# Update of the European Strategy for Particle Physics: UK accelerator science and technology view

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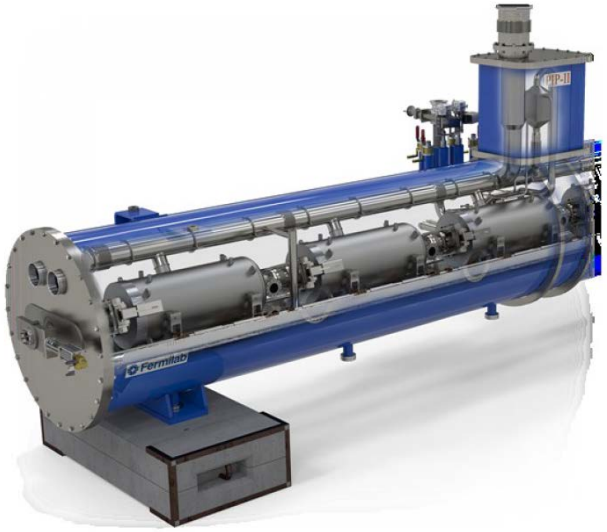
(with help from colleagues @ JAI, ASTeC, CI, & PWASC)

# 1. Major developments from the 2013 Strategy

- The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.
  - The UK is fully involved with the HL-LHC accelerator upgrade leading contributions in crab cavities, cold powering, laser engineered surfaces for electron cloud, novel diagnostics and accelerator physics studies.
  - We welcome this recommendation. This is the first time in the past two decades the UK accelerator groups have made a major contribution to a CERN frontier accelerator and we want this model to continue.

- Europe, and CERN through the Neutrino Platform, should continue to support long baseline experiments in Japan and the United States.
  - Daresbury laboratory is contributing key SRF cryomodules to the PIP-II programme, little university support at present but this could increase



# 3. High-priority future initiatives

- An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:
  - the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;
  - Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.
  - The timely realisation of the electron-positron International Linear Collider(ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

- The UK has led developments in MDI, Beam delivery, Collimators, Crab cavities, feedback & diagnostics, vacuum coatings, damping rings, positron sources, and RF sources for ILC, CLIC and HL-LHC and we are able to contribute and lead these activities on any e+e- collider
- We also have capabilities to build RF cavities with UK industry given experience in HL-LHC, CLIC and PIP-II
- For CLIC & ILC we also have developed novel tuneable permanent magnets
- No technical leadership in FCC$e^+e^-$ in UK at present but have some scattered activities, well established leadership in linear colliders with current lead roles in CLIC
- No current ILC activities but previously had major leadership and these roles could be re-obtained
- HL-LHC-UK -> FCC pp natural switch, all technologies developed need major upgrades for FCC pp. UK very well positioned here. But is a long way off and initial work is magnets and civil, so the UK community will likely look at this post HL-LHC

# 3. High-priority future initiatives

- The European PP community **must intensify accelerator R&D and sustain it with adequate resources**.
- Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. The European particle physics community must intensify accelerator R&D and sustain it with adequate resources.

  - Establishing an accelerator roadmap within Europe makes sense and STFC should be asking the UK accelerator community for input on our priorities.
  - UK has slipped behind in the development of high field superconducting magnets, but have history at RAL. High field SC magnets is not a UK strength and we shouldn't ty to compete in this particular technology, instead we should focus on UK strengths.
  - UK is building infrastructure in thin-film superconducting RF as well as SRF testing and cryomodule development
  - CLF & SCAPA excellent facilities providing focus for UK plasma community (plus University smaller scale facilities), the PWFA-FEL project, which is focused on generating high-brightness beams from beam-driven plasma accelerators suitable for driving FELs.
  - We have expertise in high-gradient accelerating structures both SRF and NCRF
  - Led muon research at MICE and for neutrino factory; UK community generally has more interest in nuSTORM as a physics and technology demonstrator and R&D test bed on the road to the muon collider. Experience with polarized muon rings at g-2.
  - ASTeC is a leader in ERLs within Europe because of experience from ALICE and ongoing collaborations with European and American institutes on many ERL initiatives so we should capitalise on that as a country and play a major role in any demonstrator project.

