



MAX-PLANCK-INSTITUT
FÜR PHYSIK

PHYSICS OPPORTUNITIES AND DETECTOR DESIGN FOR THE FCC-EE

Oliver Kortner

Liverpool, 14.09.2025

Outline

- ▶ European strategy for future collider projects
- ▶ FCC-ee physics opportunities
- ▶ Detector requirements
- ▶ Detector concepts
- ▶ Summary

The background of the slide is composed of two large, overlapping geometric shapes. A teal-colored shape occupies the top-left corner, while a light beige shape occupies the bottom-left corner. The rest of the slide is white. The text is positioned in the white area.

European strategy for future collider projects

The LHC legacy so far

- **Standard Model (SM) confirmed to high accuracy up to energies of several TeV**
(thanks to a firm control of exp. & th. syst. uncertainties, the LHC became a precision machine)
- **Higgs boson discovered** at the mass predicted* by LEP precision EW measurements
*within the Standard Model

- **Absence of new physics**

TeV-scale Naturalness might not explain DM/baryogenesis

Traditional New Physics models are under siege

New approaches: relaxion, Nnaturalness, clockwork...

Cosmology might settle the vacuum of the SM

We need a broad, versatile and ambitious programme that

1. sharpens our knowledge of already discovered physics
 2. pushes the frontiers of the unknown at high and low scales
- together FCC-ee & FCC-hh combine these 2 aspects —

more PRECISION and more ENERGY, for more SENSITIVITY to New Physics

Need for Higgs boson precision measurements

“The Higgs isn’t everything; it’s the only thing!”*

The scalar discovery in 2012 has been an important milestone for HEP.

Many of us are still excited about it. Others should be too.

Higgs = **new forces** of different nature than the interactions known so far

- No underlying local symmetry.
- No quantised charges.
- Deeply connected to the space-time vacuum structure.

— The discovery of the Higgs opens new deep questions —

- What is the origin of the Higgs boson?
- Is it elementary and isolated, or does it emerge from a deeper underlying dynamics?
- Which role did the Higgs play during the big bang, and how did it influence the evolution of the Universe?
- Does the Higgs boson play a role in explaining other fundamental open questions in particle physics which the SM cannot address (flavour, DM, baryogenesis, inflation...)

European strategy for particle physics

Original strategy from 2006 LHC mooting of luminosity upgrade of the LHC, R&D in accelerator technologies, coordination with a potential ILC project.

1st update in 2013 High-Luminosity LHC, need for a post-LHC programme.

2nd update in 2020

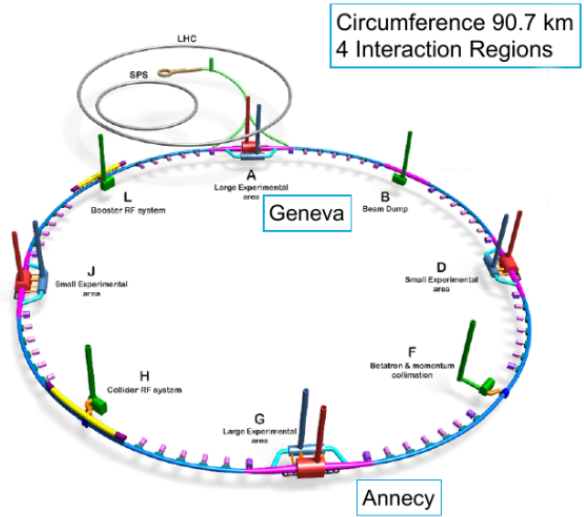
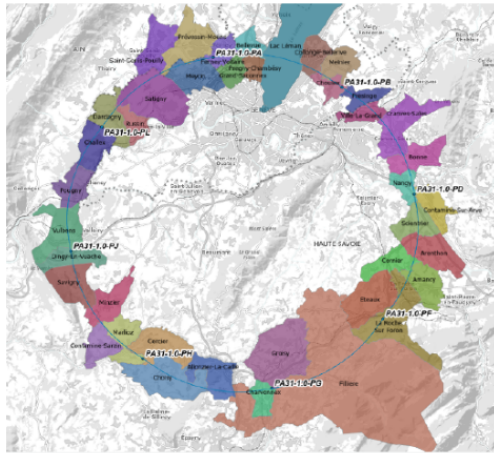
- ▶ Higgs factory highest priority after the HL-LHC.
- ▶ Future Circular Collider (FCC) feasibility study.

3rd update in 2026

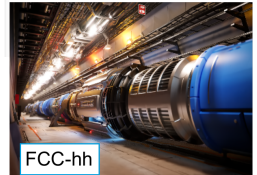
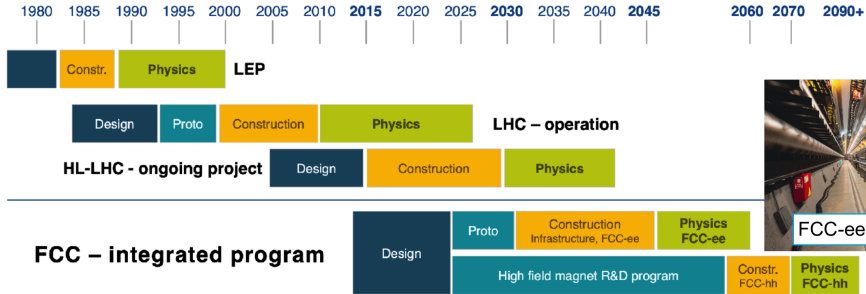
- ▶ Open symposium on the European strategy for particle physics in Venice in June:
Overwhelming support for the integrated FCC-ee/hh programme by the HEP communities in the CERN Member and Associate Member states and beyond.

