Focusing on the future

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Department of Fundamental Research Colloquium
National Centre for Nuclear Research
April 15, 2024

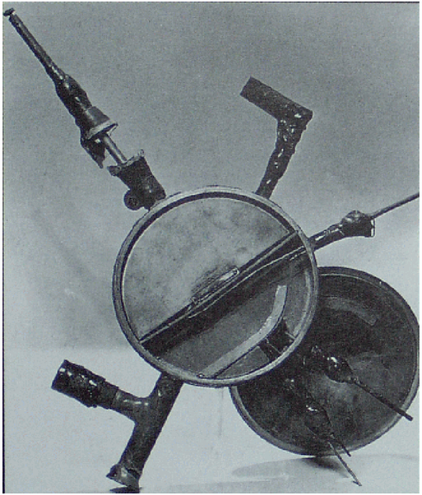
Outline:

This talk includes many contributions from other authors, slides presented at different conferences and meetings, many plots which I used in my lectures over the last 30 years. Apologies for missing references...

Motivation

Some history

1931 Lawrence cyclotron



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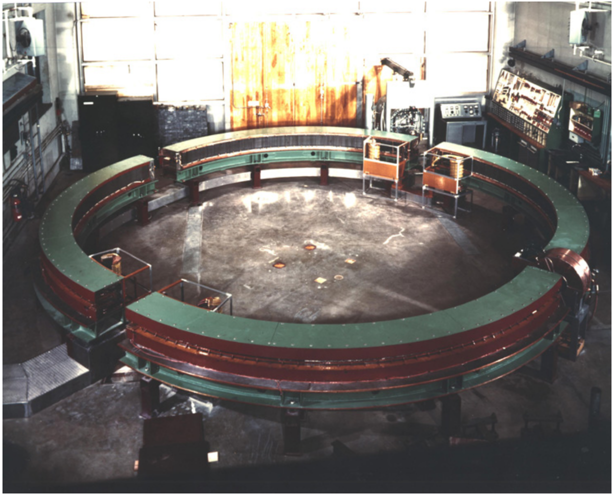

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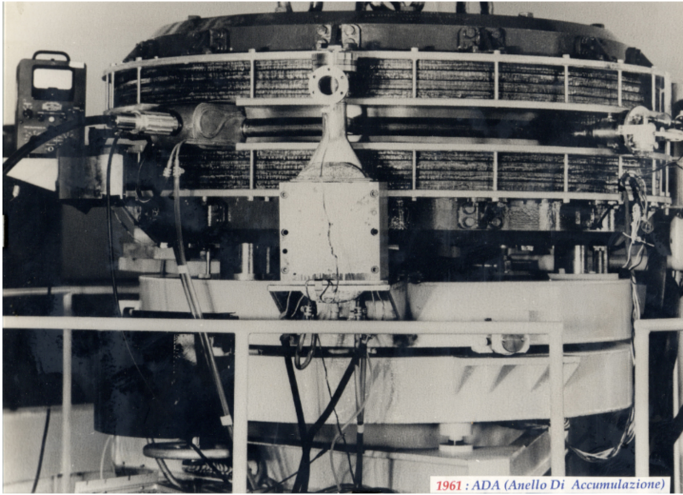
principles of operation basically unchanged since then...



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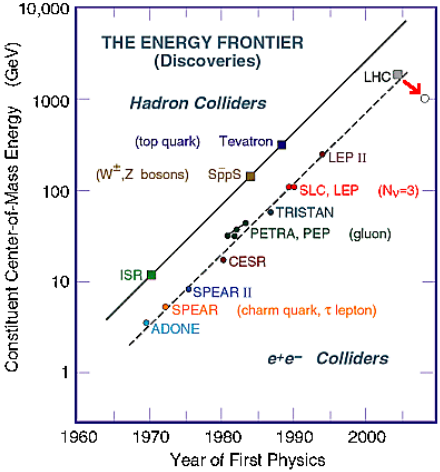
2009 LHC starts (again)

Some history

Rapid development of the particle physics in the second half of XX century was thanks to many new accelerators and colliders built in 1970s – 1990s.

Discoveries both at hadron and e^+e^- machines !

Energies increased by almost 3 orders of magnitude.



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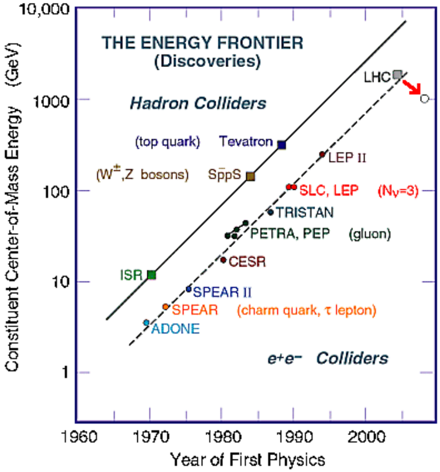

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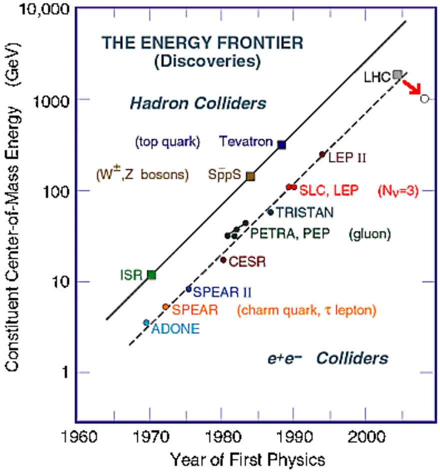
Construction of the next energy frontier collider clearly requires global consensus and cost sharing...



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Three events, which happened earlier this year, were a direct motivation for this talk:

- Focus topics document published by the physics potential working group of the ECFA study on Higgs / Top / EW factories arXiv:2401.07564

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- Focus topics document published by the physics potential working group of the ECFA study on Higgs / Top / EW factories arXiv:2401.07564
- Future Circular Collider Midterm Report presented at CERN (not public!)
- CERN Council decided about the timeline for the next update of the European Strategy for Particle Physics

European Strategy for Particle Physics

Recommendations of the 2001 ECFA report

"In the immediate future:

1) the allocation of all necessary resources to fully exploit the unique and pioneering LHC facility;
2) continued support for ongoing experiments, since they promise significant scientific results, provide an optimal physics return on previous investment, and are vital for the education of young physicists;
3) the realization, in as timely a fashion as possible, of a world-wide collaboration to construct a high-luminosity e+e- linear collider with an energy range up to at least 400 GeV as the next accelerator project in particle physics; decisions concerning the chosen technology and the construction site for such a machine should be made soon;
4) an improved educational programme in the field of accelerator physics and increased support for accelerator R&D activity in European universities, national facilities and CERN.

For the long-term:

5) a co-ordinated collaborative R&D effort to determine the feasibility and practical design of a neutrino factory based on a high-intensity muon storage ring;
6) a co-ordinated world-wide R&D effort should be made to assess the feasibility and estimate the cost of a 3-5 TeV e+e– linear collider (CLIC), a very large hadron collider (VLHC) and a muon collider; in particular, R&D for CLIC is well advanced and should be vigorously pursued."

Start of the Global Design Initiative

Nov 13-15, 2004

~ 220 participants from 3 regions, most of them accelerator experts

The Mission of the GDE

Produce a design for the ILC that includes a detailed design concept, performance assessments, reliable international costing, an industrialization plan , siting analysis, as well as detector concepts and scope.

Coordinate worldwide prioritized proposal driven R & D efforts (to demonstrate and improve the performance, reduce the costs, attain the required reliability, etc.)

Parameters for the ILC

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV

P. Raimondi
Orsay 2006

Process

Why did CERN Council decide to take responsibility for the European Strategy?

"Since CERN is an international organization, its Council is composed of government representatives, so an approval in the CERN Council implies an agreement between governments. To use the CERN Council as an intergovernmental forum to agree on a Strategy for the European Research Area has indeed support in the CERN Convention, but this is the first time that it is acted on." (CERN web)

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- The strategy process was approved the 16th of June 2005 by the CERN Council.
- An Open Symposium was held in Orsay-Paris on Jan 30 - Feb 1 2006
- Community was encouraged to submit input to the strategy (input received)
- Draft Strategy document prepared at Zeuthen workshop in May 2006
- Unanimously approved by CERN Council on July 14, 2006 in Lisbon.

The future of HEP hinges on the LHC

1st mission: look for the Higgs

$$A\left(W_L^+W_L^- \to Z_L Z_L\right) = \frac{G_F E^2}{8\sqrt{2}\pi}\left(1 - \frac{E^2}{E^2 - m_H^2}\right)$$

Without Higgs ⇨ E < 1.2 TeV

With Higgs ⇨ m_H < 780 GeV

LHC must discover Higgs or New Physics below TeV,

or else *unitarity* is violated

What screens the Higgs mass?

boson	fermion	vector
$\phi \to \phi + a$	$\psi \to e^{ia\gamma_5}\psi$	$A_\mu \to A_\mu + \partial_\mu a$
no $m^2\phi^2$	no $m\overline{\psi}\psi$	no $m^2 A_\mu A^\mu$
Spont. broken global symm.	Chiral symmetry	Gauge symmetry

} Symmetry

LITTLE HIGGS → m_H

SUPERSYMMETRY → m_H

HIGGS-GAUGE UNIF. → m_H

TECHNICOLOR → m_H

HIGGSLESS → m_H

EXTRA DIMENSIONS → m_H

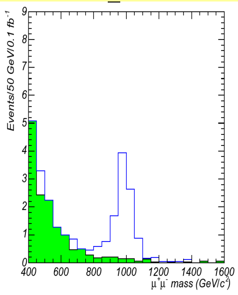
TECHNICOLOR	HIGGSLESS	EXTRA DIMENSIONS
Dynamical EW breaking	Delayed unitarity violat.	Fundamental scale at TeV

} Dynamics

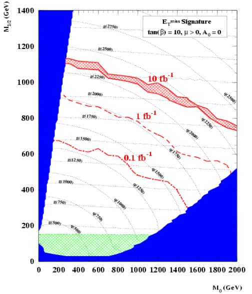
- Very fertile field of research
- Different proposals not mutually excluded

Possible discoveries at LHC with 10 fb^{-1}

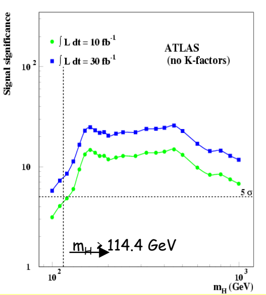
di-lepton resonance (Z',RS,Z_H,...)



inclusive SUSY



SM/MSSM Higgs



with 10 fb^{-1}:

m<~3 TeV
dep. on model

$m_{sq,gl}$<2-2.5 TeV
in mSugra

full range

K. Desch
Orsay 2006

more easy... ...more challenging

1st Summary: LHC+upgrades

- LHC and ATLAS/CMS progressing well. Expect first collisions in 2007.
- First data set with excellent prospects for discoveries (10-30 fb^{-1}) may be expected for 2009/10. Analysis needs detailed understanding of detectors and backgrounds.
- SM Higgs, SUSY (-2.5 TeV), di-lepton resonances (-3 TeV) can be seen within these data.
- Full LHC luminosity allows for discovery of very broad range of high-pt phenomena and measurements of new particle properties.
- LHC luminosity upgrade (SLHC) increases discovery reach by 20-30%, better precision for statistically limited processes.
- Energy upgrade (DLHC) has larger discovery reach but represents a significantly larger effort.

