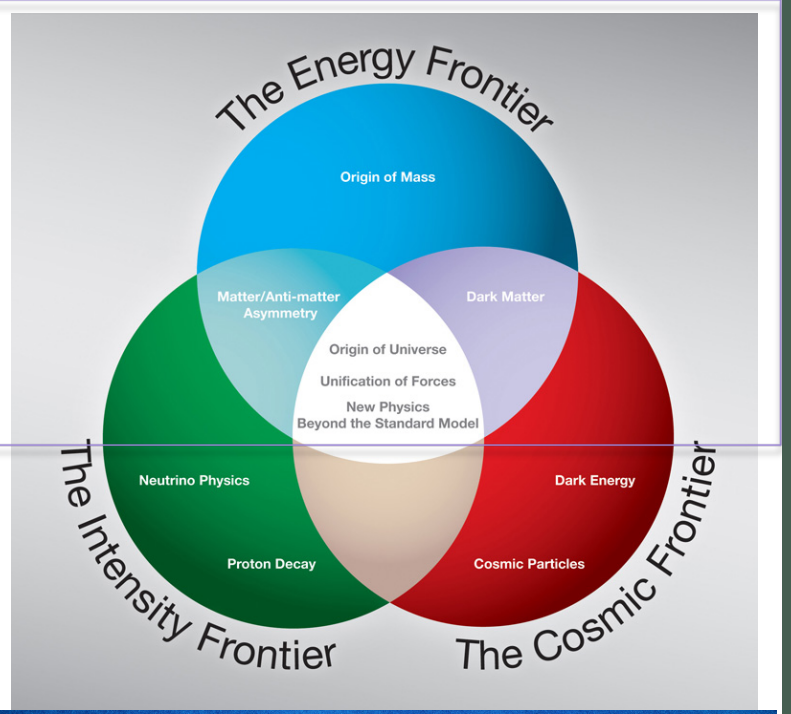

UNIVERSITY OF LIVERPOOL

Energy frontier: physics at colliders

(not including flavour)

Monica D'Onofrio

University of Liverpool

STFC Town Meeting
28/7/2020

Statements from ES

- Strategy provides **20** "recommendations" (statements).

From Halina's talk

Guide through the statements

2 statements on **Major developments from the 2013 Strategy**
a) Focus on successful completion of HL-LHC upgrade remains a priority
b) Continued support for long-baseline experiments in Japan and US and the Neutrino Platform

3 statements on **General considerations for the 2020 update**
a) Preserve the leading role of CERN for success of European PP community
b) Strengthen the European PP ecosystem of research centres
c) Acknowledge the global nature of PP research

2 statements on **High-priority future initiatives**
a) Higgs factory as the highest-priority next collider and investigation of the technical and financial feasibility of a future hadron collider at CERN
b) Vigorous R&D on innovative accelerator technologies

Letters for itemizing the statements are introduced for identification, do not imply prioritization

4 statements on **Other essential scientific activities**
a) Support for high-impact, financially implementable, experimental initiatives world-wide
b) Acknowledge the essential role of theory
c) Support for instrumentation R&D
d) Support for computing and software infrastructure

2 statements on **Synergies with neighbouring fields**
a) Nuclear physics – cooperation with NuPECC
b) Astroparticle – cooperation with APPEC

3 statements on **Organisational issues**
a) Global collaboration on projects in and out of Europe
b) Relations with European Commission
c) Open science

4 statements on **Environmental and societal impact**
a) Mitigate environmental impact of particle physics
b) Investment in next generation of researchers
c) Knowledge and technology transfer
d) Cultural heritage: public engagement, education and communication

Collider physics and high-priority future initiatives

- Strategy provides **20** "recommendations" (statements). Particularly relevant:

F. Gianotti, June Council Week

  - Full exploitation of LHC physics potential → successful completion of the HL upgrade of accelerators and experiments
  - e+e- Higgs factory as the highest-priority next collider
  - Increased R&D on accelerator technologies: high-field superconducting magnets, high-gradient accelerating structures, plasma wake-field, muon colliders, ERL → Accelerator R&D Roadmap (established by big European labs)
  - Investigation of the technical and financial feasibility of a future ≥ 100 TeV hadron collider at CERN, with e+e- Higgs and electroweak factory as a possible first stage → To be completed by next Strategy update (~ 2026).

