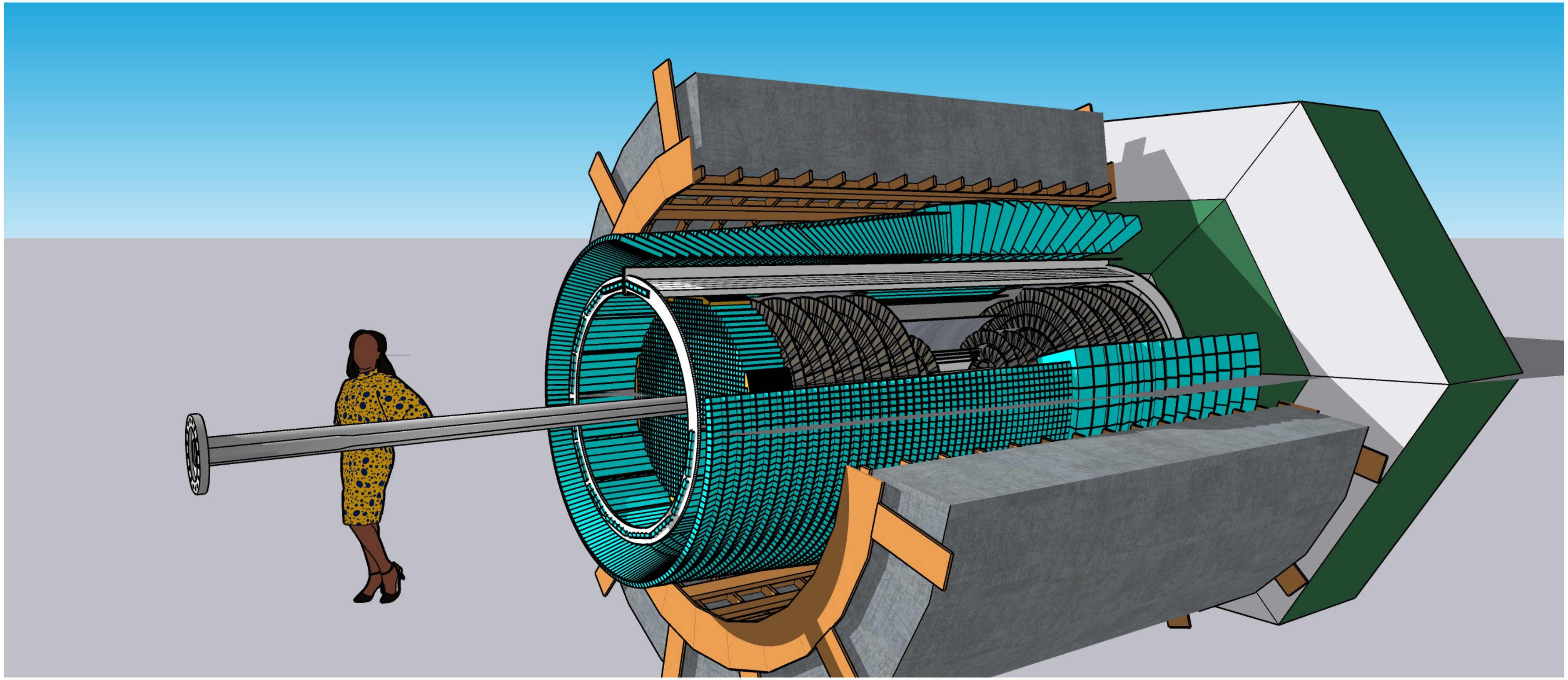
CORE: a COmpact detectoR for the EIC



Pawel Nadel-Turonski

SBU meeting, October 25, 2021

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.

Impact of the Generic EIC R&D for an EIC program

- The R&D program was very successful in brining forward technologies for the EIC

- But as a side effect, most subsystems considered for the detector proposals are identical, interchangeable, or equivalent. For example:
  - eRD1 fwd Hcal has identical module (51 layer STAR FCS)
  - eRD14 DIRC, dRICH, and mRICH (not used in CORE) are equivalent (size and cost varies)
  - eRD25-based all-Si trackers are interchangeable (CORE and ATHENA)
  - etc

- Thus, the main differences between the EIC detectors proposals come from design, layout, and emphasis rather than the technology choices. Examples of key *differences* are:
  - High luminosity for all energies (CORE priority)
  - Magnetic field and tracking resolution (CORE and ATHENA priority)
  - EM calorimetry with the best photon resolution and electron ID (CORE priority)
  - Muon ID (CORE priority)
  - High-p hadron ID for $-3.5 < \eta < -2$ (ATHENA and ECCE priority)
  - Synergies with IR8 (CORE and nominal ECCE priority)

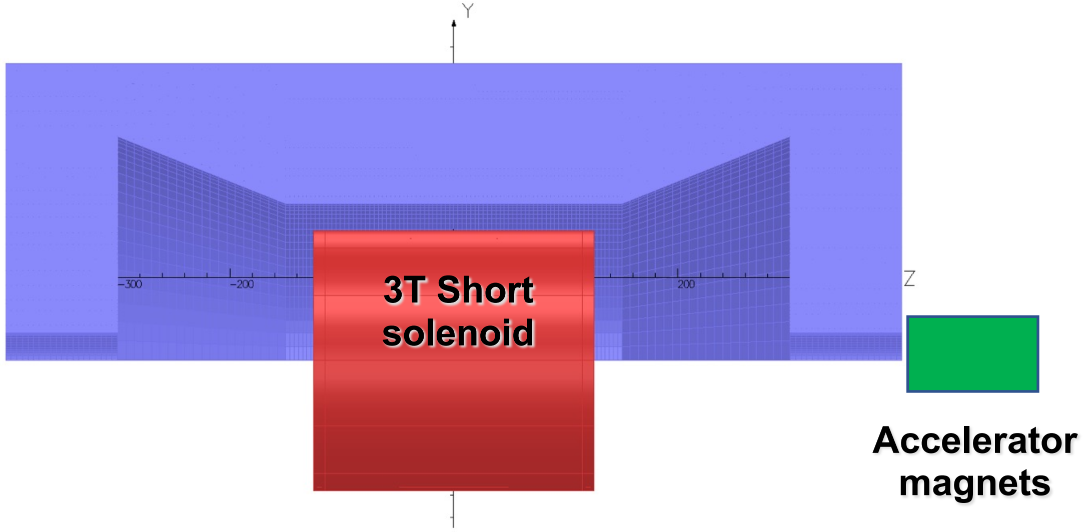
Main limitation of CORE, but relevant mainly for 18 GeV electron beams

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, allowing a higher *combined* luminosity

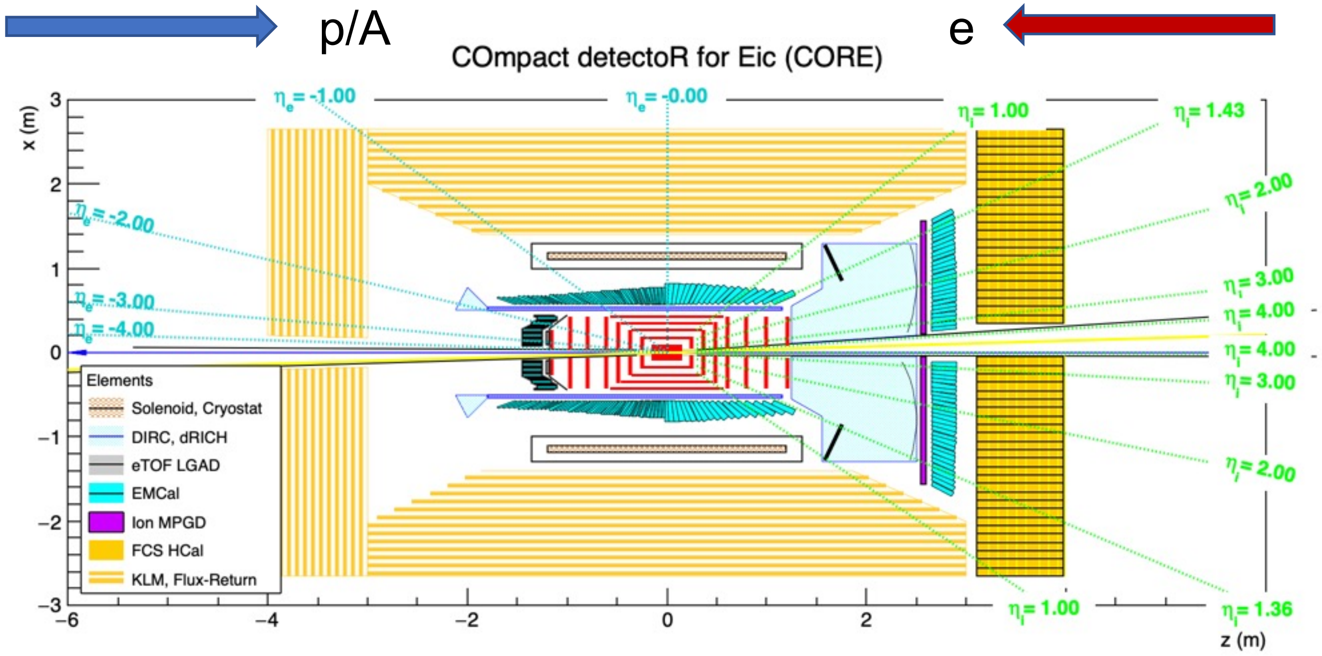


A short solenoid is essential for reaching the highest luminosity

Accelerator Magnets could be moved in even further 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)

