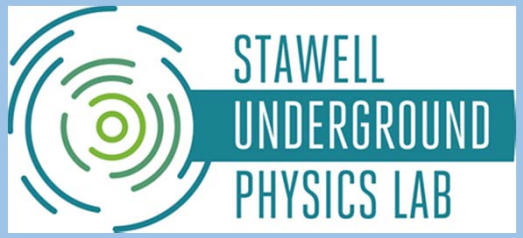
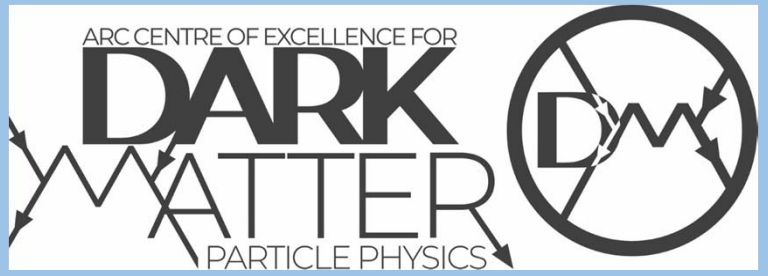
Update on the SABRE South Experiment

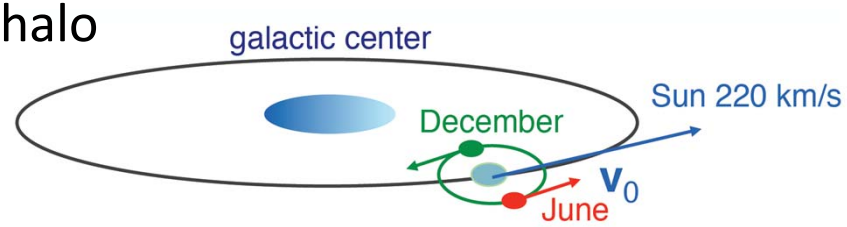
Gary C. Hill
University of Adelaide
for the SABRE South Collaboration



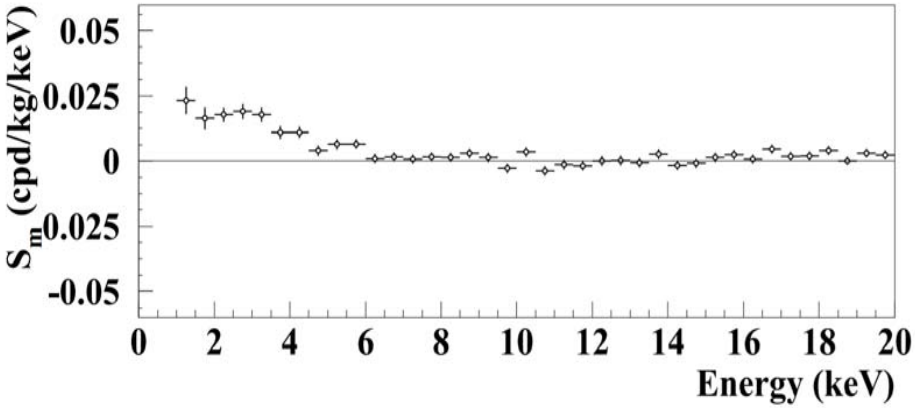


Motivation: Annual Modulation & DAMA/LIBRA

Unique model independent signal for dark matter caused by relative motion of the earth through galactic halo



$$R = R_0 + S_m \cdot \cos\left(\frac{2\pi(t - t_p)}{1\ yr}\right)$$

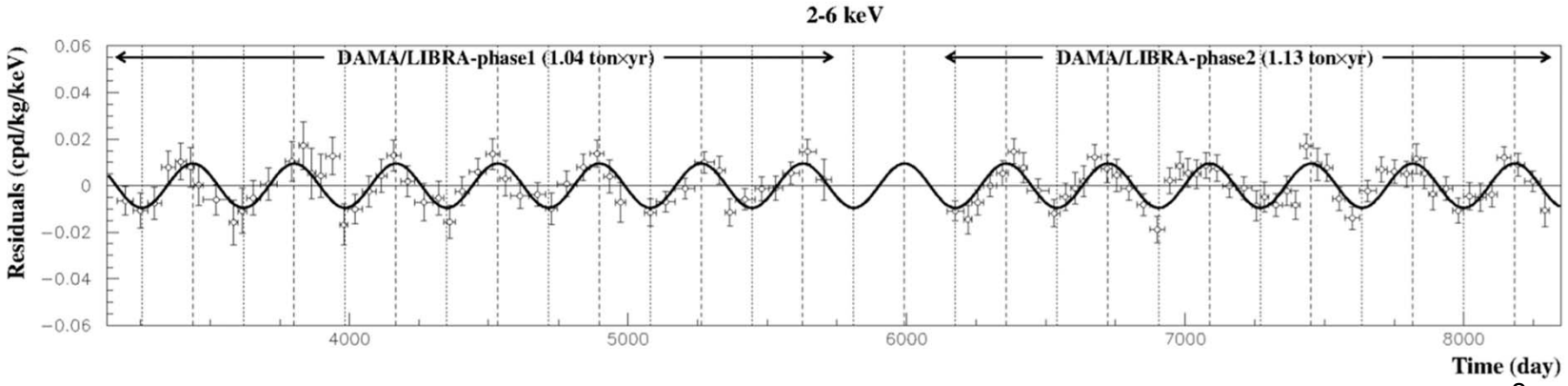


DAMA has a 20-year record of the modulation in the 2-6 keV energy range with combined significance of 12.9 σ

R. Bernabei, et al. "First model independent results from DAMA/LIBRA–phase2." *Universe* 4.11 (2018): 116.

Modulating Signal signatures:

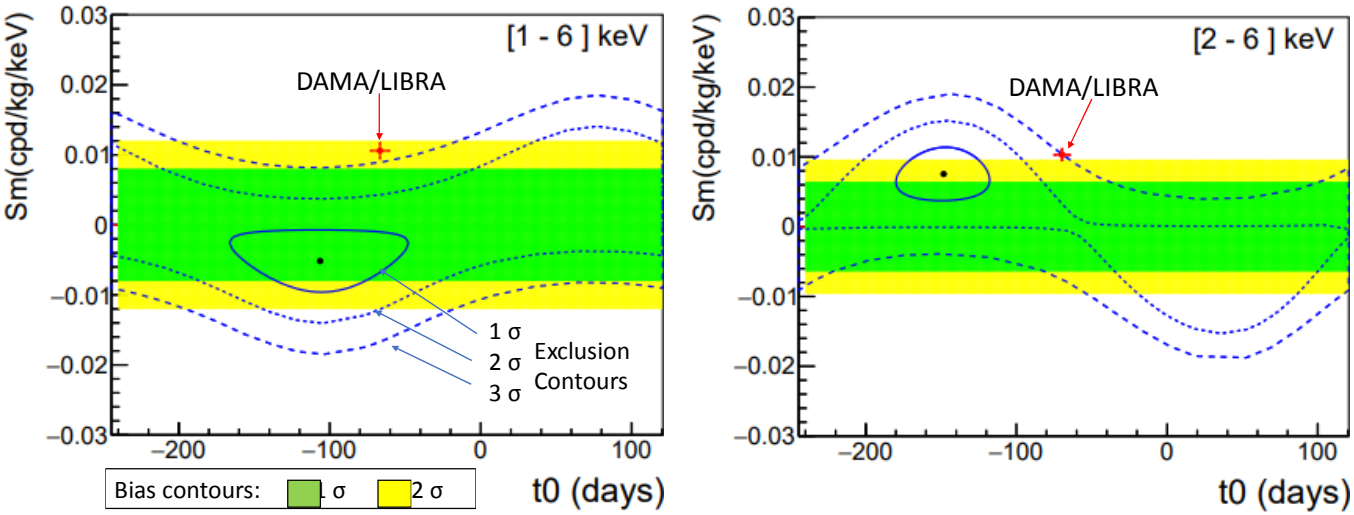
- Period of one year
- Peaks on June 2nd $t_p = 152.5\ days$
- $S_m/R_0 \approx 0.01 - 0.03$



Recent modulation results

ANAIS

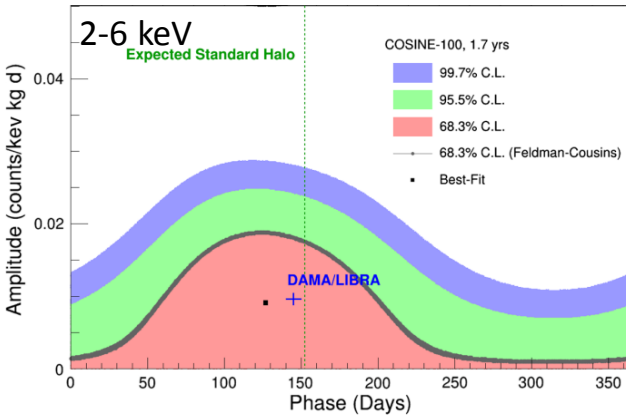
314 kg x yr exposure with no evidence of DAMA/LIBRA modulation at $\approx 3\ \sigma$ significance



J. Amaré, et al. "Annual modulation results from three-year exposure of ANAIS-112." *Physical Review D* 103.10 (2021): 102005.

COSINE-100

97.7 kg x yr exposure compatible with the DAMA/LIBRA result



G. Adhikari, et al. "Search for a dark matter-induced annual modulation signal in NaI (Tl) with the COSINE-100 experiment." *Physical review letters* 123.3 (2019): 031302.

