Second ECFA Workshop on e^+e^- Higgs/Electroweak/Top Factories

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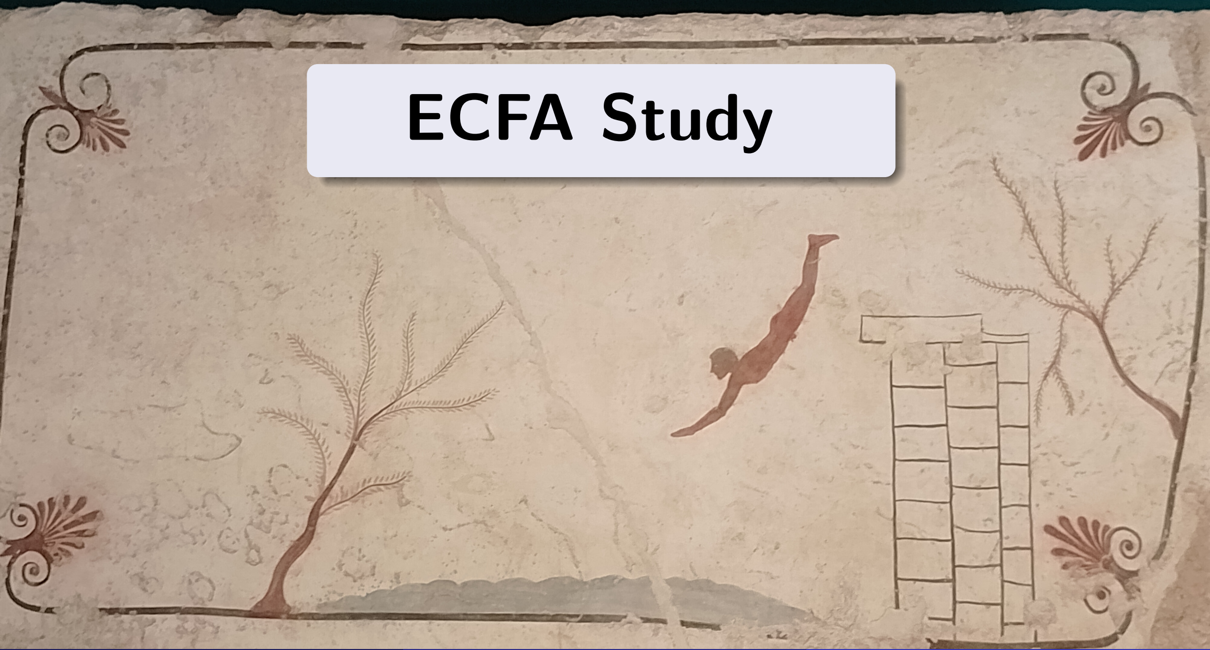
High Energy Physics Seminar
Faculty of Physics, University of Warsaw
October 27, 2023

2nd ECFA Higgs Factor Workshop

Outline:

1. ECFA Study
2. Project landscape
3. Focus topics
4. Selected highlights
5. Software & Detector
6. Concluding remarks



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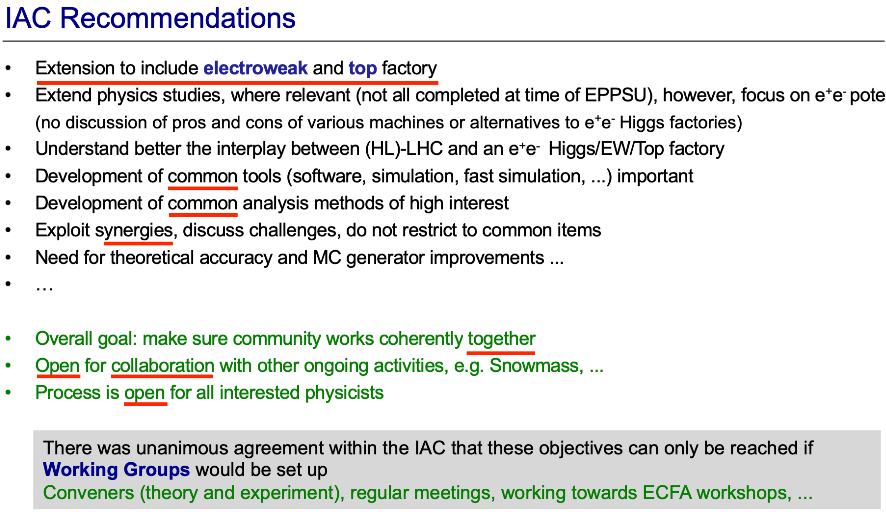
- Setting up an **International Advisory Committee (IAC)** was agreed to be the next step with involvement of some RECFA members and European leaders of possible future Higgs factories. In addition the (HL)-LHC community should be represented.

  - 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 ...
- …

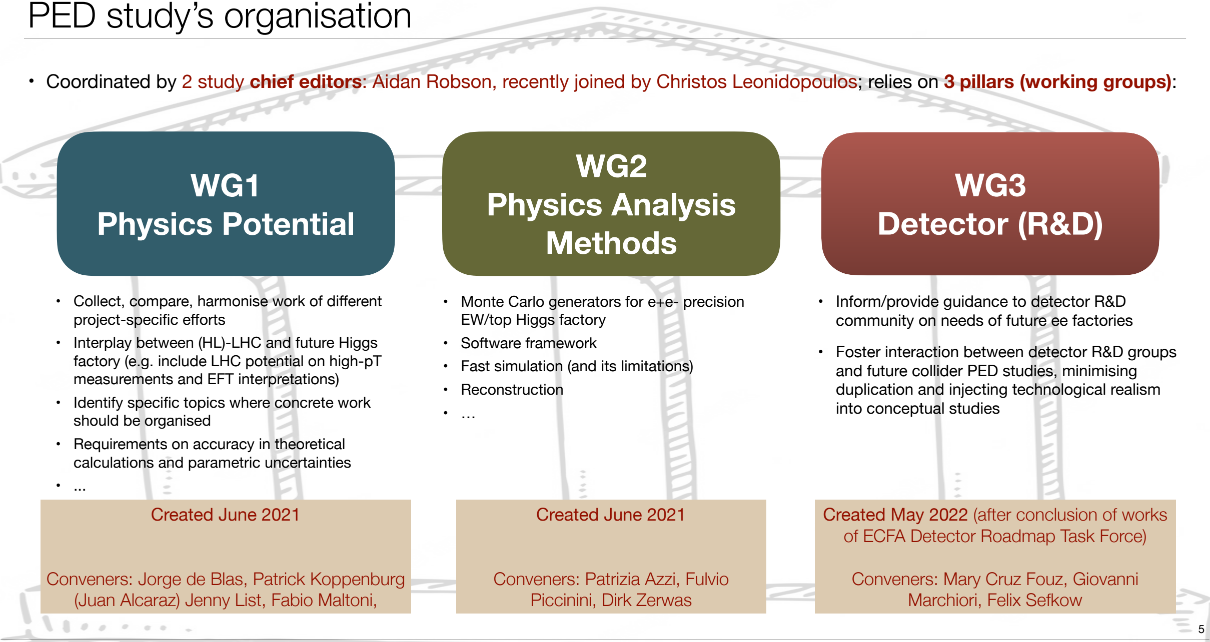
- Overall goal: make sure community works coherently together
- Open for collaboration with other ongoing activities, e.g. Snowmass, ...
- Process is open for all interested physicists

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

WG1 subgroup conveners

WG1-PREC (Precision in theory & experiment):
Ayres Freitas (Pittsburgh), Paolo Azzurri (Pisa), Adrian Irles (Valencia), Andreas Meyer (DESY) ecfa-whf-wg1-prec-conveners@cern.ch

WG1-GLOB (Global interpretations in (SM)EFT and UV complete models):
Sven Heinemeyer (IFCA/IFT), Alexander Grohsjean (DESY), Junping Tian (Tokyo), Marcel Vos (Valencia), Jorge de Blas (Granada) ecfa-whf-wg1-glob-conveners@cern.ch

WG1-HTE (TOP-HIGGS-EW and connection with LHC):
Chris Hays (Oxford), Karsten Köneke (Freiburg), Fabio Maltoni (Louvain) ecfa-whf-wg1-hte-conveners@cern.ch

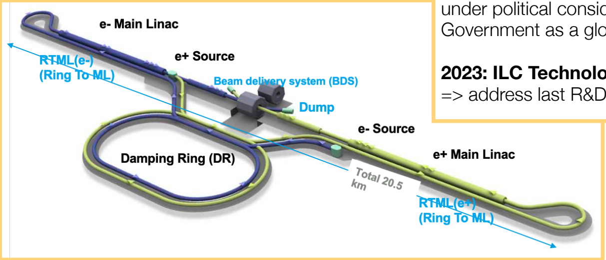
WG1-FLAV (Heavy Flavours):
David Marzocca (Trieste), Stephane Monteil (Clermont Ferrand), Pablo Goldenzweig (KIT) ecfa-whf-wg1-flav-conveners@cern.ch

WG1-SRCH (Feebly interacting particles, direct low mass searches):
Roberto Franceschini (Rome III), Rebeca Gonzalez (Uppsala), Filip Zarnecki (Warsaw) ecfa-whf-wg1-srch-conveners@cern.ch

Project landscape

The key contenders

Status overview



ILC: e^+e^- **@** 90, 160**, 250,** 350**, 500 GeV, 1TeV**
TDR in **2012; 2017:** staged start at **250 GeV**
Superconducting RF

under political consideration by Japanese Government as a global project

2023: ILC Technology Network
=> address last R&D questions on accelerator

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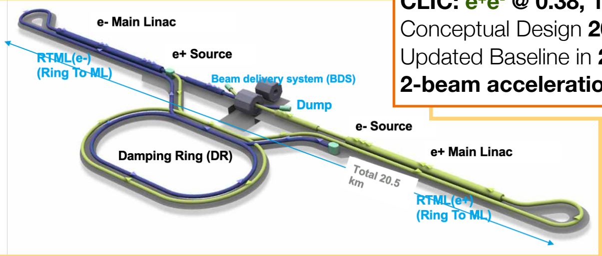
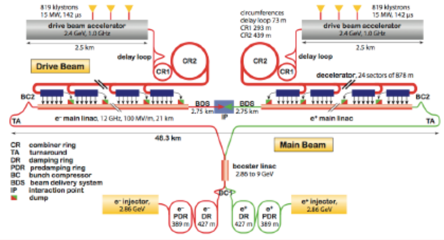


CLIC: e^+e^- @ 0.38, 1.4, 3 TeV
Conceptual Design **2013**
Updated Baseline in **2017**
2-beam acceleration



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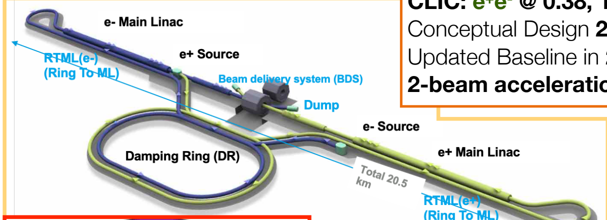

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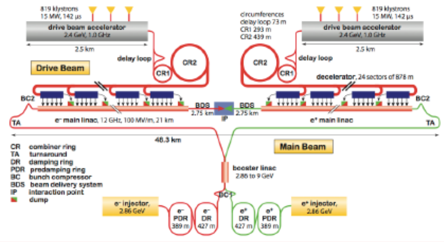

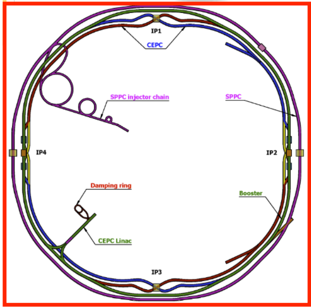

CEPC: e^+e^- @ 90-365 GeV

CDR published 2018
TDR in preparation, incl. cost review (Sep)
aiming for approval in next 5-year-plan (2025)
ranked 1st in HEP preselection

The key contenders

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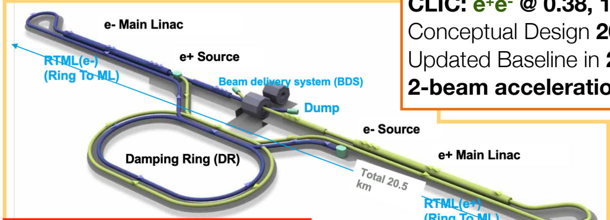

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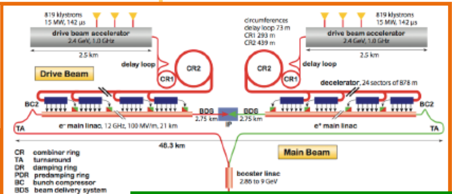
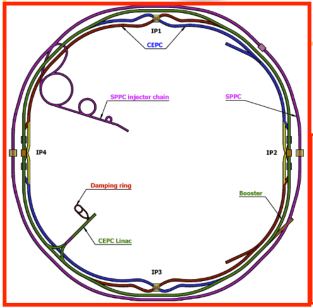




CEPC

CDR p

TDR i

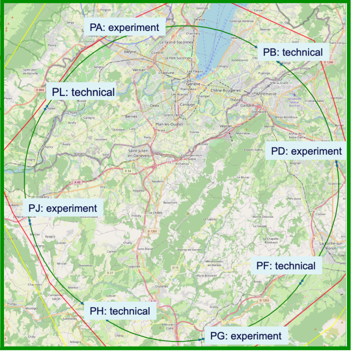
aimin

ranke

FCC-ee e^+e^- @ 90-365 GeV
CDR published in 2019

Since 2021: FCC Feasibility Study
(implementation scenario, environmental analysis, high-field magnets, ..)
=> demonstrate feasibility of FCC-ee by 2025

