

# United Kingdom mid-term ECFA report

102<sup>nd</sup> PECFA meeting, Alba Synchrotron, Spain

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London)

# Introduction

- Country profile
- HEP in the UK
- UK large scale (HEP related) infrastructure
- Community and organisation
- STFC funding
- CERN industrial return
- Physics higher education
- UK Research and innovation
- HEP and Brexit
- Major events since last ECFA visit to UK
- Theory
- **Computing**
- Accelerators (HL-LHC, ILC/CLIC, FCC, **PWA**)
- Detector R&D

UK particle physics (inc particle astro) experimental programme (uneven selection, **RED not shown**)

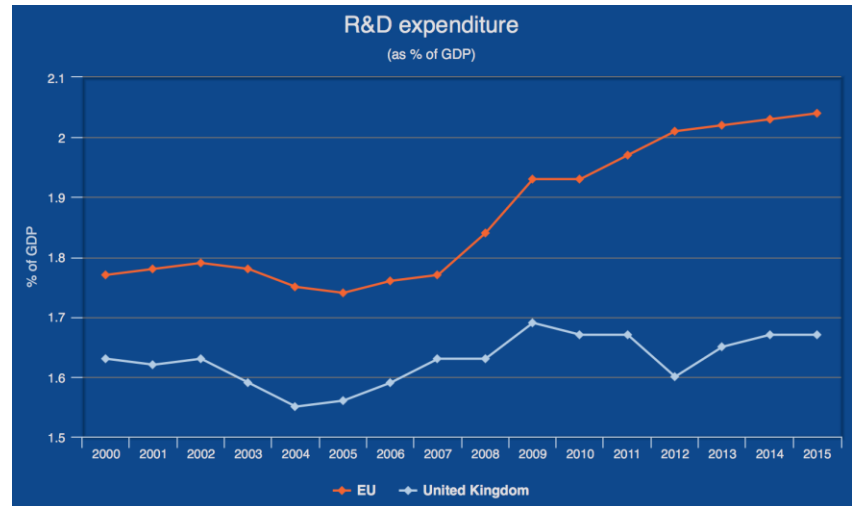
- LHC experiments
  - ATLAS, CMS, LHC-b, **ALICE**
- Neutrino physics
  - **SBND, MicroBooNE, NOvA**, T2K, DUNE, Hyper-K
- Flavor physics
  - **NA62, BES-III**
- Dark matter
  - LUX, LZ, **DEAP-3600, Darkside**
- Astroparticle
  - **CTA, LIGO**
- Precision low energy
  - **g-2, Mu2e, Mu3e, Comet, (n,e,p)EDM, SNO+, SuperNemo**
- Hidden sector
  - **SHiP**

# Country profile

- Population : 66.2 M
- Area : 242,495 km<sup>2</sup>
- GDP/capita : 33.8 k€
- R&D/GDP (2016): 1.69 %



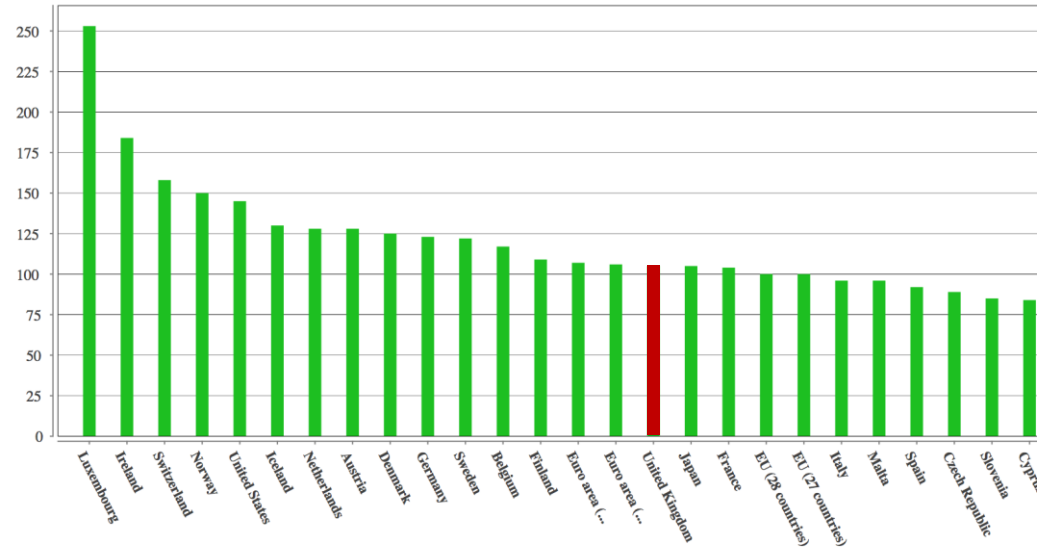
- CERN annual contribution (2018):
  - 177.9 MCHF
  - Second largest contributor



