# The European Strategy and the future of HEP

Fabiola Gianotti (CERN), HL-LHC Collaboration meeting, 15/10/2018

# Introduction

The European Strategy for Particle Physics (ESPP) is the process by which every ~ 7 years the European particle physics community updates the priorities and strategy of the field.
It also makes recommendations on related activities: education, communications and outreach, technology transfer, organisational aspects, etc.

First ESPP in 2006; first update in 2013; next update 2020.

Bottom-up process involving the community. Driven by physics*, with awareness of financial and technical feasibility.

ESPP produces the European roadmap in the worldwide context of the field.
Note: particle physics requires global coordination, given the number, size and complexity of the projects → "alignment" of the European, US and Japanese roadmaps in recent years to optimise the use of resources

The Strategy is adopted by the CERN Council.
Individual (major) projects require dedicated approval: e.g. HL-LHC

* The scientific input includes: physics results from current facilities from all over the world; physics motivations, design studies and technical feasibility of future projects; results of R&D work, etc.

# 2013 ESPP update

17 "recommendations":

- 3 : general issues
- 4 : high-priority large-scale scientific projects
- 5 : other essential scientific activities
- 2 : organisational issues
- 3 : wider impact on society

# Examples of recommendations from 2013 ESPP

The success of the LHC is proof of effectiveness of the European organisational model for particle physics, founded on the sustained long-term commitment of the CERN Member States and of the national institutes, laboratories and universities closely collaborating with CERN. *Europe should preserve this model in order to keep its leading role, sustaining the success of particle physics and the benefits it brings to the wider society.*

*Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030.*

→ HL-LHC approved by Council 2016

*CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme …*

→ Continuation of CLIC, FCC started 2014

*CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*

→ Neutrino Platform started 2014

*CERN, together with national funding agencies, institutes, laboratories and universities, should continue supporting and further develop coordinated programmes of education and training.*

# 2020 ESPP: input

## Expected input from CERN's community

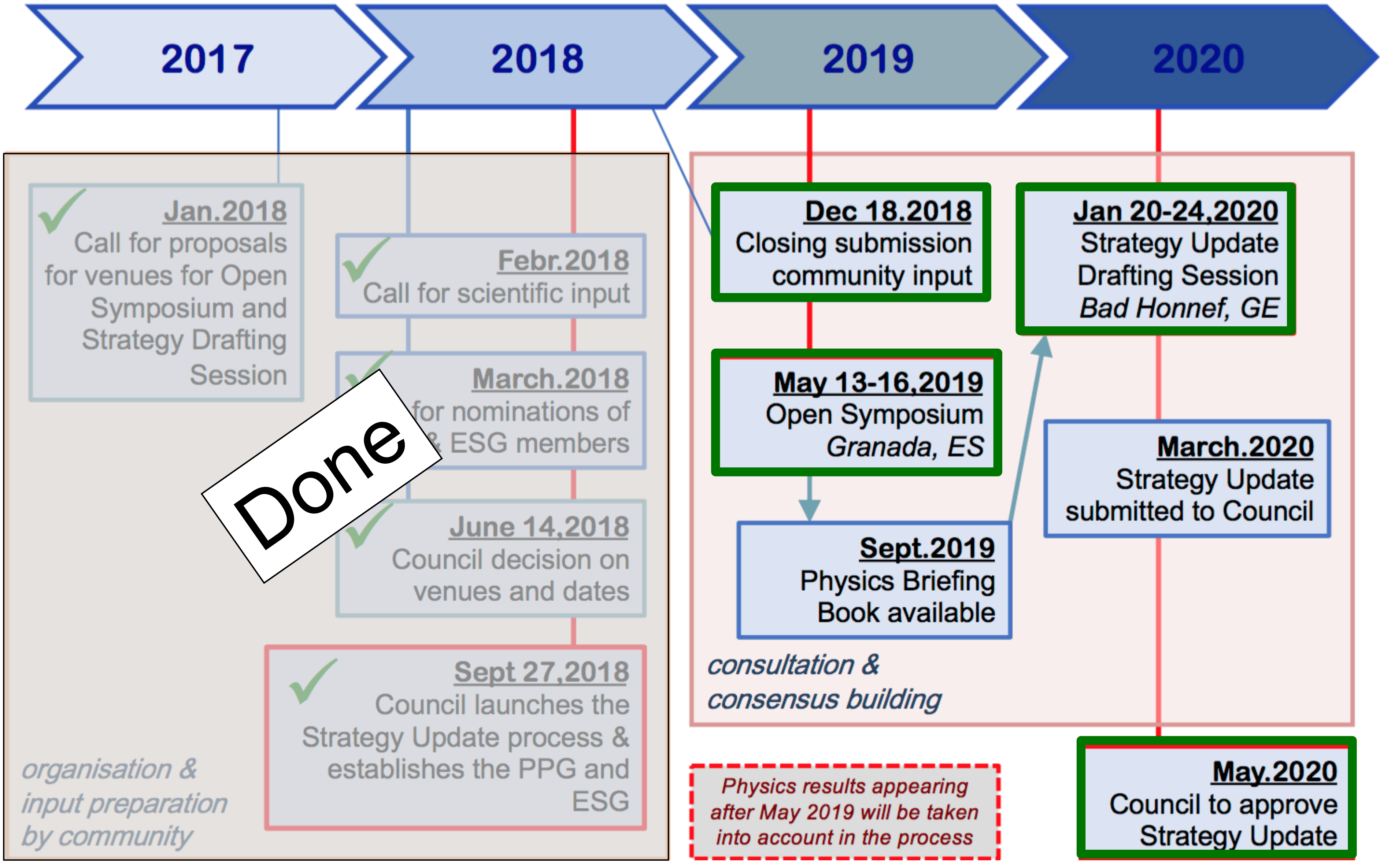
**Physics results from LHC** (Run2!) **and other ongoing experiments**

