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PHYSICS DEPARTMENT RESEARCH

Prof Tim Veal, Head of Department of Physics

Research slides prepared by Prof Monica D'Onofrio,
Head of Research & Impact, DHoD, Physics

29/10/2025, PDRA meeting

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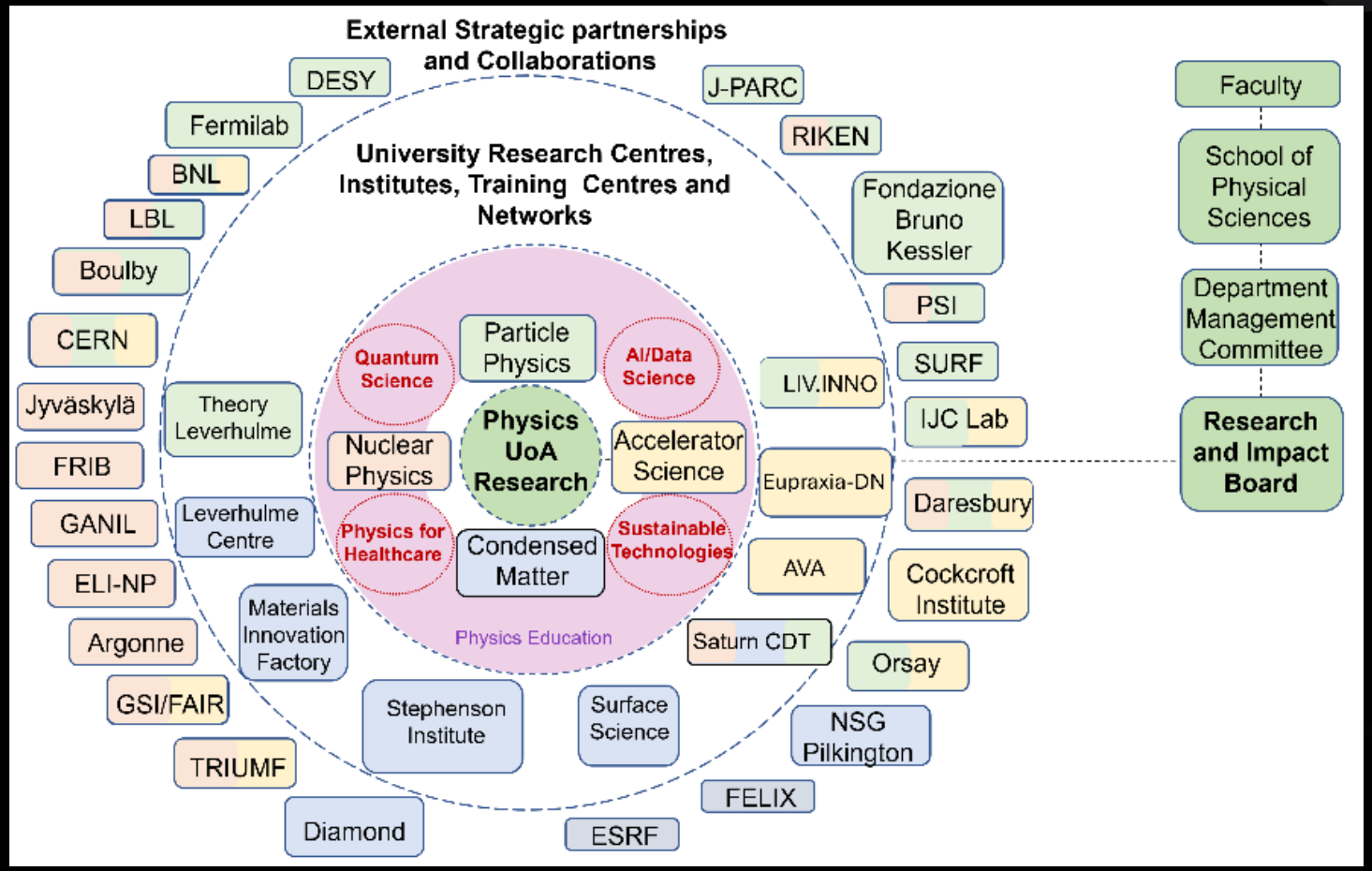
Research in the Department at a glance



>55 academic staff and fellowship holders
>100 research staff, including PDRA, engineers and technicians

- **Research clusters:** Particle Physics, Nuclear Physics, Accelerator Science, Condensed Matter.
- Physics Education overarching (Research and Enhancement)
- Research in **AI/data science, quantum, sustainable technologies, medical physics** underpinned by all clusters

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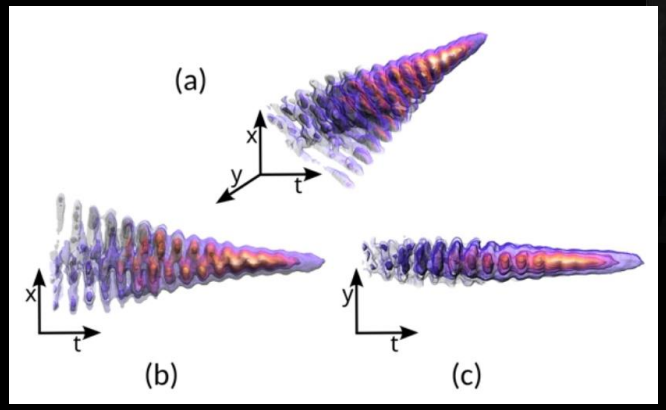
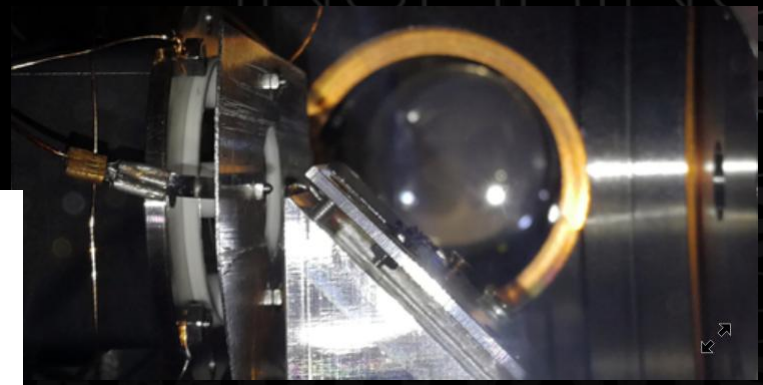
Accelerator Science

*Across Physics and Engineering key member of the **Cockcroft Institute (CI)***
5 academic staff, around 20 research staff, ~ 30 PhD and EC fellows

- *Frontier accelerators:* HL-LHC upgrade, exploitation of CLARA and RUEDI facilities ot Daresbury, ERL technology e.g. for PERLE and EIC, low energy antimatter experiments
- *novel accelerating techniques:* AWAKE experiment at CERN, micro-accelerators
- *training and communication:* EuPRAXIA consortium
- *accelerator applications:* beam and dose monitors for ion beam cancer therapy, 3D imaging systems, sensors for health tracking and memory restoration, and quantum technologies for accelerator applications.