Here: a few initial reflections on these four themes (my own view)

HL-LHC: a done deal?

- Full exploitation of LHC physics potential:
  - HL-LHC is well under way, but completion is challenging. Huge UK investment for the past 20+ years, must remain the highest priority of the particle physics community
  - The HL-LHC scientific potential **is enormous** → Studied in detail for the ES in the context of the Workshop on *"The physics of HL-LHC" (2017-2018)*

The physics potential of HL-LHC

Editors:

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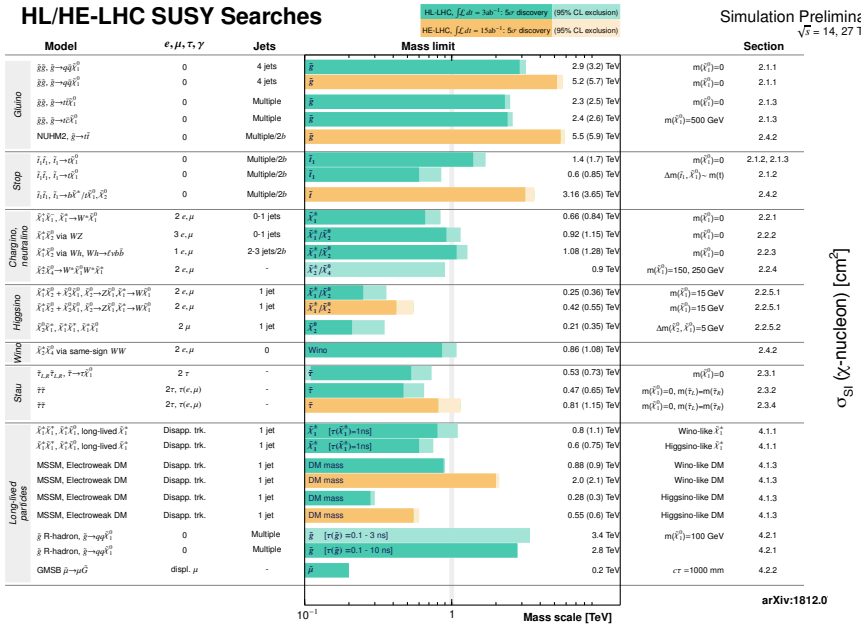
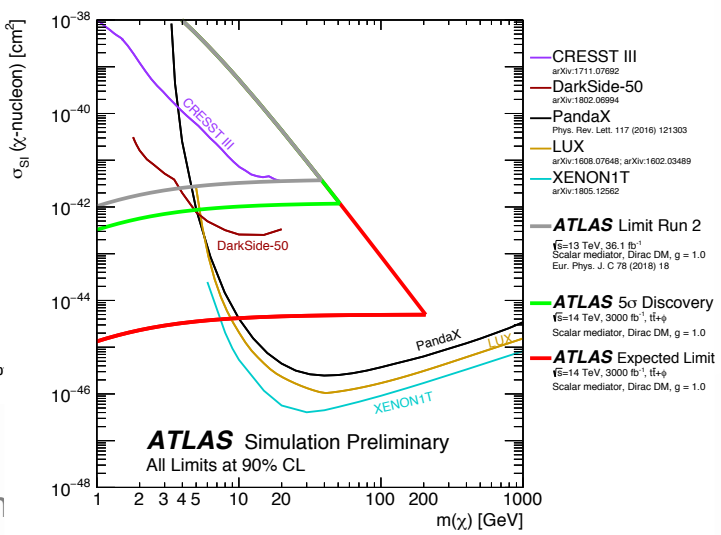
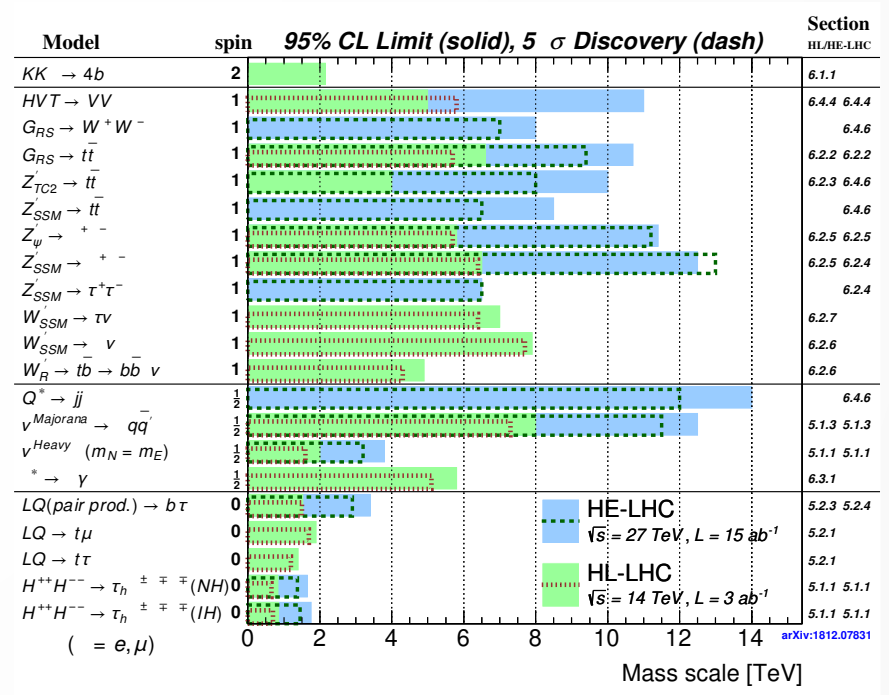


