**UK input to European Particle Physics Strategy Update**

*STFC Particle Physics Advisory Panel:*

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*(on behalf of the UK particle physics community)*

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# *Introduction*

The UK Particle Physics Advisory Panel (PPAP) is charged with providing input from the UK particle physics community to the Science and Technology Facilities Council (STFC) for use in its strategic planning processes. In 2009 the PPAP produced a UK particle physics ‘roadmap’ [1] that has recently been updated [2]. Based on the PPAP roadmap, the approved UK particle physics programme, and the current interests of the UK community, we provide here a short UK perspective for consideration by the CERN Council Strategy Group as it prepares an update to the European particle physics strategy.

## 1. Energy frontier physics

The LHC is the world’s flagship energy frontier exploration facility. It is performing spectacularly well and the discovery of a new boson consistent with being the (Standard Model) Higgs boson has just been announced.

The UK has made major investments in the ATLAS and CMS general purpose detectors (GPDs). A large number of UK particle physicists are committed to the operation and scientific exploitation of the GPDs, and UK scientists occupy a number of leading positions of responsibility within both collaborations. The UK has invested in R&D on detector upgrades to accommodate higher-luminosity operations (HL-LHC) and is playing a key role in the upgrade plans for both detectors, as well as contributing to the HiLumiLHC EU FP7 project.

The UK also participates in the ALICE experiment, which is providing new insights into the QCD phase diagram and the behaviour of deconfined quarks and gluons. In addition UK scientists hold leading positions in the LHeC proposal to upgrade the LHC with a new electron accelerator for complementing the TeV scale physics programme in particular through improved understanding of parton density functions and strong interaction dynamics.

**Recommendations:**

**The highest priority is to capitalise on the investment made in the LHC by exploiting the scientific capabilities of the GPDs with LHC operations at up to 14 TeV collision energy. Investment should be made in accelerator and GPD upgrades to enable exploitation of the full potential of the LHC.**

**Investment should continue to be made in the Grid computing facilities, physics modelling and simulations needed to support the greatly increasing data storage, handling, processing and analysis requirements.**

The LHC discovery of a 125 GeV-mass boson presents an opportunity for a high-luminosity electron-positron collider facility for making precision measurements that augment the LHC’s capabilities. The success of the Standard Model in accounting for LHC data to date also implies the need for higher luminosity LHC collisions (see above), and for consideration of a possible future higher-energy hadron (HE-LHC) or lepton collider, in order to advance longer-term direct searches for beyond-Standard Model (BSM) physics processes. Such facilities are large in scale and can only be realised via global coordination and planning.

A number of UK scientists are playing key roles in design studies for the International Linear Collider (ILC) and the Compact Linear Collider (CLIC), as well as a possible muon collider.

**Recommendations:**

**The options for next-generation collider facilities should be thoroughly reviewed in light of LHC results, and their pursuit coordinated globally.**

**A timely decision should be taken on optimal next-generation collider facilities for exploitation of LHC discoveries. Europe should develop a coherent strategy to either host the next-generation facility or to participate in a facility built elsewhere.**

**Europe should invest in the accelerator and detector technology developments needed to realise these facilities.**

## 2. Flavour physics

Key precision measurements in the flavour physics sector are sensitive to mass scales beyond those that can be probed with direct searches and such measurements currently provide some of the strongest constraints on BSM physics and sensitivity to the flavour structure of the Standard Model. The absence, so far, of direct signals for new physics at the LHC reemphasises the importance of this approach. The initial data taking of LHCb has proven the concept of a dedicated flavour physics experiment at a hadron collider, and already provides the world’s most precise measurements in many key BSM-sensitive channels. There is a large UK involvement in LHCb, as well as significant interest amongst UK scientists in the LHCb upgrade, which aims to operate at an order of magnitude higher luminosity. Whilst technically independent of the high-luminosity upgrades to LHC, the upgraded LHCb is expected to operate concurrently with the upgraded GPDs in the LHC high luminosity era.

**Recommendation:**

**The highest priority is to fully exploit the capabilities of the current LHCb detector so as to maximise its scientific output, especially in probing BSM physics. In addition, investment should be made in the LHCb upgrade to enable full exploitation of the LHC flavour physics potential.**

In the kaon sector the UK is participating in the CERN NA62 experiment, which aims to reach a new level of sensitivity for rare decay modes with branching ratios as low as 10-11. There is, in addition, UK interest in other possible future kaon experiments, as well as in participation in a high-luminosity e+e– flavour factory, and several UK groups are active in research and development towards muon conversion experiments.

In many cases the interpretation of measurements made in precision flavour experiments relies upon lattice QCD calculations (see Section 5).

