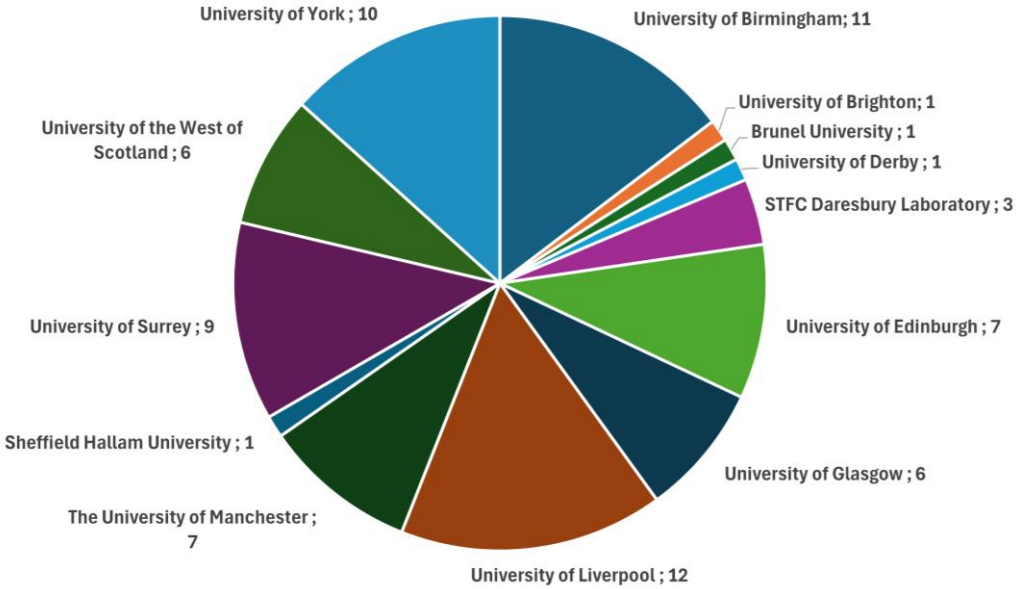
Snapshot of the UK nuclear physics community

Prof Daniel Watts (University of York)

Nuclear Physics in the UK

- 12 Universities
- 1 national laboratory
- 1 accelerator facility (MC40)



Number of NP academics per institute

Scotland
UWS (NS/NA)
Glasgow (HP)
Edinburgh (NS/NA)

North of England
Liverpool (NS/NA /HP)
Manchester(NS/NA /HT)
Sheffield (HP)
York (NS/NA /HP/NT)

Midlands
Birmingham (NS/NA /HP)
Derby (HP)

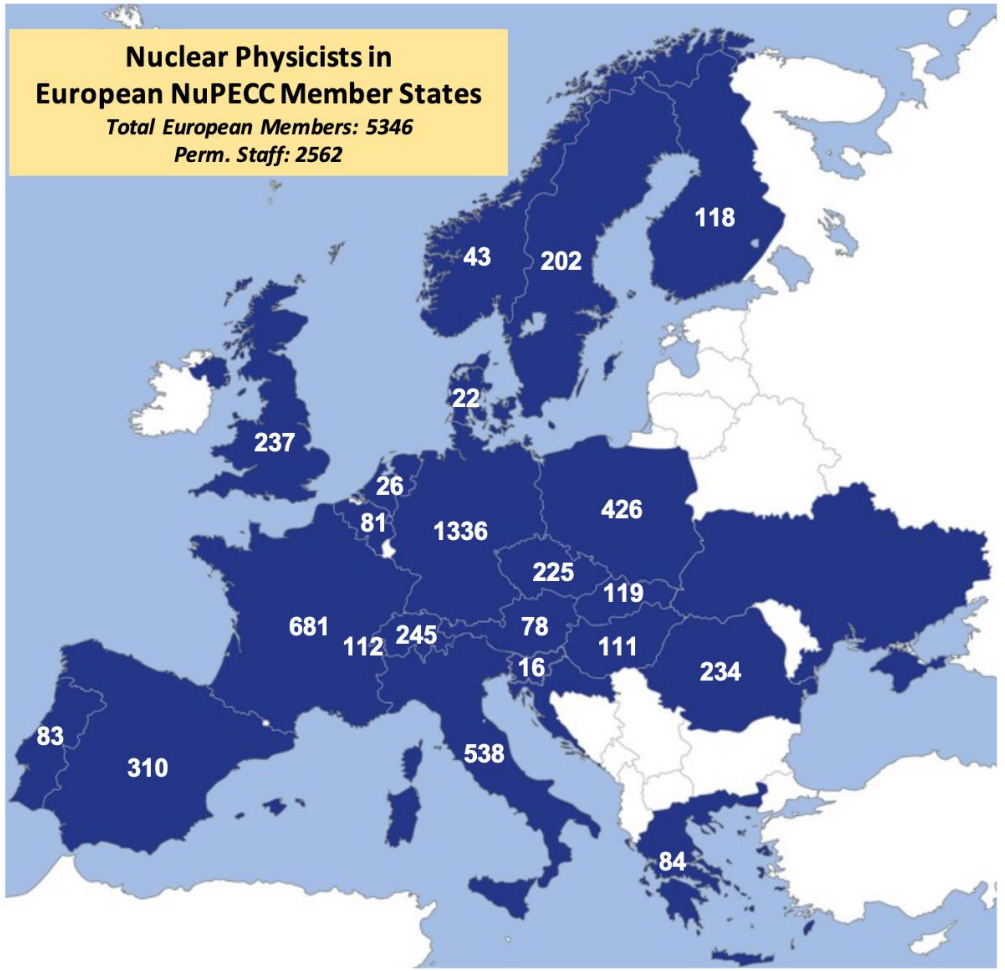
Southern England
Surrey (NS/NA/NT)
Brighton (NS/NA)
Brunel (HP)

Daresbury lab (NS/NA /HP)

MC40 proton/neutron beam facility (NS/NA)

Context within Europe

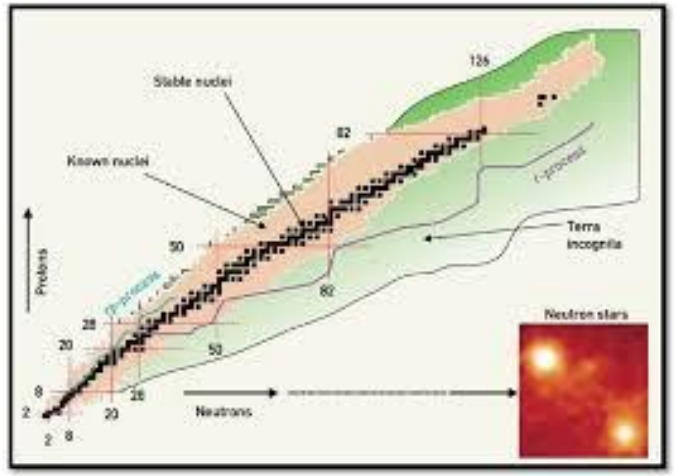
- UK NP community is smaller than comparable economies in mainland Europe
- Relative contribution of nuclear theory (~5% of academics) is smaller than in Europe, US and Asia – current priority to increase theory support