Special Council Session in Feb 2024



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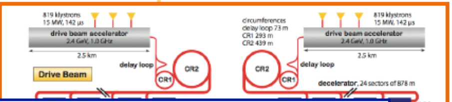
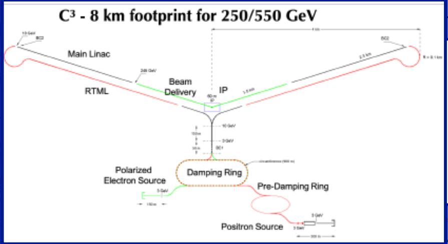
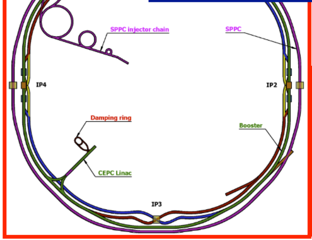



C³ - 8 km footprint for 250/550 GeV

…and the new kid on the block:
the Cool Copper Collider C3,
first proposed 2018, arXiv:1807.10195

4km, time structure compatible with ILC detectors
hoping for support by P5 for 5-year R&D program



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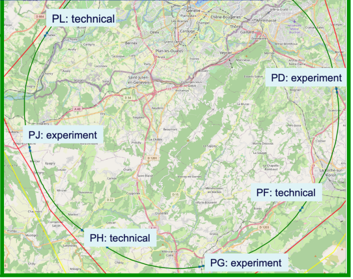

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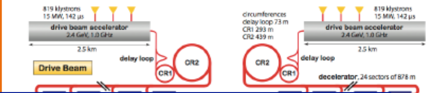

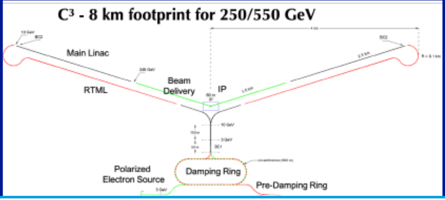

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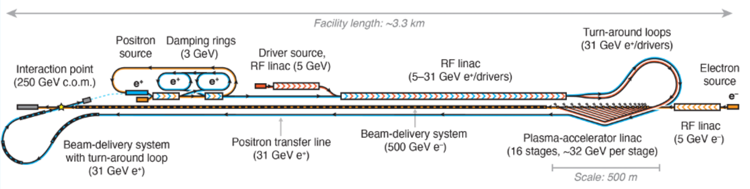
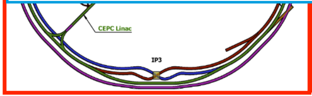
4km, time structure compatible with ILC detectors
hoping for suppo

and an even newer proposal: Hybrid Asymmetric Linear Higgs Factory HALHF, arxiv:2303.10150

some first studies on detector / physics
estimated ~10 years of R&D for PWFA part





TDR i
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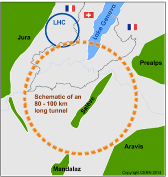
=> demonstrate feasibility of FCC-ee by 2025

Special Council Session in Feb 2024

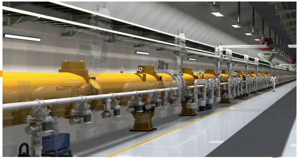
They fall into two classes

Each have their advantages



Circular e+e- Colliders

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



Linear Colliders

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

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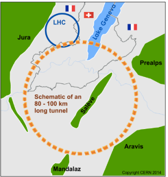

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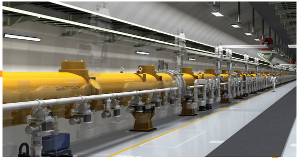
Long-term vision: re-use of tunnel for pp collider

- technical and financial feasibility of required magnets still a challenge



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Long-term upgrades: energy extendability

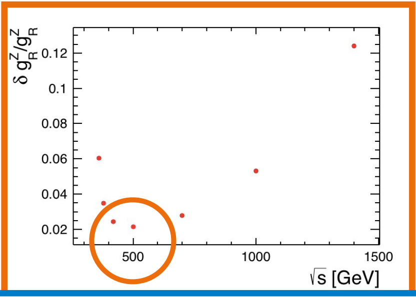
- same technology: by increasing length
- **or by replacing accelerating structures with advanced technologies**
  - RF cavities with high gradient
  - plasma acceleration ?

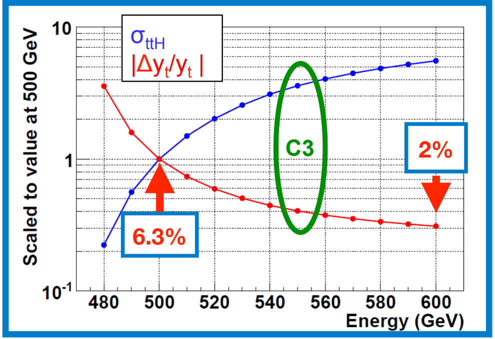
“2nd stage” energy for LCs

500…550…600 GeV?

- ECM ≈ 500 GeV is a sweet-spot for top couplings
- known ever since the Higgs discovery with mH ≈ 125 GeV: ECM=500 GeV “borderline” for ttH production
- **C3 decided for 550 GeV as baseline**
- ILC:
  - no official discussion, focus on getting 250 GeV approved
  - scientifically, it seems obvious that the 500 GeV choice needs to be re-assessed
- CLIC: completely different choice with 380 GeV and 1.4 TeV

**=> Is there a need to re-discuss
the physics-optimized energy choices for LCs
de-coupled from technology ?**





Polarization for CEPC

Longitudinal polarization for physics?

- so far CCs considered transverse polarisation of non-colliding pilot bunches for energy calibration
- **CEPC: simulations support average polarization > 50% for colliding bunches in Z and W runs**
- currently only e- , could use same scheme for e+ once a polarized e+ source meets specs
- next: integration of spin rotators and polarimeters into lattice

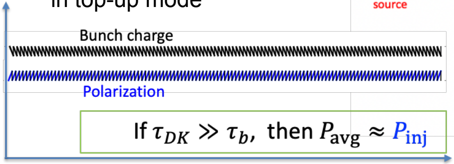
Polarized e- source
- Polarization >85%
- Ref: ILC, EIC

Linac & transport lines
- Polarization loss < 10%
- Ref: SLC, ILC

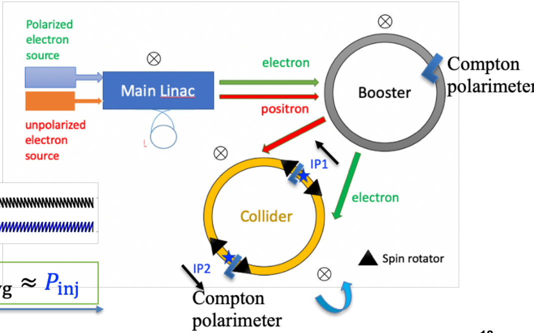
Booster
- Polarization loss < 5% for Z/W based on simulation

Collider
- $P_{inj} > 70\%$ in most cases

Colliding bunches in top-up mode

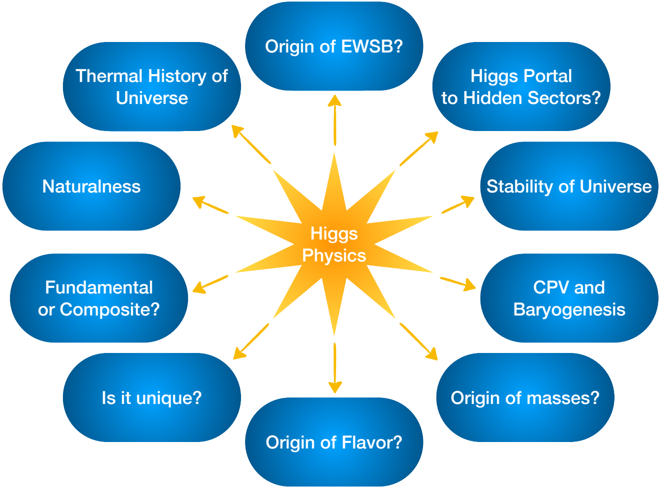


$$\text{If } \tau_{DK} \gg \tau_b, \text{ then } P_{avg} \approx P_{inj}$$



Mystery Higgs sector

Snowmass 2021 US Community Study
on the Future of Particle Physics



Higgs Physics

Origin of EWSB?

Higgs Portal to Hidden Sectors?

Stability of Universe

CPV and Baryogenesis

Origin of masses?

Origin of Flavor?

Is it unique?

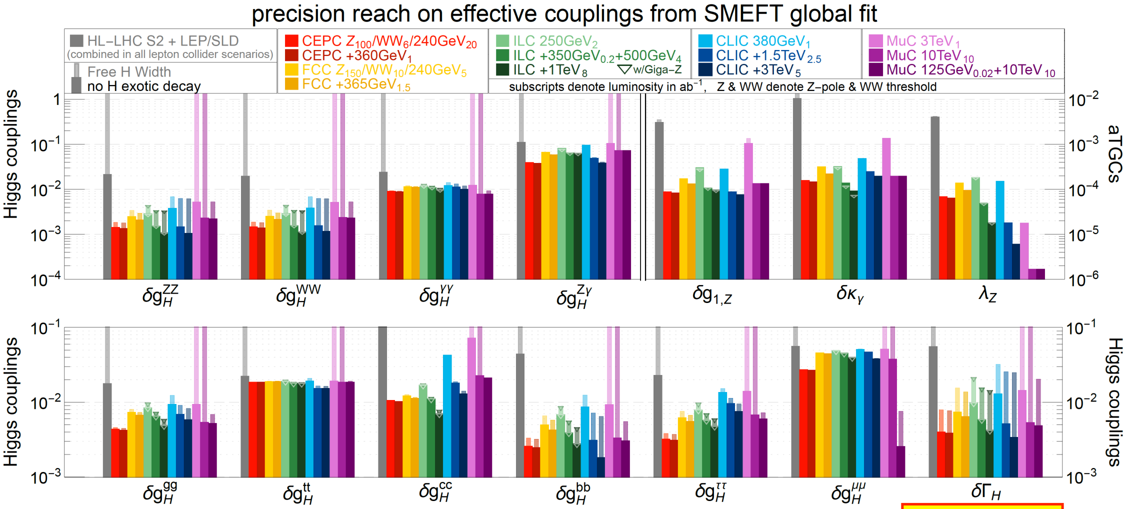
Fundamental or Composite?

Naturalness

Thermal History of Universe

Higgs Couplings: The Snowmass SMEFT fit

Rainbow-Manhattans

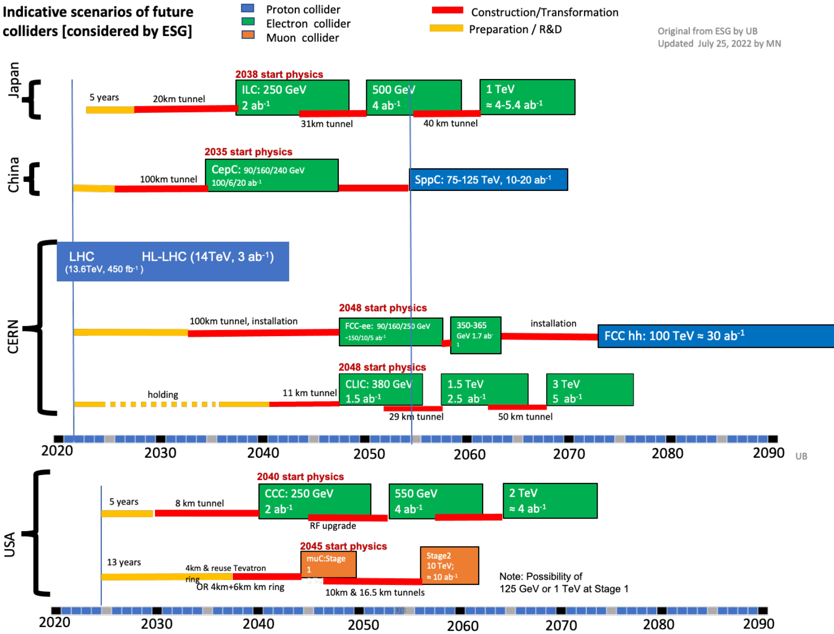


arXiv:2206.08326

Timelines

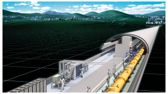
As updated for Snowmass

- **Technologically-driven => start of physics in ~late 30ies**
- **Apart from CERN projects** due to coupling to completion of (HL-)LHC programme **=> ~late 40ies**
- **ILC and CEPC require political decisions very soon** to maintain timelines drawn here
- **If Higgs Factory is built elsewhere, CERN could go for FCC-hh directly (~2060)**



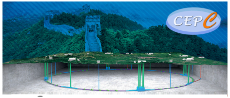
The Approval status

- **ILC:**
  - Under consideration by the Japanese Ministry / Government as a **global project**
  - 2023: increased resources, ILC Technology Network established, incl. CERN (coordination for Europe)



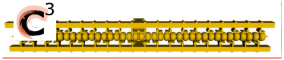
- **FCC-ee**:
  - Feasibility study ongoing, very good progress in many areas, mid-term report expected in November 2023;
  - **Priority 1 for CERN / Europe (CERN Council)**
  - Outcome (technical feasibility, costs,…) decisive for Europe

- **CEPC:**
  - TDR in preparation, incl. cost review
  - A lot of progress on the technical side
  - **Aiming for approval in next 5-year plan (2025)**
  - Ranked 1st in Chinese HEP preselection



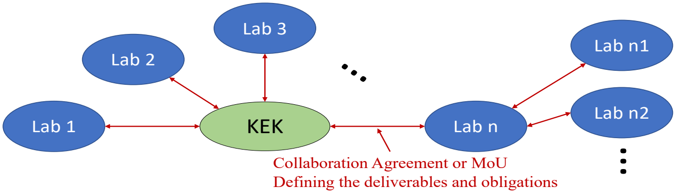
- **CLIC**:
  - Possible alternative for CERN
    CLIC community is preparing a Project Readiness Report (PRR) for the next ESPP (2026/27)

- **CCC:**
  - R&D towards a demonstrator moving forward at SLAC;
    Waiting for P5, and for a commitment of a laboratory to host it



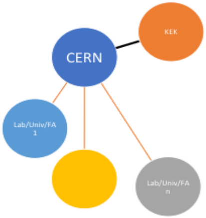
ILC Technology Network:

- ITN is dedicated to make progress in the ILC related accelerator R&D with high priority for engineering studies, profiting from the recommendation of the MEXT Expert Panel to continue R&D.
- It has been initiated as a joint effort of KEK and IDT and is based on the institutional engagement through bilateral agreements between KEK and partner laboratories (Collaboration Agreement/MoU).



