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

Aleksander Filip Żarnecki

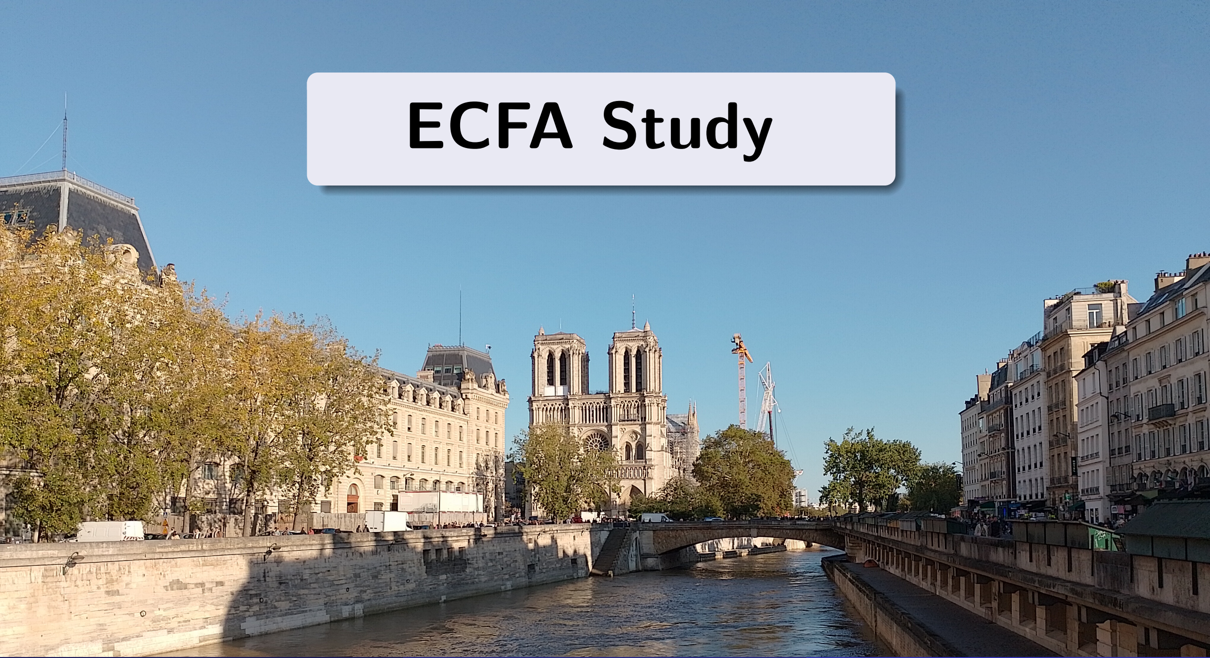
High Energy Physics Seminar
Faculty of Physics, University of Warsaw
November 29, 2024

Outline:

Mostly based on presentations given at ECFA workshops

Selection can be slightly biased by my personal preferences and involvements

ECFA Study



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

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

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

PED study - 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
- ...

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

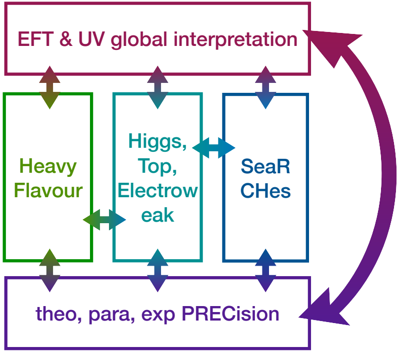
Created May 2022 (after conclusion of works of ECFA Detector Roadmap Task Force)

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!**

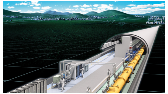
- The field is busy with LHC, Belle-II operation and data analysis, and with the challenging HL-LHC detector upgrades!

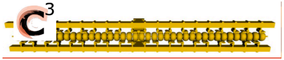
  → Synergies should be used, and duplication of work for the various projects should be avoided

- **There will – most likely – be only one e^+e^- collider!**

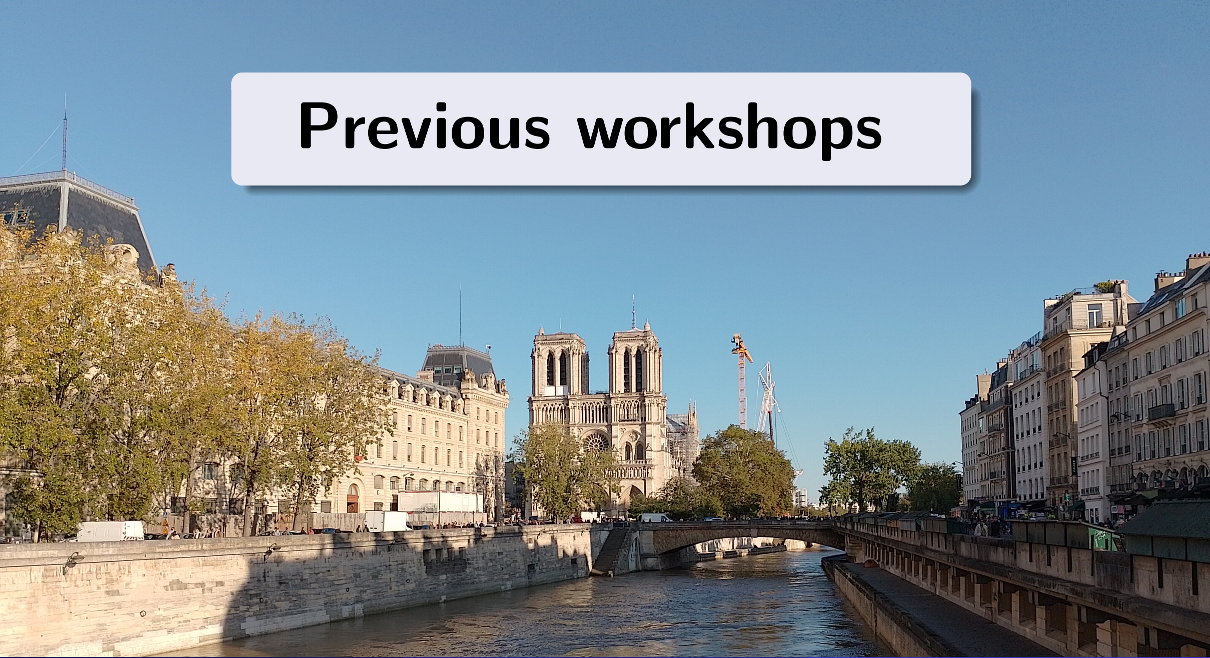
  → The ECFA study also intends to foster a **community building;**

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





Previous workshops

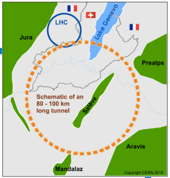


First milestone!

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

They fall into two classes

Each have their advantages

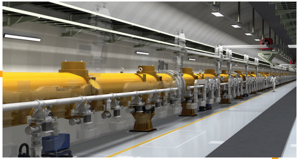


Circular e+e- Colliders

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

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

- technical and financial feasibility of required magnets still a challenge



Linear Colliders

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

Long-term 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

Electroweak Precision

push down the uncertainties on all electroweak measurements to push the SM to (hopefully beyond) its breaking point

Flavour Physics

use extremely large data sets to explore, resolve and understand the puzzles in the flavour sector

The Higgs Boson

model-independent study of all accessible couplings

The Top Quark

a precise measurement of its properties.
A possible window to new physics due to its high mass!

New Particles

searches for weakly coupled new particles with high luminosity / high energy in a clean environment

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

1. H->ssbar
2. ZH angular distributions / CP studies
3. Higgs self-coupling
4. W mass at threshold and continuum
5. Full studies of WW and evW processes, aTGCs
6. Top threshold
7. Luminosity measurement
8. New exotic scalars
9. Long-lived particles
10. Exotic top decays
11. CKM matrix elements w/ on-shell & boosted Ws
12. $B \to K^{0*}\tau^+\tau^-$
13. 2-fermion final states
14. b- and c-fragmentation functions / hadronisation
15. Gluon splitting to bb / cc (& interplay with separating h → gluons from h →bb/cc)

	lead group	relevant $\sqrt{s}$				
		91 GeV	161 GeV	240/250 GeV	350-380 GeV	$\geq$ 500 GeV
1	HTE			X	X	x
2	HTE (GLOB)			X	X	x
3	GLOB			X	X	X
4	PREC		X	X	X	
5	GLOB			X	X	x
6	GLOB (HTE)				X	
7	PREC	X	x	x	x	x
8	SRCH	x	x	x	x	x
9	SRCH	x	x	x	x	x
10	SRCH				x	x
11	FLAV		x	X	x	x
12	FLAV	X				
13	HTE	X	X	X	X	X
14	FLAV (PREC)	X	x	X	X	x
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)

