SQM2022

Simulation Study of Dual-readout Calorimeter for the EIC

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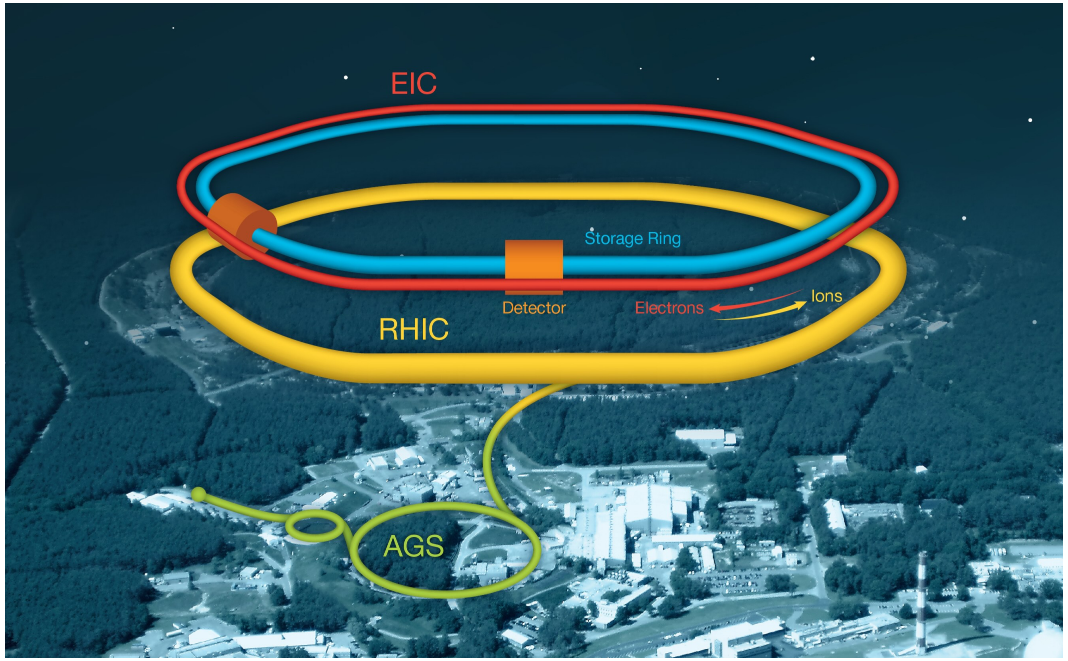
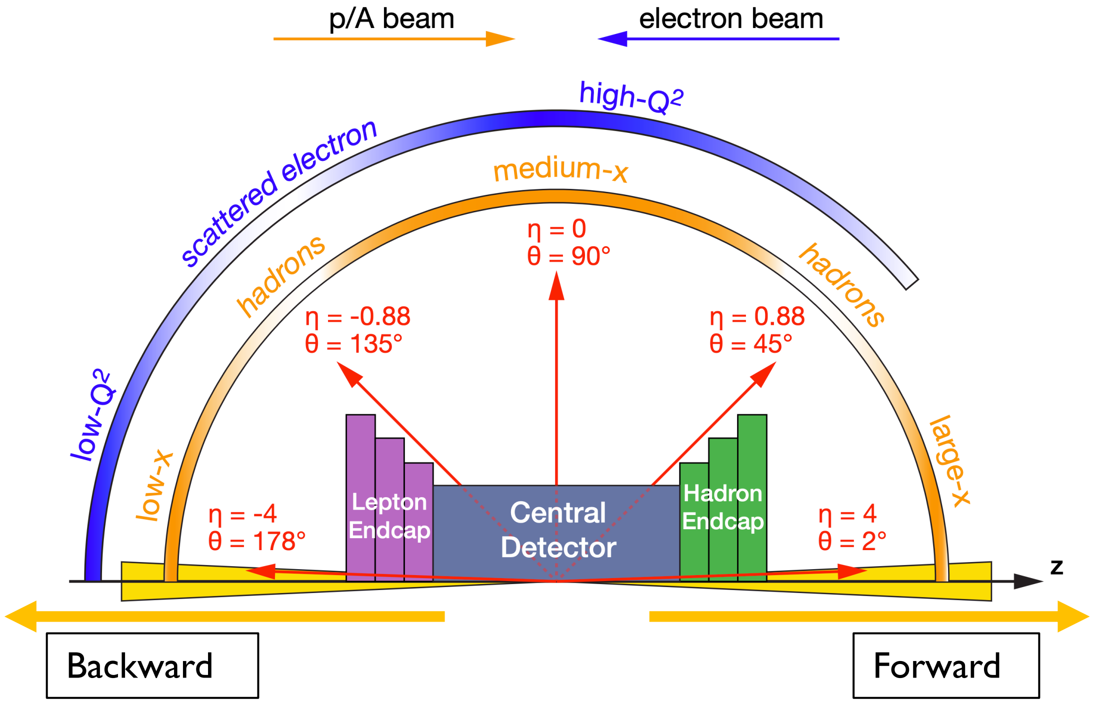
On behalf of Korea Dual-readout Calorimeter team

Supported by KiSTi www.kisti.re.kr

Electron Ion Collider (EIC)





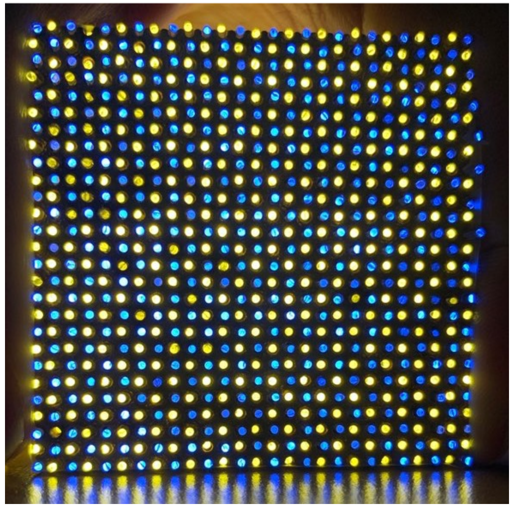
- Physics topics:
  - Origin of nucleon spin and mass
  - Spatial distribution of partons
  - Nuclear modification of PDFs
  - Cold QCD Matter

- Observables:
  - Various DIS (semi-, inclusive, …)
  - Heavy-flavor hadrons and J/ψ
  - Di-hadron correlation
  - Jet

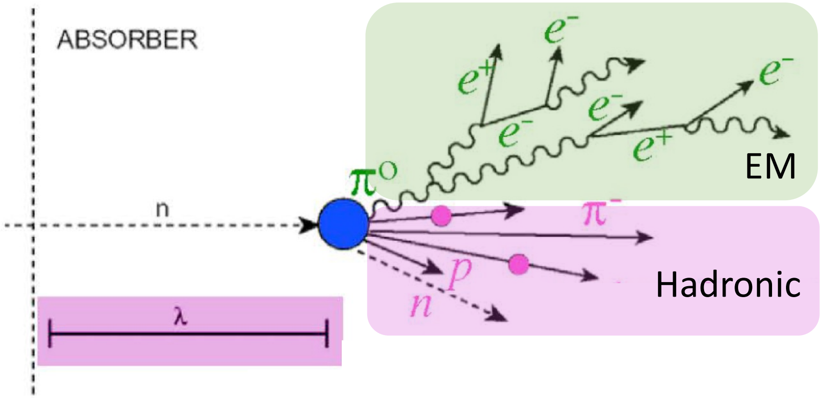
- Detector Requirements(Calorimeter):
  - EM energy resolution
    - Central : $10\% / \sqrt{E} \otimes (1\sim3\%)$
    - Backward : $2\% / \sqrt{E} \otimes (1\sim3\%)$
  - Hadron energy resolution
    - **Forward : $50\% / \sqrt{E} \otimes (1\sim3\%)$**

Dual-Readout Calorimeter (DRC)

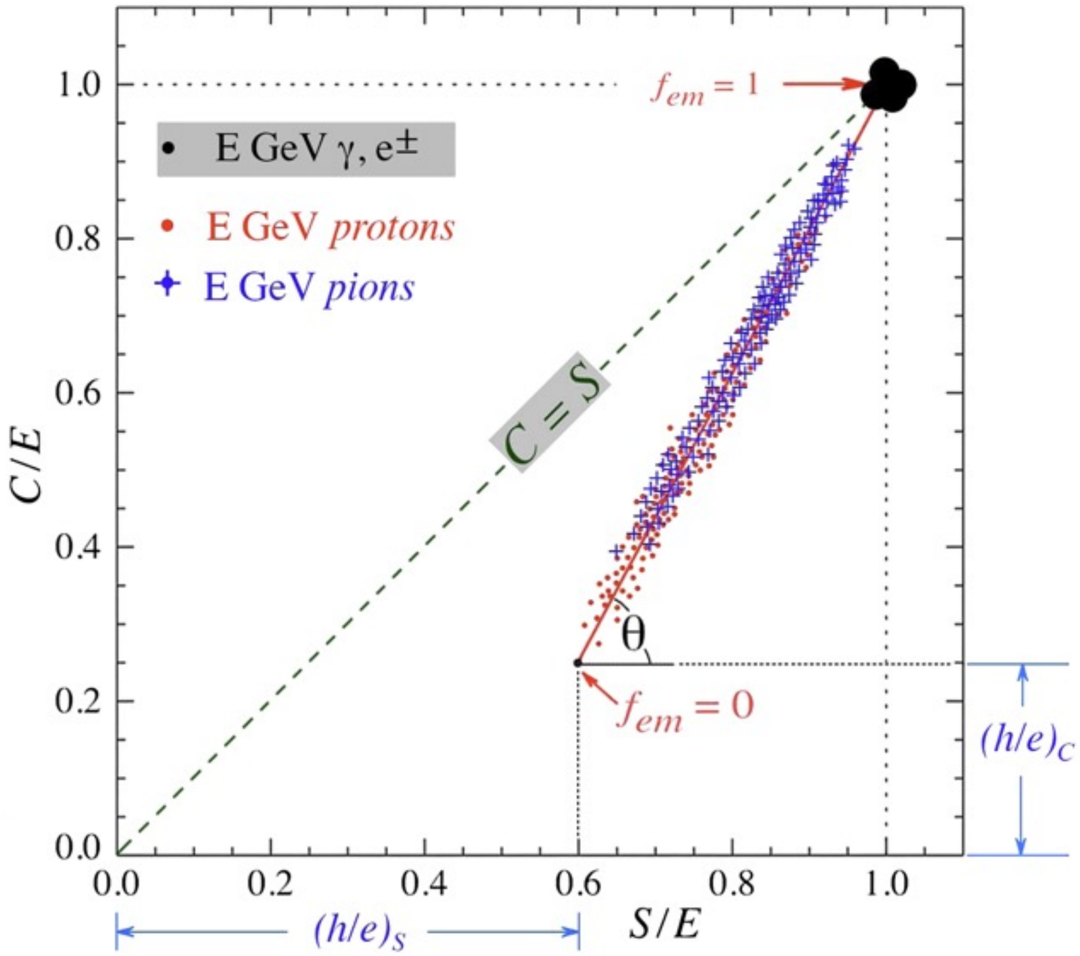
- Detector Concepts:
  - Two different optical fiber (Cherenkov & Scintillator)
  - EM fraction(f_{EM}) of hadron shower measured with different response of EM and hadronic component
  - **Excellent hadron energy resolution** by correcting energy of hadron event by event



