PDRA Away Day Cluster talk: Nuclear Physics

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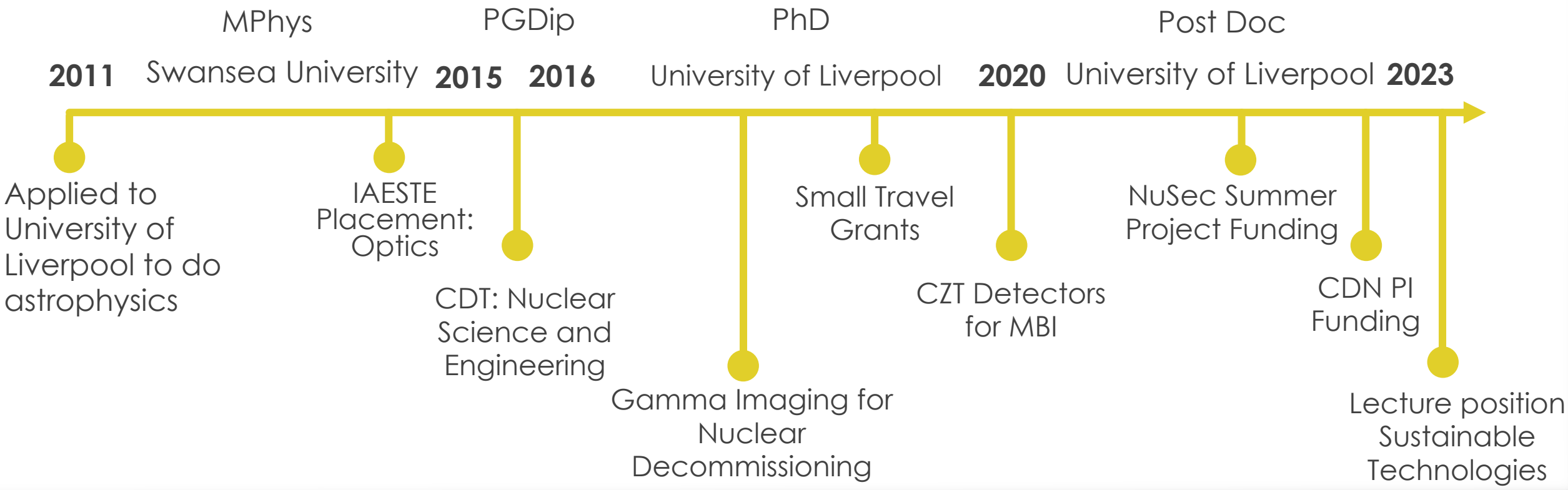
Outline

- Who am I?
- What is nuclear physics
- Nuclear Physics at Liverpool
  - History
  - Current cluster
  - Research Areas
  - Collaborations
  - Facilities
  - Funding Sources

Who am I?

PDRA in Nuclear Physics Cluster

- Background in detector physics + Gamma Imaging



What is Nuclear Physics?

The Nuclear Physics European Collaboration Committee

NuPECC Long Range Plan 2017 Perspectives in Nuclear Physics

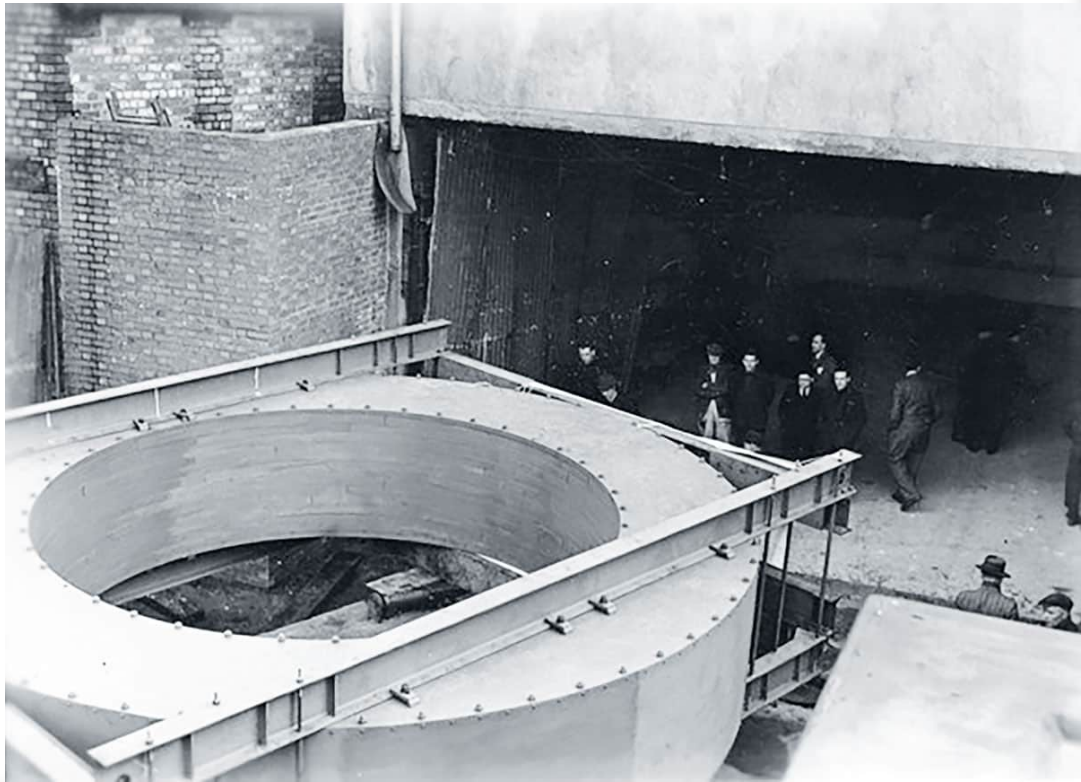
"The science of Nuclear Physics covers the study of the **atomic nucleus**, which is where the mass of the atom is concentrated. Unravelling the often complex, **structure and behaviour of the nucleus**, and its **constituents**, is key to understanding how the variety of matter we see all around us – and which underpins our own existence – is generated"

Questions:

- How does the **complexity of nuclear structure** arise from the **interaction between nucleons**?
- What are the limits of **nuclear stability**?
- How and where in the universe are the **chemical elements produced**?
- What are the properties of nuclei and **strong interaction matter** as encountered shortly after the Big Bang, in catastrophic cosmic events, and in compact stellar objects?
- How does the **strong force between nucleons** emerge from the underlying quark-gluon structure?

