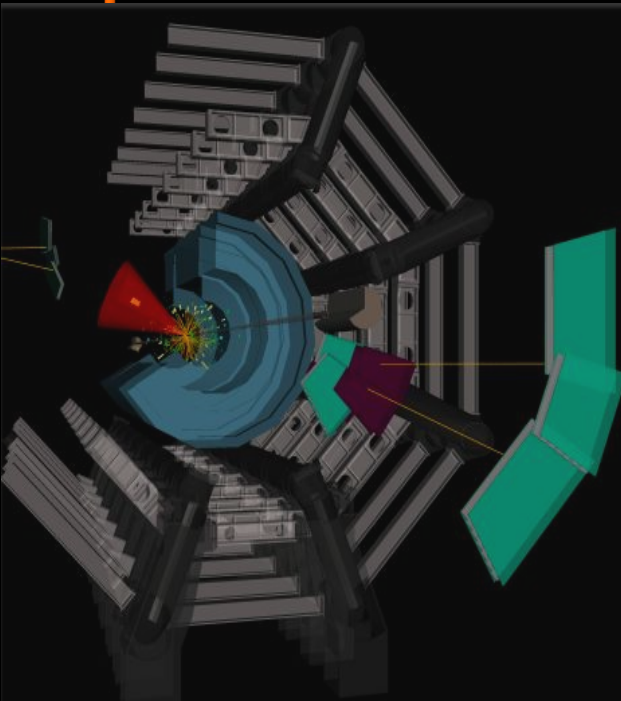


Liverpool Particle Physics

Research programme and facilities

Monica D'Onofrio



Who am I

<https://www.liverpool.ac.uk/people/monica-donofrio>

- Experimental particle physicist and Professor at the UoL Physics Department
- Deputy Head of Department, Head of Research at Liverpool and coordinator of Research Excellence Framework for Physics
- Team Leader of the FASER group at Liverpool (and chair of the Collaboration Board), former ATLAS TL, and UK national PI for both experiments
- I teach Dark Matter for Year 4 students (and was module lead for quantum mechanics for 10 yrs)

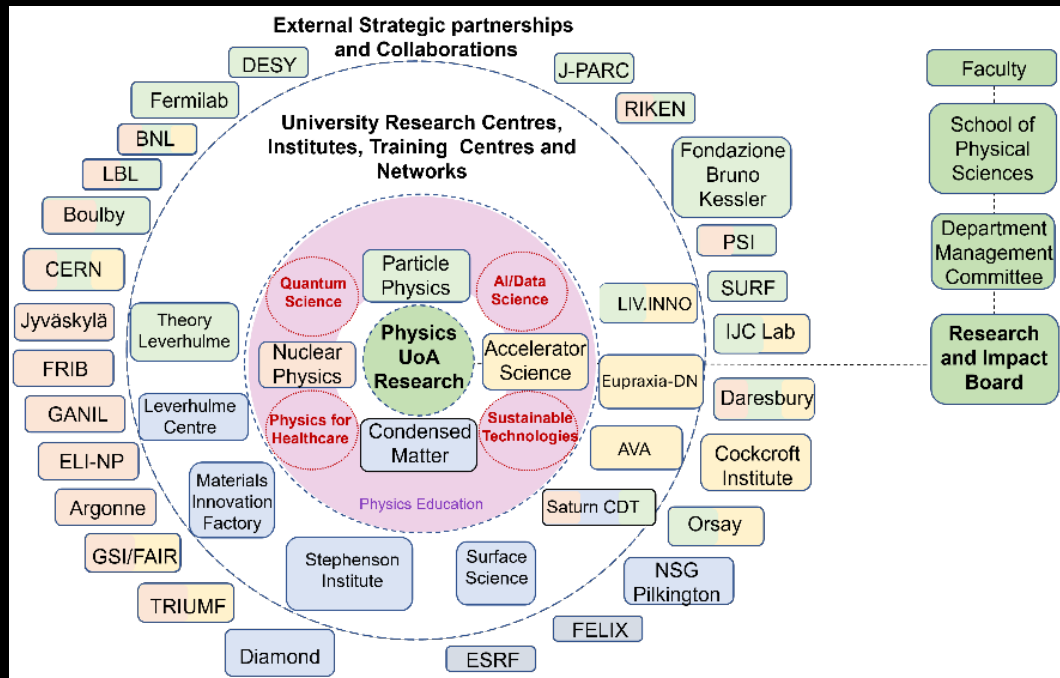


During my career, I have worked mostly on collider experiments (ATLAS, FASER, and CDF at Fermilab in the past). My main interests are on **searches for new physics** (supersymmetry, dark matter, dark sectors) also using AI tools. I also work on future experiments planned at CERN and beyond and I member of various committees and panels

The Department of Physics @ UoL

PARTICLE
PHYSICS
FUNDAMENTAL
SCIENCE
ENGINEERING
IMPACT
PHENOMENOLOGY

- **Research clusters:** Particle Physics, Nuclear Physics, Accelerator Science, Condensed Matter.
- Physics Education overarching (Research and Enhancement)



- **~55 academics** (2 joint with other departments)
- more than **100 full time research** and computer physicists, professional, technical and electronic support staff
- About **120 PhD students** enrolled in our programmes (STFC CDT on Big Data Science (LIV.DAT), Innovation in Data Intensive Science (LIV.INNO), EPSRC CDT's on New and Sustainable Photovoltaics and Risk & Uncertainty, and EU ITN on Medical Accelerators and Antimatter Physics).



Images courtesy of: Liverpool Semiconductor Detector Centre | ALICE at CERN | XMAS based at ESRF | Department of Physics

PhD applications and funding

To apply for a PhD, it is usually expected that you have a MPhys with a 1st or 2:1 or an MSC.

We have several **fully funded PhD positions**, covering both fees and stipend for usually 3.5 years. Our main funders are STFC and EPSRC. Some of the positions are under specific programmes, like the **Liverpool Centre for Doctoral Training for Innovation for Data Intensive Science (LIV.INNO)**. For LIV.INNO positions the funding is 4 years and they also include a 6-month industrial placement during the 4-year period.

Our research Clusters

Accelerator Physics



Accelerator physics at Liverpool carries out world-class research with particle accelerators and drives innovation in technologies that help boost the performance of accelerator-based research infrastructures. Our research is realized in close collaboration with our national and international partners, enhanced by the unique facilities at Daresbury Laboratory and the Cockcroft Institute, as well as our collaboration partners from around the world.

Our research activities include:

Antimatter research: investigating fundamental symmetries and interactions.

Frontier accelerators: collaborating with global research groups to design, build, and optimize world-class research infrastructures such as the LHC at CERN and its upgrade programmes, contributing expertise in beam instrumentation, accelerator design, and optimisation.

Novel accelerators: including plasma wakefield accelerators and ultra-compact accelerators-on-a-chip.

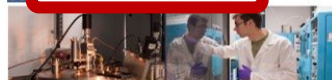
Accelerator applications: R&D into healthcare technologies and applies Data Science techniques to real-world challenges.

For more information, contact Dr Hao Zhang or visit

liverpool.ac.uk/quasar/ liverpool.ac.uk/physics/research/accelerator-physics/



Condensed Matter Physics



CMP at Liverpool embraces a wide range of physics that is aimed at making a positive impact on life, technology and innovation by developing both fundamental and applied understanding relevant to modern issues. 17 academics, 15 professional research staff and research associates, and 20 PhD students work in our five research themes:

Advanced Characterisation utilises X-rays (both at the XMAS beamline at Grenoble and in house) for X-ray diffraction, resonant X-ray scattering, grazing incidence measurements, spectroscopy and small angle scattering.

Advanced Materials includes research on Bio - and soft matter-printing, magnetic materials and structures, and quasicrystals and quasicrystalline media.

Chemical and Electrochemical Physics studies chemical physics of reaction dynamics as well as electrochemical interfaces.

Imaging and Medical Diagnostics use IR imaging in near and far-field to study biological specimens (particularly cancer biopsies).

Solar Energy Conversion research prepares and investigates new materials for both solar hydrogen and electricity production (solar cells).

For more information contact Dr Frank Jaeeck or visit

liverpool.ac.uk/physics/research/condensed-matter-physics/



liverpool.ac.uk/physics

THE ORIGINAL
REDBRICK

Nuclear Physics



Nuclear Physics at Liverpool encompasses many areas of research that range from enhancing fundamental understanding of the laws of physics by driving it to the extremes, to creating a positive impact on present issues such as medical treatment and preservation of the environment.

Our fundamental science aims to understand how nuclei can support the highest values of angular momentum; how single-particle and collective structure of nuclei evolve near the drip lines; the phenomenon of reflection asymmetry and shape coexistence in nuclei; the behaviour of the heaviest nuclei; and the phase equilibria of hadronic matter at extreme energy densities.

We perform our research at accelerator laboratories around the world, including those in Canada, Finland, Germany, Italy, Switzerland (CERN) and the USA. In many cases it exploits instrumentation that we have developed, such as **AGATA**, **ALICE** and the **ISOLDE Solenoidal Spectrometer**. This expertise in developing novel instrumentation underpins our applied research through projects like **SIGMA** and **GRIT**.

