Science & Technology Facilities Council

Accelerator Science (UK)

Susan Smith
Head of Daresbury Laboratory, Director ASTeC

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WHY ACCELERATOR SCIENCE

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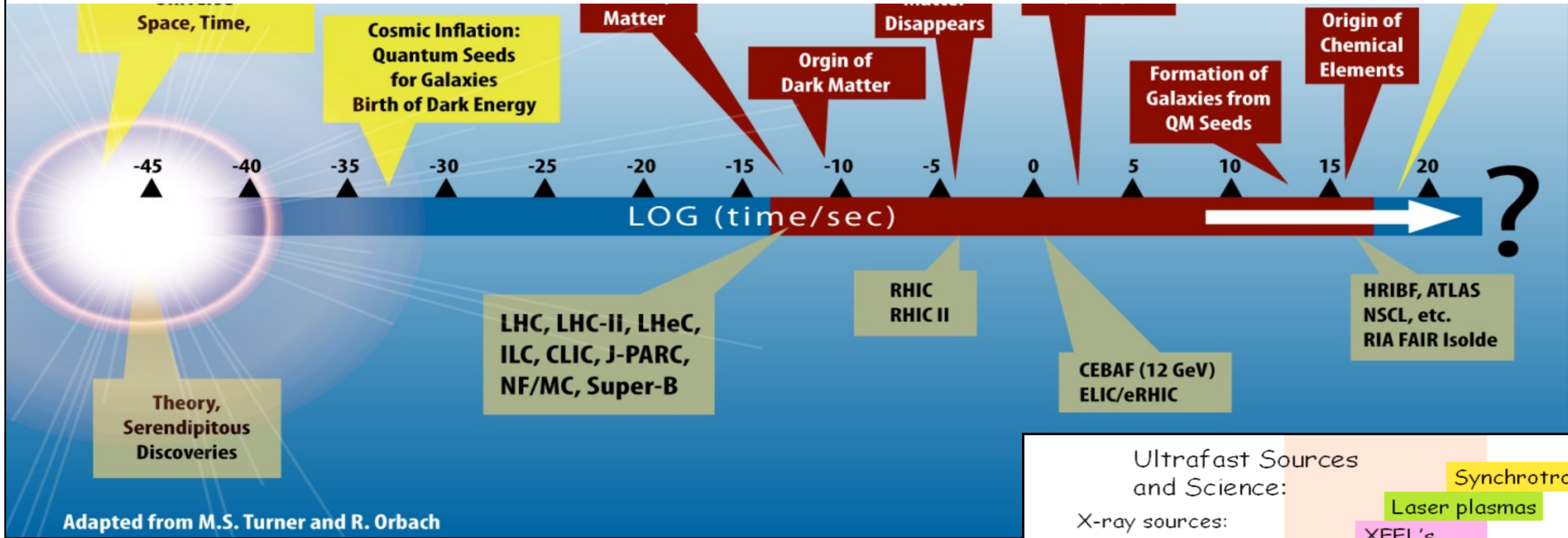
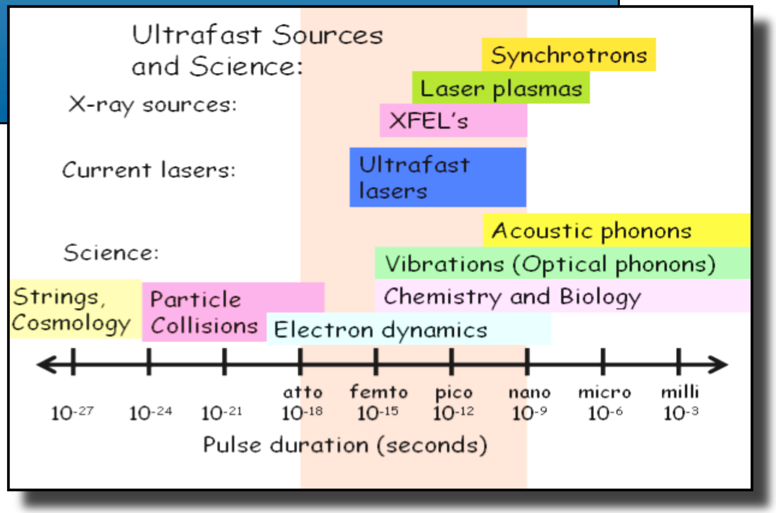
Accelerators For Science