# Country profile (GDP and R&D)

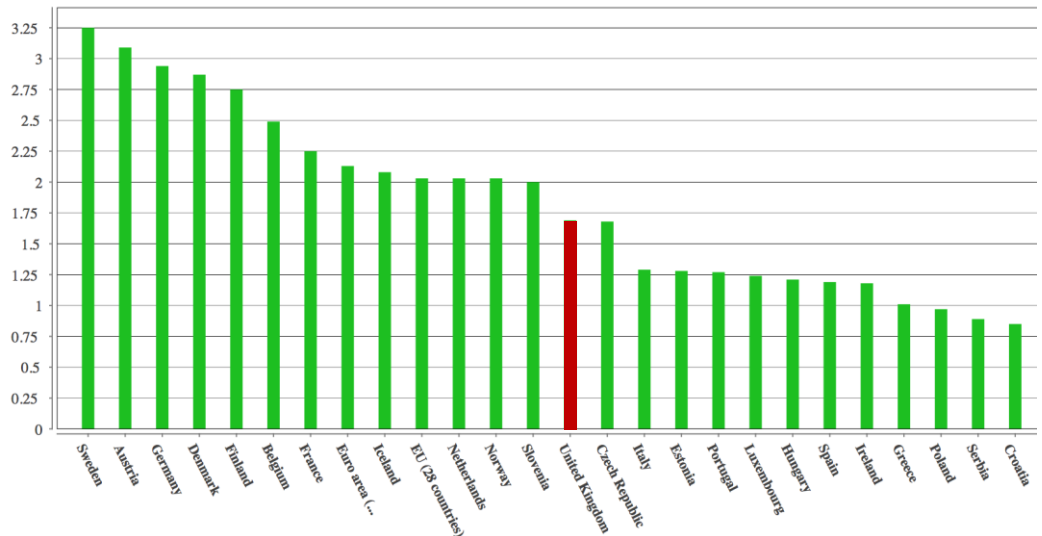
- GDP

- Units are PPE
- 13<sup>th</sup> in the EU
- Inline with EU28 average

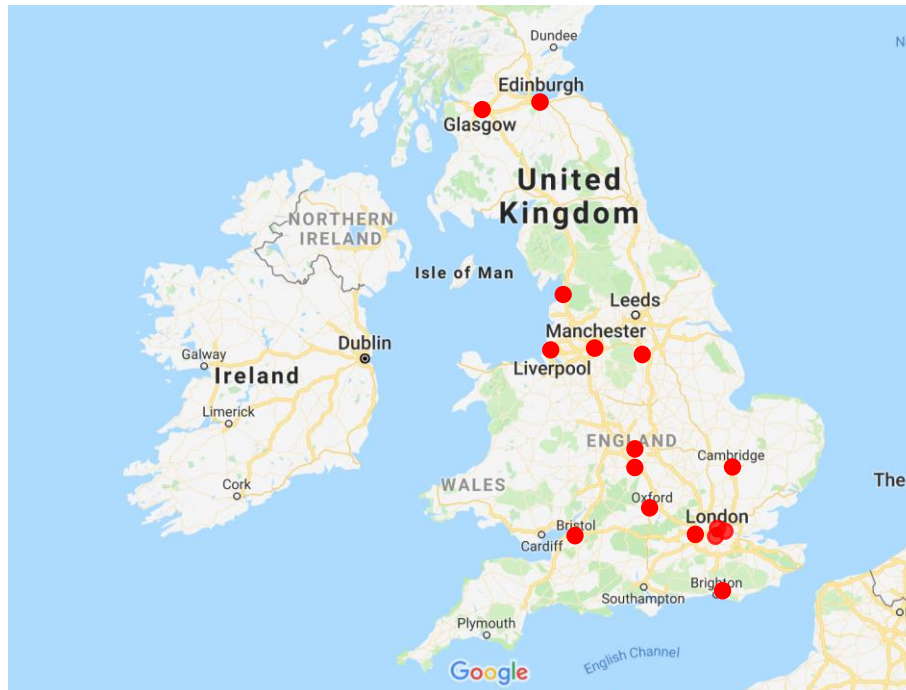


- R&D

- 1.69%
- 12<sup>th</sup> in the EU
- Below EU 28 average



# UK University experimental HEP groups



# UK University theoretical HEP groups



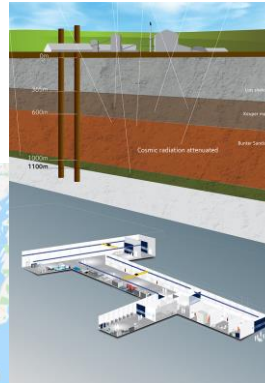


# UK large scale HEP related infrastructure

Daresbury Laboratory



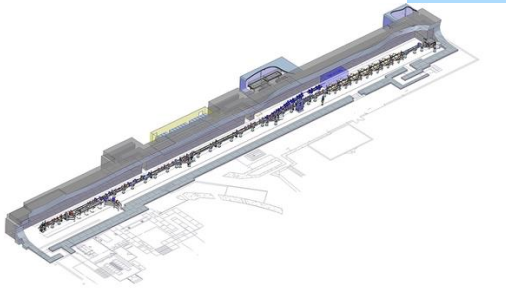
Boulby underground lab



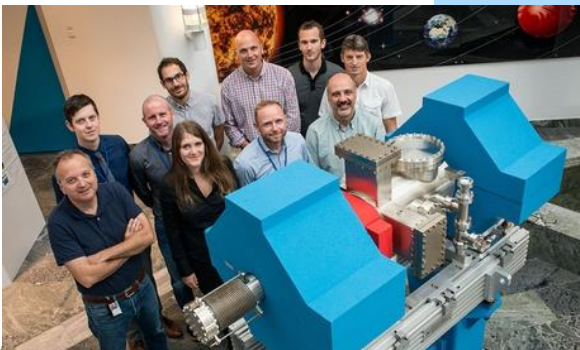
Diamond light source



CLARA



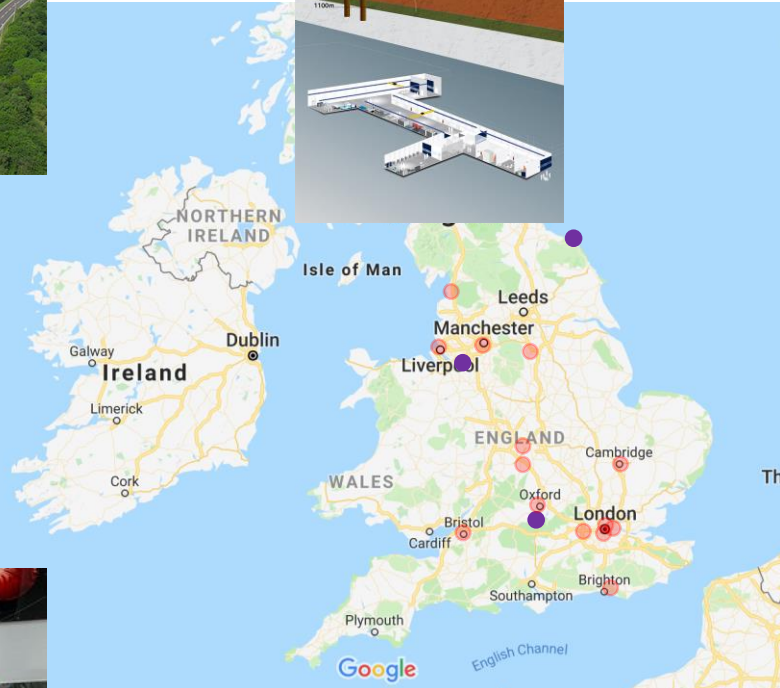
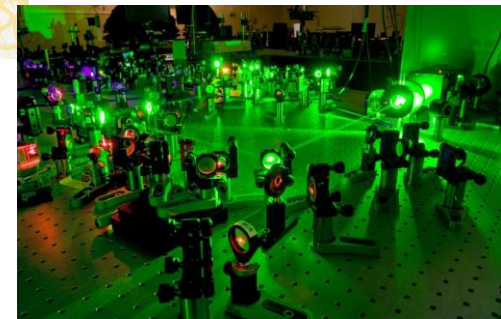
ASTeC/Engineering technology centre



ISIS neutron and muon source



Central laser facility



# HEP in the UK

- 16/22 (experimental/theoretical) University groups
- National laboratories
  - Rutherford Appleton Laboratory, Daresbury Laboratory, Boulby underground laboratory
- Experimental (16)
  - Birmingham, Bristol, Cambridge, Edinburgh, Glasgow, Imperial, Lancaster, Liverpool, Manchester, Oxford, Queen Mary, Royal Holloway, Sheffield, Sussex, UCL, Warwick
- Theoretical (22)
  - Cambridge, City, Durham, Edinburgh, Glasgow, Herriot-Watt, Imperial, Kings, Lancaster, Liverpool, Manchester, Nottingham, Oxford, Plymouth, Queen Mary, Royal Holloway, Sheffield, Southampton, Surrey, Sussex, Swansea, UCL
- Funded by Science and Technology Research Council (STFC)
  - National facilities, High energy Physics, Astronomy, Particle Astrophysics, Nuclear, Theory, Computing