The Future Circular Collider

Proposed FCC at CERN



High-energy physics timeline



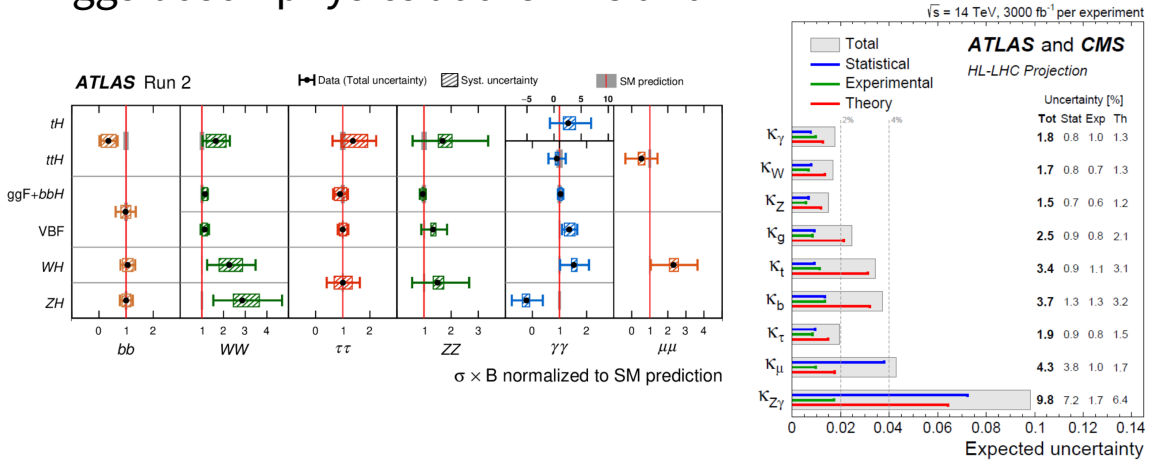
1. Stage: e^+e^- : Higgs El.weak and top factory (Z, WW, ZH, tt)
2. Stage: hh: pp physics at the energy frontier (~ 100 TeV)

F. Sefkow

The background of the slide is composed of two large, overlapping geometric shapes. A teal-colored shape occupies the top-left corner, while a light beige shape occupies the bottom-left corner. The rest of the slide is white. The text is centered in the white area.

FCC-ee physics opportunities

Higgs boson physics at the LHC and HL-LHC

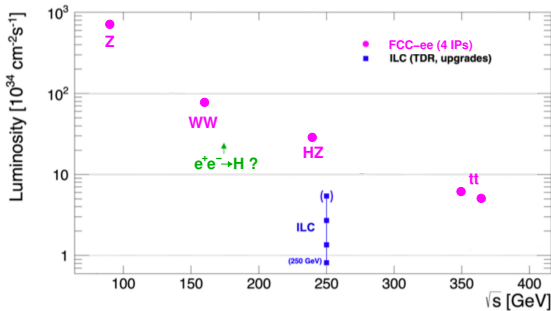


- ▶ LHC measurements revealed the existence of a scalar particle which closely resembles the prediction Higgs boson of the Standard Model (SM).
- ▶ The HL-LHC will increase the experimental sensitivity to deviations from the SM significantly by providing Higgs couplings with percent precision.

FCC-ee as Higgs factory plus EW and top factory

Higgs factory programme

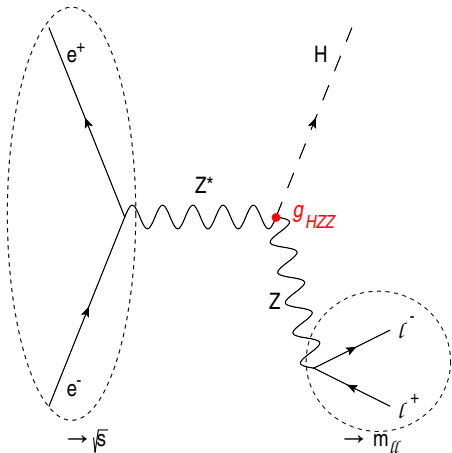
- ▶ $2 \cdot 10^6$ HZ events (similar to the HL-LHC, but higher purity and selection efficiency) and 125,000 W^+W^- events.
- ▶ Precise measurements of Higgs couplings to fermions and bosons.
- ▶ Sensitivity to Higgs self-coupling at 2-4 σ level via loop diagrams.
- ▶ Unique opportunity to measure the electron coupling in $e^+e^- \rightarrow H$ at $\sqrt{s} = 125$ GeV.



By changing the centre-of-mass energy of the collider the FCC-ee can also be operated as an electroweak and top quark factory.

- ▶ $\sim 100,000$ Z/s (1 Z/s at LEP).
- ▶ $\sim 10,000$ Ws/h (20,000 Ws in 5 years at LEP).
- ▶ $\sim 1,500$ top quarks/d.

Measurements of the Higgs boson couplings at the FCC-ee



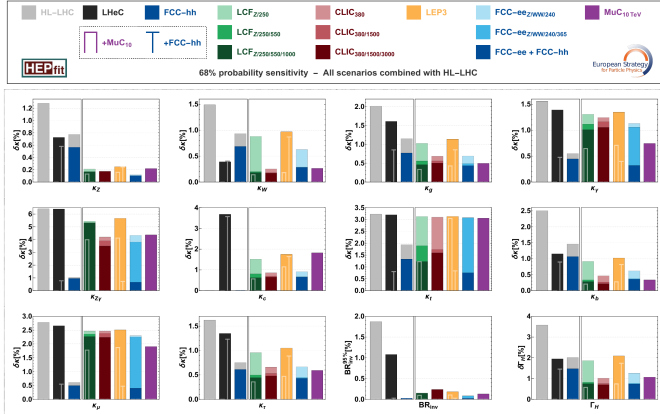
- ▶ At the FCC-ee, unlike the (HL-)LHC absolute coupling measurements are possible.
- ▶ The presence of the Higgs boson can be deduced from a peak in the recoil mass spectrum:

$$m_{recoil}^2 = s + m_{\ell\ell}^2 - 2\sqrt{s}(E_{\ell^+} + E_{\ell^-}).$$

- ⇒ $\sigma(ZH)$ obtained independently obtained from the Higgs boson decay. ⇒ Absolute determination of g_{HZZ} .
- ▶ Exclusive decays into $b\bar{b}$, $c\bar{c}$, gg , $\tau^+\tau^-$, $\mu^+\mu^-$, $\gamma\gamma$, $Z\gamma$, invisible and new BSM states provides absolute couplings to these final states.
- ▶ Combination of $\sigma(ZH)$ with $\sigma(ZH \rightarrow ZZ)$ provides the **total width** of the Higgs boson.

