Development of the SABRE experiment and Australian involvement

F. Nuti* for the Australian Collaborating Institutions

*The University of Melbourne

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Picture by M. Volpi

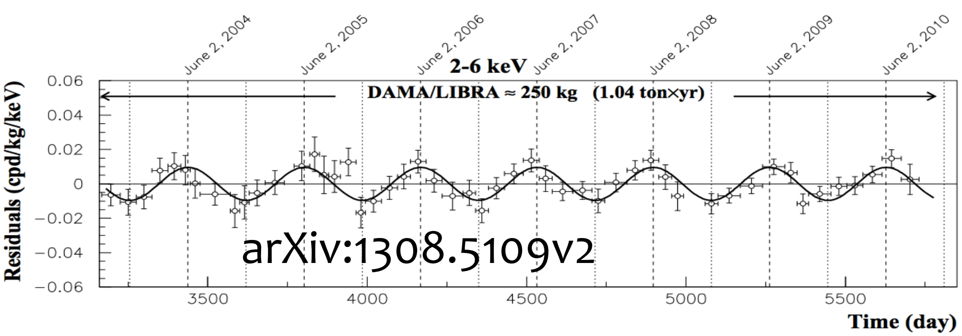
THE UNIVERSITY OF MELBOURNE

STAWELL UNDERGROUND PHYSICS LAB

SABRE

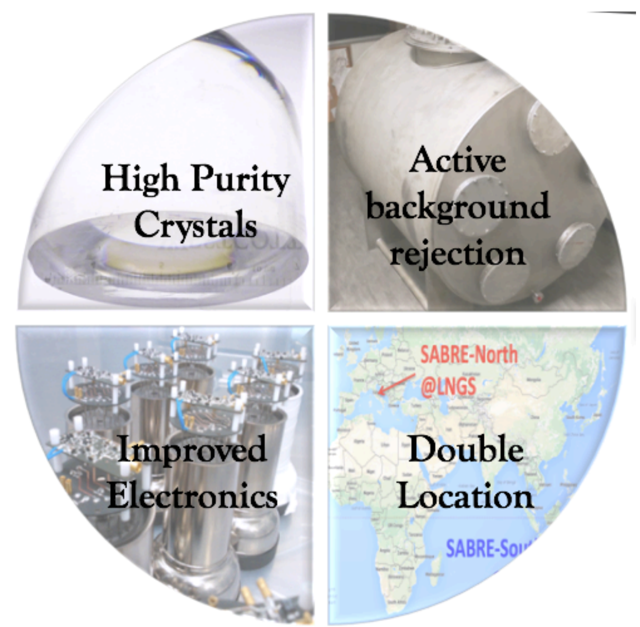
Sodium-iodide with Active Background REjection

Goal: search for annual modulation compatible with Galactic Dark Matter interactions

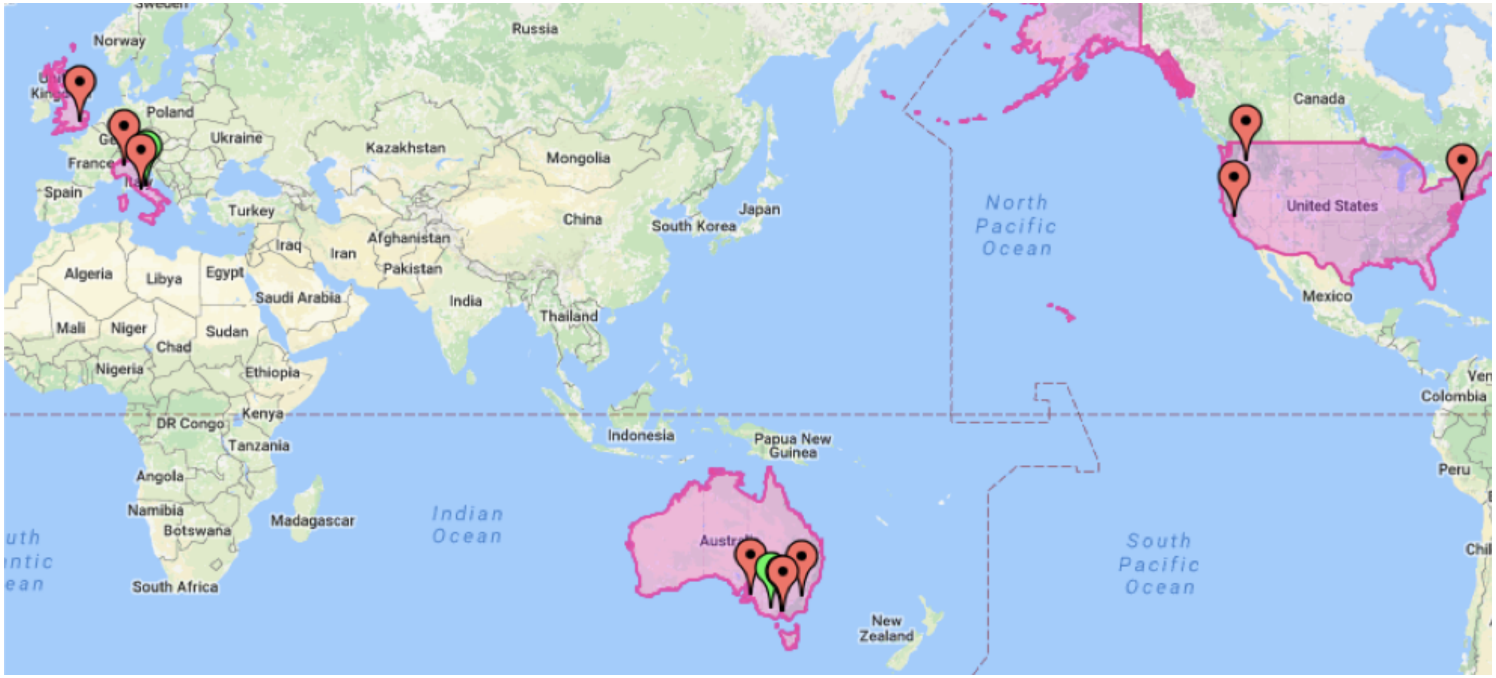


- Strong modulation observed by DAMA/LIBRA with 250Kg of NaI(Tl) crystals
- Null results with other techniques (see Xenon100/LUX results)

SABRE's key features



THE COLLABORATION



Adelaide University, ANSTO
Australian National University
Swinburne University
University of Melbourne

Imperial College London

LNGS & GSSI
INFN Rome
University of Milano & INFN

LLNL
PNNL
Princeton University

Australian Institutions

- University of Melbourne
  - Academics: Elisabetta Barberio, Chunhua Li, Francesco Nuti, Geoff Taylor, Phillip Urquijo
  - Engineer: Tiziano Baroncelli
  - Students: Dix, Mahmood, Pyke, Zhang, Zurowski, Koo

