Far Forward Region Calorimetry at EIC

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On behalf of the Detector-1 Collaboration

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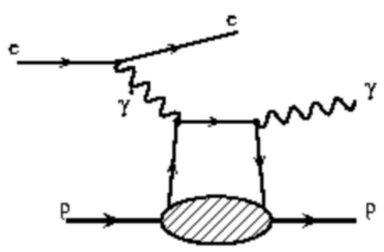
Outline

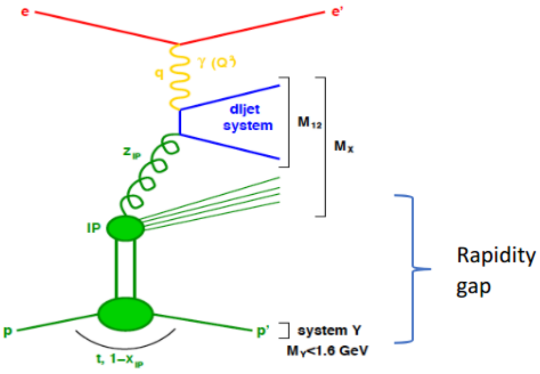
- Introduction and motivation
- Far Forward Calorimeters
  - B0 Detector
  - ZDC
- Physics studies examples
- Summary

Far-forward physics at EIC

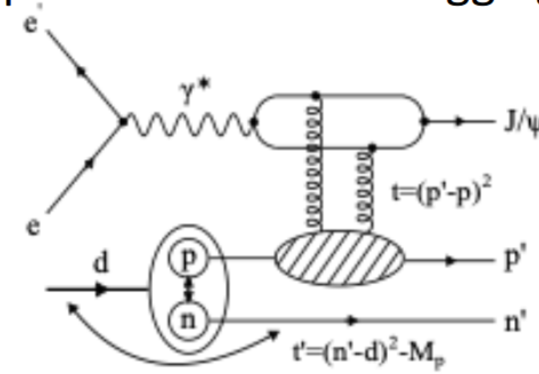
e+p DVCS events with proton tagging.



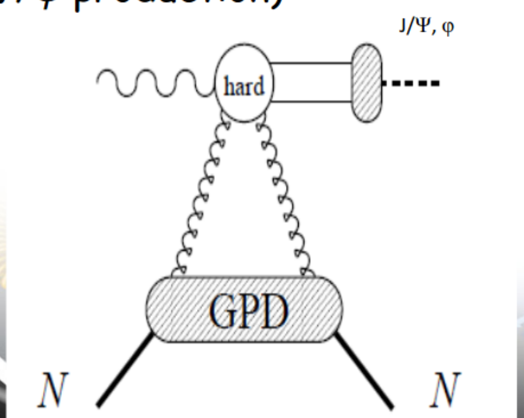
Diffraction



e+d exclusive J/Psi and DIS events with proton or neutron tagging

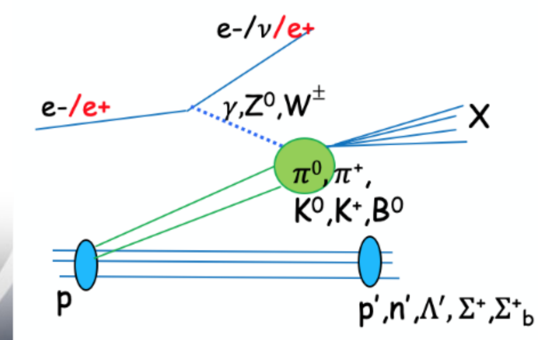


Saturation (coherent/incoherent J/ψ production)



Meson structure:

- with neutron tagging (ep→ (π) →e' n X)
- Lambda decays ($\Lambda \to p\pi^-$ and $\Lambda \to n\pi^0$)



e+He3 with spectator proton tagging.

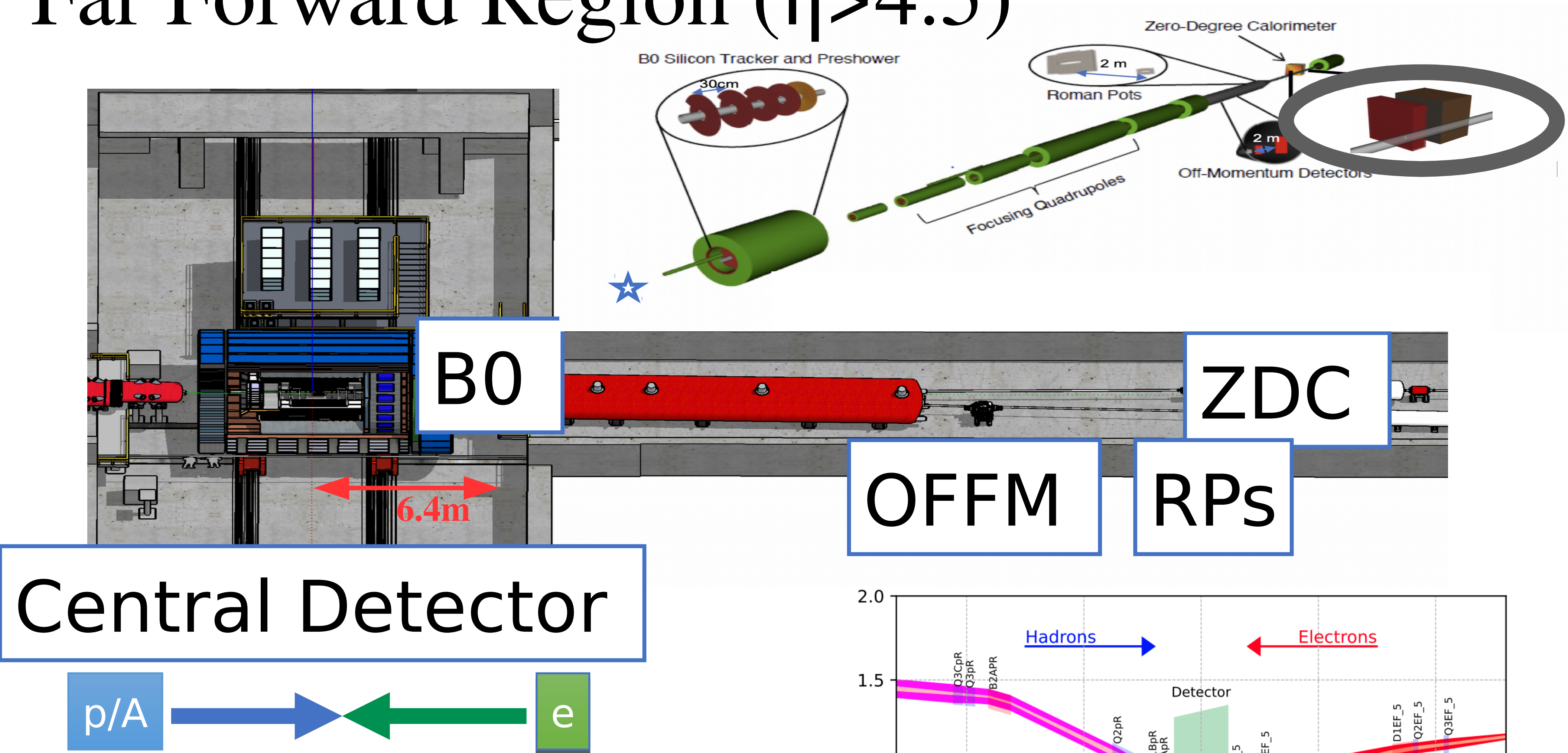
e+He4 coherent He4 tagging.

e+Au events with neutron tagging to veto breakup and photon acceptance.

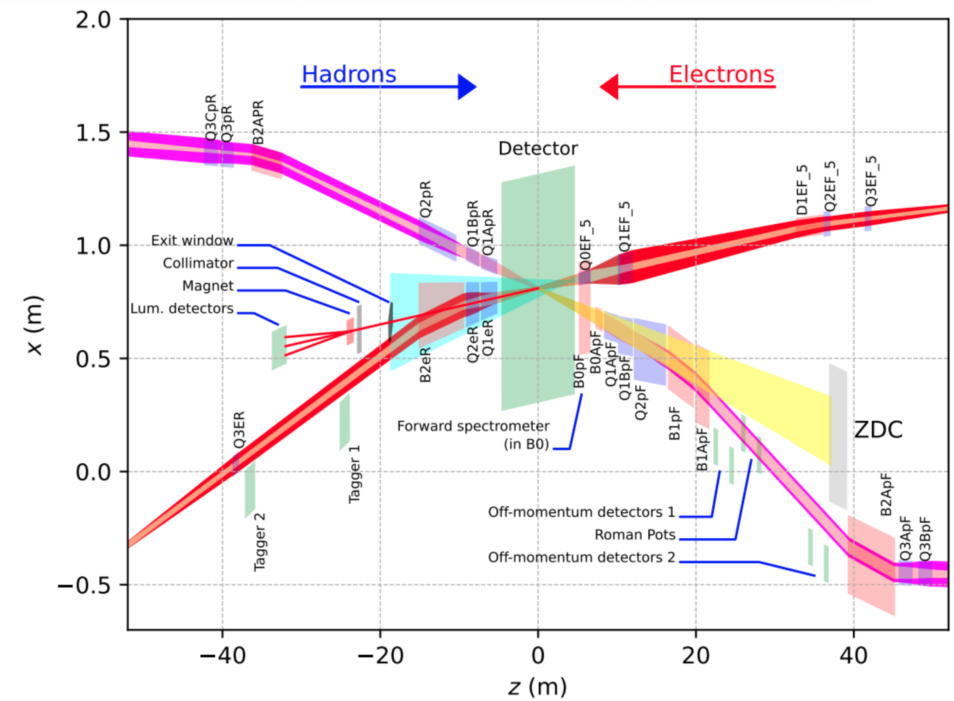
....

