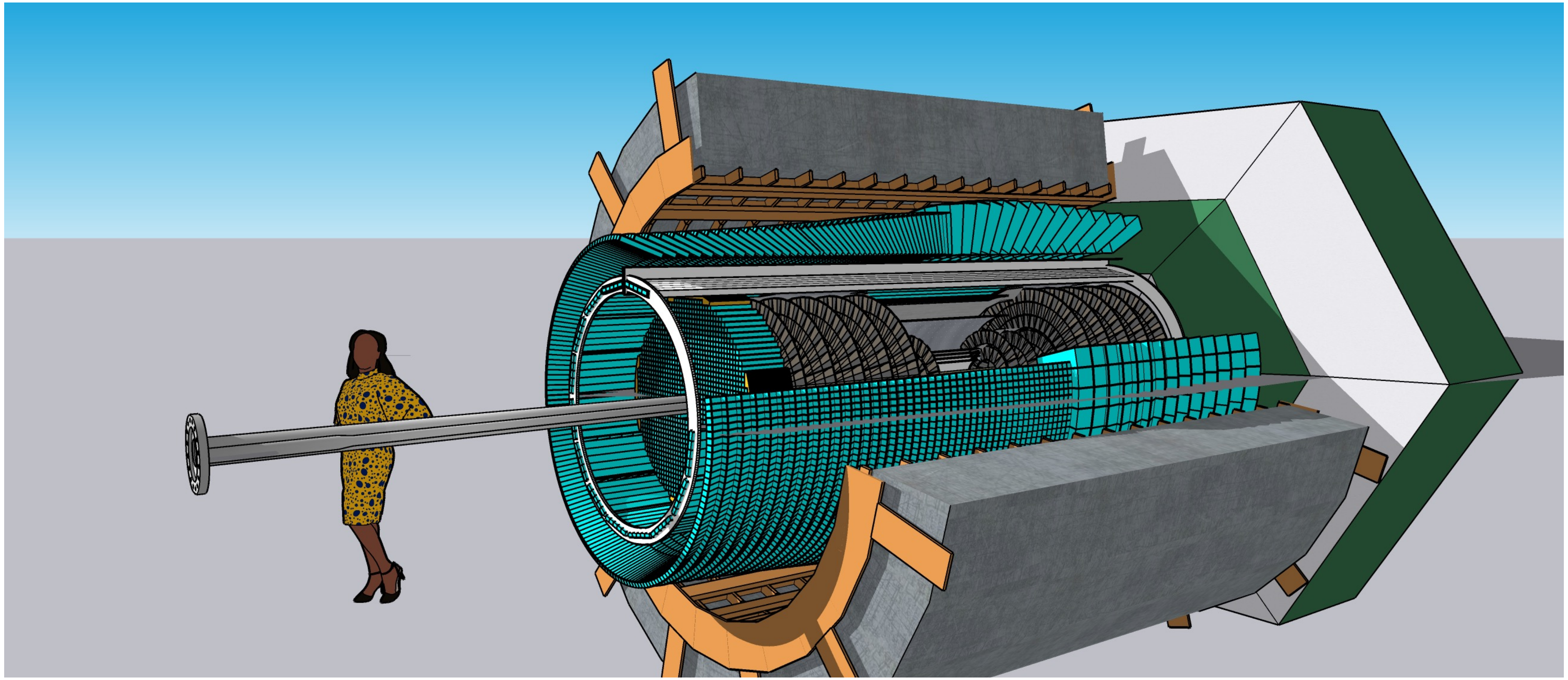
CORE: a COmpact detectoR for the EIC

EICUG Quarterly Meeting
28 Oct 2021



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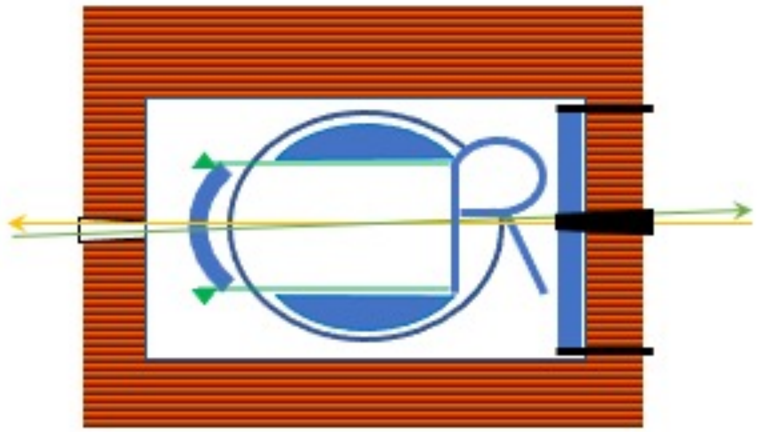
OLD DOMINION UNIVERSITY

*Support from DOE grant DE-FG02-96ER40960, & BNL R&D, CFNS

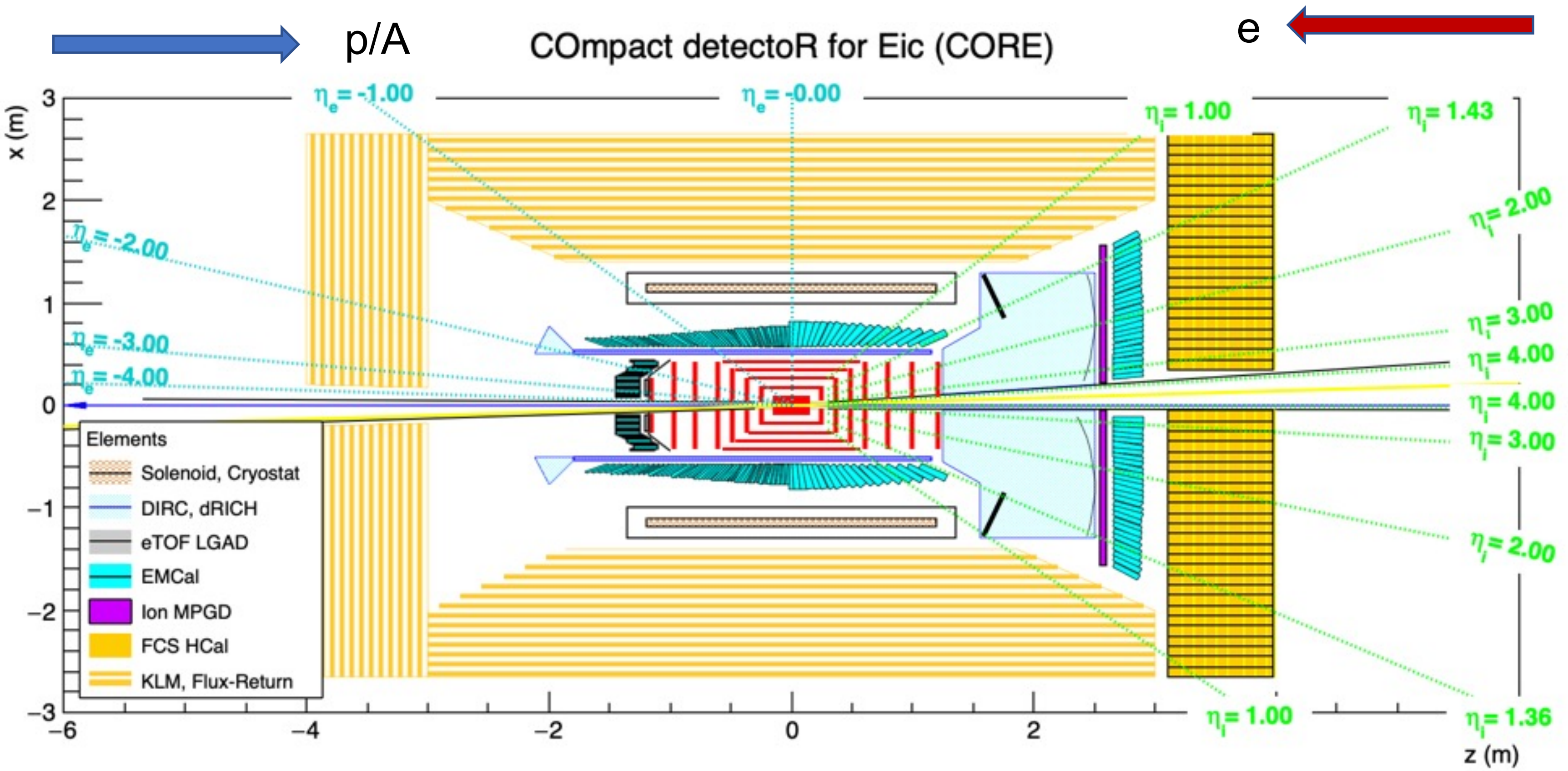
CORE Design Philosophy



- Compact design built around eRD16/25 *et alia* Si tracking study (ALICE-ITS3)
  - r ≤ 0.45 m and |z| ≤ 1.2 m, B= 3 T
  - **Minimum momentum of 0.27 GeV** to reach Barrel DIRC & EMCal.
- Short Solenoid to maximize flexibility for integration with machine lattice
  - Bore radius = 1.0 m
  - Coil length ± 1.2 m
  - **Total detector length = ± 4m**
- Particle ID from eRD14: hpDIRC, dualRICH, plus AC-LGAD
- High resolution EMCal (eRD1):
  - $PbWO_4$ for –3.5<η<0
  - W-Shaslik 0 < η < 3.5
  - B0 acceptance and ZDC
- Jet reconstruction primarily from tracking, supplemented with
  - High performance STAR FCS style HCal for eta>2
  - Hermetic muon id from Belle-II style "K_L-Muon" flux return

CORE for IR8

35 mrad crossing angle, Secondary focus



- The highest luminosity at highest ion energy, and mid-range electron energy
  - 10 x 275 GeV is the luminosity maximum.

