

2024/02/08

# DEAP-3600

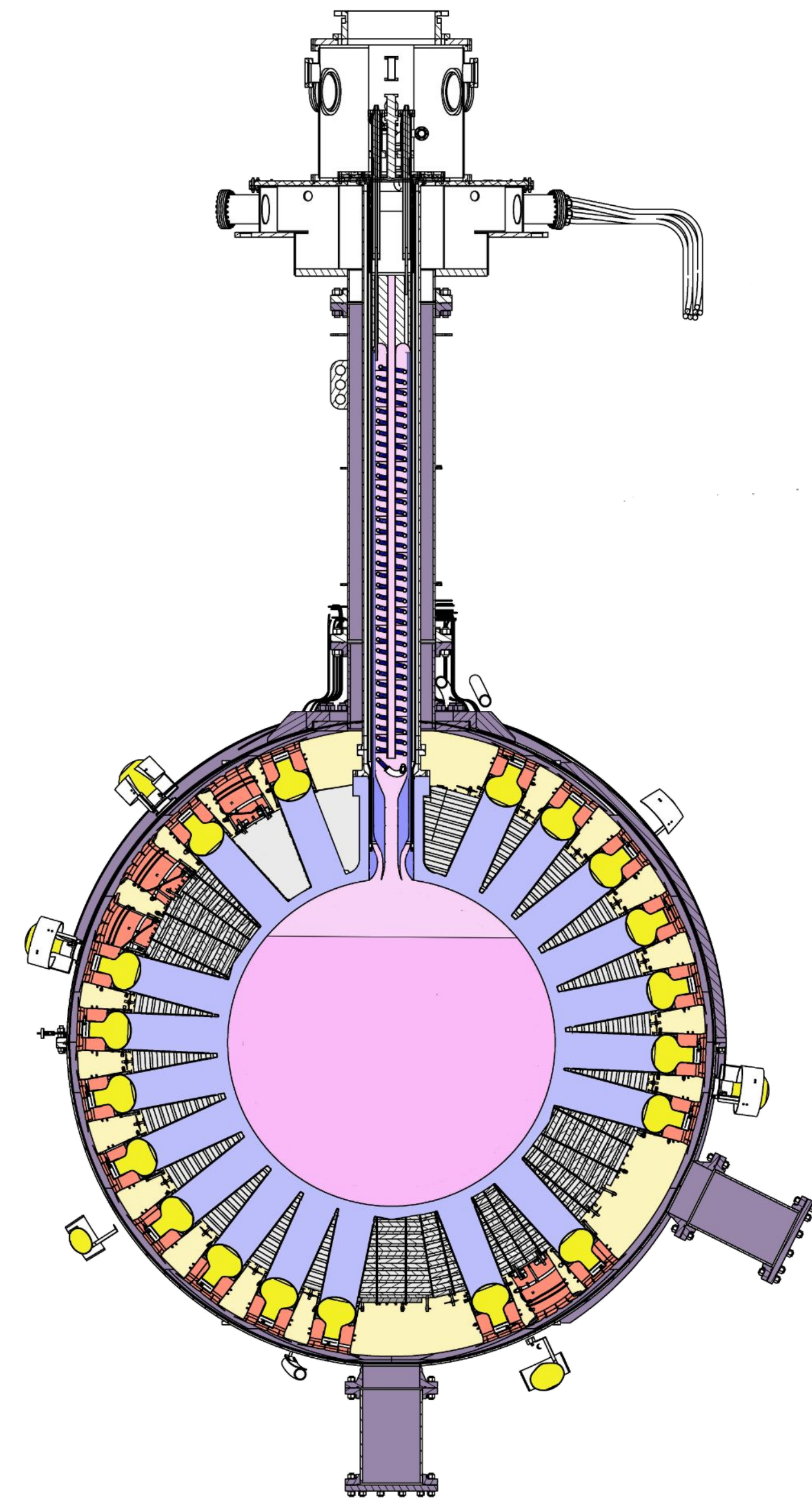


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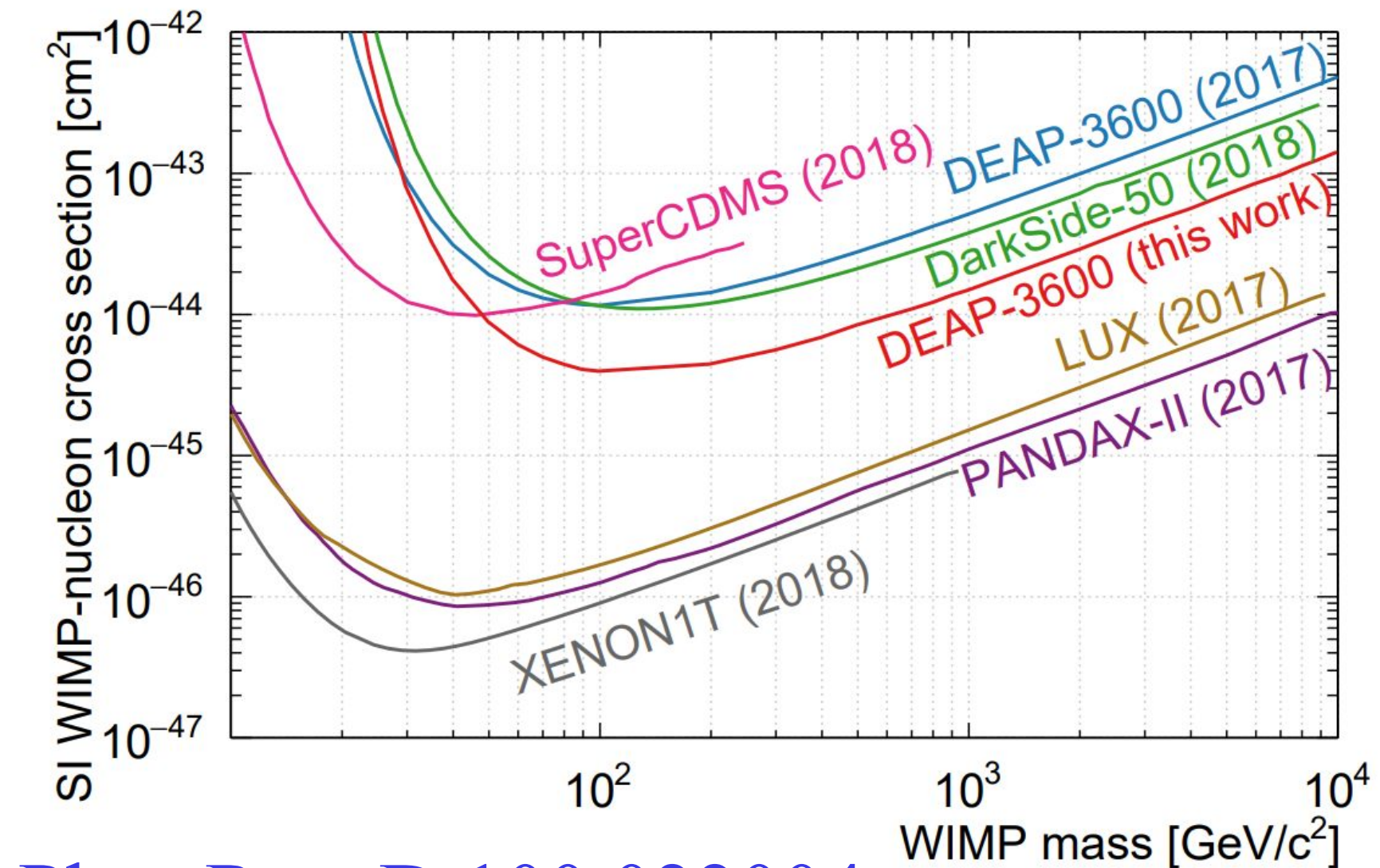
Speaker: Dr. Michela Lai  
Analysis Coordinator

# Experiment Overview

Dark Matter Experiment using Argon Pulse-shape discrimination

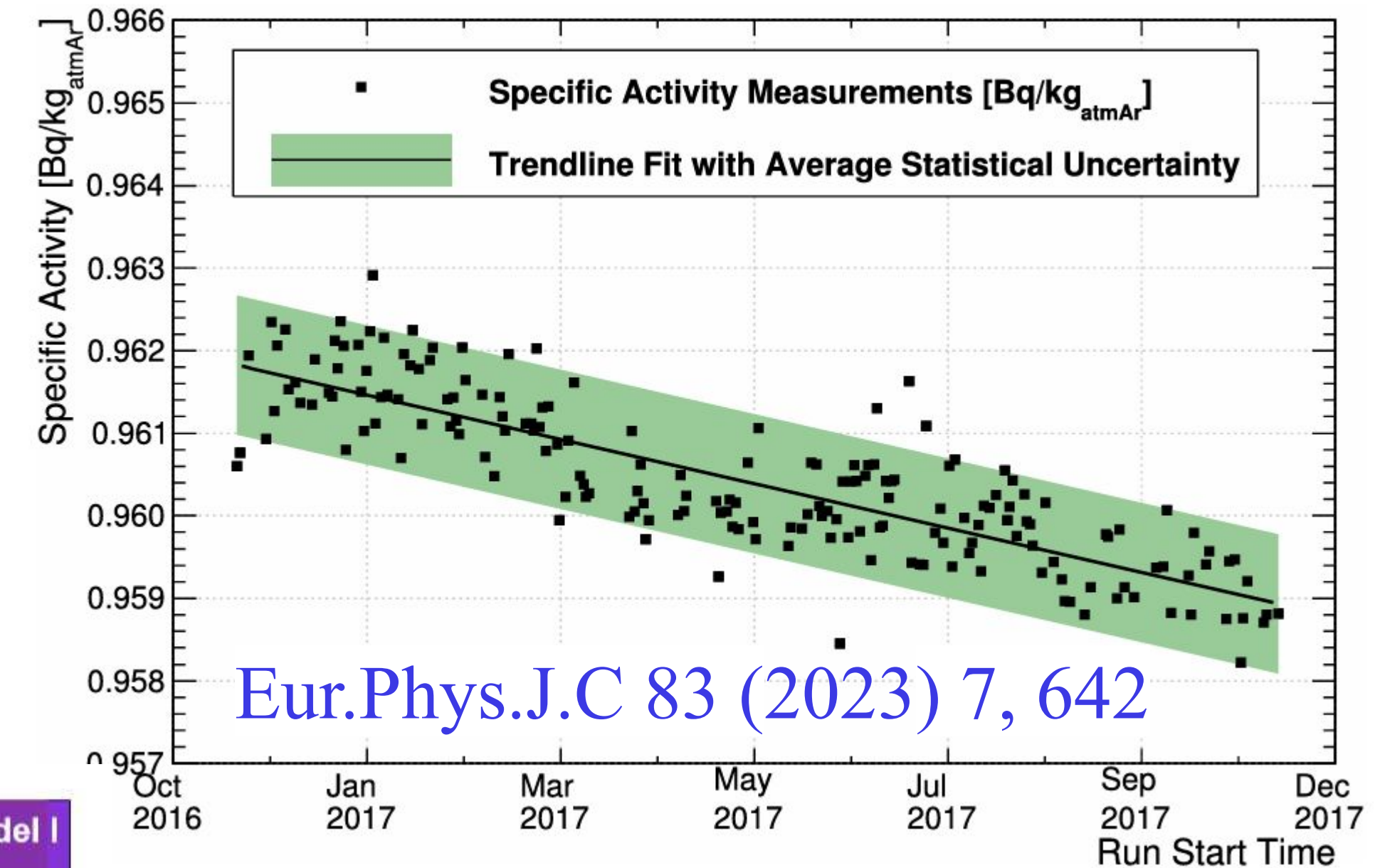


# Physics Program



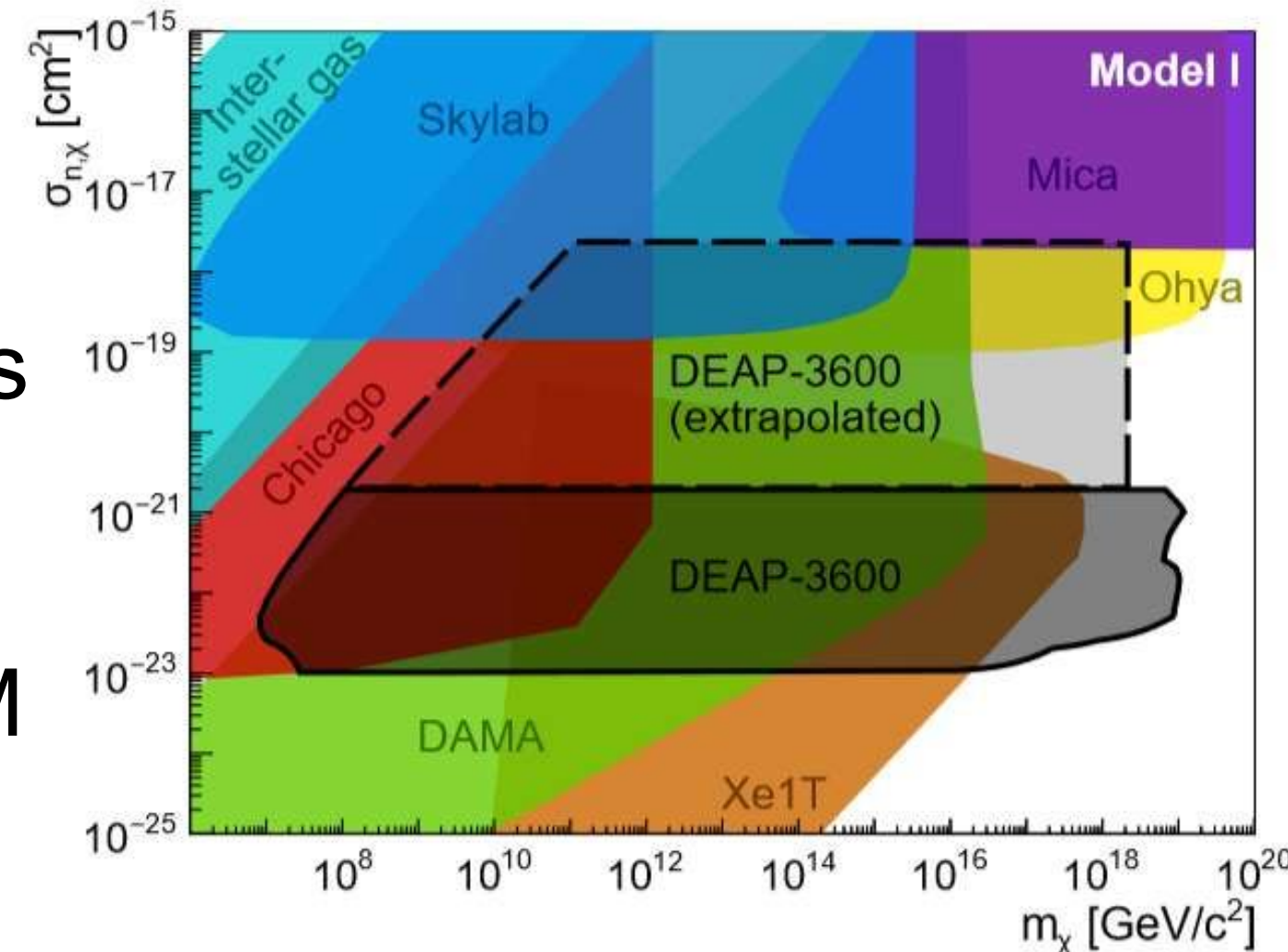
Phys.Rev. D 100,022004

- 2019: WIMP Search in 231-live days
- 2022: Re-analysis with EFT and modified halo models
- Foreseen in 2024: WIMP search with Profile Likelihood Ratio (PLR)



Eur.Phys.J.C 83 (2023) 7, 642

- 2022: Multi-scatter, heavy dark matter candidates
- Foreseen in 2024: 5.5 MeV solar axions
- Foreseen in 2025: solar neutrino absorption in argon
- Foreseen in 2025: inelastic boosted DM



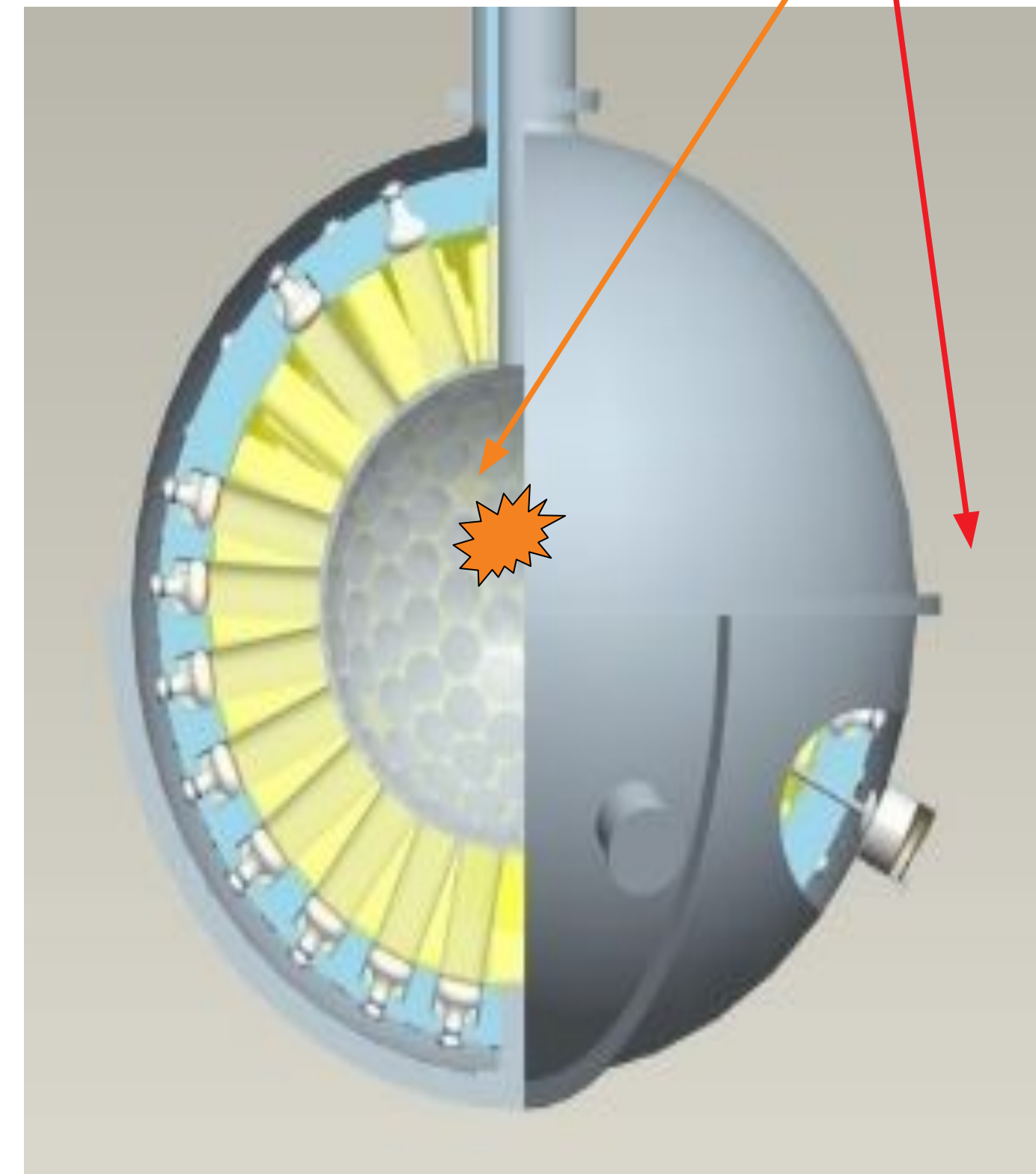
Phys.Rev. Lett. 128, 011801

- 2020: Argon Pulse shape
- 2022: Evaluation of the Pulse shape Discrimination
- 2023: Precision measurement of <sup>39</sup>Ar activity
- Foreseen in 2024: <sup>39</sup>Ar half-life measurement

# External backgrounds

- The rocks surrounding the detector suppress most of the muon incoming flux.