Nuclear Physics at Liverpool: Strong History

- 1930's – "*[Liverpool] physics department was run down and lacking equipment*"
- 1935 – James Chadwick (fresh from the neutron discovery) joins University of Liverpool
- 1936 – James Chadwick started construction of a 37-inch cyclotron + overhauls laboratories
- 1940's – Chadwick (+ Frisch and Rotblat) investigate nuclear cross section of ^{235}U (whilst dealing with bombing) – determined the feasibility of the atomic bomb
- (1943 – Chadwick leads British scientists on Los Alamos, later ignored in the Oppenheimer film…)
- 1946 – Chadwick leads construction of a synchrocyclotron under the metropolitan cathedral
- 1952 – synchrocyclotron is finished – used to extra beams of protons of ~400 MeV



Nuclear Physics at Liverpool: Strong History

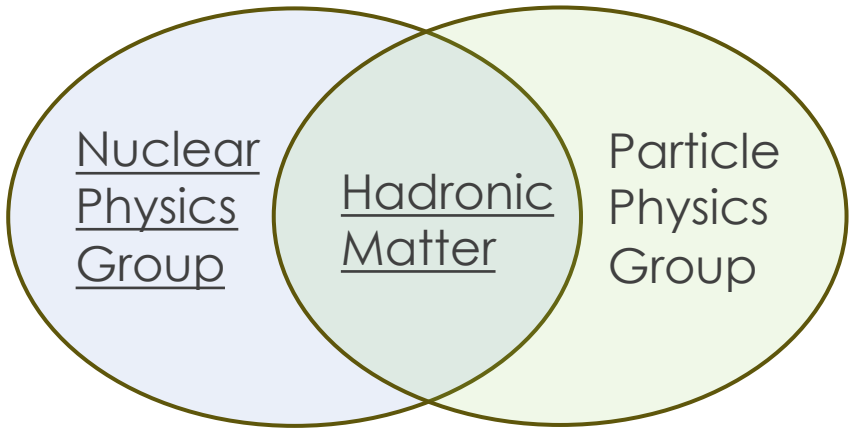
Nuclear Physics at Liverpool: Today

No cyclotron any more ☹

Group members

- 10 Academics
- 7 PDRAS
- 17 PhD students (usually more)
- Technical Support Staff

More like 2 groups



Research Areas

- Exploring the limits of nuclear existence for heavy proton-rich nuclei
- Structure of superheavy nuclei
- Ground and isomeric properties by laser spectroscopy
- Gamma-ray spectroscopy at ultra high spin
- Heavy ion collisions (ALICE)
- Astrophysical processes
- Applied nuclear physics

Research: Limits of Nuclear Existence

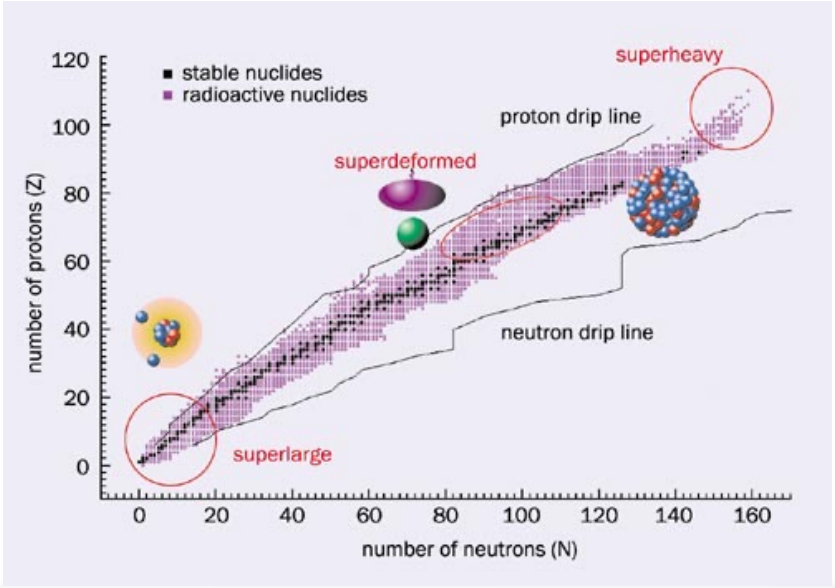
New nuclides are discovered frequently

Q: 'what are the limits on the number of protons and neutrons that can be bound inside an atomic nucleus?'

Isotopes	First Author	Journal	Ref.	Method	Laboratory	Country	Year
^{149}Lu	K. Auranen	Phys. Rev. Lett.	[1]	FE	Jyväskylä	Finland	2022
^{207}Th	H. B. Yang	Phys. Rev. C	[2]	FE	Lanzhou	China	2022
^{264}Lr	Yu. Ts. Oganessian	Phys. Rev. C	[3]	FE	Dubna	Russia	2022
^{166}Pm, ^{168}Sm, ^{170}Eu, ^{172}Gd	G. G. Kiss	ApJ	[4]	PF	RIKEN	Japan	2022
^{204}Ac	M. H. Huang	Phys. Lett. B	[5]	FE	Lanzhou	China	2022
^{251}Lr	T. Huang	Phys. Rev. C	[6]	FE	Argonne	USA	2022
^{39}Na	D. S. Ahn	Phys. Rev. Lett.	[7]	PF	RIKEN	Japan	2022
^{286}Mc	Yu. Ts. Oganessian	Phys. Rev. C	[8]	FE	Dubna	Russia	2022

Limits of observable nuclei dictated by emission of nucleons

- The proton and neutron drip lines are the borders between bound and unbound nuclei
- Drip line not well understood for heavy nuclei



At international facilities:

- Probe nuclei at proton-rich limit
- Verify validity of models describing weakly bound and heavily deformed nuclei

Research: Superheavy Nuclei

Stability occurs at ‘magic’ numbers of protons and neutrons

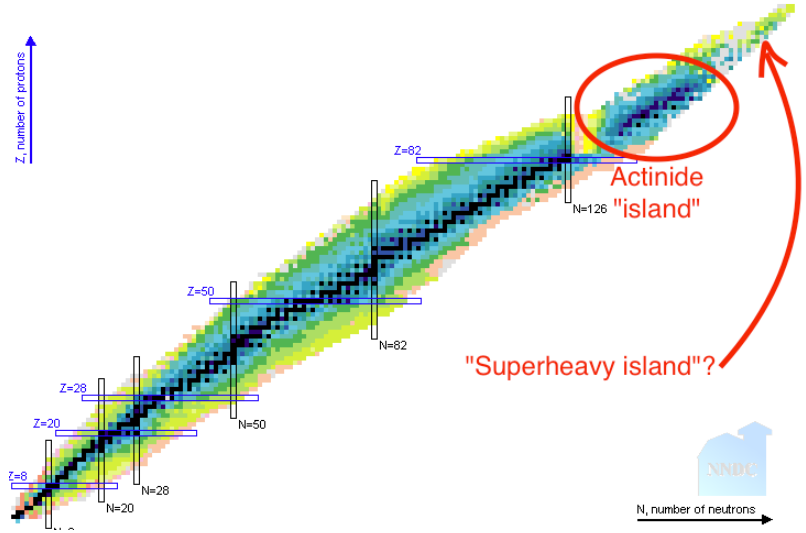
- **2, 8, 20, 28, 50, 82, and 126 (neutrons only)**

