# 03/2024 Topical Lectures: Future Colliders

This morning: Hardware and theory

Following mornings: Accelerators and various projects

- The order is a bit unnatural, dictated by availability of people

Today and tomorrow afternoon: Software tutorial valid for all projects

Friday afternoon: Elevator pitches

[indico]

**Patrick Koppenburg**
[@pkoppenburg.bsky.social] [@pkoppenburg] [patrick.koppenburg@nikhef.nl]

Nikhef

[B]

# Strategies

2020 — Update of the European Strategy: "An **electron-positron Higgs factory** is the highest-priority." "For the longer term, [...] operate a **proton-proton collider** at the highest achievable energy."

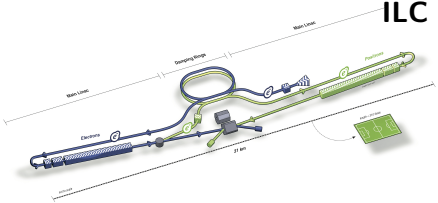

2023 — US Particle Physics Project Prioritization Panel: "An **off-shore Higgs factory**, realized in collaboration with international partners. FCC-ee and ILC meet our scientific requirements." "[...] while performing critical R&D towards a muon collider [...] on US soil. **This is our Muon Shot.**"


2025 — 15TH Chinese Five-Year Plan

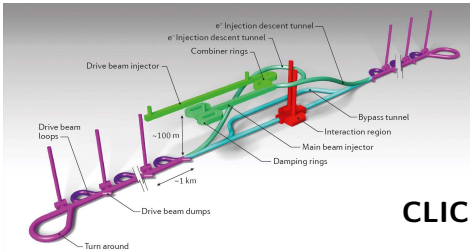
2026 (?) — Update of the European Strategy for Particle Physics

