WIMP Direct Detection: Progress and Plans

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Australian National University

Australian Government
Australian Research Council

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THE UNIVERSITY OF MELBOURNE

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Direction detection related programs

Program		2019	2020	2021	2022	2023	2024	2025	2026	2027
WIMP Direct Detection	SABRE proof-of-principle (Italy)									
	SABRE South									
	Cryogenic Detector									
	CYGNUS small prototype									
	CYGNUS $1m^3$ prototype									
WISP Direct Detection	ADMX Run 1b and Run 1c									
	ADMX Upgrade, 8-16 μeV				Design/Proto		Construct			
	ORGAN									
	ORGAN Upgrade									
R&D for WIMP & WISP Searches (including Precision Metrology)	Room temp. NaI and veto systems									
	Cryogenic bolometer/phonon sensors									
	TPC large scale									
	Precision frequency schemes									
Nuclear Metrology	ICPMS – Develop native capability									
	HPGe – Rationalise native capability									
	AMS Improve ToF system									
	AMS Improve resolution of ion chamber									
	AMS Integrate electrostatic analyzer									

Strong overlaps across research themes

CDM advantages:

- **Cross-pollination across disciplines (nuclear, particle, astro, metrology, quantum)**
- **Interplay between theory and experiment.**

Need for extensive collaboration across nodes for successful experiments

Institution	WIMP Direct Detection	
	CI	RA + Engineer/Tech
Adelaide	Hill 0.4	Bolognino (A) 1.0 Level B 0.5 (First 3 years)
ANU	Lane 0.4, Stuchbery 0.4, New tenure track 0.4	Bignell (B) 1.0, Slavkovska (A) 0.5 Level A 1.0 (2021) Level A 1.0 (starting 2022) Engineer 1.0 (2021)
Melbourne	Barberio 0.4, Urquijo 0.4, Taylor 0.2	Level A 1.0, Level B 1.0, Eng 0.5-1.0
Swinburne	Duffy 0.2, Mould 0.2	Level B 1.0, Tech 0.5
Sydney	New tenure track, 0.4	Level A 1.0
UWA	Tobar 0.1, Goryachev 0.1	McAllister (A 0.4), A/B 0.5, Osborne (Tech 0.5)
Total FTE	3.6	9.9 research, 2.5-3.0 technical

These are only
- CIs, AIs
- New appointments paid by CDM funds.

It does not include:
- Some postdocs/ engineers already in the nodes.
- Extensive and important student involvement
- Expectations for significant theoretical collaboration

WIMP DD is a **large program**, but there is still considerable room for additional personnel to get involved.

Progress and illustrative plans

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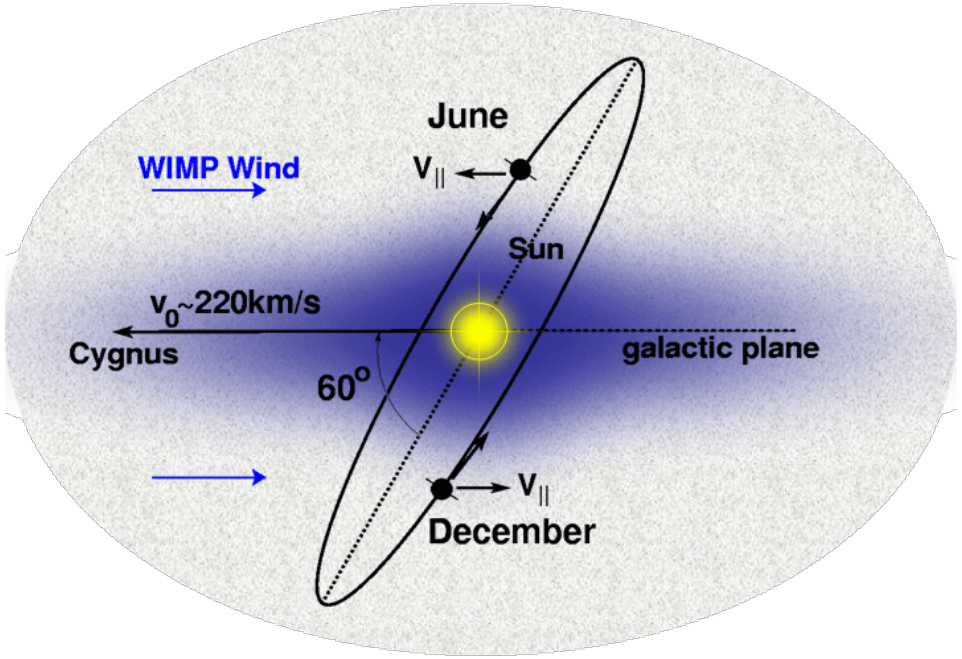
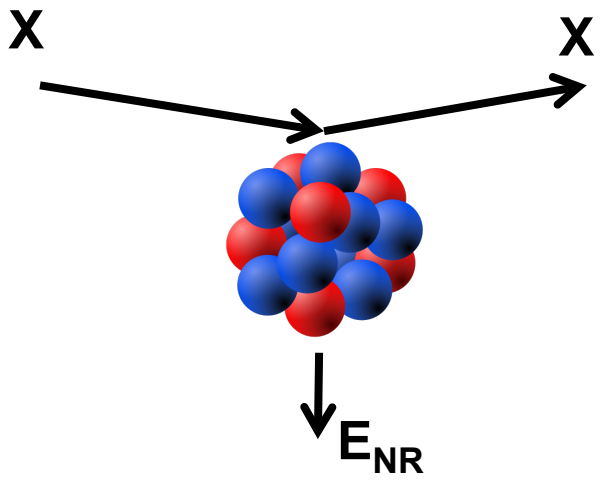
Detecting WIMPs – Annual Modulation Signature



