Electron Ion Collider

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The University of Bergen

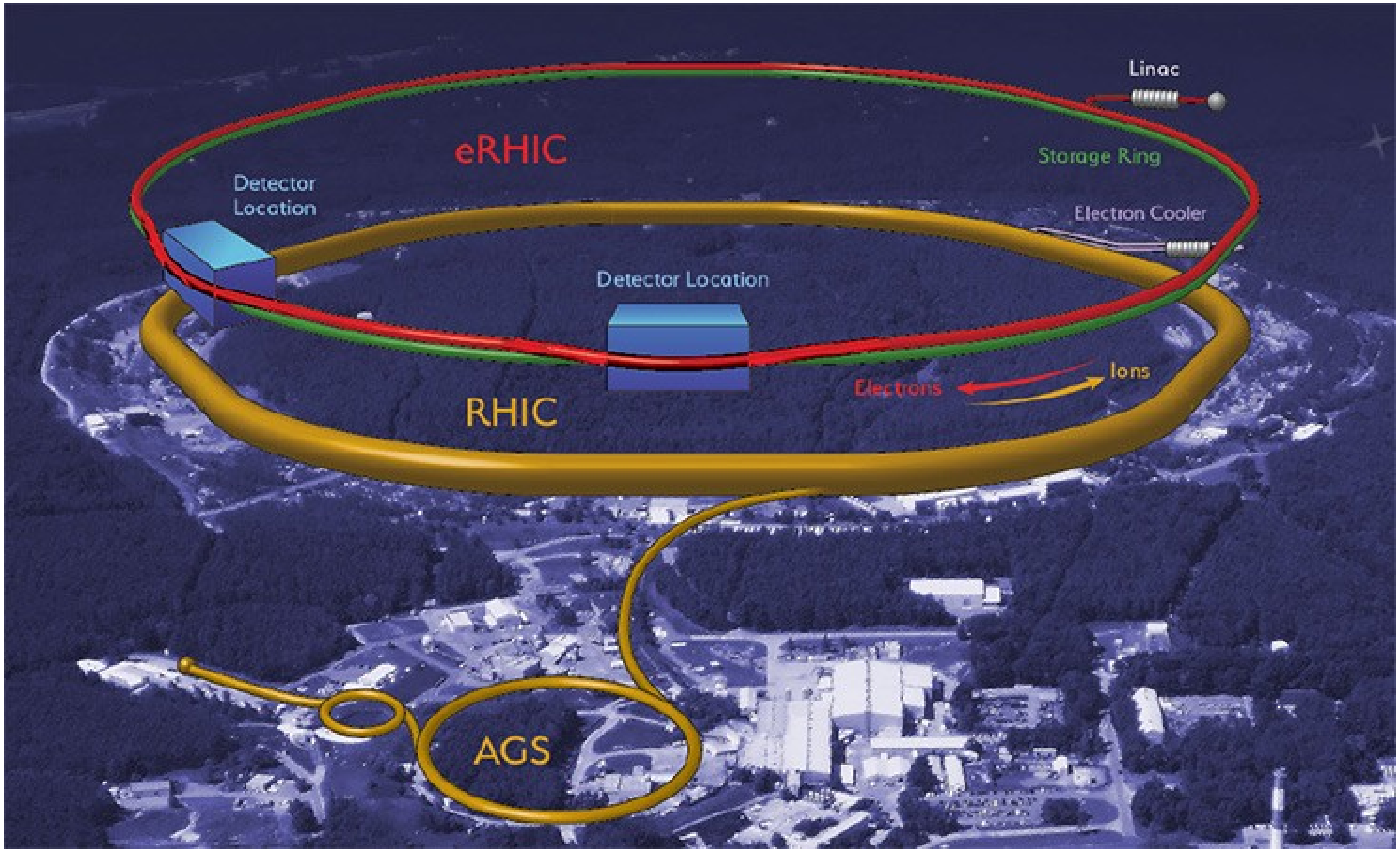
NorCC: Strategy discussion Kick-off meeting, March 11th, 2022

Outline

- EIC Accelerator and Physics
- EIC Status
- EIC opportunities for the Norwegian community
  - Far Forward Physics at EIC
    - B0 Detector
    - FOCAL-like ZDC
  - Physics studies examples
- Summary

Electron-Ion Collider

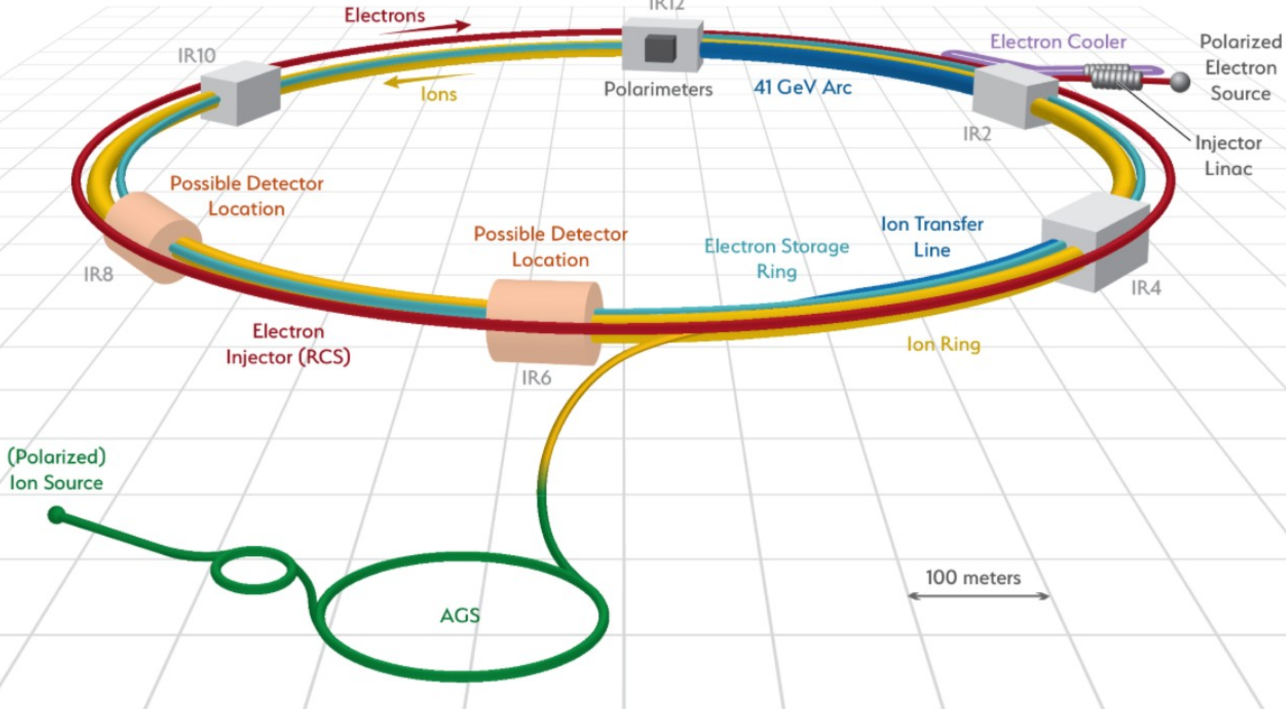
To be build around 2030 at Brookhaven National Laboratory



An EIC can uniquely address three profound questions about nucleons – neutrons and protons - and how they are assembled to form the nuclei of atoms:

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?

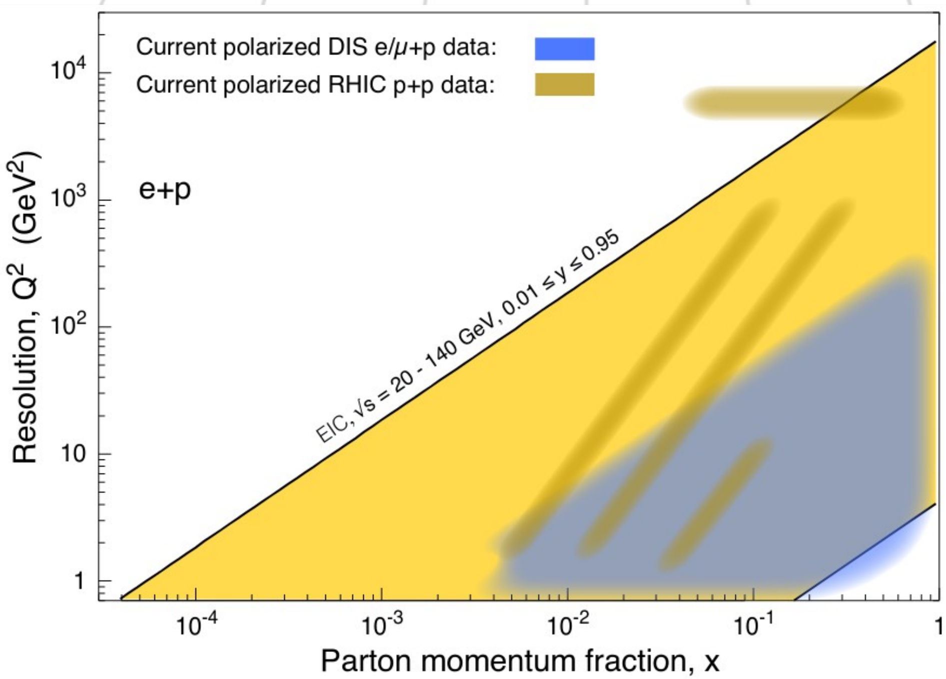
EIC Accelerator

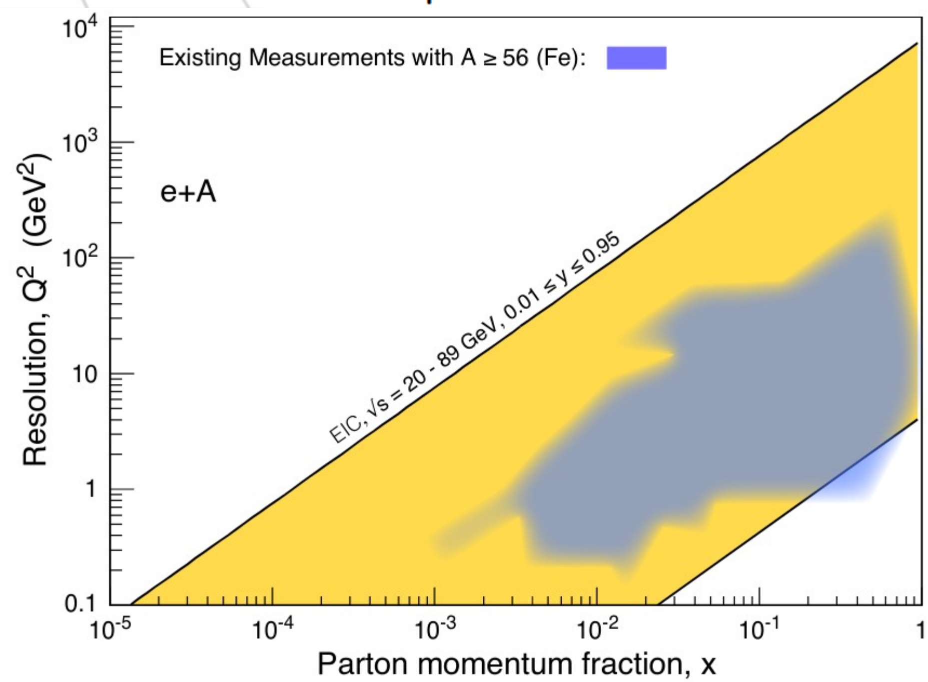


EIC will be the first dedicated facility to collide electron with ions (protons) in a wide range of c.m.s. energies.