# Community and organisation

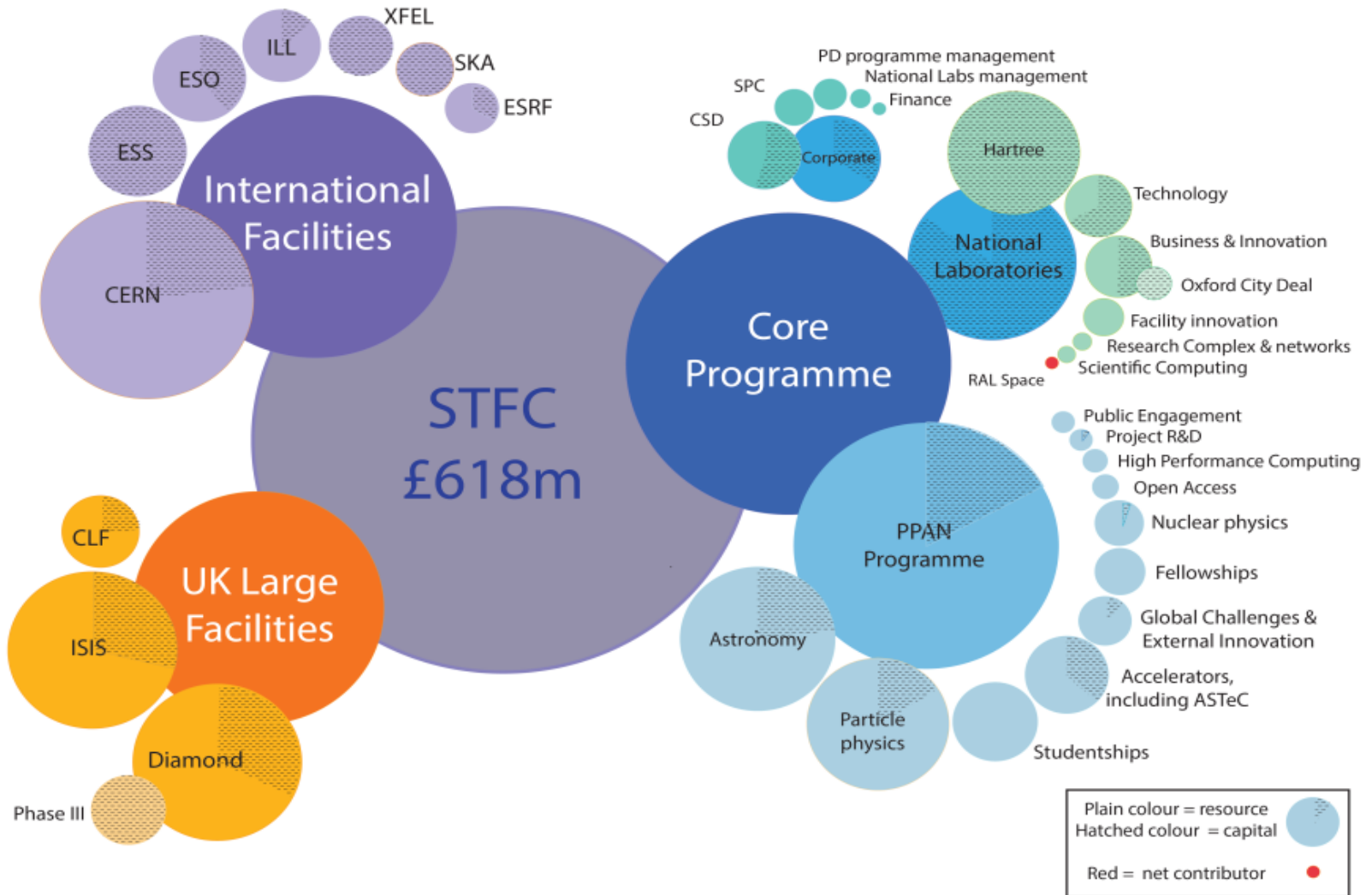
- Community well organised
  - STFC Advisory boards
  - Institute of Physics (IoP)
  - UK components of large collaborations
  - Community meetings
    - PPAP 16-17<sup>th</sup> July 2018
  - European Strategy Update Workshop
    - IPPP 16-18<sup>th</sup> April 2018

