Recent results from DEAP-3600

Dr. Michela Lai
on behalf of
DEAP-3600 Collaboration

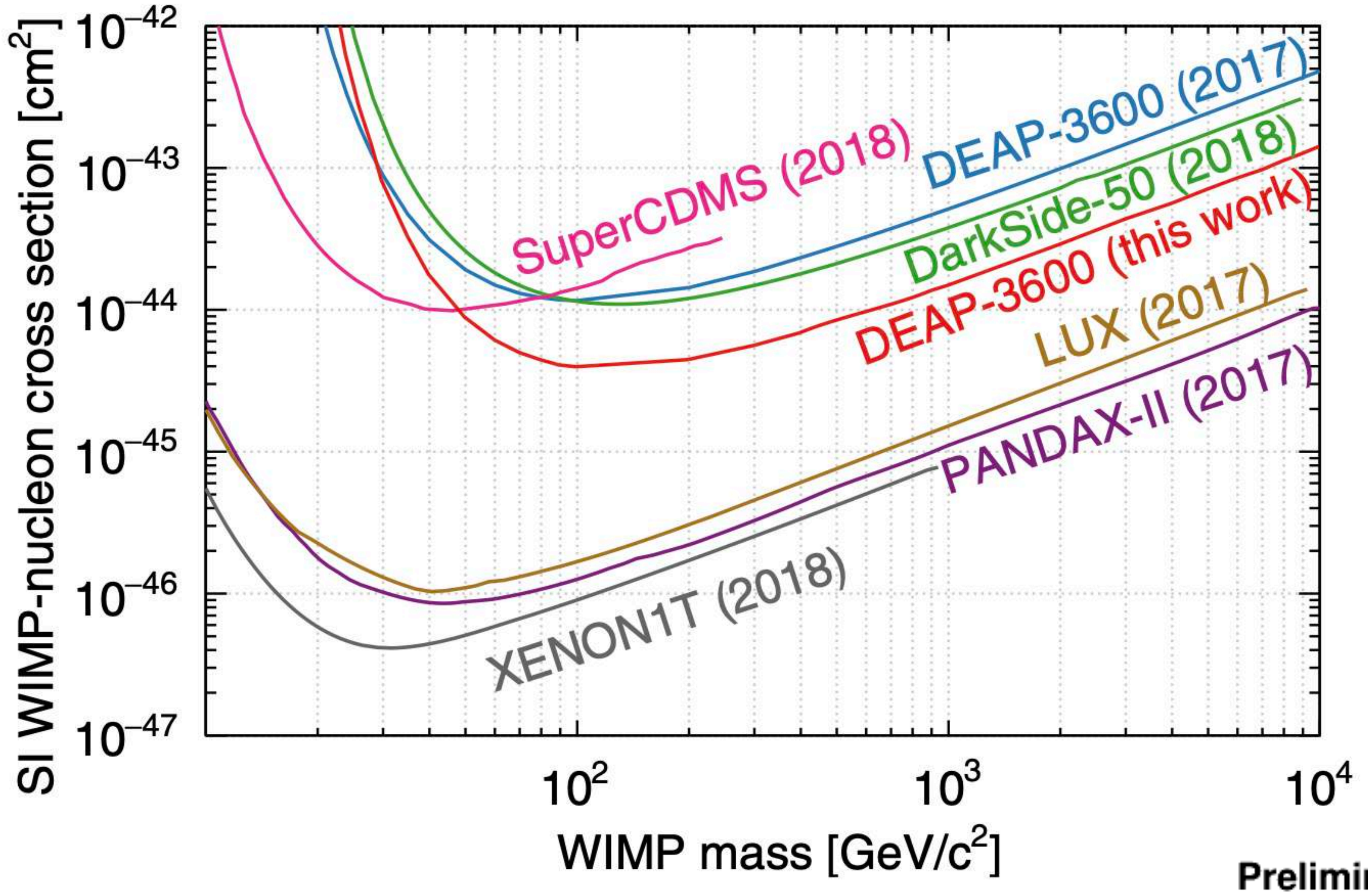
LIDINE2022 - 21 SEPTEMBER 2022

DEAP Collaboration

University of Alberta
AstroCeNT – Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences
UC Riverside
Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens
Carleton University
Gobierno de España – Ministerio de Ciencia, Innovación y Universidades – Ciemat
INFN Istituto Nazionale di Fisica Nucleare
Johannes Gutenberg Universität Mainz JGU
National Research Center "Kurchatov Institute"
Laurentian University / Université Laurentienne
Instituto de Física
Princeton University
Queen's University
Royal Holloway University of London
Particle Physics Rutherford Appleton Laboratory
SNOLAB
University of Sussex
Technical University of Munich TUM
TRIUMF

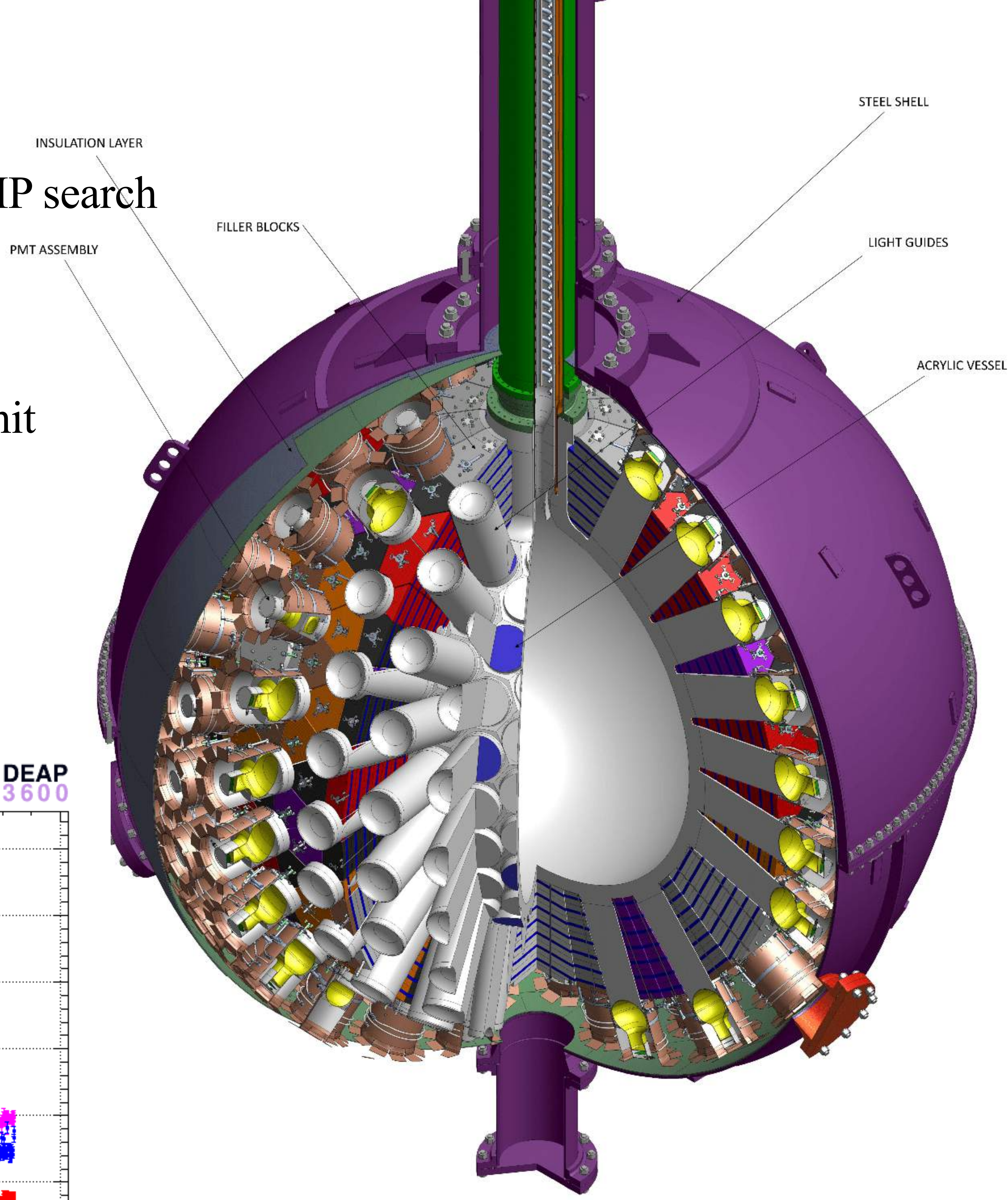
The detector

DEAP-3600 is the largest running liquid argon detector designed for the WIMP search



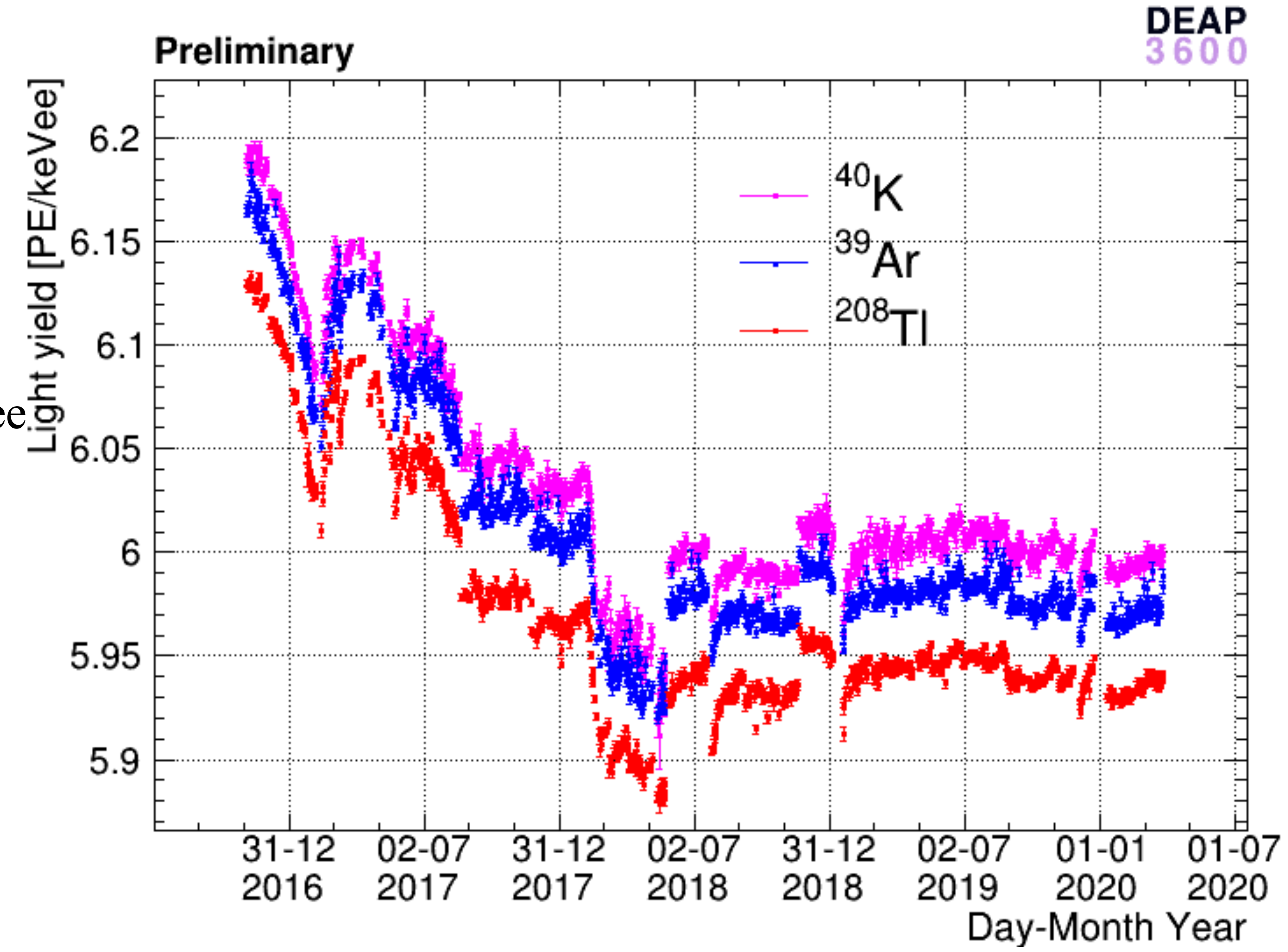
Phys. Rev. D 100, 022004

Most stringent exclusion limit in argon for WIMP masses above 20 GeV

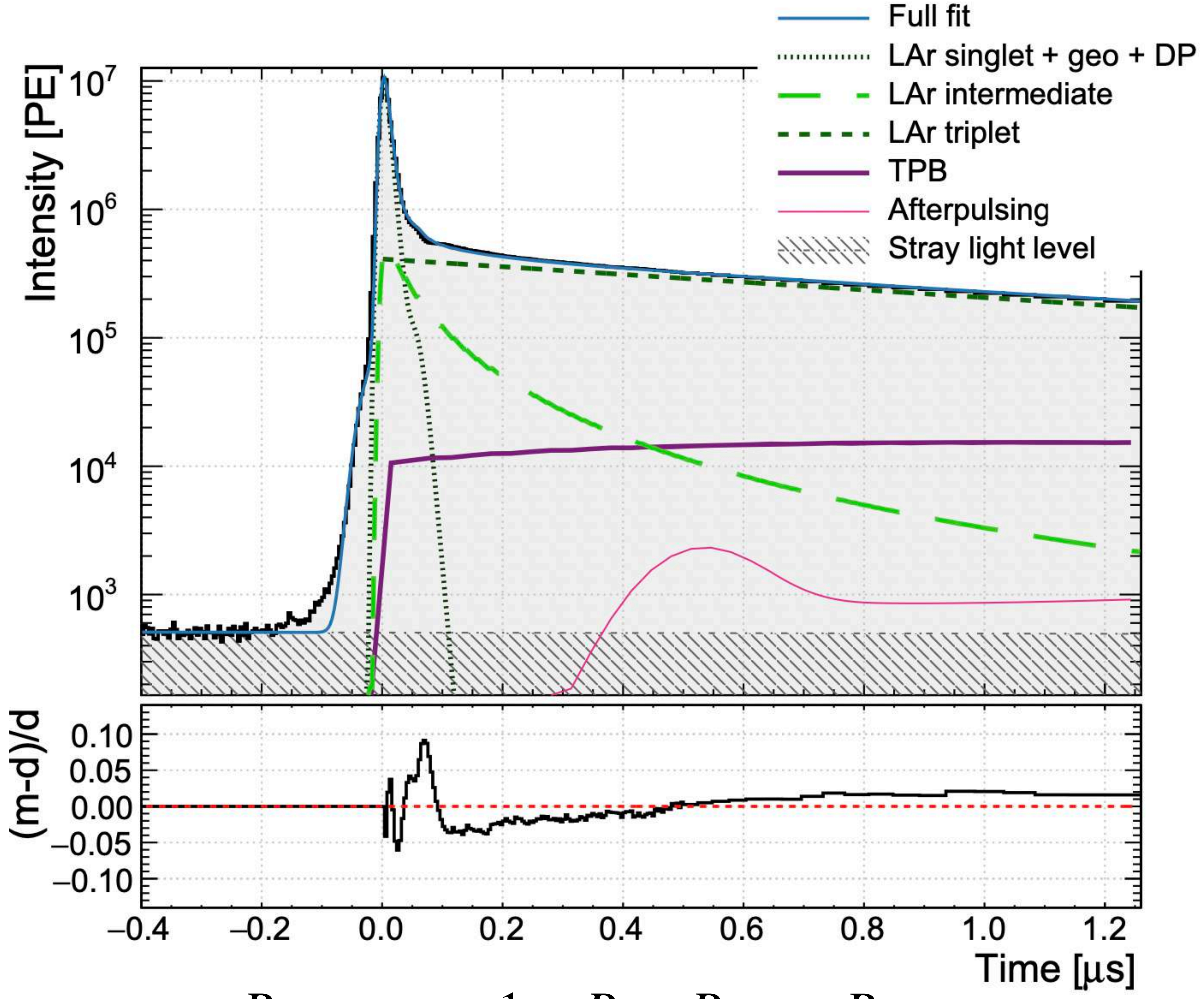


Astroparticle Physics 108 (2019) 1-23

Light yield stable within 0.3 PE/keV$_{ee}$ after the second fill



Pulse shape discrimination

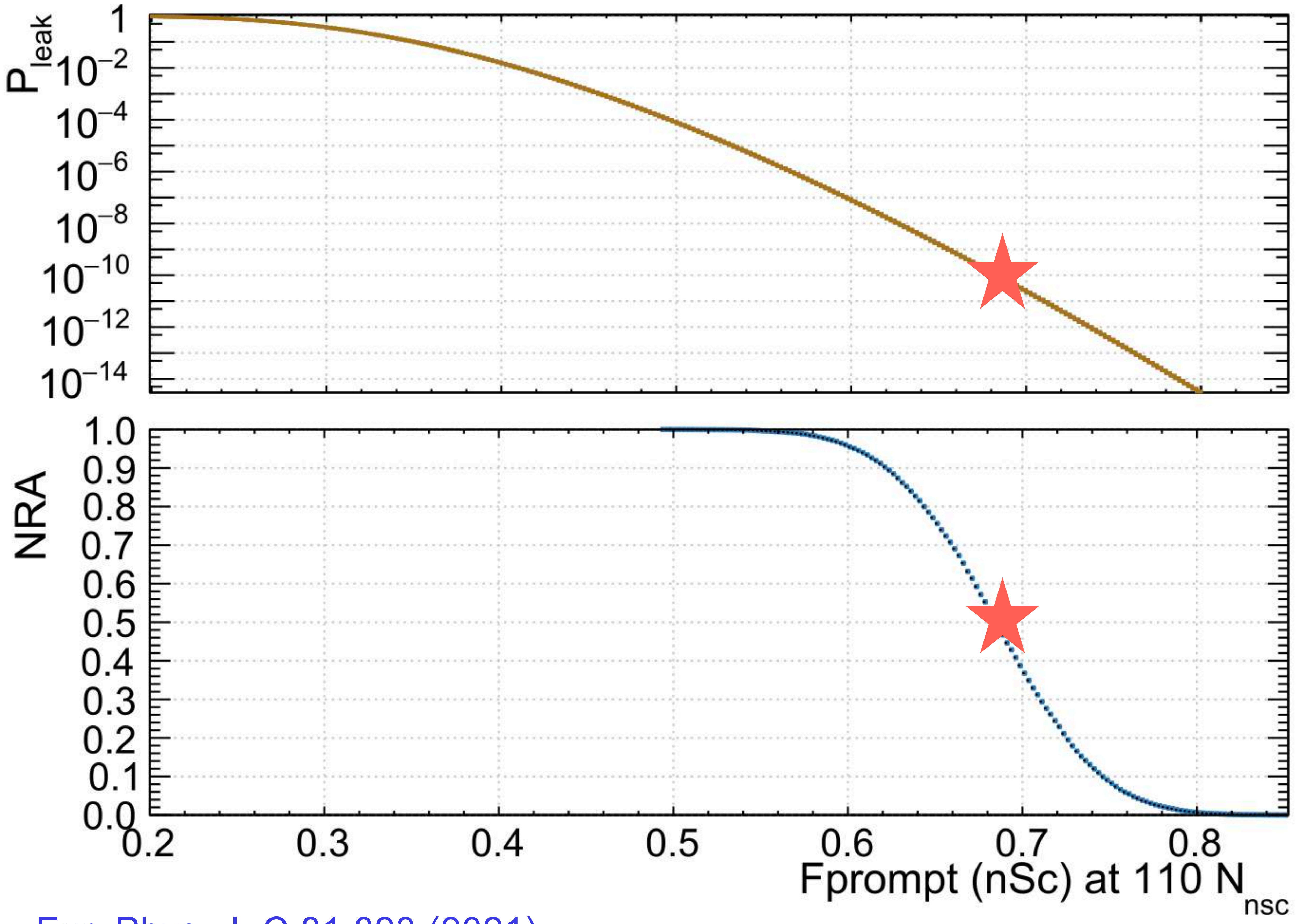


$$I_{LAr}(t) = \frac{R_s}{\tau_s} e^{-t/\tau_s} + \frac{1 - R_s - R_t}{\tau_{rec}(1 + t/\tau_{rec})^2} + \frac{R_t}{\tau_t} e^{-t/\tau_t}$$

