



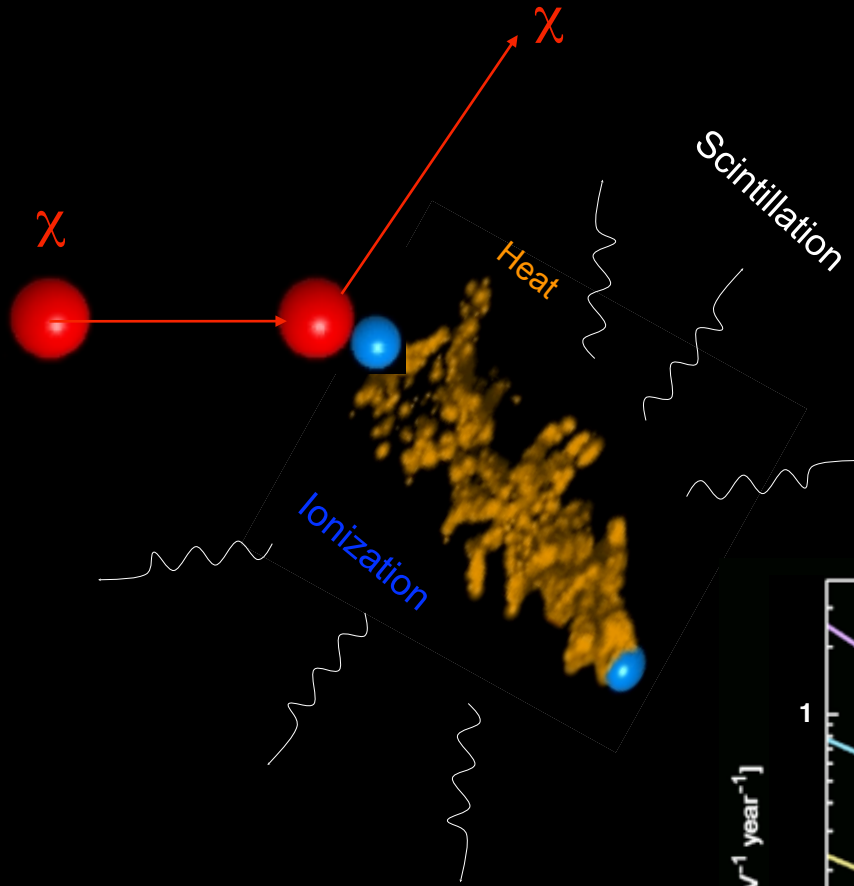
Distinctive Signals for Direct Detection (modulation, directionality, ++) – Beyond the Neutrino Fog

Jocelyn Monroe,
University of Oxford &
Rutherford Appleton Laboratory

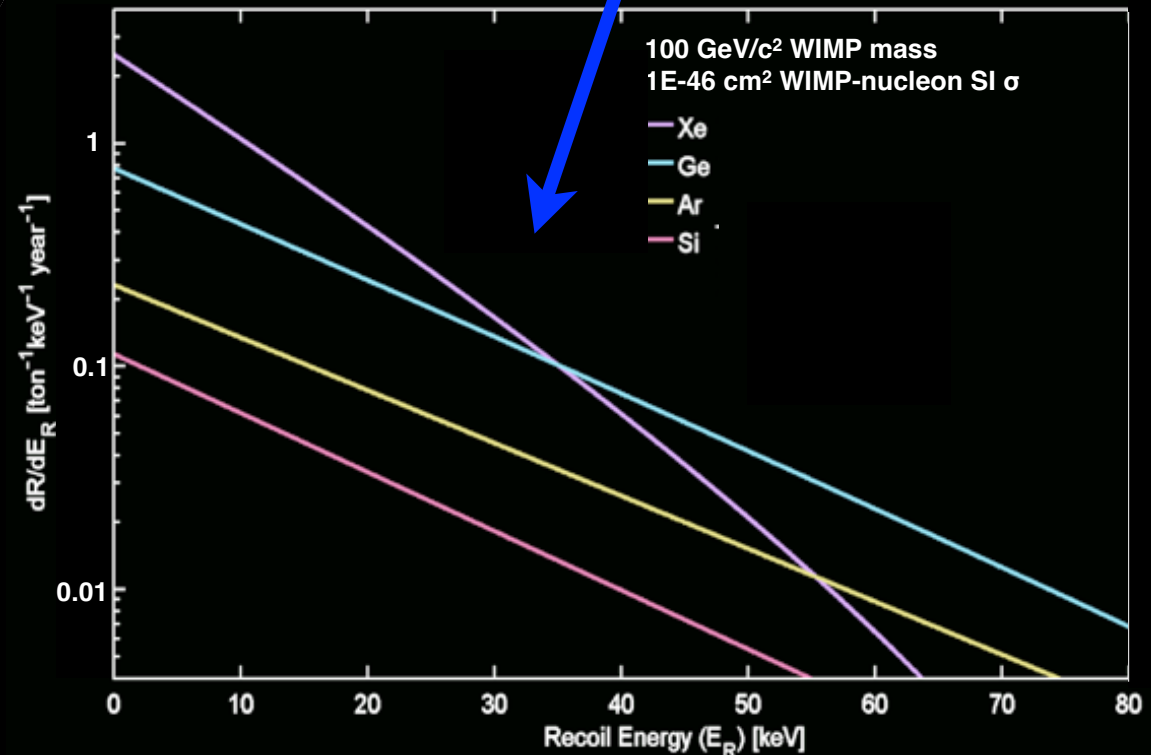
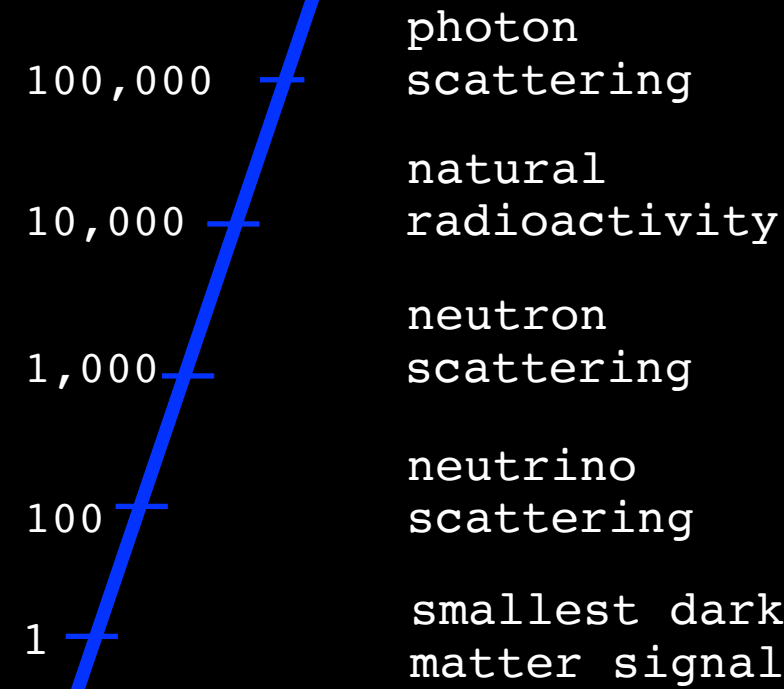
Identification of Dark Matter 2026
Zaragoza, ES
June 4, 2026



Direct Detection



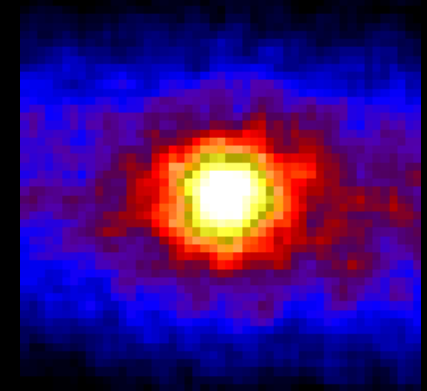
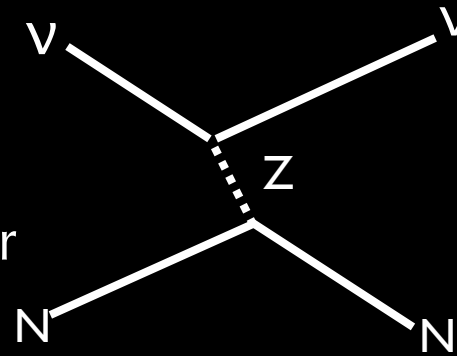
*experimental requirements:
keV-scale energy threshold +
background discrimination
at the ppm-ppb level*



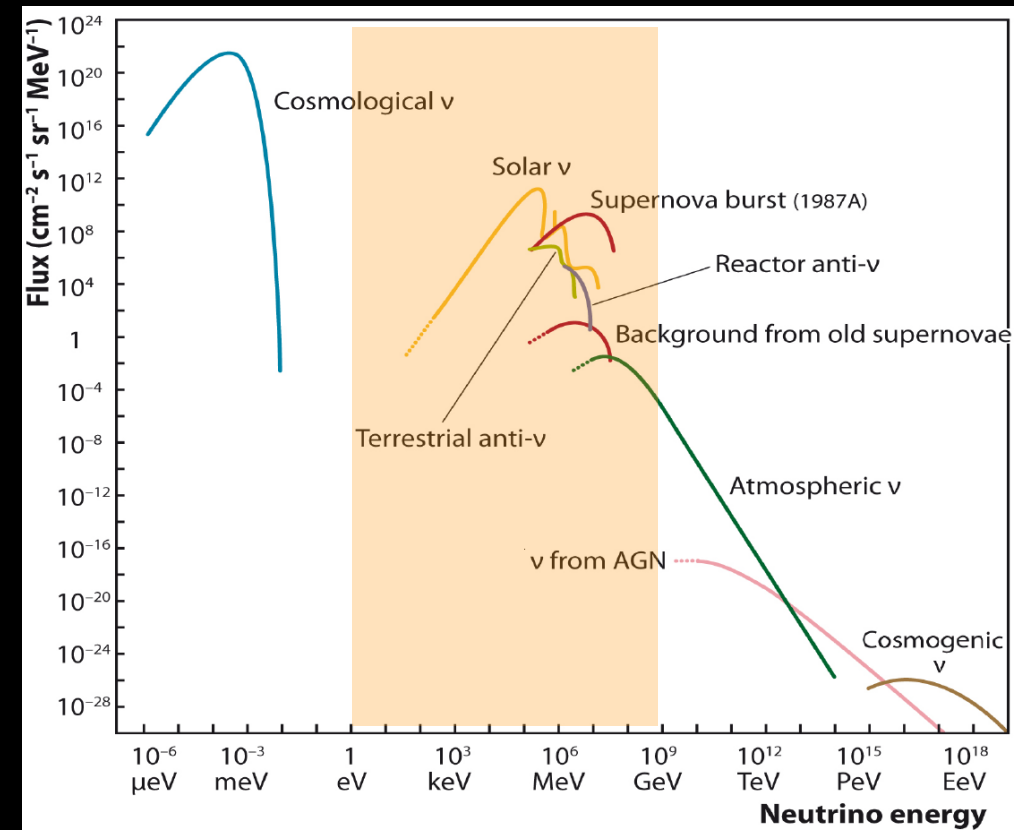
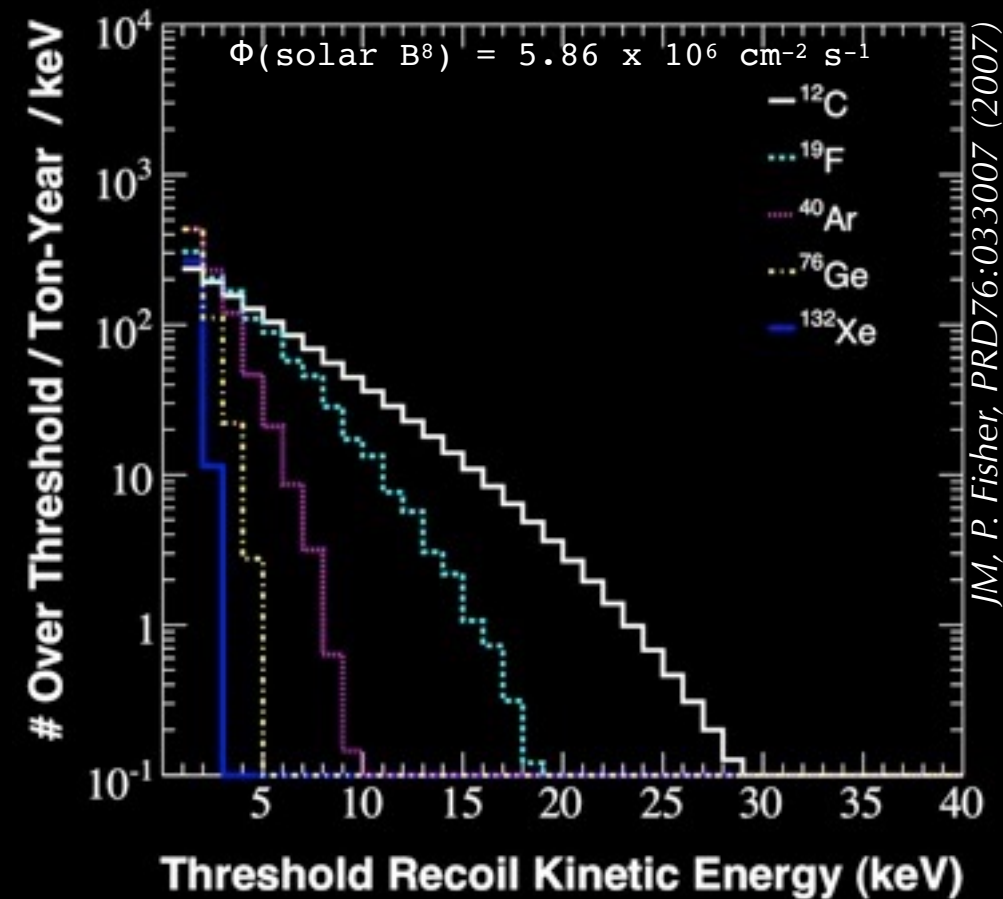
Irreducible Backgrounds

impossible to shield a detector from coherent neutrino scattering!

A limiting background at the neutrino floor



...but also an *opportunity*.

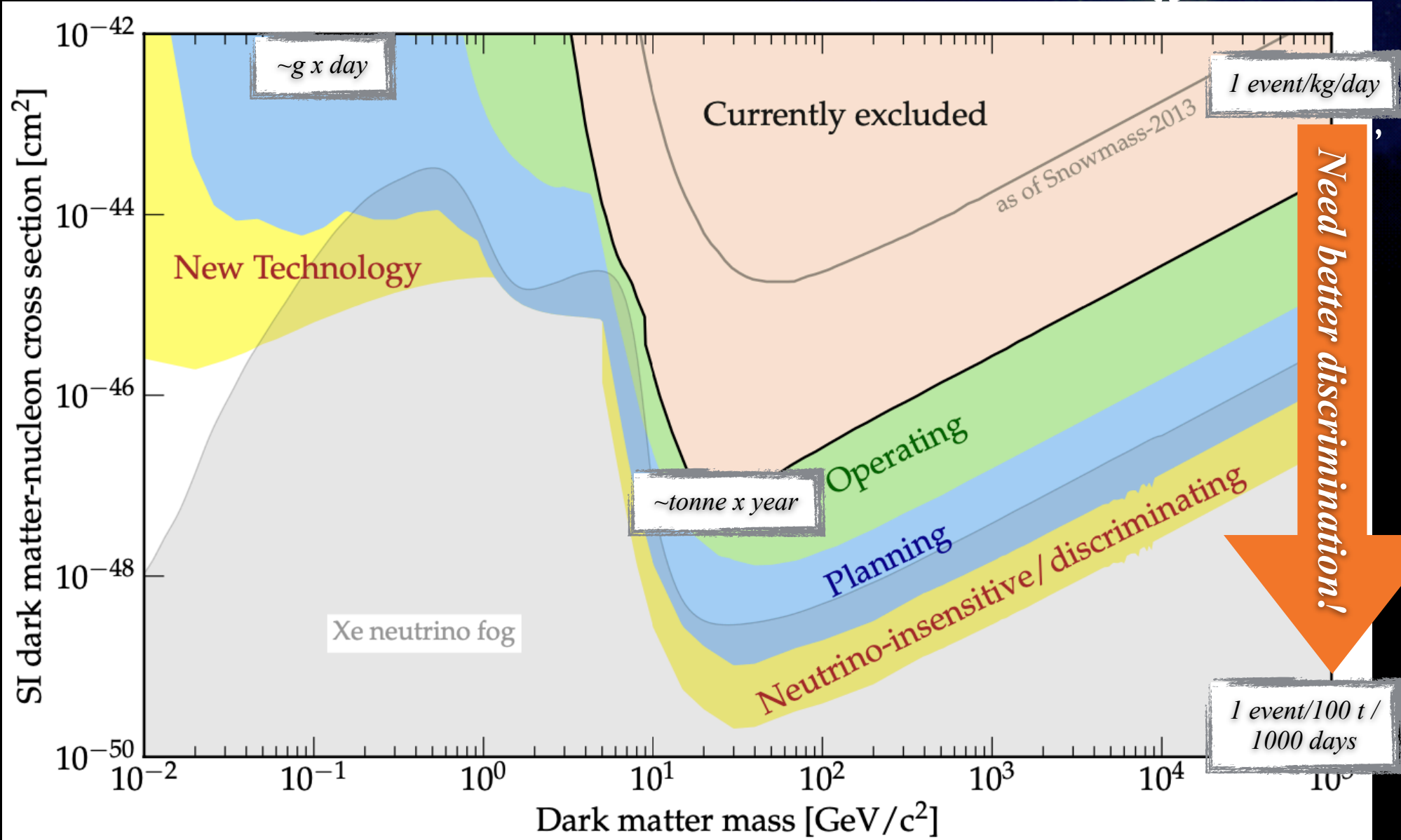


X

X

Neutrino Fog

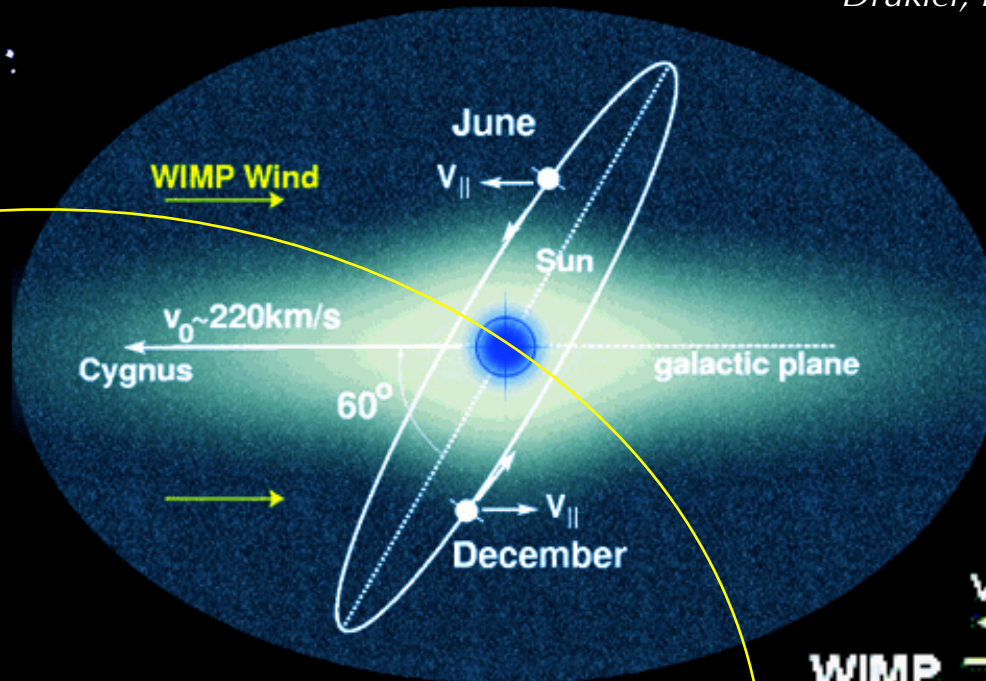
Energy measurement analysis only!



Modulation Signatures

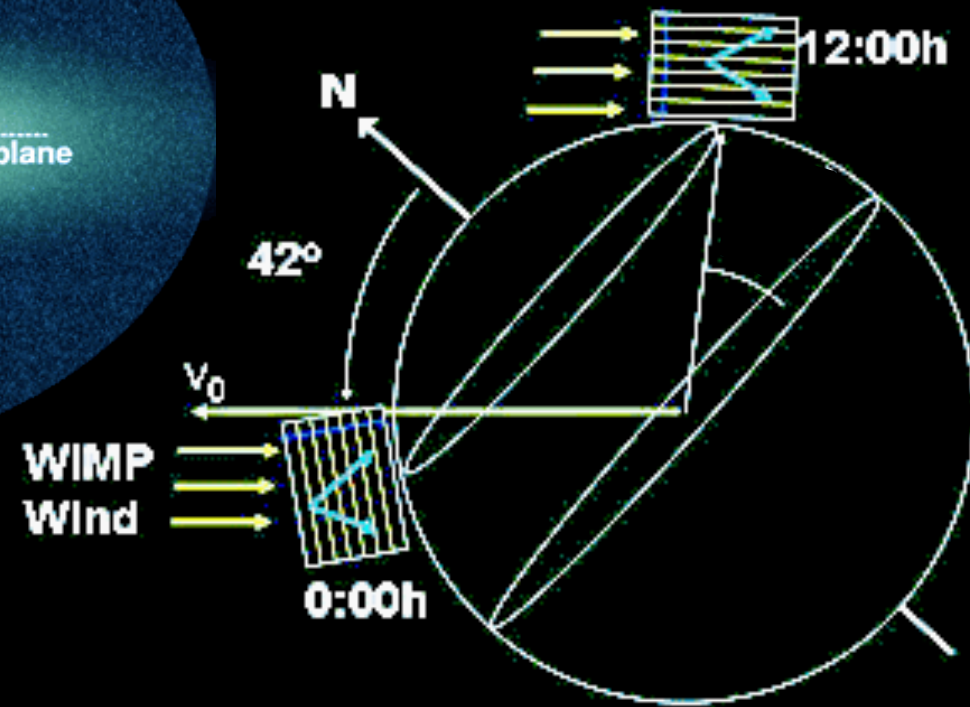
Annual event rate modulation:
June-December asymmetry $\sim 2\text{-}10\%$.

Drukier, Freese, Spergel, Phys. Rev. D33:3495 (1986)



Sidereal direction modulation:
asymmetry $\sim 20\text{-}100\%$ in
forward-backward event rate.

Spergel, Phys. Rev. D36:1353 (1988)



Strategies:

- 1) measure rate modulation
- 2) measure direction modulation

How to do a Modulation Dark Matter Experiment

To do:

1. Work really, *really*, **really** hard to reduce all background sources

How to do a Dark Matter Experiment

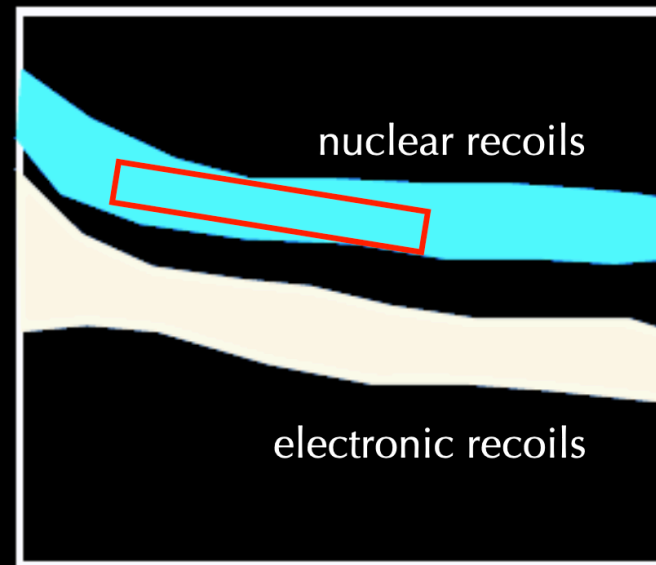
To do:

1. Work really, really, **really** hard to reduce all background sources
2. Reconstruct event properties, define signal region-of-interest.

1. using calibration data,
define signal and
background regions

2. using simulation,
define a region
with fewest expected
background events

Particle ID variable



nuclear recoil energy

How to do a Dark Matter Experiment

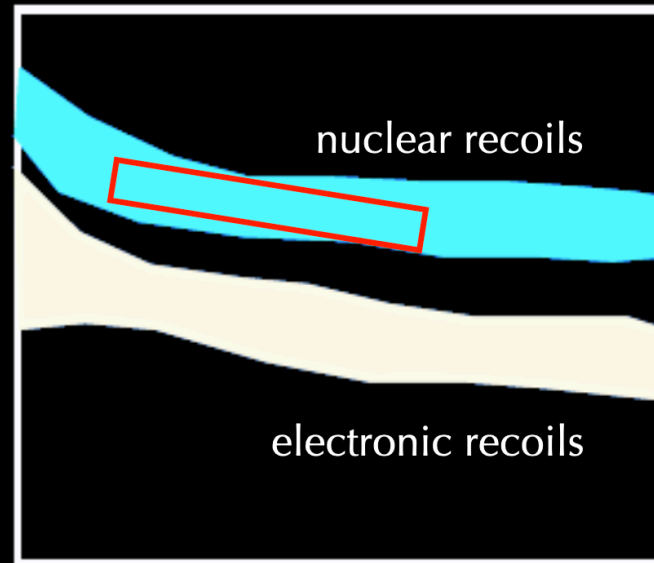
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define signal and
background regions

2. using simulation,
define a region
with fewest expected
background events

Particle ID variable



nuclear recoil energy

Assume signal final state!

How to do a Dark Matter Experiment

To do:

1. Work really, really, **really** hard to reduce all background sources
2. Reconstruct event properties, define signal region-of-interest.
3. Measure the rate of events vs. time

$$\frac{dR}{dE_R} = \frac{\rho_\chi}{m_T m_\chi} \int_{v_{\min}}^{v_{\text{esc}}} v f(\mathbf{v}, t) \frac{d\sigma}{dE_R} d^3\mathbf{v}$$

Annual Modulation:

$$\mathbf{v}_{\text{lab}}(t) = \mathbf{v}_{\text{sun}} + \mathbf{v}_{\text{orb}}(t) \longrightarrow R(E_R, t) \approx S_0(E_R) + S_m(E_R) \cos [\omega(t - t_0)]$$

Sidereal Modulation:

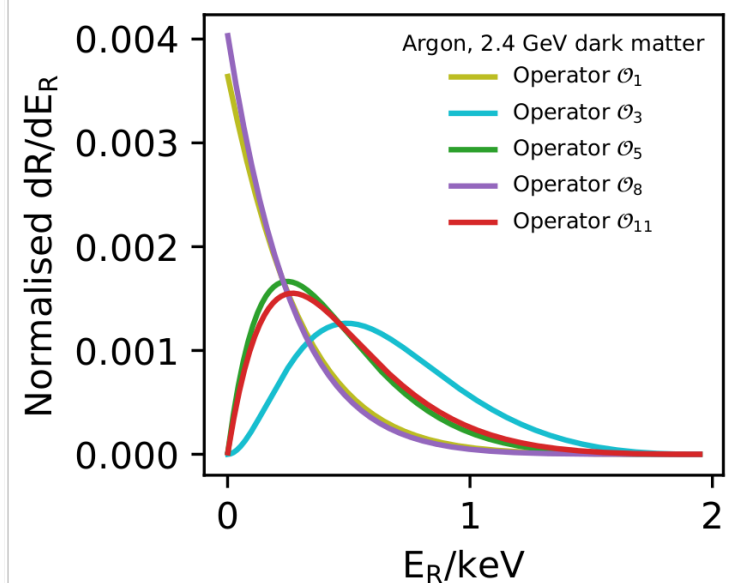
$$\mathbf{v}_{\text{lab}}(t) = \mathbf{v}_{\text{sun}} + \mathbf{v}_{\text{orb}}(t) + \mathbf{v}_{\text{rot}}(t) \longrightarrow R(E_R, t) = A_0(E_R) + A_d(E_R) \cos \left[\frac{2\pi}{T_{\text{sid}}} (t - t_0) \right]$$

How to do a Dark Matter Experiment

To do:

1. Work really, really, **really** hard to reduce all background sources
2. Reconstruct event properties, define signal region-of-interest.
3. Measure the rate of events vs. time
4. Physics interpretation: compare likelihood of background + signal hypothesis to background-only.