Tackling Instabilities in a plasma wakefield accelerator PRL



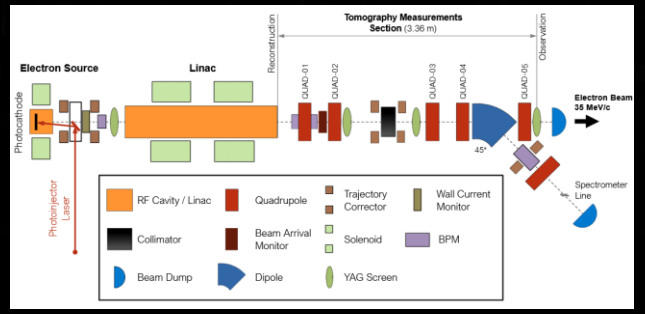


AEgIS experiment at CERN
LASER cooling positronium PRL
(AEgIS Physics Coordinator from Liv)

Methodology demonstrated at CLARA

Accelerator beam phase space tomography using machine learning to account for variations in beamline components

A. Wolski[a,c,*] D. Botelho,[a,c] D. Dunning[b,c] and A.E. Pollard[b,c]



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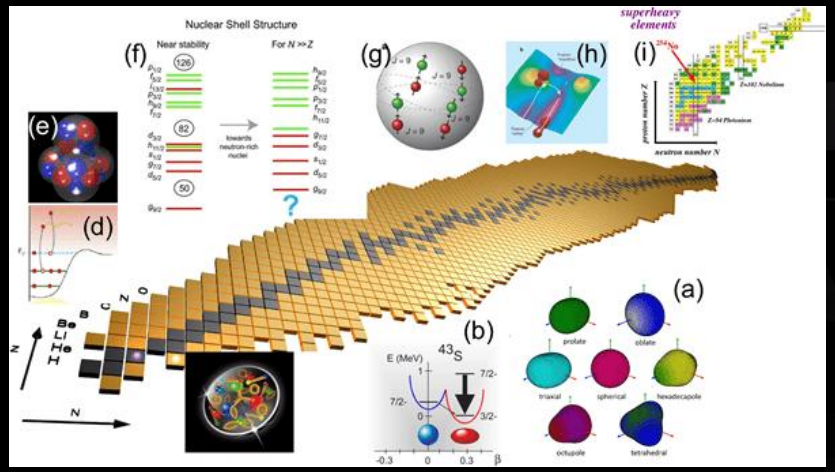
Nuclear Physics

10 academics, about 20 research staff, engineers, technicians and PDRAs, and 30 PhD students, also in close collaboration with Daresbury

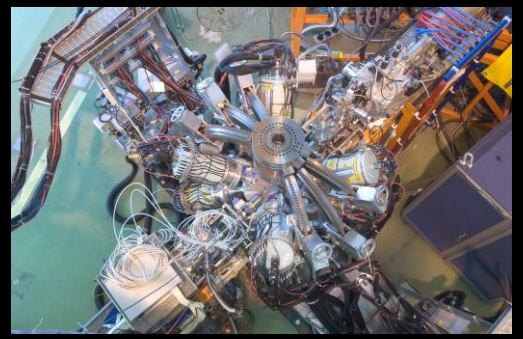
- *study of nuclear structure:* high spin atoms with AGATA, atom shapes, proton dripline, ground state properties, superheavy structure and chemistry, single particle structure and octupoles
- *applied physics and instrumentation* development of gamma ray imaging techniques, medical imaging techniques, phantoms, medical diagnostics, advanced detector concepts and materials and gamma ray tracking
- *hadron physics* study the quark-gluon plasma at ALICE experiment at CERN, future facilities such as the Electron-Ion Collider (EIC) in the USA.
- Recent addition: nuclear decommissioning with Engineering.
- Cross-collaborations with Particle Physics: LEGEND, Mu2e, EIC

NP CG: £4 M over 3 years

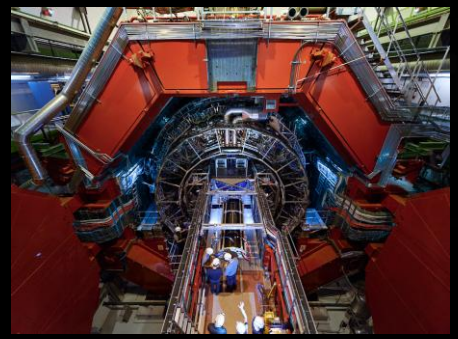


recent highlights include signing of MoU with Sizewell C

https://www.liverpool.ac.uk/physics/news/articles/university-partners-with-sizewell-c/



ISOLDE@CERN



ALICE@CERN

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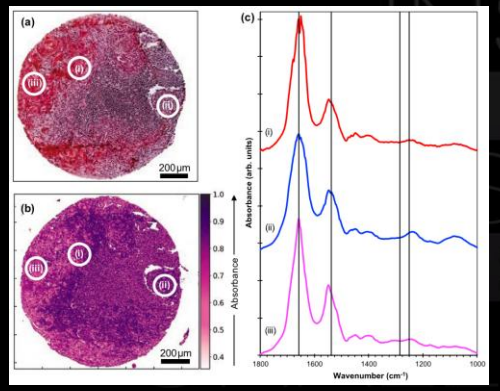
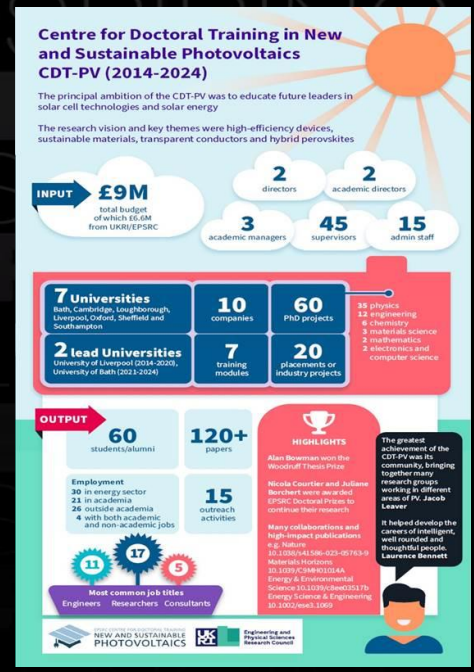
Condensed Matter Physics