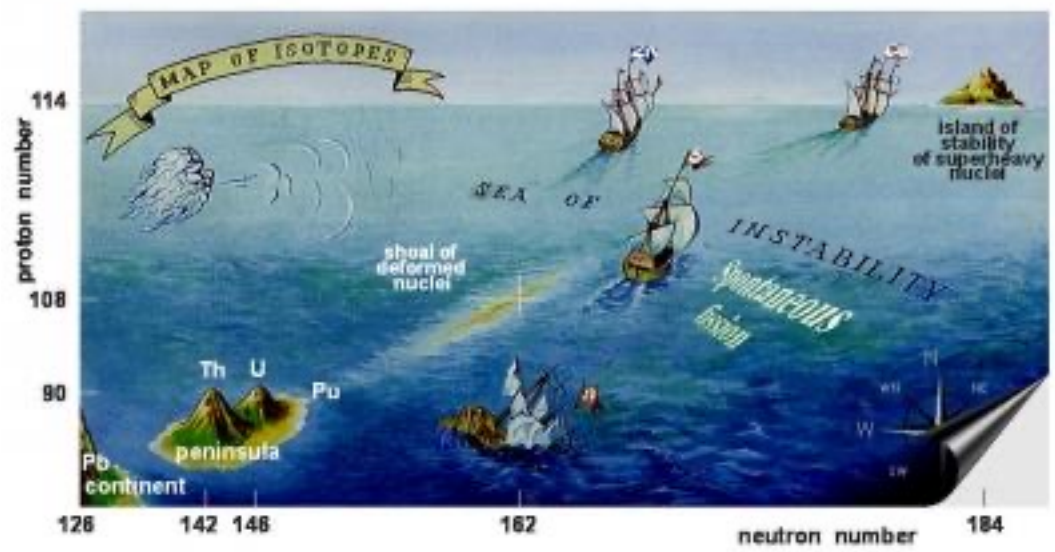
Predicted magic numbers

- Protons: **114**, 122, 124, and 164
- Neutrons: **184**, 196, 236, and 318

Study structure of superheavy nuclei

- Create short-lived superheavy nuclei to investigate potential ‘island of stability’
- Investigate deformed shells at Z=**100** and N=**152**
- Heavy ion beams
  - In-beam gamma and electron spectroscopy

