Next Generation Frontier: The Future Circular Collider

Christoph Paus, MIT

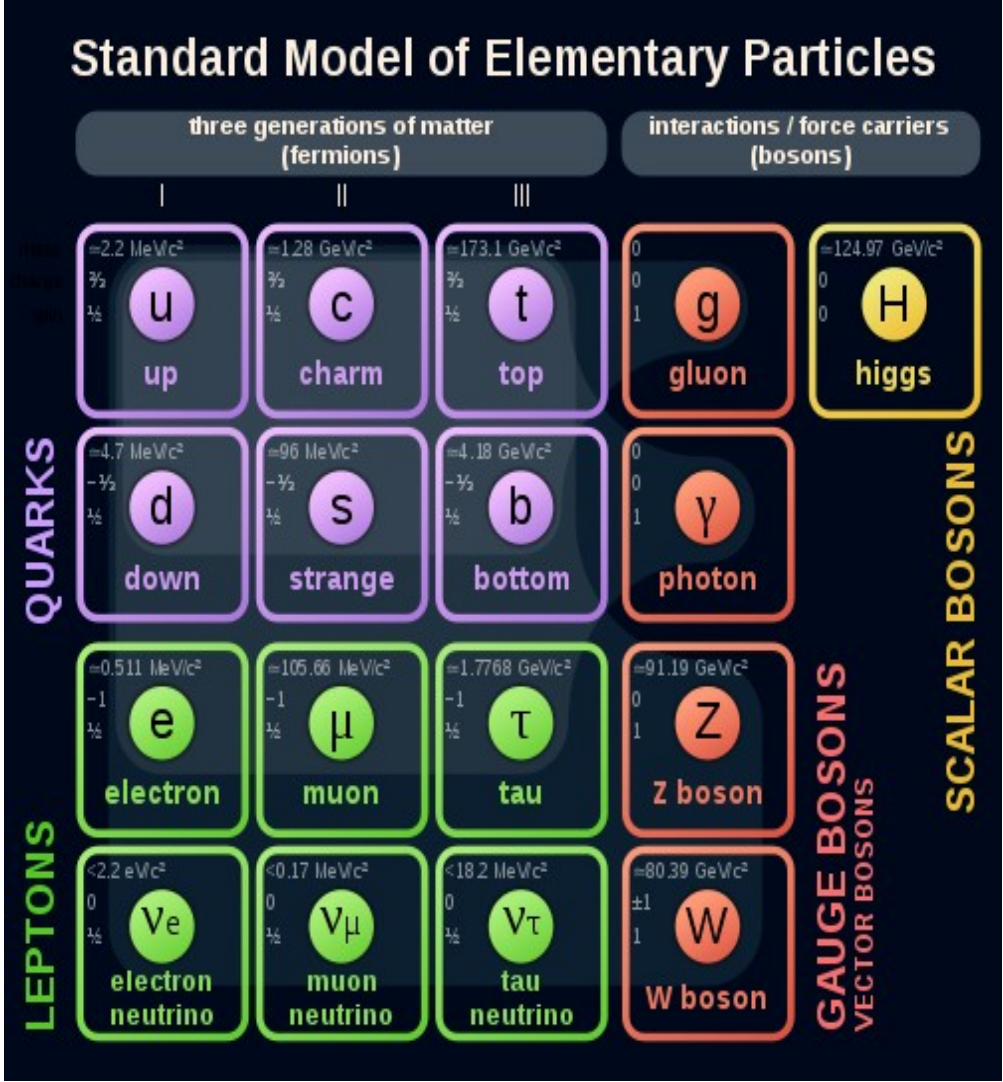
August 3, 2026
John Hill visits MIT

The world...

as we know it today!

Status

- Latest: the Higgs boson, in 2012
- It looks simple enough and complete, *are we done?*



The world... as we know it today!

Many fundamental issues

- What is dark matter?
- How does gravity fit in?
- What about matter-antimatter asymmetry?
- Higgs is weird. Why 125 GeV?
- ...

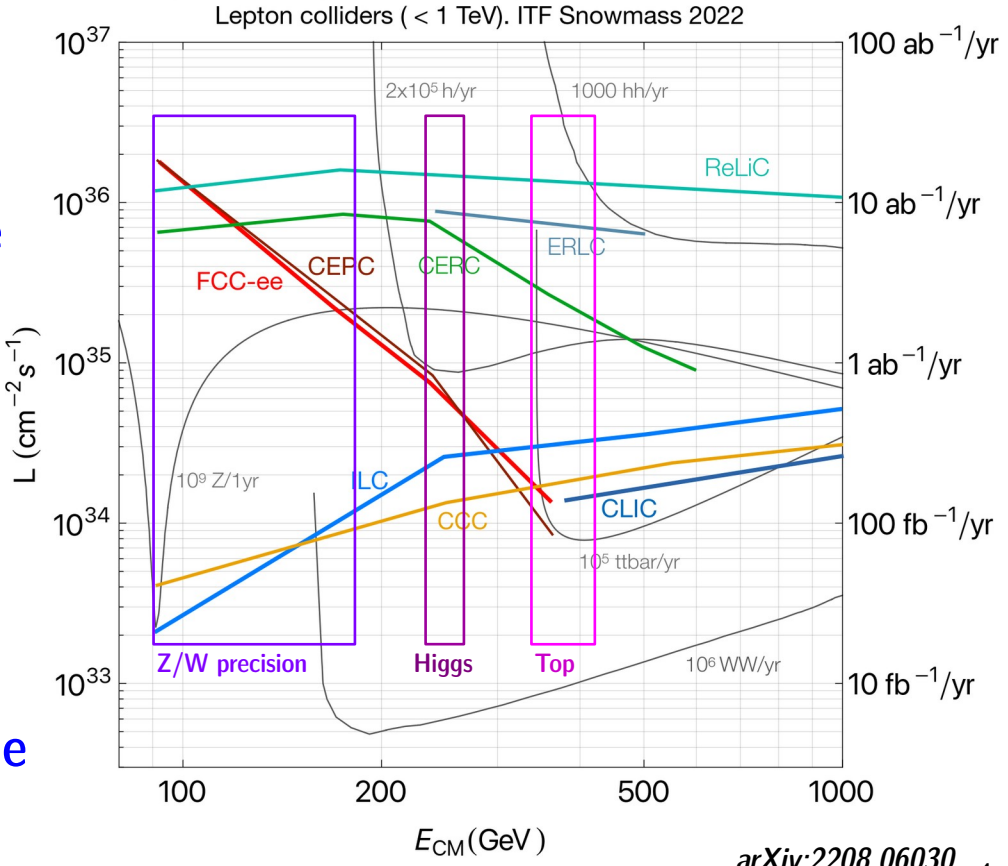
Potential of FCC-ee Machine

Higgs Physics

- Driven by the number of Higgs bosons produced
- Linear and Circular options promise ~ same number of Higgses for proposed running