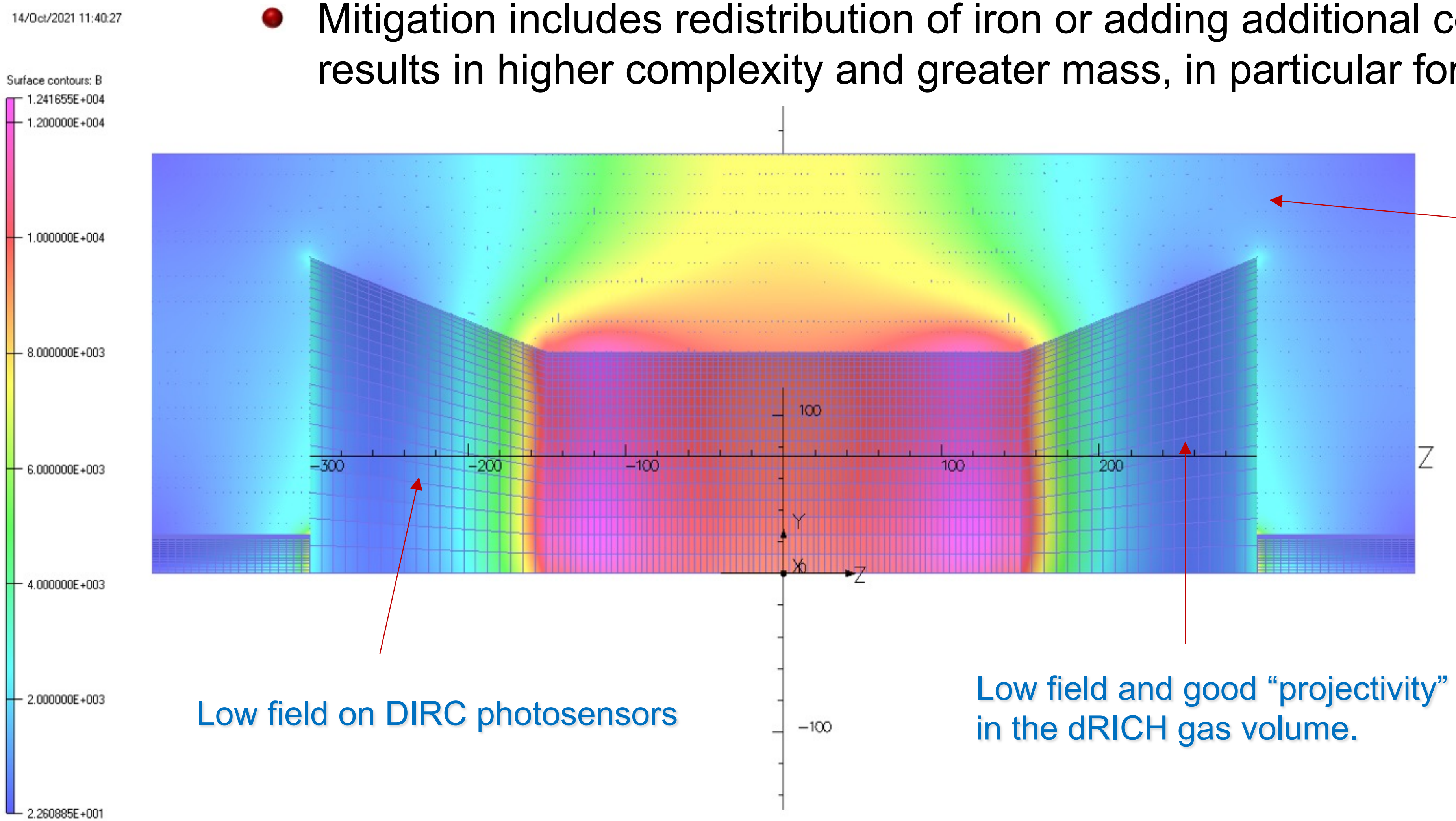


18x275	10x275	5x275	10x100	5x100	5x41
1.65×10^{33}	10.05×10^{33}	5.29×10^{33}	4.35×10^{33}	3.16×10^{33}	0.44×10^{33}

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

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

- An asymmetric iron distribution can create large forces on the coils
- Mitigation includes redistribution of iron or adding additional coils, but typically results in higher complexity and greater mass, in particular for the cryostat



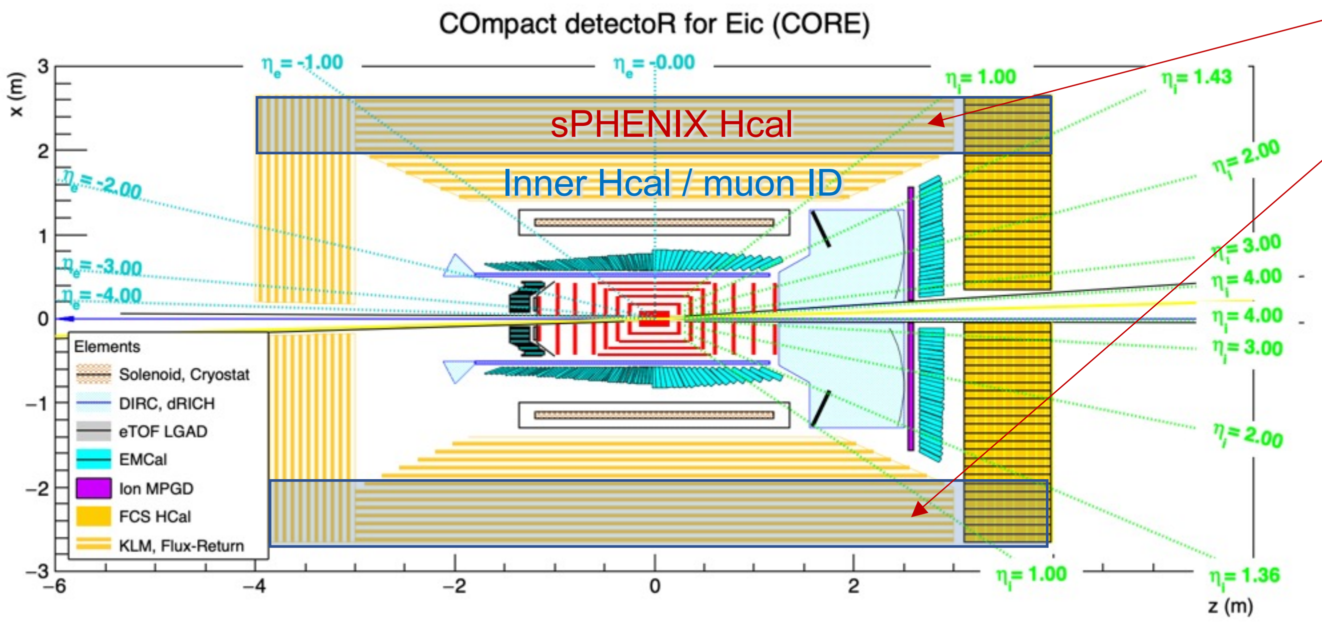
Natural access points for signal cables and services.

- Field: 3 T
- Coil length: 2.5 m
- Inner radius: 1 m
- Cost to project: $15.8M

Re-use of the sPHENIX Hcal?

- The BaBar solenoid is not ideal for an EIC detector (long, weak, old), but the barrel Hcal is new.

- A compact solenoid and an inner Hcal / muon detector would fit inside the sPHENIX Hcal.



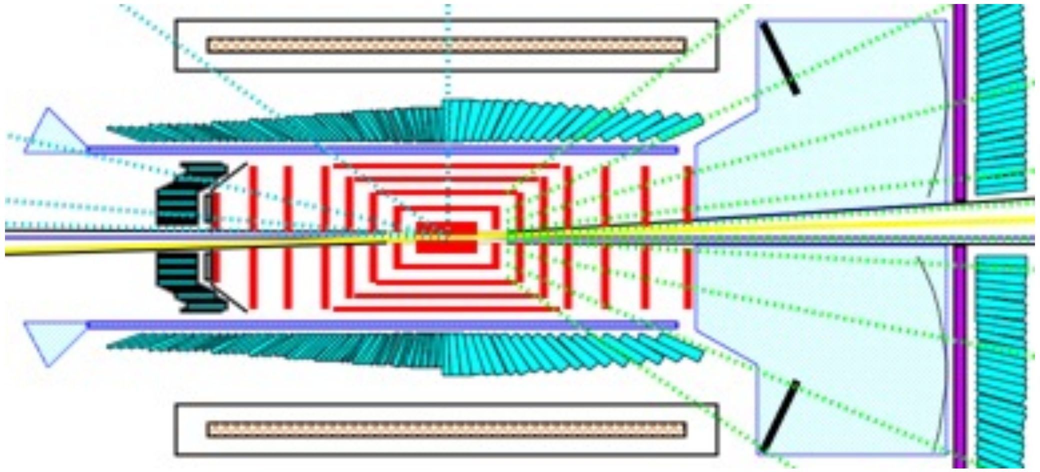
Tracking, barrel PID, and min P_T in a compact solenoid

- Low-pT 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
  - K/p ID n the 0.2-0.5 GeV/c range is not a strong physics driver
  - All momenta above are |p}, not p_T

