The SABRE South experiment at the Stawell Underground Physics Laboratory

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On behalf of the SABRE South collaboration

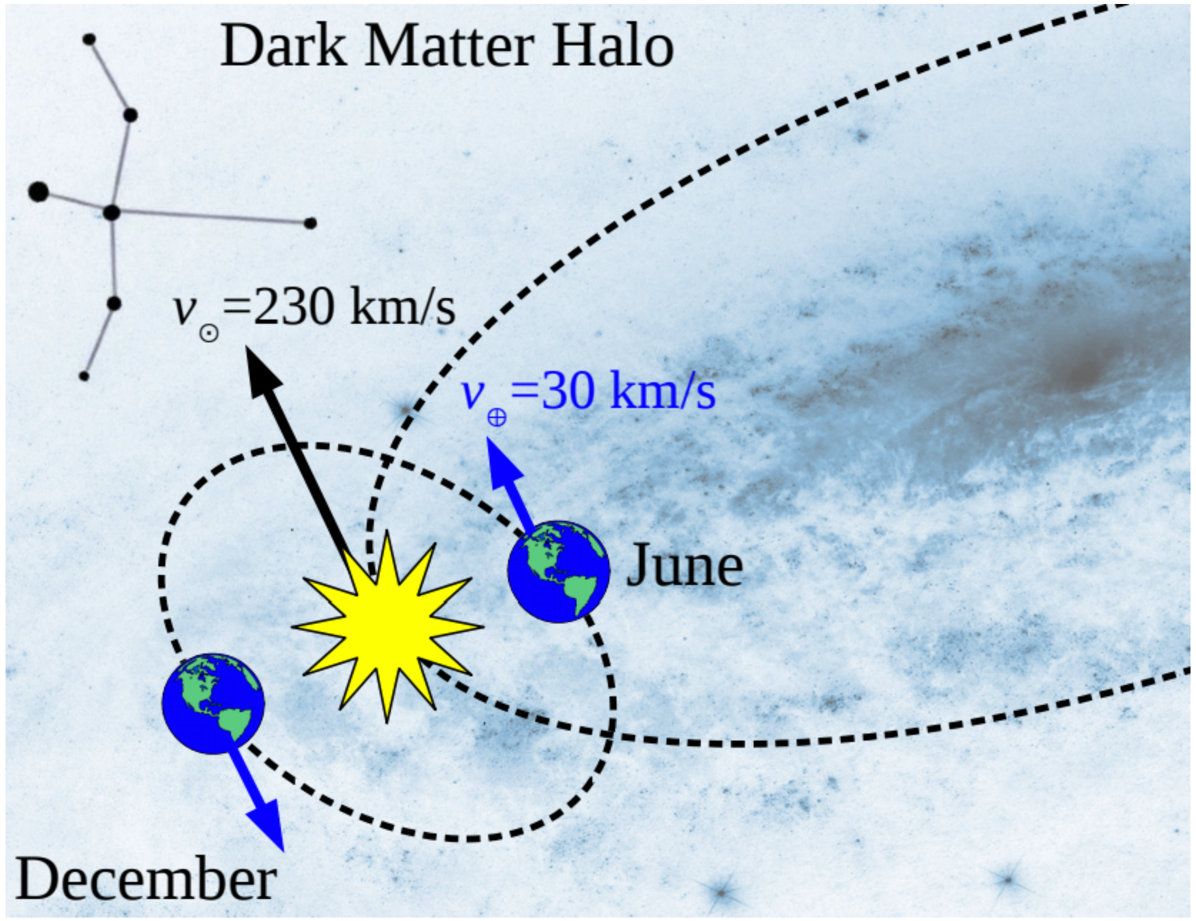
Dark Matter
direct detection
with
scintillator crystals

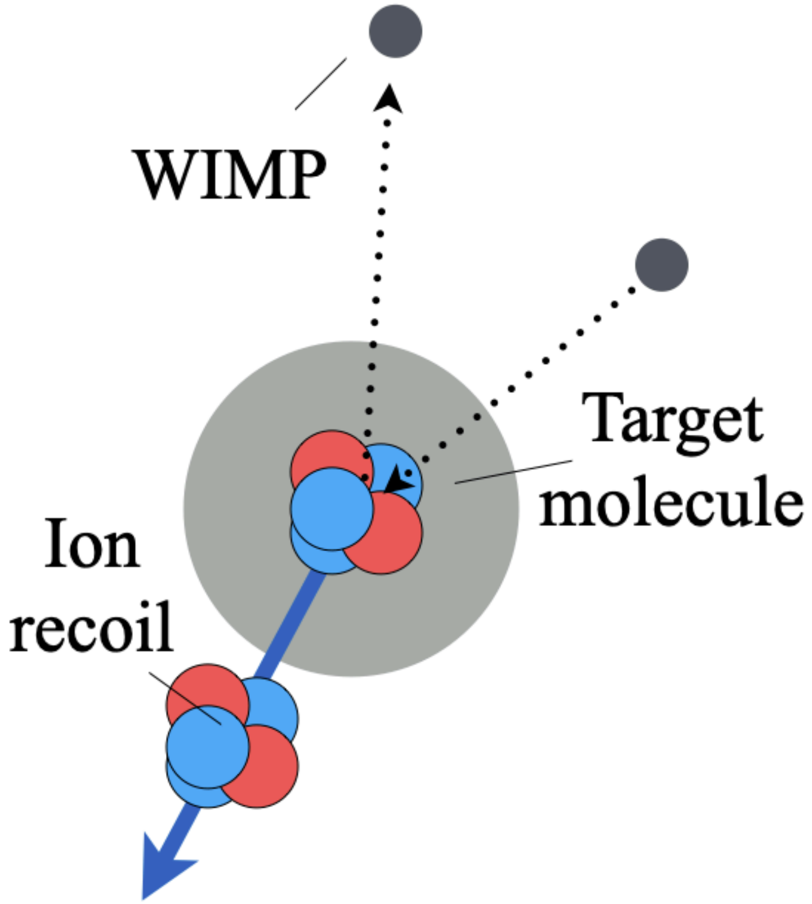
Dark Matter direct detection

Standard Halo Model:
- Canonical value for density: ρ≈0.3 GeV/cm3.
- WIMP wind:

$$v_E = v_\odot + v_\oplus \cos(\theta) \cos\left[\omega(t - t_0)\right]$$

- θ≈60° earth orbit inclination wrt galactic plane.
- Max: 2 June, Min: 2 Dec.

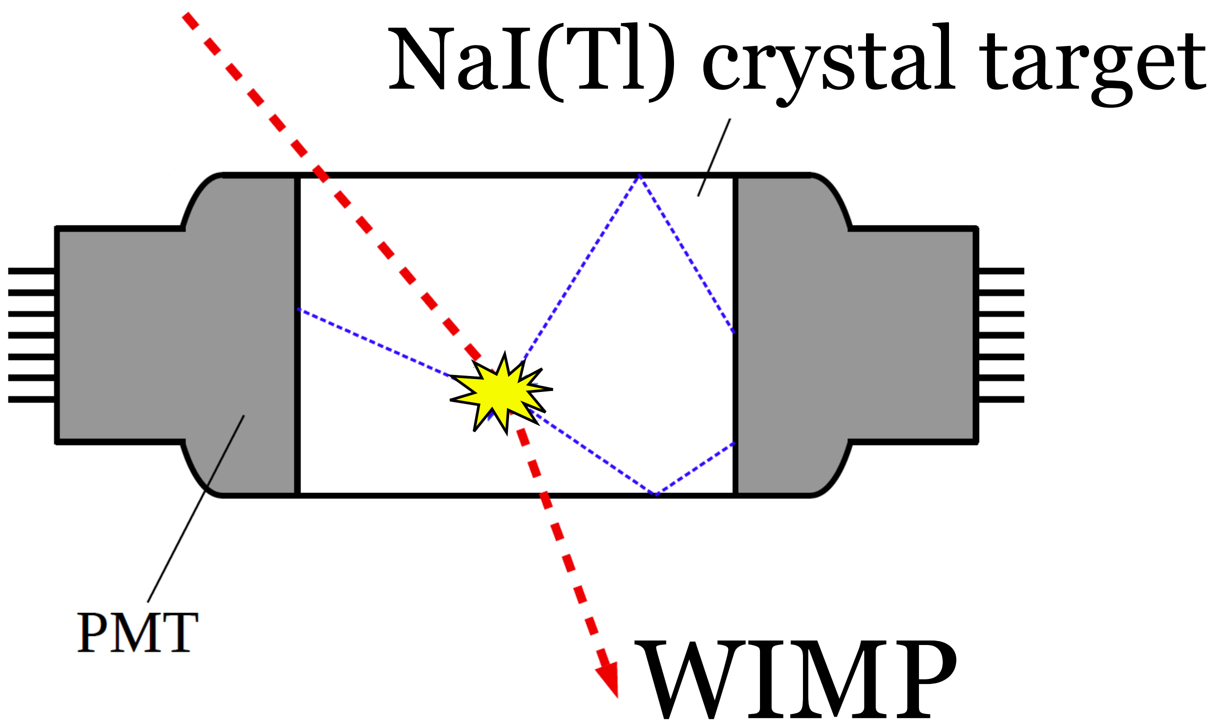


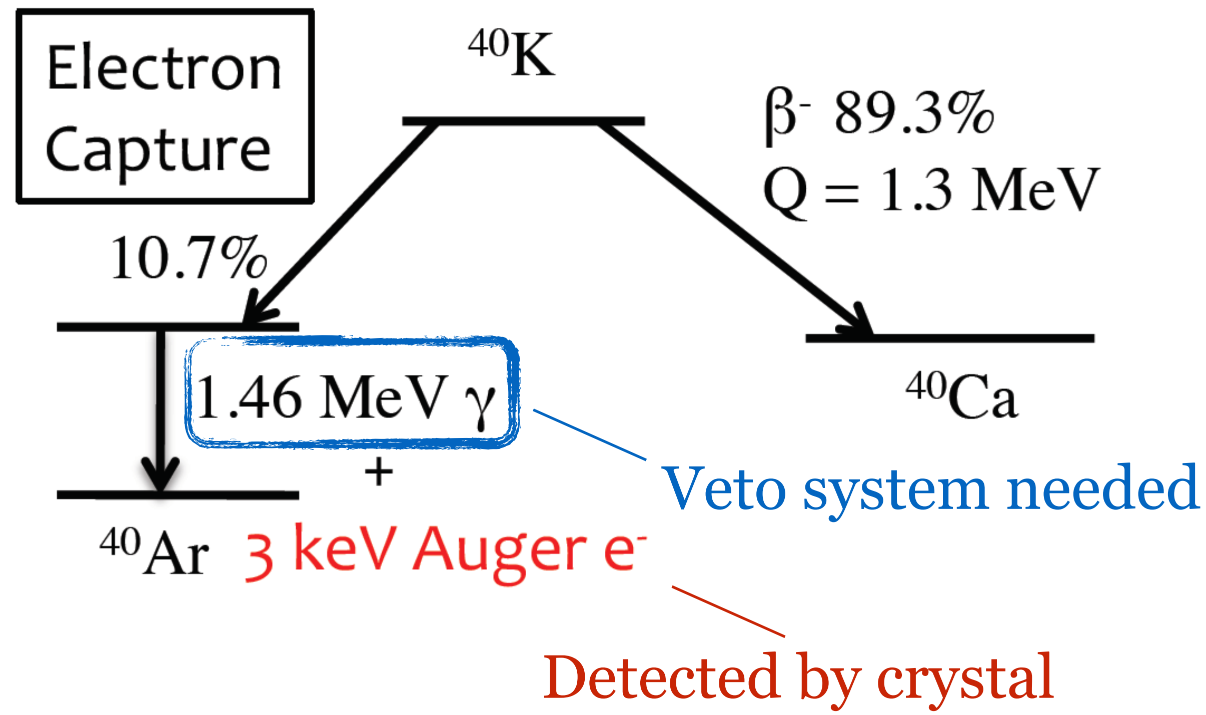


$$S(t) = B + S_0 + \boxed{S_m} \cos\left[\omega(t - t_0)\right]$$

- Elastic scattering of WIMPs on target nuclei.
- Challenging as it produces a **rare signal** concentrated at **low energies ≈ keV**.
- Modulation is small: **≈ 0.01 cpd/kg/keV**.

NaI crystal detectors





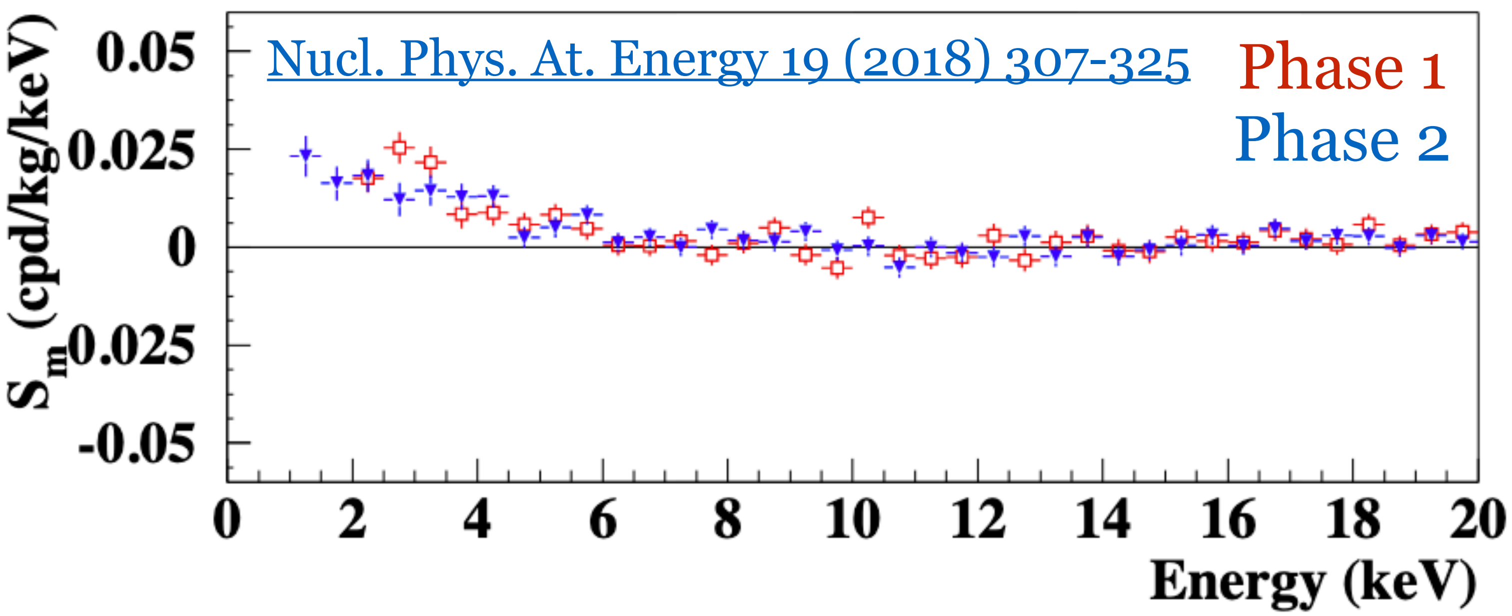
Crystal	^{nat}K (ppb)	^{238}U (ppt)	^{232}Th (ppt)	^{210}Pb (mBq/kg)	Active mass (kg)
DAMA [1]	13	0.7-10	20.5 - 7.5	5-30 x 10^{-3}	250
ANAIS [2]	31	< 0.81	0.36	1.53	112.5
COSINE [3]	35.1	< 0.12	< 2.4	1.74	106
SABRE [4]	4.3	0.4	0.2	0.5	~50 (goal)

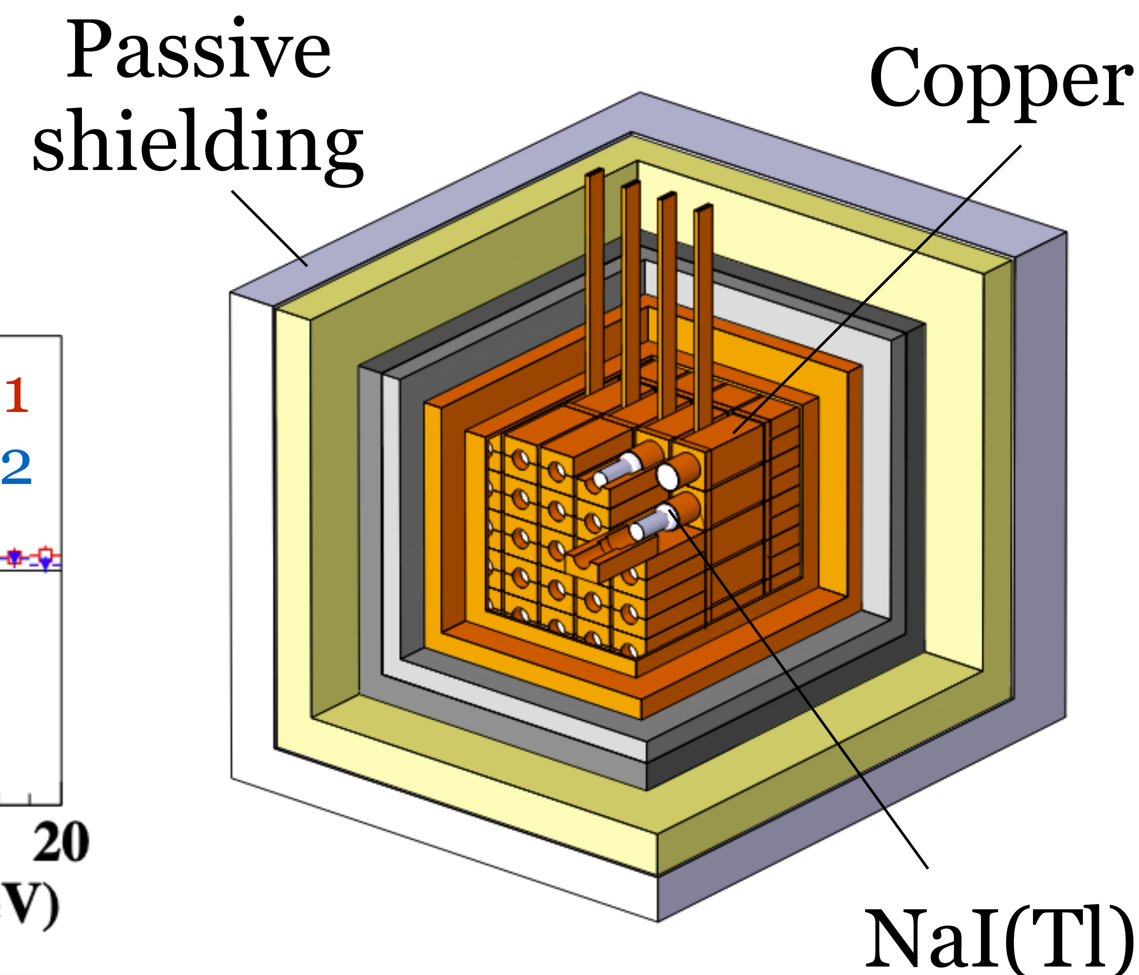
[1] NIMA 592 (3) (2008) , [2] EPJC 79 412 (2019), [3] EPJC 78 490 (2018), [4] Phys. Rev. Research 2, 013223 (2020).

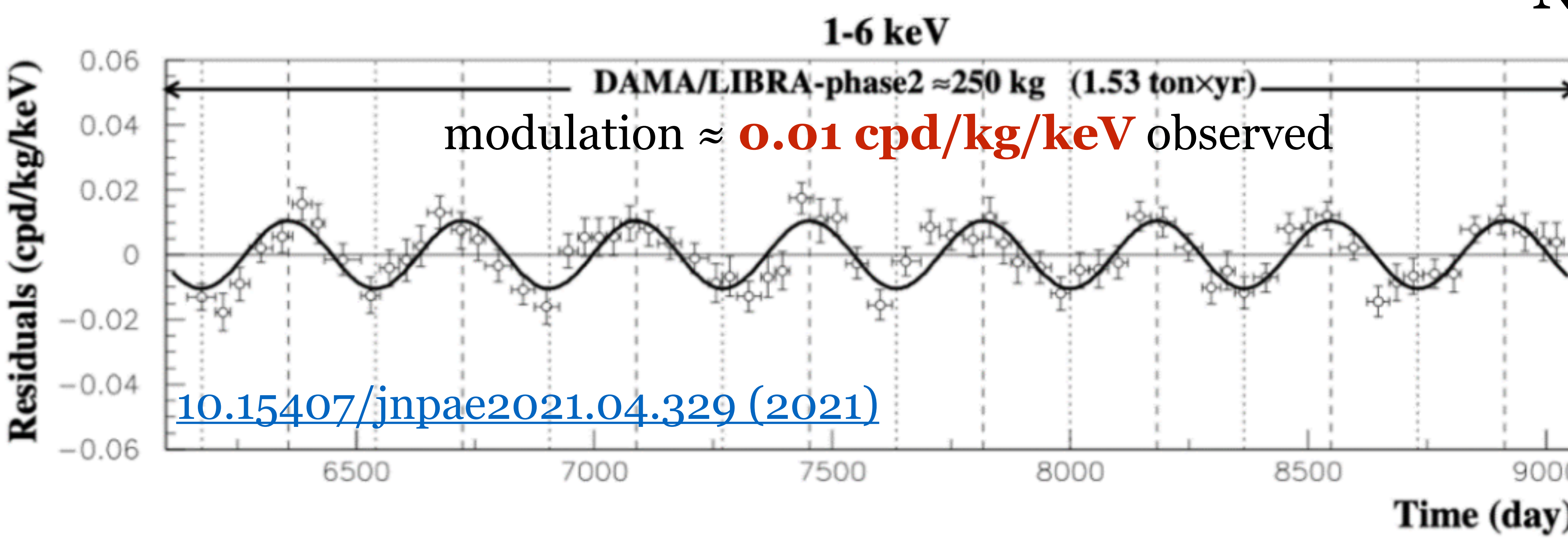
Current status

DAMA/LIBRA

DAMA/LIBRA @ LNGS
- Total target mass = 250 kg of NaI(Tl).
- Modulation observed for 22 years.
- **13.7 σ** significance!





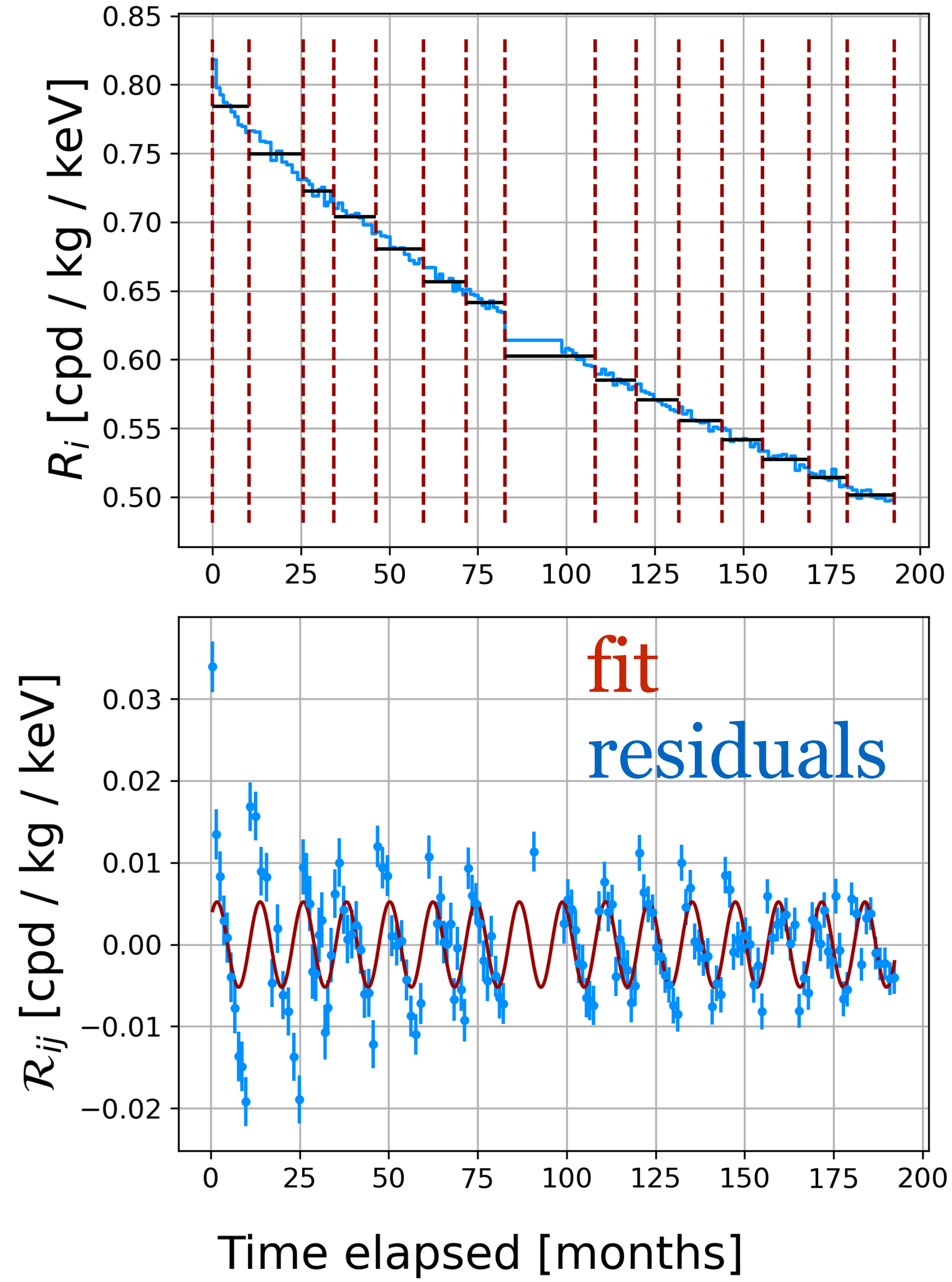


DAMA/LIBRA: a spurious signal?

- Several studies have tried to address the nature of the DAMA/LIBRA modulation:
  - Buttazzo et al.: 10.1007/JHEP04(2020)137.
  - COSINE: s41598-023-31688-4.
  - Messina et al: 10.1088/1475-7516/2020/04/037.

- Toy MC study on a DAMA/LIBRA-like dataset:
  - Using the same analysis method as DAMA.
  - Wrong phase by 180 deg.
  - Amplitude decays over time.
  - Overestimated amplitude, even with ^{3}H and ^{210}Pb levels below DAMA's limit.

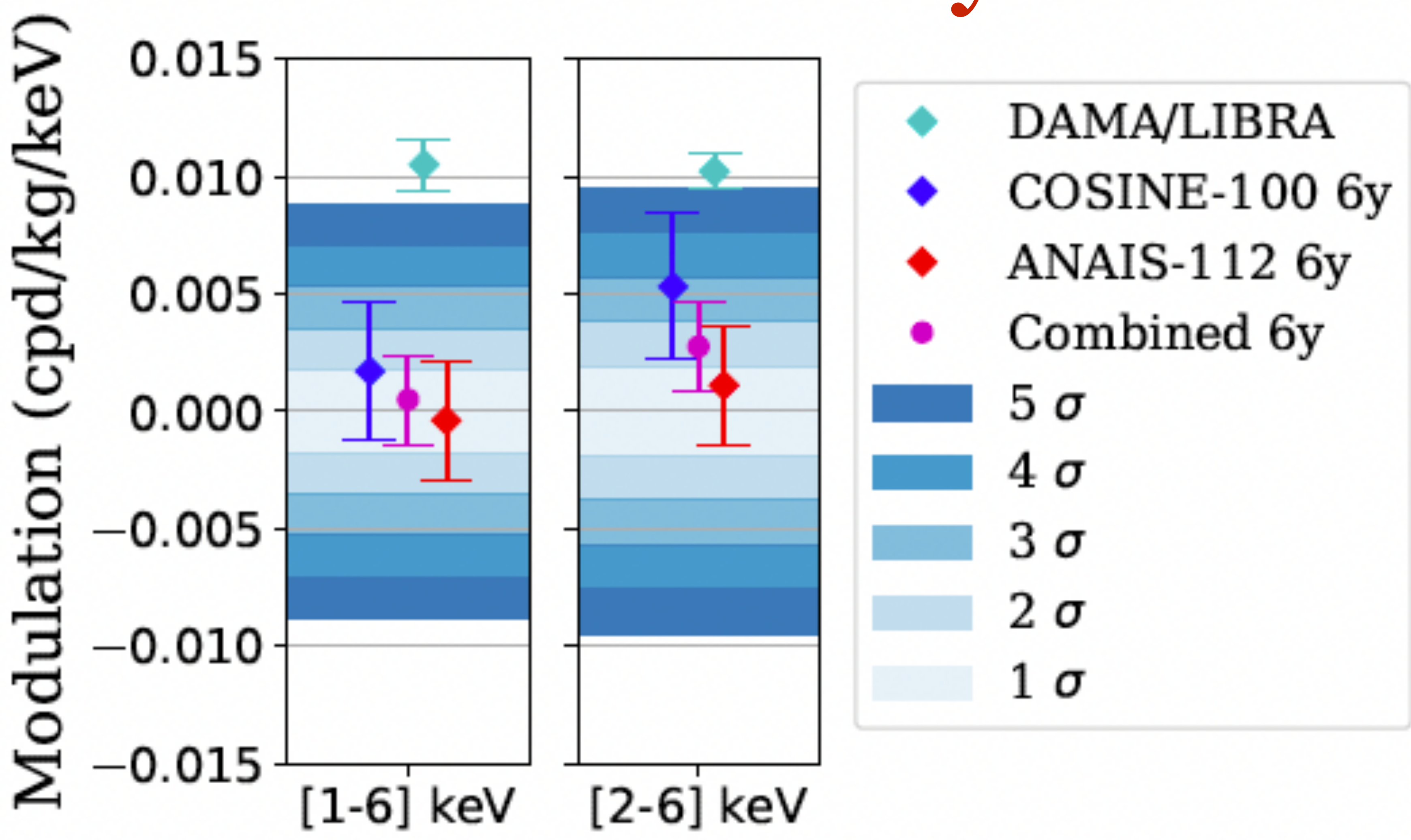
SABRE South: 2408.08697



Cannot be explained by the DAMA analysis method!

COSINE and ANAIS: combination

Preliminary!



- COSINE exposure: **358** kg × yr. (2409.13226)
- ANAIS exposure: **626** kg × yr. (2502.01542)
- Combined exposure: **984** kg × yr. (2503.19559)
- N.B. This is only combining the final results, **without a shared fit**!

SABRE South

Sodium iodide with Active Background REjection

Double location

- Identical modules in northern and southern hemispheres to exclude opposite seasonal background phases e.g. cosmic muons.

High purity crystals

- Crystal growth method developed by Princeton using ultra-high purity NaI powder.

Active bkg veto (SABRE South)

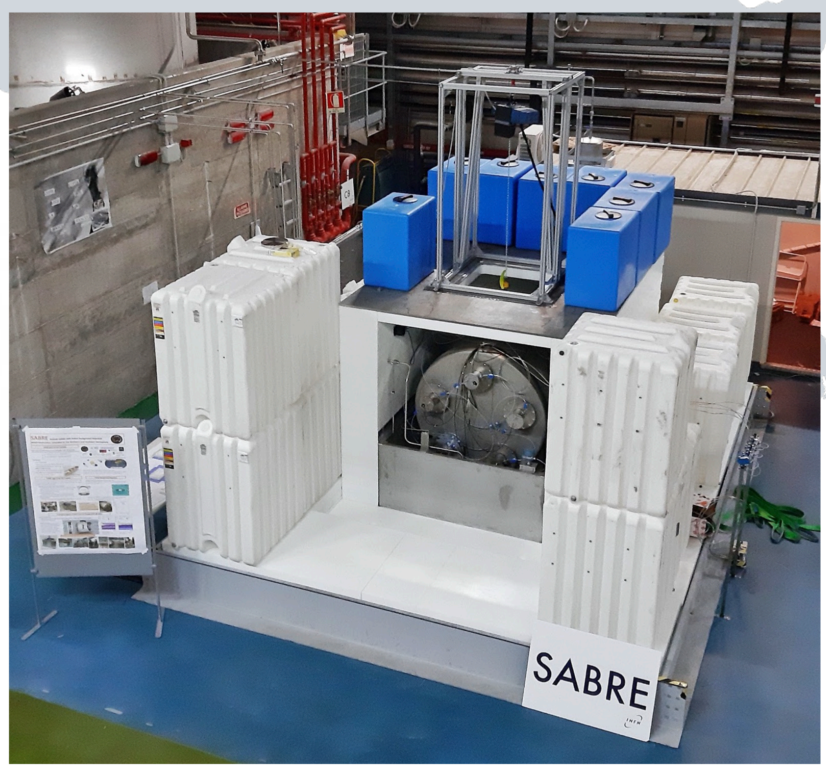
- Unprecedented background rejection at a NaI(Tl) experiment.

Low energy threshold

- High Quantum Efficiency PMTs.