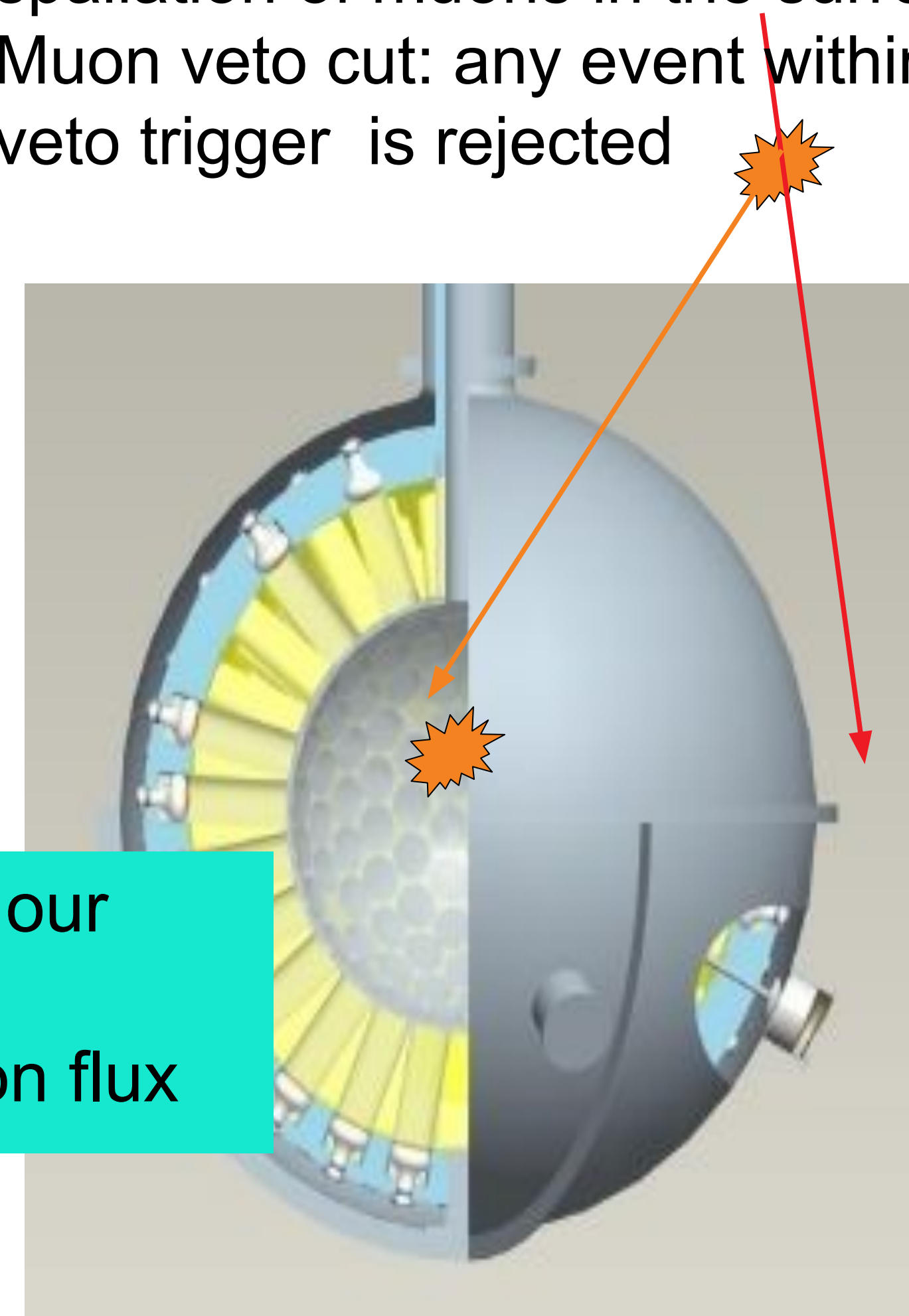
- Cosmogenics neutrons are produced from spallation of muons in the surrounding rocks
- Muon veto cut: any event within  $[-0.1, 1]$  from the veto trigger is rejected



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# Scintillation Pulse Shape

- **Photoelectron time distribution in our detector successfully modeled**
- Included the argon response in a single phase chamber, the TPB scintillation, correlated and uncorrelated noise from PMT

Eur.Phys.J.C 80, 303

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

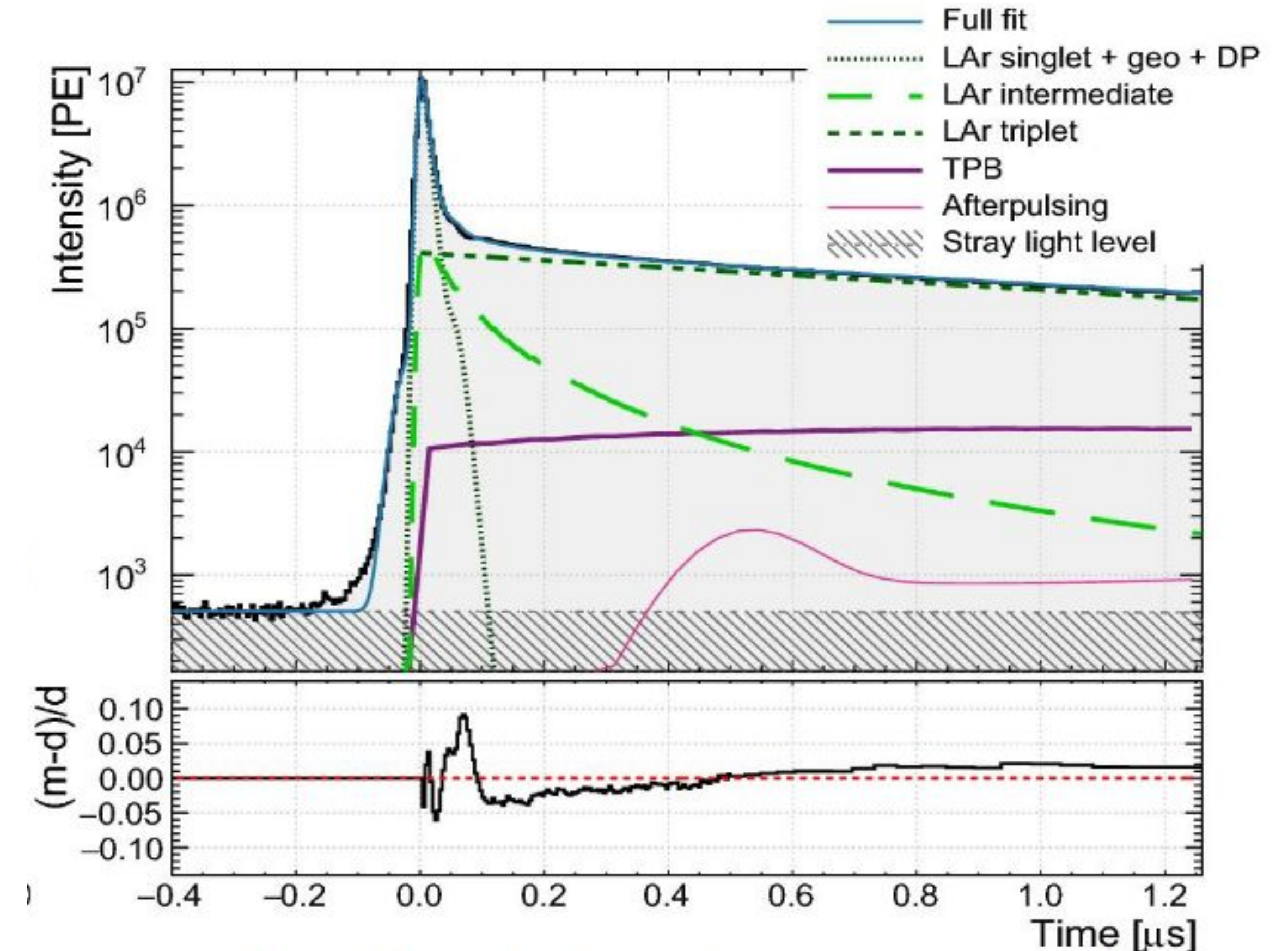
$$\tau_s = 8.2ns$$

$$\tau_{rec} = 175.5ns$$

$$R_s = 0.23$$

$$\tau_t = 1445ns$$

$$R_t = 0.71$$

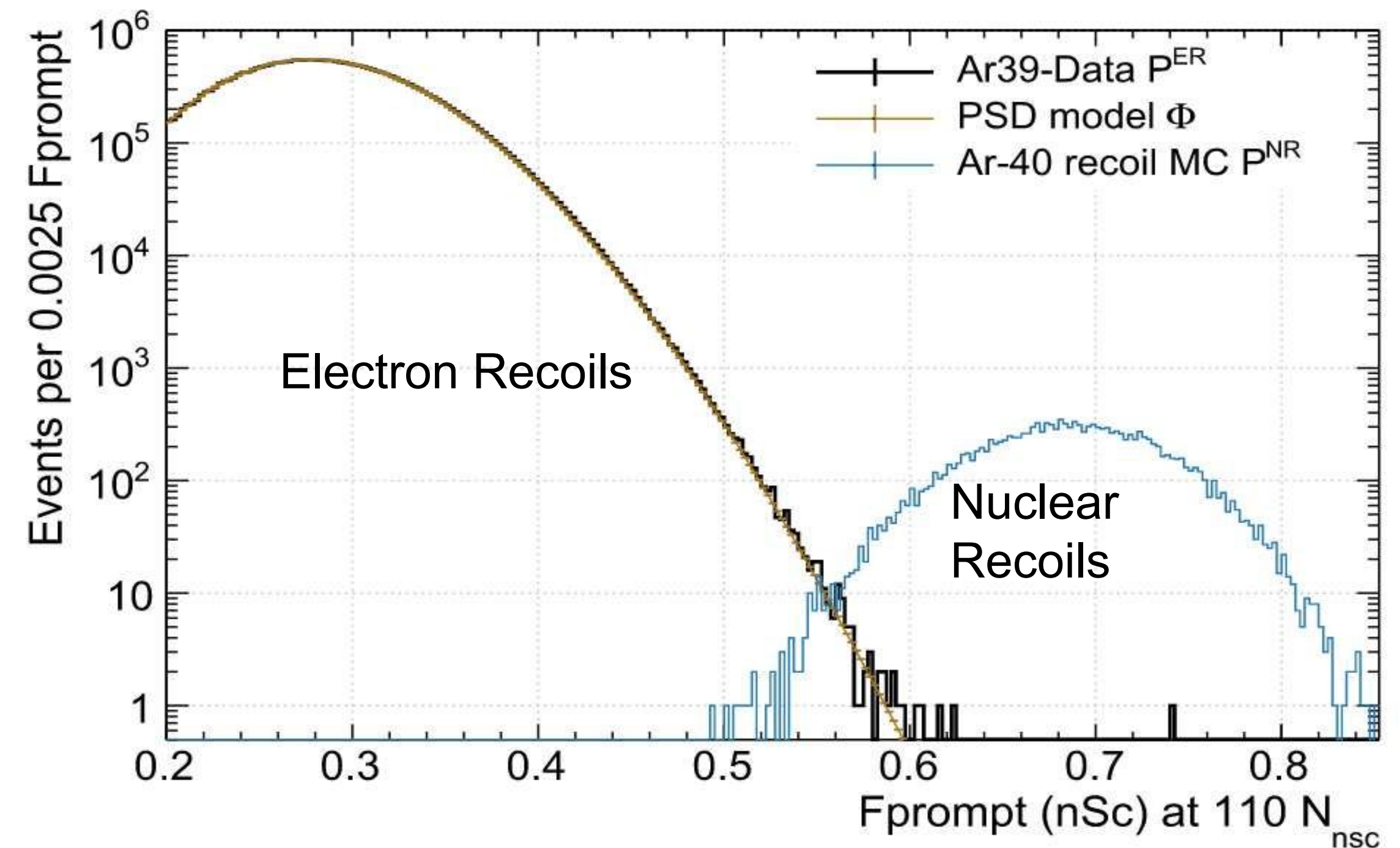
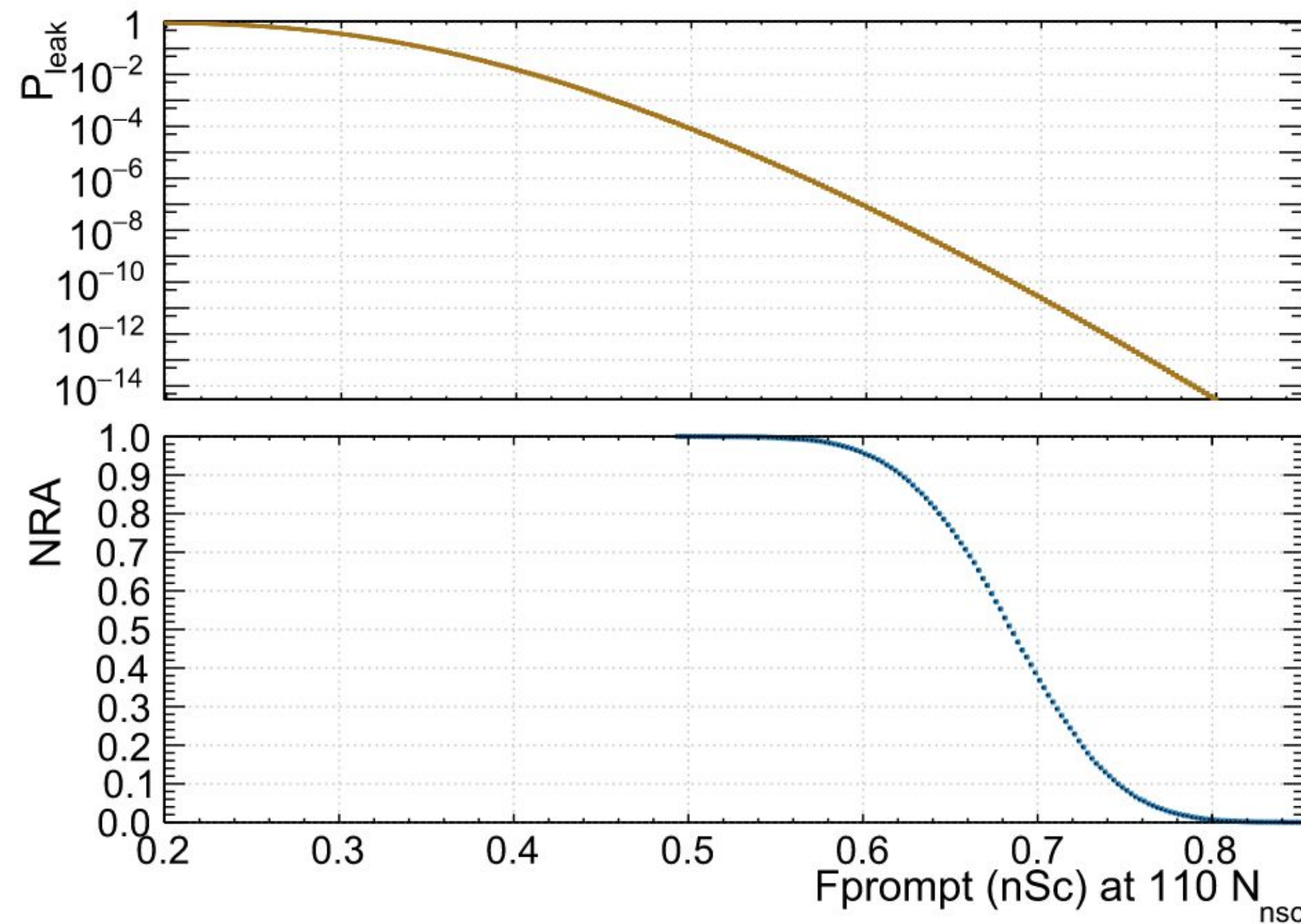