Particle, Nuclear, Photon and Neutron Sciences



Science-driven strategy for accelerator-based science, technology and facilities



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Accelerators for Society

300 B£ End Products Annually

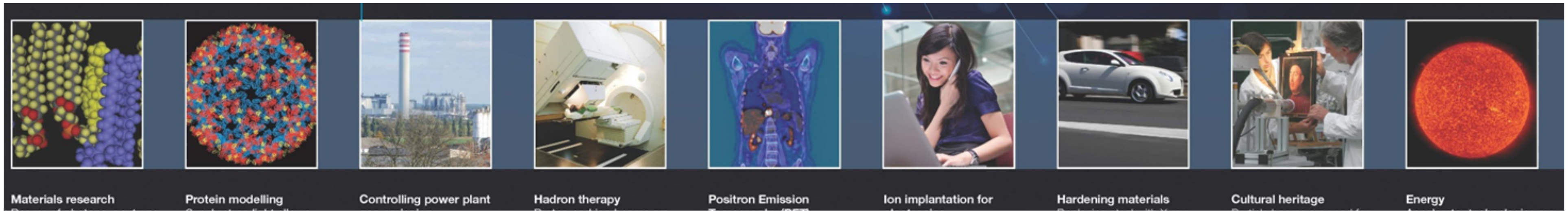
- Produced
- Sterilized
- Examined

>**35,000** Particle Accelerators Built in 60 Y

- 24,000 for Industry
- 11,000 for Cancer

200 Research Accelerators

- Costing 1.6B£ /Y



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ORGANISATION

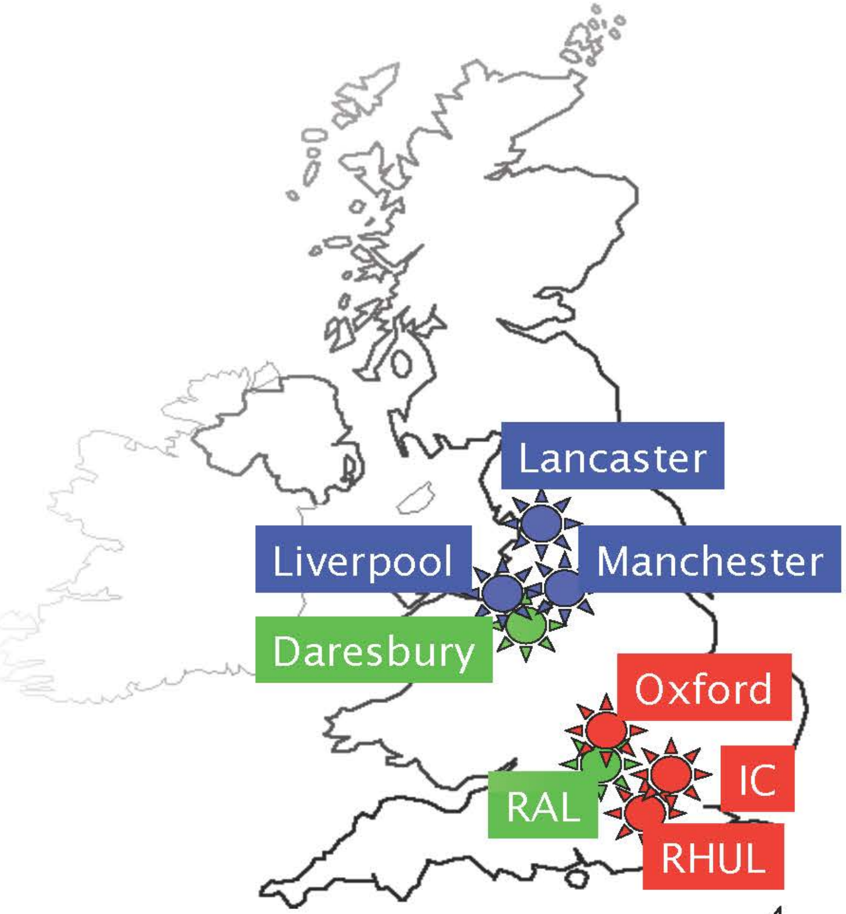
Accelerator Research Bodies

Cockcroft Institute
Lancaster, Liverpool, Manchester, and STFC

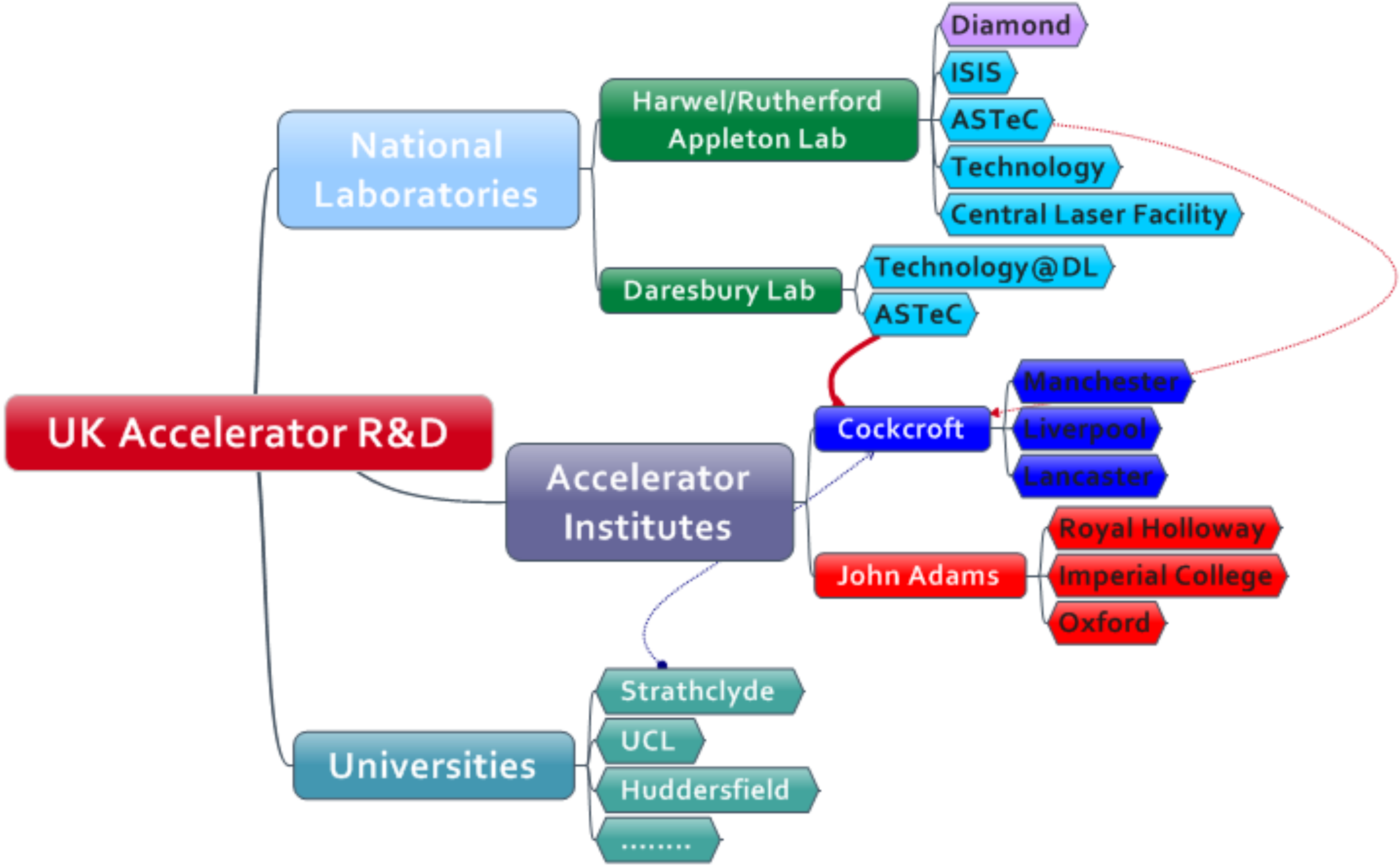
John Adams Institute
Oxford, RHUL, IC

National Laboratories
Daresbury, RAL

Other University Groups
e.g. Strathclyde, Huddersfield



Accelerator R&D



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FUNDING

Funding

- The accelerator R&D programme funded though STFC Science Programmes Office is about £12M per year
- This is complemented by resources within our national laboratories
- The programme leverages additional resources from
  - International Labs
  - Universities
  - Other research councils (EPSRC…)
  - Direct funding from the Government Department
  - European Commission programmes
  - Industry

- – …

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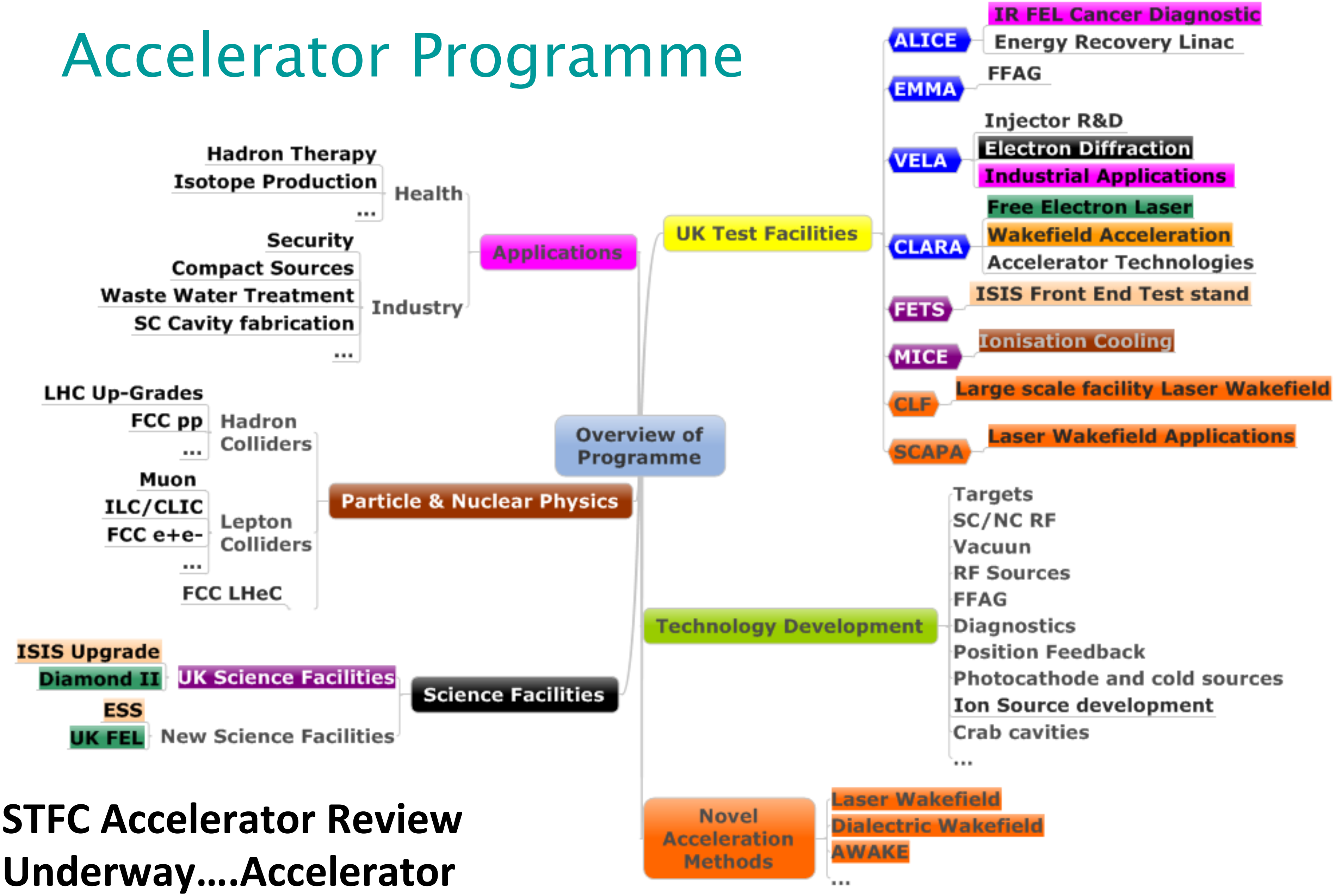
PROGRAMME

Accelerator Programme



STFC Accelerator Review Underway….Accelerator Strategy Board….