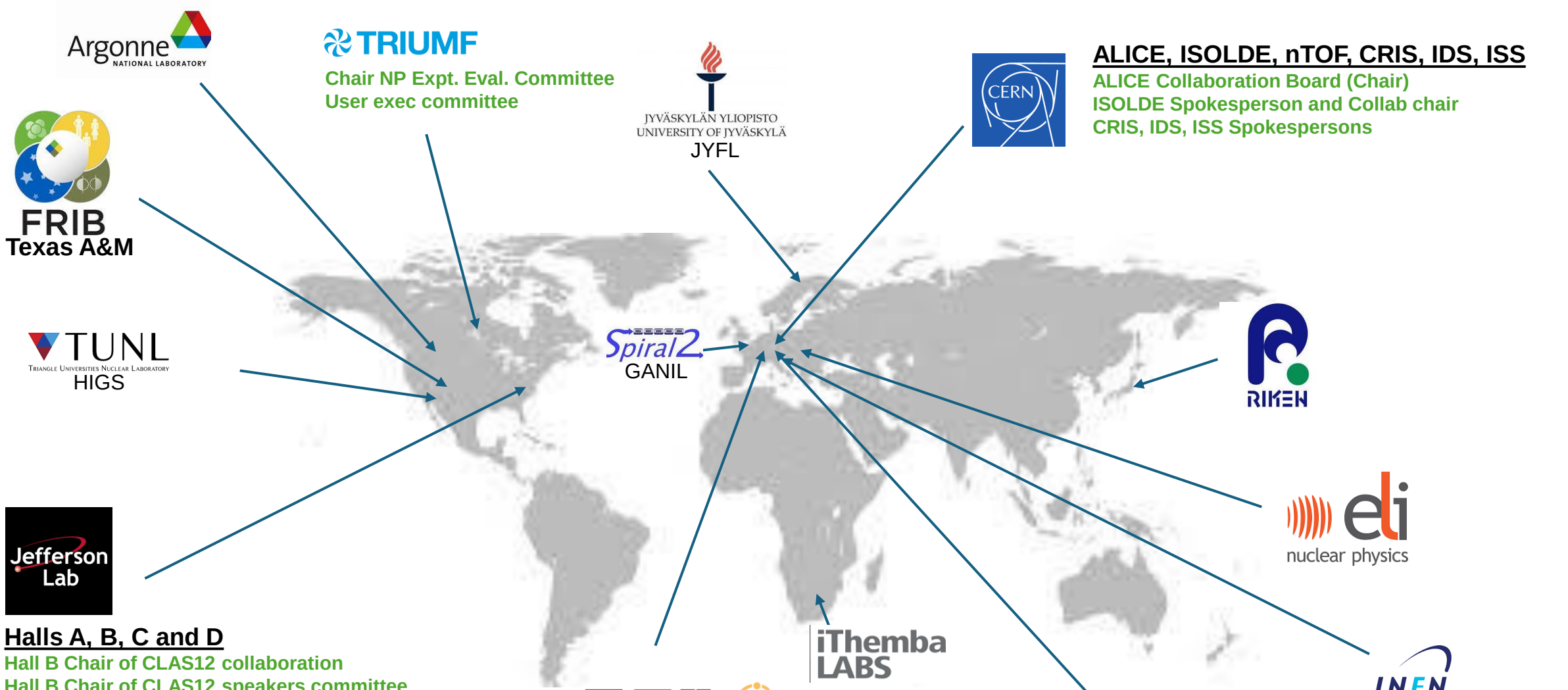
Nuclear physicists in the European NuPECC Member countries and the Associated Member CERN(source: NuPECC survey 2021 and 2023).

Fundamental science questions

- Where are the limits of nuclear existence?
- How does nuclear structure evolve in exotic nuclear systems, what mechanisms drive new structural phenomena?
- How well are nuclei described in terms of the underlying fundamental interactions based on QCD?
- What are the nuclear processes responsible for the synthesis of the elements in various astrophysical sites/conditions?
- Can the dynamics of QCD fully explain hadron (and exotic hadron) properties e.g. structure, confinement, nucleon mass, excitation spectra, spin,..?
- Is there evidence of gluon saturation in high-energy nuclear collisions? What is the nature of the quark-gluon plasma, and how does it emerge from fundamental interactions?
- How do hadron and nuclear properties relate to neutron stars, black hole formation or matter during the early evolution of the Universe?



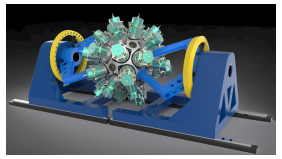
Facility map and recent UK leadership roles



Recent infrastructure leadership

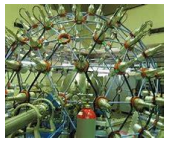
PPRP funded

FRIB
Texas A&M



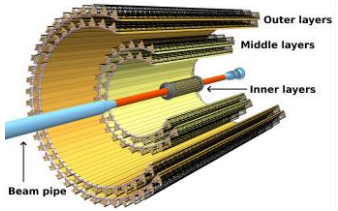
FAUST

TRIUMF



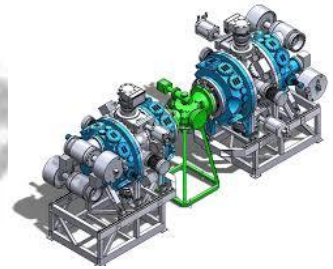
DEMAND neutron array
(also for FRIB)

CERN



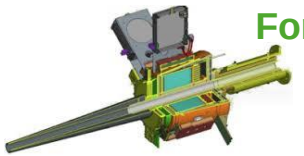
ALICE inner tracker

ALICE central trigger system

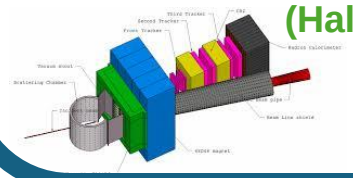


ISOL SRS

Jefferson Lab



Forward tagger (Hall B)

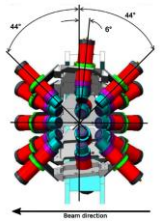


SBB spectrometer
(Hall A)

FAIR GSI

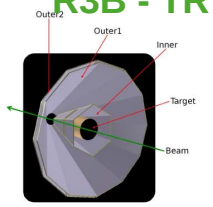
AGATA

AIDA

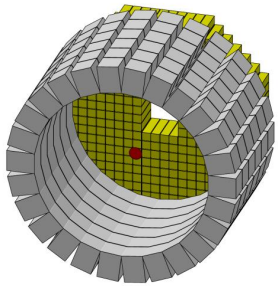


DESPEC/
HISPEC

R3B - TRT

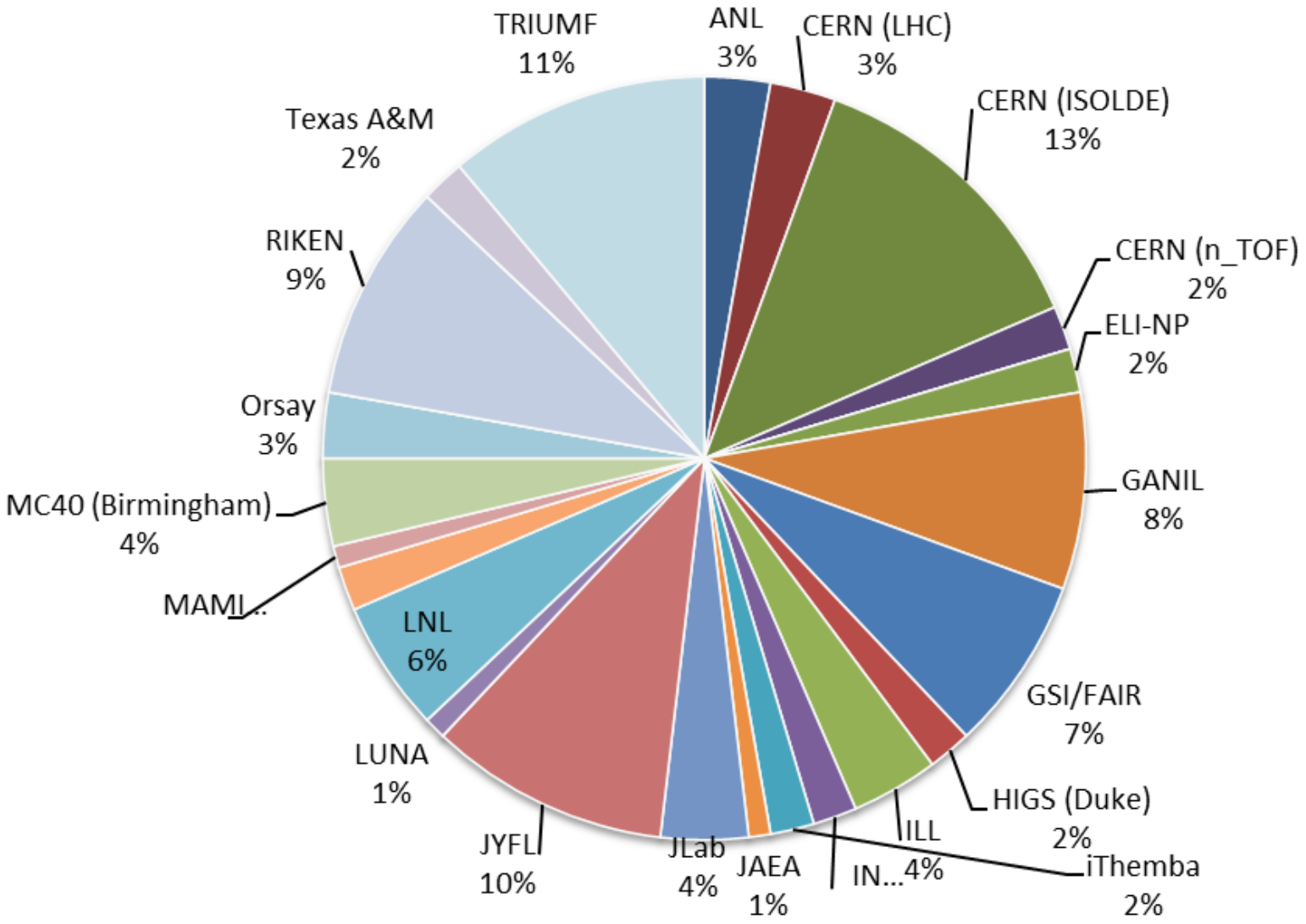


RIKEN



HYPATIA array
γRIBF

Facility use from recent STFC nuclear physics grants round (2023)



CAVEATS:

Only shows the breadth of engagement of UK community

Show the facilities mentioned in funding requests for CG research themes in 2023

Nuclear structure/astro – programmes typically based on a number of facilities

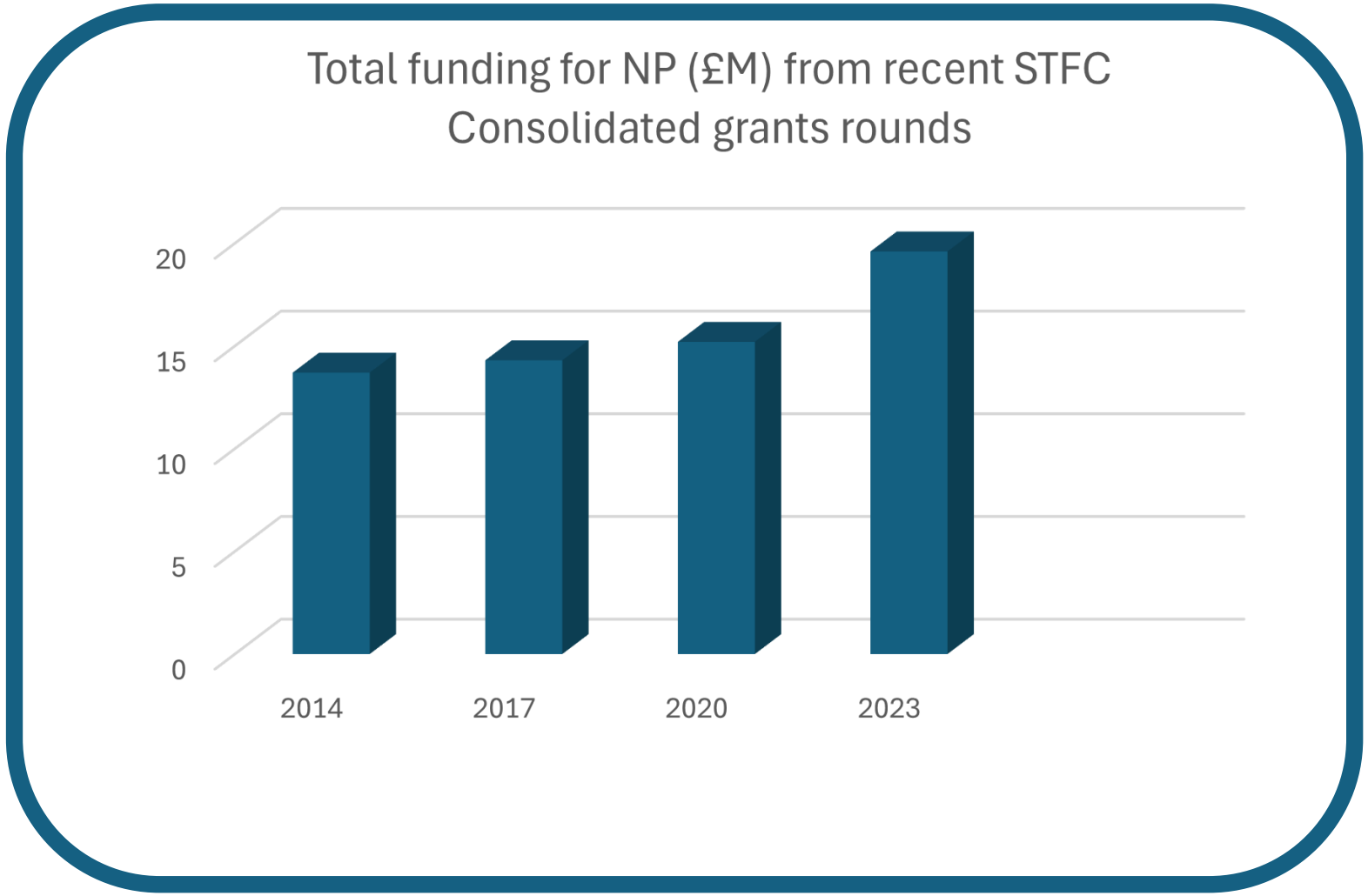
Some topics e.g. hadron physics typically focus on a single facility

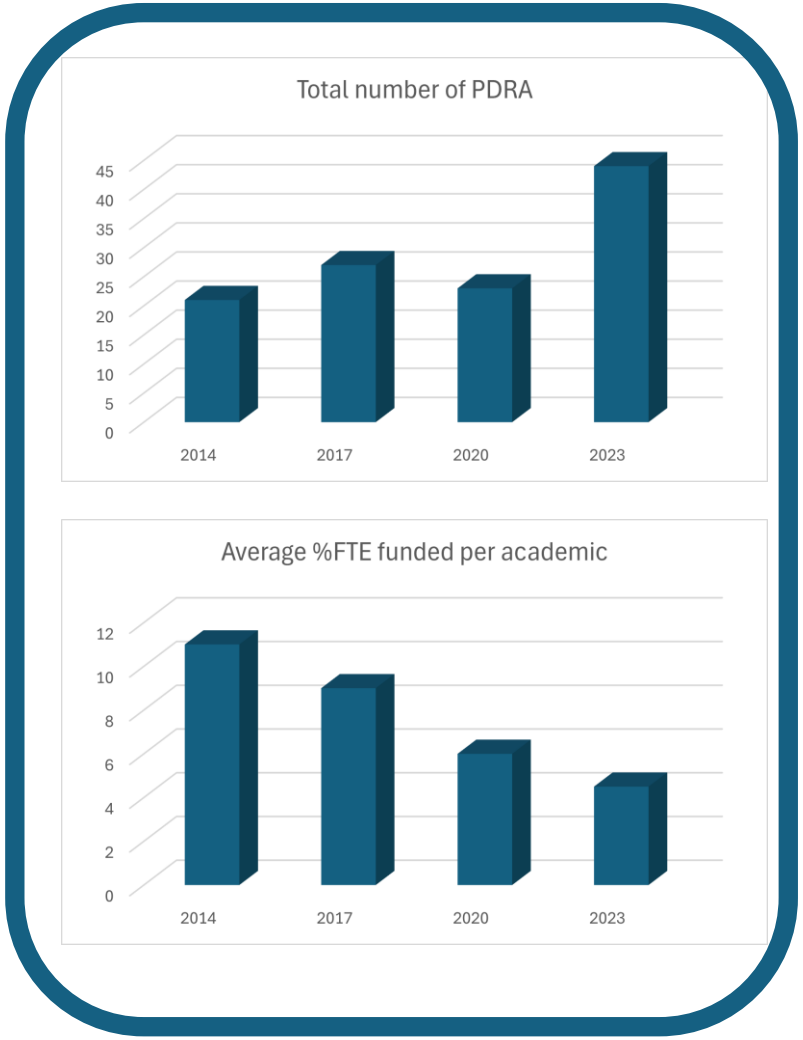
Approx facility resource split from STFC NP grants round (2023)

CAVEATS:

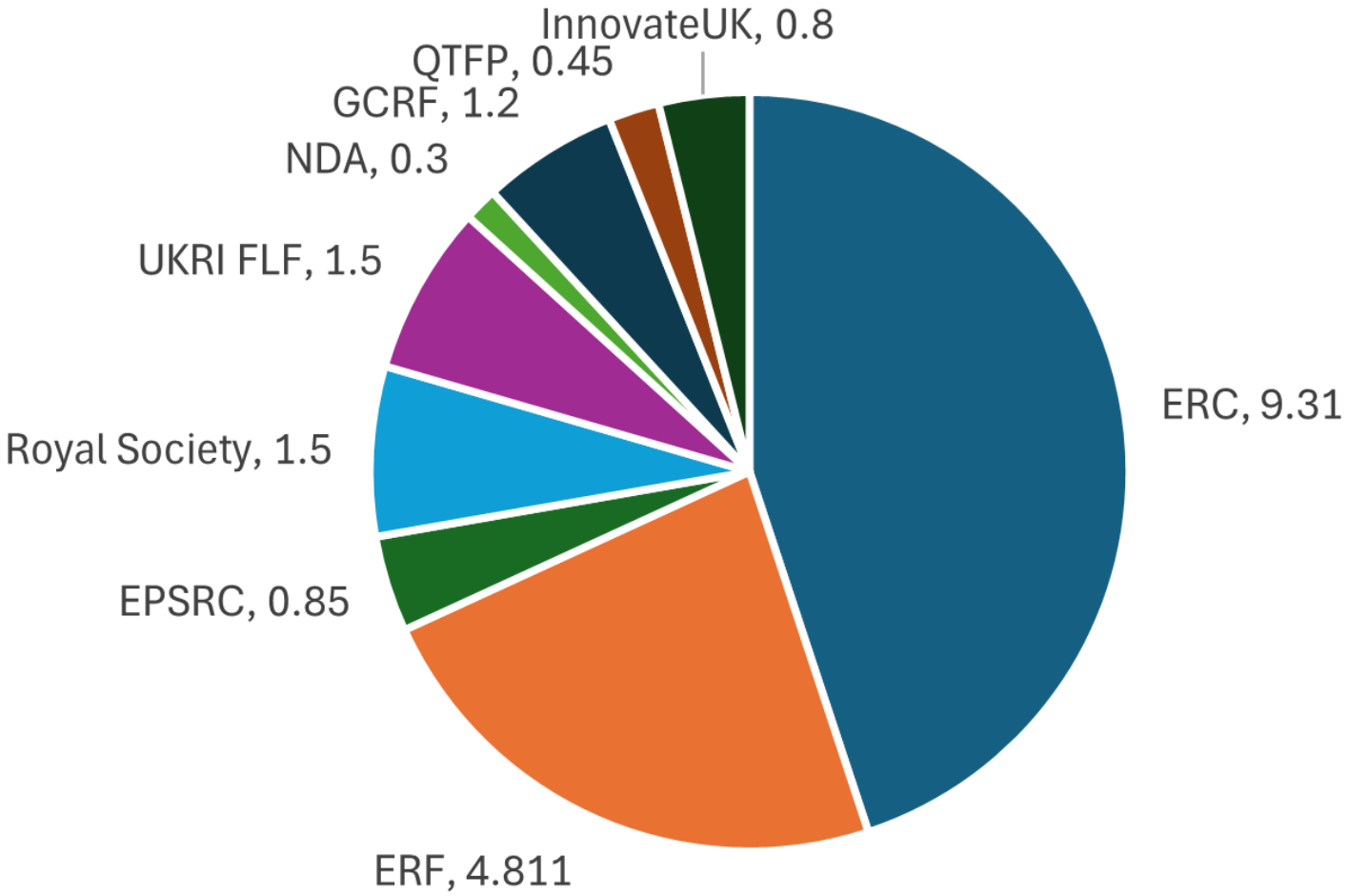
Not from complete response from community - some groups split is estimated