$\tau_t = 1445ns$ $\quad$ $\tau_s = 8.2ns$ $\quad$ $\tau_{rec} = 175.5ns$ $\quad$ $R_t = 0.71$ $\quad$ $R_s = 0.23$

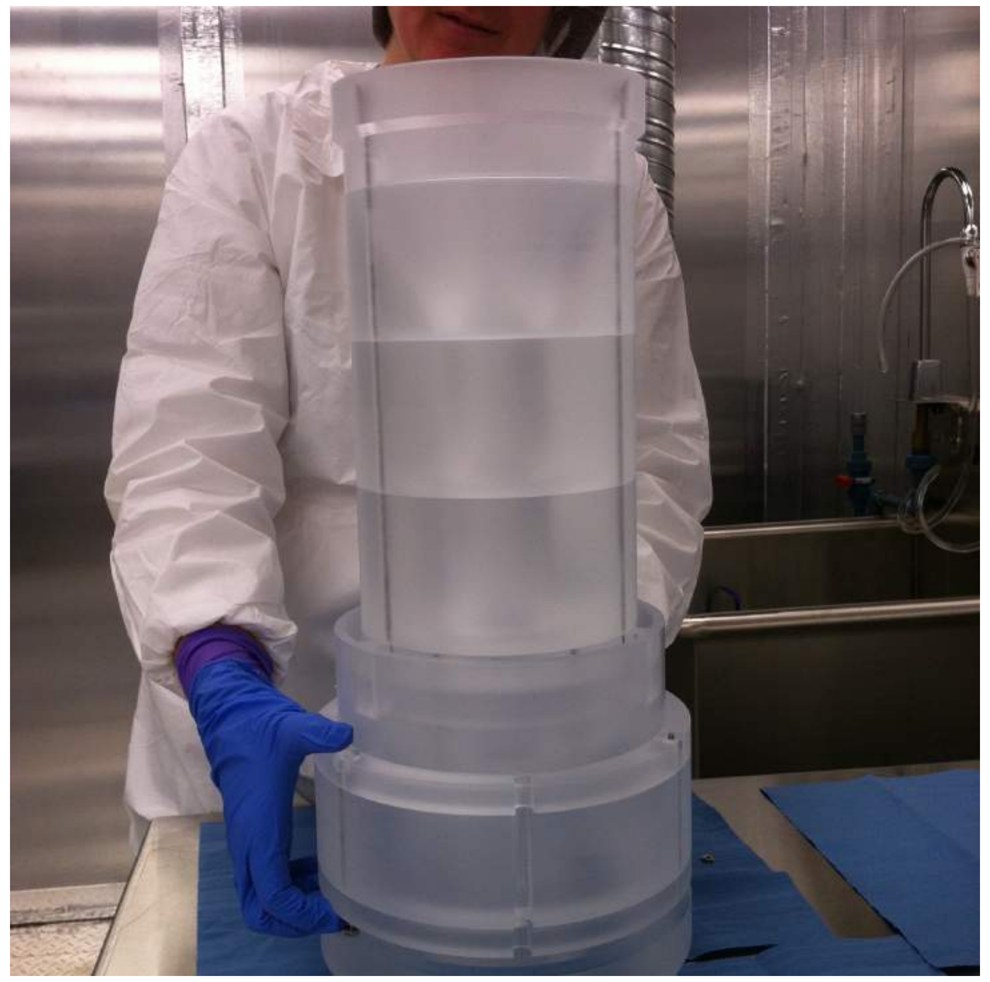
Eur. Phys. J. C 80, 303 (2020)

- ➡ Modeled scintillation pulse shape due to ^{39}Ar β decays
- ➡ At about 18 keV$_{ee}$ and a nuclear recoil acceptance of 50 % a **leakage probability** of about **10^{-10}** is reached

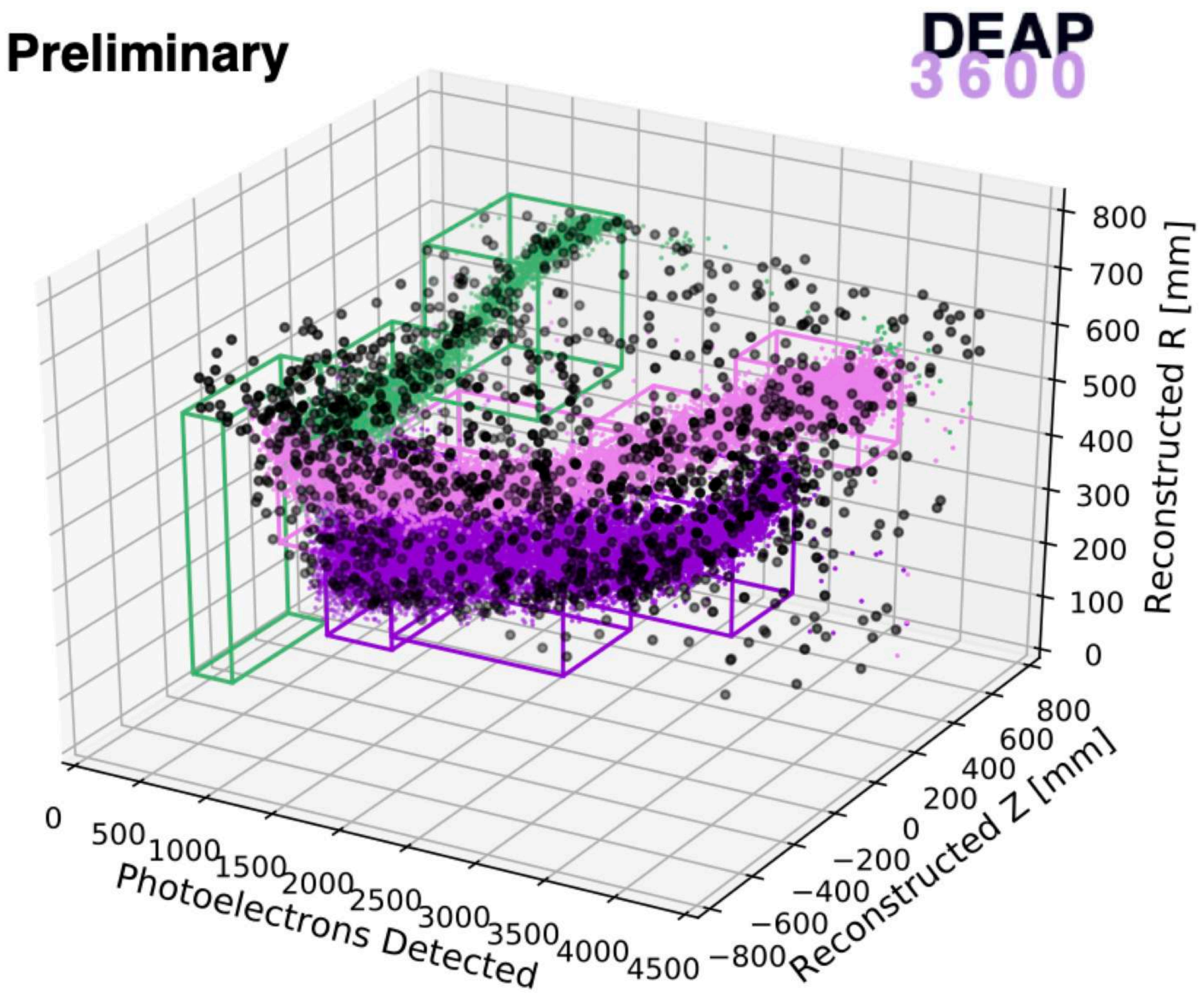


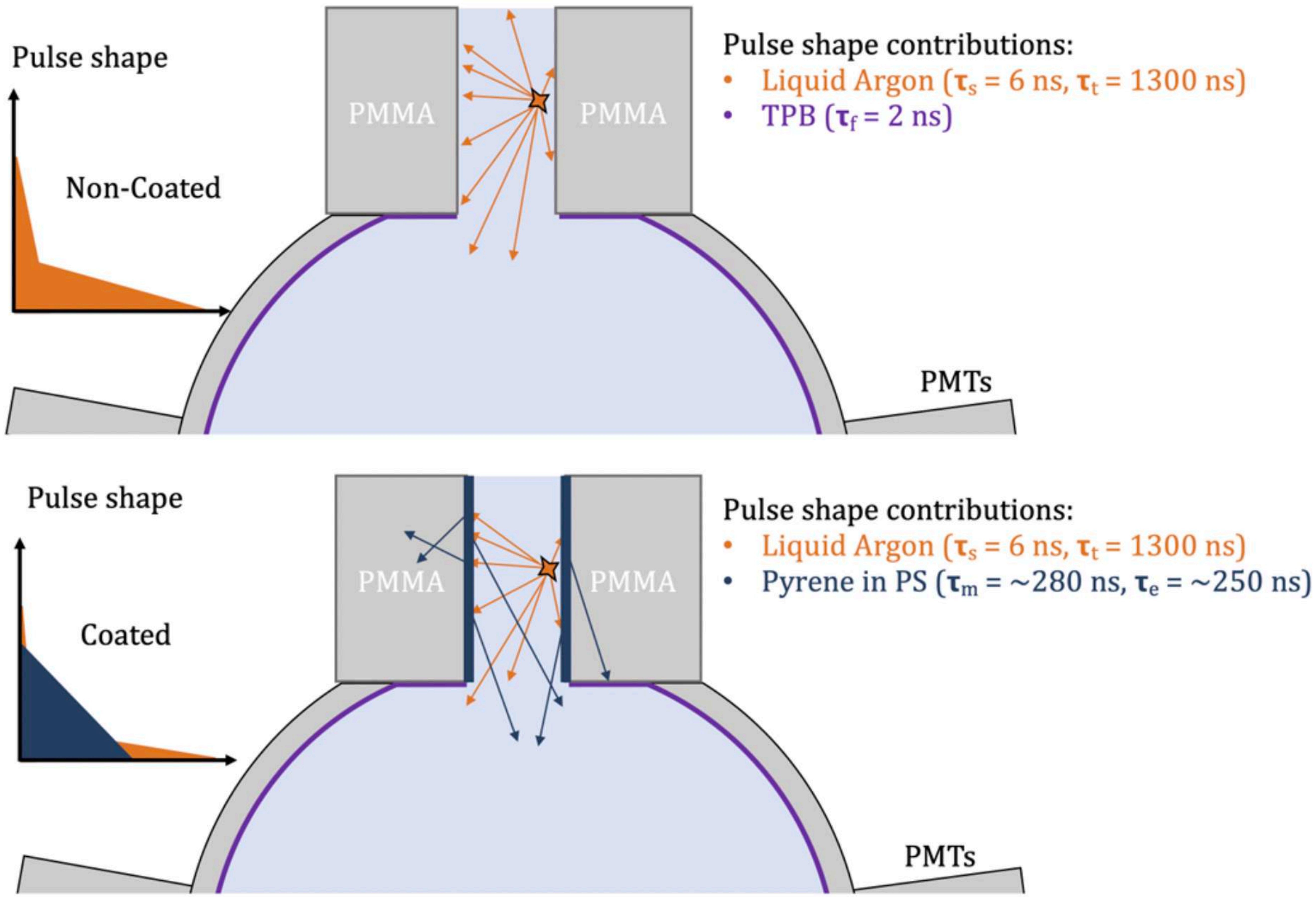
Eur. Phys. J. C 81,823 (2021)

Hardware upgrades: pyrene coating



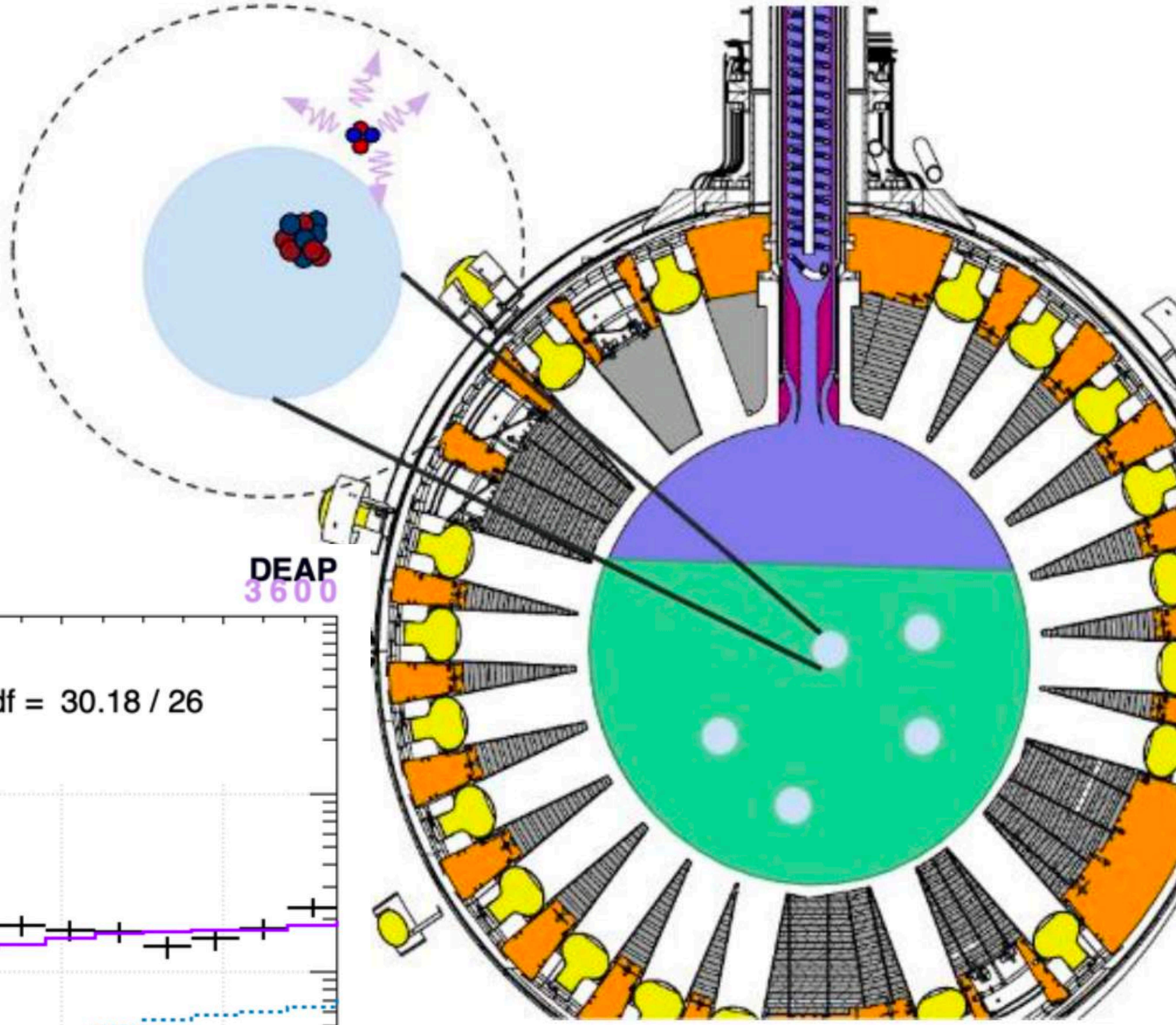
- ➡ Argon condensed on the flowguides may scintillate due to alphas from ^{210}Po
- ➡ Signal degraded by the detector geometry **eventually enters WIMP ROI**
- ➡ Change the flowguides with new ones, coated with a wavelength-shifter
- ➡ Preference for the **Pyrene**, due to the much slower time decays
- ➡ Installation of external cooling system, to prevent argon condensation on flowguides