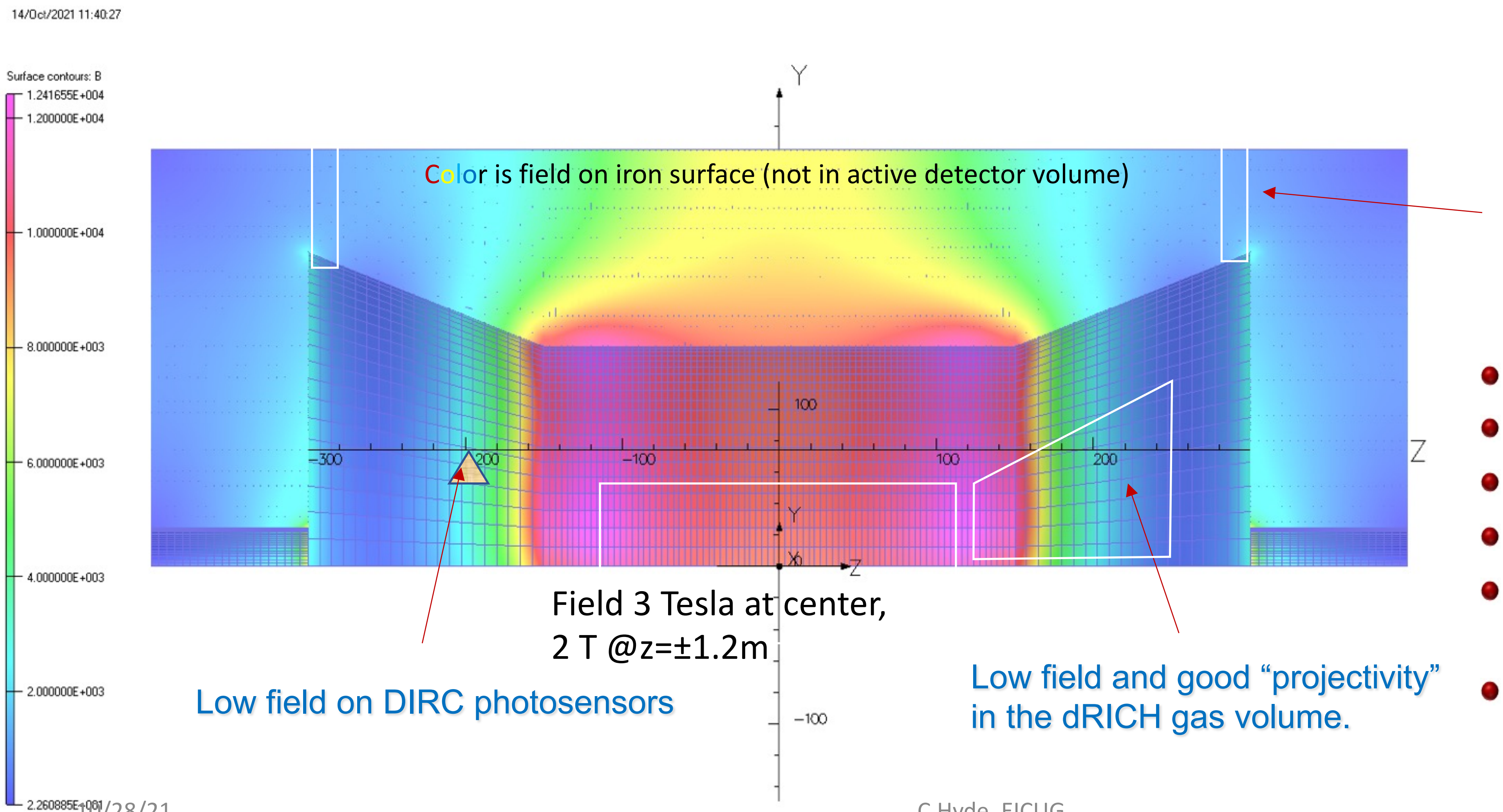
- At low proton/ion energies (41 GeV/A), space charge and beam-beam make the luminosity very low
  - *Some* mitigation possible (focusing)

18x275	10x275	5x275	10x100	5x100	5x41
1.65×10^{33}	10.05×10^{33}	5.29×10^{33}	4.35×10^{33}	3.16×10^{33}	0.44×10^{33}

Particle distributions in the endcaps follow the beam energies➔ match coverage and luminosity requirements (e.g., for PID)

Short 3T solenoid – field, coil forces, and symmetry of flux return iron

- Symmetric iron distribution minimizes net force on the coils



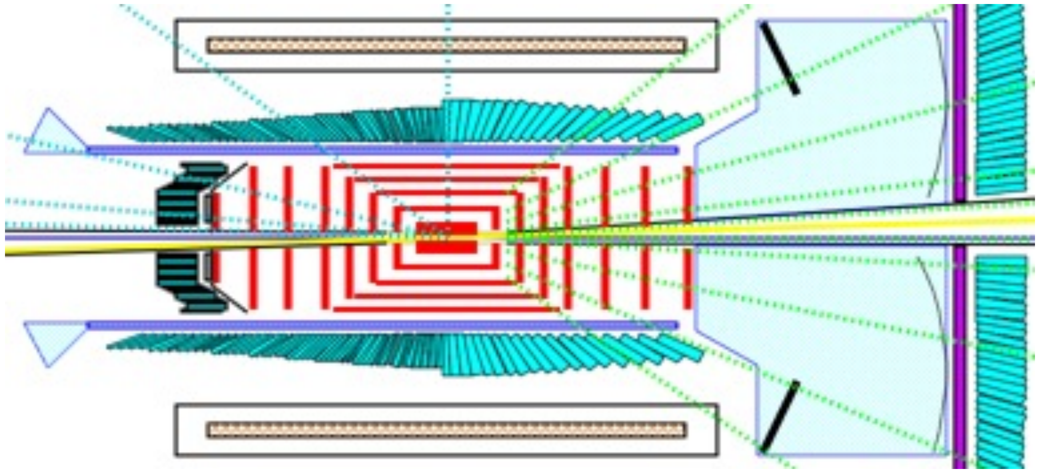
- Field: 3 T
- Coil length: 2.5 m
- Inner radius: 1 m
- Cost to project: $15.8M
- Total detector radius = 2.65 m
- Total detector length = 8 m

Tracking, barrel PID, and min P_T in a compact solenoid

- Low-p_T particles "curl up" inside the tracker and do not reach the barrel PID or EMcal
- Using a compact Si-tracker allows moving the main barrel PID system closer, improving low-p_T acceptance at high B.
  - 0.5 m vs 1 m in the YR table
  - This also reduces the cost of the DIRC
- The kaon threshold in the DIRC is 0.47 GeV/c, but in the 0.2-0.5 GeV/c range it can operate in threshold mode, separating pions from kaons and protons (without K/p separation)

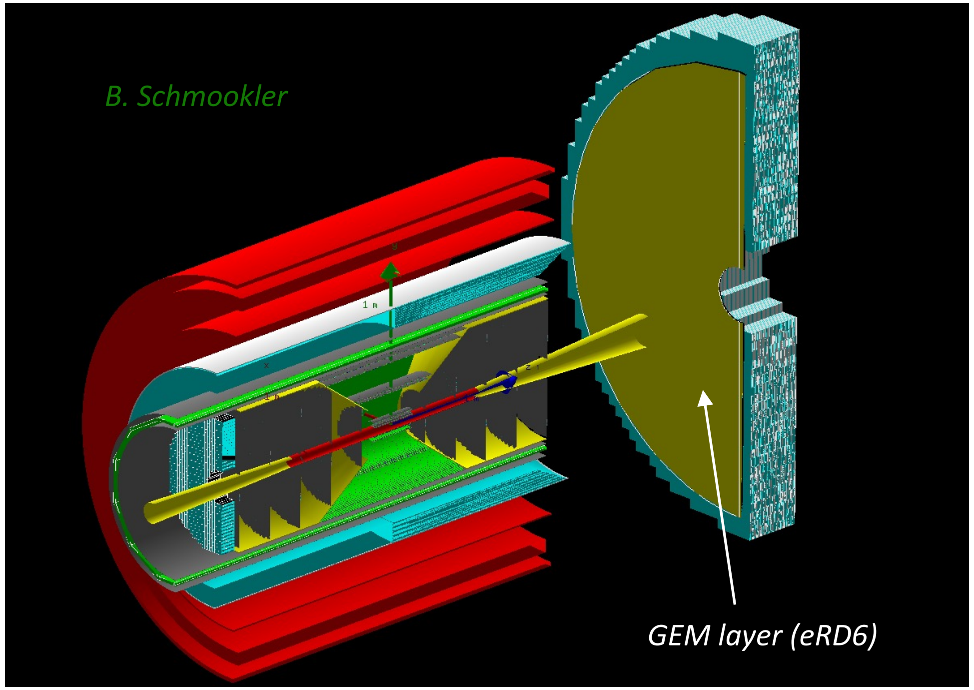
Yellow Report

lowest p_T	0.5 Tesla	1 Tesla	3 Tesla
with PID @1m	75 MeV	225 MeV	450 MeV
no PID	25 MeV	50 MeV	100 MeV
CORE			
PID, EMCal≤0.6m	45 MeV	90 MeV	270 MeV

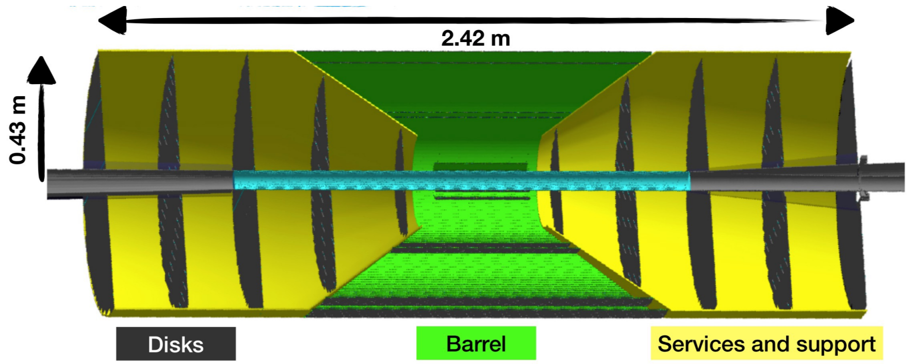


Central Si-tracker and h-endcap GEM

- The all-Si tracker developed by the Silicon Consortium is a good geometric match for CORE.
  - L: 2.4 m, D: 0.9 m
  - ALICE ITS3 technology allows for low mass, air cooling, and a very efficient vertex tracker geometry $(10\ \mu m)^2$ pixels. Thickness 30-50 μm.
- For CORE the layout was optimized to improve the track reconstruction efficiency
  - also for decays of high-energy K_S, Λ, and Σ.
  - 7 disk layers in each direction
  - 7 barrel layers (including SVT) in central region
- The last layer on the electron side is AC-LGAD instead of MAPS. It has a lower position resolution but provides TOF for pi/K at p≤2.3 GeV
- Total thickness ≤ $2\%X_0$

