Status of the SABRE South dark-matter experiment

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on behalf of the SABRE South collaboration
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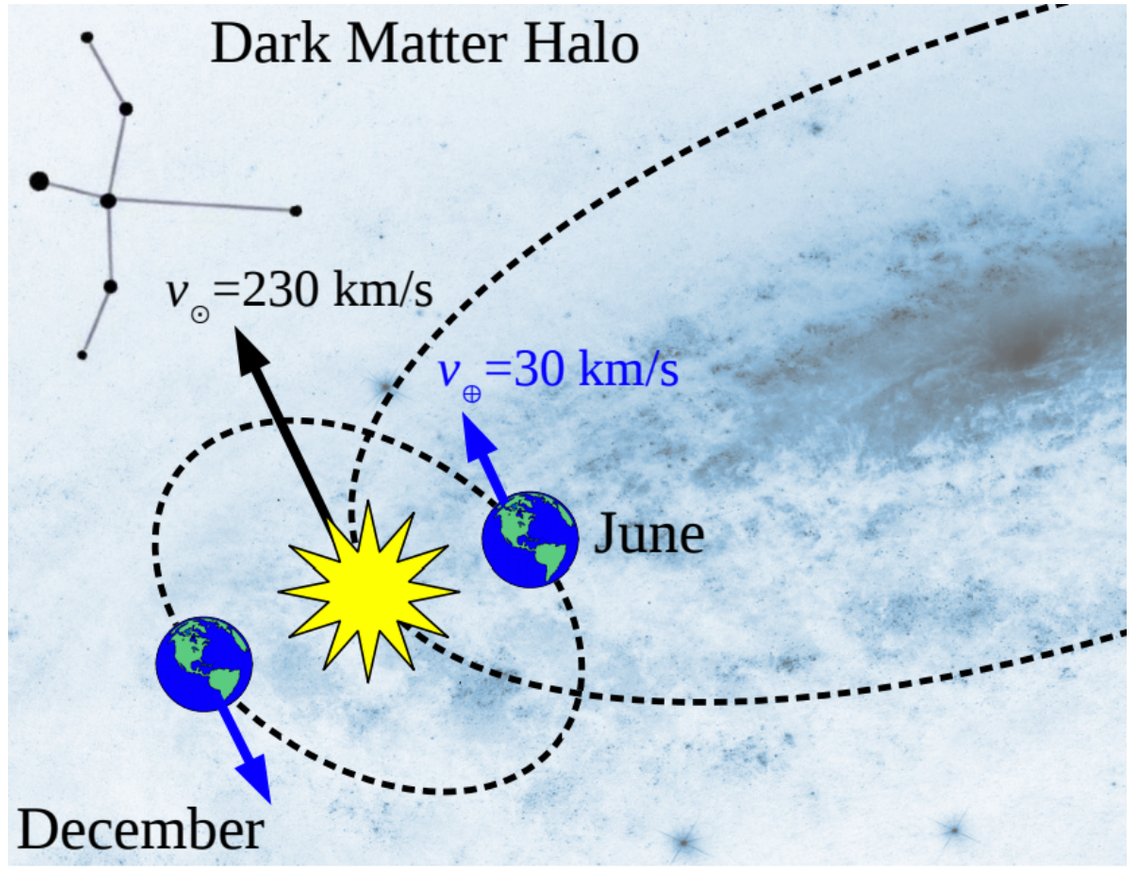
Dark matter direct detection

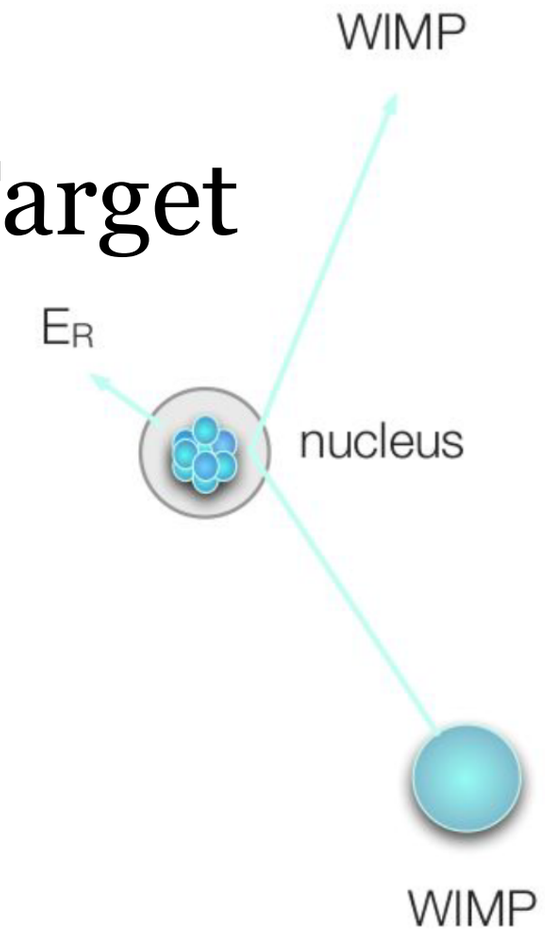
Standard Halo Model:

- "Cold" dark matter (WIMP) with Maxwellian velocity distribution in isotropic and isothermal sphere.
- Canonical value for density: $\rho \approx 0.3$ GeV/cm^3.
- WIMP wind:

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

- $\theta \approx 60^\circ$ earth orbit inclination wrt galactic plane.
- Max: 2 June, Min: 2 Dec.



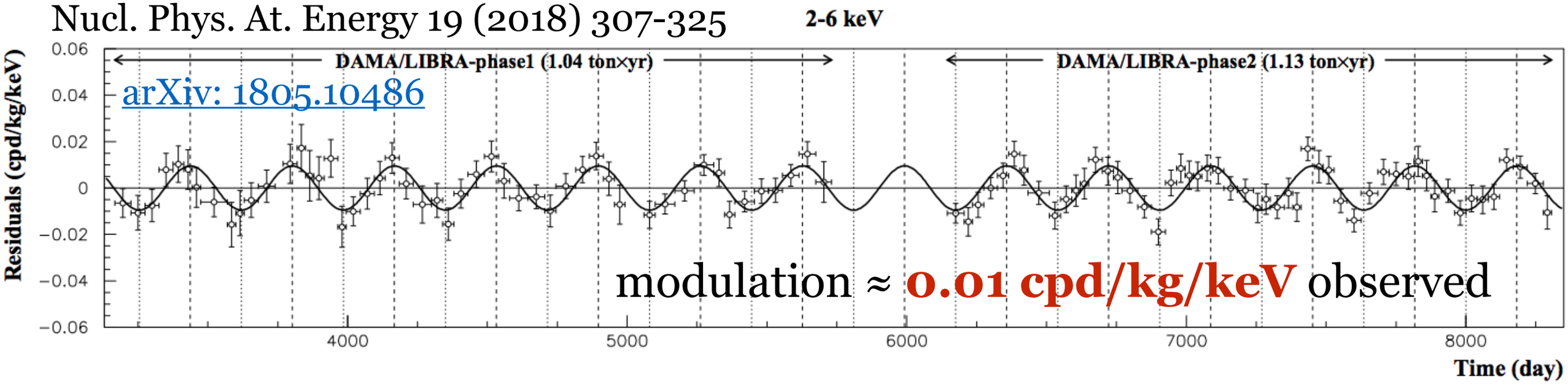


$$S(t) = B + S_0 + S_m \cos\left[\omega(t - t_0)\right]$$

- E_R in **1÷100 keV**.
- Harder to softer spectrum expected with modulation.
- Signal rate ≈ **1 count / day / kg / keV** (cpd/kg/keV).
- Small modulation expected: **$S_m/S_0 \approx O(5\%)$**.

DAMA/LIBRA results

Nucl. Phys. At. Energy 19 (2018) 307-325



DAMA/LIBRA

- Modulation observed for 14 years with **12.9 σ** significance!
- Located at Laboratori Nazionali del Gran Sasso (LNGS), Italy.
- Total target mass = 250 kg of NaI(Tl).

Claim in tension with other experiments but these are not based on NaI target.

Need **model independent** verification of result based on identical target material.

Sodium iodide with Active Background REjection

Model independent search at the SABRE South experiment at the SUPL laboratory

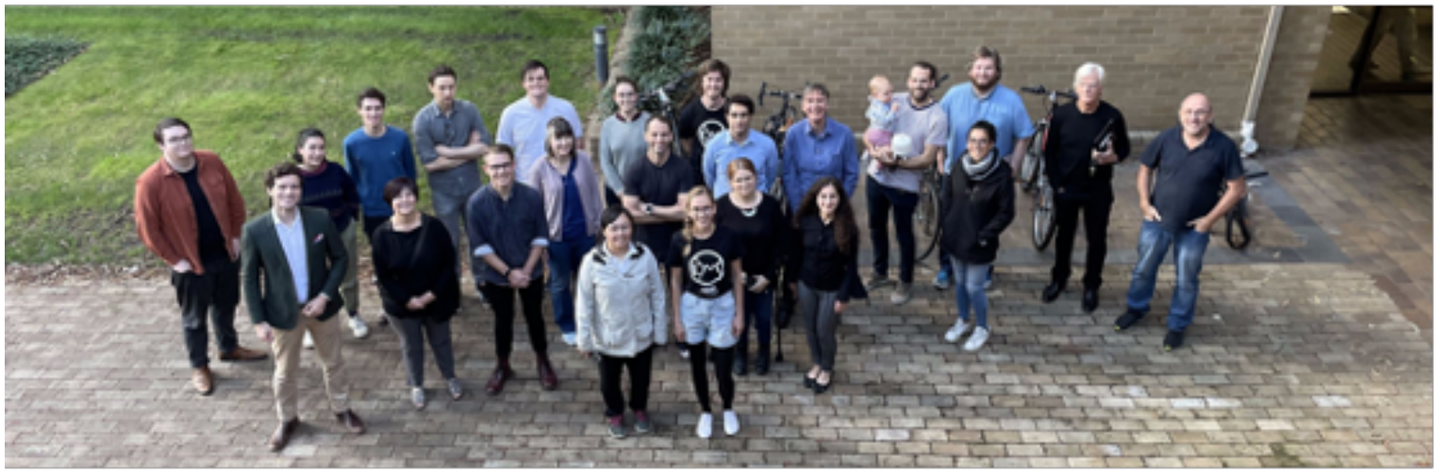
Southern hemisphere
- First NaI detector in the southern hemisphere allowing exclusion of seasonal effects.

High purity crystals
- Low K contamination.

Low energy threshold
- 1 keV threshold.

Active bkg veto
- High background rejection.

