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The SABRE South Experiment at the Stawell Underground Physics Laboratory

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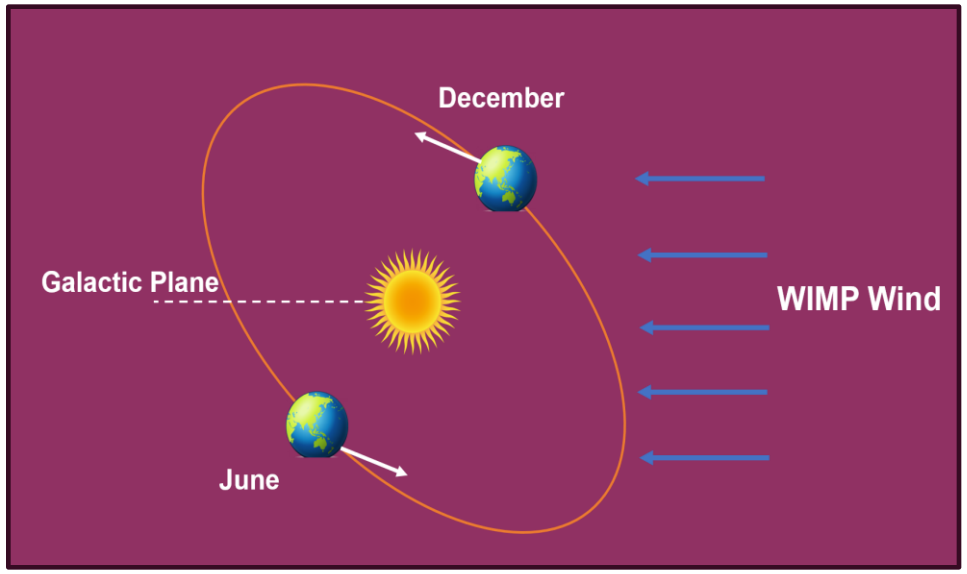
On Behalf Of The SABRE South Collaboration

Win Conference, Brighton 12 JUNE 2025

GALACTIC HALO AND ANNUAL MODULATION

Standard Halo Model cold dark matter

- Maximum in June, minimum in December



WIMP Wind peak in June – toward wind
WIMP Wind low in December – away from the wind

Experiments classically look for an annual modulation in signal

- Model independent signature
- Requires large statistics.
- Amplitude very low,
  - O(0.01 cpd/kg/keV)
  - Need strict control of backgrounds

$$\frac{dR}{dE} = S_0(E) + S_m \cos[\omega(t - t_0)]$$

Constant DM Rate

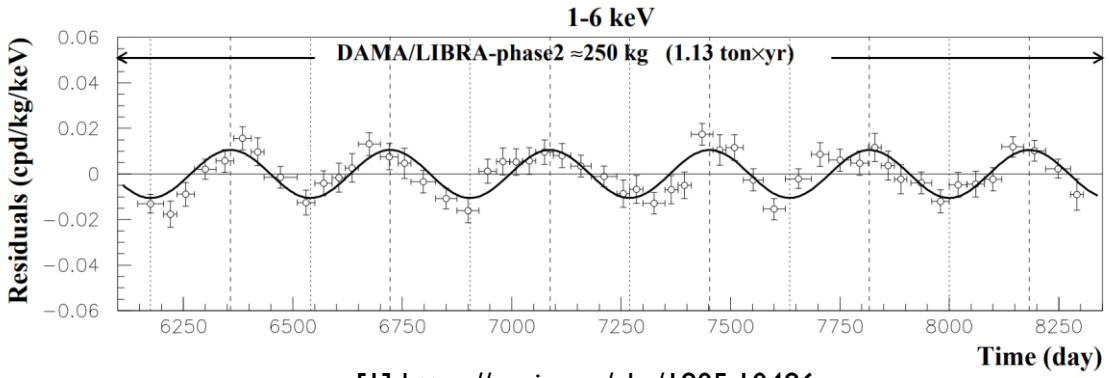
Modulating DM Rate

DAMA/LIBRA

Only experiment to have claimed an annual modulation

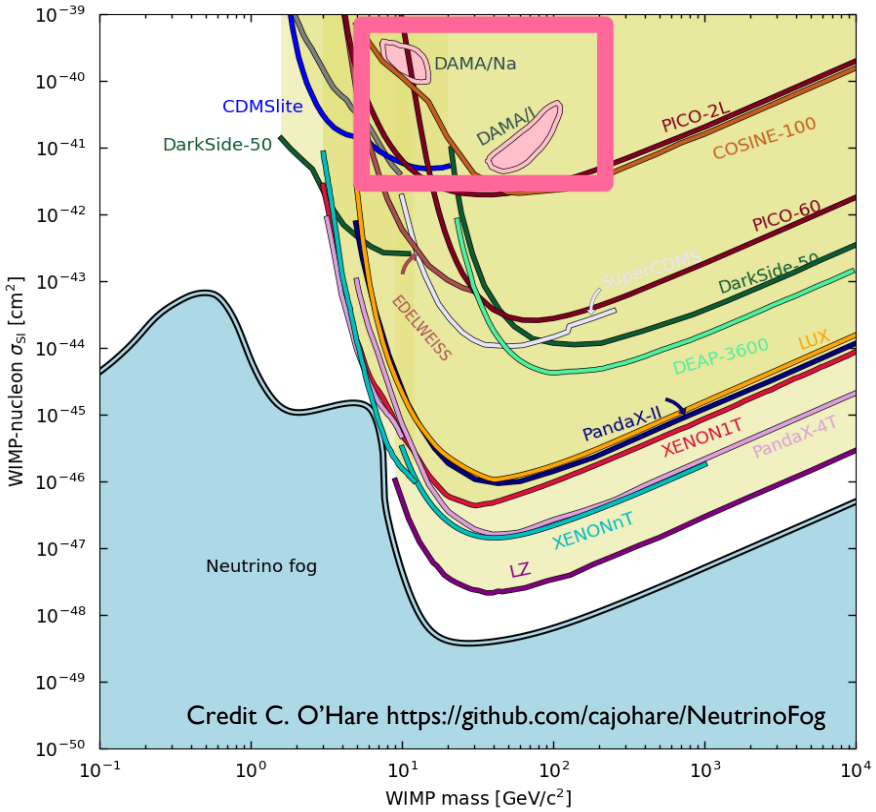
- 1-6 keV_{ee} RoI at 11.8σ [1]
- 20+ years of operation
- NaI(Tl) ultra-pure crystals