# $e^+e^-$ COLLIDERS

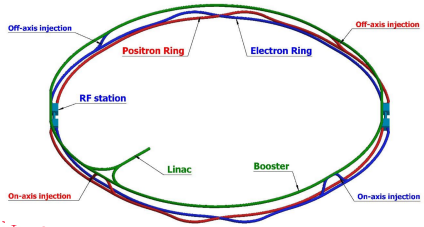
## ILC



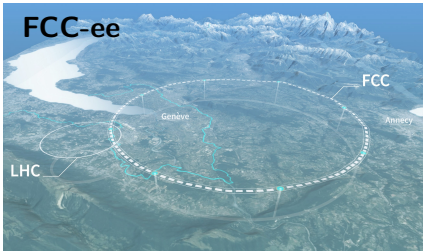

## CLIC




## CEPC

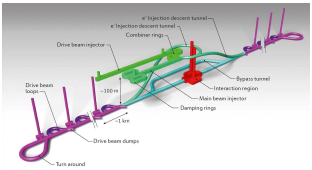



## FCC-ee

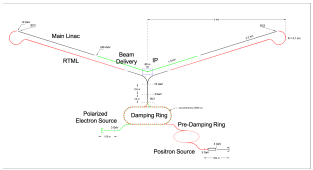


# $e^+e^-$ COLLIDERS

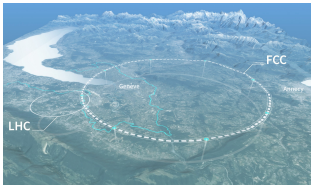
ILC



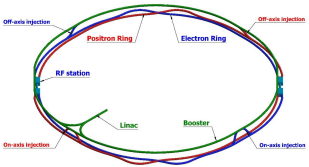

CLIC




$C^3$

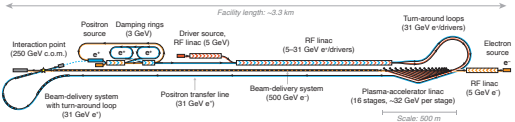



FCC-ee



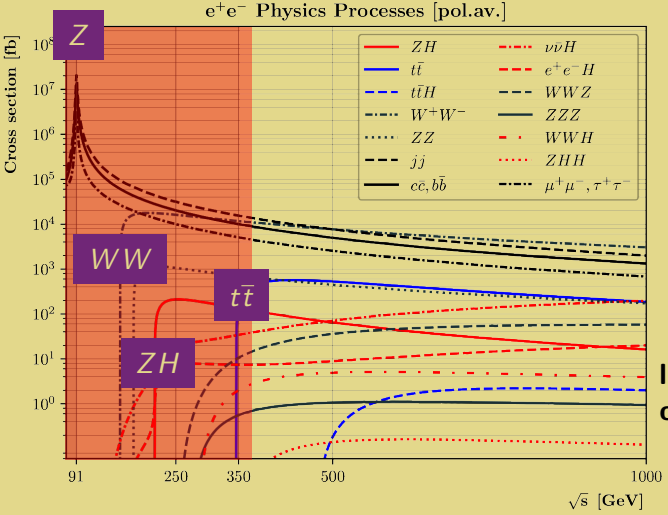

CEPC

HALHF



# ECFA $e^+e^-$ Higgs/Top/EW Factory Study

**circular colliders**



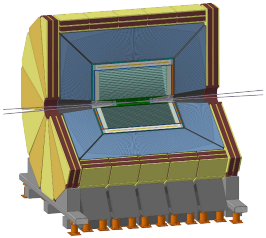

**linear colliders**

[J.R. Reuter]

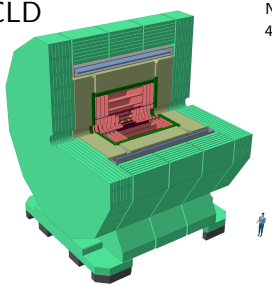
[B]

# FCC/ILC/CEPC/C$^3$ DETECTORS

IDEA

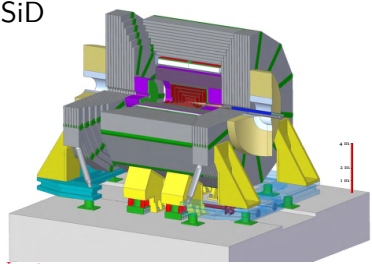


CLD

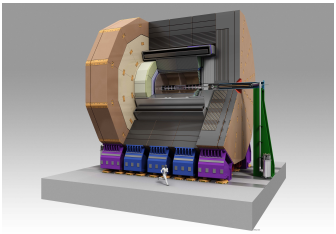


Not (yet) shown: CEPC 4$^{th}$ concept, ALLEGRO

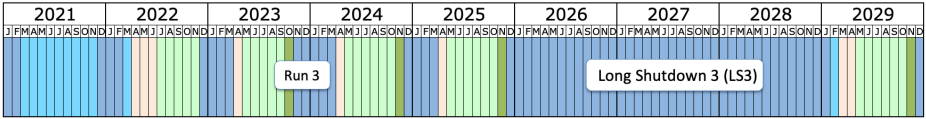
SiD

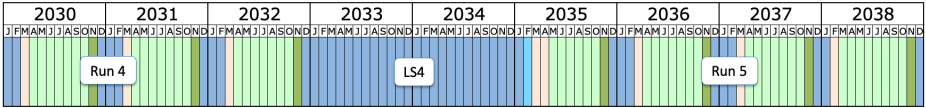


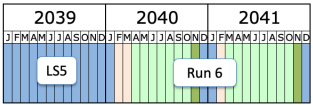
ILD



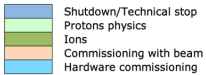
# LHC schedule (Apr 2023)