SABRE Collaboration

INFN
LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso



Australian Government
Australian Research Council

STAWELL UNDERGROUND PHYSICS LAB

PRINCETON UNIVERSITY

SAPIENZA UNIVERSITÀ DI ROMA

UNIVERSITÀ DEGLI STUDI DI MILANO

UNIVERSITÀ DEL SALENTO

KEK-JAPAN

SWINBURNE

THE UNIVERSITY OF MELBOURNE

Australian National University

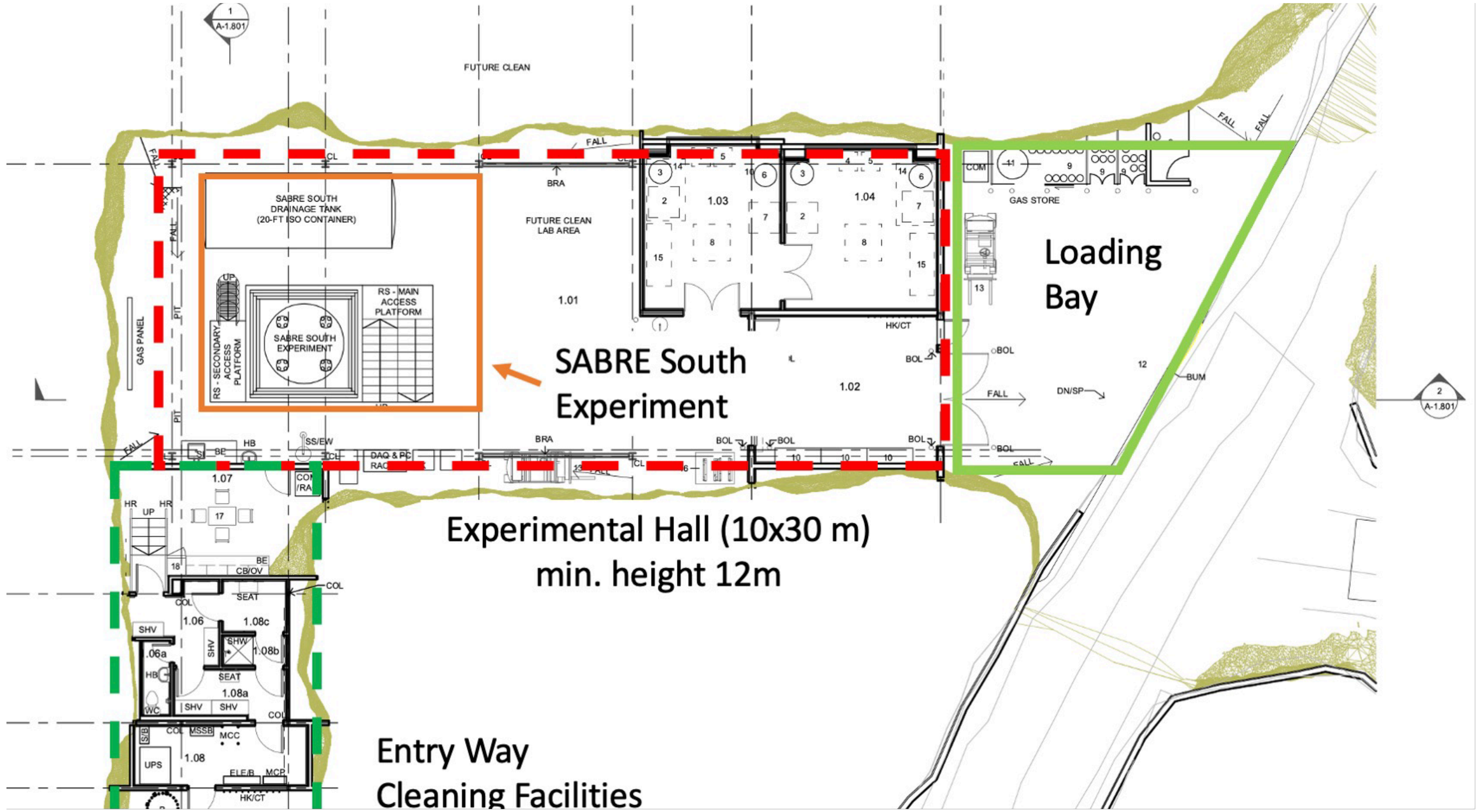
THE UNIVERSITY of ADELAIDE

THE UNIVERSITY OF SYDNEY

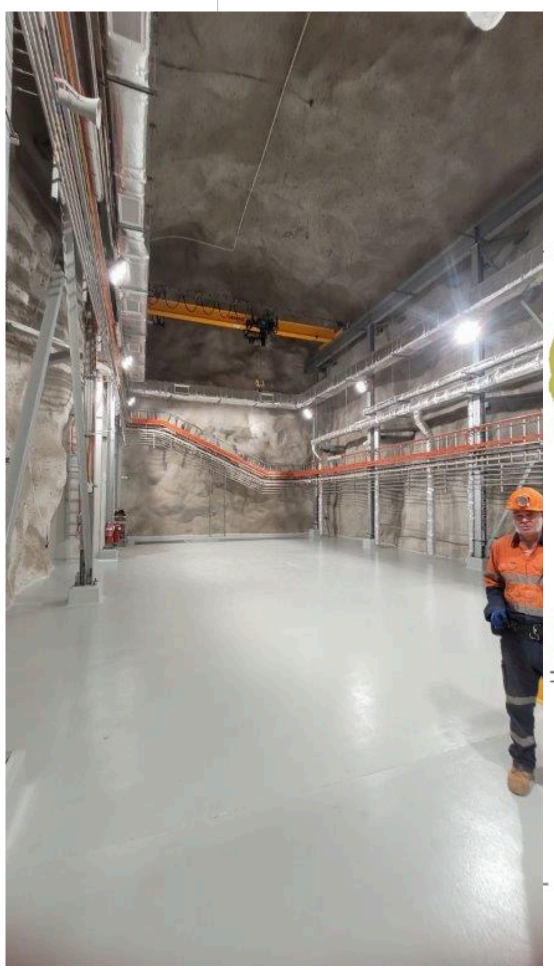
Stawell Underground Physics Laboratory

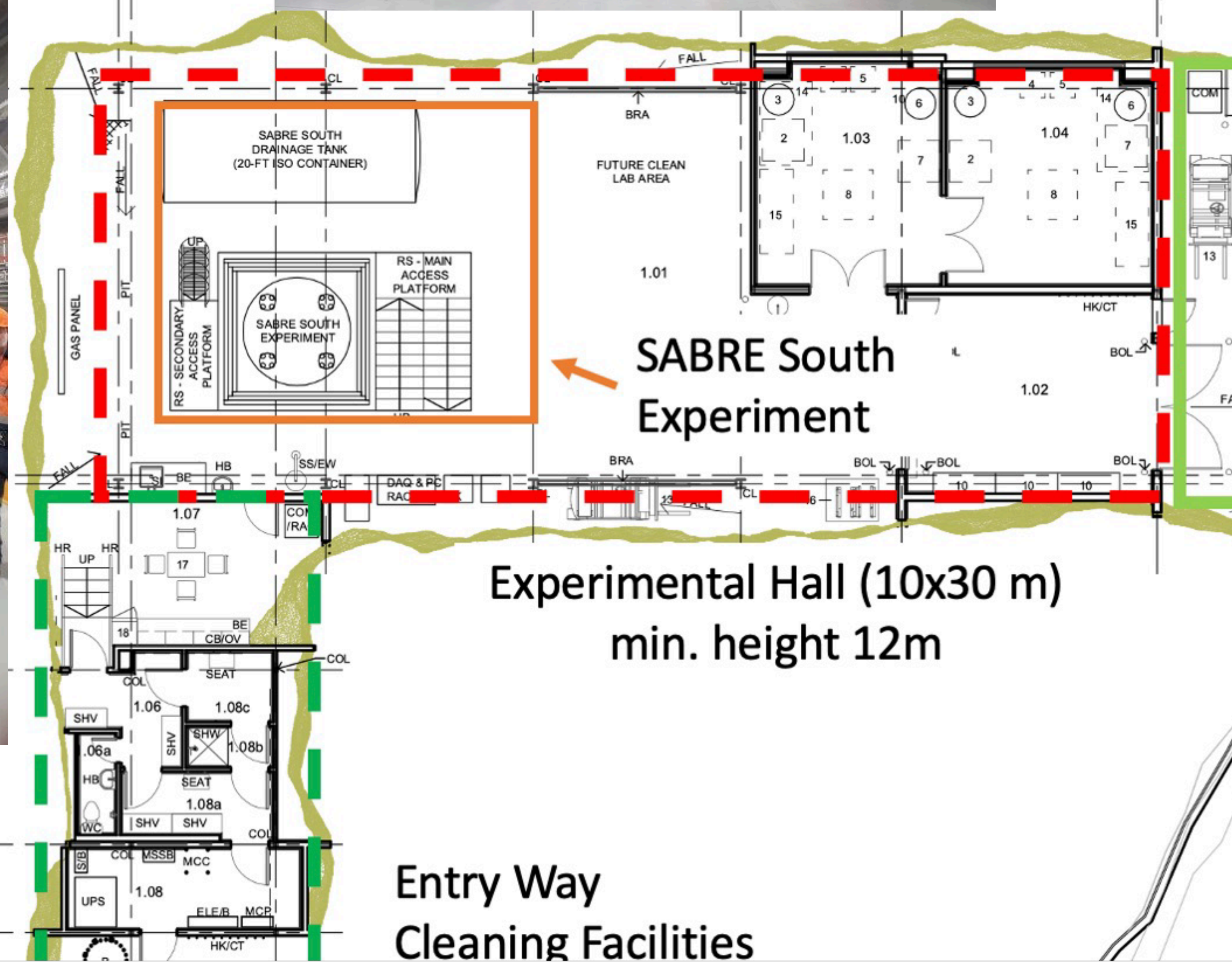
Stawell **U**nderground **P**hysics **L**aboratory (SUPL):

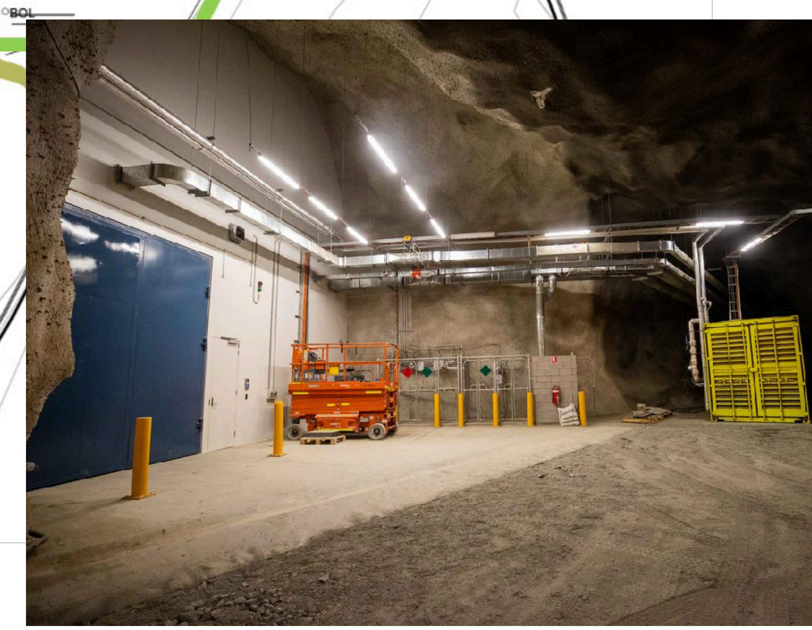
- First underground laboratory in the southern hemisphere 1025 m deep (2900 m water equivalent) with flat overburden.
- Located in the Stawell gold mine 240 km west of Melbourne.
- Construction completed in August 2022.



Stawell Underground Physics Laboratory

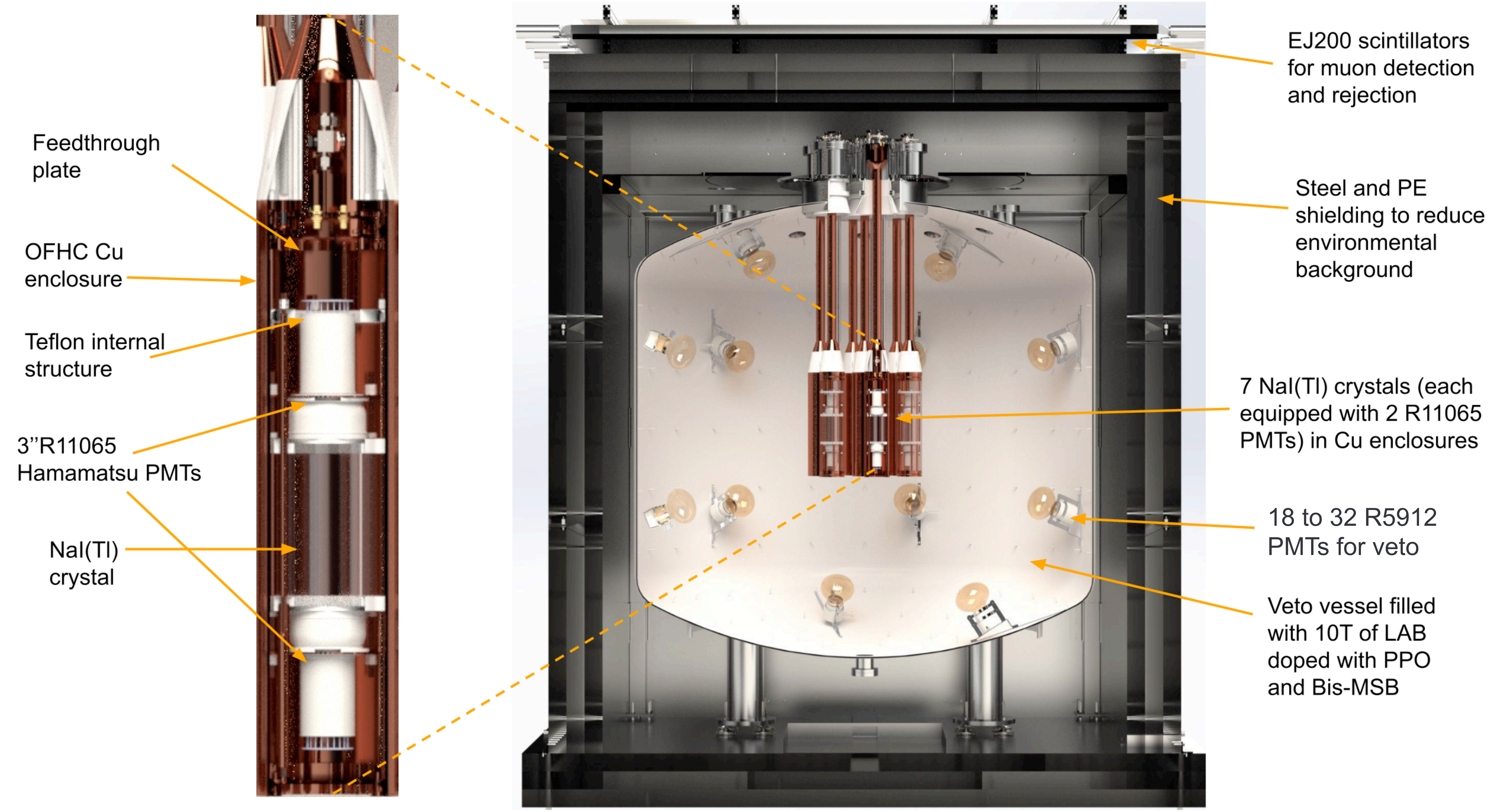






SABRE South

SABRE South TDR: [E. Barberio et al 2025 JINST 20 T04001]



- In situ evaluation and validation of the background using the large active veto.
- Highest purity crystals and largest active veto. Target mass of **50 kg**.

SABRE crystals production

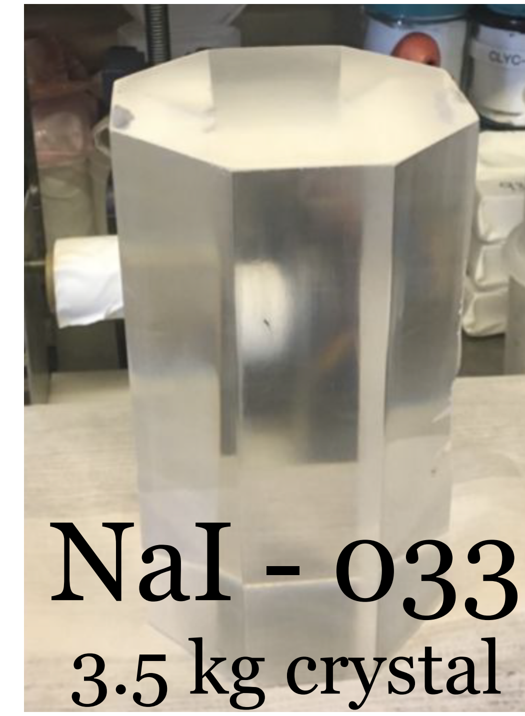
- NaI ultra-pure powder “Astrograde” from RMD with Princeton-Sigma-Aldrich (now Merck). Purification method from Princeton.
- Crystal production is underway with RMD (US) and SICCAS (China) involved.

Crystal enclosures

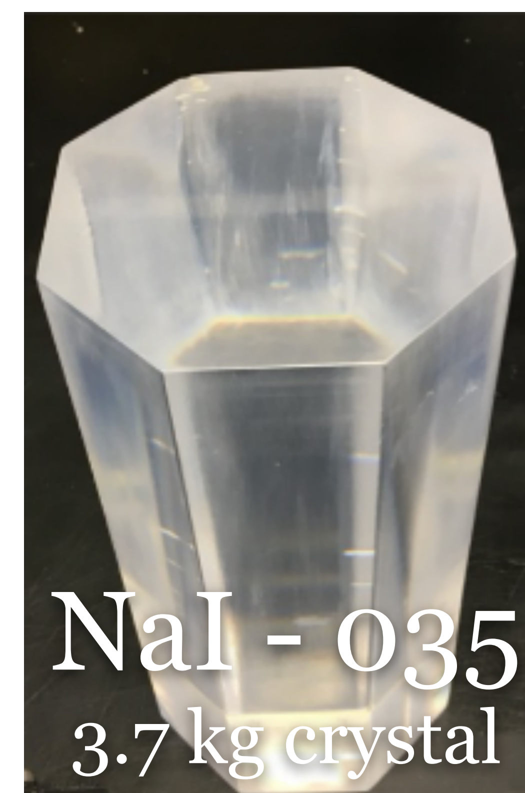
Crystal characterisation at LNGS

RMD
A Dynasil Company

Since 1928
SICCAS

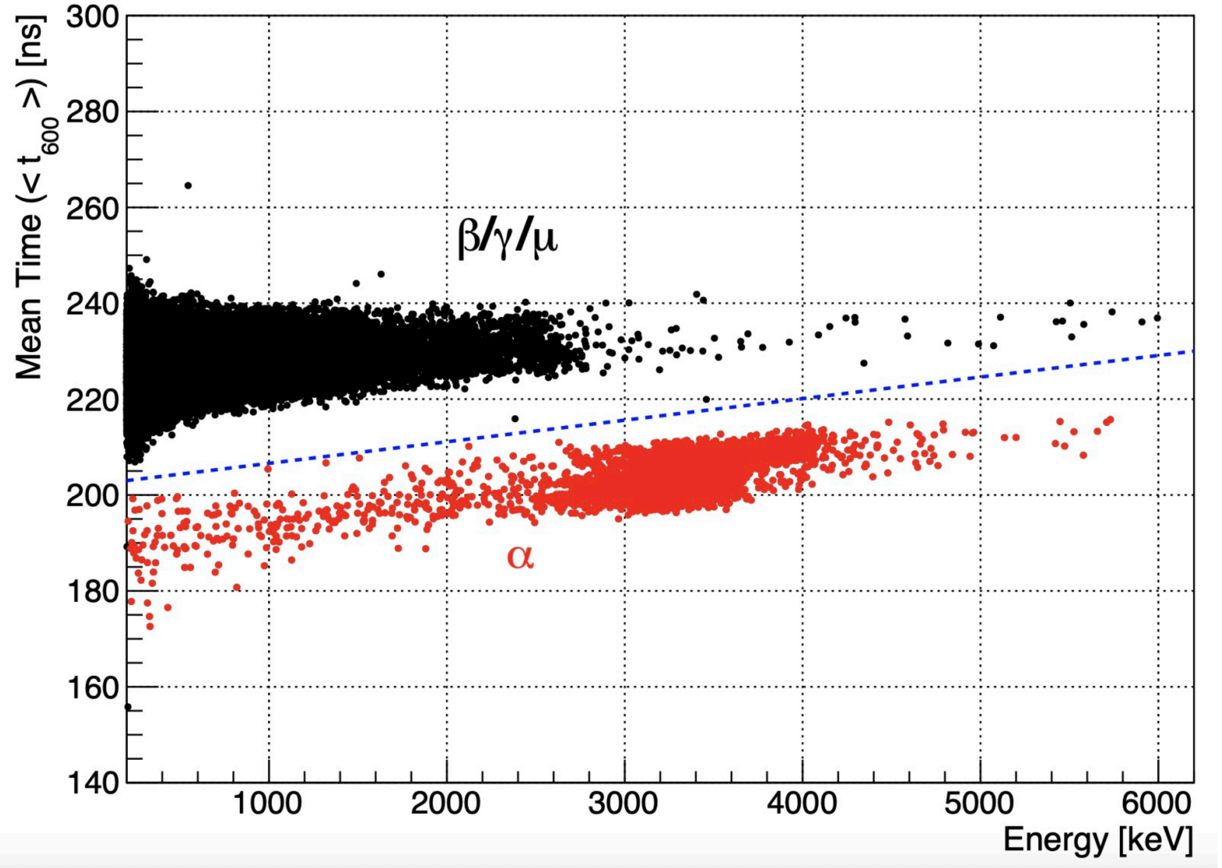


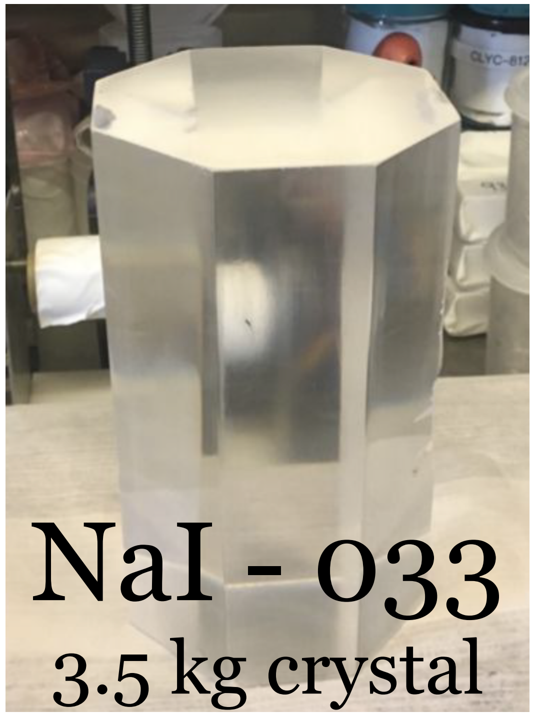
NaI - 033
3.5 kg crystal

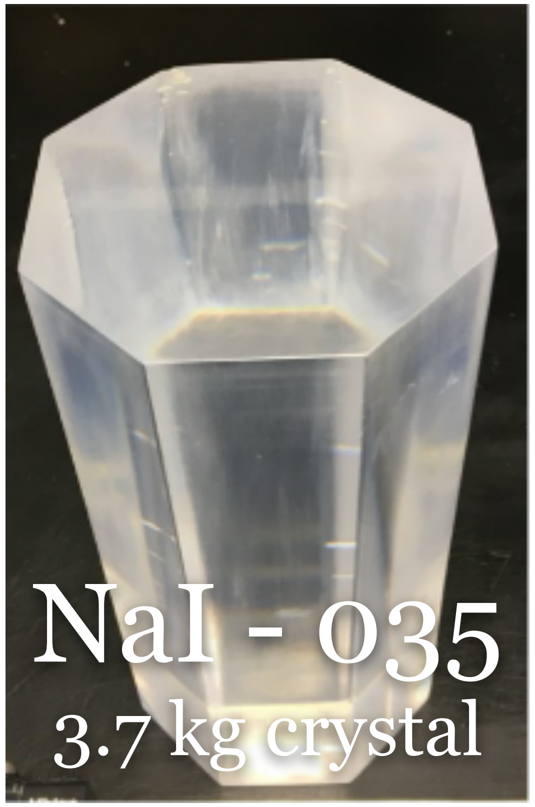


NaI - 035
3.7 kg crystal

SABRE crystals characterisation







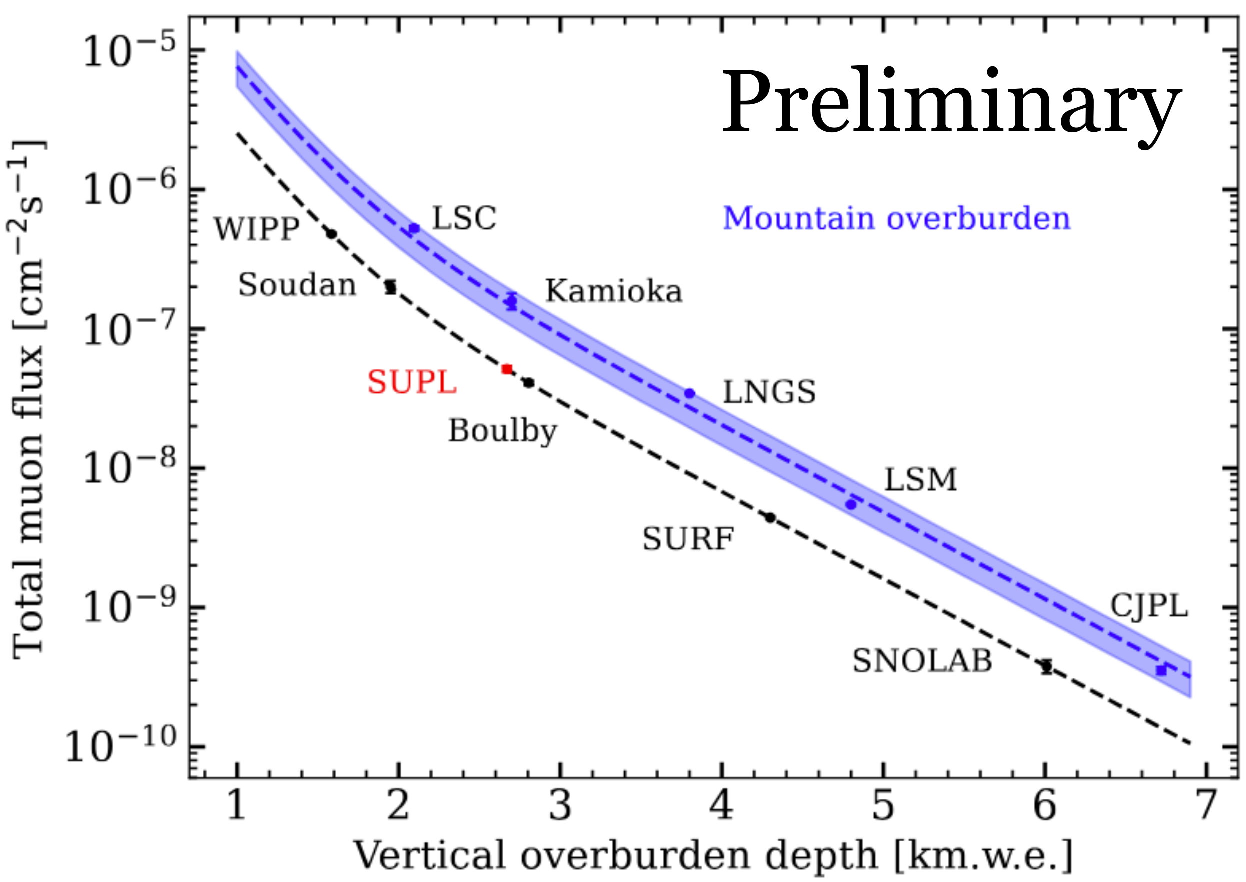
[Eur. Phys. J. C 81, 299 (2021)]

	NaI-33	DAMA/LIBRA crystals	ANAIS crystals	COSINE crystals
LY [phe/keV]	12.1 ± 0.2	6-10	15	15
FWHM/E @59.5 keV	13%	16%	11%	12%
^{238}U [ppt]	< 0.5	0.7-10	0.2-0.8	< 0.02-0.12
^{232}Th [ppt]	< 0.5	0.5-7.5	0.1-1	0.3-2.4
Alpha rate [mBq/kg]	0.54 ± 0.01	0.08-0.12	0.7-3.15	0.74-3.20
^{nat}K [ppb] (from ICP-MS)	4.6 ± 0.2	< 20	17-43	17-82

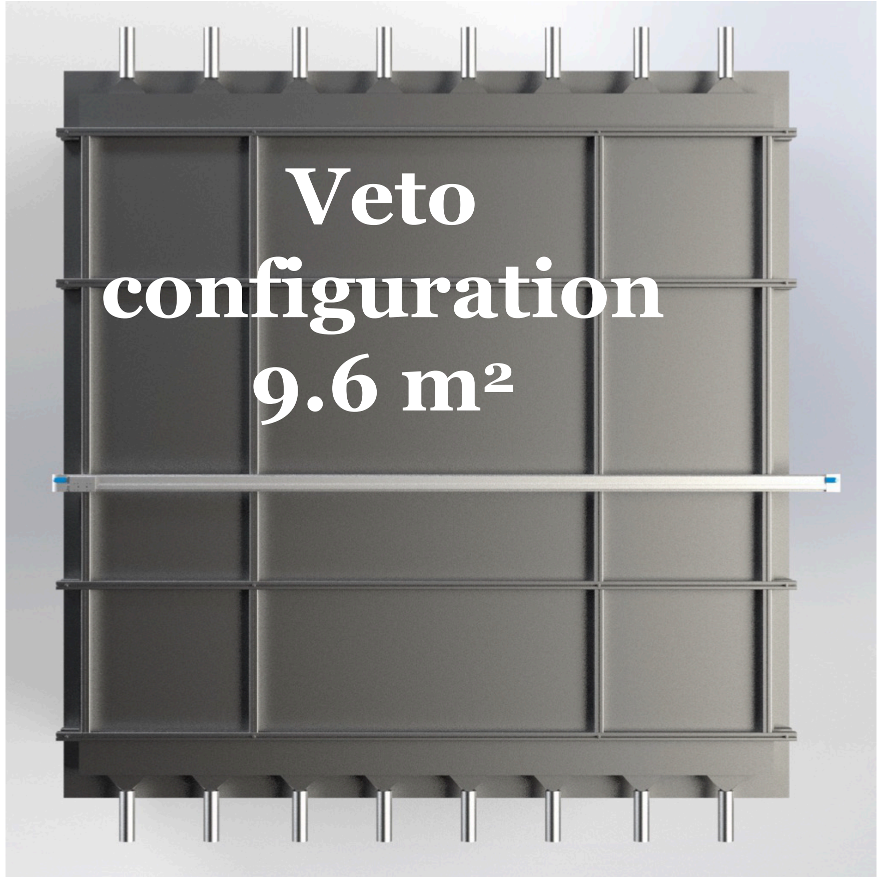
Muon flux measurement at SUPL

- Muon detectors installed at SUPL in 2024 in a telescope configuration.
- Provides the first test of the SABRE data acquisition system (DAQ) and data processing pipeline: [10.1088/1742-6596/2438/1/012061](https://doi.org/10.1088/1742-6596/2438/1/012061).
- Muon flux measured with one year of data.
- Will soon be submitted for publication.

