

ECFA Higgs/Top/EW factory study and status of the final report

Aleksander Filip Źarnecki



ILD group meeting
November 12, 2024

Update of the European Strategy for Particle Physics



3. High-priority future initiatives

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

- Setting up an **International Advisory Committee (IAC)** was agreed to be the next step with involvement of some RECFAs 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 RECFAs: 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 - mandate and goals

IAC Recommendations

- Extension to include electroweak and top factory
- Extend physics studies, where relevant (not all completed at time of EPPSU), however, focus on e^+e^- potential (no discussion of pros and cons of various machines or alternatives to e^+e^- Higgs factories)
- Understand better the interplay between (HL)-LHC and an e^+e^- Higgs/EW/Top factory
- Development of common tools (software, simulation, fast simulation, ...) important
- Development of common analysis methods of high interest
- Exploit synergies, discuss challenges, do not restrict to common items
- Need for theoretical accuracy and MC generator improvements ...
- ...

- Overall goal: make sure community works coherently together
- Open for collaboration with other ongoing activities, e.g. Snowmass, ...
- Process is open for all interested physicists

There was unanimous agreement within the IAC that these objectives can only be reached if **Working Groups** would be set up
Conveners (theory and experiment), regular meetings, working towards ECFA workshops, ...

K. Jakobs

- Working groups to carry out work over forthcoming years with regular “checkpoints” = community-wide plenary ECFA workshops
- **Final goal:** “ECFA yellow report” for input to next ESPPU

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- p_T 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

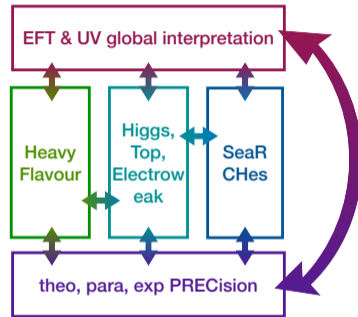
Created May 2022 (after conclusion of works of ECFA Detector Roadmap Task Force)

Conveners: Mary Cruz Fouz, Giovanni Marchiori, Felix Sefkow

ECFA Higgs Factory Study - WG1 Physics Potential

Overview

- chairs: Juan Alcaraz (CERN), Fabio Maltoni (Louvain), Jenny List (DESY)
- identified five main topics:
 - **WG1-EFT:** Global interpretation in (SM)EFT and UV complete models
 - **WG1-PREC:** Precision calculations and theoretical, parametric and experimental syst. uncertainties
 - **WG1-HTE:** Higgs, top and electroweak physics, incl. high-pT
 - **WG1-HF:** Flavour physics
 - **WG1-SRCH:** Direct discovery potential, incl. FIP



Ongoing:

- **identifying a few key people for each topic**
=> includes e+e- experts, important to get engaged
- **holding meetings with each group**
- **discussing scope, ideas, names of other people to get involved, interest to get involved etc**
- **planning 2-3 day topical workshops in first half of 2022**

First ECFA WORKSHOP.

on e^+e^- Higgs / Electroweak / Top Factories
5-7 October 2022, DESY, Hamburg


Topics:




- Physics potential of future Higgs and electroweak/top factories
- Required precision (experimental and theoretical)
- EFT (global) interpretation of Higgs factory measurements
- Reconstruction and simulation
 - Software
 - Detector R&D

INTERNATIONAL ADVISORY COMMITTEE	LOCAL ORGANISING COMMITTEE
A. Abulmuslim (UAE)	A. Abulmuslim (UAE)
C. Bacci (Italy)	C. Bacci (Italy)
F. Bazzani (Italy)	F. Bazzani (Italy)
G. Brooijmans (USA)	G. Brooijmans (USA)
H. Burkhardt (Switzerland)	H. Burkhardt (Switzerland)
J. Butterworth (UK)	J. Butterworth (UK)
K. Cheung (USA)	K. Cheung (USA)
L. Clavelle (France)	L. Clavelle (France)
M. Drees (Germany)	M. Drees (Germany)
N. Ellis (UK)	N. Ellis (UK)
O. Elia (Italy)	O. Elia (Italy)
P. Falck (Germany)	P. Falck (Germany)
R. Fleischer (Germany)	R. Fleischer (Germany)
S. Heinemann (Germany)	S. Heinemann (Germany)
T. Heine (Germany)	T. Heine (Germany)
V. Khachatryan (CERN)	V. Khachatryan (CERN)
W. Kotlarska (Germany)	W. Kotlarska (Germany)
X. L. Qiu (China)	X. L. Qiu (China)
Y. S. Kim (USA)	Y. S. Kim (USA)
Z. Tang (China)	Z. Tang (China)
A. Zaitsev (Russia)	A. Zaitsev (Russia)
A. Ziegler (Germany)	A. Ziegler (Germany)