**Design studies for future facilities and projects:**
CLIC (Compact LInear Collider: ee) Project Implementation Plan
FCC (Future Circular Collider: ee, hh, eh) Conceptual Design Report
Physics Beyond Colliders Report

**Results of R&D work**: superconducting high-field magnets, AWAKE, etc.

**Crucial input will come also from facilities, projects and experiments across the world.**
For instance: Japan's decision to build (or not) an International Linear Collider (ILC), expected by end 2018, will have an impact on which future high-E accelerators CERN should build

# 2020 ESPP update: timeline and committees



# 2020 ESPP update: timeline and committees

- **Strategy Secretariat**
  Organizes the ESPP process
  H. Abramowicz (Chair; also chair of PPG and ESG), J. D'Hondt (ECFA Chair), K. Ellis (SPC Chair), L. Rivkin (Chair of LDG=Laboratory Directors Group)

- **Physics Preparatory Group (PPG)**
  Collects community's input, organises Open Symposium, prepares briefing book
  Strategy Secretariat
  4 members appointed by Council on recommendation of SPC
  4 members appointed by Council on recommendation of ECFA
  1 CERN representative
  2 representatives from Asia and 2 from Americas (appointed by respective ICFA representatives)

- **ESG**
  Drafts the final strategy document
  Strategy Secretariat, 1 representative per CERN Member State, LDG, CERN DG,
  Invited: Council President, 1 representative per Associate Member State and Observer State, PPG, EC representative, JINR/Dubna representative, Chairs of ApPEC, NuPECC, FALC, ESFRI

For more information see:
https://indico.cern.ch/event/754792/contributions/3127781/attachments/1715899/2768187/spc-e-1115-c-e-3389_ESPP-update-composition_of_PPG_and_ESG.pdf

# A very exciting (and puzzling …) time for particle physics

Main results from LHC so far:
- ❑ discovery of the Higgs boson → Standard Model completed, it works beautifully
- ❑ no sign of physics beyond the Standard Model (yet!)

⬇

PUZZLING: the SM is not a complete theory of particle physics, as several outstanding questions remain that cannot be explained within the SM

What is the composition of dark matter (~25% of the Universe) ?
What is the origin of neutrino masses and oscillations ?
Why 3 fermion families ? Why do neutral leptons, charged leptons and quarks behave differently?
What is the origin of the matter-antimatter asymmetry in the Universe ?
Why is the Higgs boson so light (so-called "naturalness" or "hierarchy" problem) ?
Why is Gravity so weak ? Etc. etc.

These questions require NEW PHYSICS
→ Where is it: E-scale?? Couplings to SM particles ??

