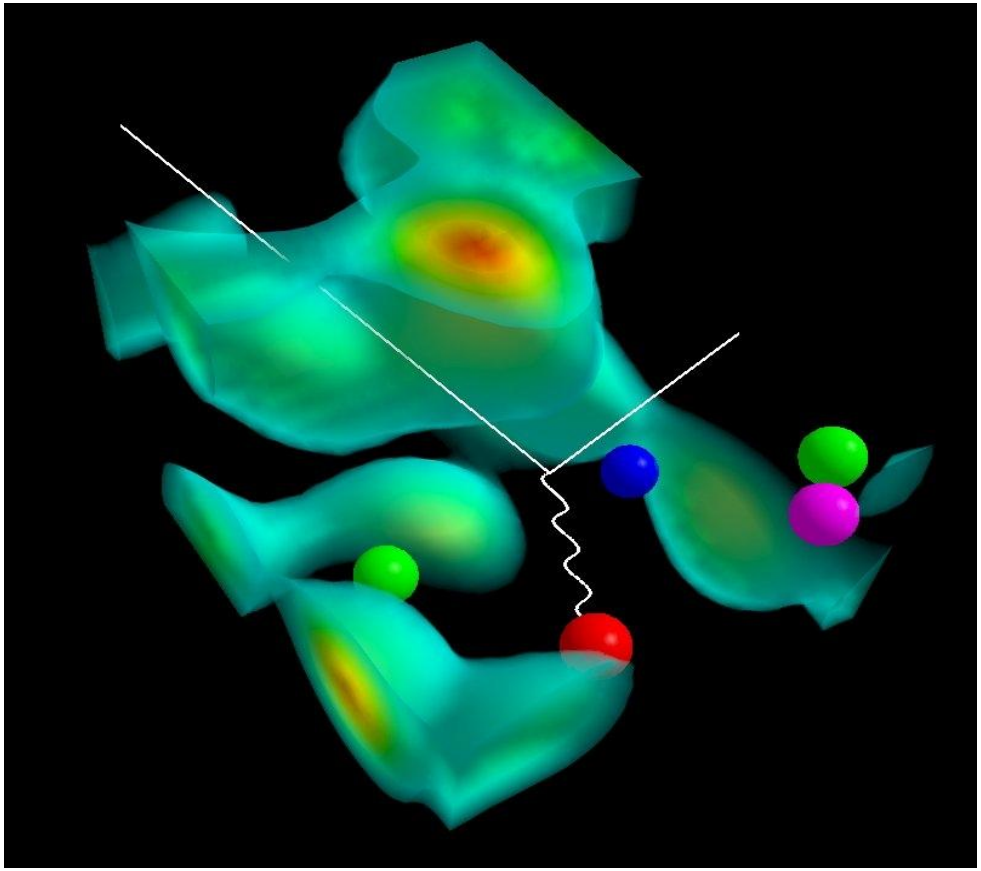
Nuclear Physics in Australia



CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

Australian Government
Australian Research Council

Anthony W. Thomas

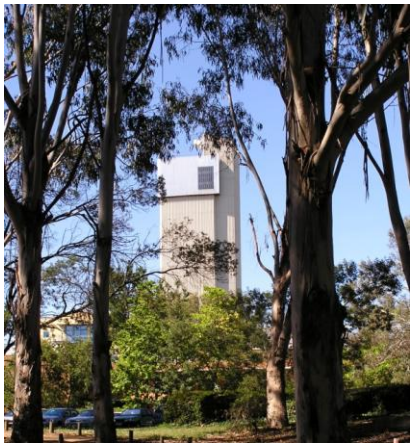
ADELAIDE UNIVERSITY AUSTRALIA

SPECIAL RESEARCH CENTRE FOR THE SUBATOMIC STRUCTURE OF MATTER

ANPhA
Sendai : 24th November 2016

Acknowledgments

- Andrew Stuchbery ANU
- Elisabetta Barberio, Melbourne
- Victor Flambaum, UNSW
- Richard Garrett, ANSTO
- Anatoly Rozenfeld, Wollongong
- Geoff Taylor, Melbourne
- Phillip Urquijo, Melbourne
- Kevin Varvell, Sydney
- ANU Nuclear Physics



Acronyms and Outline

CoEPP

Centre of Excellence for Particle Physics
- University Research
- International Links

Australian Government | ansto
Australian Nuclear Science and Technology Organisation

Australian Nuclear Science and Technology Organisation
- Applied nuclear
- Major facilities
  - OPAL Reactor
  - Australian Synchrotron

Fundamental - Particle → Nuclear - Heavy Ion → Applications

STAWELL UNDERGROUND PHYSICS LAB

SUPL – Dark Matter Search
- Combined Nuclear and Particle Effort
- New venture

proton THERAPY AUSTRALIA

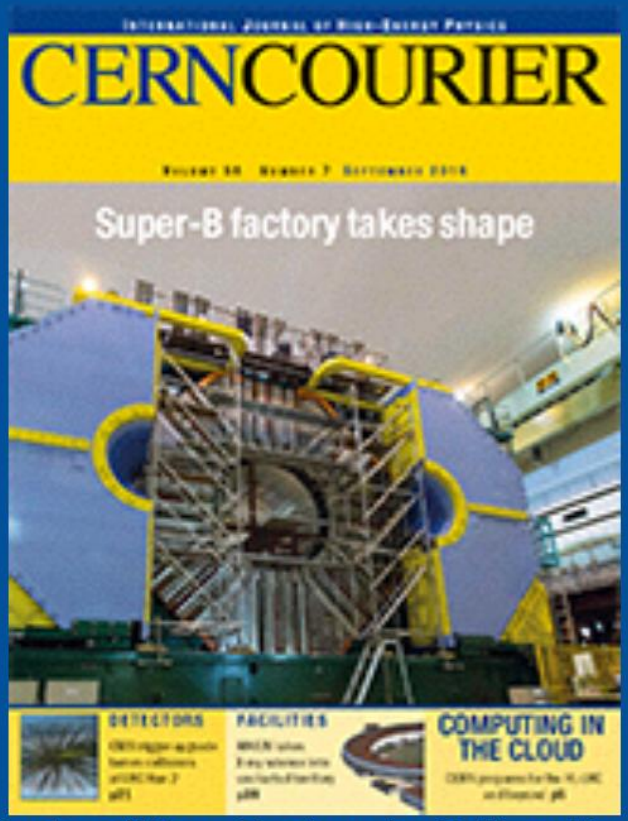
CoEPP - the ARC (Australian Research Council) Centre of Excellence for Particle Physics at the Terascale.

- Encompasses the particle physics field in Australia
- Focus for Experimental and Theoretical Particle Physics
- Funded for period 2011-2017
- Nodes: Adelaide, Melbourne, Monash, Sydney Universities
- 20 Academics, 36 post-docs, 97 research students (2015)

Research Program

- Higgs Physics
  - H to tau tau
  - WH to WWW
  - ttH to leptons
- Collider Phenomenology
- BSM and exotic models
- Search for origins of neutrino mass
- Search for Exotics

- **Precision tests of SM**
  - **Low energy QCD**
  - **Top Cross-section**
    - **Dark Matter**
  - **Collider Searches**
  - **BSM implications**
    - **SUSY**
    - **Modelling**
  - **Collider Searches**



Sept. edition. Feature by P. Urquijo

Australian Involvement in Belle II

Universities of Melbourne, Sydney, Adelaide

Belle II

THE UNIVERSITY OF MELBOURNE

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY of ADELAIDE

Australian Belle II Contribution

Belle II Management

- Belle II Physics Coordinator (Urquijo)
- Belle Executive Board (Urquijo, Sevior)
- Belle II Executive Board (Urquijo, Sevior)
- Belle CKM Analysis Group Coordinator (Urquijo)
- Belle Hadronic B decay Group Coordinator (Sevior)

Physics

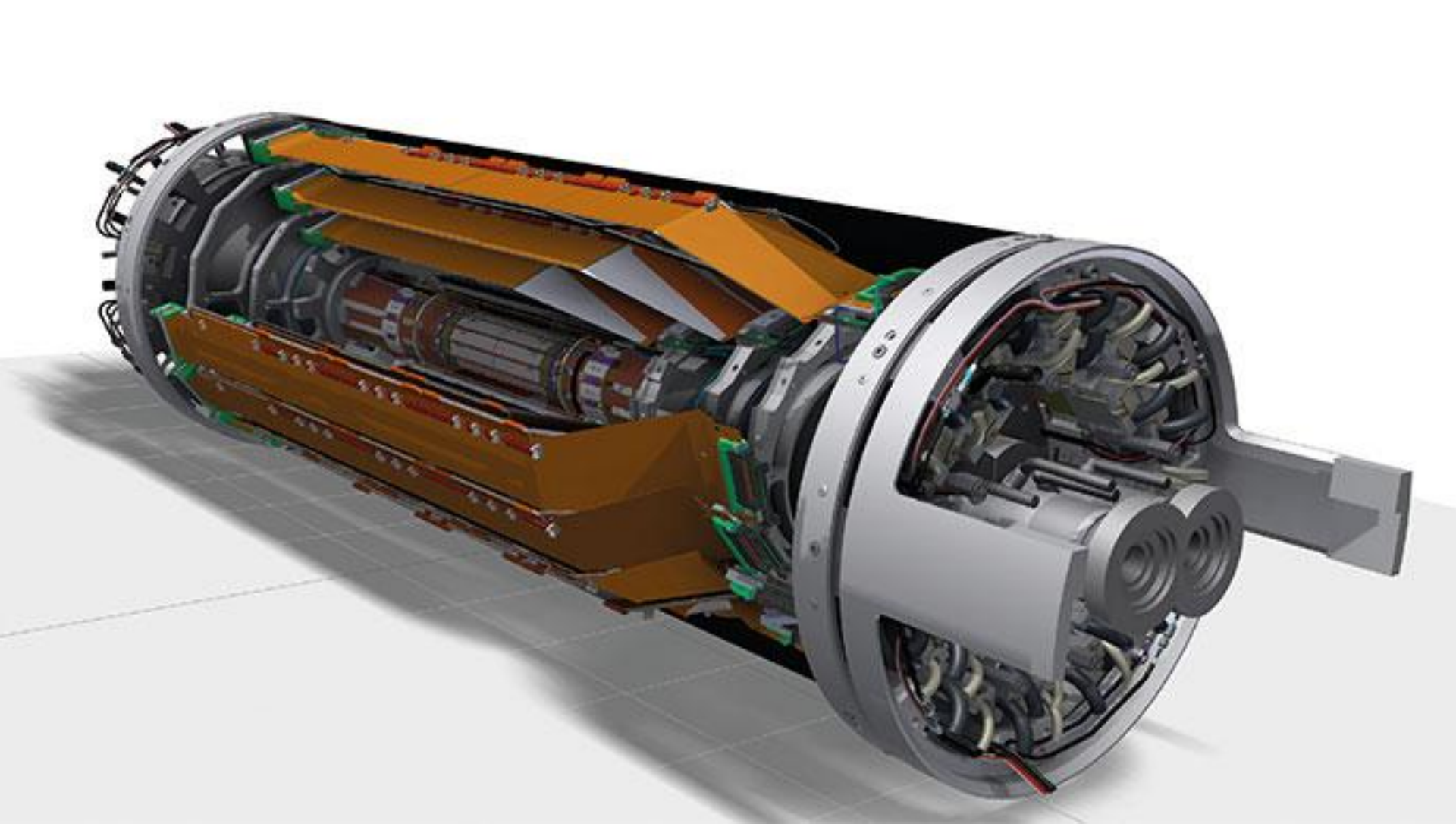
- Semi-leptonic B decays (Melbourne, Sydney):
  - Precision measurements of |Vub|, |Vcb|
  - Searches for charged Higgs
- Radiative and electroweak B decays (Melbourne)
- τ lepton flavour violation (Melbourne)
- Dark Sector searches (Melbourne)
- CP Violation in B decays (Melbourne)

