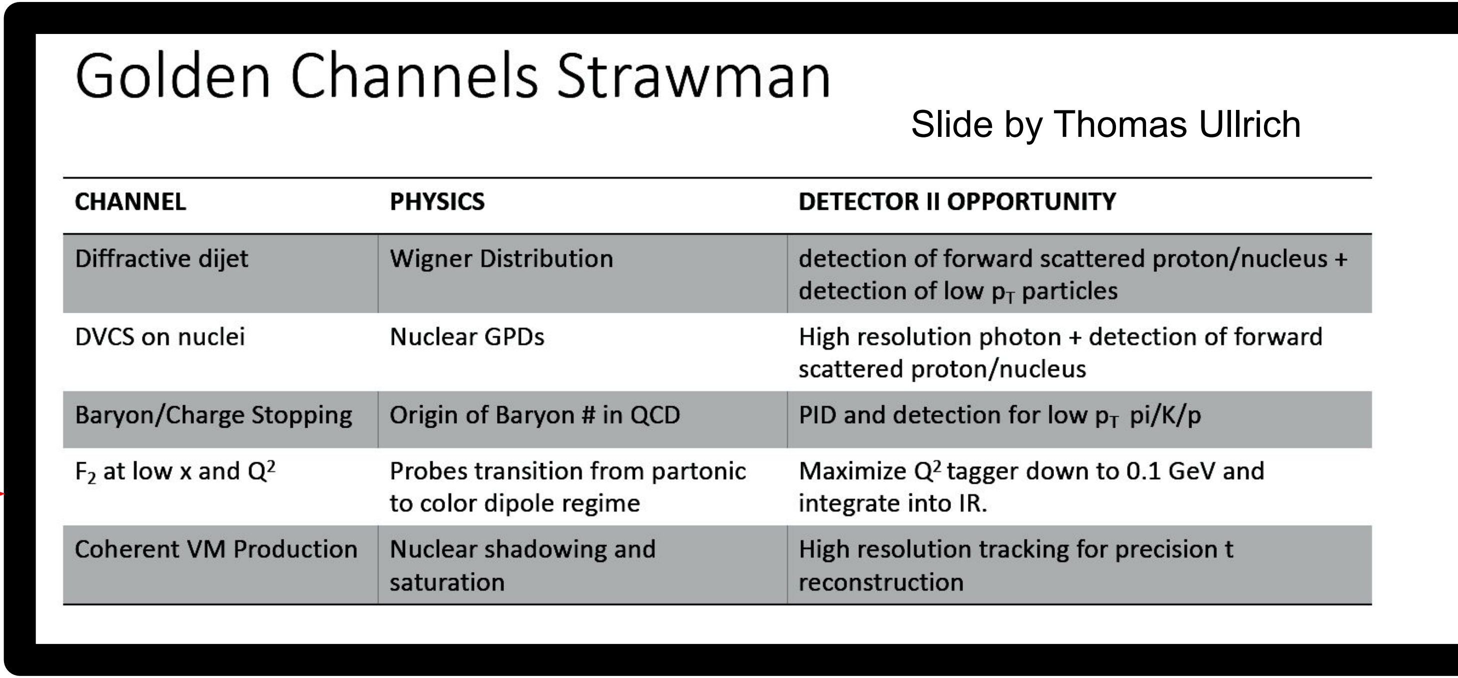
Few Degree Calorimeter (FDC)

Miguel Arratia

UC RIVERSIDE



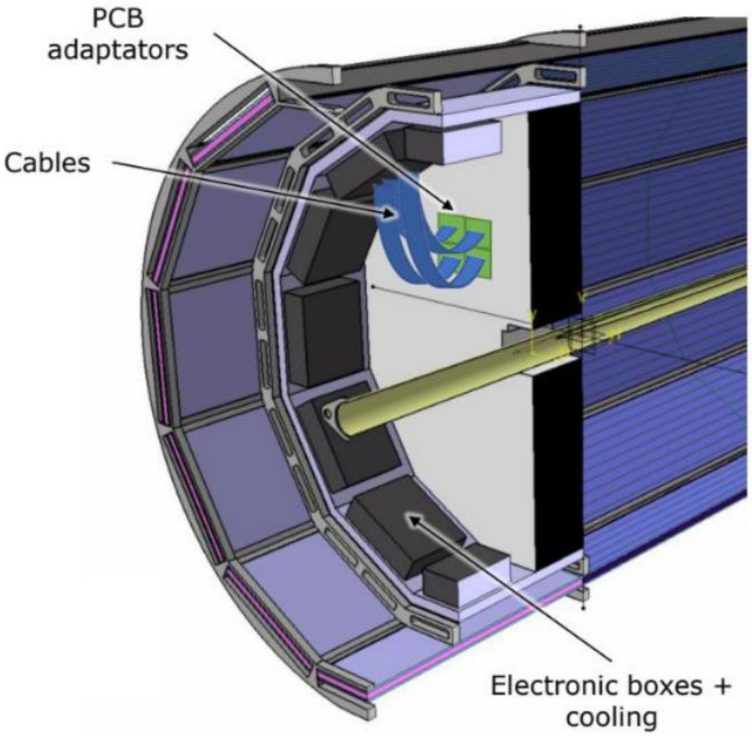
Golden Channels Strawman

Slide by Thomas Ullrich

CHANNEL	PHYSICS	DETECTOR II OPPORTUNITY
Diffractive dijet	Wigner Distribution	detection of forward scattered proton/nucleus + detection of low p_T particles
DVCS on nuclei	Nuclear GPDs	High resolution photon + detection of forward scattered proton/nucleus
Baryon/Charge Stopping	Origin of Baryon # in QCD	PID and detection for low p_T pi/K/p
F_2 at low x and Q^2	Probes transition from partonic to color dipole regime	Maximize Q^2 tagger down to 0.1 GeV and integrate into IR.
Coherent VM Production	Nuclear shadowing and saturation	High resolution tracking for precision t reconstruction

Issue#1: Limited Acceptance of crystal ECAL

- Acceptance limited by requirement that it slide past flange.
- **Realistic estimates suggest limit of η=-3.5**



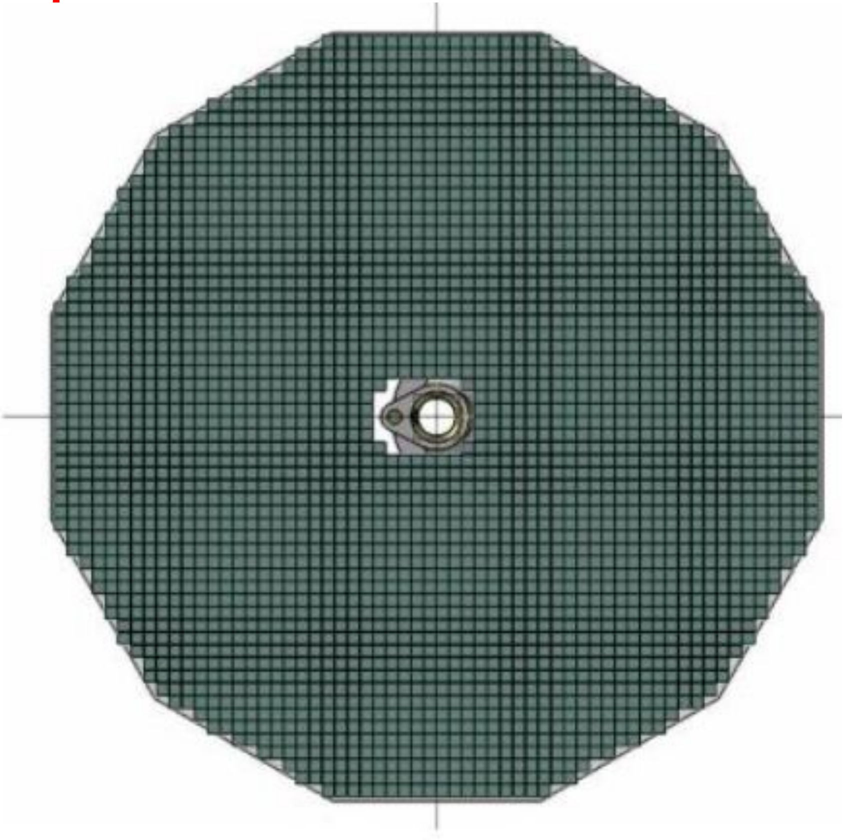
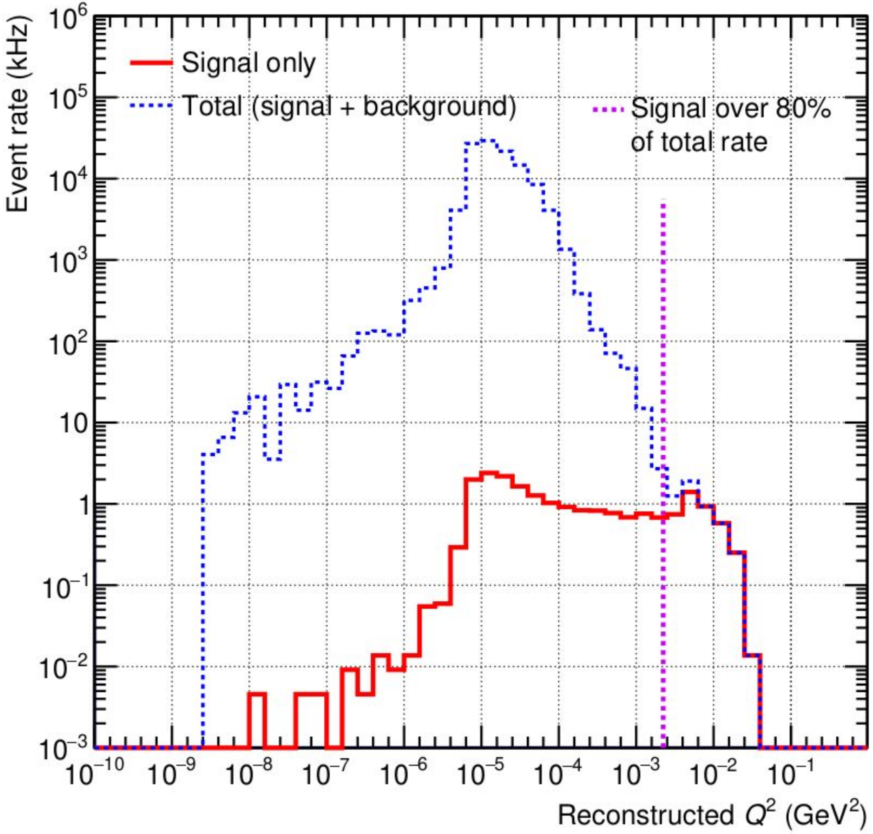


Fig. shown by Carlos Munoz in last ePIC mtg

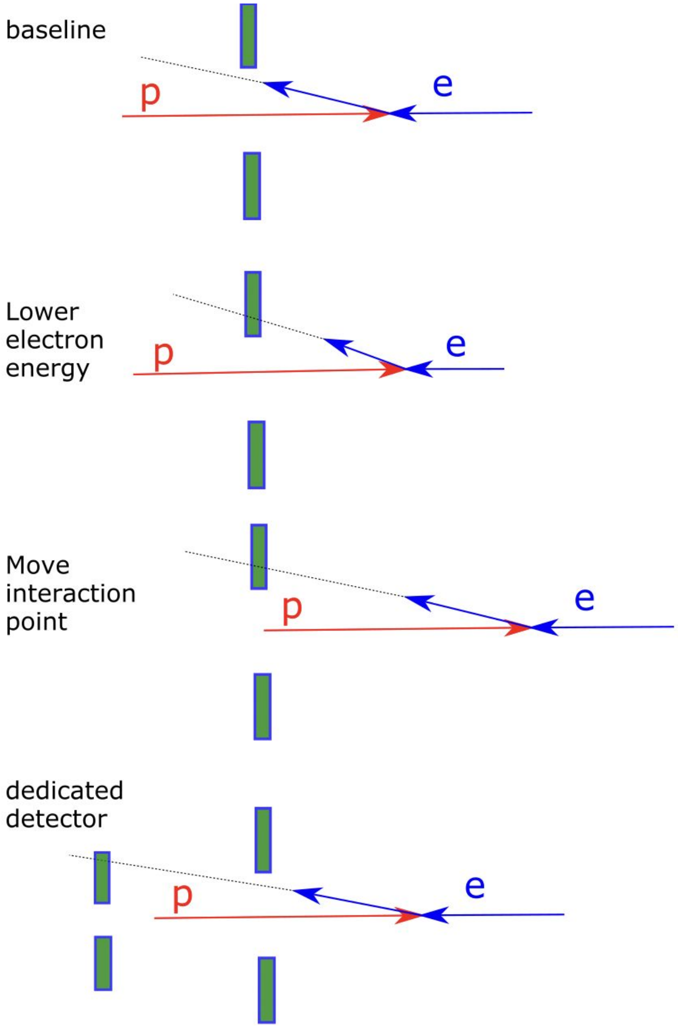
Issue#2: Far-backward taggers have limited acceptance



