

SABRE Detector performance and characterisation

Zuzana Slavkovská

CDM Annual Meeting, 23 Nov 2022





Importance of SABRE South

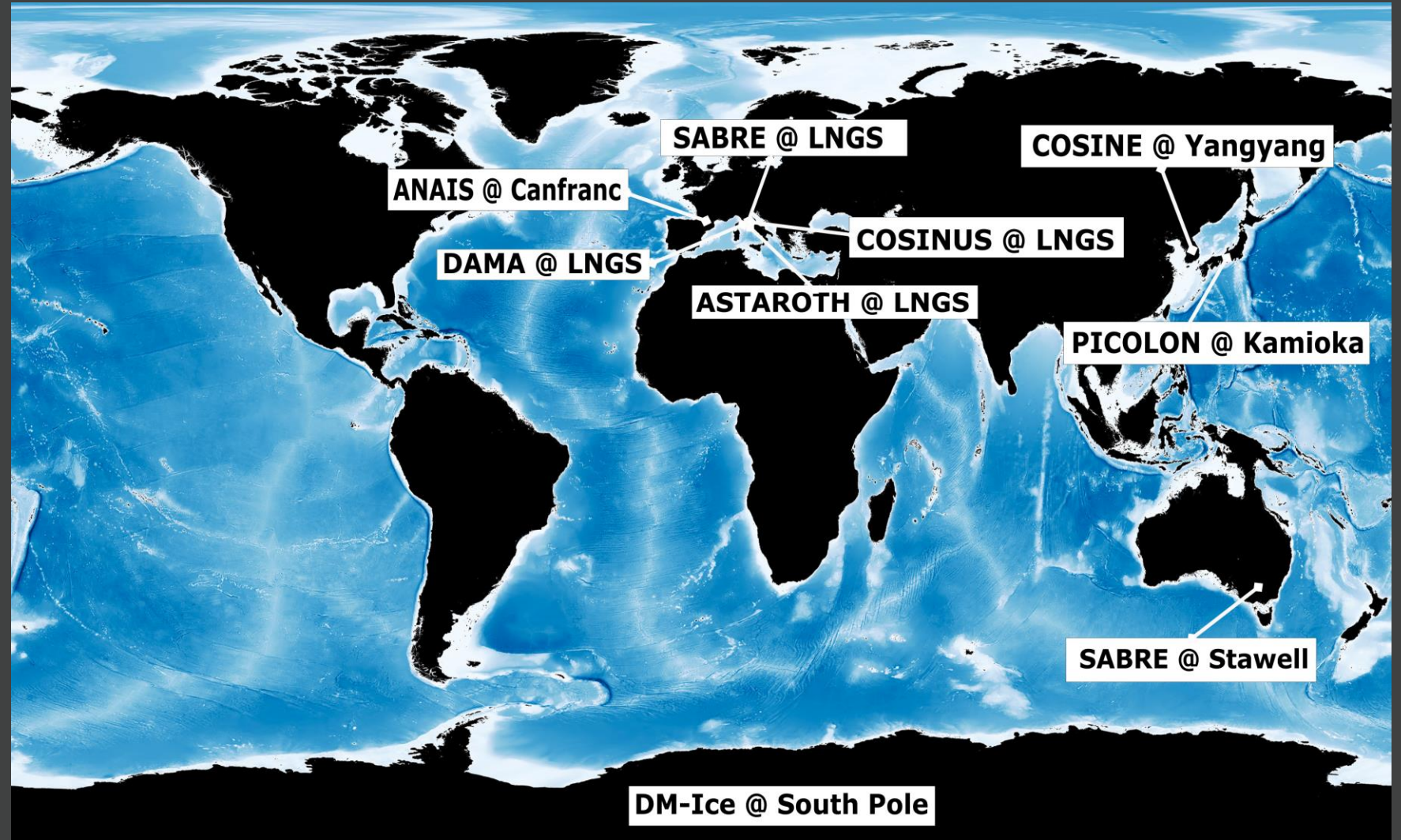
DIGGING FOR DARK MATTER



A tiny Australian mining town might hold the key to solving one of the universe's biggest mysteries – and to a local economic boom. What do scientists hope to find in a cave 1km underground?