Projections for coupling measurements

CERN-ESU-2025-001



- Substantial improvement in sensitivity for $\Gamma_{H \rightarrow ZZ}, \Gamma_{H \rightarrow c\bar{c}}, \Gamma_{H \rightarrow b\bar{b}}, \Gamma_{H \rightarrow inv.}$
- Model independent measurement of Γ_H only at an e^+e^- collider.

FCC-ee physics programme overview

Higgs factory programme

- ▶ $2 \cdot 10^6$ ZH events at $\sqrt{s} = 240$ GeV.
- ▶ 75,000 $W^+W^- \rightarrow H$ events at $\sqrt{s} = 365$ GeV.
- ▶ Measurement of Higgs couplings.
- ▶ Sensitivity to Higgs selfcoupling at the $2 - 4\sigma$ level via loop diagrams.
- ▶ Unique: $e^+e^- \rightarrow H$ at $\sqrt{s} = 125$ GeV.

Heavy flavour programme

- ▶ $10^{12} b\bar{b}, c\bar{c}, 1.7 \cdot 10^{11} \tau^+\tau^-$ in a clean environment ($10 \times$ Belle).
- CKM matrix, CP measurements.
Rare decays, CLFV searches,
lepton universality.

Precision EW and QCD programme

- ▶ $6 \cdot 10^{12}$ Z and $10^8 W^+W^-$ events.
→ $m_Z, \Gamma_Z, \Gamma_{inv.}, \sin^2 \theta, m_W, \Gamma_W, \dots$
- ▶ $2 \cdot 10^6 t\bar{t}$ events.
→ $m_t, \Gamma_t, \text{EW couplings.}$
- ▶ Indirect sensitivity to new physics.

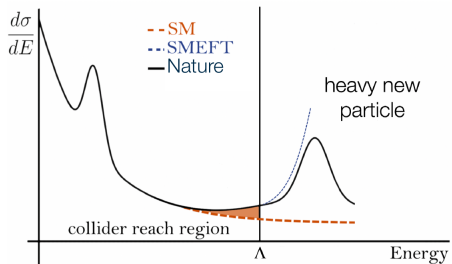
Feebly interacting BSM particles

- ▶ Opportunity to directly observe new feebly interacting particles with masses $< m_Z$.
- ▶ Axion-like particles, dark photons, heavy neutral leptons.
- ▶ Long lifetimes LLPs.

The SMEFT framework

► No statistically significant deviations from SM predictions in collider data.

⇒ Consider the SM as low-energy effective field theory of the final/exact theory.



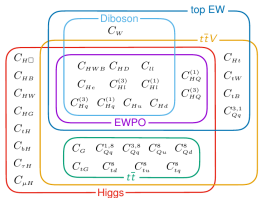
E. Celada, Corfu 2025

► The Standard Model Effective Field Theory (SMEFT) reveals high energy physics effects through precise measurements at low energy:

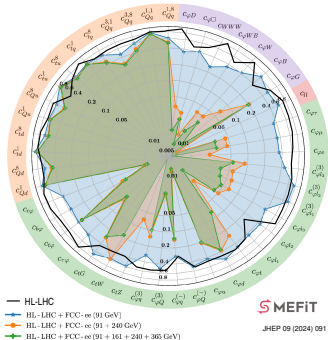
$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_k \frac{c_k^{(6)}}{\Lambda^2} \mathcal{O}_k^{(6)} + \mathcal{O}(\Lambda^{-3})$$

$$\sigma = |\mathcal{M}_{SM}|^2 + \frac{1}{\Lambda^2} \left(\sum c^{(6)} 2\text{Re}[\mathcal{M}_{SM}^* \mathcal{M}_{EFT}^{(6)}] \right) + \frac{1}{\Lambda^4} \left(\sum c^{(6)} \mathcal{M}_{EFT}^{(6)} \right)^2$$

SMEFT at FCC-ee



arXiv:2012.02779

Ratio of Uncertainties to SMEFT3.0 Baseline, $\mathcal{O}(\Lambda^{-2})$, Marginalised

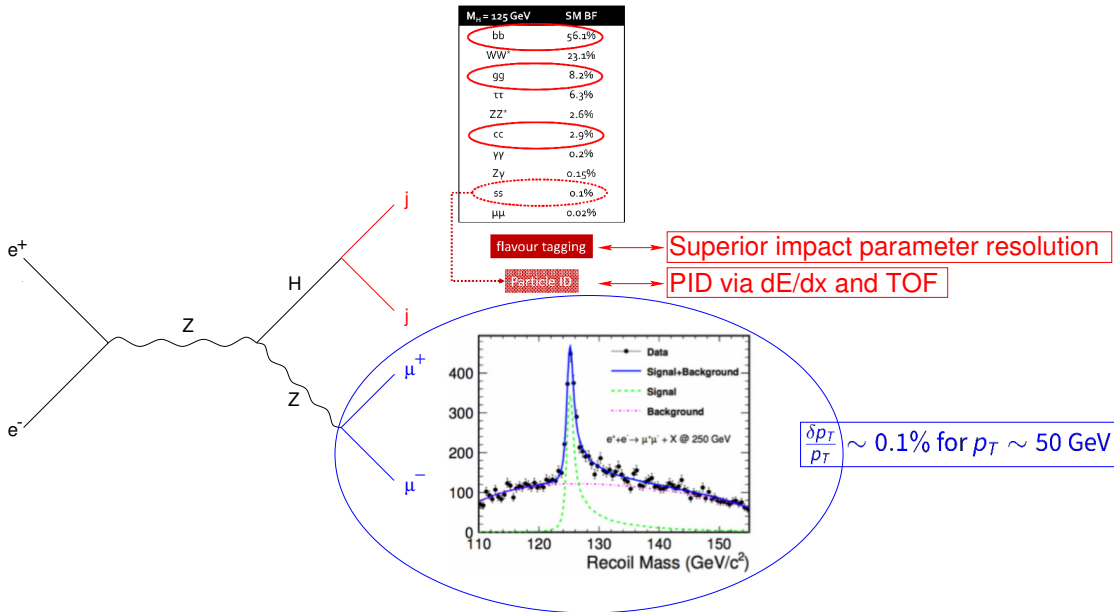
- ▶ Several Wilson coefficients appear in cross section of different processes accessible at the different centre-of-mass energies.
- ▶ Constrain the coefficients in a global fit to the entire FCC-ee data.