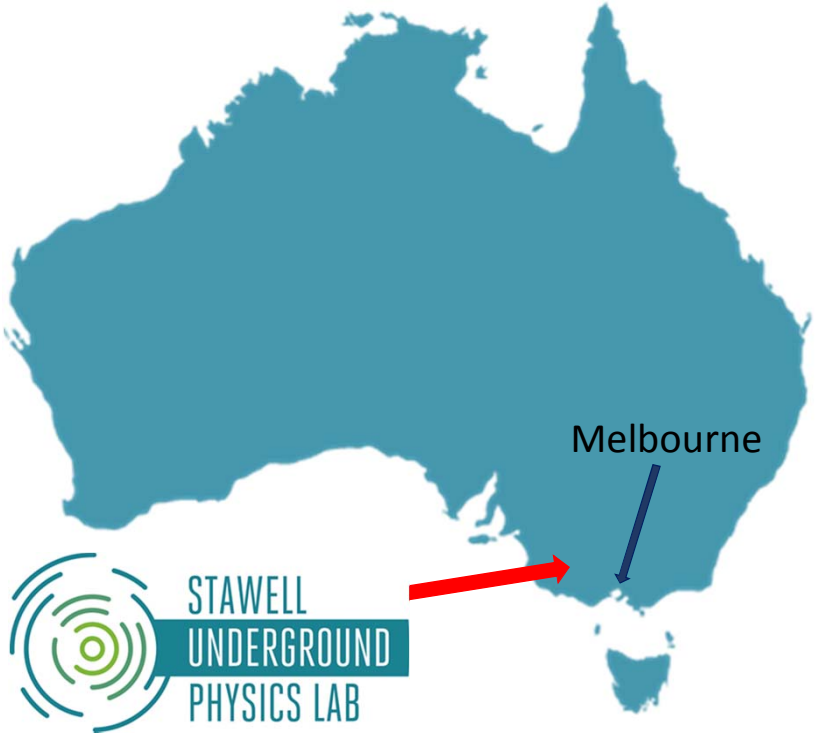
Current results inconclusive. Southern Hemisphere detector with similar sensitivity to DAMA important for replication effort

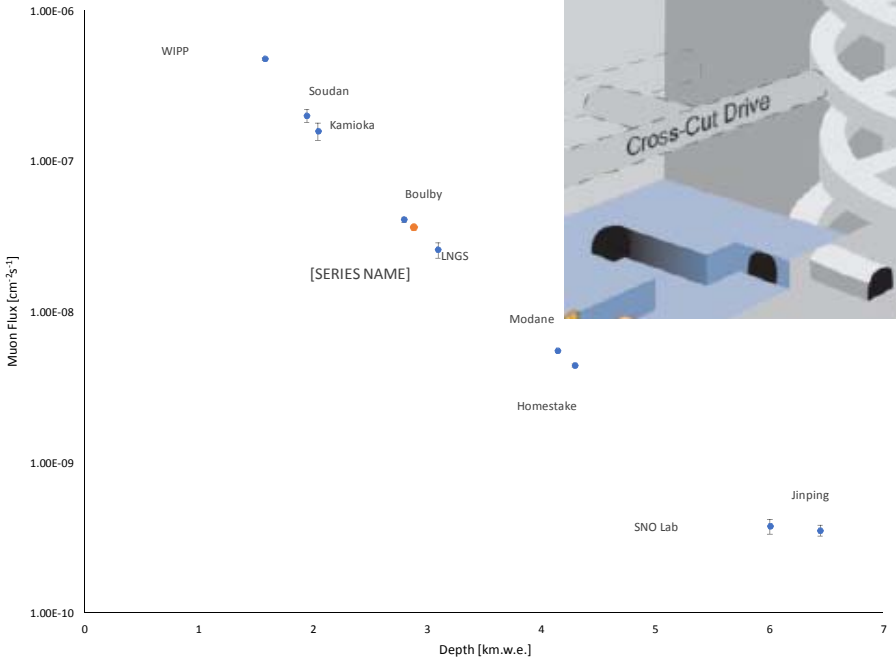
Stawell Underground Physics Laboratory

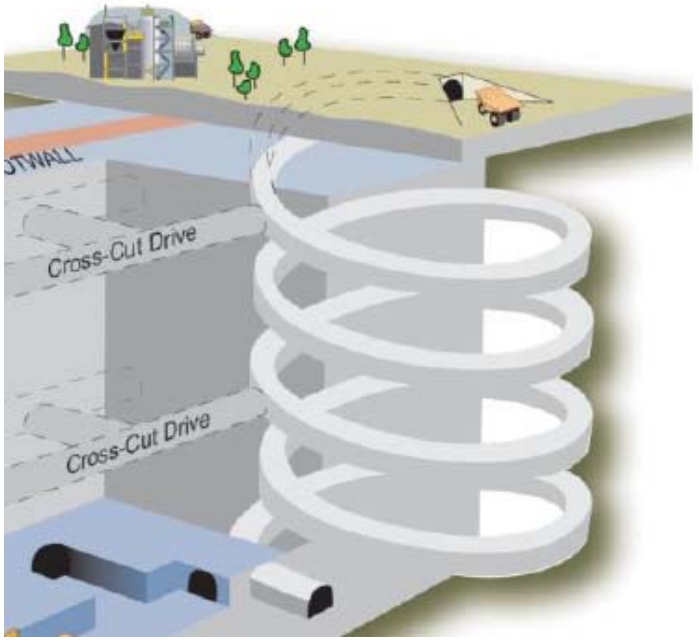
Located in active gold mine – Stawell Gold Mine in Victoria, 240 km North West of Melbourne.

Lab is 1024 m below ground with flat over burden.
Access via Helical shaft from surface.

Main cavern operated as radon suppressed clean room.

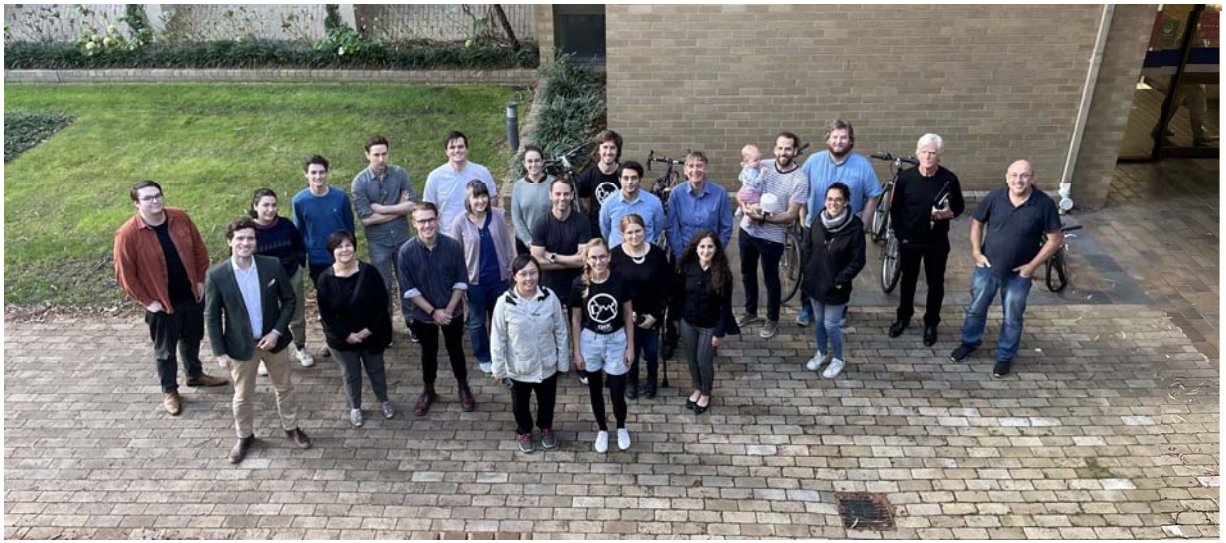






SABRE South Collaboration

46 Members across 5 institutions



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

SABRE Organisation

Speakers Committee

Chair: Michaela Froelich

Publications Committee

Chair: Gary Hill

Outreach and Inclusion Committee

Chairs: P. McGee, Y. Zhong

Management

Spokesperson: Elisabetta Barberio

Technical Coordinator: Phillip Urquijo

SUPL Liaison

Geoffrey Taylor

Financial Board

Chair: Andrew Stuchbery

Safety

Chair: Geoffrey Brooks

Physics

Convenor: Francesco Nuti

Software & Offline Computing

Convenor: Federico Scutti

Trigger and DAQ

Convenor: Matthew Gerathy

Veto Systems

Convenor: Lindsey Bignell

NaI(Tl)

