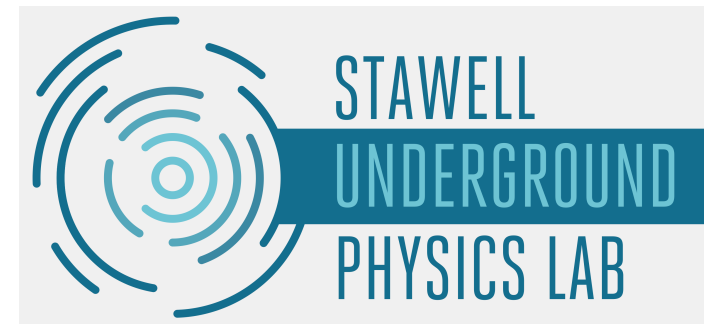


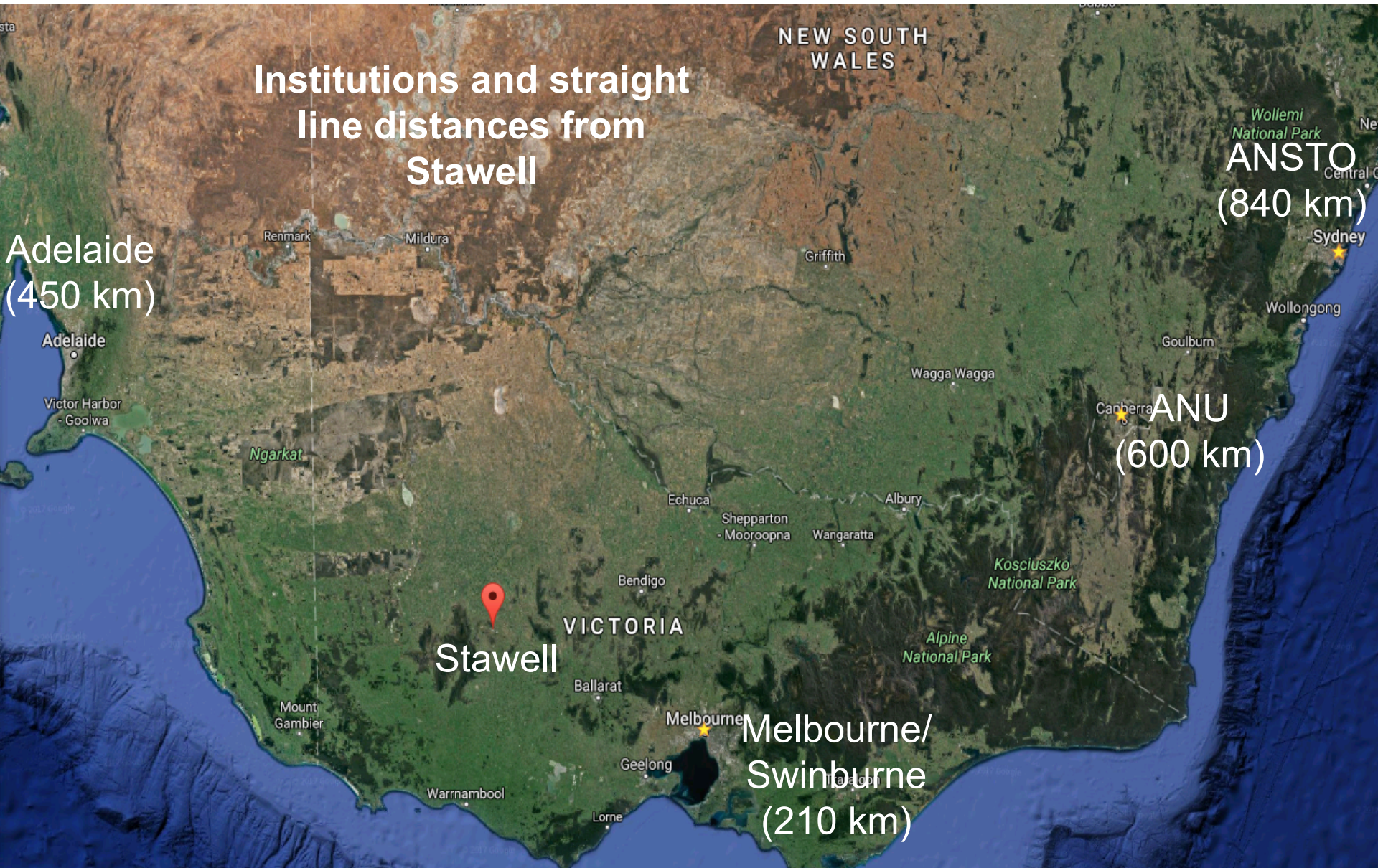
SABRE South - Activities and Updates

Greg Lane
**Australian National
University**

**on behalf of
SABRE South**



Australian Collaborating Institutions



Australian Personnel

	ANU	Melbourne	Adelaide	Swinburne	ANSTO
Academics (17)	Greg Lane, Lindsey Bignell, Andrew Stuchbery, Cedric Simenel, Anton Wallner	Elisabetta Barberio, Francesco Nuti, Phill Urquijo, Chunhua Li	Tony Williams, Tony Thomas, Gary Hill, Paul Jackson	Alan Duffy, Jeremy Mould	Dale Prokopovich, Richard Garrett
Engineers (4)	Number of technical staff	Tiziano Baroncelli	Paddy McGee	Shanti Krishnan	Adam Sarbutt
Undergrad/ Masters (3mth-1yr projects) (15)	Lawson, Krishnan, Blacker, Livingston, Zhang, Bilton, Zhong, Taloni	Dix, Pyke, Mahmood, Zhang, Zurowski, Koo	??	Lawrence	No teaching
MPhil/PhD (2-4 year projects) (zero)	Actively recruiting	Masters students to convert?			No teaching

Australian Research Council Funding

Linkage Project – for development of SUPL, not for SABRE

LP15 Australia's first direct-detection dark matter search at Stawell Gold Mine
Barberio, Mould, Urquijo, Thomas, Williams, Taylor, Garrett, **Claudia Tomei**

Linkage Infrastructure – for SABRE

LE16 Detector system for the First Australian Experiment on Dark Matter
Barberio, Mould, Stuchbery, Taylor, Thomas, Williams, Duffy, Jackson, Lane, Simenel, Urquijo, Wallner (**\$195k + our matching funds**)

LE17 Full Scale Detector System for the First Australian Dark Matter Experiment
Barberio, Stuchbery, Mould, Williams, Taylor, Urquijo, Lane, Simenel, Wallner, Duffy, Thomas, Hill, Jackson, **Frank Calaprice, Chiara Vignoli**
(**\$415k + our matching funds**)

Discovery Projects – specific research related to SABRE, not to fund it directly

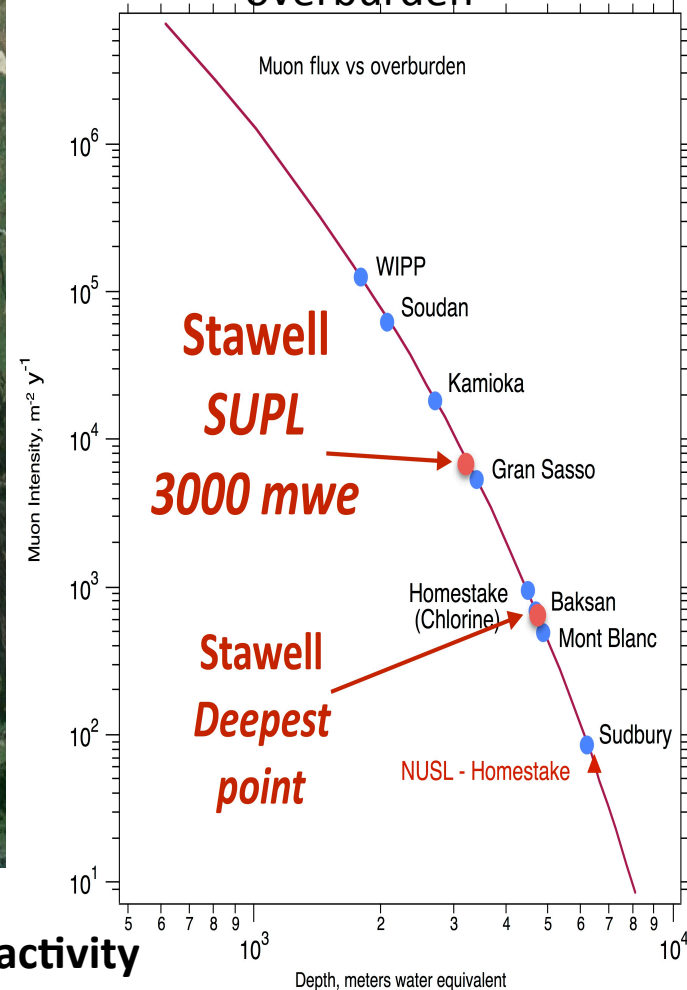
DP17 Stawell Underground Physics Laboratory: Dark Matter Detector Development, Lane, Stuchbery, Barberio, **Frank Calaprice**. (**\$427k**)