SABRE South Collaboration

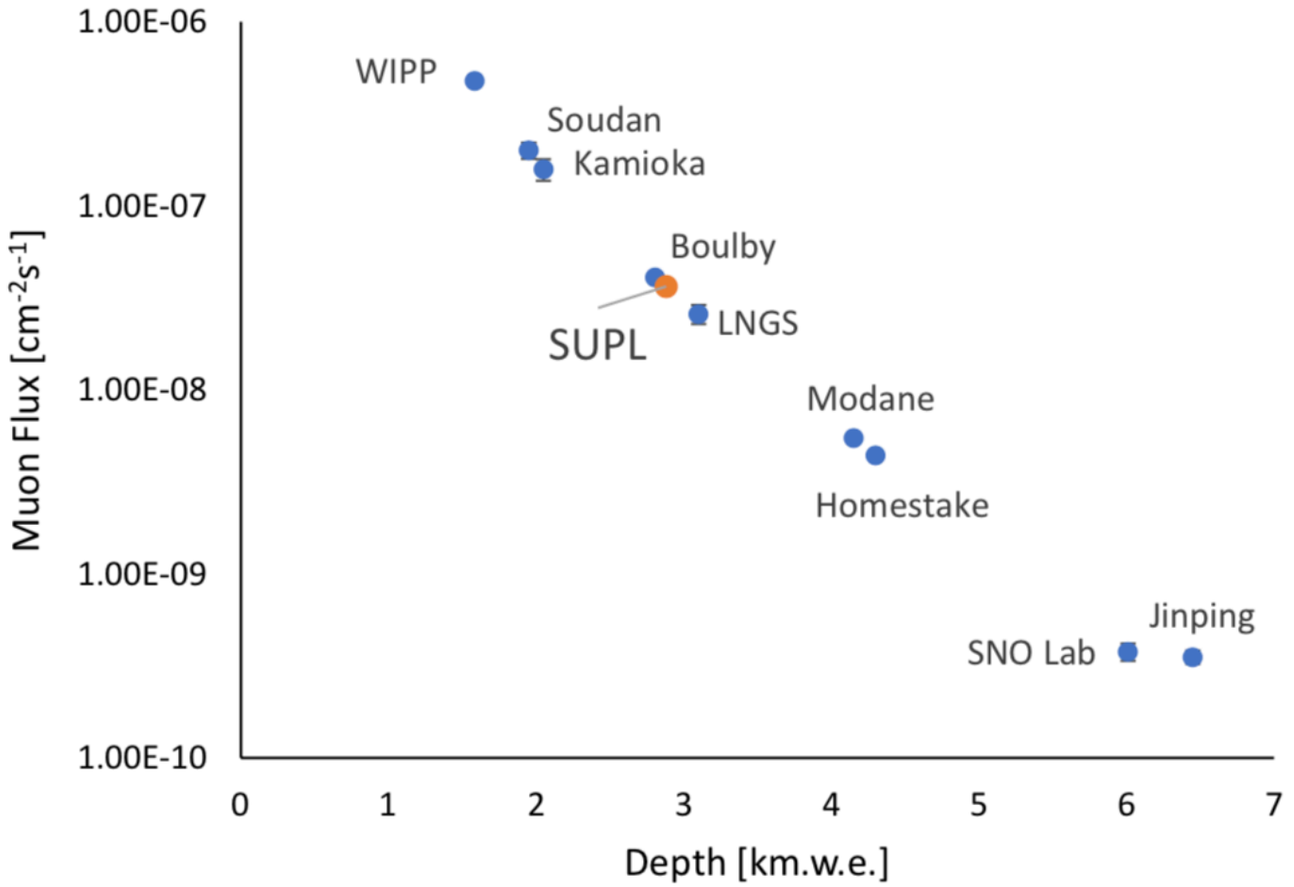


46 members among 5 institutions:

Australian National University
Australian Nuclear Science and Technology Organisation
Swinburne University of Technology
The University of Adelaide
The University of Melbourne

Stawell Underground Physics Laboratory

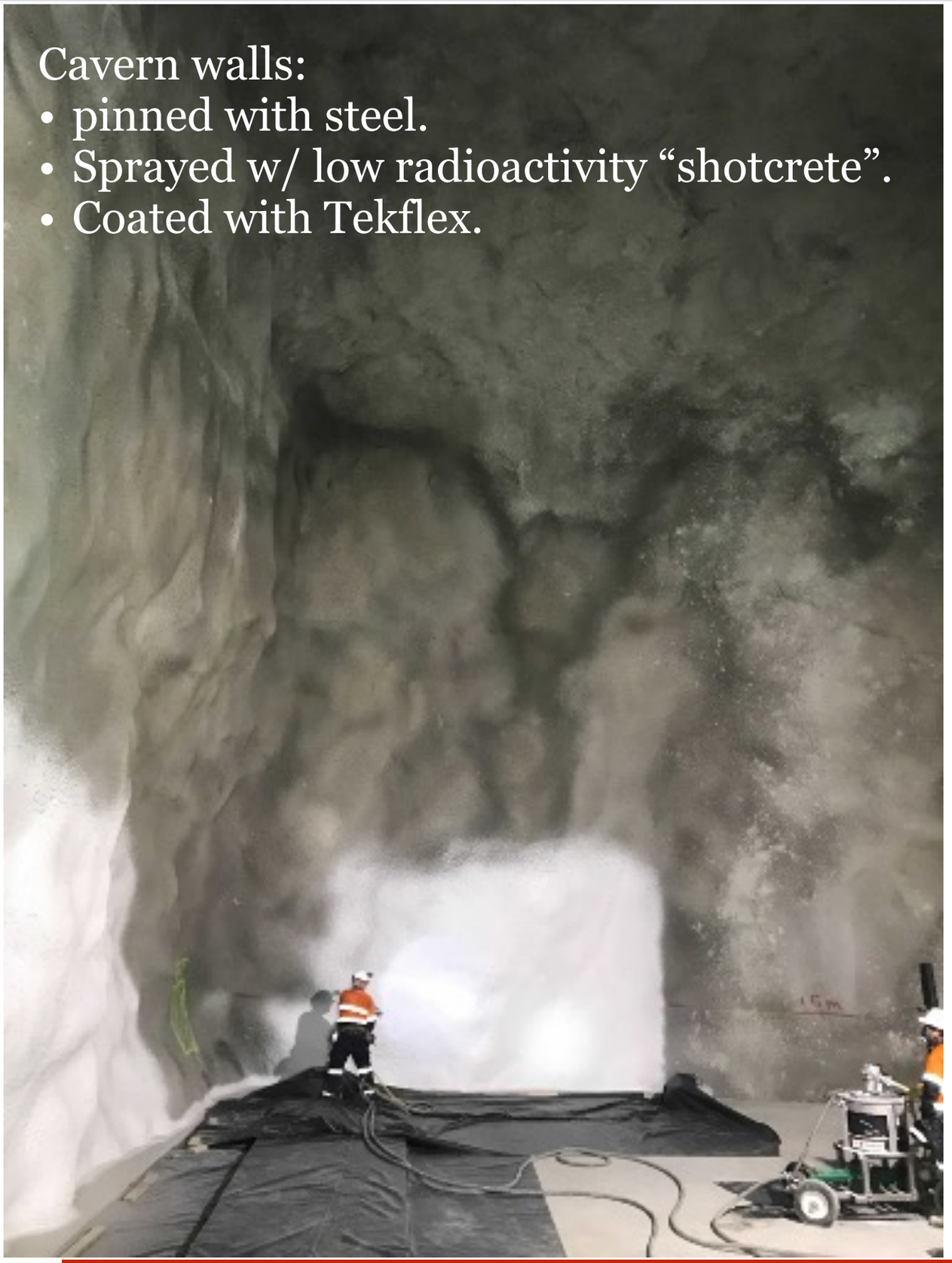
- Located in an active gold mine at Stawell ~240 km North West of Melbourne.
- Depth of 1024 m with flat over burden.



Over burden:
- Flat: WIPP, Soudan, Boulby, Homestake, SNOLab.
- Non-flat: Kamioka, LNGS, Modane, Jinping.

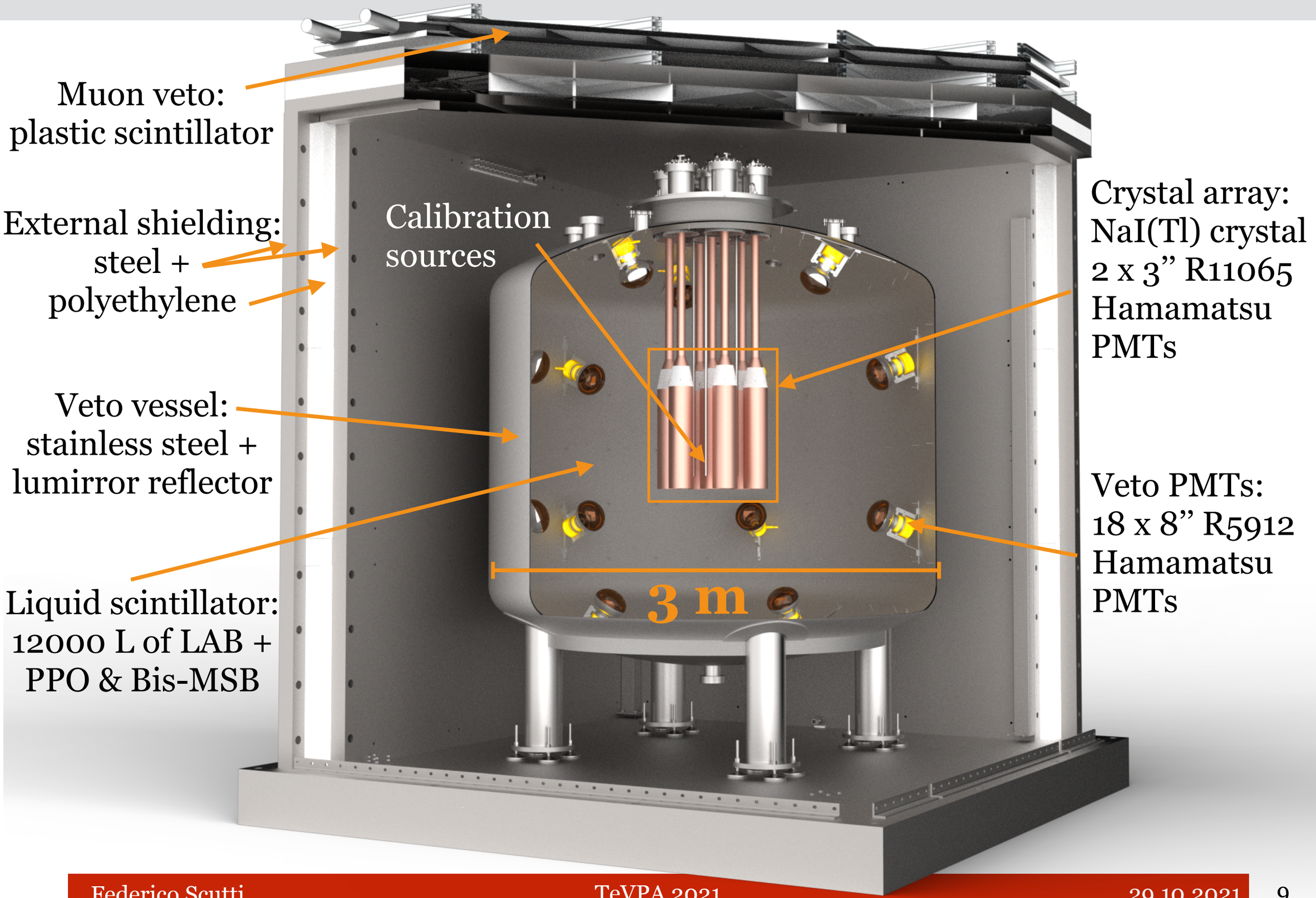
Stawell Underground Physics Laboratory

Stawell Underground Physics Laboratory



- Project funded by the Australian Government and State Government of Victoria.
- Cavern excavation completed in June.
- Construction materials screened for radioactivity.
- On track for completing construction in December 2021.
- SABRE construction and commissioning in early 2022.