Convenor: Zuzana Slavkovska

Engineering and slow control

Convenor: Tiziano Baroncelli

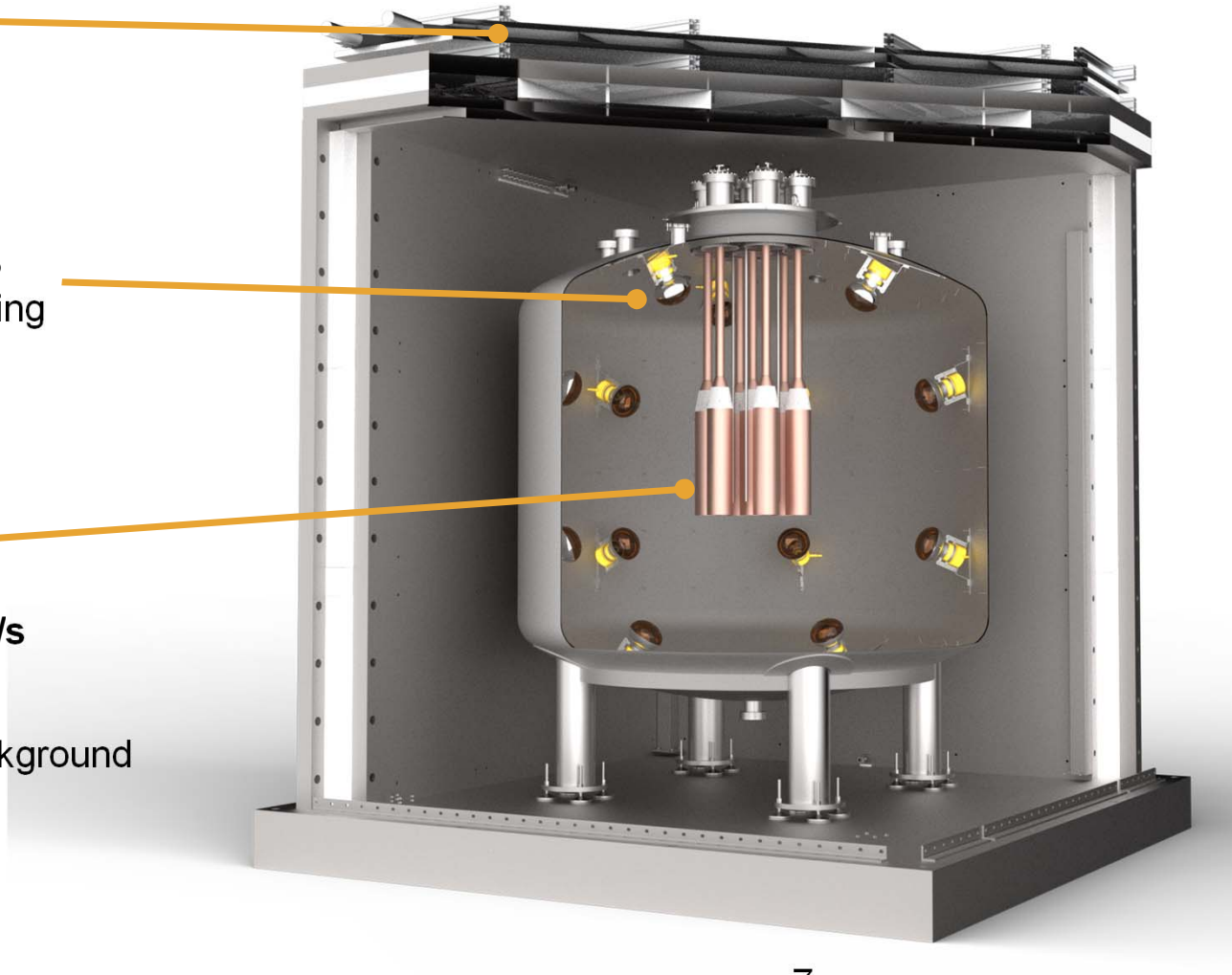
SABRE South in SUPL

- **ToF Muon System**
  9.6 m^2 x 5 cm EJ200
  R13089 PMT x 16 @ 3.2 GS/s

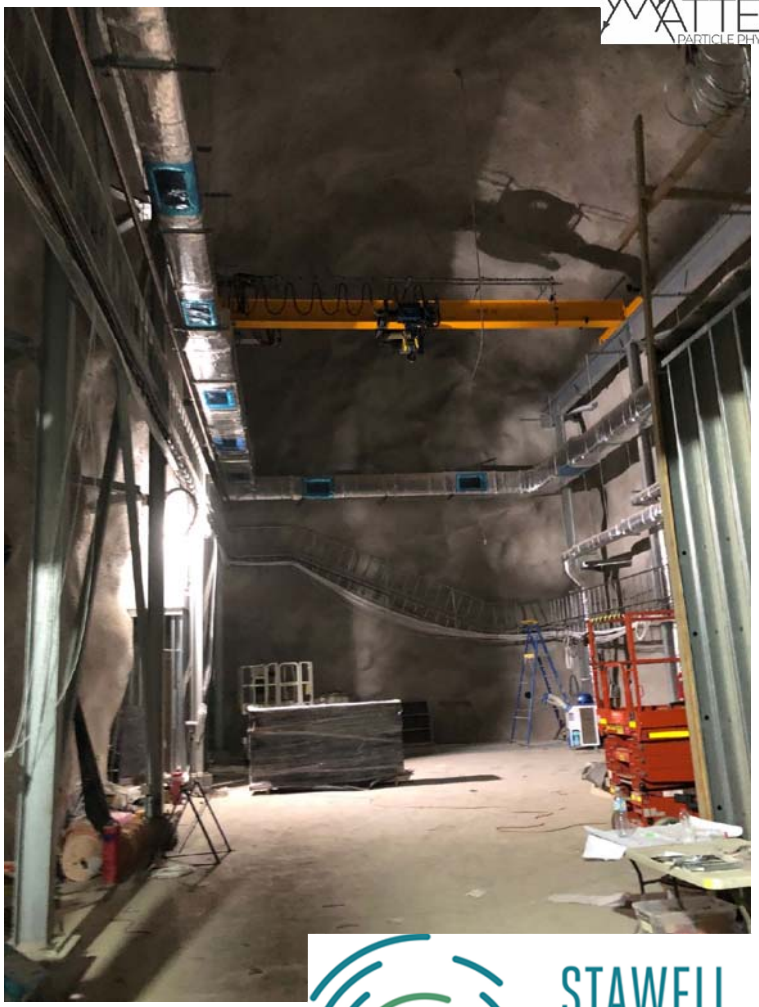
- **Veto System**
  12k litres Linear Alkyl Benzene + PPO & Bis-MSB
  Stainless steel, non-thoriated welds, lumirror coating
  Oil-proof base R5912 PMT x 18 @ 500 MS/s

- **DM Target Detector**
  NaI(Tl) Crystals
  R11065 low radioactivity PMT x ~14 @ 500 MS/s

- Key requirement to understand modulation in background contributions - requires particle ID. e.g. **μ**/γ/n.



SUPL

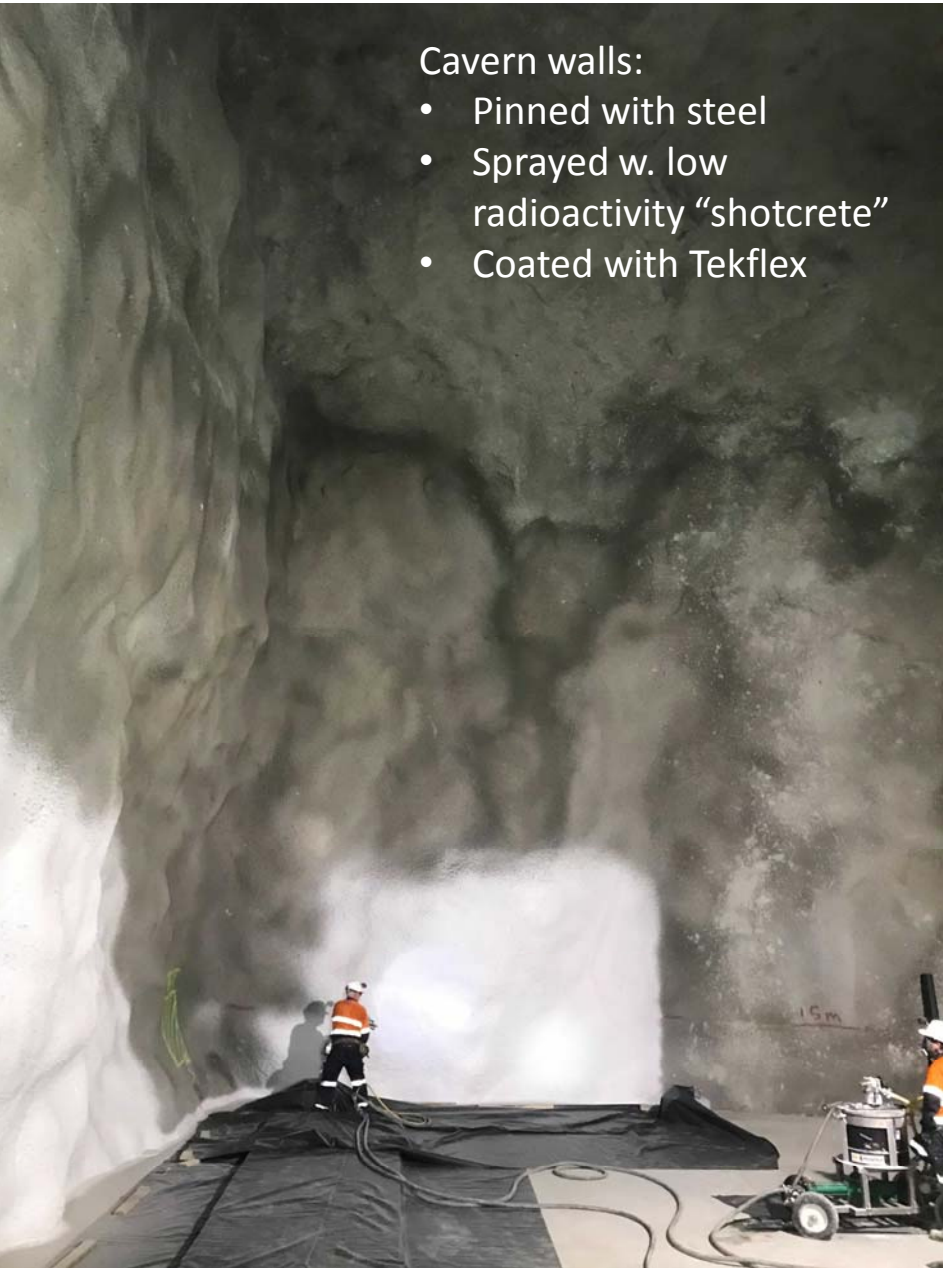


ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

STAWELL UNDERGROUND PHYSICS LAB

SUPL


HPGe Counting Facilities
SABRE South Experiment
Loading Bay
Experimental Hall (10x30 m)
min. height 12m
Entry Way
Cleaning Facilities
Rest Areas
STAWELL UNDERGROUND PHYSICS LAB
SABRE SOUTH DRAINAGE TANK (20-FT ISO CONTAINER)
SABRE SOUTH EXPERIMENT
RS - MAIN ACCESS PLATFORM
RS - SECONDARY ACCESS PLATFORM
FUTURE CLEAN
FUTURE CLEAN LAB AREA
GAS STORE
PLANT FLOOR OPENING ABOVE
PIPEWELL (UNDERSIDE)



Status of SUPL

Cavern excavated in June.