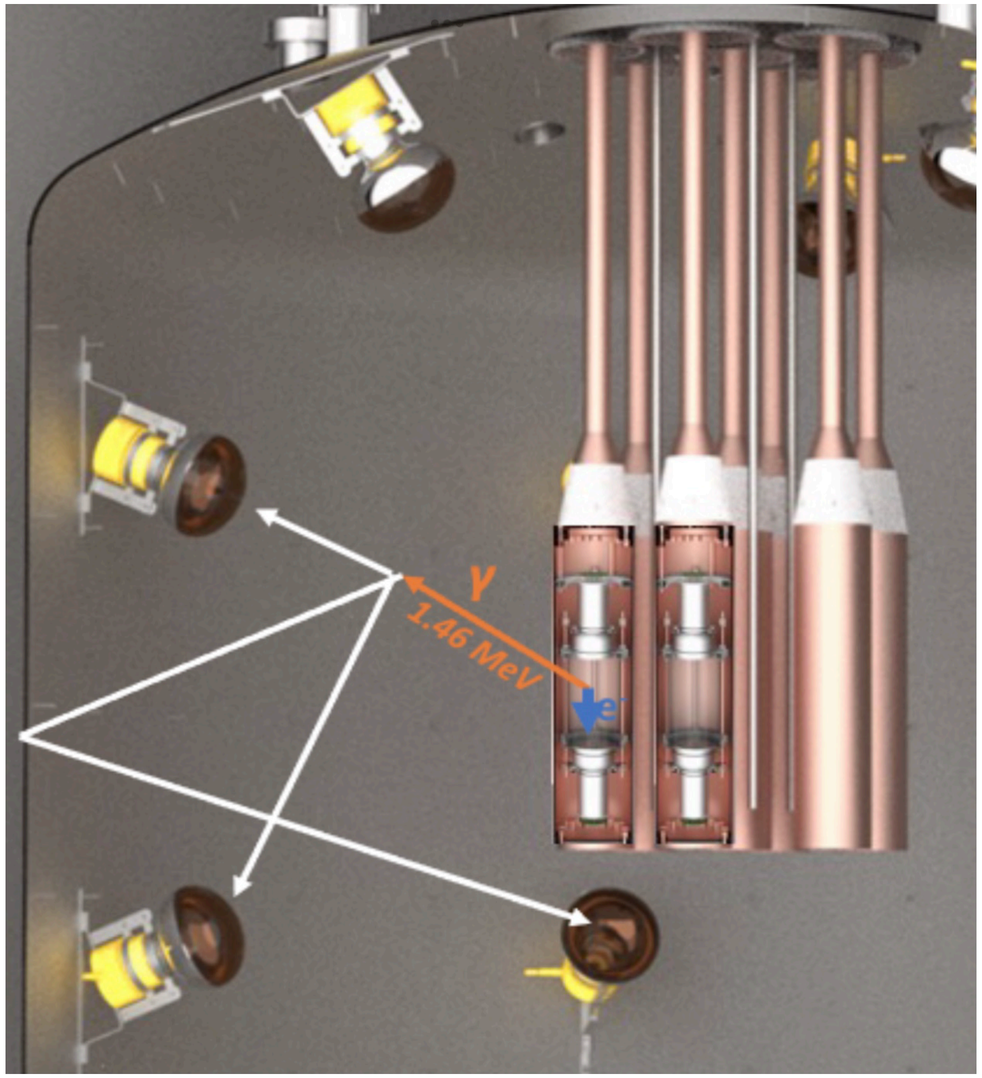
$$f = 5.127 \pm 0.029_{\mathrm{stat}} \pm 0.250_{\mathrm{sys}} \times 10^{-8}\ [\mathrm{s}^{-1} \times \mathrm{cm}^{-2}]$$

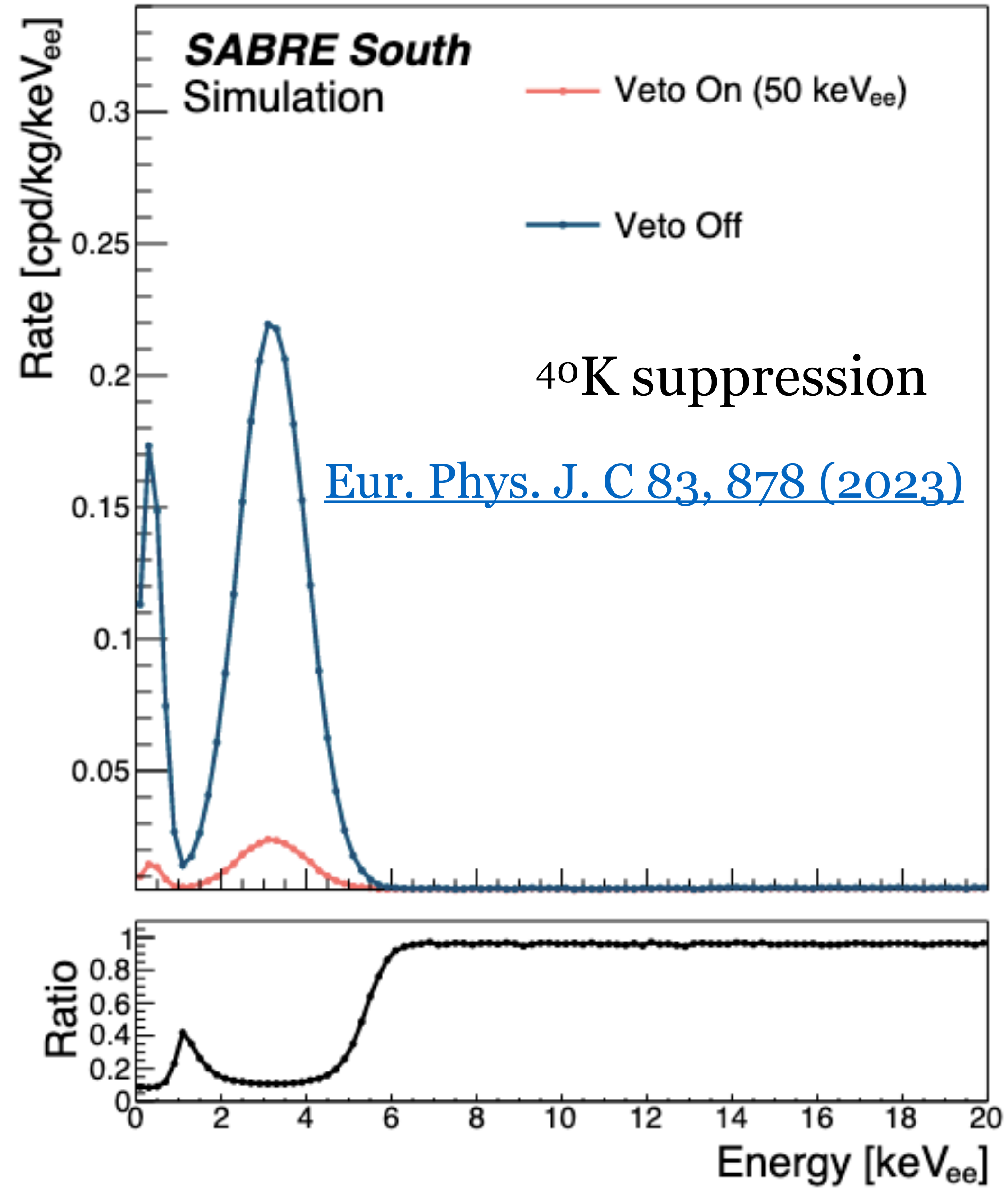


Telescope configuration



SABRE South: liquid scintillator veto



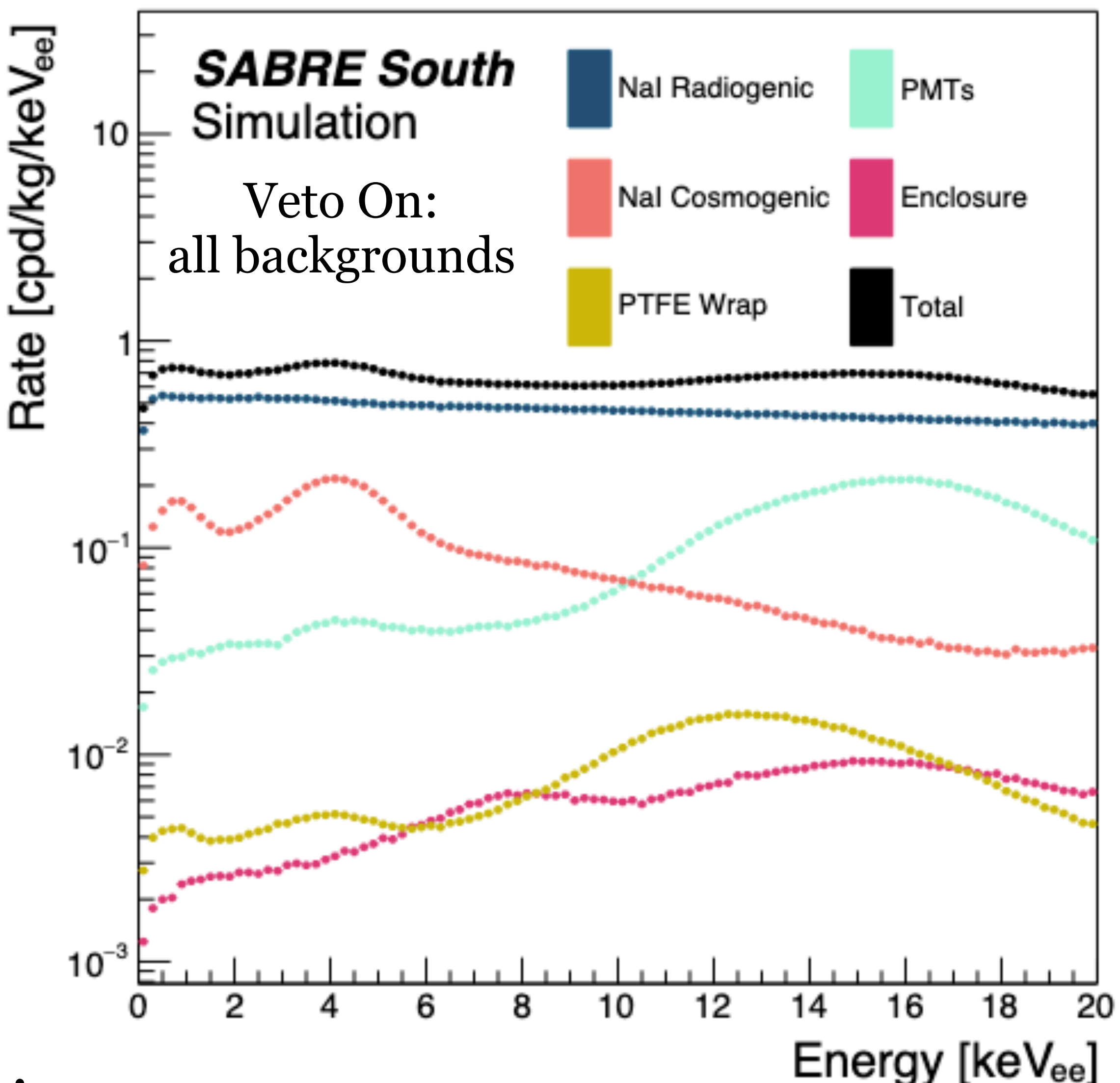


- Full solid angle coverage.
- 12 kL of liquid alkyl benzene (LAB) from the JUNO experiment.
- Photon attenuation > 20 m.
- Any radioactive decay with γ > 100 keV can be detected.
- Possibility to host b/w 18 to 32 Hamamatsu R5912 PMTs with oil-proof bases.

SABRE South: background model

Eur. Phys. J. C 83, 878 (2023)

- Crystal background > 90% of the total background.
- Intrinsic crystal radiation > 70% of the total.
- Overall veto requirement is expected to suppress **27%** of the total background.
- Expecting **0.72 cpd/kg/keV** in the region of interest.

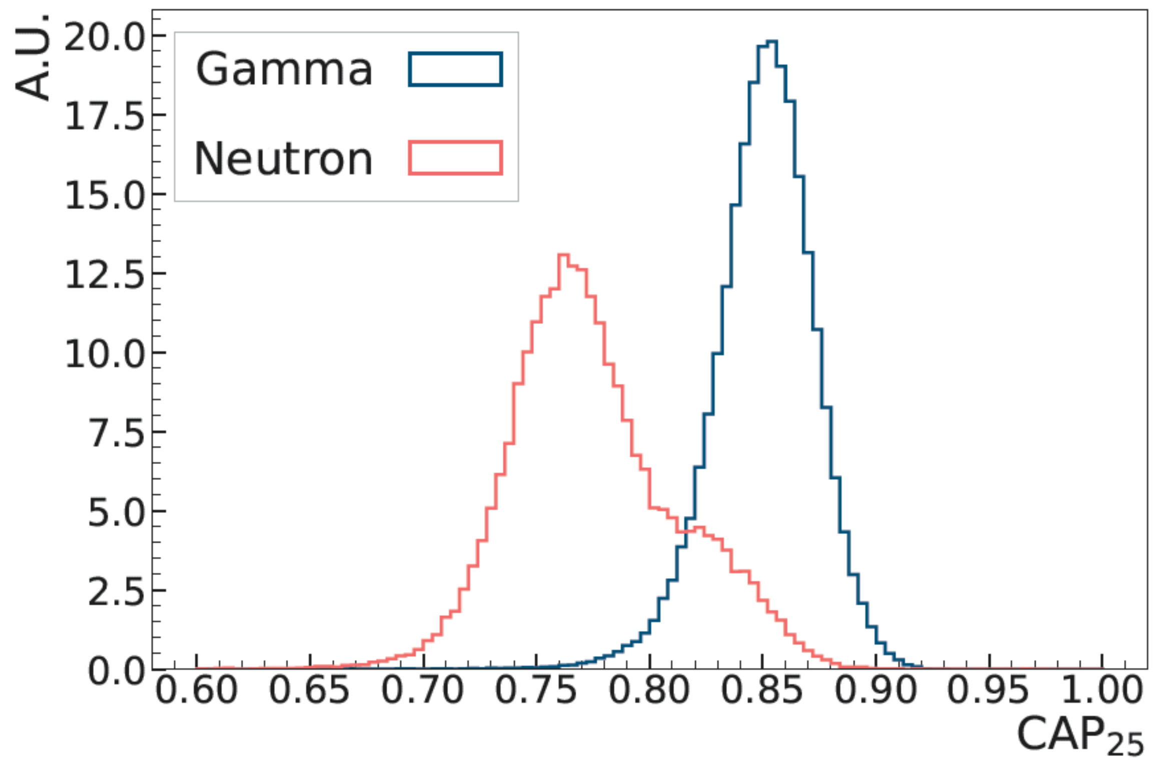


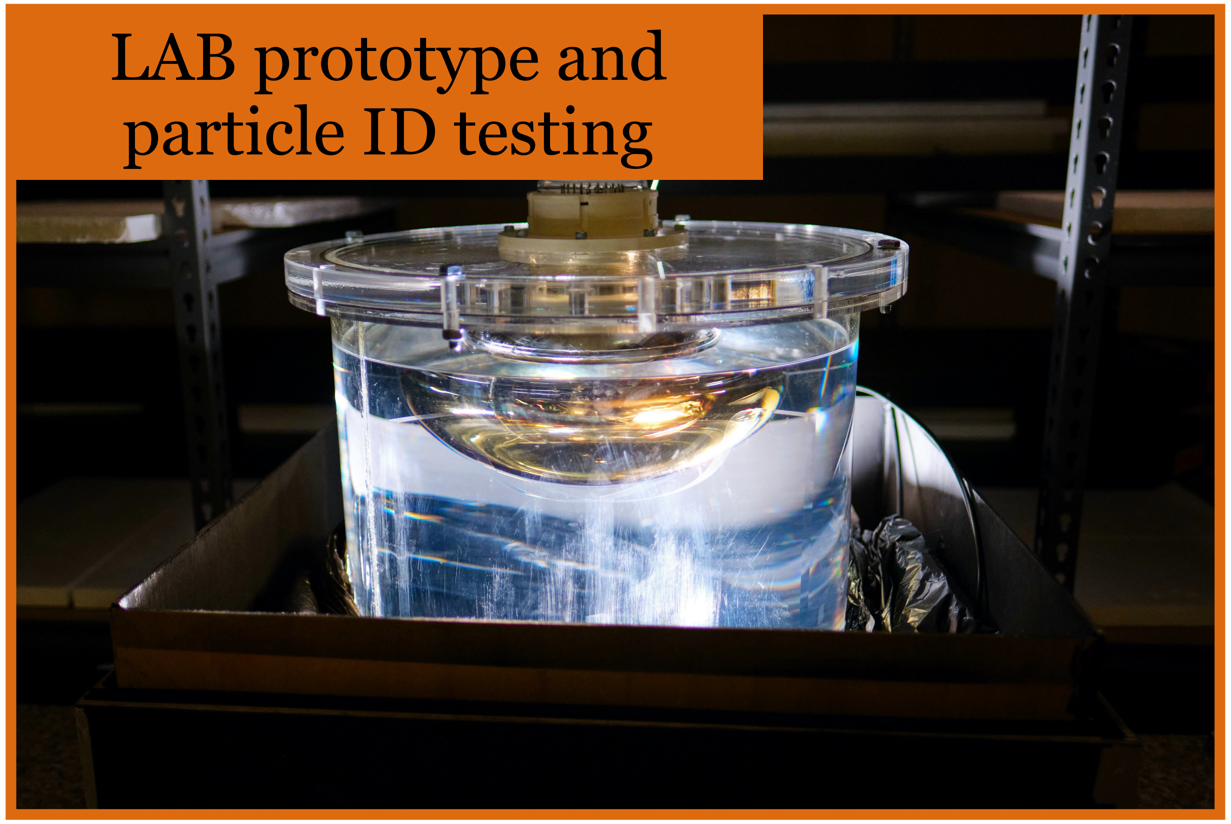
Key contaminants

Isotope	Background	Half life	Source
^{40}K	3 keV electron	10^9 y	Environment
^{210}Pb	15 keV electron	22.3 y	Rn in water
Tritium	5 keV electron	12 y	Cosmogenic

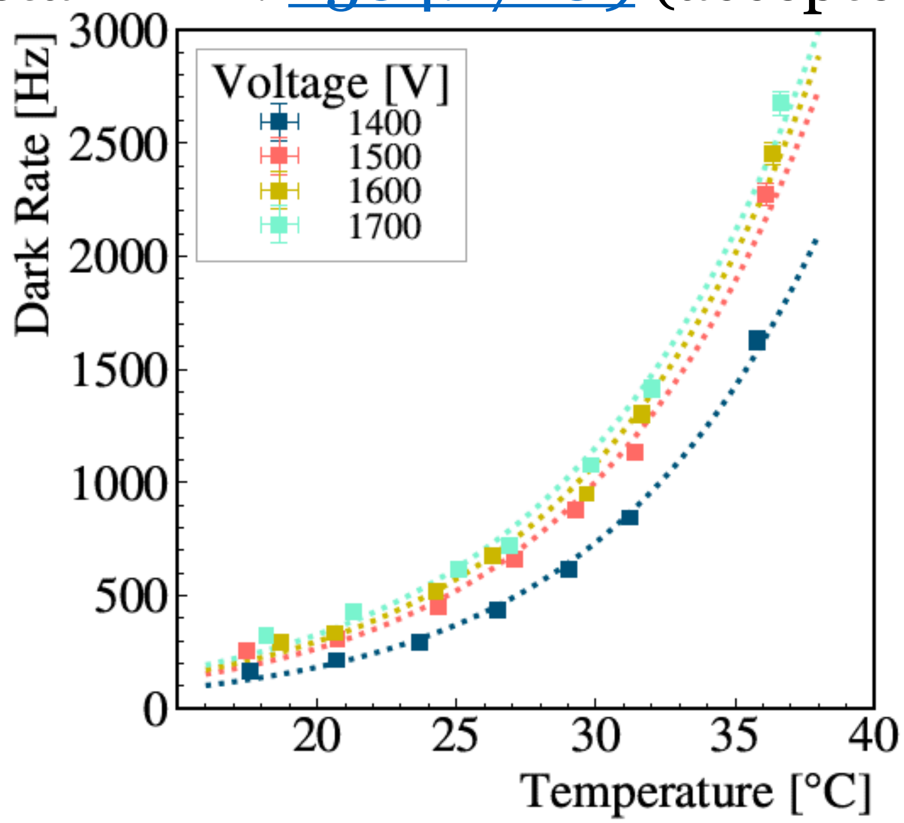
SABRE South: PMT studies

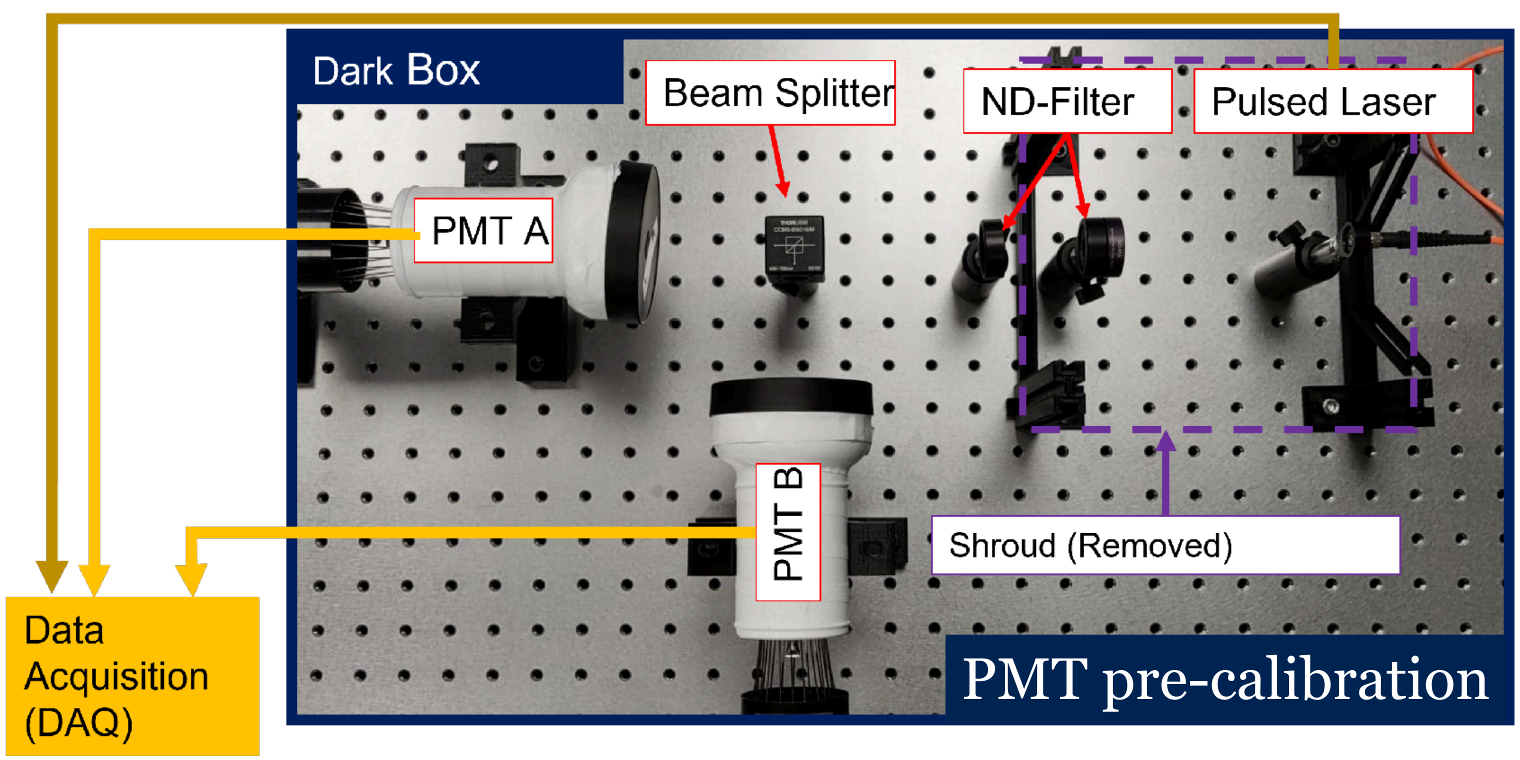
Veto PMT: 2505.10353v2 (accepted by JINST)





Crystal PMT: 2504.17209 (accepted by JINST)

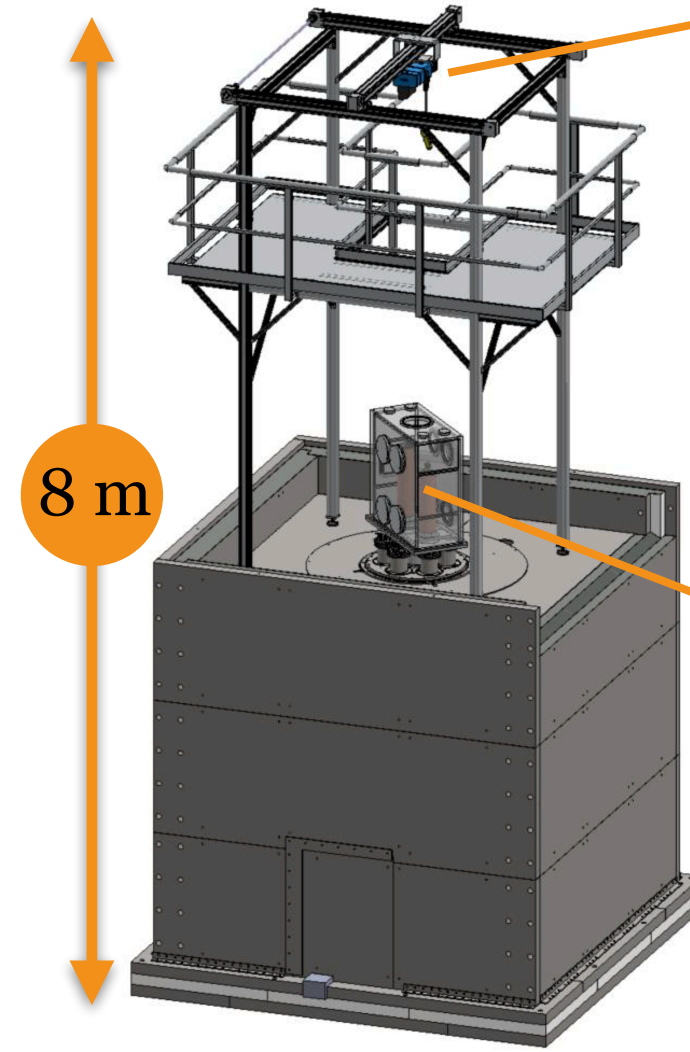




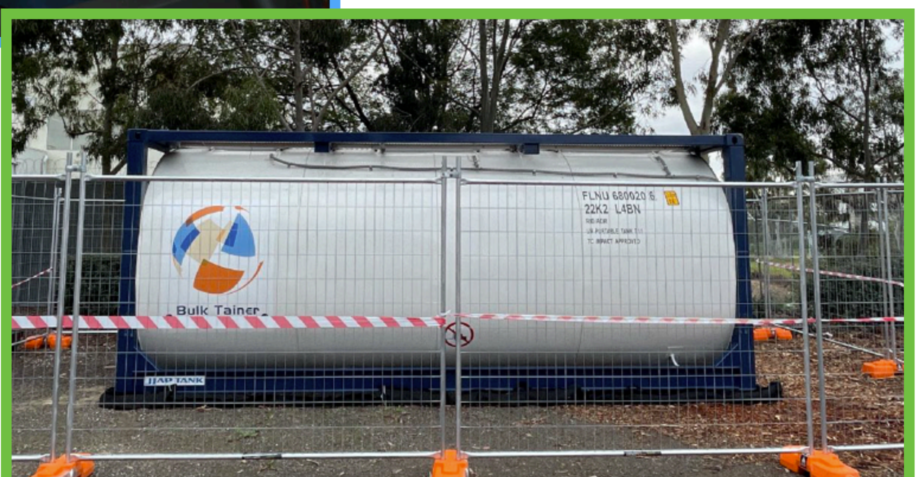
SABRE South: assembly started in 2023

Veto tank

DAQ and server



Crystal insertion system



Liquid scintillator

Gas handling system

SABRE South: sensitivity projection

Eur. Phys. J. C 83, 878 (2023)

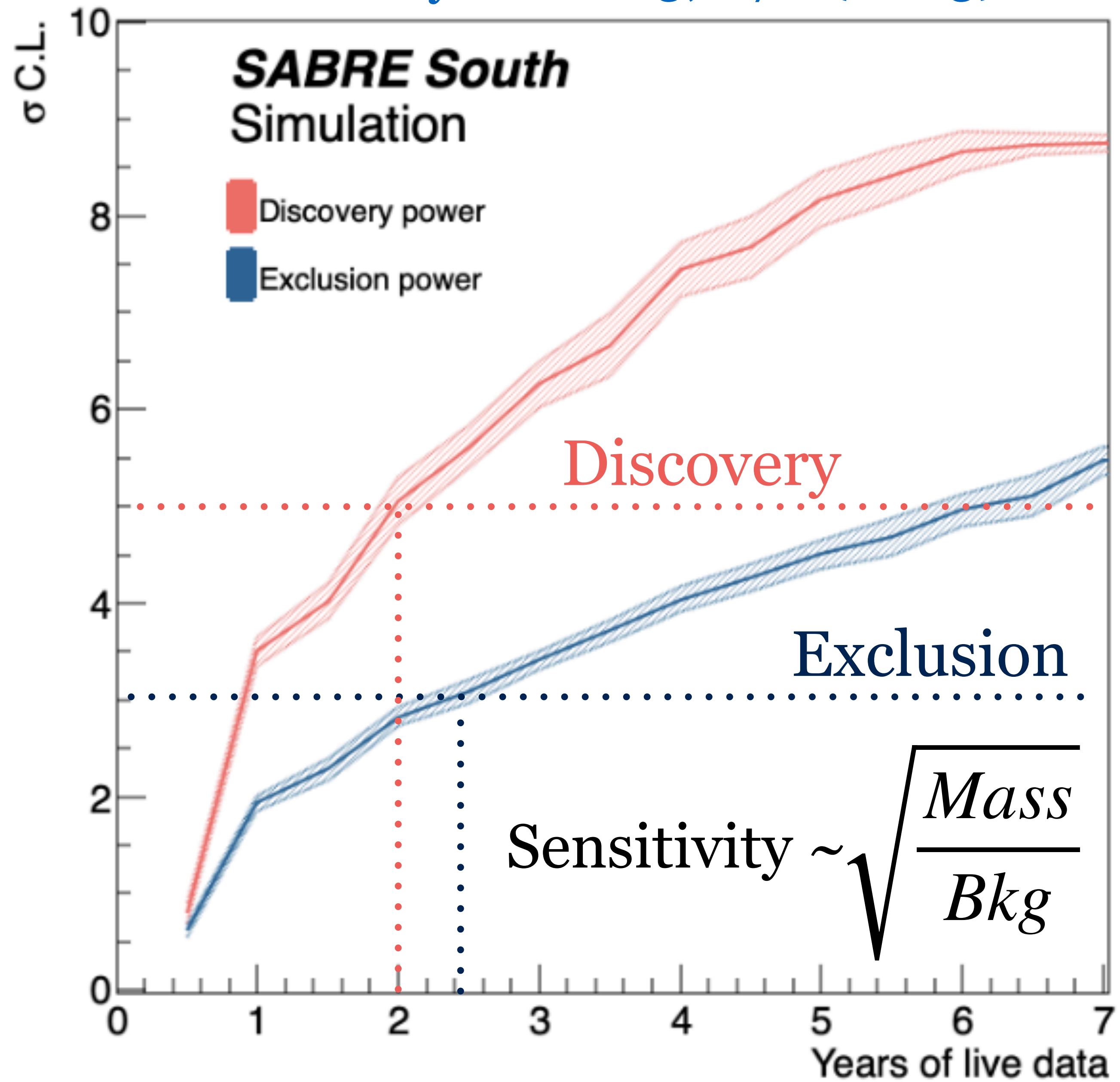


Fig. 9 The exclusion and discovery power of SABRE South for a DAMA/LIBRA-like signal. The shaded regions indicate 1σ statistical uncertainty bands.

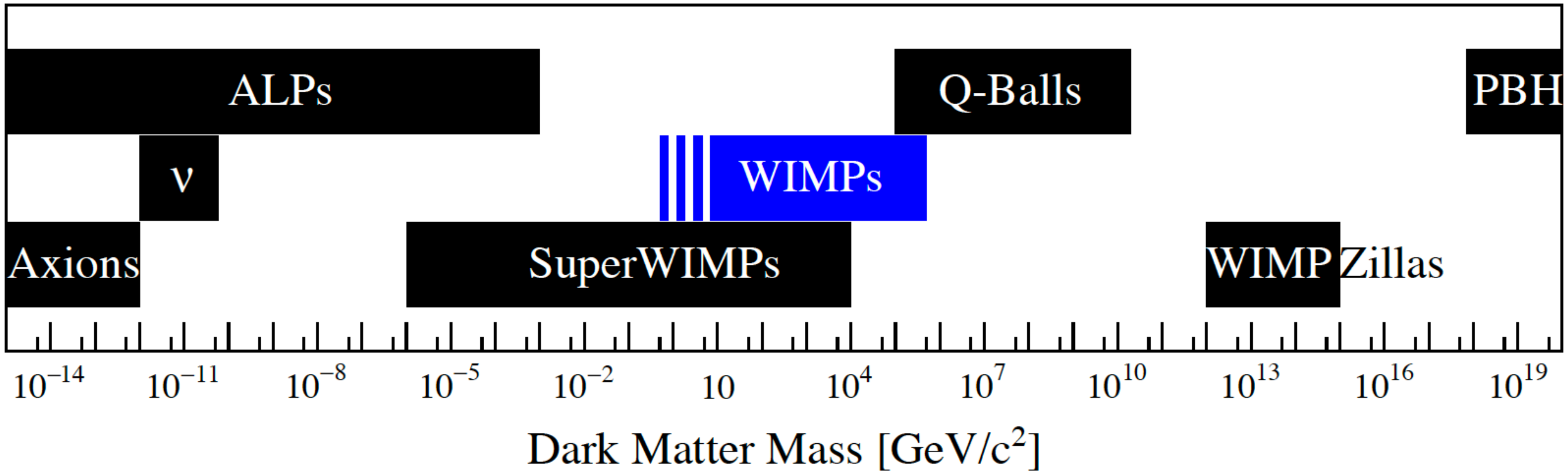
- SABRE South is expected to reject the DAMA/LIBRA modulation at 3σ (null results) or confirm it at 5σ (for a compatible modulation) within 2.5 years.

Conclusions

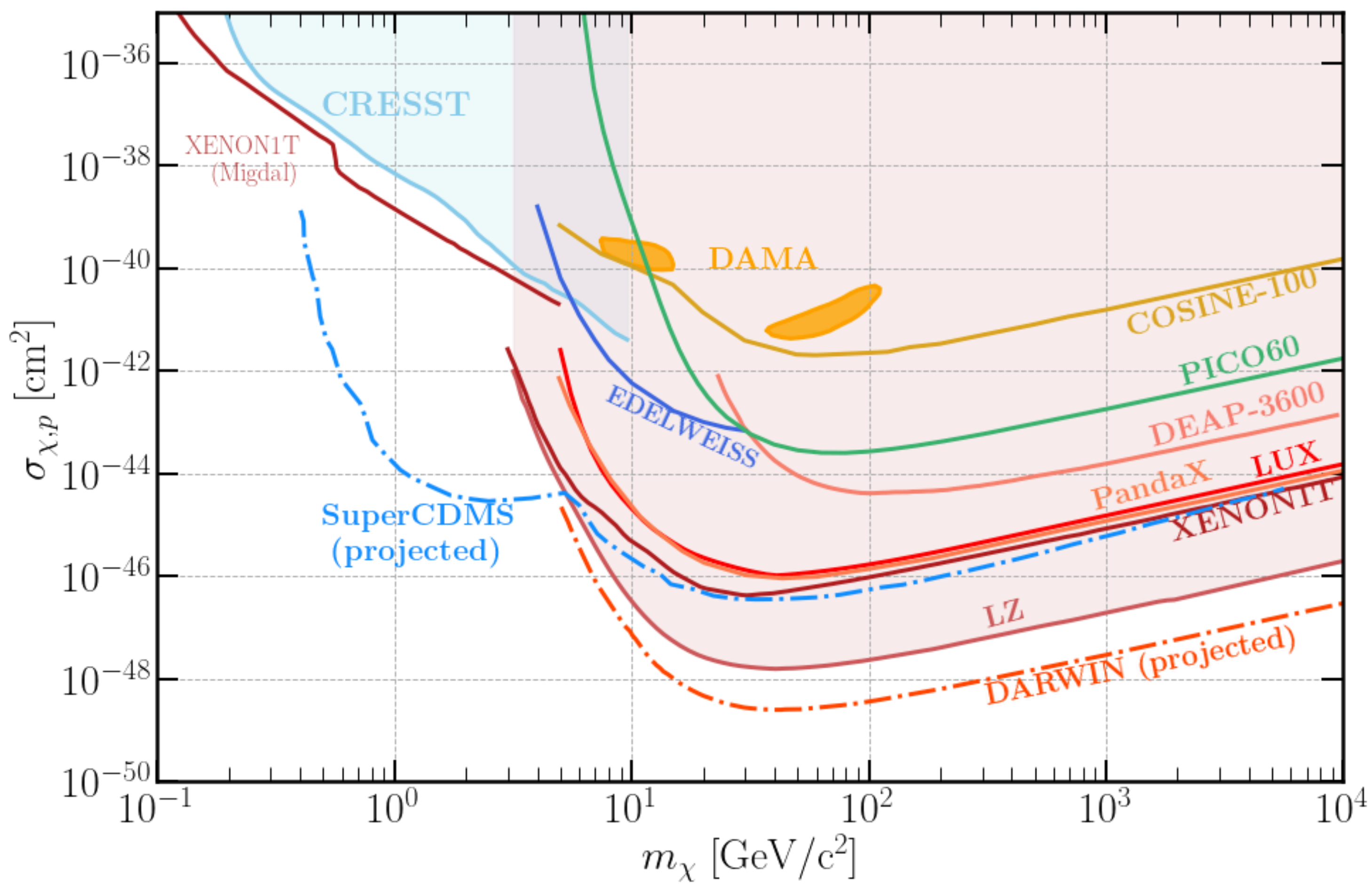
- The primary objective of SABRE is to deploy identical detectors in both hemispheres.
- SABRE has a significant technological advantage with respect to ANAIS and COSINE.
  - Ultra-high purity crystals.
  - Full coverage active veto.
  - Dual location.
- Deployment at SUPL by the end of 2025/beginning of 2026. TDR available!
- Exclusion or discovery results in 2.5-3 years of continuous operation.
- Links:
  - ARC Centre of Excellence for Dark Matter Particle Physics.
  - SABRE experiment.
  - SUPL laboratory.

