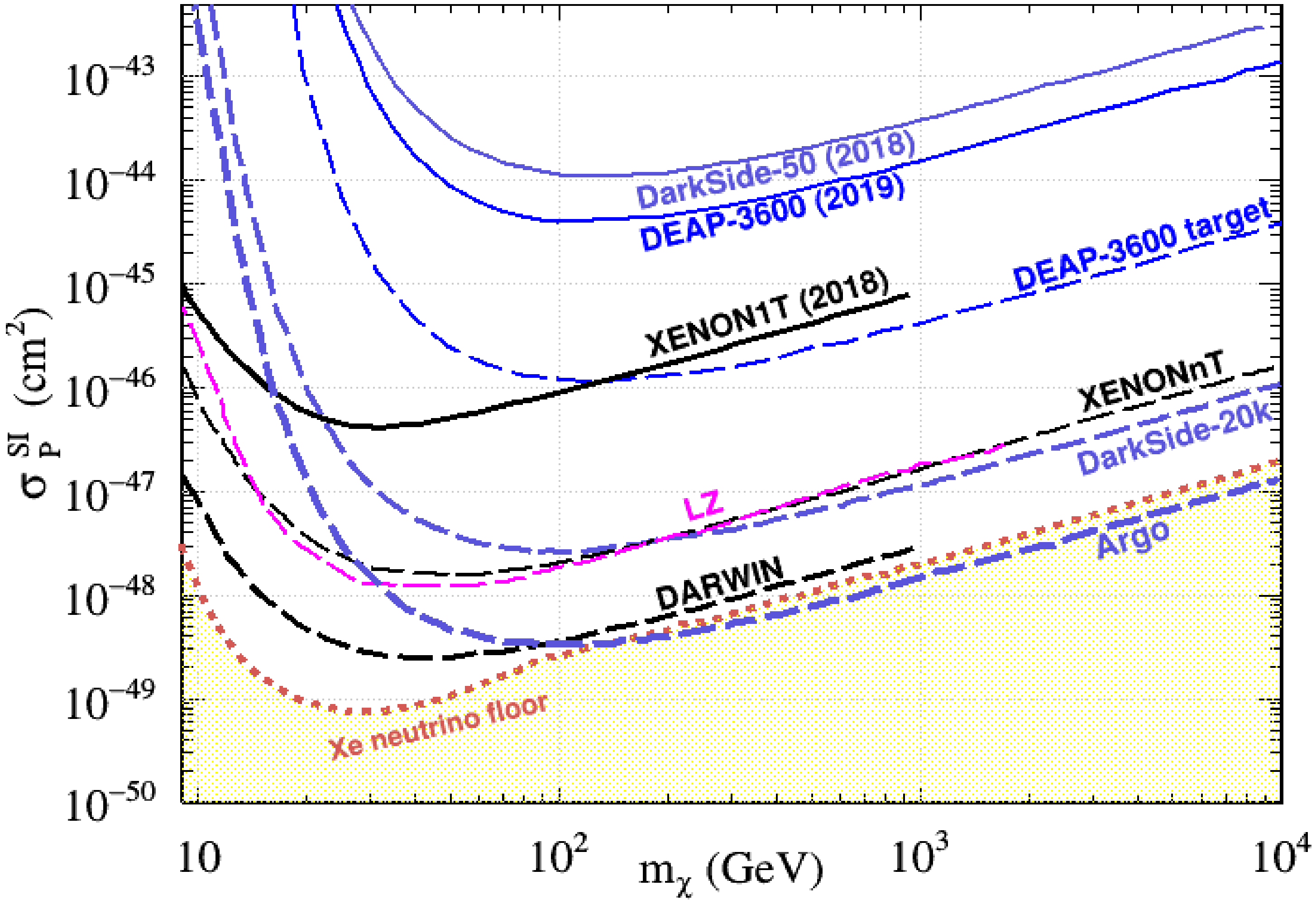
Searching for Dark Matter with Liquid Argon

DEAP-3600, DarkSide-20k, and ARGO

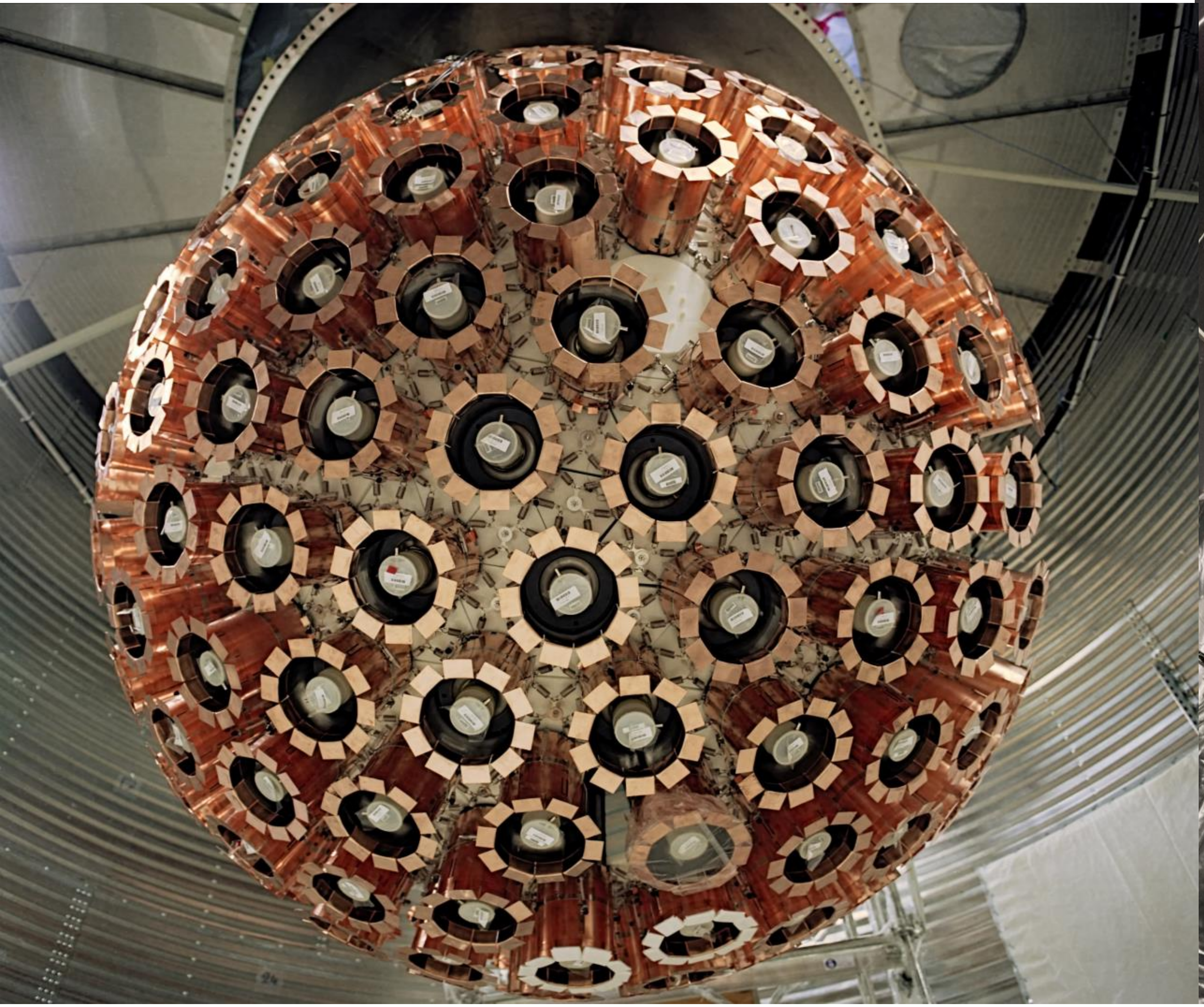
Chris Jillings

for the DEAP-3600 Collaboration and the Global Argon Dark Matter Collaboration

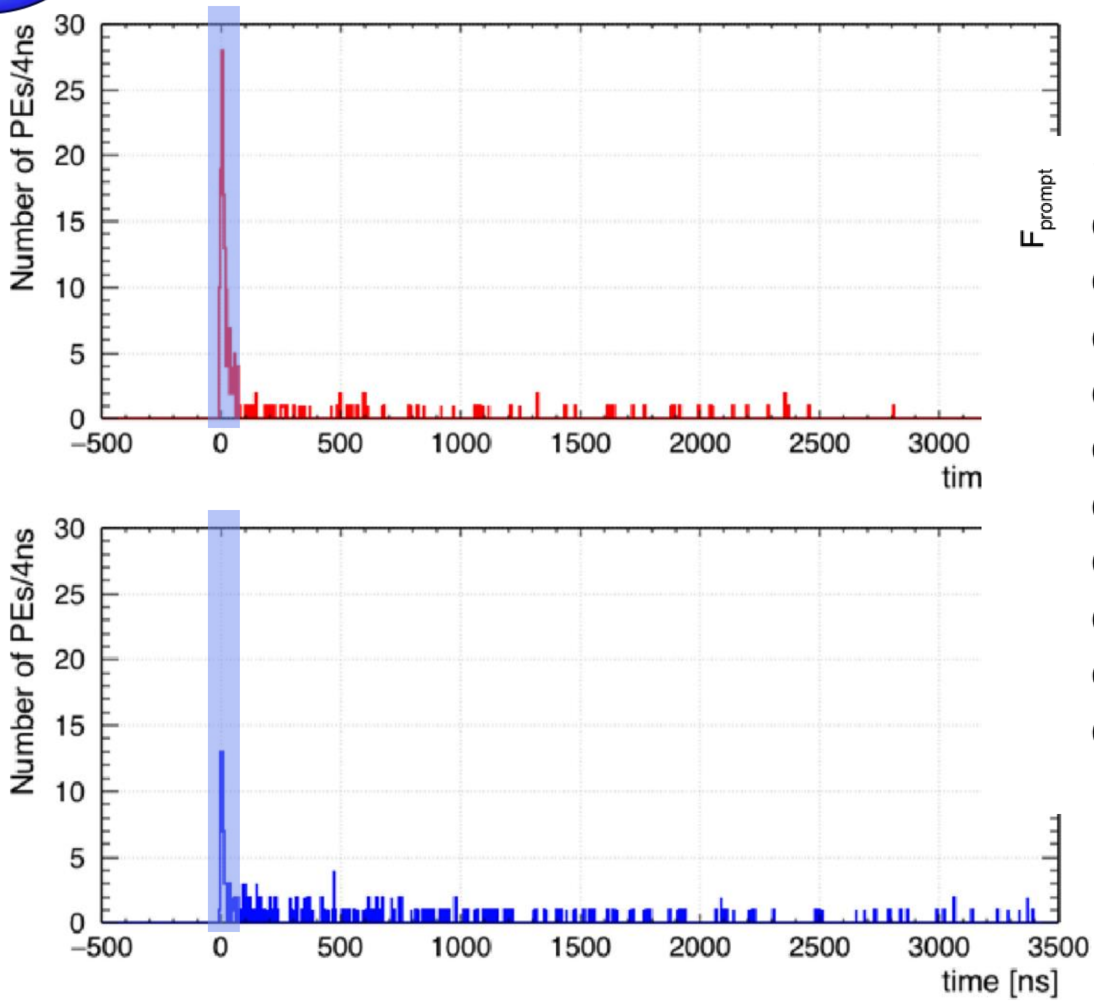
Liquid Argon is a valuable dark matter detector to and beyond the neutrino fog.