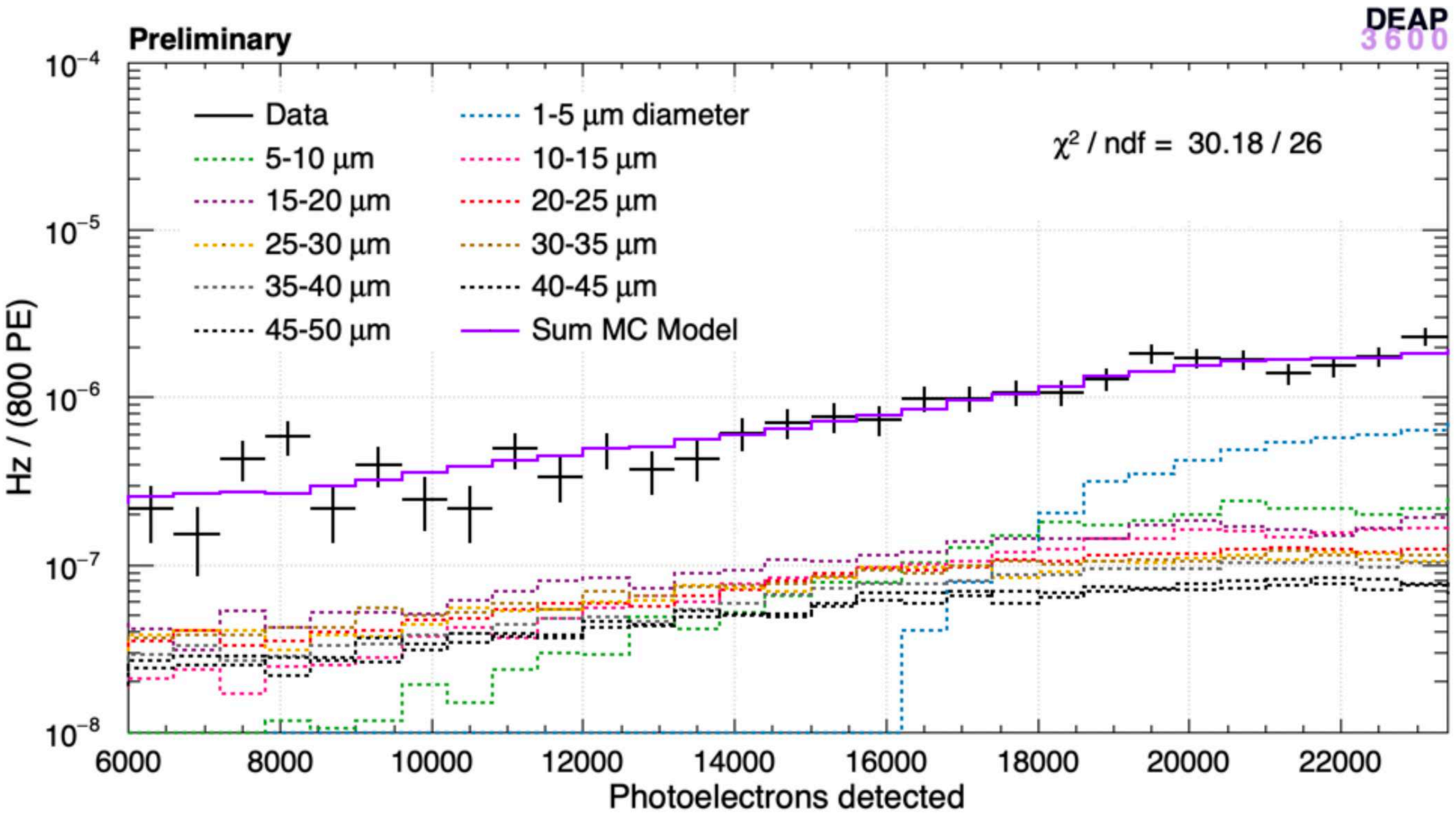




Hardware upgrades: dust removal

- ➡ Alpha decays in **particulate dust** can enter WIMP ROI
- ➡ Background modeled according to the dust radius
- ➡ Reduction of dust background by **extraction and filtration of LAr**





Constrains on NREFT interactions…

IS $\sigma_i^n = \sigma_i^p$

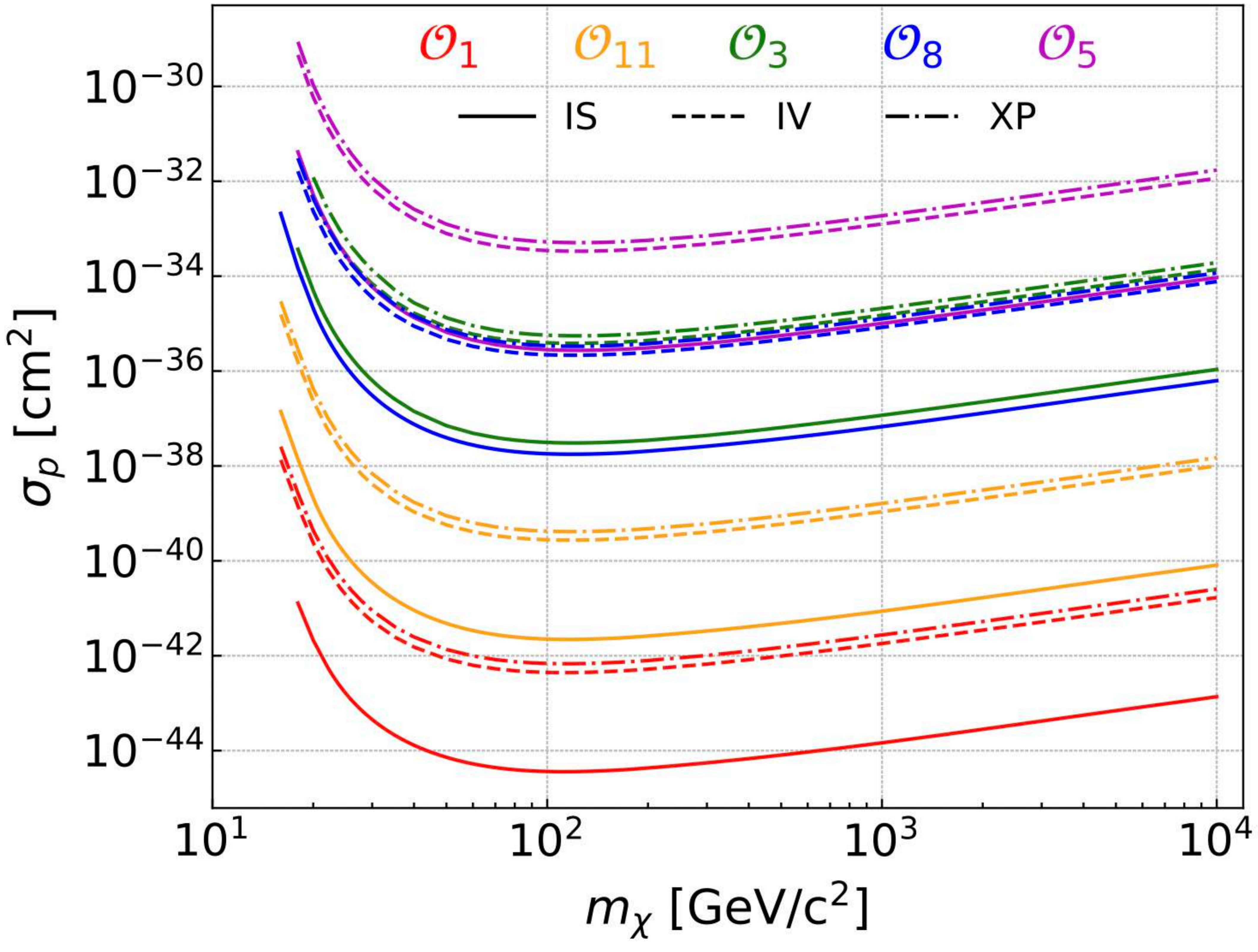
IV $\sigma_i^n = -\sigma_i^p$

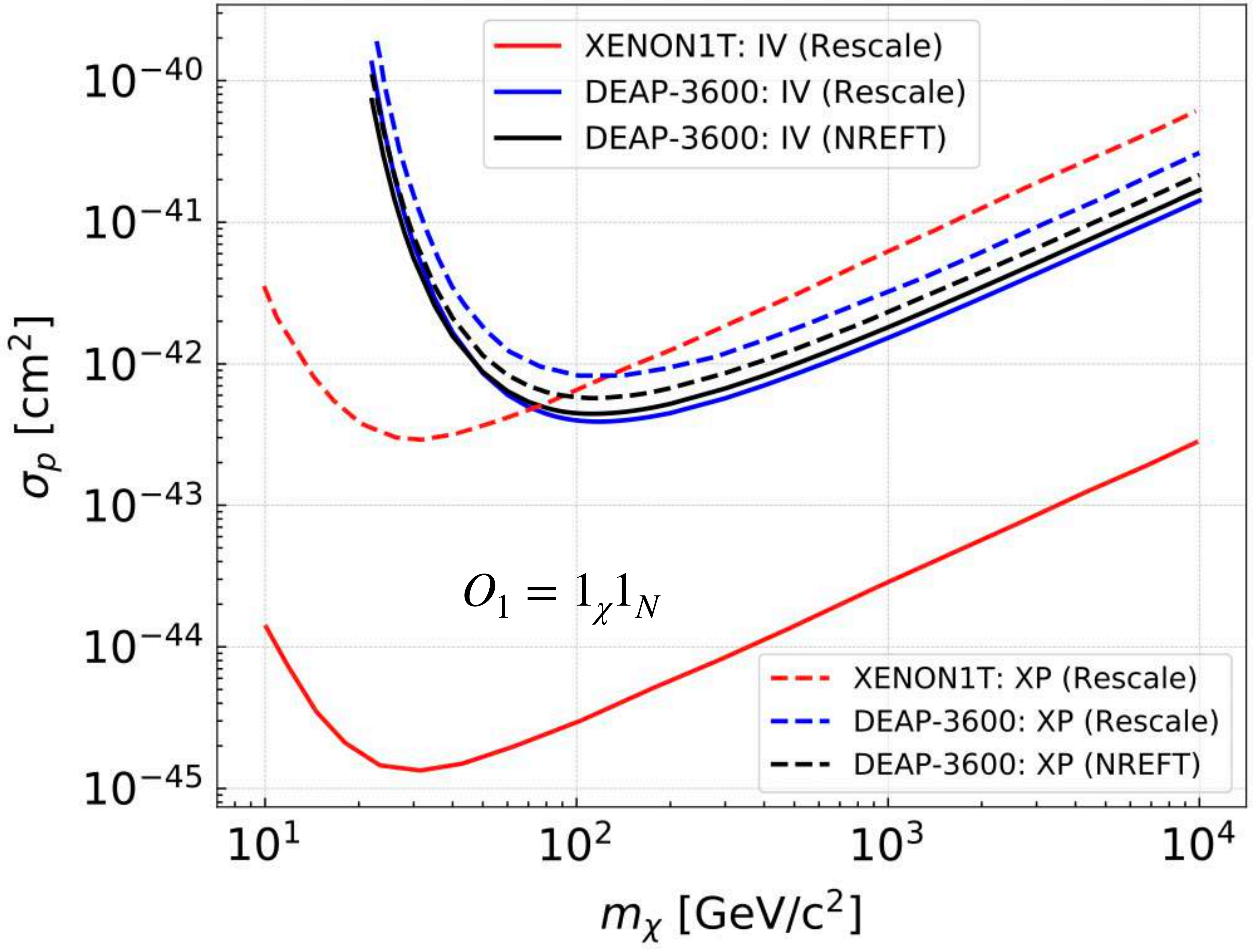
XP $\sigma_i^n = -0.7\sigma_i^p$

The results from 2019 analysis were reinterpreted in terms of a **Non relativistic effective field theory (NREFT)**

$$O_1 = 1_\chi 1_N \qquad O_5 = i\vec{S_\chi}\cdot\left(\frac{\vec{q}}{m_N}\times\vec{v_\perp}\right)$$

$$O_3 = i\,\vec{S_N}\cdot\left(\frac{\vec{q}}{m_N}\times\vec{v_\perp}\right) \qquad O_8 = \vec{S_\chi}\cdot\vec{v_\perp} \qquad O_{11} = i\vec{S_\chi}\cdot\frac{\vec{q}}{m_N}$$

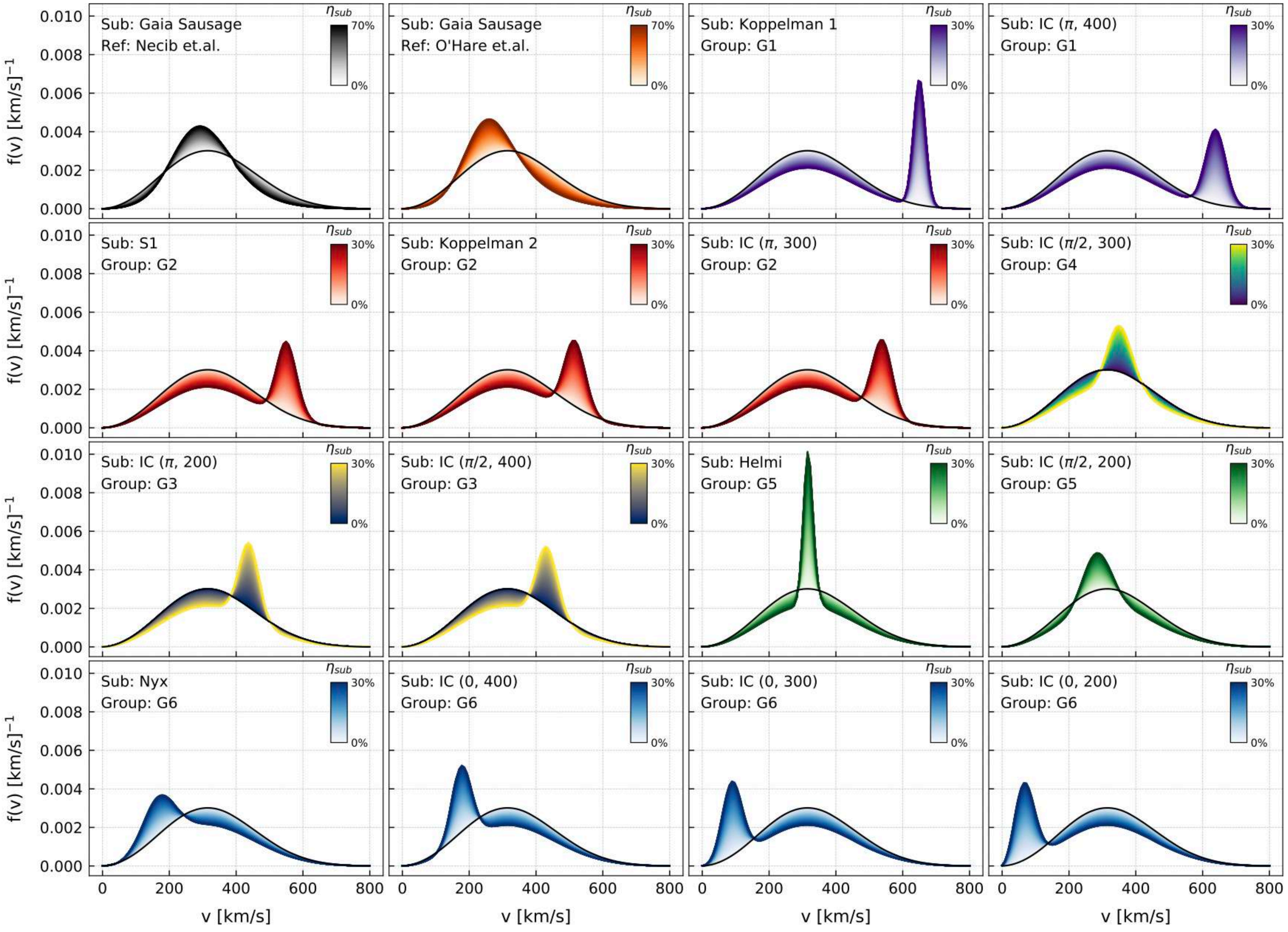




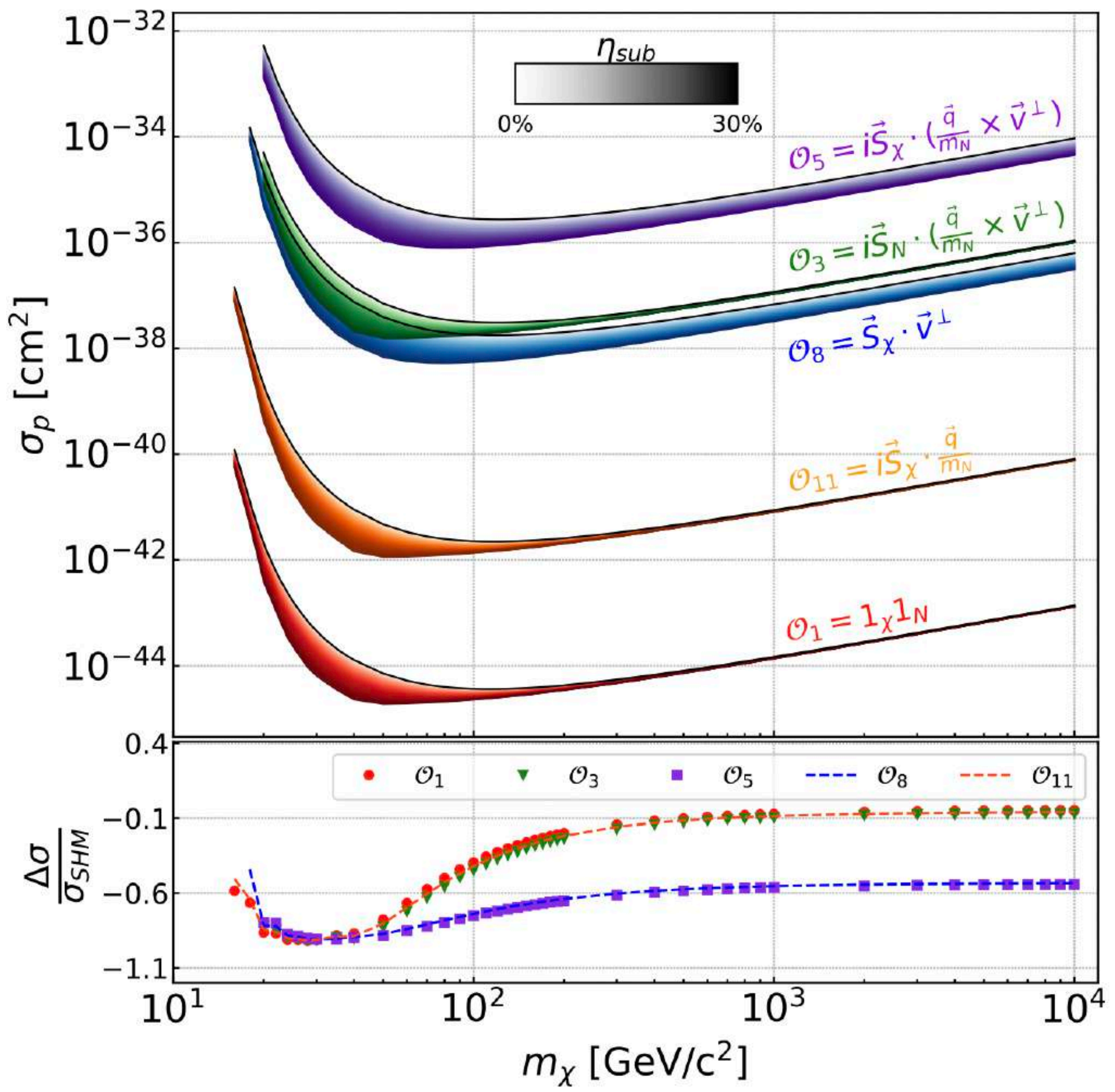
Phys. Rev. D 102, 082001 (2020)

