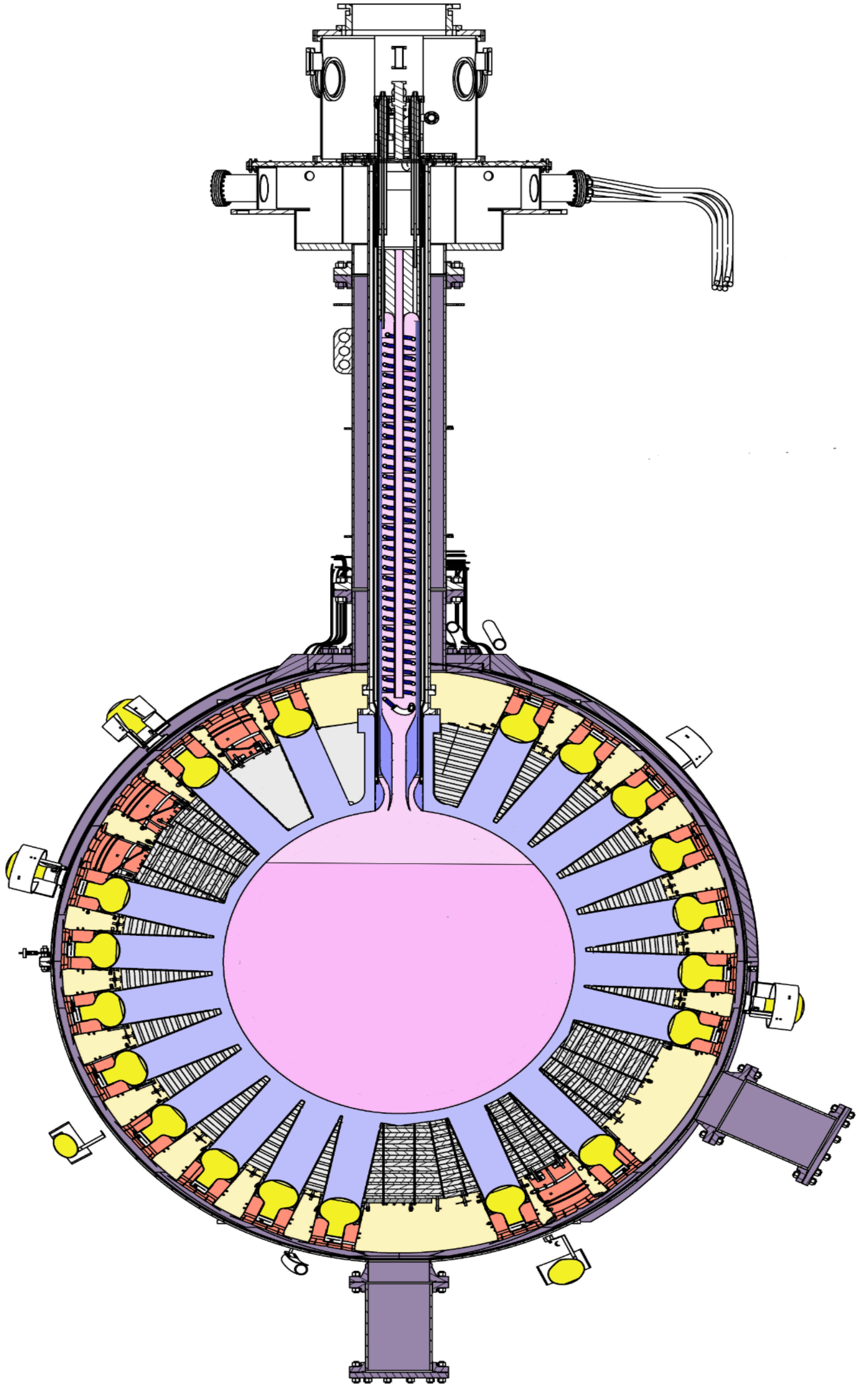
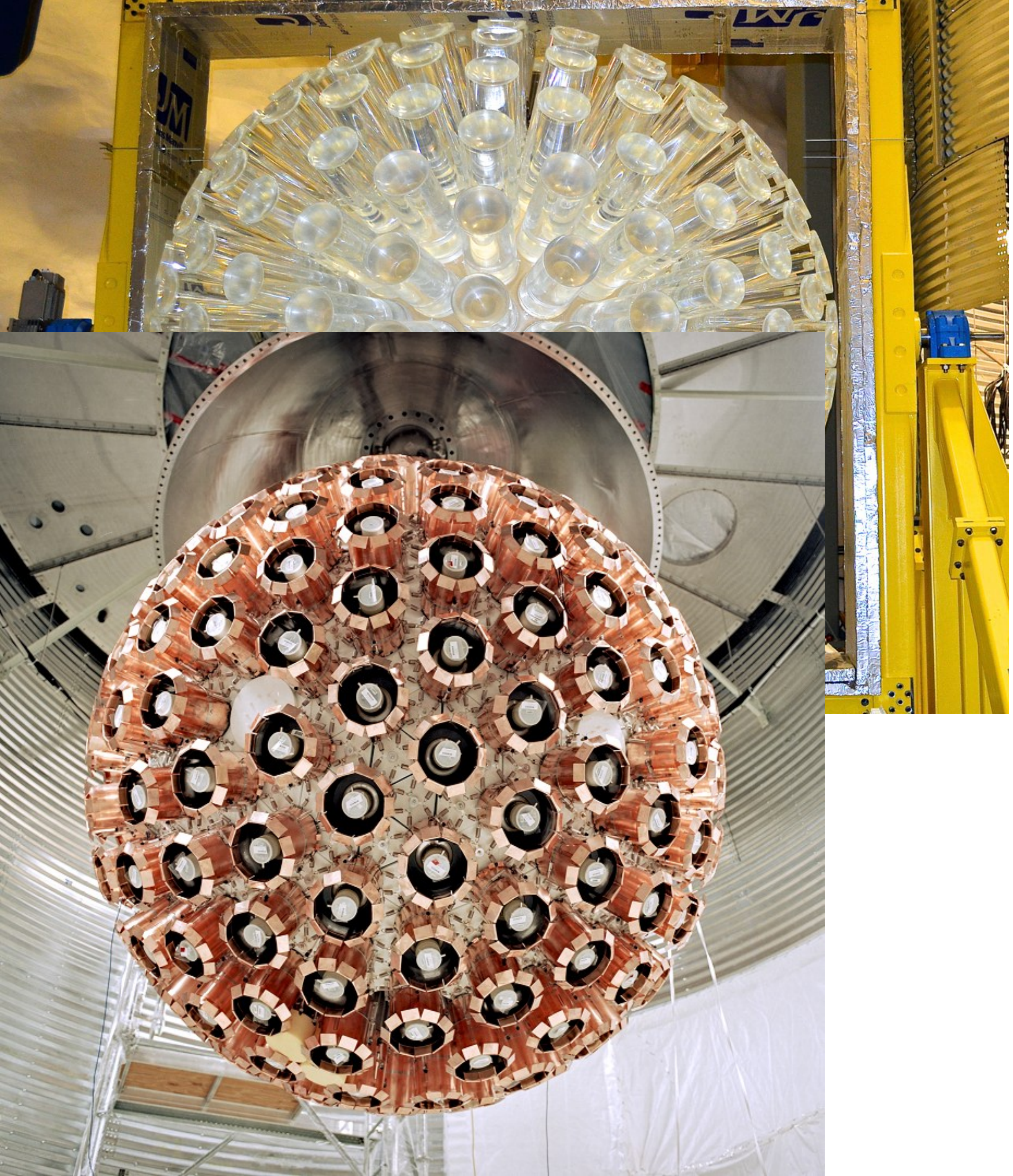
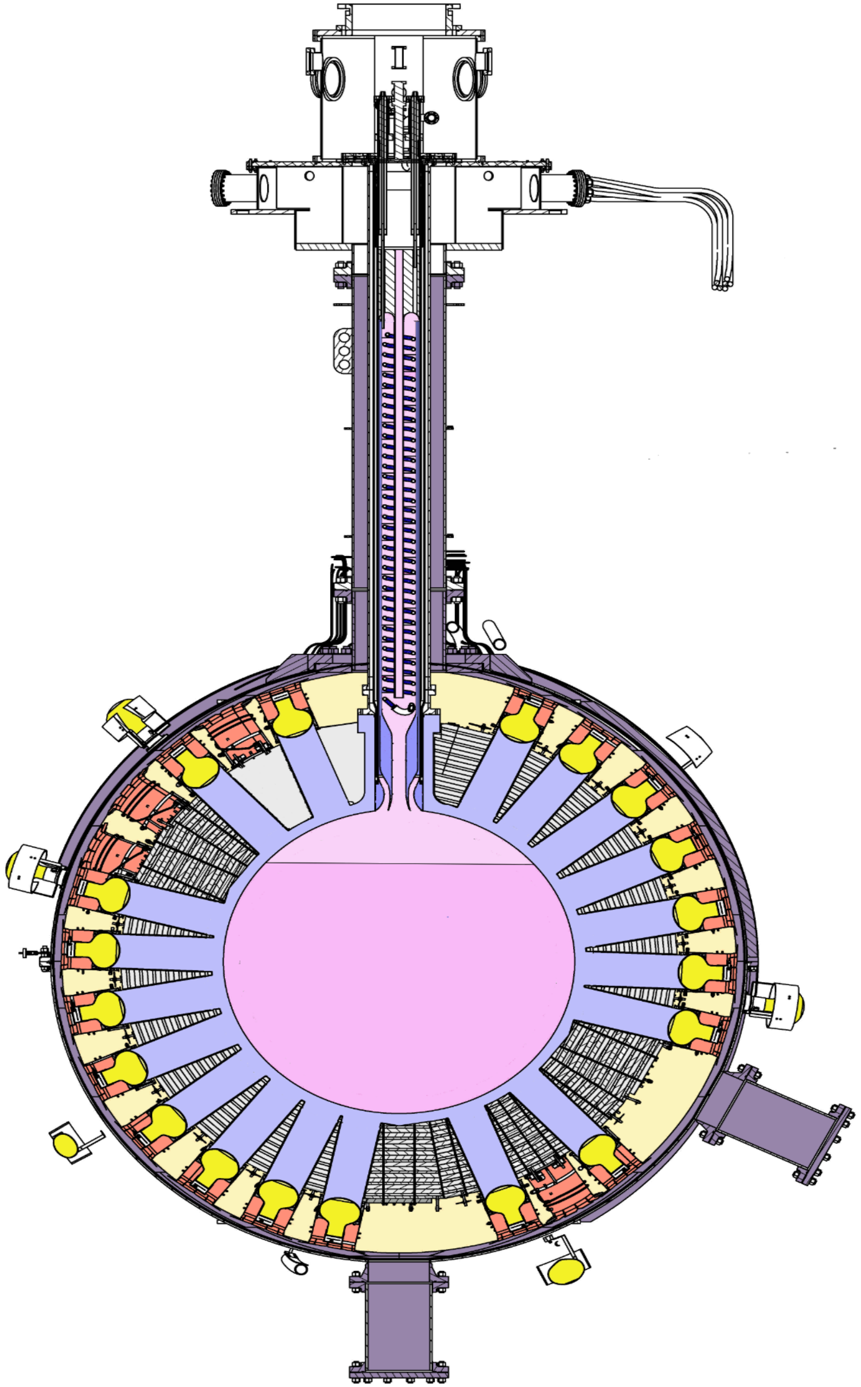
Topics in Astroparticle and Underground Physics (TAUP2025)