Moreover, it will allow studies with **highly polarized beams (not possible at HERA)**

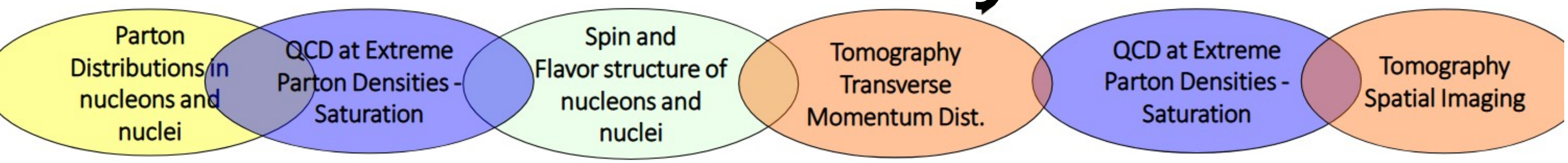
- E_e: 5 … 18 GeV
- E_p: 41, 100 … 275 GeV
- E_{ion}: 41 … 110 GeV/n
- Ions: from p to U
- Pol (e,p,He, etc): >70%
- Lum: up to 10^{34} cm^{-2} s^{-1}

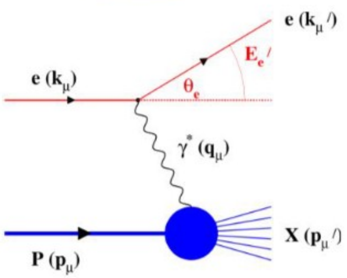


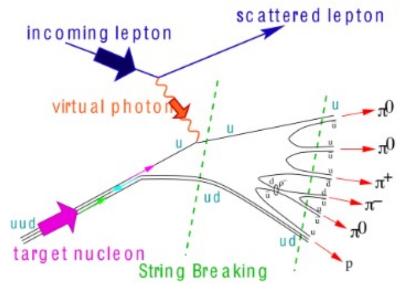


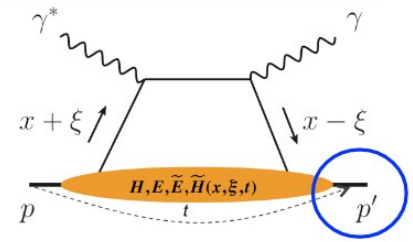
Colliding electrons to ions gives access to unexplored kinematic regions with the lowest possible *x* values.

EIC Physics









Inclusive DIS

- measure scattered lepton
- multi-dimensional binning: x, Q^2

→ reach to lowest x, Q^2 impacts Interaction Region design

→ low mass detectors, excellent e/h separation

Semi-inclusive DIS

- measure scattered lepton and hadrons in coincidence
- multi-dimensional binning: x, Q^2, z, p_T, ⟩

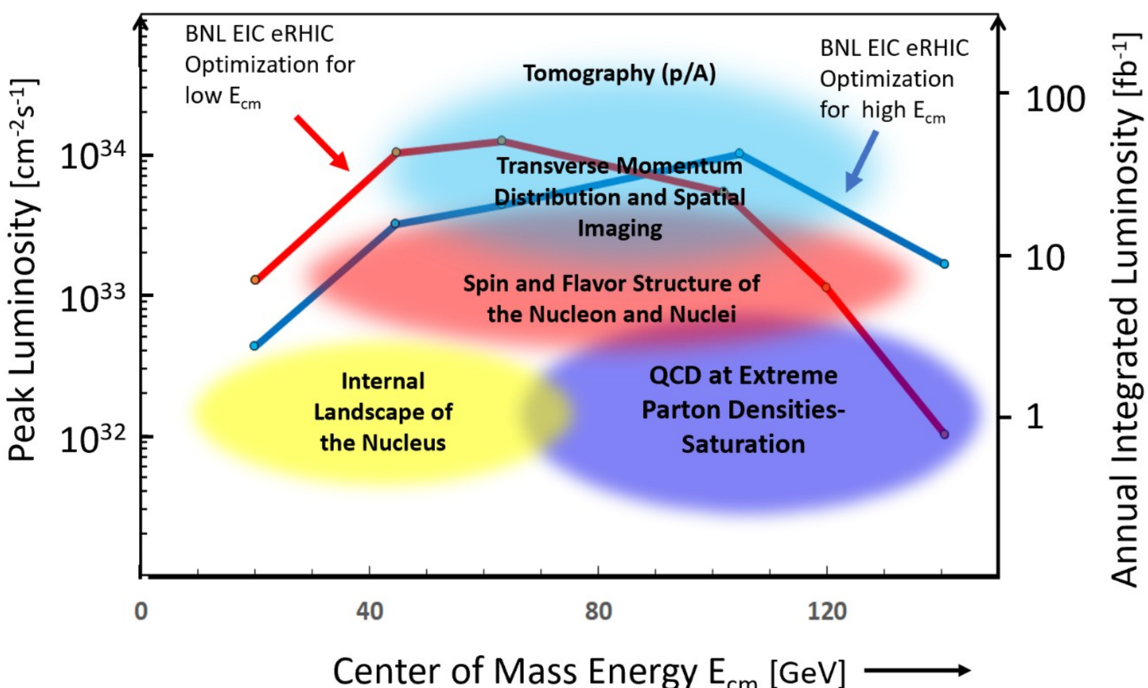
→ particle identification over entire region is critical

Exclusive processes

- measure all particles in event
- multi-dimensional binning: x, Q^2, t, ⟩
- proton p_t: 0.2 - 1.3 GeV

→ cannot be detected in main detector

→ strong impact on Interaction Region design



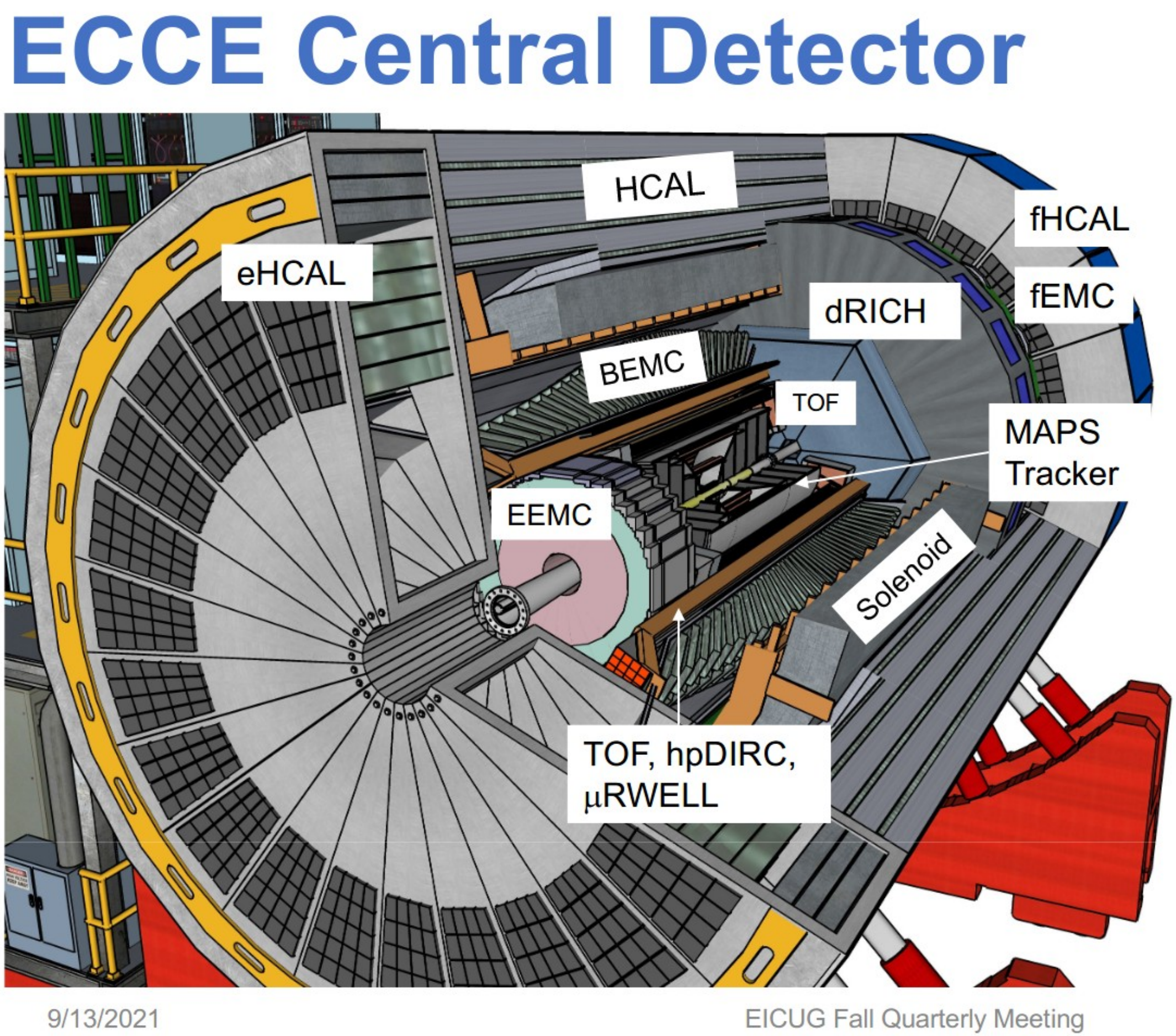
A wide range of the physics processes can be measured at EIC.

A comprehensive detector with a large rapidity ($-4 < \eta < 4$) coverage is essential for these studies.

Status of EIC

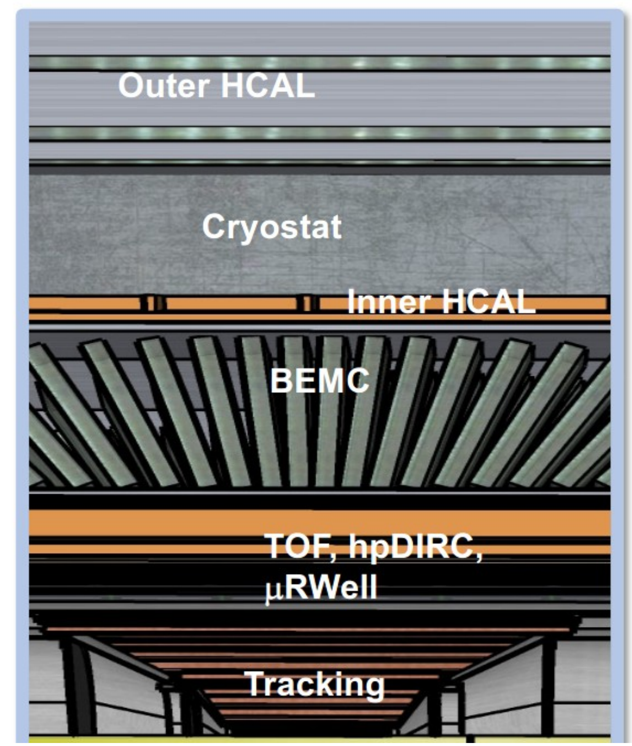
- In January 2020, Brookhaven National Laboratory (BNL) was chosen as the site for the future Electron-Ion Collider.
- On March 2021, BNL and JLab issued a call for Collaboration Proposals for Detectors at the EIC with proposals due by December 1st, 2021.
  - ECCE (the **E**IC **C**omprehensive **C**hromodynamics **E**xperiment) Consortium
  - ATHENA (**A T**otally **H**ermetic **E**lectron-**N**ucleus **A**pparatus) Collaboration
  - CORE (a **CO**mpact detecto**R** for the **E**IC)
- EIC Detector Proposal Advisory Panel Meeting 13th-15th December 2021
- On March 8th 2022 at DPAP close-out meeting it was anounced that ECCE has been unanimously selected as Detector 1
  - The scientific community strongly supports building a second detector at IP8 and this opportunity (with a possible delayed start) will be discussed later this year.

ECCE Detector



CENTRAL BARREL

Tracking: ITS3 based MAPS Si for vertexing, sagitta, and endcap discs; µRWell outer (double) layer
h-PID: hpDIRC & TOF (AC-LGAD)
Electron ID: SciGlass (plus instrumented frame)
HCAL: Fe/Sc (sPHENIX re-use)

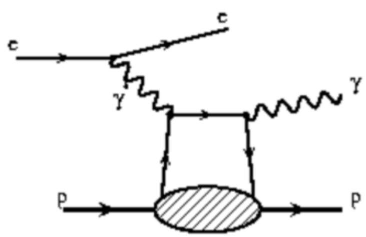


Will reuse the sPHENIX 1.5T BaBar Solenoid and Hadronic Calorimeter
Provides large rapidity ($-4 < \eta < 4$) coverage for detecting the scattered electron, jet reconstruction and Particle IDentification

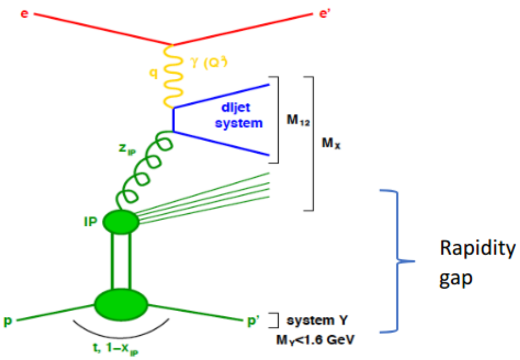
EIC opportunities for the Norwegian community

Far-forward physics at EIC

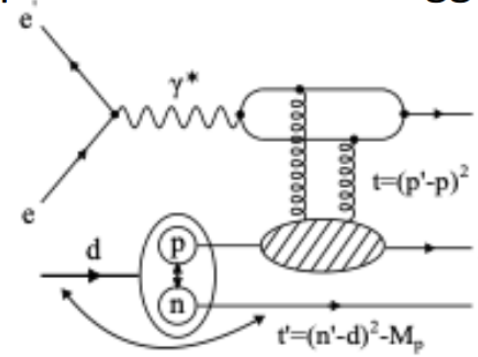
e+p DVCS events with proton tagging.