… and with non-standard halo

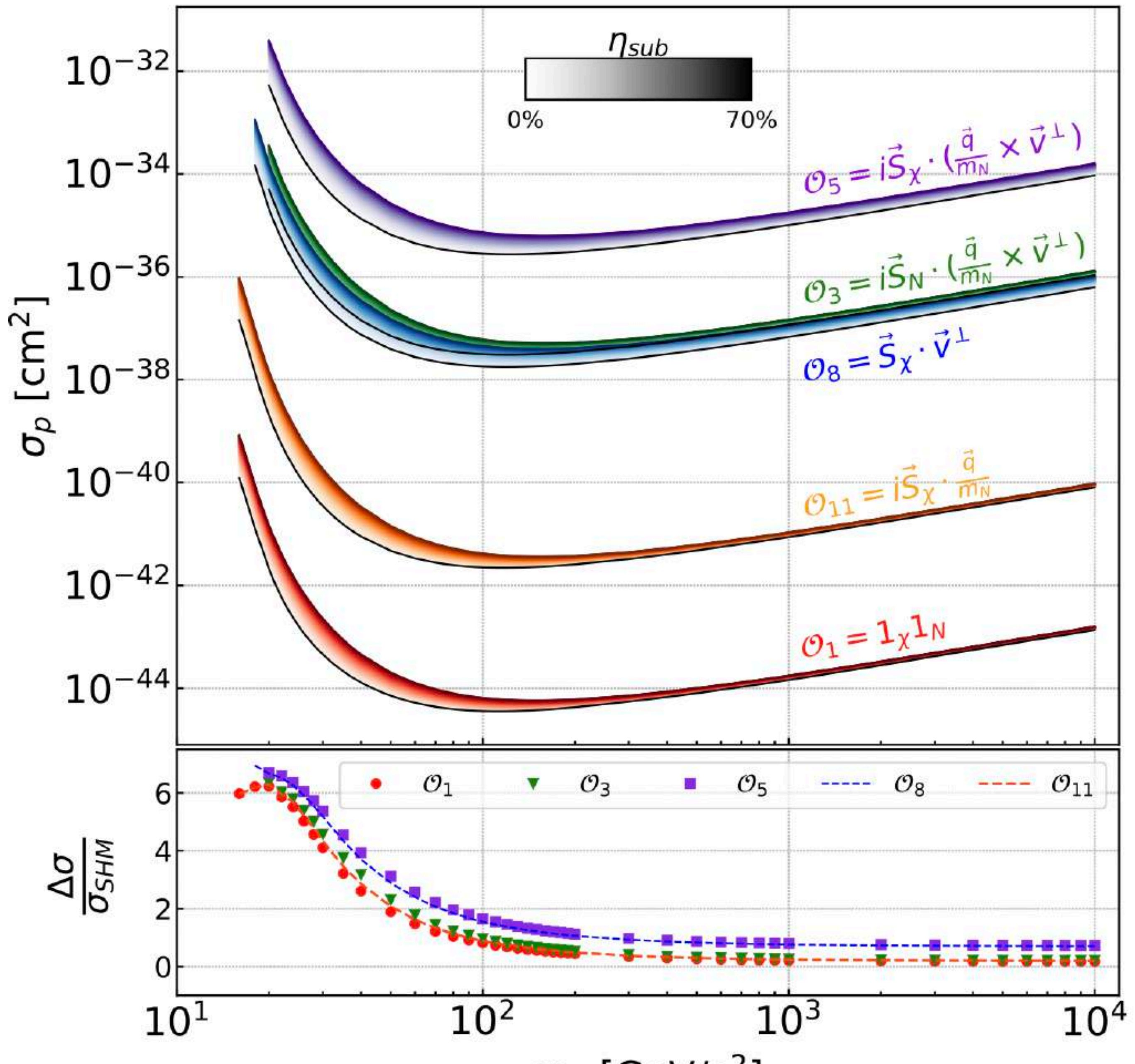
GAIA and Sloan Digital Sky Survey recently observed inflating clumps and streams around our Galaxy



Phys. Rev. D 102, 082001 (2020)



G1 stream



Gaia Sausage

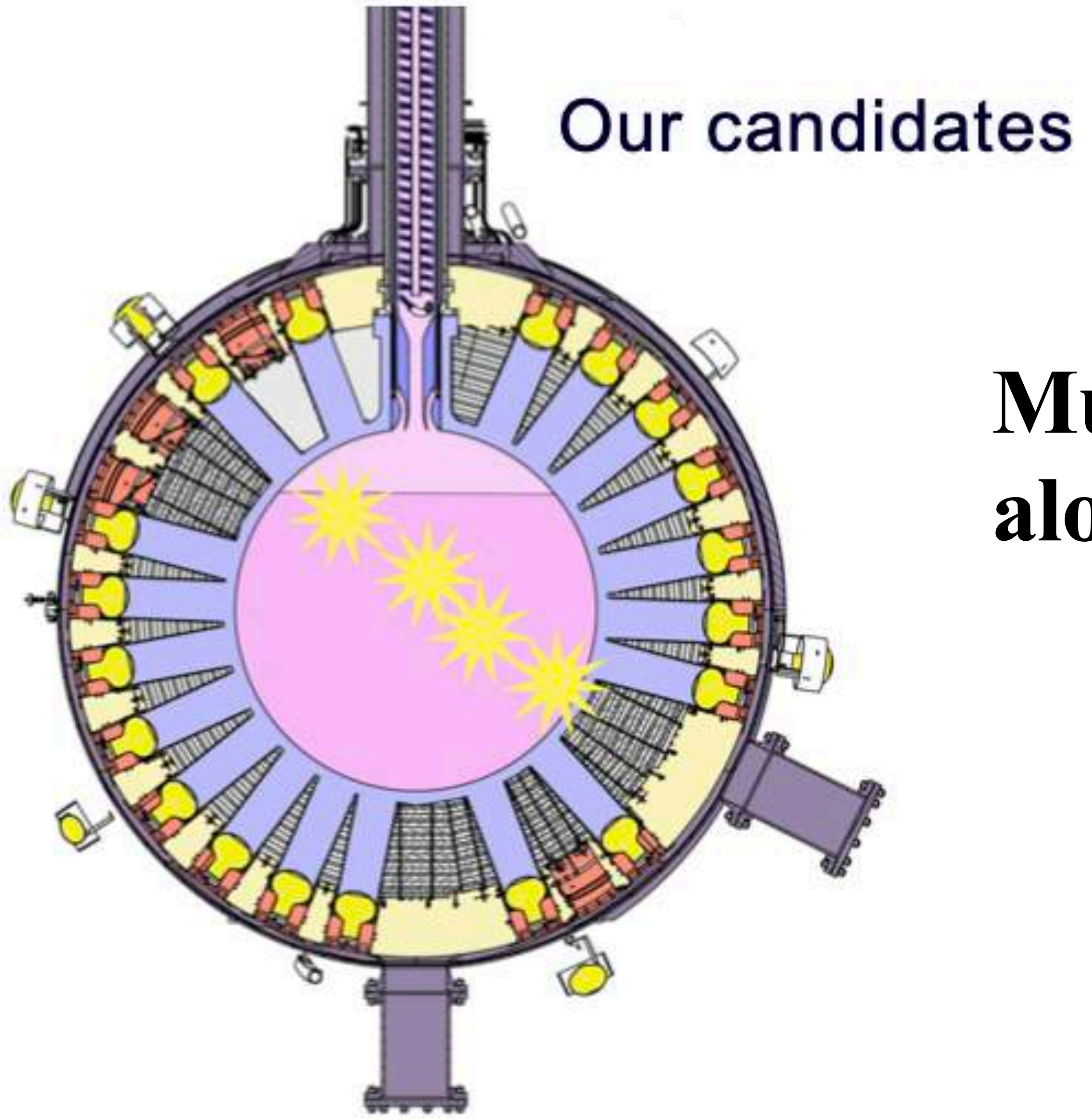
Multi-scattering search

➡**Ultra-heavy dark matter** is expected in GUTs but cannot be produced with WIMPs freeze out mechanism

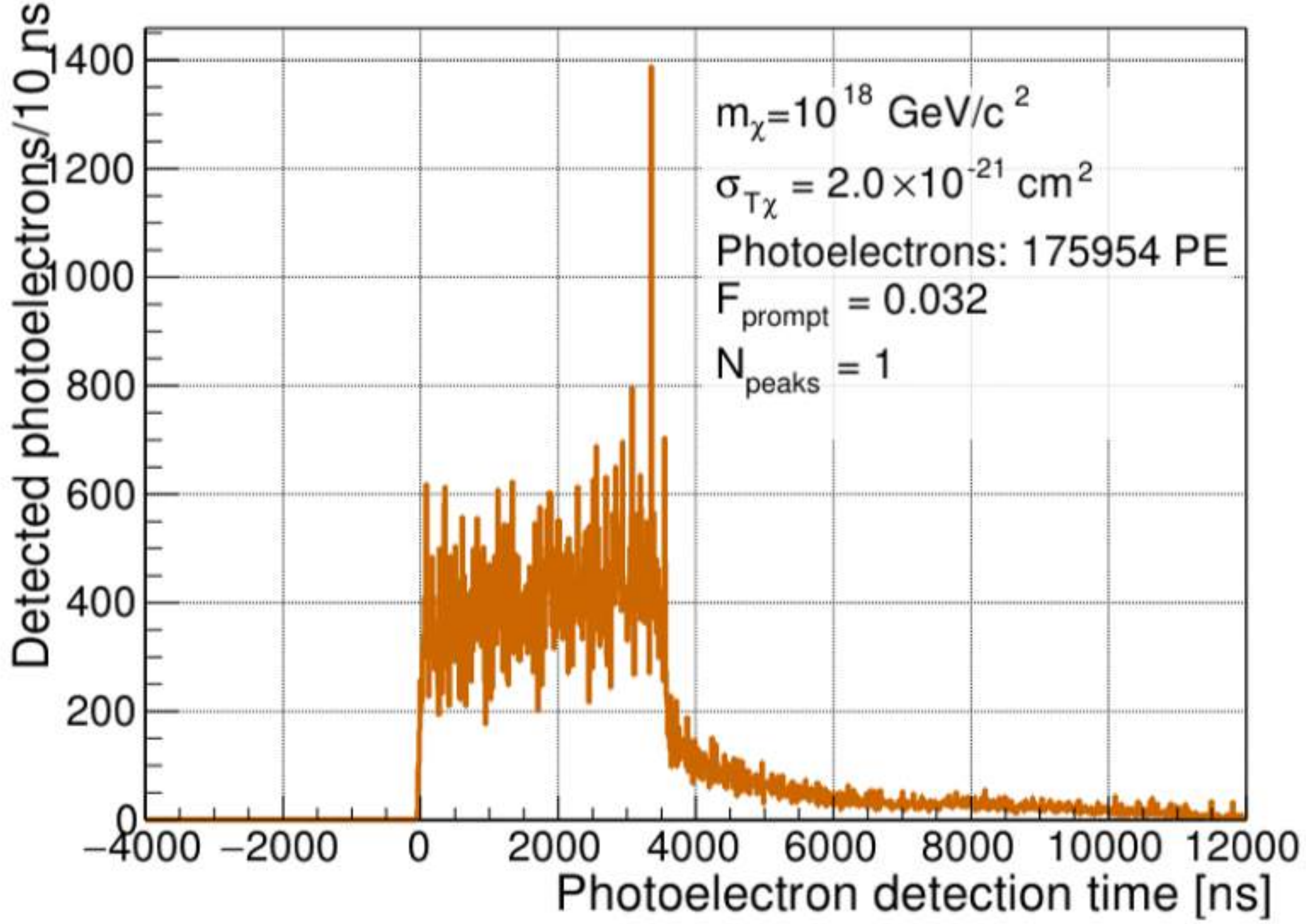
➡At such **high masses**, constrains are limited by the dark matter abundance rather than the cross-section, so a **large detector is needed**

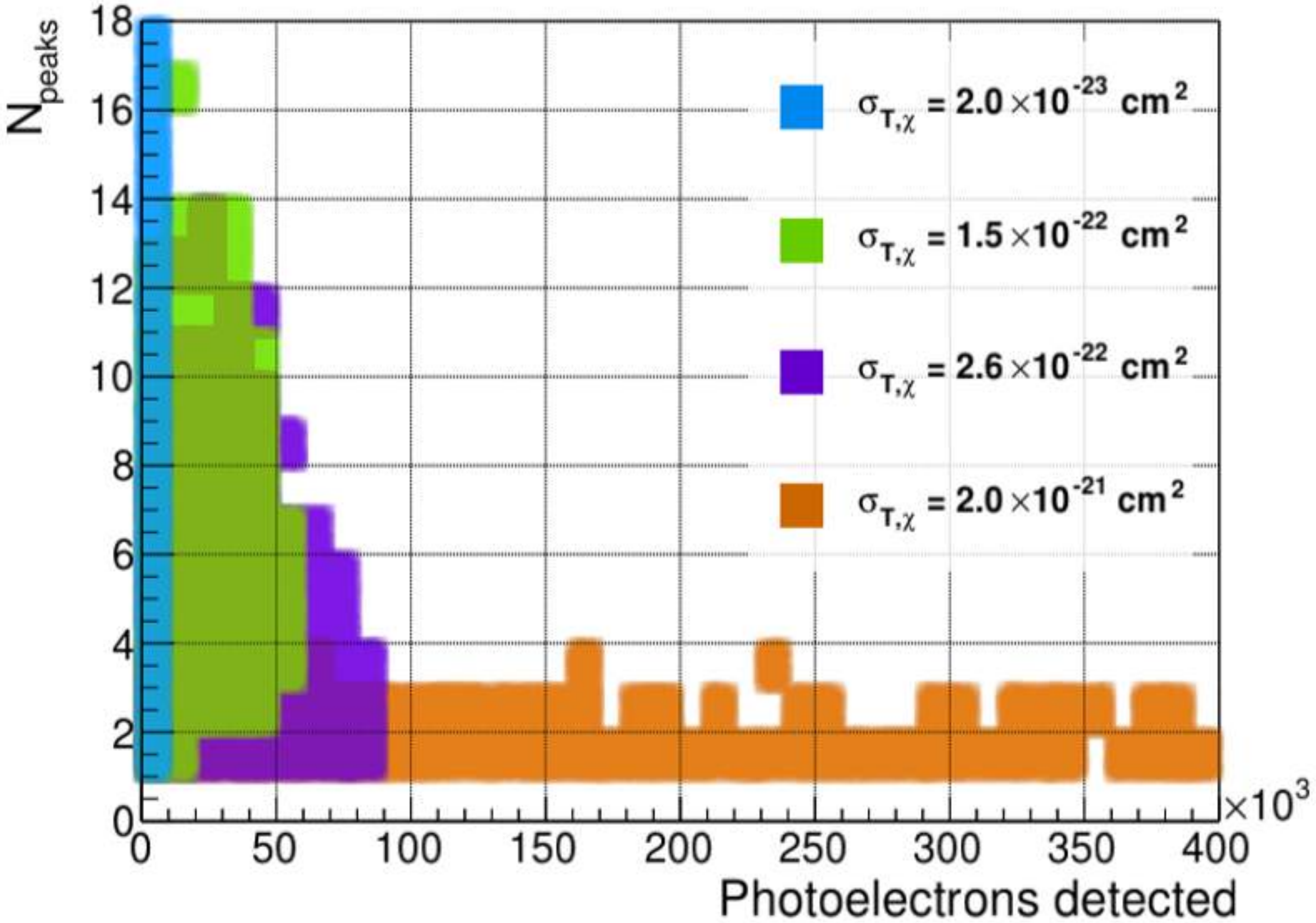
➡Experimentally allowed cross-sections are high enough to produce **multiple scatters** in the detector

➡Dark matter (DM) candidates above $\sigma_{\chi\text{-n}} \cong 10^{-25}$ cm^2 and $m_\chi \gtrsim 10^{12}$ GeV **can reach underground detectors**



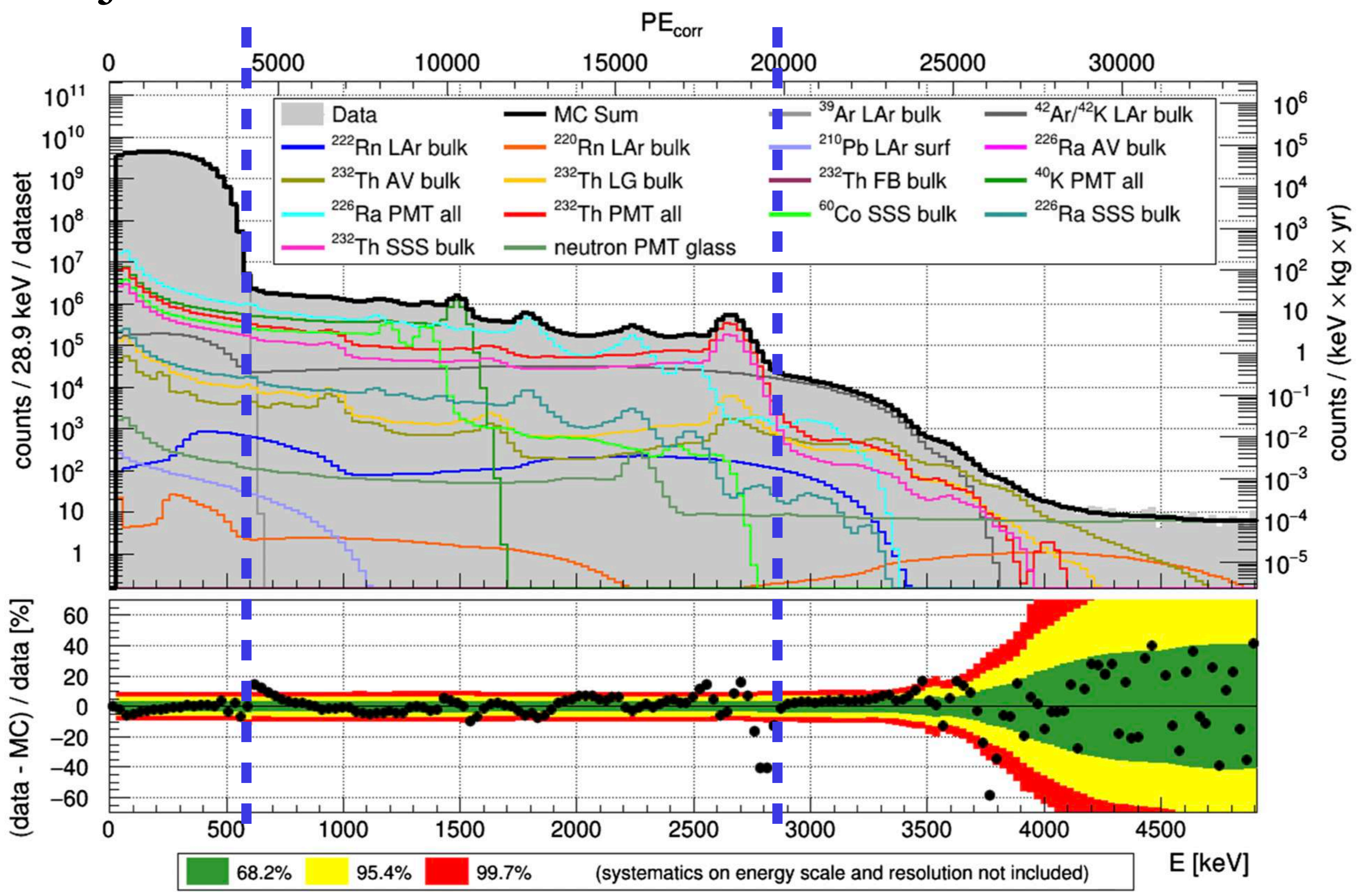
Multi-scattering particle along a collinear track



