Flavour and Dark Matter (ESPP reflection)

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Update of the European Strategy for Particle Physics

by the European Strategy Group

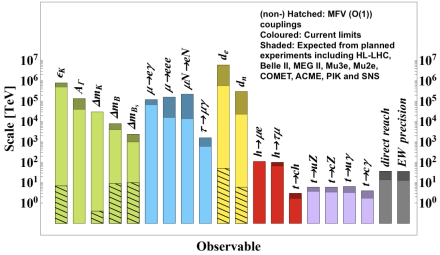
Preamble

Nature hides the secrets of the fundamental physical laws in the tiniest nooks of space and time. By developing technologies to probe ever-higher energy and thus smaller distance scales, particle physics has made discoveries that have transformed the scientific understanding of the world. Nevertheless, many of the mysteries about the universe, such as the nature of dark matter, and the preponderance of matter over antimatter, are still to be explored.

This 2020 update of the European Strategy for Particle Physics proposes a vision for both the near-term and the long-term future. It aims to significantly extend knowledge beyond the current limits, to drive innovative technological development, and to maintain Europe's leading role in particle physics, within the global context.

- A promising start!...

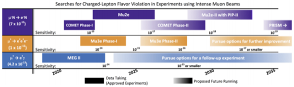
[Briefing Book]: Flavour highlights

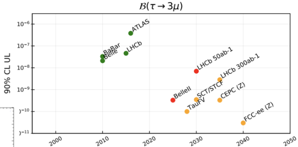


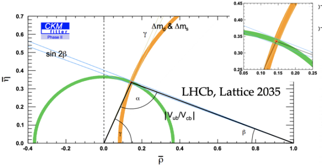
- Can be sensitive to new physics at energies beyond the reach of colliders
- Historically, heralded new physics before direct detection
- Superb measurements to-date provide stringent constraints to NP

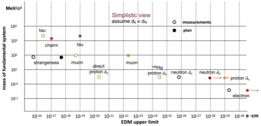
[Briefing Book]: Flavour highlights

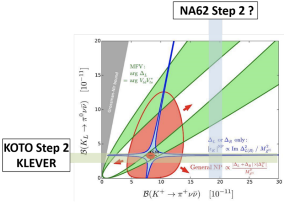
- A diverse flavour programme must form key part of EU's strategy with a suite of exquisite experiments to boot
  - Both accelerator and non-accelerator based
  - Major part of future collider programme

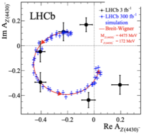


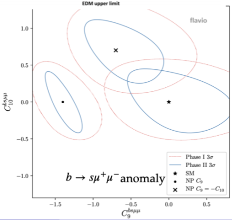








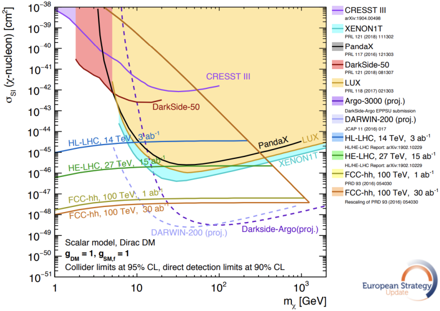


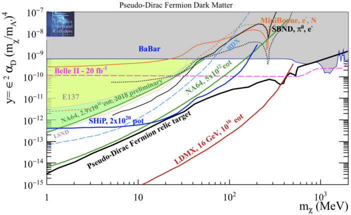


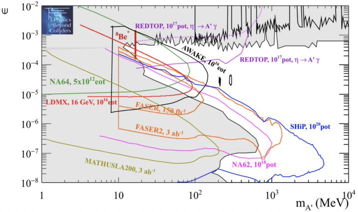
[Briefing Book]: DM highlights

- Viable DM candidates span huge range of masses (10^{-22} eV–$10M_\odot$)
- $\rightarrow$ Different ranges have varying levels of predictive power
- $\rightarrow$ Need to also explore associated Dark Sector
- No single experiment, technology or approach can cover this vast range
- Need a diverse set of experiments and approaches Direct, Indirect, Collider, Fixed-Target, Beam-Dump

  $\rightarrow$ Exploit novel synergy between Flavor Violating measurements and Feebly Interacting Dark Sector







European Strategy Update

On Flavour and DM programme

4. Other essential activities for Particle Physics

a) The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics. This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, dark sector candidates and feebly interacting particles. There are many options to address such physics topics including energy-frontier colliders, accelerator and non-accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. *Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world.*

Strong support and clear physics case for:

1. Precision flavour physics measurements
2. Dark Matter and Dark Sectors searches
3. Electric and Magnetic Dipole Moment measurements
4. Feebly interacting particle searches

Strongly support this activity across labs in Europe and worldwide

HL-LHC and LHCb

- Strong support for LHCb its planned upgrade (Upgrade 2)
  - Exploits the full potential of the HL-LHC

1. Major developments from the 2013 strategy

a) Since the recommendation in the 2013 Strategy to proceed with the programme of upgrading the luminosity of the LHC, the HL-LHC project was approved by the CERN Council in June 2016 and is proceeding according to plan. In parallel, the LHC has reached a centre-of-mass energy of 13 TeV, exceeded the design luminosity, and produced a wealth of remarkable physics results. Based on this performance, coupled with the innovative experimental techniques developed at the LHC experiments and their planned detector upgrades, a significantly enhanced physics potential is expected with the HL-LHC. The required high-field superconducting Nb_3Sn magnets have been developed. *The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques. 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.*

programme at the HL-LHC. The flavour physics programme made possible with the proton collisions delivered by the LHC is very rich, and will be enhanced with the ongoing and proposed future upgrade of the LHCb detector.