SABRE Detector



NaI(Tl) detectors

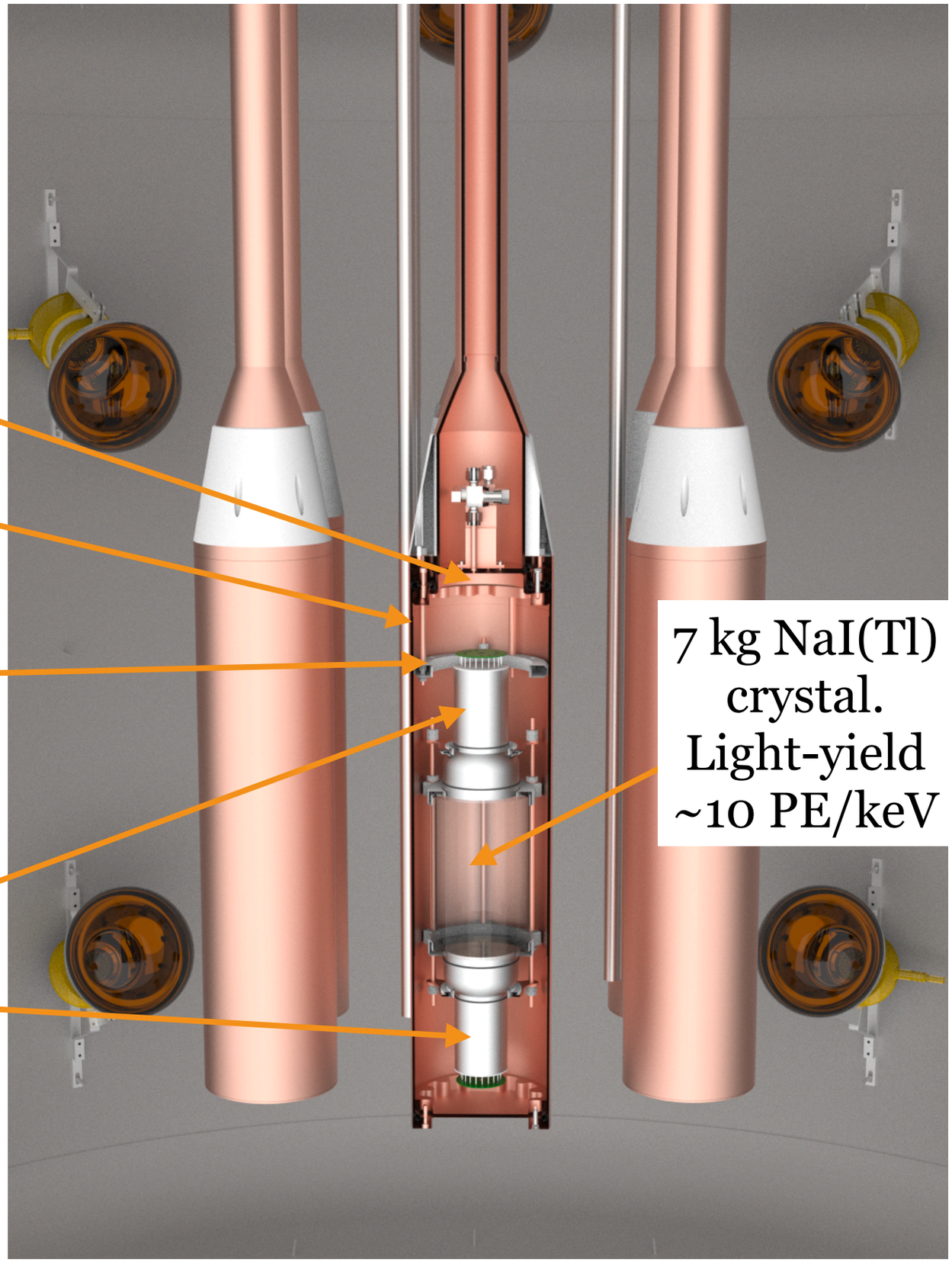
Array of 7 detectors.
Purged with high purity dry N_2.

Feedthrough plate

OFHC copper enclosure
w/ 3 mm wall thickness

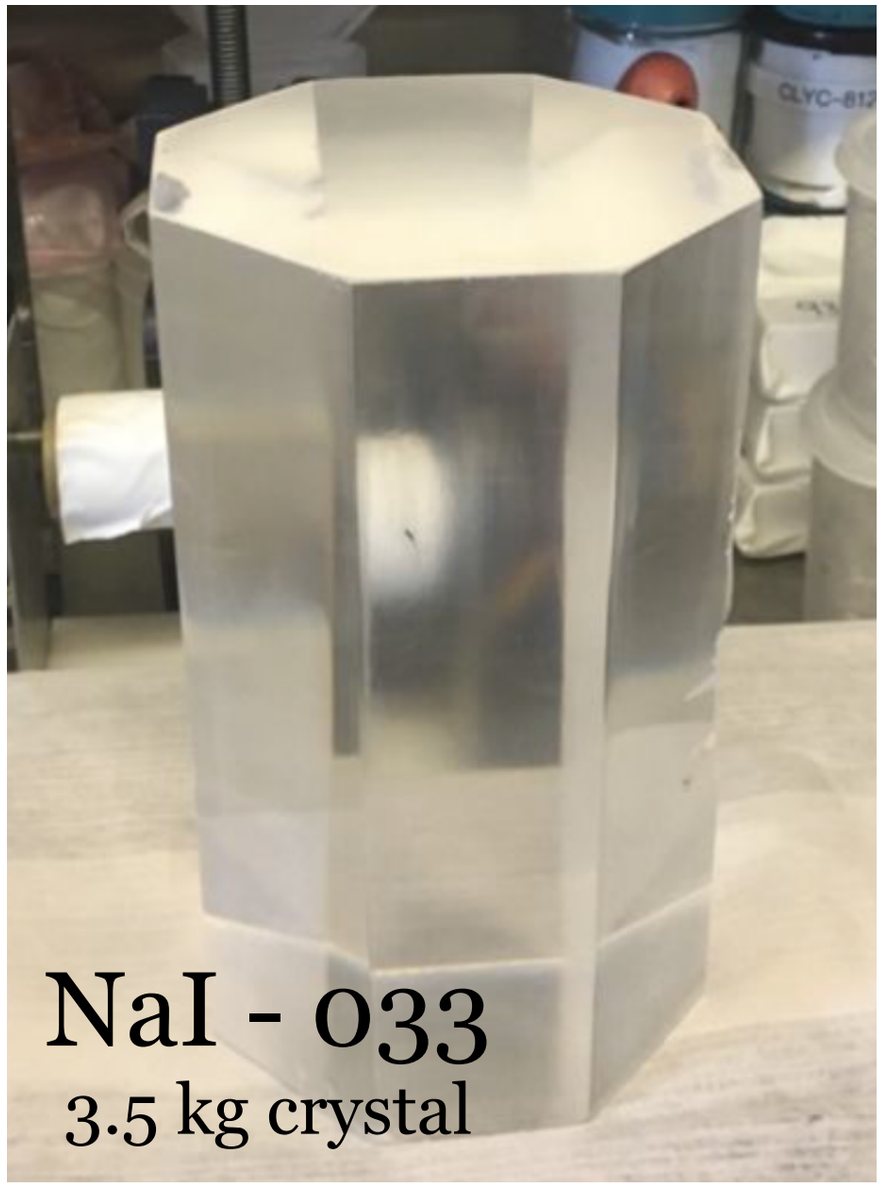
Internal Teflon structure

3” Hamamatsu R11065 PMT:
- low background metal body.
- QE > 30% @ 420 nm.
- readout @ 500 MS/s with CAEN V1730.
- operated at threshold ~0.3 SPE peak.



NaI(Tl) crystals

- Test crystal of 5 kg by RMD using the vertical Bridgman-Stockbarger method.
- Currently being prepared for testing at LNGS.
- ICPMS measured ^{nat}K: tip 5 ppb, bulk <10 ppb.
- RMD has previously grown a 3.4 kg crystal (NaI-33) for SABRE with very low background [1].

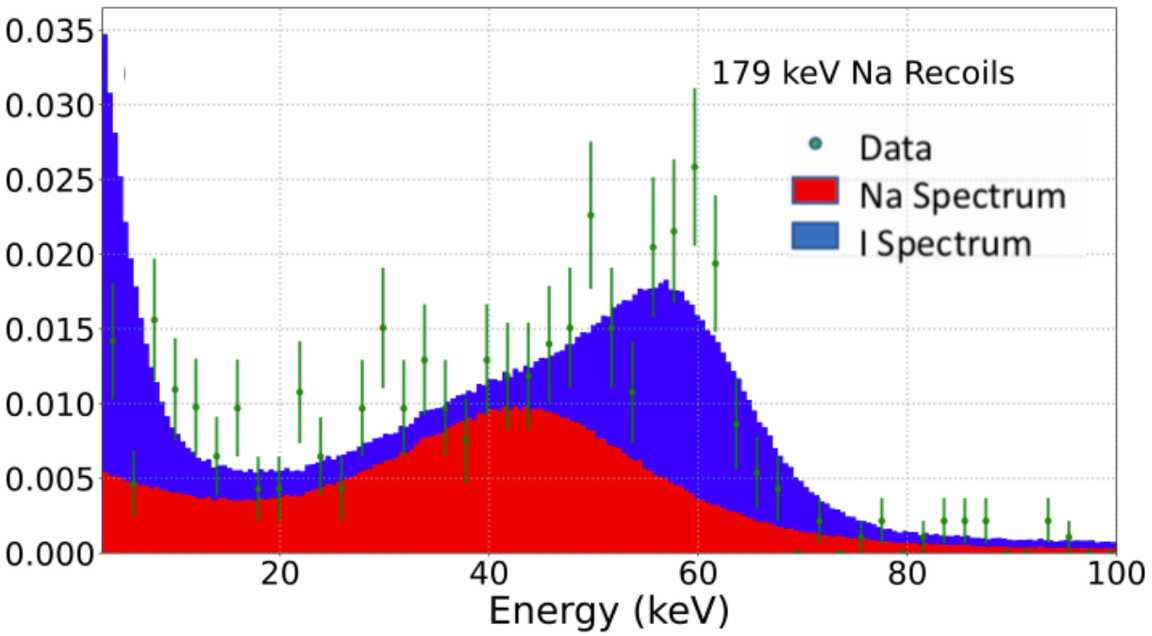


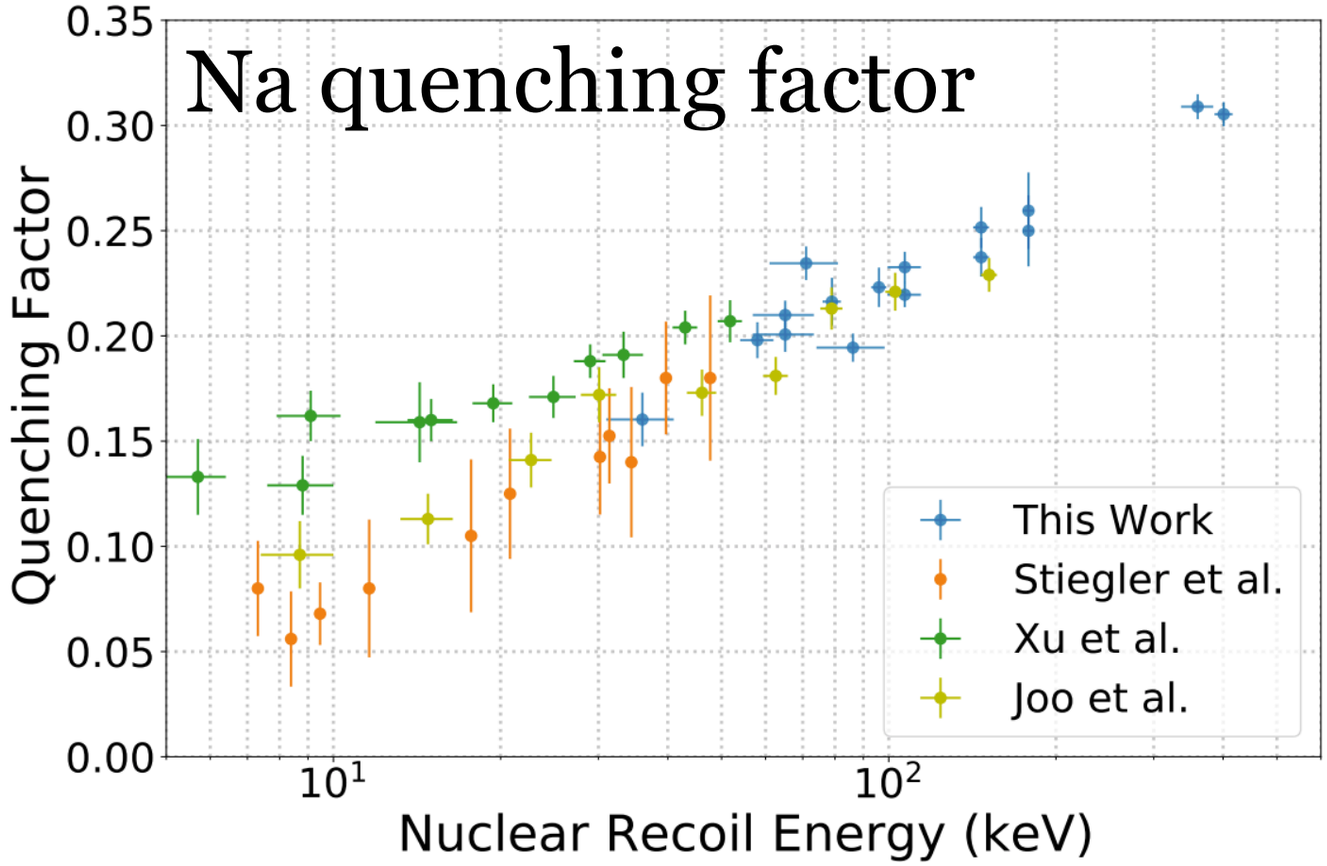
	K [ppb]	^{238}U [ppt]	^{232}Th [ppt]
SABRE[1] NaI-33	4.7±1.4	<1	<1
DAMA [2]	13	<10	<10
COSINE-100 [3]	17.8	<20	0.6