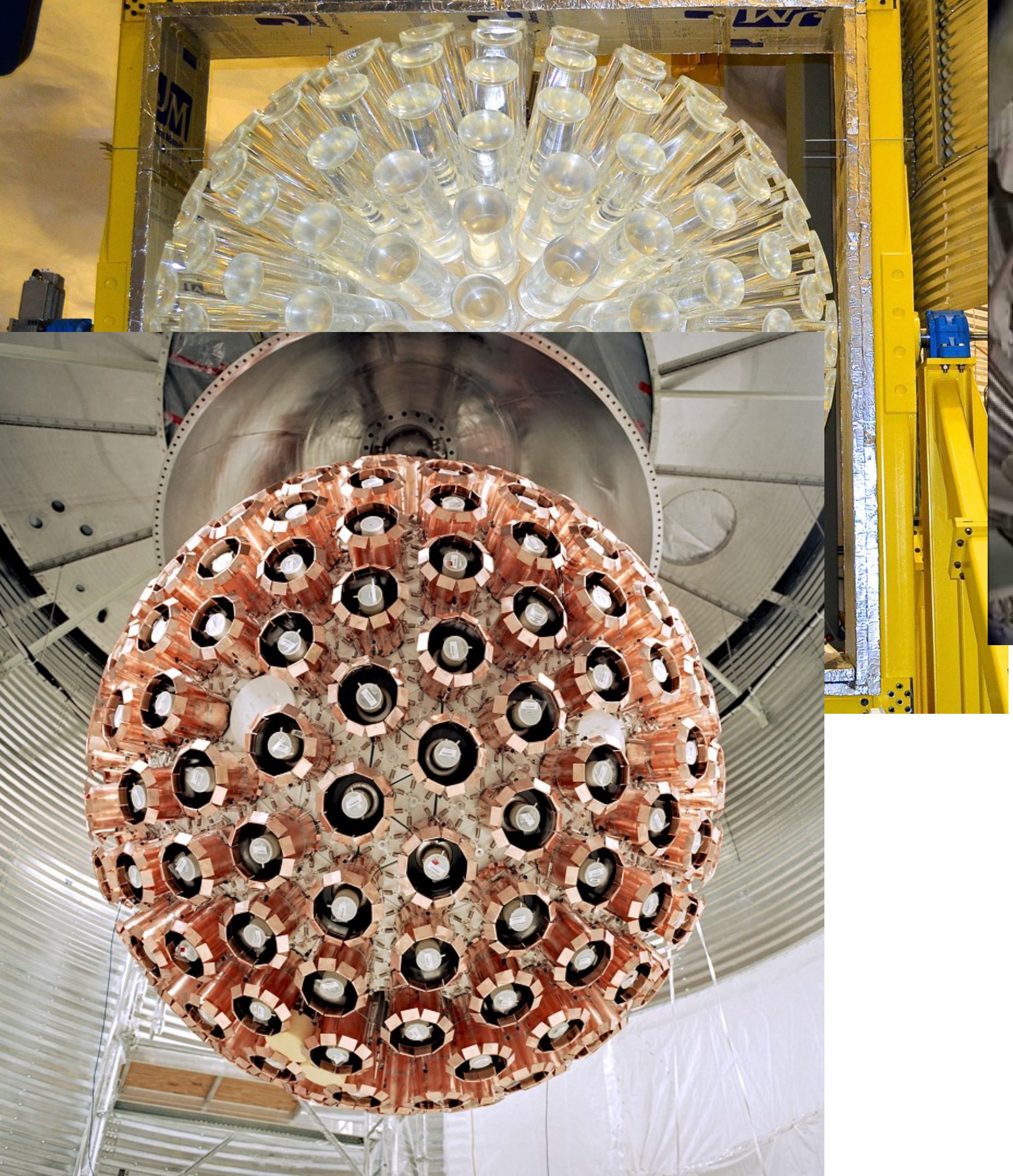
Xichang, Sichuan Province, China

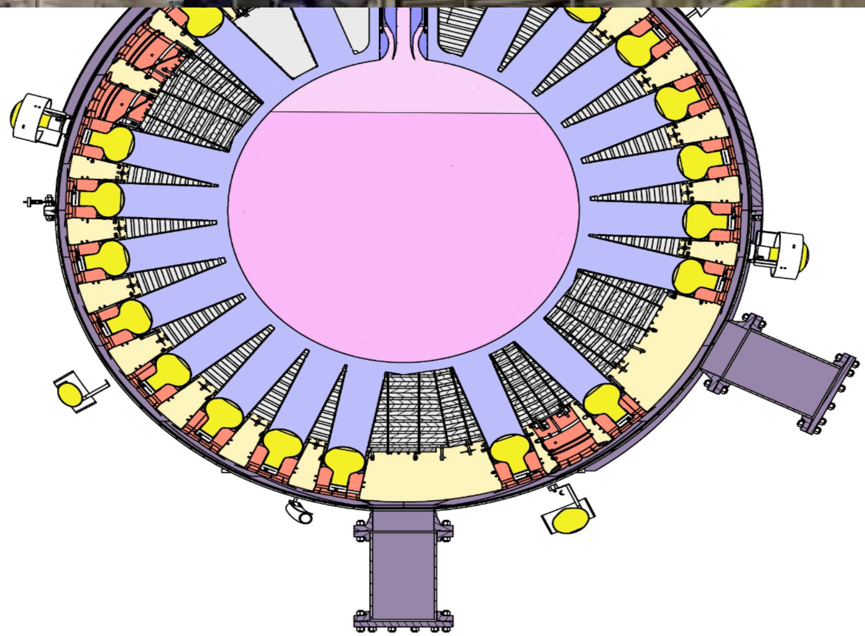






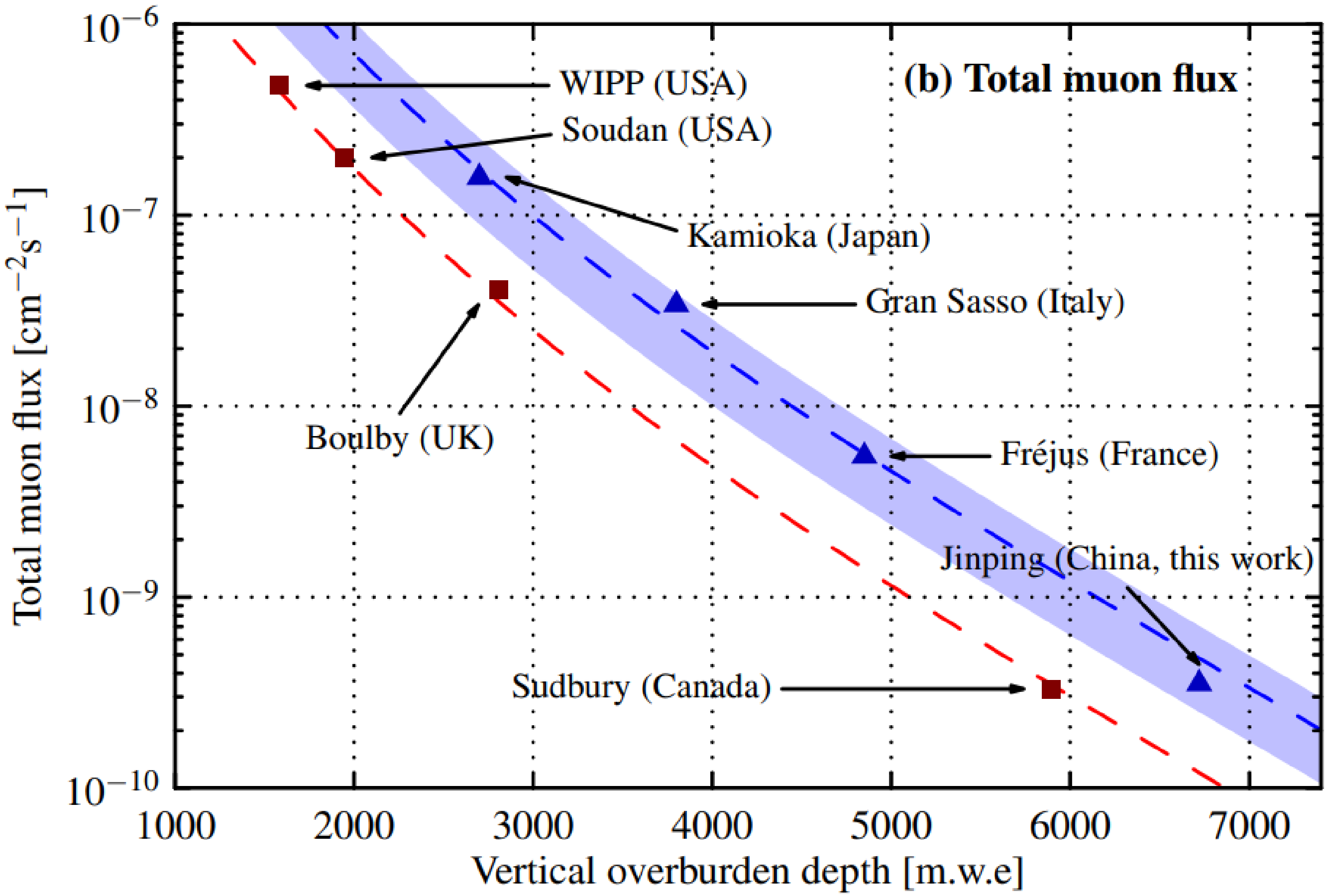




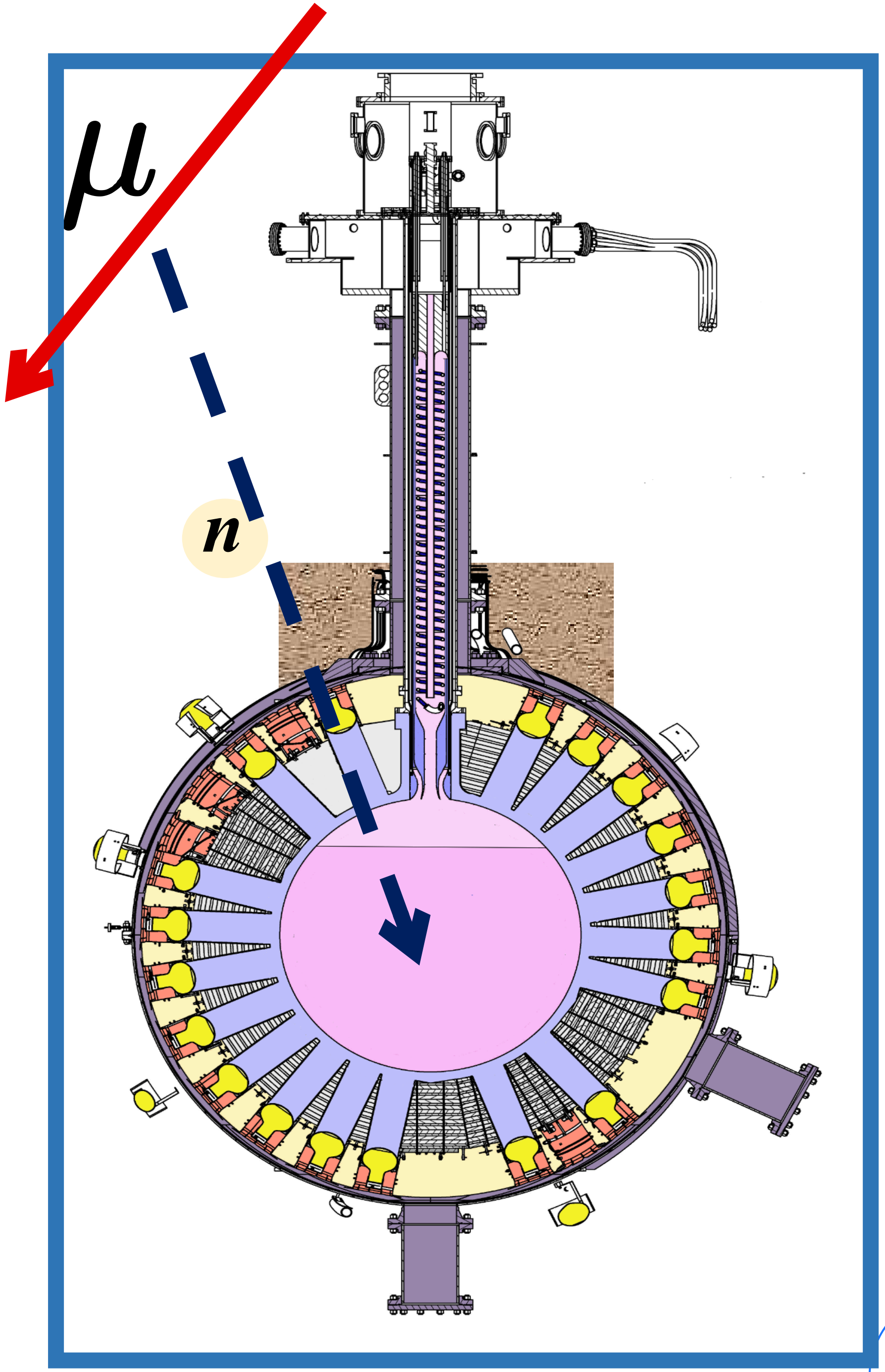


The detector

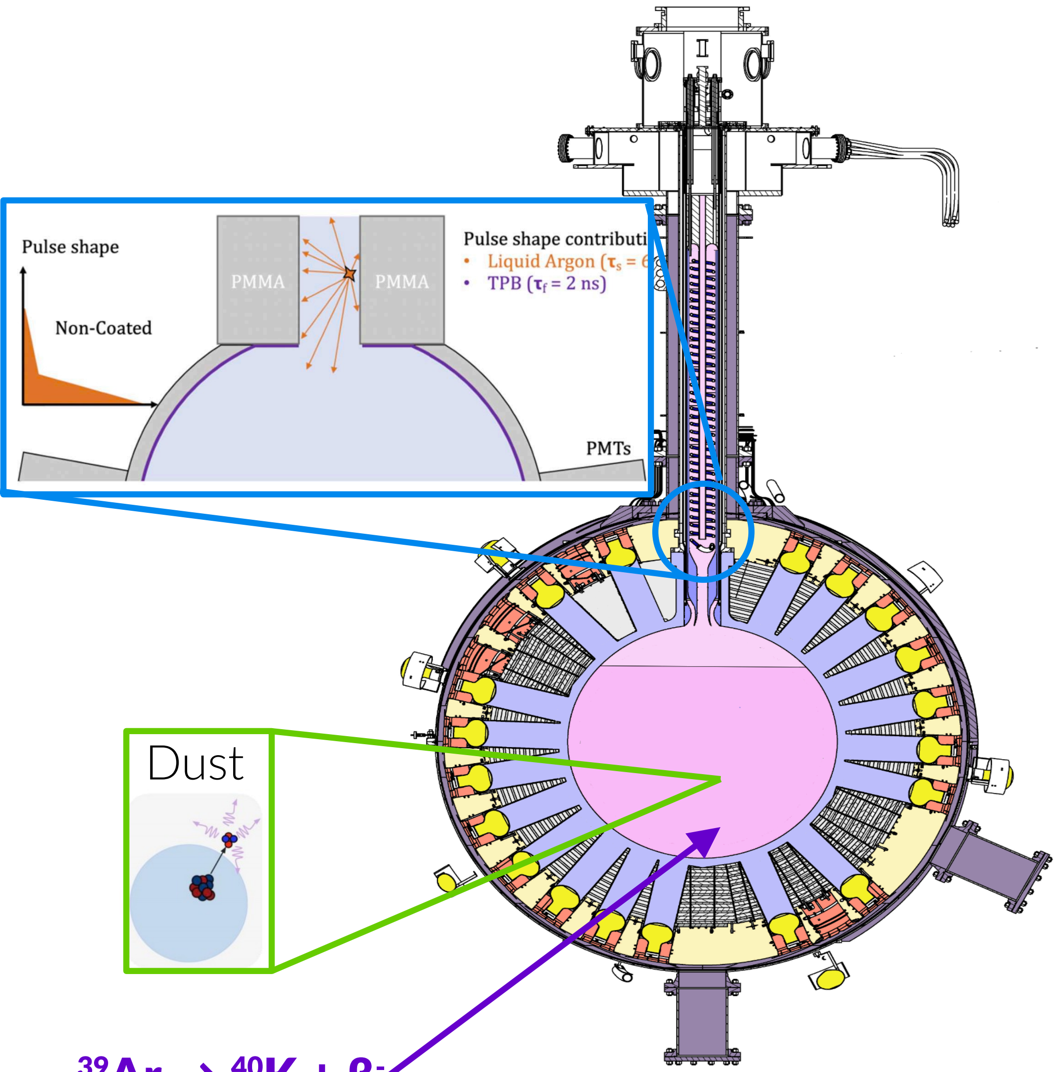
DEAP-3600 is set at SNOLAB (Sudbury, Canada), 2 km underground

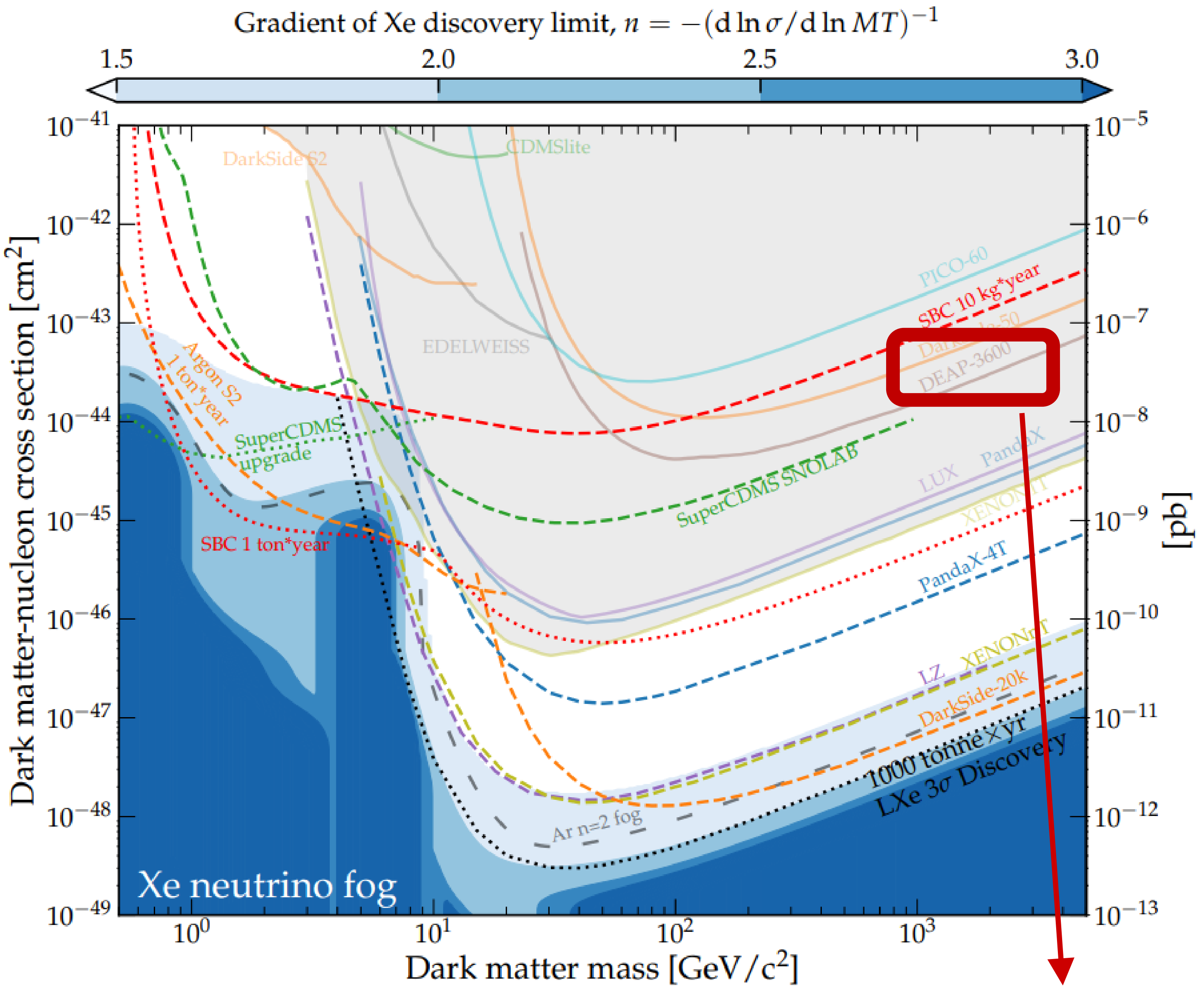


ArXiv: 2007.15925



WIMP search in LAr





$^{39}Ar \rightarrow {}^{40}K + \beta^-$

0.96 Bq/kg,

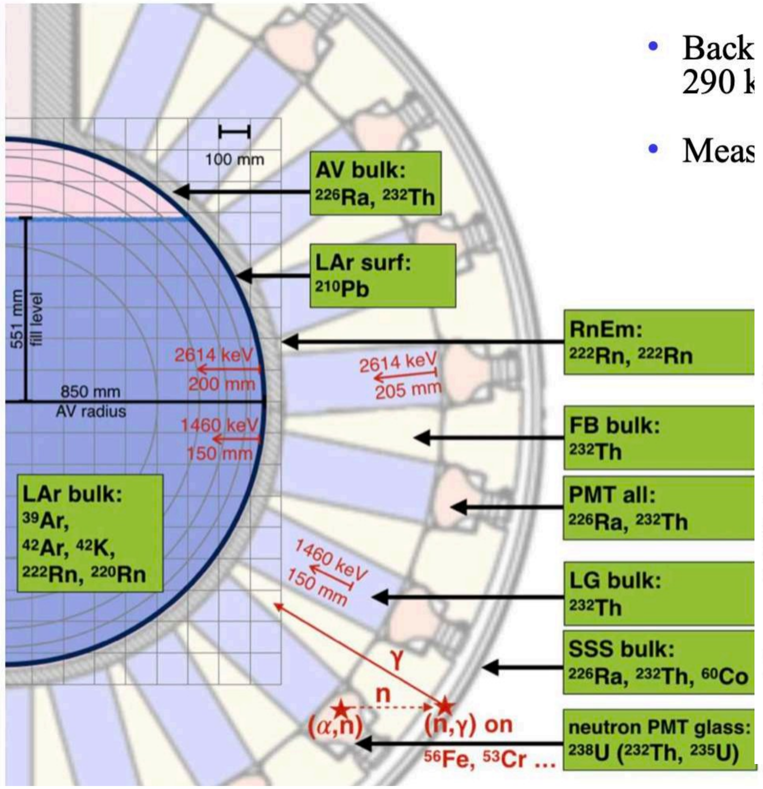
Discriminated against w/ pulse shape discrimination

arXiv: 2203.08084

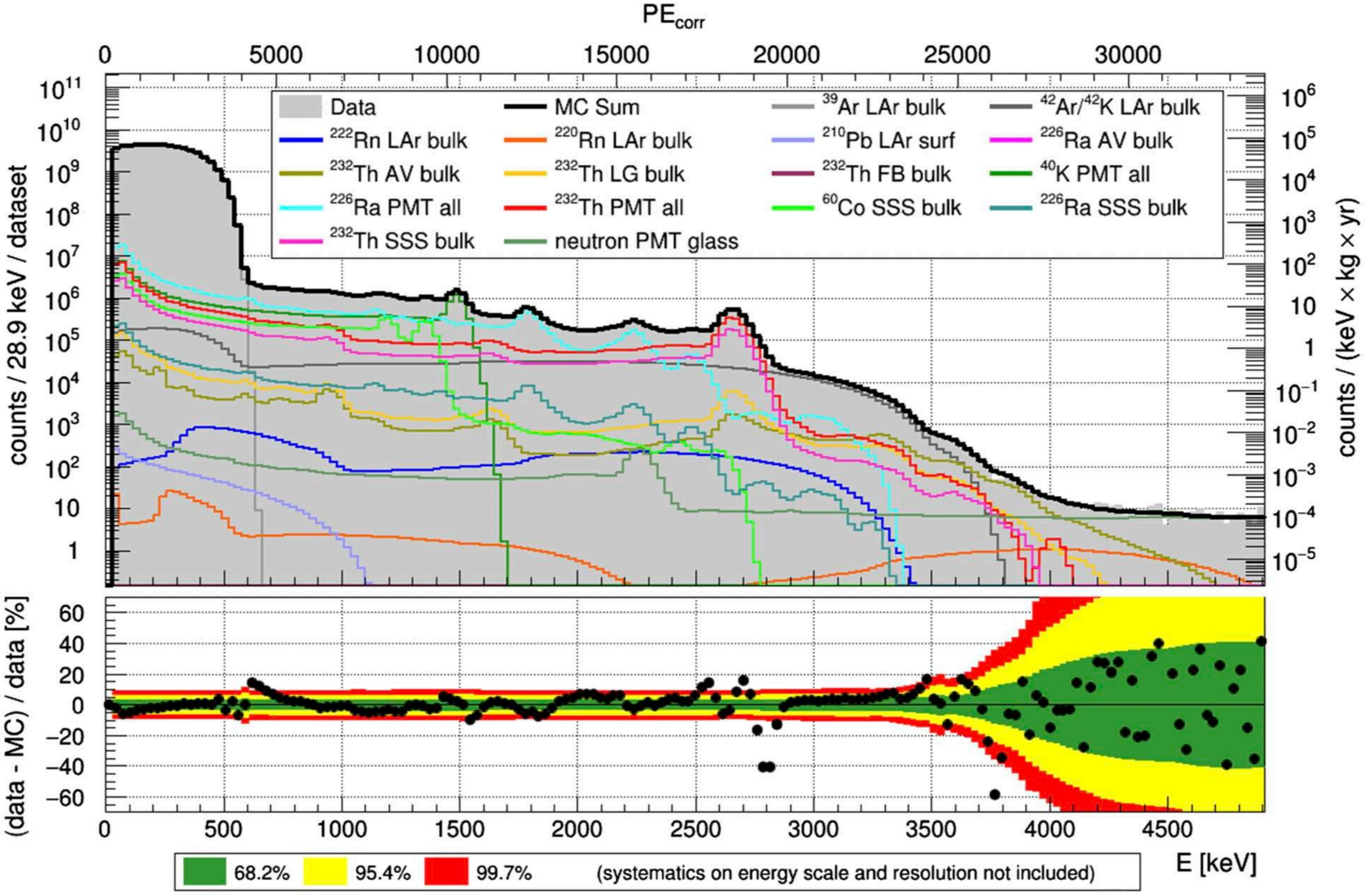
DEAP-3600. Phys. Rev. D 100, 022004 (2019)

Fully modeled EM background

Electron recoil background fully **modeled up to 10 MeV** and rejected thanks to the pulse shape discrimination



- Back
290 k
- Meas



Phys. Rev. D 100, 022004 (2019)

Phys. Rev. D, 100, 072009 (2019)

Dark matter **E**xperiment using **A**rgon **P**ulse-shape discrimination

$$I_{LAr}(t) = \frac{R_s}{\tau_s} e^{-t/\tau_s} + \frac{1 - R_s - R_t}{\tau_{rec}(1 + t/\tau_{rec})^2} + \frac{R_t}{\tau_t} e^{-t/\tau_t}$$

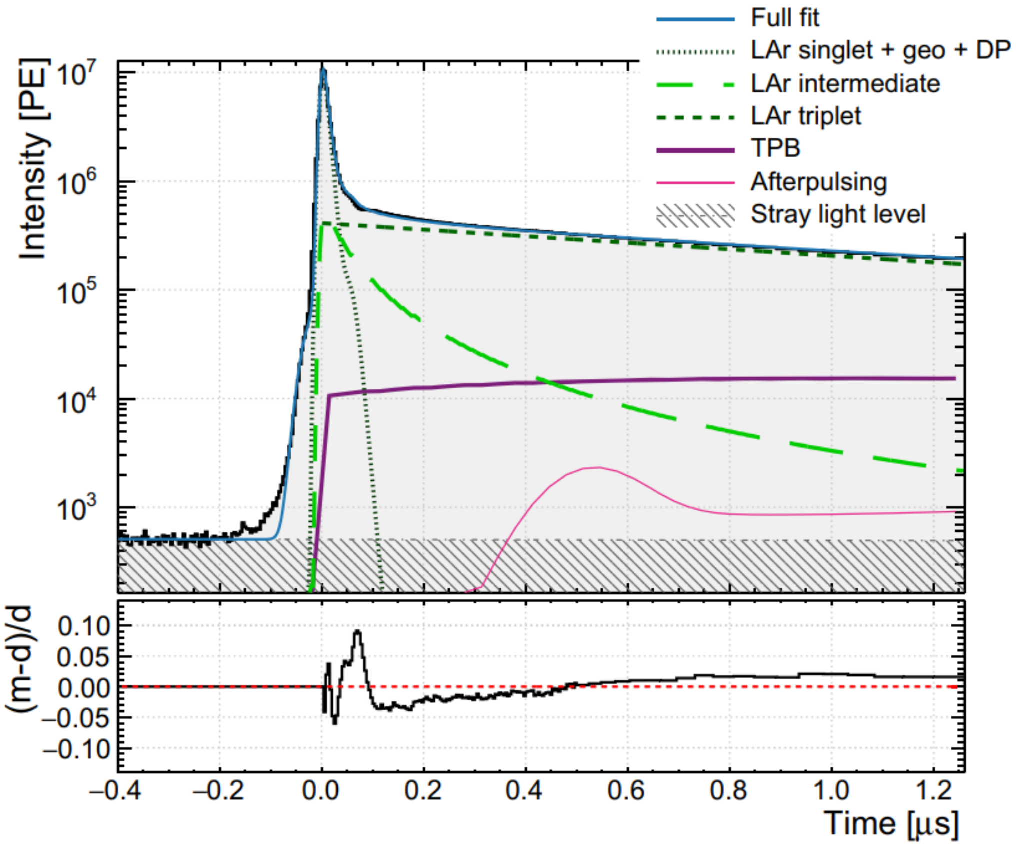
$\tau_s = 8.2 ns$

$\tau_t = 1445 ns$

$\tau_{rec} = 175.5 ns$

$R_s = 0.23$

$R_t = 0.71$



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

Dark matter **E**xperiment using **A**rgon **P**ulse-shape discrimination

Singlet state **Triplet state**

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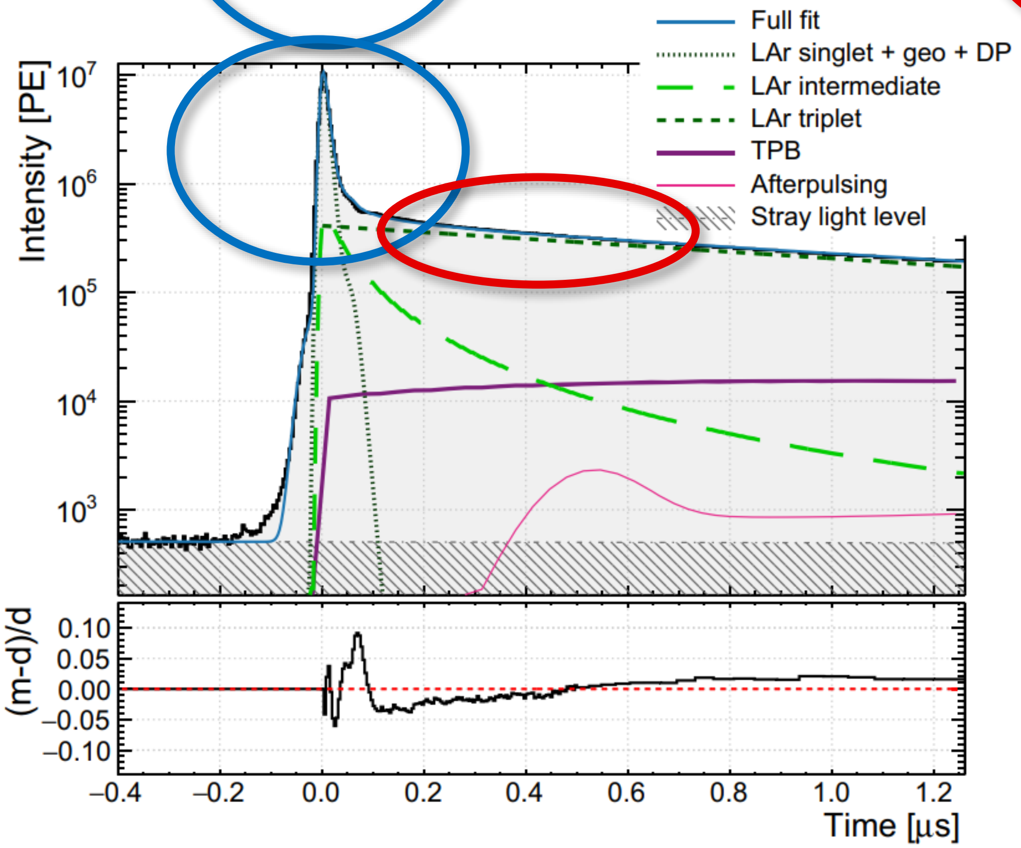