Fiber arrangement



Hadron shower schematics



Dual-Readout Calorimeter (DRC)

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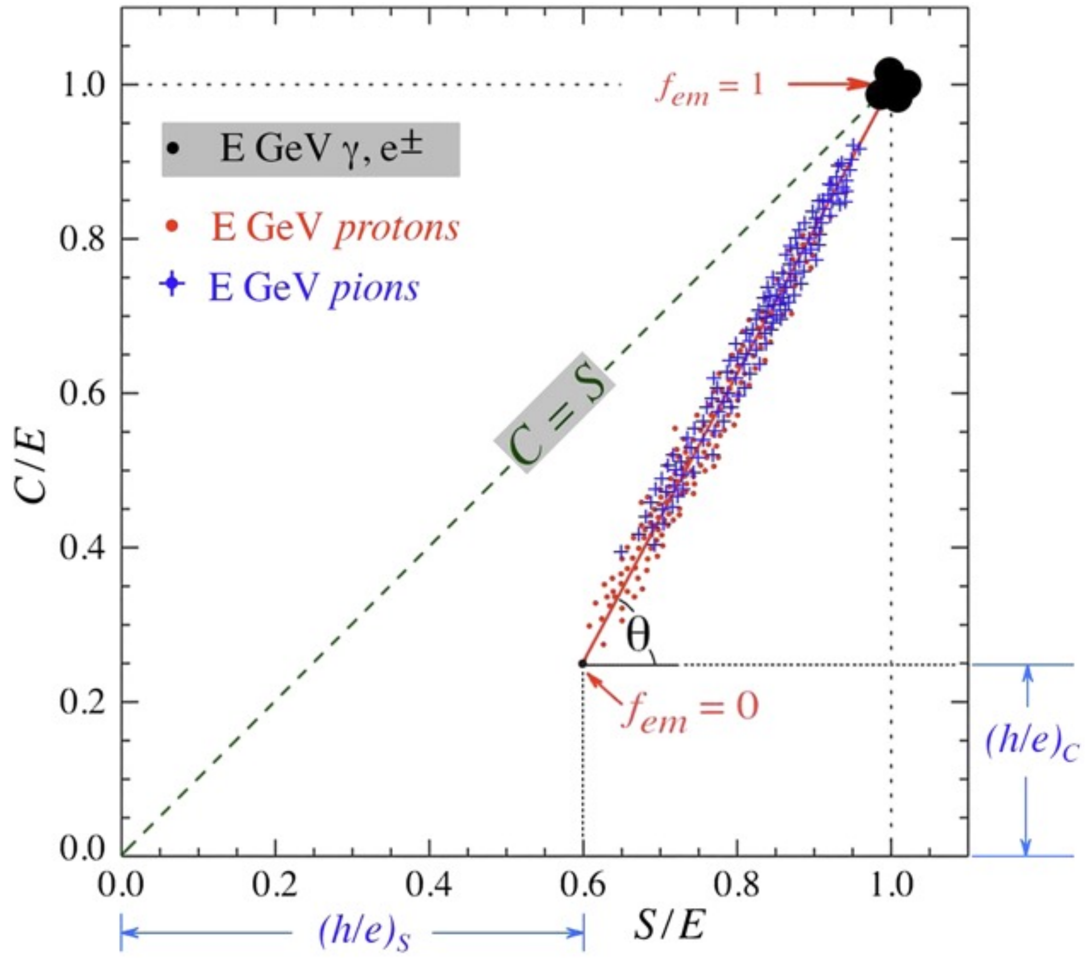
- Dual readout correction

$$E_S = E[f_{EM} + (h/e)_S(1 - f_{EM})]$$
$$E_C = E[f_{EM} + (h/e)_C(1 - f_{EM})]$$

$$f_{EM} = \frac{(h/e)_C - (E_C/E_S)(h/e)_S}{(E_C/E_S)[1 - (h/e)_S] - [1 - (h/e)_C]}$$

$$\cot(\theta) = \frac{1 - (h/e)_S}{1 + (h/e)_C} = \chi \qquad E = \frac{E_S - \chi E_C}{1 - \chi}$$

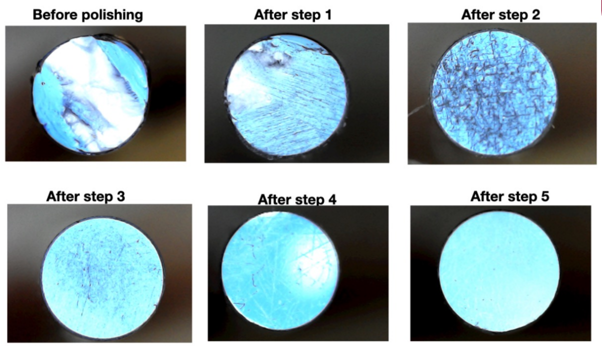
Obtain from experiment(TB)



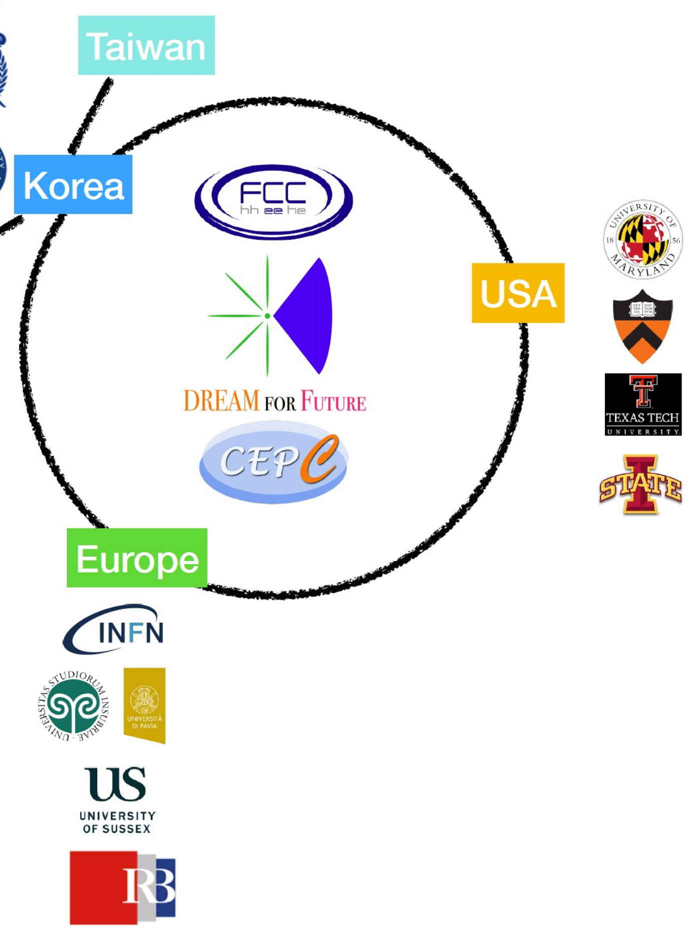
List of activities in Korean group

- Korean team led the design of the Dual-Readout Calorimeter for FCC-IDEA
  - R&D efforts are actively on-going
  - Optical fibers
  - Electronics
  - Supporter & assembly
  - Cu forming