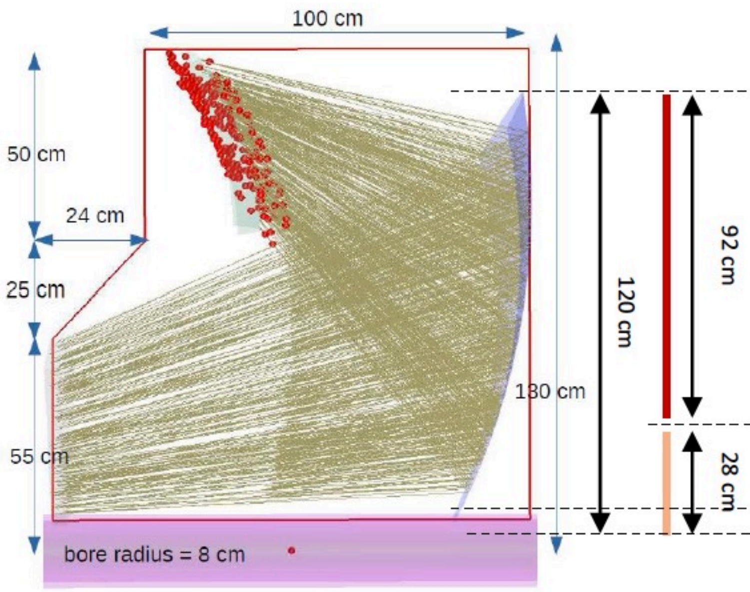


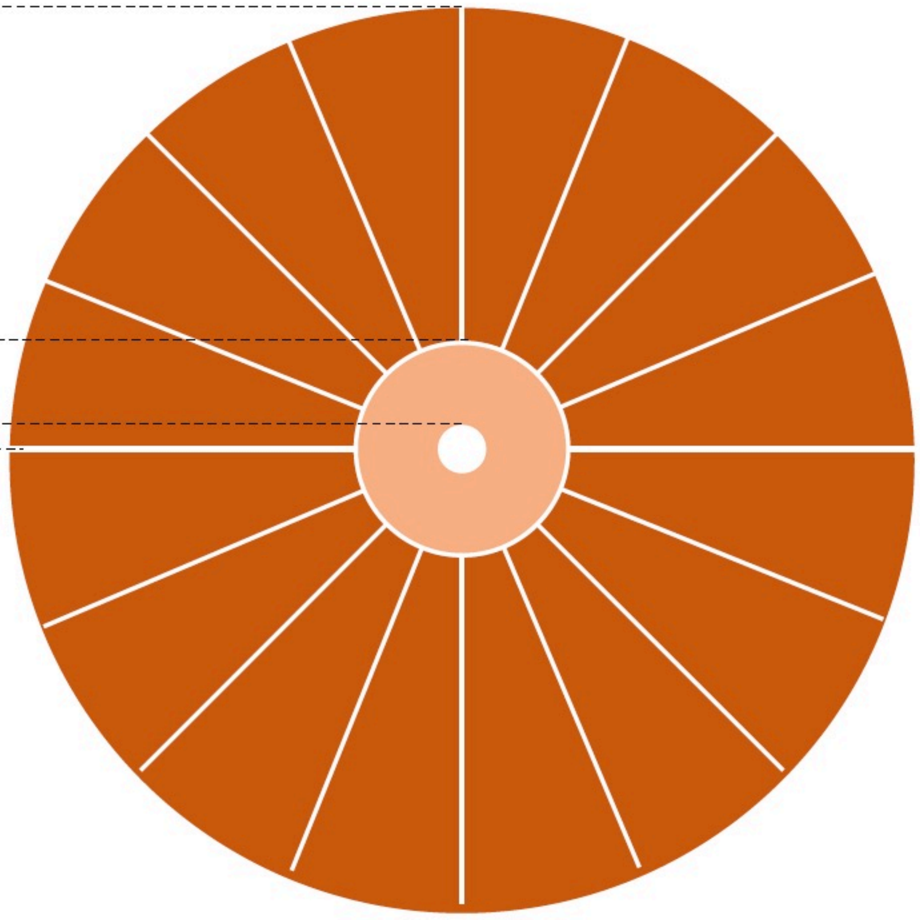
The original eRD25 Si-tracker

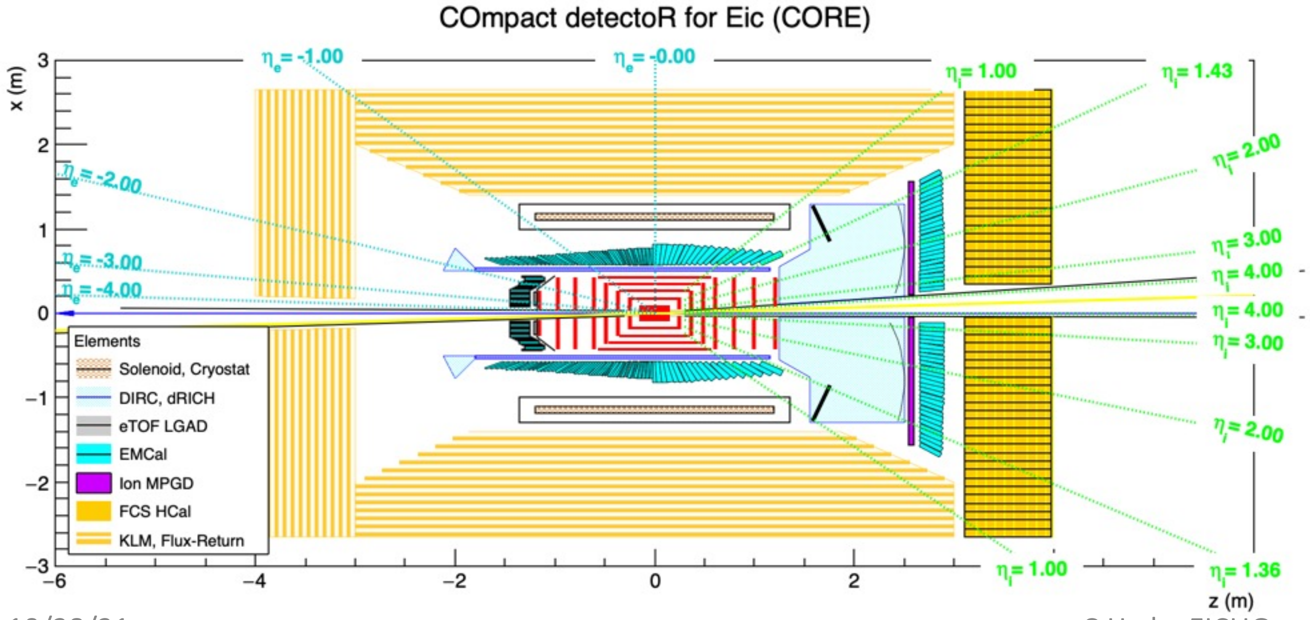


dRICH + GEM

- GEM Layout (UVA) matches the CORE dRICH



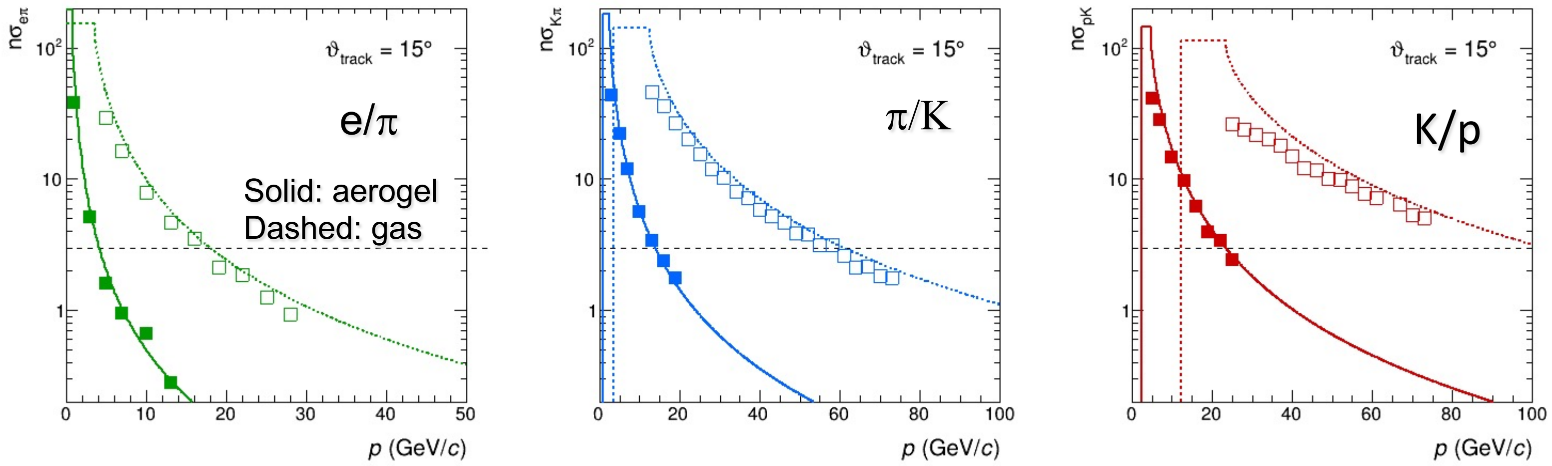


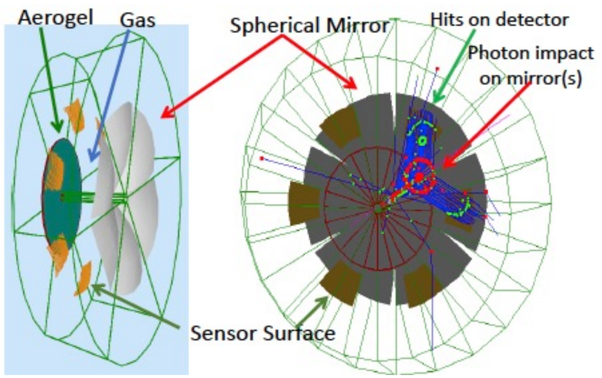


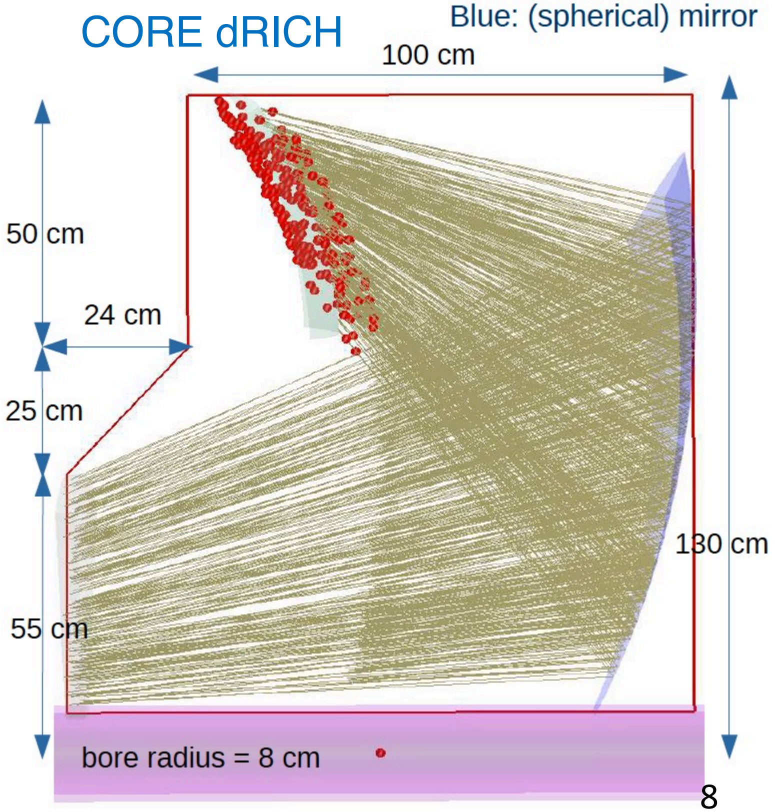
- The GEM seeds the dRICH ring finder

PID in the hadron endcap – dual-radiator RICH

Performance of the dRICH developed by the EIC PID consortium (eRD14)