Linkage Infrastructure – Pending application to complete SABRE South

LE18 Construction of SABRE, Australia's first full-scale dark matter detector, Lane, Barberio et al, **Frank Calaprice**. (**Requested \$1.2M + 400k of our matching funds, decision is imminent**)

SUPL – Stawell Underground Physics Laboratory

Gold mine with decline construction, accessible by car/truck, basalt rock, flat overburden



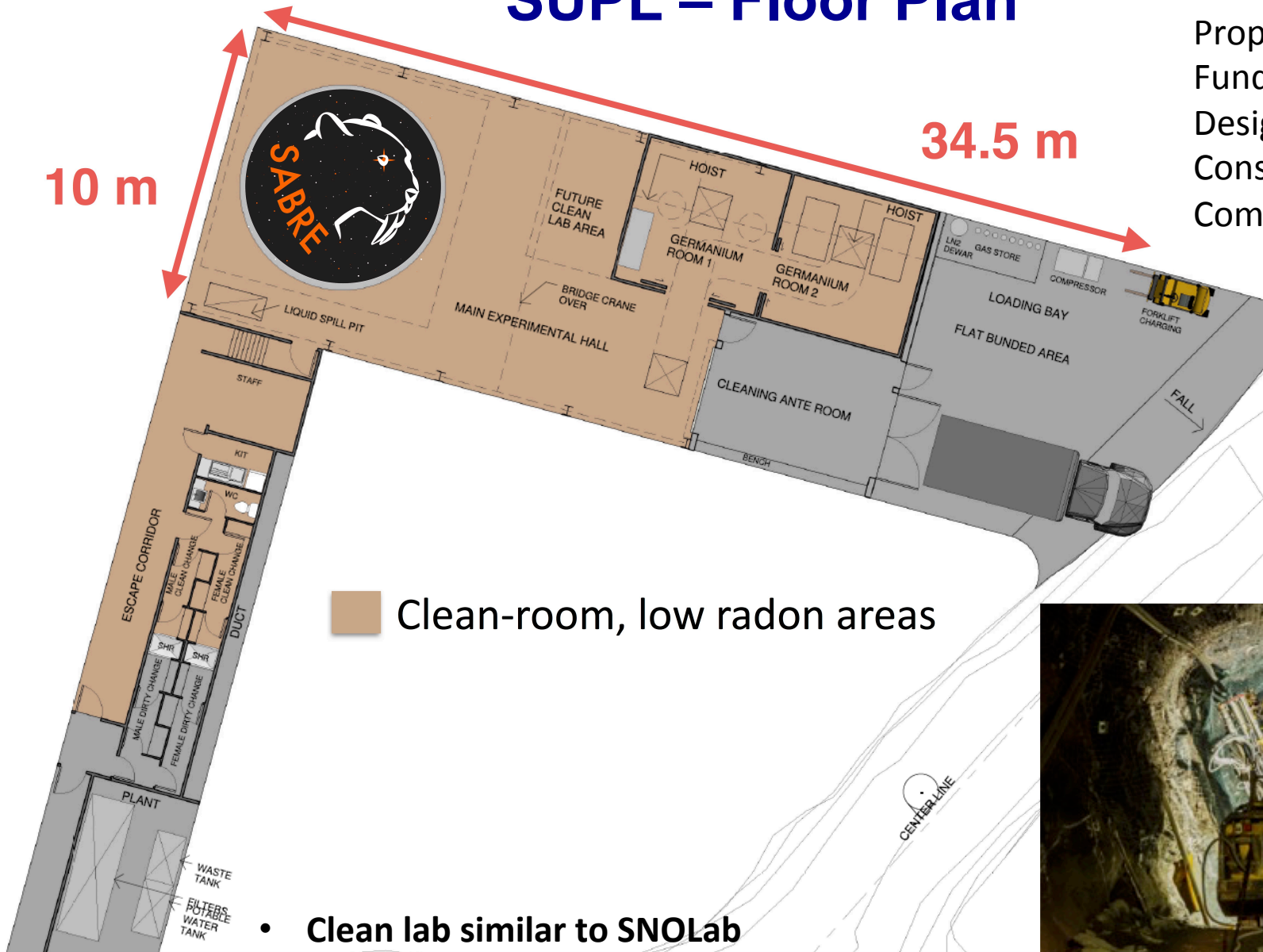
Effective depth and environmental radioactivity broadly comparable to Gran Sasso

SUPL – Floor Plan

10 m

34.5 m

Proposed: Sep 2014
Funding: May 2015
Design: 2016/2017
Construction: 2017?
Completion: 2018?



■ Clean-room, low radon areas

- Clean lab similar to SNOLab
- Designed to have Rn activity < 100 Bq/m³



SUPL – Status Update

Continued delays:

- Need to negotiate a commercial access agreement with the mining company that owns the Stawell mine, but...
- Currently up for sale – again!
- SUPL Design is ready – as little as 6 months to moving in once access is negotiated

Running costs:

- Encouraging discussions regarding the Australian National Collaborative Research Infrastructure Scheme.

Potential fallback sites – temporary?!?!

- LNGS – concentrates our total effort, but northern hemisphere...
- Jinping – has space and is deep, but northern hemisphere and politics...
- Ballarat – close to Stawell, only 700m depth.
- Rosebery – Tasmania, 1700m depth, initial discussions only happened recently.

Sabre South Meeting last week – Outcomes

- Reports from groups
- Breakdown of tasks, identify leaders, solicit helpers
- Identify critical points
- Obtain information for some much delayed and needed organisation
 - Lists of personnel, contact information, develop mailing lists for distributing information (expect this to also be addressed in Claudia's Friday talk?)
 - Finally develop a timeline/GANTT chart

Will go through the following, seeking advice!

- Breakdown of tasks
- Critical points

Sabre South Tasks – Feedback?

Names are listed on the overall tasks – key contacts in Australia

Vessel design and construction – Tiziano (see his talk)

- Going to tender soon – timing constraints discussed later
- Is this going to be used in both North and South?

CIS/Glovebox/Shielding – Tiziano

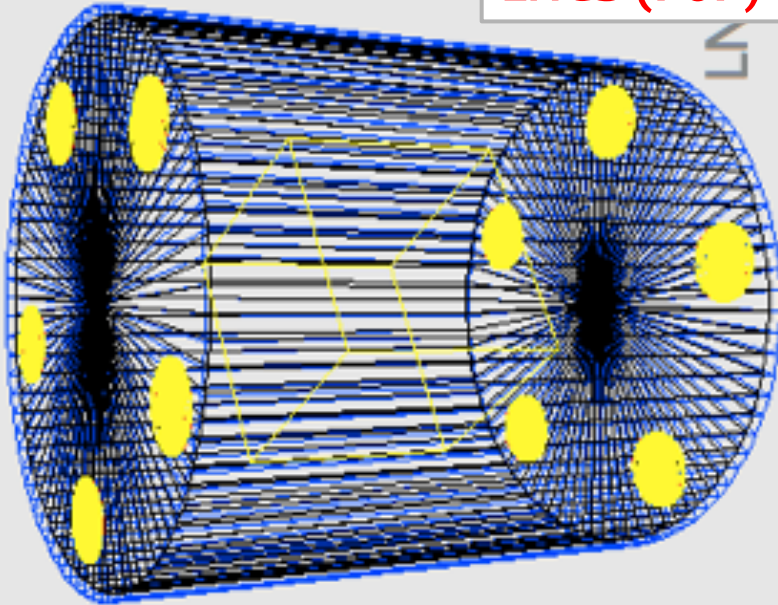
- Commonality with SABRE North?
- Separate construction?

