Experimental Nuclear Physics Research in Australia

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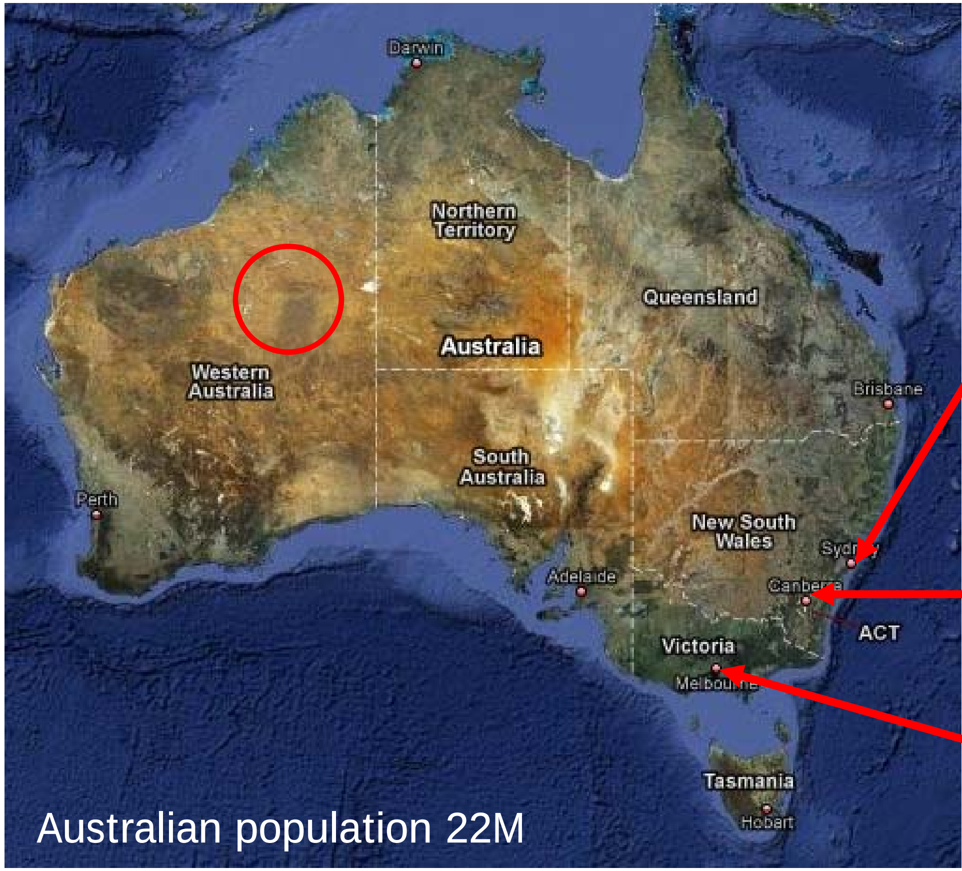
Accelerators in Australia



ANSTO
Sydney $25M
10MV tandem
Materials, AMS
(Research Reactor OPAL)

Heavy Ion Accel. Facility
15MV tandem+Linac
Canberra $50M
Nucl. Phys, AMS, Materials

Australian Synchrotron
Melbourne $200M
Electron synchrotron
3rd gen. light source

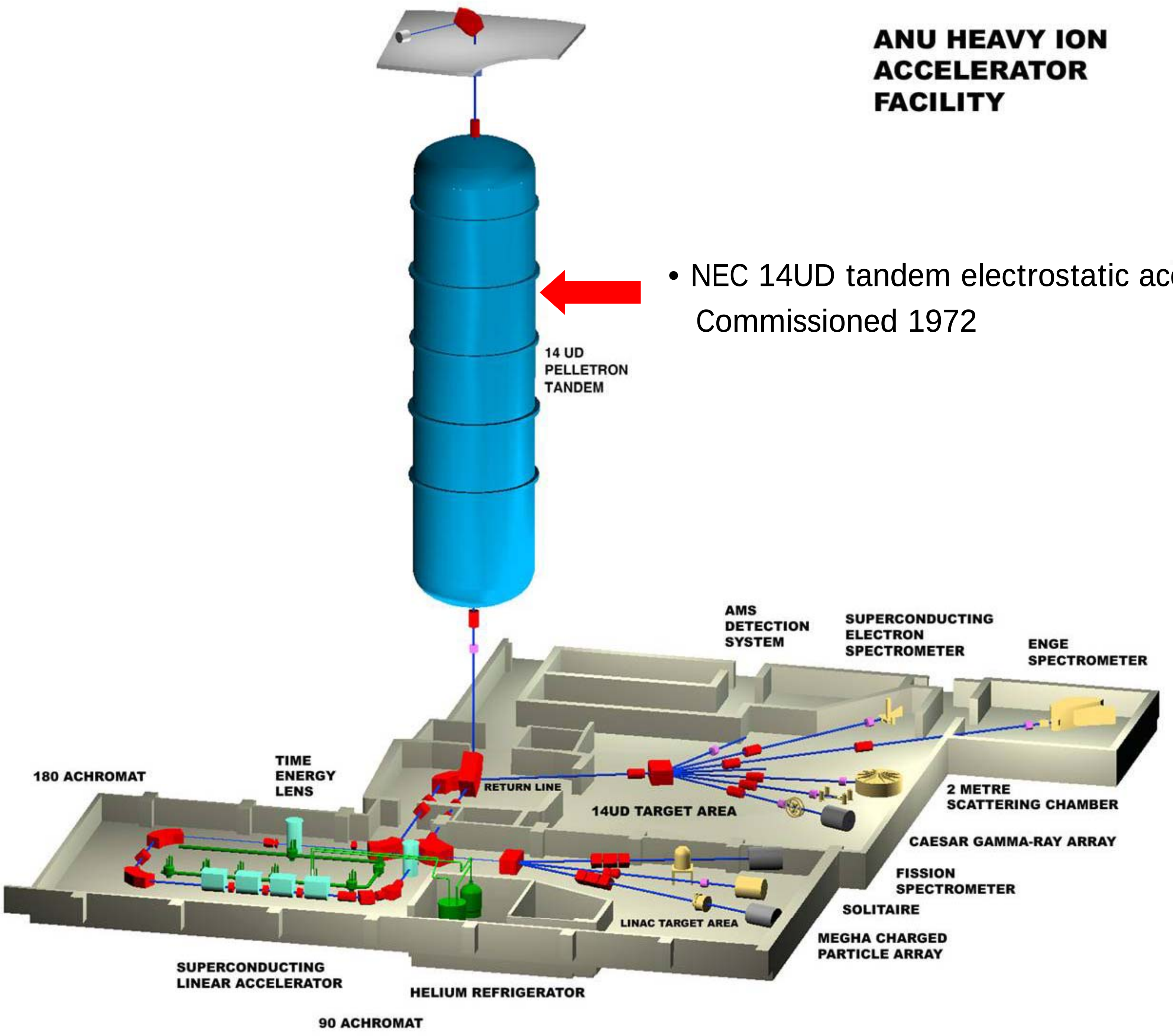
Heavy Ion Accelerator Facility, ANU, Canberra

Canberra

– Capital city of Australia

– Named in 1913, in the middle of nowhere

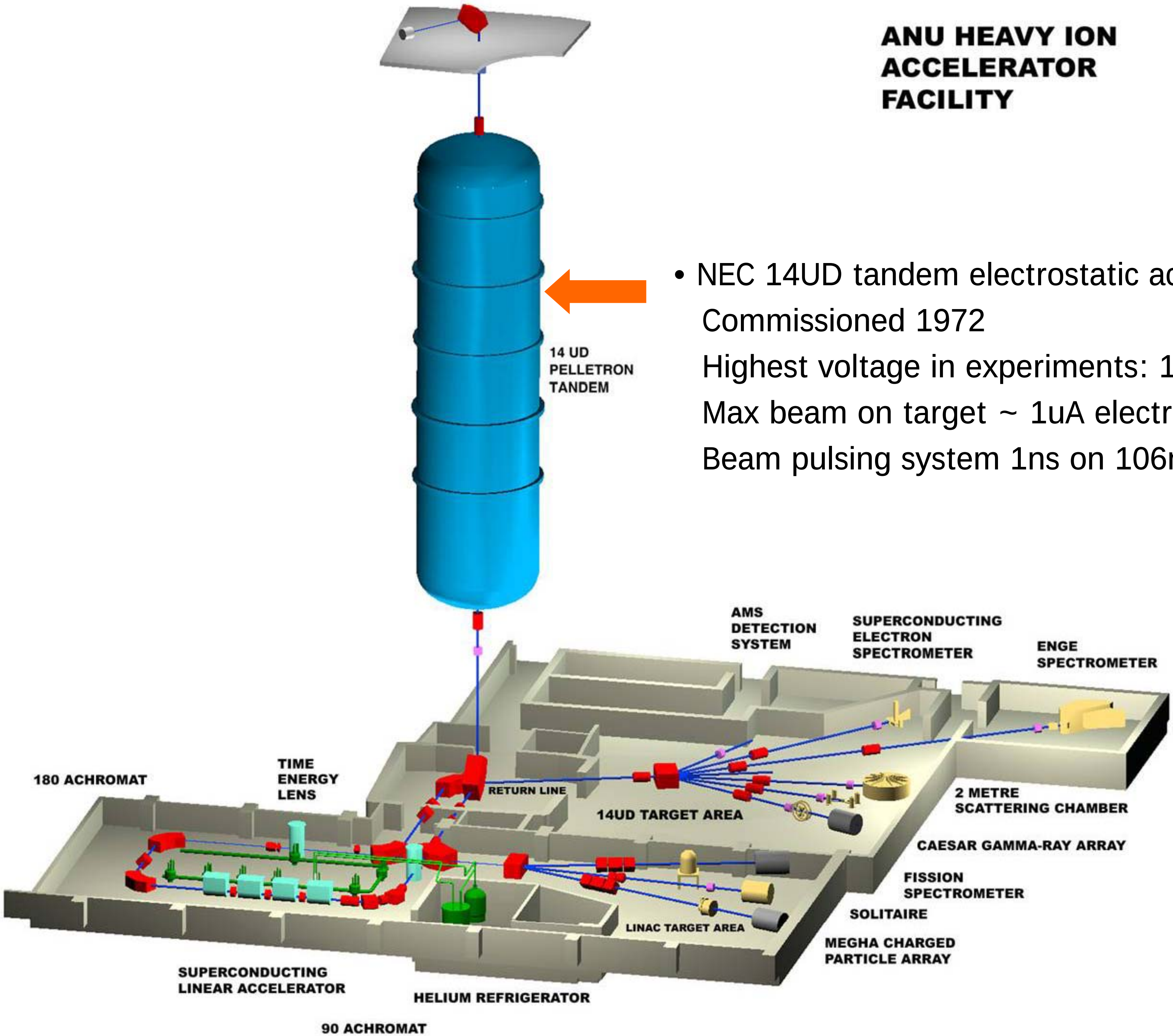
- Population now 350,000



- NEC 14UD tandem electrostatic accelerator
  Commissioned 1972

Heavy Ion Accelerator Facility, ANU, Canberra

ANU HEAVY ION ACCELERATOR FACILITY



- NEC 14UD tandem electrostatic accelerator
  Commissioned 1972
  Highest voltage in experiments: 15.85 MV
  Max beam on target ~ 1uA electrical
  Beam pulsing system 1ns on 106ns to 1s off

NEC SNICS negative ion sources

- Multi-sample SNICS (AMS)
- Gas SNICS (NP)
- p,d,Li,Be,B,C,O,F,Na,Mg,Al,Si,P, S,Cl,Ca,Ti,V,Fe,Ni,Cu,Zn,Ge..Au,Th,U