Backup

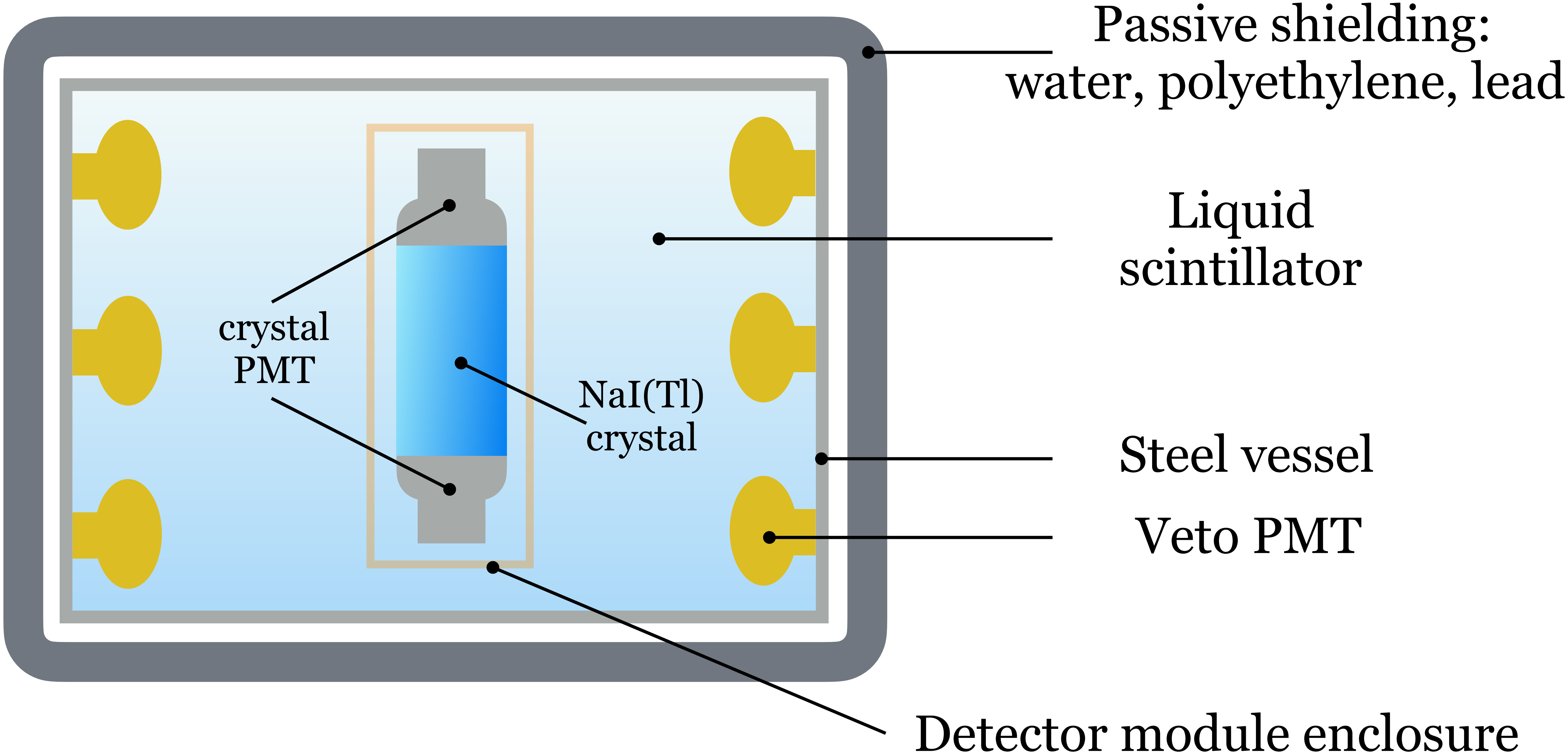
Weakly Interactive Massive Particles



- WIMPs are assumed to have masses in the range from ≈ 1 GeV to ≈ 100 TeV.
- Going below the GeV threshold requires targets lighter than a nucleus.

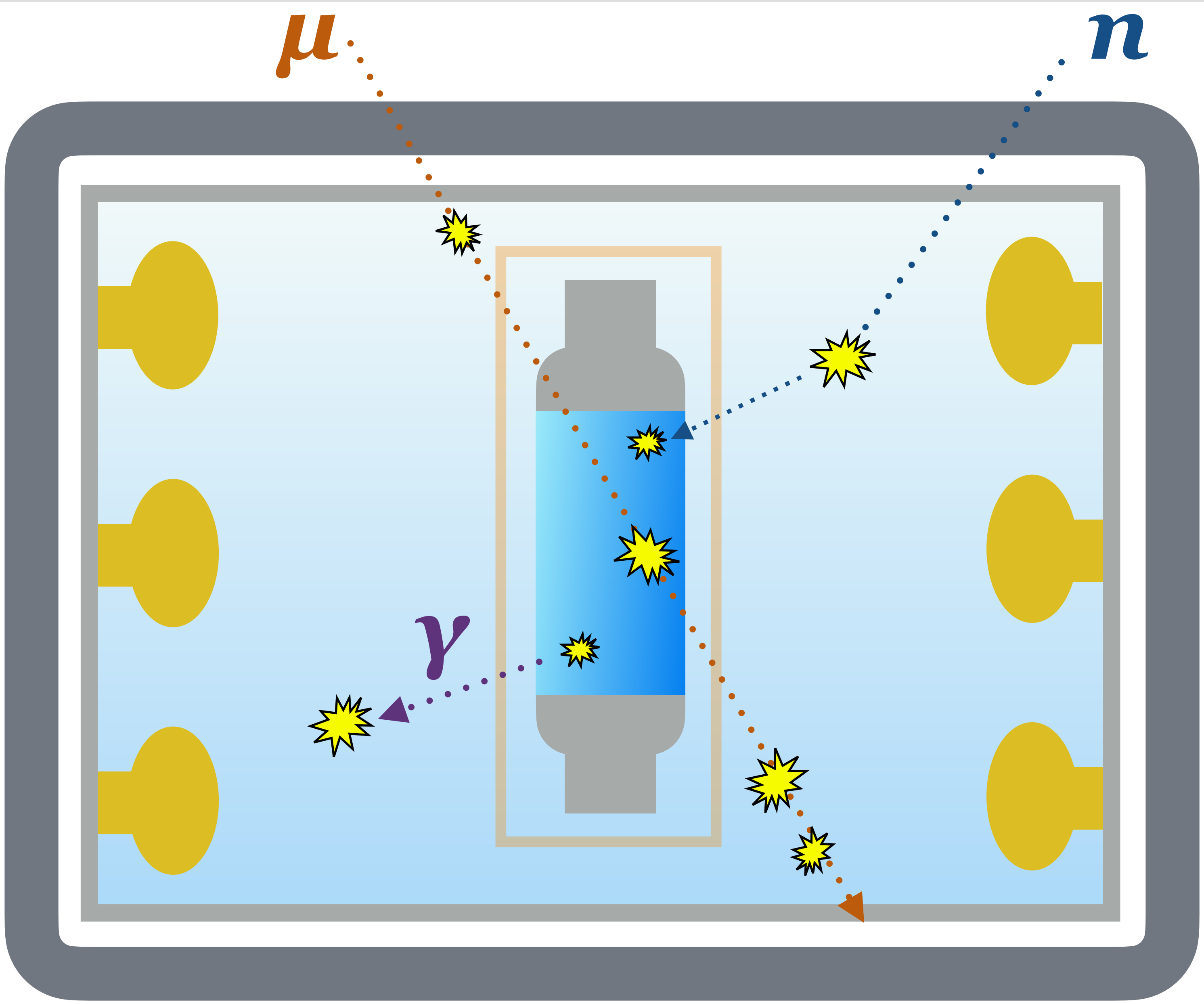


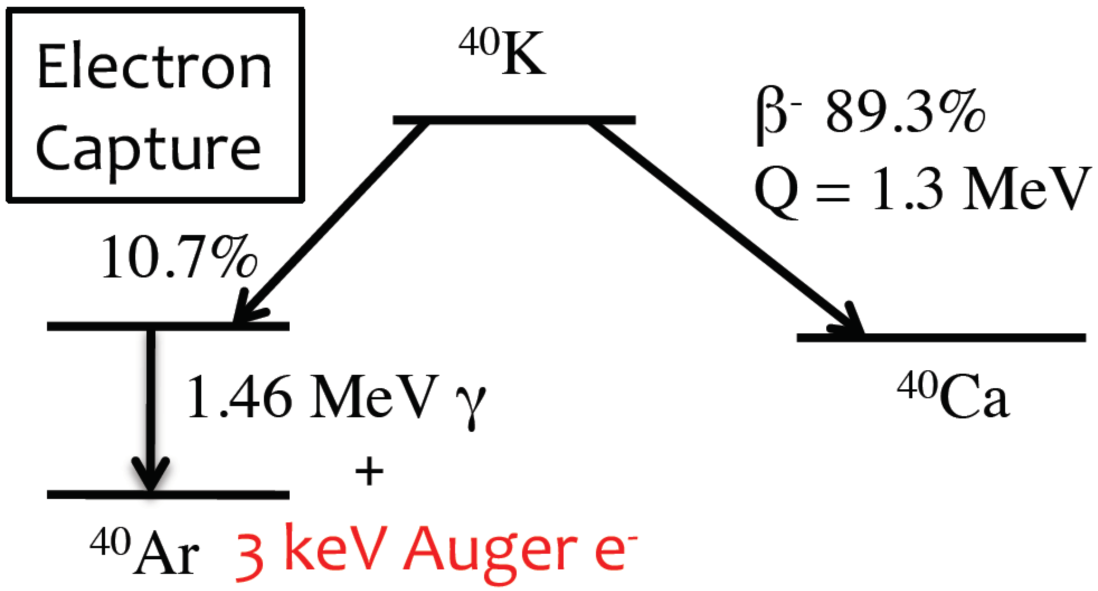
Signal detection



- Dark matter signals are rare.
- Only expected in the main detector module as a coincidence of crystal PMT signals.

Background veto





- Intrinsic and cosmogenic radioactivity within the crystal:
  - Rejected by veto: **^{40}K**, ^{22}Na, ^{238}U, ^{232}Th.
  - Not rejected by veto: **^{3}H**,**^{210}Pb**, ^{87}Rb.
- Photons (γ) and neutrons (n) from surrounding material.
- Cosmic muons (μ) inducing n.

SABRE North and South

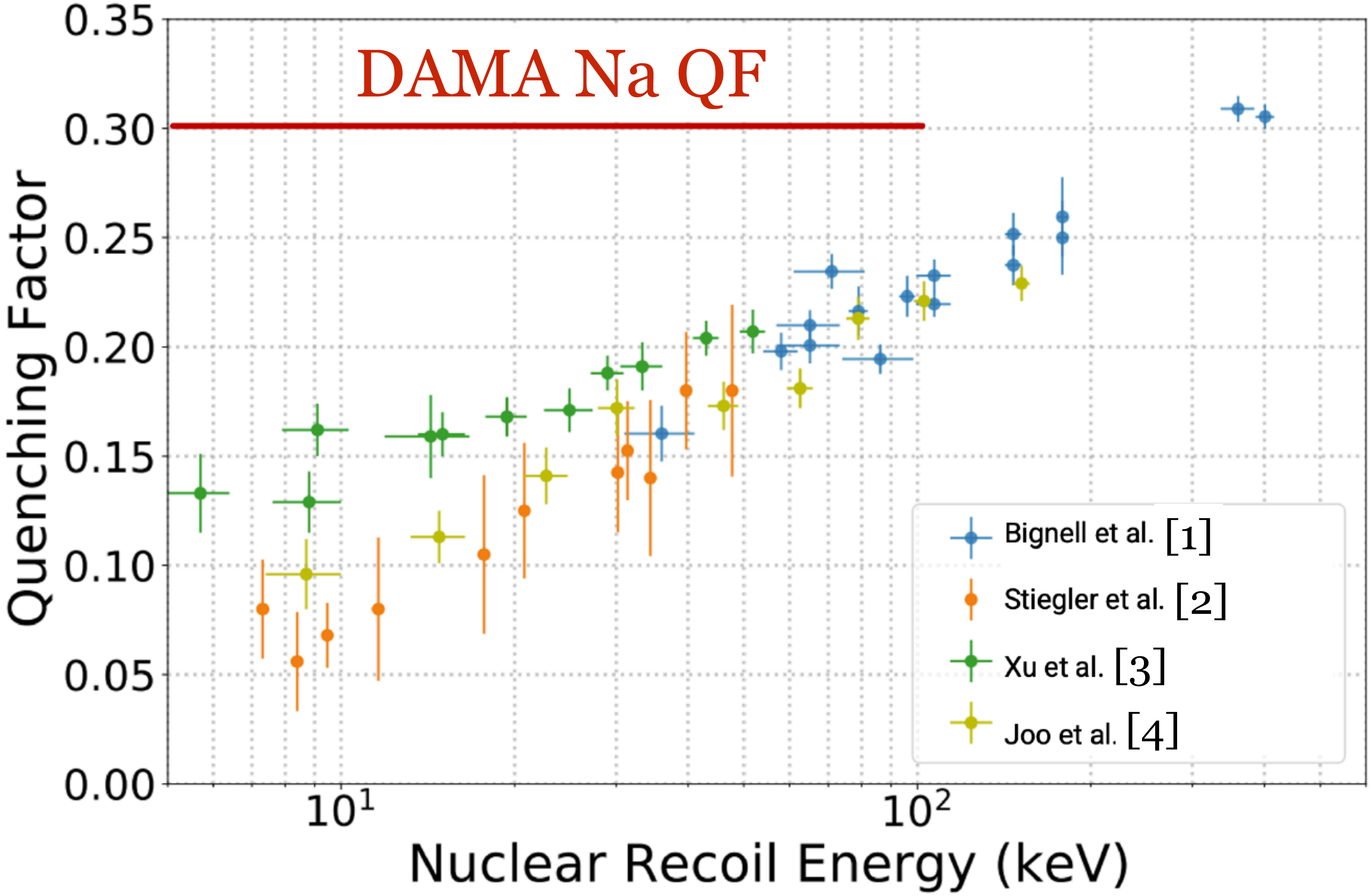
Common core features

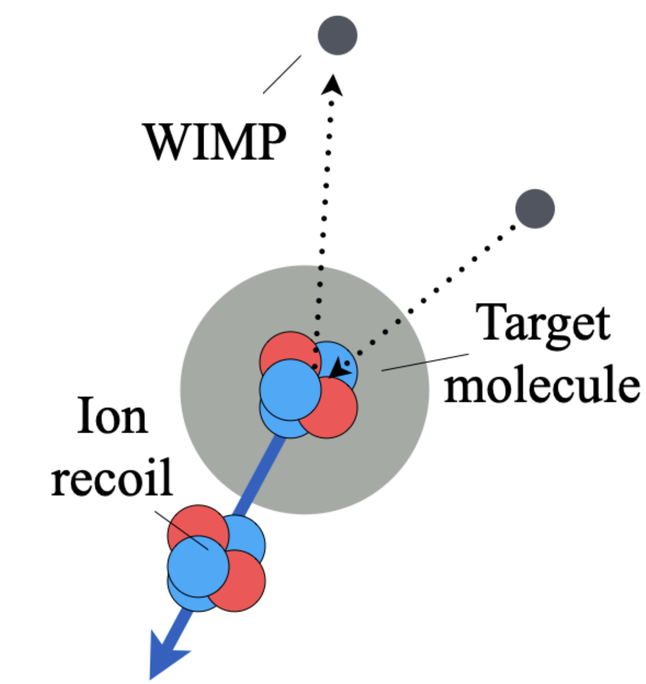
- Same detector module concept (ultra-pure crystals and photomultipliers).
- Common simulation, DAQ and software frameworks.
- Exchange of engineering know-how with official collaboration agreements between the ARC Centre of Excellence for Dark Matter Particle Physics and the INFN.

Different shielding designs

- **SABRE North** has opted for fully passive shielding due to the phase-out of organic scintillators at LNGS. Direct counting and simulation show that this is compliant with the background goal of SABRE North at LNGS.
- **SABRE South** will be the first experiment at SUPL; the liquid scintillator will be used for in-situ evaluation and validation of the background in addition to background rejection and particle identification.

Quenching factors



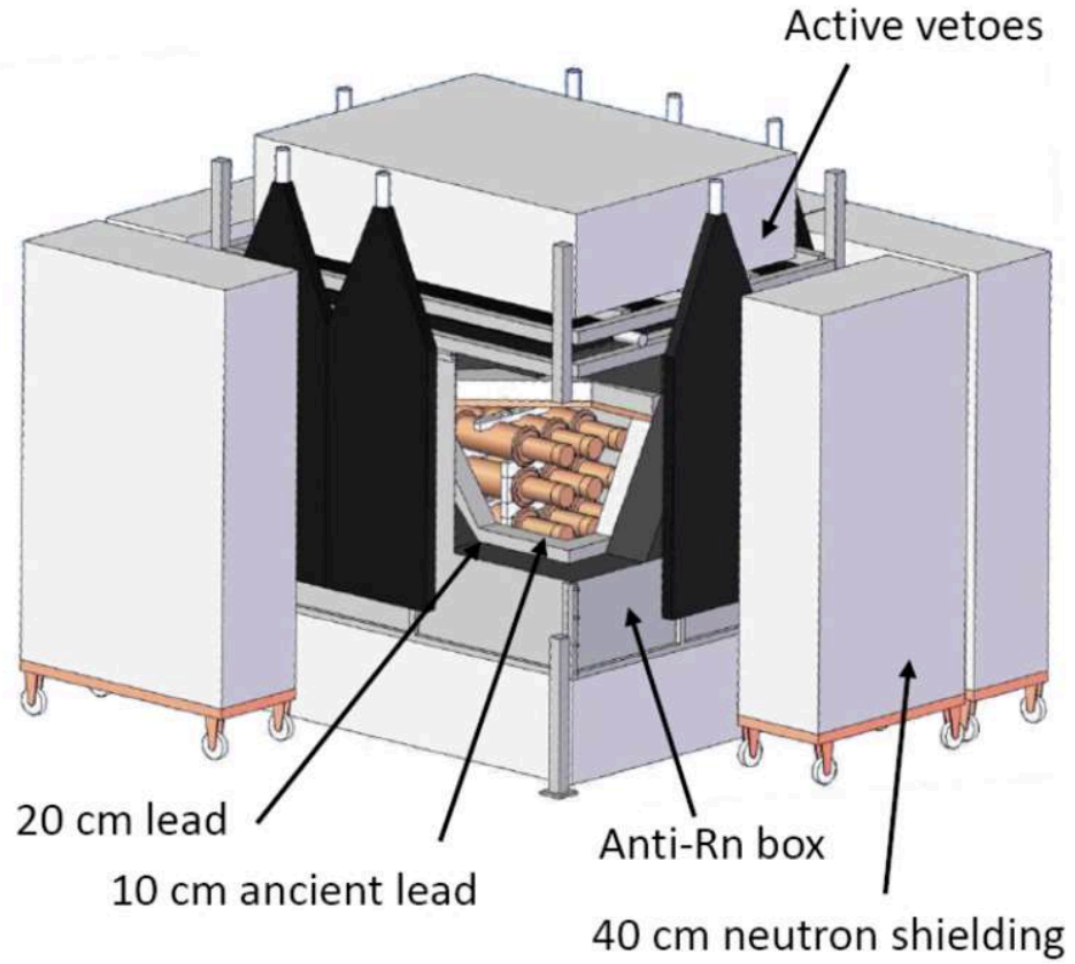


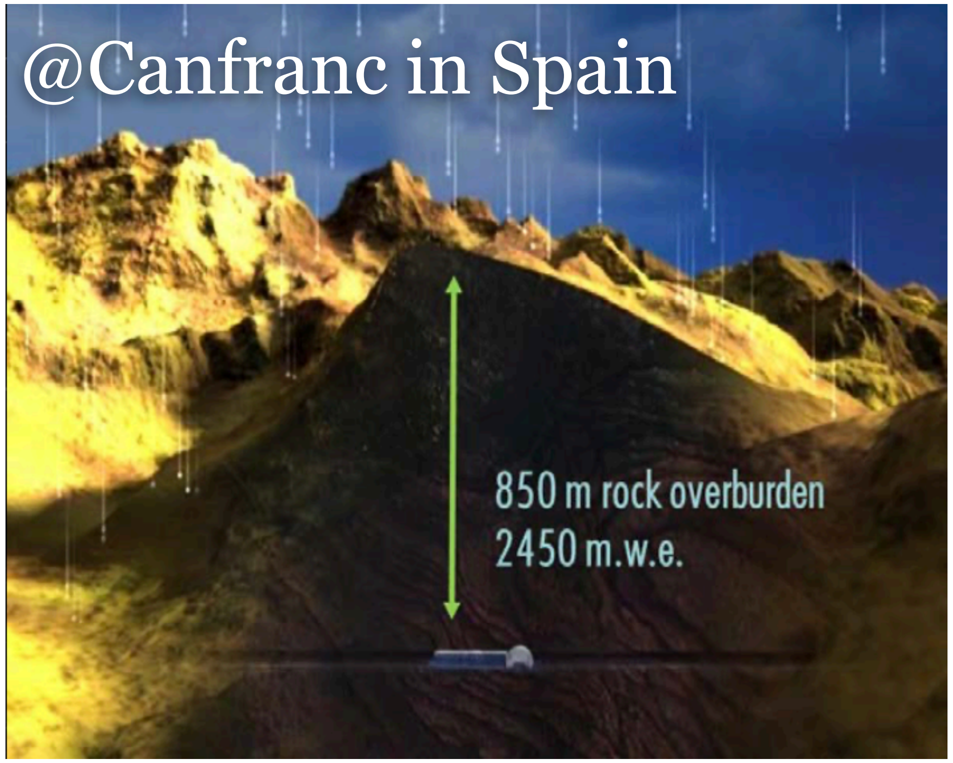
$$E_{ee} = QF(E_{NR})E_{NR}$$

- Equally energetic recoiling ions and electrons induce different detected energies.
- Changes both the amplitude and position of the signal.
- Might depend on the optical properties of the crystal affected by its growth method.
- Depends on the type of recoiling nucleus.

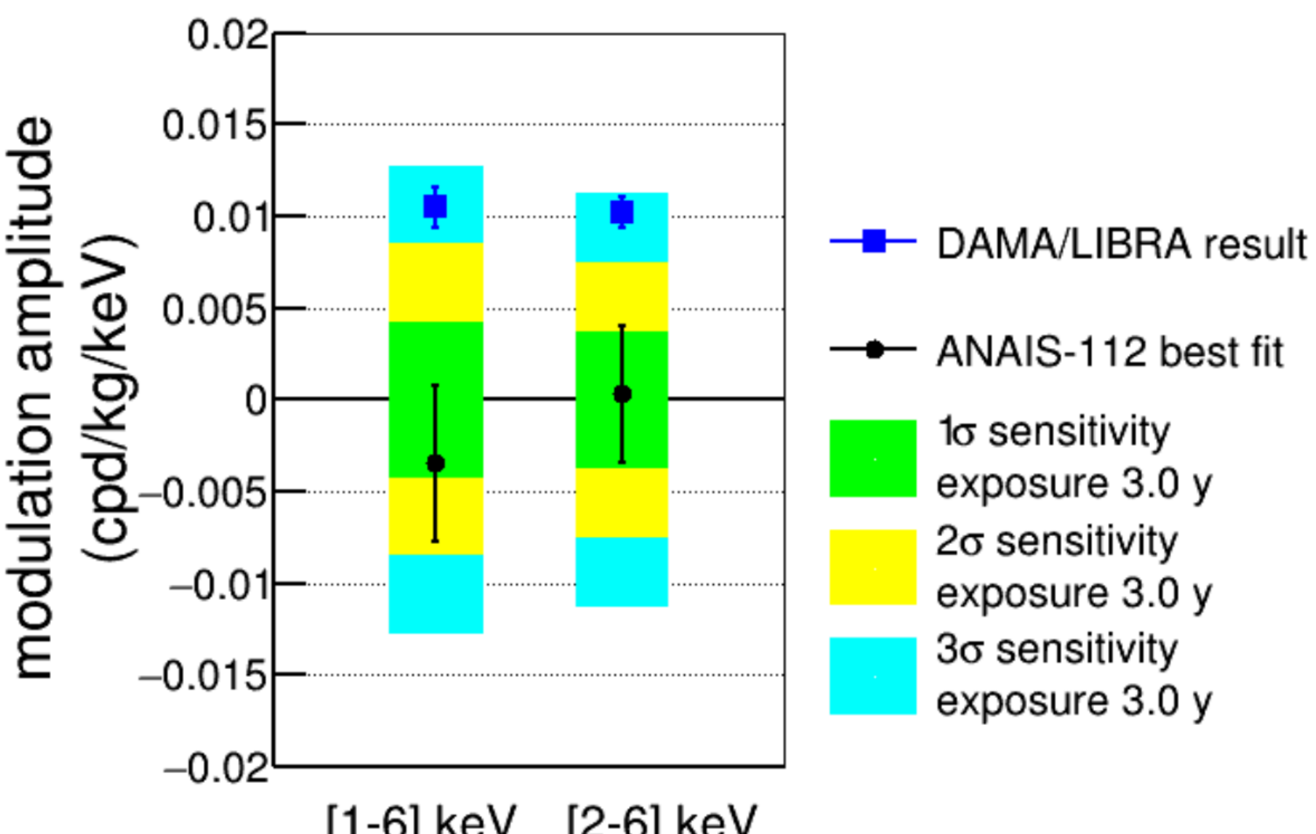
[1] JINST 16 P07034, [2] arxiv:1706.07494 , [3] 10.1103/physrevc.92.015807 , [4] 10.1016/j.astropartphys.2019.01.001.

ANAIS-112



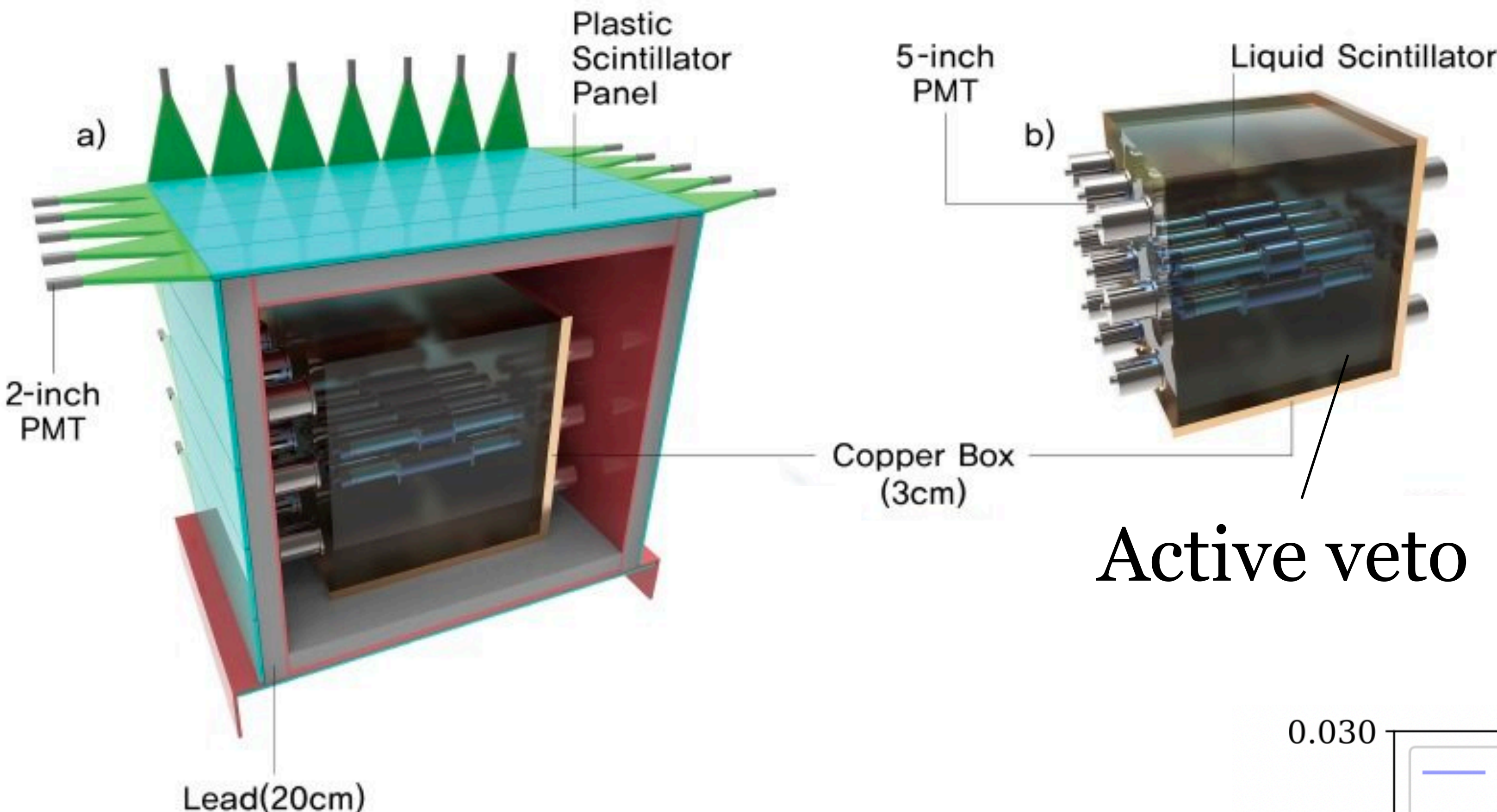


- 3 x 3 detector modules: 112.5 kg of NaI(Tl) built by Alpha Spectra company (US).
- **Five year exposure** completed by August 2022 with 95% live time. Started 3 August 2017.



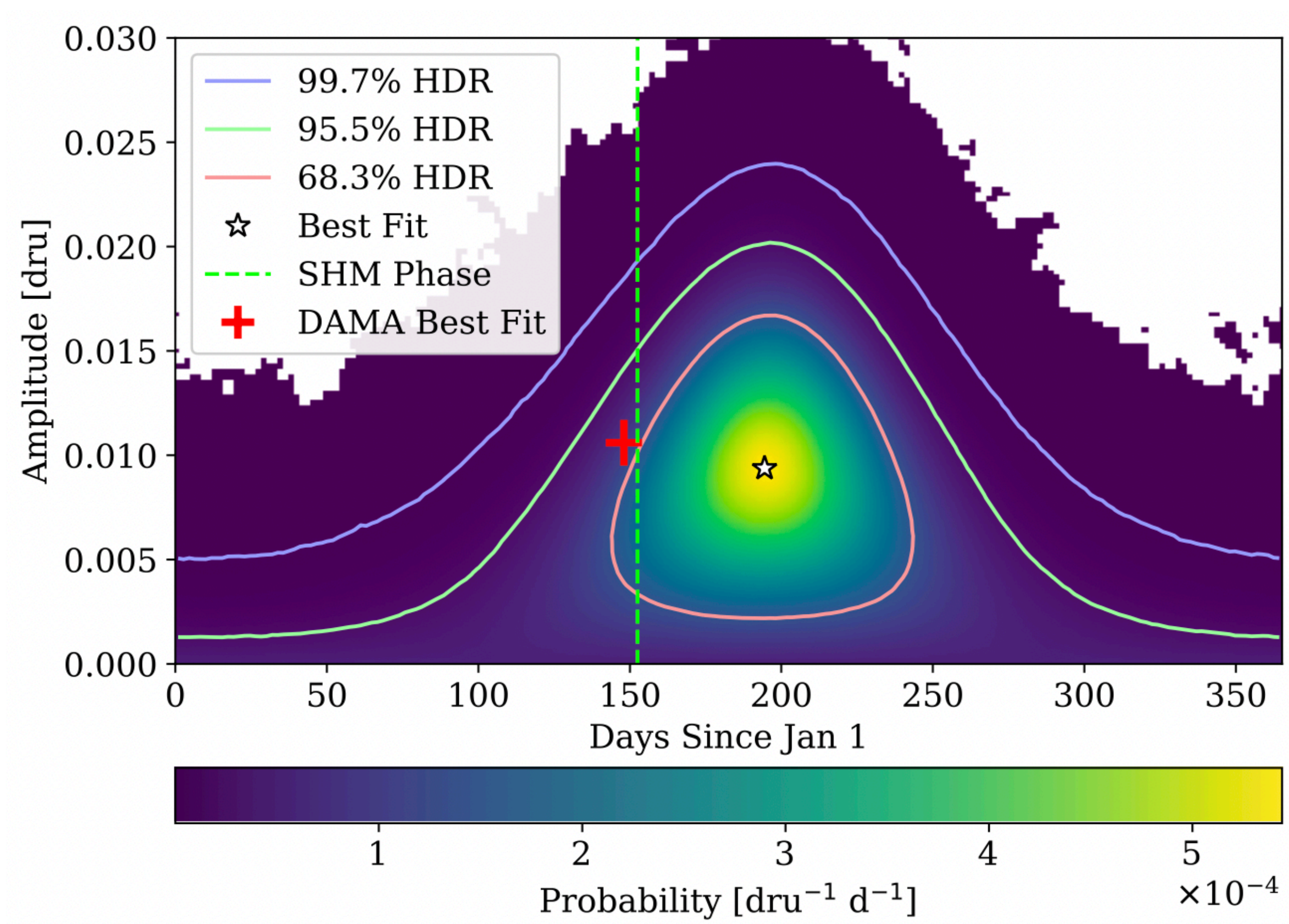
Phys. Rev. D 103, 102005

COSINE-100



- 8 detector modules from Alpha Spectra: 106 kg of NaI(Tl).
- Active since 2016.
- 2.8 years of data and 60 kg of NaI(Tl).