Simulations – Francesco (see his talk)

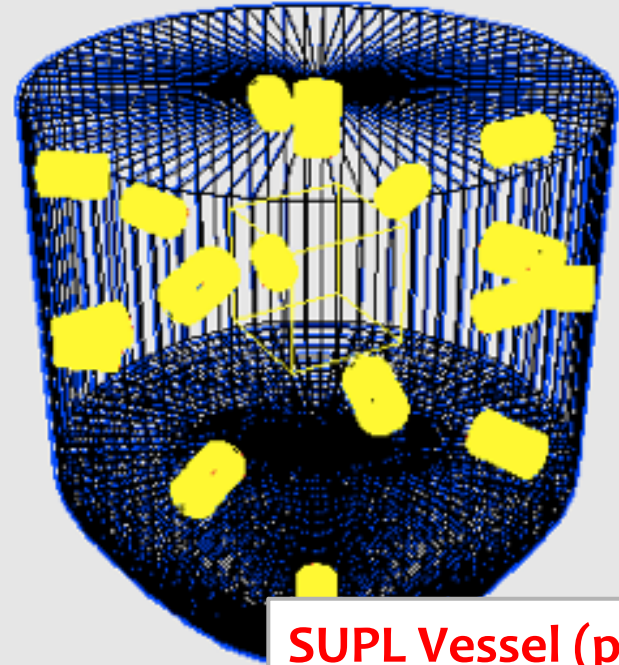
- Experiment
 - PoP – done to a large extent – iterative improvements?
 - Full expt – ongoing, still a design and performance task
 - Vessel going to tender – Are we now unable to change?
 - Optical photon transport in Geant4 (talk by Lindsey)
 - One simulation to rule them all?
 - Sensitivity studies (talks by Massimo & Valerio)

Full SABRE – Which vessel design?

LNGS (PoP)



SUPL Vessel (prelim.)



- SABRE North will proceed at LNGS after successful operation of the PoP.
- SABRE South is moving straight to a full detector.
 - Australian mine regulations prevent use of PC. Will instead use linear alkyl benzene (LAB) for the veto.

Decision about SABRE North?

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Sabre South Tasks – Feedback?

Muons – Gary

- Muons at depth and oscillations at depth must be understood
- We don't have other detectors at SUPL as compared to LNGS
 - Need our own understanding
- Surface measurements – fast, easy – see separate task
 - Parallel path - collate existing published measurements and scale to Stawell location
- Depth measurements – slow, harder
- Propagate muons with MUSIC/CORSICA to evaluate background

Muon veto for experiment – Gary/Tony

- Doubles as an at-depth measurement
- How? Coverage (top/sides?) Detector tech? See COSINE etc.
- Need to be in DAQ for coincidences?

Muon surface measurements (Alan / Shanti / Roger Clay / Paddy)

- Philanthropy – school based project in local area
- Correlate with atmospheric measurements
- Can we measure fluctuations from low to high energies? Achievable?

Sabre South Tasks – Feedback?

DAQ – Chunhua (Lindsey will talk here)

- Equipment delivered to Melbourne, student project (Bill) to get it running
- Reconstruction / event-building (talk by Davide)
- Trigger / types of data collection (philosophy)
- Will use at ANU for detector characterisation (talk by Lindsey)

PMT Characterisation – Phill

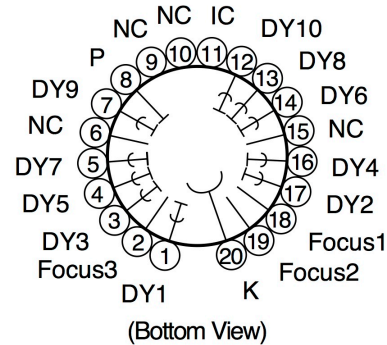
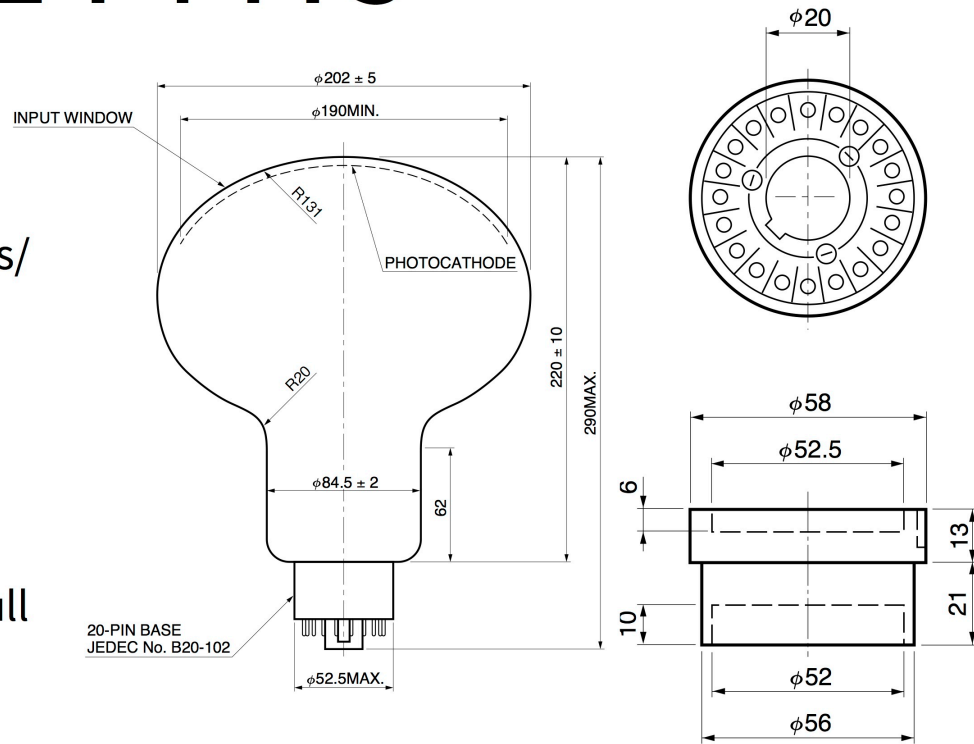
- Use full expt DAQ – develop techniques and confidence
- Dark box – exists
- Wet box – engineering required
 - Want to test PMT operation in LAB – Sealing and behaviour
 - Easy to control temperature due to thermal inertia
 - Test bed for slow control
 - Might need simulation for validation – Test photon attenuation, reflection etc.

Slow control – Shanti (talk by Lindsey/Greg)

- Overall design/topology
- Optimal placement of sensors
- Implementation
 - Initial testing (wet box PMT tests, PoP?)
 - Final implementation – use in both North and South?

R5912 PMTs

- R5912-100, 8”
 - http://www.hamamatsu.com/resources/pdf/etd/LARGE_AREA_PMT_TPMH1286E.pdf
- 2 PMTs arrived September 25.
- We plan to test before ordering 15-20 for full VV.
- Still need to build 20-pin bases (checking with Princeton) - or buy from Ortec/AMETEK.
 - <http://www.ortec-online.com/-/media/ametektortec/brochures/269-a4.pdf>



P. Urquijo, SABRE Meeting, ANU, 27/09/2017

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Experiments using R5912

- Dark Matter
 - DEAP 3600 (LAr)
- Neutrinos
 - MiniBooNE
 - MicroBooNE
 - Daya Bay
 - AMANDA
- Double β
 - SuperNEMO
- Cosmic rays
 - MILAGRO
 - Tibet Muon Detector Array
 - LHAASO

PMT Tests & Calibration

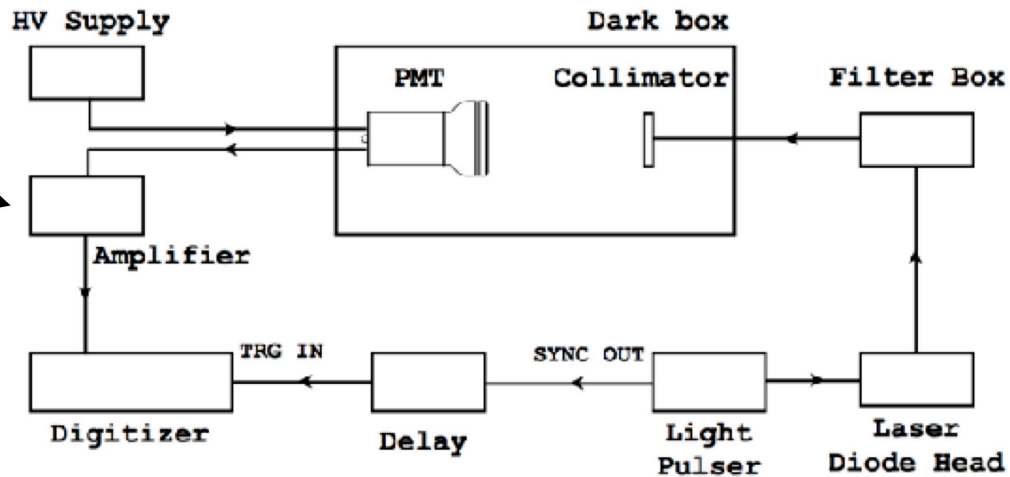
- Single photo-electron charge distribution
- Quantum efficiency
- Correlated noise
- Dark noise counts
- Pulsing characteristics, double pulsing
- Gain stability, temperature stability
- Performance in Linear alkylbenzene

Sara Cerioli (Milano Masters) has done extensive similar testing of the 3" crystal PMTs.