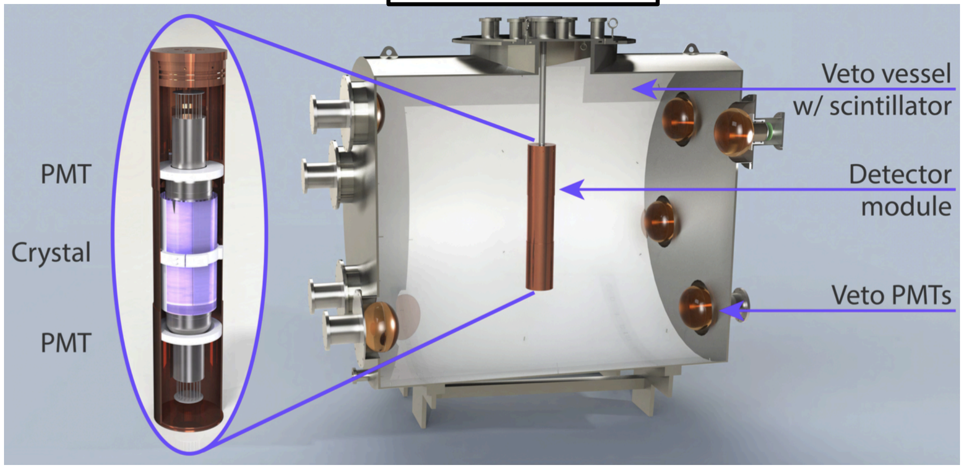
Australian Institutions

- Australian National University (ANU)
  - Academics: Greg Lane, Cedric Simenel, Andrew Stuchbery, Anton Wallner, Lindsey Bignell
  - Students: Lawson, Krishnan, Blacker, Livingston
- ANSTO
  - Academics: Richard Garrett, Dale Prokopovich
  - Engineer: Adam Sarbutt
- Swinburne University
  - Academics: Alan Duffy, Jeremy Mould
  - Engineer: Shanti Krishnan
- University of Adelaide
  - Academics: Gary Hill, Paul Jackson, Tony Thomas, Tony Williams
  - Engineer: Paddy McGee

PROJECT PHASES

- Proof of Principle (PoP) @ LNGS
  - 1 NaI(Tl) crystal (~5kg)
  - Early design of vessel and shielding
  - Measurements of crystal's contaminations (KMM) and active veto performance
- Twin full scale experiment: SABRE North @ LNGS and SABRE South @ SUPL
  - ~50Kg of crystal in each location
  - Improved design
  - Search for annual modulations compatible with Dark Matter interactions

PoP Design



Research activities

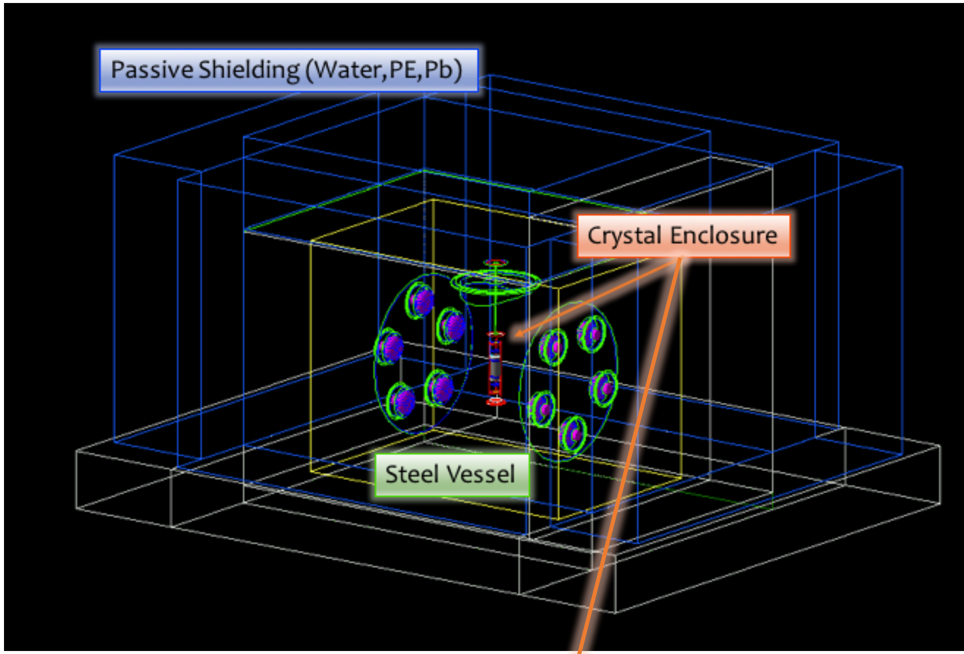
- Detector design (active and passive shielding)
  - Melb leading, ANU to help with construction
- Monte Carlo Modelling
  - Melb, ANU in collaboration with Italian groups
- On-site background measurements
  - Gamma and neutron (ANSTO, ANU, Melb)
  - Muons + possible muon veto detector (Melb, Adel)
- Slow control (Swinburne / Adelaide)
- Liquid handling, including scintillator purification
  - ANU (refurbishment of Princeton CTF setup)
- Detector characterisation (QF measurements for NaI, AMS measurements of impurities)
  - ANU leading with Melb involvement
- DAQ
  - Melb and ANU

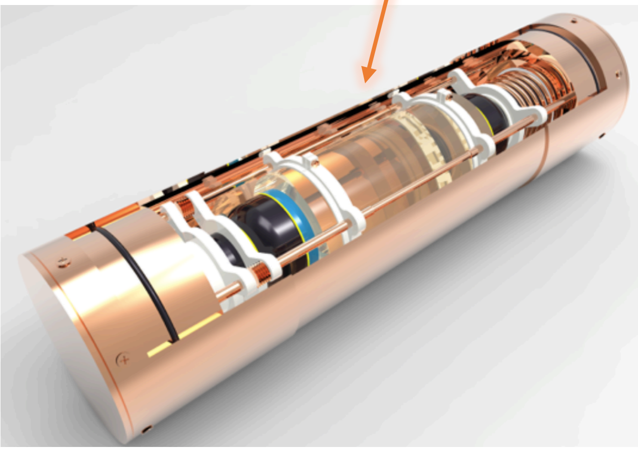
Simulation

- Estimate of radiogenic and cosmogenic background for the PoP phase
- Active background rejection studies to optimize light collection
- Study of passive shielding solutions
- Muon flux measurement, annual modulation

PoP Simulation

- GEANT4 Simulation of
  - Experimental setup
  - Physics od radioactive processes
  - Particle propagation, interaction, detection
- Background evaluated for radioactivity in
  - NaI(Tl) crystals (radiogenic+cosmogenic after 180 days)
  - Crystal wrapping + PMTs
  - Crystal enclosure
  - Crystal insertion system (CIS)
  - Veto (Vessel, Liquid Scintillator, PMTs)
- Radiopurity contaminations from preliminary measurements or from literature (XENON, CUORE, ANAIS)





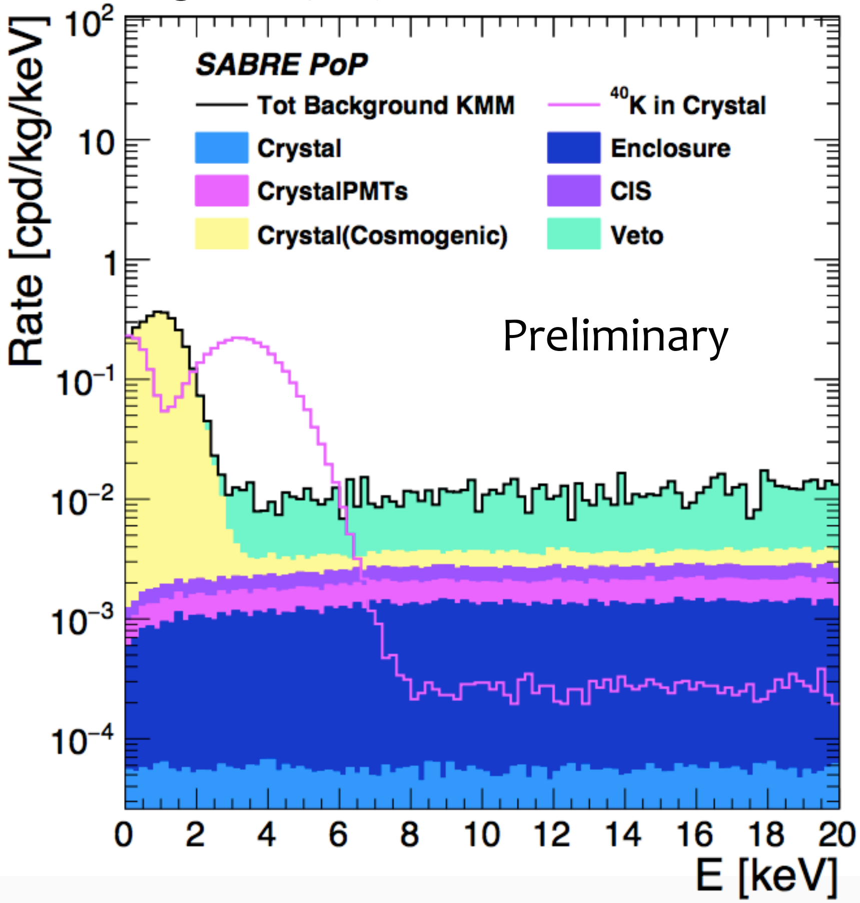
^{40}K MEASUREMENT MODE (KMM)

