ECFA workshops on e^+e^- Higgs/EW/Top factories

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High Energy Physics seminar
Faculty of Physics, University of Warsaw
October 21, 2022

First ECFA WORKSHOP.

on e+e- Higgs/EW/Top Factories, October 5-7, 2022, in Hamburg

Outline

- Introduction
- Higgs/EW/Top factory projects
- Conclusions from Snowmass
- Working group highlights
- Plans and closing remarks

Most slides taken from workshop presentations available from:
https://indico.desy.de/event/33640/

Introduction

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

Physics, Experiments & Detector studies for an e^+e^- Higgs/EW/Top factory

WG 1: Physics Potential

- Collect, compare and harmonise the work of the different project-specific efforts
- Interplay between (HL)-LHC and a future Higgs factory, e.g. include LHC potential on high-p_T measurements and EFT interpretations
- Identify specific topics where concrete work should be organised
- Requirements on accuracy in theoretical calculations and parametric uncertainties, ..
- *…*

WG 2: Physics Analysis Methods

- Monte Carlo generators for e^+e^- precision EW/top Higgs factory
- Software framework
- Fast simulation (and its limitations)
- Particle flow
- Luminosity measurement ...
- *…*

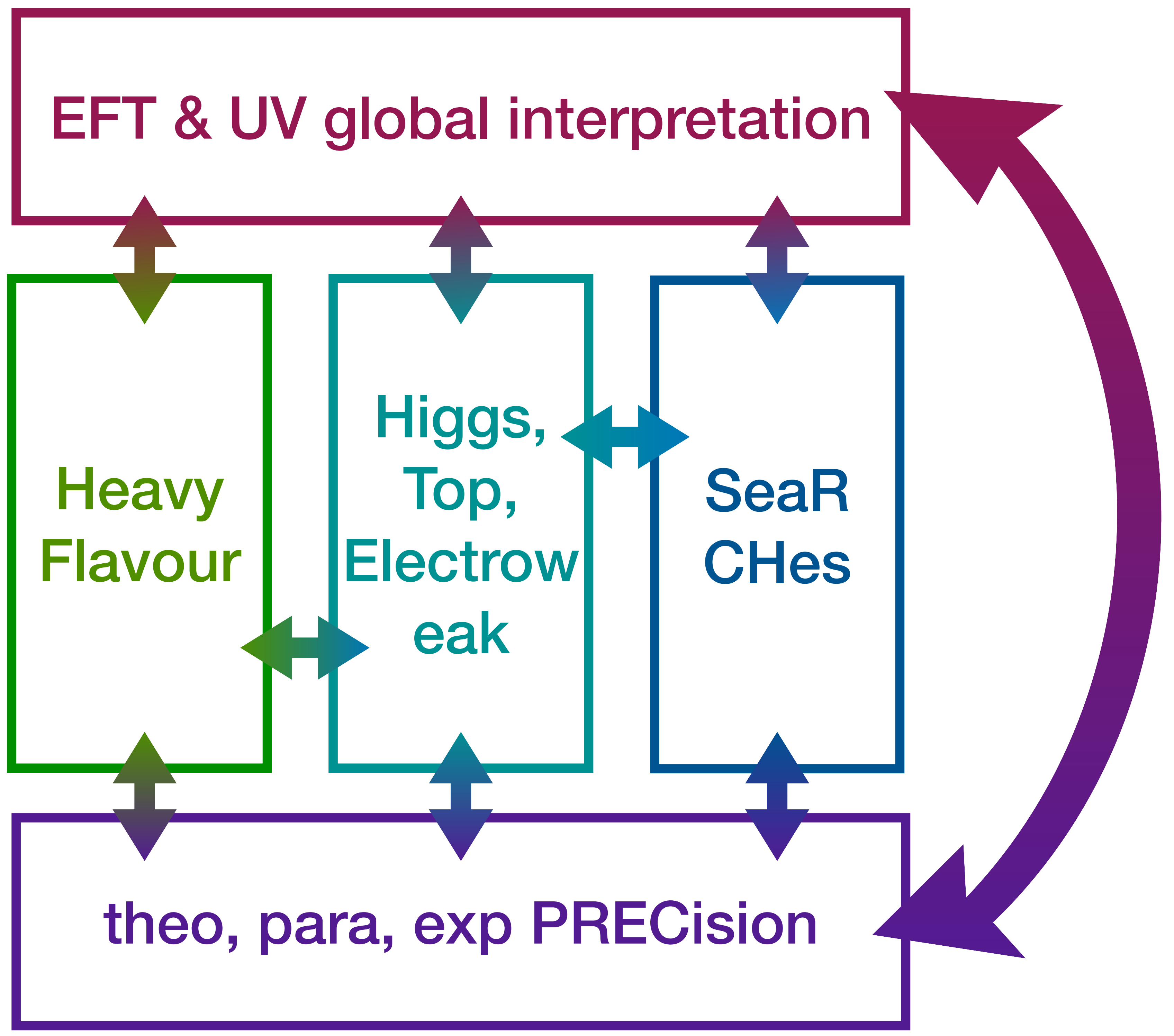
WG 3: Detector R&D

(start activities once the ECFA Detector R&D Roadmap is defined; Roadmap process currently ongoing)
First public presentation (close-to-final report) by Phil Allport (Univ. Birmingham, Chair of the Roadmap Panel) at the ECFA-EPS session on 30th July at the EPS Conference

ECFA Higgs Factory Study - WG1 Physics Potential

Overview

- chairs: Juan Alcaraz (CERN), Fabio Maltoni (Louvain), Jenny List (DESY)
- identified five main topics:
  - **WG1-EFT:** Global interpretation in (SM)EFT and UV complete models
  - **WG1-PREC:** Precision calculations and theoretical, parametric and experimental syst. uncertainties
  - **WG1-HTE:** Higgs, top and electroweak physics, incl. high-pT
  - **WG1-HF:** Flavour physics
  - **WG1-SRCH: Direct discovery potential, incl. FIP**



Ongoing:

- **identifying a few key people for each topic**
  => includes e+e- experts, important to get engaged
- **holding meetings with each group**
- **discussing scope, ideas, names of other people to get involved, interest to get involved etc**
- **planning 2-3 day topical workshops in first half of 2022**

Physics, Experiments & Detector studies for an e^+e^- Higgs/EW/Top factory

- The working groups will carry out work over the forthcoming years in preparation of community-wide plenary ECFA workshops

  Kickoff meeting today: inform the community, take stock, organise the next steps in the work programme…

- Major milestones: **ECFA workshops** are planned to be held in 2022 and 2023

  In 2021: presentation at the **Open Plenary ECFA meeting** on 19th November at CERN

- Final report: "ECFA report"
  (à la Aachen for LHC, or Aix-Les-Bains for LHC Phase-II upgrade)

- Major entry portal to collect information on the ongoing activities:

  https://indico.cern.ch/event/1044297/

- e-group will be set up;
  Your consent to be put on such a list was asked during the registration step
  → if you have not yet registered, please do it now!

First milestone!

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

Higgs(/EW/Top) factory projects

Setting the Stage

Recall the Physics

Karlsruher Institut für Technologie

Electroweak Precision

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

Flavour Physics

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

The Higgs Boson

model-independent study of all accessible couplings

The Top Quark

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

New Particles

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

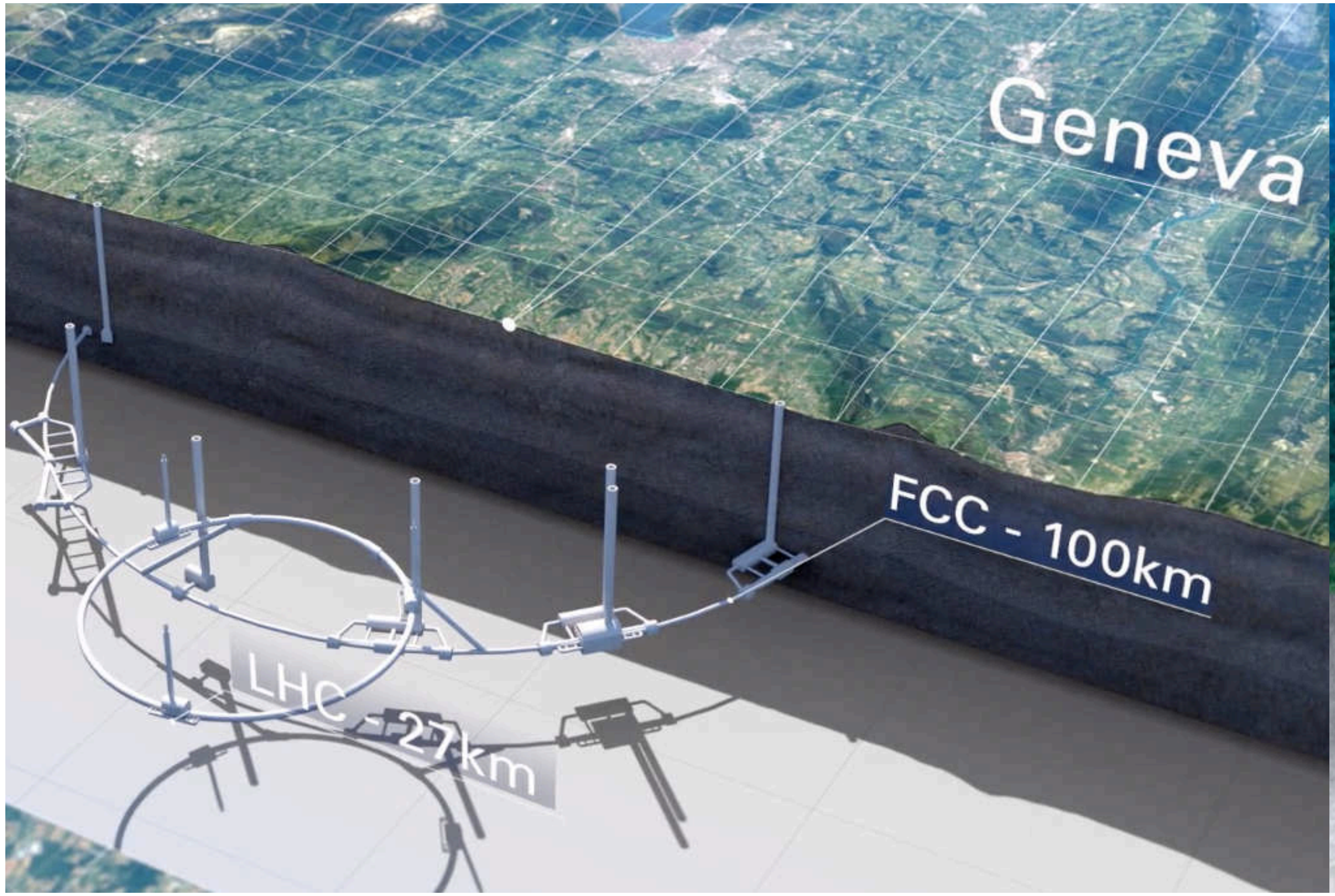
Circular Colliders

The Lineup

- Two possibilities discussed globally -
  both e^+e^- Higgs-Top-EWK factory, followed by ~ 100 TeV hadron collider

CERN: FCC-ee - FCC-hh

China: CEPC - SppC

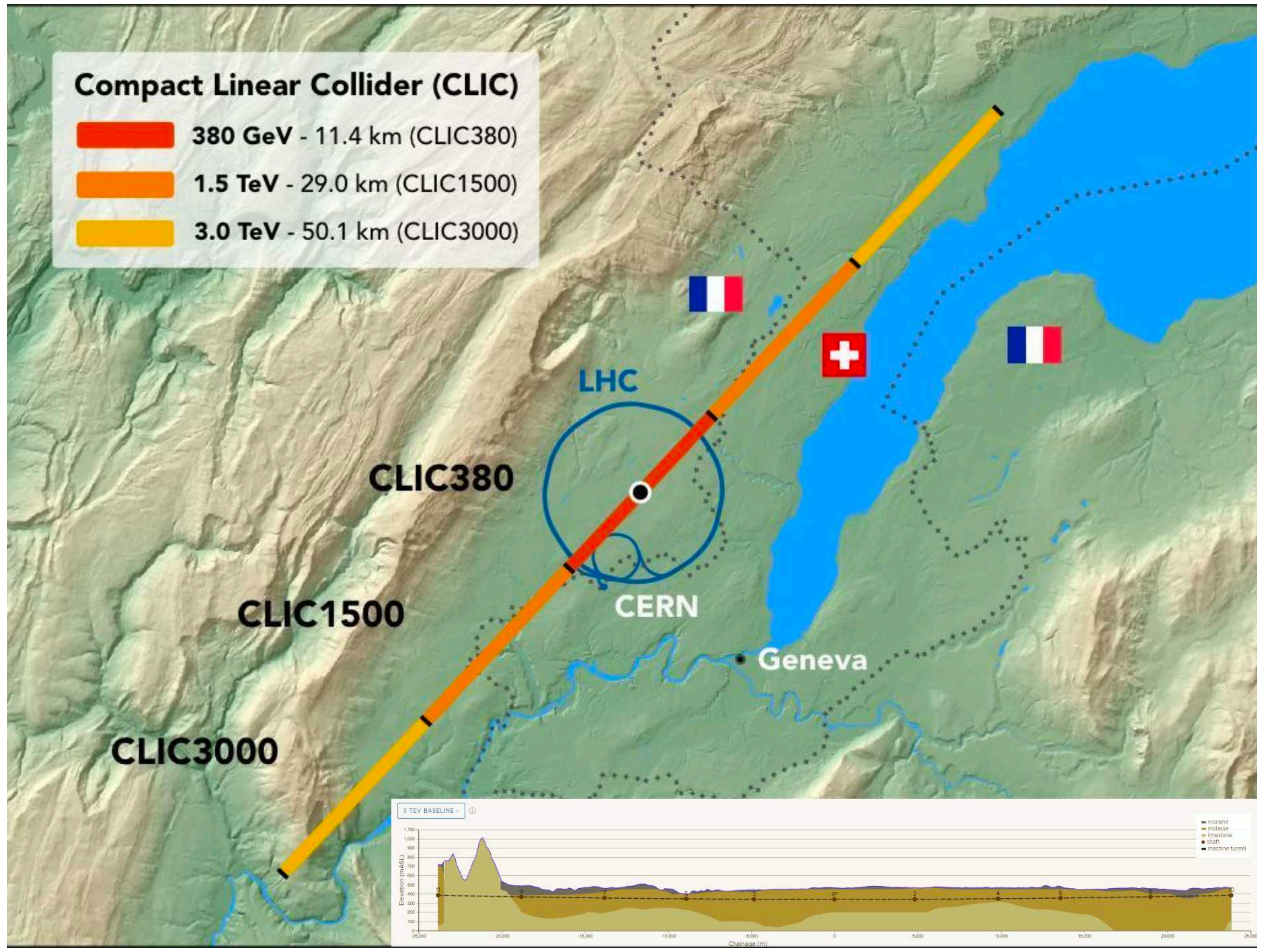


Linear Colliders

ILC & CLIC specs

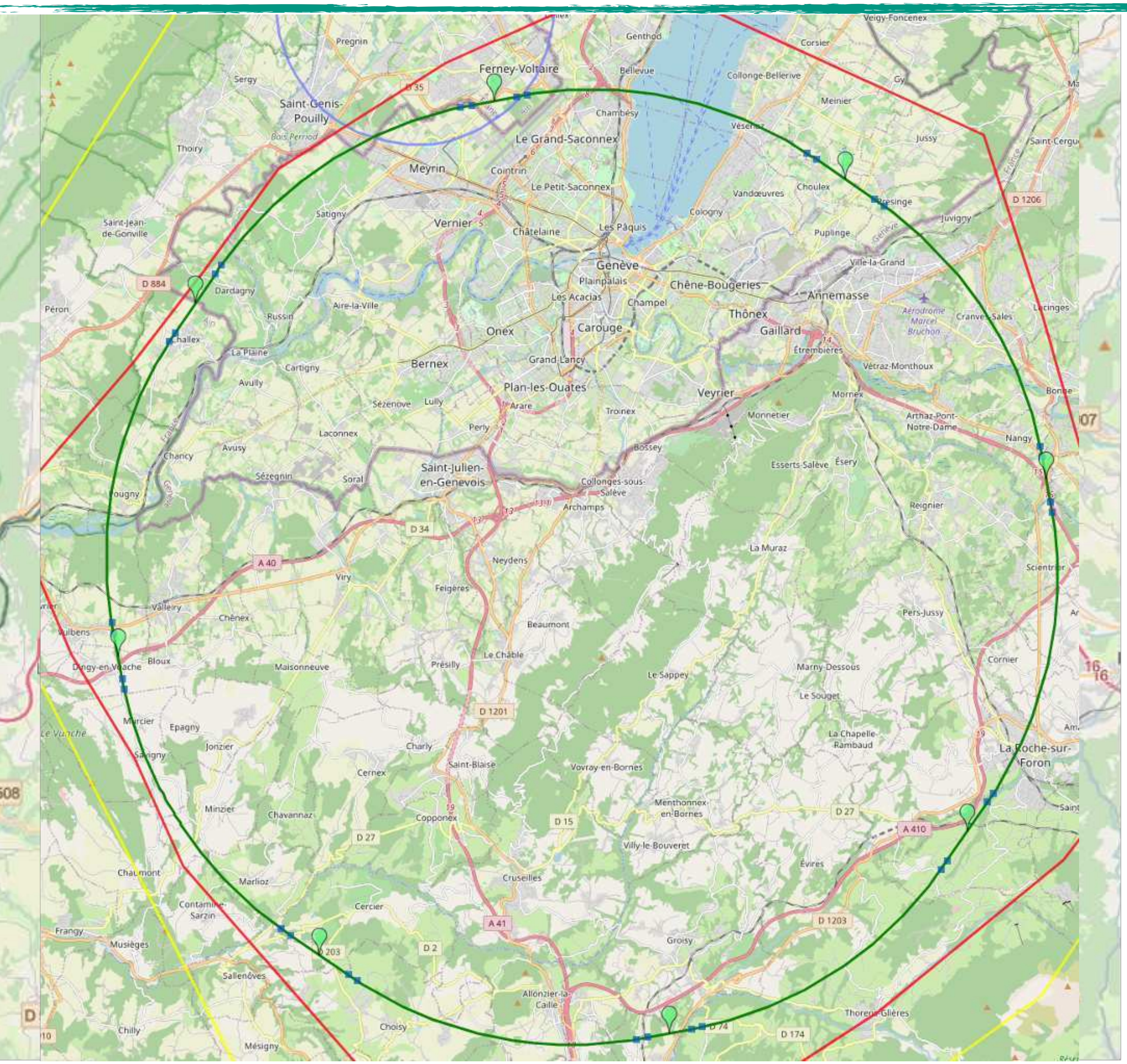
- Energy extendability to TeV scale lies in the heart of linear colliders: ILC focuses on √s from 250 GeV to 1 TeV; CLIC 380 GeV to 3 TeV; keeping options to run at Z-pole (“GigaZ”)
- Complementary approaches: “Warm” & “Cold” accelerating technologies; 72MeV/m @ CLIC380; 31.5MeV/m @ ILC250
- Polarized beams: both offering 80% for electron; 30% for positron in ILC default design

ILC250 ~ 20km

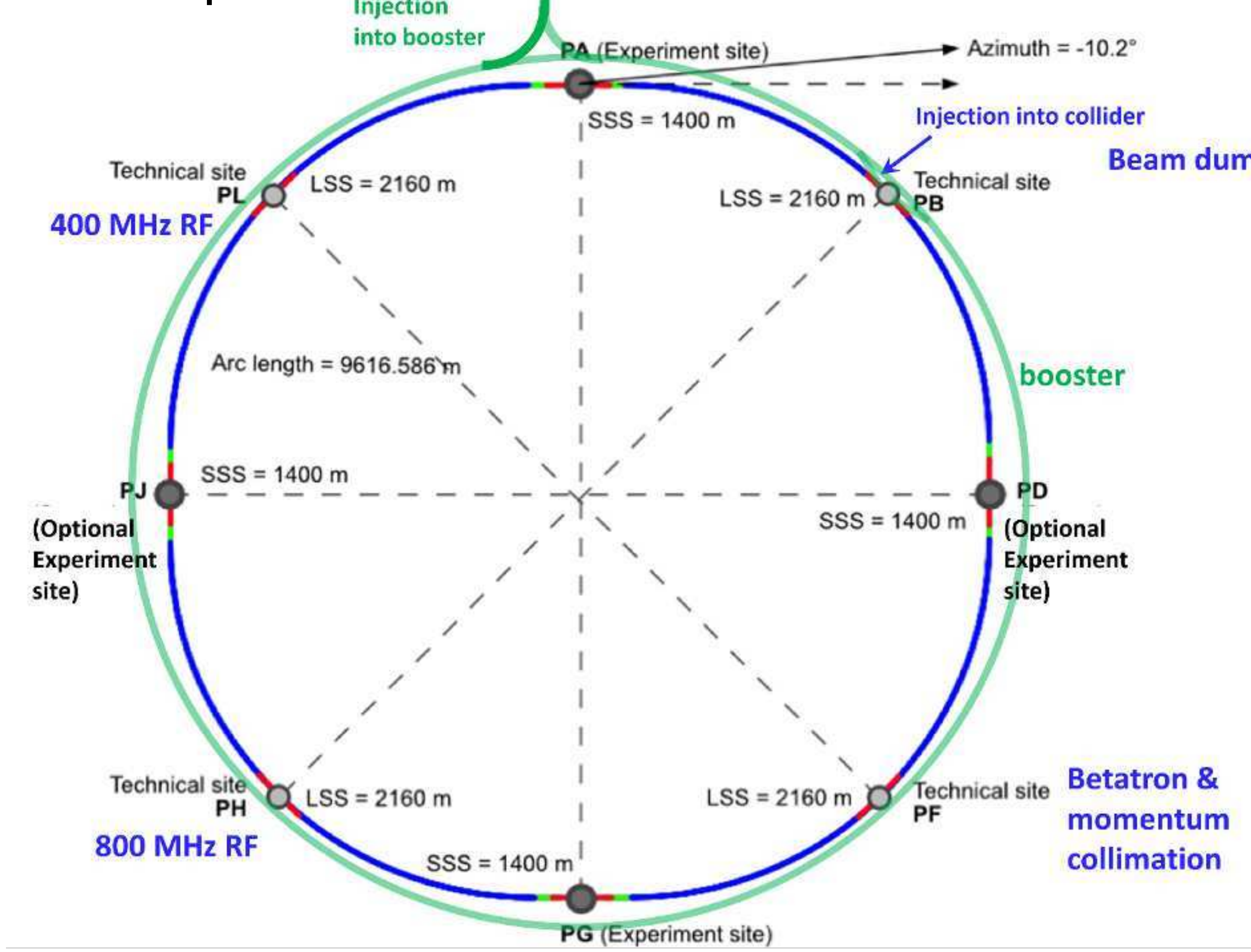


FCC-ee Facility

Converging on the high-level layout



- Detailed layout and placement optimisation: Technical, geology, territorial constraints, access, nature, economy, machine performance, …
- Converged on a baseline: 91.1 km, 8 surface sites
  4 IPs for FCC-ee possible



Frank Simon (frank.simon@kit.edu)

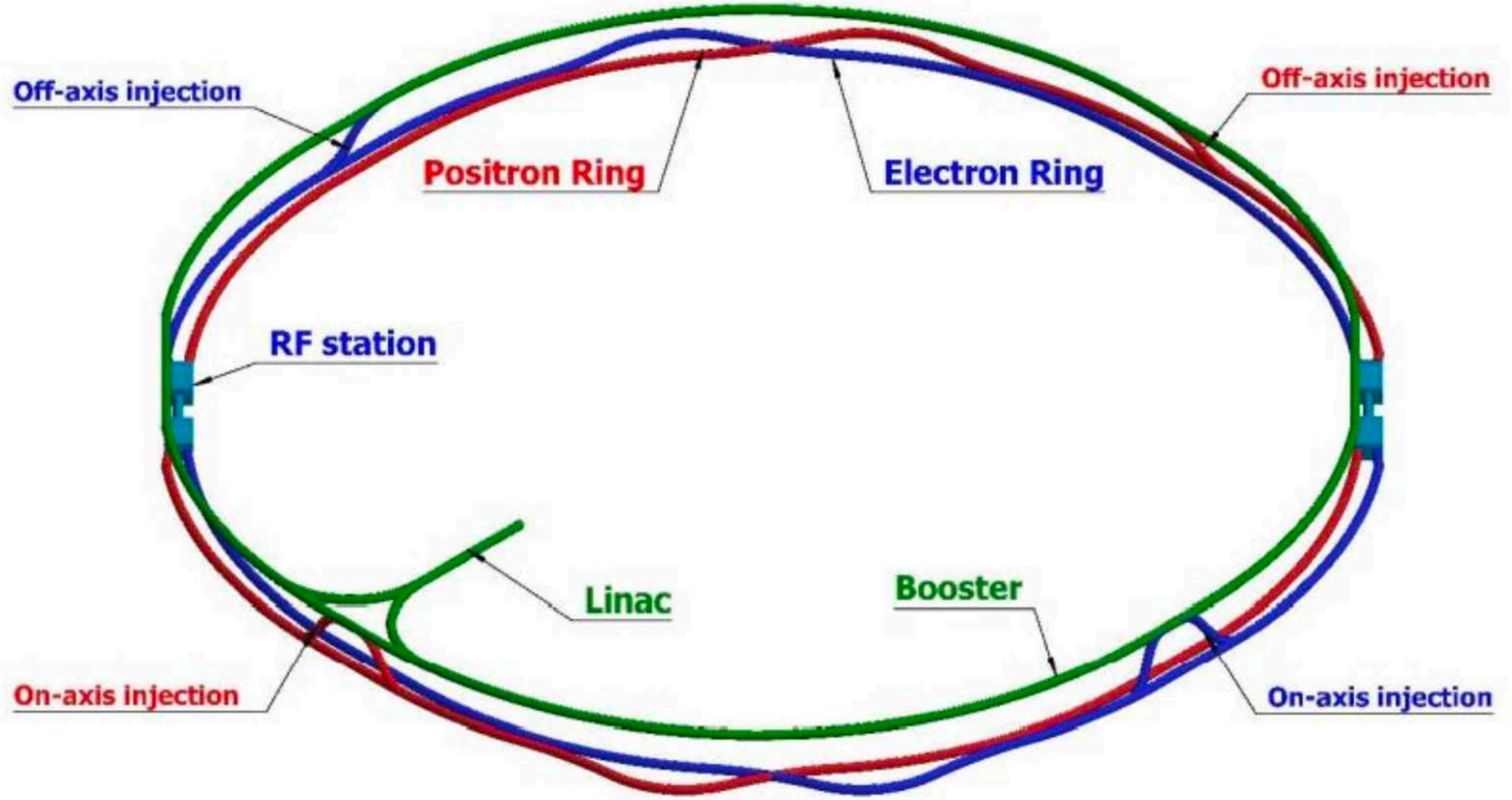
CEPC - Status and Development

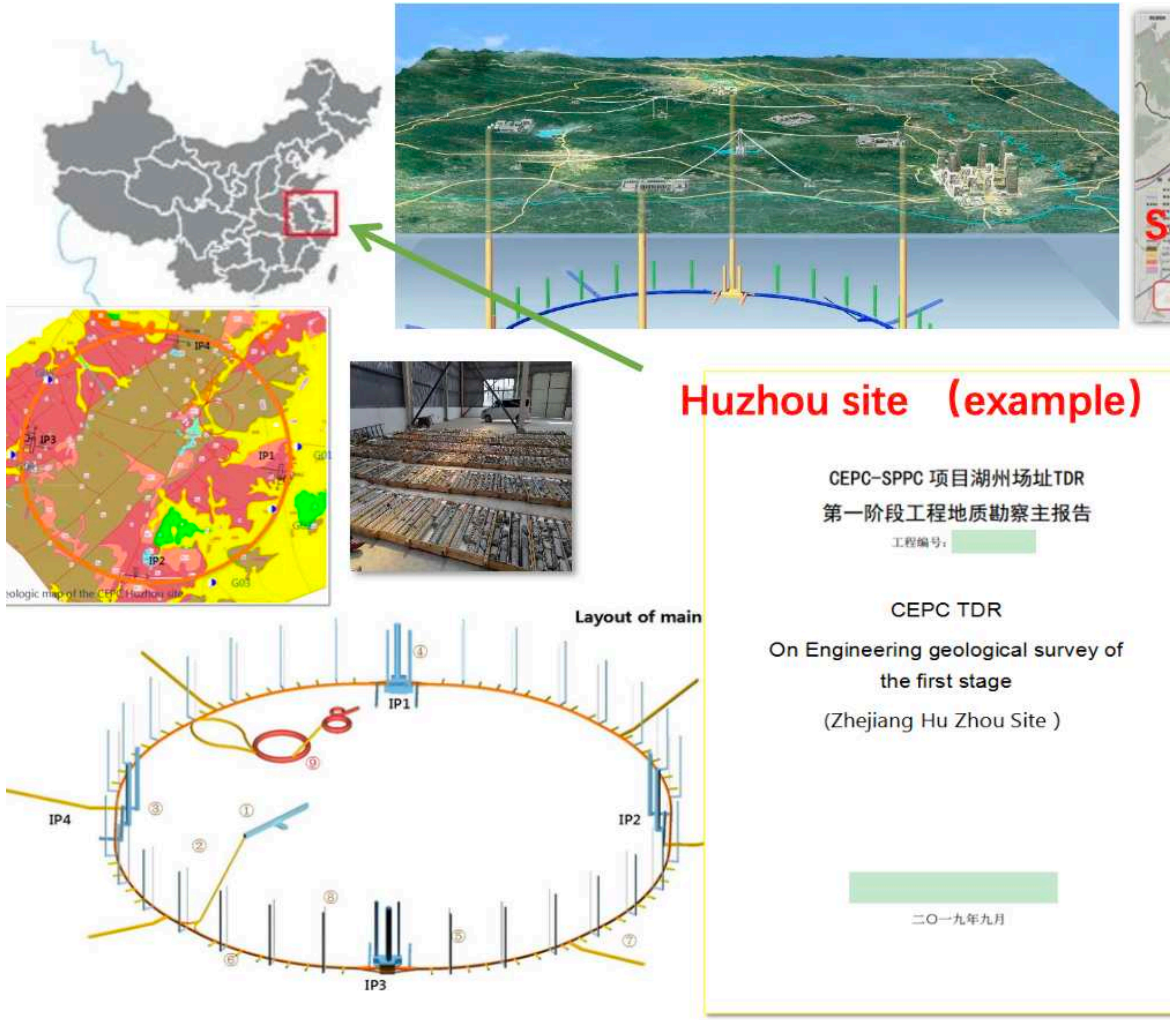
Design Updates towards TDR

- Significant evolution since the CDR in 2018:
  - Increased luminosity, ~ x8 at Z, ~x1.6 at ZH at 30 MW synchrotron radiation power
  - A 50 MW upgrade option
  - tt stage at ~350 GeV

- Preparing for a TDR for 2023
- Several sites in China under study, with a wide range of studies to evaluate the different sites.

100 km circumference





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ILC Project News

towards realization

東京大学 THE UNIVERSITY OF TOKYO

- MEXT (represents Japanese government) didn't approve the original Pre-Lab proposal [newsline]
- Not entirely negative: pointed out what directions to move forward ["hosting is not the problem", S.Asai]
- Support to carry out time-critical R&D that was in the Pre-Lab proposal
- A really encouraging sign from last month: a fact of 2 increase on KEK funding for ILC R&D submitted in the budget request by MEXT for next fiscal year 2023
- Under leadership by International Development Team (IDT), KEK and ILC-Japan.