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

Juan Alcaraz Maestre[1], Juliette Alimena[2], John Alison[3], Patrizia Azzi[4], Paolo Azzurri[5], Emanuele Bagnaschi[6,7], Timothy Barklow[8], Matthew J. Basso[9], Josh Bendavid[10], Martin Beneke[11], Eli Ben-Haim[12], Mikael Berggren[2], Jorge de Blas[13], Marzia Bordone[6], Ivanca Bozovic[14], Valentina Cairo[6], Nuño Filipe Castro[15], Marina Cobal[16], Paula Collins[6], Mogens Dam[17], Valerio Dao[6], Matteo Defranchis[6], Ansgar Denner[18], Stefan Dittmaier[19], Gauthier Durieux[20], Ulrich Einhaus[2], Mary-Cruz Fouz[1], Roberto Franceschini[21], Ayres Freitas[22], Frank Gaede[2], Gerardo Ganis[6], Pablo Goldenzweig[23], Ricardo Gonçalo[24,25], Rebeca Gonzalez Suarez[26], Loukas Gouskos[27], Alexander Grohsjean[28], Jan Hajer[29], Chris Hays[30], Sven Heinemeyer[31], André Hoang[32], Adrián Irles[33], Abideh Jafari[2], Karl Jakobs[19], Daniel Jeans[34], Jernej F. Kamenik[35], Matthew Kenzie[36], Wolfgang Kilian[37], Markus Klute[23], Patrick Koppenburg[38], Sandra Kortner[39], Karsten Köneke[19], Marcin Kucharczyk[40], Christos Leonidopoulos[41], Cheng Li[42], Zoltan Ligeti[43], Jenny List[2], Fabio Maltoni[20], Elisa Manoni[44], Giovanni Marchiori[45], David Marzocca[46], Andreas B. Meyer[2], Ken Mimasu[48], Tristan Miralles[47], Victor Miralles[49], Abdollah Mohammadi[50], Stéphane Monteil[51], Gudrid Moortgat-Pick[28], Zohreh Najafabadi[52], María Teresa Núñez Pardo de Vera[2], Fabrizio Palla[5], Michael E. Peskin[8], Fulvio Piccinini[53], Laura Pintucci[54], Wiesław Płaczek[55], Simon Plätzer[56,32], Roman Pöschl[57], Tania Robens[58], Aidan Robson[59], Philipp Roloff[6], Nikolaos Rompotis[60], Andrej Saibel[33], André Sailer[6], Roberto Salerno[61], Matthias Schott[62], Reinhard Schwienhorst[63], Felix Sefkow[2], Michele Selvaggi[6], Frank Siegert[64], Frank Simon[23], Andrzej Siodmok[55], Torbjörn Sjöstrand[65], Kirll Skovpen[66], Maciej Skrzypek[40], Yotam Soreq[67], Raimund Ströhmer[18], Taikan Suehara[68], Junping Tian[68], Emma Torro Pastor[33], Maria Ubiali[36], Luiz Vale Silva[33], Caterina Vernieri[8], Alessandro Vicini[69] Marcel Vos[33], Adrian R. Wiederhold[70], Sarah Louise Williams[36], Graham Wilson[71], Aleksander Filip Zarnecki[72], Dirk Zerwas[73,57]

[hep-ph] 15 Jan 2024

SECOND • ECFA • WORKSHOP

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

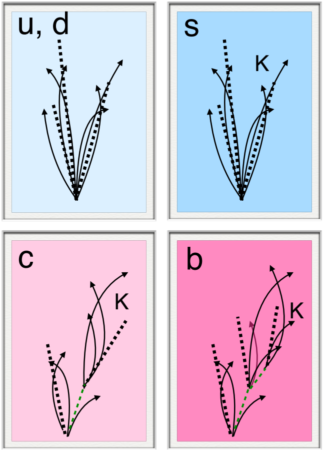
11-13 October 2023
Paestum / Salerno / Italy

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

s-tagging

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



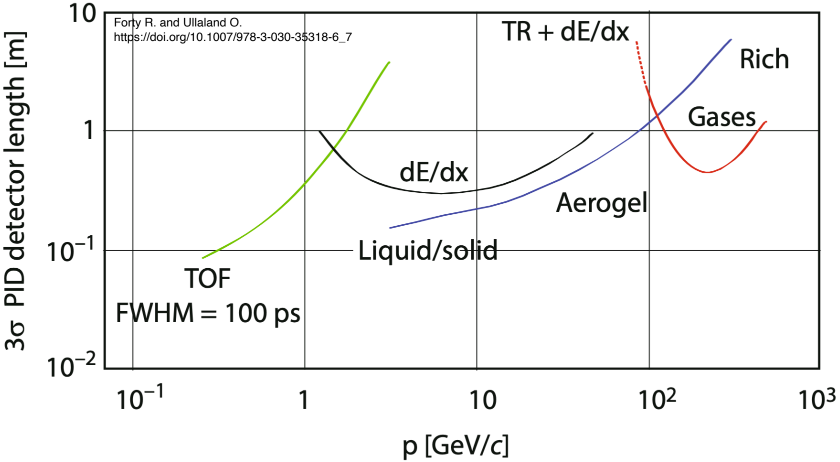
- As b,c, and s jets contain at least one strange hadron
- Strange quarks mostly hadronize to prompt kaons which carry a large fraction of the jet momentum
- Strange hadron reconstruction:
  - $K^\pm$ PID
  - K^0_L PF (neutral)
  - $K^0_S \to \pi^+\pi^-$ (~70%) / $\pi^0\pi^0$ (~30%)
  - $\Lambda^0 \to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

Distinctive two-prong vertices topology

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

Particle ID for s-tagging

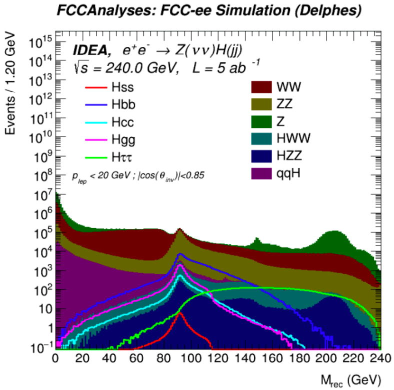
Combining different strategies for optimal PID performance across a wide p_T range

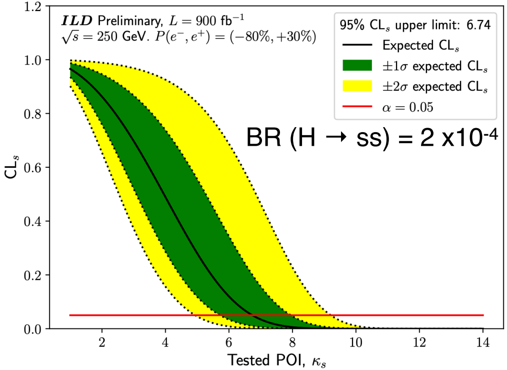


Constraints on s-coupling

Compatible results for both FCC and ILC like analyses

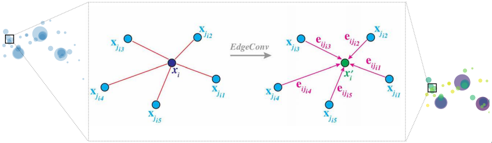
- ILD combined limit of $\kappa_s < 6.74$ at 95% CL with 900/fb at 250 GeV (i.e. half dataset)
  - No PID worsen the results by 8%
- FCC for Z(νν) only sets a limit of $\kappa_s < 1.3$ at 95% CL with 5/ab at 250 GeV and 2 IPs





BR (H → ss) = 2 x10^{-4}

ParticleNet



arXiv:1902.08570, *Pushing the Limit of Jet Tagging With Graph Neural Networks*, Huilin Qu, talk at ML4Jets2021, July 7, 2021

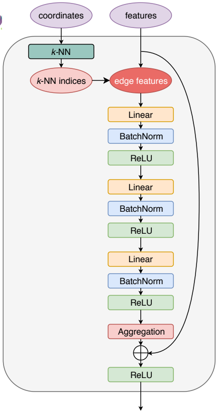
- treat jet as „particle cloud“
- input: **jet constituents**

key building block: **edge convolution**

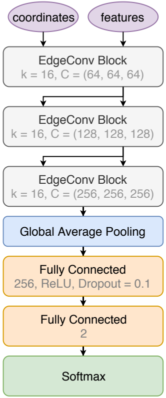
- particle cloud: graph, each point: vertex, connections between each point & k nearest neighboring points: edges
- learn an „**edge feature**“ for each pair:

$$e_{ij} = \mathrm{MLP}(x_i, x_j)$$

- **MLP**: parameters **shared among all edges**
- **aggregation** of edge features: $x_i' = \mathrm{mean}_j\, e_{ij}$



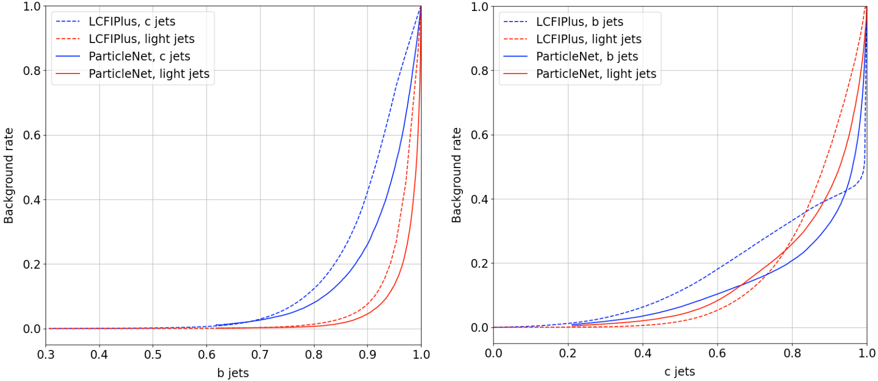
edge convolution



ParticleNet

ParticleNet: ROC curves - comparison to LCFIPlus

validation data

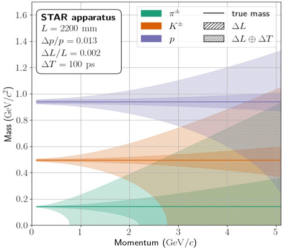


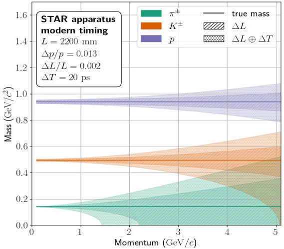
better performance than LCFIPlus **over large parts of the b and c tagging efficiencies**

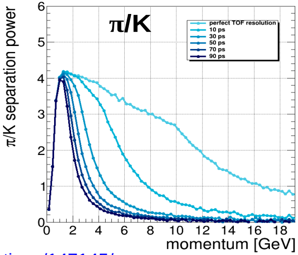
one of the first trainings with this architecture, **a lot of possibilities for optimization** (architecture, hyperparameters, features, over-training in c-jet category…)