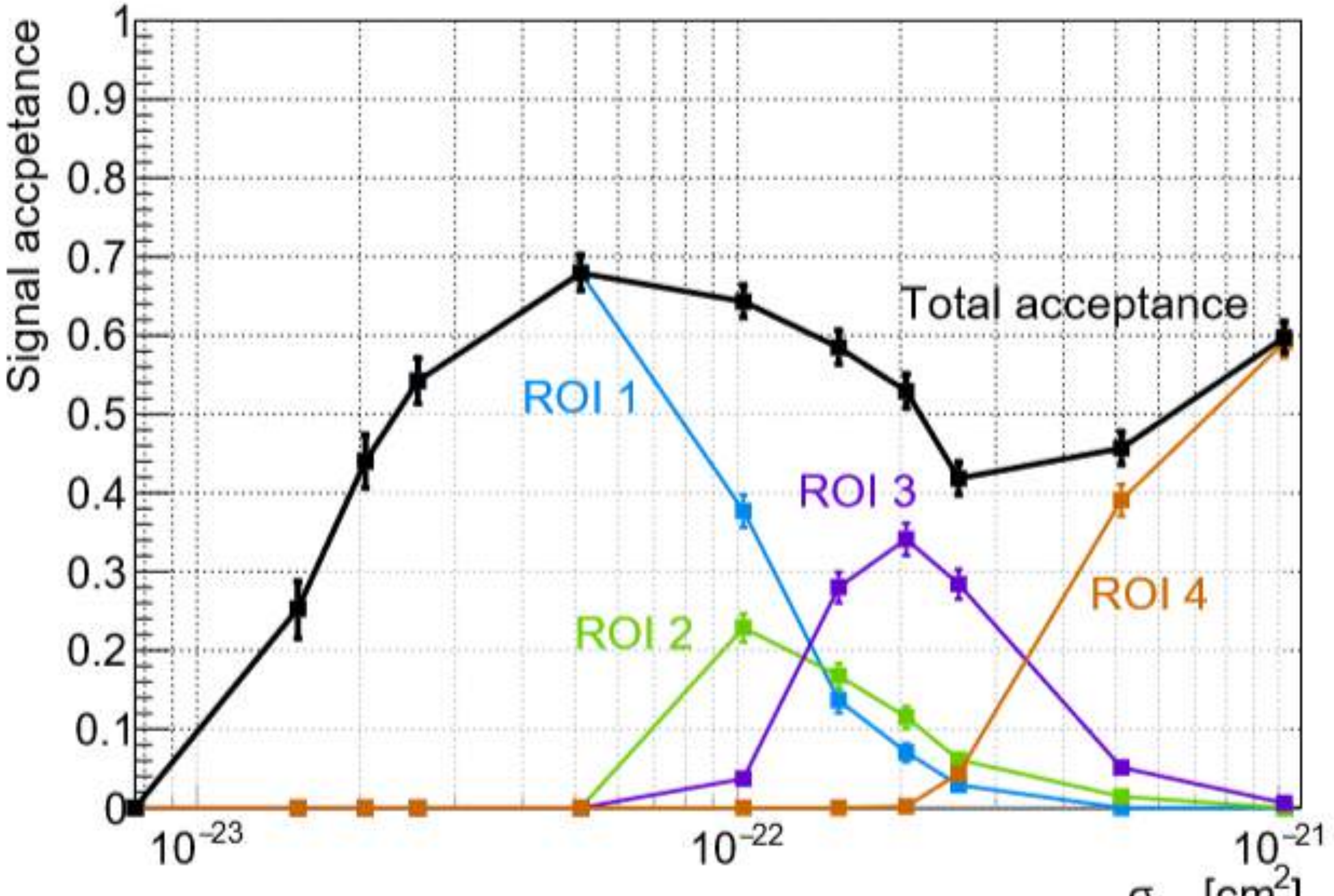


Background rejection

- Below 10 MeV: Set analysis threshold on N_{peaks}, according to the energy range to reject **pile-up events**
- Above 10 MeV: dominant background are **muons**, mainly rejected with the muon veto coincidence cut



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



Total lifetime (813 ± 8) days

Total background level = 0.05 ± 0.03

ROI	PE range	Energy [MeV$_{ee}$]	$N_{\text{peaks}}^{\text{min}}$	$F_{\text{prompt}}^{\text{max}}$	μ_b
1	4000–20 000	0.5–2.9	7	0.10	$(4 \pm 3) \times 10^{-2}$
2	20 000–30 000	2.9–4.4	5	0.10	$(6 \pm 1) \times 10^{-4}$
3	30 000–70 000	4.4–10.4	4	0.10	$(6 \pm 2) \times 10^{-4}$
4	70 000–4×10^8	10.4–60 000	0	0.05	$(10 \pm 3) \times 10^{-3}$

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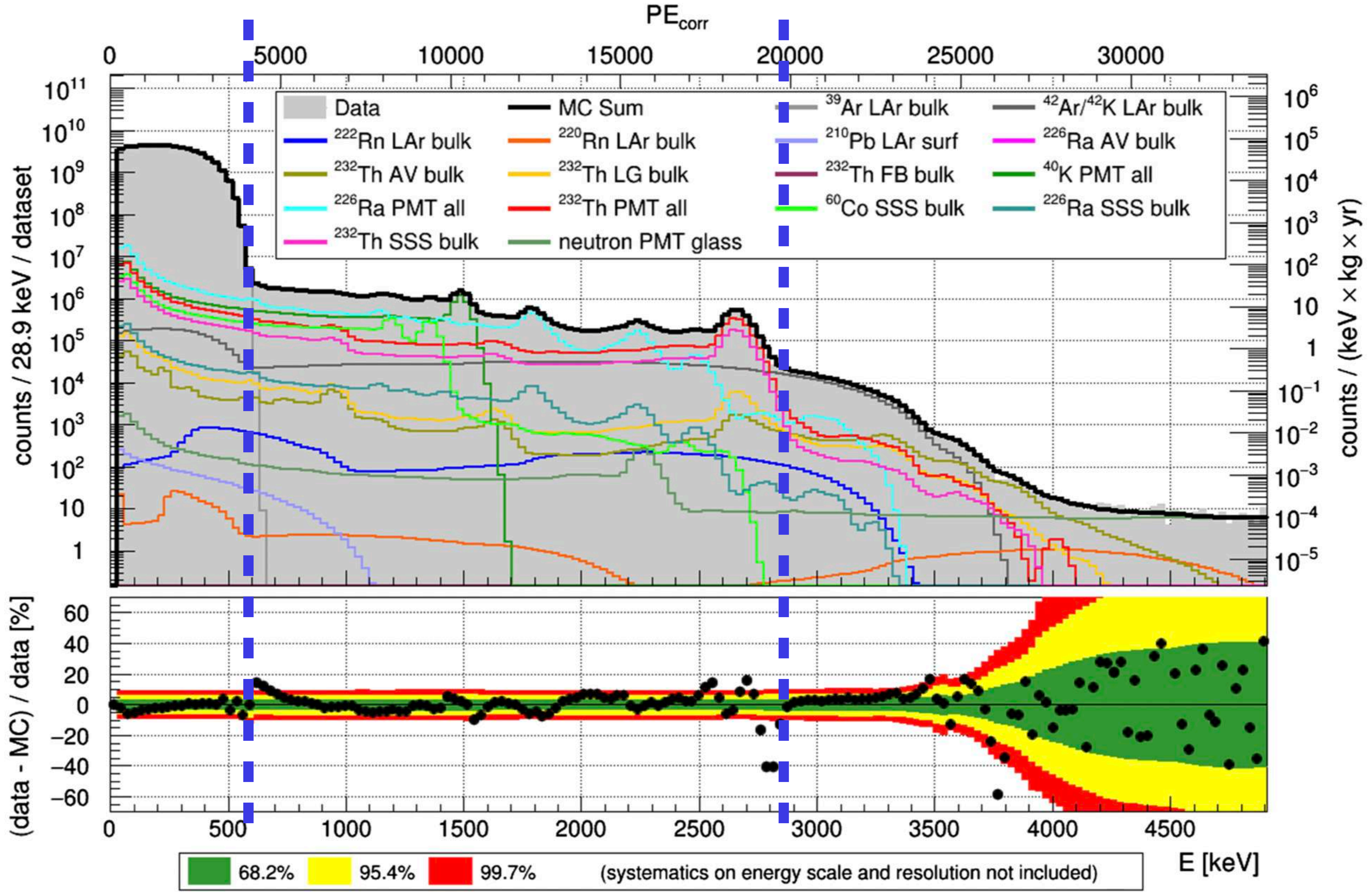
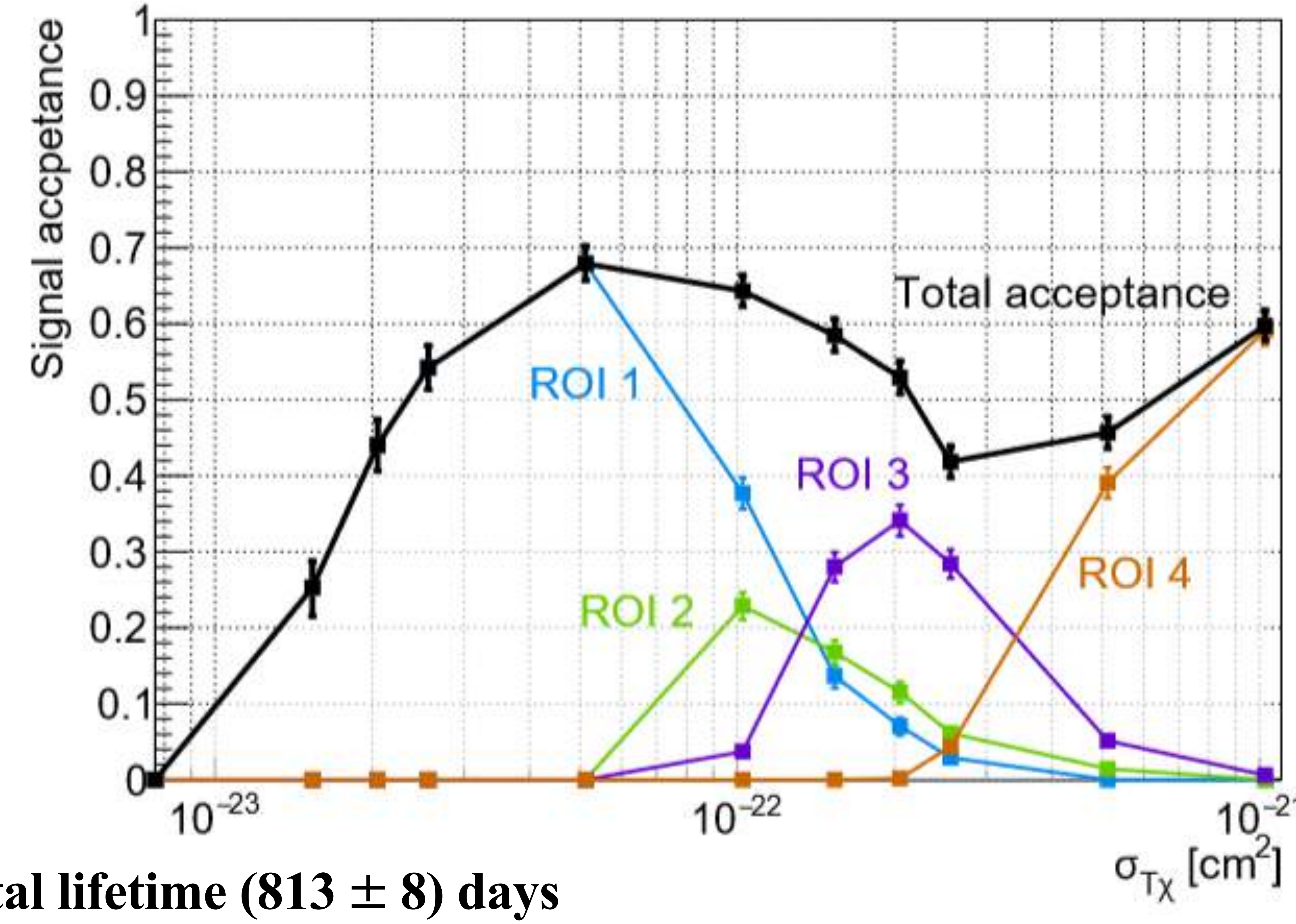


Phys. Rev. D, 100, 072009 (2019)



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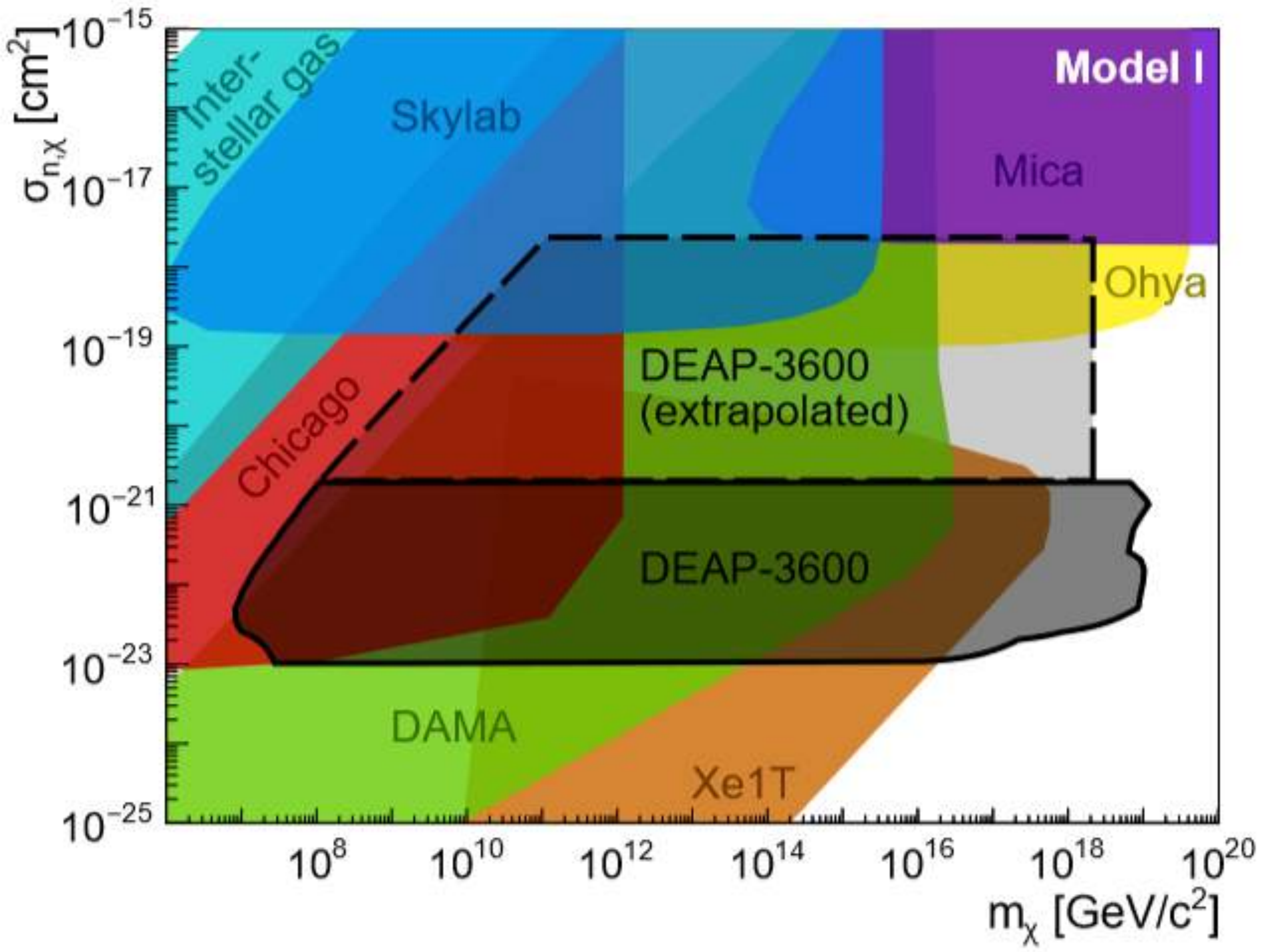
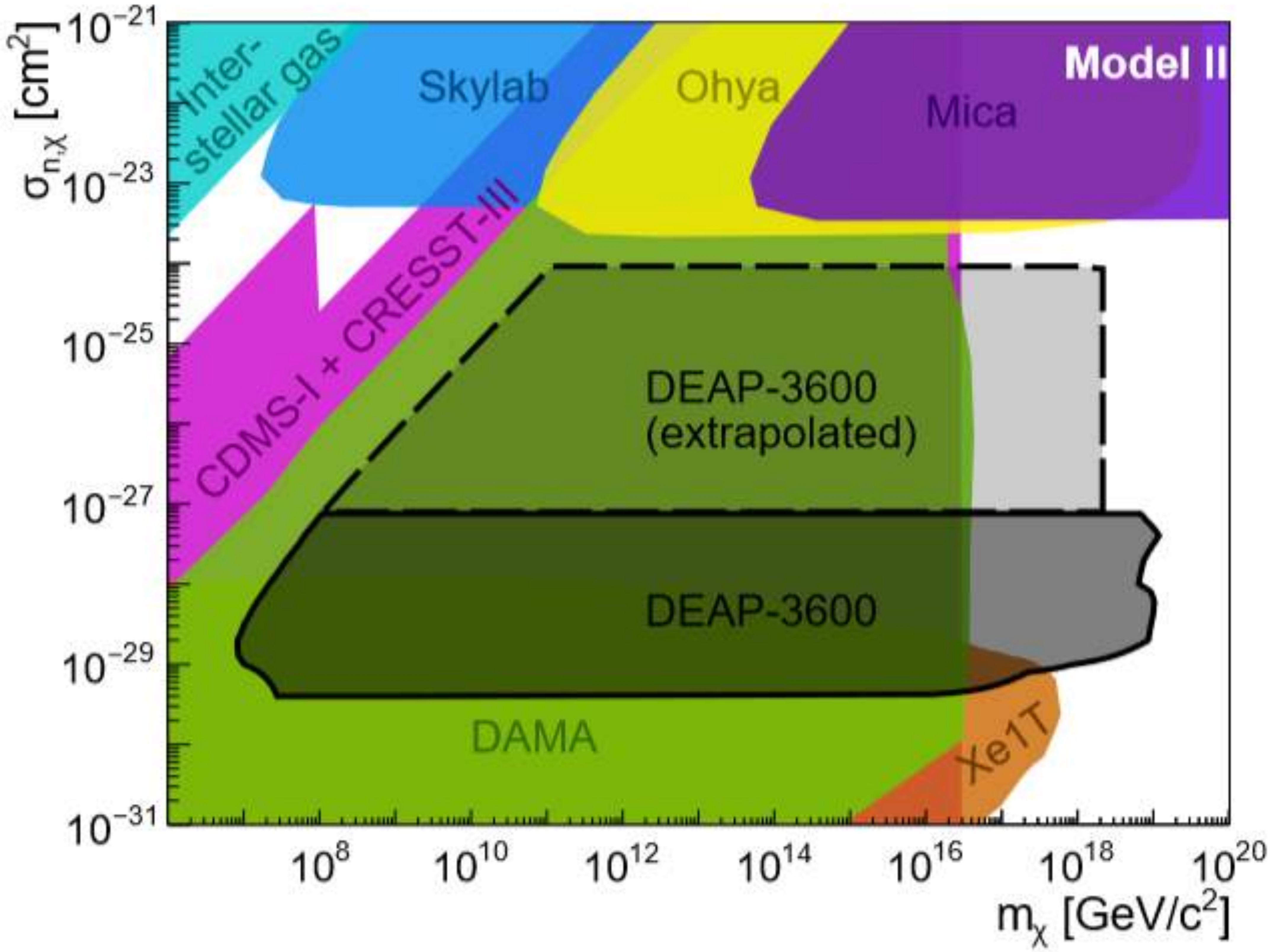
Exclusion limits on the multi-scatter frontier