Slow chopper to 1s separation

Beam bunching

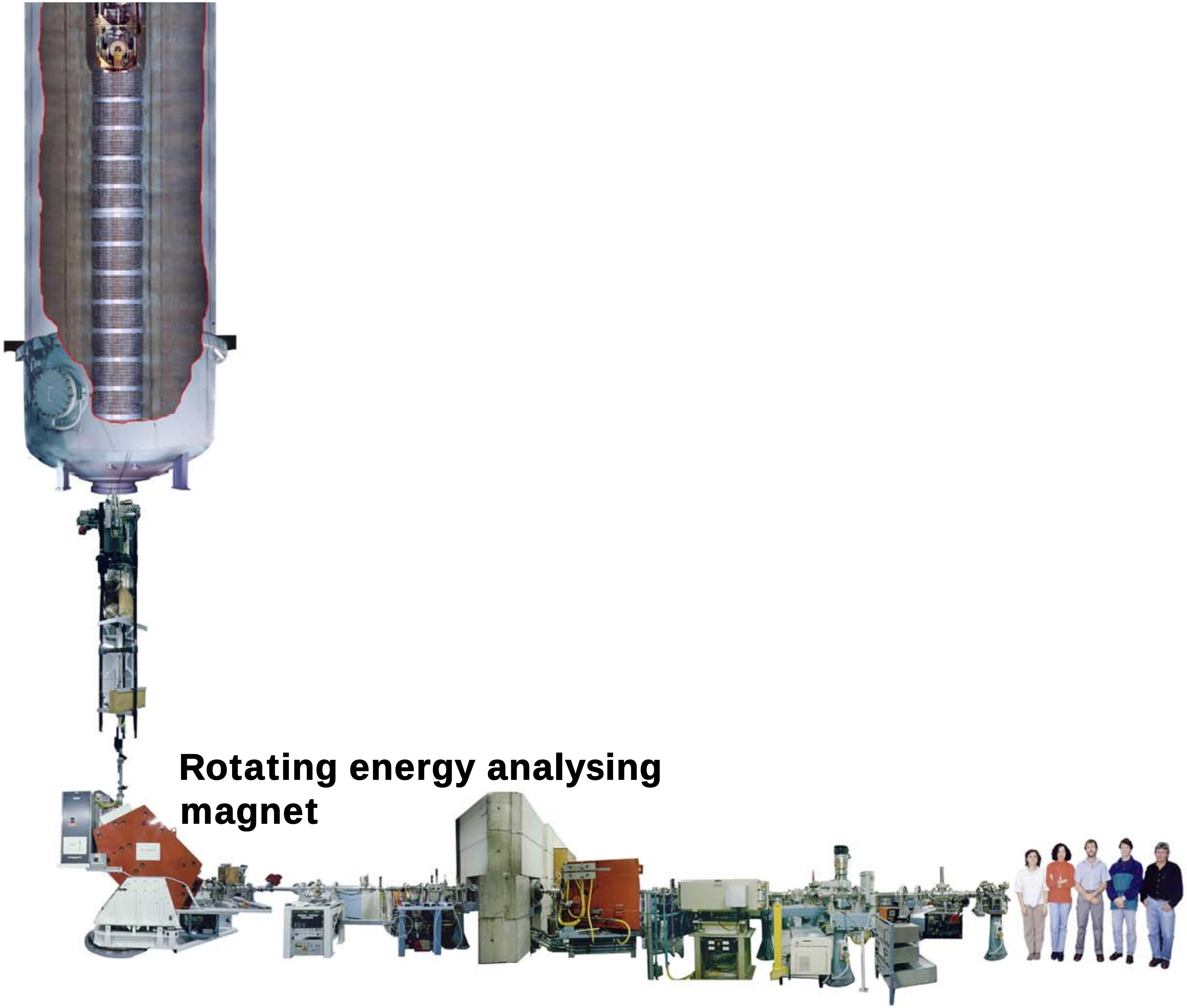
3 frequency 107ns separation

Terminal stripping
Foil stripping
Gas stripping

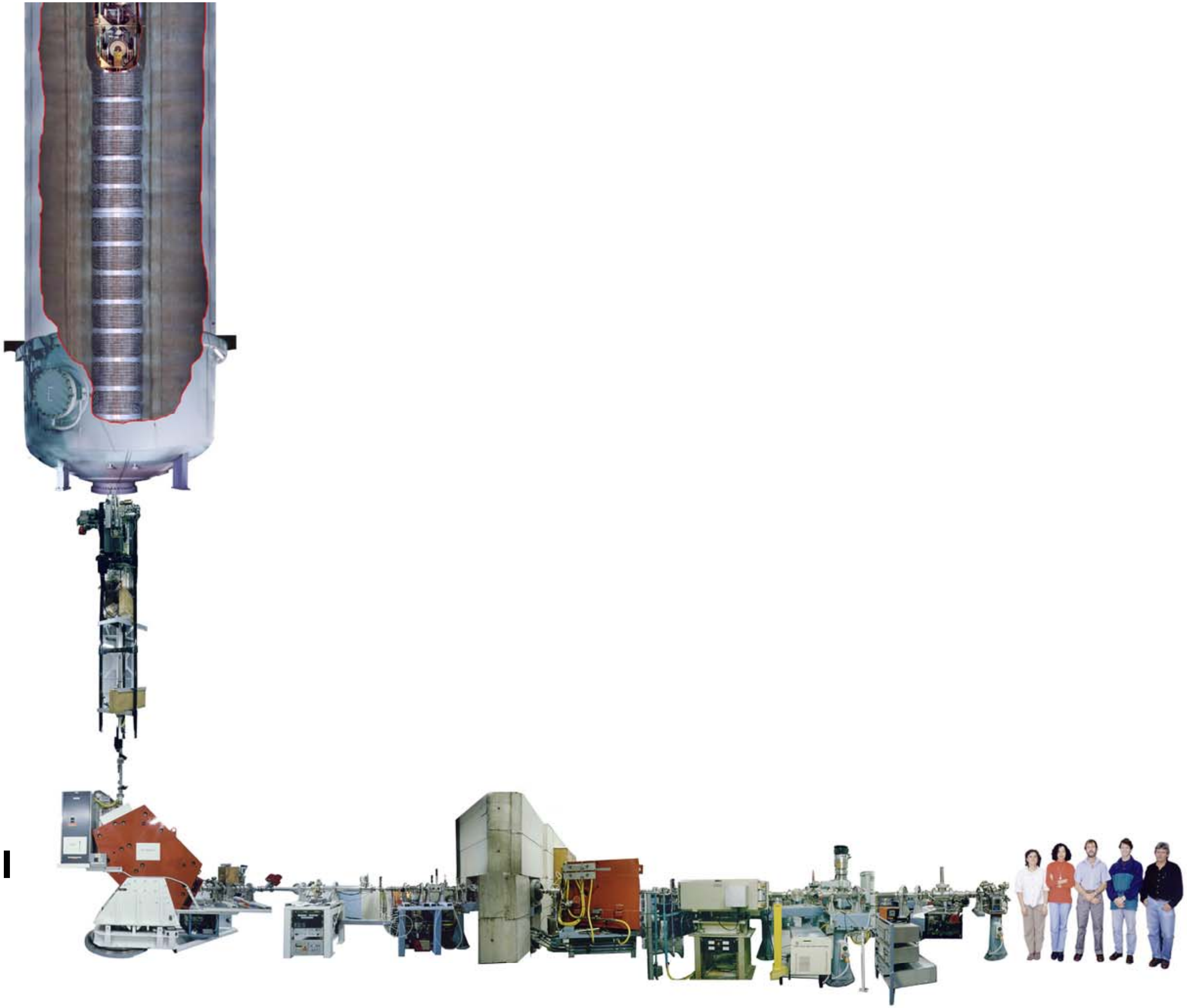
Second stripper
Foil 1/3 from terminal

Beam chopping

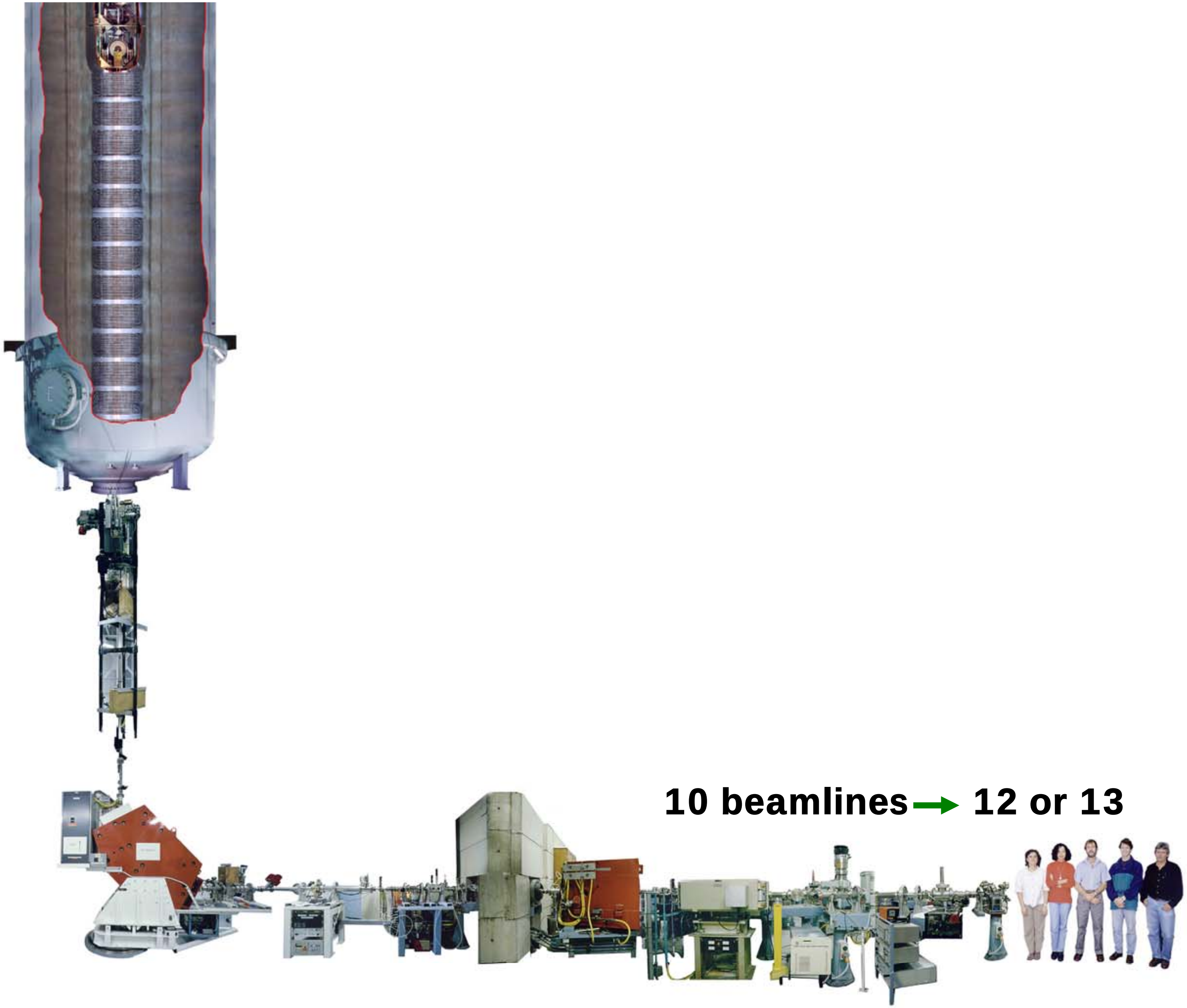
Cleans up bunched beam



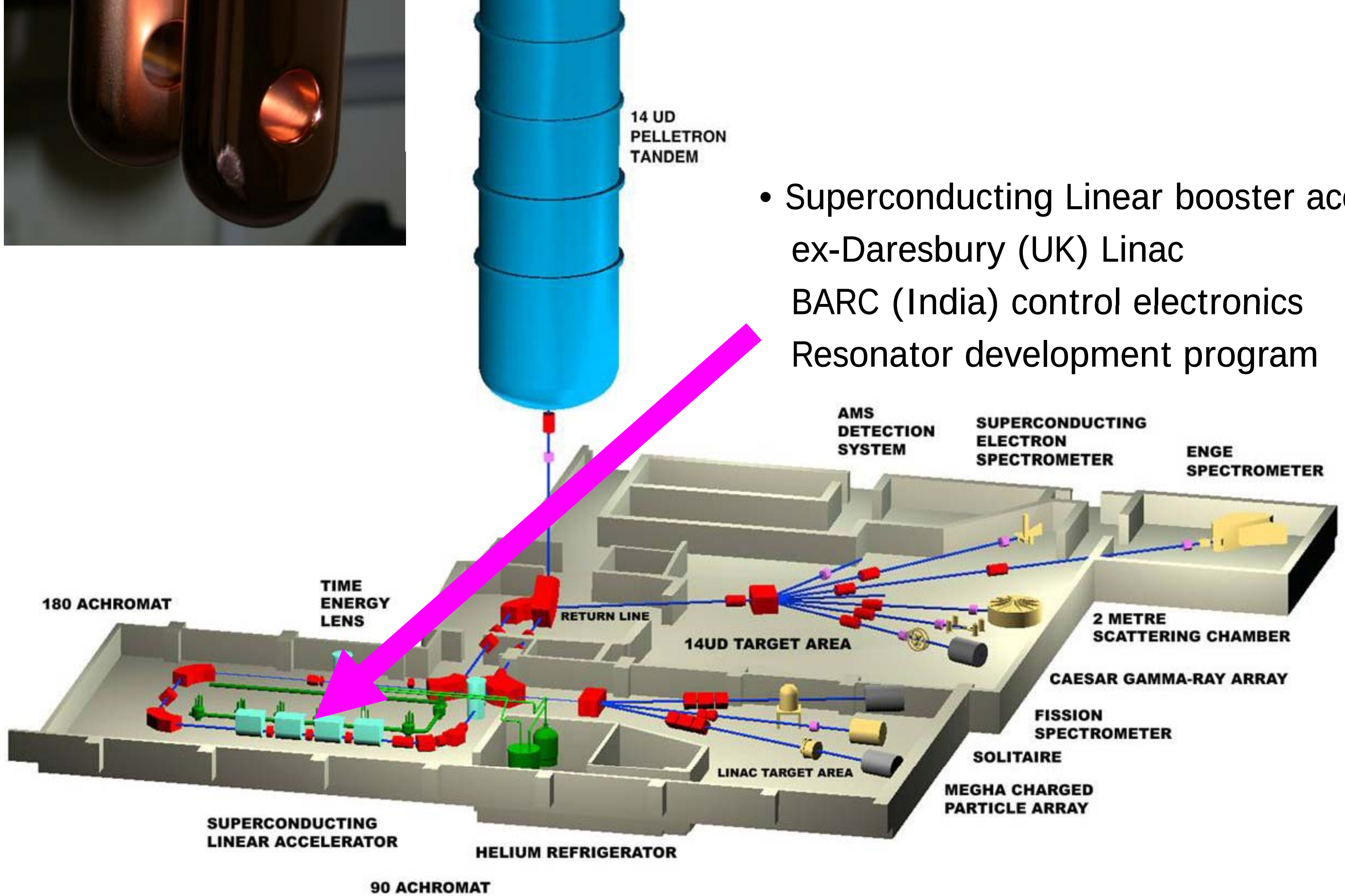
Rotating energy analysing magnet



External stripper foil to Linac


10 beamlines → 12 or 13

ANU HEAVY ION ACCELERATOR FACILITY



- Superconducting Linear booster accelerator
  ex-Daresbury (UK) Linac
  BARC (India) control electronics
  Resonator development program