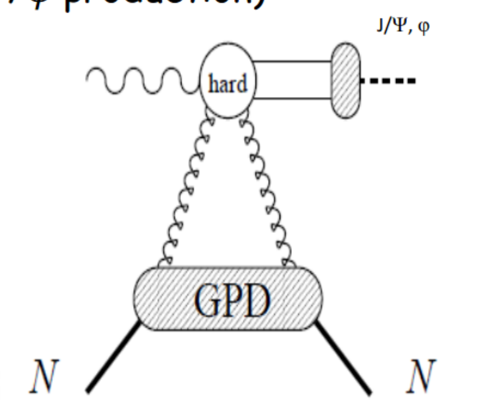
Diffraction



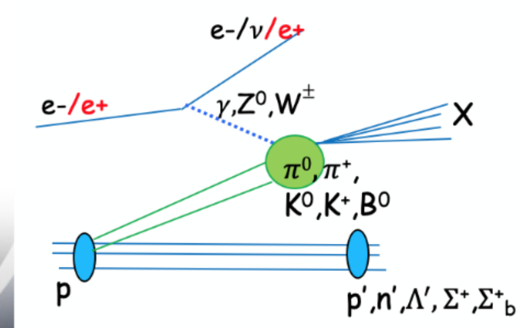
e+d exclusive J/Psi and DIS events with proton or neutron tagging



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.

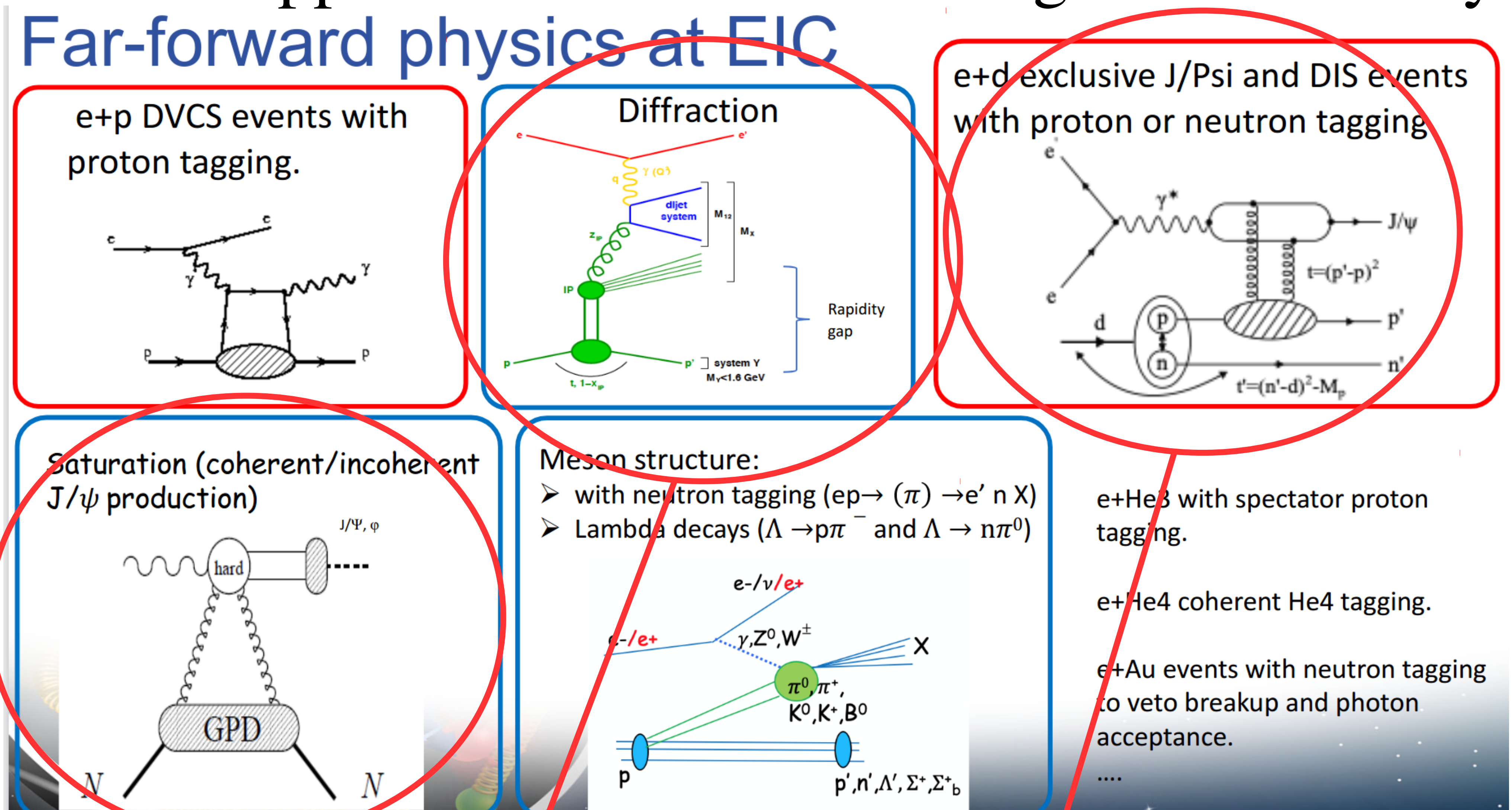
e+He4 coherent He4 tagging.

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(η>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

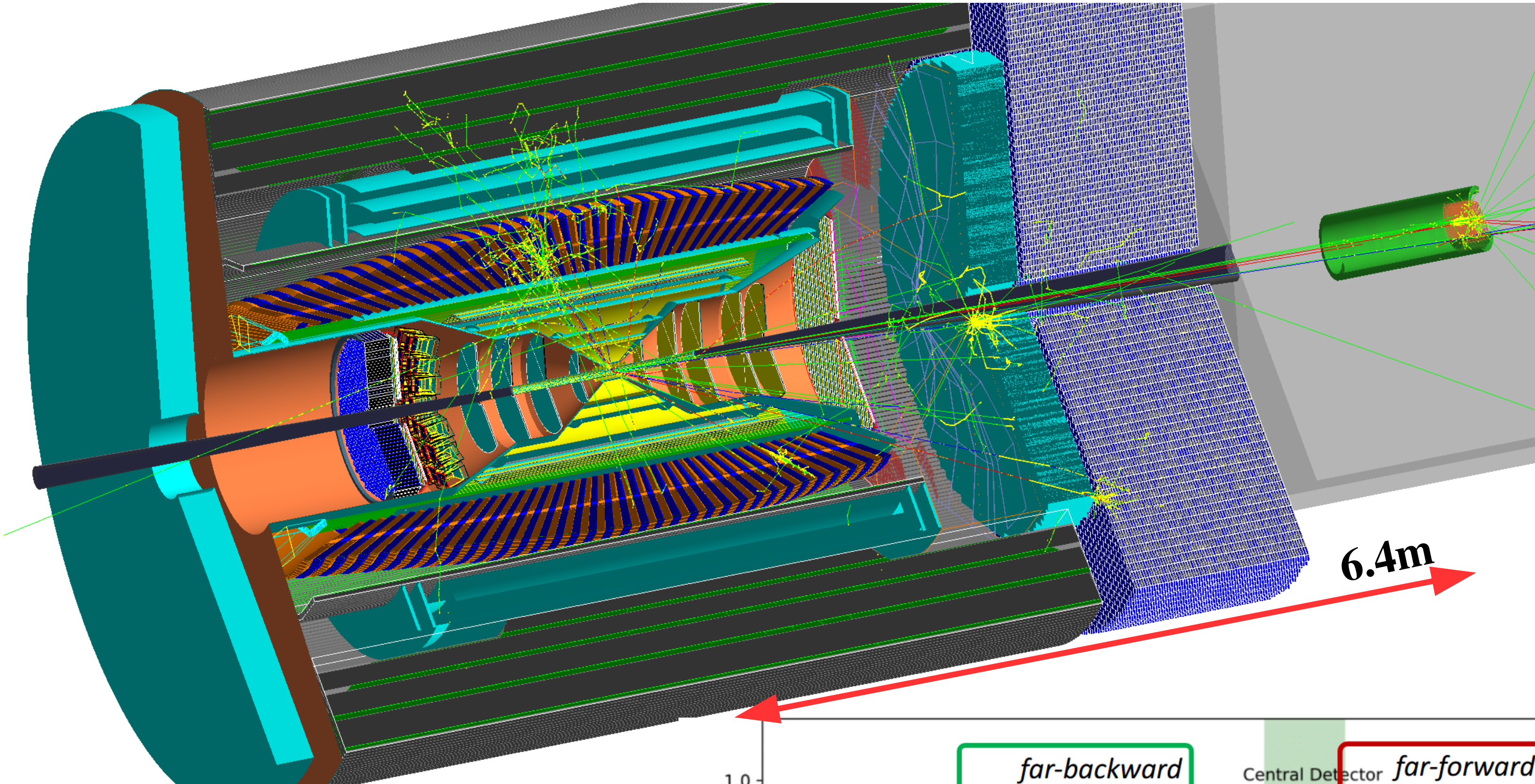
EIC opportunities for the Norwegian community

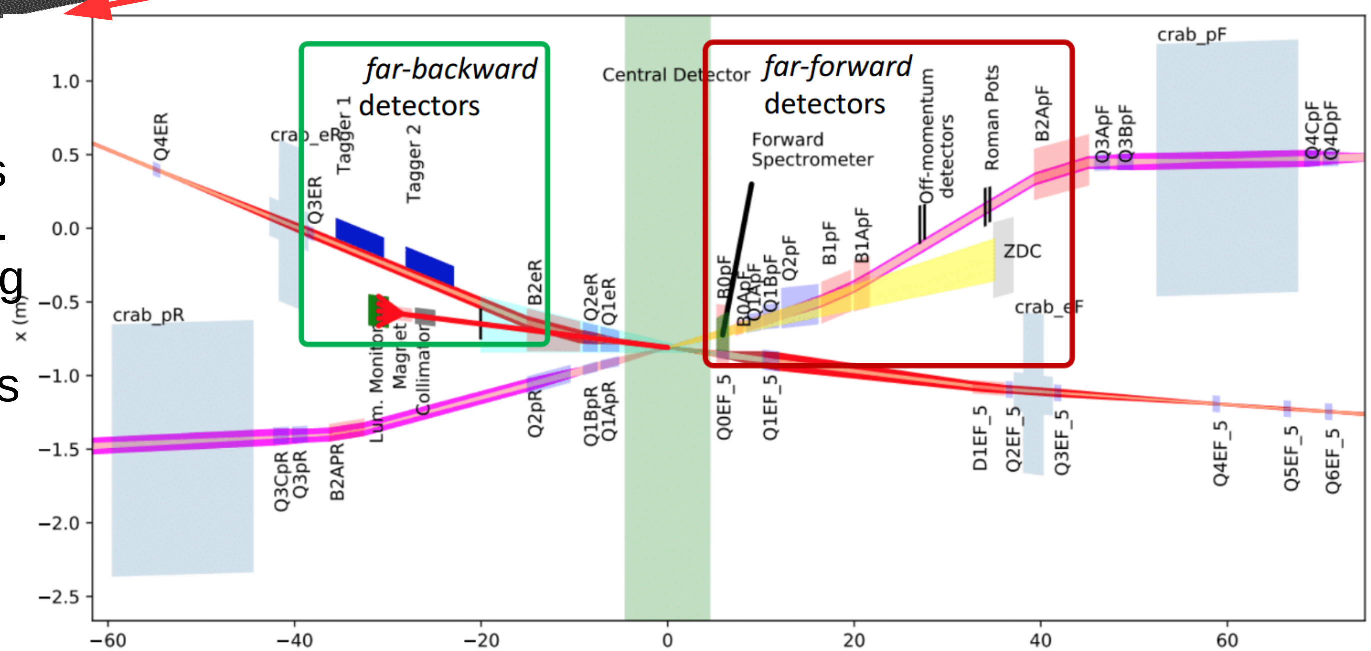


Many synergies with the existing nuclear physics program in the **ALICE Experiment at LHC**