Shown by Jaroslav Adam in ePIC mtg

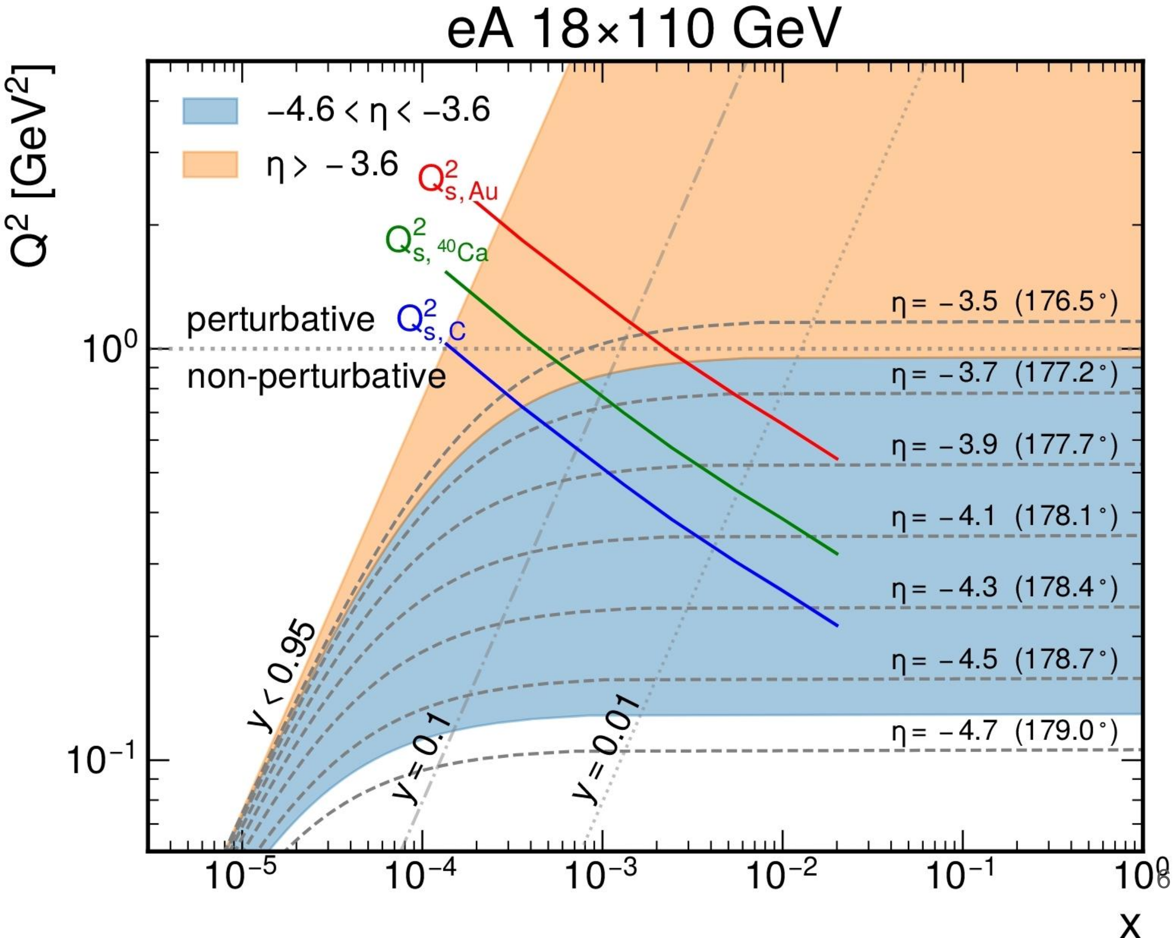
Mitigation strategies

- Lower e beam energy → lower minimum Q^2
    - Unwanted consequence of lower CoM energy (not an option for saturation)
- Move interaction point in positive z
    - Worked in HERA, but not possible in EIC due to beam-crossing angle
- Build a dedicated detector system for low scattering-angle electrons
    - Used in H1 VLQ and ZEUS BPC
    - **Our planned strategy**



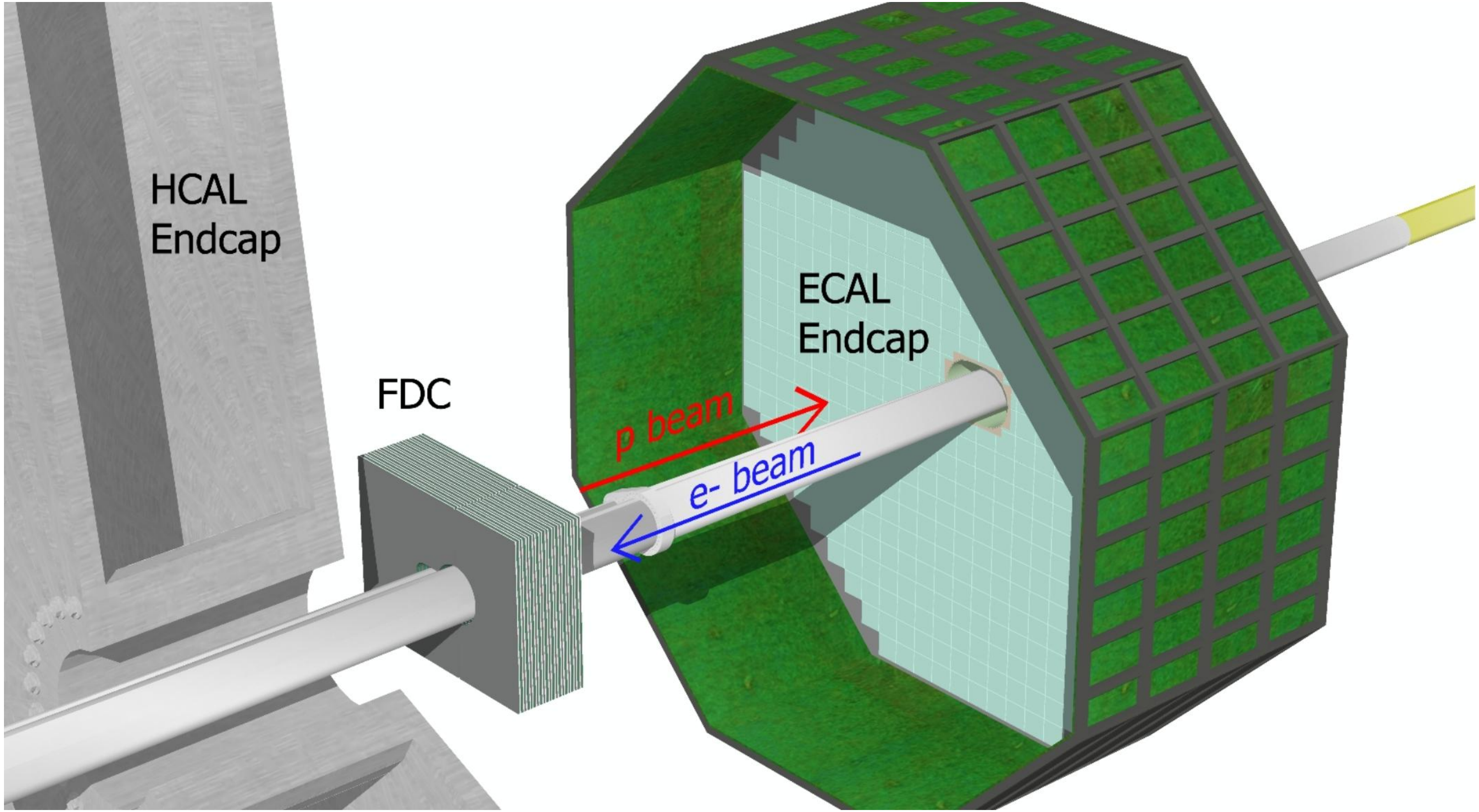
Motivation for a Few-Degree Calorimeter (-4.6<η<-3.6)

- To probe transition to perturbative regime and onset of Gluon Saturation, which requires measuring $0.1<Q^2<1.0$ GeV^2