For more information contact

Prof Robert Page or visit liverpool.ac.uk/nuclear-physics



Physics Education

The Physics Education cluster studies how students learn physics and how teaching practices affect outcomes. Comprising 4 academic staff and 1 PhD student, current research focuses on using machine learning to analyse socio-demographic disparities in degree outcomes, exploring AI's role in education, examining how institutional culture and psychology shape student identity and belonging, and developing inclusive public engagement experiences.

For more information contact Dr Andrew Low or visit

liverpool.ac.uk/physics/research/physics-education-research/



Particle Physics



Our particle physics cluster is one of the largest in the UK and we conduct research into a wide range of phenomena at facilities across the globe, including CERN, Fermilab, JPARC, Sandford, Kamioka and PSI. We specialise in physics analysis and the development and delivery of detectors. Our 23 academics, 64 research staff, and 37 PhD students work across areas including: The **ATLAS** experiment at the LHC played a leading role in the discover of the Higgs boson. We now deepen our understanding of the Higgs, search for new physics and develop detectors for the HL-LHC. This is complemented by the **FASER** experiment. **LHCb** studies the behaviour of B mesons and develops future trackers. We study **Neutrino** oscillations at T2K, **Hyper-Kamiokande**, **SND** and **DUNE**, and search for neutrinoless double beta decay with **LEGEND**. Our direct **Dark Matter** searches include **LZ** and **Darkside**, and applications of quantum technologies at **Magis** and **AION**. We make precision measurements of **Muon** properties like **g-2** and search for rare decays at **Mu2e** and **Mu3e**. Our research is underpinned by our long-standing expertise in development of new detectors including next generation silicon detectors and liquid argon time projection chambers.

For more information contact Prof Neil McCauley or visit liverpool.ac.uk/physics/research/particle-physics/



From our current PhD students

Sinead Eley (Particle Physics, LIV.INNO)

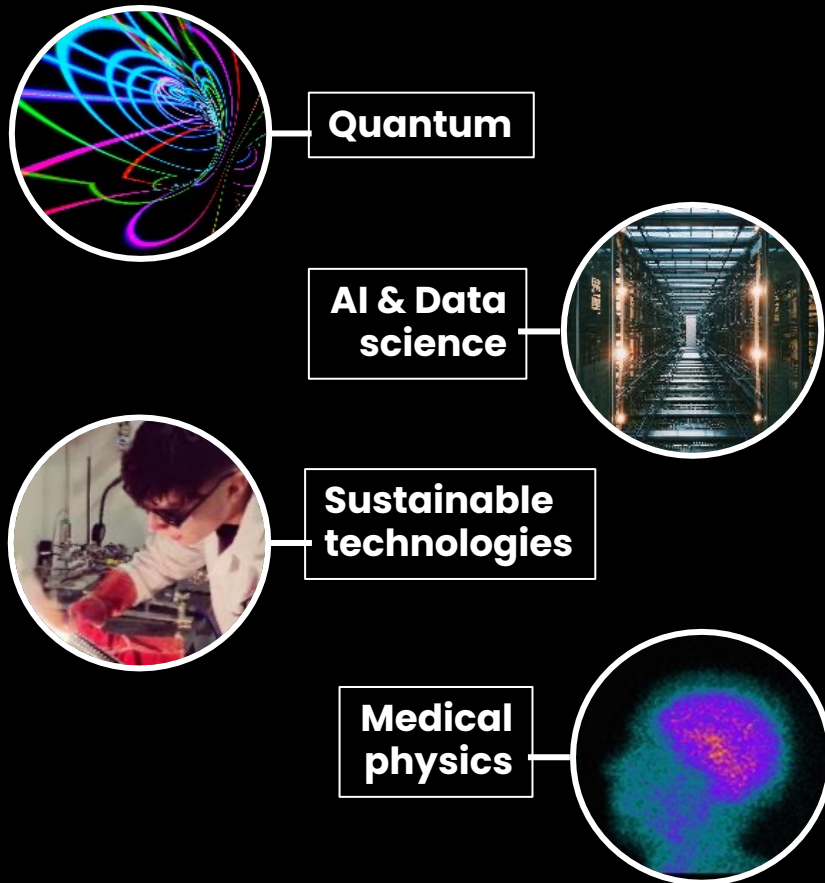
"I've just completed my first year of my PhD working on dark sector searches with the FASER detector. Having completed my undergraduate degree at Liverpool, I felt comfortable here and knew it was somewhere that I would be supported during my PhD. We have a strong community feeling here where everyone is welcoming and happy to have a chat. There have been countless opportunities during my first year, one that stands out is WONDRS, a conference specifically for gender minorities in STEM, this really helped to address the imposter syndrome many of us face as researchers."



liverpool.ac.uk/physics

THE ORIGINAL
REDBRICK

The Department of Physics @ UoL (2)

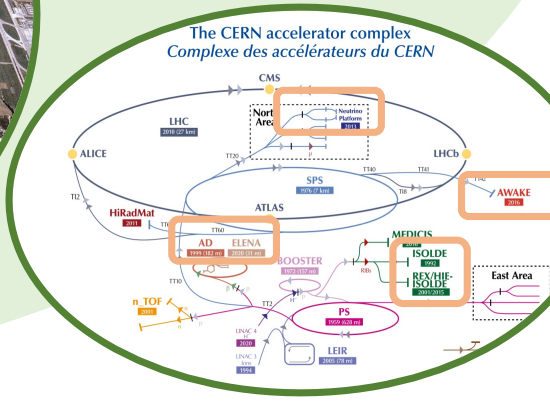
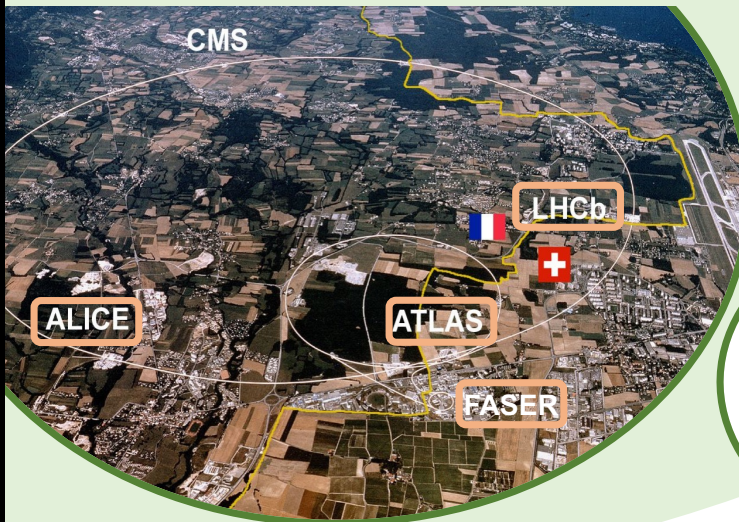


Research underpinned by all clusters in

- **AI/data science**: i.e. from particle physics data analysis to applications in healthcare
- **Quantum technologies** – sensors development
- **Sustainable technologies** - i.e. efficient computing
- **Medical physics** – from novel detectors to AI-based prognosis