Broad and rich programme of searches for new physics including Dark Matter





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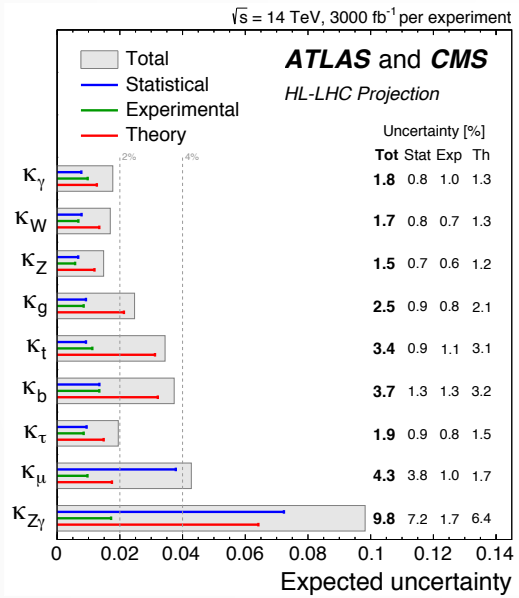
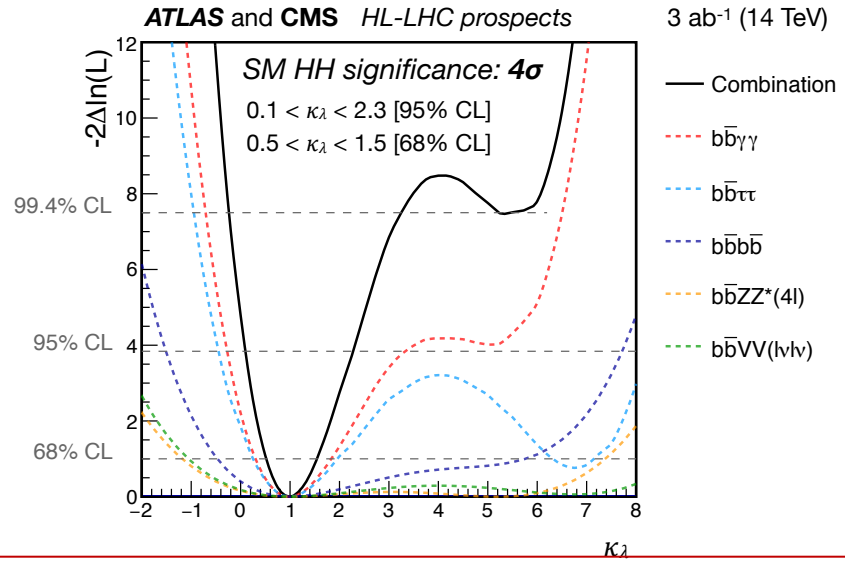