Time of Flight

- Crucial: track length uncertainty may be a limiting factor to TOF performance
  - Example below: ΔT = 10 ps ~ ΔL = 3 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



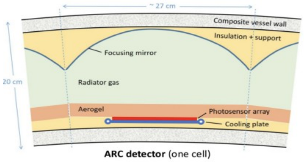


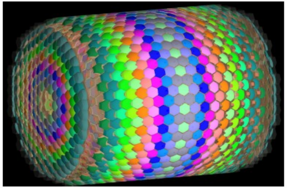


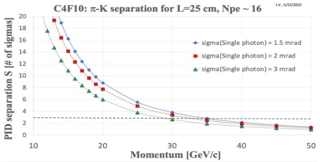
https://indico.desy.de/event/34916/contributions/147145/

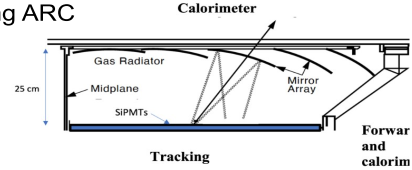
Ring Imaging Cherenkov Detectors

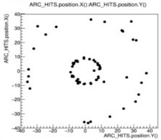
- 2 hardware proposals, aiming at PID up to 50 GeV with compact barrel+endcap RICH
- RICH for e.g. SiD, single phase
  - work ongoing on hardware and geometry
- ARC for CLD, with aerogel and gas
  - work ongoing on digitisation and reconstruction
  - allow for parametrised detector
  - provide CLD model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









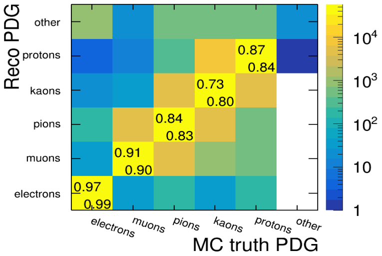


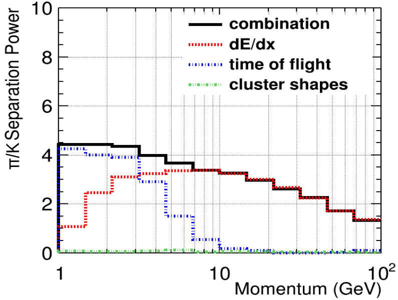
https://arxiv.org/abs/2203.07535

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

Comprehensive PID

- 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





https://indico.cern.ch/event/1283129/#1-a-comprehensive-particle-id

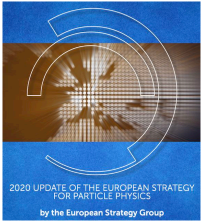
Timeframe

◆ 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



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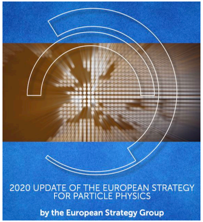


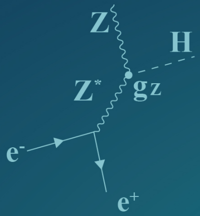
It was unfortunately reduced by one year at the beginning of 2024!

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

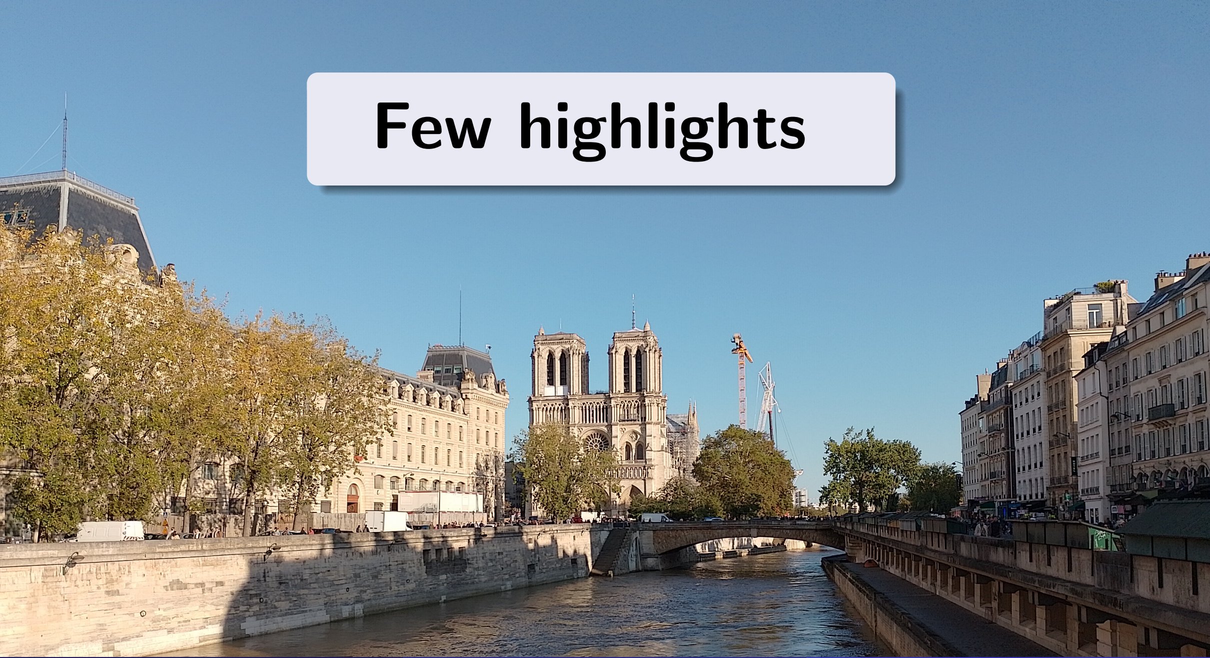
9–11 October 2024



Sorbonne Université, Campus des Cordeliers, Paris


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

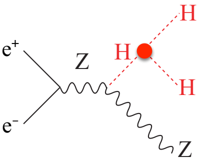
Few highlights

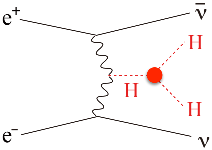


Focus topic summary by Junping Tian (U.Tokyo)

λ_{HHH}: di-Higgs & single-Higgs processes

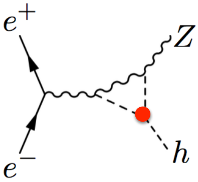
$\sqrt{s} \gtrsim 500$ GeV

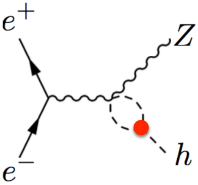




$\sigma_{HH} \sim O(0.1)$ fb

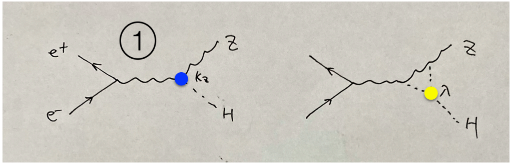
$\sqrt{s} \gtrsim 240\text{–}250$ GeV





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

(iv) How to discriminate with HZZ coupling

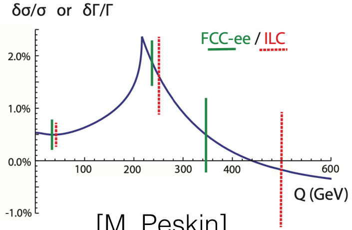


[McCullough, '13]

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

- **$\delta\sigma_{ZH} < 1\%$** is a necessity; but not sufficient
- $\delta\sigma$ could receive contributions from many other sources

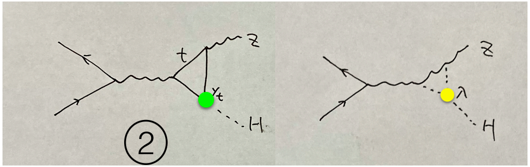
  —> **δh ~ O(500)%** at 250GeV only; [Gu, et al, arXiv:1711.03978]



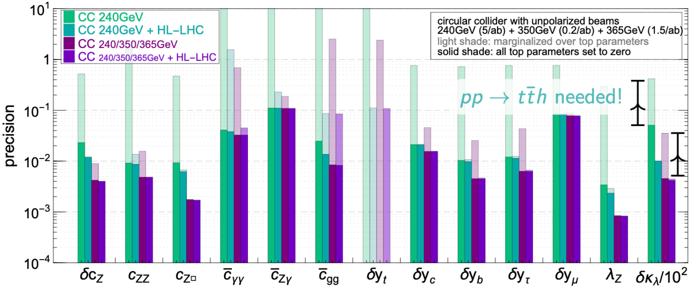
[M. Peskin]

- **"easy" solution: lift degeneracy by multiple √s**

(iv) How to discriminate with top-Yukawa coupling



- **mitigated by LHC top-Yukawa measurement**

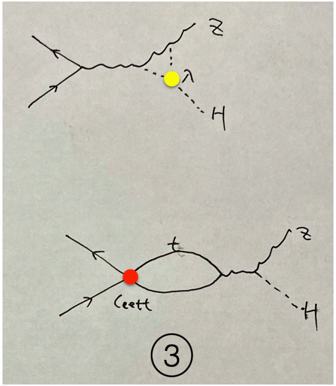


Top-quark uncertainties can impede Higgs precision!