Pick a signal model!

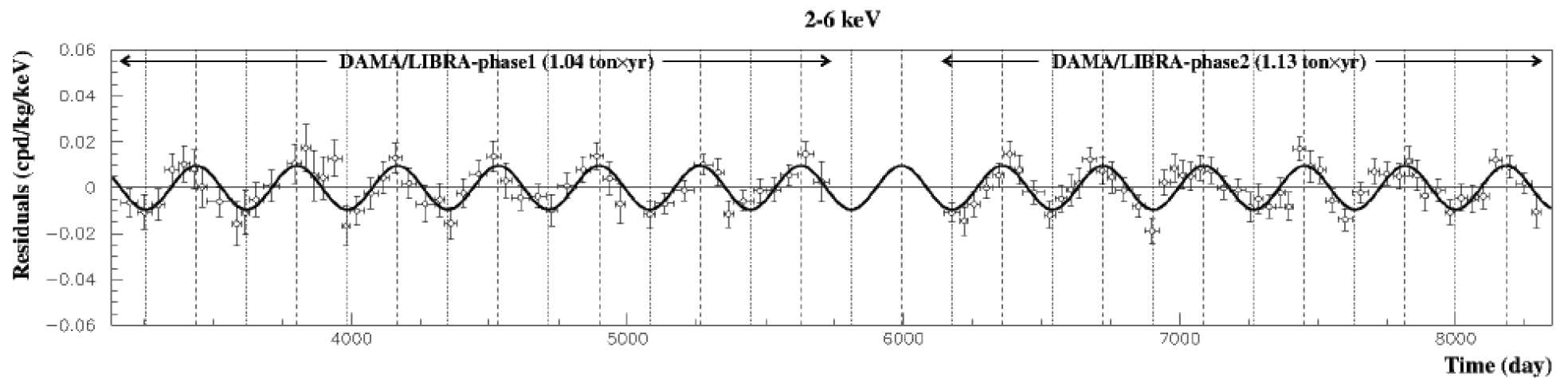
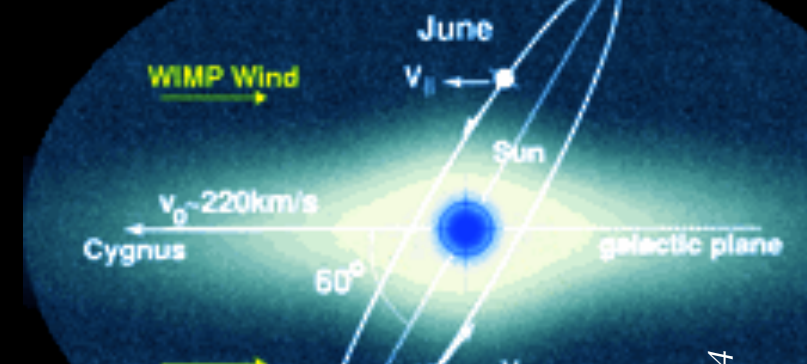




Annual Modulation Searches

Dark Matter Signals?

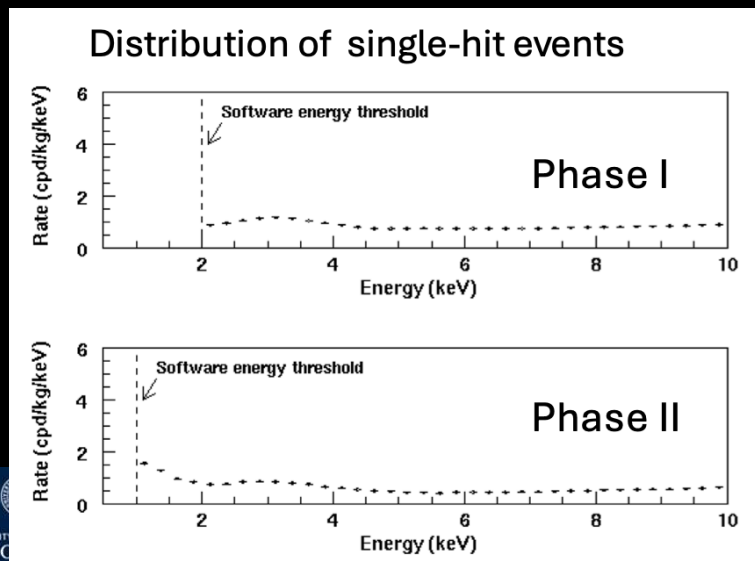
DAMA/LIBRA: 2.17 tonne-yr NaI, $>10\sigma$ modulation



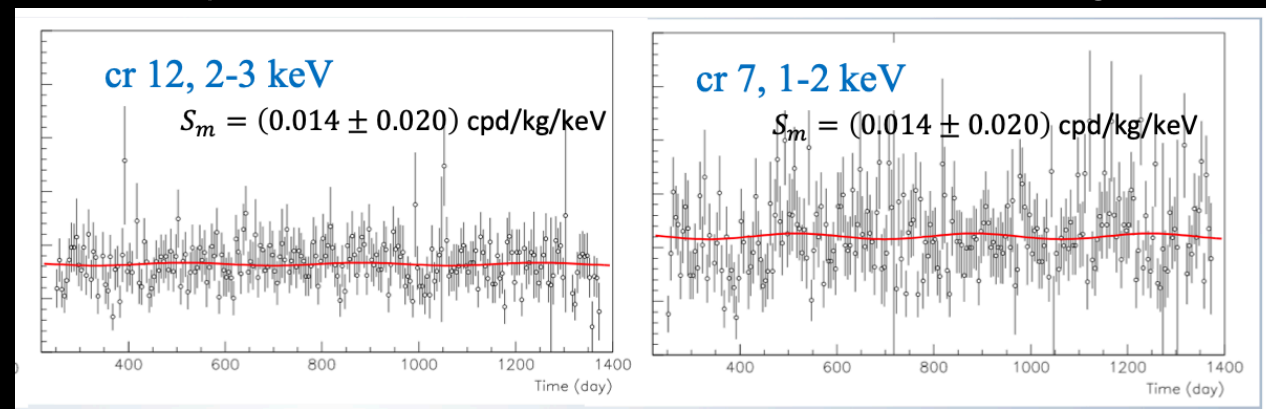
Nucl.Phys.Atom.Energy 22 (2021) 4

Phase 1: measure modulation amplitude 0.00996 ± 0.0007 cpd/kg/keV, in 2-6 keV

Phase 2: measure modulation amplitude 0.01048 ± 0.0009 cpd/kg/keV, in 1-6 keV



Phase 2 3-year dataset: no evidence of modulation of background

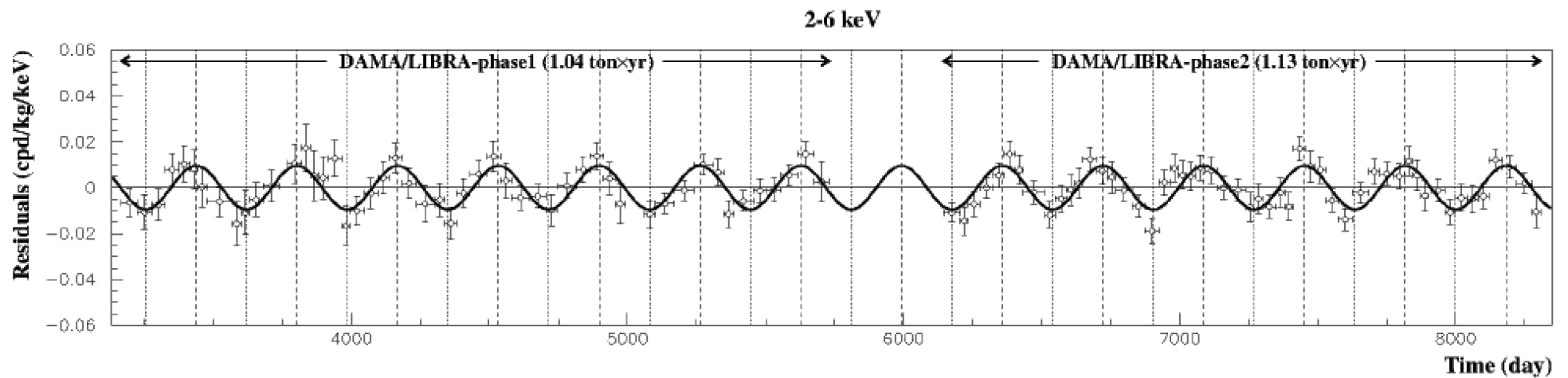
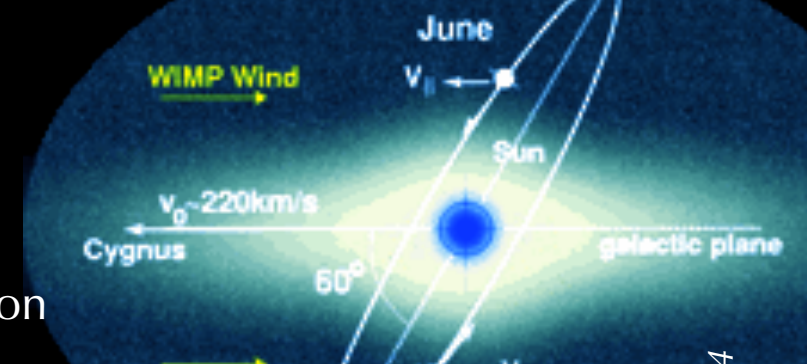


Cerulli, IDM24

June 4, 2026 p.8

Dark Matter Signals? ...BUT

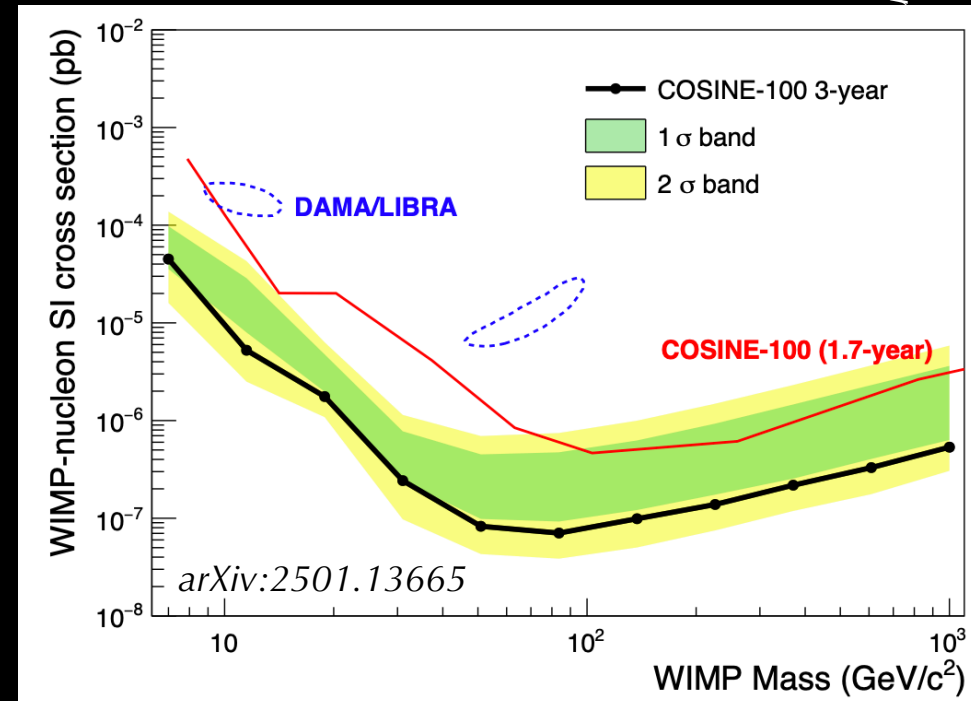
DAMA/LIBRA: 2.17 tonne-yr NaI(Tl), in LNGS, $>10\sigma$ modulation



incl. Phys. Atom. Energy 22 (2021) 4

many other searches, on Ge, CsI, Xe, etc.
observe no evidence of modulation.

- In the same underground laboratory:
XENON100: Xe, 4.8σ exclusion of DAMA
- Using the same target (NaI):
ANAIS (LSC), **COSINE-100** (Y2L), **SABRE** (AU)
Exclude DAMA signal at 3σ to date.
- Using the same target (NaI) AND same laboratory:
COSINUS (LNGS), installing now.



AN AIS (*Annual modulation with NAI Scintillators*)

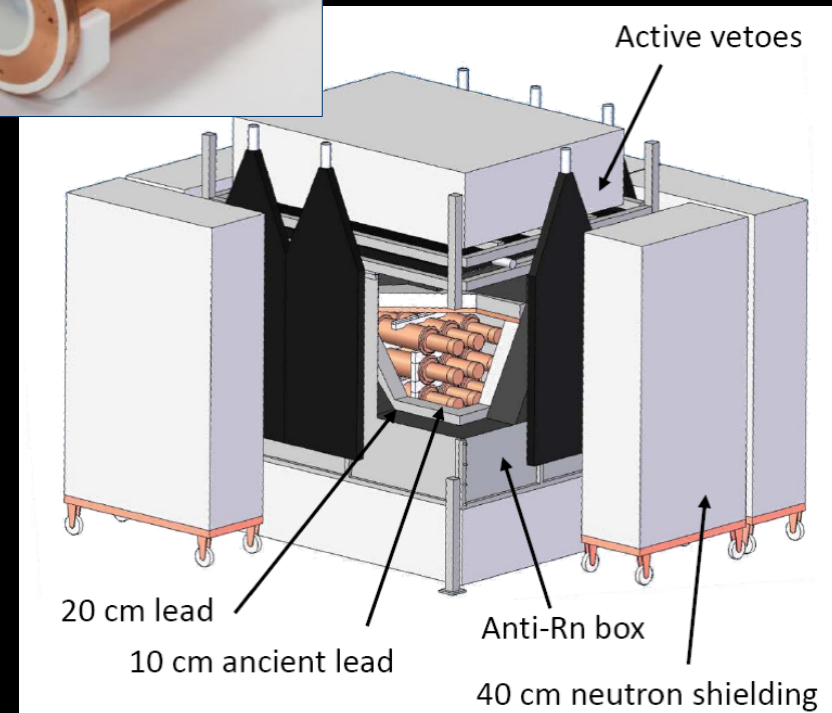
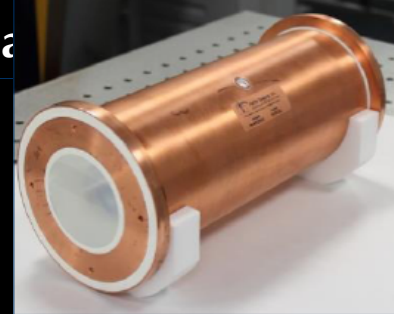
AN AIS-112: 112.5 kg NaI(Tl) in 9 detectors + blank module, Canfranc (Spain)

Data taken smoothly **from August 2017 to January 2026** to have a definitive, independent test at **5 σ sensitivity** of the **DAMA/LIBRA** **result**

- Excellent light collection: **threshold at 1 keV_{ee}**
- Detailed study of effect of **systematics** (i.e. QF)
- **Background model** reproducing data down to 2 keV, excess over background in 1-2 keV
- **Machine-learning techniques** and improved DAQ to improve noise rejection: a Boosted Decision Tree trained with neutrons (signal) and blank module events (noise)

Open data available for independent analysis at Dark Matter Data Center:

<https://www.origins-cluster.de/odsl/dark-matter-data-center/available-datasets/anais>



I. Coarasa et al, JCAP11(2022)048

Talks at IDM2026: “AN AIS–112: Towards Completing the Model-Independent Test of the DAMA/LIBRA Signal” by I. Coarasa, + I. Casas 1 June & S. Hollick, June 2 & posters: C. Seoane

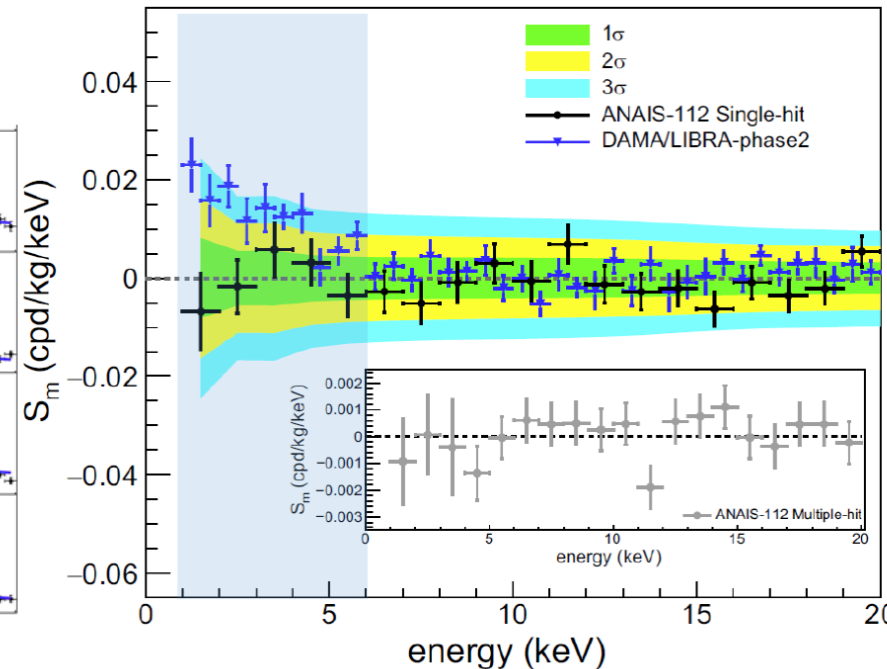
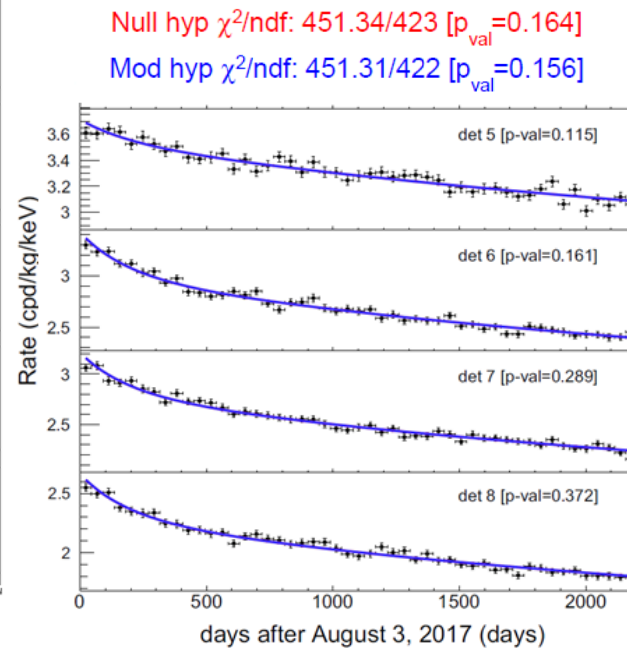
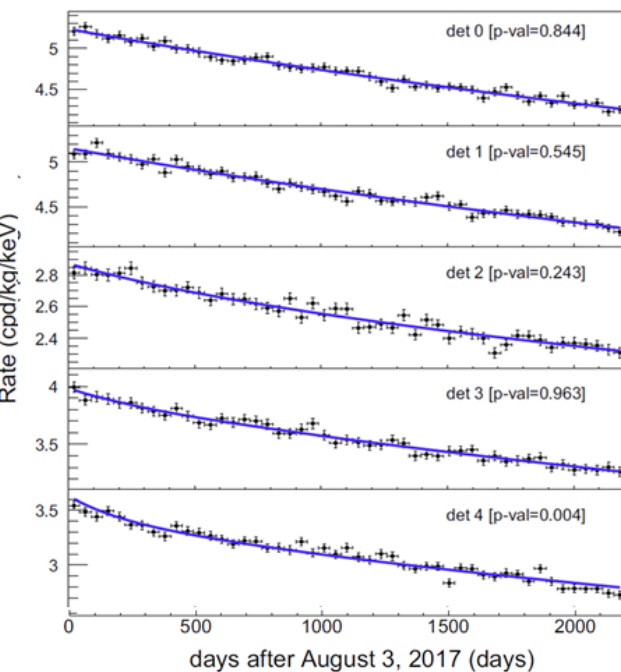
ANAIS (*Annual modulation with NAI Scintillators*)

ANAIS-112: 106 kg NaI(Tl) in 9 detectors + blank module, Canfranc (Spain)

No modulation observed: **New results** from full dataset!

8.4 y results incompatible with DAMA/LIBRA at 4.0 (**5.6**) σ in [1-6] ([2-6]) keV

Least square fit of the counting rate to derive the modulation amplitude $S_m = -0.0004 \pm 0.0025$ cpd/kg/keV, in **1-6 keV**



Upgrade to lower energy threshold planned.

J. Amaré et al, Phys. Rev. Lett. 135 (2025) 051001

Talks at IDM2026: “The ANAIS+ project: development of scintillation detectors in the 100K temperature range for dark matter searches” by J. Apilluelo, 2 June.

ANAIS (*Annual modulation with NAI Scintillators*)

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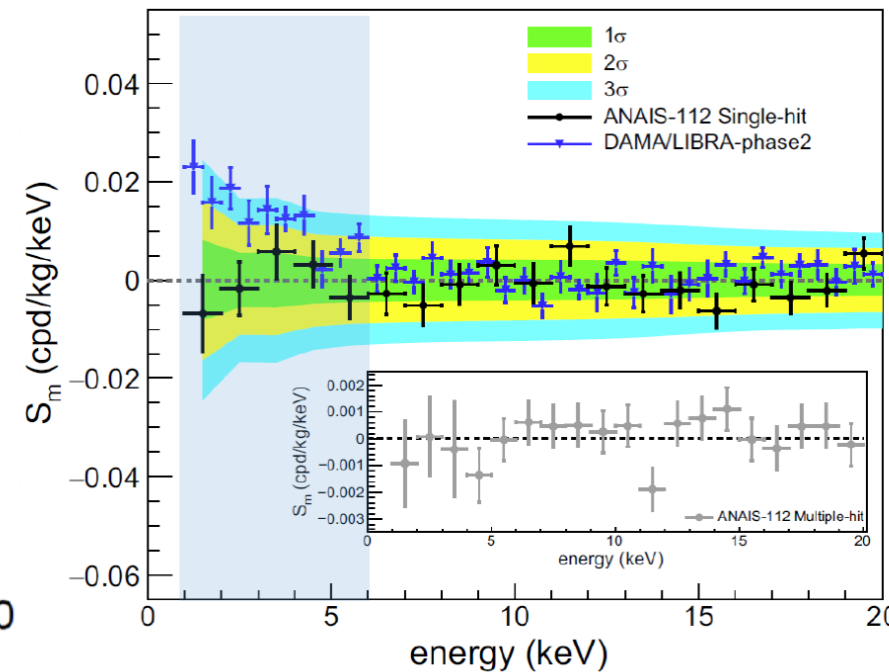
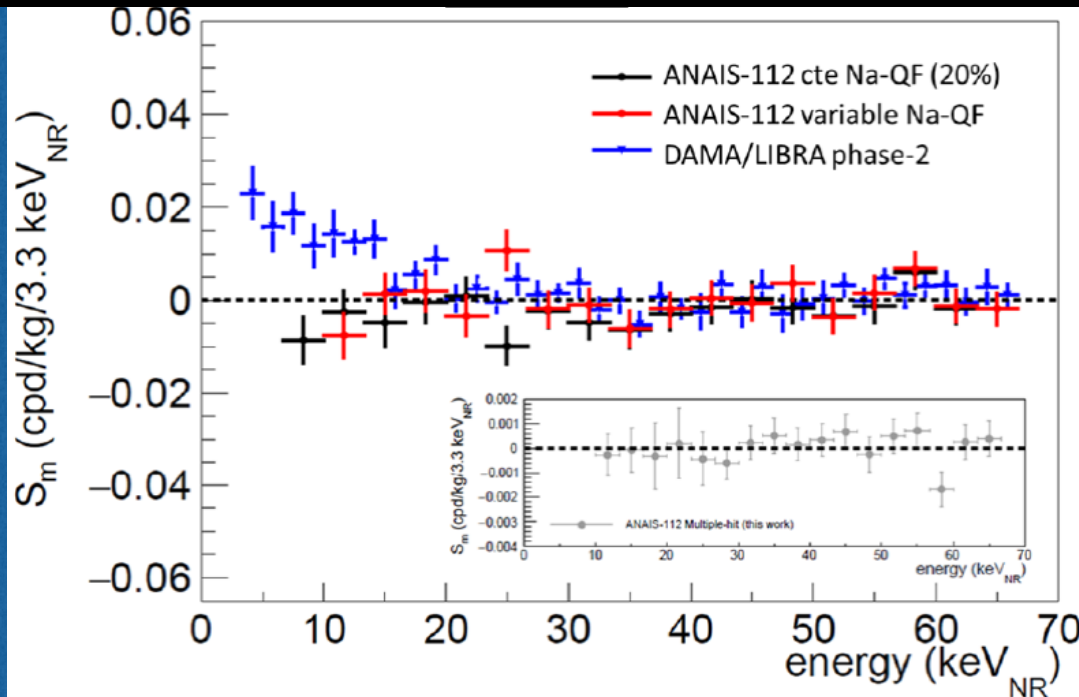
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Effect of different Quenching Factors for DAMA/LIBRA and ANAIS?



Upgrade to lower energy threshold planned.