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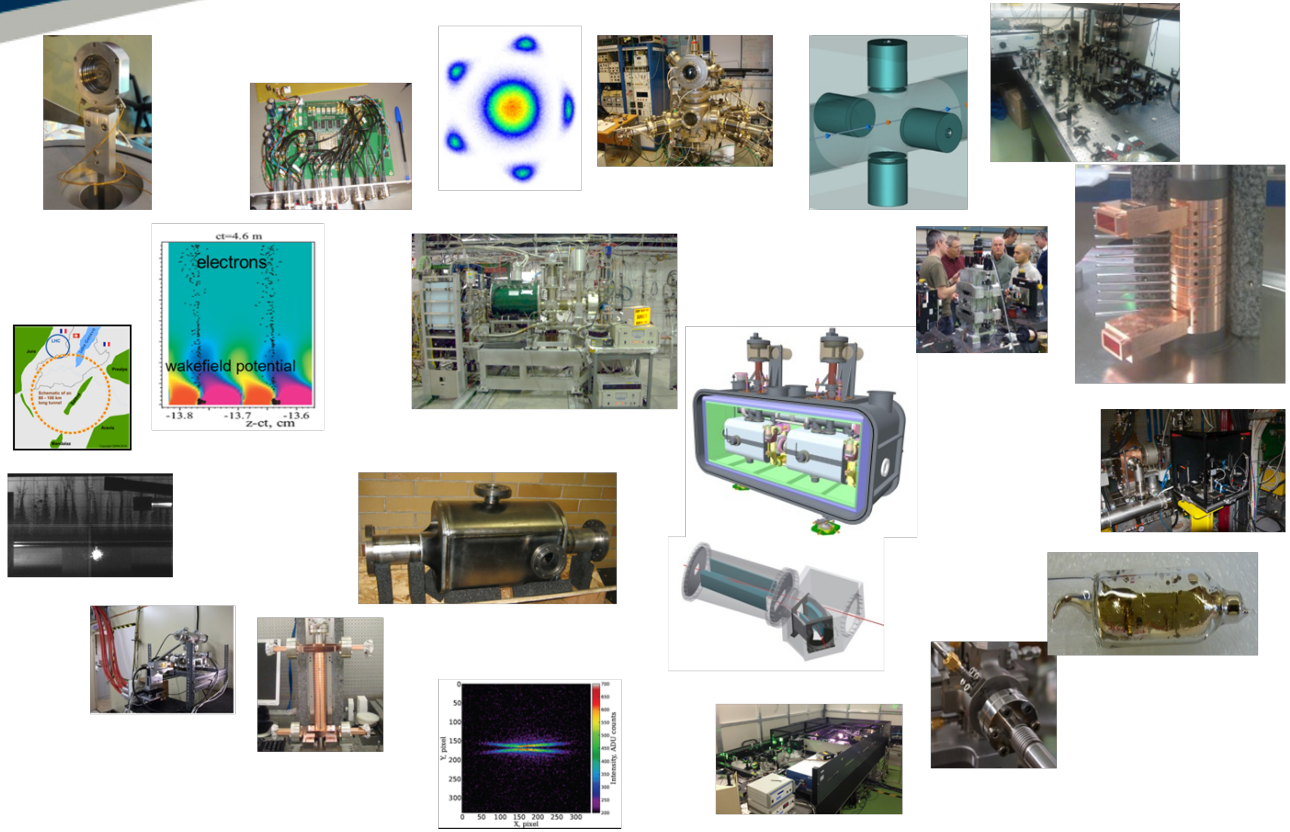
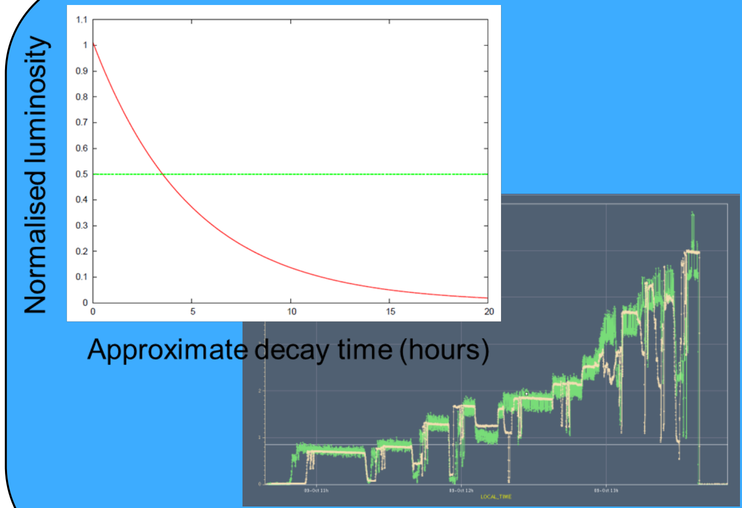


UK R&D ACTIVITIES WITH CERN AND PARTICLE PHYSICS

UK R&D Activities with CERN

- **CERN Programmes**
  - LHC
  - CLIC
  - FCC
- **CERN Projects**
  - LHeC
  - AWAKE – Plasma Wakefield
  - HIE-ISOLDE – Radioactive Ion Beams
  - ALPHA-II – Antihydrogen Catchment
  - ELENA – Antiproton Decelerator
- **Underpinning Technologies**
  - Ion Source – Linac4
  - Beam Dynamics – PS Booster Studies
  - Surface Coatings – E-Cloud Suppression
  - Targets – HiRadMat and RaDIATE Studies
  - Diagnostics – H^- Photo-detachment
- **Knowledge Exchange**
  - CERN Business Incubation Centre @ Daresbury Laboratory

HL-LHC (Nov 2011 – Oct 2015)



Luminosity vs. Time for entire shift (~ 6 hours)

Beam-Beam (WP2)

- Liverpool U (Dep: A Wolski) & STFC.
- HL-LHC strives for highest Luminosity.
- Luminosity levelling, maximises LHC luminosity availability.
- Can be achieved via; beam squeezing, varying offsets, crab cavities or combinations of each.

Crab Cavity (WP4)

•Lancaster U (Dep: G Burt) & STFC.

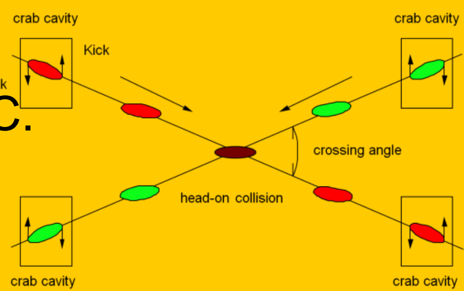
•4-rod cavity designed/built.

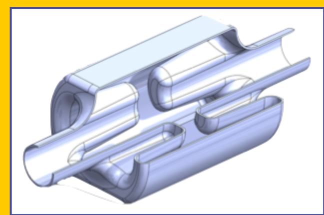
•Undergoing tests @ SM18.

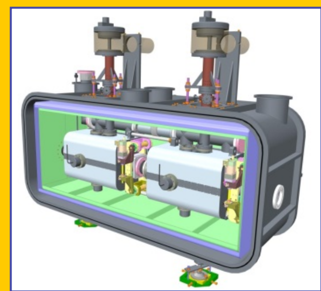
•Cryomodule being developed for beam tests on SPS.

•UK design in final down-selection.

•World’s first hadron beam test!





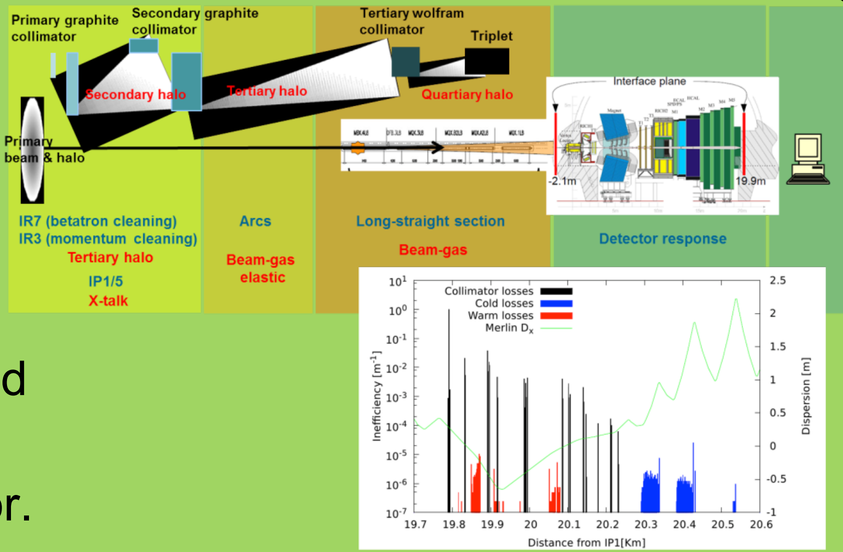


The Cockcroft Institute of Accelerator Science and Technology

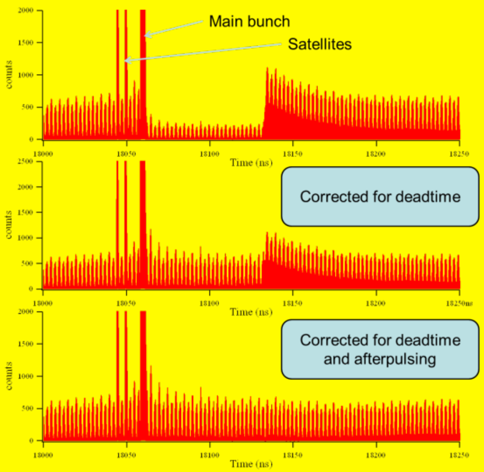
HL-LHC (Nov 2011 – Oct 2015)

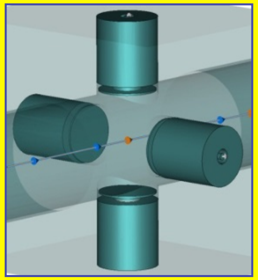
Collimation (WP5)

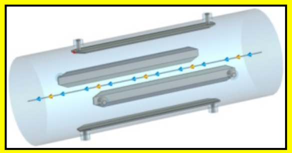
- Manchester U (Dep: R Appleby)
- Collimation configuration optimisation.
- Development of collimation model.
- Assessment of beam-gap losses and IP cross-talk.
- Beam-gas through LSS and detector.



Diagnostics (WP13)



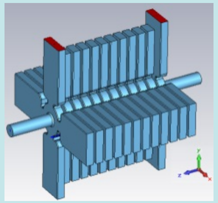




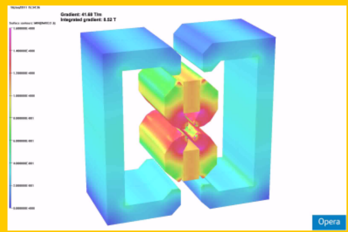
- Liverpool U
- Only small amount of 35,640 LHC buckets contain beam.
- Need large DR (~10^5) to measure 'spill' into these empty buckets.
- Longitudinal density monitor:
  - Online dead-time and after-pulse correction.
  - Critical for bunch normalisation and luminosity.
- Beam position monitors:
  - Button and strip-line variants being developed.

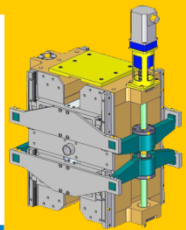
UK-CLIC (Apr 2011 – Apr 2014)

Beam Delivery System:
- Crab Cavity
  - Develop design and fabrication of CC solution for CLIC.
  - Evaluate stability tolerances for CC operation.