12 academics, 8 research staff and 12 PhD students
Key members in Stephenson Institute For Renewable Energy

- *Nanoscience:* surface physics, spintronics, electrochemical interfaces, hybrid nanomaterials, functional materials
- *Energy:* targeting reduction of CO_2 emissions, includes solar fuels, solar photovoltaic materials and devices, materials for thermoelectric and physics of advanced sustainable materials for energy applications
- *Biophysics:* new tools for cancer diagnostics, advanced investigations of tissue structure and function and image analysis for medical, biological, and other application
- *Reactions at ultra-cold temperatures, i.e.* new detection methods for monitoring trapped ions, study quantum effects in reactions at low T

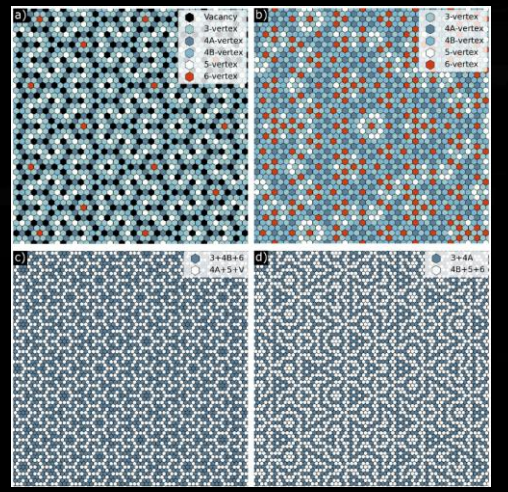


IR and ML studies of cancer



Photovoltaics CDT

XMaS facility at Grenoble new funding £9M over 5 years, half to UoL



Hexagonal quasiperiodic tilings

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Physics Education Research and Enhancement

3 academics and 2 PhD students

- → Studies how students learn physics
- → Understand how teaching practices affect outcomes

- AI and ML role is crucial in much of this research, as its role is crucial in education nowadays!

- E.g. analyse socio-demographic disparities in degree outcomes

Data Dialogue with ChatGPT: Using Code Interpreter to Simulate and Analyse Experimental Data

Andrew Low[1] and Z. Yasemin Kalender[1]

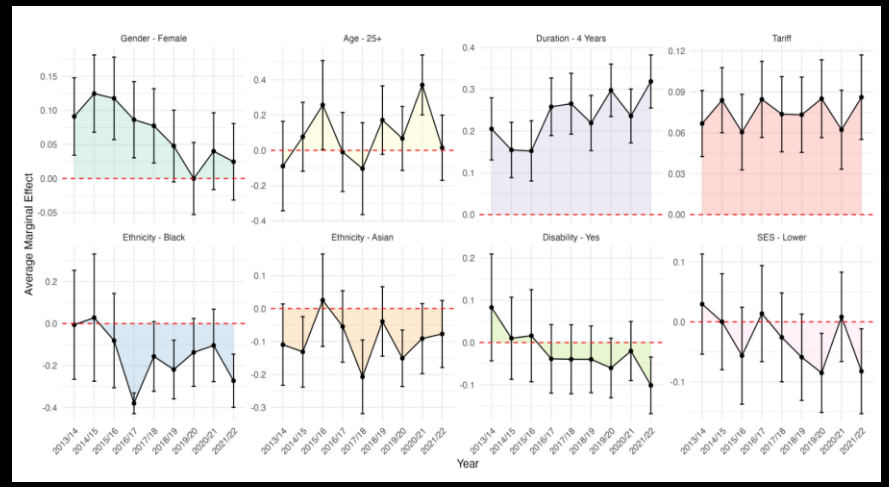
[1] *Department of Physics, University of Liverpool, Liverpool, UK, L69 7ZE*

Artificial Intelligence (AI) has the potential to fundamentally change the educational landscape. Chatbot's such as ChatGPT allow users to engage in conversations that mimic human interactions. So far, much of the physics education research relating to AI has focused on lecture-based assessment and the ability of ChatGPT to answer conceptual surveys and traditional exam-style questions. In this study, we shift the focus by investigating ChatGPT's ability to complete an introductory mechanics laboratory activity by using Code Interpreter, a recent plugin that allows users to generate and analyse data by writing and running Python code 'behind the scenes'. By uploading a common 'spring constant' lab activity using Code Interpreter, we investigate the ability of ChatGPT to interpret the activity, generate realistic model data, produce a line-fit, and calculate the reduced chi square statistic. By analysing our interactions with ChatGPT, along with the Python code generated by Code Interpreter, we assess how the quality and accuracy of ChatGPT's responses depends on different levels of prompt detail. We find that although ChatGPT is capable of completing the lab activity and generating plausible-looking data, the quality of the output is highly dependent on the detail and specificity of the text prompts provided. We find that the data generation process adopted by ChatGPT in this study leads to heteroscedasticity in the simulated data, which may be difficult for novice learners to spot. We also find that when *real* experimental data is uploaded via Code Interpreter, ChatGPT is capable of correctly plotting and fitting the data, calculating the spring constant and associated uncertainty, and calculating the reduced chi square statistic. This work offers new insights into the capabilities of Code Interpreter within a laboratory setting and highlights a variety of text-prompt strategies for the effective use of Code Interpreter in a lab context.