Detector development in the Far-Forward region is essential for these studies

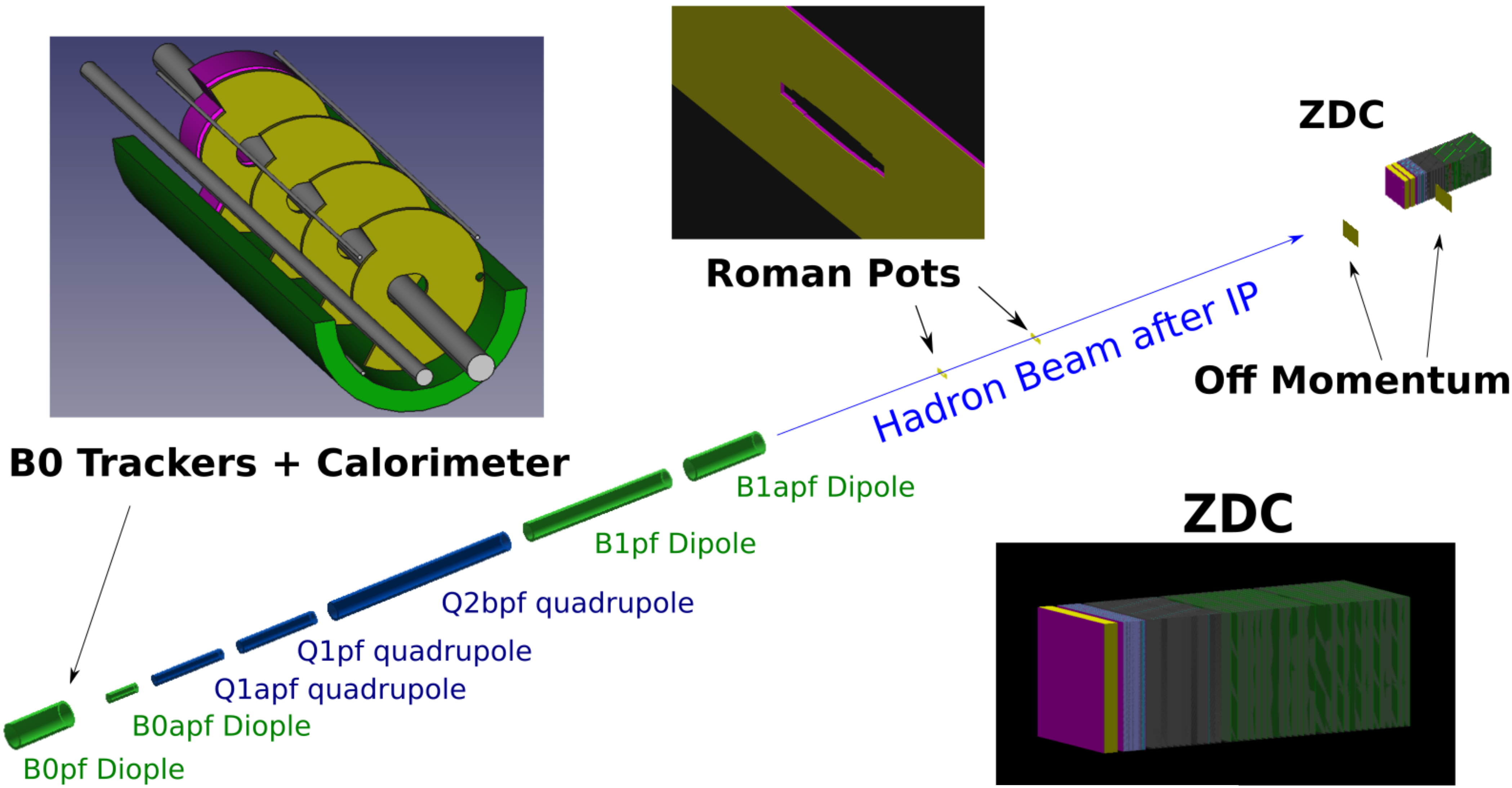
Far Forward Region





- 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
ZDC	(-0.96, 37.5)	(60cm, 60cm, 1.62m)	$\theta < 5.5$	$\sim$4.0 mrad at $\phi = \pi$
Roman Pots (2 stations)	(-0.83, 26.0) (-0.92, 28.0)	(30cm, 10cm)	$0.0 < \theta < 5.5$	$10\,\sigma$ cut.
Off-Momentum Detector	(-1.62, 34.5), (-1.71, 36.5)	(50cm, 35cm)	$0.0 < \theta < 5.0$	$0.4 < x_L < 0.6$
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

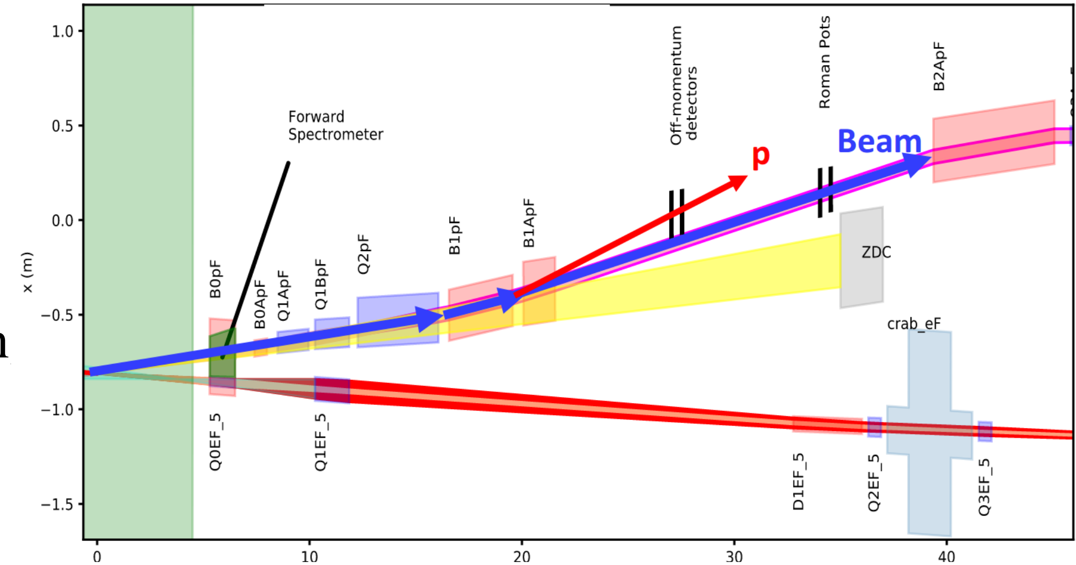
$\eta > 5.9$
$\eta > 5.9$
$\eta > 6.0$
$4.6 < \eta > 5.8$

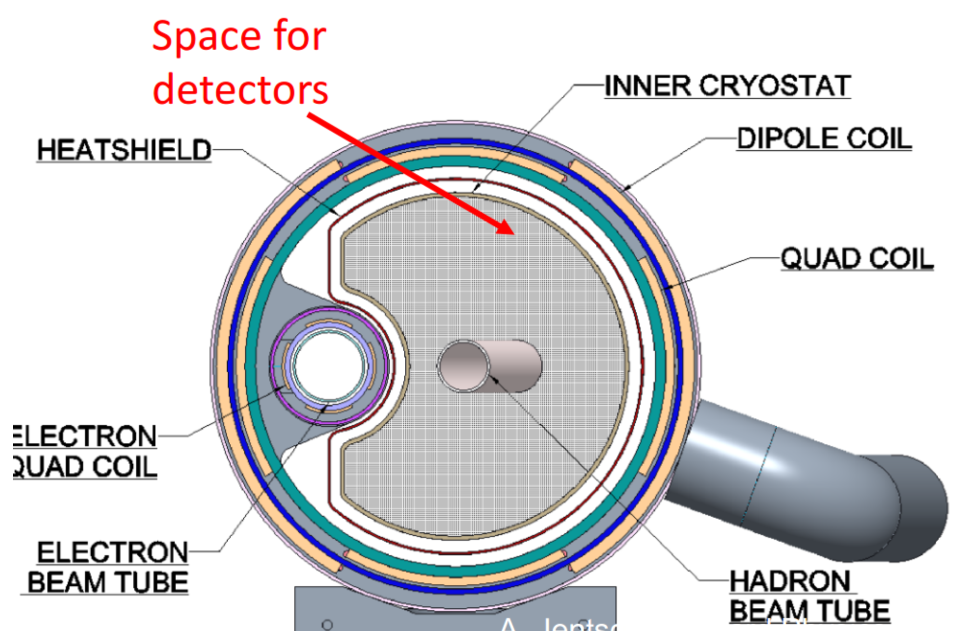
Challenges to B0 Design

1. The acceptance along z changes due to the crossing angle as the B0 is aligned with the electron beam.

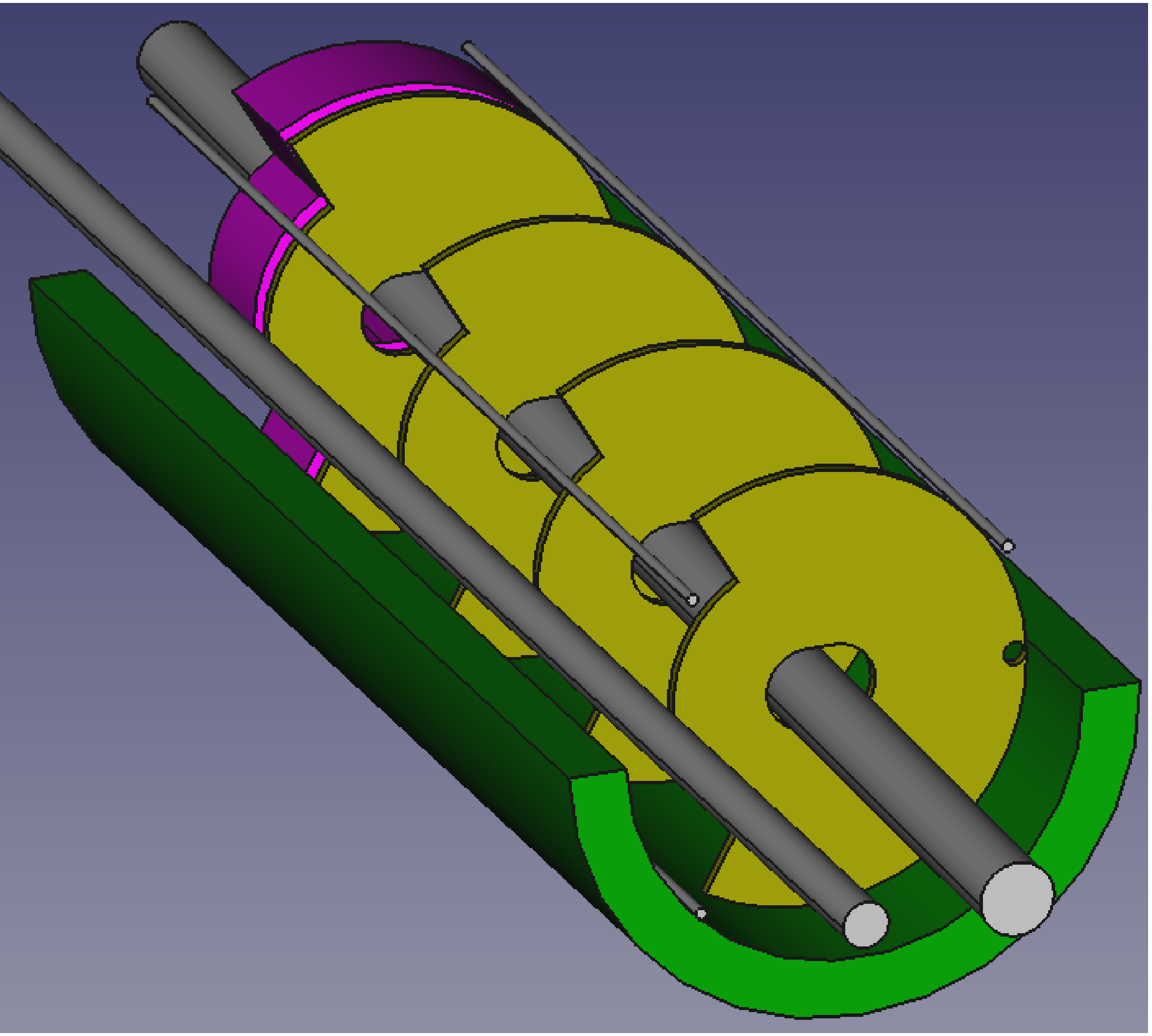
2. The B0 constitutes one of the most challengin EIC magnets:
it needs to provide both field for the proton/ion beam and no field for the electron beam, in limited space.