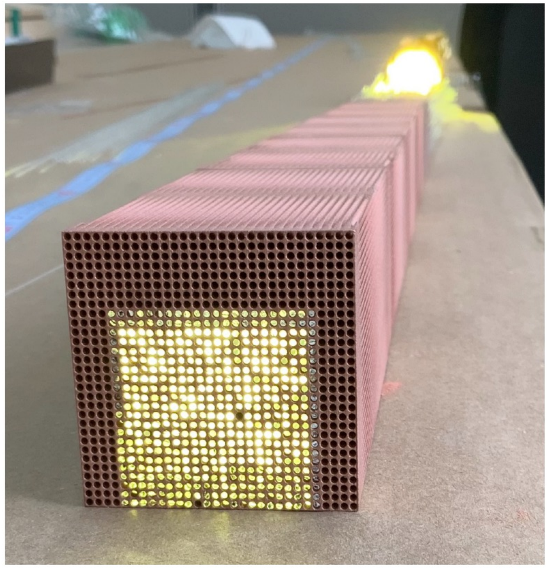
Fiber polishing



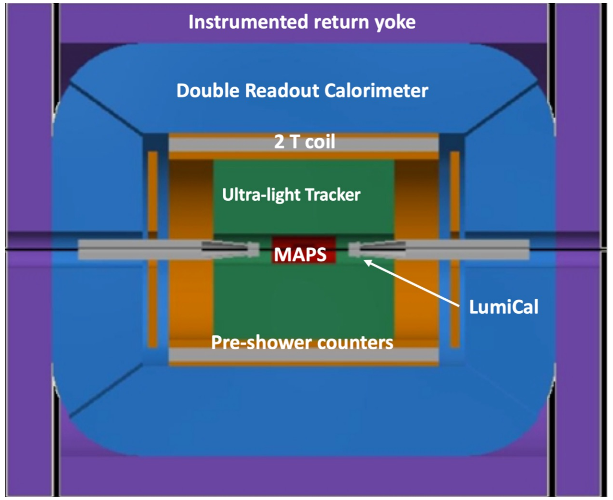
International collaboration



3D metal printing



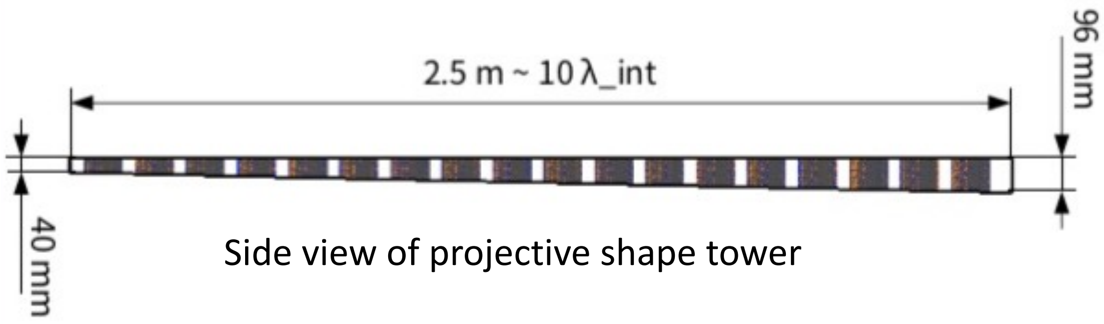
Stacking



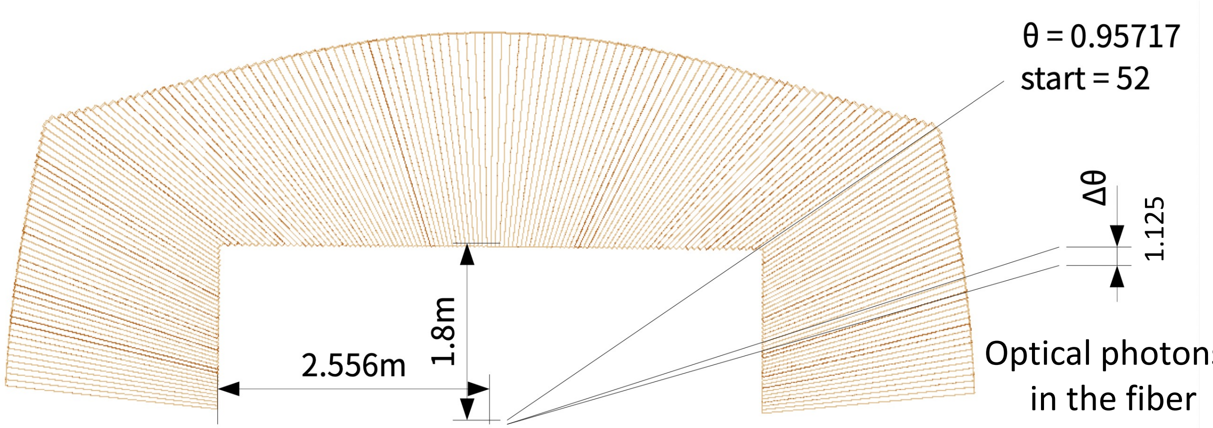
IDEA

Simulation R&D in the Korean group

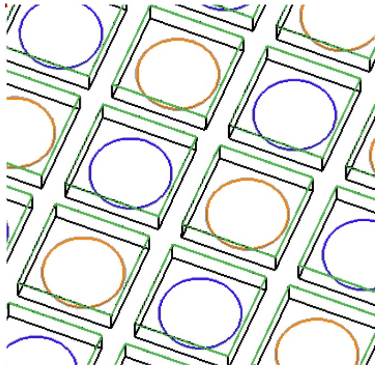
- Simulation study for the FCC-IDEA:
  - GEANT4 simulation framework based on the DD4HEP
  - Extensive performance studies to optimize the design
  - Fast simulation for optical photon transport through fibers

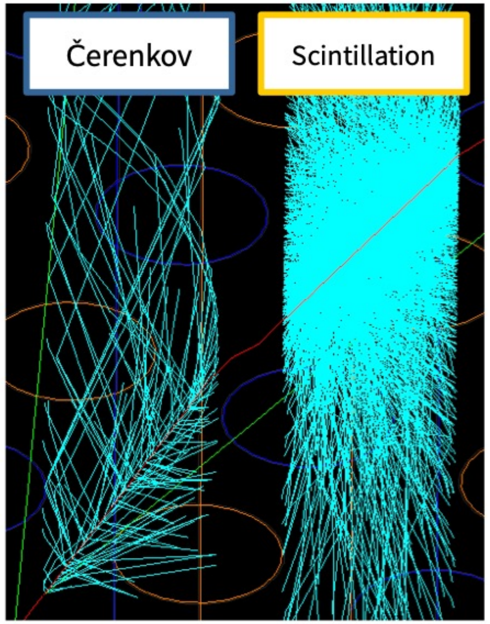


Side view of projective shape tower



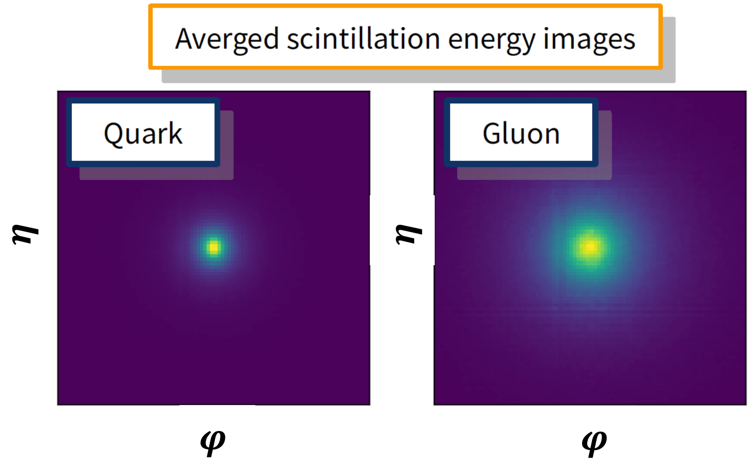
Rear end of fibers

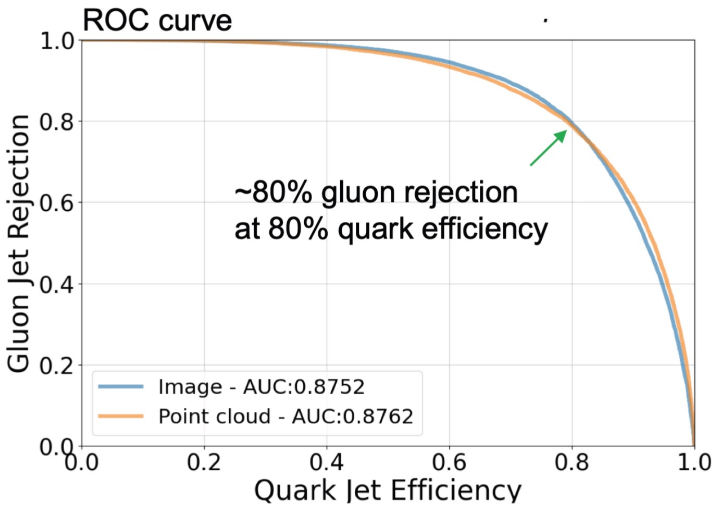




Optical photons in the fiber (Cyan line)

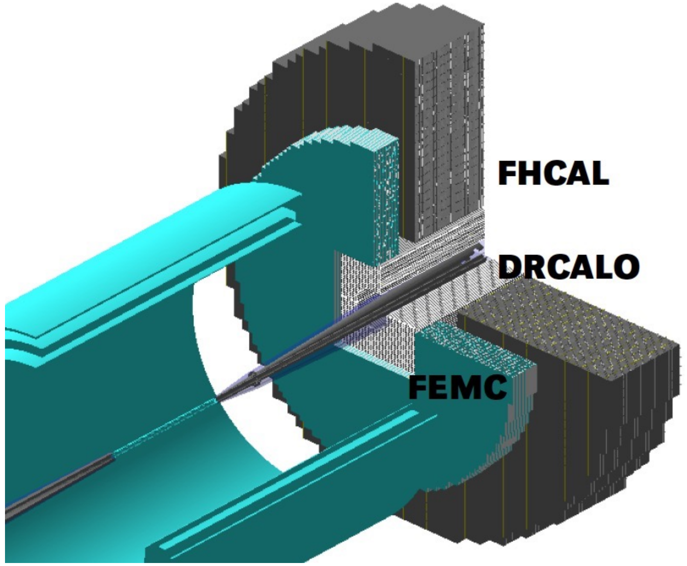
Jet identification with ML





Simulation R&D in the Korean group

- DRC in EIC simulation framework:
  - Upgrade option for the forward HCAL
  - Tower length : 1.25m (half of FCC-IDEA design)
  - **Lack of DRC details**
    Directly read energy deposition in fibers
    ➔No light propagation/attenuation
    ➔No readout simulation



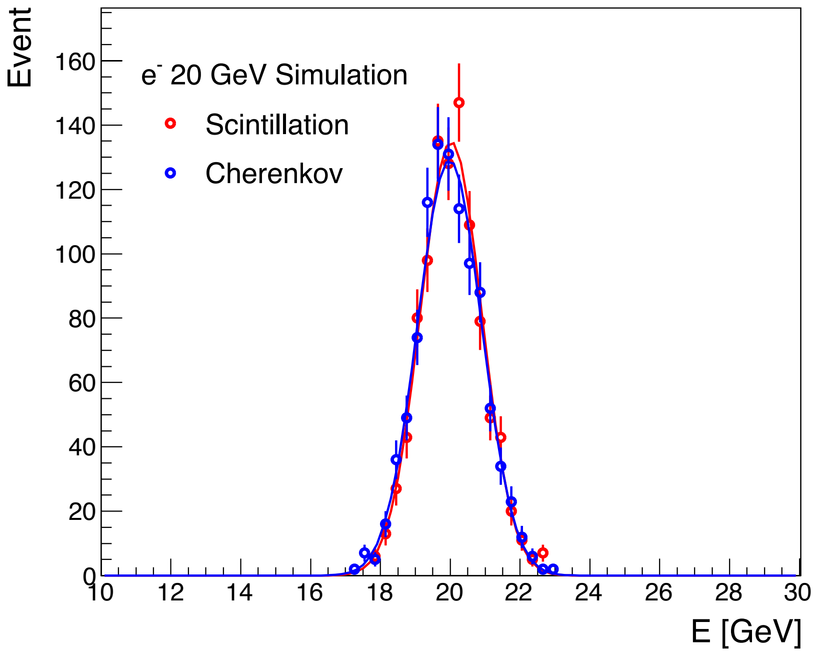
GEANT4 display with inlay DRC in EIC-ECCE

- Simulation study for the EIC:
  - With the well-developed framework for FCC-IDEA
    - SiPM implemented at the end of each tower
    - Energy deposition of propagated photons in the SiPM
  - Utilized only endcap (forward) region
  - Shorter tower length : 2.5m -> 1.25m
  - **Simulation study progressed with full details**

