ECFA Higgs/Top/EW Factory
WG 1 - Physics Potential

Higgs Top Electroweak

14 November 2023



Chris Hays, Karsten Köneke, Fabio Maltoni

ECFA-WHF-WG1-HTE-conveners@cern.ch

ECFA Higgs/Electroweak/Top Factory Workshop Series

Based on the **recommendations of the Update of the European Strategy for Particle Physics**, the **European Committee for Future Accelerators (ECFA) has decided to organise a series of workshops on physics studies, experiment design and detector technologies towards a future electron-positron Higgs/EW/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 strategy item.

To set up the relevant structures and to define a path towards such workshops, an International Advisory Committee (IAC) has been formed. It suggested to establish **three Working Groups**, led by conveners from both experiment and theory:

- WG 1: Physics Potential
  - Conveners: Juan Alcaraz (CIEMAT - Madrid), Jenny List (DESY), Fabio Maltoni (UC Louvain / Bologna) and Jorge de Blas (Univ. Granada)
- WG 2: Physics Analysis Methods
  - Conveners: Patrizia Azzi (INFN-Padova / CERN), Fulvio Piccinini (INFN Pavia) and Dirk Zerwas (IJCLab/DMLab)
- WG 3: Detector R&D
  - Starting off, as Detector R&D Roadmap documents are finished now (Synopsis and Full Document(10.17181/CERN.XDPL.W2EX))

Informational Kick-off Meeting was held online on Friday 18th June 2021.

Time frame: March 2021 – ~December 2024

Top-level indico page: https://indico.cern.ch/event/1044297/

Working Group 1 - Physics Potential

WG 1 activities (indico) and organization (twiki):

Subgroups:

- WG1-PREC (Precision in theory & experiment):
  - Conveners: Ayres Freitas (Pittsburgh), Paolo Azzurri (Pisa), Adrian Irles (Valencia), Andreas Meyer (DESY) ecfa-whf-wg1-prec-conveners @cern.ch
- WG1-GLOB (Global interpretations in (SM)EFT and UV complete models):
  - Conveners: Sven Heinemeyer (IFCA/IFT), Alexander Grohsjean (DESY), Junping Tian (Tokyo), Marcel Vos (Valencia), Jorge de Blas (Granada) ecfa-whf-wg1-glob-conveners @cern.ch
- **WG1-HTE (HIGGS-TOP-EW and connection with (HL-)LHC)**:
  - Conveners: Chris Hays (Oxford), Karsten Köneke (Freiburg), Fabio Maltoni (Louvain) ecfa-whf-wg1-hte-conveners @cern.ch
- WG1-FLAV (Heavy Flavours):
  - Conveners: David Marzocca (Trieste), Stephane Monteil (Clermont Ferrand), Pablo Goldenzweig (KIT) ecfa-whf-wg1-flav-conveners @cern.ch
- WG1-SRCH (Feebly interacting particles, direct low mass searches):
  - Conveners: Roberto Franceschini (Rome III), Rebeca Gonzalez (Uppsala), Filip Zarnecki (Warsaw) ecfa-whf-wg1-srch-conveners @cern.ch

WG1 Seminar series, workshops, etc, see this indico category

Subgroup on Higgs-Top-EW and connection with HL-LHC (HTE)

Organization:

- Group meetings: WG1-HTE
- egroup mailing list
  - You can also subscribe to the egroups of the groups; just search in egroups for “ECFA-WHF-WG1”.
- Conveners: Chris Hays (Oxford), Karsten Köneke (Freiburg), Fabio Maltoni (Louvain)
- Convener's email: ecfa-whf-wg1-hte-conveners @cern.ch
  - **Please don’t hesitate to talk to us for any ideas, suggestions, questions!**

Mandate:

- Identify measurements that the **(HL-)LHC** can perform in order to increase the physics potential of a future Higgs/Top/EW Factory.
  - High-precision inclusive measurements
  - Differential measurements, e.g., at high p_T
  - …
- The physics potential of an e^+e^- HTE factory will also be compared to the potential of other future colliders.

You can find all our events, meetings, and workshops in our HTE indico category.
Thus far, 5 workshops…

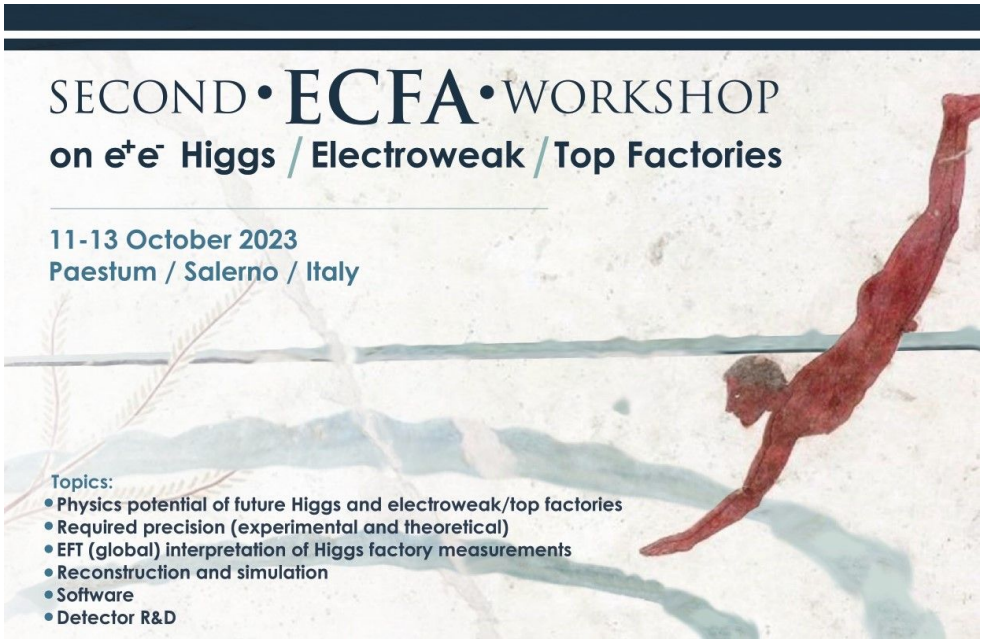
2nd ECFA Workshop on Higgs/EW/Top Factory