Detectors (Melbourne)

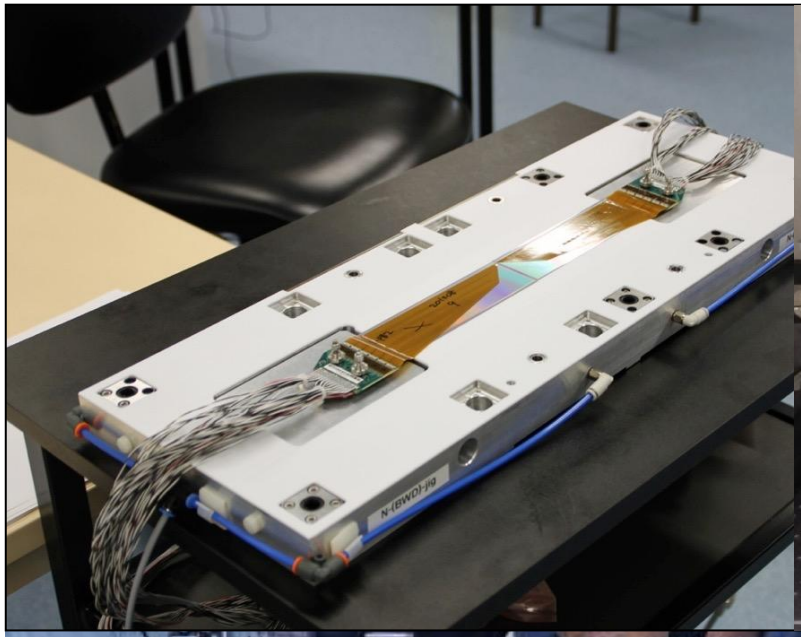
- Silicon Vertex Detector Construction and Software
- Trigger (HLT & Trigger Menu) and Data Acquisition
- Detector Calibration
- Global Computing Grid

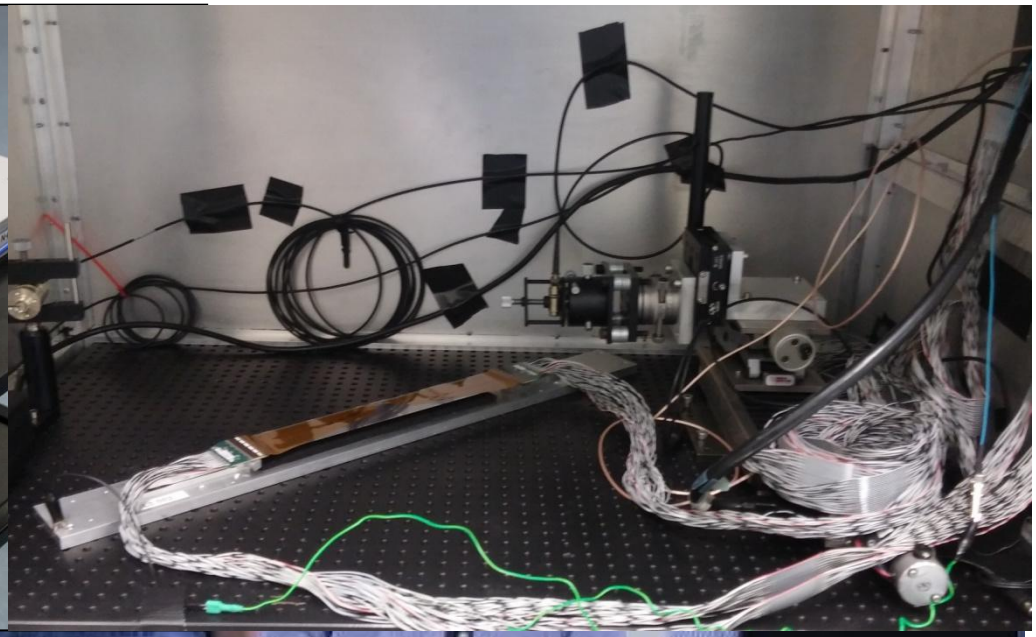
Trigger Hut, KEK, C-H Li (UniMelb)

The Belle II Vertex Detector System



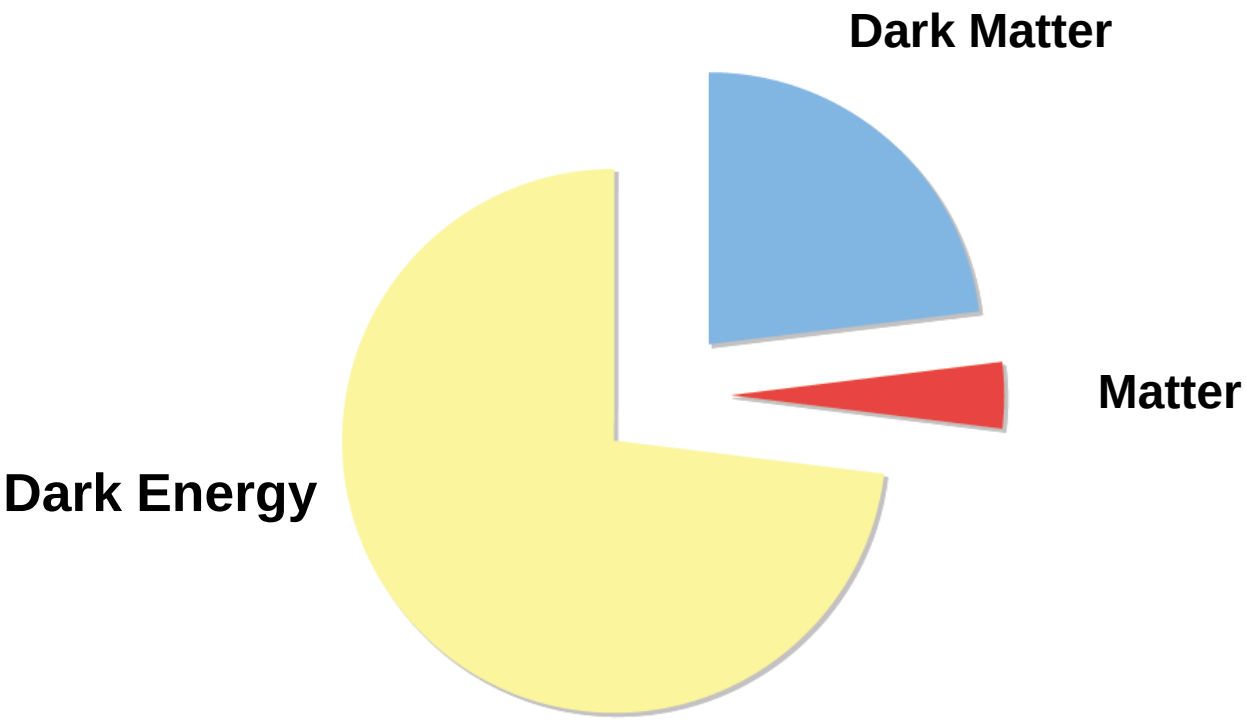
SVD Construction @ University of Melbourne





Dark Matter

Direct Dark Matter Searches

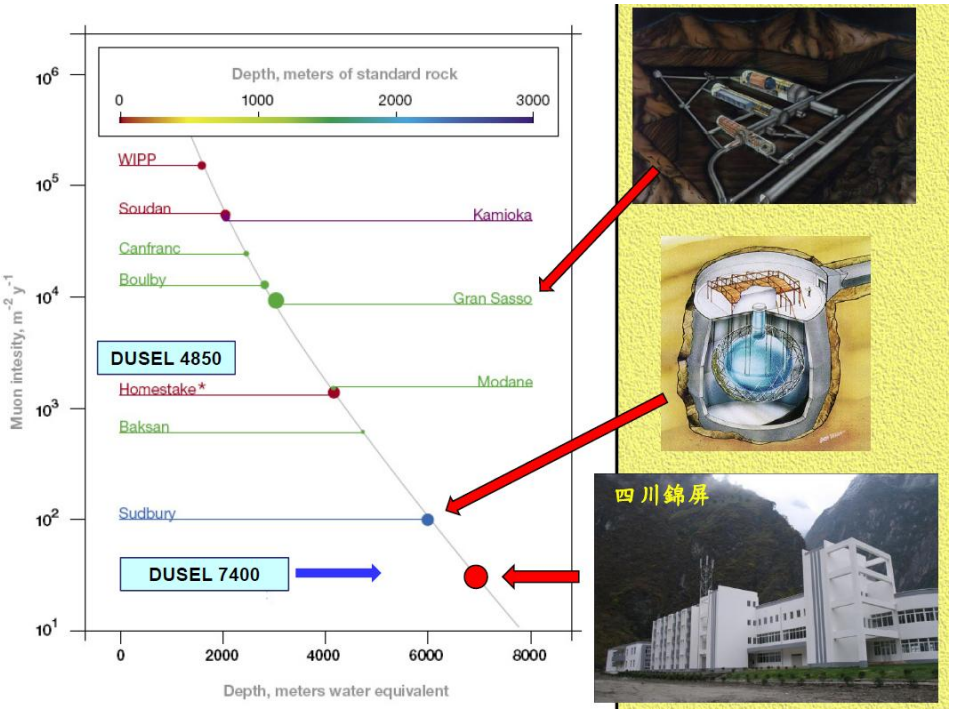


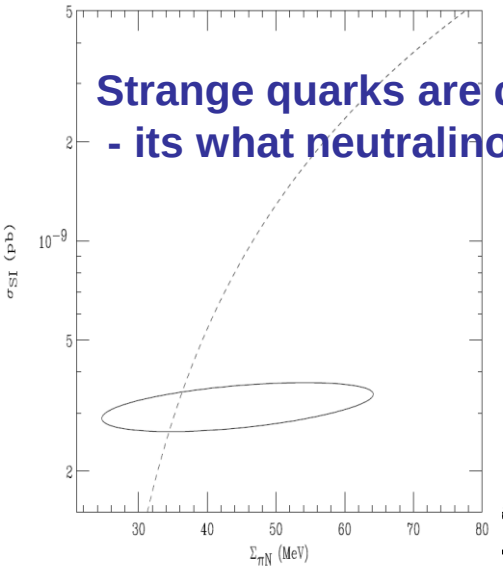
Neutralino is the Preferred Candidate

Because it arises naturally in supersymmetric extensions of the Standard Model

Can calculate its properties in a given SUSY theory

Many searches underway – indirect at LHC
– direct deep underground





Giedt et al., Physical Review Letters
103 November 12, 2009

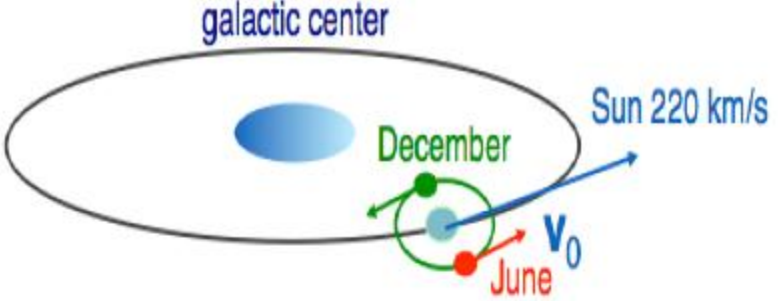
Majority of Experiments find Nothing

- **Spin dependent scattering usually ignored because spin independent cross section ~A^2**
  (coherent contribution from ALL nucleons)

