The 2023 International Workshop on Circular Electron Positron Collider (European edition)

Segmented Crystal Electromagnetic Precision CALorimeter

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3. CERN

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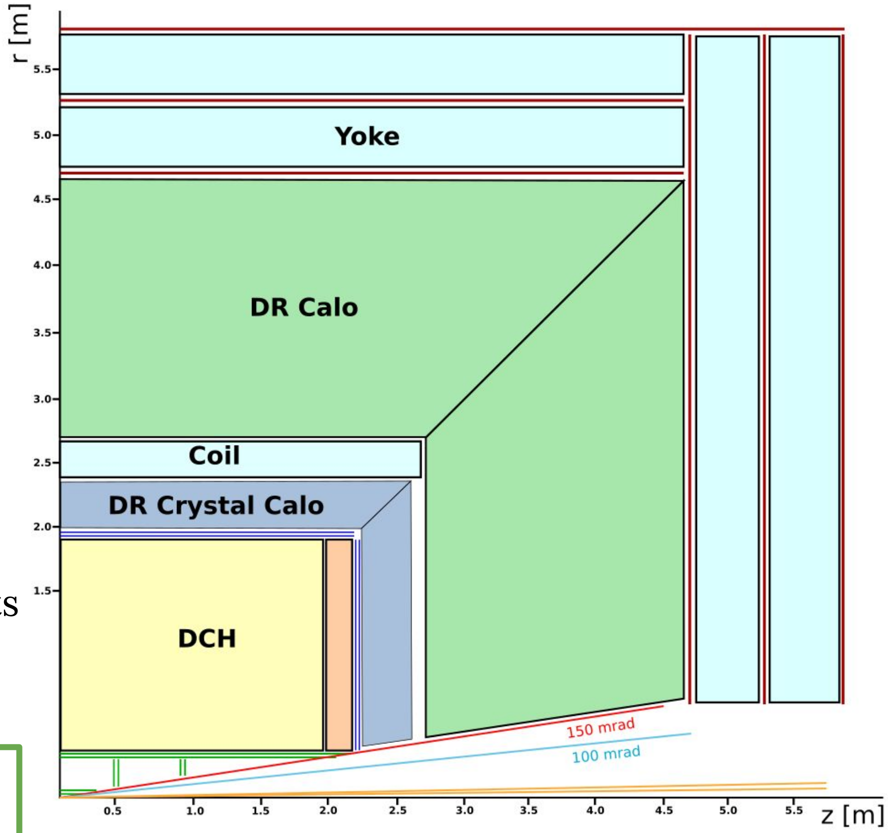
IDEA detector concept

IDEA detector for future e+e- circular colliders:

- Silicon pixel detector
- Drift chamber
- Layer of silicon micro-strip detectors
- Solenoidal magnet
- Preshower detector
- **DR Crystal calorimeter**
- **Sampling fiber calorimeter** exploiting the **dual-readout** of scintillation and Cherenkov light
  → **excellent** energy resolution for **hadrons** and jets
  → **BUT** moderate energy **EM** resolution
- Muon spectrometer within the magnet return yoke.



