Status of the IDEA software

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On behalf of the IDEA software group

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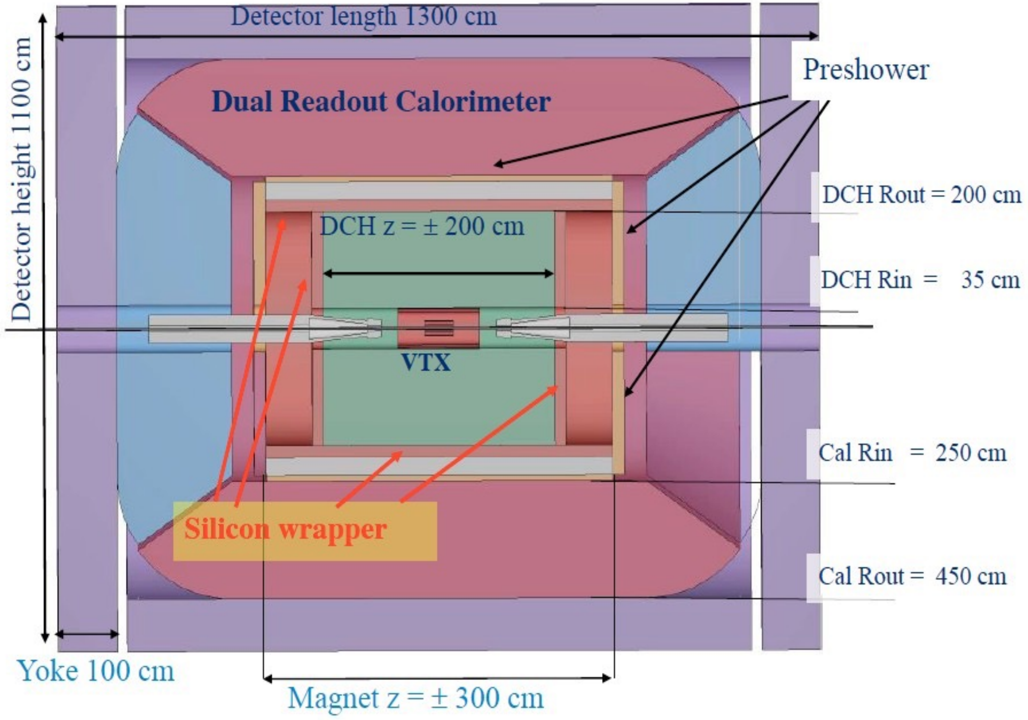
The IDEA detector at FCC-ee colliders

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

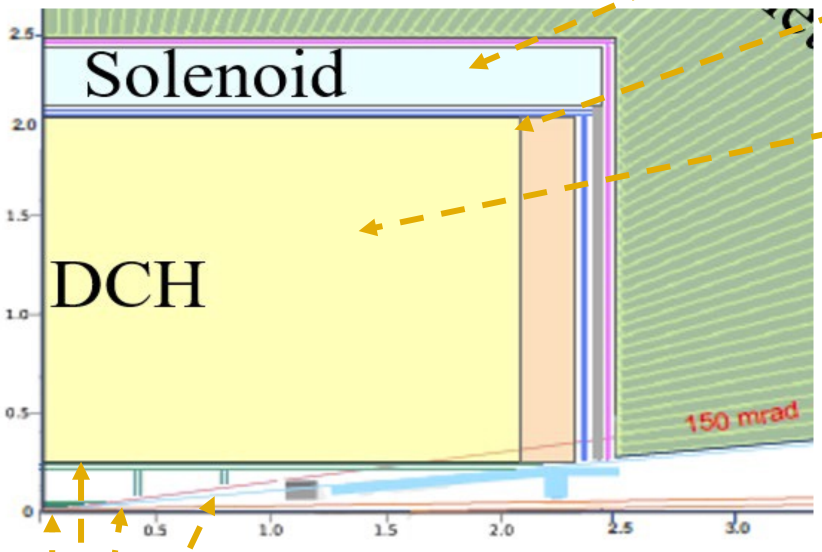
❑ IDEA consists of:

- 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.



The IDEA tracking system

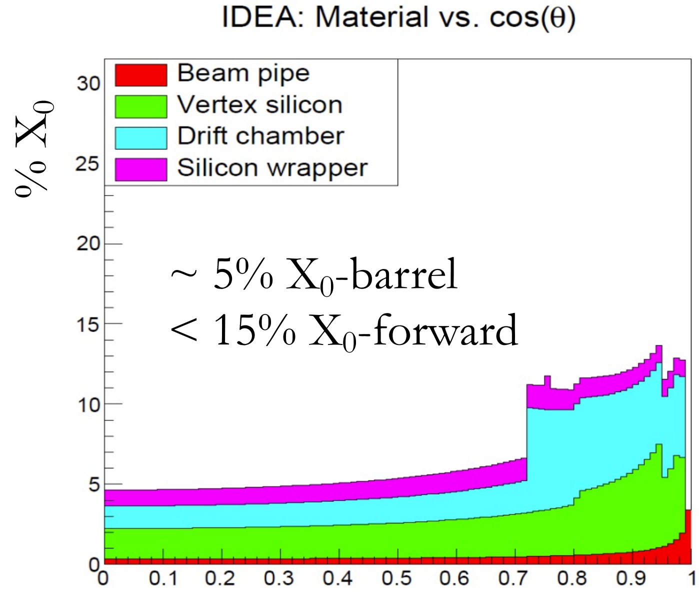
The IDEA tracking system.