**Recommendation:**

**Precision experiments in the bottom, charm, kaon, tau and muon sectors that bring complementarity and breadth to the global physics programme should be pursued, along with the associated theoretical work to maximise their impact; global coordination of national- or regional-scale programmes would be desirable.**

## 3. Neutrino physics

The recent measurement of a relatively large value for 13 represents a significant milestone in our understanding of neutrino physics. The focus of the next generation of long baseline experiments will be on determining the mass hierarchy and measuring the CP phase in the PMNS matrix. Precise measurements of the properties of the neutrino are crucial for the development of the theory of the physics of flavour and for testing theories beyond the Standard Model and are therefore complementary to the high-energy-collider programme.

The UK is already playing a leading role in a number of long baseline neutrino projects, including MINOS and T2K and their upgrades. The UK is also at the forefront of the R&D leading towards a large Liquid Argon detector, with leading efforts in the LAGUNA-LBNO FP7 Design Study and other LAr activities worldwide, and a future neutrino factory, and hosts the MICE muon cooling experiment at the Rutherford Appleton Laboratory. The UK is also playing leading roles in two neutrinoless double beta decay experiments (SuperNEMO and SNO+), with the potential to answer the fundamental question of whether the neutrino is a Dirac or Majorana particle.

**Recommendations:**

**Europe should develop a coherent strategy to either host the next generation long-baseline neutrino oscillation project or to participate in a global project.**

**Dedicated neutrinoless double beta decay experiments should be pursued; global coordination of national- or regional-scale programmes would be desirable.**

**Europe should pursue a programme of R&D into the construction of a very large scale Liquid Argon detector.**

**Europe should continue to play a leading role in accelerator R&D in high power neutrino beams.**

***4. Non-accelerator experiments***

About 23% of the material in the Universe is thought to be Dark Matter. The direct detection of Dark Matter and its identification is key to our understanding of the Universe and remains one of the high priorities for particle physics.

The UK has leading roles in three international consortia EURECA, LUX-ZEPLIN and DEAP/CLEAN, which are developing tonne-scale detectors aiming for sensitivity at the 10-11 pb level, as well as building detectors (DRIFT-CYGNUS and DMTPC) with galactic directional sensitivity. The UK also has key participation in the Cherenkov Telescope Array (CTA) and in the neutrino observatory IceCube, which will provide increased sensitivity to indirect signals of dark matter via its annihilation or decay.

**Recommendation:**

**A coordinated strategy for coherent European involvement in tonne-scale direct dark matter search experiments and efforts towards directional capability should be pursued on both the regional and global scales.**

High precision non-accelerator experiments can be sensitive to mass scales beyond those that can be probed with direct searches and can provide complementary information and constraints on BSM physics to the searches at high energy colliders and precision flavour experiments. The UK is involved in electric dipole moment (EDM) experiments which have set the world's best limits for both the neutron and electron EDM.

**Recommendation:**

**Precision dipole moment search experiments should be pursued.**

***5. Theory***

Theoretical particle physics has been pivotal in shaping and consolidating the Standard Model and continues to be crucial for the interpretation of recent discoveries and formulation of possible scenarios for future BSM discoveries. History has repeatedly shown that radical paradigmatic changes arise unpredictably from formal theoretical research and often lead to rapid and significant advances in our understanding. At the same time, experimental deviations from precise Standard Model predictions provide important hints on how current theoretical models need to be modified. A diverse and vibrant programme of theoretical physics encompassing formal theory, phenomenology (including model building), astroparticle and lattice theory therefore remains an essential ingredient of any future particle physics programme.

The formal theory activity in the UK has a substantial international profile, especially in the area of string theory, supersymmetry and related topics, with a long history of success and remains a strategic priority of the community. Particle phenomenology is another strategic priority for the UK as it facilitates an optimal exploitation and development of the ongoing and future experimental programmes and the UK hosts a dedicated phenomenology research centre, the Institute for Particle Physics Phenomenology in Durham. Similarly, lattice gauge theory plays a vital underpinning role in understanding flavour physics and the UK has invested in high performance computing for particle physics via the DiRAC (Distributed Research utilising Advanced Computing) facility.

**Recommendation:**

**For the continuing health of the particle physics programme it is essential for Europe to maintain a world-leading long-term programme across theoretical particle physics in its broadest sense, and especially in formal theory, phenomenology, astroparticle and lattice theory.**

***6. Accelerator and detector R&D***

A strong technological R&D base must be maintained to enable a long-term world-leading European particle physics programme, as well as to capitalise on future knowledge exchange opportunities. This should include generic R&D as well as that more focused on specific types of facilities or experiments. The UK has set up two dedicated accelerator institutes, the Cockcroft Institute and the John Adams Institute for Accelerator Science, which serve to focus and enhance efforts in this area.

**Recommendation:**

**In order to promote the long-term vitality of experimental particle physics it is essential for Europe to invest in R&D on advanced technologies for both future accelerators and detectors at the energy and intensity frontiers.**

References

[1] PPAP roadmap report 2009: <http://www.hep.phy.cam.ac.uk/~thomson/ppap/PPAP_report_final.pdf>

[2] PPAP roadmap update 2012: <http://www.hep.phy.cam.ac.uk/~thomson/ppap/PPAP_report_update_Jan8_2012.pdf>