Target ^{40}K contamination (3 KeV auger e^- + 1.46 MeV γ) and other radio-impurities

Element	BKG-KMM[cpd/kg/keV] (total does not include K in crystal)
Crystal	**2.06e-01**
Crystal Wrapping	7.84e-06 +/- 5e-07
Crystal PMTs	< 4.63e-04
Enclosure Internal Teflon	< 5.67e-05 +/- 2e-06
Enclosure Copper	1.71e-03 +/- 6e-06
CIS Copper	9.57e-04 +/- 1e-05
CIS Steel	< 1.31e-05 +/- 8e-07
Liquid scintillator	4.32e-08 +/- 2e-09
Vessel	< 1.36e-03 +/- 9e-05
Vessel PMTs	< 4.82e-03 +/- 4e-04
Total internal (upper limit)	**< 1.07e-02 +/- 4e-04**
PE shield (40 cm box)*	$4.5\ 10^{-4}$
External gammas**	$<(1.37 \pm 0.41) \times 10^{-2}$

Energy in Liquid Scintillator ϵ [1280,1640] KeV

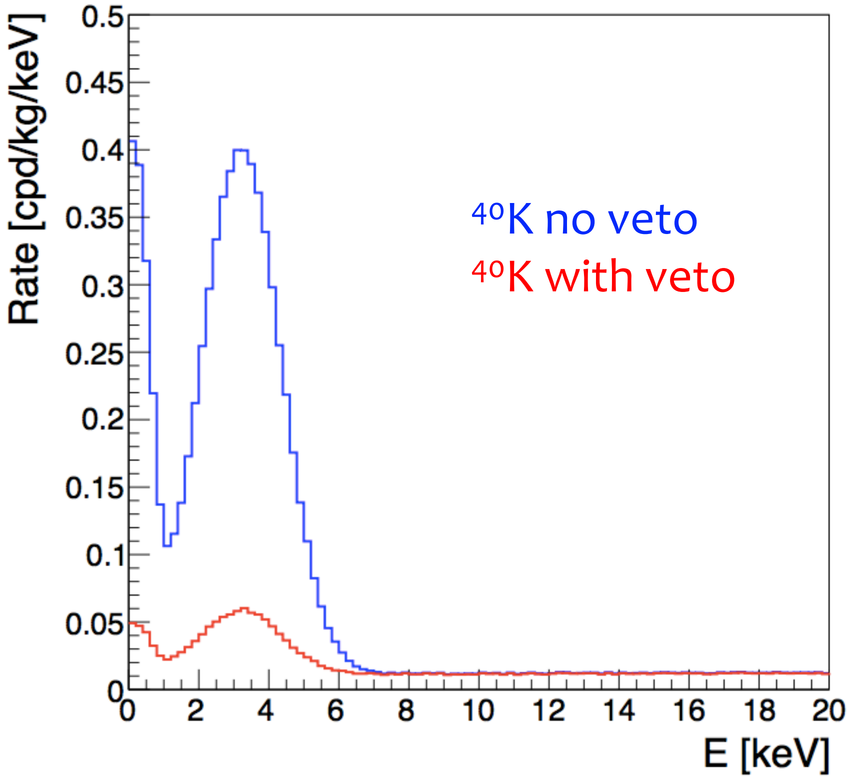
Crystal signal ϵ [2,4] KeV



Upper limits | Measurements | Past simulations

Test the active rejection power of the liquid scintillator system.
Signal of interest ϵ [2,6] KeV in crystal and < 100 KeV in scintillator