What is the goal in spring 2023? [T.Nakada @ Snowmass 2022]

- The International Network for the ILC related technology development is ready to start or even has started.
- The International Expert Panel makes a significant advancement in the discussion for Step 1

Step 1 **Developing a path for a global project adoptable for the ILC:**

Step 2 **Developing the ILC decision roadmap by adopting this path**

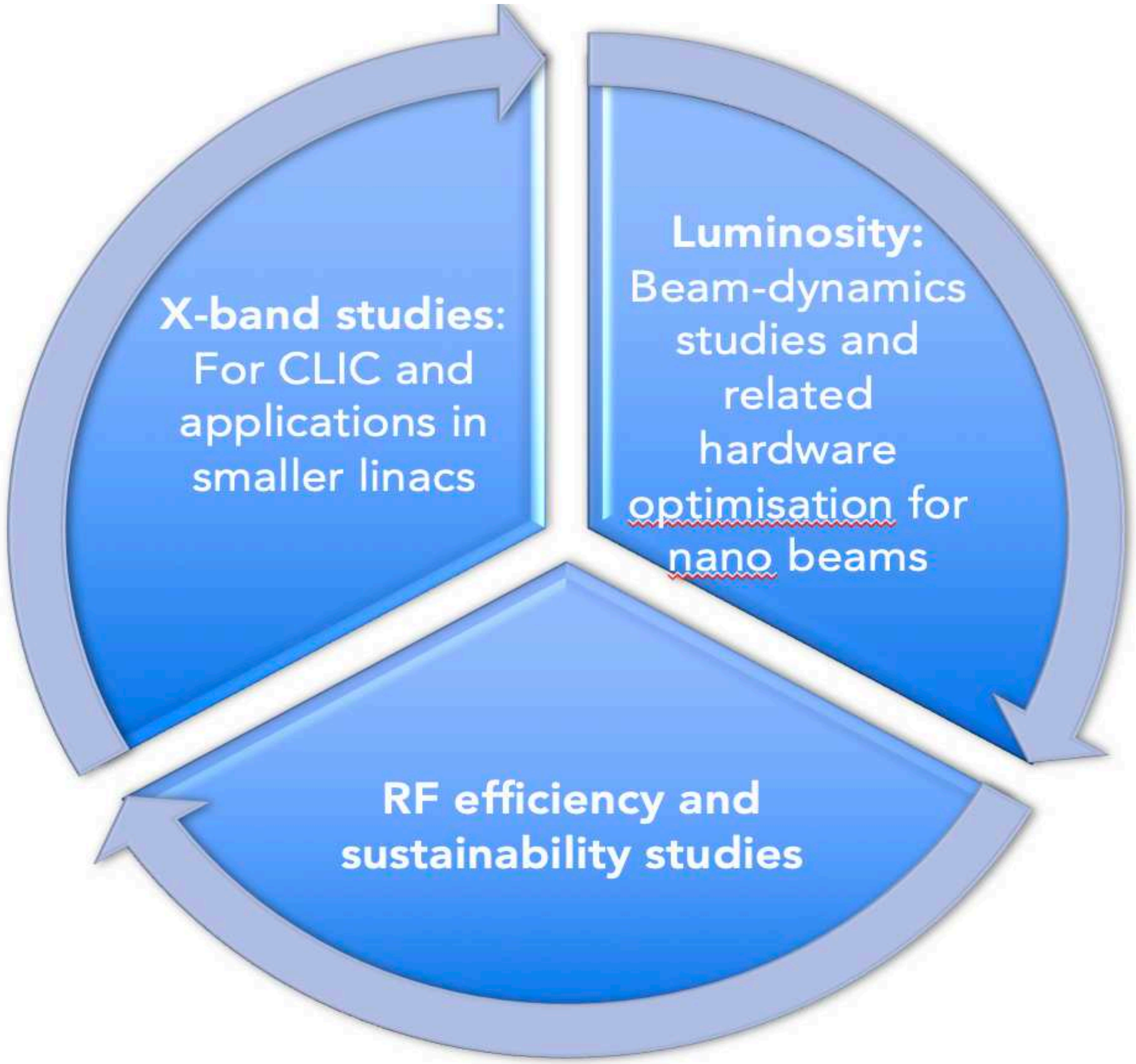
CLIC Accelerator Status

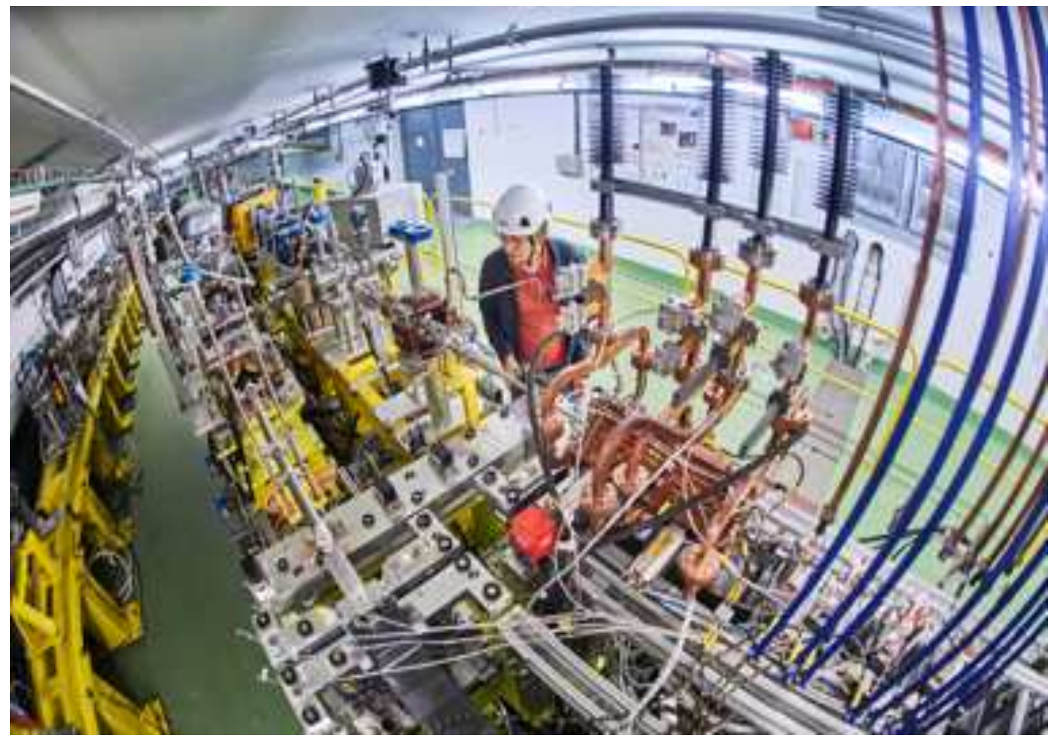
2021-2025

CLIC is working towards a Project Readiness Report 2025/26 as a step toward a TDR – for next ESPP

Focusing on:

- X-band technology readiness for the 380 GeV CLIC initial phase
- Optimizing the luminosity at 380 GeV
- Improving power efficiency for both initial phase & high energies





Linear Colliders - New Players

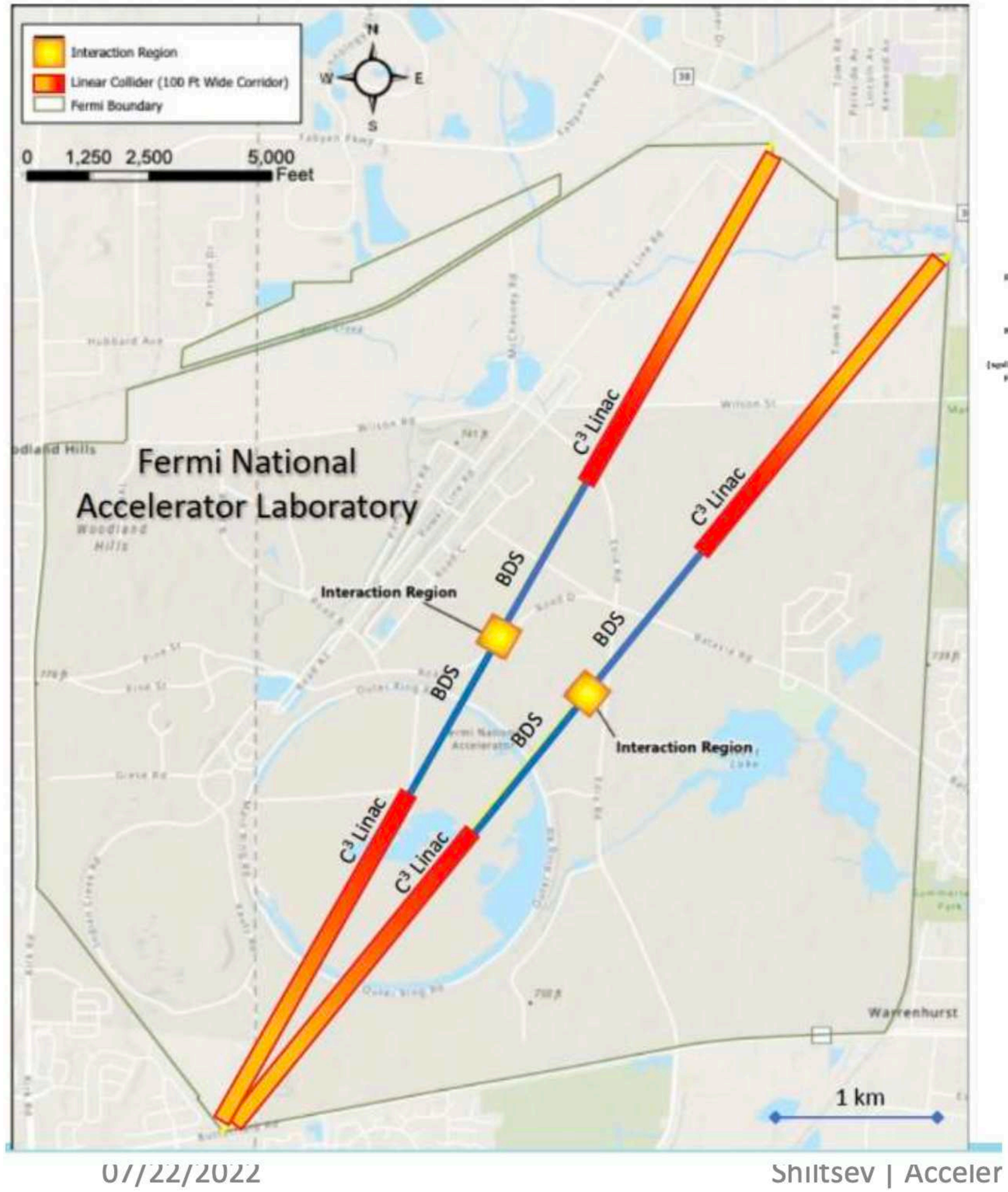
ILC "backup"

- If ILC is not moving forward as expected…
- New linear collider proposals sited in US as discussed in Snowmass 2022

C³ Workshop in next week

[V.Sheltsev @ Snowmass 2022]

arxiv:2203.08211 arxiv:2110.15800

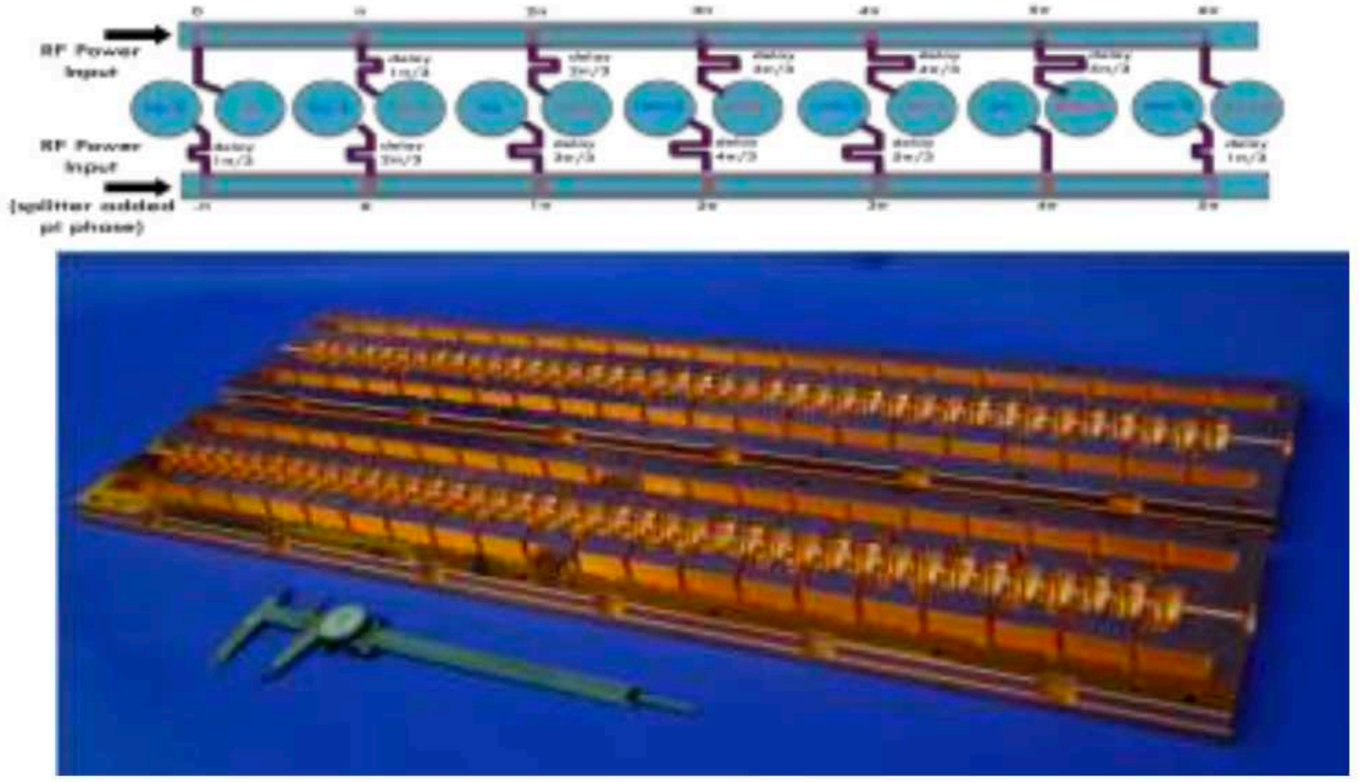


Must fit ~7 km including BDS

Required gradients of **at least 70MV/m**

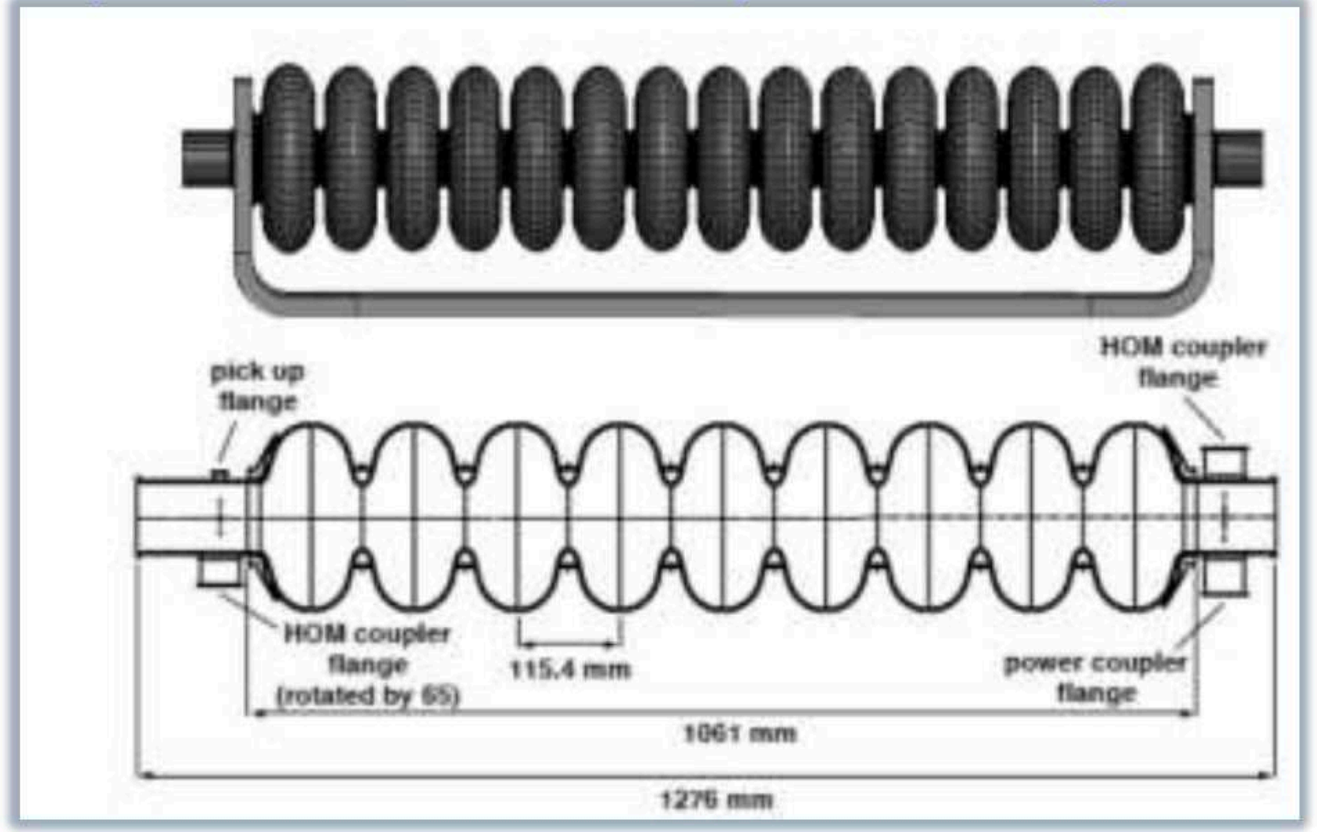
Compact → lower cost (wrt ILC/CLIC)

Option 1: Cool Copper Collider (C³)



5.7GHz
77K

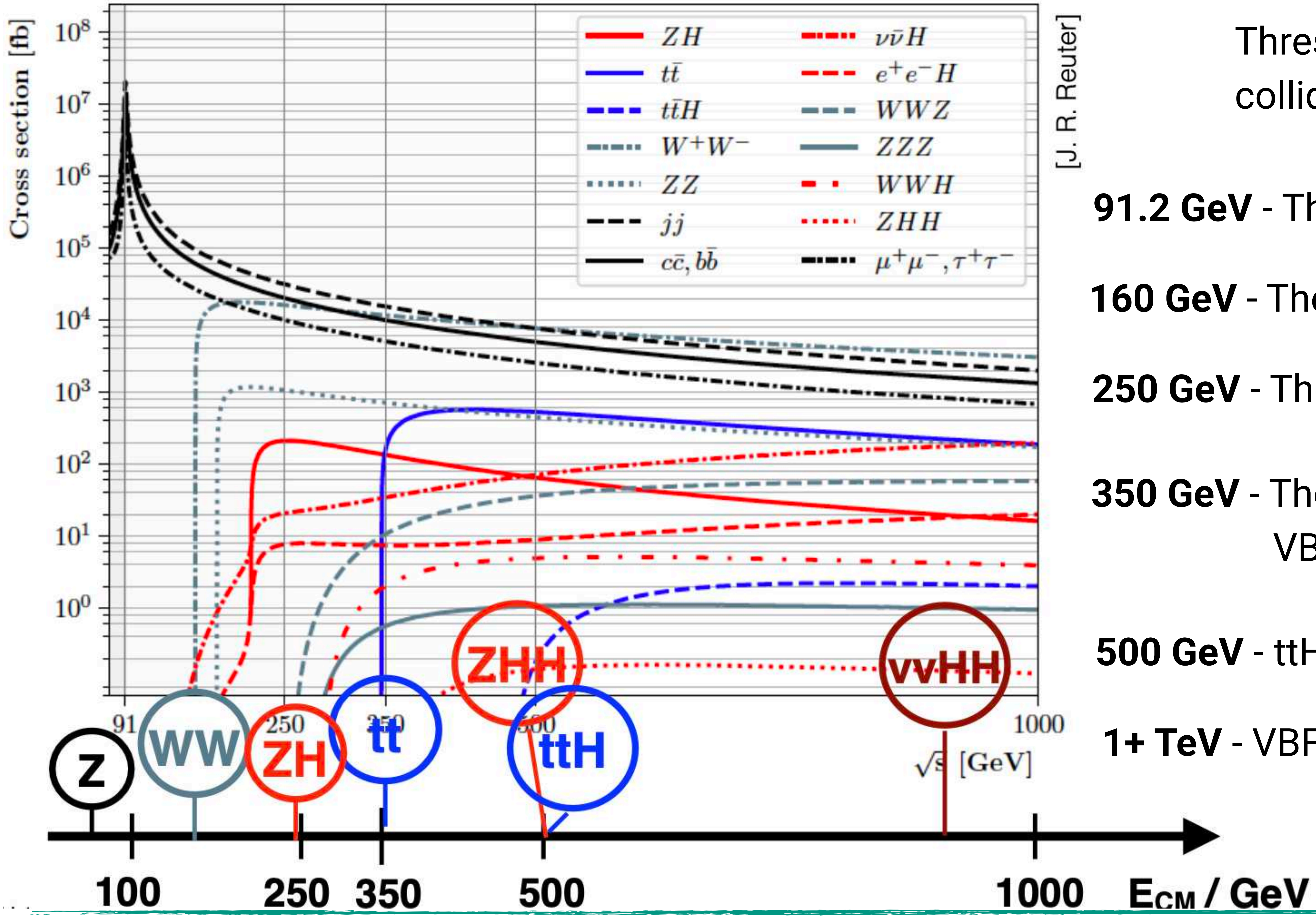
Option 2: ***HELEN*** (Travelling Wave ILC)



1.3GHz
2 K

Setting the Stage

Perspectives of Energy



Thresholds and cross sections set collider energy targets:

91.2 GeV - The Z pole

160 GeV - The WW threshold

250 GeV - The ZH maximum

350 GeV - The top threshold, VBF Higgs production

500 GeV - ttH, ZHH

1+ TeV - VBF double Higgs

Precision electroweak, Flavour, QCD, …

Higgs properties & couplings

Top properties, Top as probe

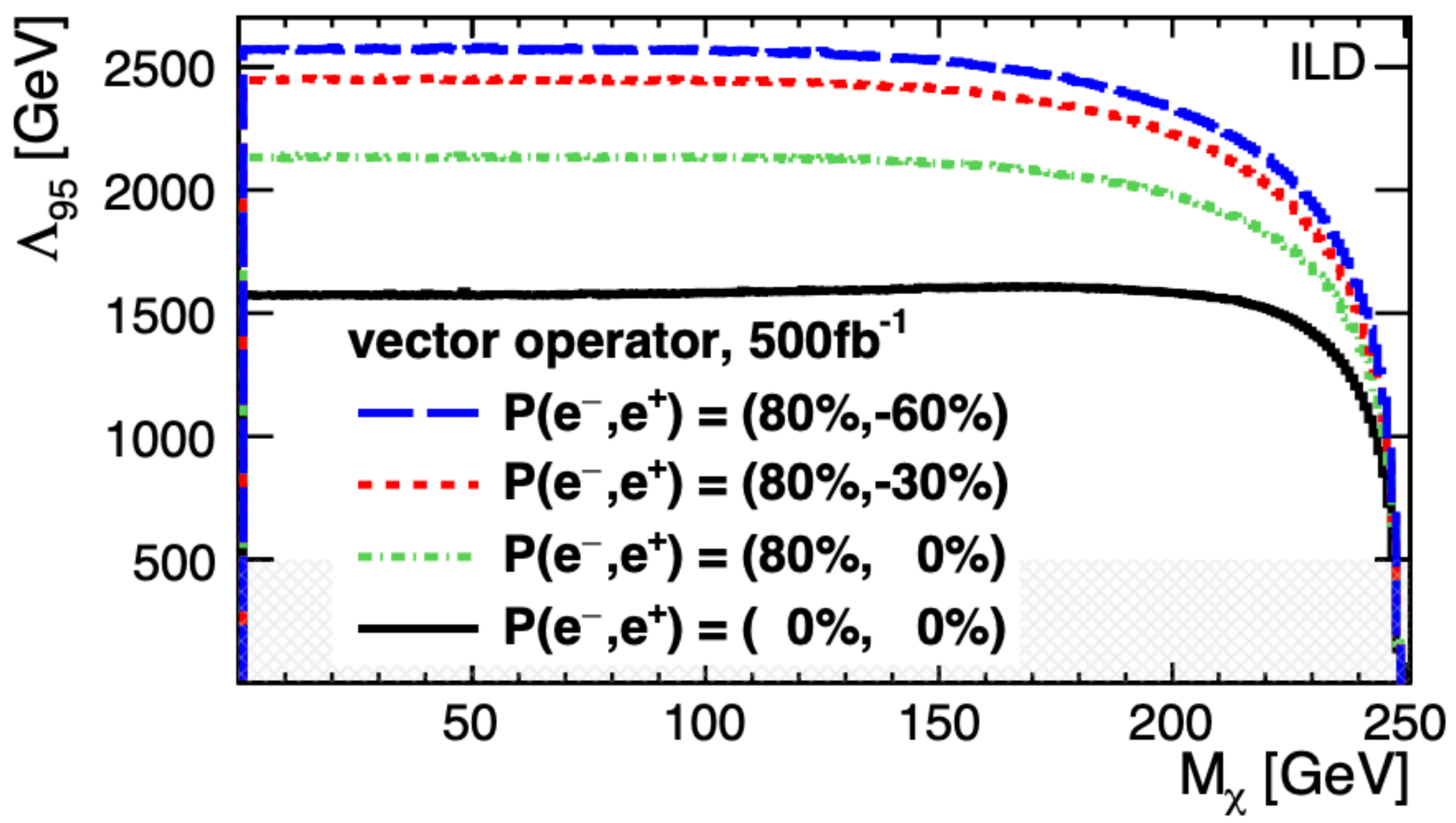
Direct top Yukawa Higgs selfcoupling

Search at the energy frontier

Physics Analysis on Role of Beam Polarizations

cornerstone for making the physics case

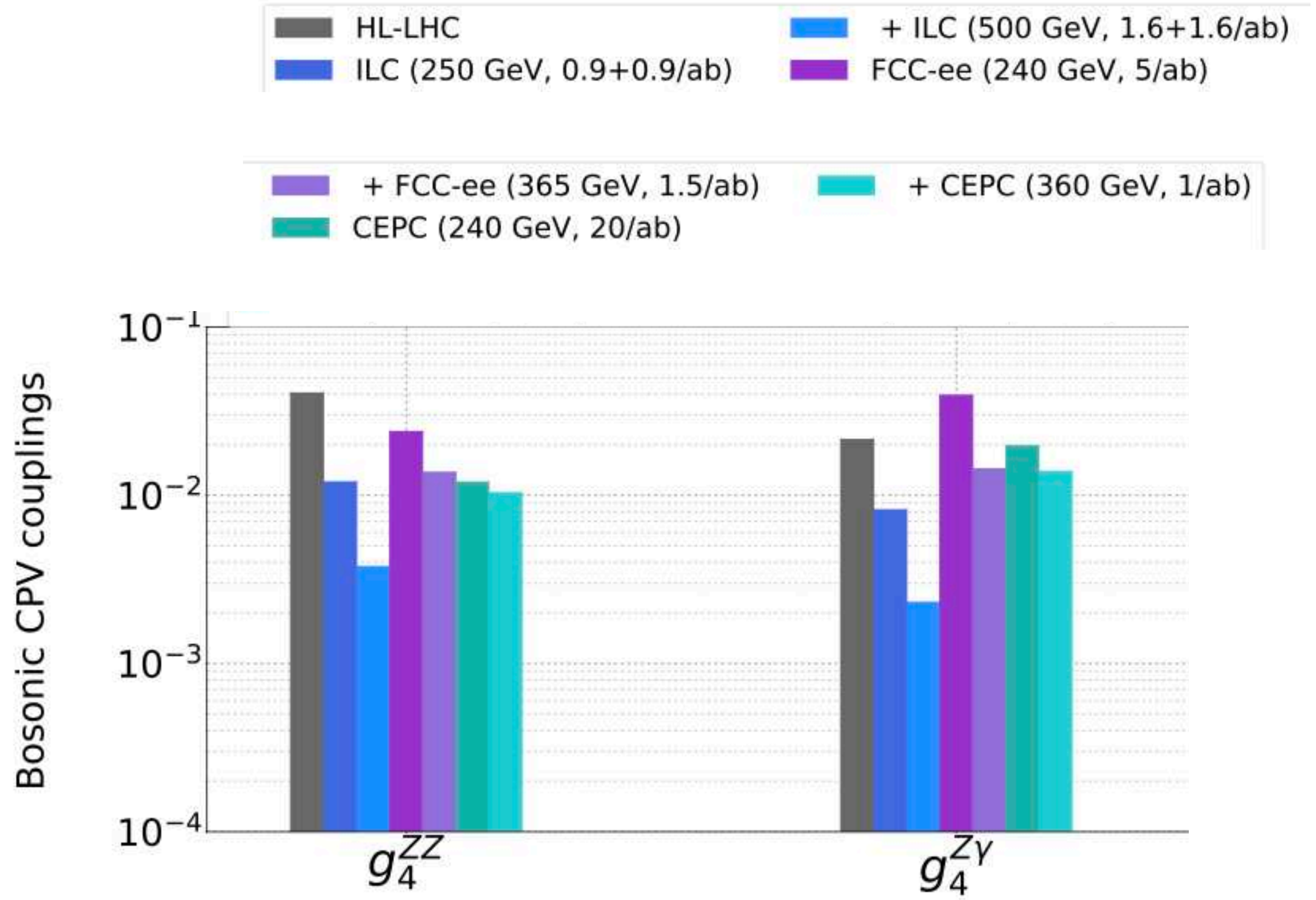
- constantly being explored what advantages polarized beams would bring in physics analysis



WIMP search

[M. Habermehl, PhD Thesis]

M. Habermehl,



CP-violating HZZ and HZγ couplings

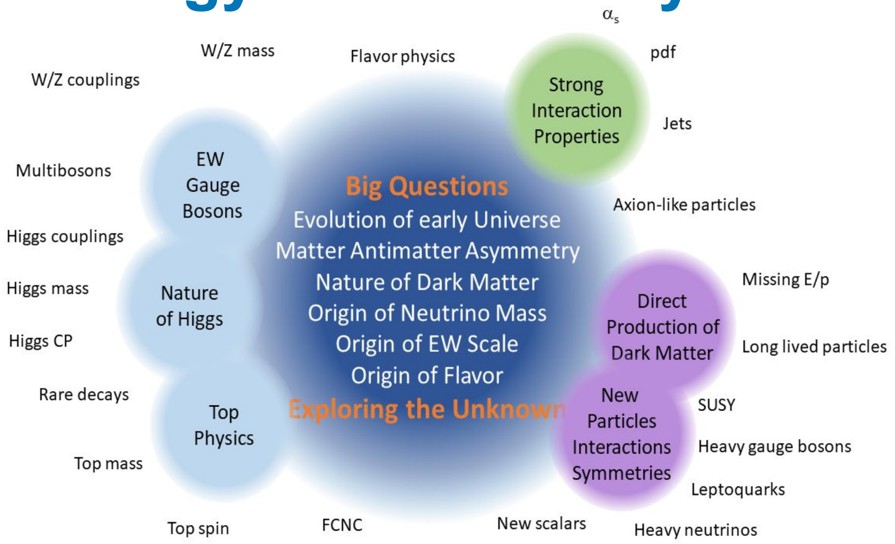
[➟talk by V.Miralles]

Conclusions from Snowmass

Energy Frontier: explore the TeV energy scale and beyond

Addressing the "**Big Questions**" and "**Exploring the unknown**" are the main scientific goals of the EF

to be pursued following



Two main avenues

➢ **Study known phenomena at high energies looking for indirect evidence of BSM physics**
   - Need **factories of Higgs bosons** (and other SM particles) to probe the TeV scale via precision measurements

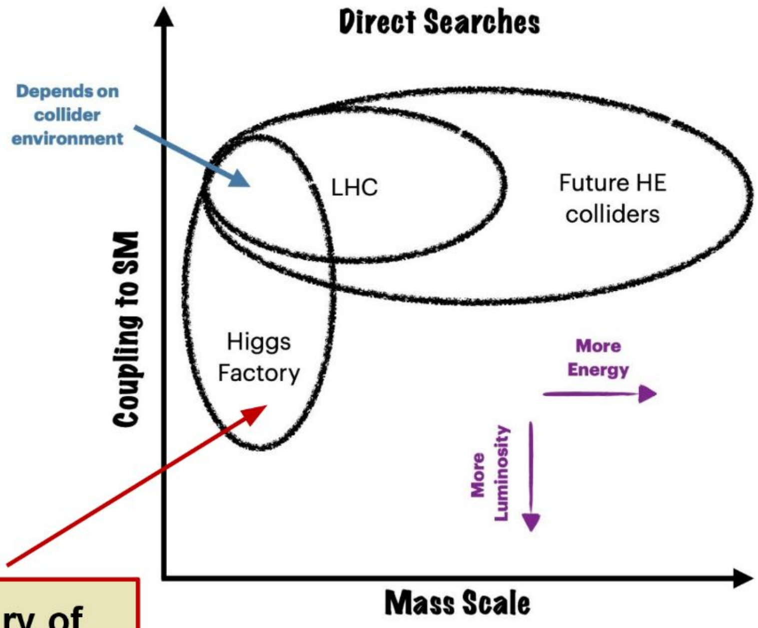
➢ **Search for direct evidence of BSM physics at the energy frontier**
   - Need to directly reach the **multi-TeV scale**

Energy Frontier Machines: energy and precision

New physics can be at low and at high mass scales: Naturalness would prefer mass scale close to the EW scale, but direct searches of specific models have placed stronger bounds around 1-2 TeV.

Depending on the mass scale of new physics and the type of collider, the primary method for discovery new physics can vary.