2023 ECFA e^+e^- Workshop in Paestum, Italy

11 – 13 October 2023:

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

- About 140 participants
- Status of Working Group activities
  - Focus topics (→ see later)
- Discussions of future plans
- Interactions between theory and experiments
- …



Next “overall” workshop planned for ~same time in 2024

The big picture – Timelines

ECFA study coherent with
next European Strategy Update

- Provisionally expected in **2026-2027**

  ⇒ expect **strategy inputs** to be due in **late 2025**

  ⇒ **2 years remaining for ECFA study**

Note: Also CEPC will know ~mid 2025, if they get on the next five year plan in China!!!

Focus Topics

1. **HtoSS** — $e^+e^- \to Zh$: $h \to s\bar{s}$ ($\sqrt{s} = 240/250\,\text{GeV}$) (JdB)
2. **ZHang** — ZH angular distributions and CP studies (JdB)
3. **Hself** — Determination of the Higgs self-coupling (JdB)
4. **Wmass** — Mass and width of the W boson from the pair-production threshold cross section lineshape and from decay kinematics ($\sqrt{s} = 158 - 380\,\text{GeV}$)
5. **WWdiff** — Full studies of WW and $e\nu W$ ($\sqrt{s} = 240/250, 365\,\text{GeV}$) (JdB)
6. **TTthres** — Top threshold: Detector-level simulation study of $e^+e^- \to t\bar{t}$ at a typical threshold-scan energy ($\sqrt{s} = 350, 365$ GeV) and threshold scan optimisation (JL)
7. **LUMI** — Precision luminosity measurement
8. **EXscalar** — New exotic scalars
9. **LLPs** — Long-lived particles
10. **EXtt** — Exotic top decays (FM)
11. **CKMWW** — CKM matrix elements from W decays (PK)
12. **BKtautau** — $B^0 \to K^{0*}\tau^+\tau^-$ (PK)
13. **TwoF** — EW precision: 2-fermion final states ($\sqrt{s} = M_Z$ and beyond) (PK)
14. **BCfrag** and **Gsplit** — Heavy quark fragmentation and hadronisation, gluon splitting and quark-gluon separation

Overall: accumulate critical mass working on each topic, reaching publications on timescale of ECFA study!
Get engaged in your topic(s) of interest!

Focus topics are intended to encompass a wide range of activities spanning

- theory & experiment,
- analysis & algorithm development,
- detector requirements & optimisation

Working on a document describing each of the 14 focus topics:

- Written by existing core expert teams (~5-10 people each)
- 2-4 pages for each, describing why it is interesting, where we stand, and what needs to be further looked into
- Goal: put it on the arXiv by December

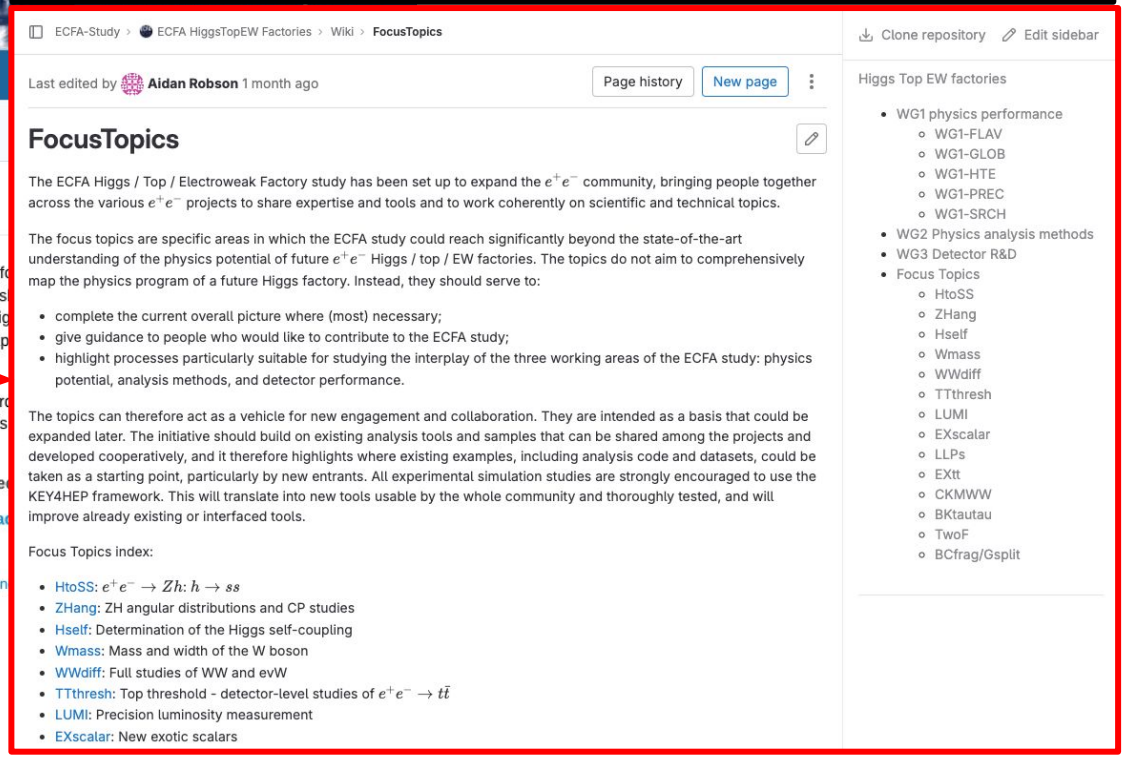
Next:

- Series of working meeting for each topic (~12-18 months)
- Aim for at least one small-author paper from each topic