Collaboration Agreement or MoU
Defining the deliverables and obligations

Tatsuya Nakada, ICFA, 28th March



CERN has coordinating role in Europe

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!**

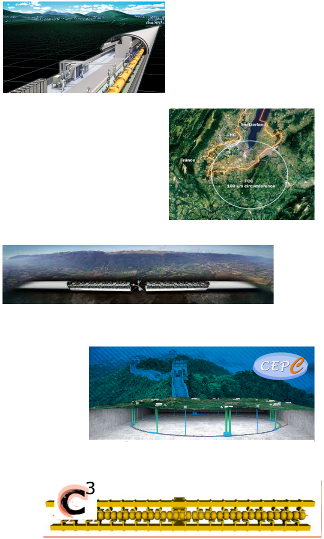
- The field is busy with LHC, Belle-II operation and data analysis, and with the challenging HL-LHC detector upgrades!

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

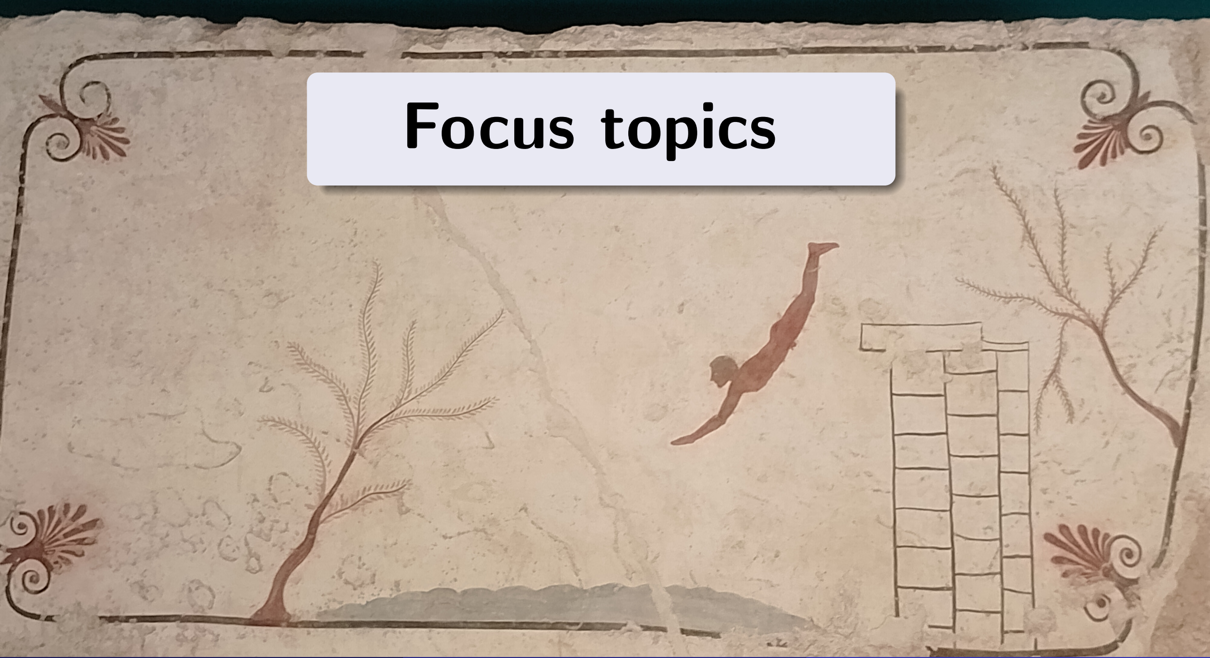
- **There will – most likely – be only one e^+e^- collider!**

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

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



Focus topics



First milestone!

First ECFA WORKSHOP.

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

5-7 October 2022, DESY, Hamburg

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

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

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

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

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

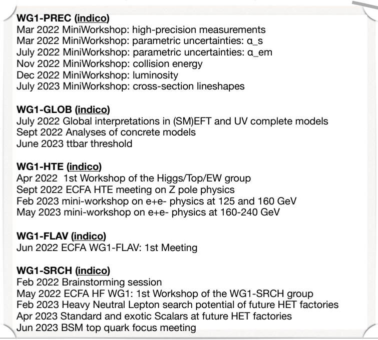
◆ Great to see so many people committed to realising an e^+e^- Higgs factory, in person here in Hamburg!

WG1 activities

- Since 1st year:
  - Setup **5 working sub-groups** on 5 main areas
  - Organisation of several **topical meetings** on these areas for
    - mapping the landscape to be covered
    - collecting expected results from other facilities before the operation of a e+e- factory (e.g. HL-LHC results for WG1-HTE)
    - identifying thematic areas that require specific efforts (e.g. WG1-PREC: uncertainties due to current limited knowledge of EM and strong coupling constant; WG1-GLOB: identification of concrete models from EFT deviations)
  - Organisation of **~monthly seminars of general interest** for ee factories + participation in defining programmes of **related events**

WG1-PREC (Precision in theory & experiment)
WG1-GLOB (Global interpretations in (SM)EFT and UV complete models)
WG1-HTE (TOP-HIGGS-EW and connection with LHC)
WG1-FLAV (Heavy Flavours)
WG1-SRCH (Feebly interacting particles, direct low mass searches)

Topical meetings



WG1-PREC (indico)
Mar 2022 MiniWorkshop: high-precision measurements
Mar 2022 MiniWorkshop: parametric uncertainties: α_s
July 2022 MiniWorkshop: parametric uncertainties: α_em
Nov 2022 MiniWorkshop: collision energy
Dec 2022 MiniWorkshop: luminosity
July 2023 MiniWorkshop: cross-section lineshapes

WG1-GLOB (indico)
July 2022 Global interpretations in (SM)EFT and UV complete models
Sept 2022 Analyses of concrete models
June 2023 ttbar threshold

WG1-HTE (indico)
Apr 2022 1st Workshop of the Higgs/Top/EW group
Sept 2022 ECFA HTE meeting on Z pole physics
Feb 2023 mini-workshop on e+e- physics at 125 and 160 GeV
May 2023 mini-workshop on e+e- physics at 160-240 GeV

WG1-FLAV (indico)
Jun 2022 ECFA WG1-FLAV: 1st Meeting

WG1-SRCH (indico)
Feb 2022 Brainstorming session
May 2022 ECFA HF WG1: 1st Workshop of the WG1-SRCH group
Feb 2023 Heavy Neutral Lepton search potential of future HET factories
Apr 2023 Standard and exotic Scalars at future HET factories
Jun 2023 BSM top quark focus meeting

Seminars and related events (indico category)

March 2023
31 Mar ECFA Higgs Factory seminars: New Particle Searches at Future e+e- colliders

January 2023
20 Jan ECFA Higgs Factory seminars: Top Physics at Future e+e- colliders

November 2022
25 Nov ECFA Higgs Factory seminars: Flavor Physics at Future e+e- colliders

June 2022
10 Jun ECFA Higgs Factory seminars: Precision physics in the e+e- -> WW region
07 Jun - 17 Jun Precision calculations for future e+e– colliders: targets and tools (FC CERN Unit Workshop)

May 2022
06 May ECFA Higgs Factory seminars: Higgs self-coupling

April 2022
08 Apr ECFA Higgs Factory seminars: Physics with light quarks

March 2022
04 Mar ECFA Higgs Factory seminars: Implications of (g-2)_mu for e+e- Higgs factories: an overview

WG1 activities

- Since 2nd year (> ~summer 2022):
  - Worked to define a series of **“focus studies”** to be used by the whole PED study’s community to e.g.
    - assess the ultimate **potential** of the future accelerator/detector proposals
    - estimate **detector limiting factors** and obtain indications about needed R&Ds
    - steer **theoretical/MC work** to support the feasibility of such studies and match the statistical precision of the measurements *(samples of 10^6 — 10^{12} events depending on accelerator design and $\sqrt{s}$)*
  - Established recently for each topic a list of **contact persons** covering a broad spectrum of expertise who will coordinate the effort *(experts from Theory/MC, ILC/CLIC/FCC-ee/CEPC/C3, LHC, Belle-II, LEP, ..)*
  - Now developing a detailed **work list** and gathering already available material for each of 15 ‘focus topics’ to lower threshold for participation to bring people to work together cross-project → great opportunity for those looking to join
  - **Detailed launch**/dedicated discussions on each topic at **Oct 2023 ECFA PED workshop** (https://agenda.infn.it/event/34841/)

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

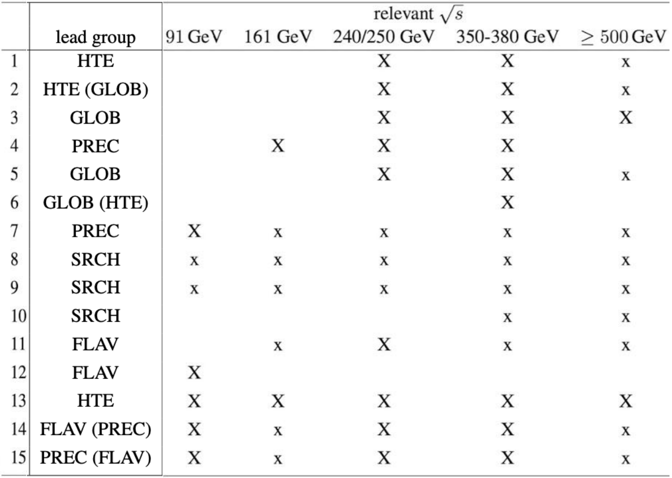
- highlight areas of shared interest across projects
- draw attention to aspects from all three WGs
- build on previous studies where there is interesting new scientific work to be done

–> 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)



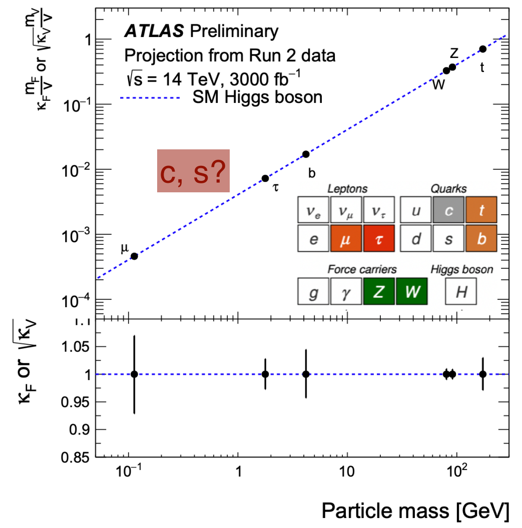
		relevant $\sqrt{s}$				
	lead group	91 GeV	161 GeV	240/250 GeV	350-380 GeV	$\geq$ 500 GeV
1	HTE			X	X	x
2	HTE (GLOB)			X	X	x
3	GLOB			X	X	X
4	PREC		X	X	X	
5	GLOB			X	X	x
6	GLOB (HTE)				X	
7	PREC	X	x	x	x	x
8	SRCH	x	x	x	x	x
9	SRCH	x	x	x	x	x
10	SRCH				x	x
11	FLAV		x	X	x	x
12	FLAV	X				
13	HTE	X	X	X	X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

Selected highlights

Higgs at HL-LHC

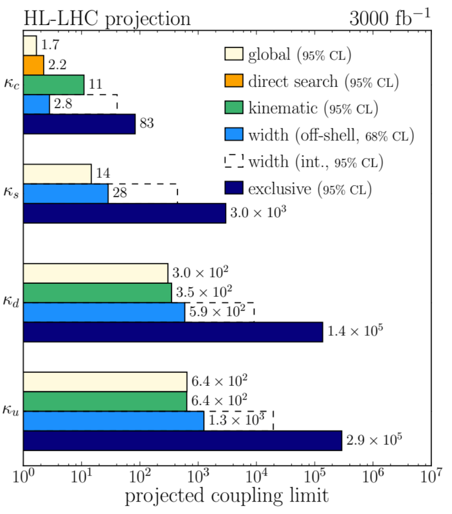


The High Luminosity era of LHC will dramatically expand the physics reach for Higgs physics:

- **2-5% precision for many of the Higgs couplings**
- **BUT much larger uncertainties on Zγ and charm and ~50% on the self-coupling**