We need to use both energy and precision to push beyond the 1 TeV scale



Focus of this talk: some highlights and a summary of the vision emerged from Snowmass EF studies

Snowmass 2021: EF Benchmark Scenarios

Higgs-boson factories (up to 1 TeV c.o.m. energy)

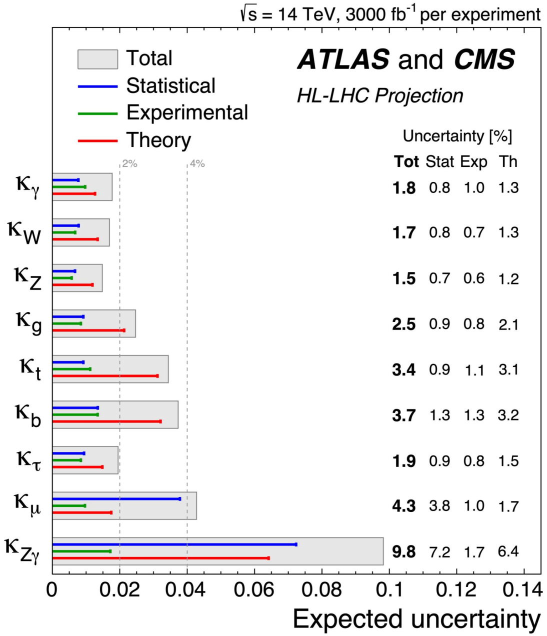
Collider	Type	$\sqrt{s}$	$\mathcal{P}[\%]$ e^-/e^+	$\mathcal{L}_{\text{int}}$ ab^{-1}/IP	Start Date Const.	Start Date Physics
HL-LHC	pp	14 TeV		3		2027
ILC & C^3	ee	250 GeV	$\pm80/\pm30$	2	2028	2038
		350 GeV	$\pm80/\pm30$	0.2		
		500 GeV	$\pm80/\pm30$	4		
		1 TeV	$\pm80/\pm20$	8		
CLIC	ee	380 GeV	$\pm80/0$	1	2041	2048
CEPC	ee	M_Z		50	2026	2035
		$2M_W$		3		
		240 GeV		10		
		360 GeV		0.5		
FCC-ee	ee	M_Z		75	2033	2048
		$2M_W$		5		
		240 GeV		2.5		
		$2\ M_{top}$		0.8		
μ-collider	$\mu\mu$	125 GeV		0.02		

Multi-TeV colliders (> 1 TeV c.o.m. energy)

Collider	Type	$\sqrt{s}$	$\mathcal{P}[\%]$. e^-/e^+	$\mathcal{L}_{\text{int}}$ ab^{-1}/IP	Start Date Const.	Start Date Physics
HE-LHC	pp	27 TeV		15		
FCC-hh	pp	100 TeV		30	2063	2074
SppC	pp	75-125 TeV		10-20		2055
LHeC	ep	1.3 TeV		1		
FCC-eh		3.5 TeV		2		
CLIC	ee	1.5 TeV	$\pm80/0$	2.5	2052	2058
		3.0 TeV	$\pm80/0$	5		
μ-collider	$\mu\mu$	3 TeV		1	2038	2045
		10 TeV		10		

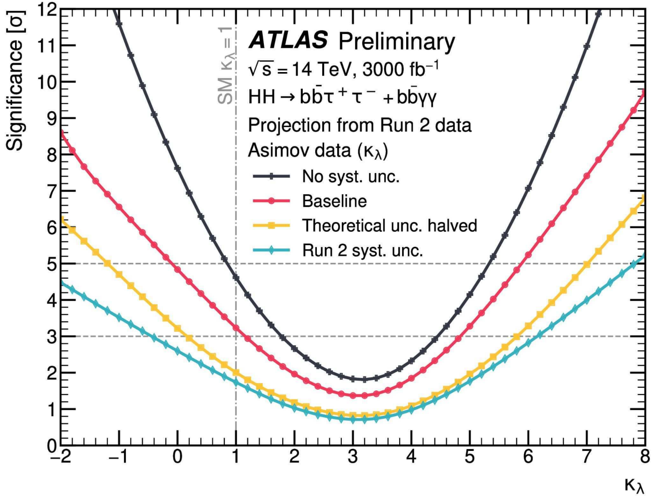
Timelines are taken from the Collider ITF report (arXiv: 2208.06030)

The physics case of the HL-LHC is very strong

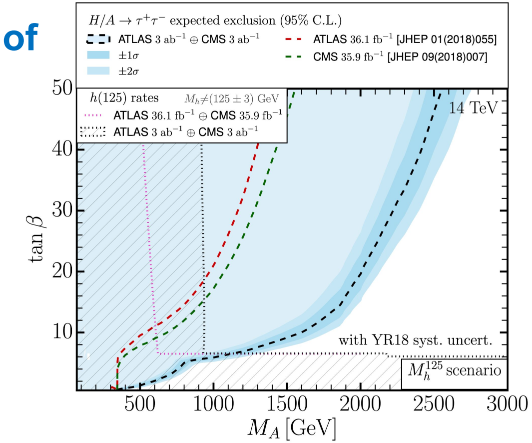


Sensitive to BSM physics in measure of Higgs couplings

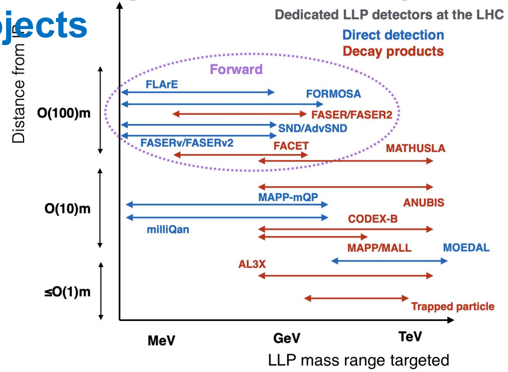
First bounds on Higgs self-coupling



Extended reach of BSM searches



Broad program of auxiliary projects

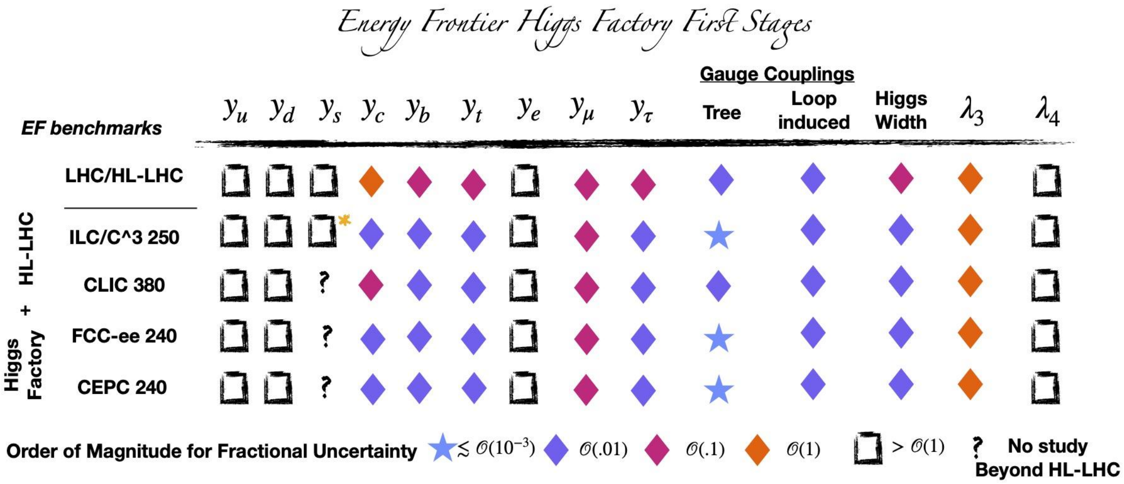


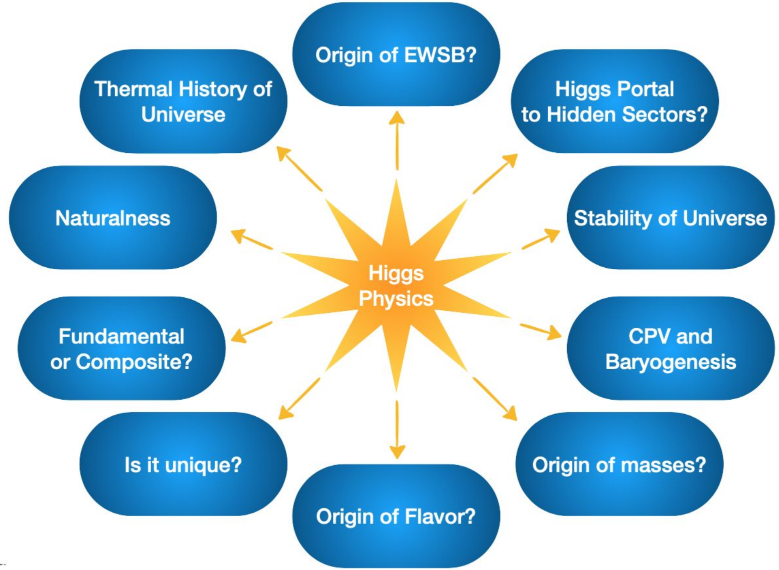
The immediate future is the HL-LHC

- During the next decade it is essential to complete the **highest priority recommendation of the last P5** and to fully realize the scientific potential of the **HL-LHC collecting at least 3 ab^{-1} of data.**
- **Continued strong US participation is critical** to the success of the HL-LHC physics program, in particular for the Phase-2 detector upgrades, the HL-LHC data taking operations and physics analyses based on HL-LHC data sets, including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions uncovered by the detector upgrades
- **For the next decade and beyond**
    - **2025-2030**: Prioritize HL-LHC physics program, including auxiliary experiments
    - **2030-2035**: Continue strong support for HL-LHC physics program
    - **After 2035**: Support continuing the HL-LHC physics program to the conclusion of archival measurements

Pushing the Higgs-boson precision program is crucial

The Higgs discovery has given us a unique handle on BSM physics and any future plan needs to make the most out of it.





Higgs Factories

- Higgs couplings at sub-percent level
- Search for exotic Higgs decays
- Explore Higgs portal to hidden sector
- Stress-test consistency of the SM
- Direct access to low-mass/weak-coupling BSM

From Snowmass 21 EF Higgs Topical Group Report (arXiv:2209.07510)

The intermediate future is an e^+e^- Higgs factory

The intermediate future is an e^+e^- Higgs factory, either based on a linear (ILC, C^3, CLIC) or circular collider (FCC-ee, CepC).

- **The various proposed facilities have a strong core of common physics goals**: it is important to **realize at least one somewhere in the world.**
- **A fast start towards construction is important**. There is **strong US support** for initiatives that could be realized on a time scale relevant for early career physicists.
- **For the next decade and beyond**
  - **2025-2030**: Establish a targeted e^+e^- Higgs Factory detector R&D for US participation in a global collider
  - **2030-2035**: Support and advance construction of an e^+e^- Higgs Factory
  - **After 2035**: Begin and support the physics program of an e^+e^- Higgs Factory

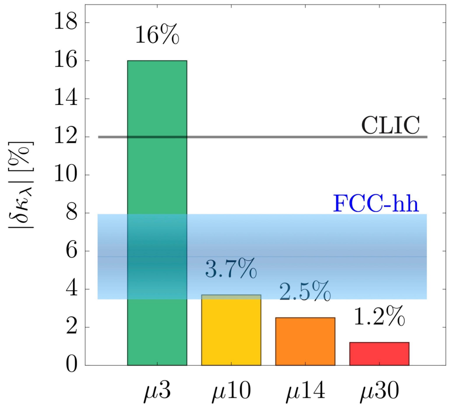
Updated reach for Higgs-self coupling

collider	Indirect-h	hh	combined
HL-LHC	100-200%	50%	50%
ILC_{250}/C^3-250	49%	–	49%
ILC_{500}/C^3-550	38%	20%	20%
$CLIC_{380}$	50%	–	50%
$CLIC_{1500}$	49%	36%	29%
$CLIC_{3000}$	49%	9%	9%
FCC-ee	33%	–	33%
FCC-ee (4 IPs)	24%	–	24%
FCC-hh	-	2.9-5.5%	2.9-5.5%
μ(3 TeV)	-	15-30%	15-30%
μ(10 TeV)	-	4%	4%

ATLAS and CMS HL-LHC updated

FCC-hh updated arXiv:2004.03505

Muon Collider reach:



arXiv:2203.07256

The long-term future is a multi-TeV collider

- A 10-TeV **muon collider** (MuC) and 100-TeV **proton-proton collider** (FCC-hh, SppC) directly probe the order 10 TeV energy scale with different strengths that are unparalleled in terms of mass reach, precision, and sensitivity.

- The main limitation is technology readiness. **A vigorous R&D program** into accelerator and detector technologies **will be crucial.**

- **For the next decade and beyond**
  - **2025-2030**:
    - Develop an initial design for a first stage TeV-scale Muon Collider in the US (pre-CDR)
    - Support critical detector R&D towards EF multi-TeV colliders
  - **2030-2035**: Demonstrate principal risk mitigation and deliver CDR for a first-stage TeV-scale Muon Collider
  - **After 2035**:
    - Demonstrate readiness to construct and deliver TDR for a first-stage TeV-scale Muon Collider
    - Ramp up funding support for detector R&D for EF multi-TeV colliders

EF Colliders: Opportunities for the US

- Our vision for EF can only be realized as a **worldwide program** and we need to envision that **future colliders will have to be sited all over the world** to support and empower an international vibrant, inclusive, and diverse scientific community.
- **Planning to proceed in multiple parallel prongs may allow us to better adapt to international contingencies** and eventually build the next collider sooner. Such a strategy will also help develop a robust long term plan for the global HEP community, with U.S. leadership in EF colliders.
- **The US EF community has expressed renewed interest and ambition to bring back energy-frontier collider physics to the US soil** while maintaining its international collaborative partnerships and obligations.
- **Attractive opportunities** to be considered are:
  - **A US-sited linear e^+e^- collider (ILC/C^3)**
  - **Hosting a 10-TeV range Muon Collider**
  - **Exploring other e^+e^- collider options to fully utilize the Fermilab site**
- Bold “new” projects offer the next generation some challenges to rise to and inspire more young people from the US to join HEP and in the long term help with strengthening the vibrancy of the field.

↳ **More than 40 contribute papers on Muon Collider studies during Snowmass 21**

↳ **New C^3 proposal gained momentum during Snowmass 21**

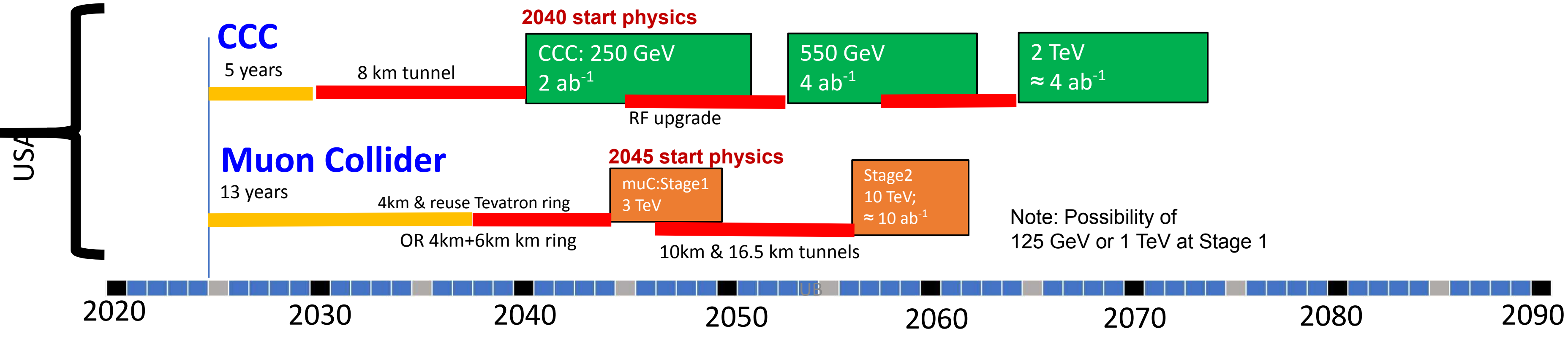
⇨ **Future Colliders Initiative started at Fermilab (series of Agora on FC)**
Call for a national R&D program on future colliders (arXiv:2207.06213)

Possible scenarios of future colliders

Proton collider
Electron collider
Muon collider
Construction/Transformation
Preparation / R&D

Original from ESG by UB
Updated July 25, 2022 by MN

Proposals emerging from this Snowmass for a US based collider



- **Timelines technologically limited**
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used as an upgrade of ILC] or a CCC only option in the US.
  - Consider hosting ILC in the US.
  - International Cost Sharing.

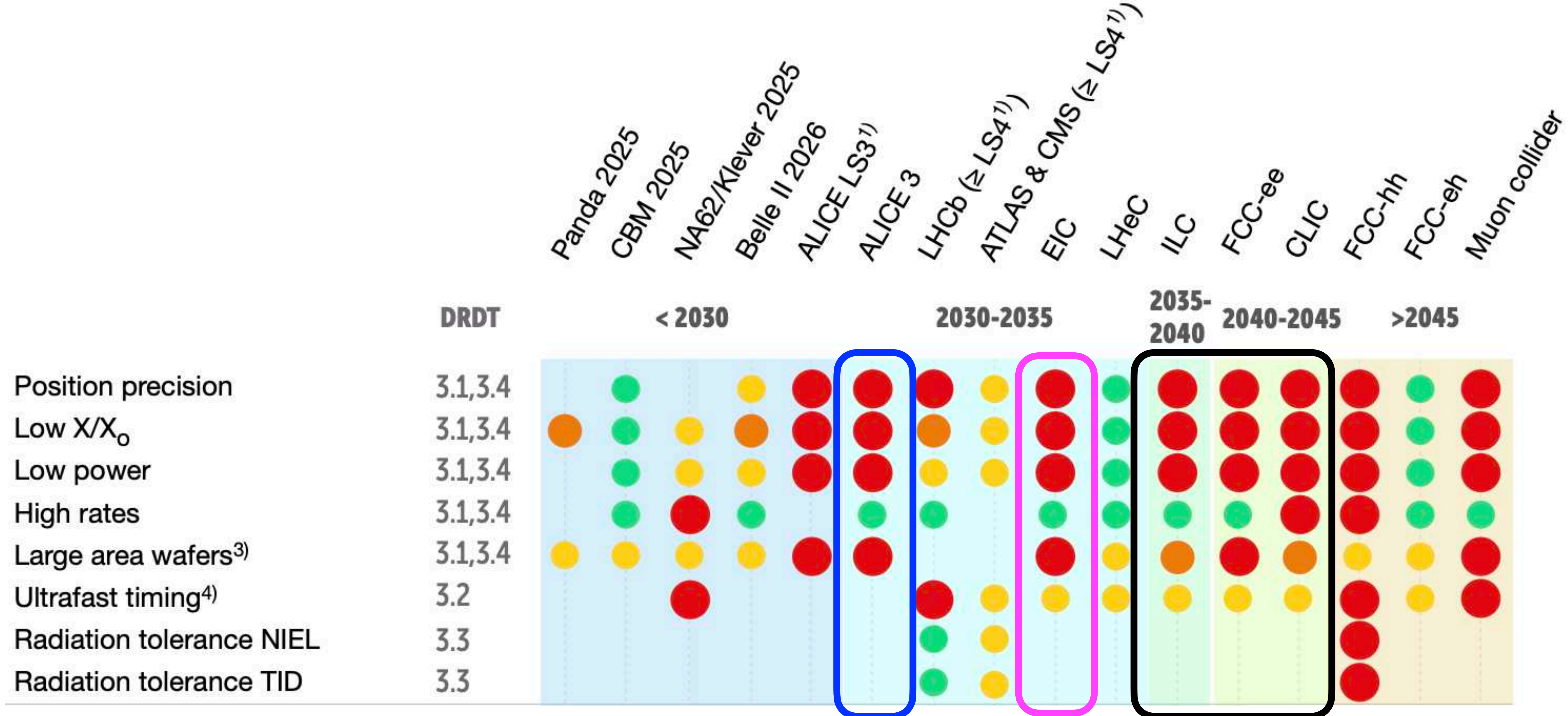
From EF Report

Working group highlights

Si pixel detectors: MIMOSIS

Ziad El Bitar

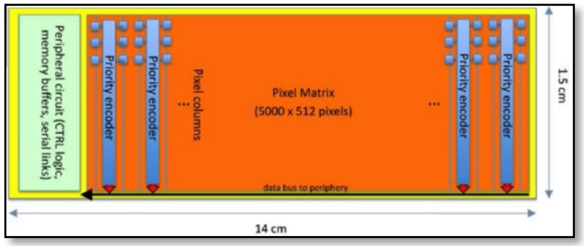
- Important similarities between vertex detector requirements for ee factories and for ALICE upgrades & EIC

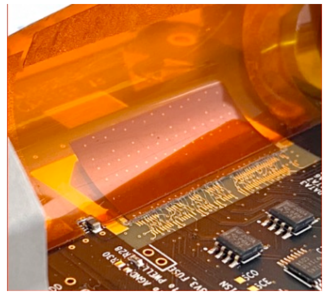


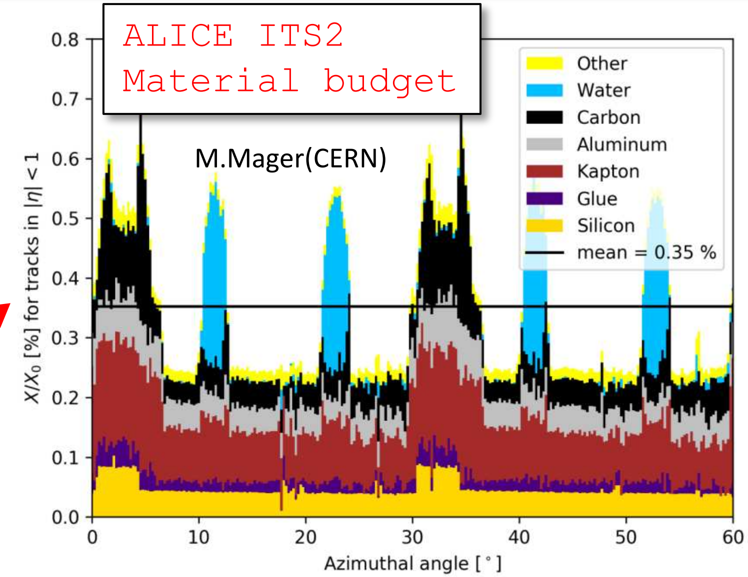
"Technical" Start Date of Facility (This means, where the dates are not known, the earliest technically feasible start date is indicated - such that detector R&D readiness is not the delaying factor)				< 2030					2030-2035					2035 - 2040	2040-2045		> 2045		
				Panda 2025	CBM 2025	NA62/Klever 2025	Belle II 2026	ALICE LS3 [1)]	ALICE 3	LHCb (≳LS4)[1)]	ATLAS/CMS (≳ LS4)[1)]	EIC	LHeC	ILC [2)]	FCC-ee	CLIC [2)]	FCC-hh	FCC-eh	Muon Collider
Vertex Detector[3)]	MAPS Planar/3D/Passive CMOS LGADs	DRDT 3.1 DRDT 3.4	Position precision σ_{hit} (µm)		≃ 5		≲ 5	≃ 3	≲ 3	≲ 10	≲ 15	≲ 3	≃ 5	≲ 3	≲ 3	≲ 3	≃ 7	≃ 5	≲ 5
			X/X_0 (%/layer)	≲ 0.1	≃ 0.5	≃ 0.5	≲ 0.1	≃ 0.05	≃ 0.05	≃ 1		≃ 0.05	≲ 0.1	≃ 0.05	≃ 0.05	≲ 0.2	≃ 1	≲ 0.1	≲ 0.2
			Power (mW/cm^2)		≃ 60			≃ 20	≃ 20			≃ 20		≃ 20	≃ 20	≃ 50			
			Rates (GHz/cm^2)		≃ 0.1	≃ 1	≲ 0.1		≲ 0.1	≃ 6		≲ 0.1	≃ 0.1	≃ 0.05	≃ 0.05	≃ 5	≃ 30	≃ 0.1	
			Wafers area (")[4)]					12	12			12			12		12		12
		DRDT 3.2	Timing precision σ_t (ns)[5)]	10		≲ 0.05	100		25	≲ 0.05	≲ 0.05	25	25	500	25	≃ 5	≲ 0.02	25	≲ 0.02
		DRDT3.3	Radiation tolerance NIEL ($x 10^{16}$ neq/cm^2)							≃ 6	≃ 2						≃ 10^2		
			Radiation tolerance TID (Grad)							≃ 1	≃ 0.5						≃ 30		

Material budget: Bent sensors & stitching

- Stitching:
  - ✓ The way to go to minimize material budget

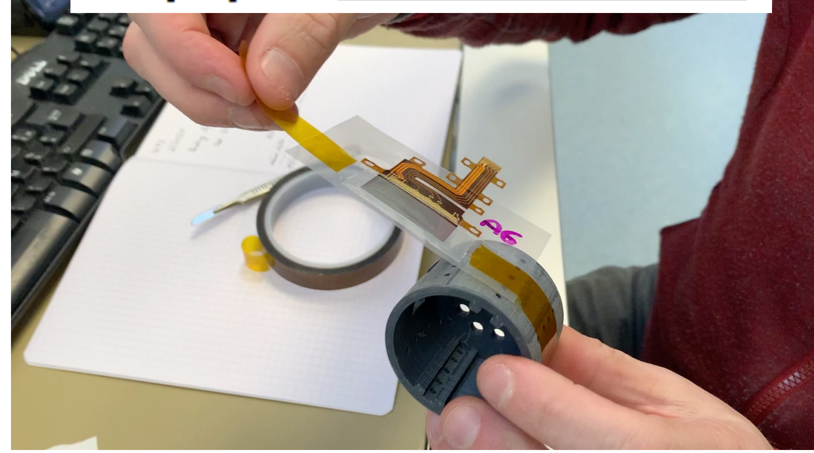


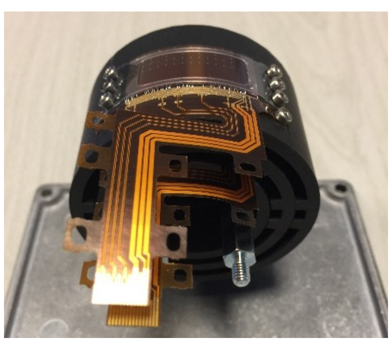


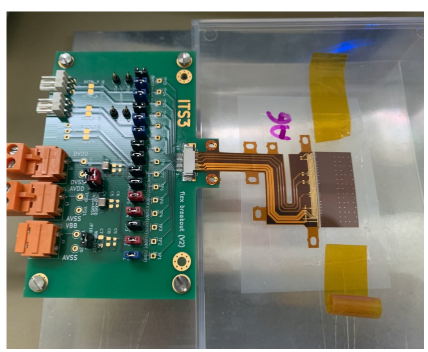


- ALICE-ITS3/CERN drive the R&D
  - ✓ Cf. M. Mager Seminar: *ALICE ITS3 – a next generation vertex detector based on bent, wafer-scale CMOS sensors*
    - https://indico.cern.ch/event/1071914/
- Micro-technics tests @IPHC
  - ✓ collaboration with ALICE-ITS3
  - ✓ Know-how acquired for bent bonding.

1st paper: arxiv:2105.13000







Bending / bonding
Or Bonding / bending
⇨Functionnal tests

Gas detectors: Time Projection Chambers

Huirong Qi

- TPC = “ultimate” drift chamber, with 3D precision tracking with low material budget and PID through dE/dx or cluster counting
- Main tracking detector for ILD and CEPC detectors
- Main recent progress on
  - Use of multiple layers of MPGDs (GEM or Micromegas) to significantly reduce ion back-flow (IBF) even without gating (crucial for circular colliders)
  - Use of MPGDs with pad/pixelated readout to reduce occupancy (crucial for high-lumi runs @Z).
- Pixelated readout also provides additional advantages:
  - High spatial resolution under (lower) 2-3T magnetic field
  - Better momentum resolution
  - Better two tracks separation

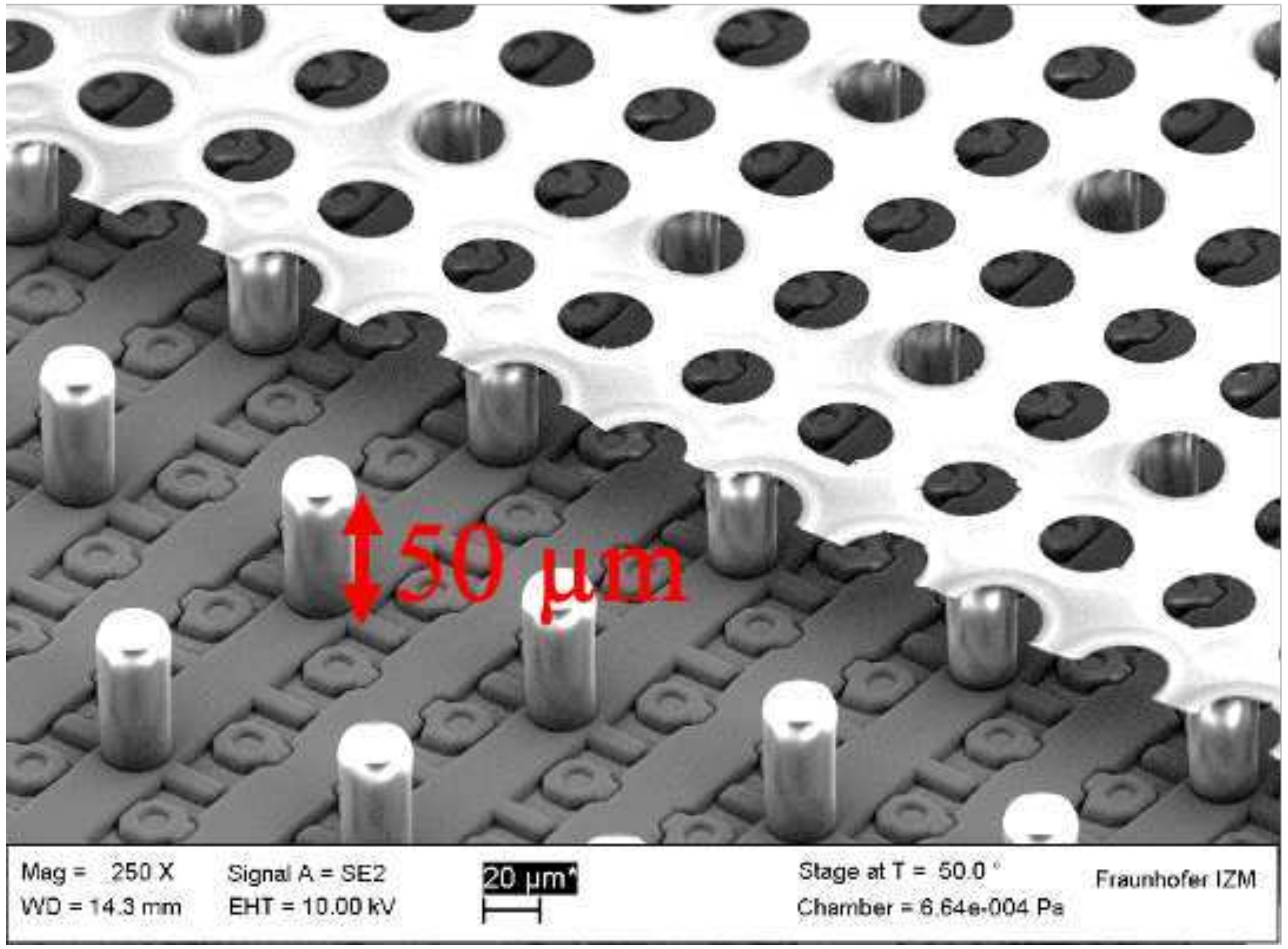
Standard charge collection:

Pads (1 mm × 6 mm)/ long strips

Pixelated readout:

Bump bond pads are used as charge collection pads.

