Mahmoud Ali on behalf of FCC Full-Sim group.

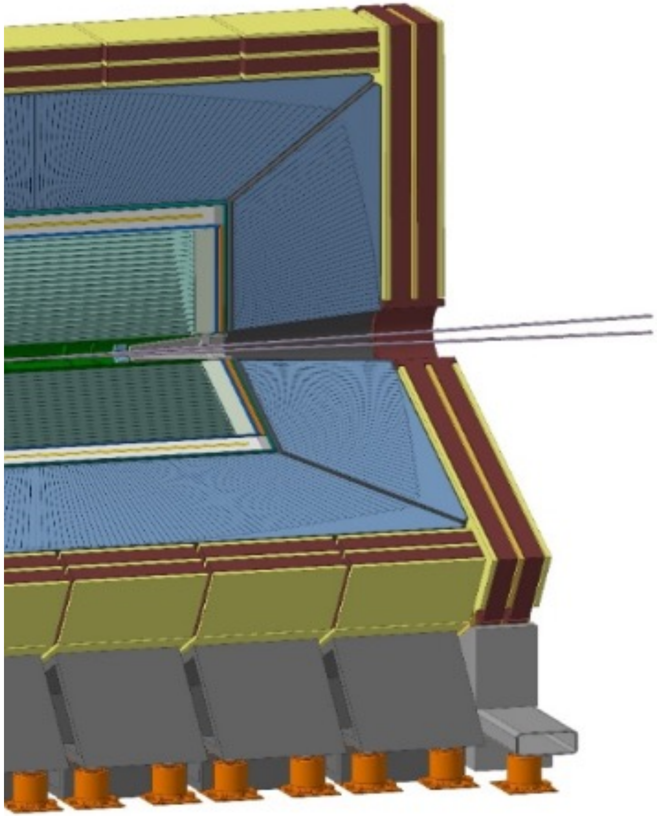
STATUS OF IDEA DETECTOR FULL SIMULATION

10th FCC Week, 11 June 2024.

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

INFN Istituto Nazionale di Fisica Nucleare

FUTURE CIRCULAR COLLIDER



Full Simulation for FCC:

The FCC Software fully adopts Key4hep;

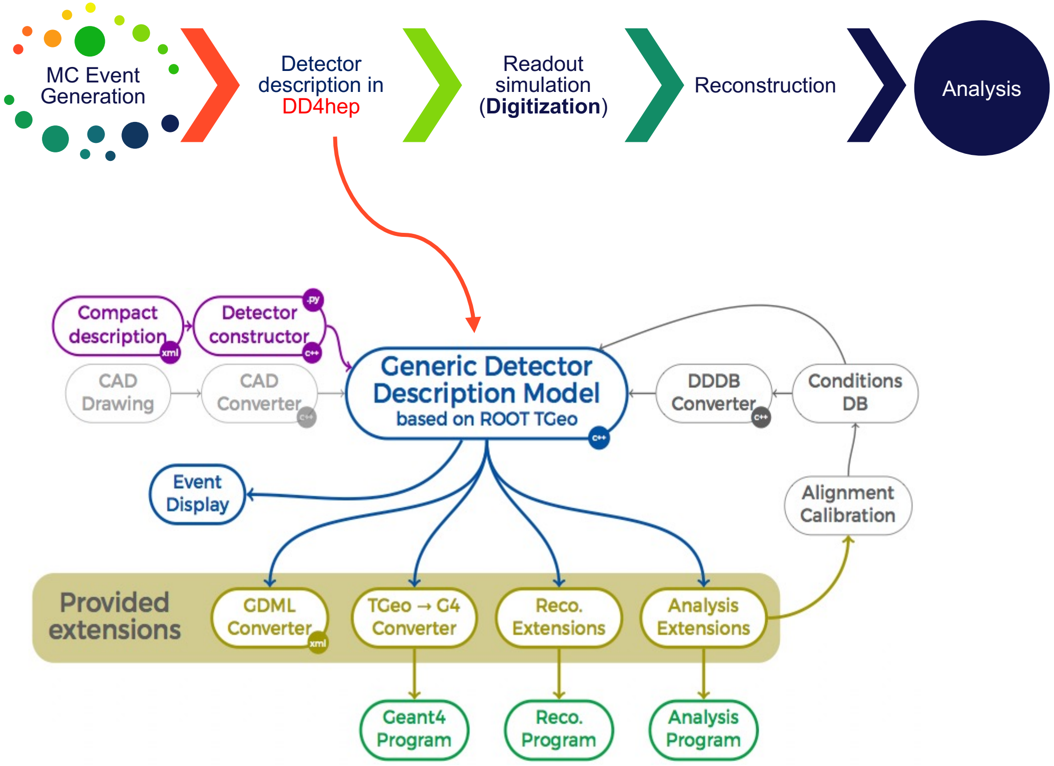
Key4hep: Complete data processing framework, from generation to data analysis

- Data format is **EDM4hep**.
- Detector description is **DD4hep**.
- Algorithm orchestration done by **Gaudi**.

We are going to discuss:

1. Detector description.
2. Digitization.
3. Reconstruction (if available).

For each IDEA sub-detector.