Predictors and Socio-Demographic Disparities in STEM Degree Outcomes: A UK Longitudinal Study using Hierarchical Logistic Regression

Andrew Low and Yasemin Kalender
Department of Physics, University of Liverpool
(Dated: November 5, 2024)

Socio-demographic disparities in STEM degree outcomes impact the diversity of the UK's future workforce, particularly in fields essential for innovation and growth. Despite the importance of institution-level, longitudinal analyses in understanding degree awarding gaps, detailed multivariate and hierarchical analyses remain limited within the UK context. This study addresses this gap by using a multivariate binary logistic model with random intercepts for STEM subjects to analyse predictors of first-class degree outcomes using a nine-year dataset (2013/14 to 2021/22) from a research-intensive Russell Group university. We find that prior academic attainment, ethnicity, gender, socioeconomic status, disability, age, and course duration are significant predictors of achieving a first-class degree, with Average Marginal Effects calculated to provide insight into probability differences across these groups. Key findings reveal that Black students face a significantly lower likelihood of achieving first-class degrees compared to White students, with an average 16% lower probability, while students graduating from 4-year degree programmes have an average 24% higher probability of achieving a first-class degree relative to those on 3-year programmes. Although male students received a higher proportion of first-class degrees overall, our multivariate hierarchical model shows higher odds for female students, underscoring the importance of model choice when quantifying awarding gaps. Baseline odds for first-class outcomes rose considerably from 2015/16, peaking in 2020/21, indicating possible grade inflation during the COVID-19 pandemic. Interaction effects between socio-demographic variables and graduation year indicate stability in ethnicity, disability, and socioeconomic awarding gaps but reveal a declining advantage for female students over time. These findings contribute to the literature and provide a transferable, evidence-based framework for departments and institutions to monitor awarding gaps, helping to guide the development of targeted, equity-driven policies that support a diverse and inclusive STEM workforce in the UK.



Outputs directly feeding into teaching practice!

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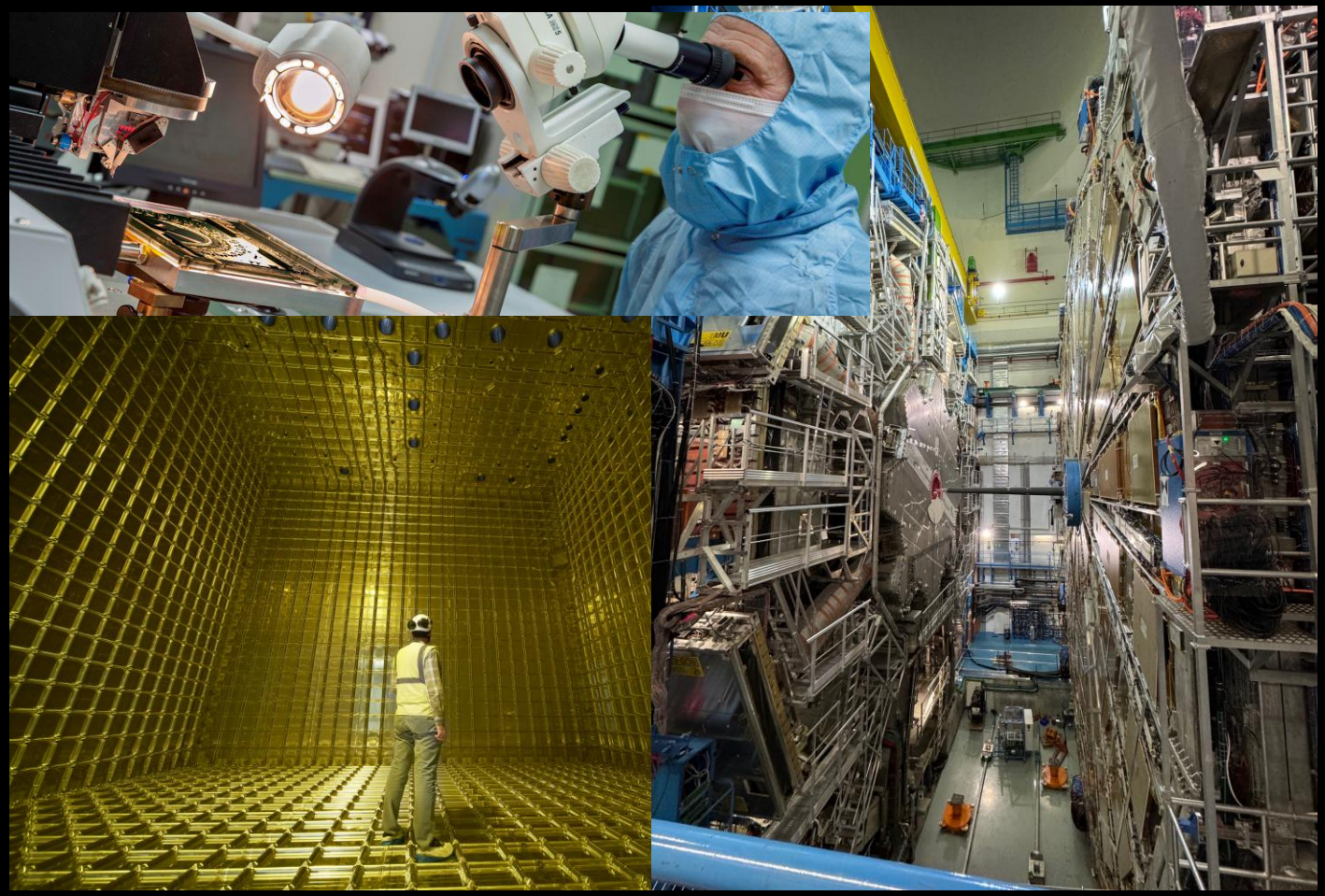
Particle Physics



Research income > £8.5M/yr
>850 publications 2018-23
International leadership
USP: One stop technology conception to new science realization
29 academics and fellows
41 researchers
25 engineers/technicians/support
60 PGR students

Wide range of international experiments and partners…..