Pb re-plated Cu quarter-wave resonators
330 W LHe refrigerator
LHe distribution system
6 MeV/q energy gain

National Engineering Excellence Award 2007

Parliament House, Canberra

Linac overview

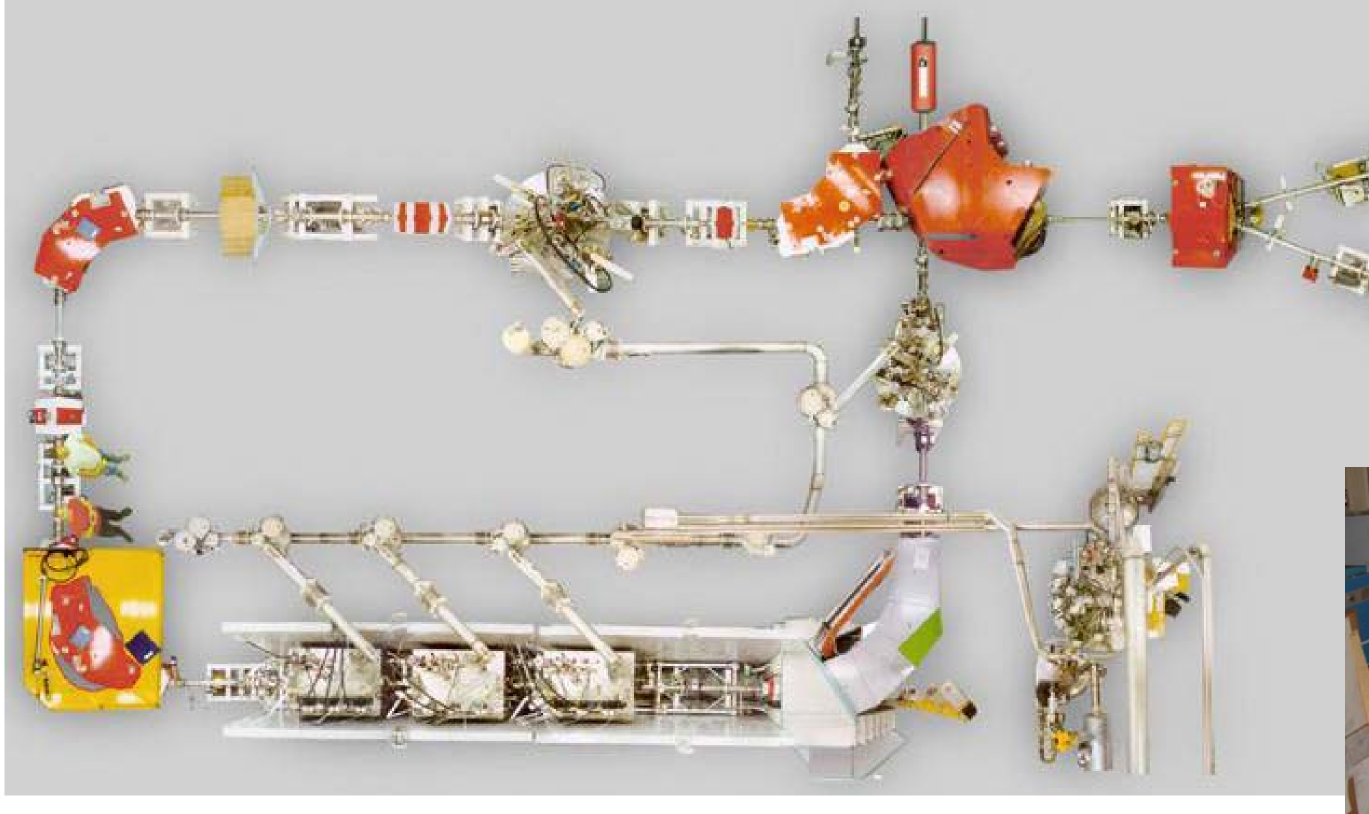
Pb re-plated Cu quarter-wave resonators
330 W LHe refrigerator
LHe distribution system
6 MeV/q energy gain

Linac runs ~once per year

14UD provides most experimental requirements

National Engineering
Excellence Award 2007

Parliament House,
Canberra



Linac runs ~once per year

14UD provides most experimental requirements

Heavy Ion Accelerator Facility, ANU, Canberra

Current Department of Nuclear Physics - operates HIAF

8 continuing research staff	12/09: total researchers in department
2 AMS	3 AMS
2 Nuclear reactions	5 Nuclear reactions
4 Nuclear structure	4 Nuclear structure

~ 20 research students

~ 40 accelerator users outside department (NP, AMS, Materials)

- 3 accelerator and computing professional staff
- 7 technical staff + 1 administration staff
- Central mechanical and electronic workshops
- Currently no direct funds for facility – (user charge)

Beams, energies used in experiments

Beam	V_B on Pb (MeV)	14UD energy (MeV, MeV/A)	Linac energy (MeV, MeV/A)
^{9}Be	40	70, 7.8	-
$^{16,\mathbf{17},\mathbf{18}}$O	80	133, 8.4	165, 10.3
$^{32,34,\mathbf{36}}$S	166	210, 6.6	-
^{40,44}Ca	200	230, 5.8	325, 8.1
^{46,48,50}Ti	230	245, 5.1	300, 6.3
$^{58,\mathbf{64}}$Ni	290	280, 4.8	340, 5.3
^{197}Au	(ERDA)	200, 1.0	-

Near-barrier (E/A~5 MeV) - reactions, spectroscopy, (AMS, Materials)

14UD provides most experimental requirements

Future Developments (2010-2013)

- Australian Government response to Global Financial Crisis:
- A$7.6M given (not taken away!) over 4 years for upgrades

Accelerator enhancements

- Beam pulsing update and upgrade – 200 ps pulses RTB
- Linac pilot project to replace Pb plating by Nb – 12 MV/q
- Two to three new beamlines, target stations
- Second dedicated s/c solenoid beamline (RIB, spectroscopy)
- Upgrade of AMS capability – automation
- Migrate accelerator computer control and D/A from VAX
- Modern pumps and magnet power supplies

Infrastructure Enhancement

Facility is part of University – teaching commitments

- New undergraduate teaching area
- New detector development labs
- Renewal of accelerator control room

Future Needs

Direct facility funding

- Support international visitors and accelerator users
- Take pressure off research grants funding facility

- Play a stronger role in region
- Accelerator is reliable, performs well, unique instrumentation

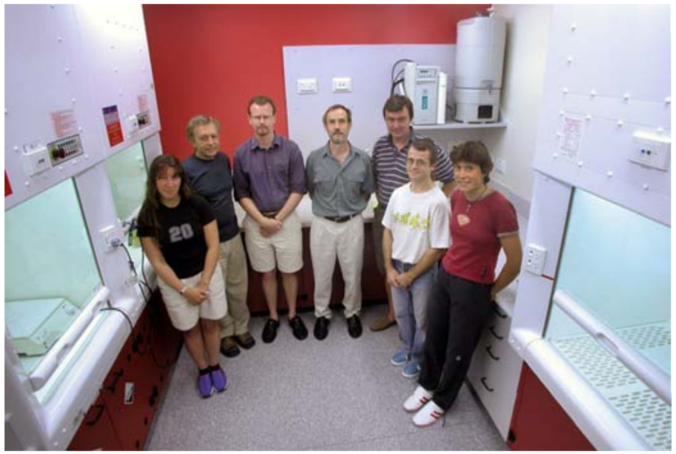
Research Areas

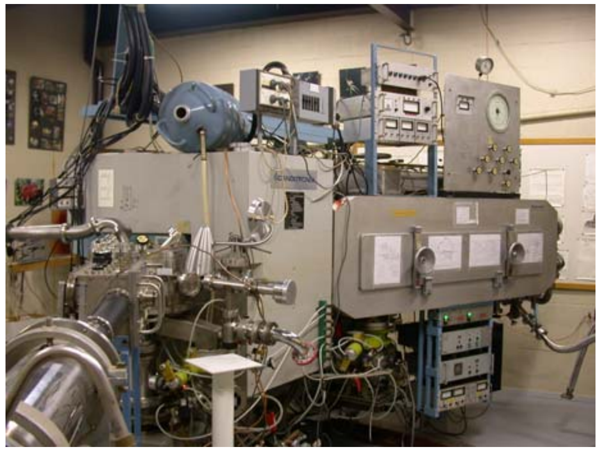
- Accelerator Mass Spectrometry (AMS)
- Materials modification and characterization (external users)
- Nuclear Structure
- Nuclear Reaction Dynamics

Accelerator Mass Spectrometry

Equipment

- Sample preparation/chemistry laboratory
- Multi-sample SNICS source
- Velocity Filters + Gas ionization DE-E detectors
- Gas-filled magnet (ENGE split pole)





Accelerator Mass Spectrometry

Equipment

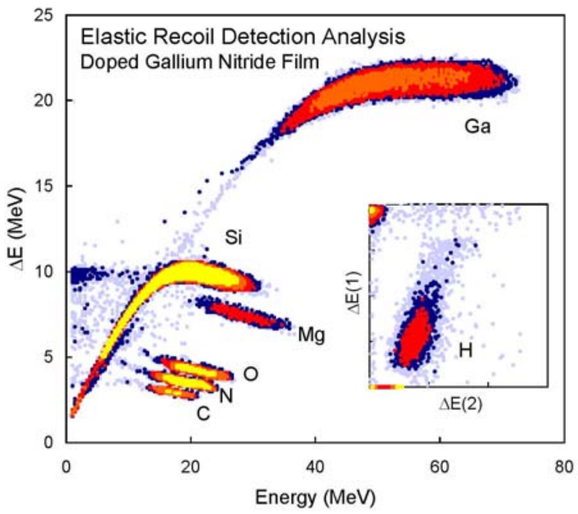
- Sample preparation/chemistry laboratory
- Multi-sample SNICS source
- Velocity Filters + Gas ionization DE-E detectors
- Gas-filled magnet (ENGE split pole)

^{10}Be, ^{14}C, ^{27}Al, ^{36}Cl, ^{55}Mn, ^{239}Pu,...

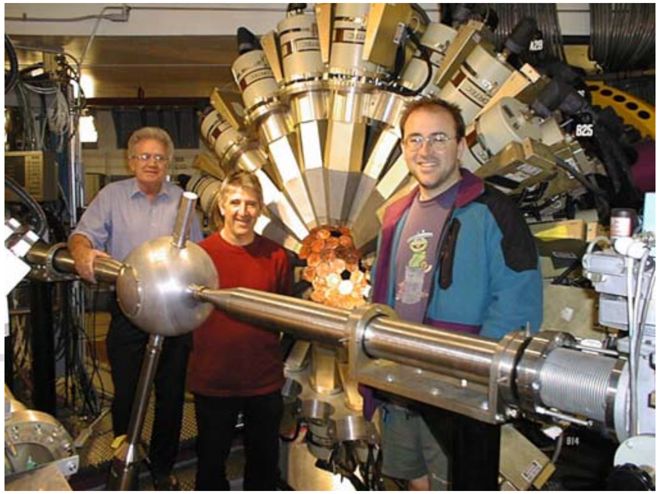
Materials modification and characterization

Equipment

- Beam rastering for material implantation/modification
- Large gas ionization ΔE-E detector for ERDA
- PAC array for γ-ray decay following implantation



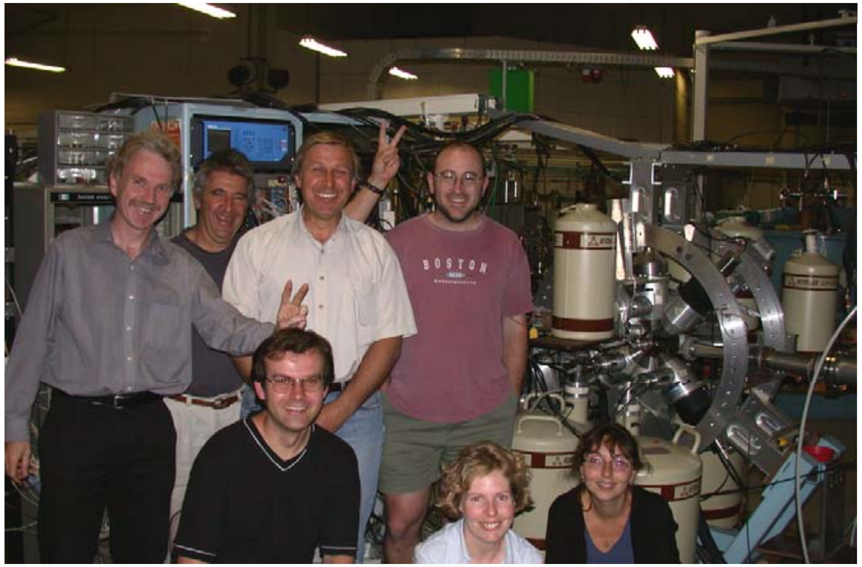
Gammasphere
ANL



Nuclear Structure

Equipment

- CAESAR Ge γ-ray array: level schemes and lifetimes
- Superconducting electron spectrometer: conversion coefficients
- γ-ray angular correlation array, cryo-cooled target: magnetic moments
- SOLENO-GAM - γ-ray+electron module behind SOLITAIRE