DAMA/LIBRA WIMP modulation



[1] https://arxiv.org/abs/1805.10486

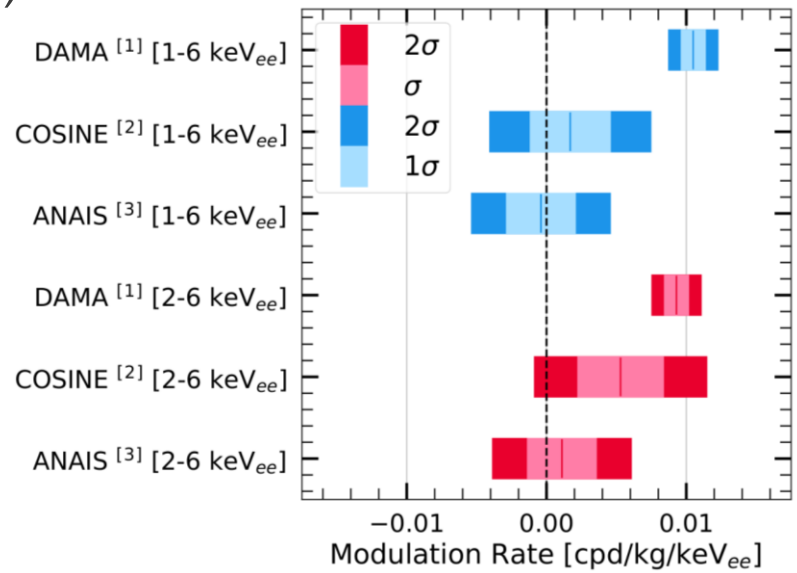
Modulation not consistent with SI WIMP



NaI EXPERIMENTS

Experiments trying to test results

- Same target material
- Model-independent test
- ANAIS (Canfranc, Spain), COSINE (Yangyang, South Korea)

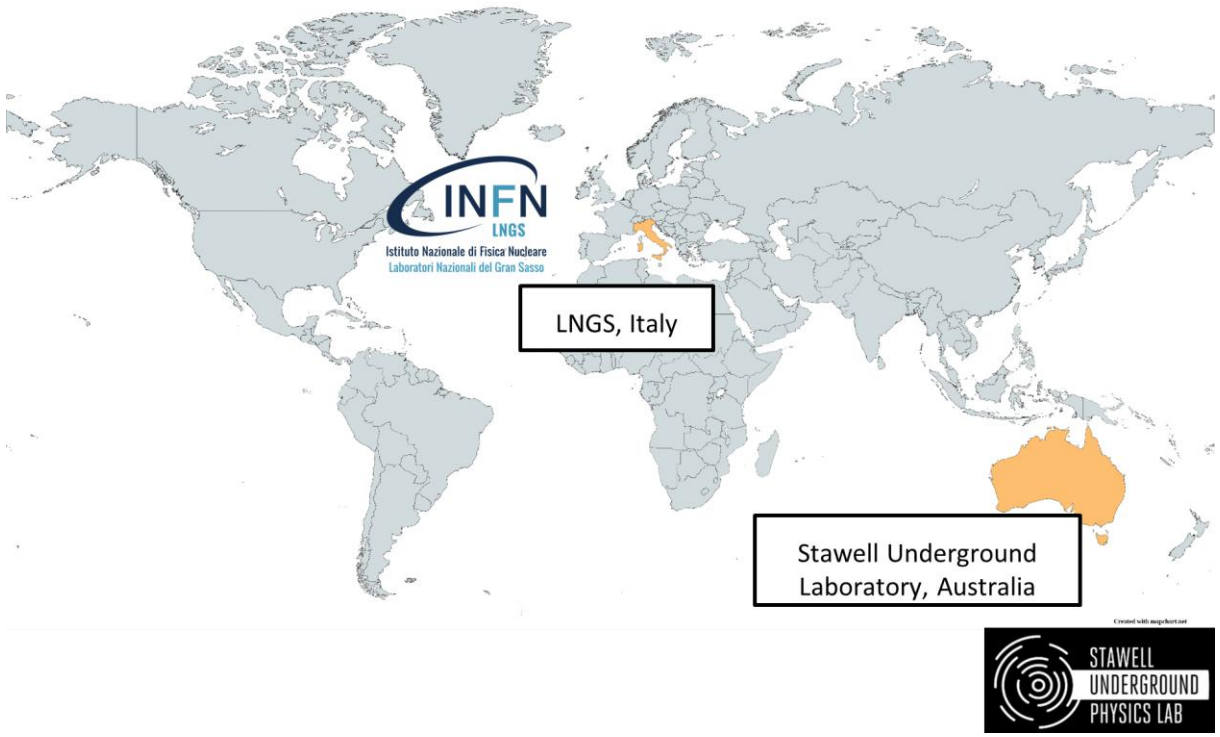


Experiment	Target Mass [kg]	Backgrounds [cpd/kg/keV$_{ee}$]
DAMA/LIBRA Phase 2 [1]	250	0.8
COSINE-100 [2]	61.3	2.7
ANAIS-112 [3]	112.5	3.2

Larger backgrounds make it hard to rule out the modulation.