J. Amaré et al, Phys. Rev. Lett. 135 (2025) 051001

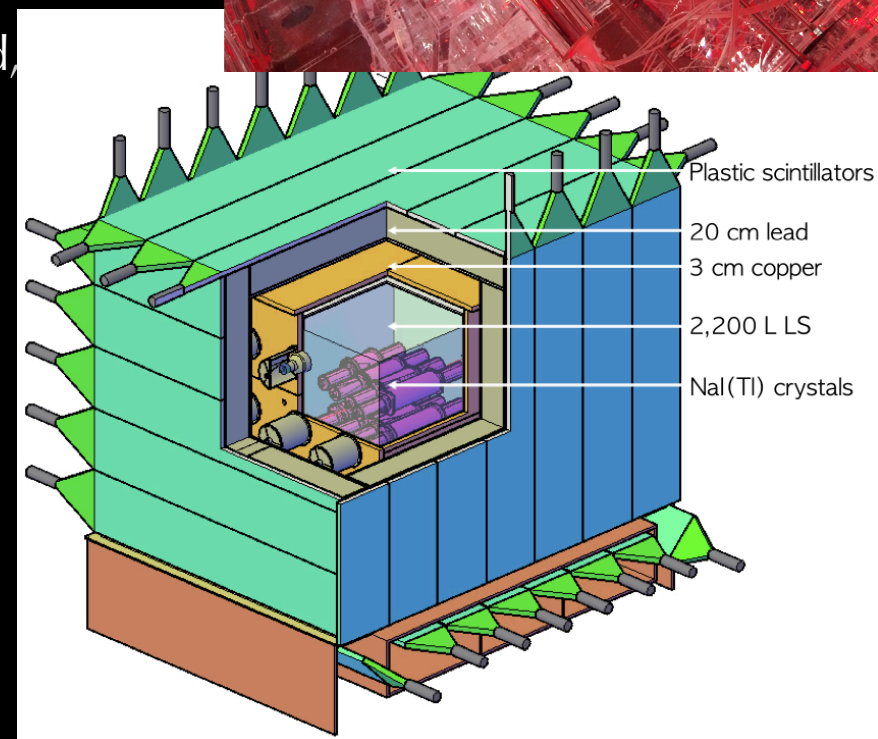
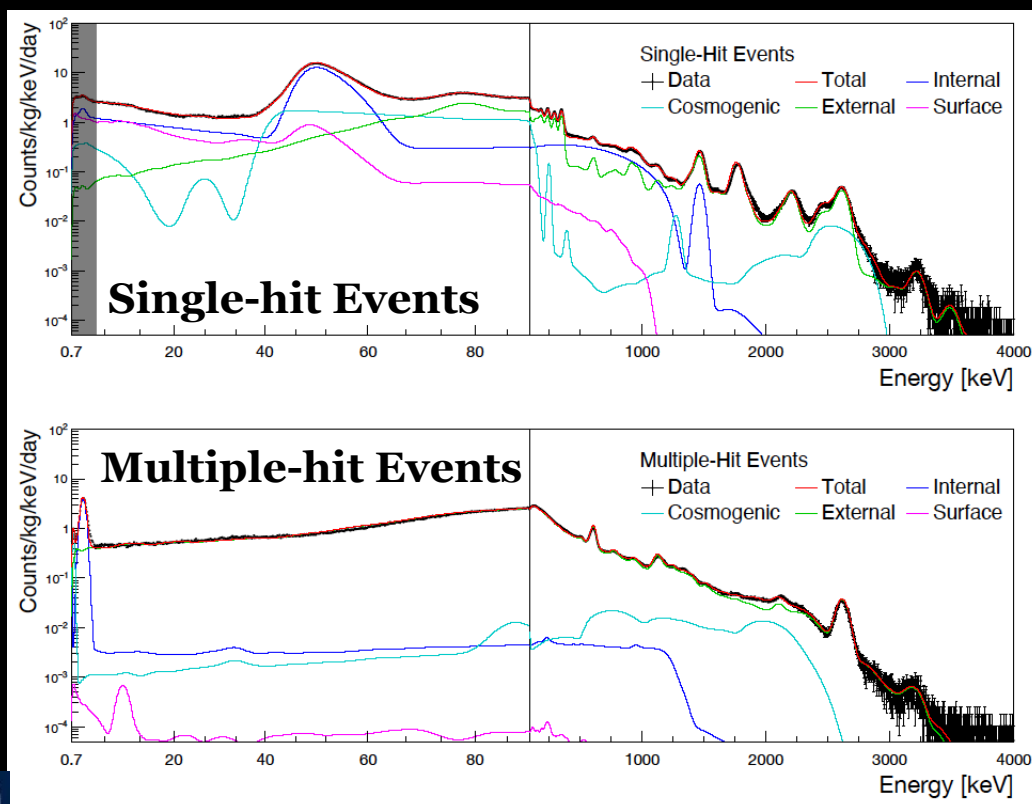
Talks at IDM2026: "The ANAIS+ project: development of scintillation detectors in the 100K temperature range for dark matter searches" by J. Apilluelo, 2 June.

COSINE-100

106 kg NaI(Tl) detectors, YangYang Underground Lab (Korea)

Data taken from September 2016 through March 2023,
detector moved to Yemilab for upgrade to increase light yield

- Excellent light collection: **threshold at 0.85 keV_{ee}**
- Detailed study of effect of QF energy dependence
- **Background model** reproduces data down to threshold, constrain time-dependence of backgrounds in >6 keV



Talk & Posters at IDM2026: J. Kim, June 1;
G. Yu, June 1; W. K. Kim, June 2 &
L. Franca, V. Machado.

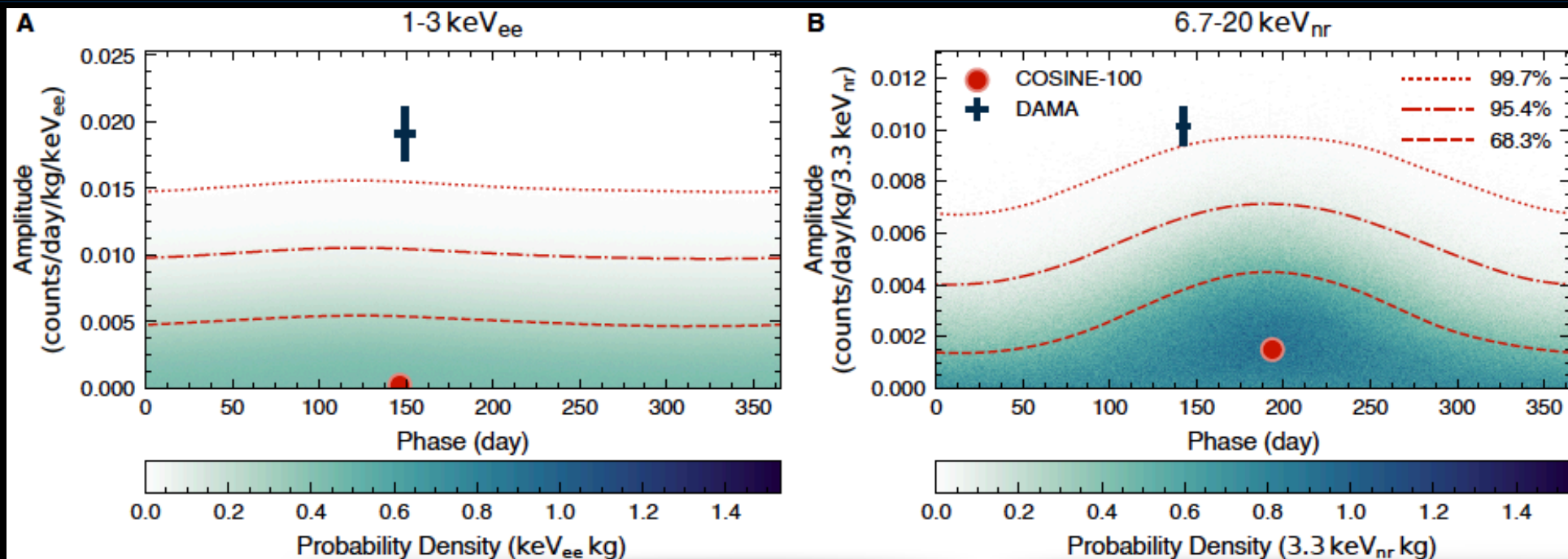
June 4, 2026 p.12

COSINE-100

106 kg NaI(Tl) detectors, YangYang Underground Lab (Korea)

No modulation observed:

COSINE-100 full dataset disfavors DAMA/LIBRA in both electron recoil and nuclear recoil ($> 4.0\sigma$)



Sci. Adv. 11, eadv6503 (2025)

E (keV _{ee})	A (counts/day/kg/keV _{ee})	
	COSINE-100	DAMA/LIBRA
1~3	0.001 ± 0.005	0.019 ± 0.002
1~6	0.002 ± 0.003	0.010 ± 0.001
2~6	0.005 ± 0.003	0.010 ± 0.001

E (keV _{nr})	A (counts/day/kg/3.3 keV _{nr})	
	COSINE-100	DAMA/LIBRA
6.7~20	0.001 ± 0.003	0.010 ± 0.001

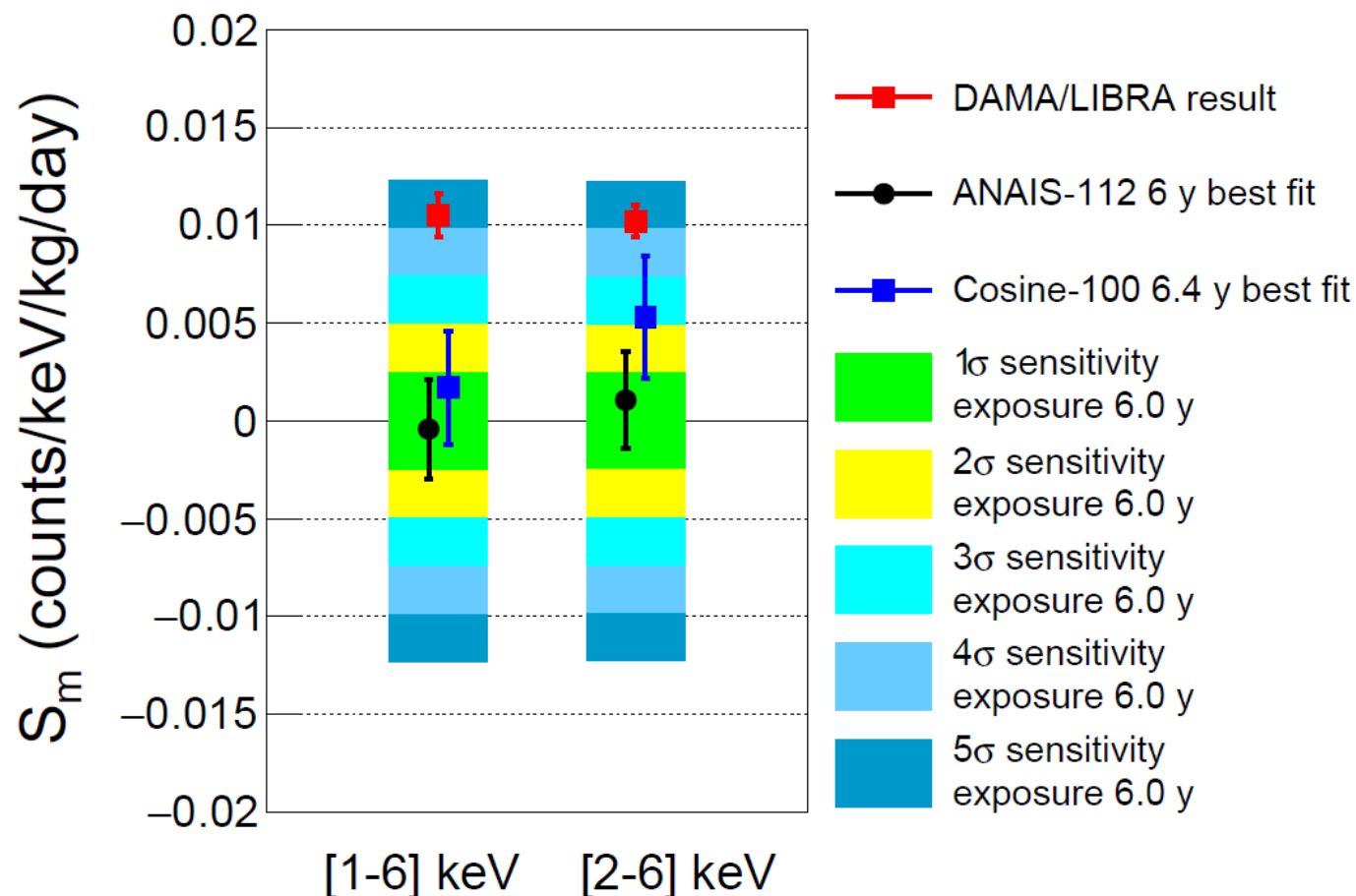
ANAIS & COSINE-100

Combined Analysis:

statistical combination of 6-y datasets
incompatible with DAMA/LIBRA at **4.7**
(3.5) σ in 1-6 (2-6) keV

N. Carlin et al, Phys. Rev. Lett. 135 (2025) 121002

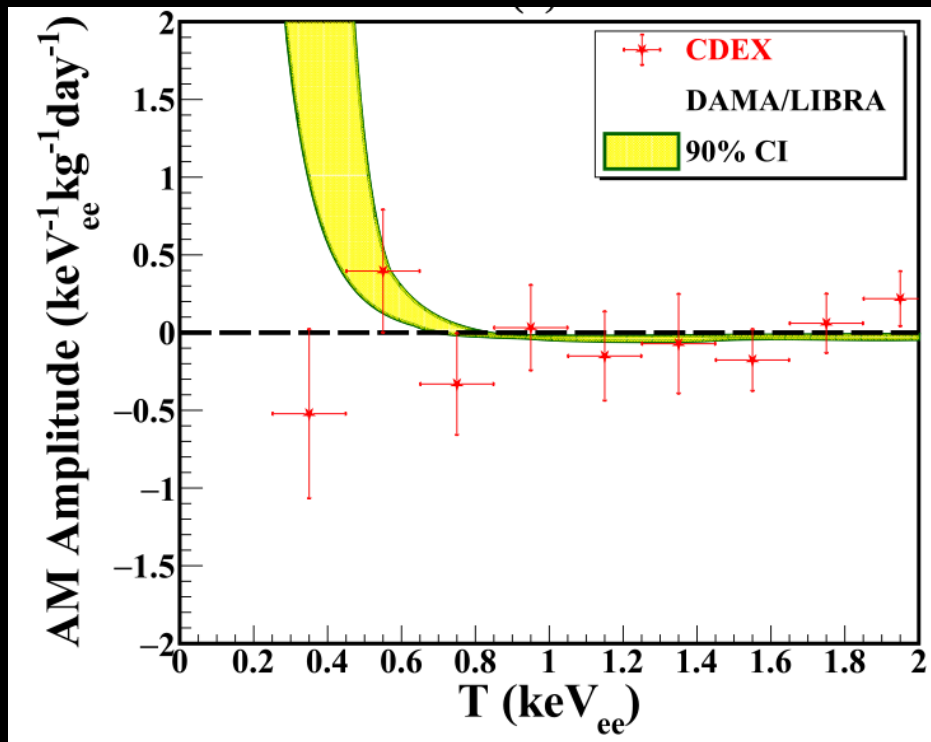
Energy ROI	Combined result	DAMA Exclusion
1-6 keV	0.0005 ± 0.0019	4.68σ
2-6 keV	0.0027 ± 0.0019	3.53σ



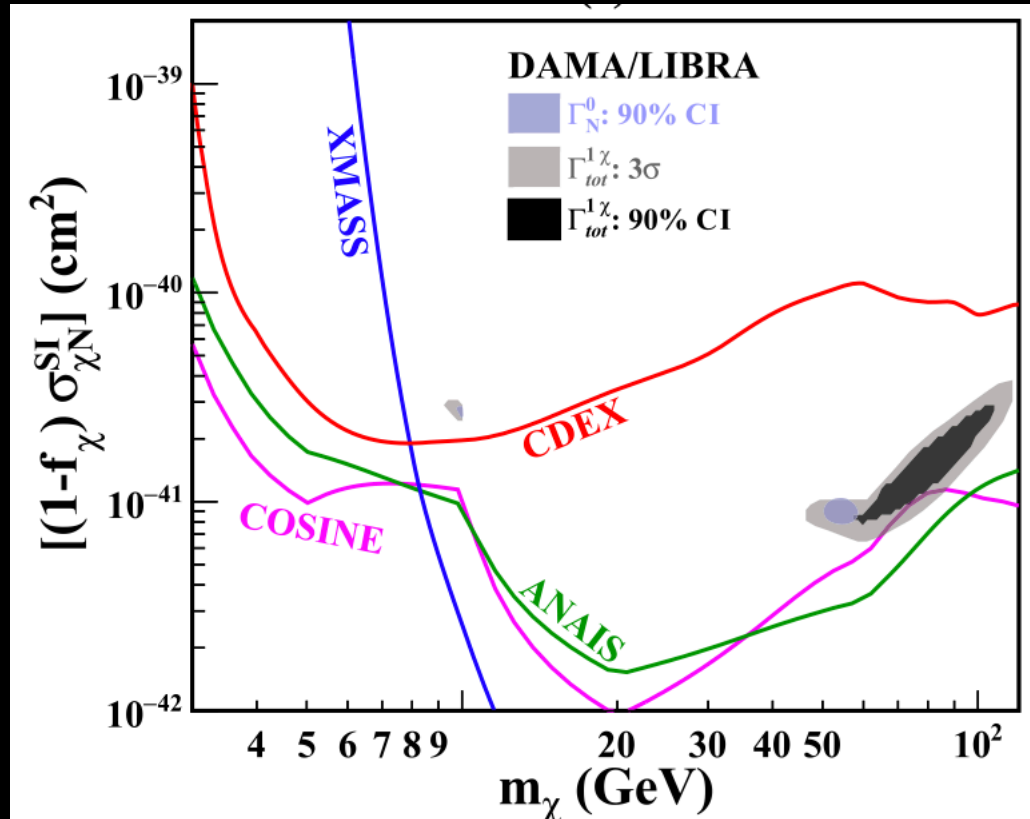
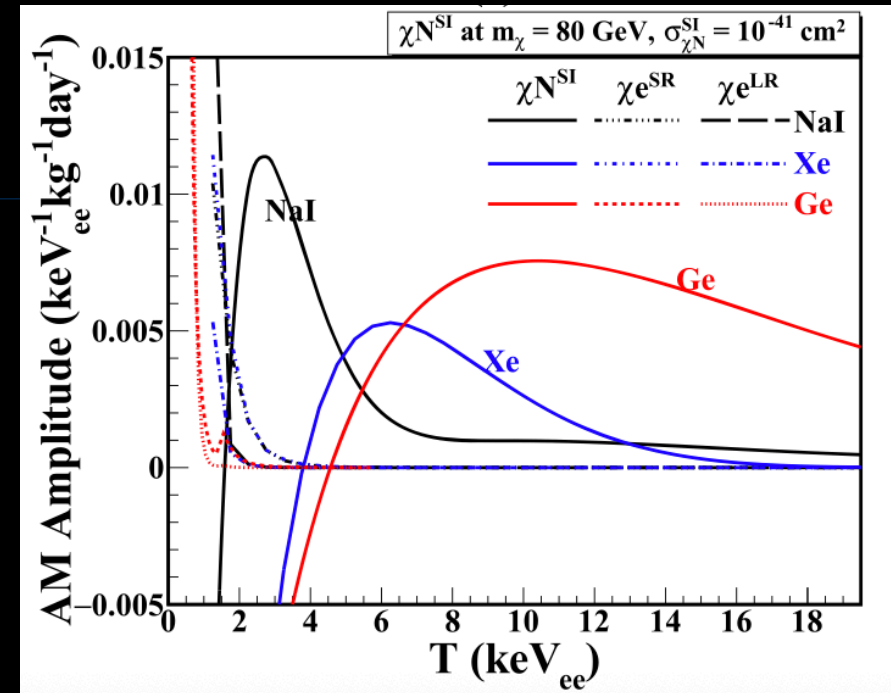
TEXONO Global Analysis

Combined Analysis of nuclear recoil AND electronic recoil signals, across experiments NaI, Xe, Ge targets

CDEX 0.94 kg Ge detector with 0.25 keV_{ee} threshold



Nb. Ge data strongly constrains scenarios with 2 DM states that interact (separately) with e⁻, N (shown here is interpretation with 1 DM state interacting with both)



SABRE

SABRE North + South: Opposite sign of seasonal systematics. SABRE North (LNGS) demonstrated crystal growth with zone refining, next: use method radiopure COSINE-100 powder, test within '27.

SABRE South

Nal(Tl) modulation experiment at the Stawell Underground Physics Laboratory, Australia

Modulation budget

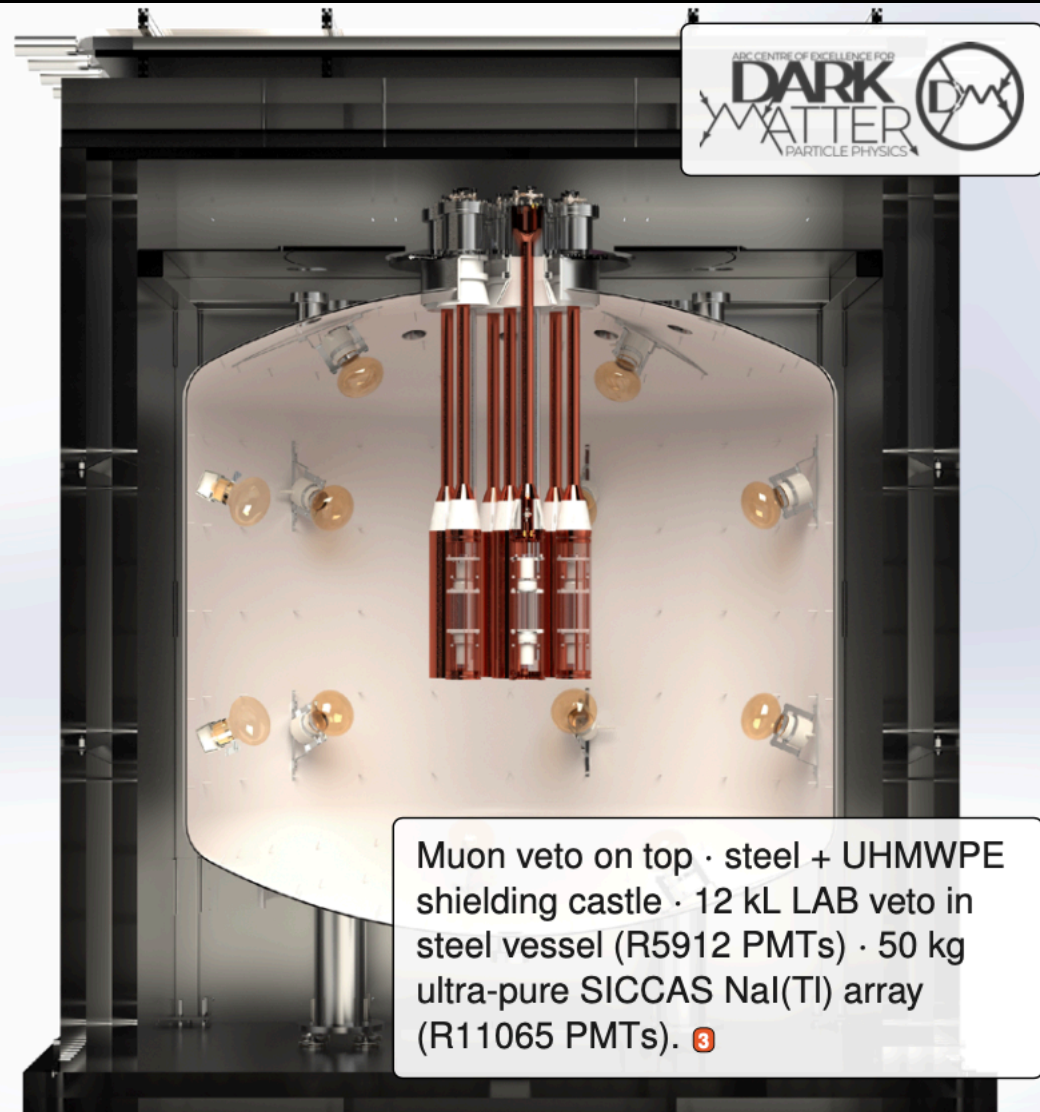
$$R(t) = B + R_0 + R_m \cos(\omega(t-t_0))$$

$R_m \sim 0.01$ cpd/kg/keV on $R_0 < 1$ cpd/kg/keV;

$t_0 = 152.5$ d (SHM).

Strategy

- ◆ Southern hemisphere → opposite-sign seasonal systematics; same Nal(Tl) target as DAMA / ANAIS-112 / COSINE-100.
- ◆ Ultra-pure Nal(Tl) crystals; projected total background ~ 0.7 dru.
- ◆ 1 keV_{ee} analysis threshold in the 1–6 keV_{ee} ROI (paired-PMT BDT) ¹.
- ◆ Large active background veto with particle-ID capability ².



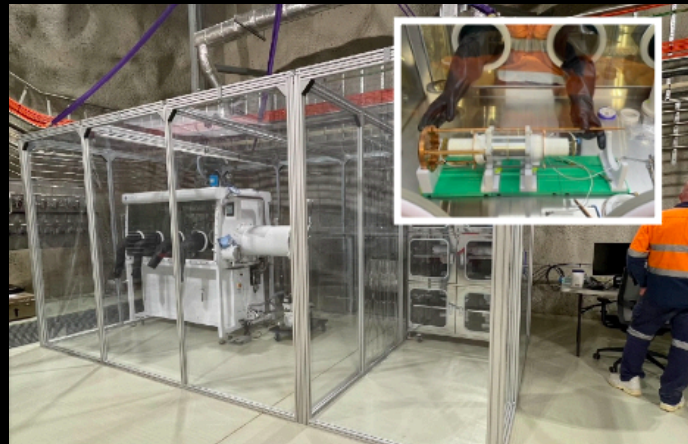
¹ Stanley et al., *JINST* 20 (2025) P07052

² Milligan, Urquijo et al., *JINST* 20 (2025) P07049

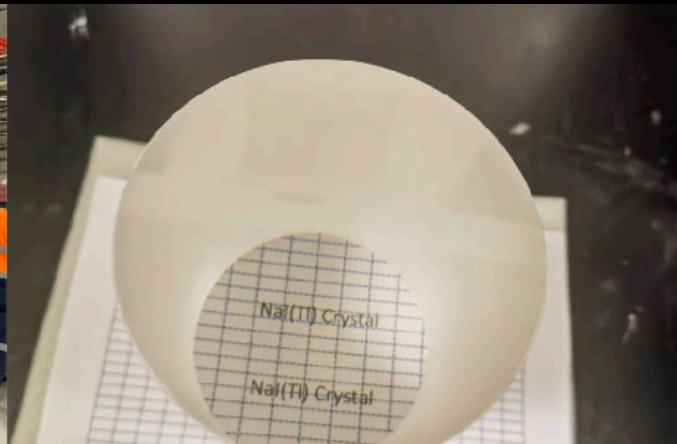
³ SABRE South TDR, *JINST* 20 (2025) T04001

SABRE South

In commissioning at SUPL!