Not aware of SABRE testing of the 8-inch tubes? Princeton? If missed this, apologies!

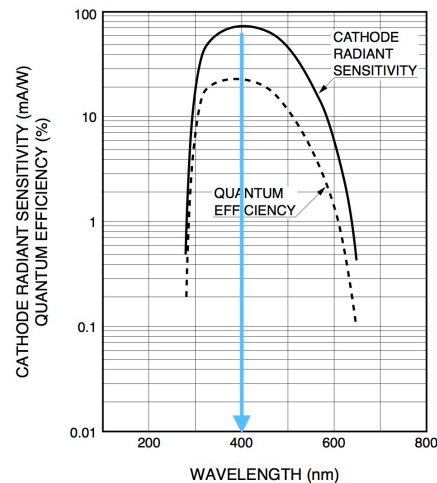
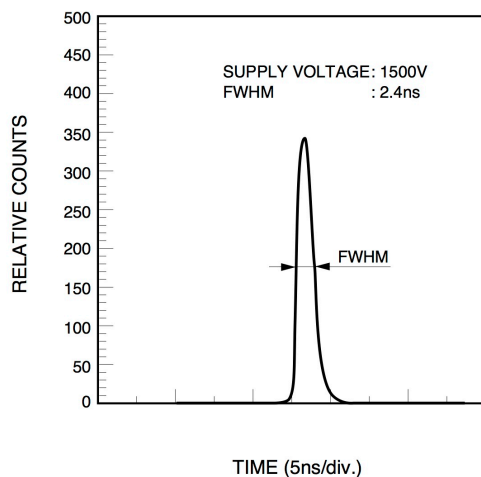
8" PMT Tests

Not sure if we need



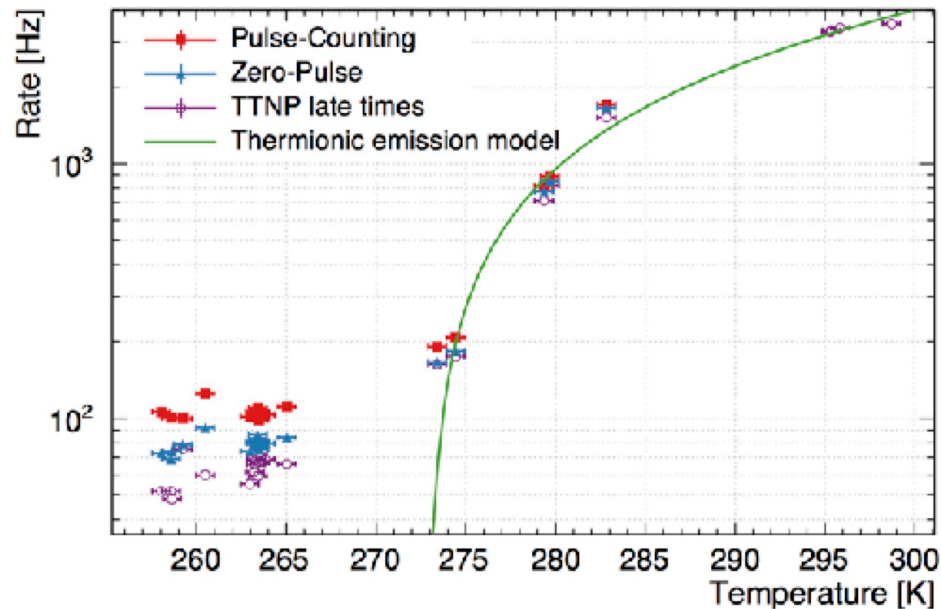
Could also use LED

Hamamatsu sheet



Dark noise rate in DEAP

- <https://arxiv.org/pdf/1705.10183.pdf>



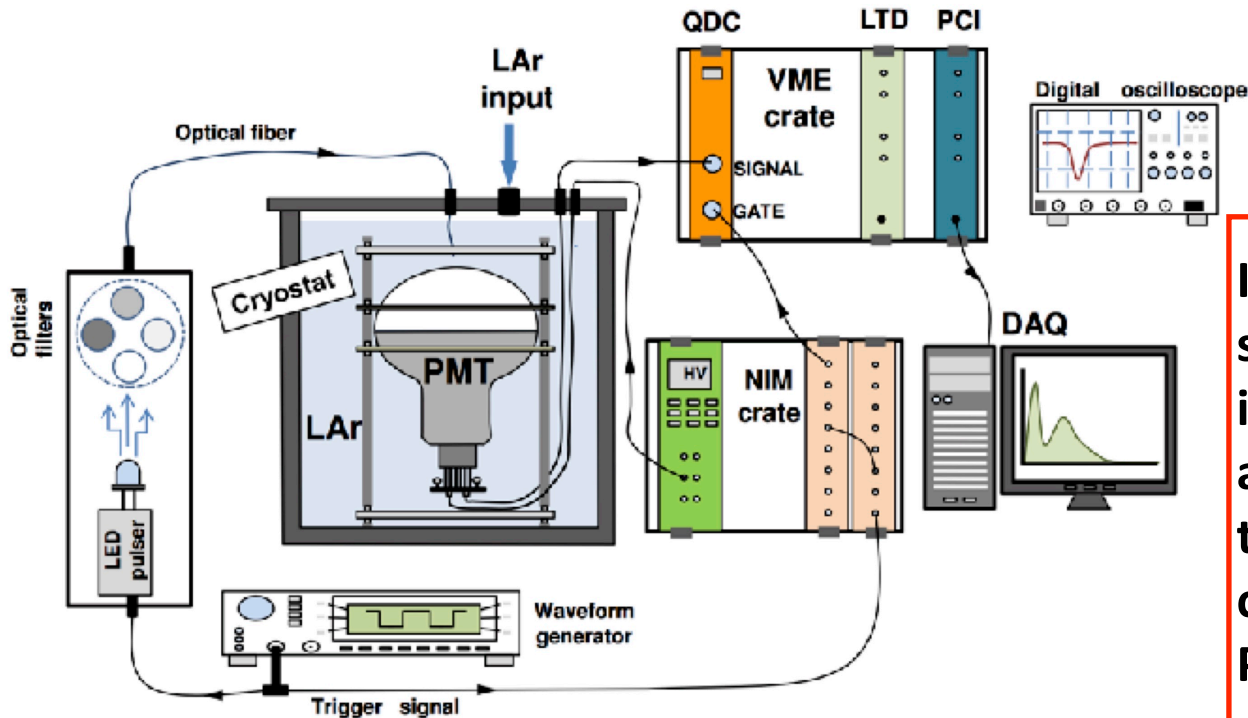
DEAP is a liquid argon detector, but we are not.

Warrants investigation!

Figure 17. The dark noise rate for PMTID 253 versus PMT temperature, measured using the three different methods described in the text. The fit uses Eq. (7.4). Error bars are statistical only, and the systematic shift between the analysis methods is due to some afterpulses being counted as dark noise in the pulse-counting and the zero-pulse methods.

Example setup for tests with liquid scintillator

- <https://arxiv.org/pdf/0711.3592.pdf>
- This is a cryogenic test setup - not needed for us. Can we just partially immerse the PMT for testing?
- Test liquid scintillator and PMT responses.