[Durieux, Gu, Vyronidou, Zhang, '18]

(iv) How to discriminate with 4-fermion interaction

[talk by P. Giardino]

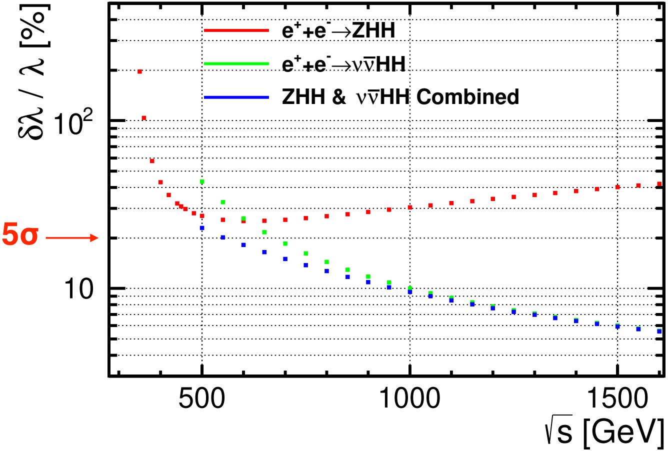


- the effects from (many) eett operators have just been calculated! [Asteriadis, Dawson, Giardino, Szafron, arXiv:2406.03257]

	$\sqrt{s} = 240$ GeV		$\sqrt{s} = 365$ GeV	
	Δ_i/Λ^2	$\bar{\Delta}_i/\Lambda^2$	Δ_i/Λ^2	$\bar{\Delta}_i/\Lambda^2$
C_ϕ	$-7.22 \cdot 10^{-3}$	0	$-1.00 \cdot 10^{-3}$	0
$C_{uW}[3,3]$	$-1.63 \cdot 10^{-3}$	$4.01 \cdot 10^{-3}$	$3.36 \cdot 10^{-3}$	$6.25 \cdot 10^{-3}$
$C_{uB}[3,3]$	$0.15 \cdot 10^{-3}$	$-2.22 \cdot 10^{-3}$	$-2.96 \cdot 10^{-3}$	$-3.20 \cdot 10^{-3}$
$C_{u\phi}[3,3]$	$0.32 \cdot 10^{-3}$	0	$-1.09 \cdot 10^{-3}$	0
$C^{(1)}_{\phi q}[3,3]$	$-1.34 \cdot 10^{-3}$	$-4.10 \cdot 10^{-3}$	$-4.39 \cdot 10^{-3}$	$-4.31 \cdot 10^{-3}$
$C^{(3)}_{\phi q}[3,3]$	$0.51 \cdot 10^{-3}$	$4.12 \cdot 10^{-3}$	$4.15 \cdot 10^{-4}$	$7.58 \cdot 10^{-4}$
$C_{\phi u}[3,3]$	$-0.54 \cdot 10^{-3}$	$3.49 \cdot 10^{-3}$	$5.37 \cdot 10^{-3}$	$3.11 \cdot 10^{-3}$
$C_{eu}[1,1,3,3]$	$0.01 \cdot 10^{-3}$	$-1.39 \cdot 10^{-2}$	$-3.73 \cdot 10^{-2}$	$-3.23 \cdot 10^{-2}$
$C_{lu}[1,1,3,3]$	$-0.02 \cdot 10^{-3}$	$1.73 \cdot 10^{-2}$	$4.64 \cdot 10^{-2}$	$4.01 \cdot 10^{-2}$
$C^{(1)}_{lq}[1,1,3,3]$	$-0.37 \cdot 10^{-2}$	$-1.80 \cdot 10^{-2}$	$-6.09 \cdot 10^{-2}$	$-4.18 \cdot 10^{-2}$
$C^{(3)}_{lq}[1,1,3,3]$	$-0.37 \cdot 10^{-2}$	$1.29 \cdot 10^{-2}$	$4.54 \cdot 10^{-2}$	$3.29 \cdot 10^{-2}$
$C_{qe}[3,3,1,1]$	$0.30 \cdot 10^{-2}$	$1.45 \cdot 10^{-2}$	$4.90 \cdot 10^{-2}$	$3.36 \cdot 10^{-2}$

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

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



Discovery can be guaranteed

ILC500: 23%

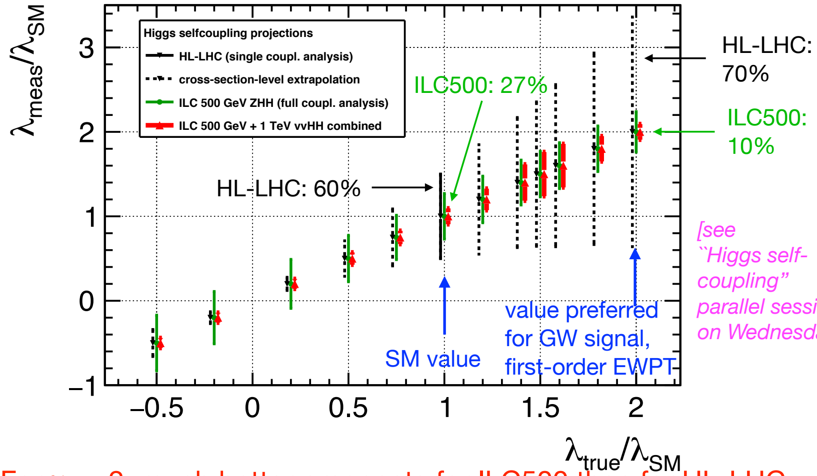
ILC550: 20%

ILC600: 18%

note: this is still based on old ILD DBD analysis

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

[J. List et al. '21]



[see "Higgs self-coupling" parallel session on Wednesday!]

⇒ For $\varkappa_\lambda \approx 2$: much better prospects for ILC500 than for HL-LHC

Reason: different interference contributions

Bottlenecks in the ZHH analysis

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

- jet pairing and jet misclustering: “perfect“ jet clustering $\rightarrow$ 40% improvement
  improve di-jet mass resolution
- removal of $\gamma\gamma$ overlay: 15% improvement expected
  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
- more modern ML architectures for signal/background selection
  improvement expected when transitioning from BDTs to (e.g.) transformer-based models etc.
- separation of ZHH diagrams with/without the self-coupling
  would directly improve the sensitivity on λ (lower sensitivity factor)

All improvements are relative

Expected improvements from DESY-Thesis-16-027

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)

marcel.vos@ific.uv.es

SMEFiT results (Jaco ter Hoeve)

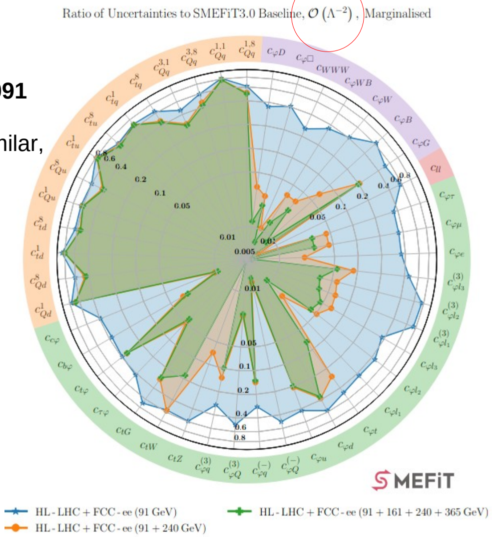
Higgs/EW/top fits on projections

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



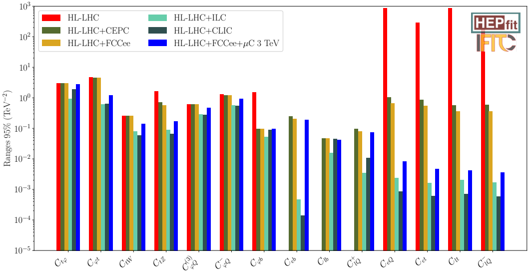
[1804.05033] Aebischer, Kumar, Straub

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:

Quadratic global:	O(1)
Linear individual:	O(1-10 TeV^{-2})
Linear global:	**O(100 TeV^{-2})**

e+e- colliders on eett operators:

Linear fit, circular machine:	**O(1 TeV^{-2})**
Linear fit, linear machine@1-3 TeV	**O(10^{-2} TeV^{-2})**

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

marcel.vos@ific.uv.es

Gauge Higgs Unification models vs SM discrimination power

2-fermion final states focus topic

ILD

m_Z'
19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z'
8.52 TeV
7.19 TeV

GHU vs SM discrimination power (σ-level)

	ILC250♦ (no pol.) O	ILC250♦ (no pol.) E	ILC250♦ (no pol.) N	ILC250 O	ILC250 E	ILC250 N	ILC250 +500 O	ILC250 +500 E	ILC250 +500 N	ILC250 +500 +1000* O	ILC250 +500 +1000* E	ILC250 +500 +1000* N
B_3^+	0.3	0.4	0.4	0.5	0.7	0.7	0.9	1.2	1.3	2.1	2.5	2.5
B_3^-	0.2	0.4	0.4	0.5	0.8	0.9	1.7	2.6	2.7	4.2	6.5	6.7
B_2^+	0.5	0.7	0.7	0.9	1.4	1.5	1.7	2.1	2.2	3.8	4.4	4.4
B_2^-	0.3	0.6	0.7	0.8	1.3	1.4	2.9	4.5	4.6	8.0	>10	>10
B_1^+	1.1	1.5	1.6	2.2	3.1	3.2	3.4	4.3	4.4	5.7	6.7	6.8
B_1^-	0.6	1.2	1.4	1.4	2.4	2.7	5.9	9.3	9.6	>10	>10	>10
A_2	2.2	3.2	3.3	3.3	4.7	4.8	>10	>10	>10	>10	>10	>10
A_1	2.7	3.8	3.9	3.5	4.9	5.0	>10	>10	>10	>10	>10	>10