# Main open questions and main approaches to address them

The breadth and complexity of the outstanding questions, and **the lack of clear indications of where new physics might be** require a variety of approaches: **particle colliders**, neutrino experiments, dark matter direct and indirect searches, **measurements of rare processes, dedicated searches,** cosmic surveys → **scientific diversity** is crucial.

| | High-E colliders | Dedicated high-precision experiments | Neutrino experiments | Dedicated searches | Cosmic surveys |
|---|---|---|---|---|---|
| H, EWSB | x | x | | x | |
| Neutrinos | x ($\nu_R$) | | x | x | x |
| Dark Matter | x | | | x | x |
| Flavour, CP, matter/antimatter | x | x | x | x | x |
| New particles, forces, symmetries | x | x | | x | |
| Universe acceleration | | | | | x |

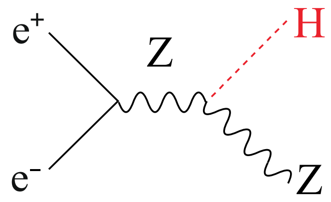
Historically: accelerators have been main tool of exploration

Combination of diverse, complementary scientific approaches necessary to directly and indirectly explore the largest range of E scales and couplings, and to properly interpret signs of new physics → with the goal to build a coherent picture of the underlying theory

# 3 main complementary ways to search for (and study) new physics at accelerators

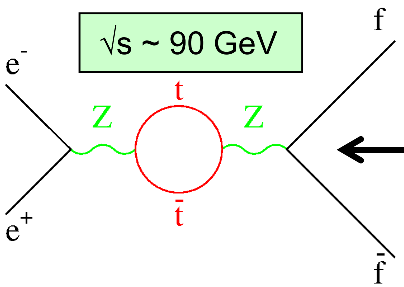
**Direct** — production of a given (new or known) particle

e.g. Higgs production at future $e^+e^-$ linear/circular colliders at $\sqrt{s}$ ~ 250 GeV through the HZ process → need high E and high L

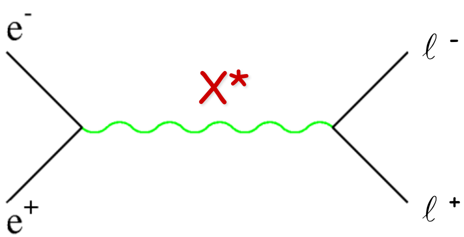



**Indirect** — precise measurements of known processes

→ look for (tiny) deviations from SM expectation from quantum effects (loops, virtual particles)
→ sensitivities to E-scales $\Lambda >> \sqrt{s}$ → need high E and high L



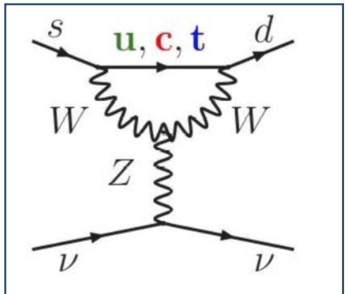

E.g. top mass predicted by LEP1 and SLC in 1993: $m_{top}$ = 177 ± 10 GeV; first direct evidence at Tevatron in 1994: $m_{top}$ = 174 ± 16 GeV




**Rare processes** — suppressed in SM → could be enhanced by New Physics

e.g. neutrino interactions, rare decays→ need intense beams and/or ultra-sensitive (massive) detectors ("intensity frontier")

E.g. $K^+ \rightarrow \pi^+ \nu\nu$ decay (NA62 experiment)
Proceeds via loops → suppressed in the SM : BR~ $10^{-10}$
Can be enhanced by new particles running in the loop.
Theoretically very clean.

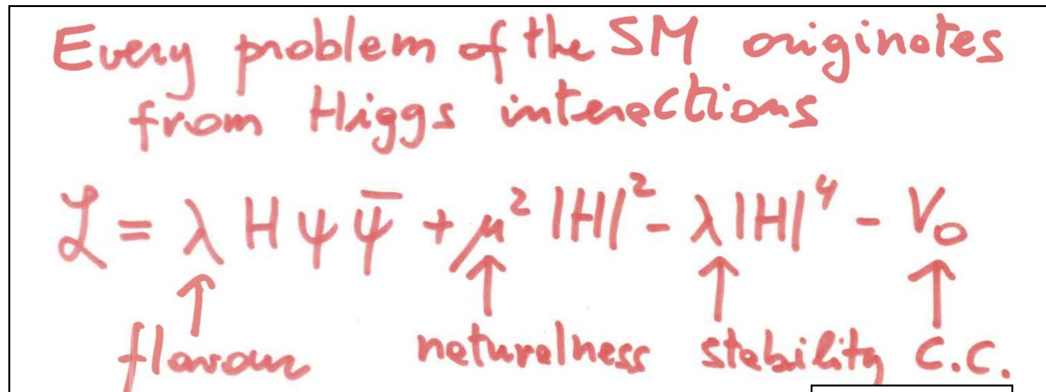


# Higgs boson: a major chapter at any future colliders

The H boson is not just … "another particle":

- ❑ Profoundly different from all elementary particles discovered previously
- ❑ Related to the most obscure sector of Standard Model
- ❑ Linked to some of the deepest structural questions (flavour, naturalness, vacuum, ...)