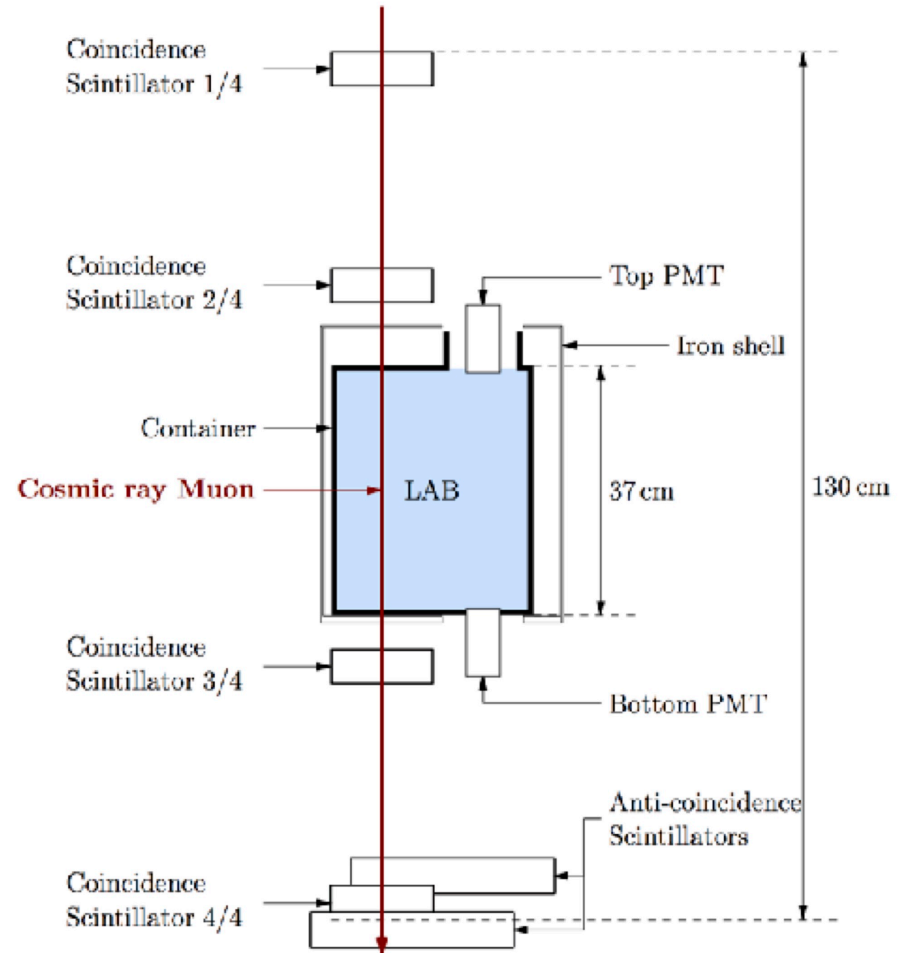
Instrument with the slow control early implementation so as to test temperature control and look at PMT temperature dependence etc.

8

P. Urquijo, SABRE Meeting, ANU, 27/09/2017

Test setup for JUNO

- <https://arxiv.org/pdf/1511.09339.pdf>
- (They also check for Cherenkov signatures)



Possible interest for us given that we may instrument our detector with muon counters

P. Urquijo, SABRE Meeting, ANU, 27/09/2017

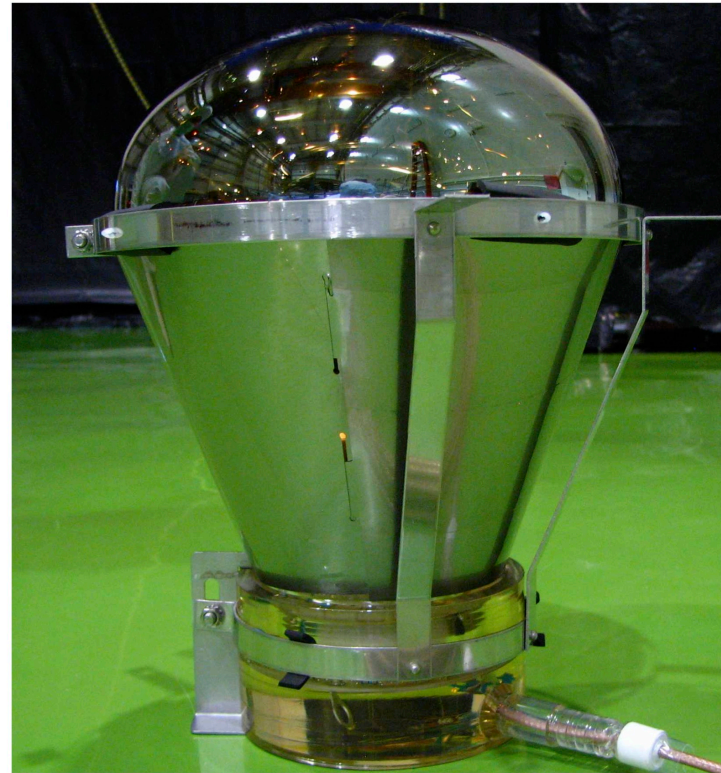
9

Oil-proof assemblies at Daya Bay

- Oil proof assembly, <http://dayabay.ihep.ac.cn/pubtalk/Neutrino2010-Poster-PMT.pdf>
- Can LNGS develop oil proof bases? Do they have them already?



Daya Bay Oil-proof R5912 Assembly



Oil-proof PMT in mount with magnetic shield

**Need
our own
R&D**

P. Urquijo, SABRE Meeting, ANU, 27/09/2017

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Sabre South Tasks – Feedback?

DAQ – Chunhua (Lindsey will talk here)

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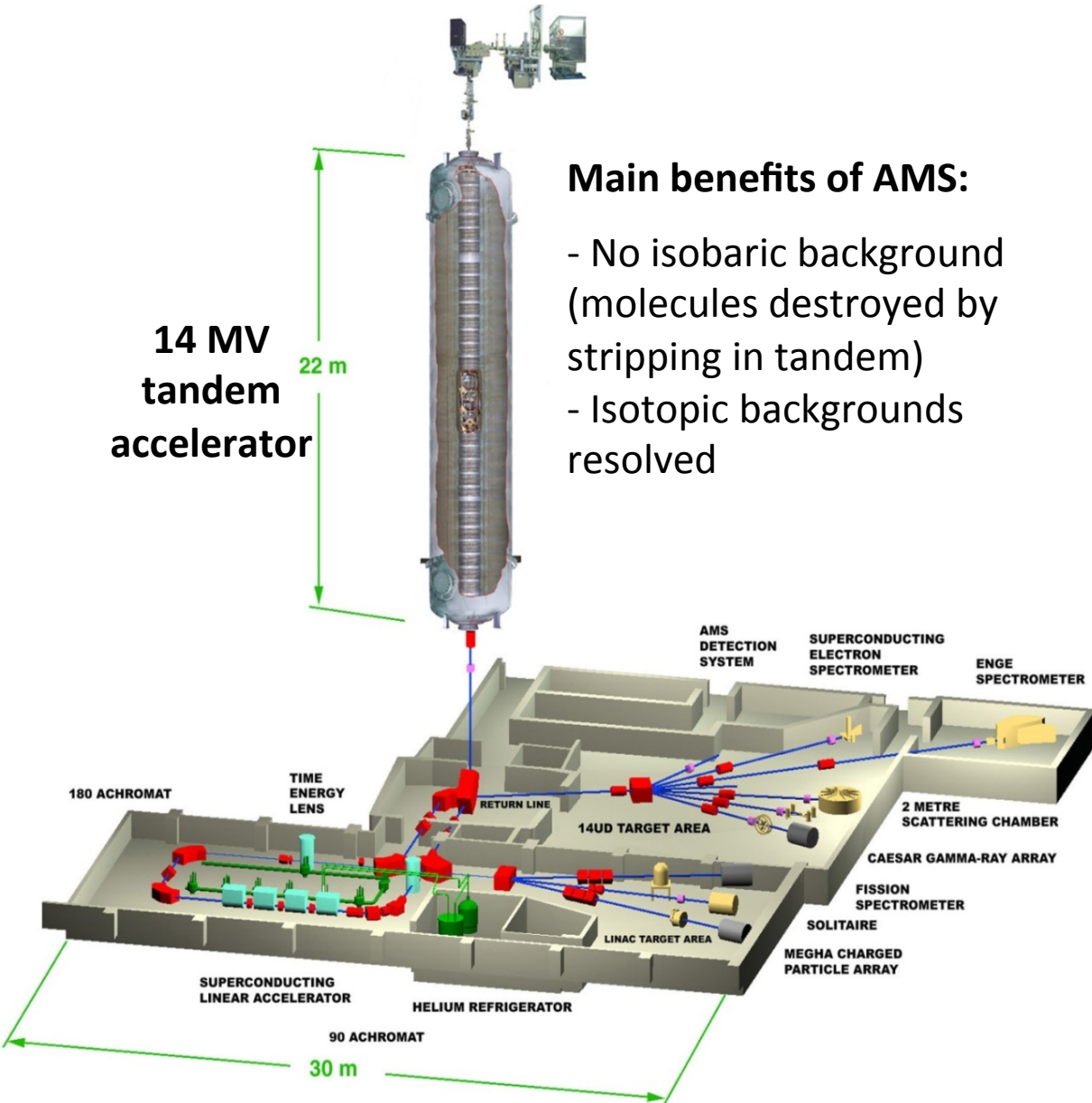
Materials testing (radioactivity) – Toni