- ▶ Small improvement of the limits on Wilson coefficients by the combination of HL-LHC with FCC-ee-Z-peak data.
- ▶ Large improvement of the limits when the FCC-ee Higgs boson data are added.
- ▶ Even better limits with the top data.

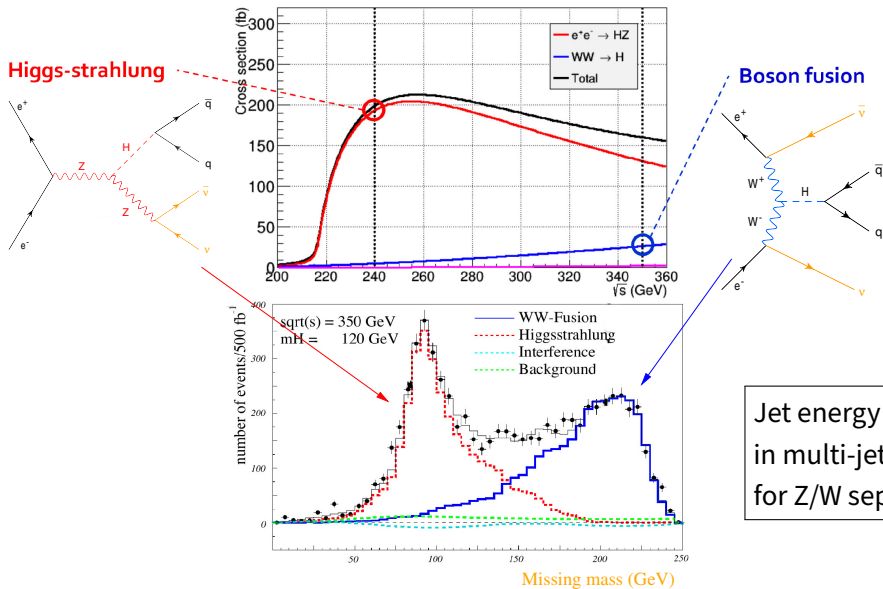
The background of the slide is composed of two large, overlapping geometric shapes. A teal-colored shape occupies the top-left corner, while a light beige shape occupies the bottom-left corner. The rest of the slide is white. The text 'Detector requirements' is centered in the white area.

Detector requirements

Inner detector requirements from Higgs boson physics



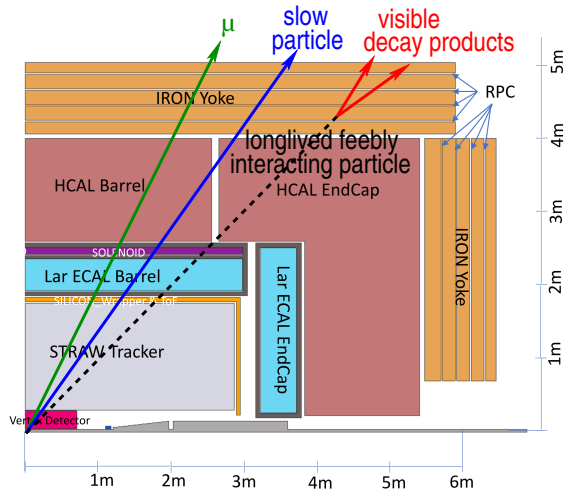
Calorimeter requirements



Jet energy resolution of $\frac{30\%}{\sqrt{E}}$
in multi-jet environment
for Z/W separation.

Muon system requirements

Topologies to covered/considered



Design goals

- ▶ 00 ps time resolution $\rightarrow$ sensitivity to $\beta = 0.995$.
- ▶ 1 mm spatial resolution $\rightarrow$ 1 mrad angular resolution.

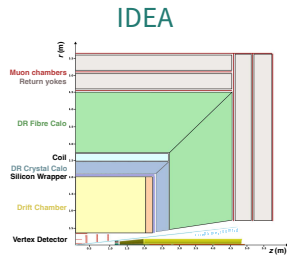
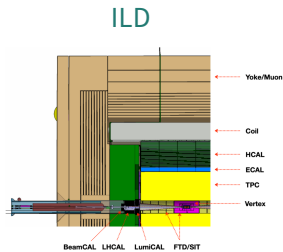
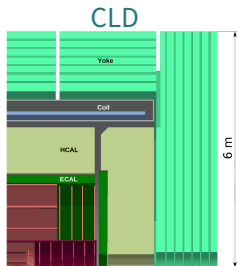
The background of the slide is composed of two large, overlapping geometric shapes. A teal-colored shape occupies the top-left corner, while a light beige shape occupies the bottom-left corner. The rest of the slide is white. The text 'Detector concepts' is centered in the white area.

Detector concepts

FCC-ee detector concepts

- ▶ 4 interaction zones at the FCC-ee allowing for 3 general-purpose detectors and one specialized detector (for instance for flavour physics).
- ▶ Detector concepts are evolving.
 - ▶ 2 detector concepts in the conceptual design review from 2019.
 - ▶ 4 detector concepts (ALLEGRO, CLD, IDEA, ILD) today.

4 FCC-ee detector concepts



Subsystem	CLD	ILD	ALLEGRO	IDEA
ID	All-silicon tracker	Silicon vertex detector TPC	Silicon vertex detector Low X ₀ drift chamber Silicon wrapper	Silicon vertex detector Low X ₀ drift chamber or straw tracker Silicon wrapper
ECAL	High-granularity silicon-tungsten		Dual read-out calorimeter	High-granularity lead/noble liquid
HCAL	High-granularity scintillator-steel		Lead-scintillating/Cherenkov fibres	Several options, no baseline yet
Muon	Steel-yoke instrumented with RPCs		Return yokes with μ Rwell chambers	Several options, no baseline yet

Introductory comments regarding the p_T resolution

Textbook formulae for the contributions to $\frac{\sigma(p)}{p}$

Position resolution contribution

$$\frac{\sigma_p}{p} = \frac{2p}{q} \frac{1}{BL^2} \sqrt{\frac{5}{N}} \cdot \sigma.$$

Multiple scattering contribution

$$\frac{\sigma_p}{p} = \frac{13.6 \text{ MeV}}{qcBL} \sqrt{\frac{N \cdot d}{X_0}}.$$

Required number of measurement layers at the FCC

$B = 2 \text{ T}, L = 2 \text{ m}$, goal: $\frac{\sigma_p}{p} = 0.1\%$ for $p = 50 \text{ GeV}/c$.