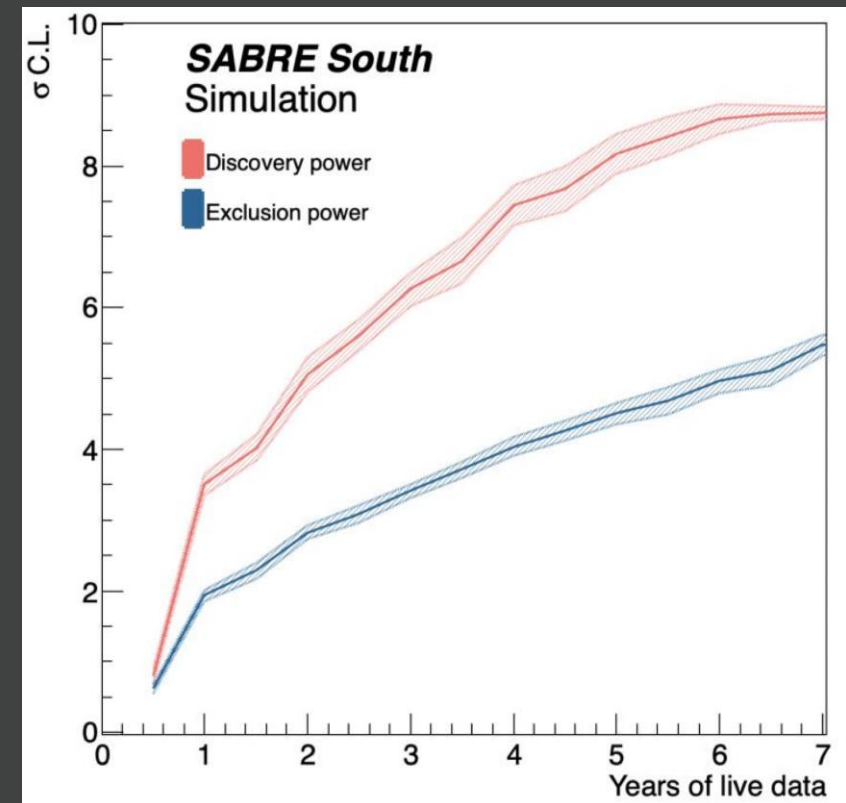
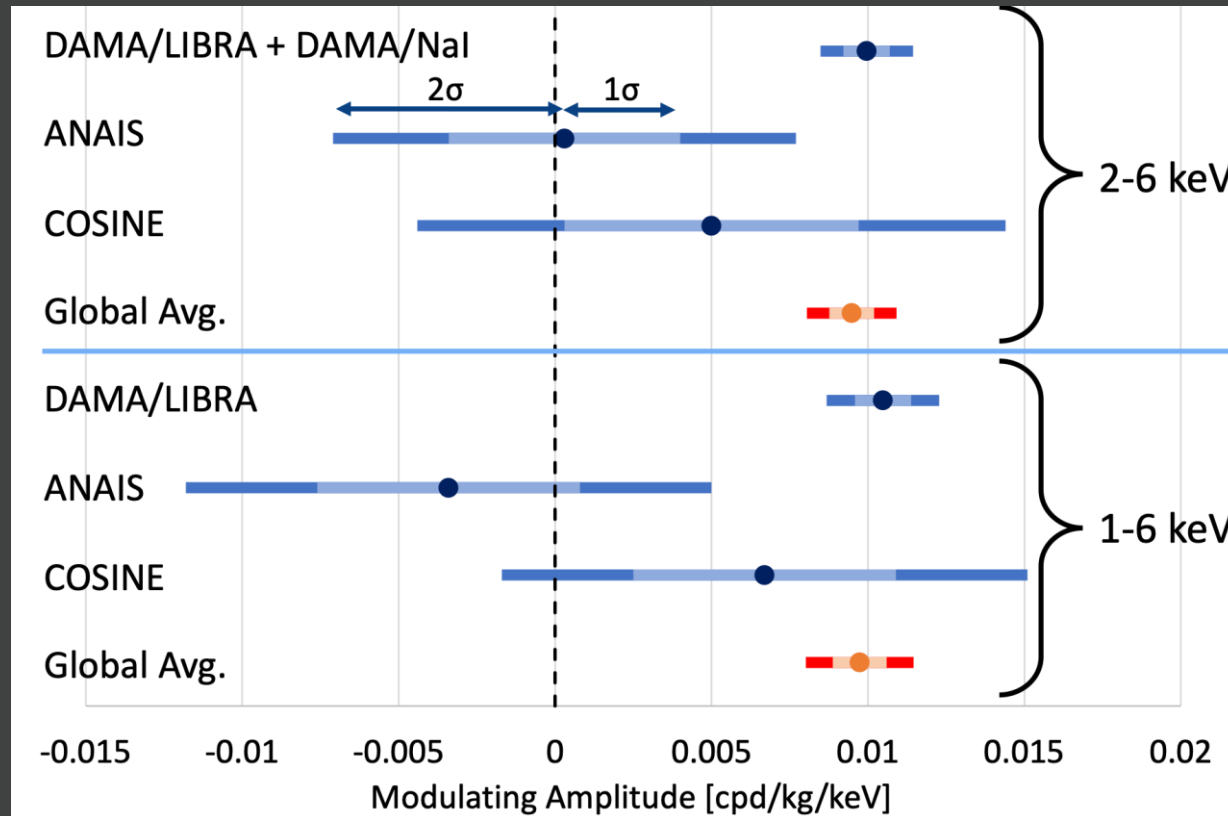
SABRE in the world



Test of annual modulation with NaI

ANAIS, COSINE and SABRE

At present time, DAMA has the smallest uncertainty and best sensitivity



SABRE South

Muon System

9.6 m² x 5 cm EJ200 scintillators

Liquid Scintillator Veto System

10 T Linear Alkyl Benzene + PPO & Bis-MSB

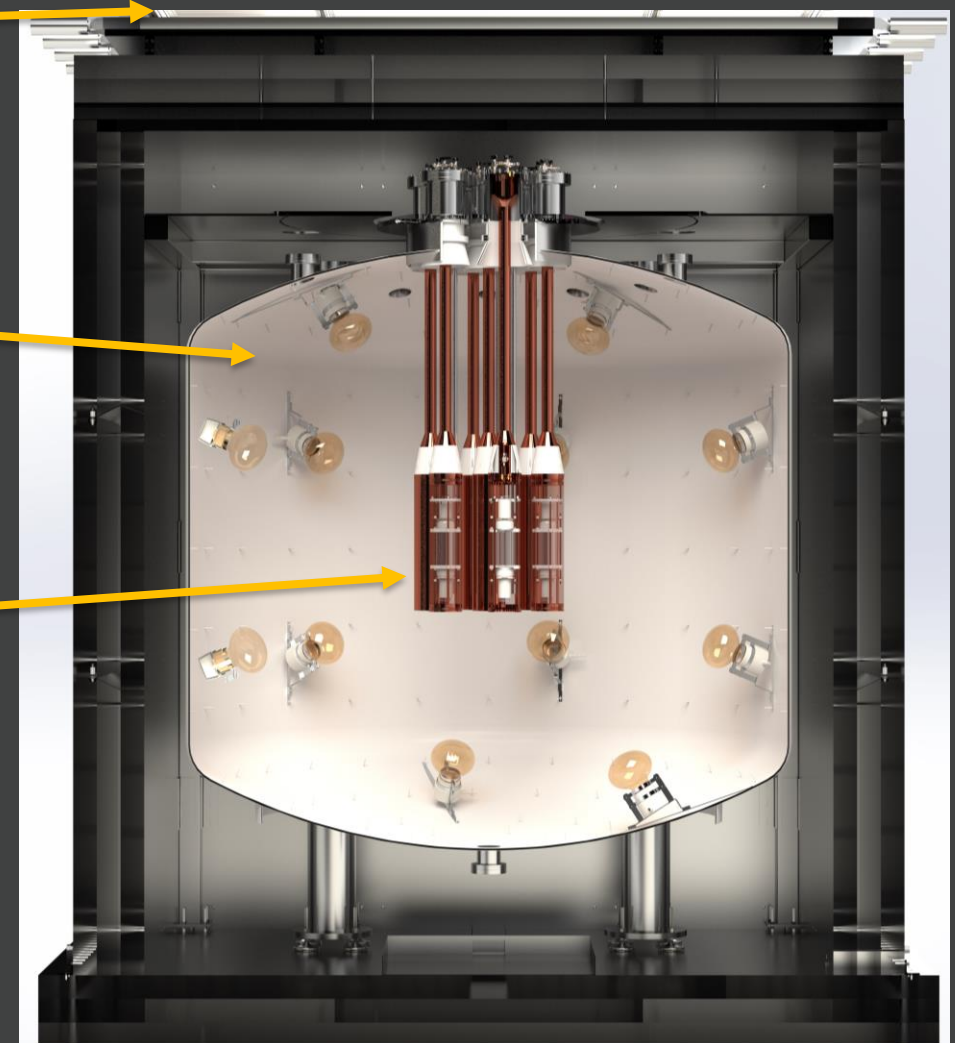
Stainless steel, non-thoriated welds, reflective lumirror layer