2nd Summary: Lepton Colliders

- Outstanding physics potential for a 90-500-1000 GeV Linear Collider (top, Higgs-Mechanism, SUSY particles, indirect reach in multi-TeV region, precision measurements of new+SM processes)
  ILC technology is at hands – complete design soon

- CLIC may provide 3-5 TeV collisions. Potential to further increase direct + indirect mass reach. Physics justification needs TeV-scale data. Experimentation more difficult. Technology?

- Muon Collider (100 GeV – several TeV). Far future. Physics justification needs TeV-scale data. Technology?? Experimentation??

General issues

1. European particle physics is founded on strong national institutes, universities and laboratories and the CERN Organization; *Europe should maintain and strengthen its central position in particle physics.*

2. Increased globalization, concentration and scale of particle physics make a well coordinated strategy in Europe paramount; *this strategy will be defined and updated by CERN Council as outlined below.*

Scientific activities

3. The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; *the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; *to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.*

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

6. Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme.*

7. A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena; *Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest.*

Strategy Statement
CERN Council 2006

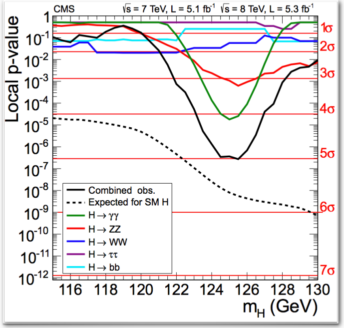
2013 Strategy Update

In September 2007, CERN Council decided that "At appropriate intervals, at most every 5 years, the European Strategy Session of Council will re-enact the process aimed at updating the medium and long-term European Strategy for Particle Physics..."

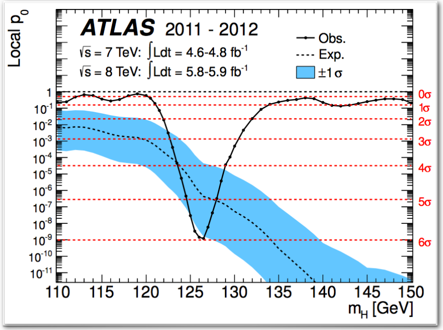
First update started in 2011, final timeline (updated in October 2012):

- Kick-off meeting in July 2011 - dedicated session at EPS-HEP 2011, Grenoble
- Invitation to submit community input: Feb 2012
  deadline: July 2012 (for symposium), October 2012 (for final document)
- **Open Symposium in Cracow: September 2012**
- Strategy Workshop in Erice: January 2013
- Final approval in Brussels: May 2013

The LHC discovery



arXiv:1207.7235v1 [hep-ex]



arXiv:1207.7214v1 [hep-ex]

expected and observed p-values....

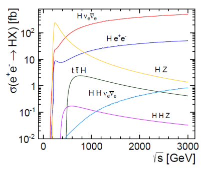
Decay mode/combination	Expected (σ)	Observed (σ)
$\gamma\gamma$	2.8	4.1
ZZ	3.6	3.1
$\tau\tau$ + bb	2.4	0.4
$\gamma\gamma$ + ZZ	4.7	5.0
$\gamma\gamma$ + ZZ + WW	5.2	5.1
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	5.8	5.0

Search channel	Dataset	m_{max} [GeV]	Z_l [σ]	$E(Z_l)$ [σ]
$H \to ZZ^{(*)} \to 4\ell$	7 TeV	125.0	2.5	1.6
	8 TeV	125.5	2.6	2.1
	7 & 8 TeV	125.0	3.6	2.7
$H \to \gamma\gamma$	7 TeV	126.0	3.4	1.6
	8 TeV	127.0	3.2	1.9
	7 & 8 TeV	126.5	4.5	2.5
$H \to WW^{(*)} \to \ell\nu\ell\nu$	7 TeV	135.0	1.1	3.4
	8 TeV	120.0	3.3	1.0
	7 & 8 TeV	125.0	2.8	2.3
Combined	7 TeV	126.5	3.6	3.2
	8 TeV	126.5	4.9	3.8
	7 & 8 TeV	126.5	6.0	4.9

- ATLAS and CMS: significance driven by the γγ, ZZ and WW channels
- besides the excess at 125-126 GeV: 95% CL exclusion of a SM-like Higgs up to ~600 GeV

HIGGS FACTORIES e+e-

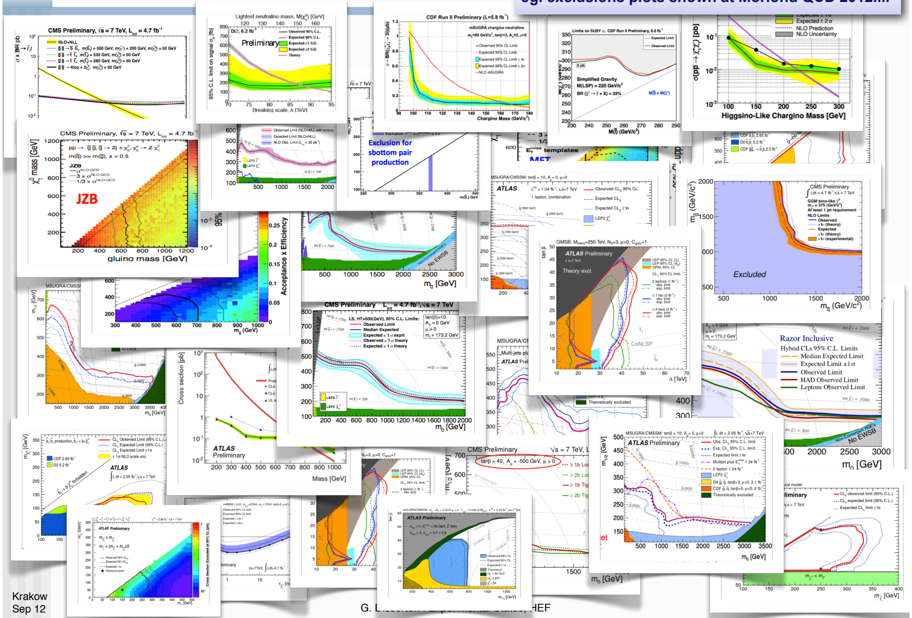
- e+ e-
  - Linear Colliders
    - ILC
      - 250 GeV
      - 500 GeV
    - CLIC
      - 250 GeV + Klystron based
      - 500 GeV
      - > 500 GeV
  - Circular Colliders
    - CERN
      - LEP3 at LHC tunnel
      - DLEP – New tunnel, 53 km
      - TLEP – New tunnel, 80 km
    - Super TRISTAN
      - 250 GeV– 40, 60 km tunnel
      - 400
      - 500



We have searched....

ETH Institute for Particle Physics

eg. exclusions plots shown at Moriond QCD 2012....



2013 Strategy Update

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *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. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. *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, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*

2013 Strategy Update

High-priority large-scale scientific activities

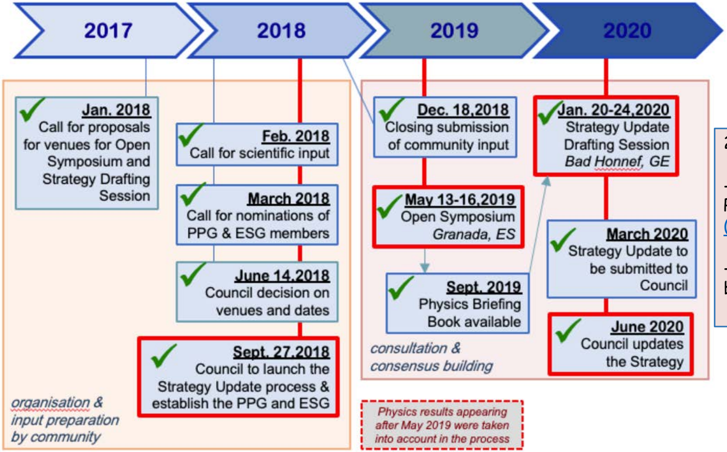
After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

e) There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *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.*

2020 Strategy Update

Timeline



2 Documents submitted to CERN Council

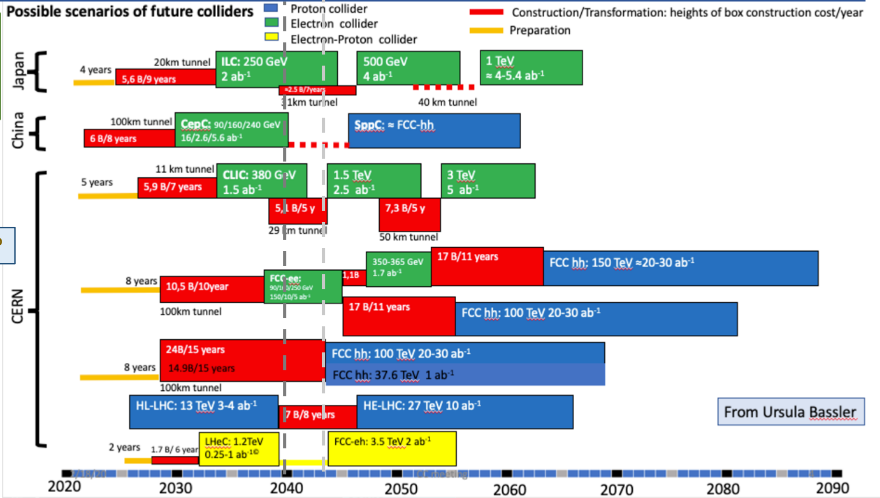
- 2020 Update of the European Strategy for Particle Physics (with preamble, statements, conclusion) (brochure)

- Deliberation Document (with in addition rational behind the statements) for information (brochure)

2020 Strategy Update

High-priority future initiatives

Map of possible future facilities submitted as input to the Strategy Update



Where is the muon collider?