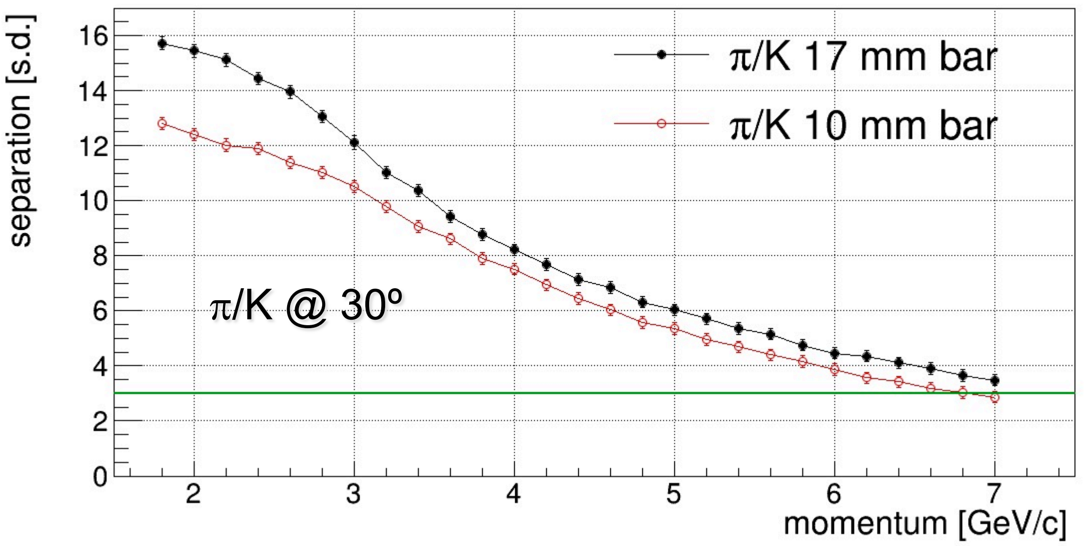


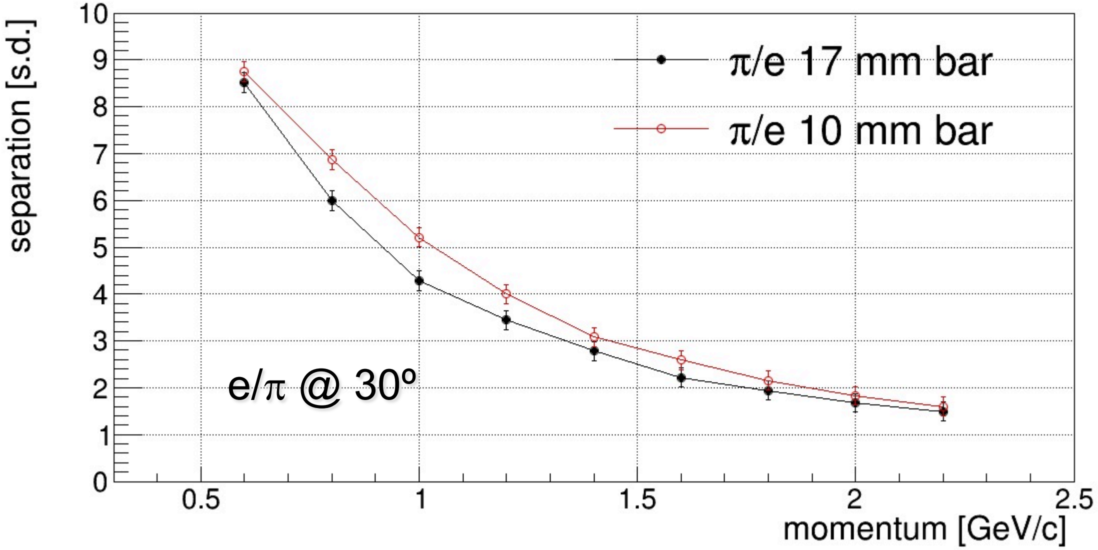




- The CORE dRICH is a scaled version of the eRD14 one
  - Good geometric match to smaller photosensor plane
  - Gas length of 1.2 m is only 25% smaller than in the original
  - 55 cm aperture (with aerogel) matches barrel EMcal
- CORE performance should be close to the eRD14 original
  - Note the excellent e/π separation (10σ at 10 GeV/c)
  - In threshold mode (indicated by a flat top), the dRICH aerogel can cover very low momenta (middle plot)

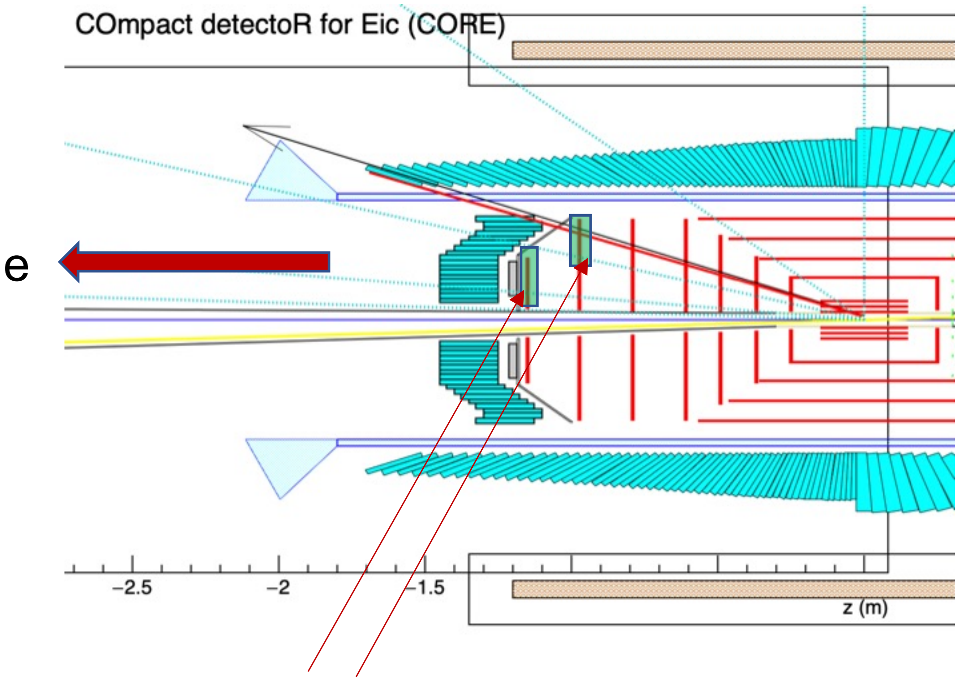
PID in the barrel – high-performance DIRC



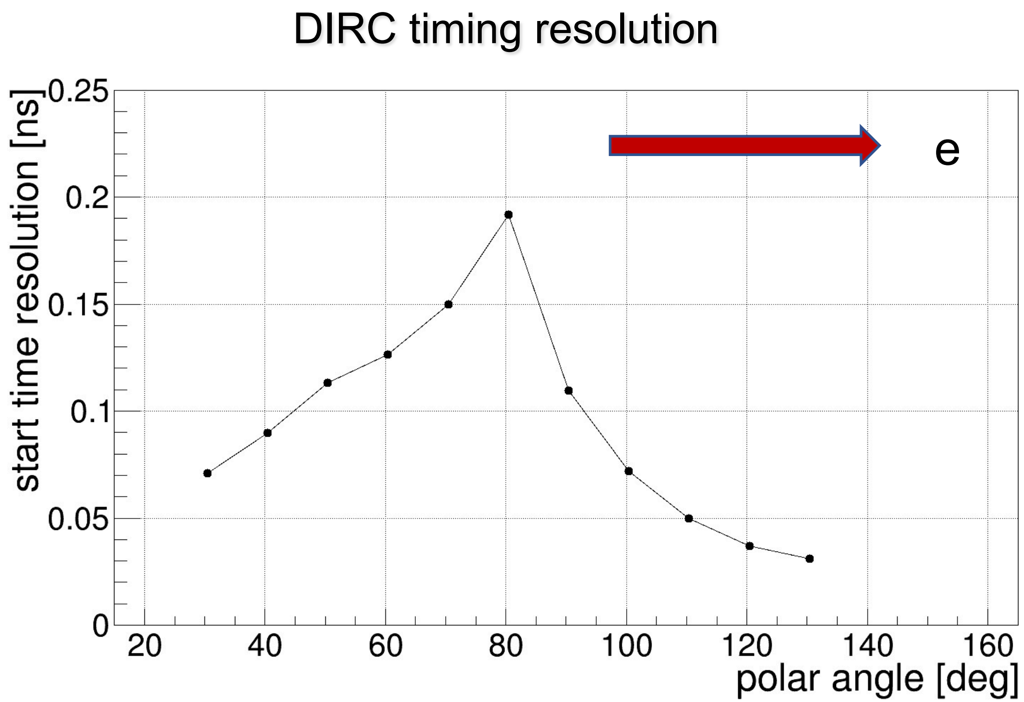


- The baseline option for CORE is re-use of the BaBar bars (17 mm).
- However, TORCH-like (10 mm) low mass bars would be an interesting option for new construction.
  - Re-use may not work or there may not be enough bars for two detectors
  - The small CORE DIRC radius makes new construction affordable
  - 40% reduction in mass benefits the EMcal
  - e/π ID around 1 GeV/c range is improved, without significantly affecting π/K ID above 4 GeV/c

Timing in the electron endcap and barrel



AC-LGADs, 25 ps



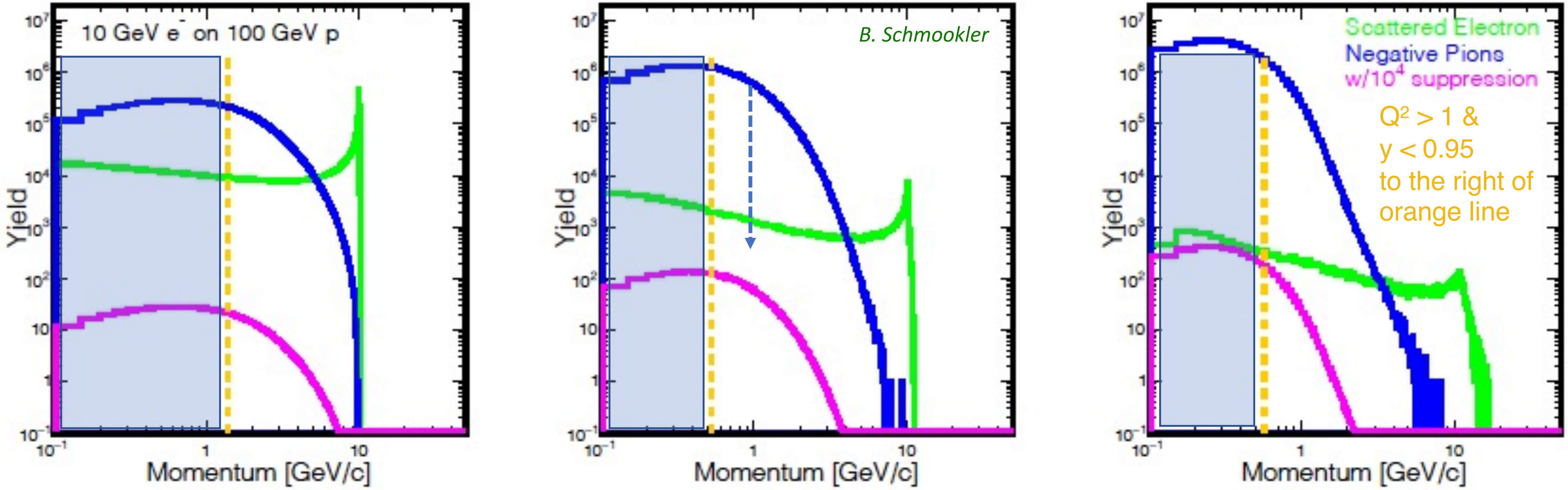
- The combination of AC-LGADs and DIRC can provide timing for the e-endcap and barrel