## Particle physics community meeting 16-17<sup>th</sup> July 2018

	<b>Report from the Durham meeting</b>	Sinead Farrington
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	11:10 - 11:35
	<b>Report from PAAP</b>	Chamkaur Ghag
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	11:40 - 11:50
12:00	<b>Future of neutrino physics and non-accelerator experiments</b>	Dave Wark
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	11:55 - 12:10
	<b>Future accelerator options</b>	Ian Shipsey
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	12:15 - 12:35
13:00	<b>Lunch</b>	
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	12:40 - 13:30
14:00	<b>UK input to the European Strategy: Discussion</b>	Claire Shepherd-Themistocleous
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	13:30 - 15:10
15:00	<b>ATLAS</b>	Dr. Gabriel Facini et al.
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	15:10 - 15:35
	<b>CMS</b>	Prof. Gavin Davies
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	15:35 - 15:55
16:00	<b>Discussion</b>	
	<i>Pickavance Lecture Theatre, Rutherford Appleton Laboratory</i>	15:55 - 16:10

<https://conference.ippp.dur.ac.uk/event/729/overview>  
<https://conference.ippp.dur.ac.uk/event/661/overview>

# STFC Funding breakdown



# Funding

- Primary funding from STFC (Science and Technology Facilities Council)
  - Subscriptions (CERN, ESO, ILL, ESRF, European XFEL, ESS, etc)
  - National Laboratories
  - University groups typically funded by 3 year “consolidated grants”
  - Specific project funding from STFC
    - LHC experiment upgrades
    - Capital investment in detector construction
- UK universities hidden funder
  - Higher education in the UK effectively student fee funded
  - Faculty staff costs
- European Union
  - FP6, FP7, ERC, MCSA, H2020

# Funding

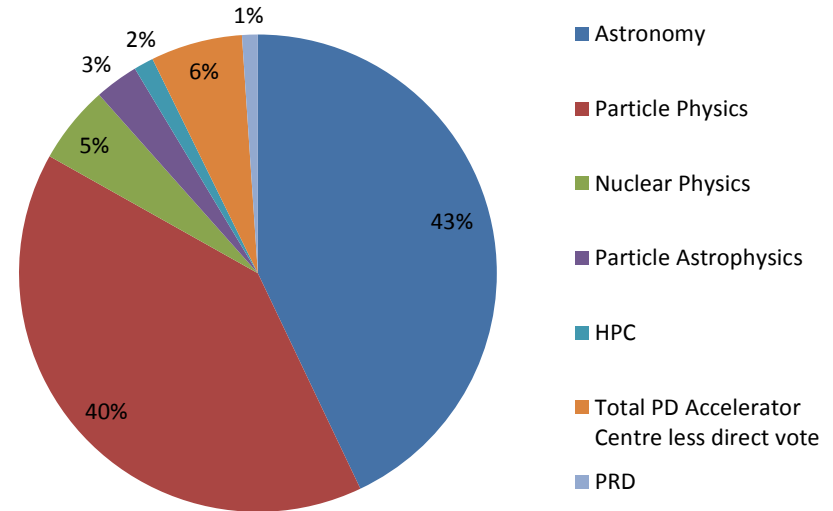
- Particle Physics, Astronomy and Nuclear (PPAN)

- 2017/18 : £107M
- Particle physics 40%
- Astronomy 43%
- Accelerators 6%
- Nuclear 5%
- Particle Astro 3%