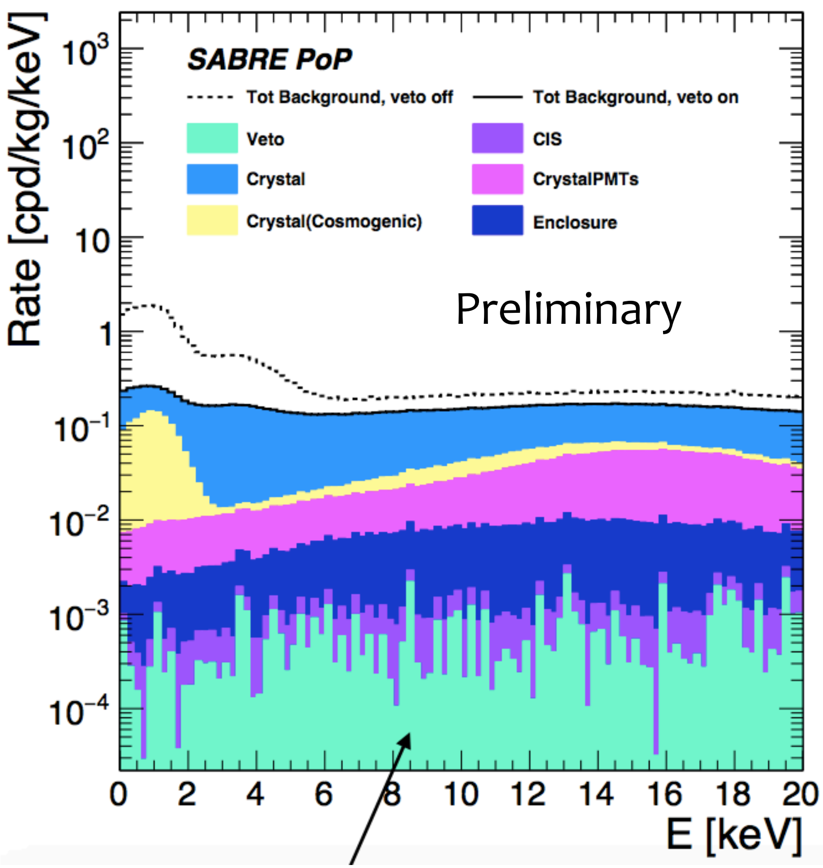
Background due to ^{40}K in crystal



Rejection power ~10

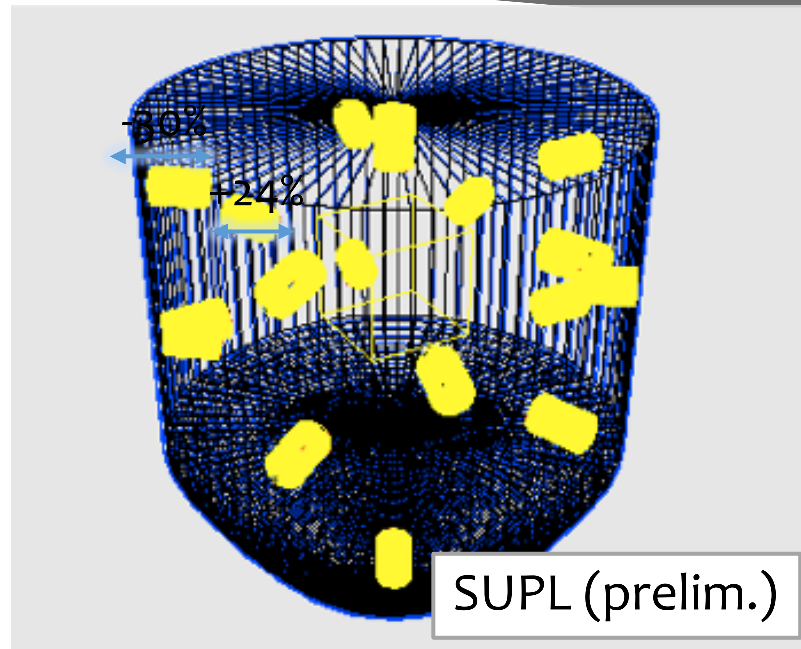
Expected total background

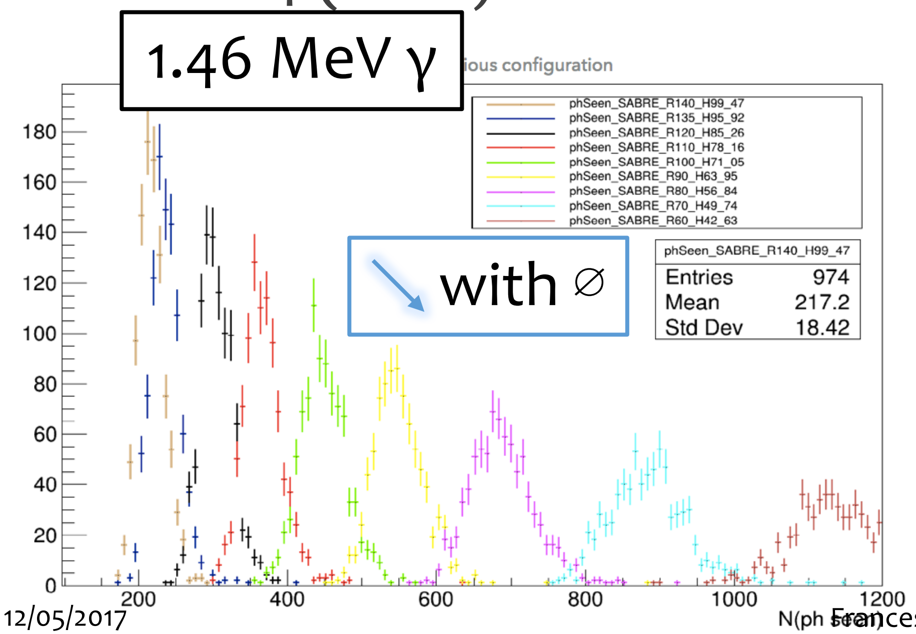
0.16 cpd/Kg/KeV

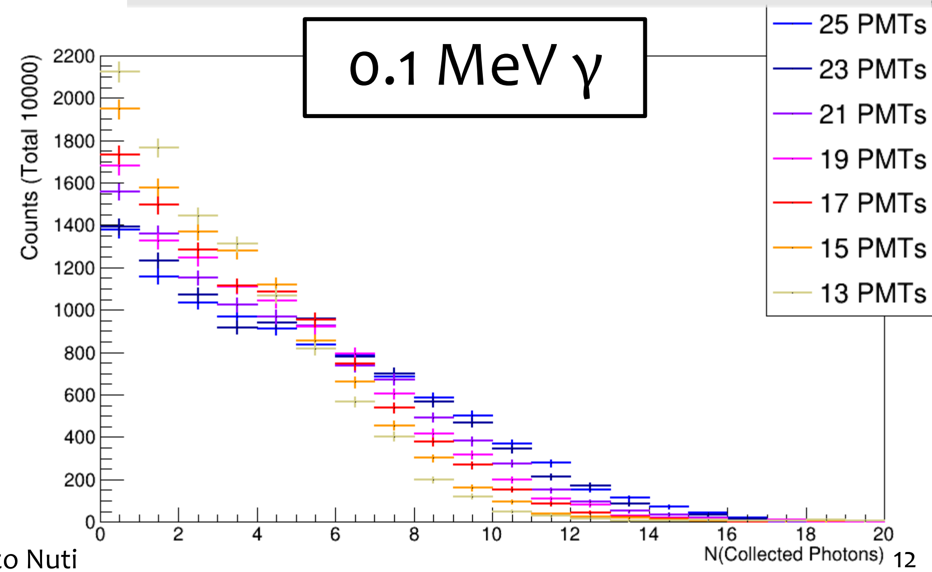


ACTIVE VETO STUDIES

- Studied light collection performance of the active veto system
- Goal: vessel size, position and number of PMTs, limit in energy sensitivity
- Simulation with Slitrani (Melbourne) compared with GEANT4 (ANU)