- **Model 1**: dark matter candidate **opaque to the nucleus**
- **Limits on strongly interacting, composite** dark matter candidates.

$$\frac{d\sigma_{T\chi}}{dE_R} = \frac{d\sigma_{n\chi}}{dE_R}|F_T(q)|^2$$

- **Model 2**: **nuclear dark matter models**, with N_D nucleons, each with mass m_D and radius r_D,

$$\frac{d\sigma_{T\chi}}{dE_R} = N_D^2\frac{d\sigma_{nD}}{dE_R}|F_T(q)|^2A^4|F_\chi(q)|^2$$

$$\frac{d\sigma_{T\chi}}{dE_R} = A^4\frac{d\sigma_{n\chi}}{dE_R}$$

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

Take home

➡Most stringent exclusion limit for high mass WIMPs in liquid argon

➡Pulse shape of the signal carefully modeled

➡Best PSD discrimination in liquid argon

➡Installation of new external cooling and filtering system

➡Installation of pyrene coated flow guides

➡Re-analysis of the WIMP results with NREFT and non-standard galactic halo

➡Unique sensitivity to heavy, multi-scattering dark matter candidates up to **Planck Scale masses**

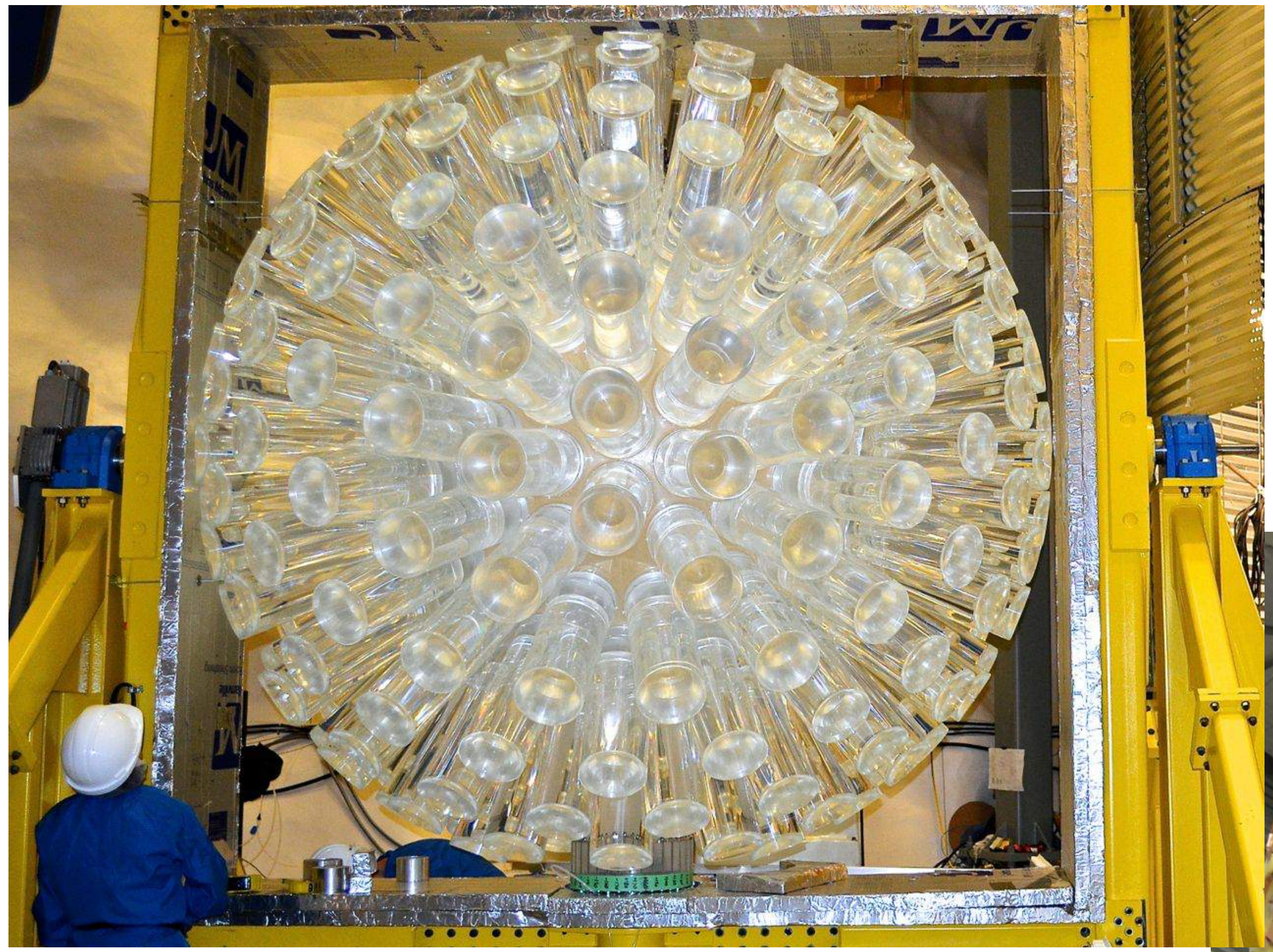
➡New WIMP search: **coming soon**!

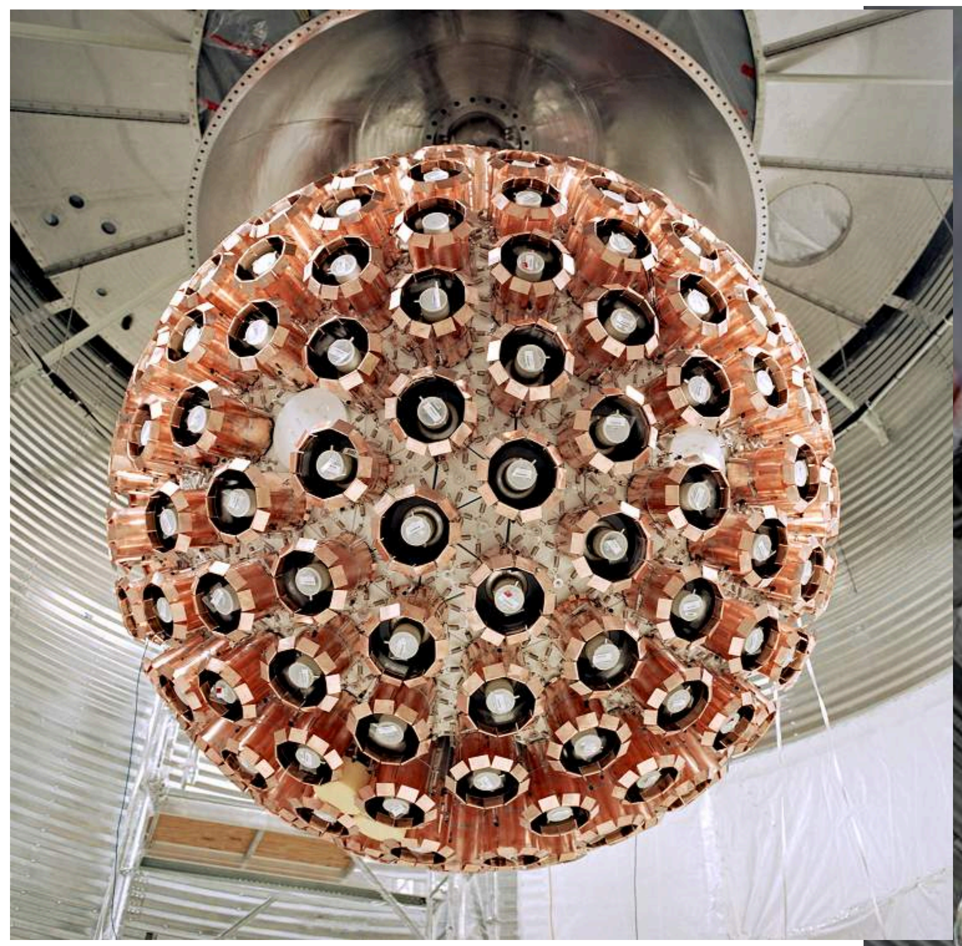
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952480 (DarkWave)