H. Abramowicz, Snowmass 2020

2020 Update of the European Strategy for Particle Physics

The 2020 update of the **European Strategy for Particle Physics (ESPP)** has defined the major priorities

(i) Full exploitation of the LHC and the High-Luminosity LHC

(ii) An **electron−positron Higgs factory** is the highest−priority next collider

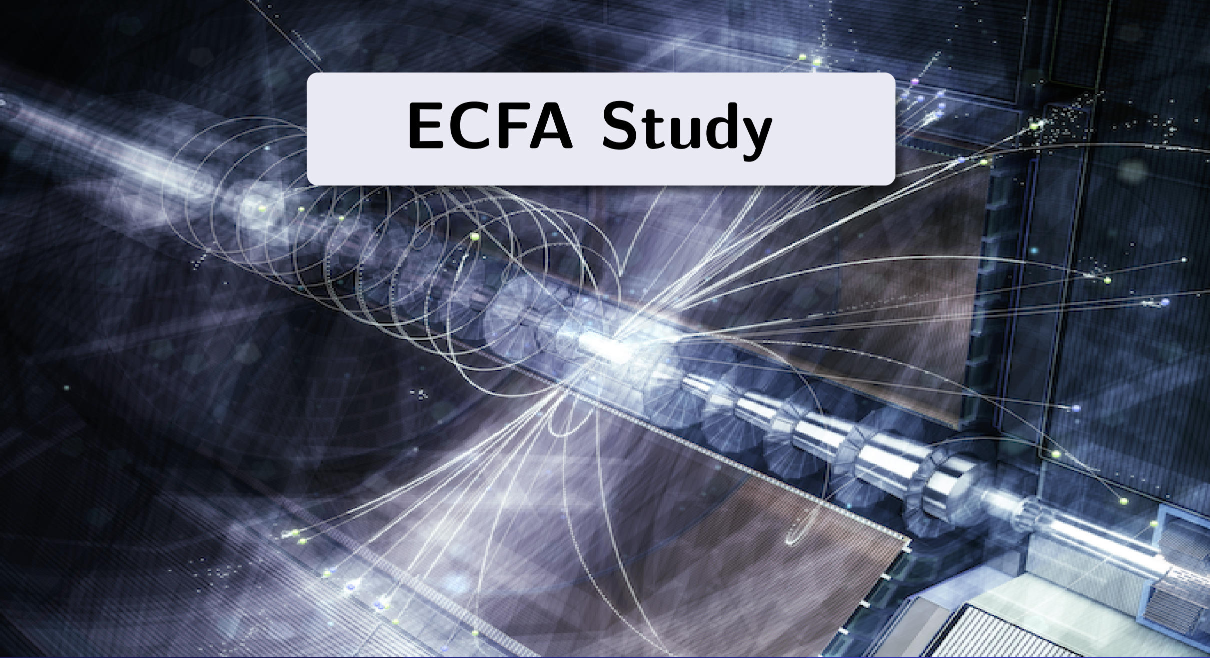
(iii) Longer term: the European particle physics community has the ambition to operate a **proton−proton collider at the highest achievable energy**

In addition: *A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics strategy (Dark Matter, exploration of flavour and fundamental symmetries)*
→ *CERN "Physics Beyond Colliders" programme, complemented by other European Laboratories*

(iv) Ramp up of R&D effort focused on **advanced accelerator technologies, in particular for high-field superconducting magnets, including high-temperature superconductors**
→ Organised by the Lab Directors Group, an ***Accelerator R&D roadmap*** should be developed

(v) Maintain a **strong focus on instrumentation**
→ *Organised by ECFA, a **Detector R&D Roadmap** should be developed*

ECFA Study



An e+e- Higgs factory is the highest-priority next collider

A clear message from EPPSU — and Snowmass

=> e+e- Higgs factory as highest priority next collider re-emphasized in the Snowmass process in the US (2022)

For the five-year period starting in 2025:

1. Prioritize the HL-LHC physics program, including auxiliary experiments,
2. Establish a targeted e^+e^- Higgs Factory Detector R&D program,
3. Develop an initial design for a first-stage TeV-scale Muon Collider in the U.S.,
4. Support critical Detector R&D towards EF multi-TeV colliders.

For the five-year period starting in 2030:

1. Continue strong support for the HL-LHC physics program,
2. Support the construction of an e^+e^- Higgs Factory,
3. Demonstrate principal risk mitigation for a first-stage TeV-scale Muon Collider.

Plan after 2035:

1. Continuing support of the HL-LHC physics program to the conclusion of archival measurements,
2. Support completing construction and establishing the physics program of the Higgs factory,
3. Demonstrate readiness to construct a first-stage TeV-scale Muon Collider,
4. Ramp up funding support for Detector R&D for energy frontier multi-TeV colliders.

https://europeanstrategyupdate.web.cern.ch/welcome

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.

ECFA statement (endorsed at the Plenary ECFA meeting on 13 July 2020)

- *ECFA recognizes 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 (ESPP).*

Goal: bring the entire e^+e^- Higgs factory effort together, foster cooperation across various projects, collaborative research programmes are to emerge

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- Setting up an **International Advisory Committee (IAC)** was agreed to be the next step with involvement of some RECFA members and European leaders of possible future Higgs factories. In addition the (HL)-LHC community should be represented.

  - ECFA-chair would act as chair: Karl Jakobs
  - From RECFA: Jean-Claude Brient, Tadeusz Lesiak, Chiara Meroni
  - With (HL-)LHC experience: Jorgen D’Hondt, Max Klein, Aleandro Nisati, Roberto Tenchini
  - For theory: Christophe Grojean, Andrea Wulzer
  - For Linear Colliders: Steinar Stapnes, Juan Fuster, Frank Simon, Aidan Robson
  - For Circular Colliders: Alain Blondel, Mogens Dam, Patrick Janot, Guy Wilkinson
  - For CERN: Joachim Mnich

PED study's organisation

- Coordinated by 2 study **chief editors**: Aidan Robson, recently joined by Christos Leonidopoulos; relies on **3 pillars (working groups)**:

WG1 Physics Potential

- Collect, compare, harmonise work of different project-specific efforts
- Interplay between (HL)-LHC and future Higgs factory (e.g. include LHC potential on high-pT measurements and EFT interpretations)
- Identify specific topics where concrete work should be organised
- Requirements on accuracy in theoretical calculations and parametric uncertainties
- ...

Created June 2021

Conveners: Jorge de Blas, Patrick Koppenburg (Juan Alcaraz) Jenny List, Fabio Maltoni,

WG2 Physics Analysis Methods

- Monte Carlo generators for e+e- precision EW/top Higgs factory
- Software framework
- Fast simulation (and its limitations)
- Reconstruction
- …

Created June 2021

Conveners: Patrizia Azzi, Fulvio Piccinini, Dirk Zerwas

WG3 Detector (R&D)

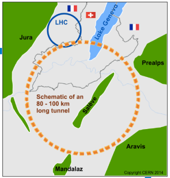
- Inform/provide guidance to detector R&D community on needs of future ee factories
- Foster interaction between detector R&D groups and future collider PED studies, minimising duplication and injecting technological realism into conceptual studies

Created May 2022 (after conclusion of works of ECFA Detector Roadmap Task Force)

Conveners: Mary Cruz Fouz, Giovanni Marchiori, Felix Sefkow

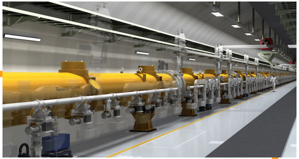
They fall into two classes

Each have their advantages



Circular e+e- Colliders

- FCCee, CEPC
- length 250 GeV: 90…100km
- high luminosity & power efficiency at **low energies**
- **multiple interaction regions**
- very clean: little beamstrahlung etc



Linear Colliders

- ILC, CLIC, C^3, …
- length 250 GeV: 4…11…20 km
- high luminosity & power efficiency at **high energies**
- **longitudinally spin-polarised beam(s)**

Long-term vision: re-use of tunnel for pp collider

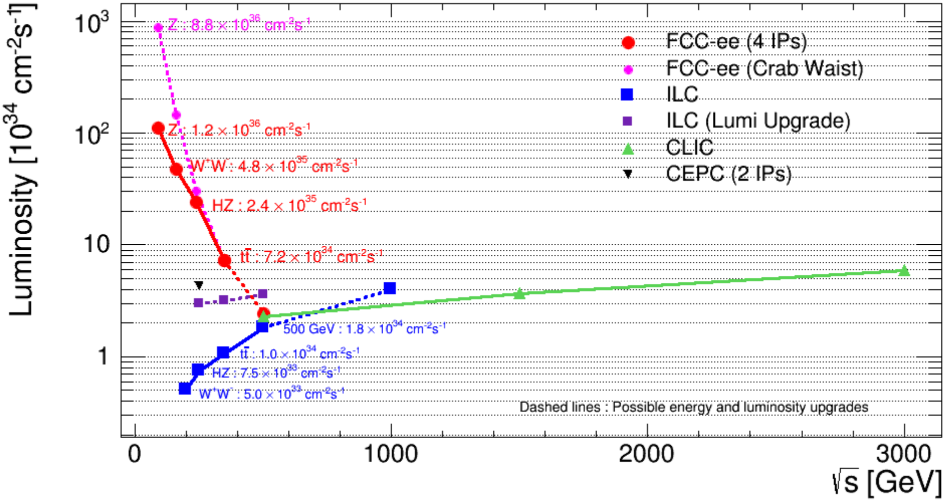
- technical and financial feasibility of required magnets still a challenge

Long-term upgrades: energy extendability

- same technology: by increasing length
- **or by replacing accelerating structures with advanced technologies**
  - RF cavities with high gradient
  - plasma acceleration ?