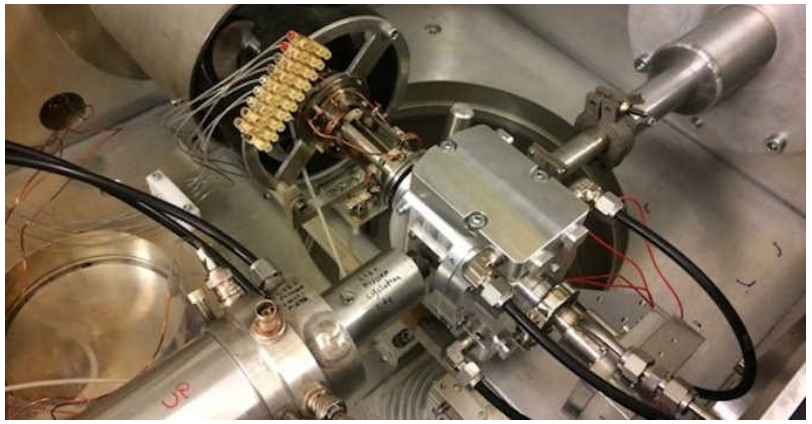


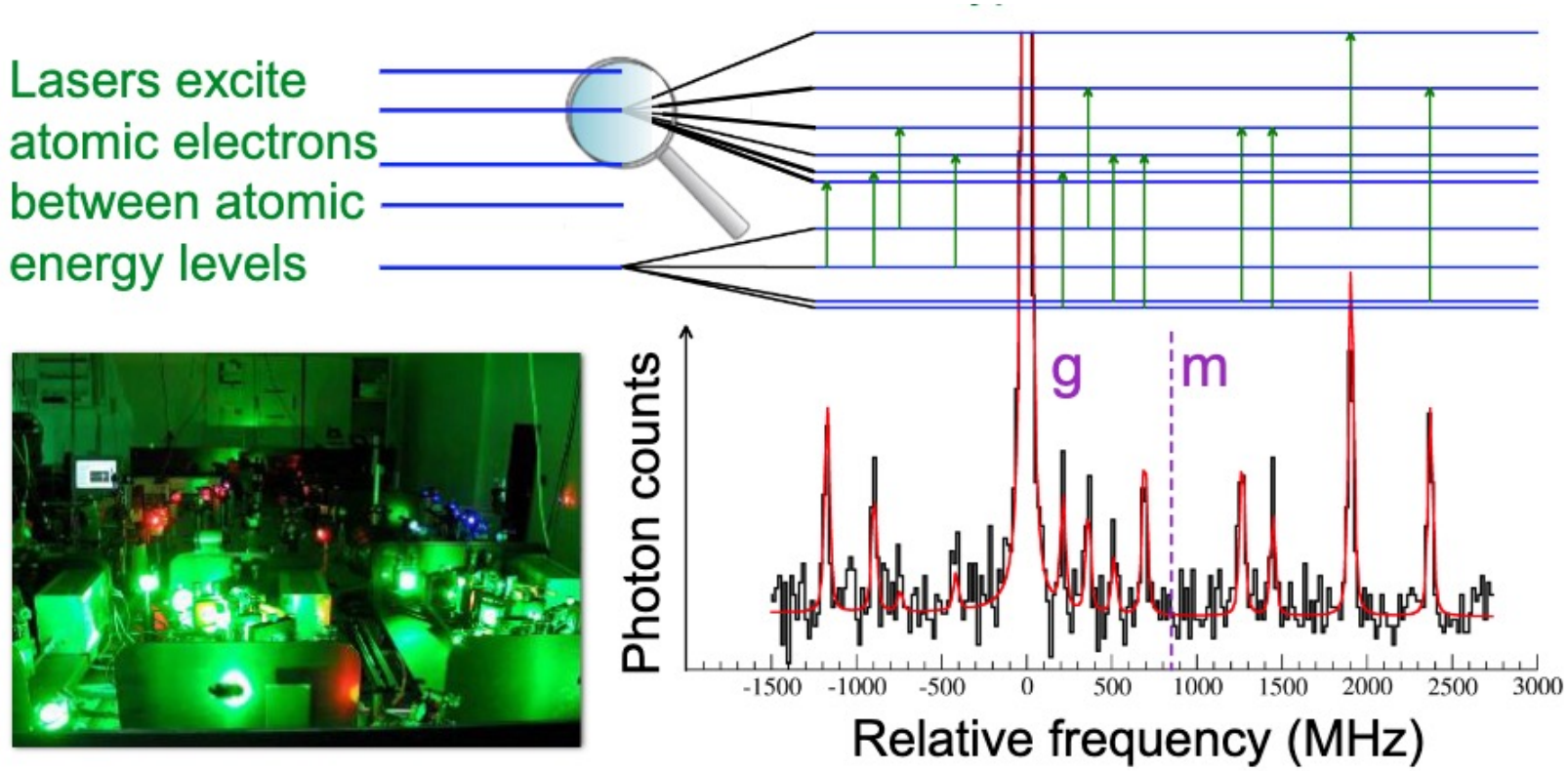


Research: Laser Spectroscopy

Probing of short-lived nuclear states through optical spectroscopy

- Excite atomic electrons between levels using lasers
- Investigate hyperfine structure – arises due to interaction between nucleus and electrons
- Reveals fundamental properties: Nuclear size, shape, magnetism, spin

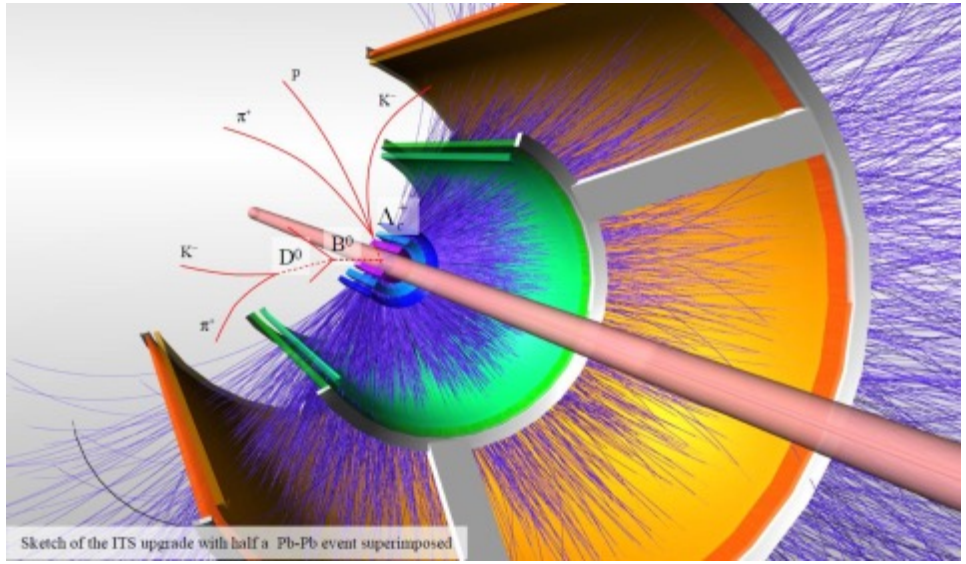


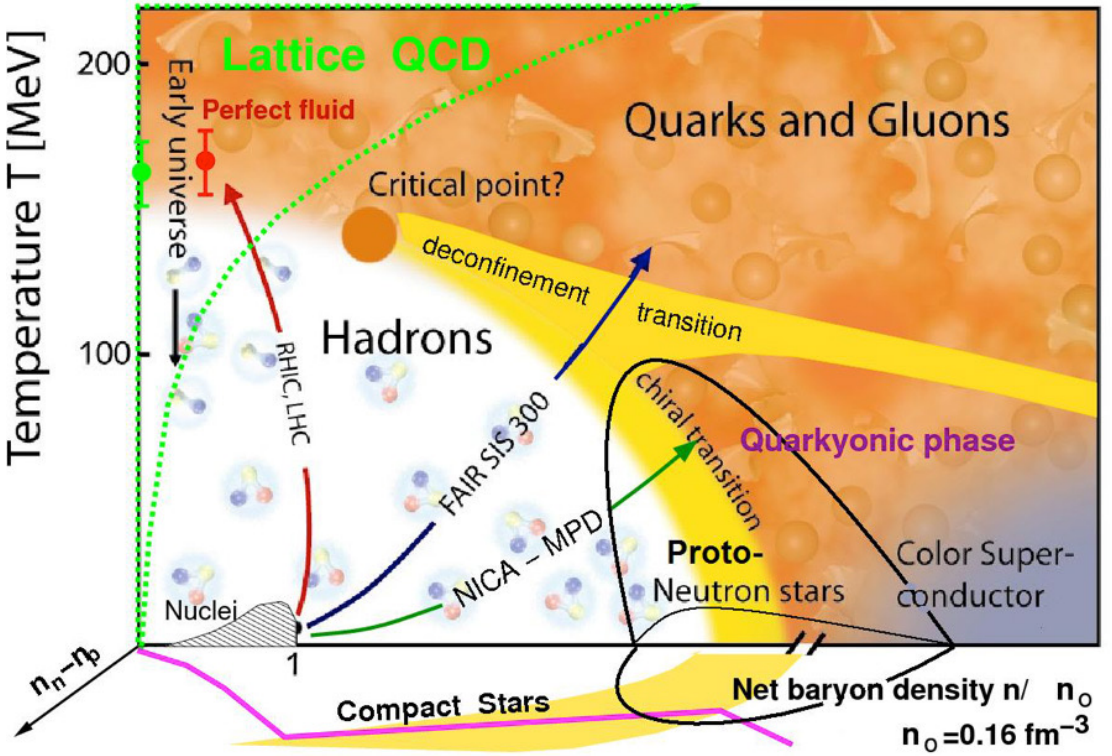


Research: Hadronic Matter

Investigate thermodynamics of QCD matter (quarks and gluons)

- QCD at high temperature using heavy quarks (charm and beauty)
- Hadronic matter at high densities
- Design and construction of charged-particle detectors
- Use heavy ion-ion collisions and interactions