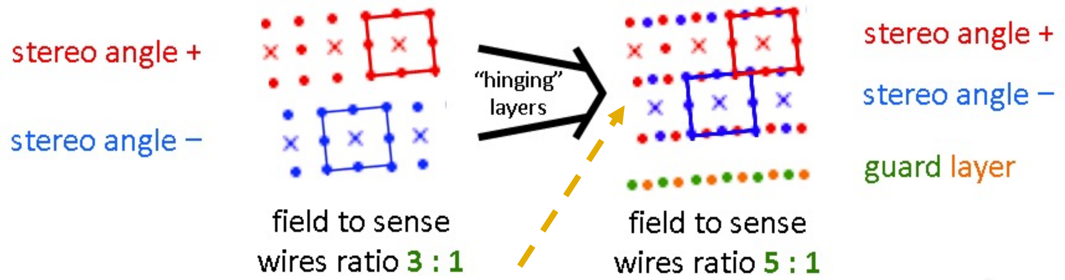
- ✓ **Solenoid:** 2 T, length = 5 m, r = 2.1-2.4 m, 0.74 X0, 0.16 λ@ 90°.
- ✓ **Si Wrapper**:2 layers of μ-strips (50 μm x 1 mm) *both barrel and forward regions.*
- ✓ **DCH**: 56448 (~1.2 cm) cells He based gas mixture (90% He –10% i-C4H10).

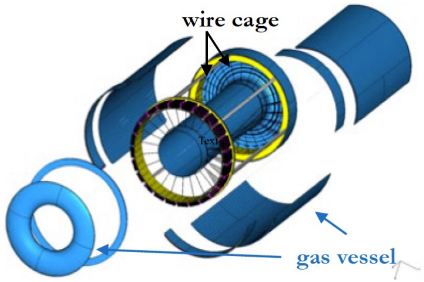
Vertex

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





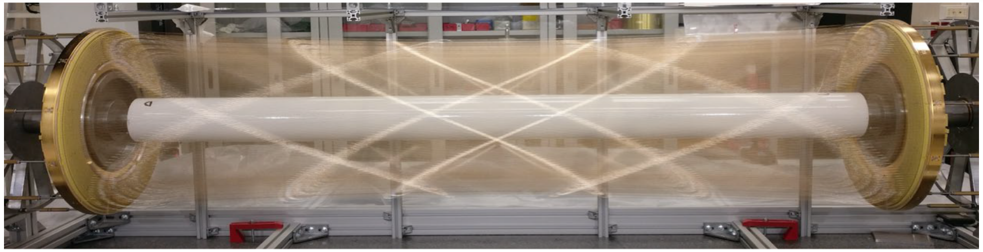
The wire net created by the combination of + and – orientation giving a high ratio of field to sense wires, and a high density of wires creating a more uniform equipotential surface.

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.

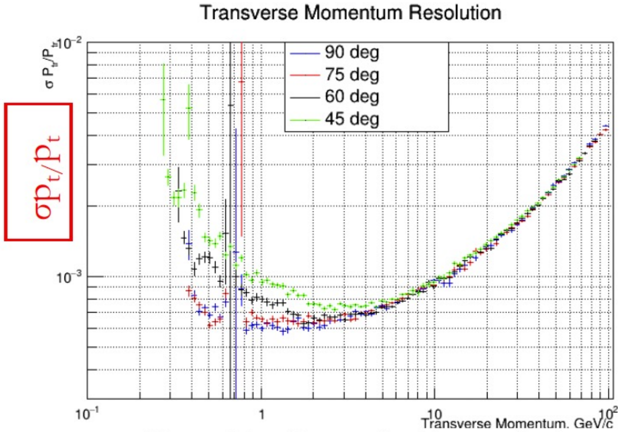
sense wires:	20 mm diameter W(Au) => 56448 wires
field wires:	40 mm diameter Al(Ag) => 229056 wires
f. and g. wires:	50 mm diameter Al(Ag) => 58464 wires
	343968 wires in total

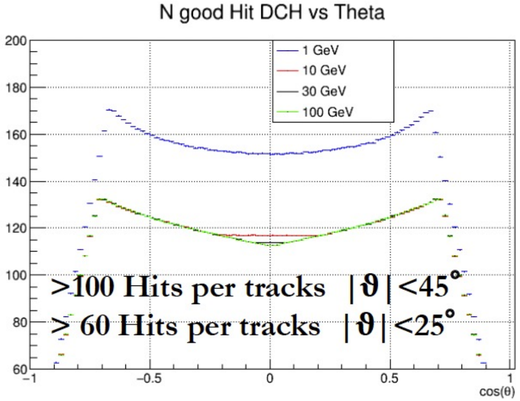
High wire number requires a non standard wiring procedure and needs a feed-through-less wiring system. The novel wiring procedure developed and used for the construction of the ultra-light MEG-II drift chamber must be used.

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

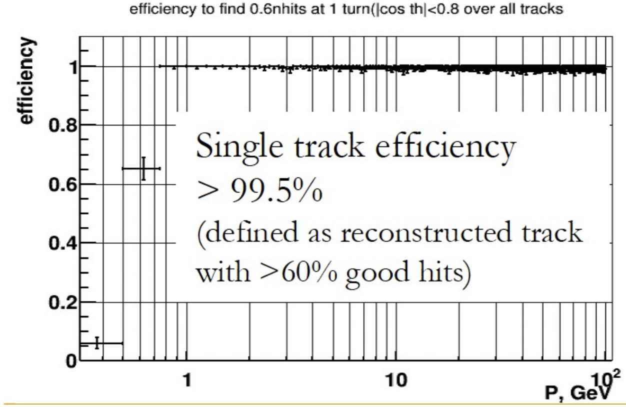


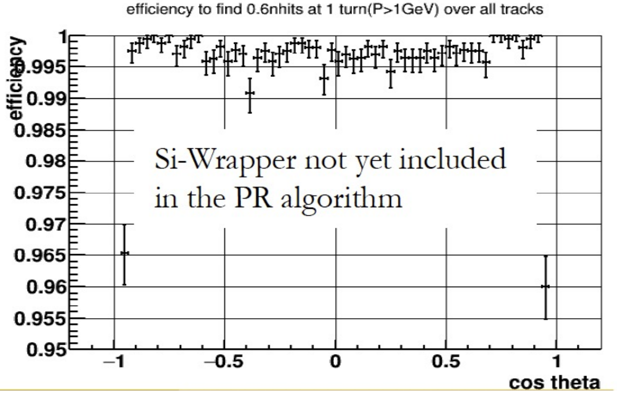
IDEA Drift Chamber Full Simulation
Pattern Recognition & Tracking Performance