- For PID, t_0 can be obtained by tracking the (identified) scattered electron (β=1) to the vertex (as in CLAS)

e/π identification in the electron hemisphere

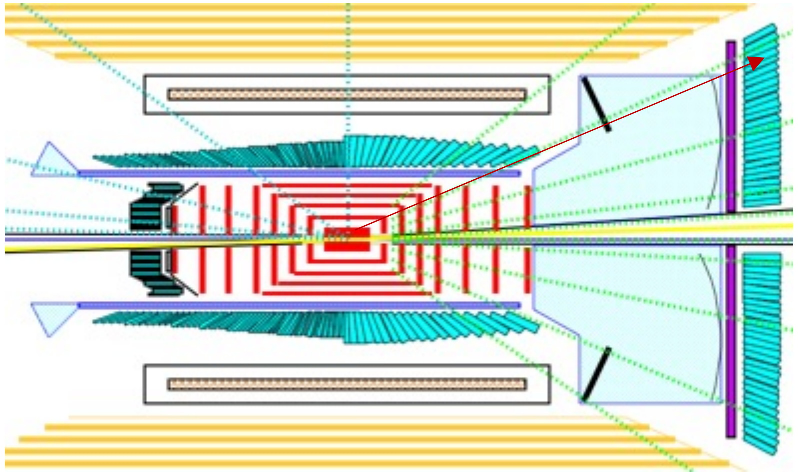
$\eta = -\ln(\tan(\theta/2))$

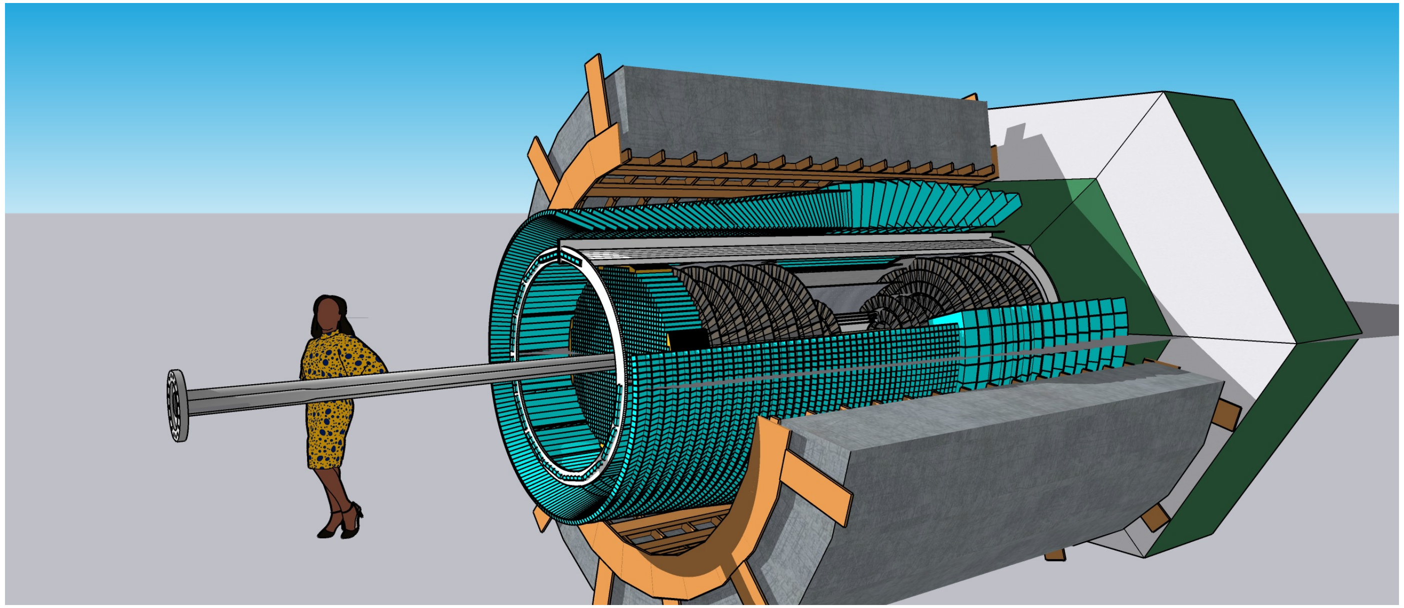
CORE endcap $-3.5 < \eta < -2.0$ | $-2.0 < \eta < -1.0$ | CORE barrel $-1.0 < \eta < 0.0$



- For the EIC, a clean identification of the scattered electron is essential.
- The barrel region poses the greatest challenge and requires the best electron ID.
- CORE addresses this issue by extending the PWO EMcal coverage up to $\eta < 0$ (or possibly -0.5)
- Additional low-momentum π/e suppression is provided by the DIRC for p<2 GeV
- EMCal p/E x Shower-shape x DIRC Total π/e suppression ≥ 1000:1 for p > 1 GeV

4π EM calorimetry





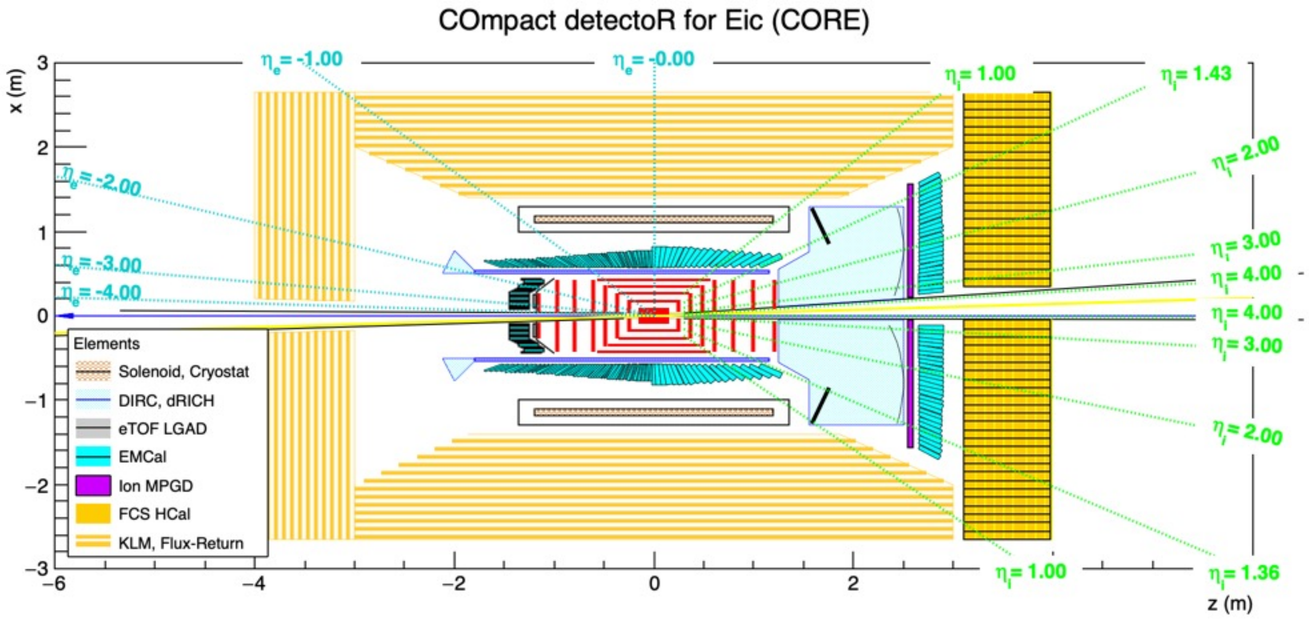
Electron hemisphere ($\eta < 0$)

- PWO (2%) – temperature controlled
- Baseline coverage is $\eta < 0$, but $\eta < -0.5$ could be sufficient (budget option)
- The endcap is only 0.6 m^2 and can be cantilevered from behind to reduce supports and improve hermeticity

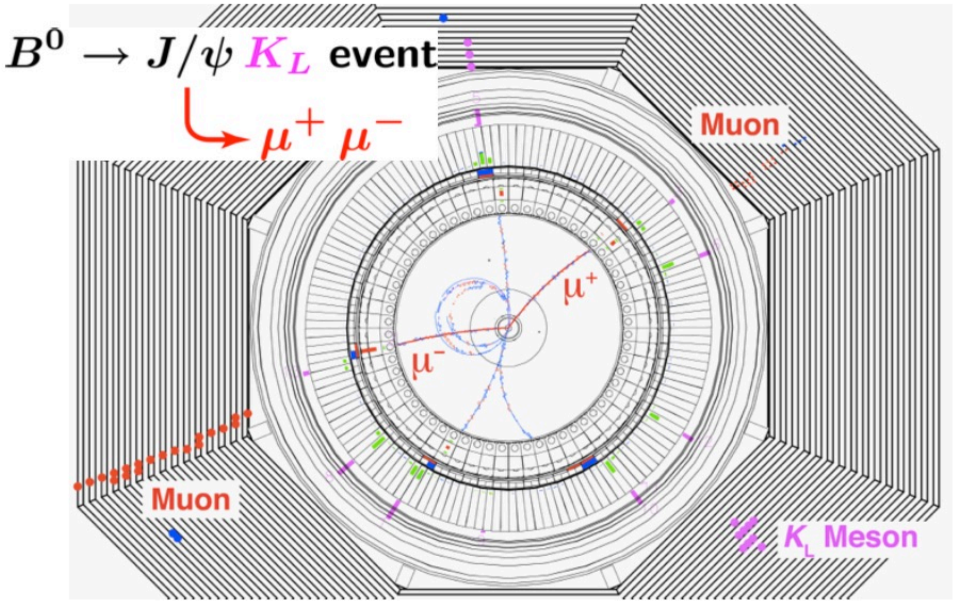
Hadron hemisphere ($\eta > 0$)

- W-Shashlyk (6%) is baseline for the hadron endcap and forward part of the barrel
- Its energy resolution is twice as good as W/SciFi and it has excellent position resolution
- The barrel-endcap transition minimizes partial showers in the edge of the barrel