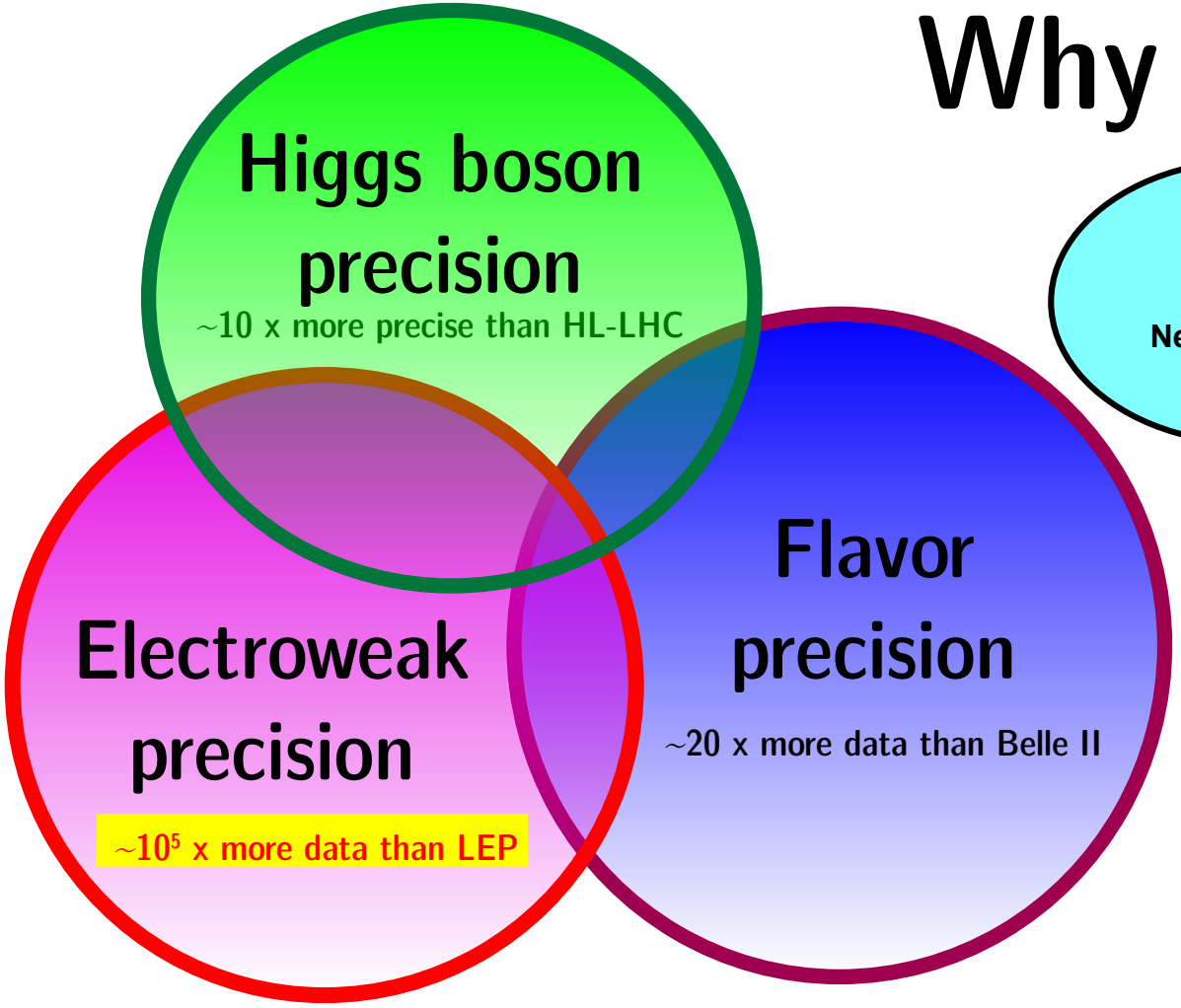
Non-Higgs physics?

- Very different
- Precision Z and W program at circular collider
- Extension to higher energies feasible with linear colliders



arXiv:2208.06030

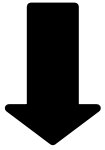
Why the FCC-ee?



Top
Never produced in e^+e^-

New Physics

'Low mass' and high luminosity



Kind of 'Intensity frontier'

Status – European Strategy

Recommendations on the next collider at CERN

FCC Week 2026 (M.Thomson)

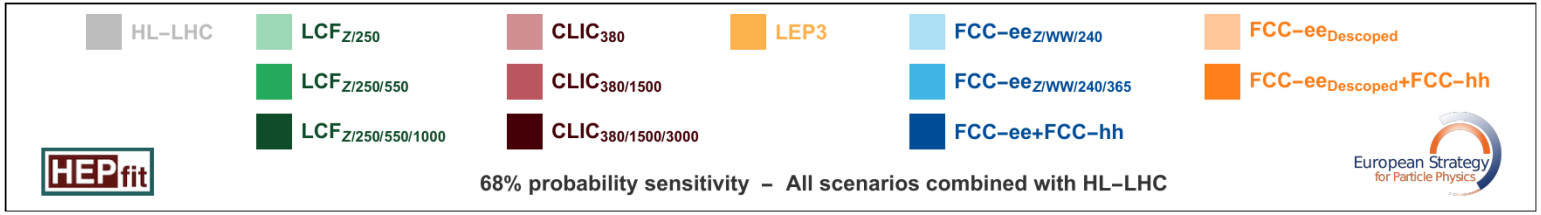
I. The *next CERN flagship collider project*

i. The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.

ii. A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN

At this stage, without knowing the reasons for which the FCC-ee would not be feasible, other alternative options are not ranked.