- **Spin-dependent nuclear cross section involves only one or two "valence nucleons"**
  (all the rest are paired to spin zero)

- **On the other hand, DAMA, using NaI crystal at Gram Sasso in Italy has reported a spectacular signal**

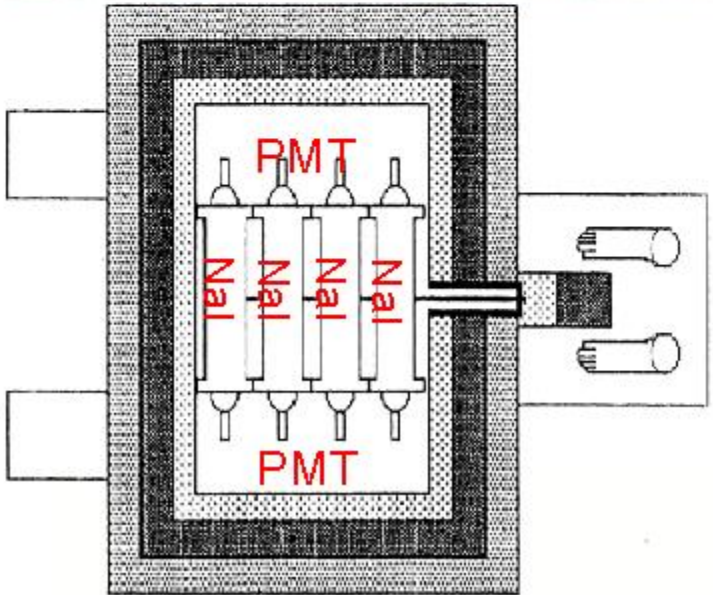
DAMA/LIBRA

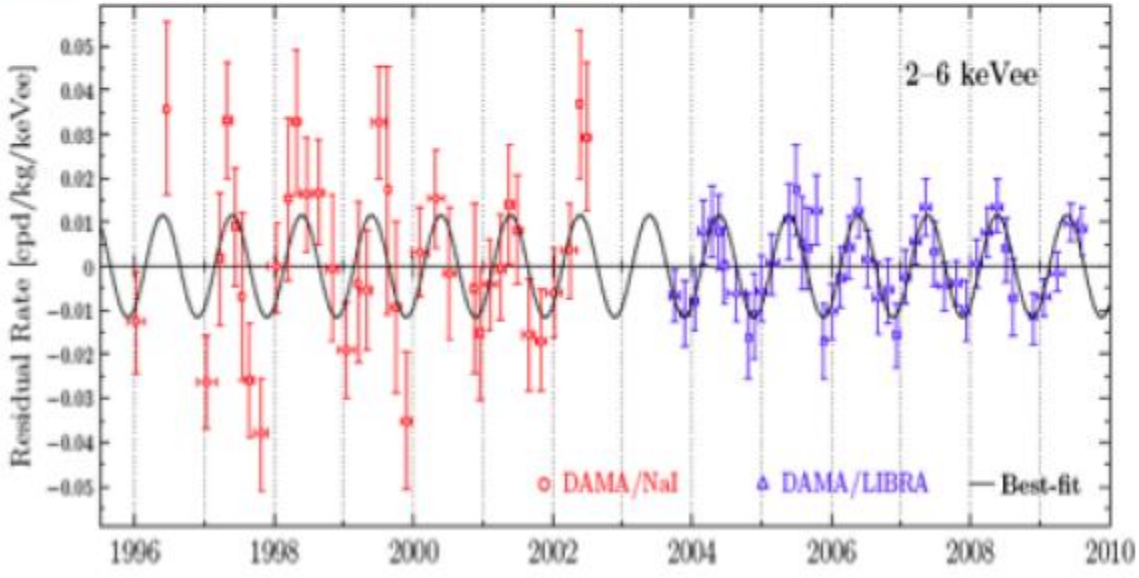


WIMP wind ~ isotropic in halo frame,
v ~ 270 km/s

Sun travels through this cloud at ~220 km/s

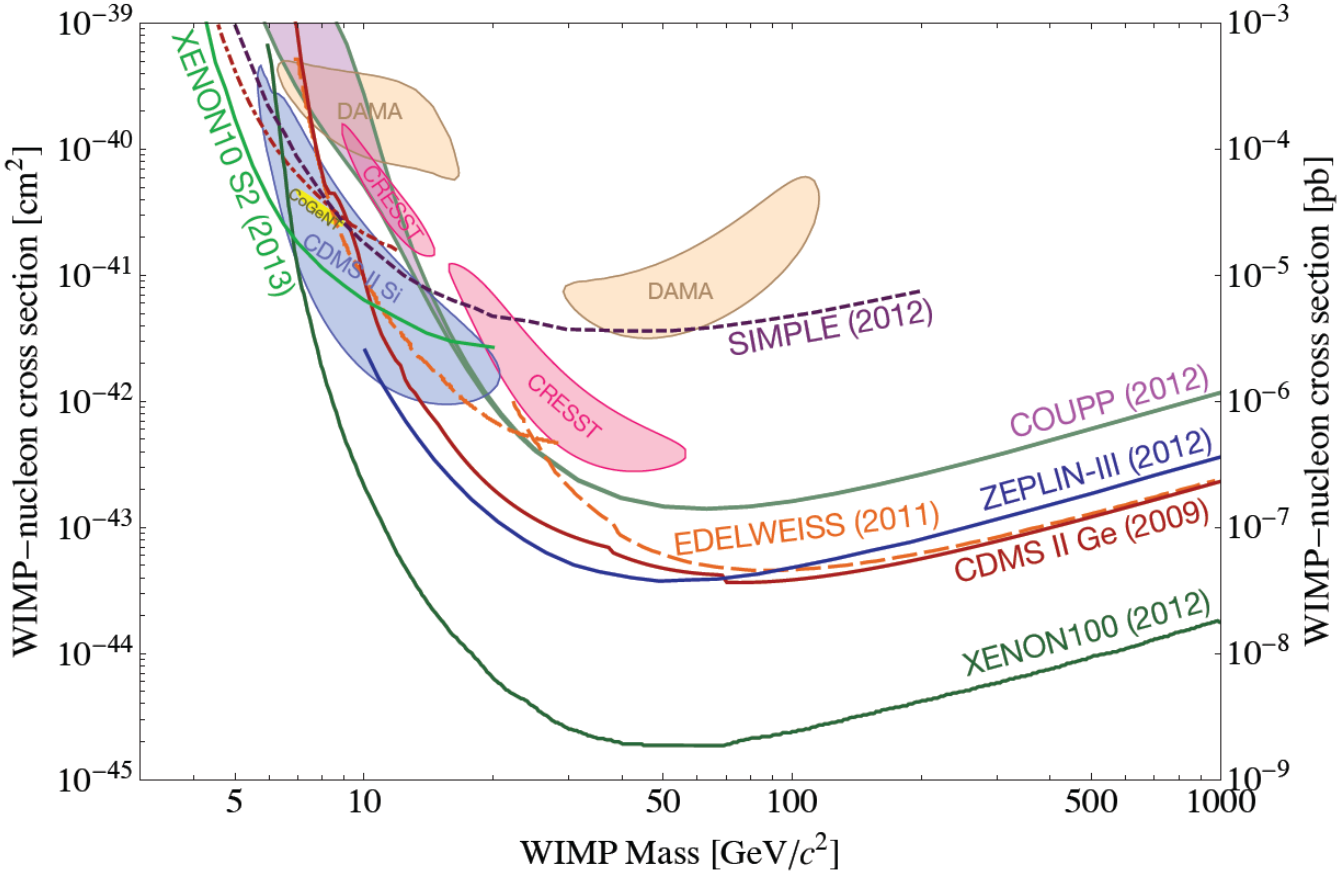
Earth adds or subtracts 15 km/s (= 30 km/s X cos 60^0) to solar velocity
Expect ± 1-few % modulation in rate





Motivation: DAMA/LIBRA

- **But apparently in contradiction with other experiments**



SABRE: **S**odium iodide with **A**ctive **B**ackground **RE**jection

- Twin detectors @ LNGS and SUPL
- Spokesperson: Frank Calaprice (Princeton)

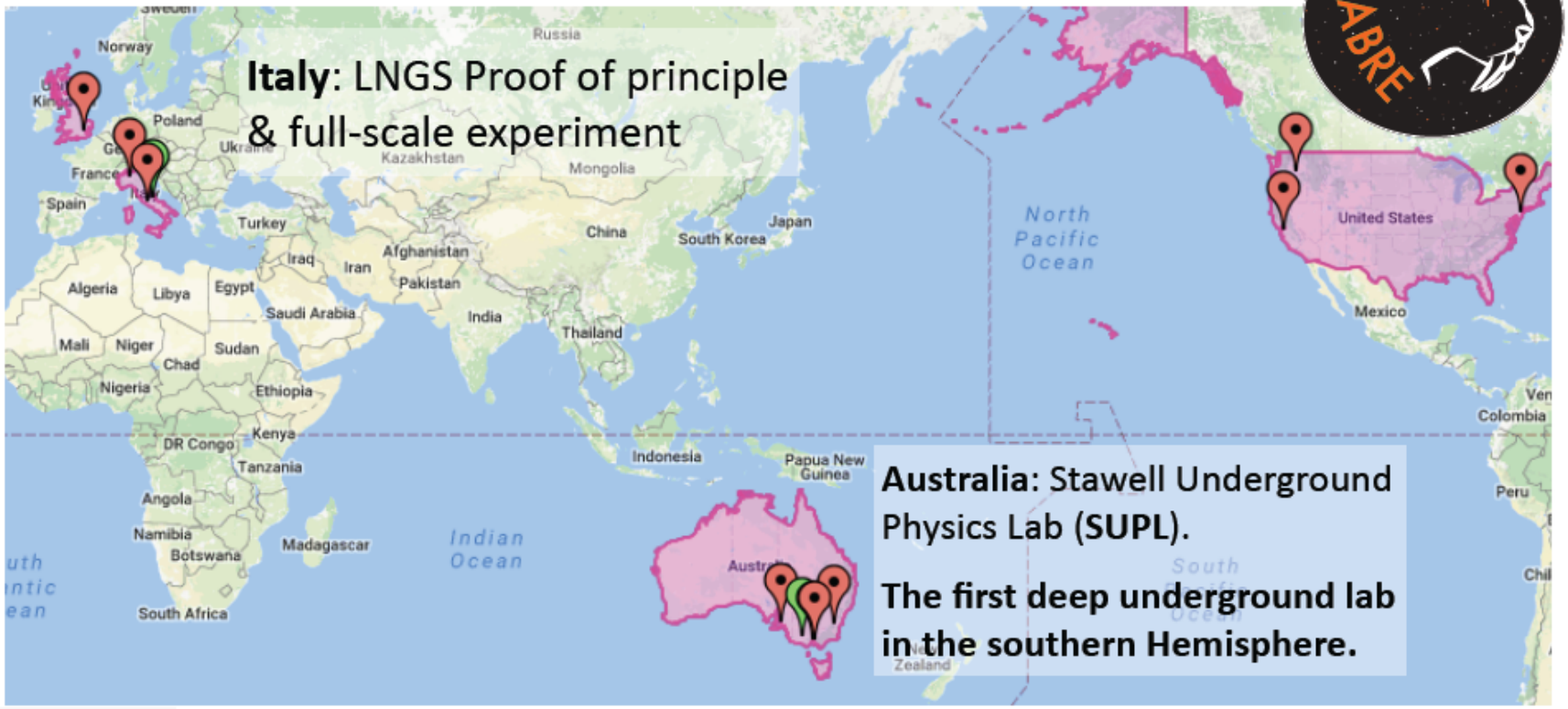
SABRE Collaboration: 11 institutes

Australia: Uni. Adelaide, Australian National Uni., Uni. Melbourne, Swinburne Uni.