STFC CG funding for UK nuclear community





Recent (indicative) funding for UK NP outside of main grants panel

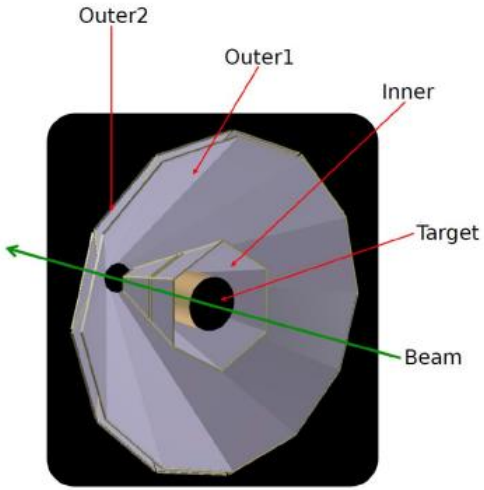


CAVEATS:

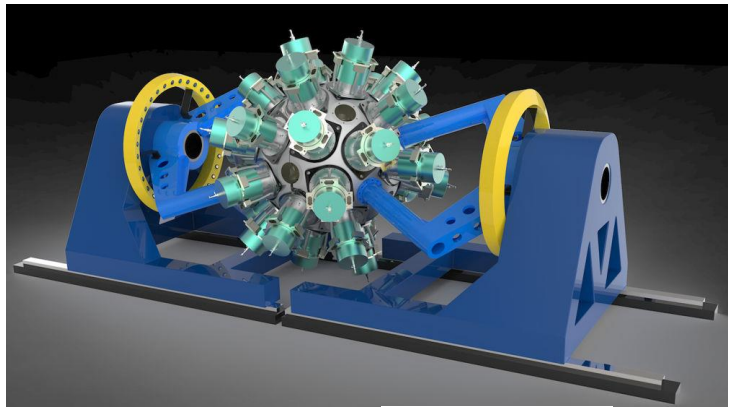
Responses from 7 of 12 groups (ERF numbers from NPAP24)

Numbers show funding awarded in £M

Projects funded by STFC PPRP in most recent round (2023)

