ECFA Workshops on e⁺e⁻ Higgs/Electroweak/Top Factories

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High Energy Physics Seminar Faculty of Physics, University of Warsaw November 29, 2024

A.F.Żarnecki (University of Warsaw)

ECFA Higgs Factory Workshops

Outline:

ECFA Study

- 2 Previous workshops
- 3 Few highlights
- Our contributions
- 5 ECFA report
- 6 Conclusions

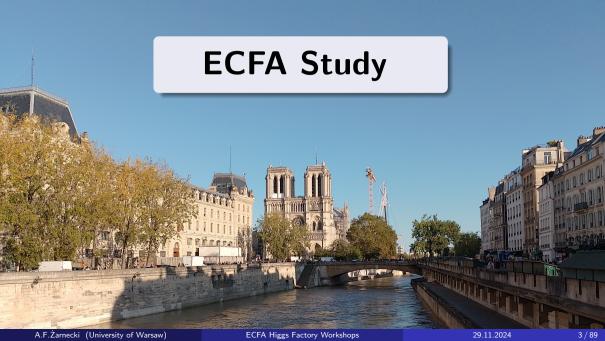
Mostly based on presentations given at ECFA workshops

Selection can be slightly biased by my personal preferences and involvements

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ECFA Higgs Factory Workshops





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 RECFA members and European leaders of possible future Higgs factories. In addition the
 (HL)-LHC community should be represented.
 - o ECFA-chair would act as chair: Karl Jakobs
 - o From RECFA: Jean-Claude Brient, Tadeusz Lesiak, Chiara Meroni
 - o With (HL-)LHC experience: Jorgen D'Hondt, Max Klein, Aleandro Nisati, Roberto Tenchini
 - o For theory: Christophe Grojean, Andrea Wulzer
 - o For Linear Colliders: Steinar Stapnes, Juan Fuster, Frank Simon, Aidan Robson
 - o 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-pT measurements and EFT interpretations)
- Identify specific topics where concrete work should be organised
- Requirements on accuracy in theoretical calculations and parametric uncertainties

Giovanni Marchiori

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

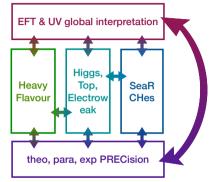
Created May 2022 (after conclusion of works of ECFA Detector Roadmap Task Force)

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

The main objectives of the ECFA e⁺e⁻ Study

- Provide a **platform for common developments** of a software infrastructure, simulation, reconstruction and analysis tools
- Theory: Monte Carlo generators
 - Understanding of the theory requirements from physics and detector precision
 - Serve as an experiment theory interface
- Provide the interface to the Detector R&D (DRD) collaborations (i.a. transmit developing detector requirements (which may change with time))
- Physics Studies: a lot is known already on the physics potential (ESPP studies, Snowmass, ...)
 - Extend towards so far uncovered areas
 - Encourage strong theory involvement
 - Encourage involvement of LHC physics community, understand better the HL-LHC potential (e.g. differential cross sections, EFT interpretations, ...)

ECFA Study on Physics, Experiments and Detectors at a Future e⁺e⁻ Factory

Why such an inclusive approach?

- Despite there is world-wide consensus that an e⁺e⁻ Higgs factory should be the next large collider, none of the projects is approved!
- The field is busy with LHC, Belle-II operation and data analysis, and with the challenging HL-LHC detector upgrades!
 - → Synergies should be used, and duplication of work for the various projects should be avoided
- There will most likely be only one e⁺e⁻ collider!
 - → The ECFA study also intends to foster a **community building**;

The support for the next collider must be broad (including the LHC community, ...)













Previous workshops

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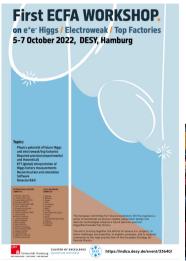
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ECFA Higgs Factory Workshops

29.11.2024

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First milestone!



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





ECFA WS

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, C³, ...



- 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

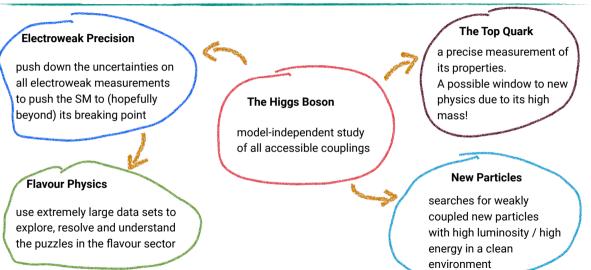
Long-term upgrades: energy extendability

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

Setting the Stage

Recall the Physics





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

Proposed focus topics

· · ·	-		relevant \sqrt{s}				
		lead group	91 GeV	161 GeV	240/250 GeV	350-380 GeV	> 500 GeV
1. H->ssbar	1	HTE			X	X	x
2. ZH angular distributions / CP studies	2	HTE (GLOB)			Х	Х	х
3. Higgs self-coupling	3	GLOB			х	х	Х
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	х
6. Top threshold	6	GLOB (HTE)				X	
7. Luminosity measurement	7	PREC	х	х	x	x	х
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 → K ⁰ •τ+τ−	12	FLAV	x				
13. 2-fermion final states	13	HTE	х	X	X	X	Х
14. b- and c-fragmentation functions / hadronisation	14	FLAV (PREC)	х	x	X	X	x
15. Gluon splitting to bb / cc (& interplay with separating	15	PREC (FLAV)	Х	x	X	Х	x
$h \rightarrow dhone from h \rightarrow hh/ce)$							

 $h \rightarrow gluons from h \rightarrow bb/cc)$

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)