[1] DoI: 10.1016/j.ppnp.2020.103810
[2] arXiv:2409.13226, arXiv:2111.08863
[3] DoI: arXiv:2502.01542v1

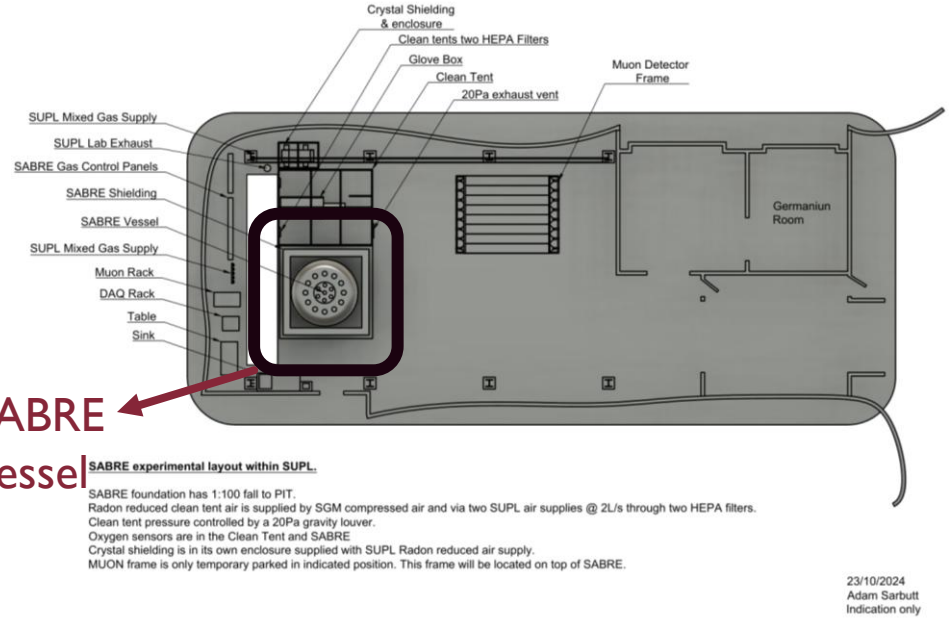
SABRE

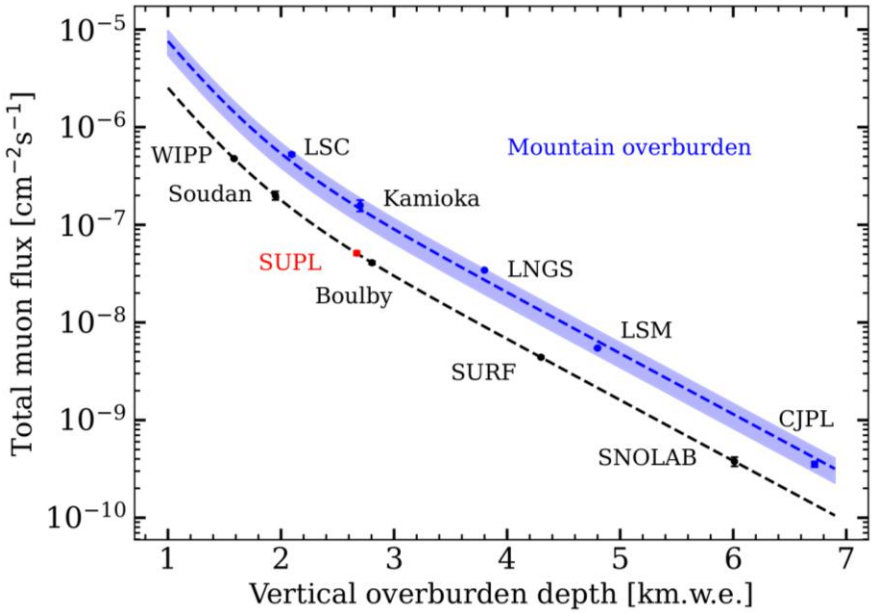


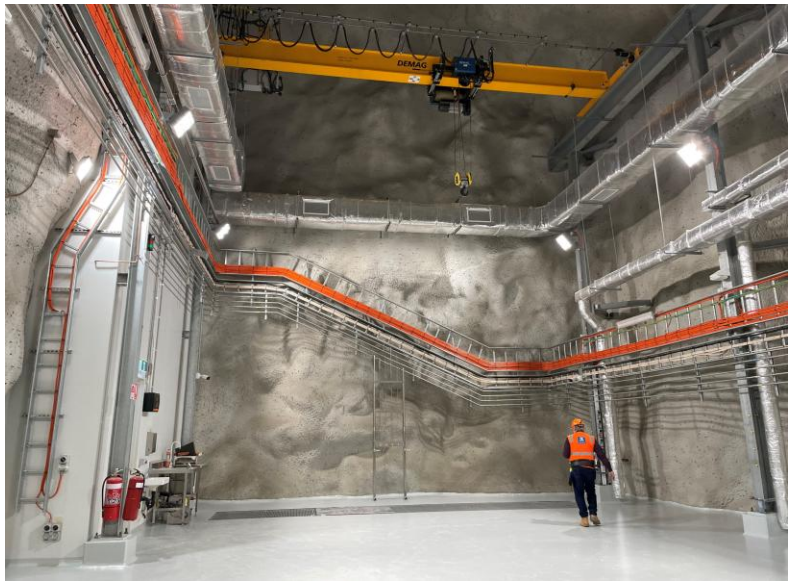
- Sodium iodide with Active Background REjection
- Envisioned to be a dual hemisphere experiment
  - SABRE North: Italy, Laboratori Nazionali del Gran Sasso (LNGS)
  - SABRE South: Australia, Stawell Underground Physics Laboratory (SUPL)
  - Remove Muon induced effects
- Strategy: employ ultra-pure NaI(Tl) target, with background rates comparable to DAMA/LIBRA **< 1 cpd/kg/keV**
- Similar set-ups, SABRE North passive shield only, no liquid scintillator veto