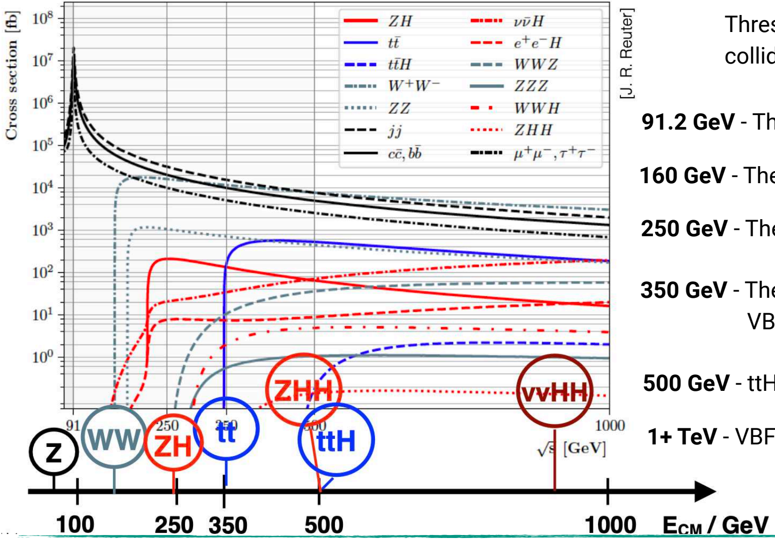
Luminosity vs energy

probably not up to date



Setting the Stage

Perspectives of Energy



Thresholds and cross sections set collider energy targets:

91.2 GeV - The Z pole

160 GeV - The WW threshold

Precision electroweak, Flavour, QCD, …

250 GeV - The ZH maximum

Higgs properties & couplings

350 GeV - The top threshold, VBF Higgs production

Top properties, Top as probe

500 GeV - ttH, ZHH

Direct top Yukawa Higgs selfcoupling

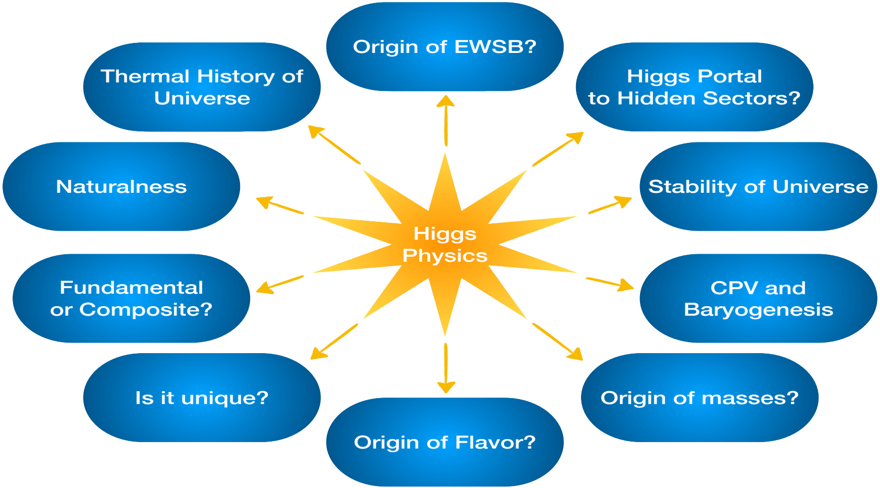
1+ TeV - VBF double Higgs

Search at the energy frontier

Physics case for Higgs factory

Mystery Higgs sector

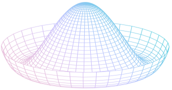
Snowmass 2021 US Community Study
on the Future of Particle Physics



Higgs boson properties

Mass and width

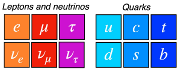
=> related to vacuum stability, exotic decays



Production and decays

=> couplings strengths

=> Higgs mechanism also for lighter fermions?



H

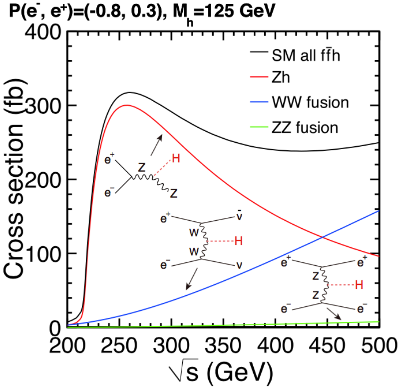
spin/CP properties of Higgs boson interactions

=> related to matter-antimatter asymmetry in the universe

See next talk!
Also for Higgs self-coupling

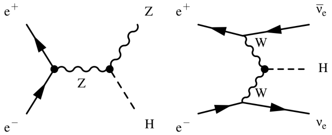
=> Is it really the Higgs boson of the Standard Model or something else?

Higgs production



Precision Higgs couplings measurements at 250/380 GeV

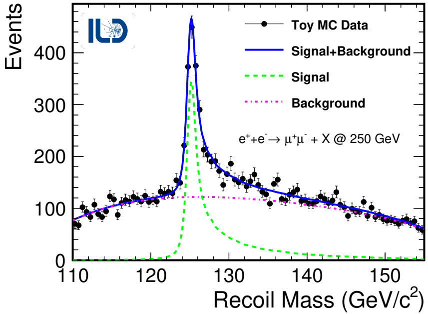
Profit from combining two production channels:



⇒ model independent analysis

Event reconstruction

In the ZH production channel (dominating below 450 GeV) we can use "Z-tagging" for unbiased selection of Higgs production events



We avoid any dependence on the Higgs decay channel!

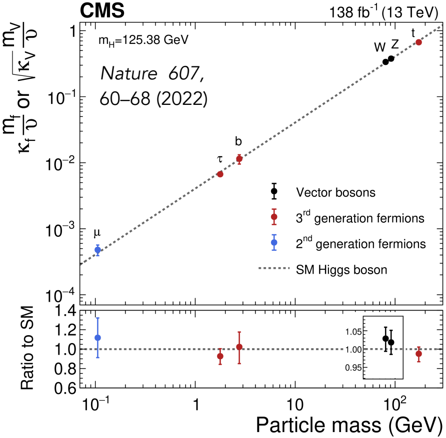
Couplings to other particles

- from all available production and decay measurements in different channels can extract couplings
- deviations expected in many **BSM models**, p.ex.
  - Composite Higgs
  - SUSY Higgs sectors
- Kappa-framework:
  - assume SM coupling structure
  - define scaling factors

$$\sigma(i \to H \to f) = \kappa_i^2 \sigma_i^{\mathrm{SM}} \frac{\kappa_f^2 \Gamma_f^{\mathrm{SM}}}{\kappa_H^2 \Gamma_H^{\mathrm{SM}}}$$

- Higgs couplings: the higher the mass, the stronger the coupling
  - to bosons: ~ (boson mass)^2
  - to fermions: ~ (fermion mass)

SM prediction

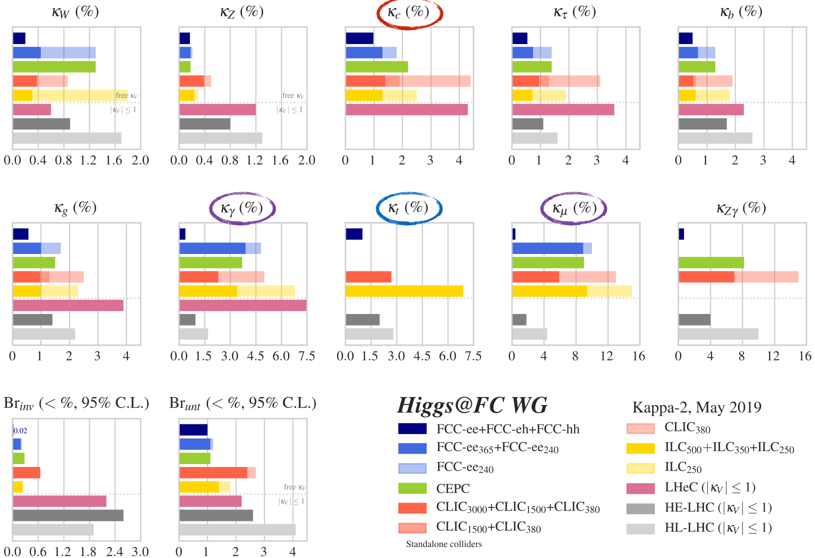


Assumptions: No new particles in the loops

Couplings uncertainties at future colliders

JHEP 01 (2020) 139

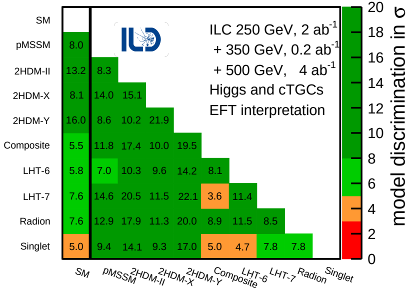
One of the main goals of HL-LHC and beyond



- Complementarity between HL-LHC and lepton colliders:
  - HL-LHC: k_t, rare decays
  - e+e-: k_c
- Lepton colliders benefit from increase in CM energies

BSM sensitivity

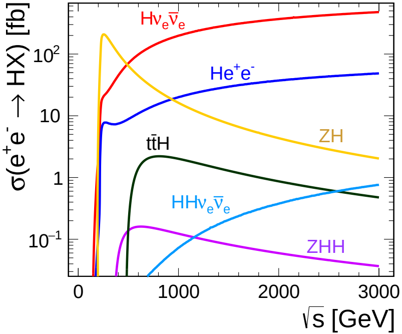
Precision of e^+e^- colliders allows to distinguish the SM expectations and other models from the global analysis of the Higgs boson couplings



arXiv:1710.07621

All considered BSM scenarios can be identified at $\geq 5\sigma$ after full ILC programme (H-20)

Higgs production



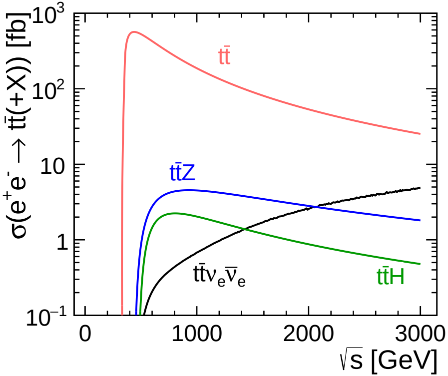
New channels open above 500 GeV

- top Yukawa coupling
- Higgs self-coupling

Even more Higgs bosons produced at TeV energies

- rare decay channels

Processes of interest



Top pair-production at and above the threshold (350 GeV)

- top-quark mass
- electroweak couplings
- rare decays

Additional processes open at high energies

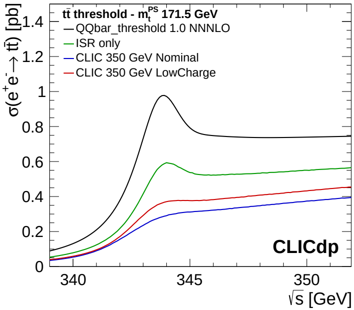
- top Yukawa coupling
- CP properties
- BSM constraints

Threshold scan

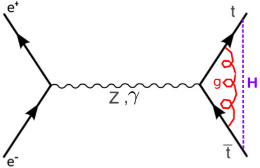
Top pair production cross section around threshold:

resonance-like structure corresponding to narrow $t\bar{t}$ bound state.