$\sigma [\mu\text{m}]$	5	7	10	80	100	120
N	3.5	8	14	890	1391	2003
	Silicon sensors			Gaseous detectors		

At least three layers of silicon sensors required.

Silicon sensors needed to achieve the required $\frac{\sigma_p}{p}$.

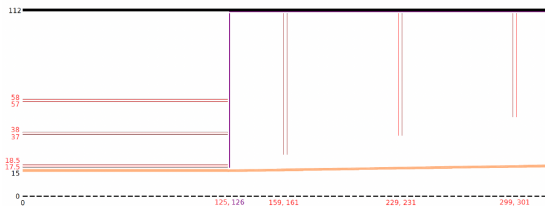
Maximum allowed material

$\frac{\sigma(p)}{p} = 0.1\%$ corresponds to $0.8\% X_0 = 0.7 \text{ mm silicon}$. $\Rightarrow$ Very thin silicon sensors needed.

$\Rightarrow$ ALLEGRO, IDEA, ILD combine silicon sensors with a light gaseous ionization detector to allow for continuous tracking for $\frac{dE}{dx}$ measurement and detection of decays of long lived particles.

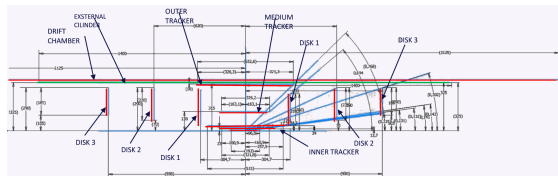
Vertex detectors

CLD/ILD



- ▶ $r_{min} = 13$ mm.
- ▶ 3 double-layer barrel layers and disk, $0.6-0.7\%X_0$ per double layer.
- ▶ $3\ \mu\text{m}$ spatial resolution.

ALLEGRO/IDEA

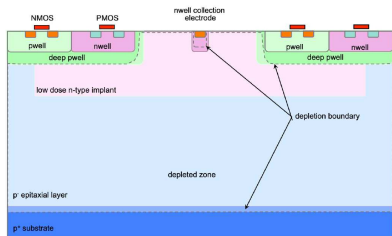


- ▶ $r_{min} = 13.7$ mm.
- ▶ 3 inner barrel singlet-layers, $0.25\%X_0$, 2 outer barrel layers and 3 disks.
- ▶ $3\ \mu\text{m}$ spatial resolution.

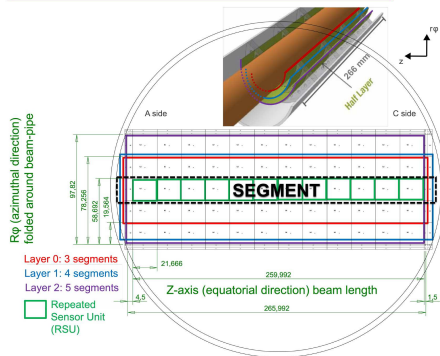
⇒ Large similarity between vertex detector designs/concepts.

F. Palla

Baseline for thin sensors: Monolithic Active Pixel Sensors



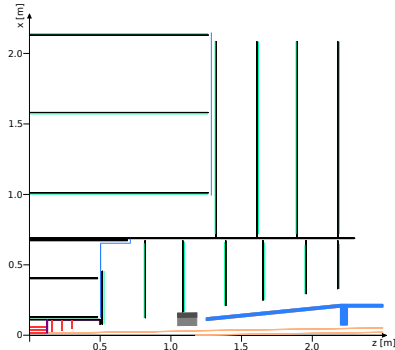
- ▶ MAPS: sensor and amplifier combined in one device.
- ⇒ Reduction of material compared to the hybrid design with bump-bonded read-out chips of the LHC experiments.
- ▶ All detector concepts assume ALICE ITS-3 like MAPS for the vertex detectors.



- ▶ ITS-3 MAPS can be stitched, bent and mounted on a cylinder.
- ⇒ Minimization of material for support structures.
- No need for overlapping modules.

All-silicon vs gas-detector combination

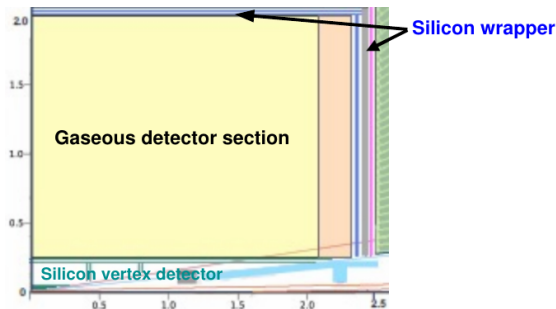
CLD/ILD concept



A. Sailer, The CLD Detector Concept, 2nd annual FCC US Workshop

- ▶ All-silicon inner detector with 9 detector layers at $\eta = 0$.
- ▶ Layers 1 to 3: $0.6\%X_0$ per layer, $3 \mu\text{m}$ spatial resolution.
- ▶ Layers 4 to 9: $1.1\%X_0$ per layer, $7 \mu\text{m}$ spatial resolution.
- ▶ Total material budget: $8.4\% \rightarrow \left. \frac{\sigma_p}{p} \right|_{MS} \approx 0.33\%$.

ALLEGRO and IDEA concepts



- ▶ 5 silicon pixel vertex layers: $2\%X_0$.
- ▶ Gaseous ionization detector: $1.3\%X_0$.
- ▶ Silicon wrapper.
- ▶ Total material budget: $3.3\% \rightarrow \left. \frac{\sigma_p}{p} \right|_{MS} \approx 0.21\%$.

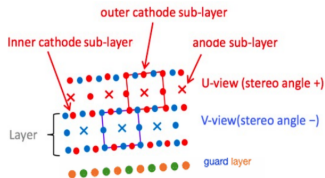
Comparing a straw-tracker with the IDEA drift chamber

Number of track points: 100 for the straw tracker and the drift chamber.