55µm × 55 µm or larger



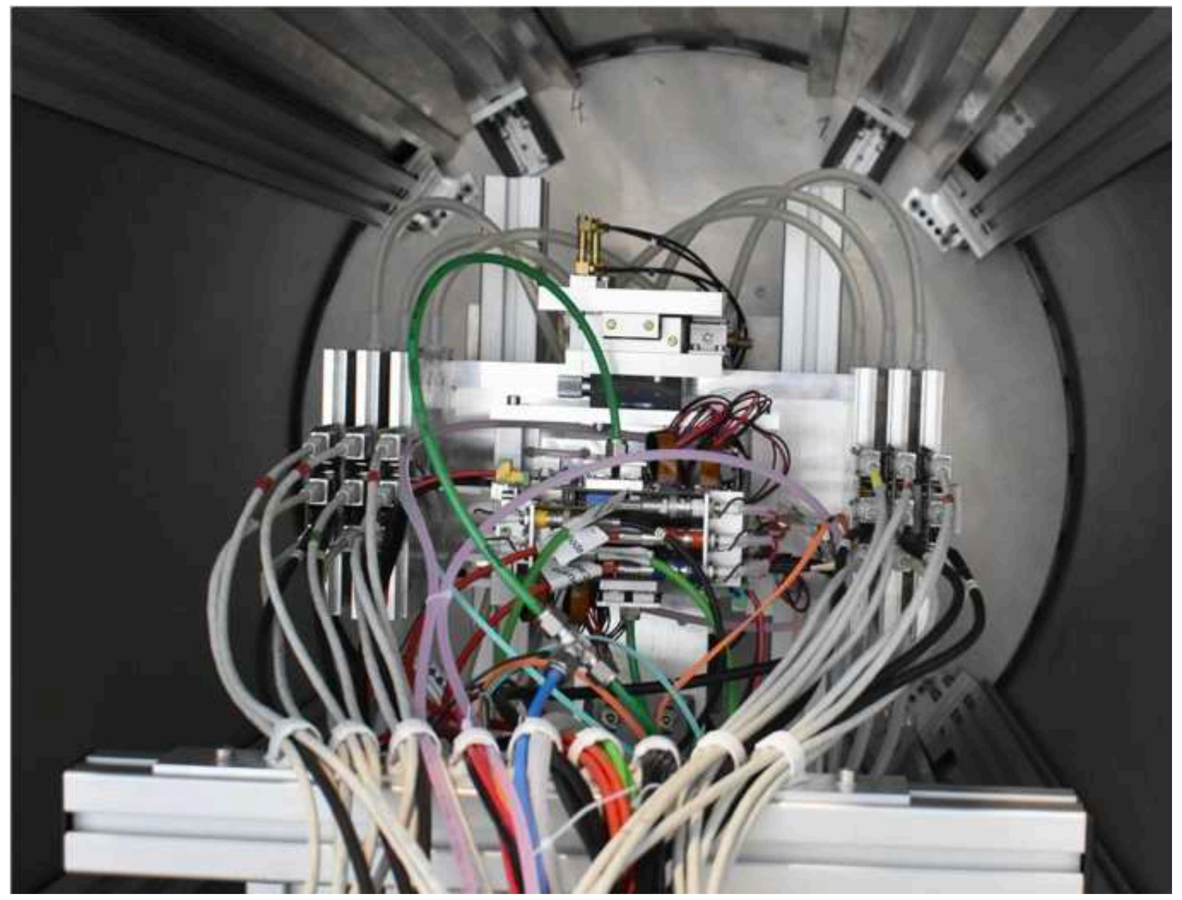
TPC R&D - pixelated technology

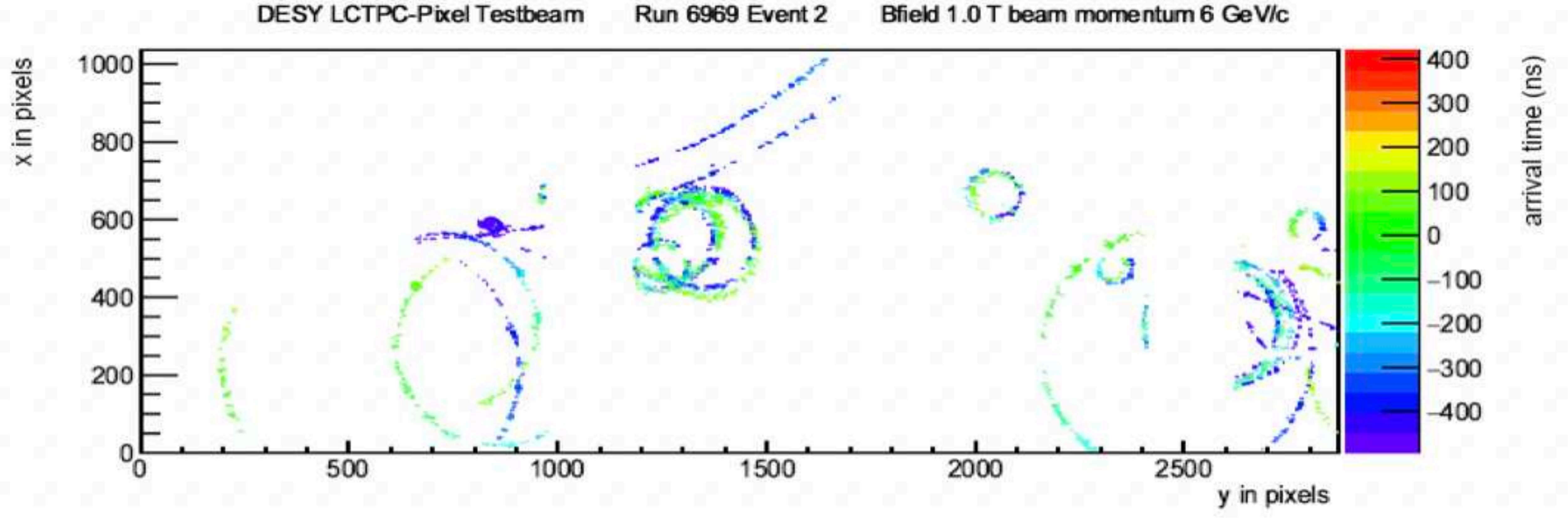
Huirong Qi

- Initial Timepix3-based GridPix detector module tests already indicate excellent tracking and dE/dx performance (4.1% resolution for 1m track length)

https://arxiv.org/abs/1902.01987

- Prototype with 160 GridPixes covering an active area of 320 cm^2 (10M pixel detector) also built and tested in beam at B=1T in DESY in June 2021, to prove large-scale production, integration, and readout => 1e6 events successfully collected

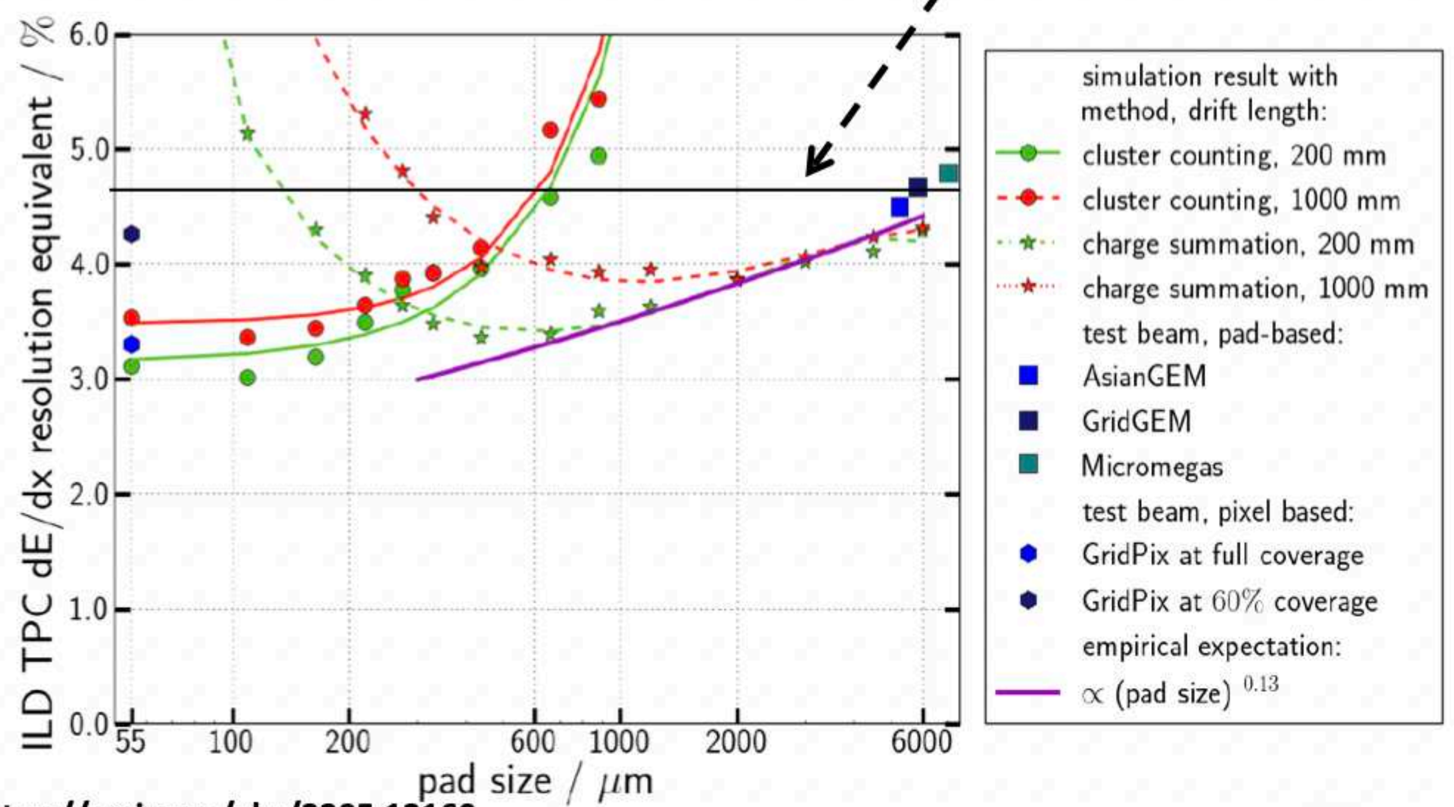




DESY testbeam in June 2021

- Development of new ASIC (Timepix4) ongoing (lower power consumption, easier assembly, better coverage)
- dN/dx cluster counting: should be feasible with high granularity readout, challenging for low power consumption, to be addressed by dedicated R&D.
- Preliminary full simulation studies (Geant4) foresee, compared to pad TPC w/ 6mm pads:
  - Momentum resolution improvement: 15%
  - dE/dx improvement: 30% (with cluster counting)

current resolution in the full ILD reco assuming 6 mm pads

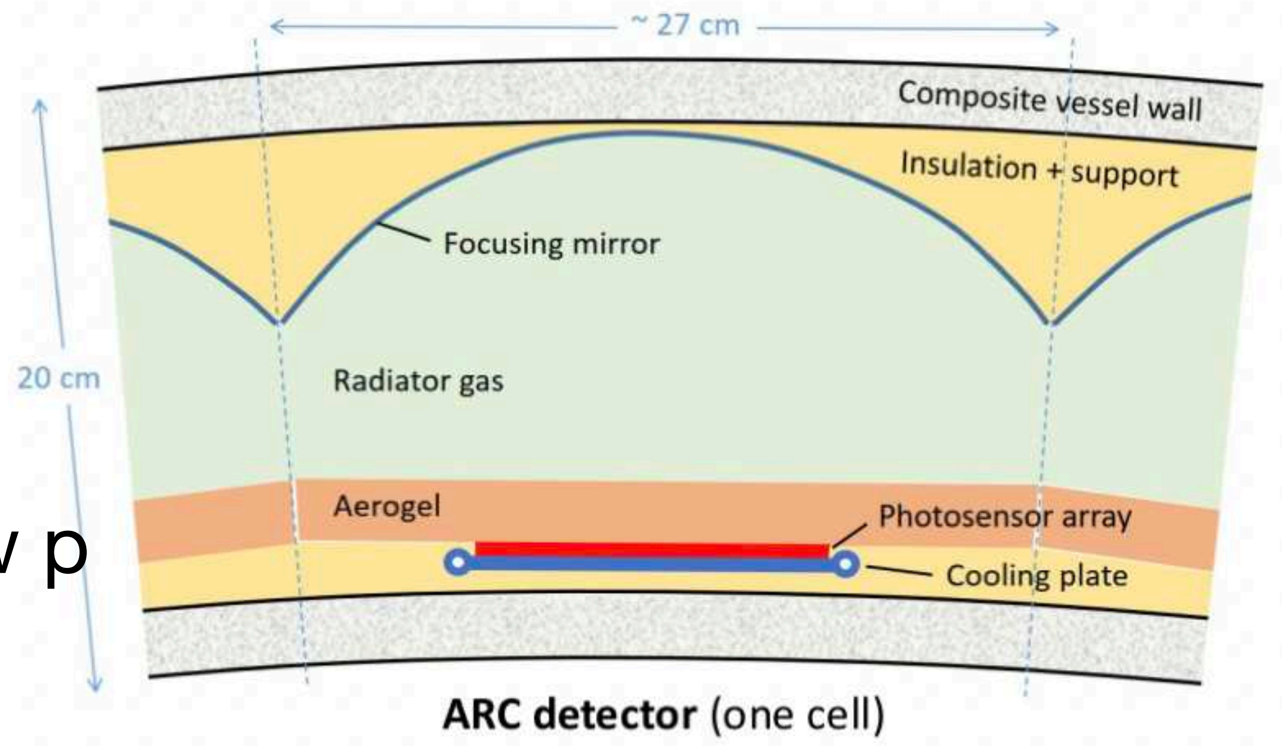


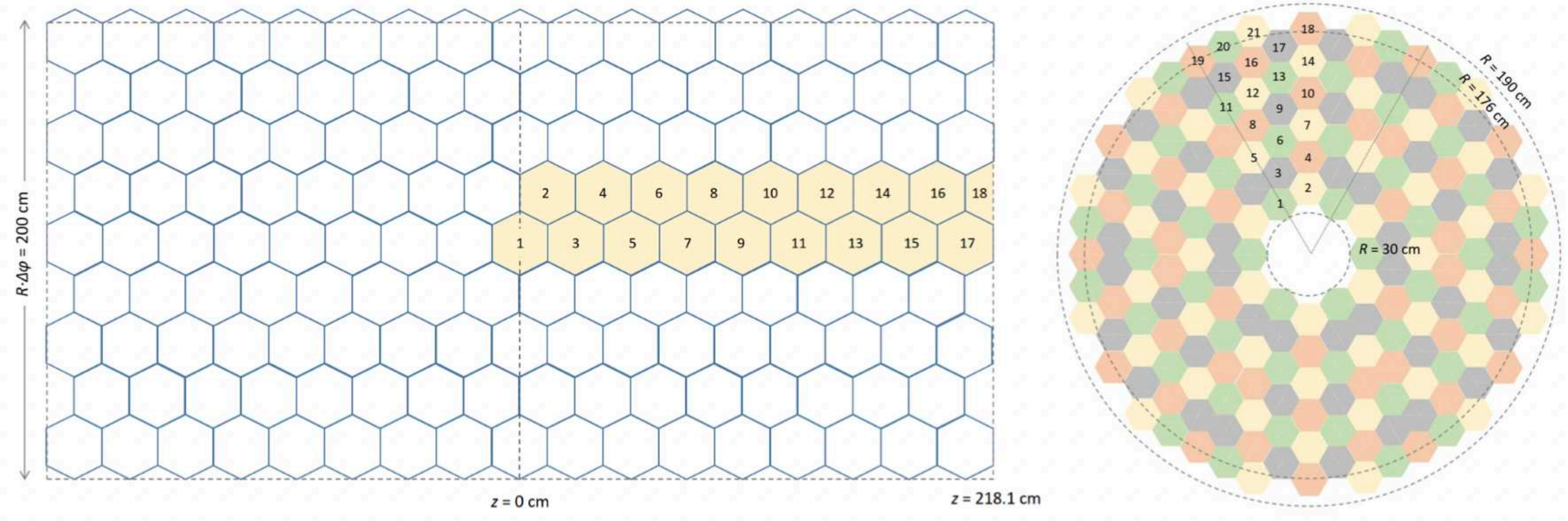
https://arxiv.org/abs/2205.12160

PID - Ring Imaging CHerenkov counters

Martin Tat

- Novel RICH detector concept for FCCee CLD detector: ARC = Array of RICH Cells (ARC):
  - Low mass (<=10%X_0), compact (20 cm in R), cellular structure similar to insect's compound eyes
- Double radiator to cover wide momentum range: gas (n=1.0014)→high p; aerogel (n=1.01-1.10)→low p





- Latest design uses non-pressurised perfluorobutane (C_4F_{10}) => simplified vessel design & cell layout
  - Could be replaced with (pressurised) Ar/Xe (10% X_0 instead of 5% X_0, slightly worse performance)

.

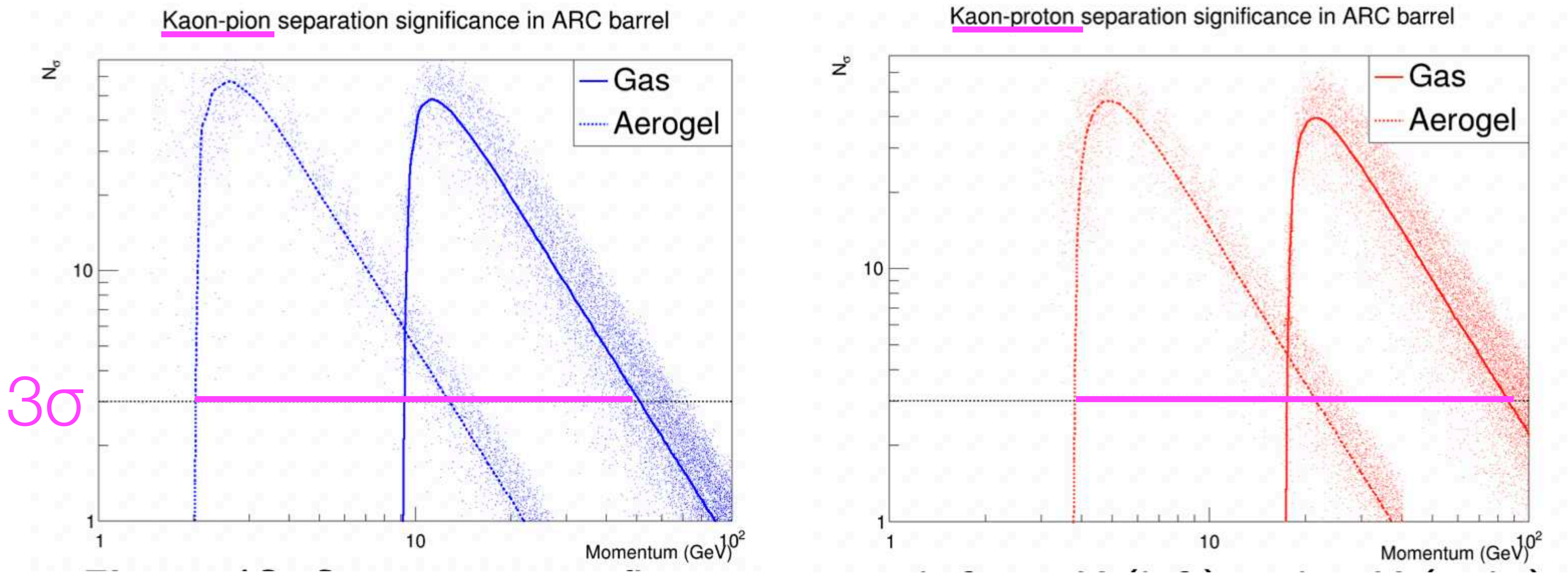
Units of radiation length X/X_0

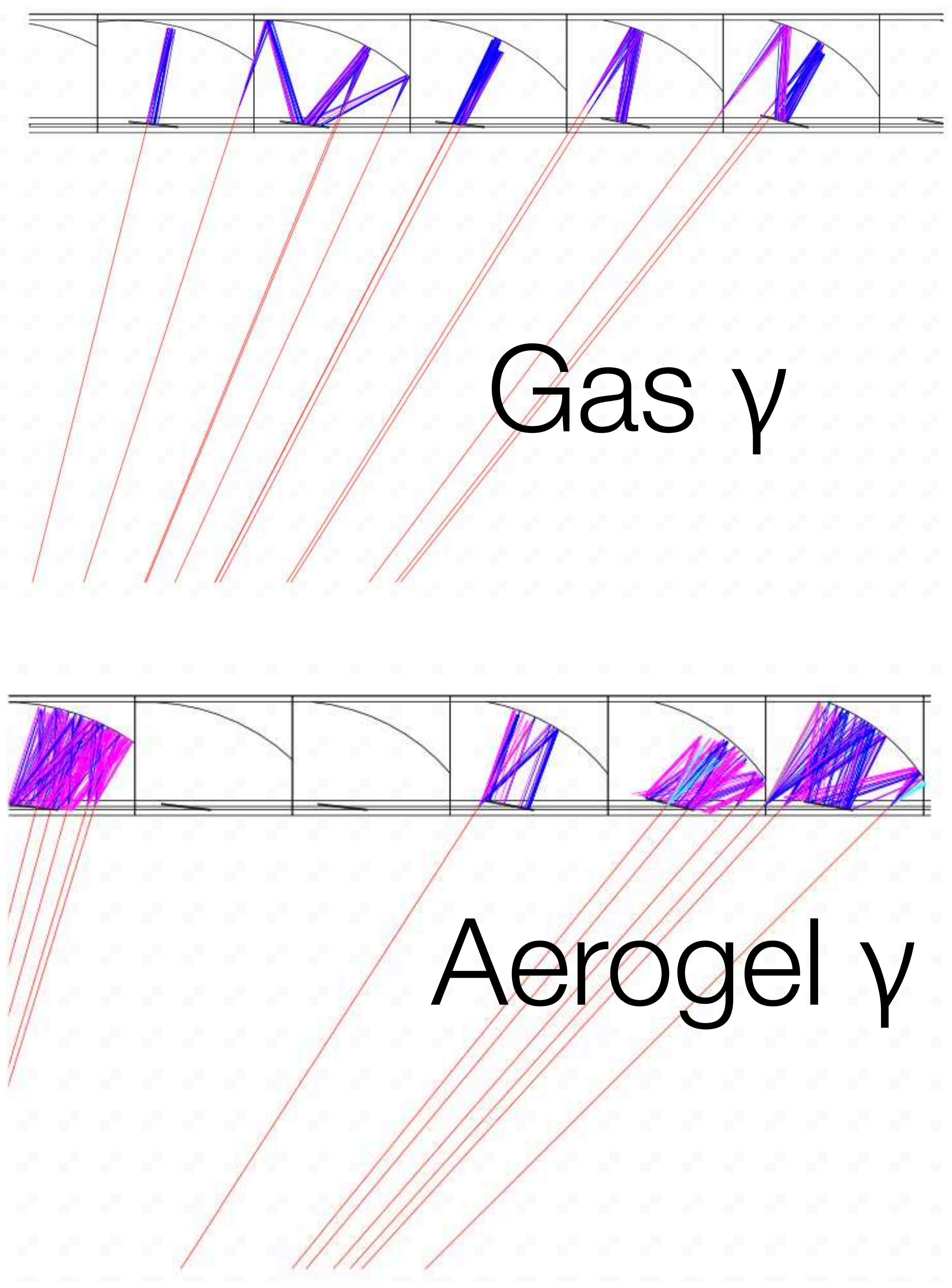
Detector component	Pressurised	Non-pressurised
Vessel walls	5%	1%
Photosensor array/electronics	1%	1%
Cooling plate (3 mm CF)	1%	1%
Aerogel ($n = 1.03$)	1%	0.5%
C_4F_{10} gas	1%	0.5%
Focusing mirror	1%	1%
Total	10%	5%

PID - RICH

Martin Tat

- Layout optimised (mirror curvature / mirror horizontal and vertical position / detector horizontal position and tilt) by minimising Cherenkov angle uncertainty (std deviation of reconstructed angles)
- Using (simplified) simulations of benchmarks processes (e.g. Bs→DsK)
- Effect of refractive index dependence on wavelength (chromatic error) included in simulation
- Gas (aerogel) provides over 3σ pion-kaon separation in the range 10-50 GeV (2-10 GeV)





- Still in conceptual phase, **next steps** will include completing the optimisation, including magnetic field effects, and R&D on photodetectors (**longer term**: engineering studies / detailed simulations / tests with prototypes)

Reminder: Physics Analysis Methods (WG2)

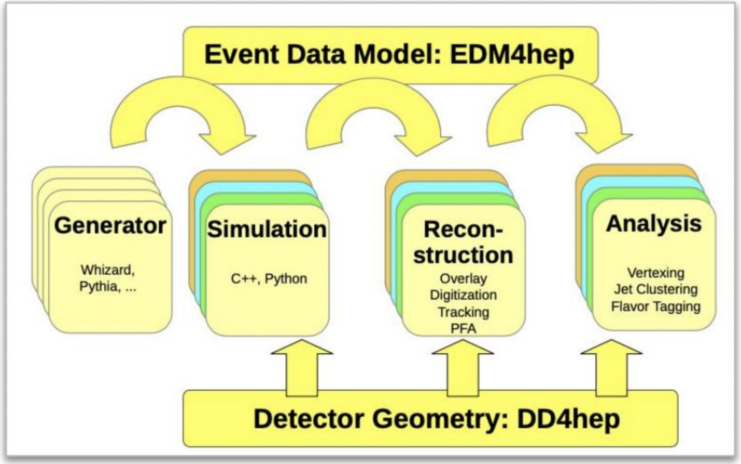
- GENERATORS
- SIMULATION
- RECONSTRUCTION
- ALGORITHMS & TOOLS
- SOFTWARE ECOSYSTEM

- Monte Carlo generators for e+e- precision EW, Flavour, Higgs, and top physics,
- Luminosity measurements
- Software framework
- Fast simulation and the limitations of such techniques
- Full Simulation
- Track and vertex reconstruction algorithms
- Jet algorithms / jet reconstruction
- Particle-flow reconstruction and global event description
- Requirements on particle identification
- Flavour tagging algorithms
- Importance of timing information
- Constrained fit

Software Ecosystem - Key4hep

Create a software ecosystem integrating in optimal way various software components to provide a ready-to-use full-fledged solution for data processing of HEP experiments

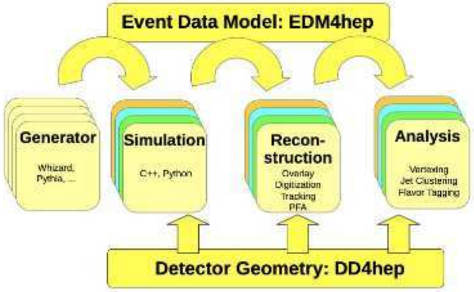
- ***Key4hep*** **federates FCC, ILC, CLIC , CEPC and other experiments**
- In use or medium term migration plan
- Supported by R&D efforts (AIDA, CERN EP etc.)
- **KEY4HEP coordinators consulted and involved in the organisation of all WG2 meetings**
  Frank Gaede
  Gerardo Ganis
  Andrè Sailer



Juraj Smieško: Reconstruction with KEY4HEP

Link

- Key4hep: Gaudi, EDM4hep, DD4hep, Spack
- Key4hep has ability to integrate other advanced reconstruction tools/frameweworks
- `k4MarlinWrapper` helps to bridge transitional period
  - DDMarlinPandora, LCFIPlus, ConformalTracking, ...
- Integration of large frameworks underway
  - K4CLUE, k4Pandora, k4ActsTracking
- Effort required to port reconstruction of already existing detector concepts to Key4hep



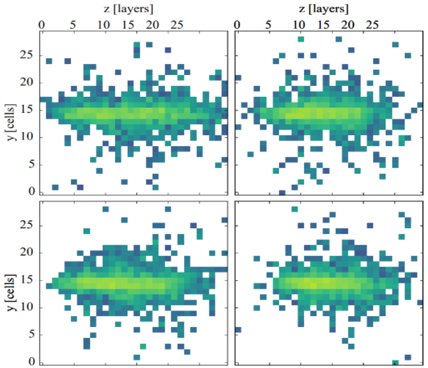
Engin Eren: Generative Models for Calorimeter Showers

Link

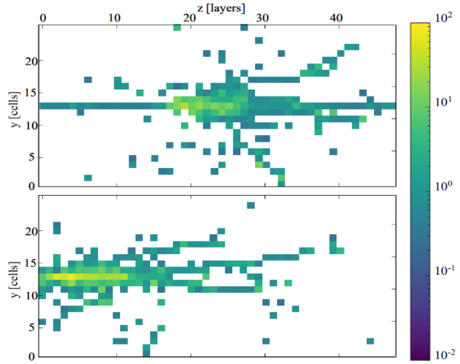
- MC simulation is computationally intensive
  - Calorimeters most intensive part of detector simulation
- **Generative models** potentially offer orders of magnitude speed up
- For the first time more challenging hadron showers in a high granular hadronic calorimeter

Hardware	Simulator	Time / Shower [ms]	Speed-up
CPU	GEANT4	2684 ± 125	×1
	WGAN	47.923 ± 0.089	×56
	BIB-AE	350.824 ± 0.574	×8
GPU	WGAN	0.264 ± 0.002	×10167
	BIB-AE	2.051 ± 0.005	×1309

*WGAN: (Wasserstein-) Generative Adversarial Neural Network
*BIB-AE: Bounded-Information Bottleneck Autoencoder

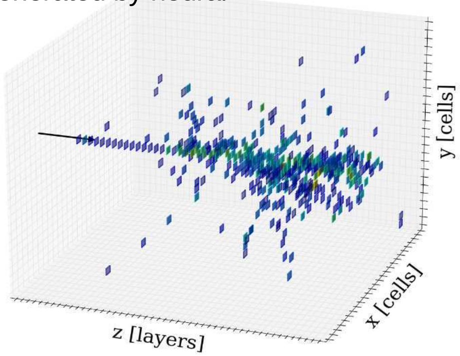


Cell Layout: 30 x 30 x 30 (Photon showers)



Cell Layout: 48 x 25 x 25 (Charged pion showers)

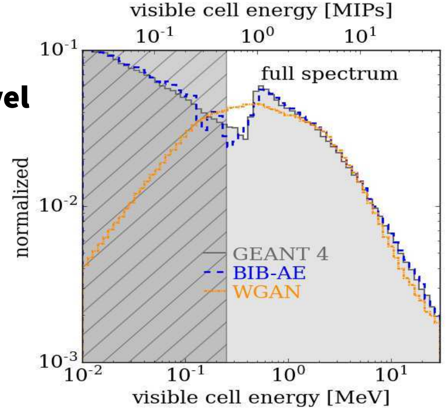
Shower generated by neural network!!

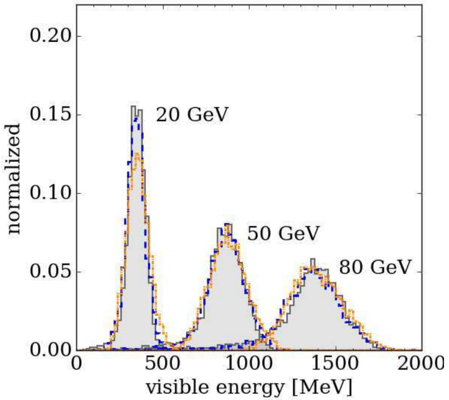


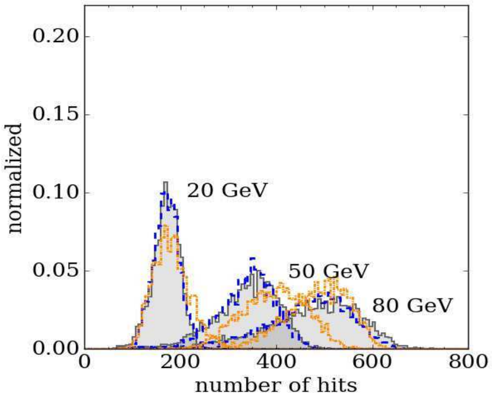
Engin Eren: Generative Models for Calorimeter Showers

Link

Generator Level

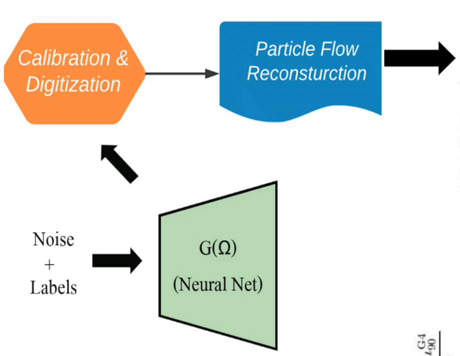


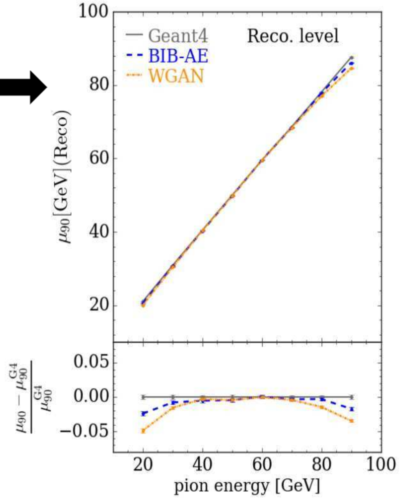


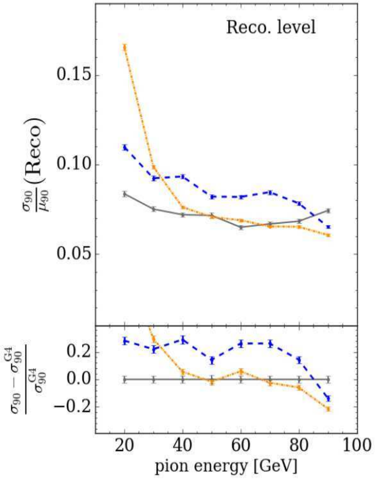


arXiv:2112.09709

Reco Level





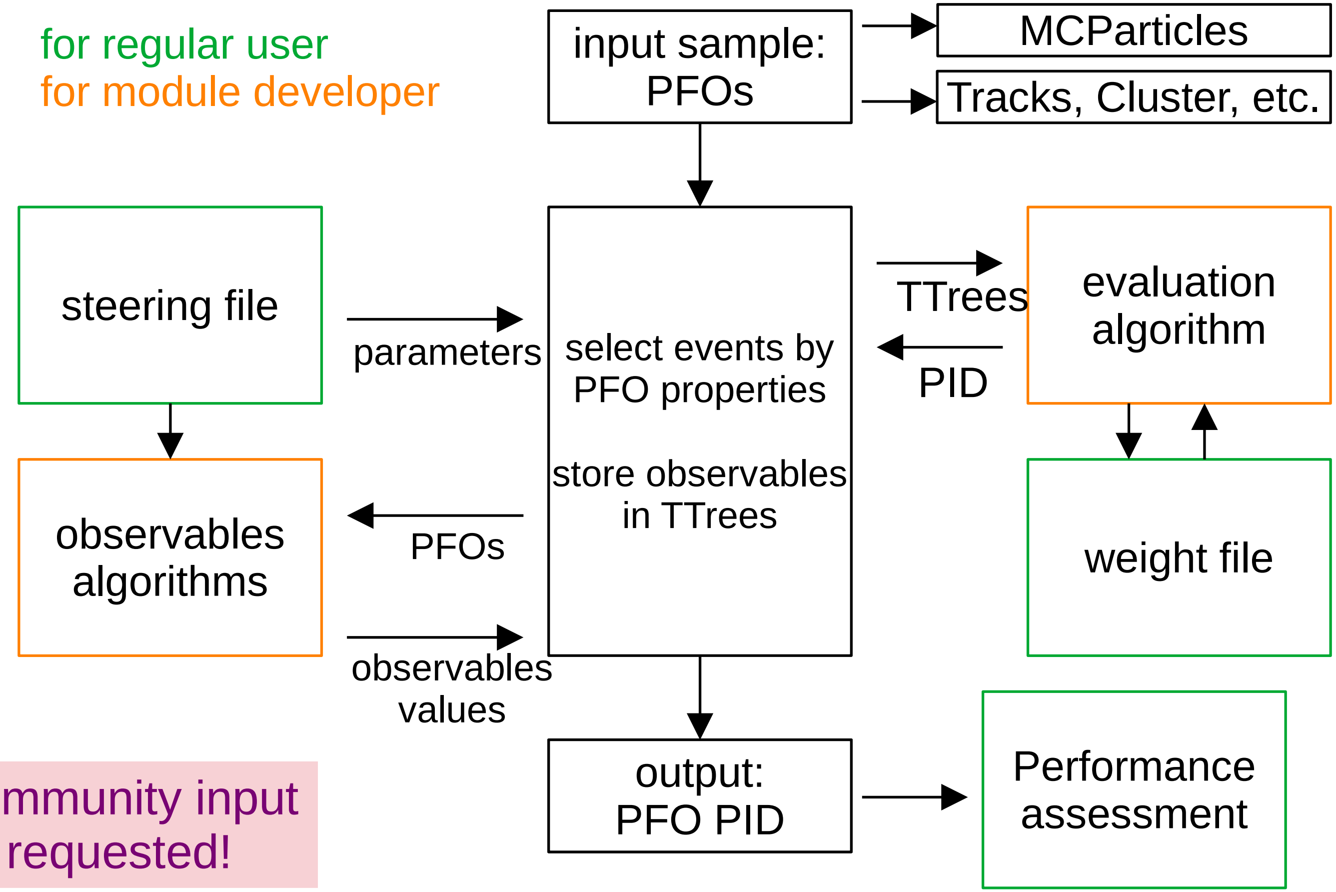


- Great progress
- Publications ongoing
- Various open questions

Uli Einhaus: A PID Framework for FHFs

Link

- Steering file
  - input sample
  - observables algorithms
  - signal categories PDGs
  - evaluation algorithm
  - weight file
  - sample cuts etc.
- Possibility to store observables and do training separately (python etc.)
- Separate performance assessment for various plots incl. eff./pur. MC PDG vs. Reco PDG and separation power



Community input requested!