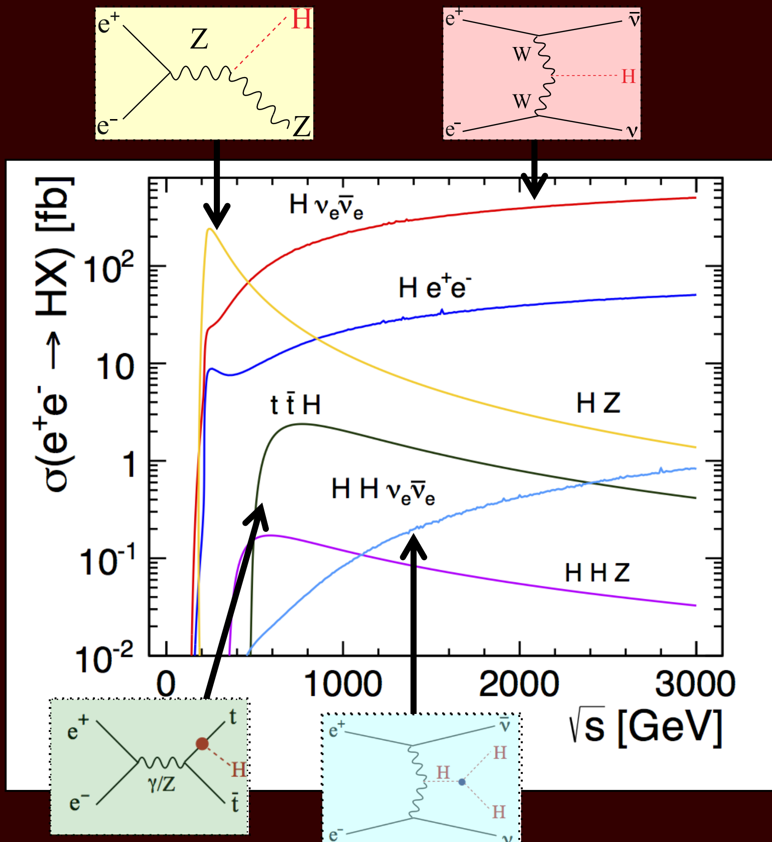
→ Its discovery opens new paths of exploration, provides a privileged door into new physics, and calls for a very broad and challenging experimental programme which will extend for decades




G. Giudice

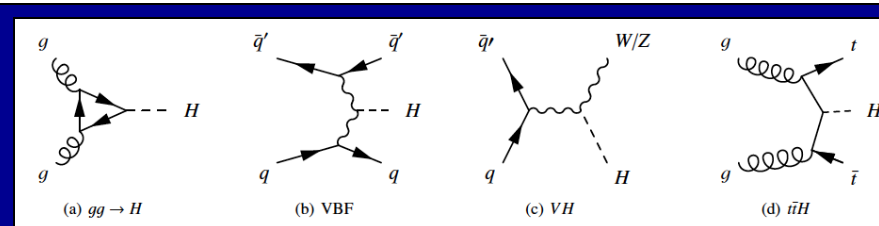
- ❑ Precision measurements of couplings (as many generations as possible, loops, …)
- ❑ Forbidden and rare decays (e.g. H→ τμ) → flavour structure and source of fermion masses
- ❑ H potential (HH production, self-couplings) → EWSB mechanism
- ❑ Exotic decays (e.g. H→ invisible) → new physics (e.g. dark matter, portal to dark sector) ?
- ❑ Other H properties (width, CP, …)
- ❑ Searches for additional H bosons
- ❑ Etc.

