The Tracking performance for the IDEA drift chamber

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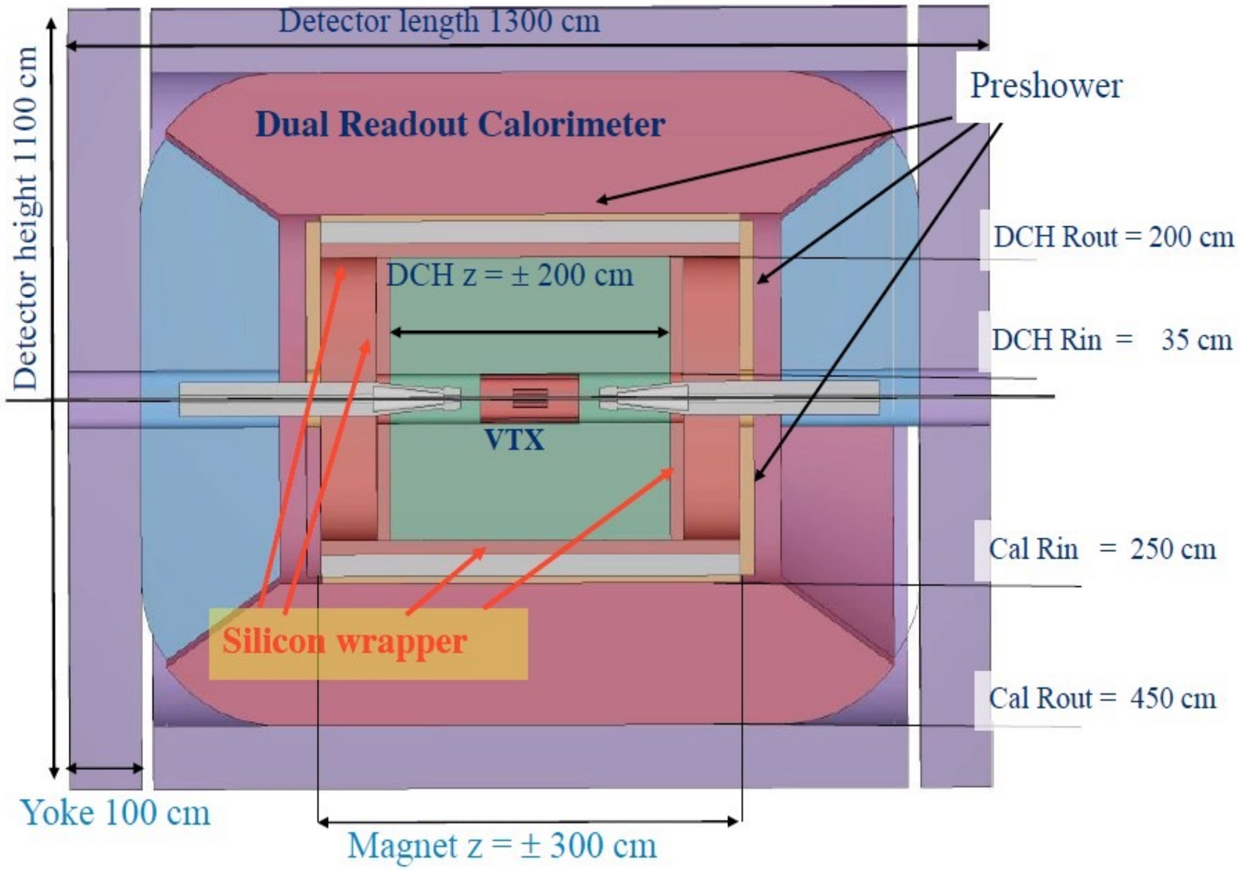
on behalf of IDEA DCH group

The IDEA detector at FCC-ee colliders

IDEA detector is Innovative detector designed for experiments at future e^+e^- colliders.

IDEA consists of:

- A silicon pixel vertex detector.
- A large-volume extremely-light drift wire chamber.
- A layer of silicon micro-strip detectors.
- A thin low-mass superconducting solenoid coil (optimized at 2 T) to maximize luminosity.
- A preshower detector.
- A dual read-out calorimeter.
- Muon chambers inside the magnet return yoke.



See here the talk by Gabriella at this conference for more details.

Tracking requirements

❑ Central tracker system:

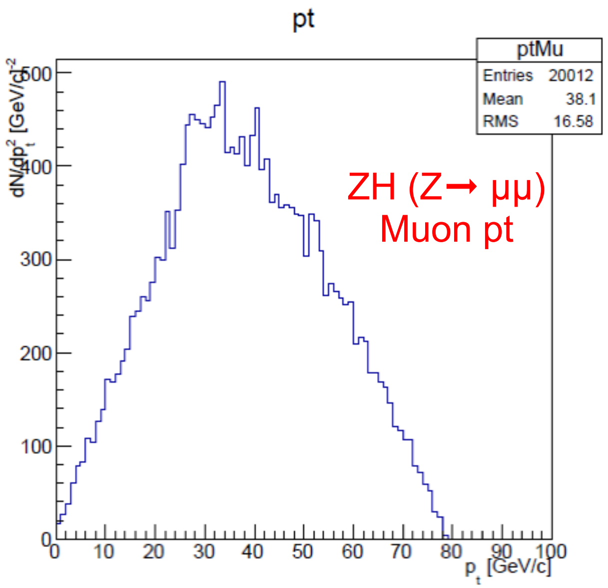
- state-of-the-art momentum and angular resolution for charged particles.
- B ~ 2T for beam emittance preservation
  - Maximize tracking volume
- bunch spacing at Z pole ~ 25 ns
  - Drift-time should be limited
- PID & π_0 ID for HF/τ physics
  - dE/dx or TOF.
- muons in ZH events have rather small p_T
  - Transparency more relevant than asymptotic resolution

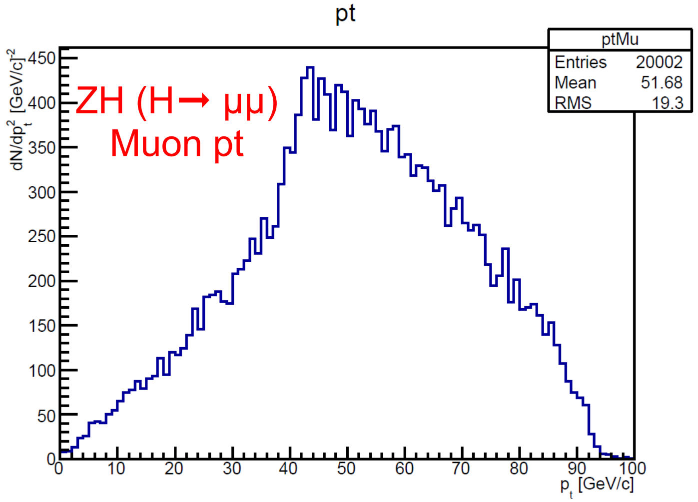
❑ Vertexing:

- excellent b-and c-tagging capabilities : few μm precision for charged particle origin.
- first layer as close as possible to IP.

❑ Challenges:

- physics event rates up to 100 kHz (at Z pole) ⇨ strong requirements on sub-detectors and DAQ systems.