ECFA Higgs Factory Study - WG1 Physics Potential

Subgroup WG1-PREC "Precision in theory and experiment"

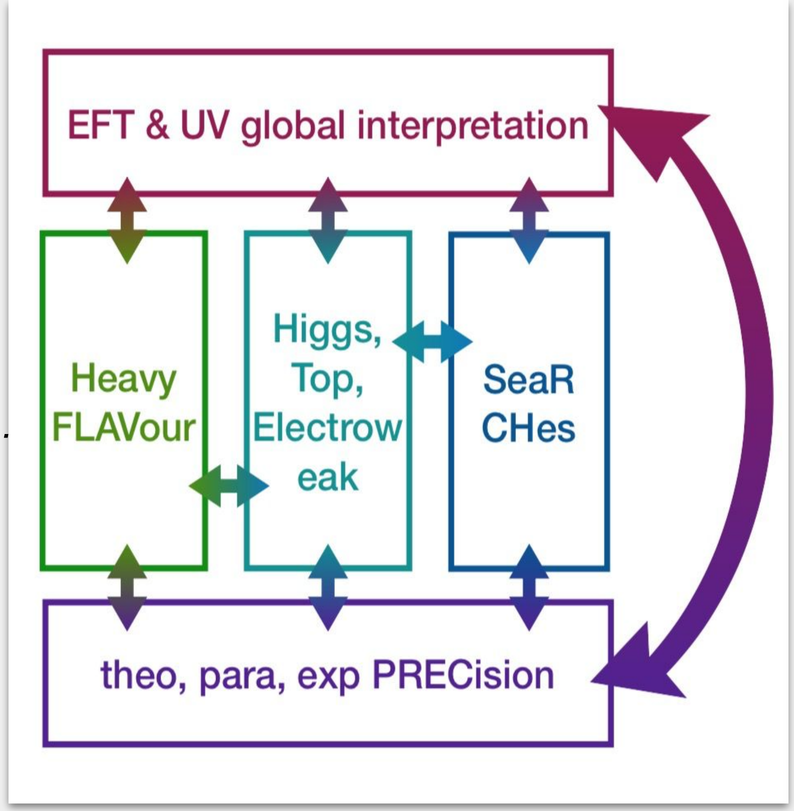
- One of five subgroups of ECFA-WHF-WG1
- Addressing very high-precision observables ($<\sim 10^{-4}$)

Topics:

- Precision calculations and measurements with related theoretical, parametric uncertainties:
  α_S, α_{QED}, m and Γ (for W, Z, H, t), W&Z decay properties, …
- Experimental syst. uncertainties (with WG2 and WG3)

Goals:

- Organize continued progress beyond Snowmass
- Bring communities together
- Facilitate comparisons between different collider options



A.Freitas, Wednesday Plenary

Parametric uncertainties

Impact of input parameter uncertainties on SM prediction for precision observables:

Snowmass EF EWK report '22

	ILC-GigaZ	FCC-ee	Param. error scen. 1	Param. error scen. 2
M_W [MeV]	2.5	0.4	2.8	0.6
Γ_Z [MeV]	0.12	<0.1	0.3	0.1
R_ℓ [10^{-3}]	6	1	3.2	1.3
$\sin^2\theta^\ell_{eff}$ [10^{-5}]	1	0.5	3.2	1.3
$\Gamma_{h\to bb}$ [%]	2	1.3	1.4	0.6
$\Gamma_{h\to WW}$ [%]	2	0.8	0.2	0.1
$\Gamma_{h\to gg}$ [%]	2.6	1.8	1.5	0.6

Parametric inputs:

	scen. 1	scen. 2
δm_t [MeV]	300	50
δm_b [MeV]	30	13
δM_Z [MeV]	0.8	0.1
δM_H [MeV]	20	10
$\delta\alpha_s$ [10^{-3}]	0.5	0.2
$\delta(\Delta\alpha)$ [10^{-4}]	1	0.3

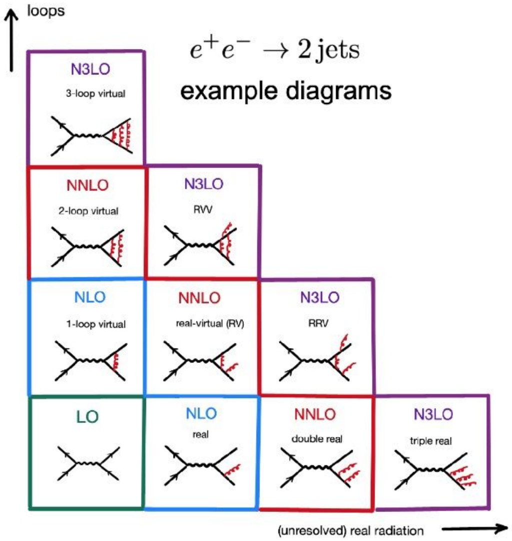
Goal: improve compatibility of uncertainty estimates across different collider options, and explore ways to reduce theory uncertainty

The "Exclusive" Frontier — fN(N)LO, Automation and MCs

- Fixed-order N(N)LO, resummation and matching in MCs
- Determination of efficiencies and systematic uncertainties
- Need $e^+e^- \to 2f, 3f, 4f, 5f, 6f, [7\text{-}10f]$ @ NLO QCD ⊕ EW
  (arbitrary cuts, fully differential)

- NLO QCD ⊕ EW automated: Sherpa, MG5, Whizard
- Caveats and fine-prints

$e^+e^- \to 2\,\text{jets}$ example diagrams



	$\sigma_{\rm LO}$[fb]	$\sigma_{\rm NLO}$[fb]	K
$e^+e^- \to jj$	622.737(8)	639.39(5)	1.027
$e^+e^- \to jjj$	340.6(5)	317.8(5)	0.933
$e^+e^- \to jjjj$	105.0(3)	104.2(4)	0.992
$e^+e^- \to jjjjj$	22.33(5)	24.57(7)	1.100
$e^+e^- \to jjjjjj$	3.583(17)	4.46(4)	1.245
$e^+e^- \to t\bar{t}$	166.37(12)	174.55(20)	1.049
$e^+e^- \to t\bar{t}j$	48.12(5)	53.41(7)	1.110
$e^+e^- \to t\bar{t}jj$	8.592(19)	10.526(21)	1.225
$e^+e^- \to t\bar{t}jjj$	1.035(4)	1.405(5)	1.357

from 2104.11141 & 2208.09438

$\mu^+\mu^- \to X, \sqrt{s} = 3$ TeV	$\sigma^{\rm incl}_{\rm LO}$ [fb]	$\sigma^{\rm incl}_{\rm NLO}$ [fb]	$\delta_{\rm EW}$ [%]
W^+W^-	$4.6591(2) \cdot 10^2$	$4.847(7) \cdot 10^2$	+4.0(2)
ZZ	$2.5988(1) \cdot 10^1$	$2.656(2) \cdot 10^1$	+2.19(6)
HZ	$1.3719(1) \cdot 10^0$	$1.3512(5) \cdot 10^0$	−1.51(4)
HH	$1.60216(7) \cdot 10^{-7}$	$5.66(1) \cdot 10^{-7}$ *	
W^+W^-Z	$3.330(2) \cdot 10^1$	$2.568(8) \cdot 10^1$	−22.9(2)
W^+W^-H	$1.1253(5) \cdot 10^0$	$0.895(2) \cdot 10^0$	−20.5(2)
ZZZ	$3.598(2) \cdot 10^{-1}$	$2.68(1) \cdot 10^{-1}$	−25.5(3)
HZZ	$8.199(4) \cdot 10^{-2}$	$6.60(3) \cdot 10^{-2}$	−19.6(3)
HHZ	$3.277(1) \cdot 10^{-2}$	$2.451(5) \cdot 10^{-2}$	−25.2(1)
HHH	$2.9699(6) \cdot 10^{-8}$	$0.86(7) \cdot 10^{-8}$ *	
$W^+W^-W^+W^-$	$1.484(1) \cdot 10^0$	$0.993(6) \cdot 10^0$	−33.1(4)
W^+W^-ZZ	$1.209(1) \cdot 10^0$	$0.699(7) \cdot 10^0$	−42.2(6)
W^+W^-HZ	$8.754(8) \cdot 10^{-2}$	$6.05(4) \cdot 10^{-2}$	−30.9(5)
W^+W^-HH	$1.058(1) \cdot 10^{-2}$	$0.655(5) \cdot 10^{-2}$	−38.1(4)
$ZZZZ$	$3.114(2) \cdot 10^{-3}$	$1.799(7) \cdot 10^{-3}$	−42.2(2)
$HZZZ$	$2.693(2) \cdot 10^{-3}$	$1.766(6) \cdot 10^{-3}$	−34.4(2)
$HHZZ$	$9.828(7) \cdot 10^{-4}$	$6.24(2) \cdot 10^{-4}$	−36.5(2)
$HHHZ$	$1.568(1) \cdot 10^{-4}$	$1.165(4) \cdot 10^{-4}$	−25.7(2)

Two major bottlenecks

- ☐ Virtual integrals with many mass scales / off-shell legs — Abreu ea., Badger ea., Baglio ea., Brønnum-Hansen ea.
- ☐ IR pole treatment / subtraction — CS, FKS, NS, Stripper, qT/sub-jettiness etc.

- ☑ FKS soft/eikonal sub
- ☑ NNLO QED (massiv
- ☑ for NNLO EW neec

Main bottlenecks for improved precision:

- Loop integrals
- IR pole treatment / subtraction

Flavour Physics @ Higgs factories

Z-pole

5×10^{12} Z bosons
$Br(Z\rightarrow b\,\bar{b}) \approx 15\%$

Particle production (10^9)	B^0 / $\overline{B}^0$	B^+ / B^-	B_s^0 / $\overline{B}_s^0$	Λ_b / $\overline{\Lambda}_b$	$c\bar{c}$	τ^-/τ^+
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-*ee*	300	300	80	80	600	150

[Table from S. Monteil]

Several positive attributes of flavour from a Z factory

Attribute	$\Upsilon(4S)$	pp	Z^0
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section		✓	
Negligible trigger losses	✓		✓
Low backgrounds	✓		✓
Initial energy constraint	✓		(✓)

Measuring b → sνν̄ at Z factories

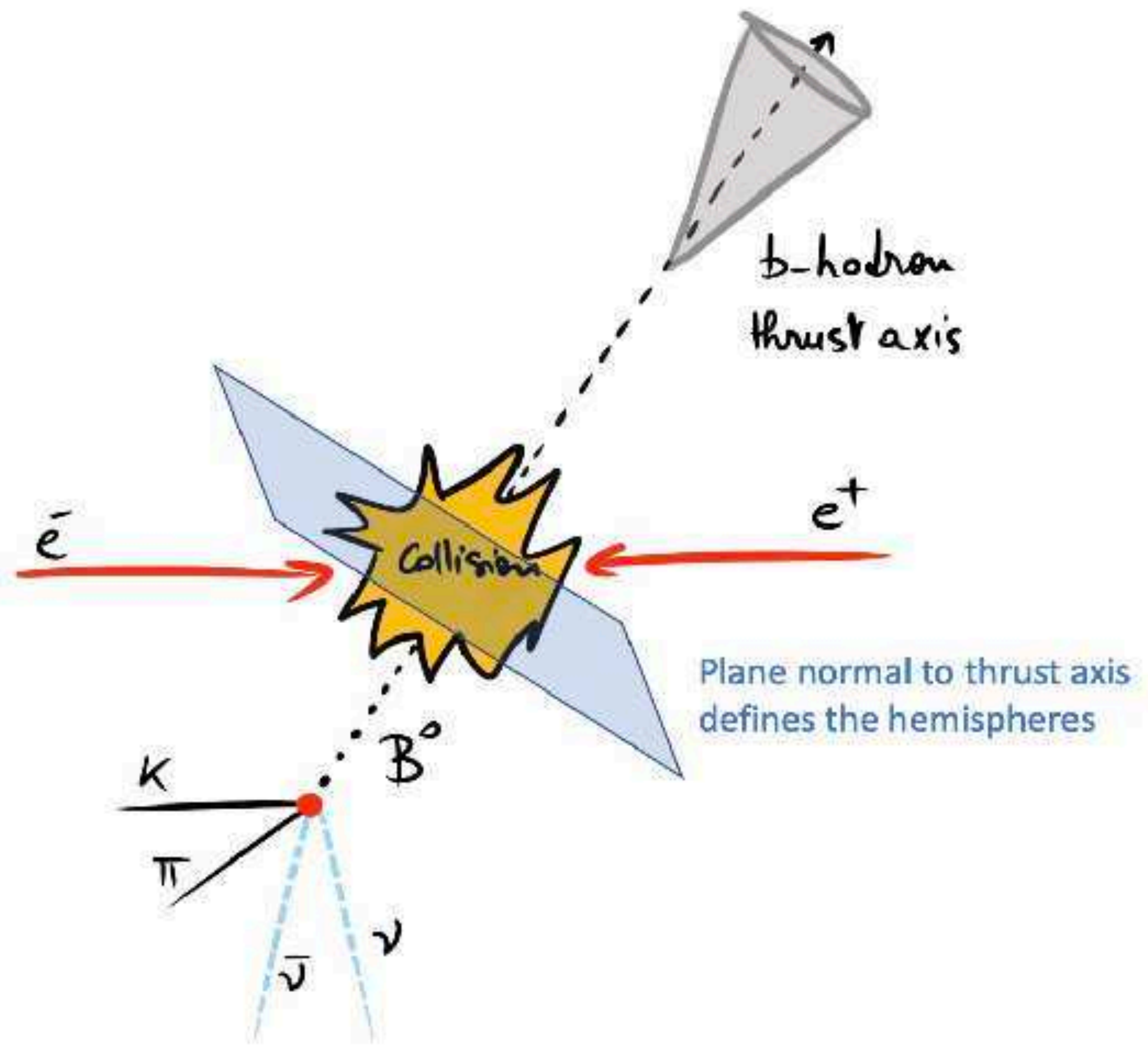
[from talk by Aidan Wiederhold]

$B^0 \to K^{*0} \nu \bar{\nu}$ Work is ongoing, most prominent backgrounds identified, work on second stage BDT required.
Feasible to have ~10^3 events for both signal and bkg: ~4% precision reasonable.

$B_s \to \varphi \nu \bar{\nu}$ CEPC could be able to achieve a sensitivity of 1.78% with a signal efficiency of 3%.

[Phys.Rev.D 105 (2022)].

See also ideas for measuring CP-violation [2208.10880]



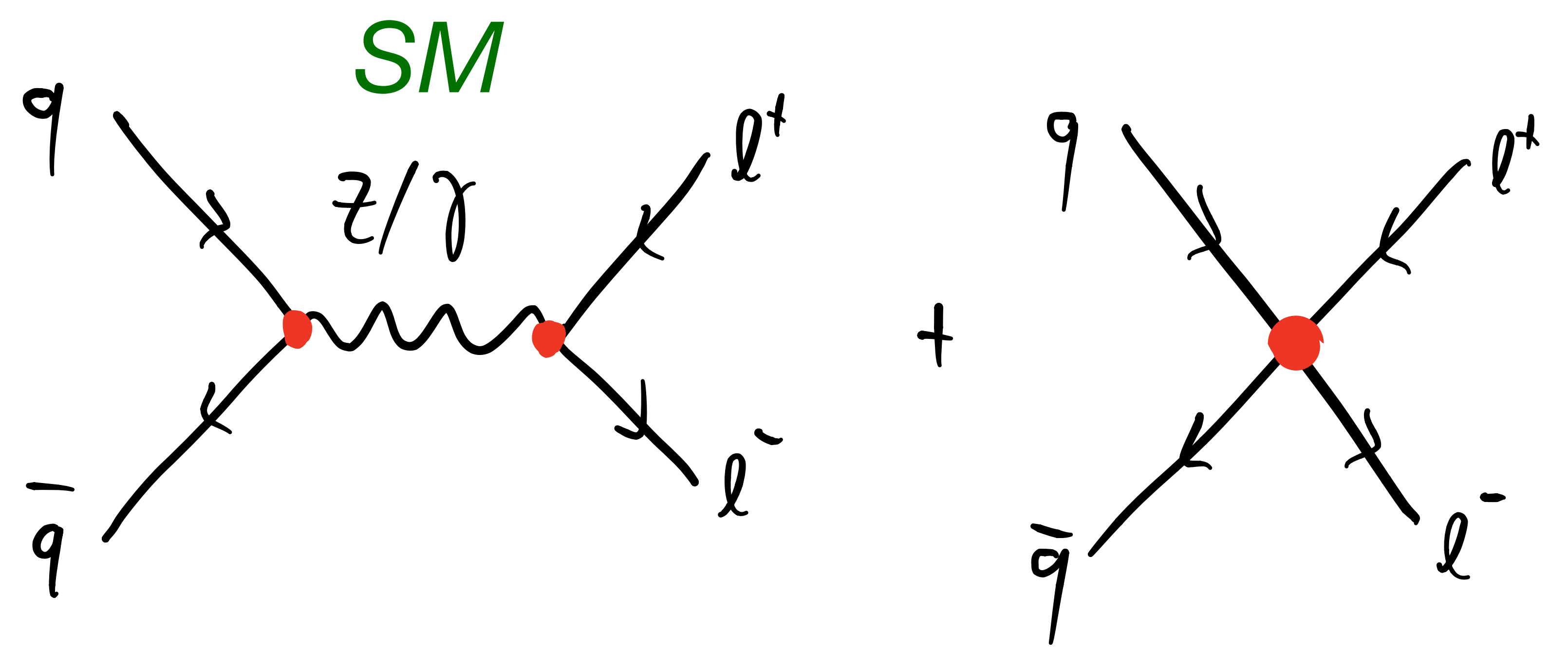
Detector requirements

- **vertexing**
  (average B0 flight distance @ FCC-ee ~3mm)

- **powerful particle id**

Flavour from $e^+e^- \to q\bar{q}'$

Four-fermion operators contribute to the scattering amplitude as contact interactions



if $E \gg m_{EW}$ $$\mathcal{A} \sim \frac{g_{SM}^2}{E^2} + \frac{c_{ij}}{M_{NP}^2} \sim \mathcal{A}_{SM}\left(1 + \frac{c_{ij}}{g_{SM}^2}\frac{E^2}{M_{NP}^2}\right)$$

EFT enhancement for high energies

For per-mille precision (see next slide) one can expect sensitivity for:

(only rough estimates!)

$\delta \approx 0.1\%$

If $\sqrt{s}$ =	250 GeV	500 GeV	1000 GeV
$M_{NP} \gtrsim$	**15 TeV**	**30 TeV**	**60 TeV**

(for c_{ij}=1)

>> typical present sensitivity of **LHC** on semileptonic operators is $M_{NP} \gtrsim$ 5 - 10 TeV

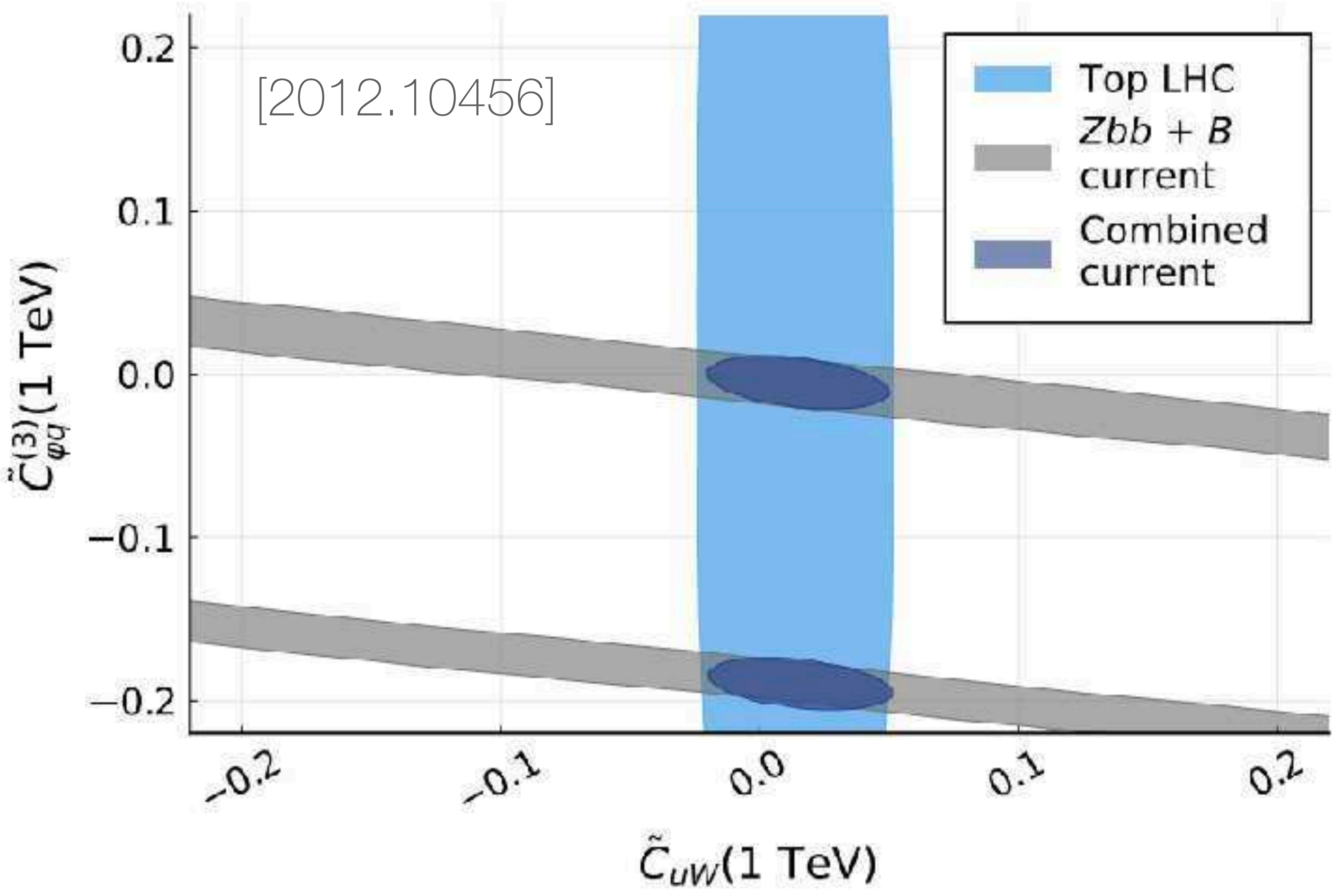
[1704.09015, 2207.10756]

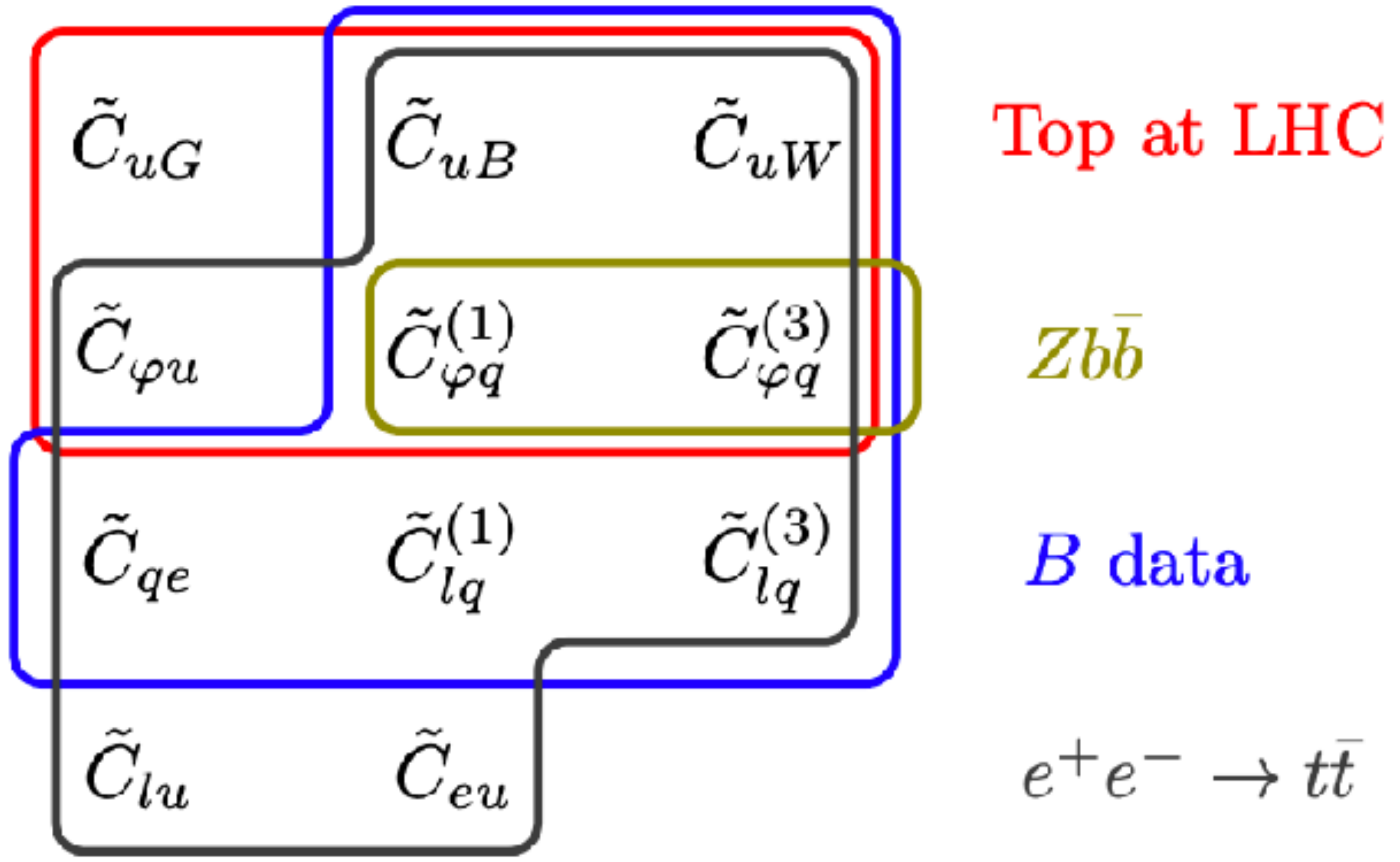
Flavour from top observables

[see talk by Lars Roehrig]

Combining top and "b"- observables:

removes flat directions in SMEFT fits → improves constraints on Wilson coefficients.





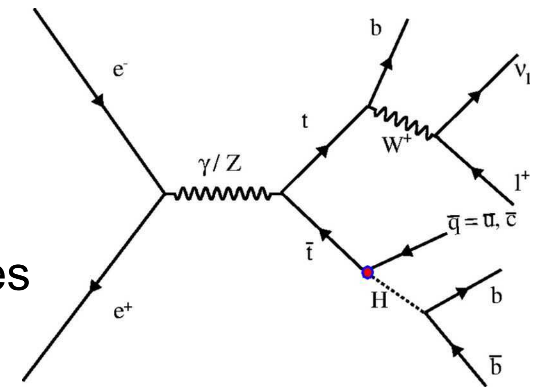
Work started on sensitivity studies on these operators from $e^+e^- \longrightarrow t\,\bar{t}$ at top factories.

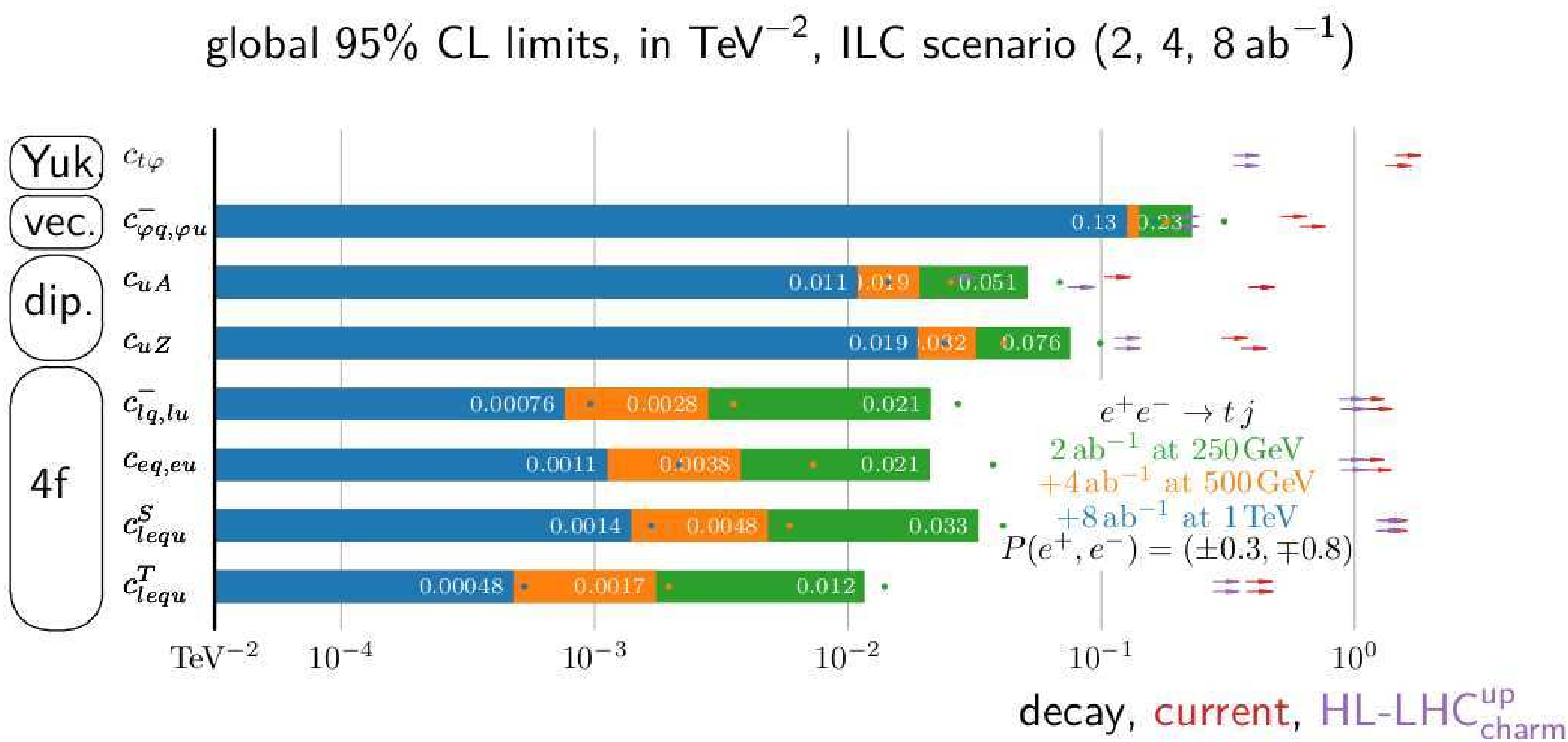
[see talk by Lars Roehrig]

Testing top FCNC at LHC and e+e- colliders

from Gauthier Durieux

- based on statistically optimal observables with extrapolated efficiency
  - benefit from off-shell region
  - 2x-4x improvements already at HL-LHC
  - dramatic improvements from future colliders
    - four-fermion operators heavily benefit from high energies





Fixing SMEFT Lagrangian with data from Higgs factories

from Michael Peskin

It is remarkable that, at (polarized) e+e- Higgs factories, it is possible to robustly independently determine all dimension-6 SMEFT coefficients that enter the key processes at the tree level.