GEANT4 display of FCC simulation framework

Single electron performance

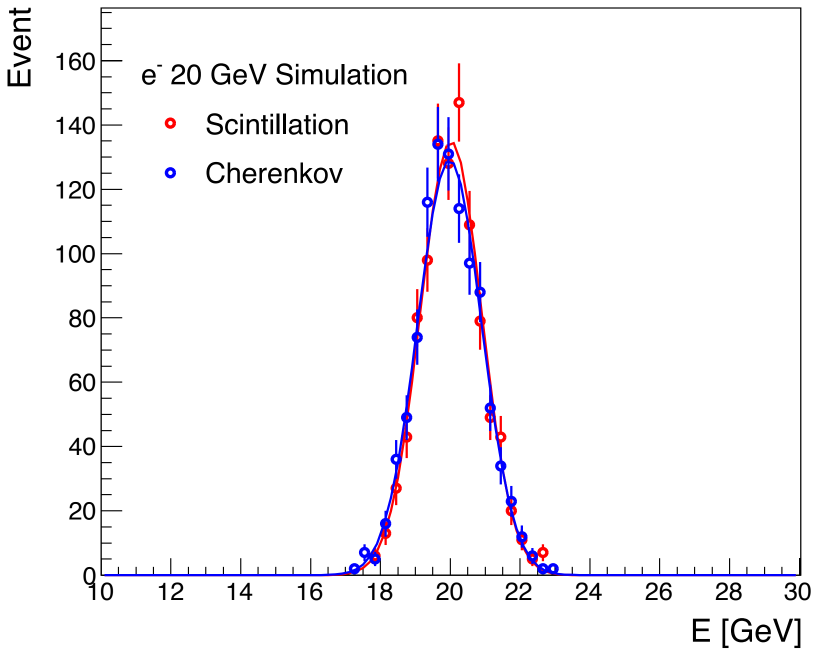
Energy deposition in two channels



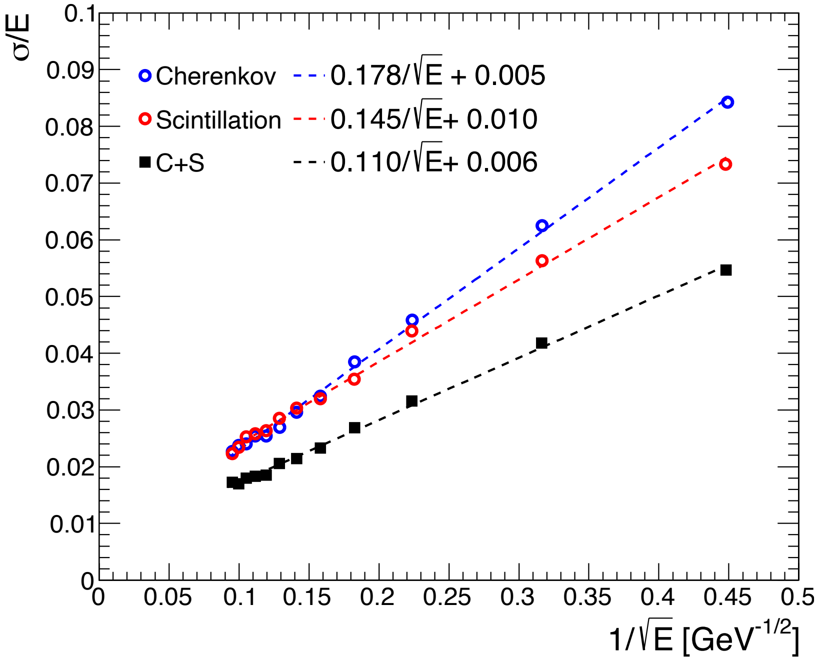
- Calibration of all endcap towers done with 20GeV e^-
- Similar response of two channels for EM shower

Single electron performance

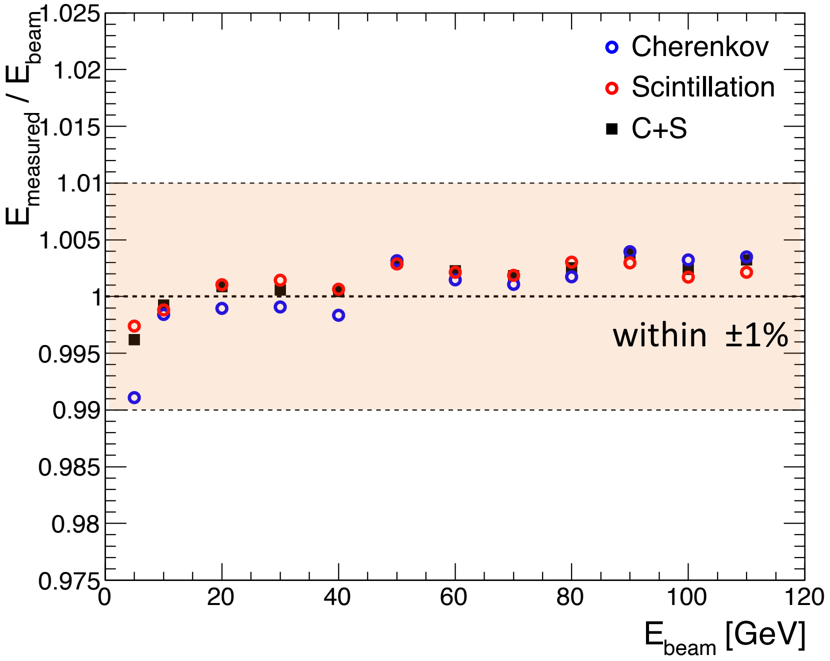
Energy deposition in two channels



EM energy **resolution**

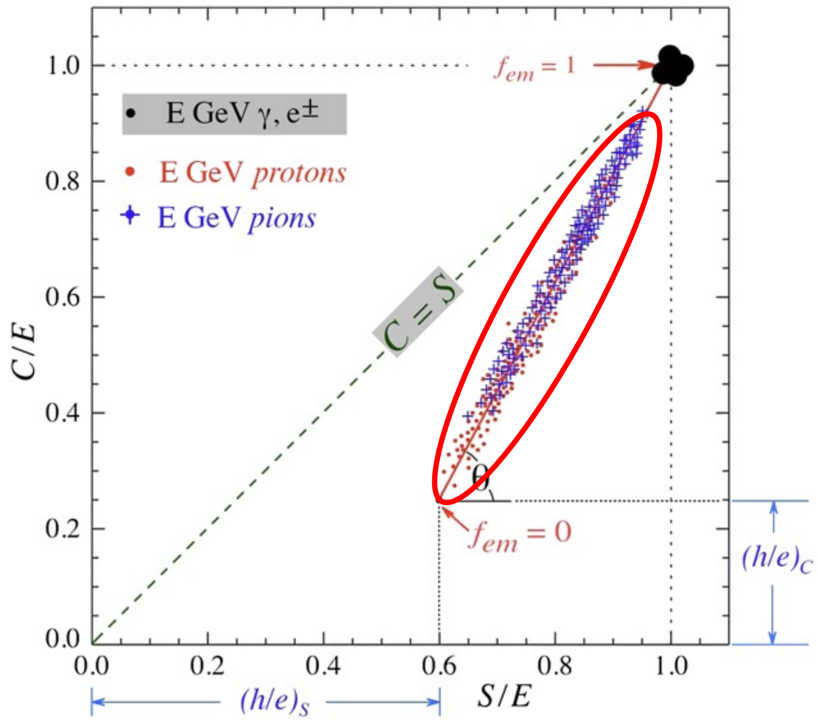


EM energy **linearity**

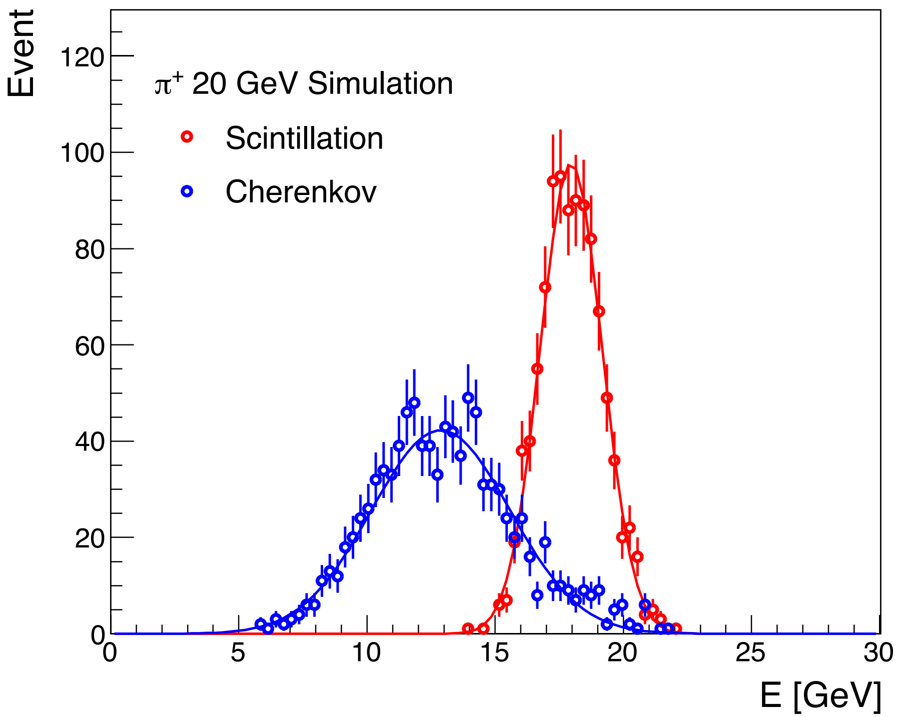


- Calibration of all endcap towers done with 20GeV e^-
- Similar response of two channels for EM shower
- Energy resolution: 11% stochastic term in the energy resolution the with combined channels
- Energy linearity: better than 1% for both and combined channels