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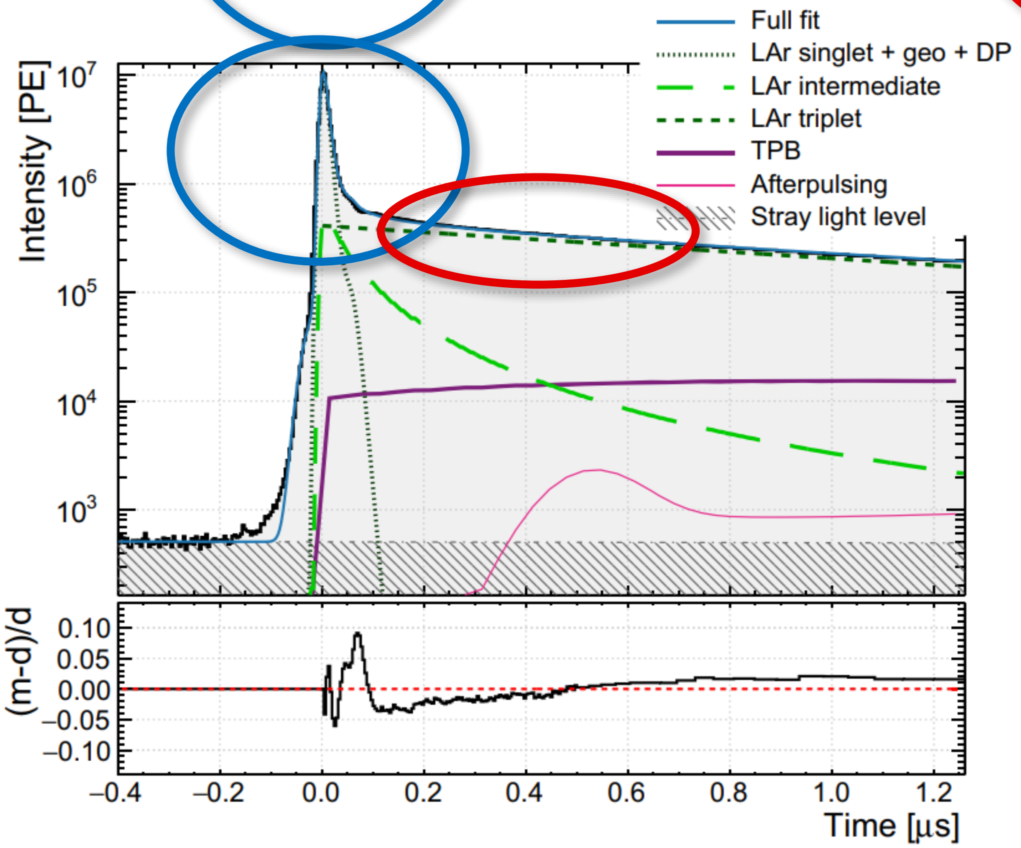
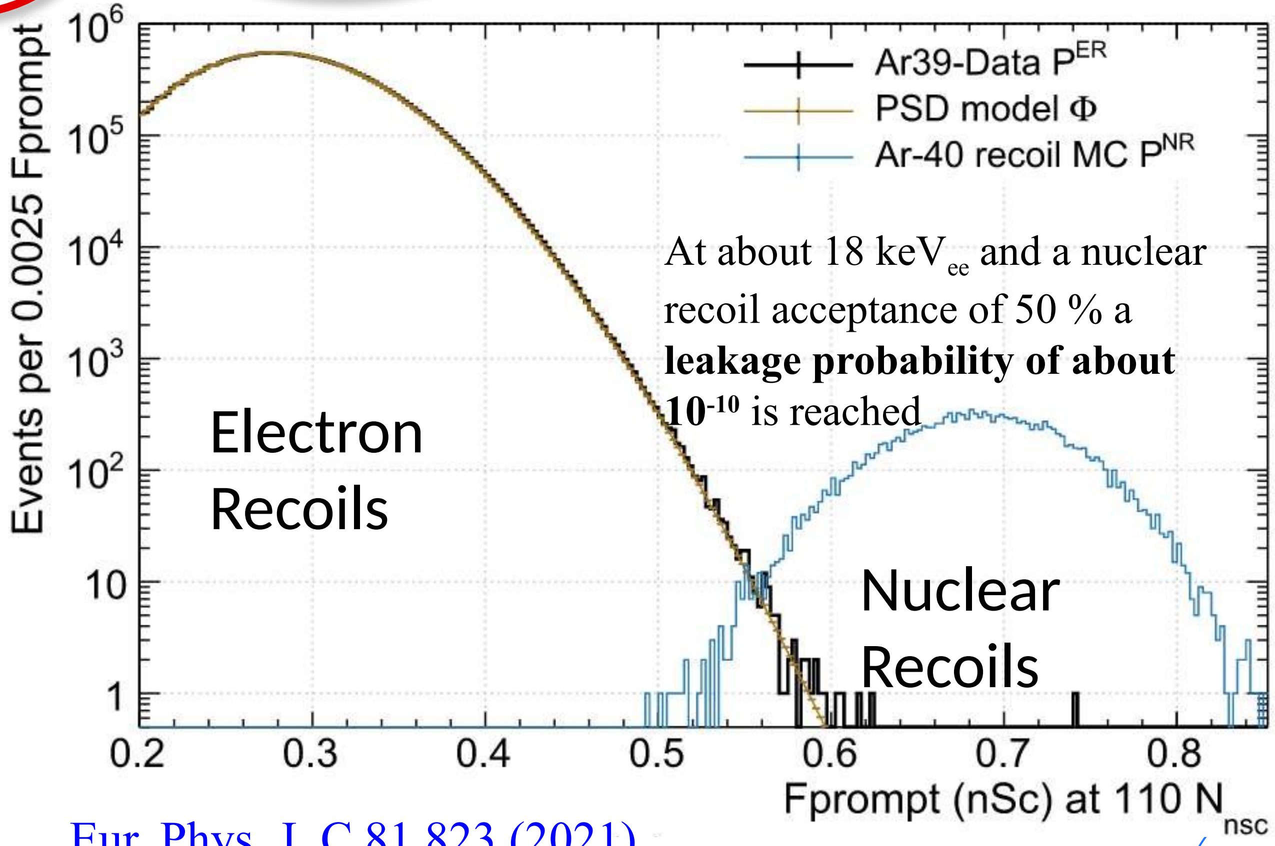


Eur. Phys. J. C 80,303 (2020)



At about 18 keV$_{ee}$ and a nuclear recoil acceptance of 50 % a **leakage probability of about 10^{-10}** is reached

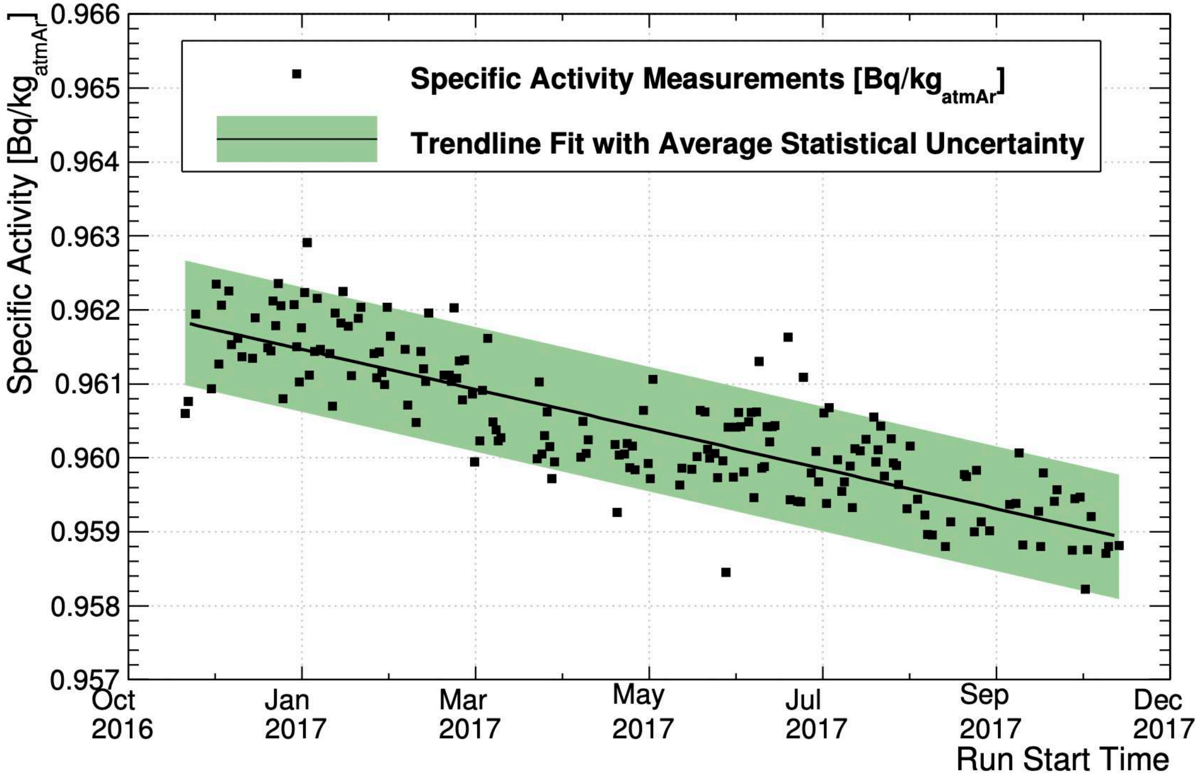
Eur. Phys. J. C 81,823 (2021)

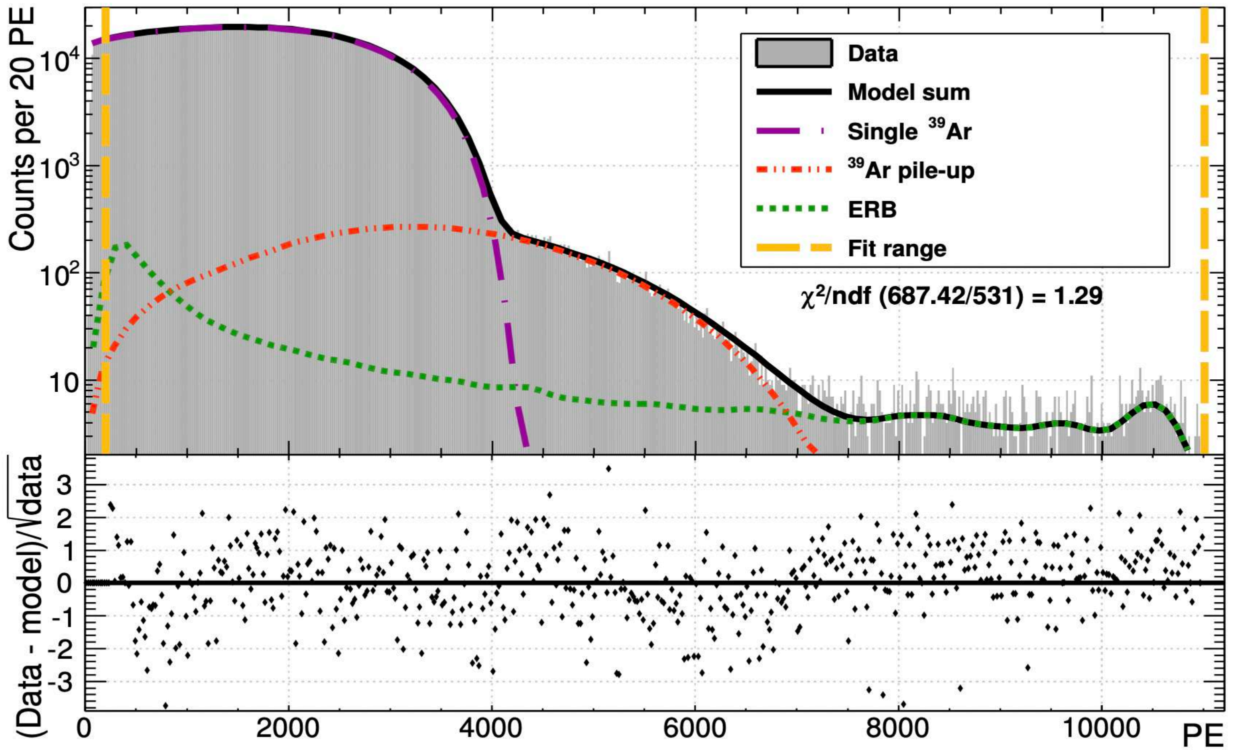
Measurements on the ^{39}Ar: the specific activity...

$$S_{^{39}Ar} = (0.964 \pm 0.001(stat) \pm 0.024(syst))Bq/kg_{Ar}$$

$$S_{^{39}Ar} = \frac{N_{single} + N_{pile-up}}{m_{LAr}T_{livetime}}$$

Analysis performed on $T_{livetime}$ = 167 days





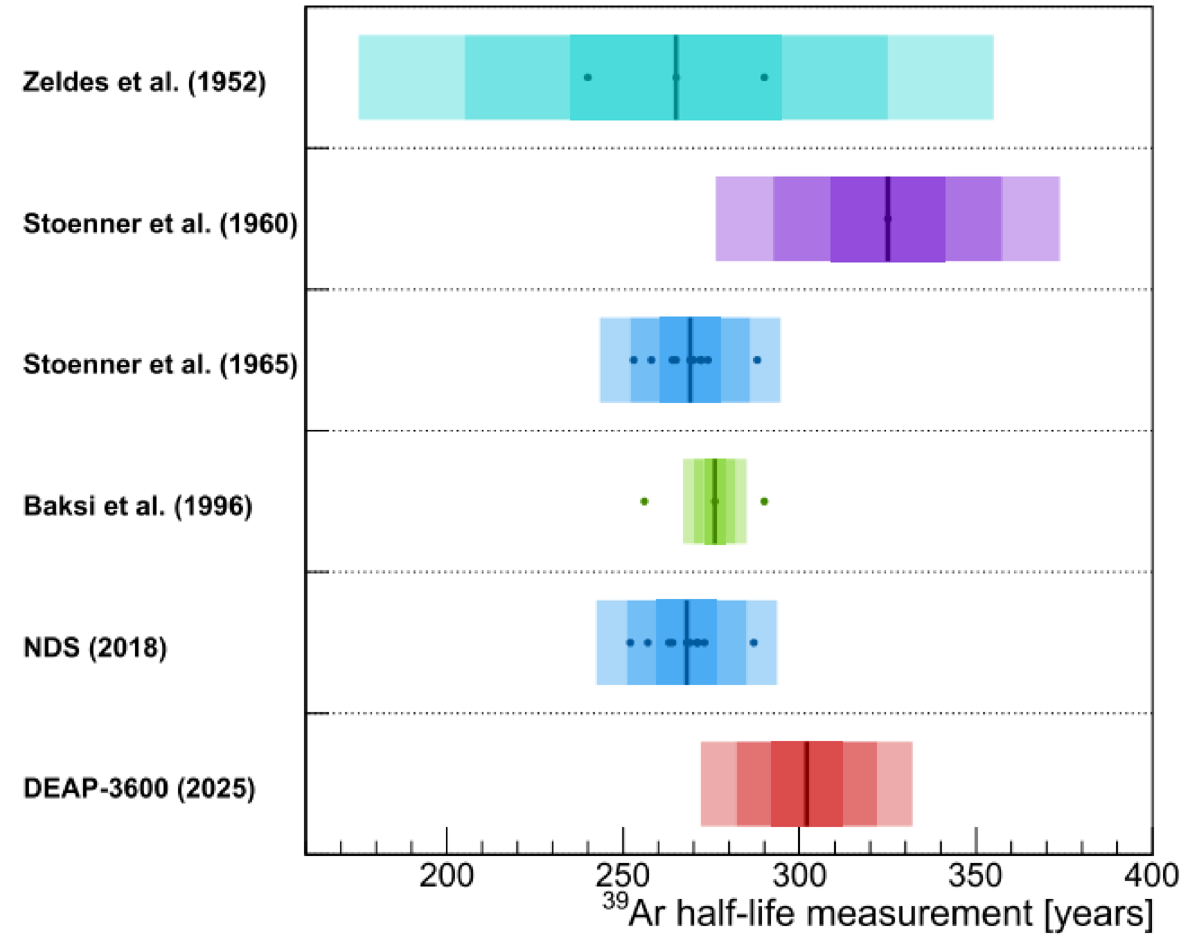
Measurement	Specific activity [Bq/kg$_{atmAr}$]
WARP [13]	1.01 ± 0.08
ArDM [14]	0.95 ± 0.05
DEAP-3600 (this work)	0.964 ± 0.024