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

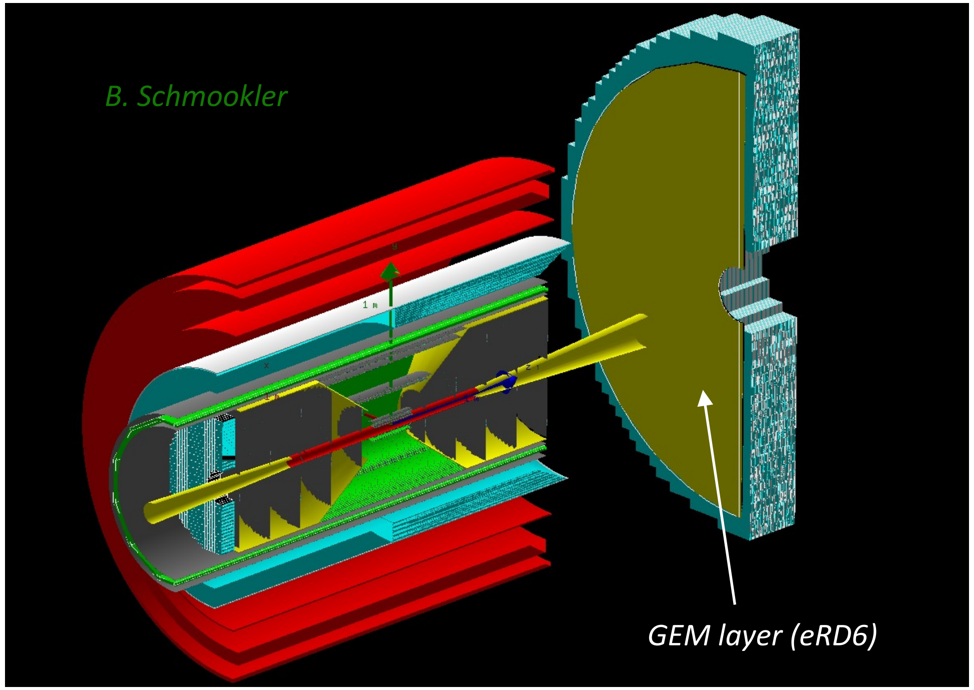


Central Si-tracker and h-endcap GEM

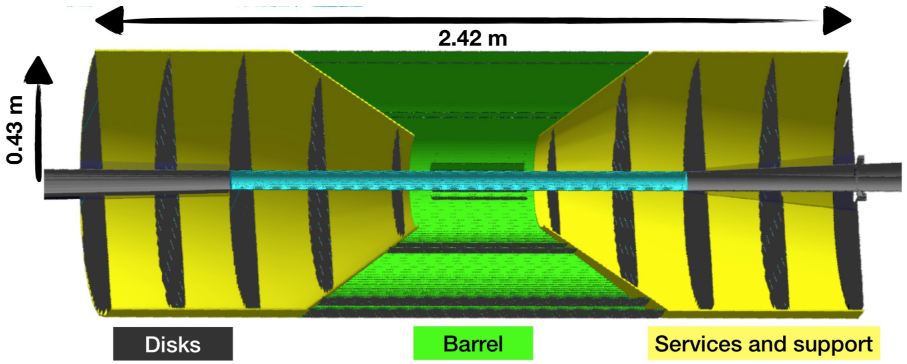
- The all-Si tracker developed by the Silicon Consortium is a good geometric match for CORE.
  - L: 2.4 m, D: 0.9 m
  - ALICE ITS3 technology allows for low mass, air cooling, and a very efficient vertex tracker geometry

- For CORE the layout was optimized to improve the track reconstruction efficiency
  - also for decays of high-energy K_S , Λ, and Σ.

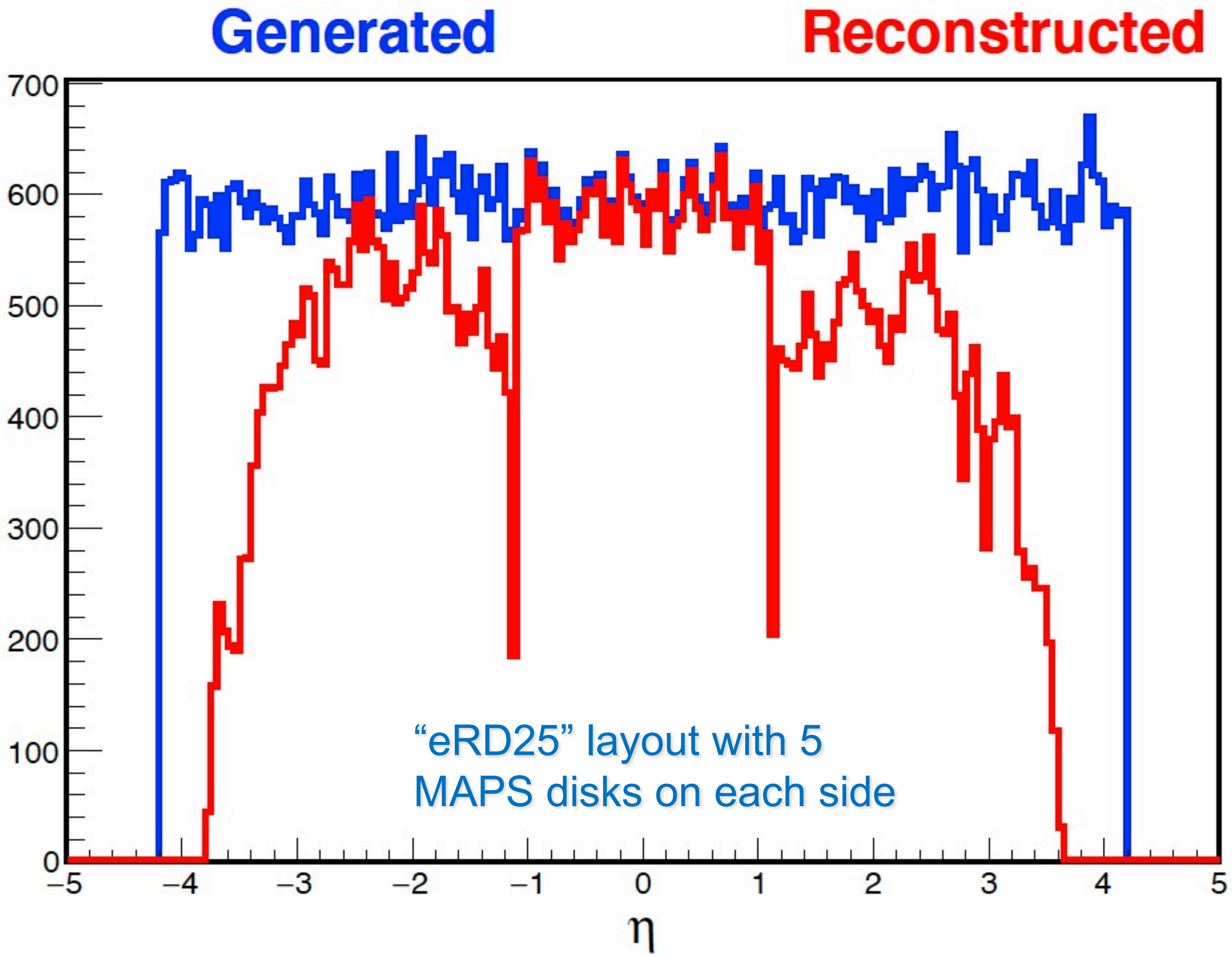
- The last layer on the electron side is AC-LGAD instead of MAPS. It has a lower position resolution but provides timing information