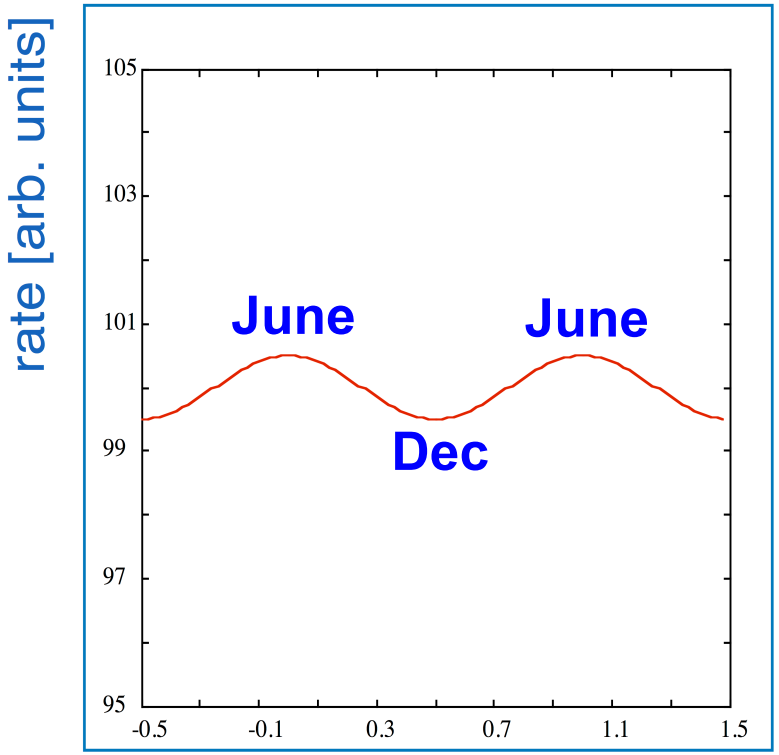
Standard halo model: Spherical halo of cold, dark matter permeating the galaxy with ρ_X~0.3 GeV/cm^3



WIMP interaction rate:

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

$2\pi/\omega$=1 yr and
t_0 on June 2nd.



Detector Signal

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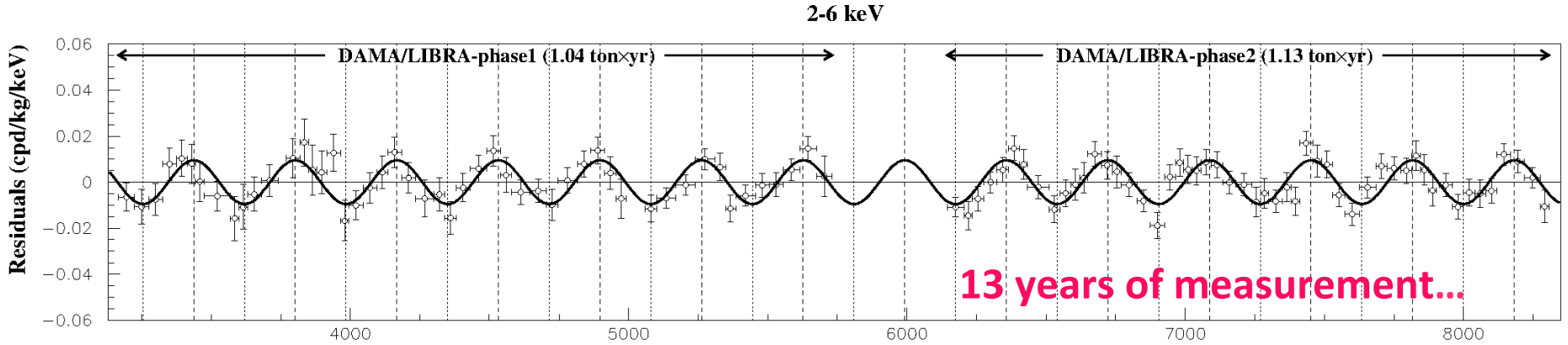
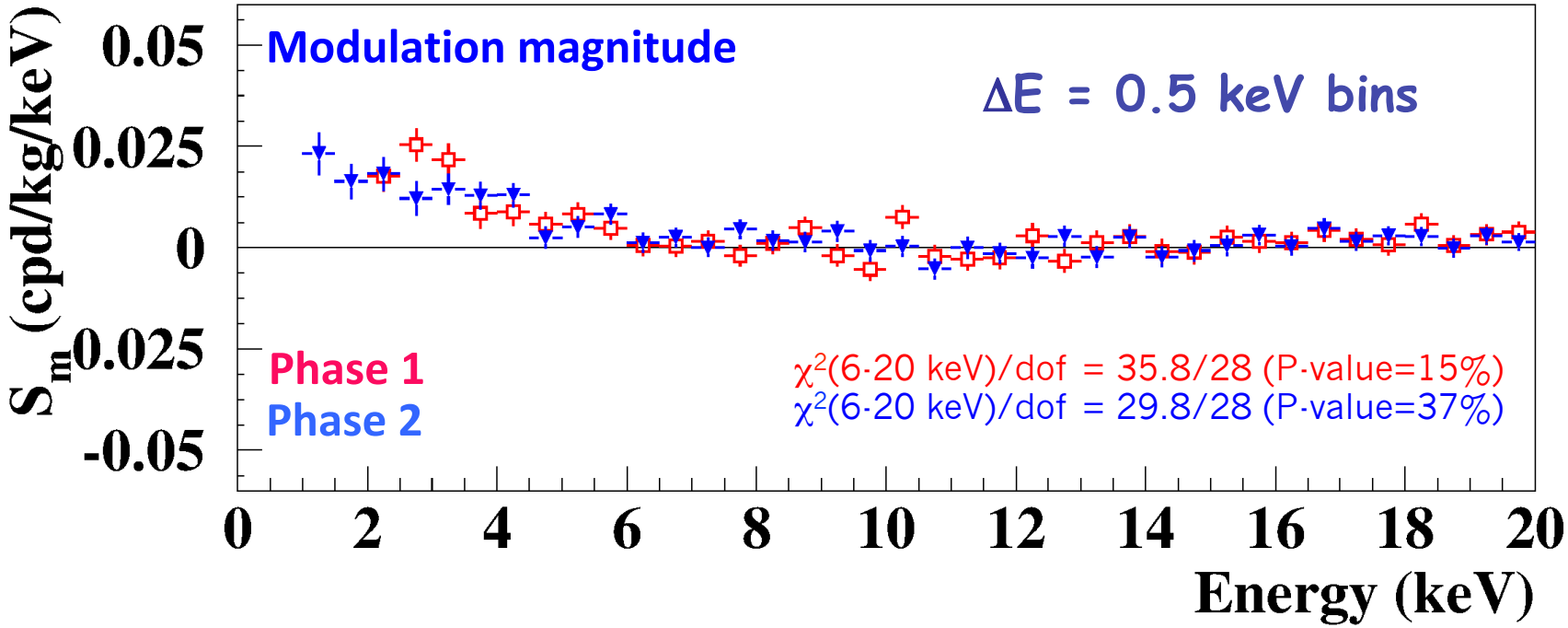
DAMA: Bernabei et al, arXiv:1805.10486

