



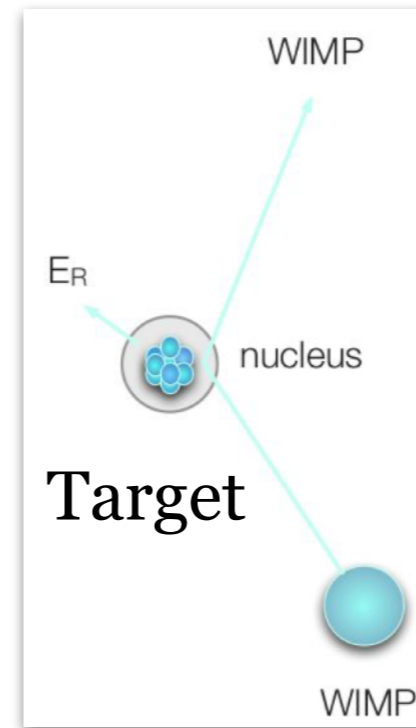
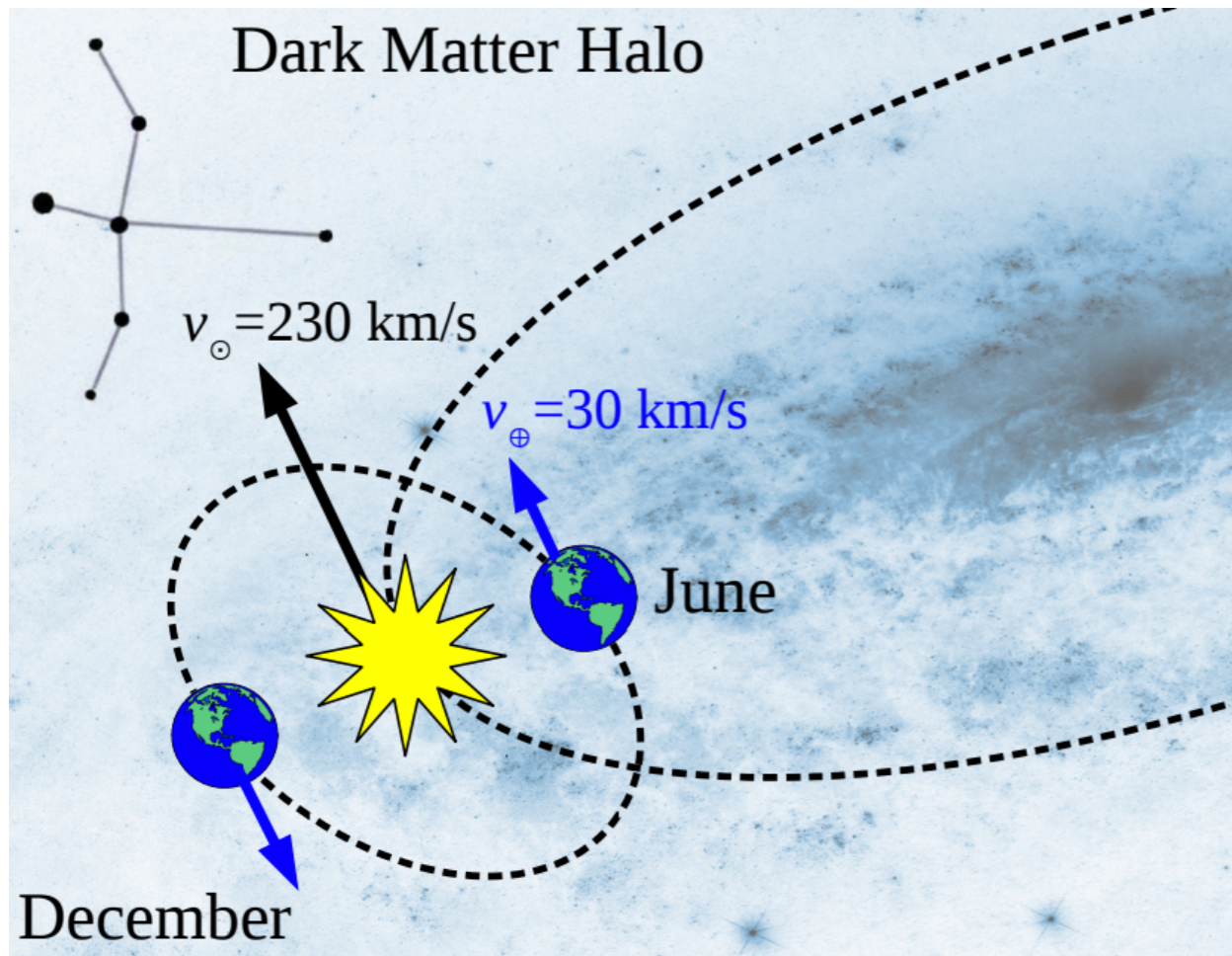
# SABRE Experiment: hardware and software status

Federico Scutti  
*postdoctoral fellow*  
**University of Melbourne**



THE UNIVERSITY OF  
MELBOURNE

# The case for the SABRE Experiment



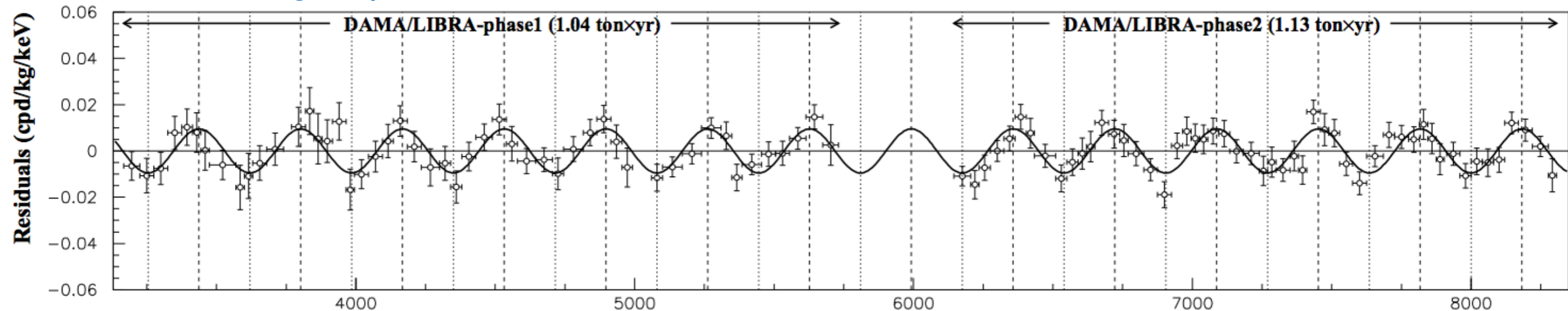
Count rate:

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

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

[arXiv: 1805.10486](https://arxiv.org/abs/1805.10486)

2-6 keV



Modulation  $\approx$  **0.01 cpd/kg/keV** observed @ **12.9  $\sigma$**  using NaI(Tl) crystals (250 kg).

# Sodium iodide with **A**ctive **B**ackground **RE**jection



Model independent search  
at the SABRE experiment

## High purity crystals

- Crystal growth method developed by Princeton (PU) and RMD company.

## Low energy threshold

- High QE PMTs by Hamamatsu.
- Direct coupling to crystals.