More in Andrea Pareti's talk

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

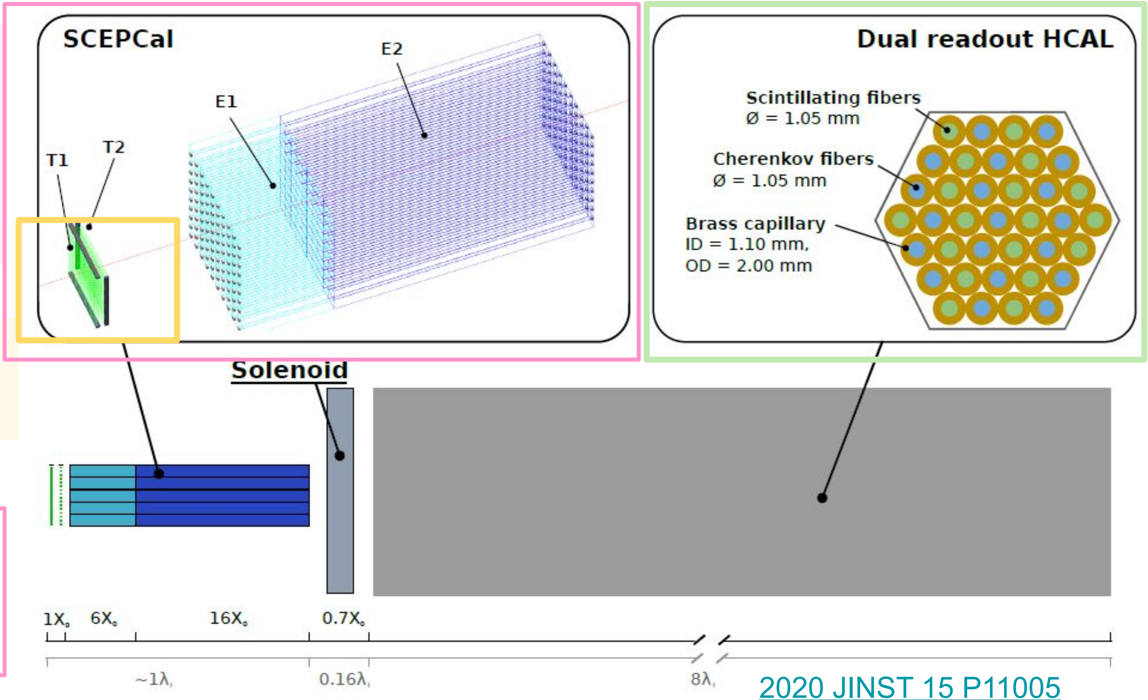
10.1393/ncc/i2020-20027-2

The DR crystal calorimeter option

- **Sampling fiber calorimeter have** moderate energy **EM** resolution → σ_E / E (EM) ~**13%/√E**
- **Segmented homogeneous dual-readout crystal calorimeter** (SCEPCal) → **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



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

2020 JINST 15 P11005

R&D for dual readout with crystals

Reading out from the same active material (**scintillating crystal**) both scintillation (S) and Cherenkov (C) components. Different options are investigated during R&D campaign:

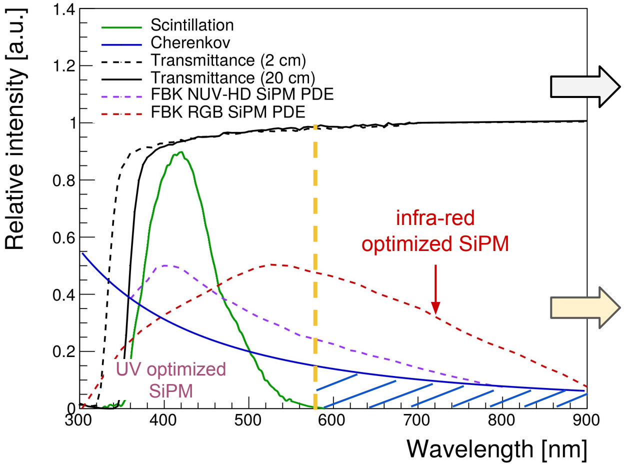
- Crystals:
  - **optimization of crystal cross section and longitudinal** segmentation
  - **choosing the of materials** → prominent candidates are **BGO, BSO, PWO** due to requirements on high density, small R_M and X_0, high refractive index (Cherenkov yield)
- Filters:
  - Development/identification of custom **thin wavelength filters** to have sufficient light yield and purity of both S and C components.
- SiPM readout:
  - dynamic range, linearity, etc
  - Explore very small cell size SiPMs (<10 um)