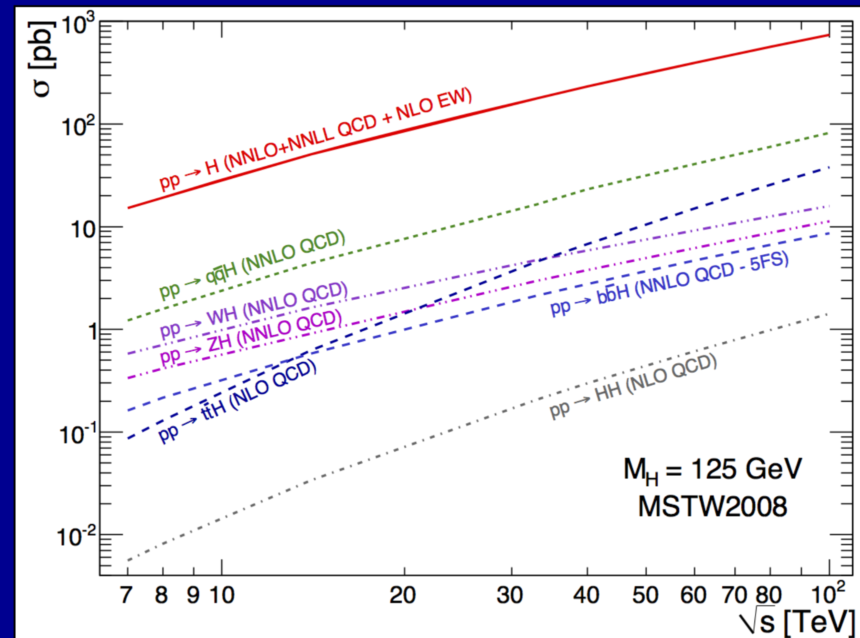
# $e^+e^-$ colliders




- ❑ Low backgrounds → all decay modes (hadronic, invisible, exotic) accessible
- ❑ Model-indep. coupling measurements
- ❑ ttH, HH production for $\sqrt{s} \geq 500$ GeV → LC

# pp colliders




- ❑ High energy, huge cross-sections → optimal for rare decays (if clean) and heavy final states (ttH, HH)
- ❑ Huge backgrounds → not all channels accessible; only fraction of events usable
- ❑ Model-dep. coupling measurements

# HL-LHC physics reach

## 1 Precise measurements of the Higgs boson

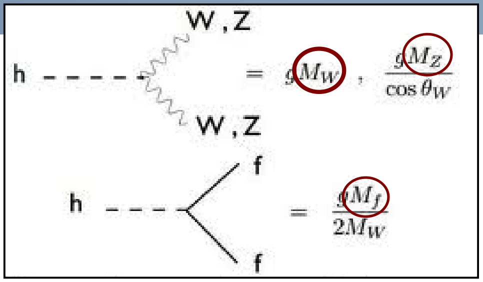
Impact of New Physics on Higgs couplings to other particles:

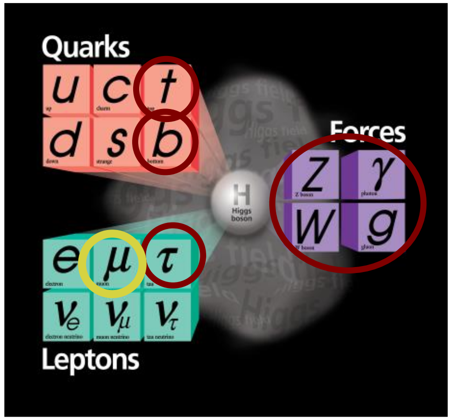
$\Delta\kappa/\kappa \sim 5\%/\Lambda^2_{NP}$ ($\Lambda_{NP}$ in TeV)

Precision ~2-5% at HL-LHC (~10% at nominal LHC)

In addition:

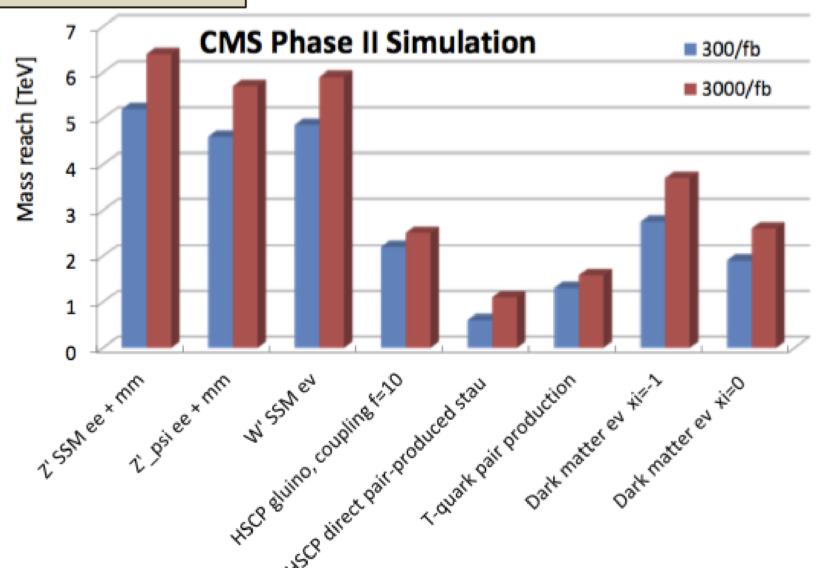
- ❑ couplings to 2nd-generation fermions through rare $H \rightarrow \mu\mu$ decay (only 3rd generation accessible to nominal LHC)
- ❑ observe HH production at $3\sigma$?
- ❑ BR (H→ invisible) < 3% (24% today)