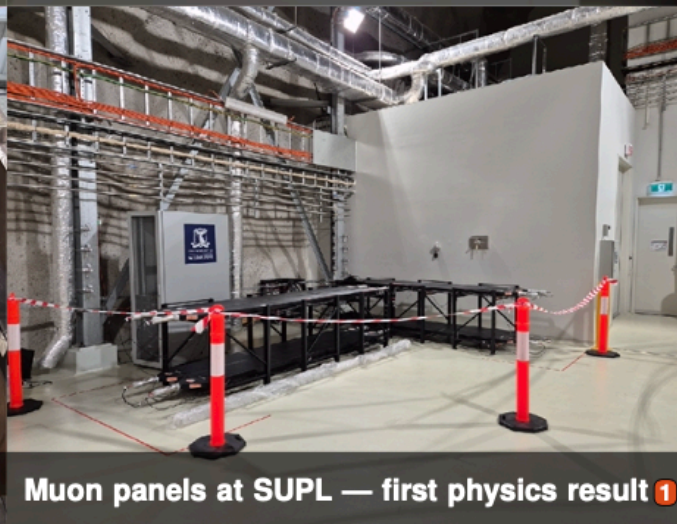
Clean tent at SUPL (inset: glove box)



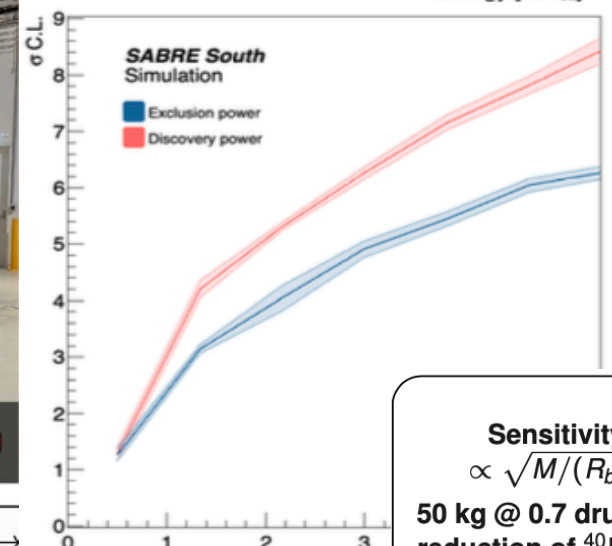
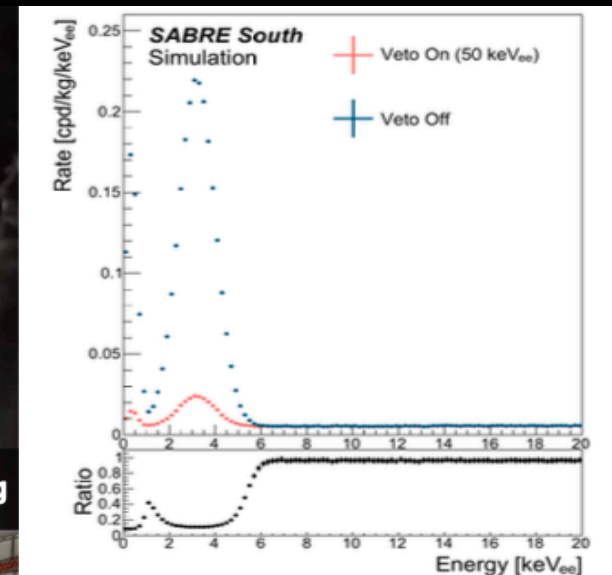
SICCAS NaI(Tl) — full production commencing



Vessel + shielding fit-up
(above-ground, manufacturer)



Muon panels at SUPL — first physics result ¹



¹ SABRE South Coll., *Astropart. Phys.* 179 (2026) 103240 ² SABRE South Coll., *EPJC* 83 (2023) 878 →

Sensitivity
 $\propto \sqrt{M/(R_b t)}$
 50 kg @ 0.7 dru · 10 ×
 reduction of ⁴⁰K from
 veto · 2–3 yr to DAMA
 (5 σ) ²

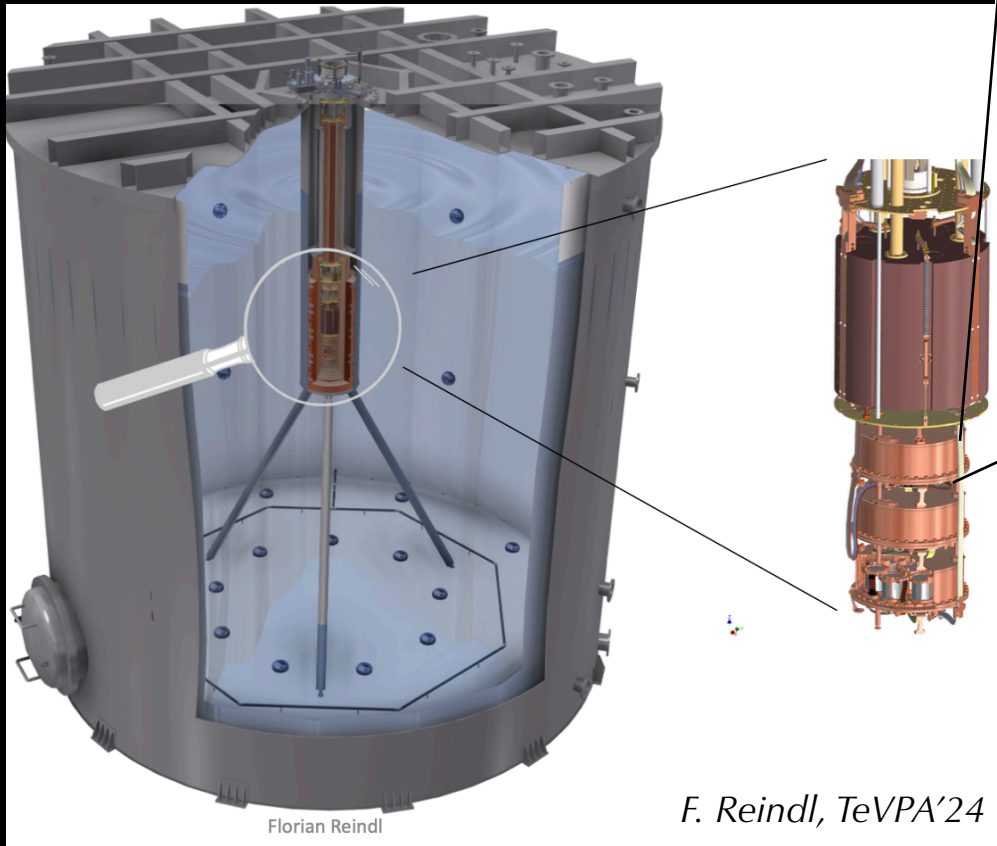
Online Q1 2027

Talks & Poster at IDM2026: L. Einfalt, June 1; C. Tomei, June 1 & D. Montanino.

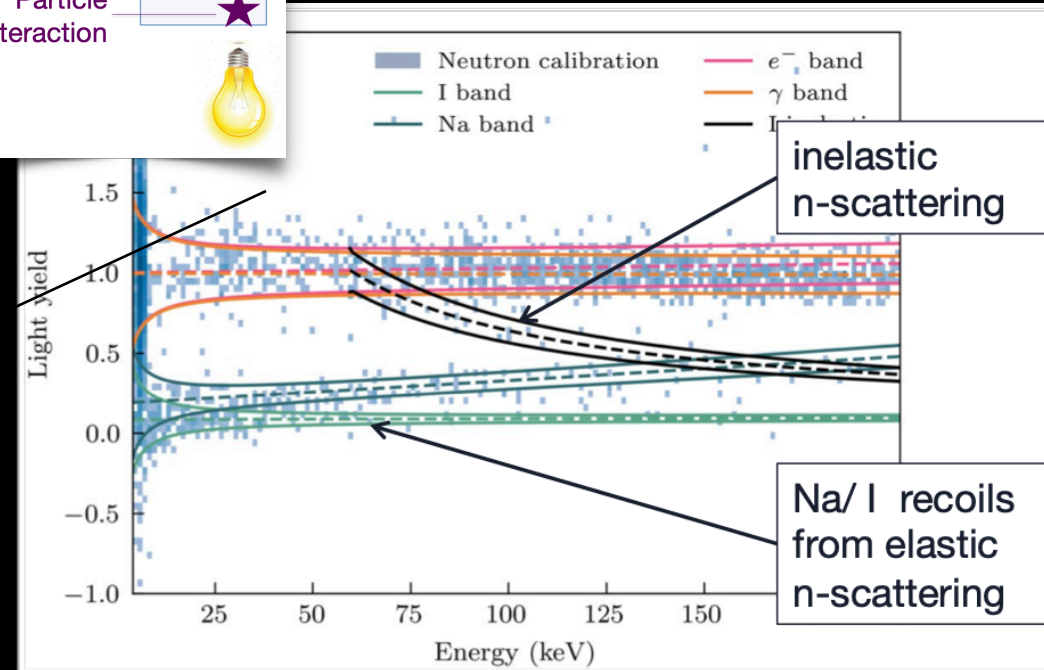
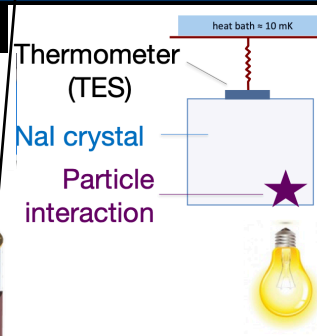
COSINUS *(Cryogenic Observatory for Signatures seen in Next generation Underground Searches)*

Cryogenic NaI(Tl) detectors + in LNGS (Italy): measure both scintillation AND heat!

First NaI detector to have event-by-event particle ID (*arXiv:2307.11066, PRD 109, 082003*)



F. Reindl, TeVPA'24



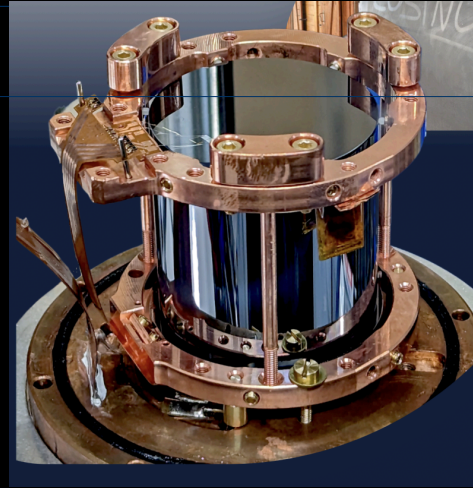
Plan: 100 kg-day exposure with threshold $< \text{keV}_{ee}$

Talks & Posters at IDM2026: M. Cabibie, June 1, L. Ziegele, June 3 & K. Heim, C. Dittmar, S. Braun, A. Boehmer, M. Stahlberg.

COSINUS *(Cryogenic Observatory for Signatures seen in Next generation Underground Searches)*

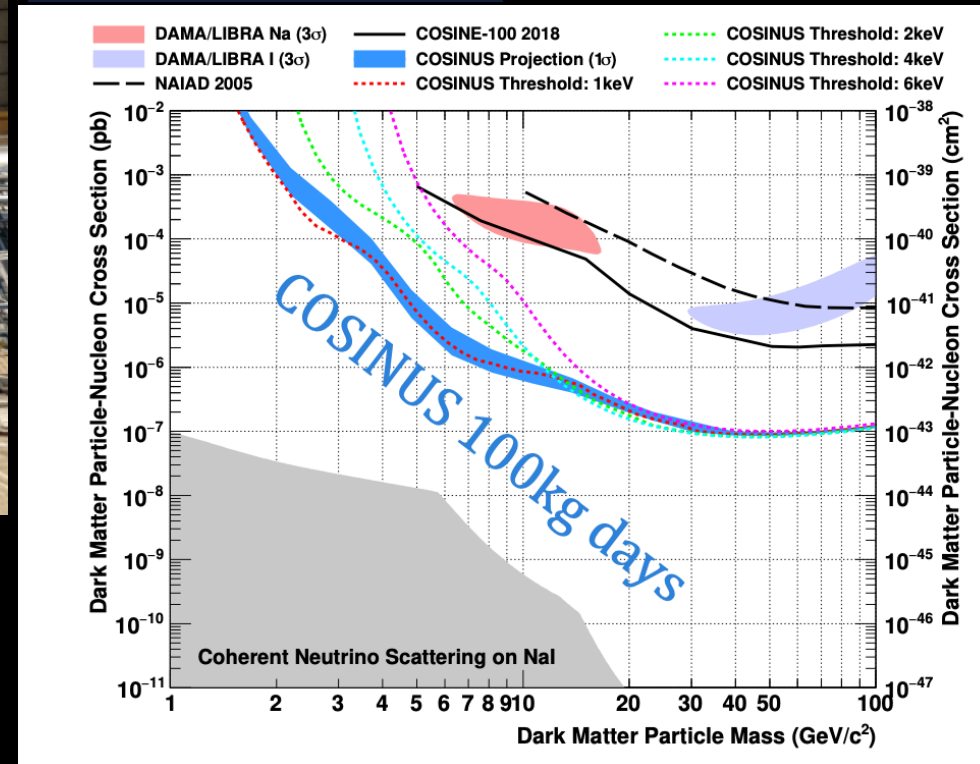
Cryogenic NaI(Tl) detectors + in LNGS (Italy): measure both scintillation AND heat!

First NaI detector to have event-by-event particle ID



arXiv:2406.12870, EPJC 84, 551, 2024

Commissioning in LNGS. Same target
AND same lab as DAMA/LIBRA. Stay tuned...



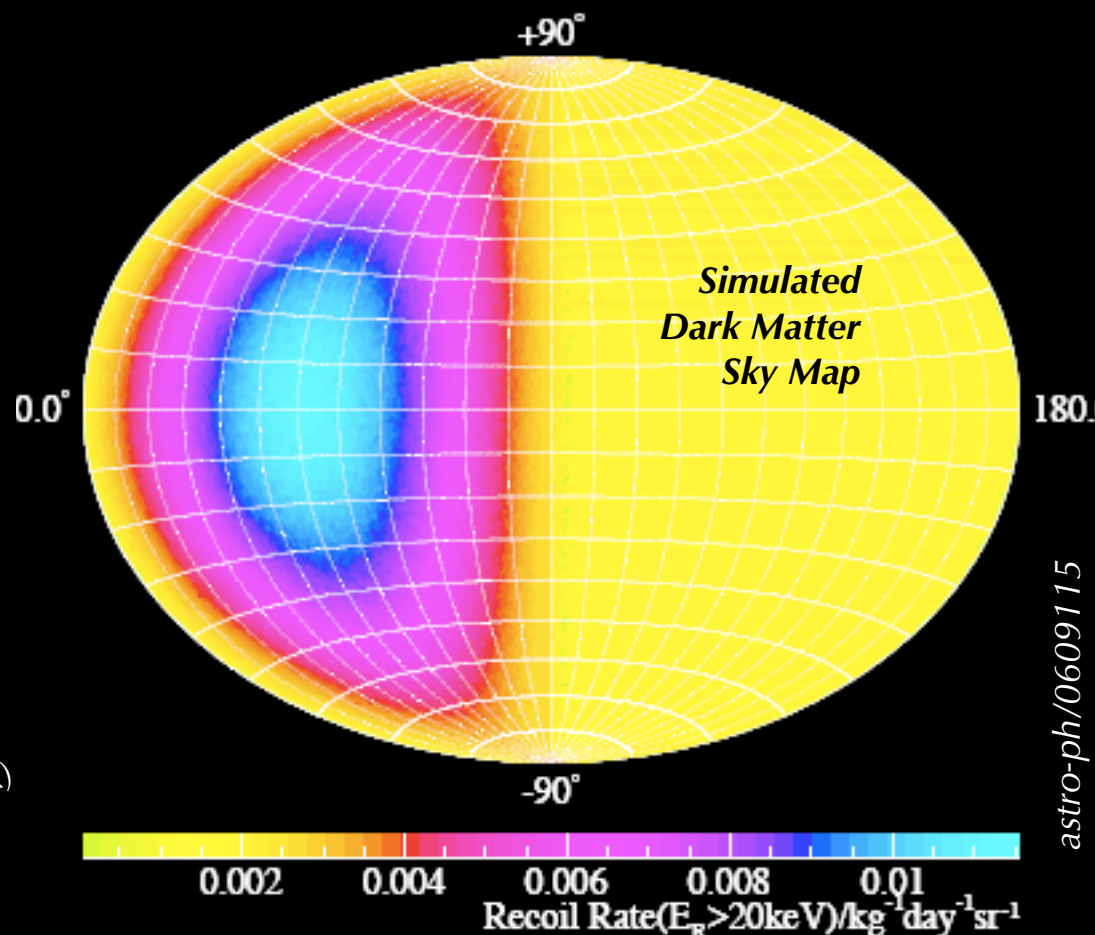
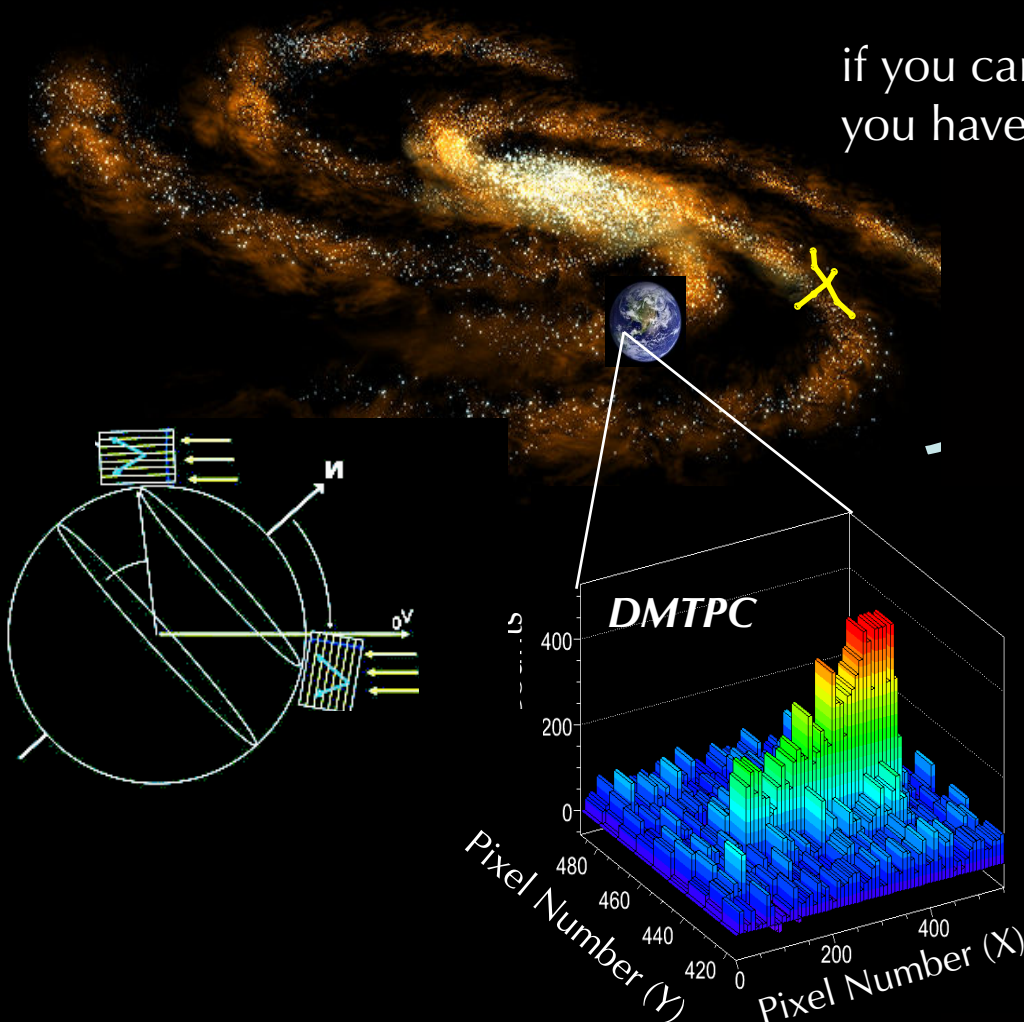


Directional Detection Searches

Directional Detection

The Dark Matter Wind “blows” from Cygnus

if you can reconstruct the energy and angle of the recoil, you have a **dark matter telescope**



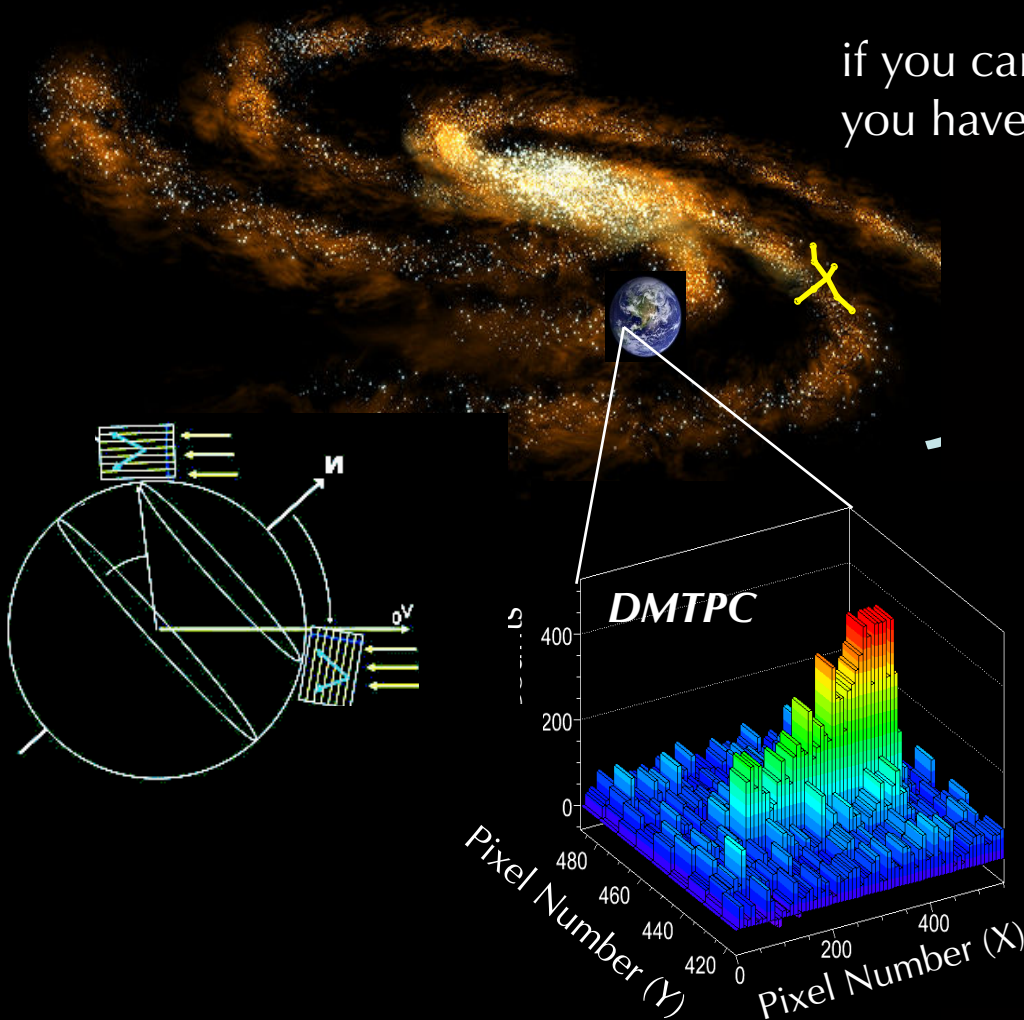
Signal characteristics:

- (i) forward-backward asymmetry in galactic frame,
- (ii) sidereal modulation in lab frame (direction, rate)

Directional Detection

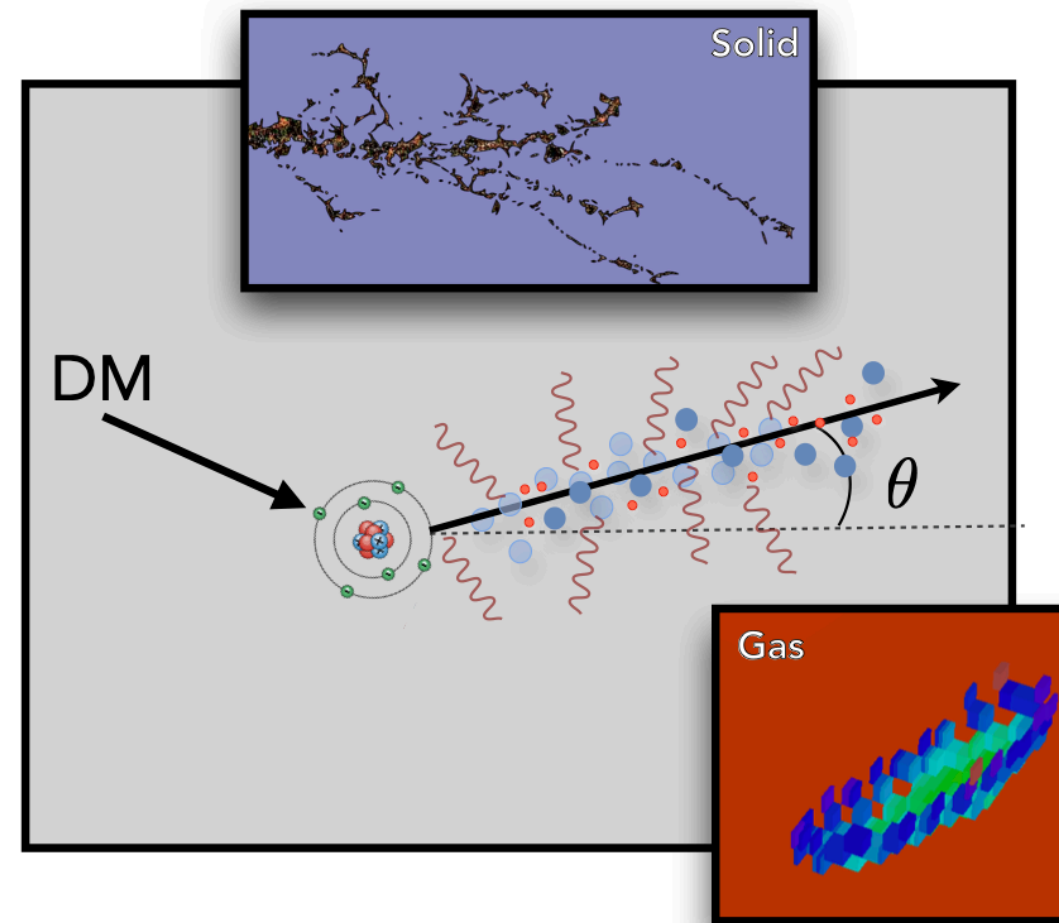
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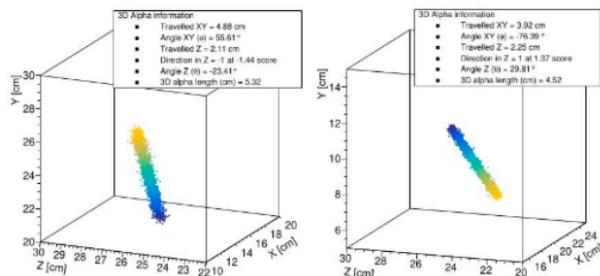
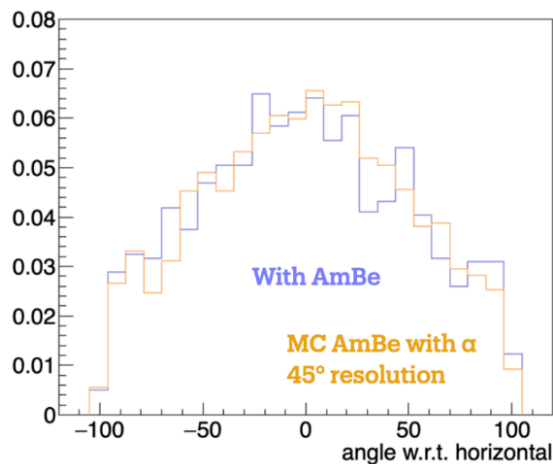
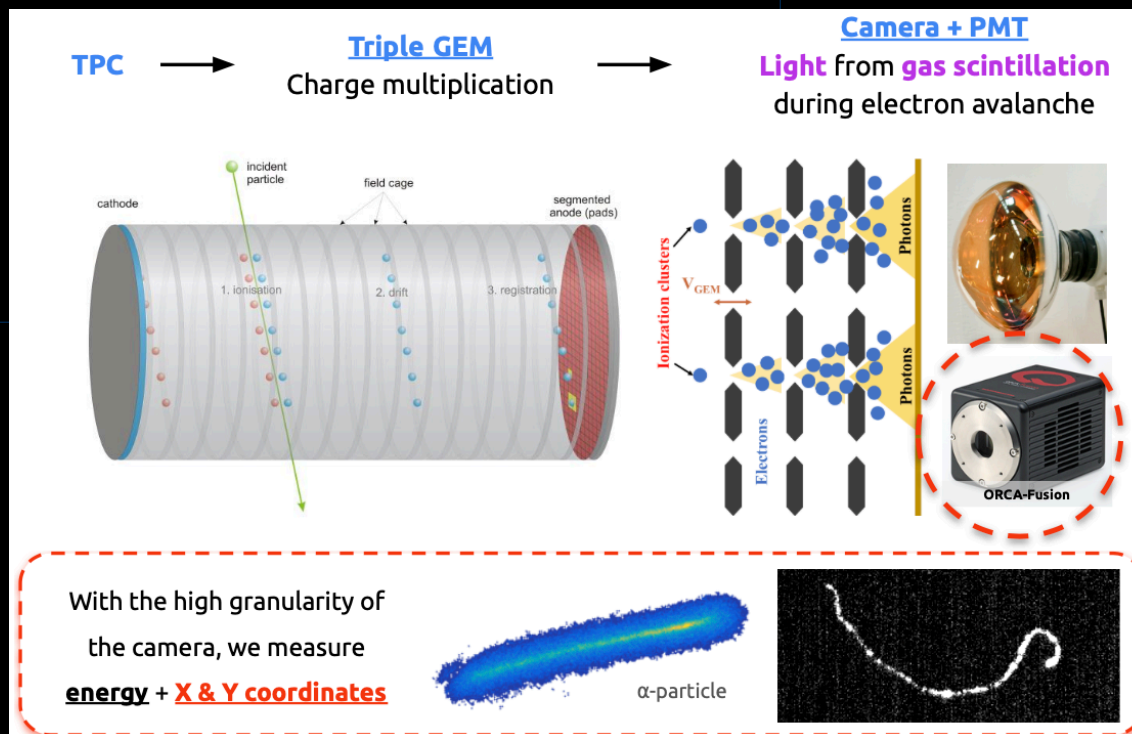


CYGNO

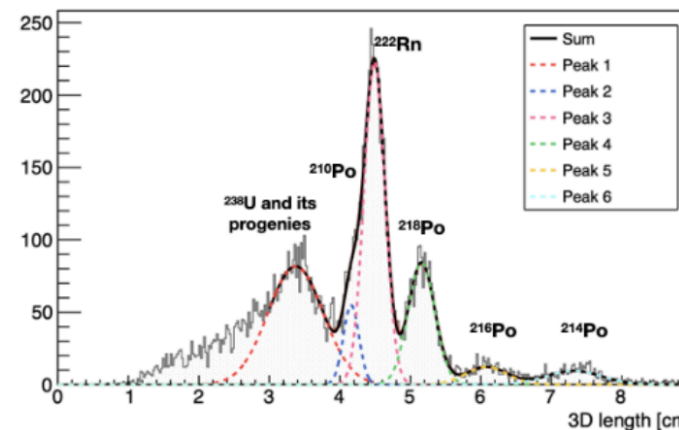
Low pressure gas TPC, optical and Q readout for direction reconstruction

–50 I LIME detector operated in LNGS for 27 months with increasing shielding to validate background model

– Calibration with AmBe source demonstrated nuclear recoil direction reconstruction with an angular resolution of 45° (over all energies)



[Eur.Phys.J.C 85 \(2025\) 11, 1261](#)



Dr. D. Marques PhD thesis, arXiv:2509.10890

L. Zappaterra Master thesis

Talk & Poster at IDM2026: S. Piacentini, June 1 & F. Scamporlino.