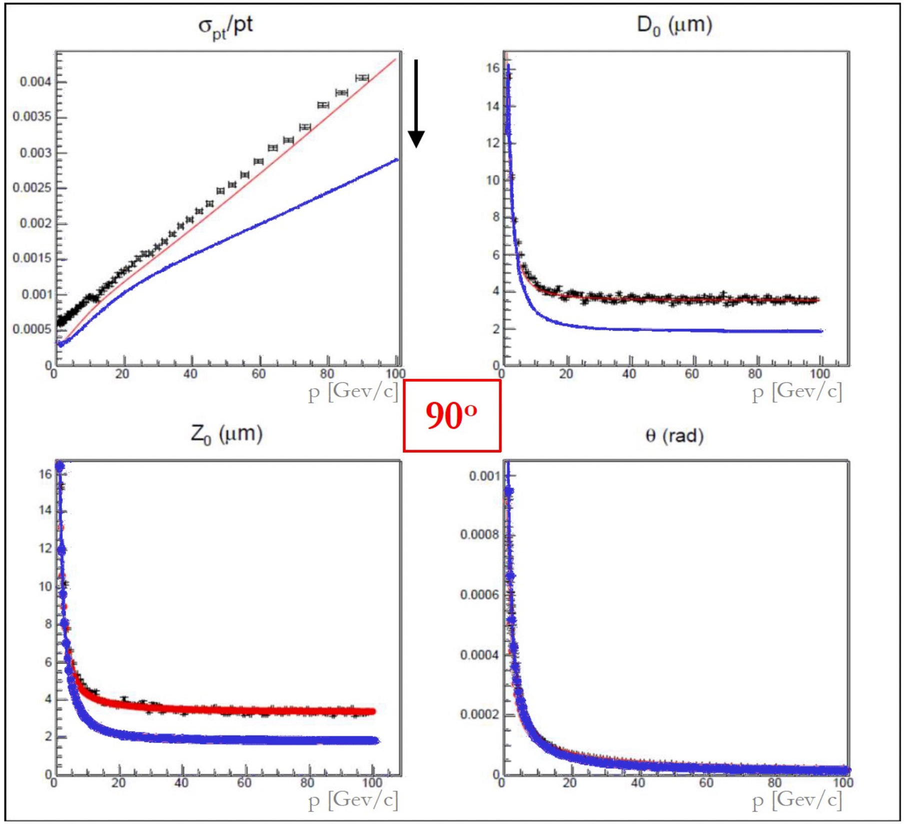


Assumed: σ_d = 100 μm and (conservative for Si detector resolution) using a simple model σ_{Si}= pitch/√12 μm





IDEA Drift Chamber simulation – Delphes model



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

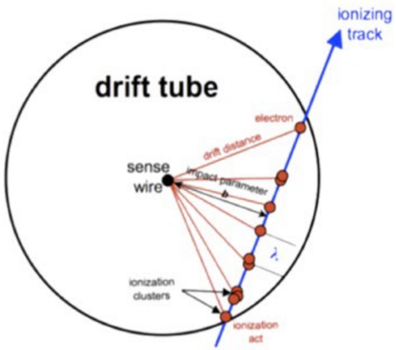
Si wrapper: 7x90 μm

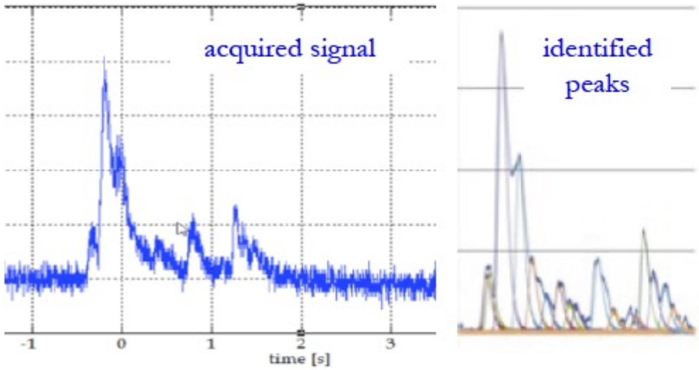
$$\frac{\sigma_{p_t}(100GeV)}{p_t^2}: \quad 4\cdot 10^{-5} \rightarrow 2.9\cdot 10^{-5}$$

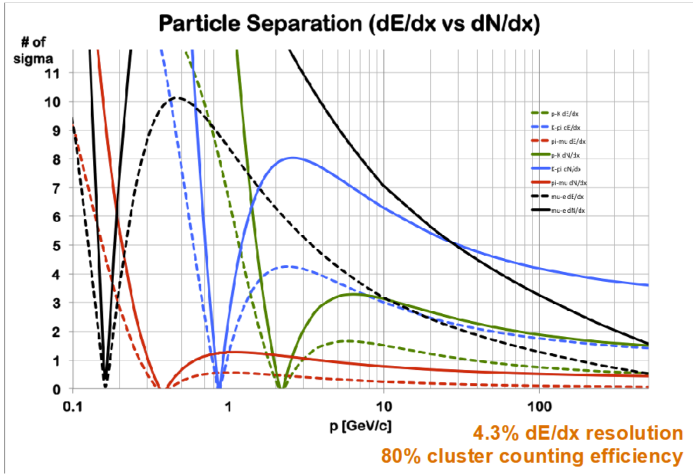
IDEA Drift Chamber simulation - Cluster Counting/Timing