25 x 10 kg NaI(Tl)
at Gran Sasso, Italy





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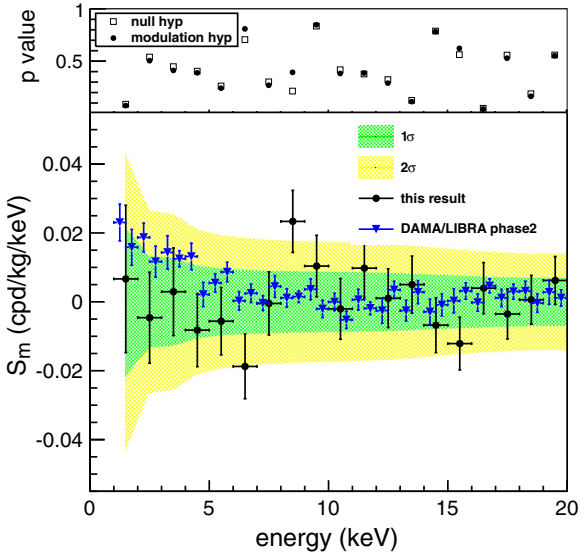
Global DM efforts with NaI(Tl)



ANAIS: PRL 123 (2019) 031301
-0.0015 ± 0.0063 cpd/kg/keV

COSINE: PRL 123 (2019) 031302
-0.0083 ± 0.0068 cpd/kg/keV

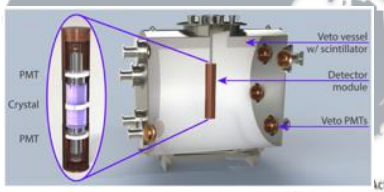
DAMA: **0.0095 ± 0.0008 cpd kg^{-1} keV^{-1}**

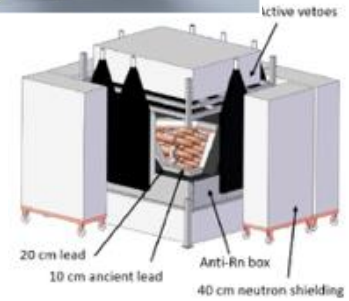
NO SMOKING GUN

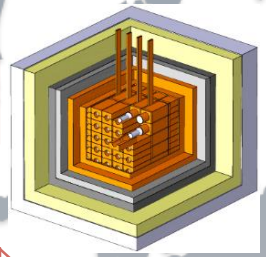
COSINUS @ LNGS

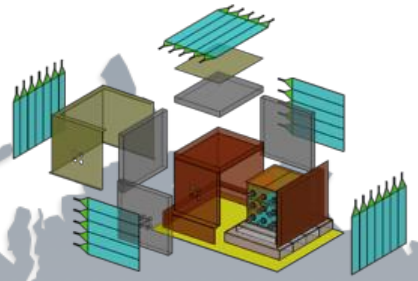
DAMA @ LNGS

SABRE @ LNGS









KIMS/COSINE @ Yangyang

Background ~ 3 dru

In Data-taking since Sept/2016

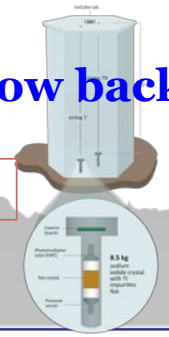
PICO-LON @ Kamioka

ANAIS @Canfranc

In Data-taking since Aug/2017

SABRE @ Stawell

COSINE, SABRE, PICO-LON are developing low background NaI(Tl) crystals



DM-Ice @ South Pole

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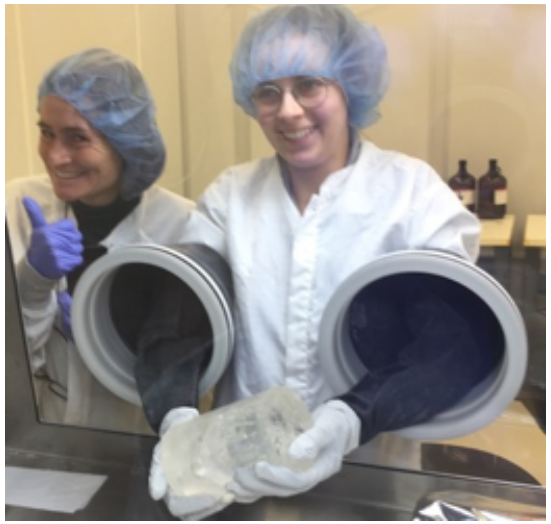
SABRE – North and South