Focus Topics

Collaborative resources: https://indico.cern.ch/event/1044297/

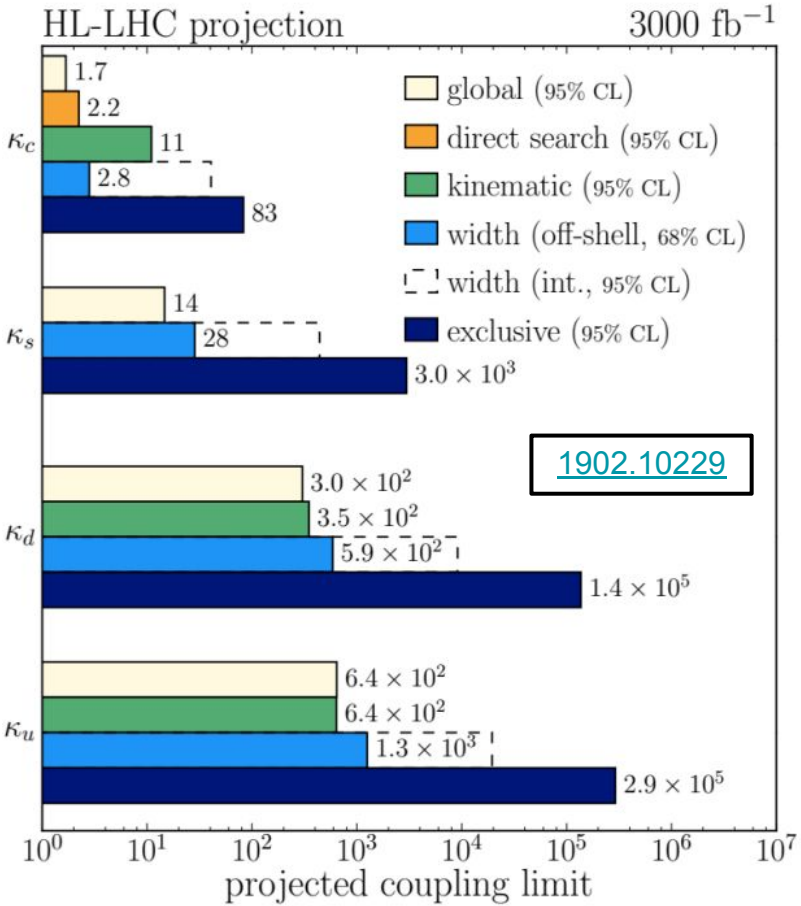
https://gitlab.in2p3.fr/ecfa-study/ECFA-HiggsTopEW-Factories/-/wikis/FocusTopics



Contacts and email lists to subscribe to are listed on these pages

Focus Topic Examples: HtoSS

See also Caterina Vernieri's slides at ECFA workshop in Paestum

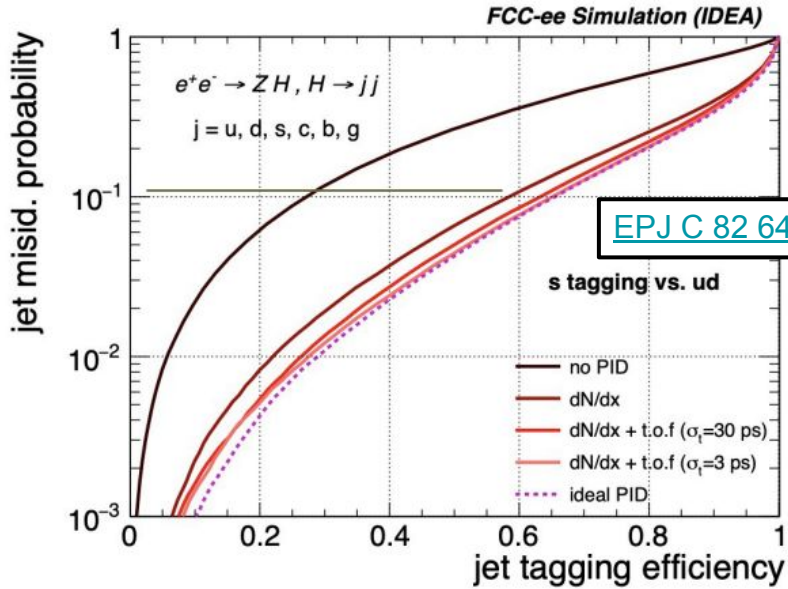


1902.10229

Light Yukawas out of reach at (HL-)LHC

(Nearly) within reach at e^+e^- collider:

- Need strange jet tagging!
- Which needs excellent PID & ML



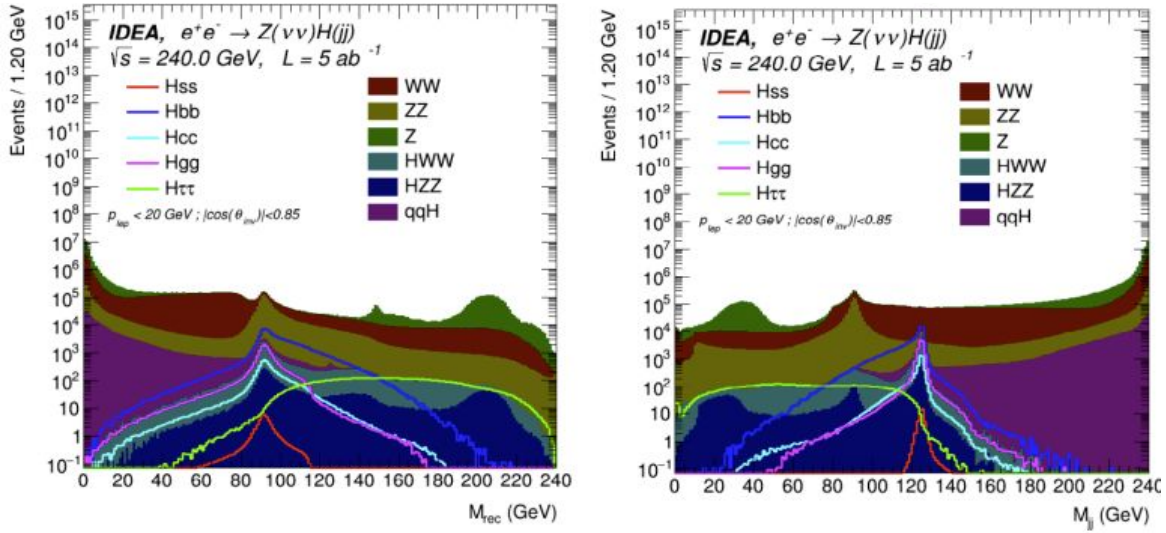
EPJ C 82 646 (2022)