-0.4 to 1.2 microseconds

# Pulse Shape Discrimination

Eur.Phys.J.C 81, 823

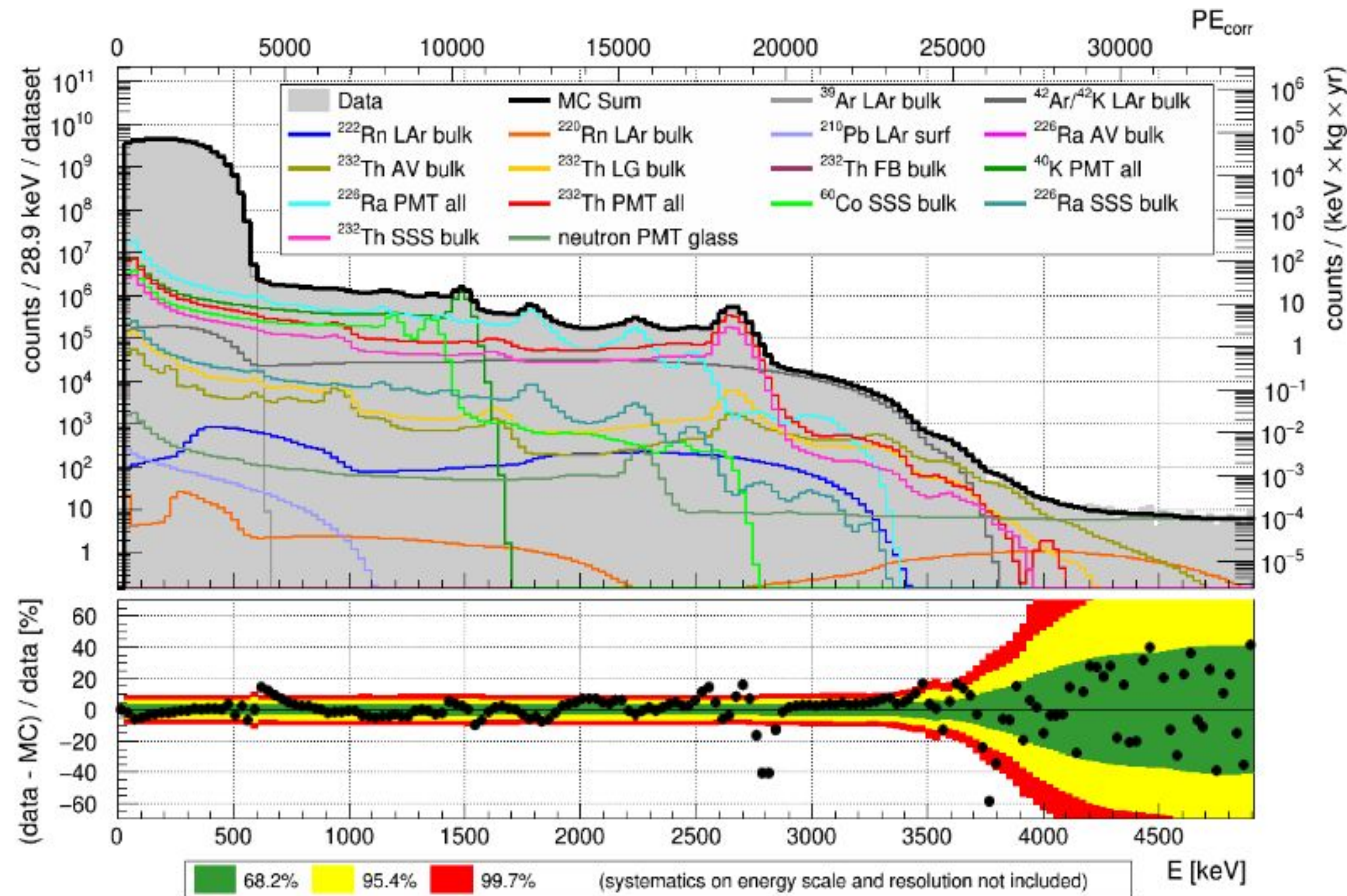
- Demonstrated world leading pulse shape discrimination
- Essential to reject gammas from inner detector material radioactivity and  $^{39}\text{Ar}$  beta decays



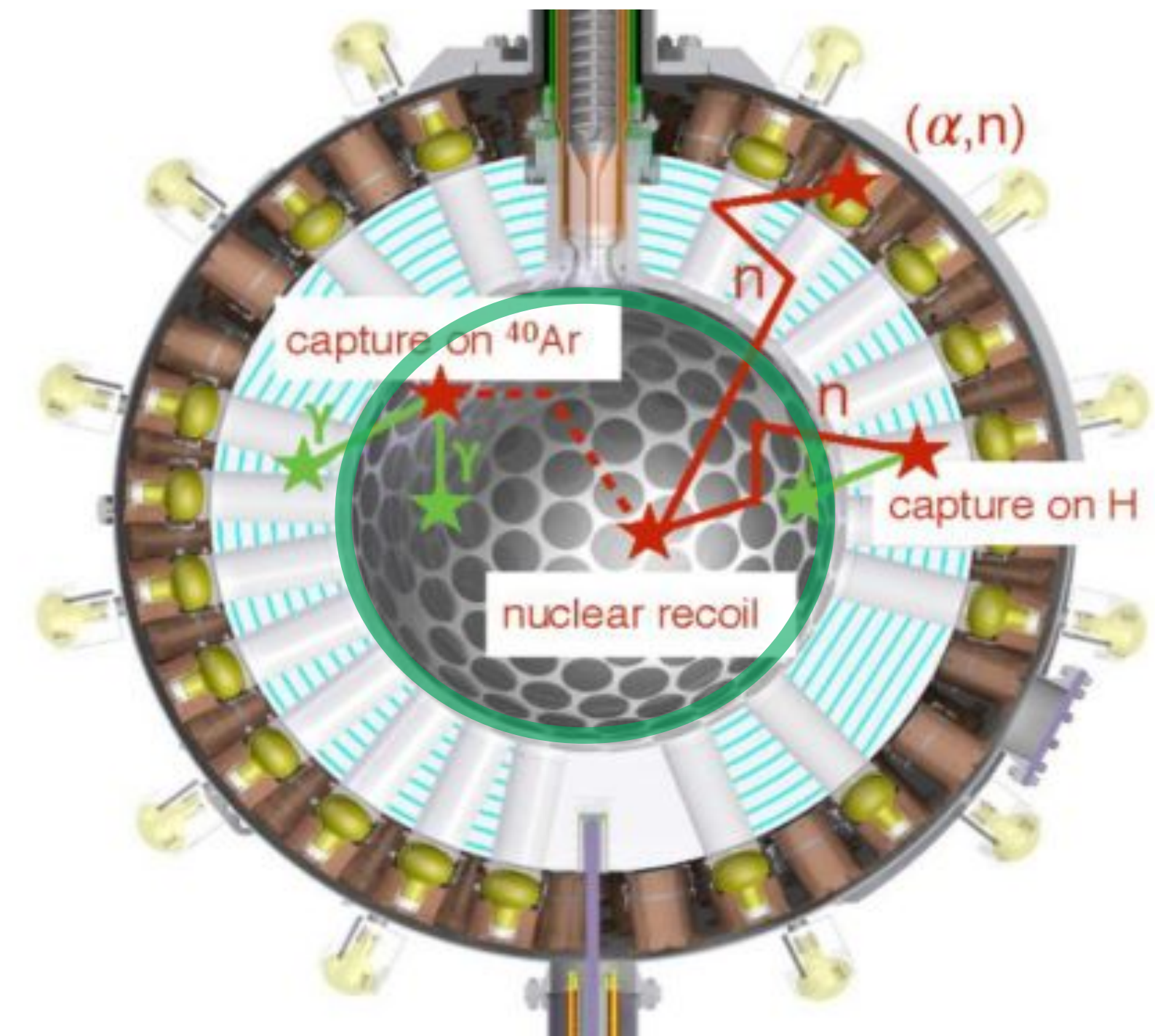
$$I_{LAr}(t) = \frac{R_s}{\tau_s} e^{-t/\tau_s} + \frac{1 - R_s - R_t}{\tau_{rec}(1 + t/\tau_{rec})^2} + \frac{R_t}{\tau_t} e^{-t/\tau_t}$$

# Internal backgrounds

- **Electron recoils background fully modeled from 290 keV to 5 MeV**
- Measured  $^{42}\text{Ar}/^{42}\text{K}$  activity =  $40.4 \pm 5.9 \mu\text{Bq/kg}$



- Radiogenic neutrons moderated by 50 cm of acrylic and rejected with radial position cuts





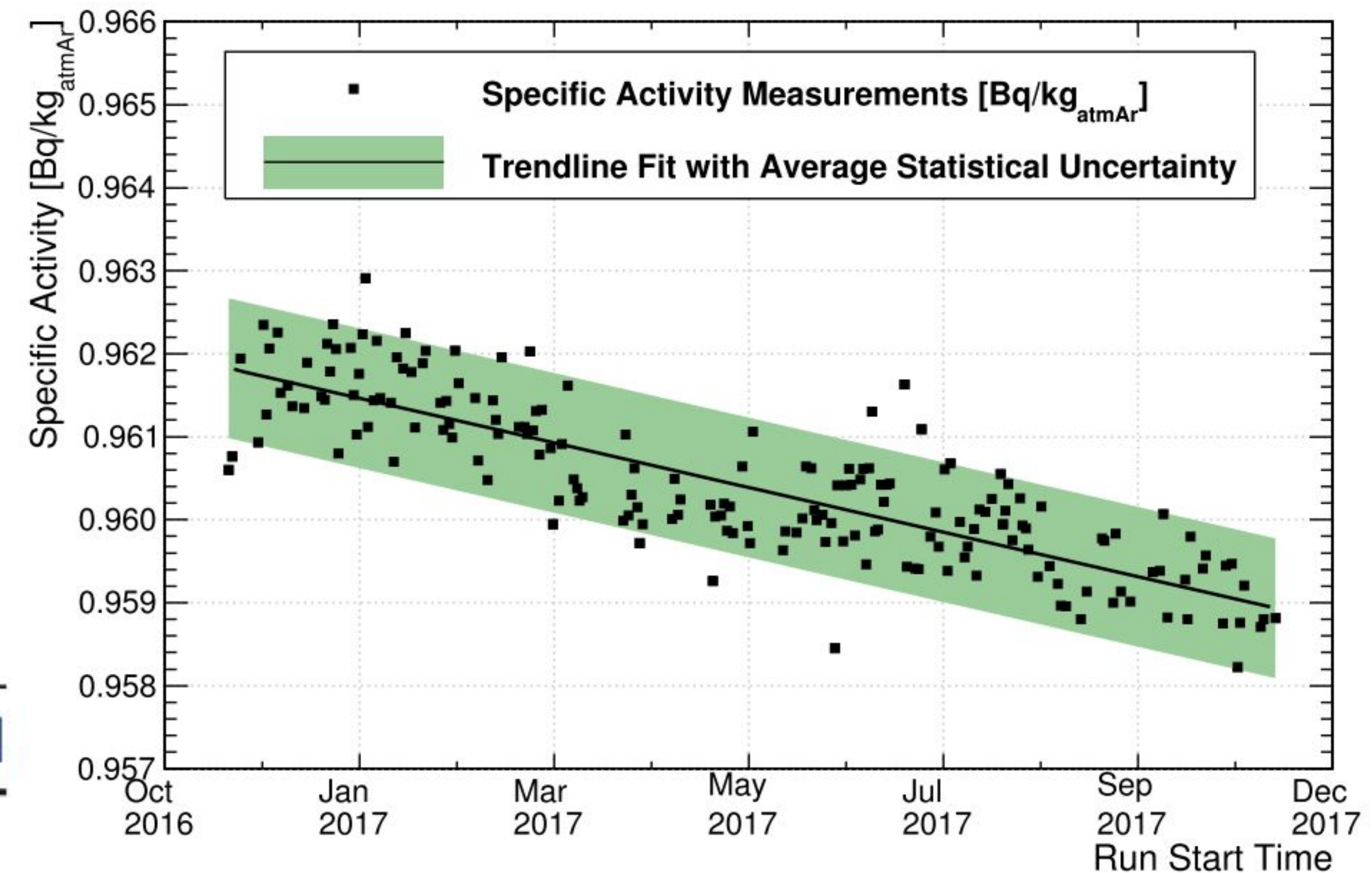
# Internal backgrounds



- Main contaminant, rejected with PSD:  $^{39}\text{Ar}$  beta decays ( $Q = 565 \text{ keV}$ )
- Produced in the atmosphere mainly by neutron capture on  $^{40}\text{Ar}$ ,  $^{40}\text{Ar}(n,2n)^{39}\text{Ar}$
- **Most precise measurement of its activity in DEAP-3600**

$$S_{\text{Ar}39} = \frac{N}{T_{\text{live}} \cdot m_{\text{LAr}}} \quad m_{\text{LAr}} = (3269 \pm 24)$$

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



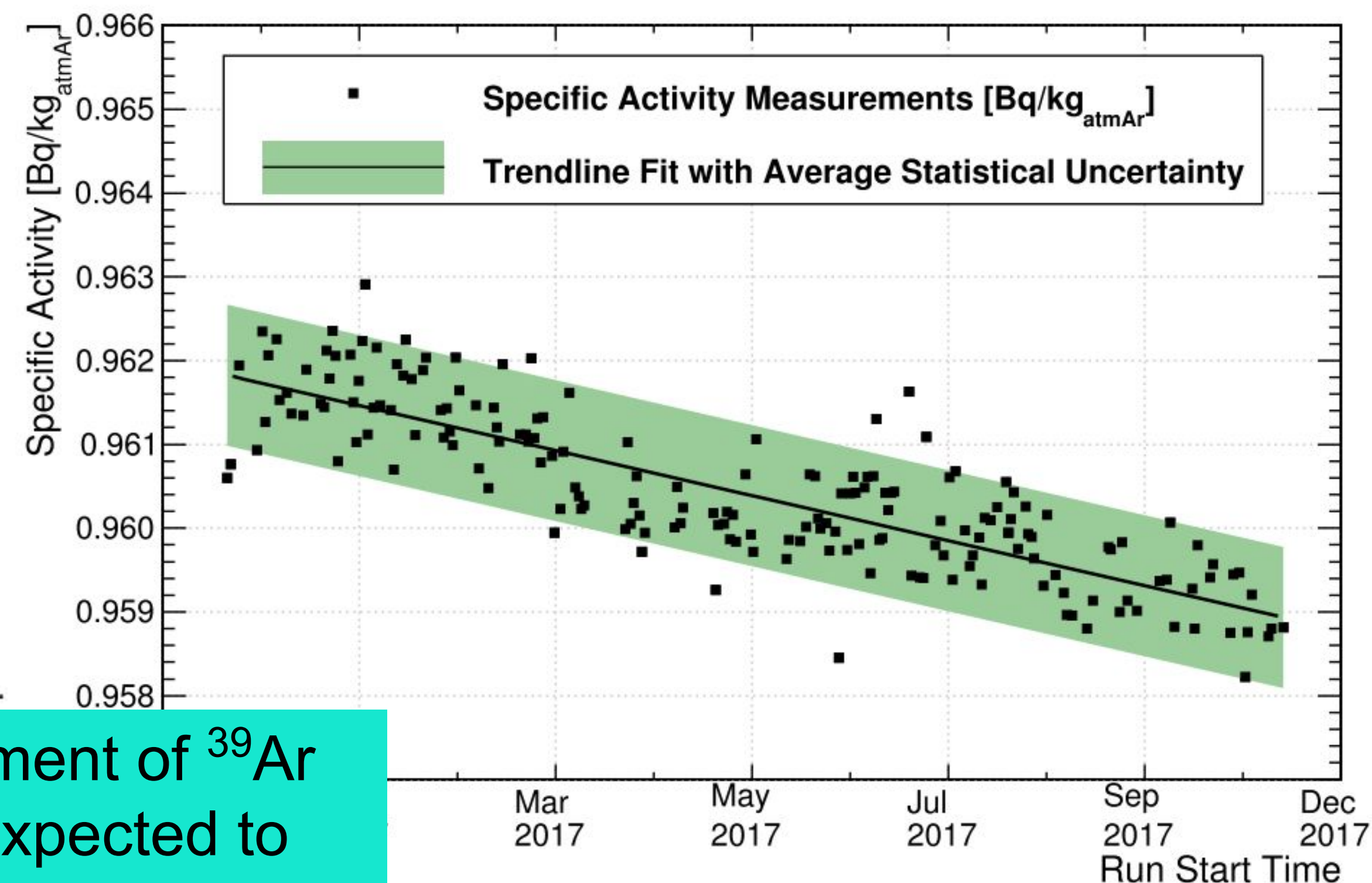
[Eur.Phys.J.C 83 \(2023\) 7, 642](#)

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In preparation: Measurement of  $^{39}\text{Ar}$  half-life in our detector, expected to be submitted in 2024

Eur.Phys.J.C 83 (2023) 7, 642

## Measurement

WARP [15]