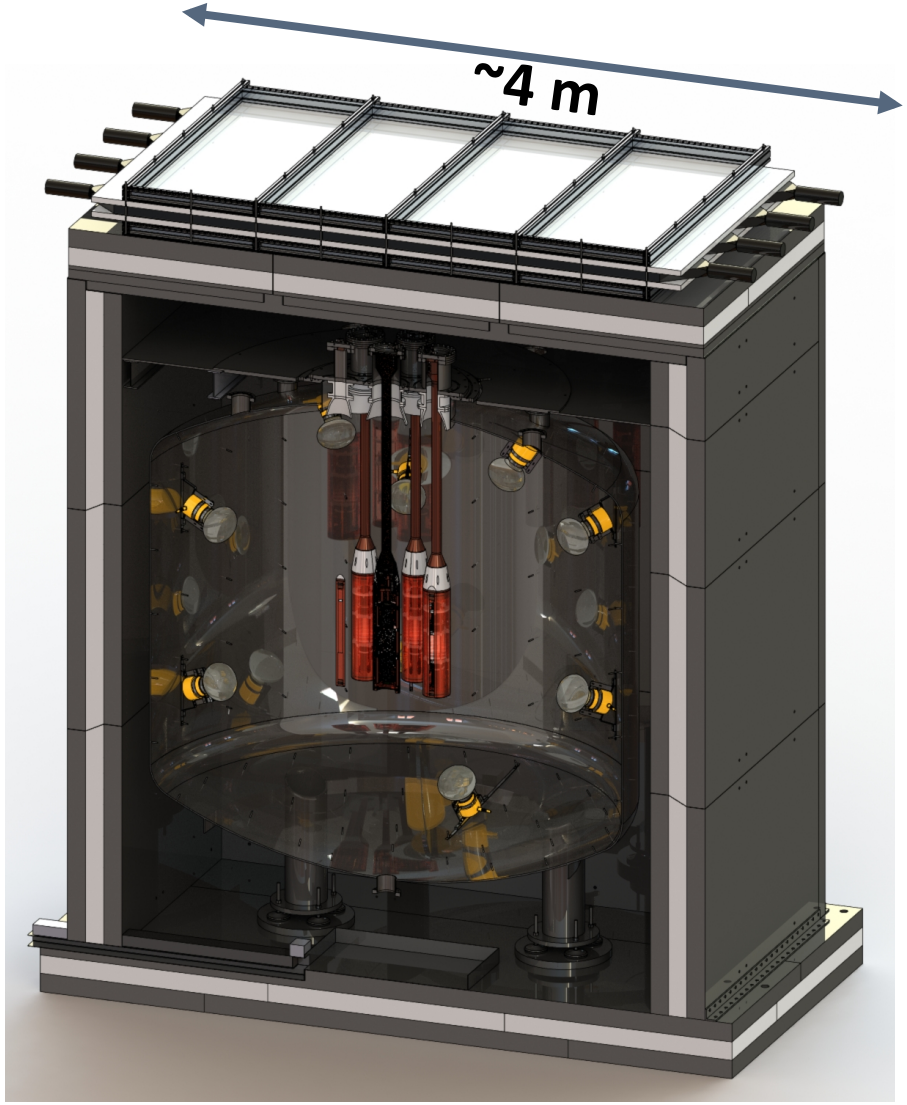
Key metric: background in 2-6 keV region:
DAMA (~1 dru), ANAIS (~3.6 dru), COSINE (~2.5 dru)
SABRE design background of 0.36 dru



NaI crystal development at Princeton

PoP (1 crystal) at LNGS in Italy

Monte Carlo simulation: Astroparticle Physics 109 (2019) 1-9.
SABRE Project and SABRE PoP: Eur Phys J C (2019) 79:363