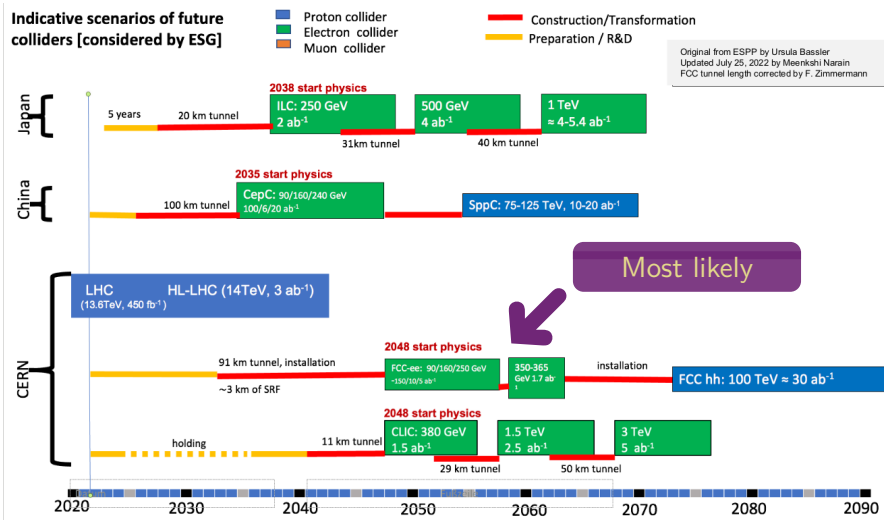




Last update: April 2023

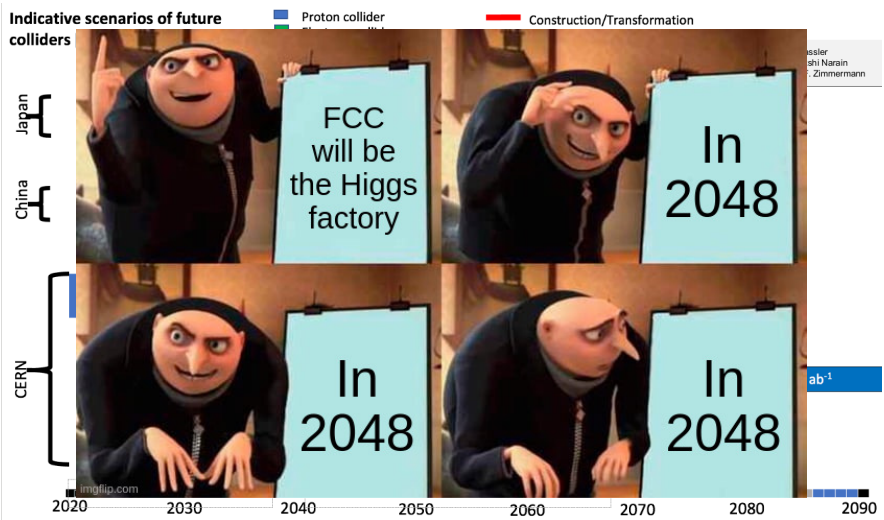


# Projects


Indicative scenarios of future colliders [considered by ESG]
Proton collider
Electron collider
Muon collider
Construction/Transformation
Preparation / R&D
Original from ESPP by Ursula Bassler
Updated July 25, 2022 by Meenkshi Narain
FCC tunnel length corrected by F. Zimmermann
Japan
2038 start physics
5 years
20 km tunnel
ILC: 250 GeV
2 ab-1
500 GeV
4 ab-1
1 TeV
≈ 4-5.4 ab-1
31km tunnel
40 km tunnel
China
2035 start physics
100 km tunnel
CepC: 90/160/240 GeV
100/6/20 ab-1
SppC: 75-125 TeV, 10-20 ab-1
Most likely
CERN
LHC
HL-LHC (14TeV, 3 ab-1)
(13.6TeV, 450 fb-1)
2048 start physics
91 km tunnel, installation
~3 km of SRF
FCC-ee: 90/160/250 GeV
~150/10/5 ab-1
350-365 GeV 1.7 ab-1
installation
FCC hh: 100 TeV ≈ 30 ab-1
2048 start physics
holding
11 km tunnel
CLIC: 380 GeV
1.5 ab-1
1.5 TeV
2.5 ab-1
3 TeV
5 ab-1
29 km tunnel
50 km tunnel
2020
2030
2040
2050
2060
2070
2080
2090

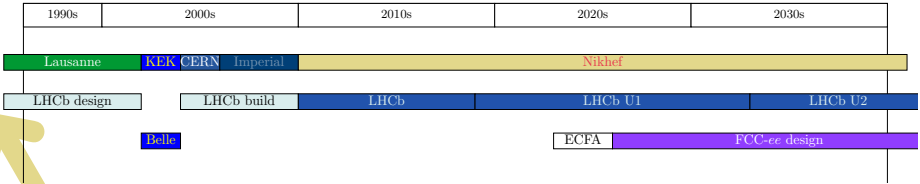
[Karl Jakobs, Oct 2023]

# Projects



# Work gantt chart (for collider folks)

**My work life is:**

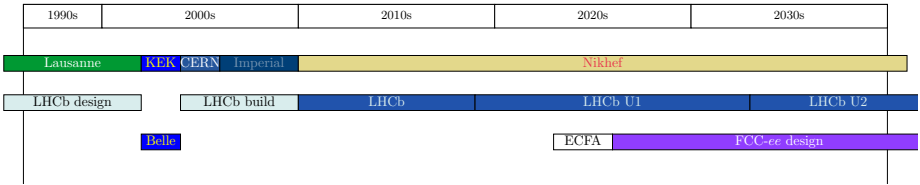



In October 1994 I was technical assistant for a conference called "*Large facilities in physics*"