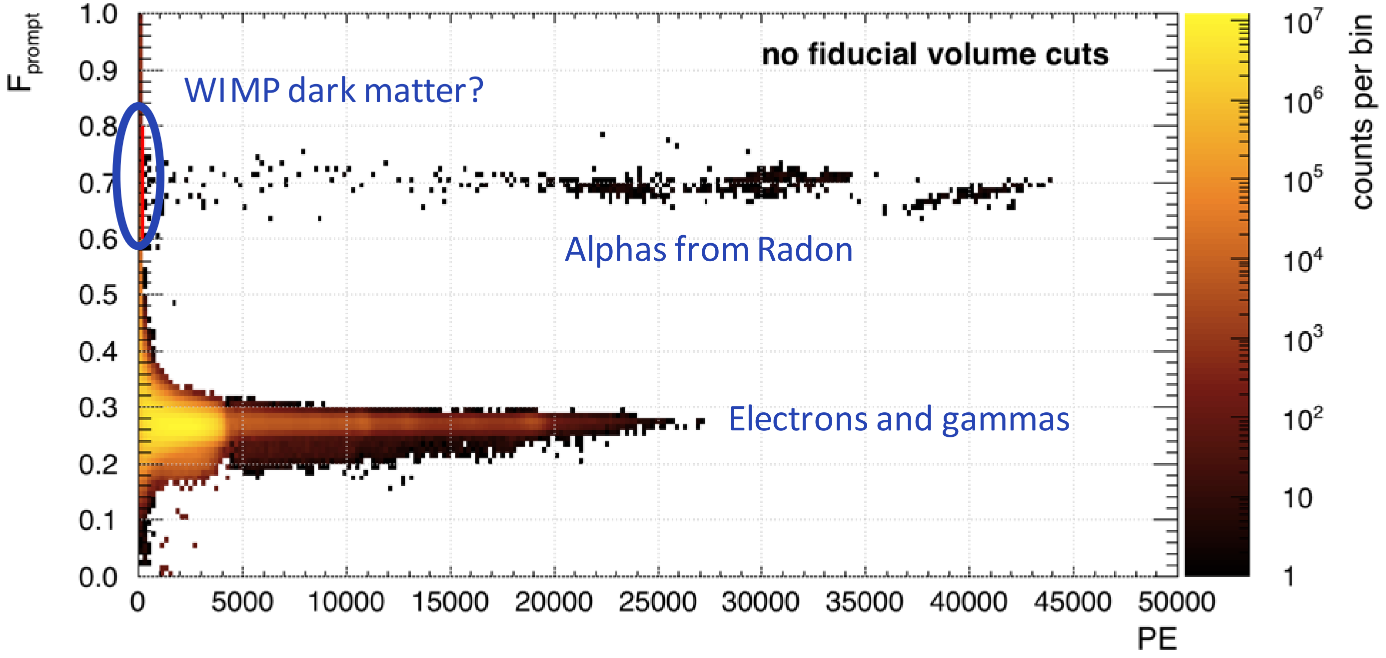
DEAP-3600



World leading Pulse Shape Discrimination



$$\text{Fprompt} = (\text{Signal in -28 to 60ns}) / (\text{Total Signal})$$



4 days data from 2016

https://doi.org/10.1103/PhysRevLett.121.071801

World leading Pulse-shape discrimination

- Nuclear recoil and electromagnetic event separation is excellent.
- Discussed in detail by this speaker at CAP 2021 virtual congress.

Fundamental bottom-up model of pulse shape from DEAP-1 prototype:

Astroparticle Physics Volume 85, December 2016, Pages 1–23

Pulse shape from DEAP-3600:

https://doi.org/10.1140/epjc/s10052-020-7789-x

Pulse-shape discrimination in DEAP-3600:

https://doi.org/10.1140/epjc/s10052-021-09514-w

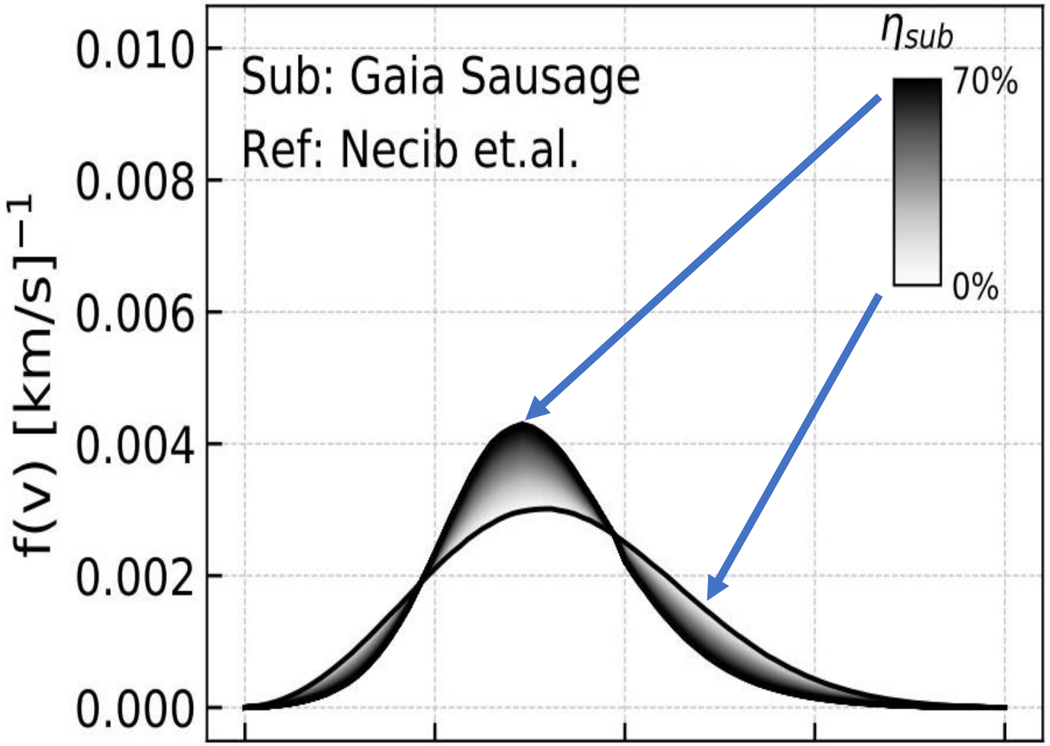
DEAP-3600 analysis includes Effective Field Theory to model WIMP-nucleon scattering and uncertainties in the galactic dark matter velocity distribution

Effective field theory

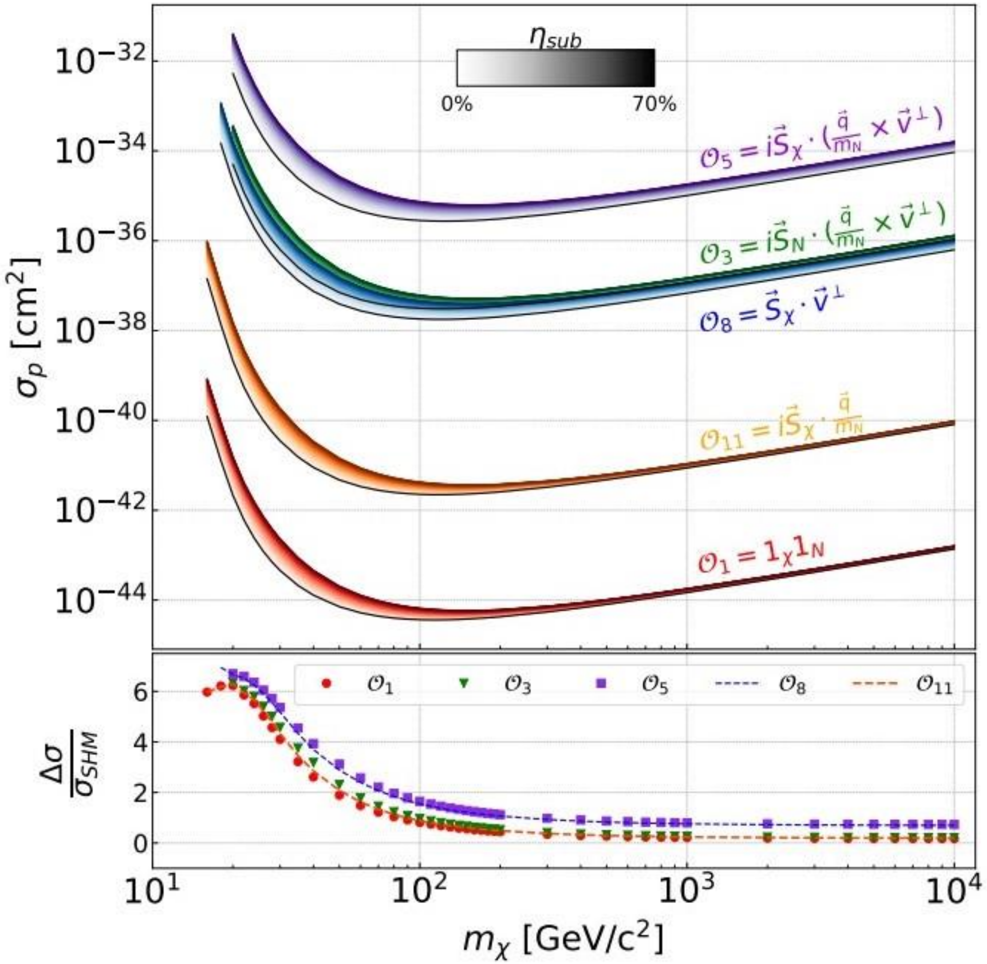
$$\frac{dR}{dE_R} = \frac{\rho_T}{m_T}\frac{\rho_\chi}{m_\chi}\varepsilon(E_R)\int_{v_{\min}}^{\infty} v f_\chi^{\oplus}(\vec{v})\frac{d\sigma}{dE_R}d^3\vec{v}$$