The IDEA tracking system

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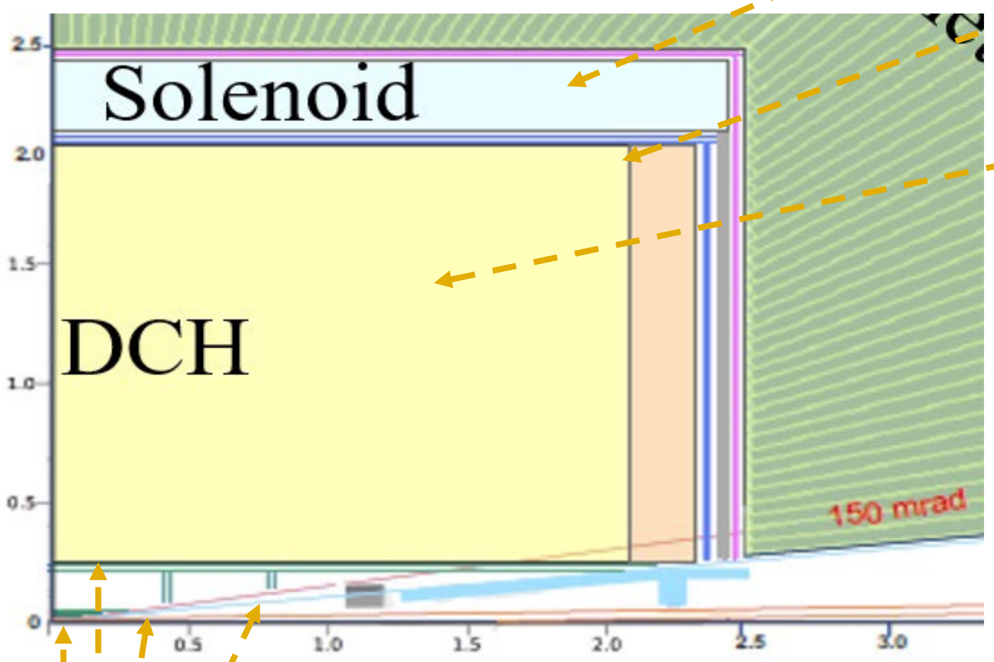
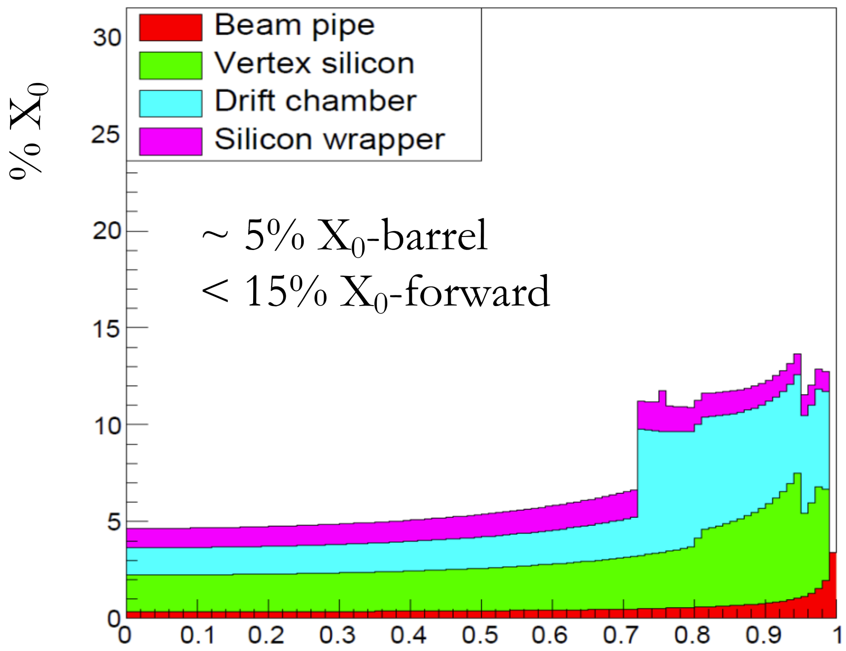


- ✓ **Solenoid:** 2 T, length = 5 m, r = 2.1-2.4 m, 0.74 X0, 0.16 λ@ 90º.
- ✓ **Si Wrapper**:2 layers of μ-strips (50 μm x 1 mm) both in barrel and forward regions.
- ✓ **DCH**: 56448 (~1.2 cm) cells He based gas mixture (90% He –10% i-C4H10).

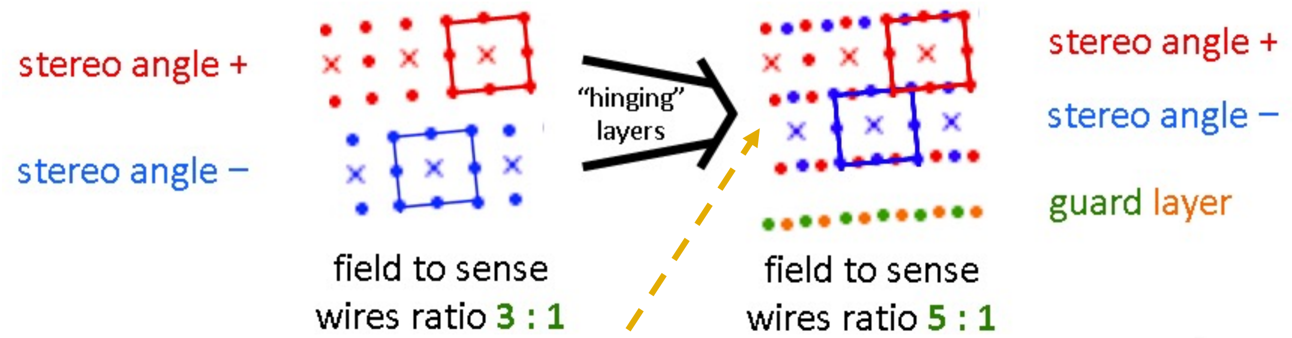
IDEA: Material vs. cos(θ)

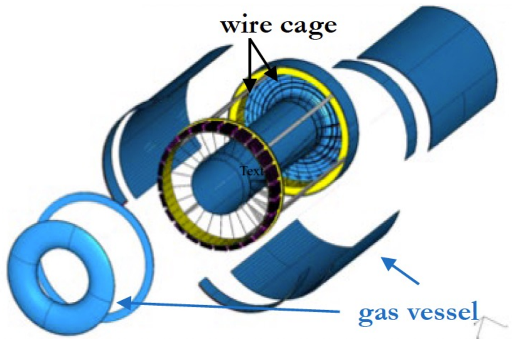


Vertex

inner: 3 single Si pixel (20 μm x 20 μm) layers of 0.3% X_0
outer: 2 single Si pixel (50 μm x 50 μm) layers of 0.5% X_0
forward: 4 single Si pixel (50 μm x 50 μm) layers of 0.3% X_0

The IDEA drift chamber



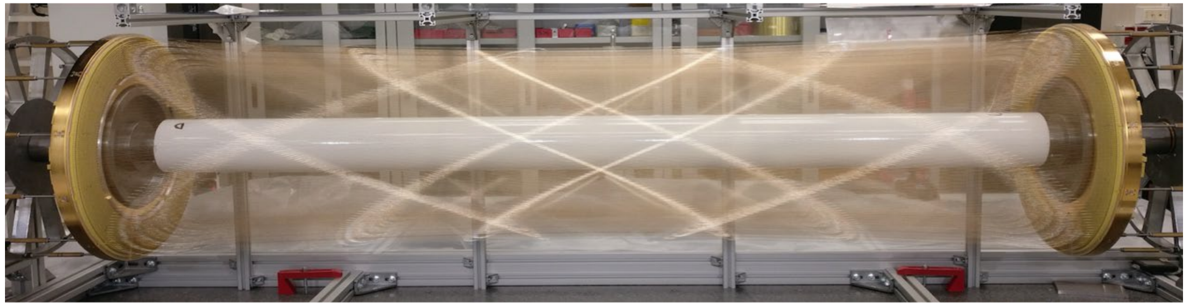


The wire net created by the combination of + and – orientation giving a high ratio of field to sense wires, and a high density of wires creating a more uniform equipotential surface.