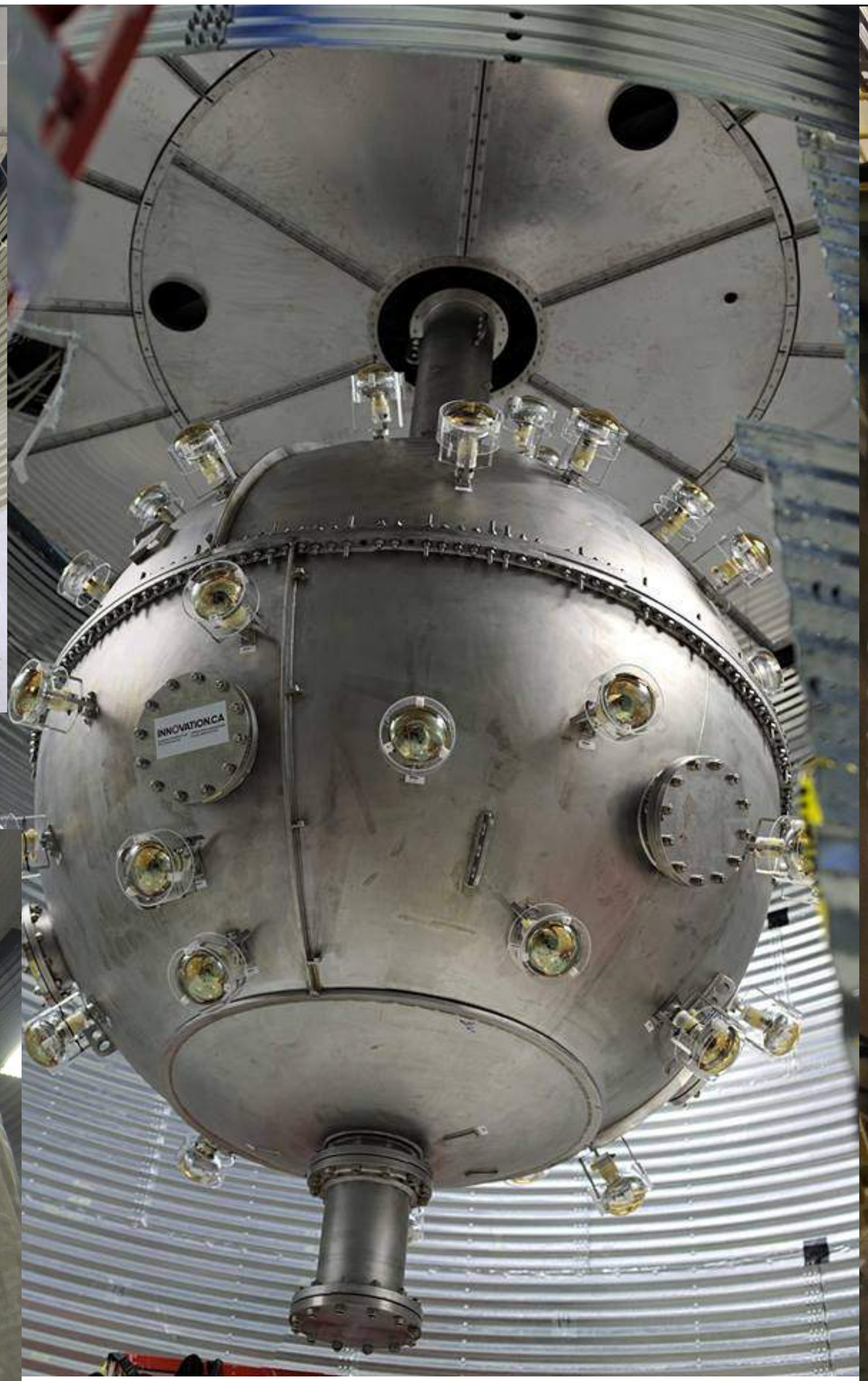
Back up

Dr. Michela Lai
on behalf of
DEAP-3600 Collaboration

The detector



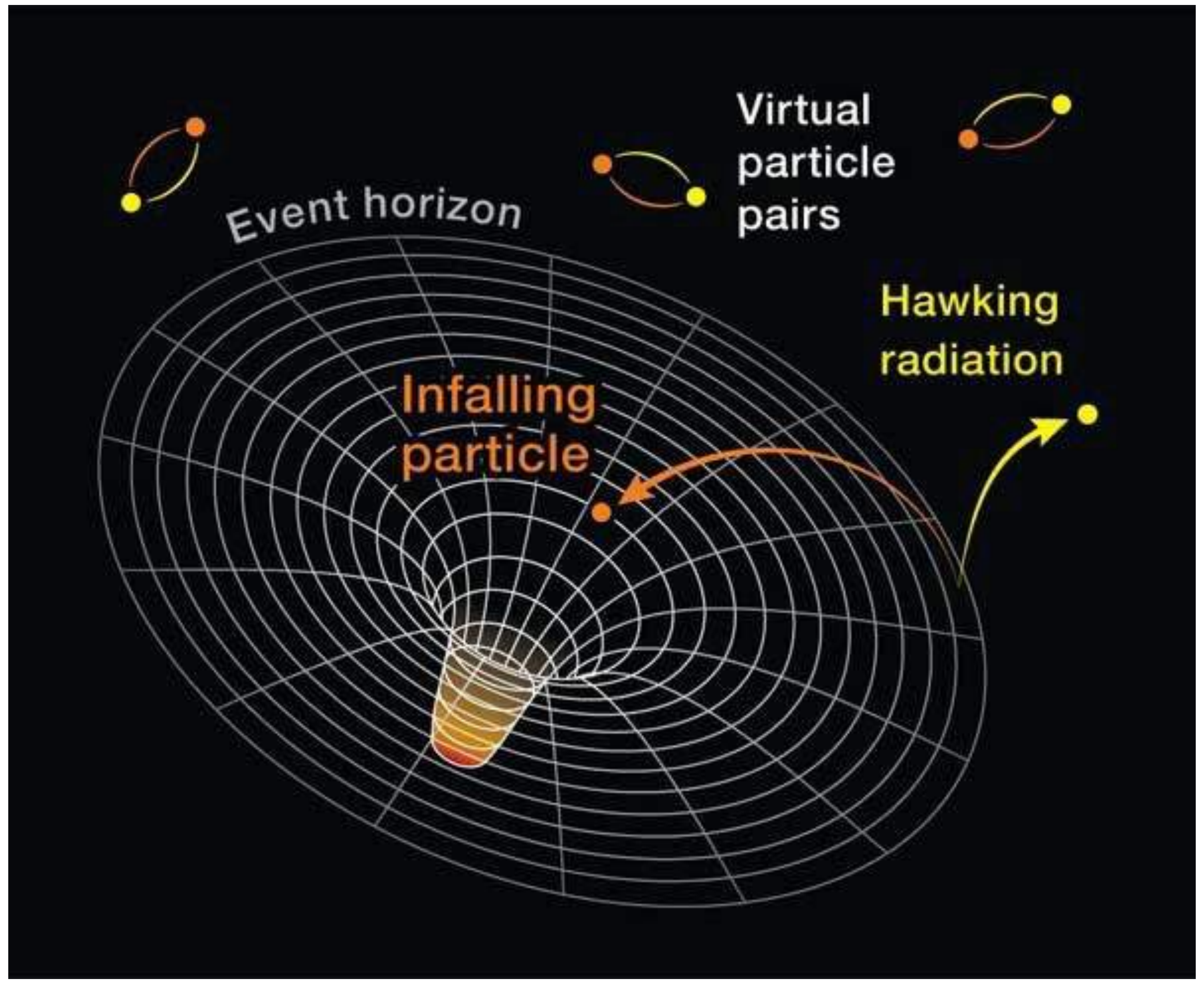




Heavy dark matter

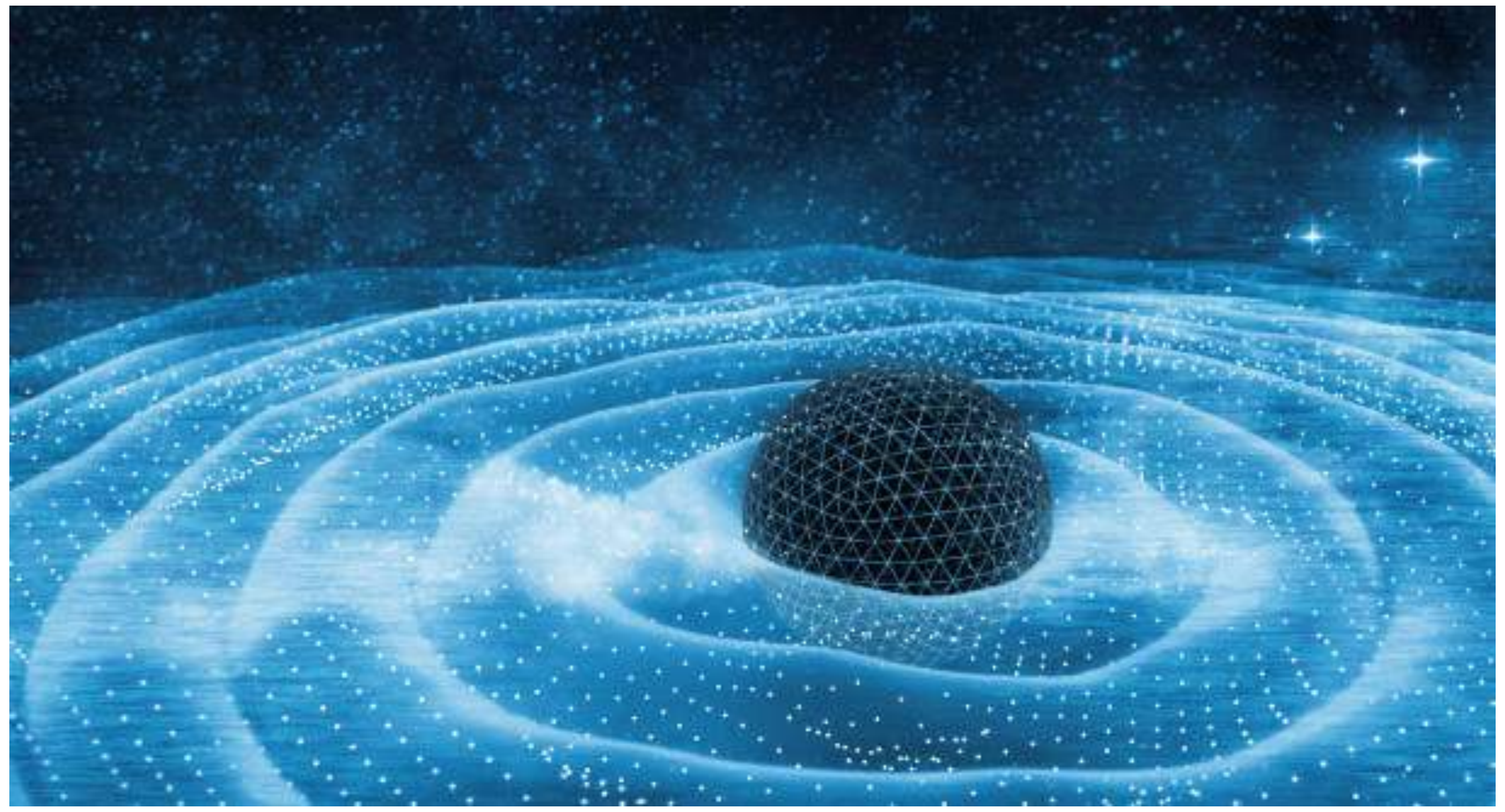
Expected in GUTs but cannot be produced with WIMPs freeze out mechanism.

Primordial black holes ($M \lesssim 5 \times 10^8 g$) can produce heavy dark matter candidates ($m_{DM} \gtrsim 10^9 GeV$) by Hawking evaporation.



J. High Energ. Phys. 2019, 1 (2019).

Inflational gravitational production, in quantum field theories in a curved spacetime, of dark matter up to Hubble inflation scale and beyond that, with higher spin dark matter.

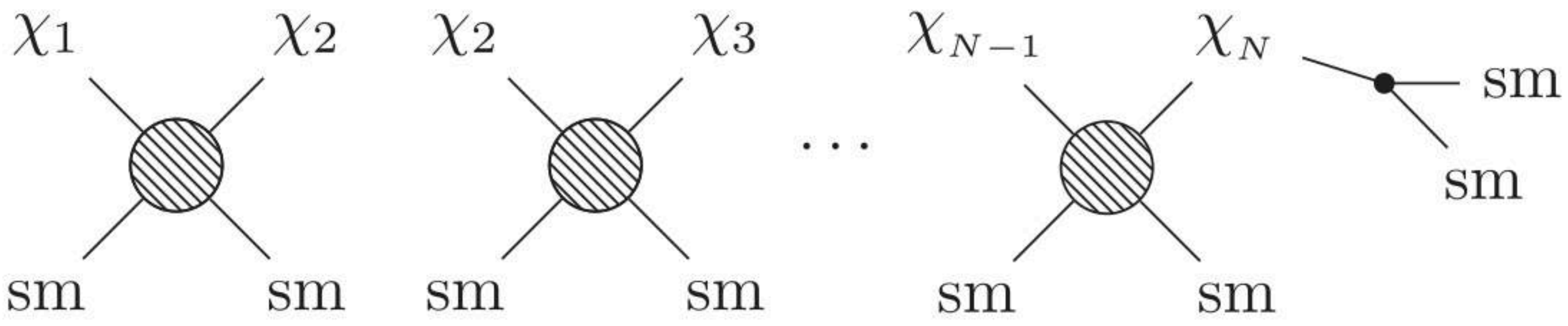


arXiv:1808.08236

Thermally produced in a **secluded sector,** where DM is a degenerate state of N particles,

$$\chi_i + SM \leftrightarrow \chi_{i+1} + SM \qquad\qquad \chi_N \rightarrow SM + SM$$

These DM particles can reach Planck scale masses.



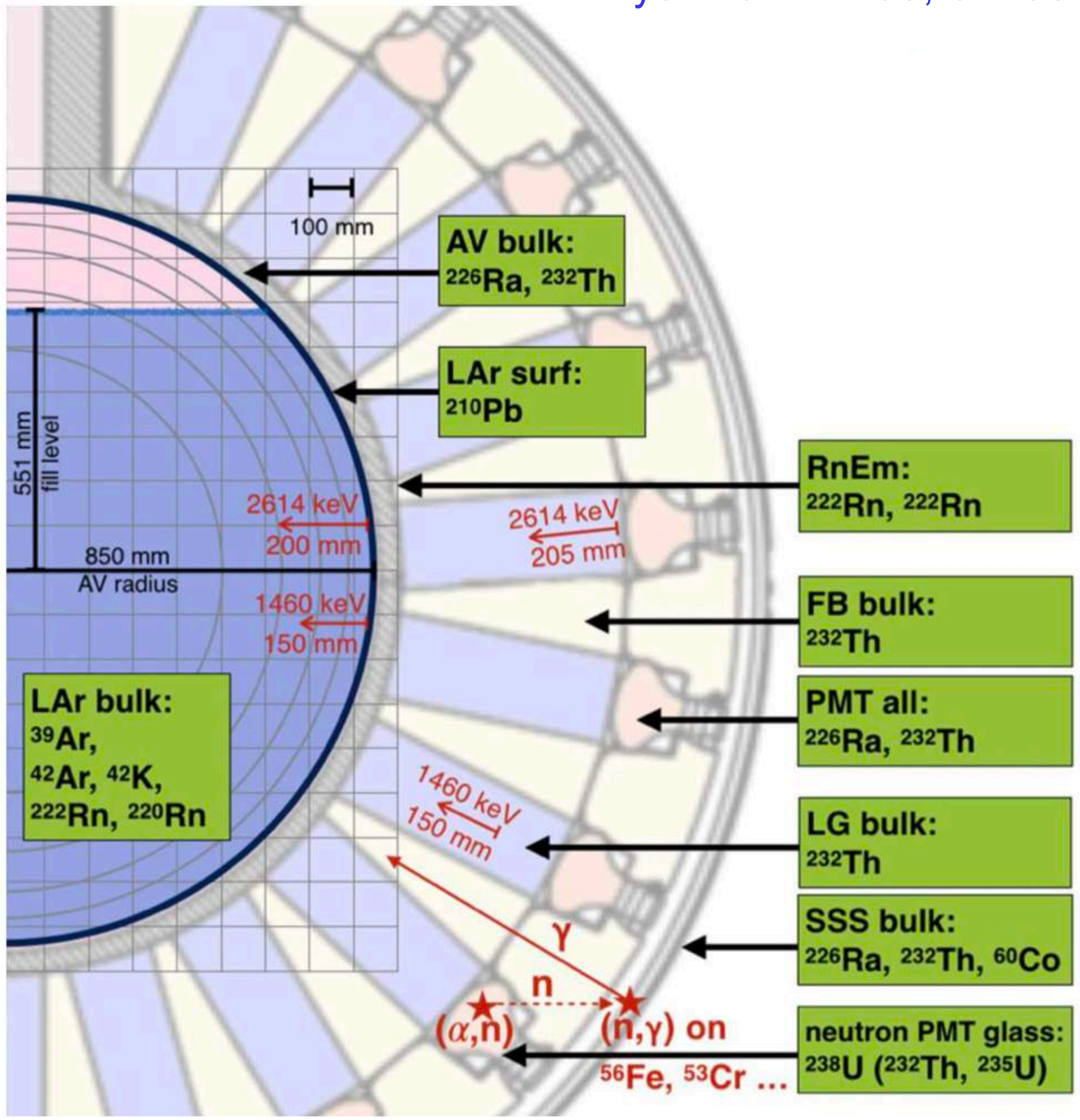
For more details: https://arxiv.org/abs/2203.06508

PRL 123, 191801 (2019)

Backgrounds

- Electron recoil background fully modeled up to 10 MeV
- Measured $^{42}Ar/^{42}K$ activity = 40.4 ± 5.9μBq/kg

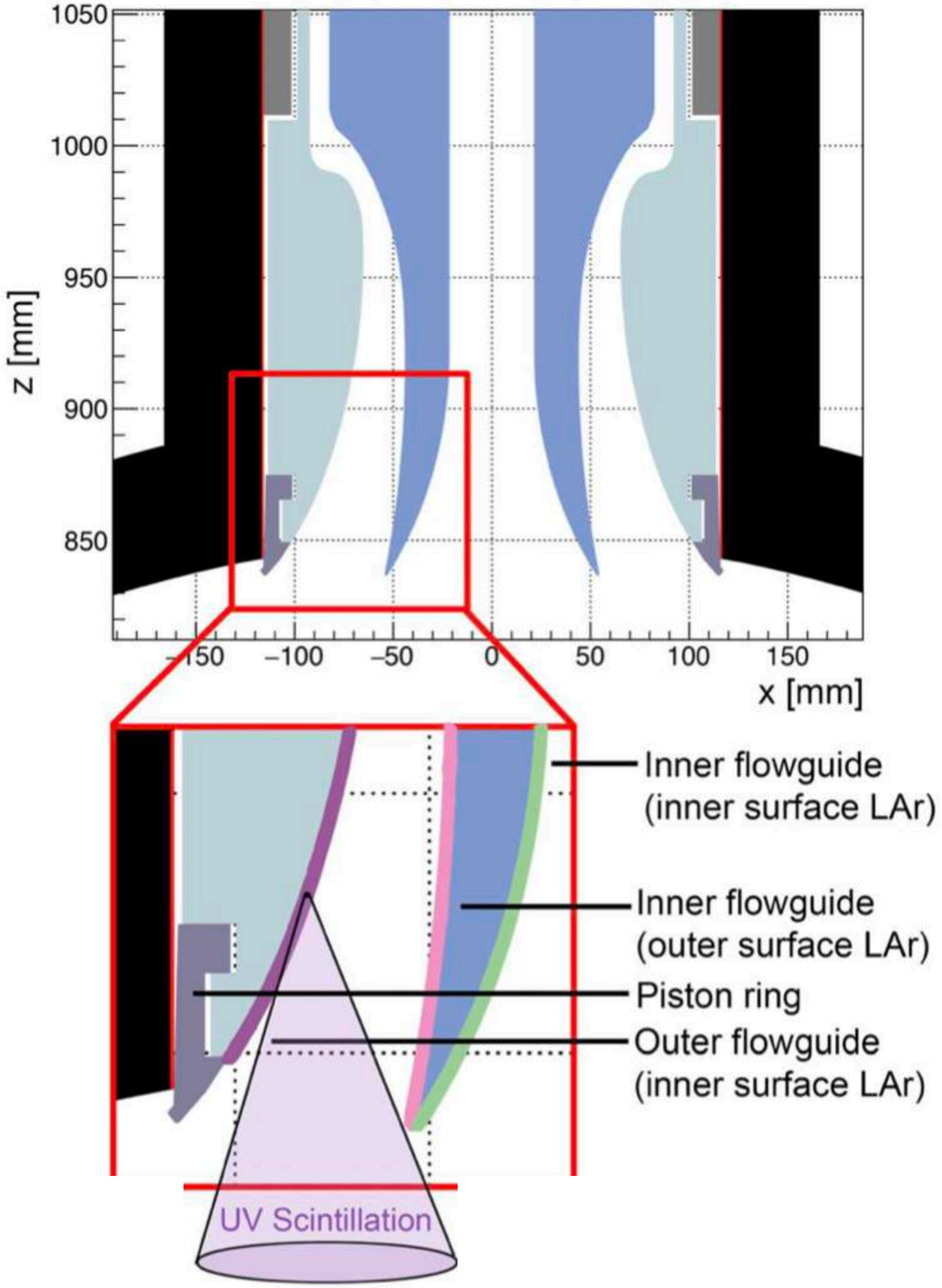
Phys. Rev. D **100**, 072009 (2019)



- Surface alphas removed with fiducial cuts, r < 630 mm

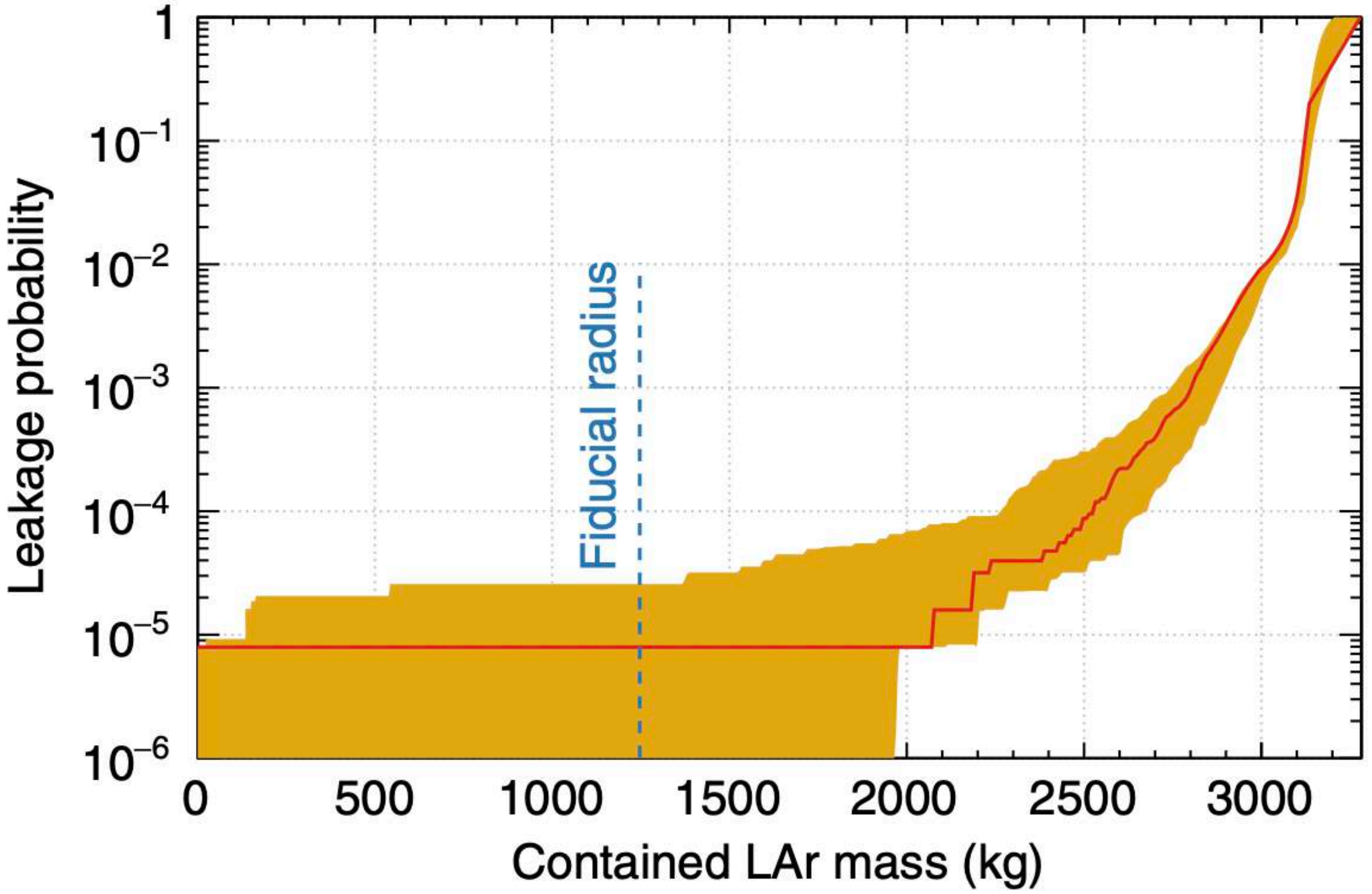
- Neck alphas removed with:

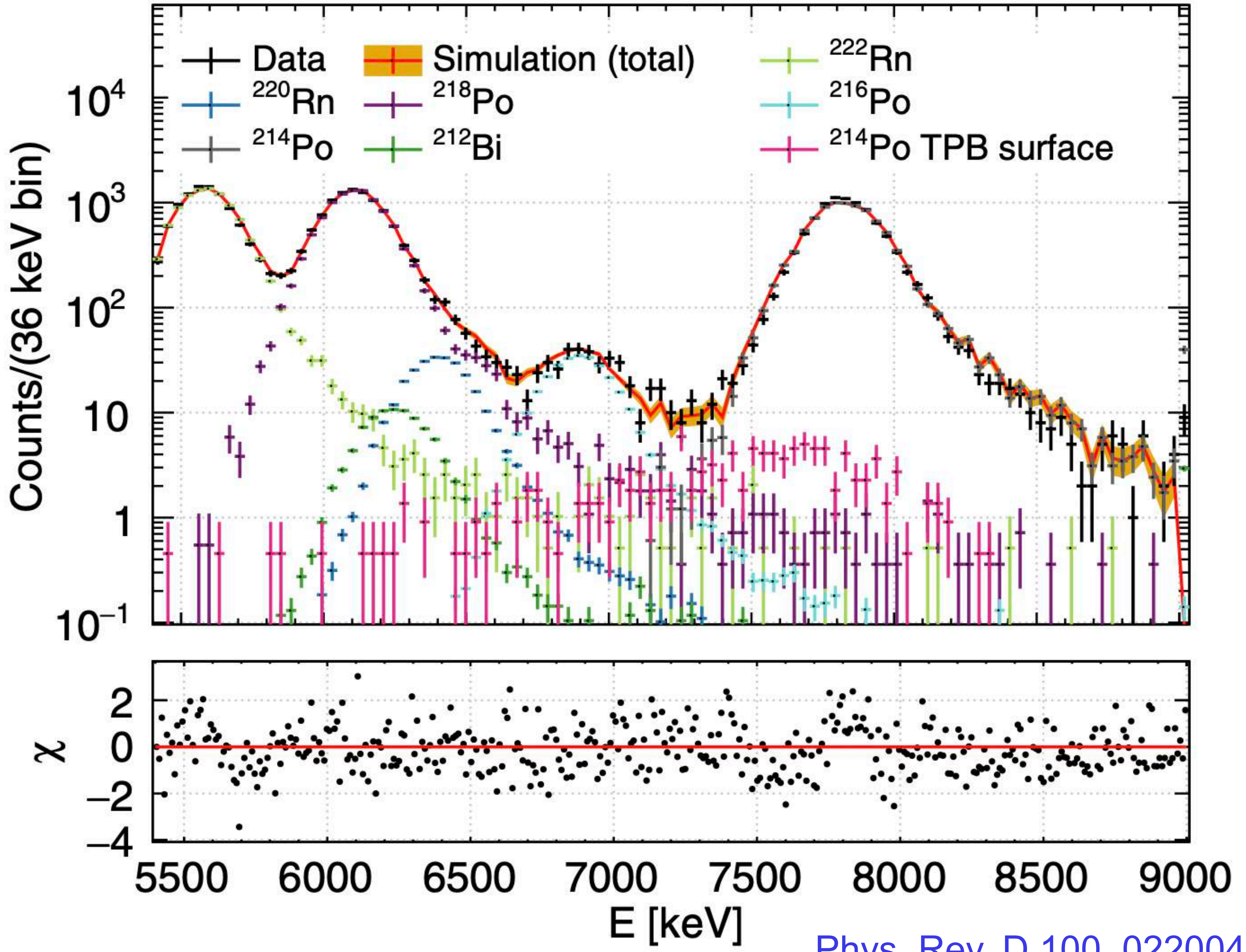
- Fprompt upper cut
- Early pulses in Gas Argon PMTs
- Charge fraction in top 2 PMT rings
- MVA selection cuts (ongoing)



Background sources

- **Bulk alphas**: energy fully deposited in LAr, much above WIMP ROI
- Surface alphas: most of the energy lost in TPB and/or acylic, giving a lower energy deposit in LAr. Might fall in WIMP ROI.
- **Fiducialization** volume cut at r < 630 mm

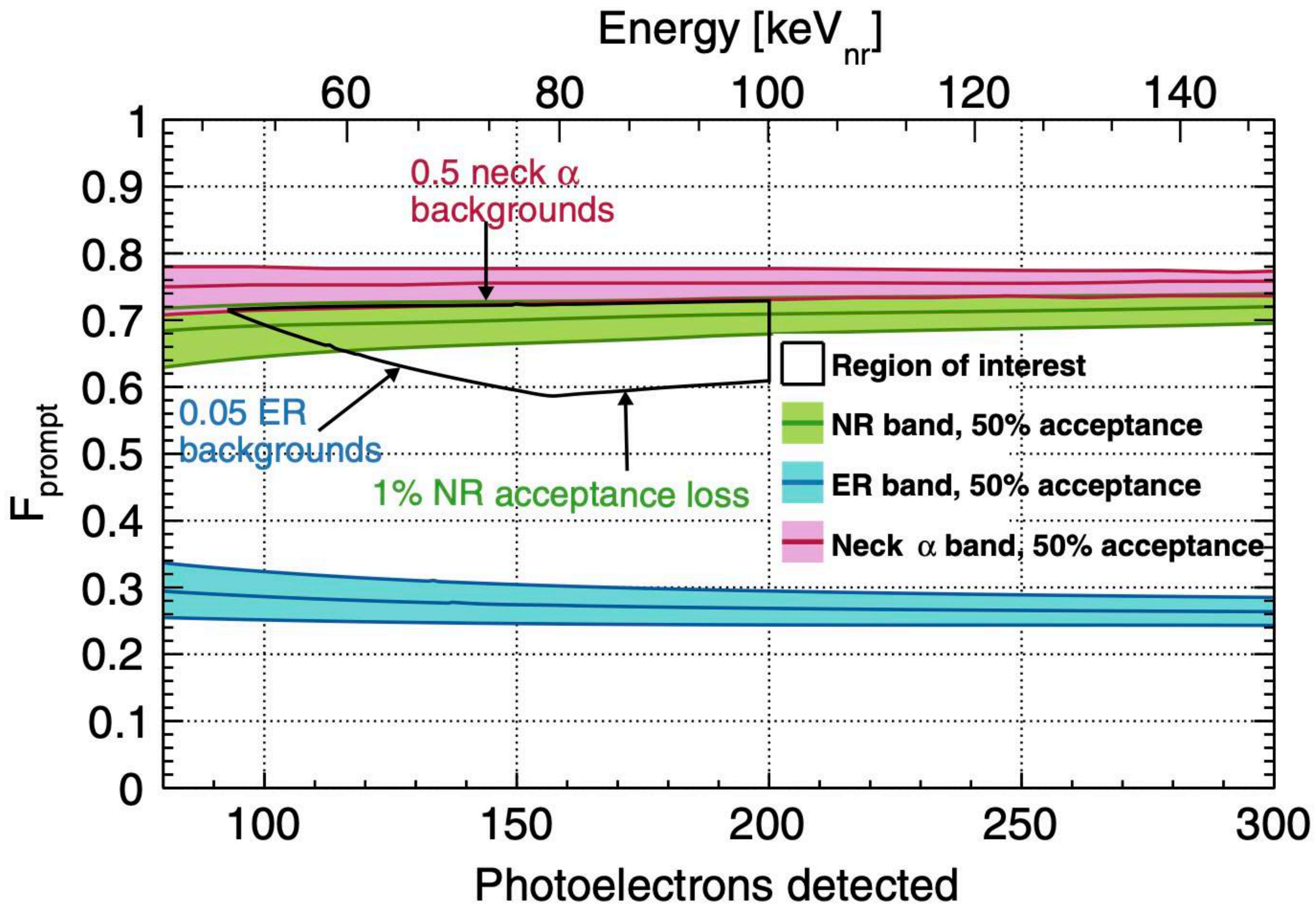


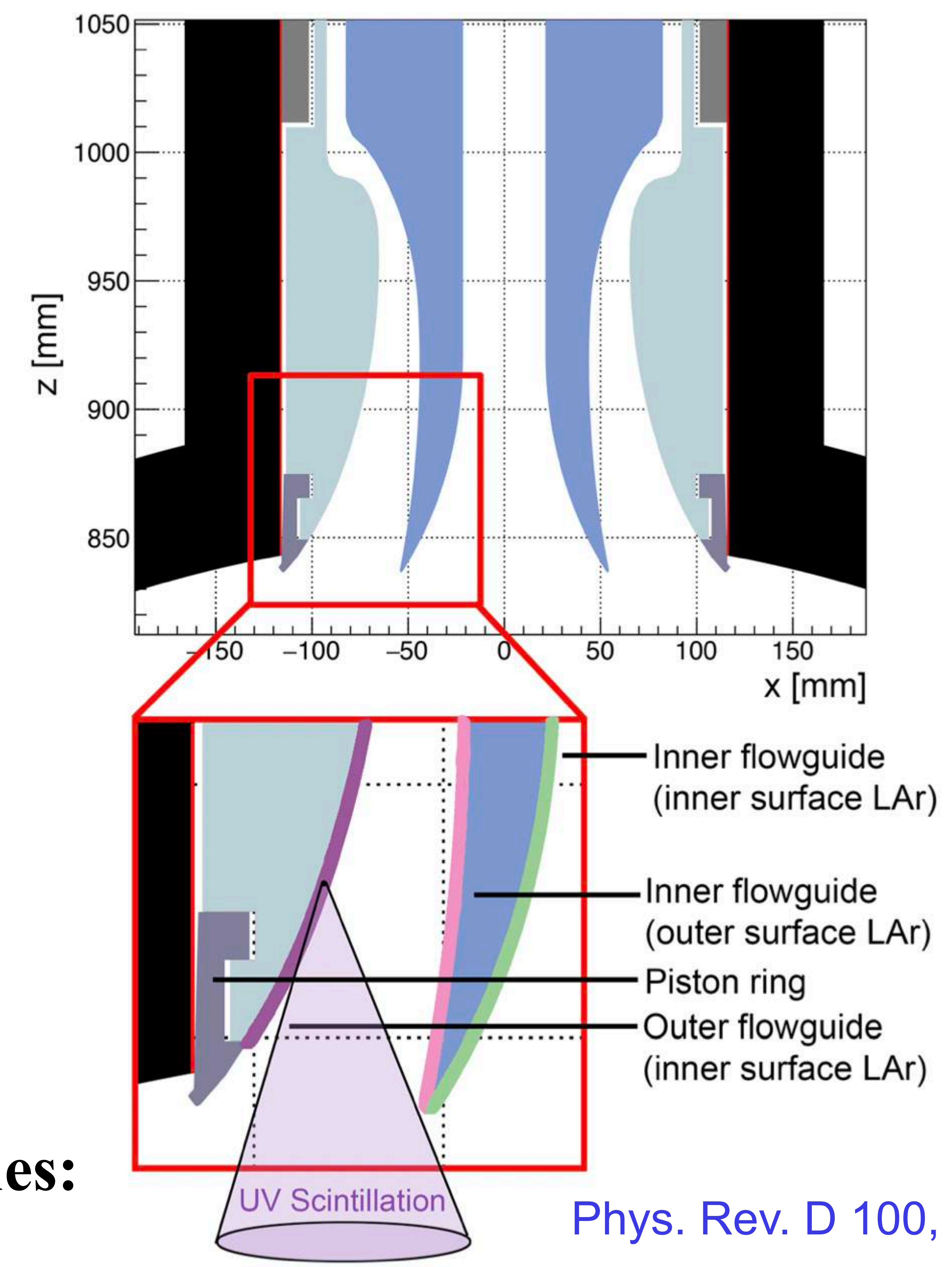


Phys. Rev. D 100, 022004

Background sources

- ^{210}Po releases alphas in the acrylic of the flowguides
- Alphas scintillate in the LAr film on the flowguides
- Their light is **shadowed** by the flowguide geometry and might enter the WIMP ROI.





Phys. Rev. D 100, 022004

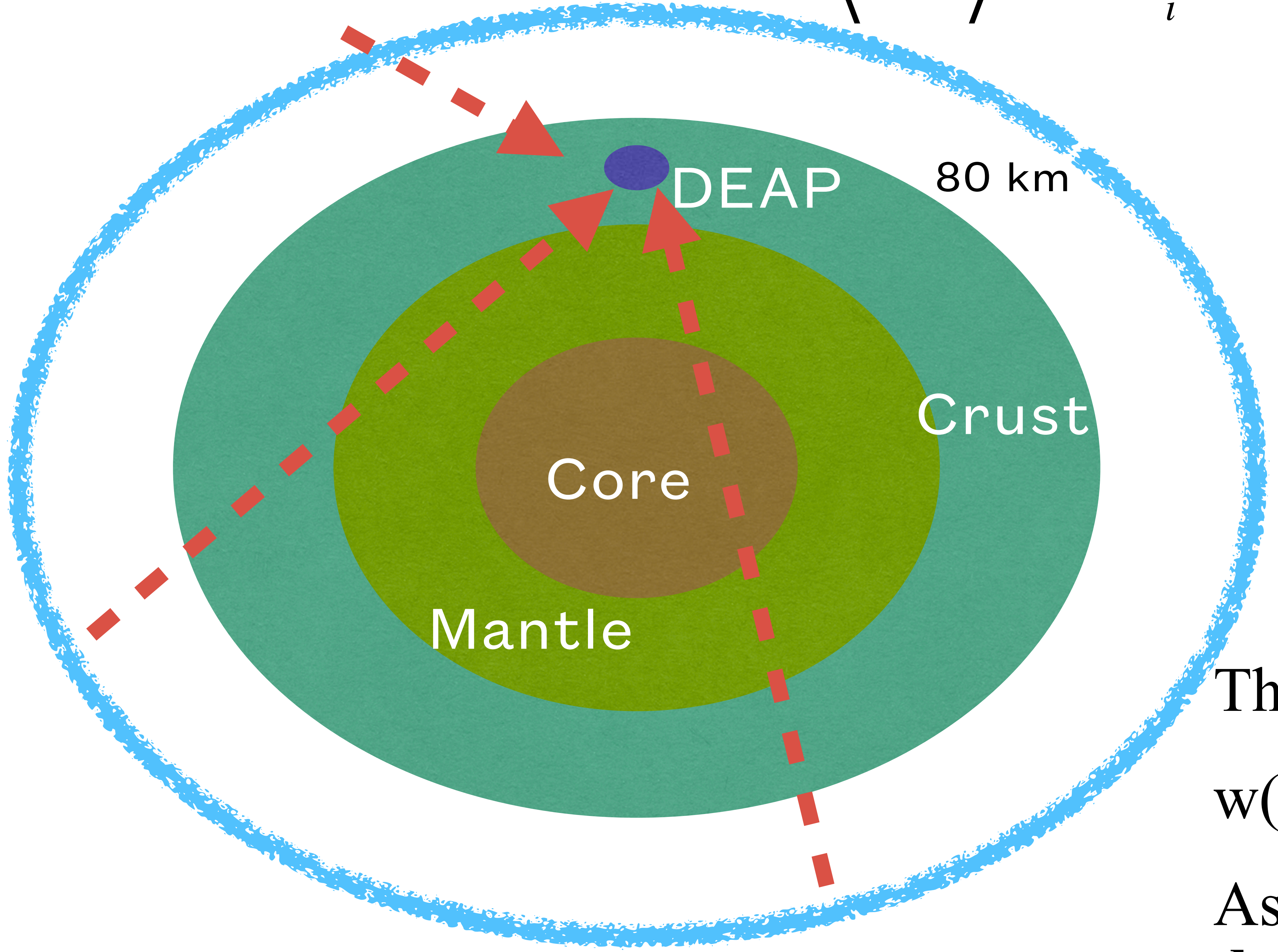
Rejection techniques:

- F_{prompt} upper cut
- Early pulses in Gas Argon PMTs
- Charge fraction in top 2 PMT rings
- Near future: **multivariate analysis** with high efficiency in vetoing neck alphas

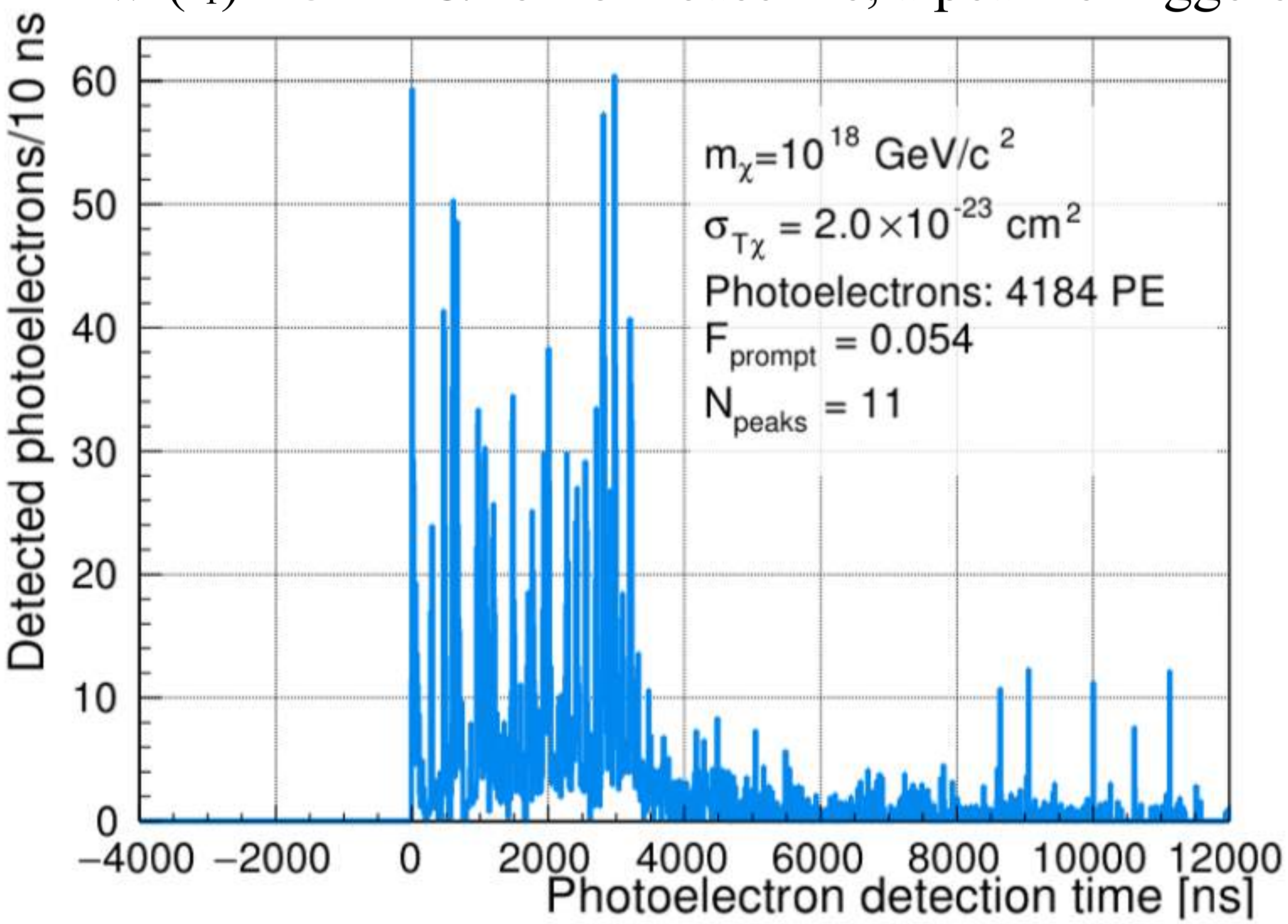
Simulation of the signal

The dark matter particle is generated at 80 km from Earth Surface. It is propagated via Monte Carlo method through the overburden. Then, if it enters the detector, its response to this signal is simulated in **Geant4 .**

$$\left\langle \frac{dE_\chi}{dt} \right\rangle = -\sum_i n_i(r)\sigma_{i,\chi} < E_R >_i v$$



If $w'(t_1) > 3$ ADC/ns from baseline, a peak is triggered.



The next peak is triggered only if "significant", so if

$w(t_3) > 5$ ADC $+ w(t_1)$

As the cross-section increases, **the significance of the peaks along the waveform decreases**, bringing to a decrease of N_{peaks}.