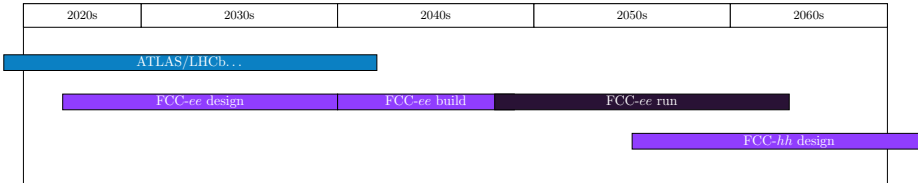
[inspireHep]

# Work gantt chart (for collider folks)

## My work life is:

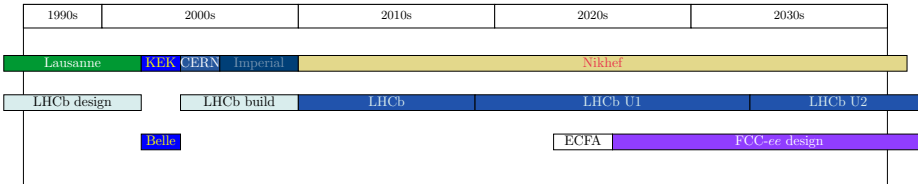



## Your work life could be:

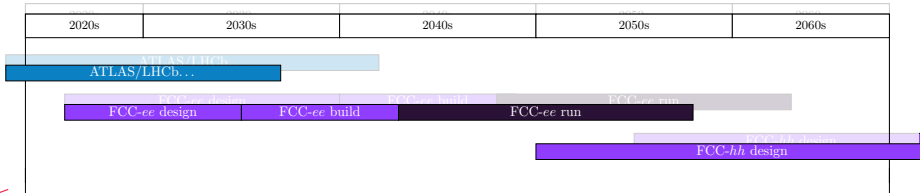


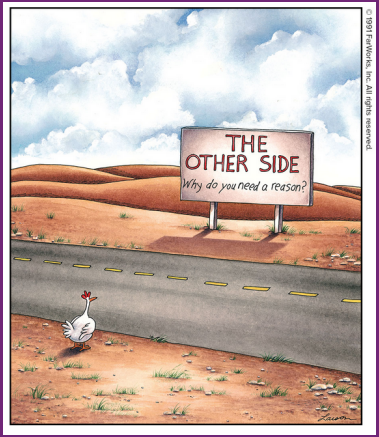
# Work gantt chart (for collider folks)

## My work life is:




## Your work life could be (accelerated):



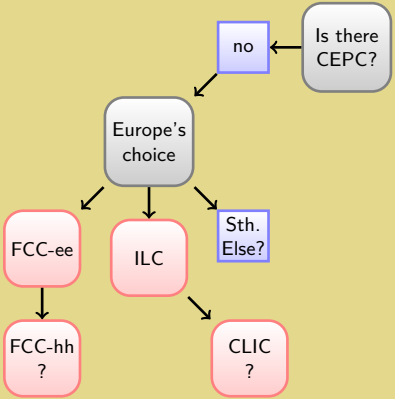

THE
OTHER SIDE
Why do you need a reason?
© 1997 FarWorks, Inc. All rights reserved.

# Backup

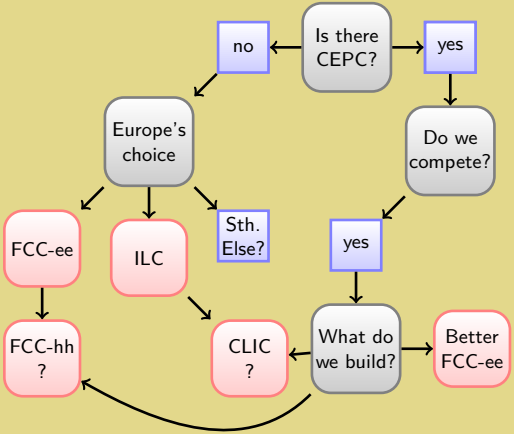
# Decision tree (CEPC centric)

Is there CEPC?