SABRE South – Straight to full scale (7 NaI crystals) at SUPL

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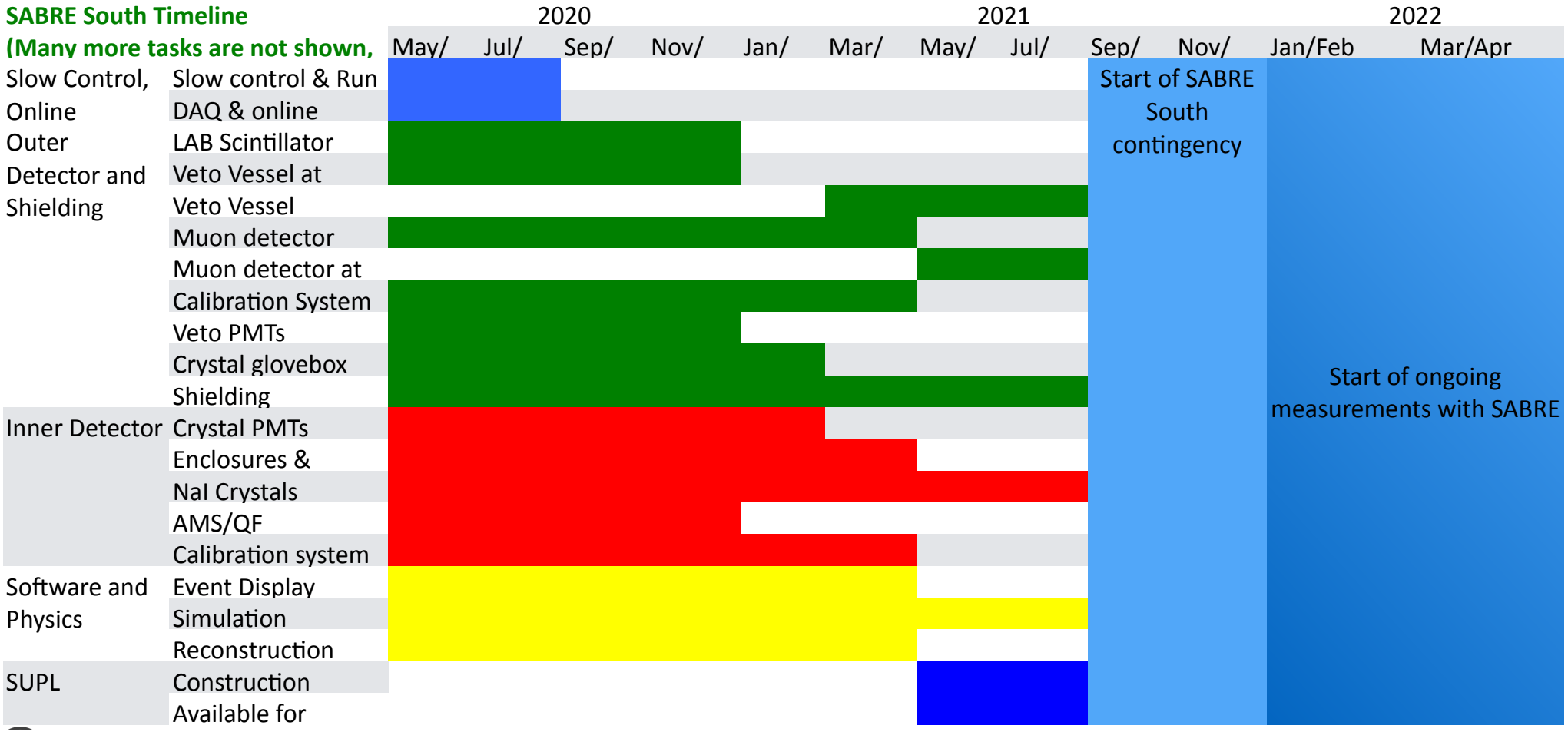
RESEARCH: SABRE



Aiming for installation in late 2021 and full operation in 2022

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SABRE South status update

Executive Group managing SABRE South progress:
Elisabetta Barberio (Spokesperson), Greg Lane (Technical Coordinator, ANU), Tiziano Baroncelli (Engineer)
Alan Duffy (Swin), Gary Hill (Adel), Geoff Brookes (Swin), Phill Urquijo (Melb)

Significant hardware exists…

- Working towards a late 2021/early 2022 start
- Obvious dependence on **SUPL completion date**
  - Long term measurement of background (muons, gammas, neutrons) within SUPL is critical for interpretation of SABRE results and future experiment planning
- Budget for SABRE from ARC LIEF – largest uncertainties are:
  - **Final price of shielding – Radioactivity measurements complete**
  - **Method of crystal production – SICCAS / RMD – in progress**
    Coordination with COSINUS (cryogenic NaI experiment at LNGS) and SICCAS (Chinese AIs Ge, Zhu and Yue) is underway.
    Also been contacted by RMD.

Many people collaborating and working very hard to get SABRE operational.

See talks from Phill Urquijo, Andrew Stuchbery, Lindsey Bignell, Federico Scutti, Francesco Nuti and possibly more… **Many students have key roles!**

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Other WIMP Detector Concepts