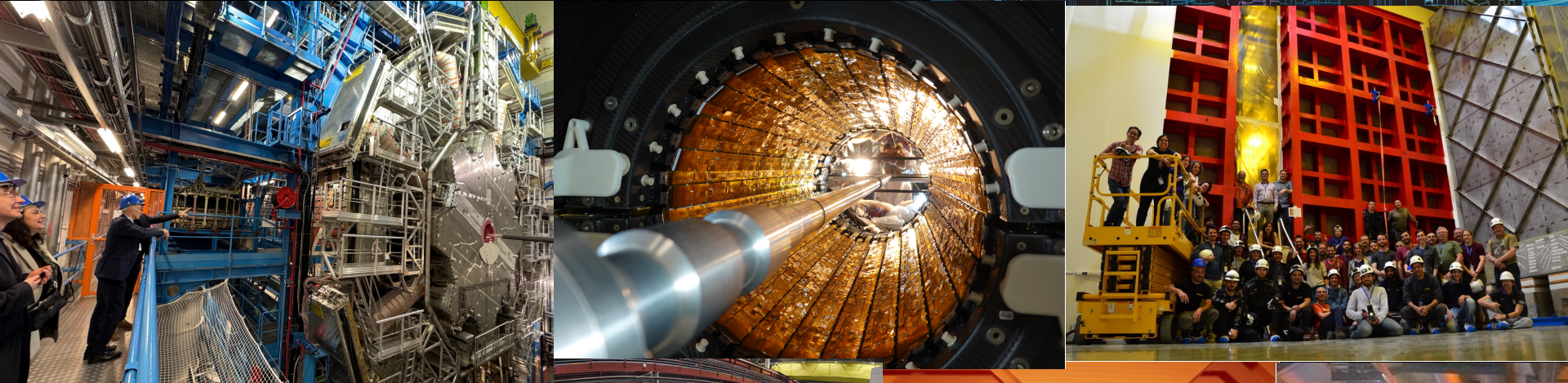
Partnership with CERN

Liverpool @ CERN

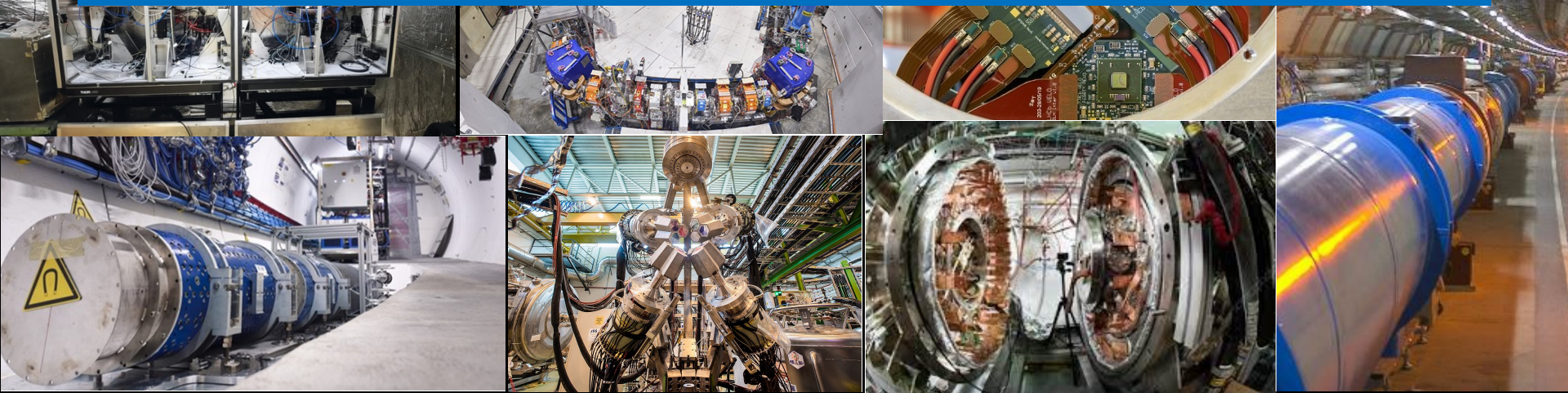


The Department of Physics is in the **top-25** list of CERN key collaborators, with strong participation in experiments at the Large Hadron Collider (LHC) and beyond.

- 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 (and **more than 60 PhD students**)



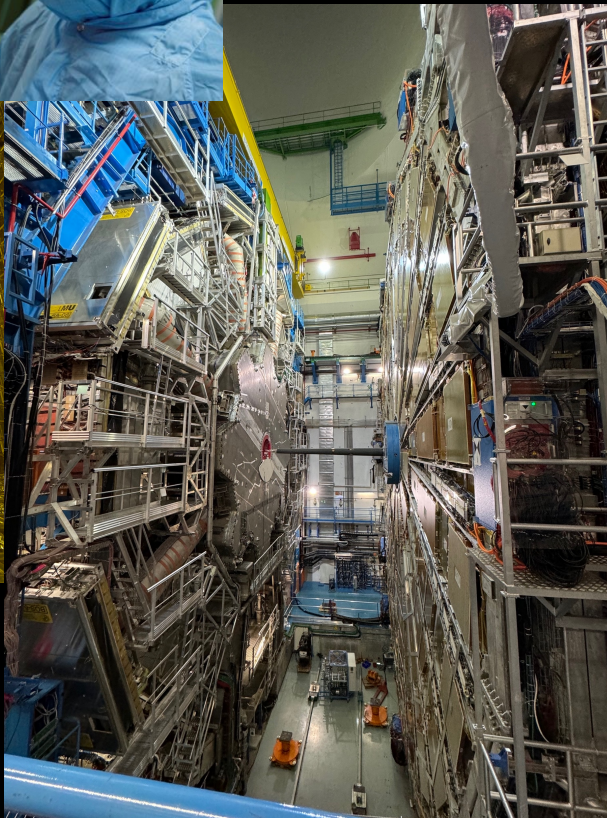
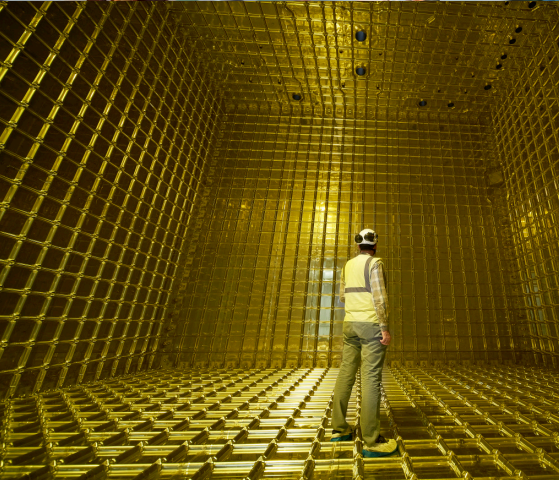
Highly-complex experiments, with large international collaborations across PP, NP and AS areas





Liverpool in High Energy Physics

One of UK's largest particle physics groups



29 academics and fellows
41 researchers
25 engineers/technicians/support
60 PGR students

Research income > £8.5M/yr
>850 publications 2018-23
International leadership

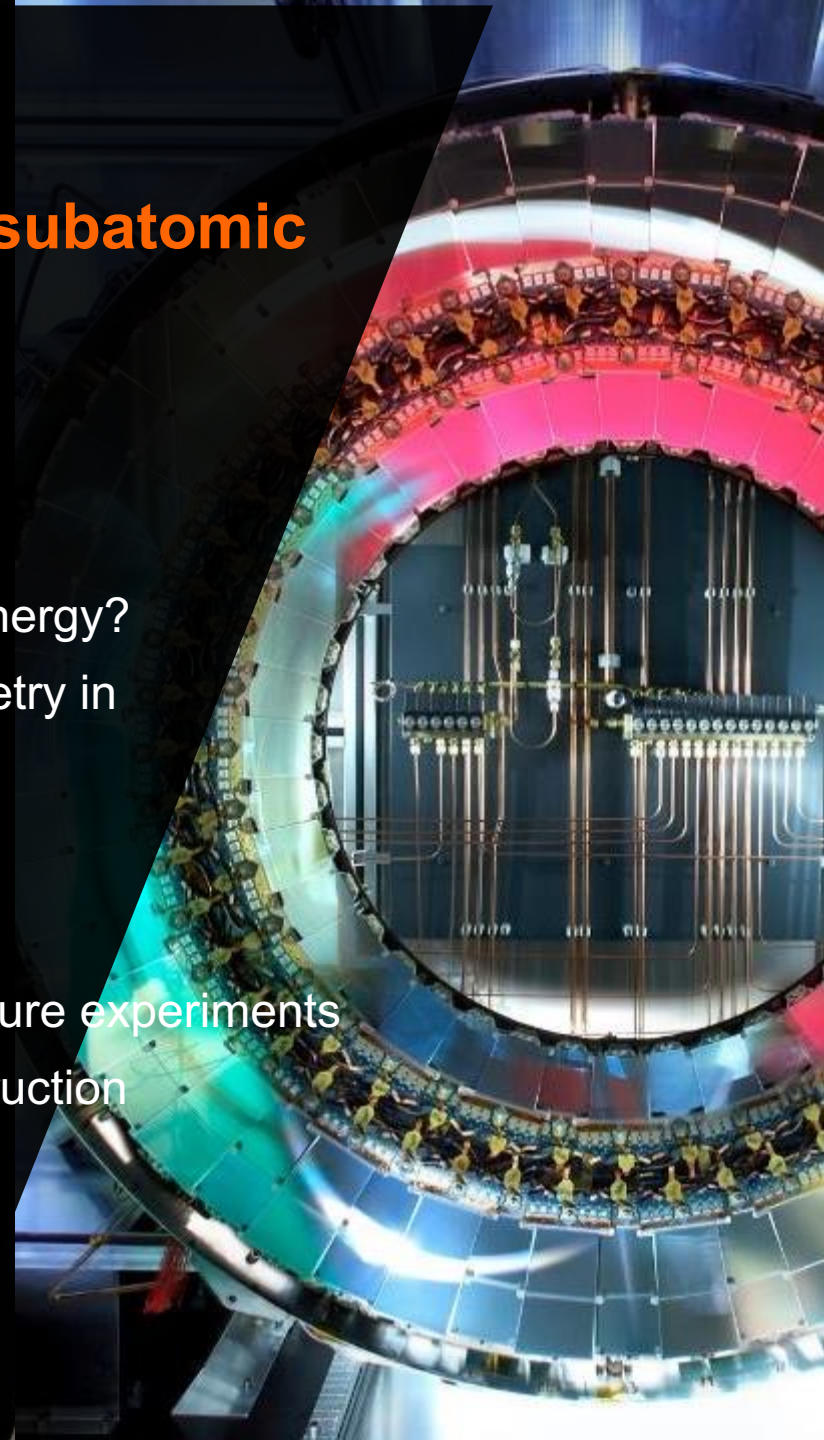
**Wide range of international
experiments and partners.....**

Key fundamental questions in subatomic physics

- What lies beyond the Standard Model?
- What is the origin of neutrino mass?
- What is the nature of dark matter and dark energy?
- What explains the matter anti-matter asymmetry in the universe today?

