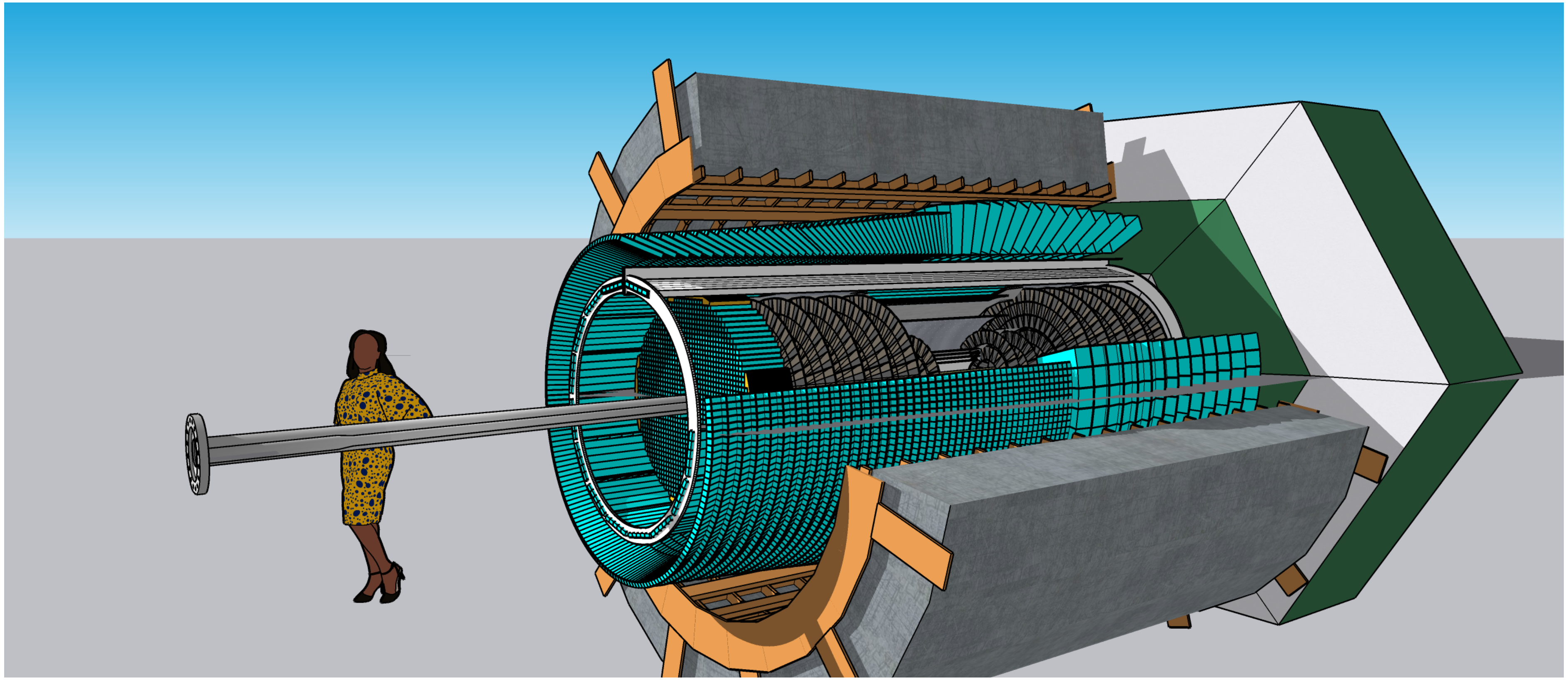
CORE: a COmpact detectoR for the EIC

EIC user meeting, August 2-7, 2021



Pawel Nadel-Turonski
Stony Brook University

Charles Hyde
Old Dominion University

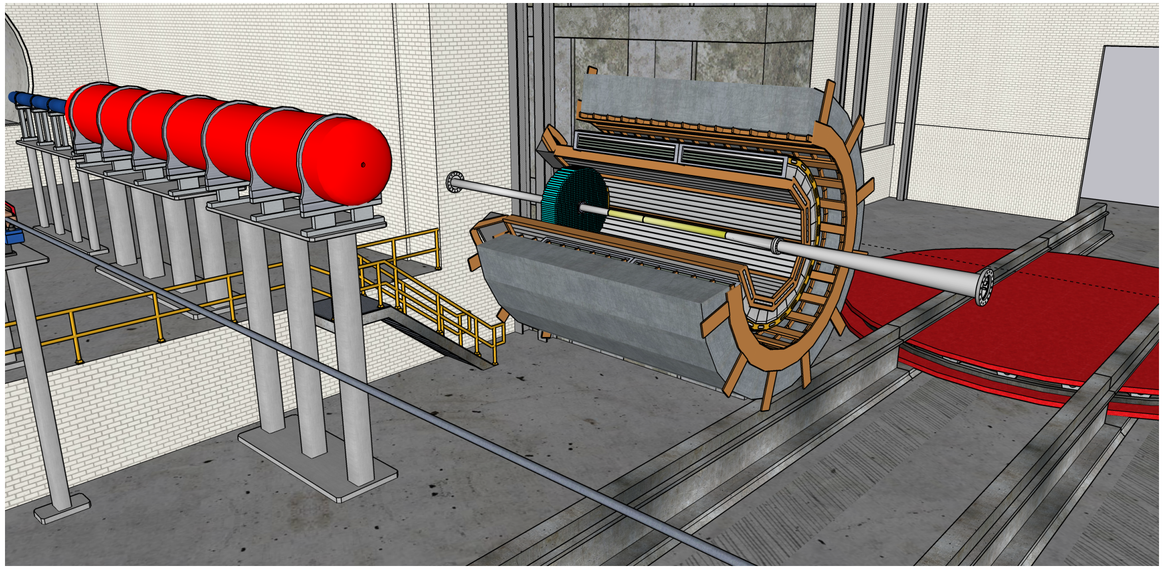
for the CORE pre-collaboration
(open to all users)

CORE proto-collaboration

https://eic.jlab.org/core

- Catholic University of America (CUA)
- Duke University (Duke)
- GSI Helmholtz Centre for Heavy Ion Research, Germany
- Erlangen-Nuremberg University, Germany (GAU)
- Hampton University (HU)
- Indiana University (IU)
- Jefferson Lab (JLab)
- Kansas University (KU)
- Oak Ridge National Lab (ORNL)
- Old Dominion University (ODU)
- Penn State University (PSU)
- Stony Brook University (SBU)
- University of the Basque Country (UPV/EHU), Spain
- University of Connecticut (UConn)
- University of Hawaii (UH)
- University of South Carolina (USC)
- University of York, U.K.