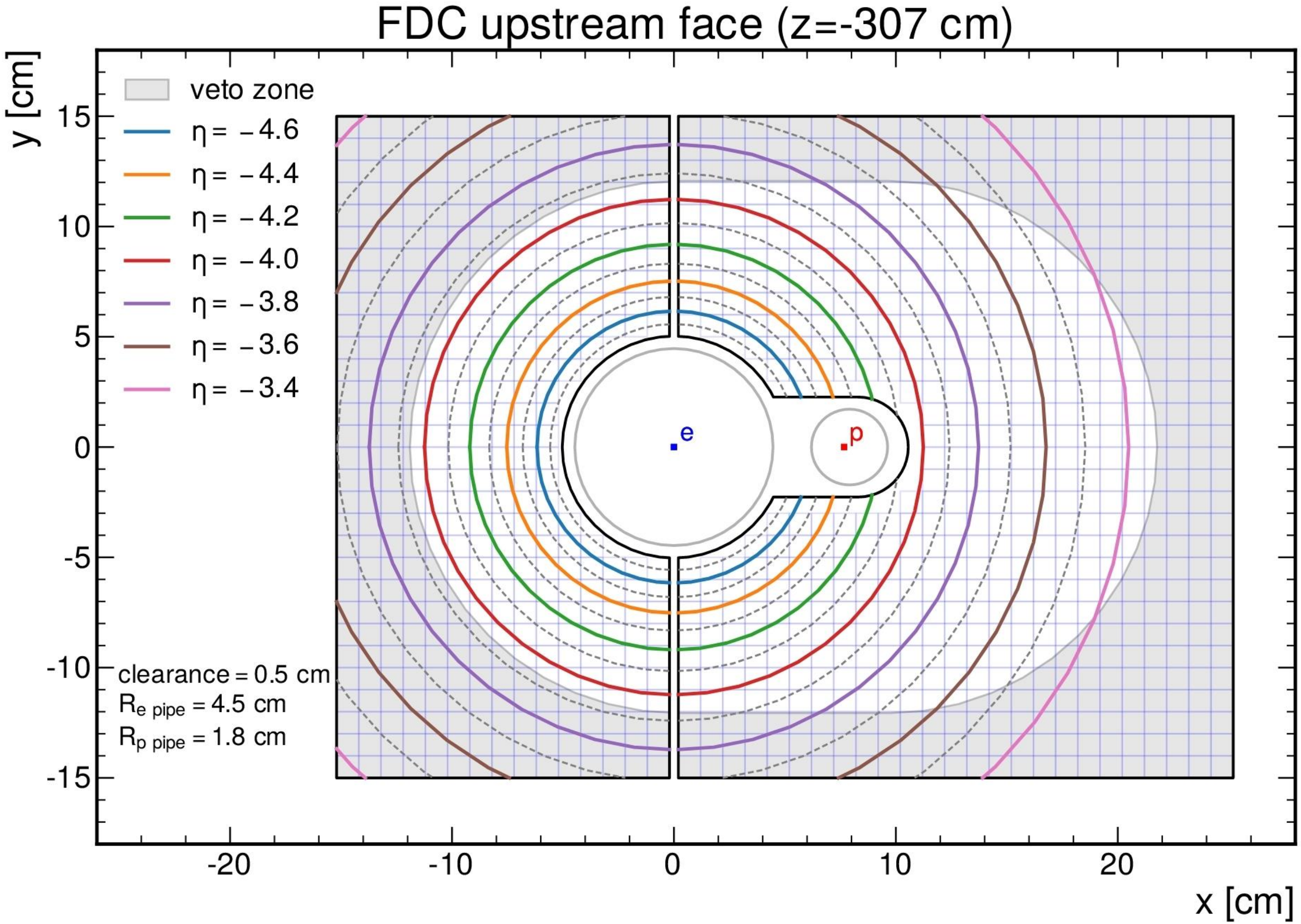
The FDC approach

- Small calorimeter behind crystal ECAL

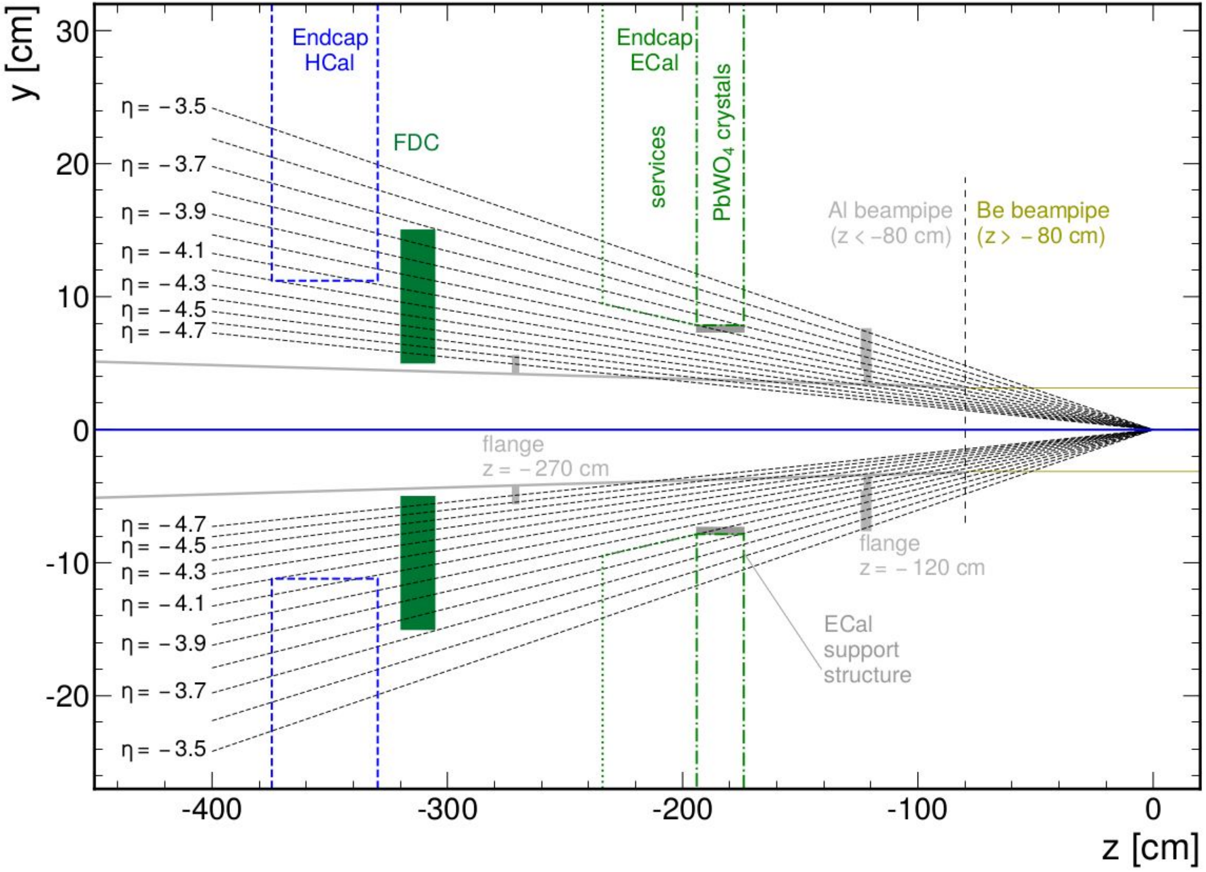


FDC Acceptance

Non-shadowed area corresponds to the crystal ECAL hole

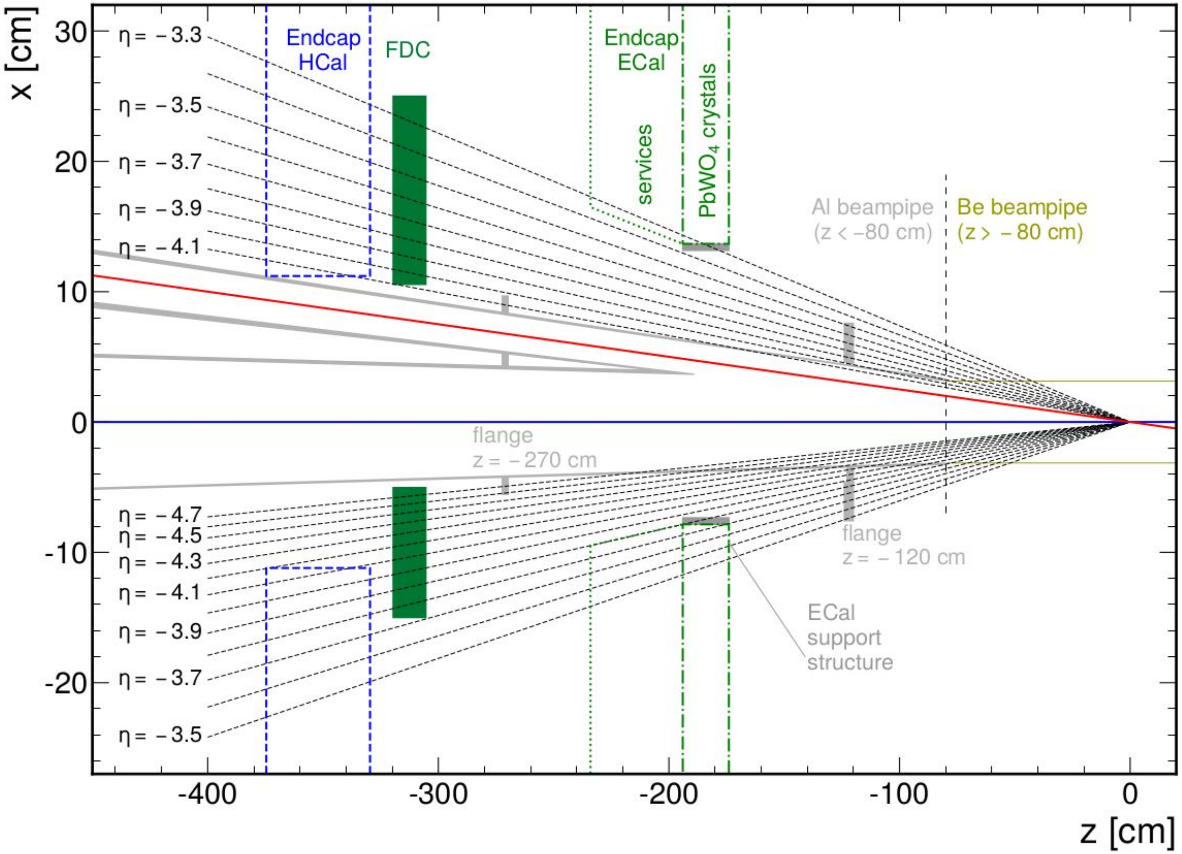


FDC acceptance in IP6 (yz plane)



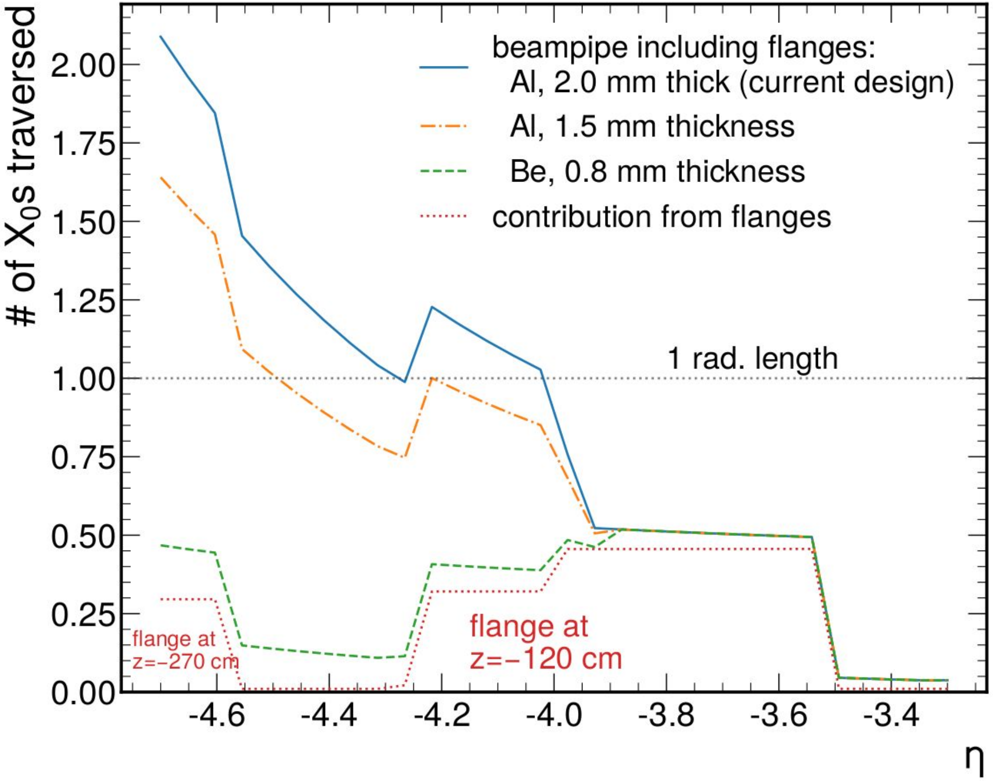
FDC acceptance in IP6 (xz plane)

Room for optimized acceptance in IP8 given larger crossing angle



Challenge: & mitigation strategy

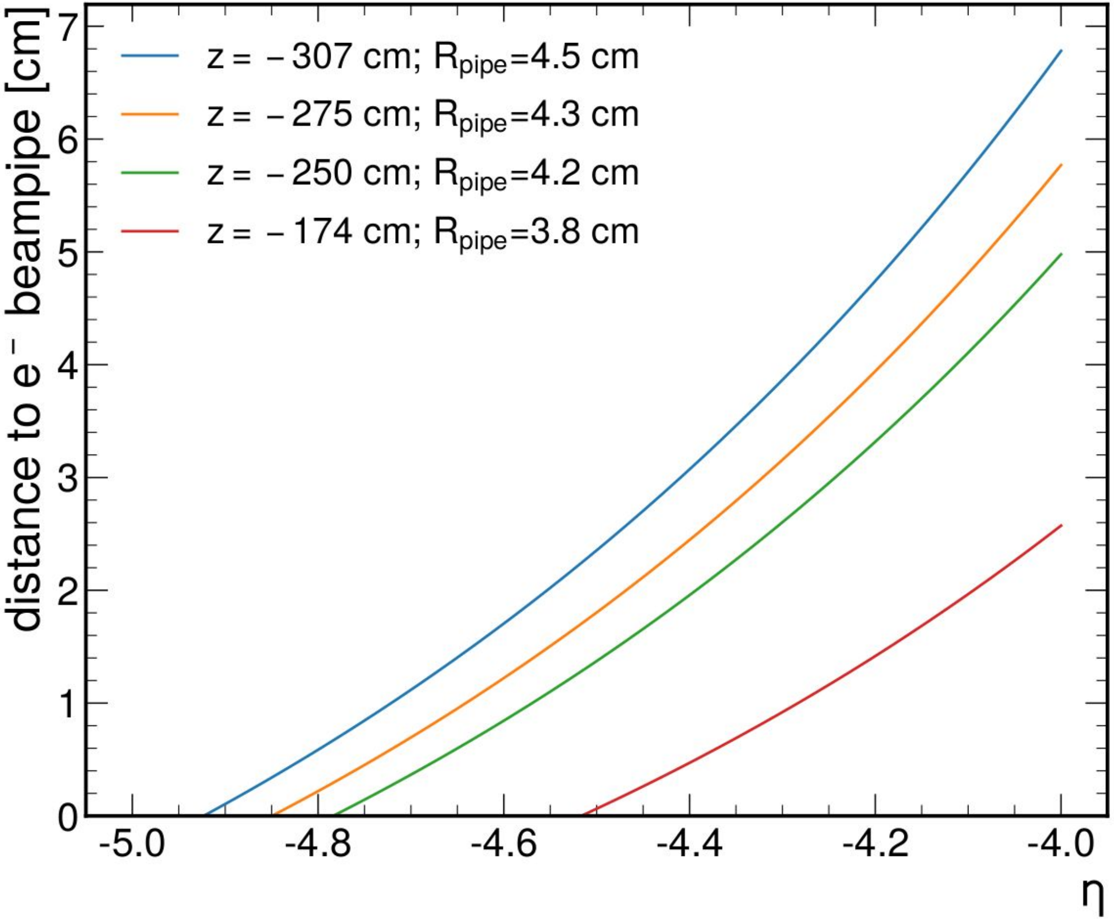
- Electron at shallow angles can graze the beampipe walls.
- Optimized beampipe (Be?) can have a huge impact.
- Thin Al would work too
- Exit window?