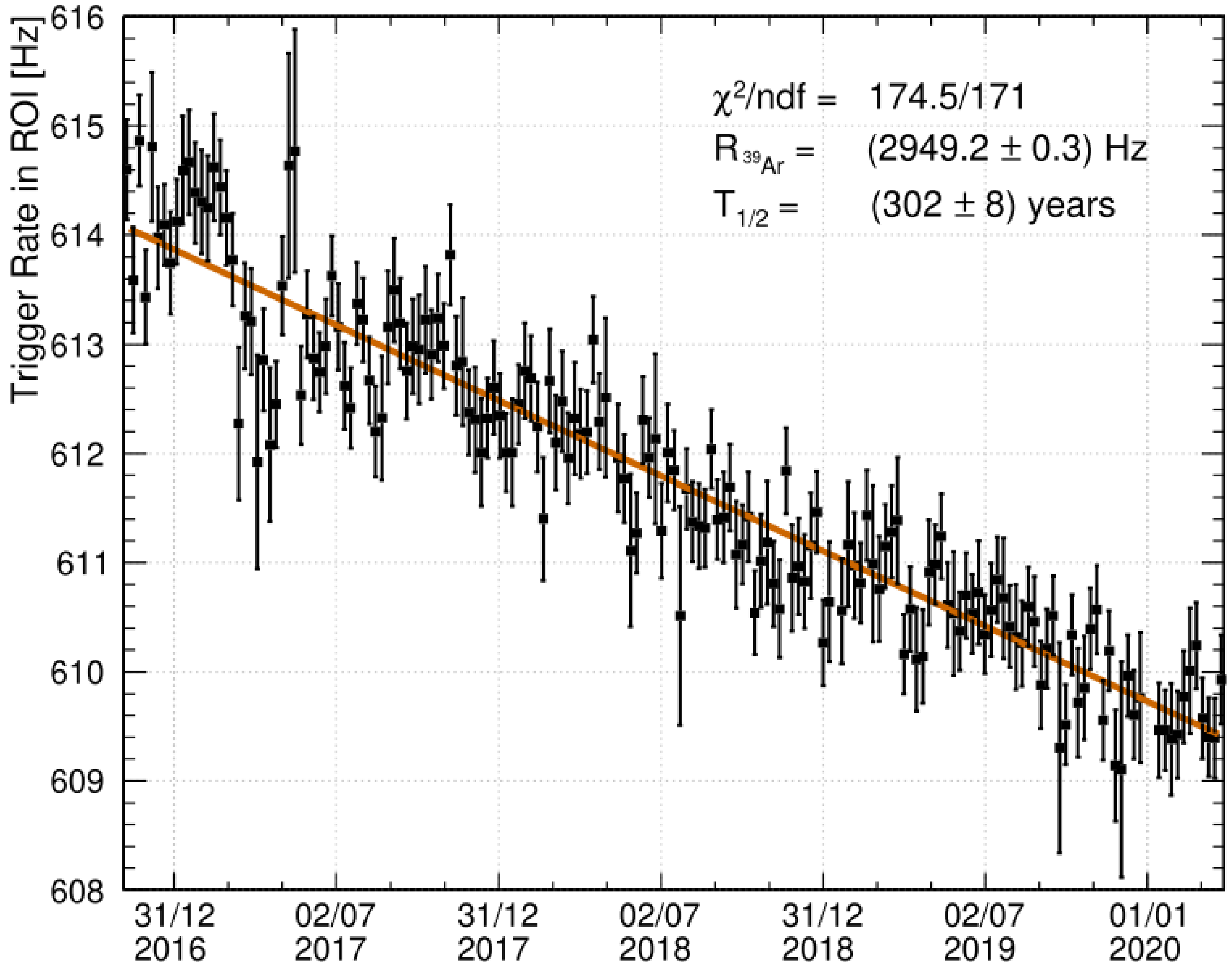
Eur. Phys. J. C (2023) 83,642

Measurements on the ^{39}Ar: half-life

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

$T_{1/2} = (302 \pm 8_{stat} \pm 6_{sys})$ years





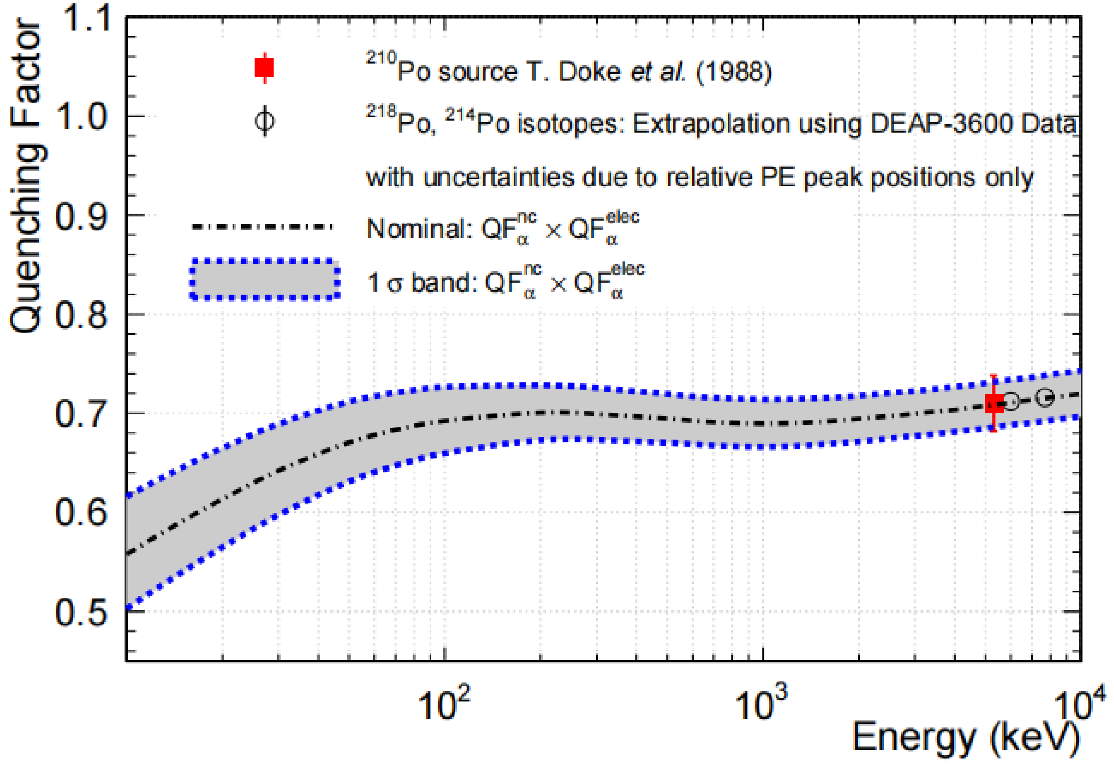
First direct measurement of the ^{39}Ar half-life

2.5σ tension with Nuclear Data Sheets (NDS)

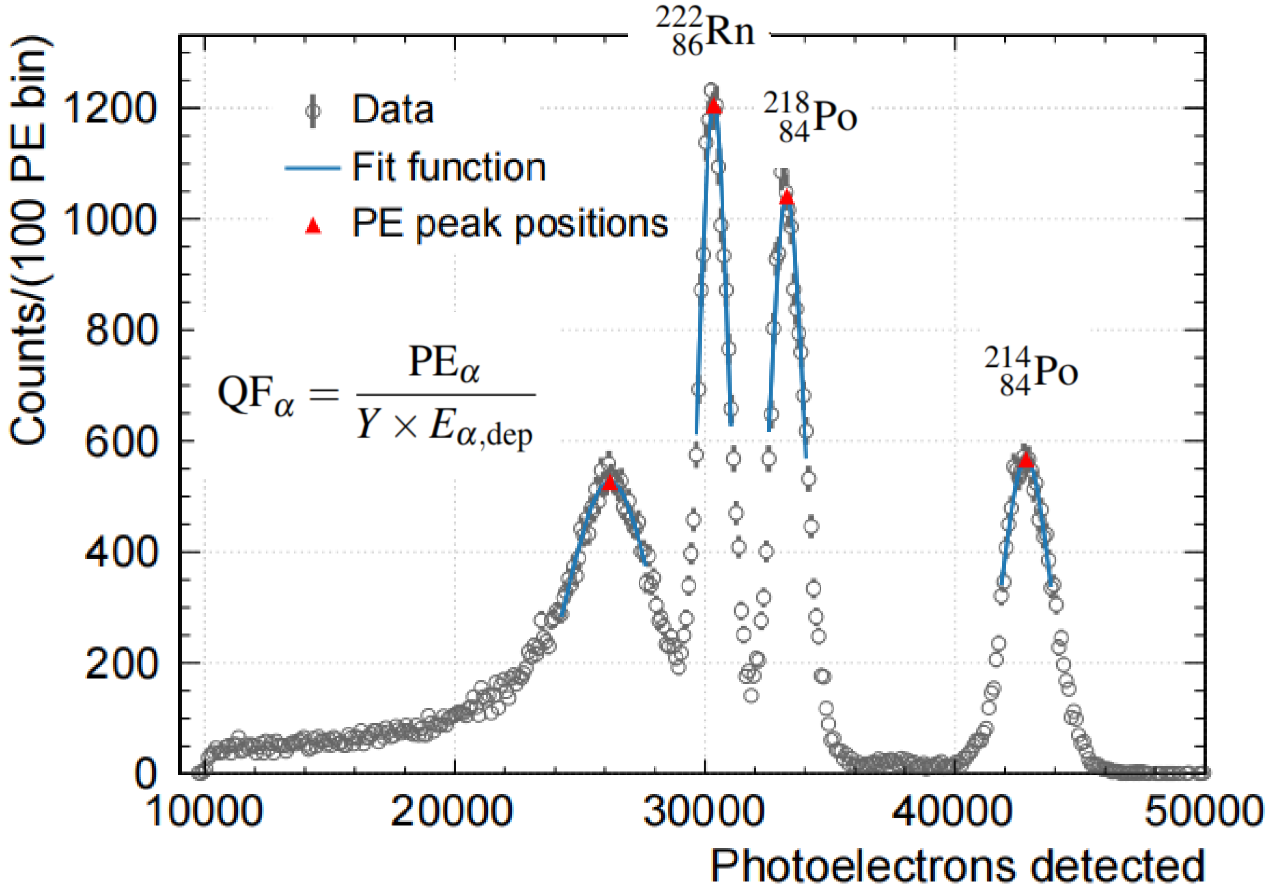
Alpha quenching in LAr

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

Three data points for the alpha Quenching Factor (QF) in the range (5.489 - 7.686) MeV



Measurements relative to ^{210}Po QF from Doke et al = 0.710 ± 0.028 (@ 5.305MeV)



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

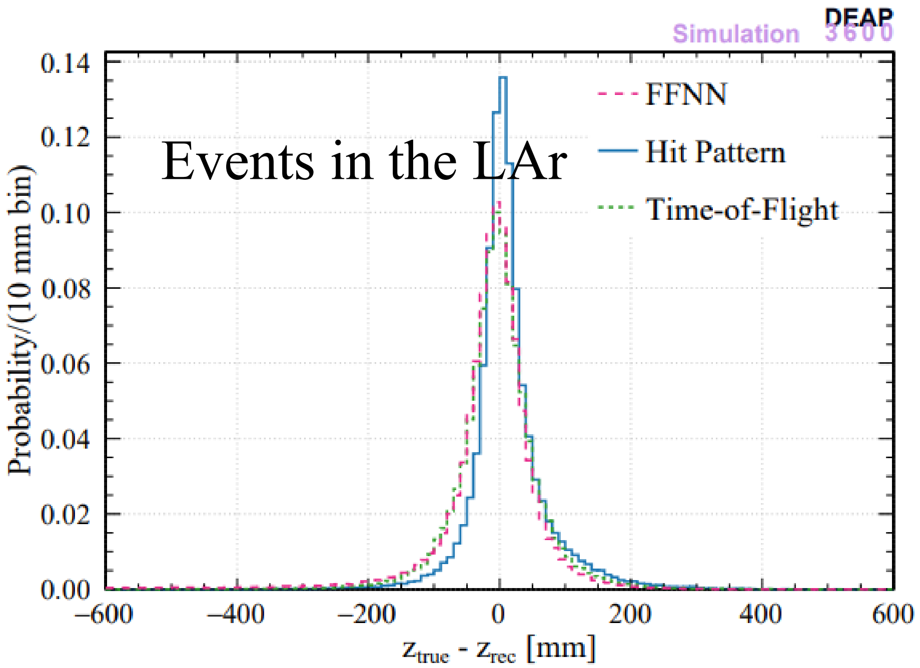
Position reconstruction

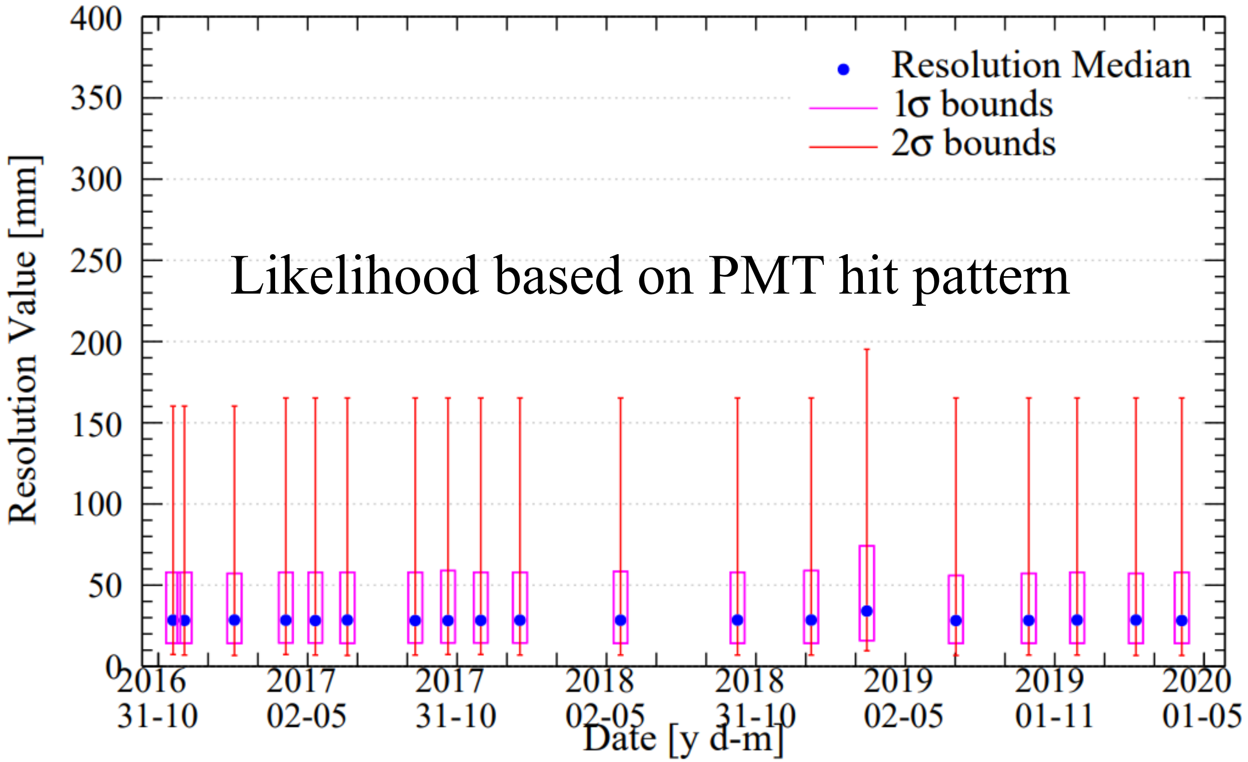
2025 JINST 20 P07012

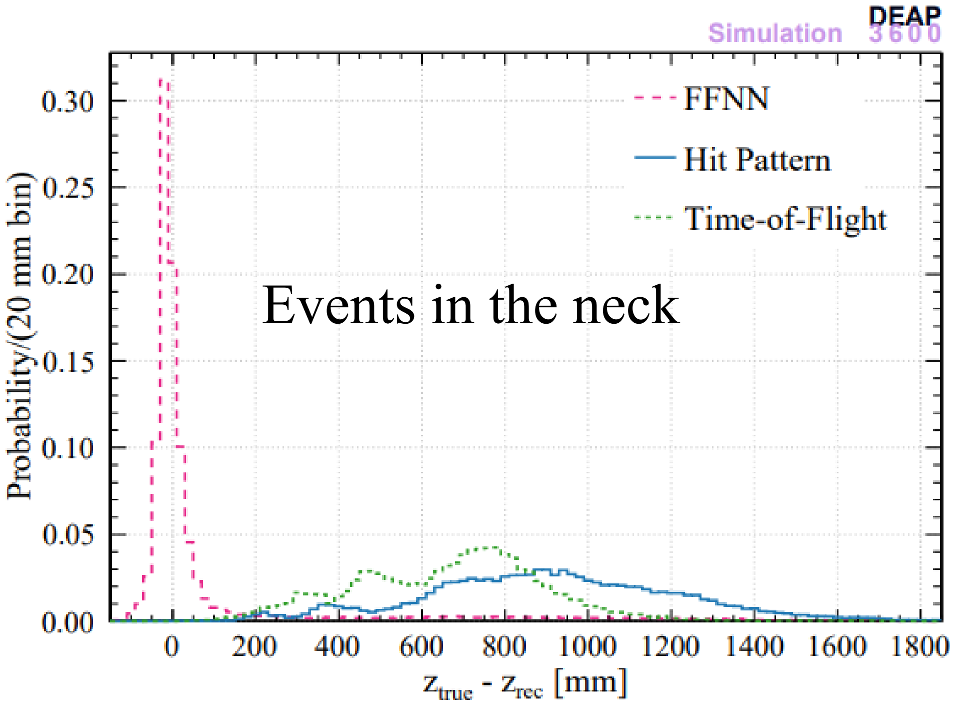
Comparison of three algorithms,

- Likelihood based on PMT hit pattern (MBL)
- Likelihood based on photon time of flight (TF2)
- Neural Network (newest algorithm)

for multiple positions within the vessel, vs time stability, **for events in the LAr and in the neck**



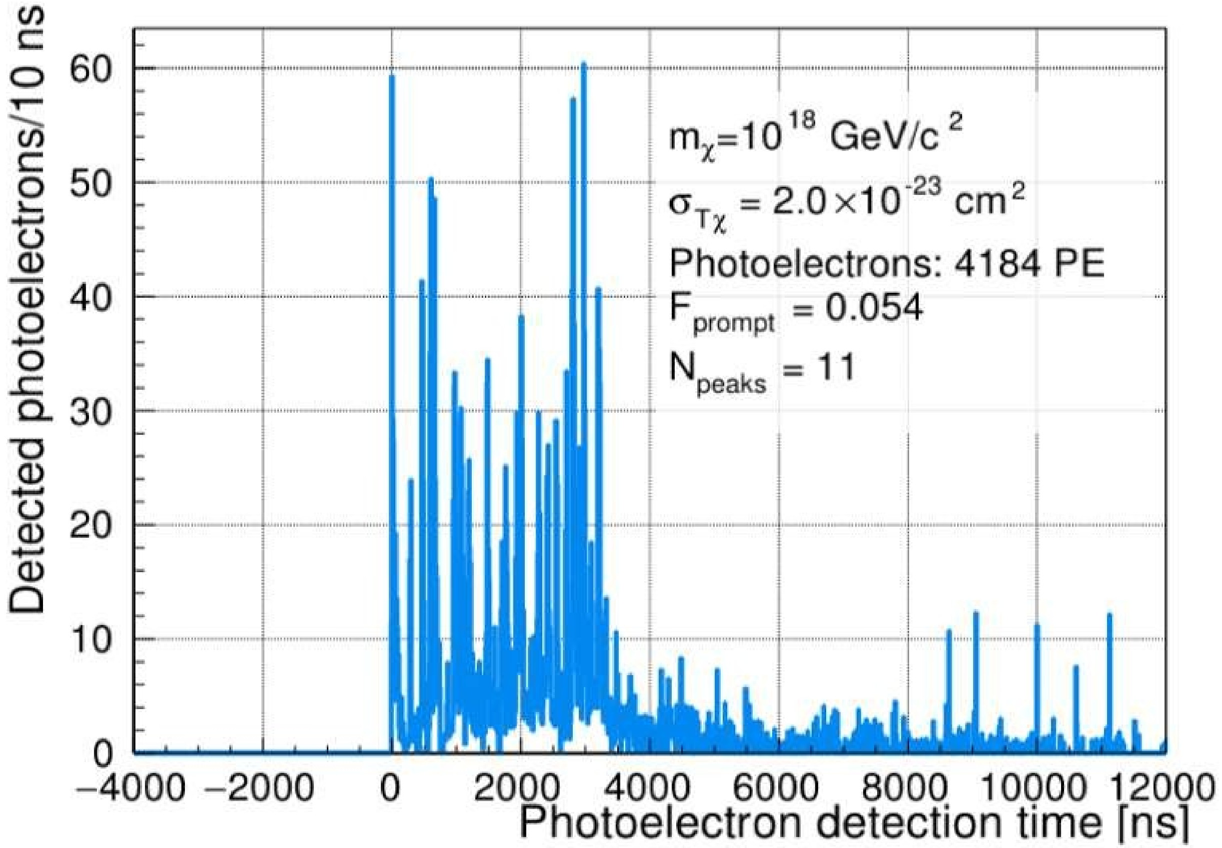


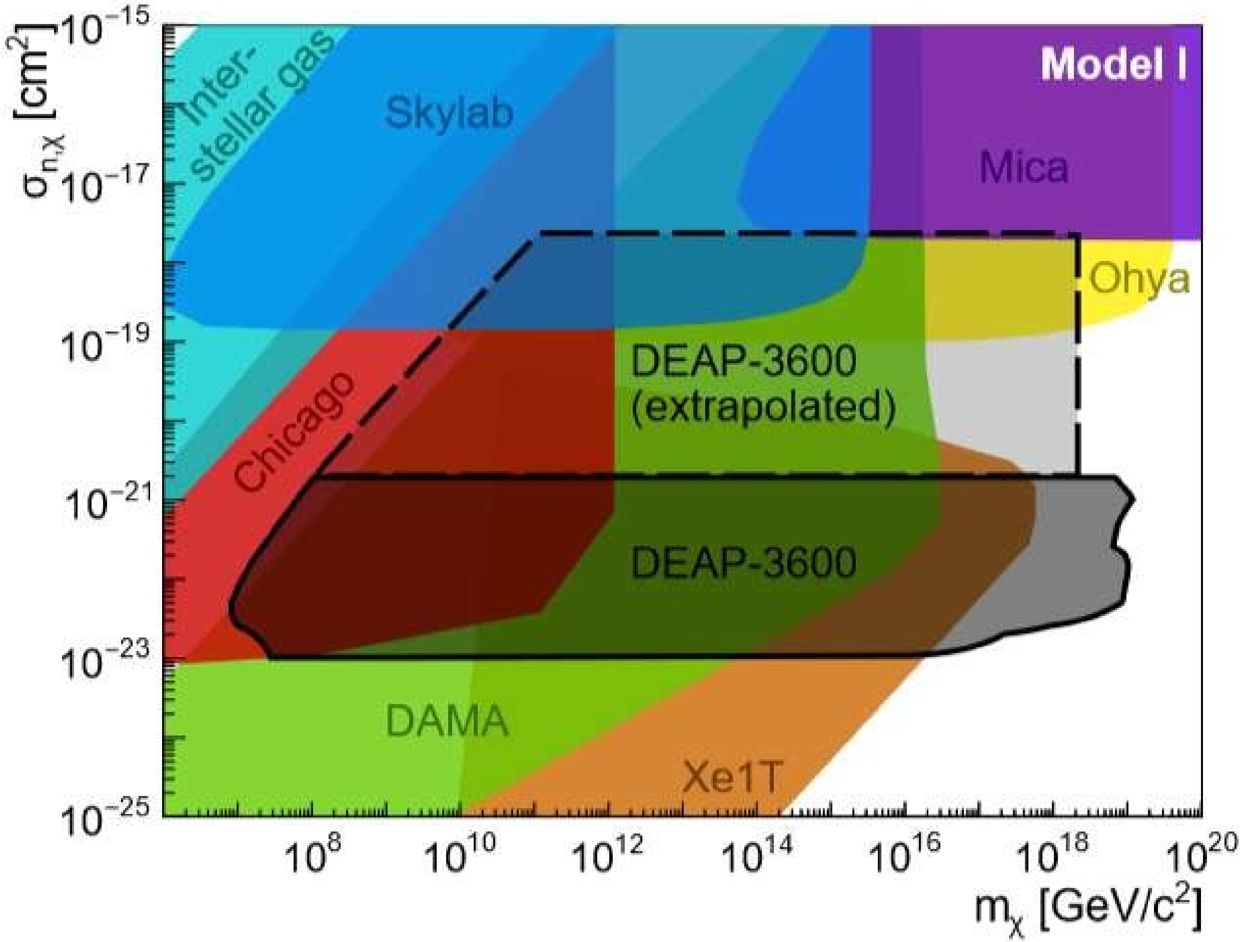


Searches at MeV-scale energy deposits

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

Ultra-heavy DM candidates: extremely low number density in the halo, need for tonne-scale exposure and pretty high cross-section, hence **multi-scattering in LAr**!