Liverpool PP activities reflect these priorities:

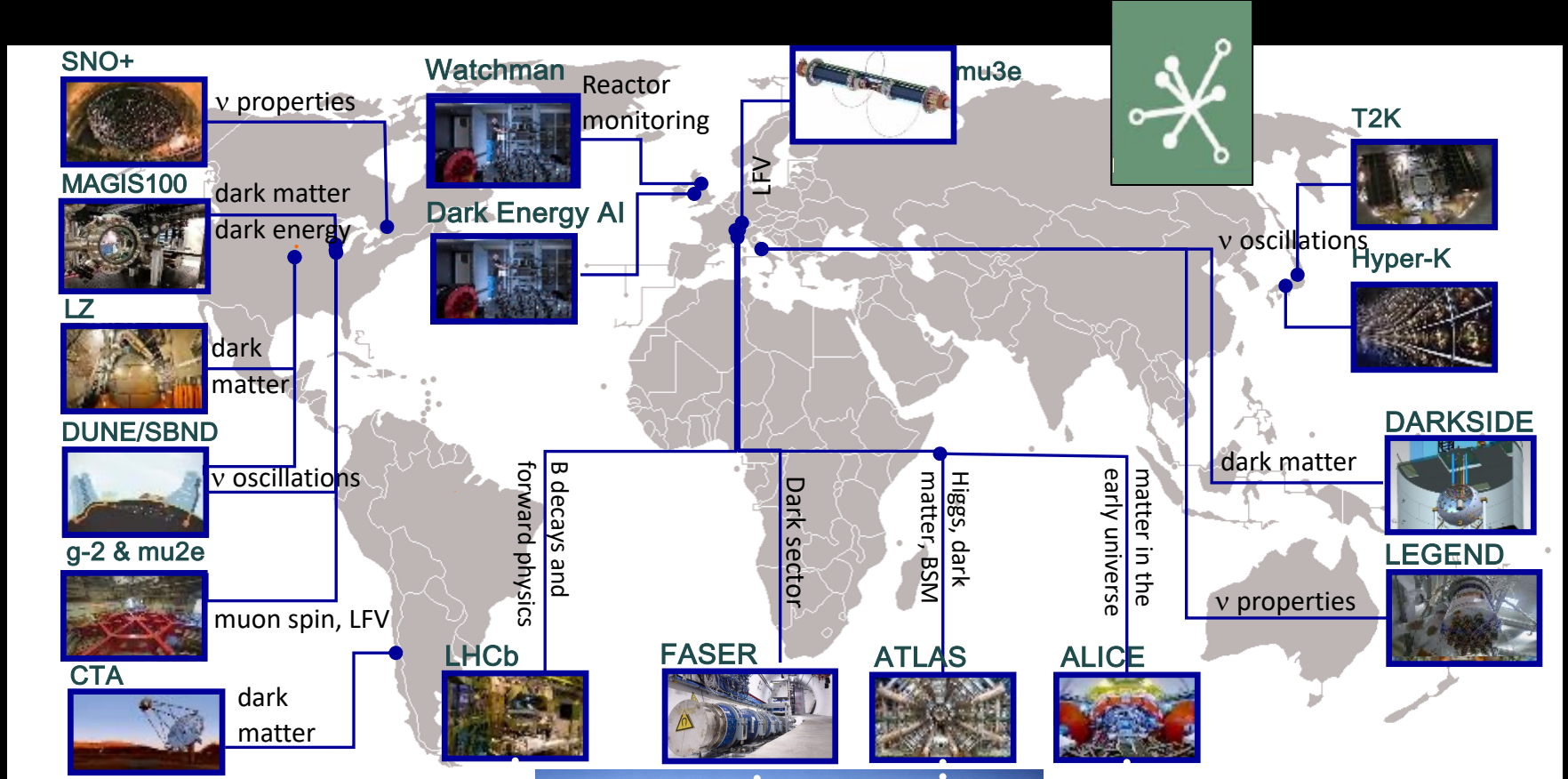
- Technology Research & Development for future experiments
- Experiment development and detector construction
- Experiment data analysis



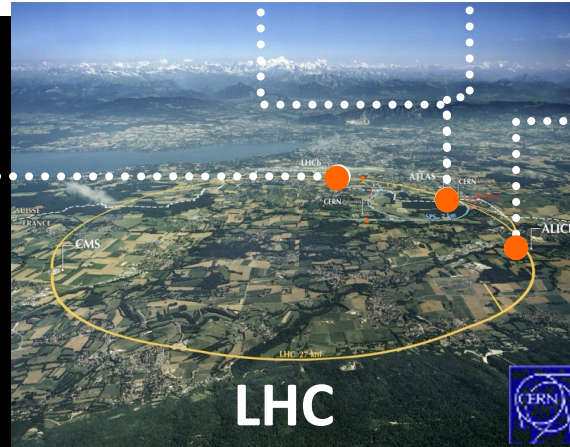
- **Energy frontier experiments** - **ATLAS** and future colliders at CERN (FCC)
- **Precision, quark and lepton flavour experiments** – LHCb and MUonE at CERN, g-2 and mu2e at FNAL, mu3e and muon-EDM at PSI, proton-EDM and more at Brookhaven NL
- **Neutrino physics** - T2K and Hyper-K in Japan, SBND/DUNE in the US, SNO+ at SNOLAB, Legend at Gran Sasso, Bute in Boulby
- **Dark universe** - LZ @ SURF, DarkSide-20k @ Gran Sasso, MAGIS @ FNAL, AION UK, CTA in Chile, FASER @ CERN

Detector R&D and construction - Internationally recognised expertise and infrastructure for detector development: radiation hard and low mass silicon sensors, Argon TPC technology R&D, silicon photonics R&D for cryogenic noble gas experiments, Atom Interferometry and quantum sensors, proton therapy for medical physics

Advanced computing: development of AI methods to be used for online data-taking and offline analyses, collaborations with Microsoft, CERN and FBK, grant from EPSRC for explainable AI



**A worldwide
programme:**
Experiments at
a glance



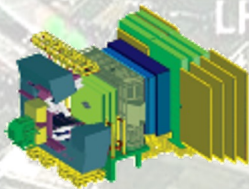
Experiments at the LHC



ALICE heavy ion collisions, quark-gluon plasma, early universe (Nuclear Physics group)

***ATLAS Higgs boson search and studies, precision measurements and search for new physics.
Higgs discovery: 2013 Nobel Prize in Physics***

FASER: search for dark sector particles and high-E neutrinos

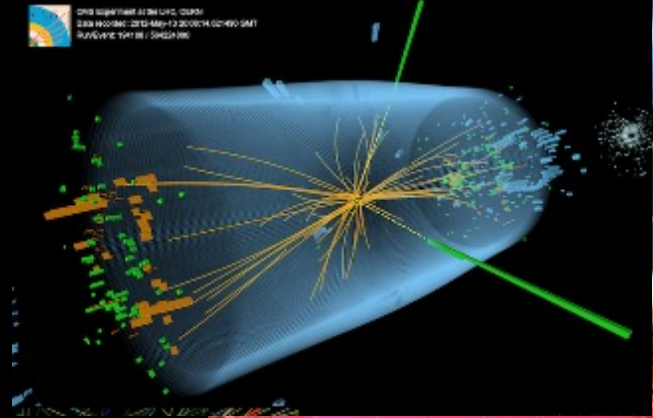


LHCb Study of CP-violation in b-mesons; precision physics in heavy flavour decays; Search for lepton non-universality