Velocity distribution of dark matter in earth rest frame

Example: Gaia Sausage and different operators



0 km/s
800 km/s

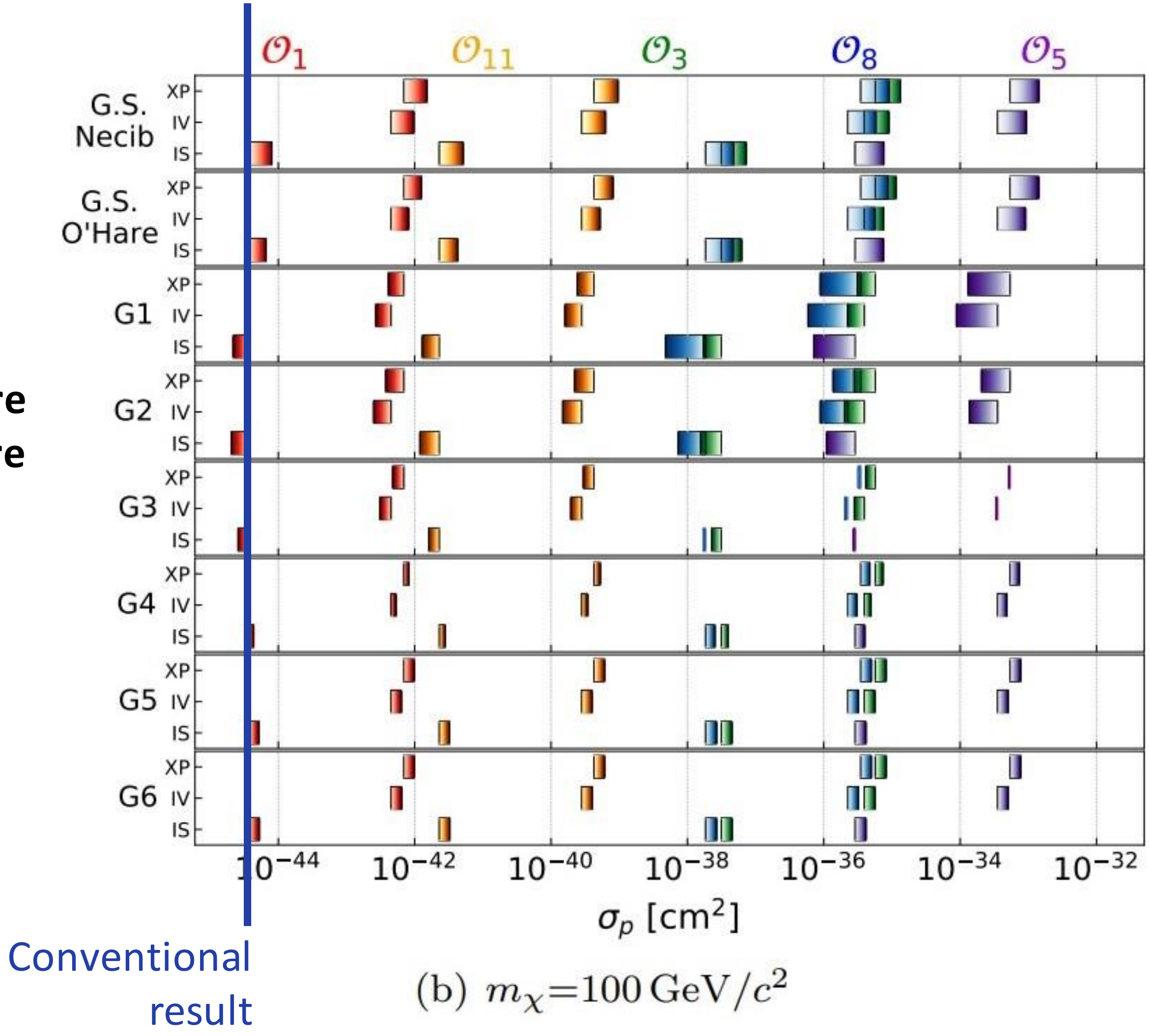


(a) *Gaia* Sausage (Necib *et al.*) [60]

DEAP-3600 results: Phys. Rev. D 102, 082001 (2020)

EFT operator (colour)

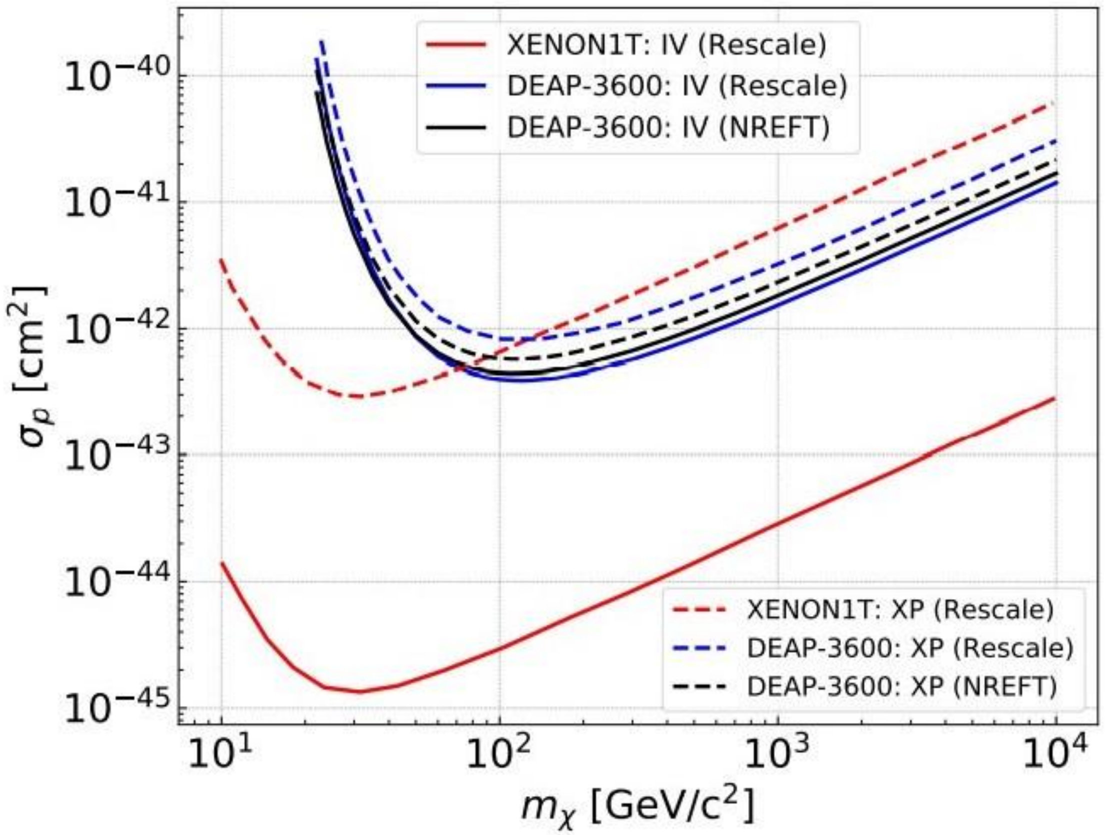
Model of galactic structure
Width of band shows fraction of DM in structure



(b) $m_\chi = 100\,\mathrm{GeV}/c^2$

Isospin violating "xenonphobic" interactions

C. Effects of isospin violation on const



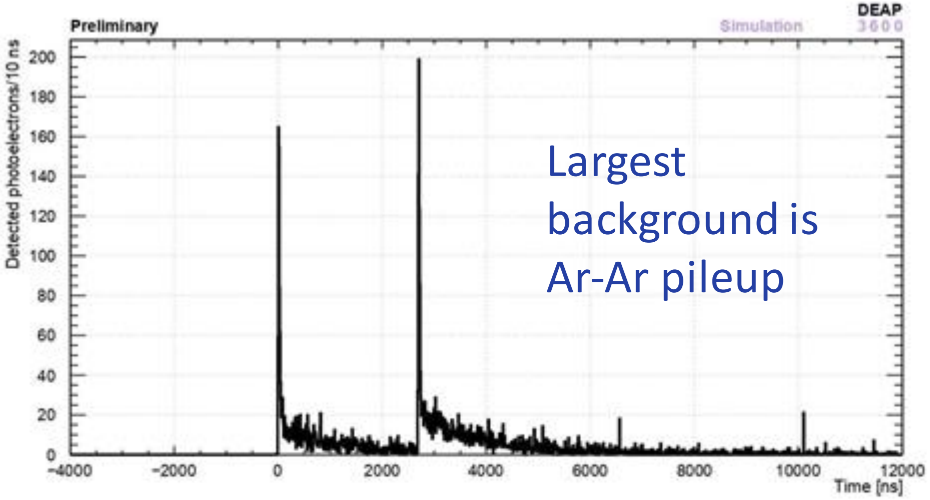
Models exist where isospin is violated and argon detectors have world leading limits in some parameter spaces.

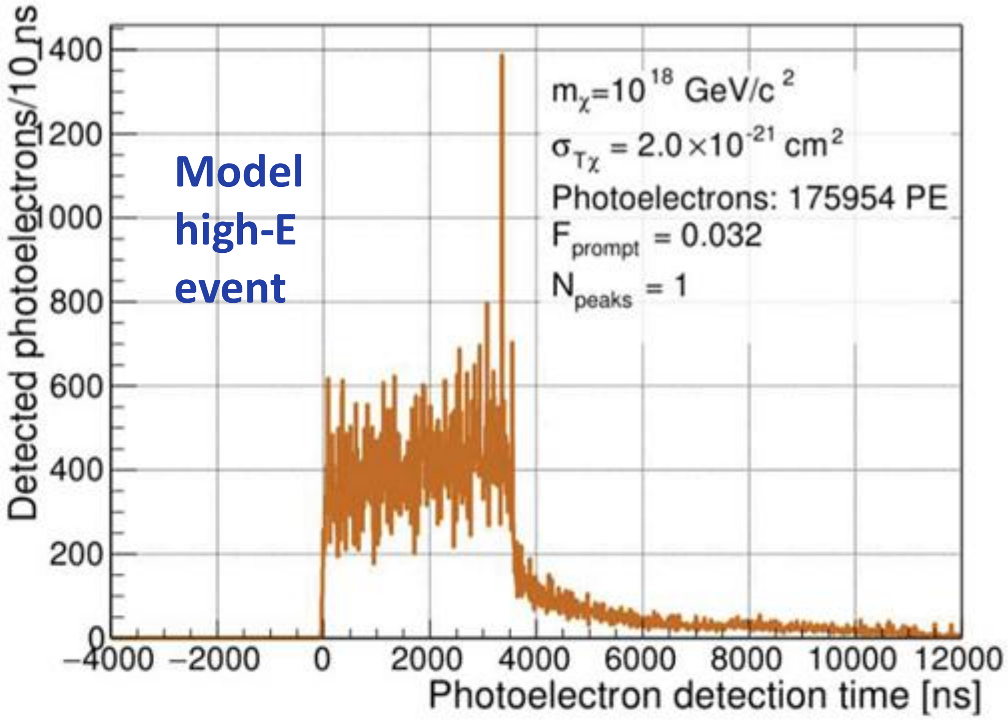
DEAP-3600 results: Phys. Rev. D 102, 082001 (2020)