Main backgrounds from ^{39}Ar + (n, $\boldsymbol{\gamma}$) pile-ups

Exclusion limits set for two composite DM models

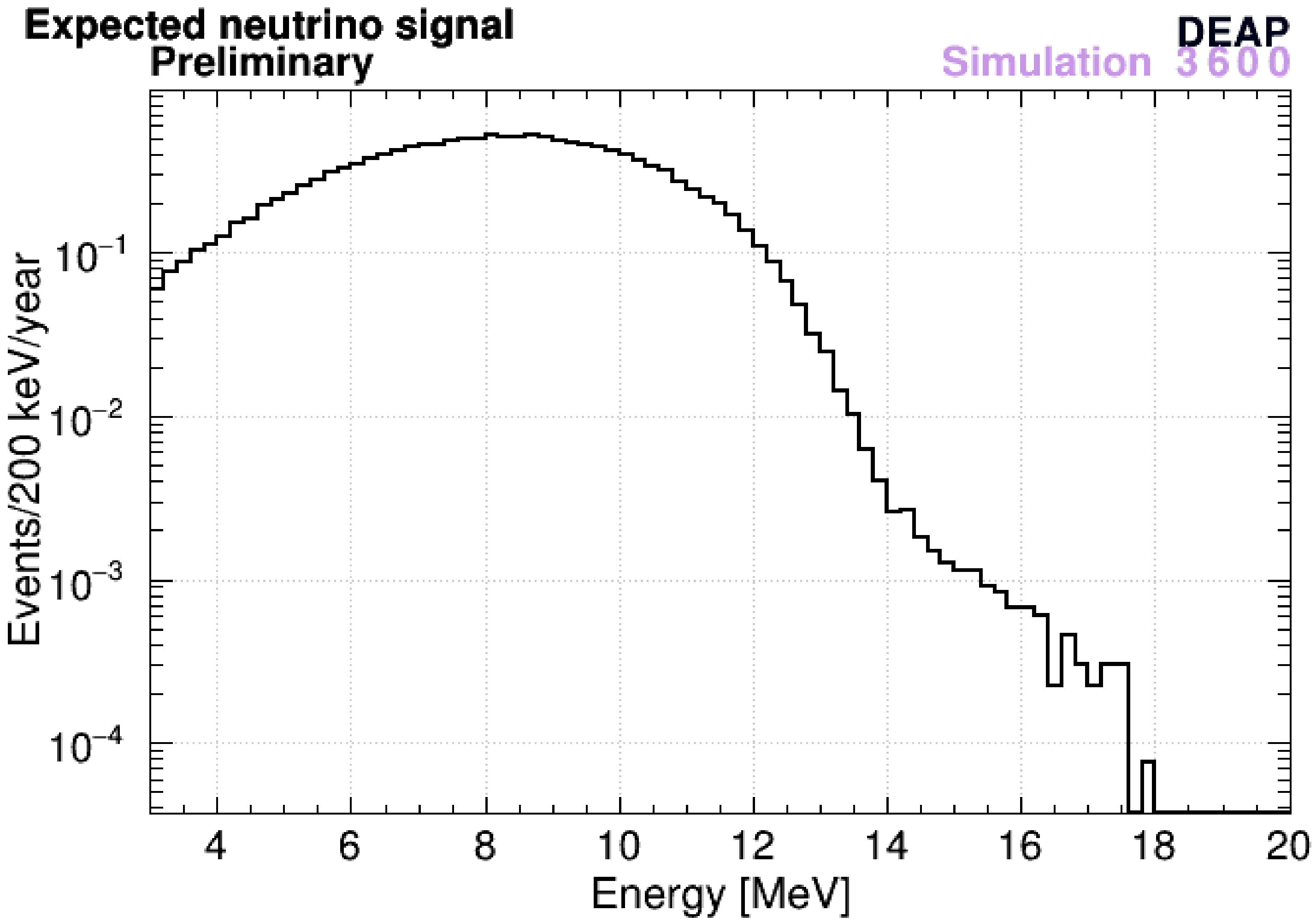
Searches at MeV-scale energy deposits

Ongoing: First search for solar neutrino absorption in ^{40}Ar

R. S. Raghavan (1986): super-allowed 0+ → 0 + Fermi transition from the ground state of ^{40}Ar to an excited state of ^{40}K.

M. Bhattacharya et al. : measured Gamow-Teller (GT) strengths for transitions from ^{40}Ar to ^{40}K*

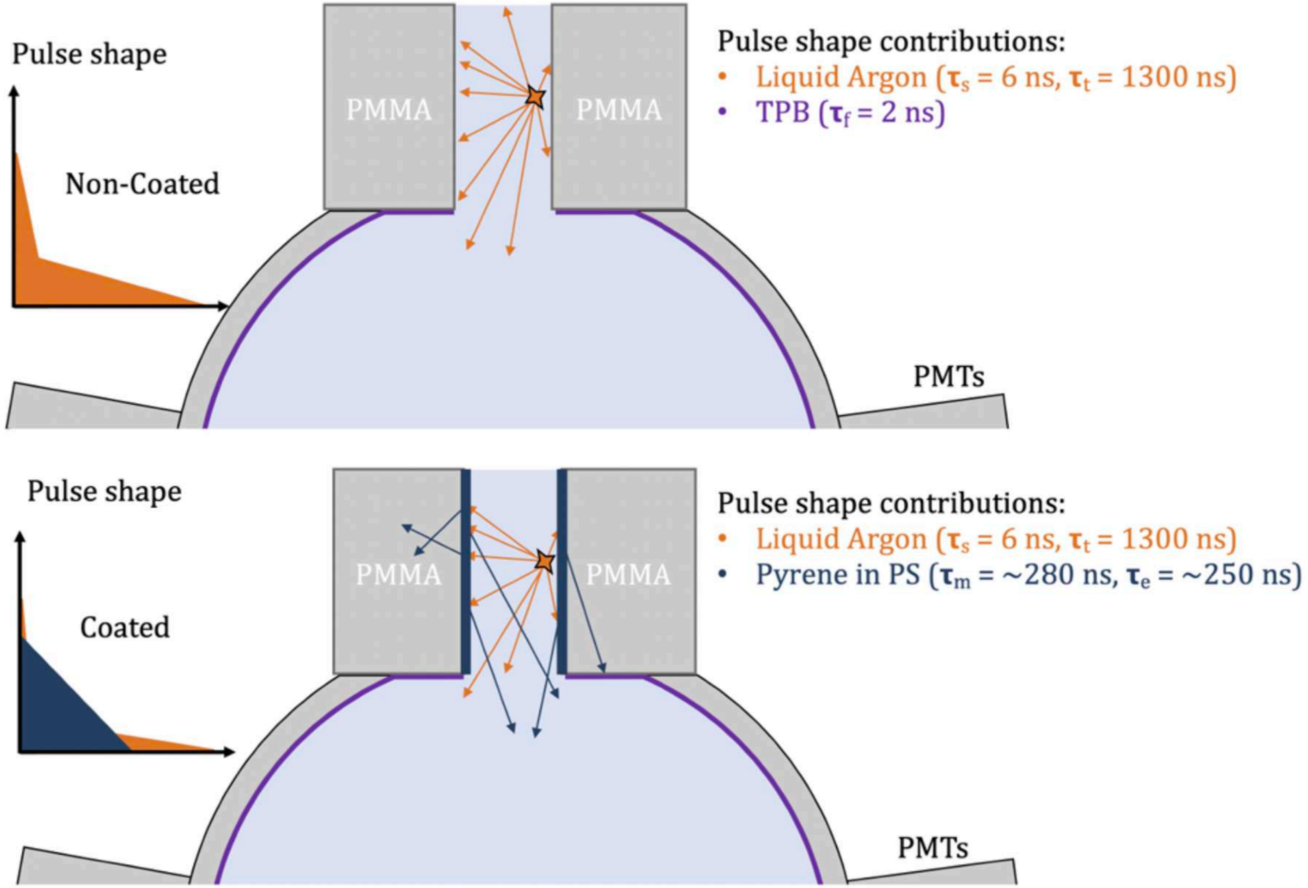
$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{K}^* + e^-$$



See my talk on Tuesday at 3pm

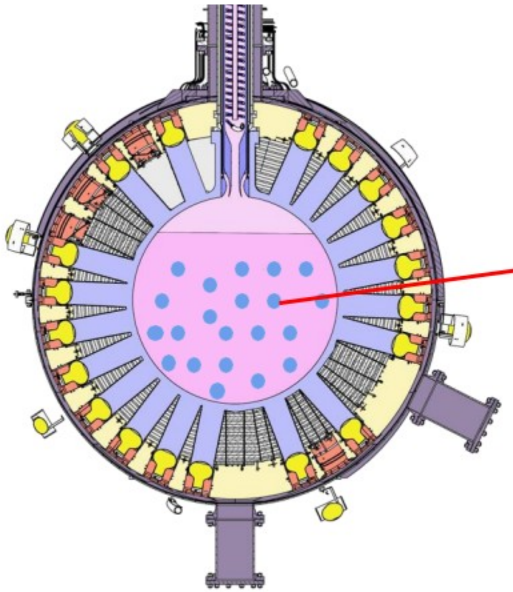
Hardware upgrades: neck alphas

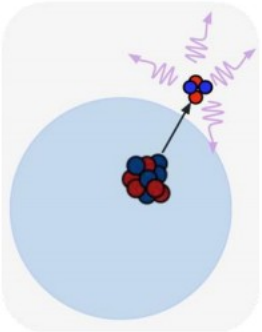
- **External cooling system** to prevent argon condensation
- Installation of pyrene coated flowguides to help alpha rejection through PSD



Nucl.Instrum.Meth.A 1034 (2022)

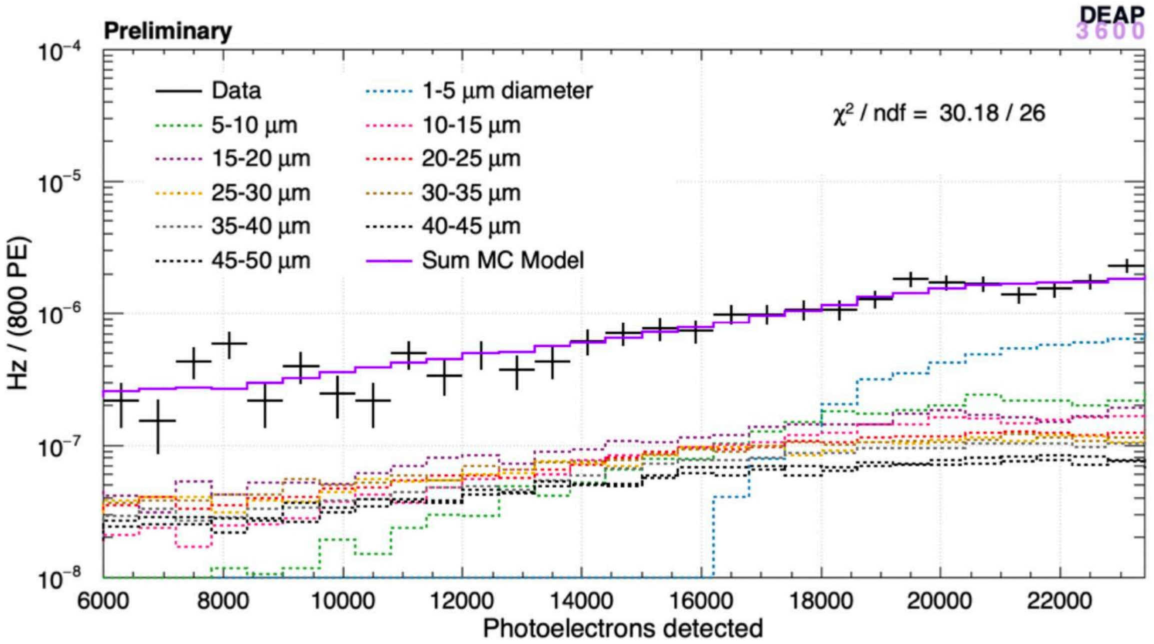
Hardware upgrades: dust alphas



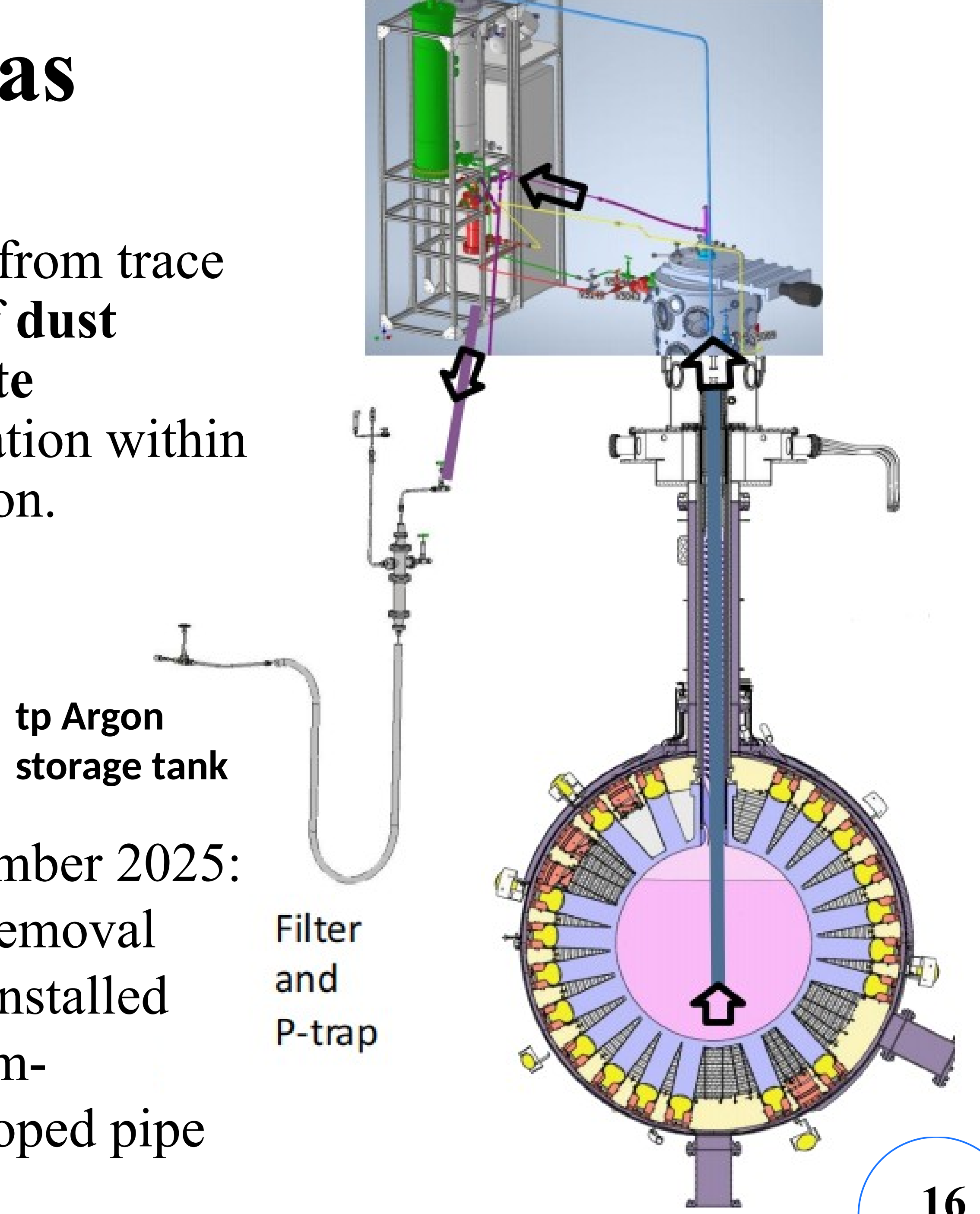


dust particle

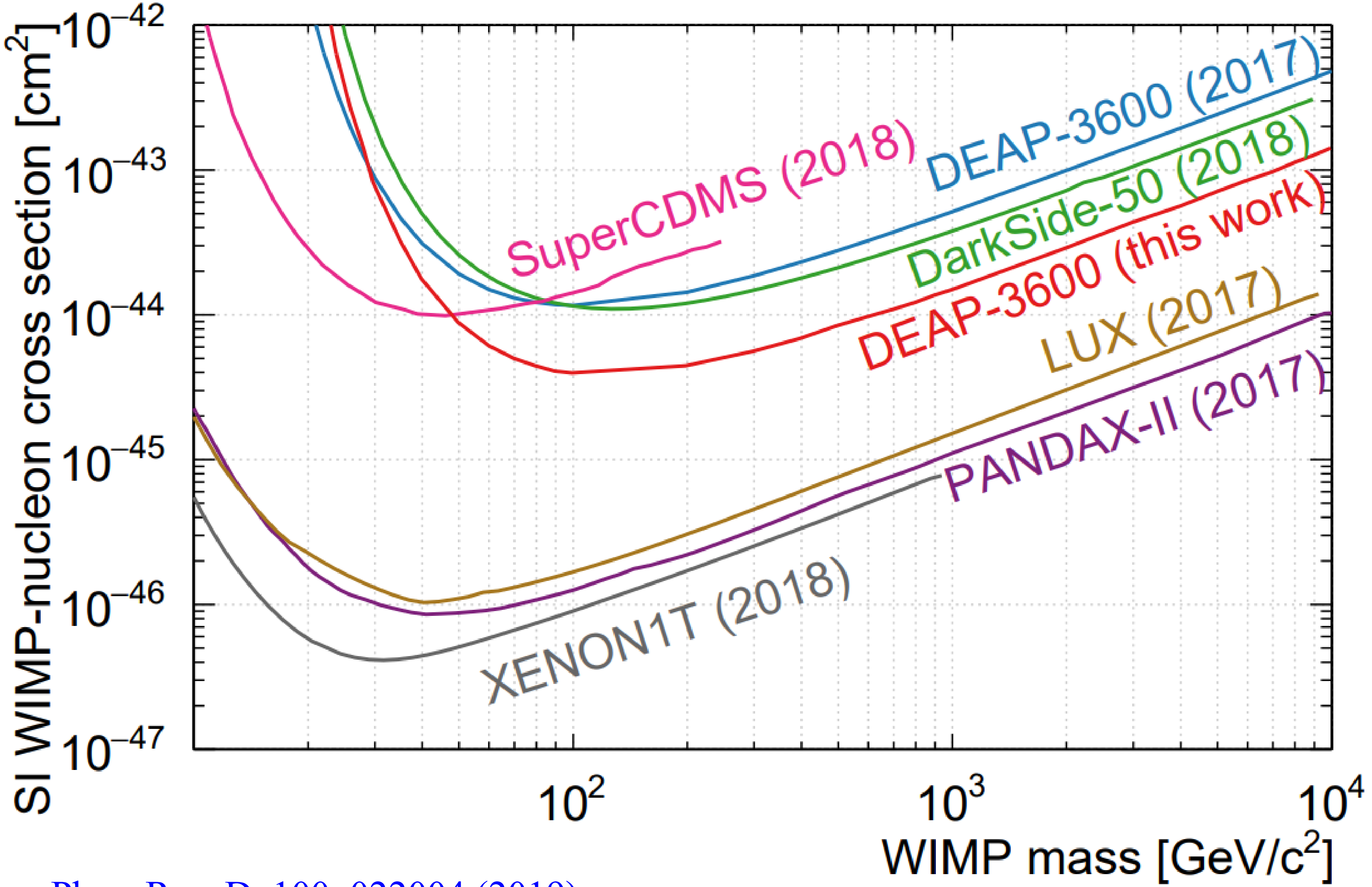
α-decays from trace amount of **dust particulate** contamination within liquid argon.