- The various physics channels require tagging of charged hadrons (protons, pions) or neutral particles (neutrons, photons) at very-forward rapidities(>4.5).
- Different final states require different detector subsystem for detection.
- Different collision systems provide unique challenges due to magnetic rigidity difference between beam and final-state particles.
- Placing far-forward detectors uniquely challenging due to presence of machine components, space constraints, apertures, etc

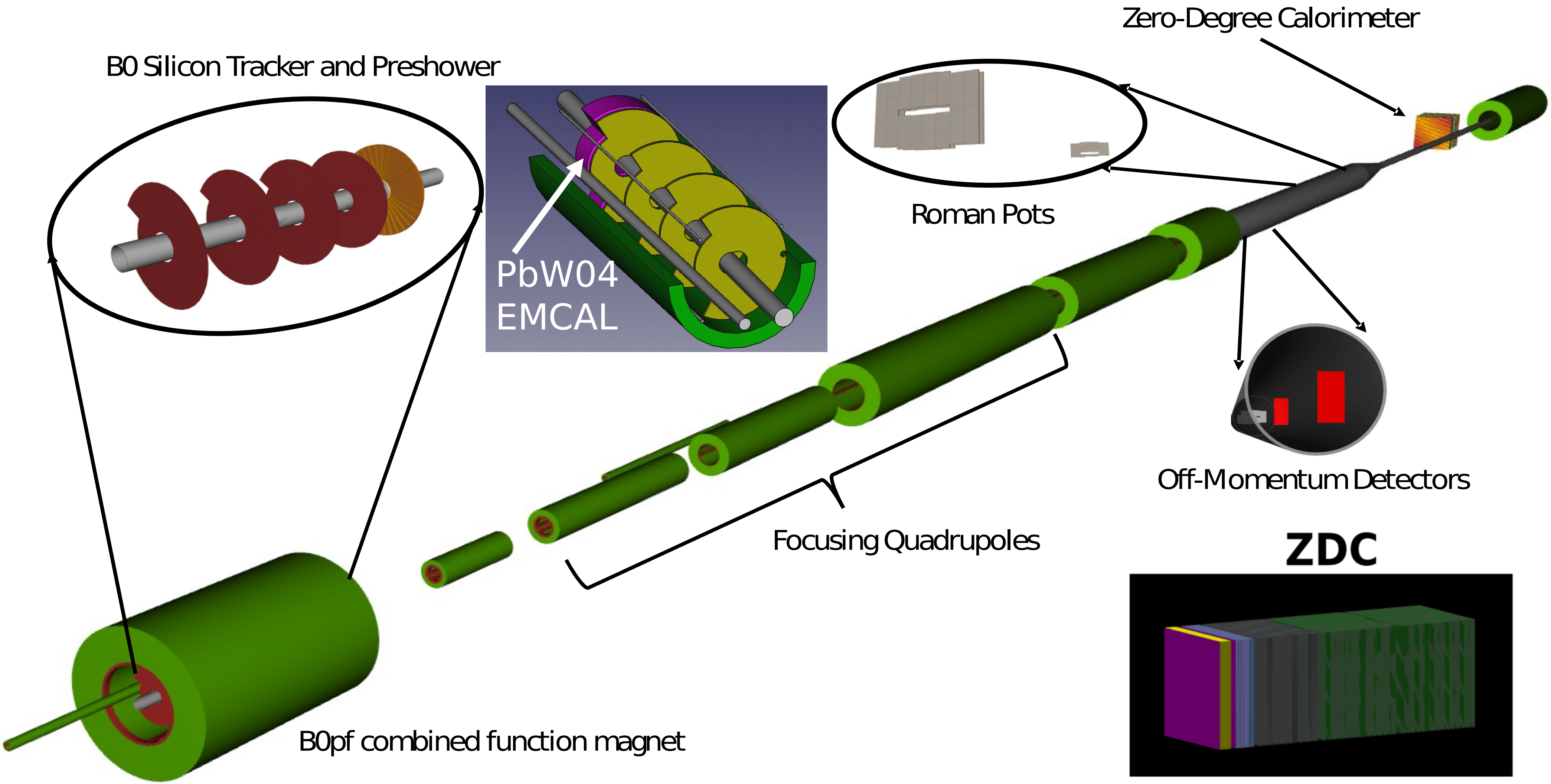
Far Forward Region (η>4.5)



- Central detector spans 9 meters and is machine-component free.
- Hadron-going and electron-going directions fully instrumented.
- Hadron and electron beam cross with an angle of 25mrad.



EIC Far-Forward region



Detector	(x,z) Position [m]	Dimensions	θ [mrad]	Notes	Acceptance
ZDC	(-0.96, 37.5)	(60cm, 60cm, 1.62m)	$\theta < 5.5$	$\sim$4.0 mrad at $\phi = \pi$	η > 6.0
Roman Pots (2 stations)	(-0.83, 26.0) (-0.92, 28.0)	(30cm, 10cm)	$0.0 < \theta < 5.5$	$10\,\sigma$ cut.	η > 6.0
Off-Momentum Detector	(-1.62, 34.5), (-1.71, 36.5)	(50cm, 35cm)	$0.0 < \theta < 5.0$	$0.4 < x_L < 0.6$	η > 6.0
B0 Trackers and Calorimeter	(x = -0.15, 5.8 < z < 7.0)	(32cm, 38m)	$6.0 < \theta < 22.5$	$\sim$20 mrad at ϕ=0	4.6 > η > 5.9

Challenges to B0 Tracking and Calorimeter Systems

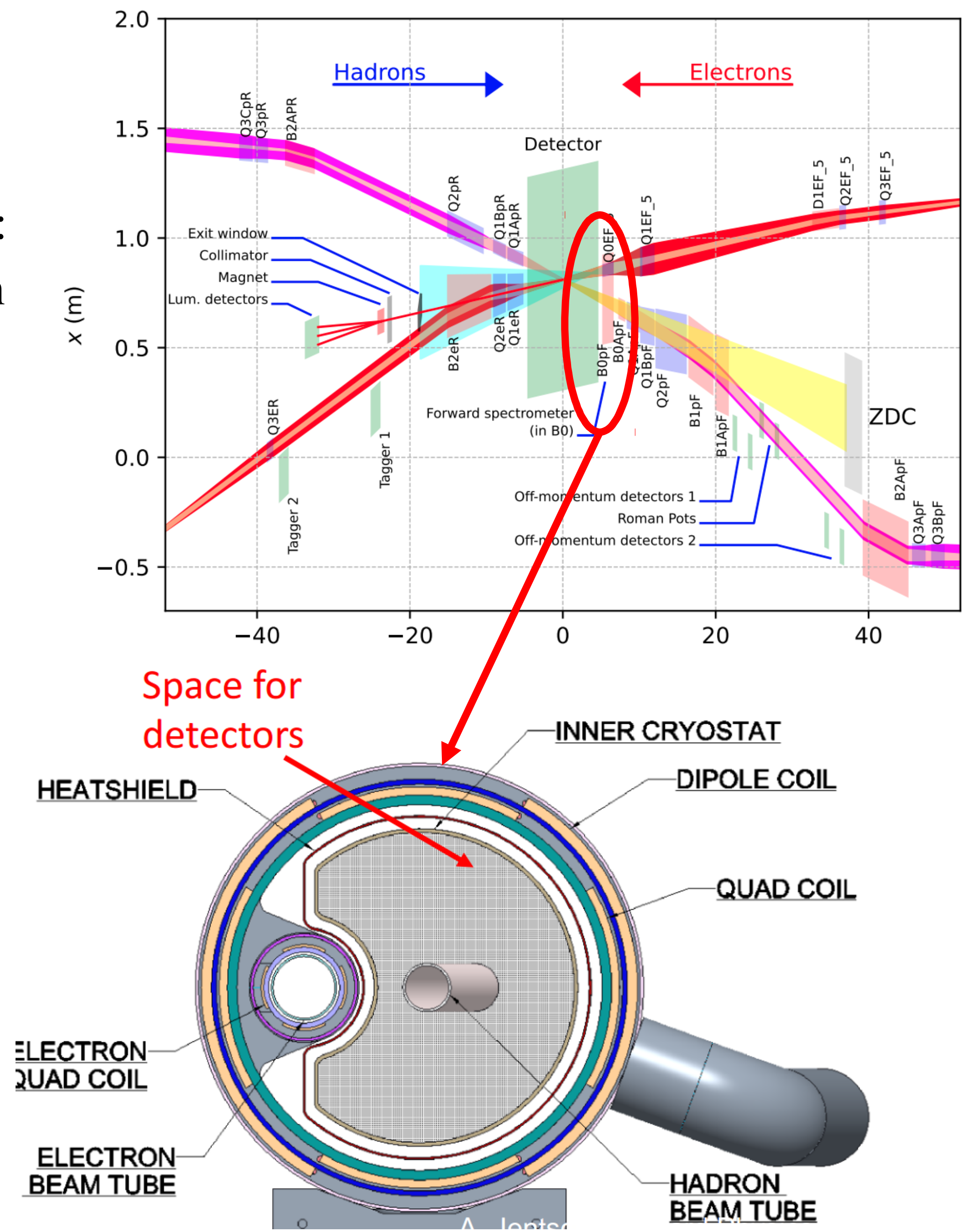
0. The whole detector is located inside a 20cm radius magnet

1. The B0 is the most challenging EIC magnet: it needs to provide both field for the proton/ion beam and no field for the electron beam, in limited space.

