Simulation for vertex and tracking systems in France

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Simulation and Detector R&D

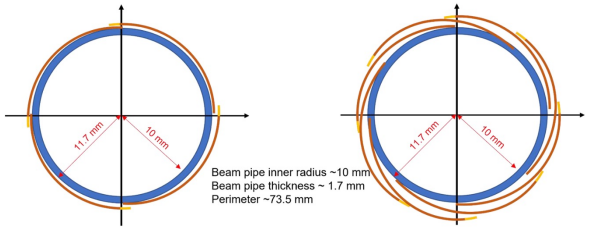
- A thorough simulation of the detector, capturing all its details, can offer valuable insights to guide the design and optimization process.
- The particles generated in the fundamental interaction undergo various physical processes both before and during detection.
- First ideas about an experiment:
  - Given physics goals, what kind of detectors to build and what detector performance we need to achieve ? Need rough and quick simulations.
- Detector concept(s) proposal:
  - Detailed simulation showing physics performance of proposed detector(s).
    - Huge effort by the community to provide full simulation of the proposed concepts
    - We need this at this stage!
- R&D and prototype (demonstrator) construction:
  - Learn from R&D, beam tests, … enables the improvement of simulation: make it more realistic
- Development and tests of algorithms (Calibration, reconstruction, analysis…).

Simulation steps in a nutshell

- Generation:
  - Generators simulate the needed physics process.
  - (not part of this talk) .
- Particle-detector interaction:
  - This step propagates each produced particle in the material of the detector and simulates its energy loss.
  - It produces energy losses for each individual particle in all the crossed material of the detector.
- Digitization:
  - This step simulates the detector response from energy losses in active detector material
- Reconstruction
  - Track reconstruction uses primarily signals in the tracking detectors to measure tracks of particles.

Simulation and Digitization developments IP2I – IPHC (pixel - tracking)

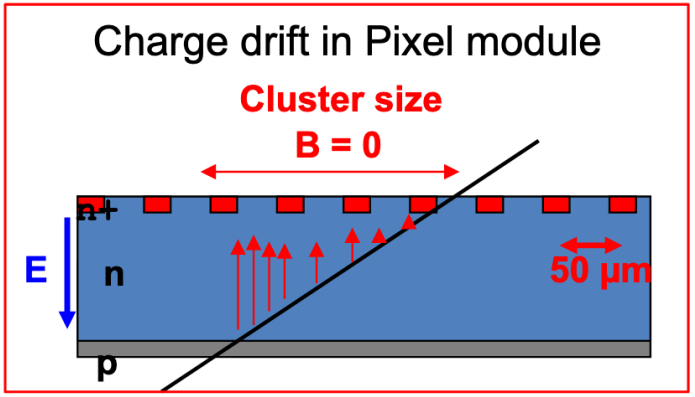
- The ongoing work includes
  - Simulation and the propagation of charge deposited by a charged particle in the sensors
  - Implementation of a cluster algorithm
    - In link with detectors R&Ds proposed in Serhiy's talk at the beginning of this session
    - Models of the charge propagation within the sensors developed within in2p3 community serve as input of the FCCSW development.
- As a second stage :
  - Built a geometry (DD4HEP) of the proposed detectors :
    - FCC – SEED
    - geometry and materials

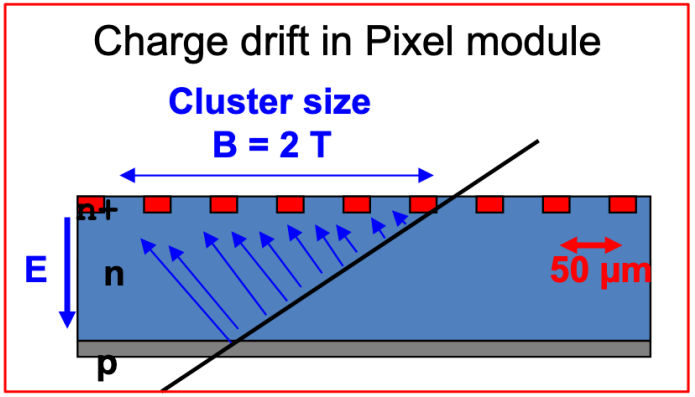


- In all stages :
  - Integration into common software efforts managed by the software group of the current PED structure at CERN.
- Eventually : Tracking and flavor tagging performance should be assessed
- Simulations
  - Should serve as inputs of the proposed R&Ds in France but also the full community using key4hep
    - Synergy with Italian R&Ds efforts