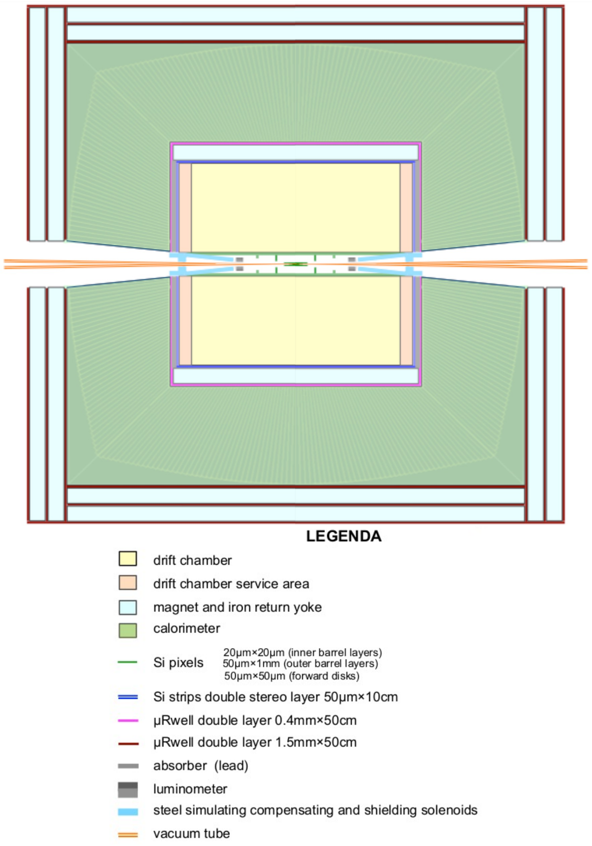


Innovative Detector for *e*+ *e*– Accelerator (IDEA)

IDEA detector concept consists of:

- Silicon pixel vertex detector.
- Large-volume extremely light drift wire chamber.
- Surrounded by a layer of silicon micro-strip detectors.
- Dual readout crystal calorimeter.
- Thin low-mass superconducting solenoid coil.
- Pre-shower detector based on *μRWELL* technology.
- Dual readout fiber calorimeter.
- Muon chambers based on *μRWELL* technology

inside the magnet return yoke.



IDEA detector layout

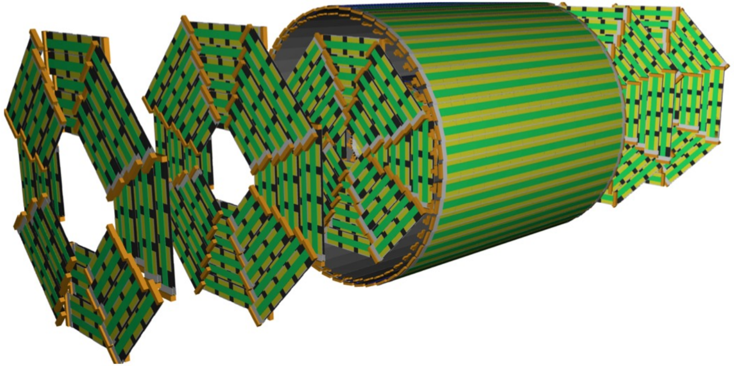
Armin Ilg

IDEA: Vertex detector

- A complete description for the detector is ready on **k4geo** repository.
- Detailed and realistic description for the sensors.
- Complex support structures are imported directly from CAD (The inner tracker support structure is not included in material budget) or implemented using proxy volumes with the correct material budget.
- Cooling cones not implemented yet.
- Vertex desk global support not implemented yet.

A Silicon pixel vertex detector :

- Modules of 25 x 25 μm^2 pixel size for inner vertex tracker.
- Modules of 50 x 150 μm^2 pixel size for outer vertex tracker.



DD4hep implementation of the IDEA vertex detector.

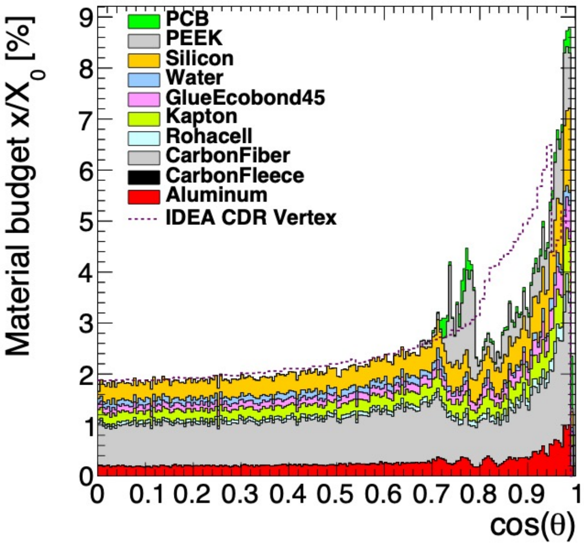
Armin Ilg

IDEA: Vertex detector

- Sophisticated calculation of the material budget, due to the detailed description.
- Material budget comparable with CDR estimate.

Digitization:

- A simple digitization of Si-hits is ready in **k4RecTracker** repository as a Gaudi algorithm.
- Applying Gaussian smearing of the hits.
- The same algorithm is applicable for Si-Wrapper and CLD silicon layers.
- The implementation of a detailed digitizer (including charge sharing) has started.



Material budget of IDEA vertex detector.