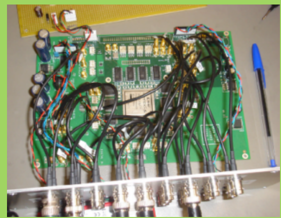


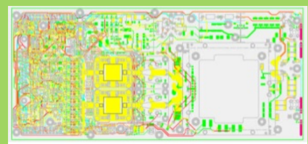
Drive Beam:
- Quadrupole Magnets:
  - To develop a tuneable, high field PM quadrupole solution for CLIC.



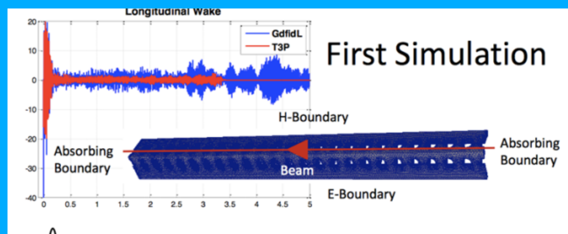


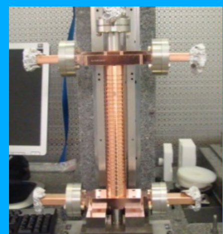

- Phase Feed-forward:
  - To develop a low latency, high bandwidth and extremely high power phase control loop, comprising:
    - Phase monitor (Frascati)
    - Signal down-mixer (CERN)
    - Feedback processor + firmware (Oxford)
    - Drive amplifier (Oxford)
    - Kickers (Frascati)


FONT Feedback Electronics


Kicker Amplifier

Main Beam:
- Structure Design:
  - To design and fabricate a wakefield suppressed X-band accelerating structure for CLIC.



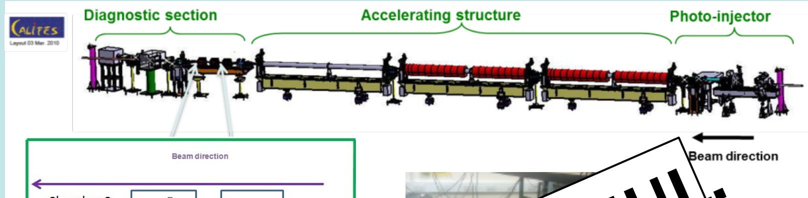


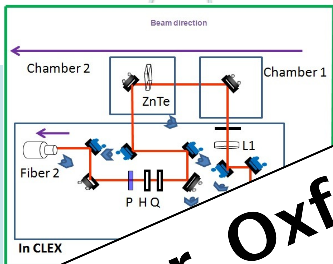
UK-CLIC (Apr 2011 – Apr 2014)

ASTeC, Dundee, Lancaster, Manchester, Oxford & RHUL.
Joint UK-CERN funded 510 man-month programme.

Longitudinal EO:

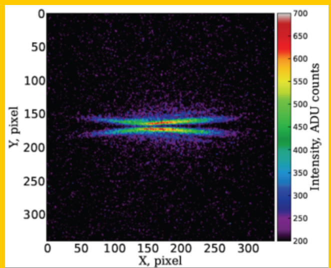
- Demonstrate bunch length measurements of 150 fs sigma electron beams with a resolution better than 20 fs for CLIC using EO techniques.
- Implementation and testing at CALIFES on CTF3.

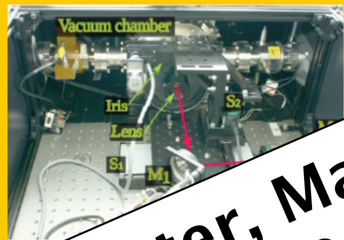




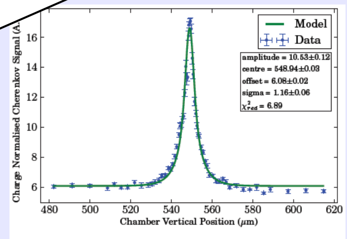
Longitudinal OTR:

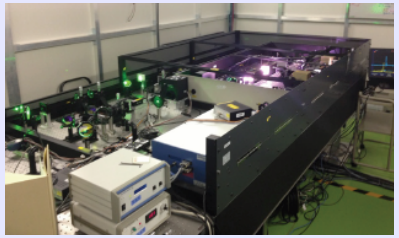
- Development of a sub-micrometer OTR beam profile monitor.





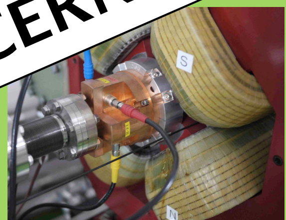
… …ting beam profile laser-wire … at PETRA and ATF-2 to achieve …rformance specifications required for CLIC.





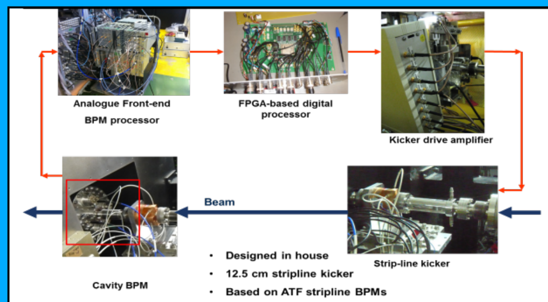
Cavity BPMs:

- Development of lo… …ccuracy.
- Beam test v… …2 as part of FONT f…



Fast Feedback and Control:

- Development of low-latency IP feedback system:
  - 37 nm beam spot achieving ~5 nm stability!
  - Testing at ATF-2 ongoing.



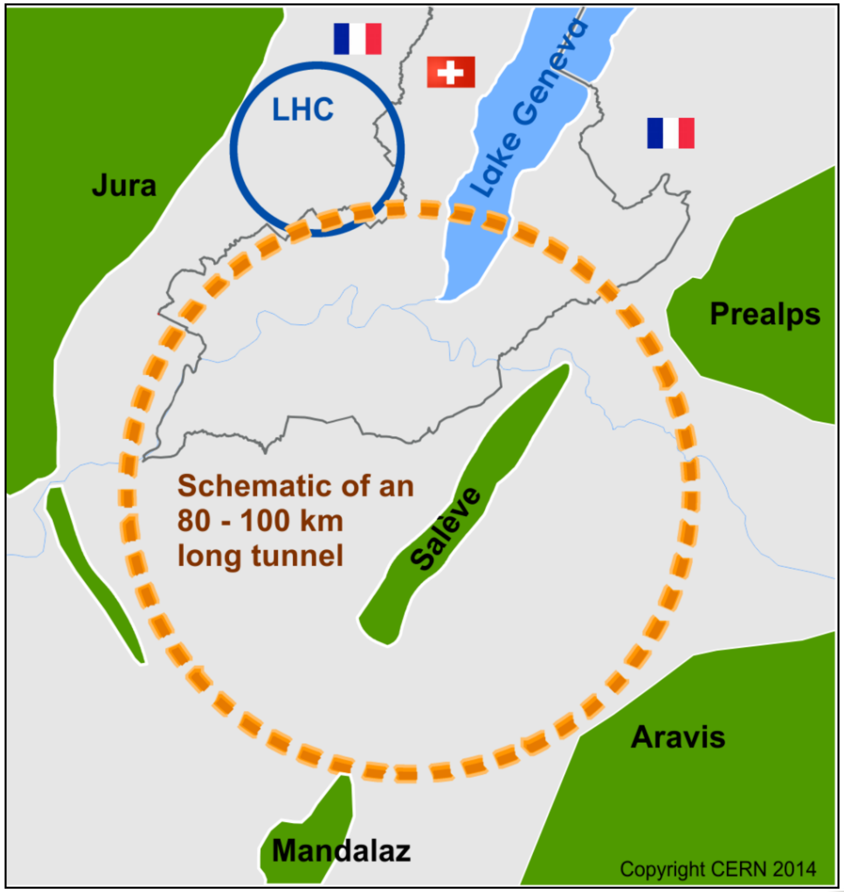
UK-CLIC2 (Apr 2014 – Apr 2017)

- Beam Delivery System:
  - BDS and MDI design optimisation and integration (Oxford & RHUL)
  - Crab cavity (Lancaster)
  - Instrumentation (ASTeC, Dundee, Oxford and RHUL)
  - Beam feedback and control (Oxford)
- Magnet Systems (ASTeC):
  - Main Beam Ring To Main Linac (MB RTML) dipoles
  - Drive Beam Turn Around Loop (DB TAL) dipoles
- Drive Beam Systems
  - Drive Beam phase feed-forward system (Oxford)
  - Drive Beam BPMs (RHUL)
- RF Systems (Lancaster & Manchester):
  - RF source efficiency optimisation
- **Joint UK-CERN funded 488 man-month programme.**

New for Phase-II

Future Circular Collider (FCC)

- Forming an international collaboration to study:
- pp-collider (FCC-hh) defining infrastructure requirements:
  - ~16 T ⇒ 100 TeV pp in 100 km
  - ~20 T ⇒ 100 TeV pp in 80 km
- e+e- collider (FCC-ee) as potential intermediate step.
- p-e (FCC-he) option ⇒ LHeC (ERL).
- 80-100 km infrastructure in Geneva area.
- **CI asked to coordinate UK FCC contributions following HL-LHC success:**
  - FCC management received list of potential UK contributors.
- UK to join CERN in H2020 FCC submission.
- **CDR and cost review for the next ESU (2018).**



