Few Degree Calorimeter (FDC) with SiPM-on-tile technology

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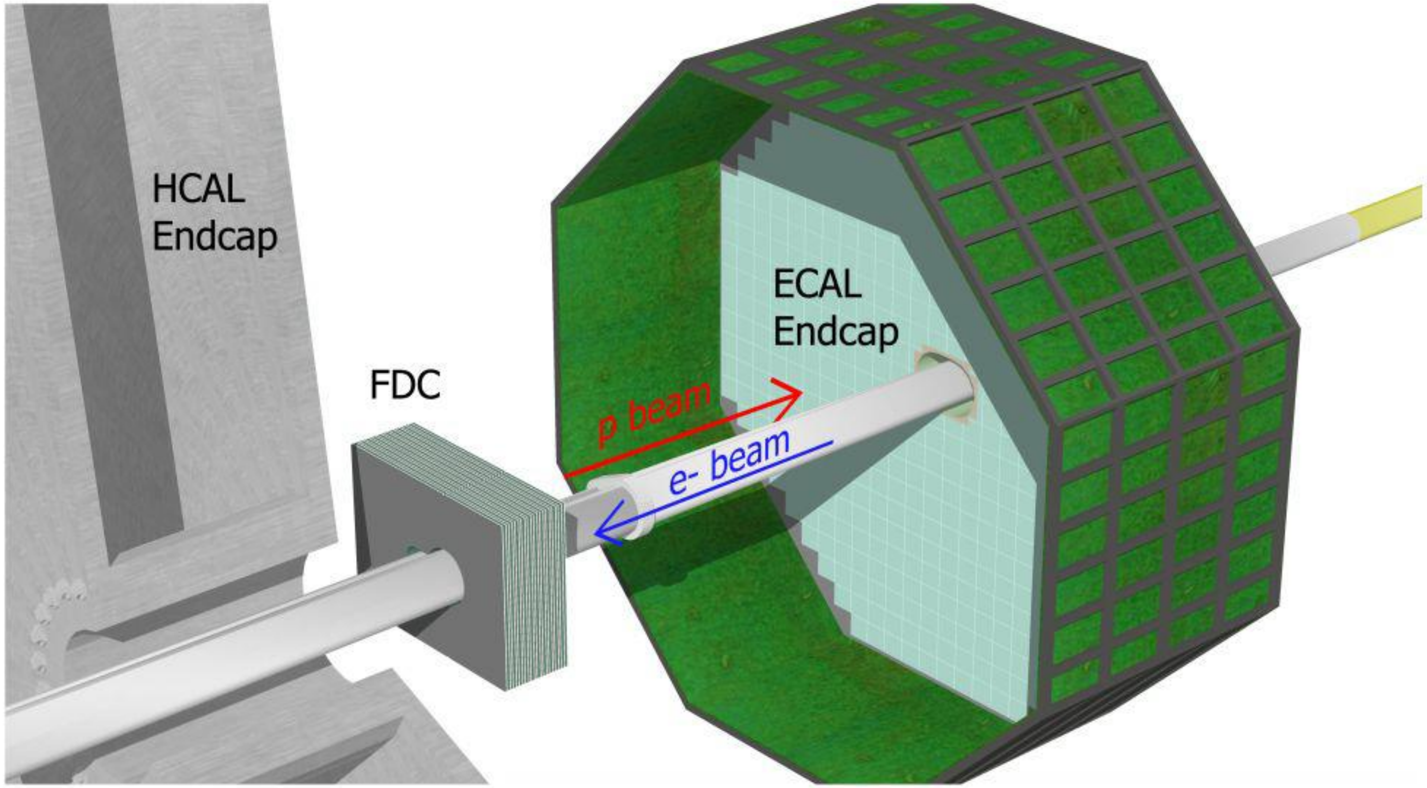
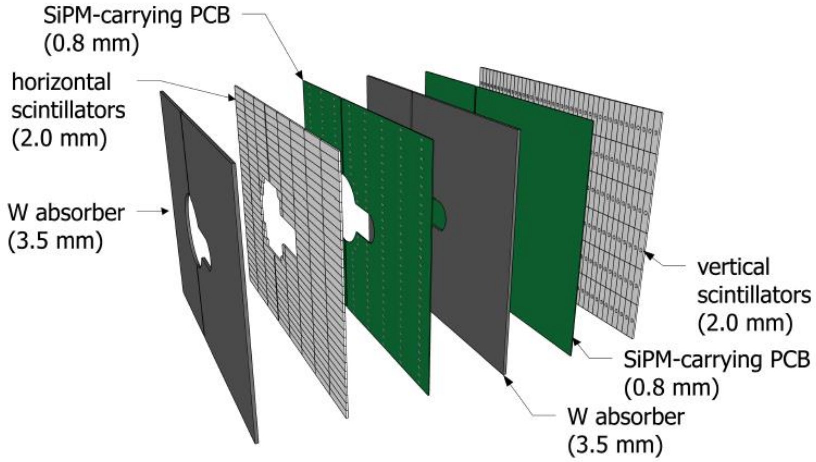
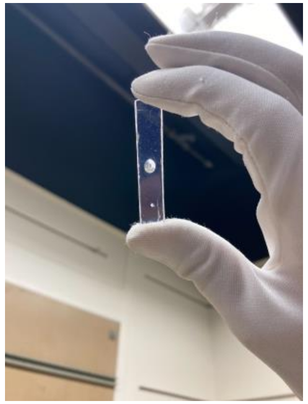
Idea and technology