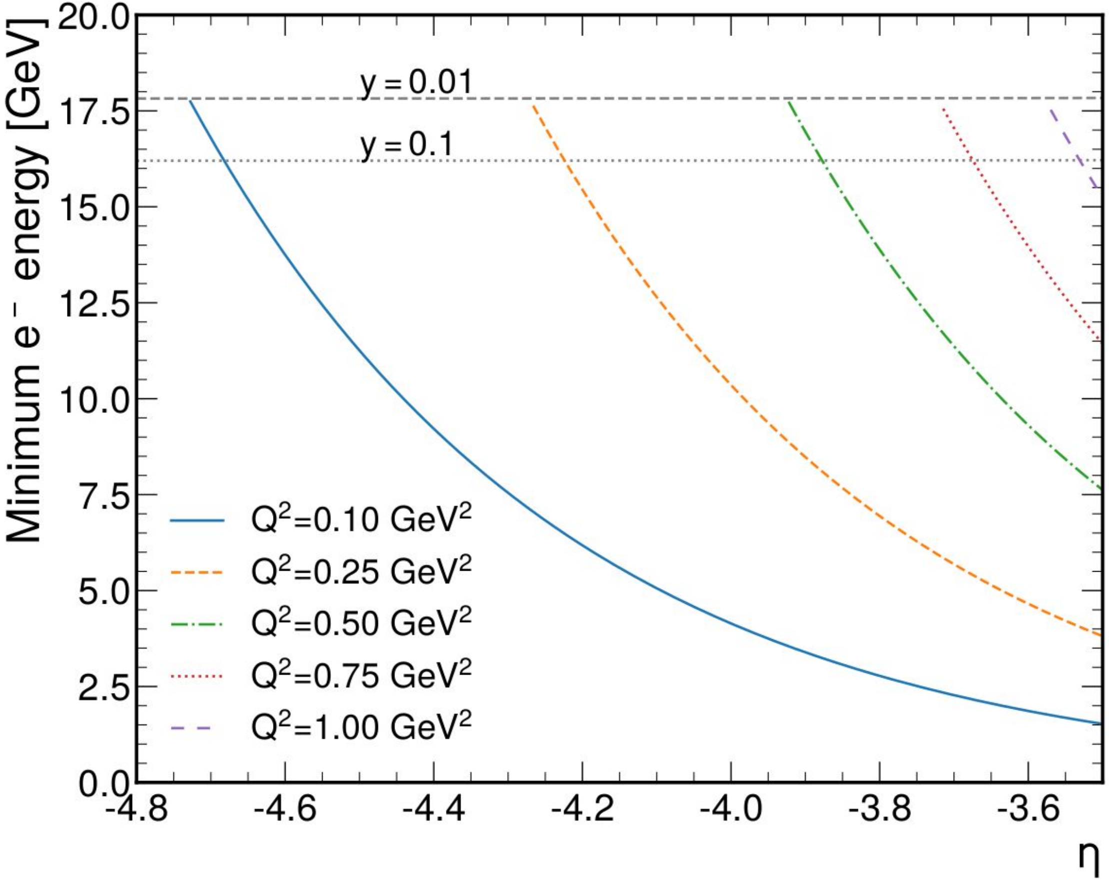
Distance to the beampipe (IP6)

We actually gain from placing FDC as far away as possible from IP

Need small Moliere radius
To maximize acceptance



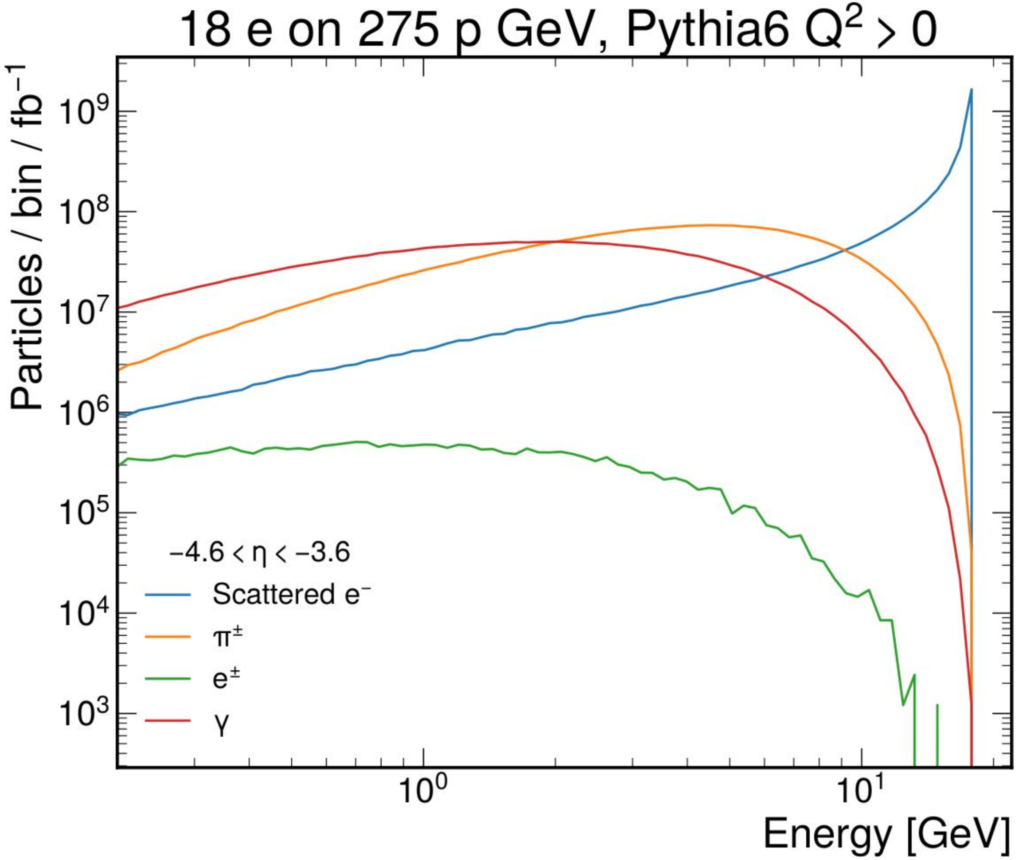
Electron energy range is 2-18 GeV



Background

Mostly photoproduction.

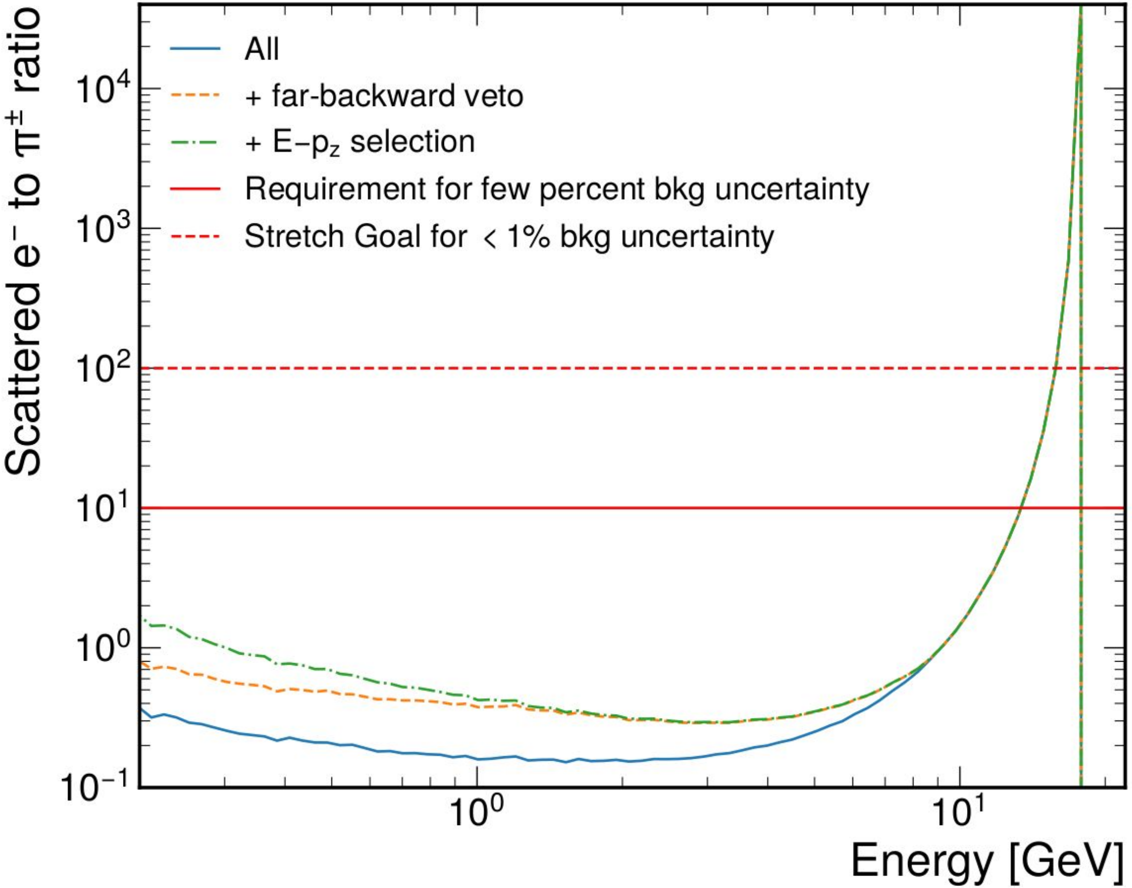
FDC ~charged-blind so positrons and positive pions also are bkg



Background rejection with standard means

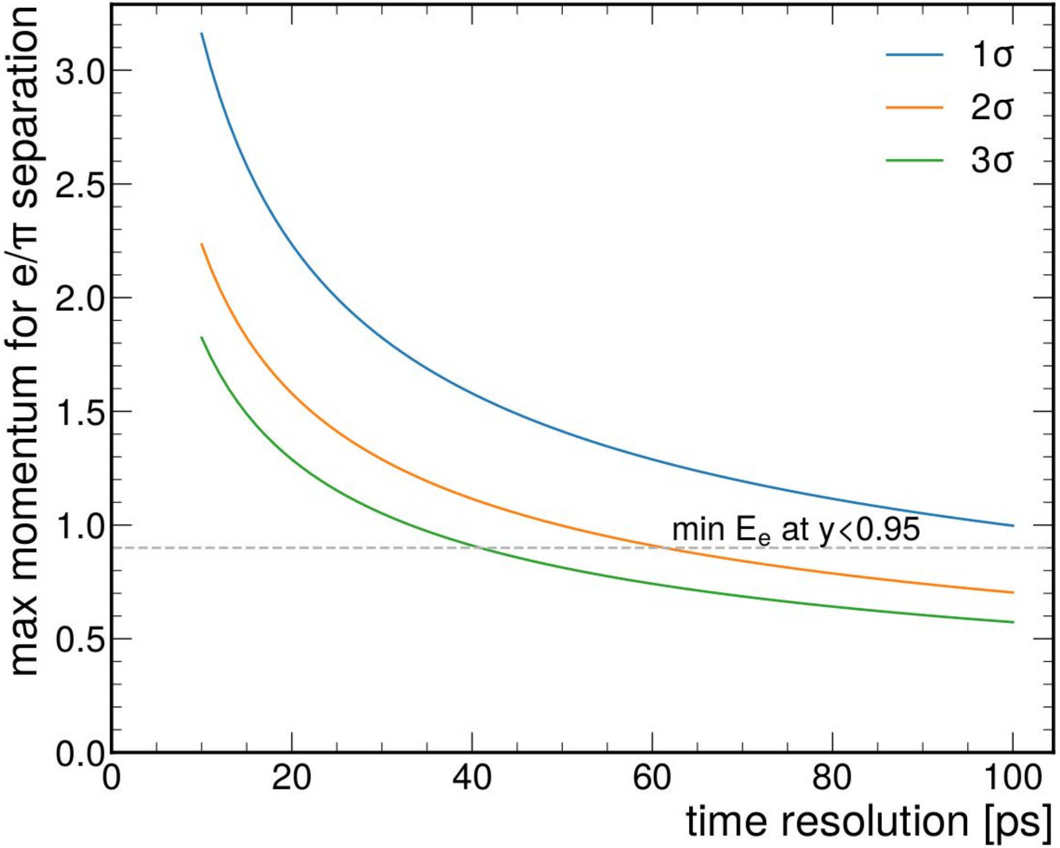
Far-backward taggers have limited acceptance

E-pz cut does not remove much because in bkg events the electron has low energy



TOF potential (at z=-307 cm)