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





B0 Design



Oval shape of the cut off for the hadron beam:

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

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

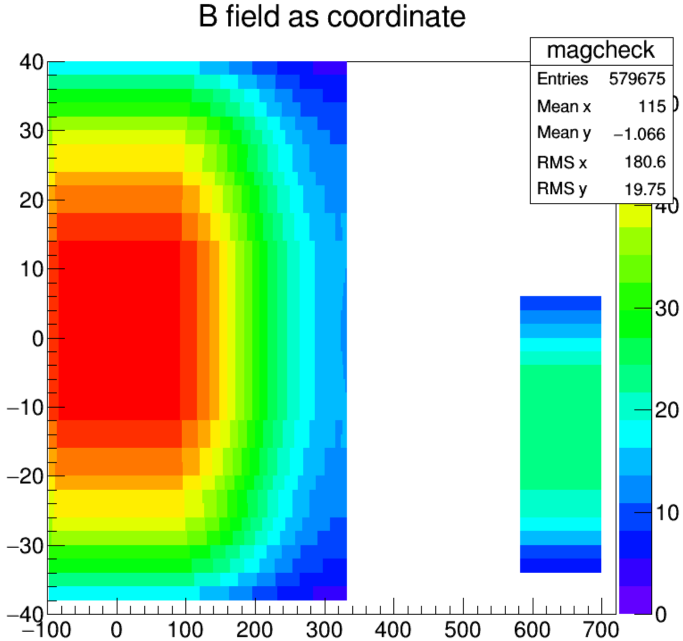
7cm at the back of the Calorimeter are assumed for its readout

Geant4 Simulation:

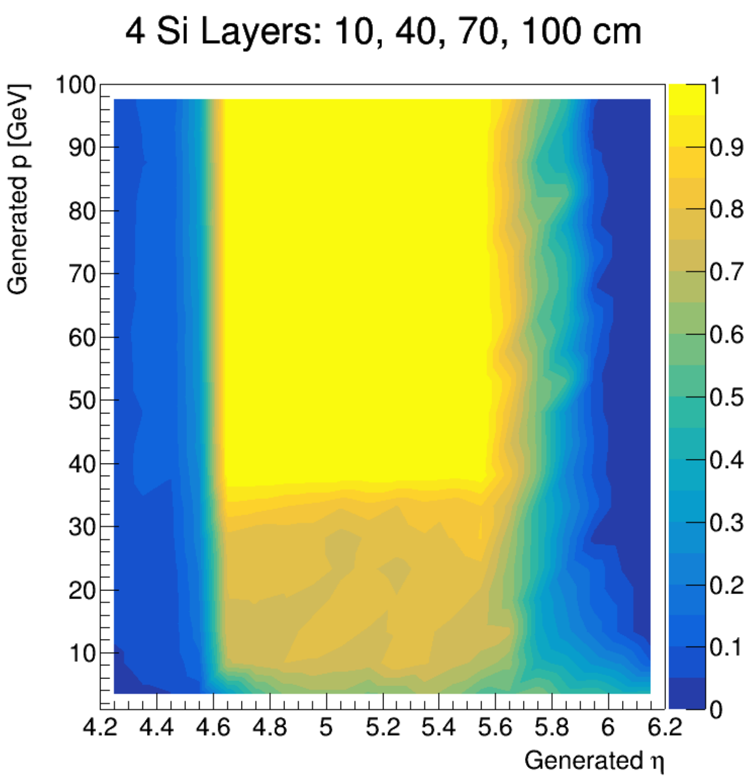
Rails will be used to slide the detector inside the magnet volume

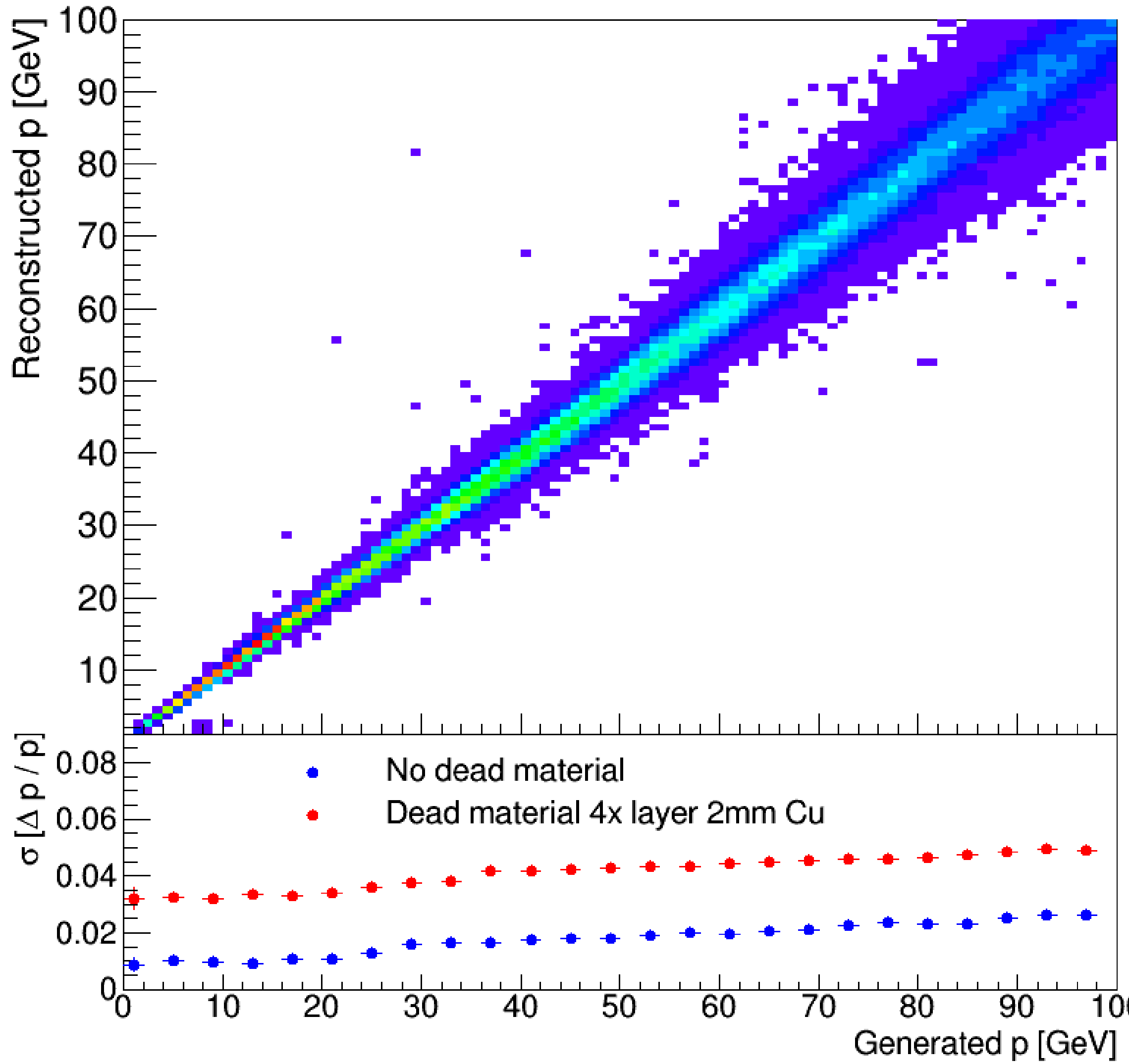
4 AC-LGAD layers are used for tracking, but MAPS is also an alternative option if good timing resolution can be achieved.

B0 Tracker

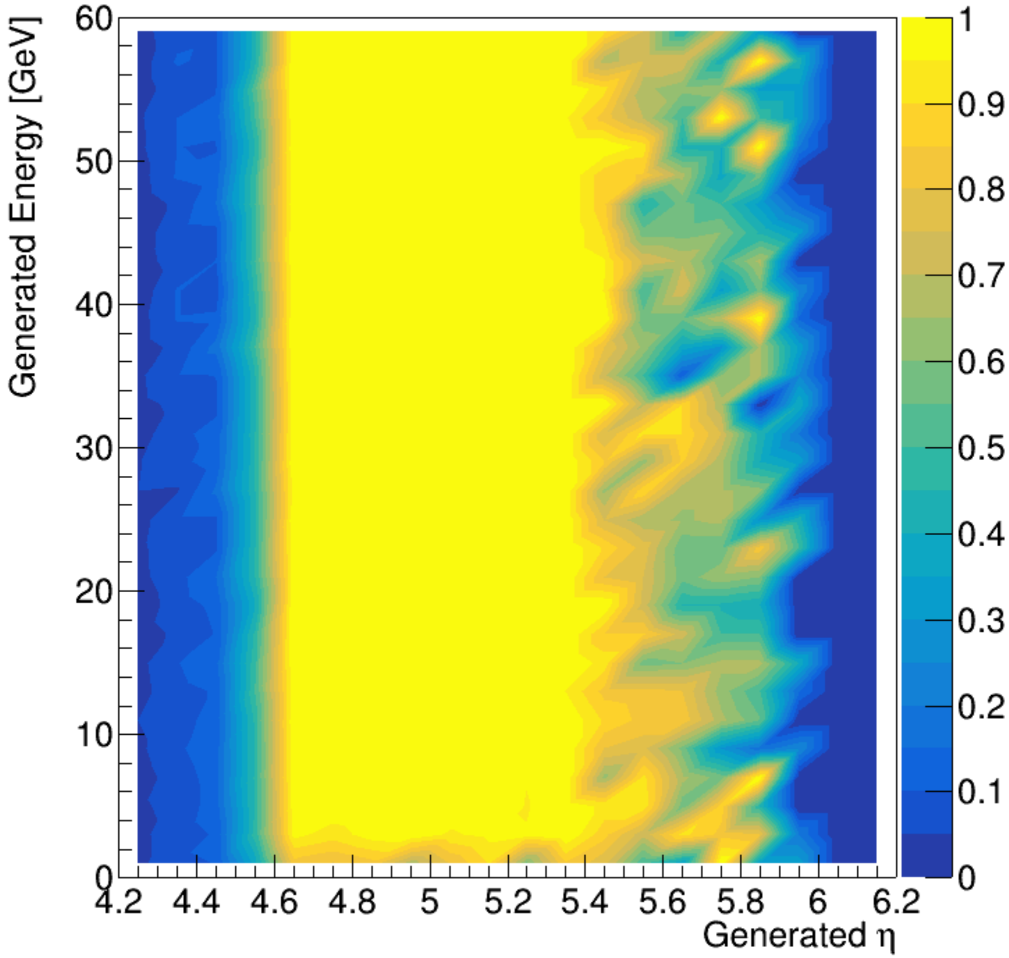


B0 dipole magnet field is added to the field map of the central detector to be passed to the Kallman filter.