18 oil-proof base R5912 PMTs

DM Target Detector

7 NaI(Tl) Crystals

14 R11065 low radioactivity PMTs



SABRE South

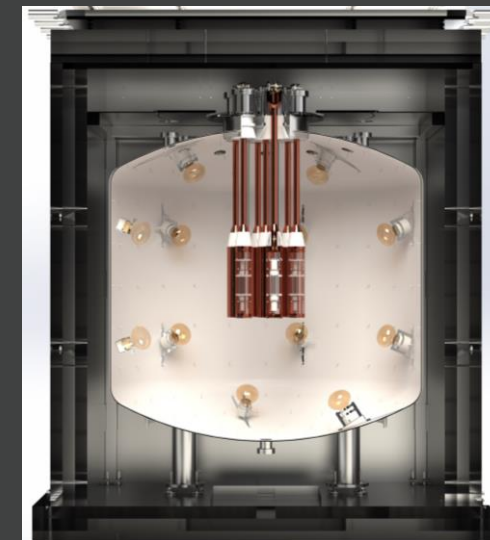
DM Target Detector
NaI(Tl) Crystals

14 R11065 low radioactivity PMTs

Currently under discussion

- 7 x 7 kg NaI crystals (total mass of ~50 kg)
- or
- 7 x 4.5 kg NaI crystals with zone refining (~35 kg)

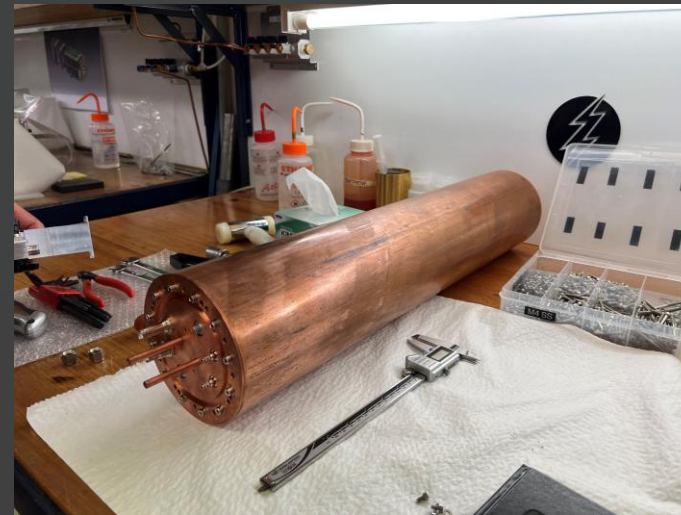
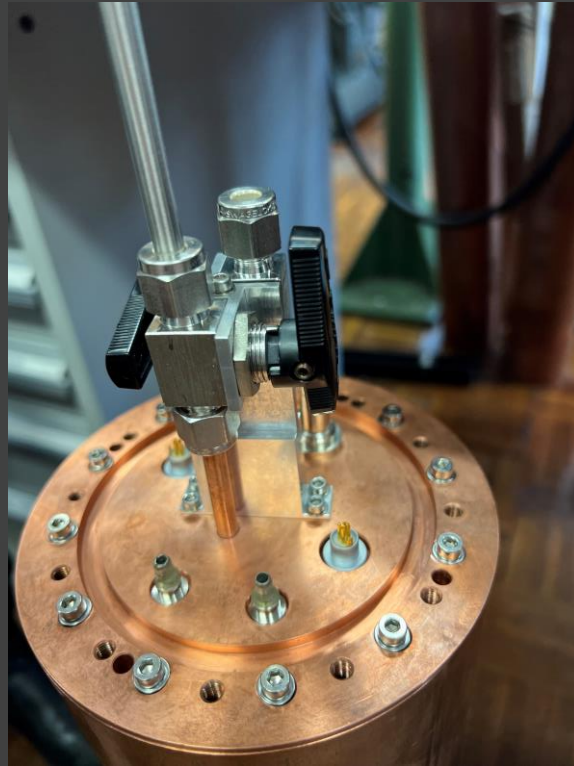
Purification method: narrow region of a crystal melted, **the molten zone moved along the crystal**, impurities concentrate at the end of the crystal and can be removed.