November 2025: dust removal with installed custom-developed pipe



Upcoming: updated WIMP limit



Phys. Rev. D. 100, 022004 (2019)

- Perfomed on the full second-fill dataset
- Based on a Profile-Likelihood Ratio method
- Modeling the main alpha-induced backgounds within the experiment

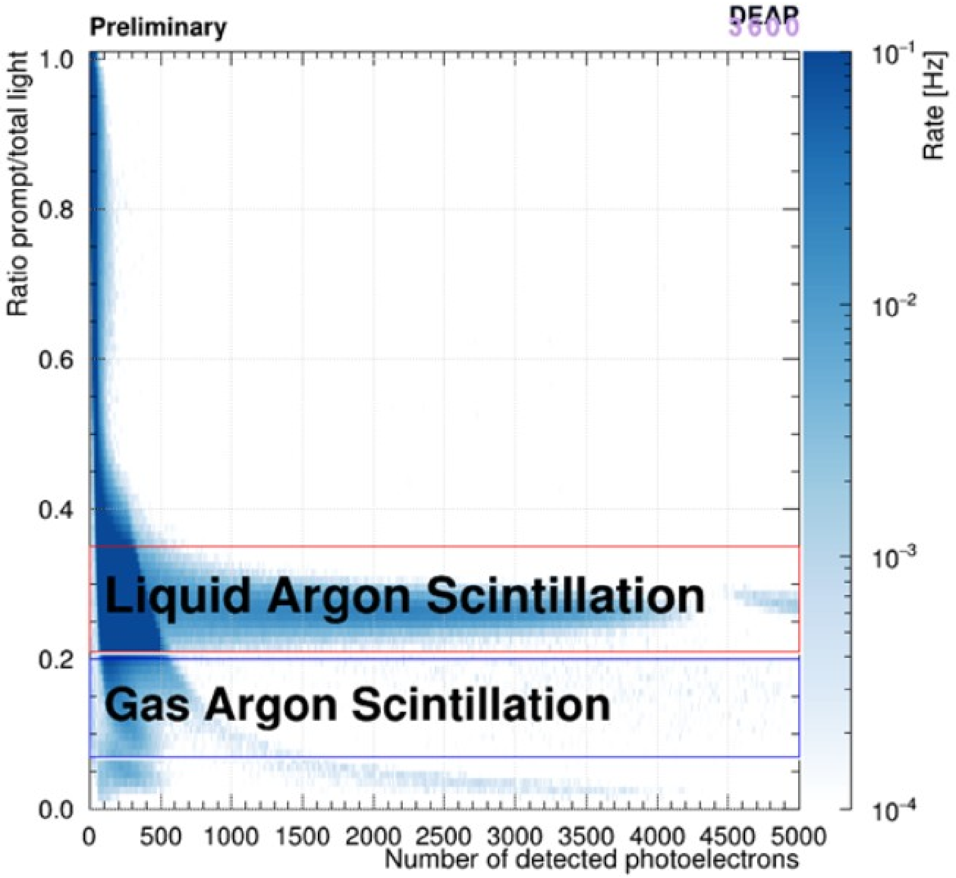
Stay tuned!

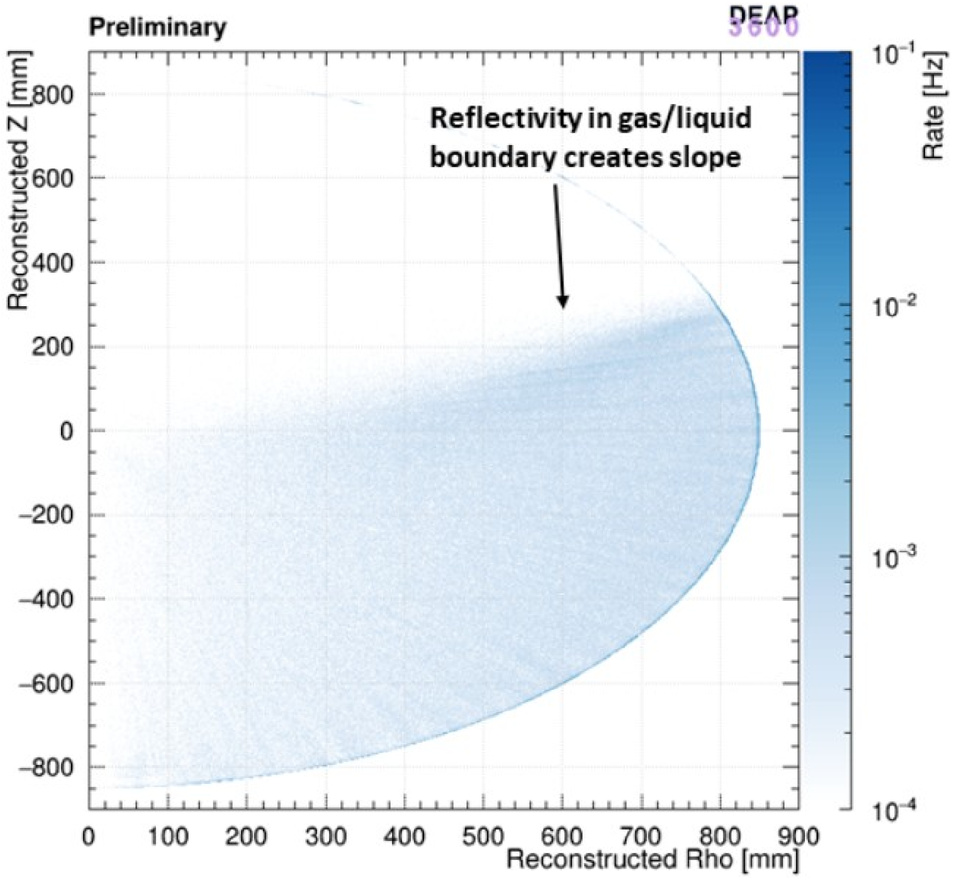
Third-fill!

- 14 April 2025: cooling down started!
- 26 June 2025: first drops of LAr

Main objectives: test the effectiveness of the hardware upgrades

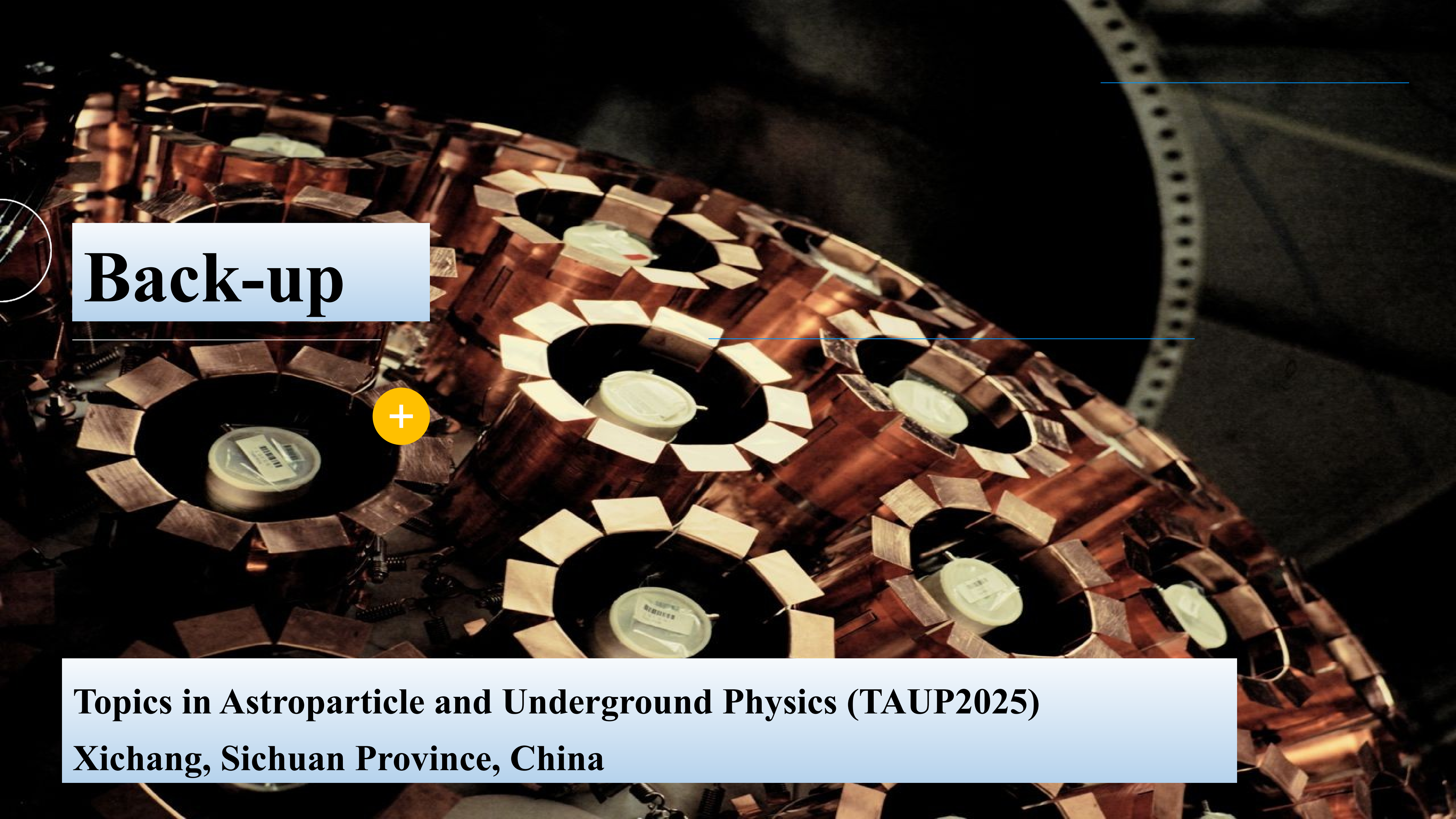
Third Fill Data (2025-07-27) – approx. 2600kg LAr in detector





Take-home

- DEAP-3600: largest running LAr experiment designed for the WIMP search
- World-leading sensitivity to WIMPs in LAr, as well as neutrino adsorption and ultra-heavy, multi-scattering DM
- Main backgrounds within the WIMP ROI: dust-alphas and neck-alpha induced events, now included in the PLR WIMP search (coming soon)
- Hardware upgrades to strongly reduce the alpha-induced backgrounds in the WIMP ROIs
- Third-fill just started, new results on the way!

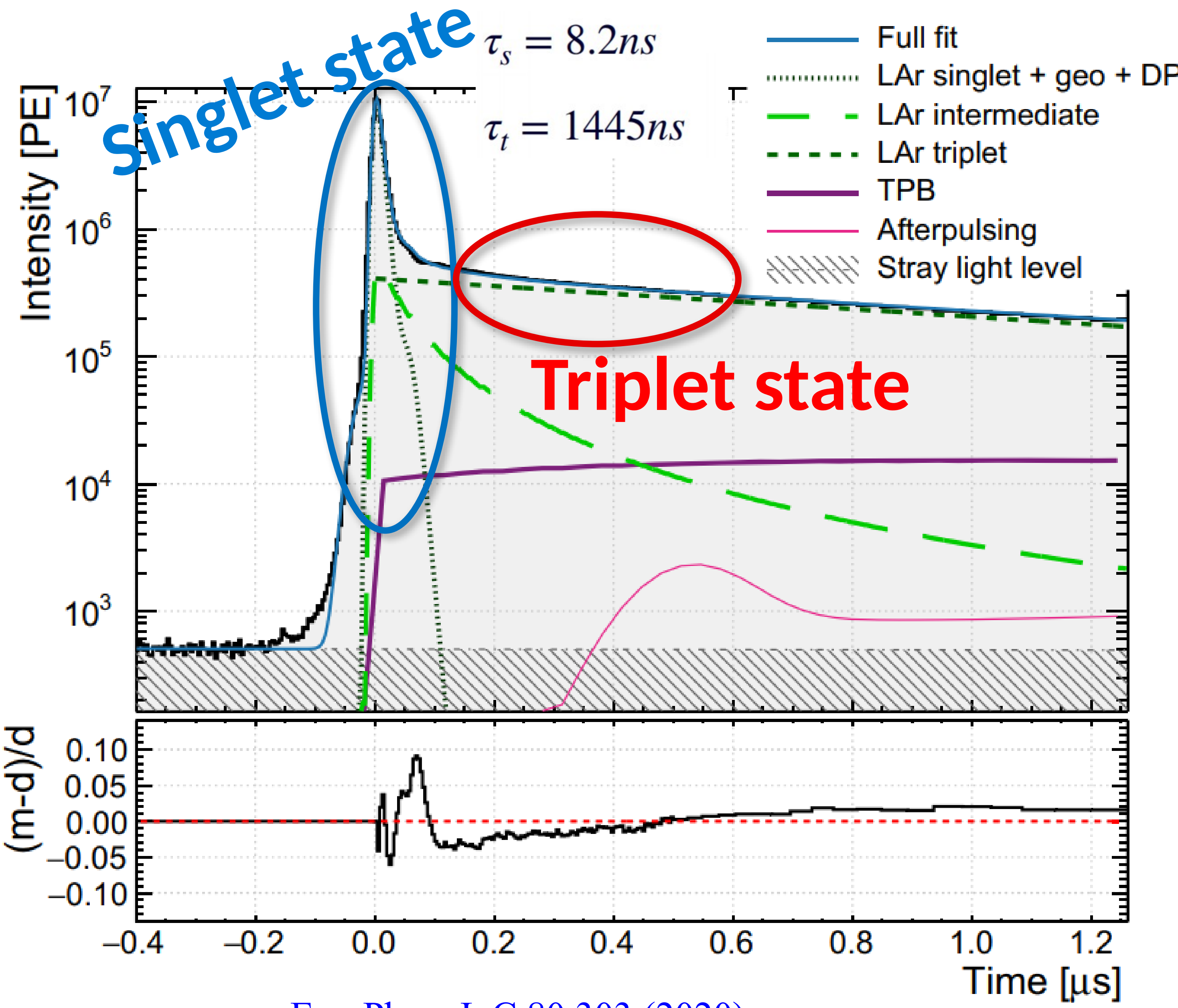


Back-up

Topics in Astroparticle and Underground Physics (TAUP2025)

Xichang, Sichuan Province, China

Dark matter Experiment using Argon Pulse-shape discrimination

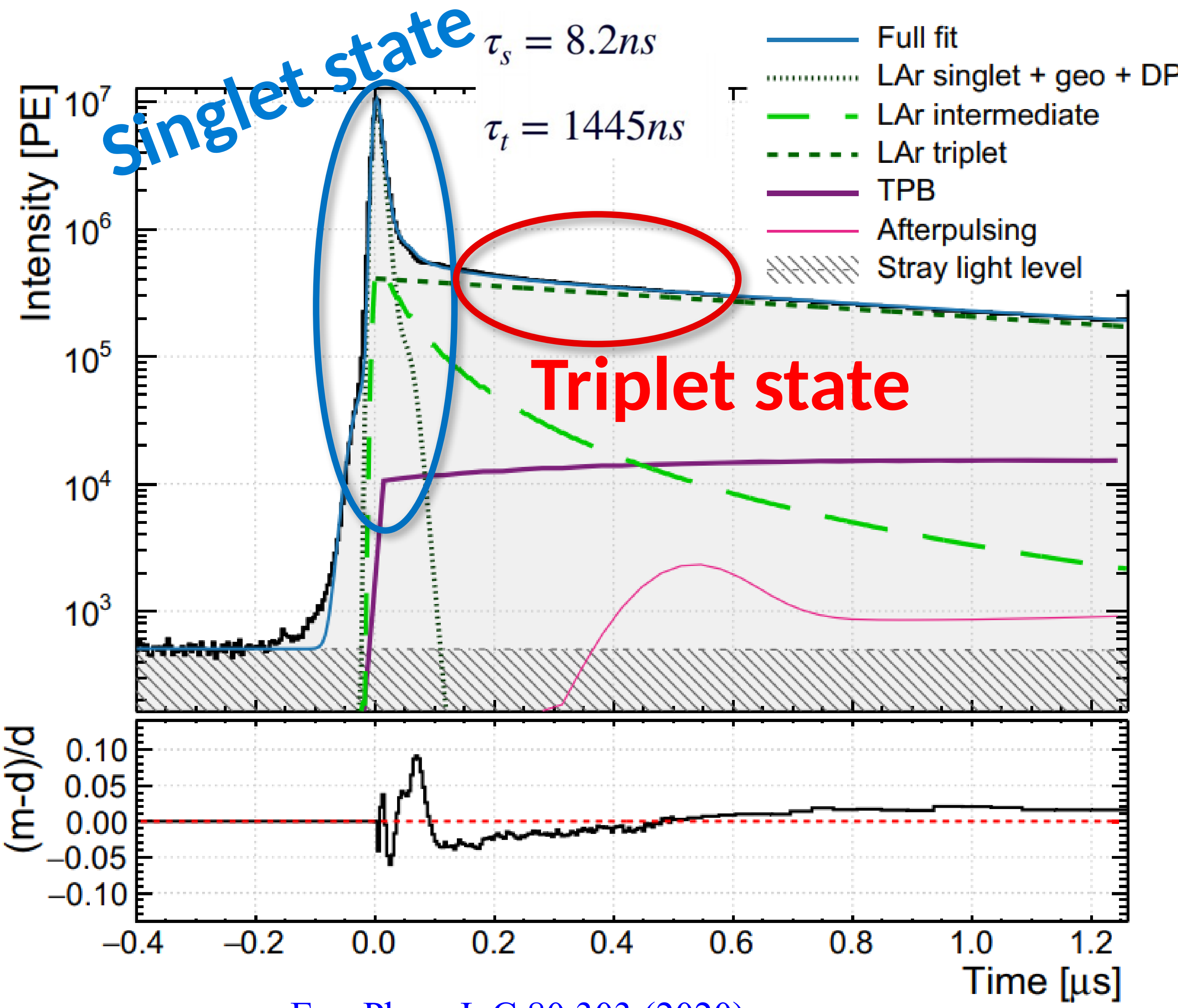


Eur. Phys. J. C 80,303 (2020)

Dark matter Experiment using Argon Pulse-shape discrimination

Nuclear recoils (DM, neutrons)

Electron recoils (e, gammas)



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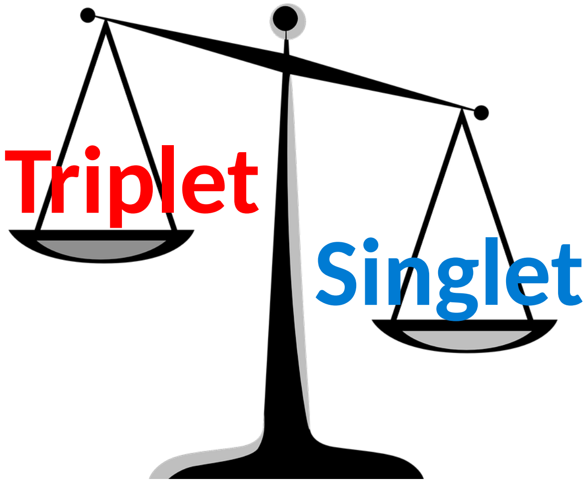