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 $\sigma \approx 4.3\%$

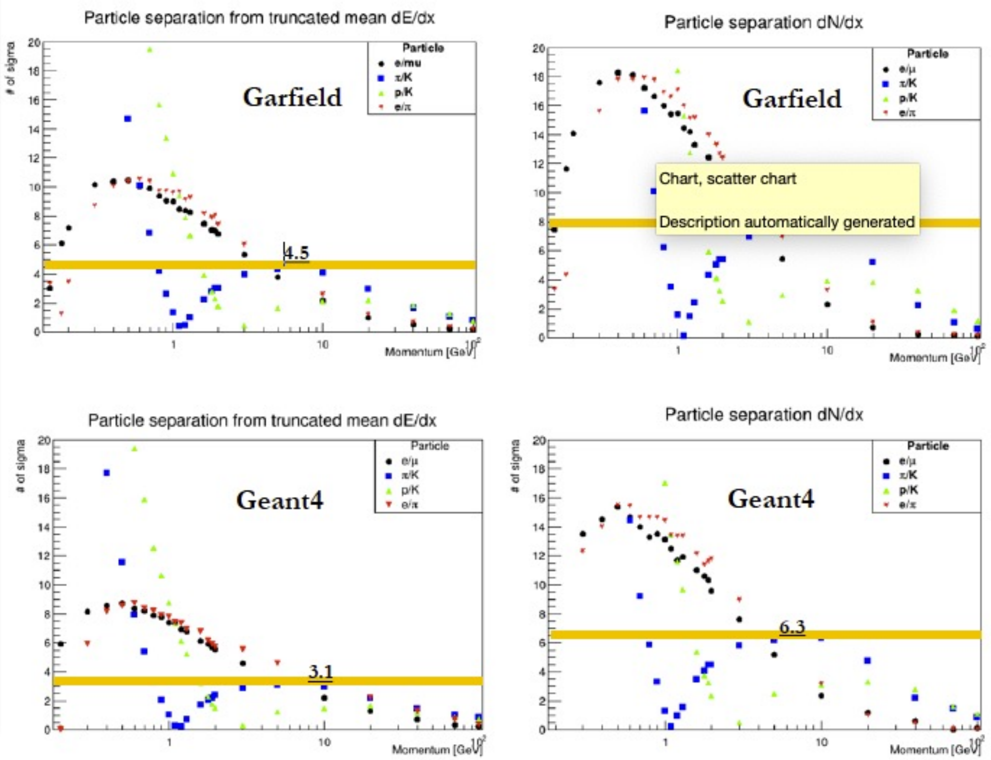
dN_{cl}/dx

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.

IDEA Drift Chamber simulation - Cluster Counting/Timing

- 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%.

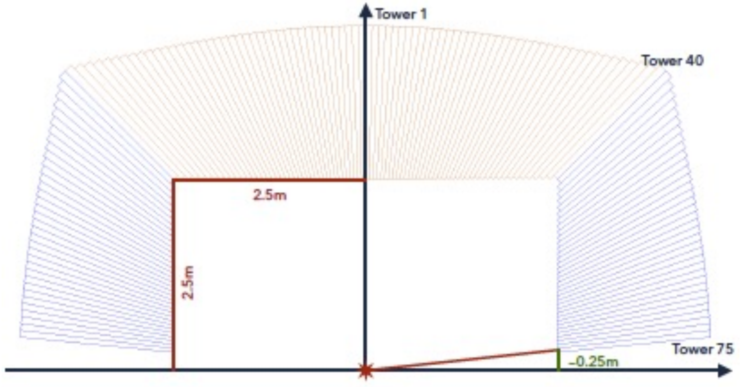
See here the talk by Francesco at this workshop for more details.

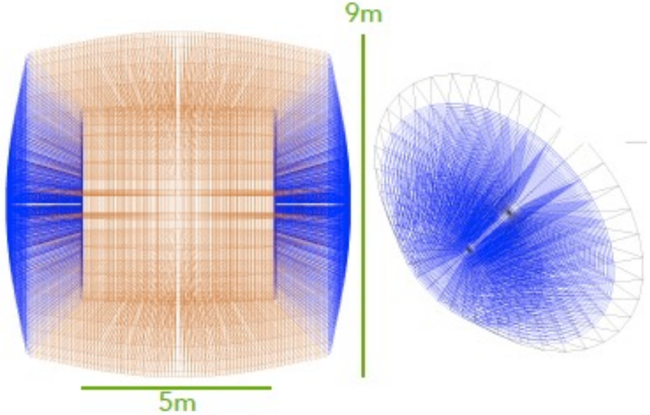
To be ported inside the full detector simulation

Dual Readout Calorimeter
A benchmark geometry

A benchmark IDEA Calo implementation:

- Towers are G4Trap() physical volumes with slightly different shapes changing with θ.
- Fibers are 1mm diameter G4Tubs(), 0.5 mm of absorber material (copper) between two adjacent fibers is considered.
- Barrel Inner length: 5m - Outer diameter: 9 m @ 90°.
- 2 m long copper based towers: ~ 8.2 λ
- 36 rotation around z axis
- Number of Towers in the barrel: 40 × 2 × 36= 2880
- Number of Towers in per endcap: 35 × 36= 1260