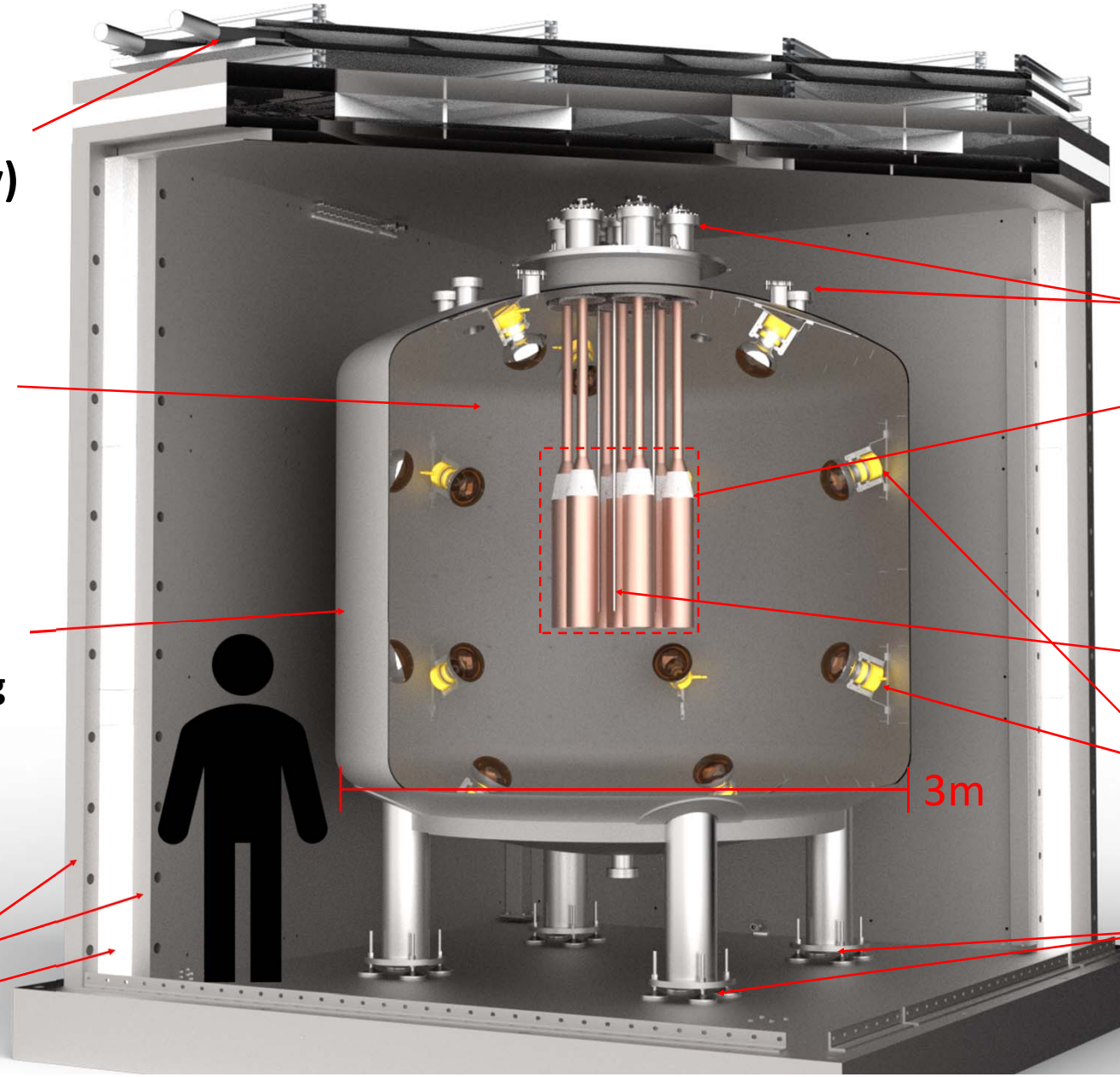
All construction materials are being screened for radioactivity with NaI(Tl) counting.

Ontrack for construction completion December 2021.

SABRE South construction and commissioning in early 2022.

Post construction background measurements:

- Muons – muon veto panels in telescope orientation
- Gamma spectrometer
- Neutrons – series of Bonner spheres & ^{3}He detector



Muon Veto
(9.6 m² array)

12,000 L
LAB with
PPO & Bis-MSB

Veto Vessel
Stainless-Steel
Lumirror coating

External Shielding
Steel
Polyethylene

Access Flanges:

Crystal Array:
- NaI(Tl) crystal
- 2x 3” R11065 Hamamatsu PMTs

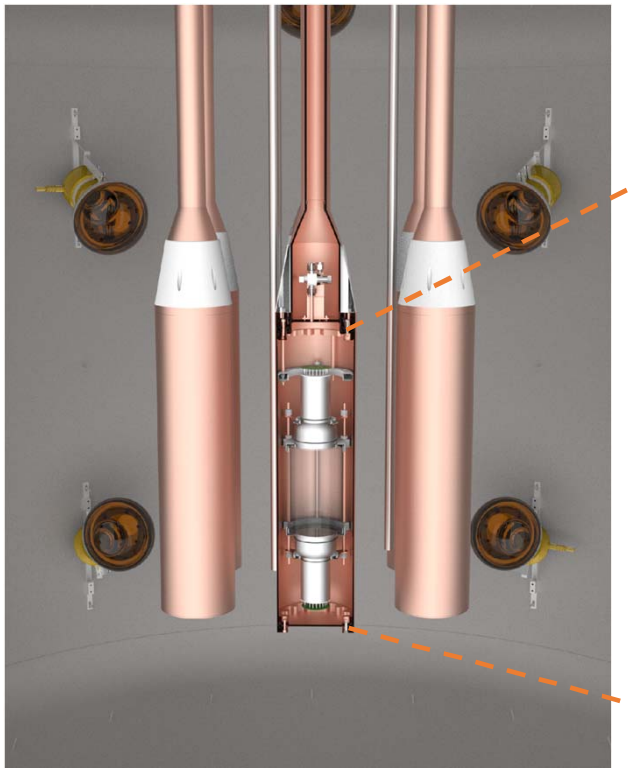
Calibration Sources

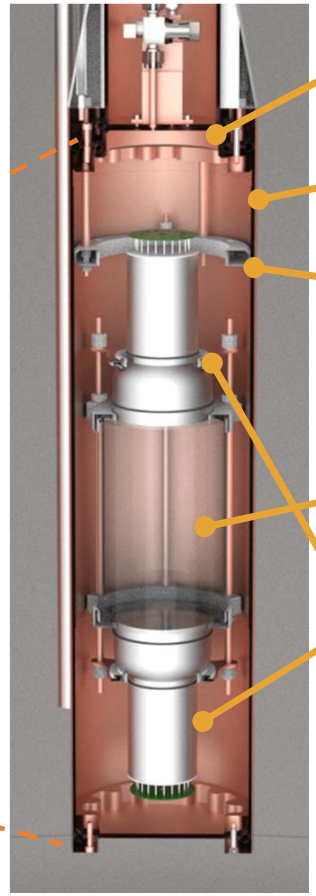
Veto PMTs
18xHamamatsu R5912

Passive Damping System

NaI(Tl) Detectors

Array of 7 NaI(Tl) detectors immersed in the liquid veto.
Minimal material between crystal and liquid scintillator.
Purged with high purity dry N_2.





Feedthrough Plate (gas & electrical)

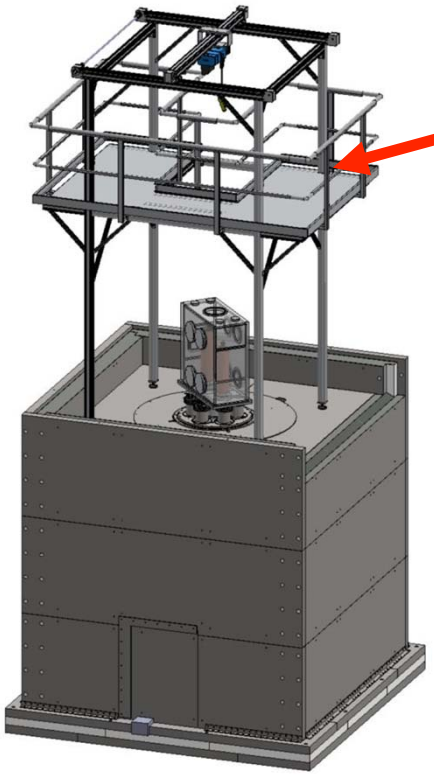
OFHC Copper Enclosure
- 3 mm wall thickness
- Internal Teflon structure

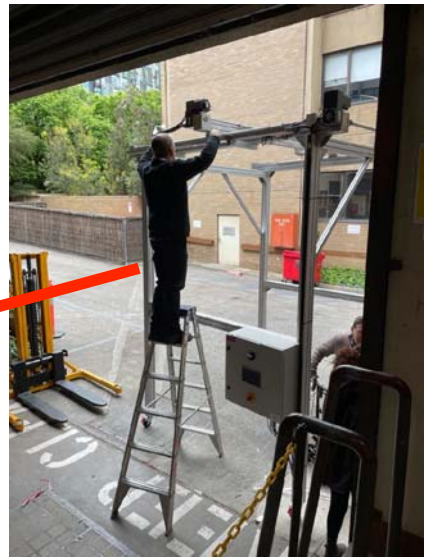
~**7** kg NaI(Tl) Crystal
- L.Y. ~ 10 PE/keV

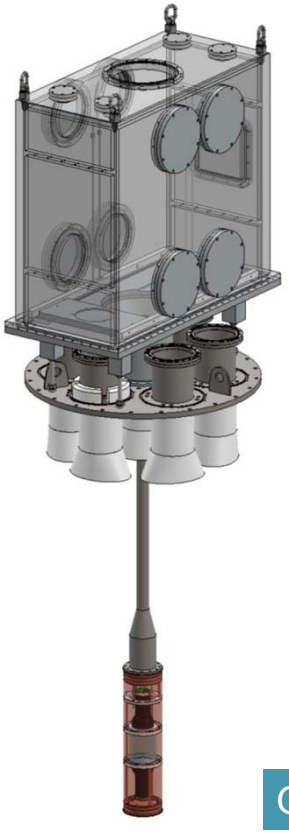
3”Hamamatsu R11065 PMT:
- Low background metal body
- QE >30% at 420 nm
- Readout at 500 MS/s with CAEN V1730.
- Threshold ~0.3 SPE peak

Crystal Insertion System

- Three procedures for CIS: insertion, extraction, substitution of crystals.