Stawell Underground Physics Laboratory (SUPL)

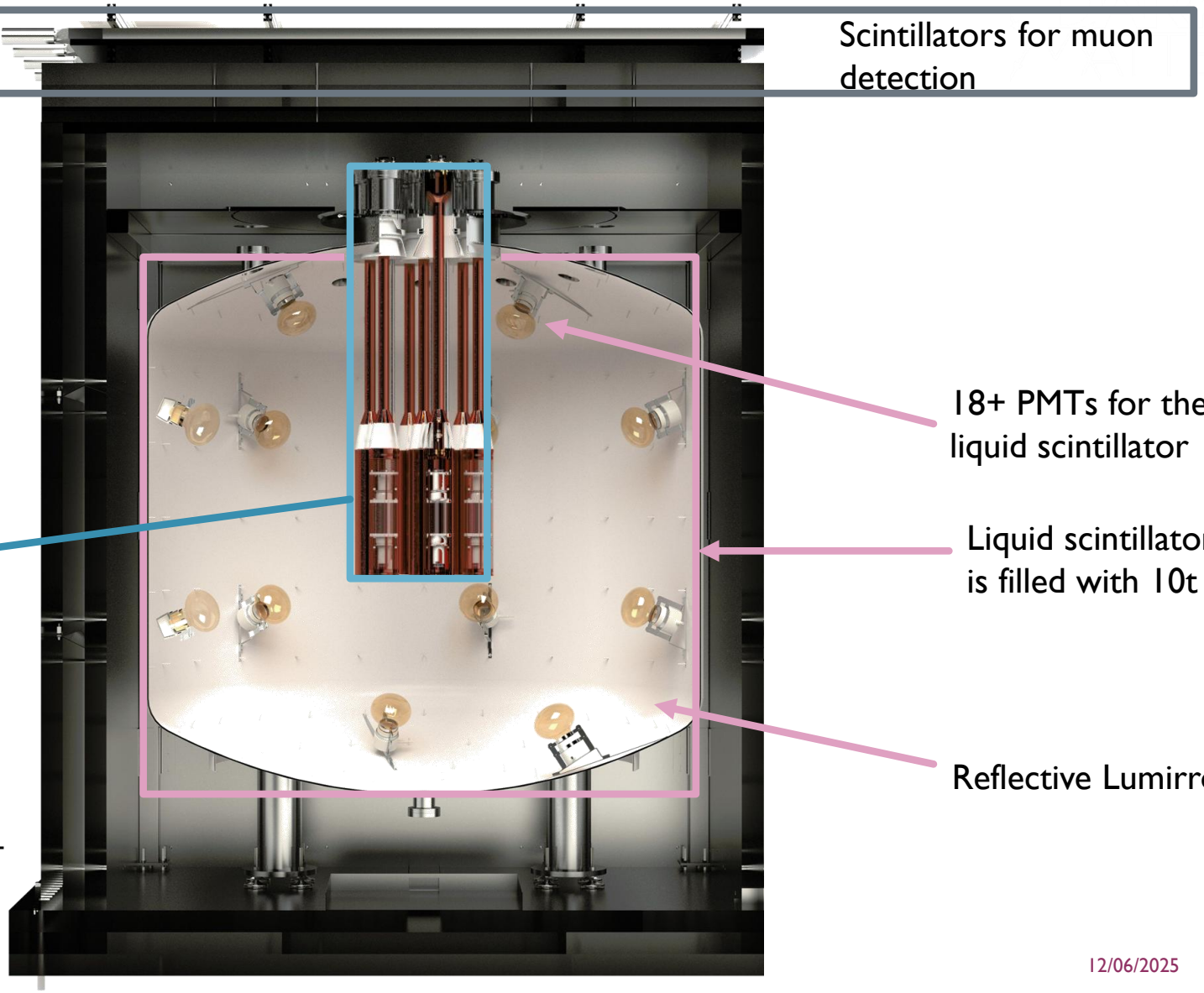
- First facility of its kind in Australia
  - only underground lab in the Southern Hemisphere
- Operating inside Stawell Gold Mine
- 1025 m (2900 m.w.e)







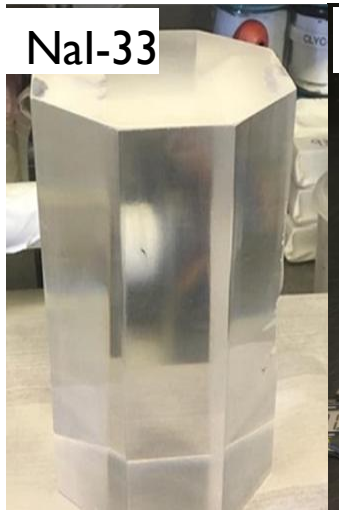
SABRE SOUTH DETECTOR

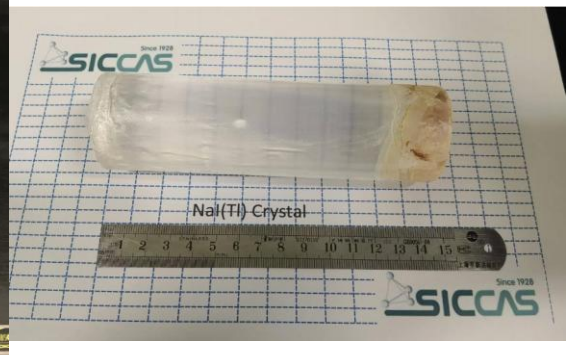


SABRE South TDR: DOI 10.1088/1748-0221/20/04/T04001

NaI CRYSTALS

- Ultra-pure NaI powder from R&D of Princeton-Sigma Aldrich (now Merck) in Australia
- Multiple high purity crystals grown and characterised
- NaI-33 one of the purest crystals ever grown with a background of ~ 1 cpd/kg/keV in ROI [1,6] keV
- R&D programs with RMD (USA) and SICCAS (China) for our final crystals using the Bridgman method.