ArDM [16]

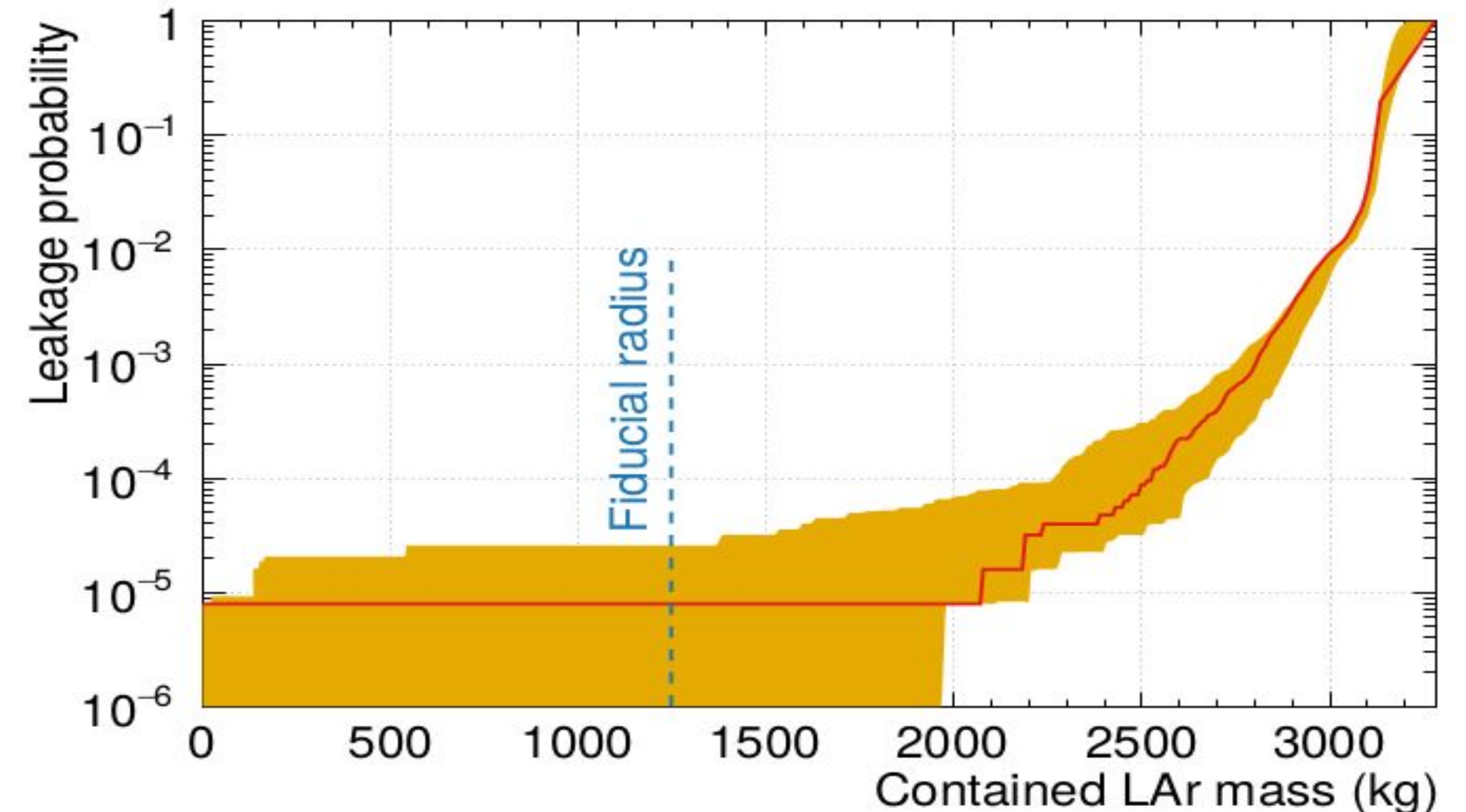
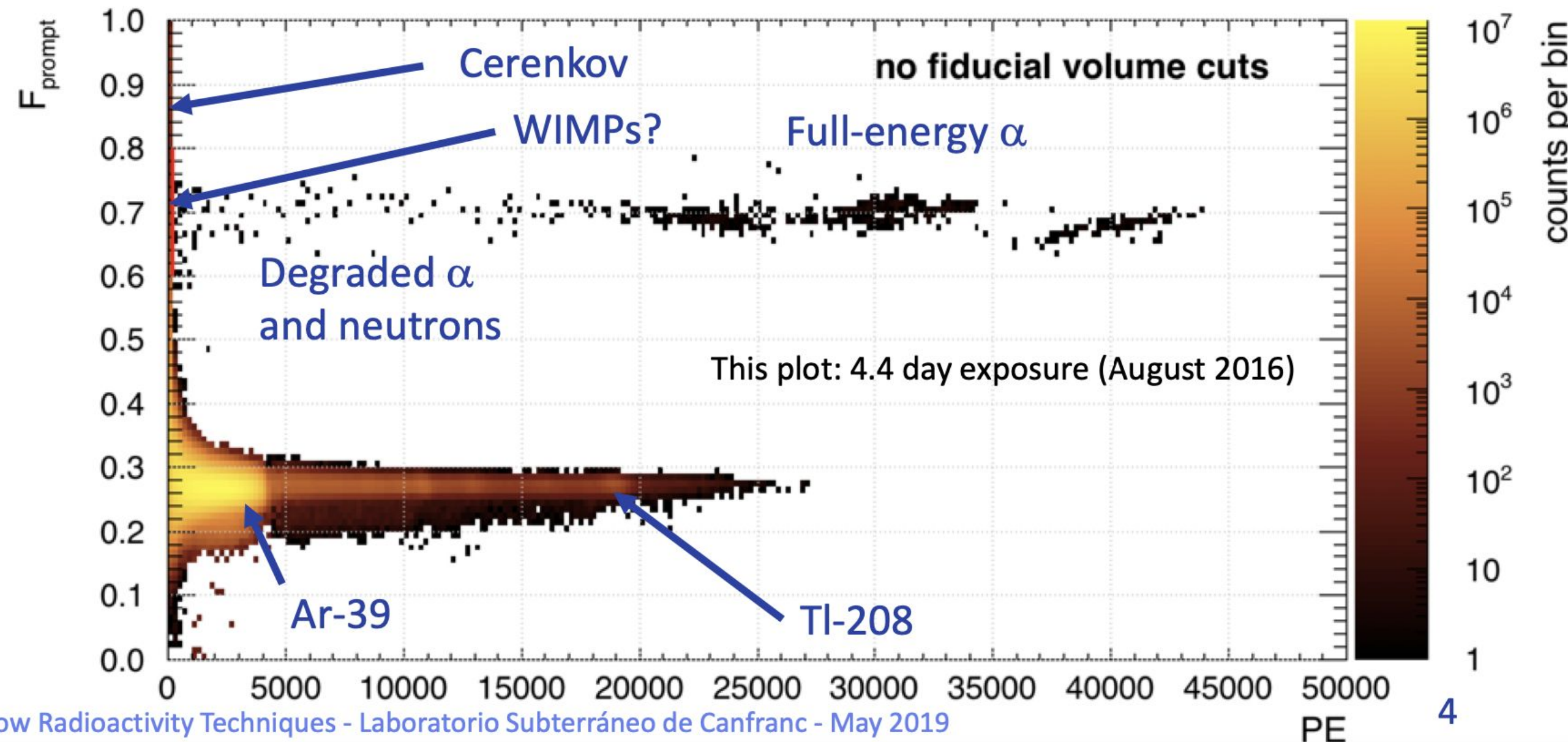
DEAP-3600 (this work)

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

# Internal backgrounds

- **Bulk alphas:** energy fully deposited in LAr. The signal # PE are much above WIMP ROI

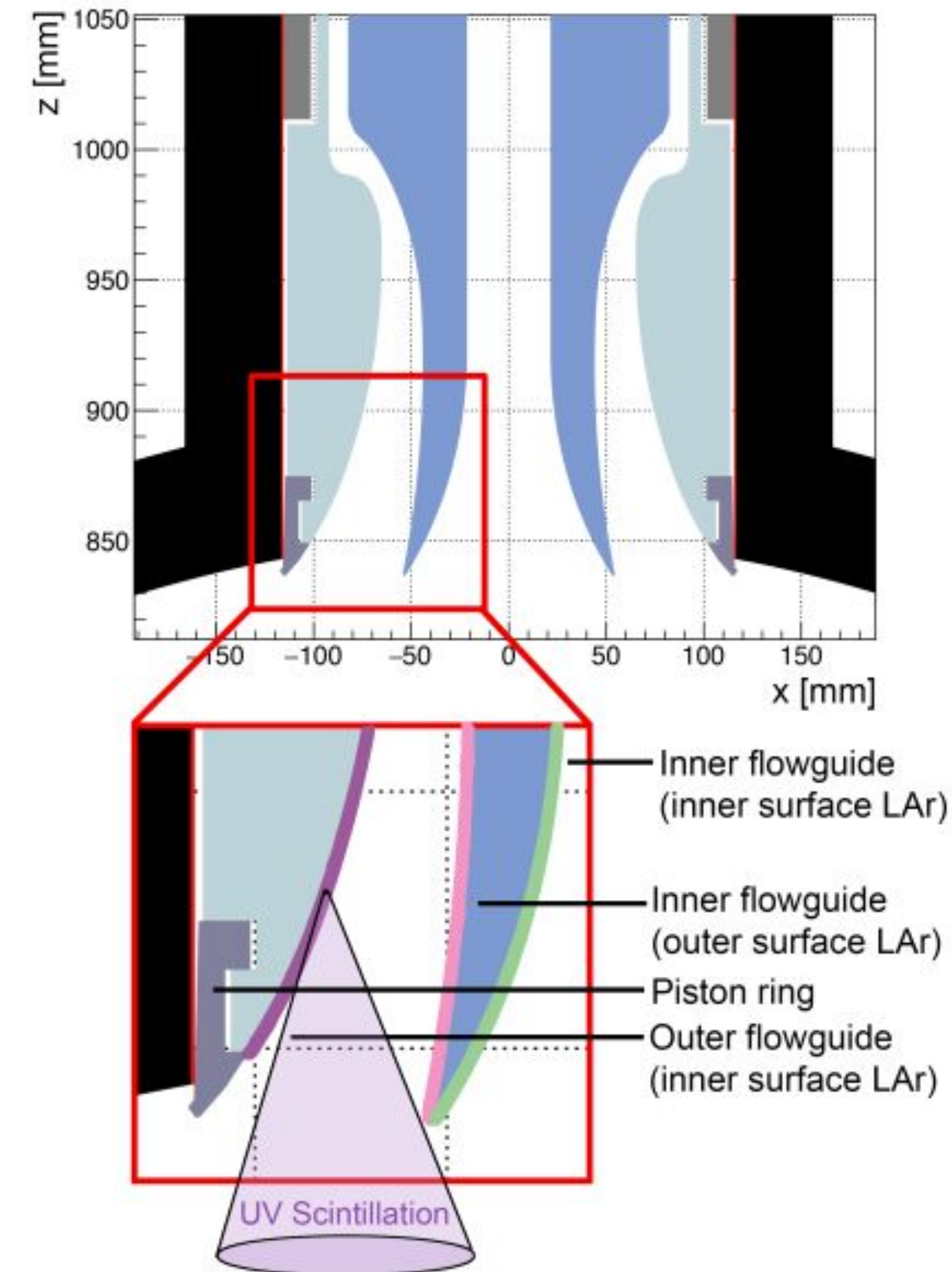
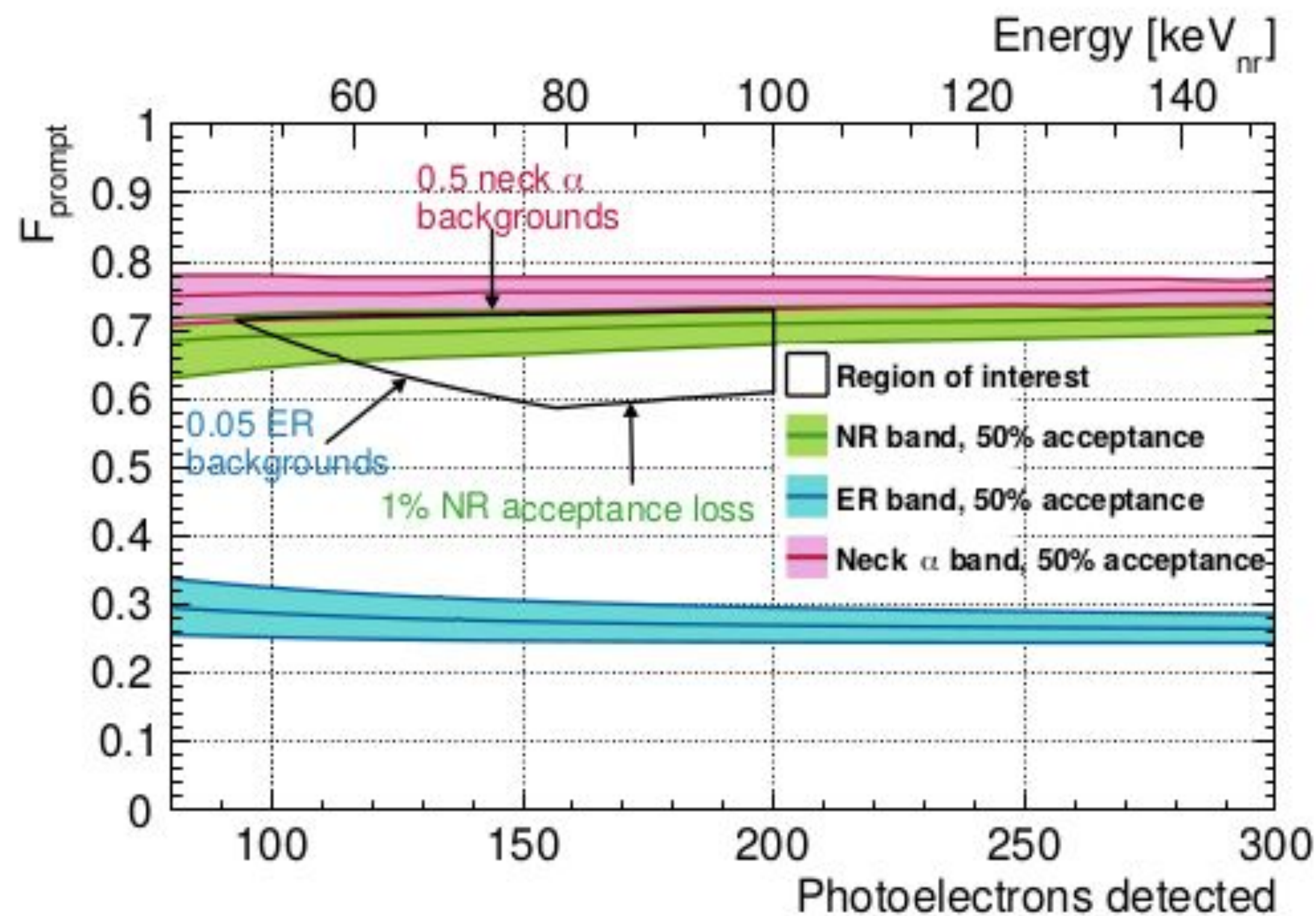
- **Surface alphas:** most of the energy lost in TPB and/or acrylic, giving a lower energy deposit in LAr. Might fall in WIMP ROI.
- Fiducialization volume cut at  $r < 630$  mm



Phys.Rev. D 100,022004

# Internal backgrounds

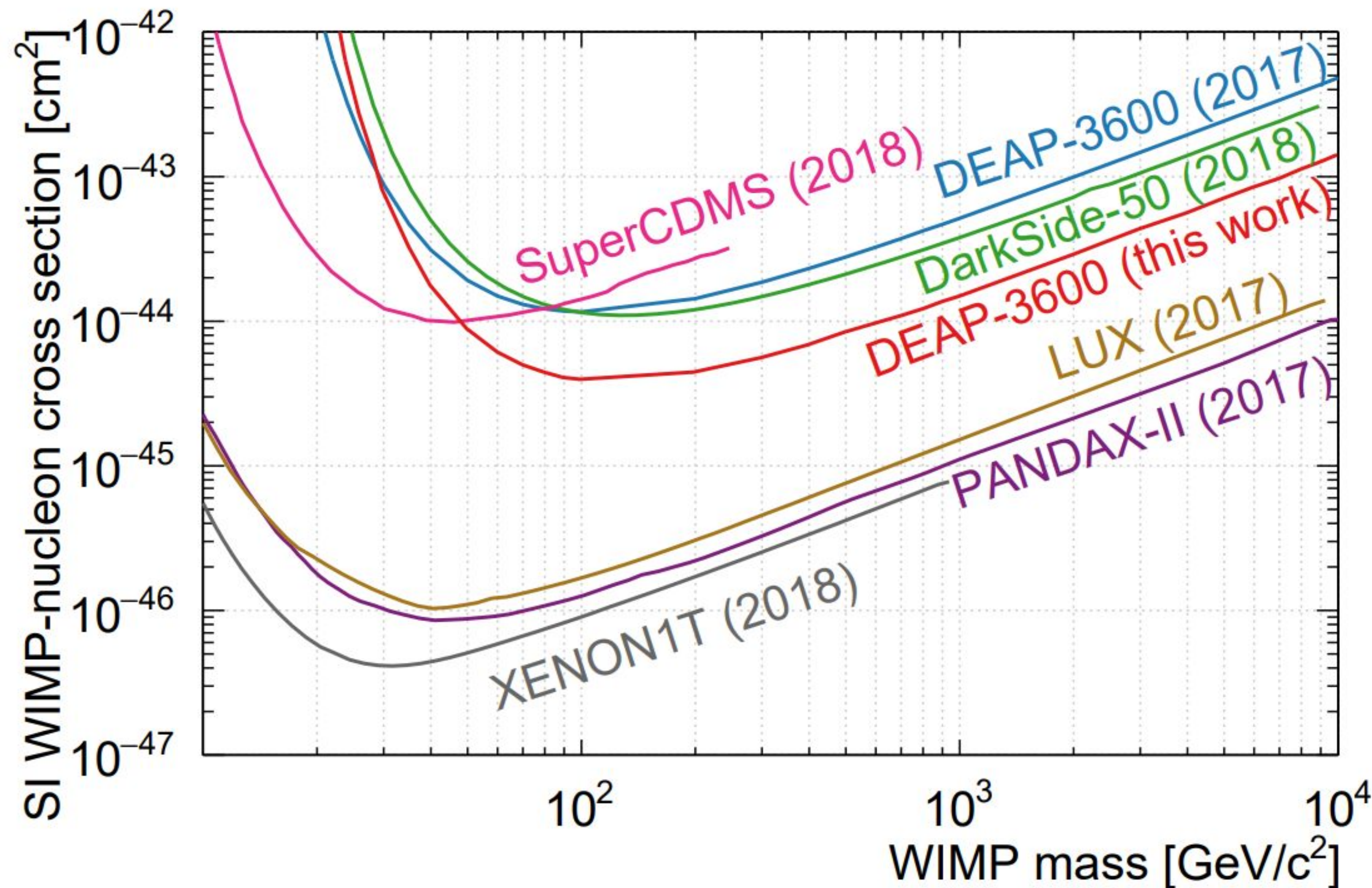
- **Neck alphas:**  $^{210}\text{Po}$  releases alphas in the acrylic of the flowguides. Alphas scintillate in the LAr film on the flowguides.
- The scintillation light is **shadowed** by the detector geometry and may enter WIMP ROI
- Rejected with  $F_{\text{prompt}}$  upper cut and the PE distribution in the PMTs