Phys. Rev. D 106, 052005

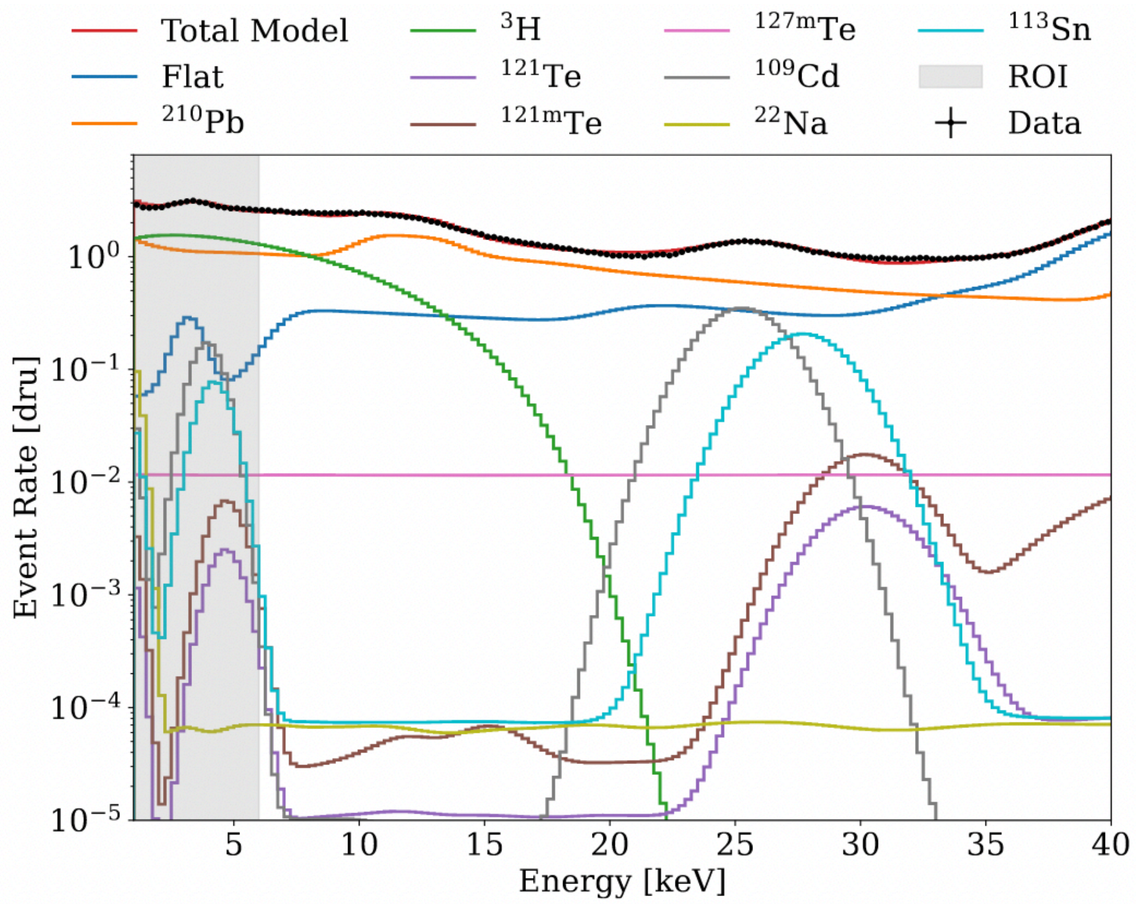


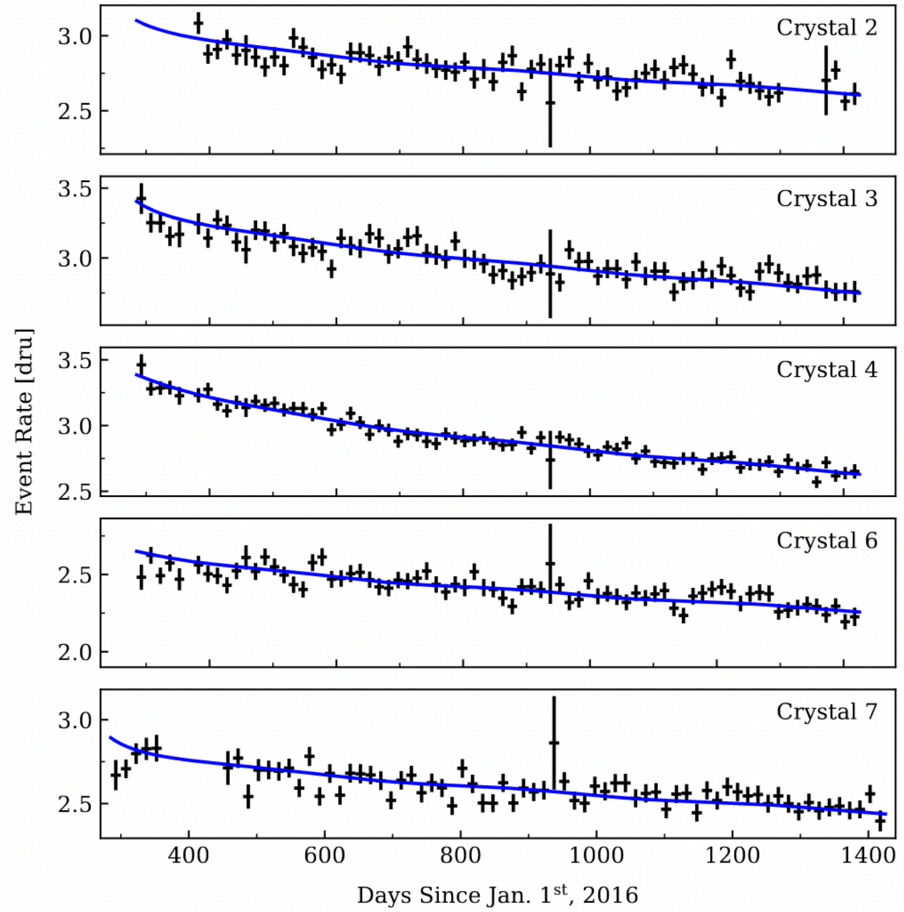
COSINE-100

Phys. Rev. D 106, 052005

Total rate: $R_i(t|S_m, \alpha_i, \beta_i) = \boxed{\alpha^i} + \boxed{\sum_{k=1}^{N_{bkgd}} \beta_k^i e^{-\lambda_k t}} + \boxed{S_m \cos(\omega(t - t_0))}$

- Dedicated model for detector *i* and background *k*.
- Flat: long lived backgrounds: ^{40}K, ^{238}U, ^{232}Th.
- Exponential: decaying backgrounds. Separate model for ^{210}Pb, ^{3}H etc.
- Modulation.



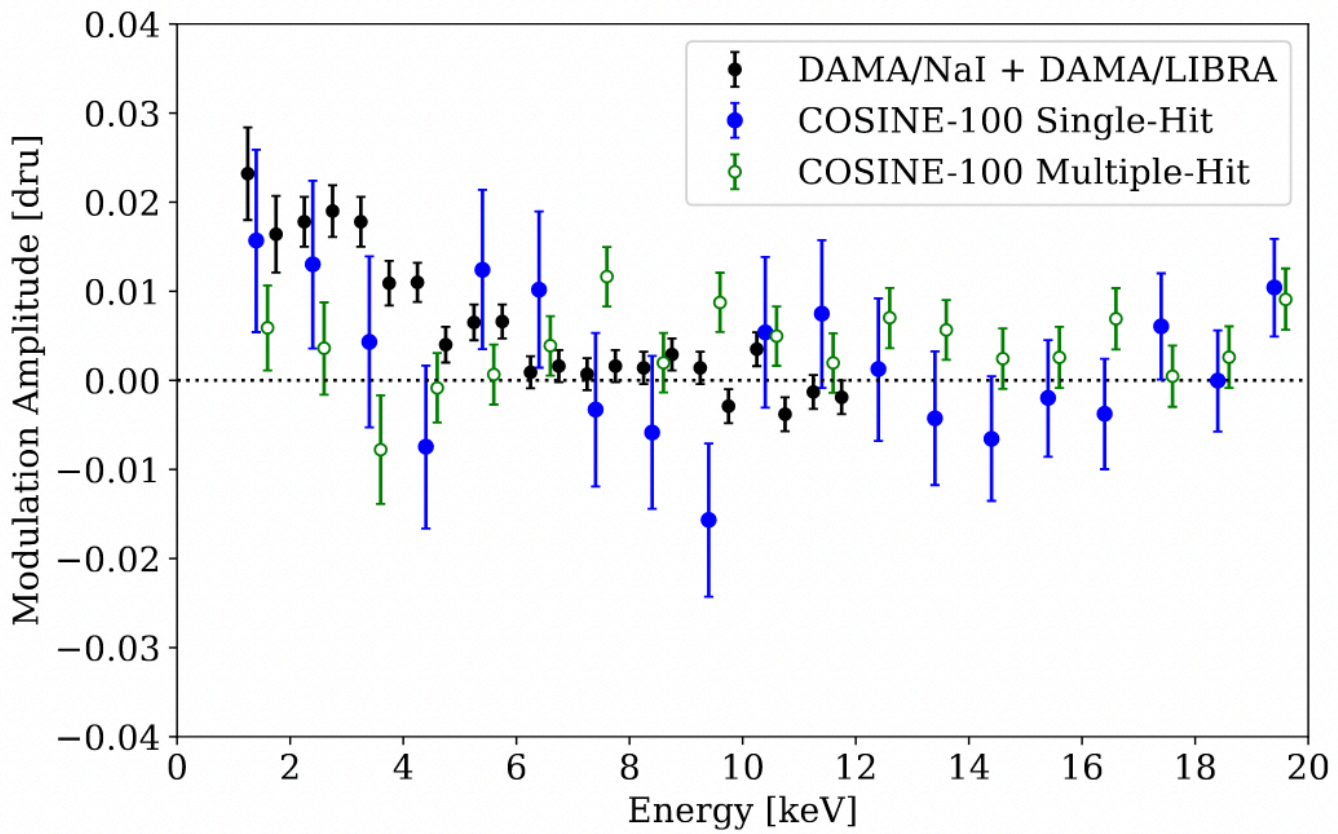


- Background model created using first 1.7 years of data + MC simulations.
- Data normalised by live-time and efficiency in 15 days bins before fitting.

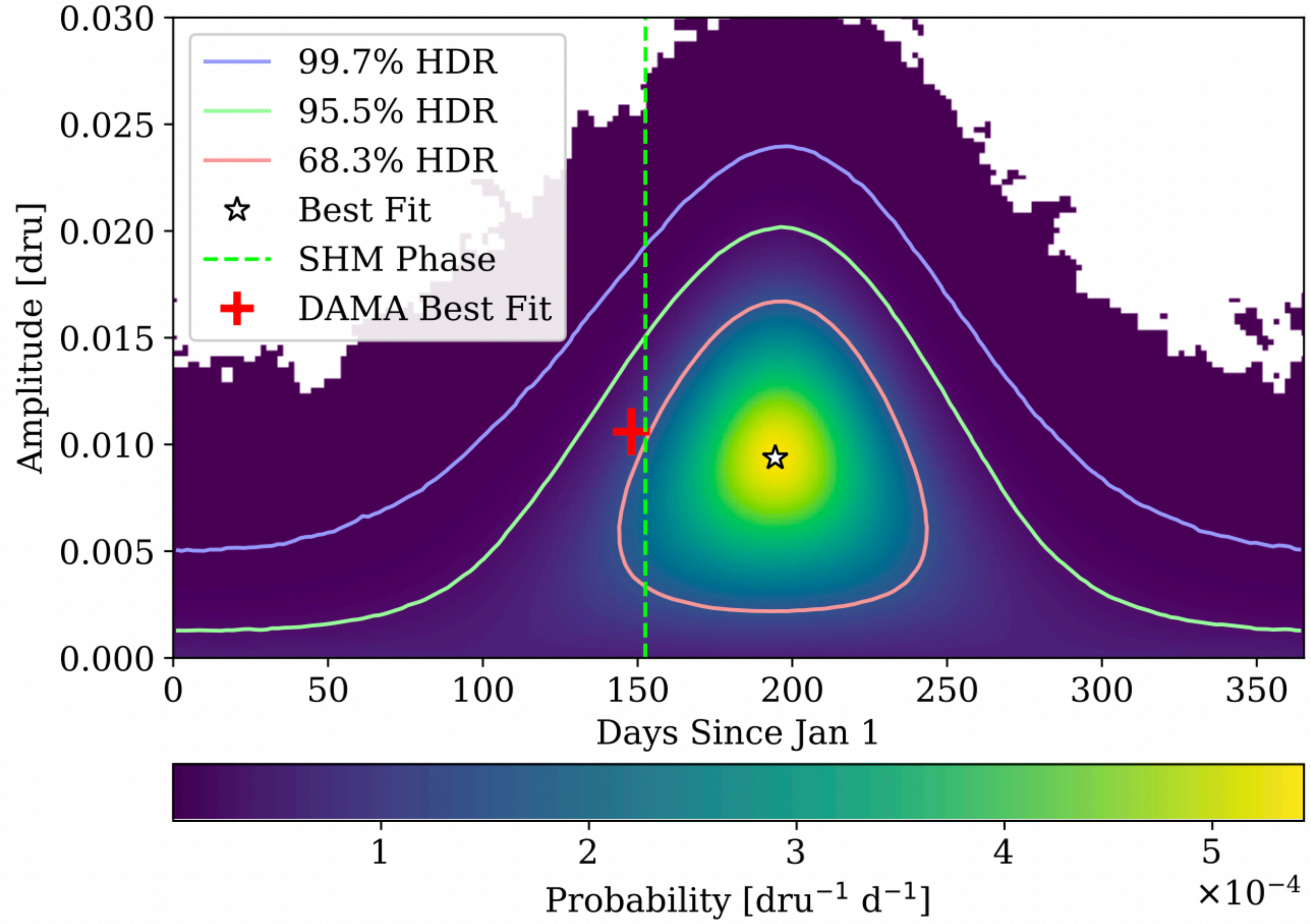
COSINE-100

Phys. Rev. D 106, 052005

Fixed phase and period
- Period = 365.25 days.
- Phase = 152.5 days.



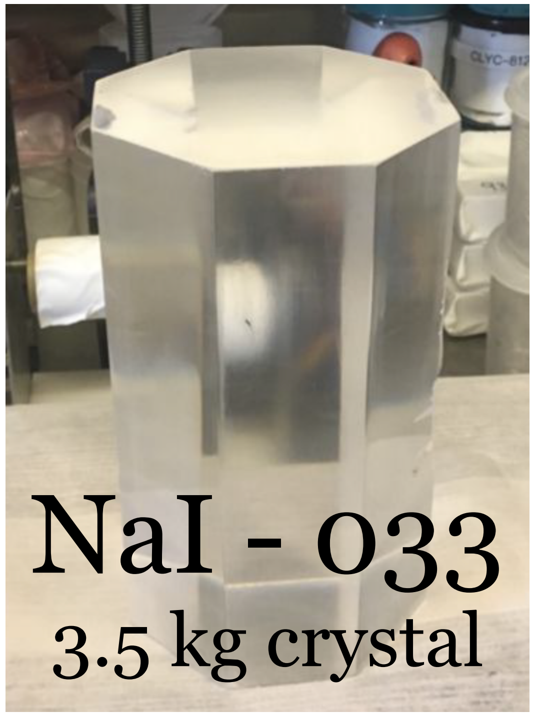
Floated phase: [1 - 6] keV

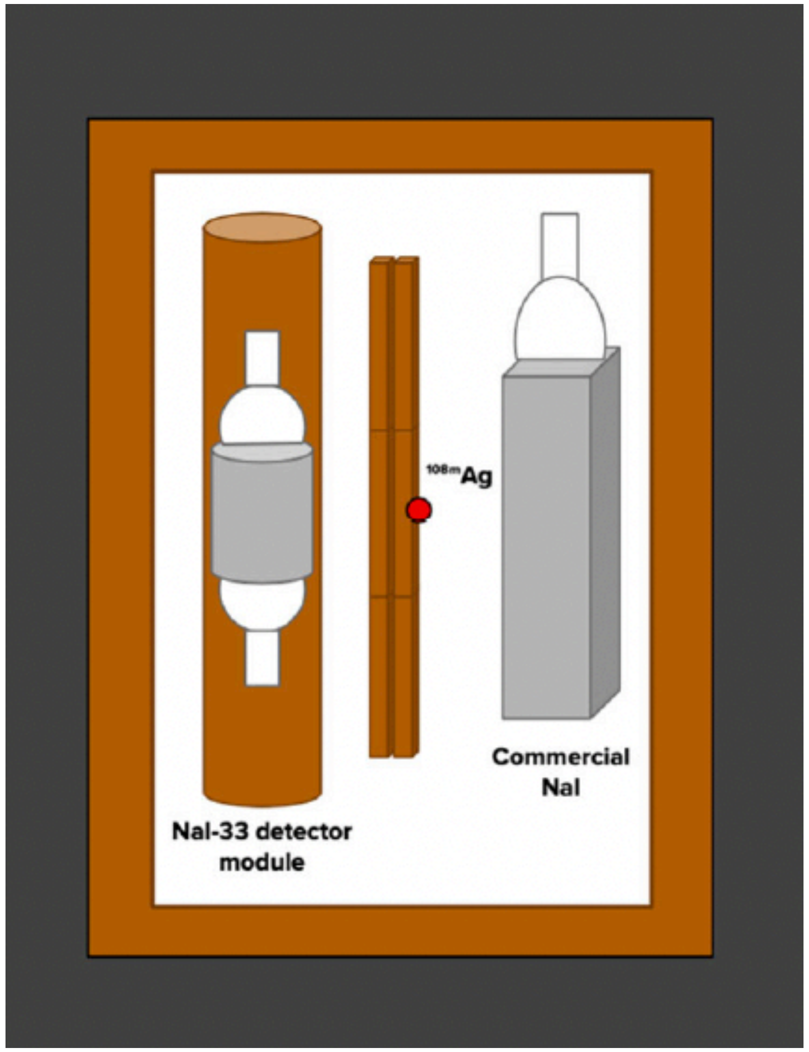


- 2.8 years of data and 60 kg of NaI(Tl)
- Both results constistent with DAMA and null hypothesis.
- Operations scheduled until late 2022 when commissioning of COSINE-200 will start.

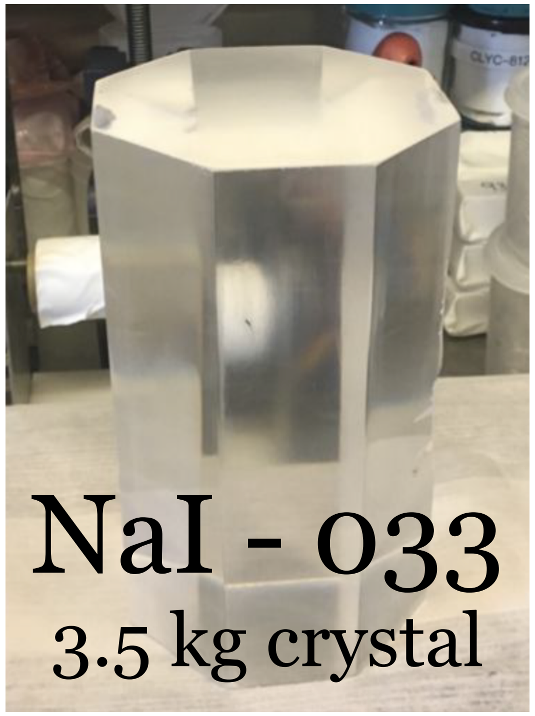
SABRE crystals

[Eur. Phys. J. C 81, 299 (2021)]





SABRE crystals [Eur. Phys. J. C 81, 299 (2021)]



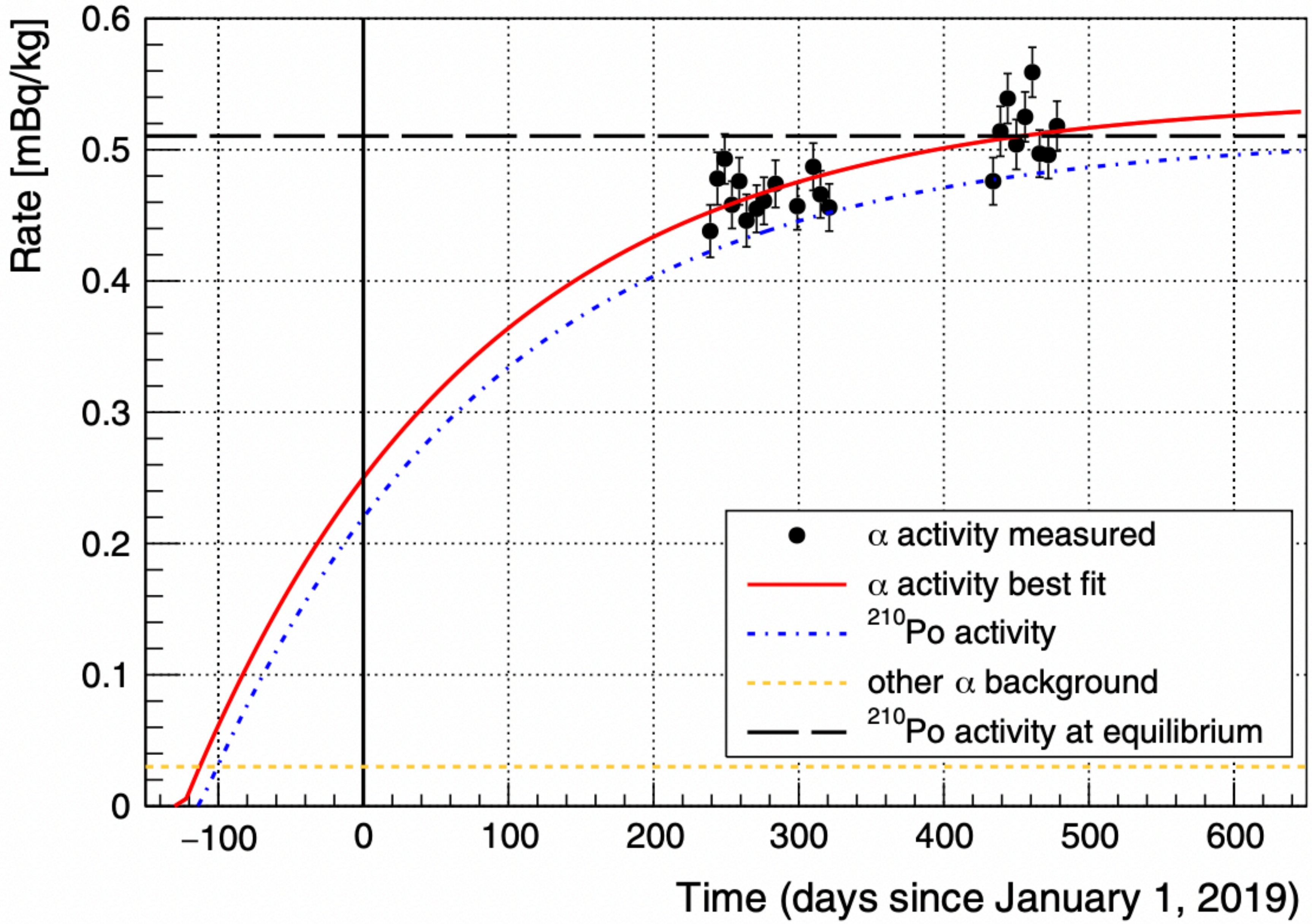
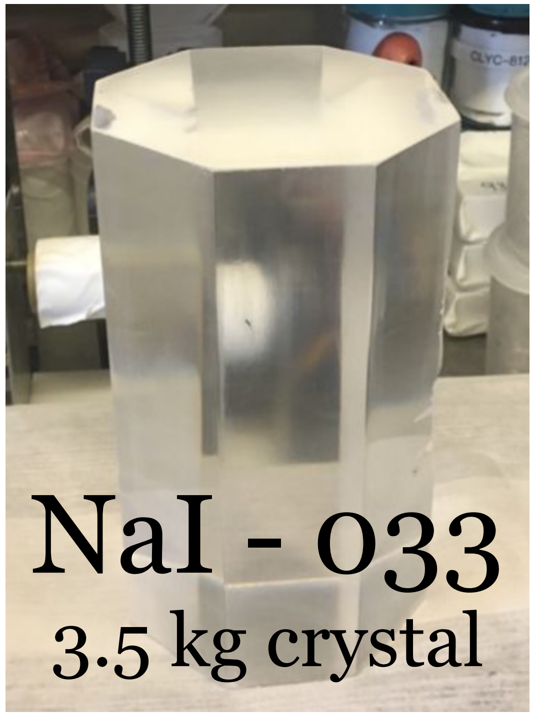


Fig. 5 α activity in ^{210}Po energy region as a function of time with 5-days binning. The best fit function to the data (red solid line) is the sum of the build-up function with the mean life of ^{210}Po (blue dotted line) and a constant component independently determined (orange dotted line). The black dashed line shows the activity of ^{210}Po at equilibrium

SABRE crystals

Eur. Phys. J. C 81, 299 (2021)



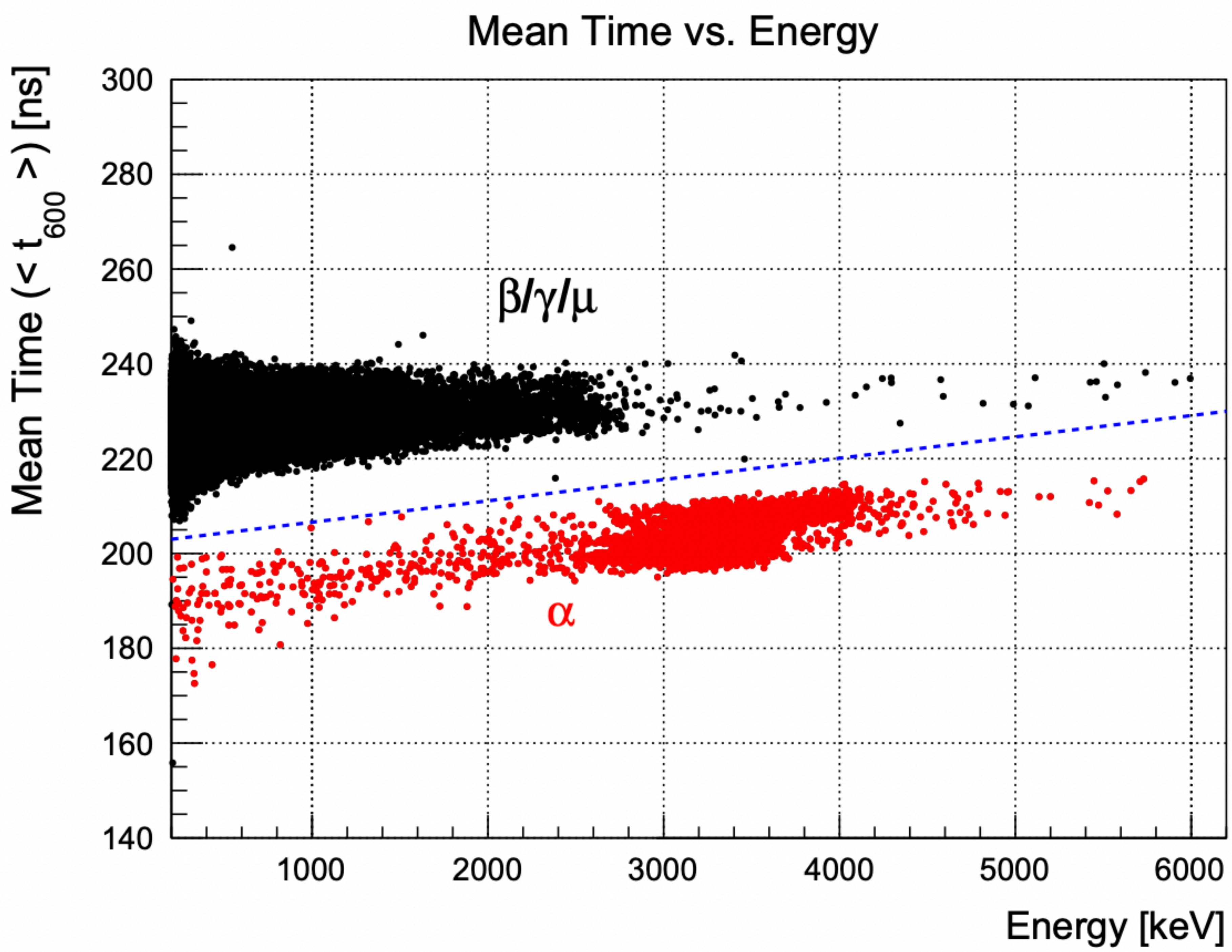
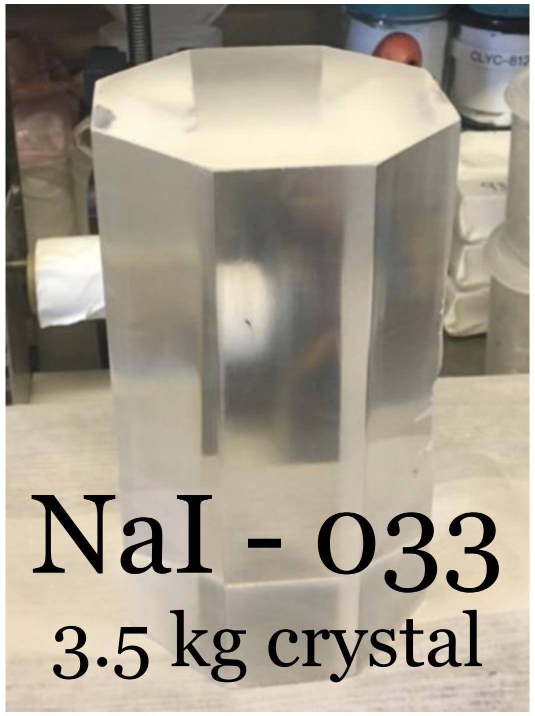


Fig. 4 Distribution of mean time vs. energy of α (red) and β/γ (black) events. The blue dotted line shows our typical separation cut

SABRE crystals

Eur. Phys. J. C 81, 299 (2021)