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Boulby Laboratory
Neutrinos

Liverpool
Liquid argon R&D
Silicon R&D
Computing R&D

CERN
LHC experiments
Muons
Neutrinos

Paul Scherrer Lab.
Muons

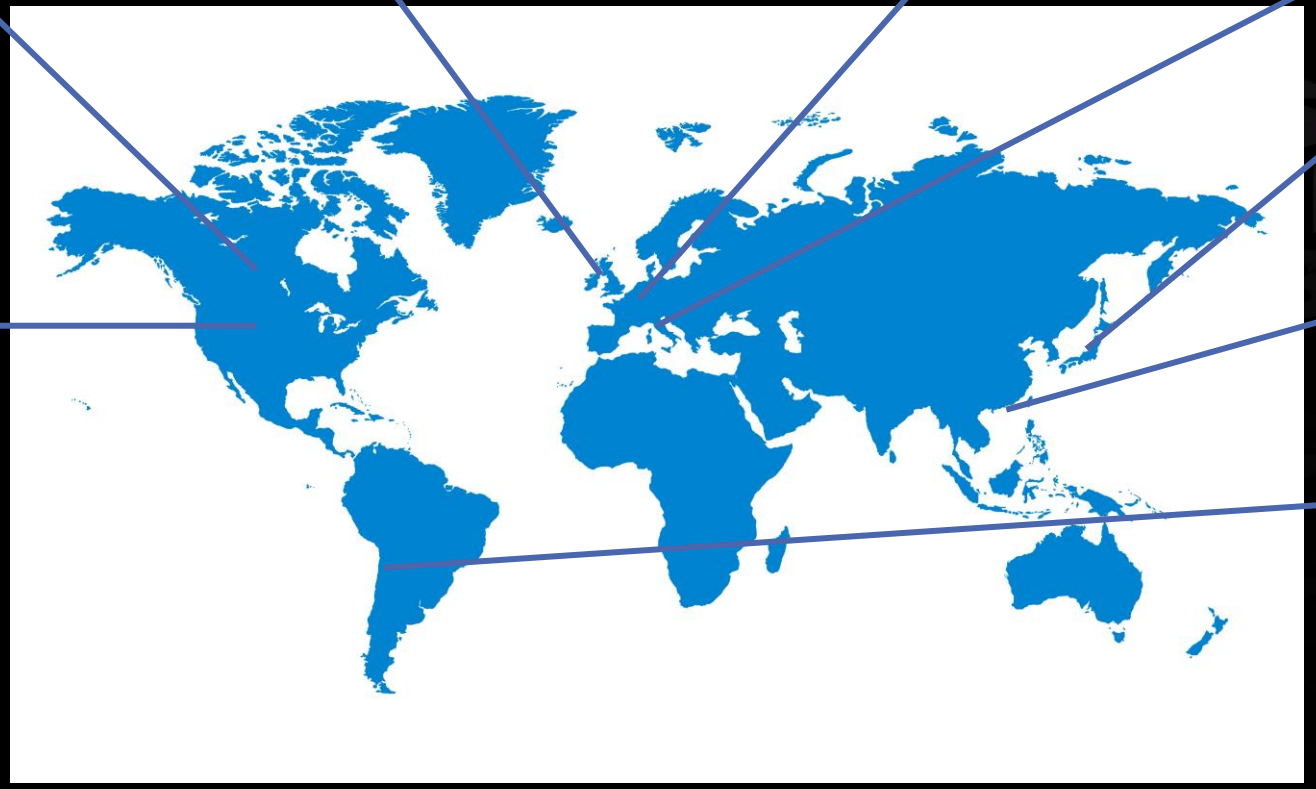
SNOLab
Neutrinos

Gran Sasso
Dark matter
Neutrinos

Brookhaven
Protons

Fermilab
Muons, protons
Neutrinos
Quantum interferometry

SURFLab
Dark matter



J-PARC
Neutrinos

JUNO
Neutrinos

Paranal
Dark matter

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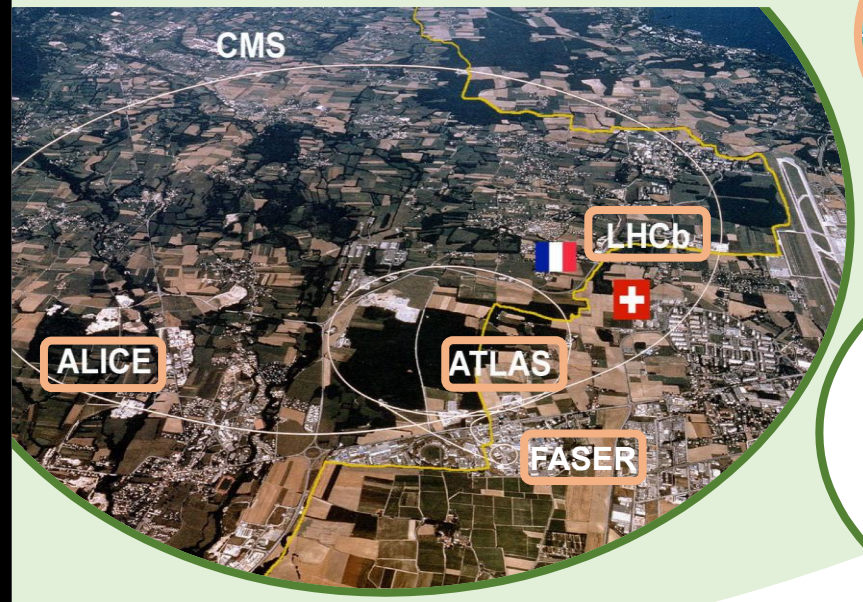
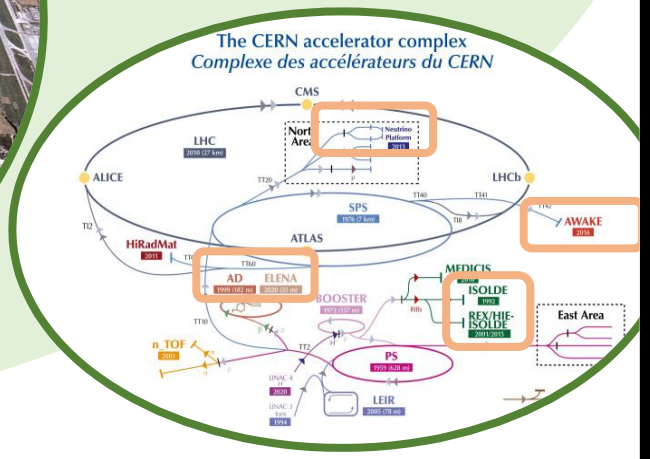
Liverpool @ CERN