# WIMP Search

- **Last published WIMP Search in 2019 using 231 days live-days**
- Stringent exclusion limits for the WIMP-spin-independent interaction were set

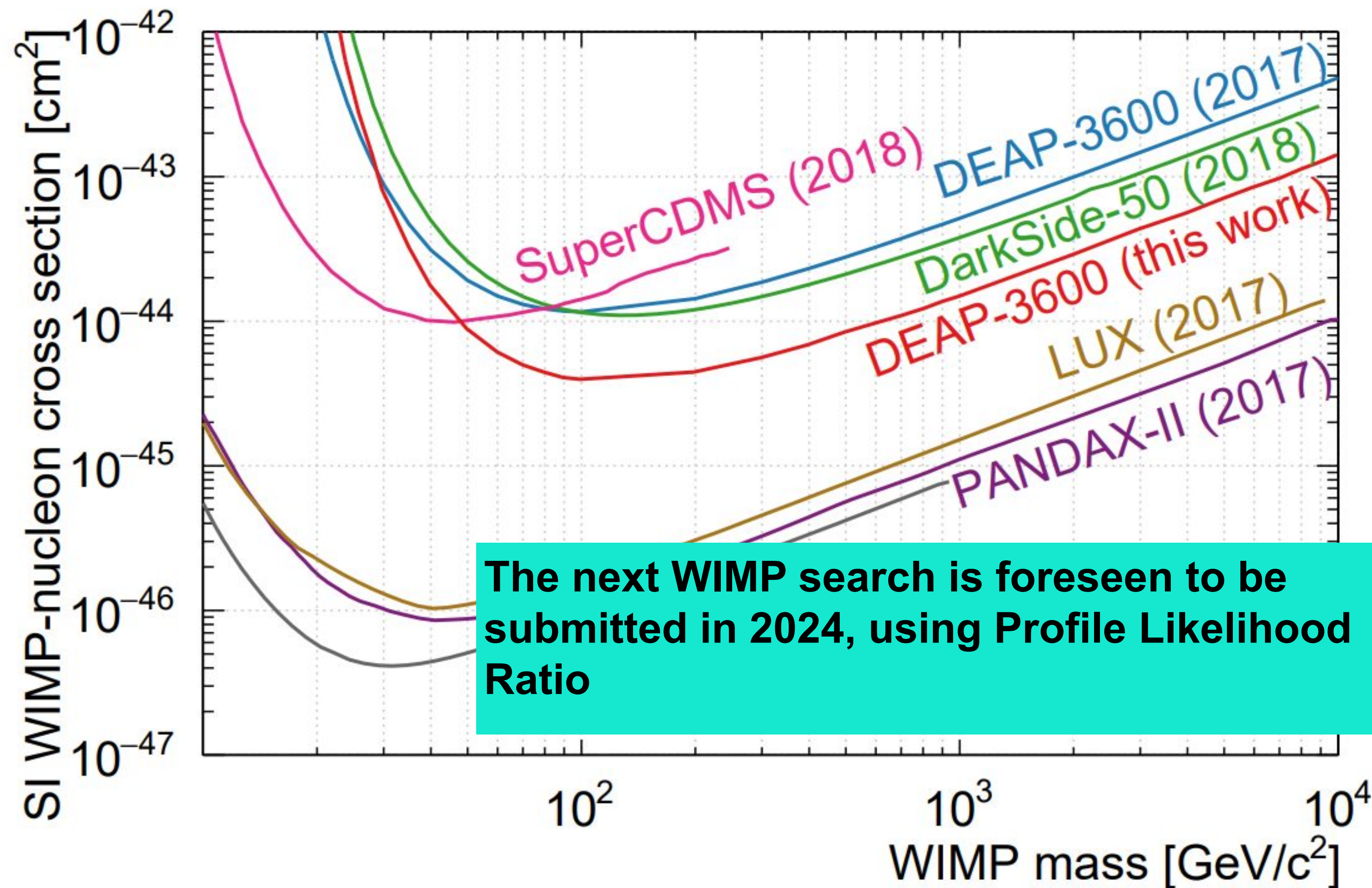
[Phys.Rev. D 100,022004](#)



# WIMP Search

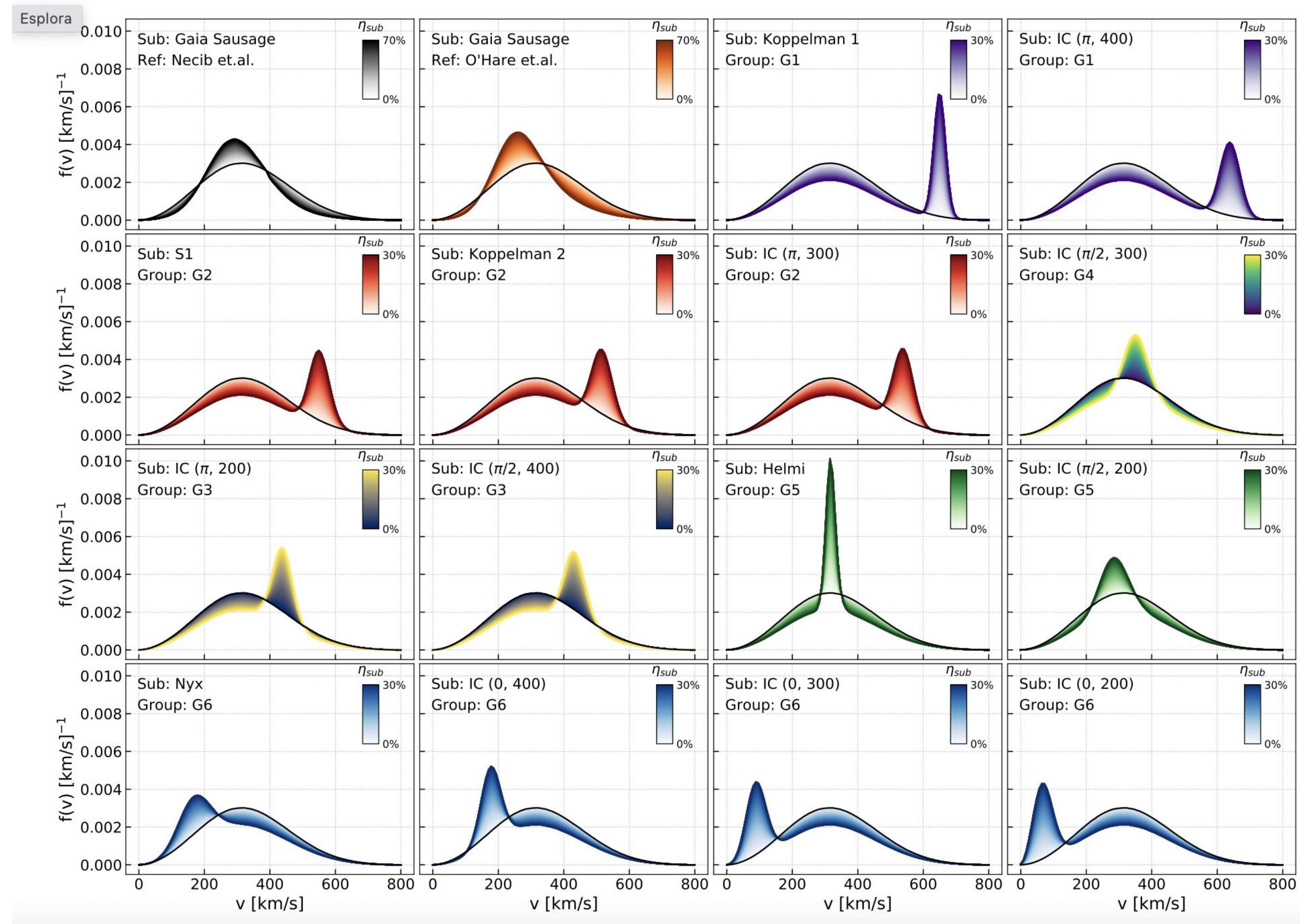
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[Phys.Rev. D 100,022004](#)



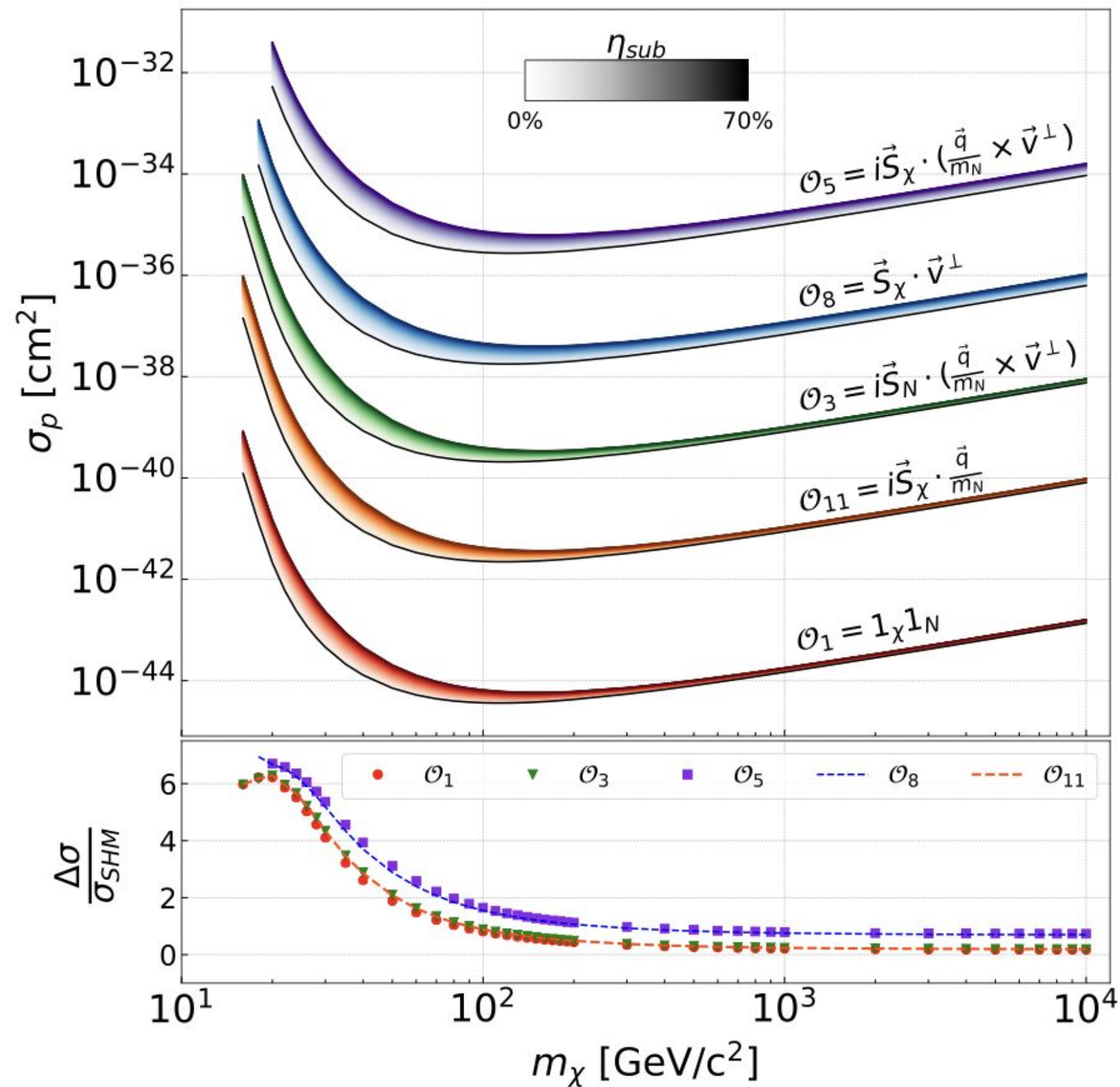
- The same result was reinterpreted according NREFT operators and modified DM distribution in the halo
- Streams and Infalling clumps (IC) are arranged in groups, according to their impact on the exclusion curves

Phys.Rev. D 102,082001



# WIMP Search

- The faster the substructure, the higher the sensitivity, as more events fall above the analysis threshold

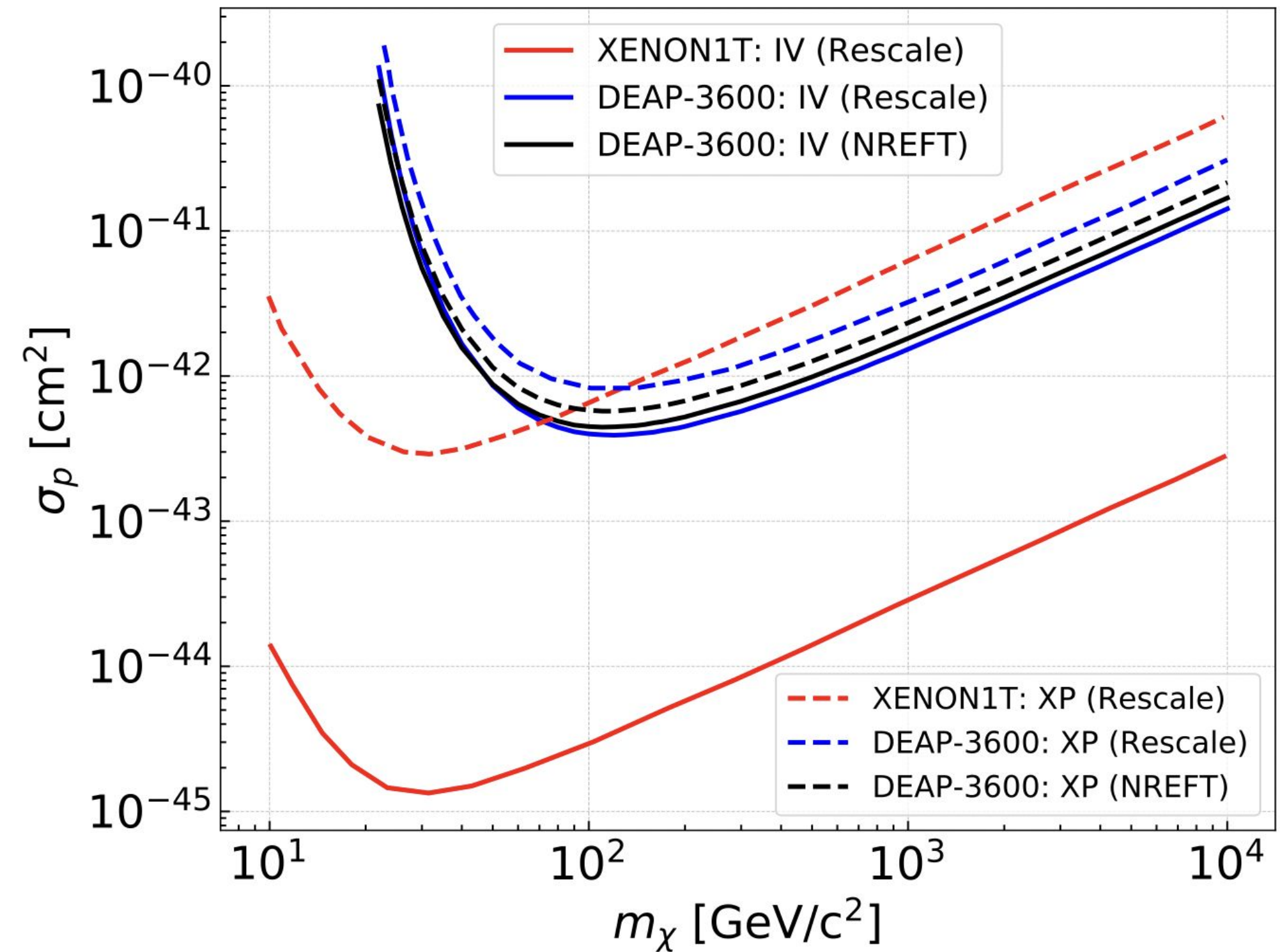


(a) *Gaia Sausage* (Necib *et al.*) [61]