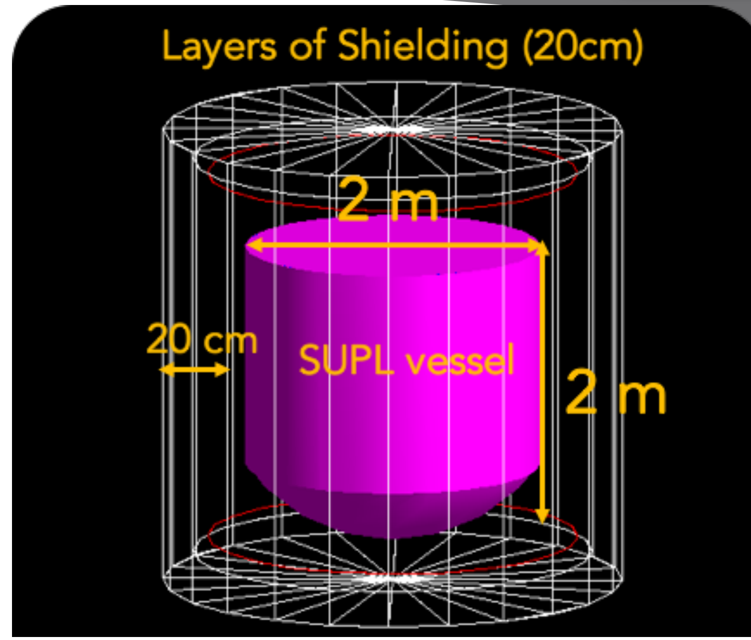


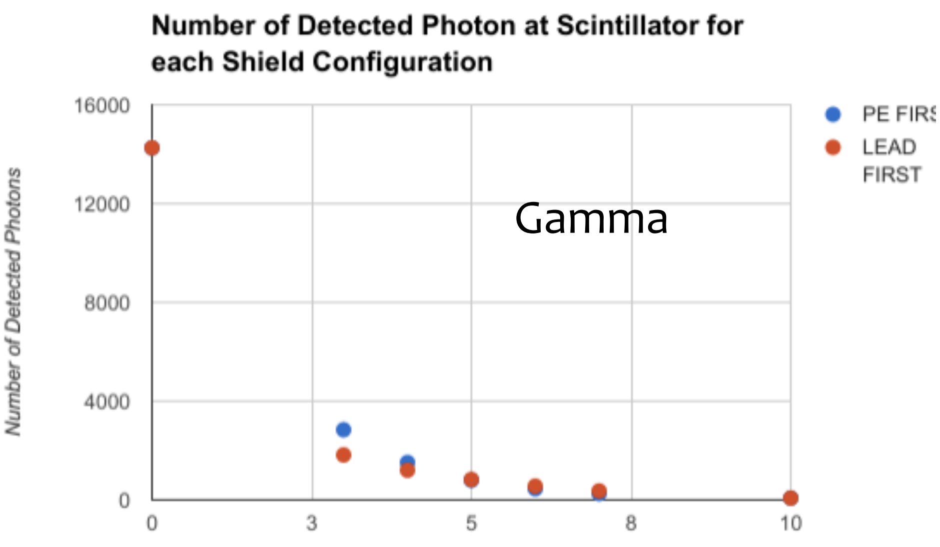


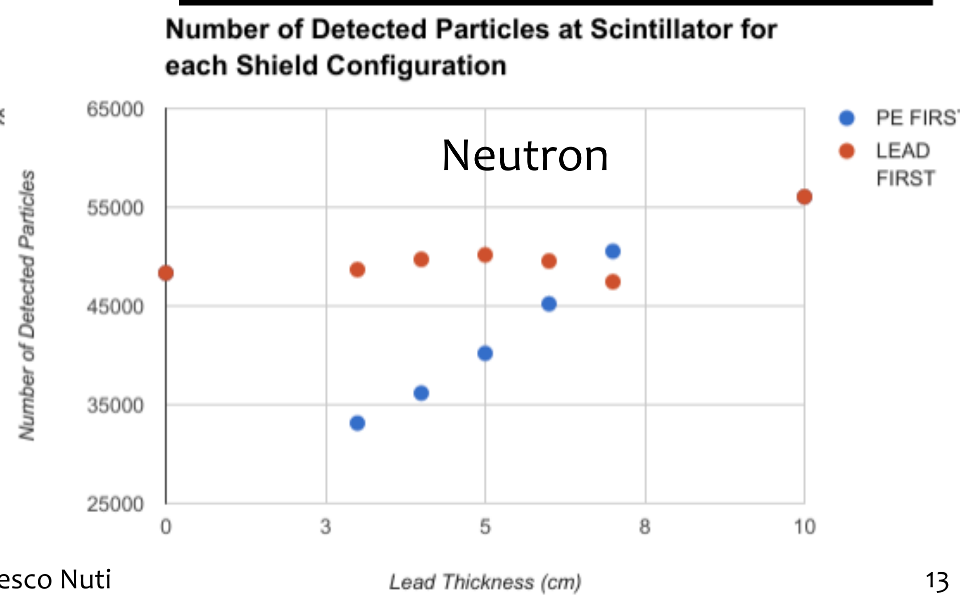


Passive shielding studies

- Characterize the performance of shielding solutions against environmental gammas and neutrons
- Studied combinations of
  - Lead (Pb)
  - polyethylene (PE)
  - polyethylene enriched with Lithium/Bismuth (PE-Li/Bi)
- Total thickness 20 cm

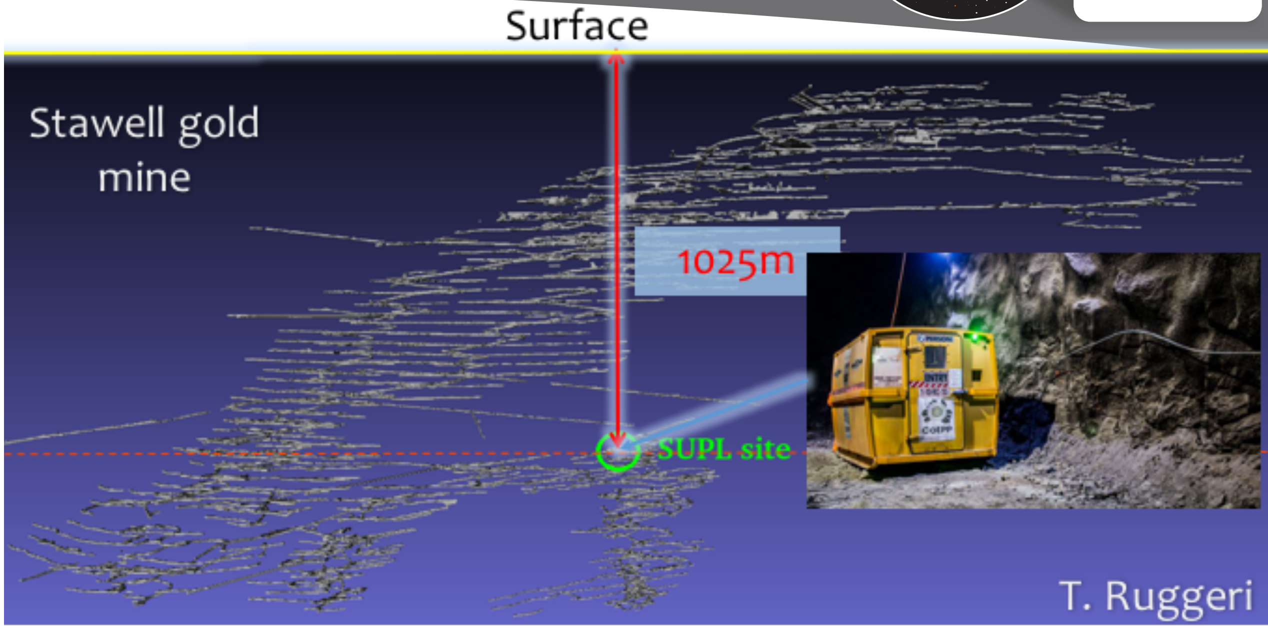






External backgrounds @ SUPL

- Preliminary measurements of the neutron, gamma, muon total flux completed (Melb, ANU)

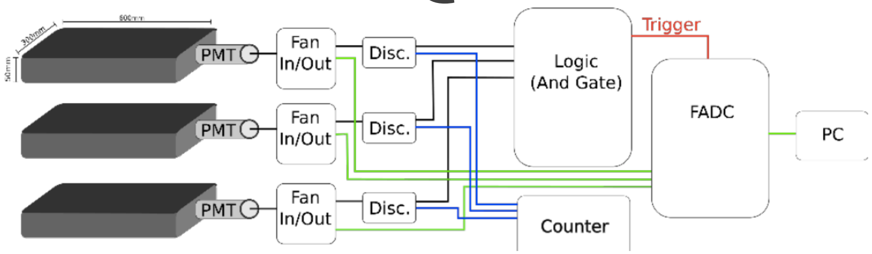


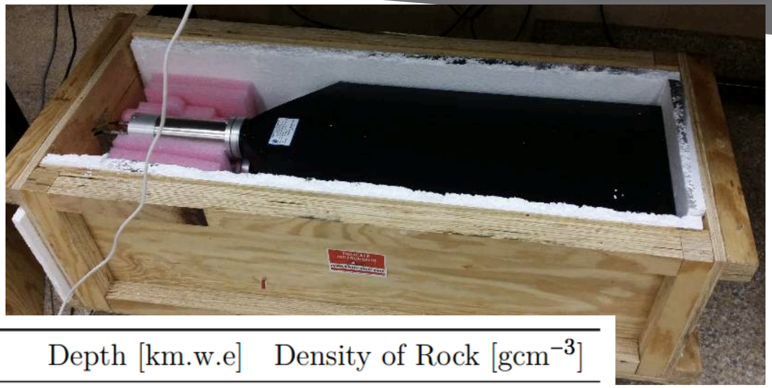
	Gran Sasso Lab. Reference	Stawell
Neutron Flux	4 x 10^{-6} n/s/	<7 x 10^{-6} n/s/cm^2 UL
Gamma-ray flux below 3 MeV	0.73 γ/s/cm^2	<2.5 γ/s/cm^2 UL
Radioactivity levels of rock		
Rock ^{238}U (ppm) @ 880m	2.63	0.64
Rock ^{232}Th (ppm) @ 880m	0.72	1.63
Refuge Radon Bq/m^3 (12 day accumulation, ventilated)	*O*(50)	36±5 21°C, 1056 kPa, 21% humidity