Single hadron (π^+) performance



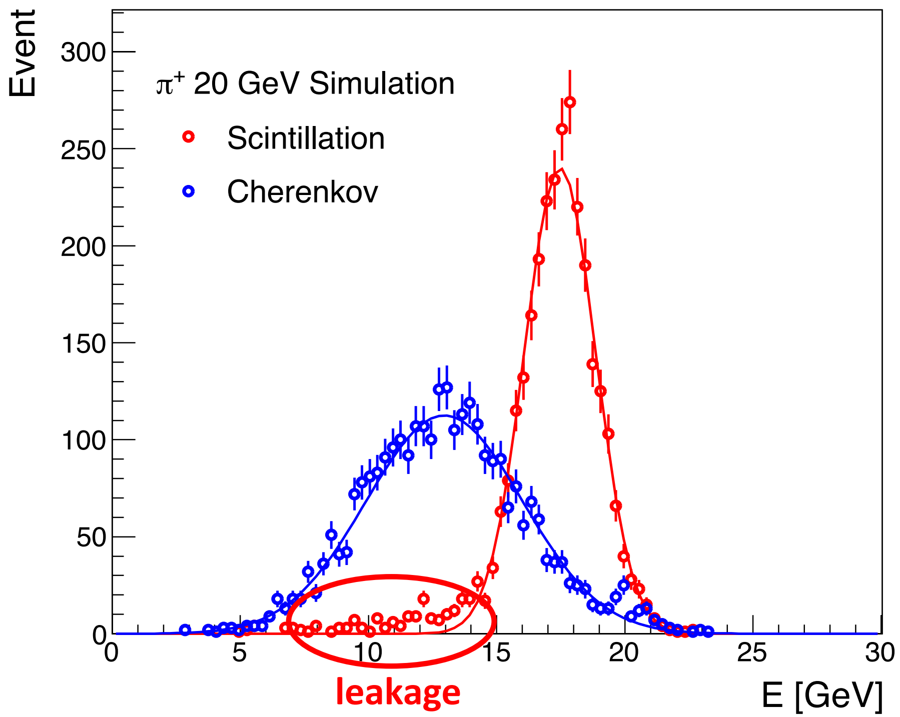
Performance of **2.5m Cu DRC**



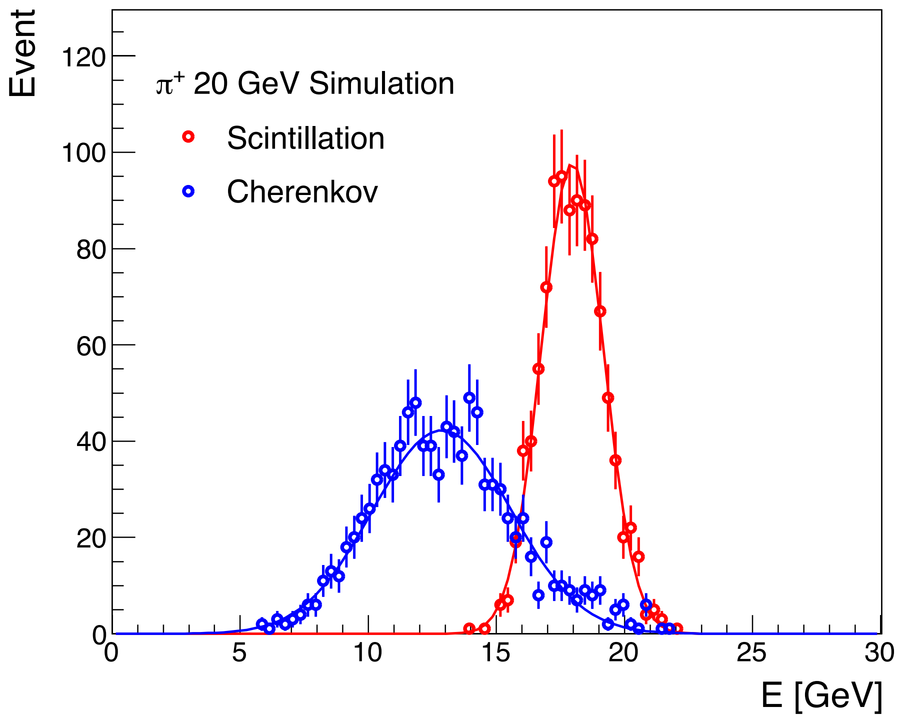
- Different responses of two channels for hadron shower
- Large shower-by-shower fluctuation due to EM fraction variation
- EM fraction (f_{em}) can be measured based on the response of two channels and θ

Single hadron (π^+) performance

Performance of **1.25m Cu DRC**

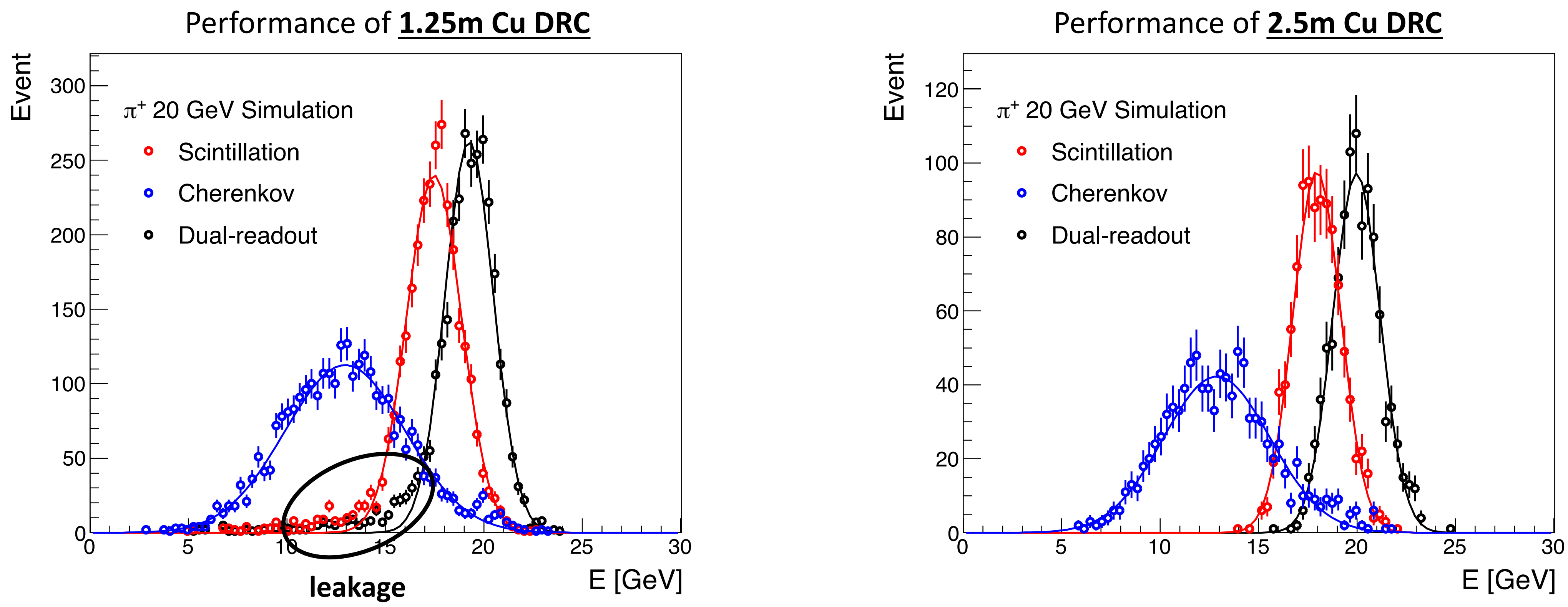


Performance of **2.5m Cu DRC**



- Different responses of two channels for hadron shower
- Large shower-by-shower fluctuation due to EM fraction variation
- EM fraction (f_{em}) can be measured based on the response of two channels and θ
- Longitudinal shower leakage with the EIC design (1.25 m of tower length)

Single hadron (π^+) performance



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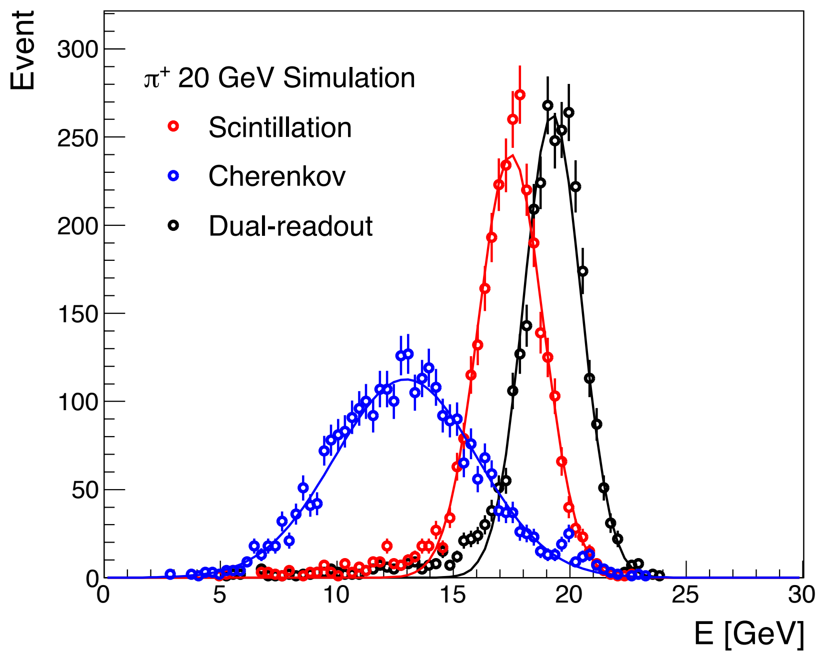
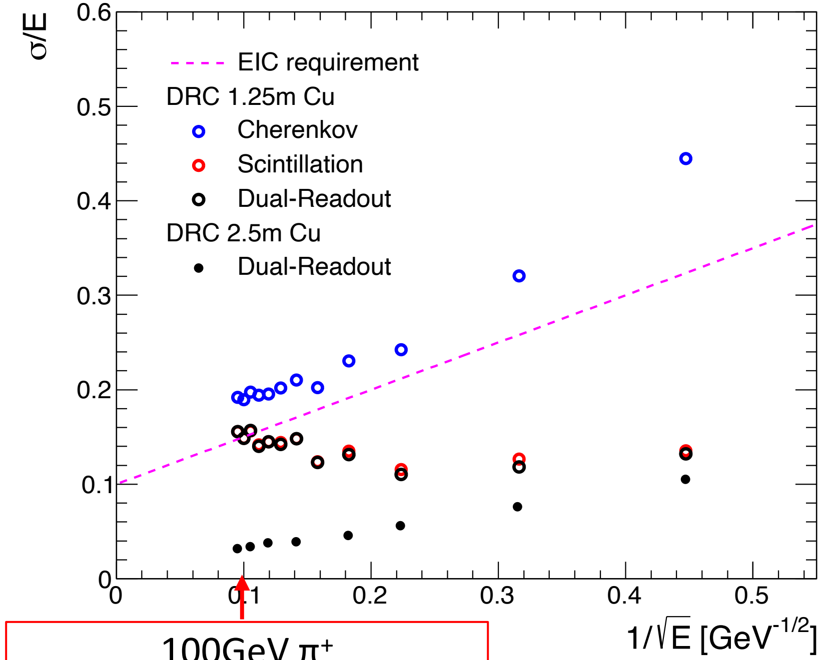
Single hadron (π^+) performance