New concept of construction allows to reduce material to ≈ 10^{-3} X_0 for the barrel and to a few x 10^{-2} X_0 for the end-plates.

sense wires:	20 µm diameter W(Au) => 56448 wires
field wires:	40 µm diameter Al(Ag) => 229056 wires
f. and g. wires:	50 µm diameter Al(Ag) => 58464 wires

343968 wires in total



High wire number requires a non standard wiring procedure and needs a feed-through-less wiring system. The novel wiring procedure developed and used for the construction of the ultra-light MEG-II drift chamber must be used.

MEG-II: muon to e-gamma search experiment at Paul ScherrerInstitut-"The design of the MEG II experiment", Eur. Phys. J. C (2018) 78:380 -https://doi.org/10.1140/epjc/s10052-018-5845-6

Full detector standalone simulation

- The standalone code was adapted for compilation on Key4hep stack on CERN lxplus machines.

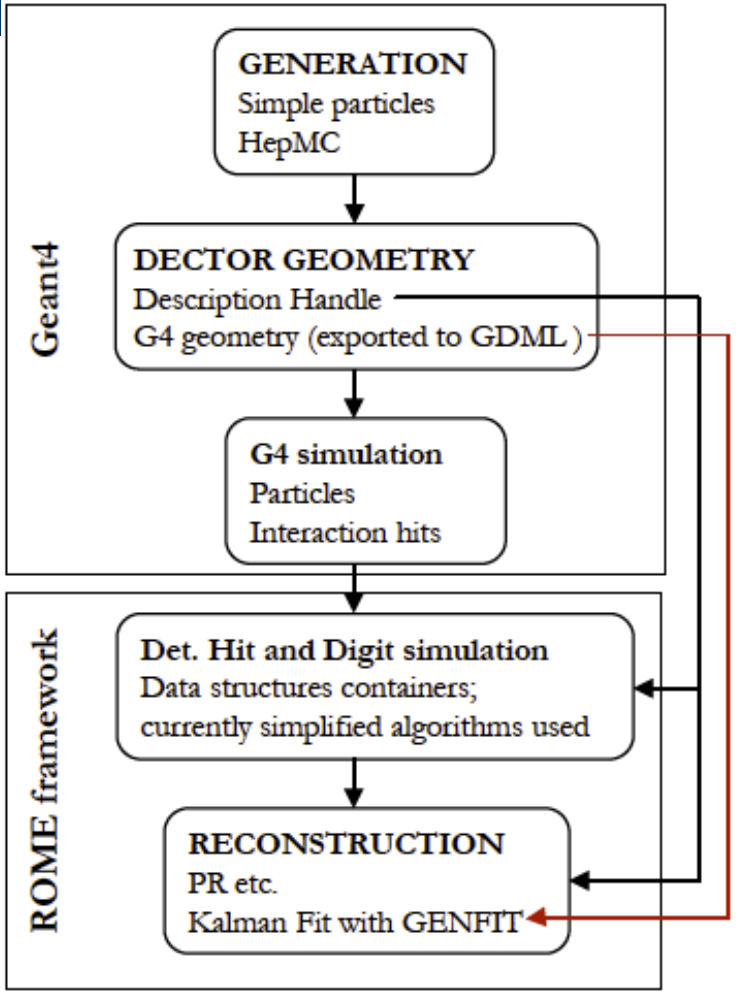
  (source /cvmfs/sw.hsf.org/key4hep/setup.sh)

The stack environment

SWs from the stack

External package to be installed locally

- key4hep-stack/2021-11-26:
- gcc8.3.0
- geant4-10.7.2
- clhep-2.4.4.0
- root-6.24.06
- genfit/02-00-00 (on the stack)
- rome master

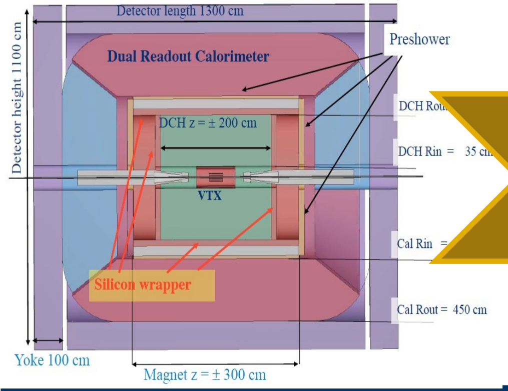


https://github.com/HEP-FCC/IDEADetectorSIM

The Migration to EDM4hep and Key4hep

Goal: port the simulation and the algorithms to a common FCC framework to develop studies, physics analysis and algorithms in the standard/final environment.

Standalone		**FCC framework**
Geant4 Monte Carlo hits (possible other data structures) reconstructed tracks	done — Covert to	*EDM4HEP*
simulation + reconstruction	In progress — port the geometry, port the algorithms, port the data format	*Key4HEP*

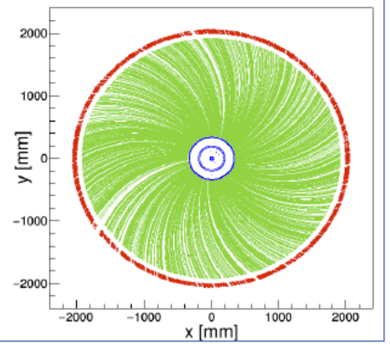


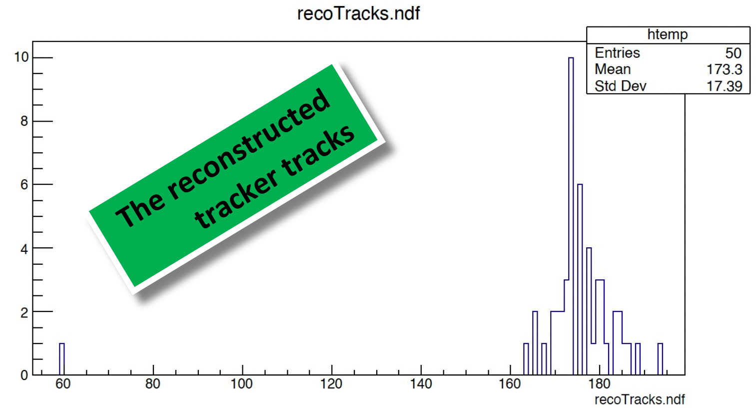
The converted tracker hits: silicon vertex tracker, drift chamber, pre–shower