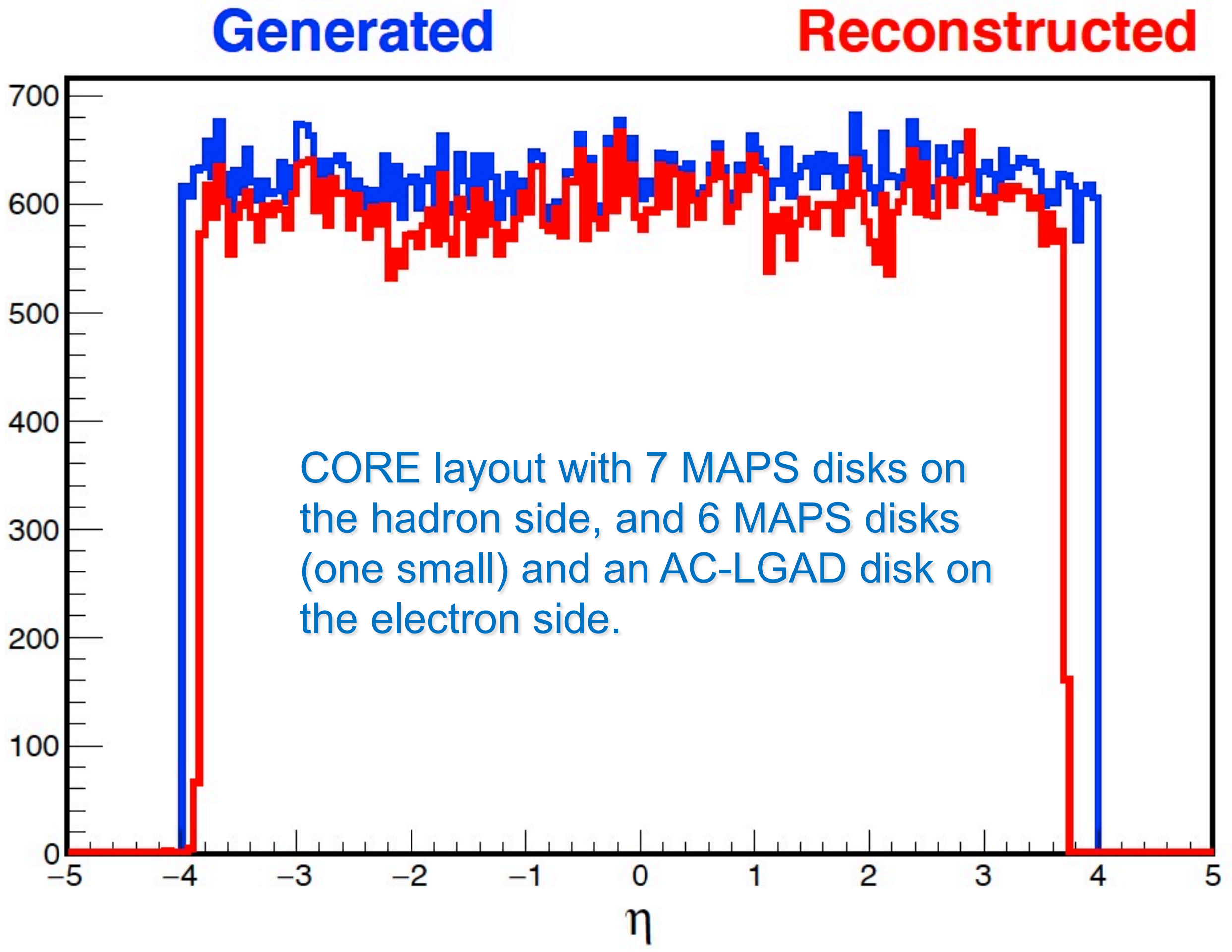


The original eRD25 Si-tracker



Si-tracker reconstruction efficiency in Fun4All

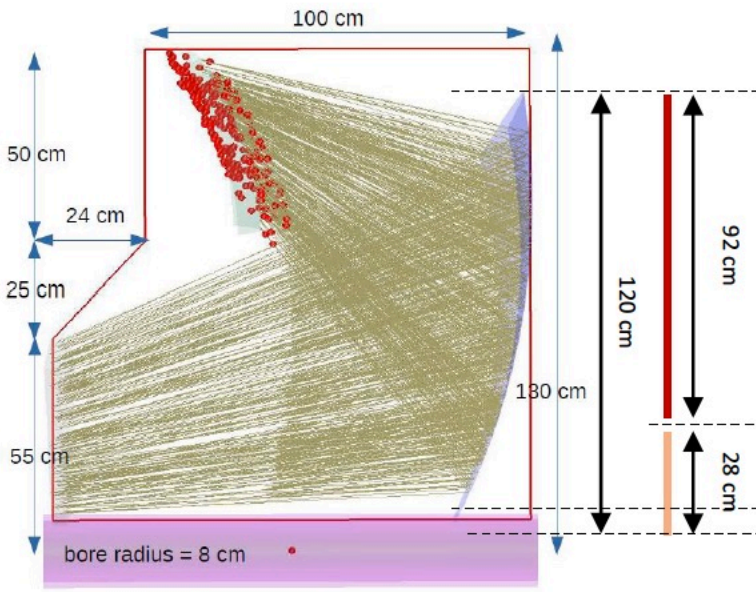


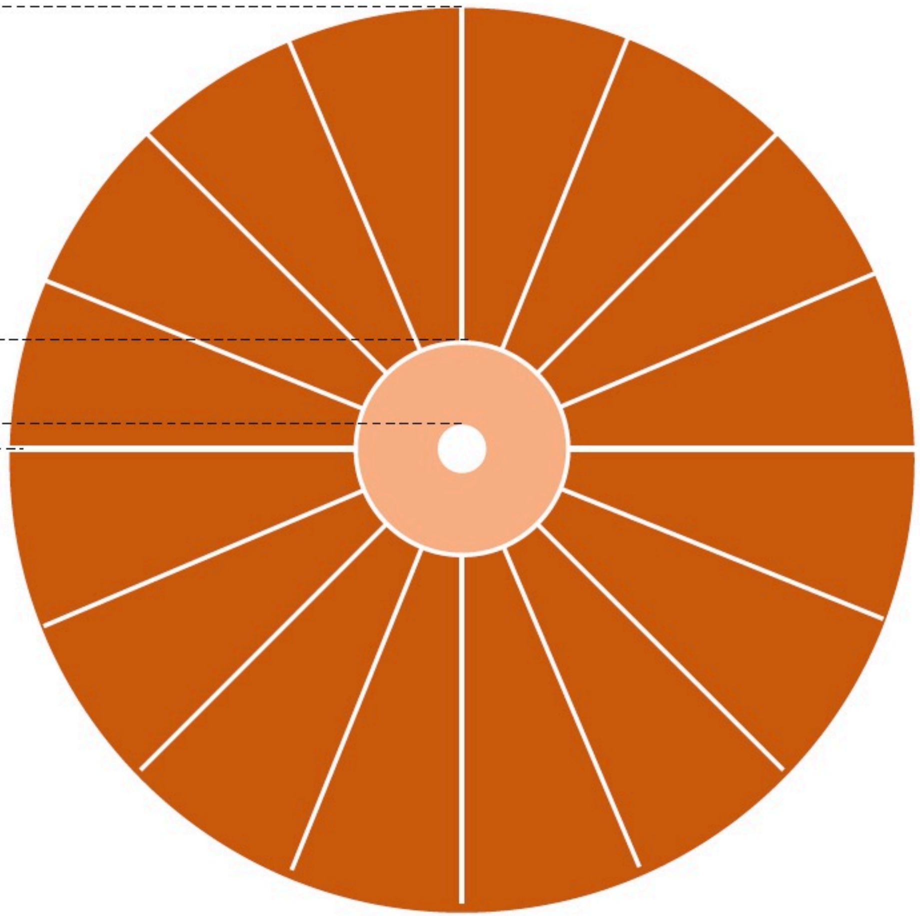


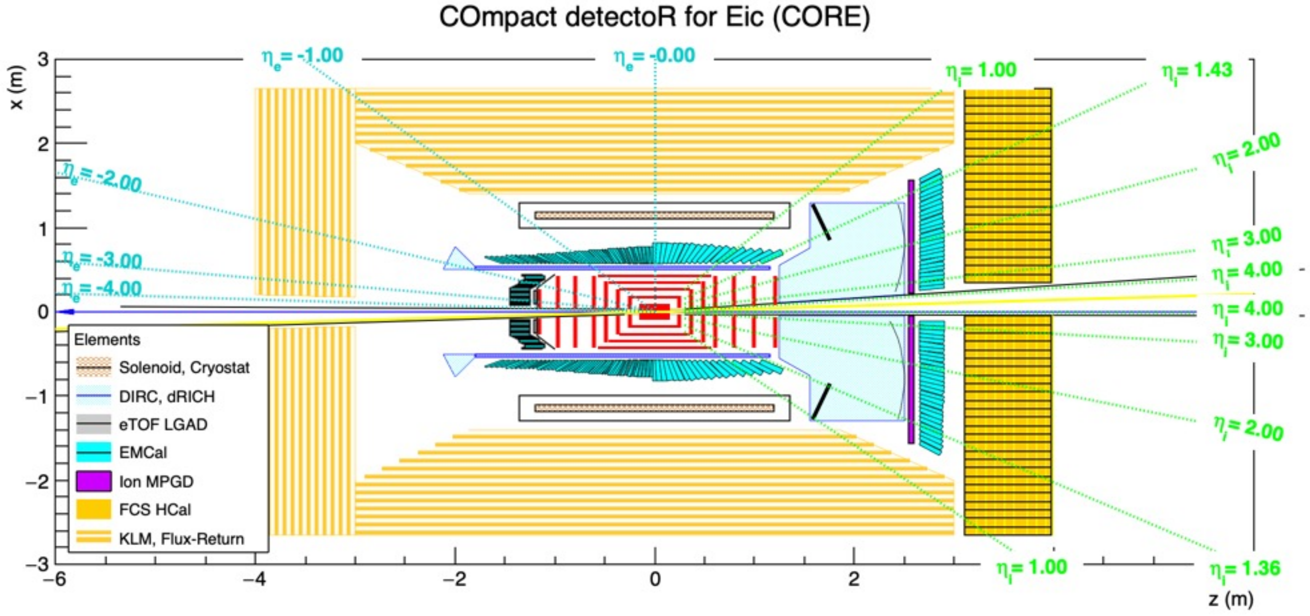
- No tweaks or optimizations were made to the track finding!

GEM

- Layout from Kondo and Marcus matches the CORE dRICH (no overlaps)