Work plan on Digitizer

- Introduction of the 'Cartesian Grid xYZ' to define the pixel cells
  - Done, Kudos to David Wilson Ceballos Buitrago was internship in Lyon, now PhD Student Perugia
- Simulation of the detector response from energy losses in the active detector material.
- Effect of the E and B Field (propagation)
- Definition of a cluster
- Introduction of the instrumental effects (noise, crosstalk, thresholds…) .
  - Presumably only thresholds at a very first stage
- Definition of (simple) validation plots

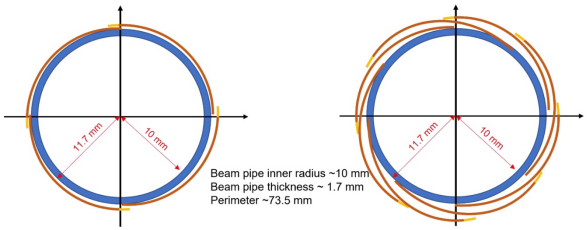




For illustration: Charge drift in Atlas pixel sensor

Geometries

- The digitizer is so far developed using the CLD detector concept
- The goal is to be as agnostic as possible of the geometries description and environment:
  - e.g position, and therefore size of the layers, sensor thicknesses hould be defined as inputs
  - Or, the magnetic field defined: 2T is of course the baseline but important to be able to vary it for comparison studies
- Introducing geometry (via DD4HEP), such as FCC-SEED presented by Serhiy, is part of the plan

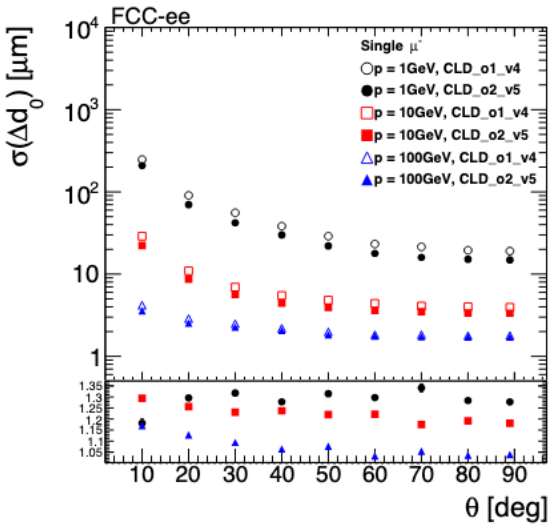


Tracking studies

- Effort started in France (G. Sadowski – IPHC Strasbourg)
- Tool in place to study the impact on the tracking resolution when varying some of the key parameters
- Work presented at the detector concept meeting in September or during the last ECFA Workshop poster session in Paris
- Few highlights presented here
  - geometry parameters, beam pipe material budget, PID, single hit resolution, or BField

Effect of shortened vertex detector and Beam Pipe material budget

Beam Pipe and Vertex geometry



- Improvement of the d_0 resolution in the new geometry (o2_v05)
  - **Smaller vertex radius compensates fully for the increased material budget in beam pipe**

CLD_o1_v04 (nominal geometry)

- Beam Pipe **radius**: **15** mm
- Beam Pipe **material**: Beryllium
- Beam Pipe **thickness**: **1.2** mm + 5 μm gold
- **X/X0** = **0.45 %**

CLD_o2_v05

- Beam Pipe **radius**: **10** mm
- Beam Pipe **material**: AlBeMet 0.35 mm + paraffin 1 mm + AlBeMet 0.35 mm
- Beam Pipe **thickness**: **1.7** mm + 5 μm gold
- **X/X0** = **0.61 %** ⇒ **+ 33 % material budget**