Hadronic calorimetry and muon ID

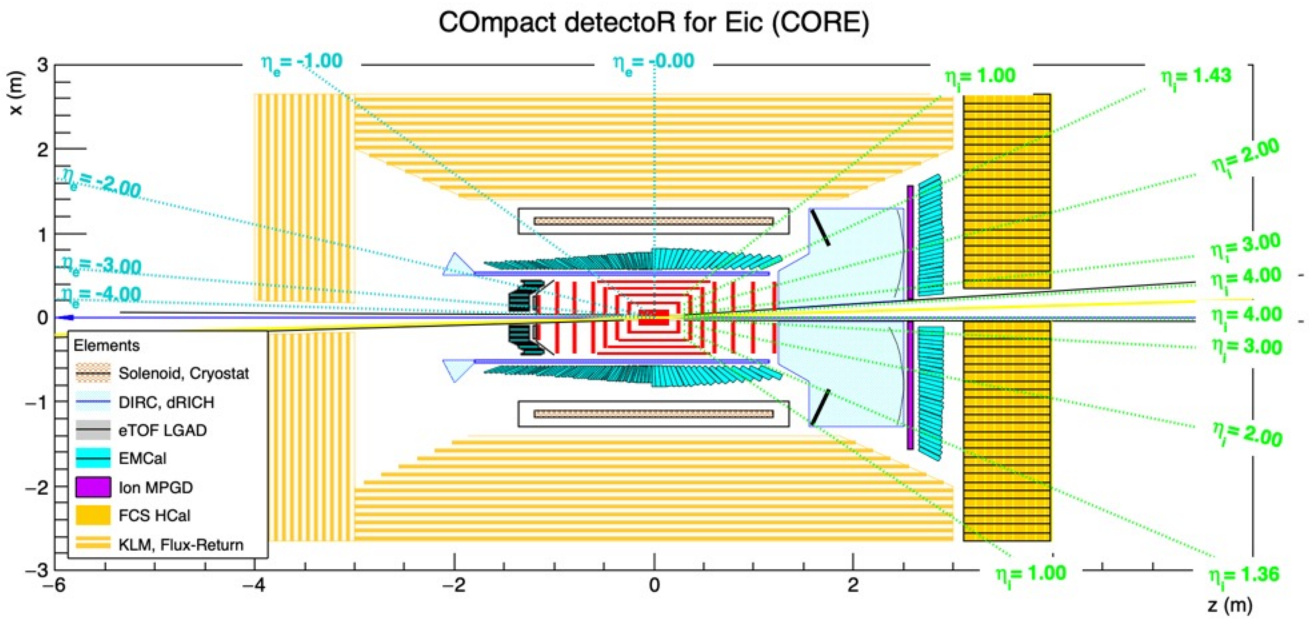


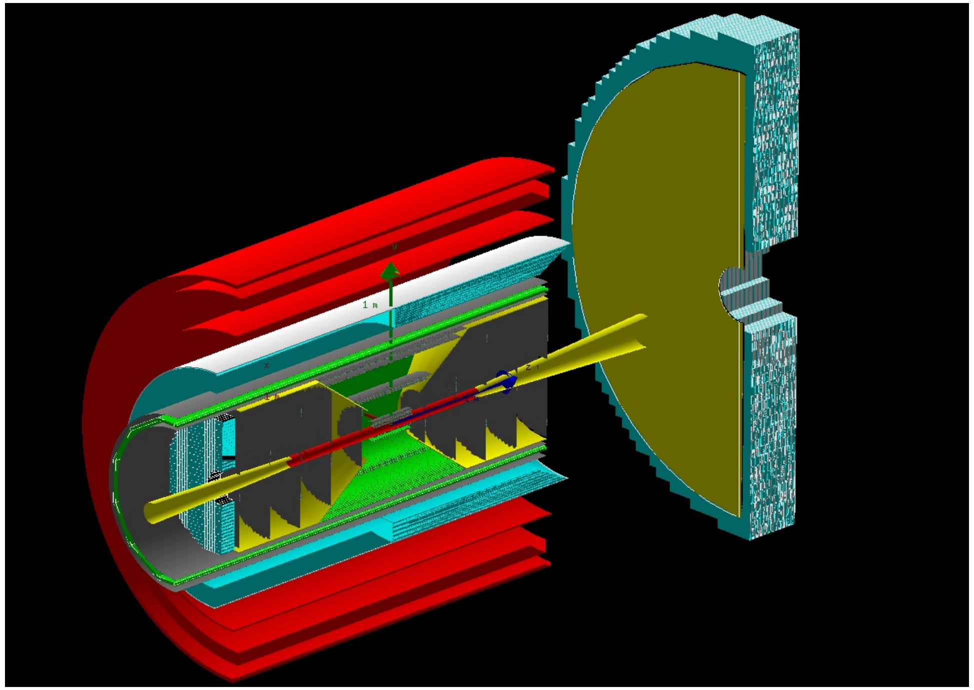
The Belle II K_L-μ (KLM) system



- High-resolution Hcal in hadron endcap (yellow) – STAR FCS w/ 51 layers
  - Important for high-x jets, J-B and DA methods for reconstruction of event kinematics, etc.
- Low-resolution Hcal with excellent muon ID elsewhere – *cf.* Belle II KLM
  - Integrated with magnetic flux return
  - Neutral hadrons for mid-rapidity jets (which are best reconstructed from individual tracks)
  - Excellent muon ID down to low momenta (exclusive di-lepton production, etc)
  - Energy resolution can be optimized if used with the sPHENIX barrel Hcal

CORE systems summary

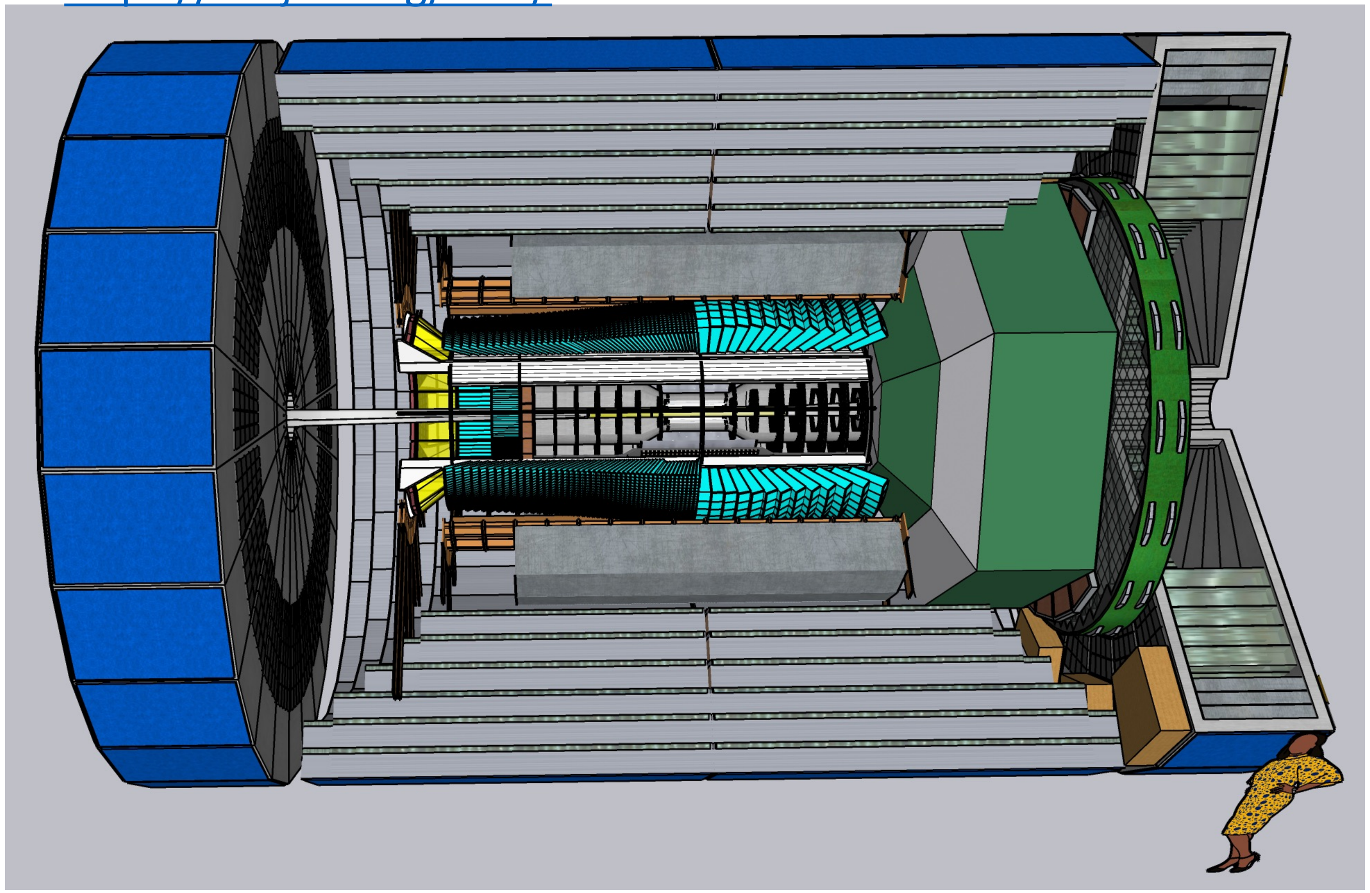




- New 3 T solenoid (2.5 m long coil, 1 m inner radius)
- Tracking: central all-Si tracker (eRD25) and h-endcap GEM tracker (eRD6)
- EMcal (eRD1): PWO for $\eta < 0$ and W-Shashlyk for $\eta > 0$
- Cherenkov PID (eRD14): DIRC (50 cm radius) in barrel and dual-radiator RICH in h-endcap
- TOF: AC-LGADs in e-endcap (eRD29)
- Fwd Hcal (eRD1): STAR FCS w/ 51 layers (rather than 36)
- Hcal / K_L-μ (KLM) in barrel and e-detector integrated with the magnetic flux return

Thank you!