Enclosure leak testing at ANU

Testing in October 2022

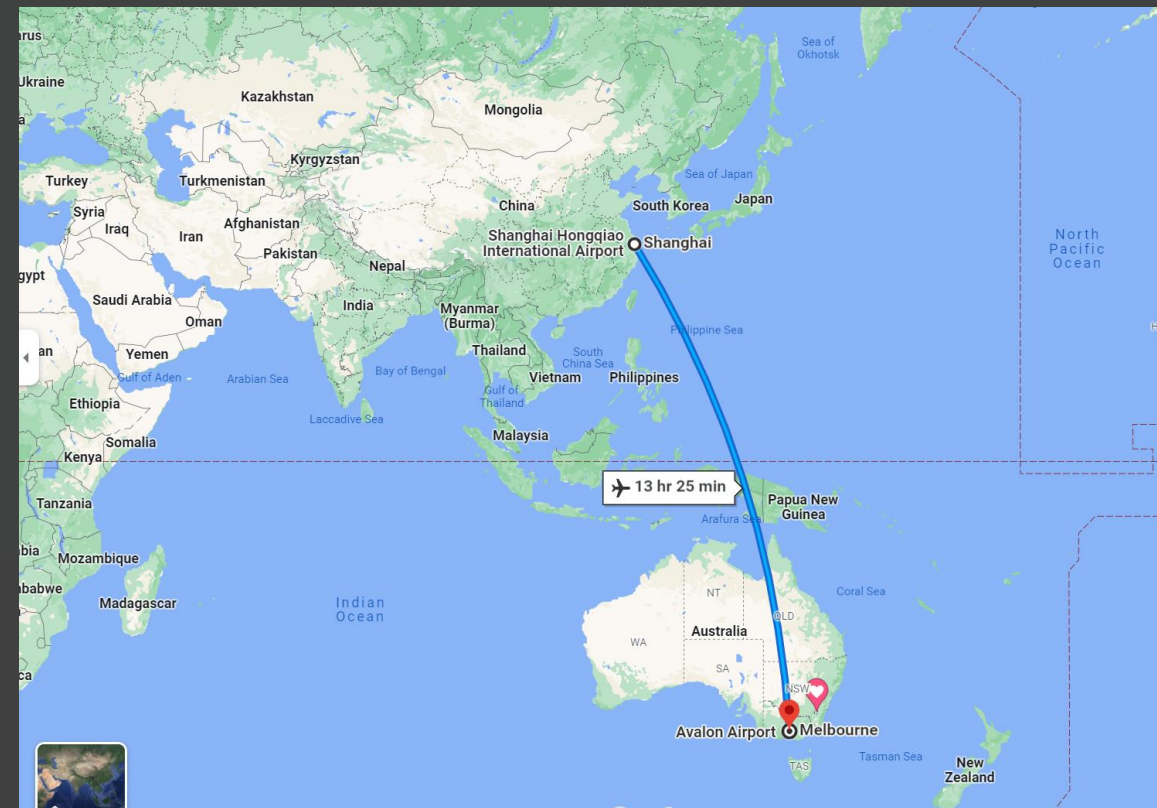
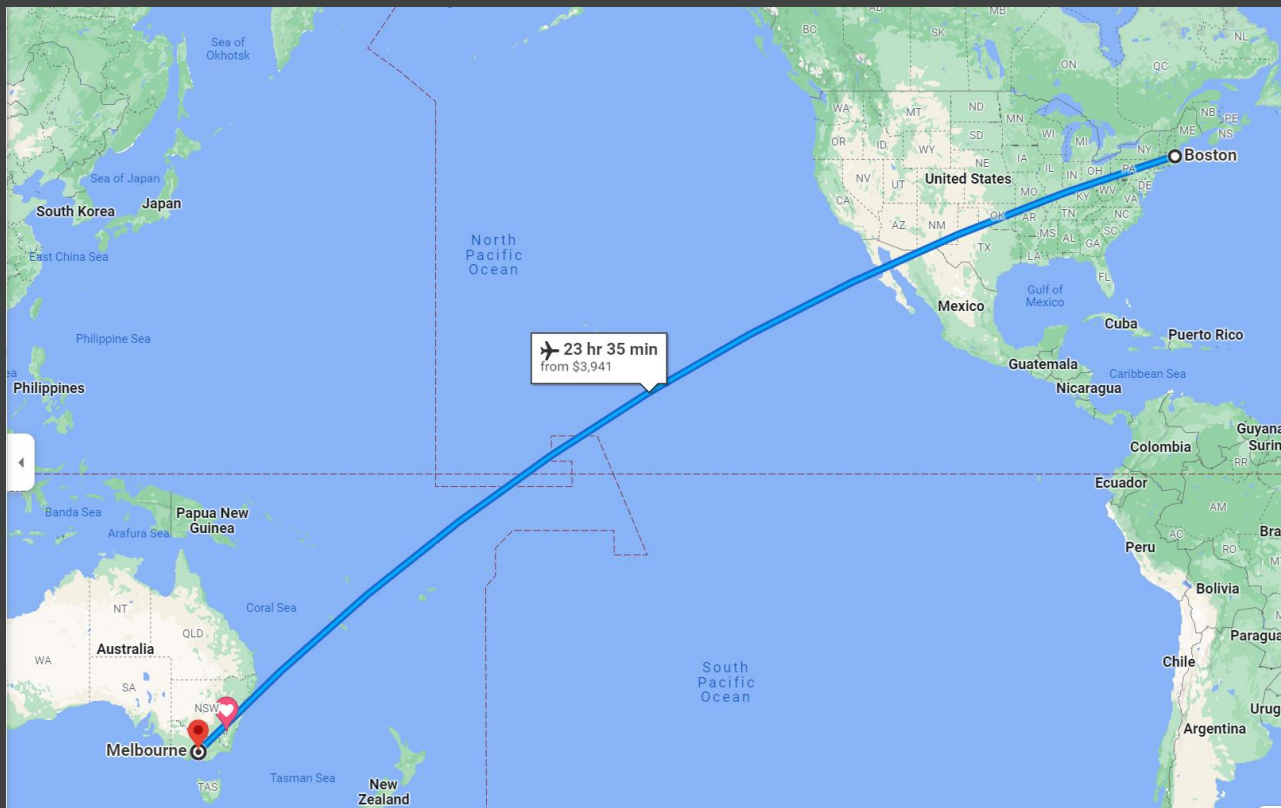
Tiziano Baroncelli (Uni Melb), Lindsey Bignell, Thomas Tunningley, Zuzana Slavkovska (ANU)



Potential crystal providers

RMD (**R**adiation **M**onitoring **D**evelopments, Boston, MA, US)

SICCAS (**S**hanghai **I**nstitute of **C**eramics, **C**hinese **A**cademy of **S**ciences)



Boston to Stawell

Shanghai to Stawell

Crystal powder

Astrograde-quality powder - 100 kg in Melbourne

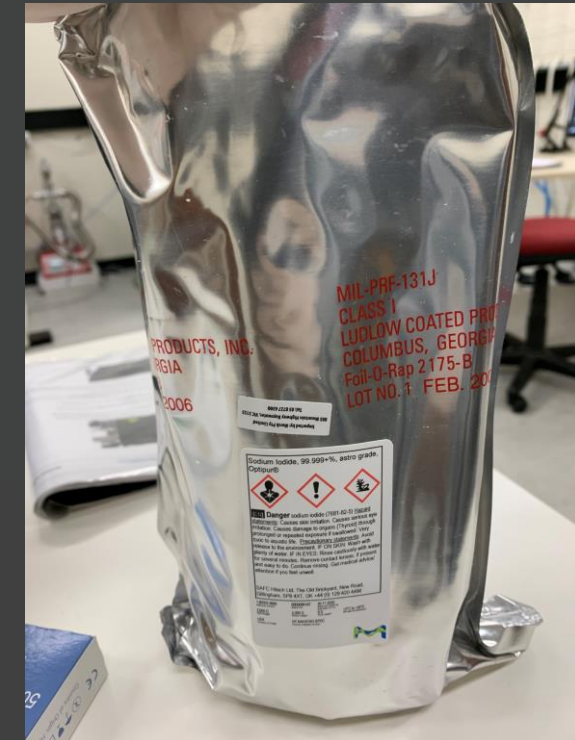
SICCAS also uses Kunshan powder for crystal growth development

Certificate of Analysis

Product: Sodium Iodide, 99.999+%, astro grade, Optipur®
Material No.: 1.89333.9999
Production Date: 03/09/2020
Expiration Date: 03/09/2022
Lot No.: 0000089188
CoA Issue Date: 11/29/2018

Test Parameter	Unit	Specification	Result
Appearance (Color)		White	White
Appearance (Form)		Powder	Powder
Water (by Karl Fischer)	ppm	≤ 300	224
ICP Major Analysis		Confirmed	Confirmed
Purity		Confirmed	Confirmed
Trace Metal Analysis	ppm	≤ 10,0	0,8
Aluminum (Al)	ppm		0,3
Potassium (K)	ppb	≤ 100,0	3,0
Lithium (Li)	ppm		0,5

Remarks:
ICP Major Analysis: Confirms Sodium Component
Purity: >=99.999% Based on Trace Metals Analysis