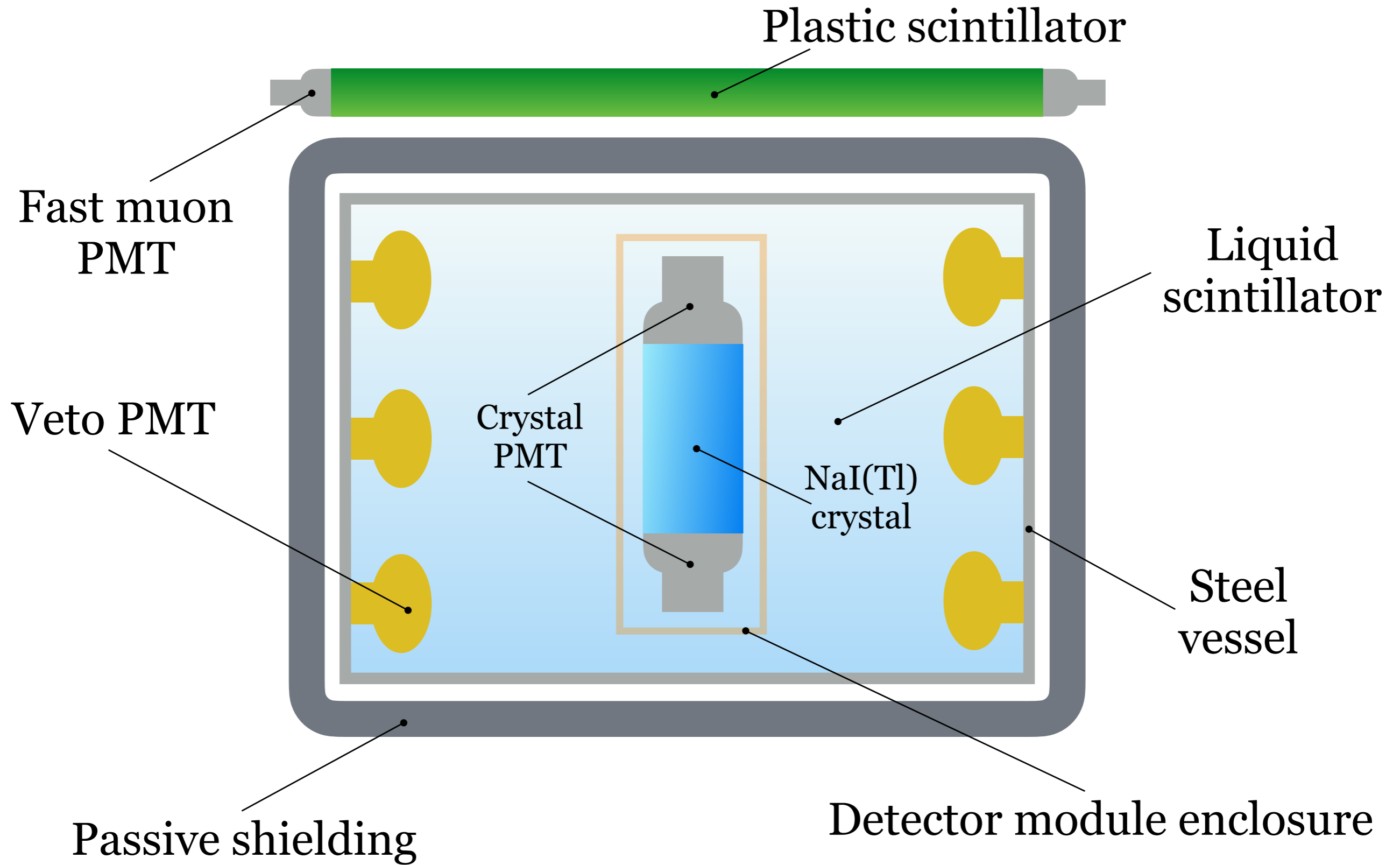
## Active bkg veto

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

## Southern hemisphere

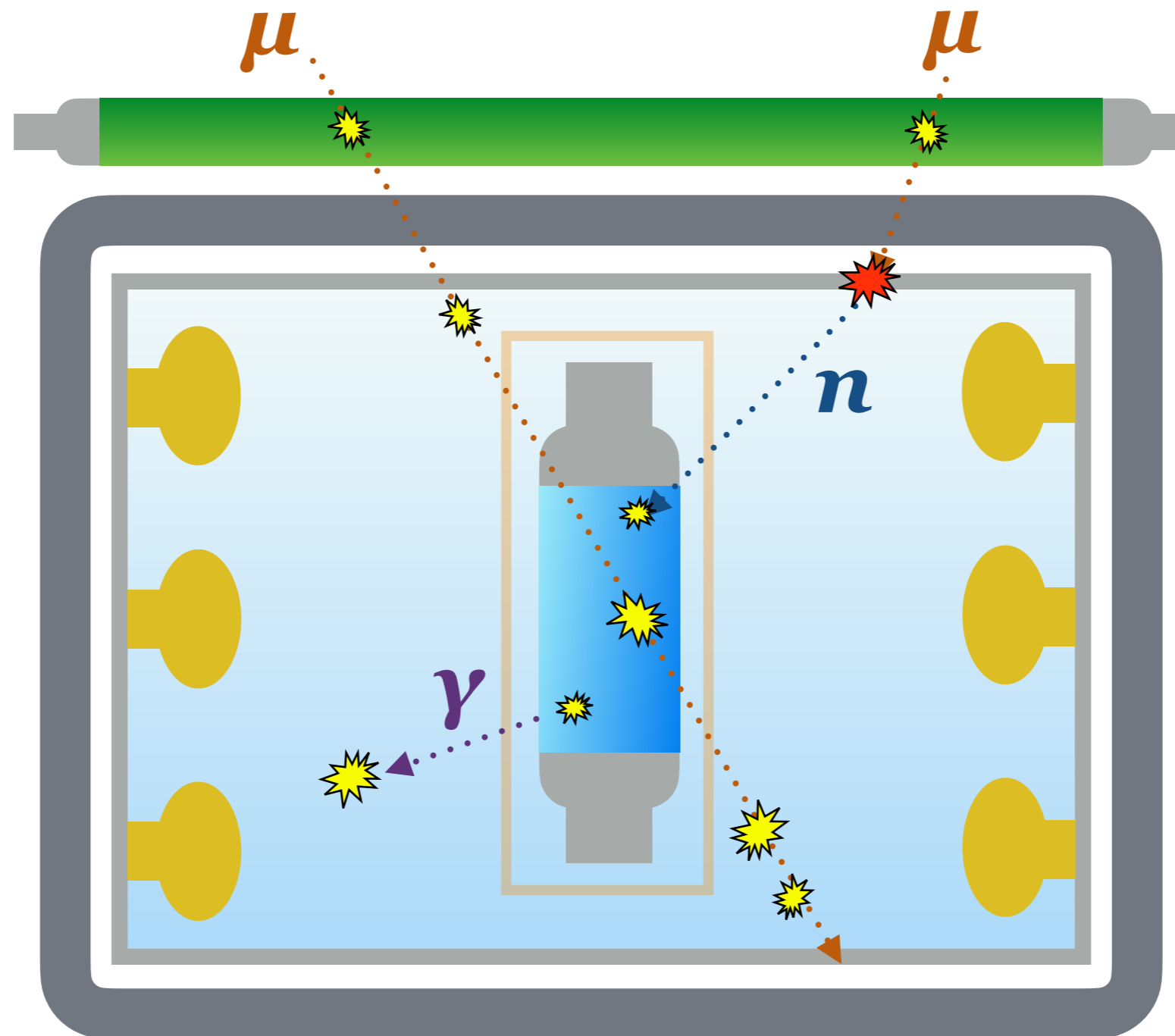
- Underground detector checking phase of northern hemisphere data excluding seasonal backgrounds.

# Signal detection



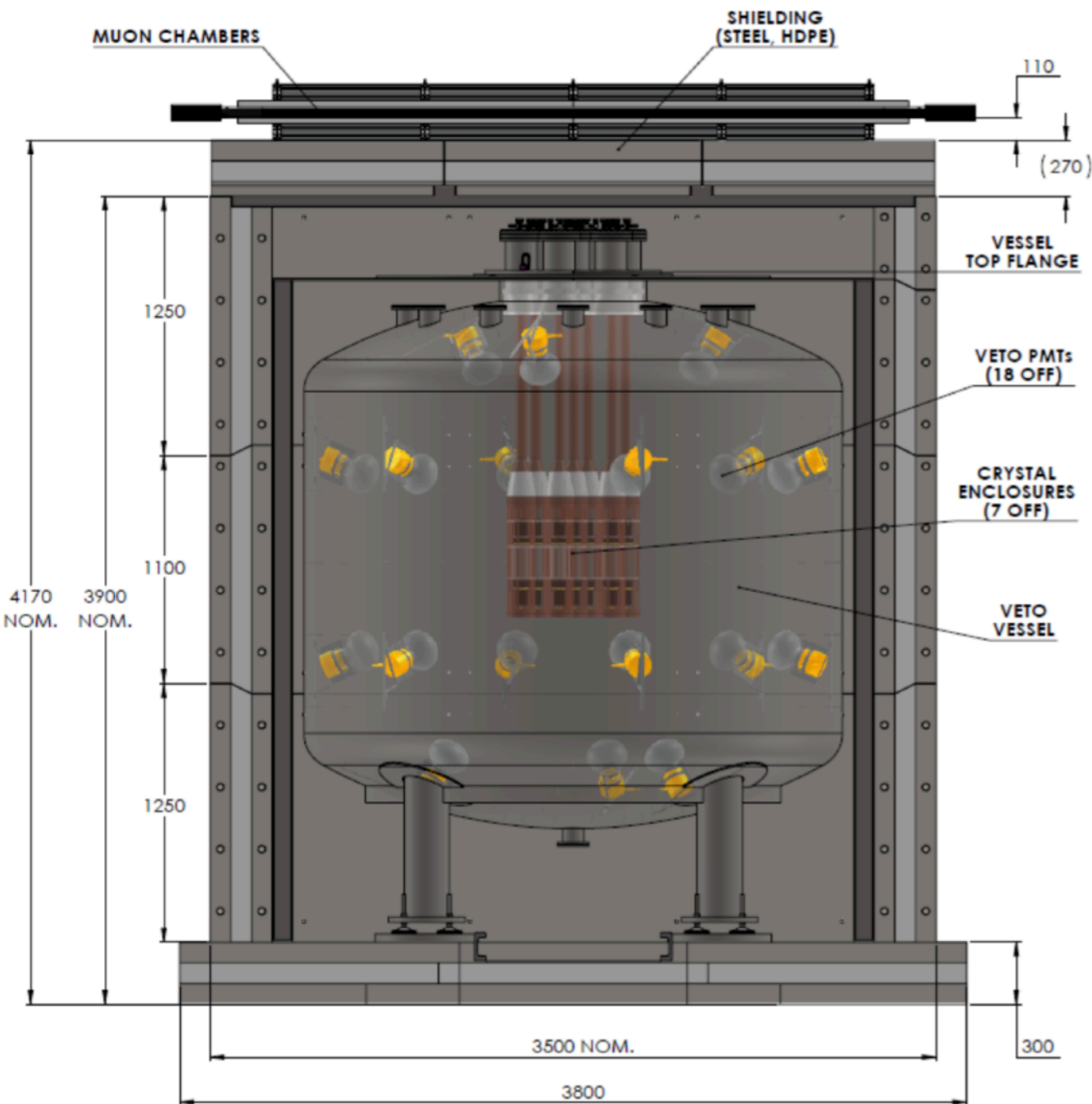


# Background veto



- **Intrinsic** and **cosmogenic** crystal radioactivity:
  - Veto effective:  $^{40}\text{K}$ ,  $^{22}\text{Na}$ ,  $^{238}\text{U}$ ,  $^{232}\text{Th}$ . Veto *not* effective:  $^3\text{H}$ ,  $^{87}\text{Rb}$ ,  $^{210}\text{Pb}$ .
- $\gamma$  and  $n$  from surrounding material.
- $\gamma$  from PMT, enclosure and veto vessel.
- Cosmic  $\mu$  and induced  $n$  and  $\gamma$ .