All are welcome!



CORE in IR8

Requirements for an EIC detector

- **We need a general-purpose detector that can carry out the EIC physics program outlined in the Yellow Report, White Paper, and other documents.**
- **We also need a detector that can support the actual program in the 2030's, which often ends up having a somewhat different emphasis than originally anticipated, and create opportunities for new discoveries.**
- The future is notoriously difficult to predict, but new insights are often gained at the intersection of accelerator and detector capabilities.
- Thus, it is worth recalling the unique features of the Electron-Ion Collider
    - an ability to scatter electrons off (almost) any nucleus
    - a high degree of polarization for protons and light nuclei
    - a potential for an extraordinary acceptance for forward protons, ions, and fragments

Suggestive of future opportunities

CORE capabilities

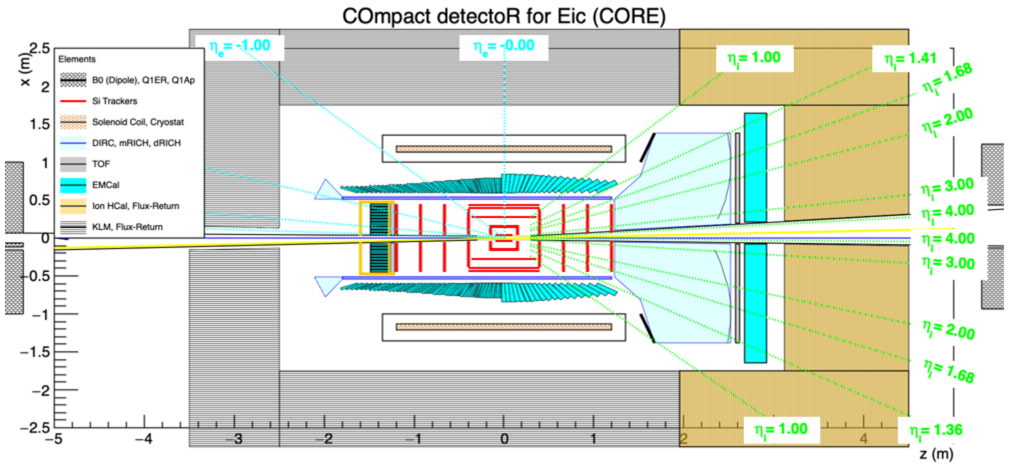
CORE is a hermetic high-performance, general-purpose detector capable of realizing the full EIC physics program.

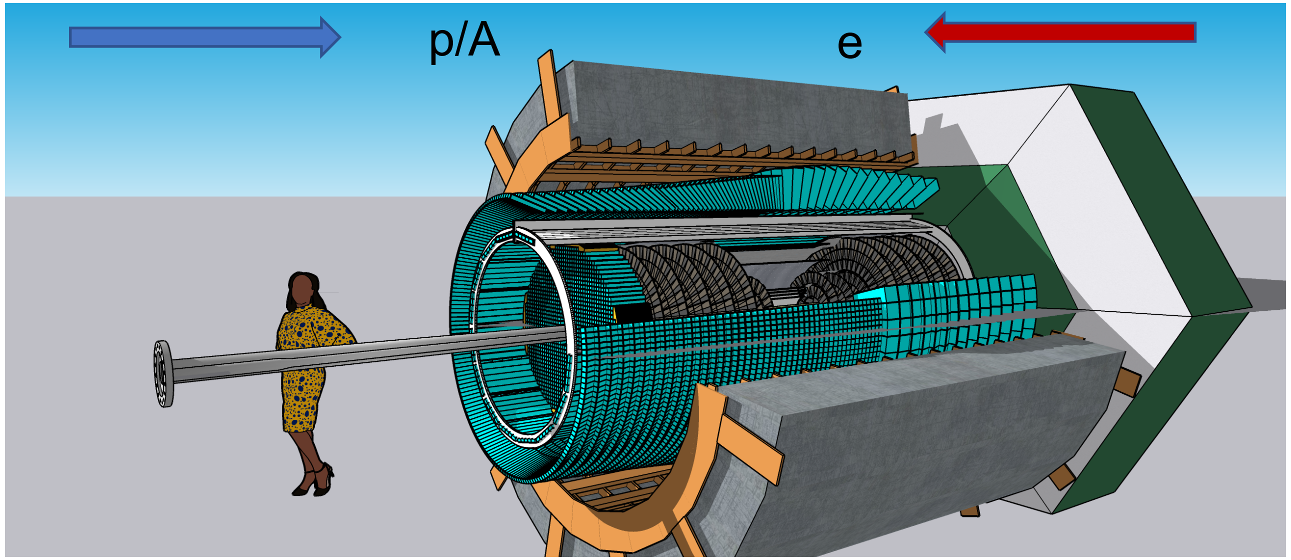
CORE is compatible with either IR, but is particularly synergetic with an IR that incorporates a 2nd focus to optimize far-forward acceptance for protons, light ions, and ion fragments (IR8).