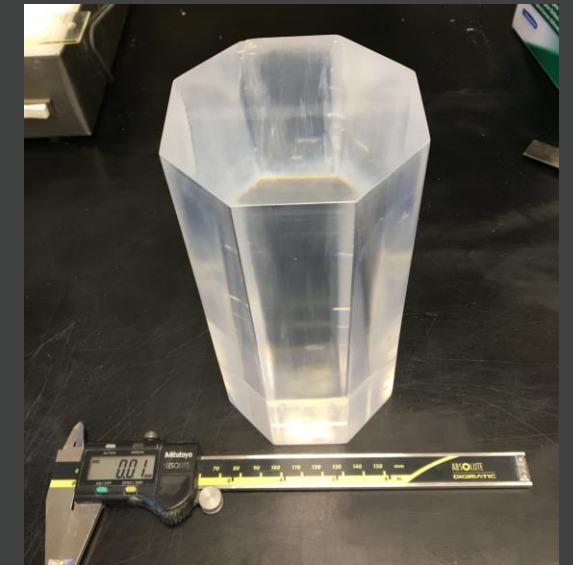
Crystal Requirements

Requirements put together based on simulations and experience at LNGS

Total intrinsic radiogenic crystal background should be < 0.4 cpd/kg/keV

Pb-210 and K-40 levels are of critical importance

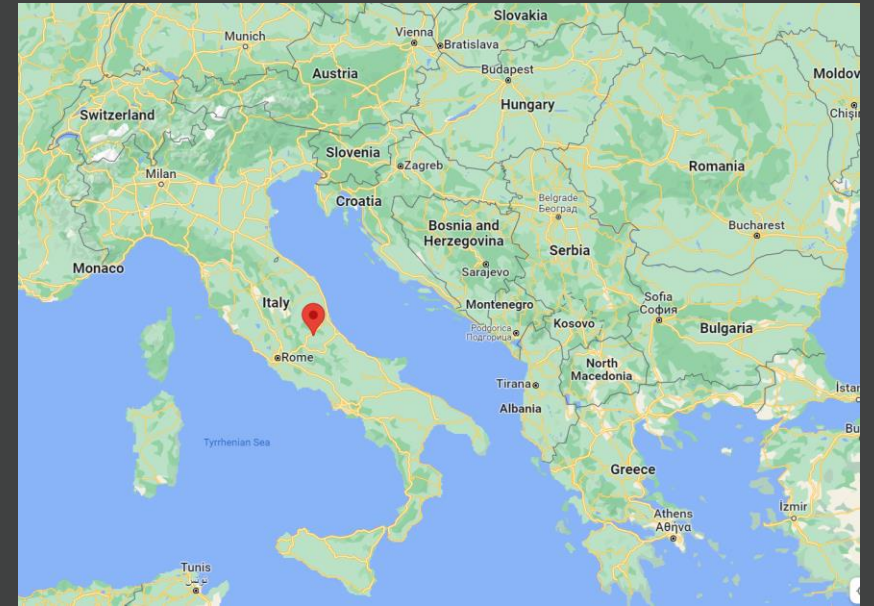
Background	Limit mBq/kg
Pb-210	< 0.3
K-40	< 0.3 (10 ppb)
Rb-87	0.31
U-238	0.05
Kr-85	0.01
Th-232	0.035



NaI-035 Crystal

Light yield should be > 10 photoelectrons/keV corresponding to ~ 30 photons/keV

NaI-035 Performance Measurements



LNGS (Laboratori Nazionali del Gran Sasso), Assergi, Abruzzo, Italy
funded by the **INFN** (Istituto Nazionale di Fisica Nucleare)

NaI-035 Performance Measurements

May 2022

SABRE South team:

Bill Melbourne (Uni Melbourne)

Ferdos Dastgiri (ANU)

Zuzana Slavkovska (ANU)

LNGS SABRE North team:

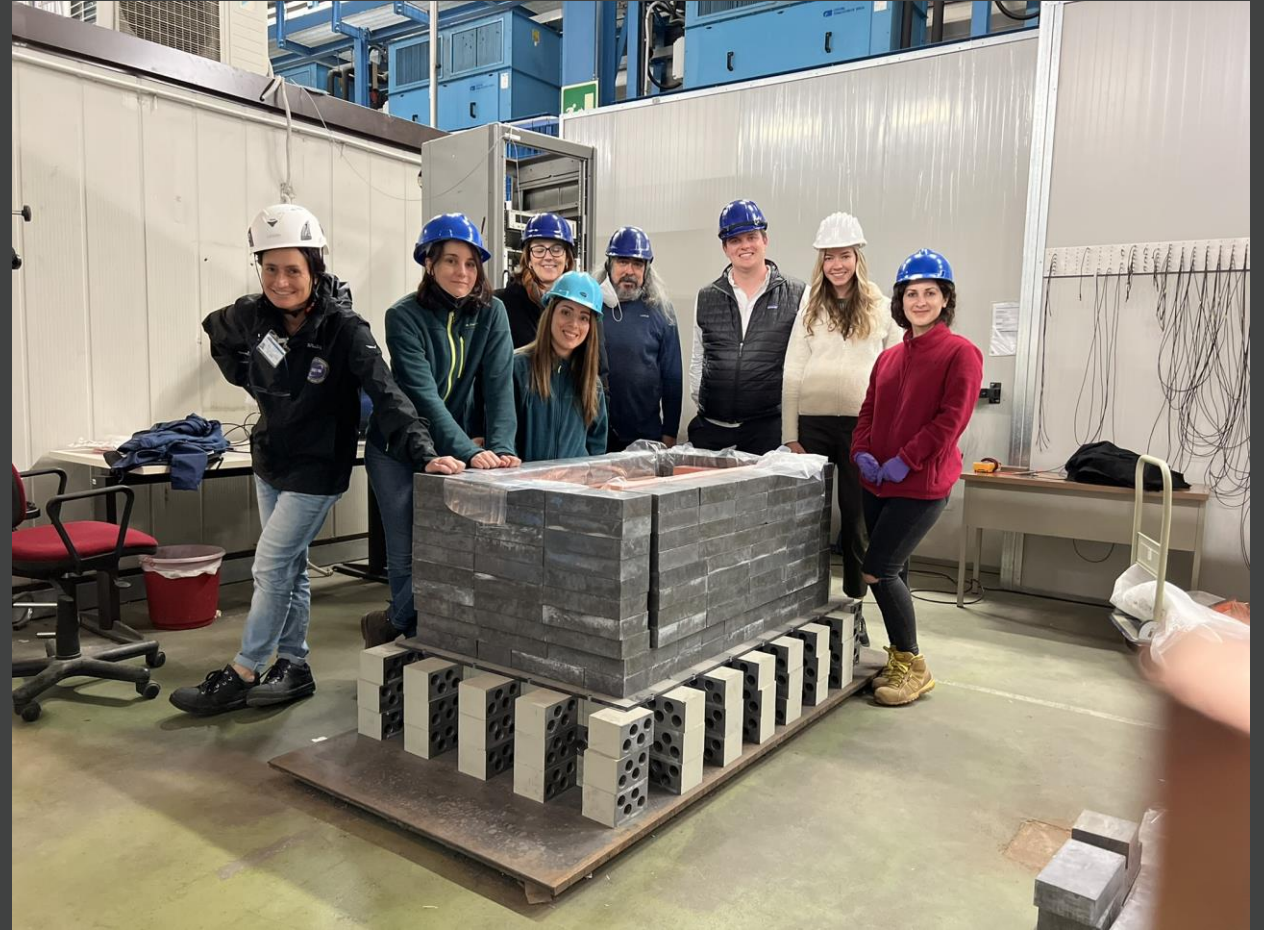
Chiara Vignoli

Giuseppe Dicarlo

Ambra Mariani

Claudia Tomei

Giulia D'Imperio



NaI-035 Performance Measurements

NaI-035 produced by **RMD** (Radiation Monitoring Devices, Boston, MA, US)

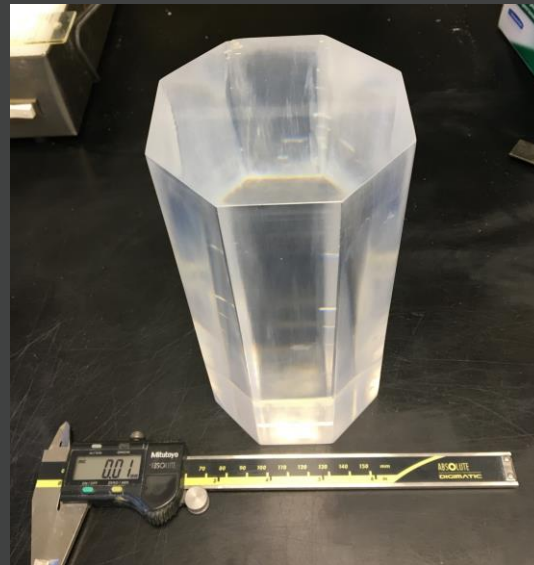
octagonal crystal

3.7 kg heavy

181 mm long

89 mm wide

in copper enclosure
with quartz windows



NaI-035 Performance Measurements

Performed measurements:

- **PMT noise run studies**
- **Series of energy calibration source runs**
(Am-241 source on different positions) to study spatial effects from the crystal growth
- Several **gamma-ray source measurements**
- **Alpha rate measurements (ongoing)**

NaI-035 Performance Measurements

- Kept in a surface laboratory for over a year thus activated by cosmics
- ICP-MS testing showed the crystal was slightly excessive in K-40 contamination

Light yield and resolution were acceptable, although compromised by the use the encapsulation

210-Pb measurements appear to show similar α rates to NaI-33, and therefore **acceptable**

The ICP-MS for NaI-35 (the test crystal prepared and grown entirely by RMD, to be sent to LNGS, shown below) is shown below (for the key contaminants). Based only on the 39K and 85Rb levels and scaling the simulation results, this crystal would already have a background of ~ 0.88 cpd/kg/keV (not including any 210Pb contamination). This is approaching the limit that allows for good results within 3 years with <50kg of crystal.

Source	Tip (ppb)	Tail (ppb)	Average (ppb)
K39	5	26	15.5
Pb208	16	37	26.5
Rb85	1	1	1
Th232	<0.8	<0.8	<0.8
U238	<0.1	<0.1	<0.1

SABRE South

Muon System

9.6 m² x 5 cm EJ200 scintillators

Liquid Scintillator Veto System

10 T Linear Alkyl Benzene + PPO & Bis-MSB

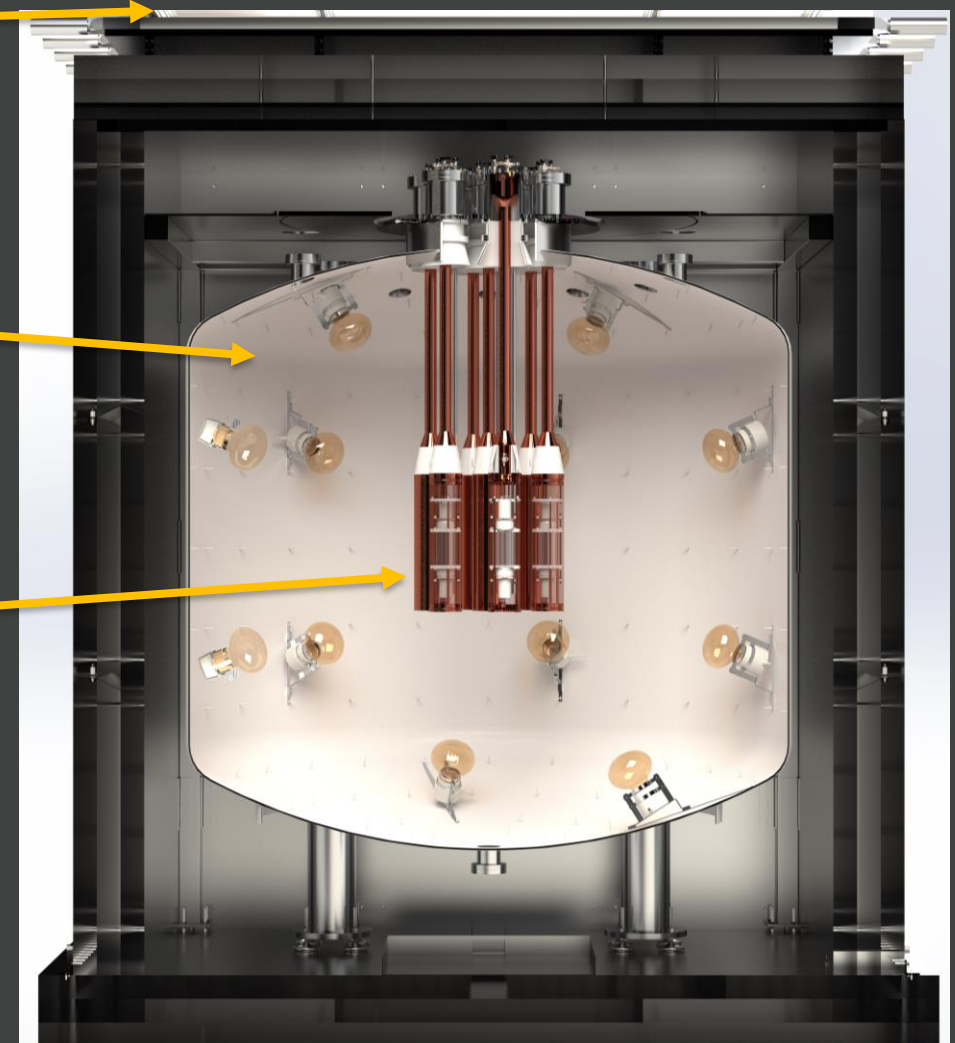
Stainless steel, non-thoriated welds, reflective lumirror layer