Italy: LNGS, Milano Uni., Roma la Sapienza Uni.

USA: Princeton Uni., PNNL, LLNL

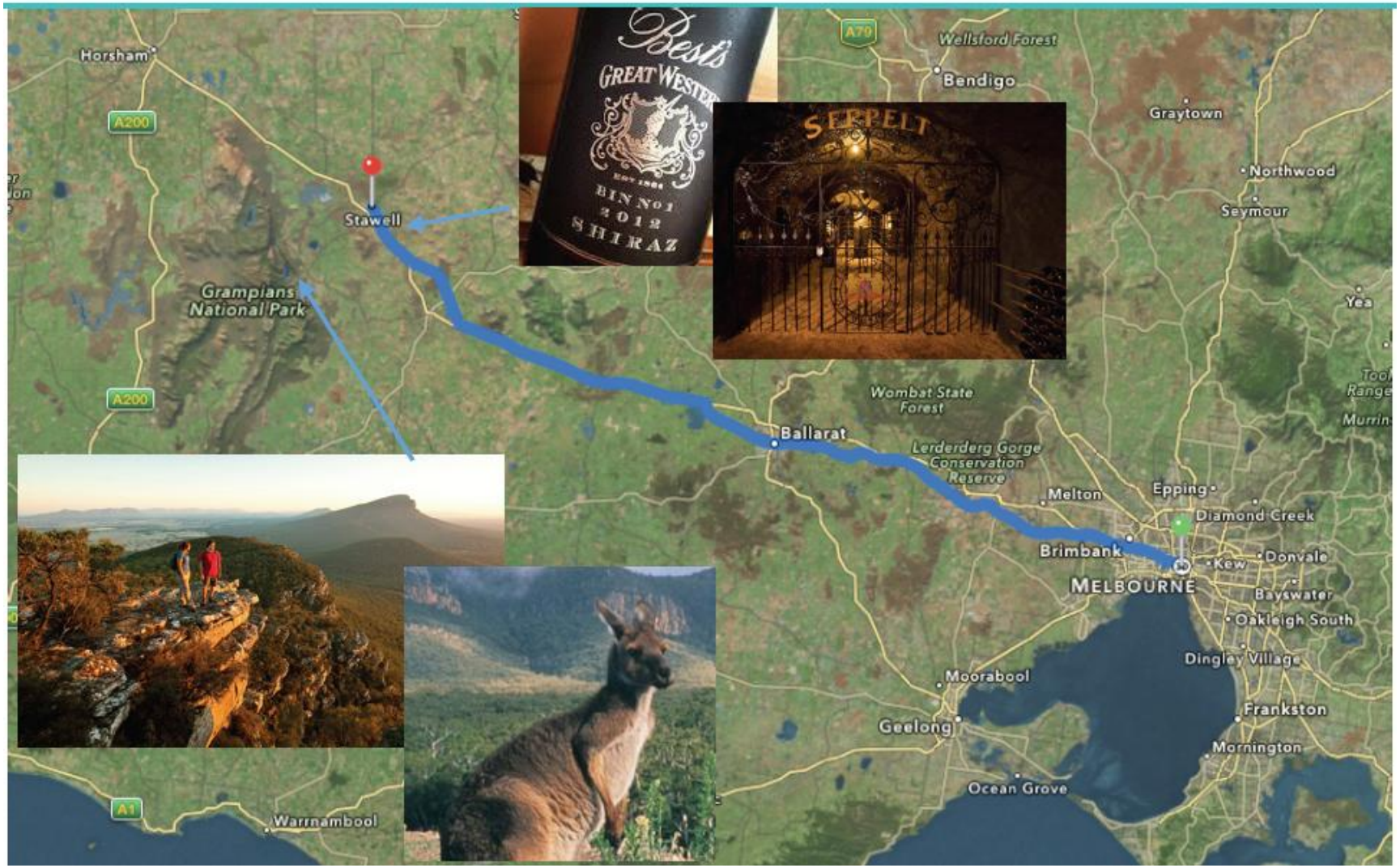
UK: Imperial College London



SABRE Strategy

- **Lower Background**
  - **NaI(Tl)** crystals with **higher purity** than DAMA/LIBRA
  - Low-radioactivity enclosure & PMTs.
  - **Active scintillator veto** reduces internal and external background.
- **Lower energy threshold**
  - **High QE** Hamamatsu PMTs **directly coupled** to NaI**.**
  - PSD based DAQ and data analysis, improved background measurements via AMS, improved quenching factors.

Stawell, 250 km from Melbourne



STAWELL GOLD MINE IN VICTORIA

The Federal and Victorian Governments have so far contributed almost $5M to this project.....

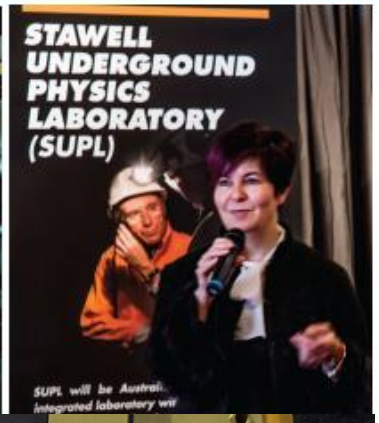
SUPL Timeline

2014
Lab proposed (Sep),
Project Leaders *E. Barberio*, *J. Mould*

2015
Funding secured (May)
Design commenced (Aug)

2016
Design Review (Feb)
Start Construction (July)
Cavern excavated (Sep)
Lab surfacing (Dec)

2017
Lab ready to use (Late 2017)
Planned experiments
SABRE-South (2017)
TPC-experiment: CYGNUS Directional Dark Matter, Neutrinoless ββ R&D
*Other possibilities **Non HEP**: Astrobiology, Cancer research*

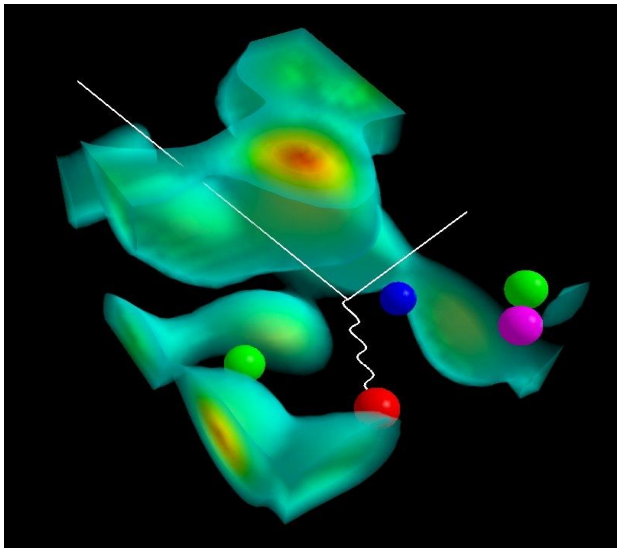


Subatomic Physics in Adelaide

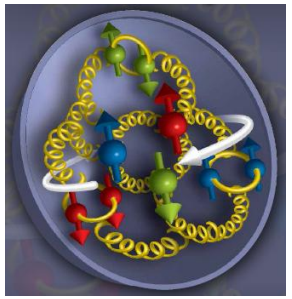
- Nuclear theory, including lattice QCD
- Particle theory and experiment
- SABRE experiment at SUPL
- 60-70 staff, postdocs, students
- Extensive International Collaborations

CSSM : Centre for the Subatomic Structure of Matter

The Strong Force, QCD & Lattice QCD

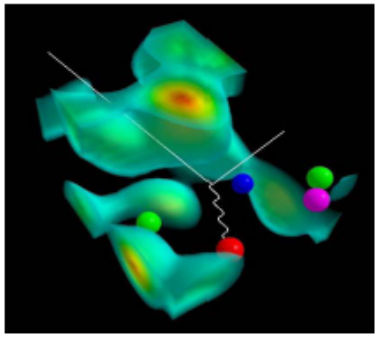


- Origins of nuclear structure
  - ✓ Quark-meson coupling (QMC) model
- Nuclear matter - Neutron stars
- Hadron structure
  - ✓ Spin of the proton

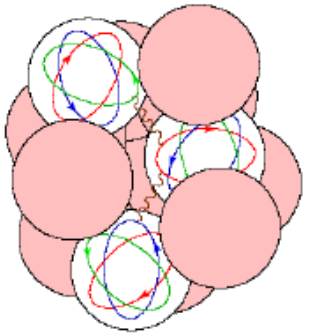


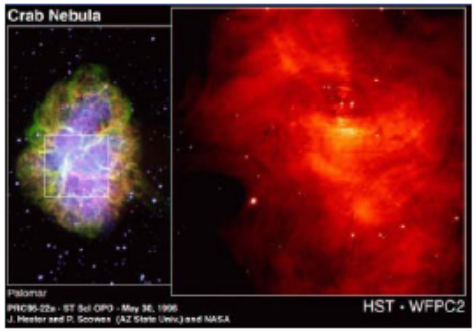
Leinweber, Thomas, Williams, Young, Zanotti