The European Committee for Future Accelerators (ECFA) organises a series of workshops on physics studies, experiment design and detector technologies towards a future electron-positron Higgs/Electroweak/Top factory.

The aim is to bring together the efforts of various e^+e^- projects, to share challenges and expertise, to explore synergies, and to respond coherently to this high-priority item of the European Strategy for Particle Physics.

 DESY

  CLUSTER OF EXCELLENCE QUANTUM UNIVERSE  <https://indico.desy.de/event/33640/>

◆ Great to see so many people committed to realising an e^+e^- Higgs factory, in person here in Hamburg!



First ECFA workshop in Hamburg October 5-7, 2022

<https://indico.desy.de/event/33640/>

1 day ($\frac{1}{2} + \frac{1}{2}$) of parallel sessions, $1\frac{1}{2}$ days of plenary sessions

Many interesting contributions from ILD:

- 12 parallel session talks
- 8 posters

Still accessible at the ILD review page

<https://agenda.linearcollider.org/event/9818/>

Proposed focus topics

	lead group	relevant \sqrt{s}				
		91 GeV	161 GeV	240/250 GeV	350-380 GeV	≥ 500 GeV
1. H- \rightarrow ssbar	1 HTE			X	X	x
2. ZH angular distributions / CP studies	2 HTE (GLOB)			X	X	x
3. Higgs self-coupling	3 GLOB			X	X	X
4. W mass at threshold and continuum	4 PREC		X	X	X	
5. Full studies of WW and evW processes, aTGCs	5 GLOB			X	X	x
6. Top threshold	6 GLOB (HTE)				X	
7. Luminosity measurement	7 PREC	X	x	x	x	x
8. New exotic scalars	8 SRCH	x	x	x	x	x
9. Long-lived particles	9 SRCH	x	x	x	x	x
10. Exotic top decays	10 SRCH				x	x
11. CKM matrix elements w/ on-shell & boosted Ws	11 FLAV		x	X	x	x
12. $B \rightarrow K^0 \tau^+ \tau^-$	12 FLAV	X				
13. 2-fermion final states	13 HTE	X	X	X	X	X
14. b- and c-fragmentation functions / hadronisation	14 FLAV (PREC)	X	x	X	X	x
15. Gluon splitting to bb / cc (& interplay with separating h \rightarrow gluons from h \rightarrow bb/cc)	15 PREC (FLAV)	X	x	X	X	x

Note: **selected topics do not aim to comprehensively map the physics program of a future ee factory**, but rather:

- complete the current overall picture where (most) necessary
- give guidance to people who would like to contribute to the ECFA study
- highlight processes particularly suitable to study interplay of 3 working areas (physics potential, analysis methods, det. performance)

- 1 **HtoSS** – $e^+e^- \rightarrow Zh: h \rightarrow ss$ ($\sqrt{s} = 240/250$ 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 $e^+e^- \rightarrow t\bar{t}$...
- 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** – $B^0 \rightarrow K^{0*} \tau^+ \tau^-$
- 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...