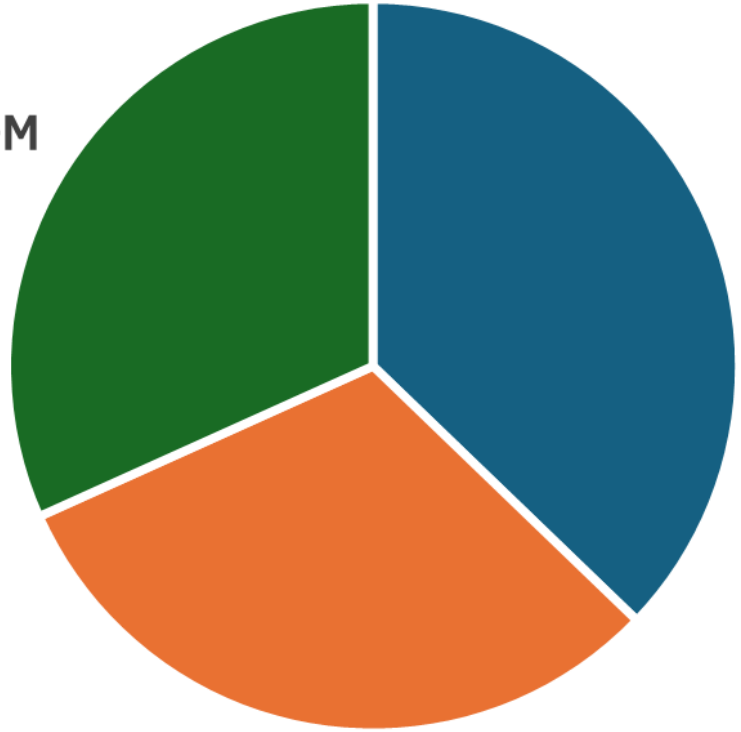


FAIR GSI

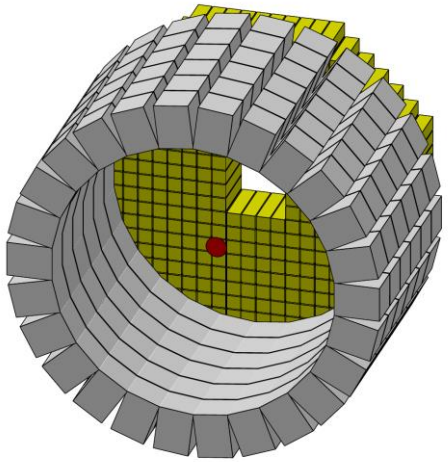


FAUST, 3.4M

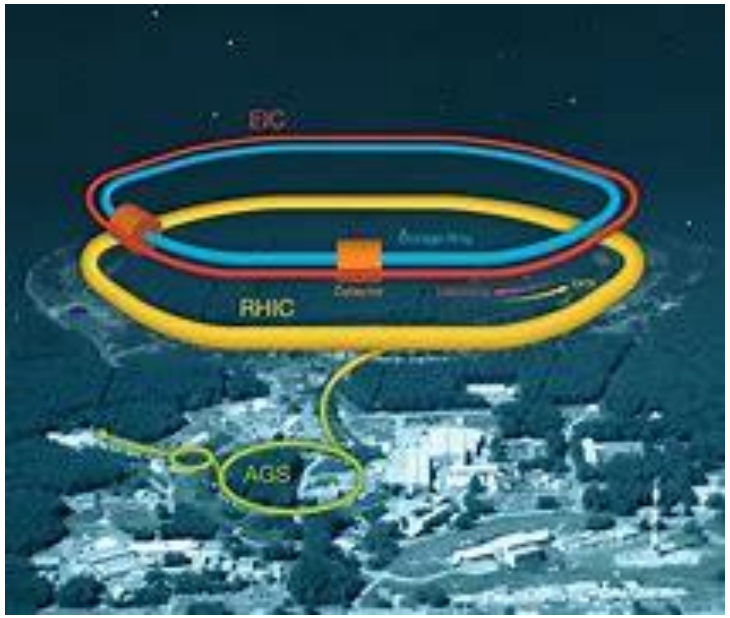
FRIB
Texas A&M

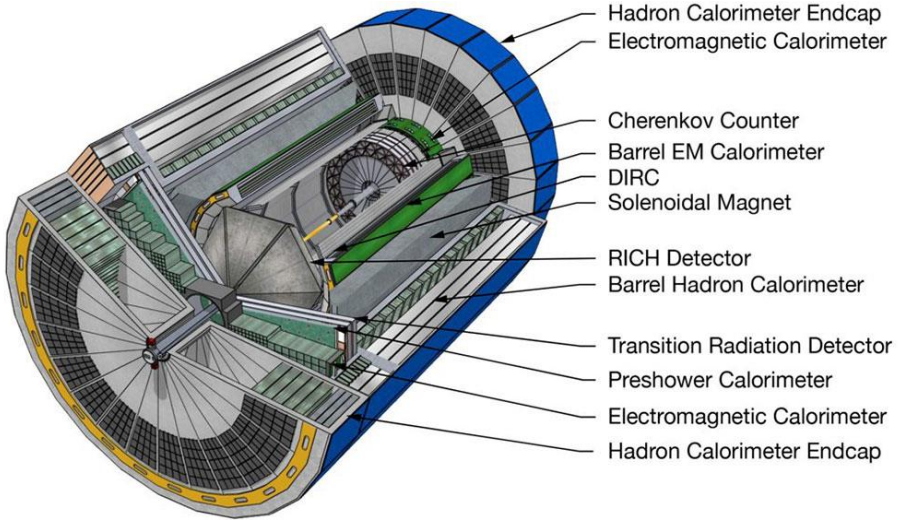


RIKEN



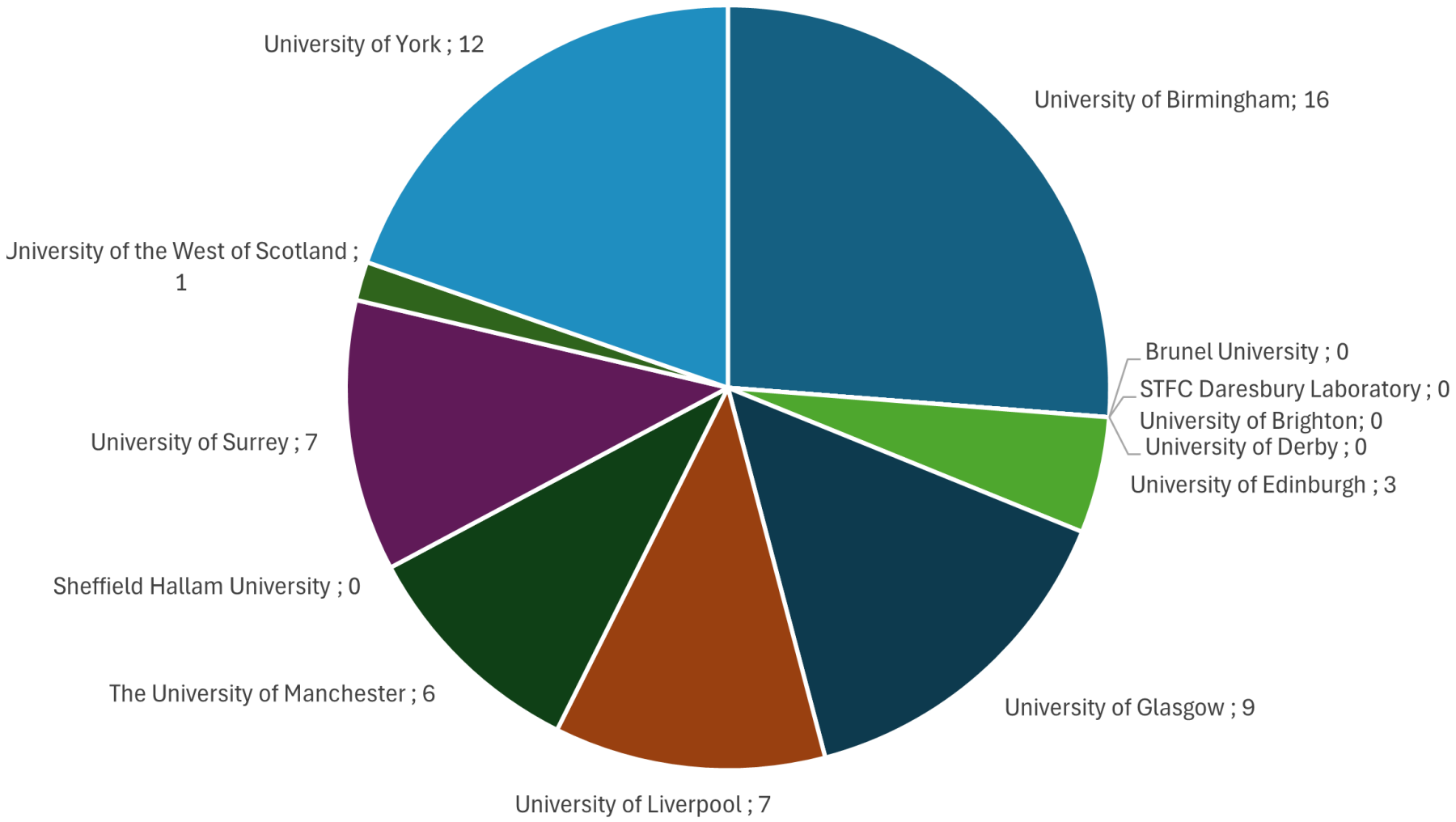
UKRI infrastructures project – Electron ion collider (Brookhaven)



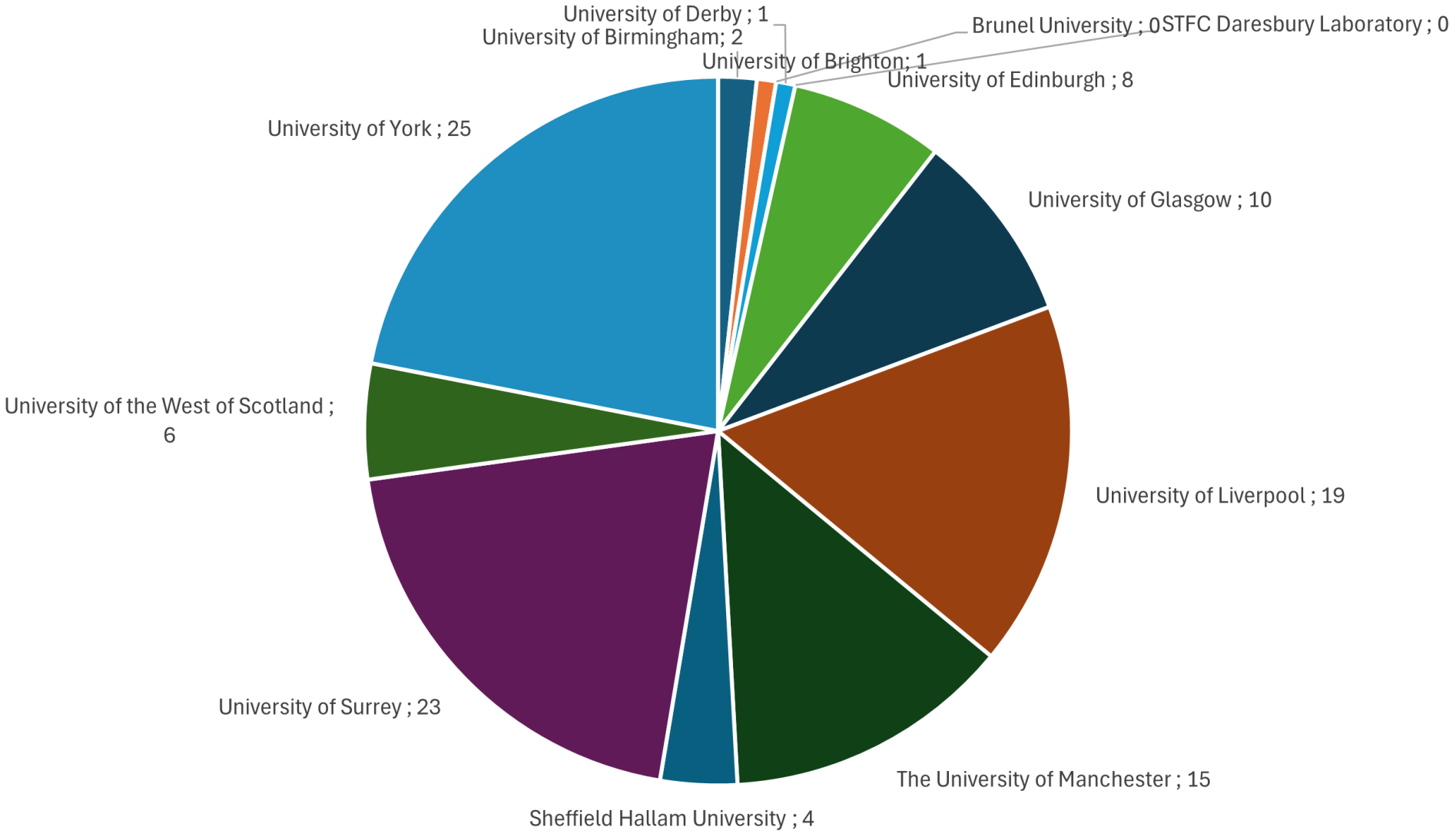


- UK contribution recently funded by UKRI infrastructure fund Seven universities and two national laboratories
- Contributions to ePIC detector :
  - (SVT (MAPS)
  - Electron tagger (TIMEPIX)
  - Calorimetry
- Also – collaboration in delivery of EIC accelerator infrastructure
- Expected to be online in 2032