+ others

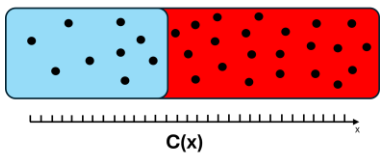
Experiment	^{40}K [ppb]	^{210}Pb [mBq/kg]	^{238}U [ppt]	^{232}Th [ppt]
DAMA/LIBRA [1]	13	0.005-0.03	0.7-10	0.5-7.5
ANAIS-112 [2]	31	1.53	<0.81	0.36
COSINE-100 [3]	35.1	1.74	<0.12	<2.4
SABRE (NaI-033) [4]	4.3	0.34	0.4	0.2

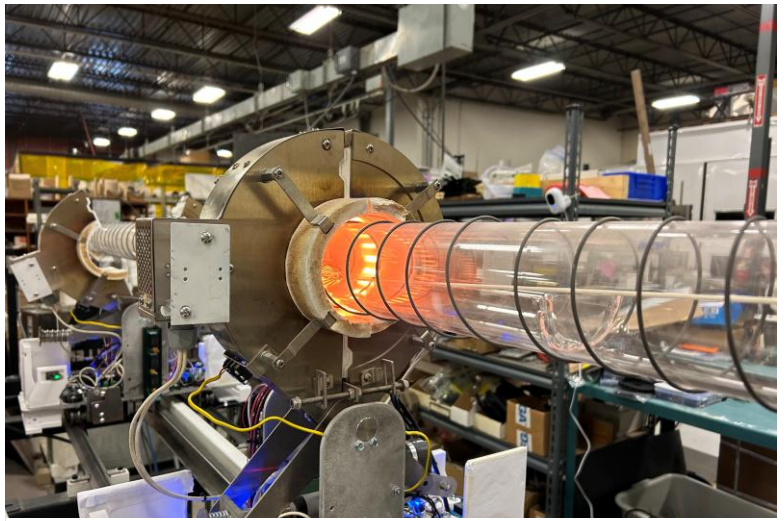
[1]https://doi.org/10.1016/j.nima.2008.04.082
[2] https://doi.org/10.1140/epjc/s10052-019-6911-4
[3] https://doi.org/10.1140/epjc/s10052-018-5970-2
[4] https://doi.org/10.1140/epjc/s10052-021-09098-5

NaI CRYSTALS

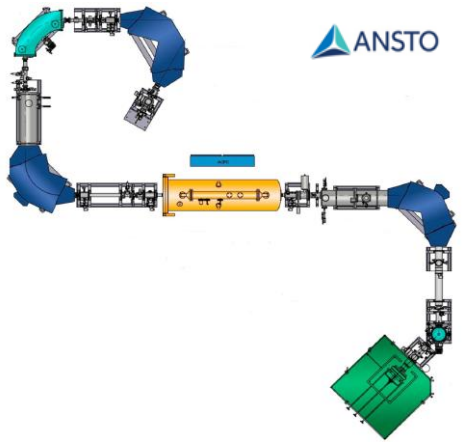
- Method being explored: Zone refining
  - decrease concentration of impurities even further [1]
  - depends on the impurity, not applicable to all
- Contaminant measurement techniques:
  - Accelerator Mass Spectrometry for highest sensitivity measurement of ^{210}Pb alongside alpha counting

Contaminant movement due to phase change

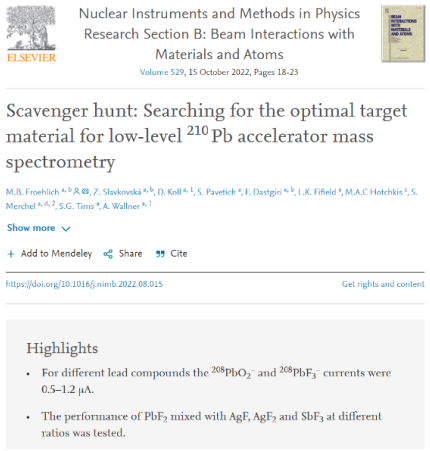




Zone refining equipment at Mellen



Schematic image VEGA, 1MV ANSTO, Sydney



Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms

Volume 529, 15 October 2022, Pages 18-23

Scavenger hunt: Searching for the optimal target material for low-level ^{210}Pb accelerator mass spectrometry

M.B. Froehlich, Z. Slavkovská, D. Koll, S. Pavetich, F. Dastgiri, I.K. Fifield, M.A.C Hotchkis, S. Merchel, S.G. Tims, A. Wallner

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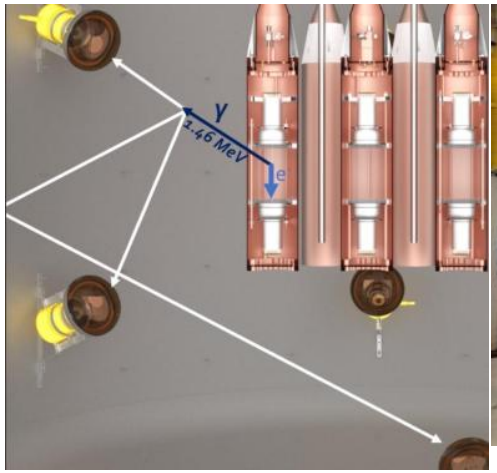
Highlights

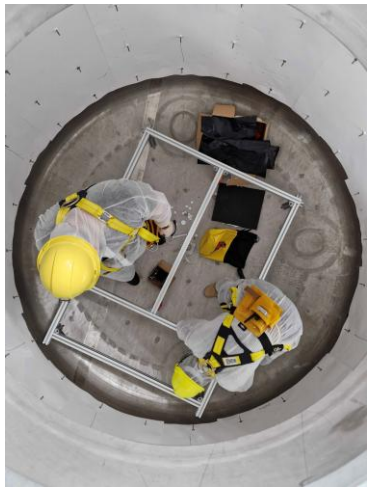
- For different lead compounds the $^{208}PbO_2^-$ and $^{208}PbF_3^-$ currents were 0.5–1.2 μA.
- The performance of PbF_3 mixed with AgF, AgF_2 and SbF_3 at different ratios was tested.