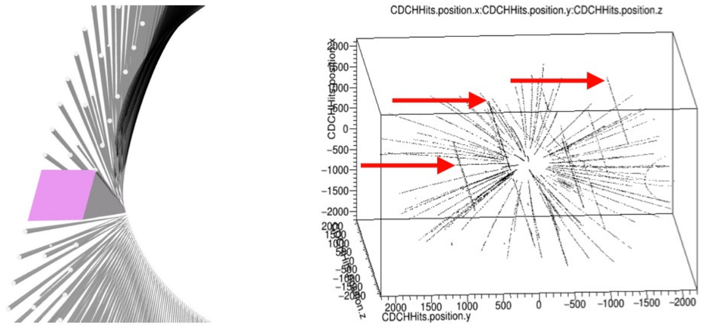
IDEA: Drift Chamber

Alvaro Tolosa-Delgado & Brieuc Francois

- A first version of drift chamber (DriftChamber o1_v01) is ready.
- A digitizer for smearing hits along wires and reconstruction algorithm were implemented.
- **BUT**, Some issues appeared, such an unbalanced geometry tree → leading to 4GB memory consumption!
- Non-suitable shapes like tube segments instead of twisted tubes → overlaps caused.
- That motivated a new implementation of the geometry.

Large-volume extremely light drift wire chamber :

- Evolving from the detectors built for KLOE and MEG2 experiments: is a full-stereo unique volume, co-axial with the 2T solenoid field, with high granularity, low mass and short drift path.



DD4hep DriftChamber o1_v01 Cross section (left). Weird behavior appears in CDCH-Hits (Right).

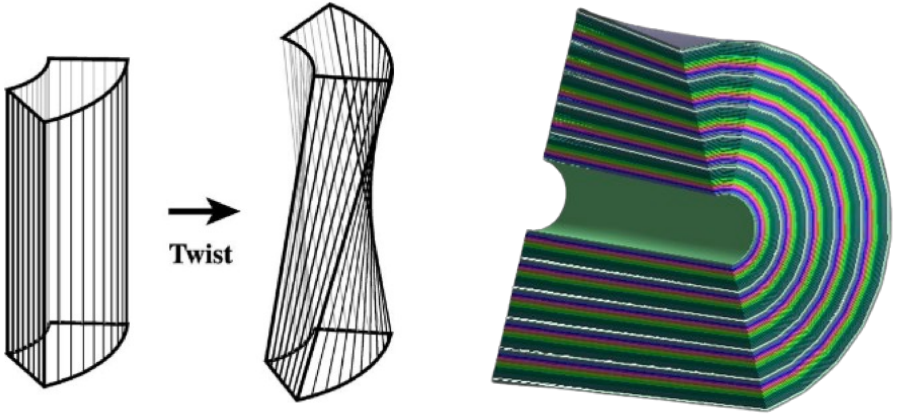
Alvaro Tolosa-Delgado
& Brieuc Francois

IDEA: Drift Chamber

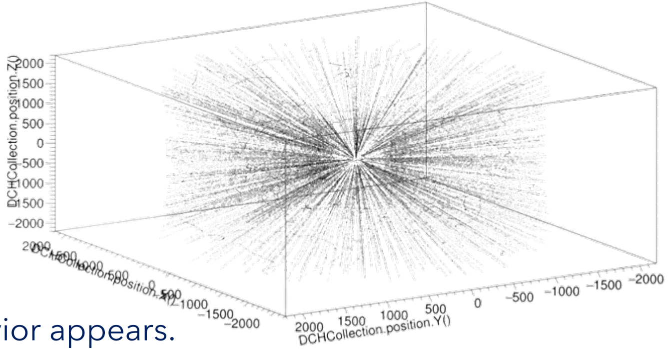
DriftChamber o1_v02

Well balanced Geometry:

- Cylindrical wall made of carbon fiber.
- Cylindrical volume filled of gas mixture.
- 112 hyperboloidal layers filled with gas mix.
- Cells are twisted tubes (twisted tube results from layer segmentation in phi, keeping the twist angle), made of gas mix. These cells are the sensitive volumes!
- Field (x5) and sense (x1) wires inside each cell.
- The new version (v02) is ready now and has been merged to [k4geo](k4geo).



DriftChamber o1_v02 Twisted tubes.



Expected behavior appears.

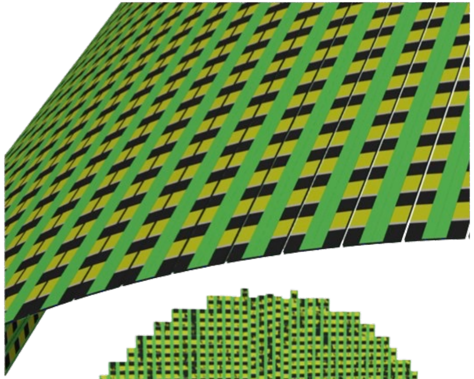
Armin Ilg

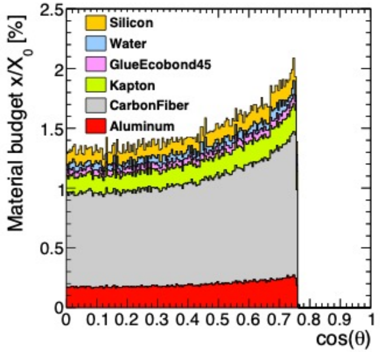
IDEA: Silicon Wrapper

- Being further away from the interaction point, the level of details needed to get accurate simulations is probably lower than for the vertex detector where we need the great details.
- By using the same detector builder and digitizer as for the vertex detector, a first version od Si-Wrapper is ready.
- Large surface (112 m^2), tiled with ~ 4x4 cm^2 modules.
- A huge number of modules → Slow and large memory consumption.
- A second version which is lighter (memory consumption-wise) is implemented. For the moment a single-layer of 0.050 x 1 mm strips.