SECOND • ECFA • WORKSHOP

on e^+e^- Higgs / Electroweak / Top Factories

11-13 October 2023

Paestum / Salerno / Italy



Topics:

- Physics potential of future Higgs and electroweak/top factories
- Required precision (experimental and theoretical)
- EFT (global) interpretation of Higgs factory measurements
- Reconstruction and simulation
- Software
- Detector R&D

Second ECFA workshop in Paestum October (10)11-13, 2023

<https://agenda.infn.it/event/34841/>

1 day of software tutorials

1 day ($\frac{3}{4} + \frac{1}{4}$) of parallel sessions

1 $\frac{1}{2}$ days of plenary sessions

16 topical contributions from ILD

Most of them accessible at the ILD review page

<https://agenda.linearcollider.org/event/10179/>

- ◆ The ECFA study is coherent with the next European Strategy Update:
 - provisionally expected in **2026–27**
 - > provisionally expect strategy inputs to be due in **late 2025**
 - > **2 years remain of the ECFA study**



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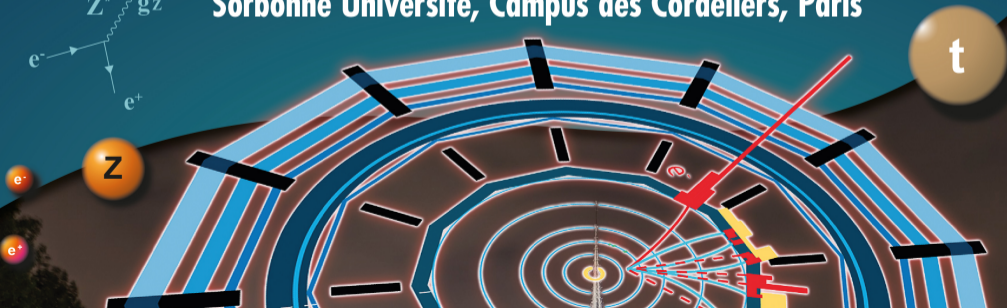
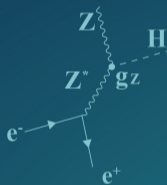
It was unfortunately reduced by one year at the beginning of 2024!

We had to accelerate our studies a lot...
Not always possible for full simulation studies...

3rd ECFA workshop on e^+e^- Higgs, Top & ElectroWeak Factories

9–11 October 2024

Sorbonne Université, Campus des Cordeliers, Paris





3rd ECFA Workshop on e^+e^- Higgs,
Top & ElectroWeak Factories
9 - 11 october 2024
Paris

Third ECFA workshop in Paris October 9-11, 2024

<https://indico.in2p3.fr/event/32629/>

1 day ($\frac{1}{2} + \frac{1}{2}$) of parallel sessions, $1\frac{3}{4}$ days of plenary sessions

16 topical contributions from ILD

Most of them accessible at the ILD review page

<https://agenda.linearcollider.org/event/10420/>

Third ECFA workshop in Paris October 9-11, 2024

<https://indico.in2p3.fr/event/32629/>

1 day ($\frac{1}{2} + \frac{1}{2}$) of parallel sessions, $1\frac{3}{4}$ days of plenary sessions

16 topical contributions from ILD

Most of them accessible at the ILD review page

<https://agenda.linearcollider.org/event/10420/>

Call for report contributions deadline October 20, 2024

Very short time between the workshop and the submission deadline.

But it was announced earlier and we were prepared!



Total of 21 contributions submitted from ILD

from the total number of 98

Most of them collected at the group review page:

<https://agenda.linearcollider.org/event/10484/>



ILD-PHYS-2024-NNN
11 September 2024

ECFA Higgs Factory Study Note

Many authors*

* *Many Institutes*



Total of 21 contributions submitted from ILD

from the total number of 98

Most of them collected at the group review page:

<https://agenda.linearcollider.org/event/10484/>



ILD-PHYS-2024-NNN
11 September 2024

ECFA Higgs Factory Study Note

Many authors*

* *Many Institutes*

Many thanks to all contributors!!!

Report Planning

We've seen a huge amount of activity and many beautiful results represented in this workshop!
The challenge now is to try to capture this in a useful report

- ◆ *Concept: a synoptic outline of the physics case and the ECFA study activities, drawing particular attention to the work that has spanned projects, concepts, and WGs, helping to strengthen and build the e^+e^- community.*

The report should:

- be self-contained and reasonably comprehensive
(but not ab initio and not extensively repeating material from previous reports)
- and be concise enough that it's a document that people can actually read
- ◆ Hope many activities will write individual notes/papers → we really encourage this
→ report will largely summarise and reference them
- ◆ Physics analysis tools and detector technologies sections will be cross-referenced with physics topics, where they are closely linked

A.Robson @ ECFA'2024

Report status

The first deadline for WG1 subgroup conveners to convert contributions received into corresponding sections in the report was **November 10th**.