50 ps or better would help tag <1 GeV pions



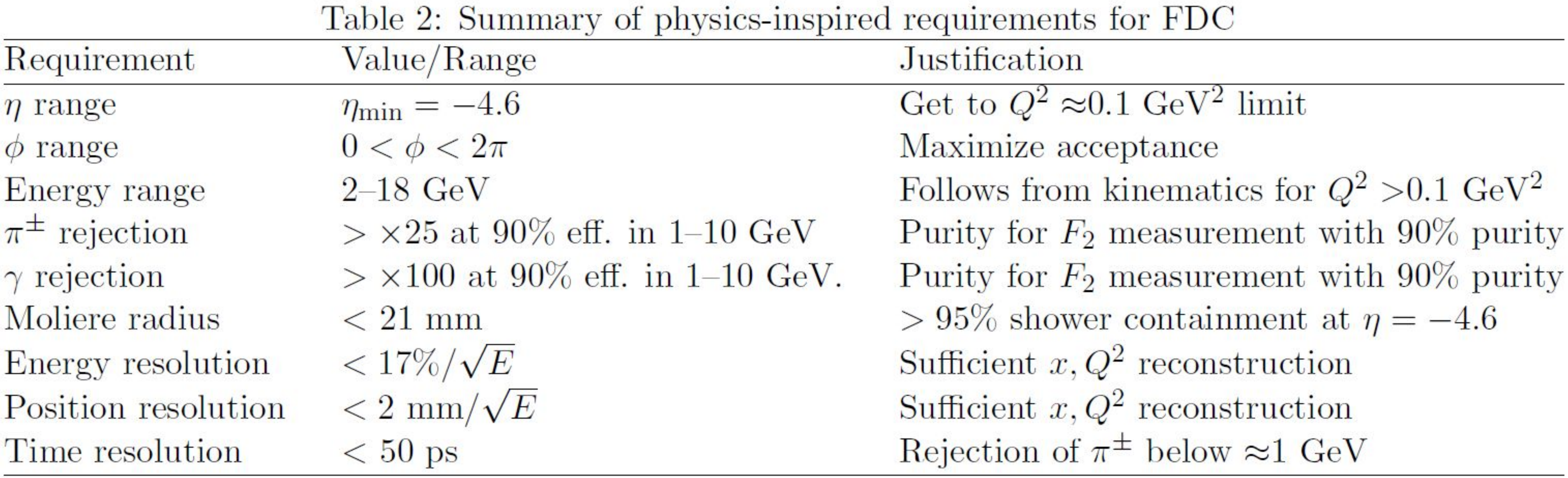
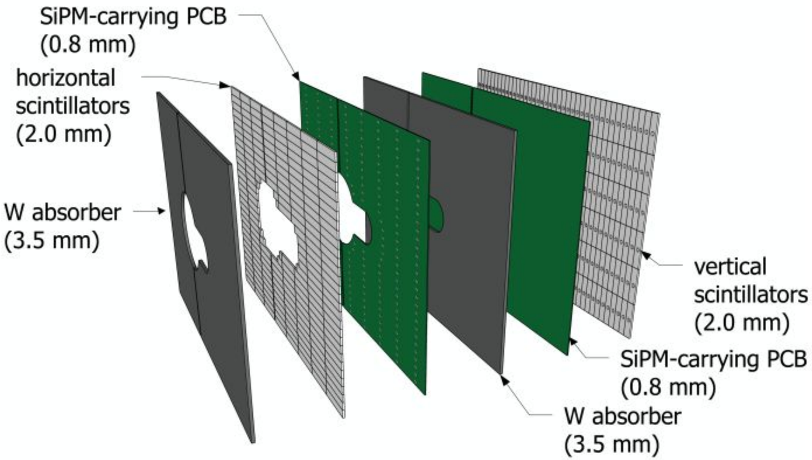
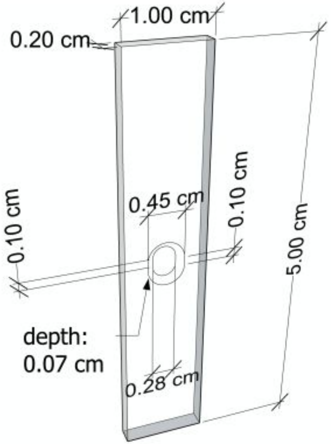


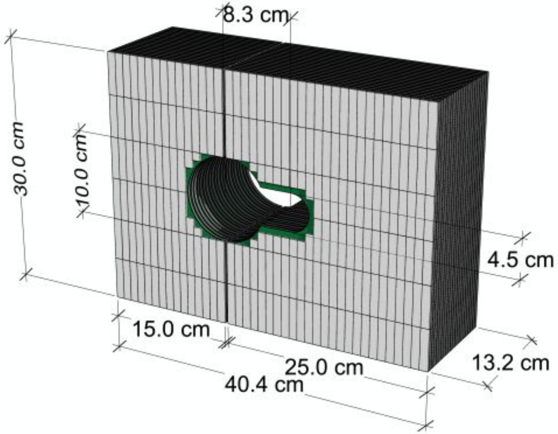
Table 2: Summary of physics-inspired requirements for FDC

Requirement	Value/Range	Justification
η range	$\eta_{\text{min}} = -4.6$	Get to $Q^2 \approx 0.1$ GeV^2 limit
ϕ range	$0 < \phi < 2\pi$	Maximize acceptance
Energy range	2–18 GeV	Follows from kinematics for $Q^2 > 0.1$ GeV^2
$\pi^\pm$ rejection	$> \times 25$ at 90% eff. in 1–10 GeV	Purity for F_2 measurement with 90% purity
γ rejection	$> \times 100$ at 90% eff. in 1–10 GeV.	Purity for F_2 measurement with 90% purity
Moliere radius	< 21 mm	$> 95\%$ shower containment at $\eta = -4.6$
Energy resolution	$< 17\%/\sqrt{E}$	Sufficient x, Q^2 reconstruction
Position resolution	< 2 mm$/\sqrt{E}$	Sufficient x, Q^2 reconstruction
Time resolution	< 50 ps	Rejection of $\pi^\pm$ below ≈ 1 GeV

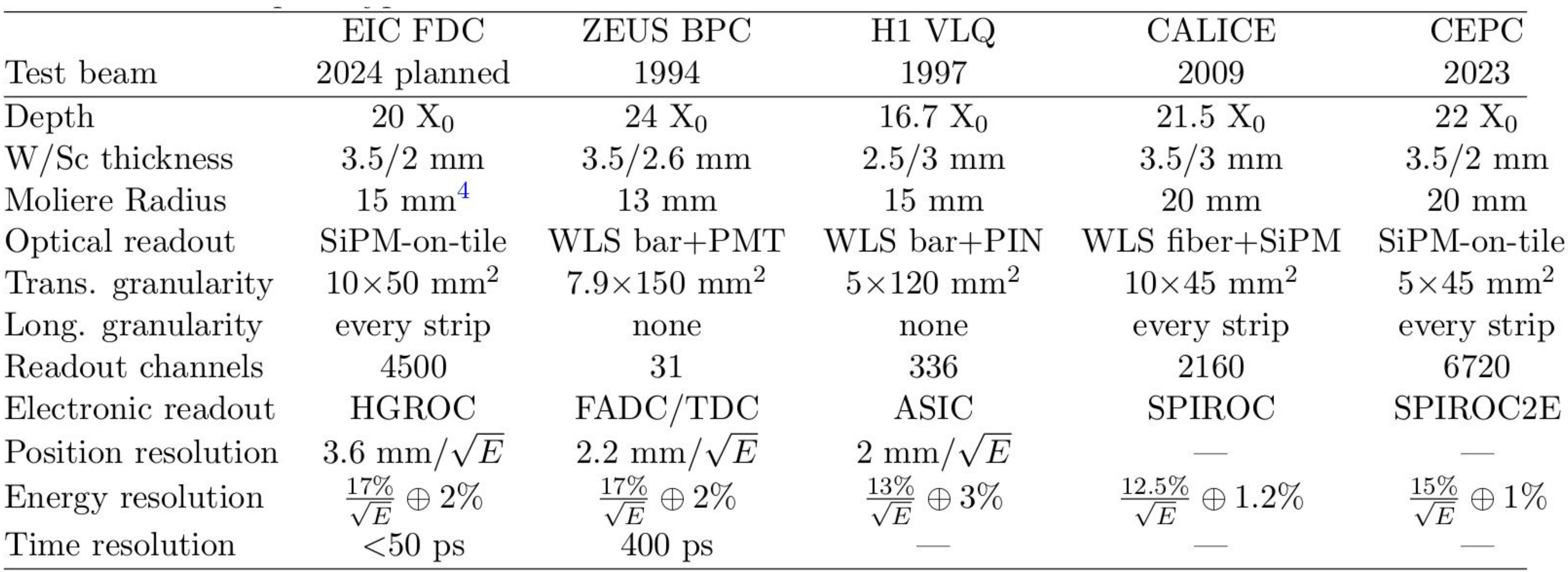
FDC design (SiPM-on-tile style, strip scintillator)