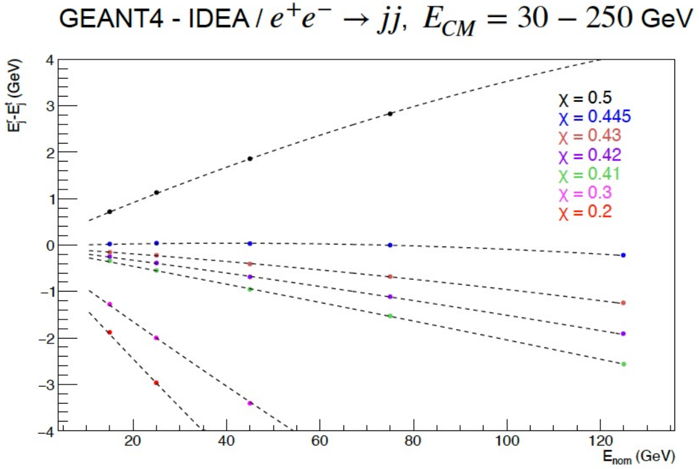


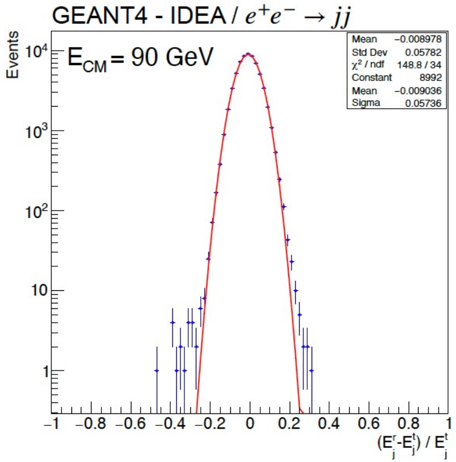


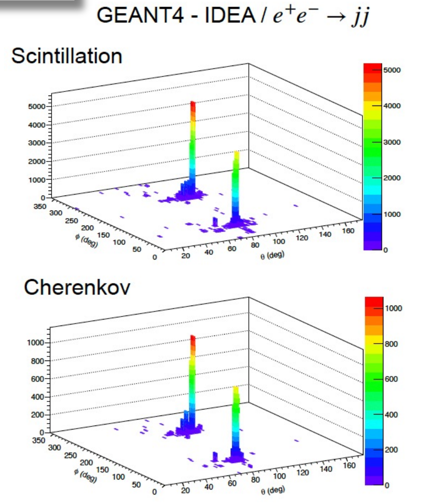
Dual Readout Calorimeter
Proof of concept

Geant4 indications on the expected performance (selected results):

- 10% – 15 % / $\sqrt{E}$ EM energy resolution.
- 25% – 30 % / $\sqrt{E}$ energy resolution for single hadrons (including neutral hadrons).
- energy resolution for jets at 50 GeV.
- Sub-percent linearity in the FCCee energy ranges for e⁻/γ, hadrons and jets.



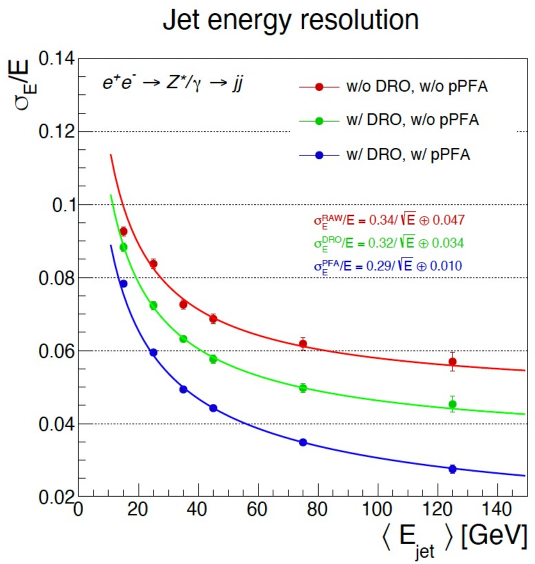


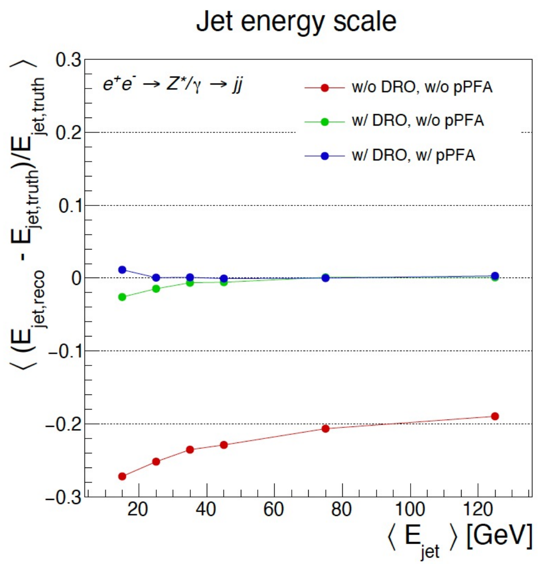


Dual Readout Calorimeter
Jet resolution in the IDEA Crystal option

Jet energy resolution and linearity as a function of the jet energy (from $e^+e^- \to jj$ events at different center-of-mass-energies) for:

- ✓ Crystals + IDEA Calo w/o DRO
- ✓ Crystals + IDEA Calo w/ DRO
- ✓ Crystals + IDEA Calo w/ DRO + pPFA



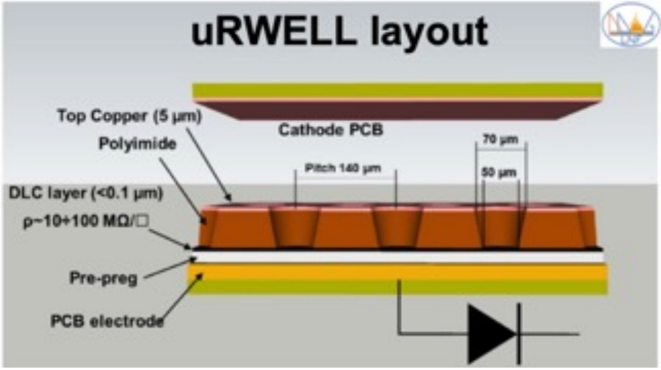


pPFA leads to a sensible improvement in jet resolution **using dual-readout information from crystals and fibers → 3-4%** for jet energies **above 50 GeV**, within the most physics requirements at Higgs factories.