- AMS – ANU/ANSTO
 - Chemistry important – Michi (ANU postdoc back from maternity leave)
- ICPMS
 - Routine at Melbourne (paid). Also available at ANU “locally”
 - Need for specialist measurements at PNNL?
- Gamma-spectroscopy – issue is timeliness and cost(?)
 - LNGS, CanFranc, ANSTO?

Liquid Scintillator – Greg

- Purchase, purification, production, storage, handling
 - Have organised storage/safety and worksite at ANU for the large volume.
 - Long-term storage? Final preparation underground? Transport purified LAB?
 - Purchase of test volume (1m³) from China imminent
 - Materials testing (do SABRE materials affect the LAB)
 - Exposure – quantities and locations for storage during exposure
 - Measurements – chemical, optical, light yield
 - Construct or identify appropriate test equipment

Accelerator Mass Spectrometry (AMS) at ANU



Main benefits of AMS:

- No isobaric background (molecules destroyed by stripping in tandem)
- Isotopic backgrounds resolved

- Measure contaminant radionuclide isotope ratios through **atom counting**
- **Ultrasensitive**
- Unstable/stable atom ratio sensitivity of $10^{-12} - 10^{-17}$
 - Requires sample-dependent chemistry
- Pacific Northwest National Laboratory (USA) performs high performance ICPMS (Inductively Coupled Plasma Mass Spectrometry).
 - Broader application but can have less sensitivity.

SABRE AMS measurements so far

Limitations:

- Need to be able to dissolve sample and extract the element of interest.
- Measures atom ratios – isotopic spike may be needed to convert to an absolute yield.

Application 1: ^{129}I , $T_{1/2}=15.7$ Myr, produced through activation.

- $Q(\beta)=189$ keV \rightarrow produces low energy β^- and a 40 keV γ .
- Sensitivity of $^{129}\text{I}/\text{I} < 10^{-14}$ has been demonstrated \rightarrow 56 $\mu\text{Bq}/\text{kg}$ of NaI.
- $^{129}\text{I}/\text{I}$ measured in growth- and astro-grade NaI powder: $2.0(1)\times 10^{-13}$
(c.f. DAMA value of $1.7(1)\times 10^{-13}$ inferred from ^{129}I decay in their crystals).

Application 2: ^{210}Pb , $T_{1/2}=22.2$ yr, environmental contamination, important background

- Pure Pb samples have demonstrated $^{210}\text{Pb}/\text{Pb}$ ratios of 10^{-14}
 - Measurement sensitivity of 1 mBq/kg under ideal conditions.
- However, efficiency/purity of the chemical extraction of Pb also matters...
- A single test measurement for ^{210}Pb in NaI has been made:
 - Much of the extracted material was not Pb, diluting the beam current
 - ~ 100 mBq/kg sensitivity achieved under these very unfavourable conditions.
- Significant improvements will be possible, but the ultimate sensitivity is not yet clear.
- Needs chemistry – Micheala Frolich (ANU postdoc) is now back from maternity leave.
- Ongoing research project with ANSTO – beam time guaranteed

Other applications?

Sabre South Tasks – Feedback?

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Sabre South Tasks – Feedback?

Detector Characterisation – Lindsey (see his talk)

- Understanding all aspects of radiation interaction with all active detector materials so as to apply particle identification wherever possible and improve signal/noise
- NaI/Lab – Pulse shape discrimination
- NaI – Quenching factor measurements
 - Resolve discrepancies between past measurements
 - Crystal dependence? Disaster!

Calibration – Tiziano

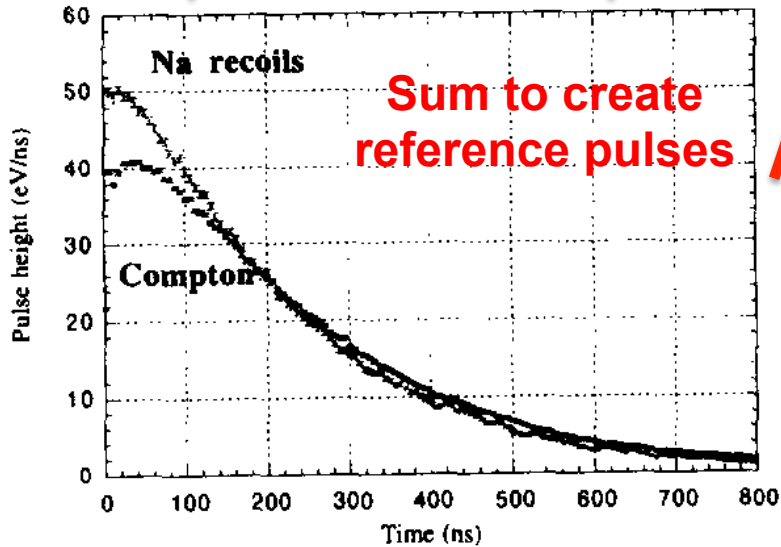
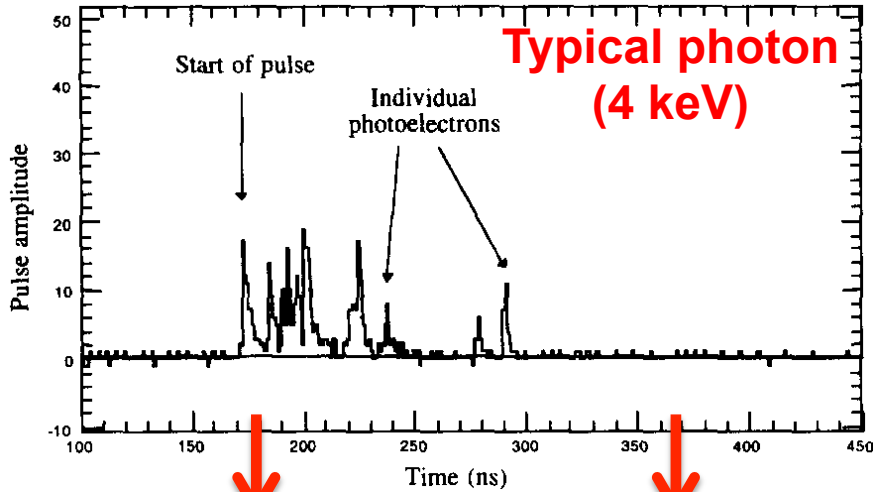
- Depends on similarities North/South – leverage of existing work?

Crystals for SABRE South – Elisabetta/Greg

- Production – RMD/Princeton? Timeline in absence of an underground site?
- Enclosure production – where? Collaboration wide?
- Transport to Australia?
- Local handling and storage – must wait until we have an underground site.
- Cost?
 - Grant money for crystal production that must be expended. Decisions needed.