Ch. had. PID
- *O: No PID*
- *E:* $\frac{dE}{dx}$
- *N:* $\frac{dN}{dx}$

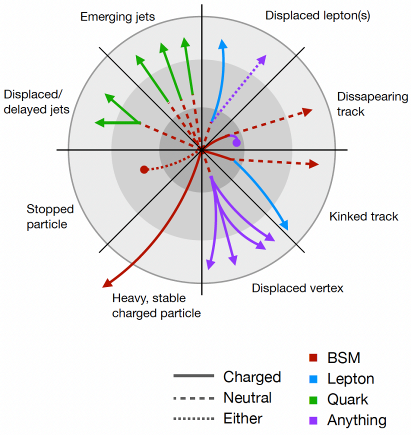
- < 3 σ
- 3-4 σ
- 4-5 σ
- > 5 σ

Eur.Phys.J.C 84 (2024) 5, 537
ILD-PHYS-PUB-2023-001
ILD-PHYS-PROC-2023-013

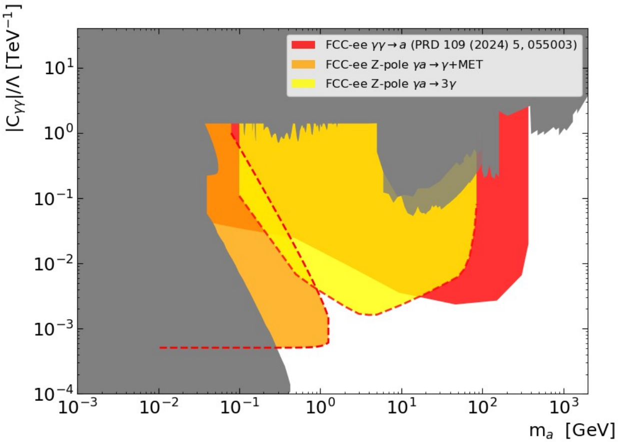
A. Irles et al

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



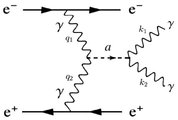
Combined plot FCC-ee



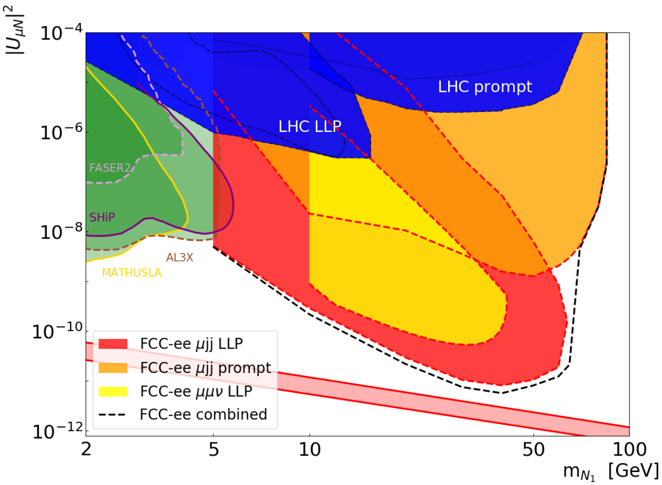
Grey areas :existing exclusions taken from ATLAS plot, to be updated with newest results

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



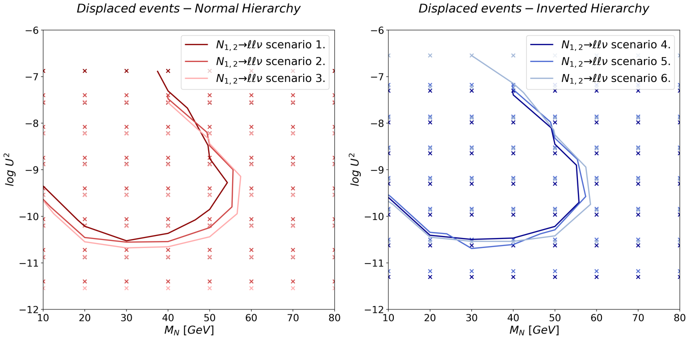
Prompt vs **long-lived** separation [radial vertex position ≲ 0.5 mm]

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

LLP RESULTS

Heavy neutral leptons (HNLs) in type I seesaw model

- 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

LLPs from Exotic Higgs Decays

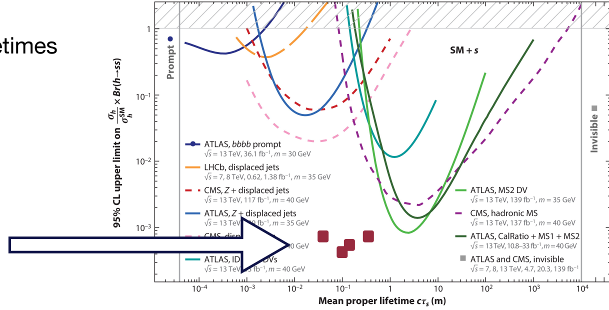
Complementary to the LHC searches!

- The sensitive signal points probes BRs ~ 4-7·10^{-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: Exotic Higgs Decays
DOI: 10.1146/annurev-nucl-102319-024147

m_s, sin θ	$c\tau$ [mm]	BR($h \to ss$)	Full event selection
20 GeV, 1e-6	341.7	6.981×10^{-4}	10.739 ± 0.243
20 GeV, 3e-6	38.0	6.981×10^{-4}	3.262 ± 0.134
40 GeV, 1e-6	136.6	5.663×10^{-4}	9.169 ± 0.203
50 GeV, 1e-6	106.6	4.422×10^{-4}	5.649 ± 0.141

Our sensitive signal points



Cepeda M, et al. 2022
Annu. Rev. Nucl. Part. Sci. 72:119–49

FACULTY OF PHYSICS
UNIVERSITY OF WARSAW

NATIONAL SCIENCE CENTRE POLAND

Long-lived particle searches with the ILD experiment

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

D. Jeans[(1)], J. Klamka[(2)], A. F. Żarnecki[(2)]
[(1)]KEK, [(2)]University of Warsaw

arXiv:2409.13492

jan.klamka@fuw.edu.pl

Strategy

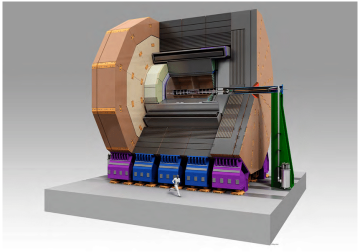
ILD especially promising with a TPC as the main tracker

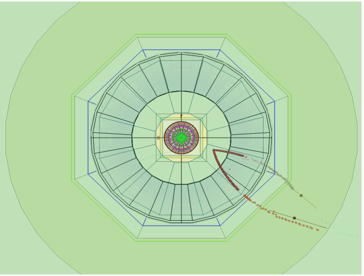
→ we want to investigate experimental aspects

→ study based on full simulation

- Study such challenging signatures from the **experimental perspective**

  → 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**

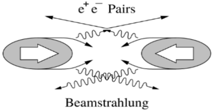


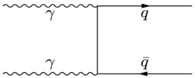


Overlay events background

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 $\gamma\gamma$ → low-p_T hadrons** events
- **O(10^5) incoherent e^+e^- pairs**, only a small fraction enters tracker

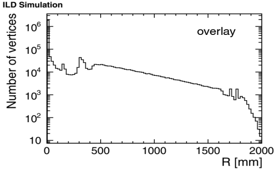


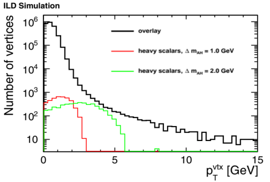


These events are soft, usually important because they **overlay** on physical events

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

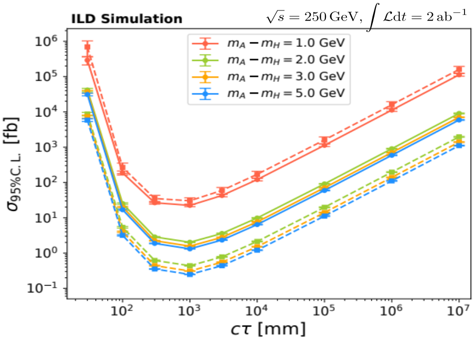
- ~10^{11} BXs per year at ILC → overwhelming number of overlay events
- Similar kinematics to the signal considered and can be busy
  → many secondary vertices (mostly fake, also V^0s and photon conversions)
  → significant background



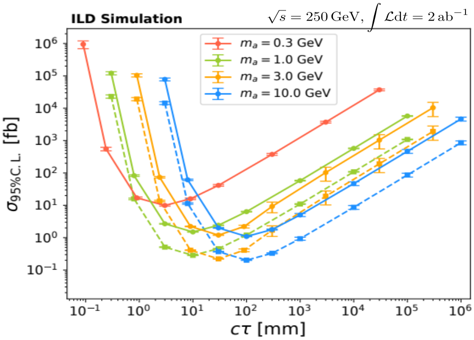


- Can be suppressed using cuts on the track pair geometry and $p_T^{vtx} > 1.9$ GeV
- Total expected reduction factor at the level of **~10^{-10}**

Cross section limits



Heavy scalars

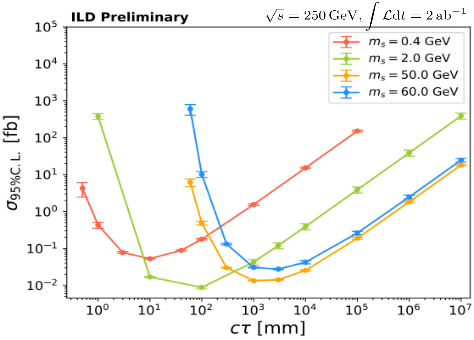


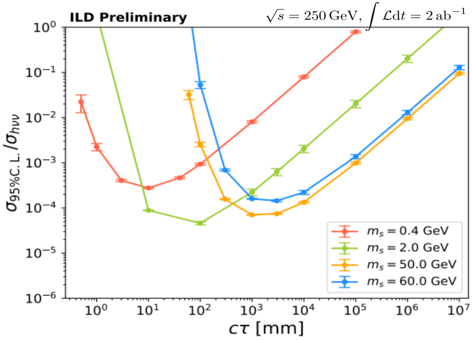
Light pseudoscalar

- 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

Higgs decays to LLPs





- 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

Heavy neutrino-antineutrino oscillations ($N\bar{N}$Os)

[2210.10738]

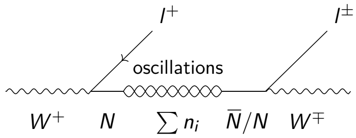
Oscillations between events that have

- Lepton number conservation (LNC) $l^\pm l^\mp$
- Lepton number violation (LNV) $l^\pm l^\pm$