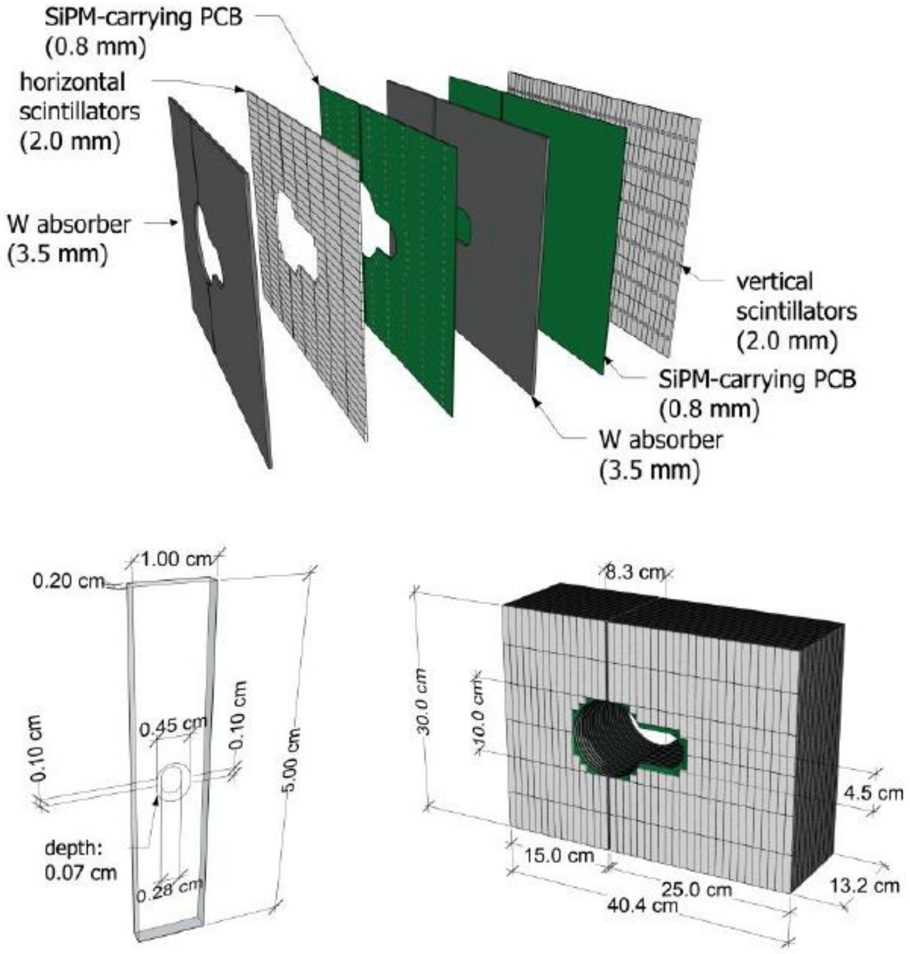
arXiv:2307.12531







Proposed FDC design



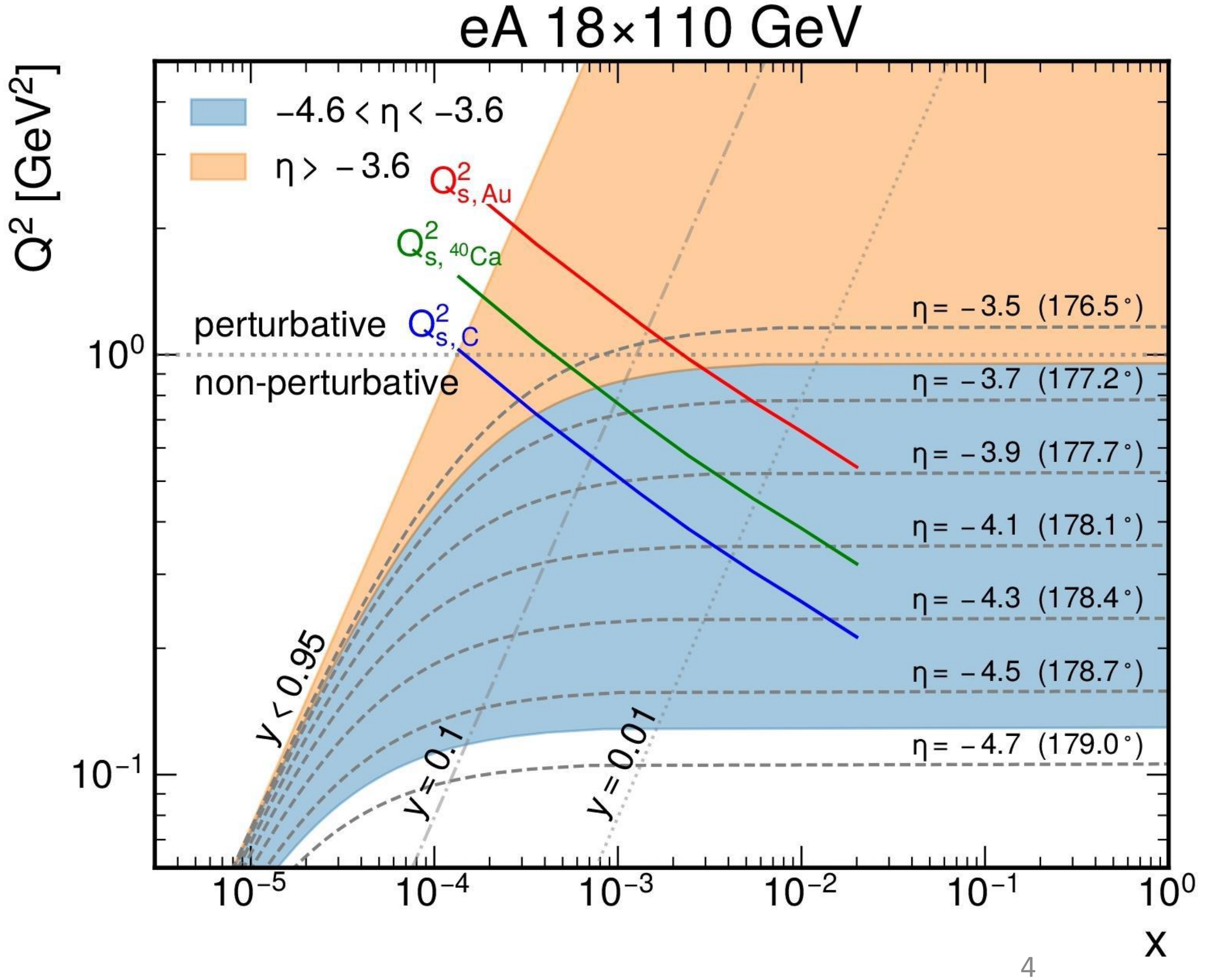
Proposed design, yet to be optimized, is a modern and improved version of ZEUS BPC

Table 3: Summary description of our proposed EIC FDC, the ZEUS BPC and the CEPC/CALICE ScECAL. The number of channels for CEPC/CALICE refer to the latest prototypes.

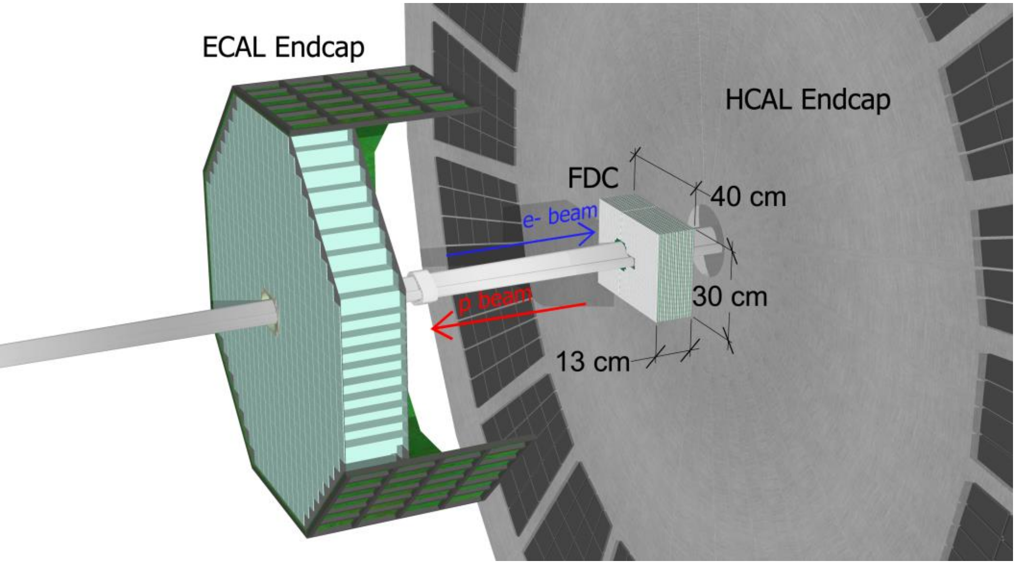
	ZEUS BPC	CEPC/CALICE	**EIC FDC**
Test beam	1994	2023	**2024 planned**
Depth	24 X_0	22 X_0	**20** X_0
W/Sc thickness	3.5/2.6 mm	3.2/2 mm	**3.5/2 mm**
Moliere Radius	13 mm	19 mm	**15 mm**
Optical readout	WLS bar+PMT	SiPM-on-tile	**SiPM-on-tile**
Trans. granularity	8×150 mm^2	5×45 mm^2	**10×50 mm^2**
Long. granularity	none	every strip	**every strip**
Readout channels	31	6720	**4500**
Electronic readout	FADC/TDC	SPIROC2E	**HGROC**
Readout location	outside	inside	**outside**
Position resolution	2.2 mm/$\sqrt{E}$	—	**2.8 mm/$\sqrt{E}$**
Energy resolution	$\frac{17\%}{\sqrt{E}} \oplus 2\%$	$\frac{15\%}{\sqrt{E}} \oplus 1\%$	$\frac{17\%}{\sqrt{E}} \oplus 2\%$
Time resolution	400 ps	—	**<50 ps**