Gas mixture: He/i-C₄H₁₀(90/10) for both options.

Gas gain: 150,000 for both options.

Cell size: Comparable cell sizes in both options.



IDEA: 12÷14.5 mm wide square cells
5:1 field to sense wire ratio.

Single hit resolution: $\sim 100 \mu\text{m}$.

Advantages of a straw tracker over a drift chamber:

- ▶ Breaking on an individual wire only affects a single tube, does not compromise the whole tracker.
- ▶ Operation at higher than atmospheric pressure possible, e.g. 2 bar.

Comments on the mechanical structure to hold the wires

Challenges for the drift chamber

- ▶ Very large forces to be beared by the endcaps to hold the wires:
30 g tension/wire → 10 t of toal load on the end cap.

Situation for the straw-tube tracker

- ▶ Only anode wires have to be tensed.
- ⇒ Only 1.6 t total load on the end cap for 30 g tension/wire.
Significantly smaller load of 5 t total load even for 100 g tension/wire.
- ⇒ Much lighter end-cap structure for a straw-tube tracker than a drift chamber, hence less material in front of the calorimeters.

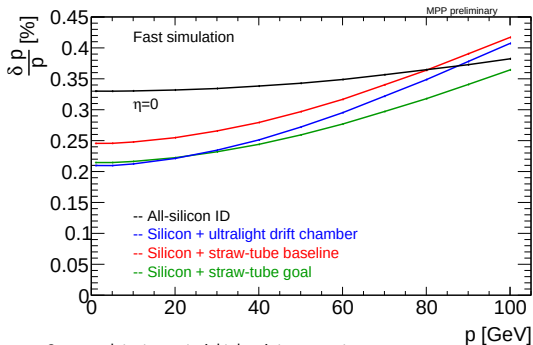
Comparison of the material budgets

IDEA drift chamber at $\eta=0$		Straw tracker baseline at $\eta=0$		Straw tracker design goal at $\eta=0$	
Component	X_0	Component	X_0	Component	X_0
Inner wall	$8.4 \cdot 10^{-4} X_0$				
Gas at atmospheric pressure	$1.3 \cdot 10^{-3} X_0$	Gas at atmospheric pressure	$1.3 \cdot 10^{-3} X_0$	Gas at 200 bar overpressure	$1.5 \cdot 10^{-3} X_0$
Anode wires (20 μm W)	$6.8 \cdot 10^{-4} X_0$	Anode wires (20 μm W)	$6.8 \cdot 10^{-4} X_0$	Anode wires (20 μm W)	$6.8 \cdot 10^{-4} X_0$
Field wires (40 μm Al)	$4.3 \cdot 10^{-4} X_0$	Tube walls (12 μm Mylar)	$1.3 \cdot 10^{-2} X_0$	Tube walls (8 μm Mylar)	$8.7 \cdot 10^{-3} X_0$
Guard wires (50 μm Al)	$1.6 \cdot 10^{-4} X_0$				
Outer wall	$1.2 \cdot 10^{-2} X_0$				
Total	$1.5 \cdot 10^{-2} X_0$	Total	$1.5 \cdot 10^{-2} X_0$	Total	$1.1 \cdot 10^{-2} X_0$
Material/measurement layer	$2.6 \cdot 10^{-5} X_0$	Material/measurement layer	$1.5 \cdot 10^{-4} X_0$	Material/measurement layer	$1.1 \cdot 10^{-4} X_0$

IDEA numbers from p.7 of https://indico.cern.ch/event/1408681/contributions/6122496/attachments/2947432/5181747/DeFilippis_DriftChamber.pdf

- ▶ The same overall material budget for the drift chamber and baseline straw-tracker design.
- ▶ 30% less material in the target straw-tracker design.
- ▶ Straw tracker: material “uniformly” distributed.
- ▶ IDEA drift chamber: Most of the material in the outer wall ($1.2\% X_0$) in front of the silicon wrapper minimizing the impact on the track reconstruction.

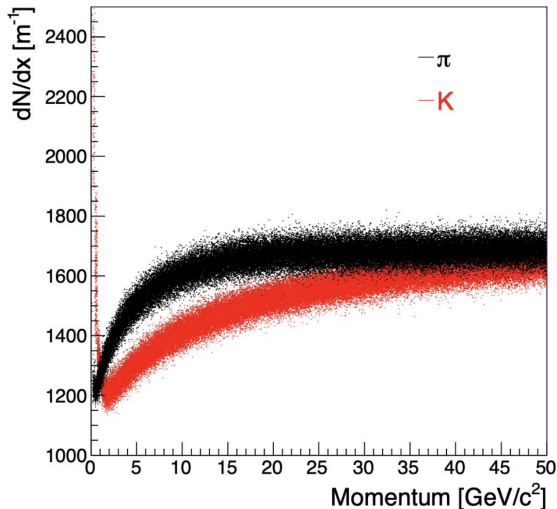
Comparison of achievable momentum resolutions



Gaseous detector material taken into account:
wires, gas, drift chamber cylinder / tube walls, anode wires, gas.

- Momentum resolution in an all-silicon option about 1.5 times worse than in the options with a gaseous ionization detector (as expected from text-book formulae).
- Momentum resolution predictions for the drift chamber and the straw trackers agree within the uncertainties of the details of the design.

Particle identification with a gaseous ionization detector



Eur.Phys.J. C 82 (2022) 7, 646

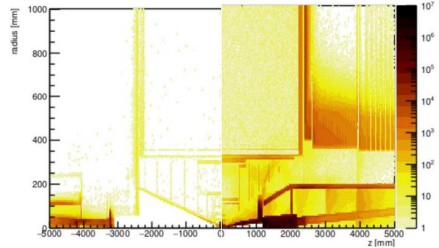
- ▶ π/K separation at $> 5\sigma$ level over a wide momentum range.
- ▶ Problematic region at $p = 1$ GeV can be closed by particle identification over time-of-flight measurements with $\mathcal{O}(10$ ps) resolution.

Open question about the TPC: Can it work at the Z pole?