[1] https://doi.org/10.1103/PhysRevApplied.16.014060

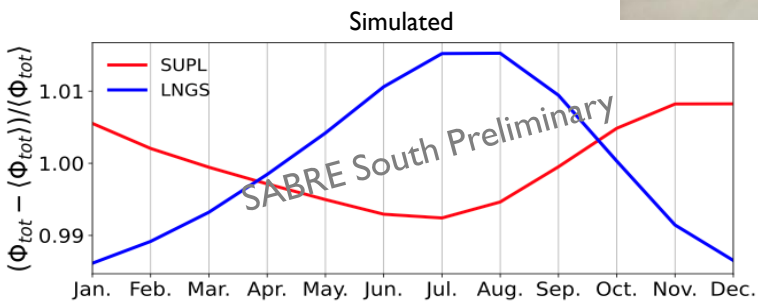
VETO AND MUON SYSTEMS

- Linear Alkyl Benzene veto obtained from Juno
  - Add Bis-MSB + PPO
- Used for vetoing backgrounds, especially ^{40}K
  - 10x background reduction 3 keV EC followed by 1460 keV γ detected in veto
  - suppress total background by ~30% [1]
  - Passive shielding from external radiation
- Veto assembly tests ongoing





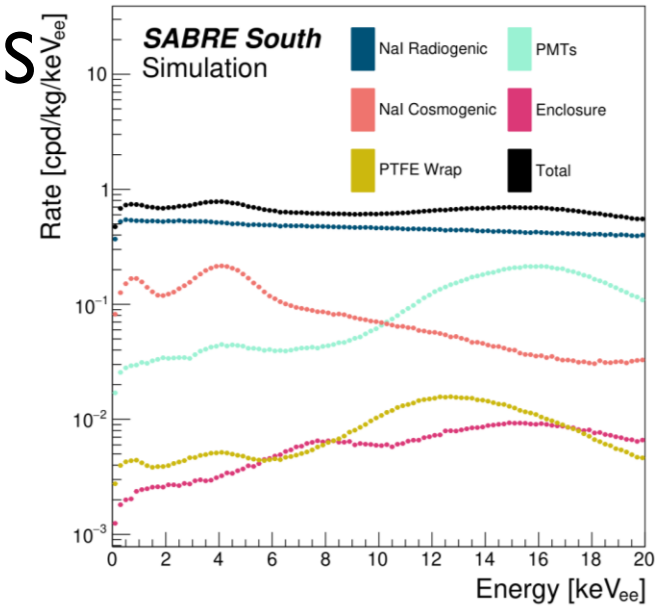
- Assembled and operating in SUPL since early 2024.
- 8x plastic scintillator panels providing 9.6 m^2 coverage above the vessel
- Measures angular distribution of muon flux in SUPL
- Measured total muon flux
- First deployment of DAQ and remote data processing pipeline.

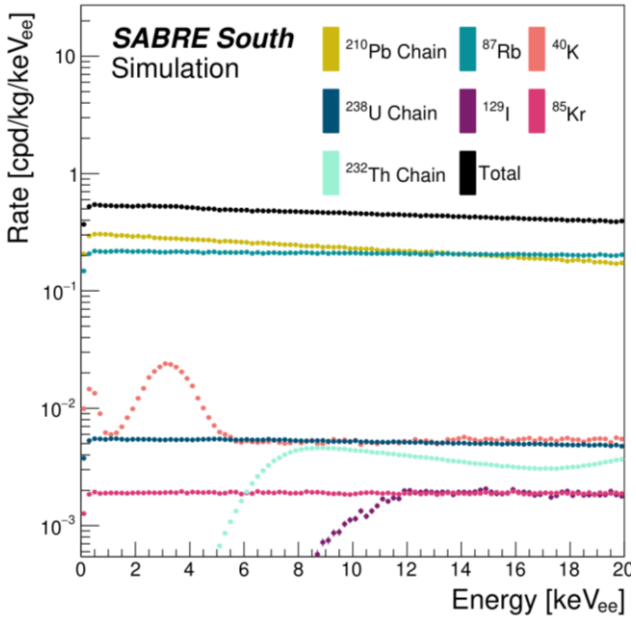


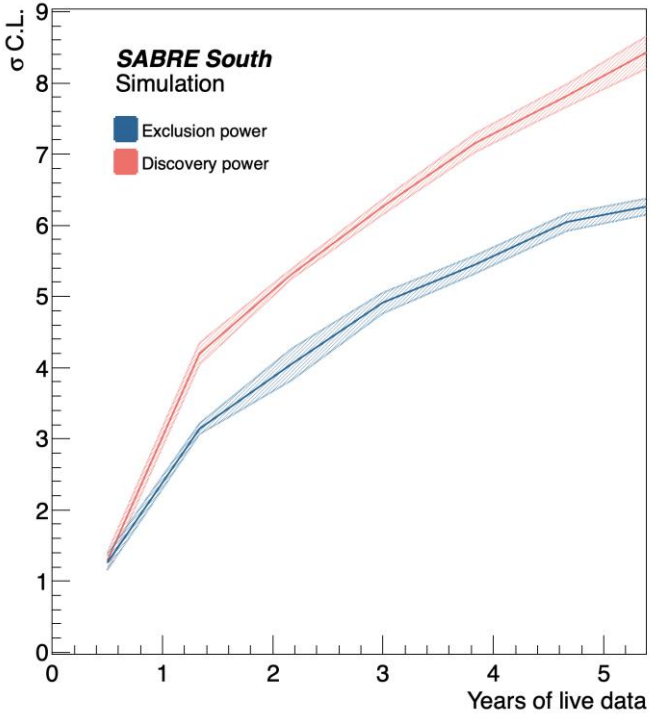
[1] https://doi.org/10.1140/epjc/s10052-023-11817-z