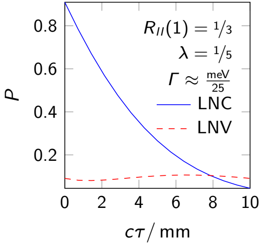
Oscillation frequency governed by Δm

$$P_{\text{osc}}^{\text{LNC/LNV}}(\tau) = \frac{1 \pm \cos(\Delta m \tau)}{2}$$

Oscillating mass eigenstates n_i

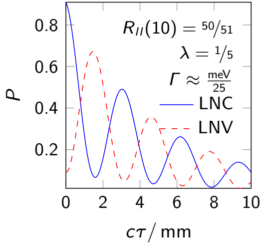


Almost Dirac limit



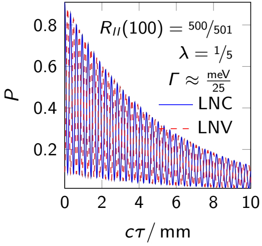
- Mostly LNC

Archetypical pseudo-Dirac



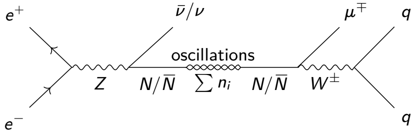
- Potentially resolvable

Double-Majorana limit



- Unresolvable
- LNV as frequent as LNC

Single charged lepton



Measurement

- LNV cannot be measured using two charges
- One can still measure angular distributions

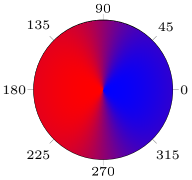
Angular dependent probability

$$P_{l^\mp}(\cos\theta, \tau) := \frac{1}{\sigma}\frac{d\sigma(\cos\theta)}{d\cos\theta} P_{\text{osc}}^{\text{LNC/LNV}}(\tau)$$

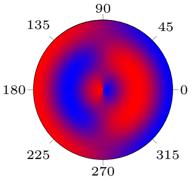
Probability of measuring charged leptons

- linked to forward backward asymmetry (FBA) of neutrino production (see 'almost Dirac limit')
- l^- from non-oscillating N or from oscillating $\bar N$ (similar for l^+)

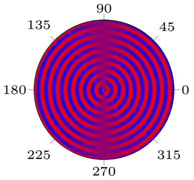
Almost Dirac limit



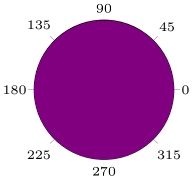
Slow oscillation



Fast oscillation



Double-Majorana limit



Our contributions

Probing the nature of HNL at lepton colliders

K. Mękała[1,2], J. Reuter[2], A. F. Żarnecki[1]

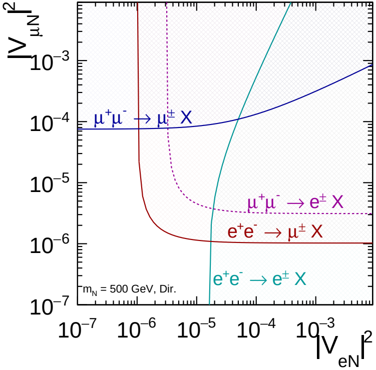
[1]Faculty of Physics, University of Warsaw
[2]Theory Group, Deutsches Elektronen-Synchrotron DESY, Hamburg

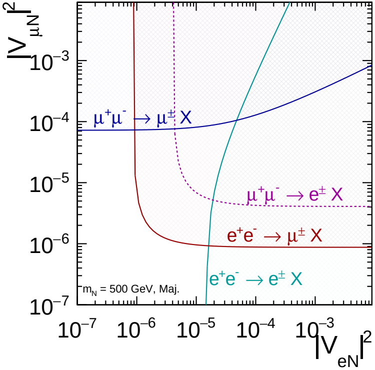
3rd ECFA workshop on e+e- Higgs, Electroweak and Top Factories
10.10.2024

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

Dirac vs. Majorana

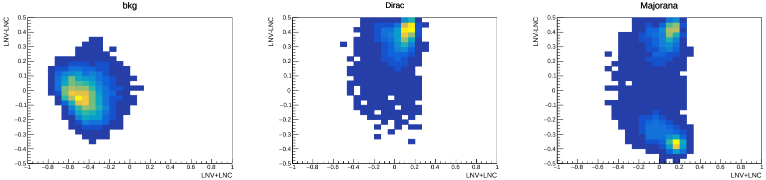
Exclusion limits are very similar for the Dirac- and Majorana-neutrino hypotheses





How to distinguish the two species of neutrinos?

1. 2 (independent) BDT trainings:
   - LNV vs. ($\alpha_{BDT} \cdot$ LNC + Background)
   - LNC vs. ($\alpha_{BDT} \cdot$ LNV + Background)
2. 2D histograms: $\mathrm{BDT_{LNV}}+\mathrm{BDT_{LNC}}$, $\mathrm{BDT_{LNV}}$-$\mathrm{BDT_{LNC}}$



3. χ^2-like statistic:

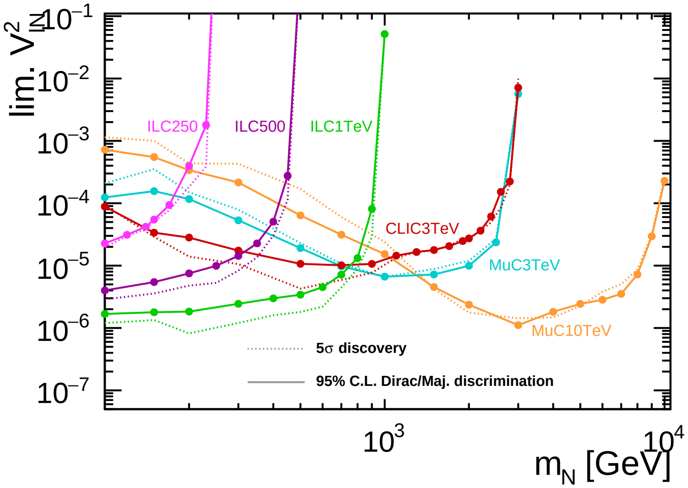
$$T' = \sum_{bins} \frac{[(B+D)-(B+M)]^2}{\frac{1}{2}[(B+D)+(B+M)]} = \sum_{bins} \frac{(D-M)^2}{B+\frac{D+M}{2}} \quad (1)$$

$$T = T' + \mathrm{DOF} \quad (2)$$

4. Statistical test:

$$T \geqslant \chi^2_{crit}(\mathrm{DOF}) \Rightarrow \text{hypotheses distinguishable}$$

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

NATIONAL SCIENCE CENTRE POLAND

3rd ECFA workshop

on e^+e^- Higgs, Electroweak and Top Factories

October 9 - 11, 2024

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:

$$e^+e^- \to Z\ S$$

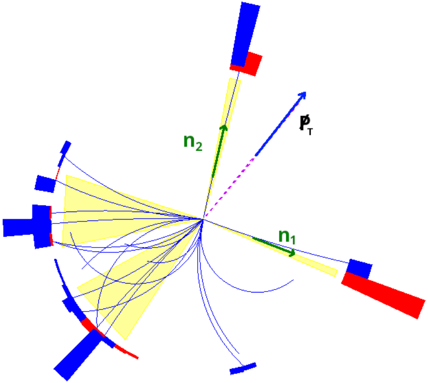
Production of new scalars can be tagged, independent of their decay, based on the recoil mass.

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.

Event reconstruction

arXiv:1509.01885

Example signal event with hadronic tau decays



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:

$$\vec{p\!\!/}_T = E_{\nu_1} \cdot \vec{n_1} + E_{\nu_2} \cdot \vec{n_2}$$

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

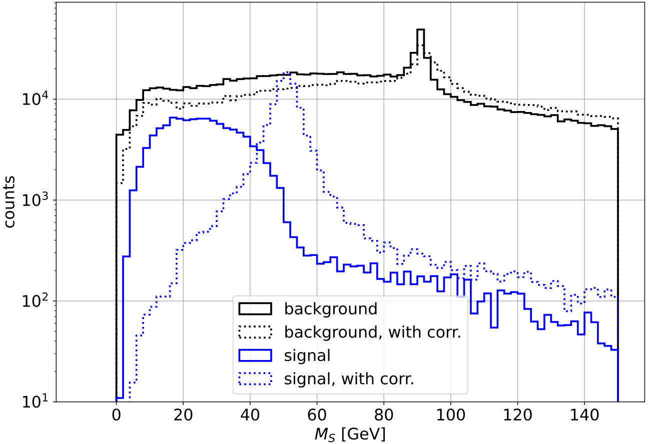
Event reconstruction

Kamil Zembaczyński (University of Warsaw)

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

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.

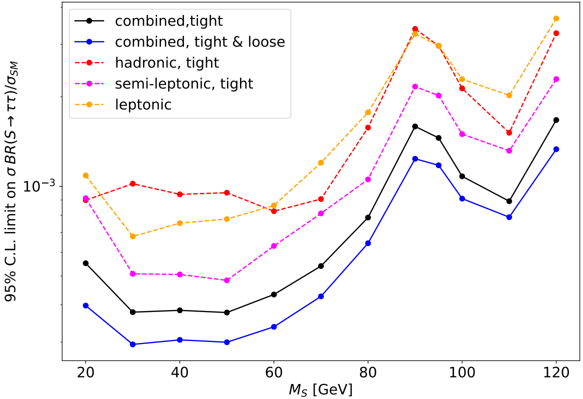


$S \to \tau^+\tau^-$

Results

Kamil Zembaczyński (University of Warsaw)

Cross section limits for $\sigma(e^+e^- \to Z\,S) \cdot BR(S \to \tau\tau)$
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).