See here the talk by Marco at this workshop for more details.

Preshower/Muon detector and simulation

- Pre-shower and the Muon Systems are designed with the μ-RWELL technology.
- A μ-Rwell essentially consists of:
  - Patterned Kapton foil (amplification stage) .
  - Resistive layer sputtered on the back of the Kapton foil to quench the multiplication and avoid sparks (DLC = Diamond Like Carbon).
  - Patterned PCB for readout.
- IDEA's Muon detector would have in total: 2800 m^2 total; 4M channels; 3 stations.



Visualization of a μ-RWELL detector in Geant4

Pre-shower — Oct.'21 TB

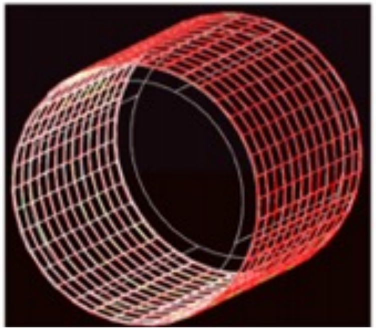
Tiles: 50x50 cm^2 with X-Y readout
Strip length: 50cm
Strip pitch: 0.4mm
Input FEE capacity ~ 70 pF

TOT: 330 m^2, 1.5×10^6 channels

Muon detector

Tiles: 50x50 cm^2 with X-Y readout
Strip length: 50cm
Strip pitch: 1.5mm
Input FEE capacity ~ 270 pF

TOT: 4000 m^2, 5×10^6 channels



IDEA Muon detector dimensions

See here the talk by Giulio at this workshop for more details.

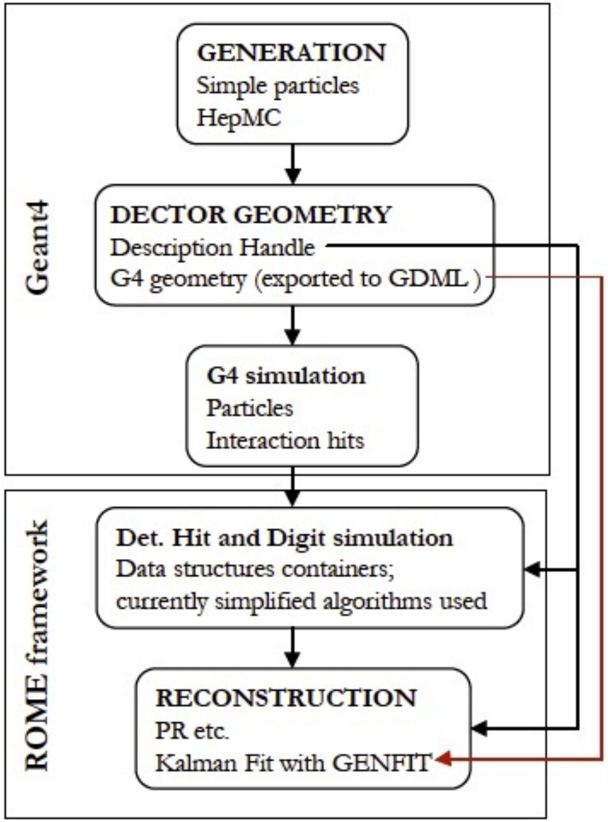
Geant4 full simulation of IDEA

- The standalone code was adapted for compilation on Key4hep stack.
- It works with the latest key4hep stack on CERN lxplus machines (source/cvmfs/sw.hsf.org/key4hep/setup.sh)

The stack environment ←
- key4hep-stack/2021-11-26:

SWs from the stack {
- gcc8.3.0
- geant4-10.7.2
- clhep-2.4.4.0
- root-6.24.06
- genfit/02-00-00 (on the stack)

External package to be installed locally ←
- rome master



Geant4 full simulation of IDEA

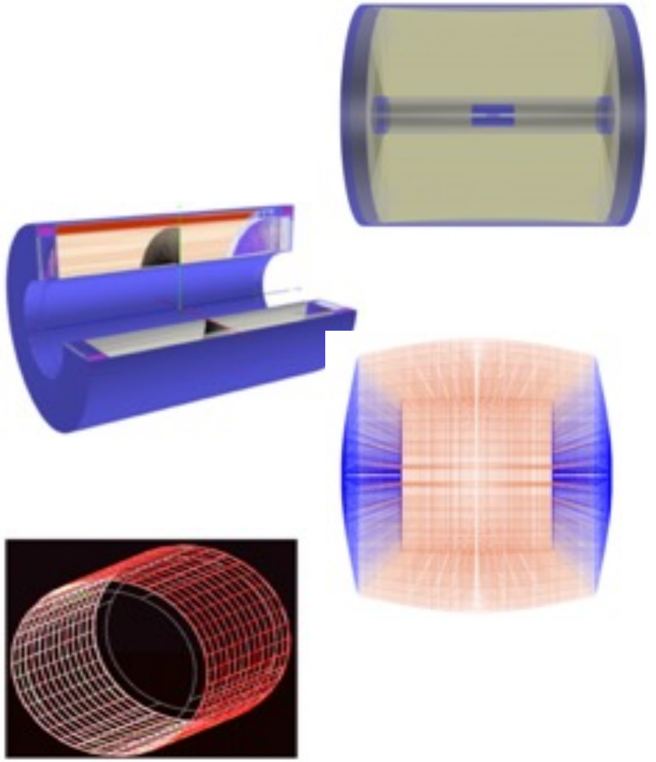
- A full standalone geant4 simulation of the IDEA **Silicon Vertex (and Si wrapper), Drift Chamber, DR Calorimeter (and Muon system).**

  - **DCH** is simulated at a good level of geometry details, including detailed description of the endcaps; hit creation and track reconstruction.