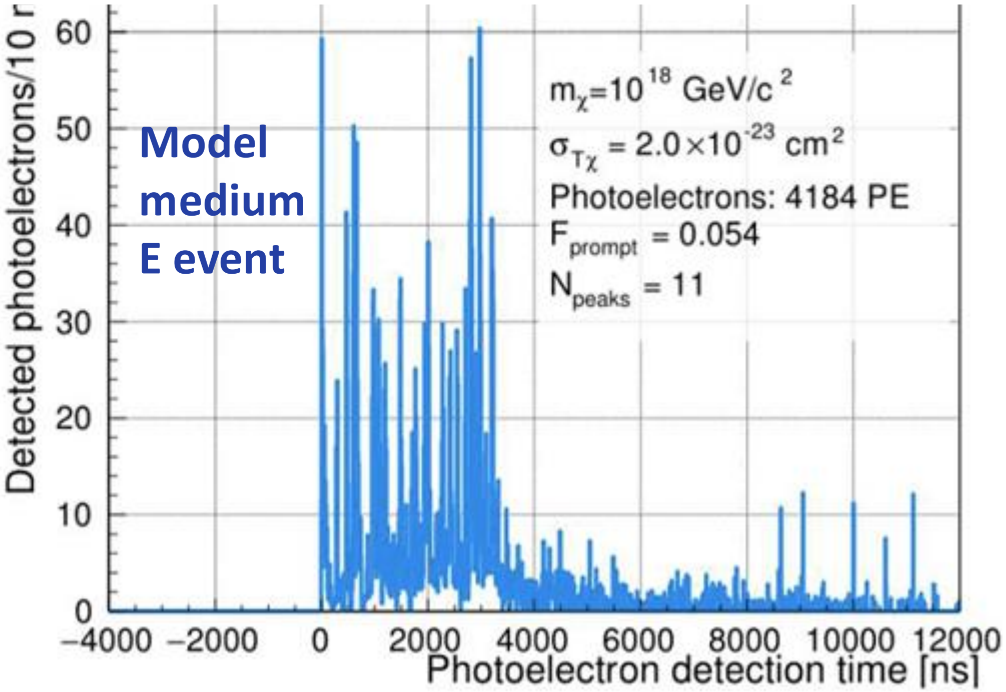
DEAP-3600 constraints on Planck Scale Dark Matter

A distinct signature from many recoils in succession.

A very high energy, low Fprompt event



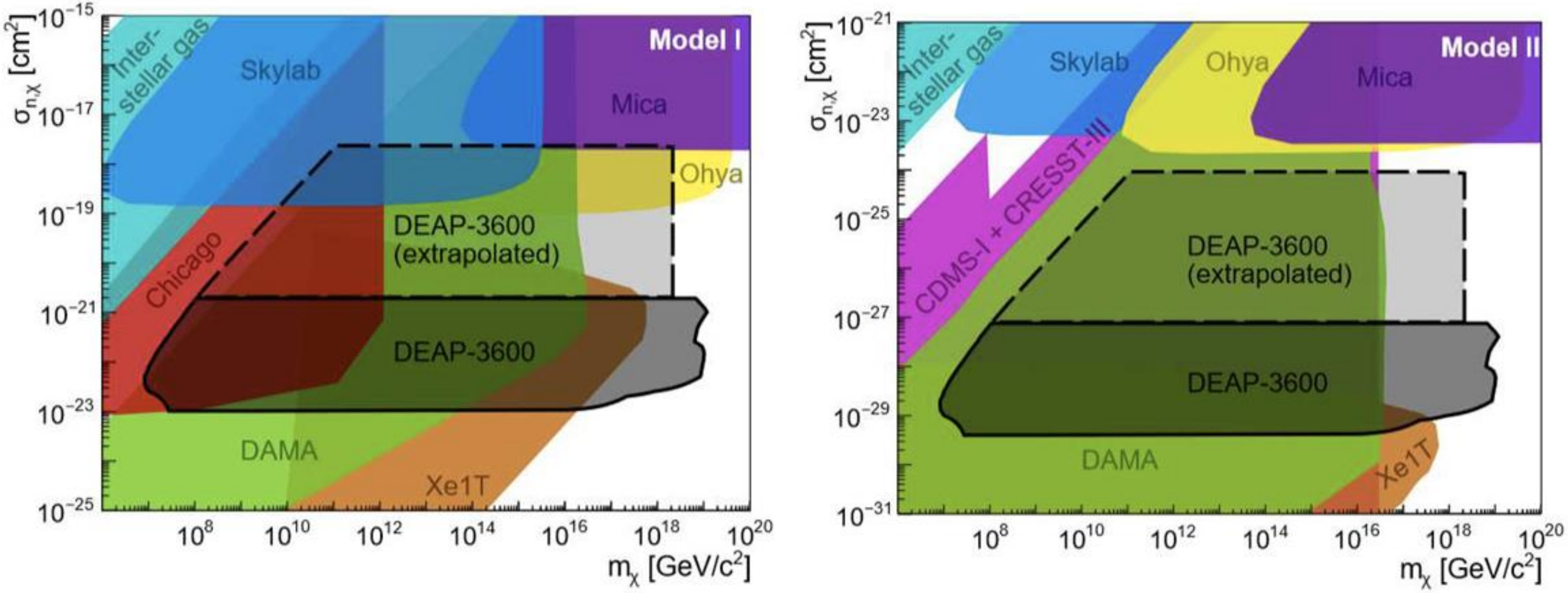




Zero events detected: world leading limits

Physical Review Letters, 128, 011801 (2022)   arXiv:2108.09405

Presented at this meeting by Shivam Garg



DEAP-3600 analysis ongoing

- Conventional WIMP search on full data set
- Solar axion search (5.5 MeV)
- Muon flux measurement
- Argon-39 rates and half life
- Boron-8 solar neutrino measurements

See talks presented at this meeting by

Gurpreet Kaur: improved Argon-39 decay rate measurement

Catherine Bina: improved pile-up calculations

Pushparaj Adhikari: improved alpha analysis

Michael Perry: alpha quenching measurements using Argon-1 test detector

Susnata Seth: improved alpha quenching model

Sean Daugherty: DEAP-3600 hardware upgrades

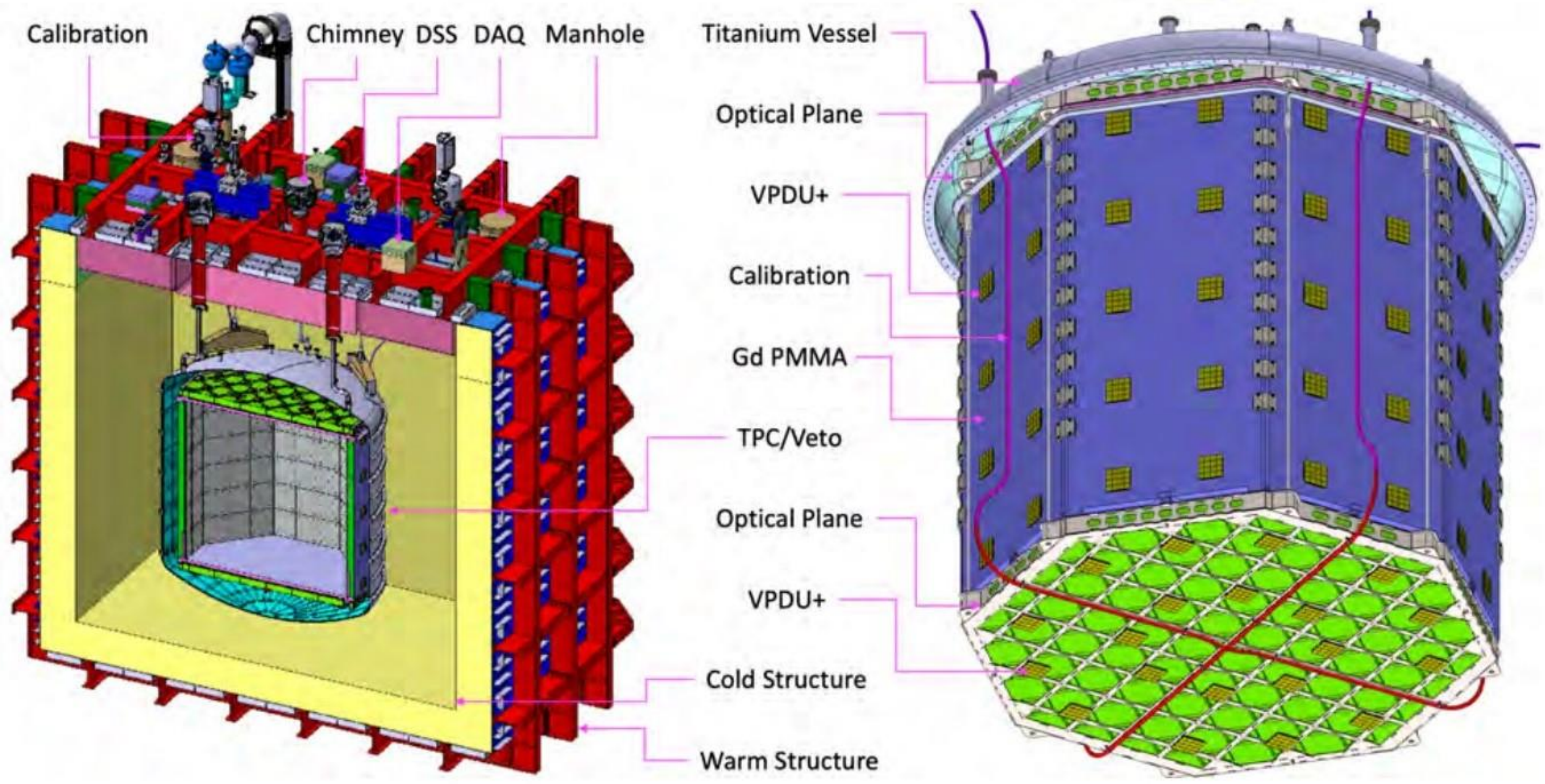
Global Argon Dark Matter Collaboration

400 scientists
14 countries

Tackle the next two generations of experiments.

DarkSide-20k will be deployed at LNGS

Complete technical design review submitted to INFN / LNGS – publication version in preparation.



A TPC design with 20-tonnes fiducial mass has been submitted to INFN.

(Publication version in preparation.)