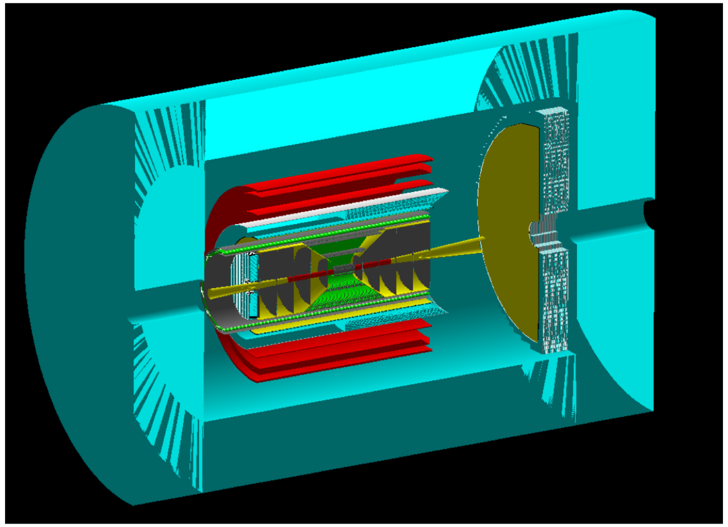
In addition, the CORE design emphasizes several key areas

- Shorter length maximizes forward acceptance and luminosity across *all* c.m. energies.
- Excellent identification of the scattered electron
- High-resolution reconstruction of the p_T using the central detector in both meson production *and* deeply virtual Compton scattering (DVCS)
  - essential for nuclei

CORE overview

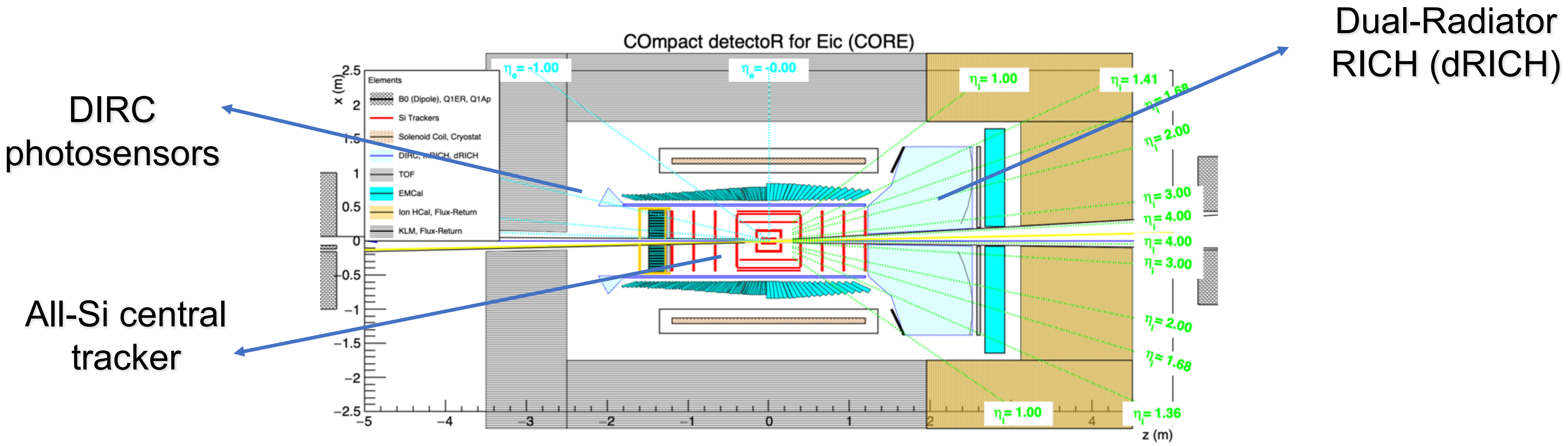






- The compact size makes CORE an affordable high-performance detector, and allows investment in key technologies
- Takes full advantage of integration with IR8
- Low technical risk
  - Makes use of technologies from the EIC R&D program (2011-2021)
  - All critical components are well understood

A shorter solenoid



- The 2.5 m long CORE solenoid reduces the overall detector length while
  - optimizing the space for the dual-radiator RICH (dRICH)
  - allowing for a quick transition from a high field in the tracker to a low field in the dRICH and on the DIRC photosensors

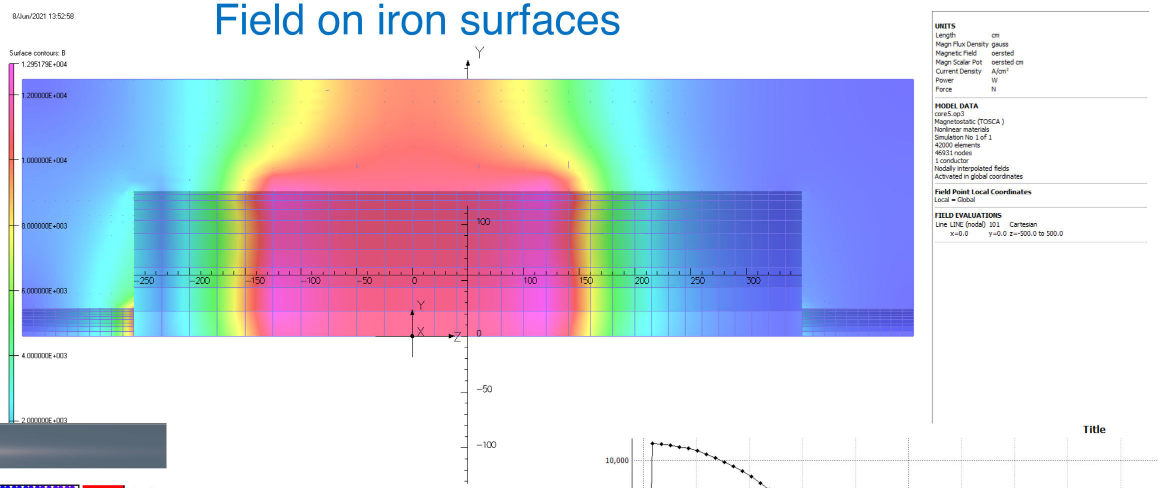
- A compact, high-resolution central Si-tracker is a natural choice for the small 3 T solenoid