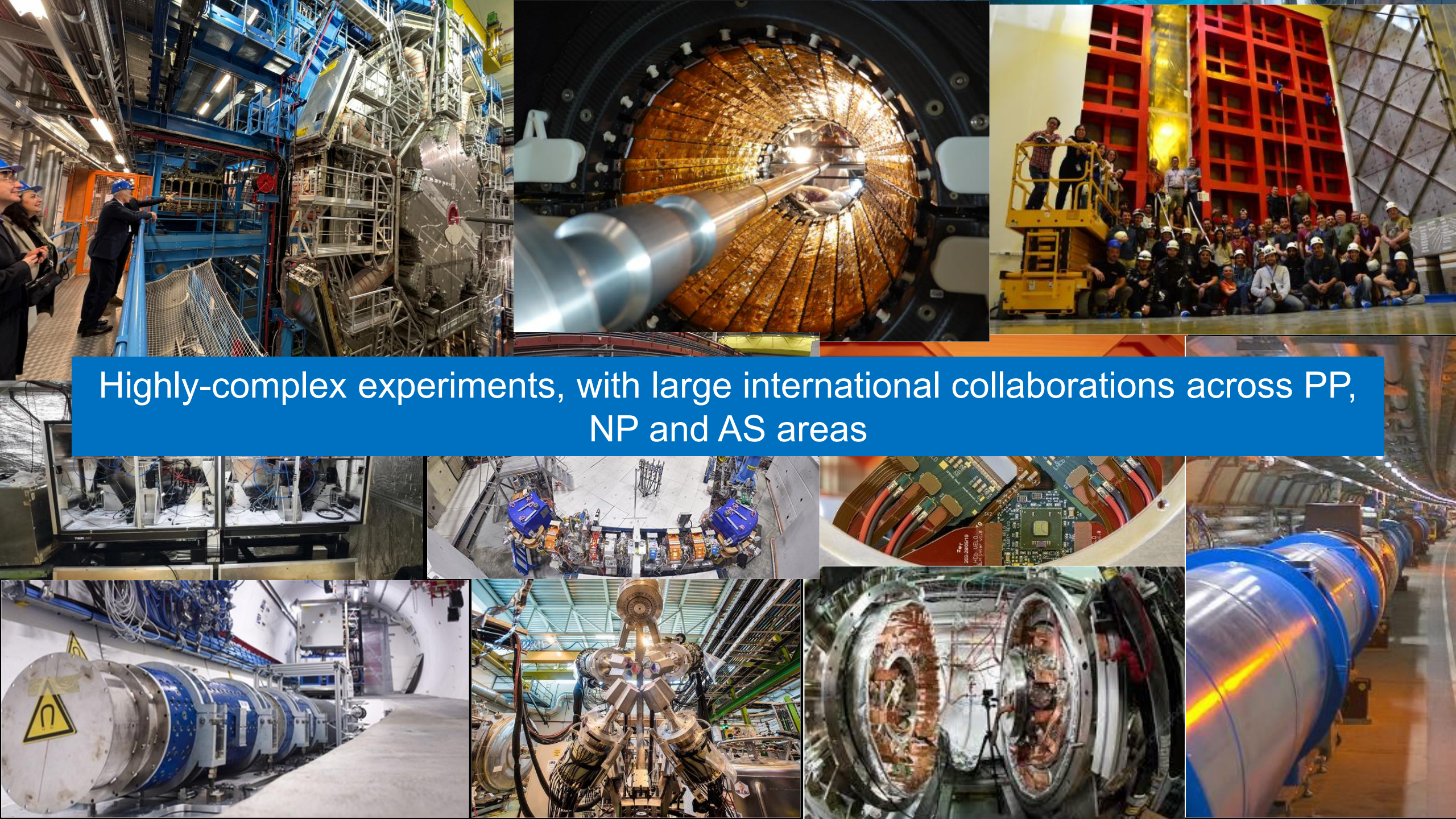


The Department of Physics is in the **top-25** list of CERN key collaborators.

- Build, upgrade, maintain, operate and exploit facilities and experiments in particle physics (**ATLAS, FASER, LHCb, neutrino platform DUNE/Ariadne, MUoNE**), nuclear physics (**ALICE, ISOLDE**) and accelerator physics (**AWAKE, AEGiS, ELENA, HL-LHC, FCC**)

- **~75%** of academic staff, researchers, engineers and technicians are engaged in CERN-related activities

We are engaged in several activities with CERN in **R&D** of new detectors, green technologies, large-scale data and AI, future facilities and more → **develop impact as an integral outcome of our research programme**



Highly-complex experiments, with large international collaborations across PP, NP and AS areas

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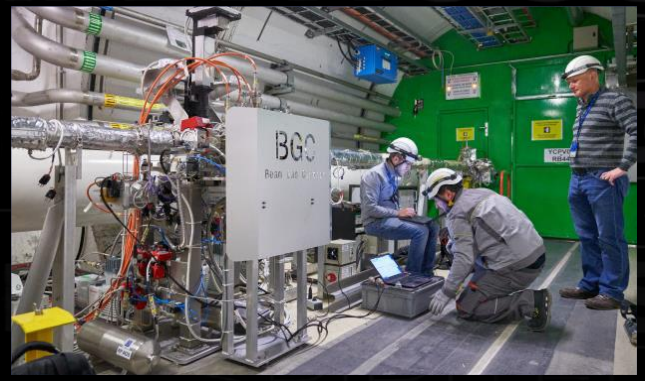
Beyond CERN: strategic partnerships

Liverpool, and CERN itself, is also a global partner of international and national labs

- Notable **international examples** are DESY and PSI in Europe, Fermilab, Brookhaven and Argonne in US, TRIUMF in Canada, RIKEN and J-PARC in Japan (we are also member of URA)
- National facilities include strong links and common activities with **Daresbury (silicon detectors, accelerator science)** as well as Boulby, NNL, NDA and Sellafield



- **Detector Research & Development**: i.e. gamma-ray and neutron sensors → waste storage monitoring, security, environmental gamma-ray imaging

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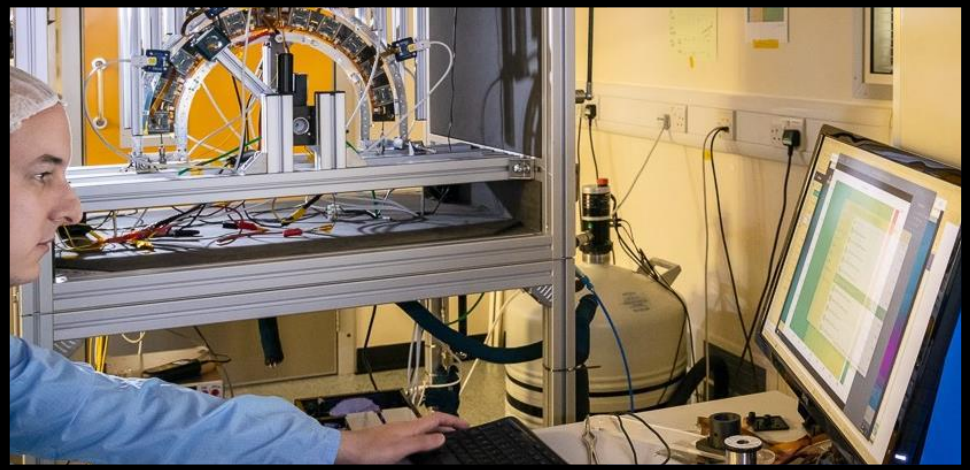
Local Laboratories and facilities

Longstanding and world-leading track record for the **development of detector technologies** and the construction of complex detector systems (silicon, liquid argon and germanium detectors, quantum sensors).