Will use underground argon and Silicon PMs for light detection

Canadian Contributions to DarkSide-20k

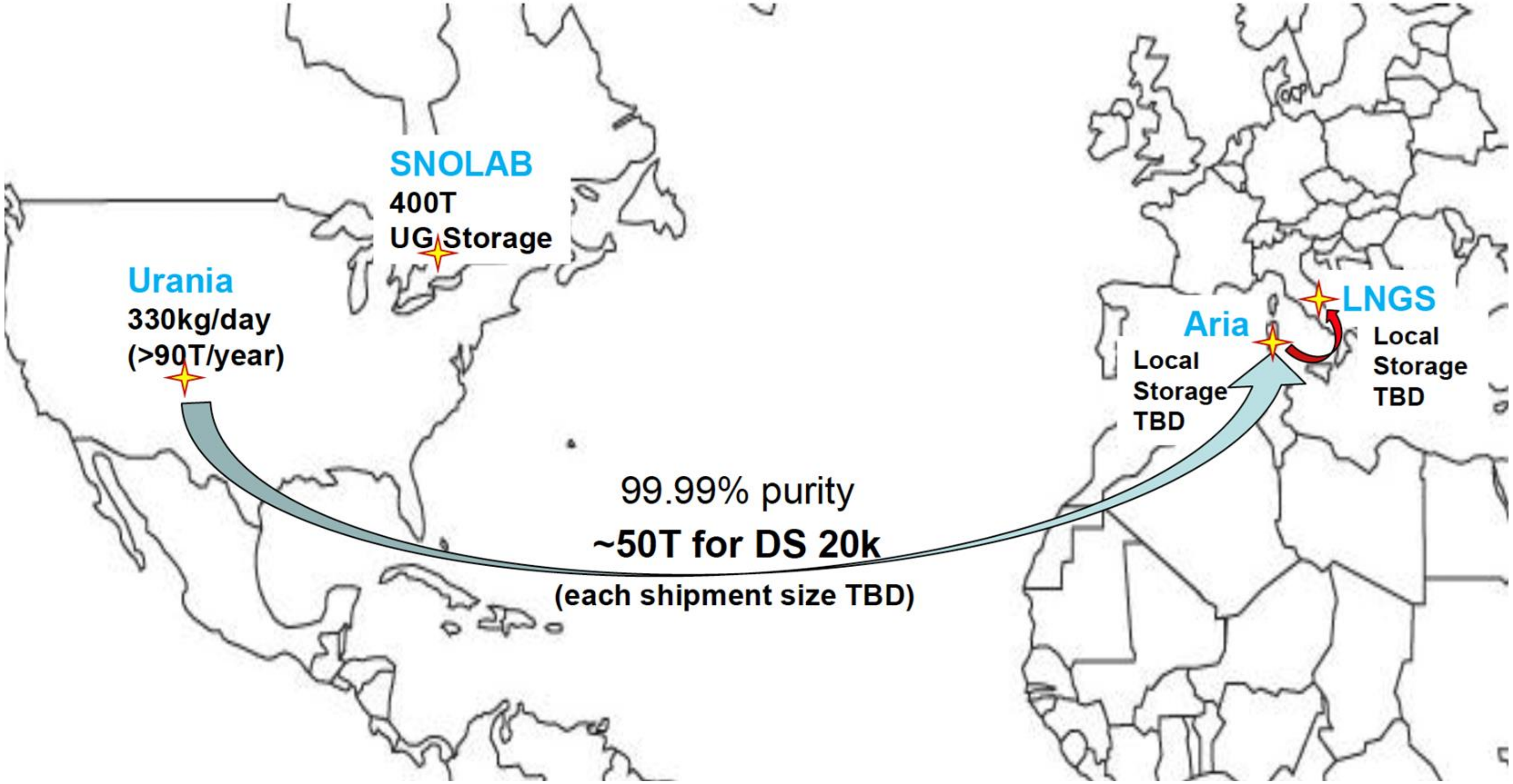
- Low radioactivity underground Argon
  extraction, transport, and assay
- Data Acquisition (MIDAS system)
- Acrylic TPC design and construction
- Surface coatings
- Silicon PM testing
- Material assay
- Studies of surface backgrounds

Underground argon will come from the Urania facility in Colorado and be shipped to the Aria facility in Sardinia where it will be purified for deployment in DS-20k.

DarkSide 50 demonstrated >1400 reduction factor in [A(Ar-39)] https://doi.org/10.1103/PhysRevD.95.069901

DArT sampling detector at Canfranc can measure [A(Ar-39)] at depletion factor of 1400 with 7% accuracy and 14000 with 40% accuracy in 1 week. https://doi.org/10.1088/1748-0221/15/02/P02024

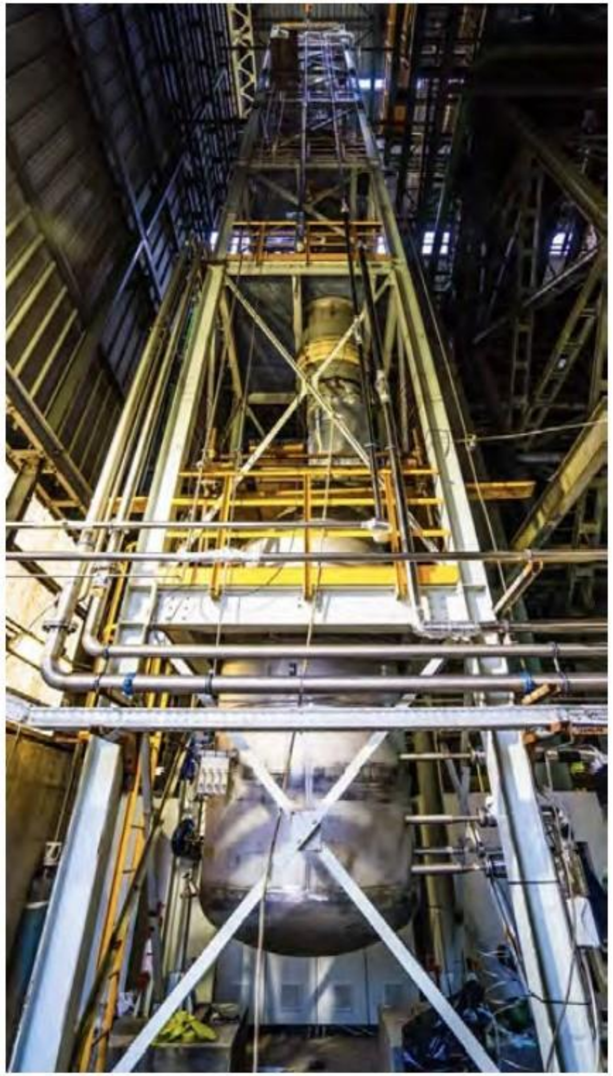
Preparation for 400 tonnes storage underground at SNOLAB and with a sampling detector, Ar2D2.



Aria has a 350m tall distillation column (Seruci-0) capable of isotopic separation.

It is installed and has passed the nitrogen commissioning tests

https://doi.org/10.1140/epjc/s10052-021-09121-9



Column before deployment

Silicon Photomultipliers

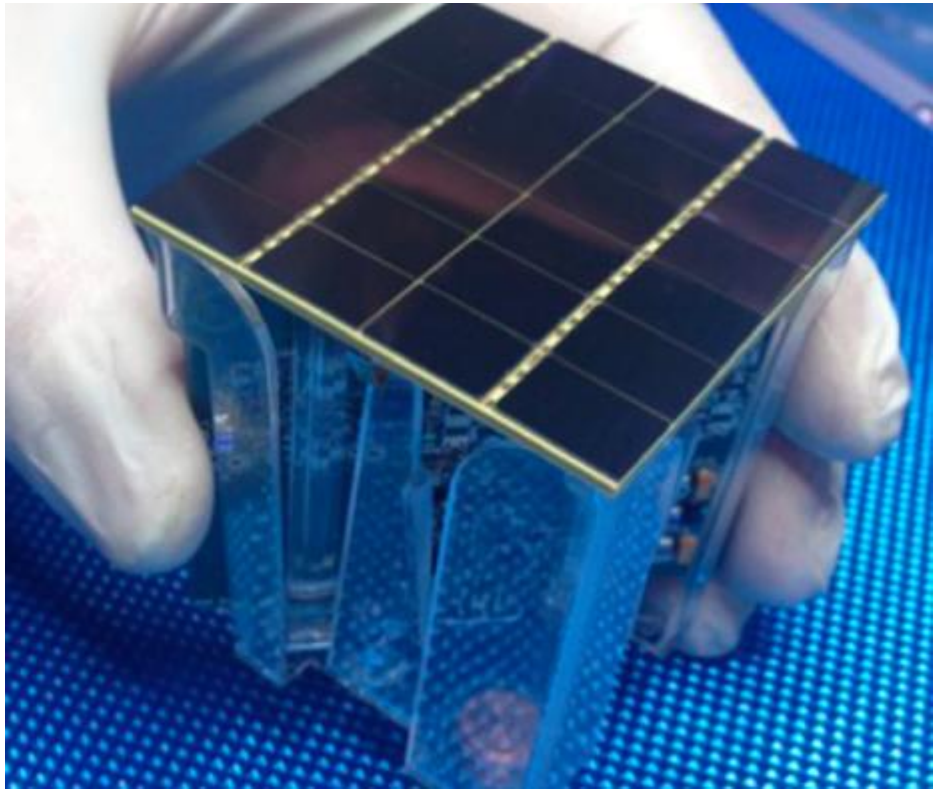
Silicon photomultipliers by Fondazione Bruno Kessler, model NUV-HD-CRYO

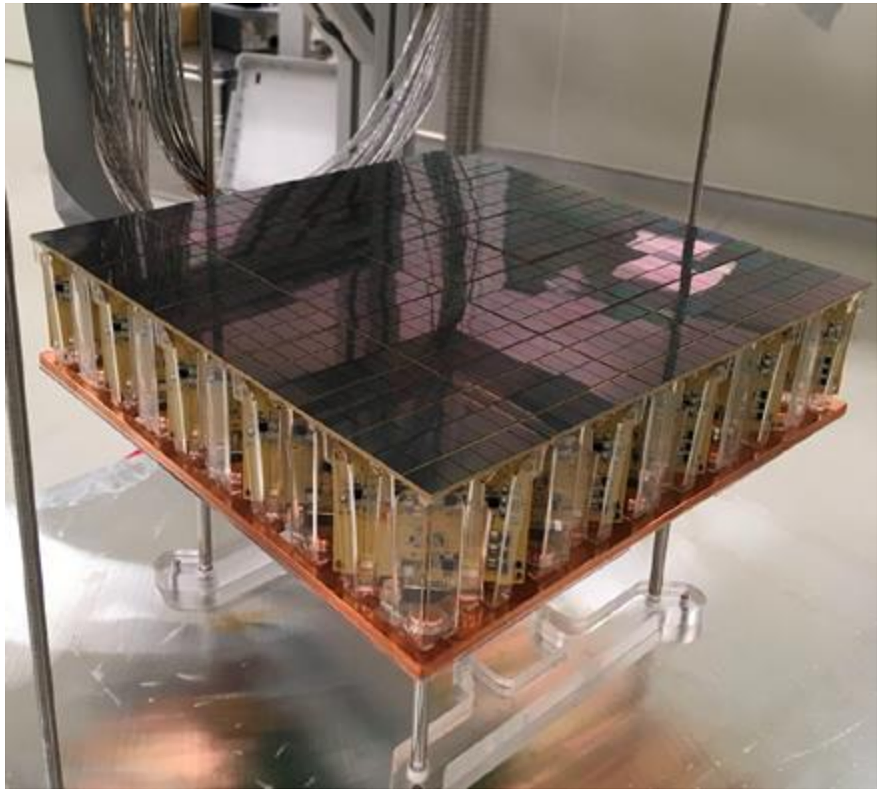
Meets all requirements on photodetection efficiency, low noise at liquid argon temp.