Pulse Shape Discrimination

PSD in NaI for LSM,
Gerbier et al AP 11 (1997) 287

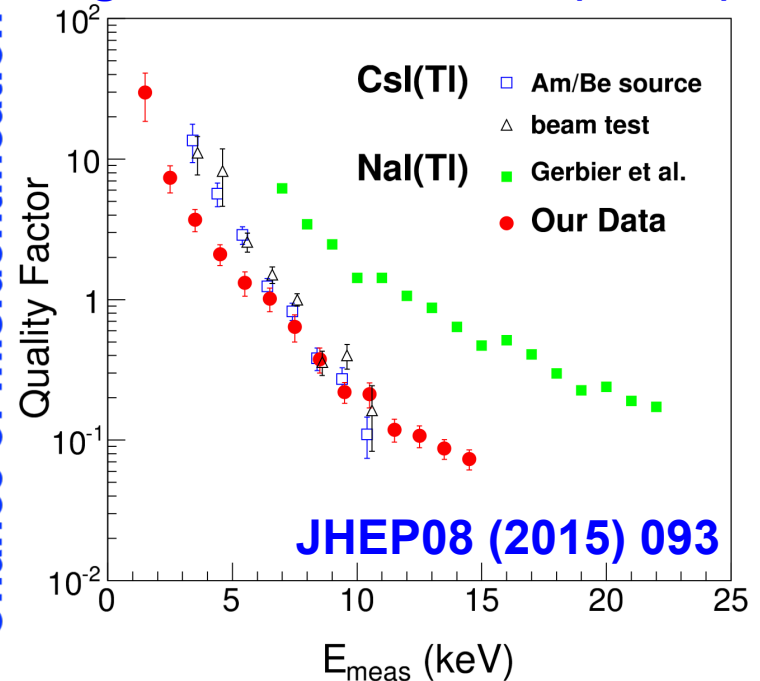


Time behaviour of signal provides NR/e⁻ discrimination (see also, e.g. NAIAD, AP 19 (2003) 691).

**No PSD used in DAMA.
PSD planned for SABRE.**

PSD also in other new NaI expts, e.g. KIMS-NaI/COSINE (below).

“Chance of misidentification”

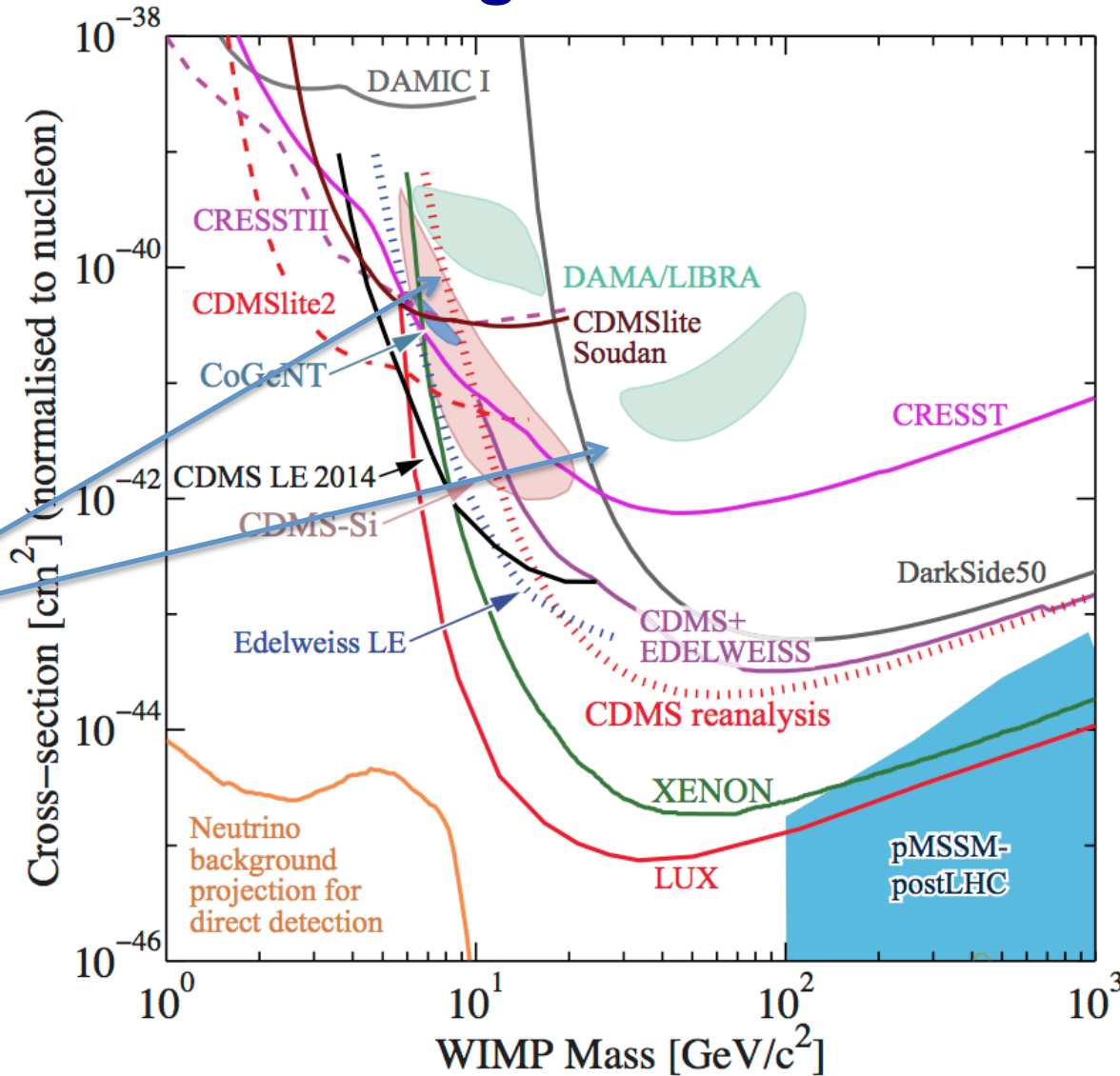


Importance of Quenching Factor

Only part of the nuclear recoil energy, E_{nr} , is transferred to electrons, $E_{ee} = Q E_{nr}$ (Q is poorly determined)

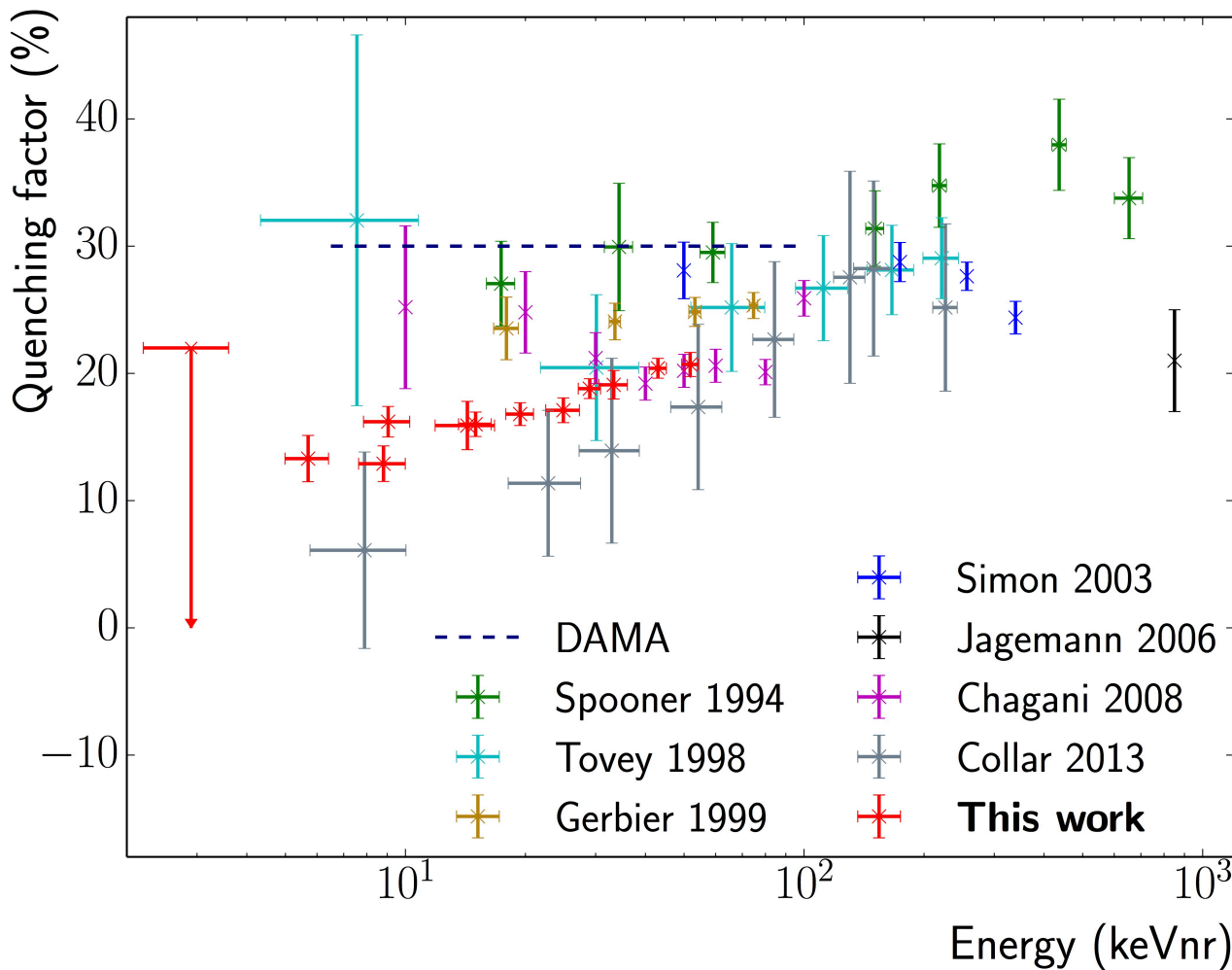
Position in exclusion plot depends on whether interaction is assumed to be with Na or I nuclei.