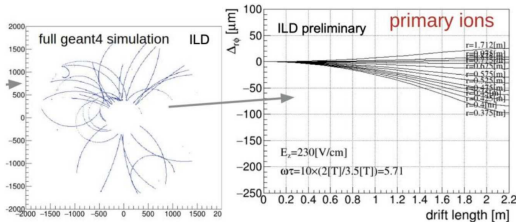
D.Jeans et al.

Study w/ full simulation in ddsim (DDG4) and GunieaPig

- simulate events in TPC at FCCee (91 GeV) from
 - e+e- physics events: $\sim 10^{10}$ ions $\rightarrow$ 100 μm distortions
 - beam induced background: $\sim 2 \times 10^{12}$ ions $\rightarrow$ 20 mm distortions
- a TPC also at TeraZ **might be feasible - yet further studies needed:**
 - mitigation strategies for drift distortions (corrections, redesign MDI elements?, ...)
 - stability of distortions wrt time, operating conditions, ...



MCParticle endpoints at FCCee 91 GeV from beam bg in ILClicklike (left) and CLDlike (right) ILD



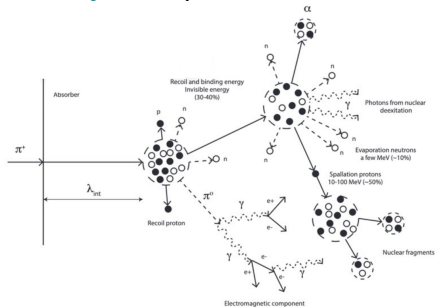
Collider	FCCee-91	FCCee-240	ILC-250
Detector model	ILD_i5_v11γ	ILD_i5_v11γ	ILD_i5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	270 k	800 k	450 k
primary ions in TPC at any time	1.8×10^{12}	1.4×10^{11}	6.5×10^8
average primary ion charge density nC/m ³	6.8	0.54	0.0025

- Primary ion density: 2500 times higher at FCCee 91GeV than at ILC(250)
- Dominated by beam background

Calorimetry at the FCC-ee

Goal: Jet energy resolution of $\frac{30\%}{\sqrt{E}}$.

Difficulty: Complex structure of a hadron shower.



- ▶ Two shower components: hadron and electromagnetic.
Large fluctuation of their fractions.
- ▶ Different calorimeter response to the electromagnetic and hadronic component.

Approaches to reach $\frac{30\%}{\sqrt{E}}$

- ▶ IDEA approach: Improve shower energy measurements by disentangling the electromagnetic and the hadronic components on an event by event basis.
- ▶ Particle-flow approach: Reconstruct the momenta of jet constituents as well as possible (ALLEGRO, CLD, IDEA, ILD).

Dual read-out calorimeter concept

Idea

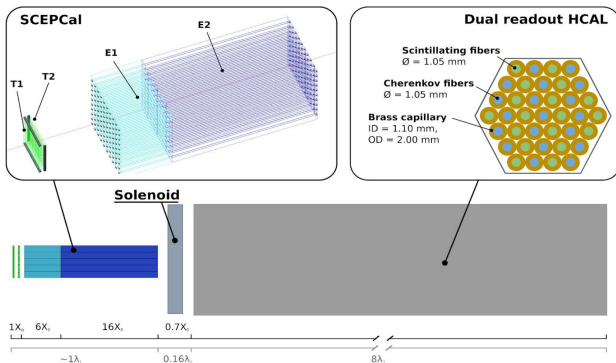
- ▶ 20% of the charged hadrons of a shower are relativistic and can produce Čerenkov light (C).
- ▶ The photons of the electromagnetic shower only produce scintillation light (S).
- ▶ Use Čerenkov and scintillation signal from electrons for calibration.
- ▶ Determine the electromagnetic fraction event by event to obtain the correct shower energy:

$$\begin{aligned}S &= E[f_{em} + (h/e)_s(1 - f_{em})] \\C &= E[f_{em} + (h/e)_c(1 - f_{em})] \\E &= \frac{S - \chi C}{1 - \chi} \text{ with } \chi = \frac{1 - (h/e)_s}{1 - (h/e)_c}\end{aligned}$$

Calorimetry at IDEA

Two options under study

- ▶ Longitudinally unsegmented dual read-out fibre calorimeter (combining ECAL and HCAL).
- ▶ Dual read-out crystal ECAL + dual read-out fibre HCAL.



ECAL ~ 20 cm PbWO_4

- ▶ 2 layers: $(6+16)X_0$
- ▶ Dual read-out with filters
- ▶ $\frac{\sigma_{EM}}{E} = \frac{3\%}{\sqrt{E}}$

Timing layer

- ▶ LYSO: Ce crystals
- ▶ $\sigma_t = 20$ ps

HCAL

- ▶ $\frac{\sigma_{had}}{E} \approx \frac{26\%}{\sqrt{E}}$

Particle-flow calorimetry concept

Motivation for particle-flow based granular calorimeters

- Goal to measure the jet energy with high resolution:

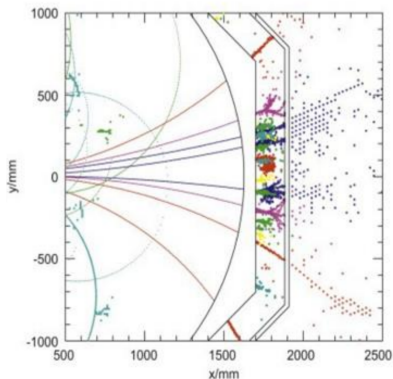
$$E_{\text{jet}} = E_{\text{charged}} + E_{\gamma} + E_{\text{neutral hadrons}}$$

Fraction	65%	26%	9%
----------	-----	-----	----

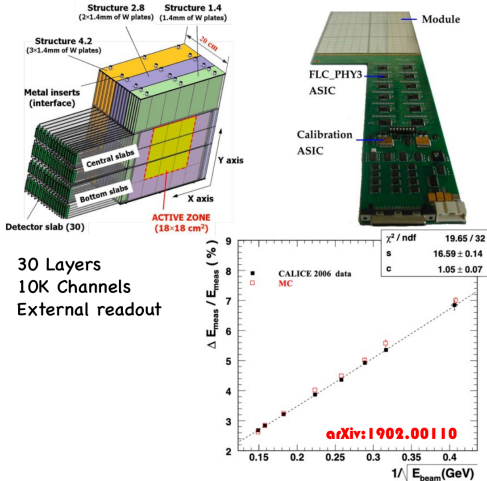
- Particle-flow algorithms construct individual particles and estimate their energy/momentum in the best suited subdetector.