Focus Topic Examples: HtoSS

See also Caterina Vernieri's slides at ECFA workshop in Paestum

Possible constraints on Hss coupling √s = 240/250 GeV:

- ILD: combined limit with 900/fb (i.e. half dataset): κ_s < 6.74 at 95% CL [2203.07535]
- FCC-ee: Z(vv)H only limit with 5/ab and 2 IPs: BR(H → ss) < 1.3 at 95% CL



Loukas Gouskos, FCC-ee Week London 2023

- CEPC: Z(vv/ll)H limit with 20/ab: BR(H → ss) < 3×SM at 95% CL [2310.03440]

Focus Topic Examples: HtoSS

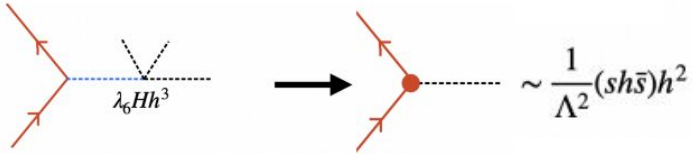
See also Caterina Vernieri's slides at ECFA workshop in Paestum

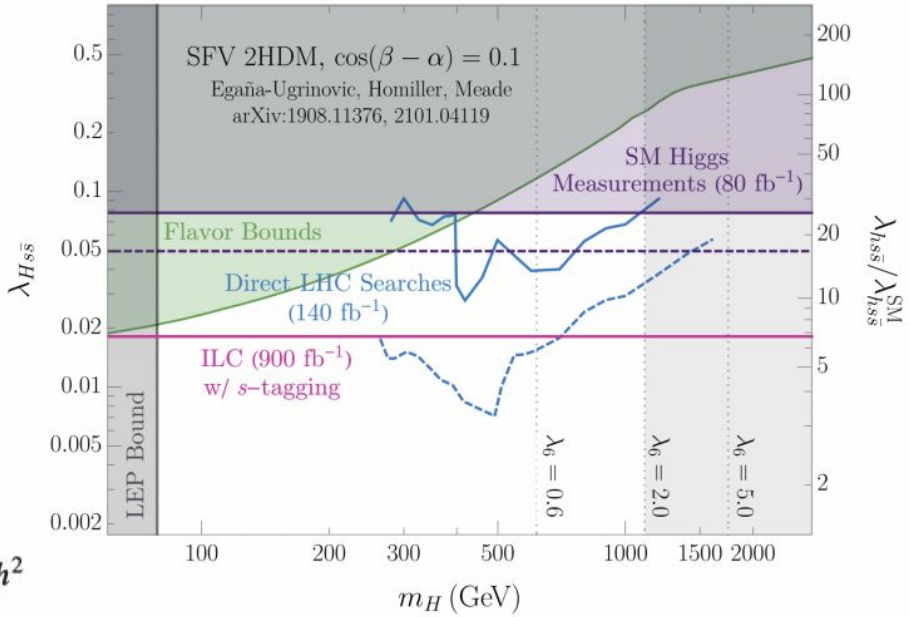
1 HtoSS — $e^+e^- \to Zh$: $h \to s\bar{s}$ ($\sqrt{s} = 240/250$ GeV) (JdB)

Expert Team: John Alison, Matthew Basso, Valentina Cairo, Valerio Dao, Loukas Gouskos, Karsten Köneke, Yotam Soreq, Taikan Suehara, Caterina Vernieri

Next steps:

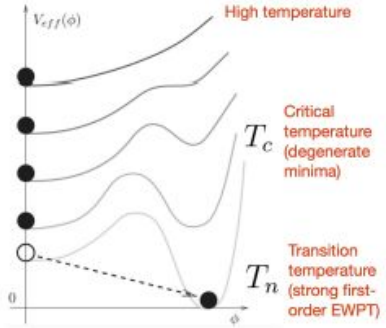
- Refine analyses and explore more avenues
- Study detector benchmarks
  - Complementarity in different PID systems
  - Reconstruction of V_0s
  - Strange tagging and s/sbar separation
- Map results into pheno models:
  - e.g.: **Spontaneous Flavor Violation**: New physics can couple in a strongly flavor dependent way if it is aligned in the down-type quark or up-type quark sectors
    - Allows for large couplings of additional Higgs to strange/light quarks
    - No flavor-changing neutral currents





Focus Topic Examples: ZHang

See also Gudrid Moortgat-Pick's slides at ECFA workshop in Paestum



Goals:

- Determination of ZH coupling
- 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

⇒ Search for additional sources of CP violation

Focus Topic Examples: ZHang

See also Gudrid Moortgat-Pick's slides at ECFA workshop in Paestum

From experiment: H125 is not pure CP-odd.