## 2 Discovery potential for new particles

~20-30% larger (up to m ~ 8 TeV) than nominal LHC



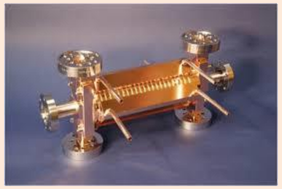

## 3 If new particles discovered in Run 2-3:

→ HL-LHC may find more and provide first detailed exploration of the new physics with well understood machine and experiments

# CLIC


Start at √s= 380 GeV for Higgs and top studies (11 km tunnel) and upgrade up to 3 TeV (50 km tunnel)

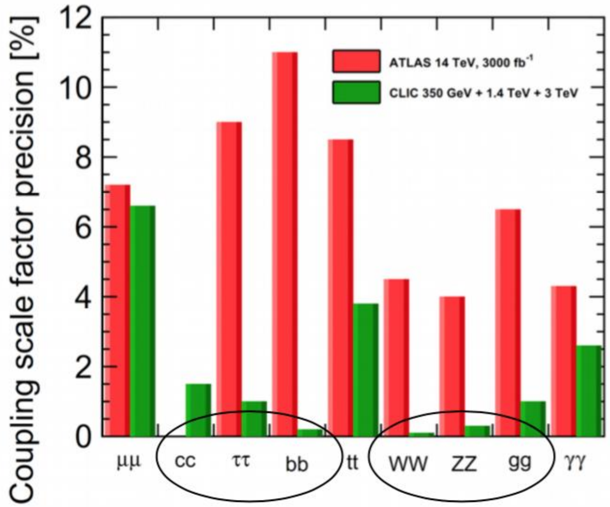
Conceptual Design Report in 2012 → now preparing a Project Implementation Plan for ESPP



Current activities include:
- ❑ cost and power reduction
- ❑ development of high-efficiency, cost-effective klystrons and modulators
- ❑ operation of X-band test stands for 12 GHz accelerating structures
- ❑ linear collider beam dynamics and design optimisation

**Technically,** construction could start in ~2026 → first beams in 2035

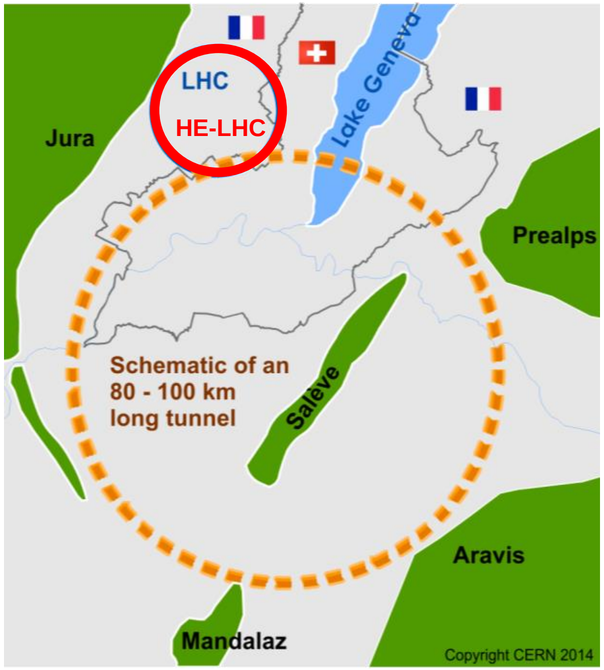
Physics goals:
- ❑ Direct discovery potential and precise measurements of new particles coupling to Z/γ* up to m~ 1.5 TeV
- ❑ Indirect sensitivity to E scales Λ ~ O(100) TeV
- ❑ Measurements of Higgs couplings, in particular: ttH ~ 3.8%, HH ~ 10%




Based on Eur. Phys. J. C 77, 475 (2017)
ATLAS-PHYS-PUB-2014-016

# Future Circular Collider (FCC)

| | | | |
|---|---|---|---|
| FCC-hh: | √s=100 TeV | $L \sim 3x10^{35}$ | 100 km ring |
| FCC-ee: | √s= 90-365 GeV | $L \sim 200\text{-}1.5 \times 10^{34}$ | 100 km ring |
| FCC-eh: | √s=3.5 TeV | $L \sim 1.5x10^{34}$ | 100 km ring |
| HE-LHC: | √s=27 TeV | $L \sim 1.6x10^{35}$ | LHC tunnel |




Major focus: development of new generation 16T $Nb_3Sn$ magnets (conductor programme, industrialisation toward dipole long models).