- [1] M. Antonello, et al.," Characterization of SABRE crystal NaI-33 with direct underground counting." *Eur. Phys. J. C* 81, 299 (2021).
- [2] R. Bernabei, et al. "The DAMA/LIBRA apparatus." Nucl. Instrum. Methods Phys. Res. A: 592.3 (2008): 297-315.
- [3] G. Adhikari, et al. "Initial performance of the COSINE-100 experiment." The European Physical Journal C 78.2 (2018): 1-19.

Quenching factors

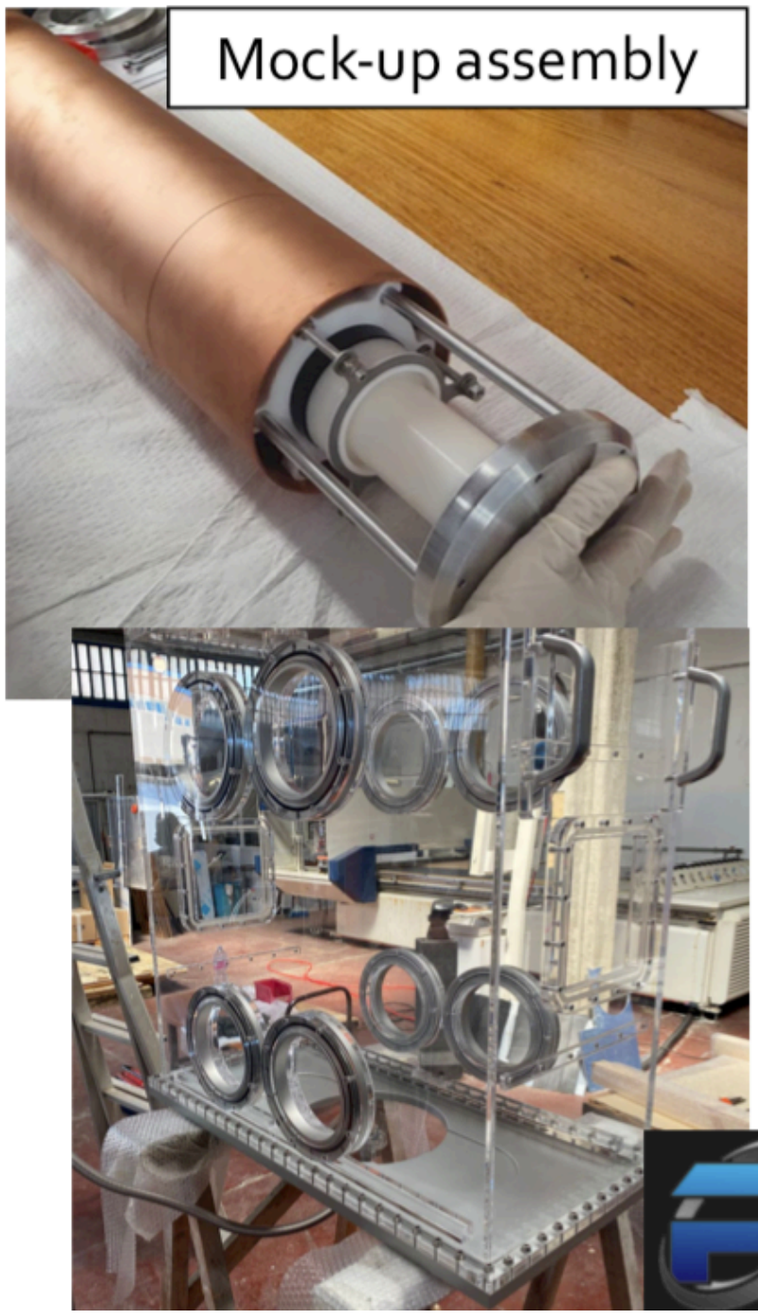
- Measured Na QF in NaI(Tl) using spectrum fitting for 30-300 keV neutron recoils.
- Used Heavy Ion Accelerator facility (HIAF) at ANU to obtain pulsed neutron beam.
- Recoil spectrum obtained using simulation and a fit to data was used to constrain the QF.
- New measurements are underway using Astrograde offcuts from SABRE South test crystal.

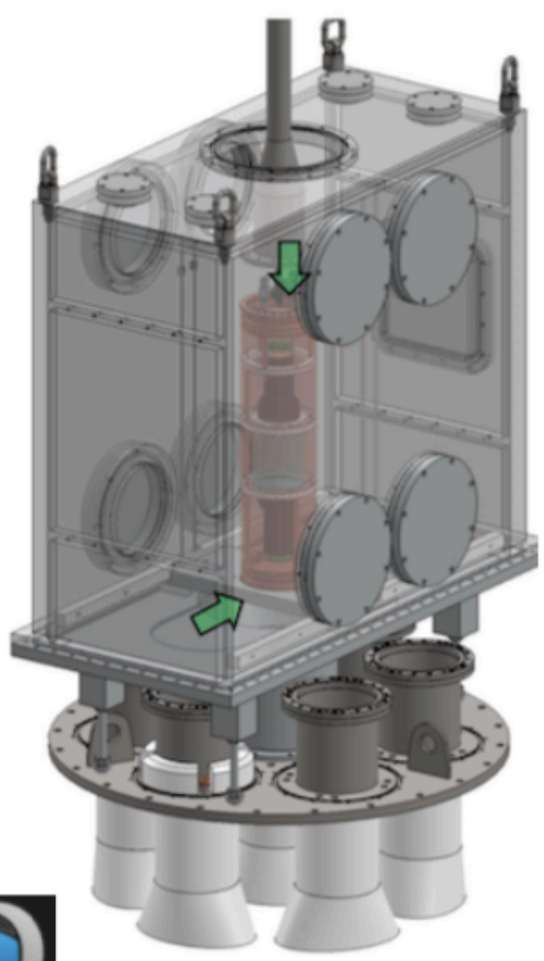


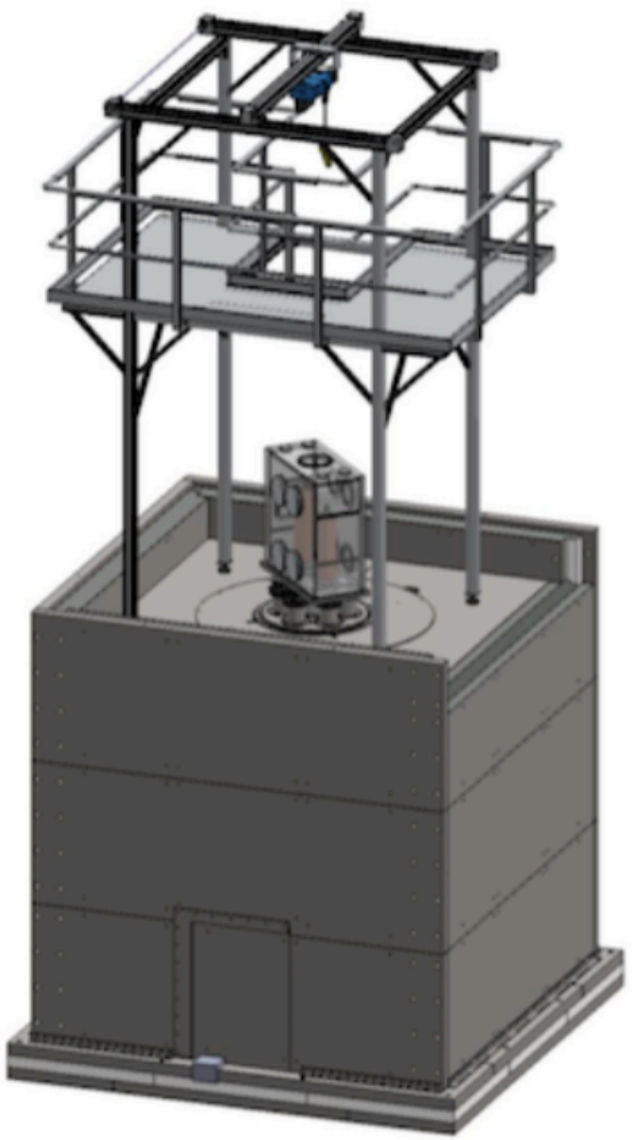


L. J. Bignell, et al. "Quenching factor measurements of sodium nuclear recoils in NaI: Tl determined by spectrum fitting." Journal of Instrumentation 16.07 (2021): P07034.