Focus topics for the ECFA study on Higgs / Top / EW factories

Juan Alcaraz Maestre¹, Juliette Alimena², John Alison³, Patrizia Azzi⁴, Paolo Azzurri⁵, Emanuele Bagnaschi^{6,7}, Timothy Barklow⁸, Matthew J. Basso⁹, Josh Bendavid¹⁰, Martin Beneke¹¹, Eli Ben-Haim¹², Mikael Berggren², Jorge de Blas¹³, Marzia Bordone⁶, Ivanca Bozovic¹⁴, Valentina Cairo⁶, Nuño Filipe Castro¹⁵, Marina Cobal¹⁶, Paula Collins⁶, Mogens Dam¹⁷, Valerio Dao⁶. Matteo Defranchis⁶, Ansgar Denner¹⁸, Stefan Dittmaier¹⁹, Gauthier Durieux²⁰, Ulrich Einhaus², Mary-Cruz Fouz¹, Roberto Franceschini²¹, Avres Freitas²², Frank Gaede², Gerardo Ganis⁶, Pablo Goldenzweig²³, Ricardo Goncalo^{24,25}, Rebeca Gonzalez Suarez²⁶, Loukas Gouskos²⁷, Alexander Grohsjean²⁸, Jan Hajer²⁹, Chris Hays³⁰, Sven Heinemeyer³¹, André Hoang³², Adrián Irles³³, Abideh Jafari², Karl Jakobs¹⁹, Daniel Jeans³⁴, Jernej F. Kamenik³⁵, Matthew Kenzie³⁶, Wolfgang Kilian³⁷, Markus Klute²³, Patrick Koppenburg³⁸, Sandra Kortner³⁹, Karsten Köneke¹⁹, Marcin Kucharczyk⁴⁰, Christos Leonidopoulos⁴¹, Cheng Li⁴², Zoltan Ligeti⁴³, Jenny List², Fabio Maltoni²⁰, Elisa Manoni⁴⁴, Giovanni Marchiori⁴⁵, David Marzocca⁴⁶, Andreas B. Meyer², Ken Mimasu⁴⁸, Tristan Miralles⁴⁷, Victor Miralles⁴⁹, Abdollah Mohammadi⁵⁰, Stéphane Monteil⁵¹, Gudrid Moortgat-Pick²⁸, Zohreh Najafabadi⁵², María Teresa Núñez Pardo de Vera², Fabrizio Palla⁵, Michael E. Peskin⁸, Fulvio Piccinini⁵³, Laura Pintucci⁵⁴, Wiesław Płaczek⁵⁵, Simon Plätzer^{56,32}, Roman Pöschl⁵⁷, Tania Robens⁵⁸, Aidan Robson⁵⁹, Philipp Roloff⁶, Nikolaos Rompotis⁶⁰, Andrej Saibel³³, André Sailer⁶, Roberto Salerno⁶¹, Matthias Schott⁶², Reinhard Schwienhorst⁶³, Felix Sefkow², Michele Selvaggi⁶, Frank Siegert⁶⁴, Frank Simon²³, Andrzej Siodmok⁵⁵, Torbjörn Sjöstrand⁶⁵, Kirll Skovpen⁶⁶, Maciej Skrzypek⁴⁰, Yotam Soreq⁶⁷, Raimund Ströhmer¹⁸, Taikan Suehara⁶⁸, Junping Tian⁶⁸, Emma Torro Pastor³³, Maria Ubiali³⁶, Luiz Vale Silva³³, Caterina Vernieri⁸, Alessandro Vicini⁶⁹ Marcel Vos³³, Adrian R. Wiederhold⁷⁰, Sarah Louise Williams³⁶, Graham Wilson⁷¹, Aleksander Filip Zarnecki⁷², Dirk Zerwas^{73,57}

SECOND • ECFA • WORKSHOP on e^te⁻ Higgs / Electroweak / Top Factories

11-13 October 2023 Paestum / Salerno / Italy



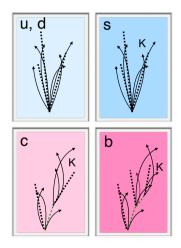
Topics:

- 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

s-tagging

2101.04119 2203.07535

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



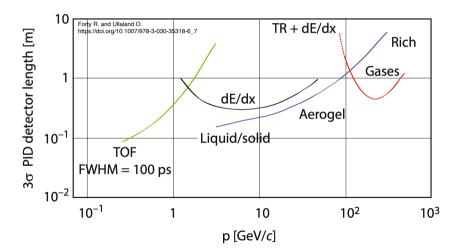
- As b,c, and s jets contain at least one strange hadron
- Strange quarks mostly hadronize to prompt kaons which carry a large fraction of the jet momentum
- Strange hadron reconstruction:
 - ・ K[±] PID
 - K⁰_L PF (neutral)
 - · $K_{0S} \rightarrow \pi^{+}\pi^{-}$ (~70%) / $\pi^{0}\pi^{0}$ (~30%)
 - Λ⁰→ pπ (~65%)

Distinctive two-prong vertices topology

Jet flavour	Number of secondary vertices (excluding V^0 s)	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		

Particle ID for s-tagging

Combining different strategies for optimal PID performance across a wide pT range



95% CL, upper limit: 6.74

Expected CL_s

12

14

 $\alpha = 0.05$

BR (H \rightarrow ss) = 2 x10⁻⁴

10

é

Tested POL K.

6

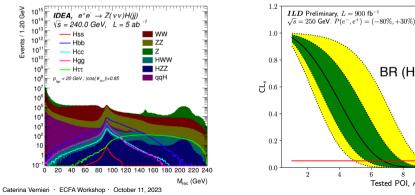
 $\pm 1\sigma$ expected CL.

 $\pm 2\sigma$ expected CL.

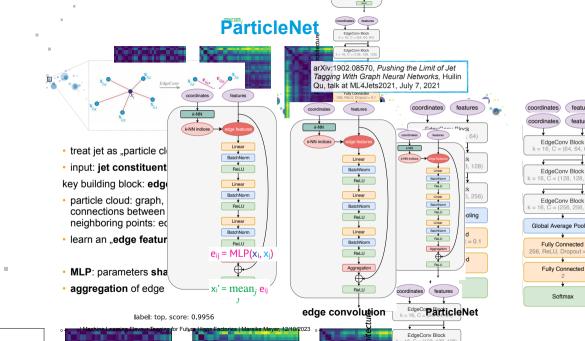
Constraints on s-coupling

Compatible results for both FCC and ILC like analyses

- ILD combined limit of $\kappa_s < 6.74$ at 95% CL with 900/fb at 250 GeV (i.e. half dataset)
 - No PID worsen the results by 8%
- FCC for Z(vv) only sets a limit of $\kappa_s < 1.3$ at 95% CL with 5/ab at 250 GeV and 2 IPs

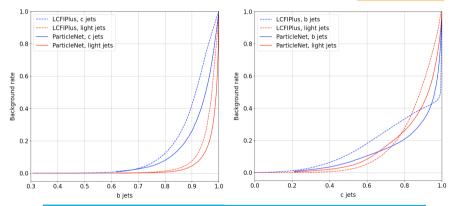


FCCAnalyses: FCC-ee Simulation (Delphes)



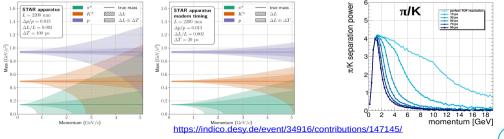
ParticleNet: ROC curves - comparison to LCFIPlus

validation data



better performance than LCFIPlus over large parts of the b and c tagging efficiencies one of the first trainings with this architecture, a lot of possibilities for optimization (architecture, hyperparameters, features, over-training in c-jet category...)