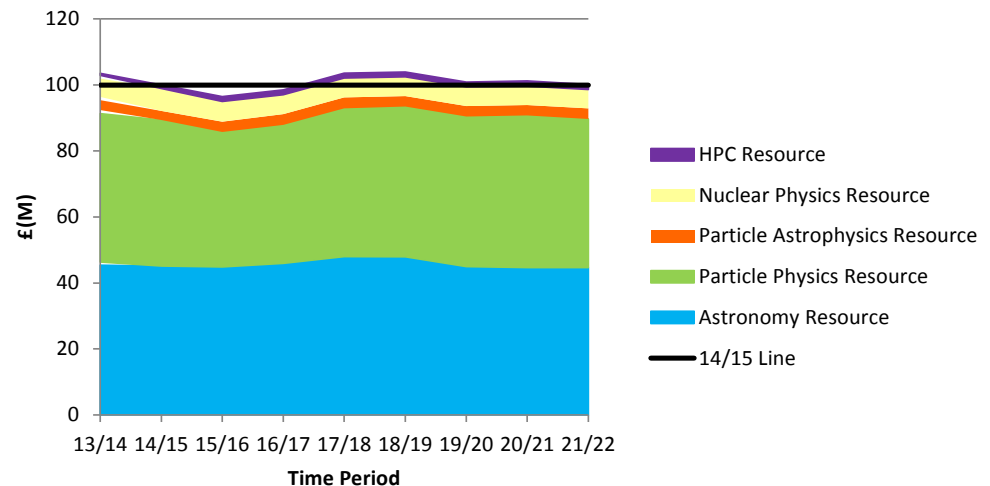
- Maintained flat funding

- 2014-2022
- Constant erosion due to inflation and exchange rate changes

**Planned 2017/2018 PPAN Subject Areas plus Accelerators & PRD**



**Actual and Projected Spend (Resource)**

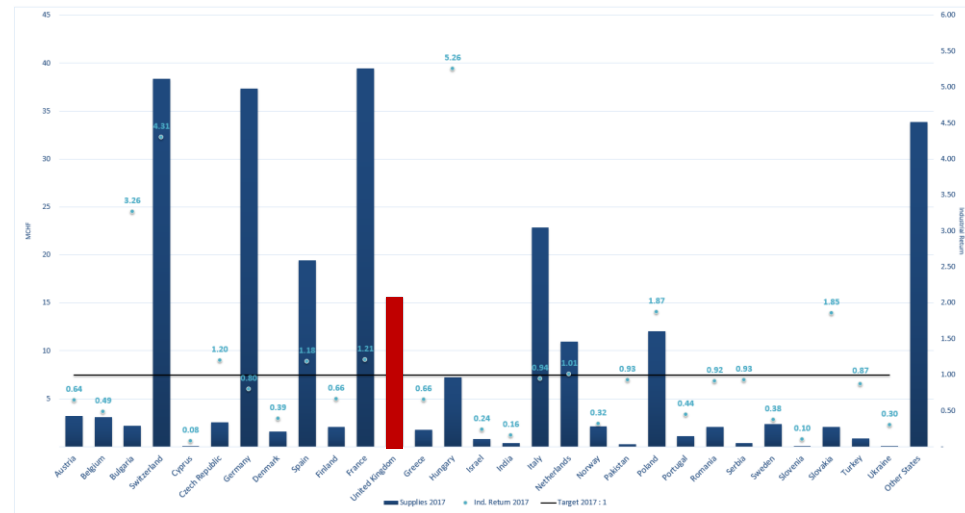
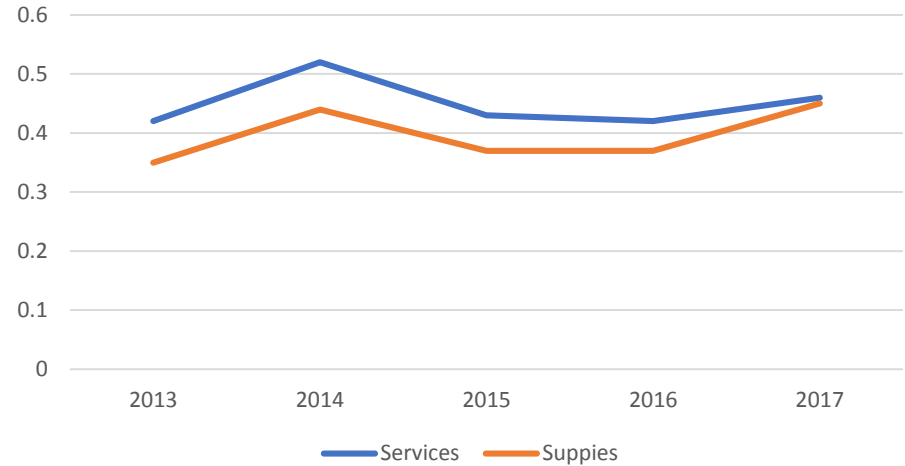


# CERN industrial return

<http://procurement.web.cern.ch/en/>

- 2017
  - Contracts in supplies
    - 15.6 MCHF
  - Contracts in services
    - 9.7 MCHF
  - Industrial return index
    - Supplies 0.45 (**poorly balanced**)
    - Services 0.46 (**well balanced**)
- LH-LHC could help to improve supplies

UK CERN industrial return coefficient





# Physics education

<https://www.hesa.ac.uk>

- Pre-university (16-18) education in UK focused on 3-4 subjects
- Applications for Physics subjects at university
  - 2012/13 : 4762
  - 2013/14 : 5304
  - 2014/15 : 5454
- 64 Universities teach physics at BSc (3 year), MSci/MPhys (4 year)
- STFC funded PhD places
  - Total expt, theory, nuclear, astro : 220 p.a
  - Experiment : approx. 80 p.a
  - Total larger (project funded, EU, university scholarships), full census needed before next RECFA visit (including diversity data)

# UK Research and innovation (UKRI)

<https://www.ukri.org>

- Restructured all government funding agencies under a coherent new entity (April 2018)
  - UK Research and Innovation (UKRI)