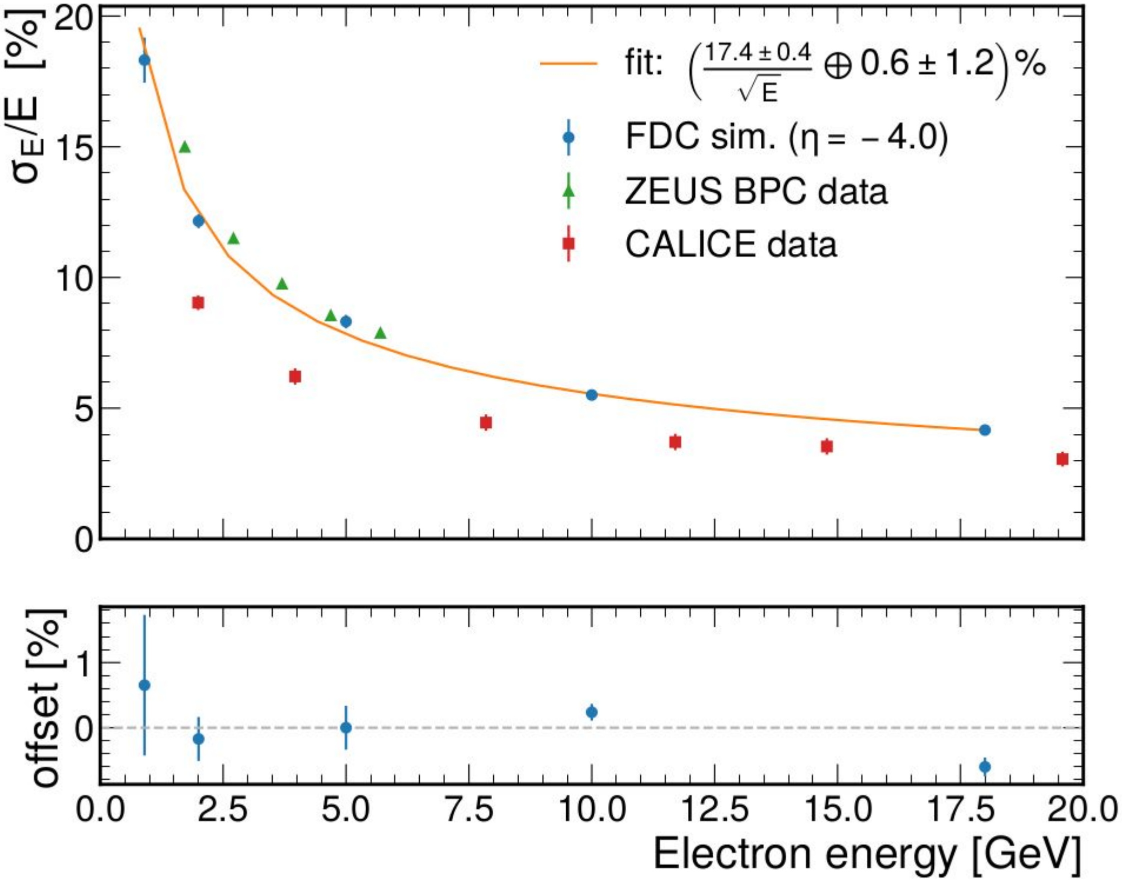


State of the art

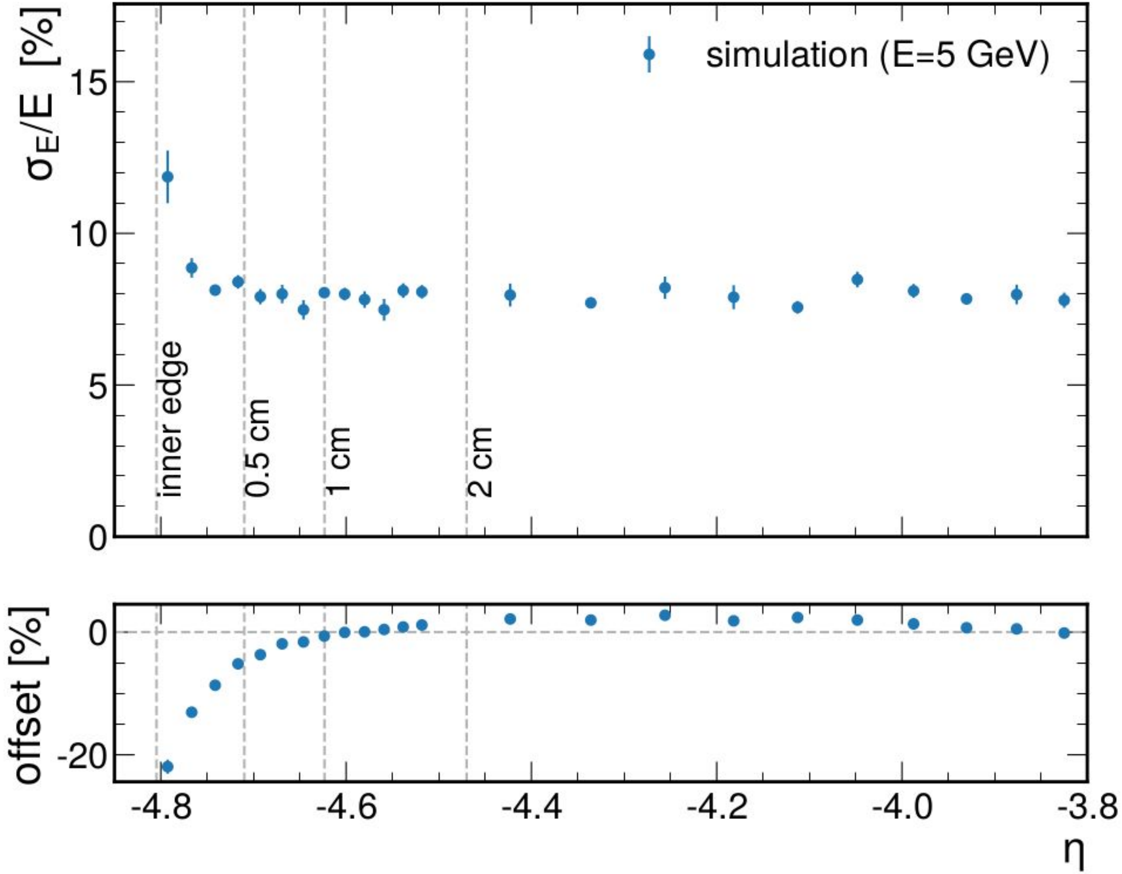


	EIC FDC	ZEUS BPC	H1 VLQ	CALICE	CEPC
Test beam	2024 planned	1994	1997	2009	2023
Depth	20 X_0	24 X_0	16.7 X_0	21.5 X_0	22 X_0
W/Sc thickness	3.5/2 mm	3.5/2.6 mm	2.5/3 mm	3.5/3 mm	3.5/2 mm
Moliere Radius	15 mm[4]	13 mm	15 mm	20 mm	20 mm
Optical readout	SiPM-on-tile	WLS bar+PMT	WLS bar+PIN	WLS fiber+SiPM	SiPM-on-tile
Trans. granularity	10×50 mm^2	7.9×150 mm^2	5×120 mm^2	10×45 mm^2	5×45 mm^2
Long. granularity	every strip	none	none	every strip	every strip
Readout channels	4500	31	336	2160	6720
Electronic readout	HGROC	FADC/TDC	ASIC	SPIROC	SPIROC2E
Position resolution	3.6 $\text{mm}/\sqrt{E}$	2.2 $\text{mm}/\sqrt{E}$	2 $\text{mm}/\sqrt{E}$	—	—
Energy resolution	$\frac{17\%}{\sqrt{E}} \oplus 2\%$	$\frac{17\%}{\sqrt{E}} \oplus 2\%$	$\frac{13\%}{\sqrt{E}} \oplus 3\%$	$\frac{12.5\%}{\sqrt{E}} \oplus 1.2\%$	$\frac{15\%}{\sqrt{E}} \oplus 1\%$
Time resolution	<50 ps	400 ps	—	—	—

Energy resolution

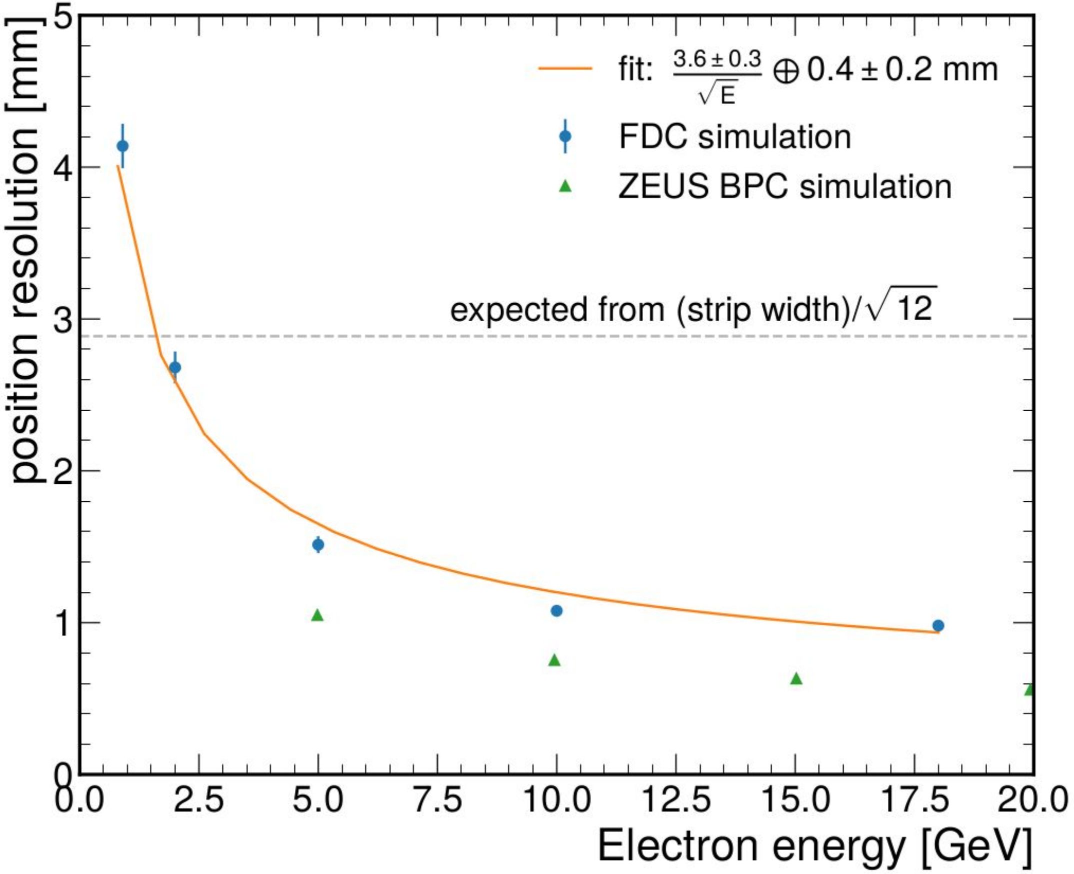


Energy resolution vs angle

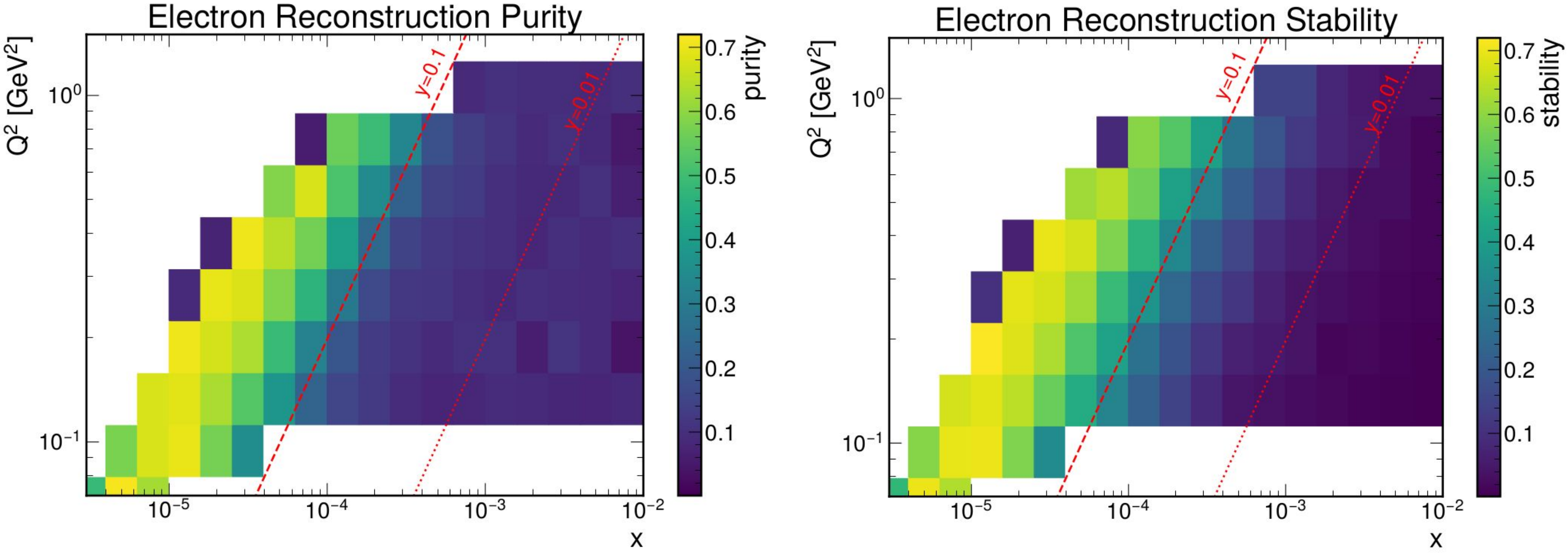


Position resolution

There is room for optimization in the algorithm, currently log-weighting with cut off of 4.0