First laboratory results in this talk

DR strategies

- **Different strategies** could be pursued for different scintillators

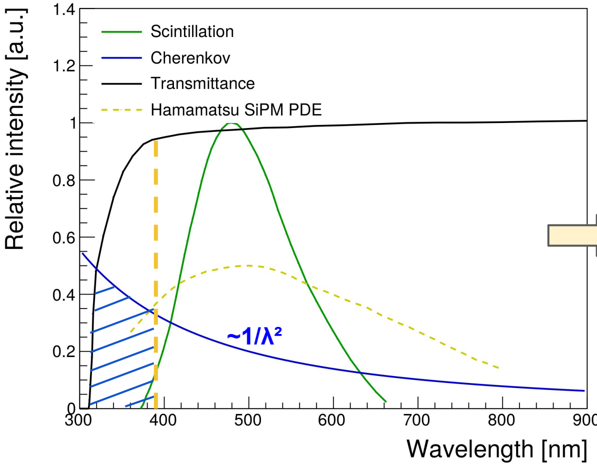
PWO



Estimated:
- >**2000 phe/GeV** for scintillation photons
- >**100 phe/GeV** for Cherenkov photons

Cherenkov photons above scintillation peak are much less affected by self-absorption

BGO / BSO



BGO/BSO have larger stokes shift, i.e. a wider range of transparency for 'UV Cherenkov'

The **key discriminant** between the crystals option is likely to be:
- Quality of the S and C signals in terms of **light yield** and **purity**

Crystals: light output

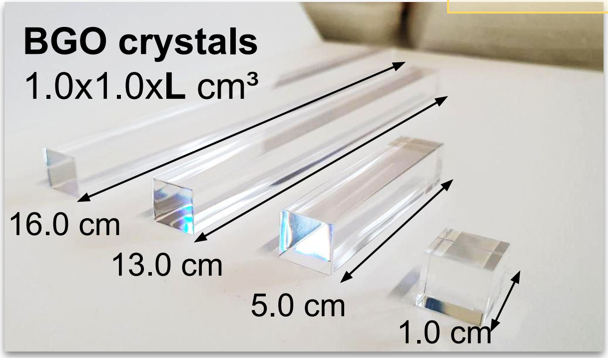
★ Measurements at University of Milano-Bicocca of **Light output:**

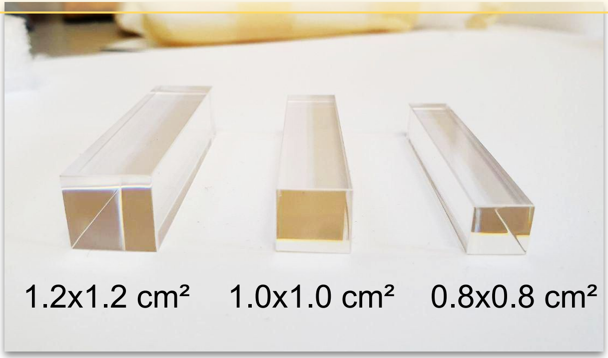
- decreases as the crystal length increases → expected a greater LO for crystals of the first calorimeter layer
- increases as the fraction of the crystal end face covered by the SiPM increases

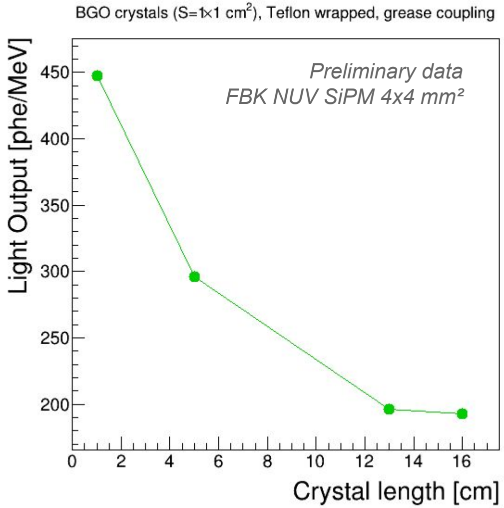
Can be used **to validate Geant4 ray-tracing** simulation