CAESAR

Super-e

Nuclear Reaction Dynamics

Equipment

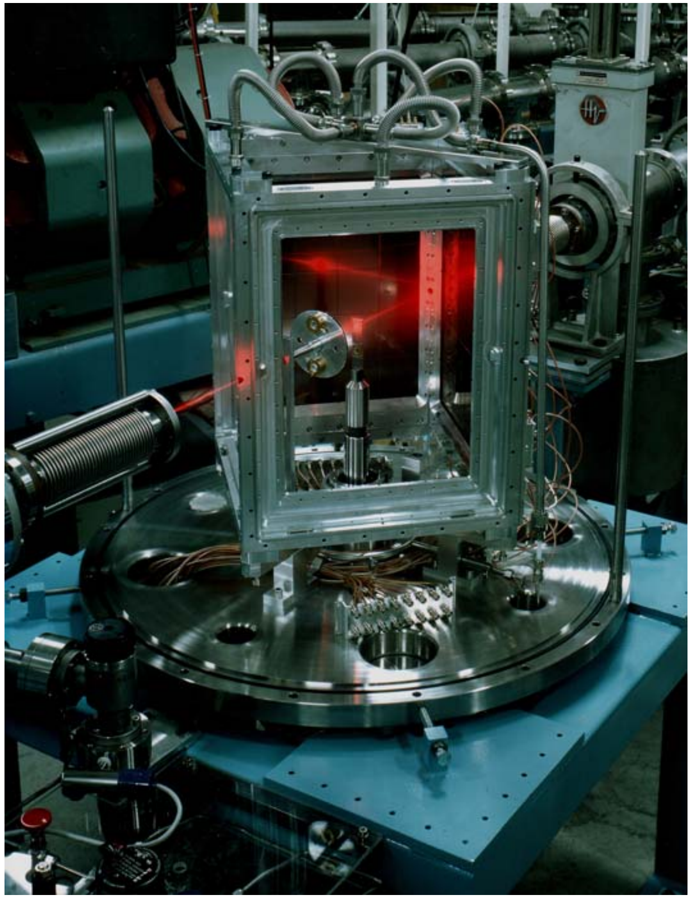
- **CUBE -** MWPC detectors for fission: heavy element formation

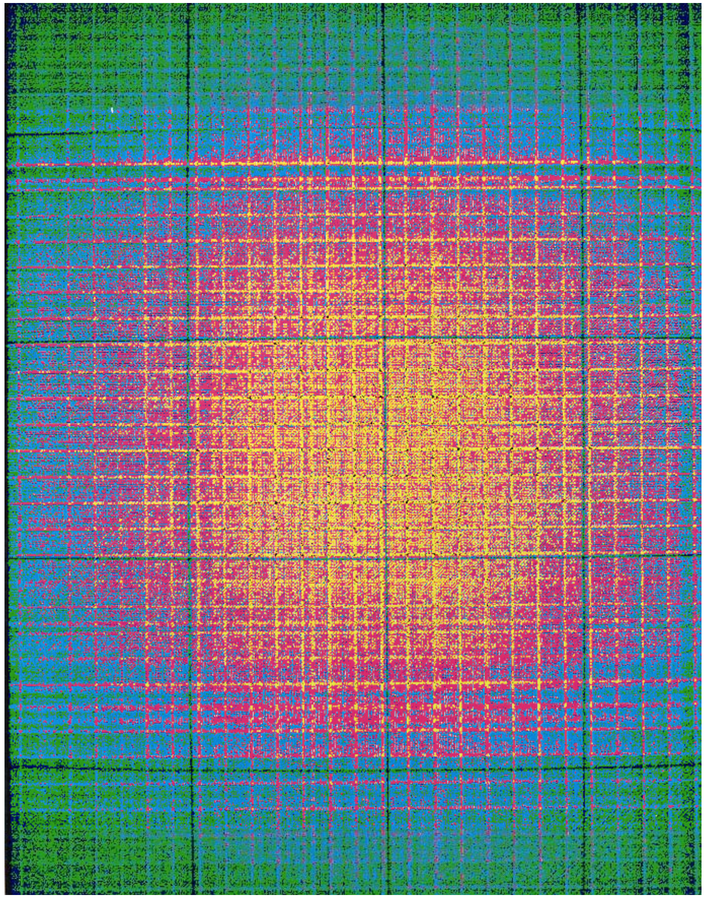
CUBE Fission **MAD**

$\Delta\theta = 70^o$

$\Delta\phi = 90^o$

284 mm





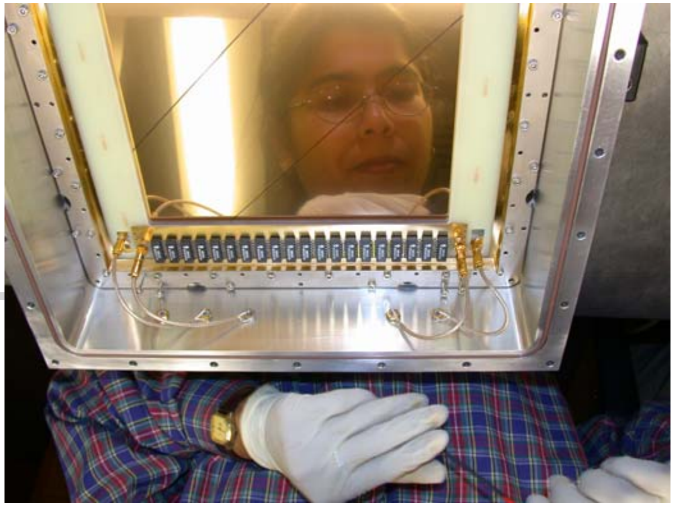
357 mm

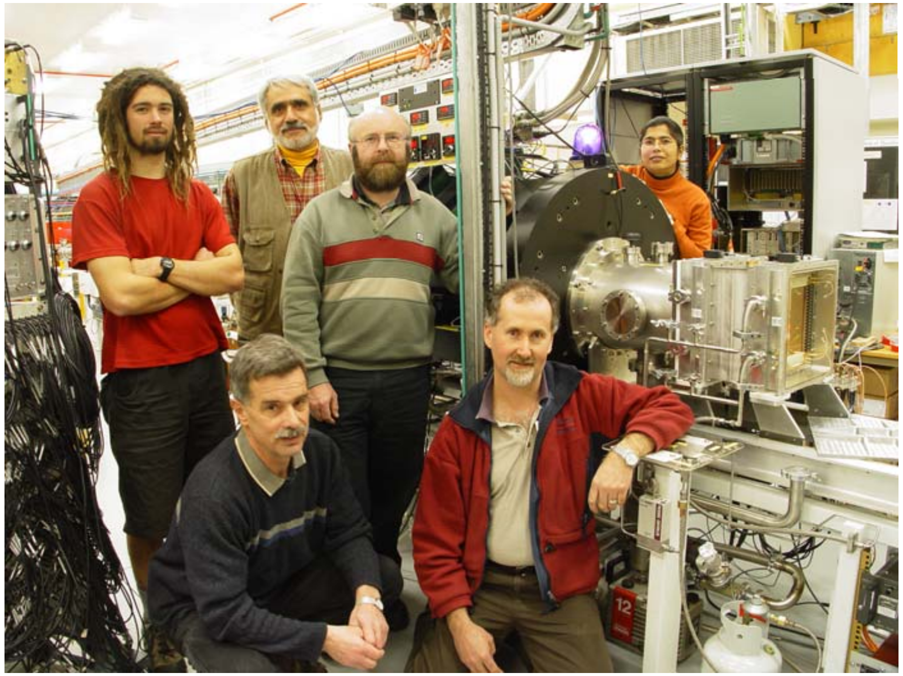
Nuclear Reaction Dynamics

Equipment

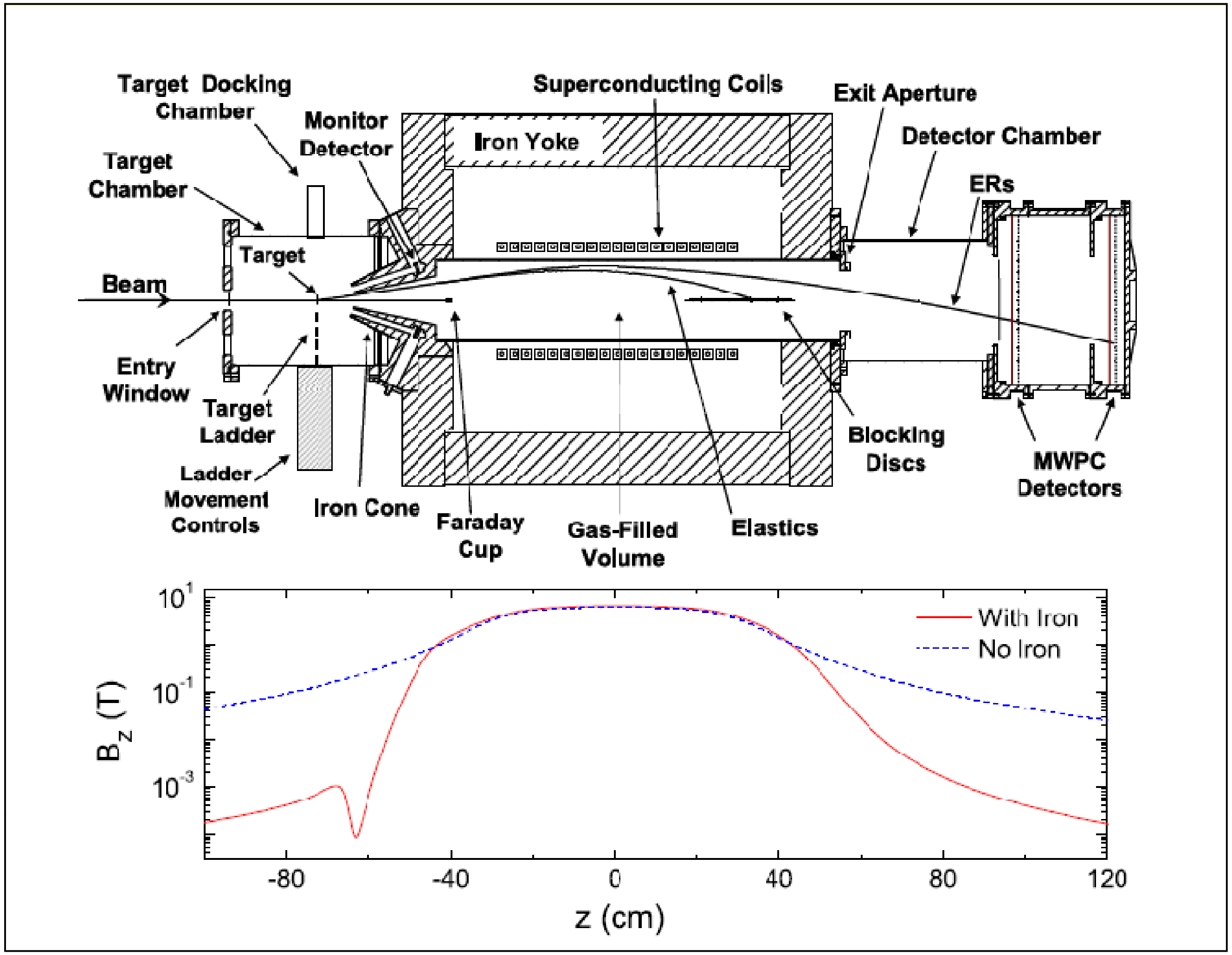
- **CUBE** MWPC detectors for fission $\Delta\theta=70^o$, $\Delta\phi=90^o$:heavy elements
- **SOLITAIRE** superconducting 6.5 T solenoid: $\Delta\theta=9.5^o$ → 86 msr
  - Heavy ion fusion: fusion barrier distributions, sub-barrier fusion
  - Radioactive beam production: ^{6}He
  - Nuclear structure - γ-ray spectroscopy: short-lived states