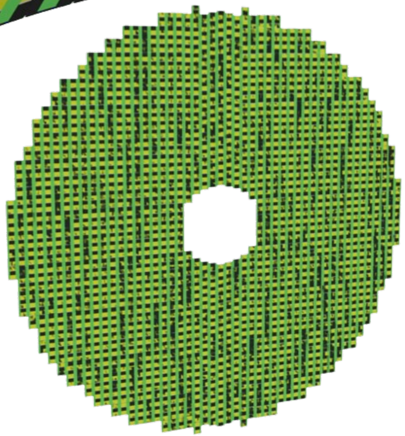
Two layers of silicon micro-strip detectors or One hermetic layer of pixels ?

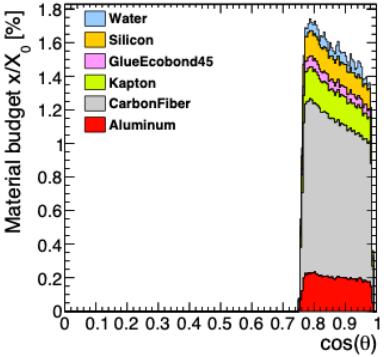
Barrel





Endcap





IDEA: Fiber sampling dual-readout calorimeter

Sanghyun Ko & Sungwon kim

Version 1:

The full simulation of fiber sampling DR-Calo has been implemented, and a PR has been opened for **k4geo**:

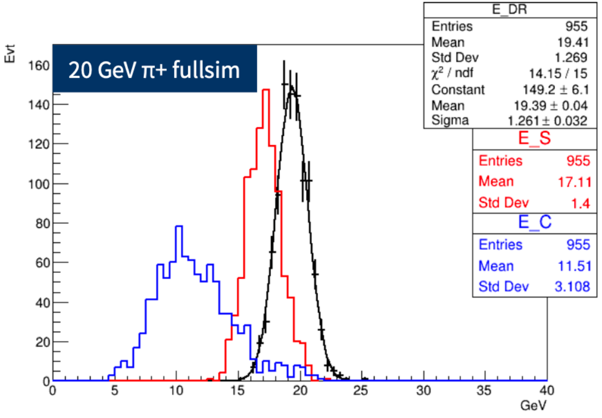
- Successfully demonstrated the principle of DR-Calo with full simulation

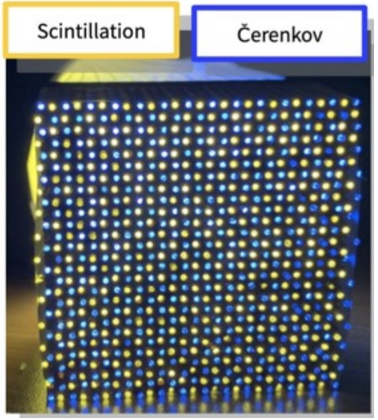
A dedicated SiPM emulation library ("SimSiPM") has been developed:

- Able to simulate the output waveform of SiPM based on parameterized inputs from the datasheet (dark counts, crosstalk, afterpulse, saturation, noise, ...)

- The major difficulty of measuring energy of hadronic showers comes from the fluctuation of EM fraction of a shower (f_{EM})

- Excellent hadronic energy resolution can be achieved by measuring f_{EM} using two independent channels with different h/e response





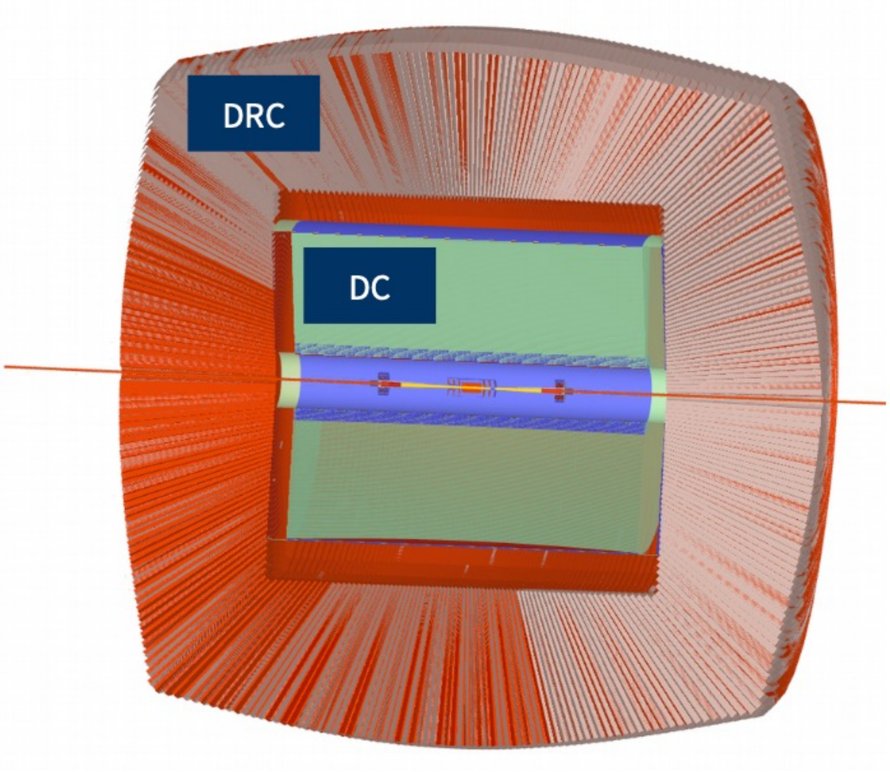
IDEA: Fiber sampling dual-readout calorimeter

Sanghyun Ko & Sungwon kim

Version 1:

Currently, the performance optimization of full simulation is ongoing ahead of full-scale production for FSR

- (e.g. CPU and memory consumption due to high-granularity optical fibers and projective towers).
- Already using fast sim for photon transportation in fiber.