# High Gradient Normal and Super conducting RF

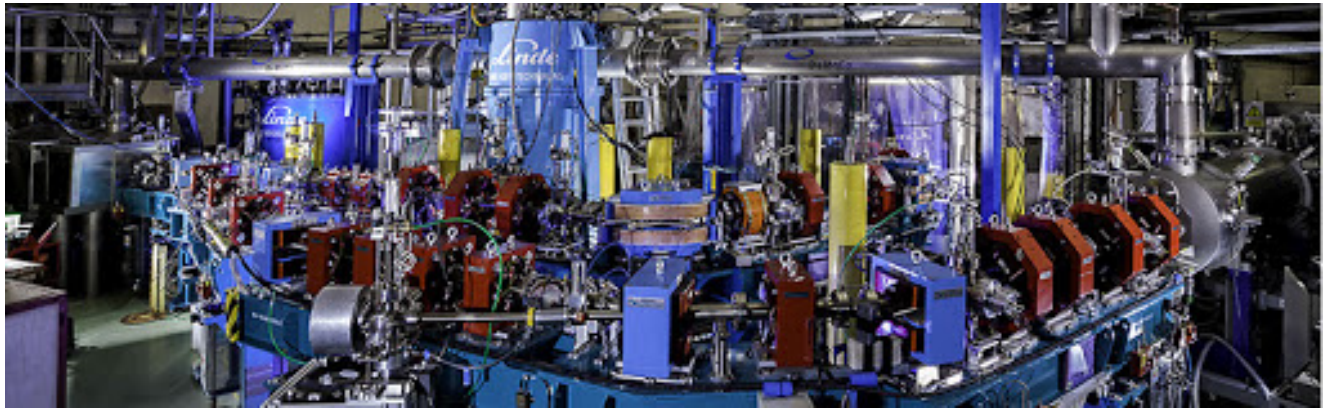
- Relevant to all future HEP machines, as well as FEL's, spallation sources and medical accelerators
  - UK is collaborating with CERN on the development of high gradient normal conducting linacs for CLIC (CI & JAI) through staff based at the X-band high gradient test lab at CERN. UK looking to develop UK-based high gradient testing in the near future.
  - UK company TMD has recently produced its first CLIC cavity, possibility for major UK industry involvement. UK industry consortium producing first SRF cavity funded by PIP-II.
  - Daresbury have expertise in thin-film SRF coating to develop higher gradient, high efficiency and/or high temperature SRF technology working with several UK universities. Research focussed on future initiatives looking at new materials and multi-layers.
  - Daresbury also have capabilities for industrial scale cavity testing and cryomodule construction to support future projects nationally and internationally.
  - Also involved in development of THz high gradient accelerators, in which the UK is world leading

# Plasma

- The UK undertakes a wide range of research in many areas of innovative accelerator technology. Much of this work is undertaken within the UK's accelerator institutes – the Cockcroft Institute and the John Adams Institute. PWASC provides oversight of the plasma wakefield accelerator component of this work.
- The UK is strongly involved in several national and international research programmes which could contribute to the goals identified in the European Strategy. Of these, the following are currently funded:
  - The AWAKE programme, based at CERN, which investigates proton-driven plasma accelerators.
  - The Extreme Photonics Application Centre (EPAC), based at Rutherford Appleton Laboratory, which will develop applications of high-intensity lasers, including laser-driven plasma accelerators.
  - **The PWFA-FEL project, which is focused on generating high-brightness beams from beam-driven plasma accelerators suitable for driving FELs.**
- The following programmes could contribute strongly to the goals of the European strategy, but as yet are not funded:
  - The EuPRAXIA (European Plasma Research Accelerator with eXcellence In Applications) project to develop the world's first plasma-accelerator-based user facilities.
  - EuPRAXIA@EPAC is a proposal to locate the EuPRAXIA laser-driven plasma accelerator at EPAC.
  - LhARA really aimed at developing a laser-driven source with novel plasma-lens focusing for bio-medical applicatons
- Our test facility, CLARA, is already supporting R&D in beam driven plasma acceleration and our capabilities will increase when we implement Phase 2 (250MeV + FEBE) with a TW laser.
- We note and agree with the statement in High-Priority future initiative B that "A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry."
- The UK is well represented on international bodies which seek to coordinate and develop advanced accelerator technology. In particular, the Advanced and Novel Accelerator (ANA) panel of the International Committee for Future Accelerators (ICFA) initiated:
  - The Advanced and Novel Accelerators Roadmap (ANAR) workshop to consider roadmaps for advanced accelerators;
  - The ALEGRO group (Advanced linear collider study group), an international team of ~ 30scientists developing a proposal for an advanced multi-TeV linear collider driven by laser or particle bunches propagating in plasma or dielectric structures.