- Working on a more accurate characterization of these processes

Muon Flux

- Rate measured @ SUPL site

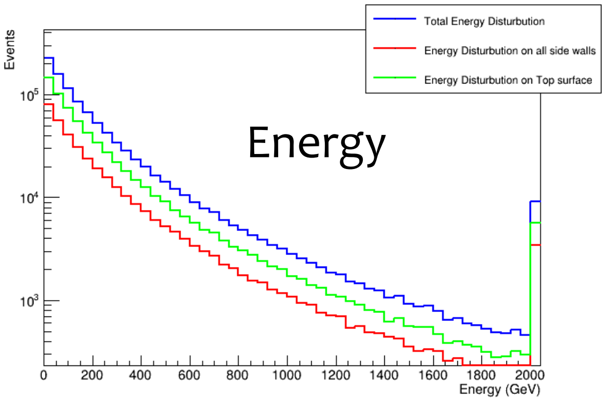


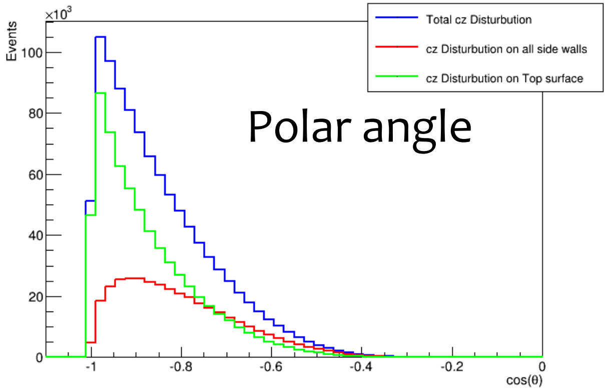


	Counts	Count Duration [s]	Muon Flux [$cm^{-2}s^{-1}$]	Flux Attenuation
Surface	134200	7800	$(1.82\pm.17)\times10^{-2}$	N/A
495m	928	858900	$(6.76\pm.43)\times10^{-7}$	$(6.30\pm.71)\times10^{-5}$
729m	394	1385200	$(1.78\pm.13)\times10^{-7}$	$(1.66\pm.20)\times10^{-5}$
1025m	105	1802000	$(3.65\pm.41)\times10^{-8}$	$(3.40\pm.50)\times10^{-6}$

	Depth [km.w.e]	Density of Rock [gcm^{-3}]
495m	$1.44\pm.02$	$2.91\pm.04$
729m	$2.0\pm.04$	$2.75\pm.05$
1025m	$2.88\pm.07$	$2.81\pm.07$

- Energy and direction estimated with MUSUN/MUSIC

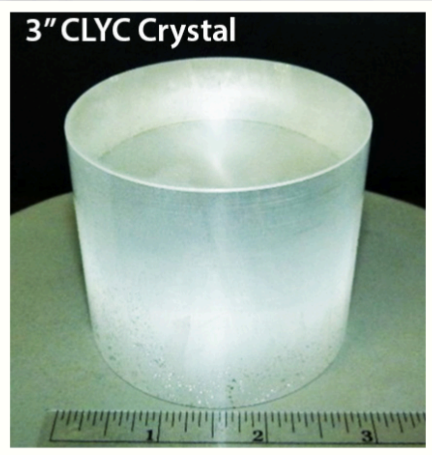


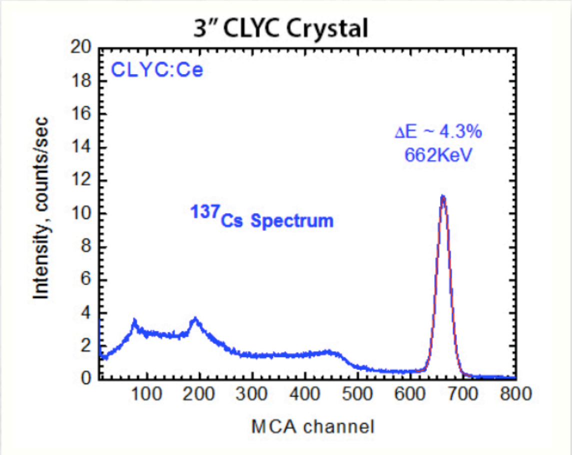


- NEXT: measure annual modulation to compare with Corsika simulation, investigate muon veto system (Melb, Adelaide)

NEUTRON/GAMMA FLUX

- Measure neutron/gamma flux and energy spectrum simultaneously with CLYC detectors (ANU, ANSTO, Melb)

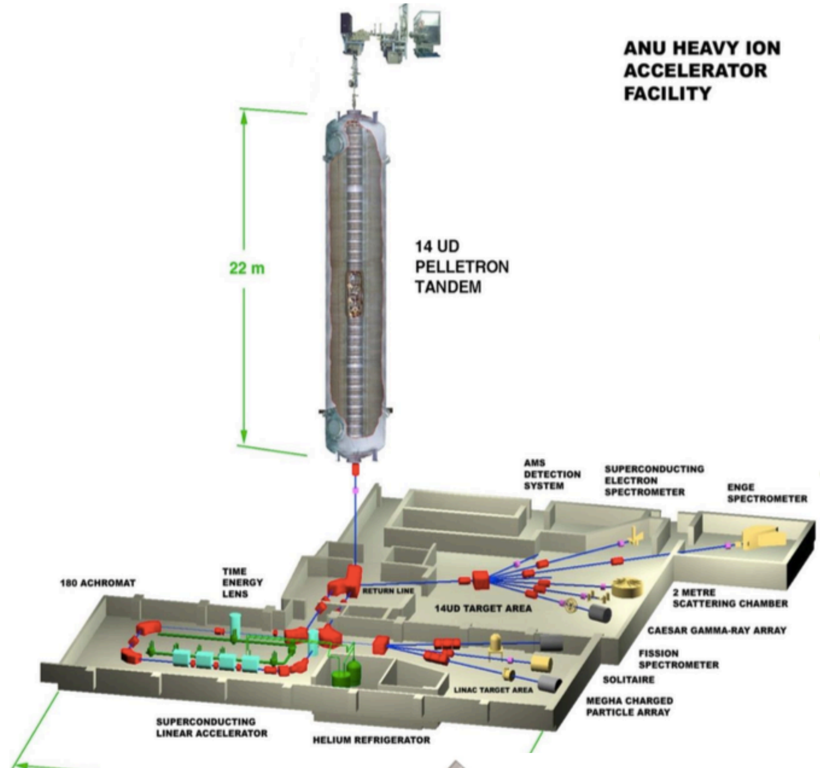


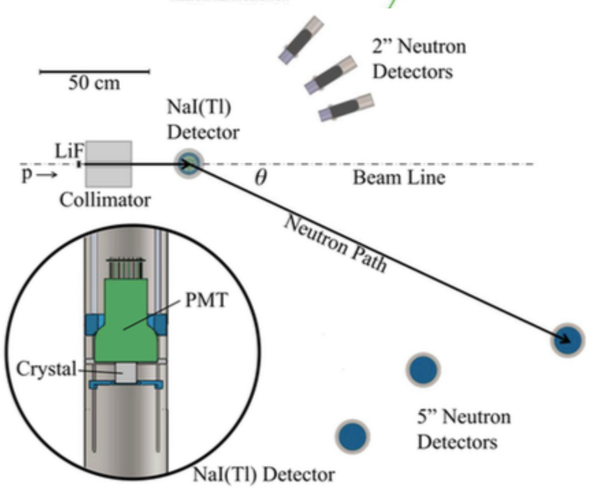


- Cs_2LiYCl_6:Ce detectors can be bought as:
  - ^{6}Li enriched to enhance sensitivity to thermal neutrons
  - ^{7}Li enriched for fast neutron spectroscopy based on reactions with 35Cl
- Pulse Shape Discrimination allows separation of neutron and gamma spectra
- This measurement needed to finalize the shielding design