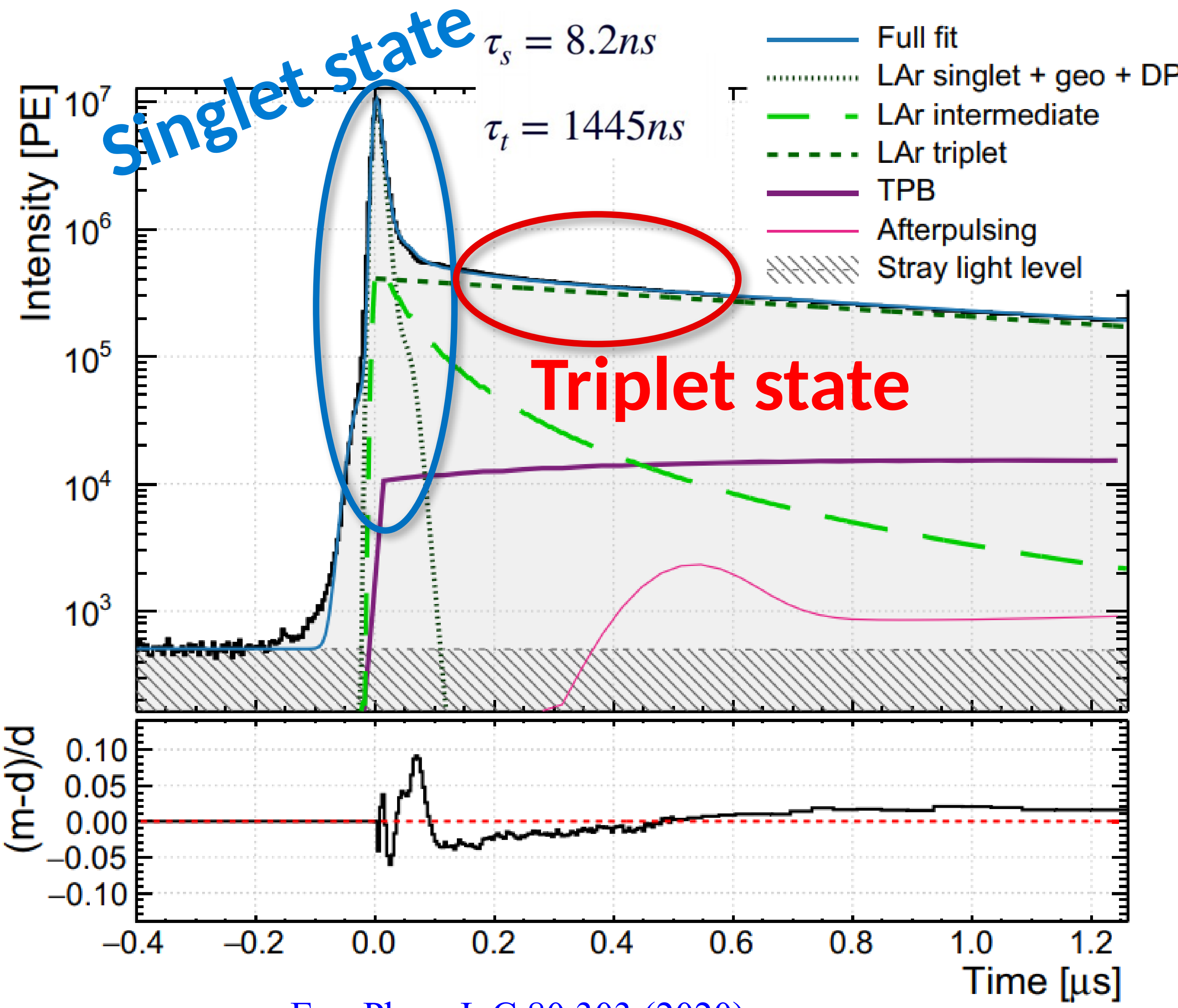

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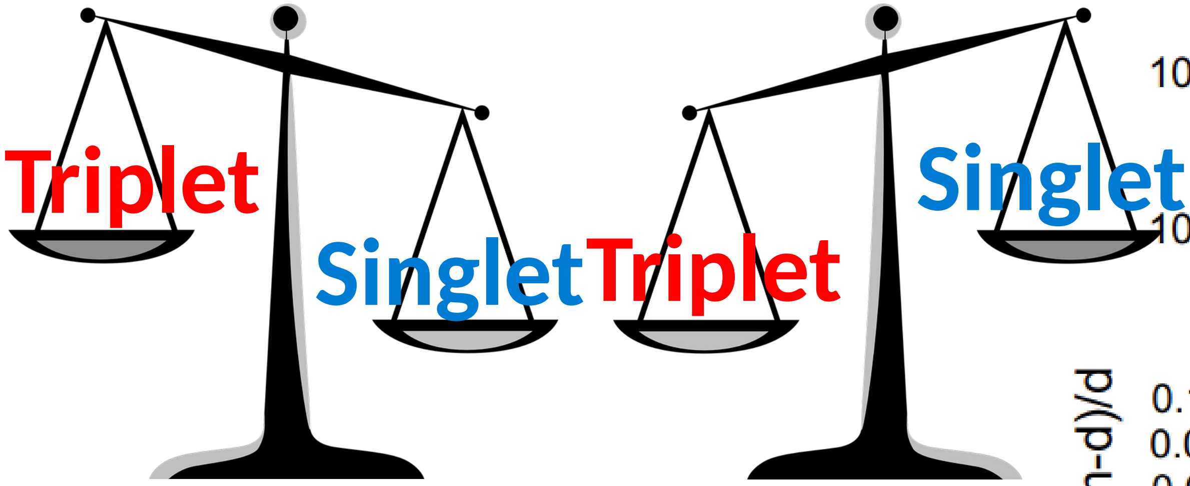
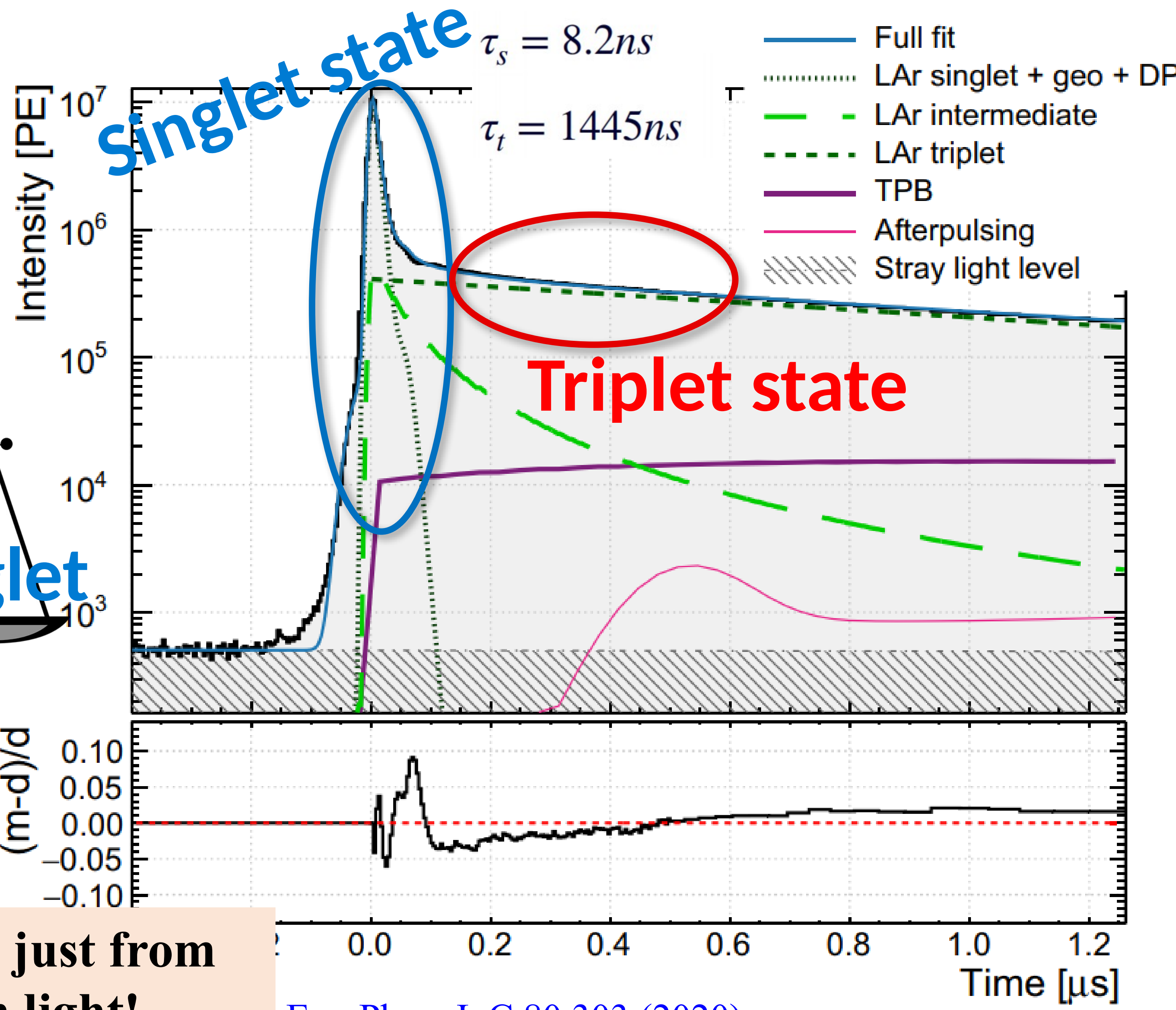


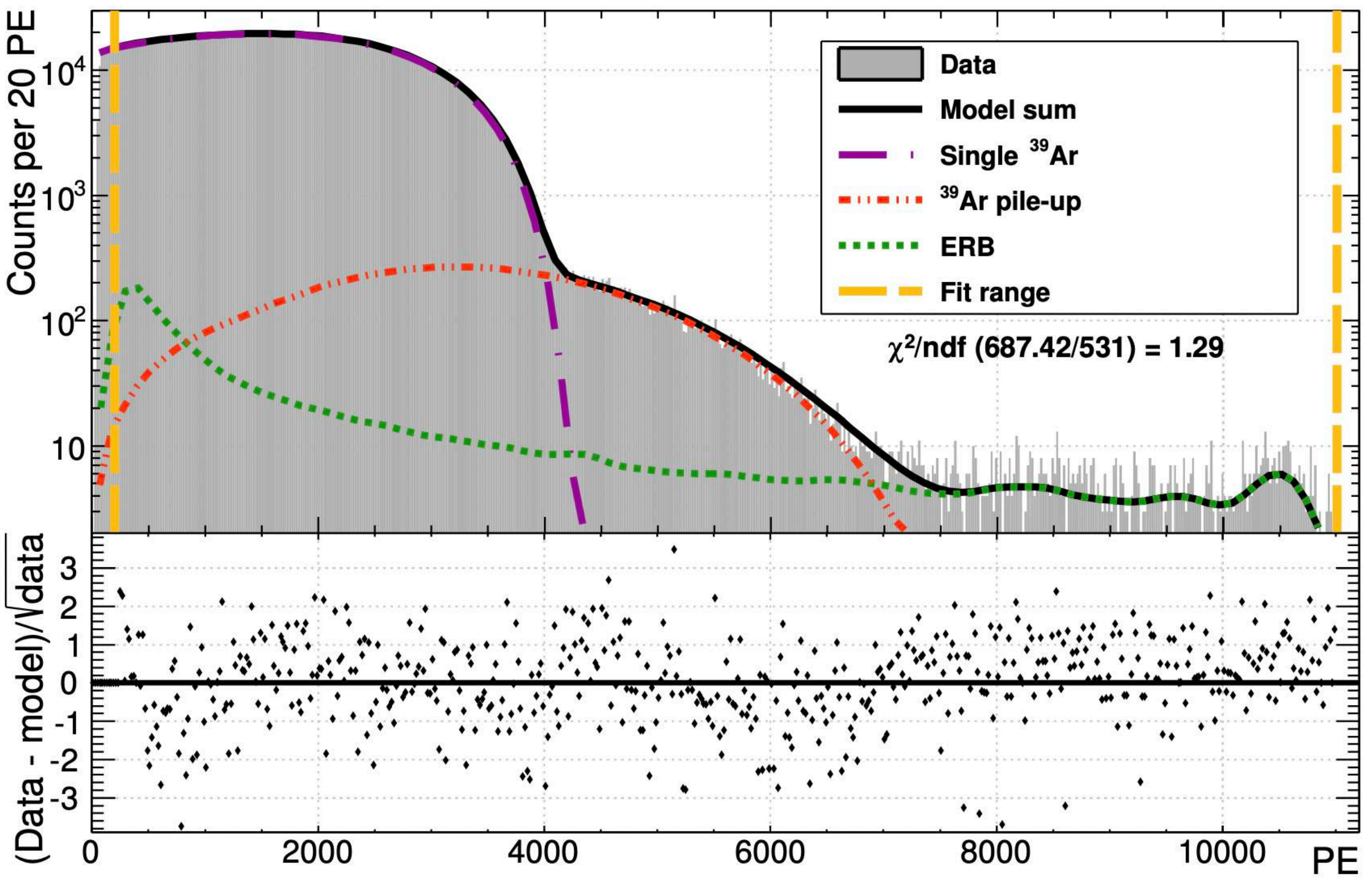


Eur. Phys. J. C 80,303 (2020)

In Argon we get Particle Identification just from the Fraction of the prompt scintillation light!

Most precise measurement of atmospheric ^{39}Ar specific activity up to date

$$S_{^{39}Ar} = \frac{N_{single} + N_{pile-up}}{m_{LAr} T_{livetime}}$$



Updated measurement for the liquid argon target

First: $m_{LAr} = (3269 \pm 96) kg$

This work!: $m_{LAr} = (3269 \pm 24) kg$

$$T_{livetime} = T_{run} - \sum_{i=1}^{N_{DCcut}} \delta t_i - N_{LLcut} \cdot \delta t_{cut} - N_{phys} \cdot (\delta t_{cut} - \delta t_{int})$$

$\delta t_{cut} = 32 \mu s$ $\quad \delta t_i \leq 32 \mu s$ $\quad \delta t_{int} = 10 \mu s$

Contribution from pile up from double and triple ^{39}Ar, other electron recoil + ^{39}Ar, Cherenkov + ^{39}Ar

$$N_{pile-up} = N_{double} + N_{triple} + N_{ERB,39Ar} + N_{hFp,39Ar}$$

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

Analysis performed on $T_{livetime}$ = 167 days

Fit performed with both Bayesian and Frequentist approaches

Digital Trigger module prescaling = 100

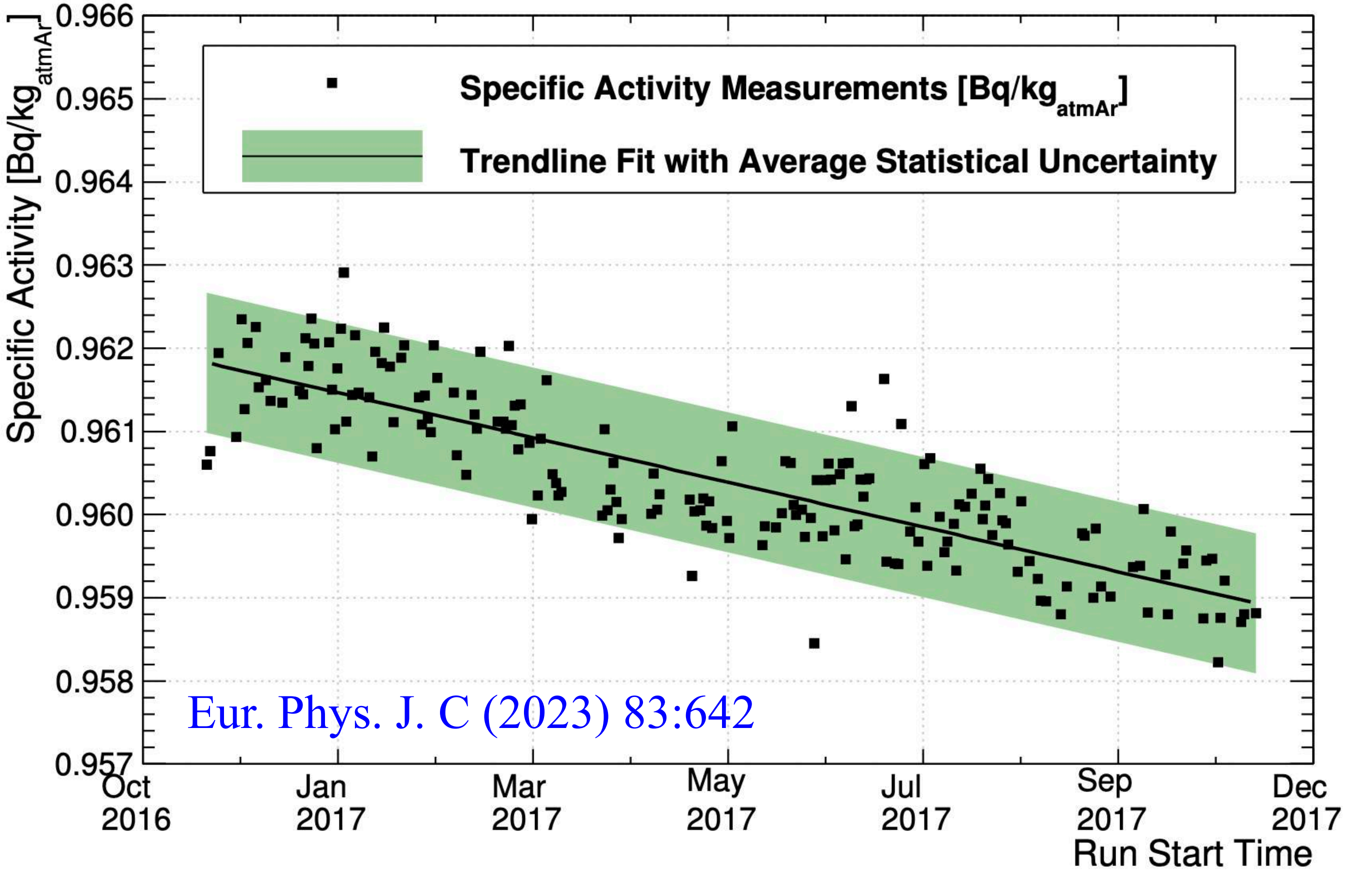
$$N_{single} = \frac{n_{fit,single} \cdot a_{presc}}{\epsilon_{fit,single} \cdot b} \qquad N_{double} = \frac{n_{fit,double} \cdot a_{presc}}{\epsilon_{fit,double} \cdot b}$$

Selection cuts efficiencies

Fit bin width = 20

$$S_{^{39}Ar} = \frac{N_{single} + N_{pile-up}}{m_{LAr} T_{livetime}}$$

$$S_{^{39}Ar} = (0.964 \pm 0.001(stat) \pm 0.024(syst)) Bq/kg_{Ar}$$



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

Measurement	Specific activity [Bq/kg$_{atmAr}$]
WARP [13]	1.01 ± 0.08
ArDM [14]	0.95 ± 0.05
DEAP-3600 (this work)	0.964 ± 0.024

Relative Measurement and Extrapolation of the Scintillation Quenching Factor of α-Particles in Liquid Argon using DEAP-3600 Data

Three data points for the alpha Quenching Factor (QF) in the range (5.489 - 7.686) MeV

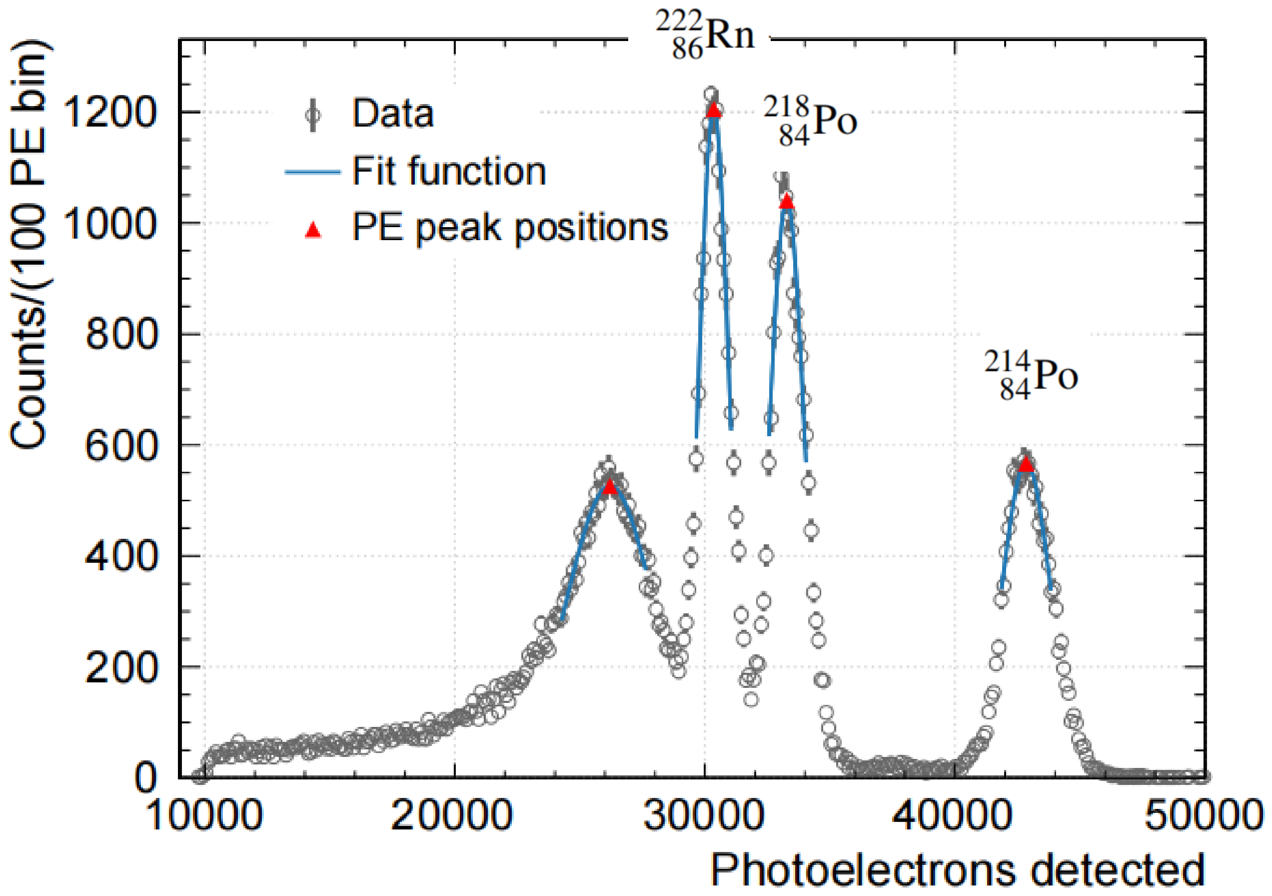
$$^{222}_{86}\mathrm{Rn} \xrightarrow{\alpha} {}^{218}_{84}\mathrm{Po} \xrightarrow{\alpha} {}^{214}_{82}\mathrm{Pb} \xrightarrow{\beta} {}^{214}_{83}\mathrm{Bi} \xrightarrow{\beta} {}^{214}_{84}\mathrm{Po} \xrightarrow{\alpha} {}^{210}_{82}\mathrm{Pb}$$