- But we do not know that it is pure CP-even

CP-odd coupling effect is suppressed in HVV, but at the same level as CP-even in Hff

- ATLAS and CMS already put various constraints on these!
  → see other talks in this workshop

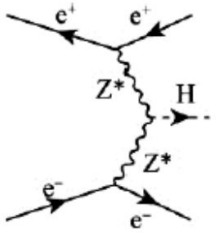
Next: two examples as teasers

Focus Topic Examples: ZHang

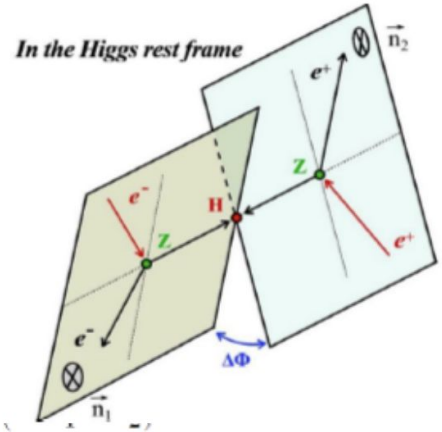
See also Gudrid Moortgat-Pick's slides at ECFA workshop in Paestum

Work in progress!

unpolarized beams: ZZ-fusion



	√s	beam polarisation	∫Ldt (baseline)
ILC	0.1 - 1 TeV	e-: 80% e+: 30% (20%)	2 ab-1 @ 250 GeV 0.2 ab-1 @ 350 GeV 4 ab-1 @ 500 GeV 8 ab-1 @ 1 TeV



Collider	pp	pp	pp	e^+e^-	e^+e^-	e^+e^-	e^+e^-	e^-p	$\gamma\gamma$	$\mu^+\mu^-$	$\mu^+\mu^-$	target
E (GeV)	14,000	14,000	100,000	250	350	500	1 TeV	1,300	125	125	3,000	(theory)
$\mathcal{L}$ (fb^{-1})	300	3,000	30,000	250	350	500	8 ab^{-1}	1,000	250	20	1,000	
HZZ/HWW	$4.0\cdot10^{-5}$	$2.5\cdot10^{-6}$	✓	$3.9\cdot10^{-5}$	$2.9\cdot10^{-5}$	$1.3\cdot10^{-5}$	$1.6\cdot10^{-5}$	✓	✓	✓	✓	$< 10^{-5}$
$H\gamma\gamma$	–	0.50	✓	–	–	–	–	–	0.06	–	–	$< 10^{-2}$
$HZ\gamma$	–	~ 1	✓	–	–	–	~ 1	–	–	–	–	$< 10^{-2}$
Hgg	0.12	0.011	✓	–	–	–	–	–	–	–	–	$< 10^{-2}$
$Ht\bar{t}$	0.24	0.05	✓	–	–	0.29	0.08	✓	–	–	✓	$< 10^{-2}$
$H\tau\tau$	0.07	0.008	✓	0.01	0.01	0.02	0.06	–	✓	✓	✓	$< 10^{-2}$
$H\mu\mu$	–	–	–	–	–	–	–	–	–	✓	–	$< 10^{-2}$

$$sgn\,(\sin\Phi): \frac{q_1 \cdot (\hat{n}_1 \times \hat{n}_2)}{|q_1 \cdot (\hat{n}_1 \times \hat{n}_2)|} \qquad \hat{n}_1 = \frac{q_{e_i^-} \times q_{e_f^-}}{|q_{e_i^-} \times q_{e_f^-}|} \qquad \hat{n}_2 = \frac{q_{e_i^+} \times q_{e_f^+}}{|q_{e_i^+} \times q_{e_f^+}|}$$

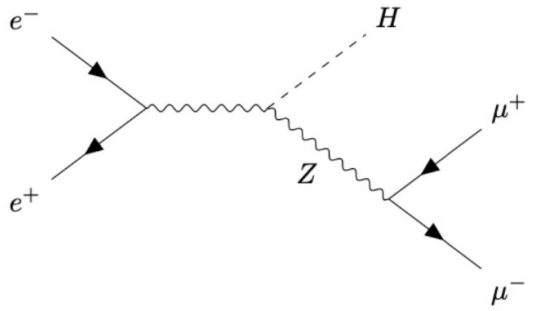
Focus Topic Examples: ZHang

See also Gudrid Moortgat-Pick's slides at ECFA workshop in Paestum

Work in progress!

transversely-polarized beams: HZ

$$|\mathcal{M}|^2 = (1 - P_-^3 P_+^3)(\cos^2\alpha\,\mathcal{A}_{\text{CP-even}} + \sin 2\alpha\,\mathcal{A}_{\text{CP-mix}} + \sin^2\alpha\,\mathcal{A}_{\text{CP-odd}}) + (P_-^3 - P_+^3)(\cos^2\alpha\,\mathcal{B}_{\text{CP-even}} + \sin 2\alpha\,\mathcal{B}_{\text{CP-mix}} + \sin^2\alpha\,\mathcal{B}_{\text{CP-odd}}) + \sum_{mn}^{1,2} P_-^m P_+^n \left(\cos^2\alpha\,\mathcal{C}^{mn}_{\text{CP-even}} + \sin 2\alpha\,\mathcal{C}^{mn}_{\text{CP-mix}} + \sin^2\alpha\,\mathcal{C}^{mn}_{\text{CP-odd}}\right)$$



$e^+e^- \to HZ, Z \to \mu^+\mu^-$

$(P^T_{e^-}, P^T_{e^+})$	Luminosity [fb^{-1}]	$\sin 2\alpha$ limit	c_{AZZ} limit
(80%, 30%)	2000	-	[-0.31,0.31]
(80%, 30%)	5000	[-0.62,0.62]	[-0.12,0.12]
(90%, 40%)	2000	[-0.79,0.79]	[-0.15,0.15]
(90%, 40%)	5000	[-0.39,0.39]	[-0.09,0.09]

so far only √s=250 GeV….
not yet exploited at higher energies
not yet exploited ZZ-fusion

…..work in progress…..

you are welcome!