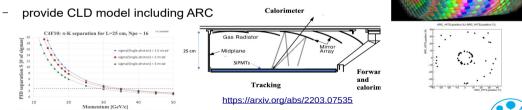
- Crucial: track length uncertainty may be a limiting factor to TOF performance
 - Example below: $\Delta T = 10 \text{ ps} \sim \Delta L = 3 \text{ mm}$
- p-value assessment of separation power includes outliers and gives more conservative estimate at low momenta (for details see backup)
- · Still missing: digitizer; e.g. effect of hit energy deposition on hit timing





Ring Imaging Cherenkov Detectors

- 2 hardware proposals, aiming at PID up to 50 GeV with compact barrel+endcap RICH
- RICH for e.g. SiD, single phase
 - work ongoing on hardware and geometry
- ARC for CLD, with aerogel and gas
 - work ongoing on digitisation and reconstruction
 - allow for parametrised detector



ę -status-of-software-for https://indico.cern.ch/event/1202105/timetable/#354-

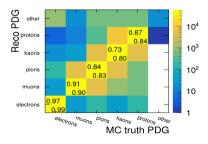
Composite vessel wall

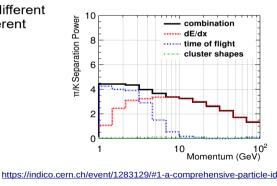
nsulation + suppor

Radiator gas

ARC detector (one cell)

- Modular approach to combined PID, both for the input observables and the training models
- Using PID observables from existing reconstruction, modules for these inputs as well as the training models to combine them
- Allows to optimise and compare different PID 'settings' in a detector or different detector with each other







Timeframe

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



Timeframe

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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...

2nd ECFA Workshop

Aidan Robson

3rd ECFA workshop on eter Higgs, Top & ElectroWeak Factories 9-11 October 2024 Sorbonne Université, Campus des Cordeliers, Paris \mathbf{Z}^* 7

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

Few highlights

A.F.Żarnecki (University of Warsaw)

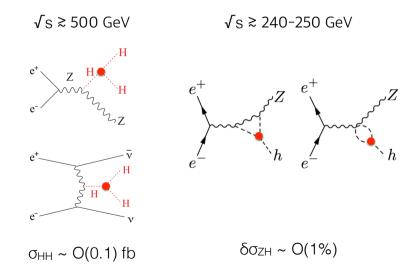
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ECFA Higgs Factory Workshops

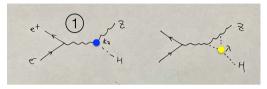
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Focus topic summary by Junping Tian (U.Tokyo) λ_{HHH}: di-Higgs & single-Higgs processes



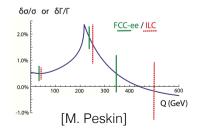
(iv) How to discriminate with HZZ coupling



[McCullough, '13]

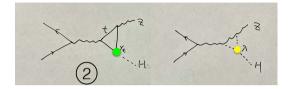
$$\delta_{\sigma}^{240} = 100 \left(2\delta_Z + 0.014\delta_h \right) \%$$

- δσ_{ZH} < 1% is a necessity; but not sufficient
- δσ could receive contributions from many other sources
 —> δh ~ O(500)% at 250GeV only; [Gu, et al, arXiv:1711.03978]

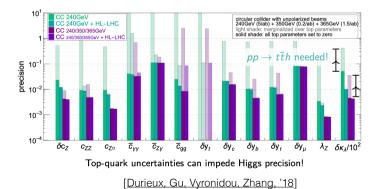


b "easy" solution: lift degeneracy by multiple √s

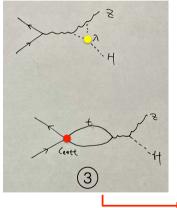
(iv) How to discriminate with top-Yukawa coupling



mitigated by LHC top-Yukawa measurement



(iv) How to discriminate with 4-fermion interaction [talk by P. Giardino]

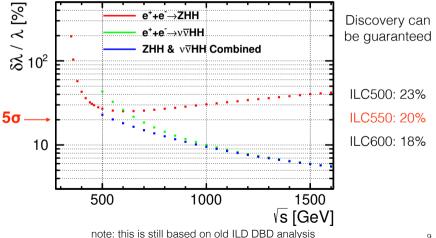


 the effects from (many) eett operators have just been calculated! [Asteriadis, Dawson, Giardino, Szafron, arXiv:2406.03257]

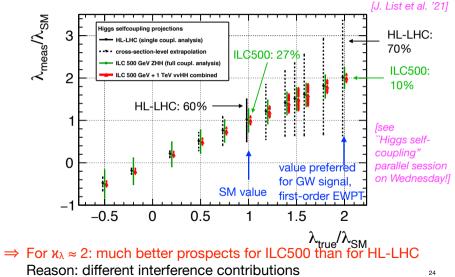
	$\sqrt{s} = 2$	40 GeV	$\sqrt{s} = 365 \text{ GeV}$		
	•	$\bar{\Delta}_i/\Lambda^2$	Δ_i/Λ^2		
C_{ϕ}	$\textbf{-7.22} \cdot 10^{\textbf{-3}}$	0	$\textbf{-1.00}\cdot\textbf{10}^{\textbf{-3}}$	0	
$C_{uW}[3,3]$	$-1.63\cdot10^{-3}$	$4.01\cdot 10^{\text{-}3}$	$3.36\cdot10^{\text{-}3}$	$6.25\cdot10^{\text{-}3}$	
$C_{uB}[3, 3]$	$0.15\cdot10^{\text{-}3}$	$\textbf{-}2.22\cdot10^{\textbf{-}3}$	$\textbf{-2.96}\cdot10^{\textbf{-3}}$	$\textbf{-3.20}\cdot\textbf{10^{-3}}$	
$C_u \phi[3,3]$	$0.32\cdot10^{-3}$	0	$-1.09 \cdot 10^{-3}$	0	
$C^{(1)}_{\phi q}[3,3]$	$-1.34 \cdot 10^{-3}$	$\textbf{-4.10} \cdot \textbf{10}^{\textbf{-3}}$	$-4.39 \cdot 10^{-3}$	$-4.31 \cdot 10^{-3}$	
$C_{\phi q}^{(3)}[3,3]$	$0.51\cdot 10^{\text{-}3}$	$4.12\cdot10^{\text{-}3}$	$4.15\cdot10^{\text{-}4}$	$7.58\cdot10^{\text{-}4}$	
$C_{\phi u}[3,3]$	$\textbf{-0.54} \cdot 10^{\textbf{-3}}$	$3.49\cdot10^{\text{-}3}$	$5.37\cdot10^{\text{-}3}$	$3.11\cdot10^{\text{-}3}$	
$C_{eu}[1, 1, 3, 3]$	$0.01\cdot 10^{-3}$	$\textbf{-1.39} \cdot \textbf{10}^{-2}$	$-3.73\cdot10^{-2}$	$-3.23 \cdot 10^{-2}$	
$C_{lu}[1, 1, 3, 3]$	$-0.02 \cdot 10^{-3}$	$1.73\cdot10^{-2}$	$4.64\cdot10^{\text{-2}}$	$4.01\cdot10^{\text{-}2}$	
$C_{lq}^{(1)}[1, 1, 3, 3]$	$\textbf{-0.37} \cdot 10^{\textbf{-2}}$	$\textbf{-}1.80\cdot10^{\textbf{-}2}$	$\textbf{-6.09} \cdot 10^{\textbf{-2}}$	$-4.18 \cdot 10^{-2}$	
$C_{lq}^{(3)}[1, 1, 3, 3]$	$\textbf{-}0.37 \cdot 10^{\textbf{-}2}$	$1.29\cdot10^{\text{-}2}$	$4.54\cdot10^{\text{-}2}$	$3.29\cdot10^{\text{-}2}$	
$C_{qe}[3,3,1,1]$	$0.30\cdot 10^{\text{-}2}$	$1.45\cdot10^{\text{-}2}$	$4.90\cdot10^{\text{-}2}$	$3.36\cdot10^{\text{-}2}$	