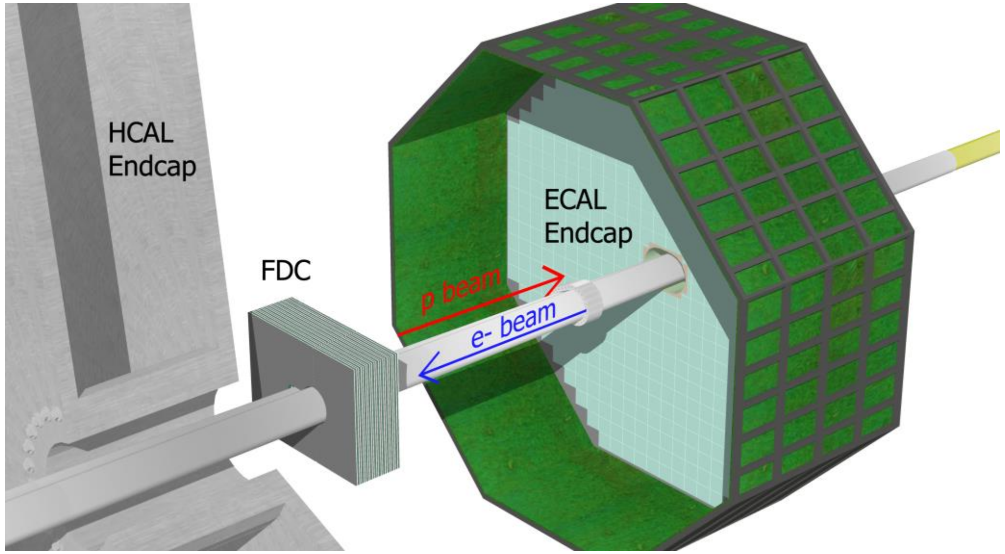
Physics motivation

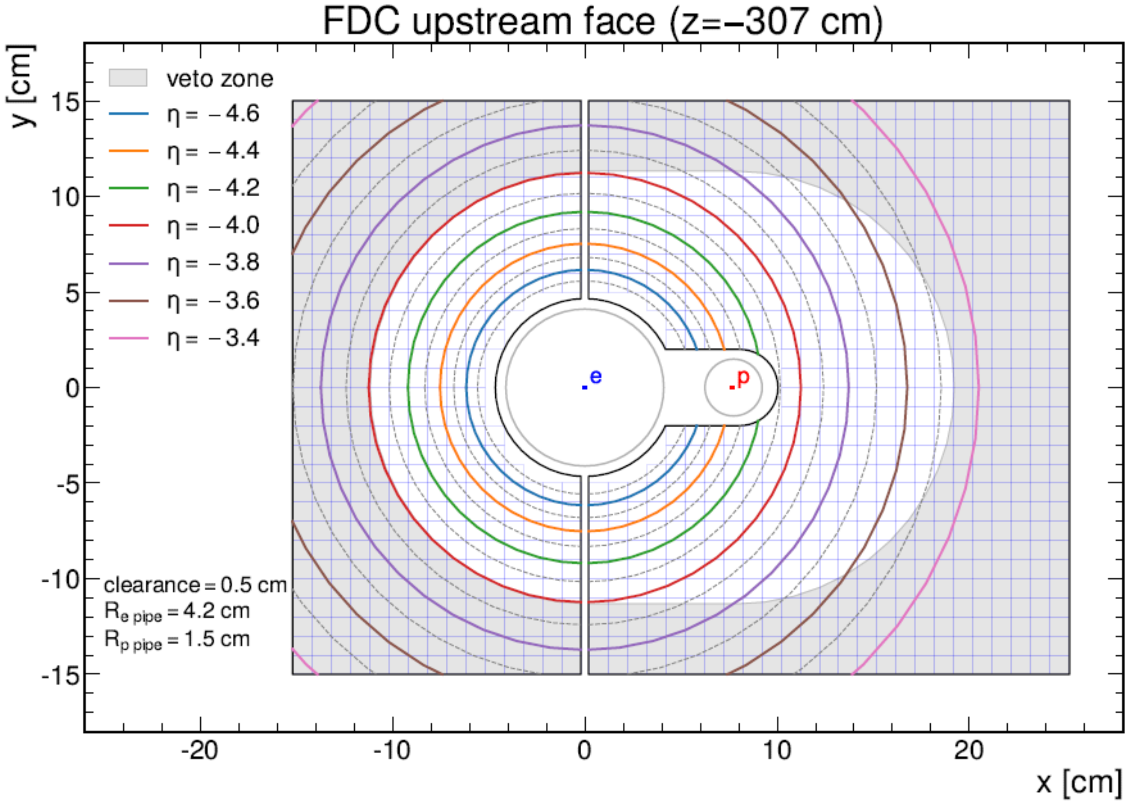
- ➢Lepton Endcap ECAL cannot cover $\eta<-3.6$, given minimum radius and location.
- ➢Covering lower angles is required to probe transition to perturbative regime and onset of Gluon Saturation, which requires measuring $0.1 < Q^2 < 1.0\ \mathrm{GeV}^2$ at top energy.
- ➢FDC is the first, and so far only, concrete proposal to solve the "Q^2 gap" between the central and far-backwards detectors.