  - **SVX and Si wrapper** are simulated as simple layer or overall equivalent material.

  - **Dual Readout calorimeter** is simulated, combining DR fibers and crystals (in a fully compensating segmented calorimeter.

  - **Muon detector**: To be inserted in official simulation (Endcap in preparation).

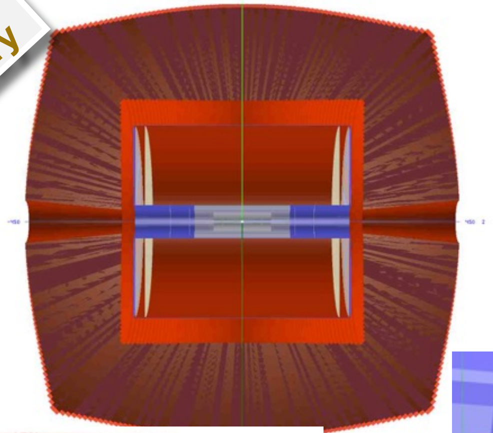


Geant4 full simulation of IDEA

The integration of the **Calorimeter geometry** description with IDEA **Silicon Vertex (SVX), Drift Chamber (DCH)** has been performed.

Visualization for the Integrated Geometry

(calorimeter+Drift chamber)

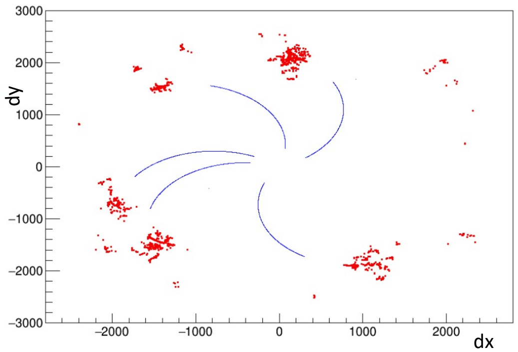


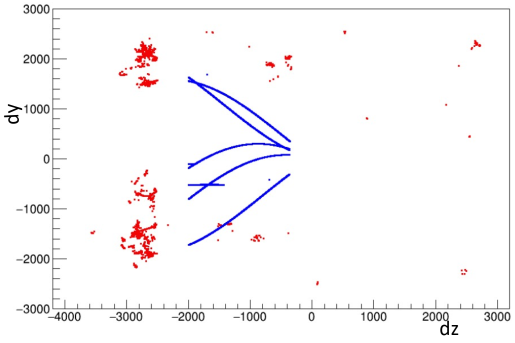
Phi volume (barrel)

Phi volume (Endcap)

Hits display

Simple display for the hits of negative energy pions of 870 MeV as seen in the different detectors (DCH & DR calo).





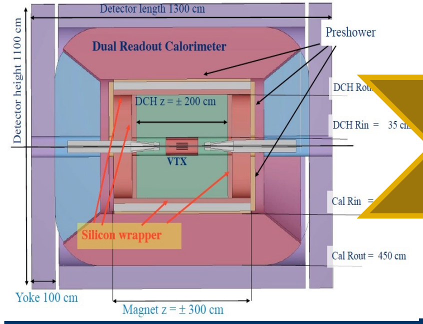
IDEA Drift Chamber simulation
Migration to EDM4hep and Key4hep

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

Geant4 Monte Carlo hits
(possible other data structures)
reconstructed tracks

simulation + reconstruction



done

Covert to

To be done

port the geometry
port the algorithms
port the data format

FCC framework

EDM4HEP

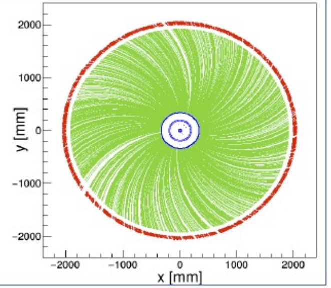
Key4HEP

present only the 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

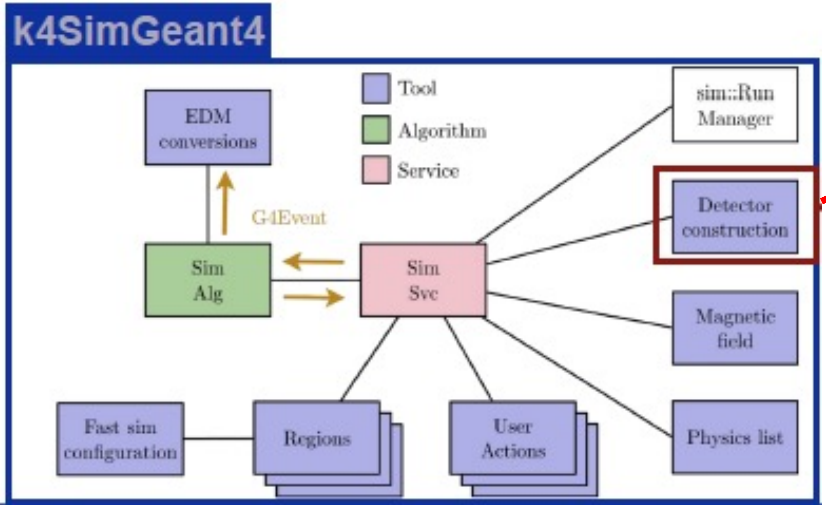
geometry
- Beam pipe
- SVX
- DCH
- PSHW
- magnetic field = 2.0 T