1902.10229
CERN-LPCC-2018-04

Higgs at HL-LHC

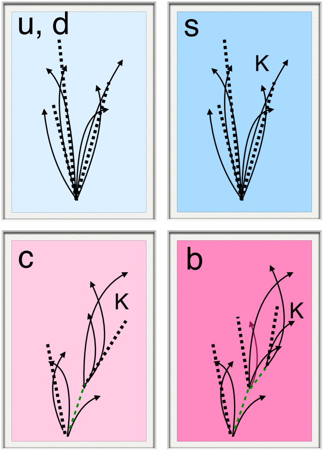


Light Yukawa out of reach in the LHC environment

2101.04119
2203.07535

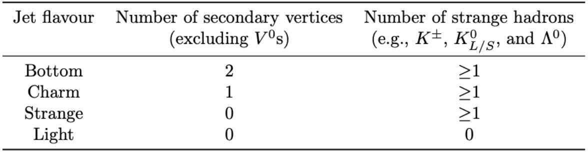
s-tagging

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

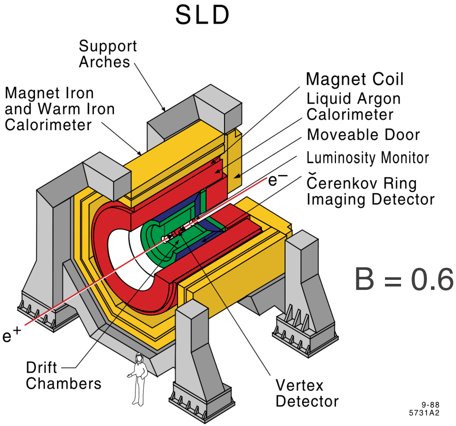


Jet flavour	Number of secondary vertices (excluding V^0s)	Number of strange hadrons (e.g., $K^\pm$, $K^0_{L/S}$, and Λ^0)
Bottom	2	≥1
Charm	1	≥1
Strange	0	≥1
Light	0	0

PRL 85 (2000), 5059
SLAC-R-520

s-tagging in the past

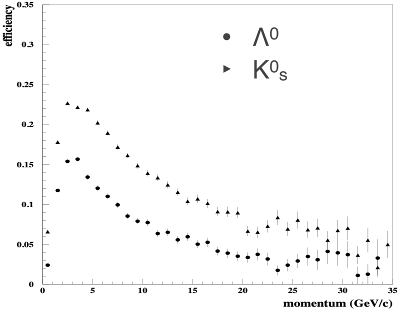
SLD at SLC (e+e- at the Z) measured asymmetry in $Z \rightarrow s\bar{s}$



B = 0.6 T

A Cherenkov Ring Imaging Detector combined with a drift chamber and vertex detector

- CRID only available for $K^{\pm}$ with $p_T > 9$ GeV with a selection efficiency (purity) of 48% (91.5%)
- K^0_S efficiency (purity) of 24% (90.7 %)



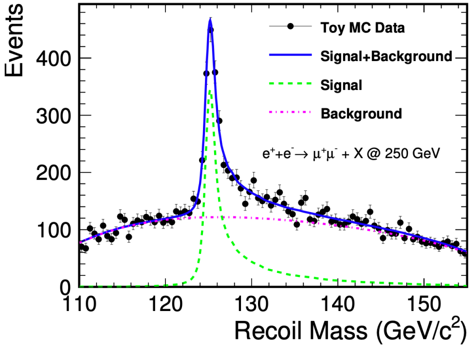
arXiv:2003.01116

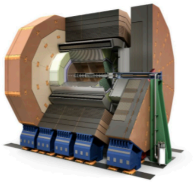
Detectors at future e^+e^-

Stringent detector requirements from ZH reconstruction

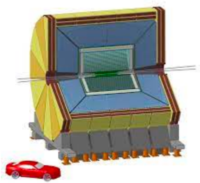
Detector designs at e^+e^- colliders are converging to very similar strategies

- Strong magnetic field 2-5 T
- (Ultra) low material budget tracker (<0.3% X0)
  - Close to the interaction region (10-25 mm)
- High granularity calorimetry
  - Particle Flow reconstruction → plays a big part in many designs

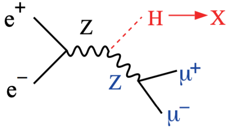




ILD



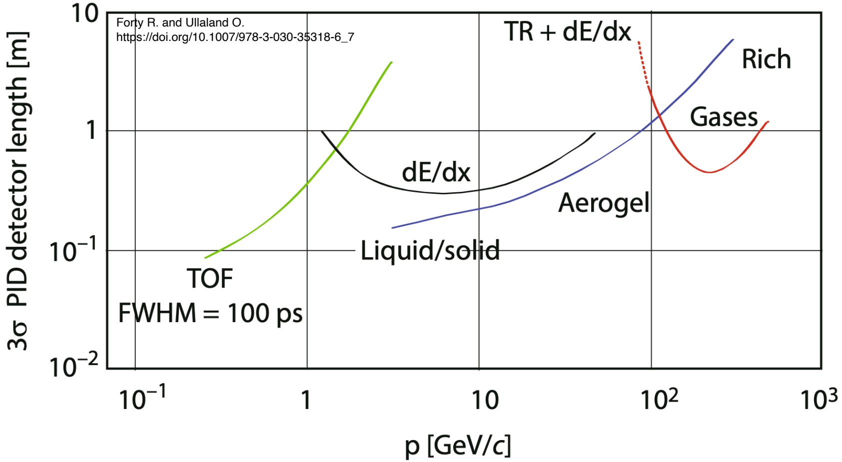
IDEA



1912.04601
e2019-900045-4

Particle ID for s-tagging

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

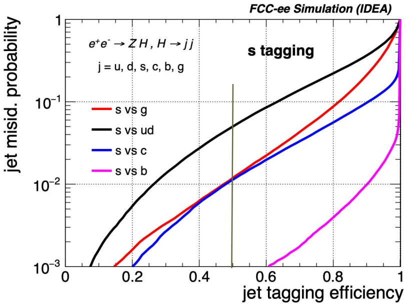

Forty R. and Ullaland O.
https://doi.org/10.1007/978-3-030-35318-6_7

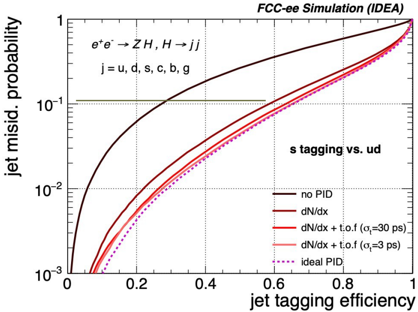
PRD 101 056019 (2020)
EPJ C 82 646 (2022)
L. Gouskos @FCC week

Strange tagging performance 1/2

IDEA-like detector and Particle cloud graph neural network (fast sim)

- Both TOF and dN/dx ($3\sigma < 30$ GeV) included as inputs
- No PID to PID with dN/dx → at fixed mistag, efficiency doubles





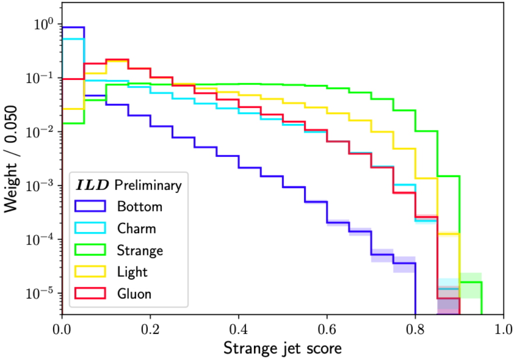
WP	Eff (s)	Mistag (g)	Mistag (ud)	Mistag (c)	Mistag (b)
Loose	90%	20%	40%	10%	1%
Medium	80%	9%	20%	6%	0.4%

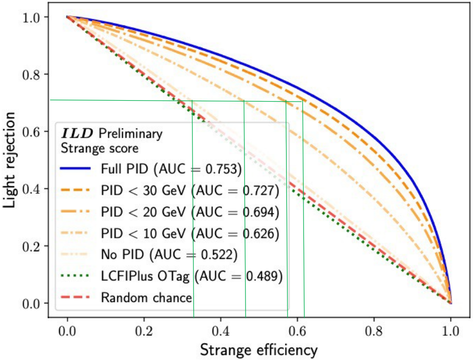
2203.07535

Strange tagging performance 2/2

ILD-like detector with full simulation and Recurrent NN

- Includes PDG-based PID → assuming perfect detector capability
- At 50% s-tag efficiency, 90% background rejection
- No PID to PID < 10 (30) GeV → at fixed mistag, 1.5x (2x) efficiency



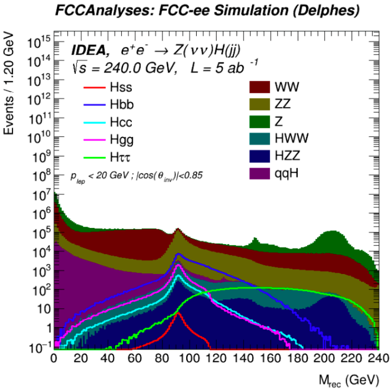


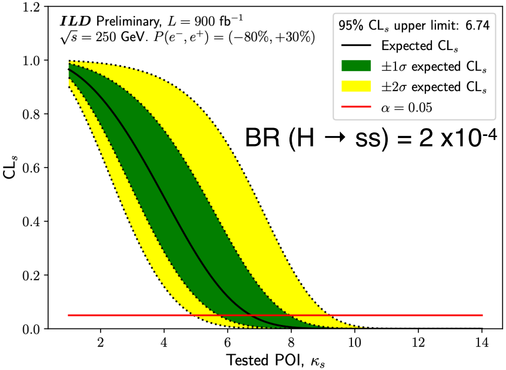
arXiv:2203.07535
L. Gouskos @FCC week

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

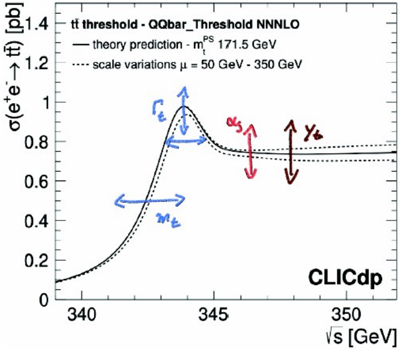




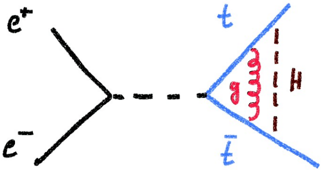
BR (H → ss) = 2 x10^{-4}

e+e- threshold scan

A scan of the e^+e^- center-of-mass energy through the pair production threshold allows for the ultimate mass measurement *(Gusken & Kuhn '85, Peskin & Strassler '91)*
Experimental studies: Martinez & Miquel, hep-ph/020735, Seidel et al., arXiv:1303.3758
Part of the operation plan for all e+e- collider projects: Higgs & top factory!



Art-work: Frank Simon



The threshold position is sensitive to the top quark mass, the shape to the width
The normalization is sensitive to strong coupling and top quark Yukawa coupling
Just measure the cross section vs. sqrt(s) shape and derive all parameters

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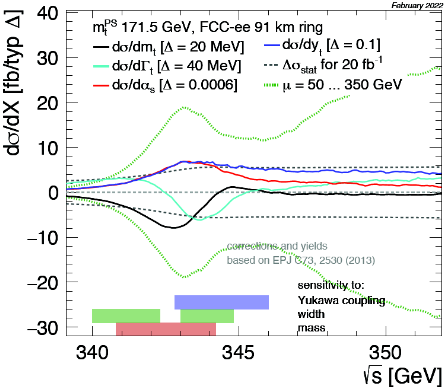
Top quark mass

Frank Simon’s seminar
Snowmass top physics report



Statistical uncertainty - - - - can be made small with 1-2 years of operation

Theory uncertainty …… requires calculation beyond NNNLO (QCD) + NNLO (EW). Resummation is available and can be added.

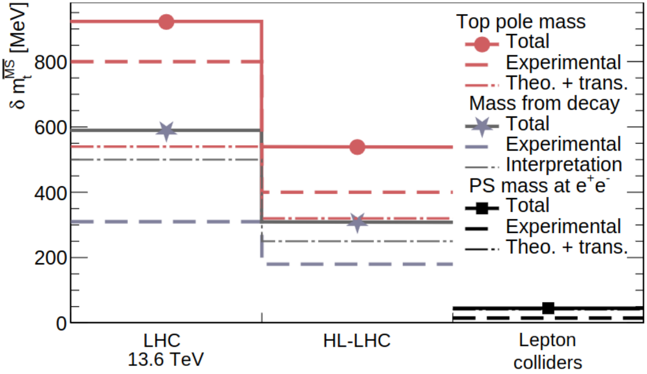
Note: interpretation unambiguous, translation to MS scheme with O(10 MeV) QCD scale uncertainty, parametric uncertainty from α_s requires care, as well as EW corrections

Top quark mass to **approx. 50 MeV**, limited by theory uncertainty and to first order independent of collider design (luminosity spectrum has 2nd order effect)

Top quark width to 45 MeV → bounds on invisible decays+SMEFT arXiv:1907.00997
Precision for α_s ~ 0.001 and y_t ~ 12% not competitive, but good cross-checks

Top mass summary

Snowmass report, arXiv:2209.11267



The e+e- programme

A broad programme above the $t\bar{t}$ threshold

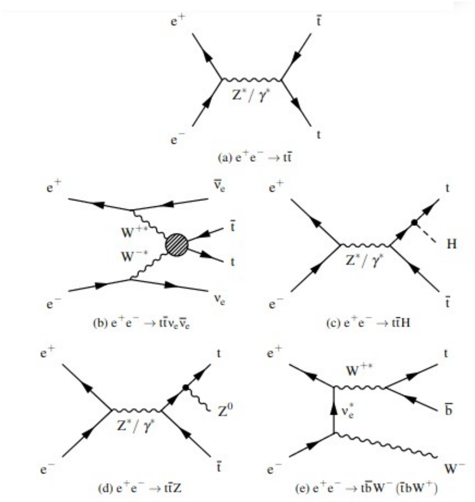
– pair production (a)
– single top production (b)