# Construction



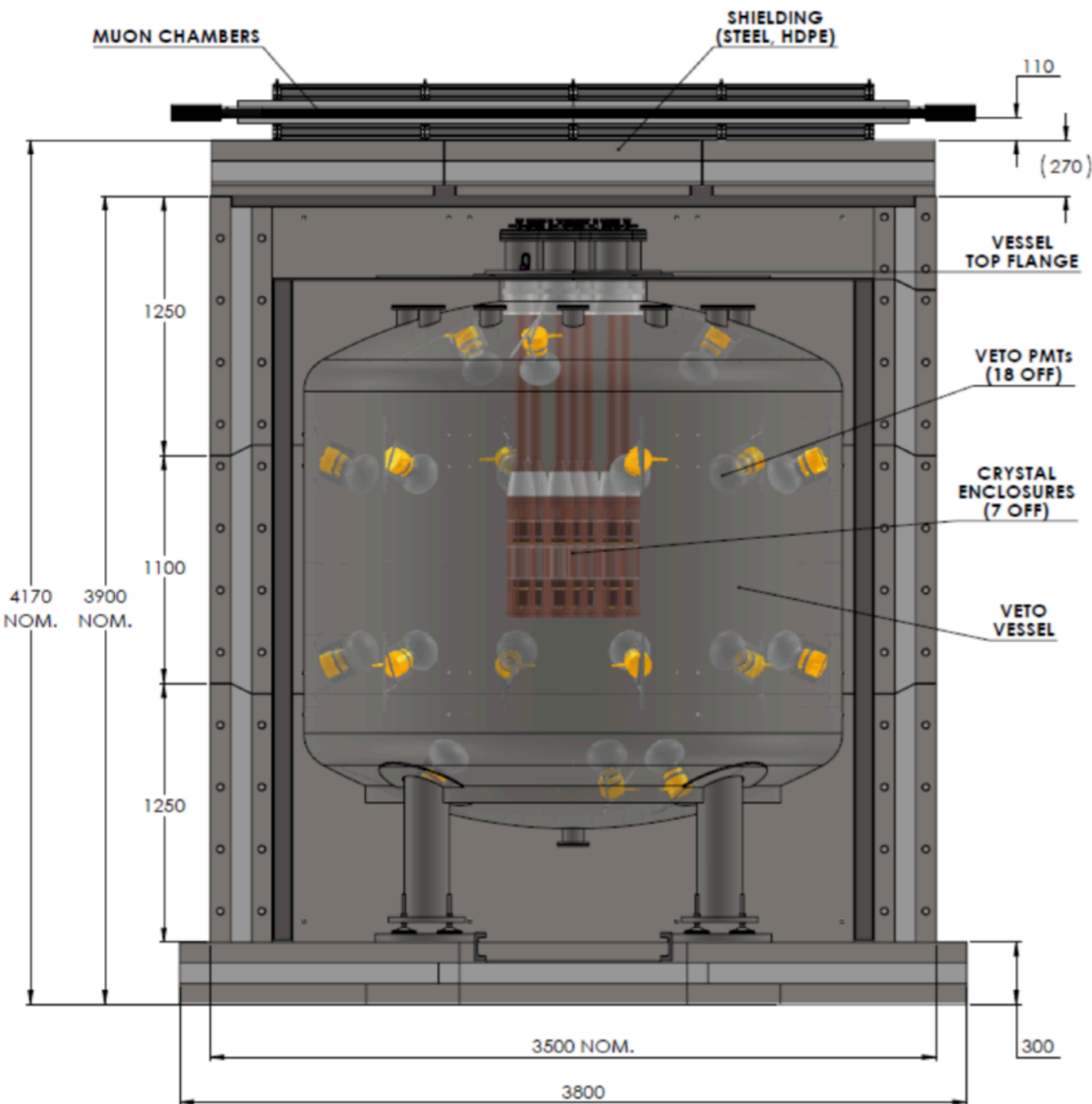
- **PMTs (Hamamatsu):**

- **Veto:** 18 oil-proof base 8" R5912 @500 MS/s. Full order finalised.
- **Crystal:** 14 low-radioactivity 3" R11065 @500 MS/s. Full order finalised.
- **Muon system:** 16 R13089 @3.2 GS/s. Already procured.

- **Veto vessel:** manufactured in 2019 by Tasweld Engineering (stainless steel). Pressure and leak tests completed. Lumirror reflector coating procured. Lumirror installation will be tested in March together with PMT mounts. Vessel currently at Swinburne Uni (Wantirna).

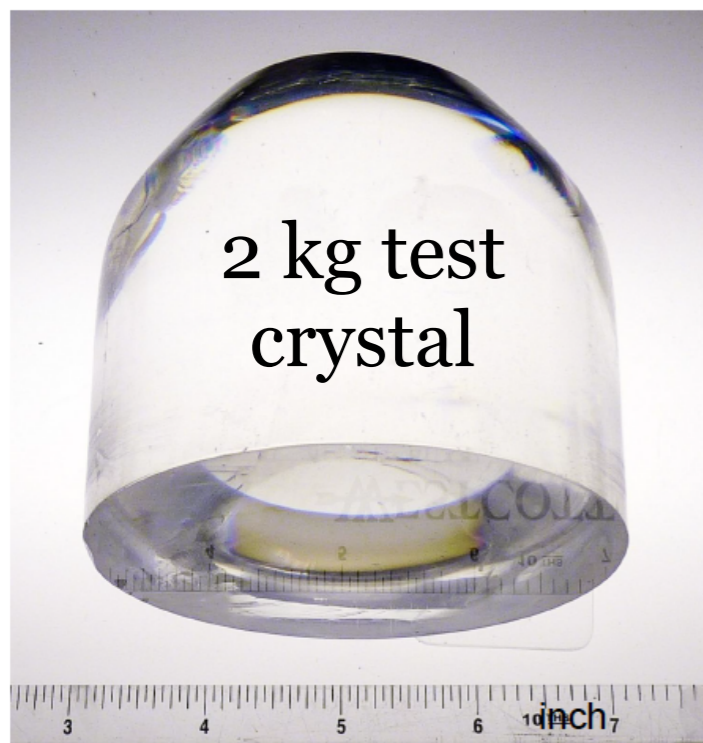
- **Shielding:** carbon steel + high density polyethylene (HDPE). Design almost completed. Awaiting sign-off by engineering firm (WSP). Material procurement ongoing.

# Construction



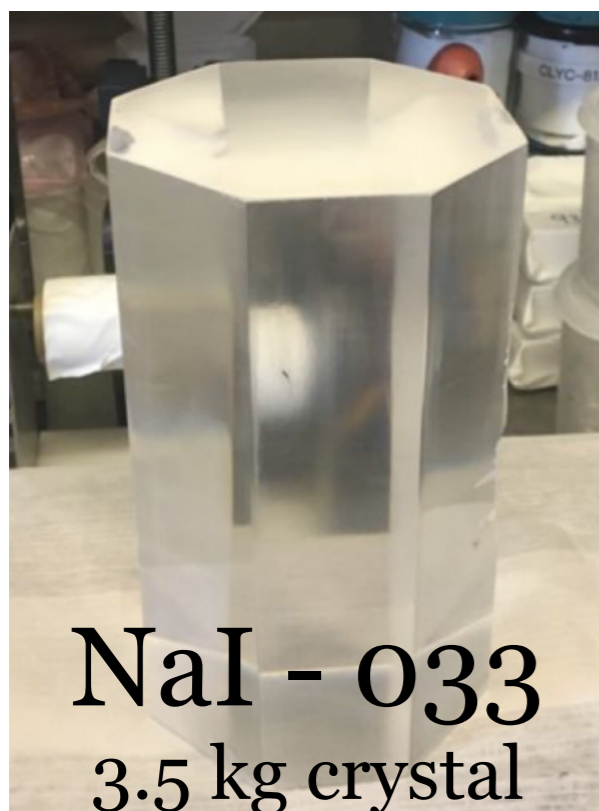
- **Crystal enclosures:** oxygen-free high thermal conductivity copper (OFHC) + teflon components (all procured). Manufacturing design finalised in late 2020. First prototype manufactured at ANU b/w November and January 2021. Assembly test in incoming weeks.
- **Crystal insertion system:** insertion, extraction and substitution of enclosures in “wet” conditions. Design finalised in December 2020.
  - **Crystal glove box (GB):** acrylic. Safety for manoeuvring enclosures. Contract for manufacturing signed with Palazzi srl. Shipping expected in mid-2021.
  - **Aluminum framing:** supplied by Eljay Engineering in early 2020. Soon will be delivered and tested in Melbourne.
  - **Support block:** PVC bellow for mechanical vertical decoupling b/w GB and framing (Palazzi + Ipromo). Hollow pipe for mechanical connection b/w GB and framing from ANU workshop later in 2021.
- **Fluid handling system:** draft of piping and instrumentation diagram finalised in mid-2020 and issued for revision in collaboration with INFN-LNGS in February-March 2021.
- **Calibration system:** in conceptual design phase.