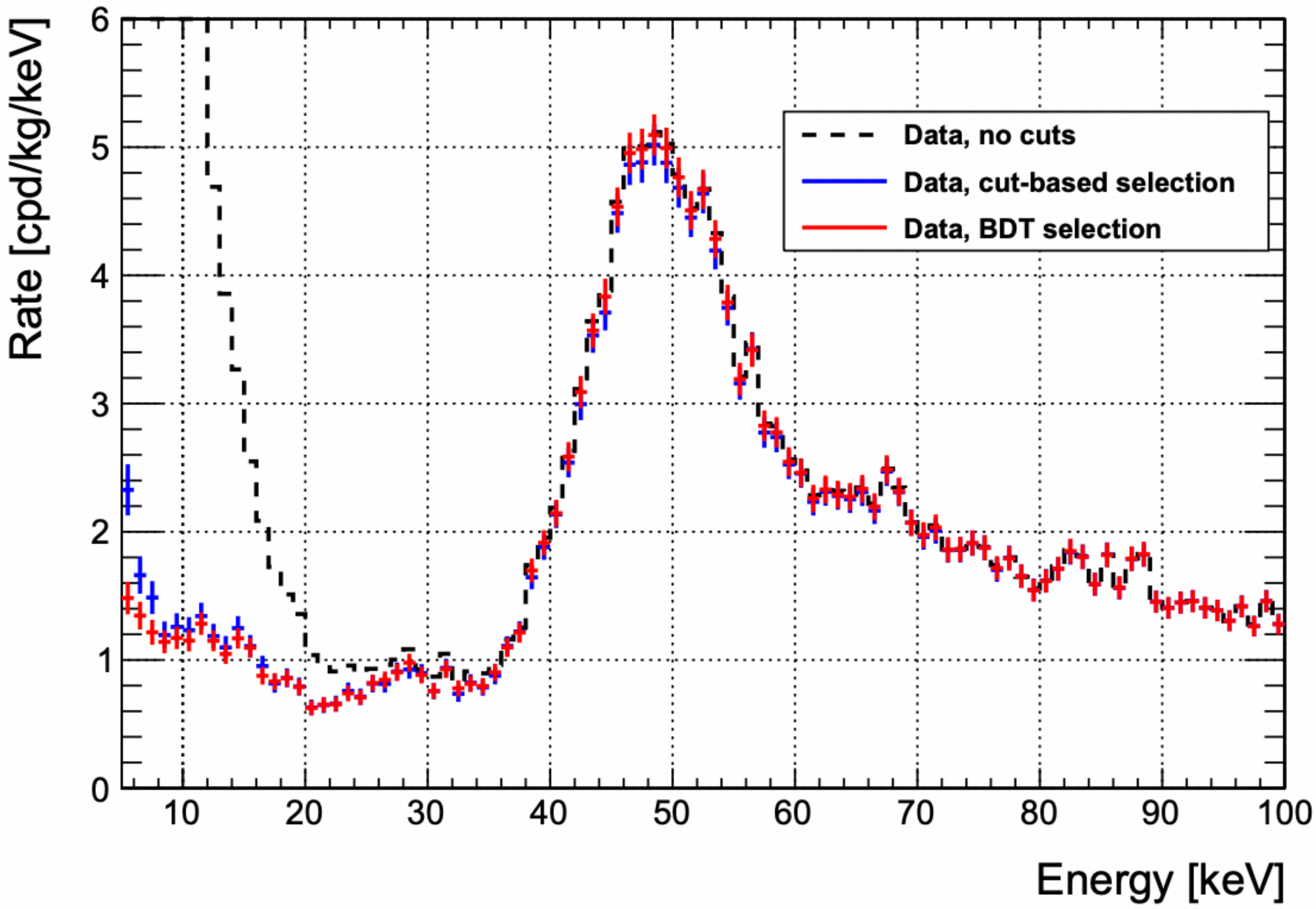
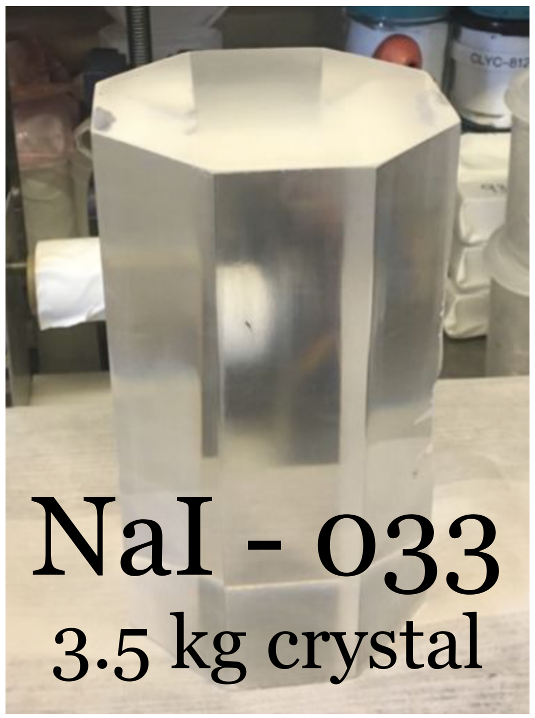
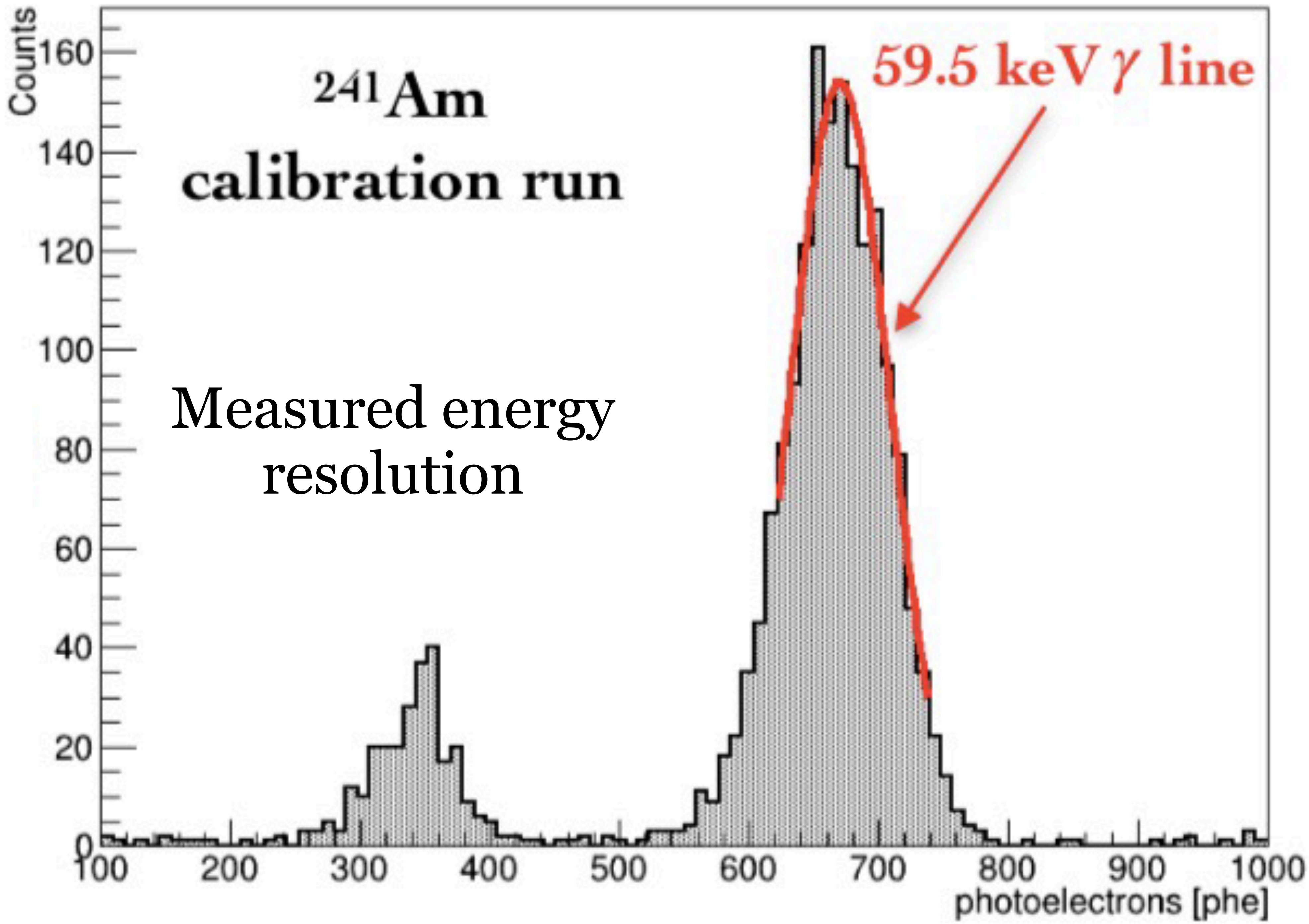


Fig. 11 NaI-33 low energy spectrum before (black dashed line) and after noise rejection. We show the result of the cut-based (blue points) and multivariate BDT (red points) analyses. The blue and red histograms are corrected by the respective cut acceptance

SABRE crystals

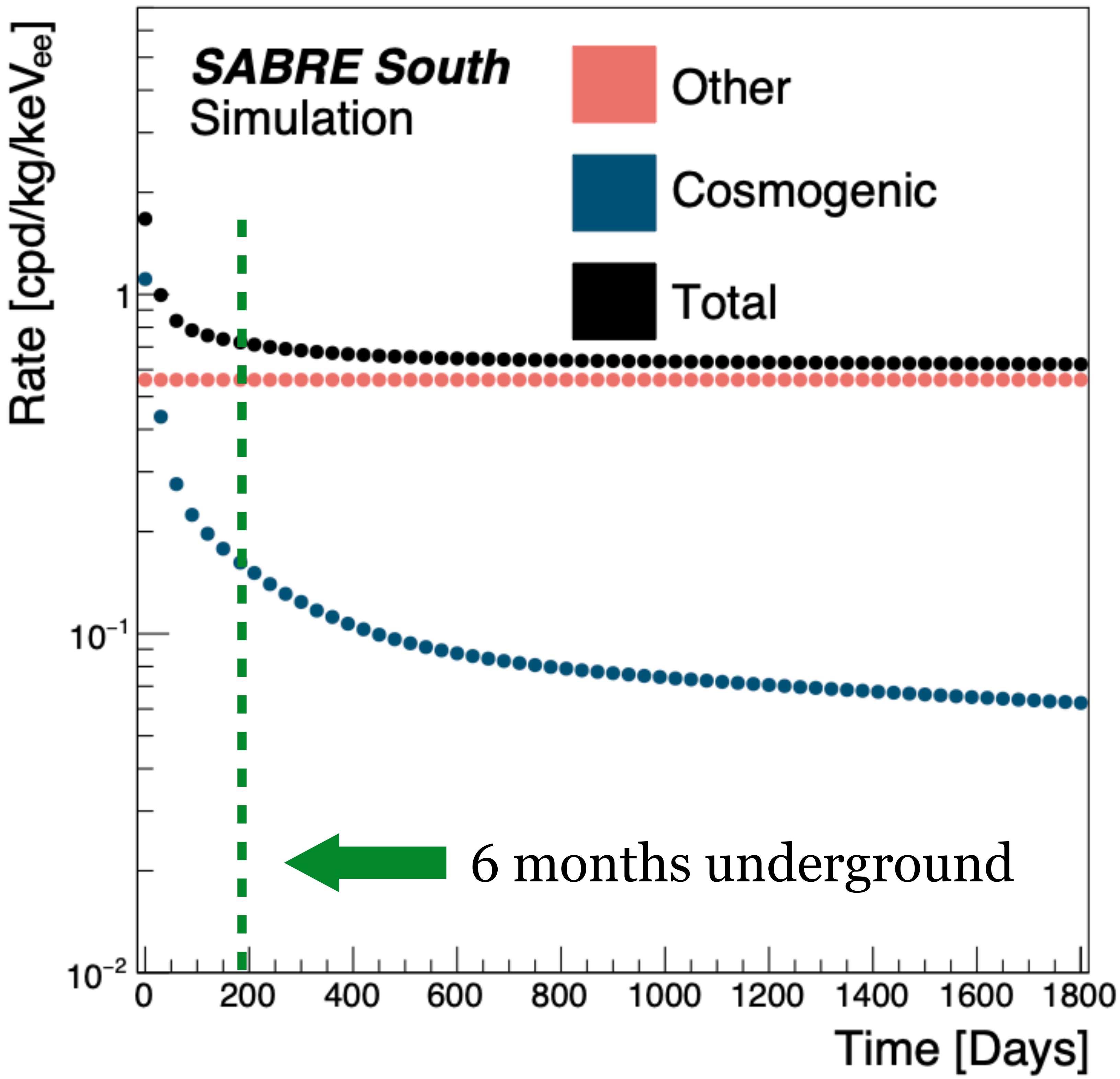
Eur. Phys. J. C 81, 299 (2021)





SABRE South

arXiv: 2205.13849

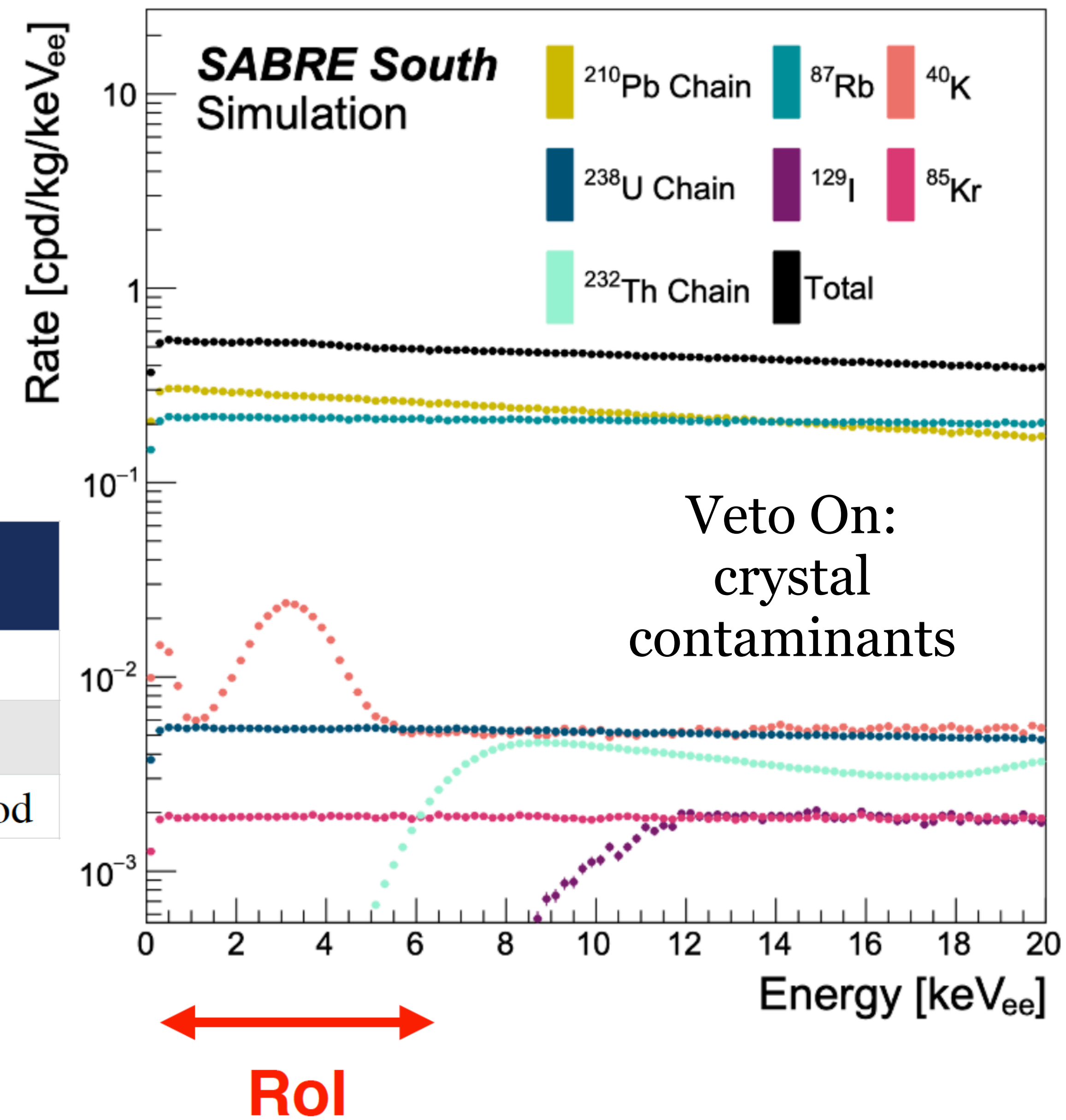


High purity NaI(Tl) crystals

- Crystal background >90% of total background
- Intrinsic crystal radiation >70% of total
  - Key contaminants ^{40}K, ^{210}Pb, ^{3}H

Isotope	Background	Half life	Source	Reduction method
^{40}K	3 keV electron	10^9 y	Environment	Veto
^{210}Pb	15 keV electron	22.3 y	Rn in water	Distilled water
Tritium	5 keV electron	12 y	Cosmogenic	transport method

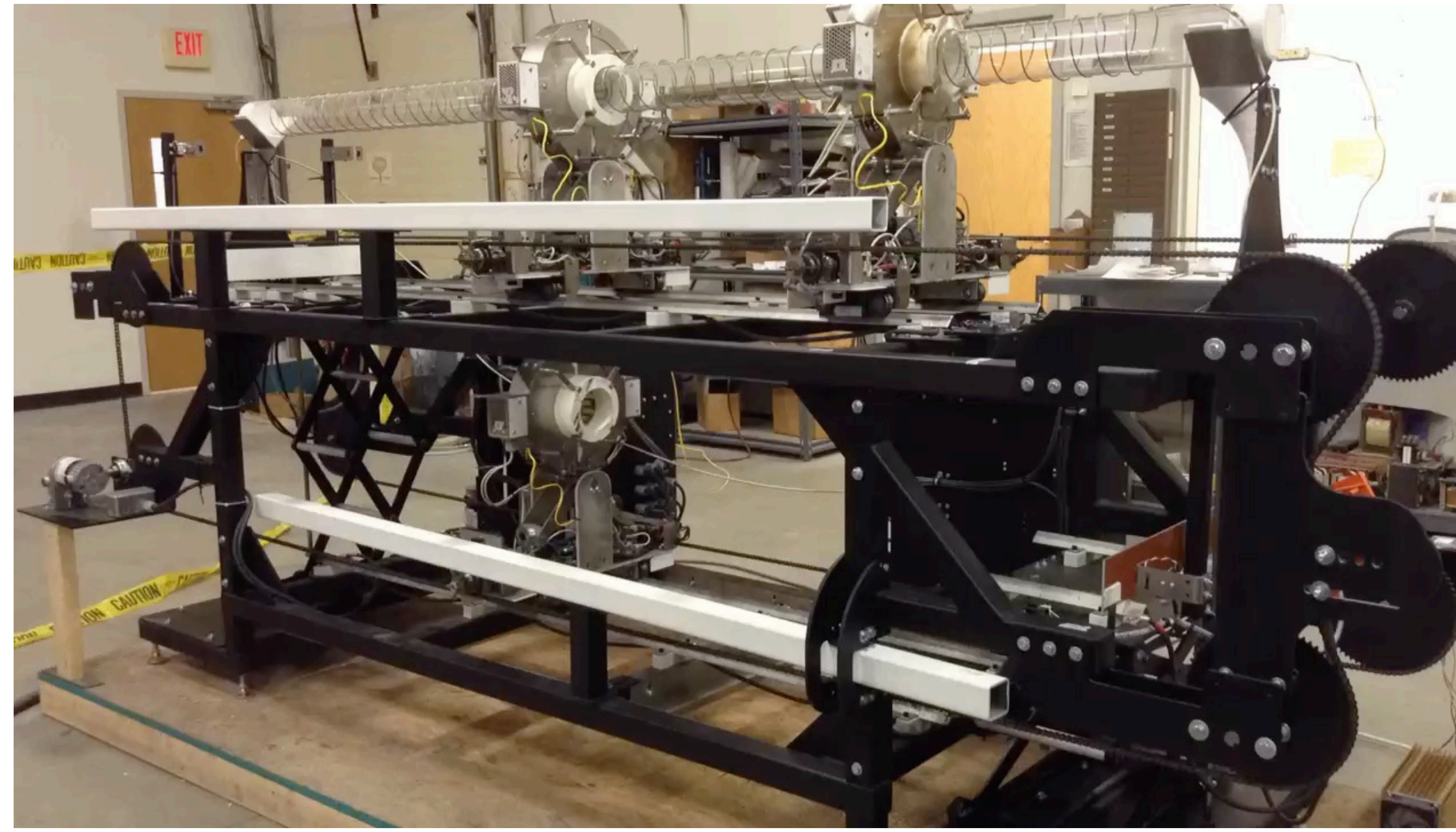
- Light yield should be ~ 10 p.e./keV (to achieve keV thresholds)



See B. Melbourne poster (P16)

SABRE crystals: zone refining

- Strategic and unique to the SABRE project is the idea to zone-refine the powder prior to growth.
- A zone refiner suitable for ~100 kg crystal production has been built in collaboration with MELLEN.
- The zone refiner is being moved to RMD for growing a test crystal.



Phys. Rev. Applied 16, 014060

- Impurities are pushed to the end of the refining tube and removed from the ingot before the crystal growth. Reduction factors of:
  - **^{40}K: 10 - 100**.
  - **^{210}Pb: 2**.
  - **^{87}Rb: 10 - 100**.
- The final crystal intrinsic background is **≈ 0.3 cpd/kg/keV**, lower than the current world record of ≈ **1 cpd/kg/keV**.

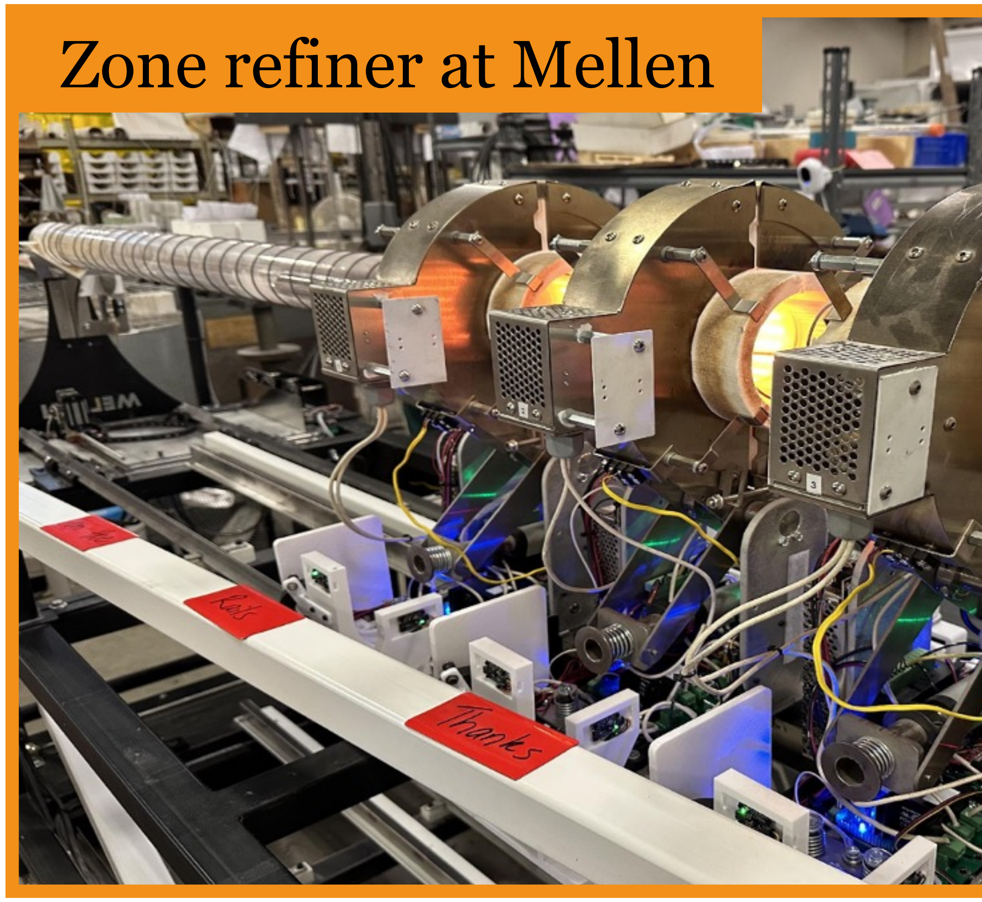
Coast to coast and around the globe
MELLEN
the Hotter the Better
Furnaces Controls Motion Software Waterjet Cutting

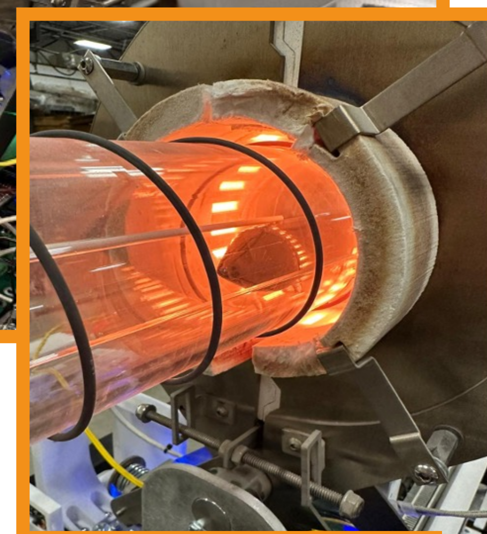
RMD
A Dynasil Company

SABRE crystals: zone refining

- Zone refining technique successfully used in the semiconductor industry.
- Impurities are segregated to one side of the ingot by the moving ovens.
- Tested on NaI Astrograde powder by Princeton group at Mellen (USA).
- Four runs with Astrograde powder have been performed.
- Ampoule preparation and handling by RMD (USA).
- Zone refining will significantly reduce internal background components: ^{40}K: ≈ 10, ^{210}Pb: ≈ 2.
- The final crystal intrinsic background is expected to be **≈ 0.3 cpd/kg/keV**, lower than the current world record of **≈ 1 cpd/kg/keV**.

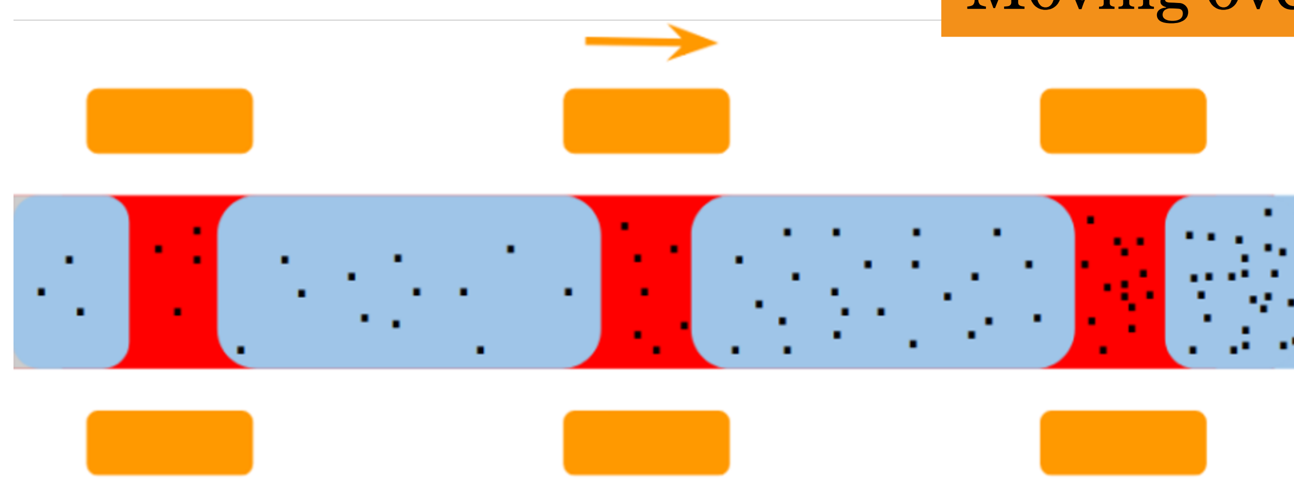
Zone refiner at Mellen





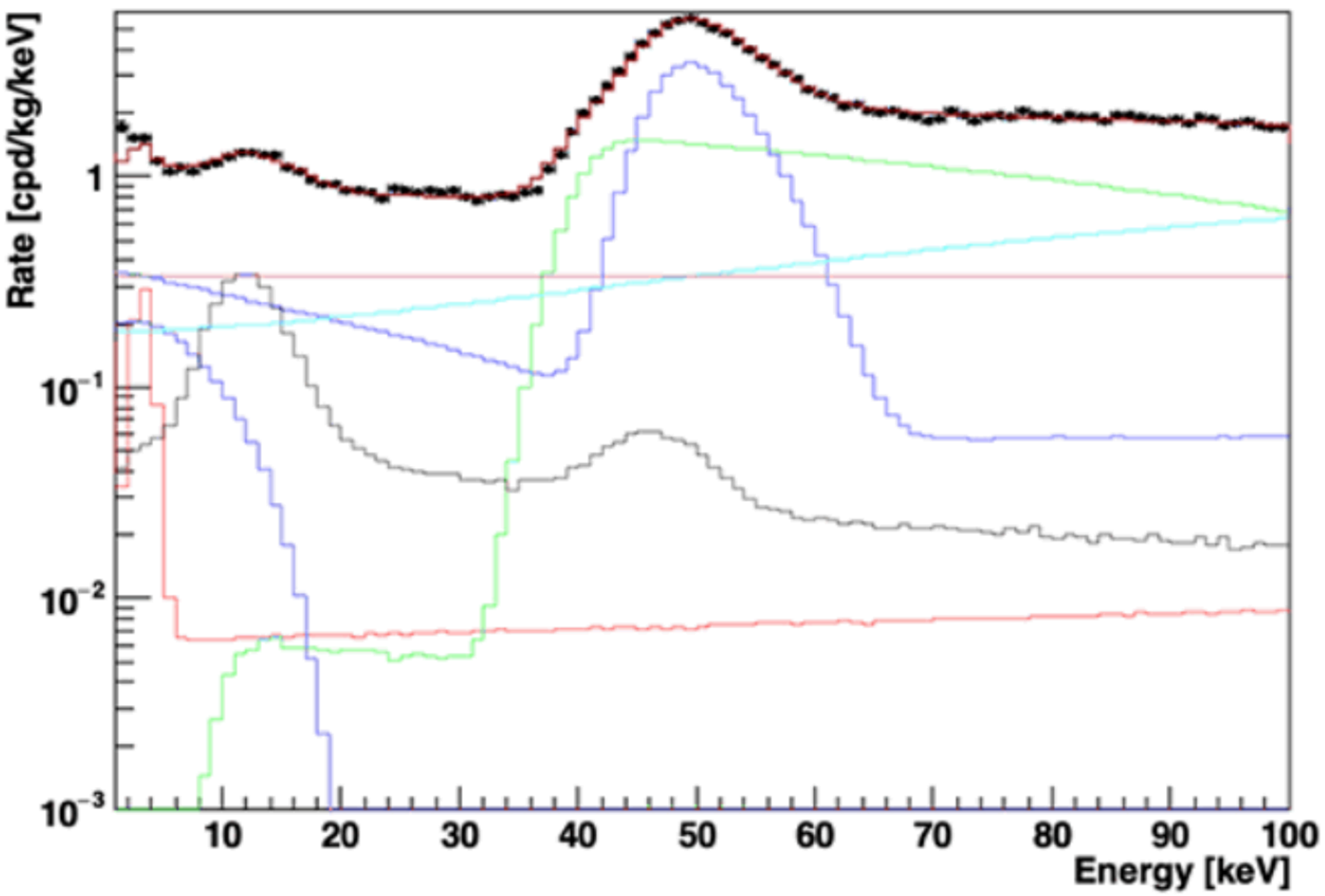
Moving oven

Phys. Rev. Applied 16, 014060



NaI(Tl) crystals in-situ background

Source	Rate in ROI [1,6]keV in cpd/kg/keV	Fit results
^{40}K	0.125	0.16±0.01 mBq/kg
^{210}Pb bulk	0.333	0.49±0.05 mBq/kg
^{210}Pb reflector bulk	0.054	11±1 mBq/kg$_{PTFE}$
^{210}Pb reflector surface	0.023	<0.6 mBq/m^2
^{3}H	0.198	24±2 μBq/kg
^{129}I	0.0003	1.03±0.05 mBq/kg
^{238}U	0.006	5.9±0.6 μBq/kg
^{232}Th	0.0003	1.6±0.3 μBq/kg
PMT	0.003	1.9±0.4 mBq/PMT
External	0.185	0.89±0.05
Other β's	0.333	297±15
TOTAL	**1.26±0.27**	



Na-33 crystal intrinsic background 0.66 cpd/kg/keV dominated by ^{40}K and ^{210}Pb

SABRE South

[M. Zurowski, SciPost Phys. Proc. 12, 027 (2023)]

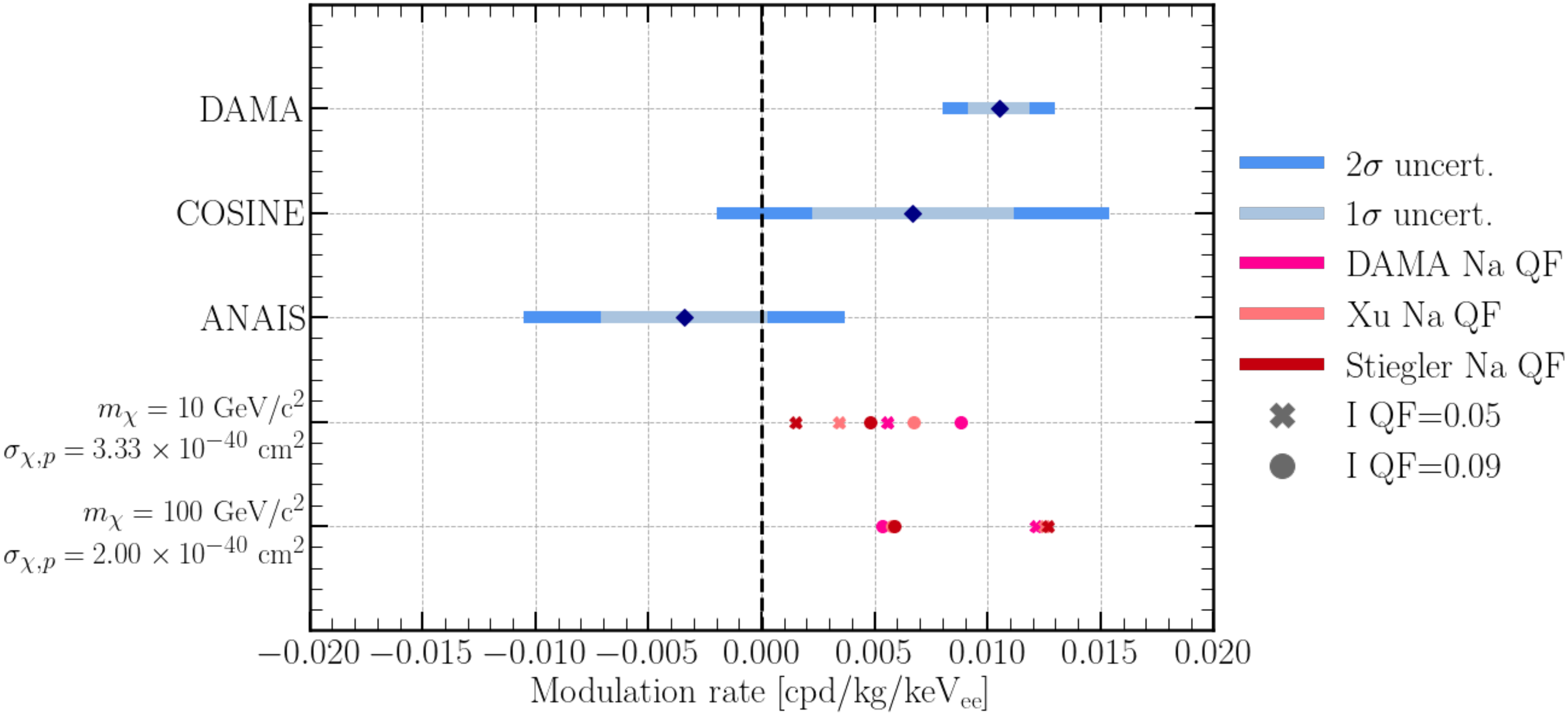


Figure 3: The modulation rate observed in the 1-6 keV region for the various operational experiment compared with the expected modulation for a 10 or 100 GeV/c^2 WIMP under the assumption of various QFs.