Andreas Loeschcke Centeno

IDEA: Fiber sampling dual-readout calorimeter

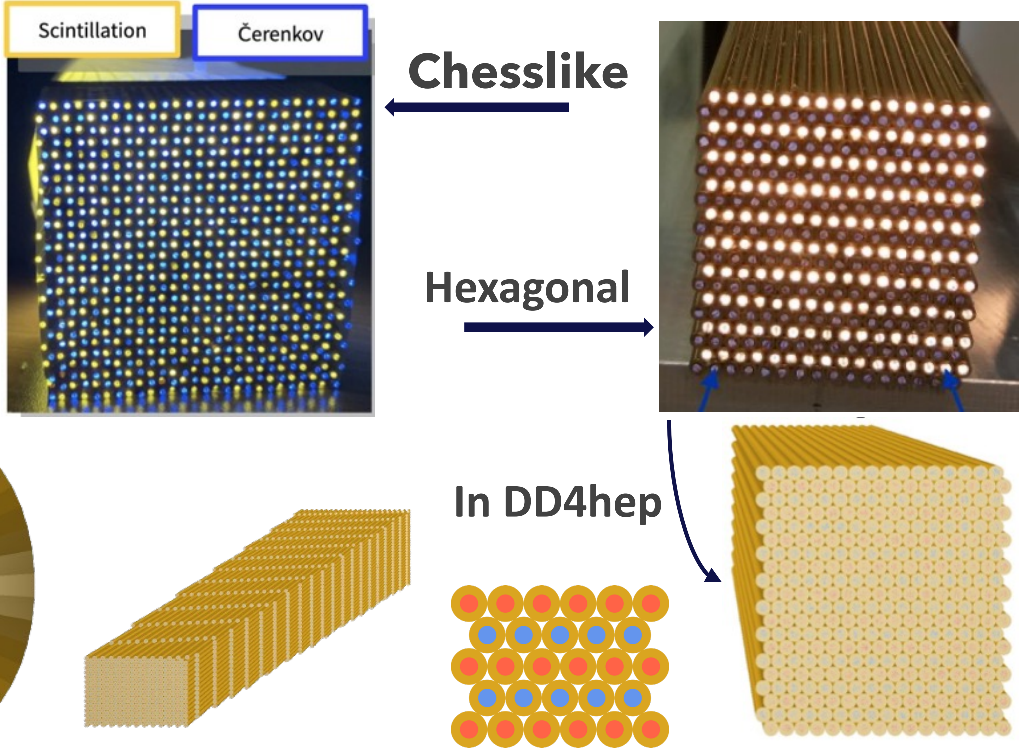
Version 2:

The full simulation of ***Bucatini*** modules fiber sampling DR-Calo is still under construction:

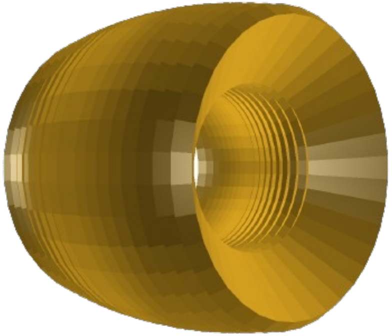
The implementation of geometry and materials of the barrel part is ready.

- ➢ Ongoing work to implement the endcap.

Difference in construction of tower



DD4hep implementation of the IDEA barrel DRC.



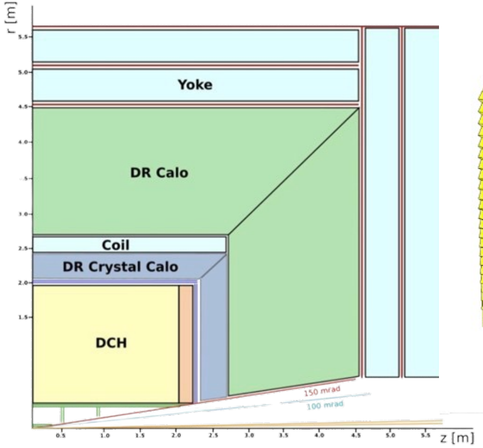
IDEA: Crystal-based dual-readout calorimeter

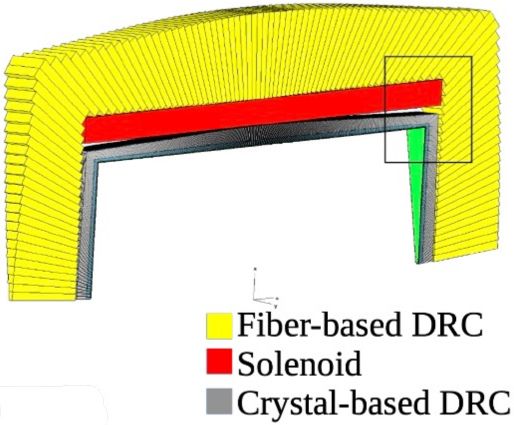
W. Chung & M. Lucchini

Another version of IDEA adding dual readout crystals. To start with: drift chamber untouched, fiber DR calo pushed away.

