

ECFA activities towards an e^+e^- Higgs factory



*2nd ECFA Workshop, Paestum
12th October 2023*

Karl Jakobs, ECFA Chair

ECFA

European Committee for Future Accelerators





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.

4. Other essential scientific activities for particle physics

C. The **success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures**. To prepare and realise future experimental research programmes, the community must **maintain a strong focus on instrumentation. Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities.** ...

Deliberation Document:

“Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields. ...”

Implementation of these recommendations

- FCC feasibility study → CERN
- Accelerator R&D Roadmap → Lab Directors Group (LDG)
- Detector R&D Roadmap → ECFA
- ECFA study on e^+e^- factory → ECFA

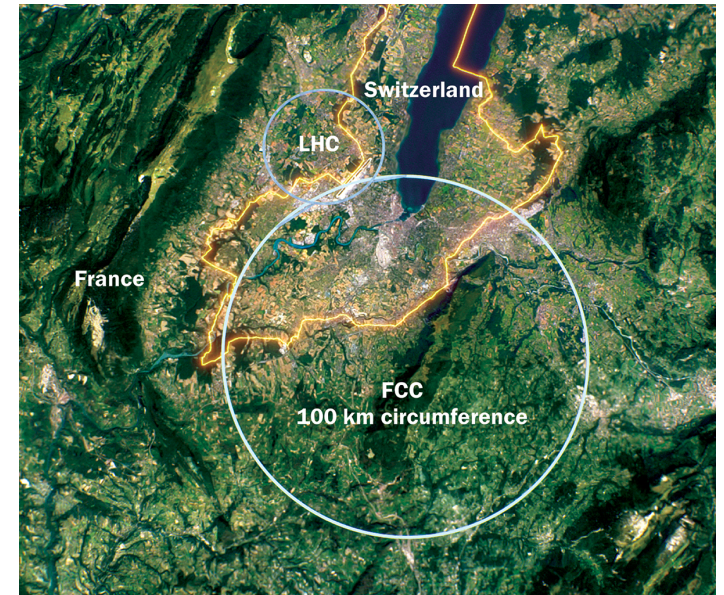




FCC Feasibility Study

Explore the feasibility for an integrated FCC-ee / FCC-hh programme at CERN

- Study and its organisational structure have been approved by CERN Council in June 2021
- Report to be released by end of 2025
→ Basis for a decision at the next Strategy Meeting 2026/27
(mid-term report in Nov. 2023)
- Major deliverables and milestones
 - Understand the realisation (geology, infrastructure, political, ...)
 - Collider design, with clear focus on FCC-ee
 - Timeline and cost for FCC-ee
 - Contributions from outside CERN
 - Physics case and experiment design
 - Sustainable operational model for the colliders and experiments (environmental aspects, energy efficiency, ...)
- Address technical issues of Hadron Collider
Large technological challenges, 16 T superconducting magnets not yet available

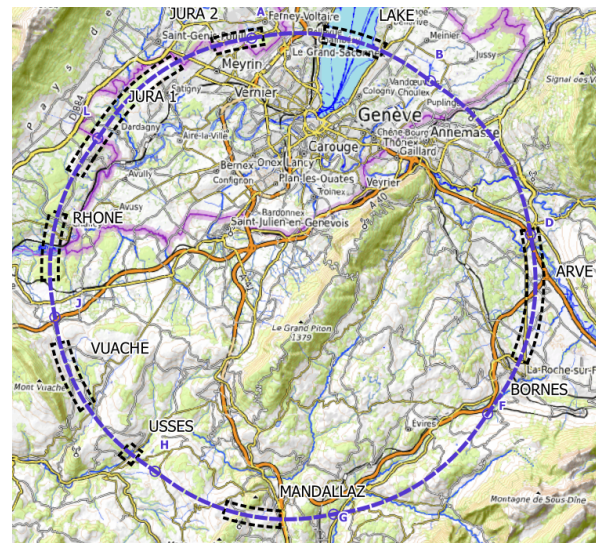




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Converging on a “low risk” placement with circumference of 91 km

(4-fold symmetry, 8 surface points, 2-4 e^+e^- experiments)

Significant progress on many fronts,
→ talk by M. Benedikt at next ECFA Plenary meeting on 17 Nov. 2023 at CERN (open to full community)