Location and acceptance in ePIC

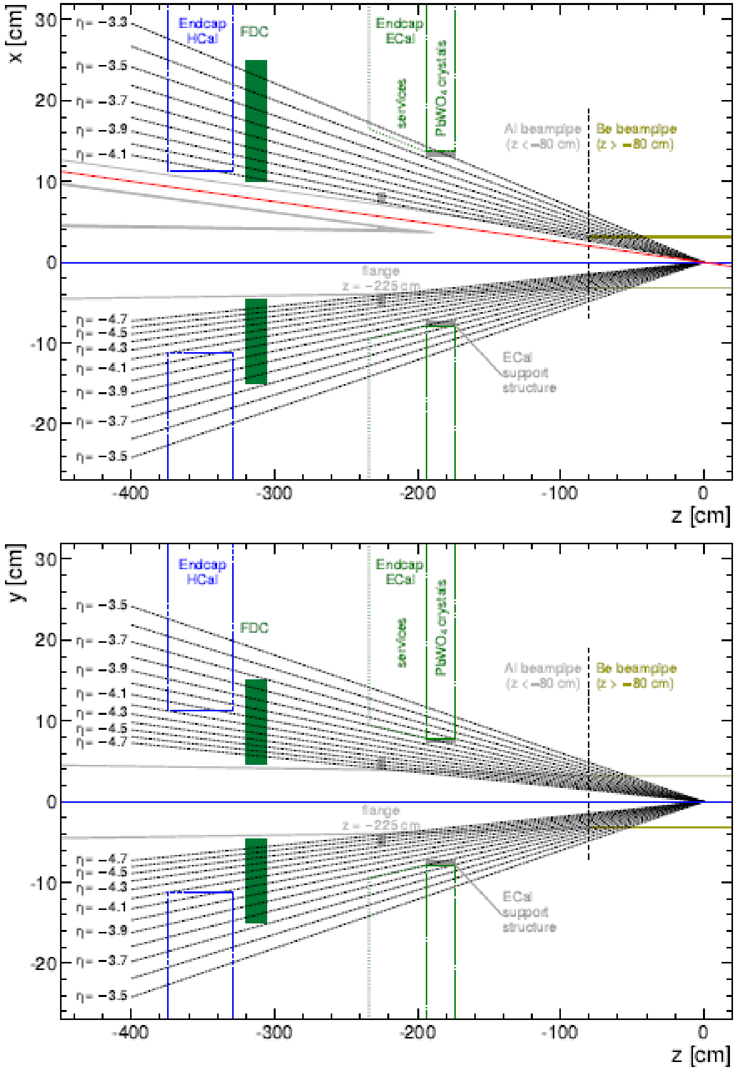


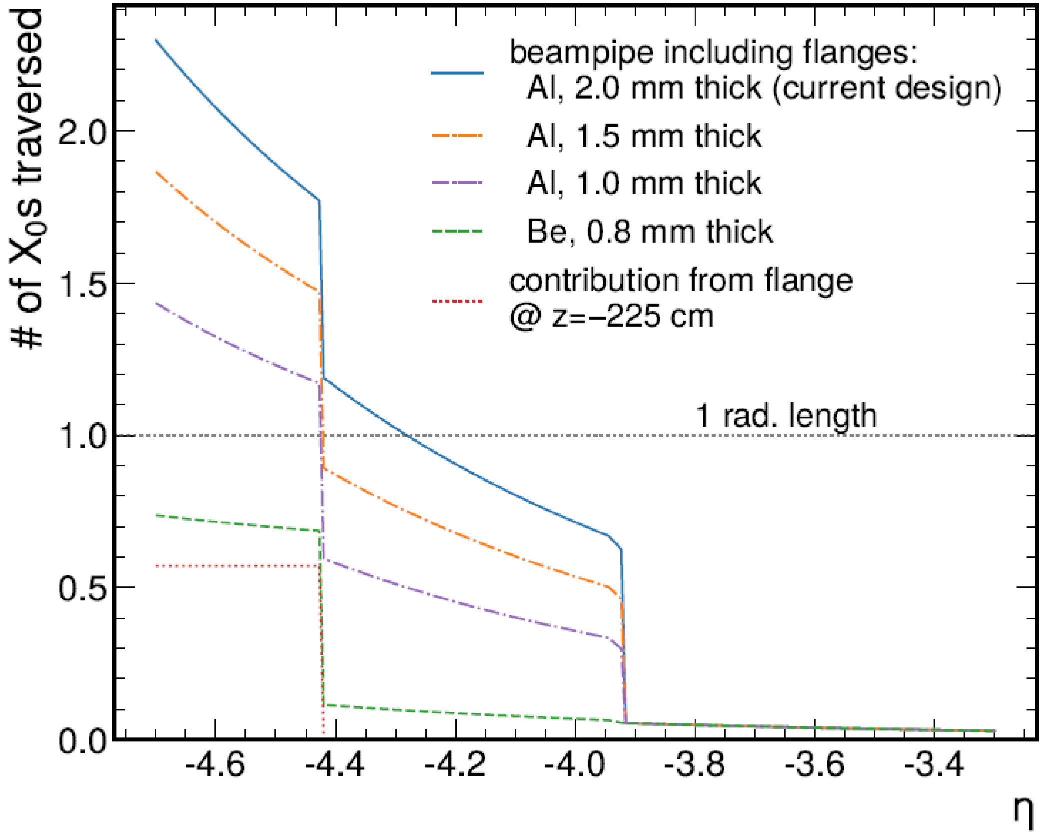




Transverse view of the FDC, assuming a location at z = −307 cm, with rings of constant η superimposed. The electron and hadron beampipes are represented by their transverse cut, along with a 10×10 mm² grid for reference. The non-shaded area is a projection from the ECAL hole.

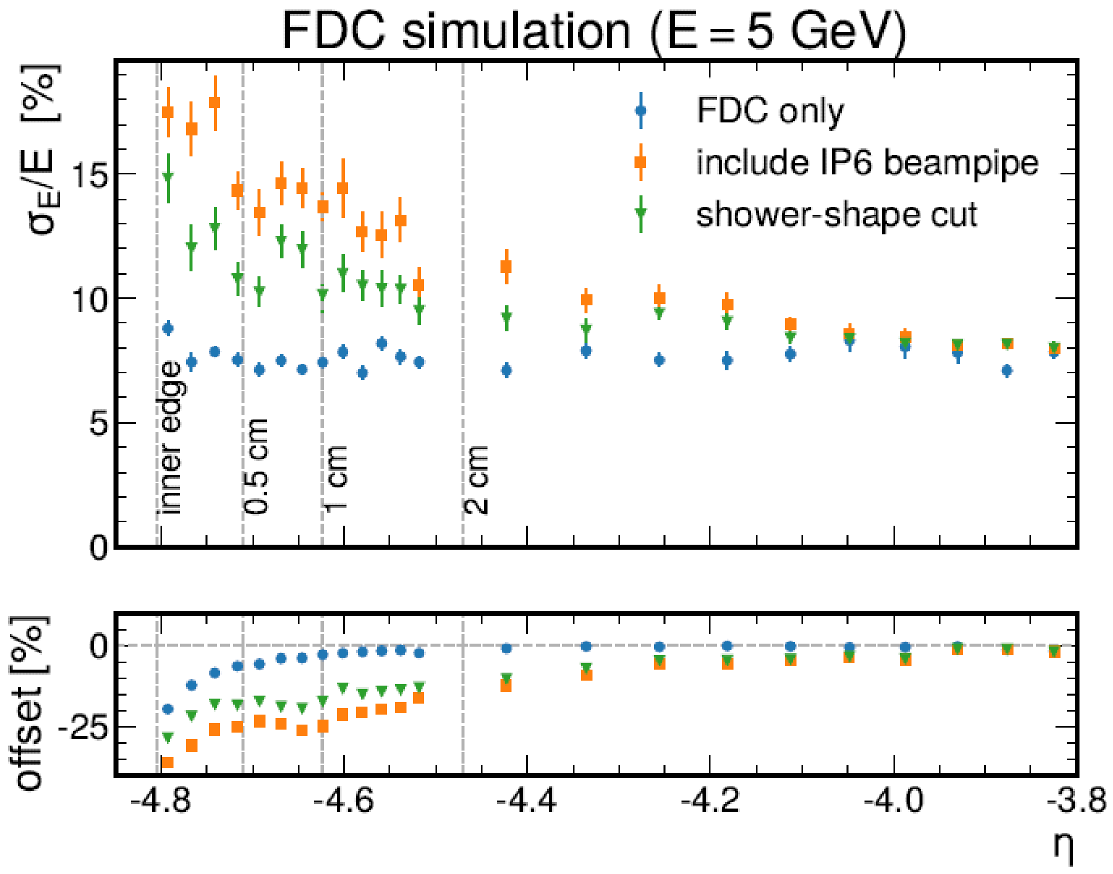
Effect of ePIC beampipe





Simulation of FDC in DD4Hep – energy resolution

For a worse-case scenario of 2 mm Al pipe with IP6 layout, we see a degradation of performance, see right. This can be mitigated with a simple shower shape cut (green).
Performance still would still be sufficient to perform measurements within the fiducial region η>-4.6.
We estimated a bin-migration purity and stability for 5 bins per decade in Q2 an x to be above 60%.
On the other hand, a Beryllium beampipe or an exit window would largely mitigate the material budget issues.