SOLITAIRE



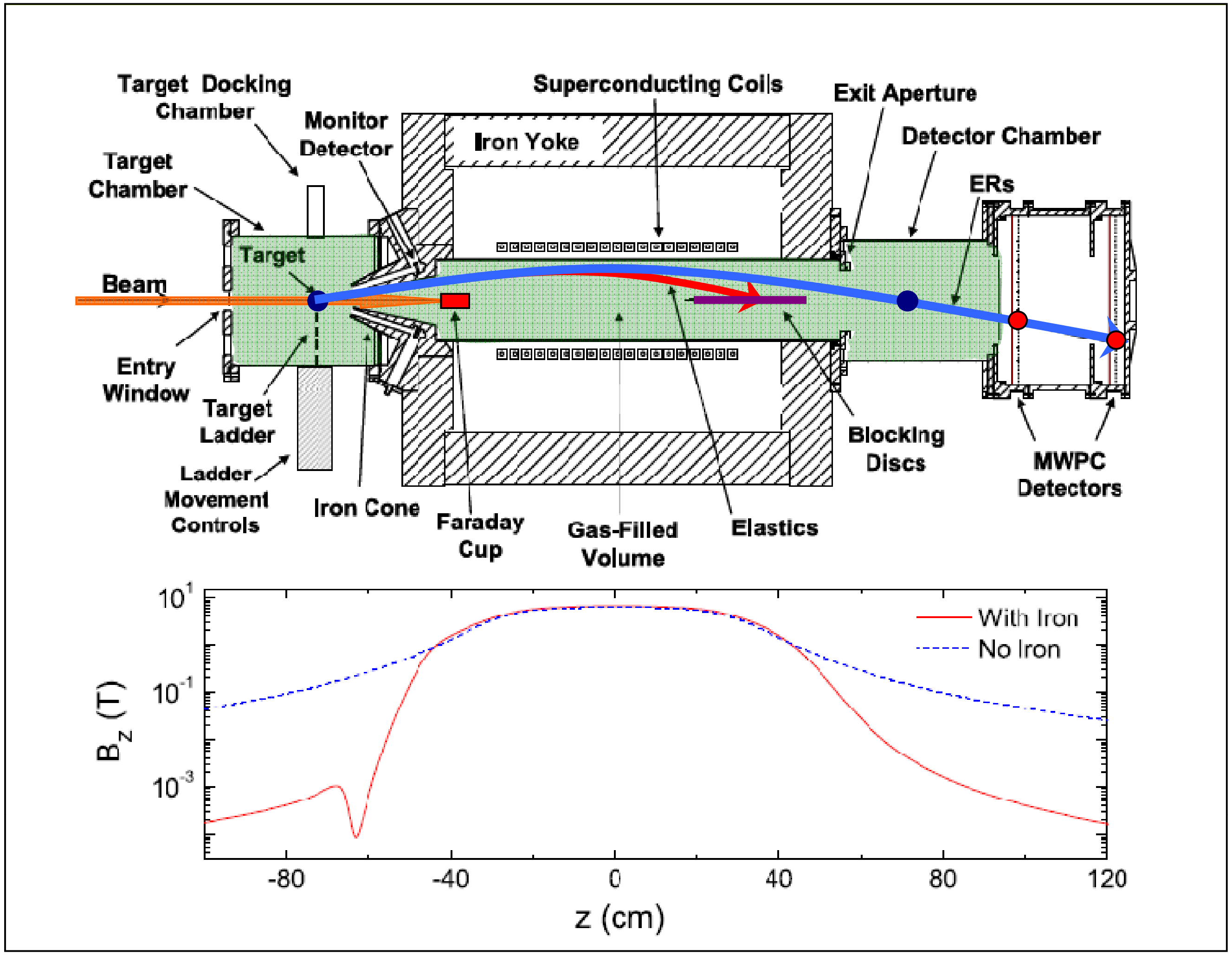


SOLITAIRE



Target Docking Chamber
Superconducting Coils
Exit Aperture
Monitor Detector
Iron Yoke
Detector Chamber
Target Chamber
ERs
Target
Beam
Entry Window
Target Ladder
Ladder Movement Controls
Iron Cone
Faraday Cup
Gas-Filled Volume
Elastics
Blocking Discs
MWPC Detectors
With Iron
No Iron
B_Z (T)
10^1
10^{-1}
10^{-3}
-80
-40
0
40
80
120
z (cm)

SOLITAIRE



Target Docking Chamber
Superconducting Coils
Exit Aperture
Monitor Detector
Iron Yoke
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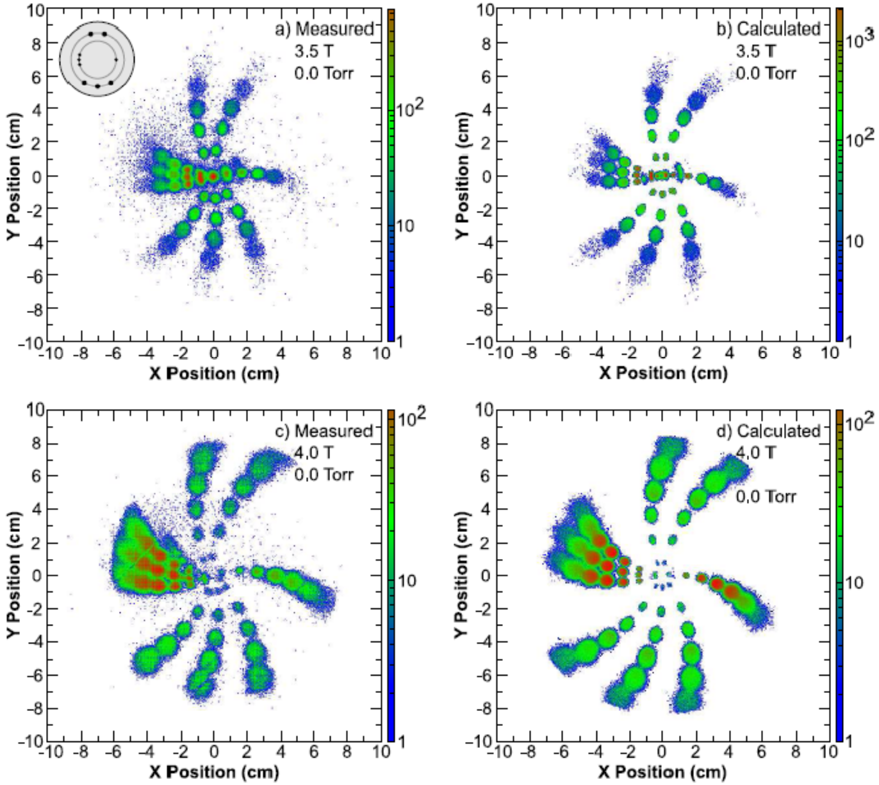
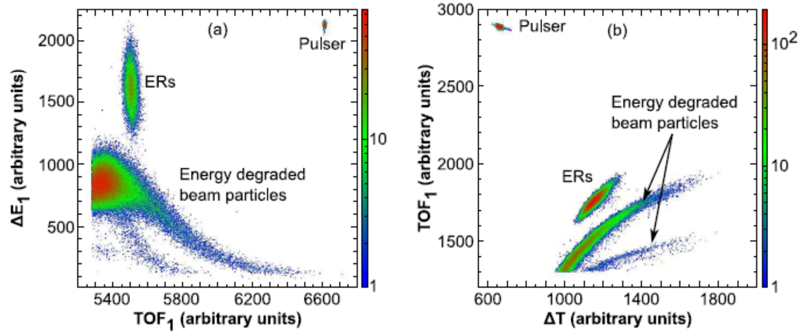
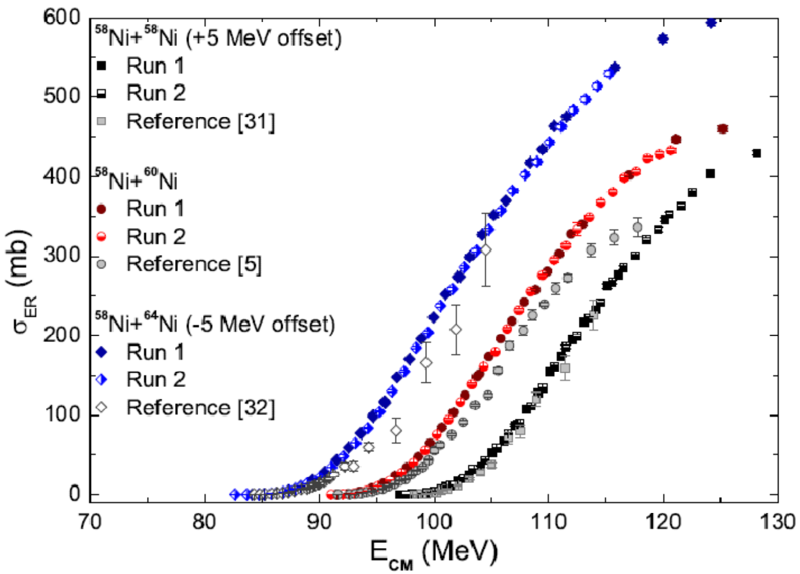
Ladder Movement Controls
Iron Cone
Faraday Cup
Gas-Filled Volume
Elastics
Blocking Discs
MWPC Detectors
With Iron
No Iron
B_z (T)
z (cm)

SOLITAIRE Nuclear Reaction Dynamics

M.D. Rodriguez et al., NIM A (2010) in press







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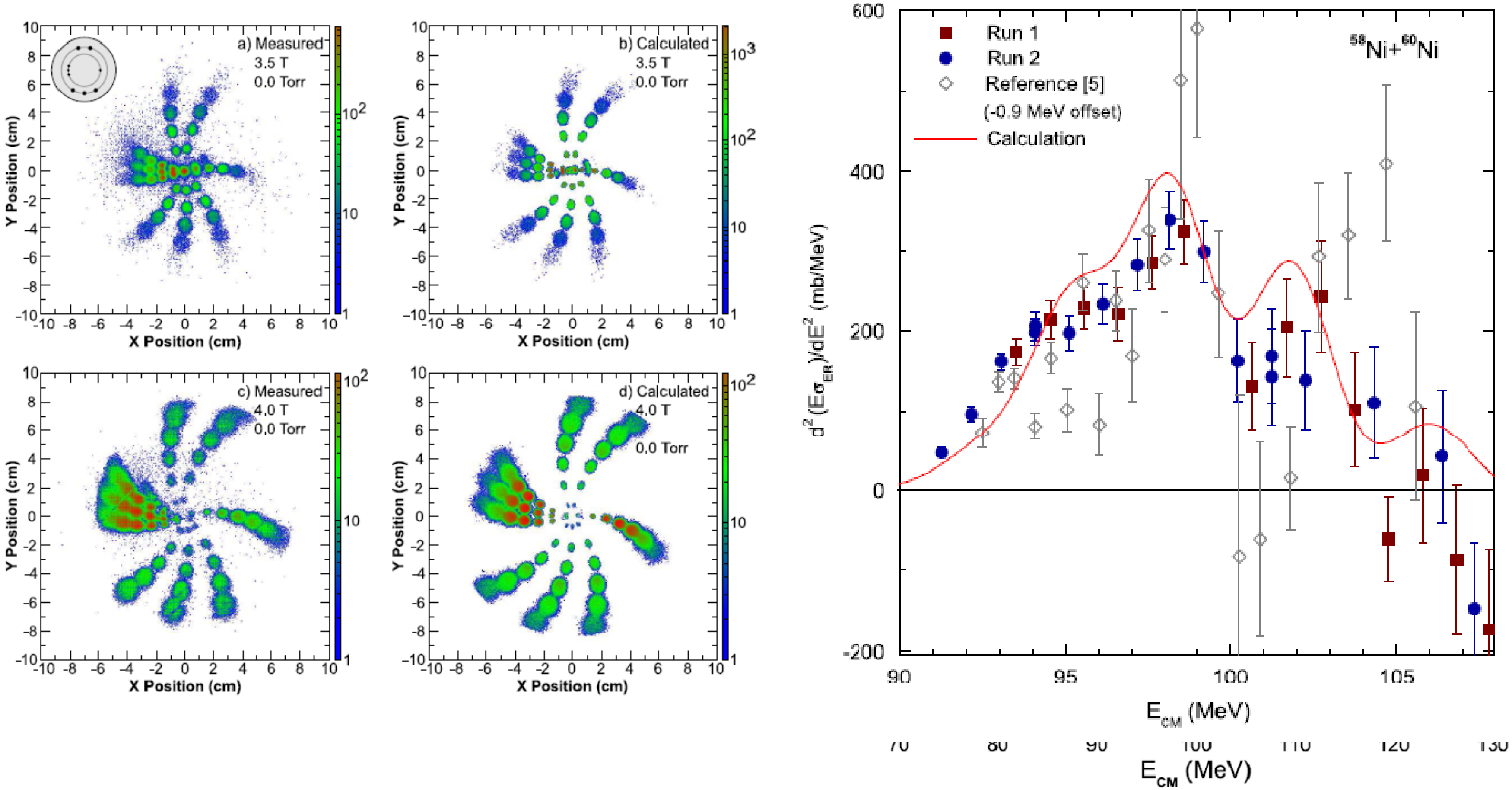
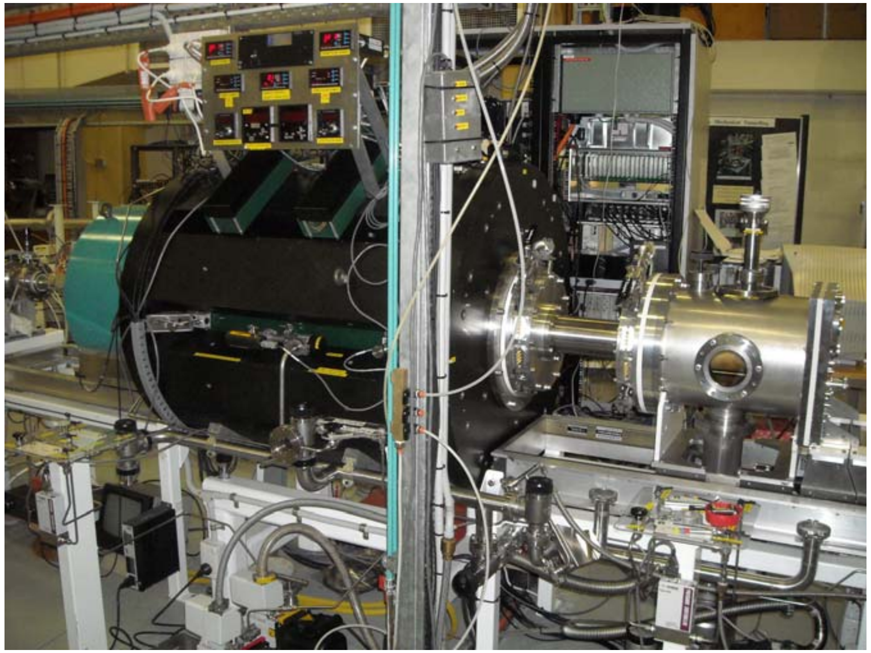