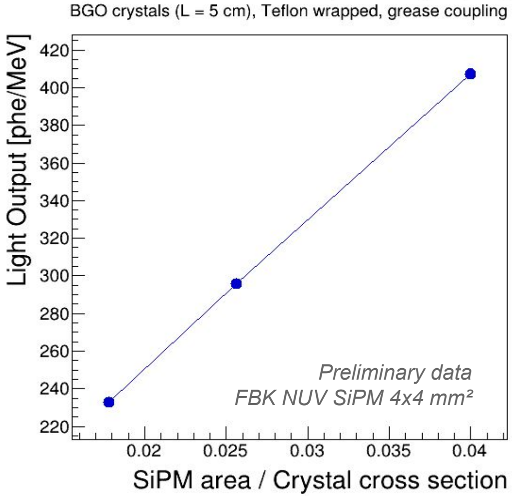
○ Similar measurements on **PWO and BSO w and w/o filters** are ongoing...

First prototypes crystals purchased from **SICCAS**







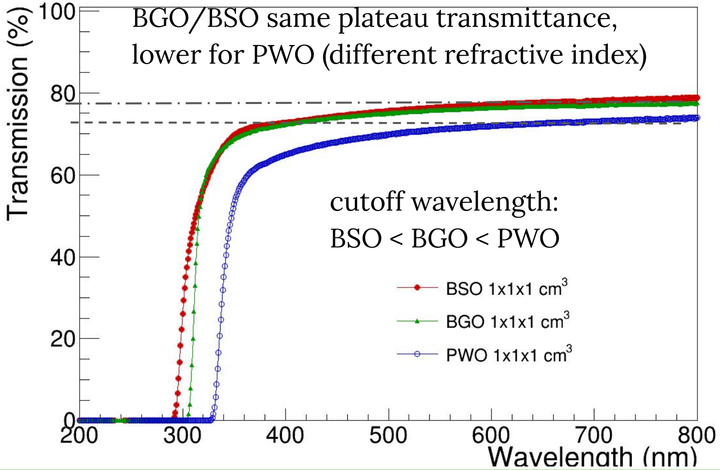


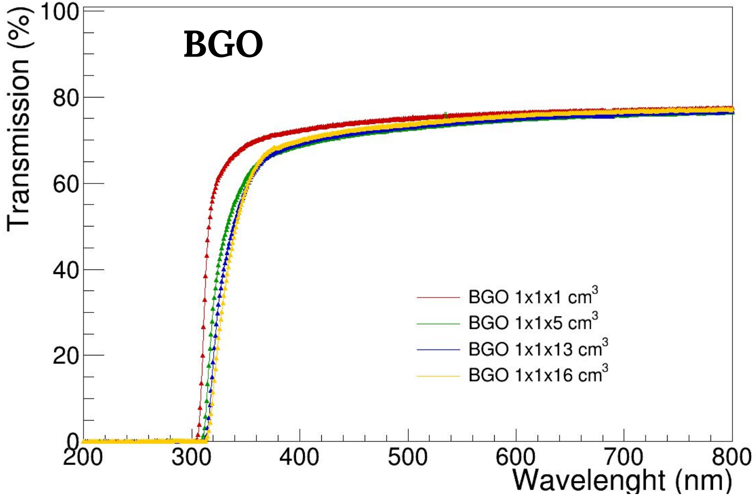
Crystals: transmission

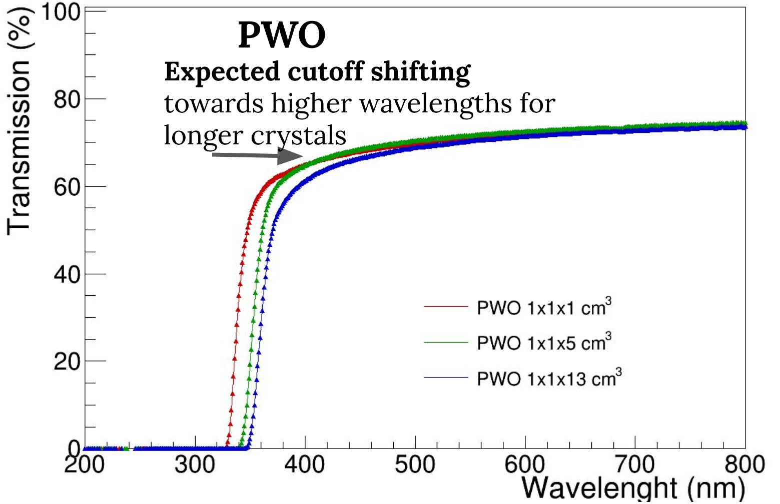
Transmission of crystals measured at CERN Lab27 for:

Etiennette Auffray, Roberto Cala'

- **Transmission after the edge** looks good (good quality of crystal and surface state/polishing)

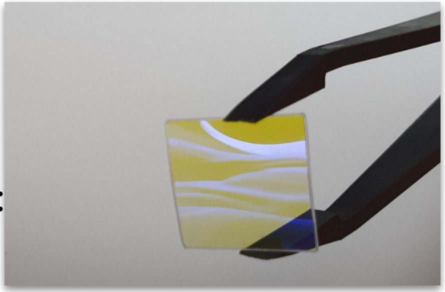






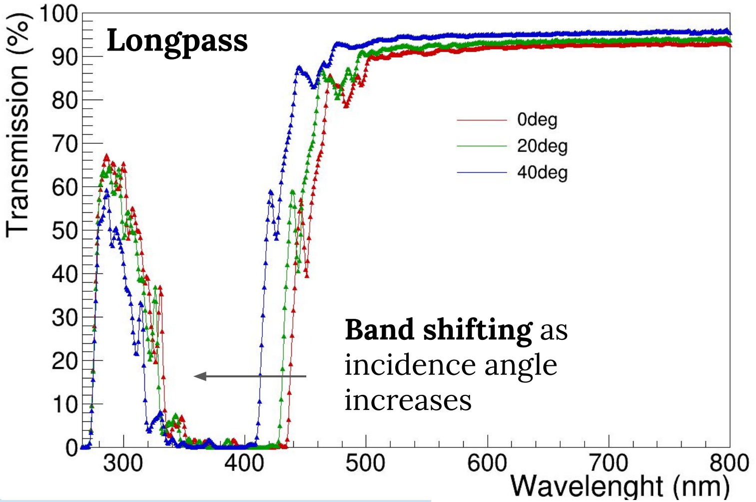
Filters: first results

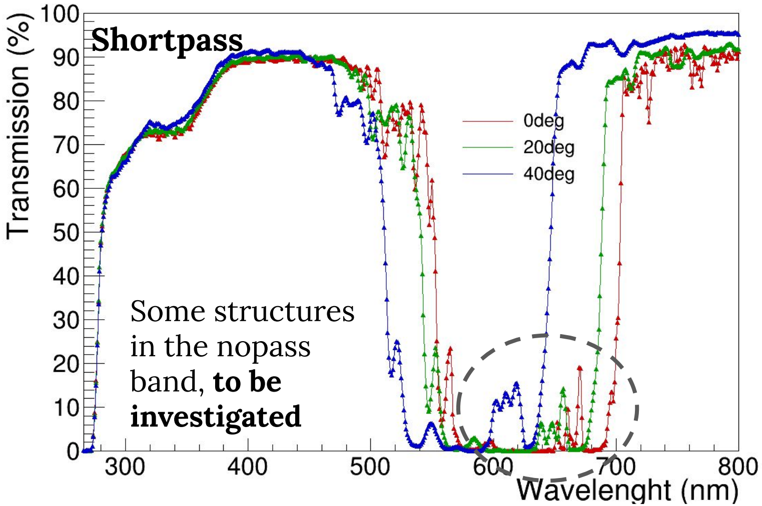
Etiennette Auffray,
Roberto Cala'



Optical filters transmission measured at CERN Lab27 for:

- First test on 5 thin (200 um) **Everix** off-the-shelf filters of different type:
  - 3 longpass, 2 shortpass filters (below some examples)
  - **thin filters** may be embedded in SiPMs window
  - measured transmission for **normal (0°), 20°, 40° of light incidence**:
    - the effect observed will be investigated more through simulation



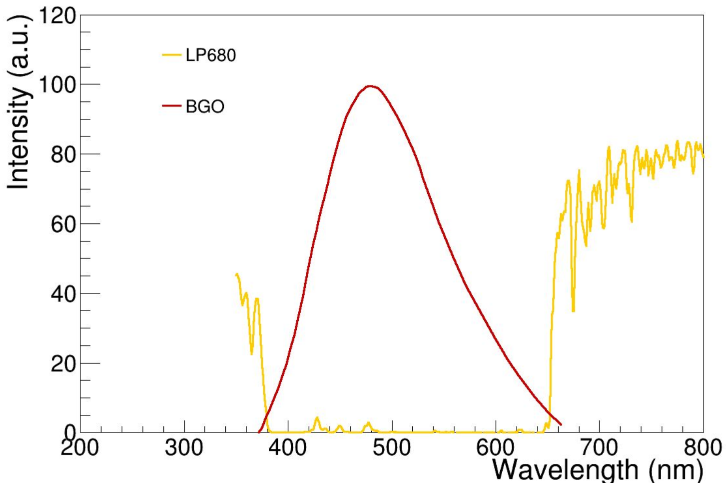


Filters: working on

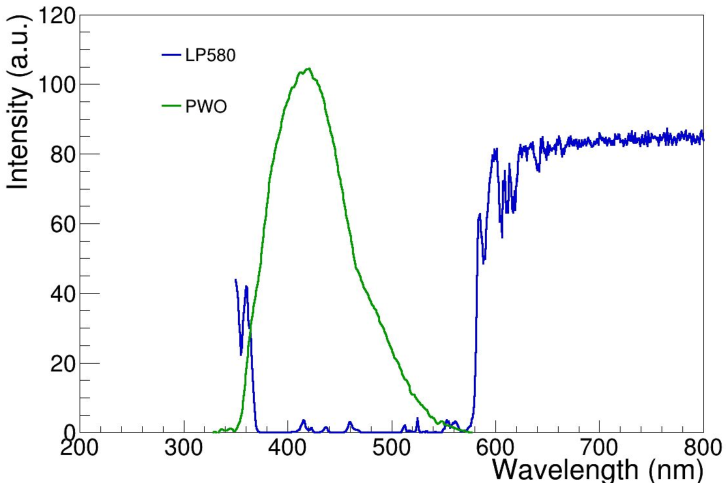
Working on customized thin filters from Everix are under study:

- **Transmission curves** from Everix with **emission** of BGO and PWO superimposed on
  - Expected about 99% (BGO) - 94% (PWO) of scintillation light filtered out
- impact of filter transmission variation with photon angle to be studied with **dedicated light yield measurements**