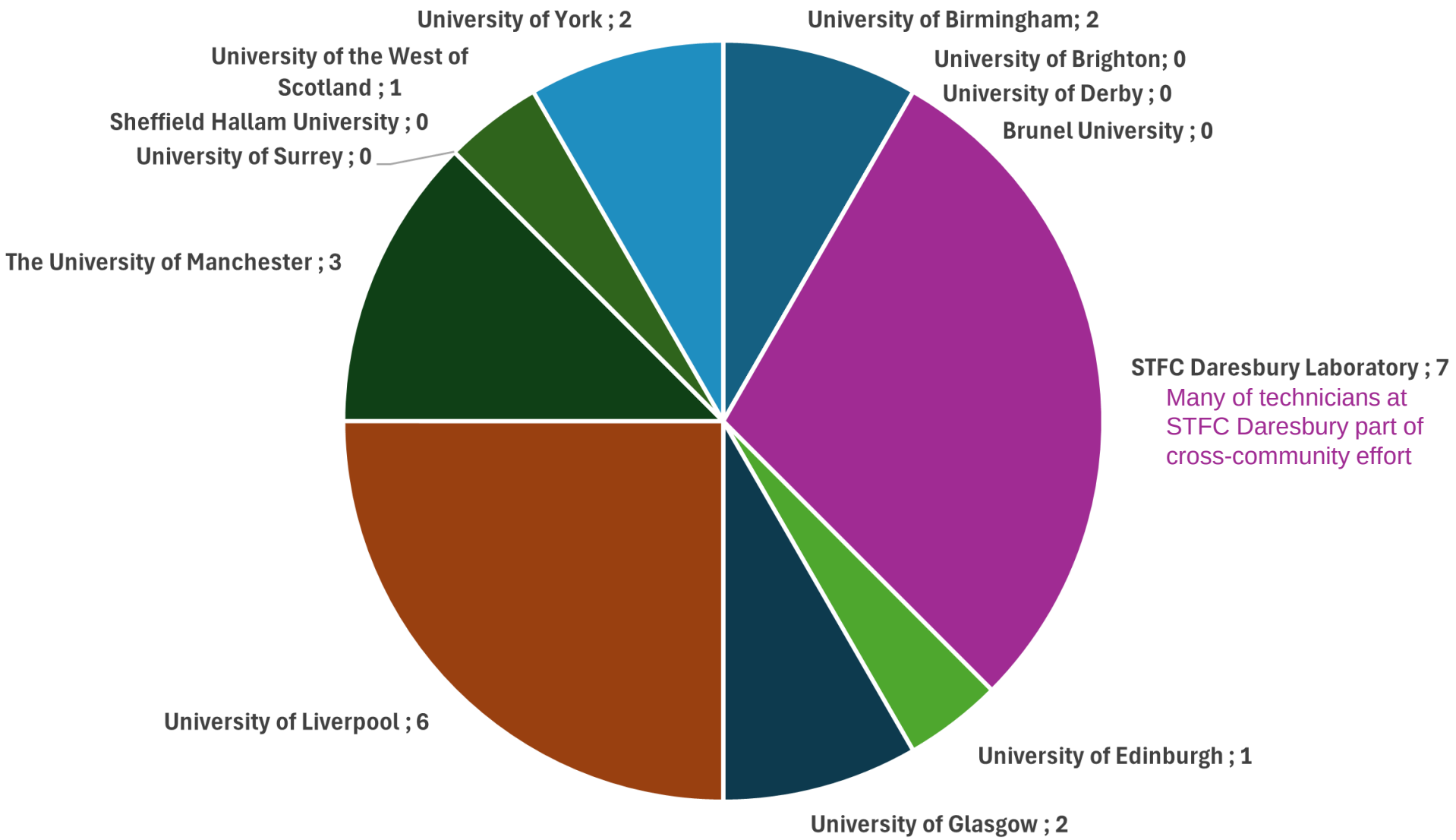
Nuclear PDRA in the UK by institute (source NPAP24)



Nuclear PhD students in the UK by institute (source NPAP24)



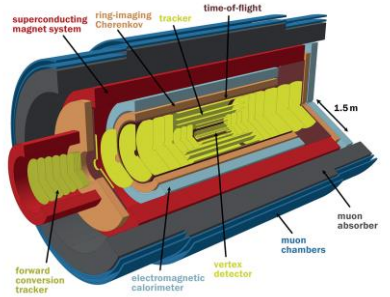
Nuclear technicians in the UK by institute (source NPAP24)



Future projects in the UK roadmap

AGATA upgrade – Progress from 3π to 4π spectrometer

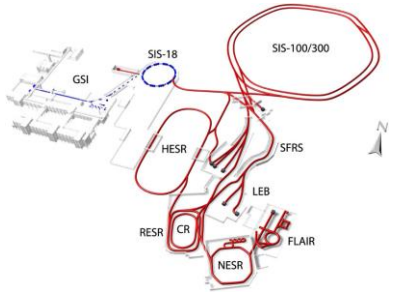
ALICE upgrade - Collaboration proposes a novel detector - ALICE3 - with high readout rate, superb pointing resolution and excellent tracking and particle ID using advanced silicon (MAPS) detectors. LHC Runs 5,6 (2035).



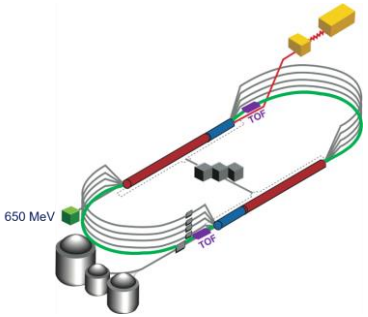
Legend 1000 – Neutrinoless double β decay; isotopically enriched ^{76}Ge

E1-M2 Mössbauer – Nuclear CP violating moment in odd mass pear shaped nucleus.

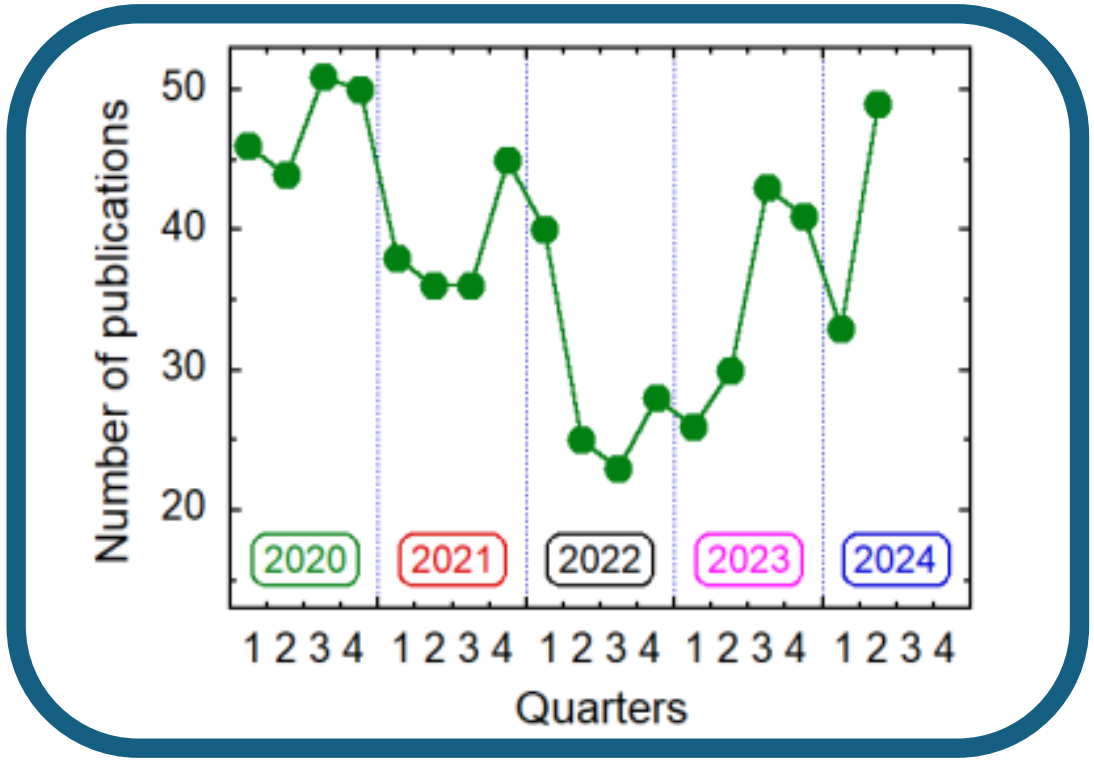
GSI/FAIR upgrade - New storage ring taking beams directly from the new SIS100 - SuperFRS accelerator/fragment separator. Increased beam intensities, transmission -> new detector infrastructure



JLAB upgrade – Upgrade from 12 GeV to 22 GeV proposed. Enhanced capabilities for 3D imaging of nucleon; exceed J/psi threshold, new meson structure programmes,…
Also: UK leadership in (pre-upgrade) neutral Kaon beam facility (KLF in Hall D)