SABRE SOUTH BACKGROUNDS AND SENSITIVITY

- Intrinsic background major contribution to overall backgrounds
  - within this the ^{40}K and ^{210}Pb largest contributors
- SABRE South will provide 5σ discovery in 2 years and 5σ exclusion within 3 years of data taking
  - at 50 kg target mass
  - 0.72 cpd/kg/keV$_{ee}$







SABRE South TDR: DOI 10.1088/1748-0221/20/04/T04001

https://doi.org/10.1140/epjc/s10052-023-11817-z

CONCLUSION

- SUPL access in 2024
- First underground laboratory in the Southern Hemisphere
  - + First dark matter direct detection experiment
- SABRE South to provide 5σ discovery in 2 years and 5σ exclusion within 3 years of data taking
- First real test of software, DAQ, Computing and Database systems on the muon detector
- SABRE South fully funded and under construction through 2025
  - excellent progress on crystal production and handling equipment
- Upcoming papers on Crystal and Veto PMT characterisation, ultrapure crystal background characterisation, and muon flux measurements

SABRE

Australian National University

THE UNIVERSITY OF ADELAIDE AUSTRALIA

SWINBURNE

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF MELBOURNE

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

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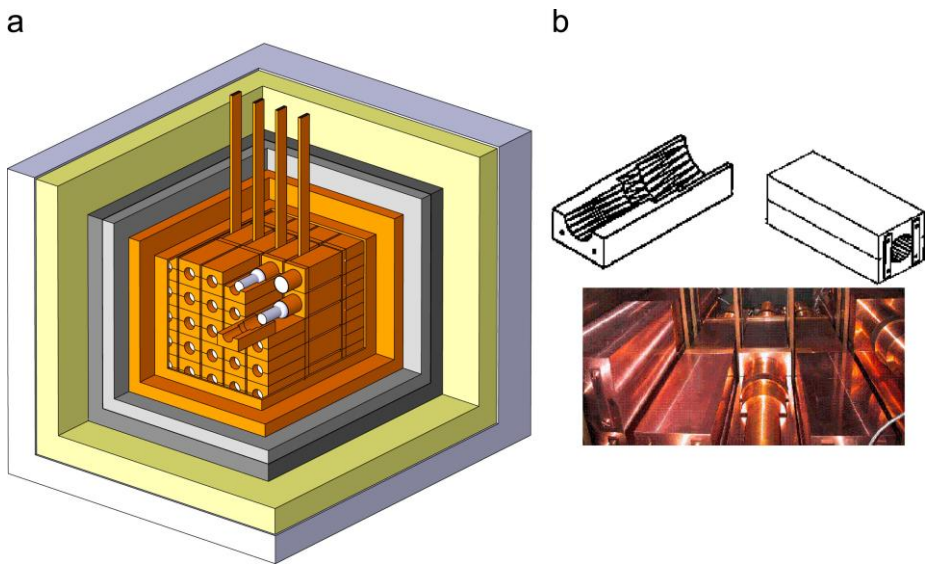
BACKUP DAMA/LIBRA

- 2-6 keV Modulation amplitude: 0.01014 cpd/kg/keV with a
  - phase 142.4 ± 4.2 days
  - period 0.99834 years
- 1–6 keV recoil energy range (reported for DAMA/LIBRA-phase2 only) this modulation occurs with an amplitude of 0.01058 ± 0.00090 cpd/kg/keV, period of 0.99882 ± 0.00065 years and phase of 144.5 ± 5.1 days
- Recent results – background averaging technique (if performed over a time dependent background) could have induced the modulation.
  - after reproducing a best estimate of their backgrounds, we find:
    - reproduced background is too low for modulation to be induced on the same scale as their reported signal
    - resulting induced modulation is opposite in phase to DAMA's.

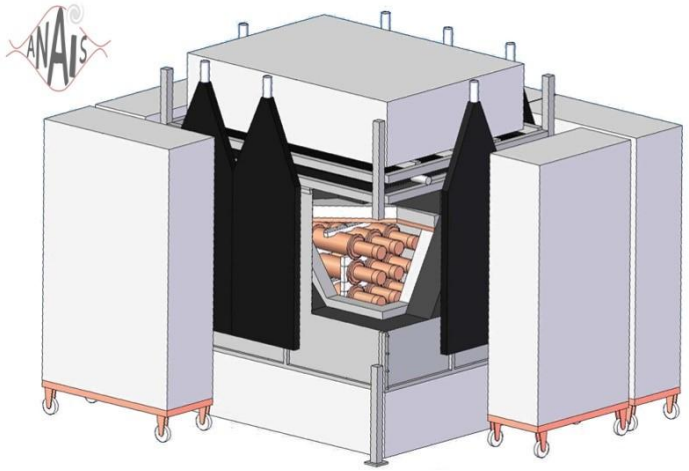


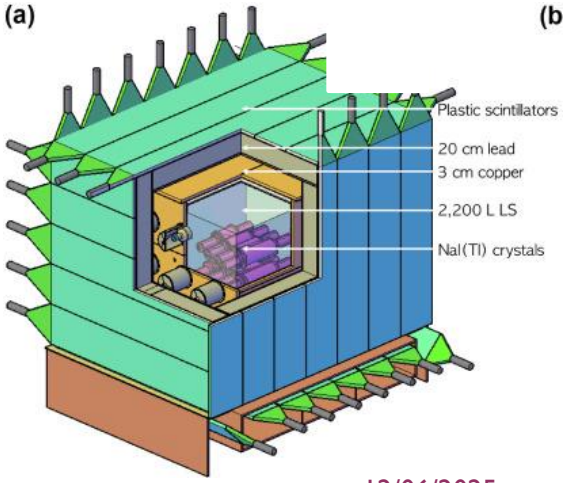
CRYSTAL MANUFACTURE

- 50 kg – SICCAS – at the 0.72 dru 5sigma exclusion in 3 years and 5sigma discovery in 2 years
- 35 kg – RMD with zone refining and Brigman methods – requires more stringent total background < 0.5 dru – achievable using ZR.
- Astrograde powder Merck has ^{39}K < 10 ppb.
- length ~15–20 cm, dia. ~10 cm
- ^{87}Rb is just an upper limit and is expected to be significantly lower.