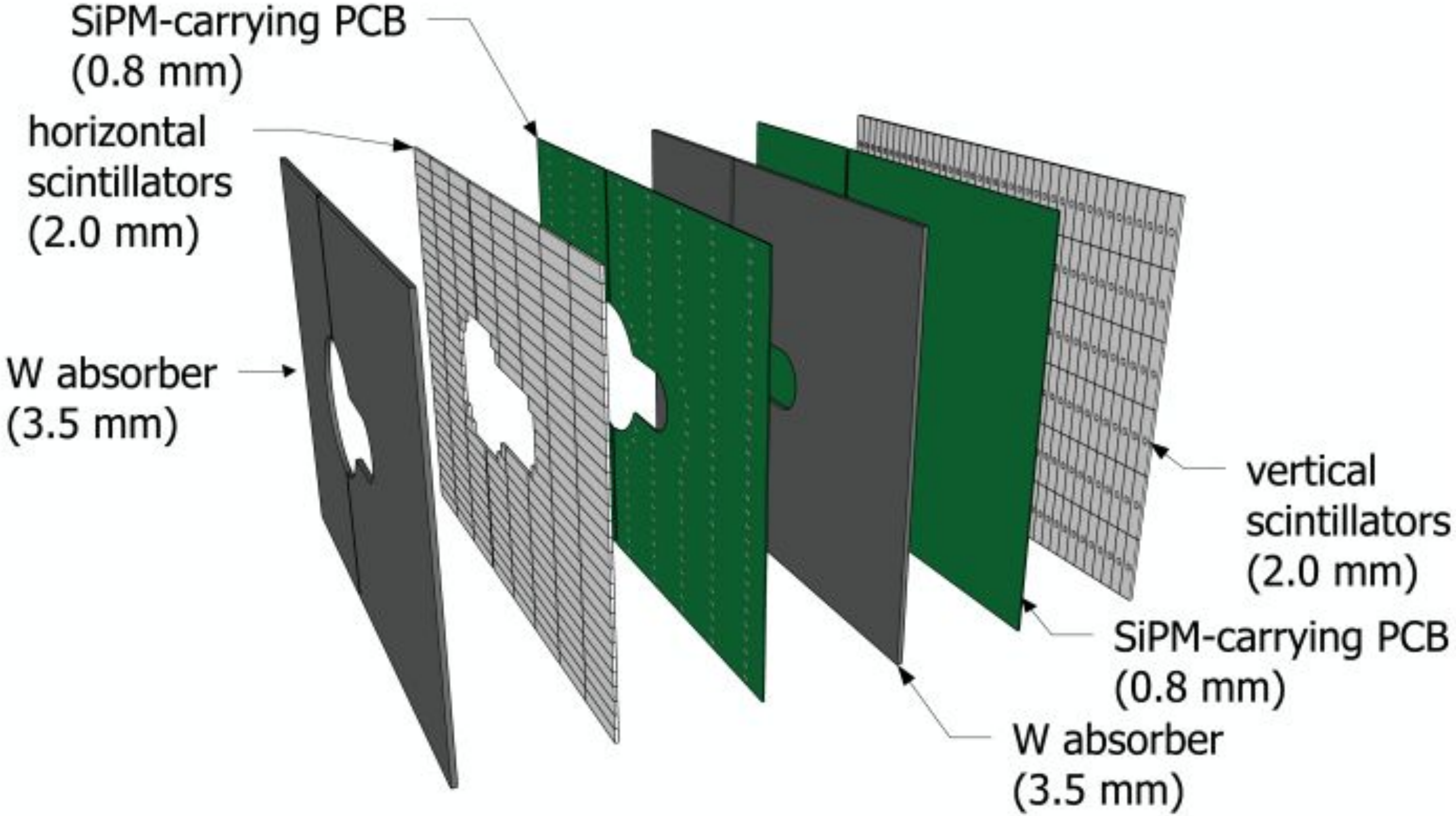


Performance for kinematic variables



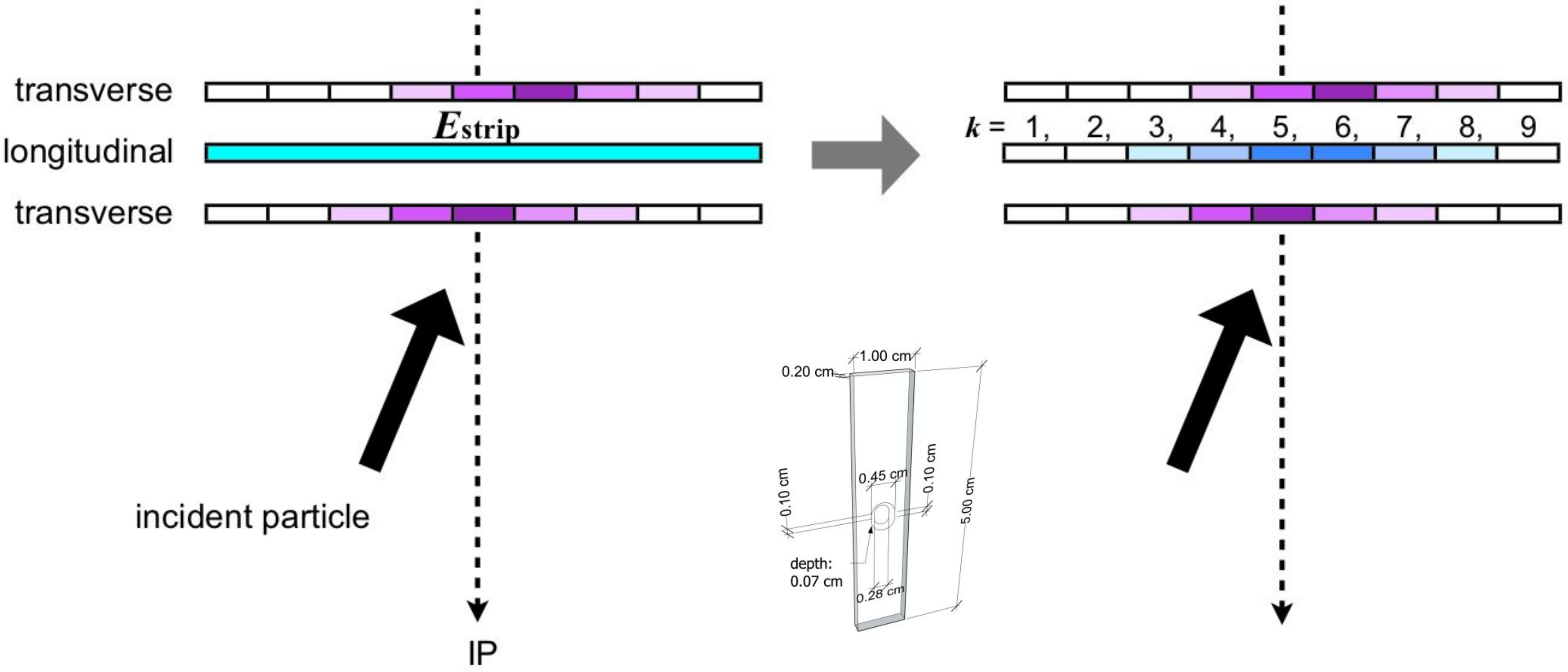
Does the job for 5 bins per decade

High-granularity brings opportunities for electron ID



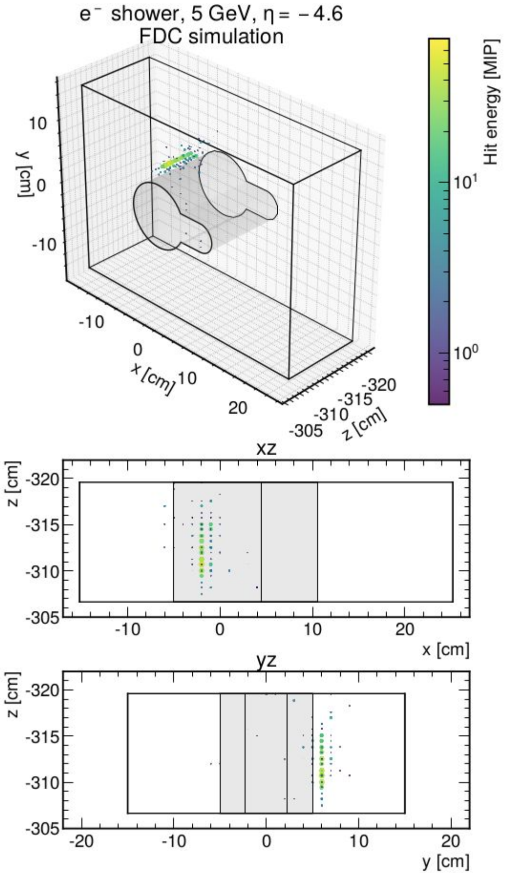
“Strip split algorithm” can squeeze performance out of alternating strips

K. Kotera et al. / Nuclear Instruments and Methods in Physics Research A 789 (2015) 158–164



Highly granular shower shapes can yield standalone electron tagging

(shown is “effective” granularity of strip width**2)



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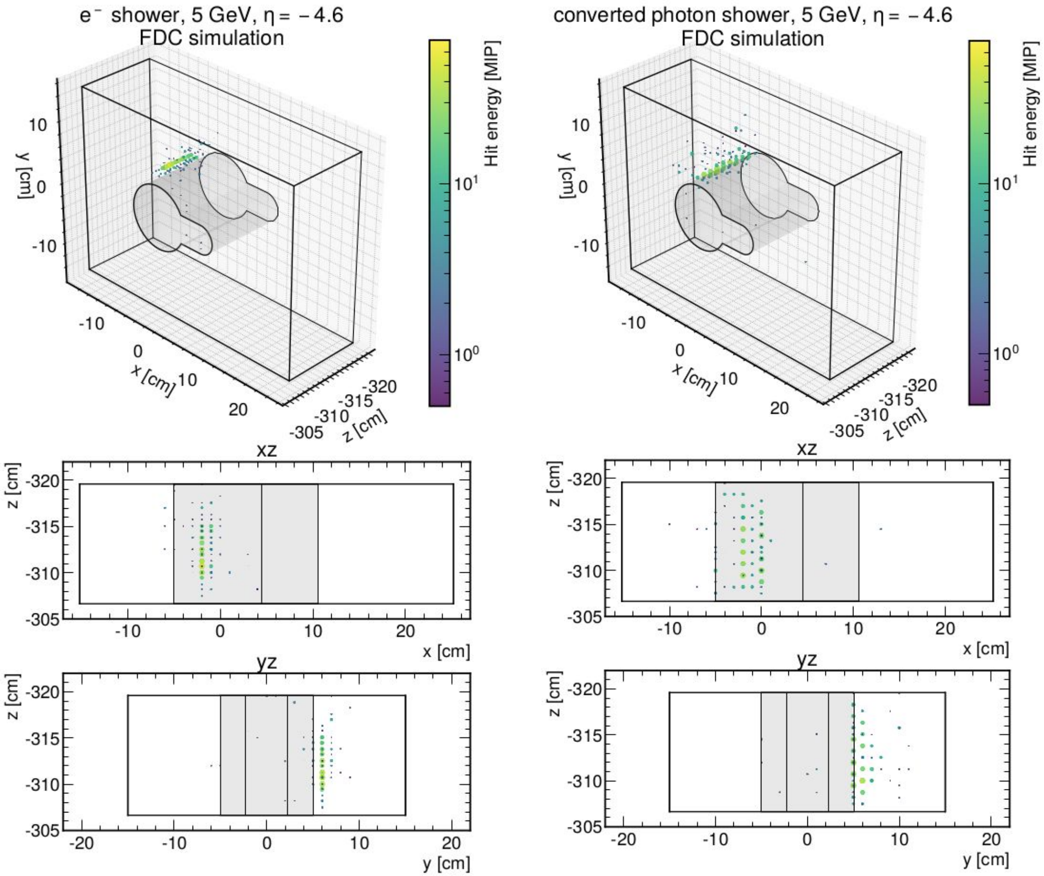

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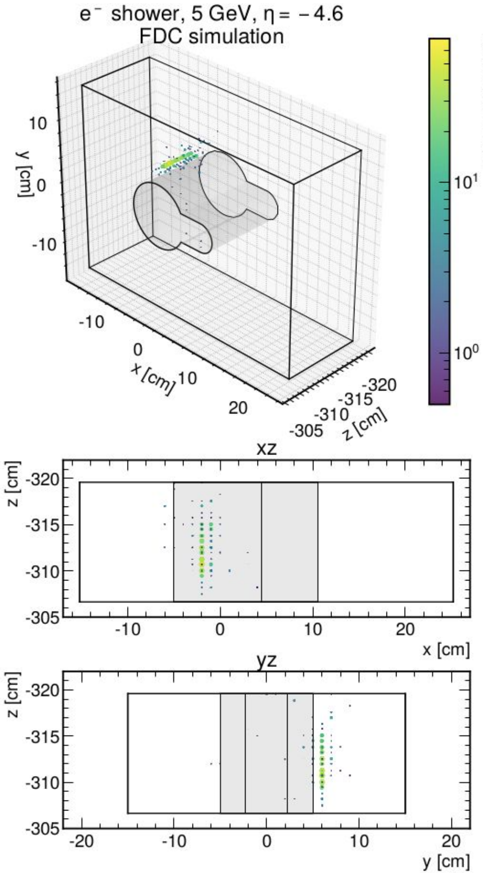
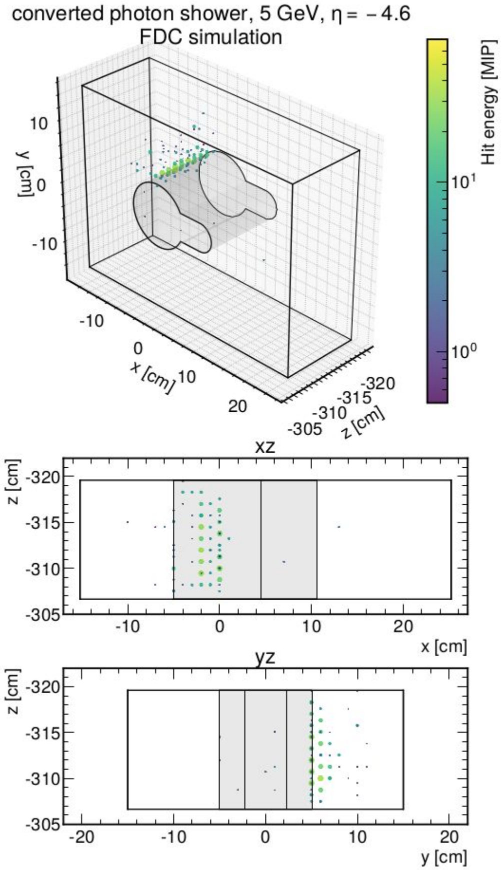
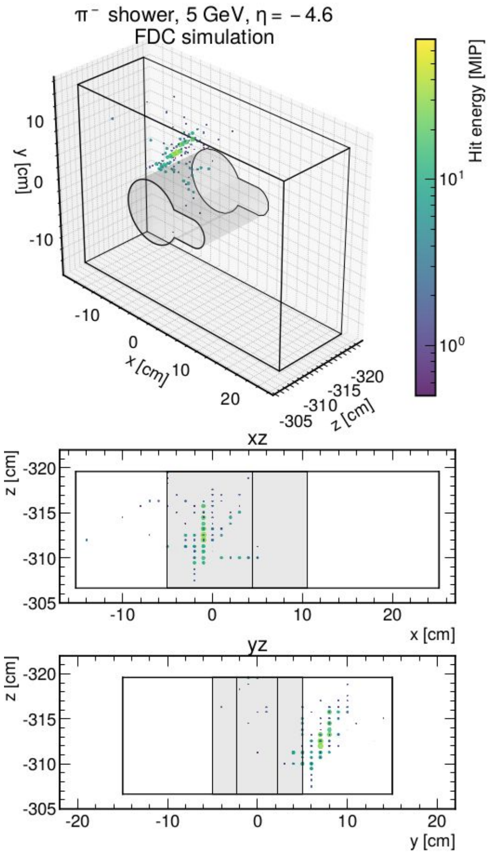
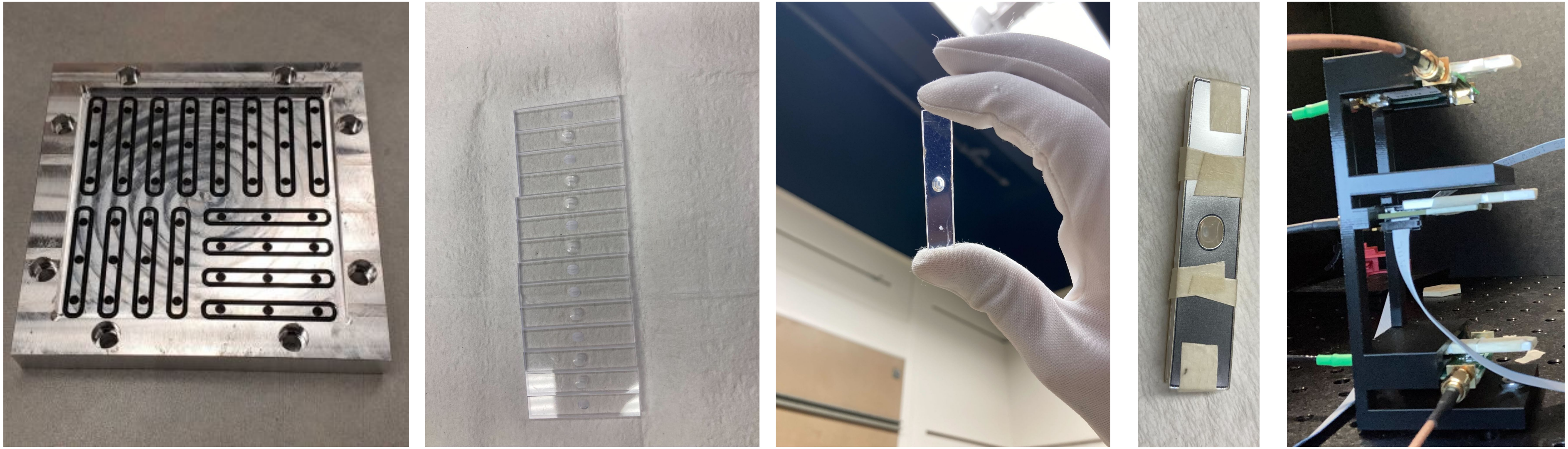