QF for ^{210}Po from Doke et al = 0.710 ± 0.028 (5.305MeV)

$$\frac{\mathrm{QF}_{\alpha,^{218}\mathrm{Po}}}{\mathrm{QF}_{\alpha,^{222}\mathrm{Rn}}} = \frac{\mathrm{PE}_{\alpha,^{218}\mathrm{Po}}}{\mathrm{PE}_{\alpha,^{222}\mathrm{Rn}}} \times \frac{E_{\alpha,^{222}\mathrm{Rn}}}{E_{\alpha,^{218}\mathrm{Po}}} \equiv R_2 \times \frac{E_{\alpha,1}}{E_{\alpha,2}},$$

$$\frac{\mathrm{QF}_{\alpha,^{214}\mathrm{Po}}}{\mathrm{QF}_{\alpha,^{222}\mathrm{Rn}}} = \frac{\mathrm{PE}_{\alpha,^{214}\mathrm{Po}}}{\mathrm{PE}_{\alpha,^{222}\mathrm{Rn}}} \times \frac{E_{\alpha,^{222}\mathrm{Rn}}}{E_{\alpha,^{214}\mathrm{Po}}} \equiv R_3 \times \frac{E_{\alpha,1}}{E_{\alpha,3}}.$$

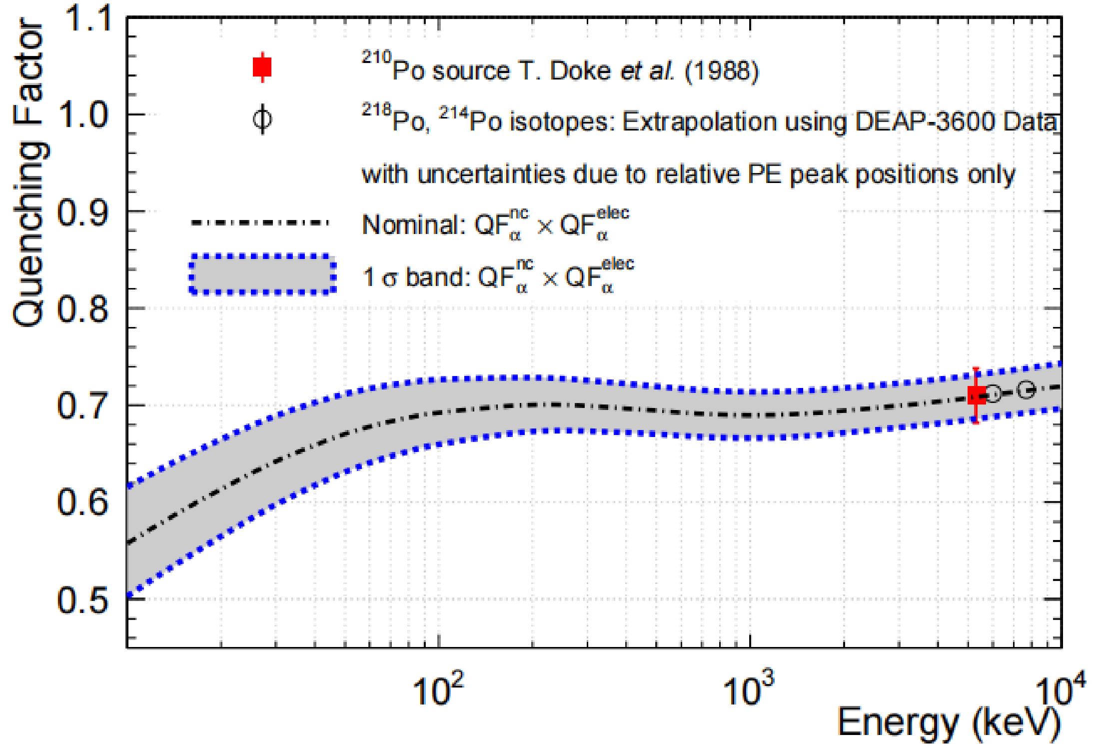
$$\mathrm{QF}_\alpha = \frac{\mathrm{PE}_\alpha}{Y \times E_{\alpha,\mathrm{dep}}}$$



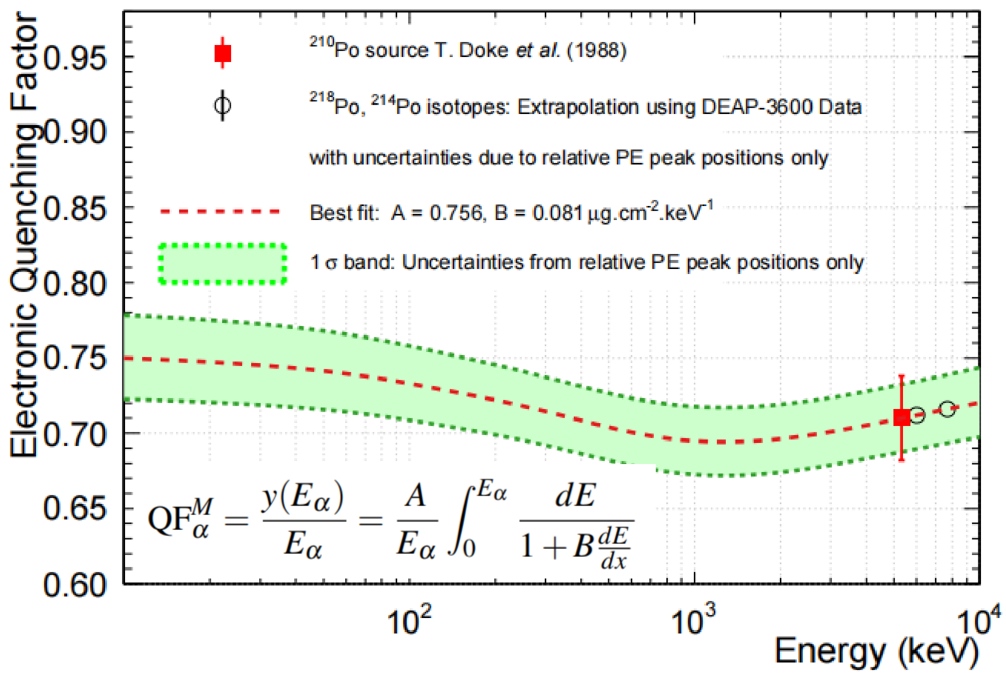
arXiv: 2406.18597v1

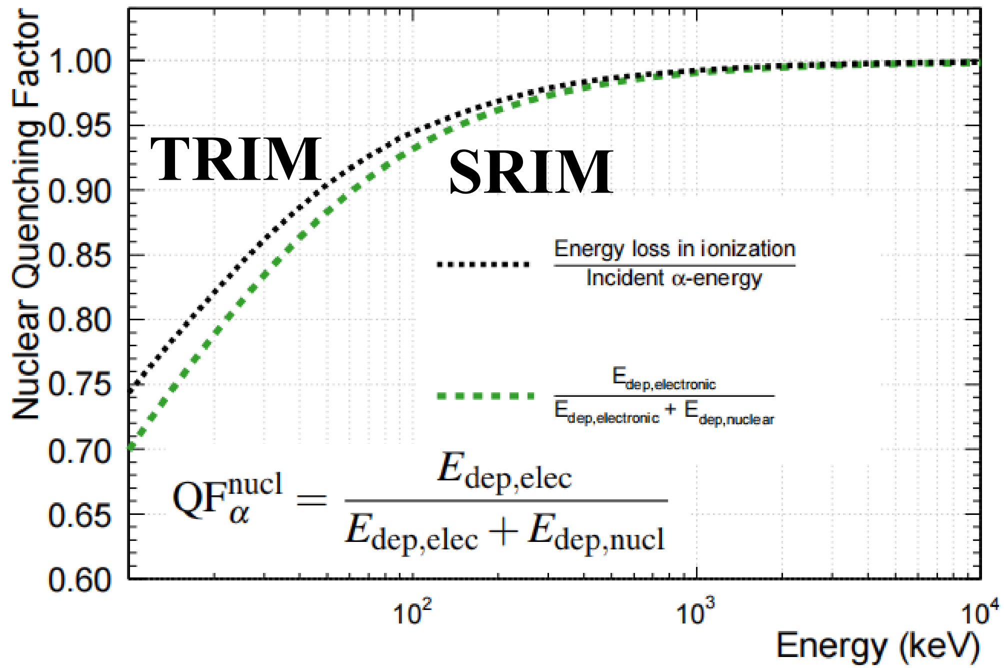
Extrapolation of the QF values into the low-energy region down to 10 keV

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

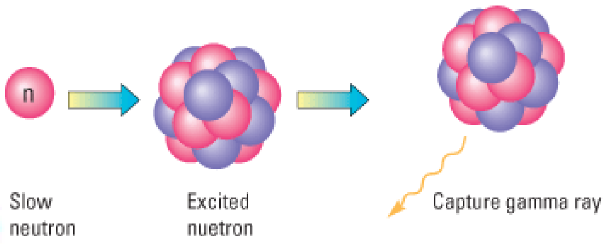


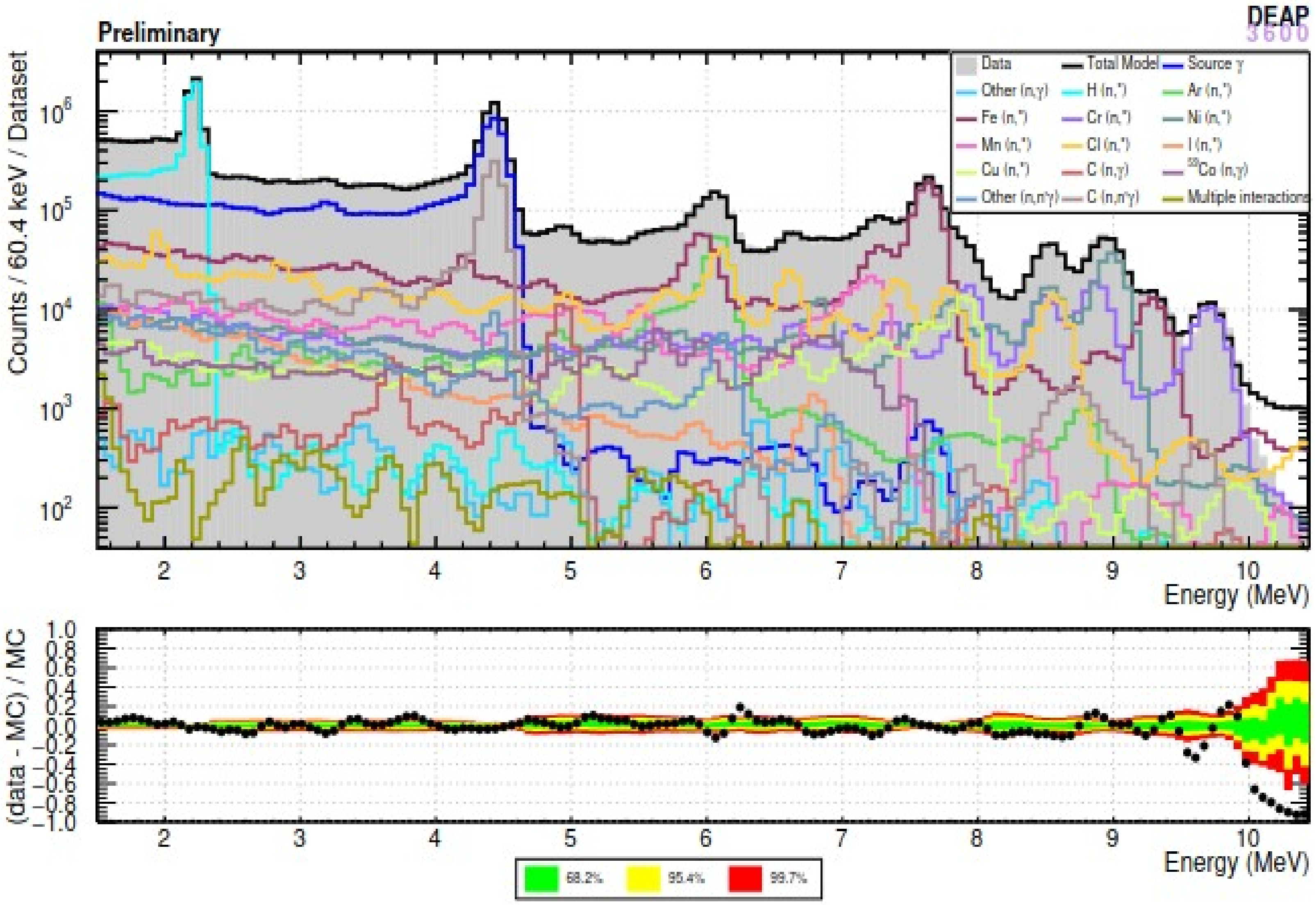
arXiv: 2406.18597v1





Searches at MeV-scale energy deposits

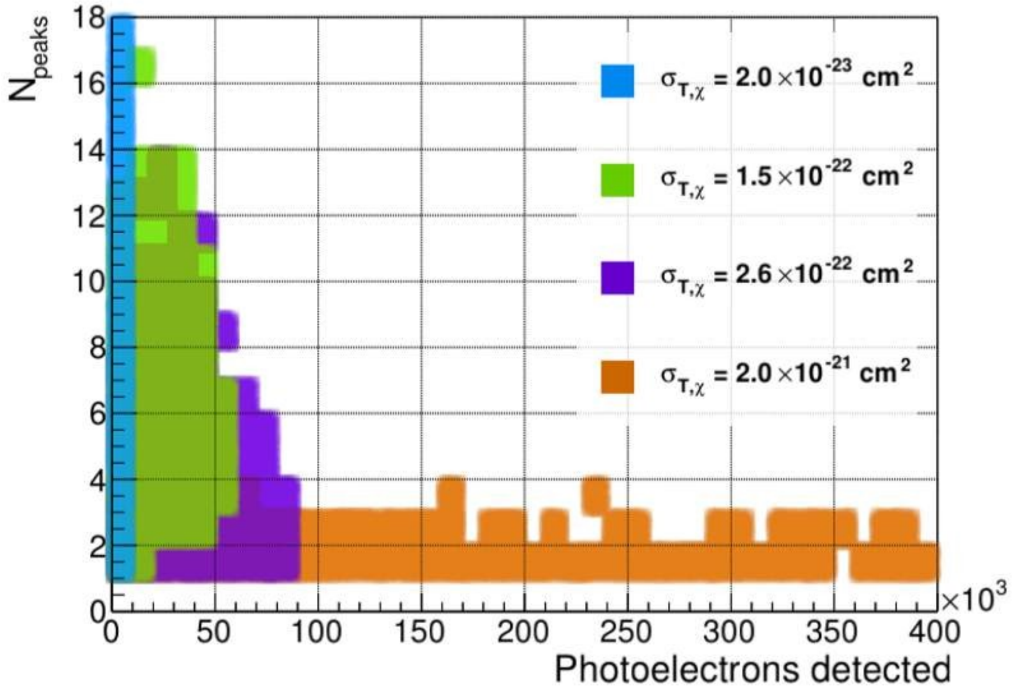


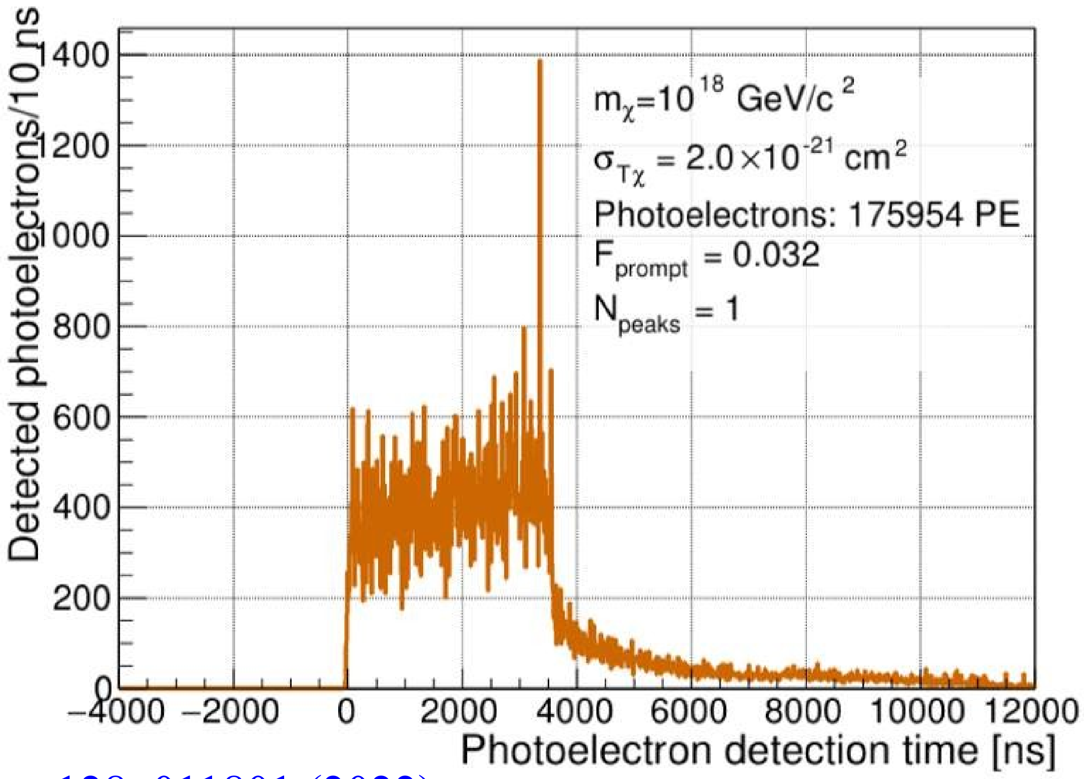


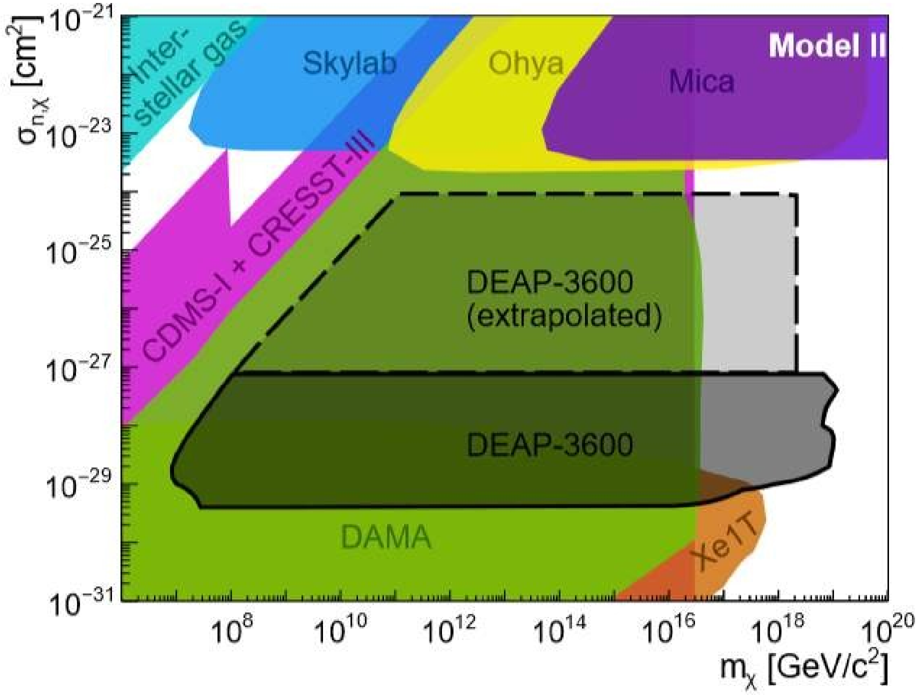
Ultra-heavy DM candidates: extremely low number density in the halo, need for tonne-scale exposure and pretty high cross-section, hence **multi-scattering in LAr**!

Main backgrounds from ^{39}Ar + (n, $\boldsymbol{\gamma}$) pile-ups

World-leading exclusion limits among direct detection experiments at Planck scale masses







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