SOLITAIRE

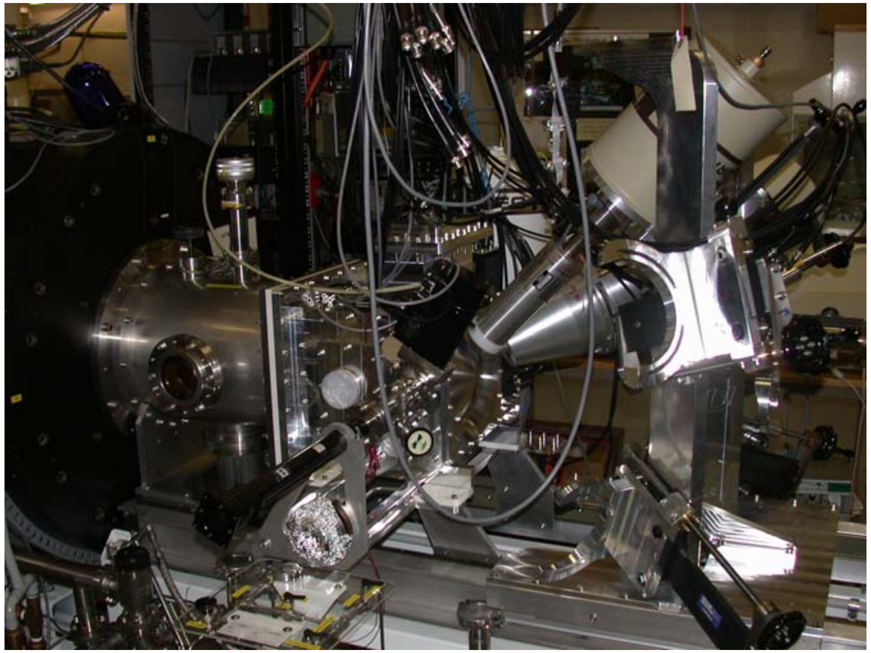
RIB

^6He



NUCLEAR STRUCTURE

SOLENO-GAM



Nuclear Reaction Dynamics

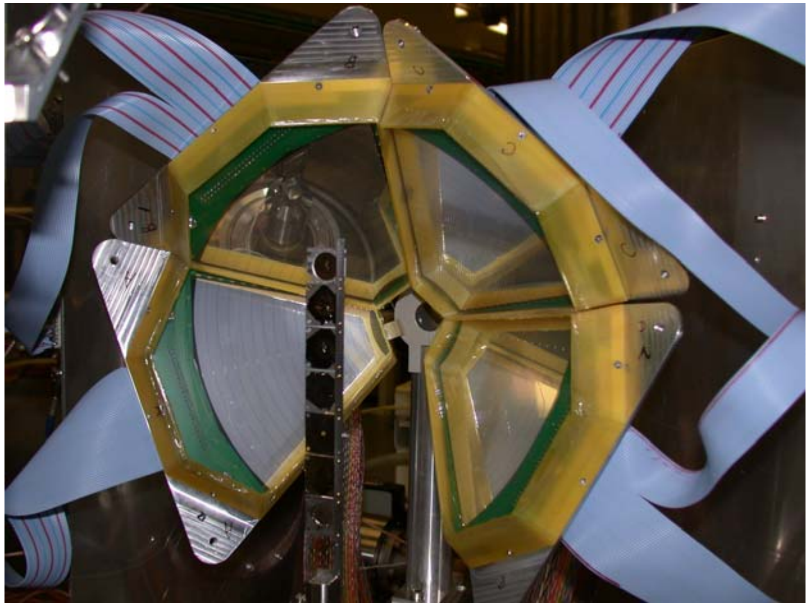
Equipment

- **CUBE** MWPC detectors for fission $\Delta\theta=70^o$, $\Delta\phi=90^o$:heavy elements
- **SOLITAIRE** superconducting 6.5 T solenoid: 86 msr
  - Heavy ion fusion: fusion barrier distributions
  - Radioactive beam production: ^6He
  - Nuclear structure - γ-rays, electrons: short-lived isomers
- **BaBrA** Back-angle 512 pixel Si array (2.6 sr): sub-barrier breakup
- 2m diameter scattering chamber: velocity filter for fusion

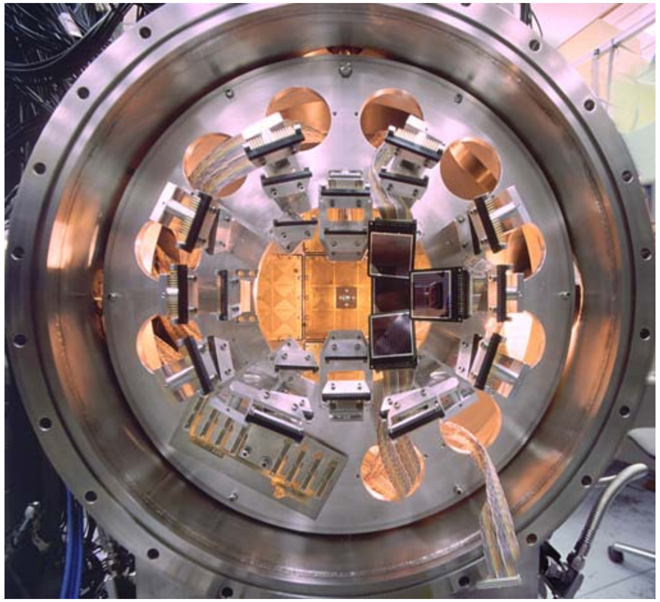
- UK CHARISSA **MEGHA** detectors: α-cluster states in light nuclei

Nuclear Reaction Dynamics

512 pixel Si array



MEGHA (UK)

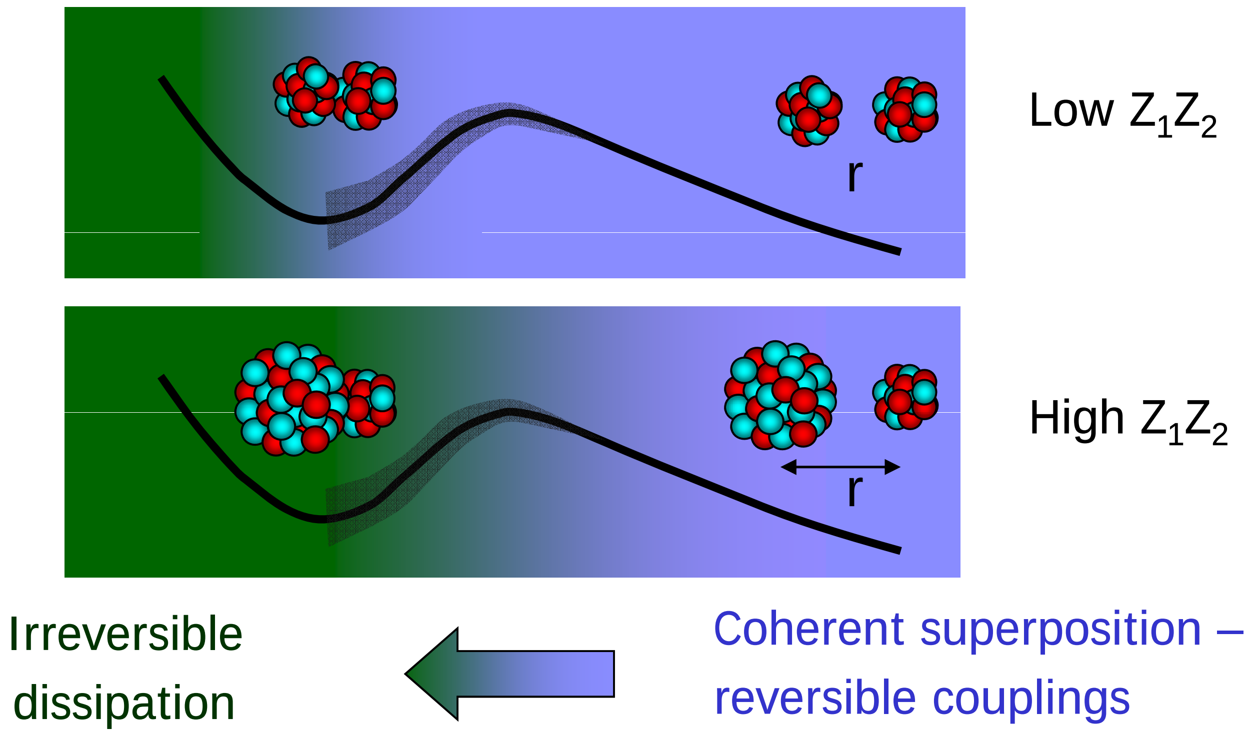


Some of our research programs

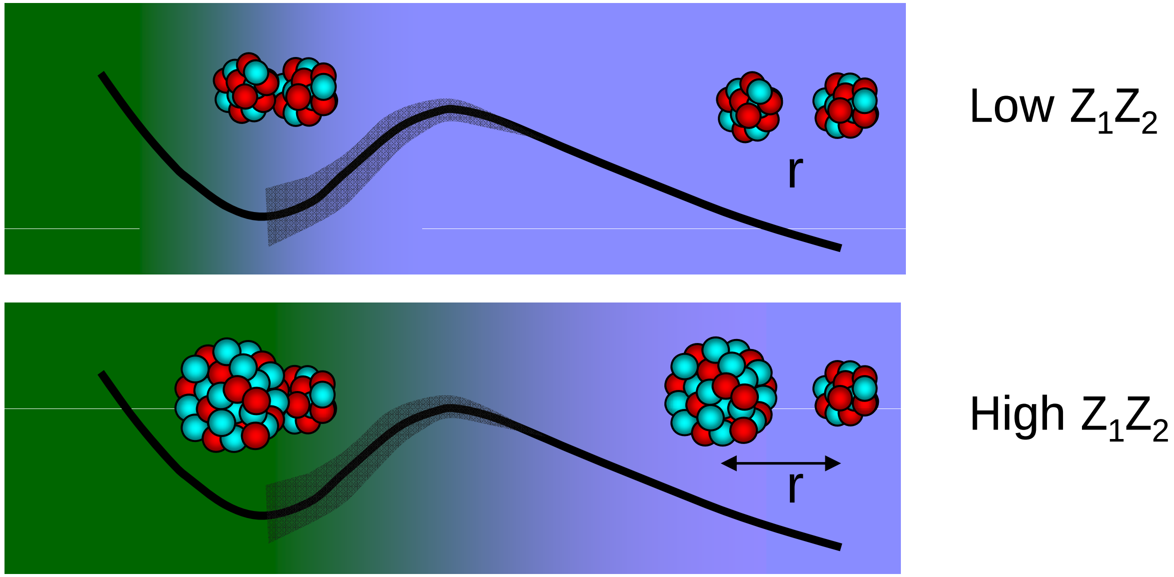
Nuclear Reaction Dynamics

- Fusion barrier distribution
- Quantum decoherence in nuclear collisions
- Breakup of weakly-bound nuclei
- Heavy element formation dynamics

Quantum decoherence in nuclear collisions

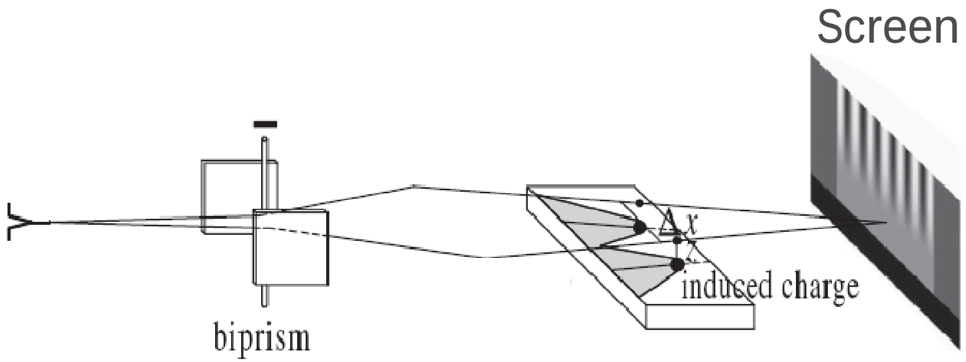


Quantum decoherence in nuclear collisions



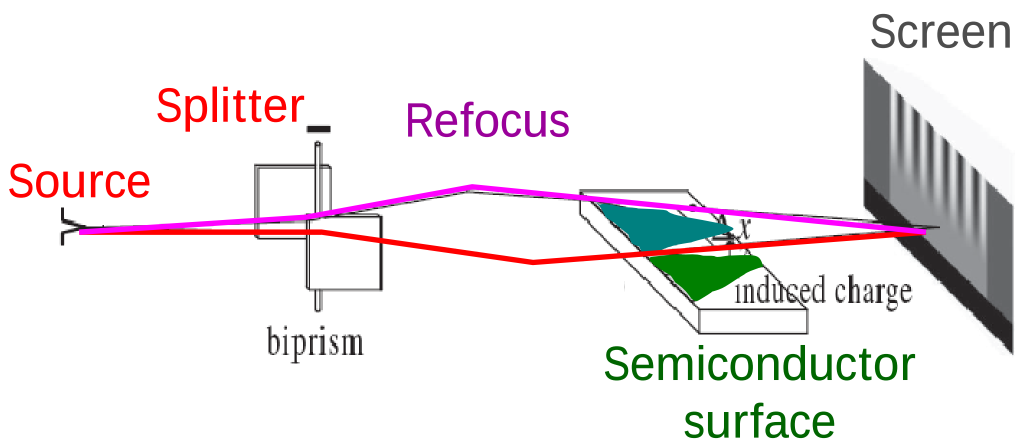
Where is the transition?
It is gradual or sharp?
How does it affect reactions?