CORE magnetic field

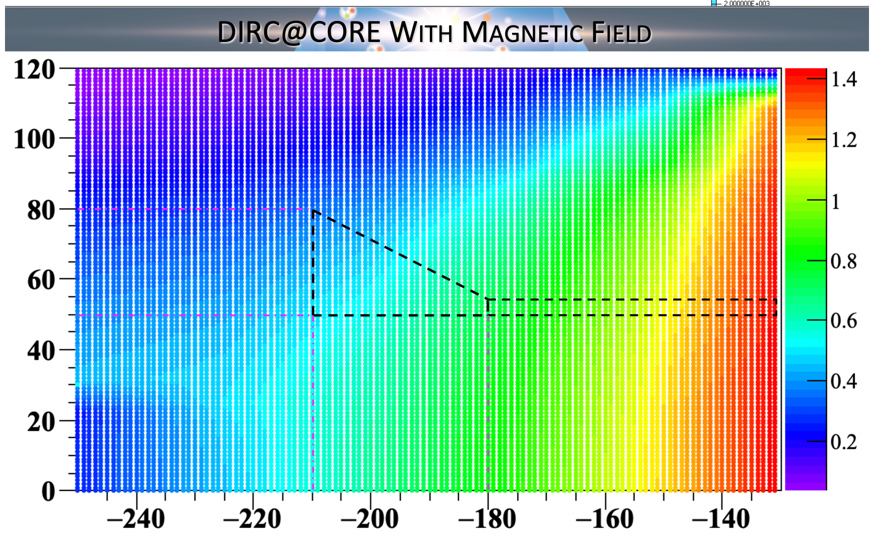
- A very low field on the DIRC photosensors and excellent projectivity in the dRICH suggests lots of headroom in the design even at 3 T central field.

Paul Brindza

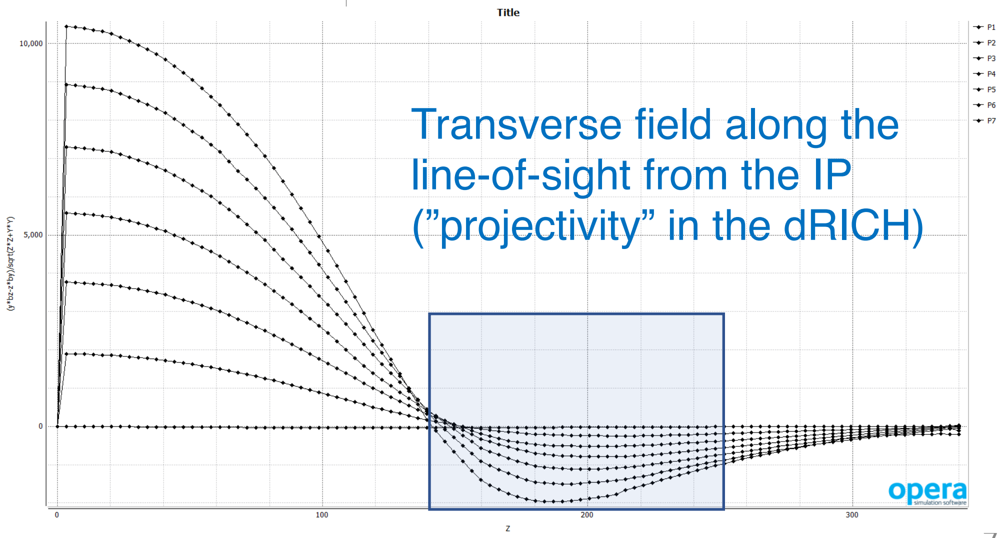
Field on iron surfaces



Field on DIRC photosensors < 0.5 T



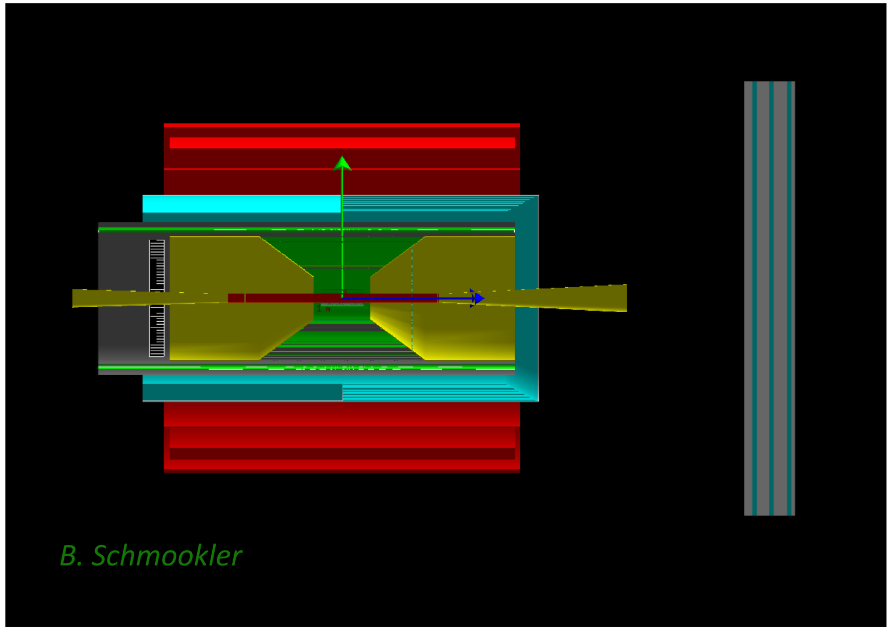
2.6 T central field shown



Transverse field along the line-of-sight from the IP ("projectivity" in the dRICH)

CORE solenoid

- Coil: 2.5 m long
- Cryostat: 1 m inner radius, 2.8 m long
- Magnetic field at IP: 3 T (baseline)
- Note: with a magnetic volume of only 7.8 m^3, any field in the 2 - 4 T range would be affordable, but 2.5 - 3 T seems to offer the best balance between cost and performance.