Higgs, $e^+e^- \to W^+ W^-$

precision electroweak inputs: $\alpha(m_Z),\ G_F,\ G_{F\tau}$

HL-LHC expected ratios of BRs:

$$BR(H \to \gamma\gamma)/BR(H \to 4\ell)/BR(H \to \mu^+\mu^-)$$

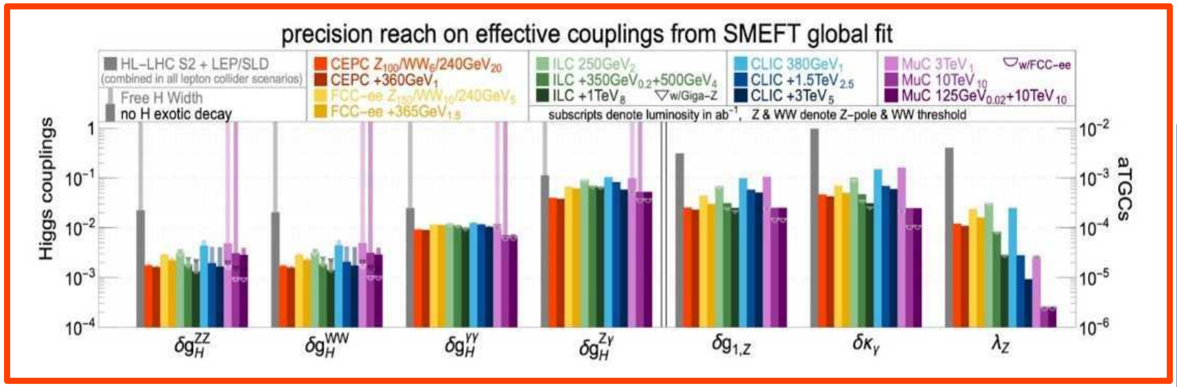
$$\Gamma(Z \to \ell^+\ell^-),\ A_\ell,\ BR(W \to \ell\nu)$$

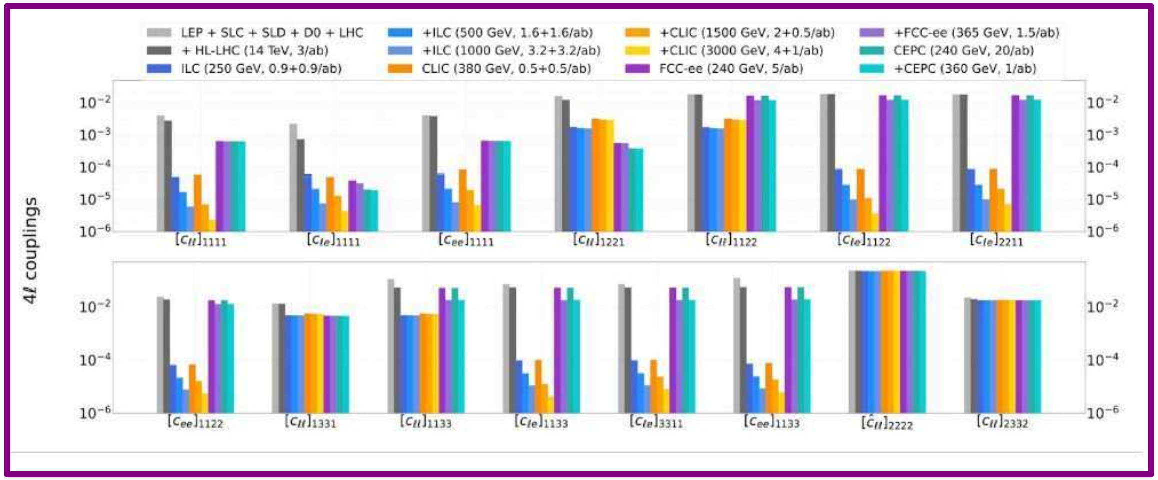
dropping lepton universality:
+ 2 x 3 Hl^+l^- couplings

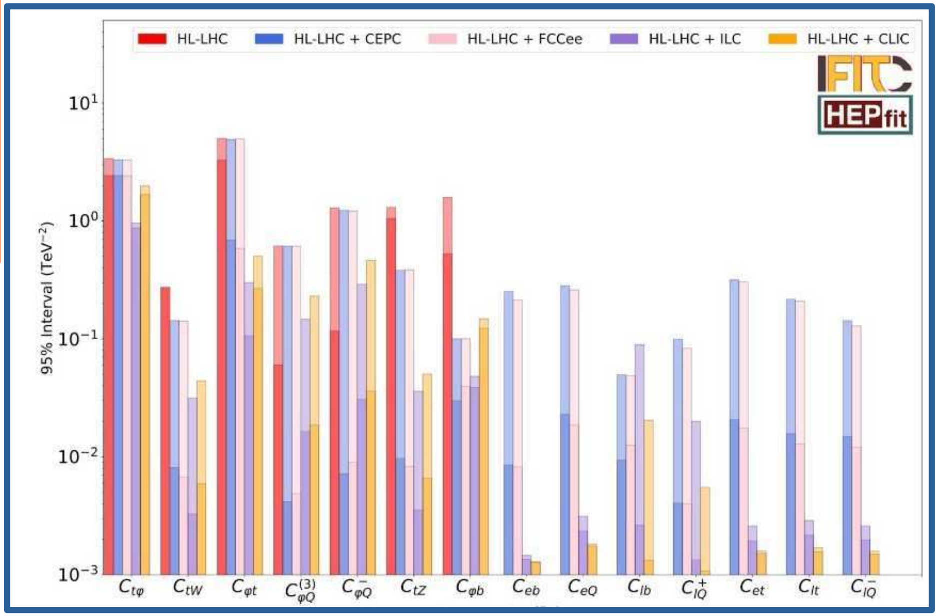
ILC250	original (16+6)	all leptons (22+6)
$g(HWW)$	0.48	0.45
$g(HZZ)$	0.49	0.45
$g(Hbb)$	0.99	0.97
$g(Hcc)$	1.82	1.81
$g(Hgg)$	1.61	1.61
$g(H\tau\tau)$	1.13	1.11
$g(H\gamma\gamma)$	1.09	1.07
Γ_h	2.30	2.27
c_{HLe}	0.024	0.020
c'_{HLe}	0.024	0.027
c_{HEe}	0.035	0.023
$c_{HL\mu}$		0.034
$c'_{HL\mu}$		0.046
$c_{HL\mu}$		0.036
$c_{HL\tau}$		0.040
$c'_{HL\tau}$		0.045
$c_{HL\tau}$		0.037

What's next ? - Future plans

- going beyond Snowmass 2021
  - SMEFT fits covered different sectors in a separate manner (EW+Higgs, top sector, EW including 4 fermions, ...)

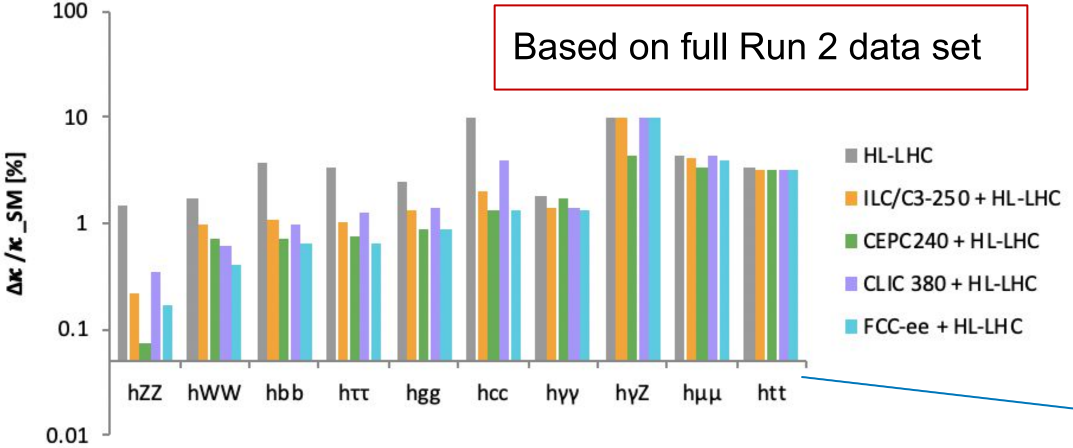




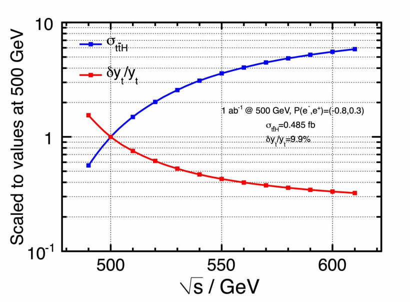


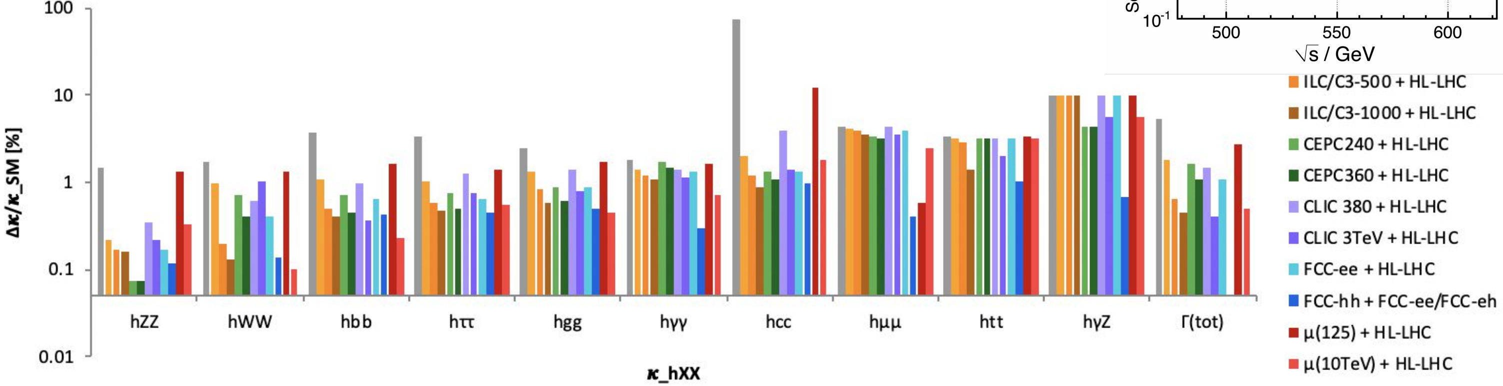
Updated reach for Higgs-boson coupling measurements

Based on full Run 2 data set



Initial stages of future e+e- machines



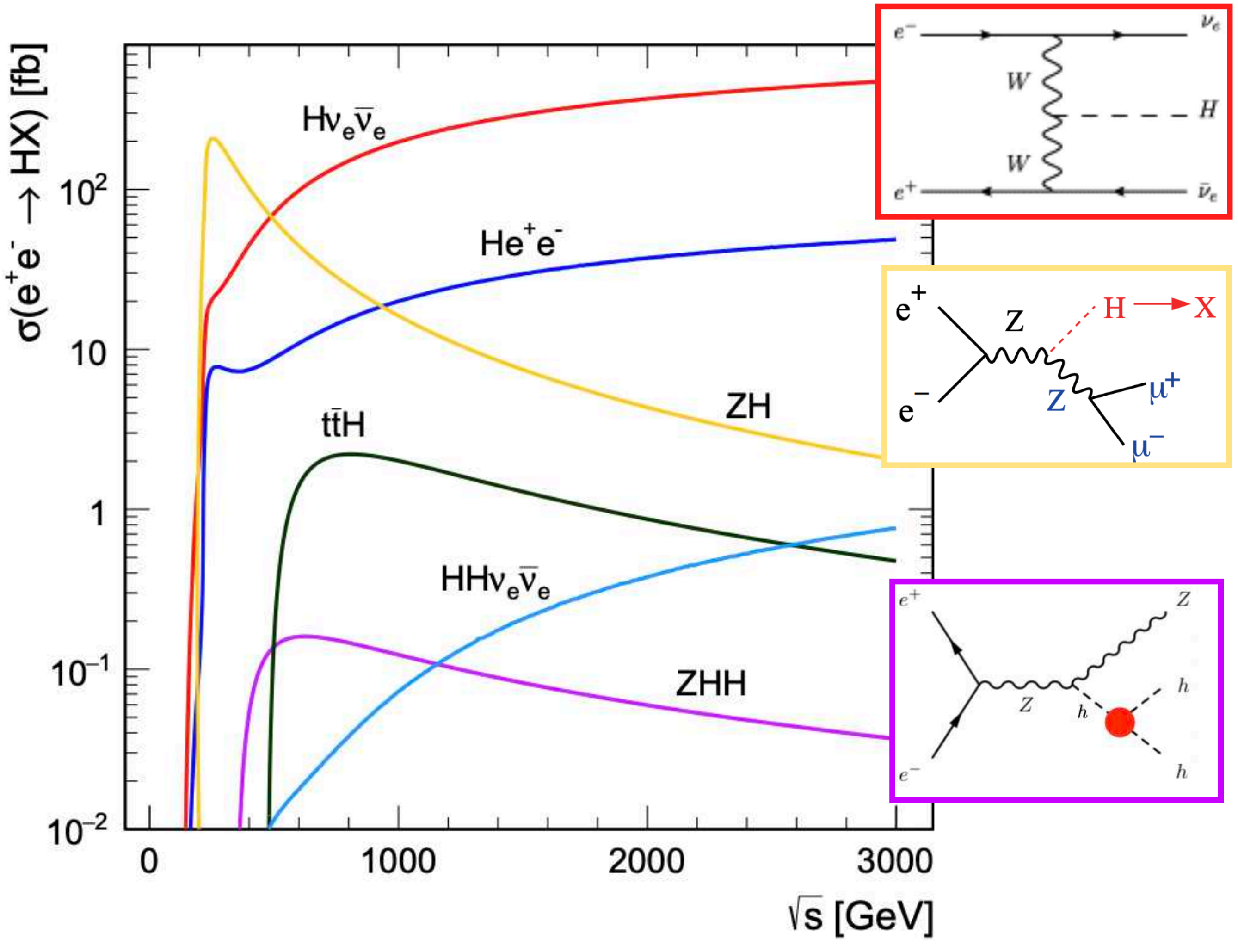


Final reach of all considered future colliders

From Snowmass 21 EF Higgs Topical Group Report (arXiv:2209.07510)

Higgs self-coupling

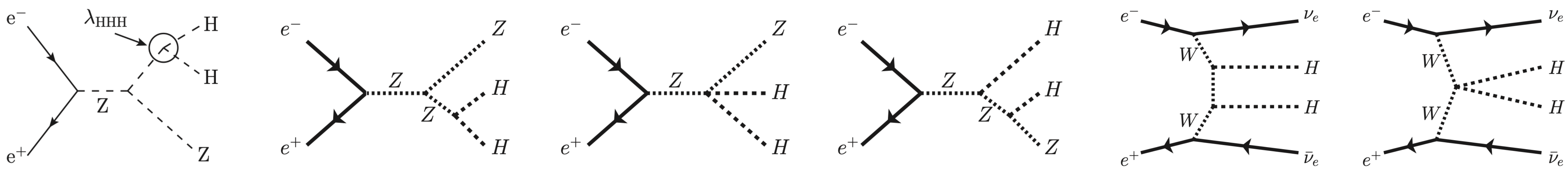
The next big thing in Higgs physics

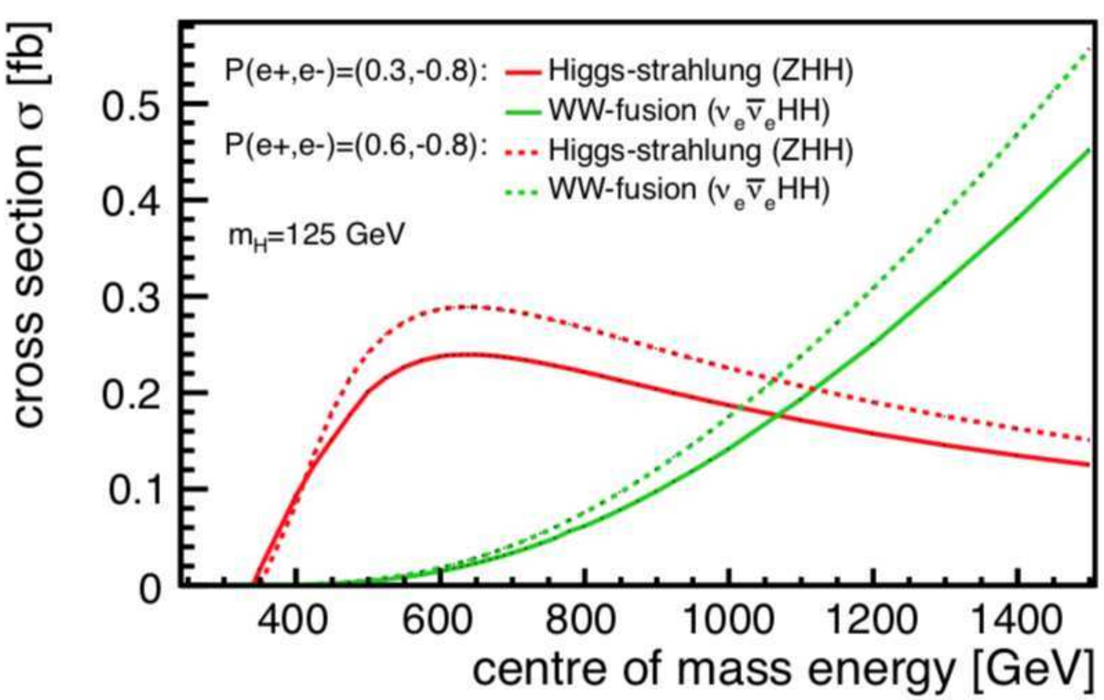


collider	Indirect-h	hh	combined
HL-LHC	100-200%	50%	50%
ILC_{250}/C^3-250	49%	–	49%
ILC_{500}/C^3-550	38%	20%	20%
$CLIC_{380}$	50%	–	50%
$CLIC_{1500}$	49%	36%	29%
$CLIC_{3000}$	49%	9%	9%
FCC-ee	33%	–	33%
FCC-ee (4 IPs)	24%	–	24%
FCC-hh	-	2.9-5.5%	2.9-5.5%
μ(3 TeV)	-	15-30%	15-30%
μ(10 TeV)	-	4%	4%

Higgs self-coupling

Interference diagrams:





Strategy for improving the Higgs self-coupling measurement at ILC

State-of-the-art projections at ILC performed 6-9 years ago
Meanwhile $\rightarrow$ significant improvements in our analysis tools

Jet clustering
Perfect jet clustering
$\rightarrow \sim 40\%$ relative
improvement in $\Delta\sigma_{\text{ZHH}}/\sigma_{\text{ZHH}}$
Flavour tagging

✔ Better *b*-tagging efficiency

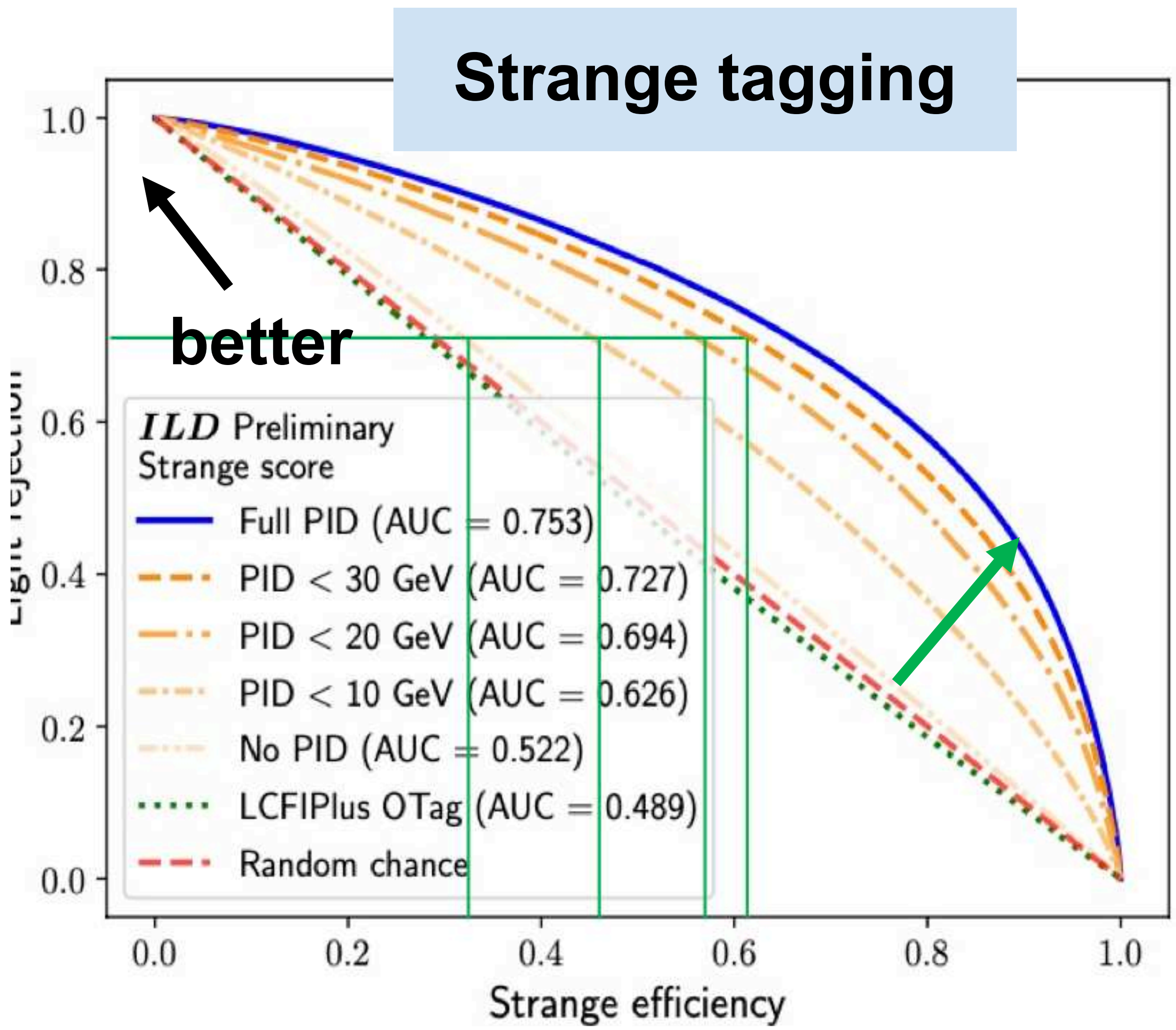
5% relative improvement
$\rightarrow 11\%$ relative improvement

Next steps: Continue work of propagating improvements in reconstruction tools to ZHH analysis

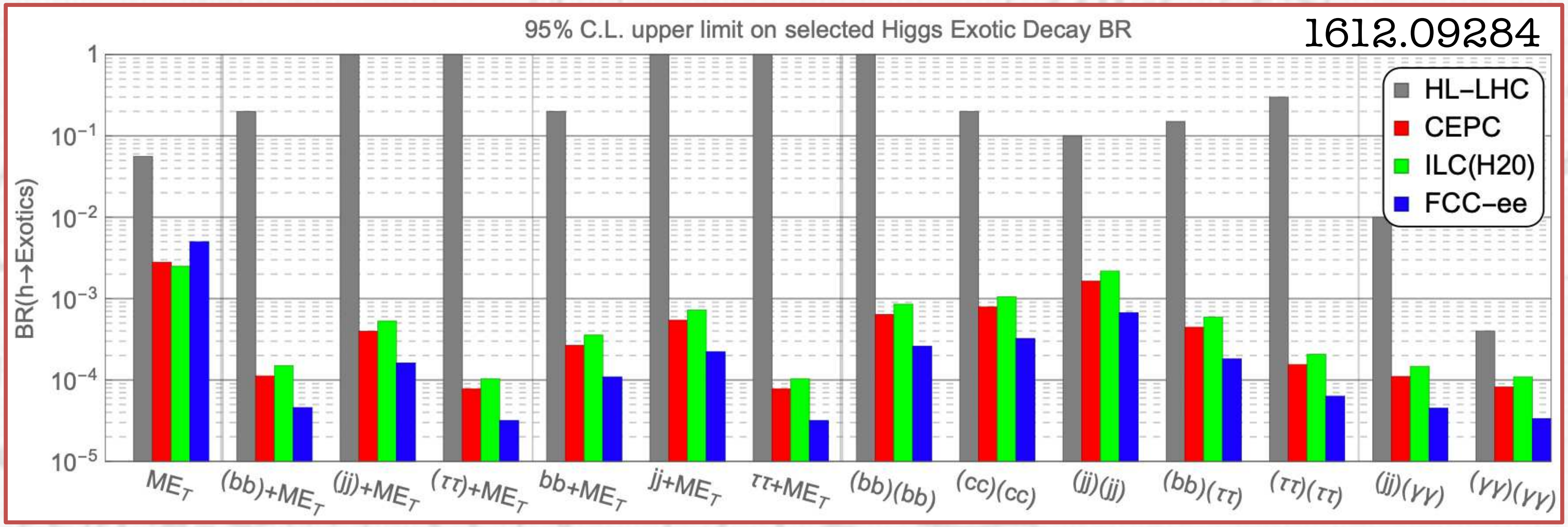
Strange-quark tagging

Strange-quark tagging studied using various multivariate approaches

Variable	Description
	Kinematics
$E_{\text{const}}/E_{\text{jet}}$	energy of the jet constituent divided by the jet energy
θ_{rel}	polar angle of the constituent with respect to the jet momentum
ϕ_{rel}	azimuthal angle of the constituent with respect to the jet momentum
	Displacement
d_{xy}	transverse impact parameter of the track
d_z	longitudinal impact parameter of the track
$\text{SIP}_{2\text{D}}$	signed 2D impact parameter of the track
$\text{SIP}_{2\text{D}}/\sigma_{2\text{D}}$	signed 2D impact parameter significance of the track
$\text{SIP}_{3\text{D}}$	signed 3D impact parameter of the track
$\text{SIP}_{3\text{D}}/\sigma_{3\text{D}}$	signed 3D impact parameter significance of the track
$d_{3\text{D}}$	jet track distance at their point of closest approach
$d_{3\text{D}}/\sigma_{d_{3\text{D}}}$	jet track distance significance at their point of closest approach
C_{ij}	covariance matrix of the track parameters
	Identification
q	electric charge of the particle
$m_{\text{t.o.f.}}$	mass calculated from time-of-flight
dN/dx	number of primary ionisation clusters along track
`isMuon`	if the particle is identified as a muon
`isElectron`	if the particle is identified as an electron
`isPhoton`	if the particle is identified as a photon
`isChargedHadron`	if the particle is identified as a charged hadron
`isNeutralHadron`	if the particle is identified as a neutral hadron



Is the Higgs a portal to new light states?



Orders of magnitude improvement in coverage of exotic Higgs decays.

Introduction

Negative results of direct BSM searches at the LHC suggest that we need to change the perspective. BSM scales does not need to be large.

- new particle interactions can be very week, the signal could be below our experimental sensitivity,
- long-lived or feebly-interacting particles can give exotic signatures, beyond traditional BSM searches

⇒ We need to be sure that our searches are not biased by particular model assumptions

⇒ We should try to be as model-independent as possible.

Proposed High-Priority Topics on Direct Discovery Potential

What can ECFA HF Study add beyond state-of-the-art?

8. $e^+e^- \rightarrow$ (very) weakly coupled / light / long-lived particles
   - detector-level studies of "exotic" signatures: "kinks", "prongs", "V0", …
   - detector requirements, pattern recognition, reconstruction algorithms
   - interface to BSM interpretations: plethora of models!

     => can one develop a "matrix"/"database" to map experimental performance given eg in terms of boost, lifetime, decay mode onto model parameter space of BSM models predicting LLPs ?

Highlights

Possible scenario:

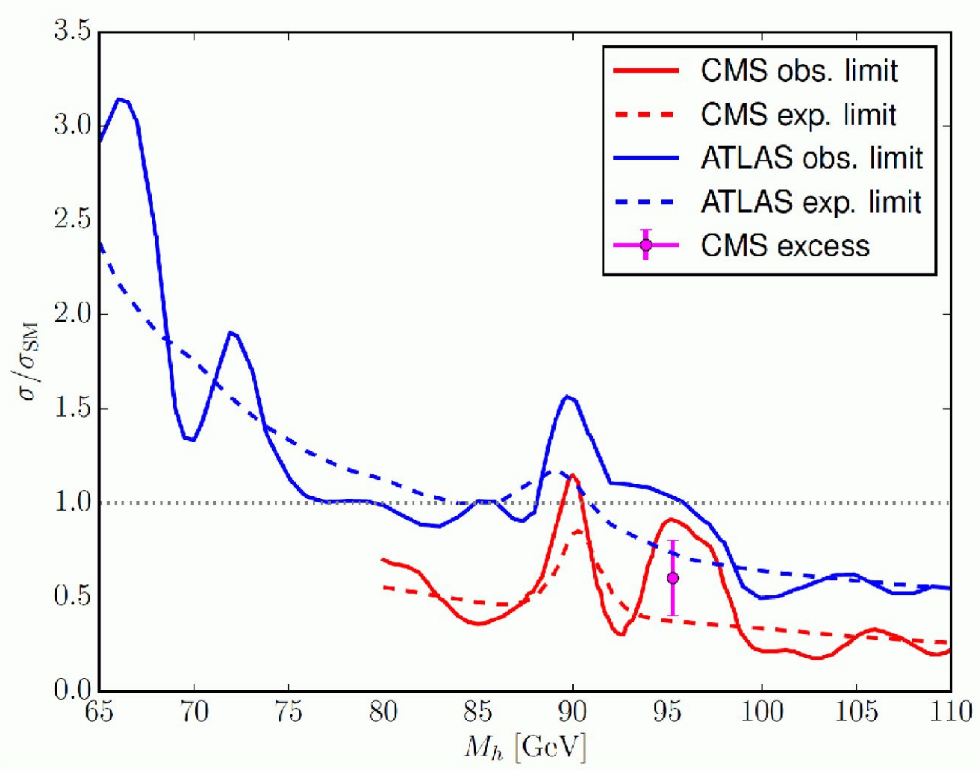
Next-Two Higgs Doublet Model (N2HDM)

Opening also many other observation possibilities at e^+e^- Higgs Factory

Case study: Search for $pp \to \phi \to \gamma\gamma$: excess at $m_\phi \sim 95$ GeV

[CMS '17, ATLAS '18, S.H., T. Stefaniak '18]

$\mu_{\rm CMS} = 0.6 \pm 0.2$



$\Rightarrow$ if there is something, it would look exactly like this!

Now we have three excesses at ~ 95 GeV

$$\mu_{bb}^{\text{exp}} = 0.117 \pm 0.057, \quad {\mu_{\gamma\gamma}}^{\text{exp}} = 0.6 \pm 0.2, \quad {\mu_{\tau\tau}}^{\text{exp}} = 1.2 \pm 0.5$$

corresponding to

$$\mu_{bb}^{\text{exp}} \sim 2\,\sigma, \quad \mu_{\gamma\gamma}^{\text{exp}} \sim 3\,\sigma, \quad \mu_{\tau\tau}^{\text{exp}} \sim 2.4\,\sigma$$

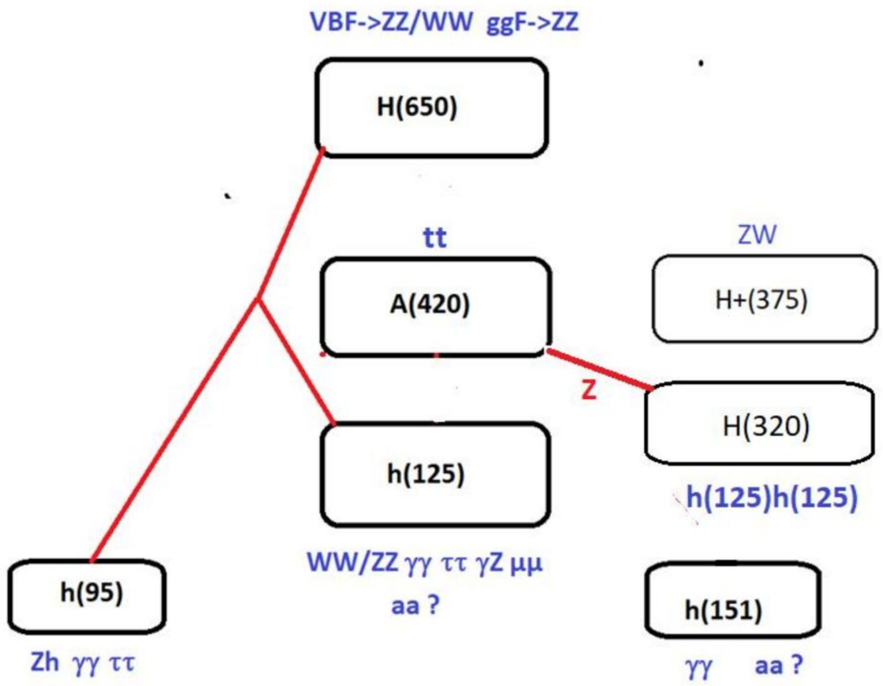
Three (effectively) independent channels
$\Rightarrow$ no LEE (as theorist I am allowed to add naively)

$$\Rightarrow \sim 4.3\,\sigma$$

$$\chi^2_{95} = \frac{(\mu_{bb}^{\text{theo}} - 0.117)^2}{(0.057)^2} + \frac{(\mu_{\gamma\gamma}^{\text{theo}} - 0.6)^2}{(0.2)^2} + \frac{(\mu_{\tau\tau}^{\text{theo}} - 1.2)^2}{(0.5)^2}$$

Can we fit all excesses together?