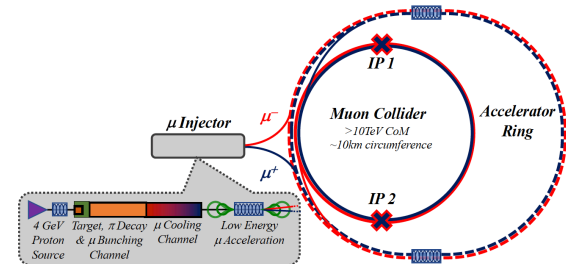
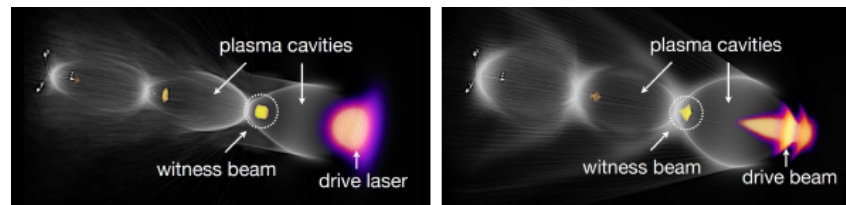
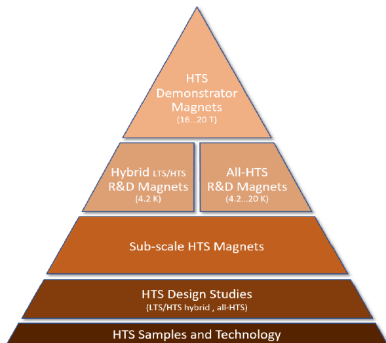
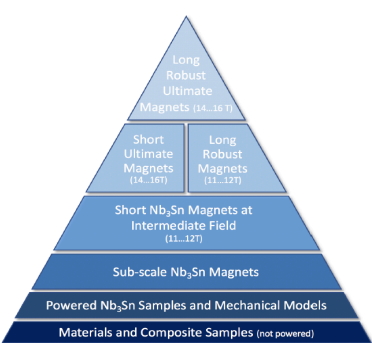
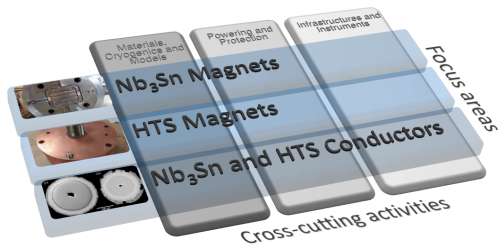
Research and Development on Accelerator Technologies

From the European Strategy:

Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry.

The technologies under consideration:

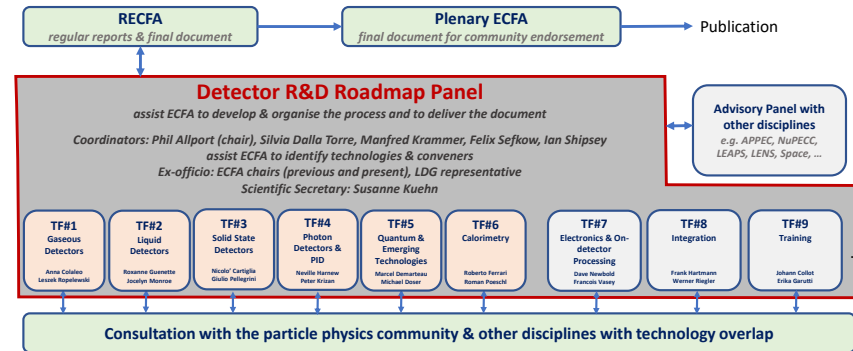
High-field magnets, high-temperature superconductors
Plasma / Laser acceleration
Bright muon beams (→ Muon collider)
Energy recovery linacs
+ High-gradient RF structures



ECFA Roadmap on Detector R&D



- As suggested by the 2020 Update on the European Strategy a Roadmap for Detector R&D has been developed;
Released at the end of 2021: <https://cds.cern.ch/record/2784893>
- The implementation of the roadmap foresees the formation of Detector R&D Collaborations (DRDs) at CERN;
One for each of the six technology areas + electronics
- Five proposals have been submitted and are under review by the newly established Detector R&D Committee (DRDC) with support by the ECFA Detector Panel (co-chaired by P. Allport, D. Contardo)
 - DRD1: gaseous detectors
 - DRD2: liquid detectors
 - DRD3: solid state detectors
 - DRD4: particle identification and photon detection
 - DRD6: calorimeters



DRD5 (quantum, emerging technologies) and
 DRD7 (electronics, transversal activity) will submit proposals by the end of this year
 (later timescale due to: internal coord. (DRD5), coordination with other DRDs (DRD7))

- Collaborations are open for world-wide collaboration; participation from outside Europe is very welcome!