Energy deposition in two channels

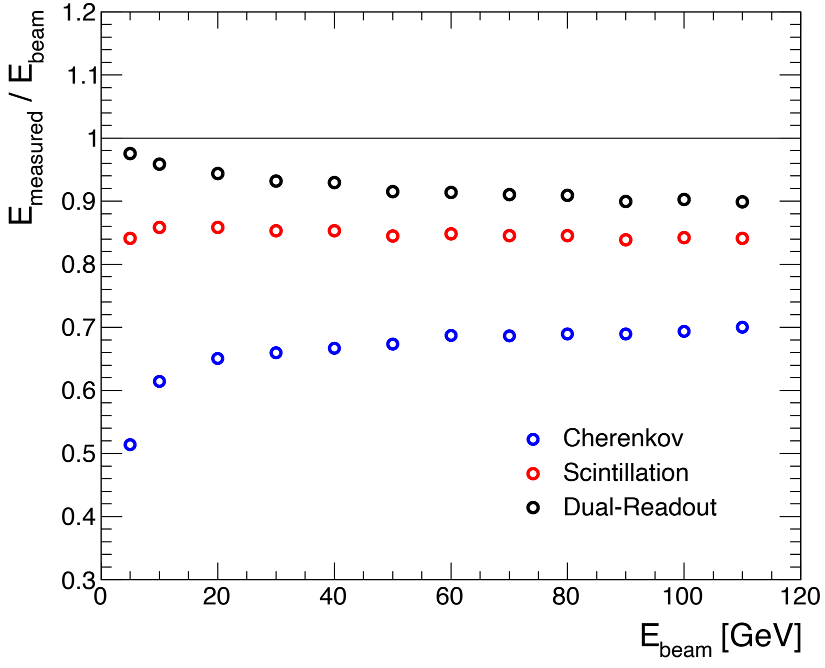


Hadron energy **resolution**



100GeV π^+
Too energetic in EIC energy

Hadron energy **linearity**



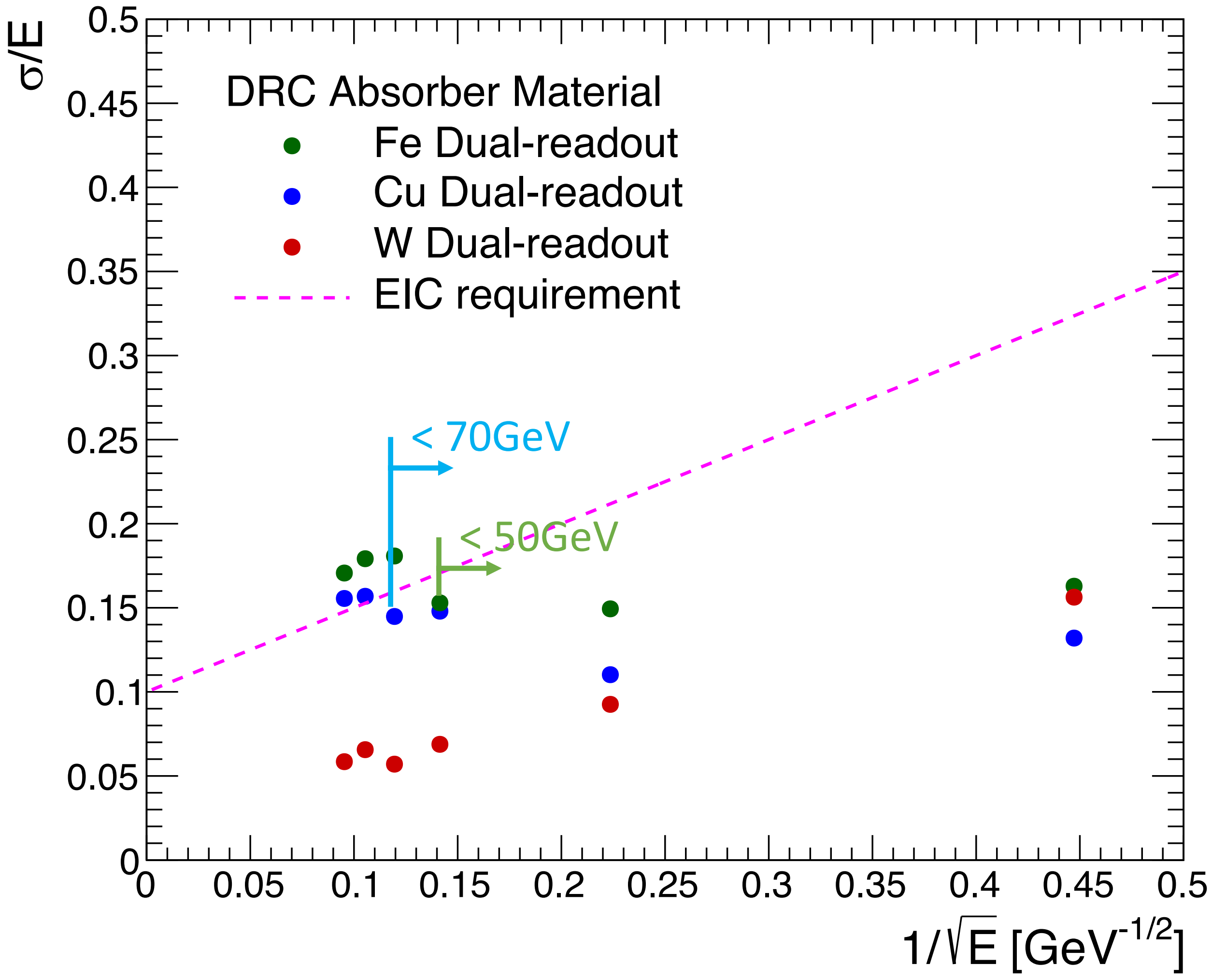
- Energy resolution with 1.25 m towers:
  - Worse resolution in higher energy due to shower leakage
  - Still satisfy the resolution required for the EIC

Performances using various absorber materials

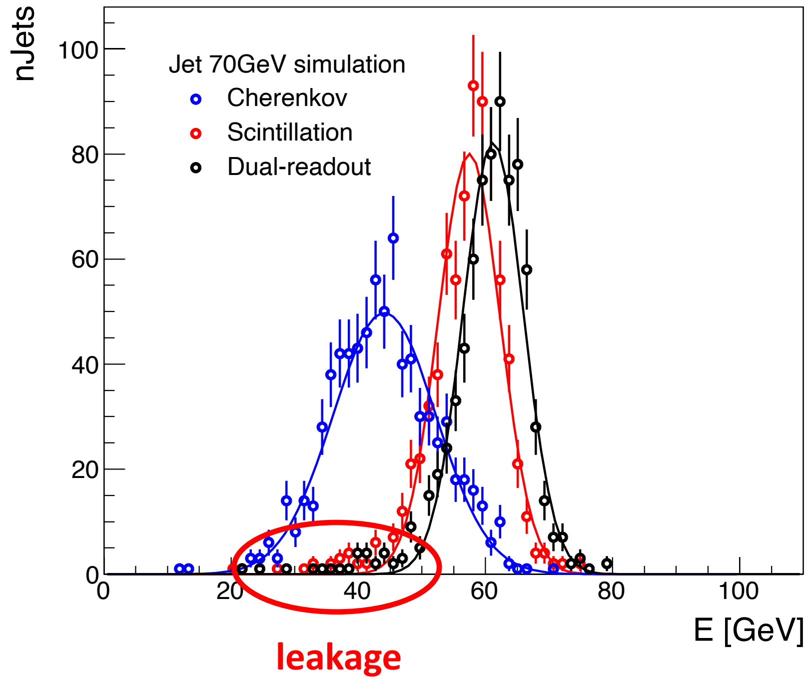
- Simulation:
  - Particle species : π^+
  - Tower length : 1.25m (EIC-DRC)
  - Same correction factor for all materials

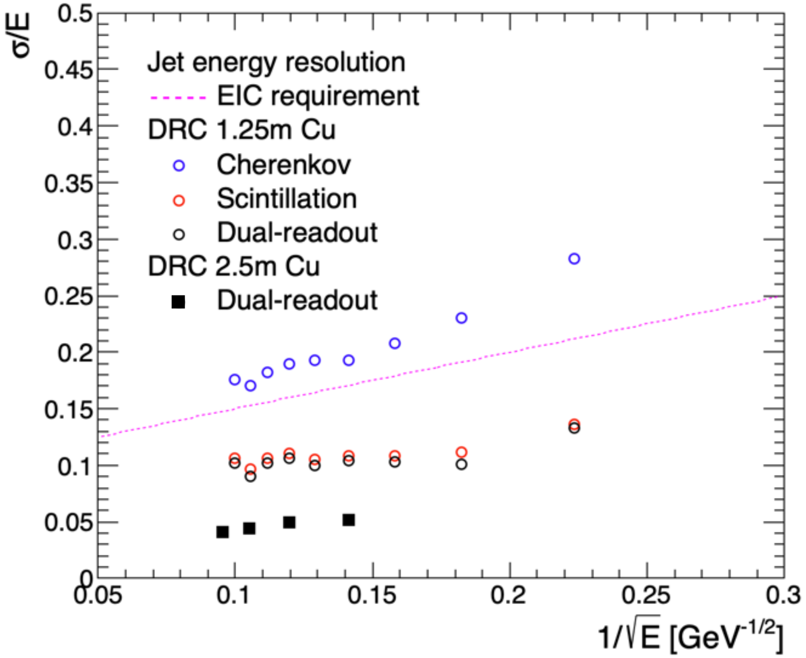
    $\chi_{copper} = 0.291$

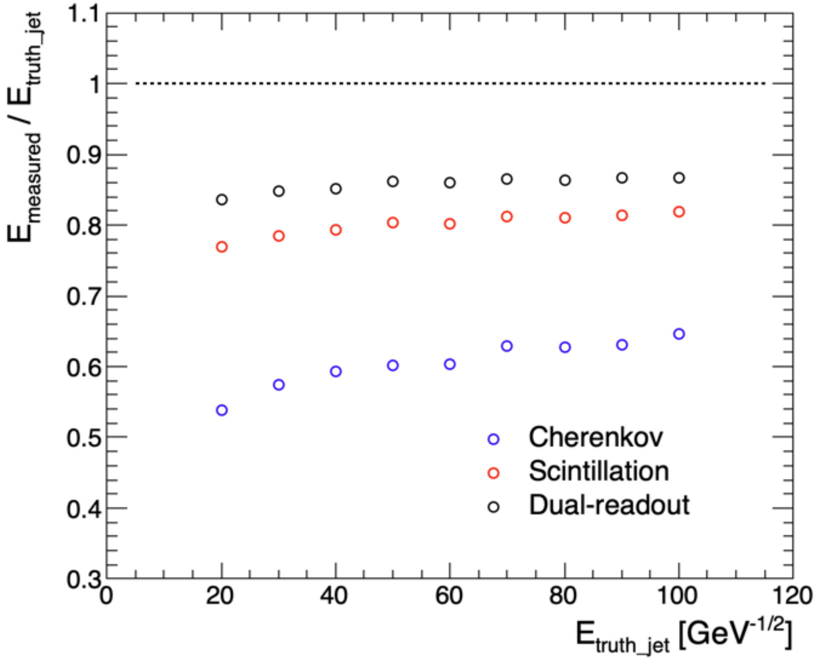
- Iron
  - Recommended material for flux return
  - Satisfy the requirement at E<50 GeV
- Copper
  - Do not strongly interact in the magnetic field
  - Satisfy the requirement at E<70 GeV
- Tungsten
  - Highest density
  - Best performance (No leakage)