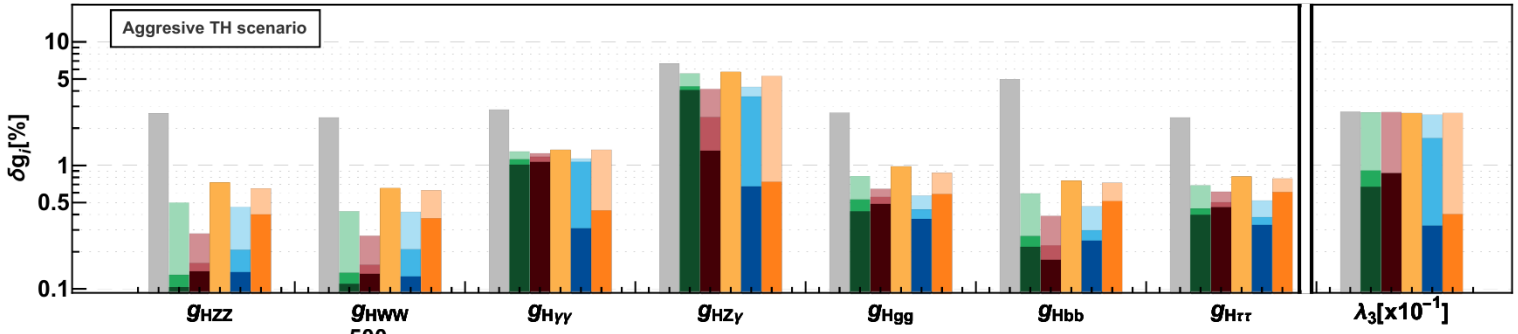
Electron-Positron Options



Higgs coupling sensitivity to new physics

- Small is good

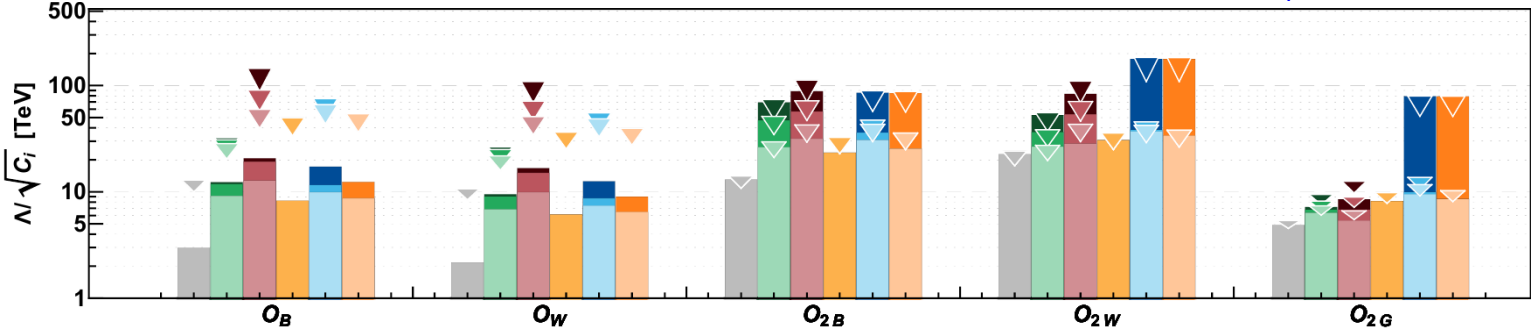
FCC is leading the way



ESG Report 2026

New Physics Scale reach

- Large is good



Status – CERN's Strategy

FCC

FCC Week 2026 (M.Thomson)

The key points from the European Strategy Group (ESG) report regarding FCC:

- Overwhelmingly strong endorsement of the physics and strategic case for FCC-ee as the next flagship collider at CERN
  - Near consensus within the particle physics communities in CERN's Member States
- A descoped/staged FCC is preferred to other options as the alternative
- No explicit prioritization of LEP 3, LHeC, LCF, CLiC. **FCC is far ahead**

The update of ESPP, endorsed FCC-ee as CERN's scientific vision for the future:

- ***Our clear aim is to be ready* for a decision on FCC-ee in 2028**
- CERN's highest long-term objective is to be in a position in 2028 to propose to Council FCC-ee as CERN's next flagship collider
  - Seeking a go/no-go decision – this is not a choice between options
- We will make the case based on FCC-ee
  - noting that it provides a potential future pathway to a very-high energy hadron collider

Taking FCC-ee to a decision point is CERN's highest long-term scientific priority

Present MIT Involvement

MIT involvement in the FCC

- MIT joined FCC early, registered member: Christoph Paus, Eluned Smith (deputy)

Specific FCC coordination appointments

- Higgs and top, electroweak precision, flavor rare decay performance conveners
- U.S. tracking convener → U.S. overall detector convener

FCC organizational

- Organized the 2nd U.S. FCC Workshop in 2024 at MIT
- Organize a yearly student FCC workshops in January (2023, 2024 and 2025)
  - Total of about 60 student mostly from MIT but also from a number of other US universities
  - Many students, including undergraduate students gave community wide presentations on their work
- Bi-weekly work meetings on tracker, particle Id and machine detector interface organized by postdocs Anja Beck and Jan Eysermans at MIT

Collaboration with BNL

Project lead in U.S. at BNL

- BNL: Srini Rajagopalan is DOE contact, Christoph Paus is part of the Steering Board, U.S. L1 manager for FCC-ee detectors

FCC organizational

- MIT and BNL were involved in several annual U.S. FCC Workshops
- Significant MIT students participation in the Inaugural U.S. FCC workshop at BNL
- Organized the 2nd U.S. FCC Workshop in 2024 at MIT with significant BNL participation

Joint January School/Workshop?

- There is significant overlap in physics, computing and potential detector work
- Can we organize a January intense school/workshop for students to work on FCC

Annual student FCC Workshop at MIT


2024 crowd


2023 crop starting it all
Road trip to U.S. FCC Workshop at BNL


2025 crowd in the initiation lecture

Student workshops in January

- Co-Organized by Eluned Smith and
- Christoph Paus
- 2026 was impossible, resuming 2027

2024 U.S. FCC Workshop at MIT

Heavy student participation

- Organized by Christoph Paus

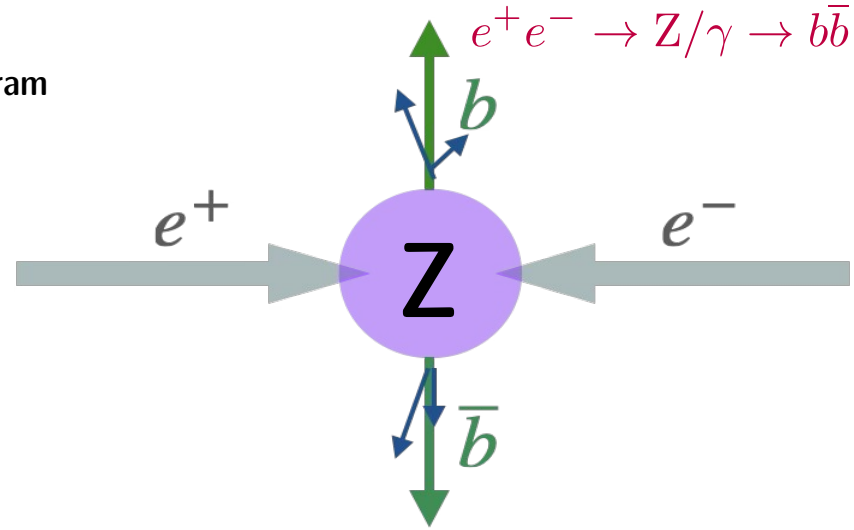
Highlights from Working Groups

B Physics

Smith is a convener of FCC-ee flavor program

- An order of magnitude more b hadrons than Belle II
- Z bosons provide all b hadrons and with significant boost (proper time)
- An order of magnitude less tracks than LHCb (very clean)
- Key advantages in neutrino, neutral and flavor reconstruction and polarization
- Particle ID will be close to perfect

Smith et al.