- A 1 m inner radius leaves 50 cm between the DIRC and solenoid

cost (2020 M$) = 1.8 x 0.458 x (stored energy)$^{0.7}$

M. A. Green and S. J. St. Lorant, Adv. Cryo. Eng. **39**

solenoid	field (T)	volume (m^3)	2020 cost (M$)
Large 3T	3	29	21
CORE	**3**	**7.8**	**8.5**
CORE	2.5	7.8	6.6
CORE	2	7.8	4.8

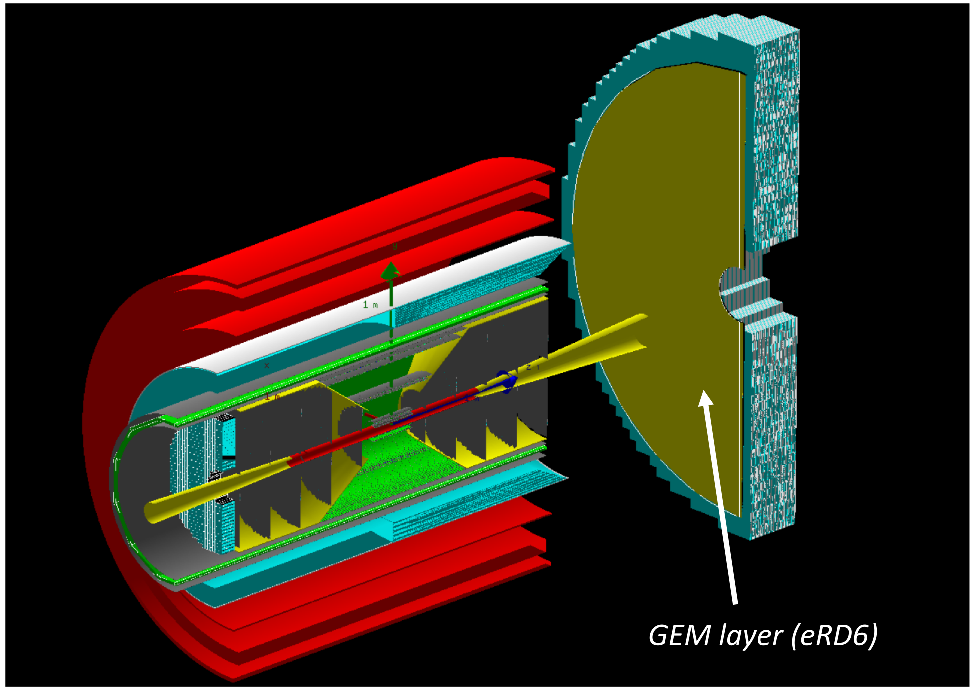
- The smaller radii of the tracker, DIRC, and barrel EMcal make it possible to take full advantage of a high magnetic field while minimizing the penalty in low-p_T acceptance.
  - To extend the low-p_T acceptance even further, the magnet can be operated below maximum field.

Central Si-tracker and h-endcap GEM

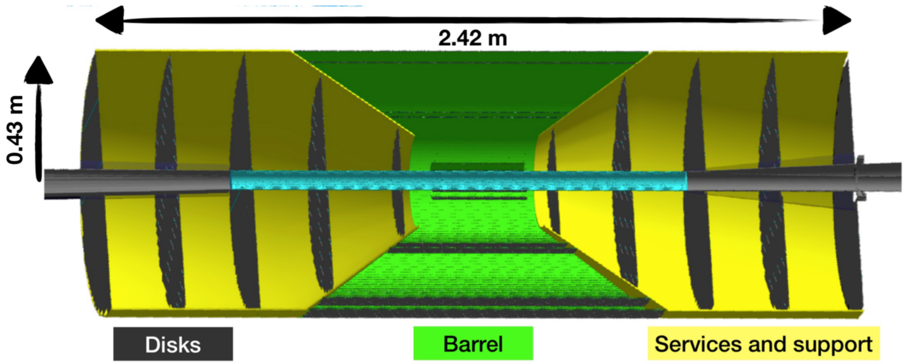
- The Si-tracker developed by the Silicon Consortium (eRD25) is a good geometric match for CORE, and an excellent staring point for simulations.
  - L: 2.4 m, D: 0.9 m
  - ALICE ITS3 technology allows for a low mass, air cooling, and a very efficient vertex tracker geometry

- The main modification for CORE would be an optimization for high-energy K_S decays.
  - *E.g.*, three separated cylindrical layers in the outer 1/3 of the barrel at mid-rapidity
  - Also beneficial for incident angle on the DIRC?

- A GEM behind the dRICH provides additional tracking
  - Helps with reconstruction in the dRICH