18 oil-proof base R5912 PMTs

DM Target Detector

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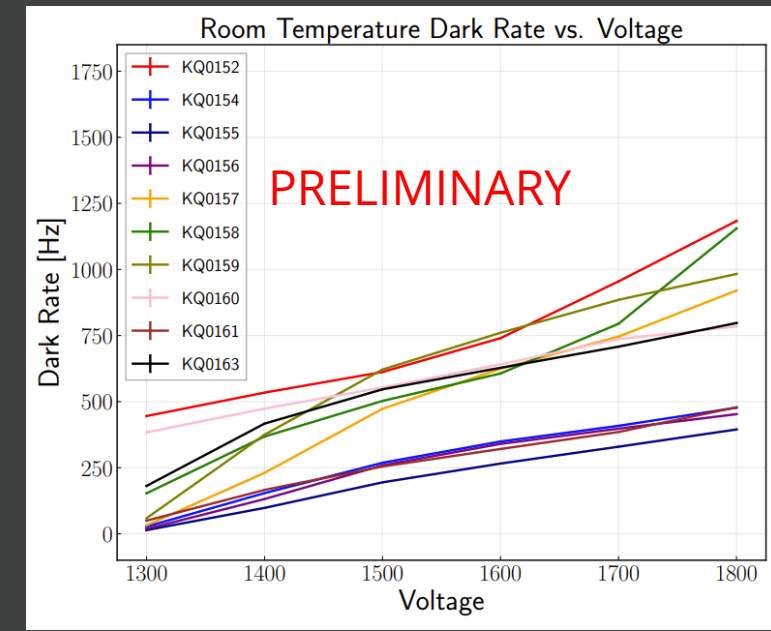
PMT Characterisation

PMT bulk characterisation underway:

- R11065 crystal PMTs (Poster: Owen Stanley, Bill Melbourne)
- R5912 oilproof veto PMTs (Lachlan Milligan)

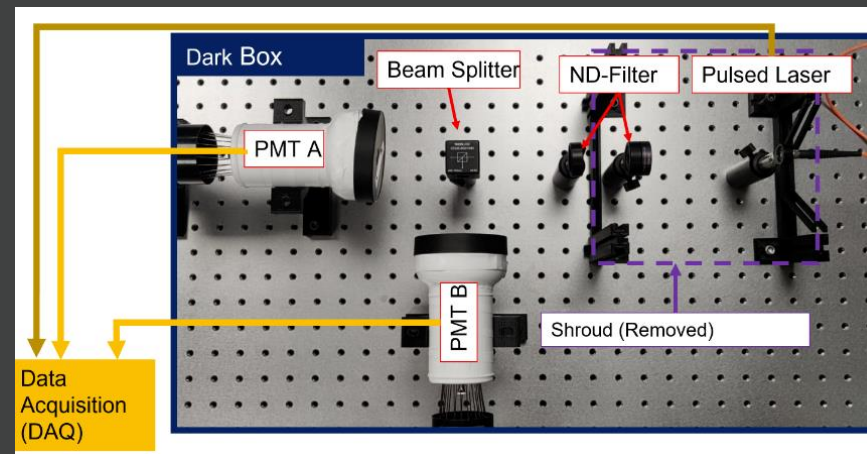
Key properties characterised for every PMT (20 veto, 16 crystal)

- Single photon response and PMT gain
- Dark rate (room temp. and temp. dependent)
- Quantum efficiency
- Transit time and transit time spread



R5912 veto PMT

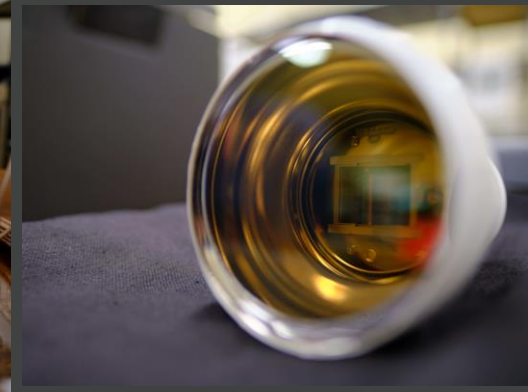
Single Photon Setup



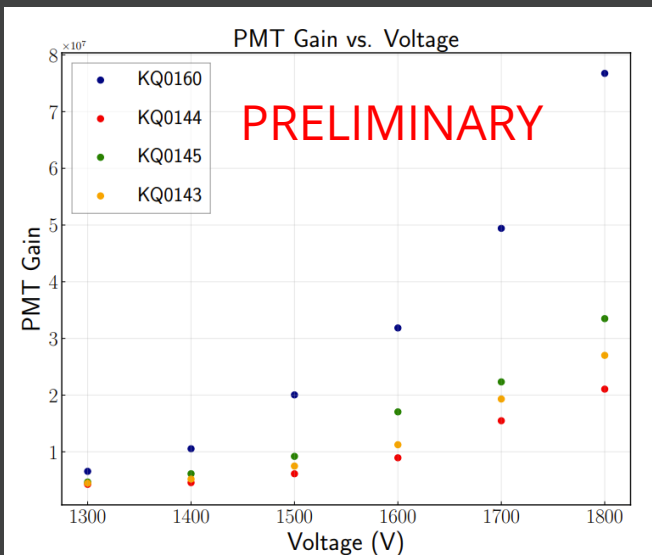
CDM Annual Meeting



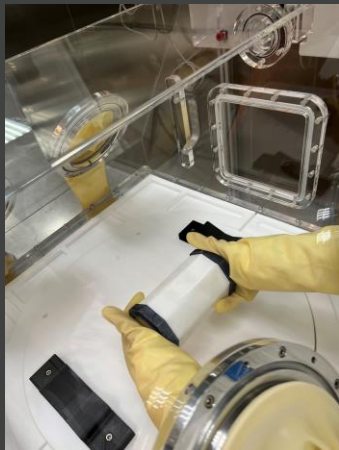
R11065 crystal PMT



Zuzana Slavkova



Glove box



Glove box at LNGS

Glove box built by Palazzi SRL, Italy
CIS tested at Uni Melbourne

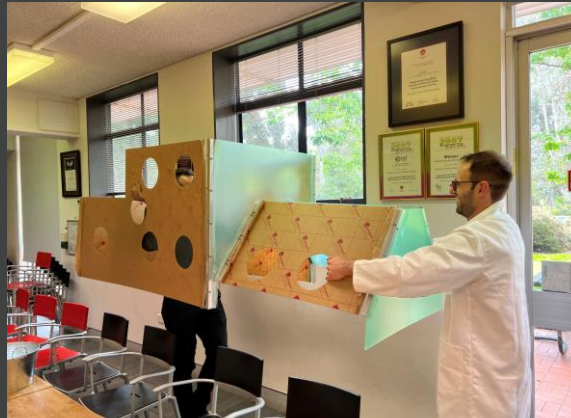
Glove box mock-up

Testing in October 2022

Tiziano Baroncelli (Uni Melb), Lindsey Bignell, Thomas Tunningley, Zuzana Slavkovska (ANU)