Example of simulation

particle
- 1090 events
- 1 muon/event
- theta in [88.5, 90.5] deg
- energy = 1 GeV

geometry
- Beam pipe
- SVX
- DCH
- PSHW
- magnetic field = 2.0 T



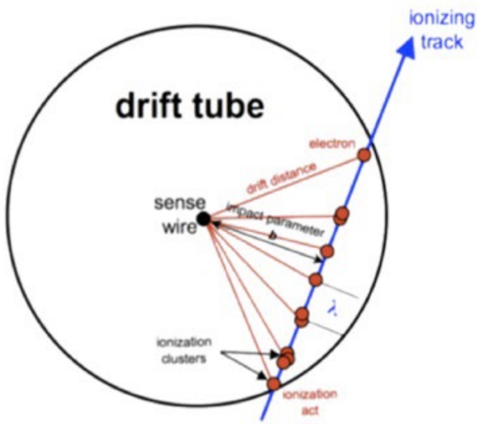


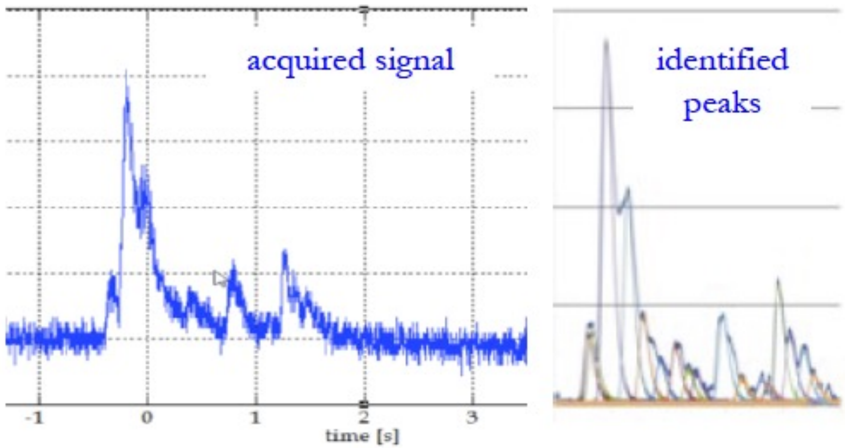
The reconstructed tracker tracks

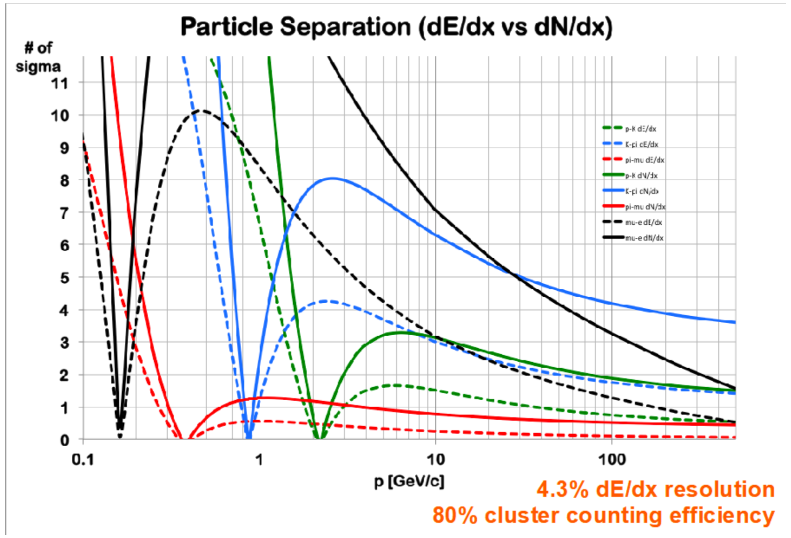
Cluster Counting/Timing and P.Id. expected performance

Principle: In He based gas mixtures the signals from each ionization act can be spread in time to few ns. With the help of a fast read-out electronics they can be identified efficiently.

• By counting the number of ionization acts per unit length (dN/dx), it is possible to identify the particles (P.Id.) with a better resolution w.r.t the dE/dx method.







dE/dx

Truncated mean cut (70-80%) reduces the amount of collected information. n = 112 and a 2m track at 1 atm give $\sigma \approx 4.3\%$

dN_{cl}/dx

δ_{cl}= 12.5/cm for He/iC4H10 = 90/10 and a 2m track give $\sigma \approx 2.0\%$

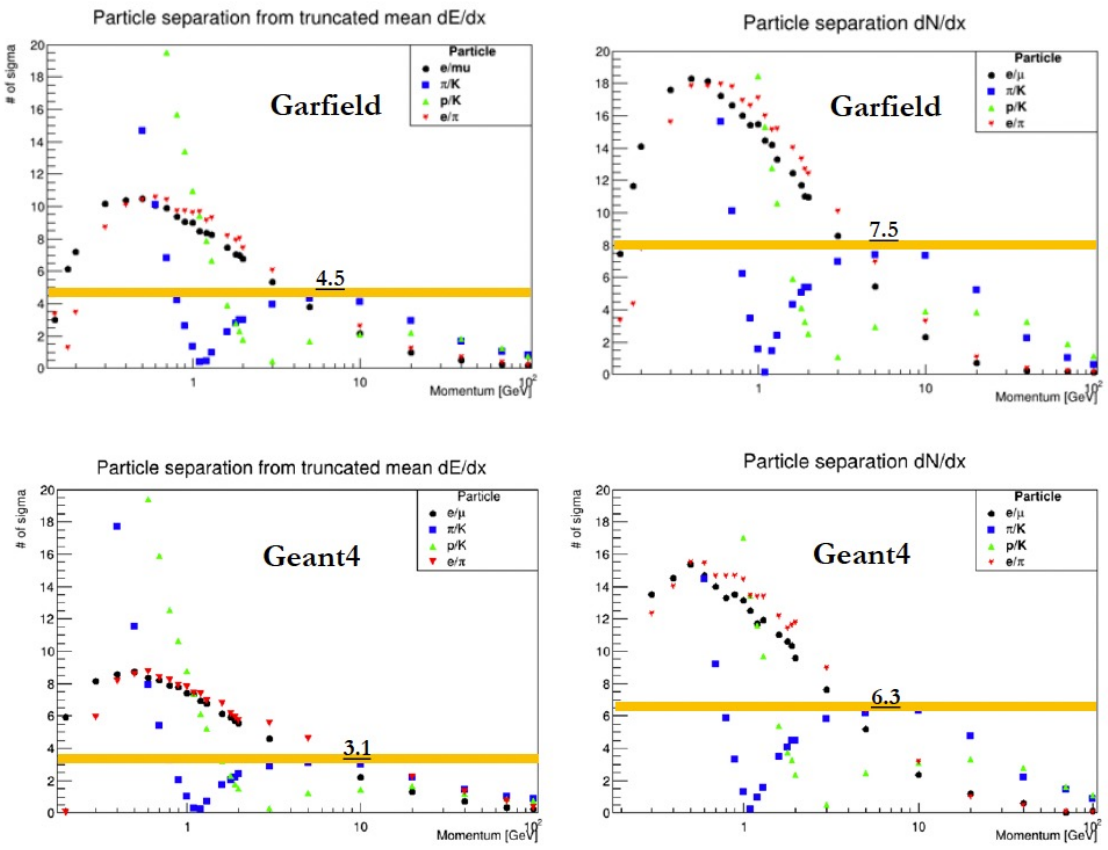
- Cluster Counting/Timing in DCH for good P.Id. Performance.
- Expected excellent K/π separation over the entire range except 0.85<p<1.05 GeV (blue lines).
- Could recover with timing layer.