(iii) di-Higgs: updated projection $\Delta \lambda_{HHH}$

- two production channels **combined** at all \sqrt{s} : WW-fusion channel rapidly becomes useful just a little above 500 GeV
- luminosity now also scaled **proportionally** to *I*s



LCWS'2024Prospects for measuring the trilinear Higgs coupling: HL-LHC vs. ILC (500 GeV, Higgs pair production)



Physics case for e+e at 500 GeV and above, Georg Weiglein, LCWS2024, Tokyo, 07 / 2024

Bottlenecks in the ZHH analysis

- > jet pairing and jet misclustering: "perfect" jet clustering $\rightarrow 40\%$ improvement improve di-iet mass resolution
- important to tackle initial state radiation (ISR) Flavor tagging: 11% improvement expected from 5% eff. increase with newer LCFIPlus important as $H \rightarrow b\bar{b}$ is the dominant Higgs decay channel
- > adding $Z \rightarrow \tau \tau$ channel: 8% improvement expected include a yet unaccounted decay channel

> removal of $\gamma\gamma$ overlay: 15% improvement expected

> more modern ML architectures for signal/background selection improvement expected when transitioning from BDTs to (e.g.) transformer-based models etc.

would directly improve the sensitivity on λ (lower sensitivity factor) from DESY-Thesis-16-027 Higgs self-coupling measurement at ILD via the ZHH Process at multiple COM energies | 3rd ECFA Workshop on e+e- Higgs/EW/Top Factories | 2024/10/10 | Paris | Brvan Bliewert

separation of ZHH diagrams with/without the self-coupling



Expected improvements



All improvements are relative

Status of studies in the GLOBal interpretation group SMEFT fits

[Of determining the Higgs couplings]

The traditional κ parametrization is not up to the task. We suggest that a method based on SMEFT is more physical, complete, and model-independent. Michael Peskin's talk

Previous strategy update: Higgs coupling projections in the kappa and EFT framework. The next strategy update: EFT only, using fits with linear D6 dependence as baseline. (my proposal, up for discussion)

SMEFiT results (Jaco ter Hoeve)

Higgs/EW/top fits on projections

Results beyond JHEP 09 (2024) 091

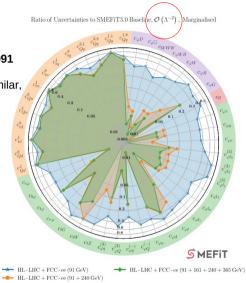
Linear-only bounds: quadratic is similar, except for qqtt operators

RGE evolution: small changes, except tttt operators

Todo: eett operators, different collider projects



[1804.05033] Aebischer, Kumar, Straub



9

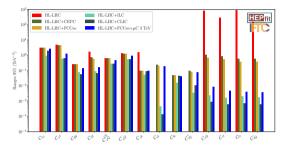
marcel.vos@ific.uv.es

Fit to the top sector

IFIT/C collaboration fits top and bottom operators

Excellent bounds on operators that affect EW interactions of the top quark

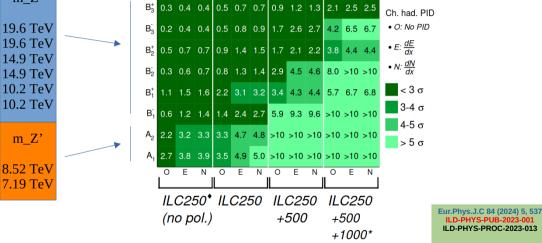
TO DO: finalize fits, compare to SMEFiT, write paper



HL-LHC on eett operators:	e+e- colliders on eett operators:
Quadratic global: O(1) Linear individual: O(1-10 TeV ⁻²) Linear global: O(100 TeV ⁻²)	Linear fit, circular machine:O(1 TeV-2)Linear fit, linear machine@1-3 TeVO(10-2 TeV-2)

All e+e- top data is good, high energy data are excellent

Gauge Higgs Unification models vs SM discrimination power 2-fermion final states focus topic ILD GHU vs SM discrimination power (σ -level) m_Z' B[±] 0.3 0.4 0.4 0.5 0.7 0.7 0.9 1.2 1.3 2.1 2.5 2.5 Ch had PID 19.6 TeV B₀ 0.2 0.4 0.4 0.5 0.8 0.9 1.7 2.6 2.7 4.2 6.5 6.7 · O: No PID 19.6 TeV



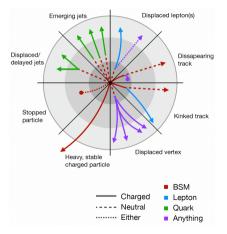
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11 D.DHVS.DI IR.2023-001 II D.PHYS.PROC.2023-013

A Irles et al

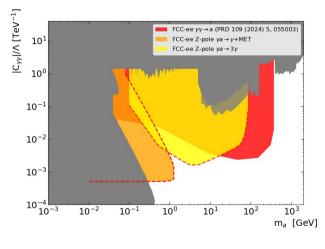
We all know about LLPs

- Particles with relatively long lifetimes, that decay after going through the detectors some distance
 - They produce unconventional experimental signatures (displaced, but also delayed, emerging, disappearing, kinked...)
 - They have in general low backgrounds
 - Due to the experimental focus on prompt decays in high energy colliders: trigger, reconstruction, and analysis algorithms can miss them
 - Require customization and out-of-the-box approaches