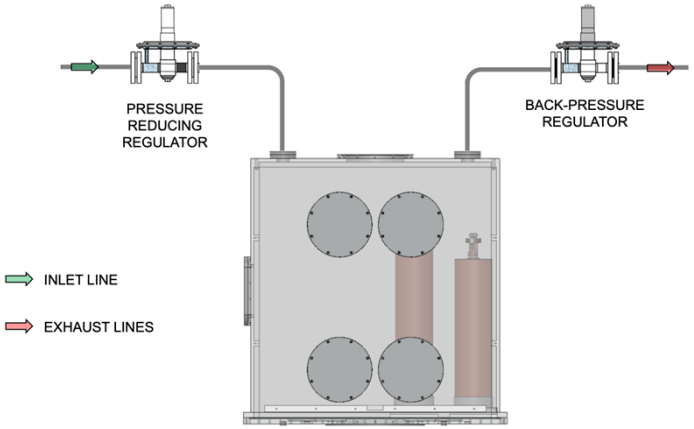






SABRE

- Basic GB fluid handling design:



GB built by Palazzi SRL (Italy). CIS Crain at UniMelb.

Low Background NaI(Tl)

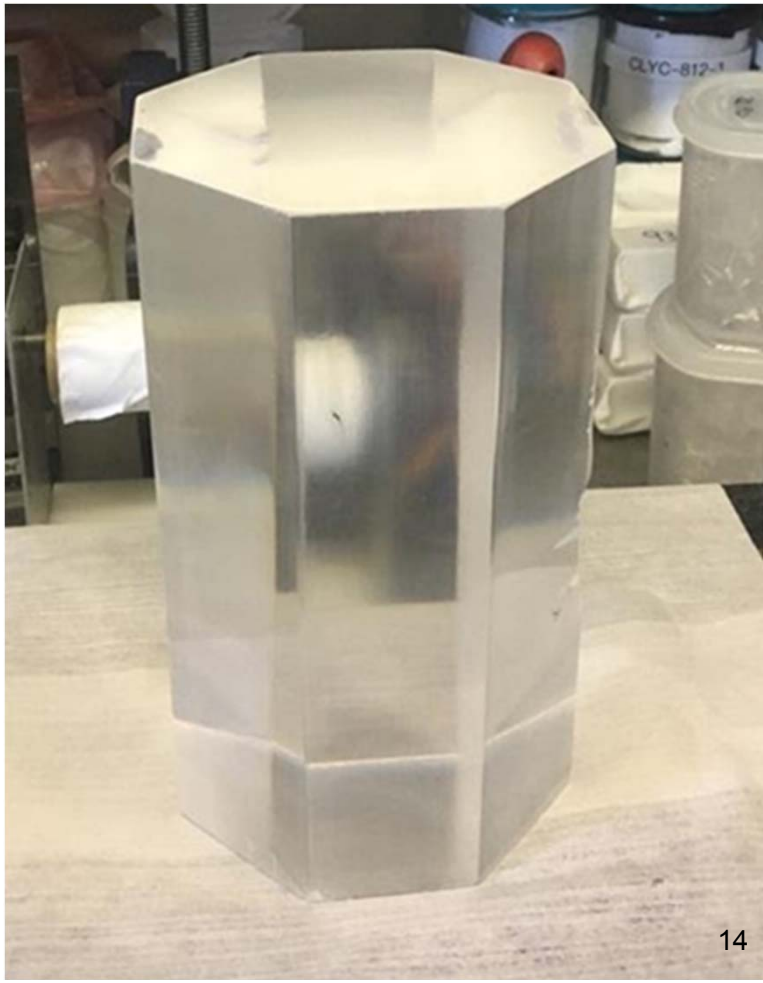
1. The SABRE Collaboration has successfully grown very low background NaI(Tl) crystals [1].

For more details see A. Mariani "Characterisation of an ultra-high purity NaI(Tl) crystal scintillator with the SABRE Proof-of-Principle detector"

2. SABRE South test crystal (new) – 5 kg grown by RMD using Bridgman-Stockbarger process developed with SABRE.
ICPMS measured K: tip 5 ppb, bulk <10 ppb.
Currently being prepared for counting at LNGS.

	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

Ongoing: AMS measurements of ^{210}Pb content in Astro-Grade NaI powder at ANU



[1] – M. Antonello, et al.," Characterization of SABRE crystal NaI-33 with direct underground counting." *Eur. Phys. J. C* 81, 299 (2021)
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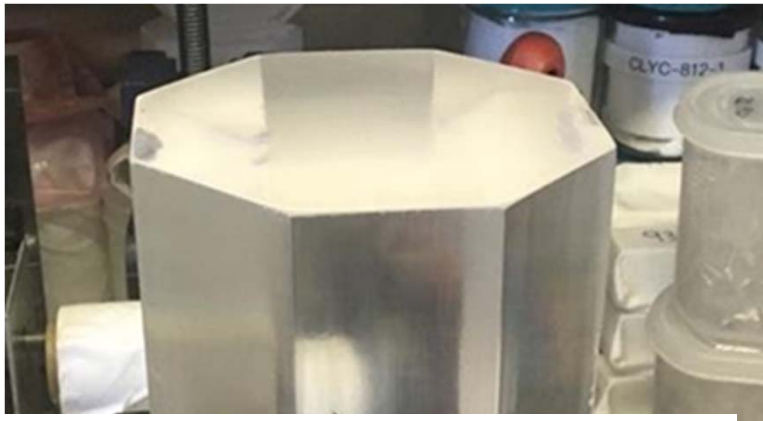

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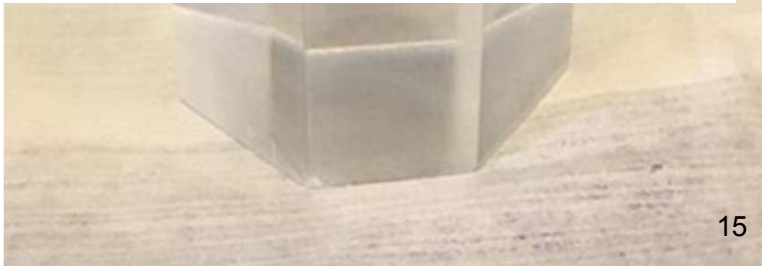
DAMA [2]	13	<10
COSINE-100 [3]	17.8	<20

- In discussion with SICCAS on their capabilities:
- they are preparing to grow the largest NaI crystal they can
- they have ability to grow all crystals simultaneously
- We aim to measure the background and light yield of a SICCAS crystal at SUPL in the new year

Ongoing: AMS measurements of ^{210}Pb content in Astro-Grade NaI powder at ANU



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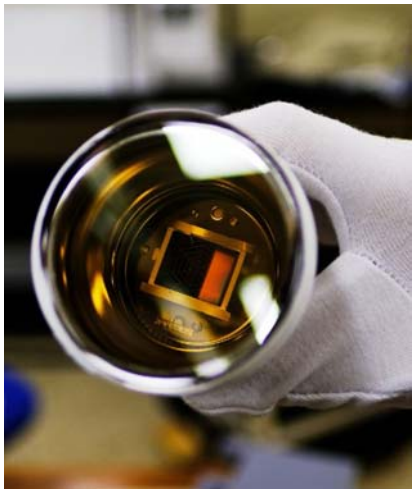
PMTs



R11065 Crystal PMTs
3” head-on
Metal body
Low radioactivity
High quantum efficiency
(QE>30% requirement)

R5912 Veto PMTs
8” hand blown glass body
Large acceptance
Oil-proof base (Resin filled Acrylic)

+ μ System PMTs

For 1keV threshold in NaI(Tl) detectors require

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

- Measurement of all PMTs:
  - Quantum Efficiencies, photocathode surface scans, Dark current and dark rate (ML suppression algorithm training), Gain, Temperature dependence, spontaneous light emission in bases, after-pulses, transit time spread.
- Testing facility at UniMelb.
  - Picosecond pulsed light source, W-Halogen lamps + grating, reference PD, thermal chamber, trigger PMTs, CAEN readout.
- Parallel studies
  - HV Polarity and pre-amplification and early dynode readout for dynamic range, location of splitters, cable noise studies.
  - Noise rejection tools & ER/NR classifiers.

R11065 delivered to UniMelb. R5912 in production. μ System PMTs installed.