Very sensitive to top properties and model parameters:



- top quark mass m_t
- top quark width Γ_t
- strong coupling α_s
- top Yukawa coupling y_t



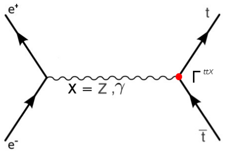
Significant cross section smearing due to luminosity spectra and ISR

Smearing due to luminosity spectra can be reduced by using dedicated running configuration

Top-quark pair production

Pair production provides direct access to top electroweak couplings

Possible higher order corrections
⇒ sensitive to "new physics" contribution



New physics effects can be constrained through measurement of:

- total cross-section
- forward-backward asymmetry
- helicity angle distribution in top decays

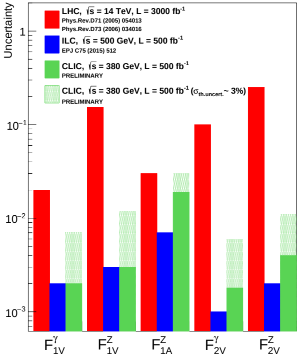
Additional constraints obtained by:

- using electron (and positron) beam polarisation
- measurements at different $\sqrt{s}$

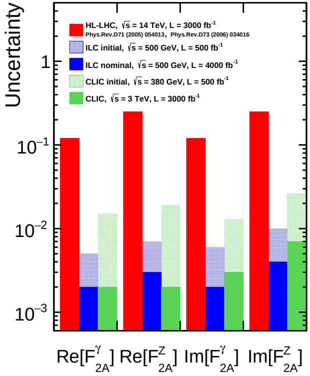
Top EW couplings

Expected sensitivity to electroweak couplings of the top quark

CP-conserving form factors



CP-violating form factors



arXiv:1710.06737

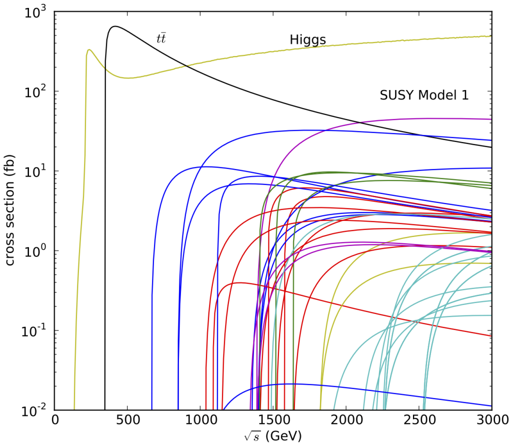
Two complementary approaches

Strong limits expected at HL-LHC for many scenarios.

Complementary searches at LC:

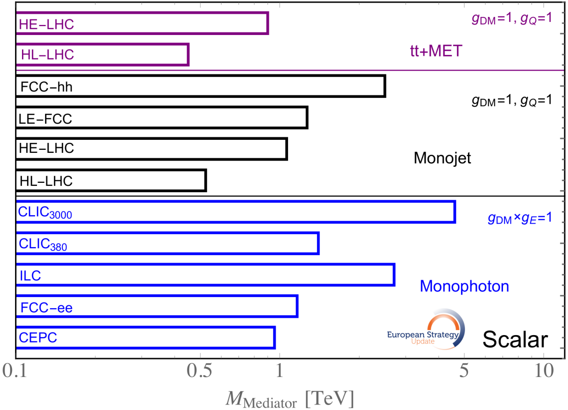
- direct searches
  models with weak couplings or soft signatures
- indirect searches
  high sensitivity

CLIC CDR



Dark Matter searches

Comparison of extracted mediator mass limits



ILC/CLIC mass reach comparable with that of FCC-hh !!!

Focus Topics

Focus Topics

Main aims of the ECFA study are to bring people together (across projects) and to attract more people (e.g. LHC) into the community

–> we have been developing a set of 'focus topics' through bottom-up discussions to provide concrete entry points for contributions

- highlight areas of shared interest across projects
- draw attention to aspects from all three WGs
- build on previous studies where there is interesting new scientific work to be done

–> promote enhanced cooperation and new engagement

- develop common code / tools / datasets and person-skills that will have a wider application/impact, beyond the focus topics themselves

Focus Topic Overview

Many of you contributed - many thanks!

- started with a list of topics, iterated with IAC
- formed "Expert Team" for each topic
  - charge:
    - capture state-of-the-art (science / tools)
    - define future work needed

  => "Focus Topic Document" arXiv:2401.0xxx submitted yesterday - but will only appear tomorrow: "Apparently there was some sort of arxiv holiday yesterday (Martin Luther King day) which delays the announcement to tomorrow. Just annoying for Jenny who won't have an id for her talk at ILD today."
- ILD contributed a lot
  => should be well aligned with ILD plans
- NOW:
  - FORM TEAMS who actually DO THE WORK
  - ideal point in time for new students etc to join!
  - check out https://gitlab.in2p3.fr/ecfa-study/ECFA-HiggsTopEW-Factories/-/wikis/FocusTopics for "living" information
  - **never hesitate to contact Jenny and/or Filip!**

	Topic	Lead group	Relevant $\sqrt{s}$ [GeV] 91	161	240–250	350–380	≥ 500
1	HtoSS	HTE			✓	✓	✓
2	ZHang	HTE (GLOB)			✓	✓	✓
3	Hself	GLOB			✓	✓	✓
4	Wmass	PREC		✓	✓	✓	✓
5	WWdiff	GLOB			✓	✓	✓
6	TTthres	GLOB (HTE)				✓	✓
7	LUMI	PREC	✓	✓	✓	✓	✓
8	EXscalar	SRCH			✓	✓	✓
9	LLPs	SRCH	✓	✓	✓	✓	✓
10	EXtt	SRCH				✓	✓
11	CKMWW	FLAV		✓	✓	✓	✓
12	BKtautau	FLAV	✓				
13	TwoF	HTE (PREC)	✓	✓	✓	✓	✓
14	BCfrag and Gsplit	PREC (FLAV)	✓	✓	✓	✓	✓

ECFA Focus topics

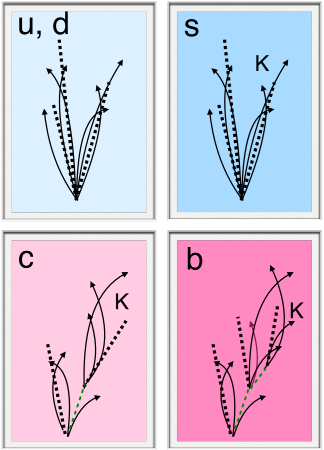
1. **HtoSS** – $e^+e^- \to Zh$: $h \to ss$ ($\sqrt{s} = 240/250$ GeV)
2. **ZHang** – Zh angular distributions and CP studies
3. **Hself** – Determination of the Higgs self-coupling
4. **Wmass** – Mass and width of the W boson ...
5. **WWdiff** – Full studies of WW and $e\nu W$
6. **TTthres** – Top threshold: Detector-level simulation study of $e^+e^- \to t\bar{t}$ ...
7. **LUMI** – Precision of the luminosity measurement
8. **EXscalar** – New exotic scalars
9. **LLPs** – Long-lived particles
10. **EXtt** – Exotic top decays
11. **CKMWW** – CKM matrix elements from W decays
12. **BKtautau** – $B^0 \to K^{0*}\tau^+\tau^-$
13. **TwoF** – EW precision: 2-fermion final states ($\sqrt{s} = M_Z$ and beyond)
14. **BCfrag** and **Gsplit** – Heavy quark fragmentation and hadronisation, gluon splitting...

s-tagging

HtoSS – $e^+e^- \to Zh \;\; h \to s\bar{s}$

2101.04119
2203.07535

Tagging strange is a challenging but not impossible task for future detectors at e+e-



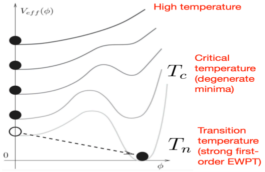
- As b,c, and s jets contain at least one strange hadron
- Strange quarks mostly hadronize to prompt kaons which carry a large fraction of the jet momentum
- Strange hadron reconstruction:
  - $K^\pm$ PID
  - K^0_L PF (neutral)
  - $K^0_S \to \pi^+\pi^-$ (~70%) / $\pi^0\pi^0$ (~30%)
  - $\Lambda^0 \to p\pi^-$ (~65%)

Distinctive two-prong vertices topology

Jet flavour	Number of secondary vertices (excluding V^0s)	Number of strange hadrons (e.g., $K^\pm$, $K^0_{L/S}$, and Λ^0)
Bottom	2	≥1
Charm	1	≥1
Strange	0	≥1
Light	0	0

Focus Topic: ZHang - CP

- **Determination of ZH couplings**
- **Access to CP-properties of H**



Why important? Are there additional sources for CP violation in Higgs sector?

Baryogenesis: creation of the asymmetry between matter and anti- matter in the universe requires a strong first-order electroweak phase transition (EWPT)

First-order EWPT does not work in the SM
The amount of CP violation in the SM (induced by the CKM phase) is not sufficient to explain the observed asymmetry between matter and anti-matter in the universe

First-order EWPT can be realised in extended Higgs sectors could give rise to detectable gravitational wave signal

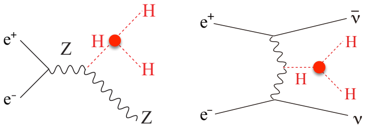
$\Rightarrow$ ***Search for additional sources of CP violation***

But: strong experimental constraints from limits on electric dipole moments (EDMs)

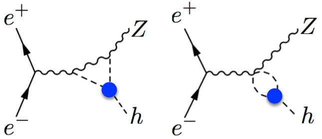
Higgs self-coupling
Junping Tian @ ILD2024

λ_{HHH}: Starting point - ESU 2020

[Physics Briefing Book]

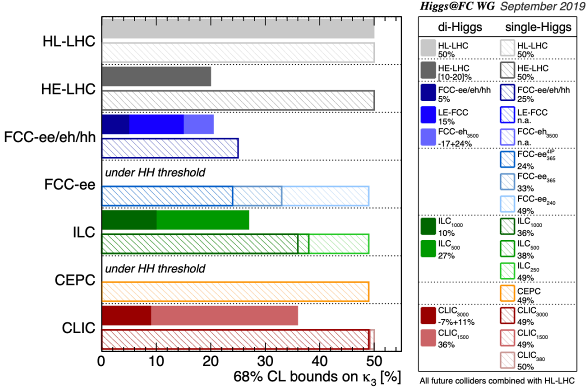


$\sigma_{HH} \sim O(0.1)$ fb



$\delta\sigma_{ZH} \sim O(1\%)$

- two approaches: di-Higgs & single-Higgs
- based on global SMEFT fits
- HL-LHC di-Higgs contribution was always combined