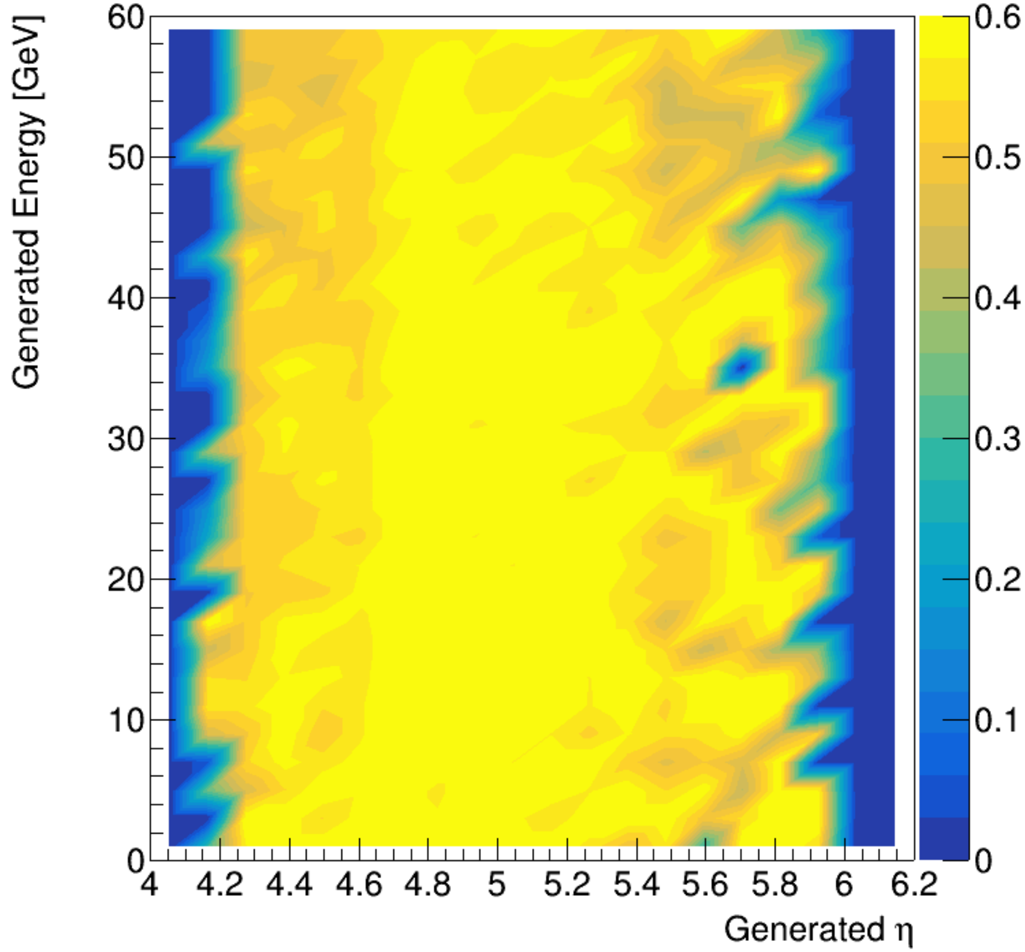




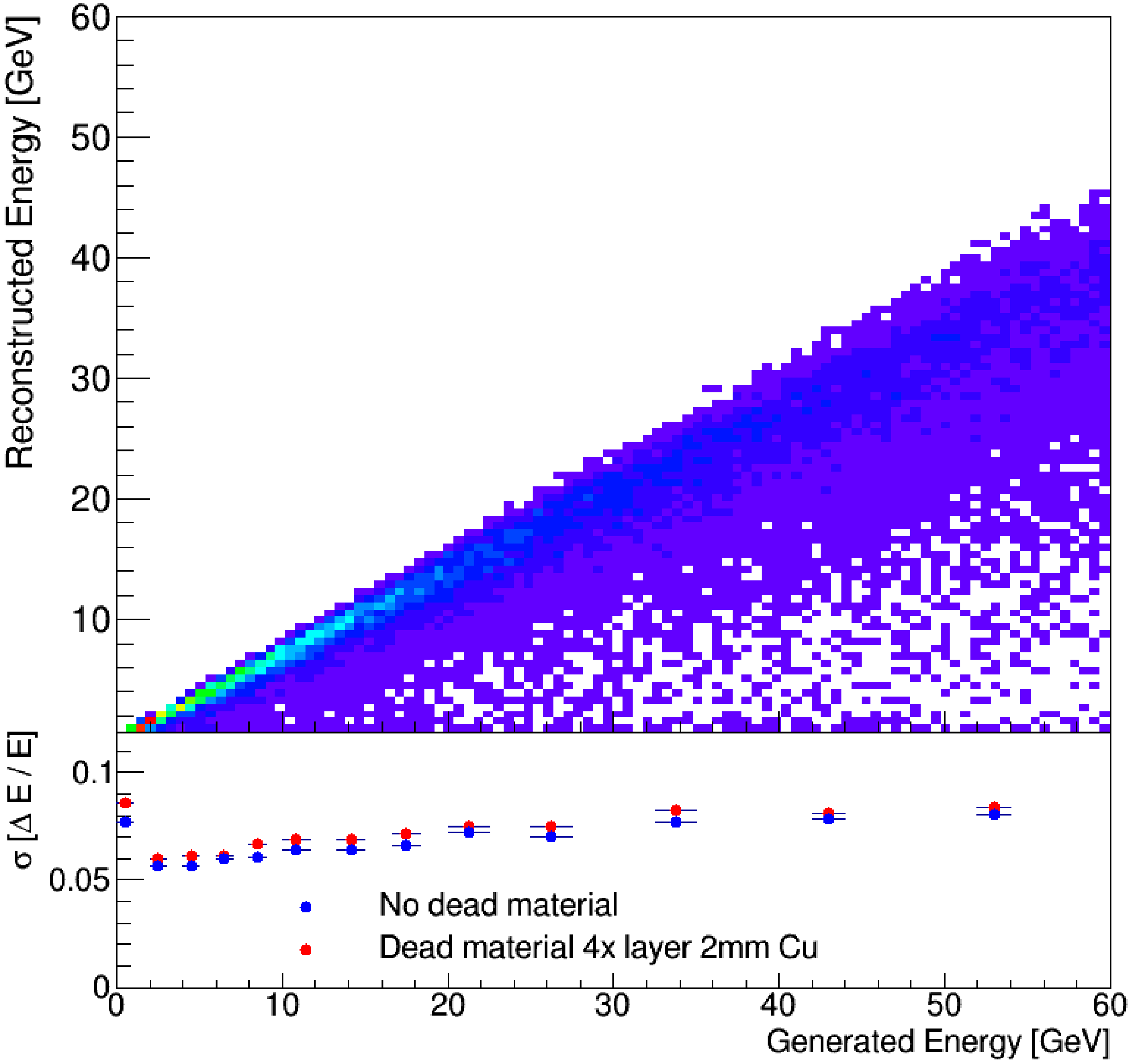
B0 calorimeter acceptance



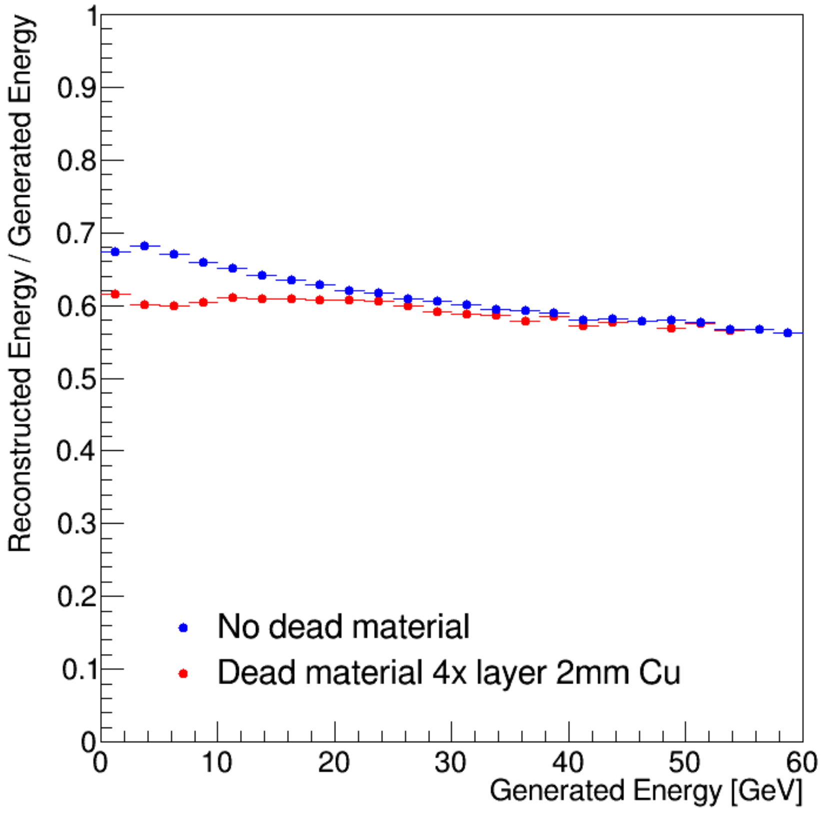
Reconstructed / Generated Photon Energy



B0 calorimeter resolution



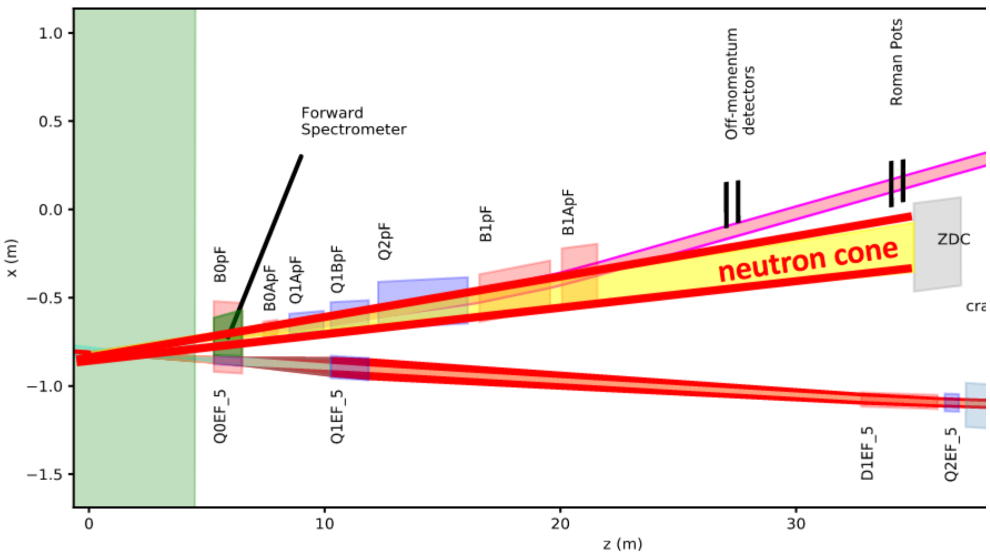
Effect of the presence of dead material (for cooling and readout) after each tracking plane is estimated.

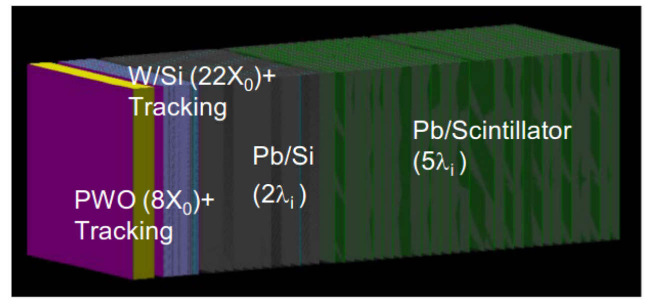


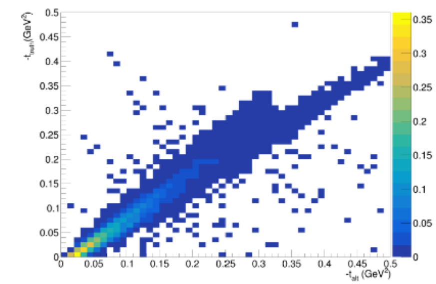
The photon energy resolution is found to be below 7% for the studied kinematic region.