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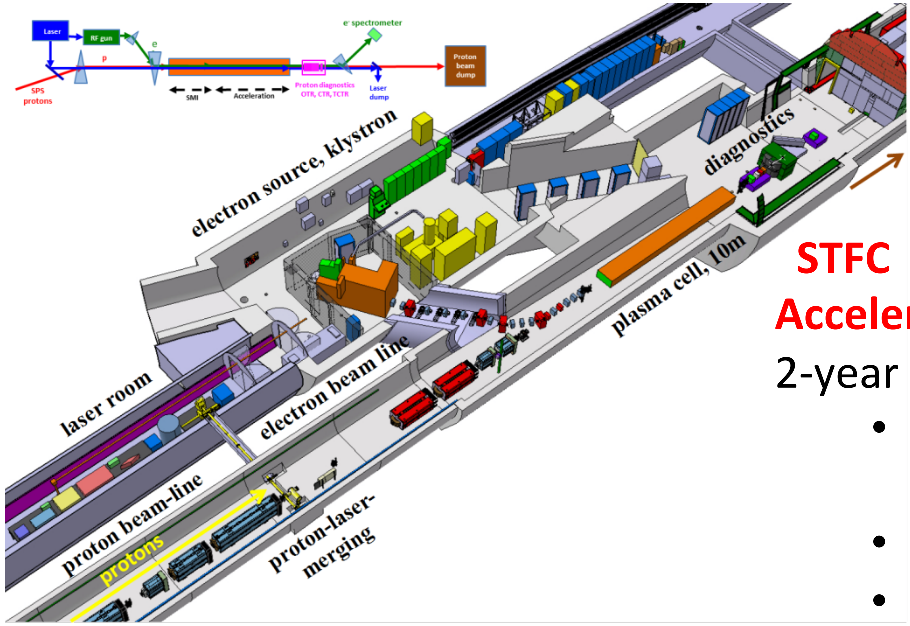
AWAKE

Future "compact" Higgs factory or high energy frontier collider?

- Study proton driven plasma wakefield acceleration using SPS beam from CNGS
- First goal of 1 GeV electron energy gain

10 m plasma

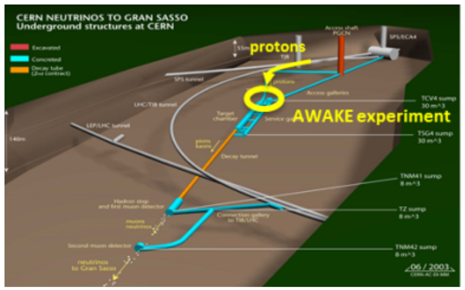


STFC PPRP Award: Proton-driven Plasma Wakefield Acceleration - A New Route to a TeV e+e- Collider:

2-year grant (10/12 – **10/14**):

- CI/Liverpool for plasma simulations plus some diagnostics
- Imperial for discharge plasma cell development
- CLF for laser based plasma diagnostics
- UCL for the electron spectrometer
- Increased Oxford contribution being arranged

Collaborative opportunity for UK to work with CERN to deliver low energy electron beam injector



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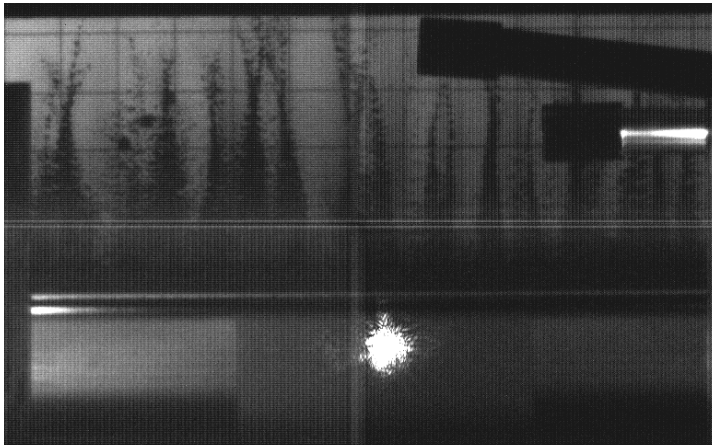
Target Beam Experiments at CERN

HiRadMat Facility:

- 1^{st} 440 GeV tungsten powder experiment carried out in 2012.
- Beam request submitted for 2^{nd} experiment after LHC long shutdown:
  - To separate gas, powder and interface effects.
- Beam request also submitted for beryllium window experiment (STFC, Fermilab and CERN).



RaDIATE Collaboration:

- MoU signed by 5 US/UK institutes, two CERN groups to join.
- Apply expertise to target and beam window issues.
- Co-ordinate in-beam experiments and post-irradiation examination.

RaDIATE Collaboration
Radiation Damage In Accelerator Target Environments

Particle accelerator for science and innovations PASI programme (CERN FNAL and UK)

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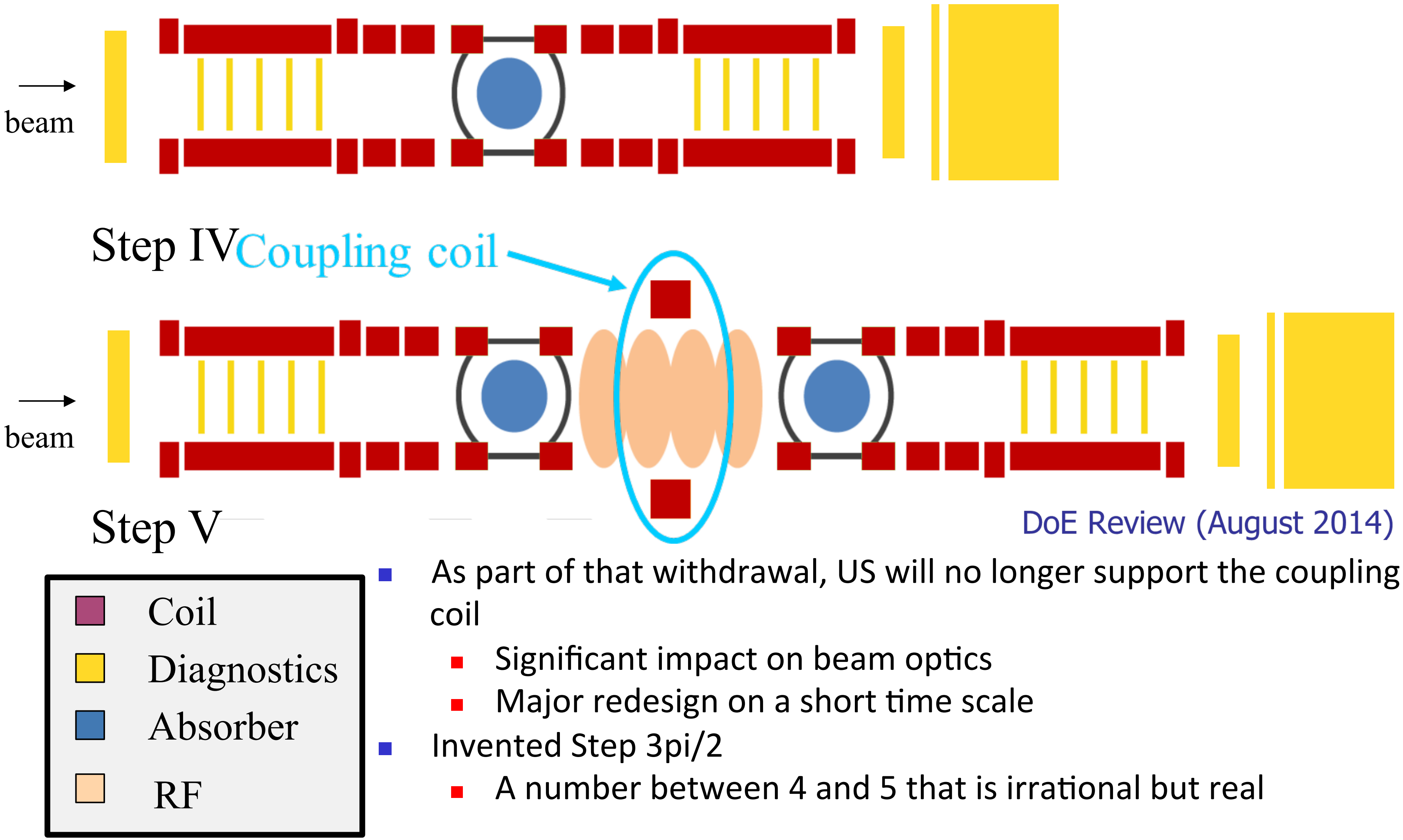
UK-CERN Resources

Activity	UK Resources (Staff Years)
UK-CLIC	43 (phase-I) and 41 (Phase-II)
Targets	22 - 24
HL-LHC	[illegible]
LHeC	[illegible]
ALPHA-II	[illegible]
AWAKE	4 - 7
ELENA	3 - 4
PS-[illegible]	1 - 2
[illegible]	1
[illegible]gnostics	1
Ion Source	0.5
E-Cloud	Developing

>150 SY of UK accelerator effort over ~6 year period
Equivalent of >25 FTEs!