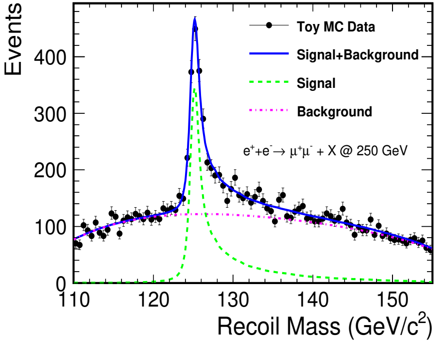
LABS – previous(ongoing) ILC/ILD work

	LEP [131]	FCC-ee (Z pole)	ILC [133], [134] ($\sqrt{s} > 250$ GeV)
LumiCal distance from IP [m]	2.5	1.1	2.48
Precision target	3.4×10^{-4}	10^{-4}	10^{-3}
Tolerance for			
inner radius [μm]	4.4	$\mathcal{O}(1)$	4
outer radius [μm]	?	$\lesssim 3$	?
distance between two LumiCals [μm]	$\mathcal{O}(100)$	< 100	200

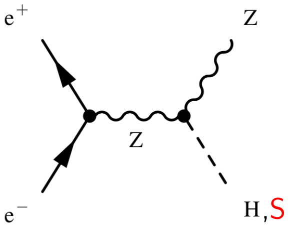
- (133) A. Stahl, Luminosity measurement via Bhabha scattering: Precision requirements for the luminosity calorimeter, LCDET2005004, Apr 2005 (2005). – a dedicated study on metrology at ILC energies needed
- H. Abramowicz, Forward instrumentation for ILC detectors, Journal of Instrumentation 5 (2010) P12002 (physics background, detector design and performance), arXiv:1009.2433
- I. Bozovic Jelisavcic et al., Luminosity measurement at ILC, JINST 8 (2013) P08012, arXiv:1304.4082 (correction of the beam-induced effects)

Motivation

Precision Higgs measurements are clearly the primary target for future Higgs factory.



At 250 GeV we will focus on H_{125} production

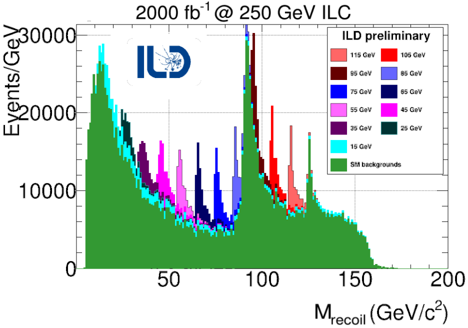


But production of additional, light exotic scalar states is still not excluded by the existing data!

Existing results

New scalar search in scalar-strahlung process

arXiv:1902.06118 arXiv:2005.06265

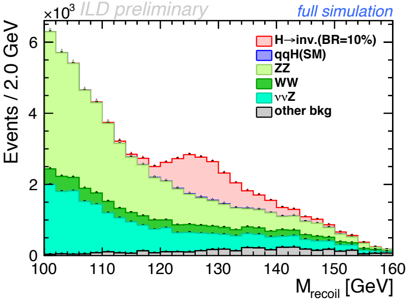


Search independent on the scalar decay:

$e^+e^- \rightarrow Z\,S^0 \rightarrow \mu^+\mu^- + X$

New scalar production in 125 GeV Higgs decays

⇒ sensitivity via invisible decays

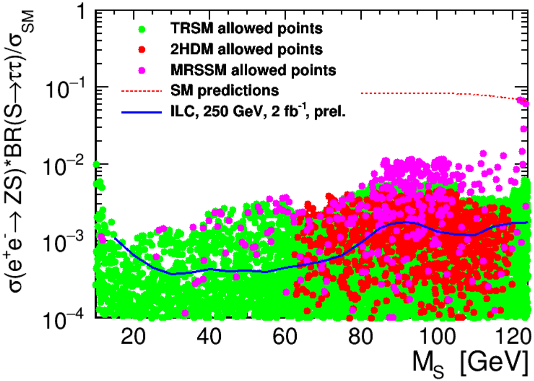


Expected 95% C.L. limit for 2 ab^{-1} collected at 250 GeV ILC: 0.23%

arXiv:2002.12048

Status and plans

First results on $\sigma(e^+e^- \to Z\,S) \cdot BR(S \to \tau\tau)$ sensitivity (DELPHES)



compared with presented benchmark point selections...

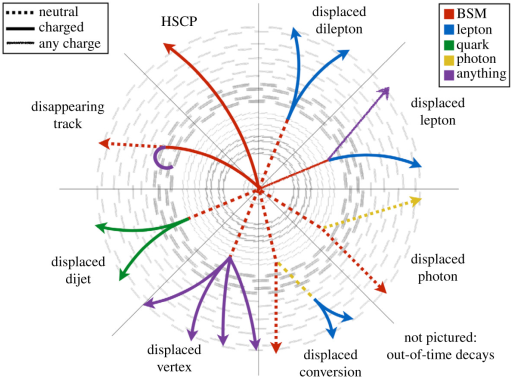
Motivation

New long-lived particles (LLPs) could provide answers to many open questions of the SM.

Possible scenarios:

- Heavy Neutral Leptons (HNLs)
- Axion-Like Particles (ALPs)
- exotic decays of the Higgs boson
- ...

Possible signatures:

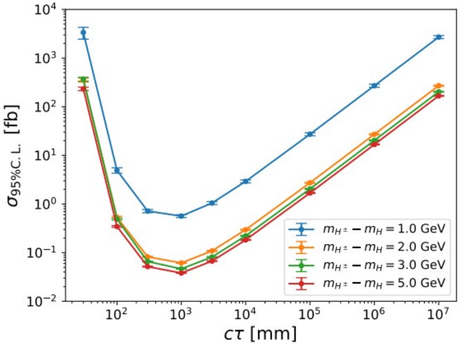


Phil. Trans. R. Soc. A.377: 20190047

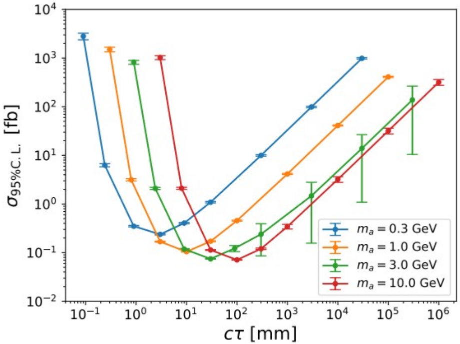
Status and plans

Expected cross section limits for processes with single displaced vertex (work in progress)

Heavy scalars (IDM)



Light pseudoscalar (ALP)



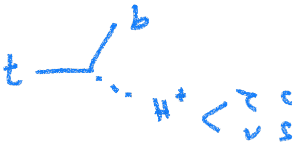
J.Klamka, S&A meeting, Dec 6, 2023

Top quark decay

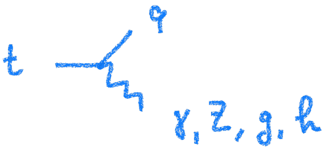
Traditional topic for top factories is the possibility of BSM decays

Especially when the direct reach was limited (e.g. LEP and TeVatron times) the top quark might have been our “window” to new physics

e.g. $t \to H^+ b$ in MSSM or general 2HDM



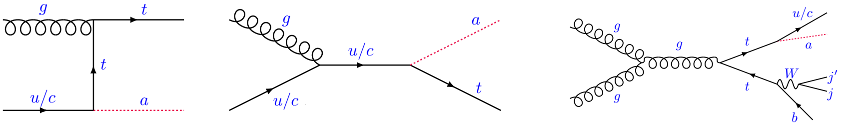
e.g. $t \to Vq$ in MSSM or general 2HDM and many other models



Such light H^+ is hardly tenable* these days. The possibility of flavor violation, instead, is more subtle.

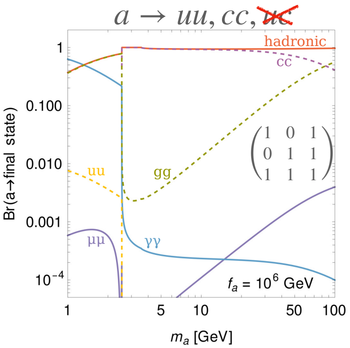
$t \to a u_i,\ a \to uu, cc, uc$

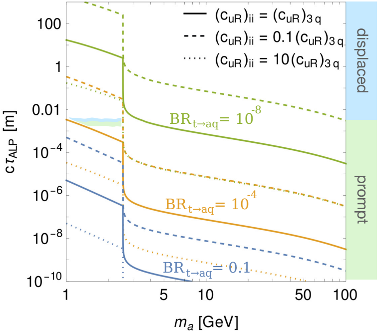
2101.07803, 2202.09371 - Carmona, Elahi, Scherb, Schwaller

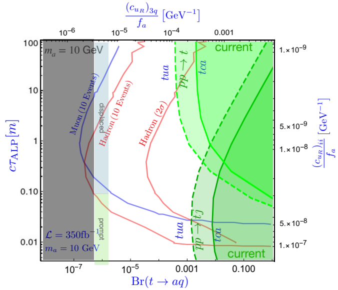


$$\mathcal{L} = \frac{1}{2}(\partial_\mu a)(\partial^\mu a) - \frac{m_a^2}{2}a^2 + \frac{\partial_\mu a}{f_a}\left[(c_{u_R})_{ij}\bar{u}_{Ri}\gamma^\mu u_{Rj}\right]$$

$$c_{u_R} \sim \begin{pmatrix} 2 & 3\epsilon & 3\epsilon^2 \\ 3\epsilon & 1 & \epsilon \\ 3\epsilon^2 & \epsilon & \epsilon^2 \end{pmatrix}$$







focus on displaced flavor-conserving decay so far

Ample room for improvement with top factory studies for prompt decays $a \to jj, uc, cc$ and invisible

- Use W decays to measure CKM matrix elements $|V_{ij}|$, ~ directly by counting
- Allows for direct, model-independent access to 6 CKM elements (without top)
- Of particular interest: $V_{cb}, V_{cs}, (V_{ub})$
  - test of unitarity of the CKM matrix
  - V_{cs} for comparison with indirect leptonic charmed meson decays
  - V_{cb} to resolve discrepancy between in- & exclusive determinations via semilep. B decays, controls unitarity triangle normalisation $\rightarrow$ already systematically limited at Belle!
  - V_{ub} as test of lattice QCD needed for results from Belle II
- With 100% reconstruction efficiency: $\delta^{th}_{V_{ij}} = \frac{1}{2} N_{ev}^{-1/2}$

for 10^8 W:

$W^- \rightarrow$	$\bar{u}d$	$\bar{u}s$	$\bar{u}b$	$\bar{c}d$	$\bar{c}s$	$\bar{c}b$
BR	31.8%	1.7%	4.5×10^{-6}	1.7%	31.7%	5.9×10^{-4}
N_{ev}	64×10^6	3.4×10^6	900	3.4×10^6	63×10^6	118×10^3
$\delta^{th}_{V_{ij}}$	0.0063 %	0.027 %	1.7 %	0.027 %	0.0063 %	0.15 %

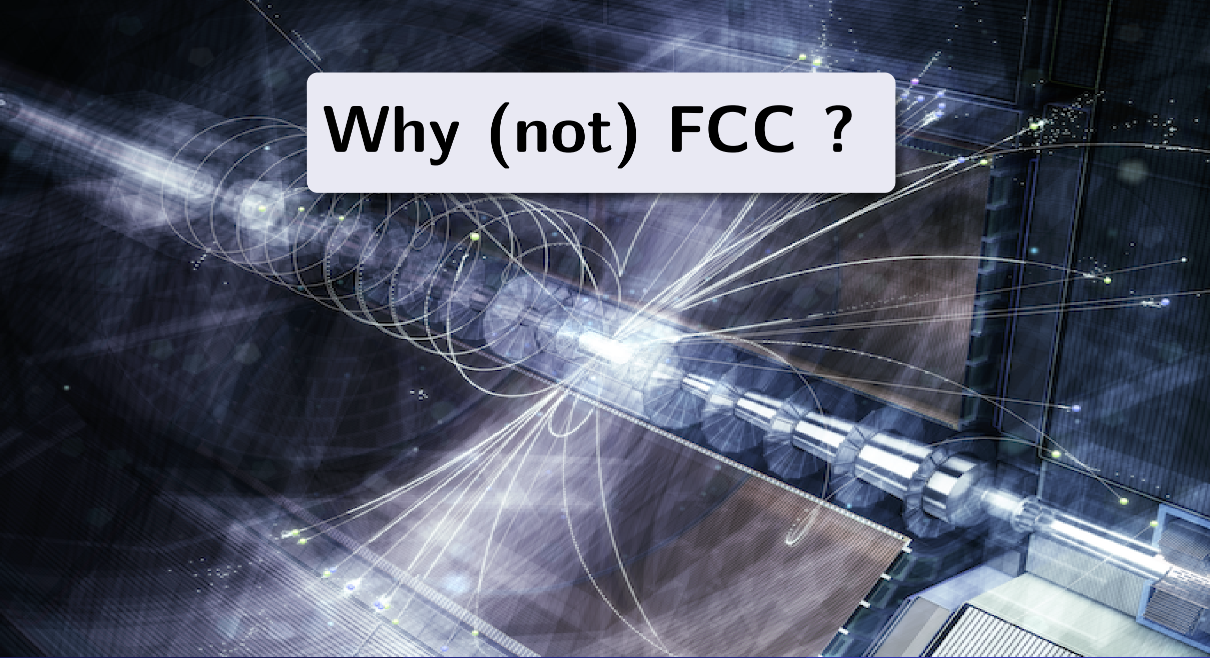
Focus Topics

Most focus topics profit from high energy running

arXiv:2401.07564

Topic		Lead group	Relevant $\sqrt{s}$ [GeV] 91	161	240–250	350–380	≥ 500
1	HtoSS	HTE			✓	✓	✓
2	ZHang	HTE (GLOB)			✓	✓	✓
3	Hself	GLOB			✓	✓	✓
4	Wmass	PREC		✓	✓	✓	✓
5	WWdiff	GLOB			✓	✓	✓
6	TTthres	GLOB (HTE)				✓	✓
7	LUMI	PREC	✓	✓	✓	✓	✓
8	EXscalar	SRCH			✓	✓	✓
9	LLPs	SRCH	✓	✓	✓	✓	✓
10	EXtt	SRCH				✓	✓
11	CKMWW	FLAV		✓	✓	✓	✓
12	BKtautau	FLAV	✓				
13	TwoF	HTE (PREC)	✓	✓	✓	✓	✓
14	BCfrag and Gsplit	PREC (FLAV)	✓	✓	✓	✓	✓

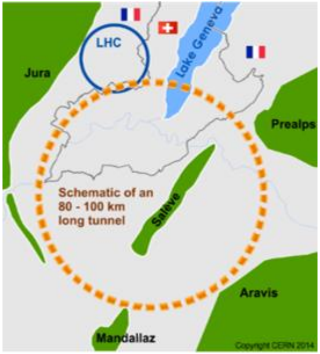
Why (not) FCC ?

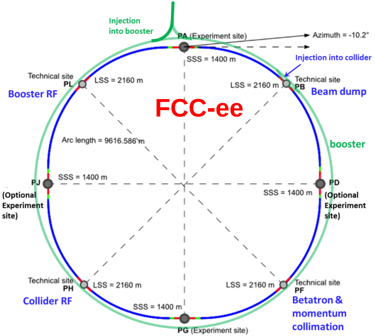


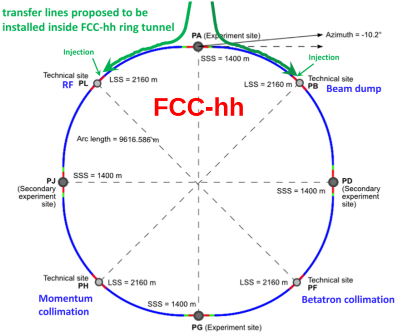
FCC integrated program

comprehensive long-term program maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC







FUTURE CIRCULAR COLLIDER

FCC-ee: main machine parameters

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1270	137	26.7	4.9
number bunches/beam	11200	1780	440	60
bunch intensity [10^{11}]	2.14	1.45	1.15	1.55
SR energy loss / turn [GeV]	0.0394	0.374	1.89	10.4
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.1/0	2.1/9.4
long. damping time [turns]	1158	215	64	18
horizontal beta* [m]	0.11	0.2	0.24	1.0
vertical beta* [mm]	0.7	1.0	1.0	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.71	1.59
vertical geom. emittance [pm]	1.9	2.2	1.4	1.6
horizontal rms IP spot size [μm]	9	21	13	40
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_y	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	140	20	5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

Design and parameters dominated by the choice to allow for 50 MW synchrotron radiation per beam.

- x 10-50 improvements on all EW observables
- up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output

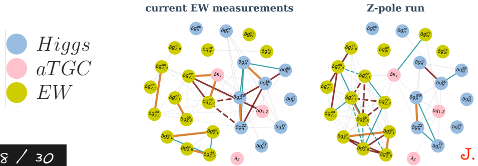
F. Gianotti

Higgs @ FCC-ee.

- Absolute normalisation of couplings (by recoil method)
- Measurement of width (from ZH>ZZZ* and WW>H)
- $\delta\Gamma_H \sim 1\%, \delta m_H \sim 3\,\mathrm{MeV}$ (resp. 25%, 30 MeV @ HL-LHC)
- Model-independent coupling determination and improvement factor up to 10 compared to LHC
- (Indirect) sensitivity to new physics up to 70 TeV (for maximally strongly coupled models)

$$(\delta\kappa_X = v^2/f^2 \quad \& \quad m_{\mathrm{NP}} = g_{\mathrm{NP}}\, f)$$

— Higgs programme needs Z-pole —



Higgs coupling sensitivity

Coupling	HL-LHC	FCC-ee (240–365 GeV) 2 IPs / 4 IPs
κ_W [%]	1.5*	0.43 / 0.33
κ_Z [%]	1.3*	0.17 / 0.14
κ_g [%]	2*	0.90 / 0.77
κ_γ [%]	1.6*	1.3 / 1.2
$\kappa_{Z\gamma}$ [%]	10*	10 / 10
κ_c [%]	–	1.3 / 1.1
κ_t [%]	3.2*	3.1 / 3.1
κ_b [%]	2.5*	0.64 / 0.56
κ_μ [%]	4.4*	3.9 / 3.7
κ_τ [%]	1.6*	0.66 / 0.55
$\mathrm{BR_{inv}}$ (<%, 95% CL)	1.9*	0.20 / 0.15
$\mathrm{BR_{unt}}$ (<%, 95% CL)	4*	1.0 / 0.88

Table from mid-term report

$$\kappa_X = \frac{g_{hXX}}{g_{hXX}^{\mathrm{SM}}}$$

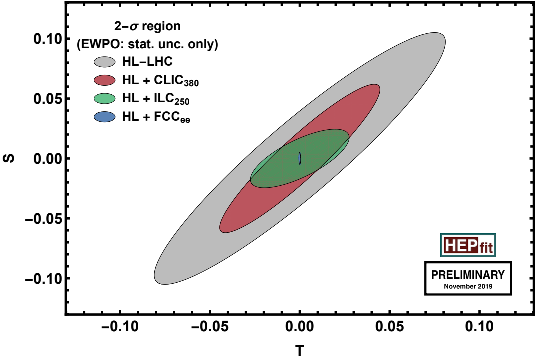
J. De Blas et al. 1907.04311

Tera-Z EW precision measurements.

- The target is to reduce syst. uncertainties to the level of stat. uncertainties.
  (exploit the large samples and innovative control analyses)
- Exquisite √s precision (100keV@Z, 300keV@WW) reduces beam uncertainties (EPOL)

➡ ~50 times better precision than LEP/LSD on EW precision observables

w/ stat. and param. only



Indirect sensitivity
to 70TeV-scale sector
connected to EW/Higgs

(For the impact of the theory uncertainties on the EW fit, see bonus slides)

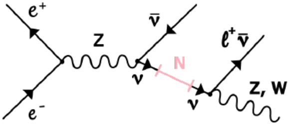
Z-couplings

- https://arxiv.org/pdf/2203.07622.pdf

Quantity	Value	current $\delta[10^{-4}]$	Z pole $\delta_{stat}[10^{-4}]$	Z pole $\delta_{sys}[10^{-4}]$	ILC250 $\delta_{stat}[10^{-4}]$	ILC250 $\delta_{sys}[10^{-4}]$
boson properties						
m_W	80.379	1.5	-	-		0.3
m_Z	91.1876	0.23		0.022	0.08	-
Γ_Z	2.4952	9.4	0.5	-	6	-
$\Gamma_Z(had)$	1.7444	11.5		4.	-	-
Z-e couplings						
$1/R_e$	0.0482	24.	2.	5	5.5	10
A_e	0.1513	139.	1.5	1.2	12.	9.
g_L^e	-0.632	16.	1.0	3.2	2.8	7.6
g_R^e	0.551	18.	1.0	3.2	2.9	7.6
Z-ℓ couplings						
$1/R_\mu$	0.0482	16.	2.	2.	5.5	10
$1/R_\tau$	0.0482	22.	2.	2.	5.7	10
A_μ	0.1515	991.	2.	5	54.	3.
A_τ	0.1515	271.	2.	5.	57.	3
g_L^μ	-0.632	66.	1.0	2.3	4.5	7.6
g_R^μ	0.551	89.	1.0	2.3	5.5	7.6
g_L^τ	-0.632	22.	1.0	2.8	4.7	7.6
g_R^τ	0.551	27.	1.0	3.2	5.8	7.6
Z-b couplings						
R_b	0.2163	31.	0.4	7.	3.5	10
A_b	0.935	214.	1.	5.	5.7	3
g_L^b	-0.999	54.	0.32	4.2	2.2	7.6
g_R^b	0.184	1540	7.2	36.	41.	23.
Z-c couplings						
R_c	0.1721	174.	2.	30	5.8	50
A_c	0.668	404.	3.	5	21.	3
g_L^c	0.816	119.	1.2	15.	5.1	26.
g_R^c	-0.367	416.	3.1	17.	21.	26.