# NaI(Tl) crystals

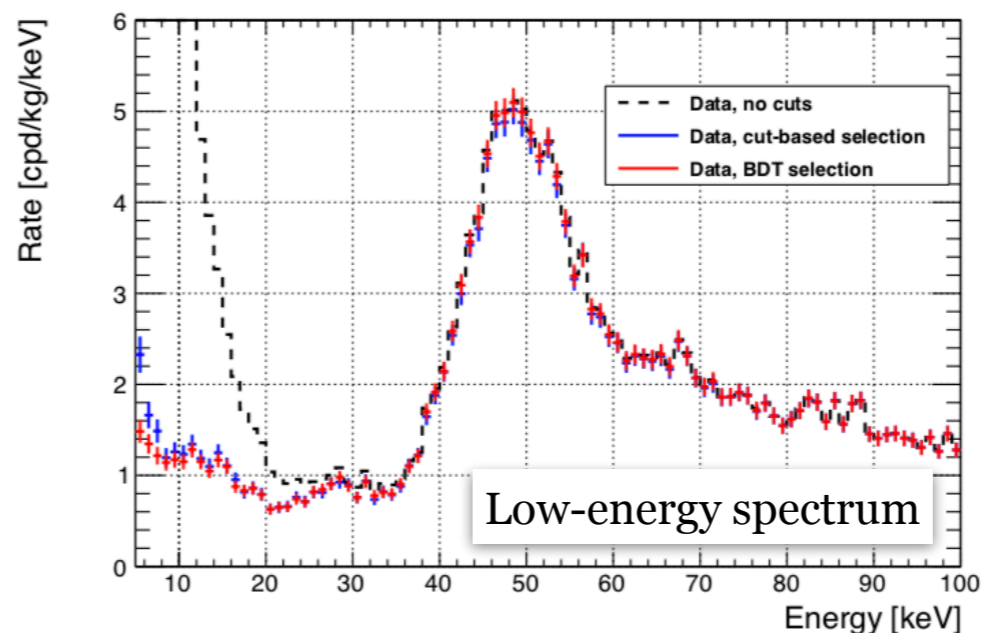


- First successful growth in 2015 led by Princeton University.
- Astrograde NaI powder & crucible by Princeton.
- Growth by RMD using vertical Bridgeman technique in a sealed ampoule.
- High sensitivity ICP-MS test shows excellent purity:

| Element | DAMA powder<br>[ppb] | DAMA crystals<br>[ppb]   | Astro-Grade<br>[ppb] | SABRE crystal<br>[ppb] |
|---------|----------------------|--------------------------|----------------------|------------------------|
| K       | 100                  | ~13                      | 9                    | 9                      |
| Rb      | n.a.                 | <0.35                    | <0.2                 | <0.1                   |
| U       | ~0.02                | $0.5-7.5 \times 10^{-3}$ | $<10^{-3}$           | $<10^{-3}$             |
| Th      | ~0.02                | $0.7-10 \times 10^{-3}$  | $<10^{-3}$           | $<10^{-3}$             |

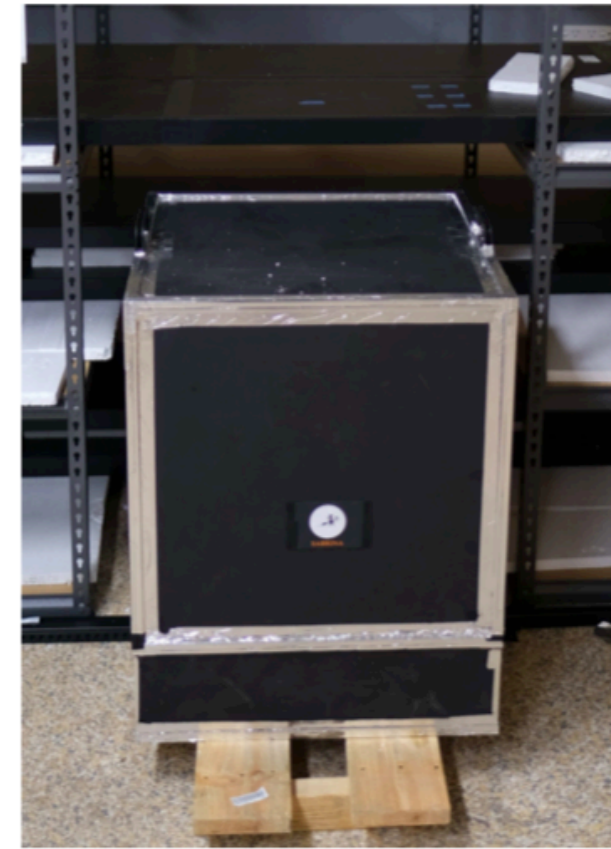
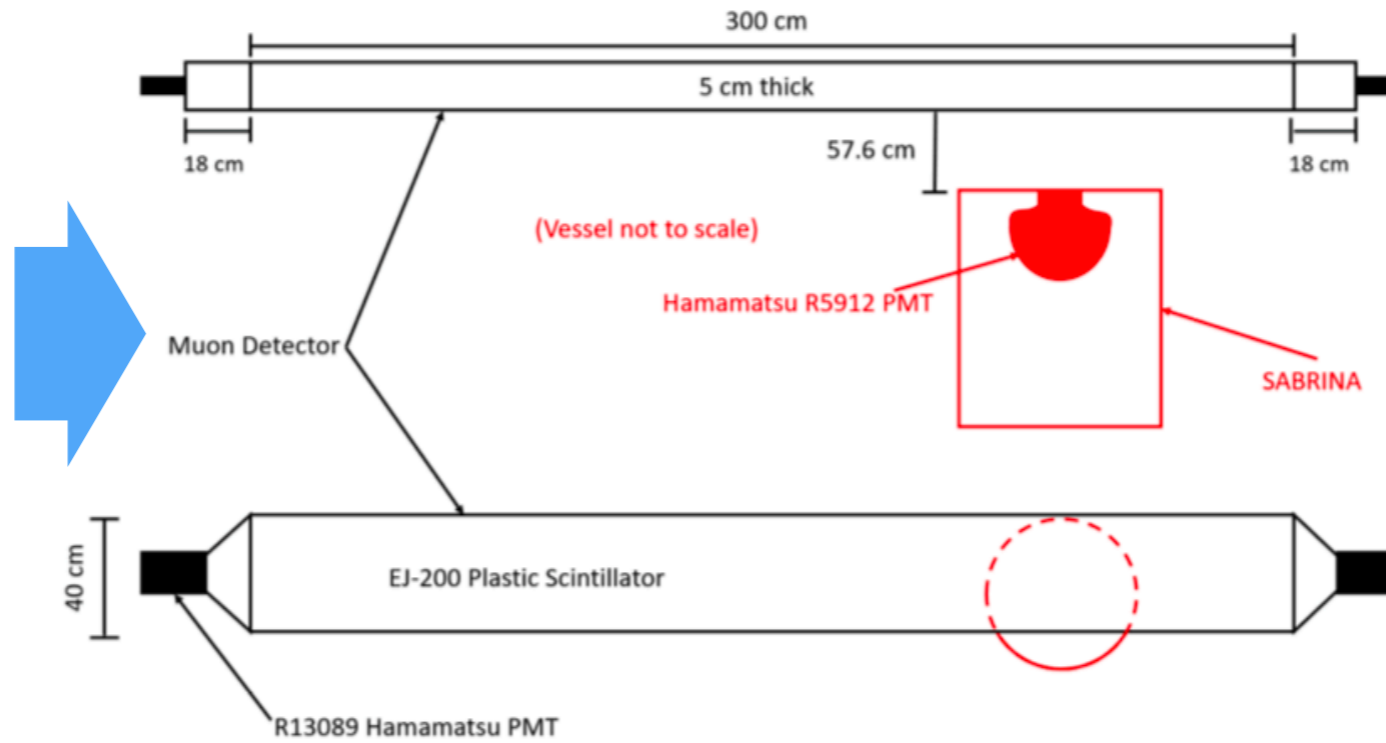


- Latest crystal ready since October 2018 and assembled in May 2019.
- Arrived on 6 August 2019 by boat @LNGS. Characterisation finalised and about to be published. More details in **F. Nuti's** talk.