Advanced study: Jet energy measurement

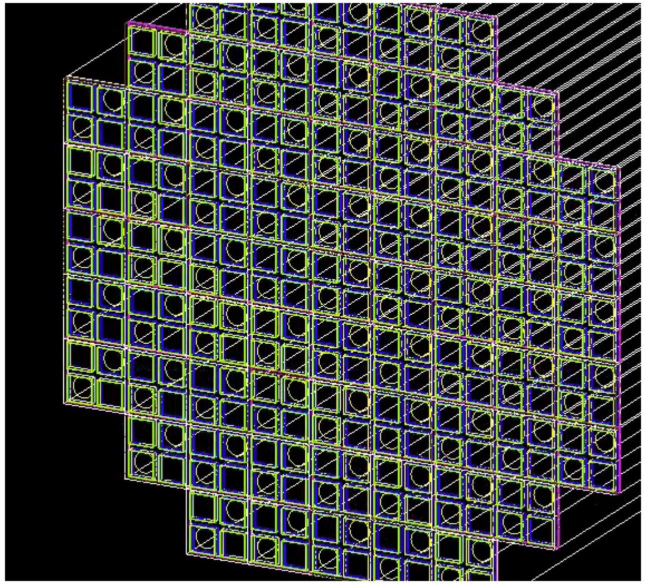




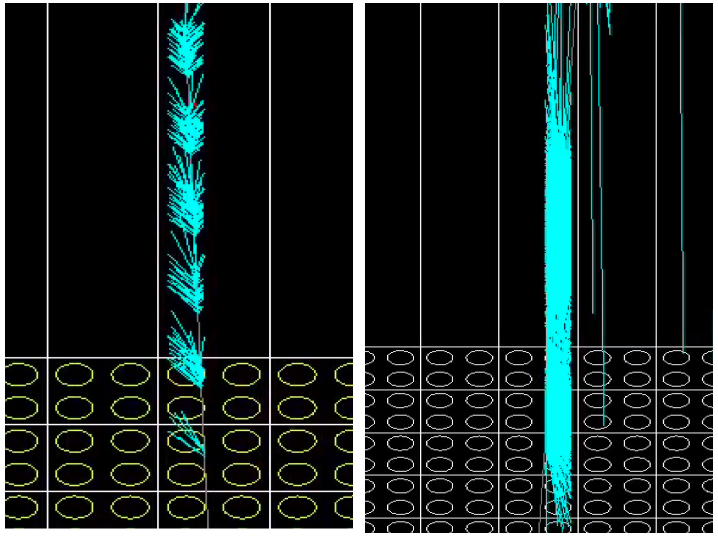


- Di-jet events of u-quark pair, jet reconstruction with the anti-k_T algorithm (R=0.8)
- DRC with 1.25 m Cu towers satisfies the EIC requirement even with a small shower leakage
- Jet measurement with other absorber material is underway

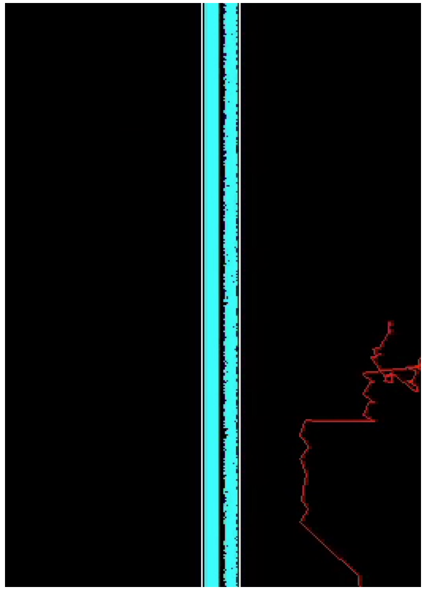
Status & Plan – Simulation for the EIC



End of towers in EIC framework



Without optical photon propagation

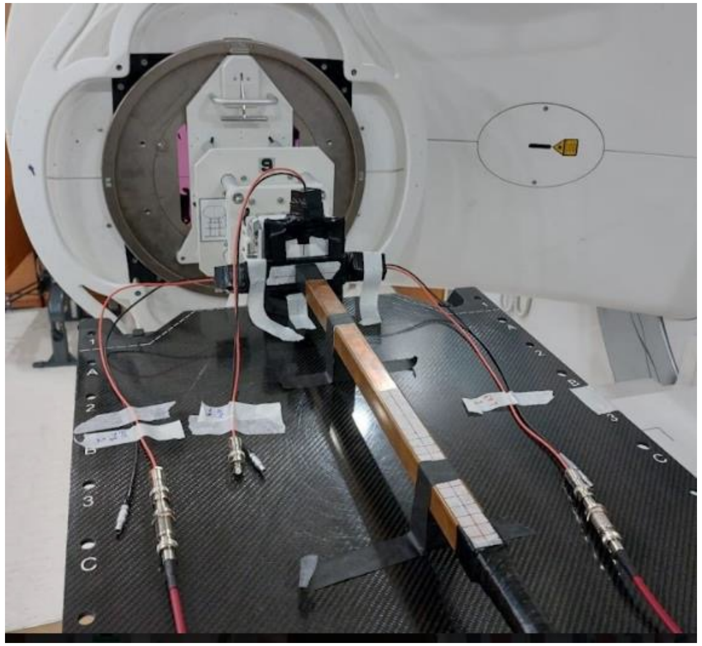


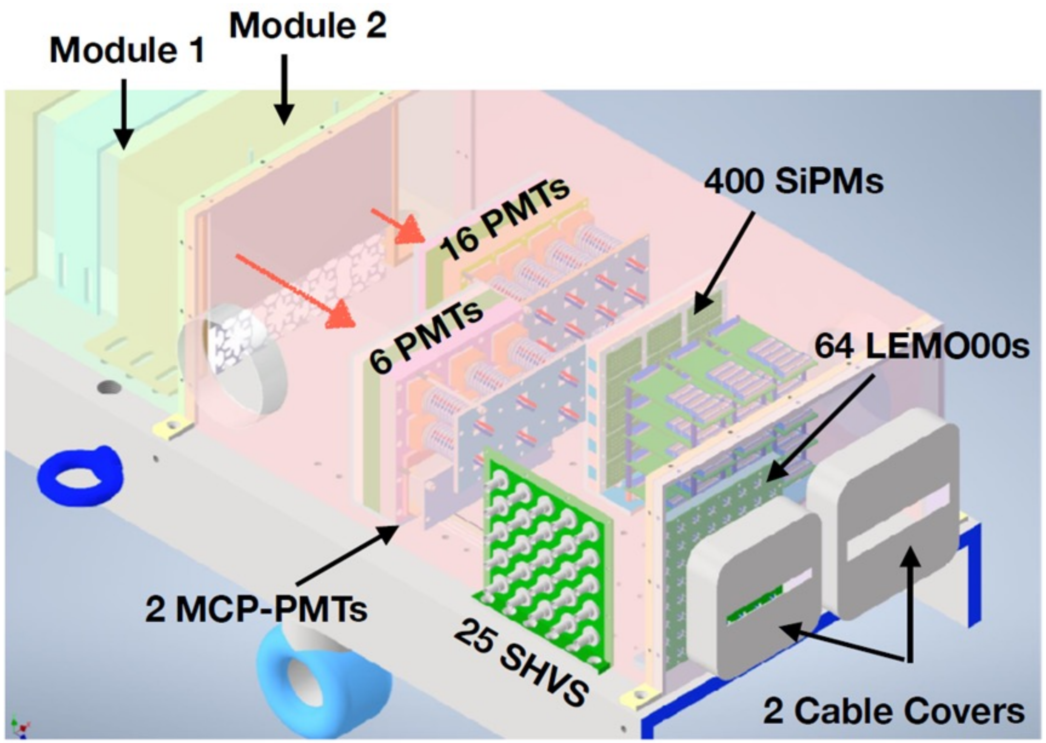
With optical photon propagation

- Implementation of simulation details to the EIC simulation framework
  - Optical photon propagation
  - Readout with SiPM
  - Current status:
    - Validation of optical propagation
    - SiPM material at the end of each fiber

Status & Plan – Beamtest of prototype

Beam test of DRC module at Severance





Beam test plan at CERN

DRC module building

- Goals of beam-test:
  - Check the operation of DAQ and electronics using electron beams with prototype module (length = 50cm)
    At Severance, June 4th & July 3rd(Planned)
  - Optimize the performance of DRC full size module (length = 2.5m) and readout using beams at SPS
    At CERN, August 17 - 18

Summary

- Electron-Ion-Collider will be built for a detailed study on nucleon and nucleus

- Dual-Readout Calorimeter for a forward calorimeter
  - Two channels: Scintillation and Cherenkov
  - Excellent energy resolution by measuring the fraction of EM components
  - R&D efforts in Korean groups (originally for HEP experiments)

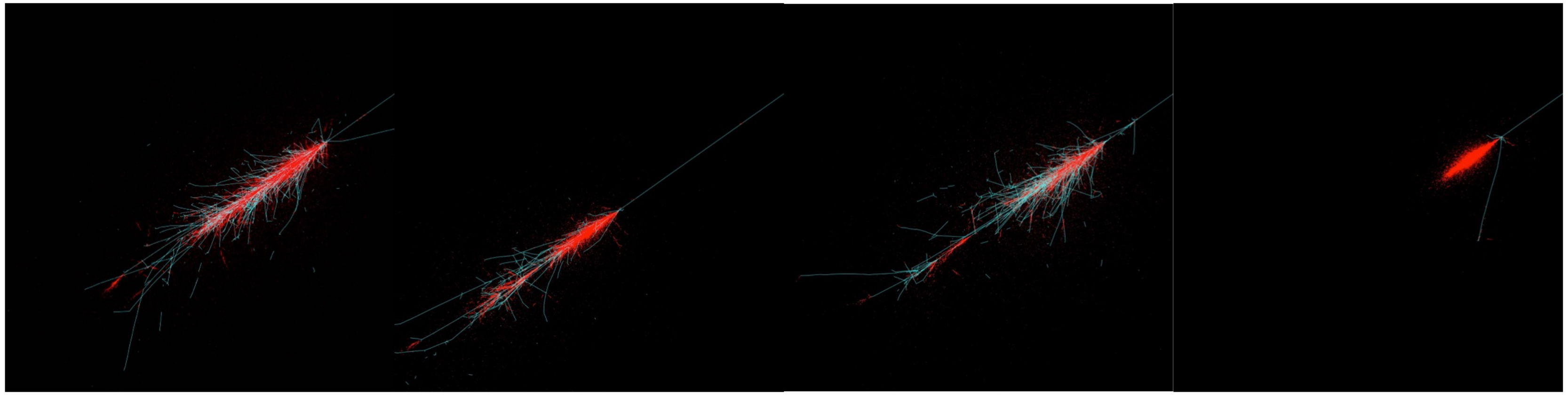
- Simulation study for the EIC
  - 1.25 m tower length for the EIC-ECCE
  - Satisfy the requirement of hadron and jet energy resolution even with a small longitudinal leakage