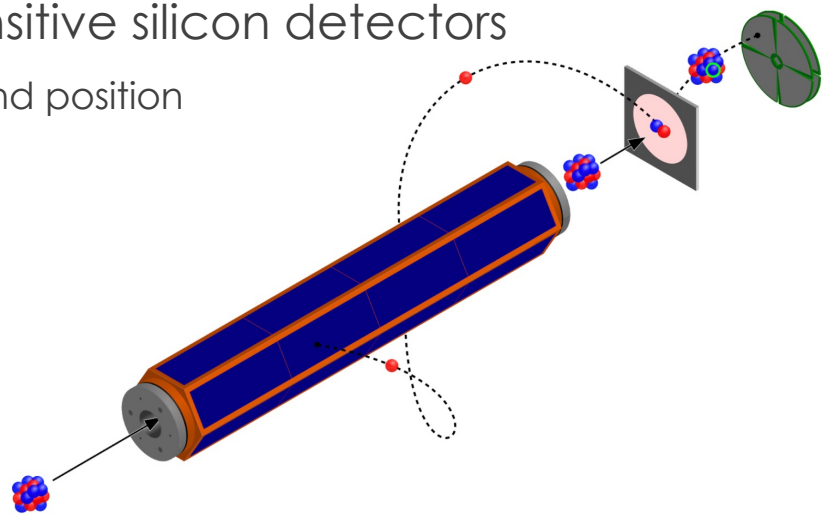
Research Area: Astrophysical Processes

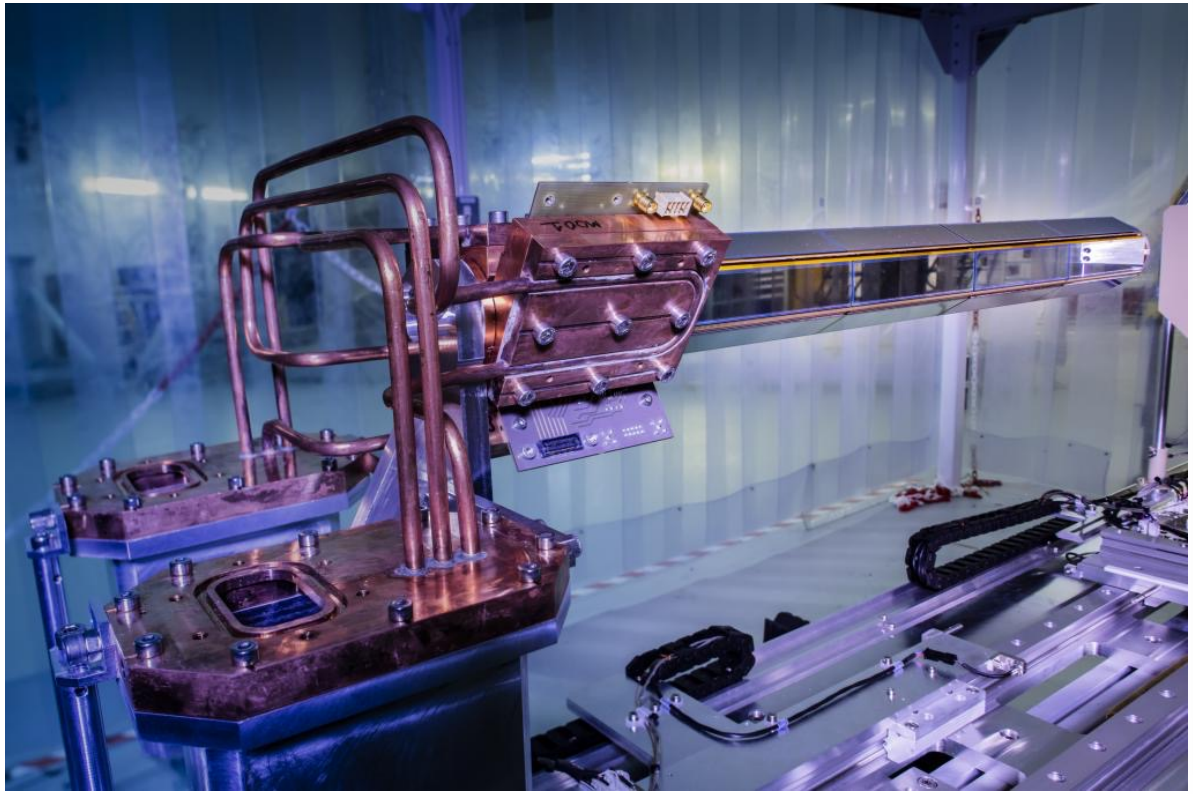
Radioactive beams for studying astrophysical r process

- r process: rapid neutron captures in stellar nucleosynthesis -> produces heavy elements
- Measure atomic nuclei in conditions replicating those found in stellar nucleosynthesis

ISS (ISOLDE Solenoidal Spectrometer)Array

- Ex-MRI 4T solenoid magnetic
- Thin target and accelerated radioactive beams
- Nuclear reaction produces are bent in spiral paths
- Position sensitive silicon detectors
  - Energies and position





Research: Gamma Spectroscopy and Imaging

Research in support of nuclear physics

- Gamma-ray detection for the study of weak features at the extremes of nuclear spin and deformation
- Highly efficient gamma detector arrays
  - EUROGAM
  - GAMMASPHERE
  - MINIBALL
  - EXOGAM
  - EUROBALL

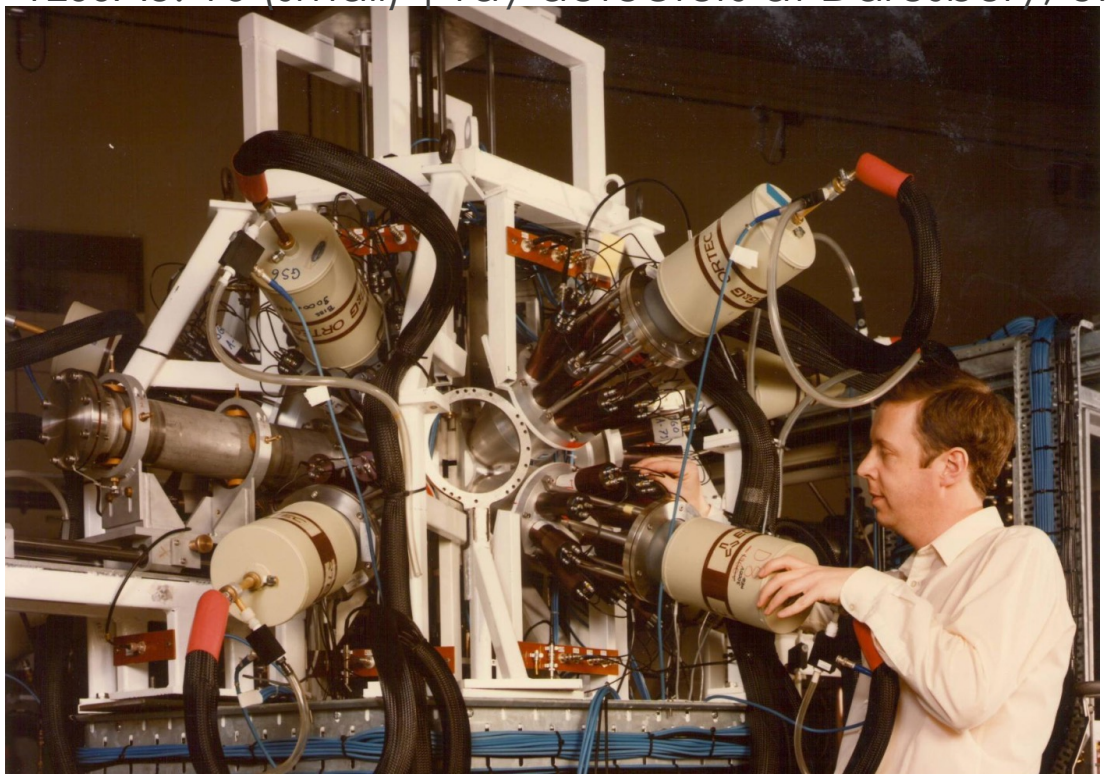
GRETA (US)