- DRDC has been set up and is complete:
<http://committees.web.cern.ch>
- Recommendations on approval are expected to be issued by the DRDC early December
 - Final decision on approval by the CERN Research Board shortly after
- Start-up of new Collaborations in January 2024;
- During 2024 Memoranda of Understanding with Funding Agencies are expected to be signed.

Funding-agency involvement is planned via RRB-like meetings
(Details are still under discussion with CERN management)

Detector R&D Committee (DRDC)

BERGAUER, Thomas	HEPHY, Vienna, Chairperson
TROSKA, Jan	CERN, Scientific Secretary
Members - Referees	
BENTVELSEN, Stan	NIKHEF
BRESSLER, Shikma	Weizmann Institute of Science
BUDKER, Dimitry	Helmholtz Institute Mainz and Johannes Gutenberg University
FORTY, Roger	CERN
GEMME, Claudia	INFN and University, Genoa
GIL BOTELLA, Ines	CIEMAT
MERKEL, Petra	Fermilab
PESARESI, Mark	Imperial College
SERIN, Laurent	IJCLab - Laboratoire de physique des 2 infinis
Members Ex-officio	
ALLPORT, Phil	ECFA Detector Panel (EDP) Co-Chair
CONTARDO, Didier	ECFA Detector Panel (EDP) Co-Chair

Detector R&D Roadmap: General Strategic Recommendations

- GSR 1 - Supporting R&D facilities
- GSR 2 - Engineering support for detector R&D
- GSR 3 - Specific software for instrumentation
- GSR 4 - International coordination and organisation of R&D activities
- GSR 5 - Distributed R&D activities with centralised facilities
- GSR 6 - Establish long-term strategic funding programmes
- GSR 7 - Blue-sky R&D
- GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts → ECFA Training Panel
- GSR 9 - Industrial partnerships
- GSR 10 - Open Science

ECFA-LDG Working group to address the remaining General Strategic Recommendations has started its work
Chairs: Stan Bentvelsen (Nikhef) and Marko Mikuz (Ljubljana)

ECFA Training Panel

The conclusions of the detector R&D roadmap document (<https://cds.cern.ch/record/2784893>) explicitly stress the need to train and maintain a work force in instrumentation for particle physics, targeting, with the highest priority, graduate students and Early Career Researchers (ECR).

→ **ECFA Training Panel** has been set up;

Chairs: Erika Garutti (Hamburg), NN

Goals:

- Enhance the synergies between existing training programmes and stimulate the creation of complementary ones where relevant, in particular multidisciplinary schools or academia-industry-joined training programmes.
- Creation of a European master's degree programme in HEP instrumentation

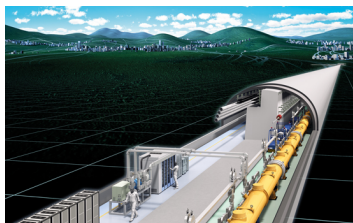
During the roadmap process it was realised that there was a **mutual interest to also involve training in accelerators and to support cross-disciplinary activities** with this area. As a result, the recommendations state that the same panel should also coordinate the synergies between HEP instrumentation and accelerator training provision.

2. ECFA Study on Physics, Experiments and Detectors at a Future e^+e^- Factory

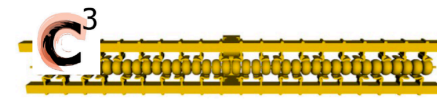
“ECFA recognizes the need for the experimental and theoretical communities involved in physics studies, experiment designs and detector technologies at future Higgs factories to gather. **ECFA supports a series of workshops** with the aim to **share challenges and expertise, to explore synergies in their 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

Bring together communities & activities, explore synergies, discuss challenges

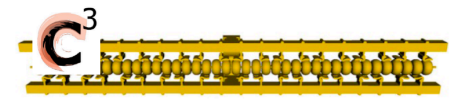
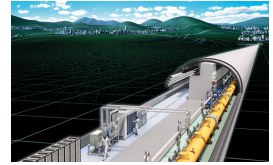