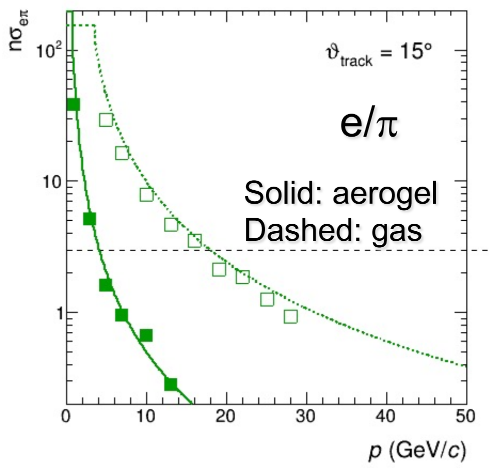


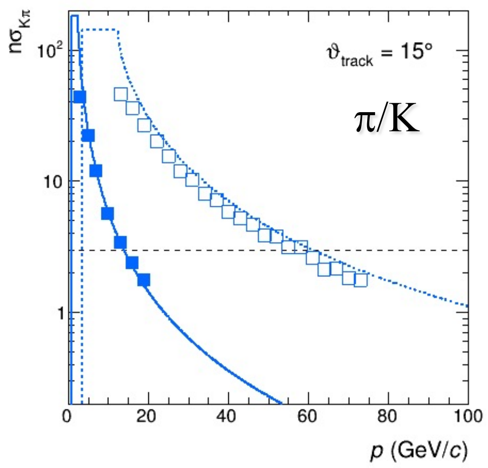


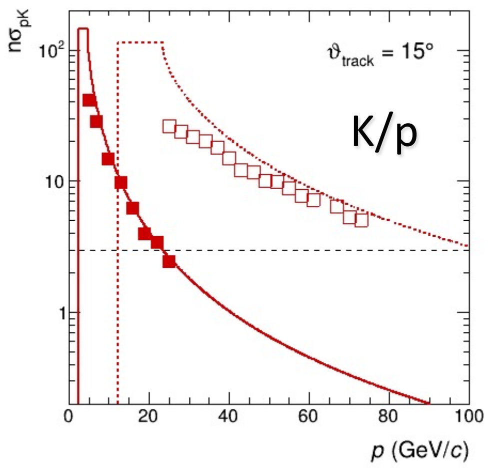
- The GEM seeds the dRICH ring finder

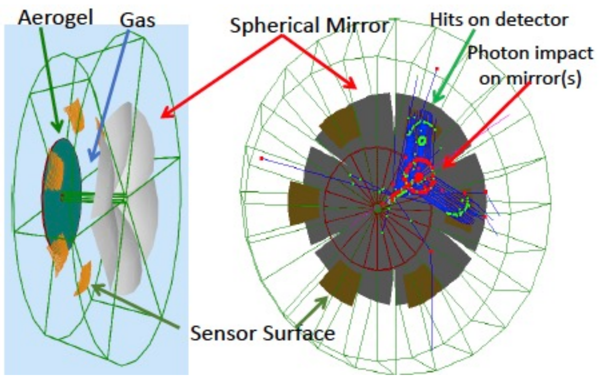
PID in the hadron endcap – dual-radiator RICH

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



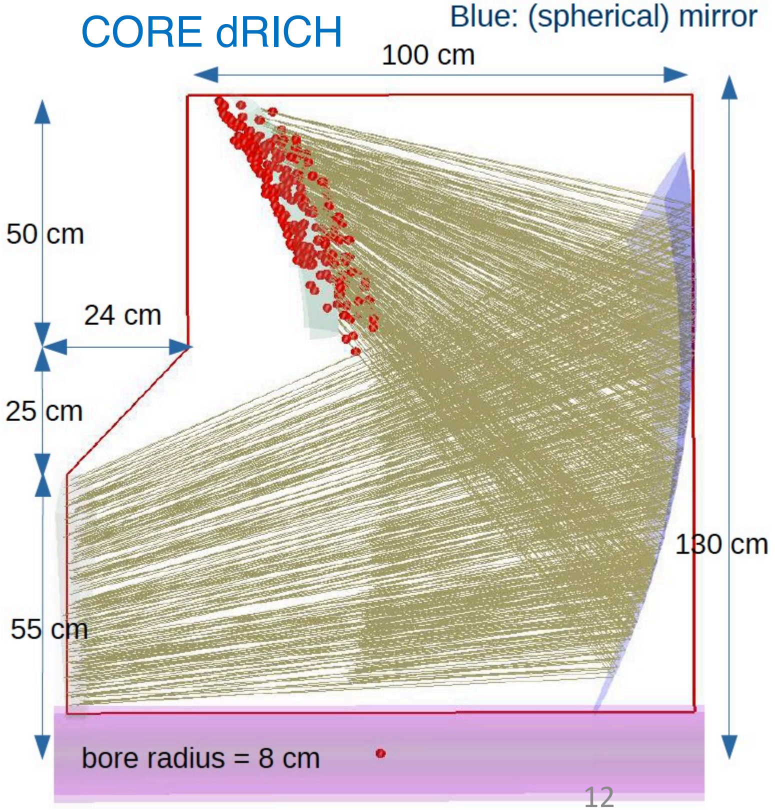






eRD14 dRICH

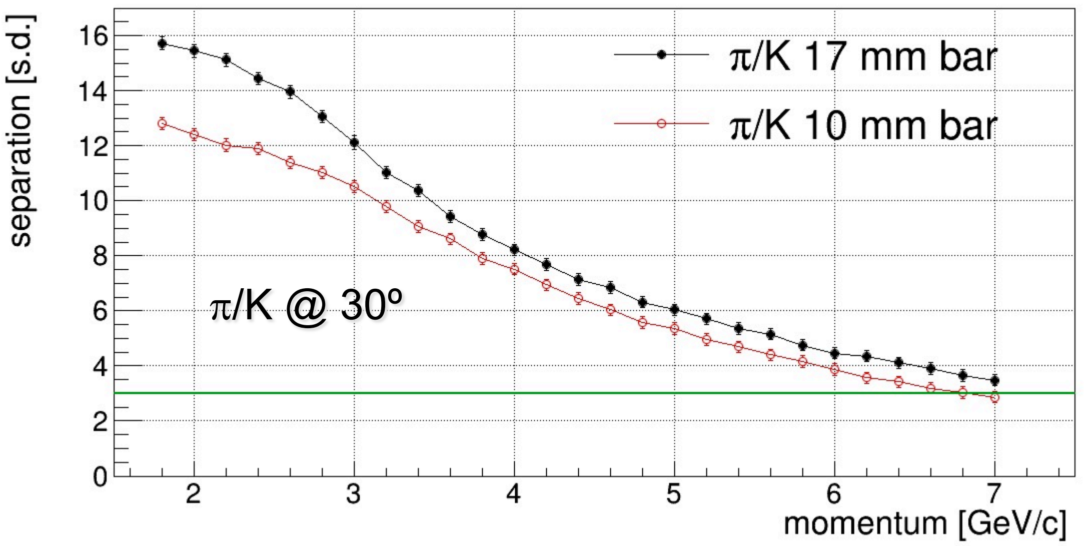
CORE dRICH

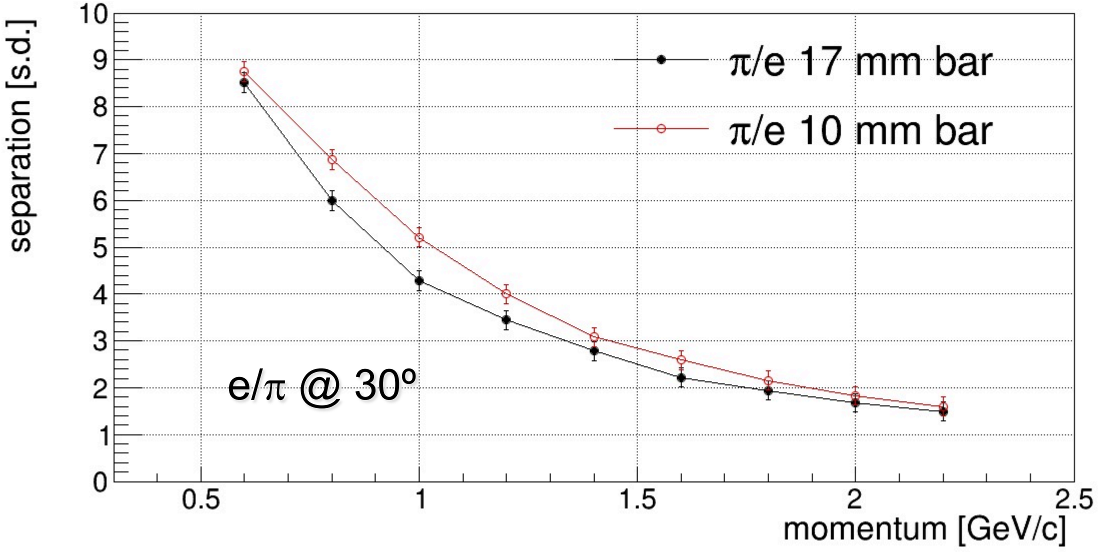


- The CORE dRICH is a scaled version of the eRD14 one
  - Good geometric match to smaller photosensor plane
  - Gas length of 1.2 m is only 25% smaller than in the original
  - 55 cm aperture (with aerogel) matches barrel EMcal

- 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)

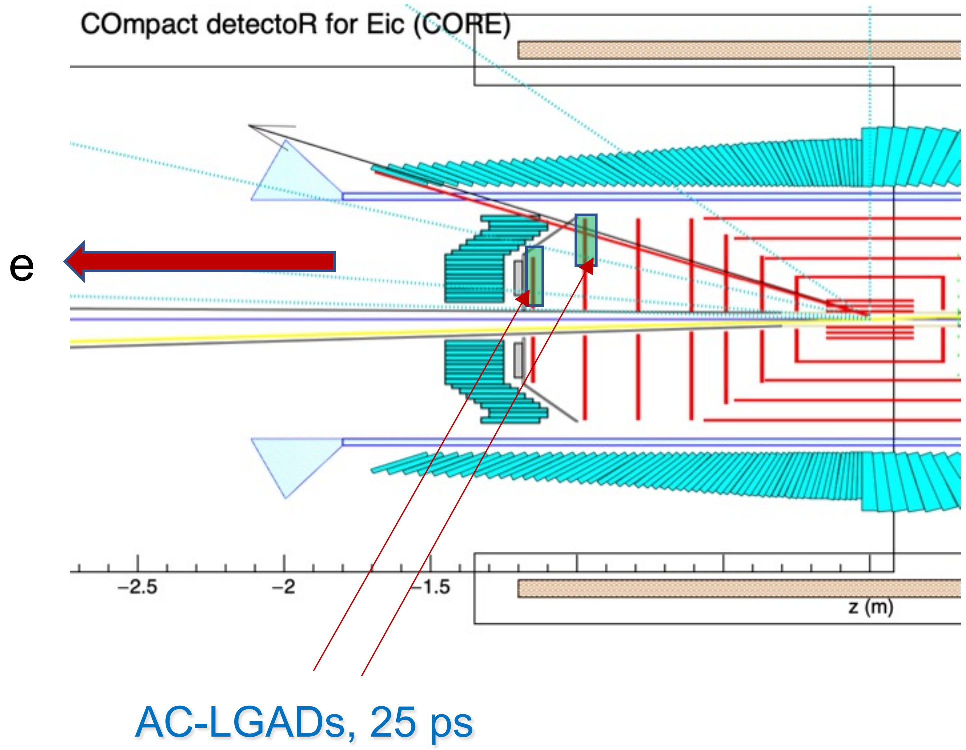
PID in the barrel – high-performance DIRC