NaI(Tl) detector assembly and insertion

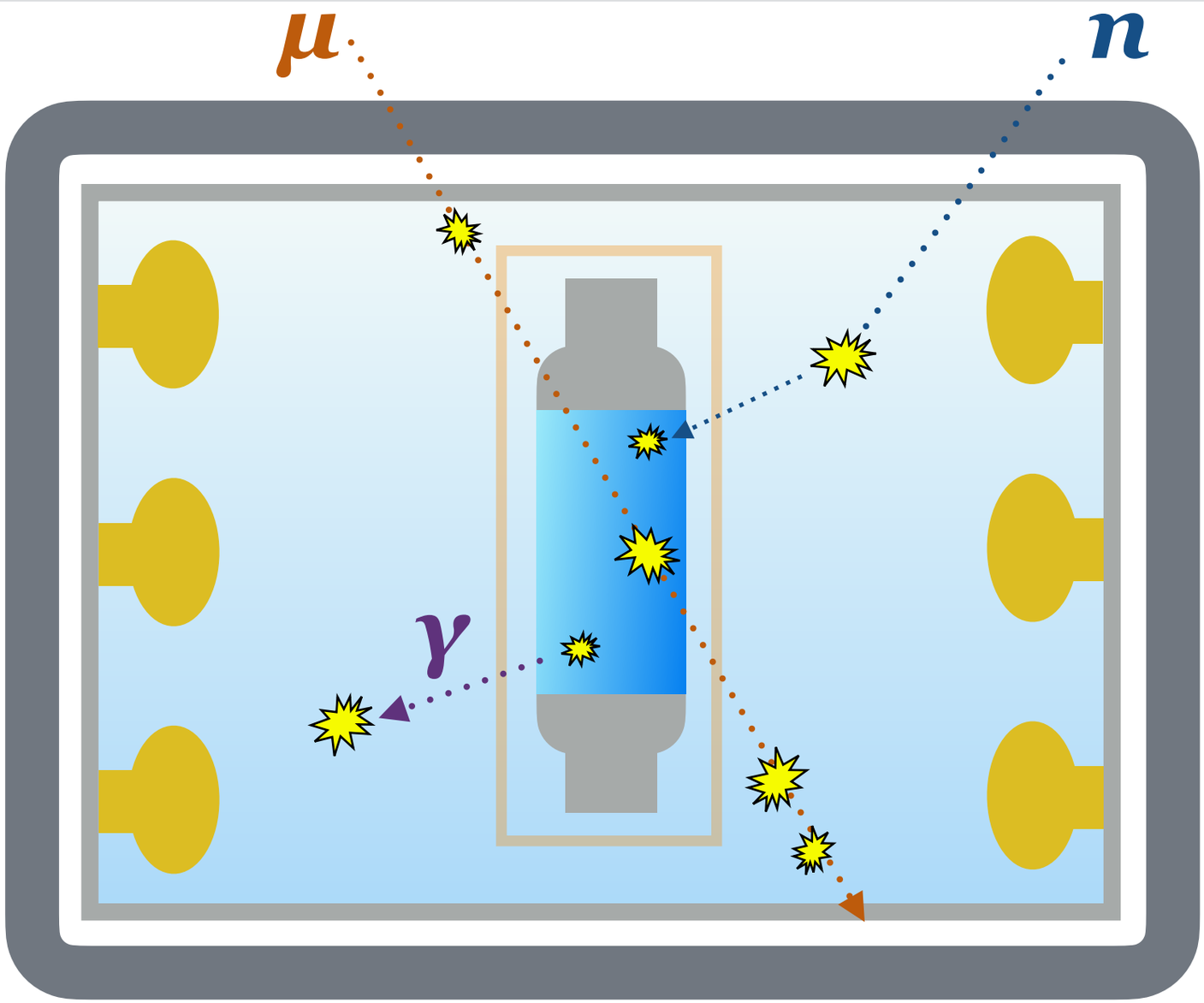


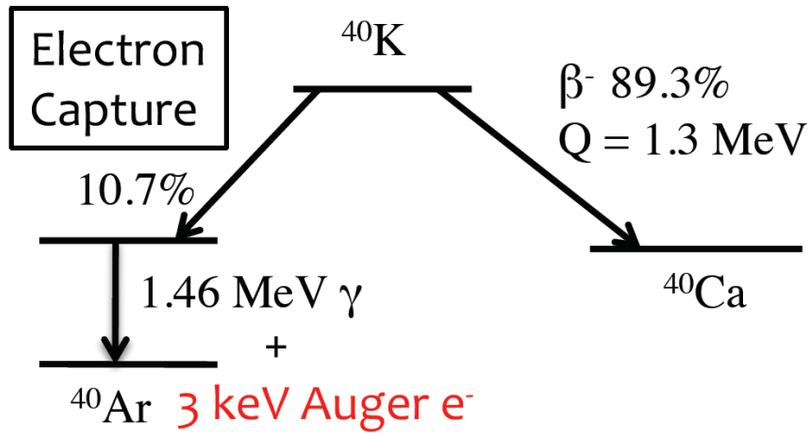


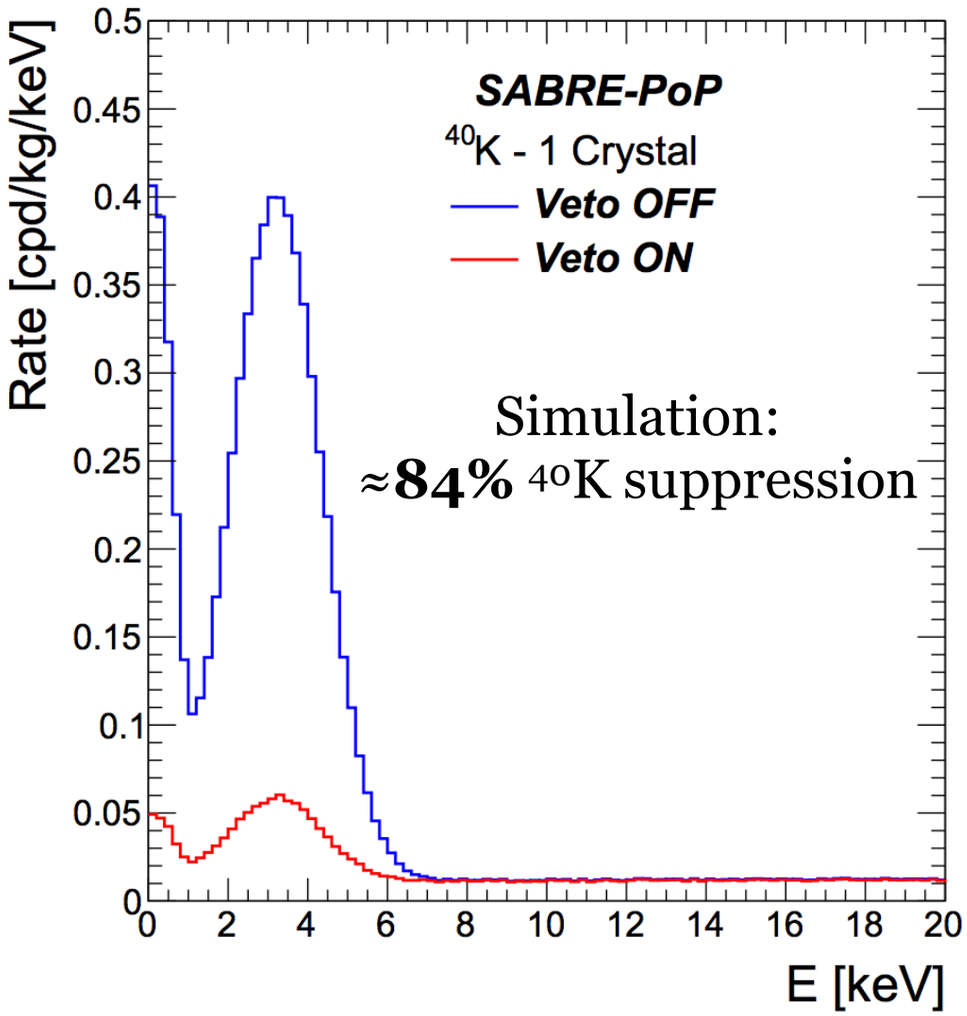


- Assembly procedure validated with mock-up enclosure.
- Crystal insertion/extraction system developed in collaboration with INFN Roma.
- The operation requires the removal of a shielding top section and the use of a glove box.
- Glove box built by Palazzi SRL has passed leak tests.

Active veto system







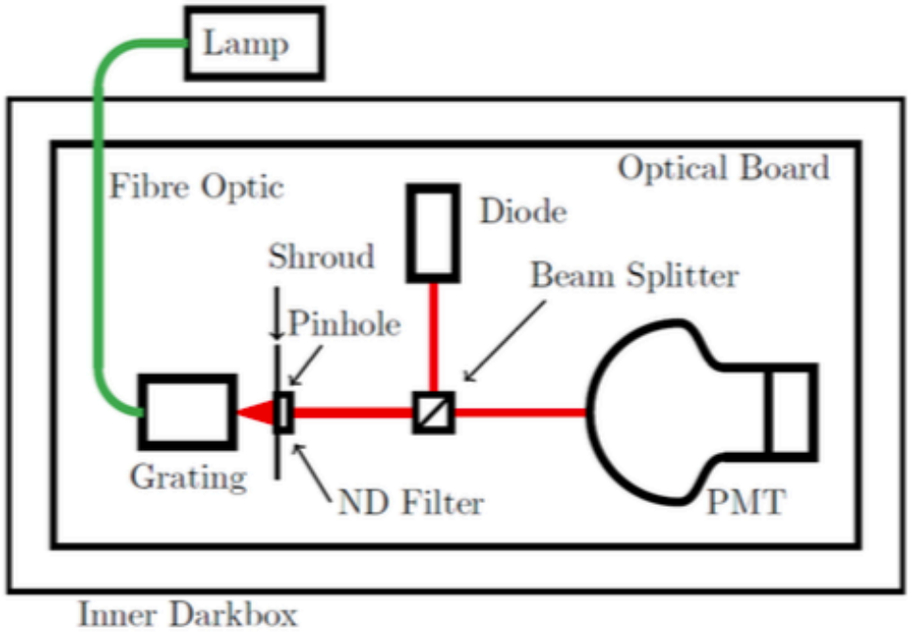
- Intrinsic and cosmogenic crystal radioactivity:
  - ^{40}K, ^{22}Na, ^{238}U, ^{232}Th.
  - ^{3}H, ^{87}Rb, ^{210}Pb: veto not effective.
- Sensitive up to >100 keV of energy deposition.
- Veto PMT readout @ 500 MS/s.

M. Antonello, et al.,"Monte Carlo simulation of the SABRE PoP background." Astropart. Phys. 106, (2019).

PMT characterisation

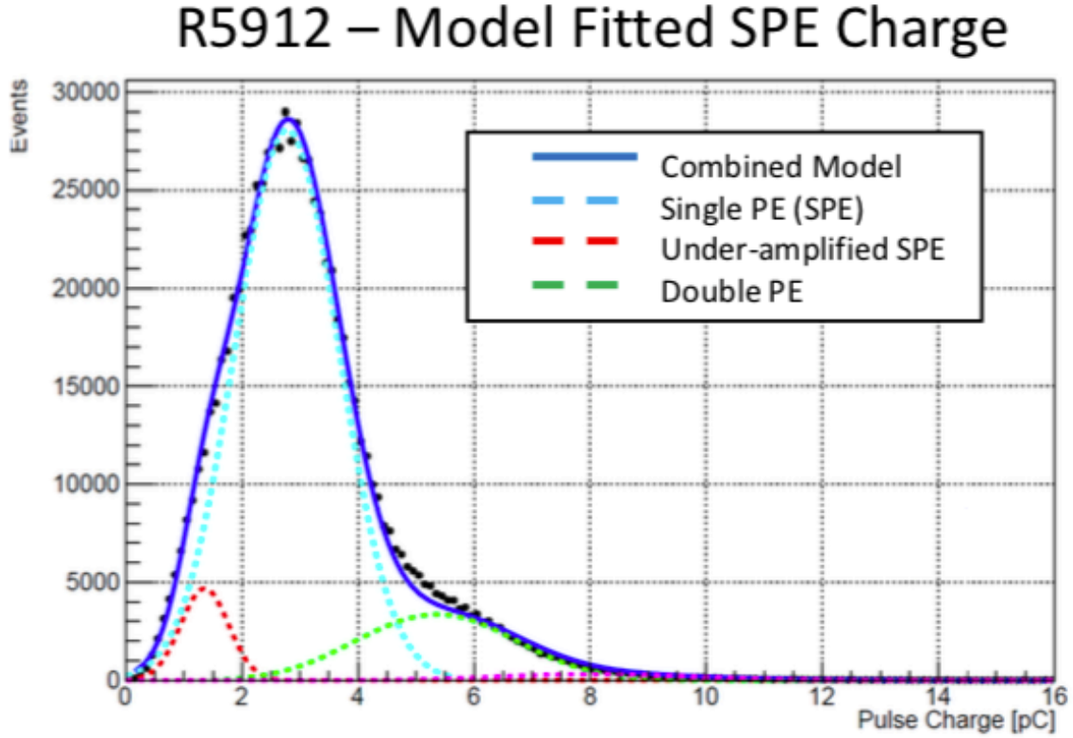
For 1 keV threshold in NaI(Tl) detectors require