Cluster Counting/Timing and P.Id. expected performance

- A simulation of the ionization process in 1 cm long side cell of 90% He and 10% iC4H10has been performed in Garfield++ and Geant4.

- Geant4 software can simulate in details a full-scale detector, but the fundamental properties and the performances of the sensible elements have to be parameterized or an "ad hoc" physics model has to be implemented.

- Three different algorithms have been implemented to simulate in Geant4, *in a fast and convenient way*, the number of clusters and clusters size distributions, using the energy deposit provided by Geant4.



We are assuming a cluster counting efficiency of 100%.

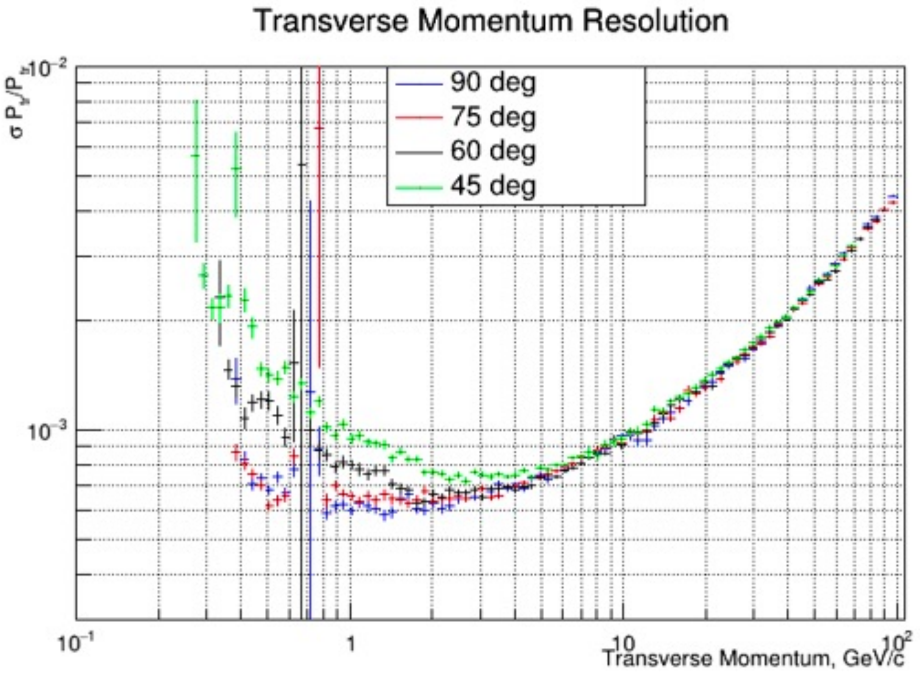
See here the talk by Federica at this conference for more details.

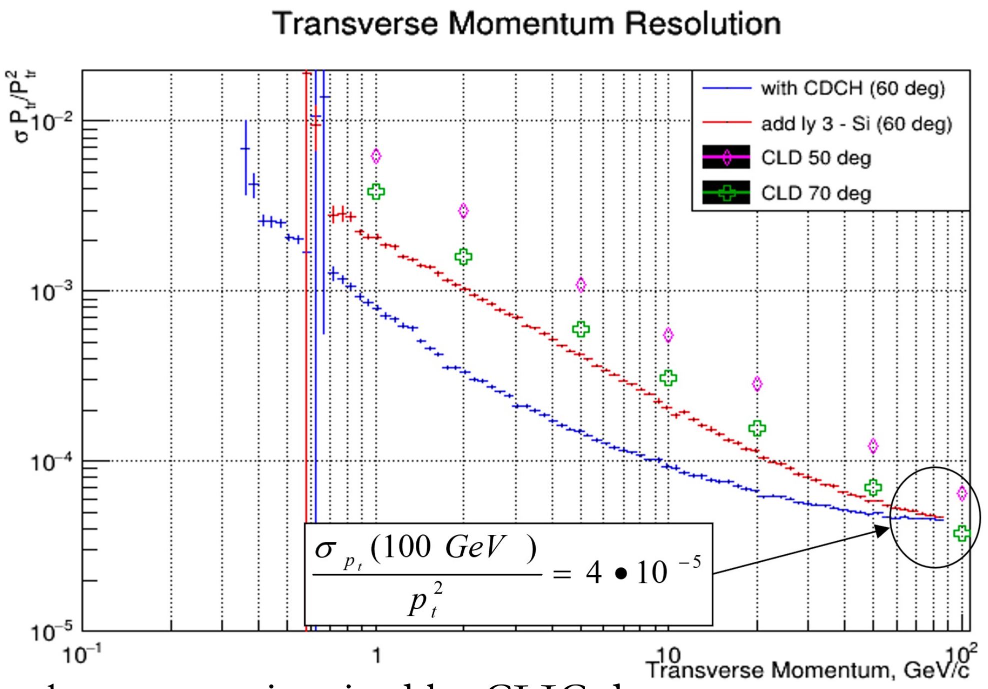
To be ported inside the full detector simulation

The Expected Tracking Performance

➢A Geant4 simulation has been performed to estimate the performance of the IDEA tracking system, assuming a single cell resolution of 100 μm for the CDCH and conservative spatial resolution (σ_{Si}= pitch/√12 μm) for Si detectors. the IDEA tracking system meets the expected performance.