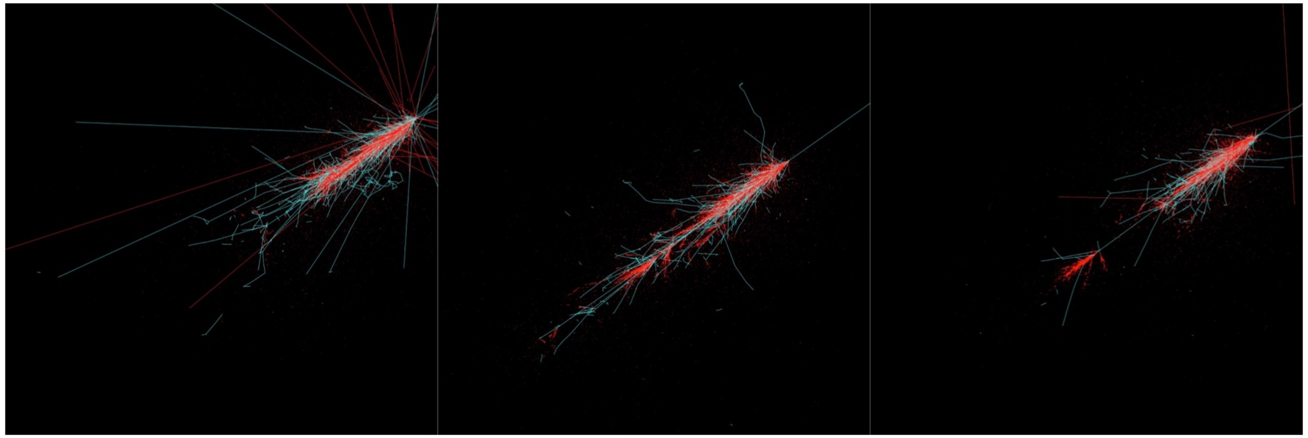
- Plan
  - Test beam at CERN on Aug (soon!)
  - Migration of simulation details to the EIC simulation framework

Fluctuations of Hadron Showers

500 GeV Pions, Cu absorber

Red: e^-, e^+ **Cyon: Other Charged Particles**





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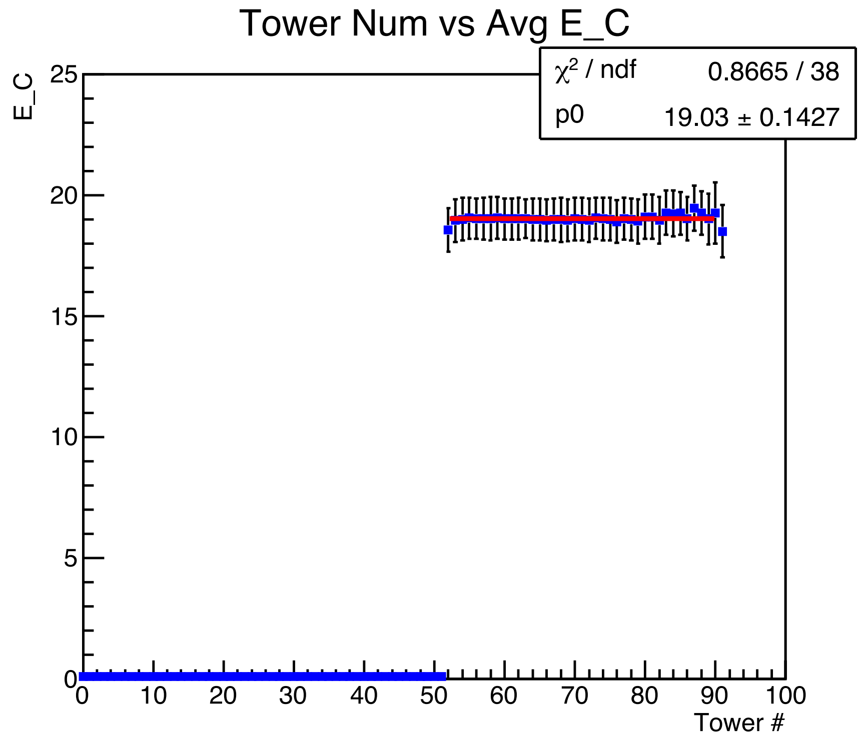
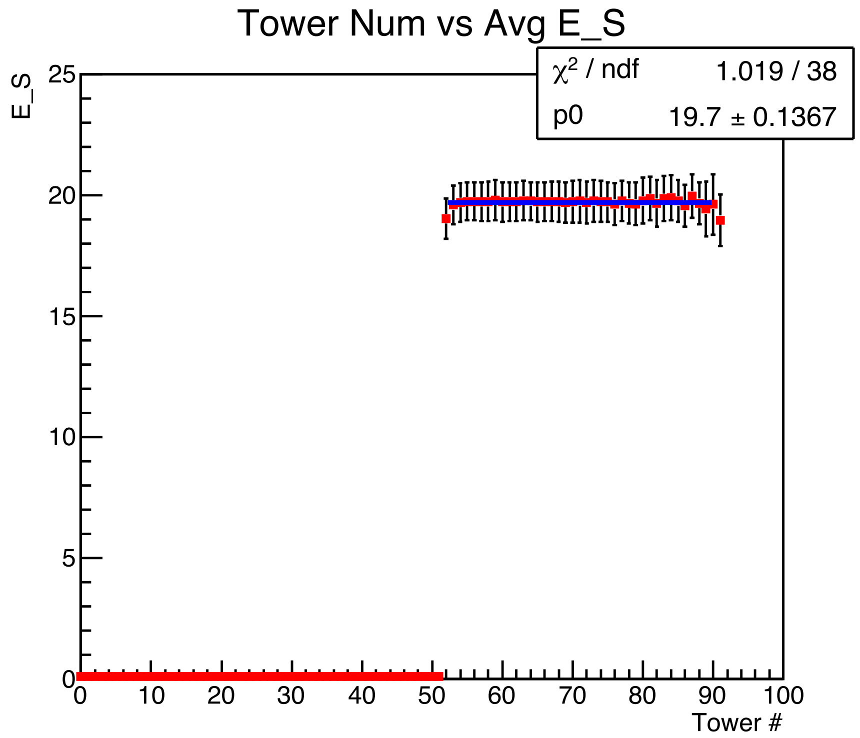
Backup

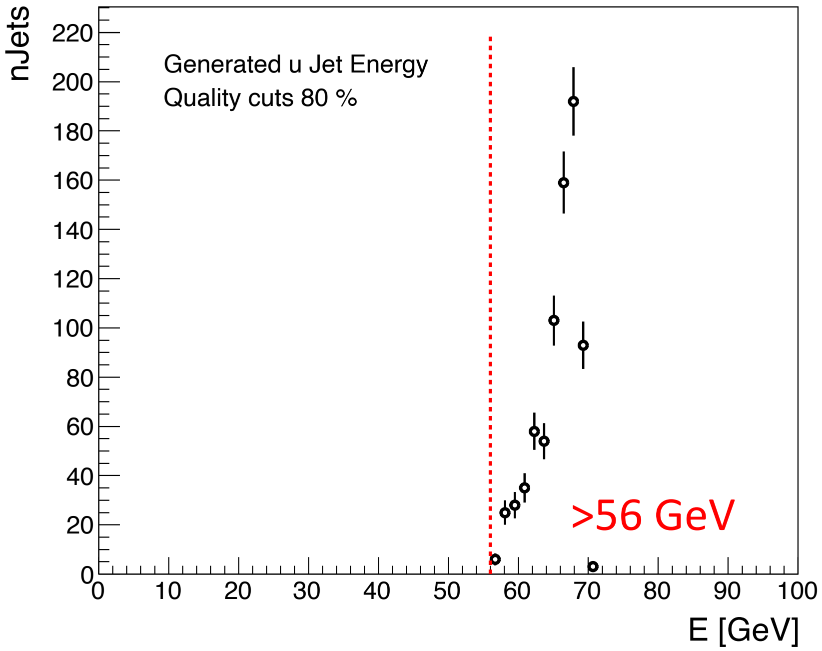
- Calibration

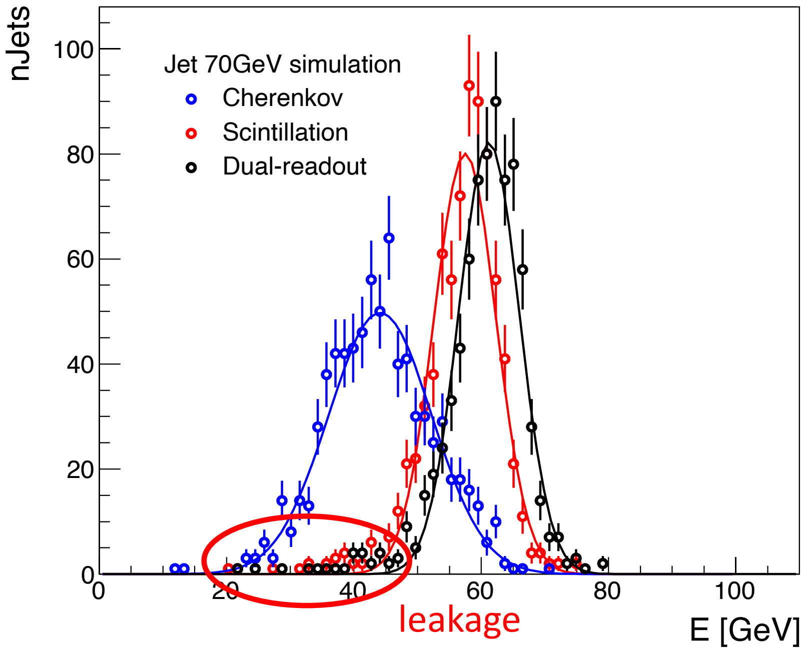




- Uniform calibration constant as a function of the tower number
- Barrel : 0 ~ 51th tower
- Endcap : 52 ~ 91th tower

Backup. Jet generation / reconstruction





- Generation:
  - Used PYTHIA8 for jet event generation
  - 500 di-jet events of u-quark pair
  - With various energy (20 ~ 100 GeV)
- Quality cut
  - Applied 80% of truth energy cut
- Reconstruction:
  - Used anti-k_T algorithm
  - Used jet cone radius R = 0.8
  - For matching jets to calculate DR corrected energy, dR < 0.3 is required