AGATA (EU)

The Hulk destroys GAMMASPHERE

Made no sense…

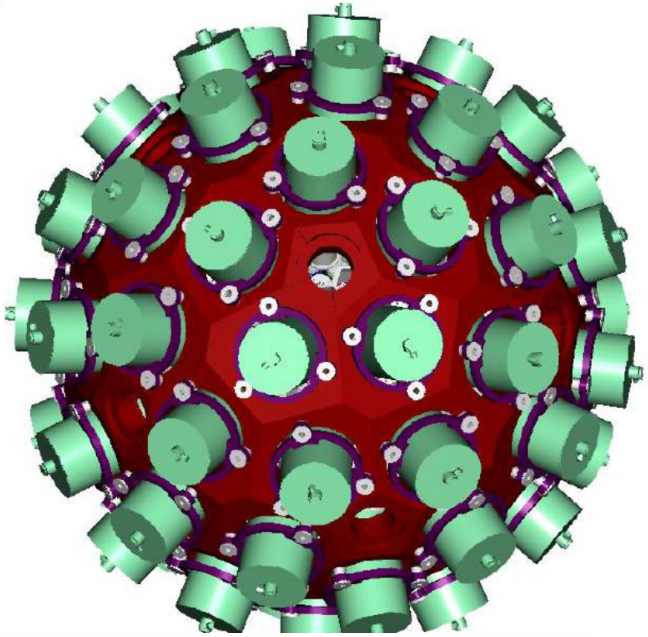
TESSA3: 16 (small) γ-ray detectors at Daresbury, UK

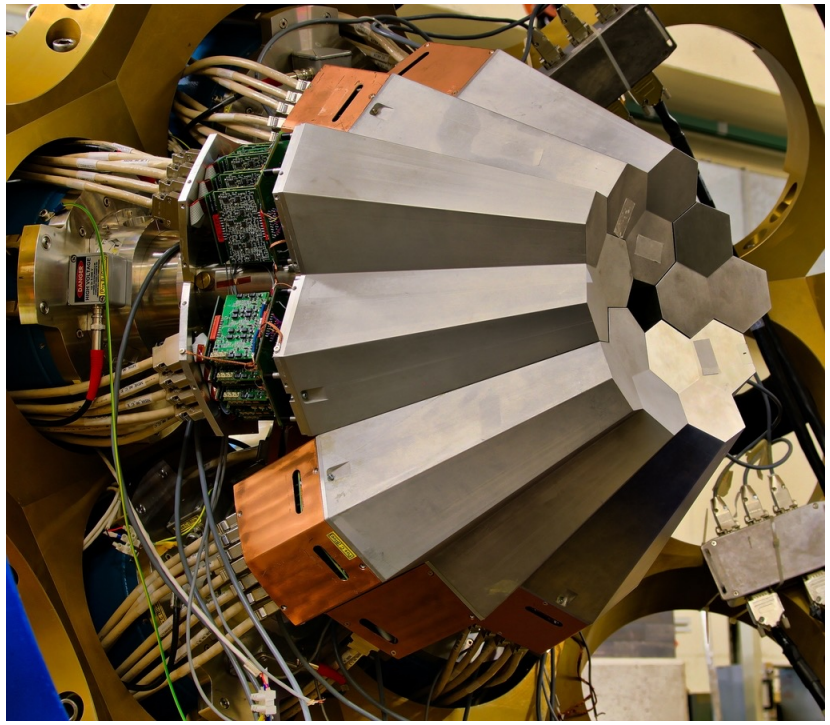


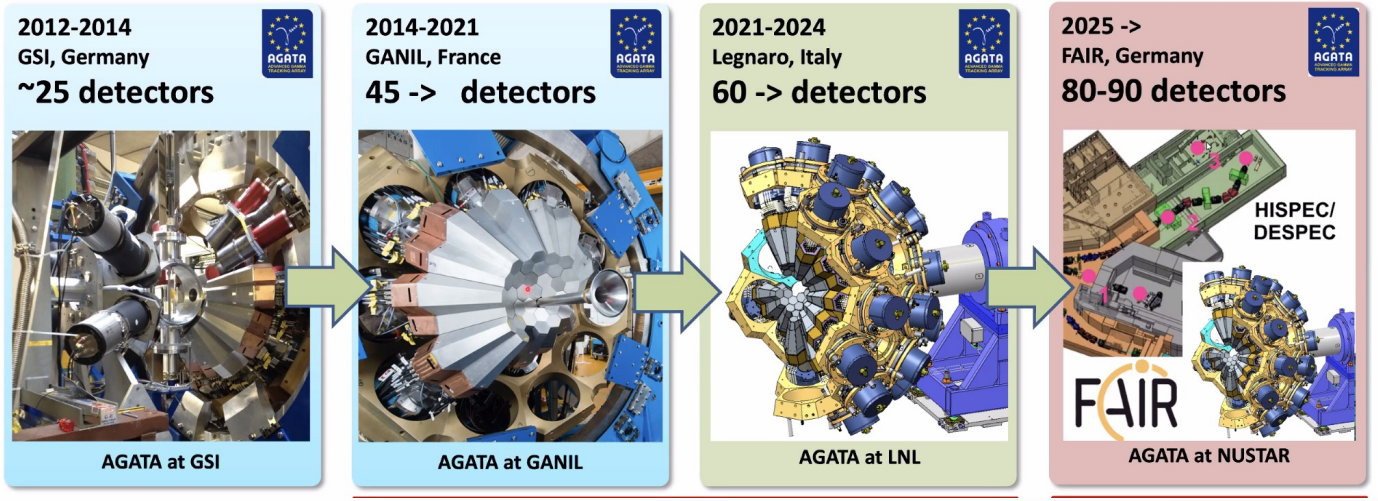
Research: AGATA

Advanced **GA**mma **T**racking **A**rray (AGATA)

- European gamma-ray spectrometer used for nuclear structure studies
- 4π Array of detectors for unmatched efficiency
- Highly segmented High Purity Germanium (HPGe) detectors