Huge potential in Higgs physics



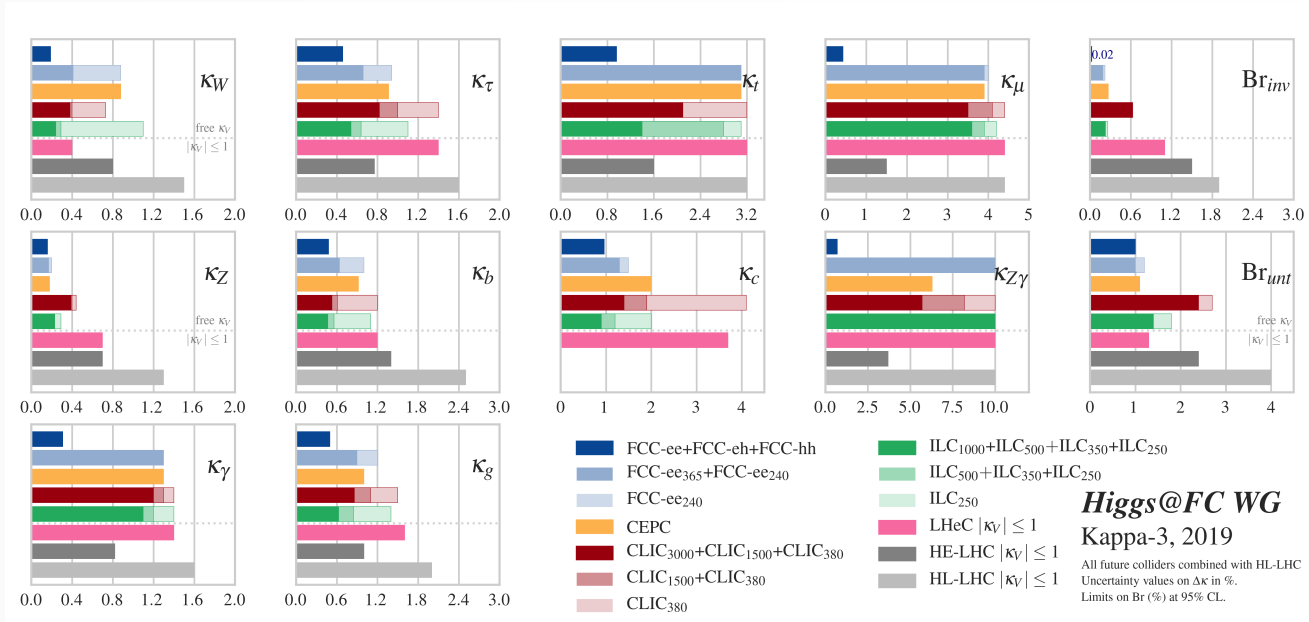
- Rate measurements show that **percent level precision can be reached for most couplings**
- An upper limit on the **Higgs invisible BR of 2.5%** will be reached.
- **Di-higgs:** Assuming SM Higgs self-coupling λ, **observation sensitivity of 3 s.d. per exp., 4 s.d. combined**