https://eic.jlab.org/core/



CORE - a COmpact detectoR for the EIC

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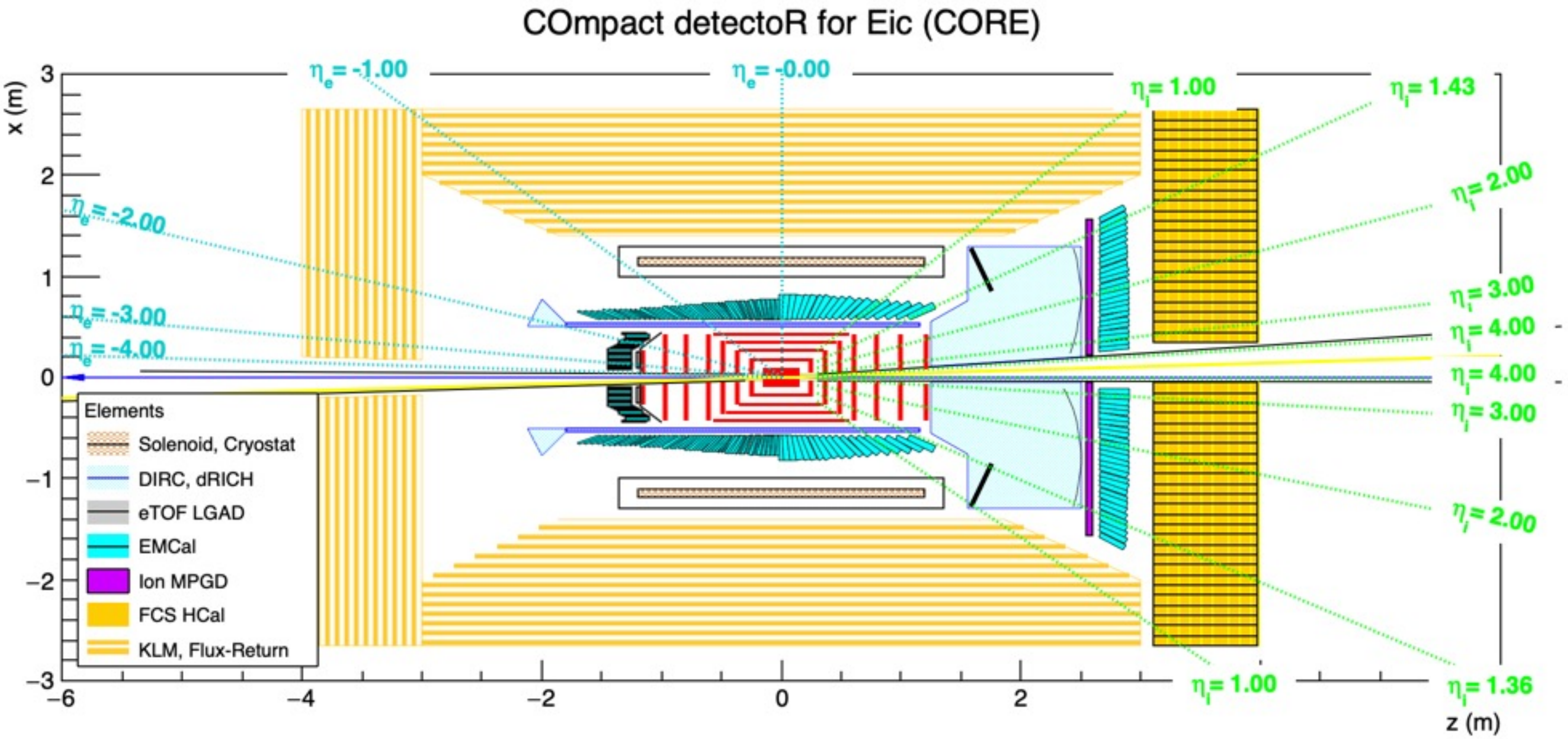
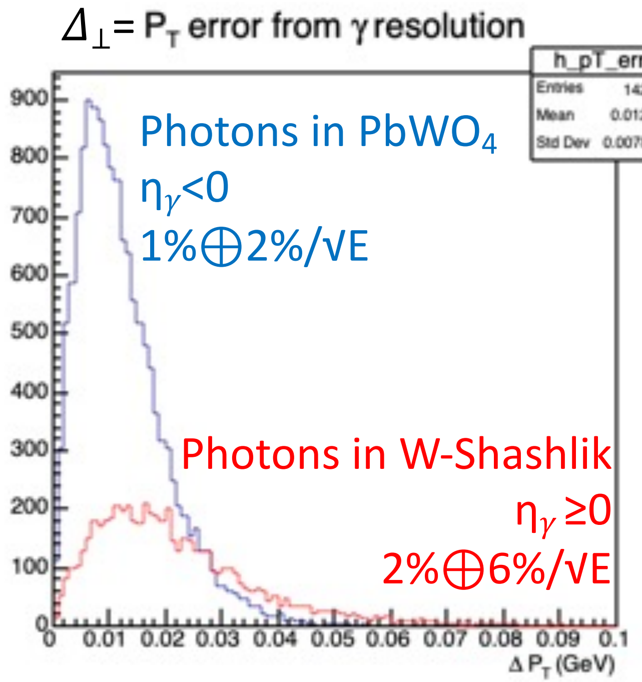
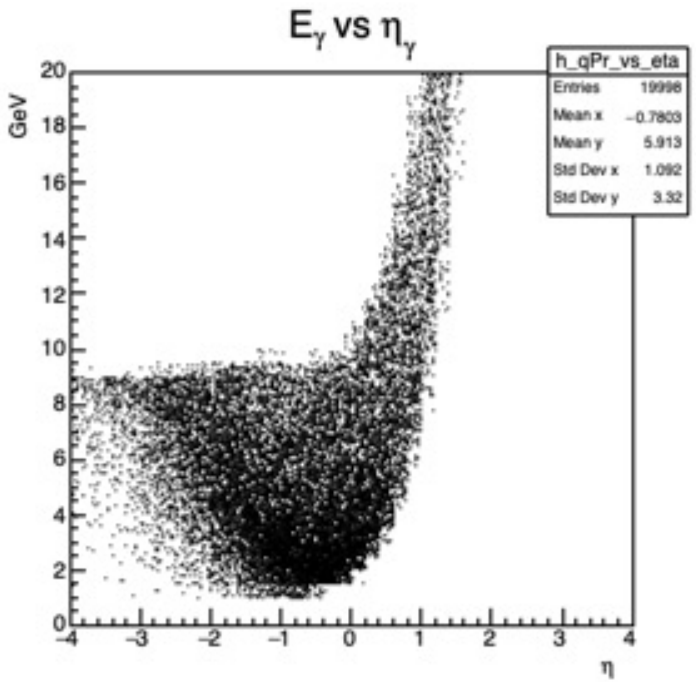


Backup slides

^{4}He(e,e'γ)$\boldsymbol{\alpha}$: 10GeV$\otimes$100GeV/u

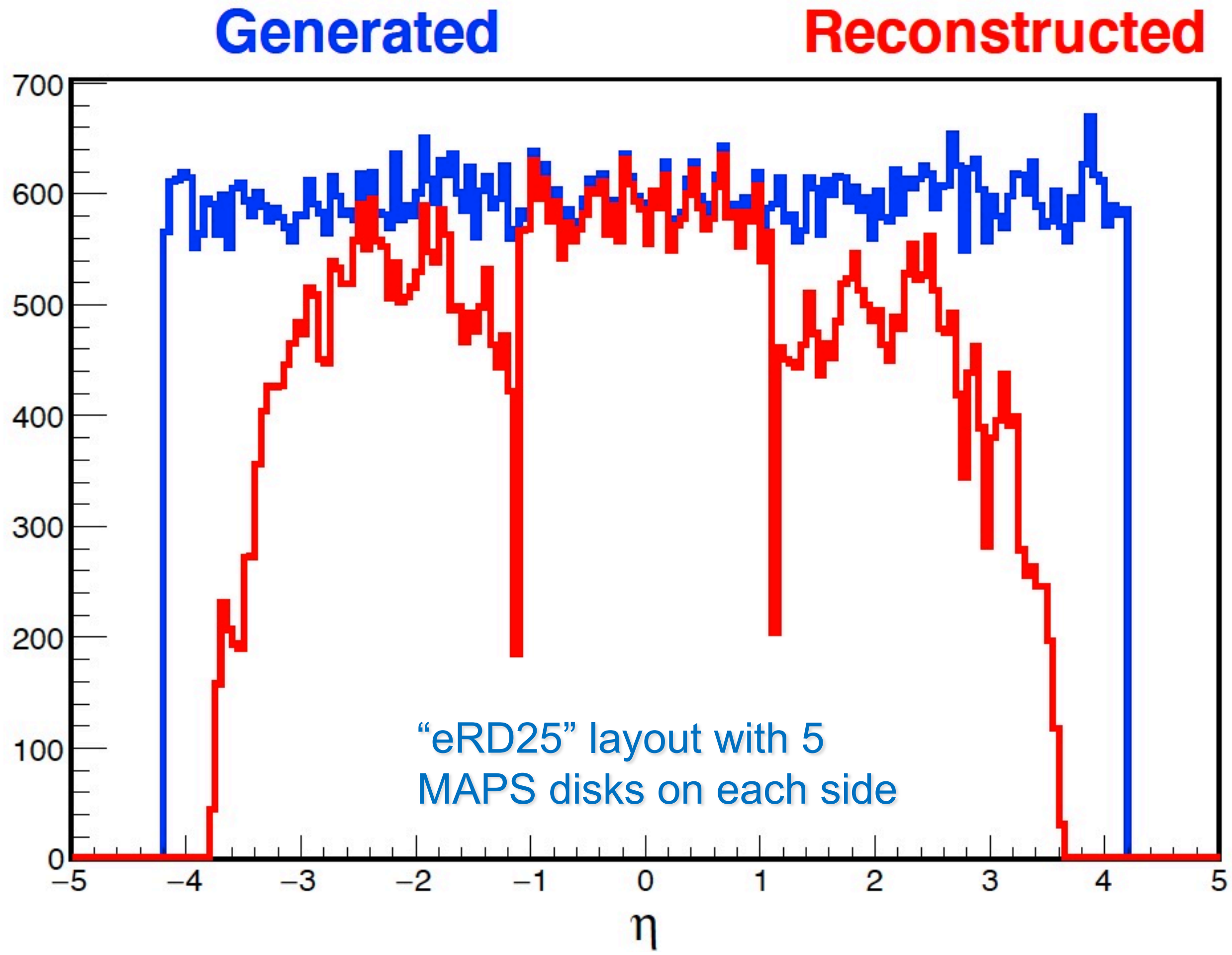
- Phase space distribution only
  Δ^μ = (k-k'-q')$^\mu$ = (q-q')$^\mu$ $\Delta_\perp \bullet$q=0= $\Delta_\perp \bullet P_{He}$ by definition of $\Delta_\perp{}^\mu$

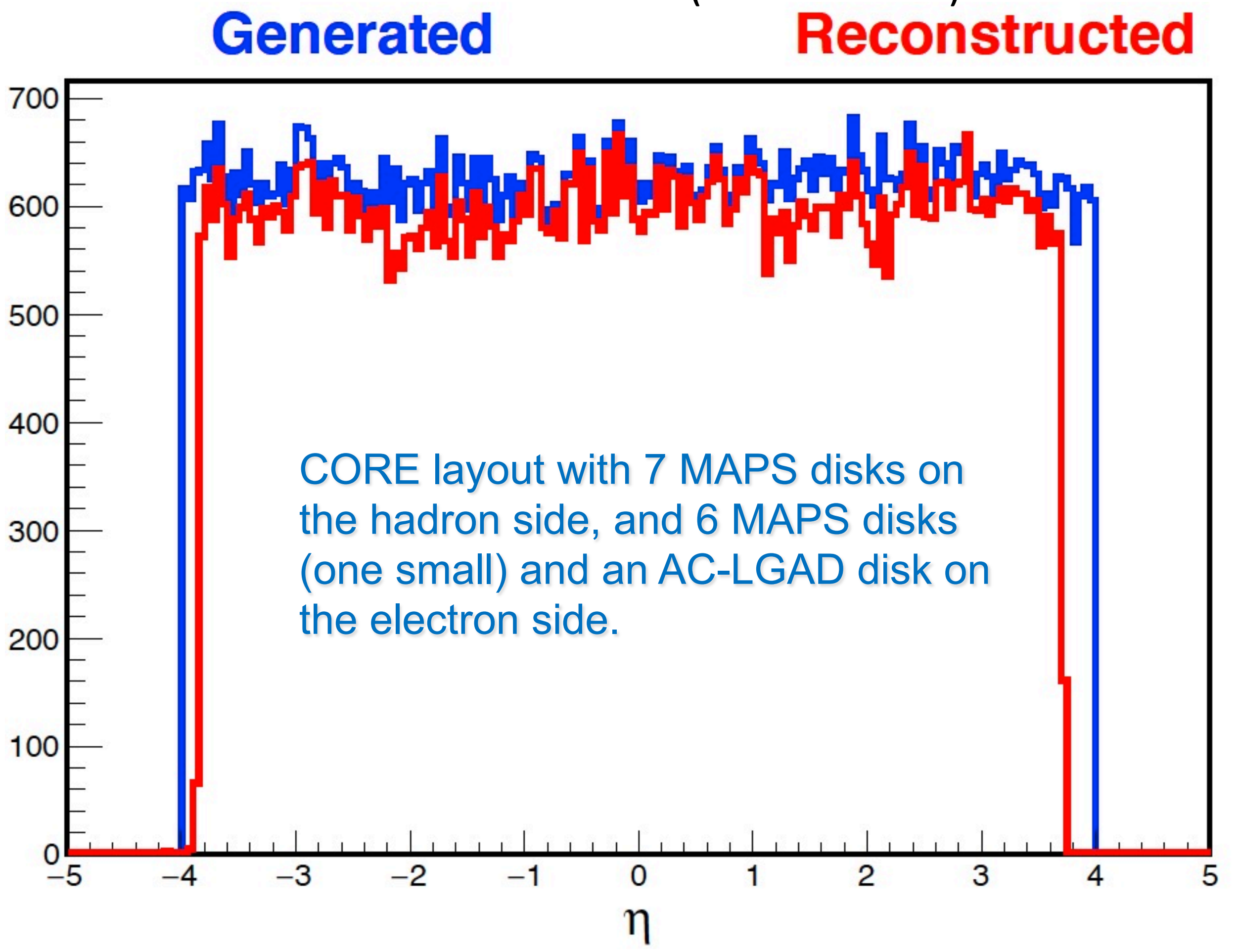




Si-tracker reconstruction efficiency in Fun4All

(S.Bueltmann)