ALP searches

Combined plot FCC-ee



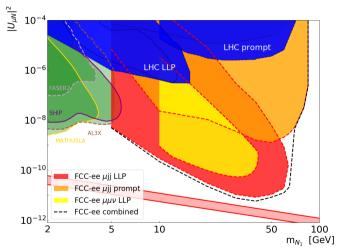
Grey areas :existing exclusions taken from ATLAS plot, to be updated with newest results

Yellow and orange areas are the two analyses of this talk

Red area is analysis of Rebello Teles et al. addressing ALP production in photon-photon fusion



N→µjj sensitivity



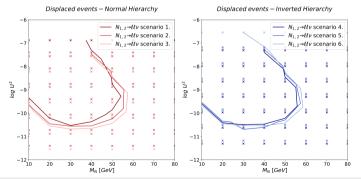
Prompt vs **long-lived** separation [radial vertex position ≤ 0.5 mm]

Selection for long-lived analysis reduced to minimal one, so to have **no background** in the long-lived regime

LLP RESULTS



- Contours for 4 long-lived HNL events show good performance across the parameter space sampled
- The lower couplings region is accessible
- Not so sensitive for higher masses (shorter lifetime)
- The different mixing hypotheses give similar results



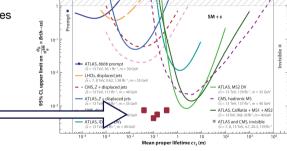
Comparison to existing limits

Complementary to the LHC searches!

- The sensitive signal points probes BRs ~ 4-7 \cdot 10^{-4} and span the mean proper lifetimes of ~ 40-400 mm
- Reaching slightly shorter lifetimes compared to the best existing limits
 - LHC: BR ~ 10-3 for lifetimes 1-10m
- · About two orders better sensitivity at similar lifetimes
 - LHC: BR ~ 2.10⁻² for lifetimes 1mm 1m

Reference DOI: 10.1146/ar	: Exotic Higgs	147
		 77772

LLPs from Exotic Higgs Decays



$m_s, \sin heta$	$c\tau ~[{ m mm}]$	$BR(h \rightarrow ss)$	Full event selection
20 GeV, 1e-6 20 GeV, 3e-6 40 GeV, 1e-6 50 GeV, 1e-6	341.7 38.0 136.6 106.6	$\begin{array}{c} 6.981 \times 10^{-4} \\ 6.981 \times 10^{-4} \\ 5.663 \times 10^{-4} \\ 4.422 \times 10^{-4} \end{array}$	$\begin{array}{c} 10.739 \pm 0.243 \\ 3.262 \pm 0.134 \\ 9.169 \pm 0.203 \\ 5.649 \pm 0.141 \end{array}$







Long-lived particle searches with the ILD experiment

3rd ECFA Workshop on Higgs/top/EW factories 10 October 2024, Paris

> D. Jeans⁽¹⁾, <u>J. Klamka</u>⁽²⁾, A. F. Żarnecki⁽²⁾ ⁽¹⁾KEK, ⁽²⁾University of Warsaw

> > jan.klamka@fuw.edu.pl

arXiv:2409.13492

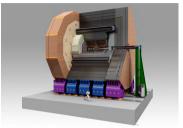


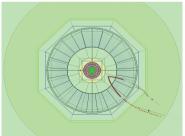
Strategy



ILD especially promising with a $\underline{\mathsf{TPC}}$ as the main tracker

- \rightarrow we want to investigate experimental aspects
- \rightarrow study based on full simulation
- Study such challenging signatures from the experimental perspective
 - \rightarrow experimental/kinematic properties, not points in a model parameter space
- Focus on a generic (and most challenging) case two tracks from a displaced vertex
- No other assumptions about the final state, approach as general as possible







Overlay events background



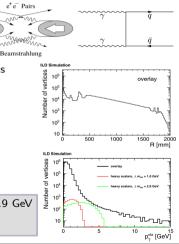
At linear e⁺e⁻ colliders beams are strongly focused and radiate photons, so $\gamma\gamma$ interactions also occur in detector. On average, in each bunch-crossing (BX) at ILC250, produced are:

- 1.55 γγ → low-p_T hadrons events
- O(10⁵) incoherent e⁺e⁻ pairs, only a small fraction enters tracker

These events are soft, usually important because they **overlay** on physical events

...but can also look like signal on their own

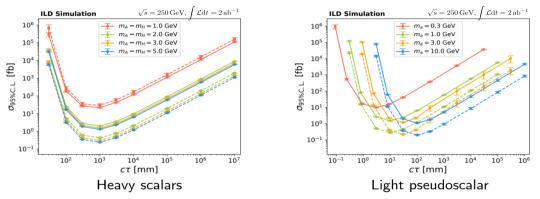
- ~10^{11} BXs per year at ILC \rightarrow overwhelming number of overlay events
- Similar kinematics to the signal considered and can be busy
 - \rightarrow many secondary vertices (mostly fake, also V⁰s and photon conversions)
 - → significant background
 - Can be suppressed using cuts on the track pair geometry and $p_{_{\rm T}}^{_{_{\rm Vtx}}} > 1.9~\text{GeV}$
 - Total expected reduction factor at the level of ${\sim}10^{\text{--}10}$





Cross section limits

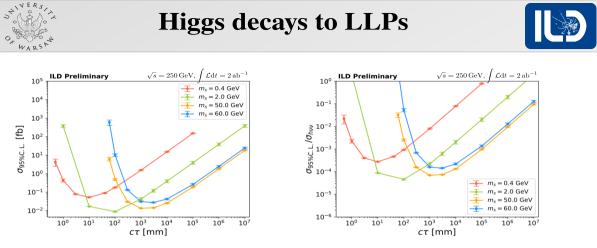




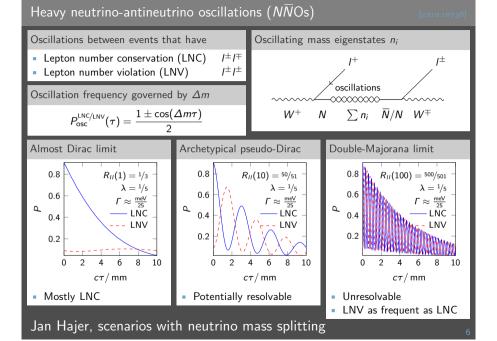
- Tight selection: dashed line, standard selection: solid line
- A wide range of models with heavy scalars with small mass splittings, or light pseudo scalar particles, can be excluded down to 0.1 fb
 arXiv:2409.13492