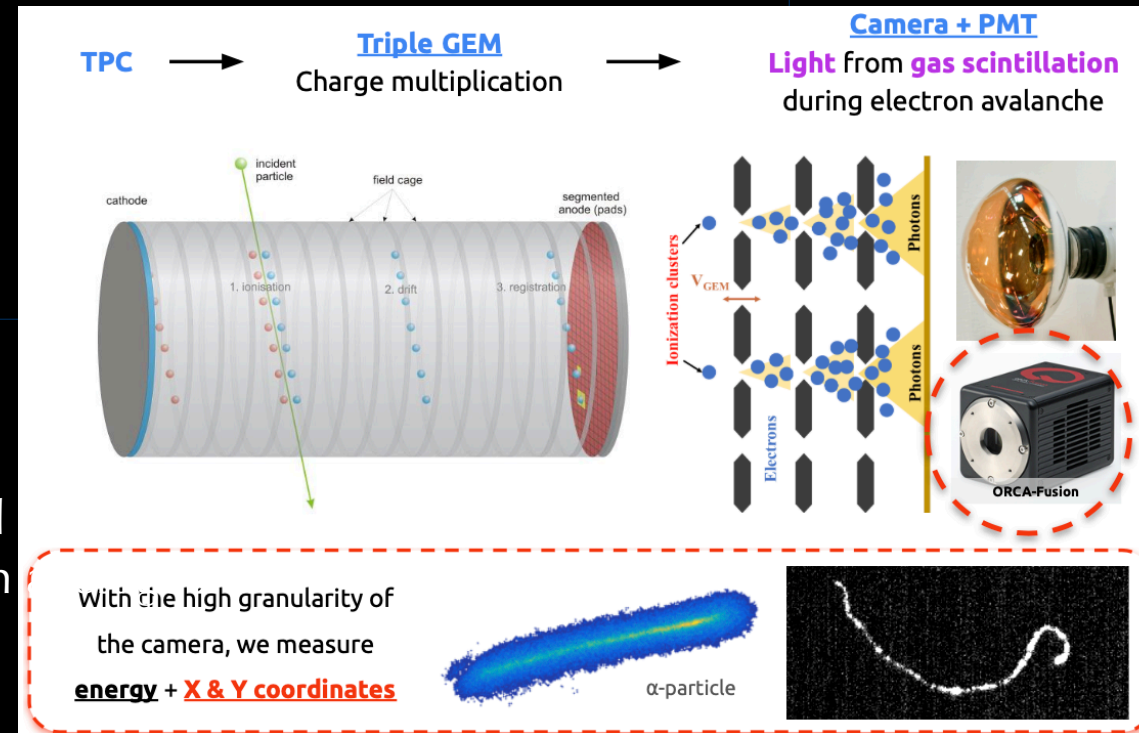
CYGNO

Low pressure gas TPC, optical and Q readout for direction reconstruction

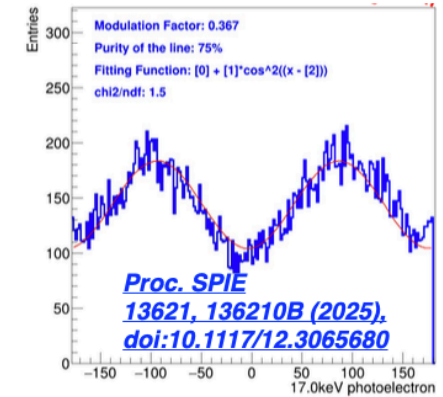
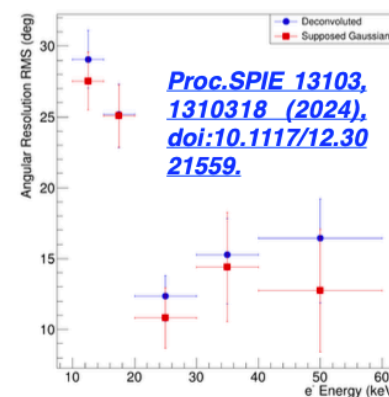
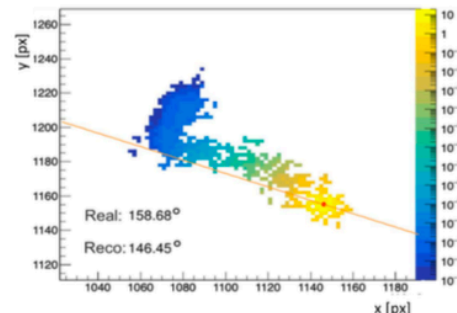
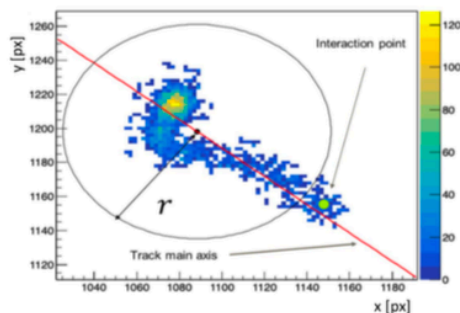
-50 I LIME detector operated in LNGS for 27 months with increasing shielding to validate background model

– Calibration with AmBe source demonstrated nuclear recoil direction reconstruction with an angular resolution of 45° (over all energies)

Improved angular resolution with PMT signal!



- Measured angular resolution on low energy ER between 10° and 30° in the 10-50 keV range, with polarimetric capability down to 17 keV



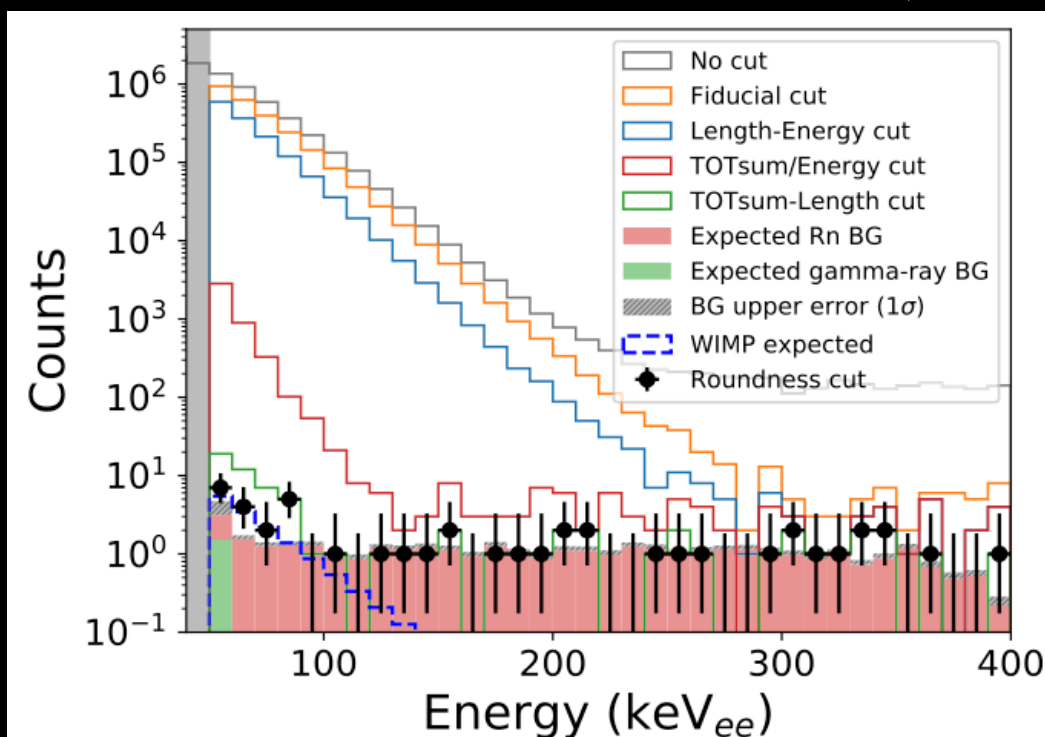
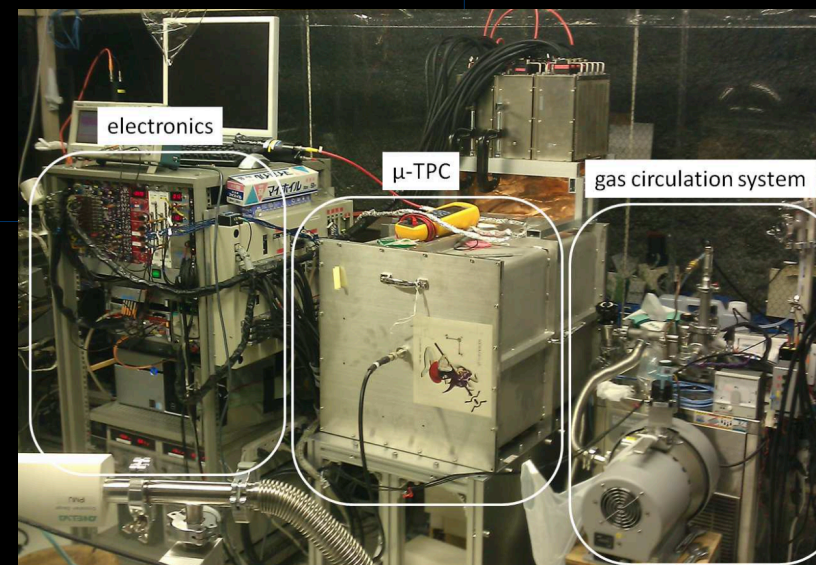
Larger **CYGNO-04** detector at LNGS installation '26-'27

NEWAGE

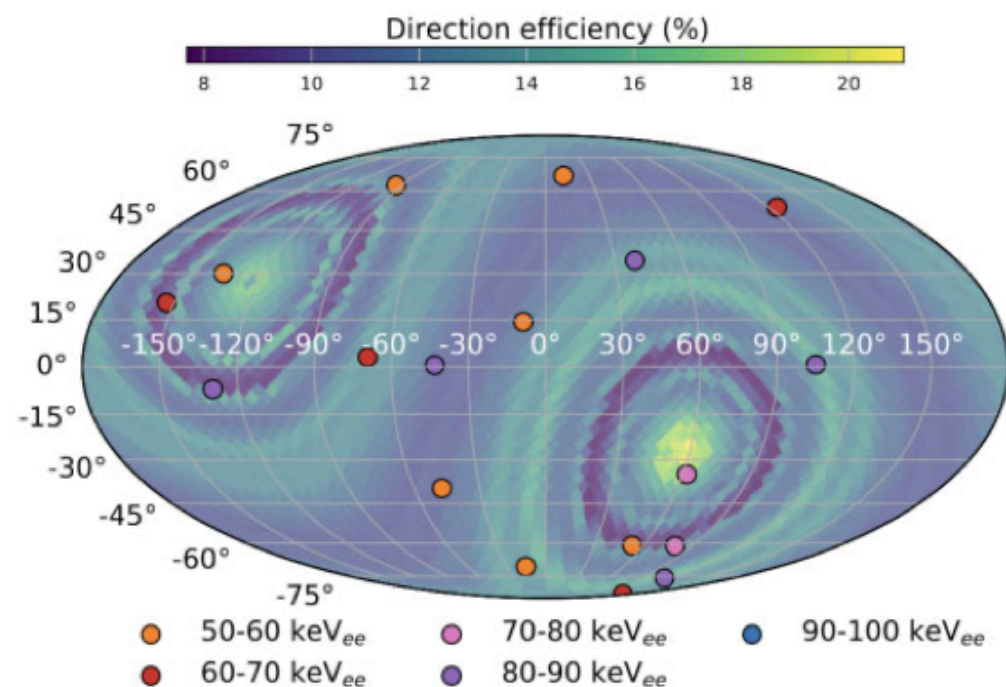
Low pressure gas TPC detectors, Kamioka (Japan)

- $30 \times 30 \times 41$ cm³ fiducial volume with CF₄ gas (0.1 atm)
- Direction reconstruction with 3D pixel readout
- **NEWAGE'23** result reaches the DAMA/LIBRA region

PTEP 2023, 103F01



- Sensitivity limited by internal Rn and gamma
- new run underway with upgraded gas system has reduced Rn by $\sim 1/3$



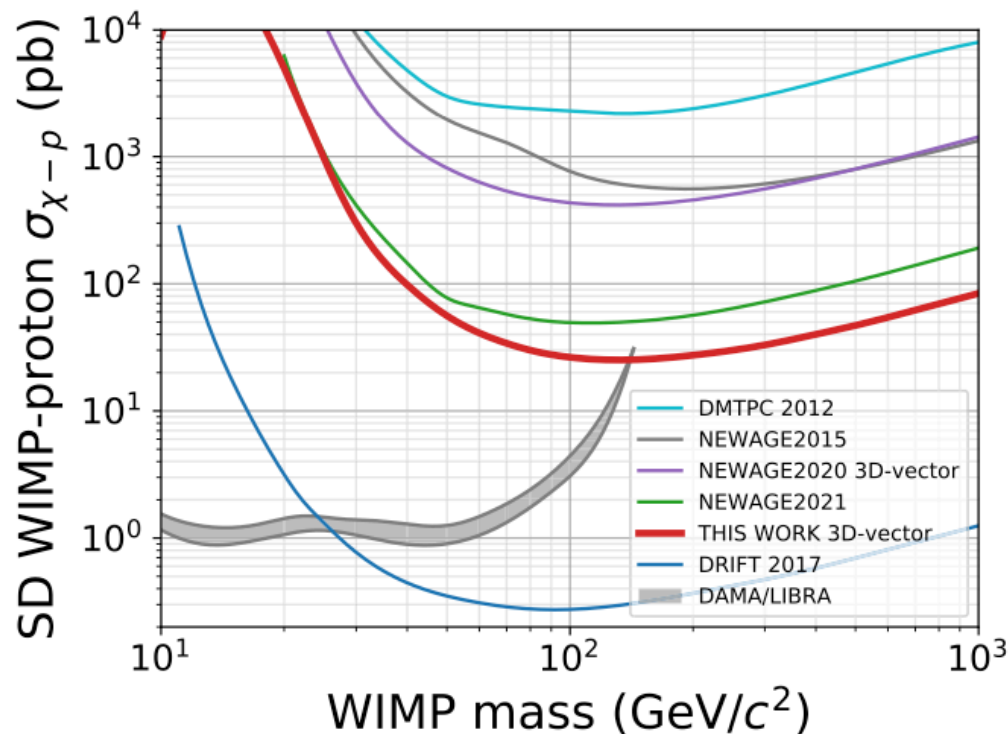
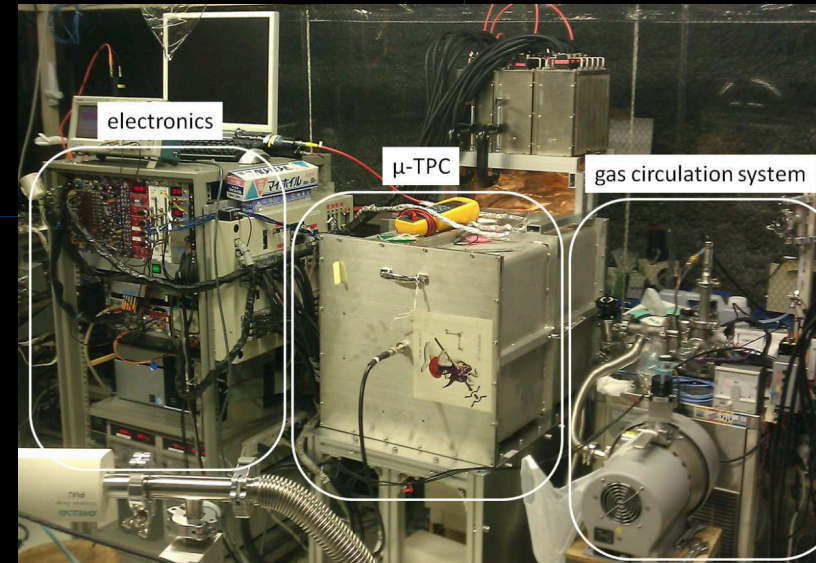
Talk at IDM2026: S. Higashino, June 1

NEWAGE

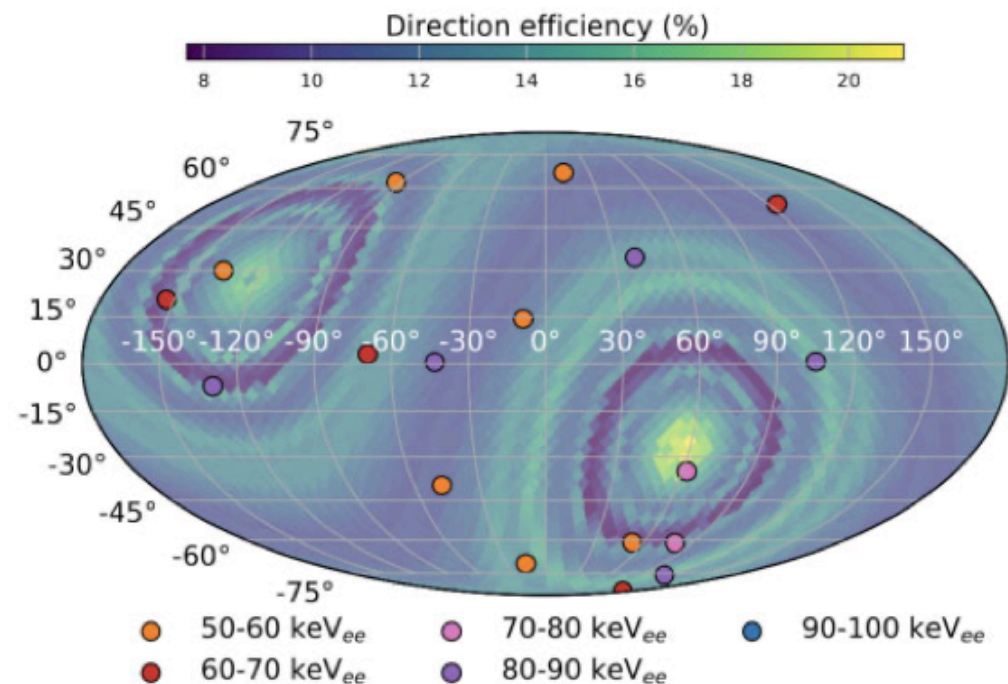
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Talk at IDM2026: S. Higashino, June 1

MIMAC (Micro-tpc MAtrix of Chambers)

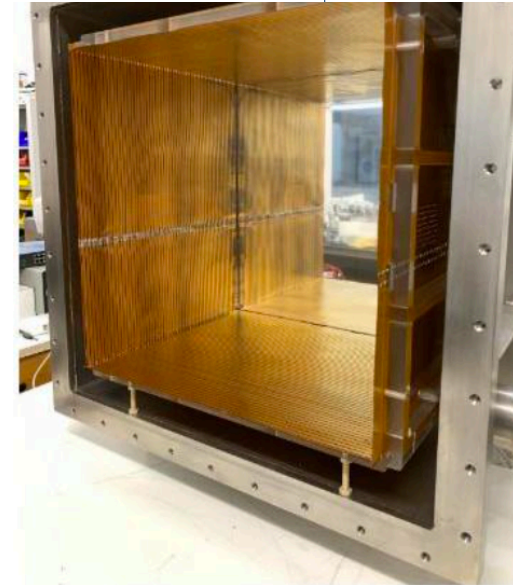
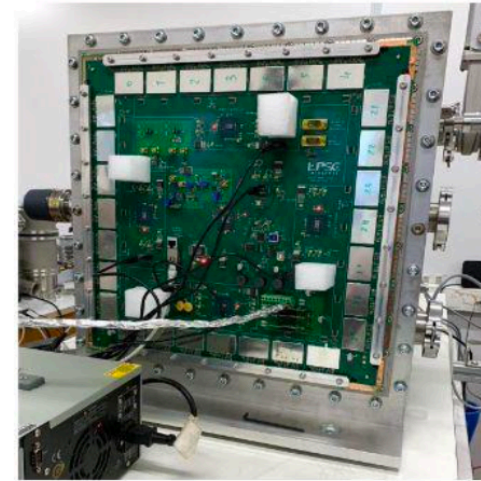
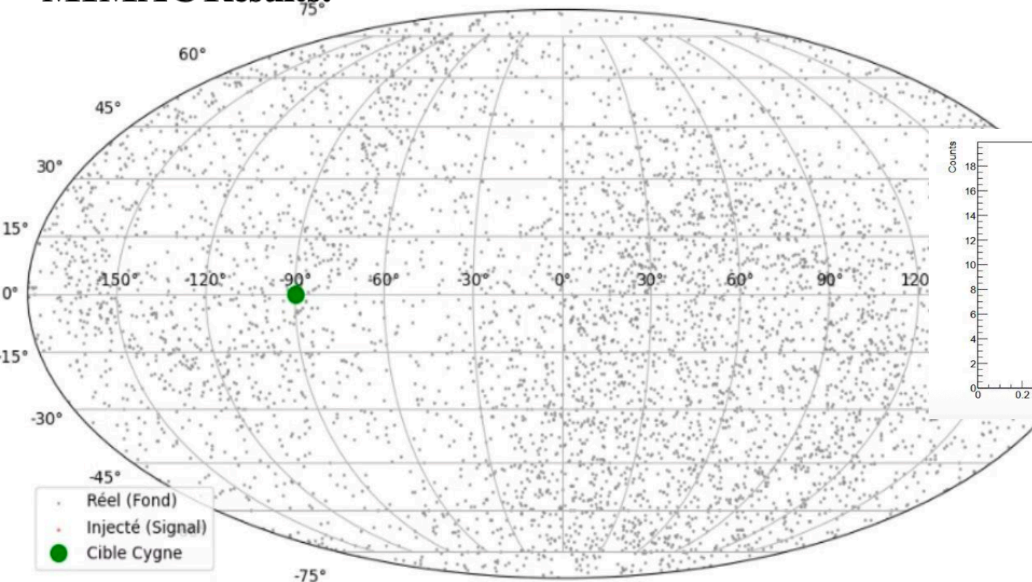
Direction measurement from 3D track reconstruction in low-pressure gas

France (Grenoble, Marseille)

China (Beijing (Tshinghua U.), Hefei (USTC))

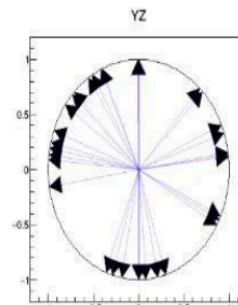
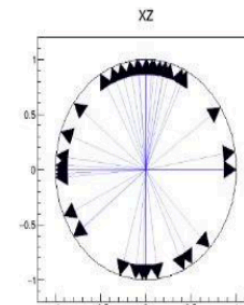
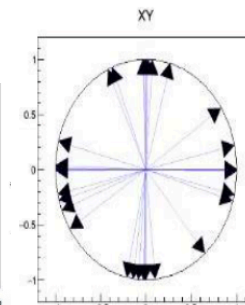
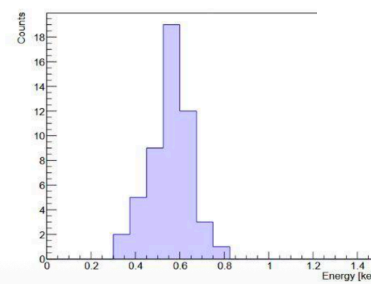
- Low-pressure micro-TPC (50% i-C₄H₁₀ + 50% CHF₃ at 30 mbar).
- Micromegas with pixelated anode (gap: 512 μm).
- Sampling at 50 MHz (20 ns).
- Location: Modane (France)
- Volume : 2x(10.8x 10.8x 25 cm³). Threshold : 500 eV
- Duration: 371days.

