# Physics briefing book

(relevance to the Nikhef ESPP process)

https://cds.cern.ch/record/2944678

# Higgs: what's (not) there

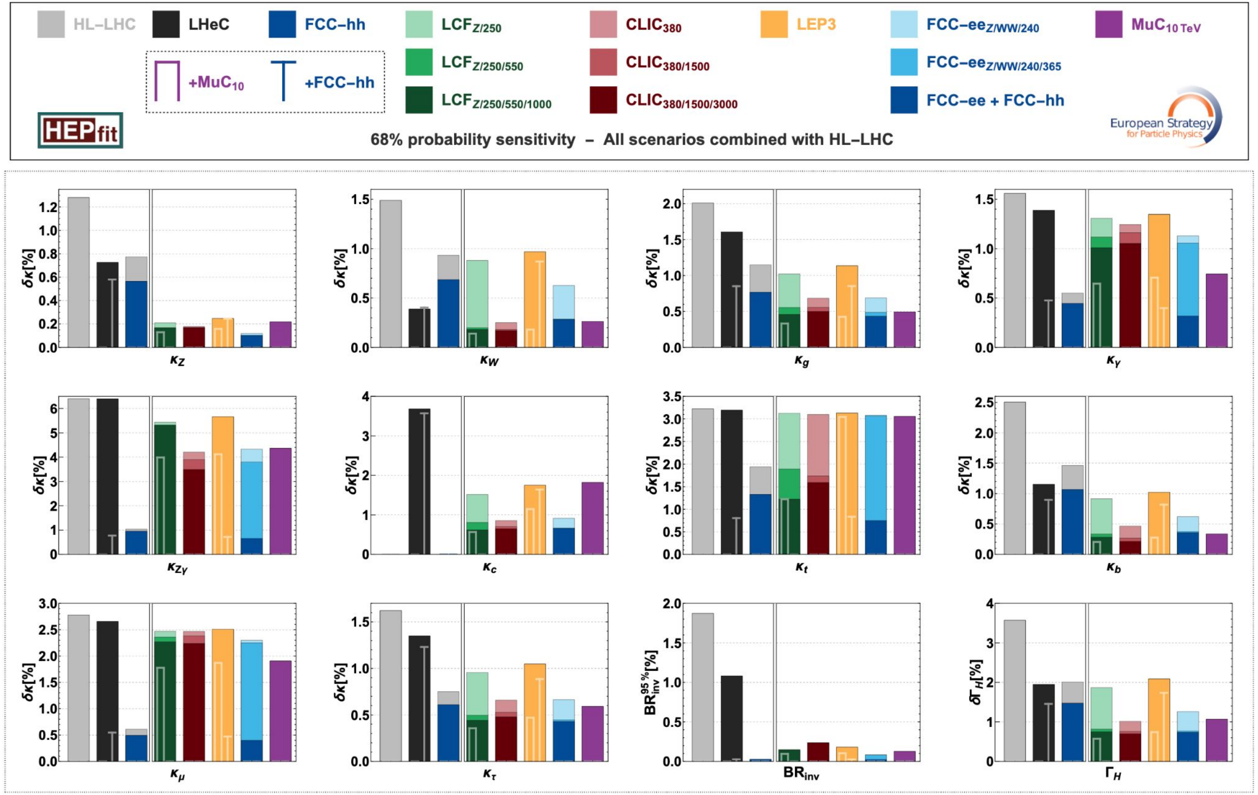
- Results for standalone FCC-hh, LHeC+FCC-hh and LEP3+FCC-hh are presented, but not for the combination LHeC+LEP3+FCC-hh.
- Physics of LEP3 and LHeC is fairly complementary though.
- Results for FCC-hh assume HL-LHC theory errors.
- Improvements from LHeC on PDFs and $\alpha_s$ are large (a factor 3 for uncertainties is mentioned) and not included. Impact of this on FCC-hh is less clear.

# Higgs: some conclusions

- Number of Higgs bosons: FCC-ee = 9x LCF, LEP3 = 2x LCF.
- Excluding invisible Higgs decays with branching fractions above:
  HL-LHC: 1.9%, FCC-ee: 0.055%, LEP3: 0.2%, LCF: 0.12% FCC-hh 0.02%.
- Without e+e- the total width is unknown, requiring model assumptions.
- Uncertainty on Higgs trilinear coupling:
  HL-LHC: 27%, FCC-ee with higher energy: 15-20%, LCF: 7 - 11%, FCC-hh: 3-4%.