Talk presented at this meeting by Juliette Martin on light emission/external cross talk

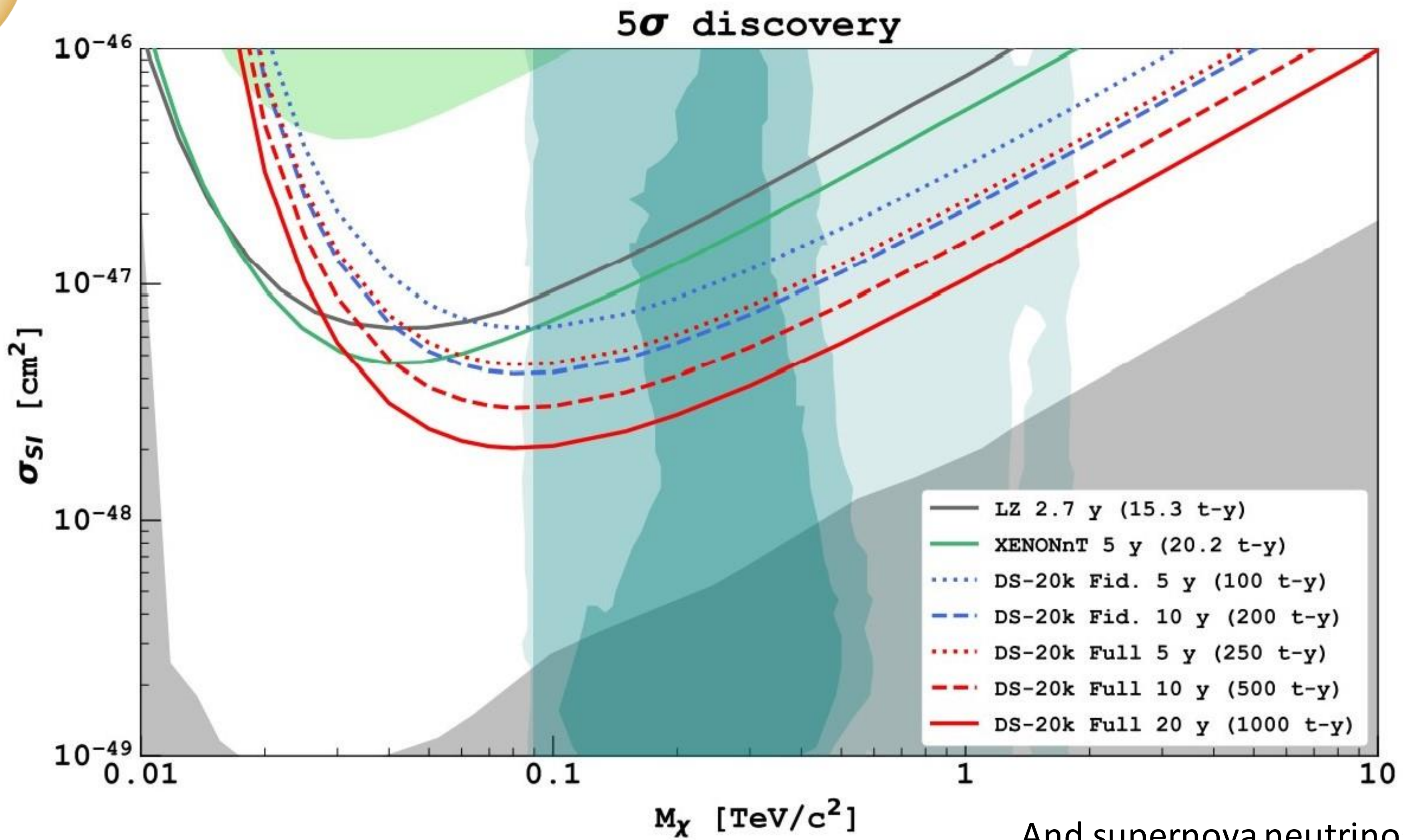
24 SiPMs are combined into a photodetector module (PDM) with area ~ 5 x 5 cm2

25 PDMs are grouped and connected to a motherboard



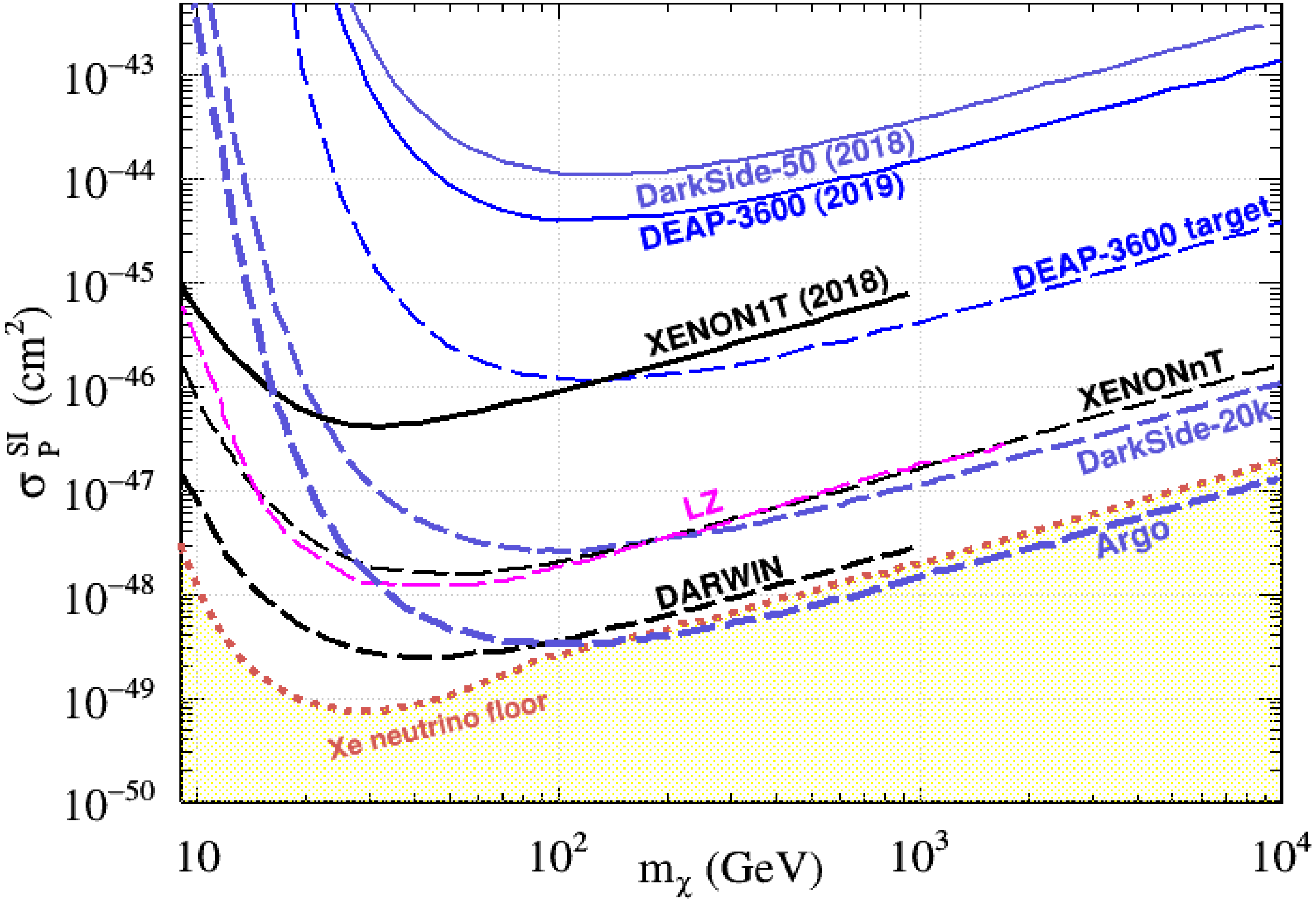


5 sigma discovery space



And supernova neutrinos too!
https://doi.org/10.1088/1475-7516/2021/03/043

ARGO



A multi hundred tonne detector with SNOLAB the preferred site.

Canadian groups are working on a single-phase design with 400 t underground argon.

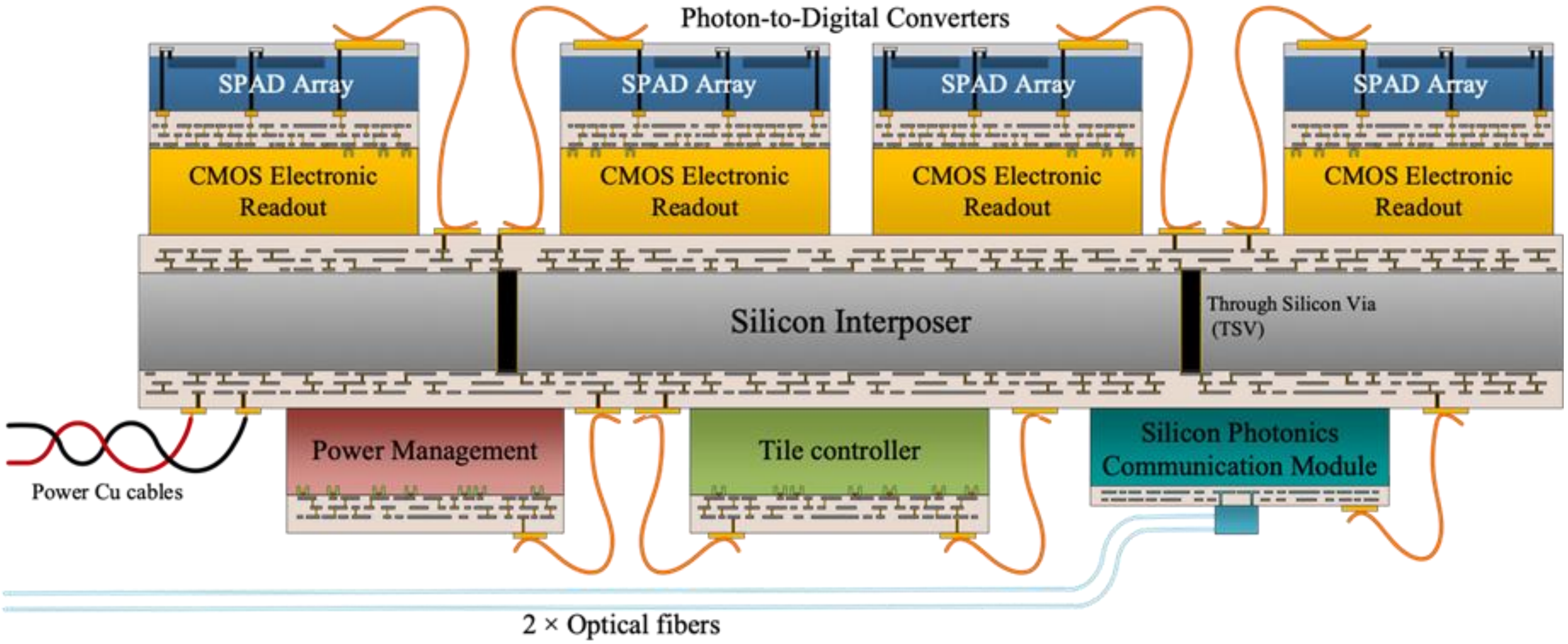
> 200m^2 of SiPM

Event ID with some reconstruction at DAQ level

Silicon Photodetector R&D for ARGO

Development of photon-to-digital converters (aka "3D SiPMs") led by U Sherbrooke.