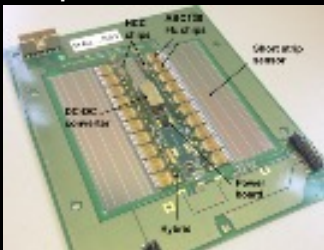
ATLAS experiment @ CERN

Strong Liverpool involvement from early conception

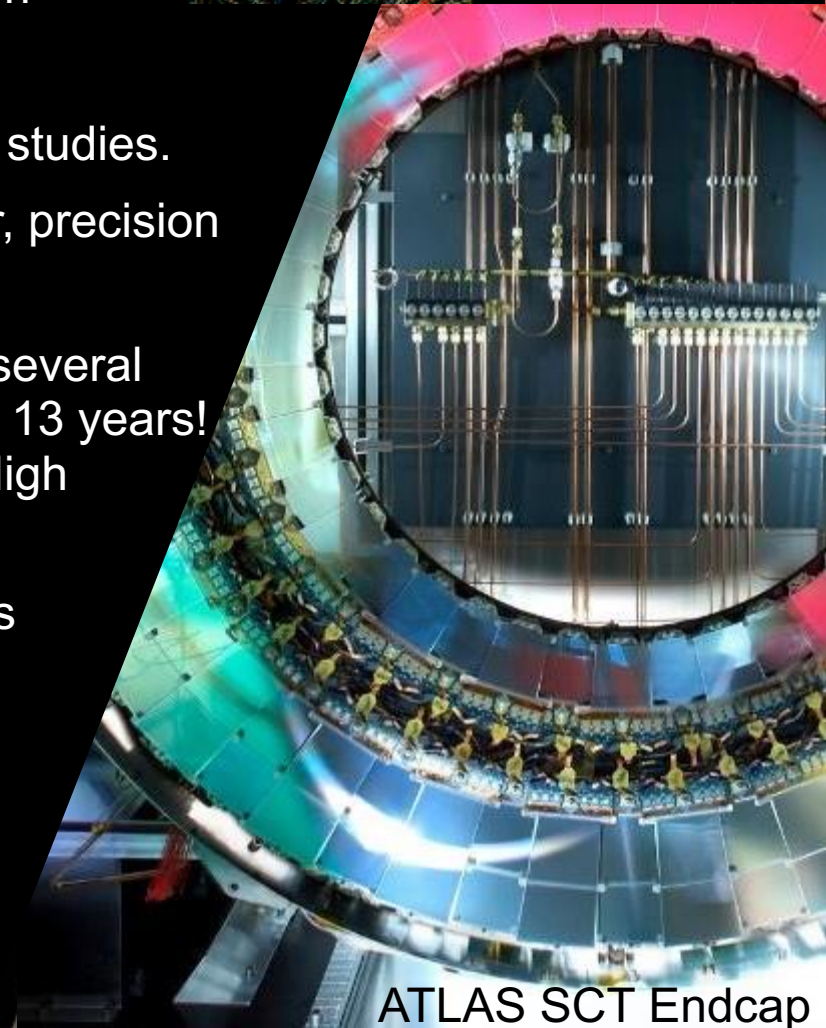
- Construction of the semiconductor tracker
- Higgs boson discovery in 2012 and subsequent studies.
- Searches for new physics, including dark matter, precision measurements of Standard model parameters.
 - Liverpool physicists work(ed) and lead/led several data analyses → over 1,200 publications in 13 years!
- Currently building the tracking detector for the High Luminosity LHC upgrades 2029-2030.
- > 30 people - academics, postdocs and students



Strip Barrel module



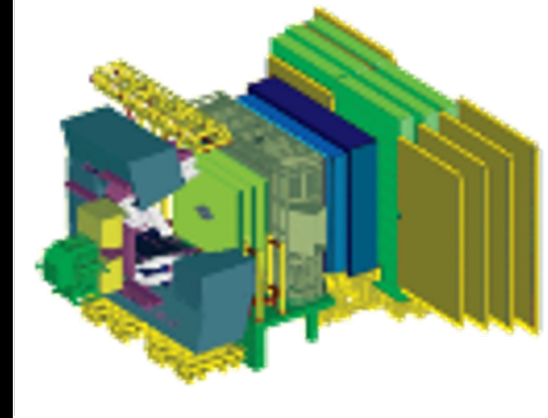
Pixel endcap test stand



ATLAS SCT Endcap

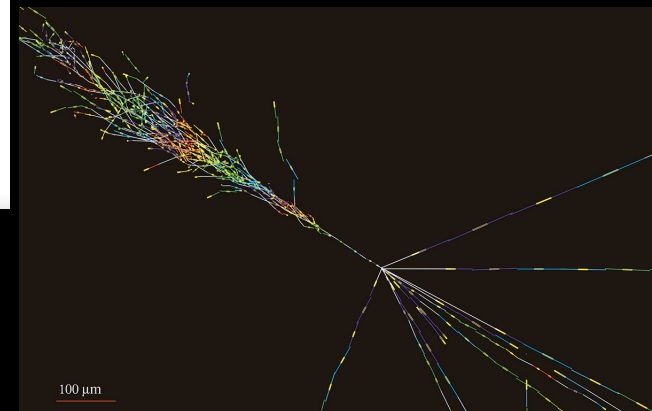
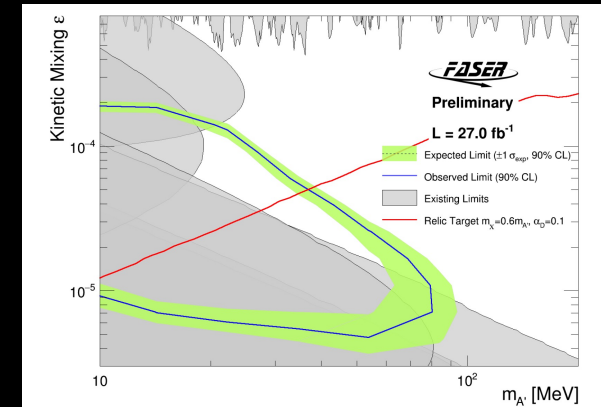
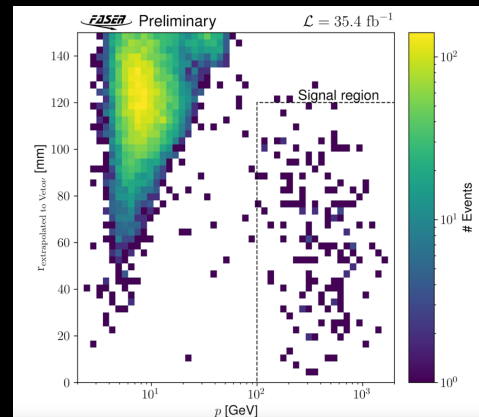
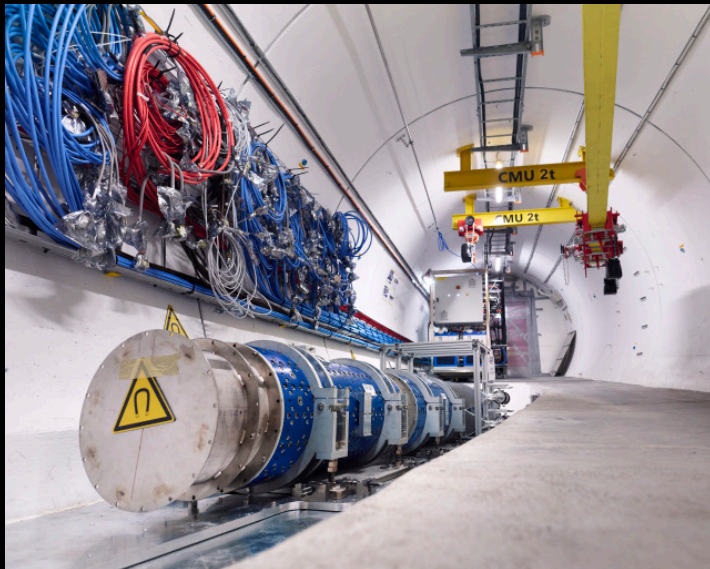
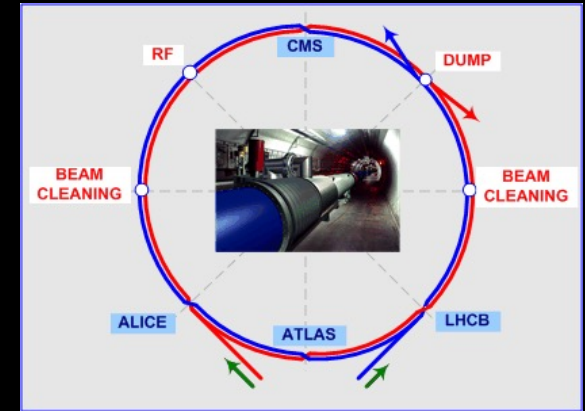
LHCb experiment @ CERN

- Second largest single experiment group.
- Development and construction of the silicon sensor modules of the tracking system
- Study of heavy flavour physics, CP violation, SM physics.
 - ~650 papers published since start-up
- coordination of new experiment wide data analysis framework
- Assembly of both halves of the new pixel tracker.



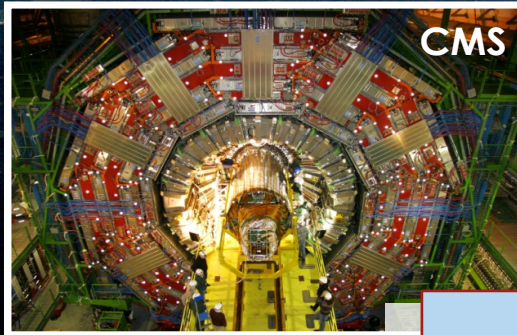
• The FASER experiment @ CERN

- FASER is a small experiment located at ~ 500 m from ATLAS interaction point – data taking started in 2022
- Dedicated to the search for new particles belonging to a hidden dark sector that could explain dark matter, as well as to the study of highly energetic neutrinos produced by the LHC
- Published constraints on new physics models and first observation of high-energy neutrinos at colliders!