# Liquid scintillator veto and SABRINA

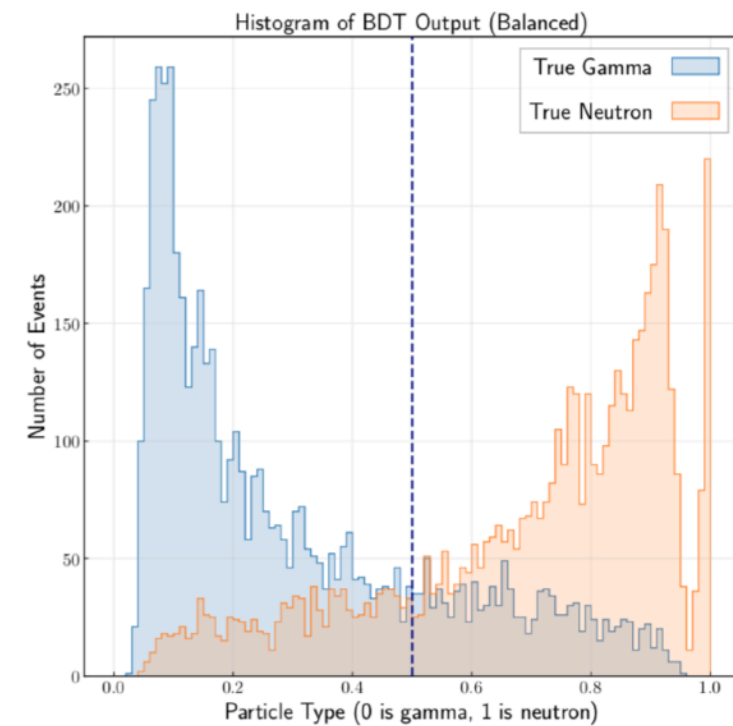
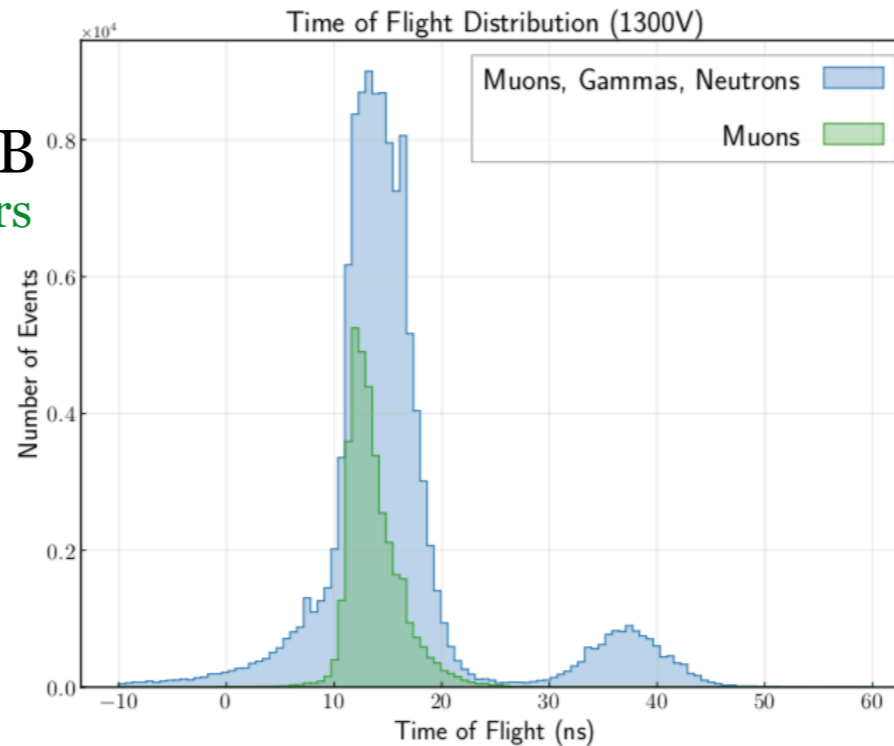


light-yield enhancer

Linear Alkyl Benzene + PPO & Bis-MSB  
 main scintillator with long attenuation length

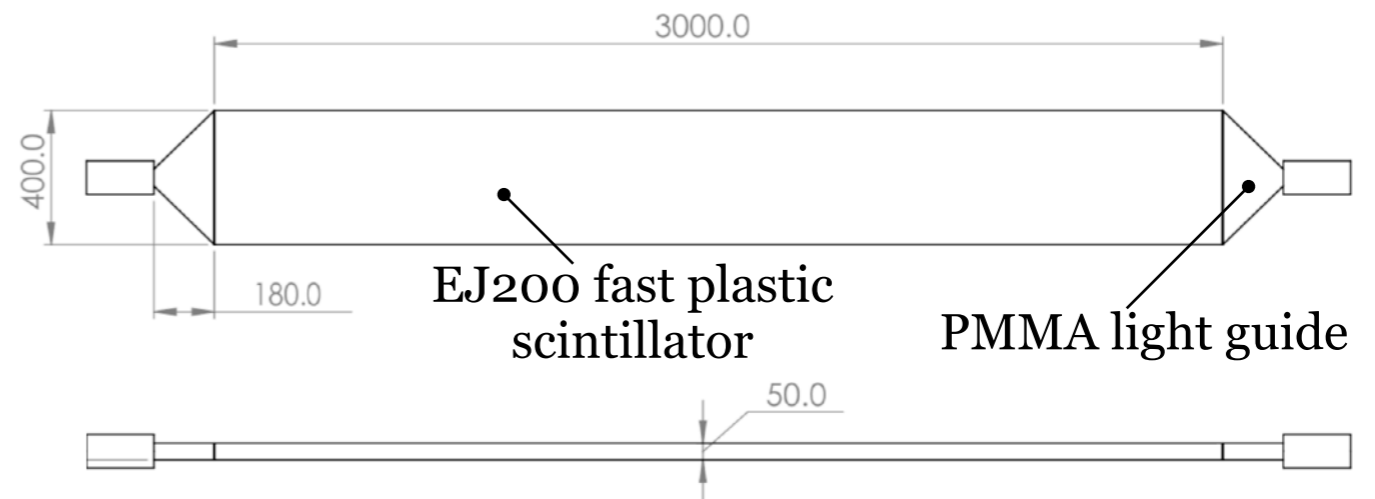
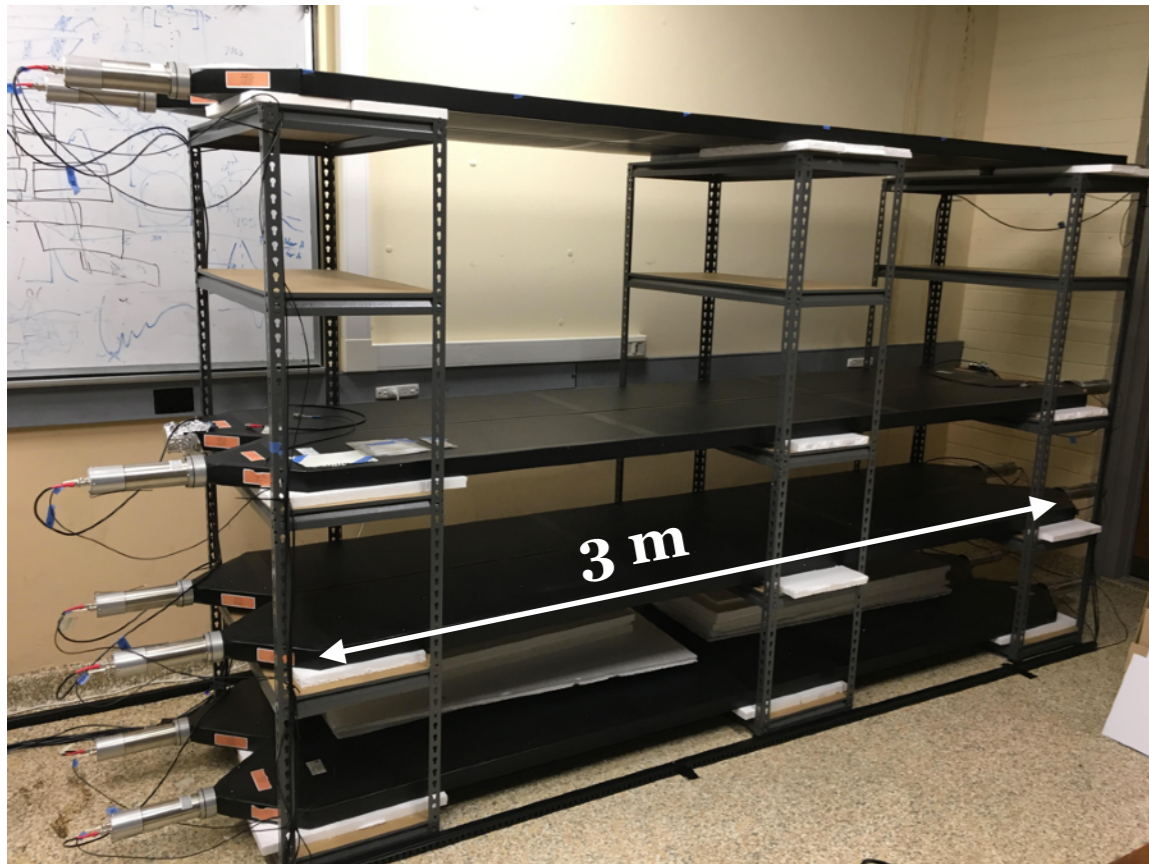
wavelength shifters

- Mockup veto system for SABRE tested in combination with the muon detector.
- Separate  $\gamma/n$  while tagging muons:
  - Time-of-Flight + multivariate analysis.
- Compatibility tests ongoing at ANU b/w liquid scintillator and SABRE materials.