N,Λ, Ξ, ω, D, J/Ψ …… in nuclear matter



QCD & hadron structure

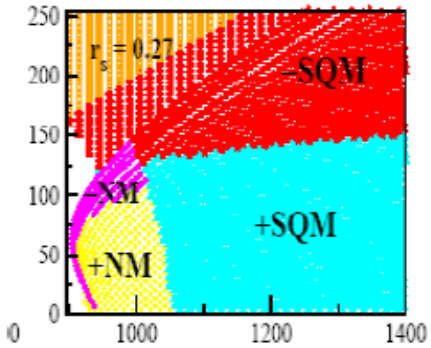




n star

∞ nuclear matter

Density dependent effective NN (and N Λ, N Ξ …) forces



quark matter

Structure of finite nuclei & hypernuclei

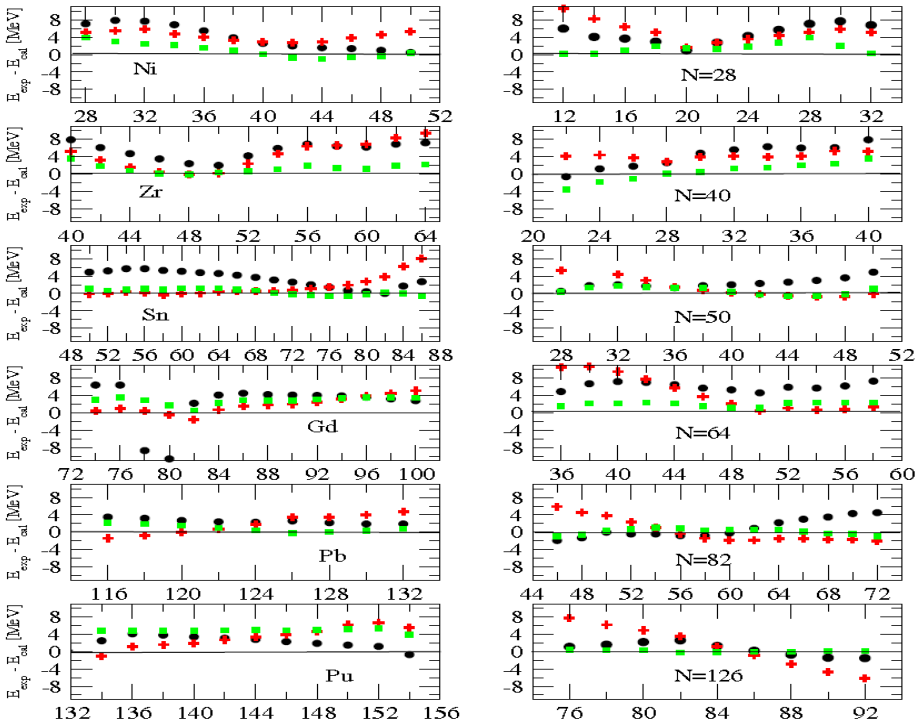
CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

ADELAIDE UNIVERSITY AUSTRALIA

CENTRE FOR THE SUBATOMIC STRUCTURE OF MATTER

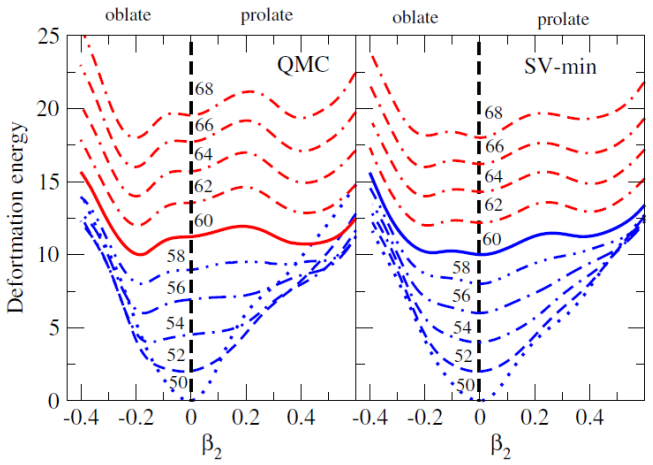
QMC Binding Energies: Isotopes & Isotones

Typically better than 0.5% across entire periodic table



Experiment QMC I QMC II

Nuclear Shapes



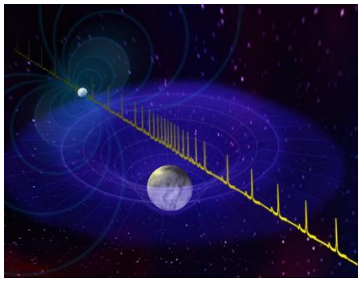
PRL **116,** 092501 (2016) PHYSICAL REVIEW LETTERS

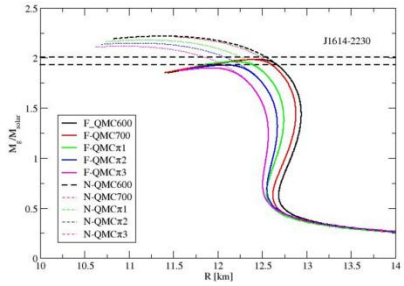
Finite Nuclei in the Quark-Meson Coupling Model

J. R. Stone,[1,2] P. A. M. Guichon,[3] P. G. Reinhard,[4] and A. W. Thomas[5]

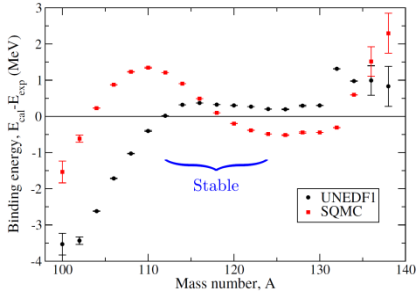
International collaboration

Neutron stars





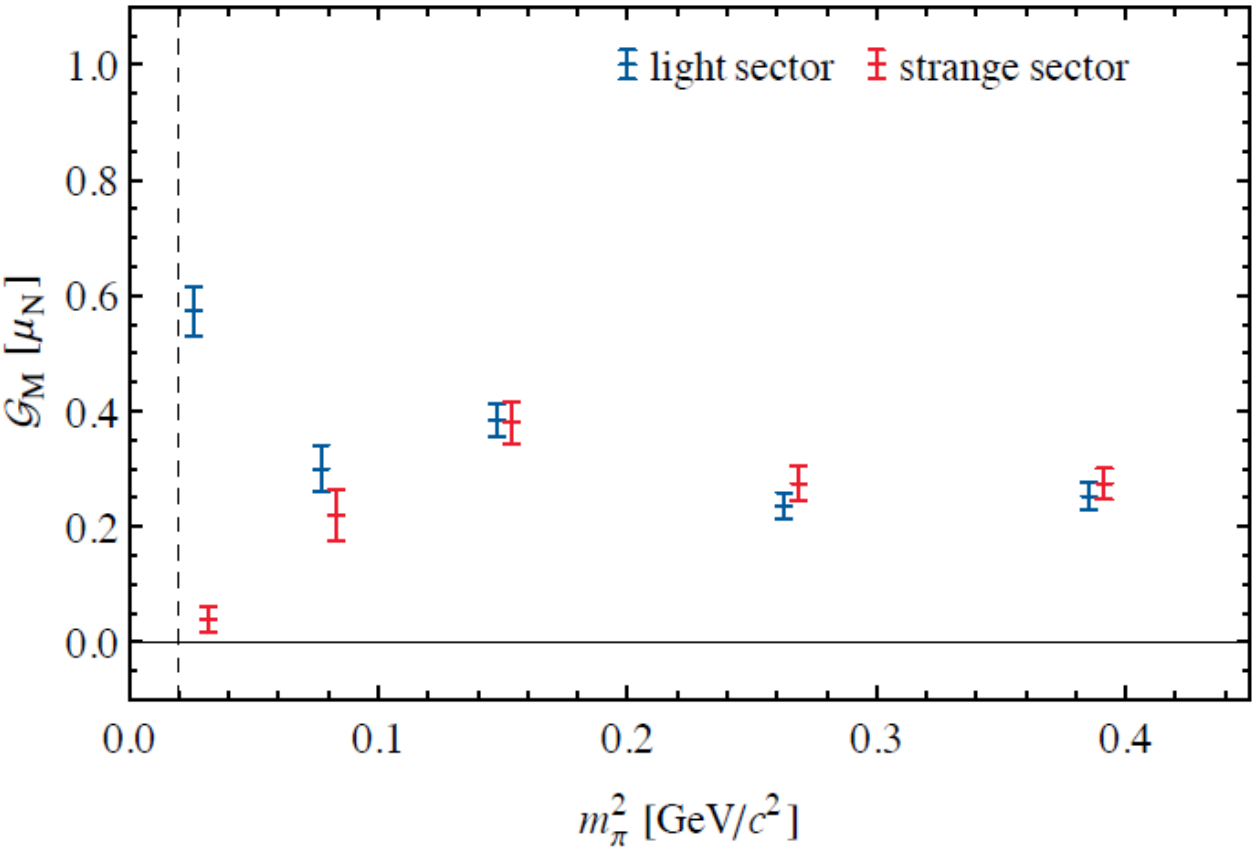
ANU collaboration



Lattice QCD – Nature of Λ(1405)

- **It is a Kbar-N bound state**

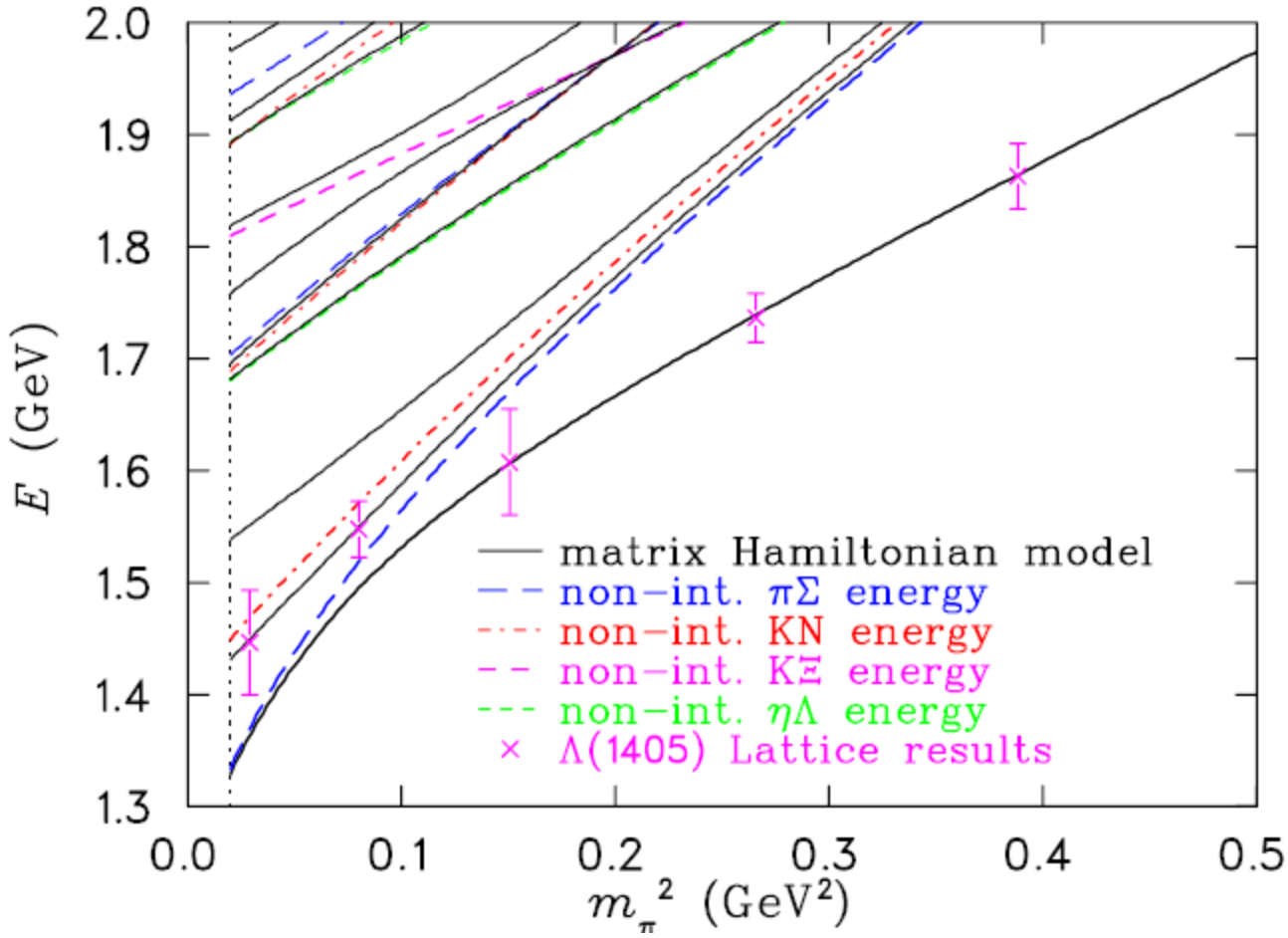
$\mathcal{G}_M$ for the $\Lambda(1405)$ at $Q^2 \sim 0.16\,\mathrm{GeV}^2$