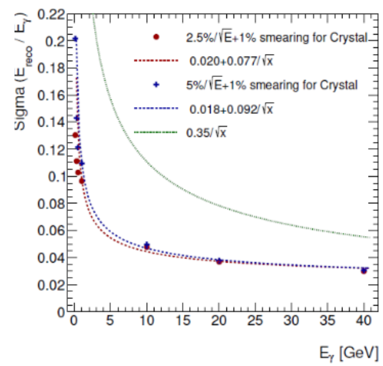
Zero-Degree Calorimeter

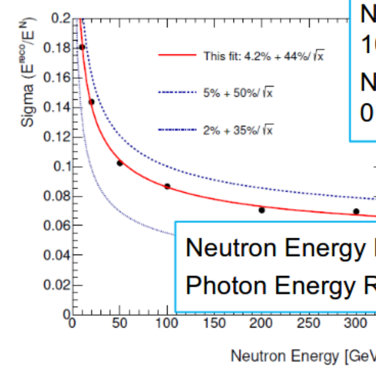
- High resolution HCAL + EMCAL for detecting neutral forward-going particles (neutrons and photons)
  - HCAL requires $\frac{\Delta E}{E} \sim \frac{50\%}{\sqrt{E}} \oplus 5\,\%$ and $\sigma_\theta \sim \frac{3\ \text{mrad}}{\sqrt{E}}$, or better.
  - ALICE FoCal assumptions used for studies thus far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











Neutron detection fraction: 100% (59% at 5 on 41 GeV)
Neutron t-resolution: 0.005-0.007 GeV^2 (0.019 GeV^2)

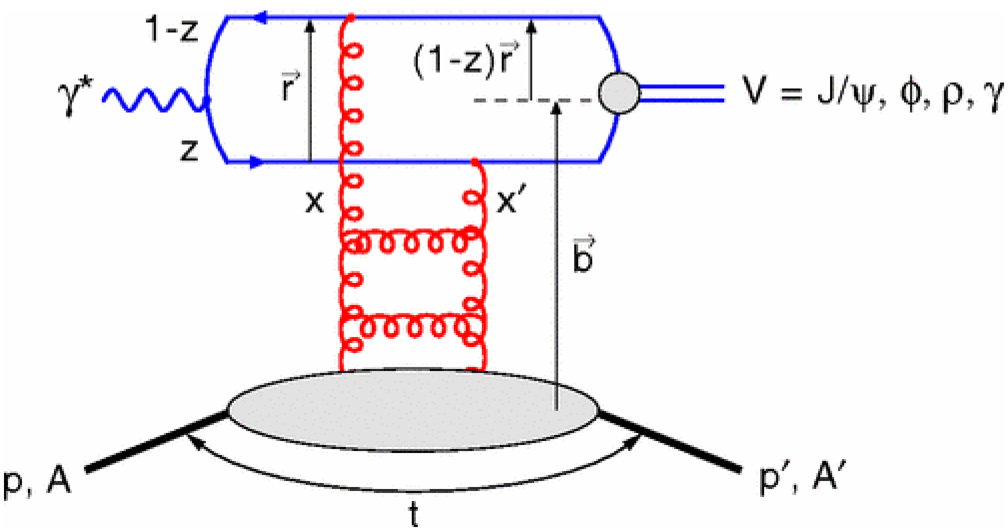
Neutron Energy Resolution: 44%/√E +4.2%
Photon Energy Resolution: 2.5%/√E+1%

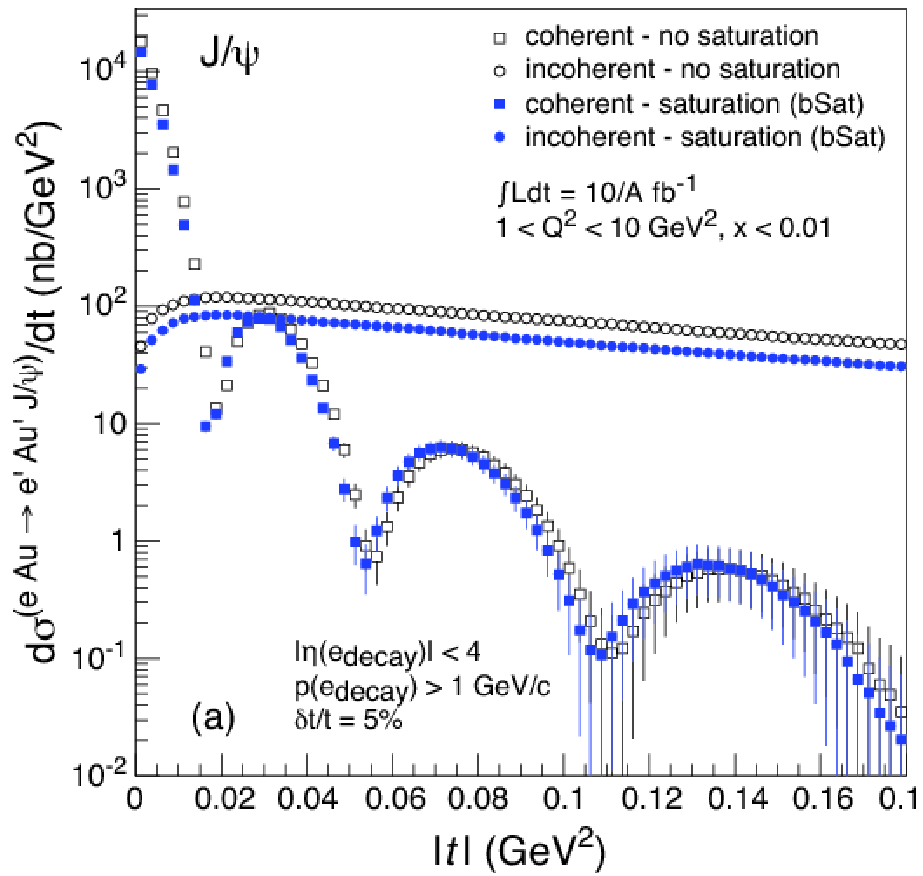
- ZDC has dimensions of 60cm x 60cm x 162cm for the needed acceptance (YR) and consists of PbWO4 crystal, W/Si layer, Pb/Si, and Pb/Scintillator layers
- ZDC provides detection for photons and neutrons (0<θ<5.5 mrad) with the required performance

B0 and ZDC applications: Exclusive VM production

Both B0 and ZDC can be used to veto events with forward going photons

T. Toll and T. Ullrich



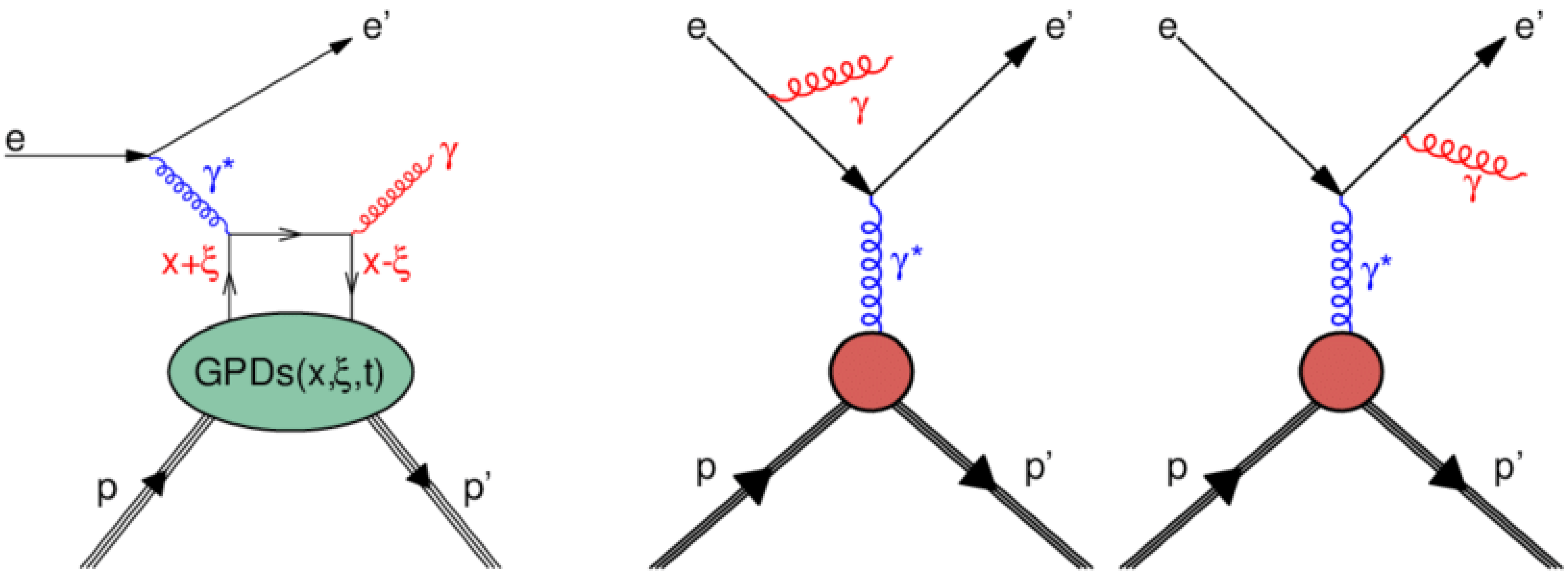


Measurement of the coherent spectrum down to the 3rd diffractive minimum requires rejection of incoherent events.

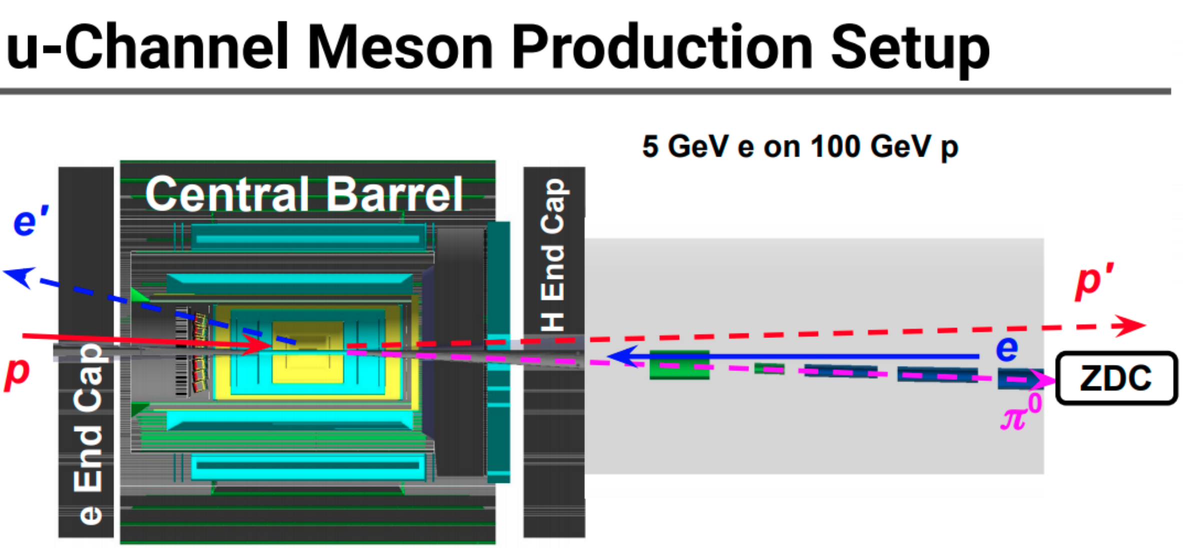
Nuclear breakup in incoherent events produces soft photons (~300 MeV) in the forward direction from the de-excitation of some of the larger nuclear fragments.