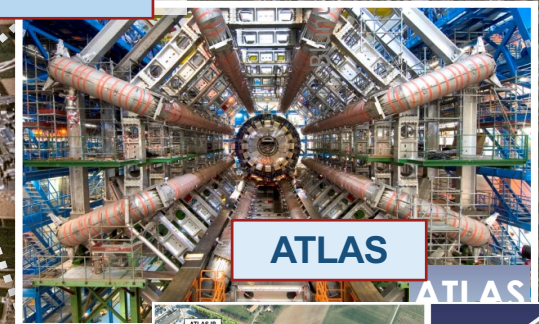
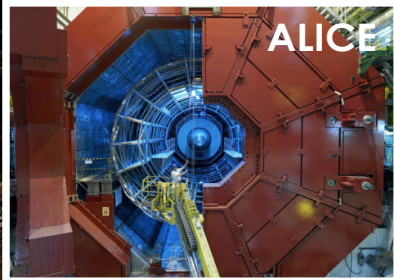


The LHC at CERN

27 km circumference



Run 3 of the LHC mid-way, a
very exciting time for all new
and old experiments



Monica D'Onofrio, Liverpool Graduate Students

... but there is much more going-on in particle physics at CERN and around the globe, and Liverpool physicists work on many more forefront experiments

Neutrino Programme

Neutrinos are very fascinating – the SM predicts them massless but experimental data tell us that when traveling long distance they can **oscillate** – means they change type, and this can only happen if they have at least a tiny mass...

Many experiments, all based on this idea...

The biggest ones:

Super-Kamiokande programme (Japan)

- Leadership in neutrino oscillation analysis (2016 breakthrough prize in fundamental physics)
- Now operating T2K and building its bigger version, Hyper-Kamiokande or HK (2026)

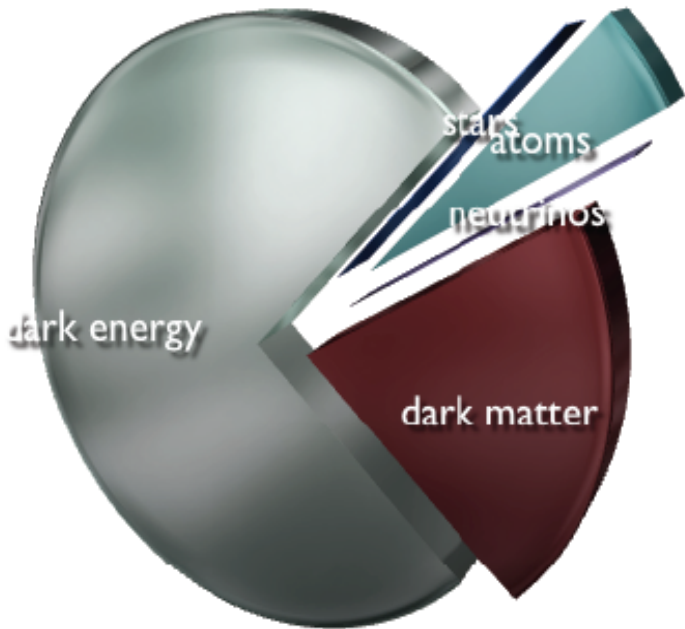
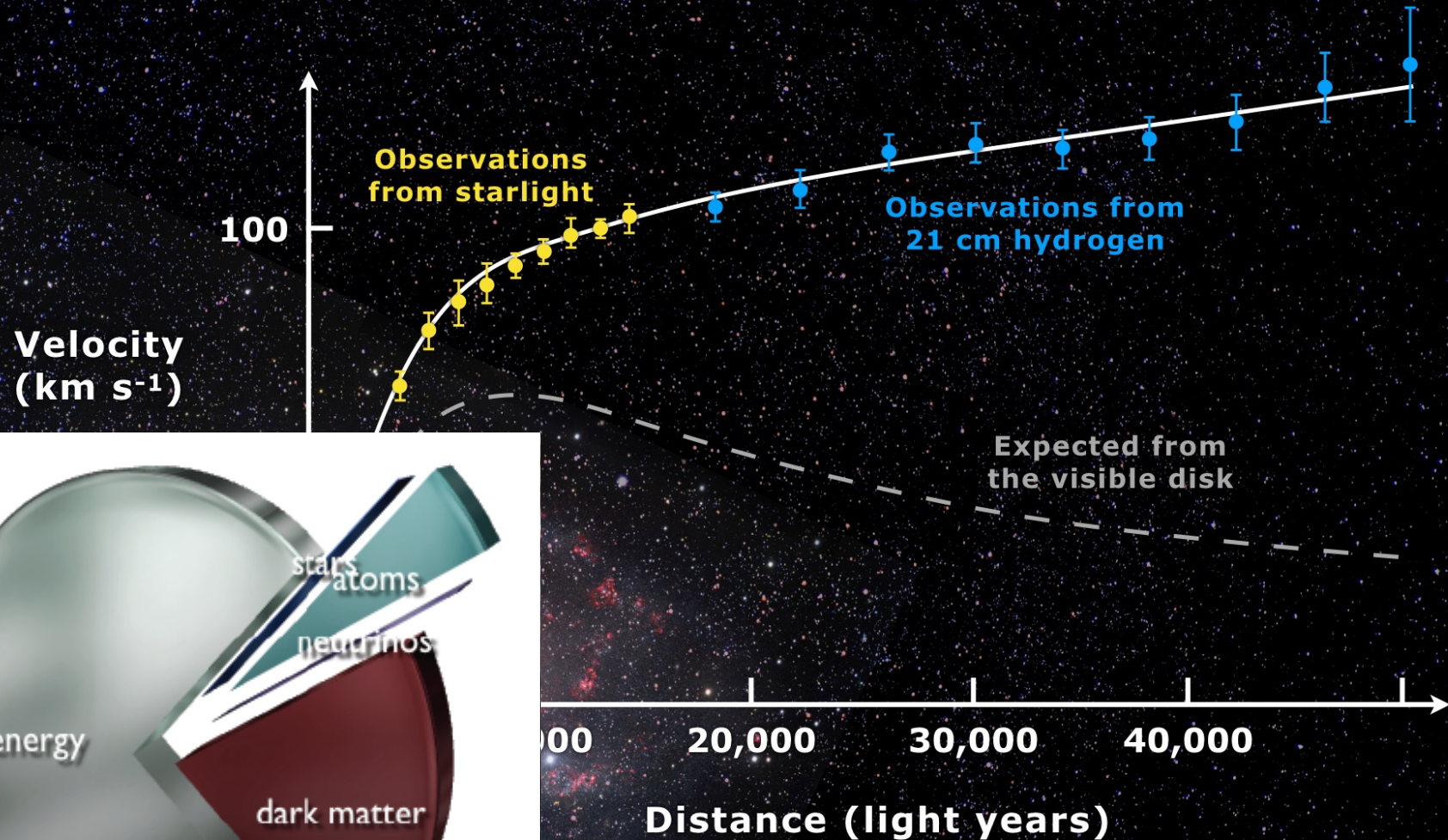
DUNE programme (US)