BGO emission and Final LP680 Filter Spectrum



PWO emission and Final LP580 Filter Spectrum



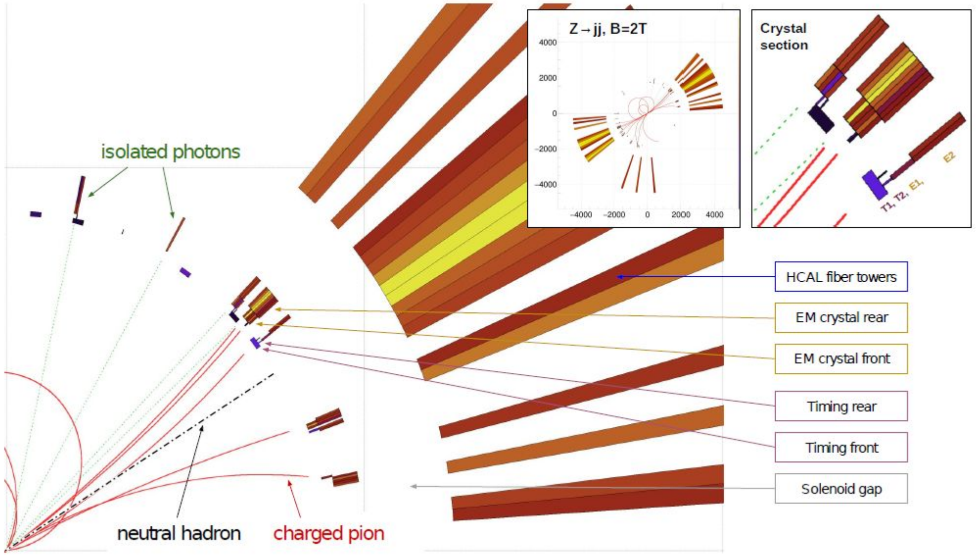
Simulation: Geant4

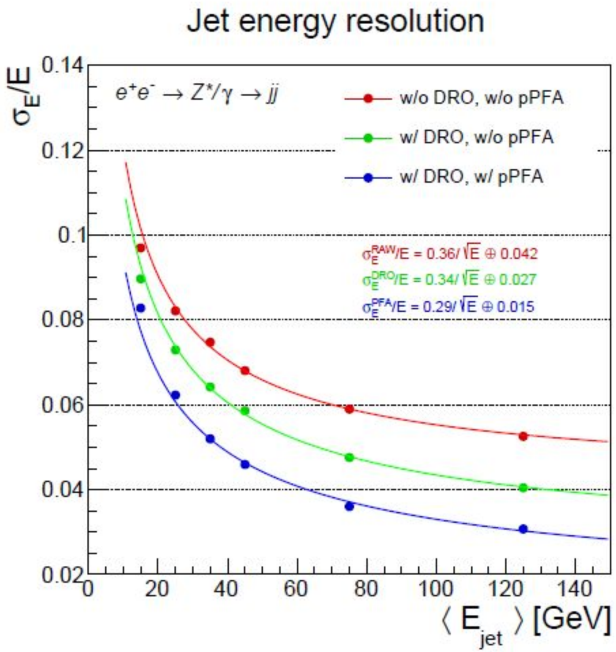
Studies on particle flow using **hybrid segmented crystal** and **fiber dual-readout** calorimeter:

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

More details in:
2022 JINST 17 P06008

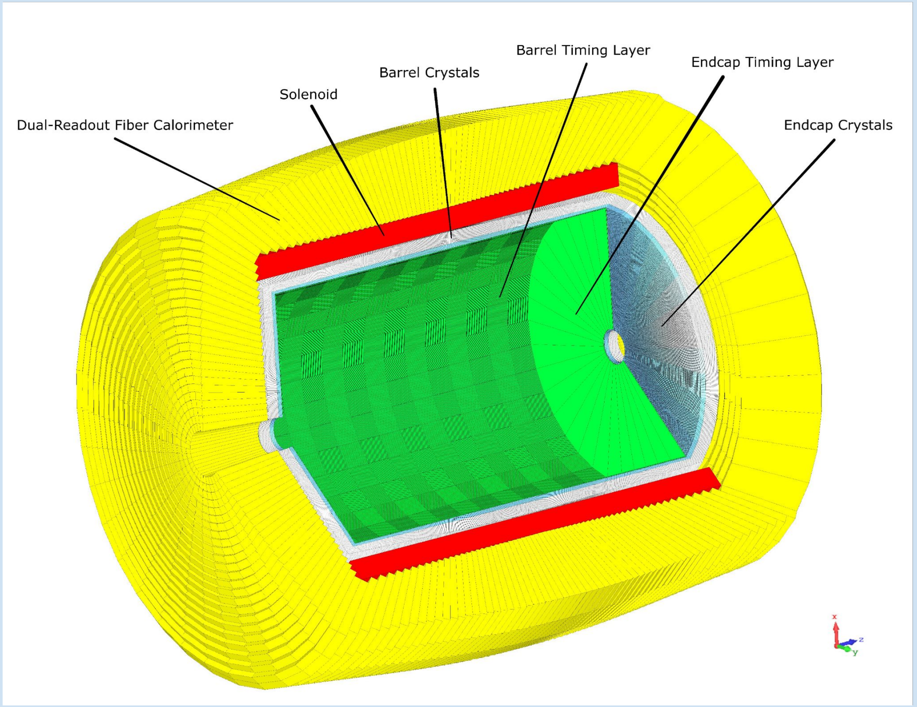
→ **Demonstrate sensible improvement in jet resolution** using dual-readout information combined with particle flow → **3-4%** for jet energies above 50 GeV