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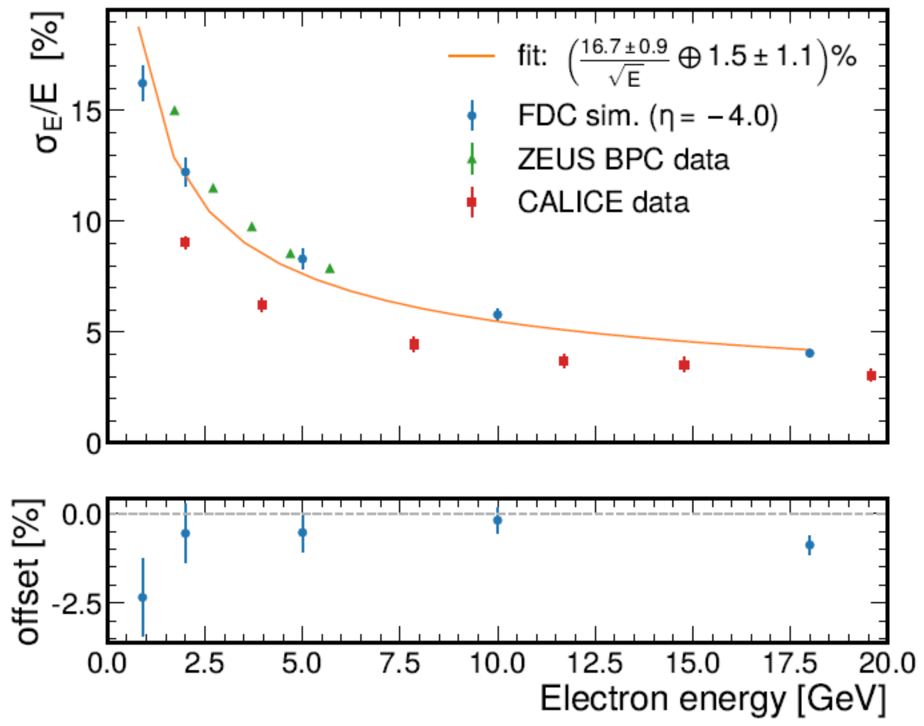
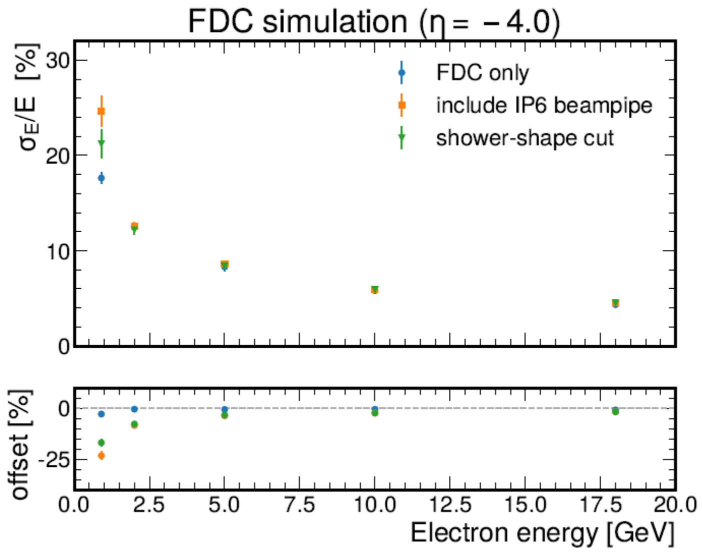
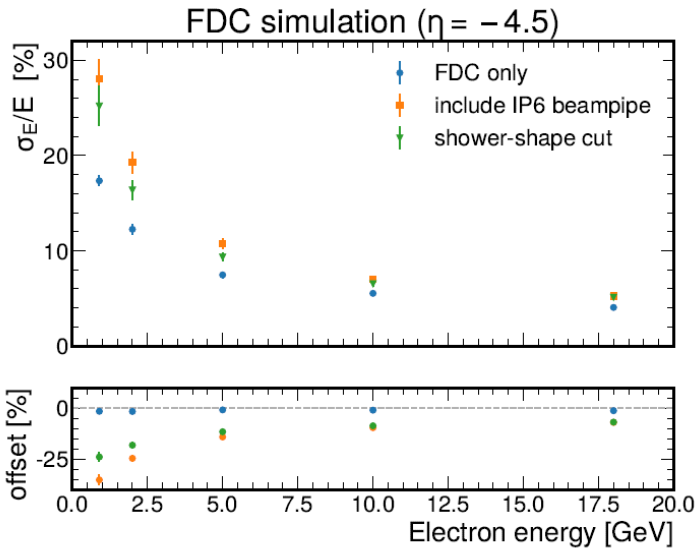
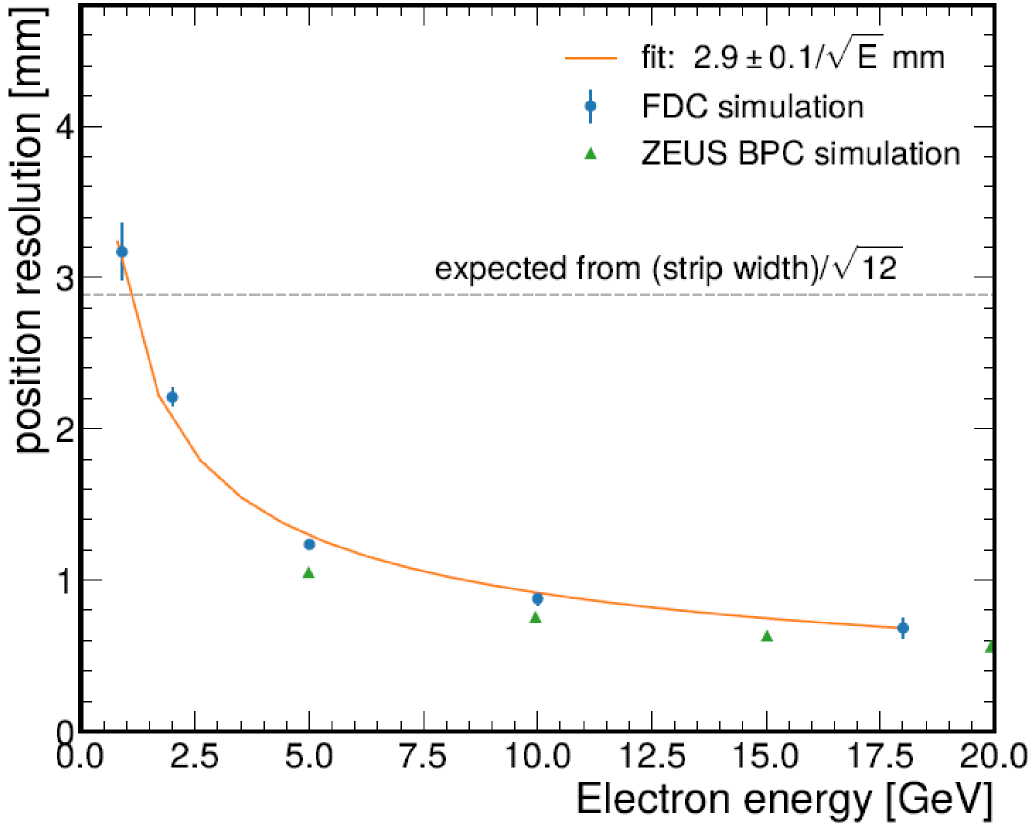






Simulation of FDC in DD4Hep – position/angle resolution



We reconstructed the x and y values following the method described in Ref. [23]:

$$x = \frac{\sum_{i \in v\, layers} w_{X,i} x_i}{\sum_{i \in V} w_{X,i}}, y = \frac{\sum_{i \in h\, layers} w_{Y,i} y_i}{\sum_{i \in H} w_{Y,i}} \tag{4}$$