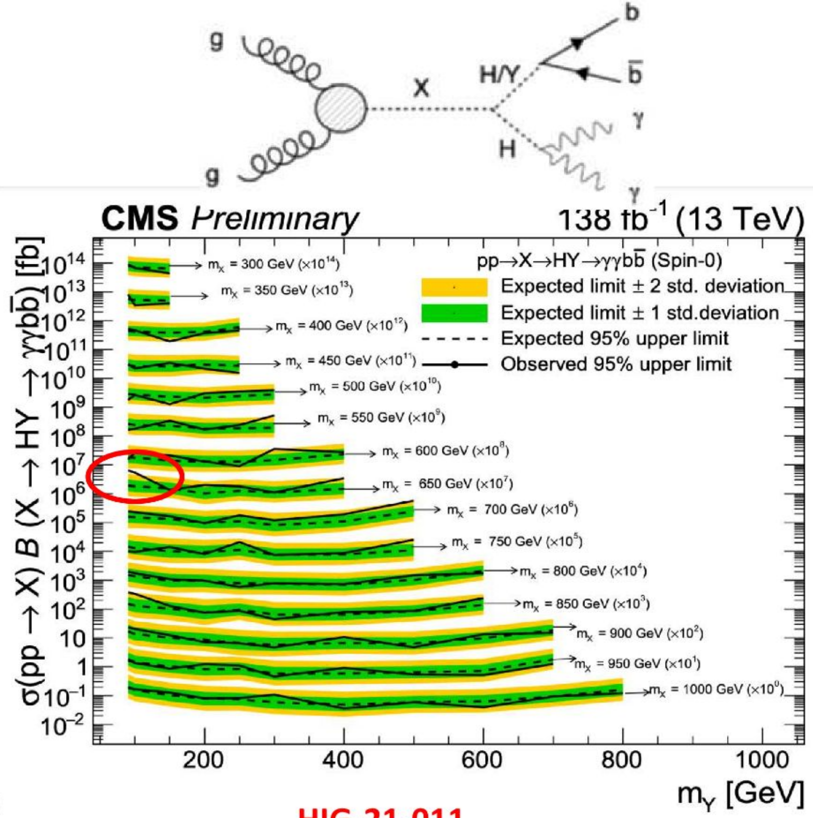
SUMMARY ON BSM CANDIDATES



Francois Richard
Searches for light scalars at LHC and interpretation of the findings

Evidence for gg+VBF->H(650)->Y(90)+h(125)->bb+γγ

- 3.8 s.d. at mH=650 GeV and mY=90 GeV at ICHEP22
- Mass resolution on Y does not allow to distinguish between Z and h(95) 2203.13180
- CP says that bb cannot come from Z->bb but could be h(95)
- The cross section is dominant over other processes ~200 fb
- Suggests that H(650) could be an

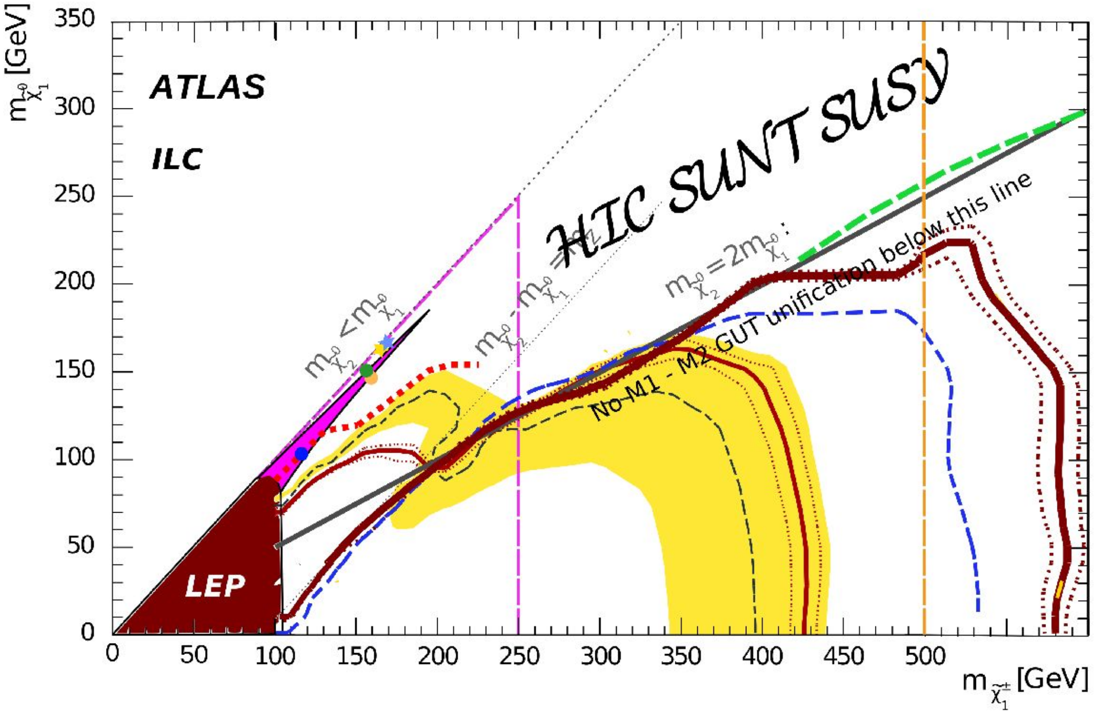


HIG-21-011

Highlights

Many regions in the SUSY parameter space remain and will remain unexplored by LHC…

Summary: SUSY - All-in-one



ATLAS Eur Phys J C 78,995 (2018), Phys Rev D 101,052002 (2020), arXix:2106.01676;

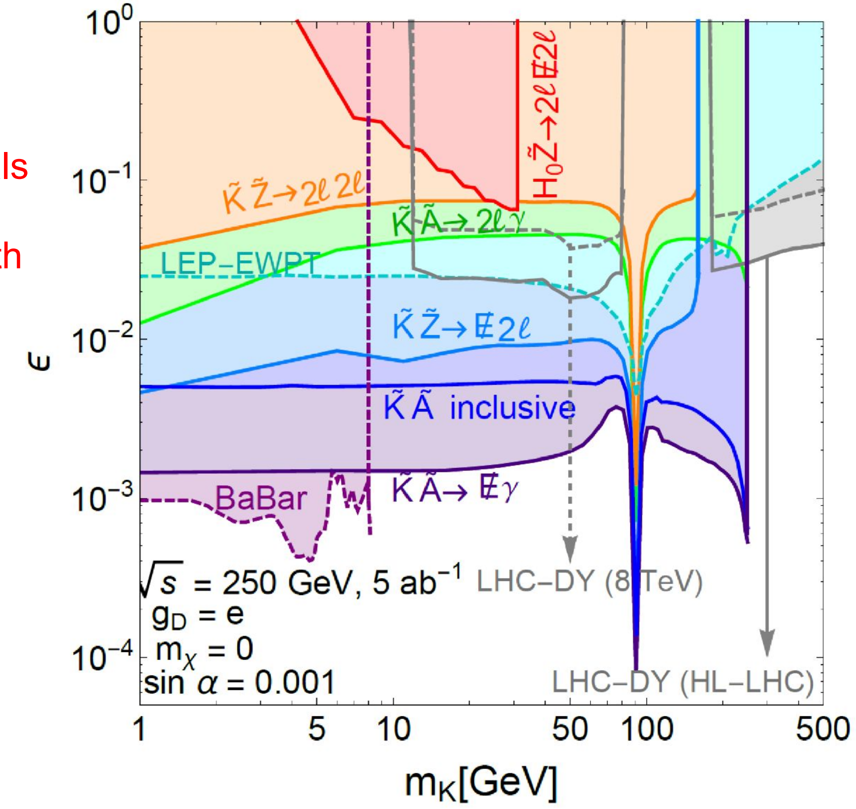
ATLAS HL-LHC ATL-PHYS-PUB-2018-048; ILC arXiv:2002.01239; LEP LEP LEPSUSYWG/02-04.1

Dark photon sensitivity

Highlights

Double Dark Portal model
simultaneous vector and scalar portals

Rich e^+e^- collider phenomenology with new light hidden particles…



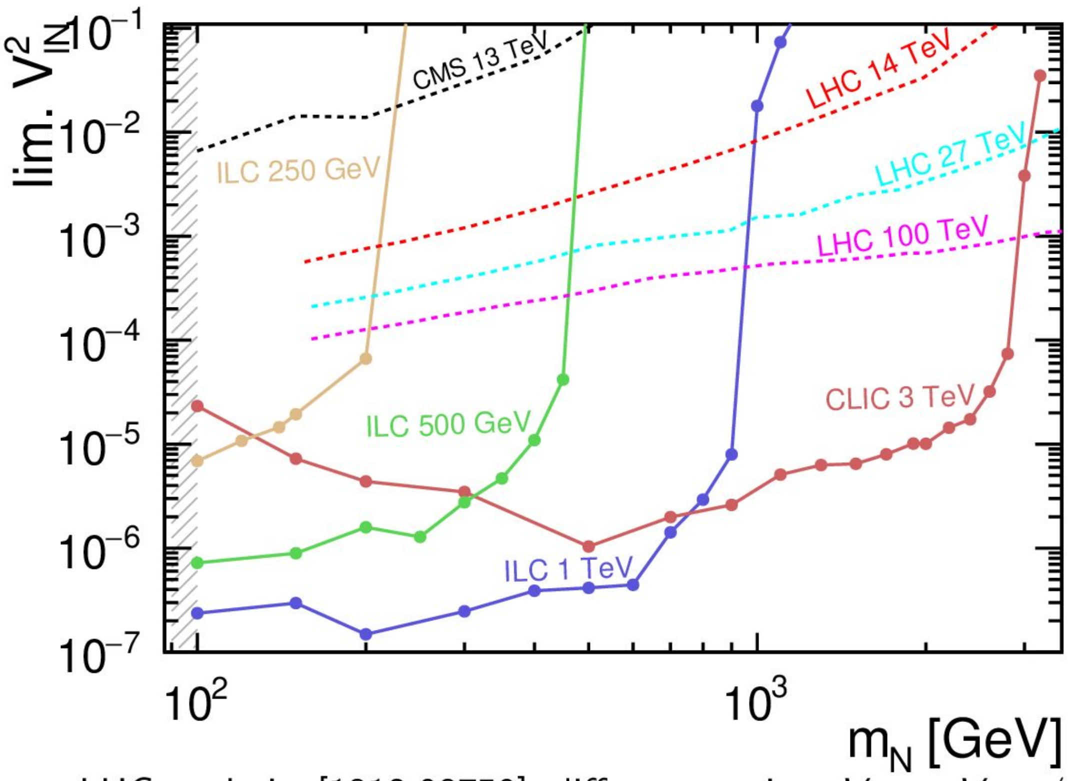
Final results

Highlights

Heavy Neutral Leptons

Above M_Z prompt decays seem to be more promising

The cross section limits can be translated into limits on the V_{lN}^2 parameter.



LHC analysis: [1812.08750], diff. assumption: $V_{eN} = V_{\mu N} \neq V_{\tau N} = 0$

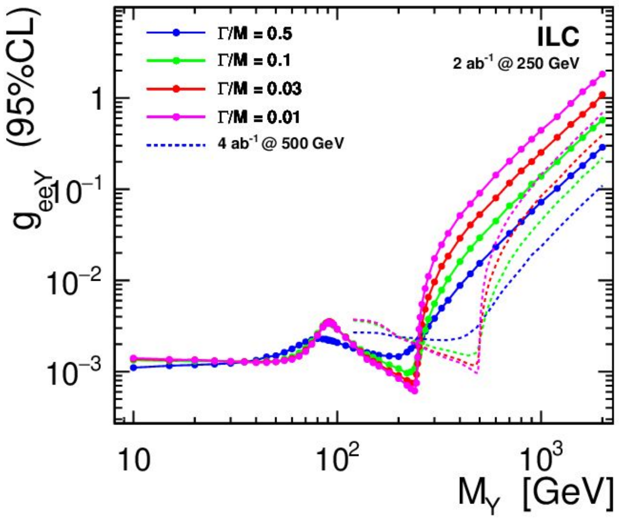
Highlights

Coupling limits for mediator coupling to SM fermions

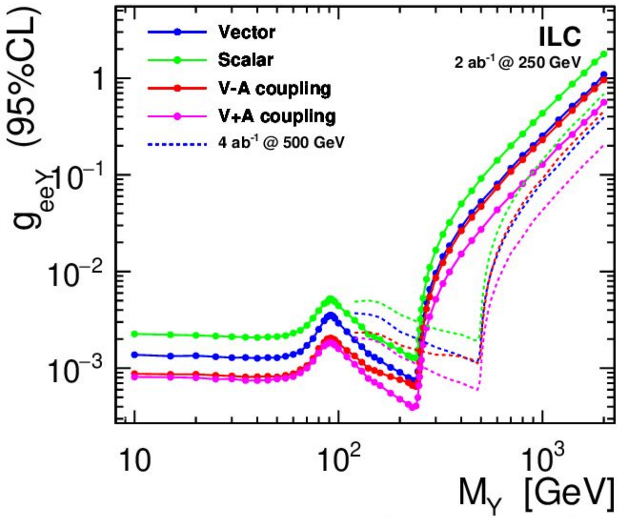
$\mathcal{O}(1)$ mediator coupling to DM, fixed by mediator width

Combined limits for ILC @ 250 GeV (compared to ILC @ 500 GeV)

Vector mediator



Mediators with $\Gamma/M = 0.03$



Almost uniform sensitivity to mediator coupling g_{eeY} up to kinematic limit

Possible signatures at e^+e^- colliders – X pair production

Assuming generic **long-lived particle X** and one **DM candidate***, the signatures can be categorised based on the possible production and decay channels:

production \ decay	X → SM, SM	X → SM, SM, DM	X → SM, DM	X → DM, DM
e^-e^+ → X, X	• 2 displaced vertices ◆	• 2 displaced vertices • $\not{E}$ ◇	• 2 displaced tracks/jets/γ • $\not{E}$ ◇	Invisible ◆
e^-e^+ → X, X, DM	• 2 displaced vertices • $\not{E}$	• 2 displaced vertices • $\not{E}$	• 2 displaced tracks/jets/γ • $\not{E}$	Invisible
e^-e^+ → X, X, Z/h/γ	• 2 displaced vertices • Z/h/γ ◆	• 2 displaced vertices • Z/h/γ • $\not{E}$ ◇	• 2 displaced tracks/jets/γ • Z/h/γ • $\not{E}$ ◇	• Z/h/γ • $\not{E}$ ◆

▭ - predicted by models mentioned on the slides 5-9

If Z_2 is imposed:

◇ - X odd under Z_2

◆ - X even under Z_2

* branches with neutrinos also marked as DM

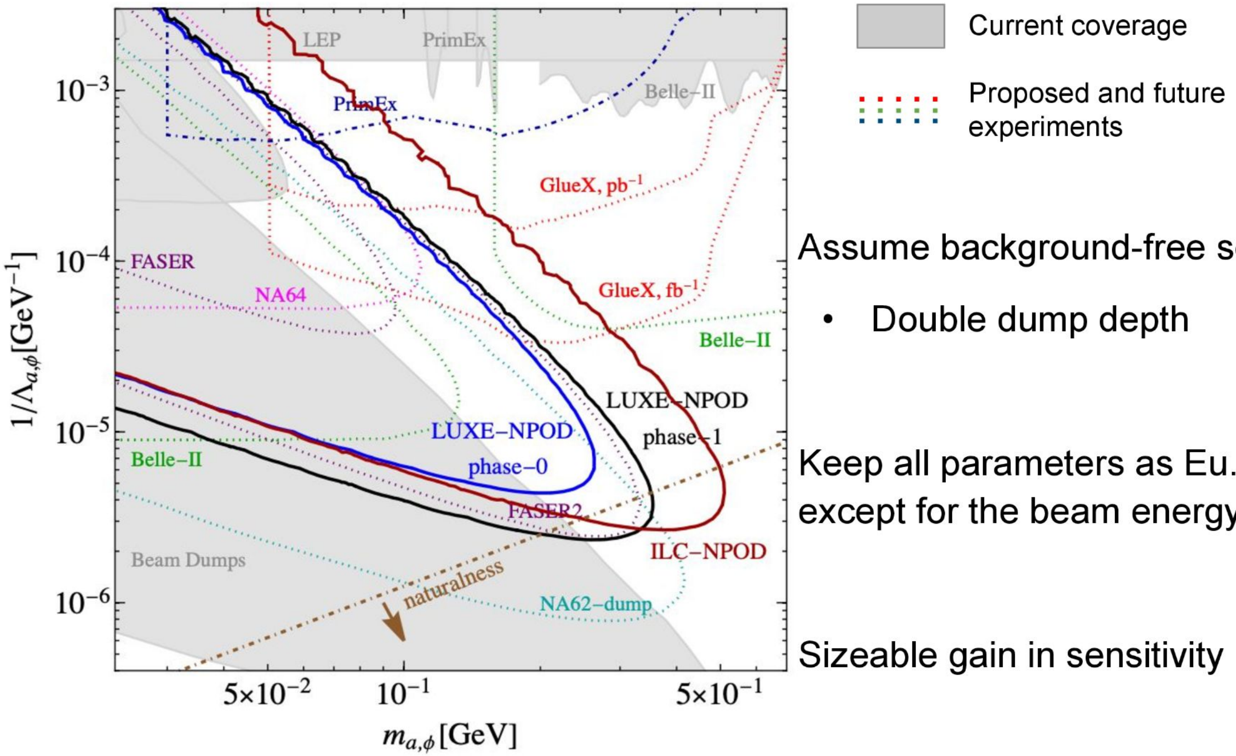
- The cells in the table can be referred back to signatures in particular models
- Mixed channel $(XX \to 2SM + 2DM)$ also possible

Highlights

LUXE concept
at ILC beam dump

Expected sensitivity gain from energy

Yotam Soreq's
talk at ILCX2021



Assume background-free scenario

- Double dump depth

Keep all parameters as Eu.XFEL, except for the beam energy

Sizeable gain in sensitivity

Plans and closing remarks

Motivation

What can ECFA HF Study add beyond state-of-the-art?

- Snowmass is ~over => cf report by Laura
- Unclear which project will be built - but to get any, a strong e+e- community is required!

=> How can HEP community engage in e+e- Higgs Factory studies after Snowmass?

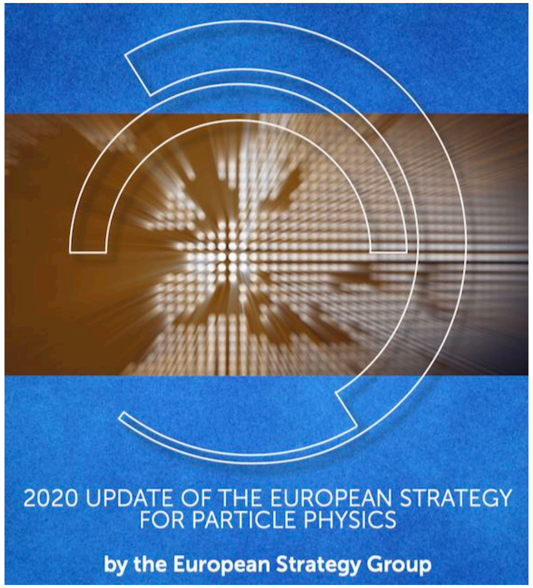
- Most can only spend only a small fraction of their time on “future topics”

  => lower threshold to contribute as far as possible
  => avoid duplication

- ECFA Study is not tied to a specific e+e- project:
  - if you hesitate to sell your soul to FCC or ILC or … , this could be the ideal place!
  - forum to present work and discuss science across projects
  - support the use of common software and exchange of data-sets via Key4HEP
- **more details on next steps, time line, final report etc on Friday in Aidan’s talk**

Timeline

- **ECFA study is a key input for the next European Strategy Update**
  –> should be coherent with the European Strategy timeline



- For the 2020 Update:
  – project inputs: December 2018
  – open community meeting: Granada, May 2019
  – drafting session: Bad Honnef, January 2020
  – strategy presented later in 2020

- The next European Strategy Update is provisionally expected in **2026–27**
  –> provisionally expect strategy inputs to be due in late 2025
- ECFA study should coordinate with project inputs and timelines, e.g.FCC Feasibility Study report is scheduled for end 2025, writing from 2025Q2
- ECFA report should be available as reference for projects' individual ESPP inputs

–> target spring 2025 for ECFA study final report

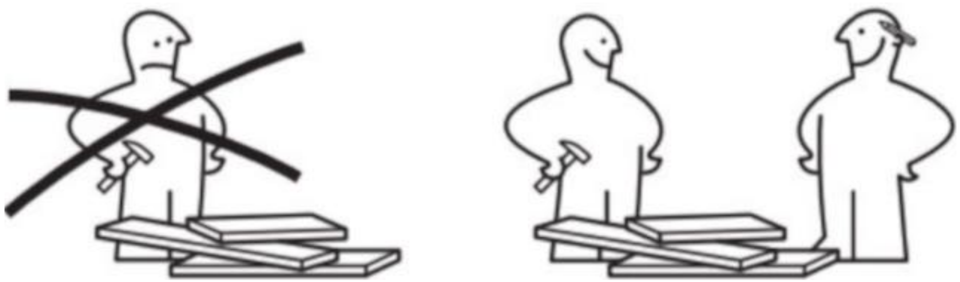
Short-term next steps

- Over the next ~2 months:
  Refining of provisional report section contents,
  consultations and input from community via WG (/activity) conveners
  –> please start thinking where your contributions will fit!

- Over the next 3–6+ months:
  Series of topical meetings (WG1 and cross-group) focused on 'high-priority topics'
  WG2 mini-workshop on Reconstruction
  WG3 mini-workshops on:
  – Tracking and Vertexing for Higgs factories (TF1, TF3)
  – Calorimetry and Particle ID for Higgs factories (TF4, TF6)
  – Electronics and integration (TF7, TF8) (separate or interleaved, t.b.d.)

- Useful practical suggestions arising from workshop discussions to follow up:
  – Unified calendar of events/meetings among concepts
  – Software tutorials to lower threshold for people to contribute

- *Let's work together towards the next collider*



Future workshops

- **Matching the ECFA study timeline to the European Strategy timeline implies two further 'overall' workshops, in both 2023 and 2024**
- Call for proposals to host the Second ECFA Workshop, in 2023, will be made soon

Thanks again to the local organisers for a wonderful welcome to Hamburg!

Got interested?

How to get involved

- Contact the WG1, WG2, WG3 coordinators: ECFA-Workshop-Higgs-factory-coords@cern.ch
  => Happy to discuss, help, point you to experts, …
- for detector-level simulation studies:
  - goal: do all in **common software Key4HEP**, which comprises iLCSoft, even exchange MC samples using EDM4HEP -> as done between SiD and ILD in the past
  - all detector concepts are **open to new collaborators**, some offer even very low-threshold **guest memberships**
  - all detector concepts are **open to new technology proposals**
  - should we (the ECFA study) **origanize tutorials**?

=> again, get in touch: ECFA-Workshop-Higgs-factory-coords@cern.ch

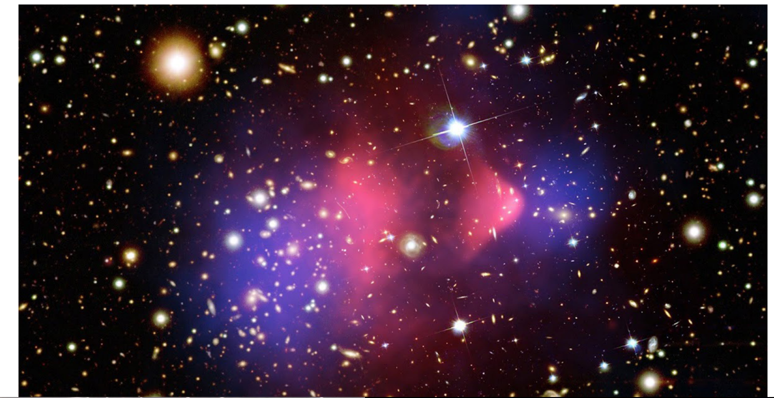

SPEICHERRING
5

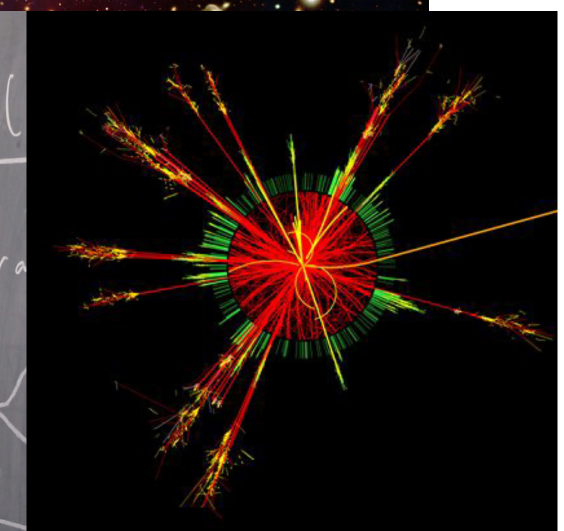
European Committee for Future Accelerators

Does the World need a new particle collider – and why?

Public talk and round table discussion

The Higgs boson: particle superhero and tour guide to new particles





The Higgs boson, discovered at the world's largest particle collider LHC ten years ago, is a very special particle. We need to study it in great detail to answer key questions of physics. The Higgs boson may have been a superhero that saved us from complete annihilation and it can be the portal to a new world of particles with possible links to dark matter and dark energy.

This lecture by the Japanese-American scientist Hitoshi Murayama is aimed at the general public. Murayama discusses the fascinating exploration of a future particle physics era with the help of a new collider. It is followed by a round-table discussion about the need for a new collider, the discoveries that could be made and the different options that are on the table. Panelists include the renowned physicists J. Butterworth (U. College London), F. Canelli (U. of Zurich), F. Gianotti (CERN), B. Heinemann (DESY), K. Jakobs (U. of Freiburg), H. Murayama (UC Berkeley and IPMU) and J. Thaler (MIT).

Prof. Dr. Hitoshi Murayama

- **Berkeley Center for Theoretical Physics**
  University of California, USA
- **Lawrence Berkeley National Laboratory**
  Berkeley, USA
- **Kavli IPMU, University of Tokyo**
  Kashiwa, Japan

October 6, 19:30 h
DESY main auditorium
https://desy.de/youtube

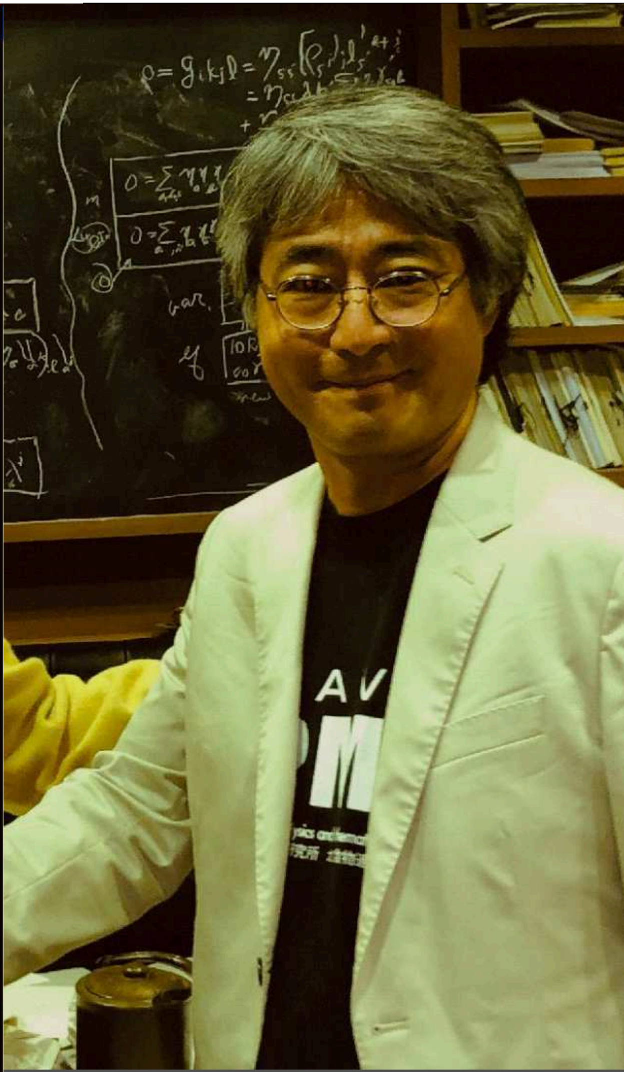
DPG
Deutsche Physikalische Gesellschaft

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

Huge Thanks to our Superhero!!

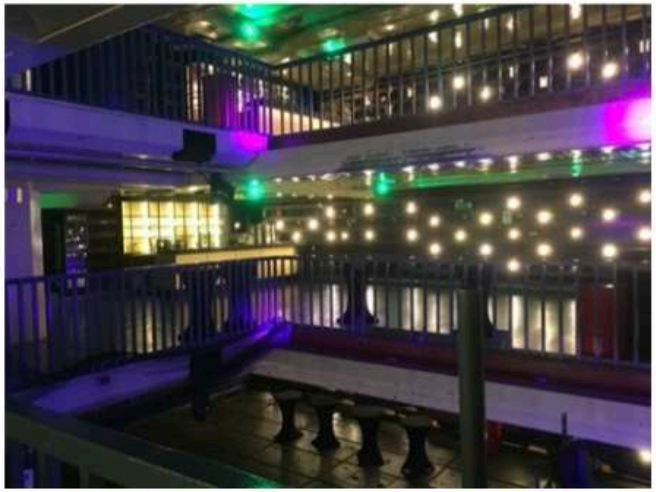


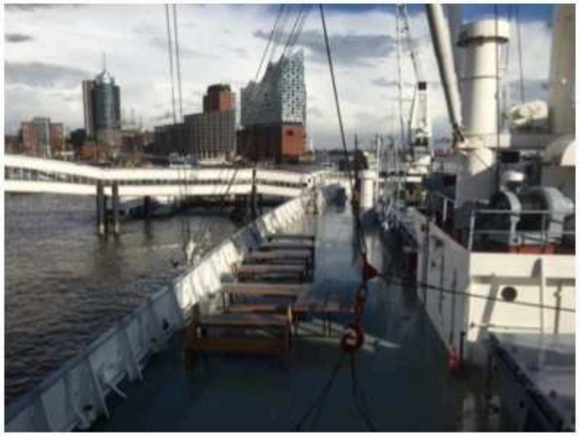
First ECFA WORKSHOP.

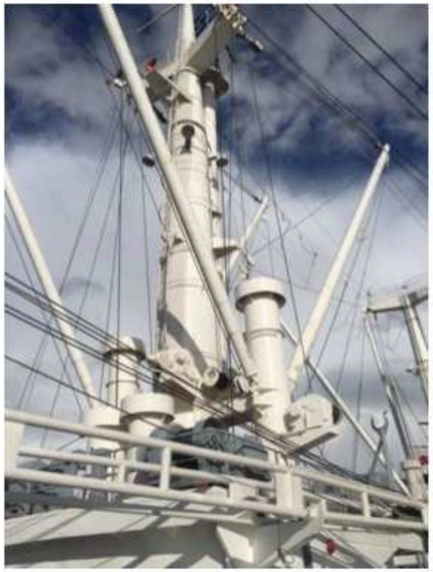
on e+e- Higgs/EW/Top Factories, October 5-7, 2022, in Hamburg

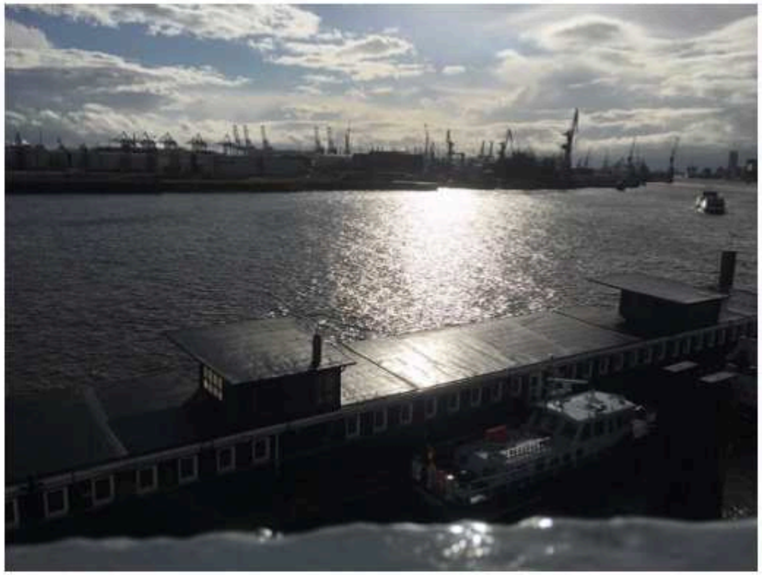
Conference Dinner:

Cap San Diego, Oct 5, 19:00









Thank you !