Preparing Conceptual Design Report for ESPP.
**Preliminary purely technical schedule** for first beams, assuming decision taken at next-but-one ESPP (~ 2026):
FCC-hh: 2043 FCC-ee: 2039 HE-LHC: 2040

# Future Circular Collider (FCC)

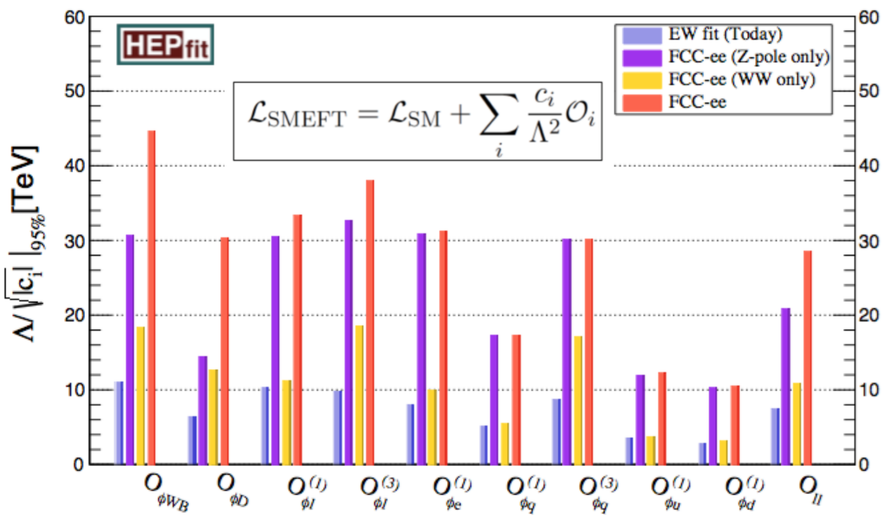
FCC-hh: a ~100 TeV pp collider is expected to:

- ❑ explore directly the 10-50 TeV E-scale
- ❑ conclusive exploration of EWSB dynamics
- ❑ say the final word about heavy WIMP dark matter

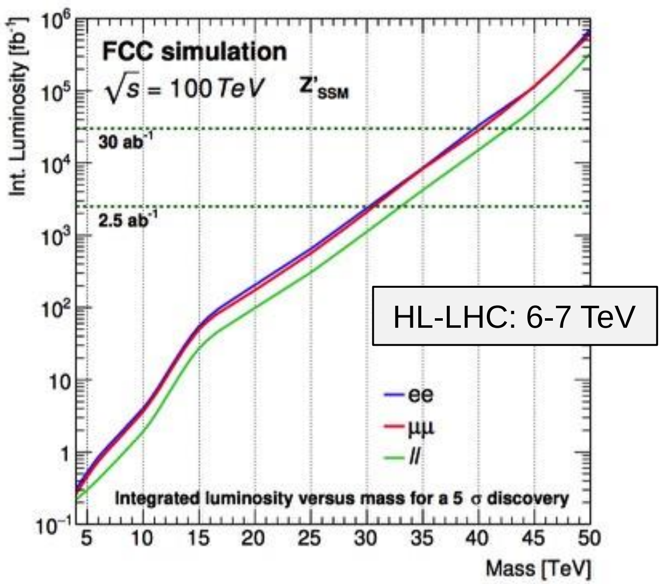
FCC-ee: 90-365 GeV

- ❑ measure many Higgs couplings to few permill
- ❑ indirect sensitivity to E-scale up to O(100 TeV) by improving by ~20-200 times the precision of EW parameters measurements, $\Delta M_W < 1$ MeV, $\Delta m_{top} \sim 10$ MeV

Sensitivity to “interaction scales” of new physics from ultra-precise EW measurements at FCC-ee