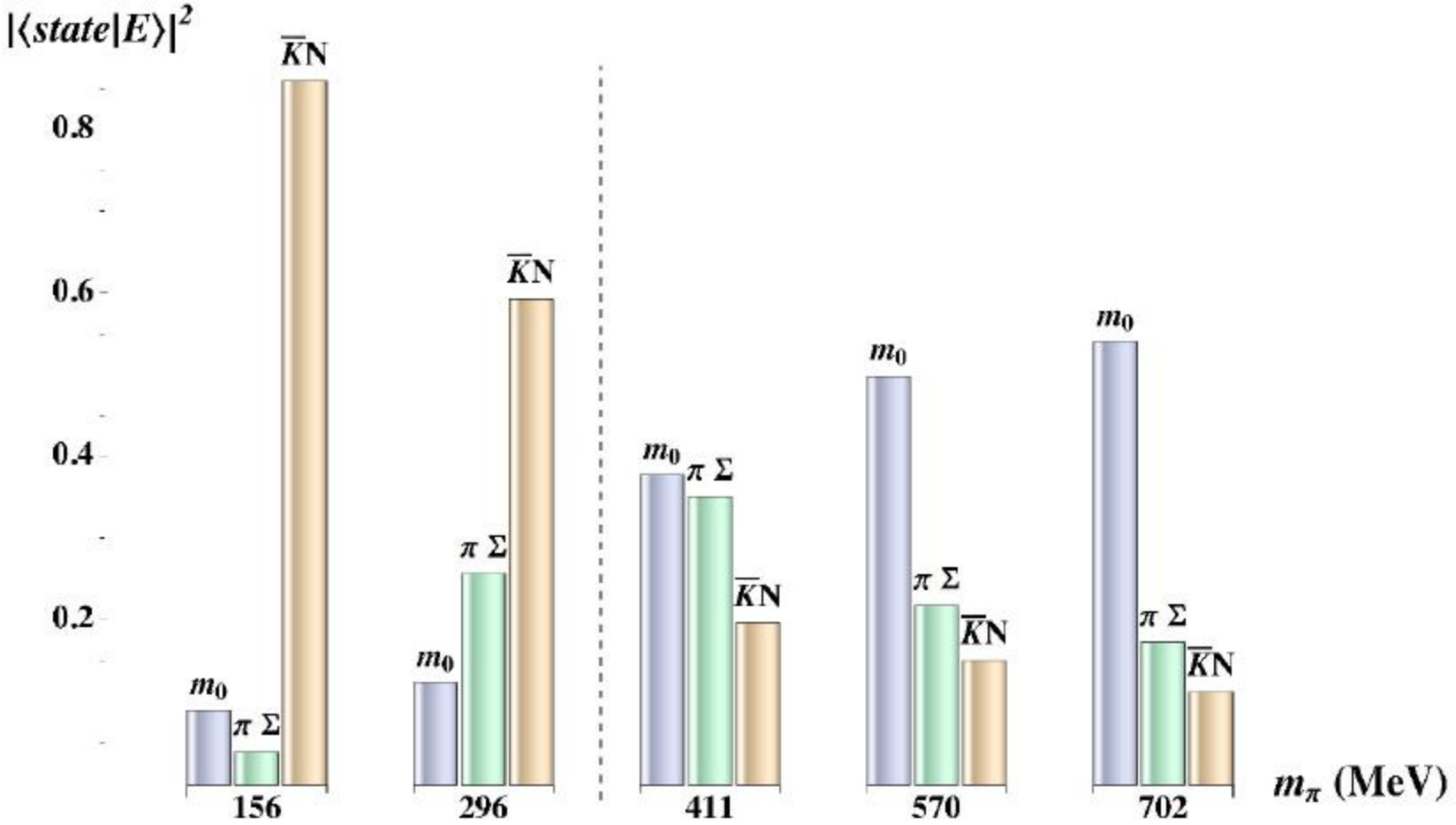
J. M. M. Hall, *et al.* [CSSM]
"Lattice QCD Evidence that the Λ(1405) Resonance is an Antikaon Nucleon Molecule"
Phys. Rev. Lett. **114**, 132002 (2015), arXiv:1411.3402 [hep-lat]

Hamiltonian analysis of Lattice data as function of quark mass: Adelaide Initiative

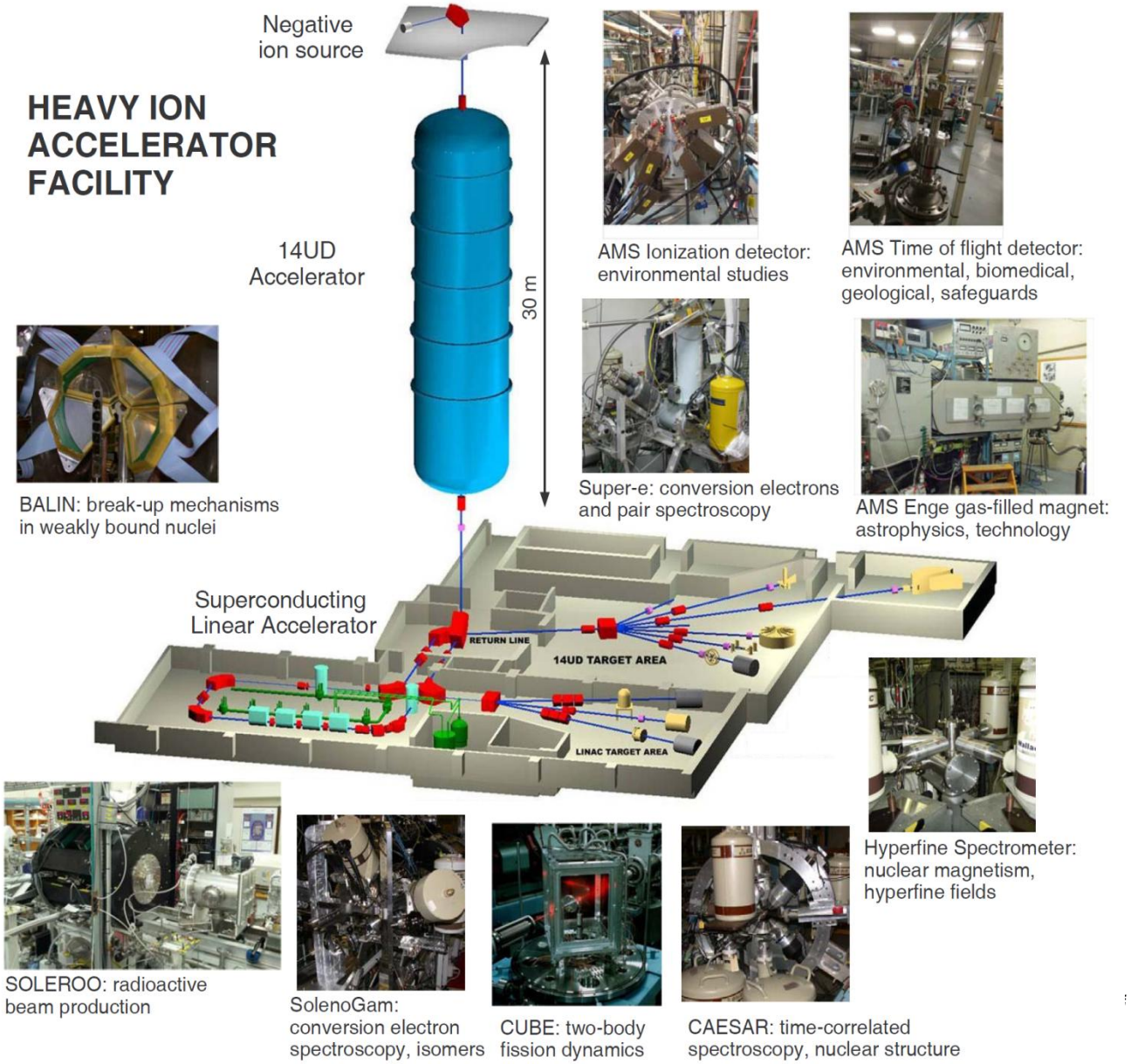
Hamiltonian model fit: Λ(1405) again



Changing Nature of S= -1 ½⁻ Resonance



ANU: Australian National University - Canberra



Australian National University

Research Areas

Quantum Physics with Nuclei

- Collectivity (Shapes, Vibrations, Fission, …)
- Correlations (Clustering, Entanglement, Shells, …)
- Tunnelling (Coupling, Dissipation, Decoherence, Fusion, Reactions, Decay,…)

Nuclei in the Cosmos

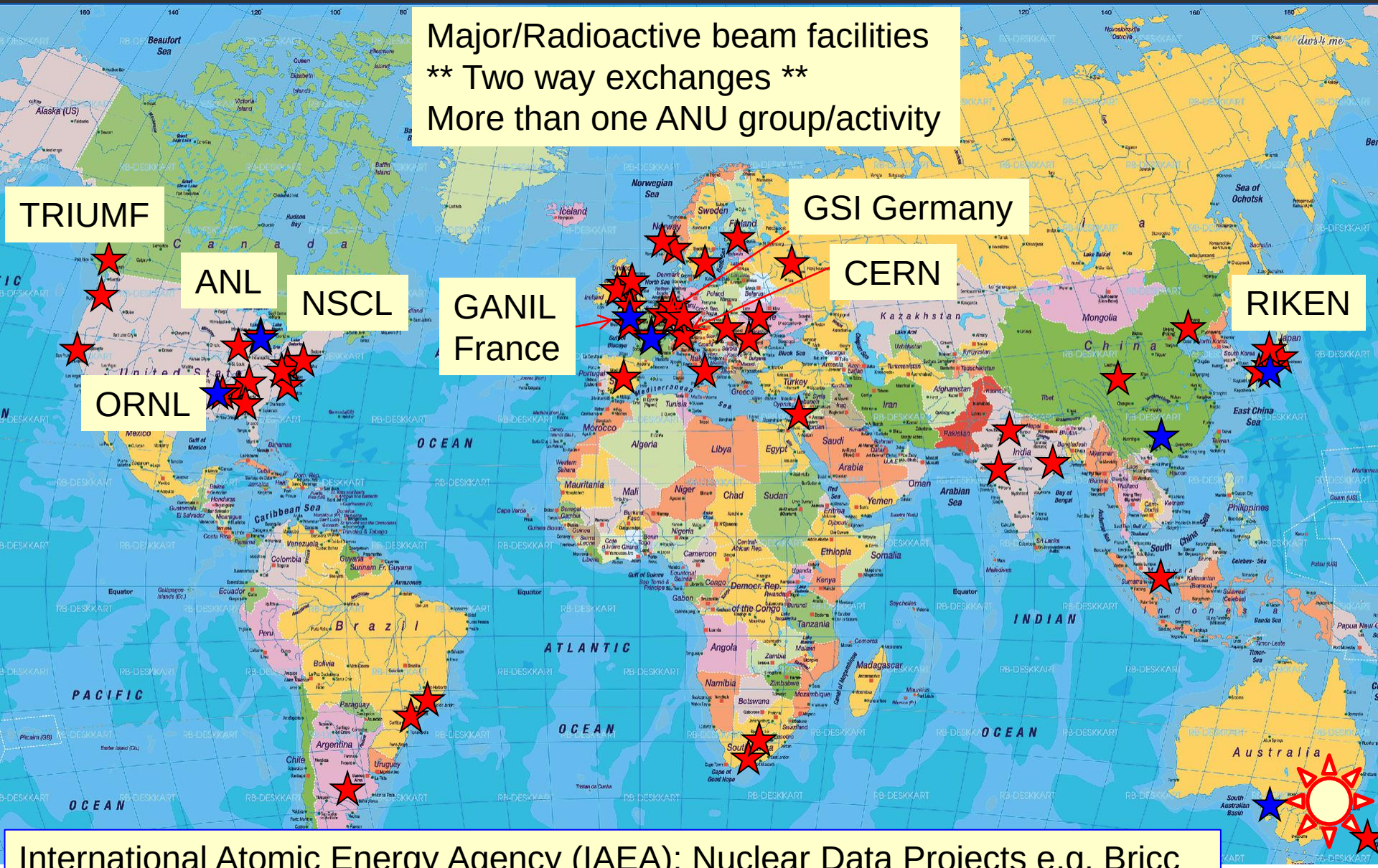
- Nucleosynthesis (Supernovae, Li problem, Hoyle State, …)
- Dark Matter (Nuclear Recoil Detection – Stawell Underground Physics Lab)