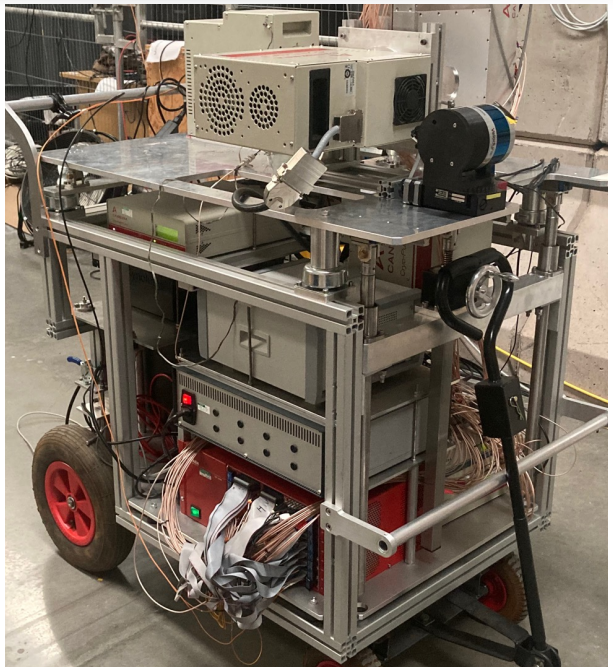




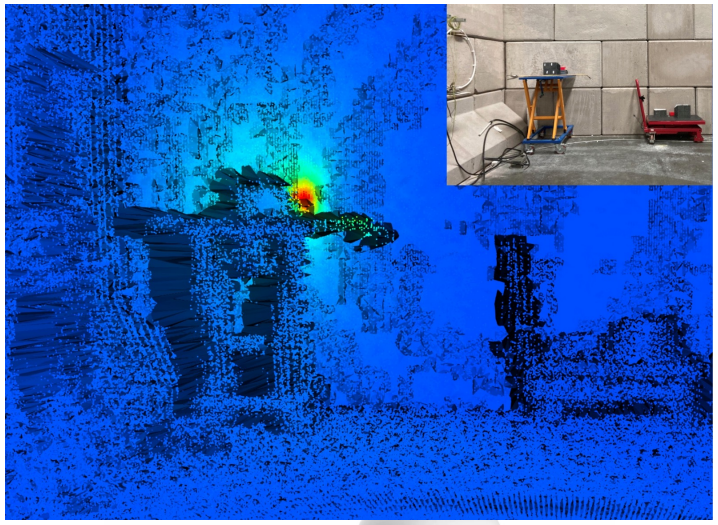
Research: Applied Nuclear Physics

Research as a result of nuclear physics

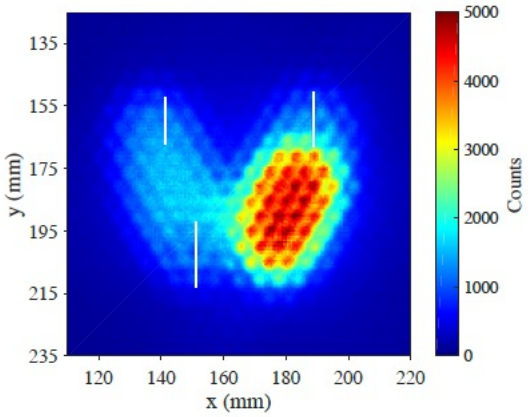
- Large volume segmented HPGe detectors

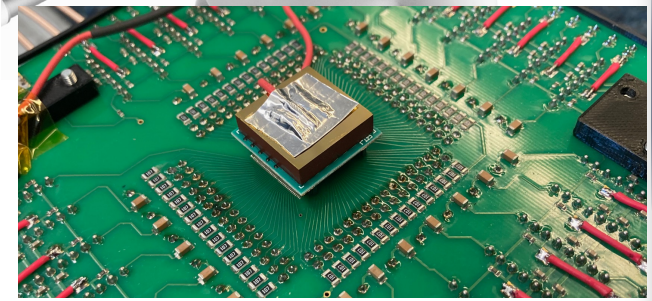


- Gamma tracking -> Gamma Imaging
  - Medical Physics
  - Nuclear Decommissioning
  - Nuclear Safeguarding
  - Environmental Monitoring



- Characterisation and simulation of alternative semiconductor detectors
  - Cadmium Zinc Telluride (room temperature)
  - Investigate radiation damage and charge trapping





Collaborations – Research Facilities


LNL, Italy


GANIL, France


ELI-NP, Romania


CERN, Switzerland


TRIUMF, Canada


Argonne, USA


LBNL, USA


GSI, Germany


JYFL, Finland

Collaborations: Industry

- Mirion Technologies
  - Manufacturer and supplier of detector systems
  - Primarily HPGe (and Silicon) - Supplies AGATA detectors
  - Strong research interest
  - Current co-funder in Liv.Inno

- Kromek
  - Manufacturer and supplier of detector systems
  - Primarily CZT
  - Strong presence in security + medical

- National Nuclear Laboratory
  - Sellafield facilities

Facilities

Nuclear physics and environmental monitoring laboratory (OLL 2nd Floor)

- Detector operation and study
  - Analogue and digital read outs - Mostly HPGe and CZT, some silicon and scintillator
  - Gamma Imaging (medical imaging – breast cancer detection, nuclear decommissioning, nuclear safeguarding)
  - Large volume HPGe: AGATA + SIGMA (next generation segmented HPGe detector)
- Alpha and gamma spectroscopy teaching set ups
- Environmental Radioactivity Research Centre
  - Radiometric dating - natural (^{210}Pb) and artificial (^{137}Cs, ^{241}Am)

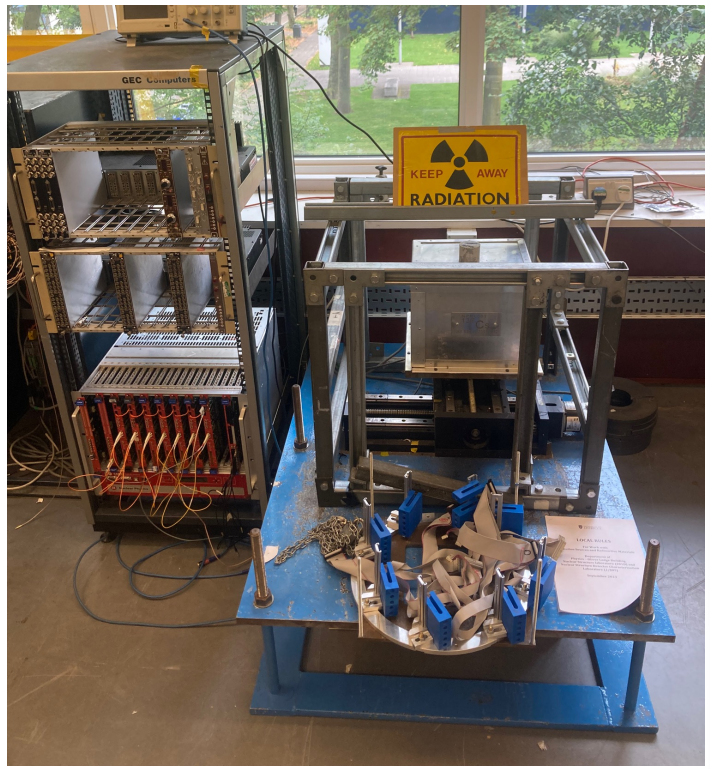
Facilities

Detector characterization laboratory (OLL 2nd Floor) – previously Environmental Radioactivity Research Centre