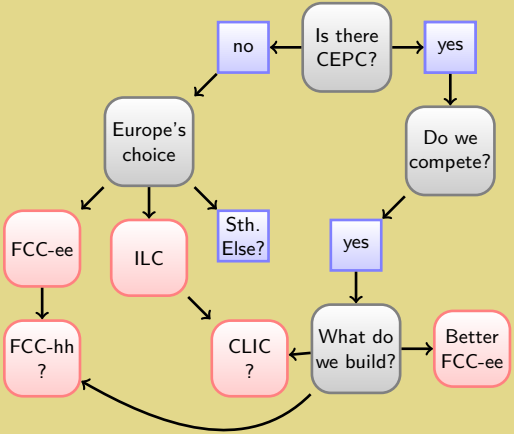
# Decision tree (CEPC centric)



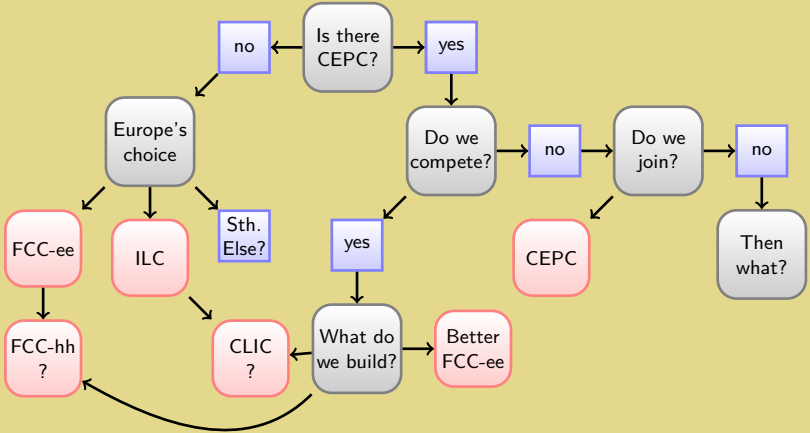
# Decision tree (CEPC centric)