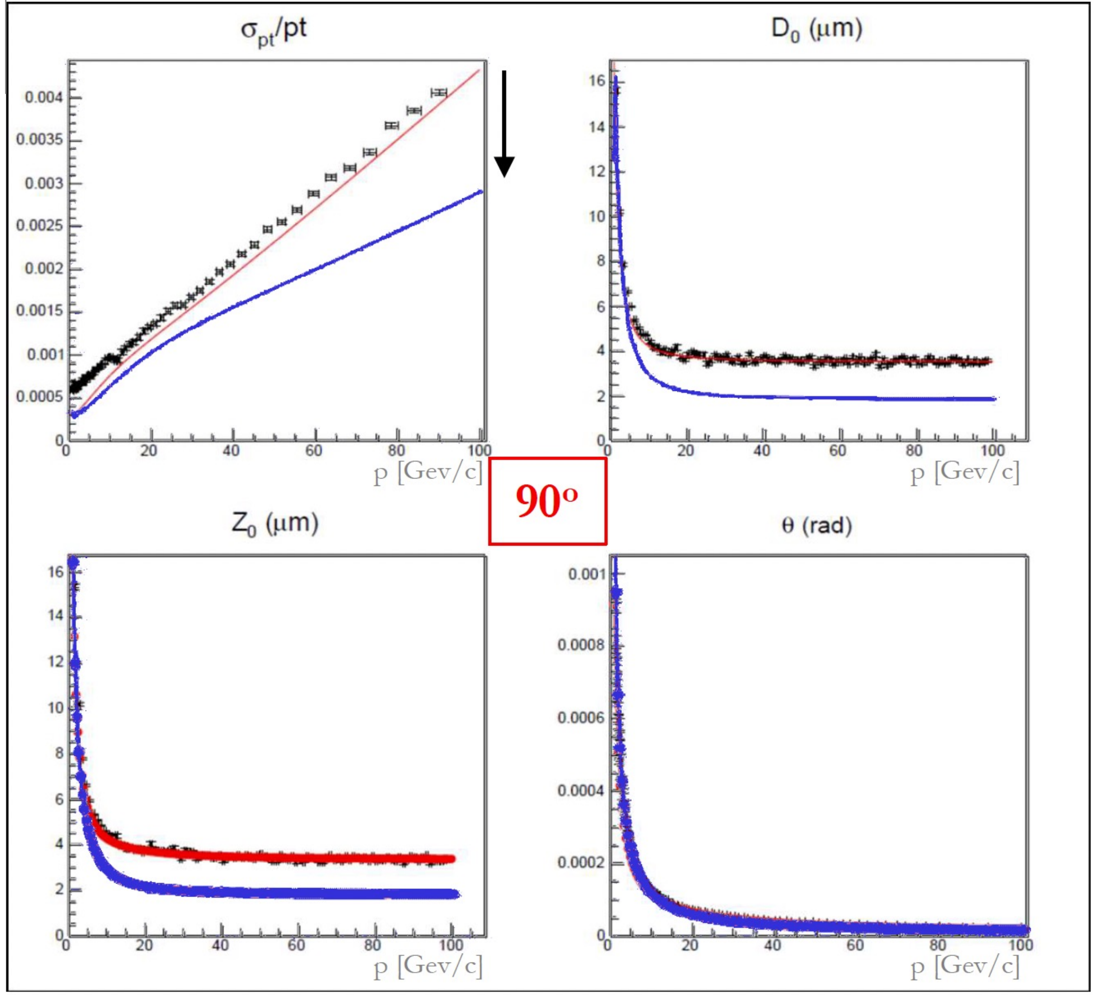
➢The lightness of the drift chamber allows to the IDEA tracking system to gain almost a factor 3 in momentum resolution respect to a full Si tracker system up to 50 GeV/c.





CLD: a detector concept for FCC-eewith a full Si-tracker system, inspired by CLIC detector.

The Expected Tracking Performance



Analytic model to evaluate full covariance matrix

black point: Full simulation
red line: analytic model with Si resolution as Full sim.
blue line: analytic model with improved Si resolutions (1)

(1) Vertex:

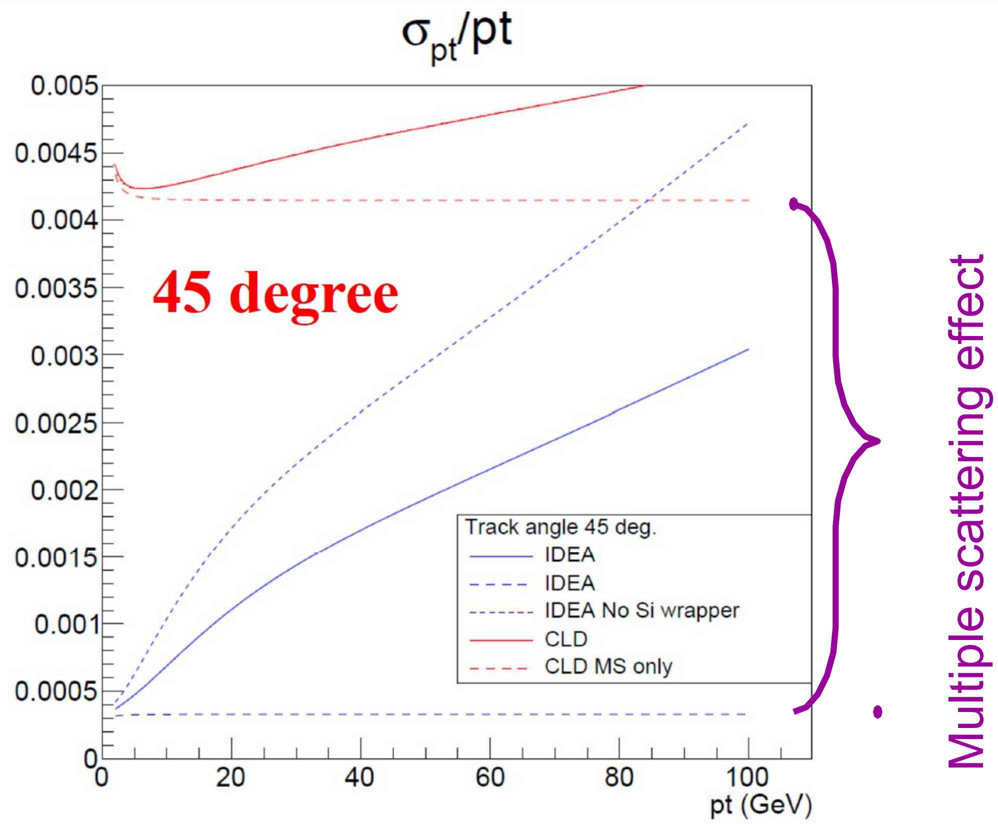
- inner 3x3 μm
- outer/forward 7x7 μm

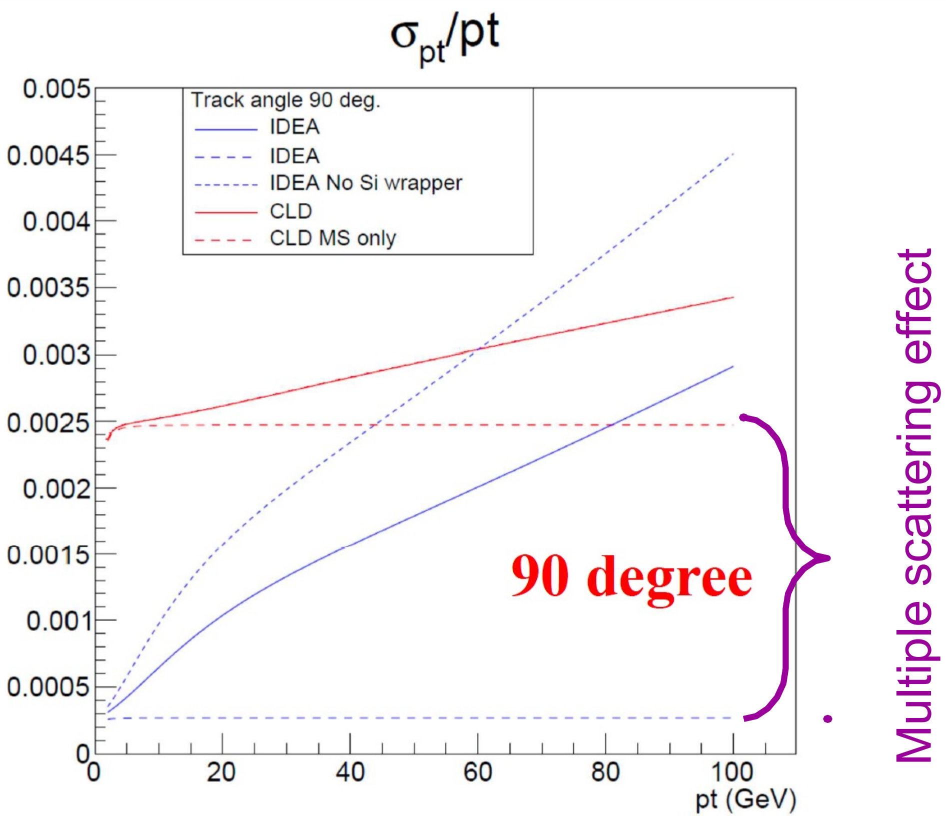
Si wrapper: 7x90 μm

$$\frac{\sigma_{p_t}(100GeV)}{p_t^2}: \quad 4\cdot10^{-5} \downarrow 2.9\cdot10^{-5}$$

The Expected Tracking Performance

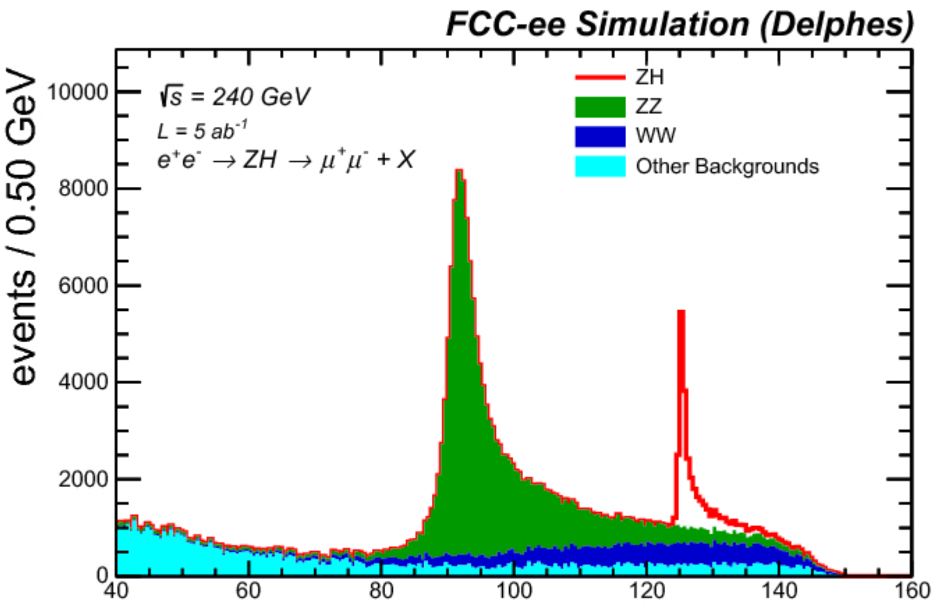
- Due to the minimization of the multiple scattering contribution, the IDEA tracking system performs better, over almost the entire momentum range of interest, than an alternative tracking system based only on Si detectors (CLD).





The Expected Tracking Performance

- The large signal-to-background ratio on the one hand, and the excellent drift-chamber muon momentum resolution on the other, offer the possibility to determine the inclusive ZH cross section and the Higgs boson mass with a statistical precision of ∼1% and ∼6 MeV, respectively.
- The muon momentum resolution achieved with the CLD Silicon tracker is affected by its larger amount of material, and therefore of multiple scattering, than in the IDEA drift chamber.



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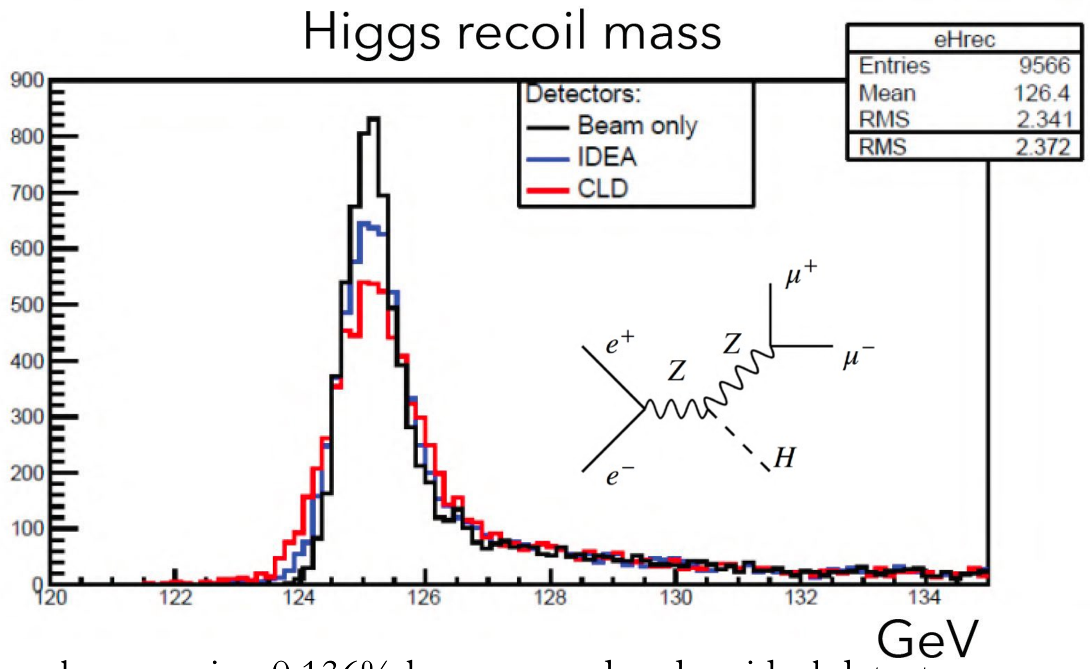
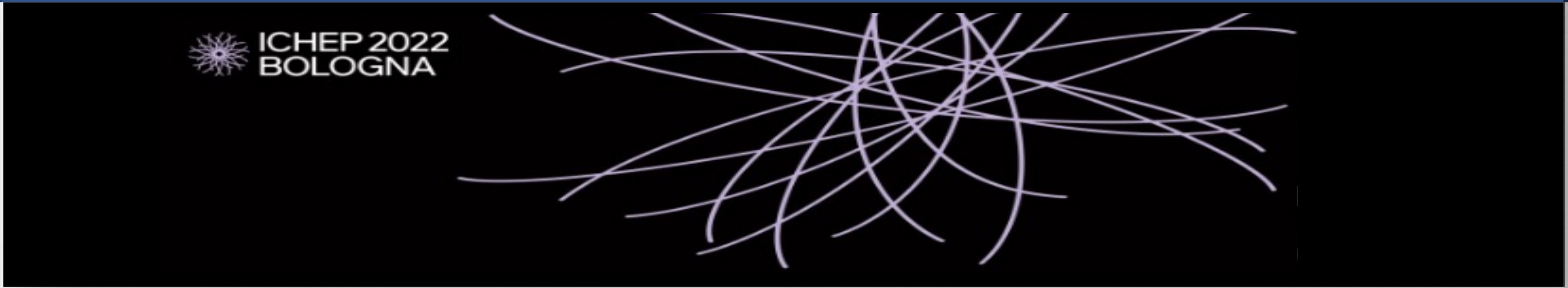