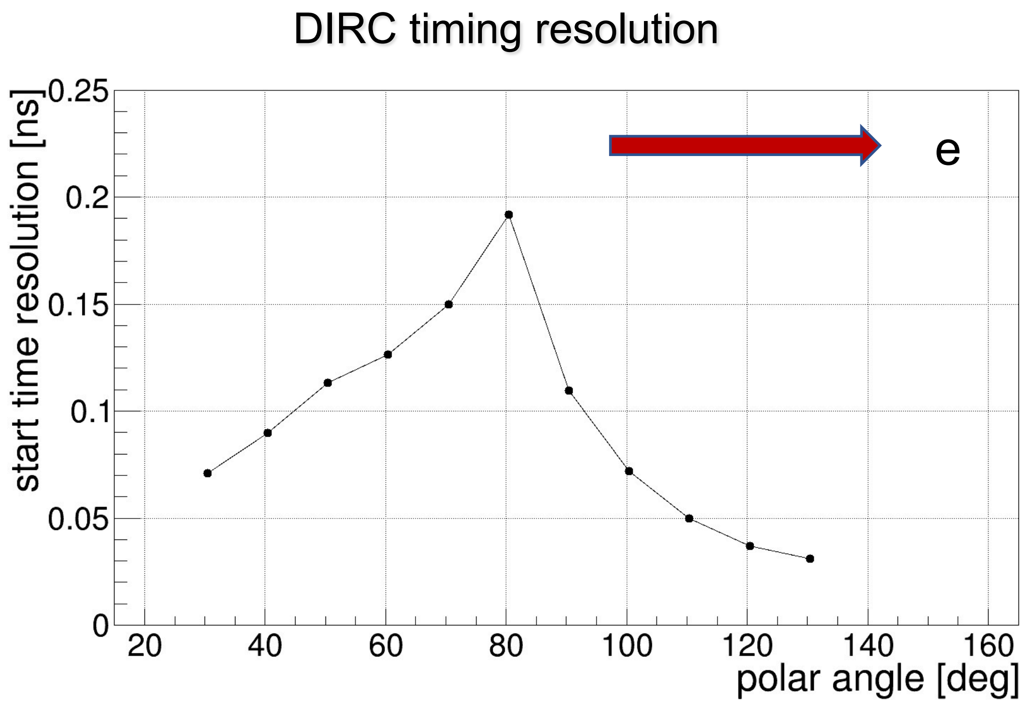




- The baseline option for CORE is re-use of the BaBar bars (17 mm).
- However, TORCH-like (10 mm) low mass bars would be an interesting option for new construction.
  - Re-use may not work or there may not be enough bars for two detectors
  - The small CORE DIRC radius makes new construction affordable
  - 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





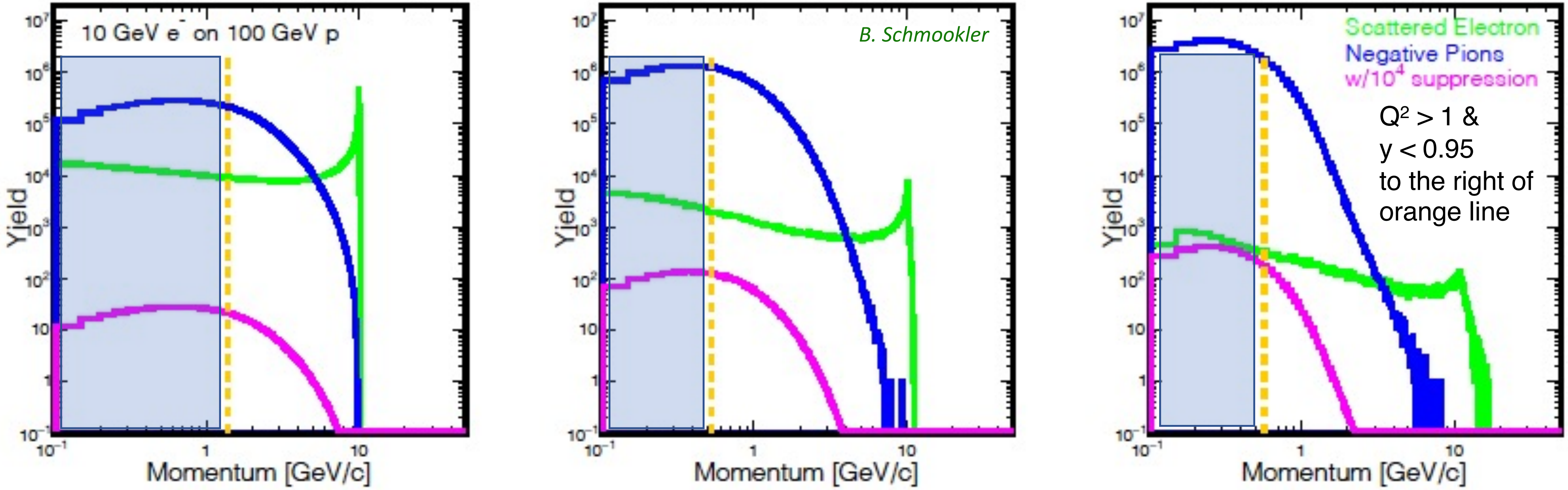
- The combination of AC-LGADs and DIRC can provide timing for the e-endcap and barrel

- For PID, t0 can be obtained by tracking the (identified) scattered electron (β=1) to the vertex (as in CLAS)

e/π identification in the electron hemisphere

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

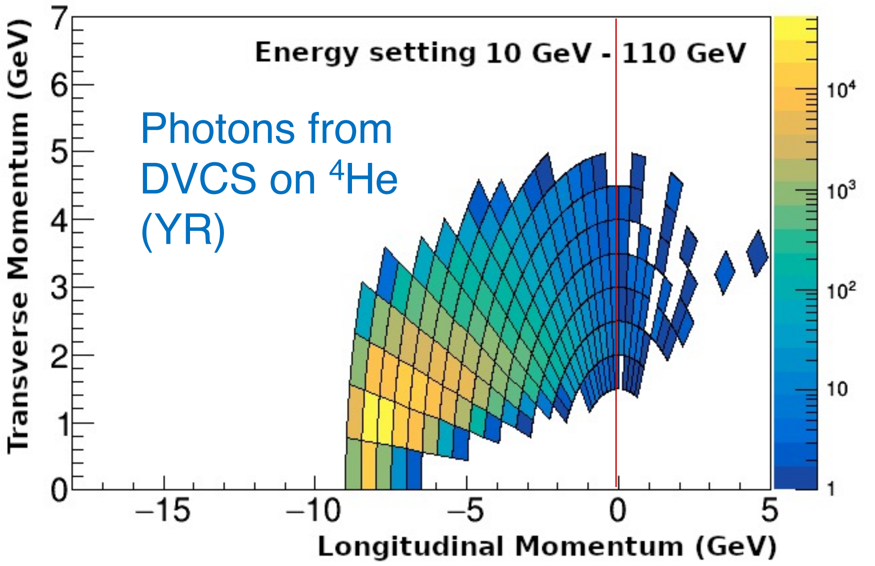
CORE endcap $-3.5 < \eta < -2.0$ $-2.0 < \eta < -1.0$ CORE barrel $-1.0 < \eta < 0.0$

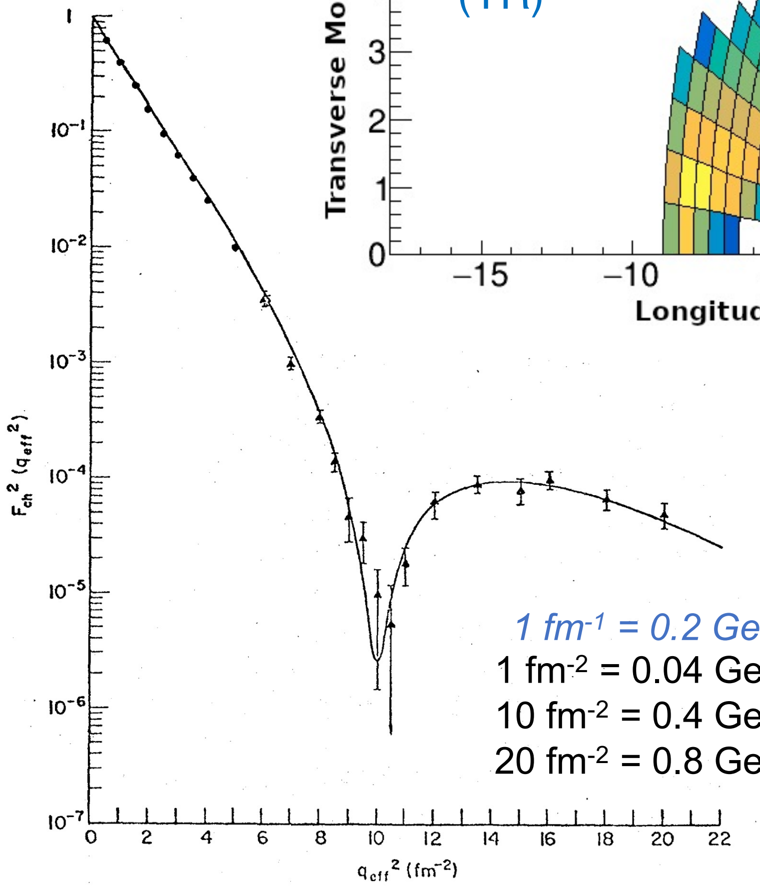


- For the EIC, a clean identification of the scattered electron is essential.
- The barrel region poses the greatest challenge and requires the best electron ID.
- CORE addresses this issue by extending the PWO EMcal coverage up to $\eta < 0$ (or possibly -0.5)
- Additional low-momentum e/π suppression is provided by the DIRC.