High energy enables further processes

– ttZ & ttH (c,d)
– VBF top production (b)

Measurements of cross section, forward-backward asymmetry, polarization, CP-odd observables

Durieux et al. *(arXiv:1807.02121)* *define* **optimal observables** *on e+e- → WbWb production*



(a) $e^+e^- \to t\bar{t}$

(b) $e^+e^- \to t\bar{t}\nu_e\bar{\nu}_e$

(c) $e^+e^- \to t\bar{t}H$

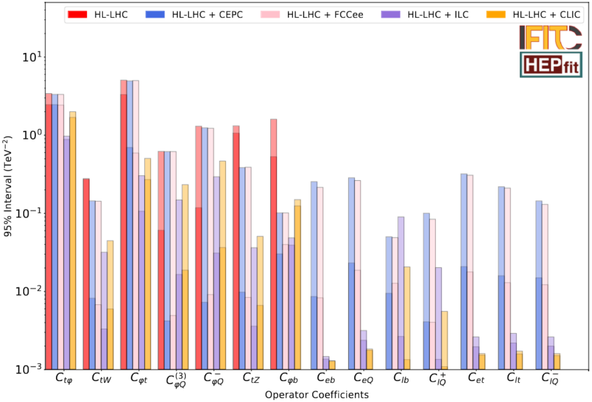
(d) $e^+e^- \to t\bar{t}Z$

(e) $e^+e^- \to t\bar{b}W^-$ $(\bar{t}bW^+)$

SMEFT fit HL-LHC + e+e- collider

EFT for e+e-: Durieux et al. , arXiv:1807.02121
top EW fit HL-LHC/e+e-: Durieux et al., arXiv:1907.1061
Snowmass top couplings, arXiv:2205.02140
Global SMEFT fit, J. De Blas et al., arXiv:2206.08326
Snowmass report, Schwienhorst et al., arXiv:2209.11267

four-quark operators (qqtt):	no progress
two-fermion top-boson:	O(1) → O(0.1)
Two-lepton-two-top (lltt):	XXX → O(10^{-1} - 10^{-3})



Snowmass SMEFT fit based on Durieux et al., with updated operating scenarios

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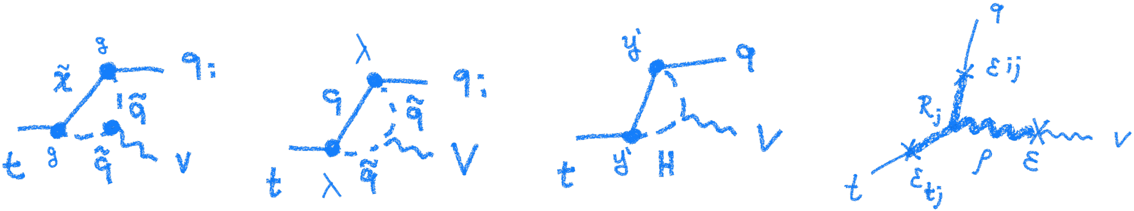
Top quark decay at the Top Factory

$t \to BSM$



$$BR \sim \left(1/M_{NP}\right)^4$$

Even a mere factor 2 stronger bounds on the particles originating flavor violation makes a factor 16 in the FCNC BR. This can take a "border-line observable at top factory" BR=10^{-5} down to 10^{-6} and ruin the party.

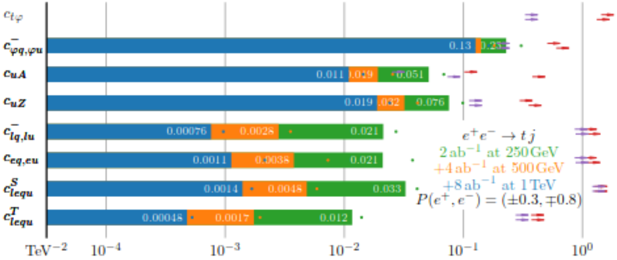
Well, e+e- colliders aren’t that bad, either.

Lepton collider is both competitive and complementary

First top physics: e+e- → tj searches at 250 GeV

More full-simulation work needed!

H. Hesari et al., arXiv:1412.8572
G. Durieux et al., arXiv:1412.7166
Shi & Zhang, arXiv:1906.04573
ILC white paper, arXiv:2203.07622
M. Arroyo et al.,arXiv:2202.04572



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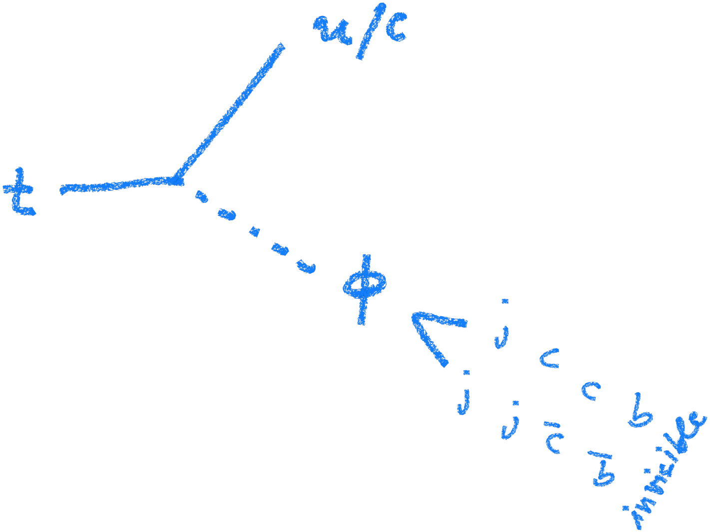
Top quark decay at the Top Factory

$t \to BSM$

- can we find a (light) state in the **mass range** not currently investigated by the LHC?
- can we find a new state in the **final states** not currently investigated by the LHC?



Reference processes for luminosity

- Instead of getting the luminosity from machine parameters, it's more effective to exploit the relation

$$\sigma = \frac{N}{L} \quad \rightarrow \quad L = \frac{N_{\rm ref}}{\sigma_{\rm theory}} \qquad\qquad \frac{\delta L}{L} = \frac{\delta N_{\rm ref}}{N_{\rm ref}} \oplus \frac{\delta \sigma_{\rm theory}}{\sigma_{\rm theory}}$$

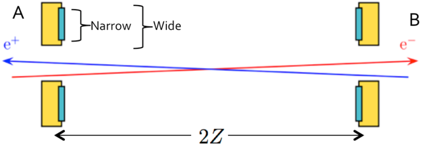
- **Reference processes required to have**
  - **large rates** (so as not to be statistics limited)
  - **low backgrounds**
  - **good control of systematics**
    - particle ID, acceptance, . . .
    - theory: differential cross sections calculable with high theoretical precision, fully exclusive Monte Carlo generators required

Luminosity precision level

- In the past (LEP)
  - ⋆ Small-angle Bhabha scattering at LEP: ∼0.05%
- In the past/at present (flavour factories)
  - ⋆ Large-angle QED processes as $e^+e^- \to e^+e^-$ (Bhabha), $e^+e^- \to \gamma\gamma$, $e^+e^- \to \mu^+\mu^-$, to achieve a typical precision at the level of $1 \div 0.1\%$
- **Realistic uncertainty target for future e^+e^- colliders?**
  - at Z pole 10^{-4} or better for the overall luminosity calibration
  - $\mathcal{O}(10^{-3})$ at $\sqrt{s} \geq 240$ GeV
  - 10^{-5} for point-to-point luminosity control (relative uncertainty between two close c.o.m. energies or two beam polarization settings)

SABS general features

- Bhabha scattering strongly peaked in the forward region $d\sigma/d\theta \sim 1/\theta^3$
$\Longrightarrow$ special lumi detector (LumiCal) covering the region $\theta < 100$ mrad centered around the outgoing beams



M. Damm, talk at ECFA MiniWorkshop: Luminosity, 16/12/2022

- **Systematics (theory)**
  - QED correcions
  - hadronic contribution to photon vacuum polarization
- **Systematics (exp)**
  - detector related uncertainties
  - beam related uncertainties
  - uncertainties originating from physics and machine related interactions
- **Large statistics $\Longrightarrow$ ideal process for the point-to-point lumi control**

Experimental challenges

- **detector aperture, position and alignment**
  - **important systematics from acceptance definition**

$$\frac{\delta\sigma^{\mathrm{acc}}}{\sigma^{\mathrm{acc}}} \sim \frac{2\delta\theta_{\mathrm{min}}}{\theta_{\mathrm{min}}} = 2\left(\frac{\delta R_{\mathrm{min}}}{R_{\mathrm{min}}} \oplus \frac{\delta z}{z}\right)$$

  - dicussed for ILC@500 GeV, should be revisited for latest proposed detector design and ILC operating scenarios
  - at FCC-ee, the design of the MDI region requires the lumi monitor to be placed closer to the IP compared to LEP or ILC, putting higher requirements on the position precision for the same angular acceptance uncertainty

	LEP [28]	FCC-ee (Z pole)	ILC [31], [32] ($\sqrt{s} > 250$ GeV)
LumiCal distance from IP [m]	2.5	1.1	2.48
Precision target	3.4×10^{-4}	10^{-4}	10^{-3}
Tolerance for			
inner radius [μm]	4.4	$\mathcal{O}(1)$	4
outer radius [μm]	?	$\lesssim 3$	?
distance between two LumiCals [μm]	$\mathcal{O}(100)$	< 100	200

LUMI: $e^+e^- \to \gamma\gamma$ for absolute luminosity

Targeting 10^{-4} precision. Cross-sections (and ratios) at $\sqrt{s} = 161$ GeV.

$\theta_{\min}$ (°)	$\sigma_{\gamma\gamma}$ (pb)	$\Delta\sigma/\sigma$ (10 μrad)	$\sigma(ee)/\sigma(\gamma\gamma)$
45	5.3	2.0×10^{-5}	6.1
20	12.7	2.2×10^{-5}	22
15	15.5	2.4×10^{-5}	35
10	19.5	2.9×10^{-5}	68
6	24.6	3.9×10^{-5}	155
2	35.7	8.1×10^{-5}	974

- Unpolarized Born cross-sections. ±24% for (80%/30%) longitudinal beam polarization. Typical HO effects: + 5 to 10%.
  Counting statistics adequate for $\sqrt{s} \gg m_Z$. Note: Use **whole** detector.
- For comparison, 10μrad knowledge for OPAL small-angle **Bhabha** lumi acceptance, corresponds to uncertainty of 100×10^{-5}.
  $\gamma\gamma$ has "relaxed" fiducial acceptance tolerances compared to Bhabhas.
- Bhabha rejection (e/γ discrimination) important. Can be aided by much better azimuthal measurements given electron bending in the B-field.
  FoM: $B\, z_{LCAL}$. ILD has 7.7 Tm. FCC about 2.2 Tm. OPAL was 1.04 Tm.
  Adequate rejection feasible within tracker acceptance? / challenging below.

$e^+e^- \to \gamma\gamma$: Pros and cons

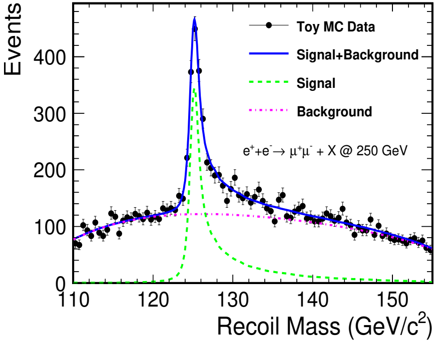
- ✓ at LO, purely QED process, ***at any energy***
- ✓ at NLO, weak corrections (loops with Z & $W^\pm$), but not fermionic loops yet (in particular, ***no hadronic loops***)
- ✓ hadronic vacuum polarization (**and its uncertainty**) enters only at NNLO (2-loops, order α^2)
- ✓ $d\sigma/d\cos\theta \sim 1/\sin^2\theta$) $\Longrightarrow$ lowest angle acceptance less critical than for Bhabha

- ✗ Large Bhabha background, in particular at Z pole
- ✗ At NNLO also Ligh-by-Light contribution present, (**with its uncertainty**)
- ✗ Statistics lower than Bhabha for respective typical event selections
- ✗ Lack of independent MC codes for cross-checks/validation

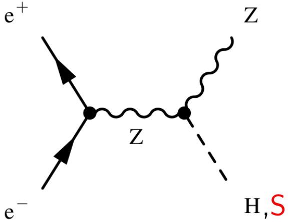
Motivation

e^+e^- Higgs factory

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



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

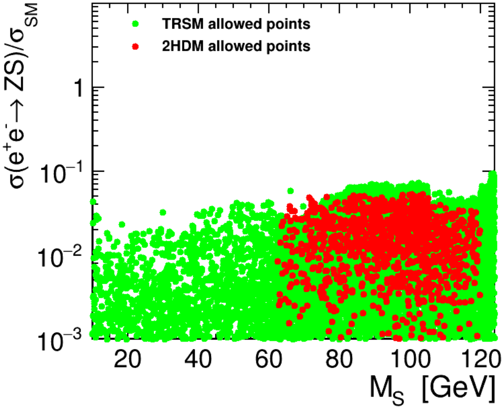


But production of additional, light exotic scalar states is still not excluded by the existing data!