→ excellent local facilities



Liverpool Semiconductor Detector Centre

Detector Development Manufacturing Facility and Advanced Material lab

Nuclear Lab Detector Characterization Centre

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Across-area activities

Four research themes of common interest:

- **Quantum**
- **Data science and AI**
- **Medical physics**
- **Sustainability**

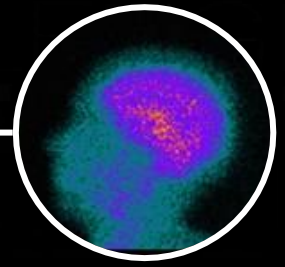
Underpinning all our research – something you could engage with too!

Quantum

AI & Data science

Sustainable technologies

Medical physics



Quantum - TEAM: Brianna Heazelwood and Gianluigi Casse
AI/Data Science – TEAM: Monica D'Onofrio and Carsten Welsch
Medical Physics – TEAM: Tim Greenshaw and James Ingham
Sustainable Technologies – TEAM: Ellis Rintoul and Jon Major

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Across-area activities

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Underpinning all our research – something you could engage with too!

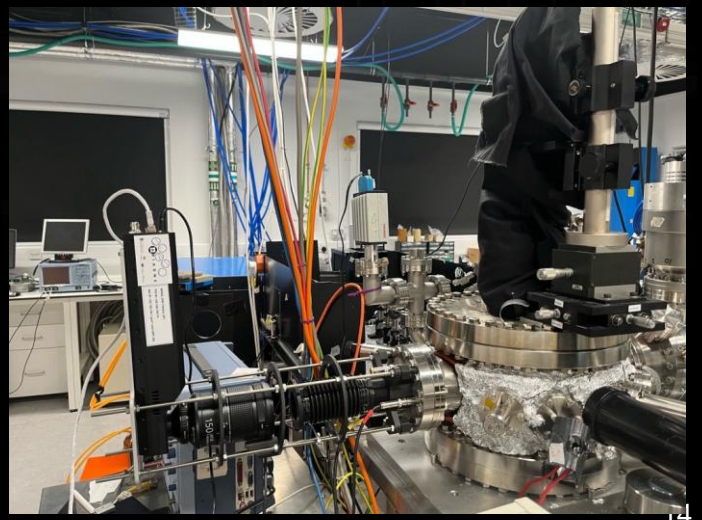
Strong programme already in place for **atom interferometry** (AION, Magis) and other QTFP consortia

Engagement with CERN: member of DRD5 Quantum collaboration

- Quantum science is an integral part of our research programme since more than a decade, with a strong focus on enabling novel fundamental physics experiments

Liverpool PP Laser laboratory, one of the few existing UK lab with in-house capability to develop **atom interferometry** devices

Cold chemical physics lab: study complex ion-neutral reaction systems at low temperature (cryogenic ion-trap)



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Across-area activities

Four research themes of common interest:

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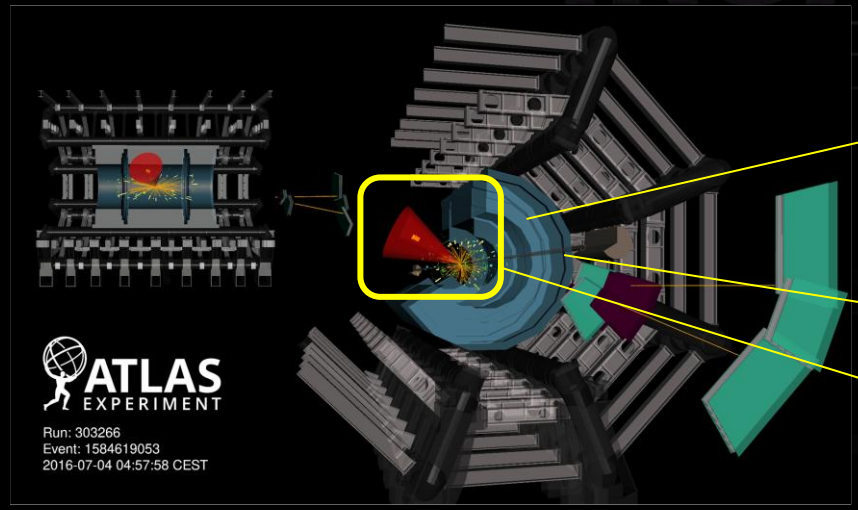
Underpinning all our research – something you could engage with too!

Accelerator Science: design, optimization and control systems of particle accelerators

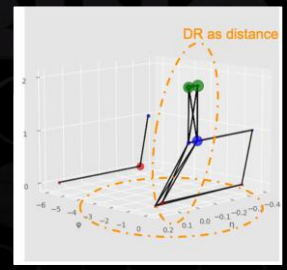
+ industry partnerships (NVIDIA, IBM), and AI applied to medical physics

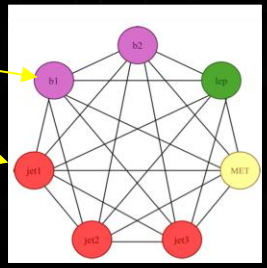
Examples in PP –

ATLAS offline data analyses: problem to be addressed → **event classification** and **process discrimination** in large and diverse datasets for discovery



or





LHCb, mu3e data reconstruction: problem to be addressed → fast and efficient reconstruction of tracks (e.g. in busy environment). ***How-to:*** ML-tracking on FPGAs algorithms

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Across-area activities

Four research themes of common interest:

- Quantum
- Data science and AI
- **Medical physics**
- Sustainability

Underpinning all our research – something you could engage with too!

PROTON THERAPY →
advanced tissue-equivalent phantom for improved accuracy in therapy planning

Lot of what we do can be relevant for healthcare

Cancer research: a decade of research on cancer by a dedicated research group within our department has resulted in the ability to predict the *prognosis* of oral cancer lesions by analysing infrared spectral images using machine learning. Patent on machine learning algorithm.