COSINE AND ANAIS

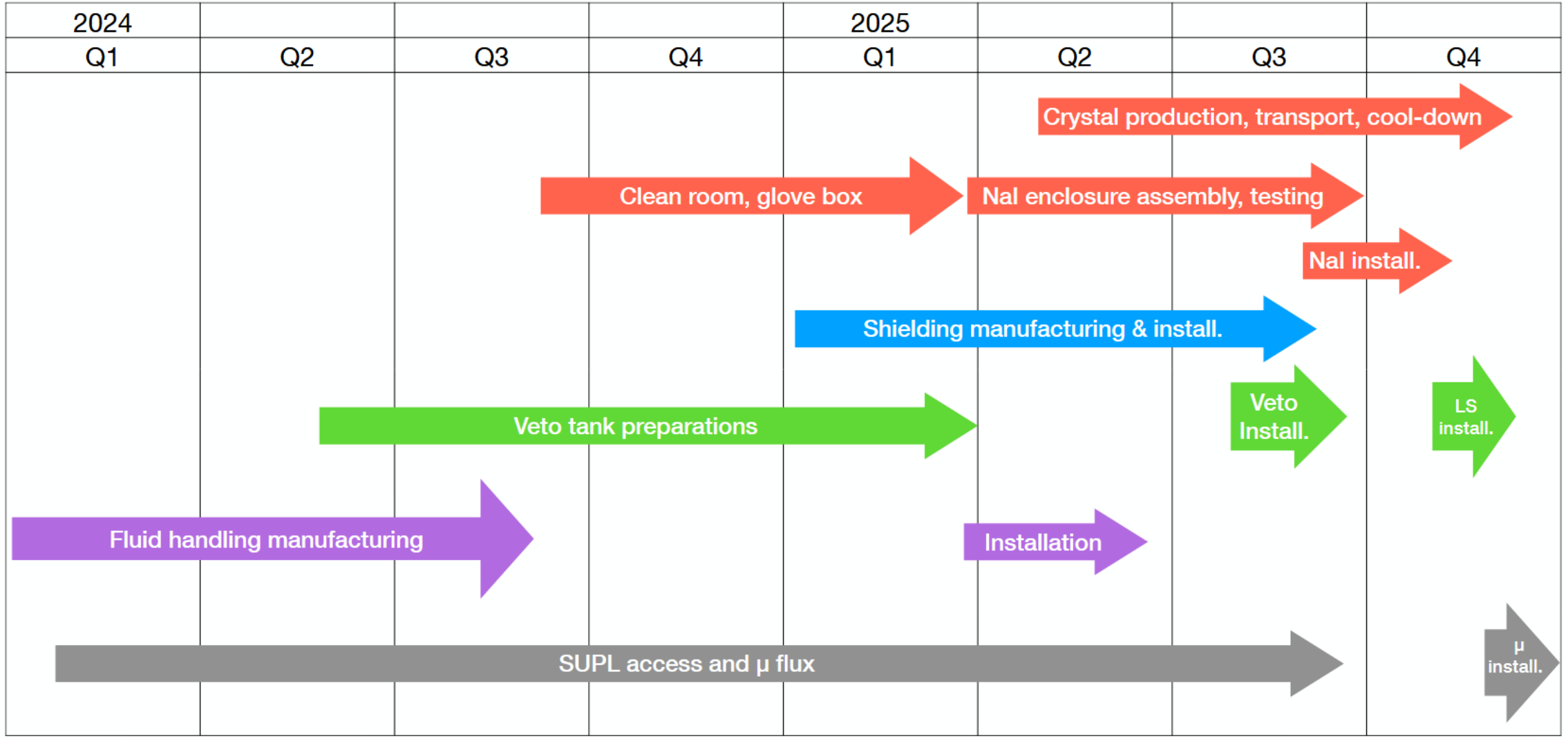
- Results in the 1–6 keV region ANAIS are known
  - impacted by higher than expected background contributions that are unexplained
  - potential cause of this is photomultiplier noise
- Signal efficiencies of event selection criteria drop steeply as 1 keV is approached.
  - eg between 1–2 keV, the ANAIS detection efficiency drops to as low as 20%, with the degree of background rejection not reported [21]. For COSINE, the detection efficiency is around 40% at 1 keV, with a sharp efficiency
- turn-on effect over the energy interval of 1–2 keV [24], which may lead to non-negligible systematic uncertainties.
- As a result, a comparison of results in the 2–6 keV region is likely more robust





Cosine 100

Timeline


2024
2025
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Crystal production, transport, cool-down
Clean room, glove box
NaI enclosure assembly, testing
NaI install.
Shielding manufacturing & install.
Veto tank preparations
Veto Install.
LS install.
Fluid handling manufacturing
Installation
SUPL access and μ flux
μ install.

CRYSTAL REQUIREMENTS

- Requirements set based on simulations
- total intrinsic crystal background ≤ 0.1cpd/kg/keV
- Light yield 10 pe/keV

85Kr 0.01	Background Limit mBq/kg
^{210}Pb	<0.3
^{40}K	<0.3 (10 ppb)
^{238}U	0.05
^{87}Rb	0.31
^{232}Th	0.035