Mock-up assembly



Mock-up glove box testing



Procedure testing inside the glove box

Nal Crystal Schedule: Smartsheet

smartsheet [Upgrade](#) Search...

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File Automation Forms SABRE Experiment ☆

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 ... 🔍 🔍 📄 Baselines

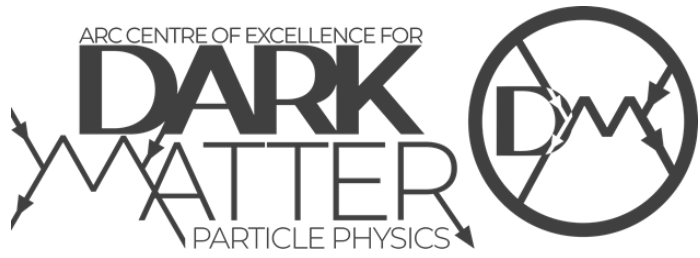
	Task Name	Duration	Start Date	End Date	Predecessors	% Comp...	Status	Comment
	2023-2024							
1	▣ TOTAL PROJECT	1332d	01/01/19	21/02/24		35%		
2	▣ SUPL READY TO HOST SABRE EQUIPMENT	0	01/12/22	01/12/22				
3	▣ Shielding, Assembly and Transportation to SUPL	472d	21/11/21	11/09/23		25%		
36	▣ LAB detector	1102d	11/07/19	13/10/23		48%	In Progress	
136	▣ Muon detector	1195d	01/01/19	14/08/23		49%	In Progress	
150	Installation in SABRE at SUPL	10d	08/02/24	21/02/24	2, 142, 145, 16, 268			Installation
151	▣ NaI Detector	994d	17/04/20	07/02/24		10%	In Progress	
299	▣ Slow Control	220d	05/08/22	08/06/23		26%	In Progress	
312								
313	▣ Milestones	157d	17/07/23	21/02/24				
319								

Nal Crystal Schedule: Smartsheet

- Nal Detector	994d	17/04/20	07/02/24		10%	In Progress
- Crystals	500d	03/02/22	03/01/24		0%	
- Crystal production	455d	03/02/22	01/11/23		0%	
Crystals size, shape and shipment procedure definition	0	03/02/22	03/02/22		90%	
All procedures approval - SABRE Technical Coordination group	230d	03/02/22	21/12/22	154		
+ Powder preparation, growing set up preparation	35d	16/03/23	03/05/23			
- Crystal Growth	160d	23/03/23	01/11/23			
Crystal growing #1	40d	23/03/23	17/05/23	157		
Crystal growing #2	40d	30/03/23	24/05/23	158		
Crystal growing #3	40d	18/05/23	12/07/23	159, 165		
Crystal growing #4	40d	25/05/23	19/07/23	160, 166		
Crystal growing #5	40d	13/07/23	06/09/23	161, 167		
Crystal growing #6	40d	20/07/23	13/09/23	162, 168		
Crystal growing #7	40d	07/09/23	01/11/23	163, 169		
- Crystal shipping and storage	165d	18/05/23	03/01/24			
Crystal shipment and storage #1	45d	18/05/23	10/07/23	165		
Crystal shipment and storage #2	45d	25/05/23	26/07/23	166		
Crystal shipment and storage #3	45d	13/07/23	13/09/23	167		
Crystal shipment and storage #4	45d	20/07/23	20/09/23	168		
Crystal shipment and storage #5	45d	07/09/23	08/11/23	169		
Crystal shipment and storage #6	45d	14/09/23	15/11/23	170		
Crystal shipment and storage #7	45d	02/11/23	03/01/24	171		
- Crystal Glovebox	181d	01/09/22	11/05/23			

NaI Crystal Schedule: Smartsheet

- Crystal Glovebox	181d	01/09/22	11/05/23			
Prototyping and testing	20d	01/09/22	28/09/22			
Final design	40d	29/09/22	23/11/22	181		
Glovebox manufacturing	90d	24/11/22	29/03/23	182		
Delivery to SUPL or alternative testing site (including instrumentation)	20d	30/03/23	26/04/23	183, 2		
GB testing	10d	27/04/23	10/05/23	184		
CRYSTAL GB READY	1d	11/05/23	11/05/23	185		
- PMT test development and procurement	135d	08/07/22	12/01/23			In Progress
Base optimisation studies	110d	08/07/22	08/12/22			
Production of PMT bases at ANU	20d	09/12/22	05/01/23	188		
Assembly of bases on PMTs	5d	06/01/23	12/01/23	189, #REF		
- Crystal PMT Bulk Testing Prior to installation	396d	03/11/21	10/05/23			0%
Crystal PMT Arrival	0	03/11/21	03/11/21			100%
+ Dark Rate - Crystal PMTs	56d	02/02/23	20/04/23			
+ Single Photon Measurements (Gain, SPE, Relative QE) - Crystal PMT	56d	13/01/23	31/03/23			
+ QE (function of position, wavelength) - Crystal PMTs	56d	22/02/23	10/05/23			
+ Gas Handling System	324d	16/05/22	10/08/23			11%
- Enclosures and Insertion system	994d	17/04/20	07/02/24			21% In Progress
- Enclosures	683d	10/06/21	22/01/24			1%
+ Mechanical design and testing	428d	10/06/21	30/01/23			2%
+ Enclosure production (7 modules)	253d	31/01/23	18/01/24	227		
+ Crystal installation in copper enclosures	95d	12/09/23	22/01/24			
+ Crystals testing and preparation for the enclosure	103d	14/09/23	05/02/24			
+ Crystal detector insertion in SABRE vessel	89d	06/10/23	07/02/24			
+ Crystal Insertion System	696d	17/04/20	16/12/22			46% In Progress
+ Slow Control	220d	05/08/22	08/06/23			26% In Progress



INTERNATIONAL PARTNER ORGANISATIONS:



The University of Sheffield.