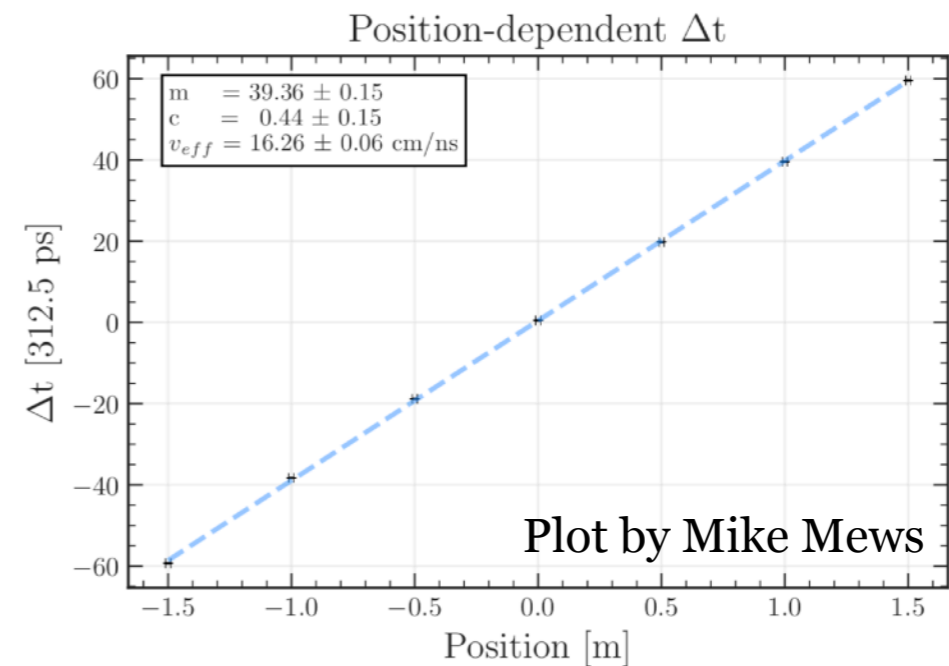
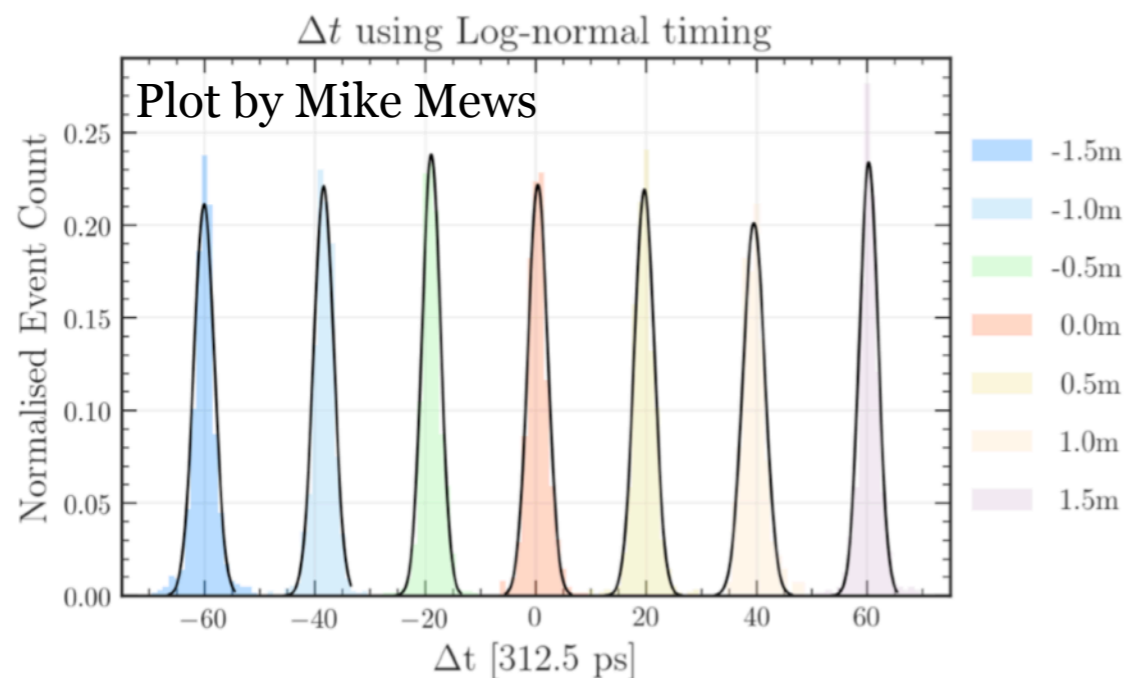


Plots by Lachlan Milligan

# Muon detector



- Incident position resolution  $\approx 5$  cm using PMT time difference  $\Delta t$ .
- Use cases:
  - Investigate muon flux using a two-layer configuration to resolve incident angle.
  - Provides  $\mu$  vs  $n/\gamma$  separation in main SABRE deployment.
- Calibration studies soon to be finalised. All equipment procured.



# Computing

- **Services + software:**

**Management:** Bitbucket, Confluence, JIRA.

**Storage + computing:** Mediaflux + Spartan.

**Coding:** python, C++, GEANT4, ROOT, MUSIC, etc.

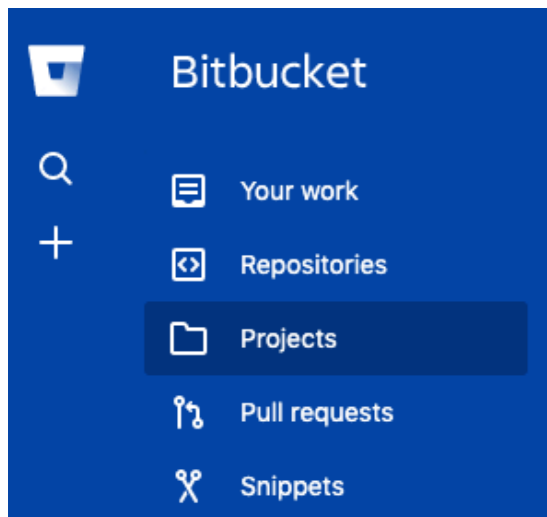
- **Disk requirements (projected usage):**

Data storage: 100 TB / year maybe more.





Simulation: 10-20 TB / year.

- **CPU requirements:**

To be estimated...

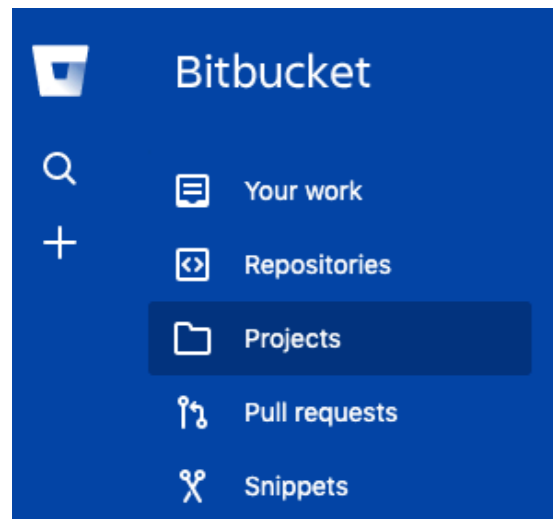


## Projects





| Project                                                                                                  | Key | Description                                                                            |
|----------------------------------------------------------------------------------------------------------|-----|----------------------------------------------------------------------------------------|
|  general - offline    | OFF | General offline software containing core functionalities and experiment-independent    |
|  general - online     | ONL | General online software                                                                |
|  general - simulation | SIM | General simulation software containing core functionalities and experiment-independent |
|  SABRE                | SAB | SABRE experiment software area                                                         |



# Offline software: structure



## Projects

| Project                                                                                                | Key | Description                                                                            |
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- **Data-preparation:**

- Offline Event Builder.
- Data-format transformations.
- Data/simulation harmonisations.



- **Event Reconstruction:**

- Pulse reconstruction.
- Calculation of discriminating variables.
- Application of calibrations.
- Waveform digitisation for simulation, etc.

Close to v1 release  
handling multi-channel chain



- **Data analysis.**

- Definition of variables.
- Selection of events.
- Plotting.

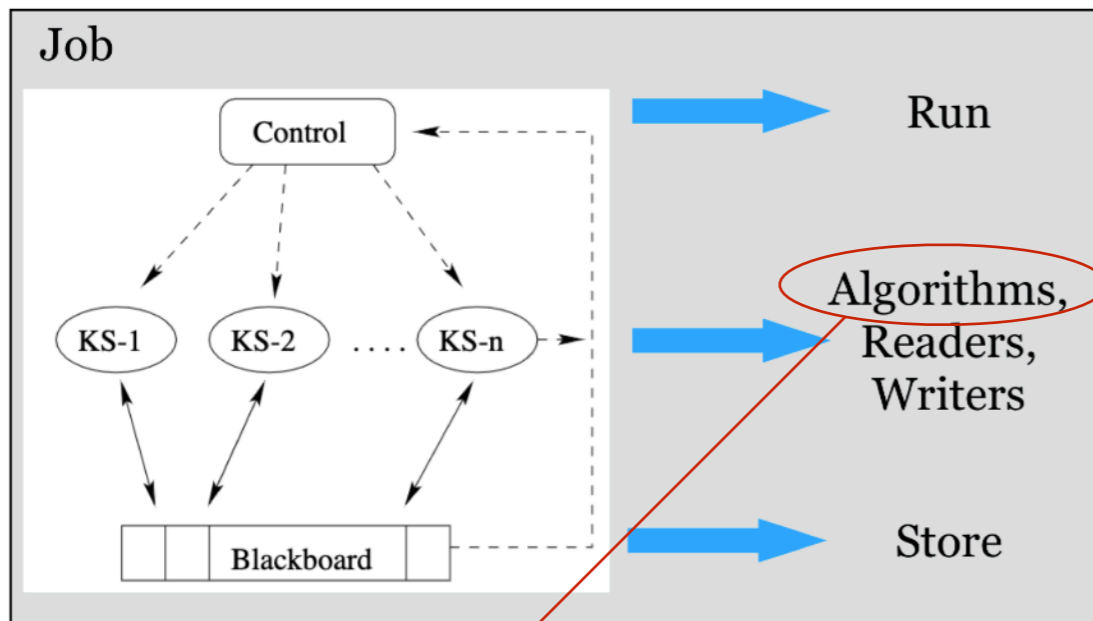


# Offline software: pyrate

- Multi-purpose offline software:
  - [pyrate framework](#).
  - python-based reconstruction, analysis, transformations, etc.
- Aim to be used in general particle physics workflows.
- High modularity and reusability of algorithms.
- Easy to use at different levels of software experience.