Synergies between central and forward detection: exclusive coherent scattering on nuclei

^{4}He

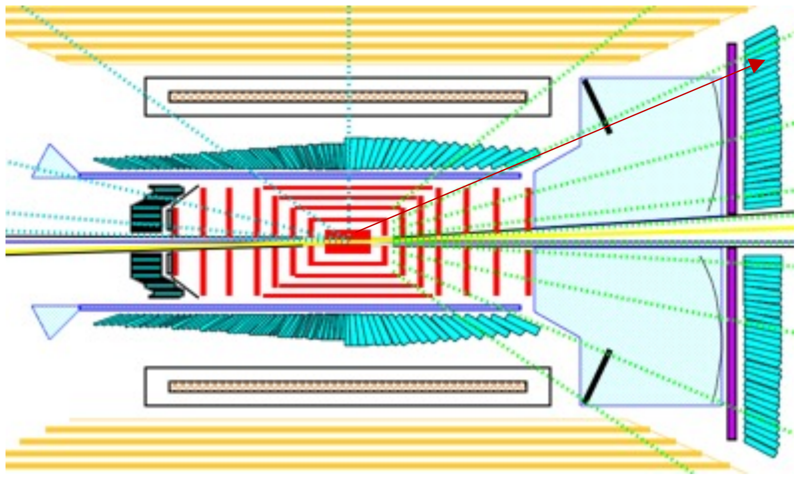


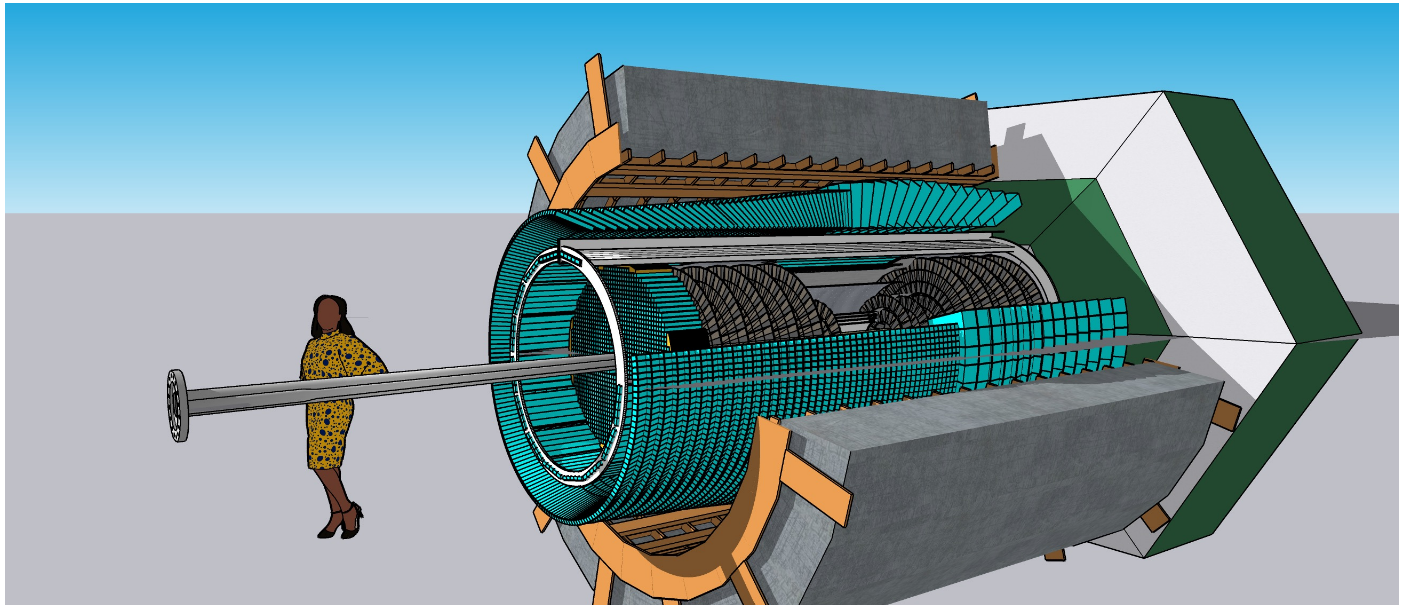


1 fm^{-1} = 0.2 GeV
1 fm^{-2} = 0.04 GeV^2
10 fm^{-2} = 0.4 GeV^2
20 fm^{-2} = 0.8 GeV^2

- An IR with a second focus (IR8) offers exceptional acceptance for protons, light ions, and ion fragments.
- To take full advantage of this, the central detector should be able to reconstruct the transverse momentum distribution with comparable resolution for production of charged mesons and DVCS photons.
  - Helpful for protons – essential for ions.
  - No sensitivity to “beam effects.”
  - Would also be useful at IP6
- The ability to ”mix” recoil detection and veto of breakup can greatly extend the x- and A-range for coherent processes on light nuclei .

4π EM calorimetry





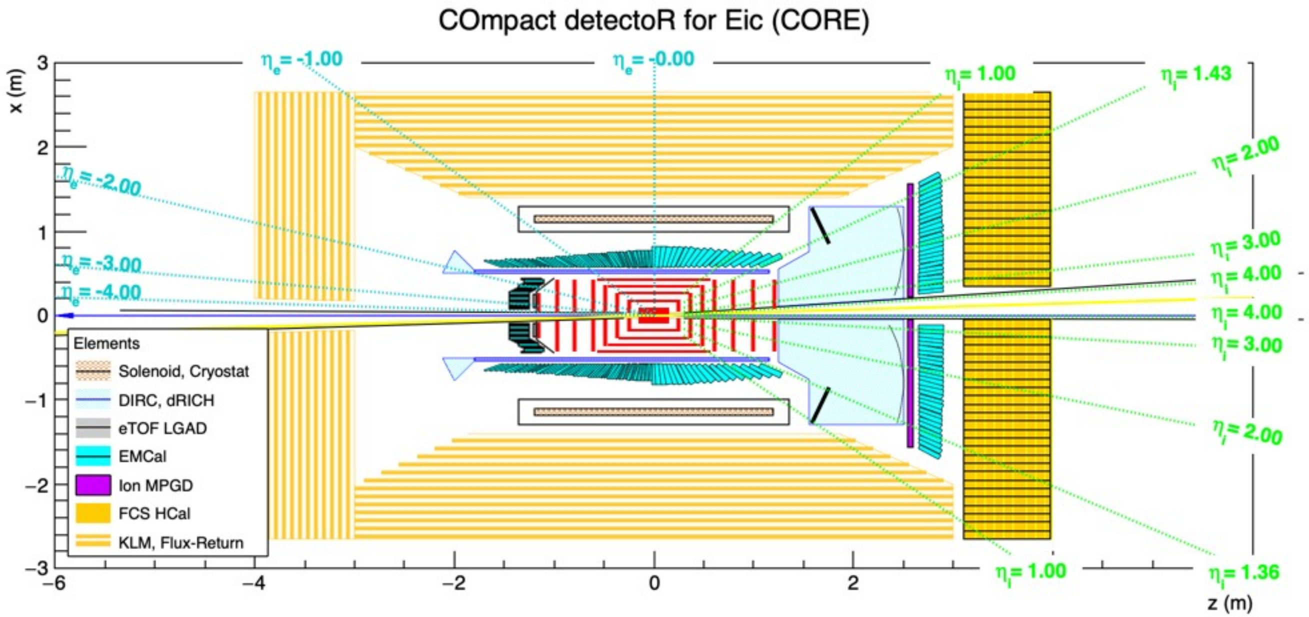
Electron hemisphere ($\eta < 0$)

- 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

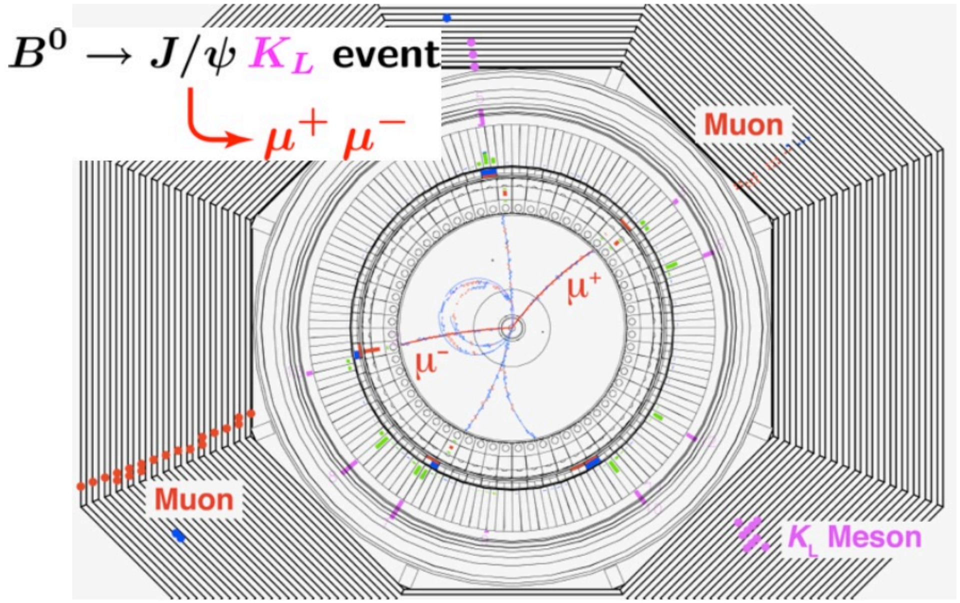
Hadron hemisphere ($\eta > 0$)