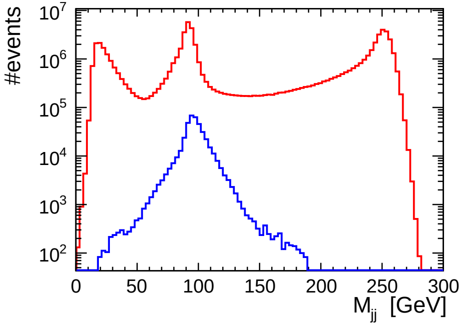
Event reconstruction

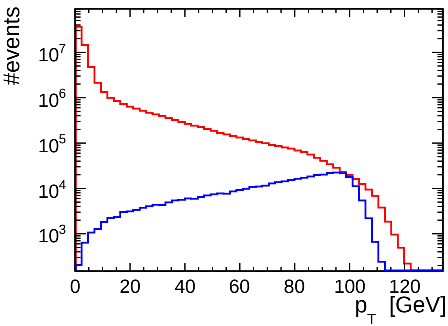
Kamil Zembaczyński (University of Warsaw)

Focusing on hadronic decays, $Z \to q\bar{q}$, 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.



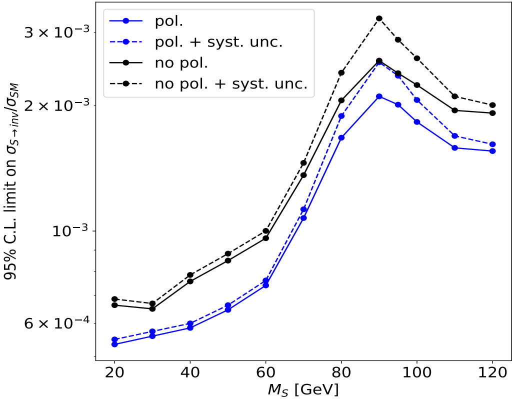


Signal normalized to 1% of SM cross section.

Results

Kamil Zembaczyński (University of Warsaw)

Cross section limits for $\sigma(e^+e^- \to Z\,S) \cdot BR(S \to \text{inv})$
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 $\gamma e^\pm$ and $\gamma\gamma$

sample normalization: 0.2% for LR and RL
0.5% for LL and RR

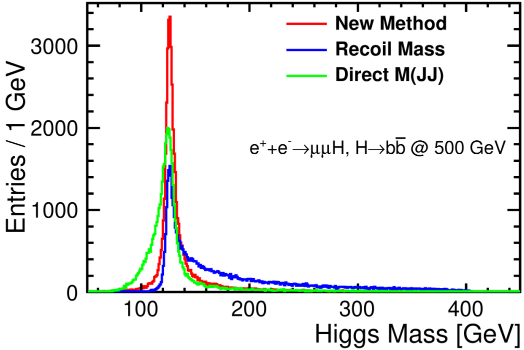
Significant impact for $M_S \sim M_Z$

Event reconstruction

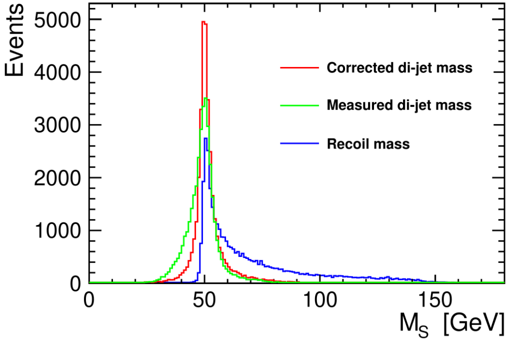
Bartłomiej Brudnowski (University of Warsaw)

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

Full simulation for H_{125} at 500 GeV



Fast simulation for 50 GeV scalar at 250 GeV

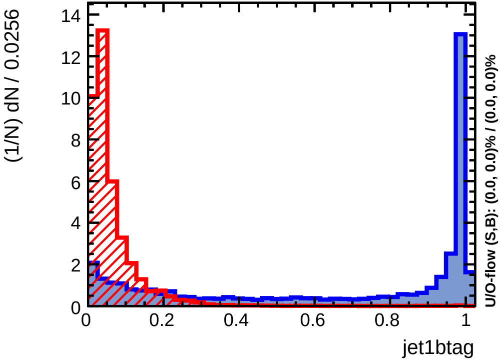


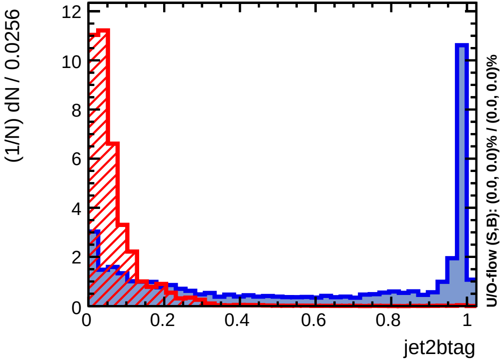
ILD-PHYS-PUB-2019-001

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

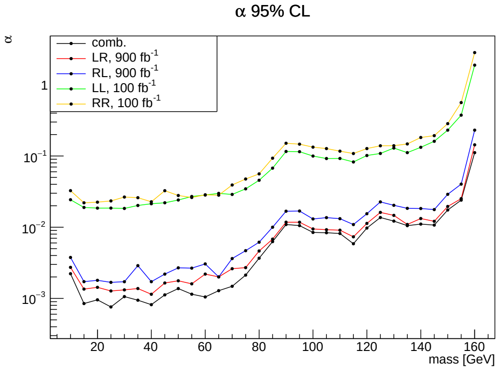




Results

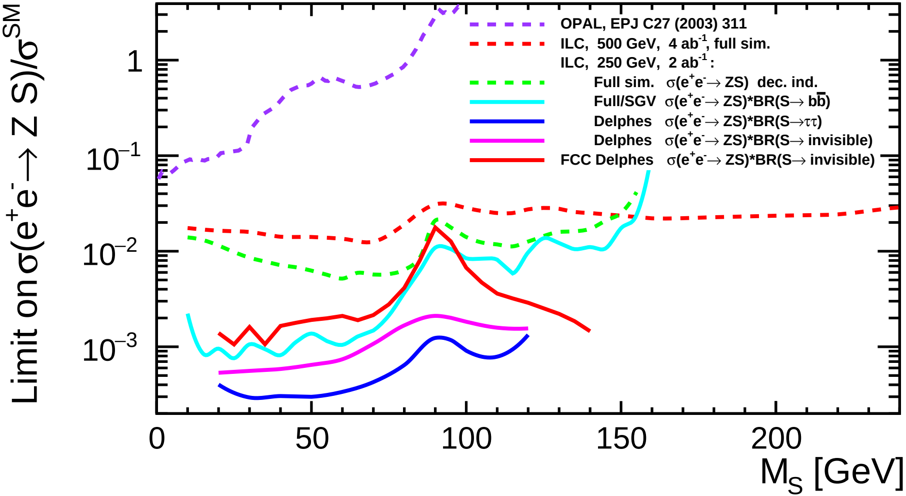
Bartłomiej Brudnowski (University of Warsaw)
supervised by María Teresa Núñez Pardo de Vera (DESY)

Cross section limits for $\sigma(e^+e^- \to Z\,S) \cdot BR(S \to b\bar{b})$
for different polarization settings and combined analysis



Little impact of the beam polarisation
Background dominated by ZZ production

Summary of results



Prospects for constraining light-quark electroweak couplings at e^+e^- colliders

Krzysztof Mękała

DESY, Hamburg, Germany

Faculty of Physics, University of Warsaw, Poland

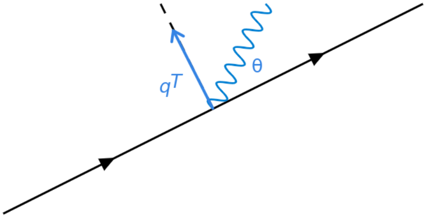
based on work in collaboration with D. Jeans, J. Reuter, J. Tian, A.F. Żarnecki

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

Resolution parameter y_{cut}

- By measuring the radiative and non-radiative 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:

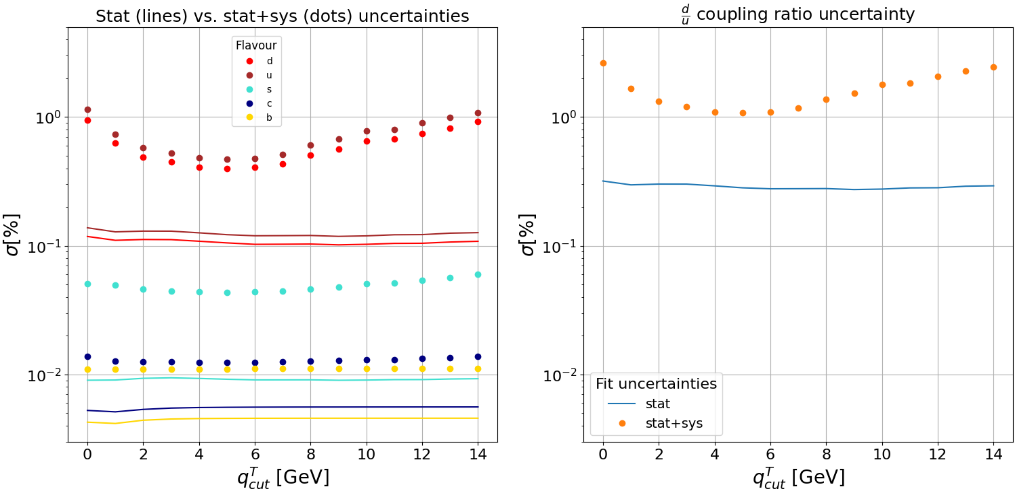
$$\Gamma_{had} \sim (3c_d + 2c_u)$$

and $\Gamma_{had+\gamma}$ *as*:

$$\Gamma_{had+\gamma} \sim \frac{\alpha}{2\pi} f(y_{cut}) \left(3q_d^2 c_d + 2q_u^2 c_u\right)$$

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:

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

- Consider 4 purely polarised beam settings:

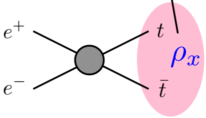
$$\{|i\rangle\} = \{|++\rangle, |+-\rangle, |-+\rangle, |--\rangle\} \qquad \rho_0^i = |i\rangle\langle i|$$

$$\mathcal{I}_x(|i\rangle\langle i|) = \varrho_x^i = \mathrm{Tr}\,\varrho_x^i \cdot \frac{\varrho_x^i}{\mathrm{Tr}\,\varrho_x^i}$$

measurable

$$\frac{\sigma_x[e^-e^+(\rho_0^i) \to t\bar{t}]}{\sigma[e^-e^+(\rho_0^{\mathrm{mix}}) \to t\bar{t}]}$$

$$e^-e^+ \to t\bar{t}$$



Quantum **State** Tomography

Y.Afik, J.Nova [2003.02280],
Ashby-Pickering, Barr, Wierzchucka [2209.13990]

Summary slide from ECR (credit: Armin Ilg)

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!