Projects exist, which are technically well advanced



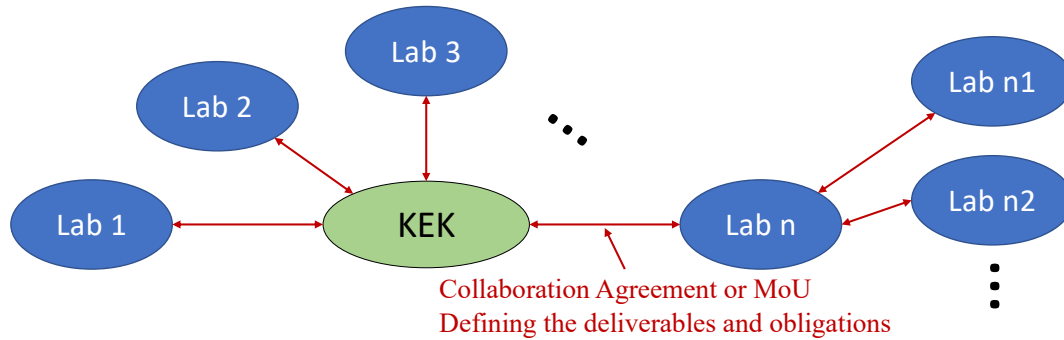
The Approval status

- **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

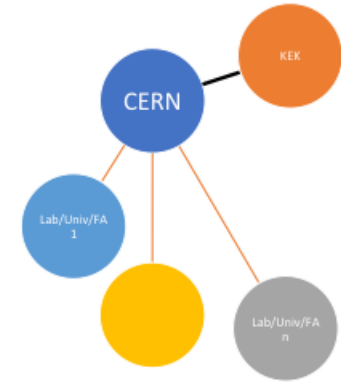


ILC Technology Network:

- 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).



Tatsuya Nakada, ICFA, 28th March

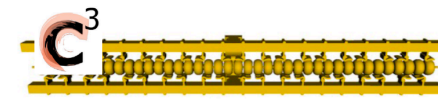
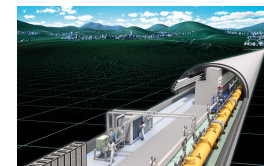


CERN has coordinating role in Europe



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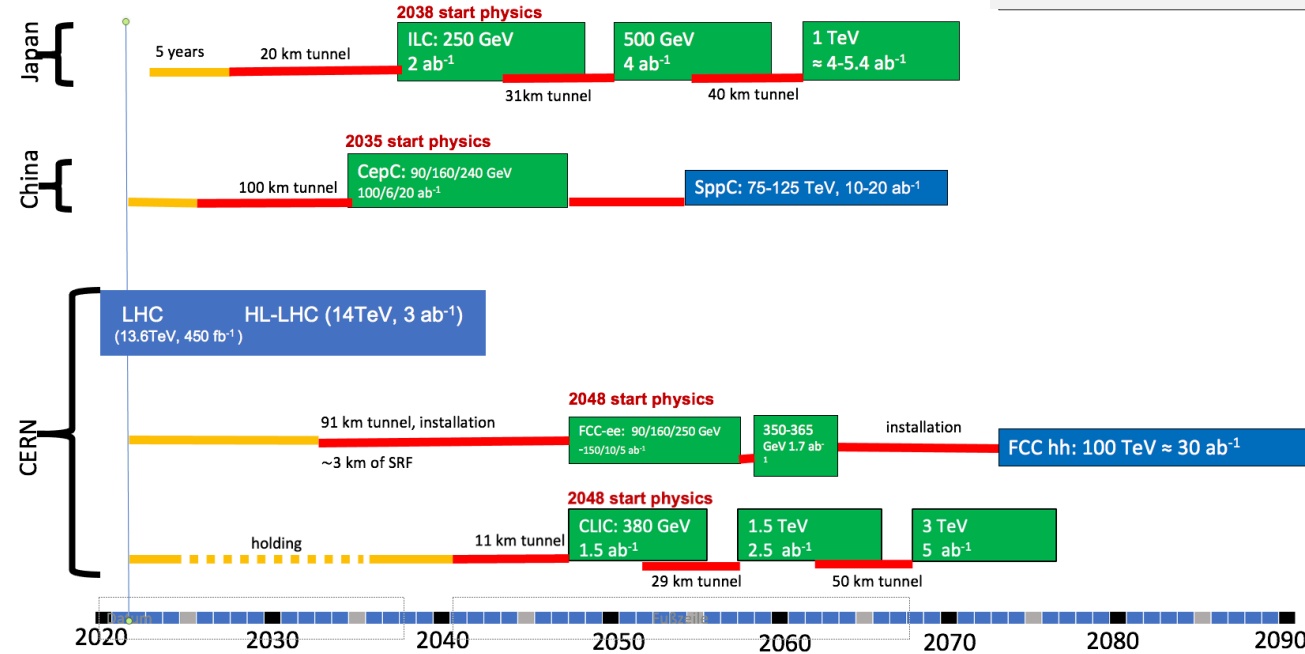