B Physics studies/publications

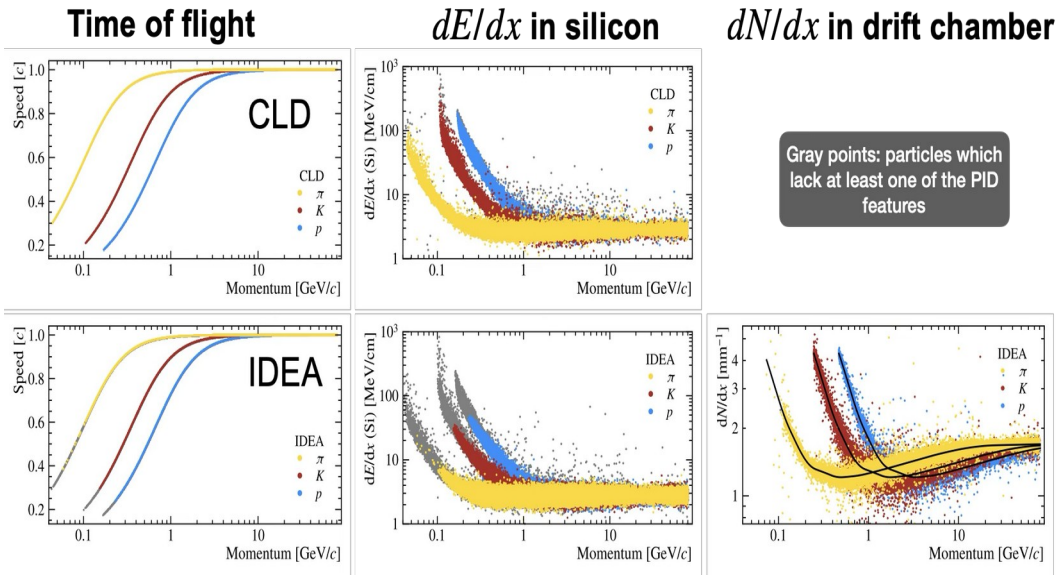
- Constraints on new physics from decays of polarized $\Lambda 0b$ baryons at the FCC-ee *Phys.Rev.D113, 055005 (2026)*
- Under study: Full event reconstruction with transformers to enable event reconstruction with neutrino

Highlights from Working Groups

Particle ID

- Detailed full simulation particle ID with the tracker
- Essential for flavor physics, in comparison to LEP detector is much advanced (vertexing and PID)
- Also huge impact on Higgs physics to identify flavors:
- $H \rightarrow bb/cc/ss$

Smith et al.



Particle ID studies/publications

- Flavor-physics benchmarks for tracker-based particle identification at the FCC-ee *Phys.Rev.D113, 072016 (2026)*
- Resulting public FCC-ee PID tool available *PID tool*

Highlights from Working Groups

Recent Higgs studies

Eysermans convened FCC-ee Higgs/Top program

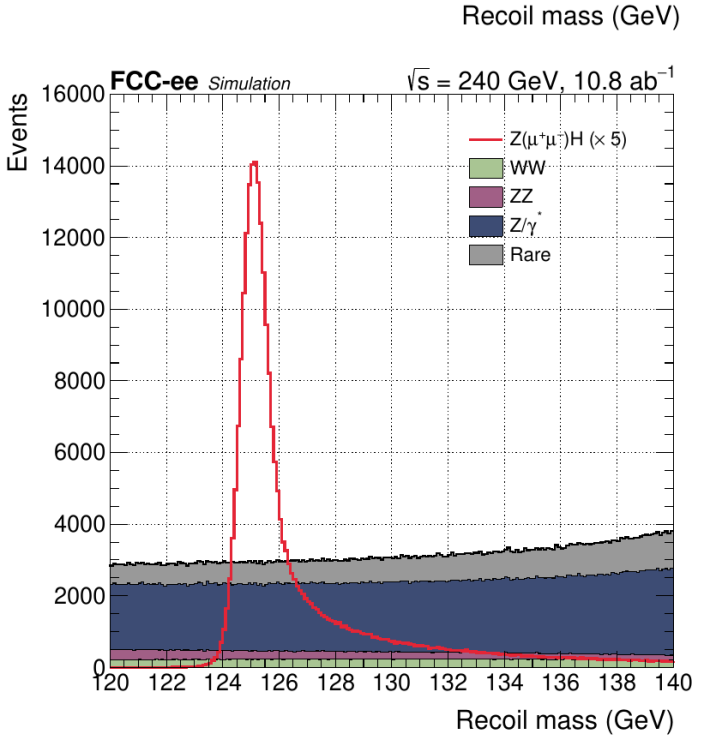
- **Higgs total cross section**

  arXiv 2512.21290 sub. to JHEP

  - Measures total Higgs width, cannot be measured at LHC
  - Full analysis including all channels performed
  - Remains statistically limited
- **Higgs mass**

  preparing for submission to PRL

  - Fundamental parameter
  - Precise measurements enable precision coupling measurements
  - Essential input for $H \to e^+e^-$: Higgs very narrow ~4 MeV need to tune to resonant Higgs production
  - Detailed study shows mass can be measured to better than 4 MeV



Both analyses rely on the recoil mass technique

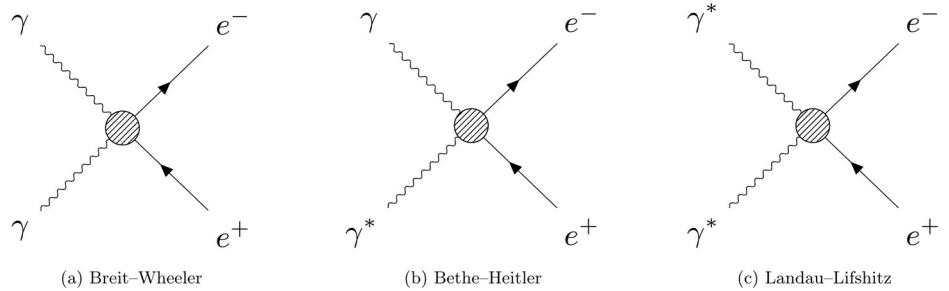
Close collaboration with Ang Li from BNL

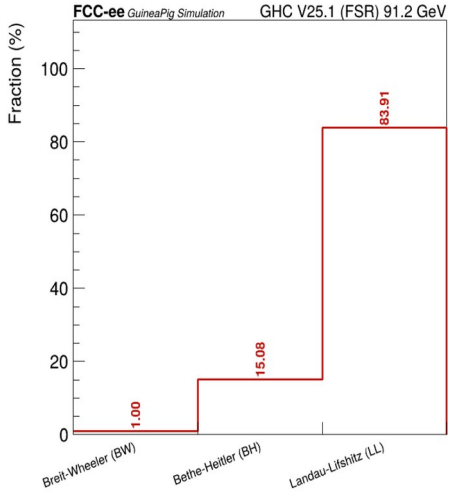
Paus et al.