10 October 2024

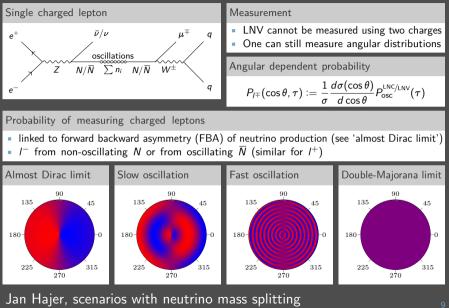
Jan Klamka, LLP searches with the ILD experiment



- ILD can improve the current constraints and probe higher lifetimes already @ ILC250 thanks to higher TPC acceptance
- The limits could be further improved by dedicated searches using vertex detector and by more data at higher energy stages



During the Z-pole run of the FCC-ee





Probing the nature of HNL at lepton colliders

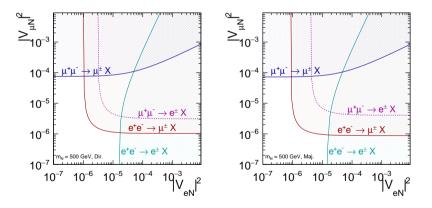
¹Faculty of Physics, University of Warsaw ²Theory Group, Deutsches Elektronen-Synchrotron DESY, Hamburg

3rd ECFA workshop on e+e- Higgs, Electroweak and Top Factories 10.10.2024

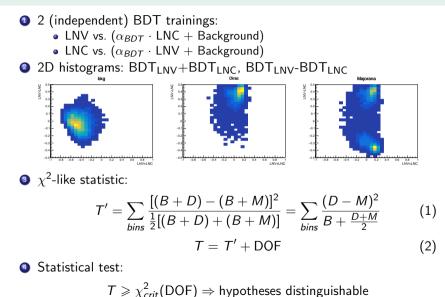
based on: [2202.06703] [2301.02602] [2312.05223]

Dirac vs. Majorana

Exclusion limits are very similar for the Dirac- and Majorana-neutrino hypotheses



How to distinguish the two species of neutrinos?



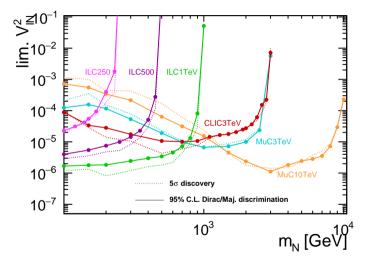
Krzysztof Mękała (FUW/DESY)

HNLs at e⁺e⁻ colliders

10.10.2024

14 / 17

Dirac vs. Majorana – results



Prospects for light exotic scalar measurements at the e^+e^- Higgs factory

Bartlomiej Brudnowski, Kamil Zembaczynski, Aleksander Filip Żarnecki

Faculty of Physics, University of Warsaw



 3^{rd} ECFA workshop on e⁺e⁻ Higgs, Electroweak and Top Factories October 9 - 11, 2024

A.F.Żarnecki (University of Warsaw)

Light scalars at Higgs factory

EXscalar - new exotic scalars



arXiv:2401.07564

Light scalar searches at future Higgs Factories were only partially studied in the past. To trigger new activities, understand the experimental challenges and prospects, they were selected as one of the focus topics, with two theoretical and phenomenological targets.

Target I Search for light exotic scalars in the process:

 $e^+e^-
ightarrow Z S$

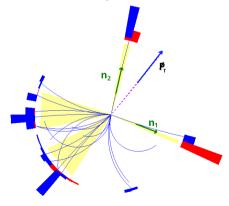
Production of new scalars can be tagged, independent of their decay, based on the recoil mass.

Different scalar decay channels e.g. $b\bar{b}$, $W^{+(*)}W^{-(*)}$, $\tau^+\tau^-$ or invisible should be considered. Non-standard decays channels of the new scalar can also be looked for.

$S \to \tau^+ \tau^-$

Event reconstruction

Example signal event with hadronic tau decays





arXiv:1509.01885

Tau leptons are very boosted \Rightarrow collinear approximation Assume tau neutrinos are emitted in the tau jet direction.

Their energies can be found from transverse momentum balance:

$$\vec{v}_T = E_{\nu_1} \cdot \vec{n_1} + E_{\nu_2} \cdot \vec{n_2}$$

where $\vec{n_1}$ and $\vec{n_2}$ are directions of the two tau jets. Unique solution !

Works also for semi-leptonic and leptonic events!

Because of small tau mass \Rightarrow small invariant mass of neutrino pair

 $S \rightarrow \tau^+ \tau^-$



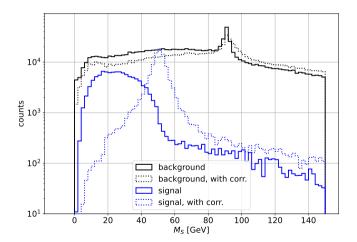
Event reconstruction

Kamil Zembaczyński (University of Warsaw)

Impact of the neutrino energy correction on the reconstructed di-tau mass distribution \Rightarrow

Signal for scalar mass of **50 GeV**. Normalized to 1% of the SM production cross section for the considered scalar mass.

Example of $\mathbf{e}_L^- \mathbf{e}_R^+$ polarisation and **tight** selection of **semi-leptonic** events.



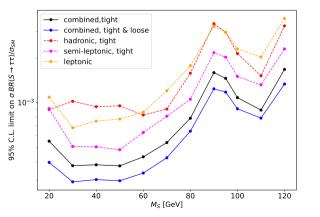
$S \rightarrow \tau^+ \tau^-$



Results

Kamil Zembaczyński (University of Warsaw)

Cross section limits for $\sigma(e^+e^- \rightarrow Z S) \cdot BR(S \rightarrow \tau\tau)$ for different event categories and combined analysis



Semi-leptonic sample most sensitive to new scalar production

Significant improvement when including loose-selection categories

Marginal impact of normalization uncertainties (theory + lumi).



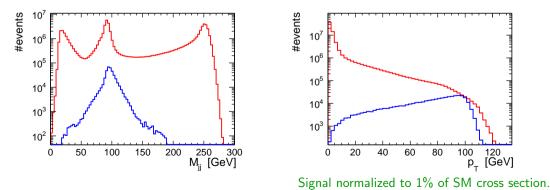
Event reconstruction

Kamil Zembaczyński (University of Warsaw)

Focusing on hadronic decays, Z
ightarrow q ar q, require no other activity in the detector.

order of magnitude higher than leptonic Z decays

Reconstructed Z (di-jet) mass and transverse momentum for 50 GeV scalar signal and SM bg.