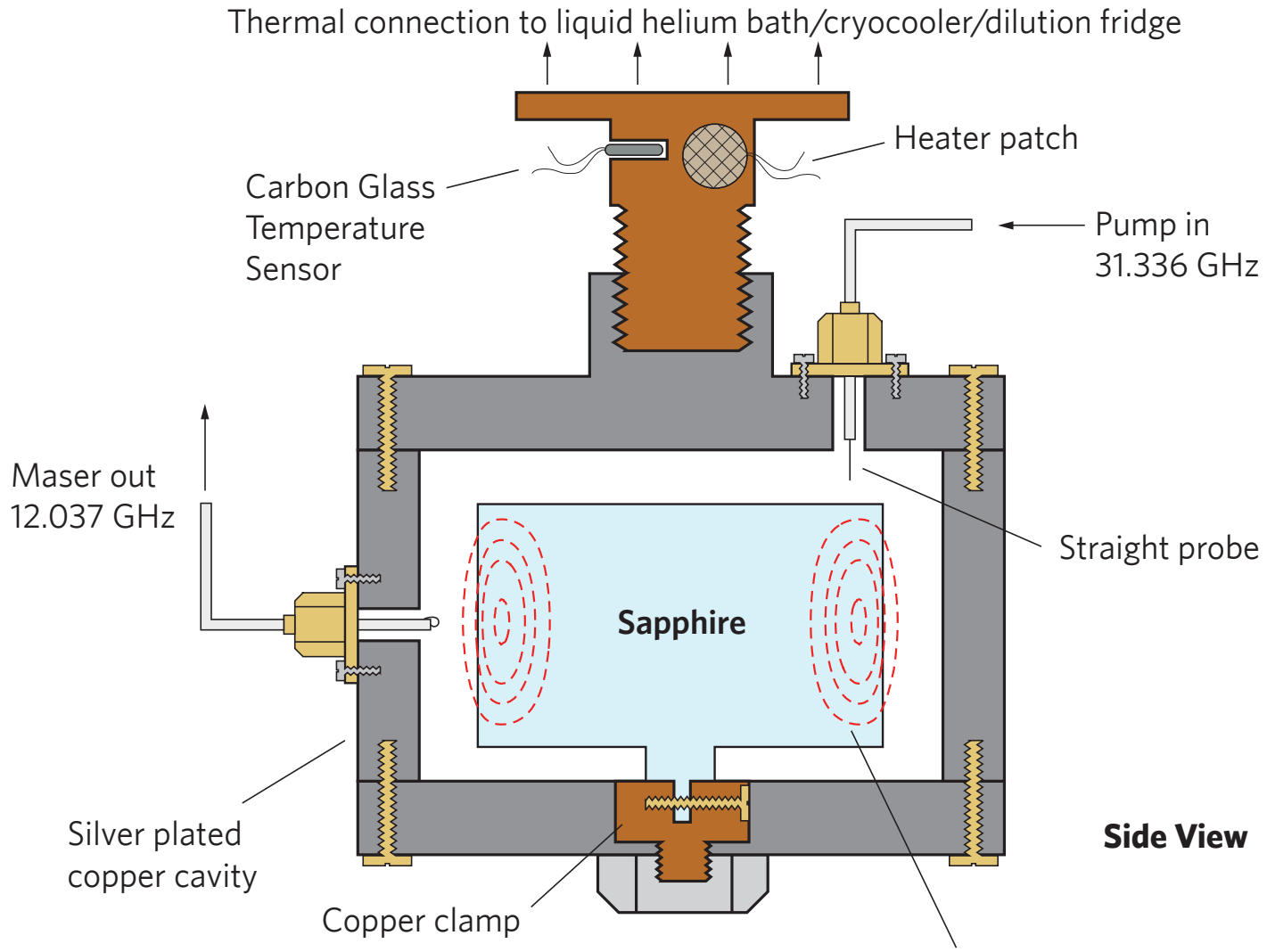
Cryo-DM

Low-mass WIMP detection with a cryogenic crystal or superfluid

Will combine R&D from WIMP and Advanced Metrology Themes

Conceptual investigations – no hardware as yet.

See Maxim Goryachev's talk



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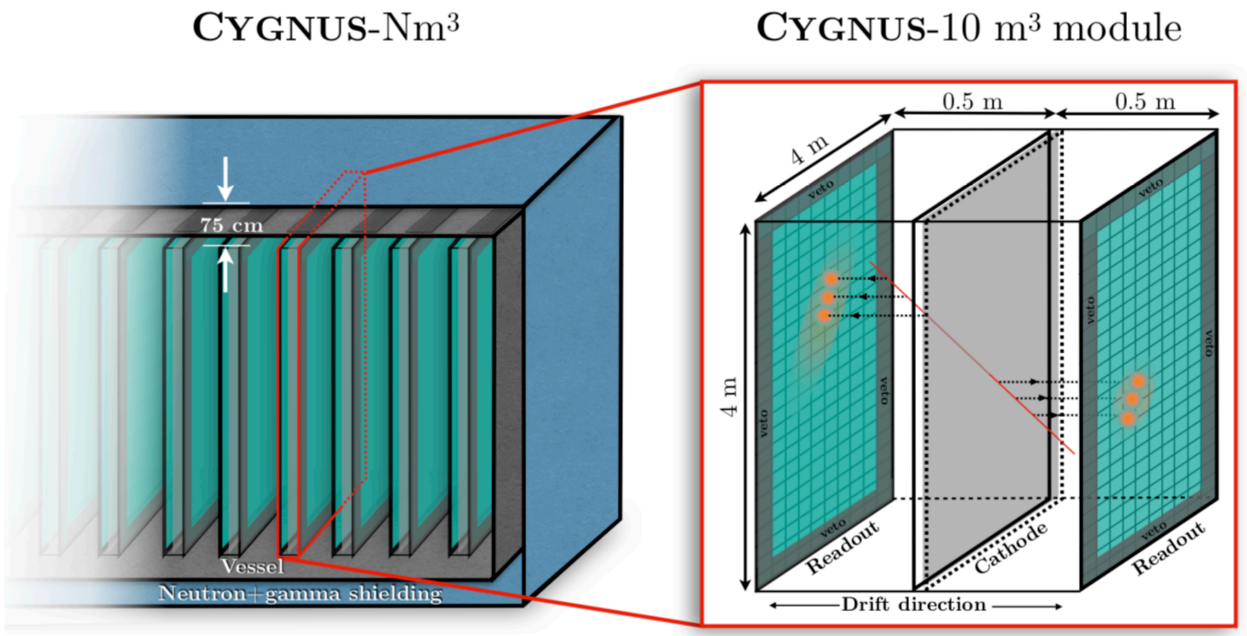
CYGNUS – Directional dark matter detection

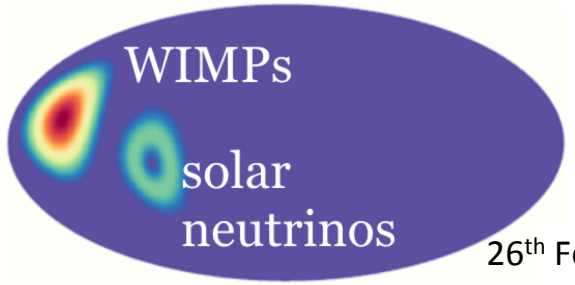
- Directional dark matter detection with gas TPCs (PI Spooner led the DRIFT experiment)
- “Proto-collaboration” with a long-term vision for a worldwide network
  - dark matter astronomy
  - important role of SUPL (southern hemisphere).
- Australia provides a member of the International Steering Committee (UK, Australia, Italy, Japan, USA).
- R&D scale detectors currently being designed/built locally at ANU and Melb.