- ➢ PbWO4 crystals + LYSO timing layer.
- ➢ With 1x1cm crystal faces/thickness:
  - ~1.12 million barrel crystals
  - ~400,000 endcap crystals
  - ~30,000 timing crystals

Crystal-based calorimeter would provide better EM resolution than fiber-based plus longitudinal segmentation [JINST2020]

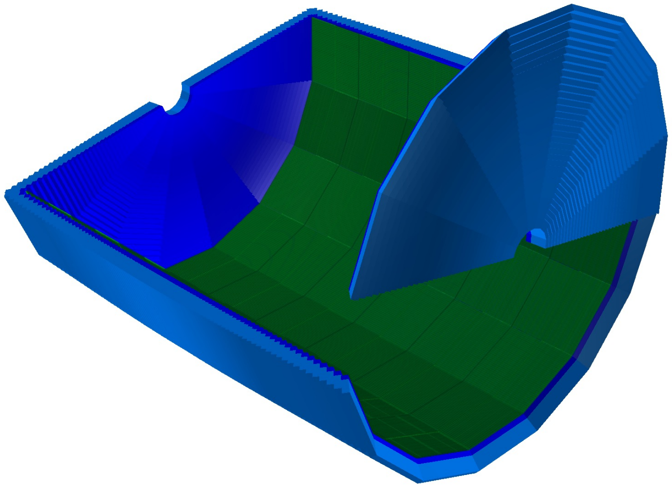




IDEA: Crystal-based dual-readout calorimeter

W. Chung & M. Lucchini

- Detector geometry is implemented in DD4hep.
- No optical physics, simply count & terminate S/C.
- In progress:
  - AI/ML reconstruction (currently evaluating different variants of neural networks suitable for detector characteristics – diffusion, transformers, etc.)
- Remaining:
  - Digitization
  - Wrapping for instrumentation, cooling, etc.



DD4hep implementation of Crystal DR-Calo

Mahmoud Ali

IDEA: Muon system based on *μRWELL* technology

- IDEA muon system primarily composed of 3 sensitive stations. Each station will consist of a large mosaic of μRWELL detectors.
- The basic μRWELL "tile" will have an active area of 50 × 50 cm^2.
- The layers are placed between layers of the iron yoke that closes the magnetic field.
- A strip pitch ~ 1.2 mm and 500 mm length.
- A 2D readout system for each individual chamber.

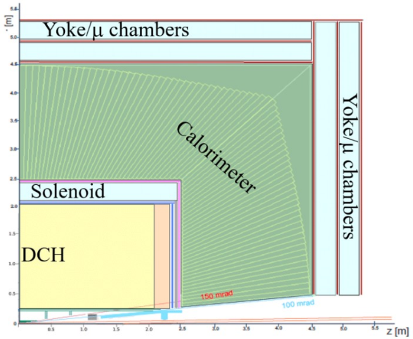
The μ-RWELL [**JINST**] is a Micro Pattern Gaseous Detector (MPGD) composed of only two elements:

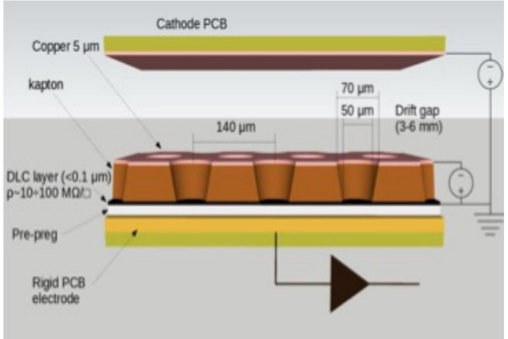
the μ-RWELL_PCB and the cathode. The core is the μ-RWELL_PCB, realized by coupling three different elements:

1. A WELL patterned kapton foil acting as amplification stage (GEM-like)

2. Resistive DLC layer (Diamond-Like-Carbon) for discharge suppression with surface resistivity ~ 50÷100 MΩ/□

3. Standard readout PCB

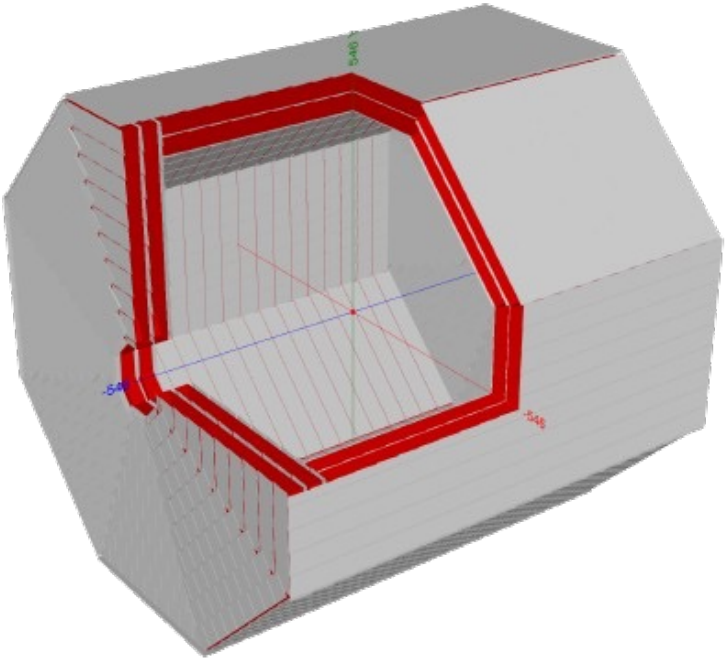




IDEA: Muon system based on *μRWELL* technology

Mahmoud Ali

- A detailed description of the muon system geometry and μRWELL material is ready, and the PR is opened at **k4geo**.
- A complete check of the geometry overlap has been done.
- A simple digitization algorithm is ready, which smears the hit position in the local μRWELL chamber plan in 2D, with the space resolution of the chamber ~ 400 μm, and more features to be added (simulates the efficiency, fake rate (noise)).
- Currently working on reconstruction (Standalone muon system alg.).