Active Veto System

Veto system provides 4π coverage

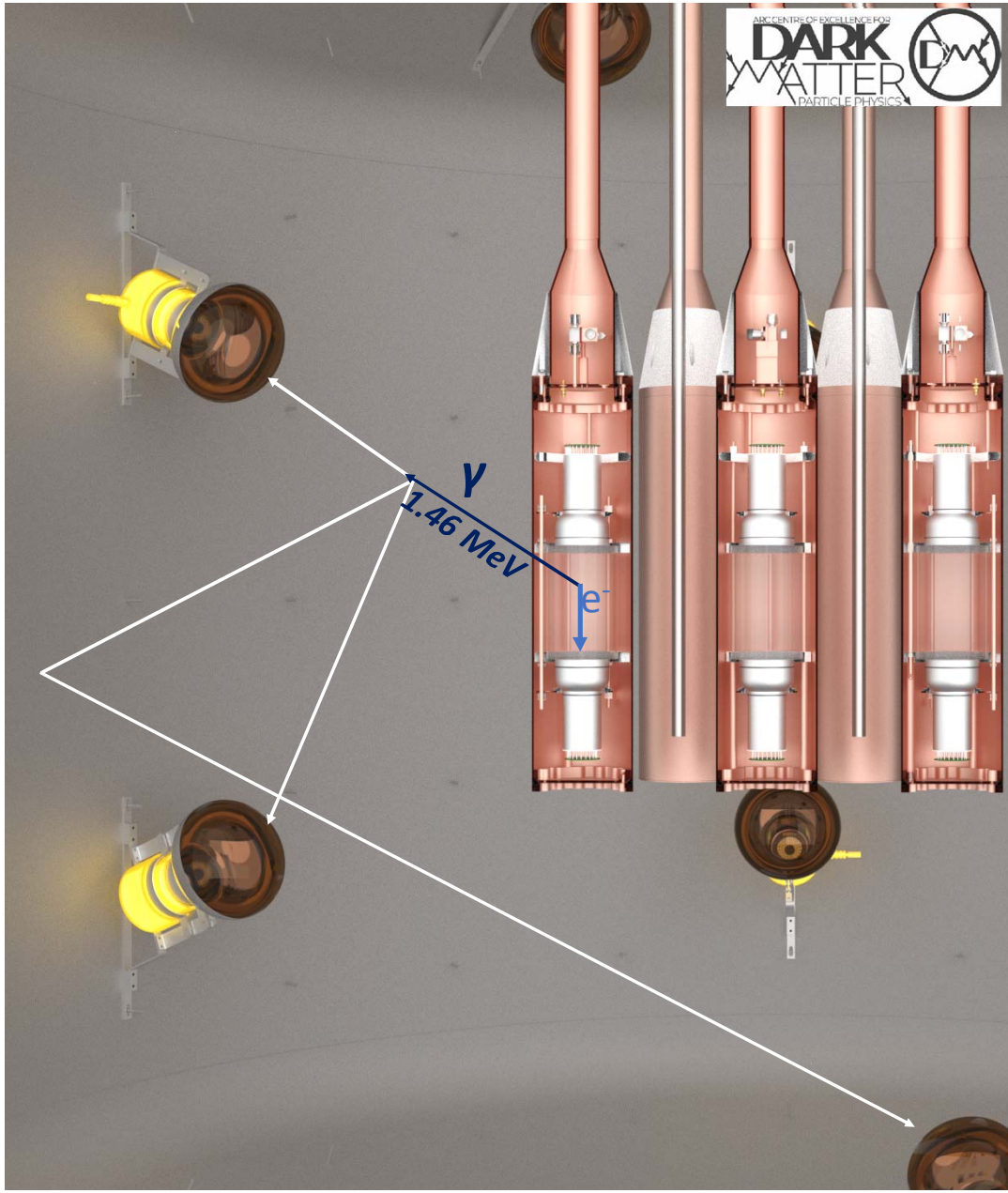
Liquid veto:

- 12,000 L of Linear Alkyl-Benzene (LAB) doped with PPO and Bis-MSB
- 18 Hamamatsu R5912 PMTs with oil-proof base. Readout at 500 MS/s (CAEN V1730)

The active veto is designed to:

- Veto potassium-40 decays in NaI(Tl) with 85% efficiency.
- Be sensitive to >100 keV energy deposition

This reduces the background by a factor of 10.



Liquid Scintillator

17,000 litres LAB scintillator base from Nanjing via JUNO/IHEP.

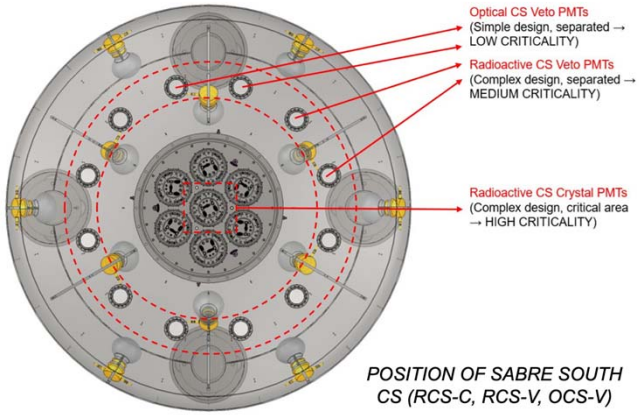
JUNO LS properties [6]

- Photon attenuation > 20 m
- $^{238}U/^{232}Th/^{40}K < 10^{-17}$ g/g

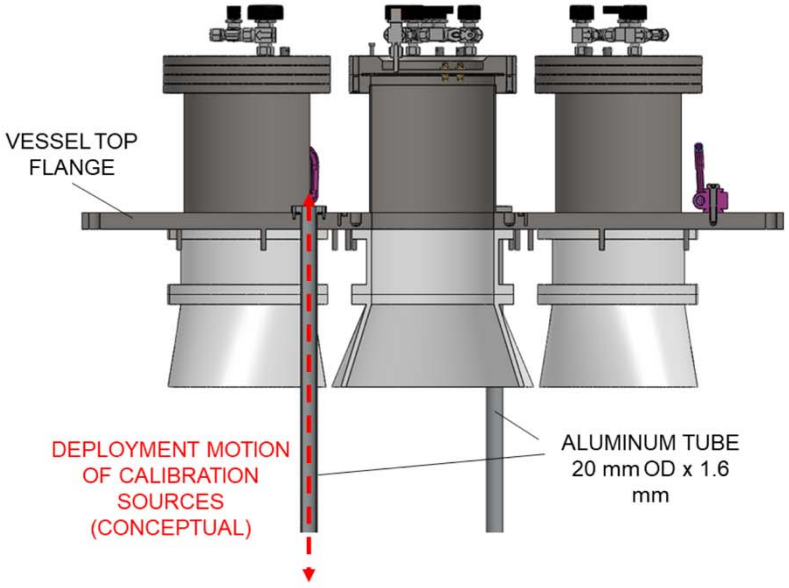
[6] – A. Abusleme, et al. "JUNO Physics and Detector." *arXiv:2104.02565* (2021).

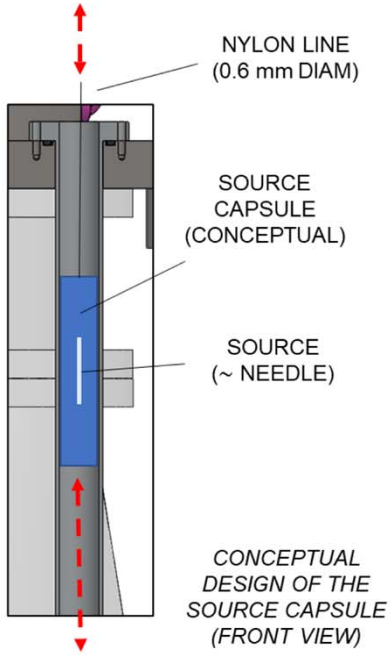
Calibration systems

- Source based system designed for NaI(Tl) and LAB detectors.
  - Calibration method has been simulated.
- Optical system under design.
  - Based on picosecond laser, optical fibre, diffuser. Similar to that used in UniMelb test-bench.

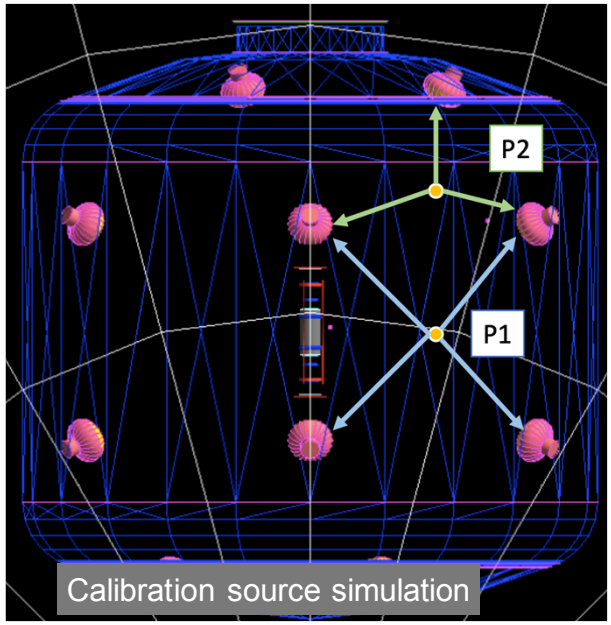


POSITION OF SABRE SOUTH CS (RCS-C, RCS-V, OCS-V)

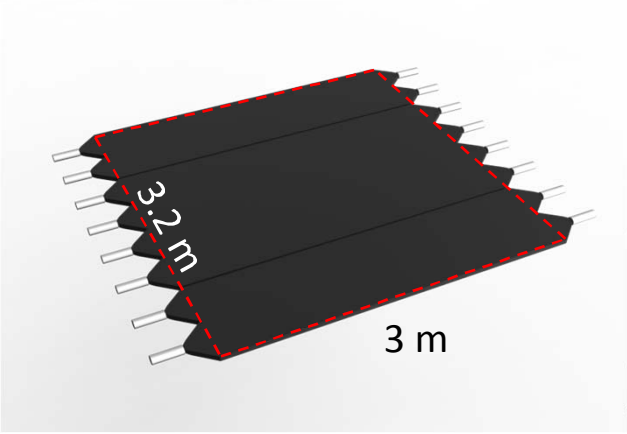




CONCEPTUAL DESIGN OF THE SOURCE CAPSULE (FRONT VIEW)