→ could reach 5 s.d. with 4/ab offering a unique window to higgs-self coupling

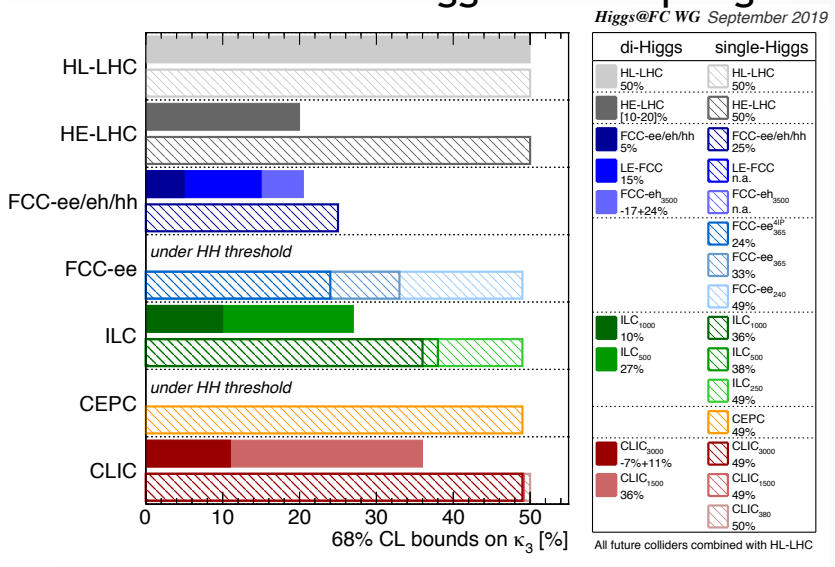
HL-LHC should not be taken for granted – continuous engagement crucial

Higgs factory as the highest-priority next collider

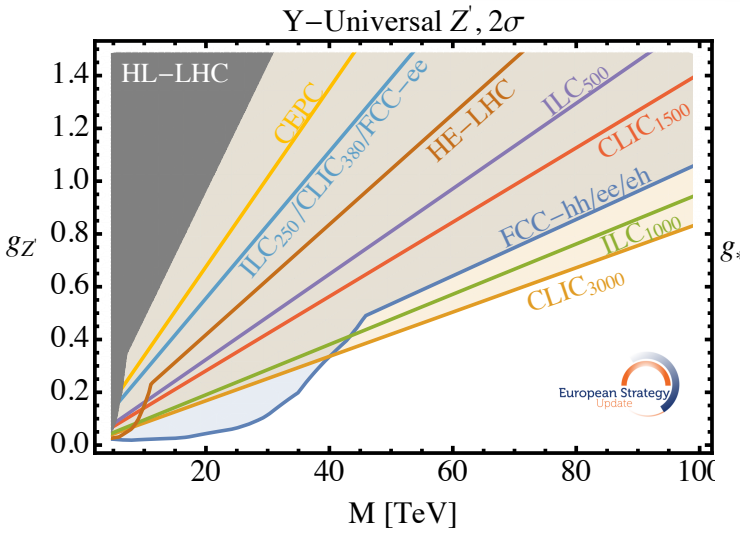
- Huge potential in the **higgs sector** for **e+e-** but also other facilities

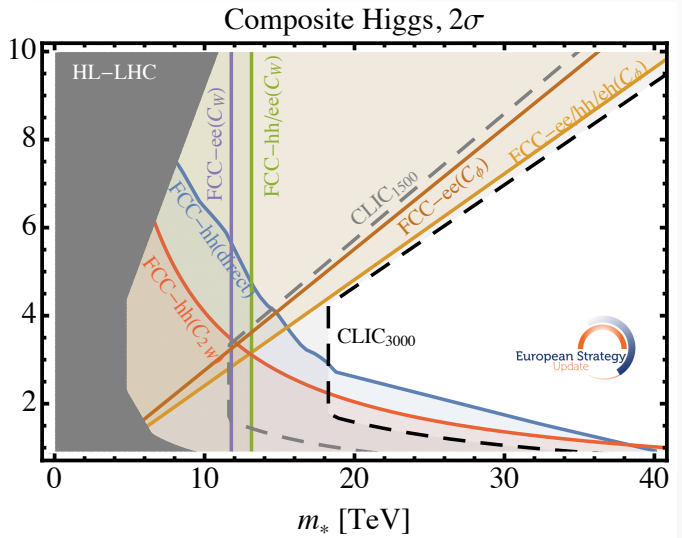


Reach on higgs self-coupling



- Indirect searches for new physics and competitiveness in direct searches for e+e- colliders at high c.o.m. energy as CLIC