Phys.Rev. D 102,082001



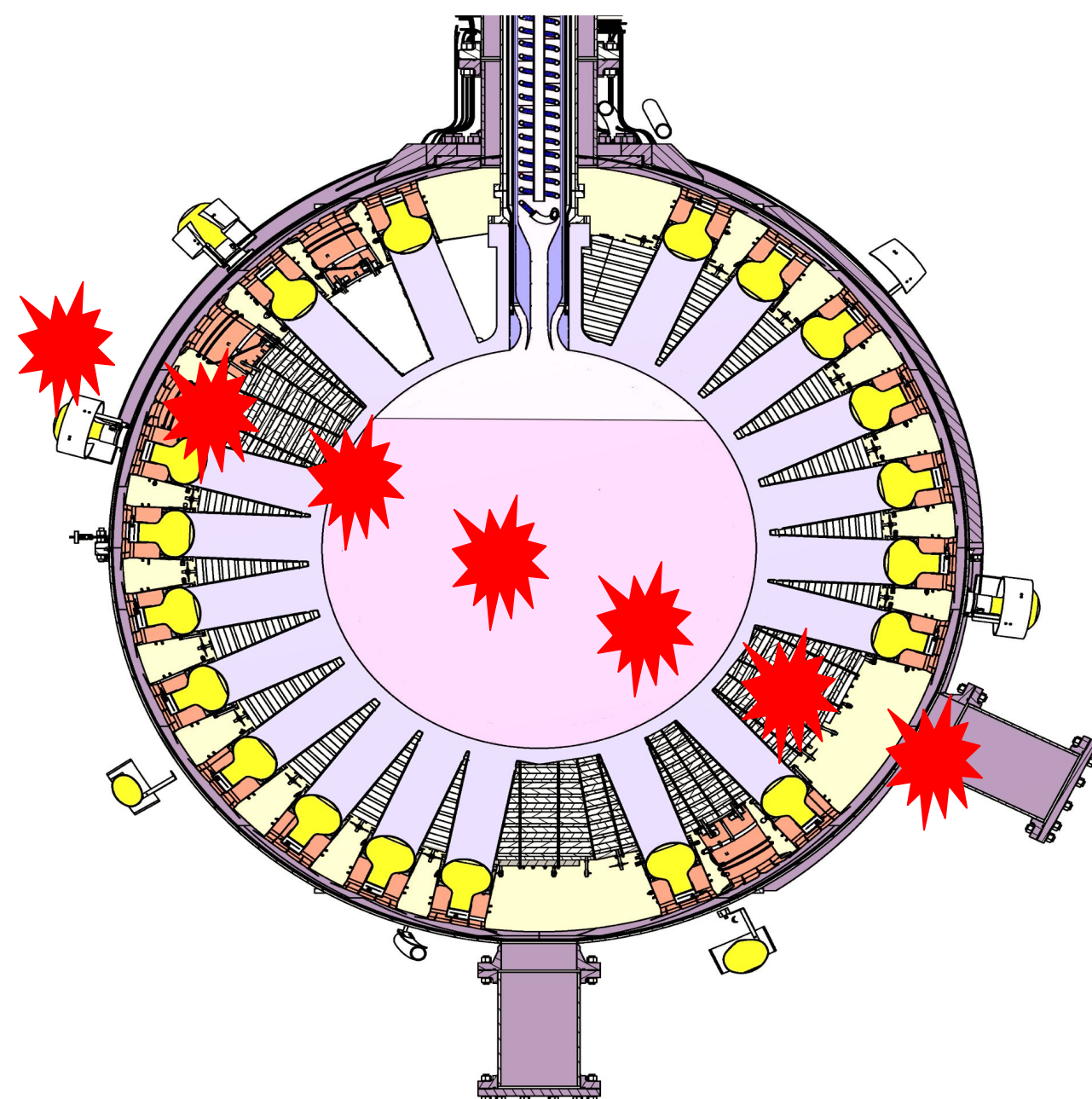
## Leading sensitivity to XenonPhobic DM for DM mass above 100 GeV/c<sup>2</sup>



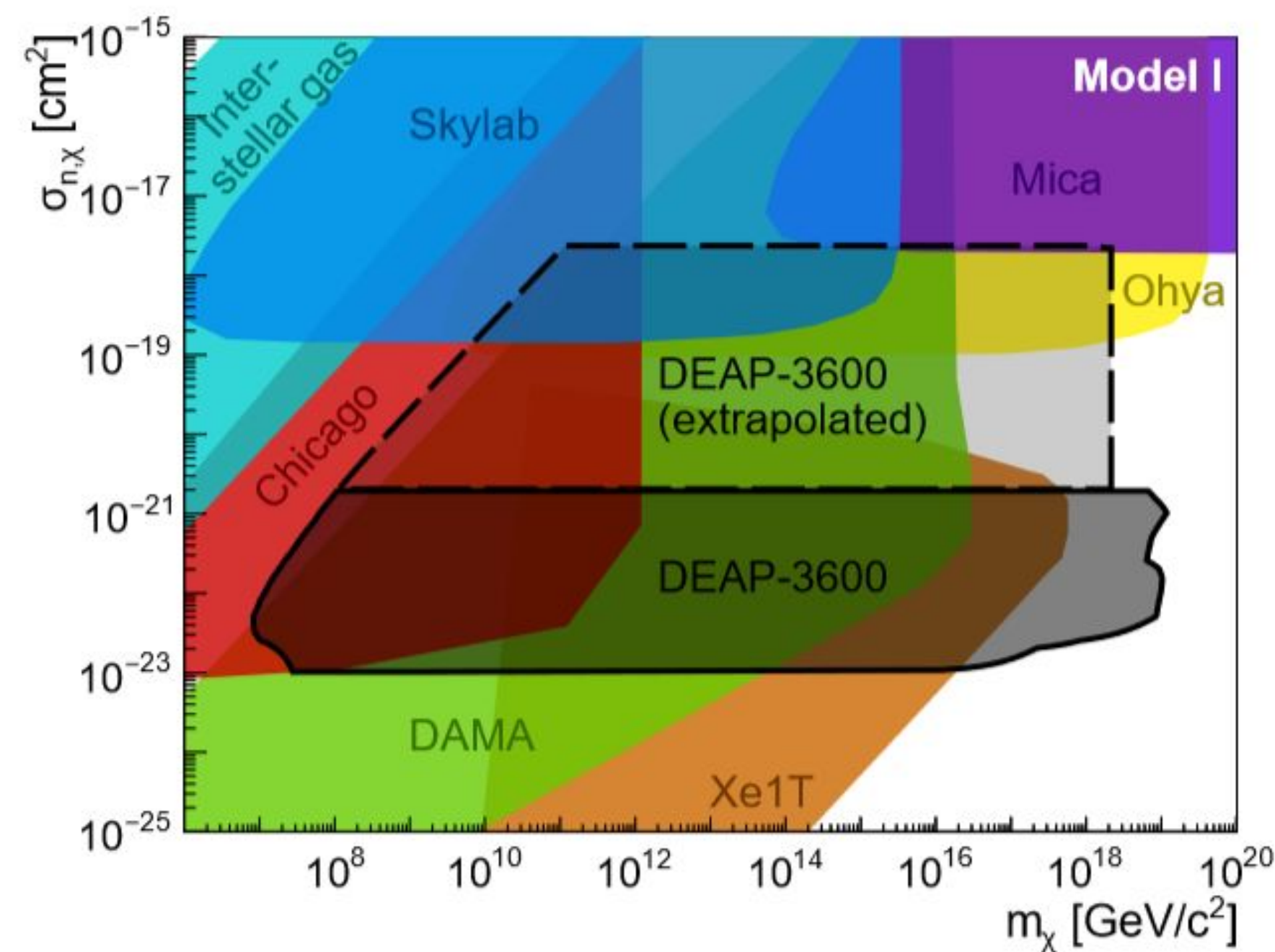
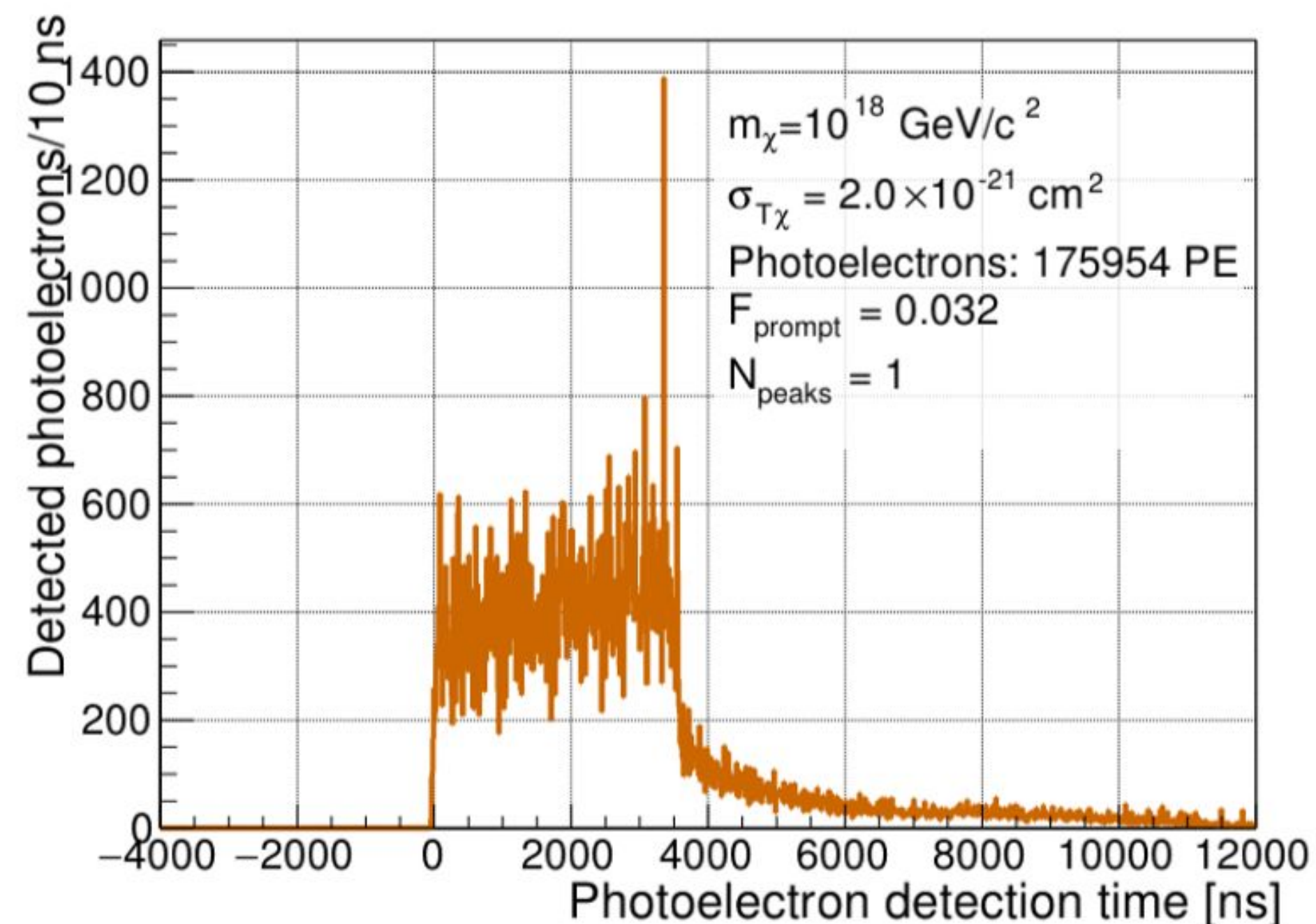


# Other searches

- First search for ultra-heavy, multi-scattering dark matter candidates in noble liquid detector
- Blind search over 813 live-days, with 4 ROIs



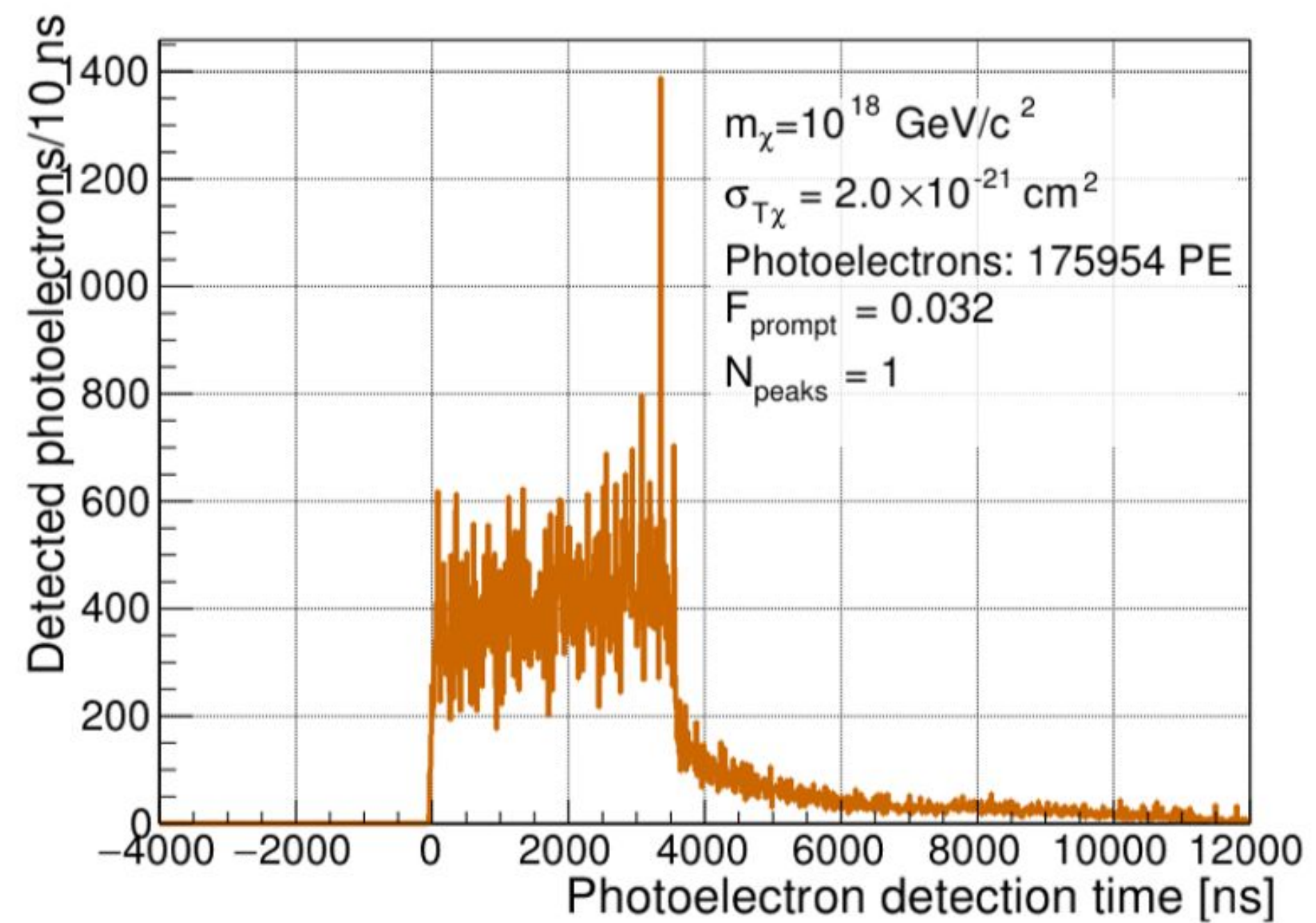
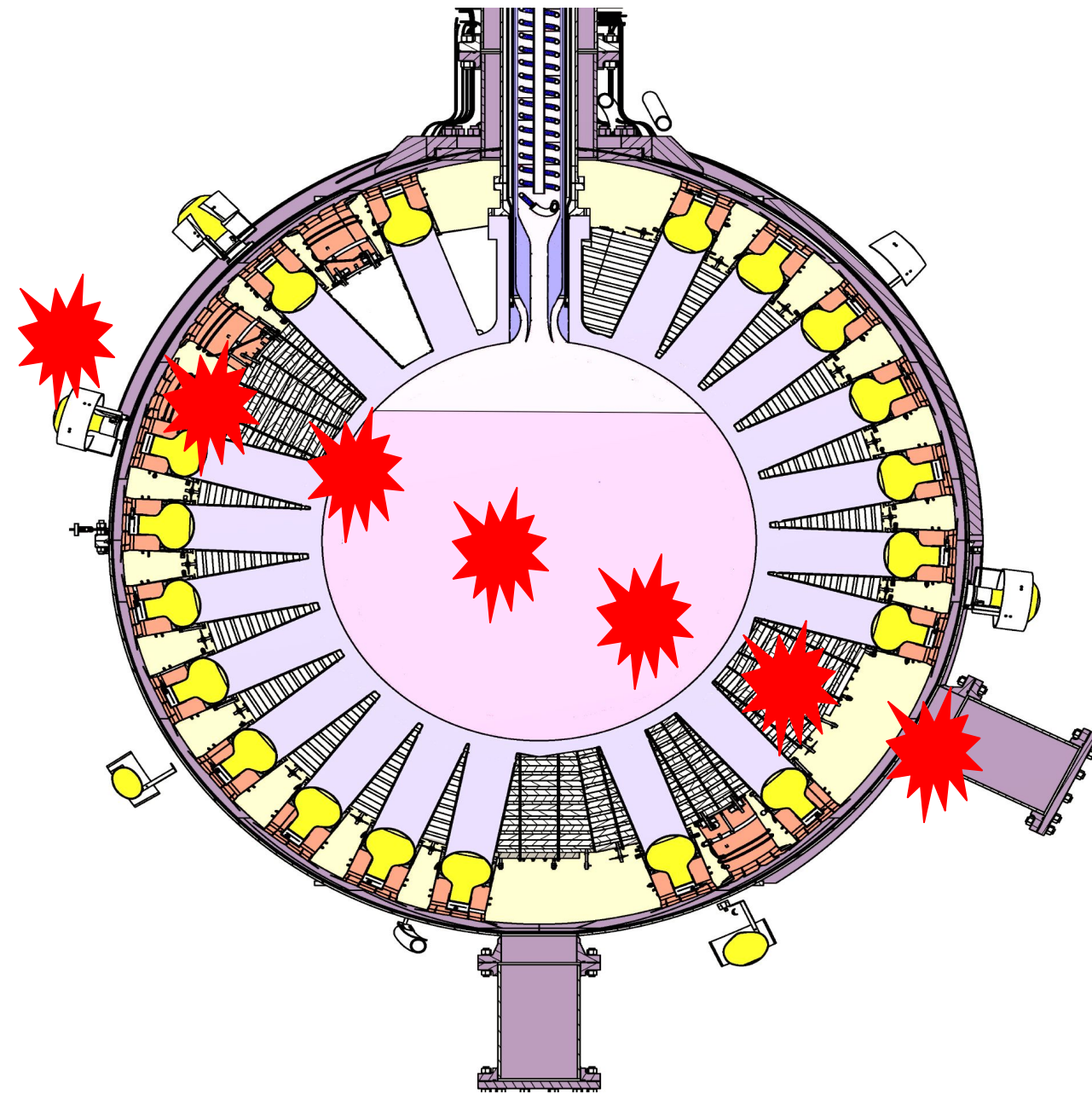
ROI	PE range	Energy [MeV]	$N_{\text{peaks}}^{\text{min}}$	$F_{\text{prompt}}^{\text{max}}$	$\mu b$
1	4000–20 000	0.5–2.9	7	0.10	$(4 \pm 3) \times 10^{-2}$
2	20 000–30 000	2.9–4.4	5	0.10	$(6 \pm 1) \times 10^{-4}$
3	30 000–70 000	4.4–10.4	4	0.10	$(6 \pm 2) \times 10^{-4}$
4	70 000– $4 \times 10^8$	10.4–60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