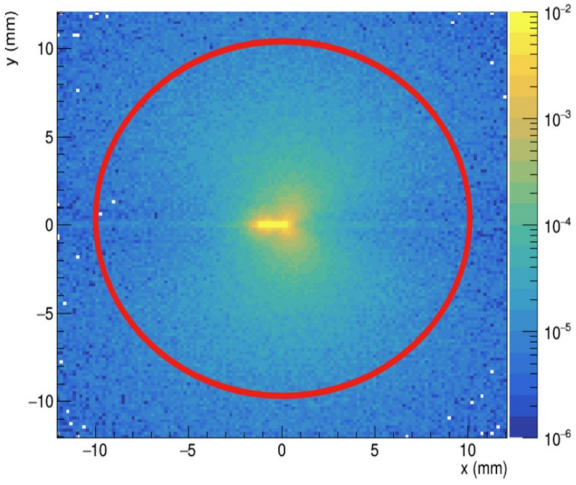
Highlights from Working Groups

Beam induced background studies

- Beam-Beam interactions significant considering high inst.luminosity: normal physics generators not enough
- Could have major implication for physics!
- GuineaPig++ is a standard tool in beam land
- Made significant extensions to GuineaPig++ to allow for realistic simulation of physics in detector
  1. Optimized background particle tracking, stopping criteria at the inner beam pipe
  2. Implemented detector magnetic field
  3. Implemented timing of particles
  4. Implemented efficient ROOT output storage format
- Extensive validation performed and produced central background samples for the FCC-ee community
- Publication in preparation...







Paus et al.

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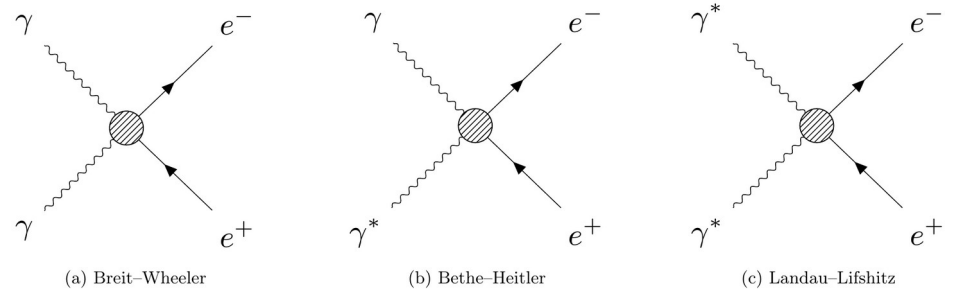
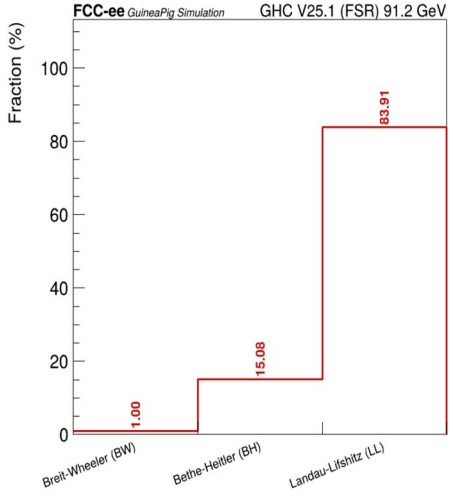
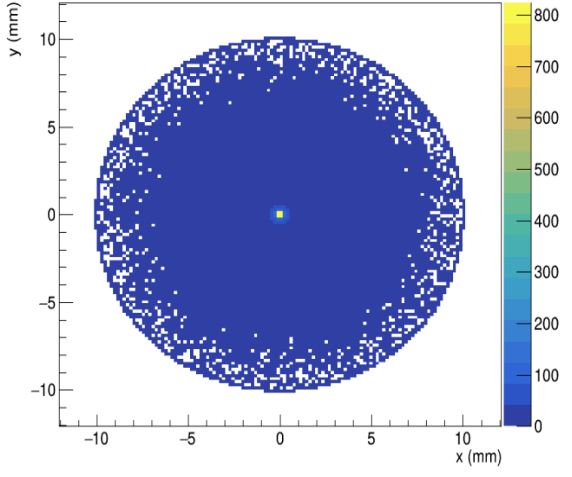




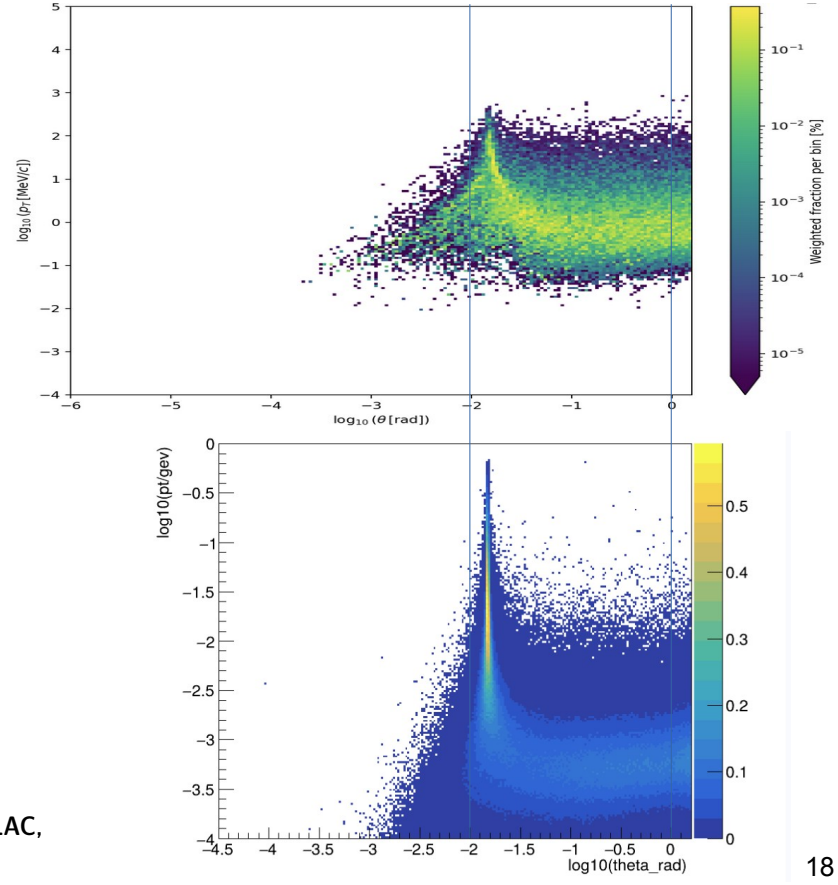


Paus et al.

Highlights from Working Groups

WarpX beams toolkit*

- Promises more efficient and alternative implementation
  1. Modern GPU-based tool to study beam-beam and model/generate beam backgrounds
  2. Features implemented in GuineaPig++ are being ported to WarpX
  3. MIT is performing extensive validation between both codes in collaboration with SLC/LBNL
- WarpX could be an interesting tool for BNL, not just for the FCC but also EIC?