Vertex Barrel [mm]	R_1	R_2	R_3	L
o1_v04	17.5	37	57	125
o2_v05	**13.0**	**35**	**57**	**109**

CLD_01_v04: BeamPipe material 100 % Be, BeamPipe radius = 15 mm
CLD_02_v05: BeamPipe material AlBeMet + paraffin, BeamPipe radius = 10 mm

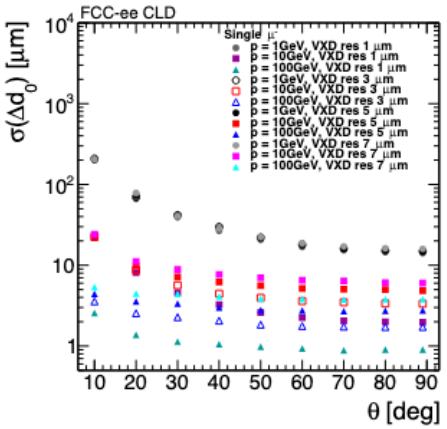
Effect of vertex spatial resolution

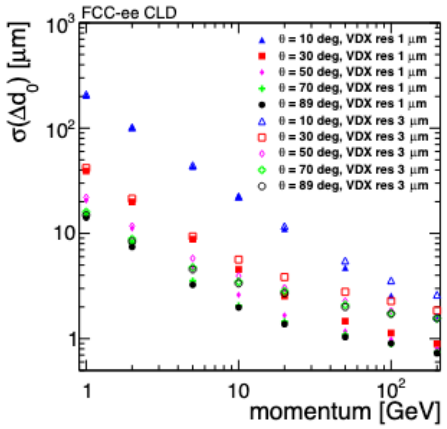
d_0 & pT resolution – single μ^- – CLD_o2_v05 (10k events)

- d_0

  As expected, very sensitive to intern layer, particularly at high p_T

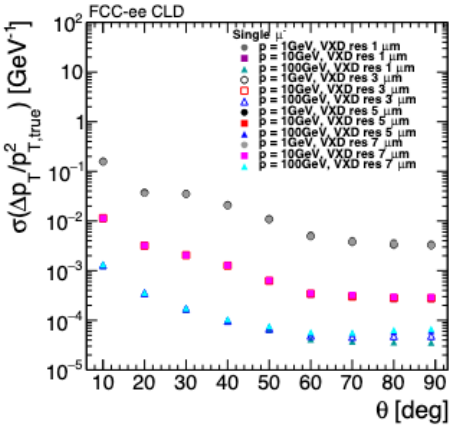
  Material budget is dominant for low p_T

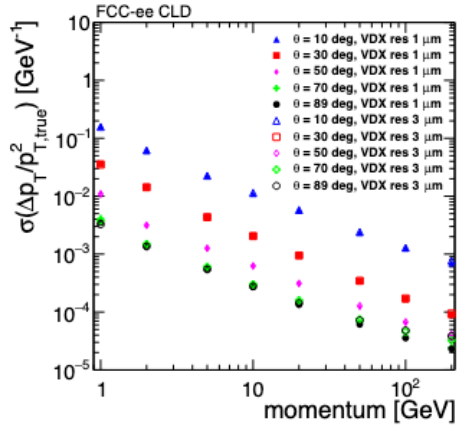




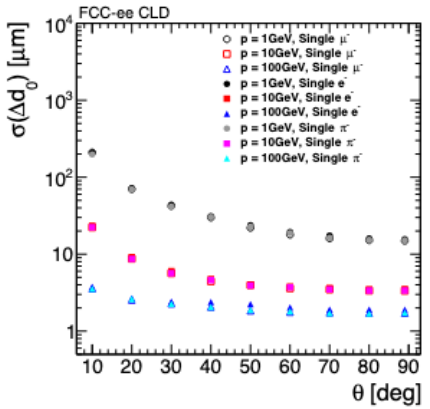
- p_T

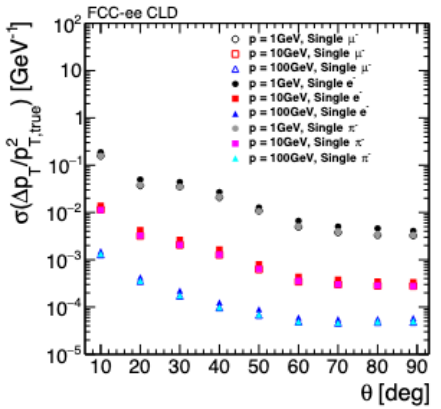
  Effect is smaller, some effect at high impulsion in barrel