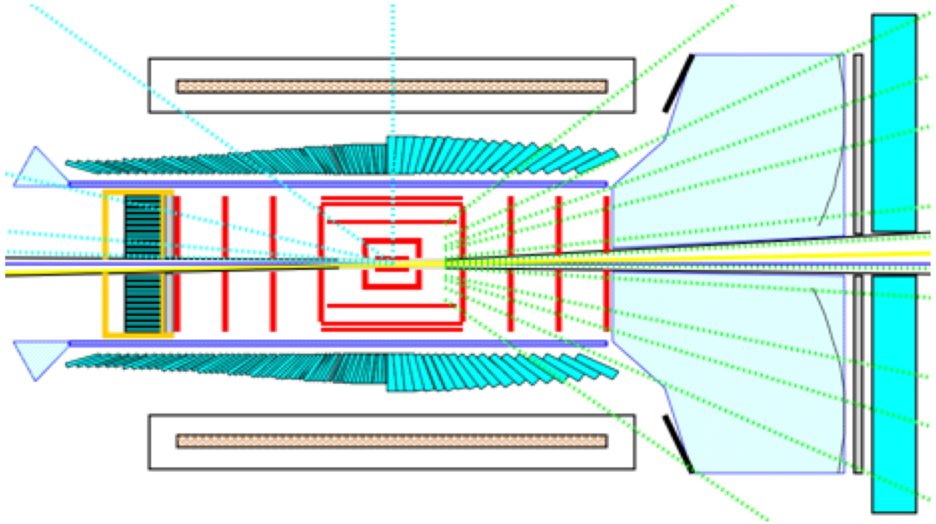


eRD25 Si-tracker



Kaon ID – complementarity between charged and neutral kaons

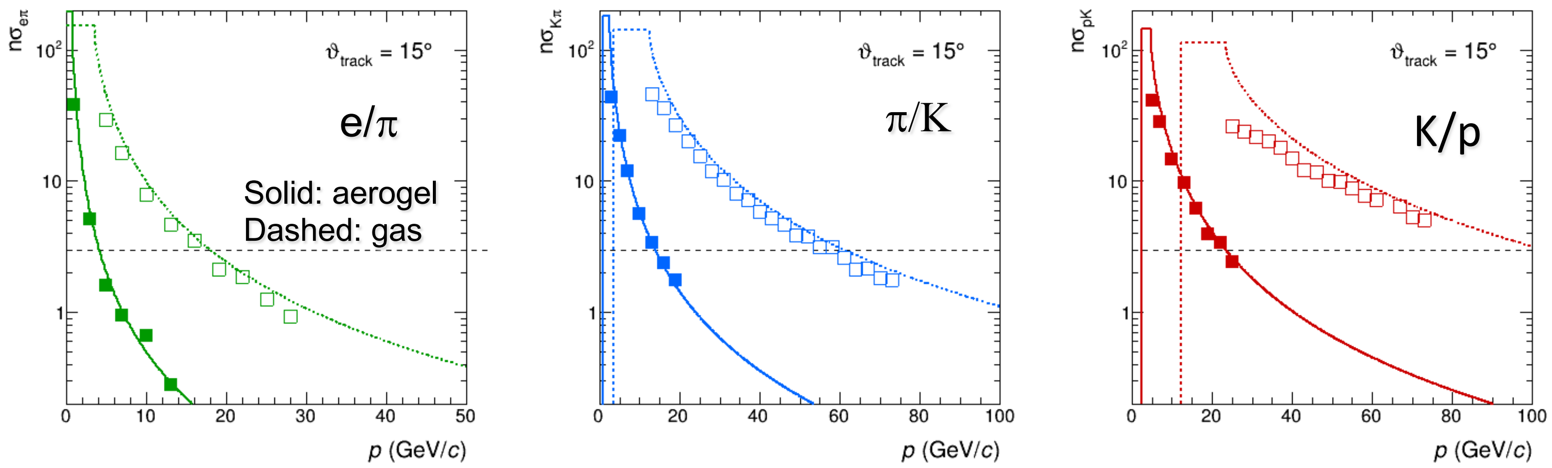
In the endcaps, 18 GeV/c K_S can be reconstructed with high efficiency.

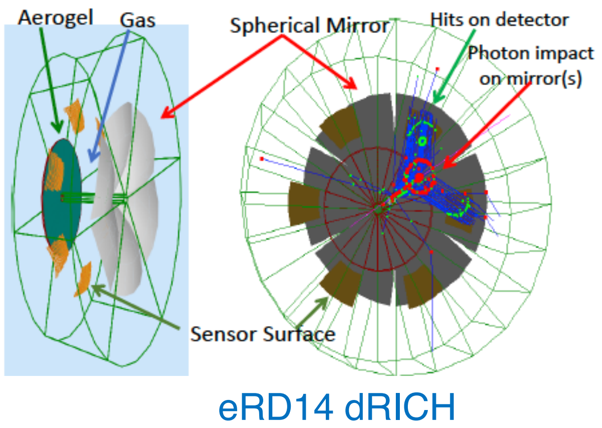


- $K_S \rightarrow \pi^+\pi^-$ decays ($c\tau$ = 2.68 cm) can be measured in the tracker.
  - Since the decays are statistical, K_S with *any* momentum can be measured, but the *efficiency* will drop at higher momenta. The *purity* will be unaffected.
  - p/π^+ ID will enhance separation of $K_S \rightarrow \pi^+\pi^-$ from $\Lambda \rightarrow p\pi^-$.
- Charged kaons ($K^{+/-}$) are identified in the PID systems (dRICH, DIRC, TOF)
  - The reconstruction *efficiency* is high, but the separation power (*purity*) drops with momentum.