Timelines

Indicative scenarios of future colliders [considered by ESG]



Original from ESPP by Ursula Bassler
 Updated July 25, 2022 by Meenkshi Narain
 FCC tunnel length corrected by F. Zimmermann



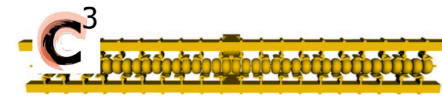
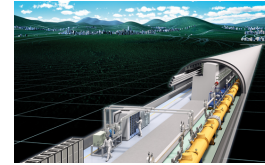
Comments:

- e^+e^- timelines are limited by approval processes
- CEPC and ILC projects need to get approval in the near future to maintain these schedules
- CERN projects are linked to completion of the HL-LHC
- hh timelines are limited by technology issues, costs, proceeding e^+e^- projects

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, ...)



The outstanding questions are compelling, difficult and interrelated

→ They can only be successfully addressed through a **variety of approaches**

- Particle colliders
- Dark matter direct and indirect searches
- Neutrino experiments
- Cosmic surveys
- Measurements of rare processes
- Dedicated searches (e.g. axions, dark-sector particles, feebly interacting particles, ...)

	High-E colliders	Dedicated high-precision experiments	Neutrino experiments	Dedicated searches	Cosmic surveys
H, EWSB	x	x		x	
Neutrinos	x (ν_e)		x	x	x
Dark Matter	x			x	x
Flavour, CP, matter/antimatter	x	x	x	x	x
New particles, forces, symmetries	x	x		x	
Universe acceleration					x

High-energy accelerators are one of the best tools for exploration; **unique** in studying the Higgs boson

Needed: Precision + Energy

- (1) **Scientific diversity**, and the **combination of complementary approaches**, are crucial to explore directly and indirectly the largest range of energy scales and couplings, and to properly interpret signs of new physics to reach the goal to build a coherent picture of the underlying theory
- (2) **Global coordination and optimisation** of the particle physics programme is necessary to maximise the opportunities of the field, given the exciting physics questions, the cost and complexity of the projects

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, ...)

Where do we stand?

After a rather slow start, the activities are ramping up!

Excellent work of the working group conveners / Programme Committee!

The **Program Committee** consists of the WG conveners:

- WG1: Jorge de Blas (U. Granada), Patrick Koppenburg (Nikhef), Jenny List (DESY / CERN), Fabio Maltoni (UC Louvain / Bologna)
- WG2: Patrizia Azzi (INFN-Padova / CERN), Fulvio Piccinini (INFN Pavia), Dirk Zerwas (IJCLab/DMLab)
- WG3: Mary-Cruz Fouz (CIEMAT), Giovanni Marchiori (IN2P3, APC Paris), Felix Sefkow (DESY)
- ECFA IAC: Christos Leonidopoulos (University of Edinburgh), Aidan Robson (University of Glasgow)

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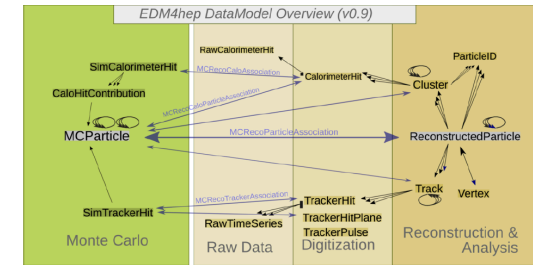
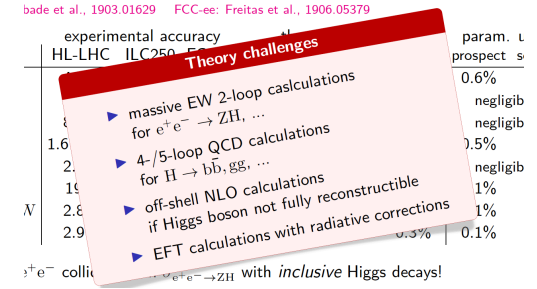
+ **Theory involvement** ramping up, good progress on generators, ... but still a lot of work required e.g. on precision calculations (→ stronger participation welcome, ECFA study provides a forum!)