Charged track resolution	$\frac{\delta p}{p} \sim 0.1\%$
γ energy resolution	$\frac{\delta E}{E} \sim \frac{12\%}{\sqrt{E}}$
Neutral hadron energy resolution	$\frac{\delta E}{E} \sim \frac{45\%}{\sqrt{E}}$

- Particle-flow algorithms require highly granular subdetectors including the calorimeters.



CLD/ILD silicon-tungsten ECAL



Absorber: Tungsten ($\lambda_0 = 3.5 \text{ mm}$).

Sensor: Silicon.

Read-out: Pads of $5 \times 5 \text{ mm}^2$.

Advantages:

- ▶ Narrow showers allowing for good separation of particles in the transverse direction.
- ▶ Compact design.
- ▶ Timing information at 10 ps level can be achieved by utilizing LGADs in the first layers.

- ▶ Mature technology developed by the CALICE collaboration for years.
- ▶ Technology used in the CMS HGCal.

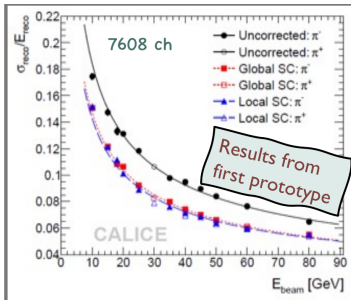
CLD/ILD scintillator-stell HCAL

Absorber: Stainless steel.

Sensor: Plastic scintillator.

Read-out: Tiles of $3 \times 3 \text{ cm}^2$ read out with SiPM.

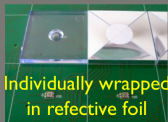
- ▶ Mature technology developed by the CALICE collaboration for years.
- ▶ Technology used in the CMS HGCAL.



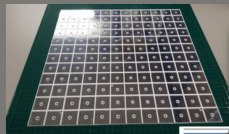
SC= Software Compensation

New Developments

Single Tile design



Glued one by one
Light Tightness 👍
Dead areas between tiles 👎



Megatile design

Large scintillator plate with optically separated trenches filled with reflective TiO_2

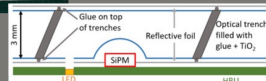


Plate wrapped in reflective foil
Easier assembly and no dead areas 👍
Not fully light tight 👎

Mary-Cruz Fouz, Corfu 2024

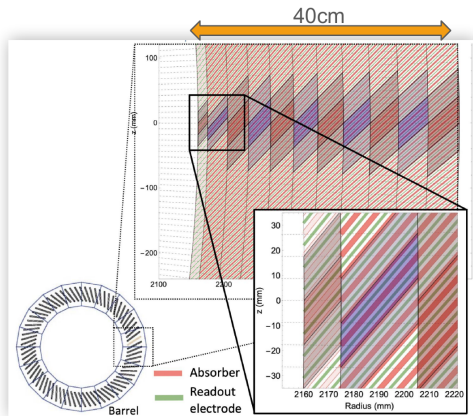
ALLEGRO noble liquid ECAL

Advantages of a noble-liquid calorimeter

- ▶ High intrinsic stability in gain and pedestals.
- ▶ Mature technology successfully applied in ATLAS, DO, H1, ...

New feature for FCC-ee

- ▶ 10 times higher granularity than in ATLAS to allow for particle-flow reconstruction.



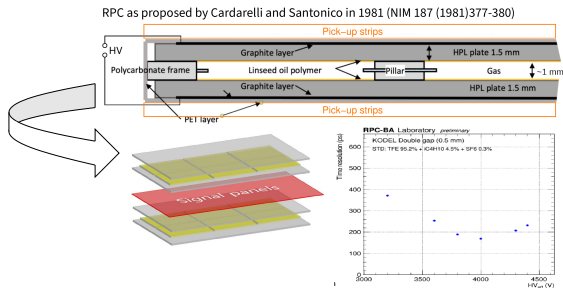
Barrel design

- ▶ 1536 straight absorber plates with 50° inclination.
- ▶ Liquid argon as active material.
- ▶ 11 longitudinal layers ($22 X_0$).
- ▶ Typical cell size:
 $\theta \times \phi \times r \sim 2 \times 1.8 \times 3 \text{ cm}^3$.

Muon system instrumentation

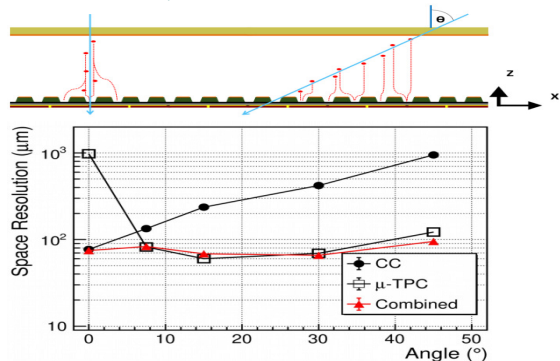
- ▶ Large area to be instrumented, i.e. cost-effective choice important.
- ⇒ All current proposal used gaseous ionization detectors.
- ▶ Baseline for the CLD/ILD and IDEA muon systems: RPCs, μ -RWELL.

Resistive plate chambers



Replace 1 mm single gap by a bigap of 0.5 mm gaps to increase the time resolution to 200 ps.

μ -RWELL chambers



High spatial resolution $\sim 100 \mu\text{m}$ achievable.

The background is composed of two large, overlapping geometric shapes. A teal-colored shape occupies the top-left corner, while a light beige shape occupies the bottom-left corner. The rest of the background is white. The word "Summary" is centered in the white area.

Summary

Summary

- ▶ Higgs factory highest priority after the HL-LHC.
- ▶ The Future Circular e^+e^- Collider (FCC-ee) as next step will provides us a deeper insight into BSM physics via precision measurements.
- ▶ Detector concepts for FCC-ee exist and are evolving.
- ▶ A lot of opportunities in detector R&D for FCC-ee.