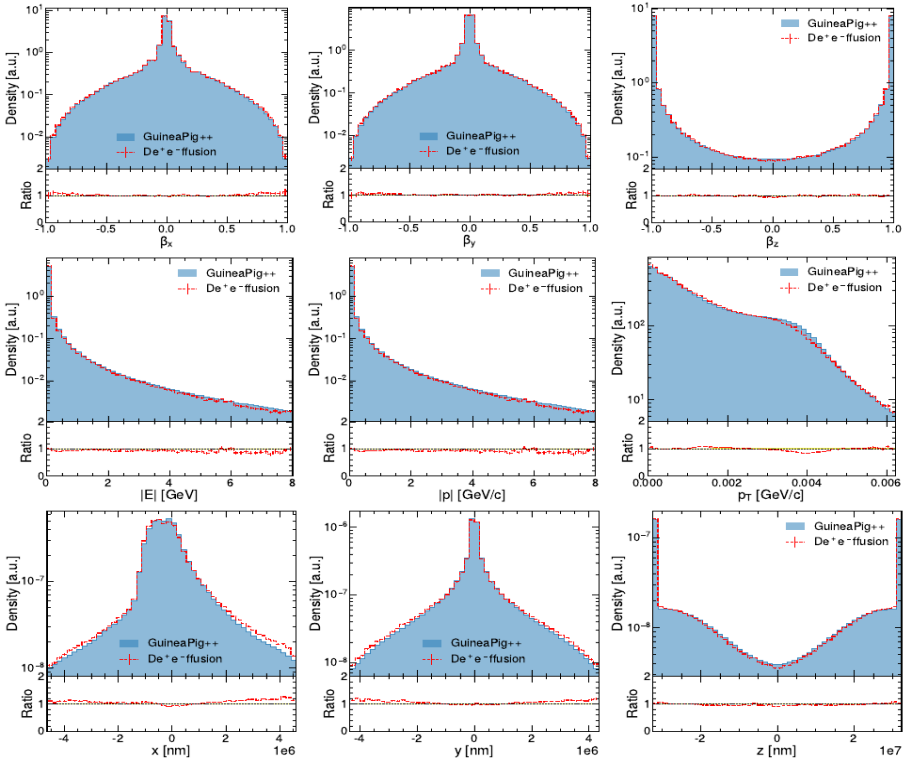
Paus et al.

* Primary WarpX contributors are with LBNL, LLNL, CEA-LIDYL, SLAC, DESY, CERN, Helion Energy, TAE Technologies, and Realta Fusion.

Highlights from Working Groups

Employ AI to speed it up

- GuineaPig++ generator is the de-facto standard with most complete implementation
- Use significant GuineaPig++ sample to train diffusion model to reproduce GP++ approximately, but very fast



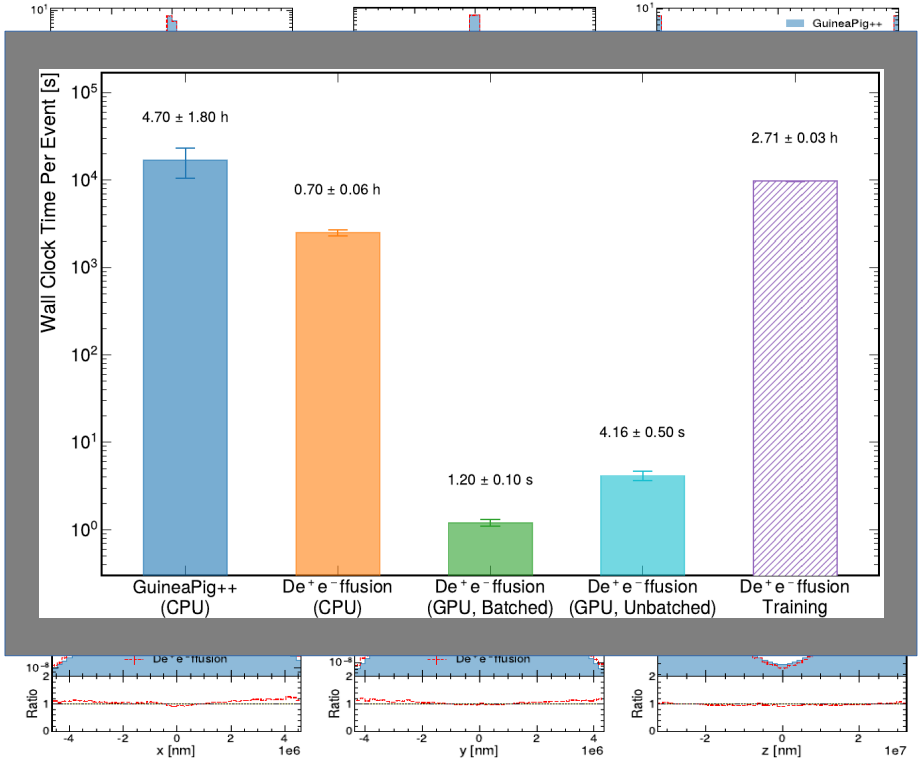
De+e--ffusion: Capturing the Beam-Beam Physics of e^+e^- Collisions with Diffusion Models *arXiv 2607.18512*

Paus et al.

Highlights from Working Groups

Employ AI to speed it up

- GuineaPig++ generator is the de-facto standard with most complete implementation
- Use significant GuineaPig++ sample to train diffusion model to reproduce GP++ approximately, but very fast
- Speedup factors: 7 from technique, and about 2100 by using GPU



De+e--ffusion: Capturing the Beam-Beam Physics of e^+e^- Collisions with Diffusion Models *arXiv 2607.18512*

Paus et al.

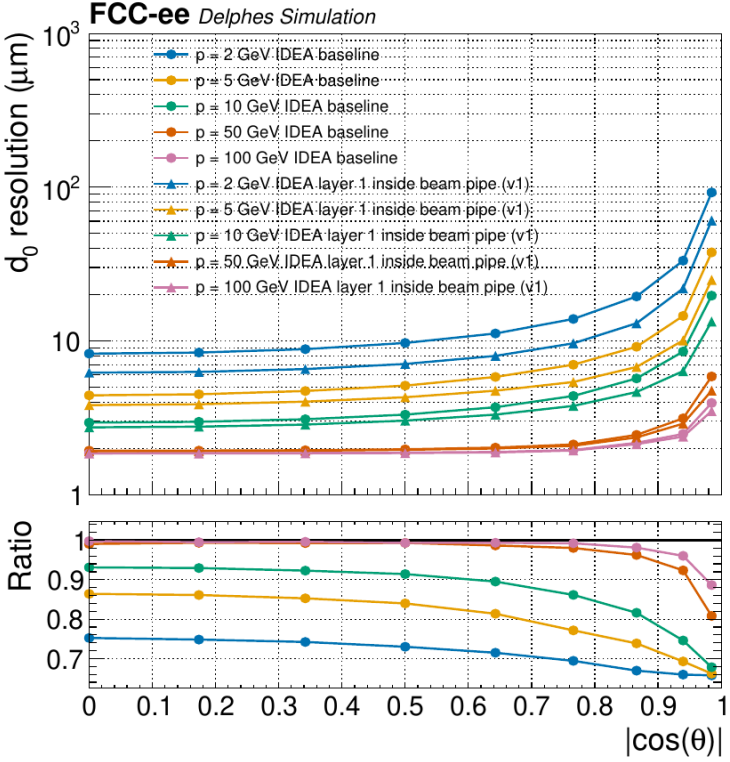
Highlights from Working Groups

Vertex detector geometries

- Testing the extreme vertex detector geometry options
- Options ranging from ultralight, to long barrel, and even a vertex layer inside the beam pipe
- Conclusion is that the detailed vertex detector design is critical and will need extensive studies
- Benchmarks to optimize toward are crucial
- MAPS FCC/EIC synergy is very interesting

