ECAL Crystal simulation in DD4HEP

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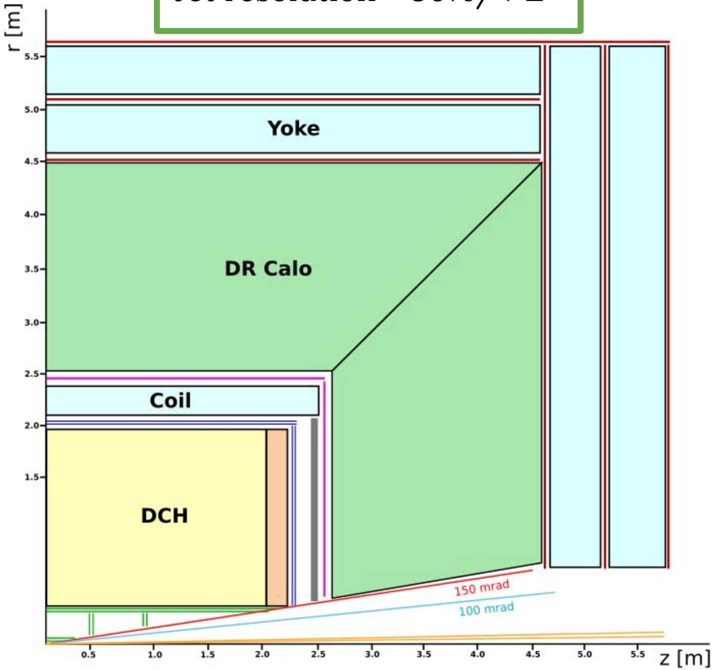
IDEA detector

IDEA detector for future e+e- circular colliders:

- **sampling fiber calorimeter** exploiting the **dual-readout** of scintillation and Cherenkov light
  → **excellent** energy resolution for **hadrons** and jets
  → **BUT** moderate energy **EM** resolution

- **segmented homogeneous dual-readout crystal calorimeter** (SCEPCal) 2020 JINST 15 P11005
  → improve the resolution to EM particles to **3%/√E**
  - **transverse and longitudinal segmentation** → optimized to give useful info to DR particle flow algorithms
  - **timing layers** → time resolution **~20 ps** for both MIPs and EM showers

IDEA calorimeter
σ_E /E (EM) ~**13%/√E**
σ_E /E (HAD) ~31%/√E
Jet resolution ~ 30%/√E



CP violation studies arXiv:2107.05311
Clustering of π0 's photons JINST 15 P11005
Resolution of Z→ee decays arXiv:1811.10545

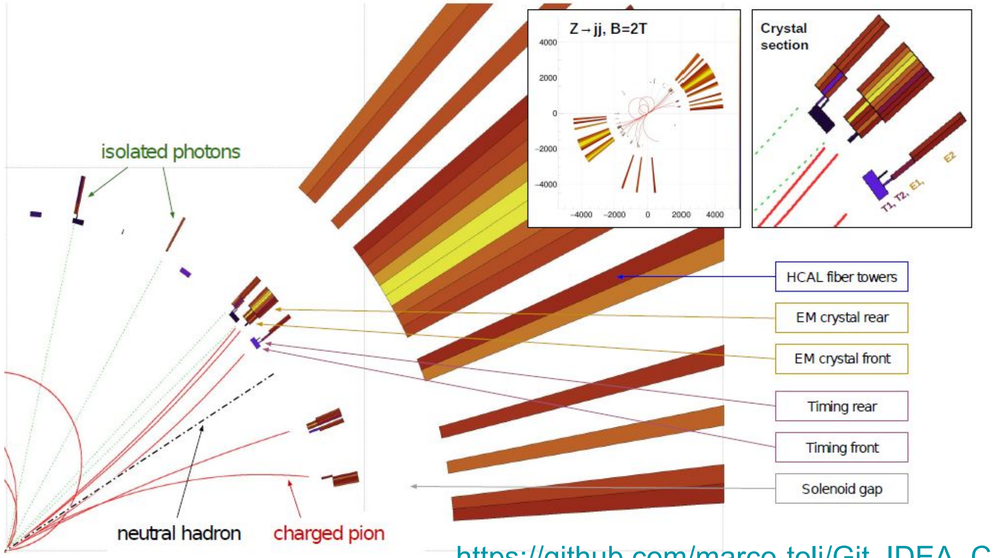
State of the art

Studies on particle flow using **hybrid segmented crystal** and **fiber dual-readout** calorimeter:

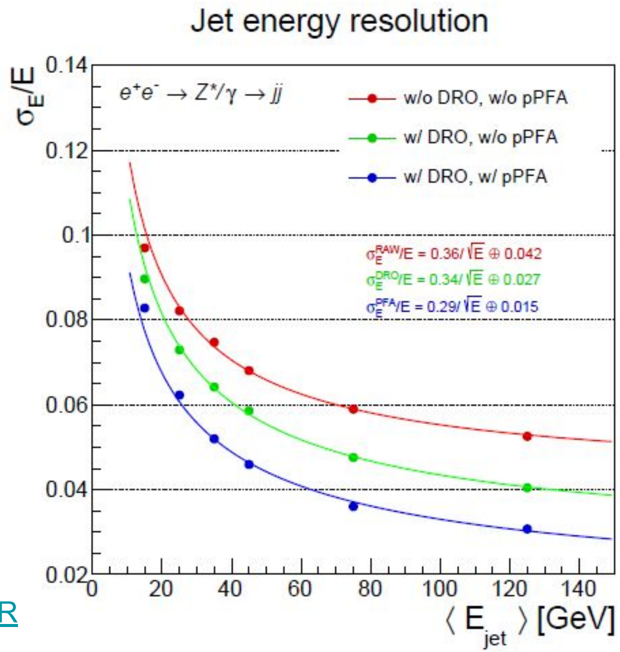
- standalone **4π Geant4** simulation, do not include a full tracker description;
- DR-oriented **particle flow** algorithm.

More details in:
[2022 JINST 17 P06008]

→ **Sensible improvement in jet resolution** using dual-readout information combined with particle flow → **3-4%** for jet energies above 50 GeV



https://github.com/marco-toli/Git_IDEA_CALO_FIBER



Goal of the fellowship

- Integrate the **crystal DR calorimeter** option in the **Full Simulation of the IDEA detector** and validate the simulation tool:
  - integration in the **key4Hep** framework to allow the long-term use and maintenance of the software
    - **DD4HEP** -- the crystal calorimeter geometry
    - **edm4hep** -- data model for the event reconstruction

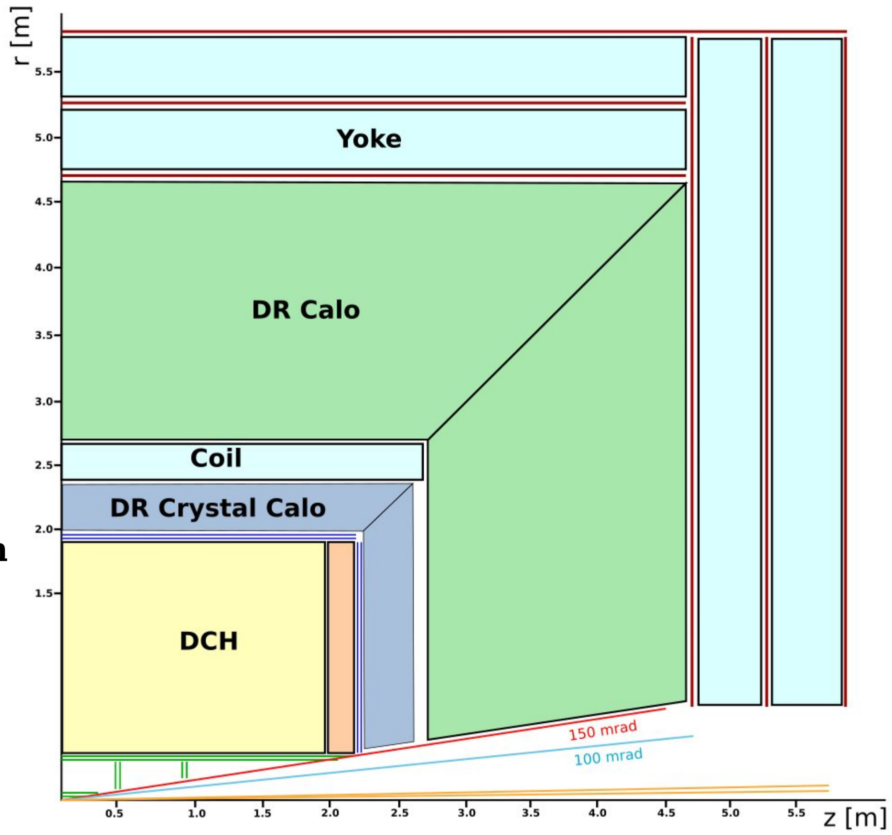
- **After validation** of this simulation tool:
  - working on a **dedicated particle flow algorithm**, using both the information from dual-readout and from the SCEPCal
  - possibility to study the impact of an **improved energy resolution on physics program** of FCC-ee:
    - CP violation studies through B0 meson decays
    - BSM studies for Axion Like Particles (ALPs)