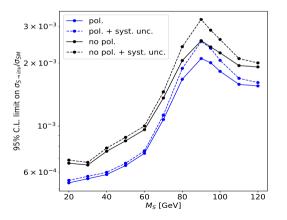
S ightarrow invisible



Results

Kamil Zembaczyński (University of Warsaw)

Cross section limits for $\sigma(e^+e^- \rightarrow Z S) \cdot BR(S \rightarrow inv)$ for H-20 scenario and unpolarized running with the same luminosity



Visible impact of systematic uncertainties theory predictions: 0.2% for e⁺e⁻ 1% for γe^{\pm} and $\gamma \gamma$ sample normalization: 0.2% for LR and RL

0.5% for LL and RL

Significant impact for $M_S \sim M_Z$

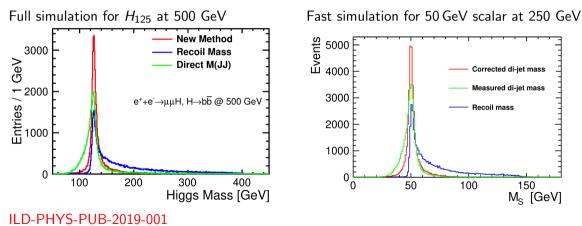
 $S
ightarrow bar{b}$



Event reconstruction

Bartłomiej Brudnowski (University of Warsaw)

Focusing on leptonic decays, $Z \rightarrow e^+e^-/\mu^+\mu^-$; huge W^+W^- background for hadronic decays



$S ightarrow bar{b}$



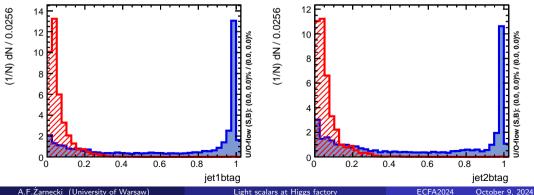
Flavour tagging

Bartłomiej Brudnowski (University of Warsaw)

supervised by María Teresa Núñez Pardo de Vera (DESY)

Tagging of b jets crucial for background suppression.

Use SM background full simulation samples for more reliable estimate of selection efficiency. Clear separation of signal events from (mostly light flavour) SM backgrounds

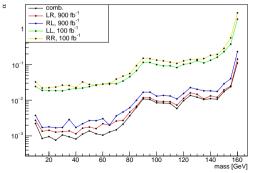


 $S \rightarrow h\bar{h}$



Results

Bartłomiej Brudnowski (University of Warsaw) supervised by María Teresa Núñez Pardo de Vera (DESY) Cross section limits for $\sigma(e^+e^- \rightarrow ZS) \cdot BR(S \rightarrow b\bar{b})$ for different polarization settings and combined analysis

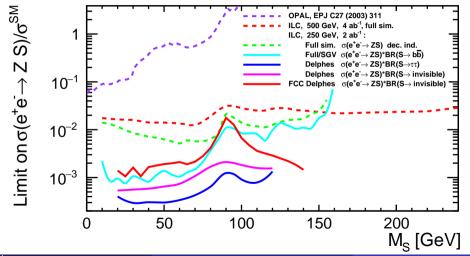


α 95% CL

Little impact of the beam polarisation Background dominated by ZZ production



Summary of results



Prospects for constraining lightquark electroweak couplings at e^+e^- colliders

Krzysztof Mękała

DESY, Hamburg, Germany

Faculty of Physics, University of Warsaw, Poland

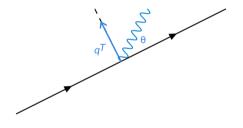
based on work in collaboration with D. Jeans, J. Reuter, J. Tian, A.F. Żarnecki

3rd ECFA workshop on e+e- Higgs, Electroweak and Top Factories, 10.10.2024

Resolution parameter y_{cut}

- By measuring the radiative and nonradiative decays, one can disentangle c_d and c_u. The definition of a radiative event is crucial.
- The photon resolution criterion may depend on an arbitrarily chosen isolation parameter, e.g. the photon transverse momentum w.r.t. the jet direction, q^{T} :

$$q^{T} = E_{\gamma} \sin(\theta_{j\gamma})$$



General idea

We want to measure quark couplings:

$$c_f = v_f^2 + a_f^2$$

They are given in the SM by:

$$v_f = 2I_{3,f} - 4Q_f \sin^2 \theta_W \qquad a_f = 2I_{3,f}$$

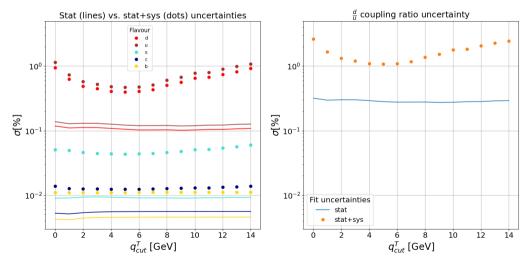
 Γ_{had} scales as:

$$\Gamma_{had} \sim (3c_d + 2c_u)$$

and $\Gamma_{had+\gamma}$ as: $\Gamma_{had+\gamma} \sim rac{lpha}{2\pi} f(y_{cut}) \left(3q_d^2 c_d + 2q_u^2 c_u
ight)$

The correction factor $f(y_{cut})$ to be determined for a given value of the resolution parameter y_{cut} .

Preliminary results



Virtual Overflow Session

Testing Quantum Mechanics at polarised e+e- colliders

Kazuki Sakurai

(University of Warsaw)



Collaboration: Clelia Altomonte, Alan Barr, Michał Eckstein, Paweł Horodecki

2024/10/16 European Committee for Future Accelerators meeting

QPT with *polarised* lepton colliders

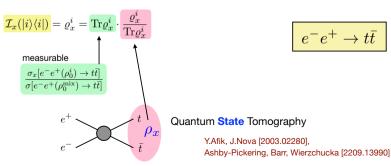
· Reconstruction of the diagonal part:

$$\widetilde{T}_{x} = \frac{1}{4} \begin{pmatrix} \mathcal{I}_{x}(|++\rangle\langle++|) & \mathcal{I}_{x}(|++\rangle\langle+-|) & \mathcal{I}_{x}(|++\rangle\langle-+|) & \mathcal{I}_{x}(|++\rangle\langle--|) \\ \mathcal{I}_{x}(|+-\rangle\langle++|) & \mathcal{I}_{x}(|+-\rangle\langle+-|) & \mathcal{I}_{x}(|+-\rangle\langle-+|) & \mathcal{I}_{x}(|+-\rangle\langle--|) \\ \mathcal{I}_{x}(|-+\rangle\langle++|) & \mathcal{I}_{x}(|-+\rangle\langle+-|) & \mathcal{I}_{x}(|-+\rangle\langle--|) & \mathcal{I}_{x}(|-+\rangle\langle--|) \\ \mathcal{I}_{x}(|--\rangle\langle++|) & \mathcal{I}_{x}(|--\rangle\langle+-|) & \mathcal{I}_{x}(|--\rangle\langle--|) & \mathcal{I}_{x}(|--\rangle\langle--|) \end{pmatrix}$$

 e^-e^-

Consider 4 purely polarised beam settings:

$$\{|i\rangle\} = \{|++\rangle, |+-\rangle, |-+\rangle, |--\rangle\} \qquad \rho_0^i = |i\rangle\langle i|$$