MIMAC Results:



Energy threshold of 300 eV

3D-Directional distribution of the 51 deuteron events

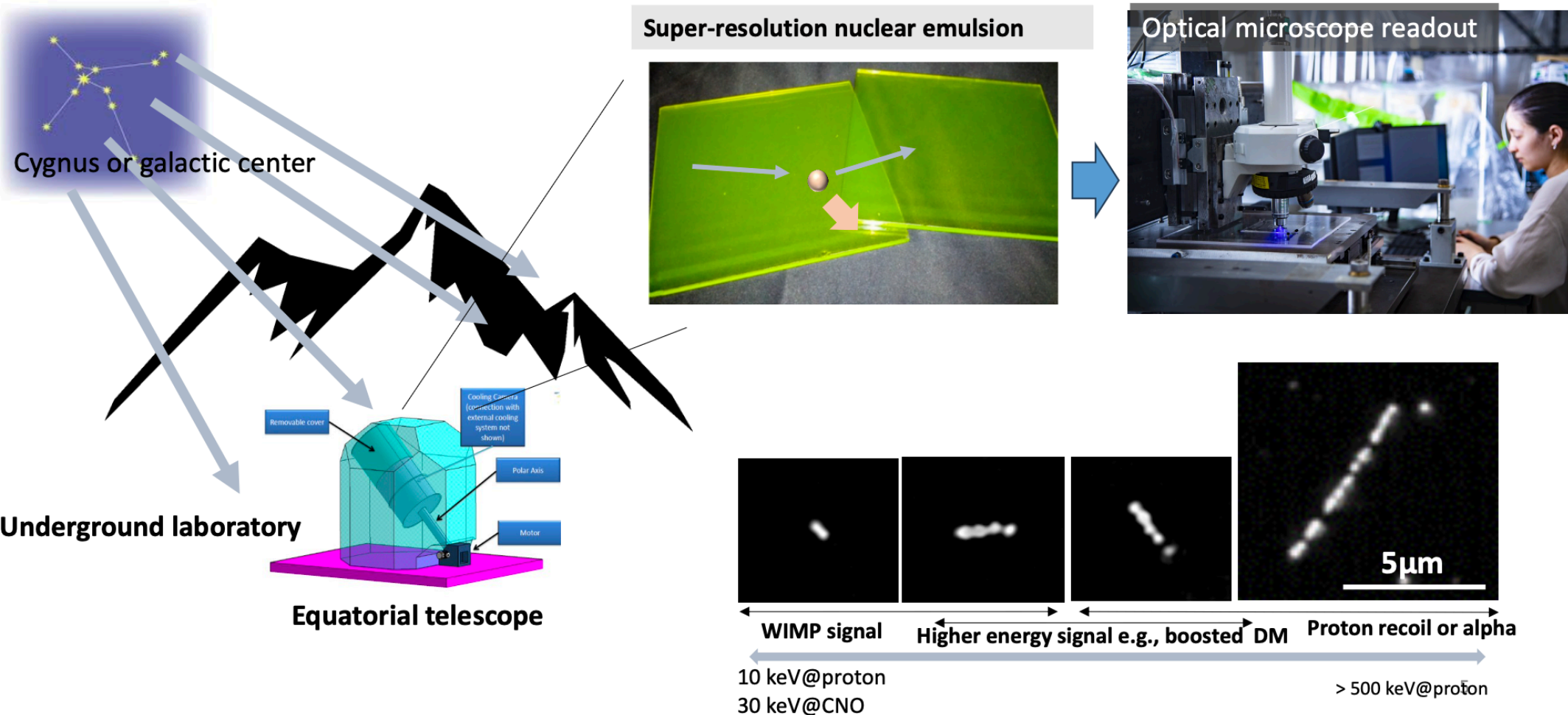


Exclusion curve (without any shielding) soon...

NEWSdm *(Nuclear Emulsions for WIMP Search directional measurement)*

Direction measurement from 3D track reconstruction in optimised nuclear emulsion (a **solid!**)

Direction Sensitive Dark Matter Search with Super-high resolution nuclear emulsion



NEWSdm *(Nuclear Emulsions for WIMP Search directional measurement)*

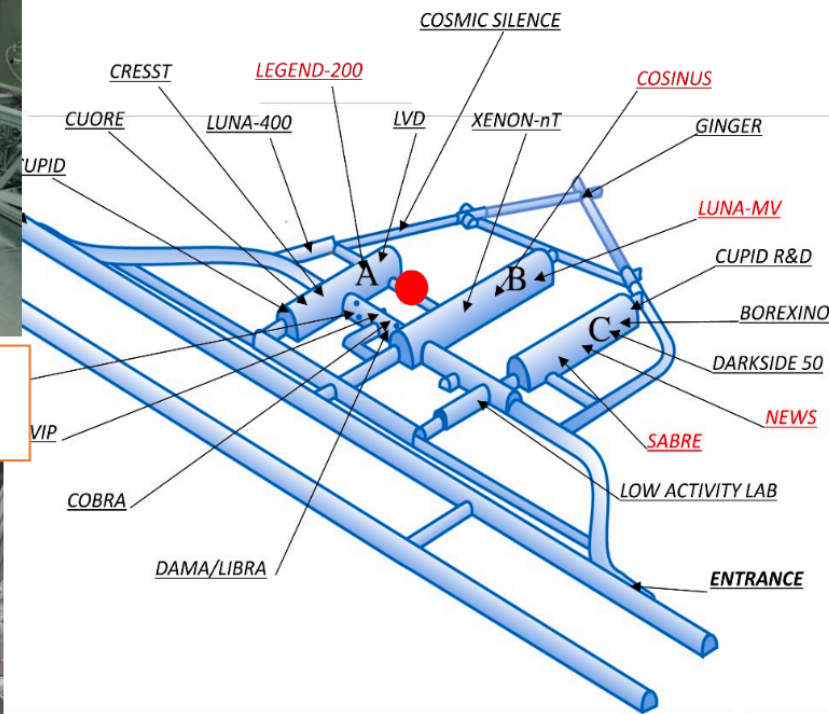
Underground activity and status at LNGS



Larger scale device



Environment for 0.1 kg scale production at CR-1 pit (Rn free room)



Preparing the telescope run with 10 kg · day exposure both WIMP and boosted DM search

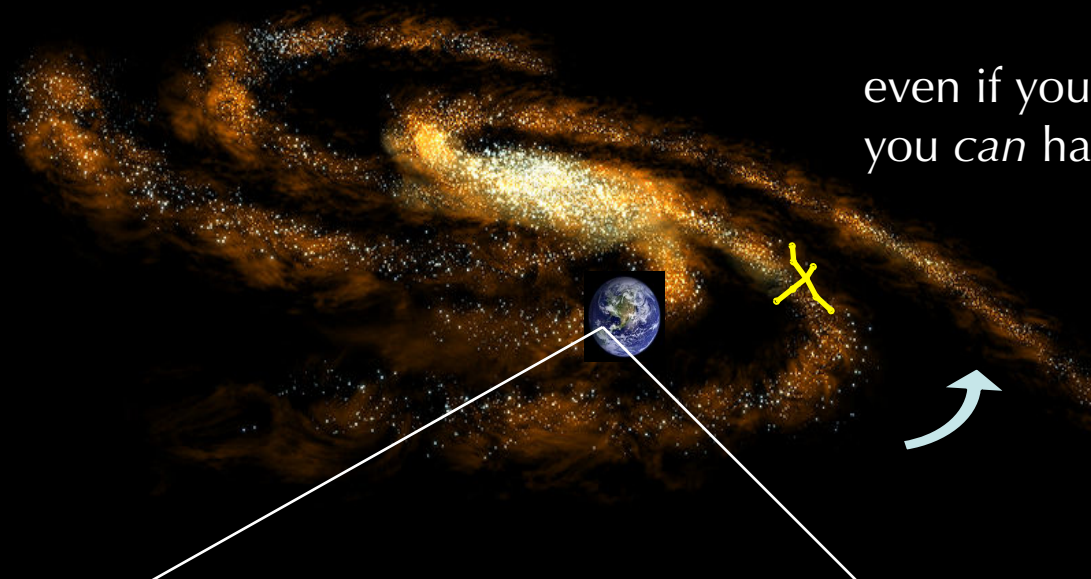
10

Sidereal Rate Modulation Searches



Sidereal Modulation Detection

The Dark Matter Wind “blows” from Cygnus



even if you *cannot* reconstruct the energy and angle of the
you can have a **sidereal rate modulation above threshold**

Detector Material:

- anisotropic **response**

DM velocity distribution:

- anisotropic **source**

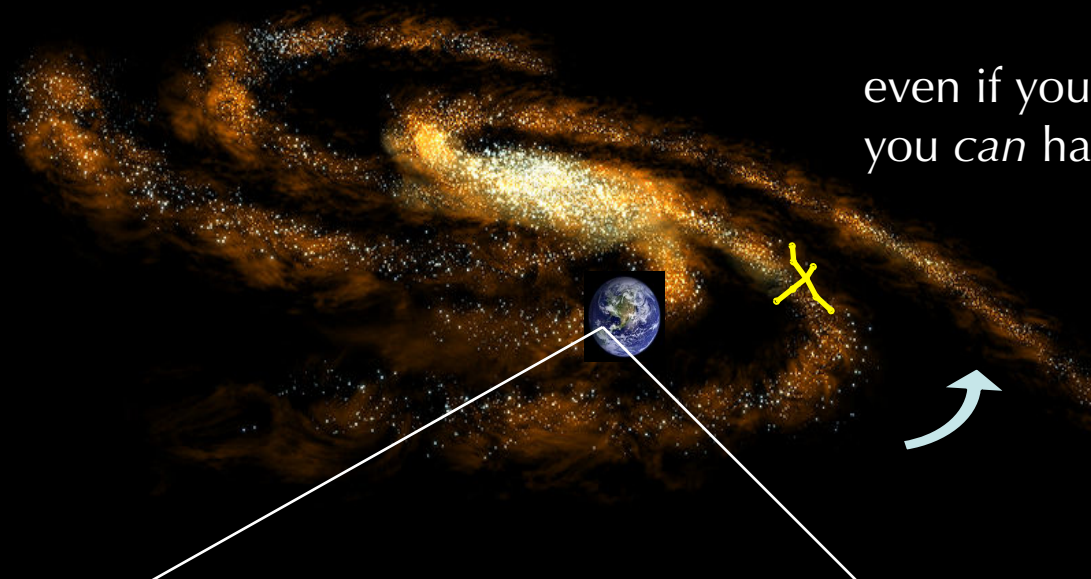
Scattering rate $R(t)$:

- varies with Earth rotation every **23.93 hours**
- $R(t)$ profile depends on DM mass, mediator type, details of NR EFT, astrophysics...

For axions too... [arXiv:2602.18006](https://arxiv.org/abs/2602.18006)

Sidereal Modulation Detection

The Dark Matter Wind “blows” from Cygnus



even if you *cannot* reconstruct the energy and angle of the
you can have a **sidereal rate modulation above threshold**

and this can gain sensitivity, even
in the absence of DM signal!

Detector Material:

- anisotropic **response**

DM velocity distribution:

- anisotropic **source**

Scattering rate $R(t)$:

- varies with Earth rotation every **23.93 hours**
- $R(t)$ profile depends on DM mass, mediator type, details of NR EFT, astrophysics...

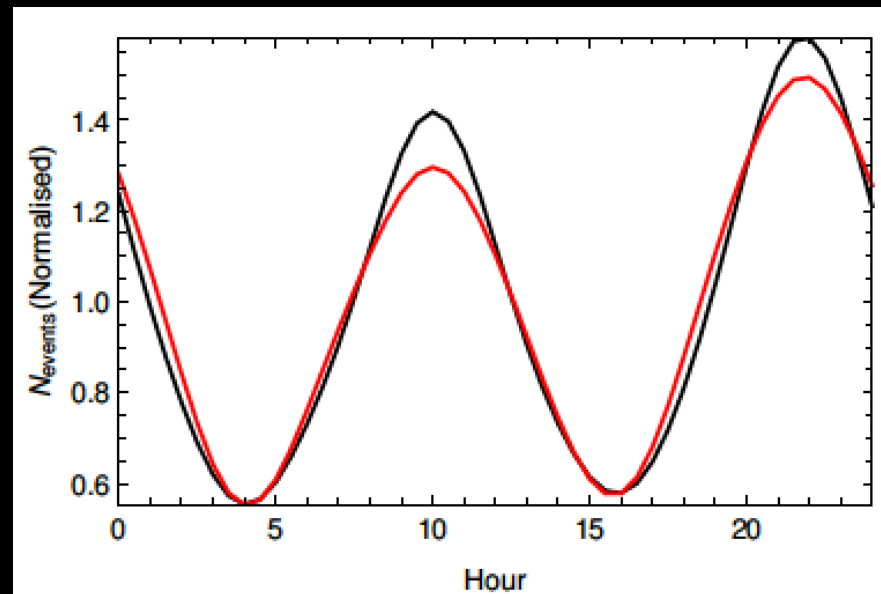
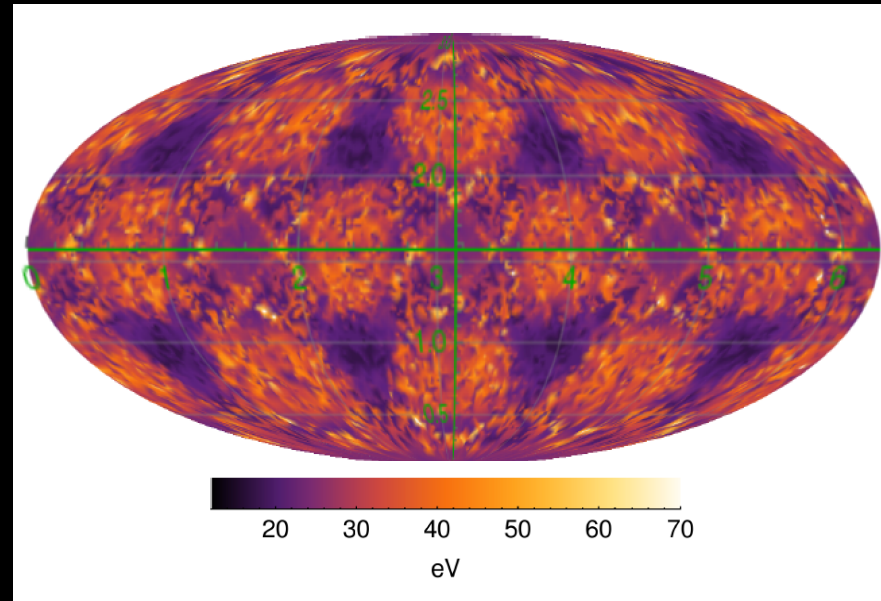
For axions too... [arXiv:2602.18006](https://arxiv.org/abs/2602.18006)

Direction Signatures with Silicon

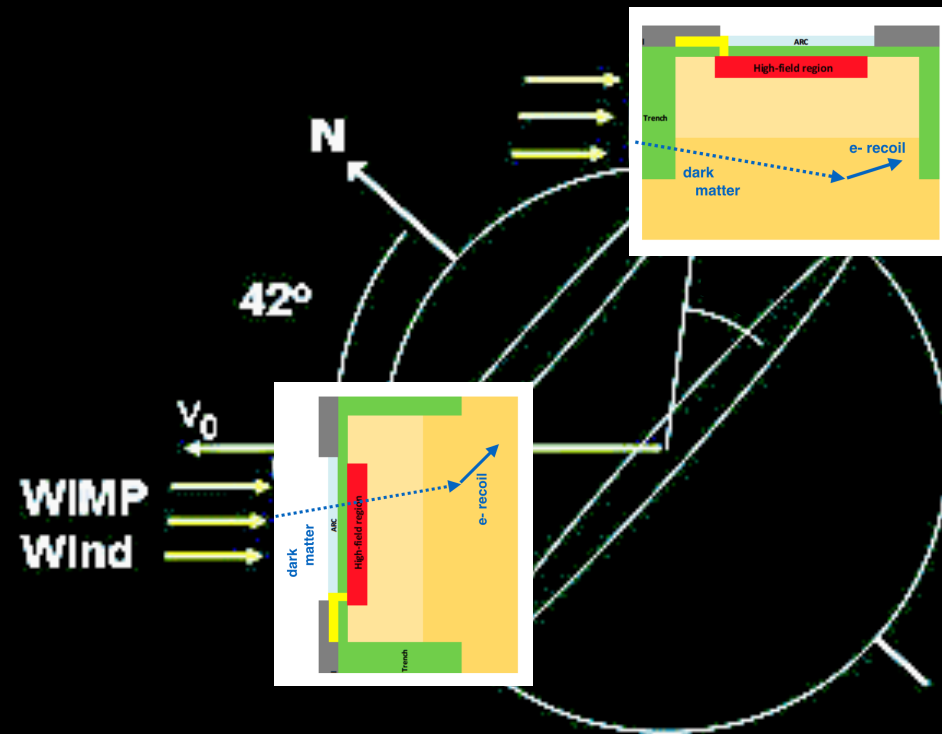
- Si is a crystal! Minimum recoil energy to create a stable defect depends on *direction* recoil relative to Si lattice

DAMIC, arXiv:2511.13961; SENSEI, arXiv:2510.20889

- planar geometry of crystal opens potential for sidereal modulation search for dark matter interactions in Si arrays (~gm to 27 kg!)



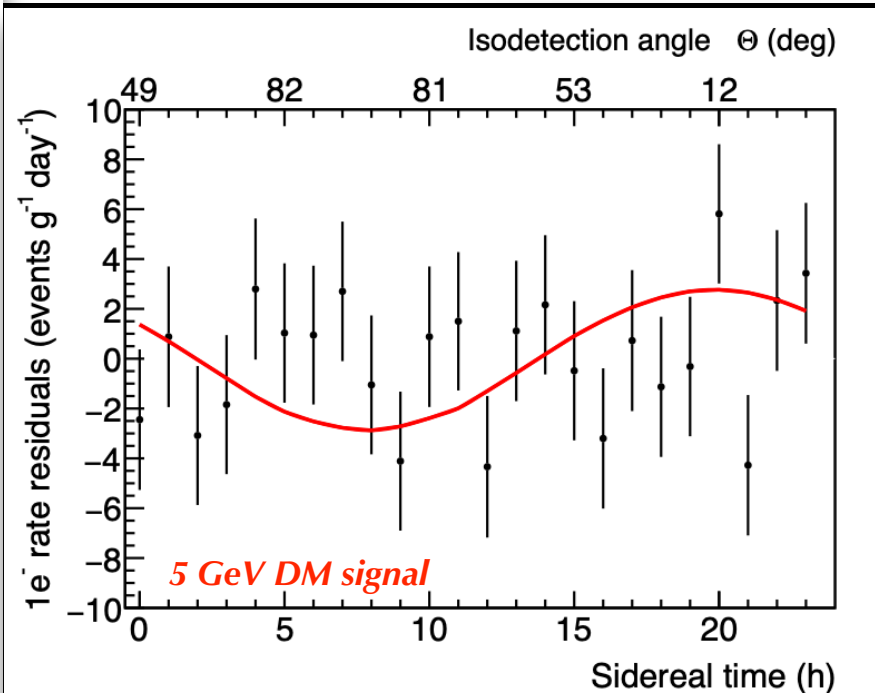
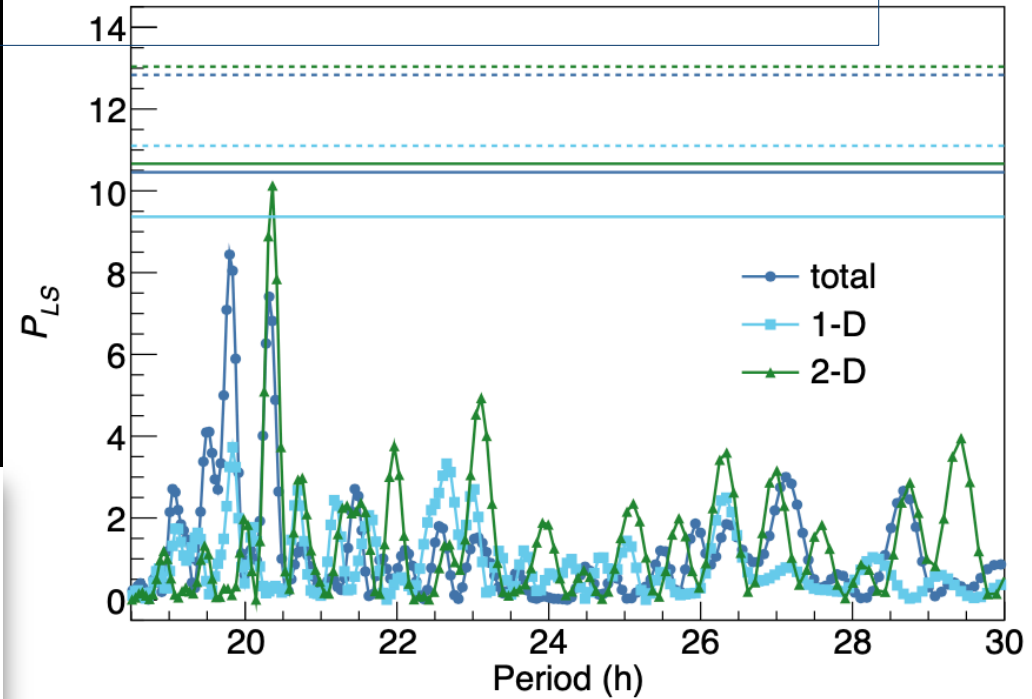
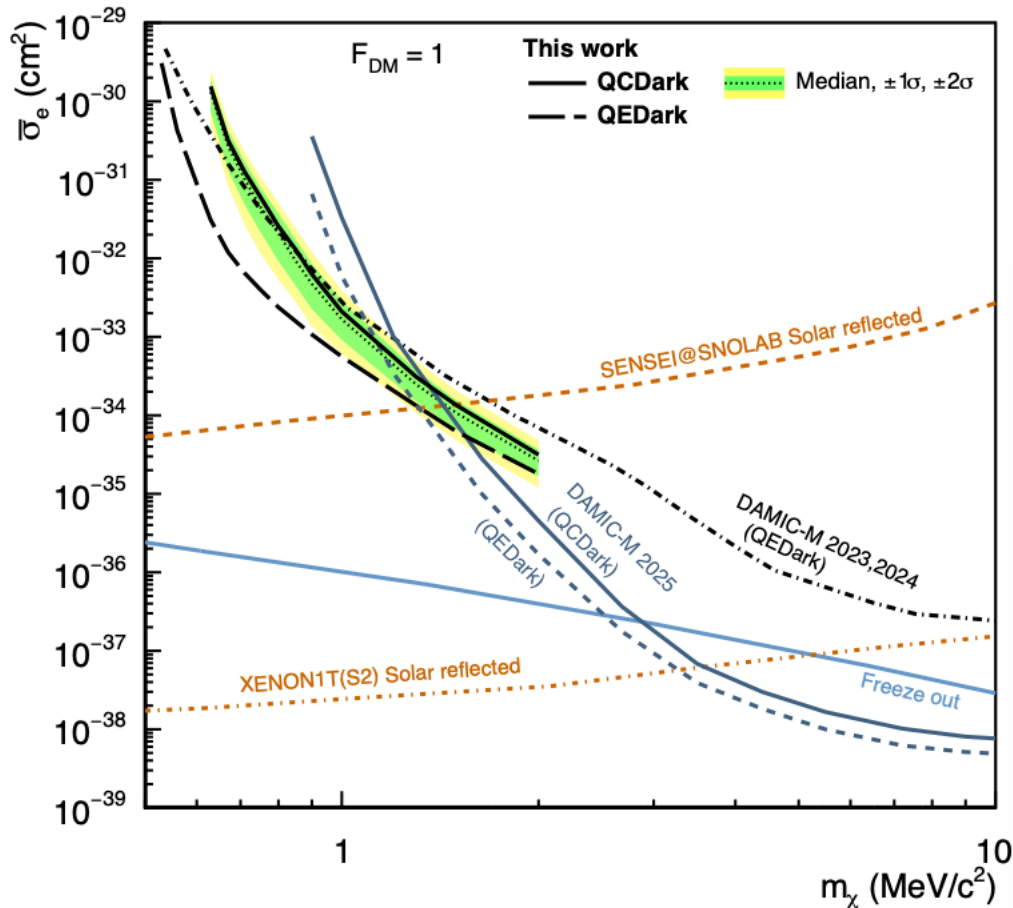
Heikinheimo et al., PRD99, 103018 (2019)



DAMIC-M

- Search for periodicity in 1 e- events shows no statistically significant modulation
- Searching for DM sidereal rate modulation improves sensitivity relative to energy-only search for $< \text{MeV}$ masses in 1 e- event sample

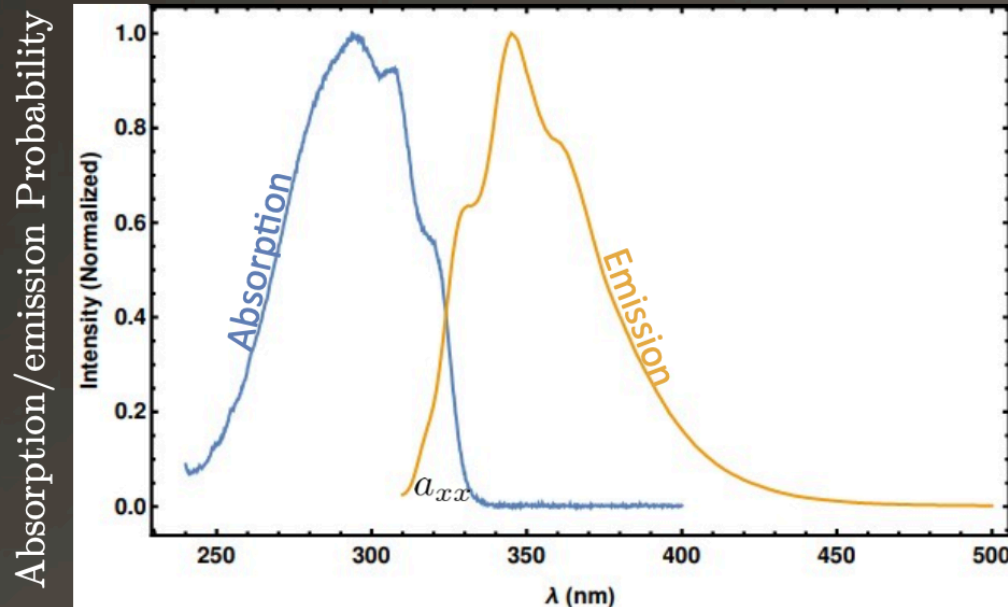
arXiv:2511.13962



Can We Design a More Anisotropic Target?