PID in the hadron endcap – dual-radiator RICH

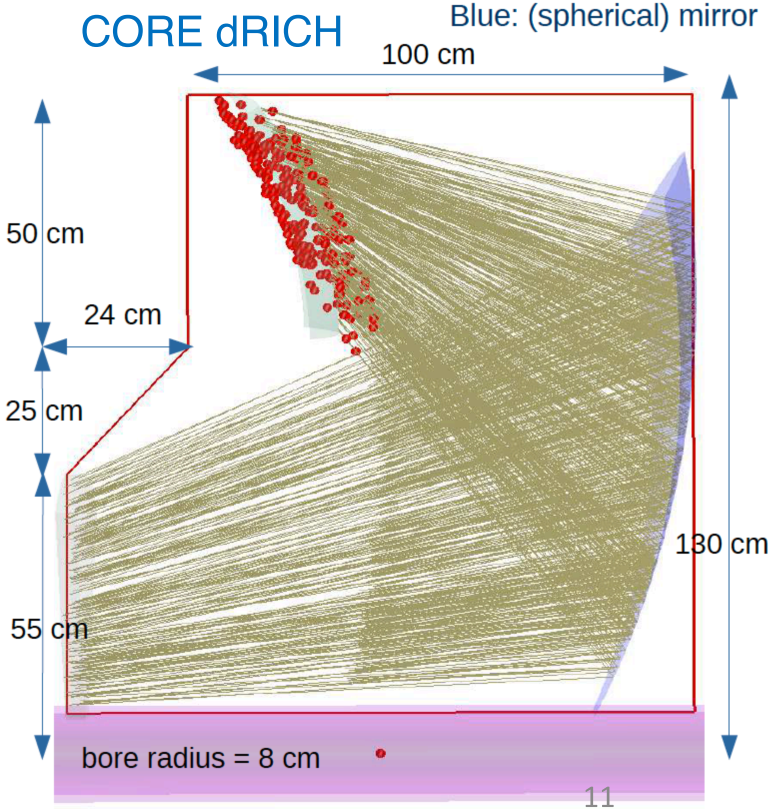
Performance of the dRICH developed by the EIC PID consortium (eRD14)





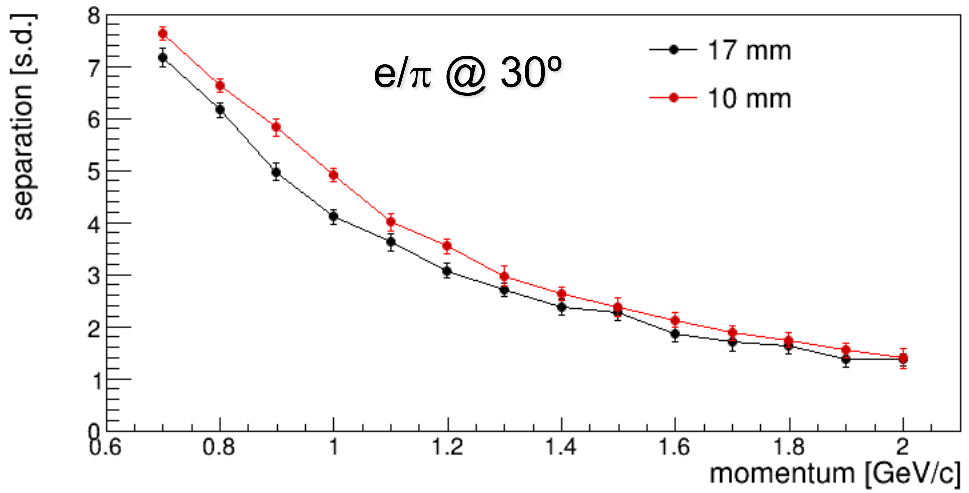
- The CORE dRICH is a scaled version of the eRD14 one
  - Good geometric match to smaller photosensor plane
  - Gas length of 1.2 m is only 25% smaller than in the original
  - 55 cm aperture (with aerogel) matches barrel EMcal

- 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)