CFI IF 2017, 2020, and 2023



Develop Conceptual Design for Single Phase ARGO

- Background budget
  - Neutrons
  - Cosmogenics
  - EM rejection (Pulse shape discrimination in argon will work!)
- Photon-to-digital converter specifications
- Sensitivity projections
- Neutrino studies

A wide and exciting science program awaits!

DEAP 3600

University of Alberta

Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

Carleton University

UC Riverside joining in July

University of Sussex

Particle Physics
Rutherford Appleton Laboratory

Gobierno de España
Ministerio de Ciencia, Innovación y Universidades
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Laurentian University
Université Laurentienne

Princeton University

Royal Holloway University of London

Technical University of Munich
TUM

INFN
Istituto Nazionale di Fisica Nucleare

National Research Center "Kurchatov Institute"

Instituto de Física

Queen's University

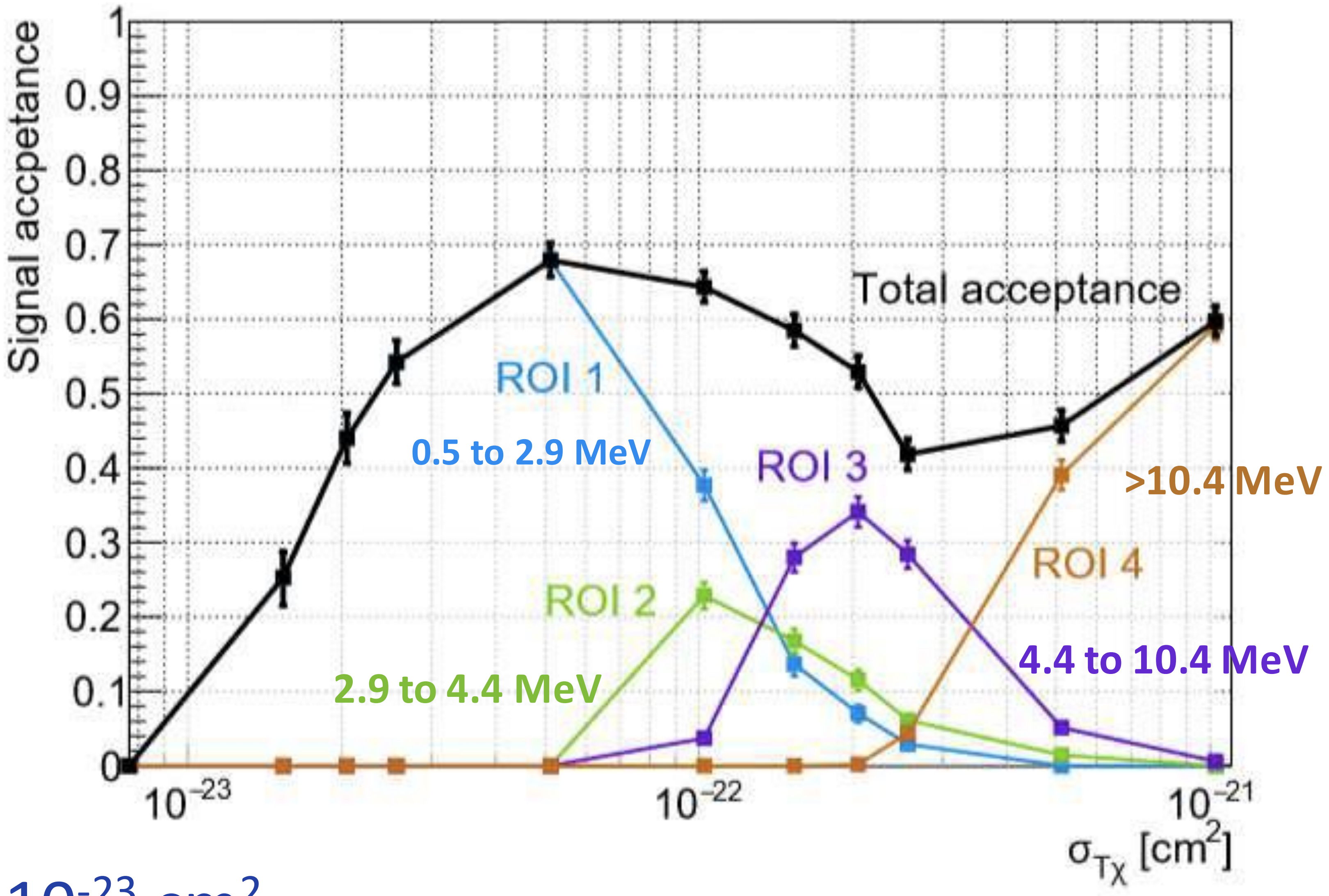
SNOLAB

TRIUMF

Extra Slides

DEAP-3600 constraints on Plank Scale Dark Matter

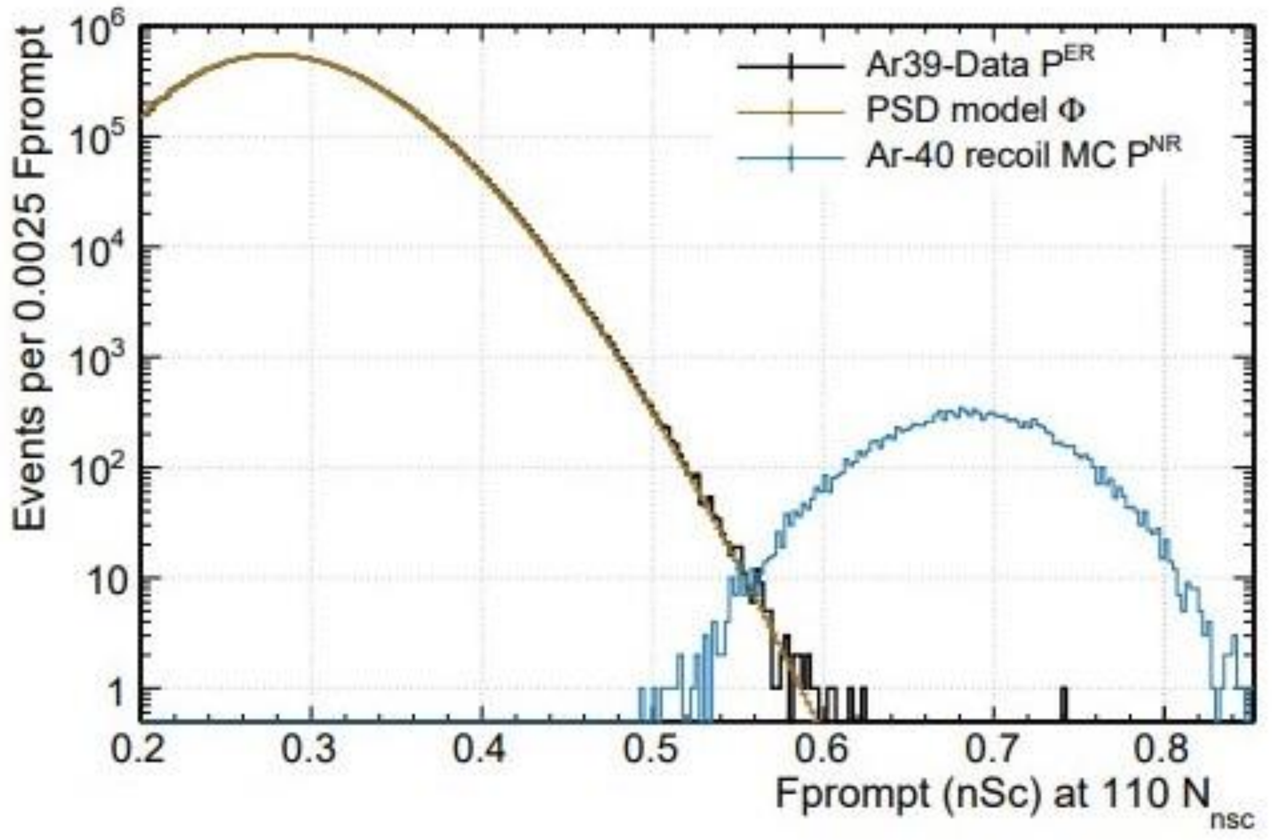
Acceptance



10^{-23} cm^2

10^{-21} cm^2

Data at ~18 keV_{ee}