+ Lot of progress on **software tools (key4hep)**! Full simulation and reconstruction on the way, appreciate tutorials & documentation

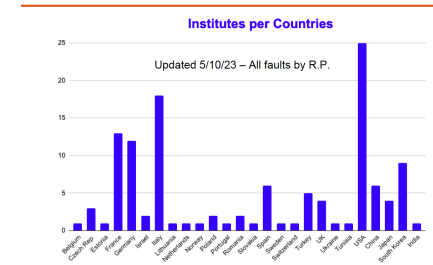
+ **Detector interface** group started activities; Good to see integration in detector R&D;

+ Definition of **Focus Topics** was a good idea, ramping up, but definitely room for more people to join;

This would also allow to extend the topics and broaden the physics coverage towards the next ESPP.



DRD Calo – Overall Interest



Where do we stand?

- Despite being busy with LHC data analysis, Phase-II detector upgrades or Belle-II, a stronger engagement of LHC or Belle-II people would be desirable
 - e.g. via mixed thesis projects LHC + future collider e^+e^- studies, ...
- Very happy to see participation of non-European colleagues joining (US, Asia, ...)
Not only in DRDs, but also beyond in the ECFA studies!
- To improve the person power situation, we must continue to work on Funding Agencies / Institutes that resources for future collider studies are provided

→ ECFA

Where do we go from here?

- Results of the study will be documented in an **ECFA report**
- This report is a key input for the next update of the European Strategy of Particle Physics (ESPP) (targeted for 2026/2027)

Submission date of FCC Feasibility study: end of 2025

(→ Dec. 2025 is a reasonable assumption for the input date for the strategy process)

- **More details about the plans will be presented by Aidan Robson tomorrow, at the end of the workshop** (driven by Main Editors (Aidan Robson, Christos Leonidopoulos) and WG conveners, obviously timeline will be adapted to changes of strategy timeline)
- We should use the remaining time to achieve as much as possible (Focus topics; eventually expand to enlarge the scope (additional topics))
- One more ECFA workshop planned: ~ autumn 2024;
Call for hosting the next ECFA workshop will go out soon

Final Comments

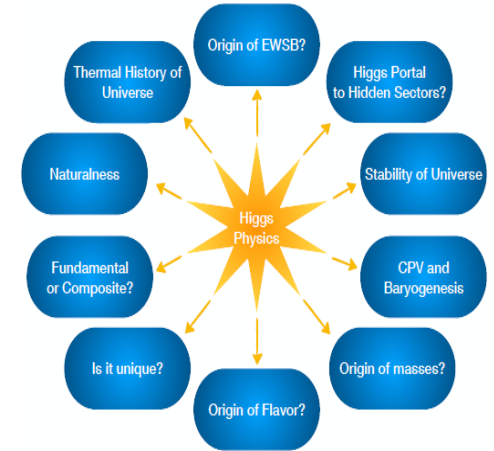
- High-energy future colliders will play a key role in the exploration of crucial fundamental questions of physics
- Consensus:
 - Exploration of the Higgs sector is vital
 - To be addressed with an e^+e^- collider in a first stage

Mature options for the realisation of such a collider exist:
FCC-ee, CLIC (at CERN), ILC (JP) CEPC (CN), (C³, US)

Long timescales → approval process must converge soon!

@Europe: a decision must be taken at the next ESPP (2026/27)!
(CERN, definition of the next project is vital)

- Longer-term options: High-energy Hadron Collider (FCC-hh, SppC)
Significant R&D is required and must probably be intensified!
→ Coherent and large effort on magnet R&D is needed!
+ Muon Collider (is it an alternative?, significant R&D required)



Final Comments

- **Important for the realisation of the next collider(s):**
 - * Broad support within the HEP community is needed!
 - * Early career researchers should get involved
 - * Convince decision makers and the public of the incredible physics case and of the vital role of high-energy colliders
 - more efforts needed (in line with the discussion today!)
 - * Continue optimisation efforts on power reduction!