- Liverpool led prototypes programme at CERN



And many more: SBND, SNO+, LEGEND etc

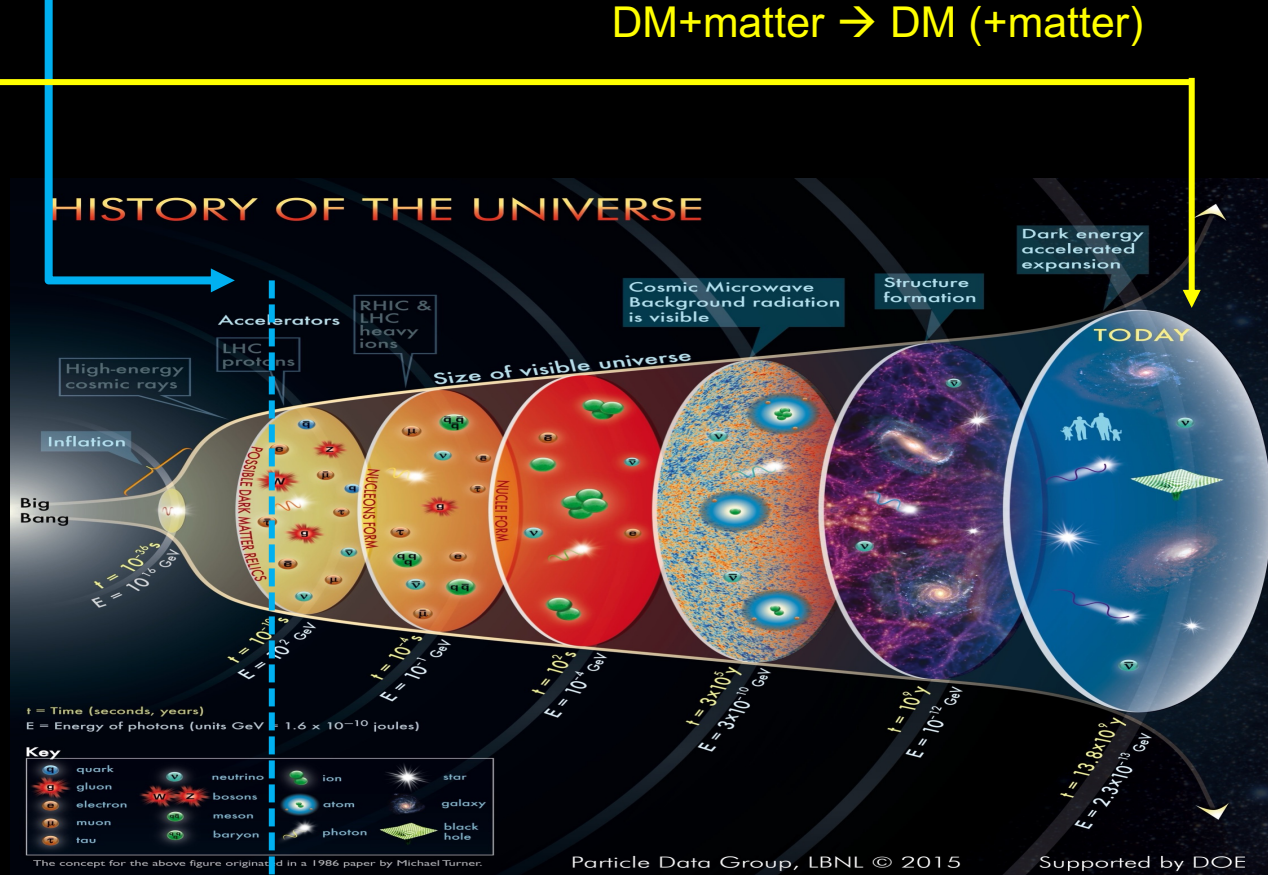
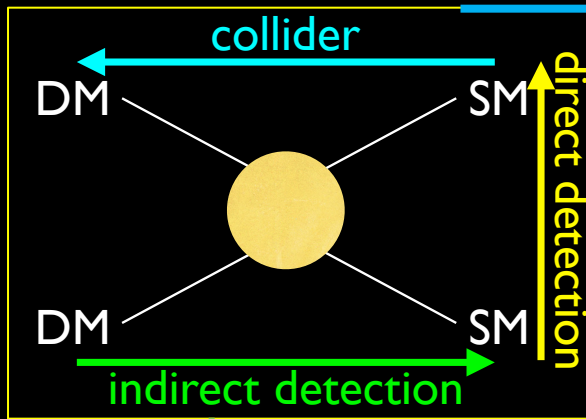
DARK MATTER



We can search for dark matter at the LHC but we also have dedicated experiments.



Searching for Dark Matter: how



Dark Matter Experiments

At the LHC: can study DM if it is a new particle produced in the protons smash

→ Idea behind ATLAS, FASER but also LHCb searches for DM!

At dedicated experiments made of large volume of dense material in the hope that DM particles from space interact:

LuxZeplin: Liquid Xenon detector for dark matter in US (since 2021)

Darkside20k – Liquid Argon detector (start ~2025)

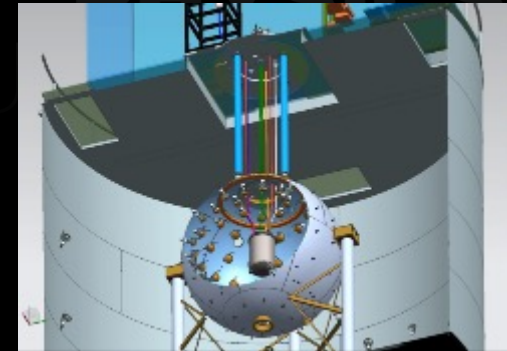
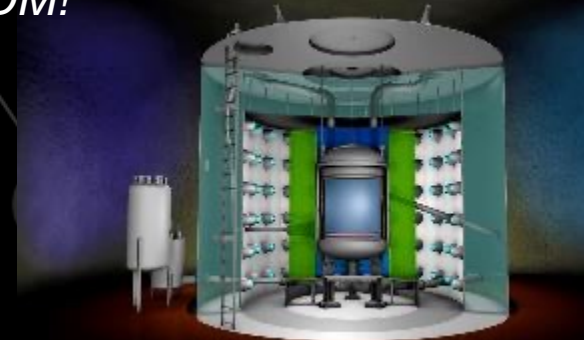
+ number of experiments based on 'Quantum' principles for ultra-light DM

With arrays of telescopes:

Cherenkov Telescope Array (CTA) in Chile

Search for gamma rays from DM annihilation in galactic centre using a set of telescopes

PARTICLE
PHYSICS
FUNDAMENTAL
SCIENCE
ENGINEERING



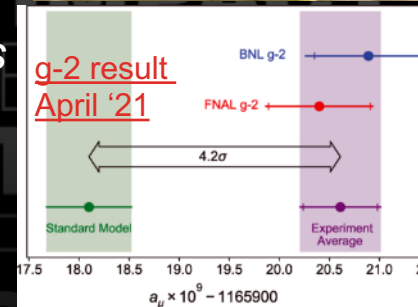
Muon precision programme

Strongly growing area for Liverpool.

The most precise measurements in physics can be made with leptons. In particular muons allow to test for extremely small effects caused by new physics that is otherwise out of reach.

g-2 @ FermiLab: Magnetic moment of the muon

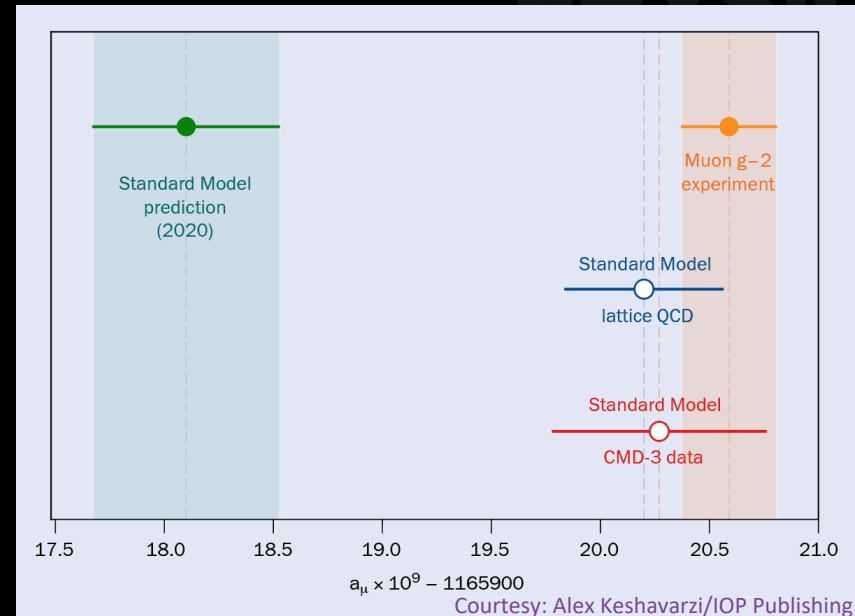
Liverpool built trackers were key to exciting results in 2021.



Final results released in 2025

Huge efforts at Liverpool on experimental and theoretical side!

<https://news.fnal.gov/2025/06/muon-g-2-most-precise-measurement-of-muon-magnetic-anomaly/>



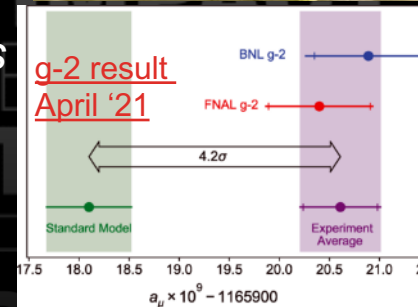
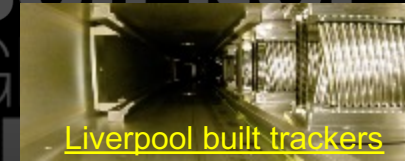
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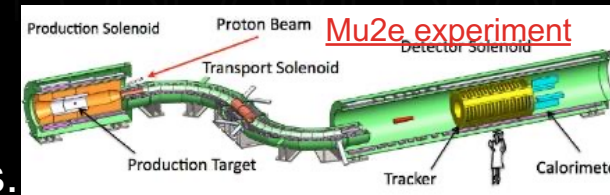
Liverpool built trackers were key to exciting results in 2021.



Search for extremely rare lepton flavour violating muon decays (< 1 in 10^{16})

Mu2e @ FermiLab

Collaboration PP and NP groups on Germanium detectors.



Mu3e @ PSI, Switzerland

Lowest mass silicon tracker ever built. Liverpool led project.