## UK Research and Innovation



Innovate UK



# New opportunities from UKRI

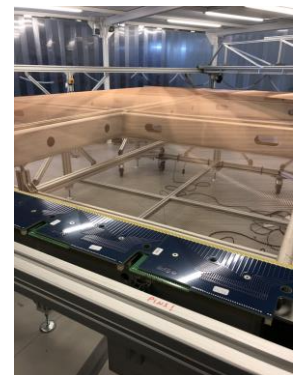
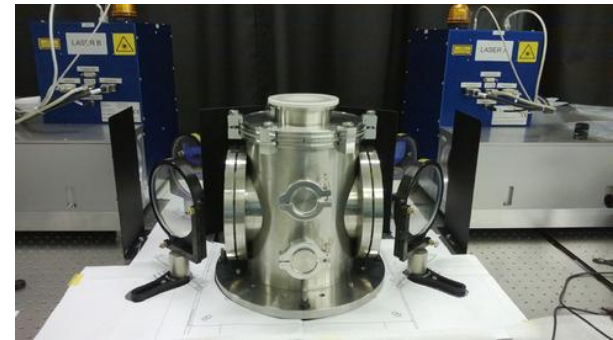
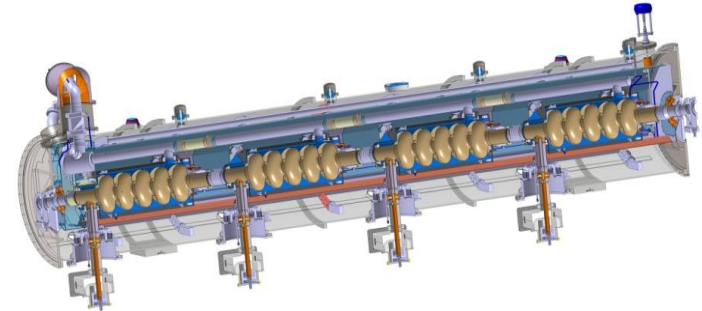
- **Industrial Strategy Challenge Fund (ISCF)** – Wave 2 challenges launched, open call for Wave 3 ideas
- **Global Challenges Research Fund (GCRF)** – up to £200 million of the £1.5 billion total collective fund unallocated
- **Strategic Priorities Fund (SPF)** – £755 million over three years, bids from any BEIS-funded research and development organisation
- **Talent Fund** – £300 million over three years
- **Commercialisation Fund** – £108 million
- **Strength in Places Fund** – £115 million over three years for collaborative bids between research organisations and business to support regional growth
- **Fund for International Collaboration** – £110 million over three years

# HEP funding and Brexit

- Potential overall reduction in HEP funding in the UK
  - Significant problems anticipated if UK government does not step in
  - Pressure on whole research programme in the UK (not just HEP) might have a knock-on effect on HEP
- Other important effects
  - UK has significant internationalised community
  - Potential brain drain from UK universities and laboratories
  - UK could be seen as less attractive to researchers

# Events since last RECFA visit to the UK

- European Spallation Source
  - Officially joined 30/06/2016
  - 10% of 1.8 B€ project
  - 165 M€ contribution
  - Instruments, cryomodules, engineering
- European XFEL
  - Officially joined 19th March 2018
  - 26 M€, 2% of construction cost
  - 2% of operation budget
  - Mainly X-ray instruments
- LBNF/DUNE
  - Announced 21 September 2017
  - 65 M€ capital investment
  - DUNE, proton target, PIP-II





# Theory

- World leading activity based on long and history
- Lattice field theory
  - LHCb, NA62, muon  $g-2$ , QCD parameters (quark masses and coupling)
- Phenomenology
  - PDFs, MC generators, precision QCD, Higgs (SM and BSM), neutrino physics (SM and BSM), dark matter
- QFT
  - Amplitude calculations; exact solutions (SUSY); integrability; applications of AdS/CFT correspondence; solitons; speculative ideas such as Lorentz-violating theories.
- **Cosmology**
- **Strings**
- Particle physics theory funding
  - £6.6M/p.a
  - **32 post-docs awarded in 2016**
- Subject areas
 

• Cosmology	17%
• Lattice	16%
• Phenomenology	30%
• QFT	21%
• Strings	17%
- **Clear need to improve and support the numbers of post-docs**