- Just moved into the lab! Not yet set up…
- High activity collimated gamma sources – range of energies
- Scanning systems (1 functional, 2nd being commissioned -> double characterisation capacity)

Specialised techniques that allow characterisation of detector response to gammas as a function of interaction position in three dimensions

- One of only a few facilities capable of these measurements
- Work closely with Mirion on detector characterisation

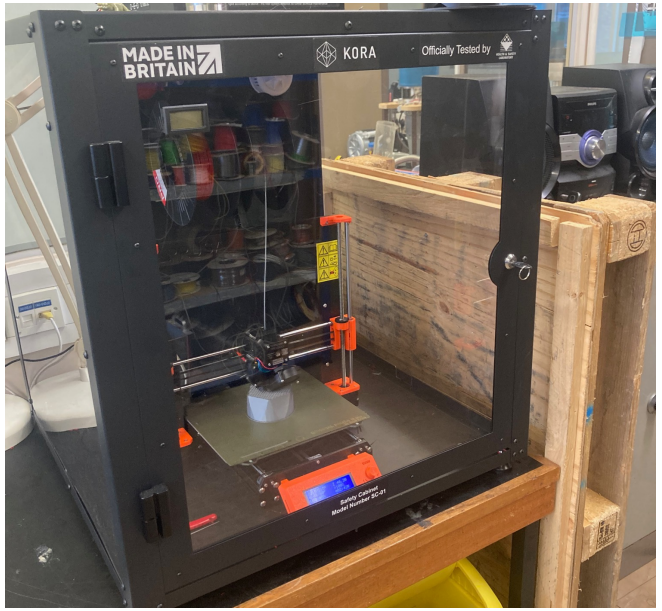


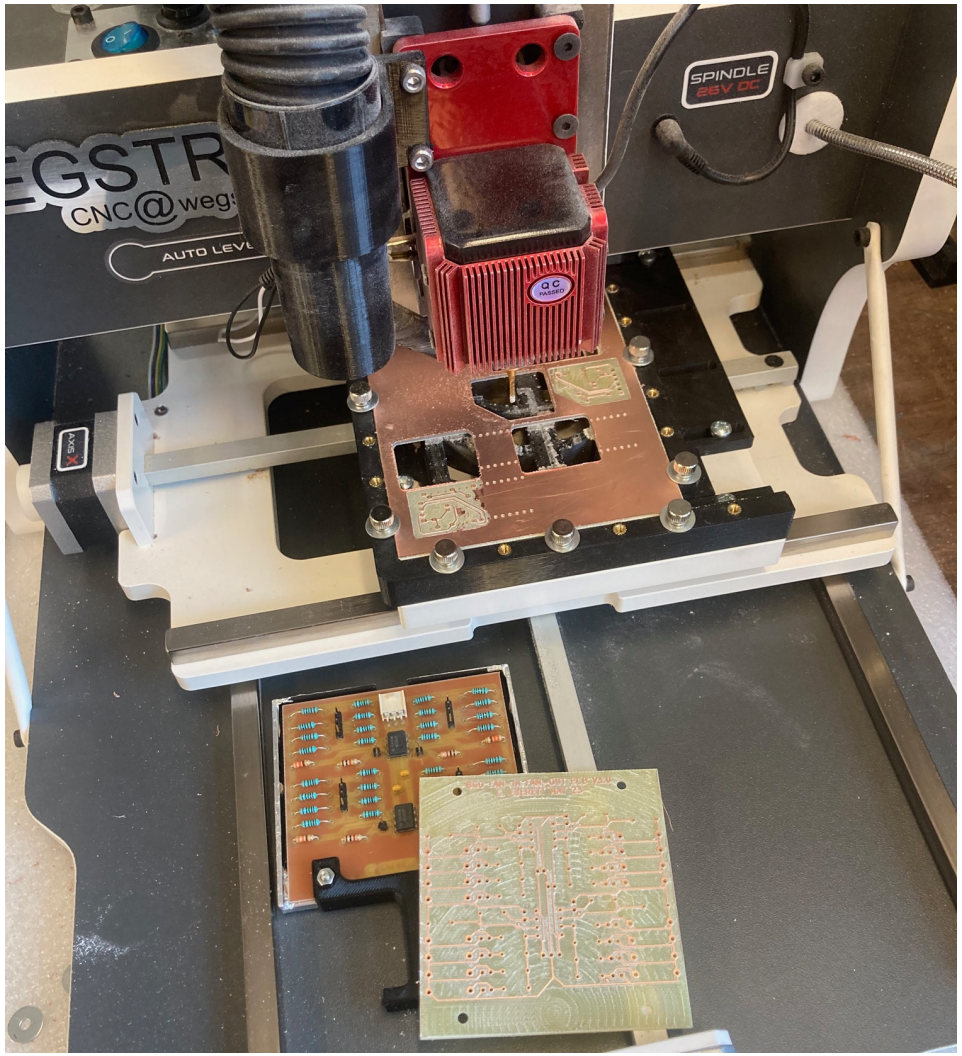
Facilities

Electronics Workshop (OLL 2nd Floor)

- Technical and electronics support for nuclear physics
  - 3D printing
  - Vacuum capabilities
  - PCB Milling
  - Environmental chamber (in development)
- Rapid prototyping

Dedicated technical support staff





High performance computing

Machine Learning (GPU-accelerated) computers

High performance PCs for simulation and machine learning algorithms

- 2x NVIDIA A6000 GPU – Shared Cluster Resource
- 2x RTX 5000
- 2x Nvidia Quatro P5000

NVIDIA Omniverse Platform

COMSOL License – Semiconductor packages

Funding Sources

Research Grants

- STFC Consolidated grant
  - Nuclear Structure + Relativistic Heavy Ions
  - 3 Year Rolling Grant: Sep 21 - Sep 24
- STFC: AGATA
- STFC: Medical Physics + CZT
- STFC: Large Volume HPGe Detectors (SIGMA)

Almost entirely STFC

Studentships a mix: STFC, EPSRC, Industry, Externally/government funded

7 new students this year: 3 Government funded, 1 Industry funded, 3 STFC

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Cluster talk:
Nuclear Physics

Any questions?

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