Paus et al.

see Gian Michele's talk on EIC



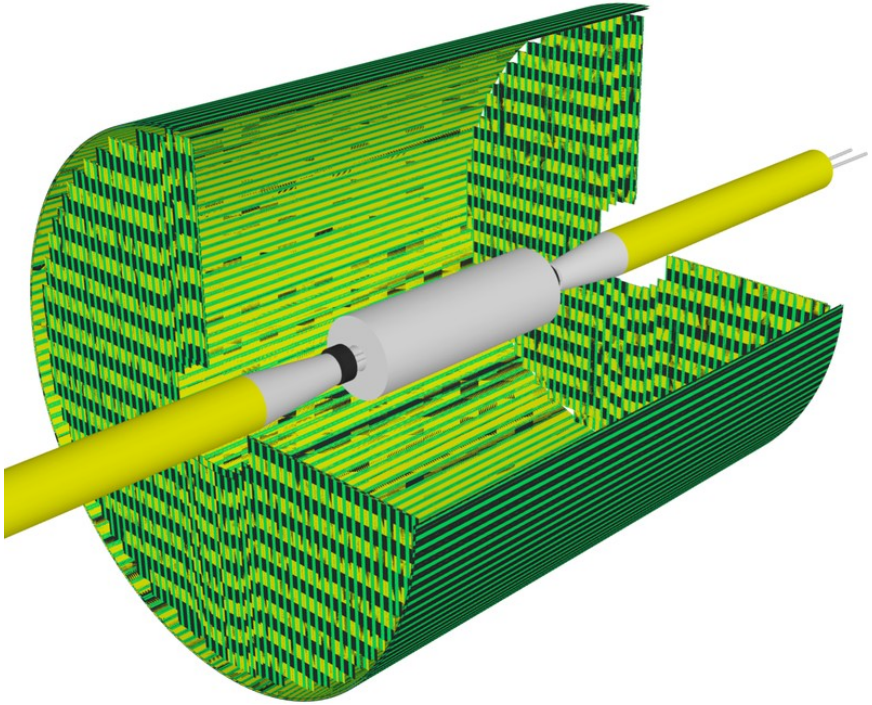
Studies of Alternative Vertex Detector Geometries for the FCC-ee IDEA Detector Concept -- internal doc. to be submitted soon

Planning detector involvement

LGADs for tracker wrapper

- Provides precise point at the end of the tracking volume for momentum resolution (r = 240cm; ~100ps, ~10μm)
- Add precise TOF point for particle ID
- From our upcoming timing layer involvement in CMS this could be a great spinoff
- Additional point for t_0 and for low momentum tracks
  - Suggest: r = 30cm with $<$ 30ps resolution
- Possible collaboration with BNL?

Paus et al.



IDEA detector concept tracker wrapper *IDEA link*

Summary: FCC @ MIT and BNL

MIT made an early decision to join the FCC

- Feasibility study had major and diverse contributions from MIT
- Significant organizational responsibilities, close contact with BNL
- Worked together successfully on key Higgs physics analyses
- Young people education/research could be a win-win for MIT-BNL
- Start beam/detector R&D, with potential collaboration with BNL

FCC physics opportunities are very impressive

- U.S. is very supportive, Europe/CERN take it as next big collider
- Official decision planned for 2028
- Unfortunately funding is very slim, but we do what we can

The end

SMEFT

Generically beyond SM

Global use of precision measurements

Theory ... needs to come up with lots of calculations

- Present theory calculations do not match experimental precision
- Intense program needs to start soonish, so exp. precision can be fully used

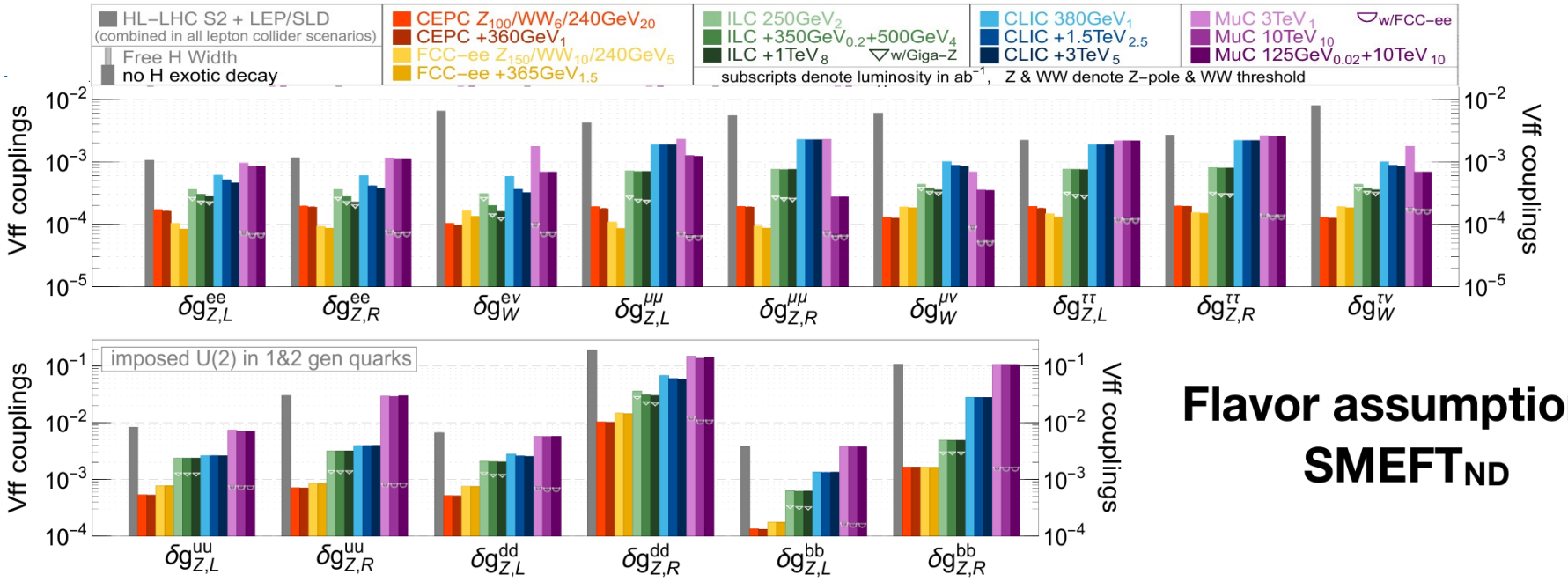
SMEFT

- SMEFT – Standard Model Effective Field Theory
- Systematic approach to characterize potential deviations from the Standard Model in terms of operators