It turned out to be very tight (**not very realistic ?**) taking into account number of contributions received (**40 contributions submitted to WG1-SRCH in particular**).

Most focus topics and physics related studies were already there on Sunday.

But still many “holes”, contributions not included...

Also, many “general” sections were still missing...

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194 pages plus 65 pages with 1089 references

as on Sunday evening, November 10th

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It is very difficult to give a clear status, summary of the report, as it is now. **Still work in progress...**

My general impression is rather positive.

The focus is on the physics case and there is no significant bias towards any of the projects.

It is clearly visible in some contributions or topics, but not on larger scale...

I do hope it stays like that.

Example of complementary results \Rightarrow

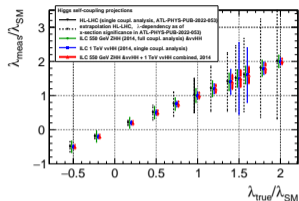


Figure 17: Projected accuracies for λ_{hhb} at the HL-LHC and a 550 GeV e^+e^- collider in dependence of the actual value of λ_{hhb} that is realised in nature [436] [plot to be updated before January 2025].

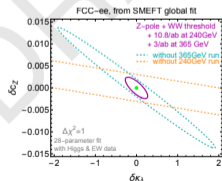


Figure 18: Sensitivity achievable on the trilinear self-coupling of the Higgs (shown on the x axis) with 240 and 365 GeV runs at the FCC-ee. Aside from the single Higgs coupling to the Z boson (shown on the y axis), 26 additional Higgs and EW coupling modifications have been marginalised over to obtain the ellipses shown.

Another example

Quantity	current	ILC250	ILC-GigaZ	FCC-ee	CEPC	CLIC380
$\Delta\alpha(m_Z)^{-1} (\times 10^3)$	18*	18*		3.8 (1.2)	18*	
Δm_Z (MeV)	2.1*	0.7 (0.2)	0.2	0.004 (0.1)	0.005 (0.1)	2.1*
$\Delta\Gamma_Z$ (MeV)	2.3*	1.5 (0.2)	0.12	0.004 (0.025)	0.005 (0.025)	2.3*
$\Delta A_e (\times 10^5)$	190*	14 (4.5)	1.5 (8)	0.7 (2)	1.5 (2)	60 (15)
$\Delta A_\mu (\times 10^5)$	1500*	82 (4.5)	3 (8)	2.3 (2.2)	3.0 (1.8)	390 (14)
$\Delta A_\tau (\times 10^5)$	400*	86 (4.5)	3 (8)	0.5 (20)	1.2 (20)	550 (14)
$\Delta A_b (\times 10^5)$	2000*	53 (35)	9 (50)	2.4 (21)	3 (21)	360 (92)
$\Delta A_c (\times 10^5)$	2700*	140 (25)	20 (37)	20 (15)	6 (30)	190 (67)
$\Delta\sigma_{\text{had}}^0$ (pb)	37*			0.035 (4)	0.05 (2)	37*
$\delta R_e (\times 10^3)$	2.4*	0.5 (1.0)	0.2 (0.5)	0.004 (0.3)	0.003 (0.2)	2.5 (1.0)
$\delta R_\mu (\times 10^3)$	1.6*	0.5 (1.0)	0.2 (0.2)	0.003 (0.05)	0.003 (0.1)	2.5 (1.0)
$\delta R_\tau (\times 10^3)$	2.2*	0.6 (1.0)	0.2 (0.4)	0.003 (0.1)	0.003 (0.1)	3.3 (5.0)
$\delta R_b (\times 10^3)$	3.1*	0.4 (1.0)	0.04 (0.7)	0.0014 (< 0.3)	0.005 (0.2)	1.5 (1.0)
$\delta R_c (\times 10^3)$	17*	0.6 (5.0)	0.2 (3.0)	0.015 (1.5)	0.02 (1)	2.4 (5.0)

Table 7: Electroweak precision observables extracted from two-fermion processes at future e^+e^- colliders: statistical error (estimated experimental systematic error). Δ (δ) stands for absolute (relative) uncertainty, while * indicates inputs taken from current data [480]. Table adapted from Ref. [477].