Backup slides

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, ...

Physics, Experiments & Detector studies for an e^+e^- Higgs/EW/Top factory

- More detailed **mandates** for Working Groups 1 and 2 have been prepared
  → more in the final discussion today, talk by Jenny List

- **Conveners** for both working groups have been appointed:

WG 1: Physics Potential

Juan Alcaraz (CIEMAT - Madrid)
Jenny List (DESY)
Fabio Maltoni (UC Louvain / Bologna)
James Wells (Univ. Michigan)

WG 2: Physics Analysis Methods

Patrizia Azzi (INFN-Padova / CERN)
Fulvio Piccinini (INFN Pavia)
Dirk Zerwas (IJCLab)

High-priority topics

- Proposed 'high-priority topics' are not intended to map the physics programme comprehensively. Instead, should serve to:
  – complete the current overall picture where it's (most) necessary
  – offer guidance for contributing to the ECFA study
  – highlight processes particularly suitable for studying the ***interplay of the three WGs***

Higgs

1. $e^+e^- \rightarrow Zh$ at $\sqrt{s}$ = 240..250 GeV and 350 GeV:
- comparisons of theory calculations and MC generators for $e^+e^- \rightarrow f\bar{f}h$
- reconstruction of production (all channels)
- and decay angles ($h \rightarrow ZZ^*/WW^*/Z\gamma$) incl CP angles
- dependence on detector performance and reconstruction capabilities:
  - Higgs restframe reconstruction, also for $Z \rightarrow qq$ / $\tau^+\tau^-$
  - q vs qbar separation, ...
- SMEFT interpretation

Most studies of Higgs couplings and SMEFT interpretation so far assume CP conservation – add CP studies

2. $e^+e^- \rightarrow Zh$ with $h \rightarrow ss$ ($Z \rightarrow$ anything) at $\sqrt{s}$ = 240..250 GeV:
- branching fraction precision / discovery reach
- dependence on detector performance and reconstruction capabilities:
  e.g. $K^\pm$ ID, $K^0_S \rightarrow \pi^+\pi^-$, JER, ...
- SMEFT & BSM interpretation

H->ss addressed only recently – reconstruction and PID challenges, and interpretation

High-priority topics

◆ W/Z

3. W Couplings in $e^+e^- \rightarrow$ W W and e**ν**W at $\sqrt{s}$ = 240..250 GeV and ~350 GeV including e.g.:
- comparision of theory predictions and MC generators
- detector-level studies including full differential angular information, reconstruction of CP angles, optimal observables / interface to global interpretations
- CP violating operators and other effects beyond "standard" TGCs

add full detector-level studies at 240GeV; include CPV operators

4. W mass from $e^+e^- \rightarrow$ W W and e**ν**W at threshold and continuum
- theory predictions and MC generators
- detector-level studies including mass reconstruction techniques
- systematic limitations and calibration strategies

M_W ultimate precision? assessment/development of analysis and calibration methods to highlight aspects of detector performance requirements

5. $e^+e^- \rightarrow$ bb, cc, ss, **τ**+**τ**− at $\sqrt{s} = M_Z$ and above including e.g.
- comparision of theory predictions and MC generators
- detector-level studies of differential cross-section / asymmetry measurements
- interface to global interpretations
- for **τ**+**τ**− : **τ** polarisation and A_e extraction

2-fermion production hardly studied at Z. Focus on channels with detector/reco challenges; include **τ** polarisation

High-priority topics

◆ Top

6. $e+e- \rightarrow tt$ at a typical threshold-scan energy, $\sqrt{s}$ = ~350 GeV
- detector-level studies of total & differential cross-section, asymmetries, CP observables
- detector requirements and reconstruction/analysis methods
- interface to global interpretations

full analysis at threshold (threshold calculations not all reflected in MC generators, polarisation & beam spectrum etc)

7. threshold scan optimisation, including
- theory predictions and MC generators
- backgrounds, polarisation, energy-step optimisation
- interpretation incl. "classic" threshold scan parameters as well as electroweak coupling parameter extraction, also CPV

◆ Direct discovery potential

LLPs with exotic signatures

8. $e^+e^- \rightarrow$ (very) weakly coupled / light / long-lived particles
- detector-level studies of "exotic" signatures: "kinks", "prongs", "V0", ...
- detector requirements, pattern recognition, reconstruction algorithms
- interface to BSM interpretations: plethora of models!

=> can one develop a "matrix"/"database" to map experimental performance given eg in terms of boost, lifetime, decay mode onto model parameter space of BSM models predicting LLPs ?

High-priority topics

◆ Flavour

9. $B_s \rightarrow D_s K$ at $\sqrt{s} = M_Z$
- detector-level study with all backgrounds
- dependency on vertexing, Kaon-ID, ...
- global interpretations...

10. $B_s \rightarrow K^{0*}\tau^+\tau^-$:
- detector-level study with all backgrounds
- topological reconstruction,
- dependency on τ and K* reconstruction, vertexing...
- global interpretations

B mesons that are too heavy to be produced at Belle-II; final states that are difficult at LHCb, e.g. τ

High-priority topics

◆ Systematics

11. Luminosity measurement from low-angle Bhabha scattering
- theory and MC generators: comparison of state-of-the-art and ultimate requirements
- detector-level simulations at all $\sqrt{s}$, including backgrounds etc
- measurement strategies
- requirements on LumiCal: resolutions, alignment

Understand how to control with unprecedented precision

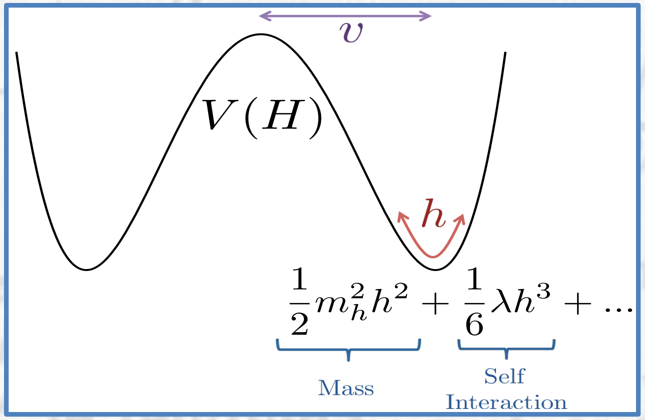
12. Measurement of b- and c-fragmentation functions / hadronisation
- detector-level study with all backgrounds
- new ideas how to model them theoretically => new measurement strategies?

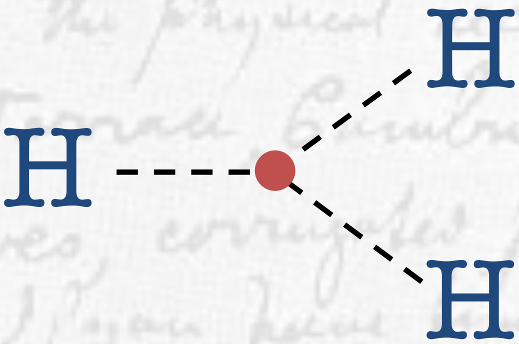
13. Measurement of gluon splitting to bb / cc
& interplay with separating h → gluons from h →bb/cc

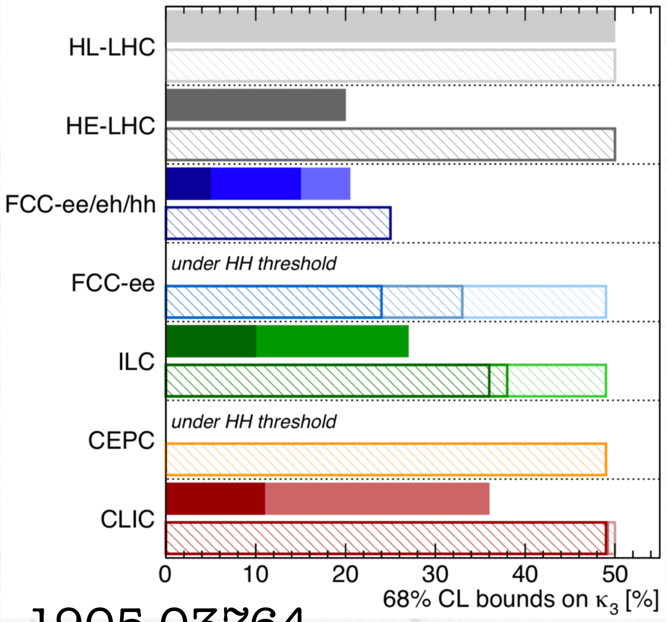
Understand how well these can be constrained, as input to precision Higgs and EWK measurements

Self-Coupling: Higgs Factories

Higgs factories can give us valuable new insights into the nature of the Higgs potential.



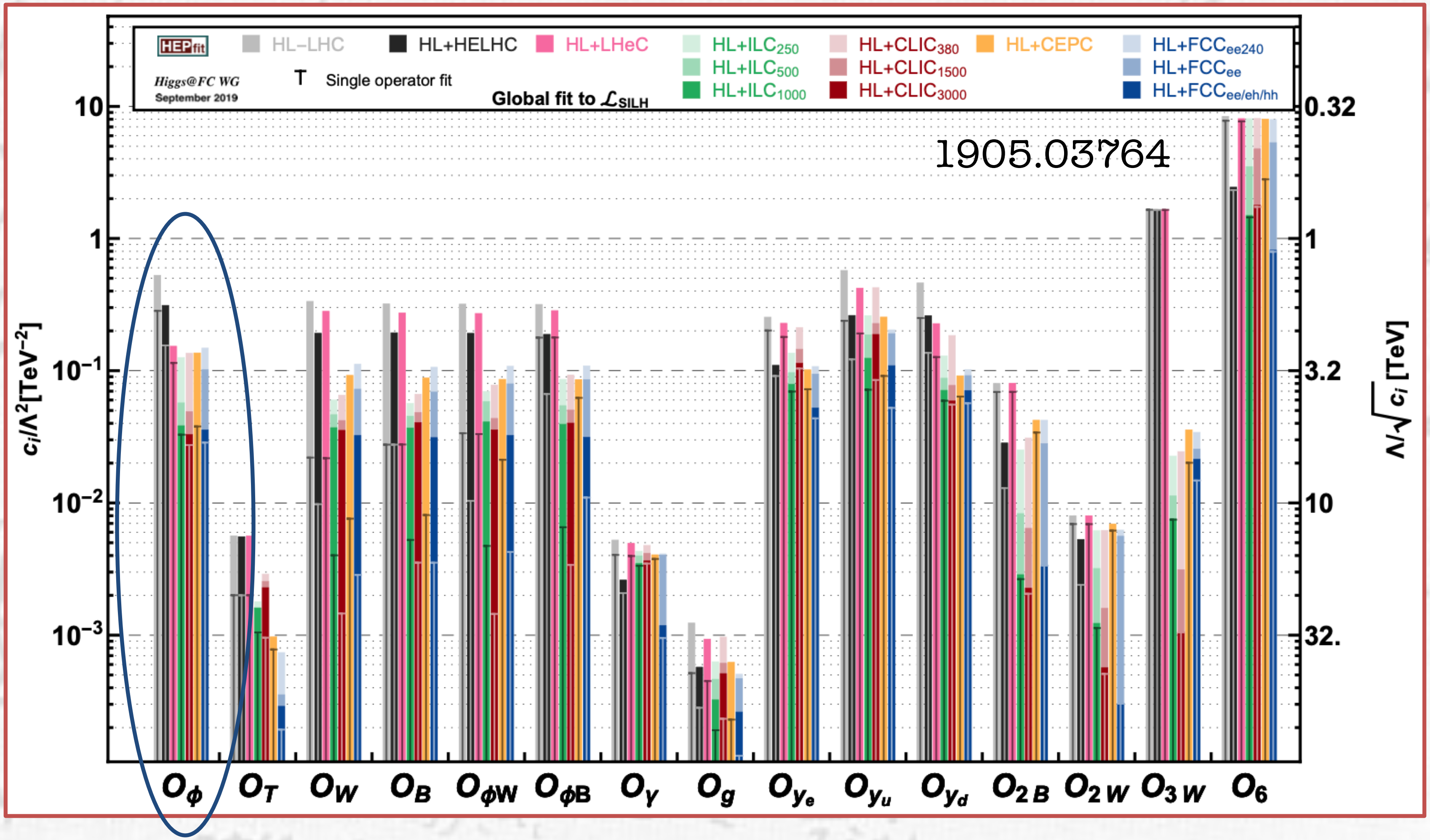




1905.03764

Rich interplay between direct/indirect, HL-LHC and Higgs factory.

What is the Higgs made of?



If the Higgs has substructure, one or more of these operators will have non-vanishing coefficients.

Running Scenarios

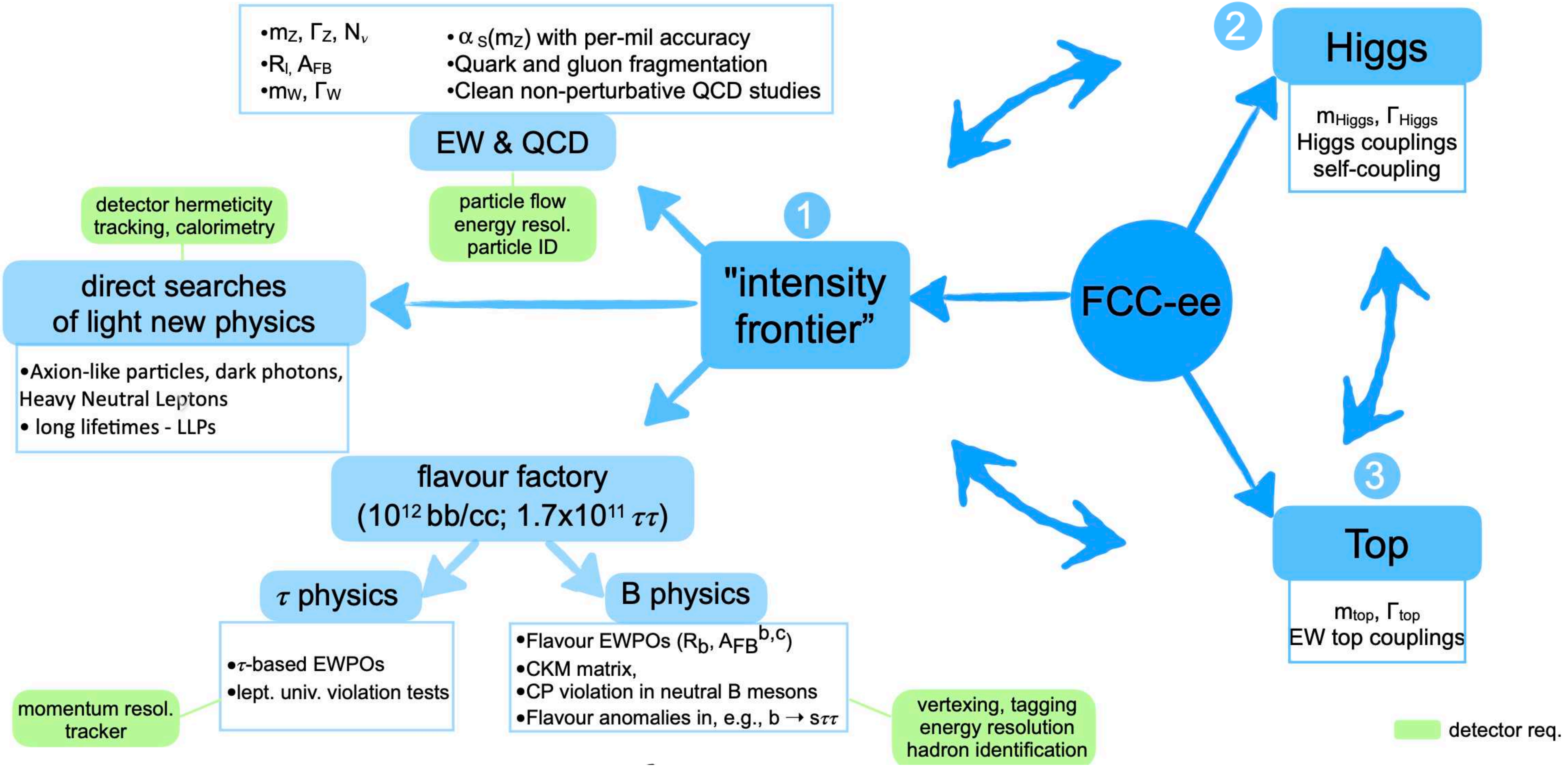
Turning physics goals into results

- For FCC-ee, the RF of the machine is reconfigured depending on collision energy: Optimisation of luminosity, required RF units / staging of cost

NB: The order of stages is under study - considering physics and machine aspects.

Developing the Physics Case

Informing Energy Stages, Luminosity Goals, Detector Requirements



C. Grojean, 02/2022

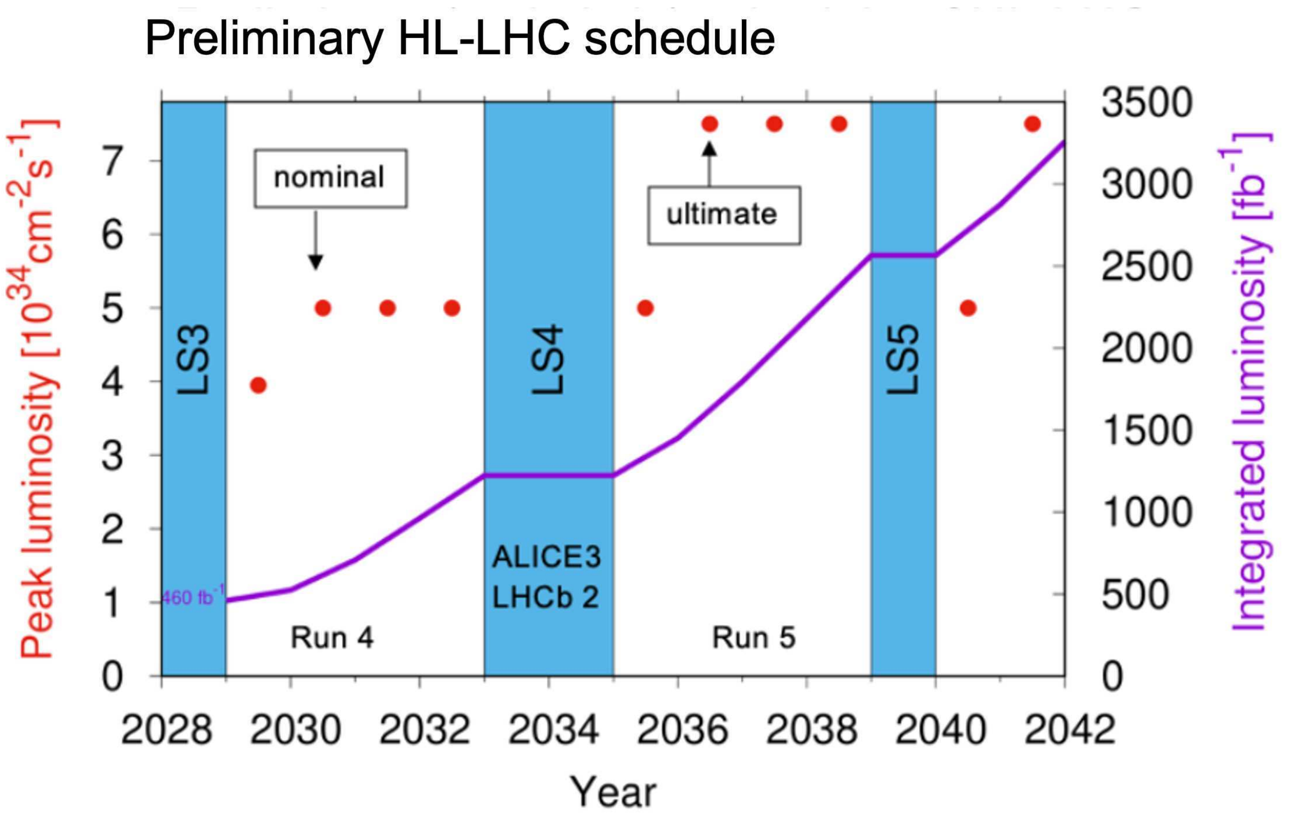
Current HL-LHC timeline

- Run 3 started in 2022 → goal is to roughly double the luminosity in ATLAS and CMS

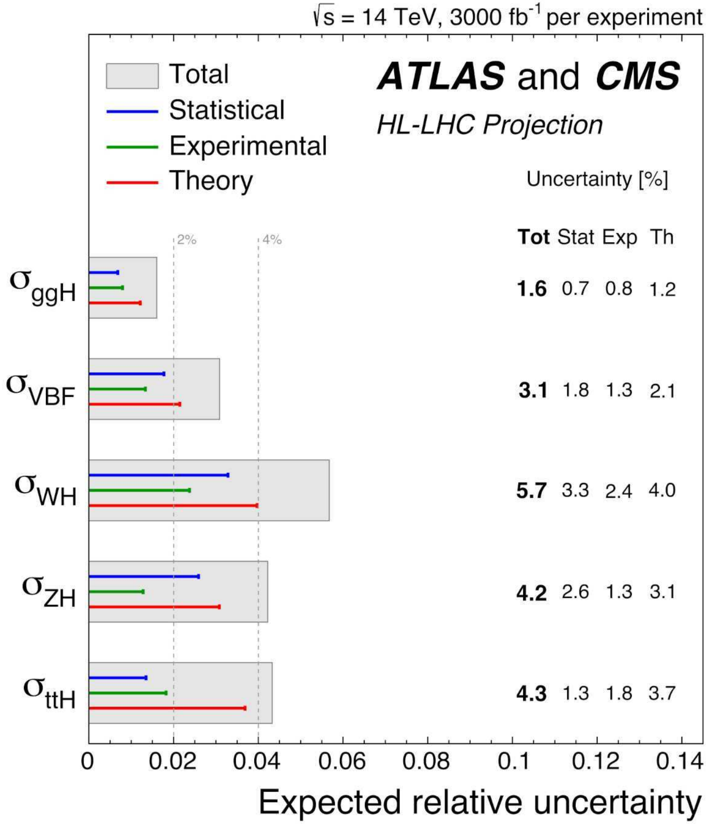
- Upgrade to accelerator, ATLAS and CMS in LS3 (2026-2028) → luminosity increased by factor 5-7

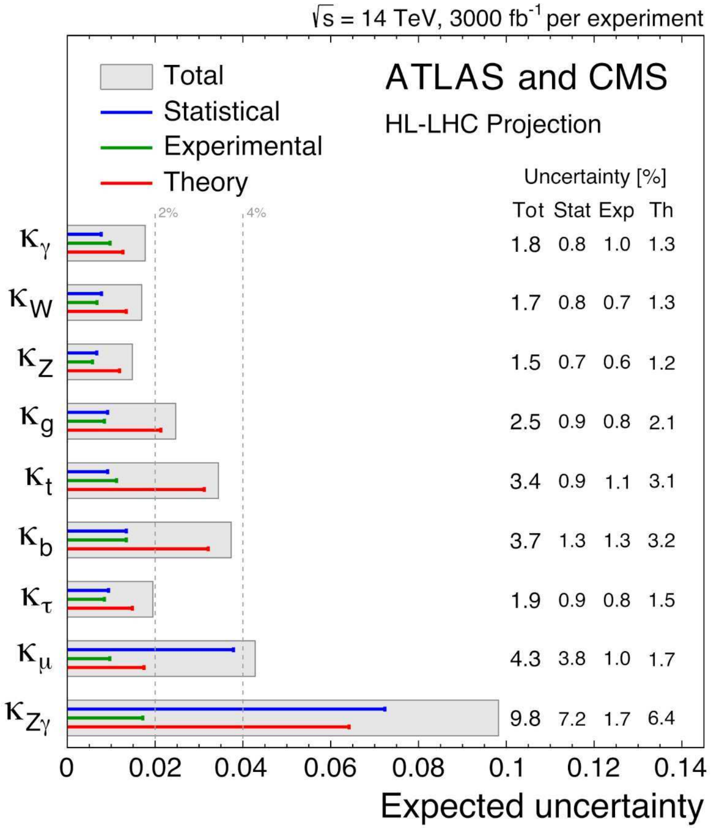
- The final goal is at least 3000 fb^{-1}

- LHCb Upgrade II (and ALICE 3) during LS4 → later in this talk



Higgs production and couplings





- "kappa framework": $\kappa_i^2 = \sigma_i / \sigma_i^{SM}$ or $\kappa_i^2 = \Gamma_i / \Gamma_i^{SM}$
- Most coupling scale factors with a few percent precision

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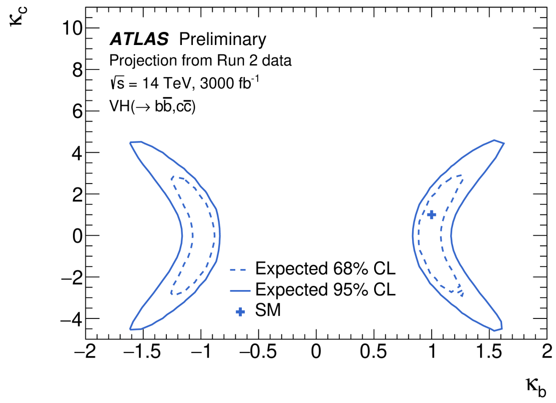
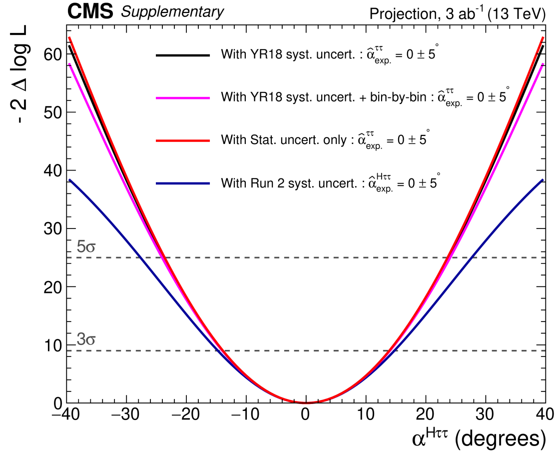
More Higgs properties

Charm-Yukawa coupling



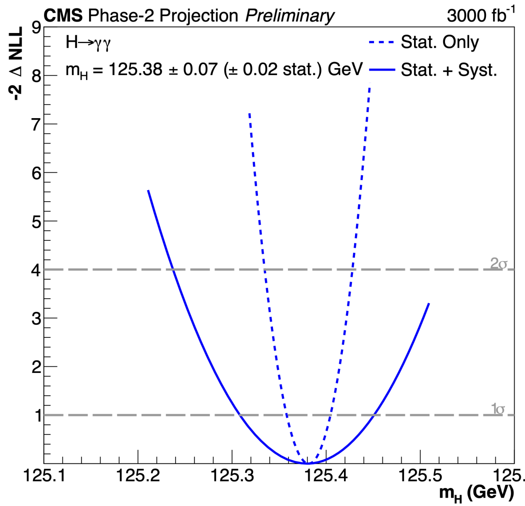
- Simultaneous measurement of $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$
- Benefit from improved flavour tagging and boosted object reconstruction
- ATLAS/CMS/LHCb combination could potentially reach 100% uncertainty on κ_c

CP structure of the Hττ coupling



$\alpha^{H\tau\tau} = 0°$ (90°): pure scalar (pseudoscalar) coupling

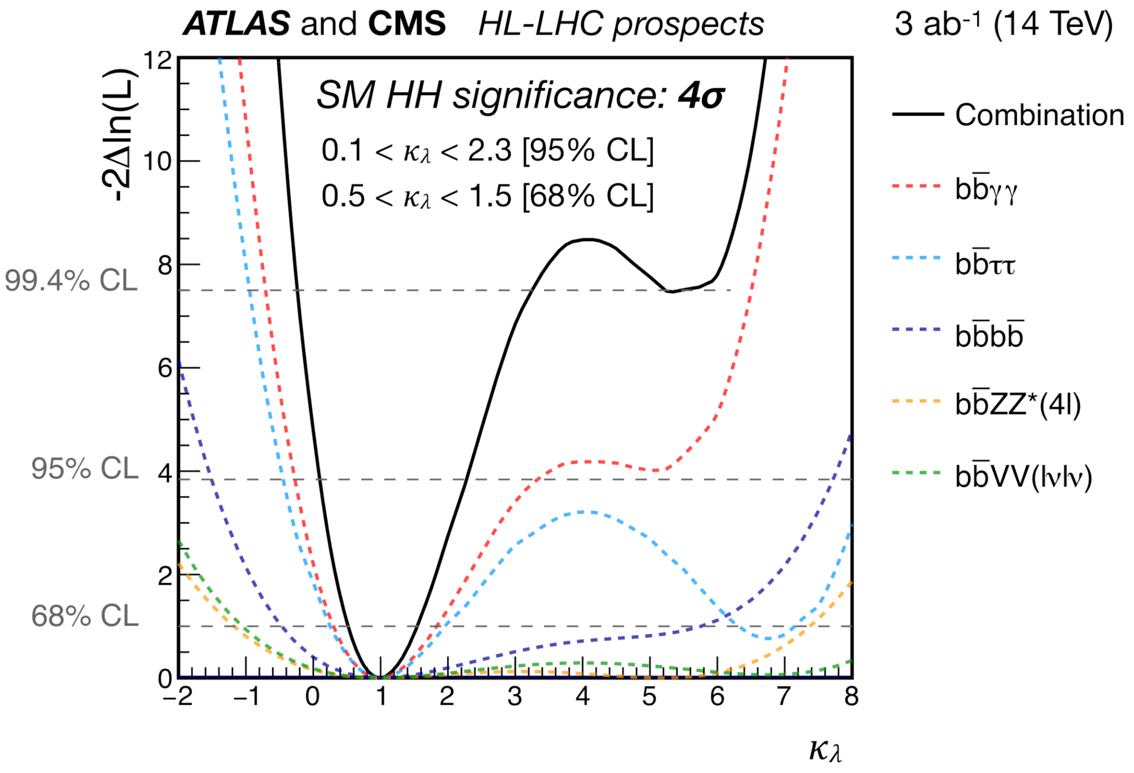
Higgs boson mass



- Overall precision of 10-20 MeV expected

arXiv:1902.00134
ATL-PHYS-PUB-2022-018 / CMS PAS-FTR-22-001

Double Higgs production and self-coupling



- 4 sigma measurement of the double Higgs production cross section
- 50% precision on self-coupling κ_λ assuming its SM value
- Improvement on by adding single Higgs projections marginal

JHEP 01, 139 (2020)
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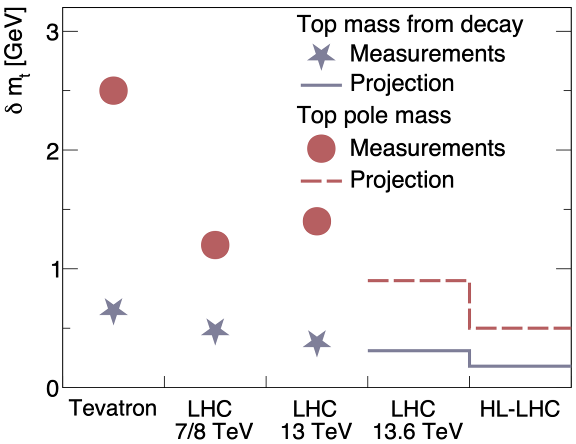
Top-quark properties

Top-quark mass

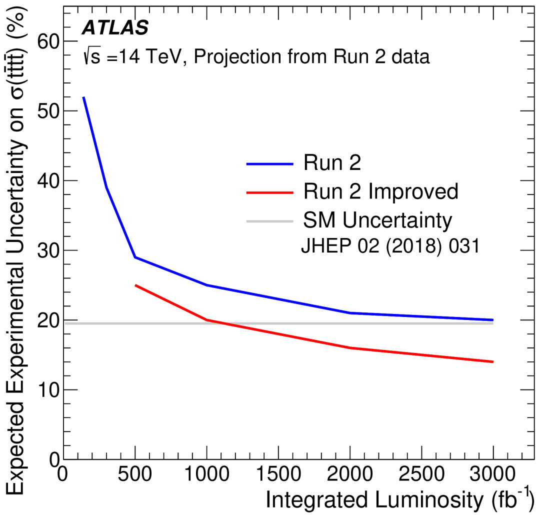


- Precision of better than 200 MeV expected
- Pole mass limited to 500 MeV

arXiv:2209.11267

Production of 4 top quarks

Rare process: $\sigma_{t\bar{t}t\bar{t}} \approx 12$ fb
→ 4-5σ expected at HL-LHC



Top-quark FCNC effects

$\mathcal{B}$ limit at 95%C.L.	3 ab^{-1}, 14 TeV
$t \to gu$	3.8×10^{-6}
$t \to gc$	32.1×10^{-6}
$t \to Zq$	$2.4 - 5.8 \times 10^{-5}$
$t \to \gamma u$	8.6×10^{-6}
$t \to \gamma c$	7.4×10^{-5}
$t \to Hq$	10^{-4}

NB: Current 95% CL limits typically at the level of 10^{-3} to 10^{-4}

CERN-LPCC-2018-06
ATL-PHYS-PUB-2022-018 / CMS PAS-FTR-22-001