Muon Veto System

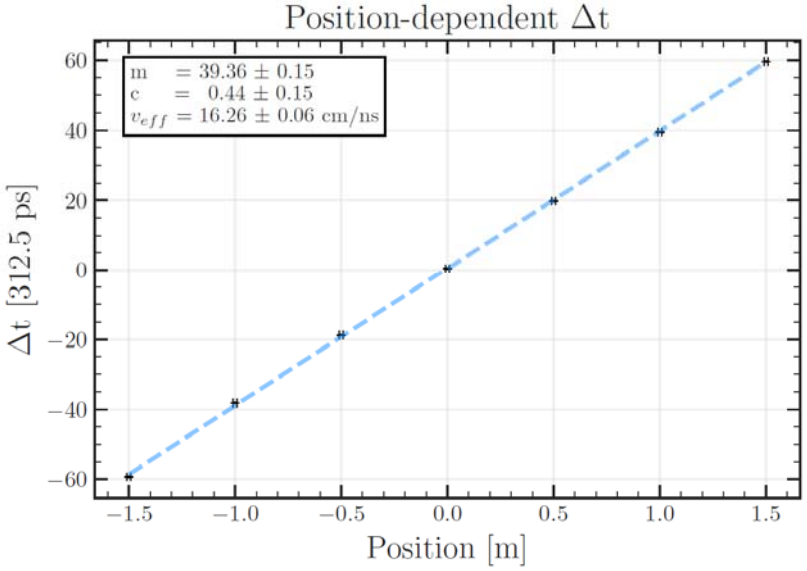


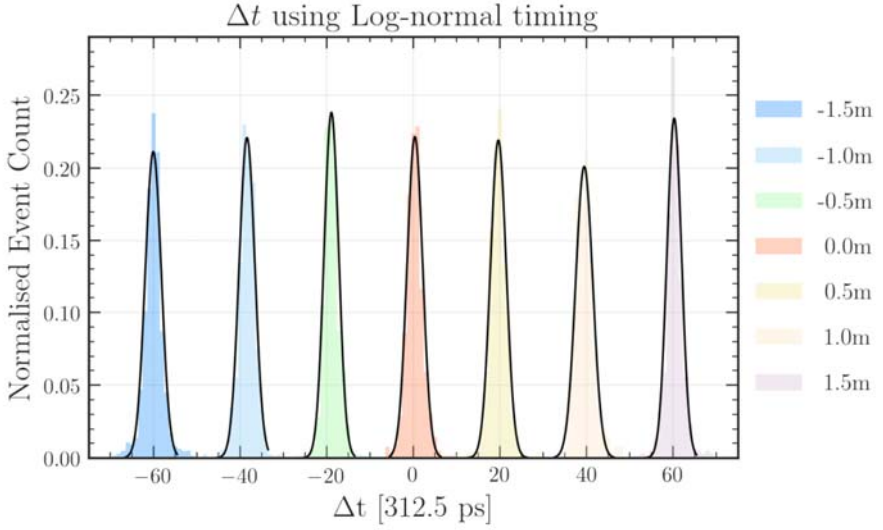
Provides additional tagging of cosmic muons.

Required for measurements of muon modulation at SUPL (in combination with the veto vessel)

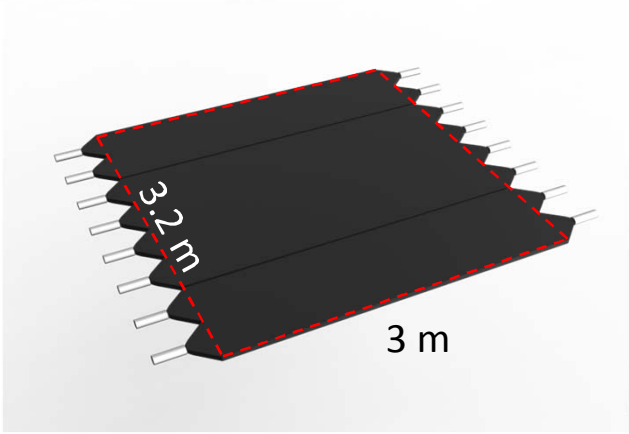
8 x EJ200 organic scintillator panels (3x0.4x0.05 m) with PMTs at opposite ends.

Readout at 3.2 GS/s which gives longitudinal position resolution of 5 cm.





Muon Veto System



Prov

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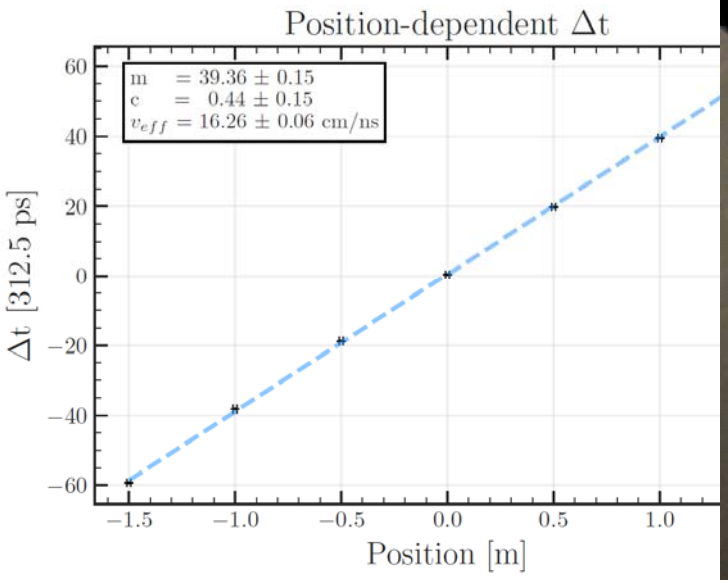
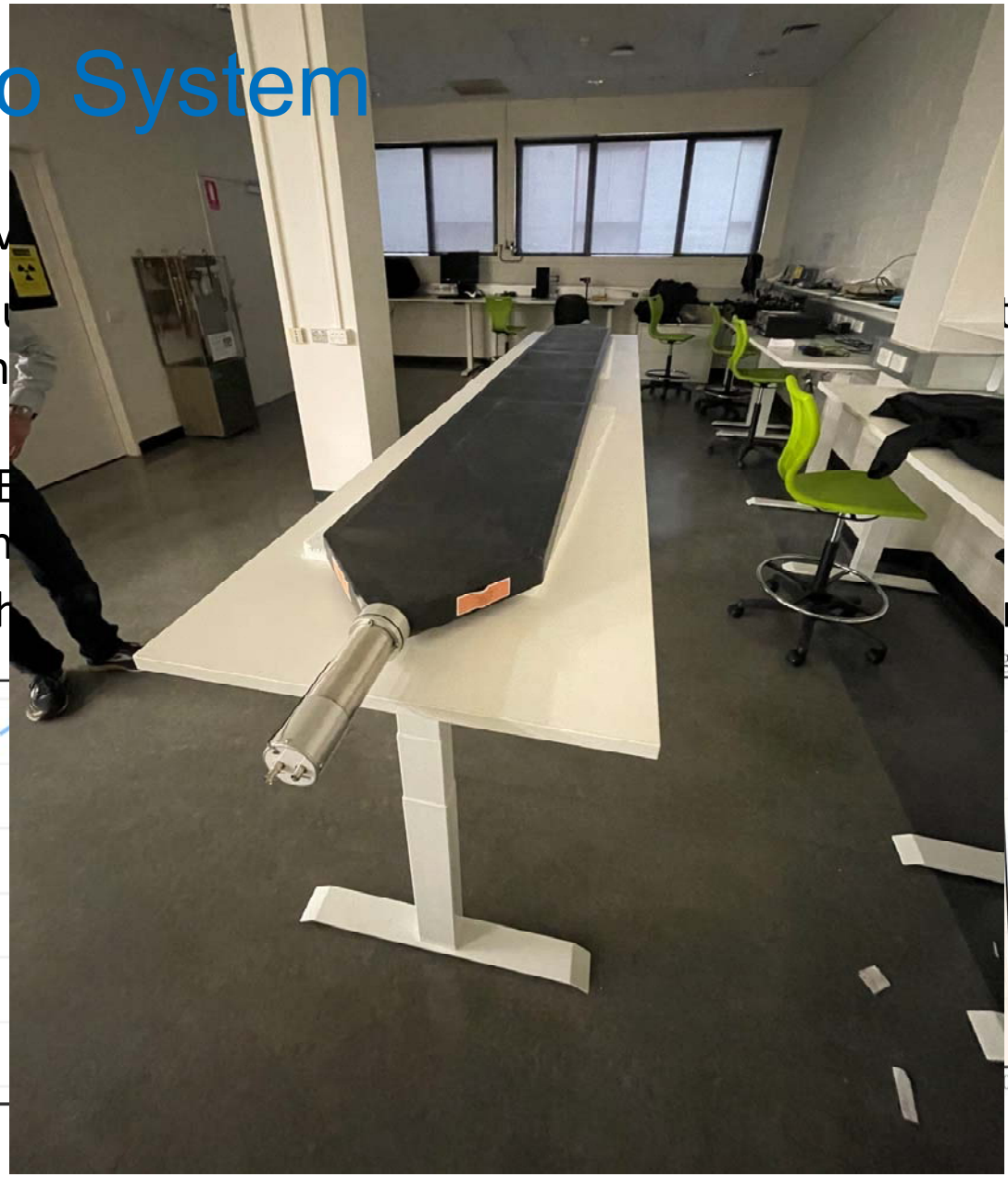
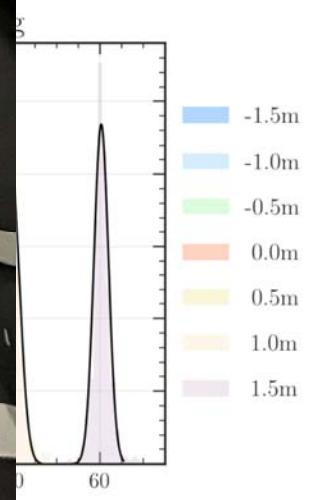
8 x B
with