Phys.Rev. Lett. 128, 011801

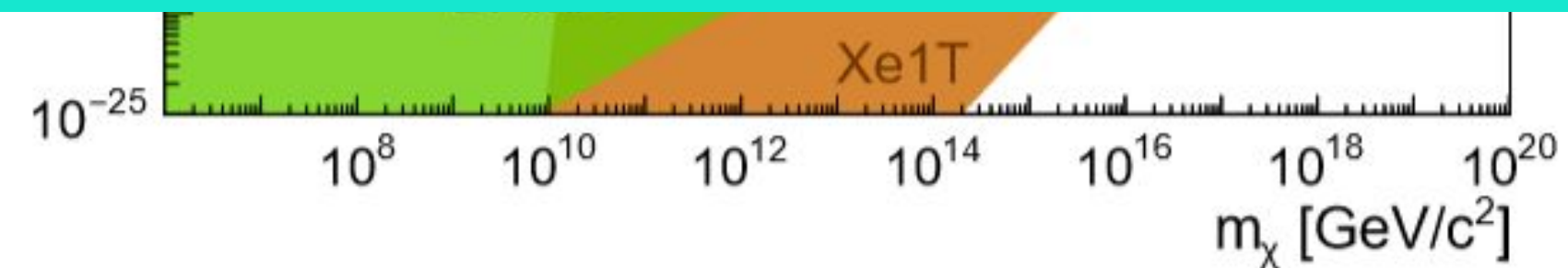
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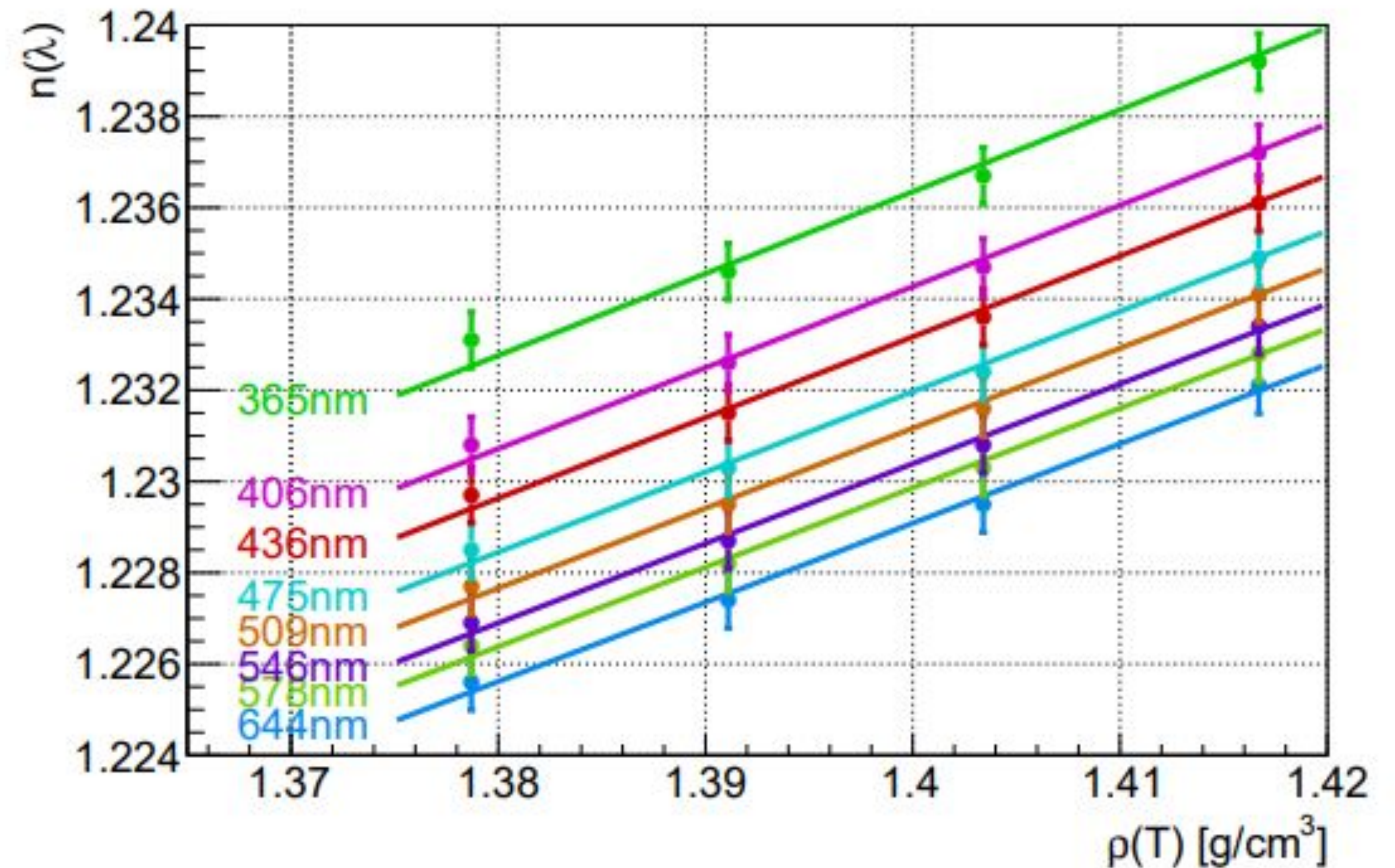


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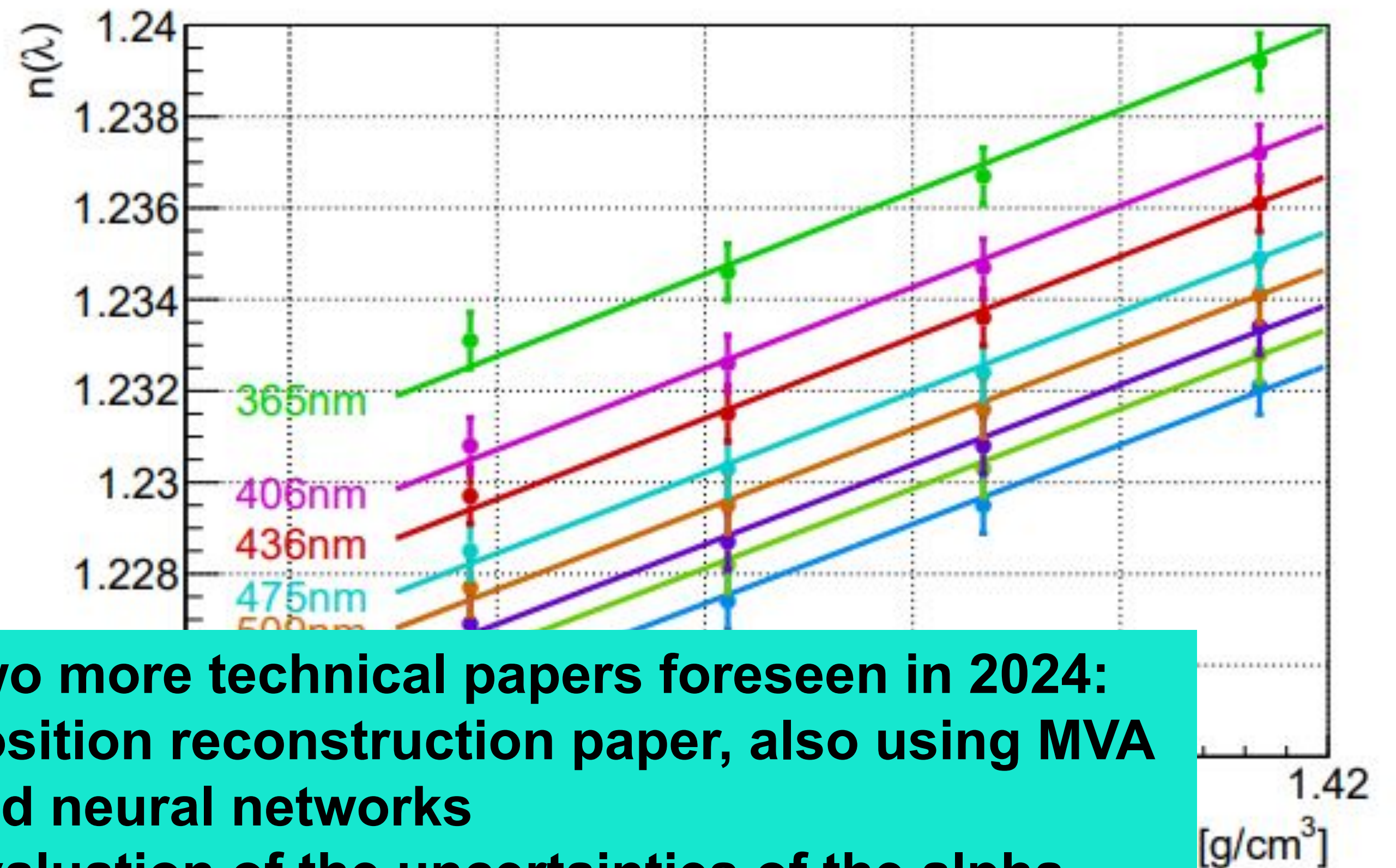
Other searches for MeV scale recoil energy:  
 -5.5 MeV solar axion particles  
 -8B solar neutrino absorption in argon  
 -Inelastic boosted dark matter



- **The liquid argon optical model**
  - Our optical model includes the most recent measurements in argon, such as the Rayleigh scattering length, refractive index, group velocity
  - Merges the existing measurements with thermodynamics models, in-situ measurements
  - Model further validated by data collected in the detector
  - Method also for future large argon detectors to propagate the uncertainties on optical parameters through the simulations.
  - Soon on JINST in early 2024 as LIDINE 2023 conference proceeding
  - Updates of the NEST software



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**Two more technical papers foreseen in 2024:  
Position reconstruction paper, also using MVA  
and neural networks  
Evaluation of the uncertainties of the alpha  
quenching factor**

# Collaboration Health



- Code of Conduct clearly requiring a inclusive, accessible, diverse and equal collaboration
- Two ombudspersons to refer to in case of unrespectful behaviours
- Two young members representatives assuring dialogue with the Scientific Board
- Organization of Spotlight talks within the collaboration meeting, to increase the accessibility of the analyses
- Set up of a dedicated TWiki pages, with useful resources to actively promote EDI practices
- Set up of a EDI-task-force, which communicates with a slack channel

**Main**

**Hello MichelaLai**  
All Users  
I am new, Help!  
GettingStarted on analysis  
AnalysisNotes  
MonteCarloDatasets  
Organizing shifts and data  
Data quality plots [↗](#)  
AnalysisOrganization  
Slow control [↗](#)

**Phone Calls**  
All call links

**Conferences**  
ConferenceCalendar  
ApprovedPlotsPage  
Proceedings Review

**Key Docs**  
BoardPublic  
Safety  
ProceduresDEAP3600  
IssueTracker  
STRs  
Drawings [↗](#)  
2010 Reviews  
Specifications  
ElectronicsDocs  
PapersOrganizationPage  
UnblindingProcess  
RadiopurityDB [↗](#)  
Outreach

**Large Meetings**

TWiki > Main Web > EquityDiversityInclusion (2024-01-16, SimonViel)

## Equity, Diversity and Inclusion



This page is dedicated to all the material, the talks and the activities which help boosting EDI values in our co collaboration effort and intent in pursuing EDI practises along the daily activities within the collaboration.

If you want to report any incident, any event in which you felt not included in your research group, or any conc [deap3600taskforce@gmail.com](mailto:deap3600taskforce@gmail.com) reporting the case, eventually keeping the anonymity, according to your prefe any information pointing to the injured party.