Focus Topic Examples: ZHang

See also Gudrid Moortgat-Pick's slides at ECFA workshop in Paestum

2 ZHang — ZH angular distributions and CP studies (JdB)

Expert Team: Cheng Li, Chris Hays, Gudrid Moortgat-Pick, Ivanka Bozovic, Jorge de Blas, Ken Mimasu, Markus Klute, Sandra Kortner

Topics being discussed:

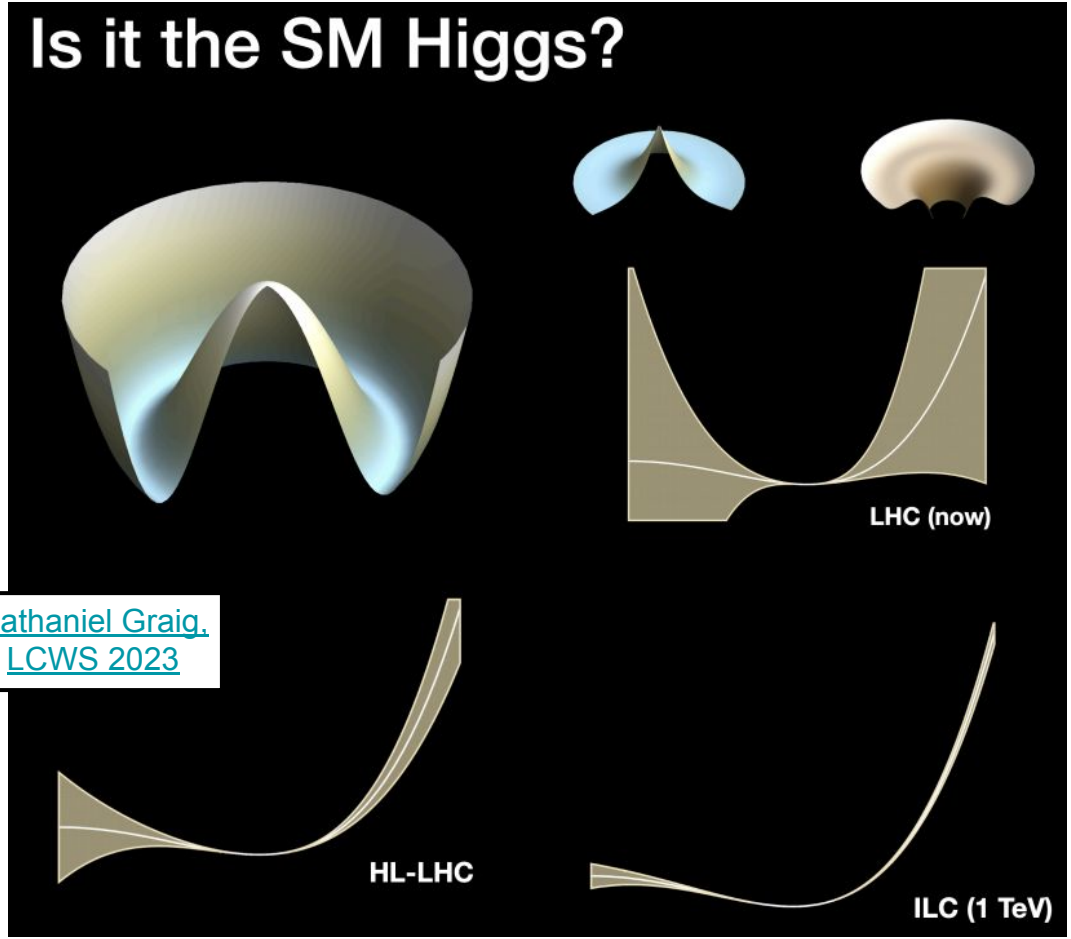
- Reconstruction of production and decay angles
- CP-violation in H-Z coupling
- Higgs couplings in HZ production
- CP-odd observables
- Global context, CP-conserving SMEFT,...

Many areas of work needed in:

- Pheno
- MC
- Reco
- …

Focus Topic Examples: Hself

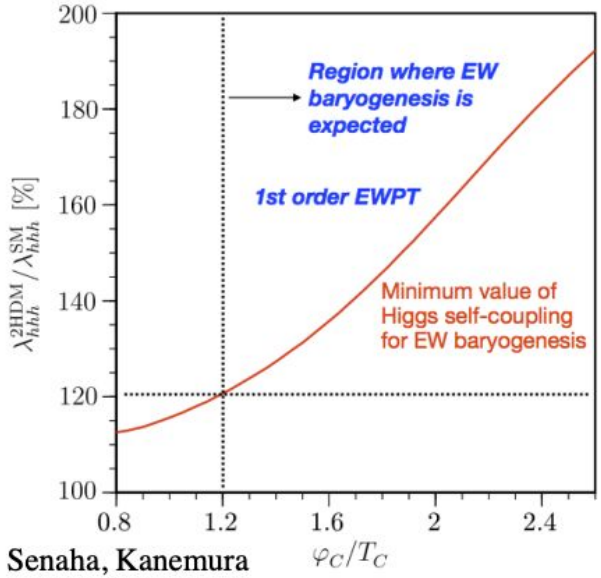
See also Junping Tian's slides at ECFA workshop in Paestum



Nathaniel Graig, LCWS 2023

Also:

- O(1) deviation of λ_{HHH} (preferred in certain BSMs)
- Light degrees of freedom, i.e., extra Higgs bosons