Electron-positron collider(s)

- **No consensus in European community on which type of future e+e- collider (linear or circular)**

F. Gianotti, June Council Week

- If FCC feasibility study successful and project approved → FCC-ee is natural choice at CERN
- ILC: compatible with ESPP if timely (otherwise conflict of resources with next collider at CERN)
  - **are ILC and FCC-ee complementary enough in terms of physics? No consensus**
- Chinese colliders (CepC, SppC): direct competition → if CepC goes ahead, Europe would go directly to FCC-hh (if feasible)

My own view: go directly to FCC-hh also in case ILC goes ahead. In the medium term: UK should (continue to) engage in the 4 e+e- ongoing projects(*), and look for synergies in detector R&D.

This is also in-line with the ECFA strategy. From Jorgen D'Hondt ECFA meeting (10.7.2020)

- **Detector, Experiment and Physics studies towards a Higgs Factory**

  (aligned with the ECFA initiative to map the potential of Higgs physics at future colliders)
- **Organize the development of a Detector R&D Roadmap**

  (additional to the ECFA Detector R&D Panel)

(*) various UK initiatives already in progress, e.g. ILC engagement meeting, 18th September

Higgs Physics as a Key Topic for Future PP

From Jorgen D'Hondt ECFA meeting (10.7.2020)

Physics, Experiment & Detector studies towards a Higgs Factory

Support for and Acknowledgement of a series of PED@HF workshops

PED@HF – Physics, Experiments and Detector studies at Higgs Factories

ECFA acknowledges the need for the experimental and theoretical communities involved in Physics studies, Experiment designs and Detector technologies at future Higgs Factories to gather. ECFA supports a series of workshops with the aim to share challenges and expertise, to explore synergies in their efforts and to respond coherently to this priority in the European strategy for particle physics.

Such *Aix-les-Bains-type* workshops would focus on PED studies for a Higgs Factory which would match a previous ECFA initiative mapping the potential of Higgs studies at future colliders. Setting up an International Advisory Committee (IAC) would be the next step, involving some RECFA members and European leaders of the most relevant colliders (e.g. CLIC, FCC, ILC, CEPC, LHeC, muon collider) with a mandate to setup a Program Committee (PC) that would develop an agenda in consultation with the IAC, and embracing the global nature of these projects.

Higgs Physics as a Key Topic for Future PP

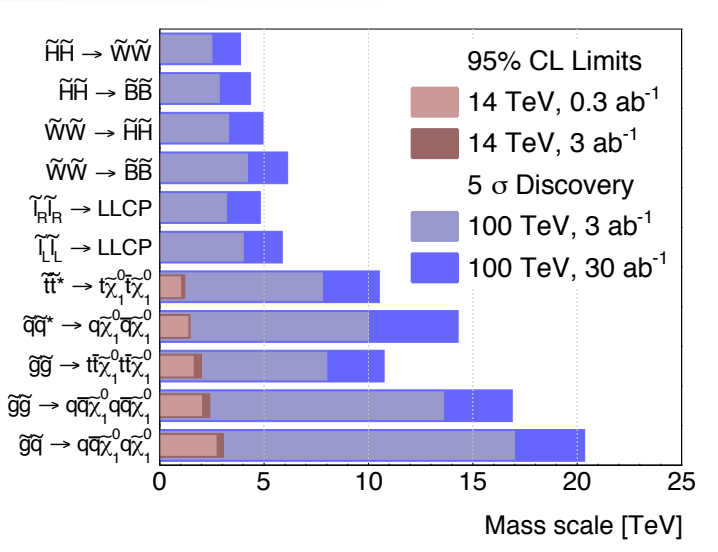
- ECFA suggests to perform synergic studies on a variety of colliders relevant for the higgs sector, beyond e+e- CLIC, FCC-ee, ILC and CepC
- Important also in the context of increased R&D on accelerator technologies:
  - From ES recommendations: " The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, **bright muon beams**, **energy recovery linacs**
    - Energy Recovery Linac for e-p colliders (LHeC, FCC-eh)
      - PERLE demonstrator well under way
      - synergies of eh physics programme with hh and e+e- clearly demonstrated
    - Bright muon beams for muon collider → growing interest within the community
      - Muon Collider Collaboration Meeting https://indico.cern.ch/event/930508/
      - Strong synergies with neutrino programme (nuSTORM)