Motivation

Possible scenarios

Benchmark points consistent with current experimental and theoretical bounds



Two-Real-Singlet Model
thanks to Tania Robens
see arXiv:2209.10996 arXiv:2305.08595

Two Higgs-Doublet Model
thanks to Kateryna Radchenko
thdmTool package, see arXiv:2309.17431

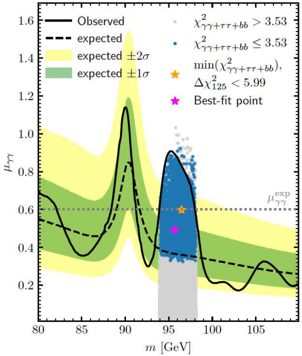
Motivation

Experimental hints...

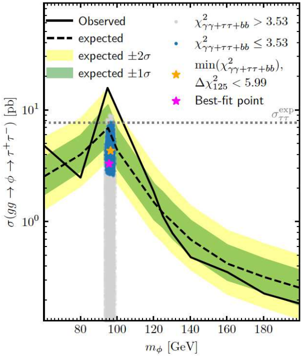
T. Biekötter, S.Heinemeyer, G. Weiglein arXiv:2203.13180

Some discrepancies point to new scalar with mass of ∼95 GeV and dominant decay to $\tau\tau$...

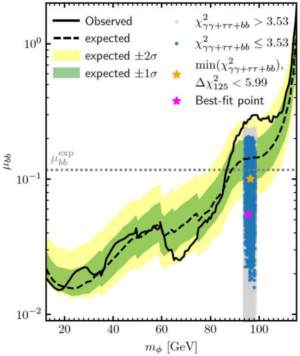
$pp \to h_{95} \to \gamma\gamma$



$gg \to h_{95} \to \tau^+\tau^-$



$e^+e^- \to Zh_{95} \to Zb\bar{b}$



Sven Heinemeyer @ First ECFA WS on e^+e^- Higgs/EW/top factories, October 2022

Focus topic

Theoretical and phenomenological targets

Higgs factories are best suited to search for light exotic scalars in the process:

$$e^+e^- \rightarrow Z\,\phi$$

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

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

For maximum sensitivity, feasibility of including hadronic Z decays should be explored.

Focus topic

Theoretical and phenomenological targets (2)

As as second benchmark scenario for the EXscalar focus topic,
light scalar pair-production in 125 GeV Higgs boson decays is proposed:

$$e^+e^- \to Z\ H \to Z\ \phi\ \phi$$

Here again, different decay channels should be considered, both SM-like and exotic.

While new scalar states could in general be long-lived, only scenarios with prompt decays are included in this focus topic (while a dedicated topic focuses on LLPs, see next presentation).

Analysis

Signal scenarios

Consider production of light scalar in scalar-strahlung process:

$$e^+e^- \quad \rightarrow \quad Z\ S$$

with hadronic Z decays (for statistics) and scalar decays to tau lepton pairs:

$$Z \rightarrow q\,\bar{q} \qquad S \rightarrow \tau^+\tau^-$$

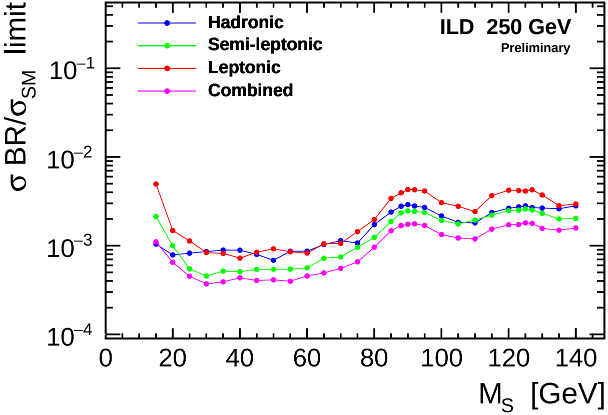
⇒ look for fully hadronic ($jjjj$), semi-leptonic (ℓjjj) or leptonic ($\ell\ell jj$) final state depending on the decays of two tau leptons

Considered mass range $M_S = 15 - 140$ GeV

Results

Cross section limits Combined data, polarisation not taken into account!

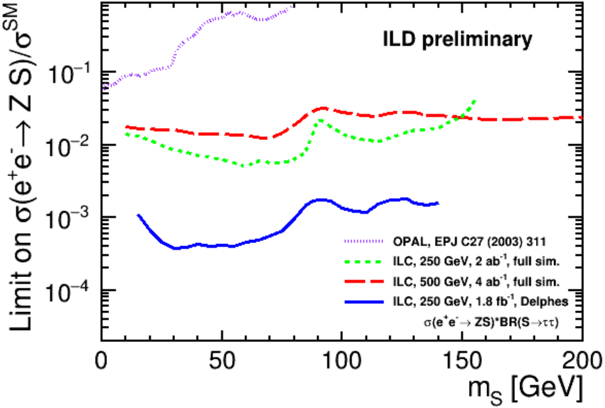
Cross section limits with BDT response cut (optimized for 1% signal level)



Results

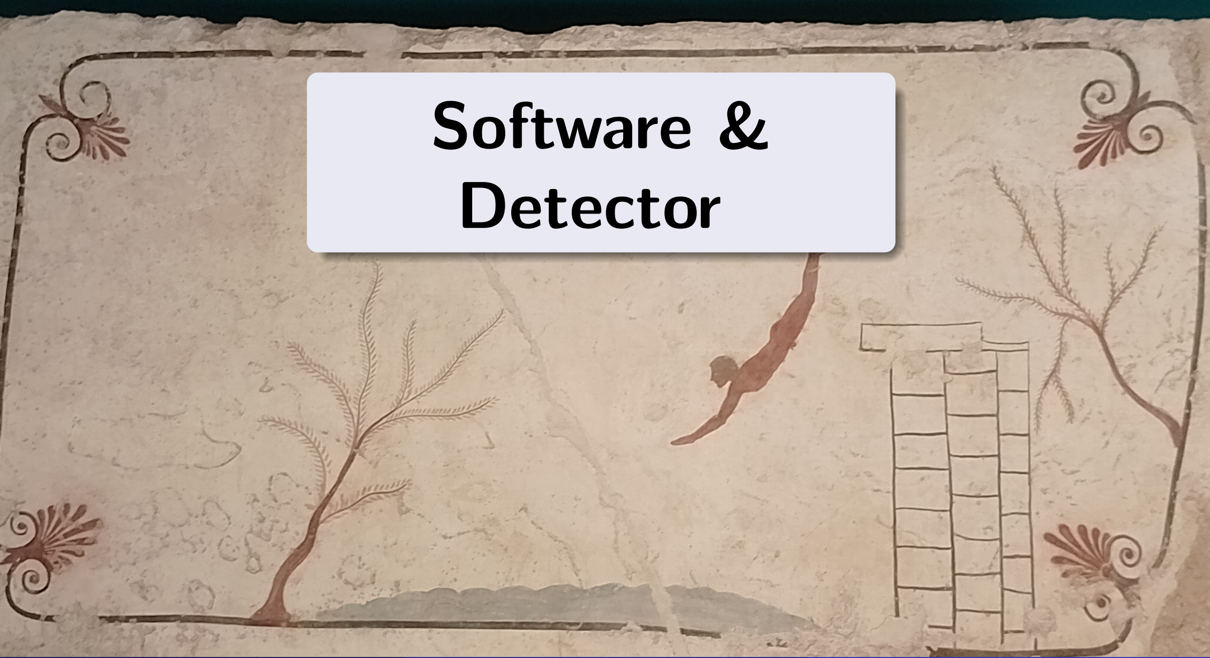
Cross section limits

Cross section limits for $\sigma(e^+e^- \to Z\,S) \cdot BR(S \to \tau\tau)$
compared with decay independent limits on σ/σ_{SM} from earlier studies



Targeted analysis results in order of magnitude increase in sensitivity...

Possible gain in discovery reach depends on the BR!



Software & Detector

Machine Learning Flavour Tagging for Future Higgs Factories

Mareike Meyer

Second ECFA Workshop on e+e- Higgs/EW/Top Factories, 12/10/2023

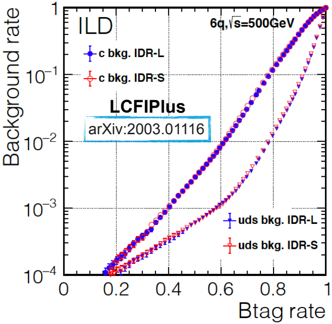
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

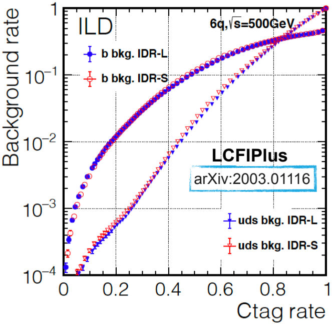
Introduction

- **current standard** for heavy flavour tagging at ILD: **LCFIPlus**
- based on TMVA (BDTs)

arXiv:1506.08371,
https://github.com/lcfiplus/LCFIPlus



LCFIPlus
arXiv:2003.01116

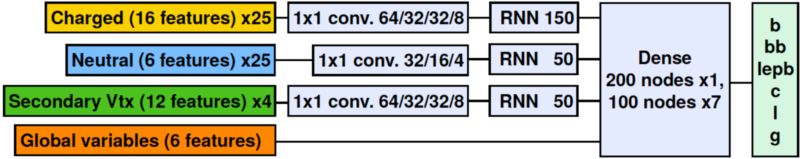


LCFIPlus
arXiv:2003.01116

➡ Can the **heavy flavour tagging** be **improved** by replacing the BDTs used in LCFIPlus **with (deep) NNs**?

this work: **application of CMS DeepJet and ParticleNet to ILD**

CMS DeepJet



Charged (16 features) x25 → **1x1 conv. 64/32/32/8** → **RNN 150**

Neutral (6 features) x25 → **1x1 conv. 32/16/4** → **RNN 50**

Secondary Vtx (12 features) x4 → **1x1 conv. 64/32/32/8** → **RNN 50**

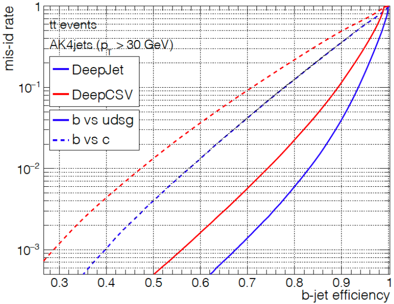
Global variables (6 features)

Dense 200 nodes x1, 100 nodes x7

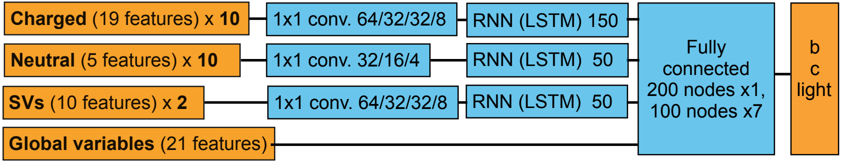
b
bb
lepb
c
l
g

- successfully applied in many CMS analyses
- allows for **usage of low-level features** from **many jet constituents**
- able to deal with **variable length of inputs**
- allows for **ordering** of particles **according to** their assumed **importance**
- **large gain in performance** compared e.g. to FCNN (DeepCSV)

Jet Flavour Classification Using DeepJet arXiv:2008.10519, *Identification of heavy-flavour jets with the CMS detector in pp collisions at 13 TeV* arXiv:1712.07158



DeepJet: architecture


Charged (19 features) x **10**

Neutral (5 features) x **10**

SVs (10 features) x **2**

Global variables (21 features)

1x1 conv. 64/32/32/8

1x1 conv. 32/16/4

1x1 conv. 64/32/32/8

RNN (LSTM) 150

RNN (LSTM) 50

RNN (LSTM) 50

Fully connected 200 nodes x1, 100 nodes x7

b
c
light

- classify jets into **three classes**: b jets, c jets & light jets
- **ordering of input particles** by (as applied in CMS)
  - impact parameter significance for charged jet constituents
  - shortest angular distance to a secondary vertex (by momentum if there is no secondary vertex) for neutral jet constituents
  - flight distance significance for secondary vertices

DeepJet: input features

global variables

p^{jet}, p_T^{jet},

$N_{\text{charged jet const.}}$, $N_{\text{neutral jet const.}}$, N_{SV}

additional global variables from LCFIPlus

21 input features

charged jet constituents

p^{track}/p^{jet}, p_T^{track} (rel. jet), $\vec{p}^{\,track} \cdot \vec{p}^{\,jet}/p^{jet}$

ΔR(track, jet)

impact parameter & significances

track reconstructed in PV?

lepton related variables

pid variables

$\chi 2/\mathrm{ndf}$

19 input features

neutral jet constituents

$p^{\text{neutral const.}}$, $p^{\text{neutral const.}}/p^{jet}$

ΔR(jet, neutral const.)

is photon?