	QE	Gain	Dark Rate @ 0.3*SPE Peak
R11065 – crystal	> 30%	10^7	<1000 Hz
R5912 – veto	~ 25%	10^7	<2000 Hz



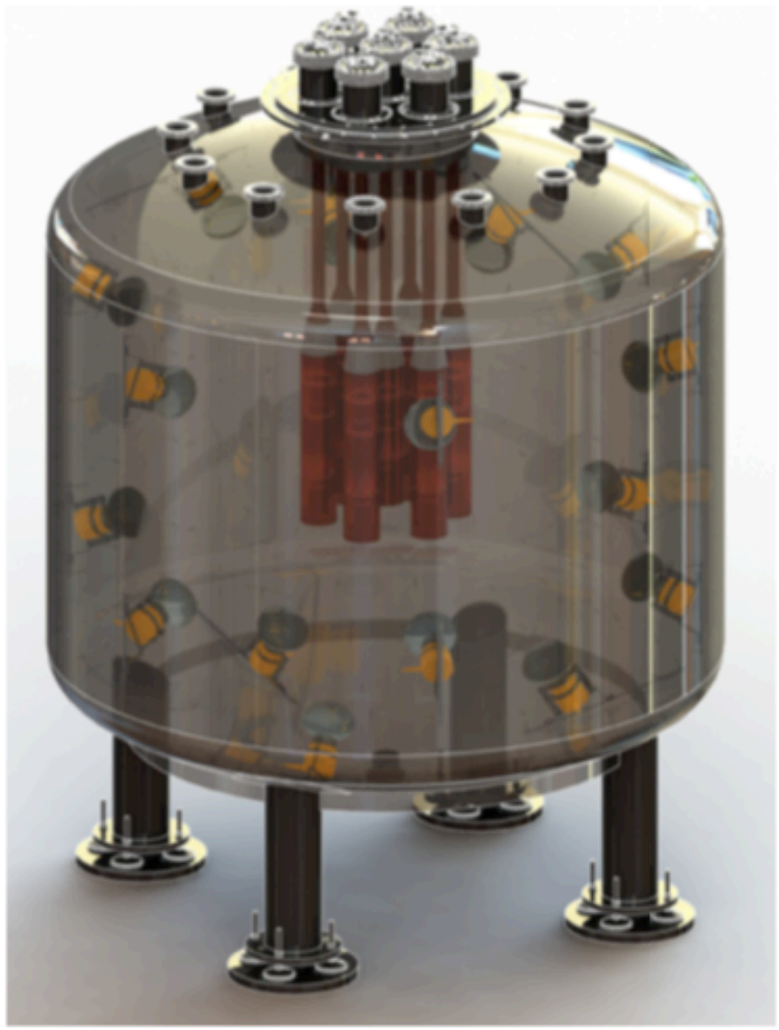
Developed characterisation process for:

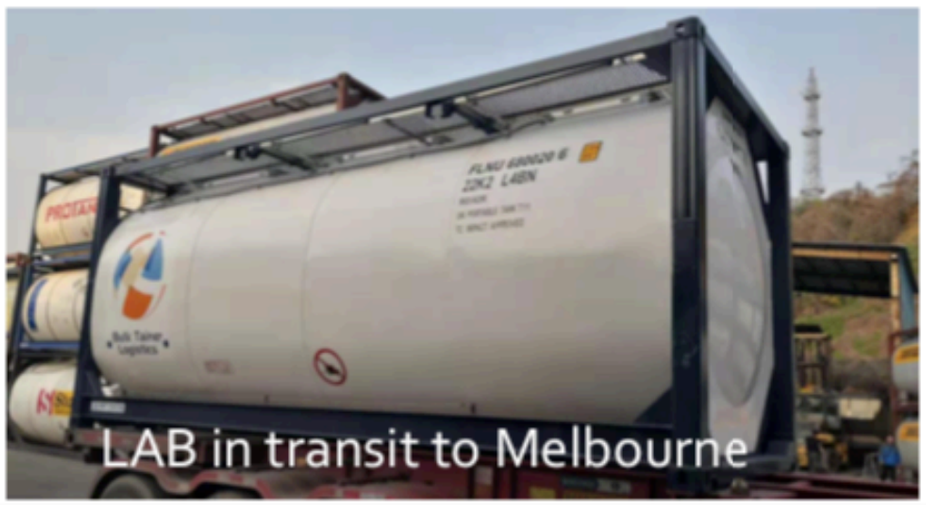
- Absolute Quantum Efficiency (QE).
- Single PhotoElectron (SPE) response and Gain.
- Dark rate as a function of voltage and temperature.
- Timing characteristics.



Active veto system

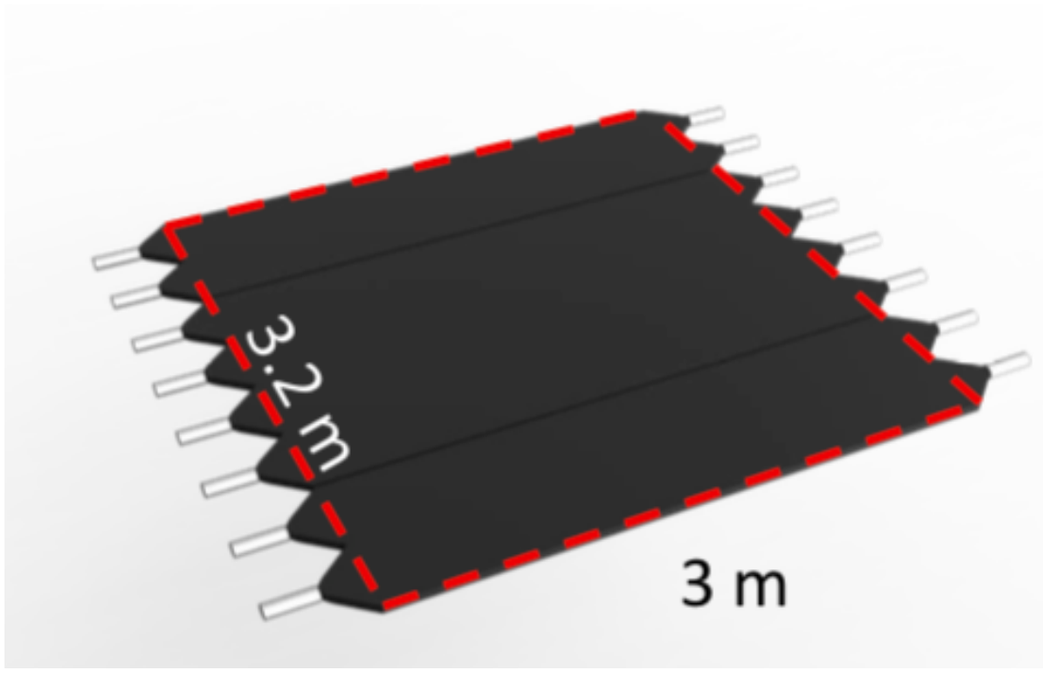
- Vessel built by [Tasweld Engineering](#) and delivered in 2019.
- Liquid scintillator (LAB) from Nanjing via [JUNO](#)/IHEP.
  - Photon attenuation > 20 m.
  - $^{238}U/^{232}Th/^{40}K < 10^{-17}$ g/g.