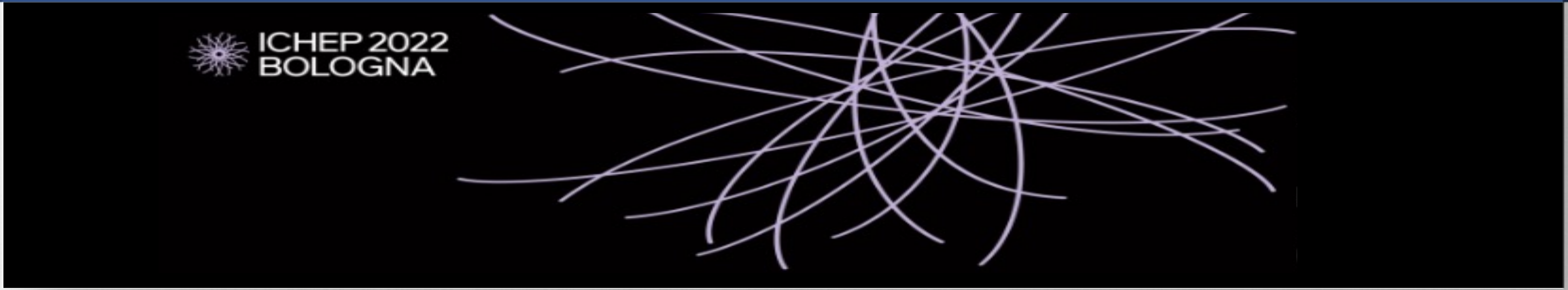
Beam only: assuming 0.136% beam spread and an ideal detector.

Summary

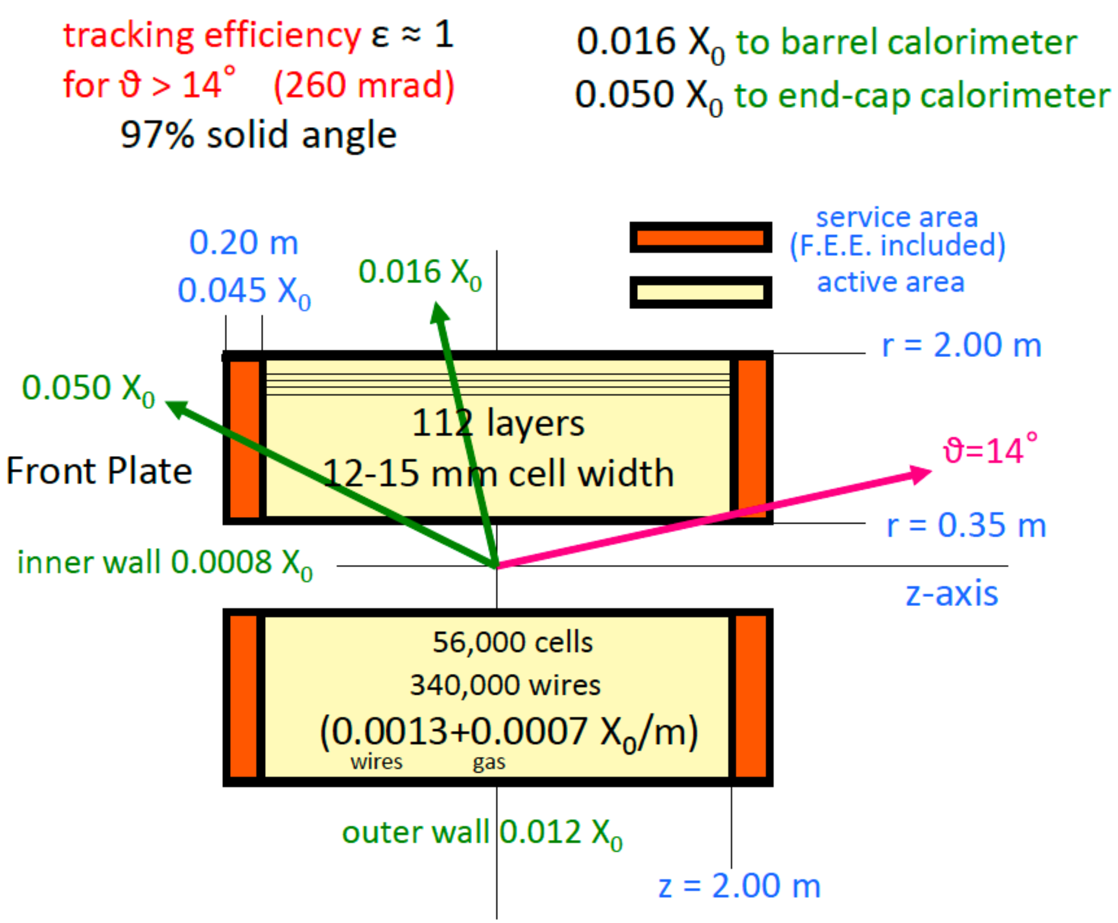
- A Geant4 simulation of the Drift Chamber and tracking system is set and working.
- data output conversion to EDM4Hep has been developed.
- Performance studies with Geant4 simulations and analytic calculations were performed in the context of FCC-ee.
- The Cluster Counting technique provides major improvements in PID performance over traditional dE/dx approaches.
- The IDEA tracking system is very light, providing excellent resolution over the momentum range of interest.



Backup



IDEA drift chamber

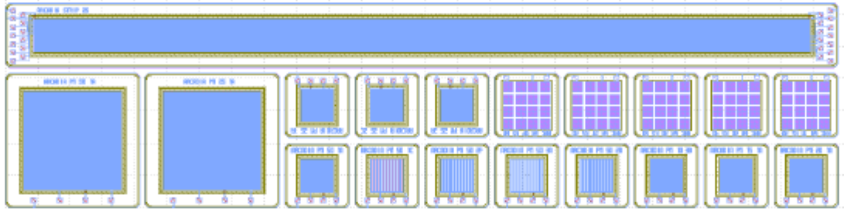


- IDEA: Extremely transparent Drift Chamber
  - Gas: 90% He – 10% iC_4H_{10}
  - Radius 0.35 – 2.00 m
  - Total thickness: 1.6% of X_0 at 90º
    - Tungsten wires dominant contribution
  - 112 layers for each 15º azimuthal sector
  - max drift time: 350 ns

IDEA Vertex detector

Inspired by ALICE; based on MAPS technology, using the ARCADIA R&D program

- Pixels 20 × 20 μm^2
- Light
  - Inner layers: 0.3% of X_0 / layer
  - Outer layers: 1% of X_0 / layer
- Performance:
  - Point resolution of ~3 μm
  - Efficiency of ~100%
  - Extremely low fake rate hit rate



5 MAPS layers:

R = 1.7 - 2.3 - 3.1 cm

Pixel size: 20 x 20 μm^2

R = 32 - 34 cm

Pixel size: 50 x 100 μm^2