# Higgs: a figure

- LHeC excels at W.
- LEP3 and LHeC comparable for b, (indirect) Higgs width.
- LEP3 better for c, but LHeC also ok (HL-LHC can’t do it).
- LEP3 better for Z, invisible decays.



# 5) Flavour Physics

The flavour sector remains a fundamental pillar of identifying UV-complete models with a massive amount of experimental observables / dim-6 operators in SMEFT, and mostly concerns itself with the structure of Yukawa couplings (Higgs), connected to flavour non-universality and flavour-changing neutral currents. \\

Flavour physics is dominated by the HL-LHC with LHCb, highlighting the importance of completing the full HL-LHC programme.
Beyond that, major progress is expected with FCC-ee at tera-Z, especially in tau decays and final states involving neutrino's. That should not be underestimated - but requires dedicated features of detectors. \\

Flavour physics progress is not only made at large accelerators, but also in "table-top" experiments like electric dipole-moments (EDMs) and dedicated charged lepton flavour violation (cLFV) or rare kaon/pion decay experiments. Part of the beauty (and strength) of flavour physics is the ability to constrain related observables at such completely diverse energy scales and experimental approaches. \\

Dedicated theoretical improvements (QCD) are essential, such as lattice QCD.

# 6) Neutrinos

Several exciting particle physics conclusions are expected from the neutrino sector in the coming decade(s): the mass ordering, the CP-violating phase, Majorana nature and the absolute mass scale, with European involvement. In addition this sector holds potential for BSM particles / DM candidates in the form of light sterile neutrinos (LSNs) or heavy neutral leptons (HNLs).
Beyond particle physics, there is a lot of potential for neutrino astrophysics and cosmology (nCMB) measurements, sometimes within the same experiments. \\

CERN contributes to long-baseline neutrino programme (DUNE) and oscillation experiments (HyperK) via the neutrino platform, but also TeV-scale neutrino interaction measurements through e.g. FASER and later FPF are deemed essential input to neutrino astrophysics. \\

# 7) Cosmic Messengers

Many cosmological and astrophysical questions are intricately related to HEP.

A center for collaboration in astroparticle theory, EuCAPT was realized at CERN after the last strategy update, and is deemed very important to keep.

Also collaboration on civil engineering, vacuum systems, DAQ and sensor development are key parts of synergy with HEP.

# 9) Dark Matter and Dark Sector

The identification of a dark matter particle, or dark sector, is a major goal of HEP. A major contribution lies in the search for dark portal channels or missing energy at a large collider experiment. \\

Beyond colliders, ultra-light dark sectors (ULDM, sub-eV) searches is a relatively recent field employing haloscopes and helioscopes to search for axion-like particles, where CERN contributes in terms of CAST and future IAXO, and further experiments are being deployed in European laboratories. \\

Further, there is ample European involvement in direct detection of light dark sectors (keV-GeV) with experiments like XENON and future XLZD aiming to be the ultimate direct detection experiment reaching the neutrino floor.

# Magnet readiness

“The design of a next-generation high energy hadron collider lies on the solid foundation of the LHC and HL-LHC designs, construction and operational experience, however, it faces significant technological challenges, namely HFMs, cryogenics, vacuum and machine protection.

The FCC-hh technical timeline is largely determined by progress on the development and industrialization of the arc dipole magnets.

The baseline Nb3Sn magnet production could be ready to start around 2045 and could take roughly 10 years while, with current knowledge, the timeline for HTS magnets is around 5 to 15 years longer, conditional on the successful demonstration of the feasibility of an accelerator-class FCC-hh short HTS dipole.

A decision point on the conductor technology is expected around 2035 at the earliest. This timeline is ambitious and subject to significant uncertainties, given the low TRL of HTS technology for accelerator-class magnets.”

- Physics Briefing Book: pg. 189

# Muon Colliders

“MCs could be an option for achieving HE lepton collisions but they have not yet reached the level of maturity of the other large-scale collider project proposals...

The proton-driver for the muon beam production shares the technology and beam-dynamics challenges of high intensity-proton accelerators developed for PBC and would benefit from the common R&D in that domain.

Particularly critical is the demonstration of the 6D ionization cooling which requires a dedicated medium-sized test facility. A variety of technological challenges is associated with the MC cooling channel and the downstream accelerators.

Start-to-end simulation tools need to be further developed to validate the overall performance of MCs. Neutrino flux mitigation remains a critical subject and is being studied.”

- Physics Briefing Book: pg. 189