$E_{HCAL}/E_{HCAL+ECAL}$

5 input features

secondary vertices

m_{SV}

$N_{\text{tracks in SV}}$

ΔR(SV, jet)

E_{SV}/E_{jet}, E_{SV}

cos(flight direction$_{SV}$, $\vec{p}_{SV}$)

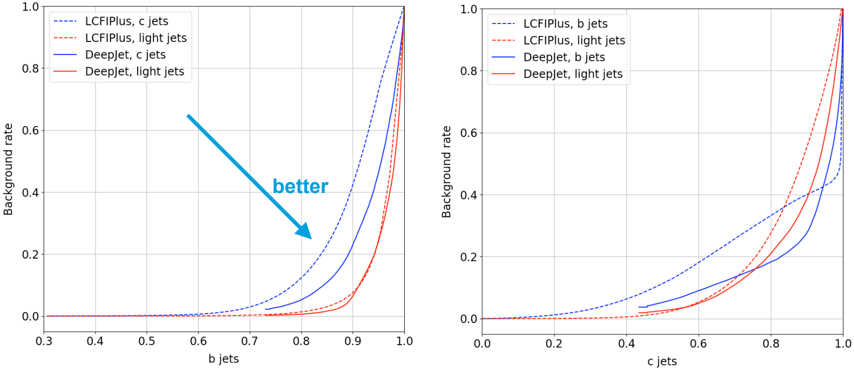
3D IP and significance

$\chi 2$, ndf

10 input features

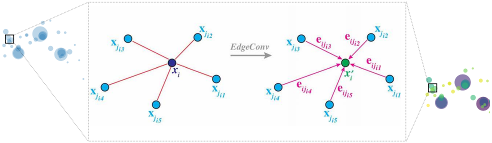
DeepJet: ROC curves - comparison to LCFIPlus

validation data



better performance of DeepJet training **over large parts of the b & c tagging efficiencies** w.r.t default LCFIPlus used in ILD

ParticleNet



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

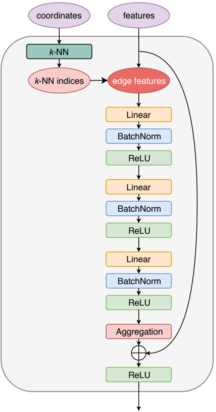
- treat jet as „particle cloud“
- input: **jet constituents**

key building block: **edge convolution**

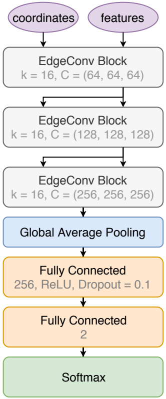
- particle cloud: graph, each point: vertex, connections between each point & k nearest neighboring points: edges
- learn an „**edge feature**“ for each pair:

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

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



edge convolution



ParticleNet

ParticleNet: input features

jet constituents: coordinates

$\Delta\eta$, $\Delta\Phi$

jet constituents: features

$\Delta\eta$, $\Delta\Phi$

$\log(p_T)$, $\log(E)$, $\log(p_T/p_T^{jet})$, $\log(E/E^{jet})$, $\vec{p}^{\,track} \cdot \vec{p}^{\,jet}/p^{jet}$

ΔR

q

isElectron, isMuon, isChargedHadron, isNeutralHadron, isPhoton

impact parameter & significances

track used in PV?

lepton related variables

pid variables

$E_{HCAL}/E_{HCAL+ECAL}$

$\chi 2$/ndf

28 input features

secondary vertices: coordinates

$\Delta\eta$, $\Delta\Phi$

secondary vertices: features

$\Delta\eta$, $\Delta\Phi$

$\log(p_T)$, E_{SV}/E_{jet}, E_{SV}

η

m_{SV}

$N_{\text{tracks in SV}}$

$\chi 2$/ndf

impact parameters &significances

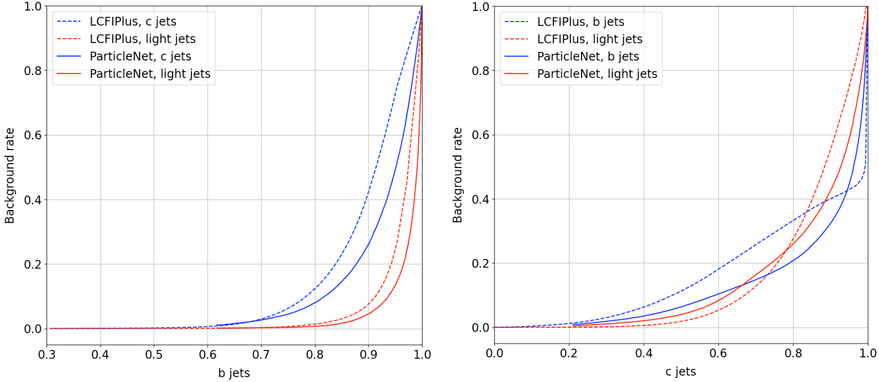
cos(flight direction$_{SV}$, $\vec{p}_{SV}$)

14 input features

2 SVs & all jet constituents considered, no ordering of inputs

ParticleNet: ROC curves - comparison to LCFIPlus

validation data

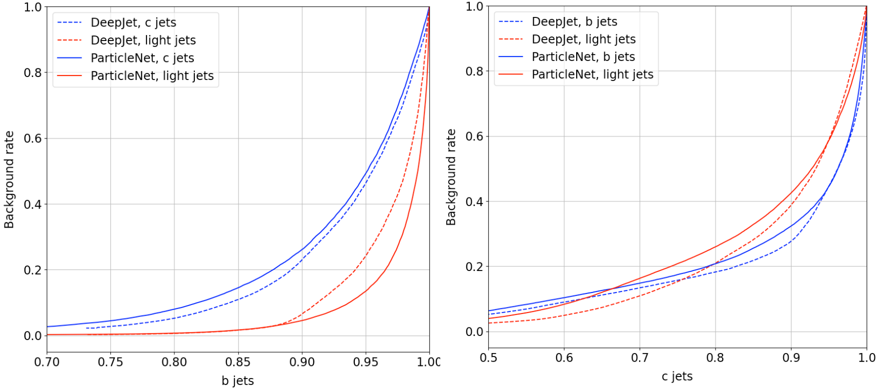


better performance than LCFIPlus **over large parts of the b and c tagging efficiencies**

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

ParticleNet: ROC curves - comparison to DeepJet

validation data

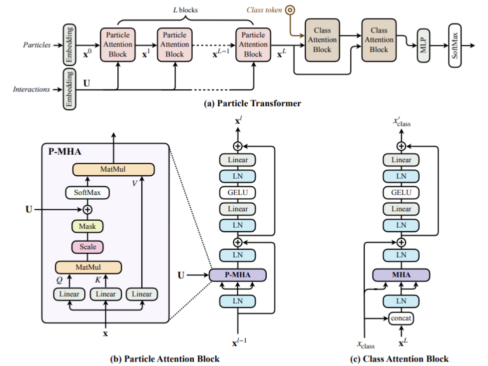


better performance with **DeepJet** for **b vs. c identification and for c vs. b & light jet identification**

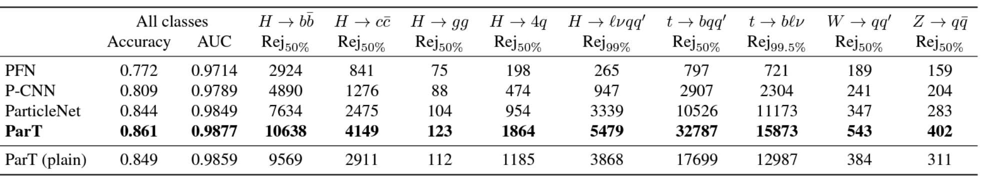
better performance of **ParticleNet** for **b jet vs. light jet identification**

Particle Transformer (ParT)

- Transformer: self-attention based algorithm intensively used for NLP (e.g. chatGPT)
  - Weak biasing: possible to train big samples efficiently (with more learnable weights)
    but demanding big training sample for high performance
- ParT is a new Transformer-based architecture for Jet tagging, published in 2022[2].
- Surpasses the performance of previous architectures
- Easily usable with TTree input and XML steering file



erformance on event categorization (ie. not direct flavor tagging but flavor information is essential for the categorization)

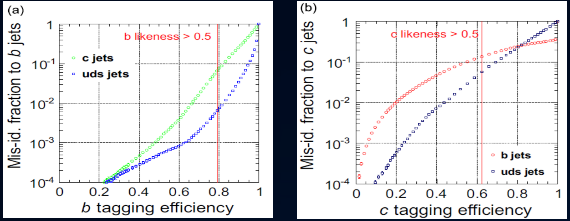


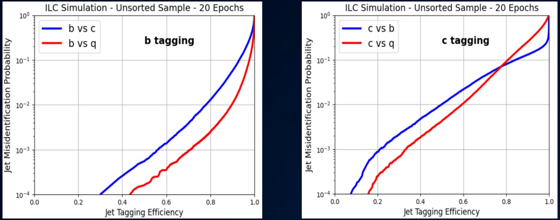
	All classes		$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to 4q$	$H \to \ell\nu qq'$	$t \to bqq'$	$t \to b\ell\nu$	$W \to qq'$	$Z \to q\bar{q}$
	Accuracy	AUC	$\text{Rej}_{50\%}$	$\text{Rej}_{50\%}$	$\text{Rej}_{50\%}$	$\text{Rej}_{50\%}$	$\text{Rej}_{99\%}$	$\text{Rej}_{50\%}$	$\text{Rej}_{99.5\%}$	$\text{Rej}_{50\%}$	$\text{Rej}_{50\%}$
PFN	0.772	0.9714	2924	841	75	198	265	797	721	189	159
P-CNN	0.809	0.9789	4890	1276	88	474	947	2907	2304	241	204
ParticleNet	0.844	0.9849	7634	2475	104	954	3339	10526	11173	347	283
ParT	**0.861**	**0.9877**	**10638**	**4149**	**123**	**1864**	**5479**	**32787**	**15873**	**543**	**402**
ParT (plain)	0.849	0.9859	9569	2911	112	1185	3868	17699	12987	384	311

Application of ParT to ILD data

(ILD qq 91 GeV, 0.8M jets for training)

- Jet tagging performance is greatly improved by ParT immediately.
- The performance is improved by 4.05 – 9.80 times compared to LCFIPlus with the same set of data.
- 20 epochs are taken,
  200 epochs do not help improving performance but give overtraining

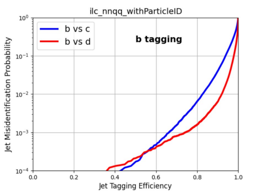


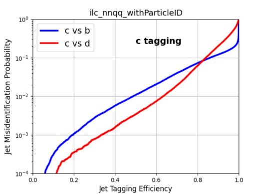


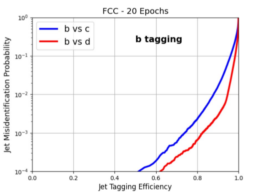
	b-tag 80% eff.		c-tag 50% eff.	
Method	c-bkg acceptance	uds-bkg acceptance	c-bkg acceptance	uds-bkg acceptance
LCFIPlus	10%	1%	10%	2%
ParT	1.29%	0.25%	1.02%	0.43%

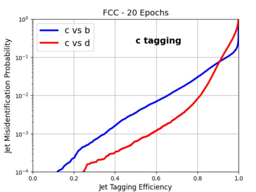
Comparison with FCC data[3]

- Trained with same condition as ILD data for fair comparison. (800k data size, 20 epochs, etc.)
- FCC data has ~ 3 times the performance compared to ILD data.
- Possible cause of the difference:
  - Particle ID: too pessimistic for ILD
  - Definition of some variables
    - Theta, phi etc.
  - Difference on full and fast sim
    - Especially different on tails of distributions
  - Assumed detector resolution (?)







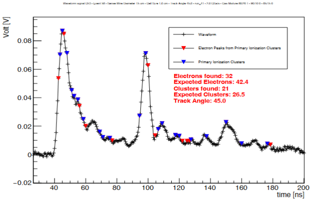


Data	Particle ID	Impact Parameters	Jet Distance	Track Errors	c-bkg acceptance @ b-tag 80% eff.	b-bkg acceptance @ c-tag 50% eff.
ILD **(νvqq 250 GeV)**	▨	▨	▨	▨	**0.64%**	**1.09%**
FCC	▨	▨	▨	▨	**0.23%**	**0.35%**

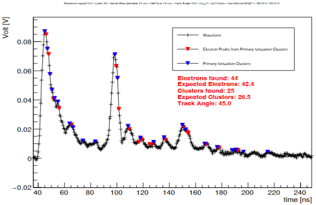
Specific Energy Loss

- IDEA Drift Chamber, Bari group
- Simulation in geant4 and Garfield, compared against test beam
- Measurement of dN/dx, i.e. cluster counting dN/dx (~ factor 2 better than dE/dx) via timing, testing 2 algorithms to extract number of clusters from the signal
  - Derivative algorithm: scan through signal in small steps and use 1st and 2nd derivative to determine peak
  - Running template algorithm: template fit of experimental pulse shape, cut on χ^2

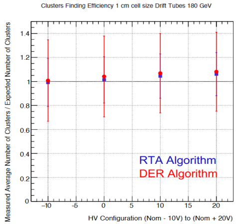
DERIV Algorithm



RTA Algorithm



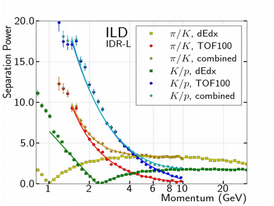
1 cm drift tubes



https://agenda.infn.it/event/34841/contributions/208865/

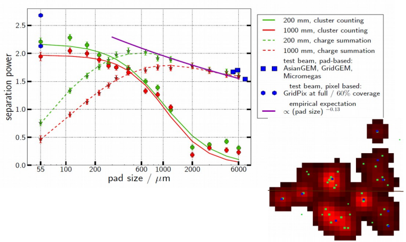
Specific Energy Loss

- ILD Time Projection Chamber
- Measurement of dE/dx: reconstruct geant4-based full-simulation ionisation
- Dedicated simulation shows potential of high granularity PixelTPC for enhanced dE/dx (30-40% higher performance) and possibly cluster counting (dN/dx)
- CEPC (ILD-based) TPC coming to similar results



https://arxiv.org/abs/2003.01116

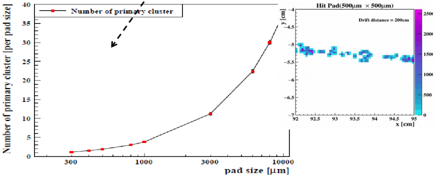
LCTPC



https://arxiv.org/abs/2205.12160

CEPC

Simulation of the primary cluster along the drift length

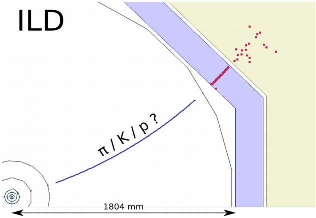


https://indico.desy.de/event/34916/contributions/147134/

Time of Flight

- 30ish-ps timing in Silicon for LHC pile-up rejection can be used for low-mom PID
- Mathematically simple to implement a first estimate with a given timing T precision
  - included in DELPHES
- In ILD sim/reco based on calorimeter hits, different algorithms
  - 'full' reconstruction implemented with reconstructed harmonic means of track length L and momentum p

$$m = p\sqrt{\frac{c^2T^2}{L^2} - 1}$$

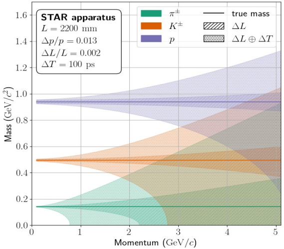


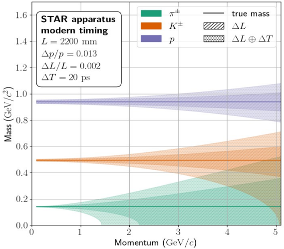
$$L = \sum_{i}^{N_{\mathrm{hits}}} L_i = \sum_{i}^{N_{\mathrm{hits}}} \frac{|z_{i+1} - z_i|}{|\tan\lambda_i|}\sqrt{1 + \tan^2\lambda_i}$$