Nuclei for Society

- Environment (Erosion rates, …)
- Health (Auger electrons from radioisotopes, …)
- Security and Safeguards (Education, …)

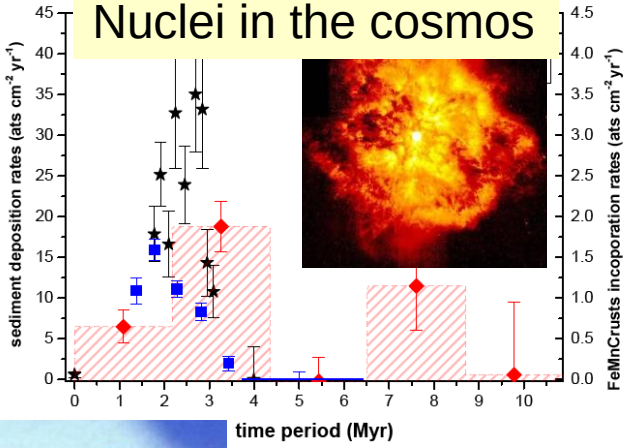
Nuclear Structure; Nuclear Reactions; Accelerator Mass Spectrometry; Hyperfine Interactions; Medical Applications

International connections



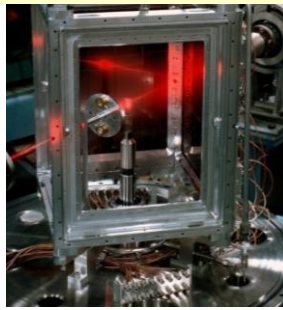
Research overview: some examples

Nuclei in the cosmos



^{60}Fe from supernovae - found on Earth by AMS

Quantum physics with nuclei

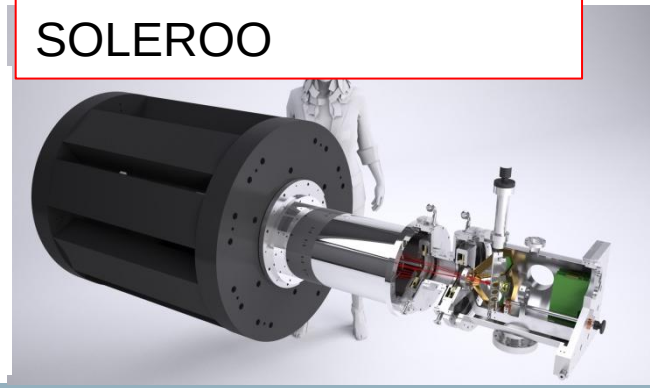


Isomeric decays and the structure of many-particle excitations near ^{208}Pb

Making the heaviest elements

Nuclear shape changes in very neutron-rich nuclei: a measurement at CERN.

Reactions with radioactive beams – SOLEROO



Hoyle state in ^{12}C: Making carbon in the cosmos

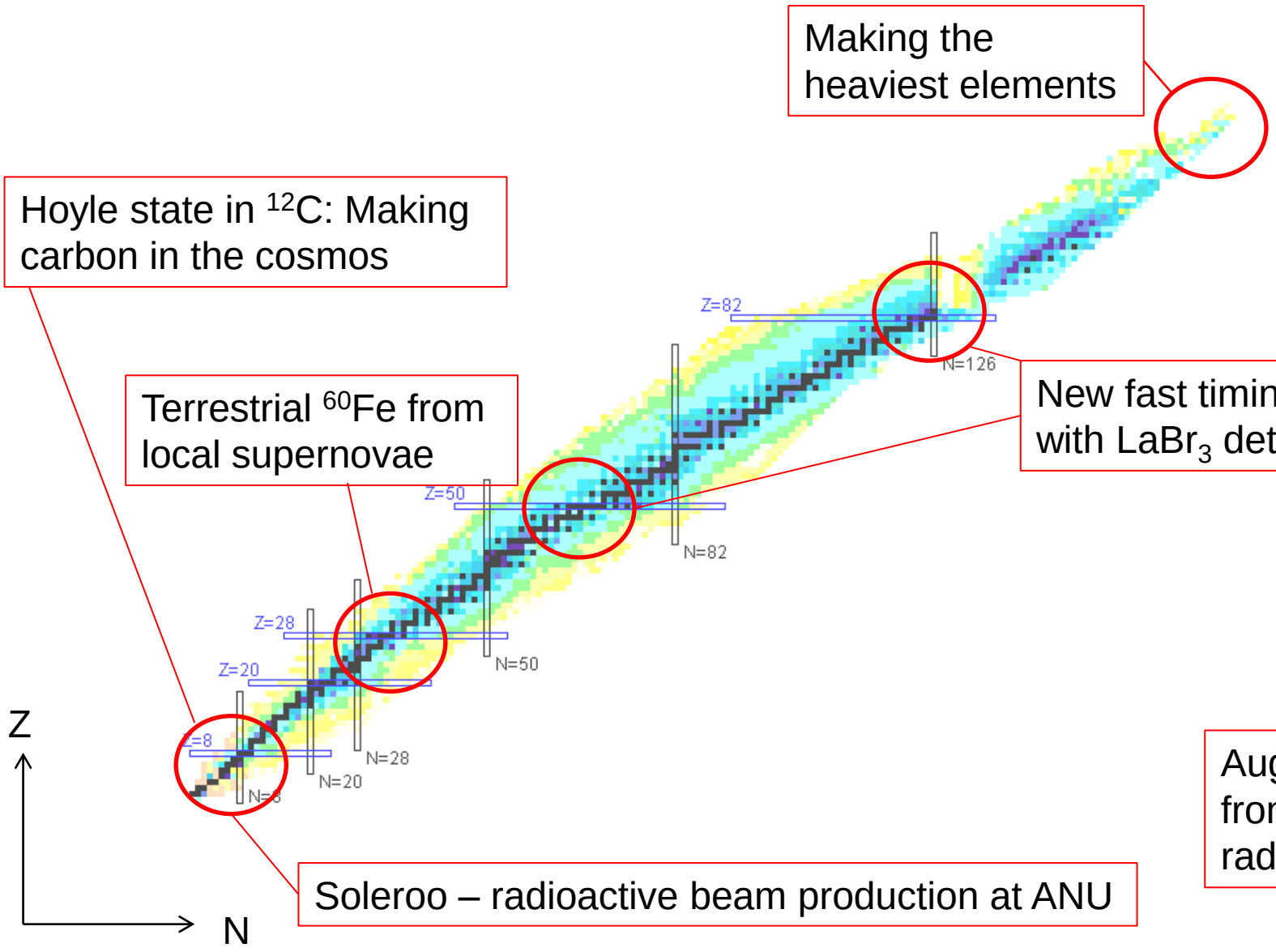
Research at ANU

Making the heaviest elements

Hoyle state in ^{12}C: Making carbon in the cosmos

Terrestrial ^{60}Fe from local supernovae

New fast timing capability with $LaBr_3$ detectors



Auger electrons from medical radioisotopes

Soleroo – radioactive beam production at ANU

Quasifission & Making Heavy Nuclei

112 ms

294
117

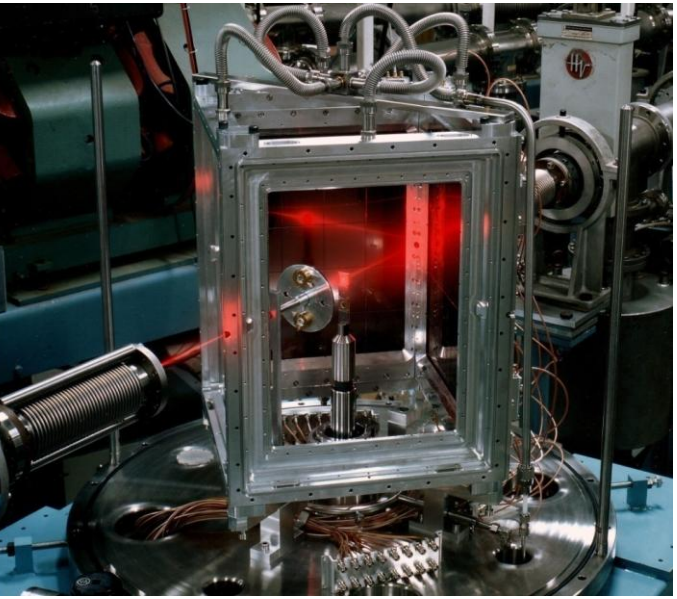
α_1

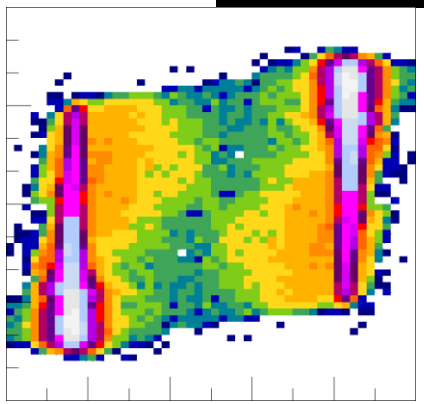
10.81 MeV

Time Dependent
Hartree Fock

(Cedric Simenel)

$^{40}Ca + {}^{238}U \rightarrow (Z=112) \rightarrow {}_{82}Pb + {}_{30}Zn$





PRL 113, 182502 (2014) PHYSICAL REVIEW LETTERS week ending 31 OCTOBER 2014

Interplay between Quantum Shells and Orientation in Quasifission

A. Wakhle, C. Simenel,* D. J. Hinde, M. Dasgupta, M. Evers, D. H. Luong, R. du Rietz, and E. Williams
Department of Nuclear Physics, Research School of Physics and Engineering, Australian National University, Canberra, Australian Capital Territory 2601, Australia