UK should build upon current expertise, on-going efforts and interest and exploit synergies

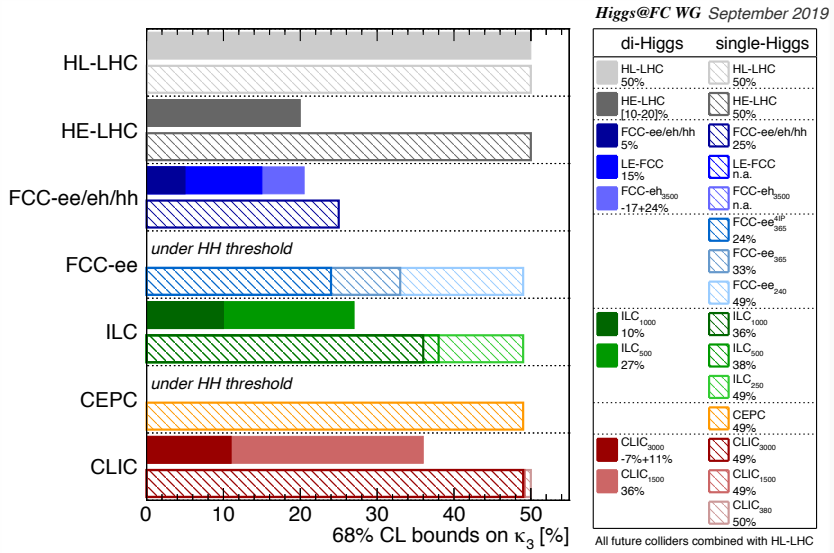
The future hadron collider

- [F.G.@June Council]: Investigation of the technical and financial feasibility of a future ≥ 100 TeV hadron collider at CERN, with e+e- Higgs and electroweak factory as a possible first stage → To be completed by next Strategy update (~ 2026).
- The potential of an FCC-hh is enormous
  - no guarantee of discovery of new particles **BUT** the foreseen reach is almost unbeatable, also in the higgs sector (e.g. di-higgs)

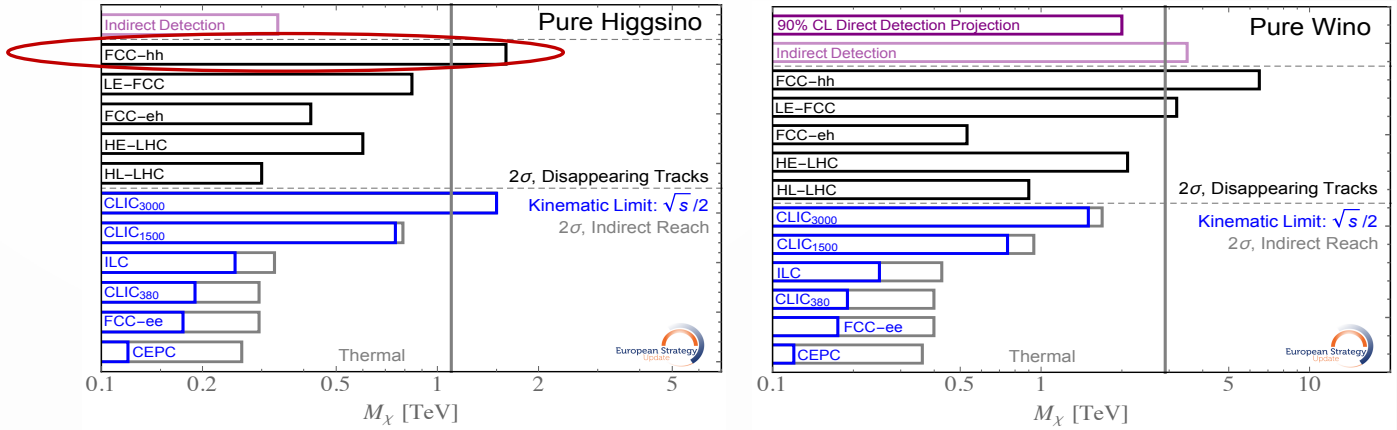
New particles reach O(10 TeV)