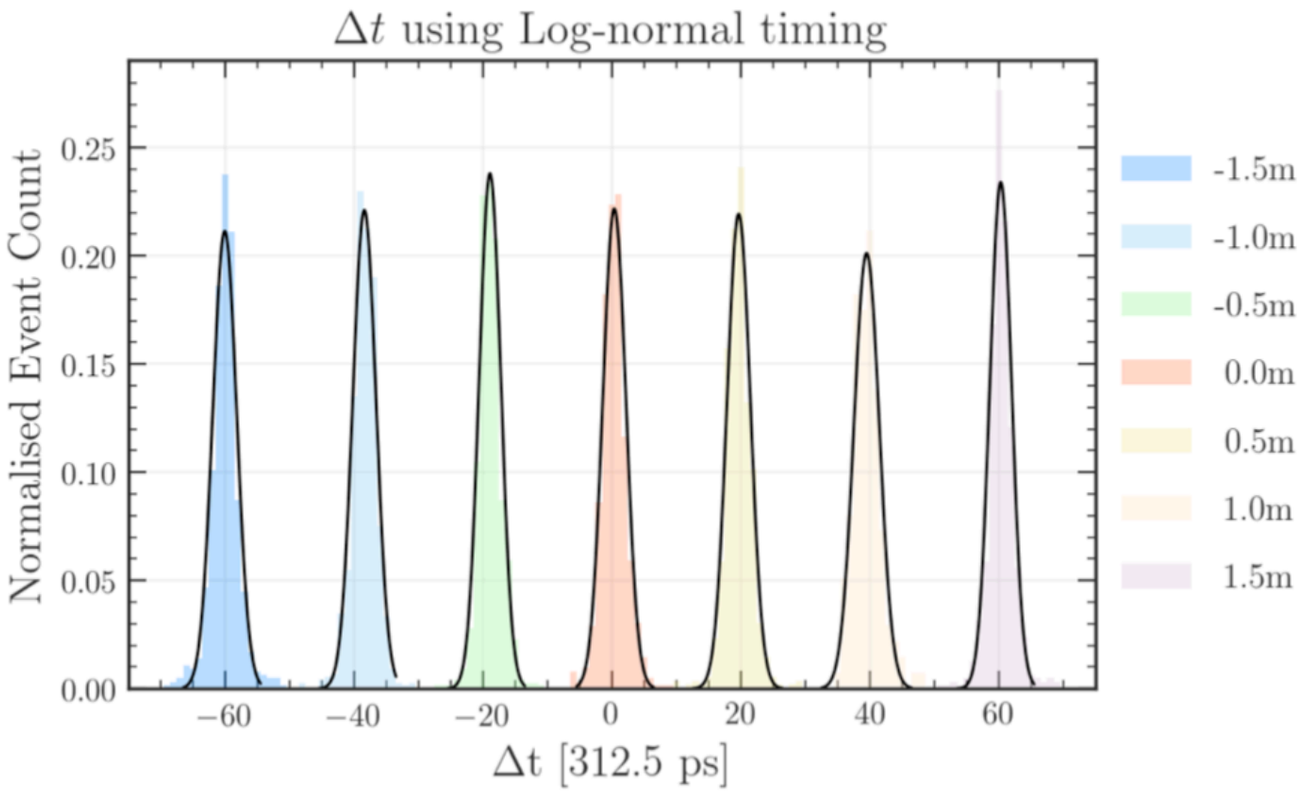


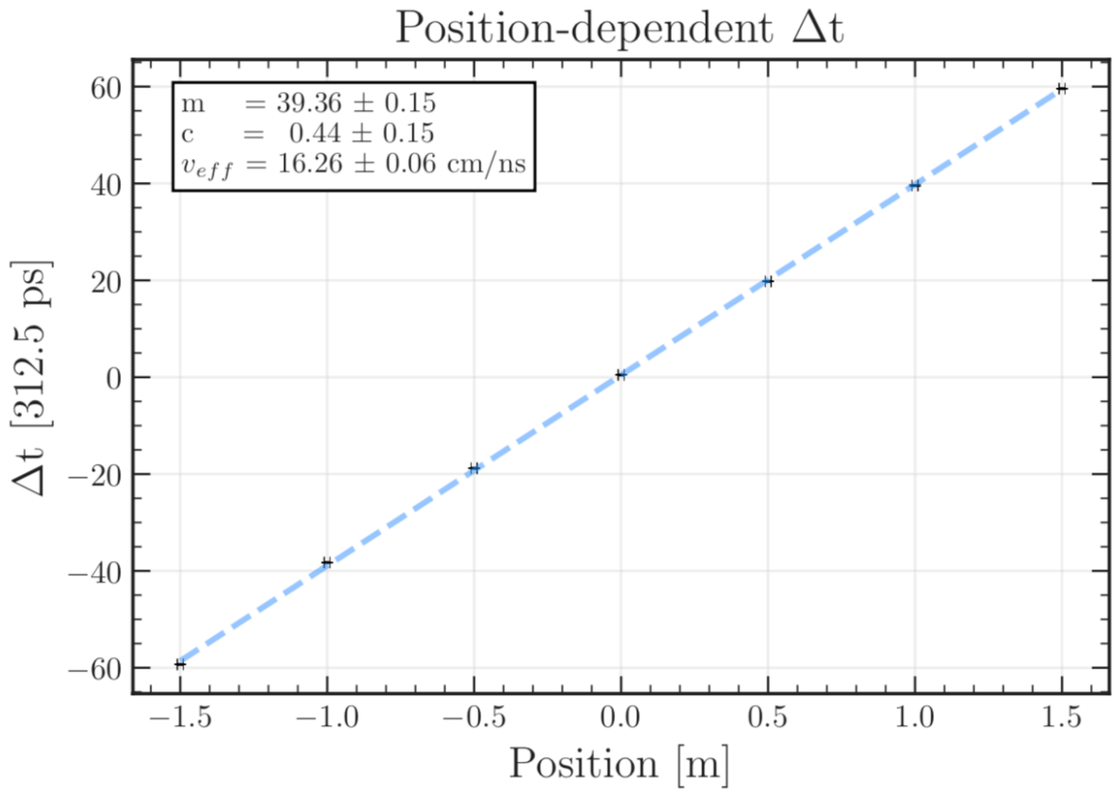
TASWELD

Muon veto system



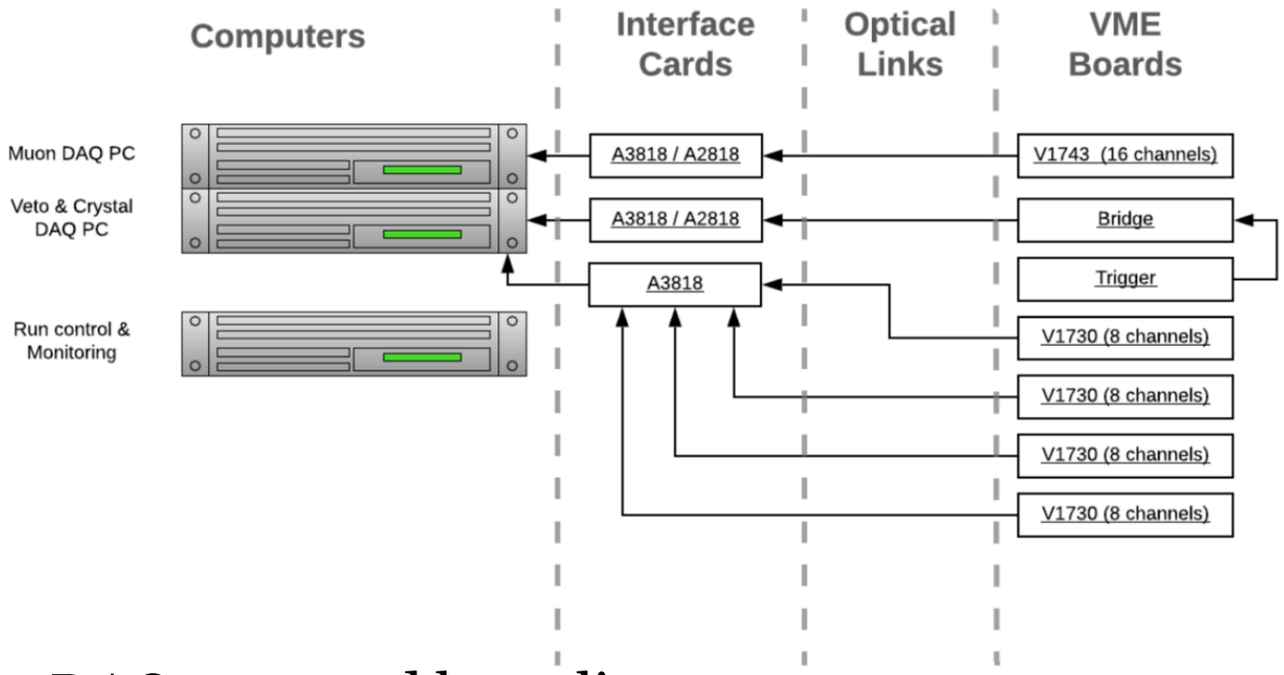
- Panels of EJ200 plastic scintillator (3 x 0.4 x 0.05 m) with PMTs at both ends. Readout @ 3.2 GS/s.
- Additional tagging of cosmic muons.
- Required for muon measurements at SUPL in combination with vessel veto.





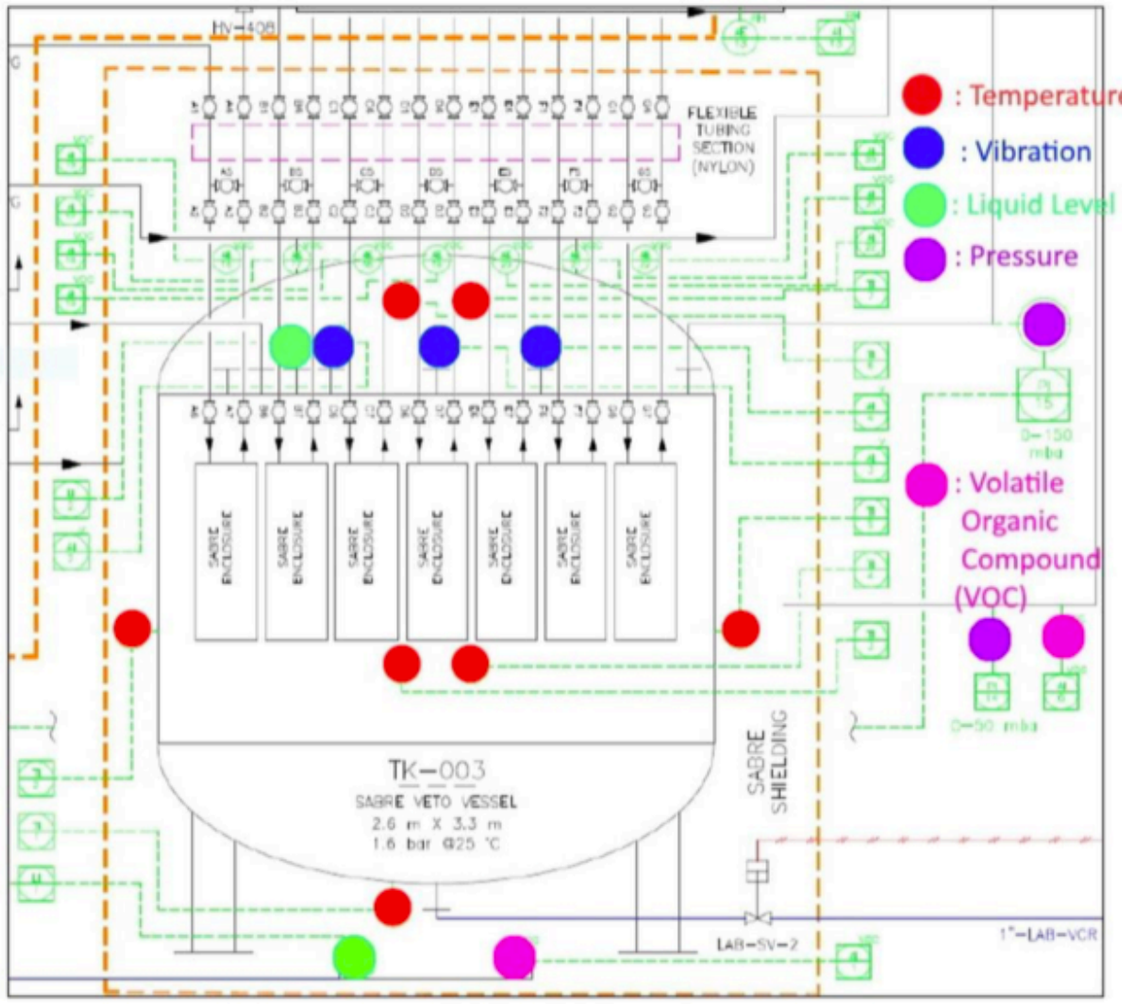
DAQ and conditions monitoring

DAQ



- DAQ managed by online systems.
- Each subdetector has dedicated digitisers with shared clock.
- Readout via fiber optics.
- External trigger board applies trigger logic for event triggers.
- Basic event building performed on-site before data transmission to Melbourne.

Conditions



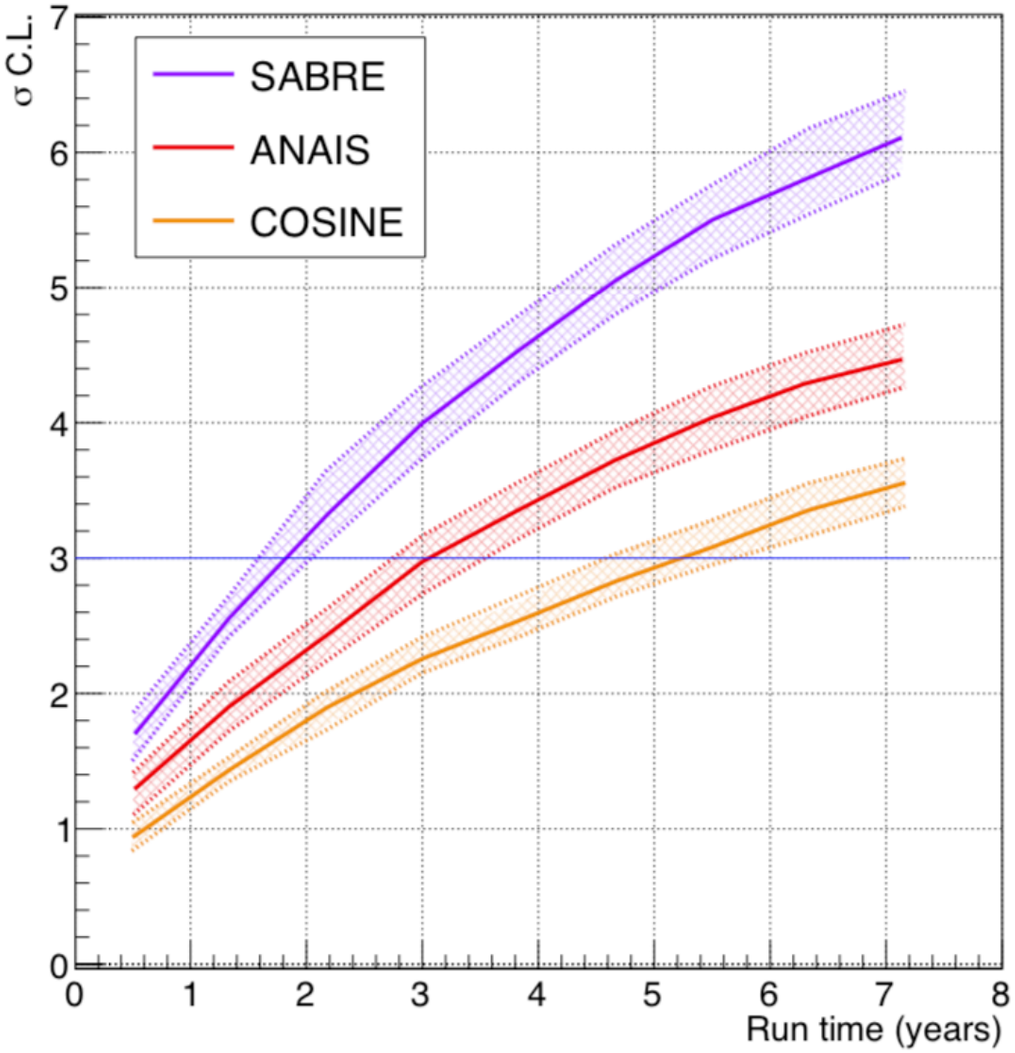
Monitoring: PMT HV, temperature of crystal units, humidity, Radon, vibrations.