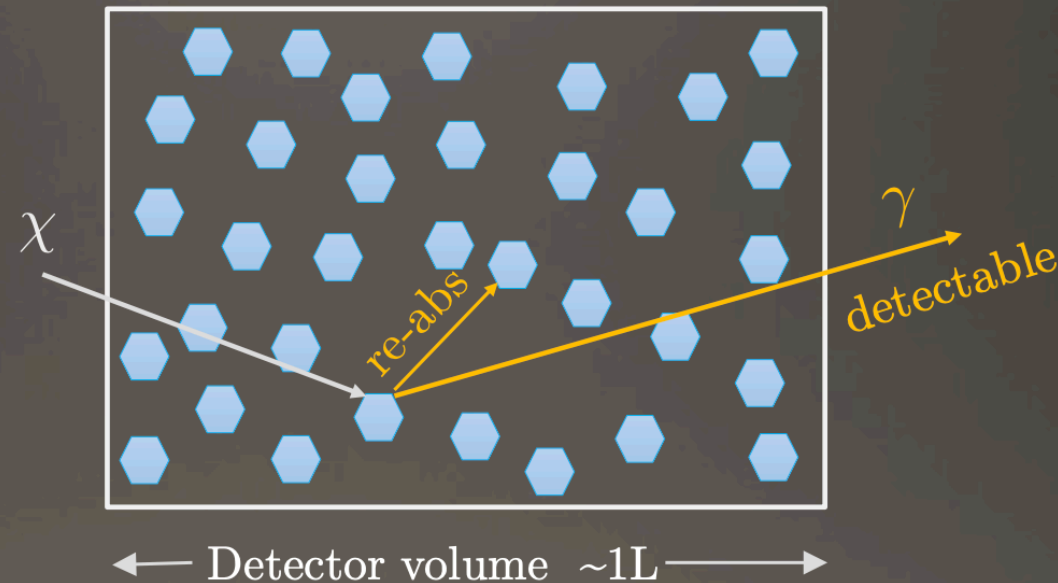
Fluorescence with DM

fluorescence spectra



Decreasing energy (E) $\rightarrow$

⬡: Chromophore:



Probability for the photon to free stream

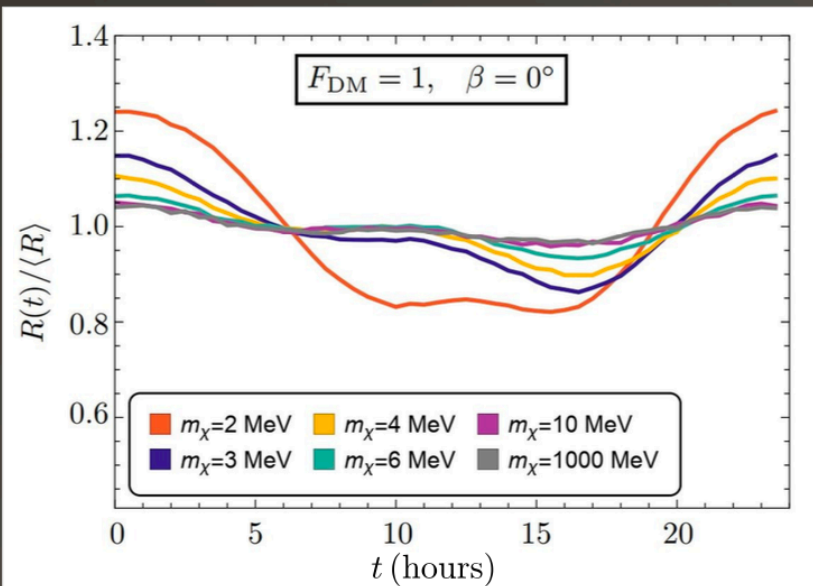
$$\Phi_{\text{FB}} \sim (1 - a_{xx}) \quad \text{e.g. molecular crystals: } \Phi_{\text{FB}} \approx 65\%$$

Carlos Blanco - 2026

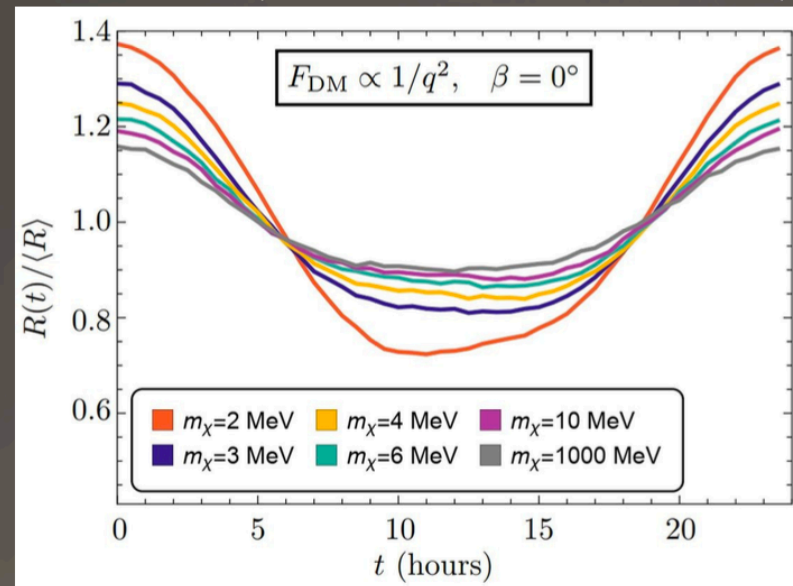
Can We Design a More Anisotropic Target?

Fluorescence with DM

(Contact interaction)



(Long-range interaction)



Predicted rate changes by up to 70% throughout the day.

That's a verifiable signal!

CB, Kahn, Lillard, McDermott: 2103.08601]

Modulation amplitude remains as high as 10% even at the highest masses. This is due to the **fundamental anisotropy of the molecular form factor**.

$$f_{\text{RMS}} = [5\% - 25\%]$$

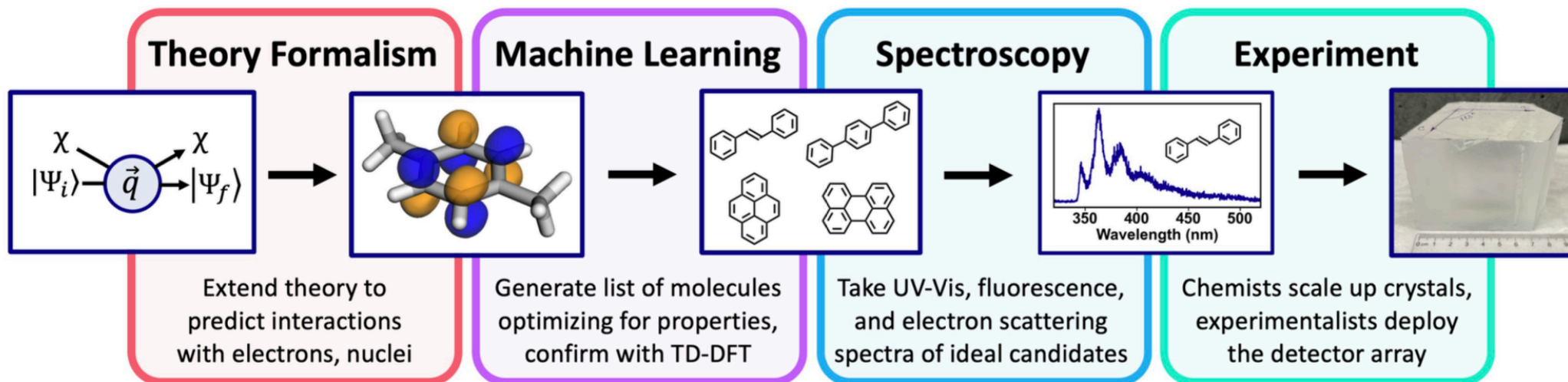
$$N_\sigma \sim f_{\text{RMS}} \sqrt{N_{\text{events}}}$$

Carlos Blanco - 2026

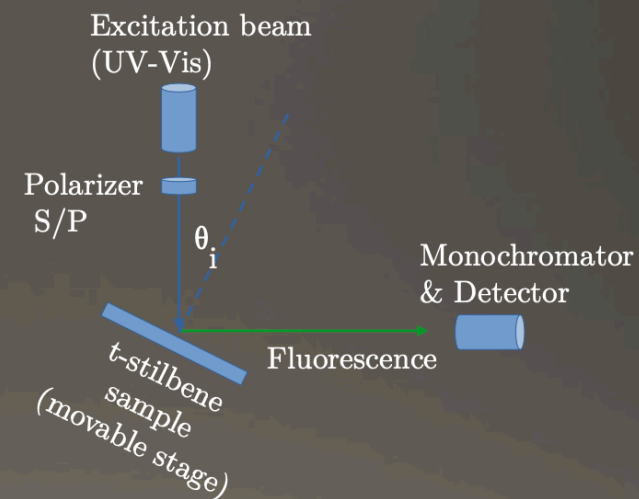
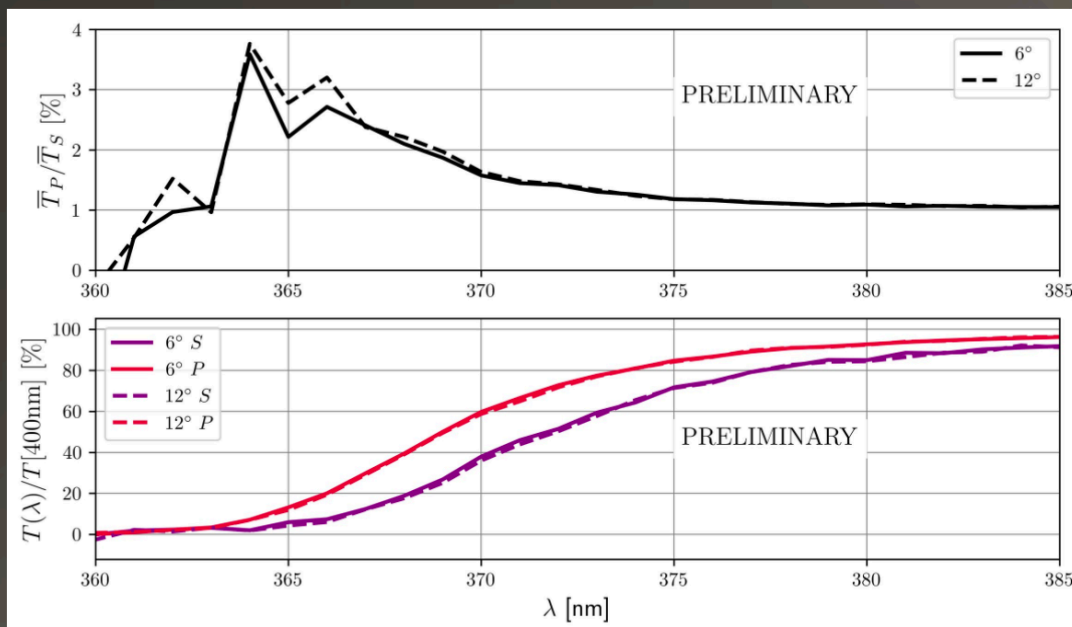
[CB, Foster, Kahn, Lillard: 2602.15947]

Can We Design a More Anisotropic Target?

Development pipeline for designer molecules:



Calibrate
anisotropy
via photo-
absorption



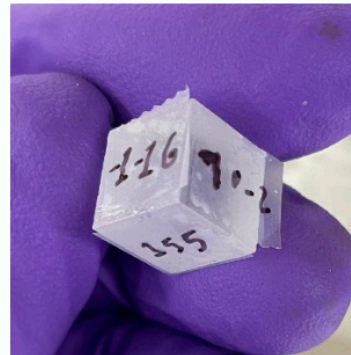
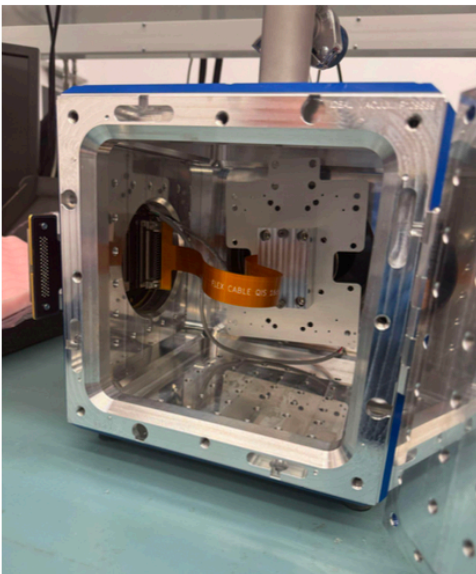
$$A_{UV} \sim n_{\text{mol}} |\vec{\epsilon} \cdot \langle \Psi_f | \mathbf{r} | \Psi_i \rangle|^2 \quad A_{UV} \approx \text{const} - T_{UV}$$

Prototype Experiment at Fermilab!

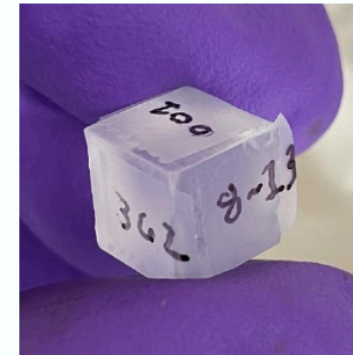
DIANA:

Daily modulation in an
Intrinsically Anisotropic Array

- Eight (8) gram-sized trans-stilbene crystals
- Skipper CCD for single-photon readout
- Calibrating detector response now, then on to MINOS!



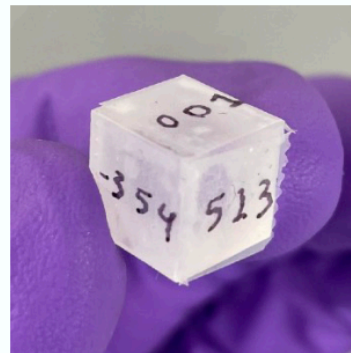
$(-1,-1,6), (7,0,-2), (1,5,5)$



$(0,0,1), (8,-1,3), (3,6,2)$



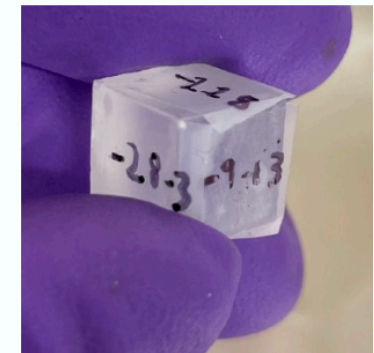
$(-9,0,4), (0,1,7), (-1,5,-3)$



$(0,0,1), (5,1,3), (-3,5,4)$



$(0,0,1), (2,0,1), (1,-4,0)$



$(-1,1,8), (-9,-1,-3), (-2,8,-3)$

*T-stilbene photos and normal vectors
from Dane Johnson (MIT)*

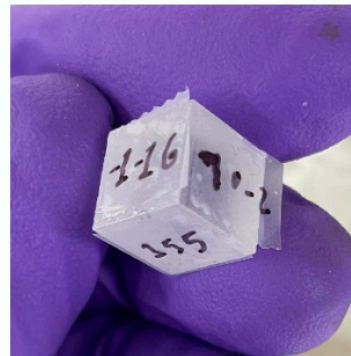
Nora Hoch, "Developing Novel Light Detectors for MeV Dark Matter Experiments", CPAD 2024, Nov 22 2024

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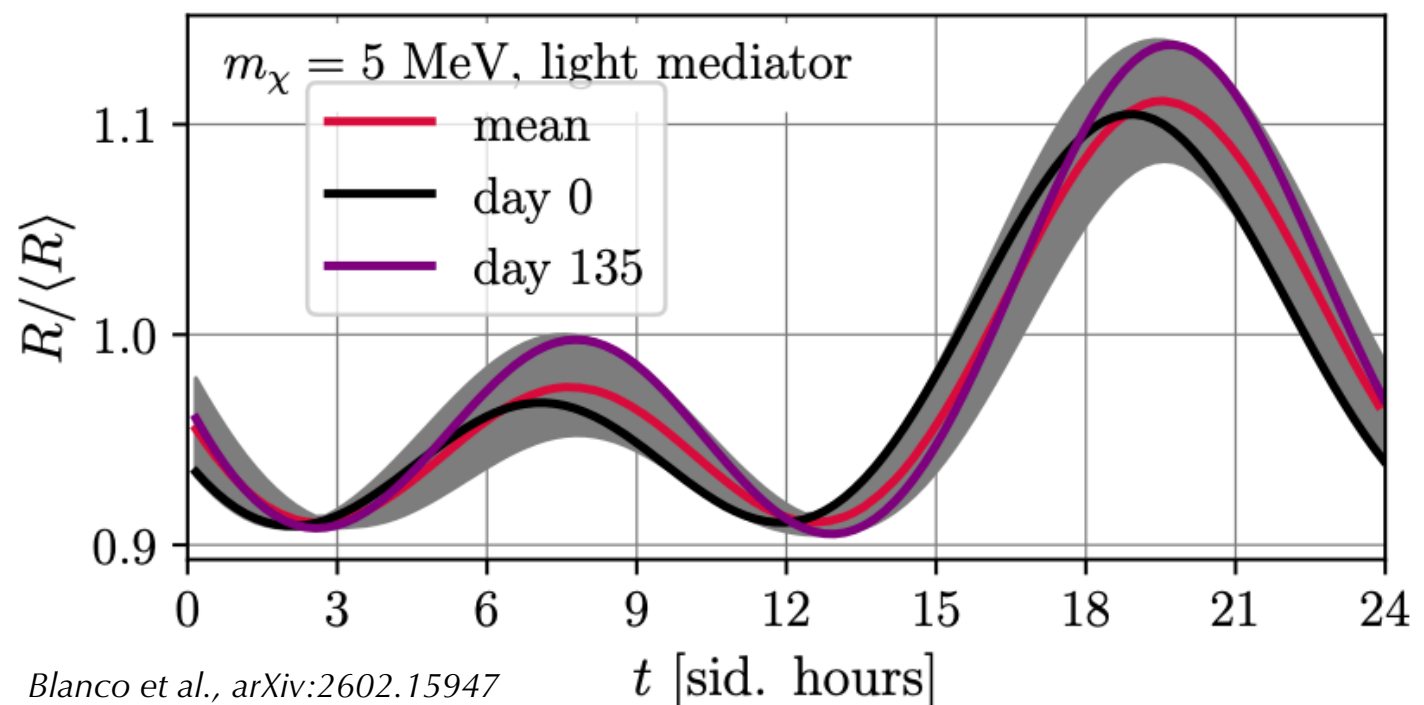
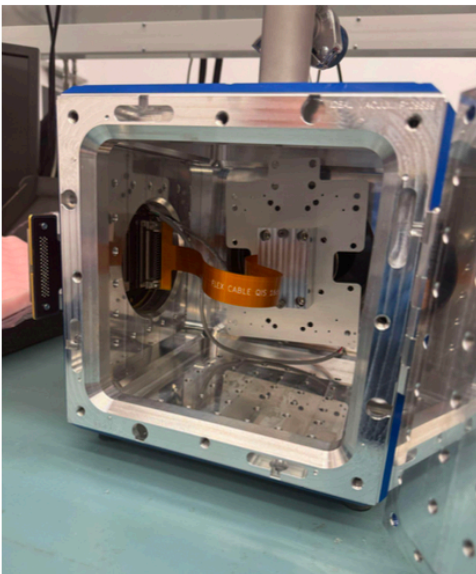
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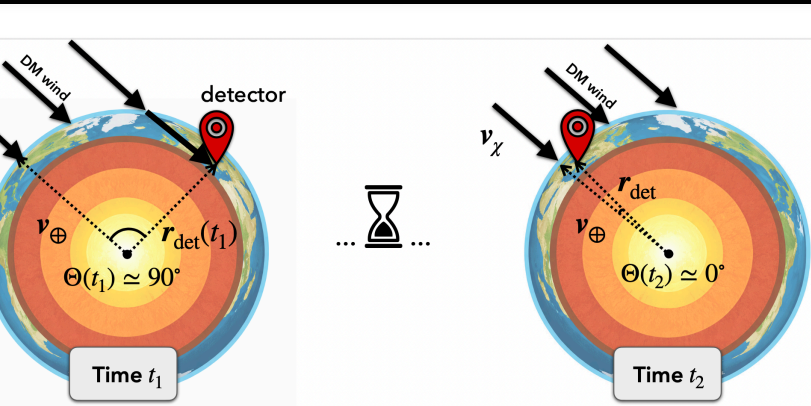


$(-9,0,4), (0,1,7), (-1,5,-3)$



Anisotropic Dark Matter Flux

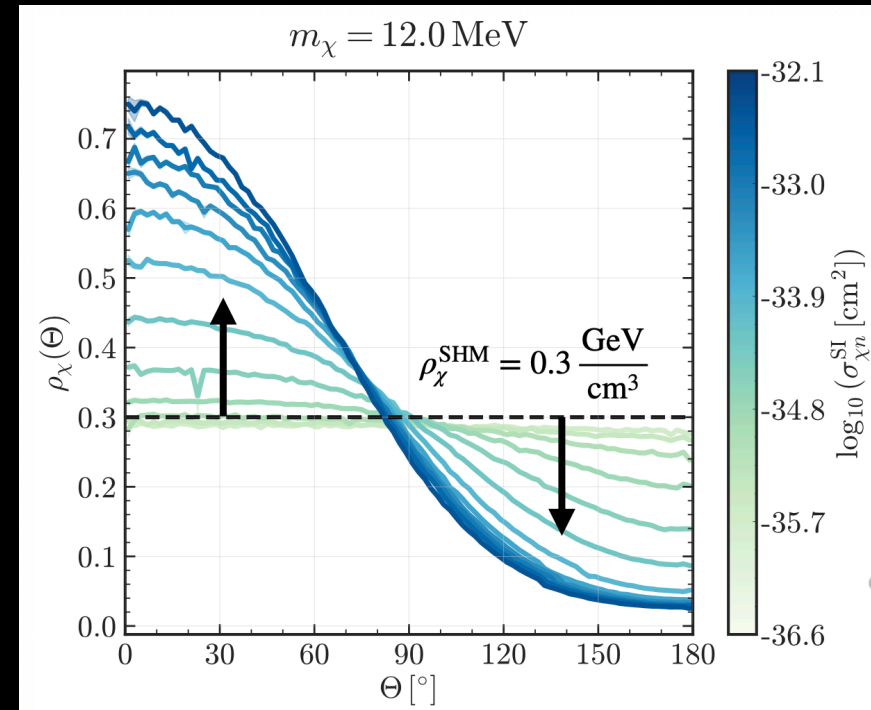
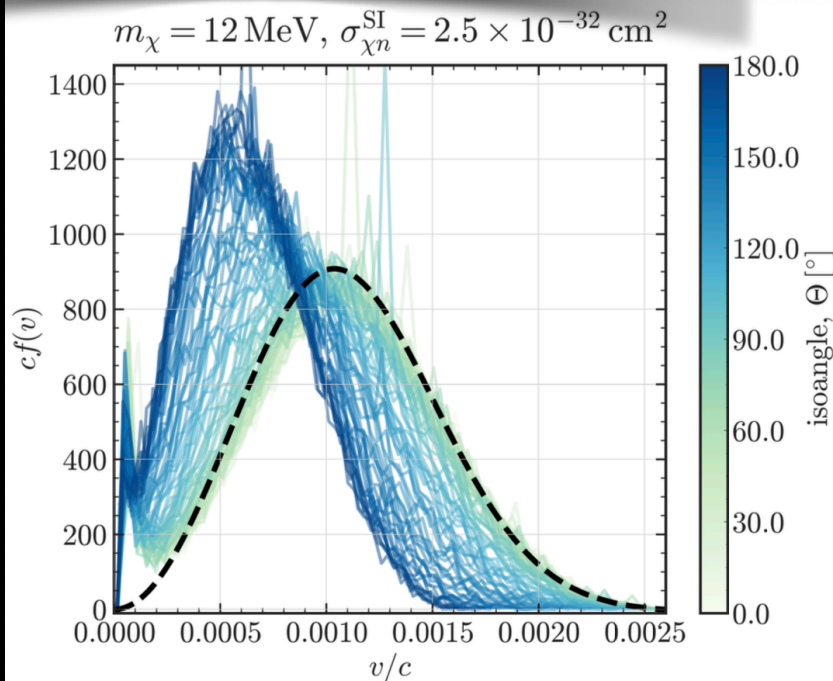
Direction modulation + earth shadowing
modifies both incident dark matter
velocity distribution AND density at the detector



Scattering rate Sun's velocity around the galaxy WIMP velocity

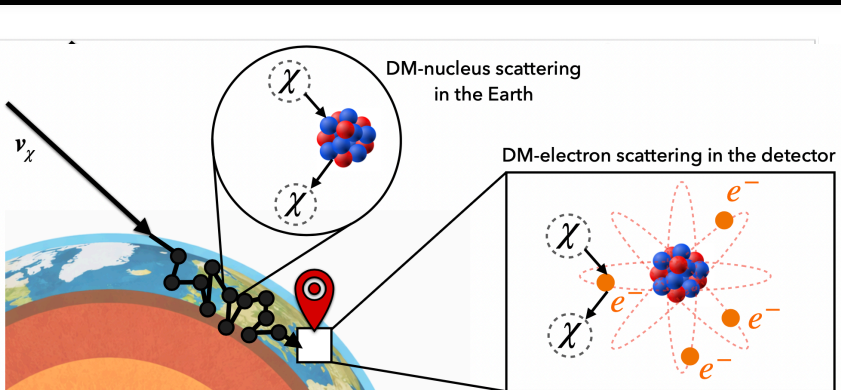
$$\frac{dR}{dQ} = (\sigma_0 \rho_0 / \sqrt{\pi} v_0 m_\chi m_T^2) F^2(Q) T(Q)$$

WIMP energy density, 0.3 GeV/cm³ Form factor



Anisotropic Dark Matter Flux

Direction modulation + earth shadowing
modifies both incident dark matter
velocity distribution AND density at the detector



$$\frac{dR}{dQ} = (\sigma_0 \rho_0 / \sqrt{\pi} v_0 m_\chi m_T^2) F^2(Q) T(Q)$$

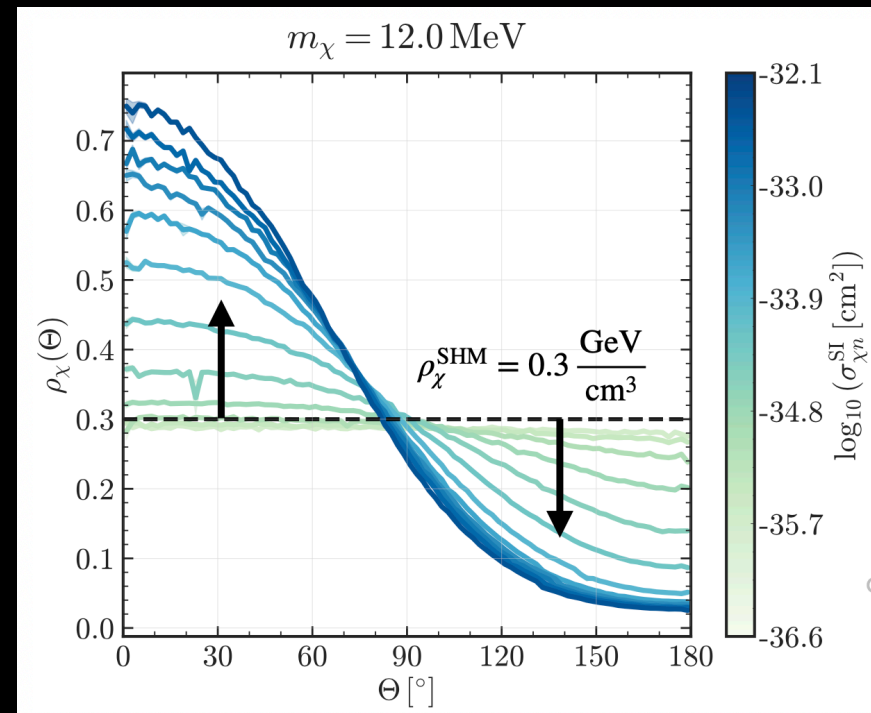
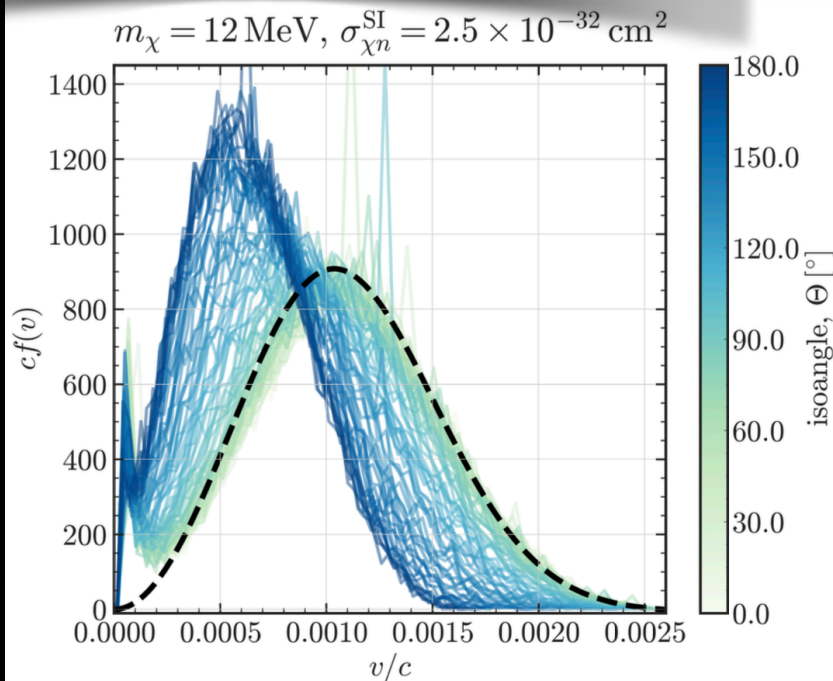
Scattering rate