EM crystal calo radial envelopes: baseline

- ★ Silicon pixel vertex detector (MAPS):
  - R = 1.7 - 34 cm
- ★ Drift chamber:
  - R = 35 - **190** cm
- ★ Si wrapper (micro-strip layer)
  - R = **190 - 200** cm
- ★ **Crystal Calorimeter**
  - **200 - 230 cm**
- ★ Thin Solenoid (2T, 0.7X0)
  - R = **230 - 260** cm
- ★ ~~Pre-shower (μRwell behind absorber)~~
  - ~~R = 240 - 250 cm~~
- ★ Dual readout calorimeter
  - R = 260 - 460 cm
- ★ Muon chambers (μRwell)
  - R = 460 - 570 cm

-10 cm

+10 cm



Plans

- Implementation of the **SCEPCal in DD4HEP**:
    - Coordinate with the US community within the **CalVision** project, we are in contact with Wonyong Chung (Princeton)
        - ongoing implementation of the geometry of the detector
        - reconstruction and validation still to be performed
        - in touch to understand where we can help.

- Towards the integration of SCEPCal in the IDEA detector:
    - **tracker system**, coordinate with the simulation of the drift chamber (geometry in DD4HEP implemented, should have flexible radial envelope to adapt to the 2 scenario w and w/o SCEPCal, reconstruction still missing → Lorenzo Capriotti)
    - **dual readout fiber calorimeter,** coordinate with korean group and a student from Sussex

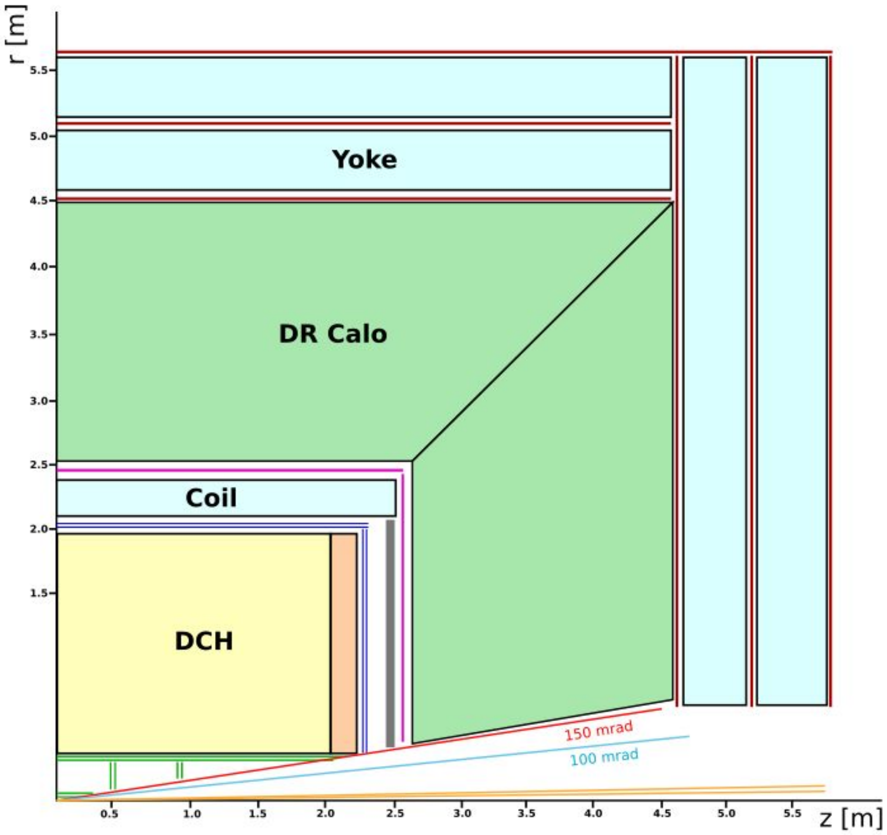
- Working on the **validation of a full simulation** dataset, that could be used to develop dedicated **dual-readout particle flow algorithms** using machine learning techniques (Adelina D'Onofrio)