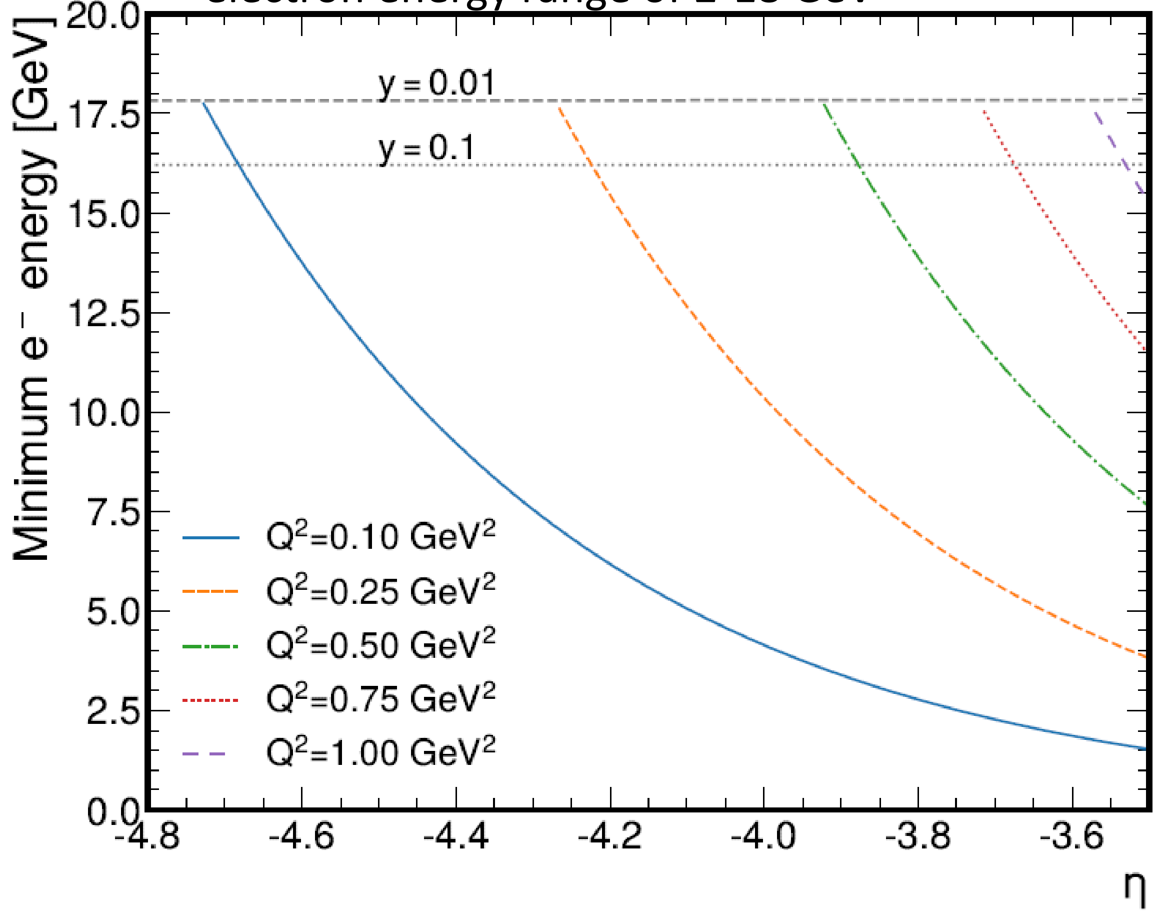
where the weights $w_{X,i}$ and $w_{Y,i}$ are determined by

$$w_{X,i} = \max\left(0, w_0 + \log \frac{E_i}{E}\right) \tag{5}$$

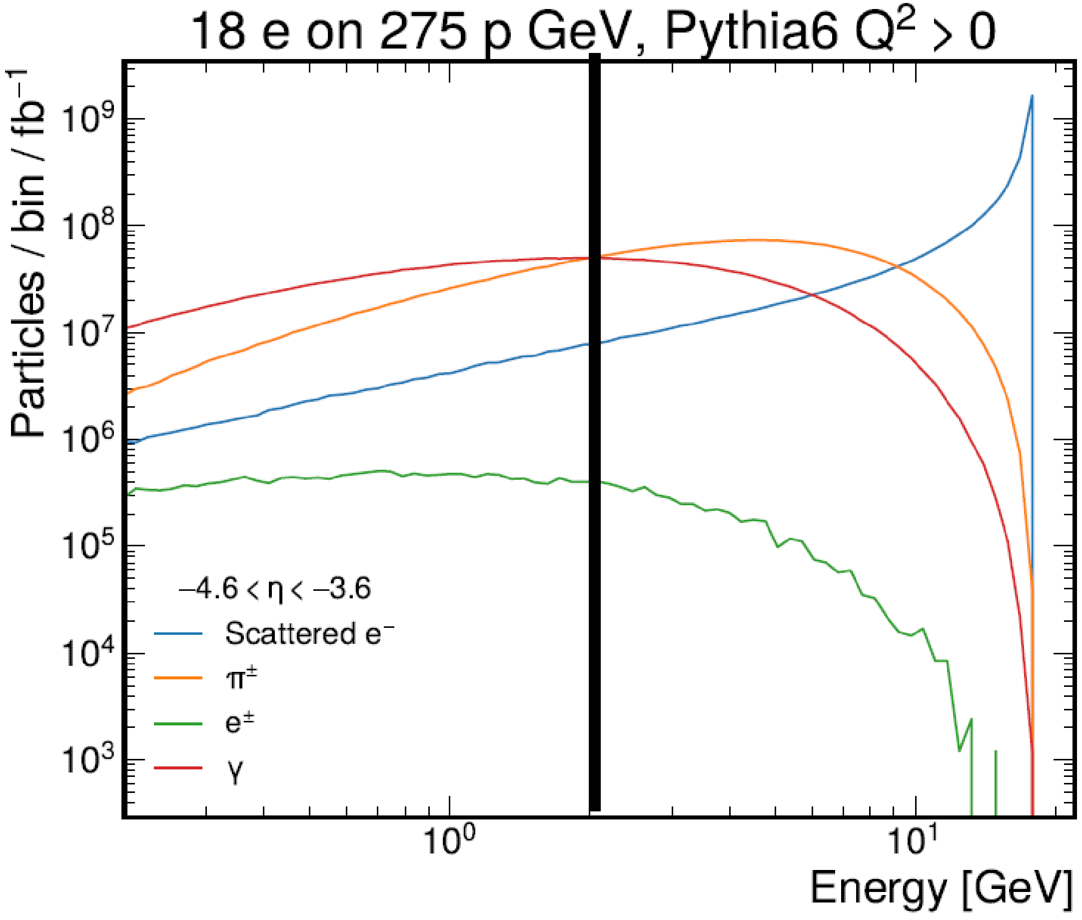
$$w_{Y,i} = \max\left(0, w_0 + \log \frac{E_i}{E}\right) \tag{6}$$

Background to the scattered electron

For $Q^2 > 0.1$ GeV^2, we have a scattered electron energy range of 2-18 GeV



Standalone bkg rejection required (without momentum from tracking!)