Focus Topic Examples: Hself

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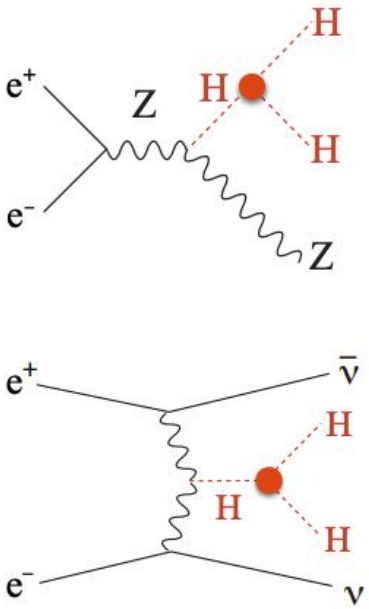
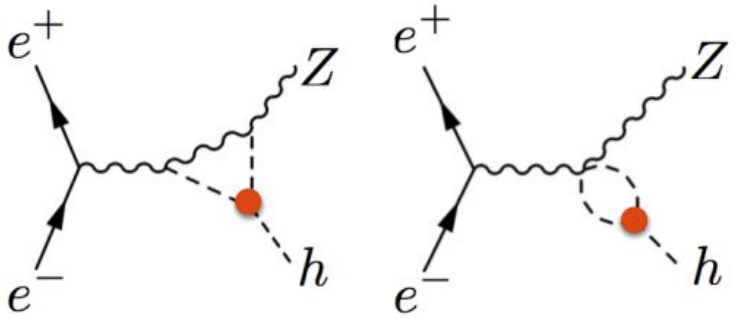
At e^+e^- collider:

$\sqrt{s} \gtrsim 500$ GeV



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

$\sqrt{s} \gtrsim 240$–250 GeV

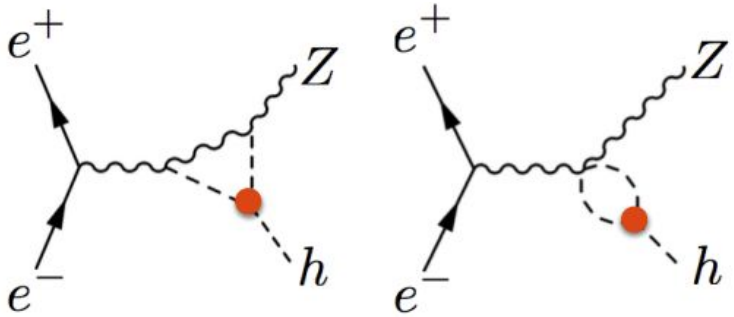


$\delta\sigma_{ZH} \sim O(1\%)$

Focus Topic Examples: Hself

See also Junping Tian's slides at ECFA workshop in Paestum

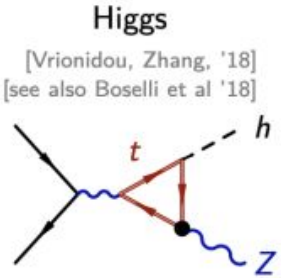
Questions related to single-Higgs processes



$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$

Matthew McCullough, 1312.3322

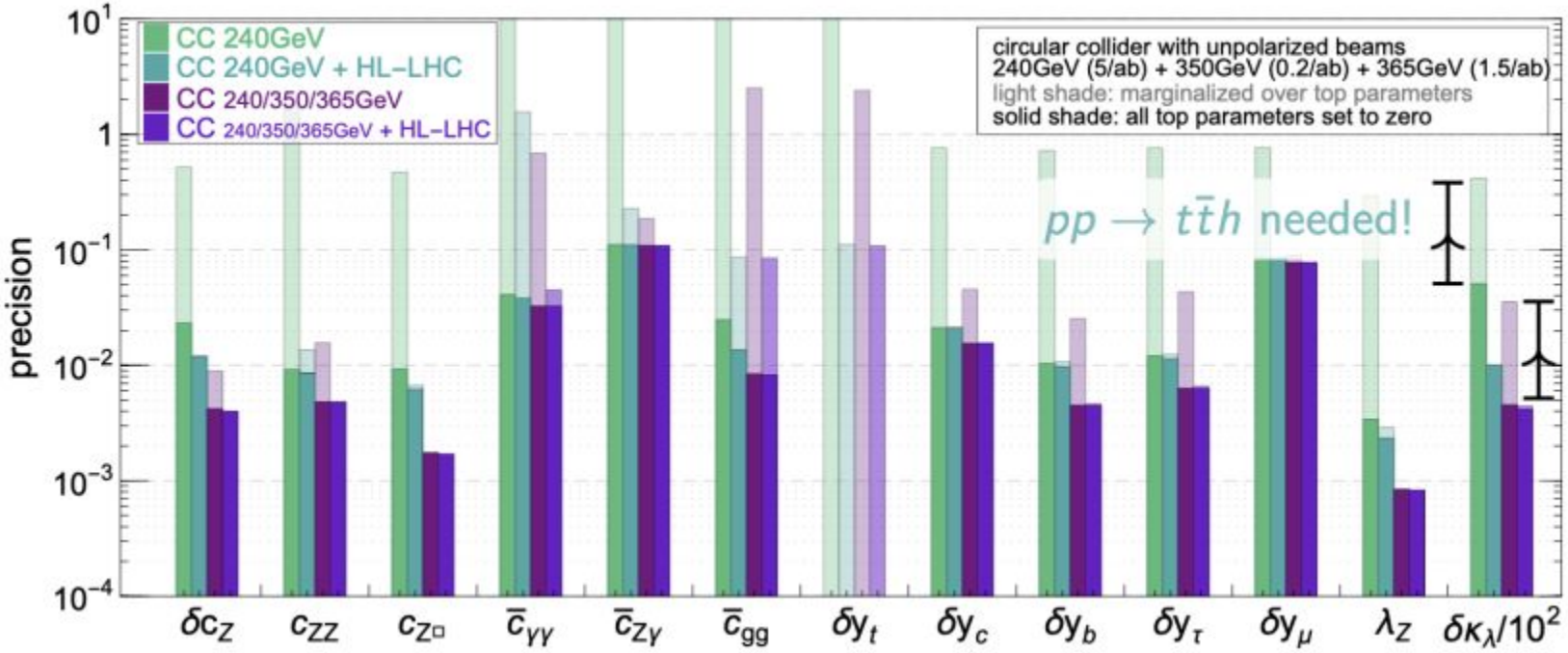
- If only δh is deviated → δh ~ 28%
- If both δz and δh deviated → δh ~ 90%
- δσ could receive contributions from many other sources
  - δh ~ 500% at 250 GeV only; [Gu, et al, arXiv:1711.03978]
  - δh ~ 50% + 350/500GeV [Peskin, Yong, Tian, paper in preparation]
- Can we lift the degeneracies by new observables, e.g. ZHang?
- What if we include other NLO effects as well, e.g. top?