S. Krishnan, et al. "A scalable and reconfigurable industrial-grade Slow Control System for SABRE-South Dark matter experiment." Journal of Instrumentation 16.03 (202 1): P03002.

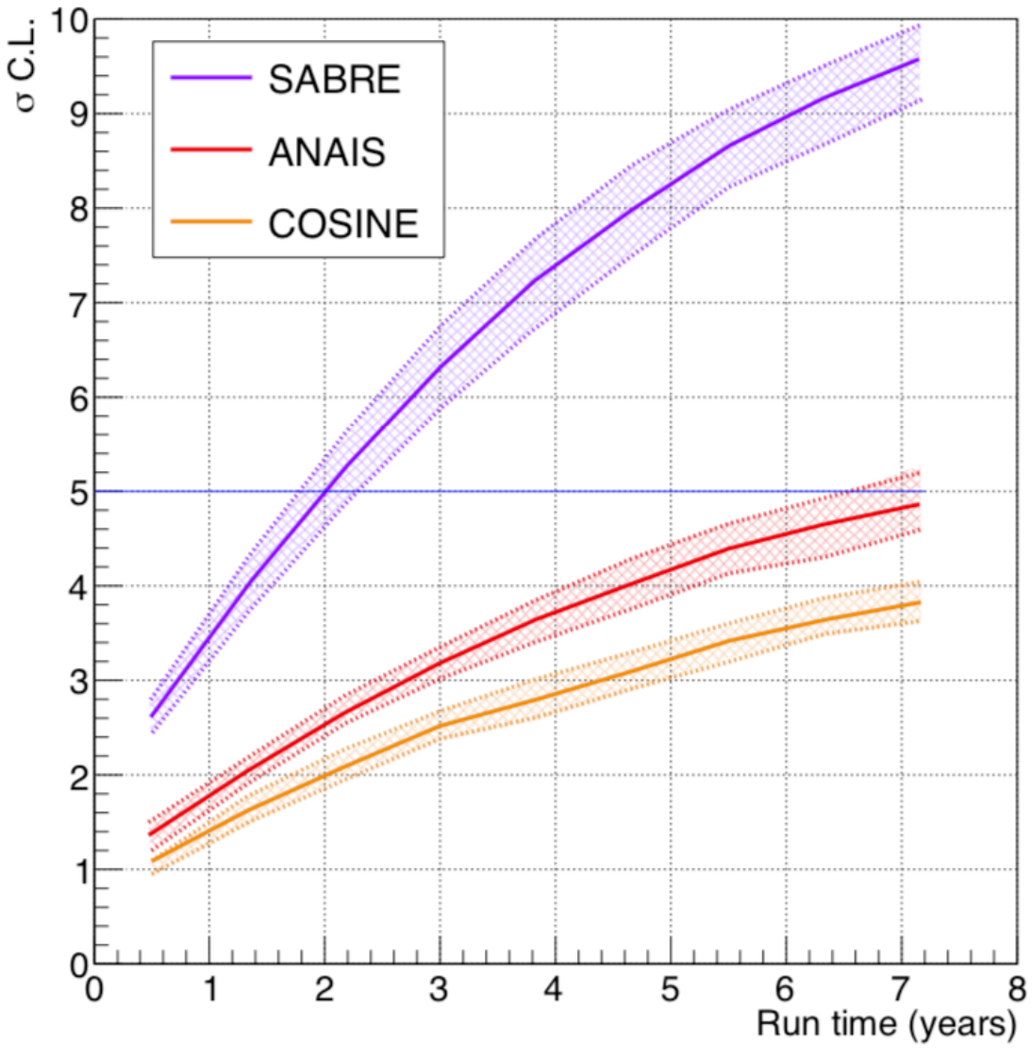
Expected sensitivity

- Sensitivity estimated using 50 kg NaI(Tl) and expected background rate of ~0.36 cpd/kg/keV [4].
- For a DAMA-like signal: 5 σ discovery in 2 years, 5 σ exclusion in 5 years [5].

Exclusion power



Discovery power



- [4] M. Antonello, et al. "Monte Carlo simulation of the SABRE PoP background." *Astroparticle Physics* 106 (2019): 1-9.
- [5] M. J. Zurowski, and E. Barberio. "Influence of NaI background and mass on testing the DAMA modulation." arXiv:2107.07674.

Conclusions

- SUPL construction is ongoing and expected to be completed in December 2021.
- SABRE South hosted at SUPL is expected to start running in early 2022.
- SABRE South should be able to confirm (exclude) a DAMA-like annual modulation signal at 5 σ within 2 (5) years since its start.

- Working toward publishing:
  - SABRE South background model based on simulation.
  - Photomultiplier characterisation methods and initial results.
  - Technical design report.

Backup

Expected sensitivity

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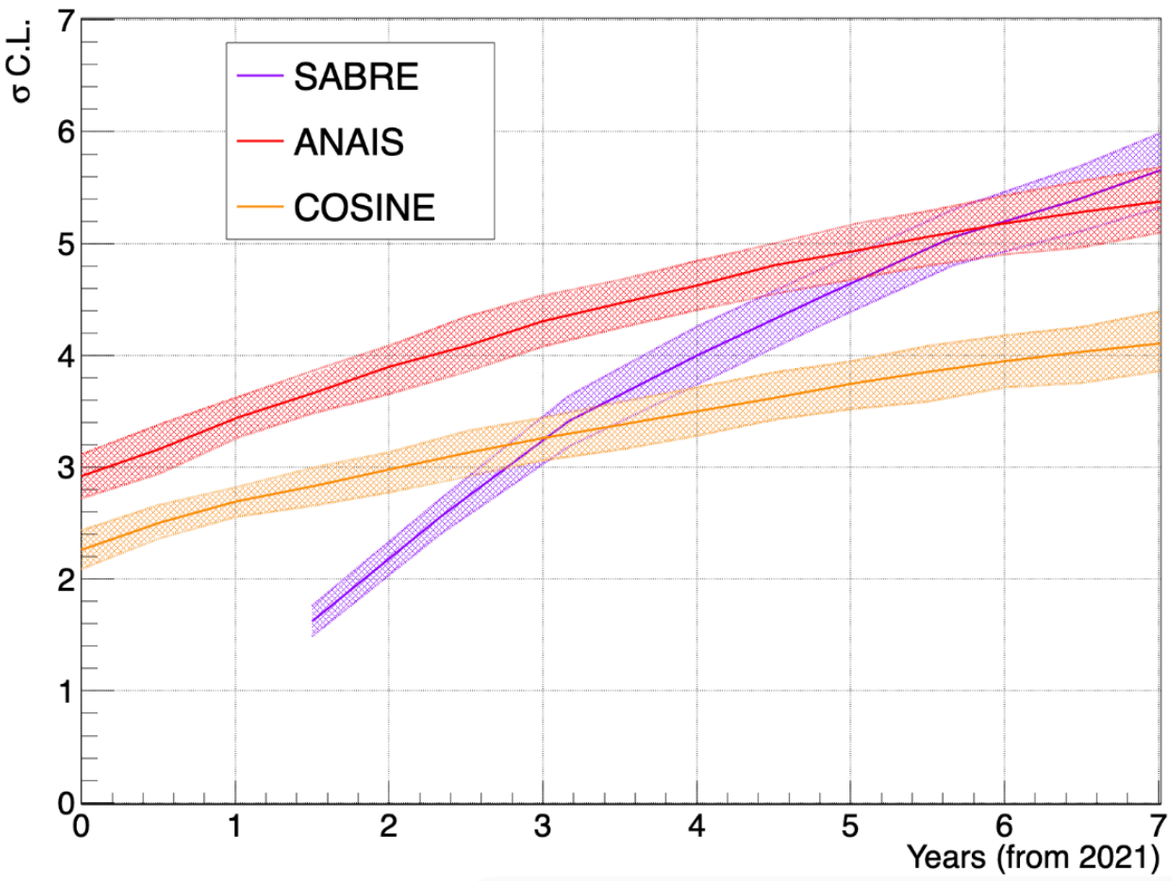
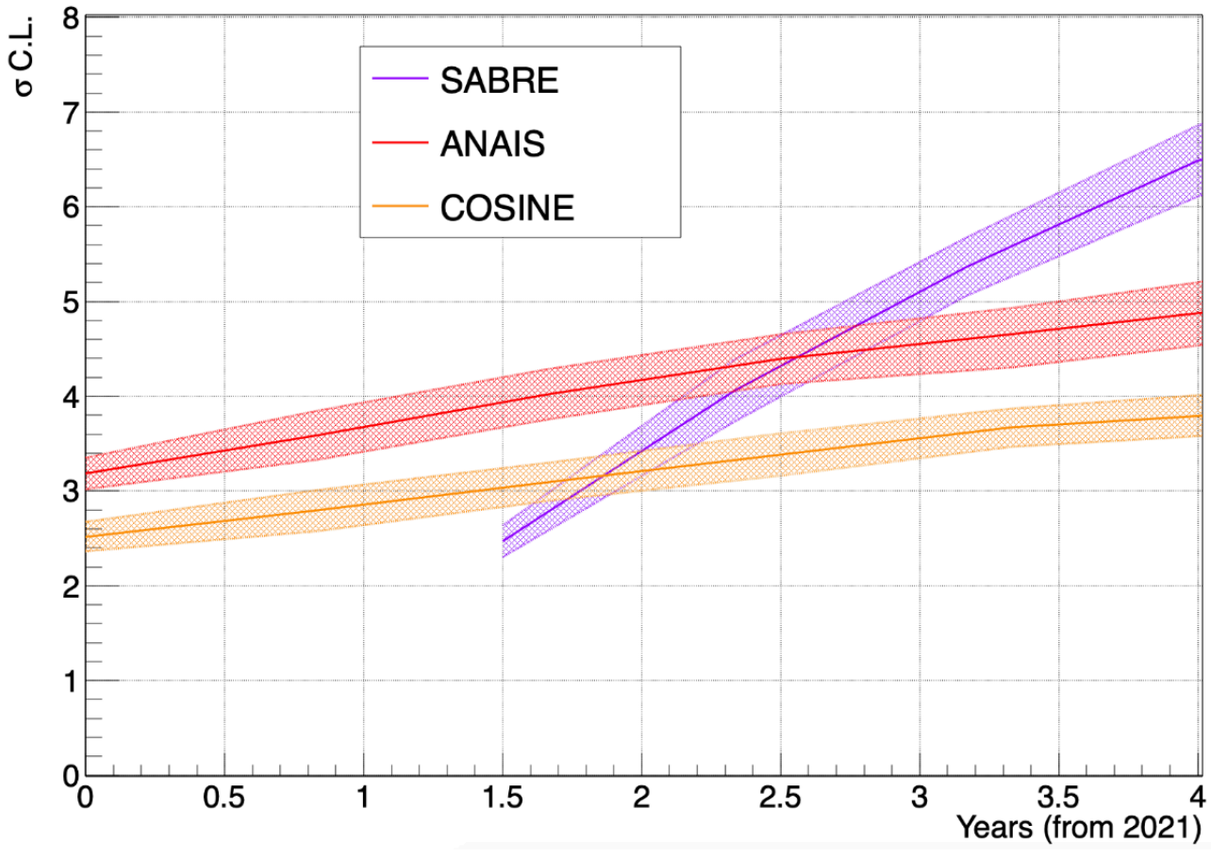
Exclusion power



Discovery power



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