ECFA report

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!

ECFA report

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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.

Third ECFA workshop in Paris October 9-11, 2024
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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.

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

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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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...

227 pages plus 66 pages with 1266 references

as on November 27th

Contents

ECFA report

It is very difficult to summarize the report.
Time was too short for preparing a comprehensive and consistent review, it is rather a collection of targeted contributions.

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 ⇒
November 10 version

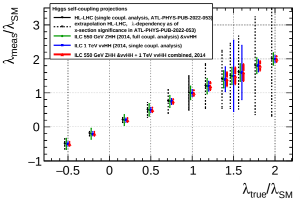


Figure 17: Projected accuracies for λ_{hhh} a the HL-LHC and a 550 GeV e^+e^- collider in dependence of the actual value of λ_{hhh} that is realised in nature [436] [plot to be updated before January 2025].

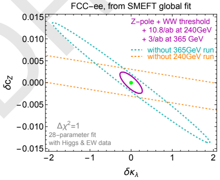


Figure 18: Sensitivity achievable on the trilinear self-coupling of the Higgs (shown on the x axis) with 240 and 365 GeV runs at the FCC-ee. Aside from the single Higgs coupling to the Z boson (shown on the y axis), 26 additional Higgs and EW coupling modifications have been marginalised over to obtained 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^*
ΔA_e $(\times 10^5)$	190^*	14 (4.5)	1.5 (8)	0.7 (2)	1.5 (2)	60 (15)
ΔA_μ $(\times 10^5)$	1500^*	82 (4.5)	3 (8)	2.3 (2.2)	3.0 (1.8)	390 (14)
ΔA_τ $(\times 10^5)$	400^*	86 (4.5)	3 (8)	0.5 (20)	1.2 (20)	550 (14)
ΔA_{b} $(\times 10^5)$	2000^*	53 (35)	9 (50)	2.4 (21)	3 (21)	360 (92)
ΔA_c $(\times 10^5)$	2700^*	140 (25)	20 (37)	20 (15)	6 (30)	190 (67)
$\Delta\sigma^0_{\mathrm{had}}$ (pb)	37^*			0.035 (4)	0.05 (2)	37^*
δR_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)
δR_μ $(\times 10^3)$	1.6^*	0.5 (1.0)	0.2 (0.2)	0.003 (0.05)	0.003 (0.1)	2.5 (1.0)
δR_τ $(\times 10^3)$	2.2^*	0.6 (1.0)	0.2 (0.4)	0.003 (0.1)	0.003 (0.1)	3.3 (5.0)
δR_{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 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].

Work in progress... November 10

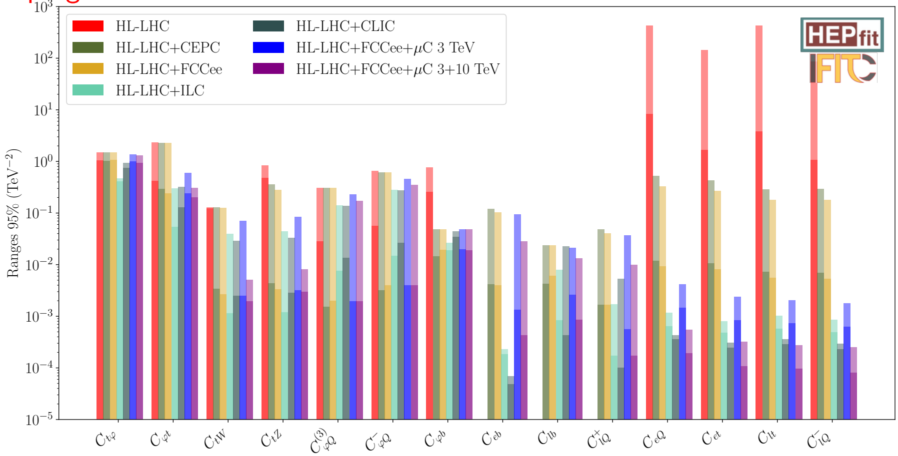


Figure 37: The 95% C.L. bounds on the Wilson coefficients of SMEFT operators involving top quarks.

ECFA report

Work in progress... November 27

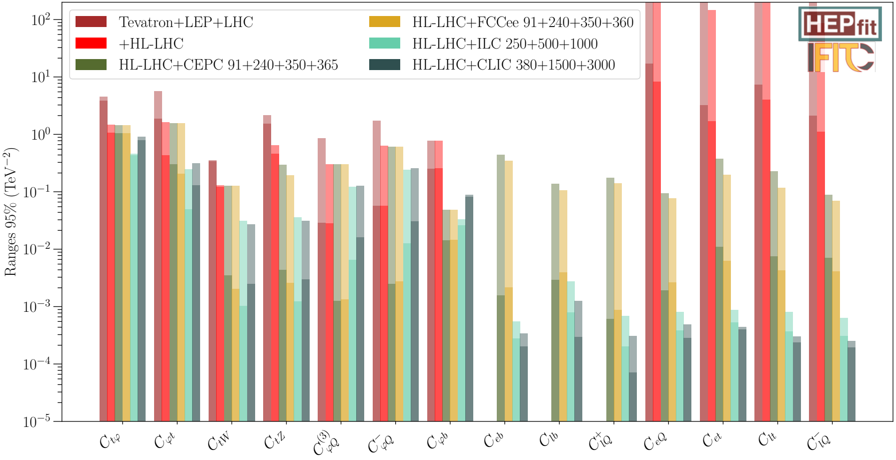


Figure 53: The 95% C.L. bounds on the Wilson coefficients of SMEFT operators involving top and bottom quarks. The four-fermion operators with two light quarks and two heavy quarks are bounded to

ECFA report timeline

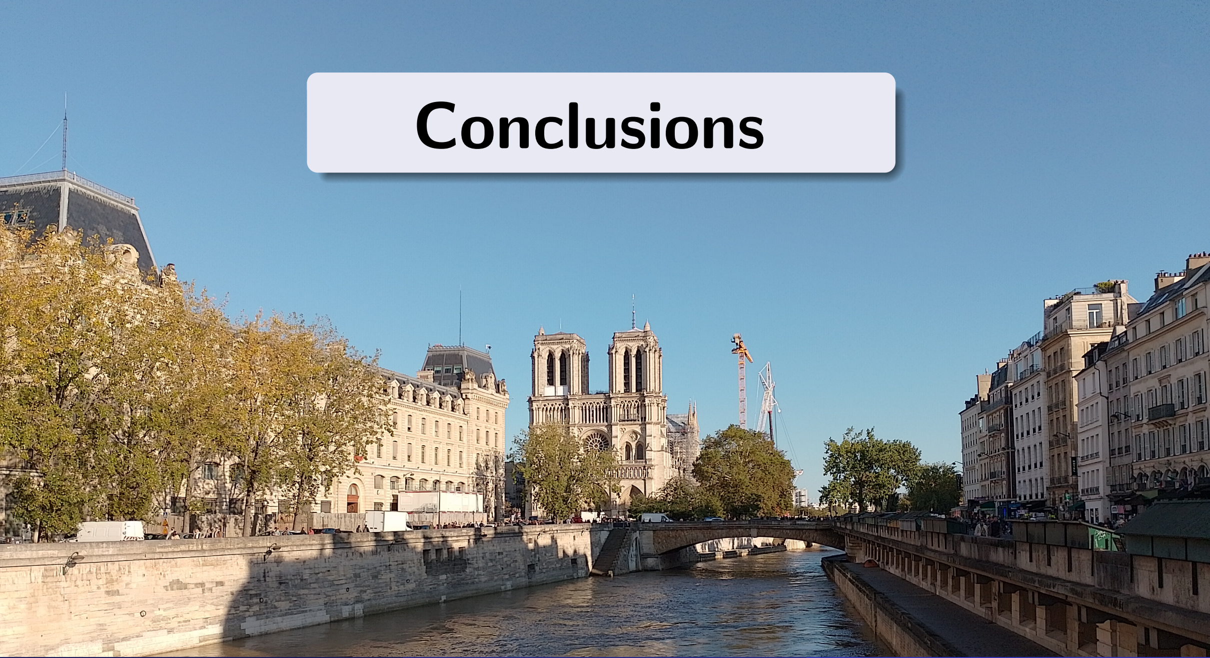
- 20/10 Deadline for physics studies to submit 2-page summary
- 20/10 – 10/11 Compilation and editing by WG1 subgroup conveners / nominated editors, and WG2/3 editors (as well as coordinators & chief editors)
  10/11 is the deadline for WG1 subgroup conveners finish their part!
- 10/11 – 27/11 Editing 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!

A.Robson @ ECFA'2024

Conclusions



Conclusions

Very busy three years!

Many new studies and new collaborations initiated.

Very many interesting results presented at topical meetings and ECFA workshops.

Conclusions

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Conclusions

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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...