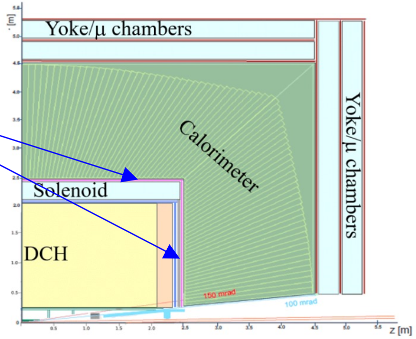


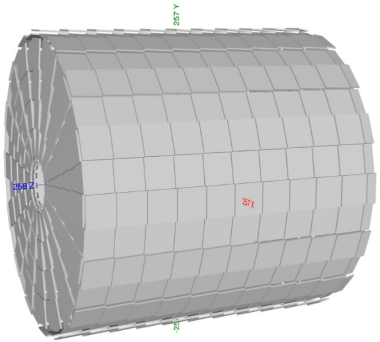
IDEA: Preshower based on *μRWELL* technology

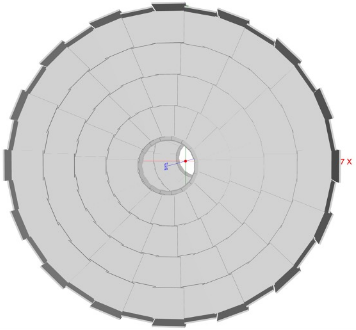
Nitika Nitika
& Mahmoud Ali

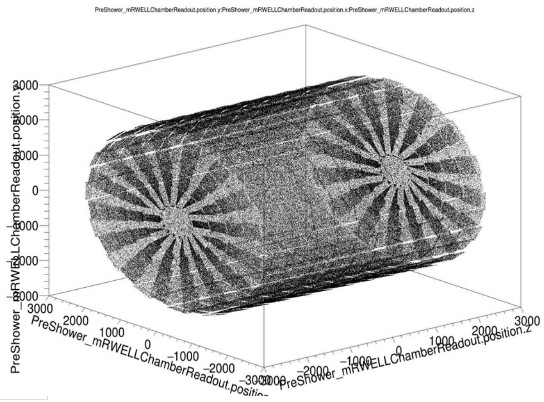
- IDEA detector envisages one layer preshower system utilizing μRWELL technology. Both the preshower and muon systems have a modular design, with both sharing the **same builder** file.
- Pitch between readout strips: 400 μm
- A 2D readout system for each individual chamber.
- The implementation is ready in Dd4hep, and a PR is opened.
- It uses the same digitization of the muon system.
- A reconstruction alg. To be implemented.

One layer encapsulate the solenoid



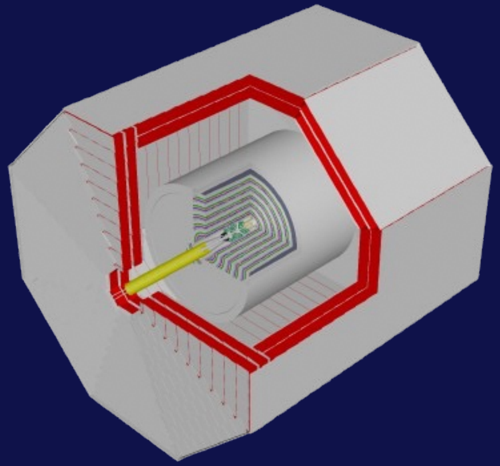






Summary & Further development:

We finally have The first full IDEA implementation in DD4hep



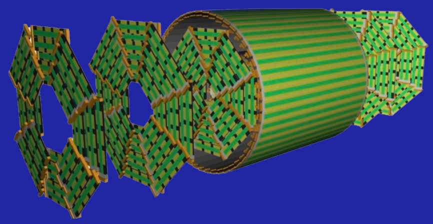
1

Vertex detector

Detector description: ✓

Digitization: ✓

Reconstruction:



- A detailed digitizer including charge sharing.
- Reconstruction.

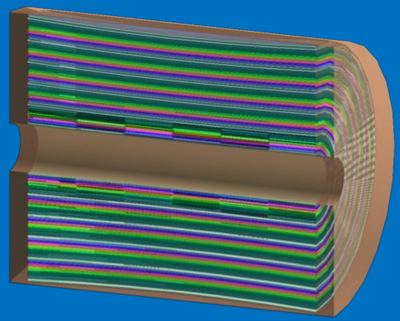
2

Drift chamber

Detector description: ✓

Digitization: ✓

Reconstruction:



- A new digitizer including cluster counting.
- Reconstruction.

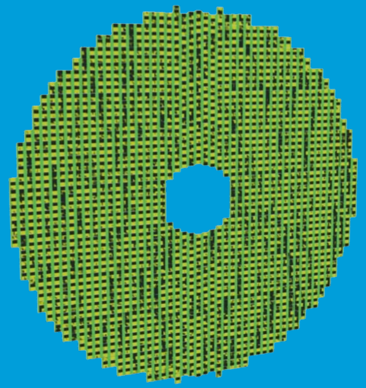
3

Silicon wrapper

Detector description: ✓

Digitization: ✓

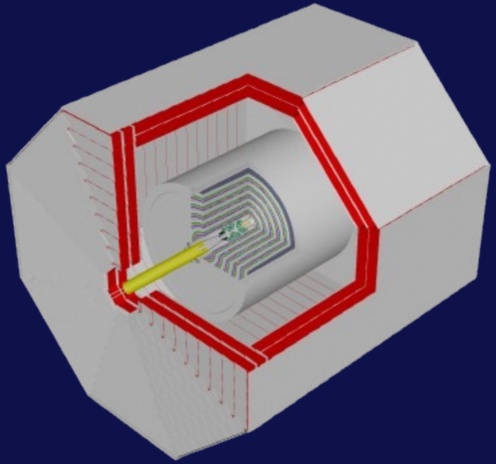
Reconstruction:



- Reconstruction.