2. The acceptance along z changes due to the crossing angle (25mrad) as the B0 is aligned with the electron beam.

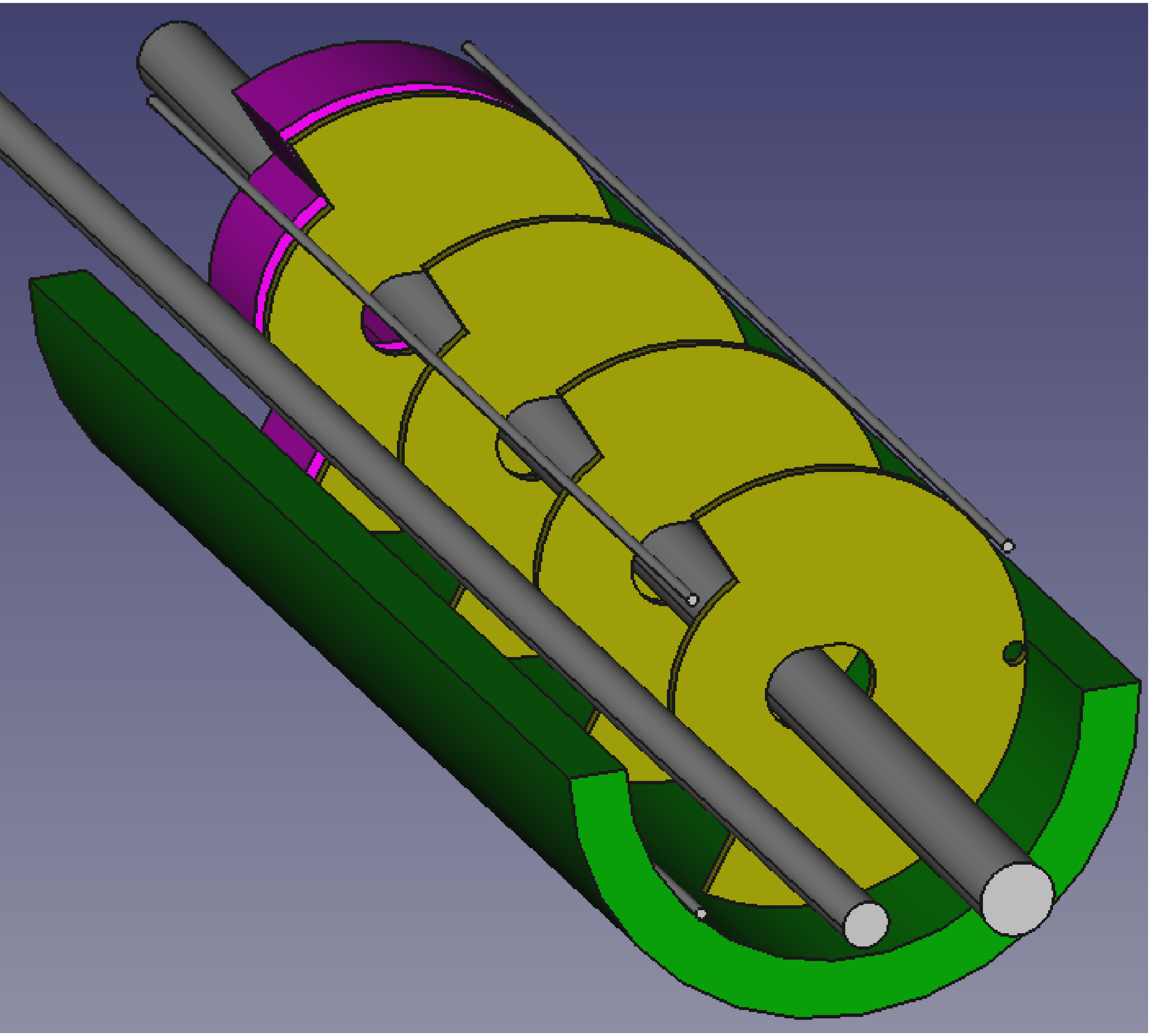
3. Access only possible from IP side, and no access from the hadron downstream side as that region is integrated with the cold mass.

4. Operation of the B0 Tracker and Calorimeter very close to the beam.



Will the calorimeter impact the tracking performance?

B0 Tracker and Calorimeter Design



Four Si tracking planes occupy 1m of 120cm

2mm of Cu after each tracking layer to model cooling and readout

They are followed by 10cm $PbW0_4$ Calorimeter

2*2cm granularity

7cm at the back of the Calorimeter are assumed for its readout

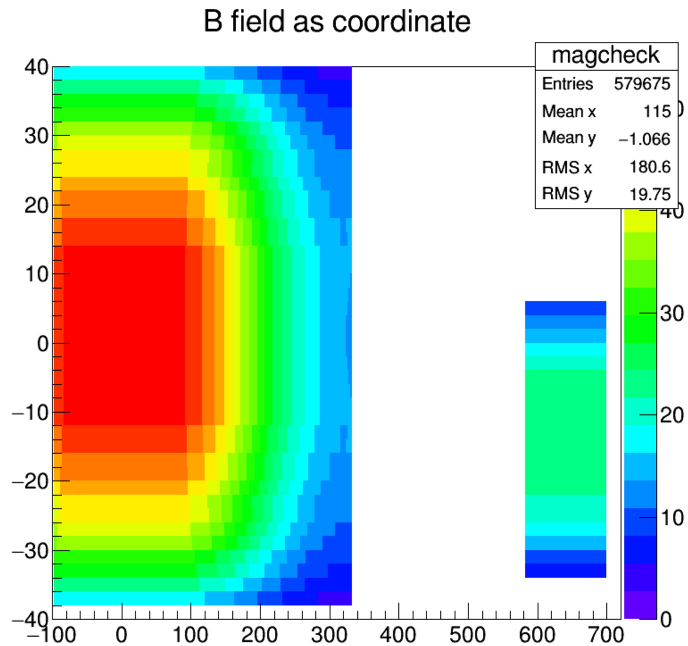
Oval shape of the cut off for the hadron beam:

- Account for the 25mrad crossing angle
- Allows to increase the acceptance at large η

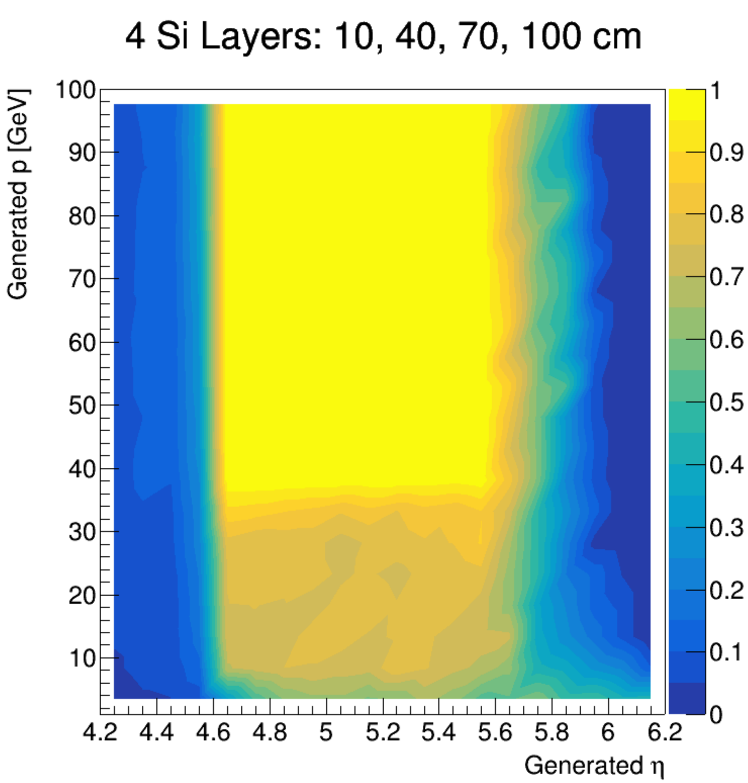
Geant4 Simulation:

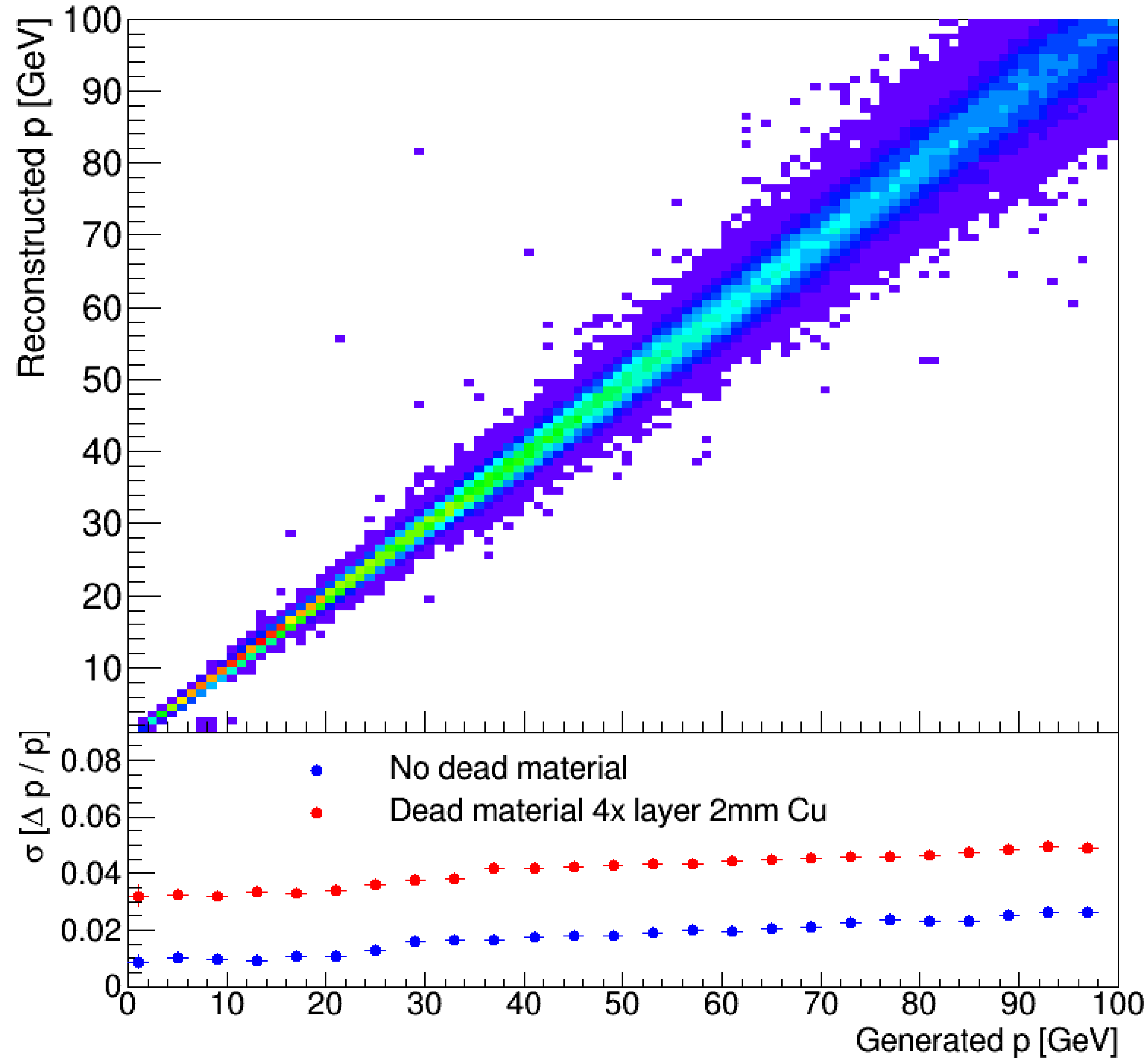
- Charged particle reconstruction and photon tagging.
    - Precise tracking (~10um spatial resolution).
    - Fast timing for background rejection and to remove crab smearing (~35ps).
    - Photon detection (tagging or full reco).

B0 Tracker



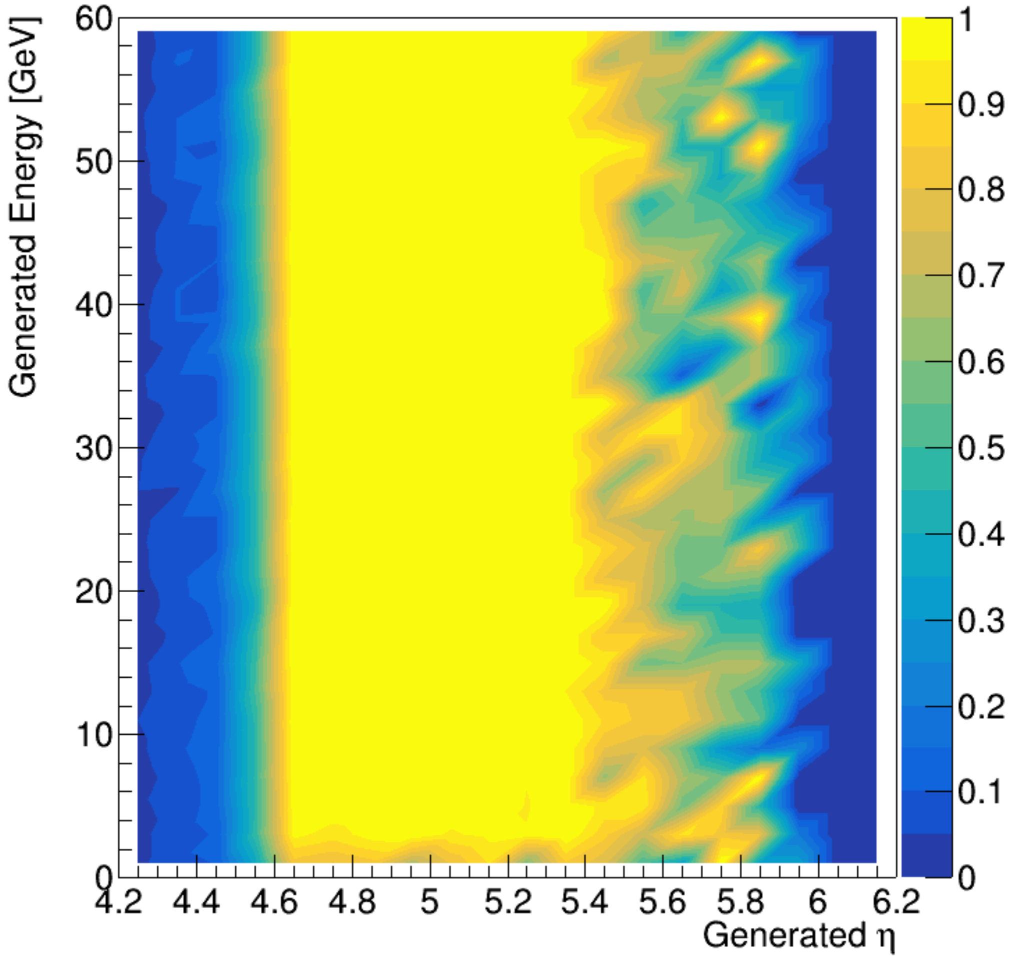
B0 dipole magnet field is added to the field map to be passed to the Kallman filter.



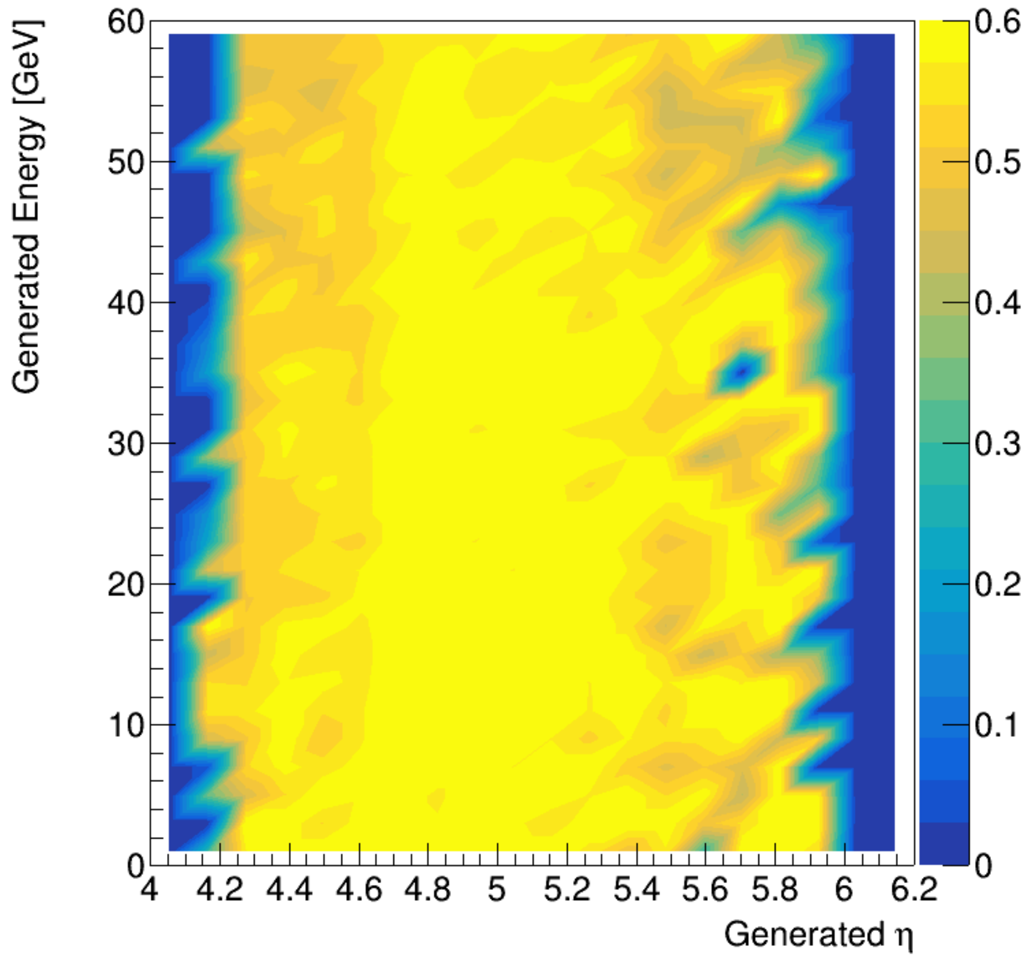


The achieved resolution is below 5% for all p_T in the realistic design assuming 2mm dead layers for readout