Readout at 3.2 GS/s wh

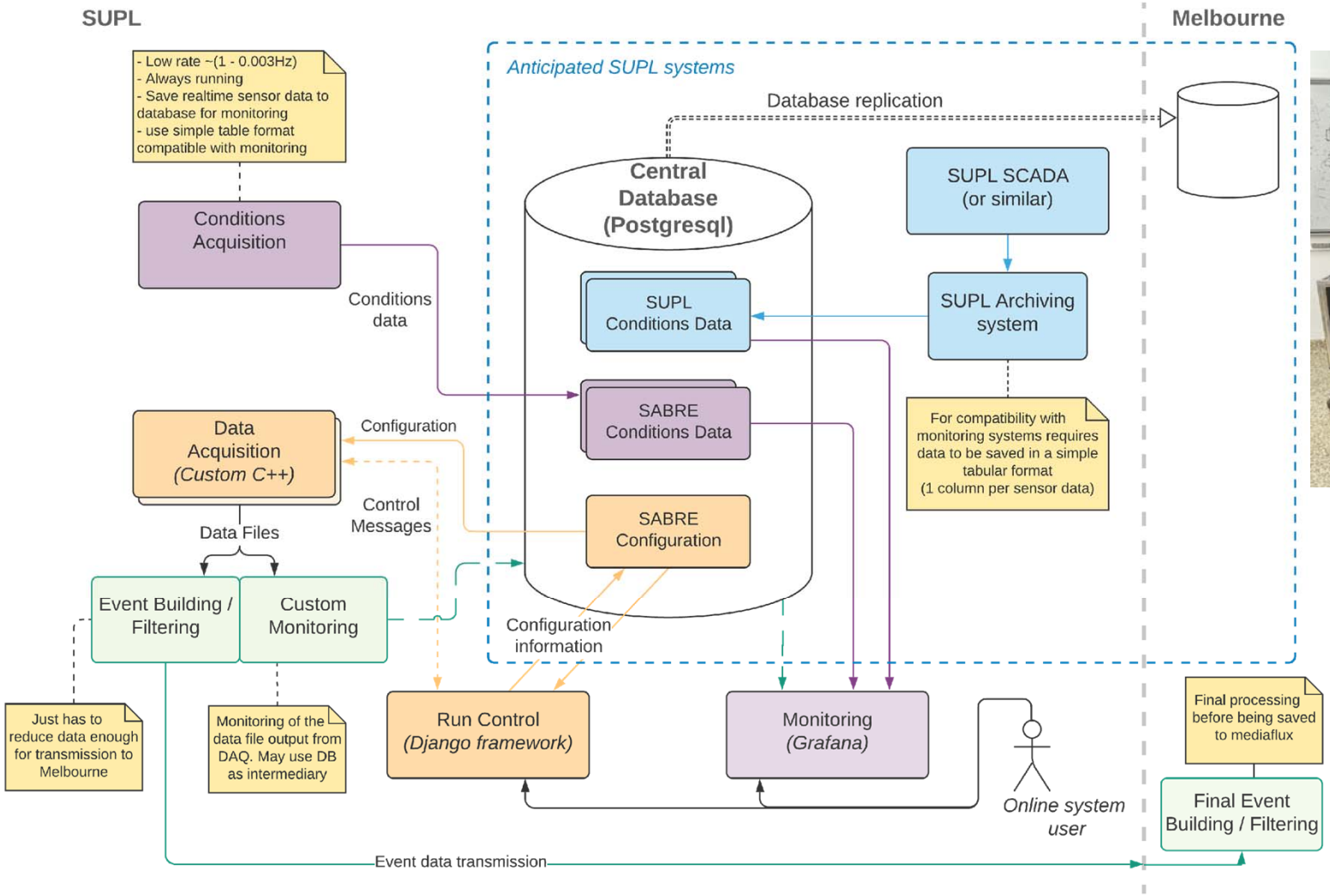
m.





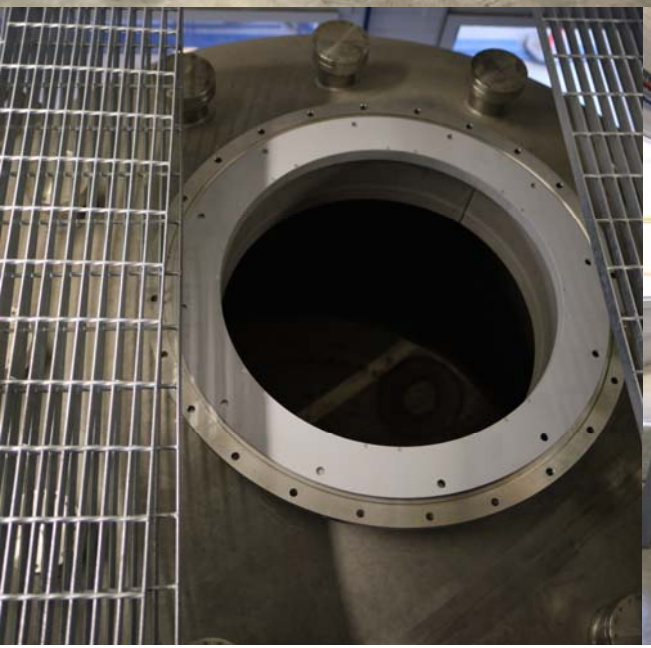


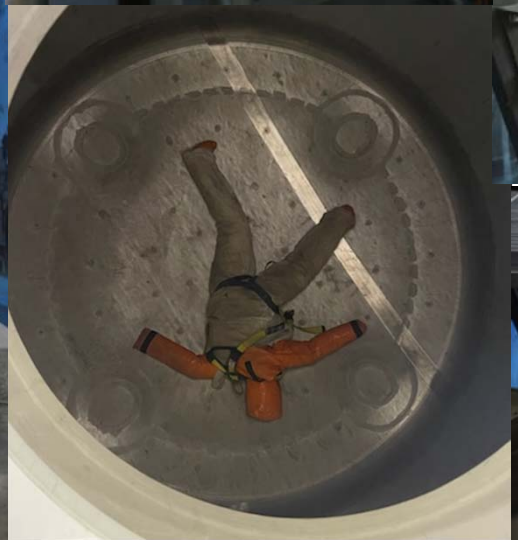
Data acquisition & Online Computing



Prototype system tested in UniMelb laboratory with large muon detectors.

Vessel safety training



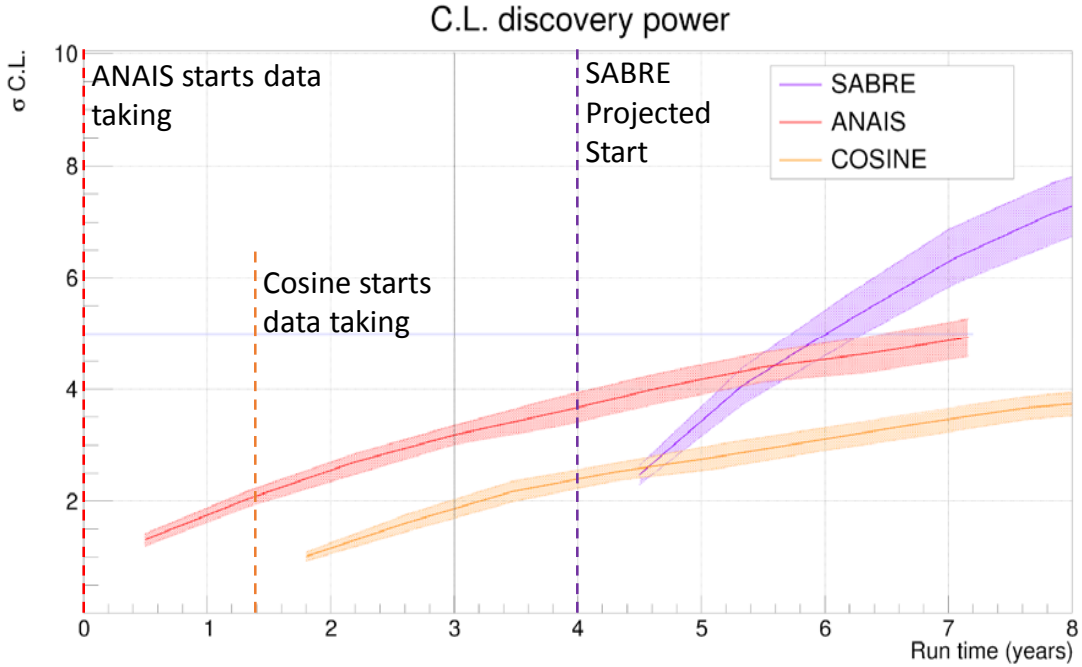


Projected sensitivity

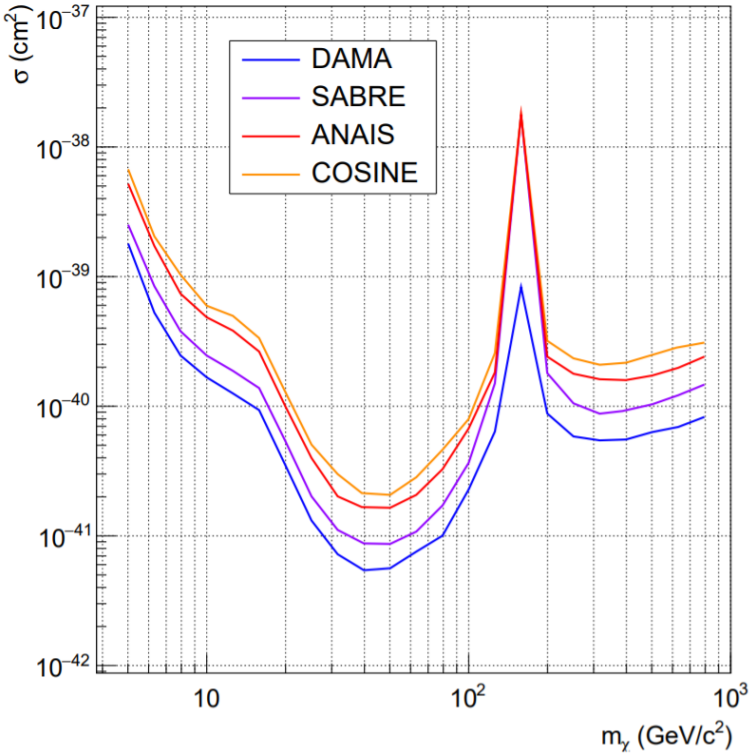
SABRE South sensitivity has been estimated by Zurowski & Barberio [4]
With 50 kg NaI(Tl)& projected background rate ~0.36 cpd/kg/keV [5]

For DAMA like signal:

- 5σ Discovery power in 2 years
- 5σ Exclusion within 5 years



SI - 90% C.L. Modulation Sensitivity 3 Yr exposure



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

Conclusion

SABRE South will be commissioned in 2022 in SUPL.

Expected to reach a 5σ discovery sensitivity to a DAMA-like signal within 2 years

Upcoming Publications:

- Monte Carlo simulation of the SABRE South background
- Photomultiplier characterisation methods and initial results
- Technical design report

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