## Blackboard design pattern

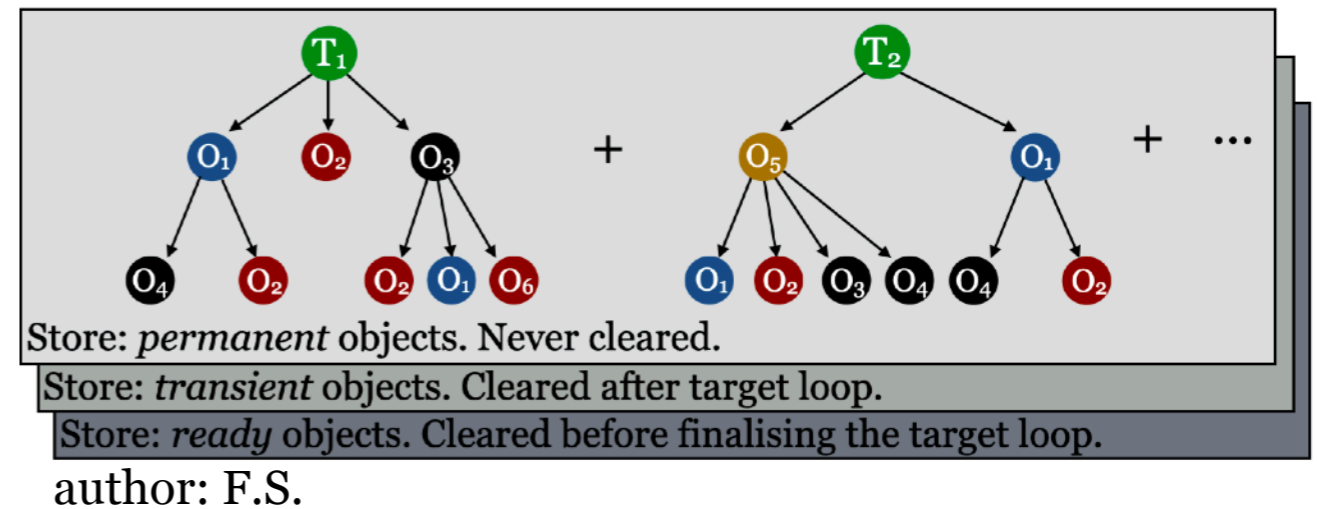


- A single algorithm instance for computing similar objects/variables.
- Lazy-evaluation of objects/variables.

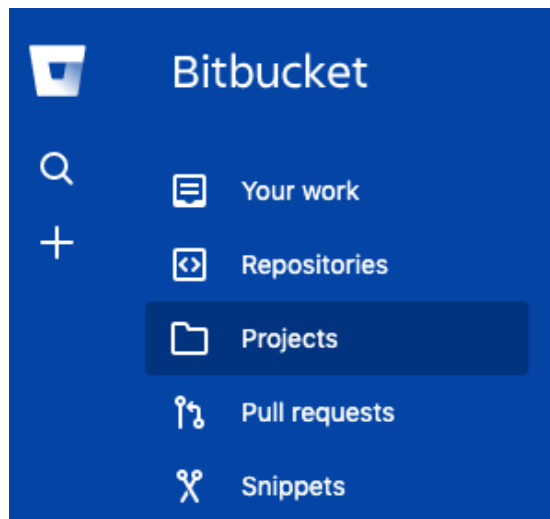
Initialise: target loop in input loop

Execute: target loop in input+event loop





Finalise: target loop only



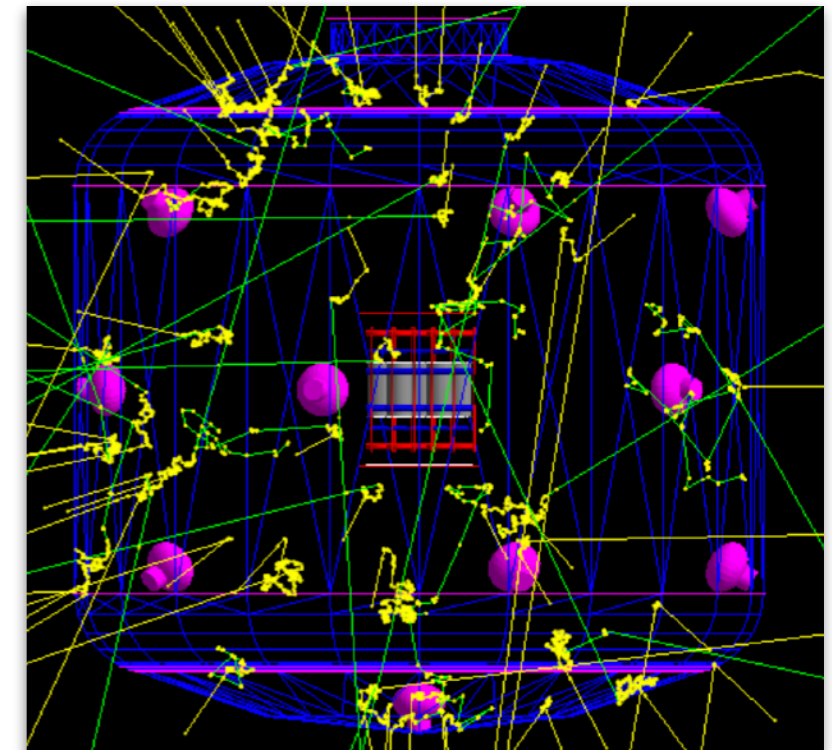
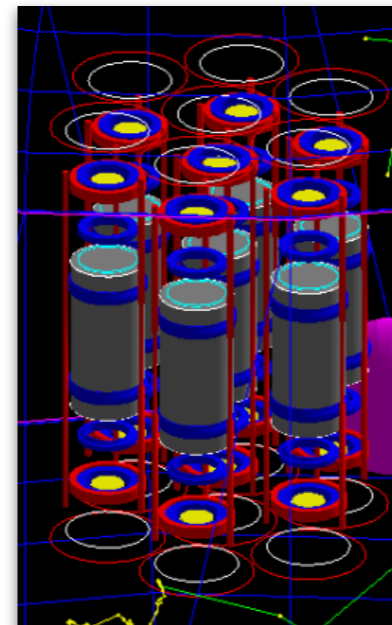
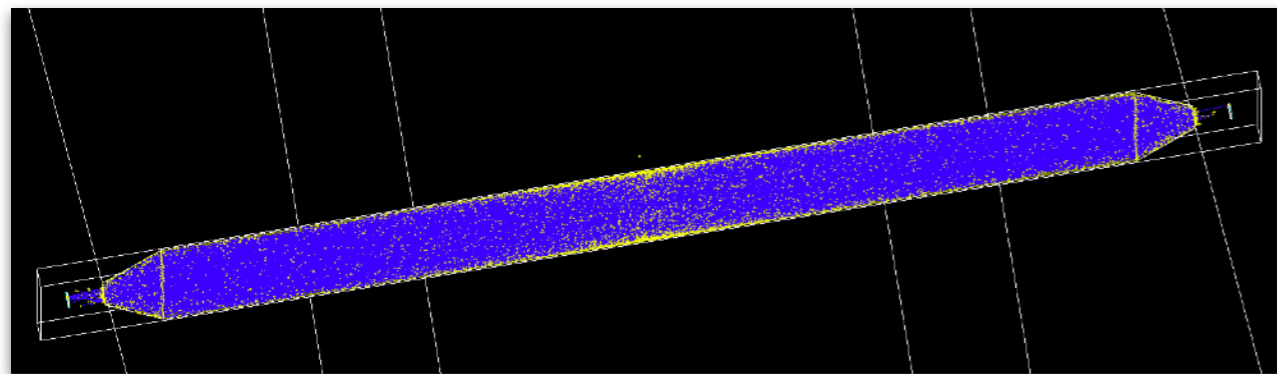
# Simulation software



## Projects

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- Geant4 10.7 + ROOT 6.22/06 in C++.
- Simulation of separate sub-systems/components finalised.
- Currently working on integrating the major components for a full background model.
- Release of v1 will soon be ready excluding waveform modelling and signal digitisations.















# Conclusions

- First round of publications under preparation:
  - Muon detector performance.
  - Offline software.
  - PMTs characterisation.
  - Full SABRE background model.
  - etc.