→ **Consolidating the UK's leading role in this activity**

Precision flavour measurements

- The strategy strongly supports a diverse flavour programme studying:
  1. Rare Kaon decays (CERN, KEK)
  2. MDMs, EDMs (FNAL, worldwide)
  3. Rare muon decays (FNAL, PSI, KEK)
  4. Beauty/Charm physics (CERN, KEK)

  → Access energy scales inaccessible by any future collider

4. Other essential activities for Particle Physics

The observed pattern of masses and mixings of the fundamental constituents of matter, quarks and leptons, remains a puzzle in spite of the plethora of new experimental results obtained since the last Strategy update. Studying the flavour puzzle may indicate the way to new physics with sensitivity far beyond what is reachable in direct searches, e.g. the evidence for the existence of the top quark that followed from the study of B-meson mixing. In addition, flavour physics and CP violation, which play a vital role in determining the parameters of the Standard Model, are explored by a wide spectrum of experiments all over the world. These include measurements of electric or magnetic dipole moments of charged and neutral particles, atoms and molecules, rare muon decays with high intensity muon beams at PSI, FNAL and KEK, rare kaon decays at CERN and KEK, and a variety of charm and/or beauty particle decays at the LHC, in particular with the LHCb experiment. New results are expected in the near future from the Belle II experiment at KEK in Japan and from LHCb (currently undergoing an upgrade) at CERN.

→ **UK has leading role in all these activities with:**
NA62, LHCb, BESIII; Muon ($g-2$); Mu3e, Mu2e, COMET; and their planned upgrades
→ **Commensurate developments in Flavour theory and Lattice QCD crucial to capitalise on experimental precision**

Dark Matter searches

4. Other essential activities for Particle Physics

There is ample evidence from galactic and cosmological observations that, within the context of general relativity, dark matter is the dominant form of matter in the universe. The existence of dark matter is another compelling evidence for physics beyond the Standard Model and detecting it in the laboratory remains one of the great challenges of particle physics. Given the present limits from multiple overlapping direct detection experiments, the mass of dark matter particles could be anything from as light as 10^{-22} eV to as heavy as primordial black holes of tens of solar masses. A comprehensive suite of experiments and techniques is required in order to cover the many possibilities. Accelerator-based beam-dump and fixed-target experiments can perform sensitive and comprehensive searches of sub-GeV dark matter and its associated dark sector mediators, complementary to high-energy colliders and other approaches.

- The strategy strongly supports a comprehensive search for DM and assosciated Dark Sectors using Direct, Indirect, Collider and Beam-Dump/Fixed-Target facilities
  - This includes experiments like: LZ, DarkSide, CMS, ATLAS, FASER(2), SHiP, NA62(Beam Dump), NA64(++), LDMX, MicroBooNE, CODEX-b, ADMXG2...

Dark Matter synergies

5. Synergies with neighbouring fields

b) Astroparticle physics, coordinated by APPEC in Europe, also addresses questions about the fundamental physics of particles and their interactions. The ground-breaking discovery of gravitational waves has occurred since the last Strategy update, and this has contributed to burgeoning multi-messenger observations of the universe. *Synergies between particle and astroparticle physics should be strengthened through scientific exchanges and technological cooperation in areas of common interest and mutual benefit.*

There are multiple synergies between particle and astroparticle physics, at the level of infrastructure, detectors, computing, interaction models and physics goals. These connections are through neutrino physics, dark matter searches, cosmic ray physics and, potentially in the future, gravitational waves. The precision measurements of the neutrino properties rely on solar and atmospheric neutrinos for the determination of several mass and mixing parameters. Large underground neutrino detectors are used both in long-baseline accelerator experiments and in astroparticle physics. Searches for dark matter are performed by dedicated underground experiments and by large astroparticle detectors like H.E.S.S., Antares or IceCube and, in the near future, the CTA observatory. The Astroparticle Physics European Consortium (APPEC) theory centre for astroparticle physics, EuCAPT, was established recently, and CERN was chosen as its first hosting hub. The need to foster these synergies has been clearly identified in the national inputs to the Strategy update.

- Clear statement supporting synergies with Astroparticle community including the searches for DM that cover detectors, infrastructure, and computing

CERN's Beam Dump Facility

The physics case for a Beam Dump Facility that will enable a diverse and world leading experimental programme (e.g SHiP, τFV) in:

1. Dark Matter/Dark Sector searches
2. Feebly Interacting Particles
3. Charged Lepton Flavour Violation
4. Neutrino physics

is clear as evidenced by explicit statements in the strategy document
(see previous slides)

in the National Laboratories and research institutes. Many of the proposals for new experiments at CERN are on a scale such that they could be considered for approval in the usual manner by the scientific committees and the Research Board. Among the proposals for larger-scale new facilities investigated within the Physics Beyond Colliders study, the Beam Dump Facility at the SPS emerged as one of the frontrunners. However, such a project would be difficult to resource within the CERN budget, considering the other recommendations of this Strategy.

- However, CERN cannot afford due to commitments to collider programme, so national labs are encouraged to advance the exploration of the lower energy regime
- Understood that CERN will continue to fund the PBC initiative and related R&D in medium term

Conclusions

- The open questions in particle physics posed in the strategy document, combined with the lack of clear evidence of a New Physics energy scale, Flavour measurements and Dark Matter searches are essential to the EU strategy.

Arguably should be high-priority sectors

A final thought (paraphrasing G. Isidori):

- The "B-physics anomalies" provide a concrete demonstration of the high discovery potential of flavour physics.
- Measurements enable fully predictive models [e.g PS³ Isidori et al] unifying quarks/leptons and explaining hierarchy of CKM matrix
- Even if they will go away, they have been very beneficial in shaking some prejudices in model building highlighting new interesting directions.

[Alguero et al '20] $> 6\sigma$ tension to SM