Status

- Can be done at various orders, for now leading order (NLO under way)
- All measurements can be included and lead to best possible constraints overall

Electroweak Couplings Precision

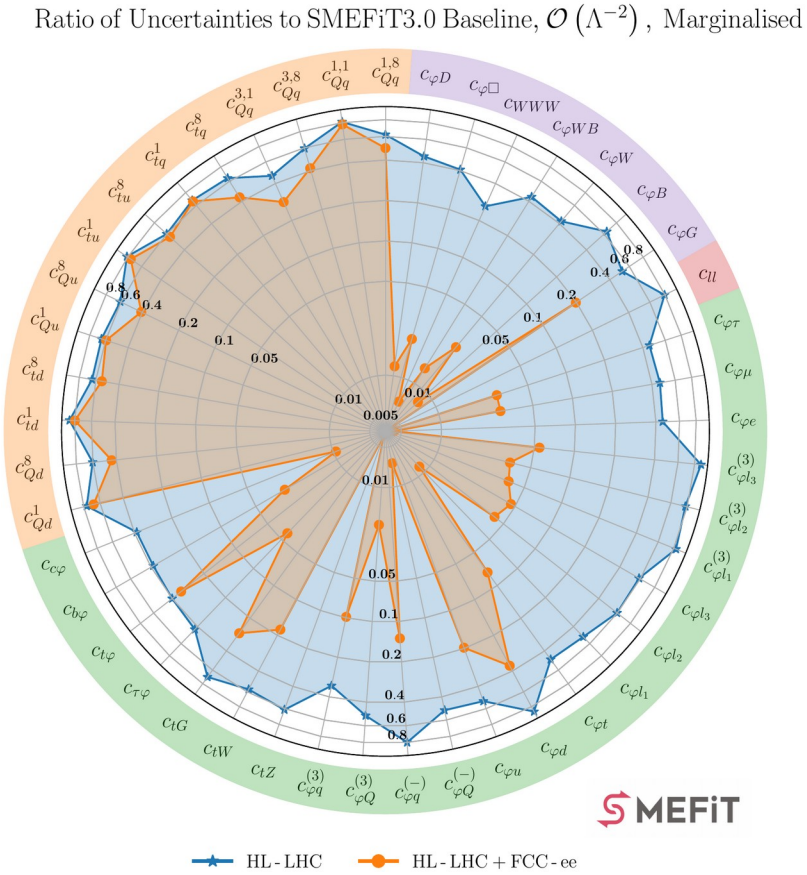


Flavor assumptions: SMEFT$_{ND}$

Electroweak couplings much improved (as expected) for e^+e^- options

- Important implications about reducing correlations between the EW and Higgs coefficients

Improvements in couplings



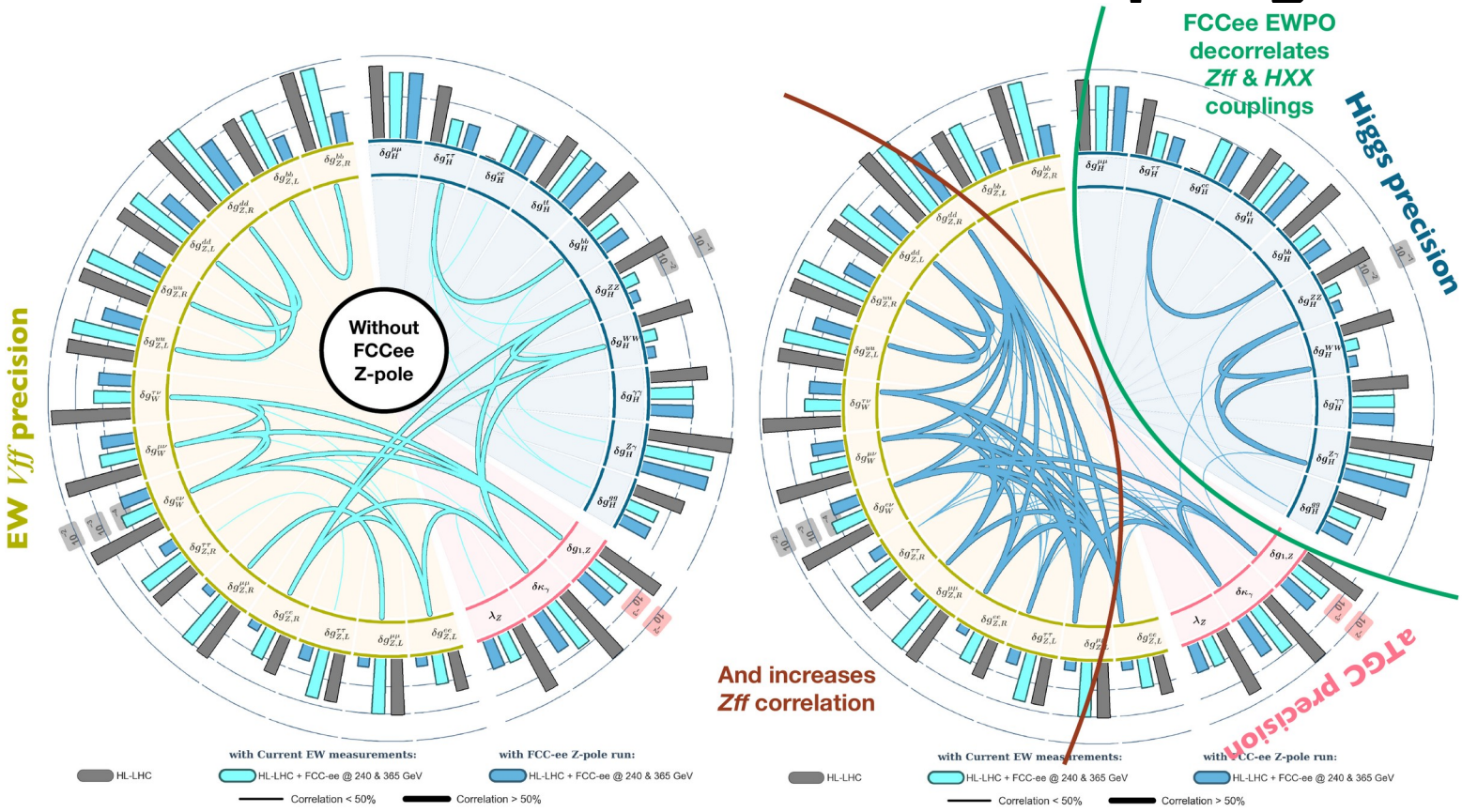
Circular plots are nice

- Shows improvement of precision on couplings with respect to the expected precision from HL-LHC
- Fit to HL-HLC + FCC-ee includes simultaneously EW, Higgs and top measurements

two-light-two-heavy operators (orange),
two-fermion operators (green),
purely bosonic operators (purple), and
the four-lepton operator $c\ell\ell$ (red).

arXiv:2404.12809

Correlations between couplings



https://indico.cern.ch/event/1439509/contributions/6286783/attachments/2997068/5280355/Global_fits_FCC_deBlas.pdf