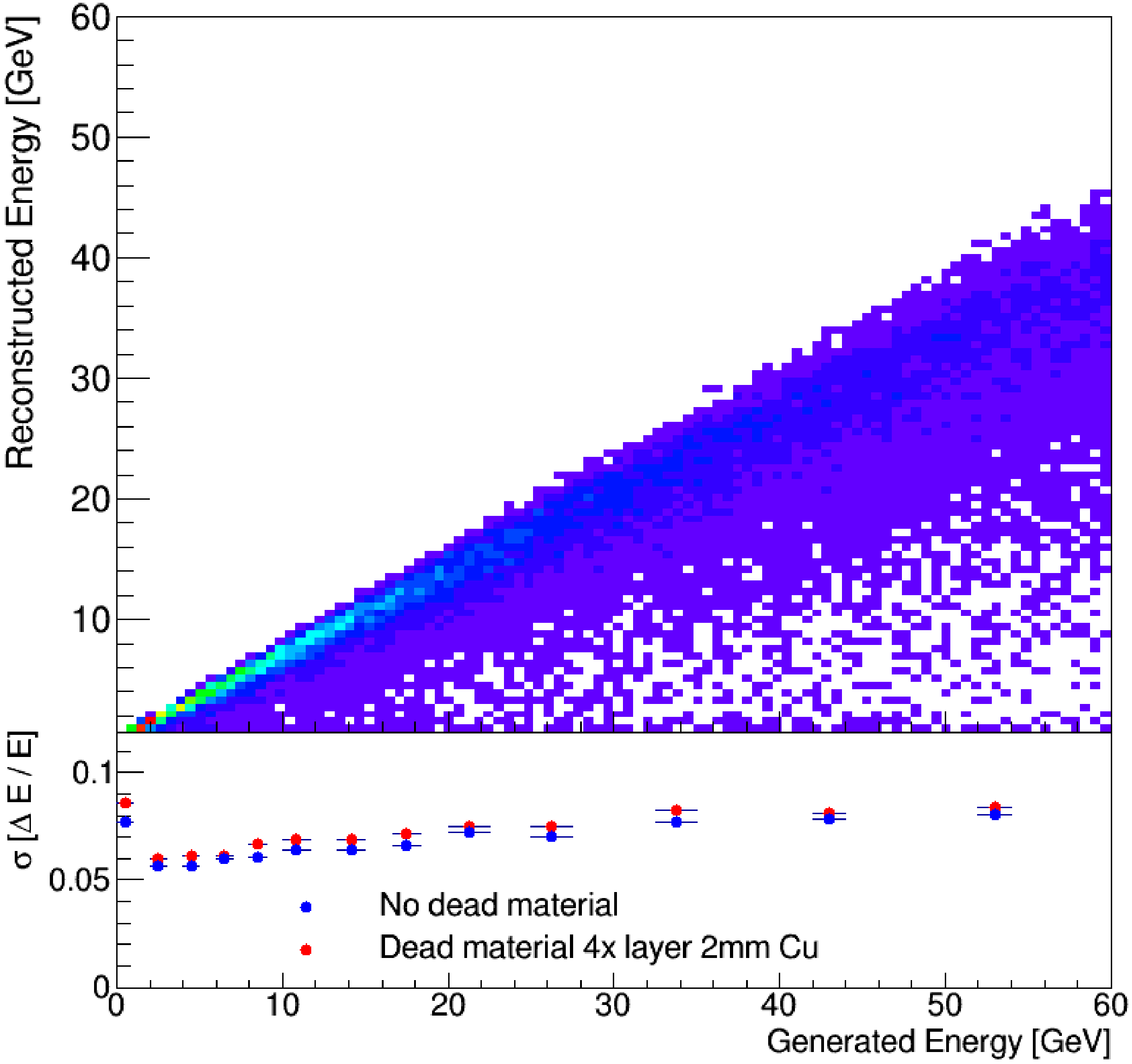
B0 calorimeter acceptance



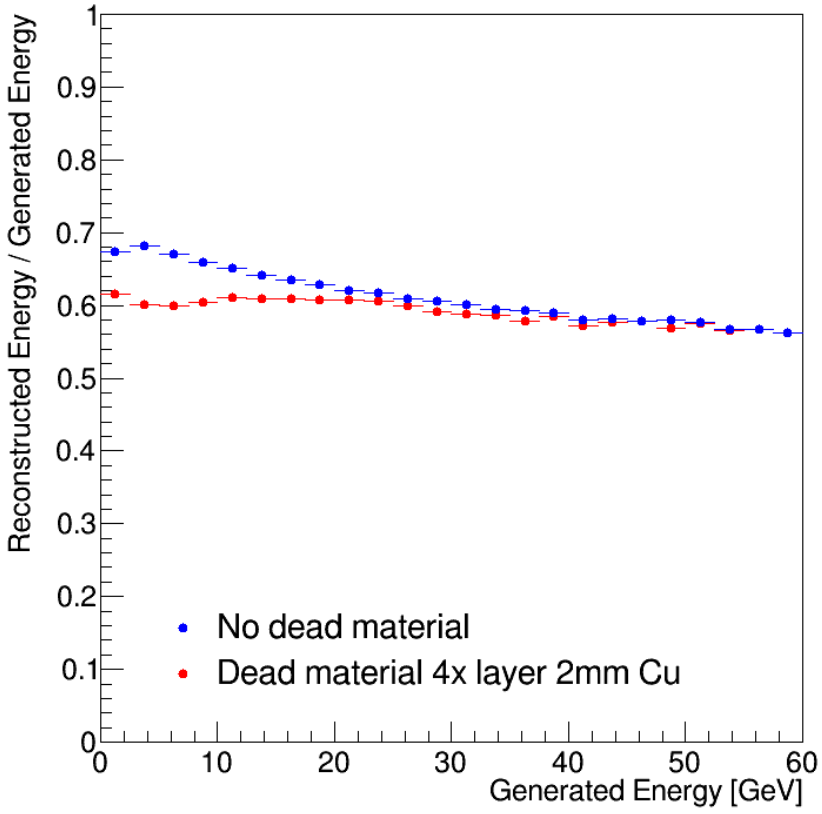
Reconstructed / Generated Energy



B0 calorimeter resolution



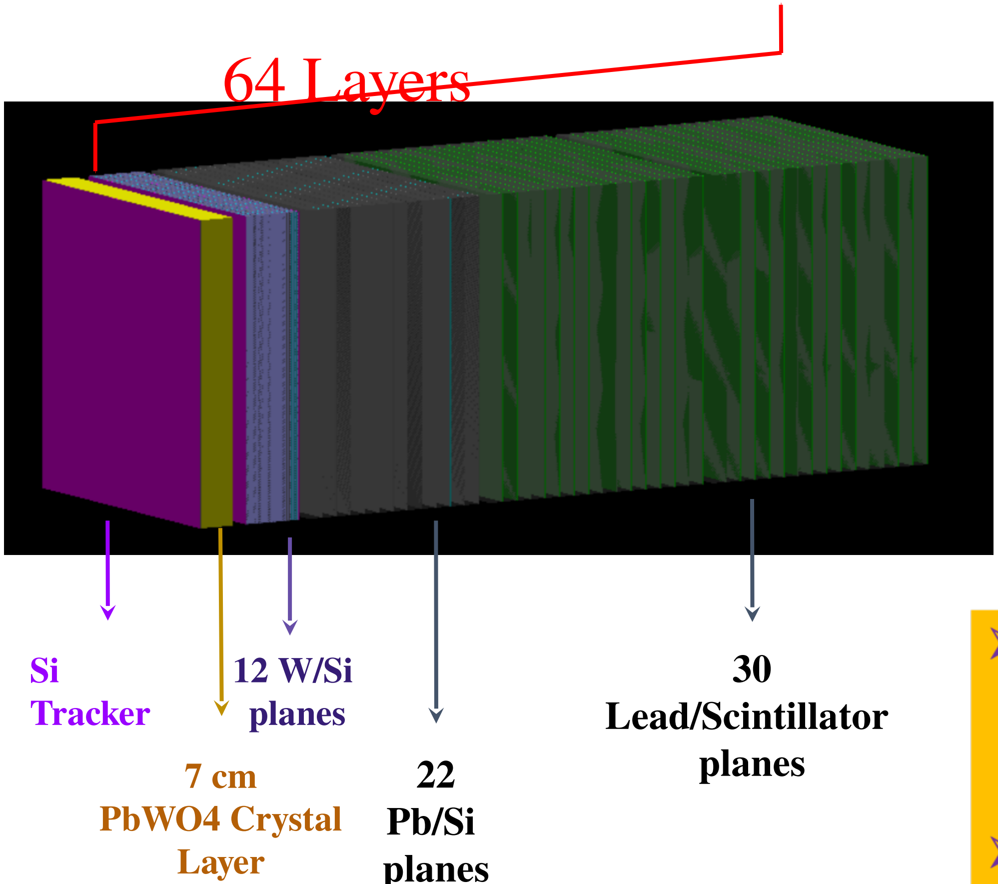
Effect of the presence of dead material (for cooling and readout) after each tracking plane is estimated.



The photon energy resolution is found to be below 7% for the studied kinematic region.

Zero-Degree Calorimeter

- High resolution HCAL + EMCAL for detecting neutral forward-going particles (neutrons and photons)
  - HCAL requires $\frac{\Delta E}{E} \sim \frac{50\%}{\sqrt{E}} \oplus 5\ \%$ and $\sigma_\theta \sim \frac{3\text{ mrad}}{\sqrt{E}}$, or better.
  - ALICE FoCal assumptions used for studies thus far (EIC R&D group started last summer).
  - Acceptance limited by bore of magnet where the neutron/photon cone exits ($0.0 < \theta < 4.5$ mrad).