HIAF @ ANU

- Fundamental for accurate measurements of:
  - Radionuclide isotope fractions (^{129}I, ^{210}Pb) via atomic mass spectroscopy
  - CLYC response characterization
  - Pulse Shape Discrimination of radiation types (gamma, neutron, alpha…) in detector materials (Scintillator, NaI)
  - Quenching Factor for NaI crystals





Slow Control and DAQ

Adelaide and Swinburne to develop a slow control system to monitor:

- Temperature (crystals, PMTs, gradient of vessel)
- Nitrogen (leak, level, pressure, valve statuses)
- Humidity (near crystal)
- Scintillator (leakage monitor)
- PMT HV
- Radon
- Muons, neutrons, gammas
- Pressure, oxygen
- Seismic/Blasting activity

DAQ to be developed by Melb and ANU

- Electronics arrived last week
- Setup and tests to start next week

Conclusion

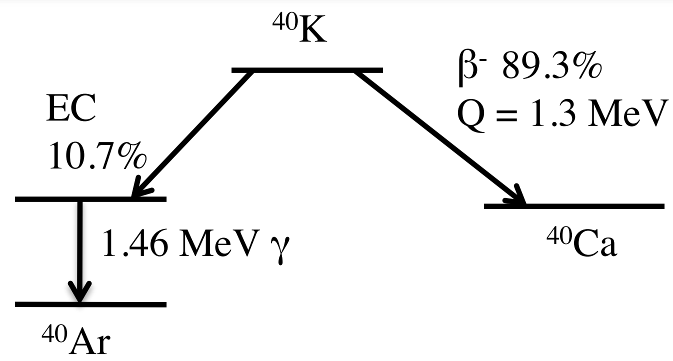
- The SABRE experiment is the result of a compact and strong collaboration between Australian, Italian, British and American institutions
- Australian institutions are involved in fundamental tasks
  - PoP: background estimate
  - Full scale experiment: development of more optimized shielding and veto systems
  - Measurement of crystal and liquid scintillator properties for background characterisation and interpretation of results
  - Measurement of environmental background at the SUPL site
- We hope to contribute to the Dark Matter discovery!

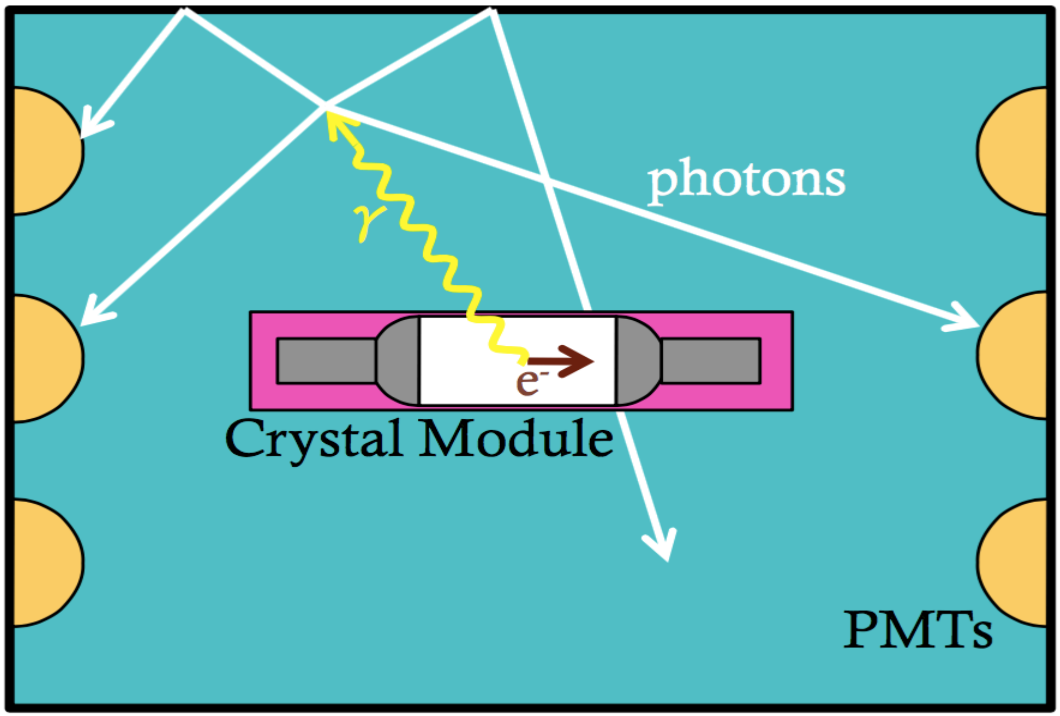
Backup

Active Background Rejection

- NaI crystals immerged in liquid scintillator
- Goal: reject external+intrinsic backgrounds (radioactive, cosmic-induced processes)
- Veto processes with significant signals in the scintillator (>100KeV)

^{40}K electron capture in crystals





SUPL CHARACTERISTICS

- Clean lab similar to SNOLab
- Rn activity < 100 Bq/m^3 in "clean area". Surface coating to inhibit Rn.
- Temp.: 19±2 °C, Relative humidity 40% - 50%, remote monitoring & control.
- Low radiation concrete and finishing; sampling all sand and cement.

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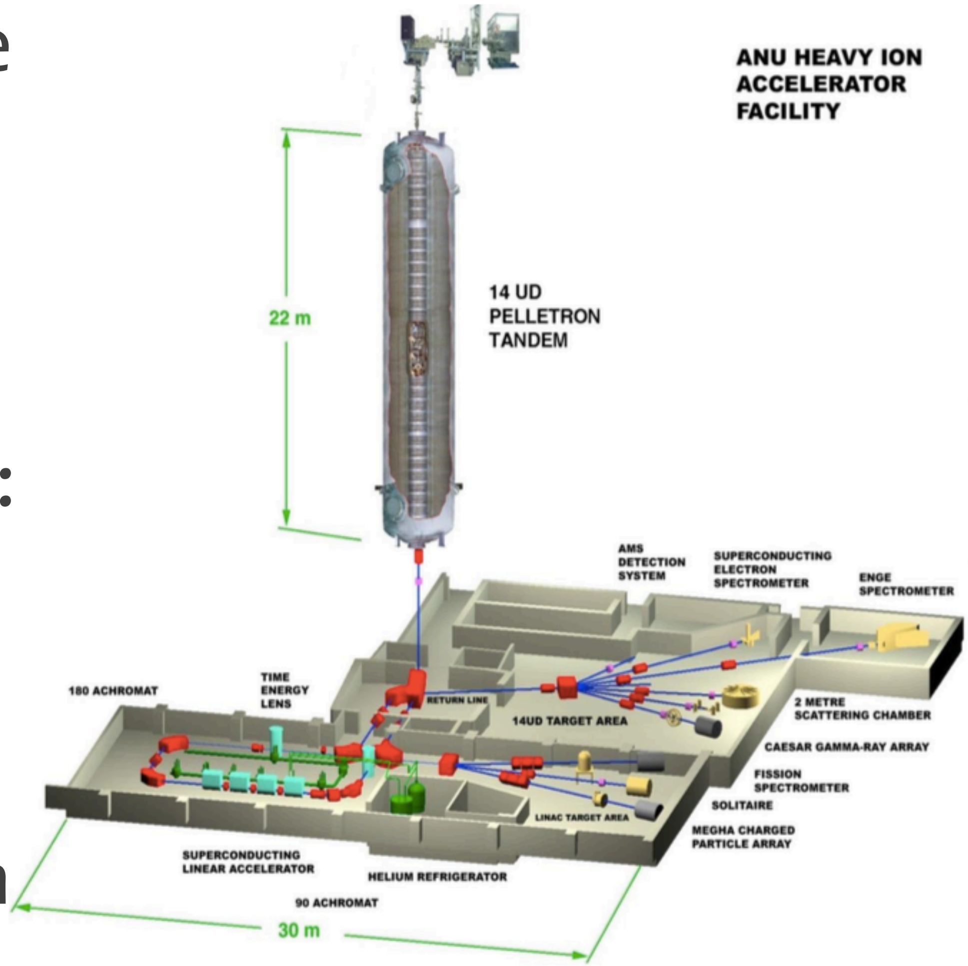
Refuge Radon Bq/m^3 (12 day accumulation, ventilated)	*O*(50)	36±5 21°C, 1056 kPa, 21% humidity