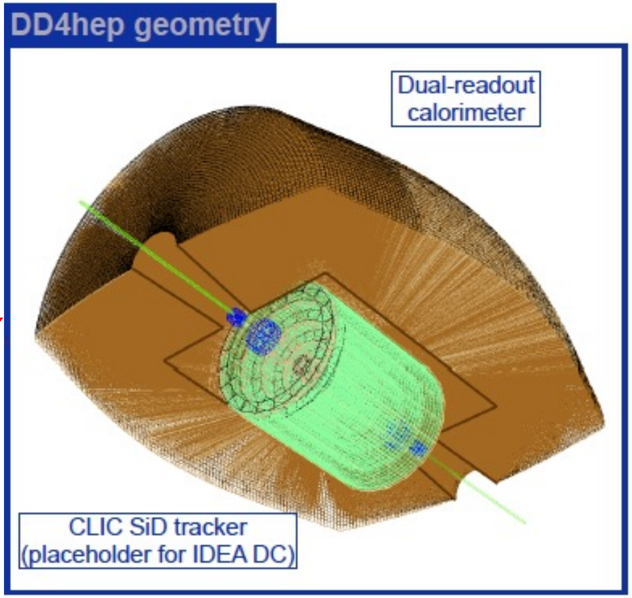


See here the talk by Lia at this workshop for more details.

DD4hep geometry migration for the DR calorimeter

- ✓ DD4hep is a main framework for detector description
- ✓ It is a first step to migrate to key4hep, common SW stack for FCC, ILC, CLIC, CEPC
- ✓ An IDEA DR-Calo description was implemented in DD4hep [git]
- ✓ To be coupled with a DD4hep description of the IDEA Drift Chamber





See here the talk by Iacopo, Roberto, Sang at this workshop for more details.

Conclusions

- Geant4 has been used to simulate **the tracking system for IDEA**:
  - the track fitting performance of the whole system (SVX+DCH+SWR+PSHW) are compatible with the preliminary estimations.
  - data output conversion to EDM4Hep has been developed.
  - reasonable algorithms to simulate the Ionization Clusters by using the Geant4 data have been developed.

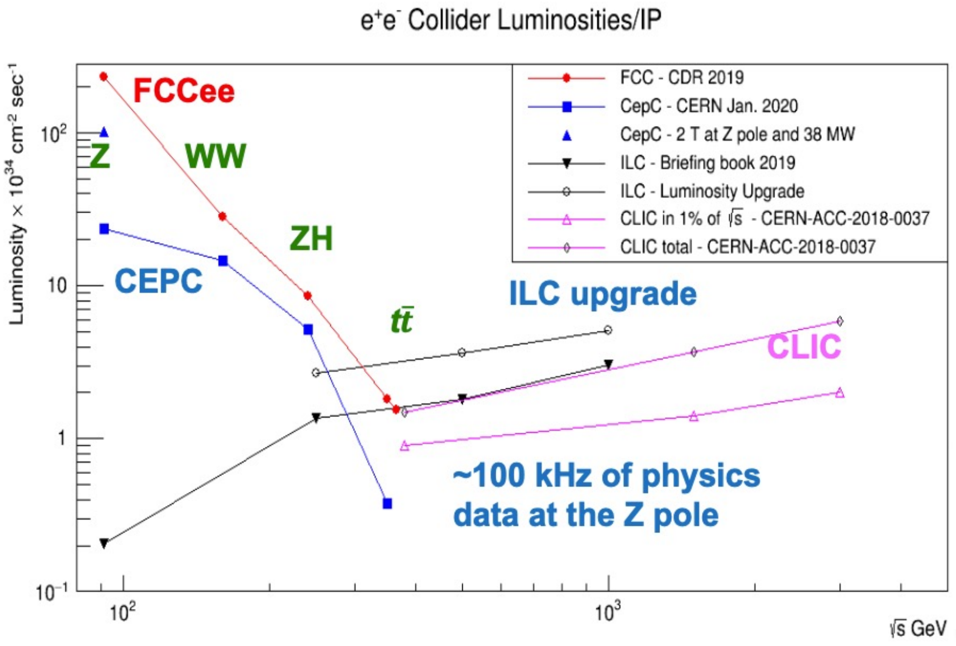
- Geant4 has been used to simulate a **dual-readout calorimeter** concept for IDEA providing good indications on the possibility of:
  - reconstructing , hadrons and jets with superior HAD resolution and linearity.
  - combining DR fibers and crystals (in a fully compensating segmented calorimeter).
  - using proto-PF approach improving the jet energy measurements.
- Migration of the DR Calo simulation to the key4hep SW stack is at an advanced level (DD4hep and EDM4hep).

- The **full IDEA simulation description (SVX+DCH+SWR+PSHW+DRCALO)** are available to be uploaded to the FCC SW soon and start studies with full IDEA description.

Backup

Machine environment for physics at FCC-ee colliders

- It is optimised to study with high precision the Z, W, Higgs and top particles, with samples of 5×10^{12} Z bosons, 10^8 WW pairs, 10^6 Higgs bosons and 10^6 top quark pairs.



- **Different running conditions depending on beam energy:**
  - High-intensity machine at the Z-pole, high-current machine at the top.
  - Bunch spacing ranging from 20 ns (Z) to 7 μs (top).
  - Large (30 mrad) crossing angle between beams + low beam emittance ⟹ detector magnetic field 2 T max.
  - Machine-detector interface structure (large angle + shielding + compensating magnets + luminometer) limit detector acceptance to ±150 mrad (100 mrad for calo) .

Physics requirements: Higgs, EWK, and Heavy Flavour

➢ Higgs boson sector

- Higgs sector definition imposes strict requirements on **hadronic resolution**, **tracking and vertexing**.

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_\mathrm{T}) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_\mathrm{T}\sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p\sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ VV$	$\mathrm{BR}(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^\mathrm{jet}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

➢ EWK

- Extreme definition of detector acceptance.
- Extreme EM resolution (crystals).

➢ Heavy Flavour:

- PID to accurately classify final states and flavour tagging.