Focus Topic Examples: Hself

See also Junping Tian's slides at ECFA workshop in Paestum

Top-quark uncertainties can impede Higgs precision!



Durieux, Gu, Vyronidou, Zhang, '18

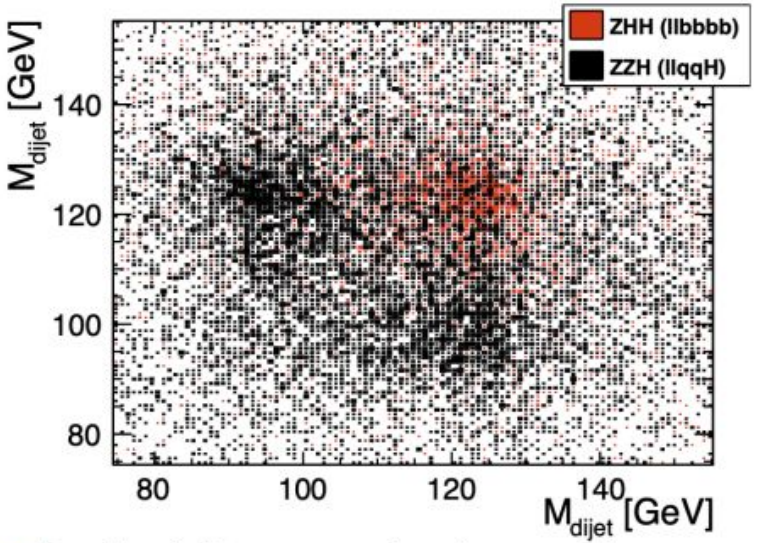
Jung, Lee, Perello, Tian, Vos, '20

Focus Topic Examples: Hself

See also Junping Tian's slides at ECFA workshop in Paestum

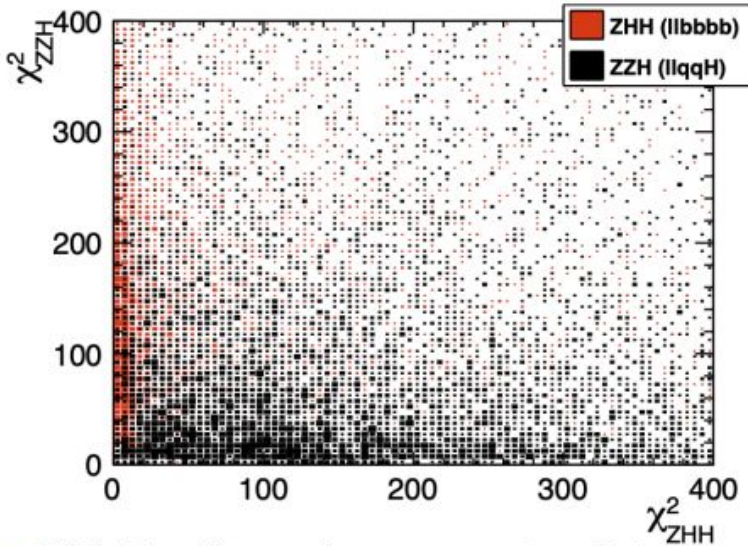
A lot of improvements possible on the analysis side, e.g.:

- Flavor tagging, jet clustering, kinematic fitting, matrix element method, machine learning, …



- Pre-fitted dijet-masses show large overlap between signal (ZHH) and background (ZZH)

→



- With ErrorFlow → larger separation of signal (ZHH) and background (ZZH)

Julie Torndal, LCWS 2023

Focus Topic Examples: Hself

See also Junping Tian's slides at ECFA workshop in Paestum

3 Hself — Determination of the Higgs self-coupling (JdB)

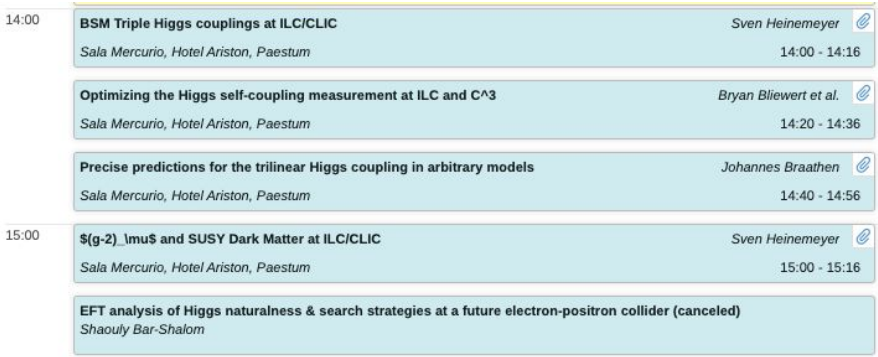
Expert Team: Junping Tian; Gauthier Durieux, Jose Goncalo, Sven Heinemeyer, Michael Peskin, Philipp Roloff, Roberto Salerno

Some items in the focus topic note:

- Theory: beyond the SMEFT
- Single-Higgs: lifting the degeneracies
- Di-Higgs production: advancing the analysis technique

Summary

Many more Higgs-related presentations in Paestum, have a look:



Summary

Many more Higgs-related presentations in Paestum, have a look!

- https://agenda.infn.it/event/34841/timetable/?view=standard

Three focus topics are directly Higgs related

- Paper describing each topic in 2-3 pages on the arXiv this year
    - Overview of topic
    - Description of what the targets are, and what remains to be done

Get engaged in the effort to prepare for the next update of the European Strategy for Particle Physics…

… and because it is really interesting!

https://gitlab.in2p3.fr/ecfa-study/ECFA-HiggsTopEW-Factories/-/wikis/FocusTopics