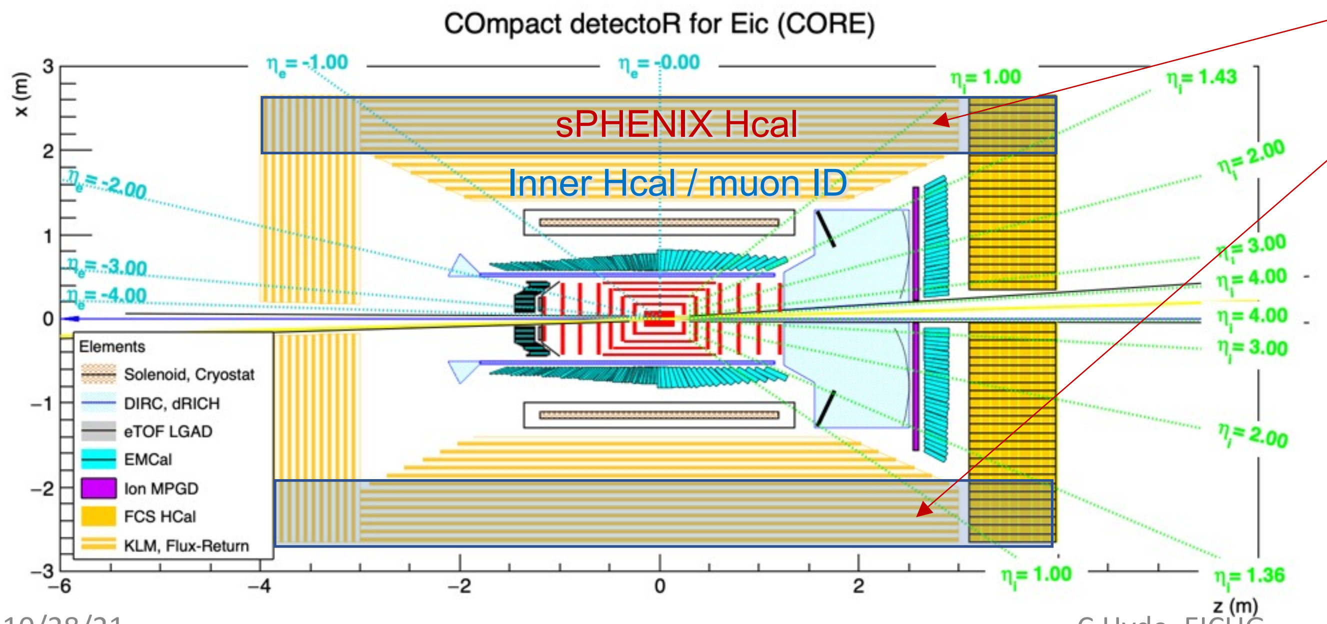




- No tweaks or optimizations were made to the track finding!

Re-use of the sPHENIX HCal?

- The BaBar solenoid is not ideal for an EIC detector (long, weak, old), but the sPHENIX barrel HCal is new.
- A compact solenoid and an inner HCal / muon detector would fit inside the sPHENIX HCal. (with 1m removed from length of sPHENIX HCal)

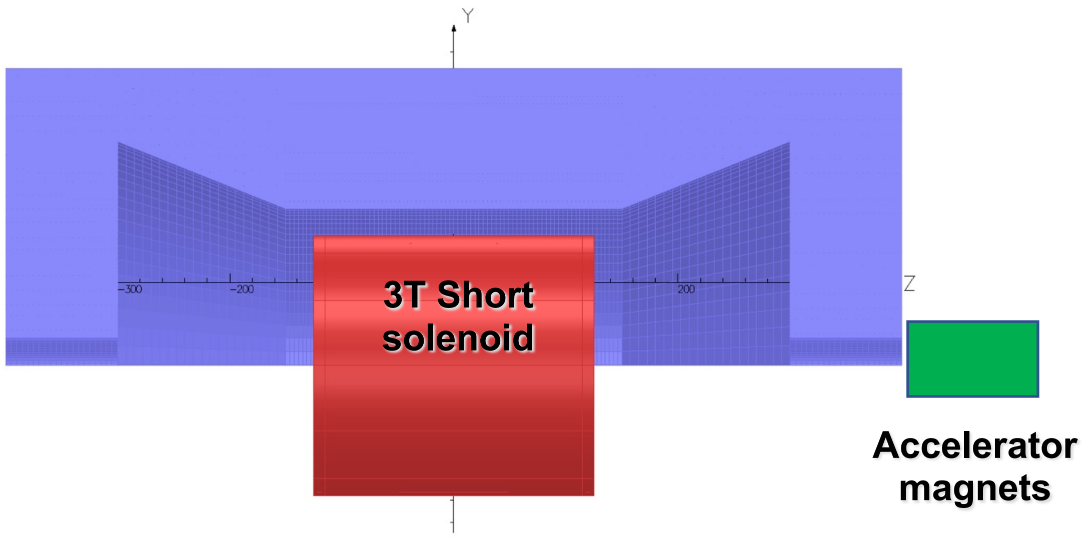


How do we make a high-luminosity EIC detector?

- *In short:* the shorter the solenoid the higher the luminosity (day 1 + upgrade path)

- Detector length (l*) dependence
  - The luminosity is to first order proportional to the detector length (β^{max} on the hadron side)
  - Moving beam magnets closer to the IP improves focusing and luminosity for *all* energies
  - Particularly important if future improvements in cooling can reduce bunch length (hourglass effect)

- Two-detector operation
  - Two detectors would have to share certain global limitations (e.g., chromaticity), reducing their luminosity – commonly known as luminosity sharing
  - A shorter detector creates a smaller chromatic contribution, potentially allowing a higher *combined* luminosity

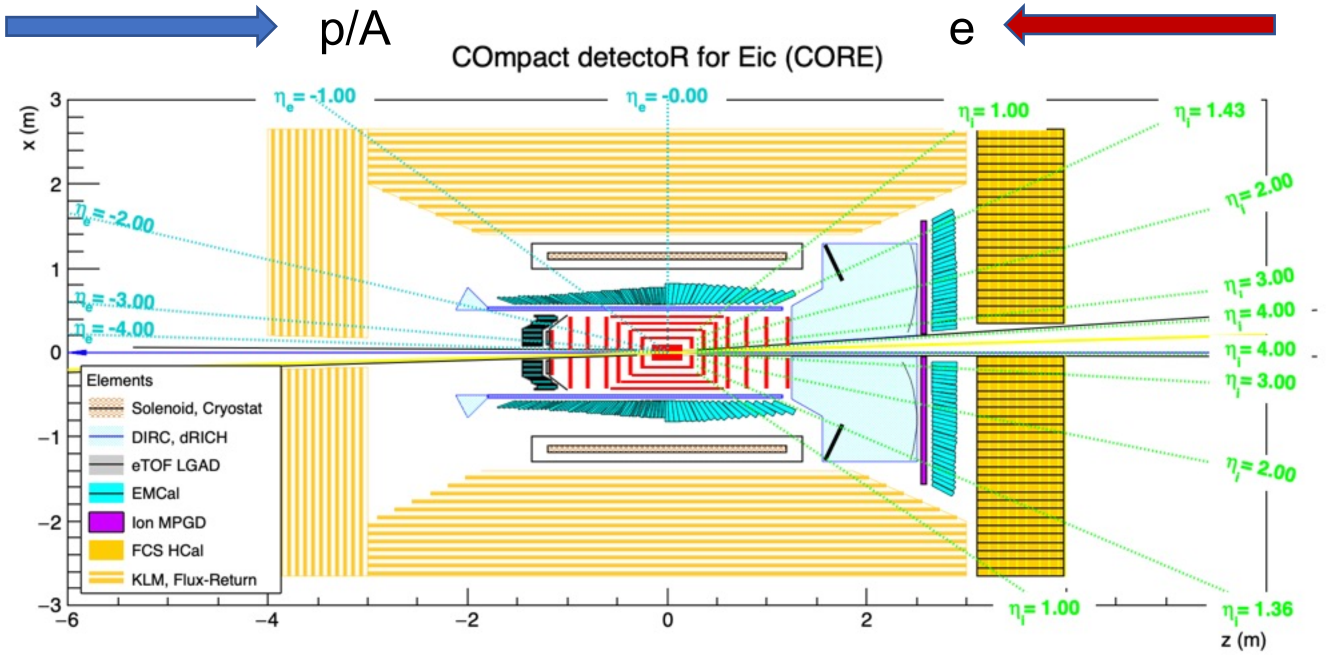


A short solenoid is advangtageous for reaching the highest luminosity

Accelerator Magnets could be moved closer in a future upgrade if optical metamaterials could replace the dRICH gas!

High-luminosity operations

- The luminosity also depends on the *individual* beam energies.
- The highest luminosity is generally achieved at the highest energy, and favors large a large asymmetry
  - 10 x 275 GeV is the luminosity maximum.
- For electron energies above 10 GeV, the challenge is the synchrotron radiation power, which limits the electron current
- At low proton/ion energies (41 GeV/A), space charge and beam-beam make the luminosity very low
  - *Some* mitigation possible (focusing)



18x275	10x275	5x275	10x100	5x100	5x41
1.65×10^{33}	10.05×10^{33}	5.29×10^{33}	4.35×10^{33}	3.16×10^{33}	0.44×10^{33}

Since particle distributions in the endcaps follow the beam energies, it is important to match coverage and luminosity requirements (e.g., for PID).

What do we want from an EIC detector?

Call for Collaboration Proposals for Detectors at the Electron-Ion Collider

- **Detector 1 Collaboration Proposals**: Experiments must address the EIC White Paper and NAS Report science case. The collaboration should ***propose a system that meets the performance requirements described in the EIC CDR and EICUG YR***. The design should be compatible with that of the accelerator and interaction region layout of the CDR. Completion of detector construction must be achieved by Critical Decision (CD)-4A, the start of EIC accelerator operations.

- **Detector 2 Collaboration Proposals**: Experiments should address ***science goals described in the EIC White Paper and possibly science beyond that and enable some complementarity to Detector 1***. The Detector 2 interaction region design should be consistent with the accelerator design as detailed in the CDR, with perhaps some interaction region optimization. The detector design should allow for an estimated construction schedule compatible with achieving detector completion by CD-4 (which follows CD-4A). Note: Currently, the EIC project scope does not include the construction of Detector 2 or the accelerator components needed for the second interaction region.