Simulation: from Geant4 to key4hep

- ★ Full Simulation of the IDEA detector would be implemented in key4hep framework:
  - transporting what was done for **Geant 4** in the new **key4Hep** framework
    - **long-term use and maintenance** of the software
    - **DD4HEP** -- the geometry
    - **EDM4HEP** -- data model for the event reconstruction
  - **modular implementation**, to test different possible scenarios combining different subdetectors

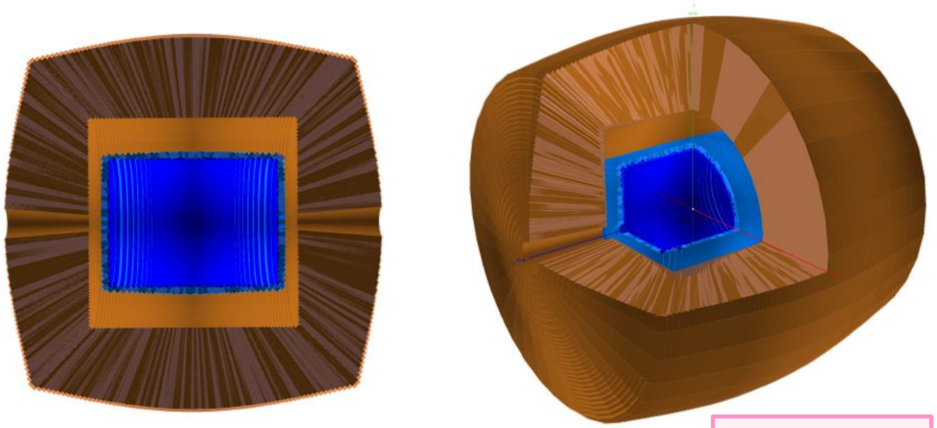


Simulation: key4hep

★ **Implementation in key4hep ongoing**:

- Integrate the **crystal DR calorimeter** option in the **Full Simulation of the IDEA detector** and validate the simulation tool
- crystal calorimeter implementation based on the work done for the **fiber calorimeter** by **Sanghyun Ko**
- **work in progress on:**
  - digitization
  - reconstruction
  - dedicated particle flow algorithm

DD4HEP -- calorimeter geometry



W.P. Chung (Princeton)

Input for:

- **optimization** of calorimeter longitudinal and transverse segmentation
- a **dedicated particle flow algorithm**
- study **on physics program**

Summary of the status/plans

The addition of a dual-readout crystal EM section calorimeter to the already proposed dual readout fiber calorimeter improves **EM** energy resolution at the **3%/√E level**

- enhance sensitivity to **low energy photons** → expand physics potential of e+e- collider experiments
- **crystal + fiber** calorimeter:
  - can meet the requirements of EM, HAD and jet energy resolution with dedicated **dual-readout particle flow** algorithms

Several efforts are ongoing to demonstrate the **feasibility** of the **simultaneous reading of S and C signals**:

- **R&D** on the optimal combination of crystals, filters and SiPM:
  - achieve the necessary **yield** and **purity** of S and C signals
- **Simulation:**
  - **key4hep** integration of the full IDEA detector
  - input for physics cases, studies on dedicated **DR particle flow** algorithm

Backup