Backup

Baseline radial envelopes

Marco Lucchini

- Silicon pixel vertex detector (MAPS):
  - R = 1.7 - 34 cm
- Drift chamber:
  - R = 35 - 200 cm
- Si wrapper (micro-strip layer)
  - R = 200 - 210 cm
- Thin Solenoid (2T, 0.7X0)
  - R = 210 - 240 cm
- Pre-shower (µRwell behind absorber)
  - R = 240 - 250 cm
- Dual readout calorimeter
  - R = 250 - 450 cm
- Muon chambers (µRwell)
  - R = 450 - 560 cm



Overview

It's a global cost-performance optimization of the full detector

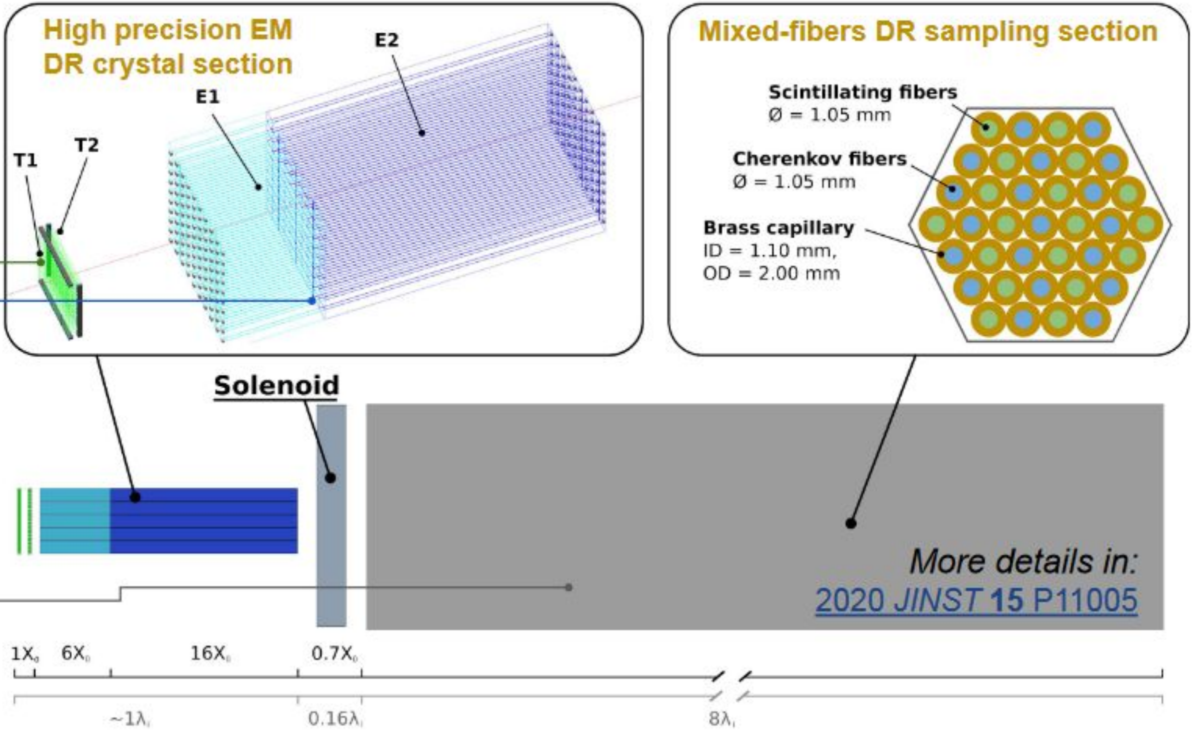
Option	DC outer radius [cm]	Crystal inner radius [cm]	Solenoid inner radius [cm]	Fiber calo inner radius [cm]	Approx crystal volume* [m³]
No crystals	**200**	**-**	**210**	**250**	**-**
Previous sim	175	185	220	250	14.0
New baseline	190	200	230	260	17.2

Note: *crystal calo is about* $1\lambda_I$ *so we could reduce the length of the fiber calo*
* *Crystal calo cost is 80% driven by crystal volume, volume ~* $R^{1.65}$

Conceptual layout

- **Transverse and longitudinal segmentation** optimized for particle identification and particle flow algorithms
- Exploiting **SiPM readout** for contained cost and power budget

- **Timing layers** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals ($\sim 1X_0$)
  - 3x3x60 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layers** — $\sigma^{EM}_E/E \sim 3\%/\sqrt{E}$
  - PWO crystals
  - Front segment ($\sim 6X_0$)
  - Rear segment ($\sim 16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)
- **Ultra-thin IDEA solenoid**
  - $\sim 0.7X_0$
- **HCAL layer** — $\sigma^{HAD}_E/E \sim 26\%/\sqrt{E}$
  - Scintillating and "clear" PMMA fibers (for Cherenkov signal) inserted inside brass capillaries



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