OBSERVATION RATE

Number of events observed as a function of observation energy E_{ee} (electron equivalent keV for scintillator detectors)

$$\frac{dR}{dE'} = \boxed{\epsilon(E')} \frac{1}{(2\pi)^{1/2}} \int_0^\infty \boxed{\frac{dR}{dE_R}} \boxed{\frac{dE_R}{dE_{ee}}} \boxed{\frac{1}{\Delta E_{ee}} \exp\left[\frac{-(E' - E_{ee})^2}{2(\Delta E_{ee})^2}\right]} dE_{ee}$$

Efficiency/threshold

Imperfect/realistic detector setup e.g., PMT QE ~30%

Interaction rate

As per last slide

Quenching factor

Transformation from nuclear recoil energy to observable energy

Resolution

Ability to resolve fine details in energy spectrum

SABRE South

M. Zurowski, SciPost Phys. Proc. 12, 027 (2023)

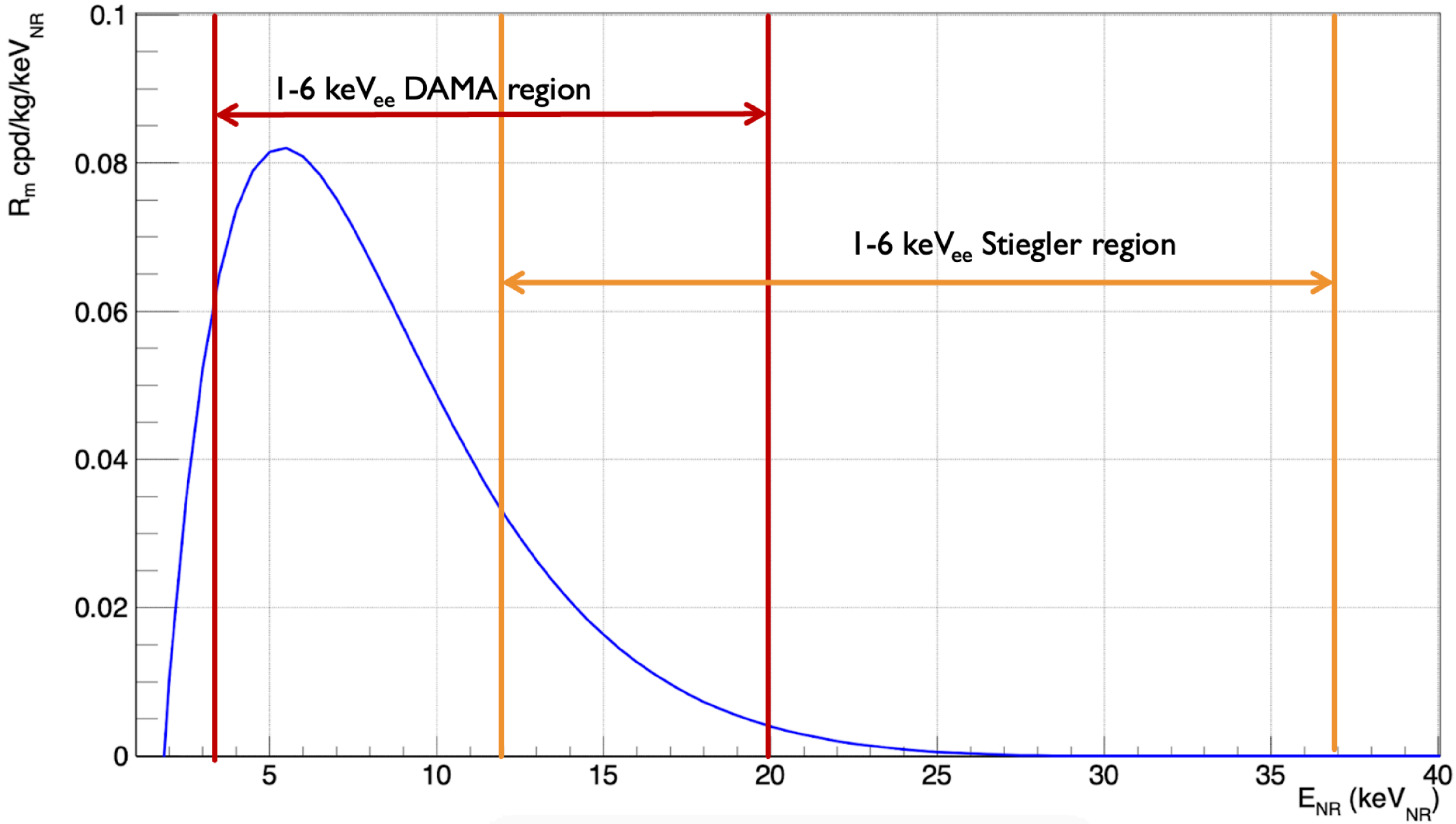
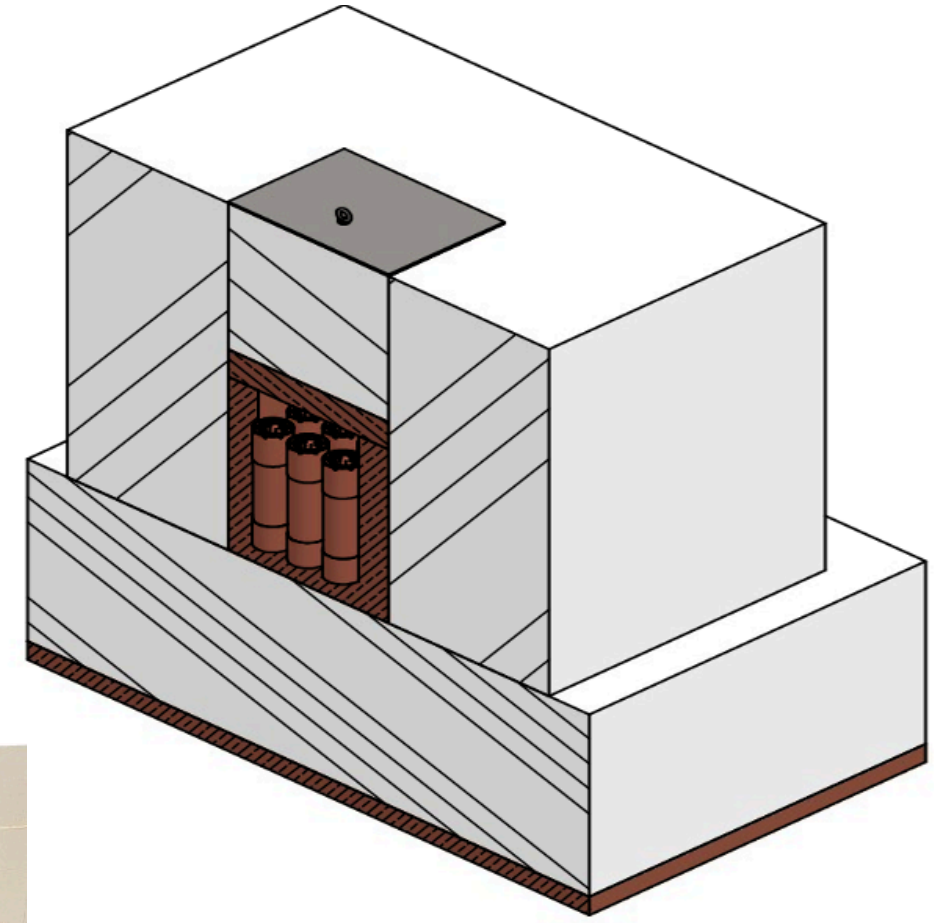
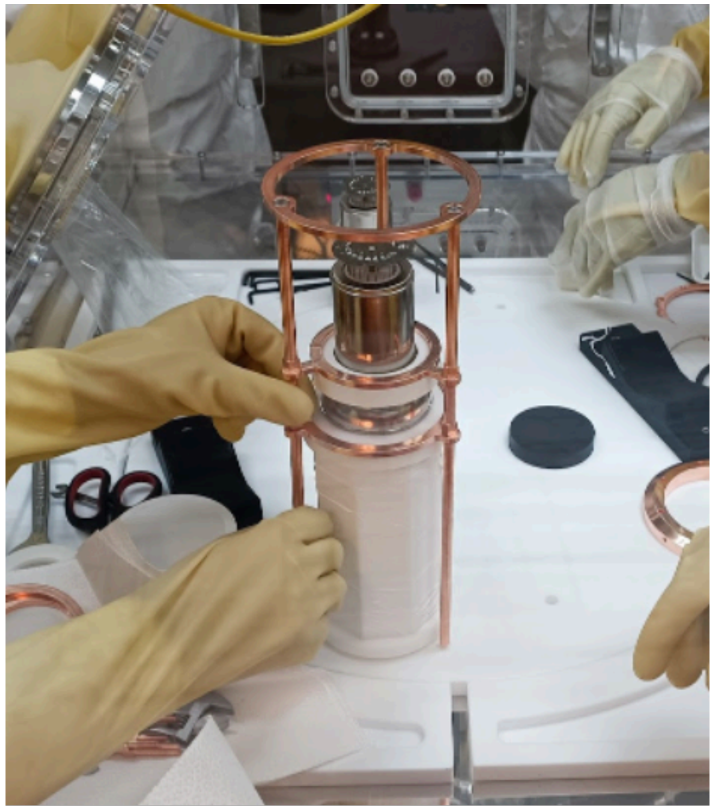


Figure 2: Recoil energy spectrum of an illustrative DM model. Superimposed in red and orange are the regions that correspond to 1-6 keV$_{ee}$ after the application of either the DAMA (red) or Stiegler (orange) QFs.

SABRE North

- Fully passive shielding and no active veto rejection due to organic scintillators phased off at LNGS.
- 3 x 3 matrix of NaI(Tl) detectors (≈**40 kg**).
- Inner 5 mm thick ultra pure Cu box.
- 10-25 cm Cu and 40-60 cm PE shielding structure (≈30 t).
- Expected background 0.5 cpd/kg/keV with zone-refining or 1 cpd/kg/keV without zone-refining.



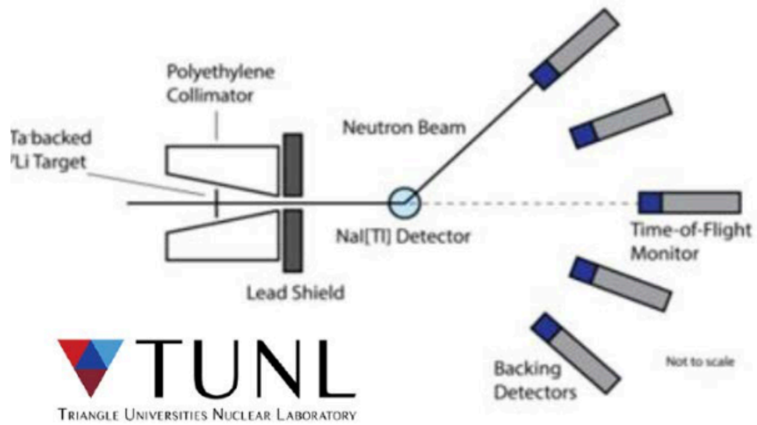


- TDR due in summer 2024. If approved, begin installation in 2025.
- Crystal production and detector deployment in 2025-2027.

ANAIS-112

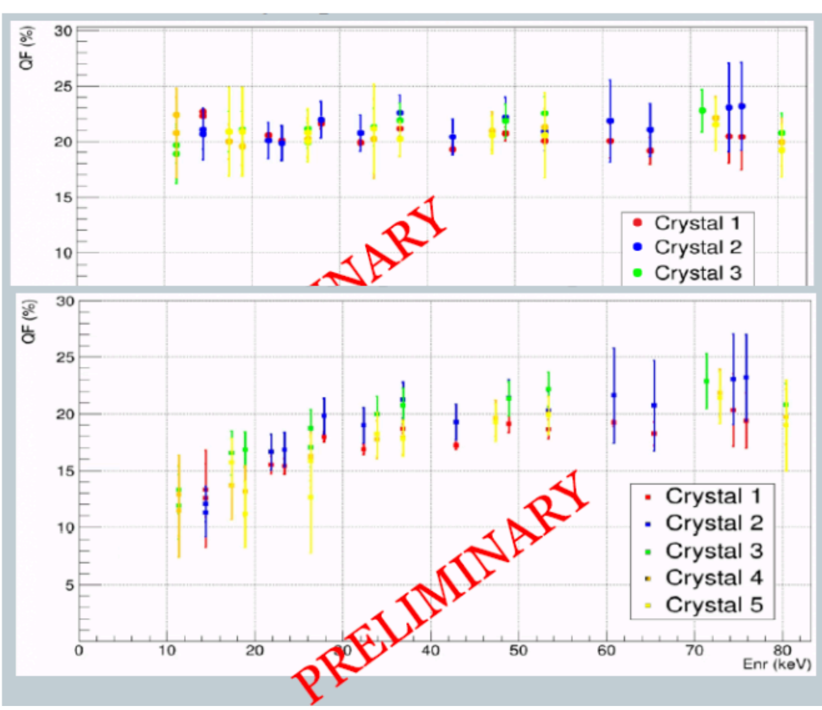
UNCERTAINTIES IN SCINTILLATION QUENCHING FACTORS ARE A RELEVANT SYSTEMATIC EFFECT for the comparison between DAMA/LIBRA and ANAIS

Na - QF derived using different methods and different calibration procedures do not agree. Dependences on the crystal properties can not be discarded



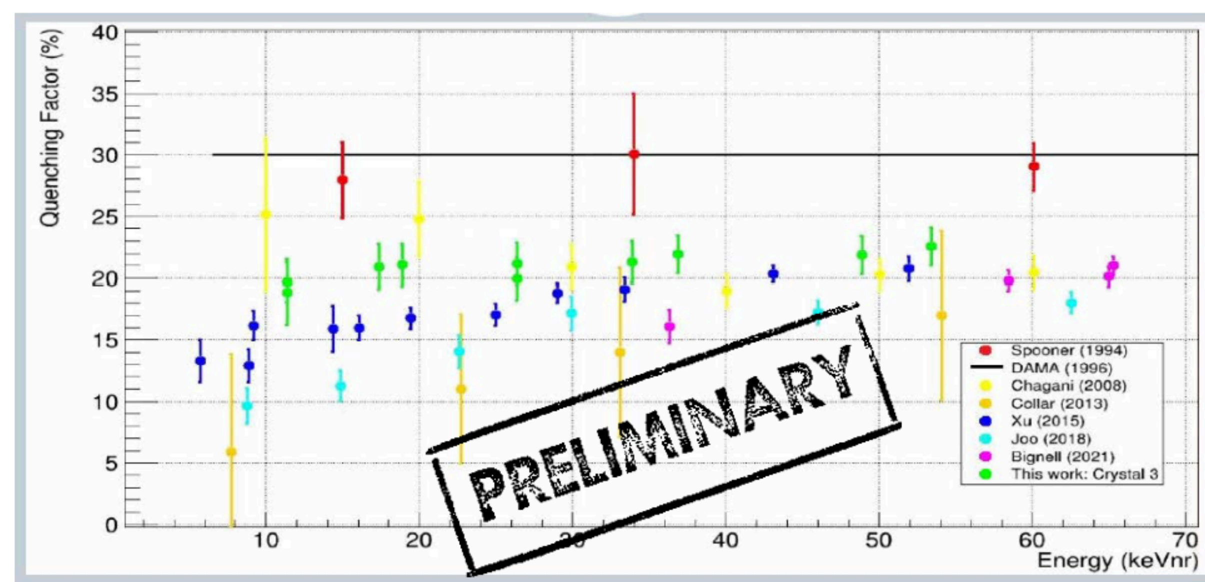
Five small AS crystals
Collaboration between Yale, Duke and Zaragoza
Measurements in 2018 @TUNL

Our best (preliminary) estimate for Na-QF in NaI(Tl)-AS crystals is 20%



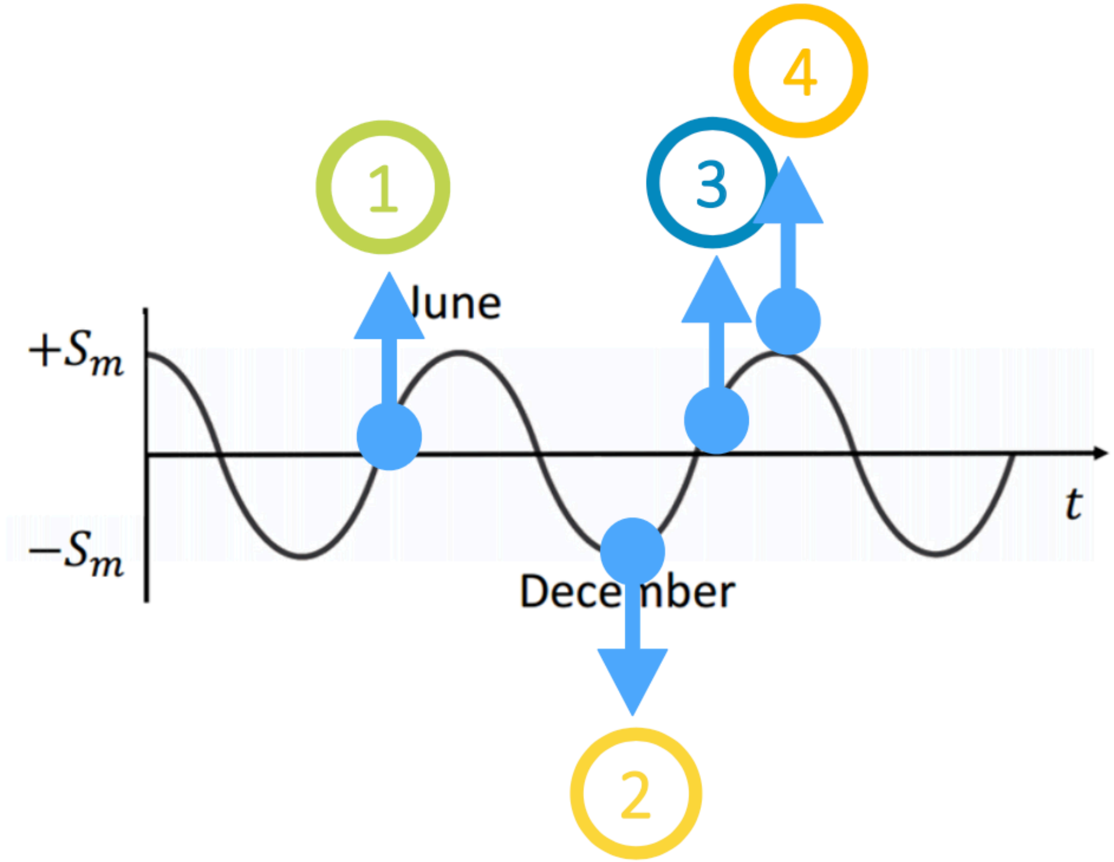
Linearizing response in energy using ^{133}Ba data

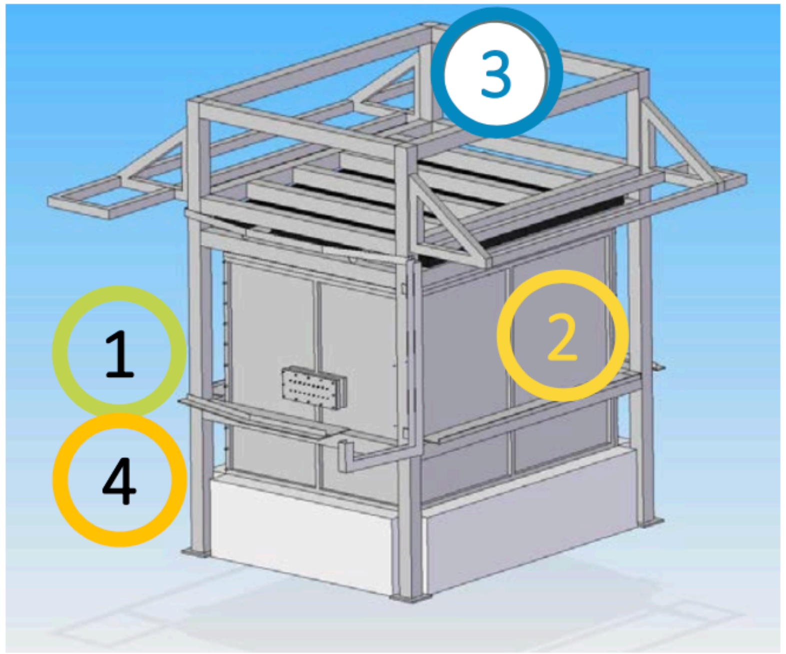
Assuming proportional response using 57.6 keV energy deposition



"onsite" neutron calibrations with the full ANAIS-112 set-up

Four calibration runs since April 2021 using ^{252}Cf neutron source at different positions in the ANAIS-112 set-up



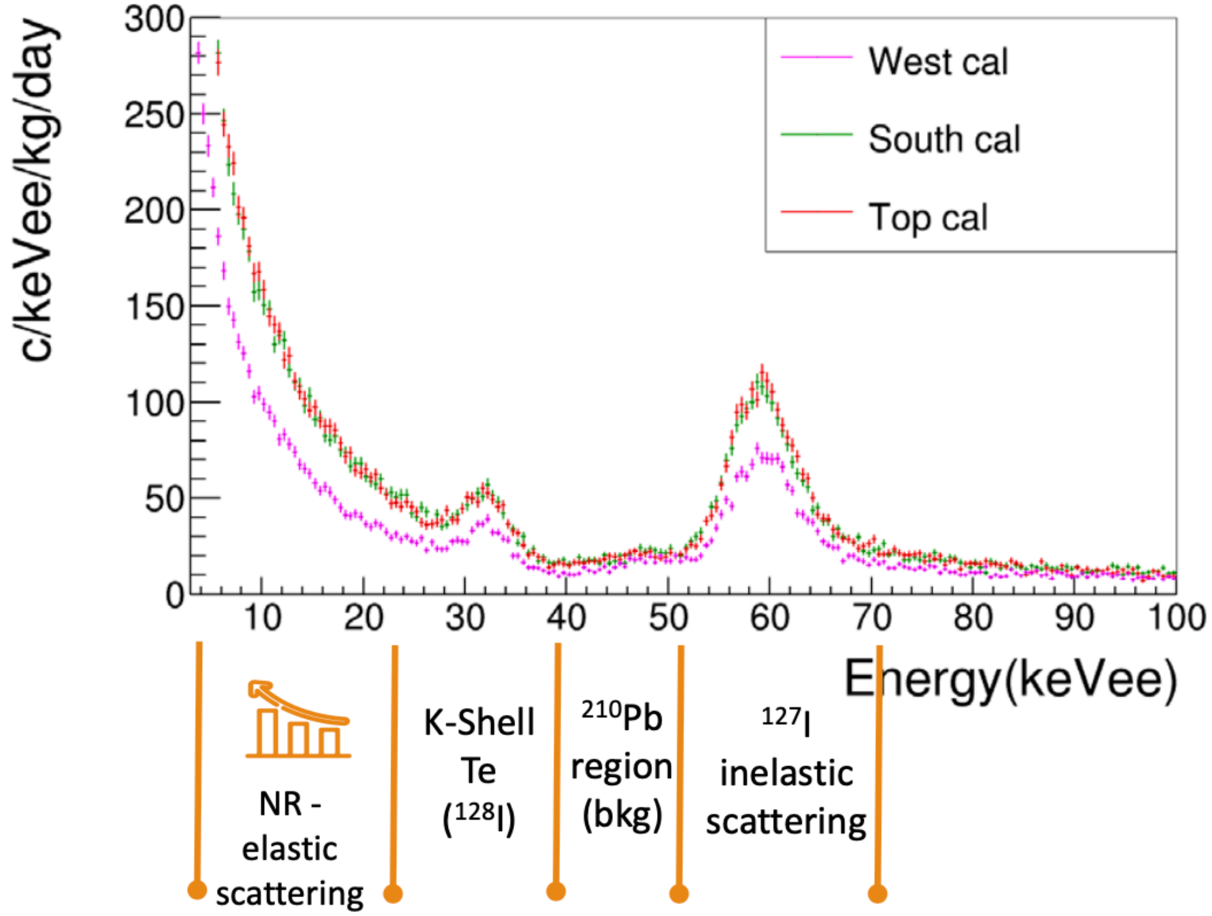


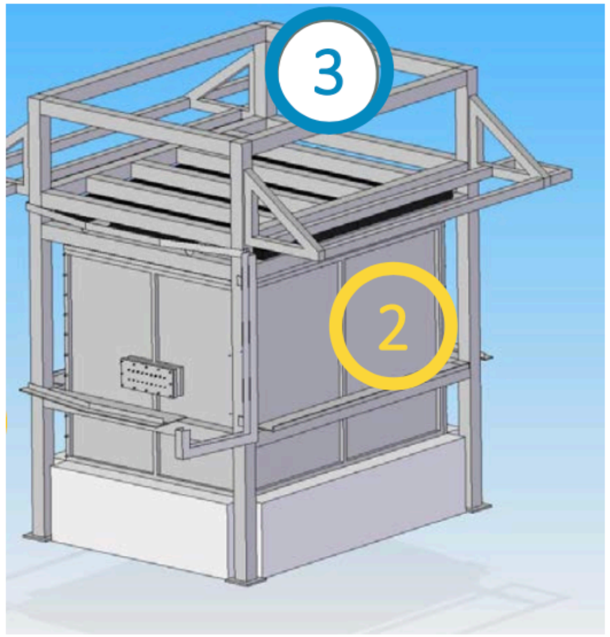
Neutrons produce many "bulk scintillation events" at very low energy

- We have a large population of events for training our new ML analysis and checking efficiency stability
- We expect to derive some information on QF by comparing simulations and measurements

"onsite" neutron calibrations with the full ANAIS-112 set-up

Four calibration runs since April 2021 using ^{252}Cf neutron source at different positions in the ANAIS-112 set-up





Neutrons produce many "bulk scintillation events" at very low energy

- We have a large population of events for training our new ML analysis and checking efficiency stability
- We expect to derive some information on QF by comparing simulations and measurements

Background model

Detailed **background models** for each detector, based on Geant4 Monte Carlo simulation and accurate quantification of **background sources**

Assessment of backgrounds of the ANAIS experiment for dark matter direct detection, J. Amaré et al, Eur. Phys. J. C 76 (2016) 429

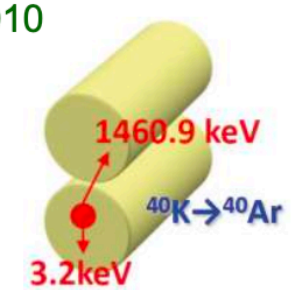
Analysis of backgrounds for the ANAIS-112 dark matter experiment, Eur. Phys. J. C 79 (2019) 412

- **Activity from external components** measured with HPGe detectors at Canfranc
- **Internal activity** directly assessed: mainly ^{40}K, ^{210}Pb

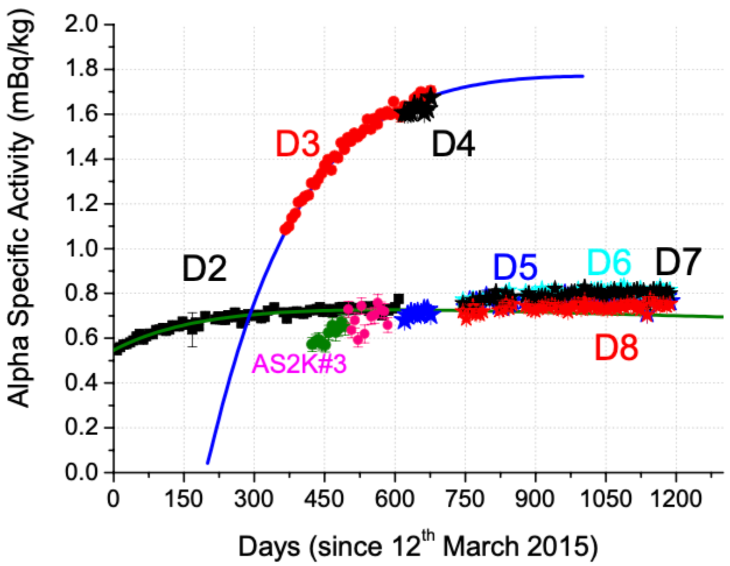
Detector	^{40}K (mBq/kg)	^{232}Th (mBq/kg)	^{238}U (mBq/kg)	^{210}Pb (mBq/kg)
D0	1.33±0.04	(4±1) 10^{-3}	(10±2) 10^{-3}	3.15±0.10
D1	1.21±0.04			3.15±0.10
D2	1.07±0.03	(0.7±0.1) 10^{-3}	(2.7±0.2) 10^{-3}	0.7±0.1
D3	0.70±0.03			1.8±0.1
D4	0.54±0.04			1.8±0.1
D5	1.11±0.02			0.78±0.01
D6	0.95±0.03	(1.3±0.1) 10^{-3}		0.81±0.01
D7	0.96±0.03	(1.0±0.1) 10^{-3}		0.80±0.01
D8	0.76±0.02	(0.4±0.1) 10^{-3}		0.74±0.01

^{40}K: by identifying coincidences

C. Cuesta et al., Int. J. Mod. Phys. A. 29 (2014) 1443010



^{232}Th, ^{238}U: determined by alpha rate following PSA and analysis of BiPo sequences at a level of a few μBq/kg, but **^{210}Pb out of equilibrium**



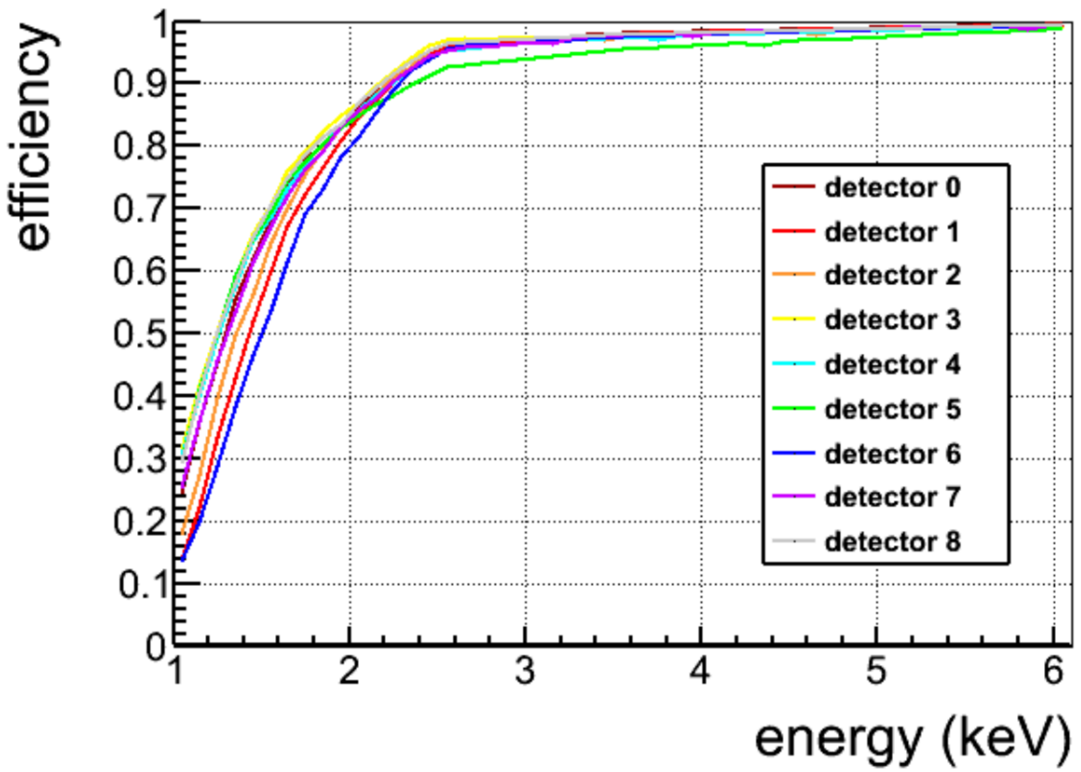
S. Cebrián, ECU2021

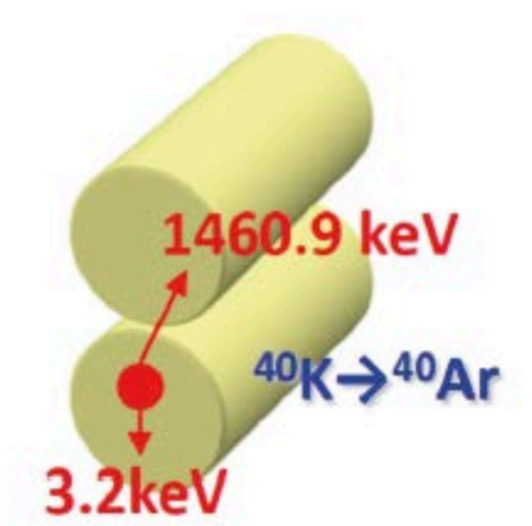
ANAIS-112

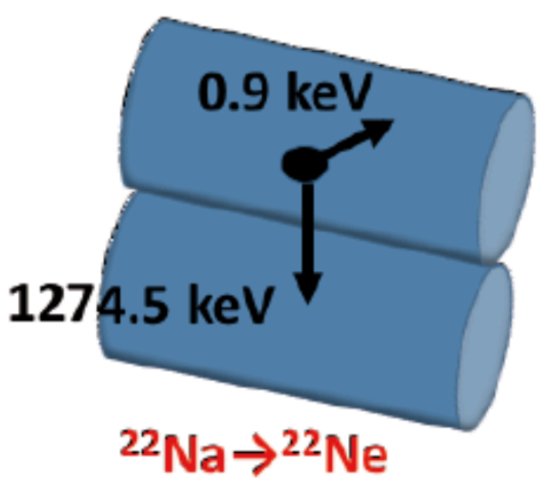
[Phys. Rev. D 103, 102005]

Analysis (3 years of data):

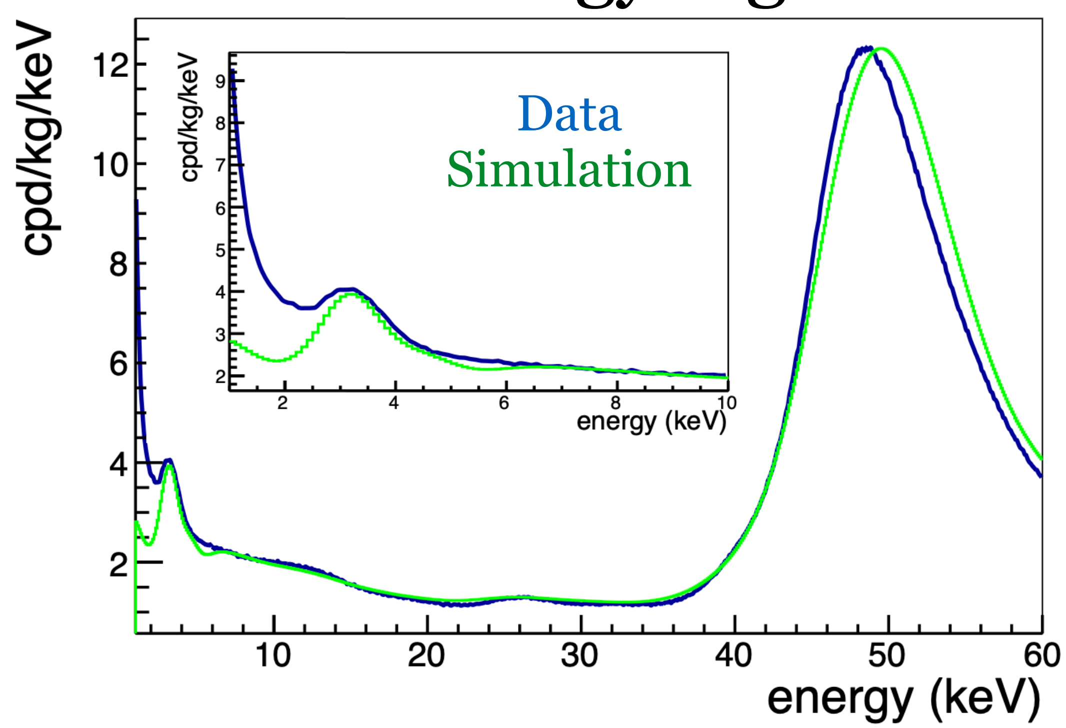
- Pulse shape cut to select events from NaI(Tl) scintillation.
- Asymmetric event rejection (E < 2 keV) to remove PMT-originated events.
- Remove 1 second after a muon passage.
- Multiplicity = 1. Remove multi-module events.