Sun's velocity around the galaxy

WIMP velocity

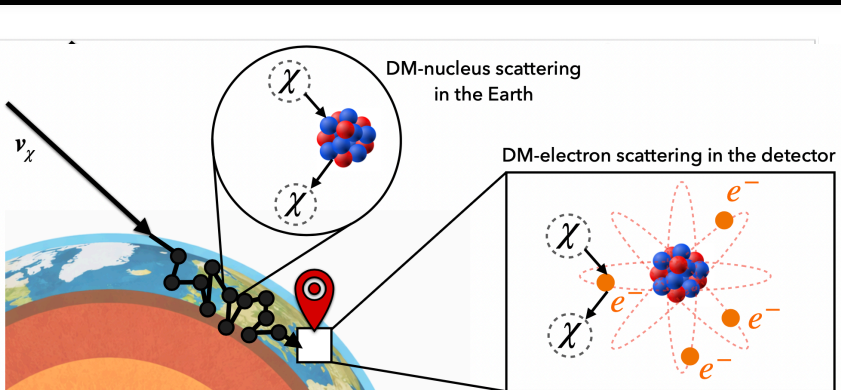
WIMP energy density, 0.3 GeV/cm^3

Form factor



Anisotropic Dark Matter Flux

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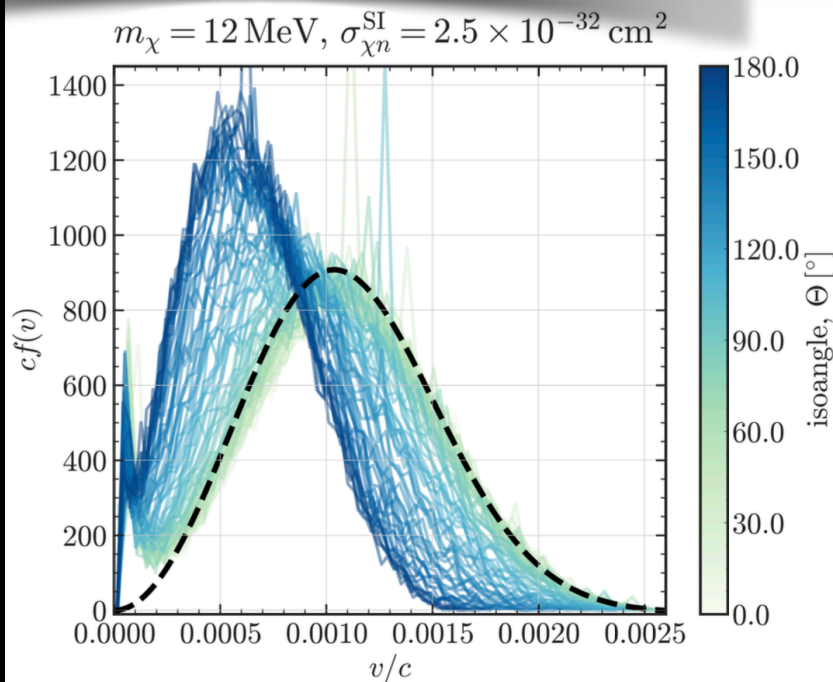
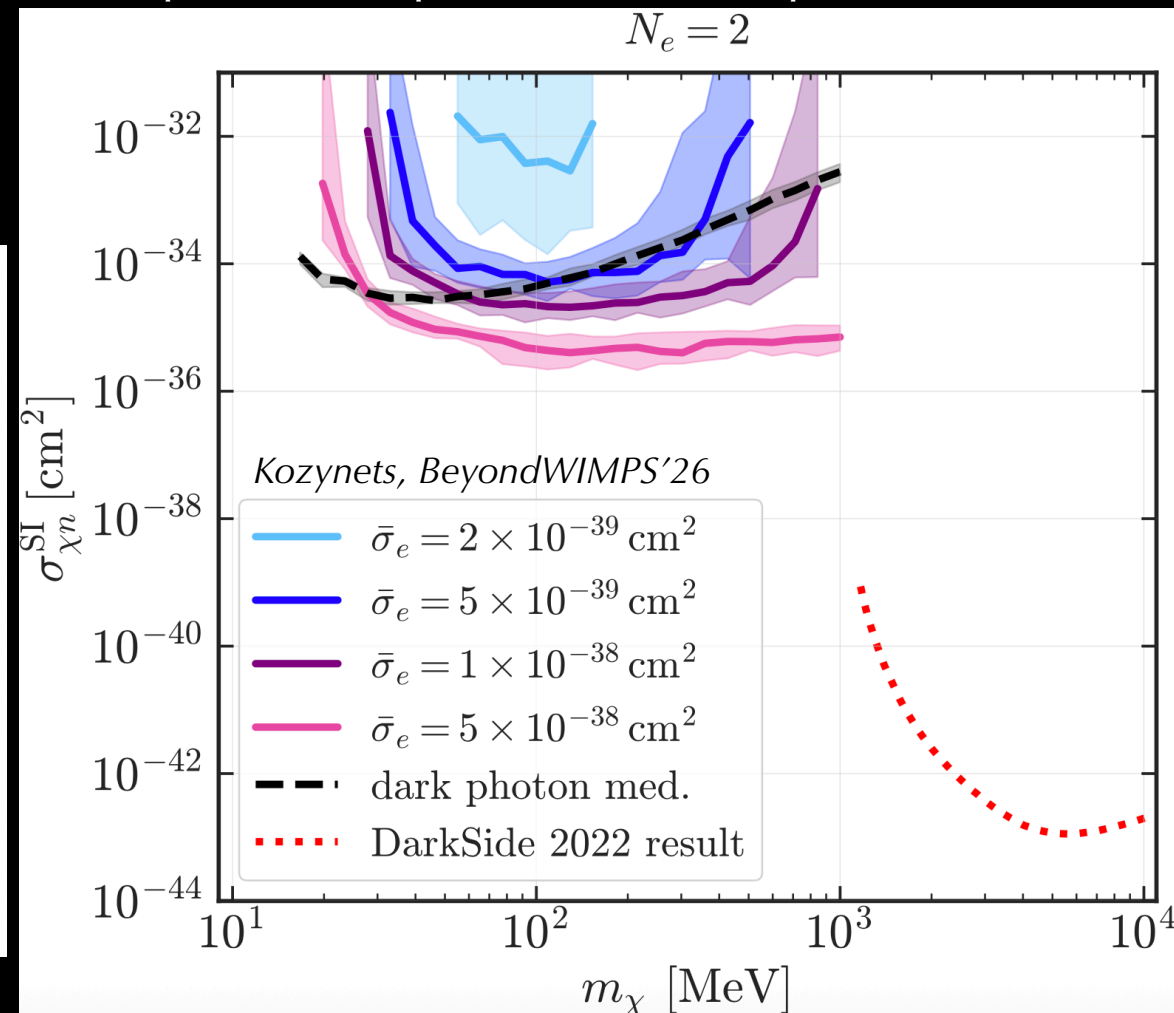


$$\frac{dR}{dQ} = (\sigma_0 \rho_0 / \sqrt{\pi} v_0 m_\chi m_T^2) F^2(Q) T(Q)$$

Labels for the equation components:

- Scattering rate: dR/dQ
- Sun's velocity around the galaxy: v_0
- WIMP velocity: v_χ
- WIMP energy density, 0.3 GeV/cm^3 : ρ_0
- Form factor: $F^2(Q)$

Reinterpretation of published data (liquid):





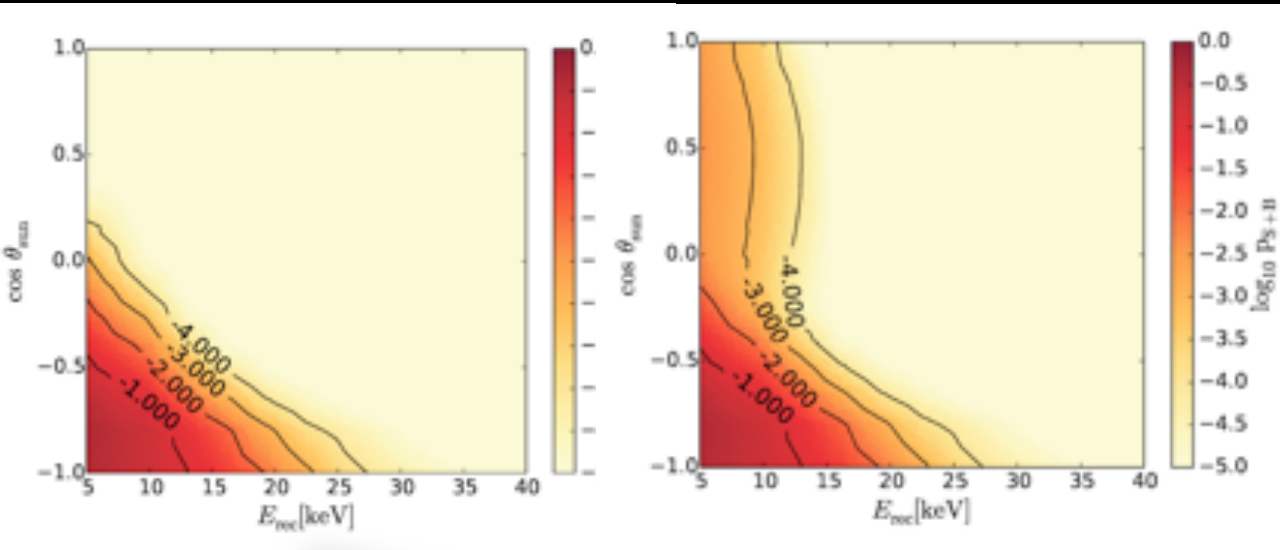
Closing thought:

Can we really get beyond
the neutrino bound with these
distinctive signatures?



There is reason for optimism!

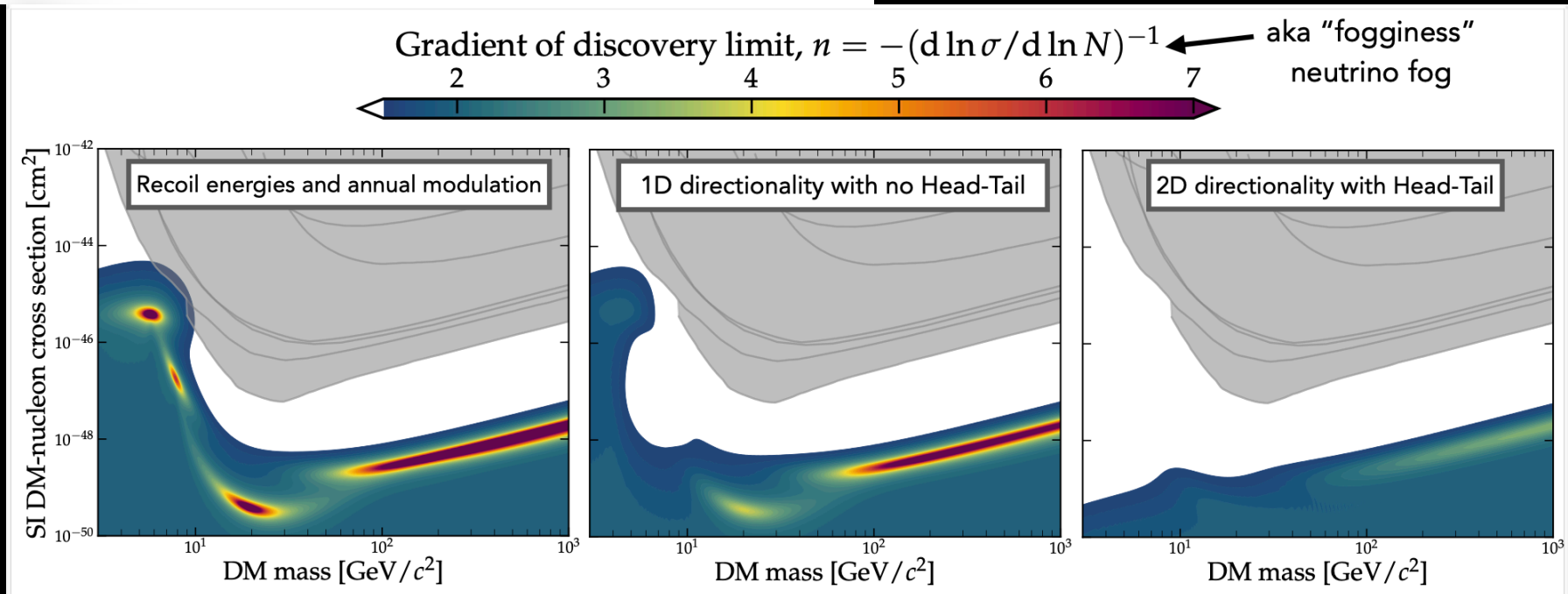
There is huge experimental progress.



Directional detectors:
(energy, angle, time) of neutrino background vs. DM signal differ.

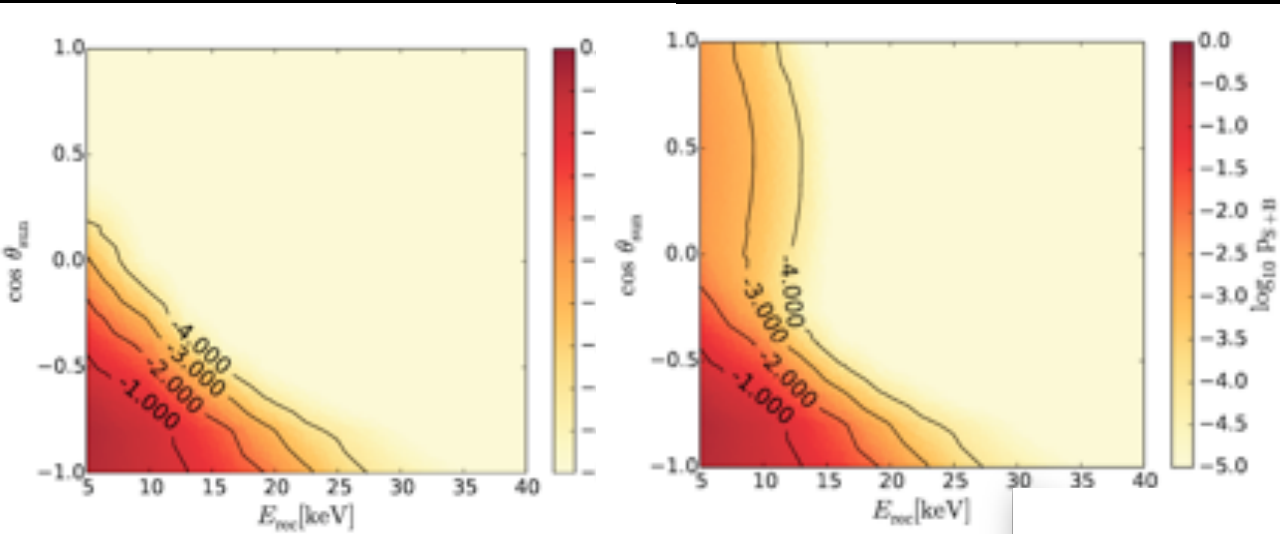
- no ν bound for directional detectors
Grothaus, Fairbairn, JM, Phys.Rev.D90 (2014)

C. O'Hare, IDM2024



There is reason for optimism!

There is huge experimental progress.

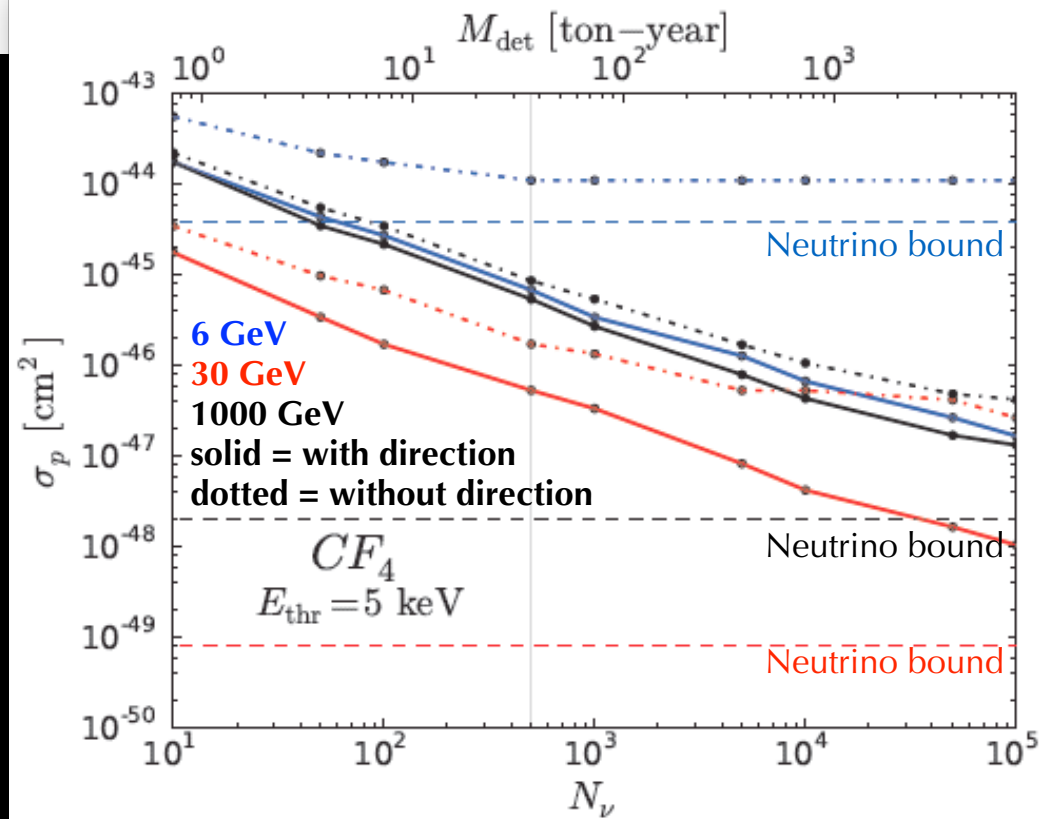


Directional detectors:
(energy, angle, time) of neutrino background vs. DM signal differ.

- no ν bound for directional detectors
Grothaus, Fairbairn, JM, Phys.Rev.D90 (2014)

Non-directional detectors:

- Rate modulation searches retain sensitivity, although gain scales with $\sqrt{\text{time}}$ instead of linearly in time (with zero background)
- Systematic uncertainty reduction becomes crucial!
- Increased effort towards global analysis, combining experiments at different latitudes



Thank you!

IDM2026

ZARAGOZA



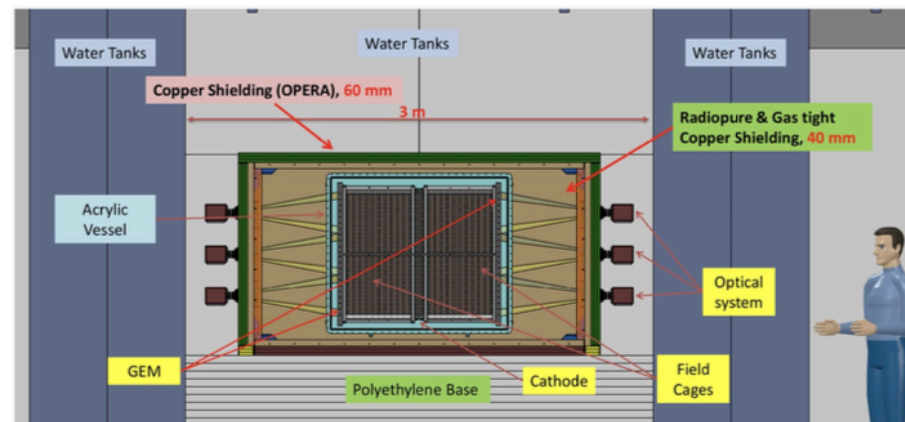
Additional Slides

CYGNO-04

[CYGNO-04 TDR, DOI:10.15161/oar.it/76967](https://doi.org/10.15161/oar.it/76967)

- **Design:**
 - TPC made of **2 chambers** with a **common cathode**.
 - Closed by 2 sets of **50 cm x 80 cm triple GEMs**
 - **Readout** of each GEM side: 3 cameras with rectangular sensors (ORCA Quest) + 8 PMTs
 - **Vessel:** low radioactivity PMMA
 - **Shielding:** 10 cm copper + 100 cm water with a polyethylene base
- Inner detector construction under completion at LNF
- Pre-commissioning at LNF Summer-Fall 2026
- Installation at underground LNGS end 2026/begin 2027

Designed at LNF and to be installed at LNGS

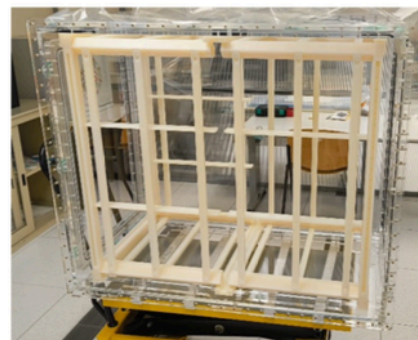


Purpose of CYGNO-04:

- Feasibility large scale detector (radiopure materials, gas purification)
- Demonstrate scalability of the technology



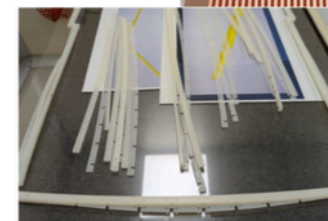
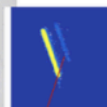
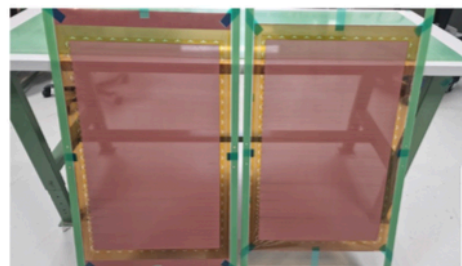
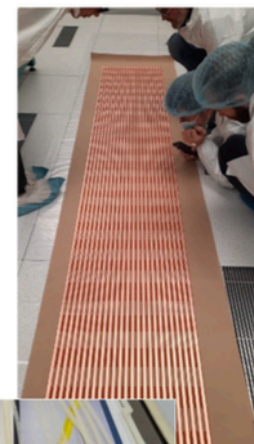
- **20mm PMMA gas-tight box** (6mm thick windows)
- **Detector structure** in Nylon 66



GEM and field cage: copper clad kapton

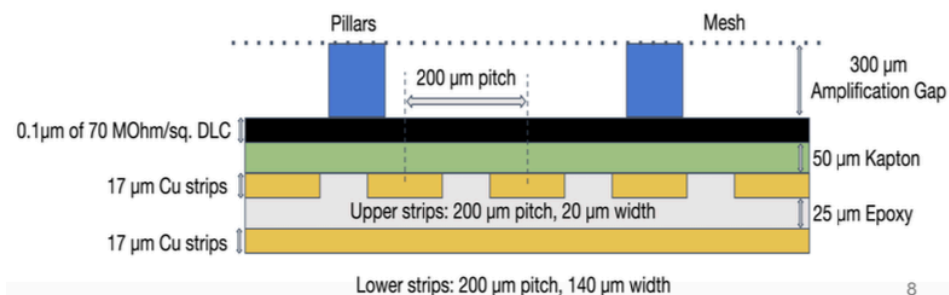
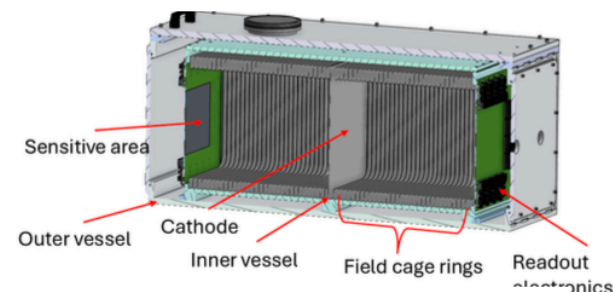
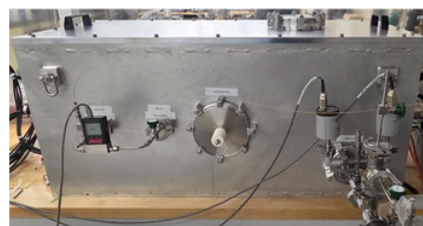
V-bonded GEMs to remove reflections (also showing much less saturation!)

Inner frame of GEM stack in **Nylon 66** (radiopure + non-igroscopic)



CYGNUS-HD

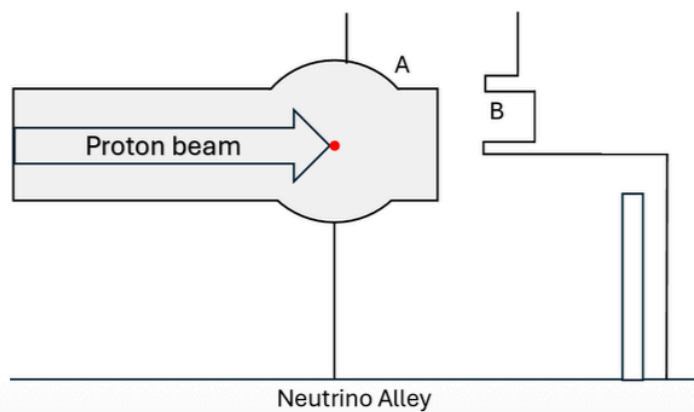
- 40 L back-to-back TPC, Micromegas + XY strip readout via CERN SRS electronics
- Vessel HV and gas system validated, low voltage commissioning ongoing, Fe55 calibration to follow
- Currently investigating the possibility of directional CEvNS measurement at Oak Ridge
- Plan to use the 40 L TPC to measure background in location A and B



<https://arxiv.org/abs/2602.19618>

Directional recoil detection for CEvNS measurements with light nuclei at the Spallation Neutron Source

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A: 6-meter position B: 12-meter position