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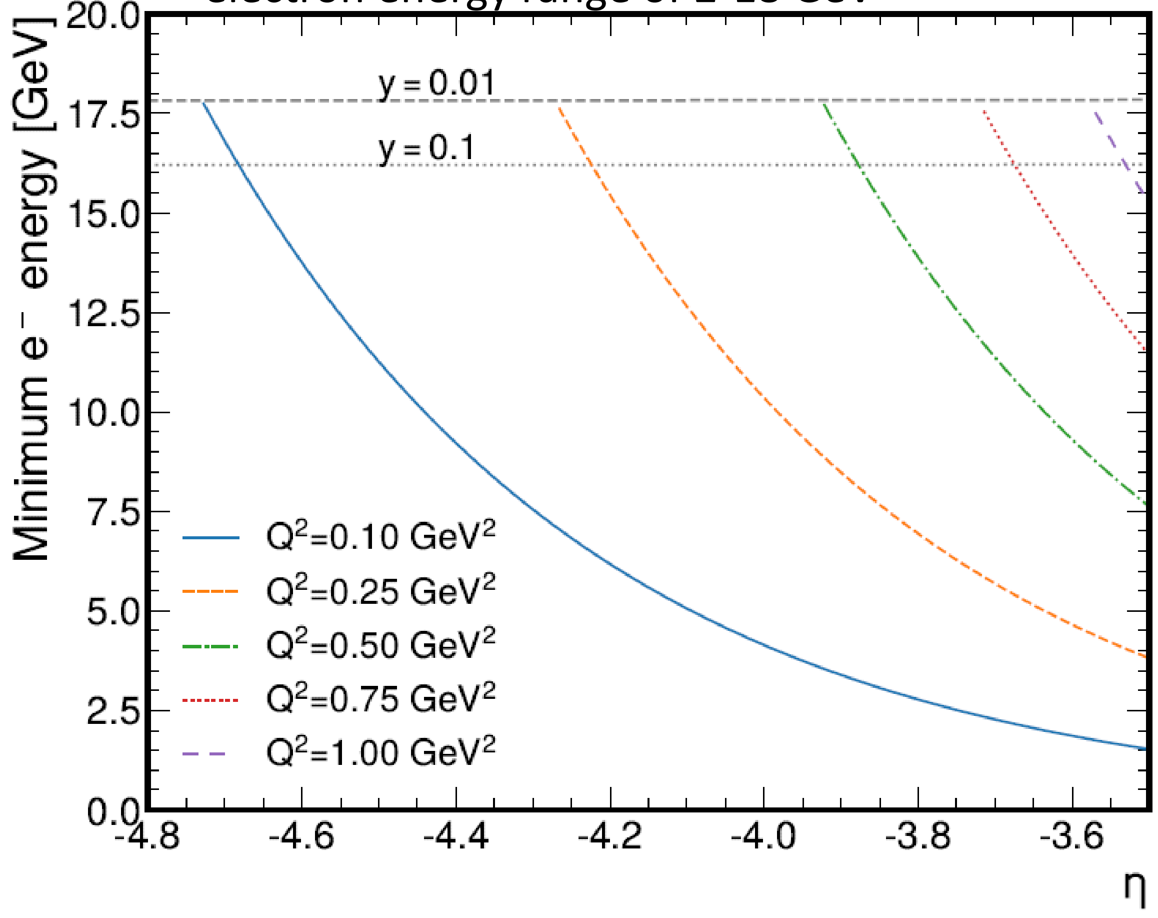

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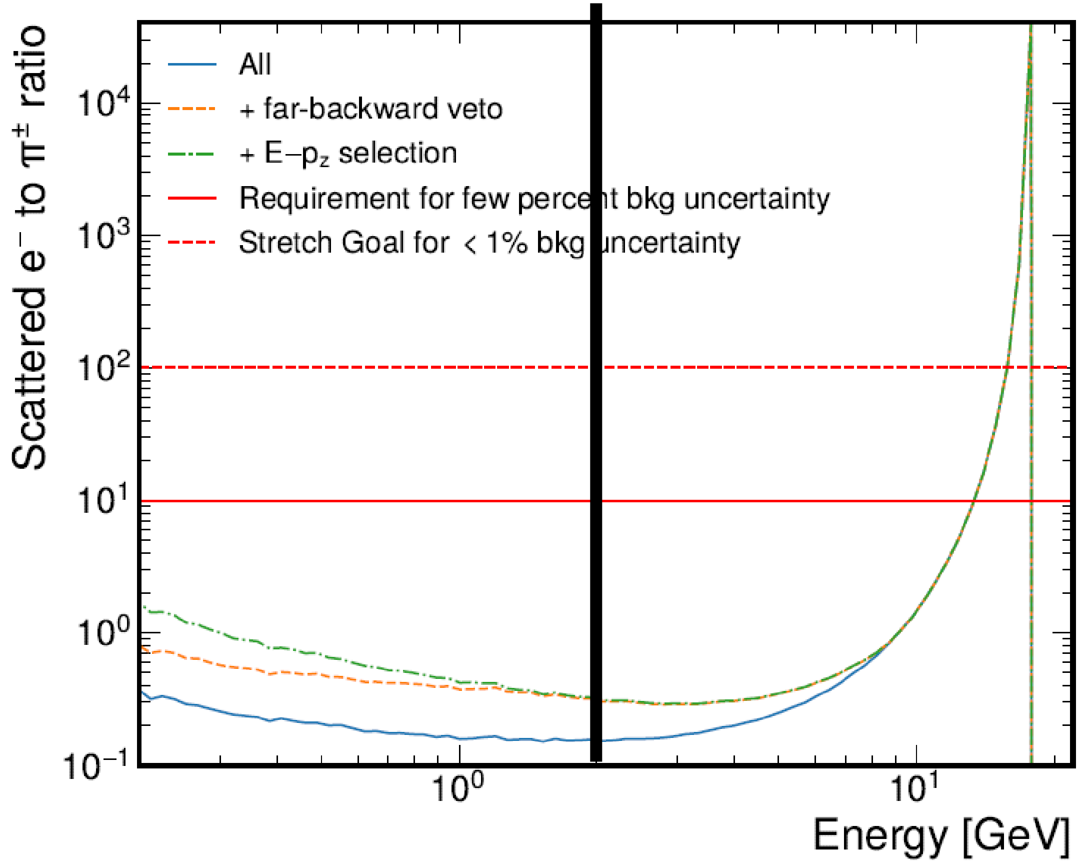
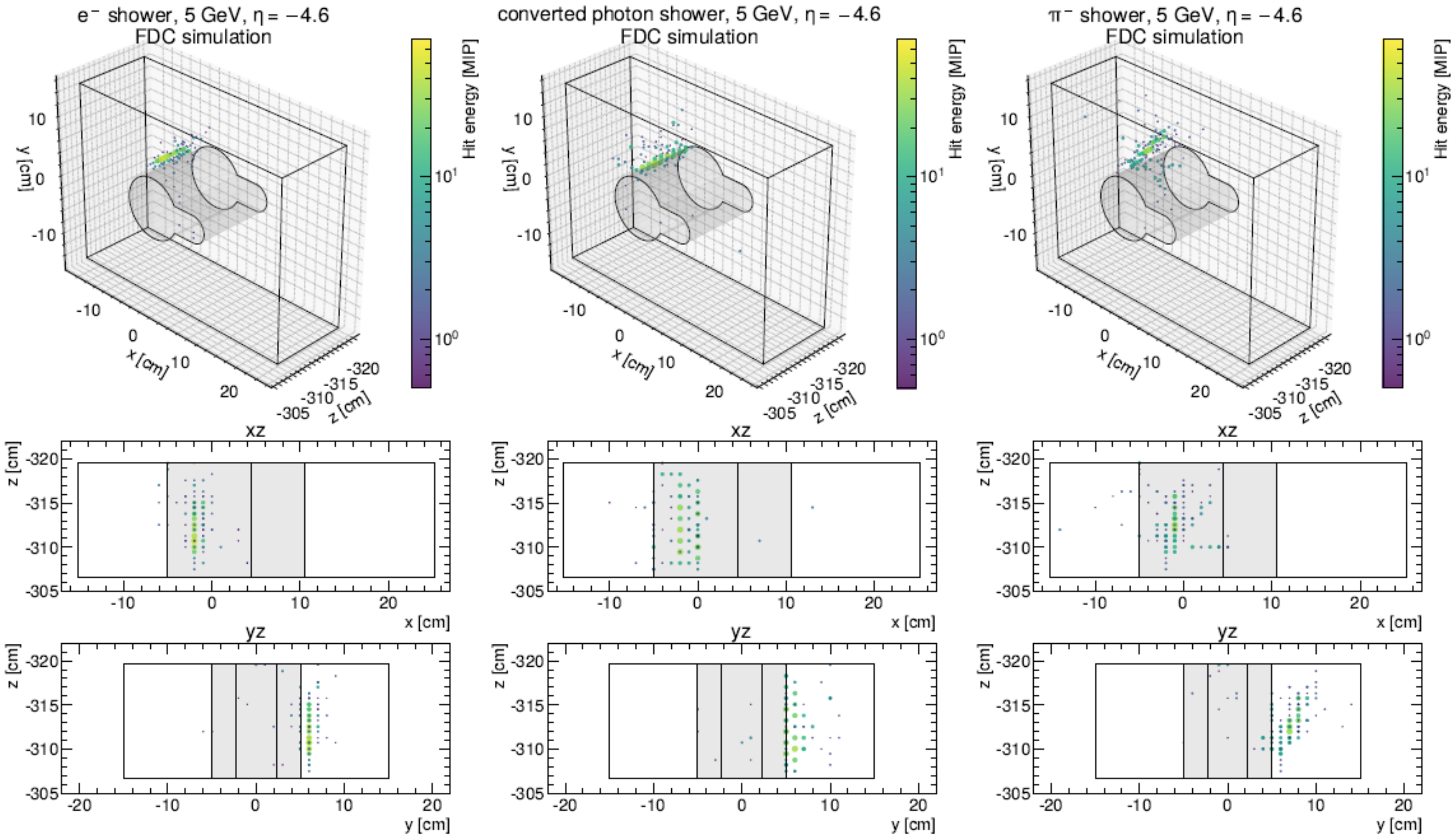
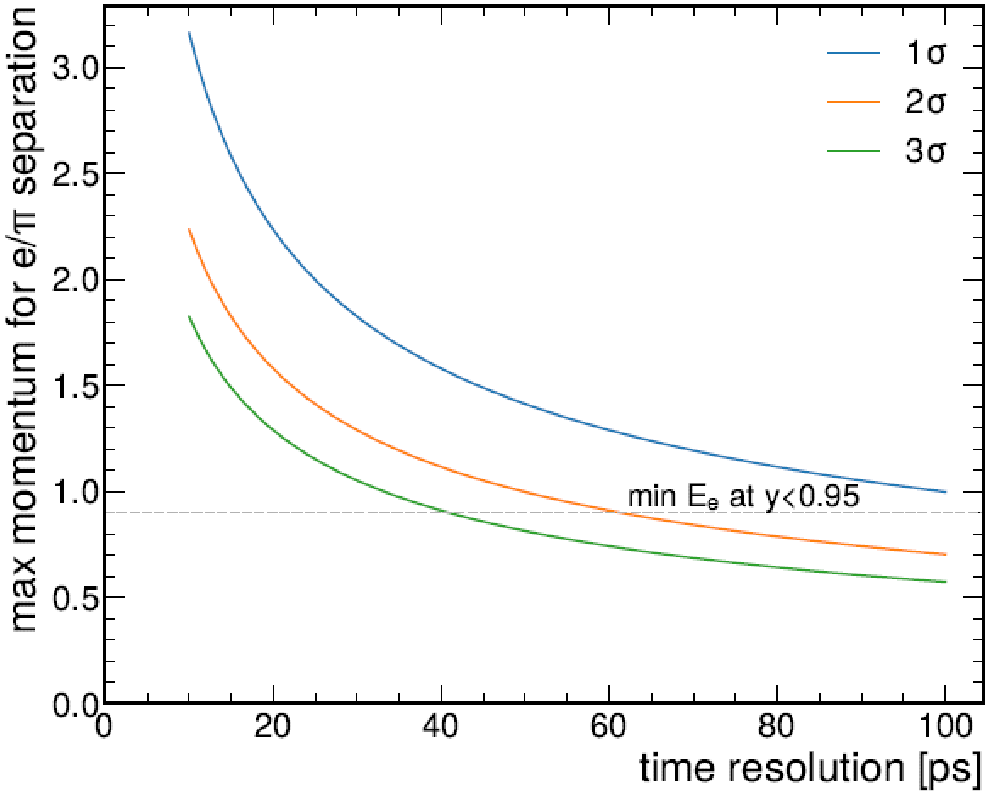