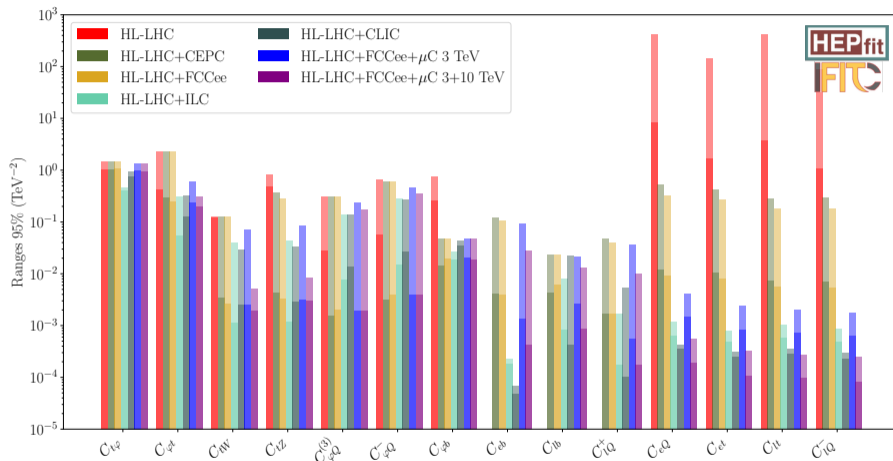


Figure 37: The 95% C.L. bounds on the Wilson coefficients of SMEFT operators involving top quarks.

Status of ILD contributions

Fast “screening” of the (Sunday version) of the report for ILD contributions:

- 17 contributions included in the draft
- higgs self-coupling: only old figure, no descriptions to be updated by January 2025 ?
- stau contribution still to be included (Mikael Berggren)
- 2 contributions look like not included (yet?):
 - 33 Search for Invisibly Decaying Higgs at the ILC (Carsten Hensel)
placeholder? results only expected in January...
 - 72 Prospects for Differential Cross-Section and Optimal Observable Measurements in W-pair and single-W Production at Future e^+e^- Colliders (André Silva) placeholder plots?

- ◆ 20/10 Deadline for physics studies to submit 2-page summary
- ◆ 20/10 – 10/11 Compilation and editing by WG1 subgroup conveners / nominated editors, and WG2/3 editors (as well as coordinators & chief editors)
10/11 is the deadline for WG1 subgroup conveners finish their part!
- ⇒ ◆ 10/11 – 27/11 Editing by WG1 coordinators, WG2/3 editors & coordinators, and chief editors.
27/11 is deadline for complete draft to be handed over to chief editors.
- ◆ 27/11 – 18/12 Editing by chief editors only
- ◆ 18/12 Circulation of version 1 to contributors and R-ECFA
- ◆ 17/1 Deadline to receive comments on version 1
- ◆ 24/1 Deadline to receive final results/plots from contributors
- ◆ February Incorporation of comments, final results, and references
- ◆ 21/2 Final version to R-ECFA
- ◆ 7–8/3 R-ECFA approval during country visit
followed by submission to arXiv

Timeline is very tight; no room for slippage!

Please expect a lot of interaction / clarification among all editors and contributors at each stage – thanks in advance!

Summary

Very many interesting results submitted as contributions to the ECFA report.

Many high quality results from ILD, most based on full simulation!

Still a lot of work to get the first version released for (internal) review

Hope to have it distributed before Christmas, as planned...

It should still be possible to make updates till January.

Please finalize your studies and update the results/plots where necessary.

Stay in touch with you group conveners/coordinators

and reply to all questions/requests promptly...

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And many thanks again to all of you who contributed to the report!