# Energy Recovery Linacs (ERLs)

- ERLs are desired as they allow us to produce electron beams with simultaneously high current (like a storage ring) AND high brightness (like a linac).
- This is done by recycling the energy of the spent beam, returning it to the linac cavity fields in order to accelerate subsequent bunches.
- This makes ERLs attractive in both industrial and research contexts
- ALICE was Europe's first energy-recovery linac, at Daresbury laboratory and as such has put the UK in a strong position for any ERL research
- UK is involved in CBETA (Cornell) and PERLE (LAL, Orsay – now part of new Irene Joliot-Curie Lab), and the ERL-based CERN LHeC conceptual design
- Promising ERL applications in industrial FEL light sources and/or gamma sources – either as standalone (DIANA) or part of a larger UK-XFEL facility
- ERLs have in electron ion colliders as an electron cooler to enable high luminosity and there is a possibility to contribute here.

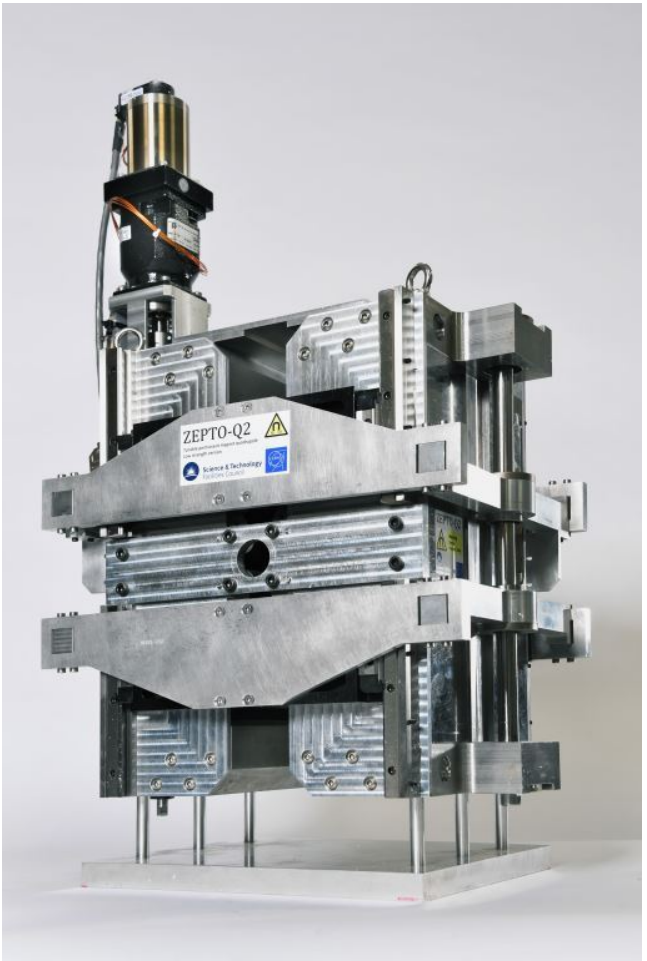


# Synergies (4&5)

- The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy.
  - UK has transferred accelerator technology (RF) into searches into dark photons, axions and axion-like particles with masses at the micro-eV scale as well as contributing to e-SPS
- In the global context, a new electron-ion collider, EIC, is foreseen in the United States to study the partonic structure of the proton and nuclei, in which there is interest among European researchers. Europe should maintain its capability to perform innovative experiments at the boundary between particle and nuclear physics.
  - Due to expertise from ALICE on ERL's and colliders, UK has several opportunities to contribute to EIC as well as test facilities such as CBeta and PERLE. Areas such as beam dynamics, final focus, crab cavities, SRF systems and ERL design fit well with the UK skill-set.
- CLIC technology is also highly relevant to UK-FEL and UK has leadership in CompactLight