Summary slide from ECR (credit: Armin IIg)

Highlights of ECR White Paper to EPPSU session

Lunch and evening sessions (dedication!) with ~60 participants

Lively discussions on topics to be addressed in White Paper

WGs to be formed

- Future colliders
- Sustainability
- Communicating the importance of HEP and future colliders
- Career prospects and leadership of future collider ECRs
- Interplay of HEP with neighbouring fields
- Still open to additional WGs!

Join eppsu-ecr@cern.ch and ECRs for EPPSU 2024 Mattermost channel

- Now: Online WG meetings, first topical discussions
- General meeting on 14th of November @CERN and online
 - > Adjacent to (Open) Plenary ECFA meeting
- ... many more steps ...
- Endorsement by ECFA ECR panel, submit to EPPSU by 31.03.2025
- Follow White Paper throughout EPPSU
 - e.g @ Open Symposium in Venice, 23-27.06.2025

Thanks to organisers and all who contributed!







A.F.Żarnecki (University of Warsaw)

ECFA Higgs Factory Workshops



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, no remote talks!



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Virtual Overflow Sessions October 16-17, 2024

For those who could not come in person. Two zoom sessions, 2 hours each.



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Call for report contributions deadline October 20, 2024

Very short time between the workshop and the submission deadline.

But it was announced earlier, most contributors were ready on time!



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

A.F.Żarnecki (University of Warsaw)

ECFA Higgs Factory Workshops

29.11.2024



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 included on time...

194 pages plus 65 pages with 1089 references

as on November 10th

Work in progress, still many "holes", mainly in WG2, WG3 and general sections...



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as on November 10th

Work in progress, still many "holes", mainly in WG2, WG3 and general sections...

227 pages plus 66 pages with 1266 references

as on November 27th



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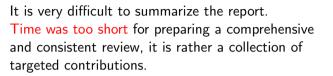
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			1.2.1 Runplans					
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			2.8.4 Algorithm R&D jet flavour tagger for H → ss					
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My personal impression is rather positive.

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...

Example of complementary results \Rightarrow

November 10 version

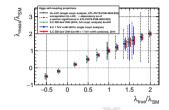


Figure 17: Projected accuracies for λ_{kbb} a the HL-LHC and a 550 GeV e⁺e⁻ collider in dependence of the actual value of λ_{bbb} that is realised in nature [436] [plot to be updated before January 2025].

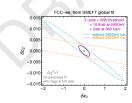


Figure 18: Sensitivity achievable on the trilinear self-coupling of the Higgs (shown on the x axis) with 240 and 365 GeV runs at the FCC-ee. Aside from the single Higgs coupling to the Z boson (shown on the y axis), 26 additional Higgs and EW coupling modifications have been marginalised over to obtained 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)
$\Delta A_{\rm b}~(\times 10^5)$	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)
$\Delta \sigma_{\rm had}^0$ (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)
$\delta R_{\tau} (imes 10^3)$	2.2*	0.6 (1.0)	0.2 (0.4)	0.003 (0.1)	0.003 (0.1)	3.3 (5.0)
$\delta R_{\rm b} \ (imes 10^3)$	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 20: 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 [448]. Table adapted from Ref. [609].

A.F.Żarnecki (University of Warsaw)

ECFA Higgs Factory Workshops



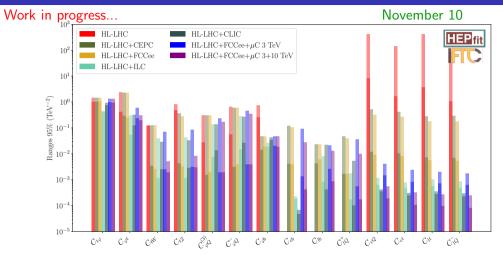


Figure 37: The 95% C.L. bounds on the Wilson coefficients of SMEFT operators involving top quarks.

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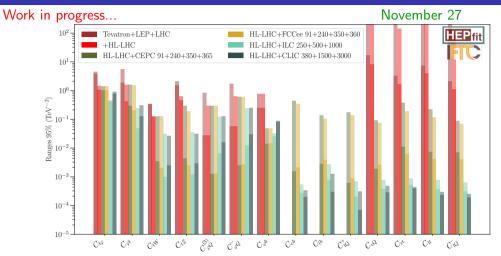


Figure 53: The 95% C.L. bounds on the Wilson coefficients of SMEFT operators involving top and bottom quarks. The four-fermion operators with two light quarks and two heavy quarks are bounded to

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ECFA report timeline

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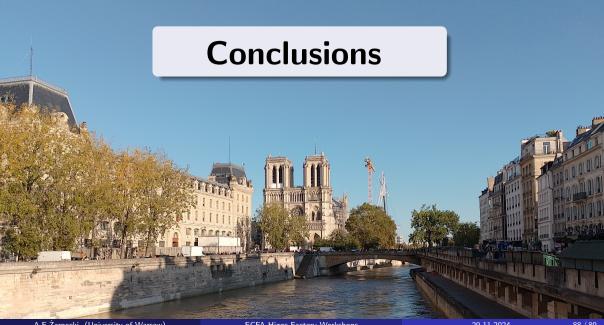
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20/10	Deadline for physics studies to submit 2-page summary	
20/10 – 10/11	Compilation and editing by WG1 subgroup conveners / editors, and WG2/3 editors (as well as coordinators & c 10/11 is the deadline for WG1 subgroup conveners fini	hief editors)
10/11 – 27/11	Editing by WG1 coordinators, WG2/3 editors & coordinators.	
	27/11 is deadline for complete draft to be handed over	r 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 v	very tight; no room for slippage!	
	ct a lot of interaction / clarification among all editors an at each stage – thanks in advance!	d A.Robson @ ECFA'2024

A.F.Żarnecki (University of Warsaw)

ECFA Higgs Factory Workshops

29.11.2024





Very busy three years!

Many new studies and new collaborations initiated.

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Many studies continue!

Results submitted for the report can still be updated until January 24 (?).

To be submitted to arXiv in March...