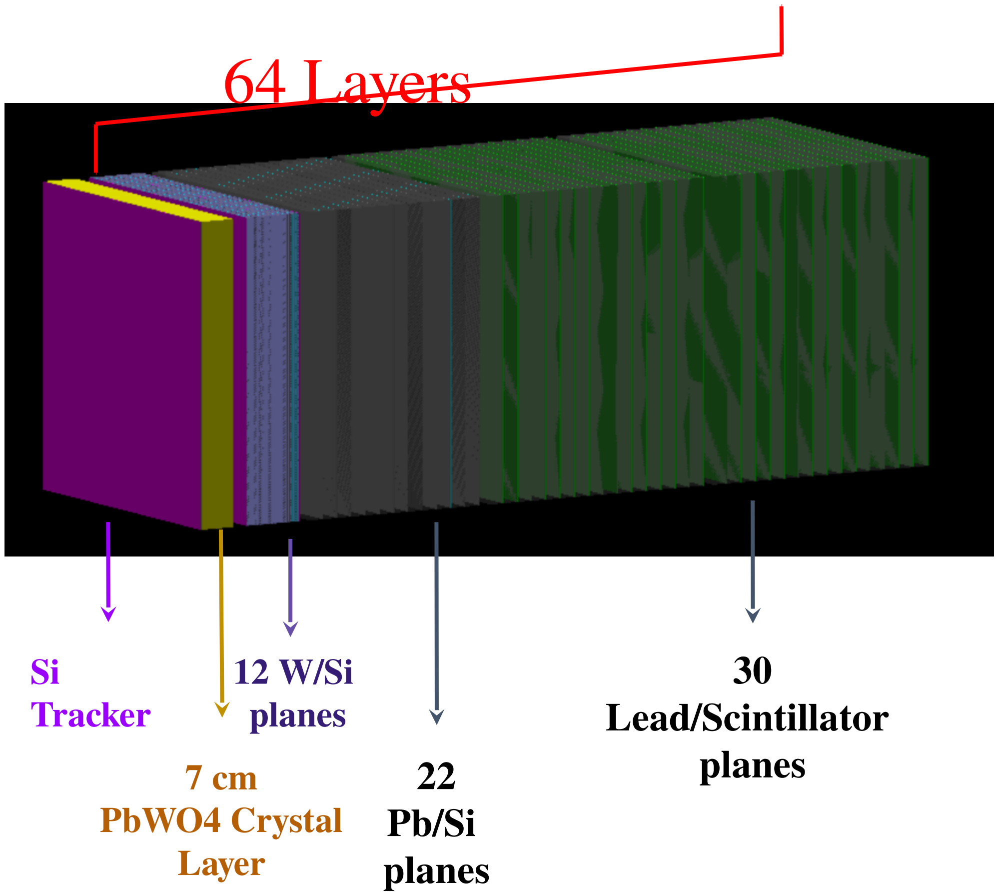


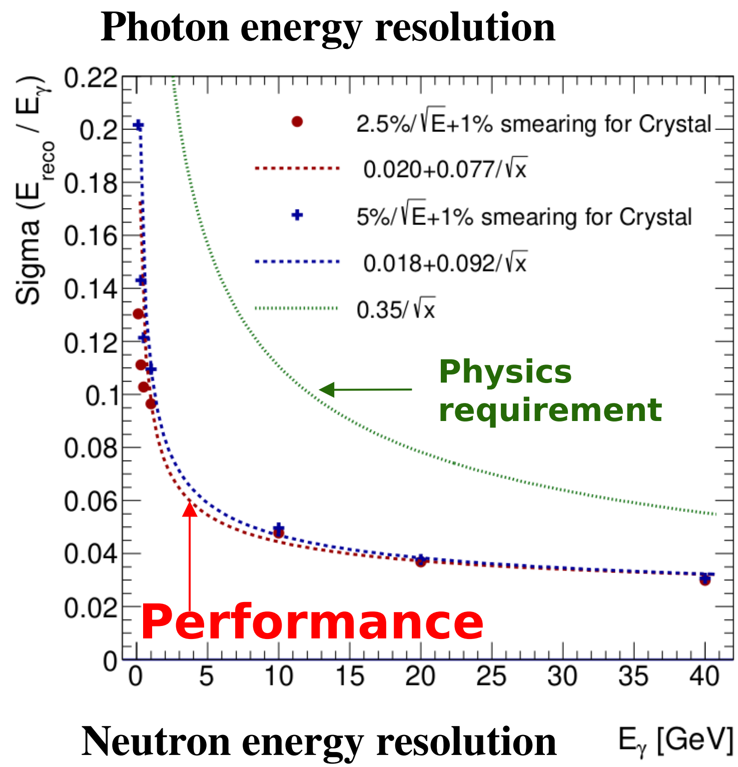
- Zero Degree Calorimeter (improved ALICE design):
  - Dimension: 60 cm x 60 cm x 168 cm
  - 30 m from IR
  - Detect spectator nucleon
  - Acceptance: +4.5 mrad, -5.5mrad
  - Position resolution ~1.3mm at 40 GeV
  - Full reconstruction of photons (EMCAL) and neutrons (HCAL)

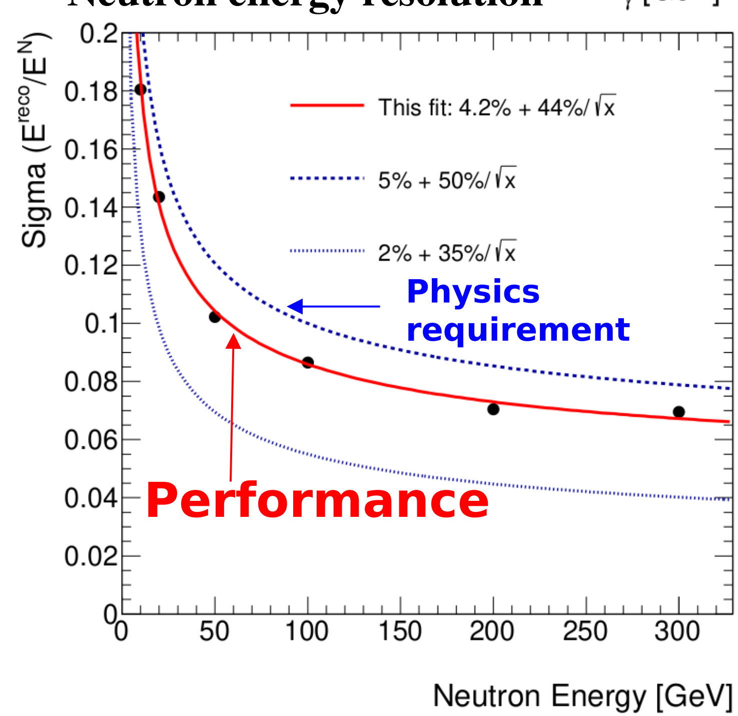
➢ Sufficient calorimeter depth (radiation lengths, X_0 for photons/electrons; nuclear interaction lengths, λ_I for neutrons/hadrons)
  - Required for good energy resolution.

➢ Granularity needed for proper reconstruction of shower.
  - Finding the center of the shower needed to provide angular resolution to get neutron transverse momentum!

Zero-Degree Calorimeter





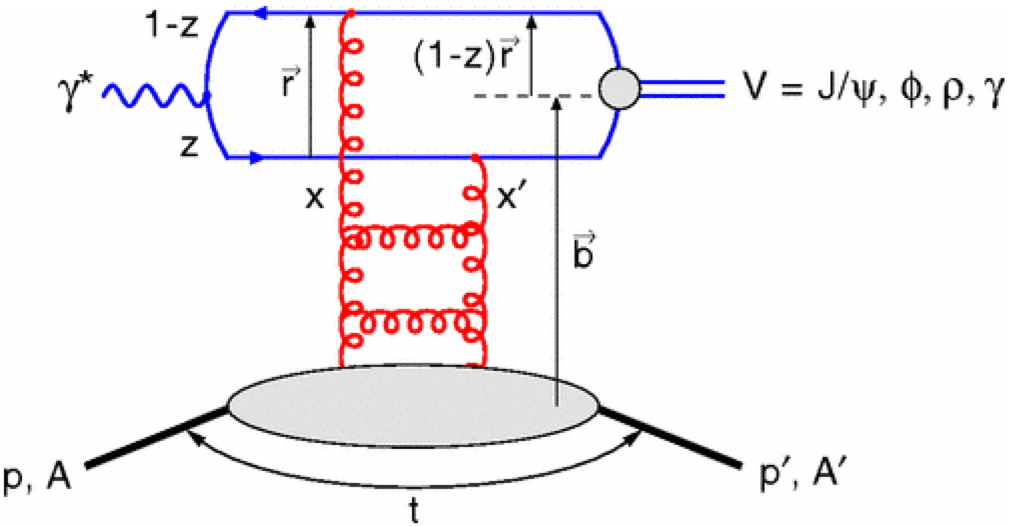


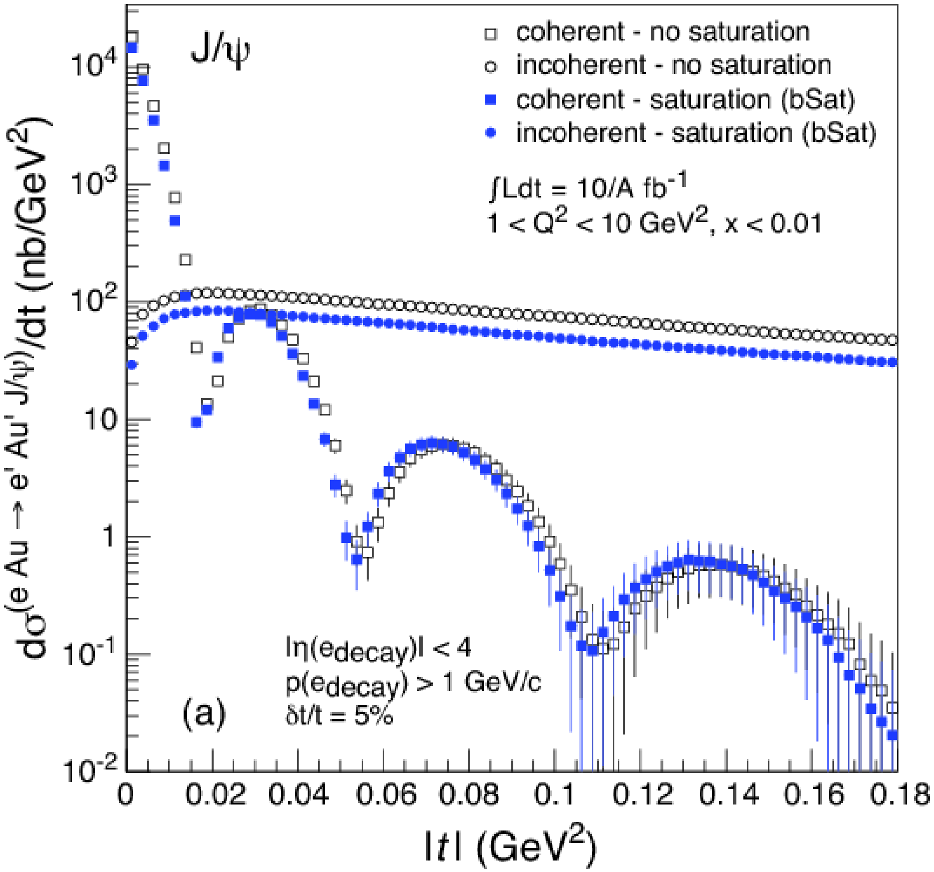
*Beam pipe effects are not included in performance studies