Summary & Further development:

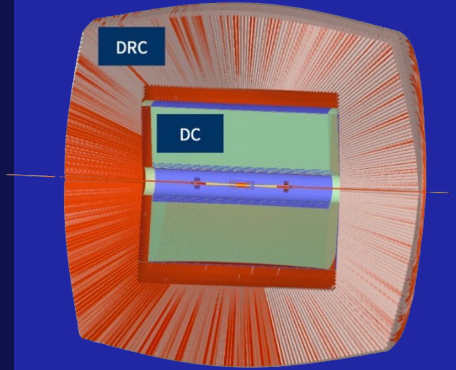
We finally have The first full IDEA implementation in DD4hep



4

Fiber DR-Calo

Detector description: ✓
Digitization: ✓
Reconstruction: (in progress)

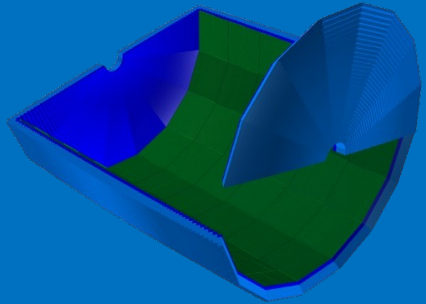


- Working on a lighter version on CPU.
- Reconstruction.

5

Crystal DR-Calo

Detector description: ✓
Digitization: (in progress)
Reconstruction: (in progress)

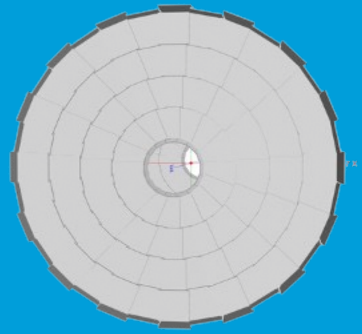


- AI/ML Reconstruction.
- Digitization.

6

Muon system & Preshower

Detector description: ✓
Digitization: ✓
Reconstruction: (in progress)



- Reconstruction.

Thank you for your attention.

Mahmoud.ali@bo.infn.it

IDEA: Drift Chamber

Alvaro Tolosa-Delgado & Brieuc Francois

DriftChamber o1_v02

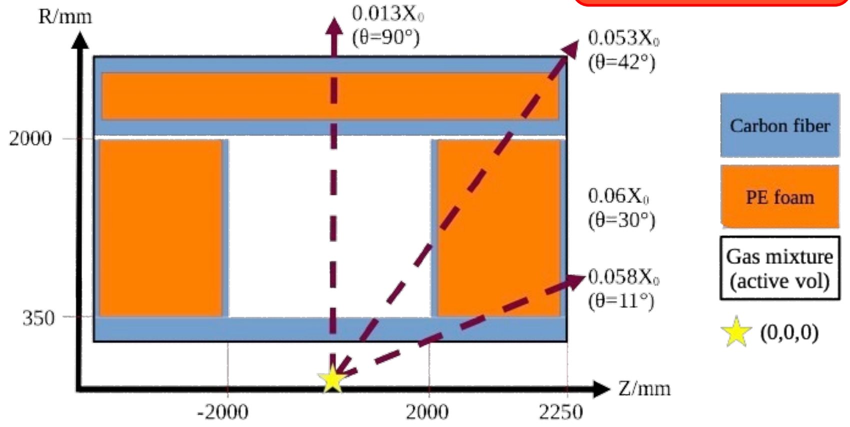
Master volume is a cylinder filled with gas, vessel parts are placed inside as in the picture:

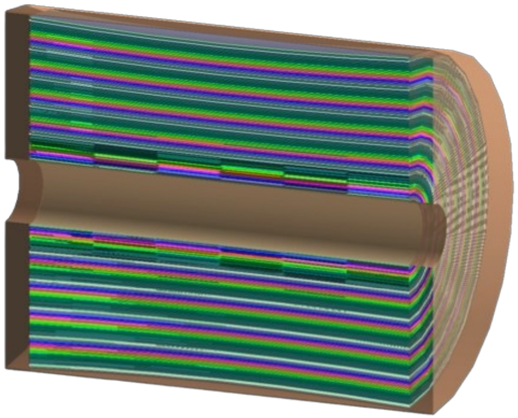
- Inner radial wall, made of 1 single thin layer (cylinder) of carbon fiber.
- Outer radial wall, made of a skin (mother cylinder) of Carbon fiber filled with PE foam (daughter).
- Endcap wall, made of a skin (mother cylinder) of Carbon fiber filled with PE foam (daughter).

Add passive materials still missing, e.g., guard wires.

A new digitizer is under construction for implementing the cluster counting, and smearing the hits.

The dimensions are exaggerated on this drawing





Detector description

W. Chung
& M. Lucchini

- **Fully parametrized construction**
- Only 7 parameters needed:
  - Inner radius
  - Z extent of barrel
  - Crystal face width (nominal)
  - Front crystal length
  - Rear crystal length
  - Timing crystal thickness (nominal)
  - Number of phi segments
    - Ensures hermeticity
    - Enables timing layer
    - Takes care of projective gaps
- Geometry optimizations
  - Intermediate envelope volumes, <1000 volumes each
  - Orange slices (barrel)
  - Rings (endcap)
  - ~10x speed/memory improvement vs. monolithic single container