MICE Plan (August 2014)



DoE Review (August 2014)

- As part of that withdrawal, US will no longer support the coupling coil
  - Significant impact on beam optics
  - Major redesign on a short time scale
- Invented Step 3pi/2
  - A number between 4 and 5 that is irrational but real

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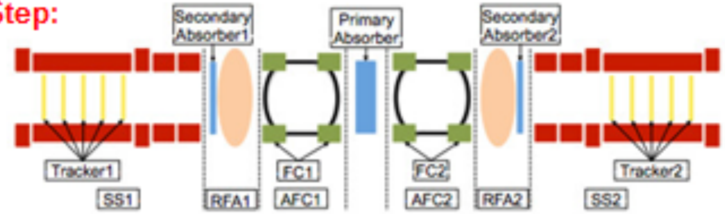
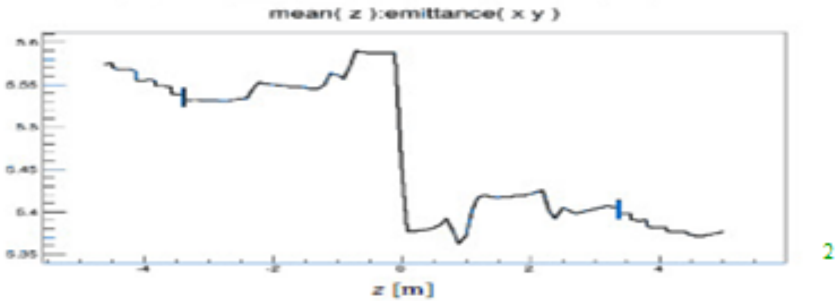
MICE Status

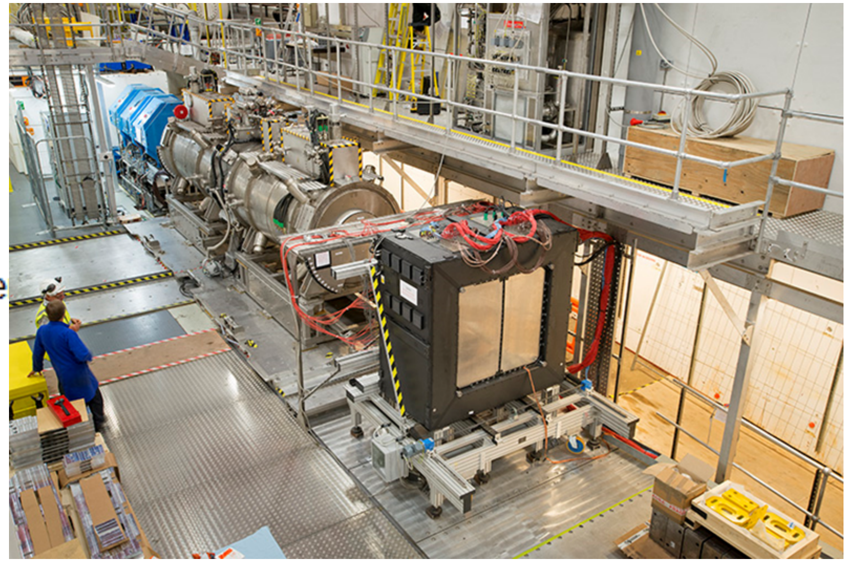
Demonstration of Ionisation Cooling

- Demonstration of Muon Ionization Cooling with Acceleration (DMICA) – formerly known as Step V
  - New configuration with two FC modules, one main absorbe and two secondary absorbers and two RF cavities

DMICA Step:







- Step IV construction by 27 May 2015
  - Commissioning ends 5 August 2015
  - Expected Step IV data : ~10 months
- New Step V configuration
- Demonstration of ionization cooling by September 2017

Summary Particle Physics

- CERN-UK major multidisciplinary activity
- 3major areas Targets, LHC and CLIC
- European programmes strengthens /enables
- Smaller programmes exploit synergies, expertise
- Multi-institutional connections
- PASI is engaging the community in FNAL activities and CERN is trying to partner with FNAL for the LBNF
- We await the LHC physics and Higgs factory initiatives but are capable to contribute a significant contribution
- There are activities with JPARC which can expand to engage as UK interest evolve in that direction
- Future technologies in FFAGs (EMMA etc.) and wakefield acceleration (AWAKE) have grown with the expanded community

LIGHT SOURCES

Diamond Upgrades

10 years plan – 2015-2024 (WIP)

Priorities identified to remain competitive in the next 10 years

Diamond II
- develop the science case and the technical design study

DDBA upgrade of one cell (possibly two)

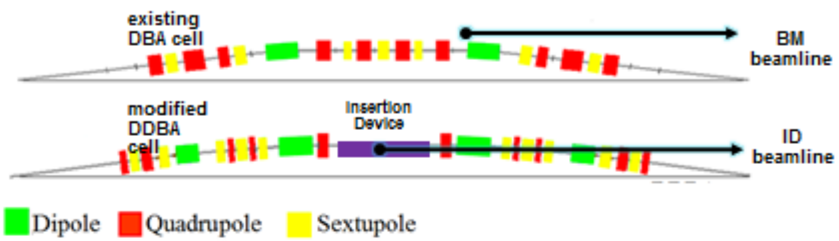
Reliability
- RF improvement: SS amplifiers (options for NC cavities)

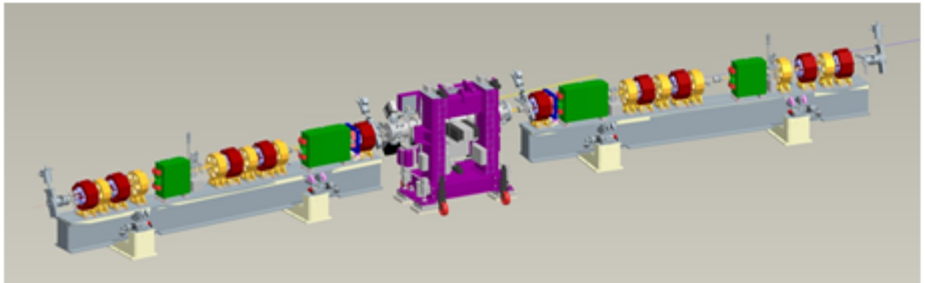
Photon beam stability (> 100 Hz ~1kHz)
- electron beam stability and photon stability at the sample

Higher current (> 300 mA) with Harmonic Cavity
Development of SCU (with ASTeC and STFC TD)

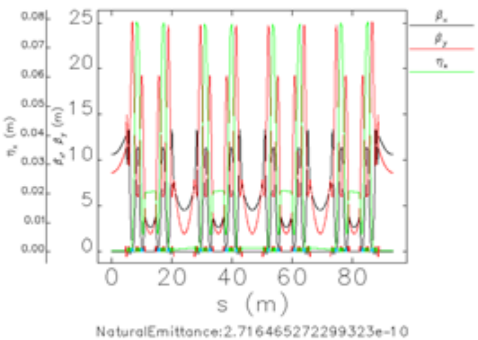
One DDBA cell in the existing lattice

One more beamline (no significant gain in emittance)





One superperiod for Diamond-II



Parameters	Modified 4BA
Circumference [m]	561.0
Emittance [pm.rad]	275
Tune Point [Q_x / Q_y]	50.76/18.36
Chromaticity(ξ_x / ξ_y)	-128/ -94
straight sections [m]	9.1 / 6.7 / 3.2
Momentum compaction	1.02e-04
Bunch length [mm]	1.77
Energy spread (rms)	7.94e-4
Damping time h/v/s [ms]	14.78/19.60/11.70
Energy loss/turn [MeV]	0.573

This lattice combines the ideas of doubling the capacity of the ring with the low emittance

FEL Activities

ASTeC, CI, CLF, DLS, JAI, and Strathclyde University all carry out FEL R&D or make contributions to FEL projects.

- Future UKFEL
  - A new science case is starting to emerge – hard X-ray, low rep rate looks likely
- ALICE (Energy Recovery Linac)
  - IR FEL (5.5 to 11μm) commissioned in 2010,
  - Development of diagnostic for cervical, oesophageal, and prostate cancer
- SwissFEL

  ASTeC contributed to SwissFEL on:-
  - collimation system to protect the FEL undulators,
  - a self-seeding scheme for the hard X-ray FEL,
  - design and fabrication of the modulator undulator for the laser heater system,
  - 2 colour FEL modelling,
  - mode locked FEL modelling, and X-band RF cavity design.

FEL Activities

- CLARA

Test new FEL concepts for generating light with attosecond pulse lengths, narrower bandwidths, greater intensity stability, two colour pulses…

–A proposed single pass 250MeV FEL test facility

- a major upgrade of VELA
- front end (up to 50MeV) to be installed in 2015

–PSI are providing three 4m long S-band accelerating linacs and 18 focussing magnets (value >1 MCHF).

–CERN propose tests of an X-band linac on CLARA (EU proposal)

–Other "experiments" investigated….