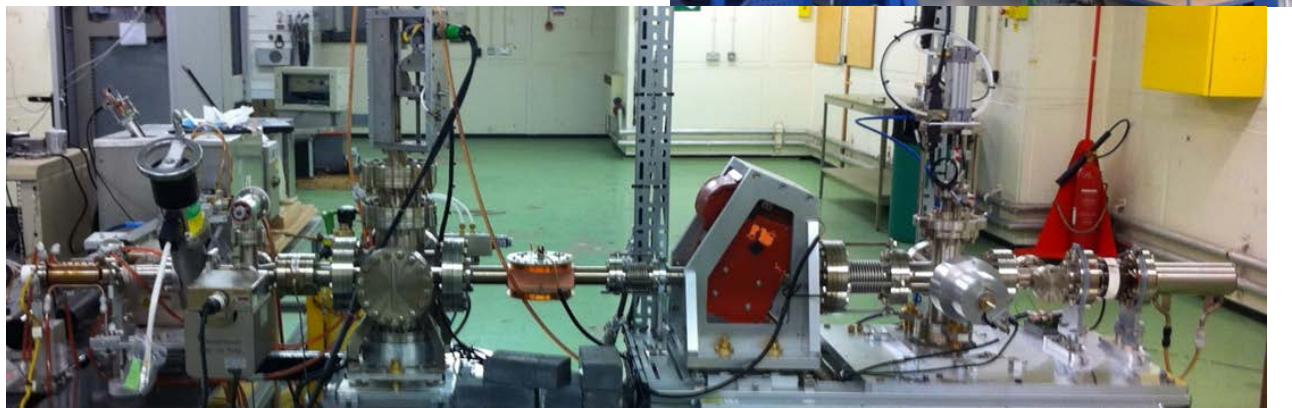
# 7. Environmental and societal impact

- The energy efficiency of present and future accelerators, and of computing facilities, is and should remain an area requiring constant attention.
  - UK is world leading in research on energy efficient accelerators
  - Developing high efficiency klystrons with CERN for LHC, CLIC, FCC etc which will increase efficiency of RF-dominated machines by 10%-20%
  - Patented ZEPTO (Zero-power tunable optics) quadrupoles and dipole magnets using permanent magnets
  - Leading Europe on energy recovery linac machines which reduce beam-loading significantly reducing power required on high current machines significantly



# 7. Environmental and societal impact

- Particle physics research centres should promote knowledge and technology transfer and support their researchers in enabling it. The particle physics community should engage with industry to facilitate knowledge transfer and technological development.
- UK very strong in this area, particularly in medical
  - Supported the NHS in setting up new proton therapy centers (Christie and UCLH), and improved operation in Clatterbridge
  - Development of EMMA machine and design of PAMELA for ion therapy
  - Development of linacs for cargo scanning, and use of machines for detector development
  - Testing of water & leather irradiation for environmental applications at Daresbury
  - Accelerator alignment technology for ILC spun out to other metrology applications
  - LhARA laser based radiobiological test accelerator design
  - Accelerators for Security, Healthcare and Environment industrial DTC at Cockcroft
  - CLARA/VELA, CLF and the Linac test facility are supporting UK industry with beamtime.
  - CLIC cavity production at TMD
  - Radiotherapy for lower middle income countries
  - High gradient proton linacs for proton therapy
  - D-Beam diagnostics spin-out at Liverpool



# Summary

- UK has strong involvement in HL-LHC across the accelerator community, and Daresbury involvement in PIP-II
- UK has world-leading expertise in beam-delivery systems for colliders and could lead this for any future collider, along with technical expertise in RF, diagnostics, feedback & control, NC magnets & vacuum coatings.
- UK would contribute a huge amount to roadmaps for superconducting RF, High gradient structures, plasma accelerators and ERLs, less so for high field magnets and muon colliders
- HEP accelerators synergetic with light sources, spallation sources, medical and industrial accelerators
- EIC is a good synergistic fit to UK expertise and we look to contribute if possible on the ERL roadmap.
- The accelerator community in the UK is already highly integrated into medical and industrial applications
- High efficiency accelerators is also a strength in the UK