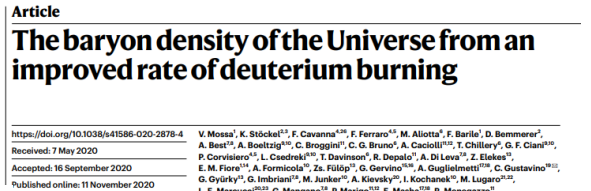


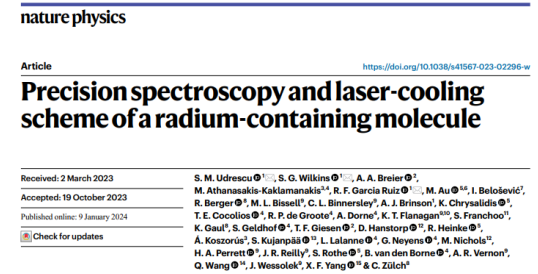
UK NP publications in refereed journals

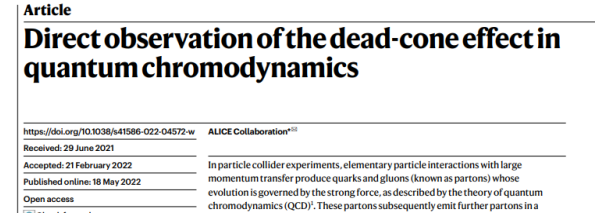


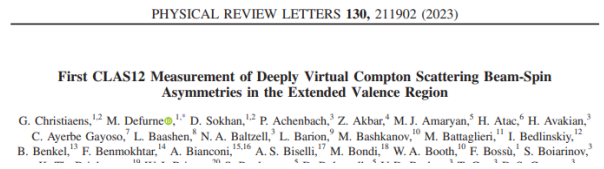
OPEN

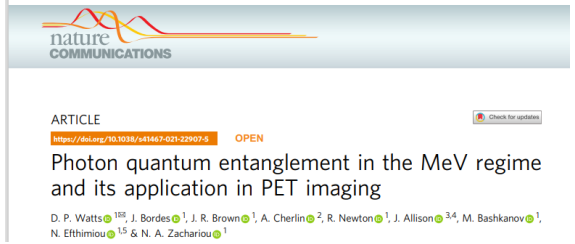
Charge radii of exotic potassium isotopes challenge nuclear theory and the magic character of $N = 32$







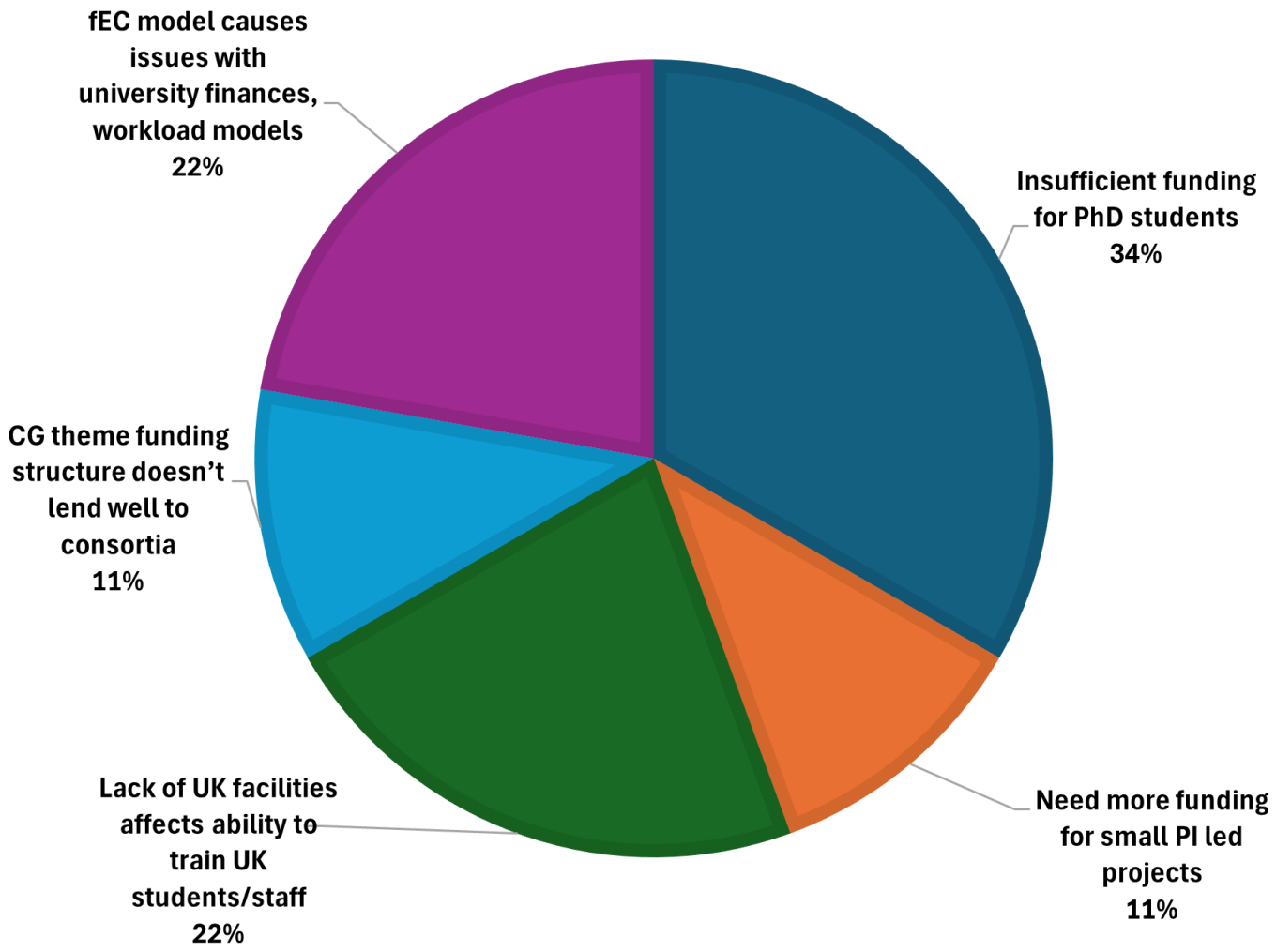




2020-2024: Nature Journals (17),
Phys. Rev. Lett.(105)
Phys. Lett. B (64)

For a list of recent research highlights from UK NP - see backup slides

Difficulties expressed by the community



CAVEATS:

Responses from 7 (of 12) groups

Thanks for listening

Some recent research highlights from UK NP

- Improved cross-sections of the deuterium burning D(p,γ)^{3}He reaction led to BBN estimates of the baryon density at the 1.6 percent level, in excellent agreement with a recent analysis of the cosmic microwave background Nature **587**, 210 (2020).
- Measuring correlations in the momentum space between hadron pairs, produced in ultrarelativistic proton–proton collisions at the CERN Large Hadron Collider (LHC), provided a precise method with which to obtain the missing information on the interaction dynamics between any pair of unstable hadrons Nature 588, 232 (2020),
- The spin polarization of the recoiling neutron in deuterium photodisintegration was measured. The results could be related to the excitation of the d*(2380) hexaquark Phys. Rev. Lett. **124,** 132001 (2020).
- High-precision measurements of states above threshold in ^{34}Ar have constrained the astrophysically important 33Cl(p,gamma)34Ar reaction, decisive in identifying the origins of pre-solar grains Phys. Rev. Lett. **124**, 252702 (2020).
- The first *ab initio* calculations of radii and charge densities for open-shell nuclei beyond Sn have been made, comparing well to experiment and paving the way for *ab initio* studies of exotic charge density distributions at the limit of the present *ab initio* mass domain Phys. Rev. Lett. **125**, 182501 (2020).
- The first a-priori lattice QCD calculation showing the presence of a hadron resonance with an exotic combination of spin, parity and charge conjugation quantum numbers Phys. Rev. D 103, 054502 (2021).
- The first mass measurements of neutron-deficient Yb isotopes at TITAN, TRIUMF, established the existence of the N=82 neutron shell up to the proton drip line. Further, the detection and mass measurement of ^{150}Yb marked the first ever discovery of an isotope at TRIUMF Phys. Rev. Lett. **127**, 112501 (2021)
- The predicted quantum entanglement in linear polarisation for annihilation gamma photons was proposed as a method to quantify and remove the unwanted backgrounds in Positron Emission Tomography (PET) Nature Communications **12**, 2646 (2021).
- Joint mass measurements at TRIUMF and NSCL/FRIB investigate the evolution of the exotic N=32 and 34 neutron shell closures in combination with state of the ab-initio calculations Phys. Rev. Lett. **126,** 042501 (2021).
- The experiment performed at CEBAF utilized the Large Acceptance Spectrometer (CLAS) detector to study the Λp→Λp elastic scattering cross section in the incident Λ momentum range 0.9–2.0 GeV/c Phys. Rev. Lett. **127,** 272302 (2021).
- A first ever measurement of timelike Compton scattering which provides a way to test the universality of the generalized parton distributions has been made with the CLAS12 detector at JLab Phys. Rev. Lett. **127**, 262501 (2021).
- ALICE confirmed the dead-cone effect and important prediction from perturbative QCD. Careful measurements using charmed quarks as partons show that small angle radiative splittings in jet evolution are suppressed for larger parton masses Nature 605, 440 (2022).
- A recent highlight from the nucleon tomography program at JLab includes a first experimental extraction of all four helicity-conserving Compton form factors (CFFs) of the nucleon as a function of Bjorken x, while systematically including helicity flip amplitudes with extremely high precision. Phys. Rev. Lett.**128**, 252002 (2022).
- From the nucleon tomography program at JLab, a first experimental extraction of all four helicity-conserving Compton form factors (CFFs) of the nucleon as a function of Bjorken x with extremely high precision has been performed Phys Rev. Lett. **128**, 252002 (2022), and a first CLAS12 measurement of deeply virtual Compton scattering beam-spin asymmetries in the extended valence region Phys. Rev. Lett. **130**, 211902 (2023).
- Measurements performed at the Triangle Universities Nuclear Laboratory were interpreted in the chiral effective field theory framework to extract the electromagnetic dipole polarizabilities of the proton Phys. Rev. Lett. **128,** 132502 (2022).
- A resonance-like structure near threshold in the four-neutron system that is consistent with a quasi-bound tetraneutron state existing for a very short time was observed Nature **606**, 678 (2022).
- First mass measurements of neutron-rich Cr isotopes established the summit of the N=40 island of inversion Phys. Lett. B **833**, 137288 (2022)
- An abrupt change in the nuclear dipole moment at N = 82 was observed. Together with the accompanying theoretical findings, it led to an understanding of how seemingly simple single-particle phenomena naturally emerge from complex interactions among protons and neutrons Nature **607**, 260 (2022).
- Recent results from two-nucleon knockout reactions in inclusive elastic electron scattering from hydrogen-3 and helium-3 mirror nuclei have yielded new insights on the pairing up of nucleons inside the nucleus Nature **609**, 41 (2022).
- Simultaneous γ-ray and electron spectroscopy demonstrated a step-up in experimental sensitivity and paves the way for systematic studies of electric monopole transitions in this region Communications Physics **5**, 213 (2022).
- Nucleon drip lines were determined using several relativistic energy density functionals with different underlying interactions, demonstrating considerable alterations of the neutron drip line with temperature increase, especially near the magic numbers Nature Comm. 14 4834 (2023)
- A new technique for determining fission barriers was demonstrated which will open the way for the study of fission properties with short-lived nuclear species Phys. Rev. Lett. **130**, 202501 (2023).
- Direct mass measurements of neutron-deficient nuclides at GSI closing on ^{100}Sn Phys. Lett. B **839**, 137833 (2023)
- ALICE measured the hypertriton $_{\Lambda}^{3}$H lifetime and Λ separation energy solving a puzzle as their values previously seemed inconsistent with models of the particle Phys. Rev. Lett. 131, 102302 (2023).
- Measurements of the vibronic structure of radium monofluoride molecules were reported, which demonstrated an improvement in resolution of more than two orders of magnitude compared to the state of the art Nature Physics **20**, 202 (2024).
- The calculations using the ^{16}O + ^{92}Zr collision showed that the inclusion of nuclear friction effects increased the fusion probability significantly, improving the agreement between the theoretical and experimental fusion barrier distributions Phys. Lett. **B 854**, 138755 (2024).
- First measurement of neutron capture on radioactive ^{204}Tl leads to reduced uncertainty in predicted ^{204}Pb abundance, which is in agreement with solar system observations Phys. Rev. Lett. **133**, 052702 (2024)
- The role of the underlying single-particle structure for the Pygmy Dipole Resonance was established Phys. Rev. Lett. **125**, 102503 (2020)

Difficulties expressed by the community

Limited number of STFC funded PhD students and PDRAs puts severe constraints on opportunities to train young researchers and capitalize on leadership roles within international collaborations.

Lack of UK facilities in NP limits opportunities for ‘in-house’ training and support to research activities overseas.

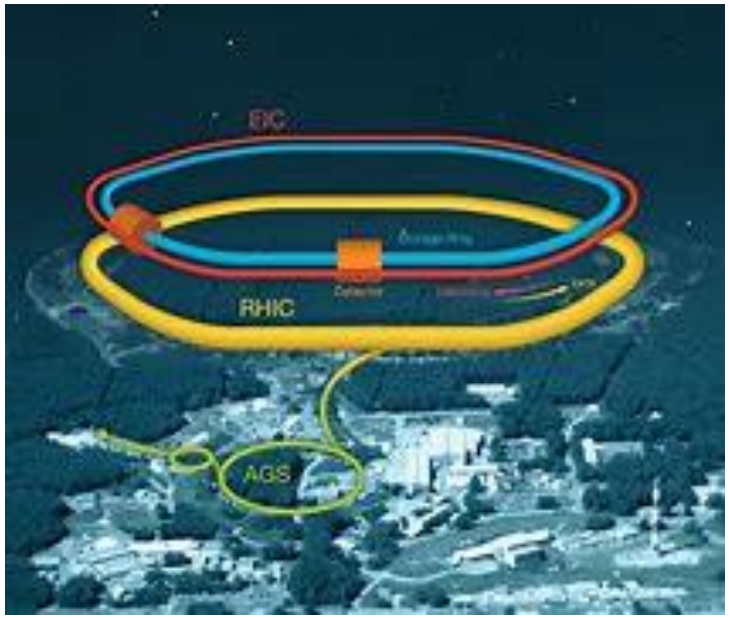
Difficulty recruiting PhD students. Most applicants are international but don’t understand that they can both be paid a bursary but that they have to contribute international portion of tuition fee (seems illogical to them), EU students no longer apply now they are international, few home students apply - very small pool of candidates. Last two studentships delayed by one year

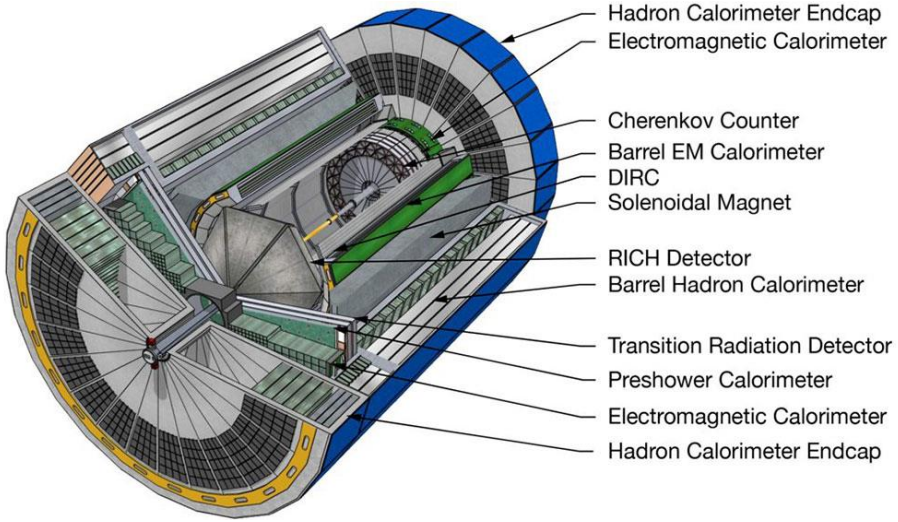
STFC funding through CG is now very far removed from fEC model as originally conceived, causes issues with university finance, inputs into ‘workload allocation models’ etc

Easier and more flexible/responsive funding scheme (funding PhD students for instance) to initiate new project ideas or collaboration is what the community is currently missing, This is important to respond quickly to new opportunities when they appear and to maintain for a growing and healthy community.

The current algorithmic method of PhD student funding significantly impacts areas that are below a certain thresho in funding/academic staff (STFC). This means that high energy physics might get x3 more students while their CG grant income is not x3 more. Involvement in large HEP projects may drive this and since a similar large investment in nuclear is not foreseen it is not possible to rebalance this. The overall talent pipeline in Nuclear Physics is

UKRI infrastructures project – Electron ion collider (Brookhaven)





In the international EIC detector collaboration (ePIC) UK provides

- Technical Coordinators Silicon Vertex Tracker and Electron Tagger
- Detector Subsystem Leader of the Far Backward Pair Spectrometer (Luminosity Monitor)
- Co-convenors of the cross-cutting Far Forward/Far Backward working group.
- Co-convenors of the Inclusive Physics working group, and Exclusive, Diffractive and Tagging working group.
- UK also represented on the ePIC Executive board

UK contribution recently funded by UKRI infrastructure fund - Seven universities and two national laboratories

Contributions to ePIC (SVT (MAPS), electron tagger (TIMEPIX), calorimetry and EIC accelerator