- electron beam driven plasma wakefield acceleration
- dielectric wakefield acceleration
- Upgrade in power for VELA

- L-FEL

–ASTeC have been contracted by a global blue chip company to contribute to the feasibility report for L-FEL, a proposed industrial Energy Recovery Linac-based FEL for use in a multi-billion pound global sector

NEUTRON SOURCES

ISIS neutron source

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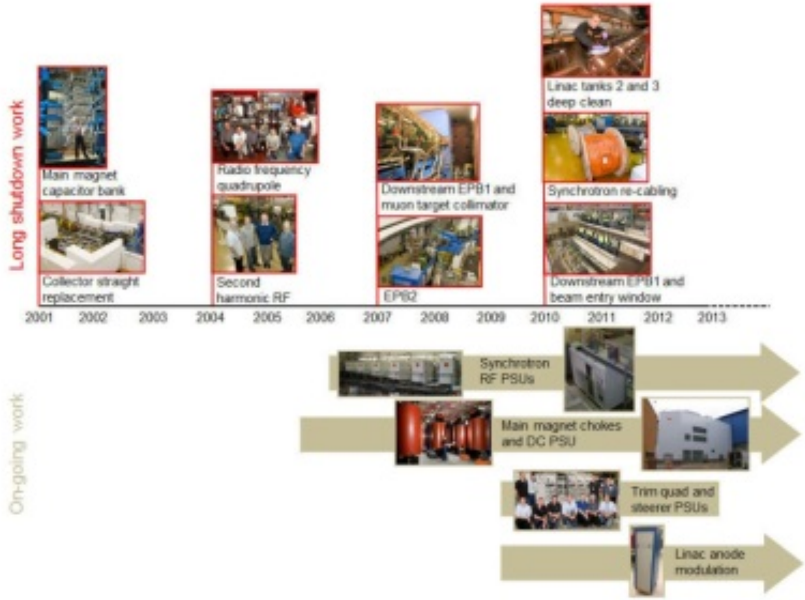
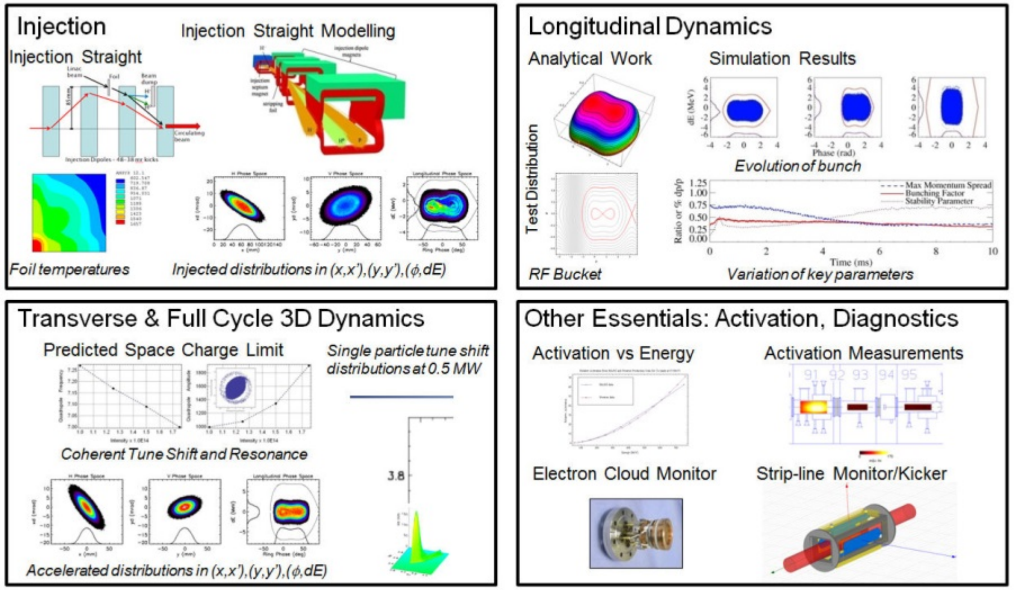
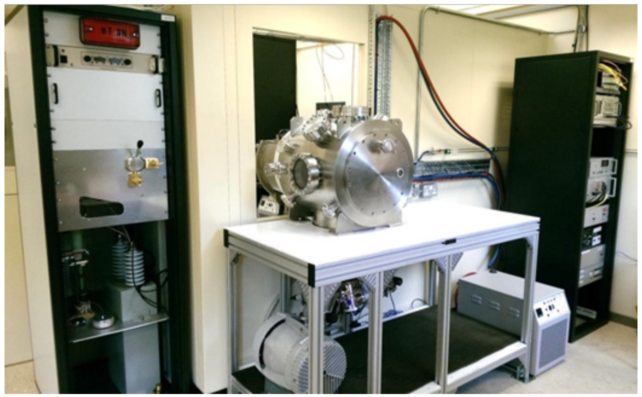
Equipment renewal and upgrades



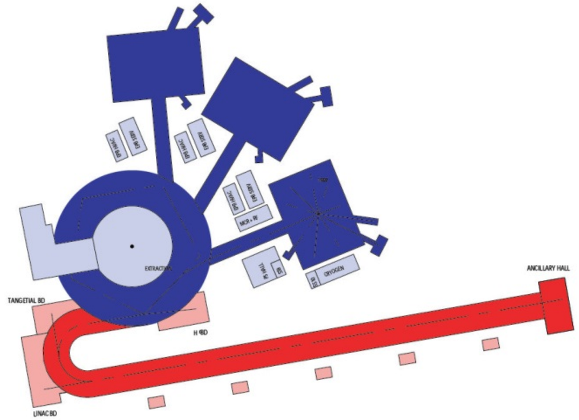
180 MeV injection



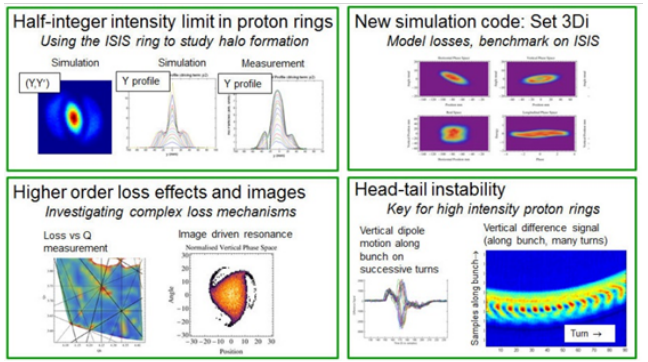
Ion source development



MW regime 'ISIS-II' scenarios



High intensity R&D studies



Targets

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Front End Test Stand

ISIS, ASTeC, JAI, Imperial College London, Uni College London, Huddersfield U, Warwick U) and ESS Bilbao.

- Proton accelerator R&D programme
- Enable a significant increase in the neutrons flux
- ISIS & (SNS, ESS, JPARC, CSNS).

High brightness H^- ion source

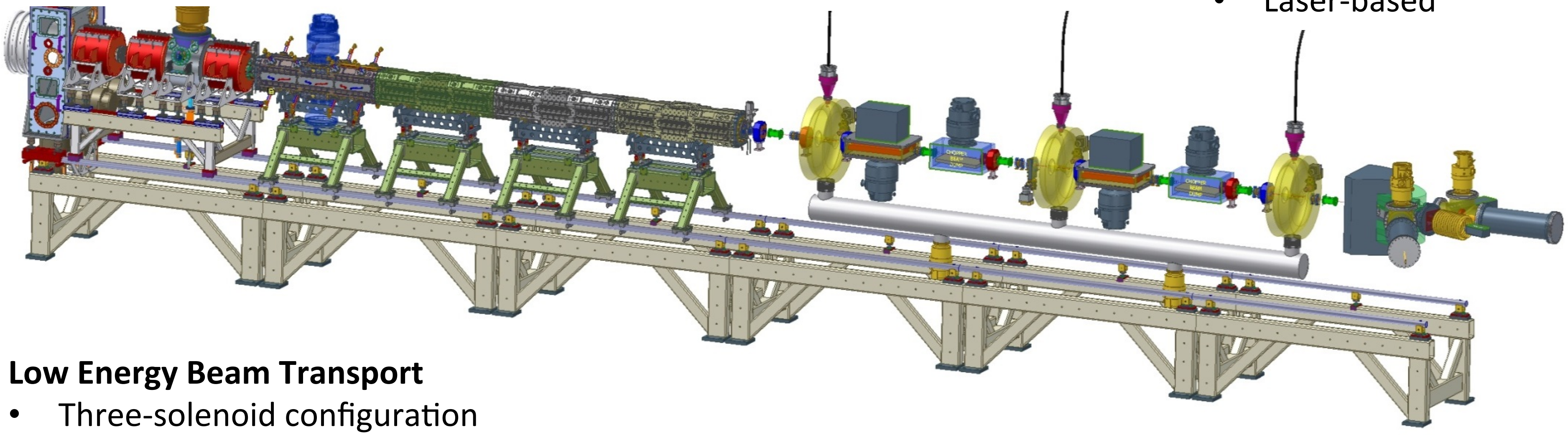
•4 kW peak-power arc discharge
•60 mA, 0.25 π mm mrad beam
•2 ms, 50 Hz pulsed operation

Radio Frequency Quadrupole

- Four-vane, 324 MHz, 3 MeV
- 4 metre bolted construction
- High power efficiency

Diagnostics

- Non-interceptive
- Well distributed
- Laser-based



Low Energy Beam Transport

- Three-solenoid configuration
- Space-charge neutralisation
- 5600 Ls^{-1} total pumping speed

Medium Energy Beam Transport

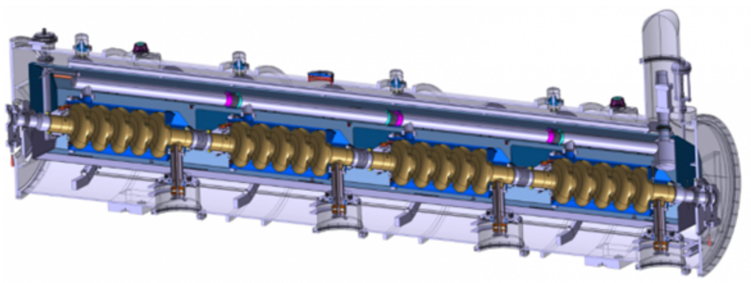
•Re-buncher cavities and EM quads
•Novel 'fast-slow' perfect chopping
•Low emittance growth

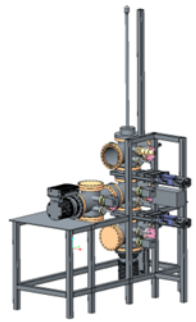
European Spallation Source

- Started construction in Sweden in 2014 and aims to produce first neutrons in 2020.
- UK contributing ~£165M 10% of the construction
- Coordinatining contributions to the ESS accelerators and target are ongoing.
- Accelerator areas being developed include SC RF cavity procurement, testing and delivery.
- The design and delivery of three laboratory vacuum test facilities
- Targets? RF Distribution?