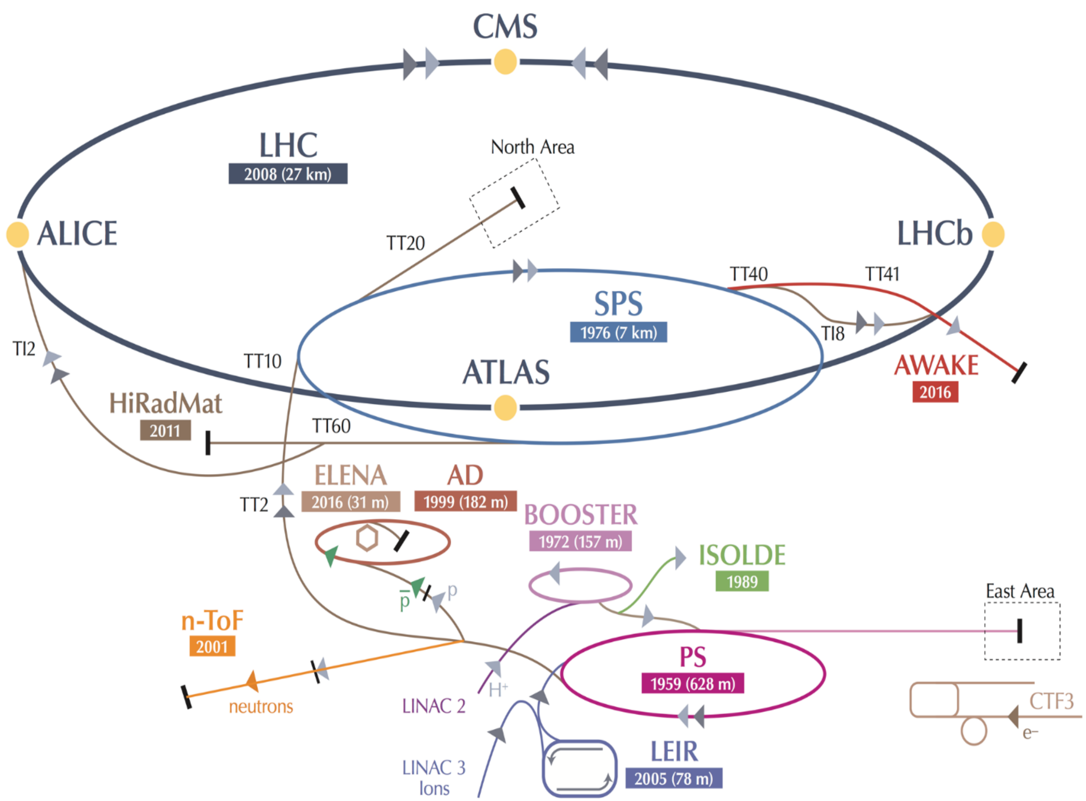



Discovery potential for new interactions (Z’ gauge boson) vs mass and luminosity at FCC-hh



# CERN scientific diversity programme

Currently: ~20 projects at the injectors
Exploit unique capabilities of CERN's accelerator complex.




Future opportunities being studied by "Physics Beyond Colliders" Study Group: proton EDM, rare decays; beam dump or electron scattering facilities to search for dark-sector particles (light, very-weakly-coupled), etc.

**AD:** Antiproton Decelerator for antimatter studies

**CAST, OSQAR**: axions

**CLOUD**: impact of cosmic rays on aeorosols and clouds → implications on climate

**COMPASS**: hadron structure and spectroscopy

**ISOLDE**: radioactive nuclei facility

**NA61/Shine**: heavy ions and neutrino targets

**NA62**: rare kaon decays

**NA63**: interaction processes in strong EM fields in crystal targets

**NA64**: search for dark photons

**Neutrino Platform:** $\nu$ detectors R&D for experiments in US, Japan

**n-TOF:** n-induced cross-sections

**UA9**: crystal collimation

# Questions to be addressed in the ESPP update (examples …)

Priority for next big collider at CERN in various scenarios (ILC yes/no, CepC-SppC yes/no)

Priorities for accelerator R&D at CERN

What about Muon Colliders?

Which non-collider projects have the highest priorities at CERN and other labs in Europe?

Which projects outside Europe should CERN and Europe participate in?

Should CERN contribute to astroparticle physics projects and to which extent?

Etc. etc.

# Conclusions

The HL-LHC is the next big project at the energy frontier for the worldwide HEP community.
It has a compelling physics potential.
Whether or not Run 3 and HL-LHC will bring new major discoveries, the LHC, over ~30 years of operation, will have had a profound impact on our understanding of fundamental physics.

The update of the ESPP in 2020 will hopefully:

- **identify the priority for a future collider at CERN**
- recommend a compelling, complementary set of projects at the injectors
- support accelerator R&D (superconducting high-field magnets, AWAKE, etc.)
- etc.

The ESPP update is a community-driven process. It concerns the future of our field.
We should all engage strongly.