B0 and ZDC applications: u-channel DVCS

Deeply Virtual Compton Scattering



DVCS **Bethe-Heitler**



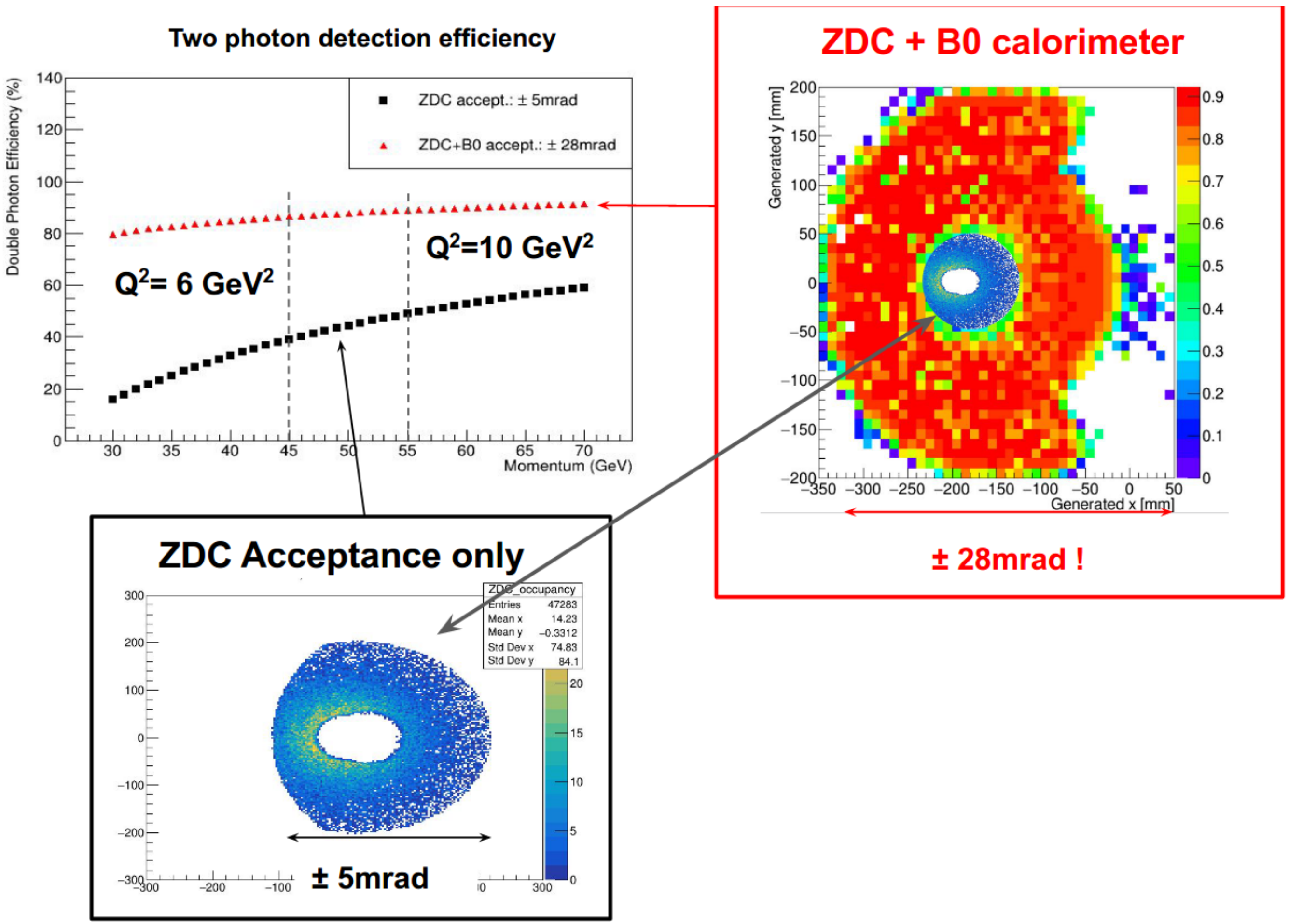
GPD: It is extracted predominantly based in the forward angle observables.

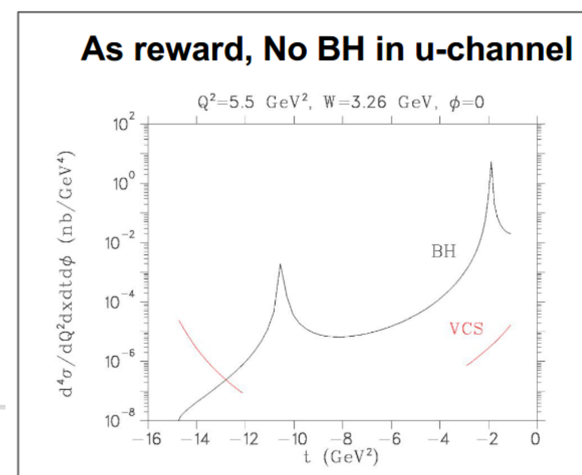
TDA: meson-nucleon Transition Distribution Amplitude (TDA) only accessible through backward (u-channel) meson production

B0 and ZDC applications: u-channel DVCS

Deeply Virtual Compton Scattering

Using both **B0** and **ZDC** to detect photons from π^0 decays allows to cleanly isolate u-channel DVCS





FOCAL-like detector with pixel planes as ZDC will be essential to separate the two photons.

*Studies by Wenliang (Bill) Li (SBU)

Summary

- The EIC will be the first dedicated facility to study the collisions between electron and ion beams (also polarized) in a wide energy range.
- There are a lot of opportunities for the Norwegian community to contribute both in physics studies and detector development in particular in the far-forward region.

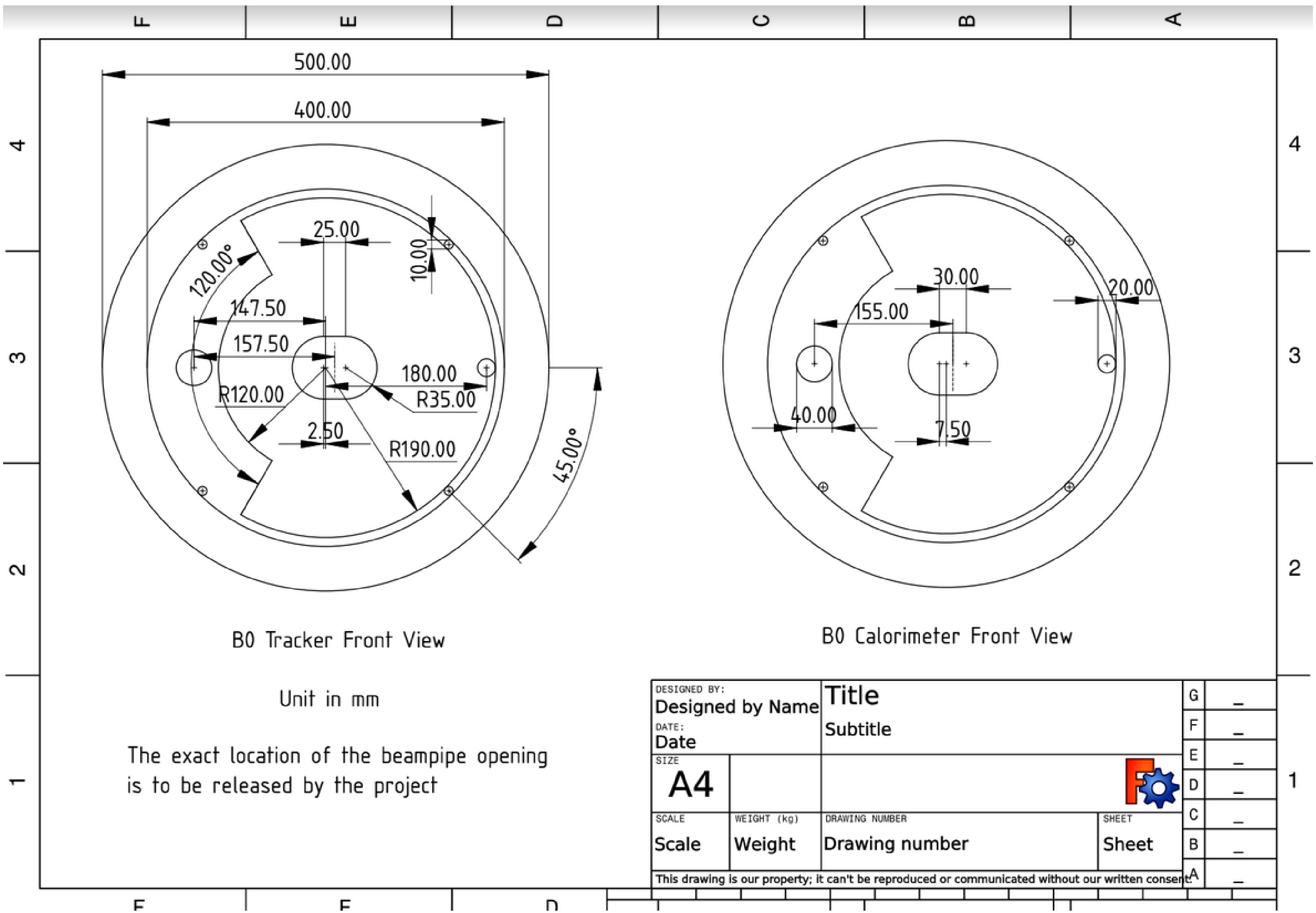
Thank you very much for your attention!

EICUG Workshop

Financial support for students is expected

Those interested to participate in person are welcome to contact the organizers: Alexander.bylinkin@gmail.com, wenliang.billlee@googlemail.com, cvanhuls@mail.cern.ch, jennifer@lbl.gov

B0 Design



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B0 Calorimeter Front View
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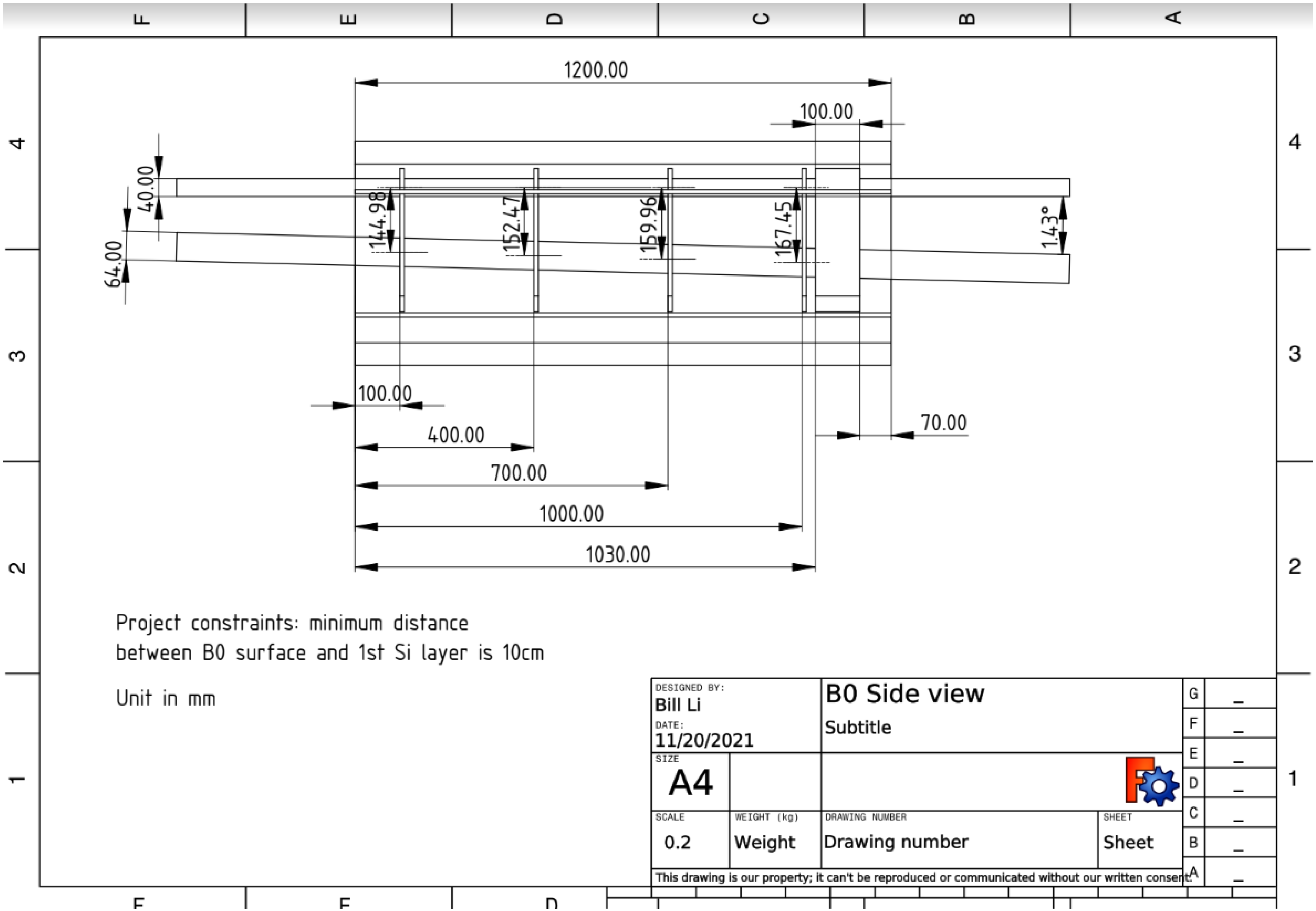
B0 Design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