Challenges

- Tight delivery schedule
- Late engagement in design and delivery of technologically challenging systems e.g. Targets .
- Timescales required for foundation of a large UK technology project
- Release of money from Government (2016/17)





INDUSTRIAL ENGAGEMENT

UK accelerator R&D – industrial engagement

1. Recognising industrial drivers/current barriers to uptake of accelerator technologies
2. Accessibility of our skills, know-how and facilities
3. Identifying priority areas for applications
4. Working with the right people
5. Quantifying and communicating successes

Industrial Drivers

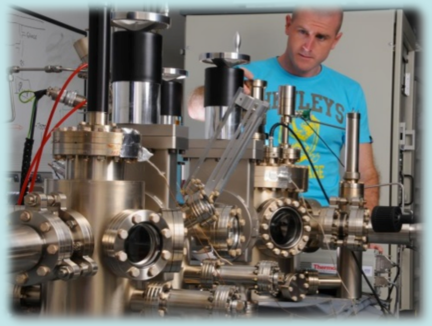
To promote uptake, we need to optimise technology solutions to commercial needs and understand the end user's challenges.

Smaller	• often replacing pre-installed equipment, smaller footprint = reduced building and infrastructure costs
Cheaper	• reduced initial capital investment
More efficient	• reduced on-going operational costs
More reliable	• reduced Mean Time Between Failure, easier maintenance
(Improved) performance	• optimised to application
Easier to operate	• fits into standard protocols and operations
Repeatable	• confident that you get the same outcome every time

Accessibility of our skills and facilities

Underpinning technologies with applications in non-accelerator areas

e.g. vacuum, RF, magnets



Maximising the sphere of influence of accelerator science

Applications of complete accelerator systems

e.g. cargo scanning, water treatment

Priority application areas

Health

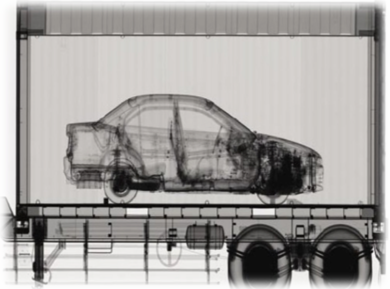
e.g. medical isotopes, proton therapy

Environment

e.g. water treatment

Security

e.g. new cargo scanning techniques



Energy

e.g. NEG coatings to improve efficiency of solar cells

Any application that generates economic impact

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Working with the right people

Networks

- Leveraging Knowledge Transfer Networks to find end users, suppliers, academic experts
- Maintaining own networks, hosting events
- STFC Innovations Club

Understanding the problem

-Engaging with end users (may not know what an accelerator is)
-Defining performance requirements

Optimising the solution

-Engaging with supply chain
-Designing system to achieve desired performance
-Working in Multidisciplinary teams (clinicians, chemists, microbiologists, engineers, …)

Funding

STFC schemes

- Innovation Partnership Scheme (IPS)
- Challenge-Led Applied Systems Programme (CLASP)
- Follow-on fund
- Proof of Concept fund
- CASE Studentships

Innovate UK schemes

- Knowledge Transfer Partnerships (KTP)
- Innovation Vouchers

EDUCATION AND TRAINING

Education and Training Report

PhD Students

2002 (5)

2012 (~60)

- ~260 people in the UK doing accelerator science (3060 across the survey)
- Around 200 trainees in UK from 2005-2009 (year averaged), then ~300 in 2010 and 2011. This includes undergraduates and lab staff. Around 60 PhDs in 2011.
- Source : TIARA report and database http://www.eu-tiara.eu/database/

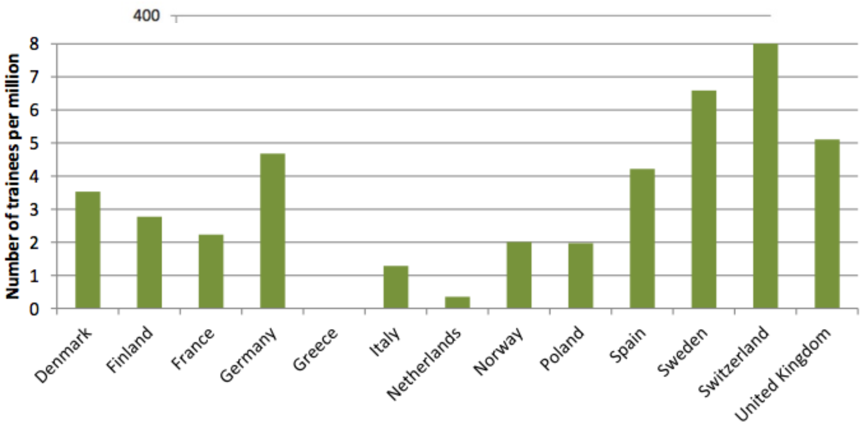
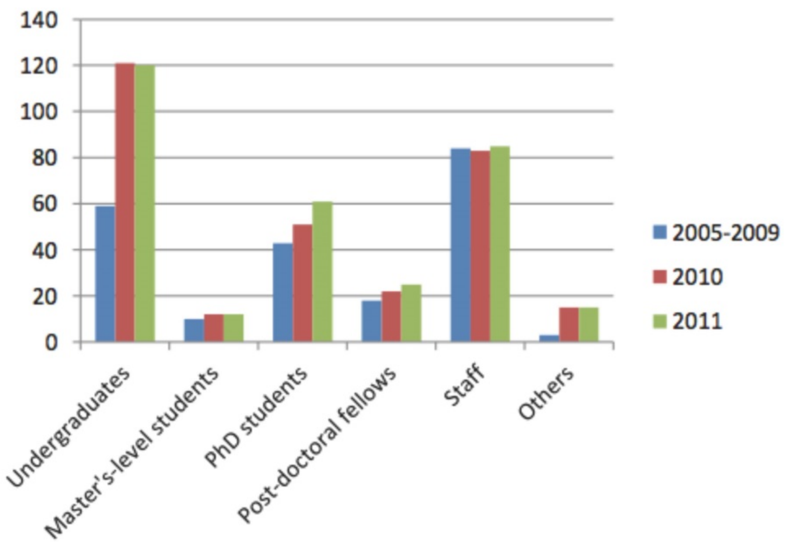


Figure 4.4: The total number of trainees in each country (for academic year 2011) normalised by the population of that country, expressed in trainees per million.



2011 (green), 2010 (red) and the average per year over the 5 years 2005-2009 (blue).

SUMMARY

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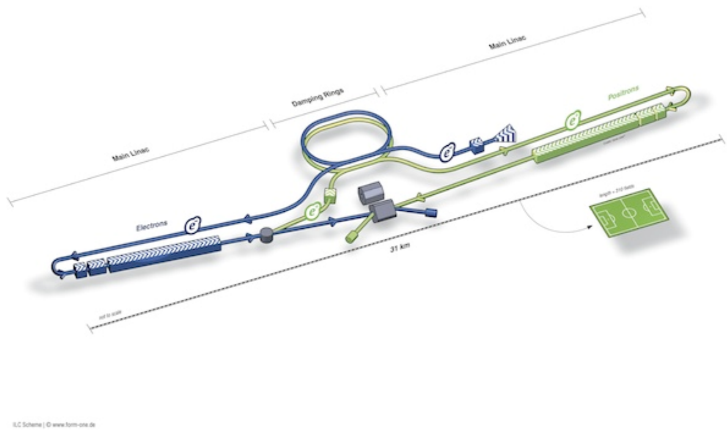
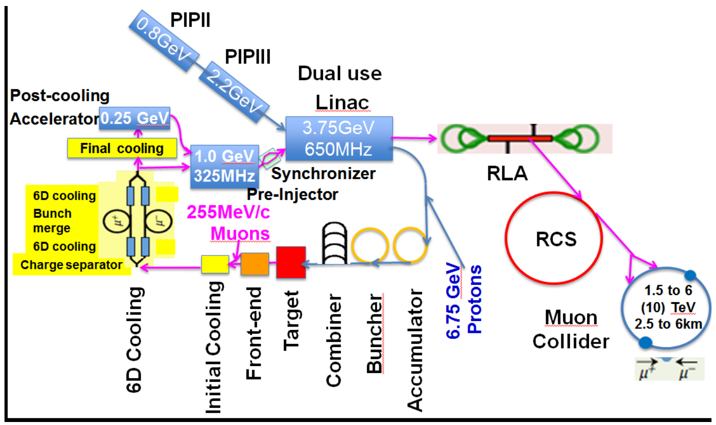
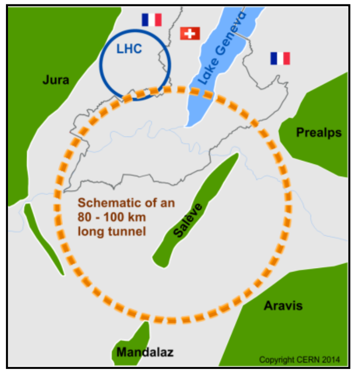
Summary

- With the internationalisation of UK accelerator science programme the UK impact and influence has grown hugely over the last 10-15 years
- We have the people to lead and impact internationally
- We have the test facilities, infrastructures, technological knowhow and academic prowess to innovate and deliver on a large scale
- We have to prepare **strategically** for the UK accelerator base to deliver a **large** contribution to the next and future particle physics contributions.







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- Katherine Robertson

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