- μ^-, e^- & π^- – VXD resolution = 3 μm



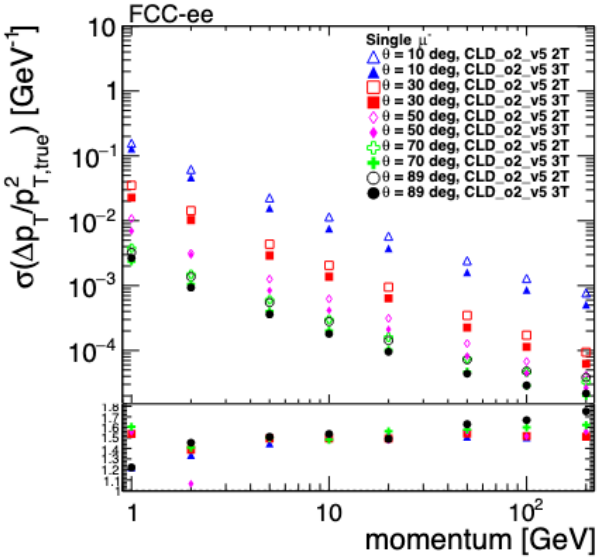


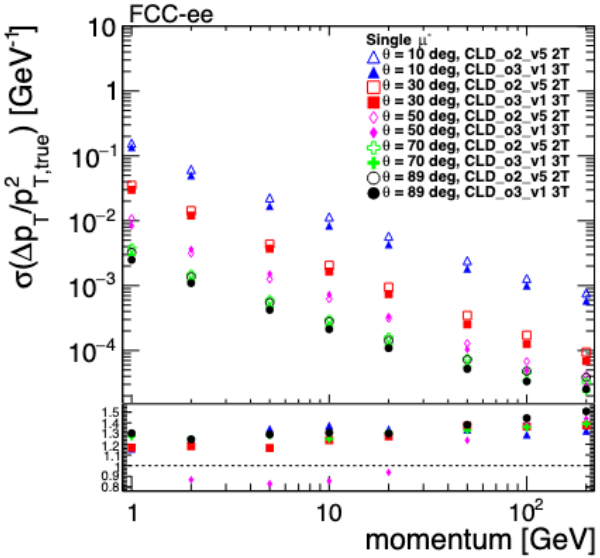
Digitisation is made by smearing simulated hits with spatial resolution values as the Gaussian width

Tracking resolution

Effect of magnetic field

- Magnetic field of **2 T** is imposed for Z peak ($\sqrt{s} = 91$ GeV)
- **2 T** to **3 T** (without any consideration of whether it is possible)increase p_T resolution and compensate the loss of p_T resolution caused by the shrunk tracker





CLD: magnetic field = 2 T

Tentative (..) timeline

- A first version of the digitizer should be provided end 2024-early 2025
- Then the development should be pursued in Iterative steps
  - Improving charge propagation wthin sensor
  - Definition of clusters (thresholds)
  - **Input to R&Ds and vice-versa**
- Once this first version is available (priority), the description of the proposed concept in DD4HEP will start (2025)
  - To eventually plug this detector into full detector concepts
- Performance (tracking but not only) studies should be pursued

Summary

- The complete simulation of the detector in all its details is a key element to:
  - derive realistic performance studies
  - guide the choice between various detector designs
  - optimise layouts
  - provide realistic rates (Support the electronics R&D)
- France (so far IPHC - Strasbourg and IP2I – Lyon, other labs could join at some point) is willing to make a significant effort to develop the local reconstruction and introduce new subdetector concepts in the full simulation to achieve those goals.
- FCC-ee detector simulation and reconstruction ecosystem based on:
  - Key4hep framework
  - EDM4hep data formats
  - Geometry description built by DD4HEP