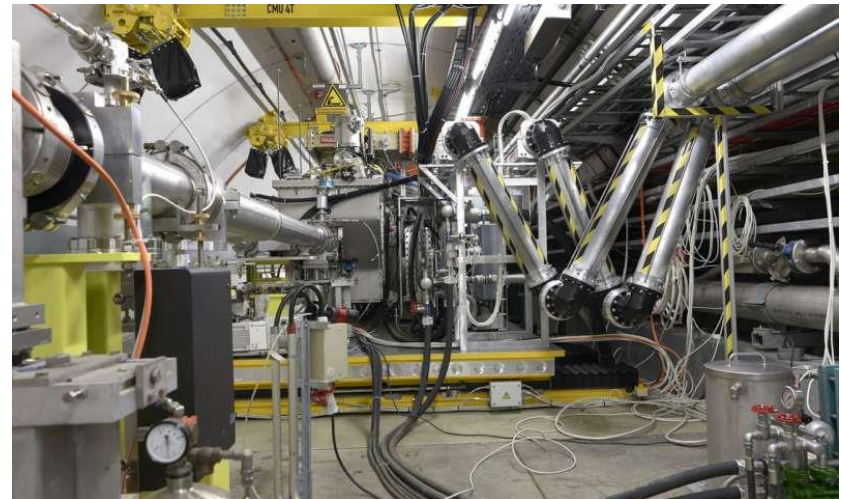
# Accelerators

- ILC/CLIC
  - Long standing (>10 year involvement)
  - Focus on beam delivery system
- LH-LHC (STFC-CERN funded)
  - More recent (~5 years), collimation, crab-cavities, beam diagnostics
- EuroCircCol EU design project
  - Machine detector integration
  - IR design
  - Inner triplet

ATF2 prototype ILC/CLIC final focus system




Crab cavity test system installed in the SPS



# Detector R&D

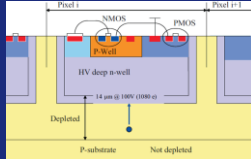
- Established strengths
  - Silicon detectors
  - Readout and DAQ
  - Trigger system
- Developing strengths
  - Neutrino detectors
  - Large scale LAr DUNE
  - LArTPC
  - HPTPC



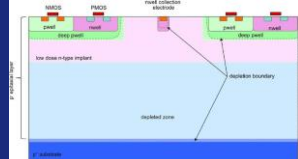
**Depleted-MAPS**

In standard CMOS charge is collected by diffusion. If the sensor bulk can be depleted the induced E-field will result in charge collection by drift. (High-Voltage-CMOS or High-Resistivity-CMOS)

Higher signal and faster charge collection. This allows to combine the benefits from Hybrid sensors (radiation tolerance and speed) with those of MAPS (integration of analogue and digital logic, lower cost, lower material).



*I. Peric, NIMA 650 pp. 158-162, 2011*




*W. Snoeys et al. DOI 10.1016/j.nima.2017.07.046*

Achievements to date: pixel sizes  $50 \times 50 \mu\text{m}^2$ ; radiation tolerance to  $\sim 2 \times 10^{15} \text{ neq/cm}^2$ ; timing 10-15 ns; shallow collection depth allows thinning to 50  $\mu\text{m}$ .

Active R&D:

- Sensor development for Mu3e and ATLAS HL-LHC pixels
- Generic R&D to push down timing resolution  $< 1 \text{ ns}$  (RD50)

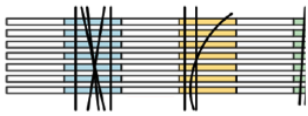



## ATLAS & CMS Phase II: need for hardware track trigger

**ATLAS**

- Based on current FTK system
- Track-filtering: pattern-recognition with AM
- Track-fitting: linearised algorithms in FPGAs

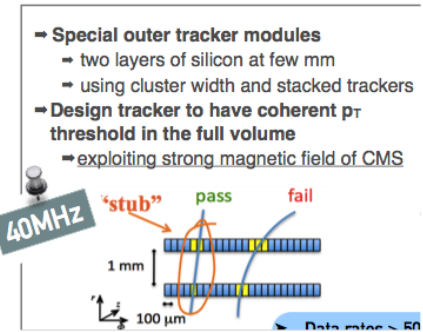
Associative Memories

**AM2020:**  
28nm technology  
250 MHz clock

**CMS**

- Special outer tracker modules
  - two layers of silicon at few mm
  - using cluster width and stacked trackers
- Design tracker to have coherent  $p_T$  threshold in the full volume
  - exploiting strong magnetic field of CMS



Track Finding stage will use FPGA (Hough Transform or Kalman Filter)

# Summary

- UK maintains a diverse and balanced programme
  - Well aligned with the current European Strategy for Particle Physics
    - Maximise scientific return from CERN/LHC
  - Positioned well for potential discoveries
  - Well evolved discussions in the UK regarding strategy update
  - Strong involvement with LHC experiments (and upgrades)
  - Large investment in future long base line neutrino programme (DUNE, perhaps HK)
  - Focused direct dark matter programme (LZ)
  - Range of low-energy precision non-collider experiments (g-2, mu2e, mu3e, COMET, nEDM)
- Issues for the next visit to the UK
  - Changes to the funding landscape (UKRI)
  - Effect of Brexit!
  - Erosion of programme due to flat cash
  - Level of investment in theory and particle astrophysics