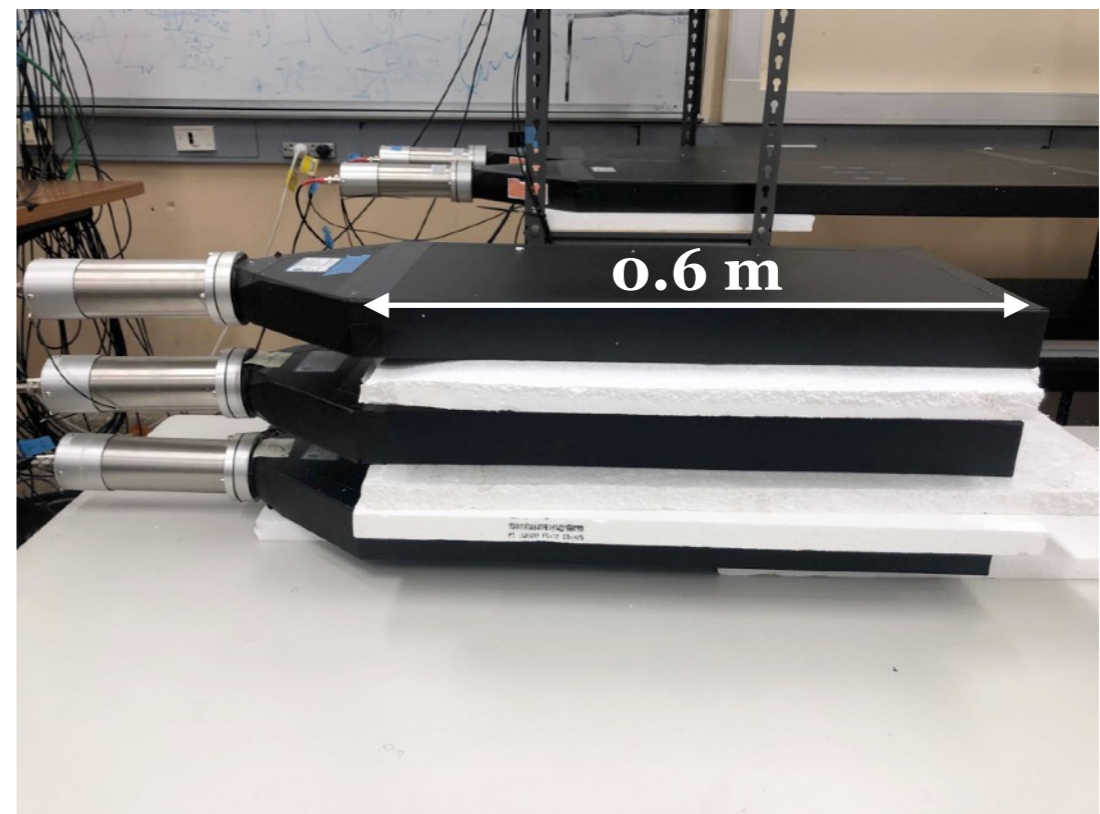
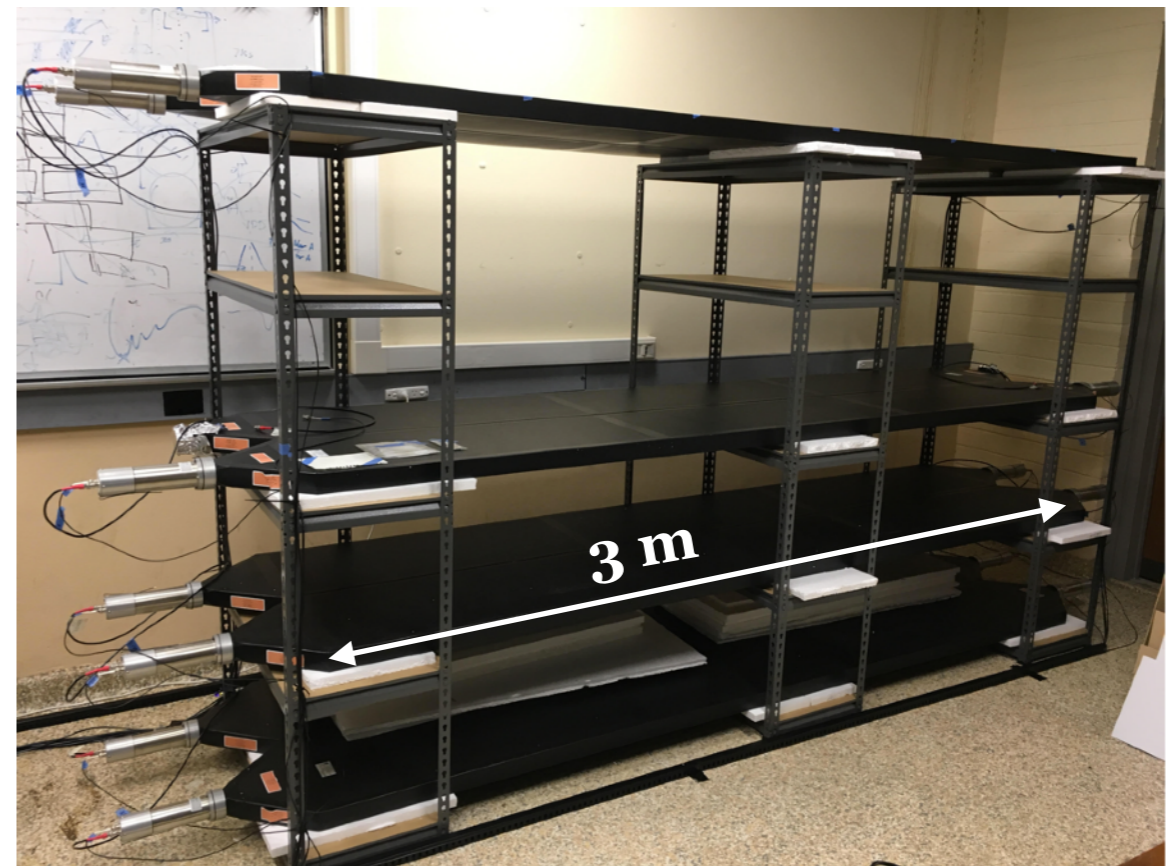
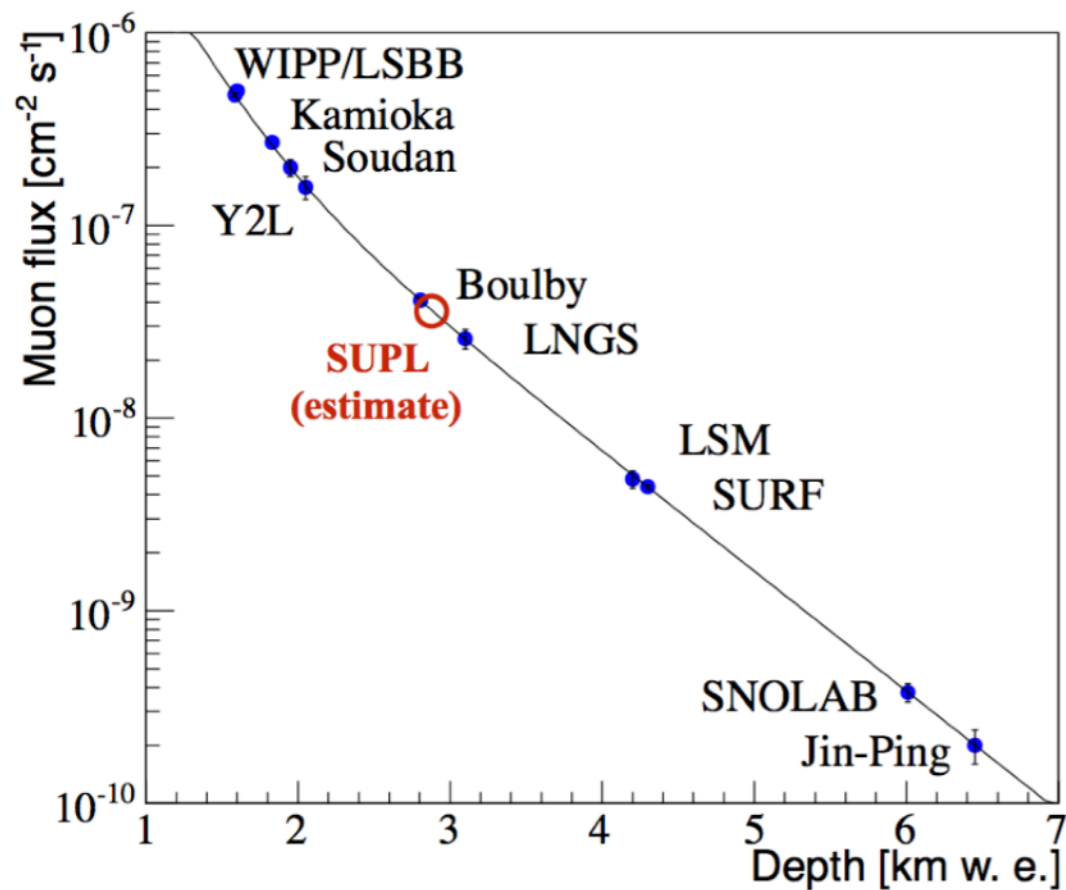
# Backup



# pyrate: development levels

|                                                                                                                                                                                              | Summer student                                                                        | Master student                                                                        | PhD student                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>• Modify configuration of objects and jobs.</li><li>• Reusing existing algorithms.</li><li>• python knowledge is not even required for this!</li></ul> |    |    |    |
| <ul style="list-style-type: none"><li>• Define algorithms for objects.</li><li>• Define algorithms for targets (rare).</li></ul>                                                             |   |   |   |
| <ul style="list-style-type: none"><li>• Define Readers (rare).</li><li>• Define Writers (rare).</li></ul>                                                                                    |  |  |  |
| <ul style="list-style-type: none"><li>• Maintenance.</li></ul>                                                                                                                               |  |  |  |

# Muons @ SUPL



- Detector performance:
  - Preliminary studies with detector at the surface.
  - Study dead time, acceptance, efficiency.
- Muon flux measurement @ SUPL:
  - Magnitude.
  - Time dependence.
  - Angle dependence.