Atomic mass spectroscopy to measure radionuclide isotope ratios

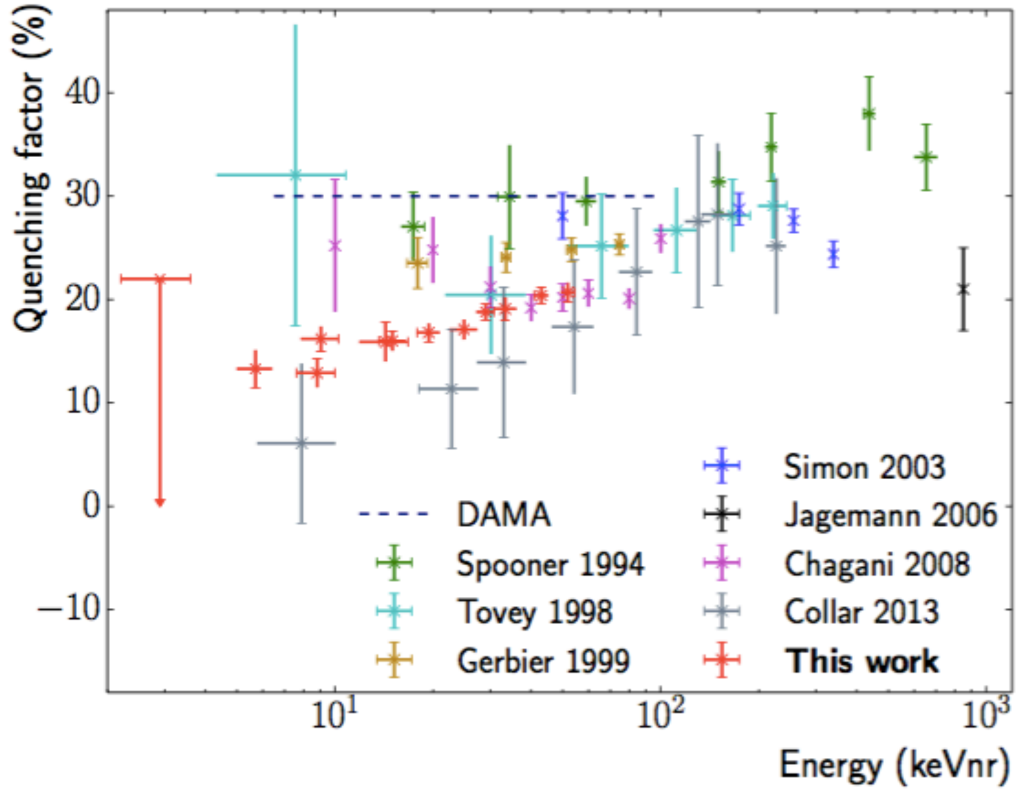
- ^{129}I sensitivity better than ^{129}I/I= 10^{-14}
- ^{210}Pb more challenging: does not easily form negative ions; various chemical forms to produce Pb beams investigated. Results in preparation



Nuclear Recoil quenching

New results on quenching factor

- more quenching at low recoil energies
- The region 2 – 6 keVee corresponds to higher nuclear recoil energies
- 9 keVnr ←→ 0.9 keVee
- ANU could measure the QF and reach lower energies with higher recision



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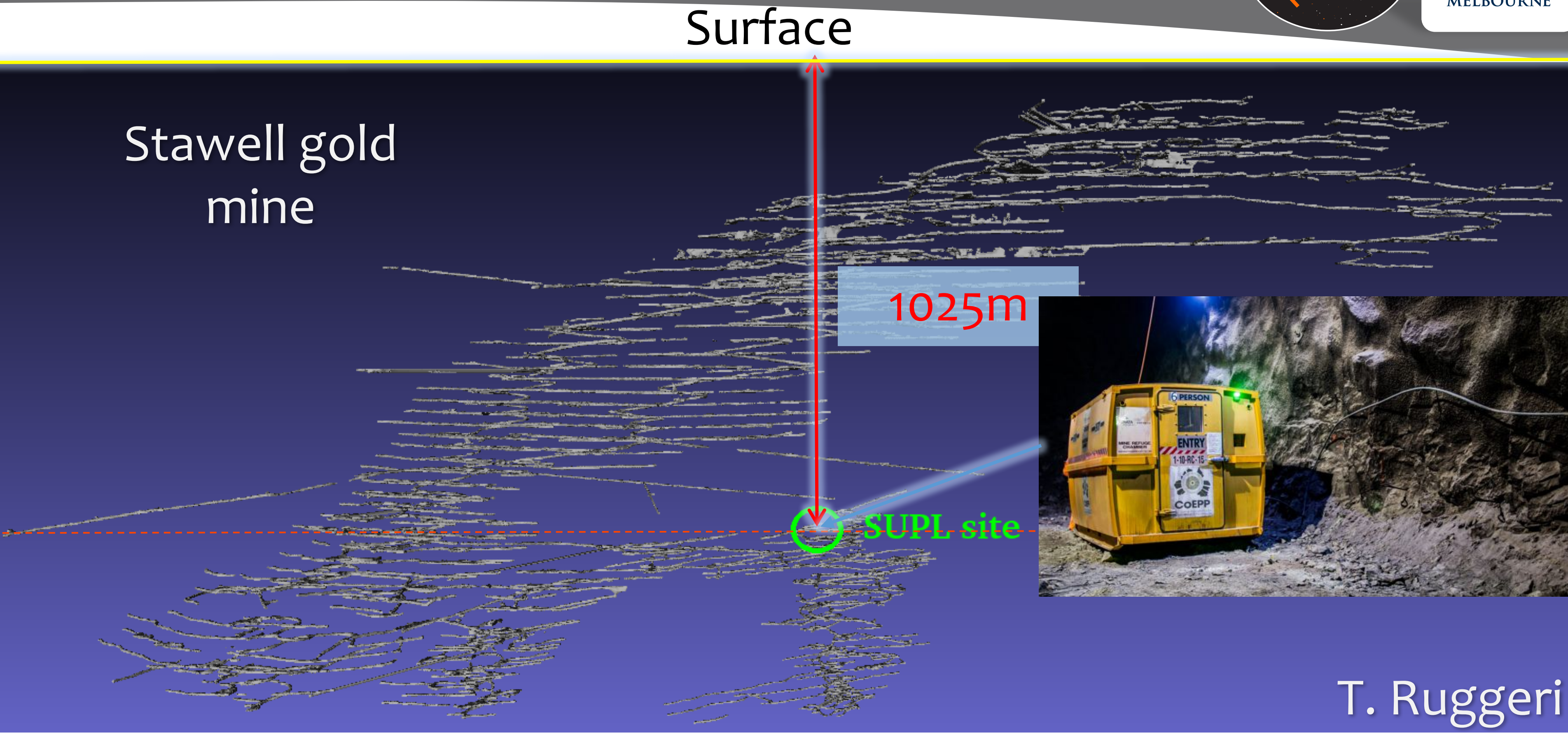
Surface
Stawell gold mine
1025m
SUPL site
PERSON
ENTRY
CoEPP
T. Ruggeri