How the device works…

But also:

- Beam monitoring & diagnostic (e.g. for LhAra)
- Applications of gamma-ray imaging etc…

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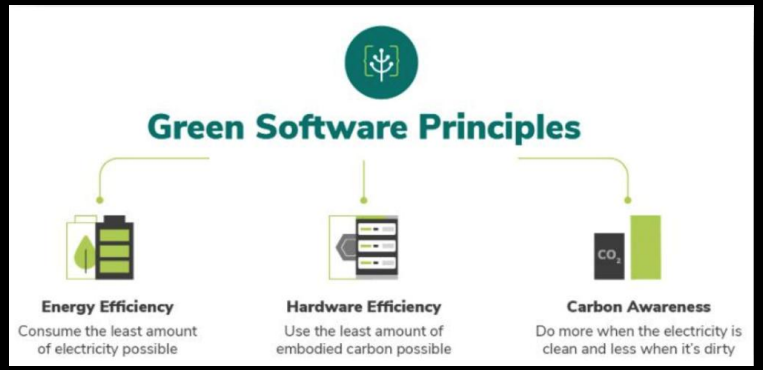
Across-area activities

Four research themes of common interest:

- Quantum
- Data science and AI
- Medical physics
- **Sustainability**

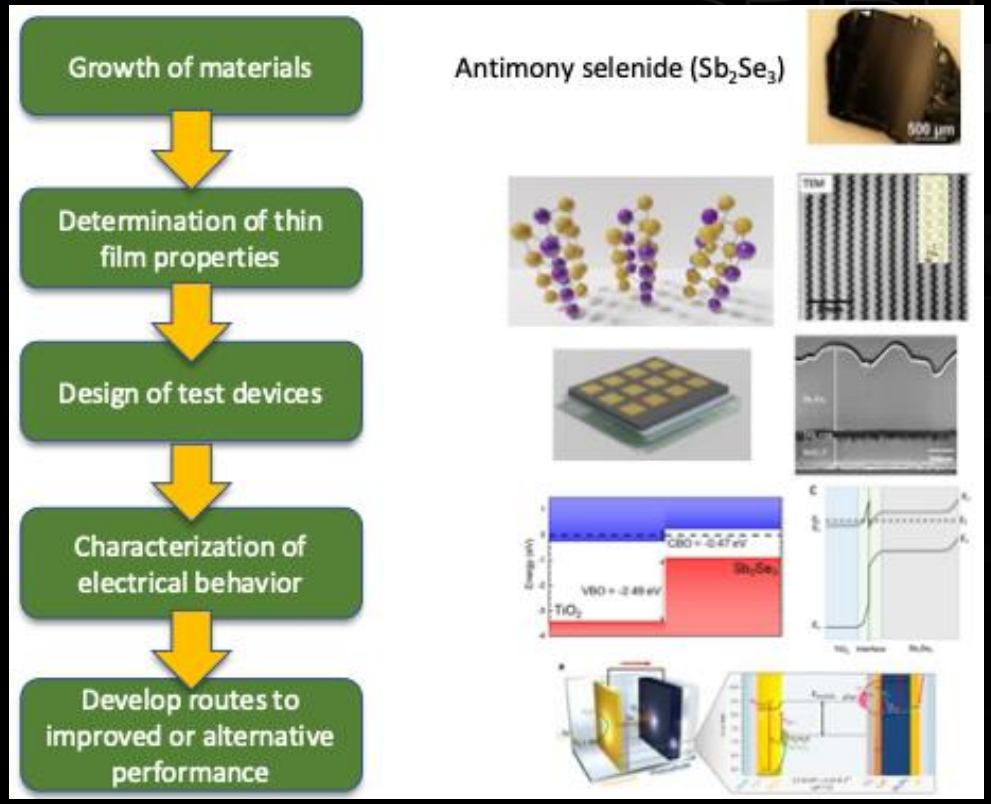
Underpinning all our research – something you could engage with too!

e.g. computing: can you help writing software that reduces Carbon footprint?



Sustainable technologies are at the core of several of our research – e.g. energy

Solar cell Devices research



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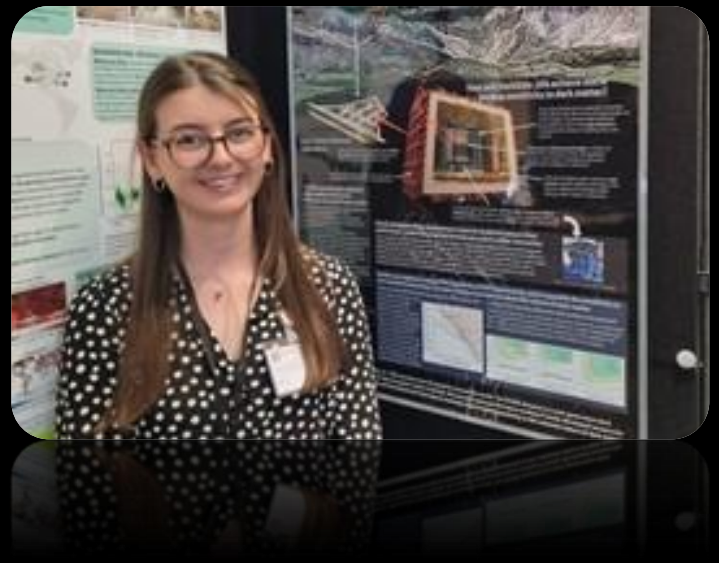
Opportunities and support

- **Courses and trainings for research:**
  - Nature Masterclasses https://libguides.liverpool.ac.uk/nature_masterclasses
    - On demand resources for designing research, Writing and Publishing, Grant-writing, Impact and Collaboration
  - Narrative output framework: https://staff.liverpool.ac.uk/research/research-funding-and-outputs-hub/outputs/
  - Consult events from The Academy (also for industry trainings)
  - Research and impact corner in bulletin - are people reading those?
    - Consult also department internal sharepoint site: Physics
- **Seminars:** not always aligned directly to your research, but widening horizons
  - Reviving departmental seminars;
  - Research clusters are encouraged to enhance their seminar programmes
- **PDRA induction:** Dedicated physics PDRA induction process and information for PDRAs is currently being created

Regular celebrations of PDRA success in Physics Bulletin, Web News and Staff Meetings



Dr Ellen Sandford awarded the John G Rutherglen Memorial Prize for outstanding work in experimental High Energy Physics

Dr Jordy Degens appointed convener of the 30-strong *tau Reco and ID group*, the team that is responsible for the tau lepton identification in the ATLAS experiment.

Dr John Anders appointed as the convener of the ATLAS "Strong" search group, the 100-person team searching for superpartners of the strongly-interacting SM particles, gluinos and squarks

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Regular celebrations of PDRA success

Dr Benjamin Rienacker becomes Physics Coordinator of the AEgIS anti-matter experiment at CERN, with its 50-person strong team.

Dr Saskia Charity awarded prestigious 5-year Ernest Rutherford fellowship for research with the g-2 and MUonE experiments about the muon anomalous magnetic moment.

Dr Jaime Norman awarded prestigious 5-year Ernest Rutherford fellowship to investigate the quark-gluon plasma at the ALICE experiment at CERN.