Background rejection



The standalone FDC's $\pi^{\pm}$ rejection power will rely on its shower-shape capabilities. Longitudinal segmentation can play a crucial role in discriminating hadrons, as they are more likely to interact deeper within the detector, while electrons tend to exhibit showers starting primarily in the initial layers. Moreover, transverse segmentation also helps, as electrons typically produce narrower and more regular showers compared to hadronic ones. This approach is expected to work well above a few GeV.

Background rejection



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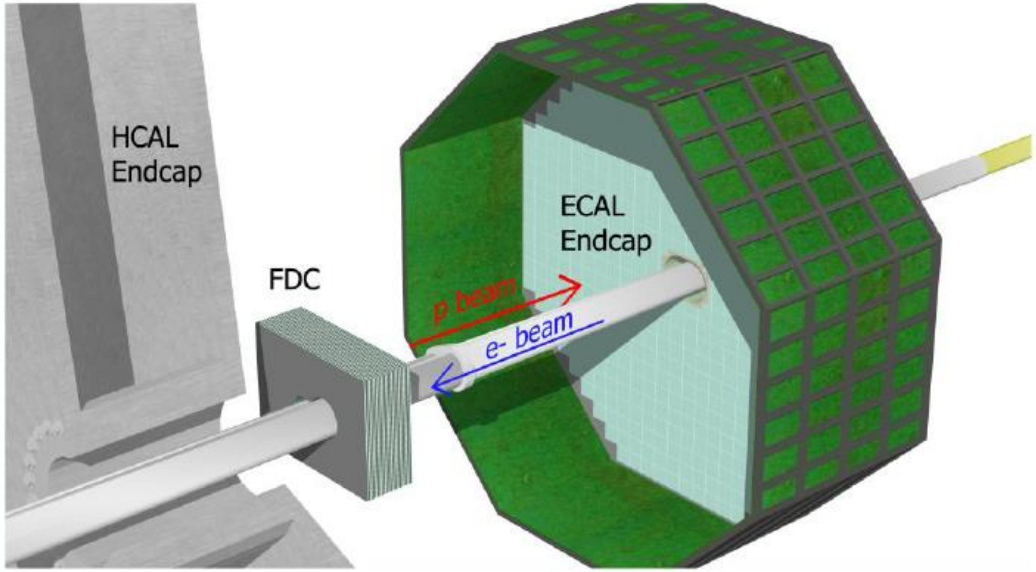
Additional background rejection can be achieved through auxiliary systems, such as a scintillator layer for tagging MIPs to reject unconverted photons, or a timing layer to reject low-energy hadrons. Figure 10 demonstrates the potential of TOF and illustrates that a time resolution of about 50 ps would be necessary to achieve a 2σ e/π separation below 1 GeV.

Possible FDC implementations

ePIC

- Cost effective, small upgrade, but beampipe was not optimized for measurements at a few degree



Detector II

- IP8 will use larger crossing angle (bigger ECAL hole) so bigger need for it.
- Offers possibility of optimized layout, e.g extended Beryllium pipe or dedicated exit window.
- Potentially access even smaller Q^2 range.

Plan going forward

- **Exploring the Potential of 5D High-Granularity for Background Rejection.** We will perform detailed simulations for comprehensive evaluations of the FDC capabilities to quantify background rejection using 5D reconstruction algorithms.
- **Test-Bench Measurements and Timing Studies.** We will develop the design of the FDC by establishing a set of baseline measurements for its building blocks. Our main emphasis will be on timing studies and timing layer development, as this area is experiencing rapid development (work ongoing by CEPC/CALICE that aim O(10) ps).
- **The First FDC prototype.** The objectives of this test beam are to validate FDC simulations, and demonstrate the production capabilities, operation, and calibration of the SiPM-on-tile strip ECAL design.