- 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

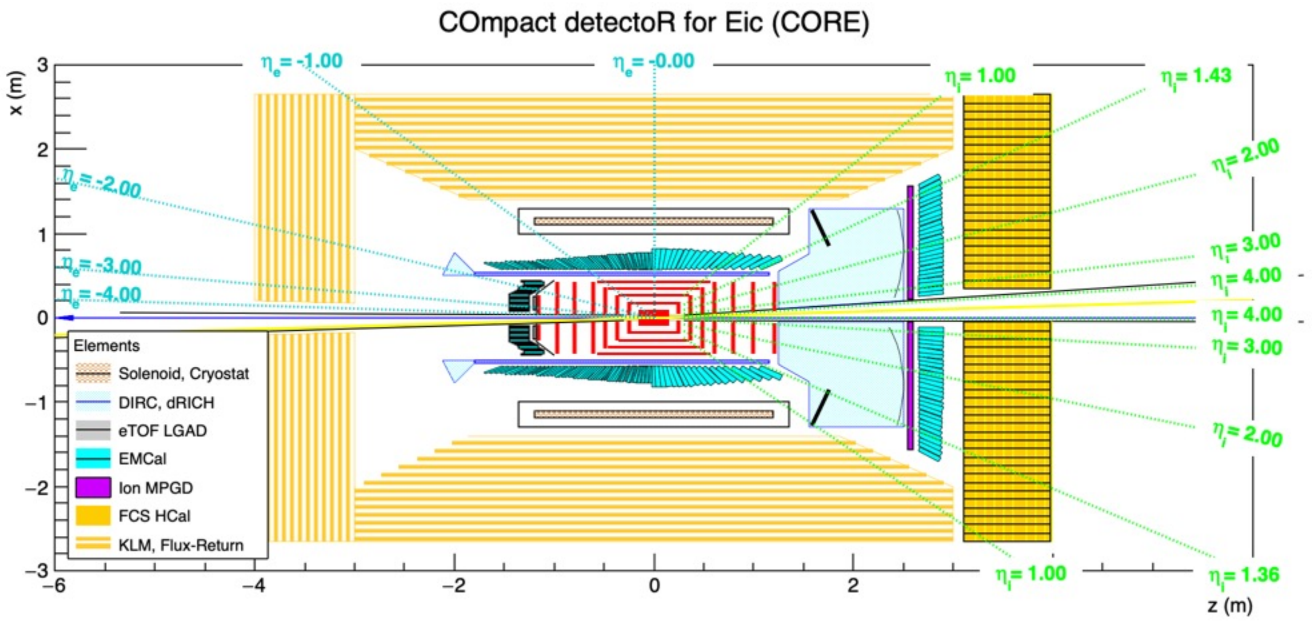


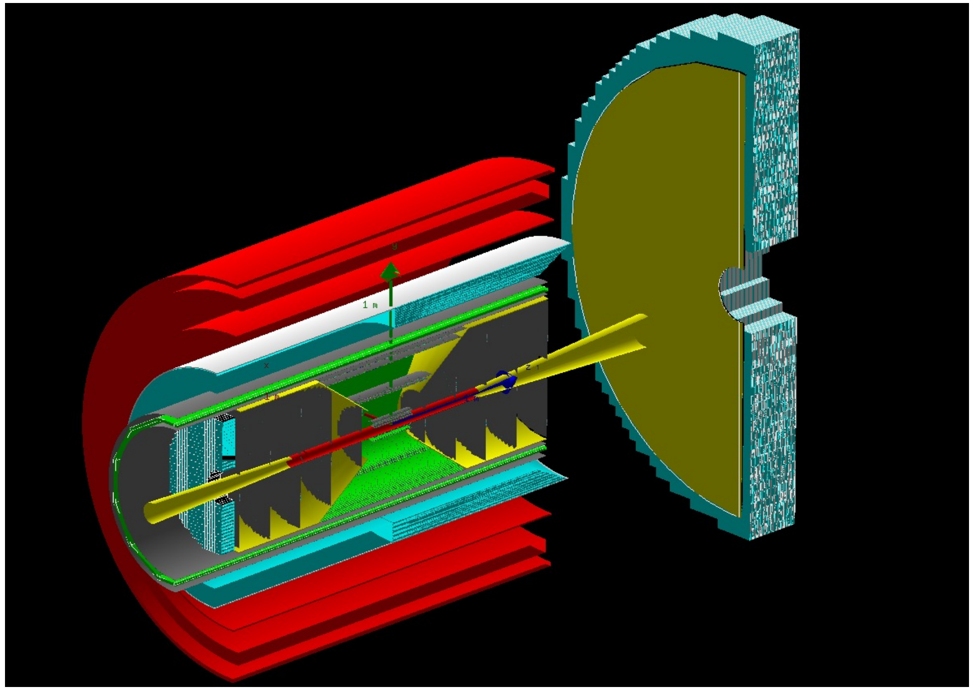
The Belle II K_L-μ (KLM) system



- 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

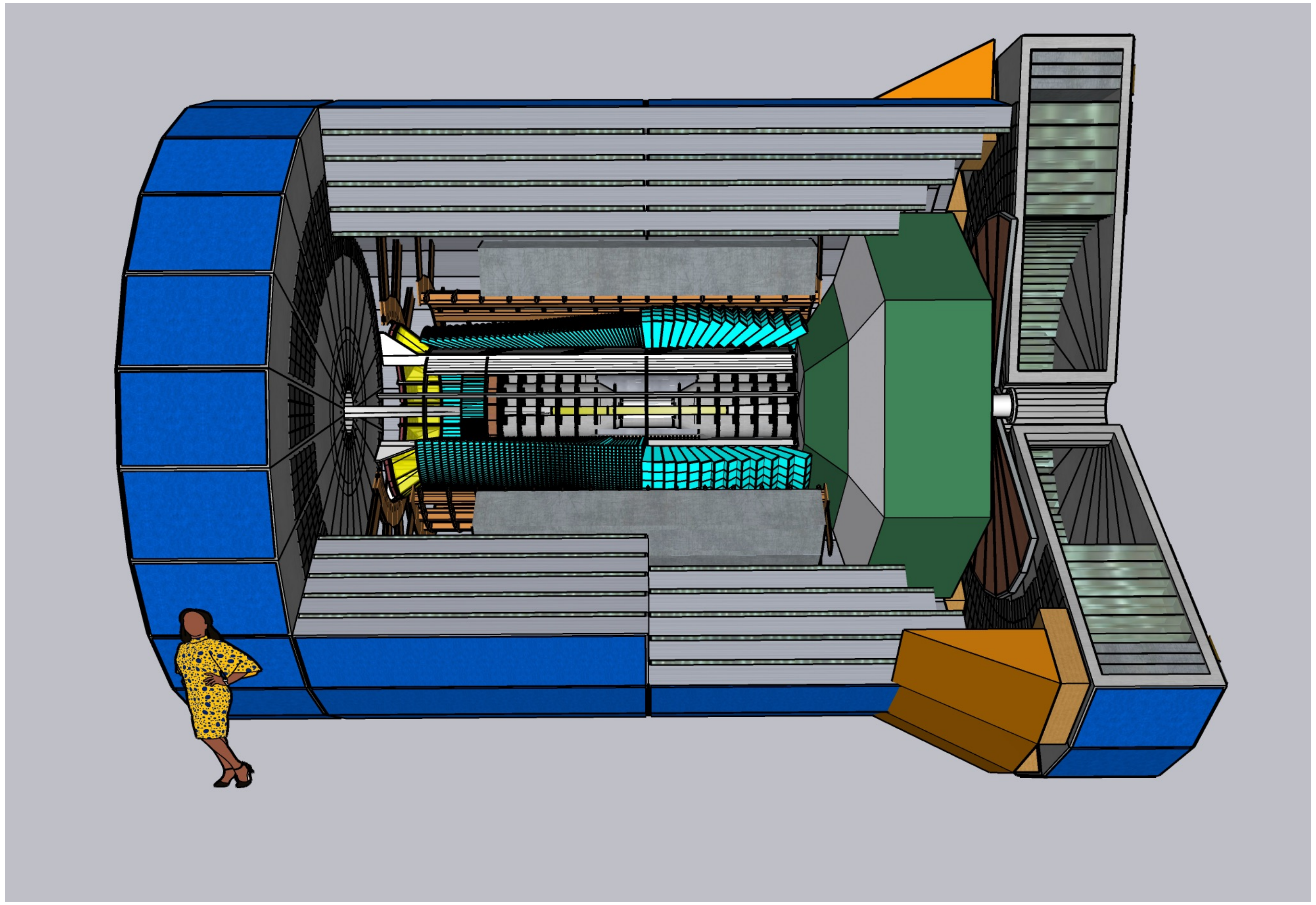
CORE systems summary





- 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!



CORE - a COmpact detectoR for the EIC

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