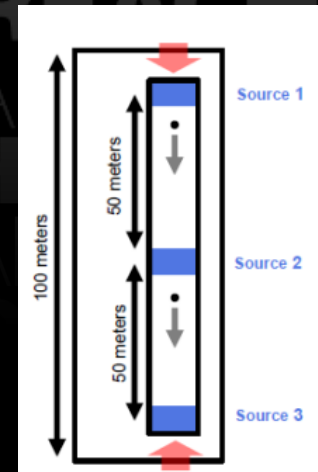
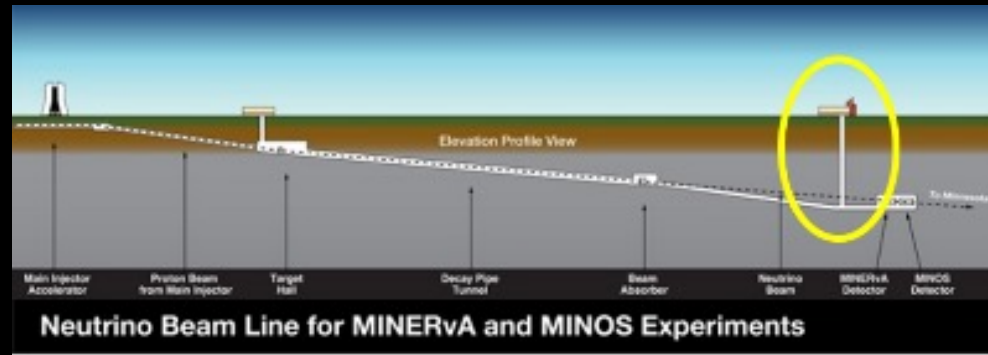
Mu3e HV-CMOS pixel tracker



Quantum Technology for Fundamental Physics

New approaches for extreme sensitivity physics measurements

AION / MAGIS-100 project – a 100m dual atomic interferometer at Fermilab, sensitive to ultralight dark matter and to gravitational waves around the 1Hz range, both invisible to current detectors.



To explore aspects of quantum physics, scientists will drop groups of atoms down a vacuum tube, followed by beams of laser light.

Silicon Detector R&D

Long area of expertise for Liverpool

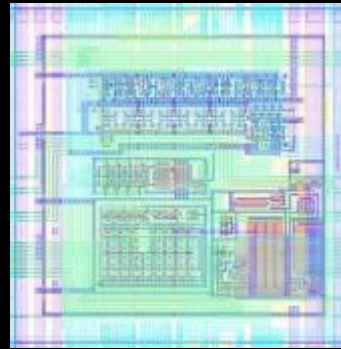
Sensor R&D focussed on high resolution, radiation hard and fast silicon sensors

Supported by excellent R&D and assembly facilities in the LSDC

- Leadership CERN RD50 collaboration
- Silicon sensor technology for LHC experiments
- Established CMOS design group - leading UK group HV-CMOS sensors

[Some of the] Spin-offs:

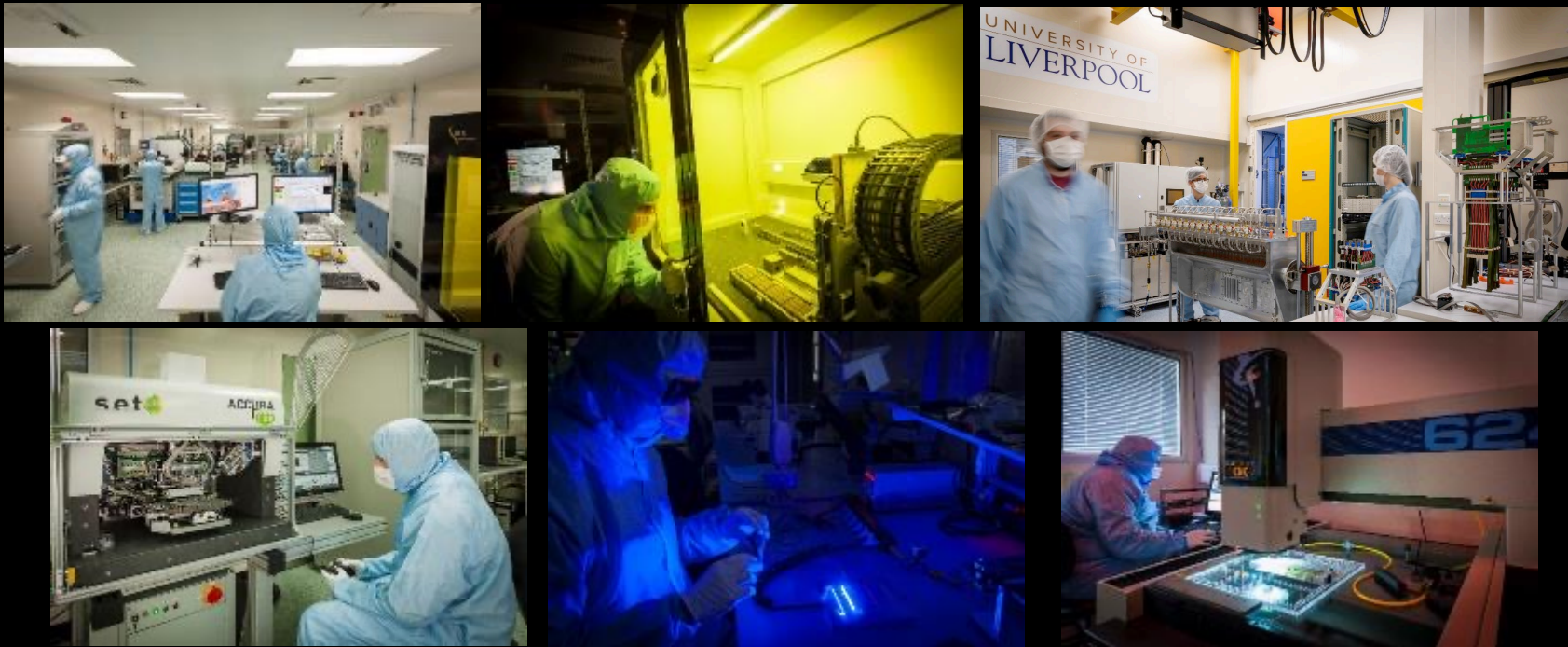
- *Applications to medical physics:* Beam diagnostics instrumentation for hadron beam therapy. New HV-CMOS sensor developed with FBK Trento for hadron beam instrument.
- *Commercial products:* patent investigation solutions for increased High Voltage operation with HV-CMOS



25

LSDC (Liverpool Semiconductor Detector Centre)

450 m² ISO certified cleanroom facility, initially built for the assembly of the large silicon detectors for the LHC. In operation since 2002. State-of-the-art equipment, infrastructure and expertise on Silicon detector development and construction are unique.



Several major construction projects were (are) hosted in the LSDC
6 detector systems for 3 LHC experiments, T2K ECAL assembly, g-2 tracker, Mu3e pixel tracker, Darkside-20k. Also several Nuclear Physics projects

26 **Detector Fabrication Facility (DFF)**

Equipment and skills build through a long stream of projects and sustained investment by STFC. Advanced equipment and high expertise provide a facility for precision manufacture that is unique in the field.



Manufacture of components for many experiments: *LHC experiments, ARIADNE, DEAI, T2K ECAL, LZ, g-2, Mu3e, NA62, MAGIS, DUNE, ... Also several nuclear physics projects*

27 **Advanced Materials Lab**

Dedicated lab for the development and manufacture of carbon-fibre components.
Large volume autoclave and oven.



Manufacture of components for many experiments: ATLAS, LHCb, CTA, Mu3e, R3B, ..
Also collaboration with students Mech. Eng. on formula student car and hand-powered bicycle

28 Computing

Particle Physics has long history in analysing high volume data and requiring high bandwidth readout electronics for experiments.

- A large fraction of the staff and students work on data analysis and on data acquisition technology to collect and analyse the data from our experiments.
 - These analyses are often very sophisticated and use all more model tools including Artificial Intelligence tool, ML and NN. Quantum computing is a recent addition.
- Wide range of work on many experiment requires maintenance of many software packages and computing infrastructure.
- Liverpool is also a major contributing site to GRIDPP computing for LHC and other experiments



Because of the above we host since long an extensive in house computing and networking infrastructure.

Summary and outlook

The Liverpool HEP group is one of the largest in the UK. Members are highly-skilled scientists working hard on many experiments and leading the field to answer the key fundamental questions in subatomic physics

Our unique facilities and the highly expert teams associated with these, are completely critical to delivering the research programme

Academics deliver dedicated and core courses sharing their knowledge with students. Students are also involved in projects since Y2 that allow them to participate and contribute to the experiments we are building and exploiting

PARTICLE PHYSICS FUNDAMENTAL SCIENCE



Summary and outlook

The Liverpool HEP group is one of the largest in

the world
the
wor
field
sub

Our
asso
deliv

Aca
sha
are
ther

experiments we are building and exploiting

For your future: in case you are thinking that particle physics is what you like, Liverpool is a great place to come to 😊

- Undergraduate students can be involved in research activities from Year 2
- Summer studentship programmes at Liverpool but also with CERN, DESY (lab in Germany) and other labs and institutes around the world
- BSc and MPhys projects on working experiments! Recently:
 - FASER and FASER2
 - ATLAS Machine Learning
 - Precision muon physics
 - Future colliders

Get in touch if you wish to have more info!