Nucleus-WIMP collision

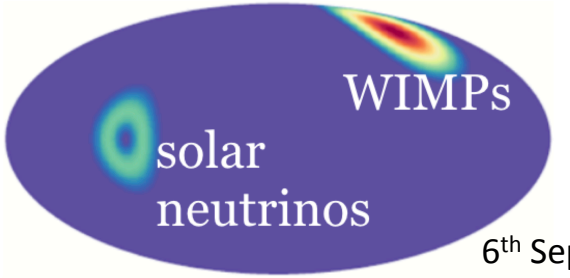
3D image of recoil track

-> WIMP direction





26th Feb



6th Sep

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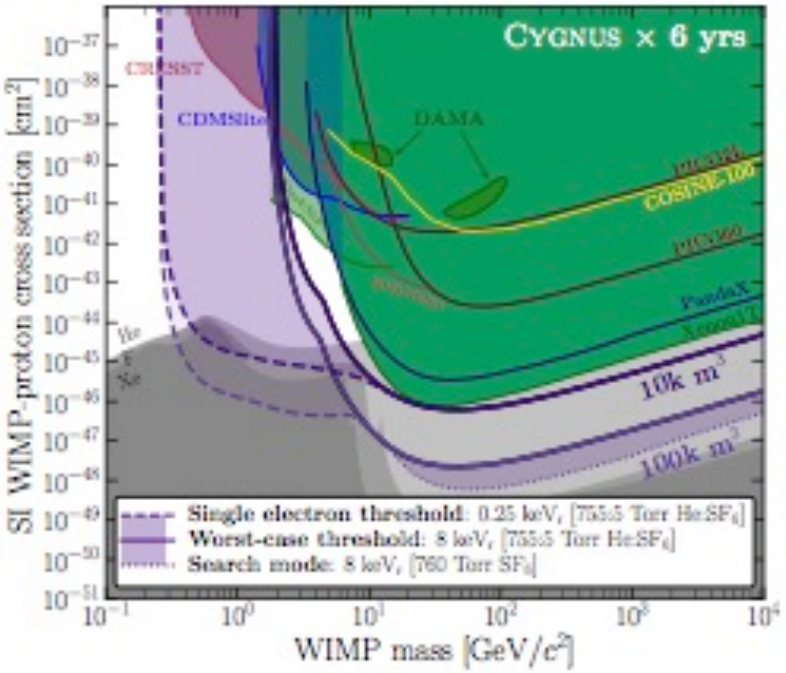
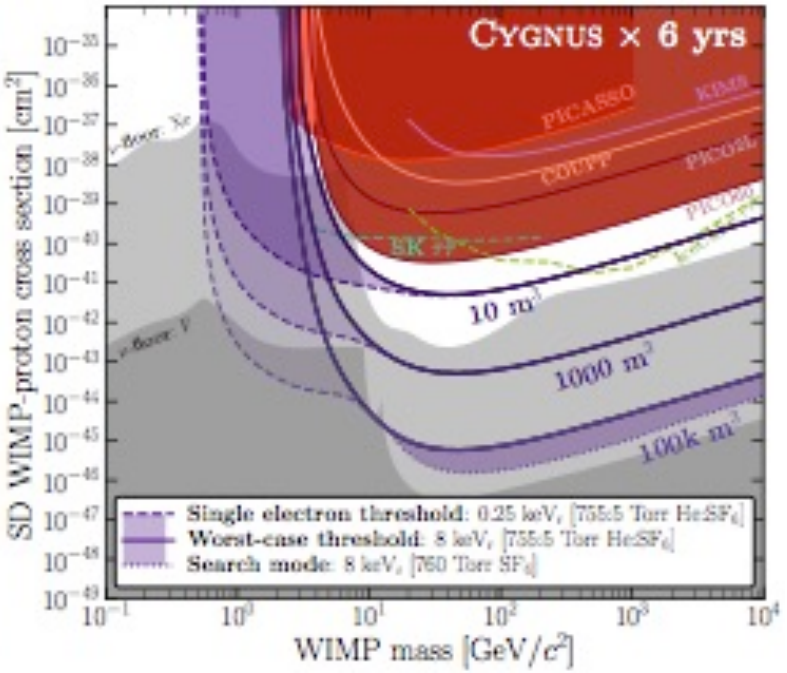
CYGNUS – Gas TPC – Really?

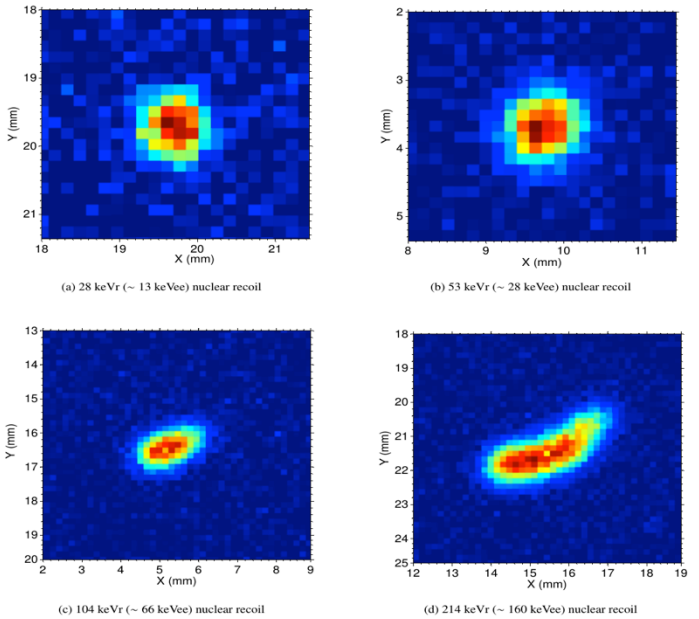
Rich event information makes up for low target mass.