### Talks, updates and invited seminars on Equity, Diversity and Inclusion

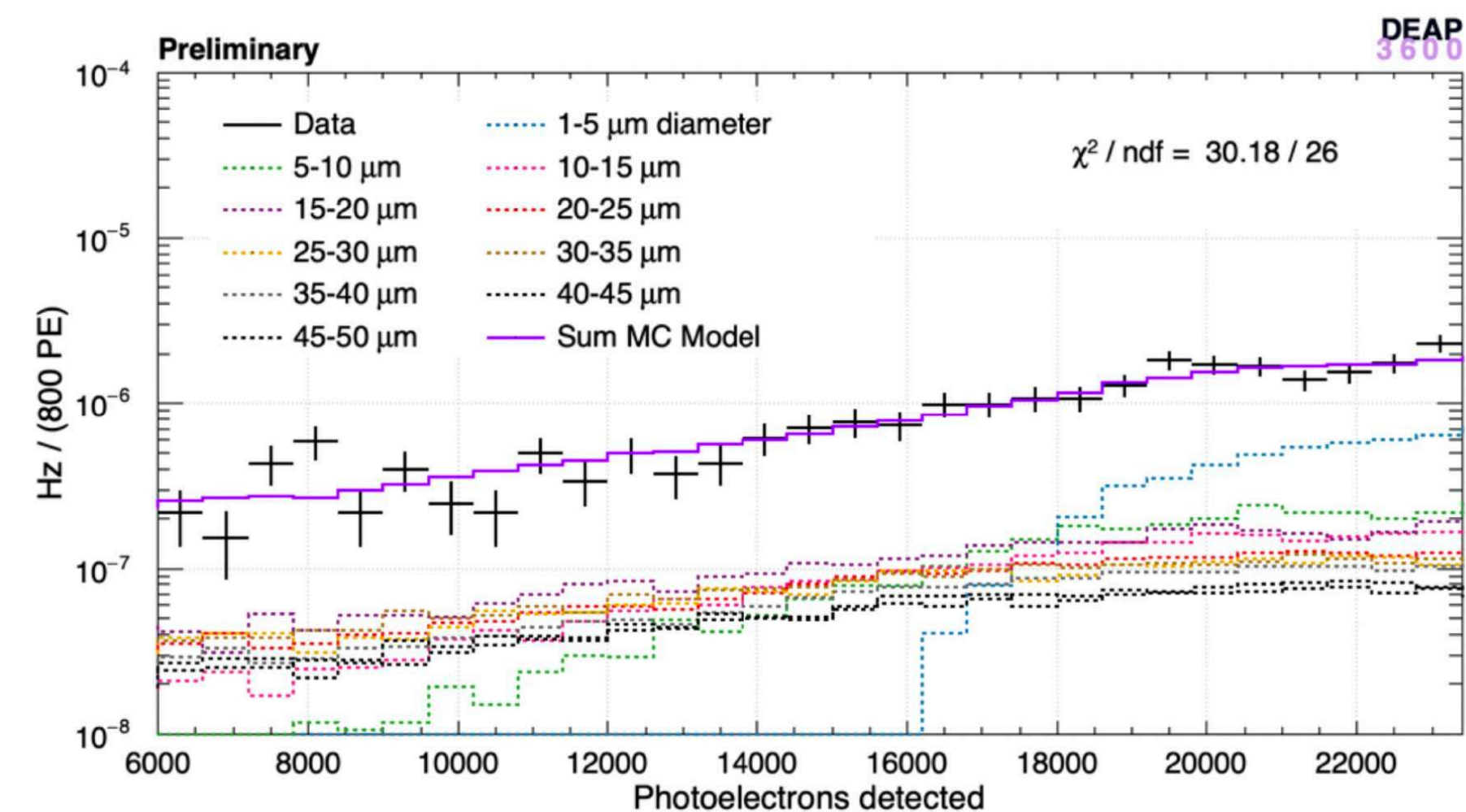
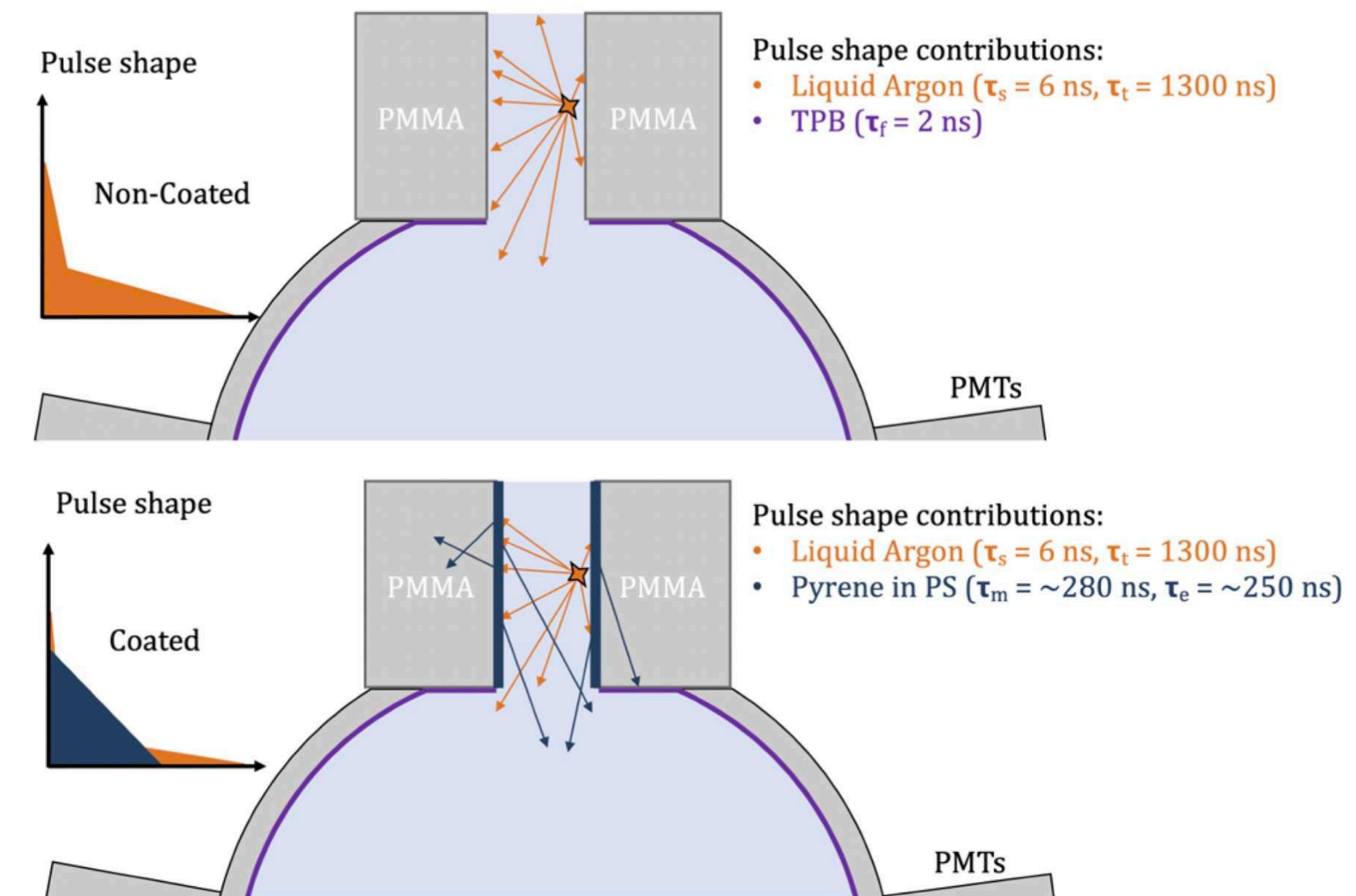
- [Talk](#) on EDI at the DEAP Collaboration general meeting in August 2022
- [Presentation](#) at ICHEP2022 from CMS Collaboration "Diversity & Inclusion in the CMS Collaboration"
- [Presentation](#) at ICHEP2022 from LHCb Collaboration "Early Career, Gender & Diversity at LHCb"
- [Presentation](#) at ICHEP2022 from ALICE Collaboration "Matters of Diversity and Inclusion at the ALICE"

# Experiment Status; Hardware Upgrades

Nucl.Instrum.Meth.A 1034 (2022) 166683

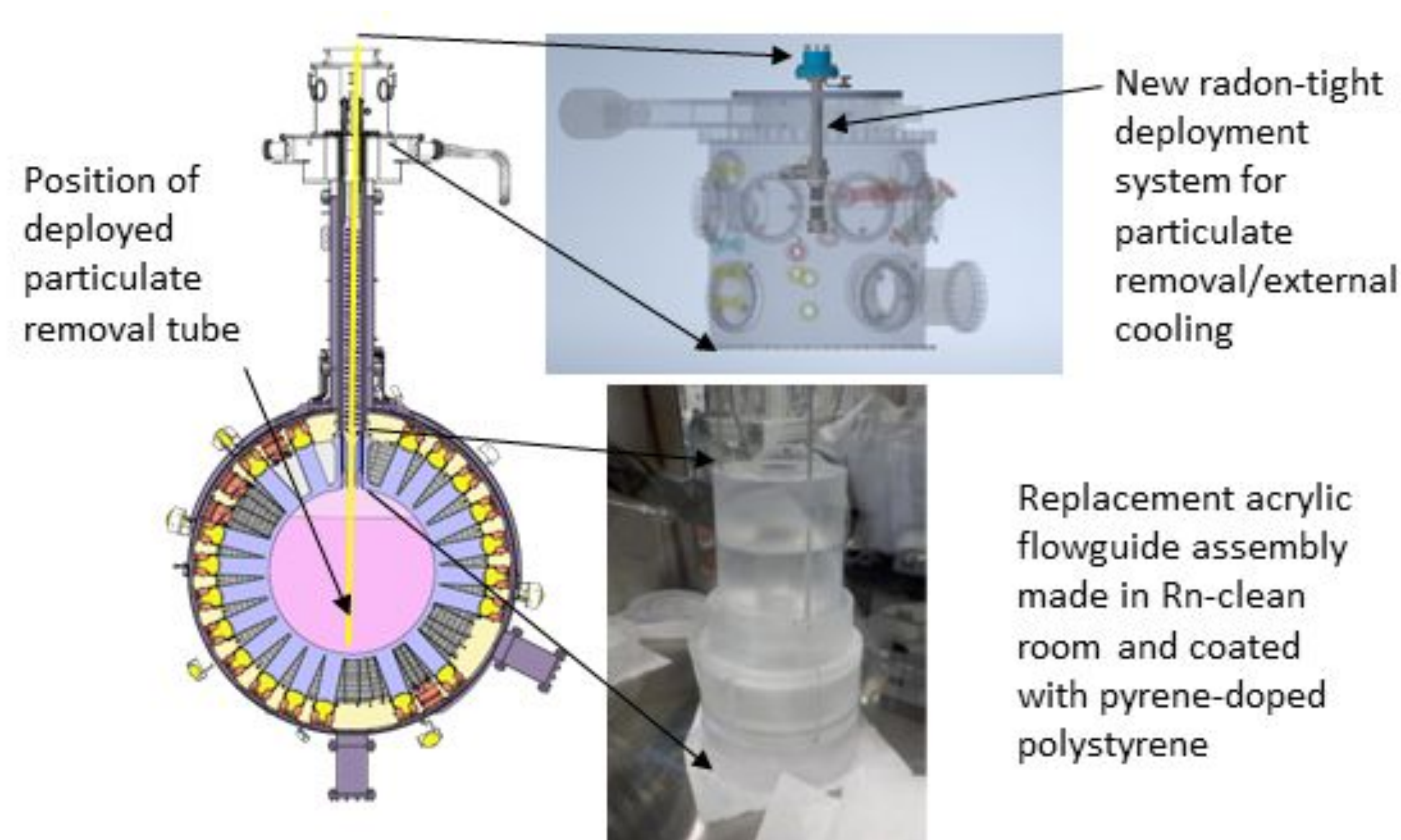
Hardware upgrades in development since 2019

- Aimed to reduce neck and dust events
- Expected rate from  $\sim 1$  per tonne-year to  $\ll 1$  per tonne-year
- Installation completed this year with new data-taking upcoming
- Allows demonstration of background reduction and improvement of physics measurements
- Valuable information for the development and operation of future detectors.



# Experiment Status; Hardware Upgrades

1. Deployable (and removable!) liquid extraction tube to remove particulates in argon
2. New flowguides with active coatings to tague neck events
3. Replacement of some veto PMTs to bring muon veto to full efficiency
4. Many maintenance steps



# Schedule impacts & milestones

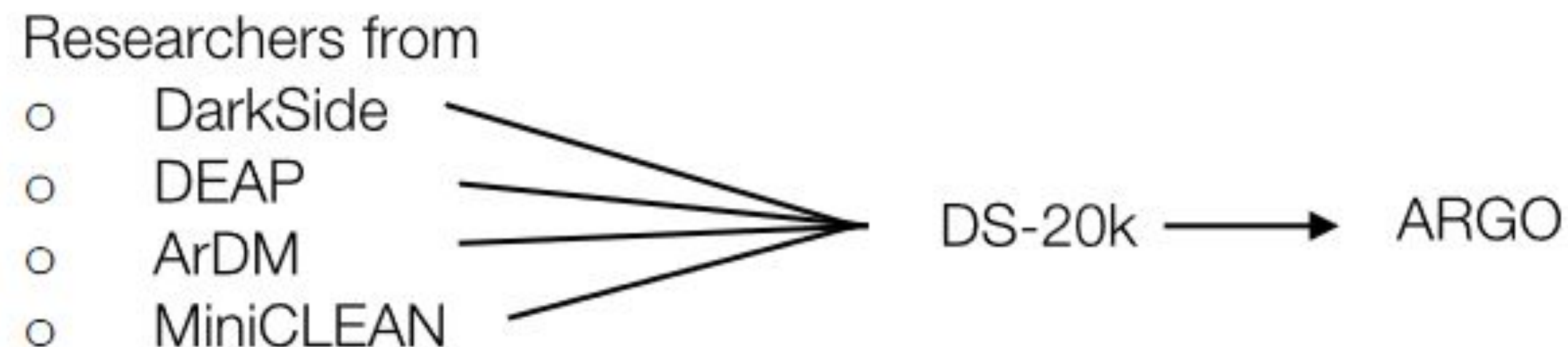


DEAP Hardware Upgrades Milestones Tracker			
Task Name	Anticipated Completion Date - March 2023	Anticipated / Actual Completion Date	% Complete
Assembly of Flow Guides @ Carleton		2021-03-23	100%
Veto PMT Replacements		2021-07-16	100%
LN2 Systems Repaired & TSSA Recertification		2021-08-18	100%
External cooling/filtration system from Alberta received underground		2022-04-20	100%
KNF Pump Re-installation & Recommission		2022-06-30	100%
Argon Dewar & Cooling Tower Commissioning Complete		2022-09-09	100%
240V UPS Replacement		2022-09-20	100%
Radon Trap Recommission		2022-10-20	100%
Fill Argon Storage Dewar with 3,000 Liters		2022-11-10	100%
New Hoist Critical Lift Test Performed / Commissioned		2022-11-22	100%
External Components ready for Deployment		2023-04-21	100%
Glovebox Disconnections	2023-04-19	2023-05-05	100%
Shield Water Filtration System Recommissioning Complete	2023-05-15	2023-06-28	100%
Neck Removal	2023-05-12	2023-07-27	100%
Neck Seal Repair Complete	2023-05-17	2023-10-11	100%
Argon line installation & cleaning complete	2023-06-08	2024-02-08	68%
Cryocoolers Repairs & Feet Replacement Complete	2023-03-31	2024-03-28	85%
Flow Guide Replacement and Neck Repair Complete	2023-07-10	2024-03-26	0%
Glovebox Reconnection Complete	2023-11-21	2024-05-09	0%
Construction Phase Complete / Ready for Cooldown	2023-11-21	2024-05-09	0%
Particulate Removal Operations	2024-01-11	2024-06-26	0%
Fill Complete	2024-04-04	2024-09-02	0%

2024-01-16



# Global Argon Dark Matter Collaboration Updates



- Completion of current program with DEAP
- Joint collaboration on DS-20k at LNGS. Detector construction and installation is underway. Plan for operations starting 2027. TPC fabrication and surface coatings, DAQ, electronics and underground argon contributions from Canada
- Developing concept for ARGO, 400-tonnes of underground argon, including detector design and photodetector development. The international collaboration will submit an expression of interest to SNOLAB next EAC meeting for ARGO development and prototyping in anticipation of the ARGO project in 2030's.

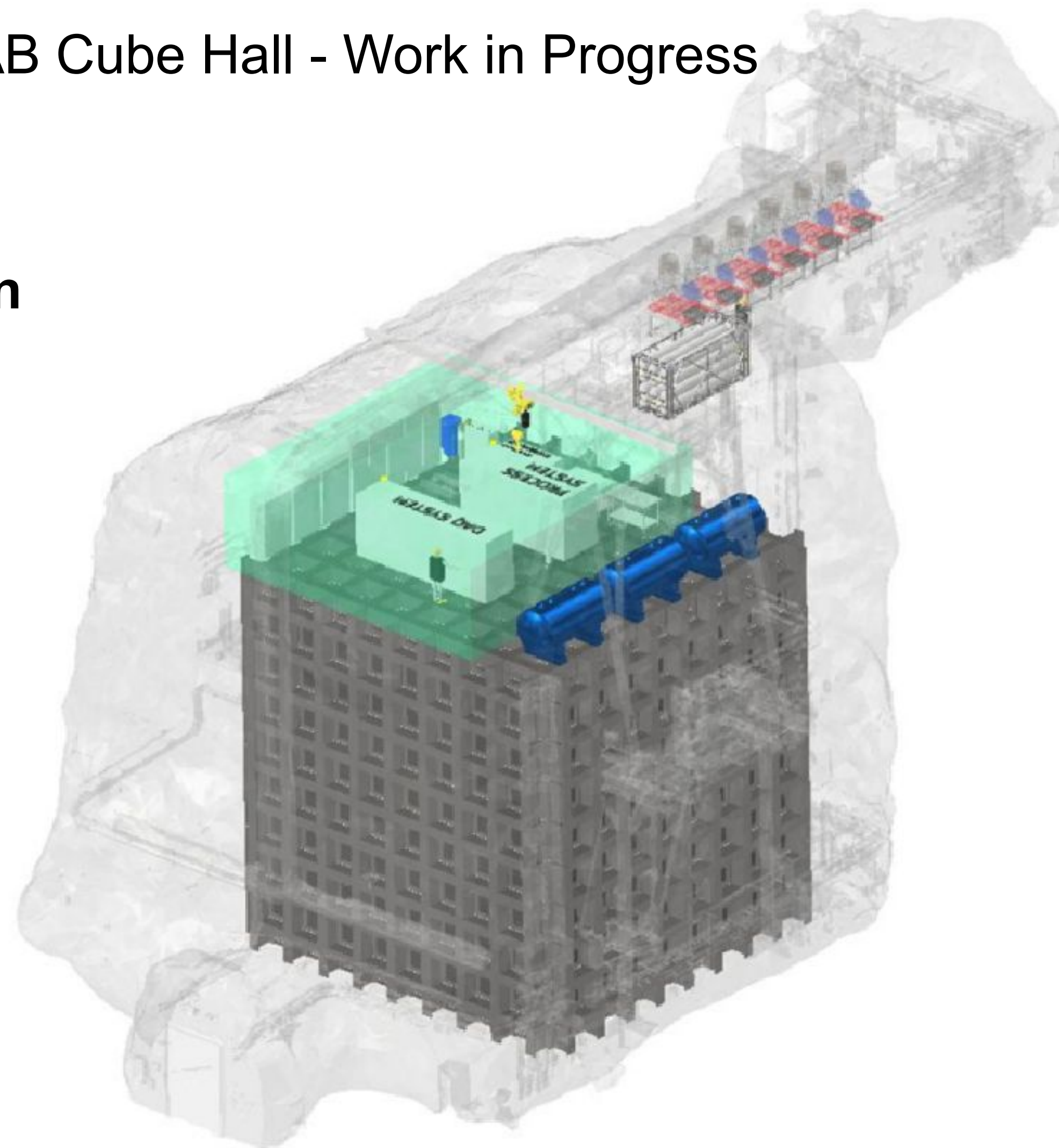
# Global Argon Dark Matter Collaboration Updates



Concept for ARGO in the SNOLAB Cube Hall - Work in Progress

**400 tonnes underground argon**

**DM sensitivity to neutrino fog**



# Conclusions

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- DEAP-3600 is showing leading results in the WIMP search in argon and MeV scale searches
- New physics results, including the PRL WIMP search, foreseen in 2024
- Detailed analysis of the  $^{39}\text{Ar}$  activity, possible thanks to the large exposure and the extremely efficient PSD
- Upgrades have been ongoing since 2019 target our two major background sources
- Expected impact: from  $\sim$ events/tonne year to  $\sim$ zero
- New run starting this year will demonstrate the improved background reduction and will improve several of the key physics measurements.
- Expect to run in upgraded mode for 1-2 more years.
- These results will also inform background reduction in future DM searches
- Vibrant and long-term program towards DM detection being developed with DS20k and ARGO