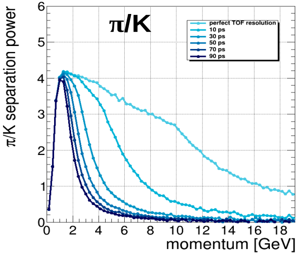
https://indico.desy.de/event/34916/contributions/147145/

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



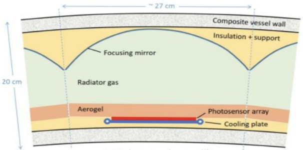




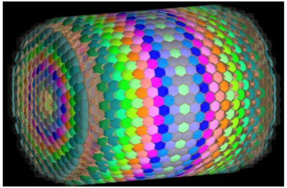
https://indico.desy.de/event/34916/contributions/147145/

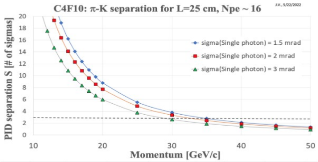
Ring Imaging Cherenkov Detectors

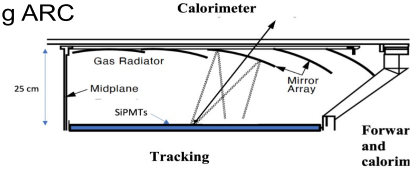
- 2 hardware proposals, aiming at PID up to 50 GeV with compact barrel+endcap RICH
- RICH for e.g. SiD, single phase
  - work ongoing on hardware and geometry
- ARC for CLD, with aerogel and gas
  - work ongoing on digitisation and reconstruction
  - allow for parametrised detector
  - provide CLD model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



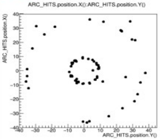
ARC detector (one cell)







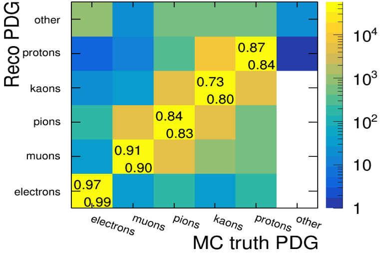
https://arxiv.org/abs/2203.07535

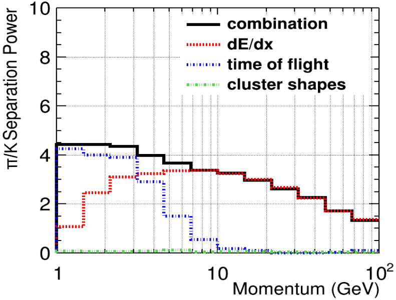


https://indico.cern.ch/event/1202105/timetable/#354-status-of-software-for-det

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

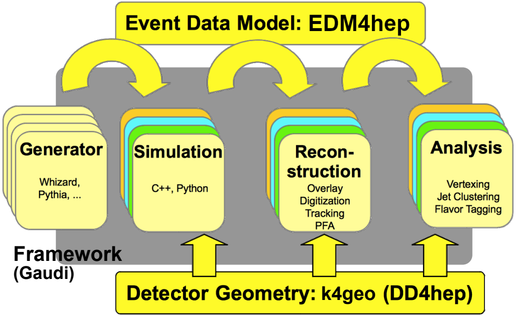




https://indico.cern.ch/event/1283129/#1-a-comprehensive-particle-id

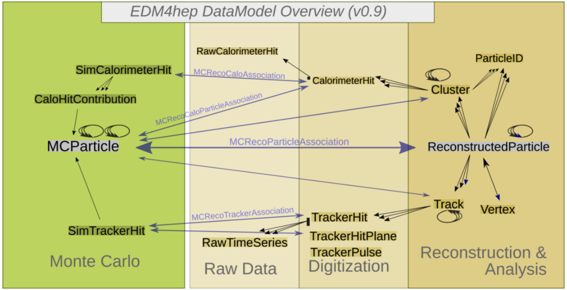
Key4hep

- Turnkey software for future accelerators
- Share components to reduce maintenance and development cost and allow everyone to benefit from its improvements
- Complete data processing framework, from generation to data analysis
- Community with people from many different experiments: C^3, CEPC, CLIC, EIC, FCC, ILC, Muon Collider, etc.



The Key4hep Event Data Model: EDM4hep

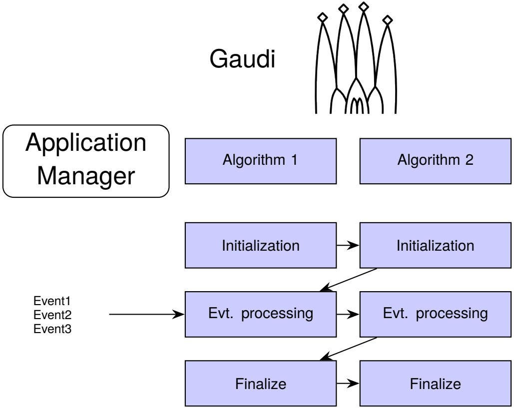
- Data Model used in key4hep, it is the language that all components must speak
- From a specification in a yaml file, and using podio, the C++ code containing all the classes and methods is generated



- Classes for physical objects, for example: MCParticle
- Associations between these, for example: between MCParticle and a ReconstructedParticle
- Adapt based on the news of the collaborators. Example: RawTimeSeries previously was TPCHit

The Key4hep Framework

- Gaudi based core framework:
  - k4Gen for integration with generators
  - k4SimGeant4 for integration with Geant4
  - k4SimDelphes for integration with Delphes
  - k4geo for detector models, previously lcgeo
  - k4FWCore provides the interface between EDM4hep and Gaudi
  - k4MarlinWrapper to call Marlin processors
  - . . .



Gaudi

Application Manager

Algorithm 1

Algorithm 2

Initialization

Initialization

Event1
Event2
Event3

Evt. processing

Evt. processing

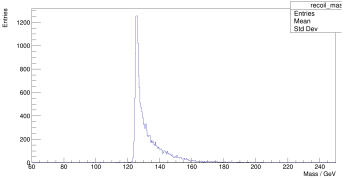
Finalize

Finalize

- Used by LHCb, ATLAS, Key4hep and others

Key4hep Tutorial

- Key4hep tutorial on Tuesday
- Several topics covered
  - EDM4hep
  - LCIO EDM4hep converters
  - Algorithms in Key4hep using Gaudi
  - Plotting from files
- Documentation will be kept online https://github.com/key4hep/key4hep-tutorials
- Feel free to ask questions / report issues about the tutorials in person or by mail or github

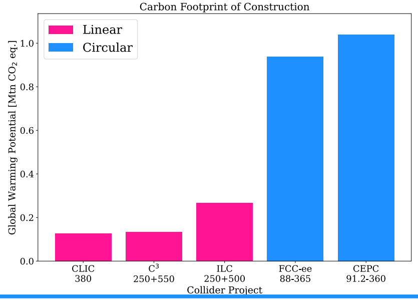


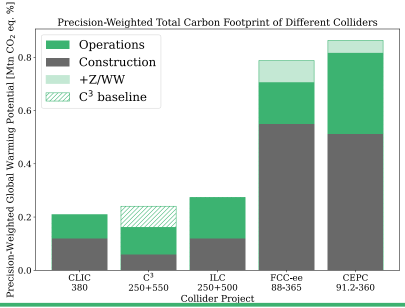
Concluding remarks

Global Warming Potential

Study by C3

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





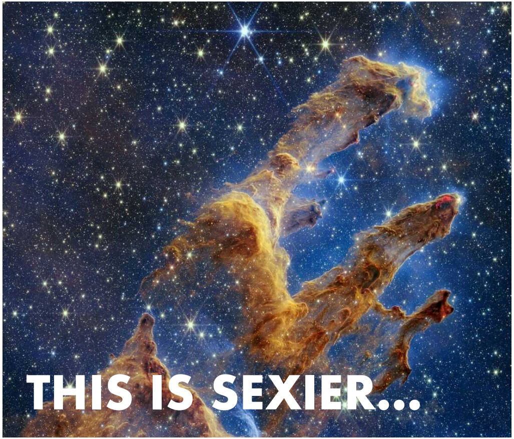
Adding operation GWP

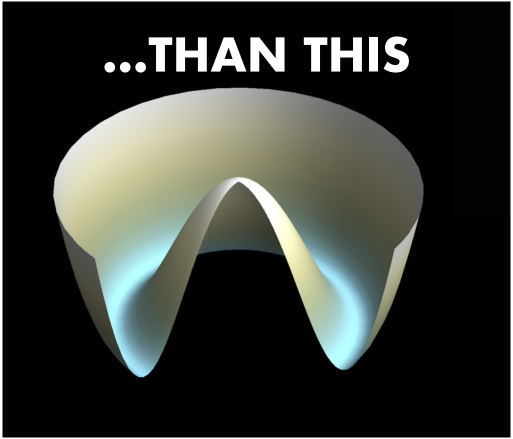
(here weighted by improvement of Higgs couplings over HL-LHC, and with power mix predictions for CERN, US, Japan, China):

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

arXiv:2307.04084

Some challenges





On Money

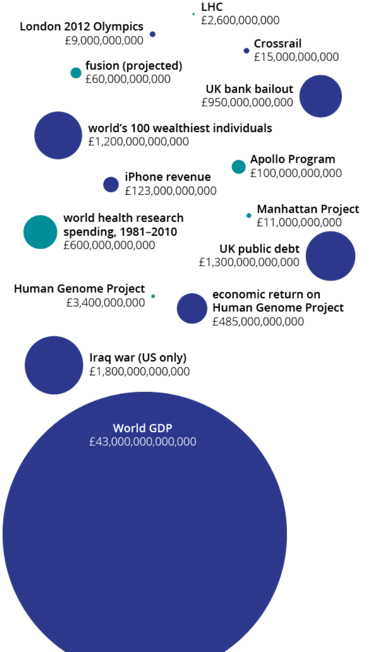
Costs of future colliders sound astronomical – tens of billions of euros/dollars.

Should try to put these costs in context – e.g. cost per citizen per year / comparison with other large projects.

Great work by Andrew Steele on this at www.scienceogram.org

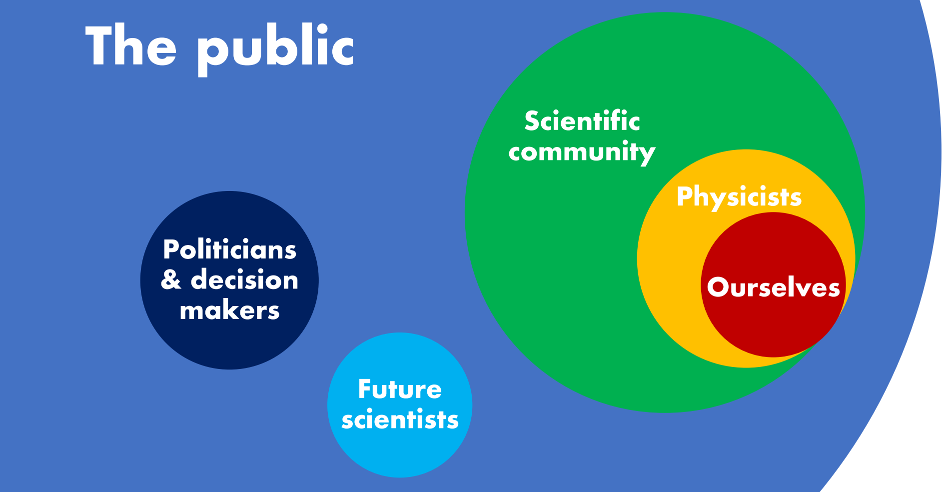
Discovering the Higgs boson literally cost peanuts.

The UK subscription to CERN and the LHC costs us £1.50 per person per year; about the same as we spend on peanuts.



Big science and big money
All values in present-day GBP

Who do we need to persuade?



The public

Politicians
& decision
makers

Future
scientists

Scientific
community

Physicists

Ourselves

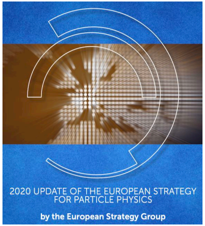
Timeframe

◆ 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



2020 UPDATE OF THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS

by the European Strategy Group

Waiting for you!