Search for ν_{RH}.

Direct observation in Z decays from LH-RH mixing



Important to understand
1. how neutrinos acquired mass
2. if lepton number is conserved
3. if leptogenesis is realised

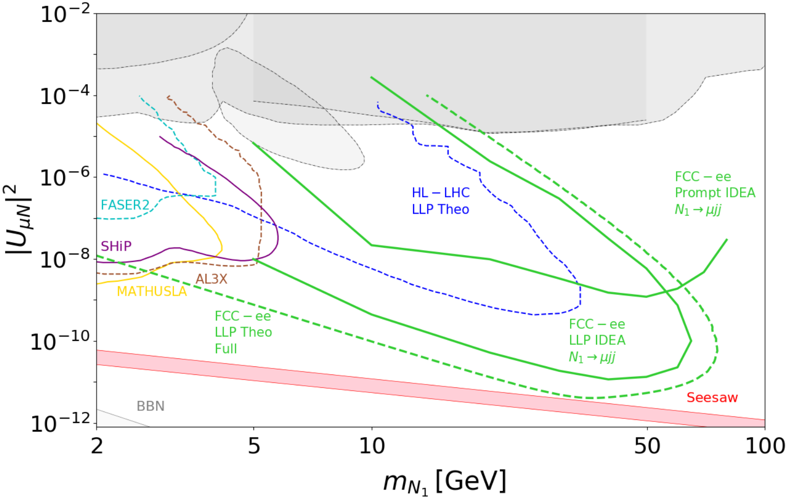
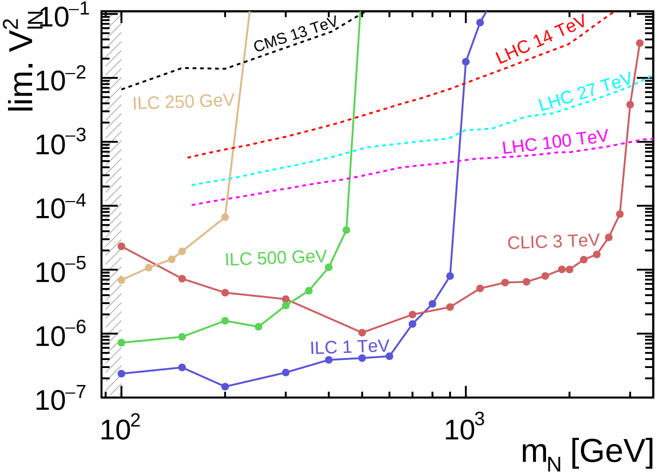


Fig. from mid-term report

HNL searches at future linear colliders (K.Mekala et al.)

The cross section limits can be translated into limits on the V_{lN}^2 parameter.

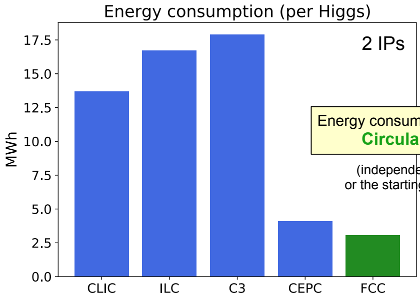


LHC analysis: [1812.08750], diff. assumption: $V_{eN} = V_{\mu N} \neq V_{\tau N} = 0$

Energy and carbon footprint.

- Our first responsibility (as particle physicists) is to do the maximum of science
  - With the minimal energy consumption and the minimal environmental impact for our planet
    - Should become one of our top-level decision criteria for design, choice and optimization of a collider

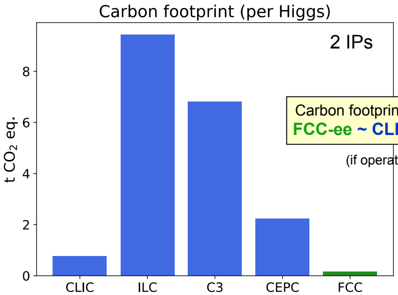
- All Higgs factories have a "similar" physics outcome (ESU'20 and Snowmass'21)
  - Natural question: what is their energy consumption or carbon footprint for the same physics outcome?
    - Circular colliders have a much larger instantaneous luminosity and operate several detectors
    - FCC-ee is at CERN, where electricity is already almost carbon-free (and will be even more so in 2048)



arXiv:2208.10466

Energy consumption / Higgs with 2IP
Circular ~ Linear / 5

(independently of the location
or the starting time of the collider)



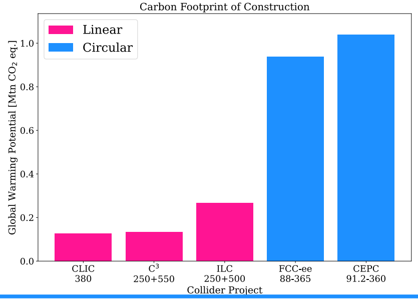
Carbon footprint / Higgs with 2IP
FCC-ee ~ CLIC / 5 ~ ILC / 50

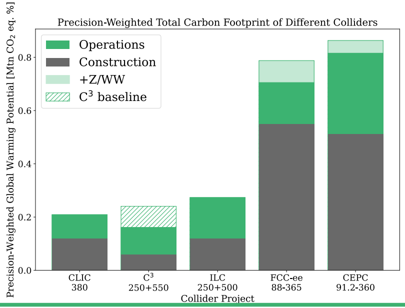
(if operating today)

Global Warming Potential

Study by C3

GWP of construction dominated by CO2 emission from the required concrete & steel => tunnel length (diameter, tunneling technique)





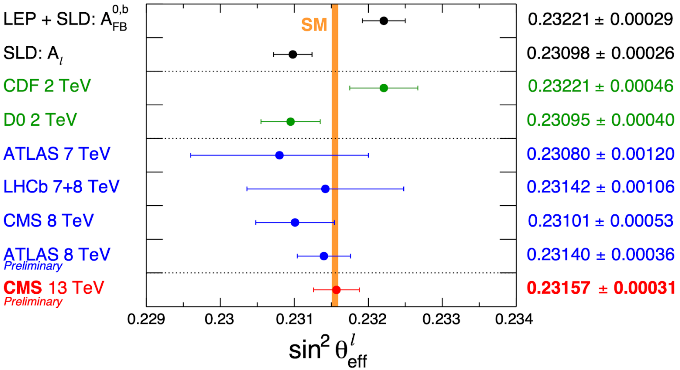
Adding operation GWP

(here weighted by improvement of Higgs couplings over HL-LHC, and with power mix predictions for CERN, US, Japan, China):

- **Operation dominates for LCs**
- **Construction dominates for CCs**

arXiv:2307.04084

Recent CMS measurement of the effective leptonic weak mixing angle



Old e^+e- data still give higher precision than LHC...

SLD result based on A_l measurement most precise!

Number of Z bosons produced factor ~ 30 smaller than at LEP. But polarized beams!!!

ILC running scenario

The unique feature of the ILC is the possibility of having both electron and positron beams polarised! This is crucial for many precision measurements as well as BSM searches.

Four independent measurements instead of one:

- increase accuracy of precision measurements
- more input to global fits and analyses
- remove ambiguity in many BSM studies
- reduce sensitivity to systematic effects

Integrated luminosity planned with different polarisation settings [fb^{-1}]

H-20 $\sqrt{s}$	$\mathrm{sgn}(P(e^-), P(e^+))$ $(-,+)$	$(+,-)$	$(-,-)$	$(+,+)$	Total
250 GeV	900	900	100	100	2000
350 GeV	135	45	10	10	200
500 GeV	1600	1600	400	400	4000

arXiv:1903.01629

Why (not) FCC?

CERN strategy

At the ICFA Seminar 2023 Fabiola Gianotti clearly stated the main reason for selecting FCC as the future project for CERN:

"This is the only project that matches the size of CERN community"

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The focus document was released very recently...

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My personal feeling is that the decision has already been taken,
and the 2026 update is only needed to justify it to the public.

CERN strategy

FCC-ee will still be based on the "classical" concepts over 60 years old ⇒ needs to be huge
Cost of FCC-ee tunnel itself is larger than the total cost of ILC-250 construction.
No upgrade option (beyond 365 GeV, required for many measurements) for e^+e^- machine!

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But there is no justification at the moment for the 100 TeV hadron collider !

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Are we ready to bet $\mathcal{O}(10)$ GCHF on this belief?!

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Cost of FCC is huge, it will have significant impact on research funding
(most likely not only in HEP!) all over Europe...

CERN strategy

There is a strange logic in this approach:

- CERN needs funding for lab running and to support its community
- FCC project can secure adequate funding for the next $\mathcal{O}(100)$ years
- CERN community supports FCC, as this is the only project securing this funding level

As most of HEP community in Europe is involved in LHC or other activities at CERN, this seems to be a good way to go...

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Are we OK with this approach?

CERN strategy

My personal opinion is that decision on building FCC at CERN will be the beginning of the end of High Energy Physics research in Europe and in the world, and of CERN.

HEP will not survive, if it is only done at CERN (and not targeting relevant topics)

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CERN should look for alternative strategies

- building "larger LEP" or "larger LHC" is only a waste or resources
- there is no need to have a project corresponding to the size of the LHC community. Most of these people will retire before the considered time scale.
- CERN should support diverse activities, focus on new acceleration technologies and look for ambiguous new project based on them
- this will give a good base for the long-term future of CERN, even if the next collider is built elsewhere

Thank you!