Need low energy threshold, absolute positioning, directionality, vector sense, and particle ID.

All demonstrated at ~10 keV or less, but not simultaneously => R&D is needed.







Sensitivity discussion in recent CYGNUS concept paper: arXiv 2008.12587.

See talk today from Ciaran O'Hare and also his recent CoE seminar

Theory/experiment collaboration required to investigate physics case:

- **electron recoil versus nuclear recoil**
- **neutrino physics**

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CYGNUS plan

- R&D over first few years at small scale – eventual move to large scale.
- Funding for initial R&D activities – PI (DSTG) may provide some. Another $150k over the first two years from node budgets.

2020/21: TPC with GEMs and MWPC/optical readout (ANU/Melb) for gas characterisation studies (concept at top right)

TPC with GEMS and Silicon readout (Melb/DSTG/ANU)

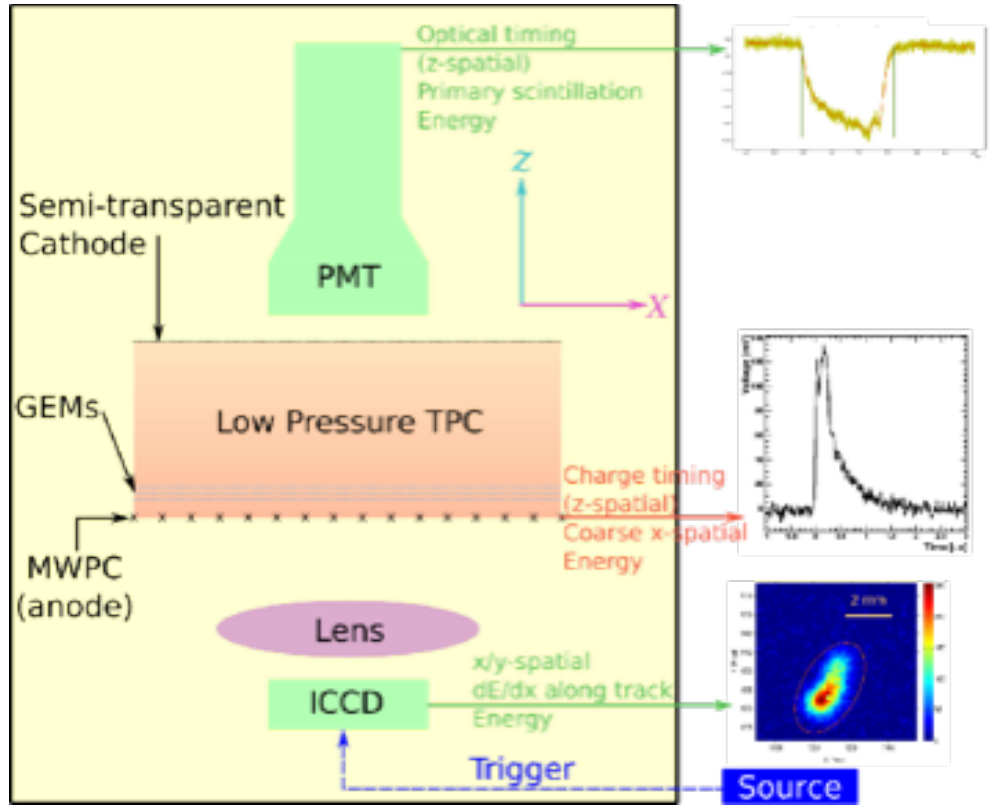
Lessons learned will feed design of 1m^3 scale CYGNUS-OZ prototype

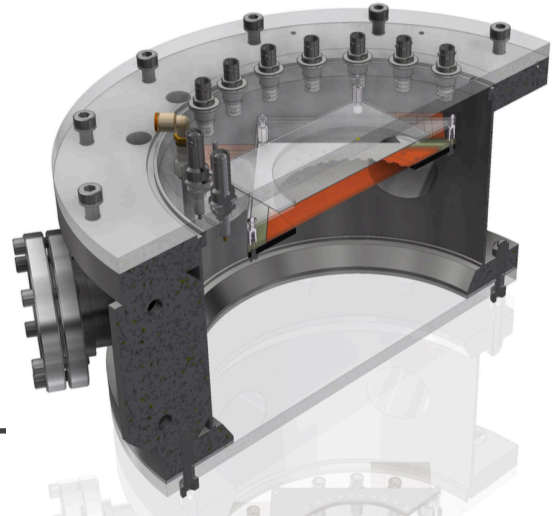
Contribute to global CYGNUS efforts (engineering design, testing across all years)

2022/23: Building 1m^3 scale CYGNUS-OZ
Design at the 10m^3 scale of CYGNUS10-OZ

2023/24: Installation of 1m^3 CYGNUS-OZ in SUPL.

2024/25: Decisions regarding SABRE / CYGNUS10-OZ priorities in SUPL.





CYGNUS – Lite
(Lachlan McKie ANU student, 2020)

See also Lindsey's talk

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Fully expect new initiatives, changes and evolution of this plan, over the lifetime of the Centre.

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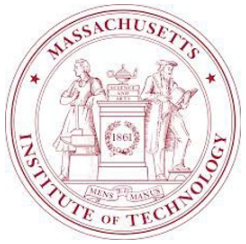
INTERNATIONAL PARTNER ORGANISATIONS:



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