Low-energy region



Revision of background model underway

ANAIS-112

Phys. Rev. D 103, 102005

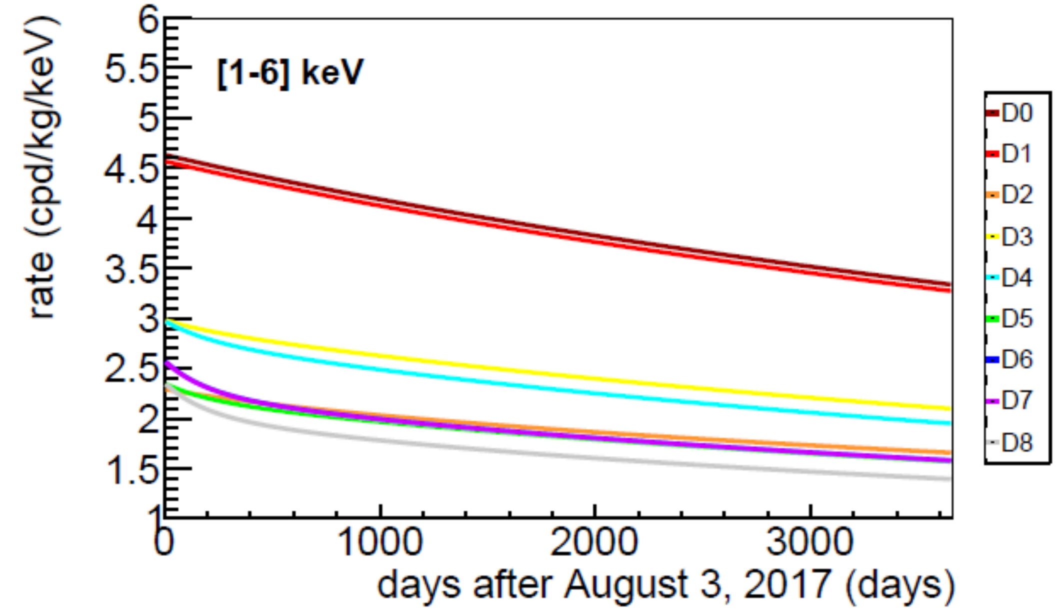
- Minimising: $\chi^2 = \sum_{i,d} \frac{(n_{i,d} - \mu_{i,d})^2}{\sigma_{i,d}^2}$

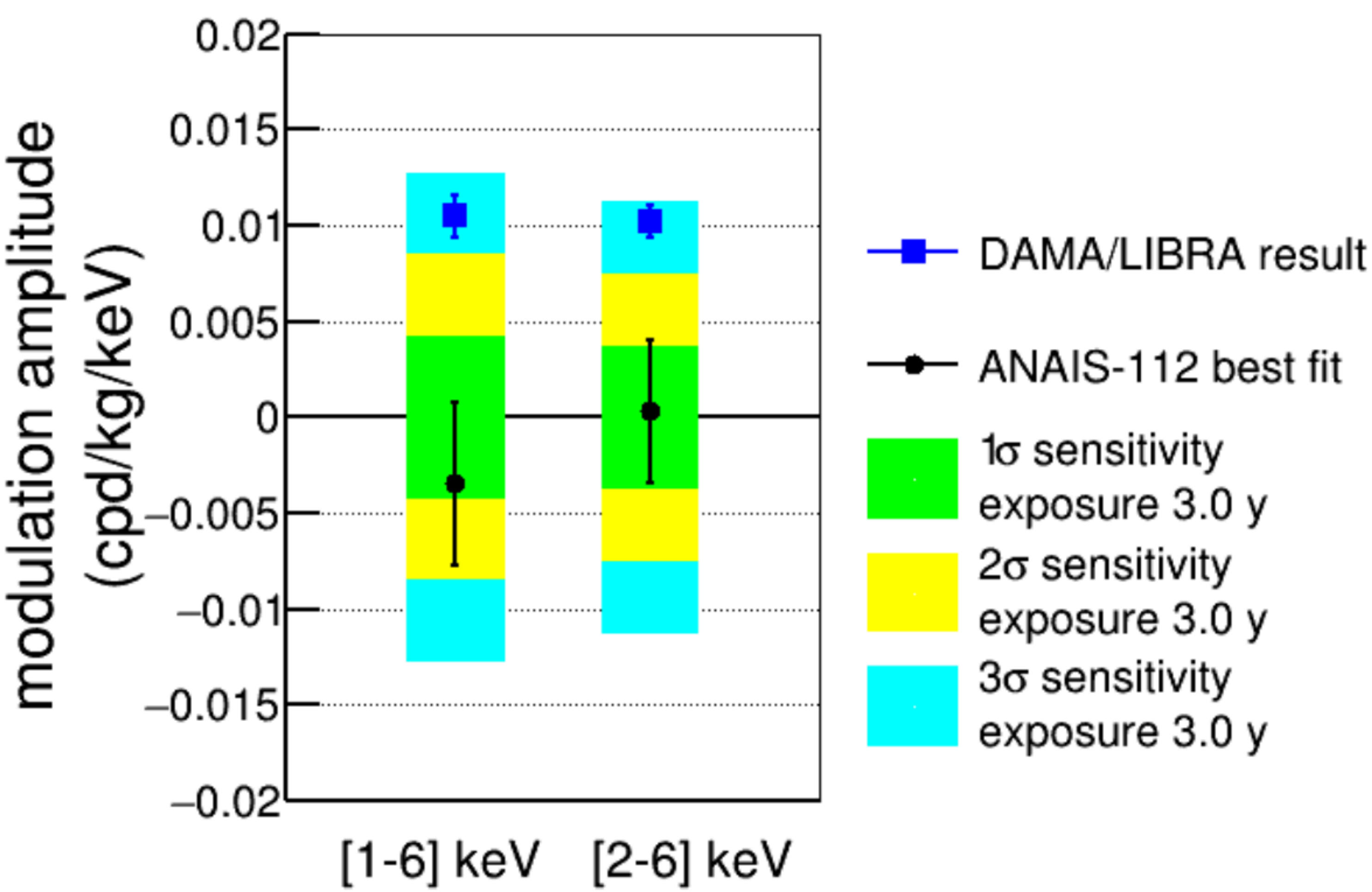
  where $n_{i,d}$, $\sigma_{i,d}$ are computed in 10 days bins i corrected by live time and efficiency for each detector d.

- Background probability distribution drawn from the background model for every detector.

$$\mu_{i,d} = [R_{0,d}(1 + \boxed{f_d \phi_{bkg,d}^{MC}(t_i))} + S_m cos(\omega(t_i - t_0))]M_d \Delta E \Delta t$$

Simulated background





- Best fits are incompatible with DAMA/LIBRA at 3.3 σ and 2.6 σ in [1-6] and [2-6] keV regions.
- Sensitivity is at 2.5 σ and 2.7 σ in the same regions respectively.
- New BDT-based analysis is in progress expected to reach a 5 σ sensitivity to DAMA/LIBRA with two more years of data.

Background model

Detailed **background models** for each detector, based on Geant4 Monte Carlo simulation and accurate quantification of **background sources**

– **Cosmogenic activity** in crystals: short-lived Te and I isotopes, ^{3}H, ^{22}Na, ^{109}Cd, ^{113}Sn

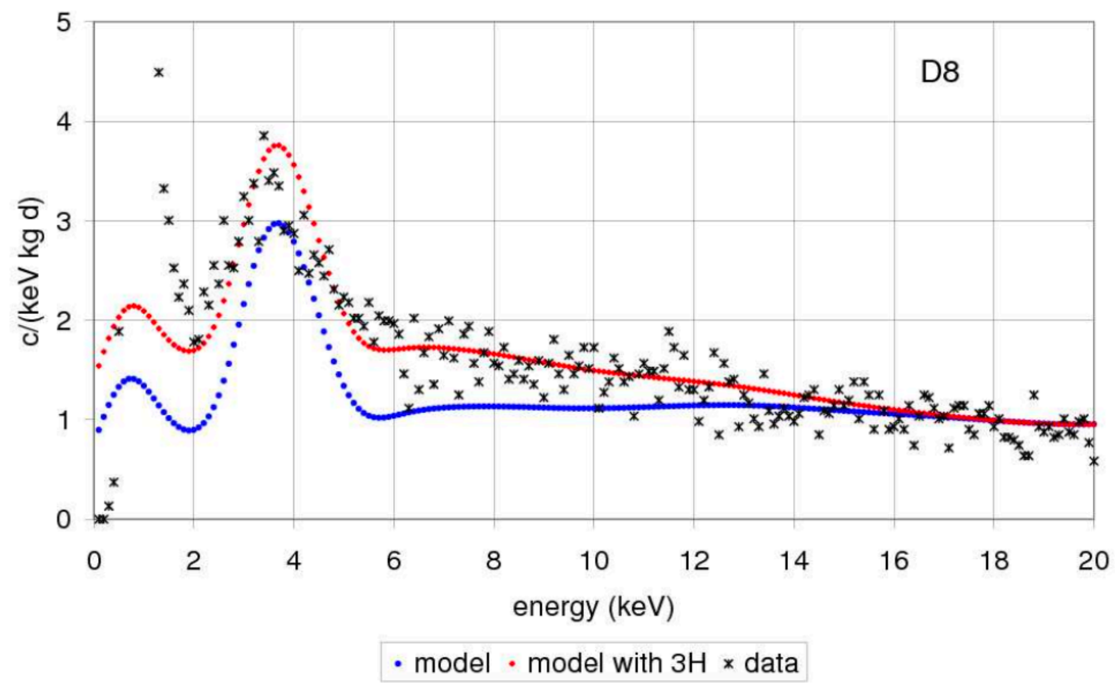
J. Amaré et al, JCAP 02 (2015) 046
J. Amare et al, Astropart. Phys.97 (2018) 96
P. Villar et al, Int. J. Mod. Phys. A 33 (2018) 1843006

^{22}Na: from analysis of coincidences

^{109}Cd, ^{113}Sn: from peaks at binding energies of K-shell electrons (after EC)

^{3}H: additional background source contributing only in the very low energy region required, which could be tritium

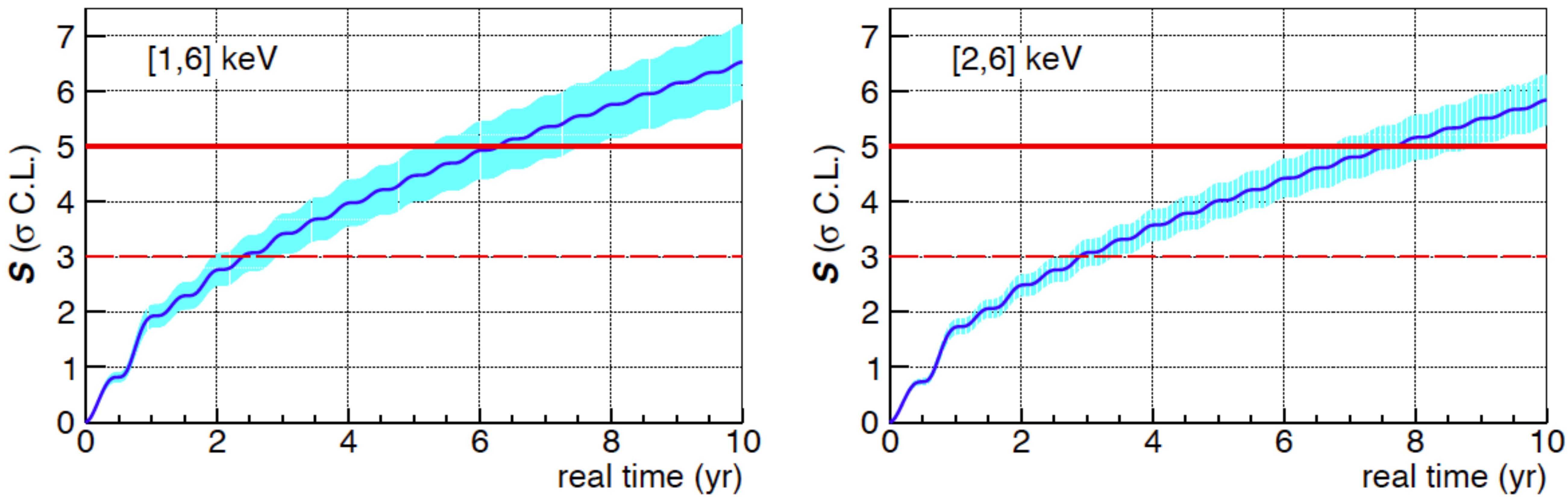
D0-D1: 0.20 mBq/kg
D2-D8: 0.09 mBq/kg (upper limit set by DAMA/LIBRA)



S. Cebrián, ECU2021

ANAIS-112

JCAP11 (2022) 048



(a) (b)

Figure 15. ANAIS-112 sensitivity to the DAMA/LIBRA signal in σ C.L. units as a function of real time in the [1,6] keV (a) and [2,6] keV (b) energy regions considering decreasing background after applying the BDT event selection. The cyan bands represent the 68% C.L. DAMA/LIBRA uncertainty.

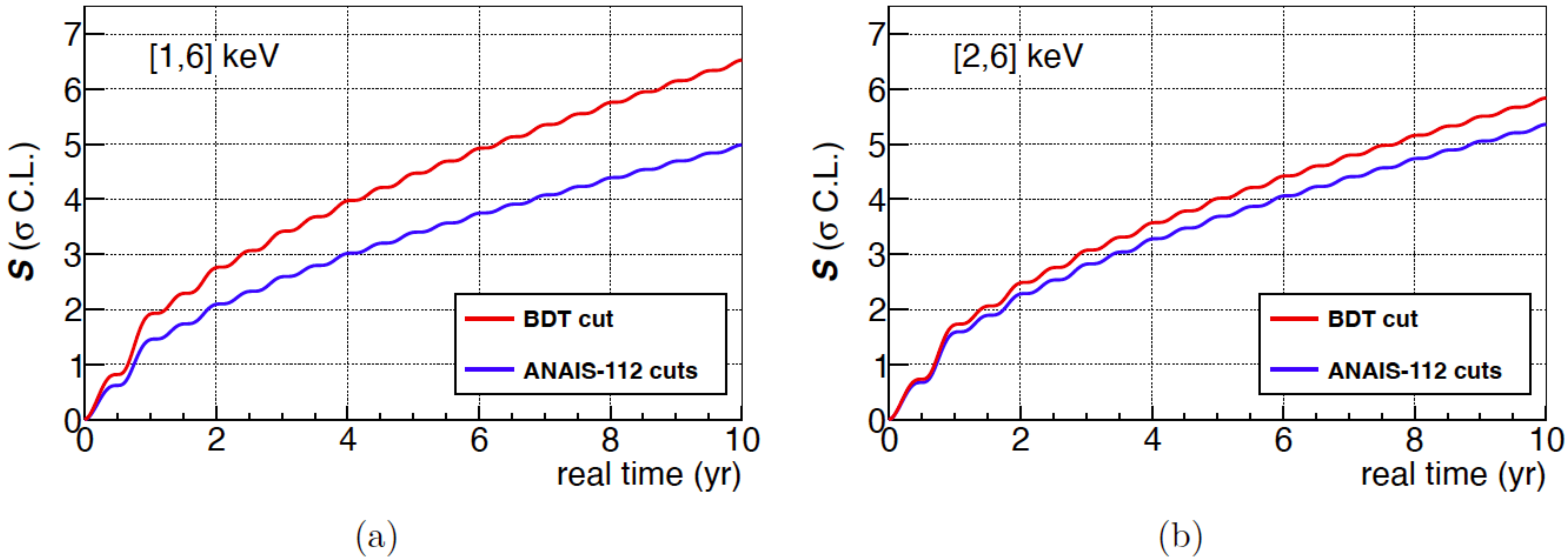
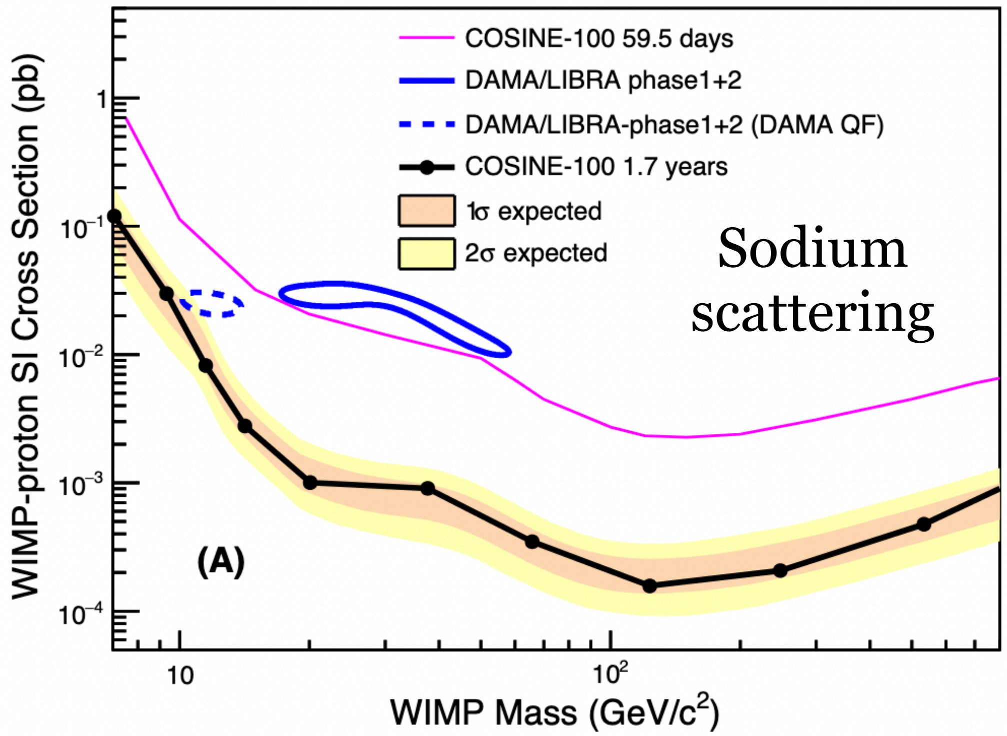
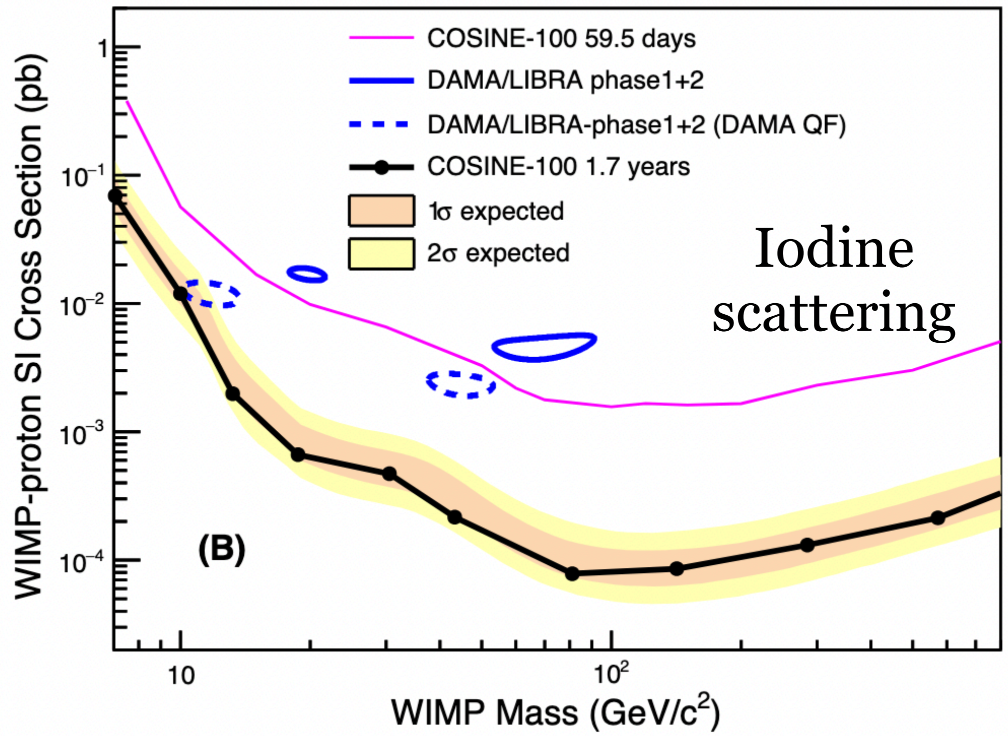


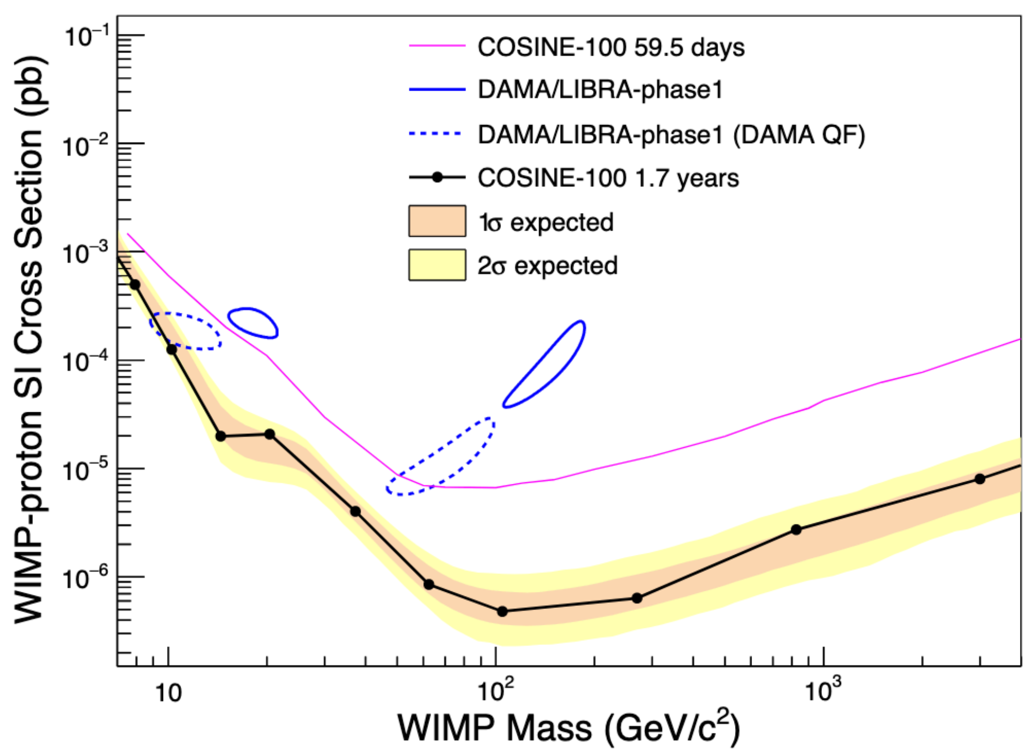
Figure 16. ANAIS-112 sensitivity to the DAMA/LIBRA signal in σ C.L. units as a function of real time in the [1,6] keV (a) and [2,6] keV (b) energy regions considering decreasing background. The blue lines show our sensitivity projection derived from applying the previous ANAIS-112 filtering procedure, whereas the red lines display the expected sensitivity from applying the BDT method, as shown in figure 15.

WIMP proton spin-independent cross section for isospin violating interactions





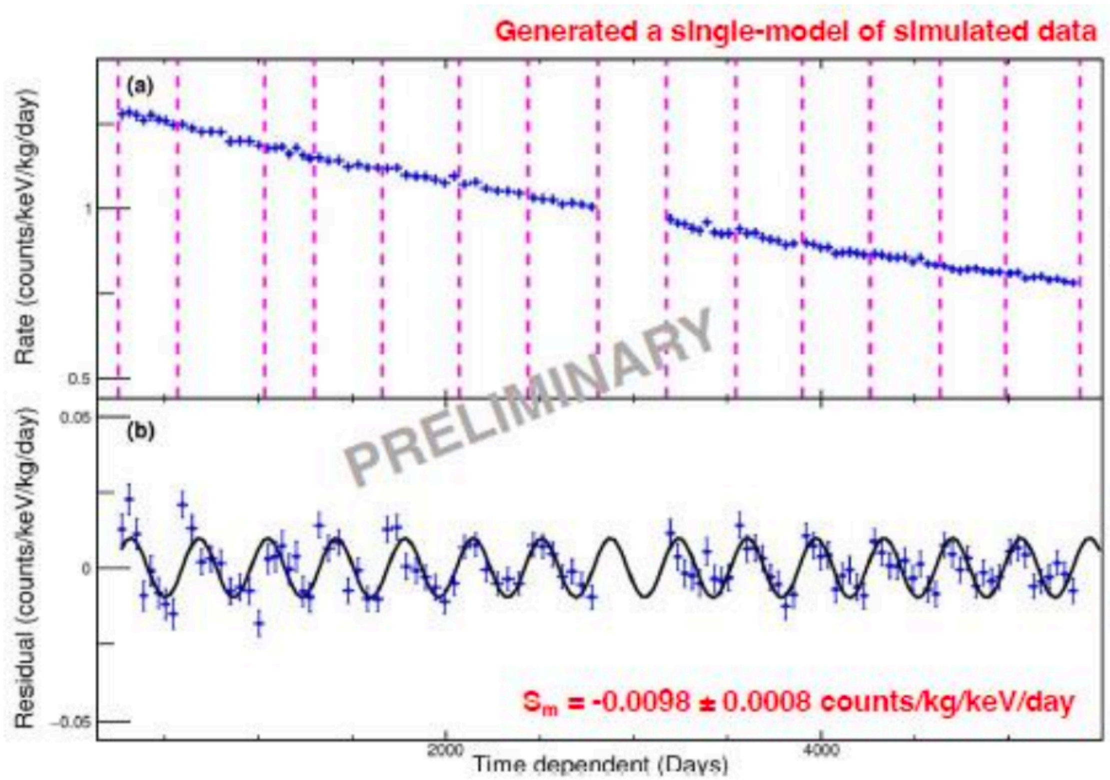
- Search performed using 1.7 years of data.
- Fully excludes DAMA with alternative WIMP EFT operators and QFs.

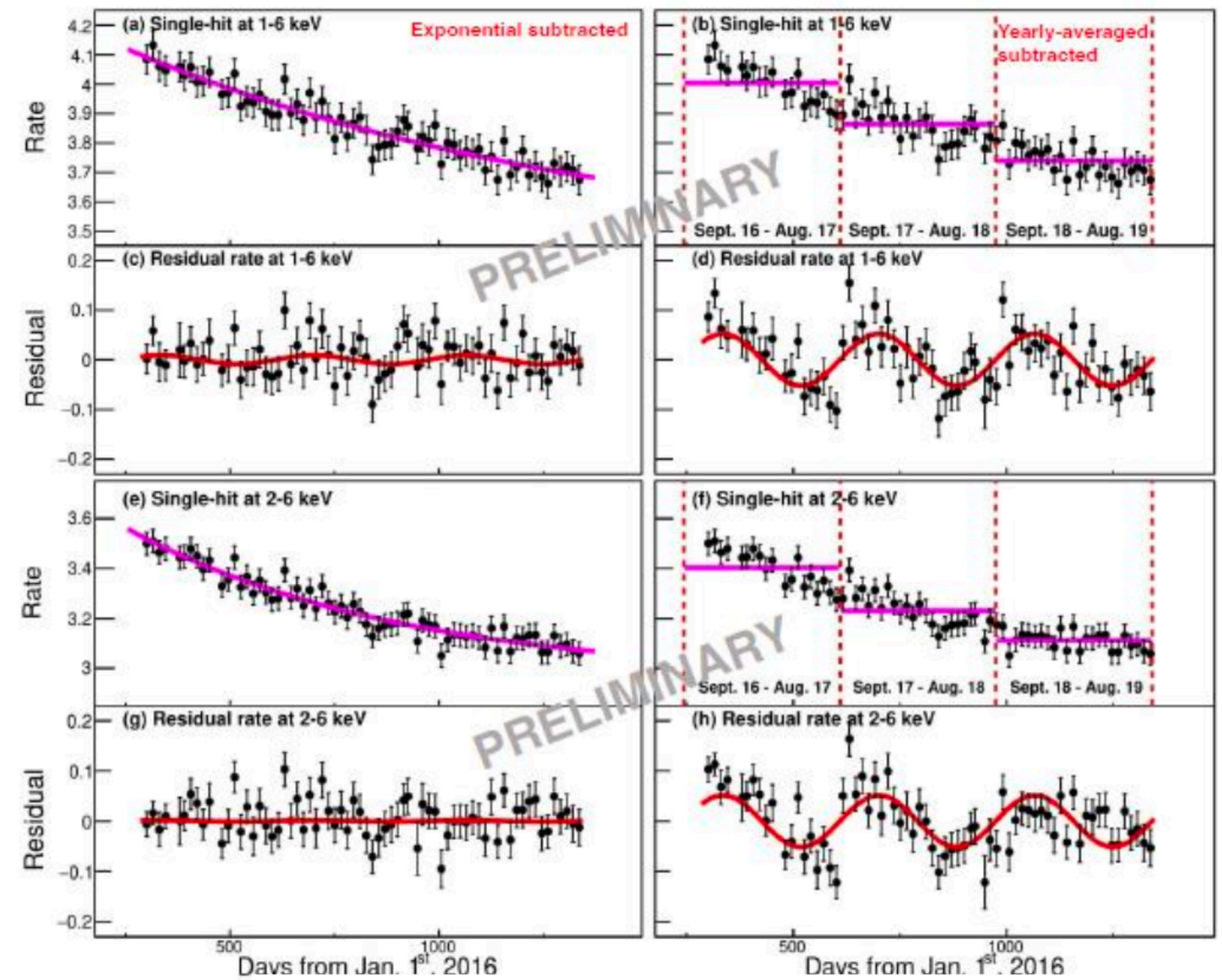


WIMP nucleon spin-independent cross section for isospin conserving interaction

COSINE data with DAMA technique

- Suggested that DAMA's analysis can generate modulation signal
- Tested with COSINE-100 data with DAMA technique and in pseudo-data to replicate DAMA data
- Negative modulation amplitude induced at DAMA phase in both cases



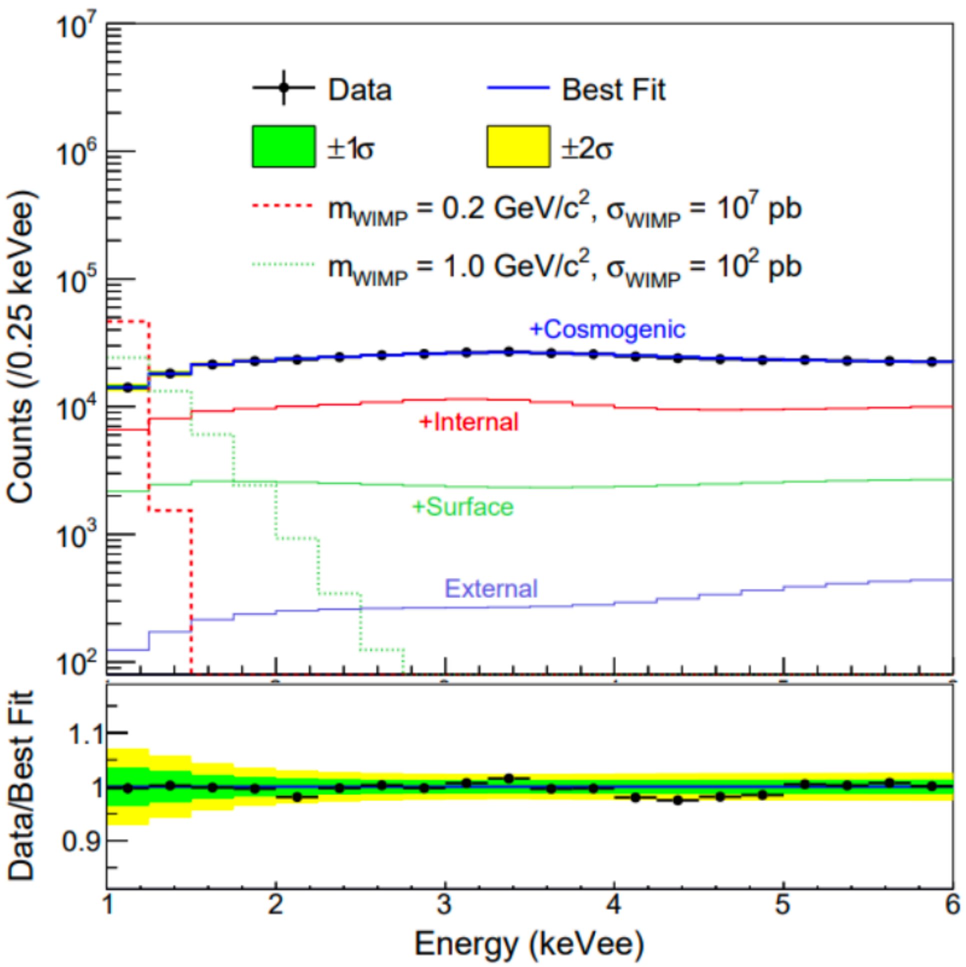


Results

counts/kg/keV/day	1–6 keV	2–6 keV
This work ✓	-0.0441±0.0057	-0.0456±0.0056
DAMA/LIBRA	0.0105±0.0011	0.0095±0.0008
COSINE-100	0.0067±0.0042	0.0050±0.0047
ANAIS-112	-0.0034±0.0042	0.0003±0.0037

WIMP search via Migdal effect

- WIMPs can interact with NaI crystals and produce energetic electrons alongside nuclear recoil via Migdal effect
  - Good candidate for searching for low mass DM
  - Search window of COSINE-100 lowered to 200 MeV/c²
- Search using 1.7 years data with 1 keV low energy threshold
- No WIMP signal observed
- Adhikari, G., et al. "Searching for low-mass dark matter via the Migdal effect in COSINE-100." Physical Review D 105.4 (2022): 042006.



Example of fit to 1.1 GeV/c² WIMP