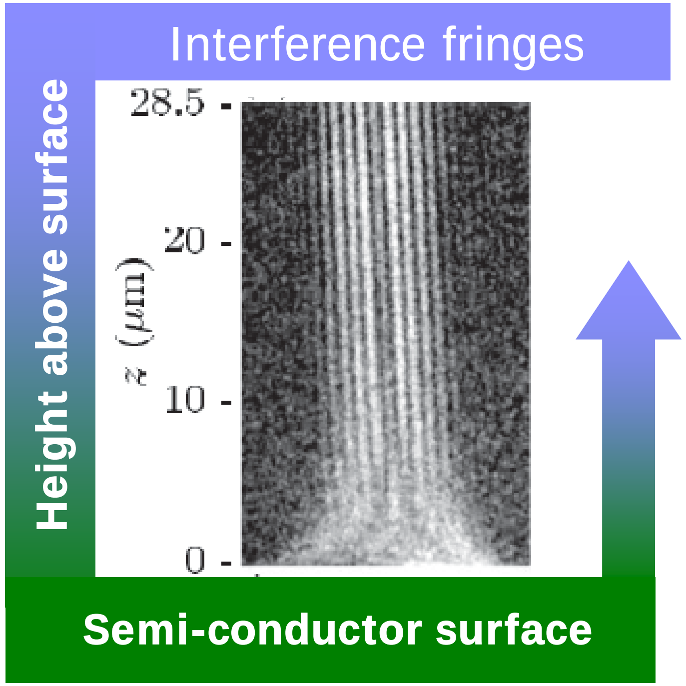
Example: Electron entanglement with a surface



- Double-slit type experiment with single electrons

Example: Electron entanglement with a surface



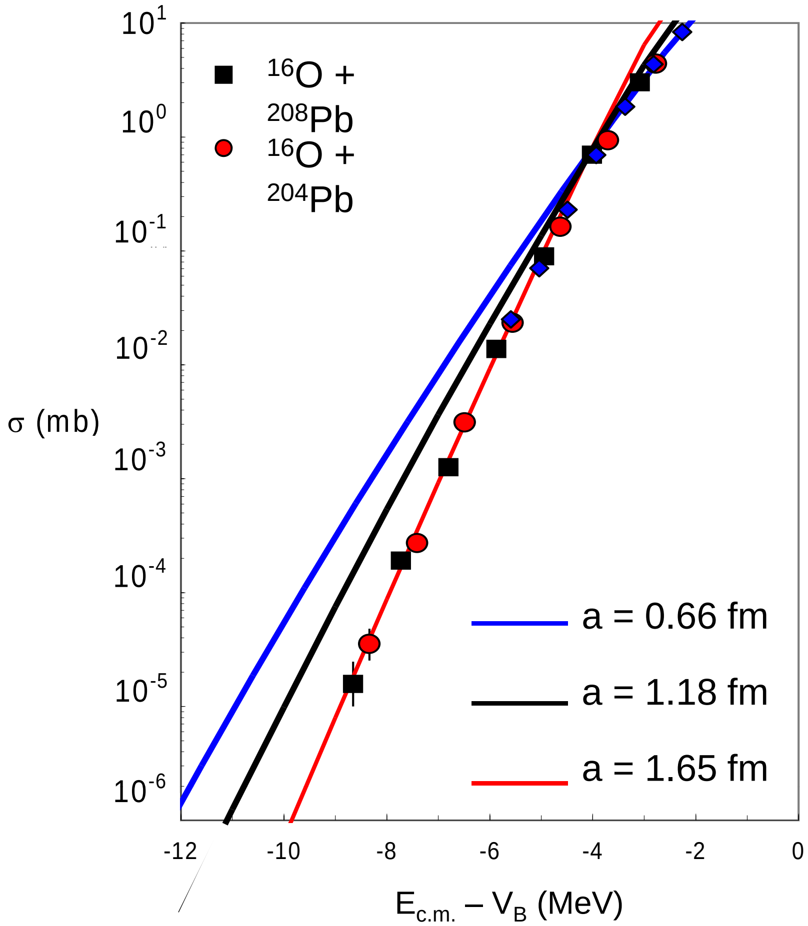


- Double-slit type experiment with single electrons
- Electron passing above disturbs electrons **in** semiconductor
- "which way" information → destroys spatial coherence

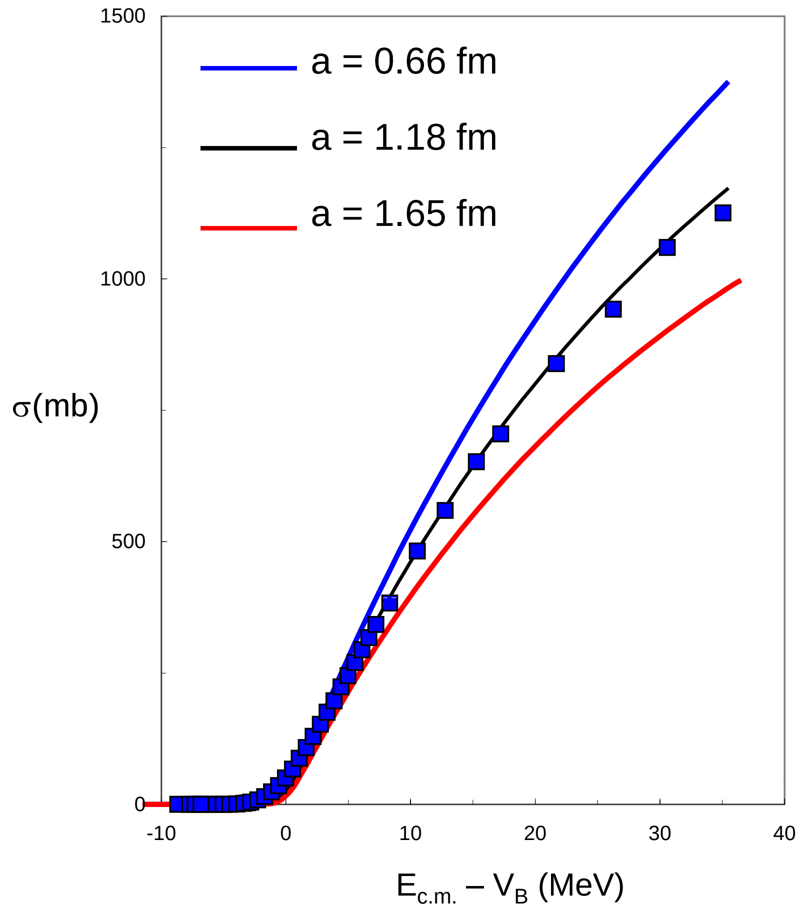
CC model fails to simultaneously describe above and below barrier fusion – probes same radial separation

Suppression of quantum tunnelling - nucleonic d.o.f.

Ni+Ni: C.L. Jiang et al., PRL 93 (2004) 012701



M. Dasgupta et al., PRL 99 (2007) 192701



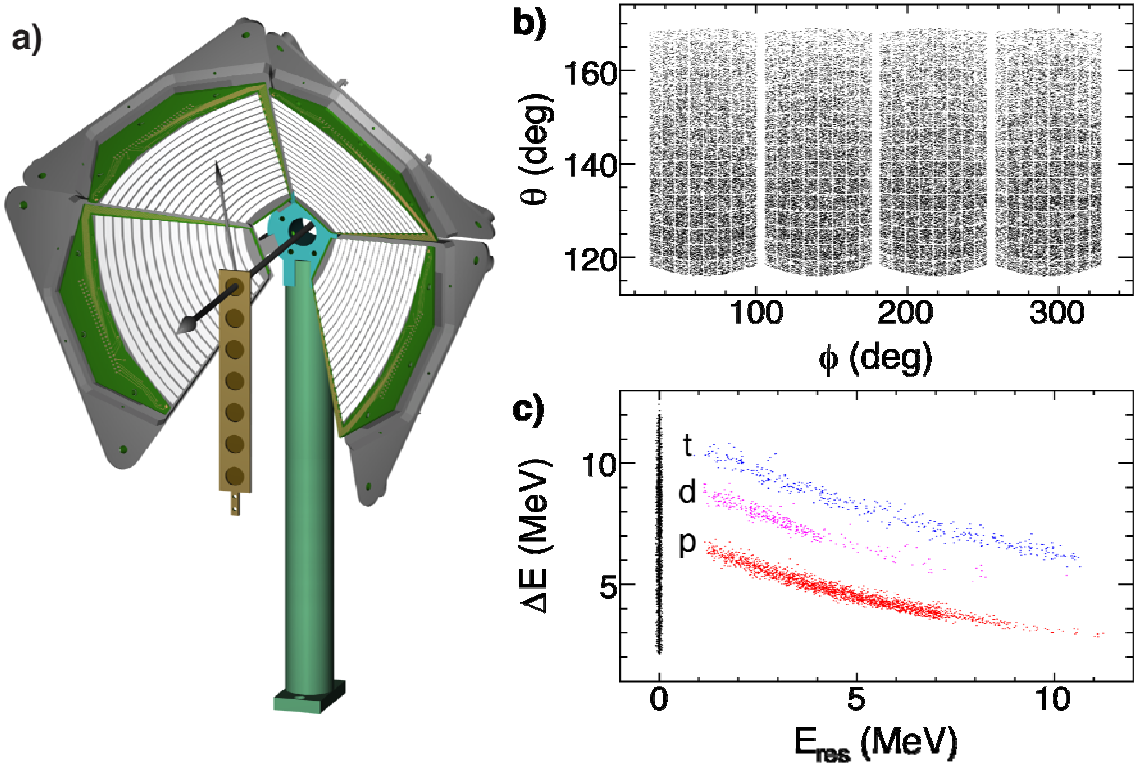
M. Dasgupta et al., PRL 82 (1999) 1395

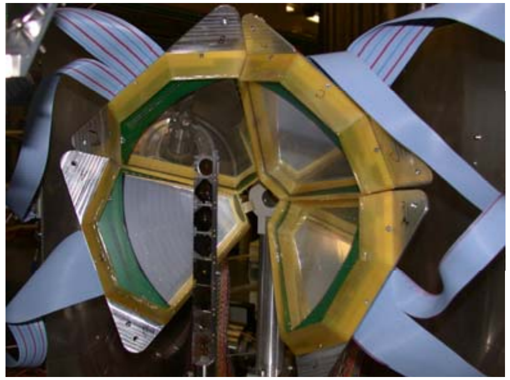
D.J. Hinde et al., PRL 89 (2002) 272701

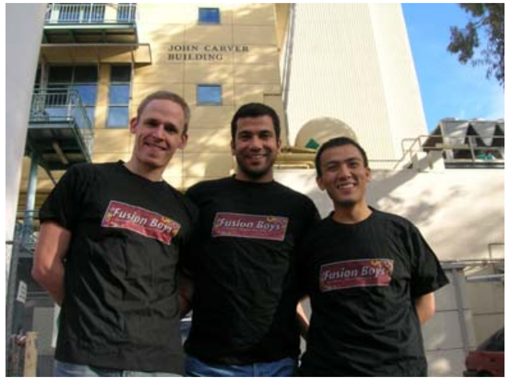
D.J. Hinde et al., Nature 431 (2004) 748