FCC-hh IS an Higgs-factory!



Unique direct reach of most credited DM candidates



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  reach is almost unbeatable, also in the higgs sector (e.g. di-higgs)
- "Technical and financial feasibility" for CERN refers mostly to the tunnel (first priority)

Although the accelerator aspects (tunnel, superconducting magnets) remain the main challenge, the community should engage on further and deeper physics studies, as well as on detector R&D

The option of a low-energy FCC has been briefly touched upon in the ES document → a valuable possibility to keep on our radar?

Note: a UK FCC meeting (11th of September 2020) is being planned to discuss coherent UK efforts in terms of detector R&D, physics studies, accelerator and theory. Mailing list: fcc-uk@cern.ch

Conclusions [or, to better say, my initial reflections]

- Thoughts on what we refer to as **"Energy Frontier"**
  - **HL-LHC** should not be taken for granted – continuous engagement is crucial, the potential is huge and must be fully exploited
  - UK should (continue to) engage in the **4 electron-positron** collider options, exploiting **synergies in the context of detector R&D**
  - Higgs Physics is the key topic for Future PP: as emphasized by ECFA, mapping the potential of Higgs studies at future colliders should involve all options
    - **ee, ep, pp, mumu all have different energy frontiers.**
  - Although the accelerator aspects (tunnel, superconducting magnets) remain the main challenge, the community should engage on further and more in-depth **physics studies at FCC-hh** and on detector R&D
    - → could be crucial in the case outlined by CERN "if CepC goes ahead, Europe would go directly to FCC-hh (if feasible)" [my note: also if ILC goes ahead]
  - The option of a **low-energy FCC** could still be a valuable possibility to keep on our radar

Given the status of PP, the duration of the HL-LHC, and the cost and technical challenges, the task is to better understand and compare the feasibility of our plans → perhaps this needs more than one next collider, and a well tuned, global programme of very intense colliders exploring the energy frontier(s).

Back up

3

High-priority future initiatives

A. 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.

B. 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. 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. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.***

From F.G. June Council talk

FCC's main challenges

Financial feasibility

Cost of tunnel: ~5.5 BCHF; FCC-ee: ~5-6 BCHF; FCC-hh: ~17 BCHF (if after FCC-ee)

→ cannot be funded only from CERN's (constant) budget + additional "*ad hoc*" contributions from Member and other States → need innovative mechanisms: EC? private funds? donations?

First priority of feasibility study: find funds for the tunnel

Governance model for an unprecedented, global project

To be developed with international partners from the outset

Technical and administrative feasibility of tunnel

- ❑ highly-populated area; two countries with different legislative frameworks
- ❑ land expropriation and reclassification
- ❑ need to gain support of local populations (with a view to public surveys and debates)
- ❑ environmental aspects

First priority of feasibility study: no show-stoppers for ~100 km tunnel in Geneva region

Technologies of machine and experiments

- ❑ huge challenges, but under control of our scientific community → "easier"
- ❑ environmental aspects (aim at "green collider"): power, energy, cooling, gases, etc.

First priority of feasibility study: magnet technology; how to minimise environmental impact

Gathering political and societal support

→ requires "political work" and vast communication campaign for "consensus building" with governments and other authorities, scientists from other fields, general public (Science Gateway,…)