B0 and ZDC applications: Exclusive VM production

Both B0 (*PS or EMCal design*) and ZDC can be used to veto events with forward going photons

T. Toll and T. Ullrich





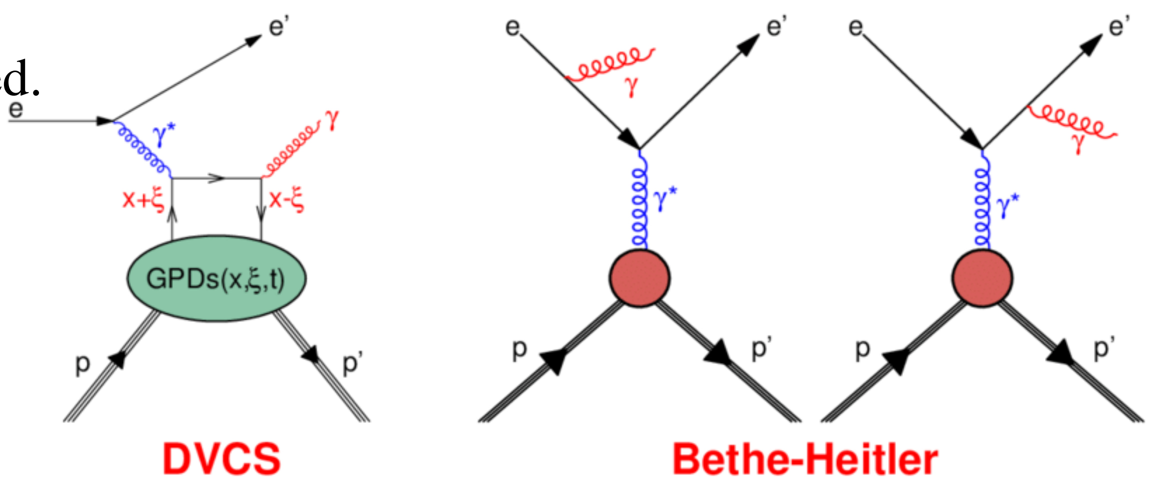
Measurement of the coherent spectrum down to the 3rd diffractive minimum requires rejection of incoherent events.

Nuclear breakup in incoherent events produces soft photons (~300 MeV) in the forward direction from the de-excitation of some of the larger nuclear fragments.

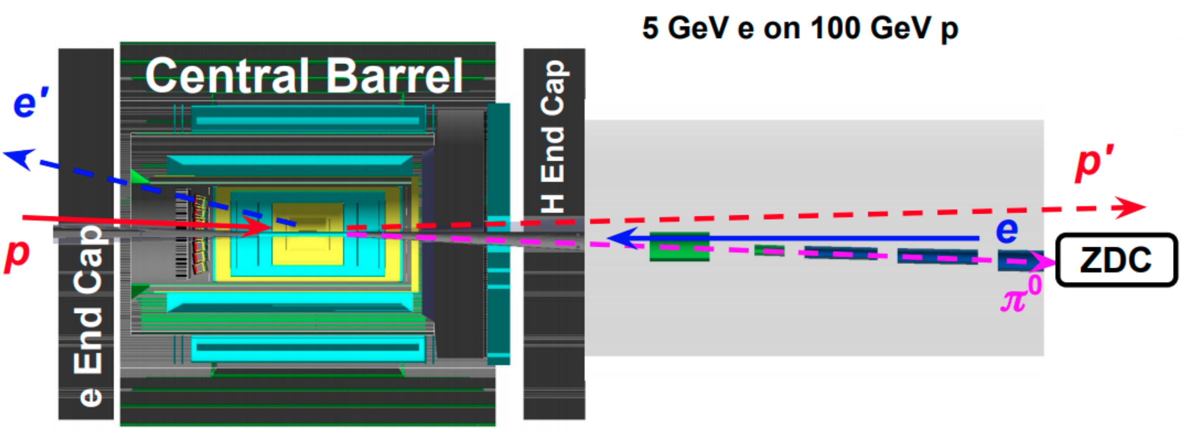
B0 and ZDC applications: u-channel DVCS

- For studies of *u*-Channel (Backward-angle) exclusive electroproduction, need capability to reconstruct photons from decays.
  - Physics beyond the EIC white paper!
- Would require full B0 EMCAL with high granularity and energy resolution.
- Longitudinal space in B0pf magnet limited.
  - Would be a great candidate for an upgrade or for IP8!

Deeply Virtual Compton Scattering



u-Channel Meson Production Setup



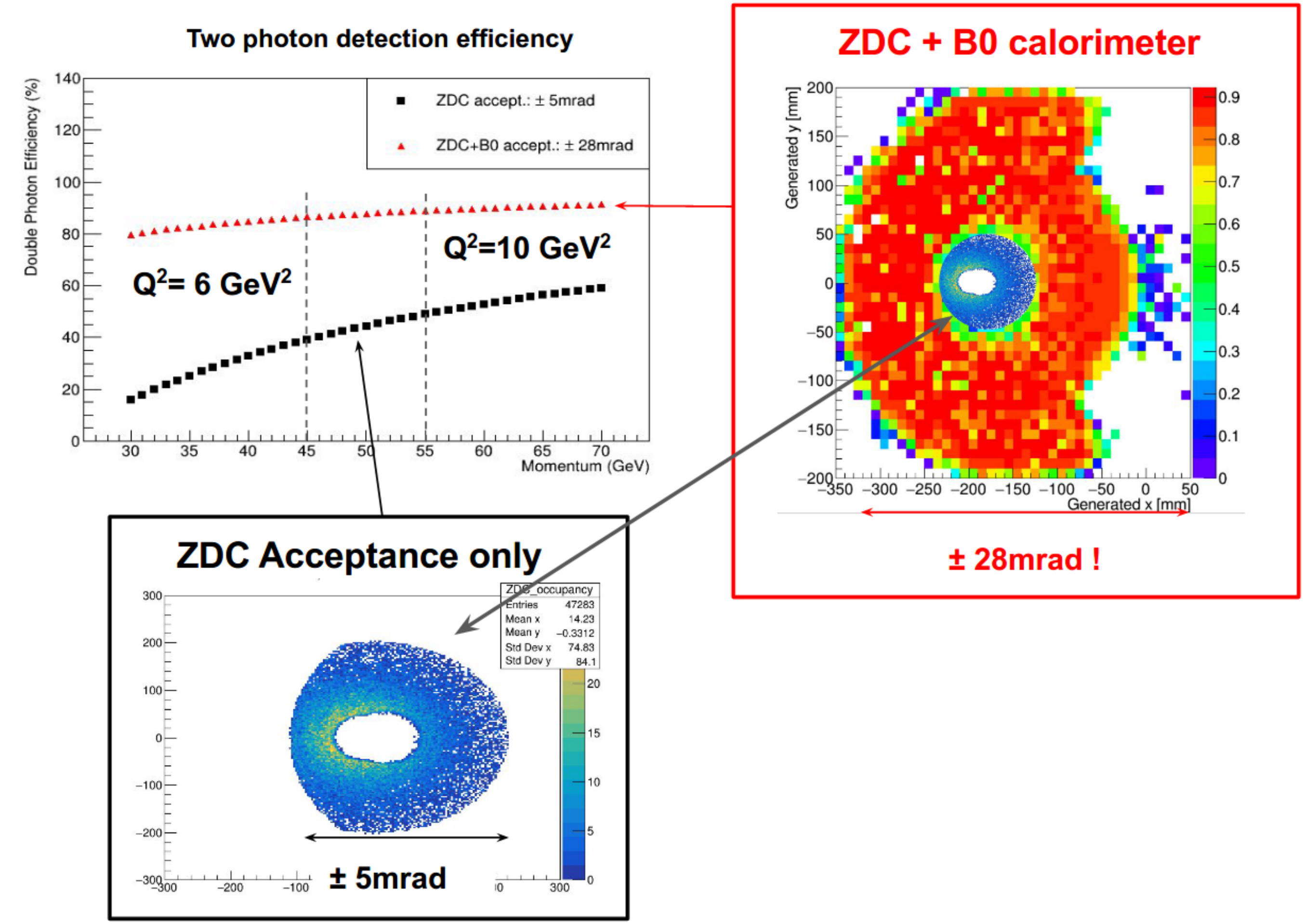
GPD: It is extracted predominantly based in the forward angle observables.