3-6 years Accelerator & Beam lines

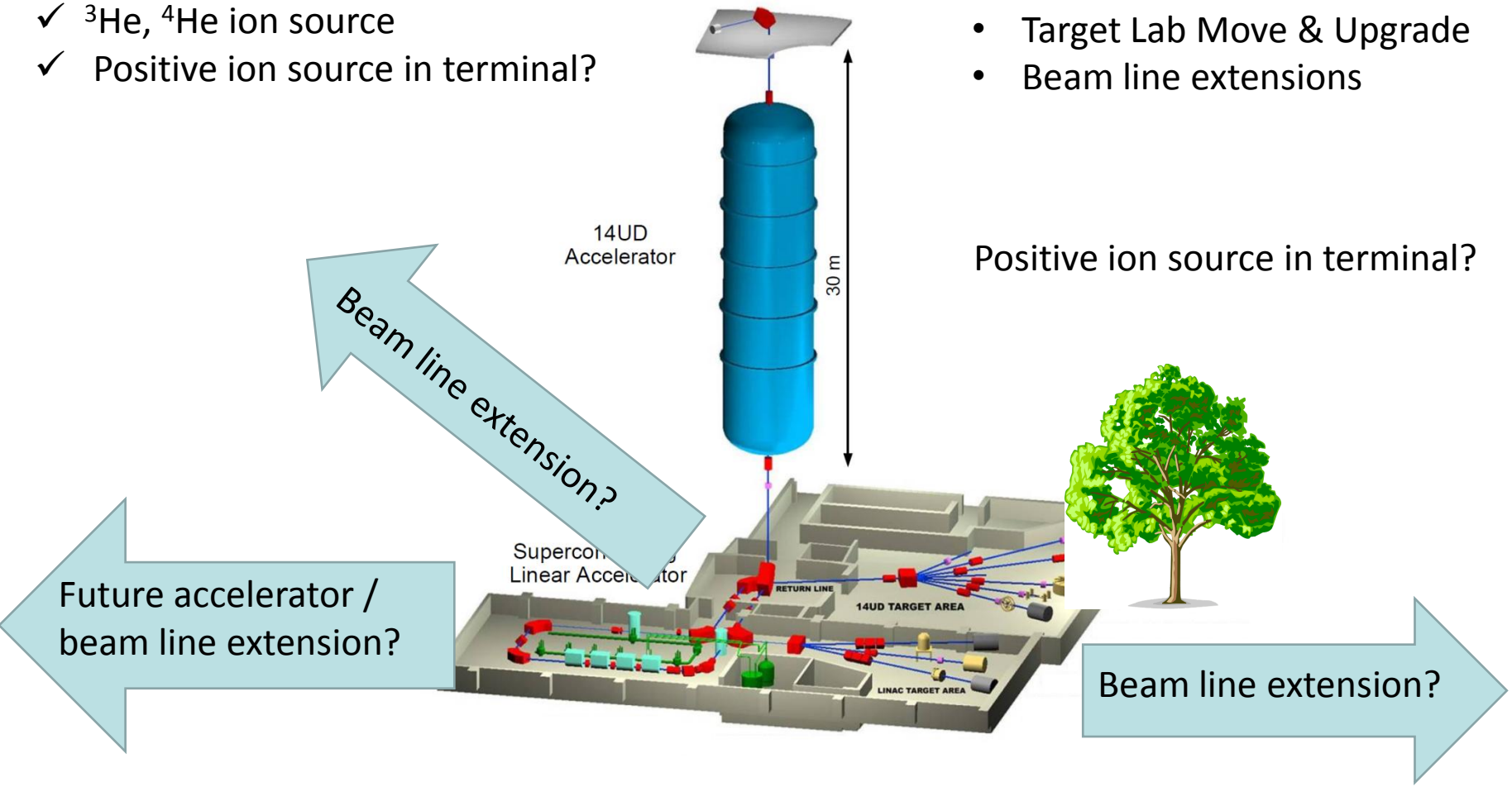
Ion source development:

- ✓ ESA injection for AMS
- ✓ ^{3}He, ^{4}He ion source
- ✓ Positive ion source in terminal?

Building program:

- Control room move
- Target Lab Move & Upgrade
- Beam line extensions

Positive ion source in terminal?



6-9 years and beyond

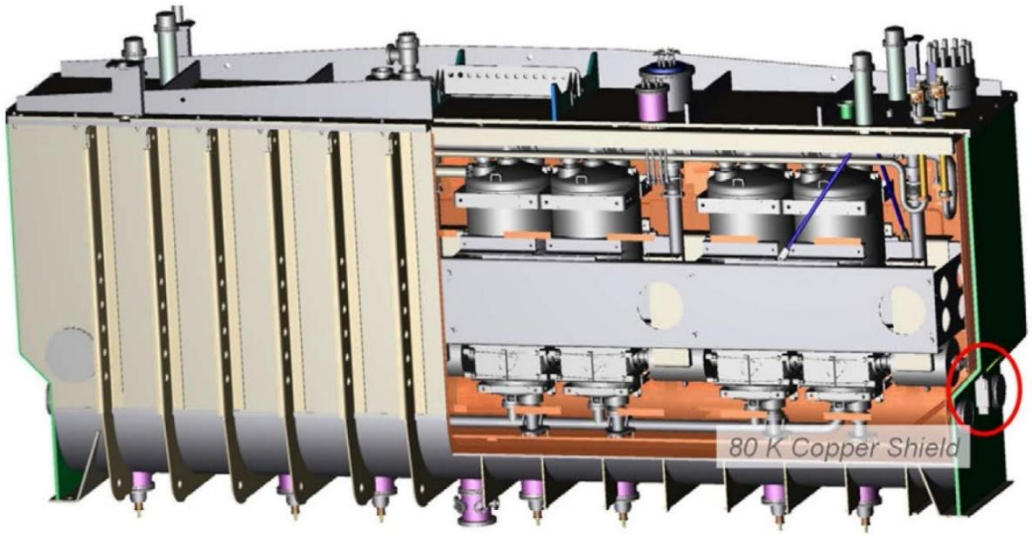
Accelerator development aspirations

Time

- New beam lines
- New Linac 4× higher field gradient
- New Linac injector
  - ✓ Parallel operation of 14UD and Linac

Cost

- Staged as funding available
- Prepared for new NCRIS infrastructure program



Argonne cryomodules

- 2 fit present Linac footprint
  - ✓ Two give 35 MV boost
  - ✓ 4 times present Linac
  - ✓ USD $4M each

GSI/FAIR alternative

- Collaborative arrangement

Australian Government

Ansto

Australian Nuclear Science and Technology Organisation

Richard Garrett

ANSTO Large Scale Research Infrastructure

Australian Synchrotron

Accelerators

Research Cyclotron

OPAL Research Reactor & Neutron Beam Instruments

Products and Indications

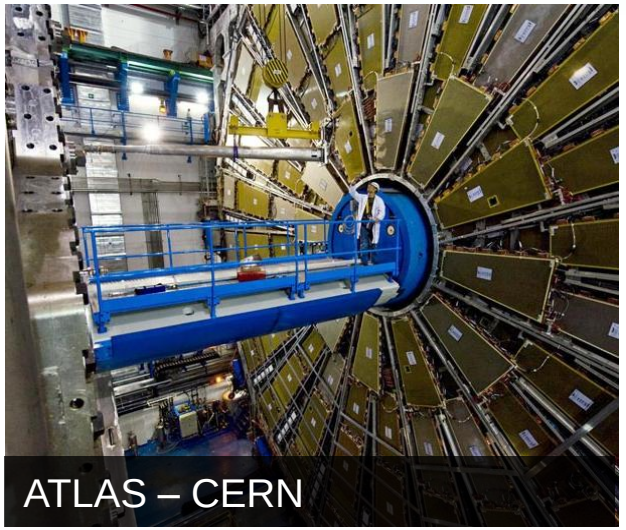
Product	Indication
Mo-99	Bulk export – Tc-99m generator
Gentech /Tc-99m	Organ imaging of the liver, lung, bone, kidney & heart
Sodium Iodide I-131	Hyperthyroidism & Thyroid cancer
Quadramet Sm-153	The relief of bone pain in patients with painful osteoblastic skeletal metastases
Chromium Cr-51	The determination of GFR rate
lutetium-177	Diagnosis and treatment of Neuroendocrine. Tumors
Gallium Ga-67	Hodgkin's Disease, lymphomas and bronchogenic carcinoma. Acute infections
mIBG I-123	Detection, staging and follow-up of neuroblastomas.
Thallium Tl-201	Myocardial perfusion imaging
^{18}F-FDG	Diagnosis, staging and monitoring of Cancer treatment

Reactor Products | Cyclotron Products

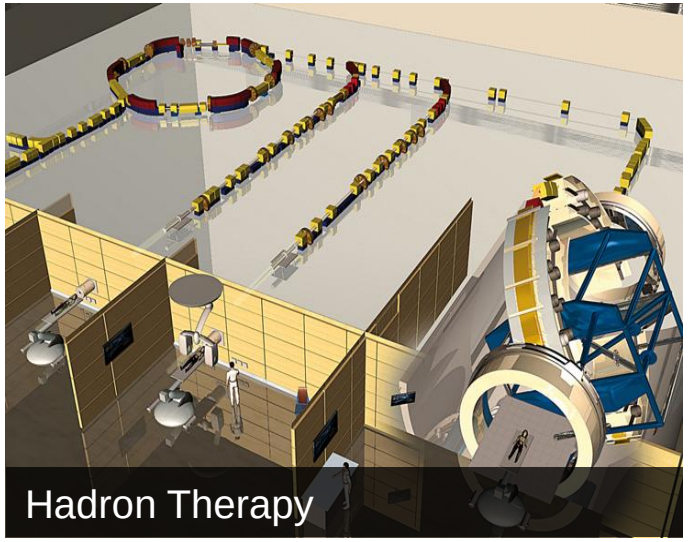
ANSTO Nuclear Partnerships and Collaboration

International Partnerships

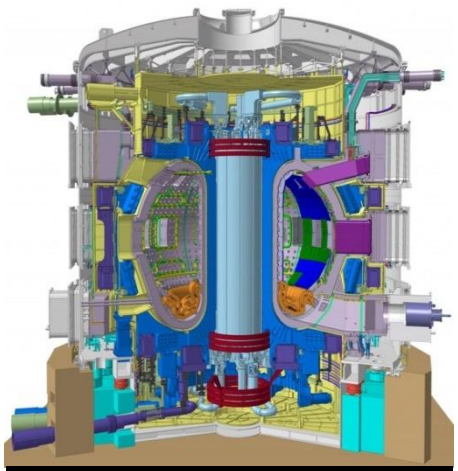
X-ray Free Electron Laser & Neutron spallation sources



ATLAS – CERN



Hadron Therapy



Fusion - ITER

Dark Matter – Gran Sasso, Italy

Particle Therapy Program Australia

Anatoly Rozenfeld

proton THERAPY AUSTRALIA

–Planning Facilities Proton and HIT facilities:

NSW –
National Particle Therapy Research and Treatment Centre at Westmead Children Hospital (2 accelerators for HIT and PT, in process of submission Steering Committee report to government

Victoria –
Proton Therapy Centre associated with new Comprehensive Cancer Centre in Melbourne

Queensland –
Proton Therapy private facility (HITACHI)

South of Australia –
Proton therapy facility

Summary

- **Much smaller community (~250) than Japan or China**
- **Nearer in size to Korea but not as ambitious in terms of facility construction**
- **Although SABRE at SUPL is a big step forward**
- **Major potential initiatives for future:**
  - **Associate membership of CERN**
  - **Formal link to FAIR**