A. Diaz-Torres et al., PRL 98 (2007) 152701

Breakup of Weakly-bound Nuclei

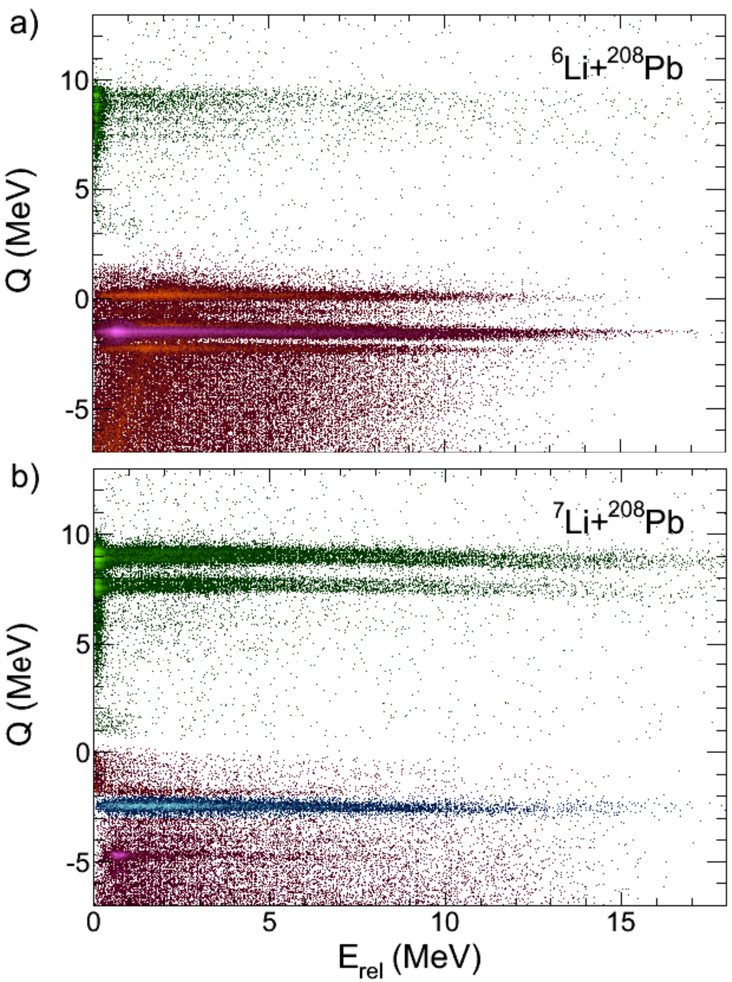


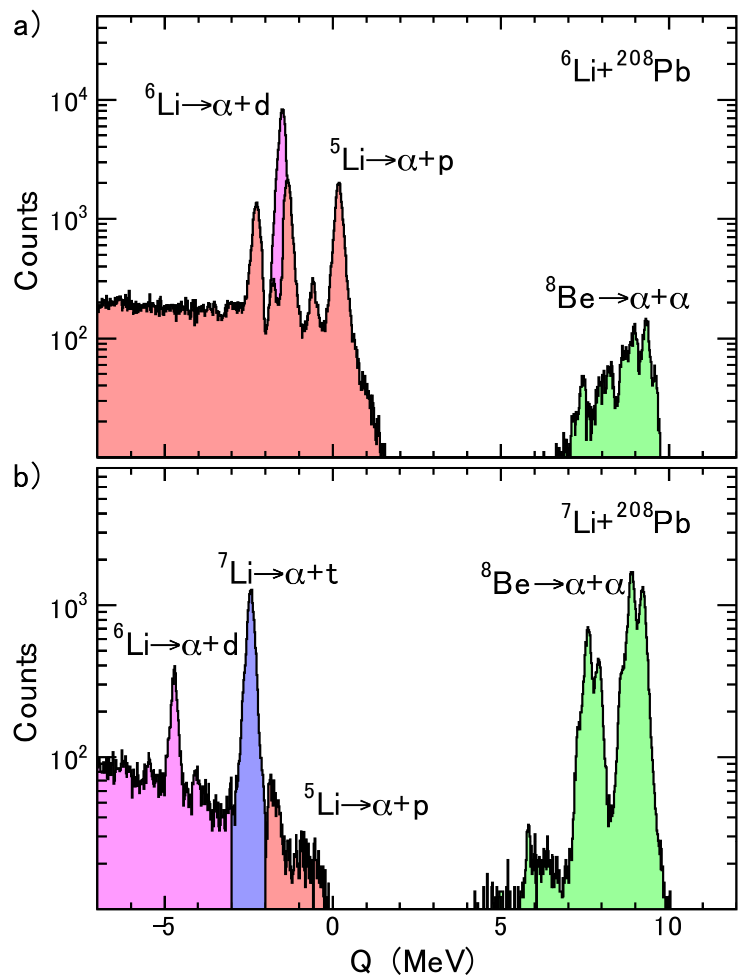




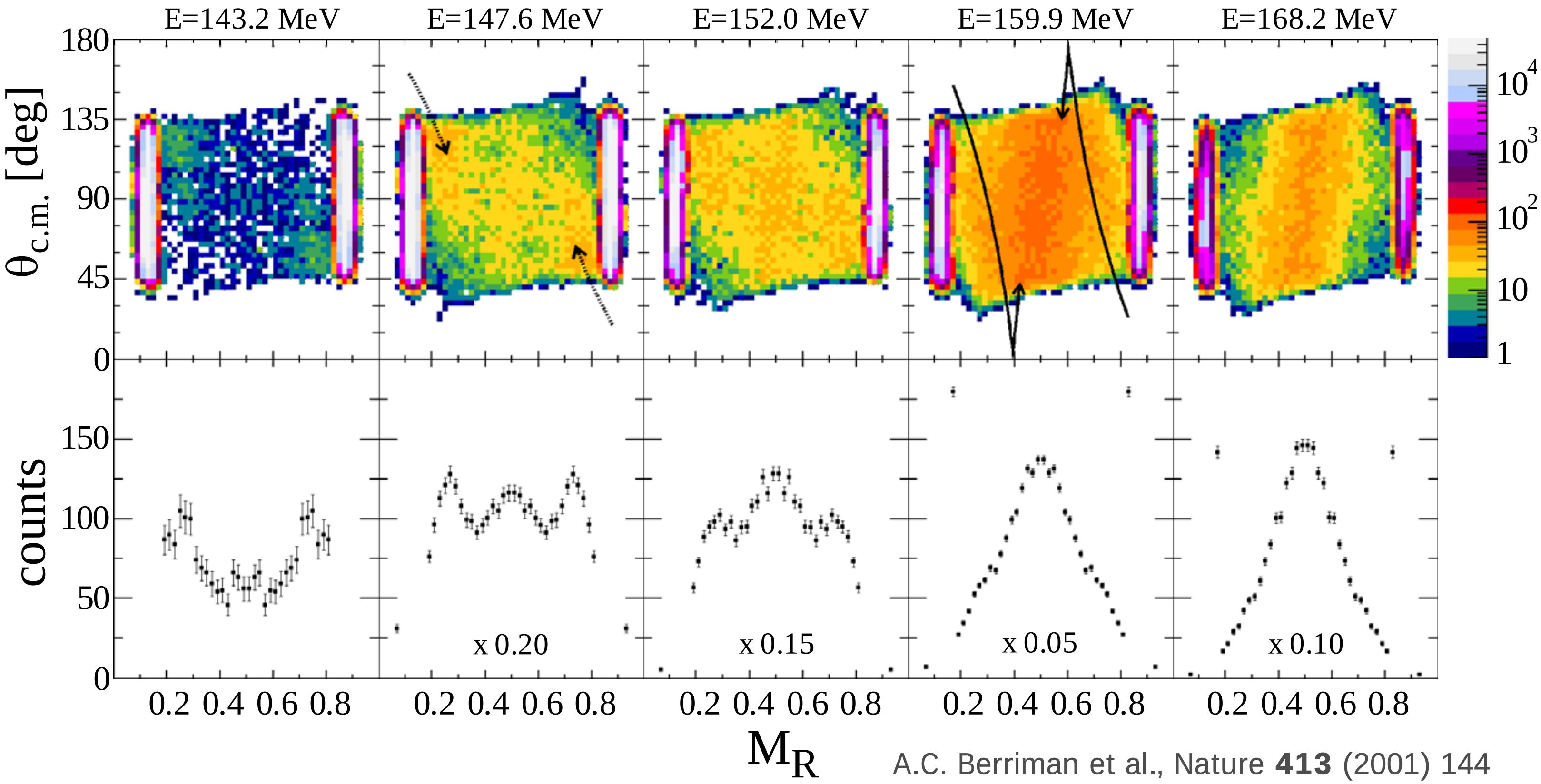
D.H. Luong et al., in preparation

Breakup of Weakly-bound Nuclei





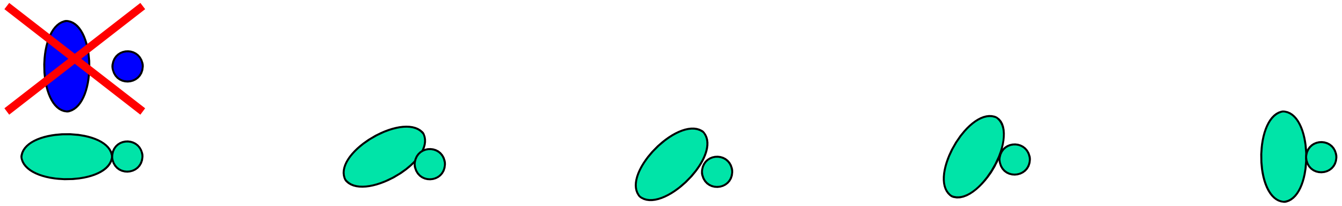
Quasi-fission timescale



A.C. Berriman et al., Nature **413** (2001) 144

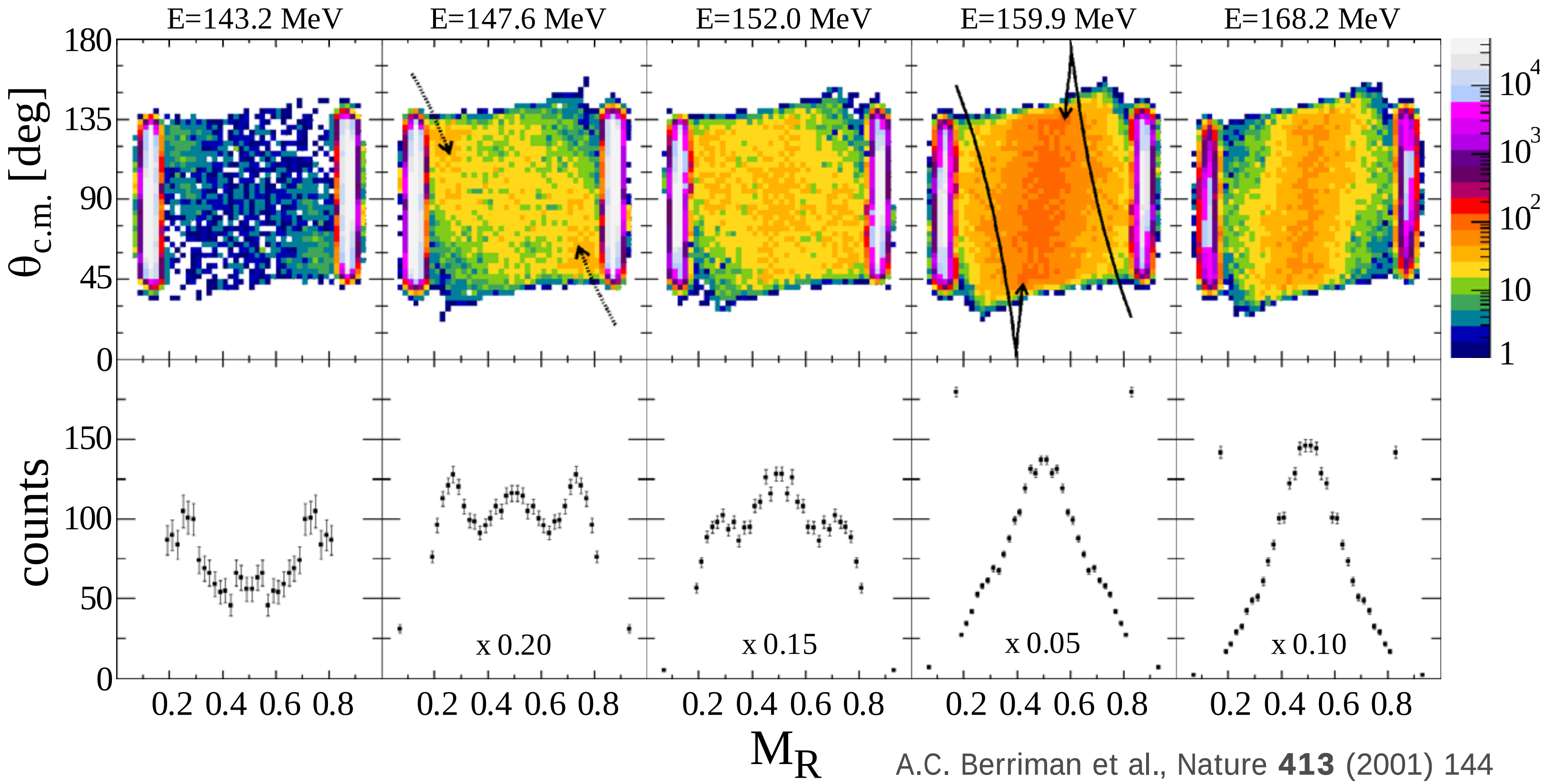
D.J. Hinde et al., PRL **101** (2008) 092702

D.J. Hinde et al., PRL **100** (2008) 202701



$^{32}S + ^{232}Th$ MAD vs. E/V_B (Timescale ~10^{-20} s)

$E/V_B = 0.93$ $E/V_B = 0.96$ $E/V_B = 0.98$ $E/V_B = 1.03$ $E/V_B = 1.09$



A.C. Berriman et al., Nature **413** (2001) 144

D.J. Hinde et al., PRL **101** (2008) 092702

D.J. Hinde et al., PRL **100** (2008) 202701

Conclusions

Situation in Australia

- Good infrastructure for near-barrier nucl phys, AMS
- Need for specific facility funding to play role of national facility