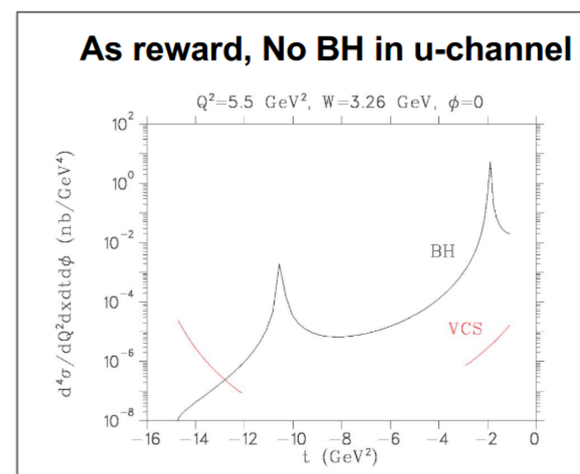
TDA: meson-nucleon Transition Distribution Amplitude (TDA) only accessible through backward (u-channel) meson production

B0 and ZDC applications: u-channel DVCS

Deeply Virtual Compton Scattering

Enhanced acceptance and resolution with B0 calorimeter





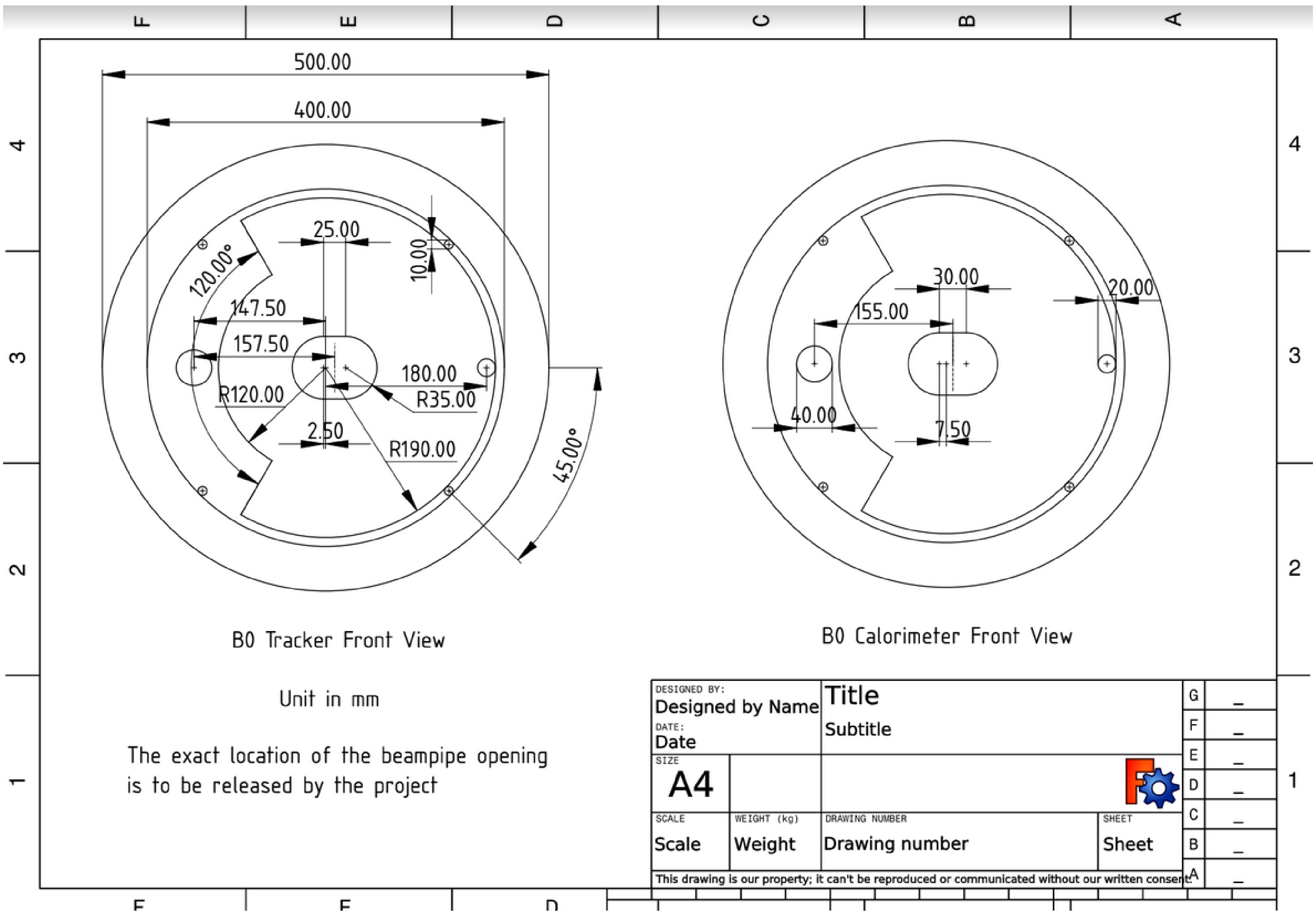
*Studies by Wenliang (Bill) Li

Summary

- Detectors in the Far Forward region are important for various physics processes.
- Combined usage of ZDC and B0 detectors significantly increases the photon detection efficiency.
- Detecting photons in this region is essential for the measurements of **u-DVCS** and **coherent VM** production.

Thank you very much for your attention!

B0 Design



500.00
400.00
25.00
10.00
120.00°
147.50
157.50
180.00
R35.00
R120.00
2.50
R190.00
45.00°
30.00
155.00
20.00
40.00
7.50
B0 Tracker Front View
B0 Calorimeter Front View
Unit in mm
The exact location of the beampipe opening
is to be released by the project
DESIGNED BY:
Designed by Name
DATE:
Date
Title
Subtitle
SIZE
A4
SCALE
Scale
WEIGHT (kg)
Weight
DRAWING NUMBER
Drawing number
SHEET
Sheet
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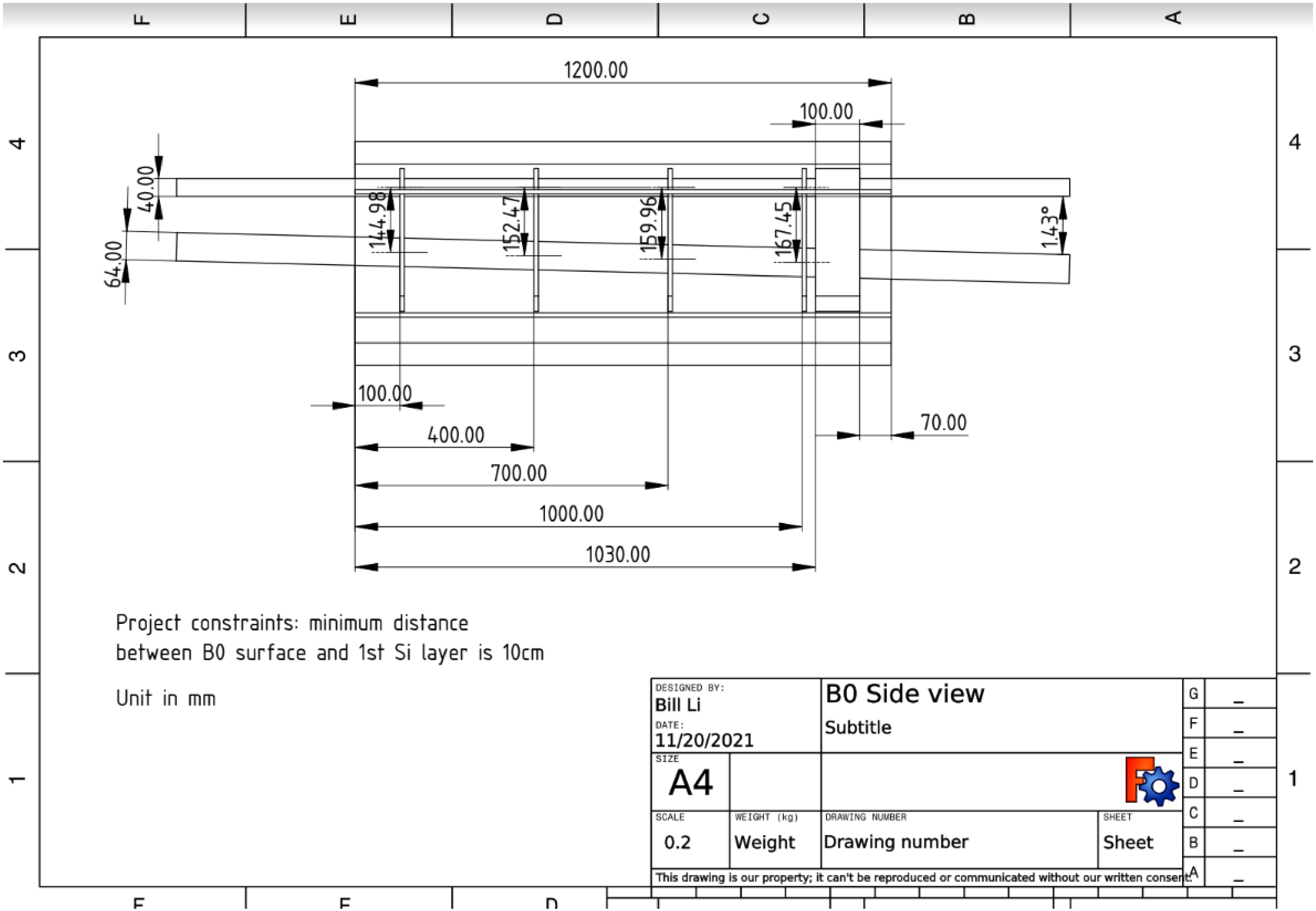
B0 Design


1200.00
100.00
40.00
64.00
144.98
152.47
159.96
167.45
1.43°
100.00
400.00
700.00
1000.00
1030.00
70.00
Project constraints: minimum distance
between B0 surface and 1st Si layer is 10cm
Unit in mm
DESIGNED BY:
Bill Li
DATE:
11/20/2021
B0 Side view
Subtitle
SIZE
A4
SCALE
0.2
WEIGHT (kg)
Weight
DRAWING NUMBER
Drawing number
SHEET
Sheet
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