R&D

SiPM-on-tile is an emerging new paradigm in calorimetry, not yet explored in EIC detector R&D program



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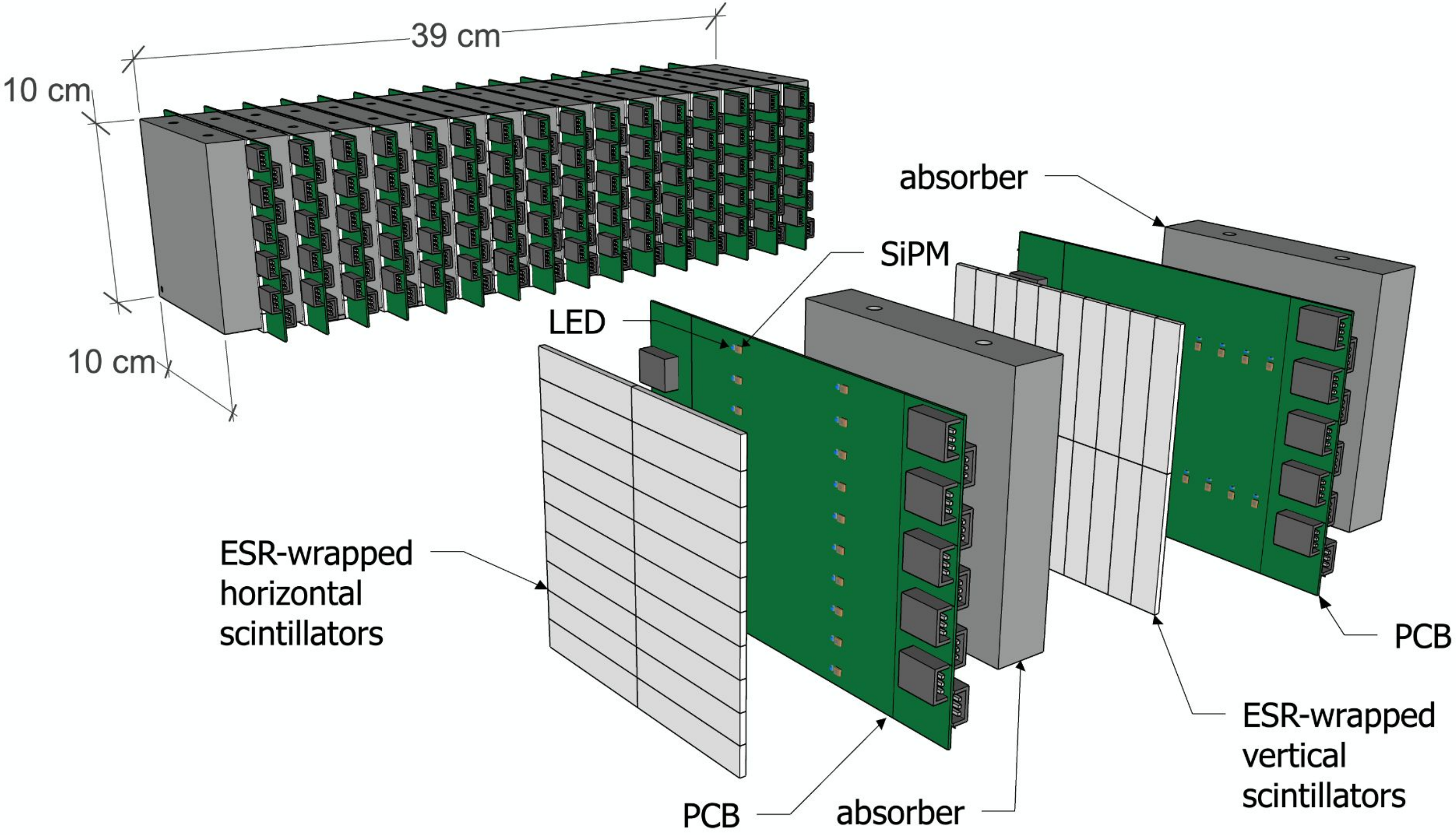
Prototype


39 cm
10 cm
10 cm
absorber
SiPM
LED
ESR-wrapped horizontal scintillators
PCB
absorber
ESR-wrapped vertical scintillators
PCB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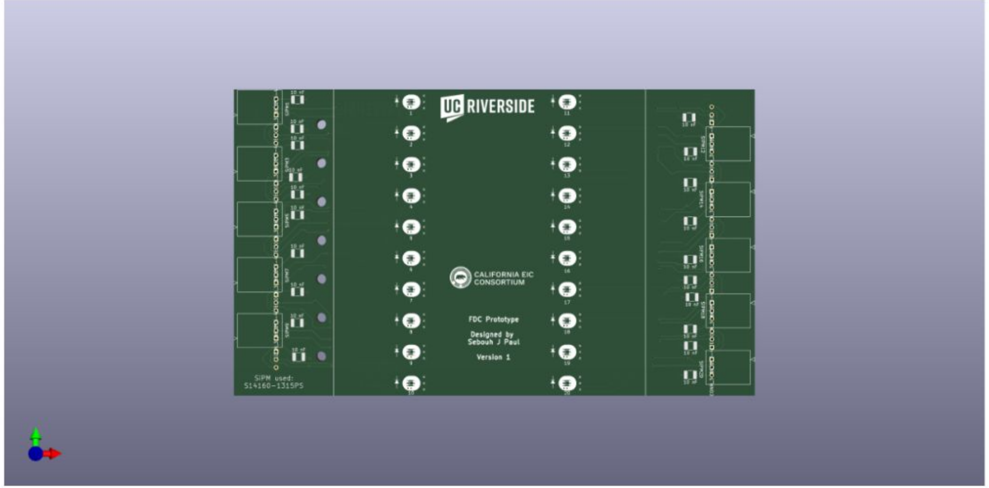
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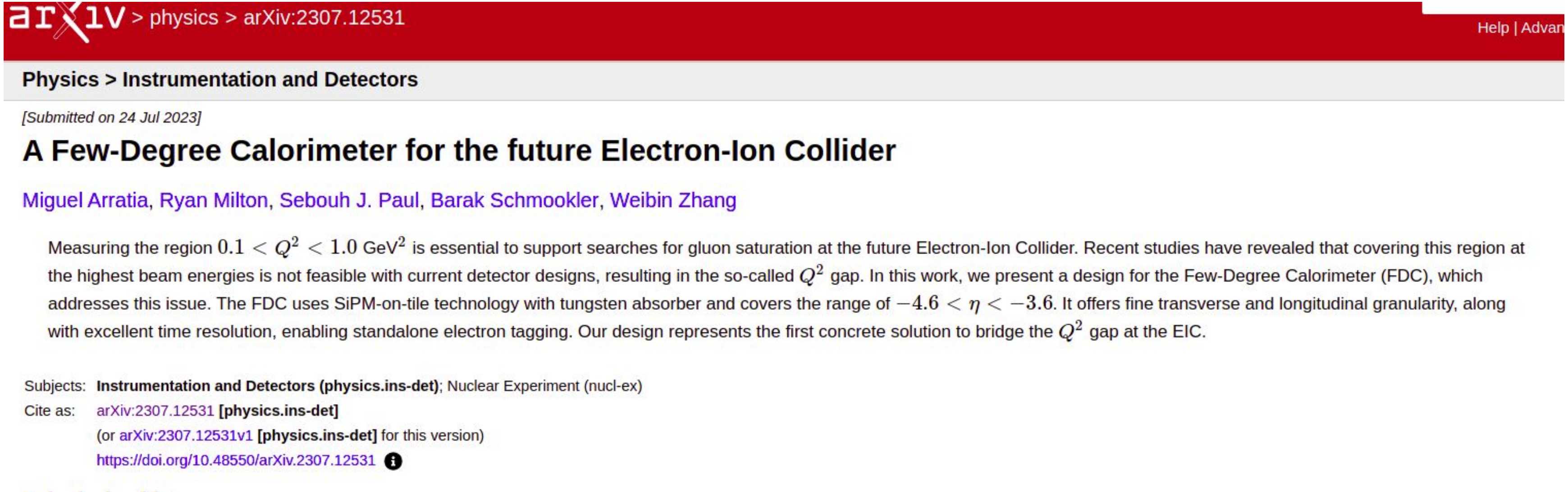
CALIFORNIA EIC CONSORTIUM
FDC Prototype
Designed by
Sebouh J Paul
Version 1
SIPM used:
S14160-1315PS
10 nF


arXiv > physics > arXiv:2307.12531

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Physics > Instrumentation and Detectors

[Submitted on 24 Jul 2023]

A Few-Degree Calorimeter for the future Electron-Ion Collider

Miguel Arratia, Ryan Milton, Sebouh J. Paul, Barak Schmookler, Weibin Zhang

Measuring the region $0.1 < Q^2 < 1.0$ GeV^2 is essential to support searches for gluon saturation at the future Electron-Ion Collider. Recent studies have revealed that covering this region at the highest beam energies is not feasible with current detector designs, resulting in the so-called Q^2 gap. In this work, we present a design for the Few-Degree Calorimeter (FDC), which addresses this issue. The FDC uses SiPM-on-tile technology with tungsten absorber and covers the range of $-4.6 < \eta < -3.6$. It offers fine transverse and longitudinal granularity, along with excellent time resolution, enabling standalone electron tagging. Our design represents the first concrete solution to bridge the Q^2 gap at the EIC.

Subjects: **Instrumentation and Detectors (physics.ins-det)**; Nuclear Experiment (nucl-ex)

Cite as: arXiv:2307.12531 **[physics.ins-det]**

(or arXiv:2307.12531v1 **[physics.ins-det]** for this version)

https://doi.org/10.48550/arXiv.2307.12531

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EIC^2

EIC Center at Jefferson Lab

Summary

- A FDC can bridge the Q2 gap. Maybe needed even more in IP8, with room for optimization in beam pipe design.

- SiPM-on-tile tungsten calorimeter meets requirements at low cost

- SiPM-on-tile technology is an emerging technology, offering a new tool for various calorimeters at EIC.

FDC