Also depends on values used for Q .



Spin-independent WIMP cross sections (normalised to a single nucleon).
C. Patrignani *et al.* [PDG], Chinese Physics C 40 (2016) 100001.

Measurements of the Quenching Factor



DAMA used constant $Q=0.3$ for Na scattering.

Q is definitely lower and energy dependent, see Xu et al (2015, red data points)

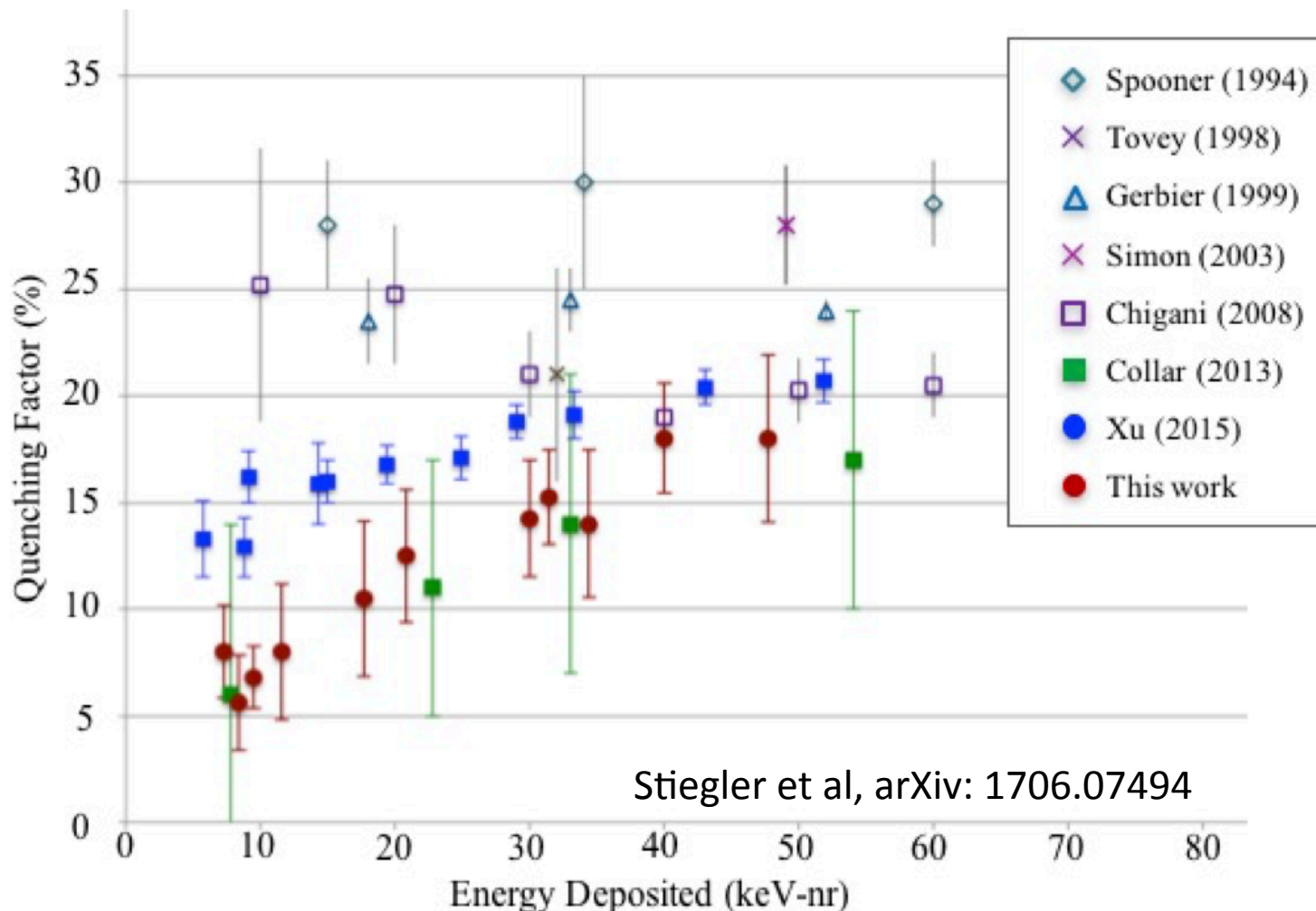
Multiple papers have looked at how changes in Q affect the WIMP exclusion plots.

Have we reached a level of confidence in the energy dependent quenching?

J. Xu et al, Phys. Rev. C 92, 015807 (2015)

Pulsed neutron beam via ${}^7\text{Li}(p,n)$. Q from scattering neutrons in NaI(Tl), kinematics, E and TOF.

Measurements of the Quenching Factor



Stiegler et al, arXiv: 1706.07494

Maybe not...

Very recent paper gives values lower than the 2015 results.

Crystal dependence?

New ANU measurements are planned:

Better beam pulsing (1ns pulse width). Lower energy threshold. Multiple crystals.

Sabre South Tasks – Feedback?

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Critical Points and Timelines

Money issues – we have to spend some!

\$200k we must spend by year end or become ineligible to receive further money.

- Steel purchase for vessel (Germany)
- Possible down payment on vessel construction (Australia)
- Minimal electronics for 2nd DAQ (Trigger unit, maybe a crate)
- Slow control early implementation
- LAB purchase / Shipping of CTF purification system to Australia
- Laser/LED and engineering for PMT characterisation
- AMS costs – separated isotope etc
- ICPMS/Gamma-spec costs for steel tests

Timing issues with spending money:

- Vessel
 - Quote -> List of steel plates -> ship samples -> measure -> purchase
Only at purchasing stage can we expend substantial money...
 - Advice on where and how to expedite gamma-spec measurements.
- CTF purification system
 - Shipped from Princeton to LNGS duty-free. Complicates transfer to Australia.
 - Find paperwork and resolve how to do this.

Critical Points and Timelines

Veto PMTs to be immersed in LAB

- Impact on vessel design that is entering production already?
- Other places have done this (Daya Bay), so should be OK, but needs testing.

LAB purchase, purification and materials testing will take months

- Impact on vessel design that is entering production already?

Background at laboratory site

- Impacts vessel design that is entering production already?
- Greater impact on shielding design – still ongoing
- Location of the lab still uncertain
 - Gamma background measurement is fast
 - Neutron measurements are slow
 - Muon measurements are really, really slow

Degree of commonality in design/implementation between North and South experiments?

- Some executive decisions may streamline overall efforts

Critical Points and Timelines

PMT purchases

- Long leadtimes.
- Recent purchase of two R5912 PMTs took far too long between order and delivery.

Location, location, location - where will the southern lab be?

- Current vessel design requires certain space, particularly head-height
- If a temporary site...
 - Radon and cleanliness issues – temporary clean room tent?
 - Inside a box with N2 fluxing?

Crystal timelines

- Can't use/accept them until we have a laboratory, but our funding and planning will depend on answering a number of questions:
 - Where they will be made?
 - Where will enclosures be made?
 - Where they will be packaged?
 - How we will pay for them?
 - Method of transport?
- Happy to contribute personnel as required towards these tasks

**Advice, feedback and
contributions are all very
welcome**