# Decision tree (CEPC centric)

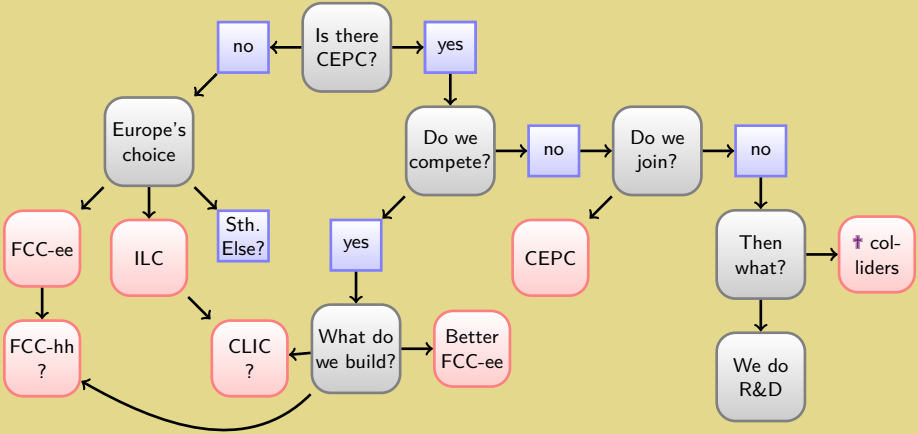


# Decision tree (CEPC centric)

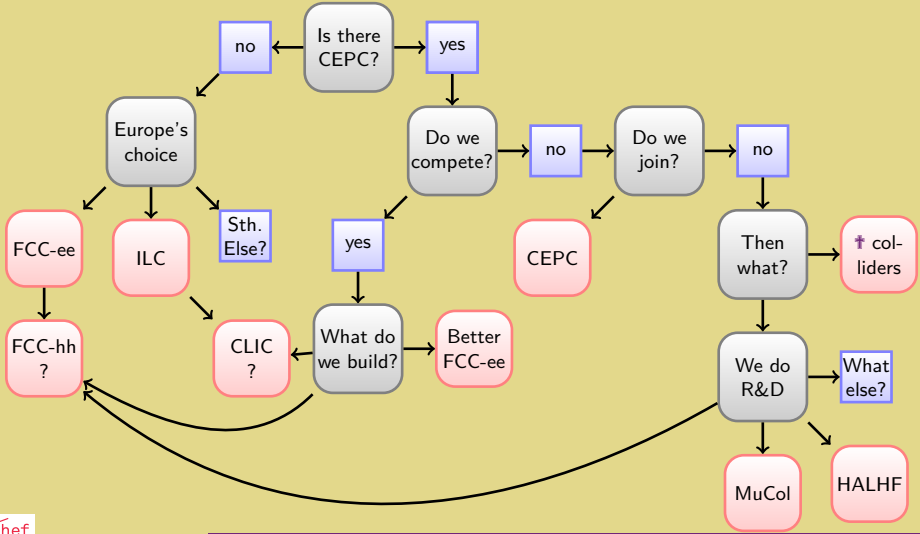



CEPC participation should be via CERN

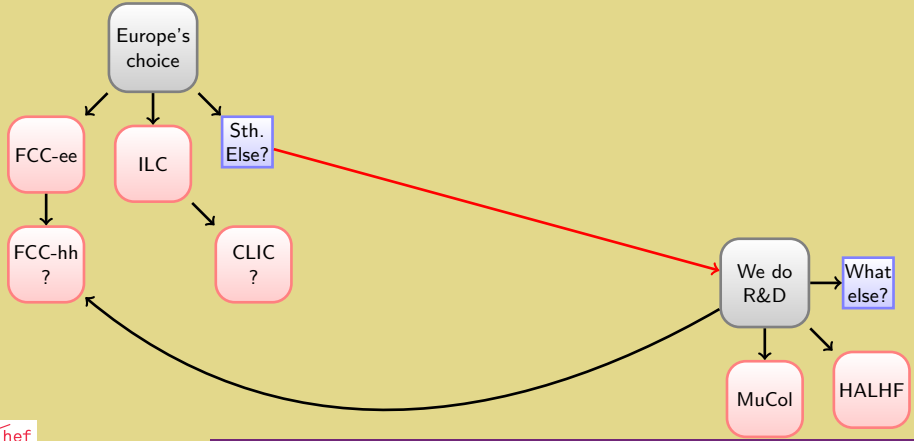
# Decision tree (CEPC centric)



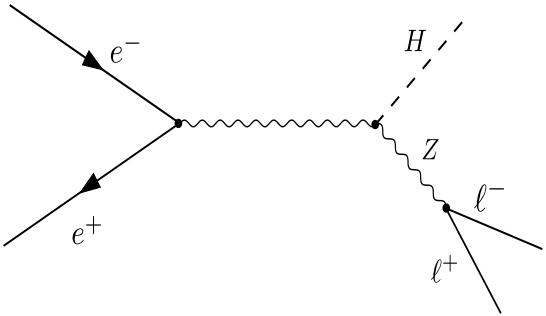
# Decision tree (CEPC centric)



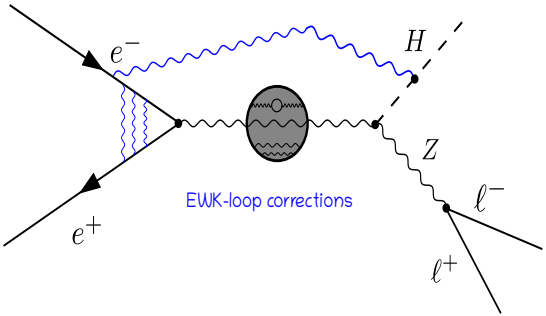
# Decision tree (Europe centric)



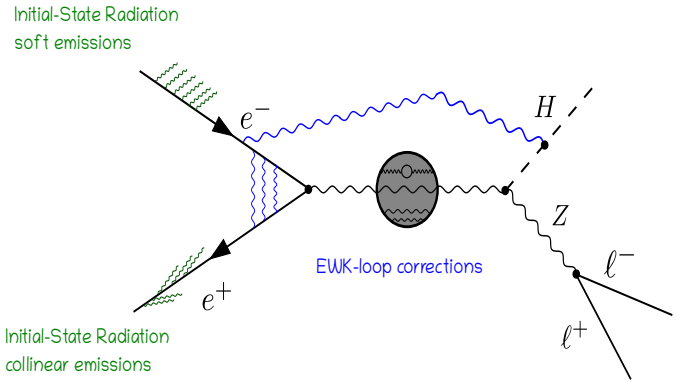
# An $e^-e^+$ collider is a clean environment