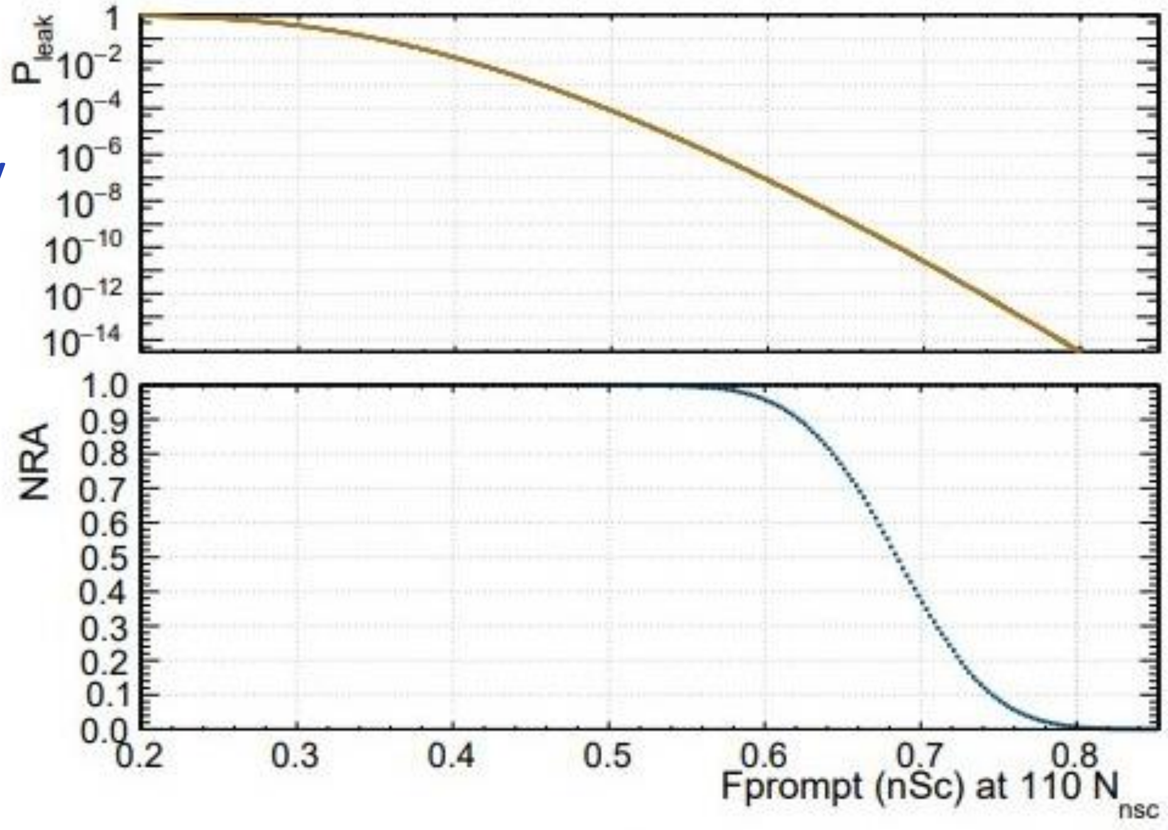


Prompt fraction after Bayesian removal of PMT effects

Data at ~18 keV_{ee}

Leakage probability of EM events

Nuclear recoil acceptance



(b)

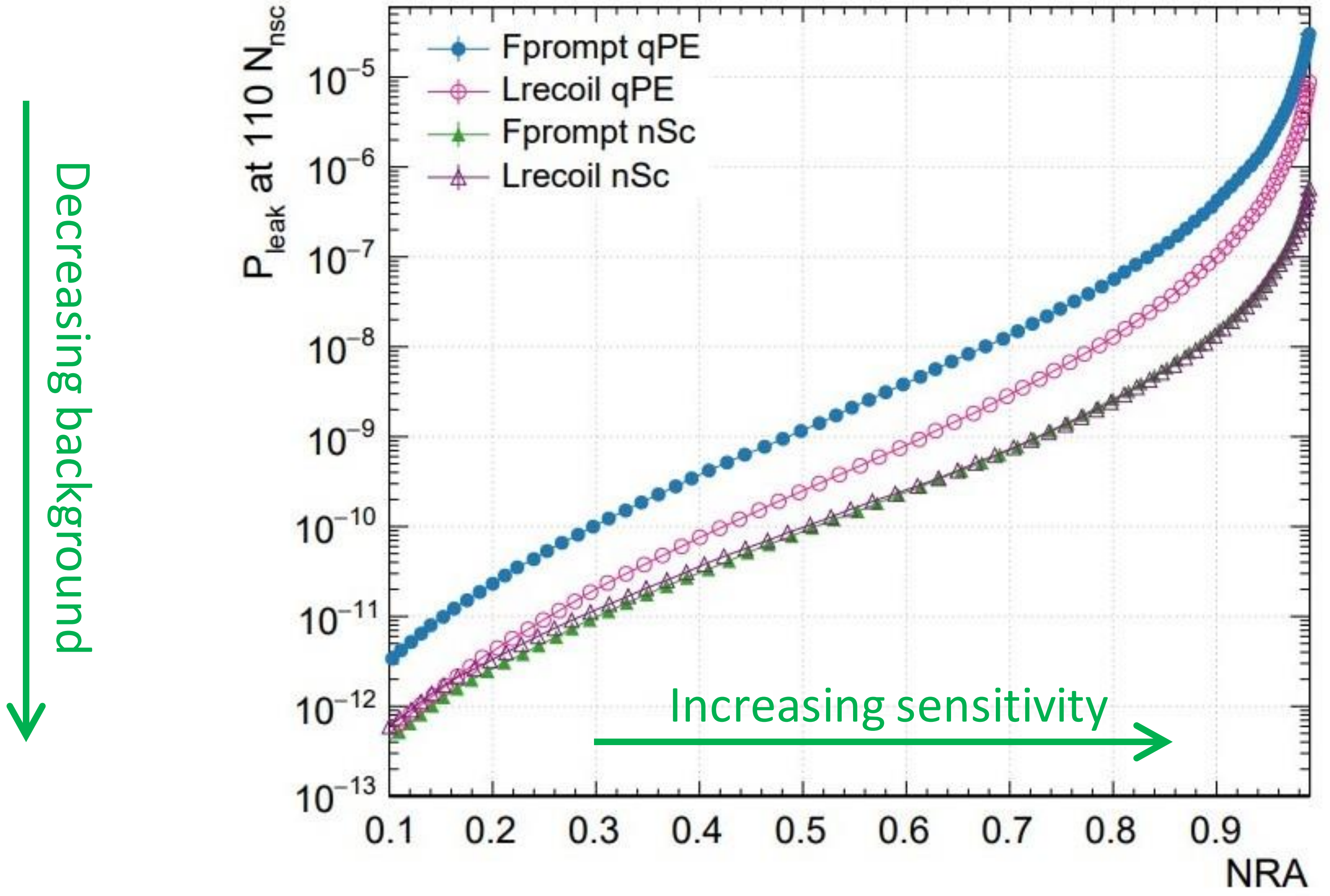
1

10^{-14}

1

0

Data at ~18 keV$_{ee}$



No PMT/TPB corrections

Prompt fraction method

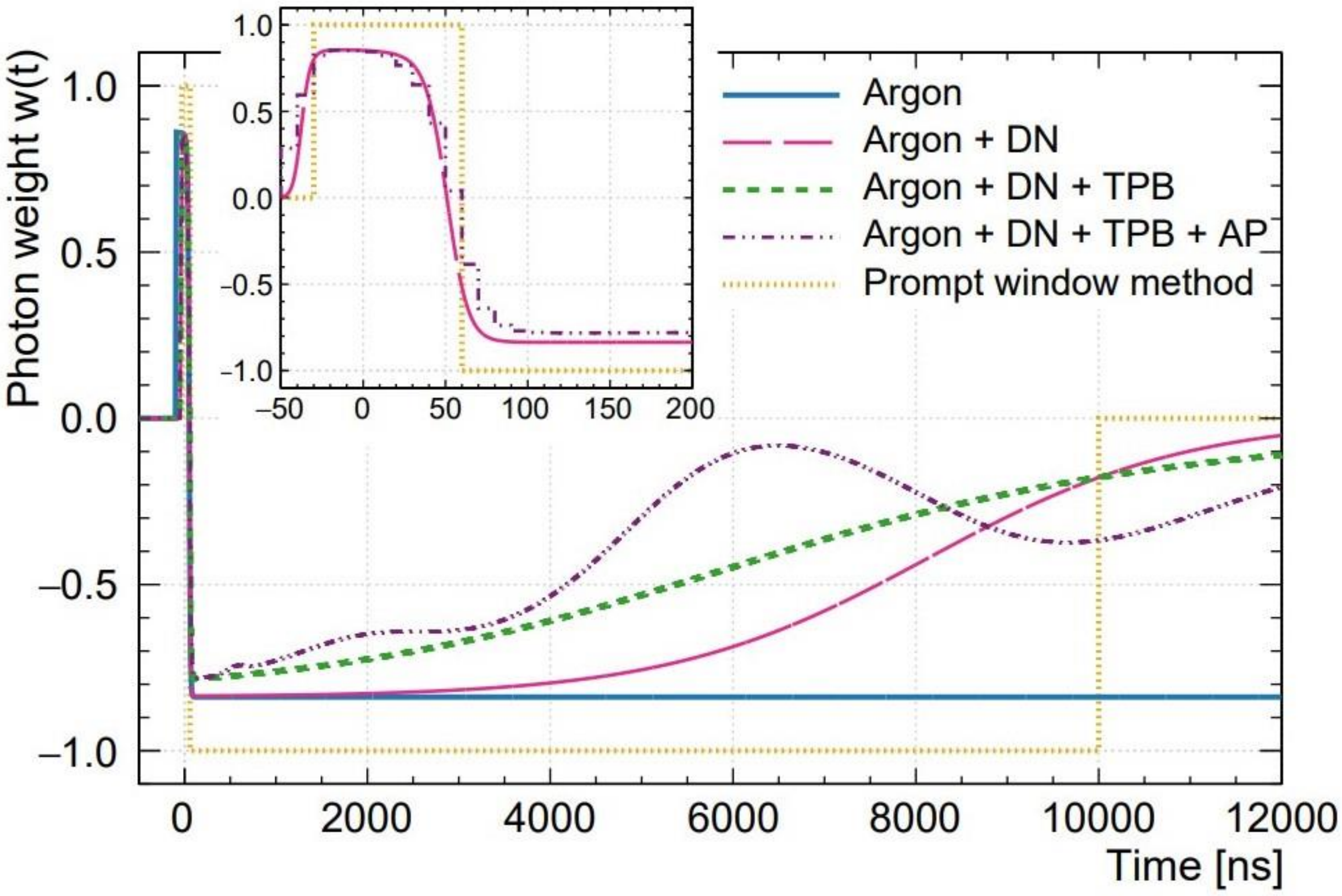
Likelihood ratio method

With PMT/TPB corrections

Prompt fraction

Likelihood ratio

After removing PMT effects, the weights in the likelihood ratio approximately give Fprompt.



$$L_{\text{recoil}} = \frac{1}{2} + \frac{\sum_{t>t_{\text{start}}}^{t<t_{\text{total}}} w(t)n(t)}{\sum_{t>t_{\text{start}}}^{t<t_{\text{total}}} n(t)}$$

with the weights defined as

$$w(t) = \frac{1}{2} \cdot \log \frac{p(t)_{\text{nr}}}{p(t)_{\text{er}}}.$$

Fprompt can be written as w(t)=1 in the prompt region and w(t)=-1 in the late region.

Summary

- PSD in DEAP-3600 works as designed to separate EM and nuclear-recoil events.
- Do the information theory when coming up with PSD methods:
  - Extra bits on disk is not the same as extra usable information
- Spend time to understand your measurement artifacts. They matter!