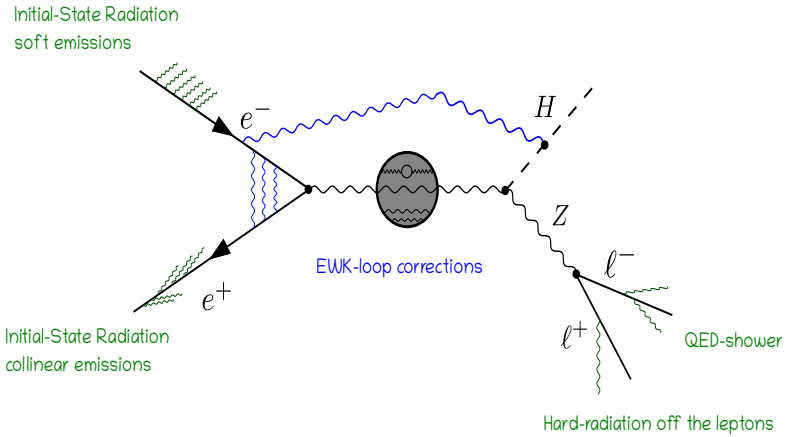
# An $e^-e^+$ collider is a clean environment



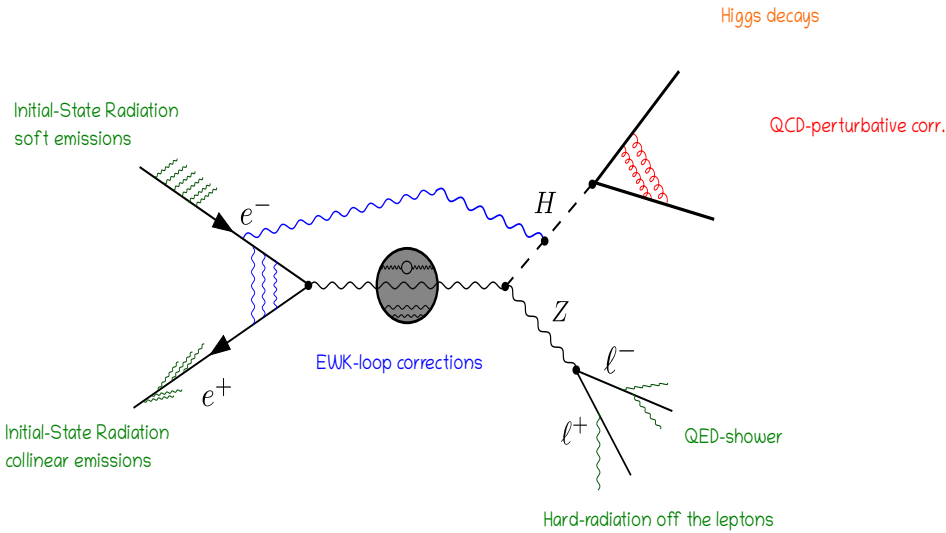
# An $e^-e^+$ collider is a clean environment



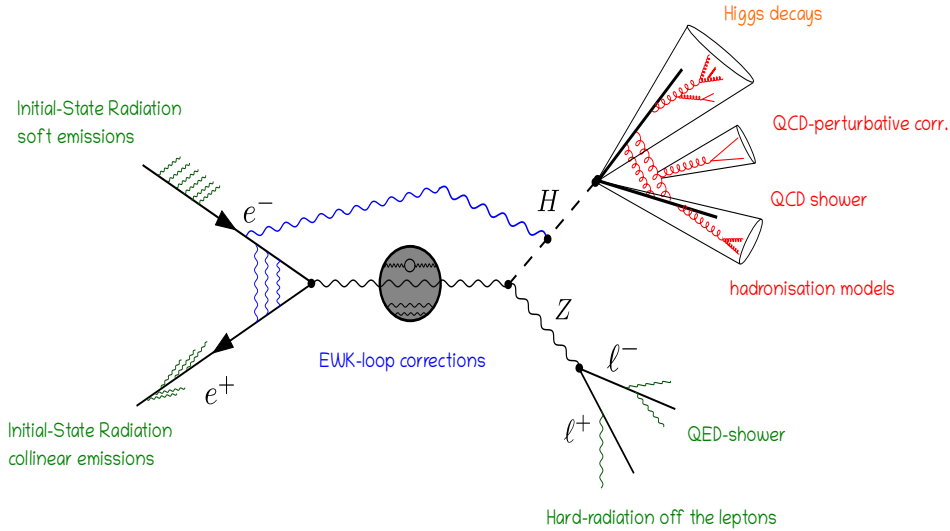
# An $e^-e^+$ collider is a clean environment



# An $e^-e^+$ collider is a clean environment



# An $e^-e^+$ collider is a clean environment



# Report on the ECFA $e^+e^-$ workshop in Paestum

- **A glimpse of what you missed**
- **. . . why you should come to the next**

Dive into my ECFA talk on [indico]

[indico]

**Patrick Koppenburg**

[@pkoppenburg.bsky.social] [@pkoppenburg] [patrick.koppenburg@nikhef.nl]

# ECFA $e^+e^-$ WG1 Focus Topics

| | Topic | lead group | Title |
|---|---|---|---|
| 1 | HtoSS | HTE | $e^+e^- \to Zh$: $h \to s\bar{s}$ |
| 2 | ZHang | HTE (GLOB) | $ZH$ angular distributions and CP studies |
| 3 | Hself | GLOB | Higgs self-coupling |
| 4 | Wmass | PREC | Mass and width of the $W$ boson |
| 5 | WWdiff | GLOB | Full studies of $WW$ and $e\nu W$ |
| 6 | TTthres | GLOB (HTE) | Top threshold |
| 7 | LUMI | PREC | Precision luminosity measurement |
| 8 | EXscalar | SRCH | New exotic scalars |
| 9 | LLPs | SRCH | Long-lived particles |
| 10 | EXtt | SRCH | Exotic top decays |
| 11 | CKMWW | FLAV | CKM matrix elements from $W$ decays |
| 12 | BKtautau | FLAV | $B^0 \to K^{0*}\tau^+\tau^-$ |
| 13 | TwoF | HTE | EW precision: 2-fermion final states ($\sqrt{s} = M_Z$ and beyond) |
| 14 | BCfrag | FLAV (PREC) | Heavy quark fragmentation and hadronisation } merged |
| 15 | Gsplit | PREC (FLAV) | Gluon splitting and quark-gluon separation } merged |

# ECFA $e^+e^-$ WG1 Focus Topics

| | Topic | lead group |
|---|---|---|
| 1 | HtoSS | HTE |
| 2 | ZHang | HTE (GLOB) |
| 3 | Hself | GLOB |
| 4 | Wmass | PREC |
| 5 | WWdiff | GLOB |
| 6 | TTthres | GLOB (HTE) |
| 7 | LUMI | PREC |
| 8 | EXscalar | SRCH |
| 9 | LLPs | SRCH |
| 10 | EXtt | SRCH |
| 11 | CKMWW | FLAV |
| 12 | BKtautau | FLAV |
| 13 | TwoF | HTE |
| 14 | BCfrag | FLAV (PREC) |
| 15 | Gsplit | PREC (FLAV) |

**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], Ivanka Bozovic[14], Valentina Cairo[6], Nuno 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[34], Daniel Jeans[35], Jernej F. Kamenik[36], 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], Kirill Skovpen[66], Maciej Skrzypek[40], Yotam Soreq[67], Raimund Ströhmer[18], Taikan Suehara[68], Junping Tian[68], Emma Torro Pastor[33], Maria Ubiali[46], Luiz Vale Silva[33], Caterina Vernieri[8], Alessandro Vicini[69] Marcel Vos[33], Aidan R. Wiederhold[70], Sarah Louise Williams[30], Graham Wilson[71], Aleksander Filip Zarnecki[72], Dirk Zerwas[73,57]

**Abstract**

In order to stimulate new engagement and trigger some concrete studies in areas where further work would be beneficial towards fully understanding the physics potential of an $e^+e^-$ Higgs / Top / Electroweak factory, we propose to define a set of focus topics. The general reasoning and the proposed topics are described in this document.

# Next steps


## Next steps (Aidan Robson)

1. Document describing the focus topics [de Blas, Koppenburg, List, Maltoni, et al., arXiv:2401.07564]
2. Inputs by end 2025
   - ➜ Report structure by 2024
     - Focus input by May 2025,
     - Editing in summer
3. Next strategy in 2026–27

Or maybe faster?