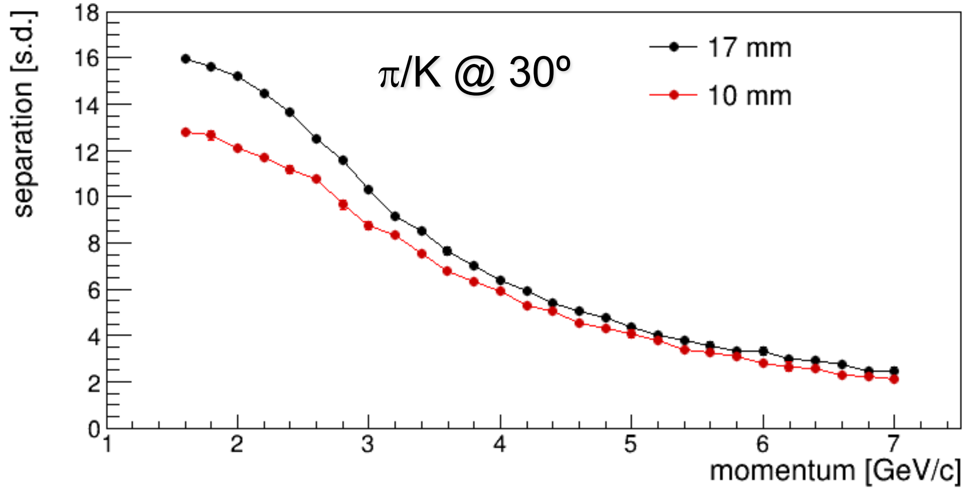


PID in the barrel – low-mass (thin) DIRC

Talk by G. Kalicy



conservative estimates shown

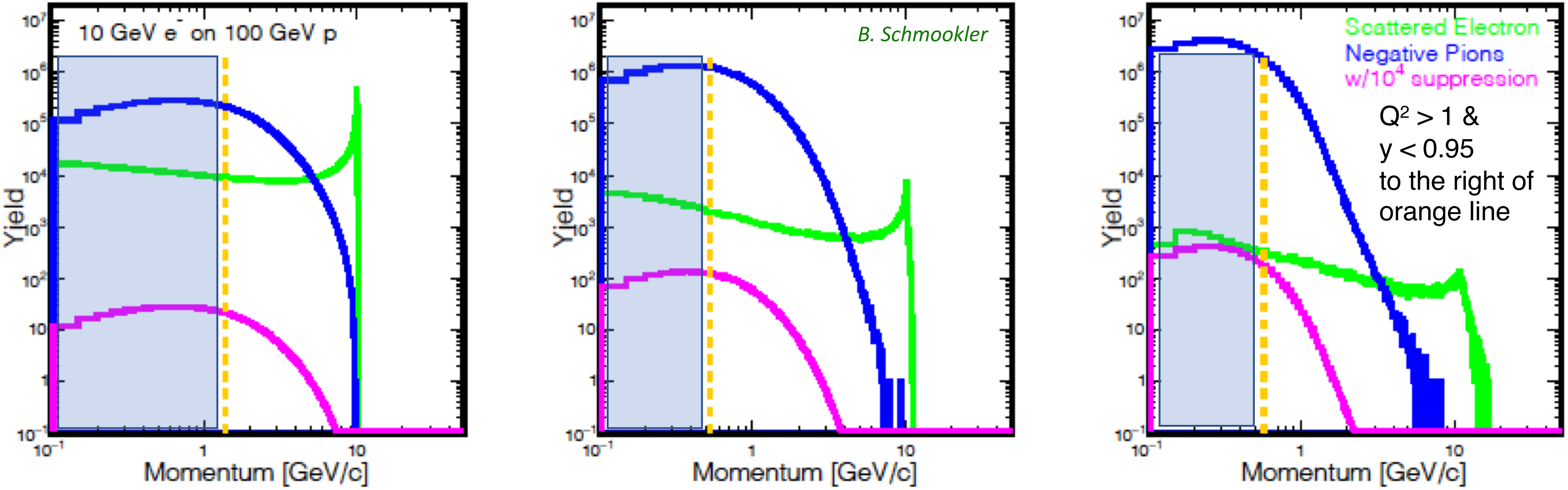


- While CORE is compatible with a re-use of the BaBar bars, the baseline is to make new ones
  - Performance can be optimized
  - A small radius makes new bars affordable
  - There may not be enough bars for two detectors
- A low-mass DIRC has several advantages
  - 40% reduction in mass benefits the EMcal
  - e/π ID around 1 GeV/c range is improved, without significantly affecting π/K ID above 4 GeV/c
  - The lower weight allows for simpler supports
- General DIRC features are retained
  - π/K separation can be extended down to 0.2 GeV/c using in threshold mode (signal from π but not K).
  - A good time resolution (50 - 100 ps) can be provided in offline reconstruction

e/π identification in the electron hemisphere

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

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

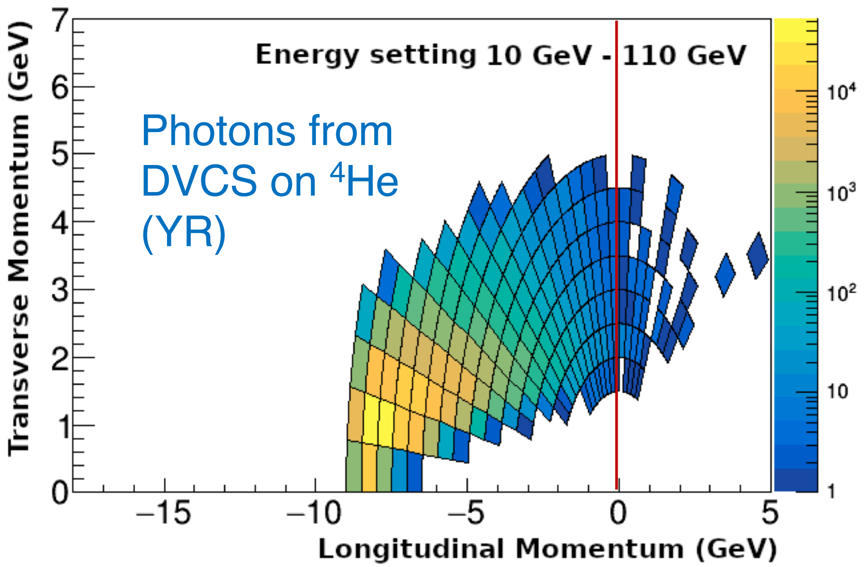


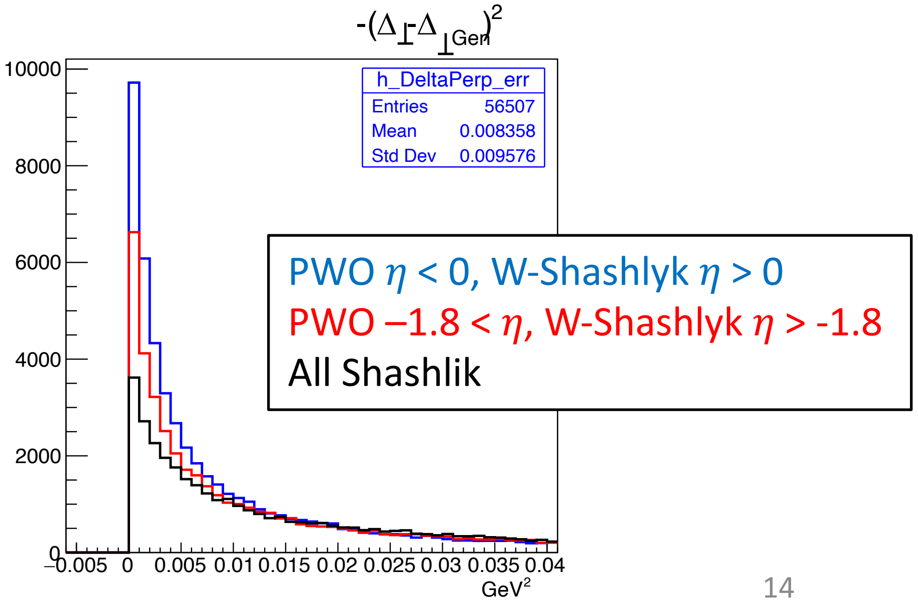
- For the EIC, a clean identification of the scattered electron is essential.
- The barrel region poses the greatest challenge and requires the best electron ID.
- CORE addresses this issue by extending the PWO EMcal coverage up to $\eta < 0$ (or possibly -0.5)
- Additional low-momentum e/π suppression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

Reconstruction of the Δ-distribution from the DVCS photon

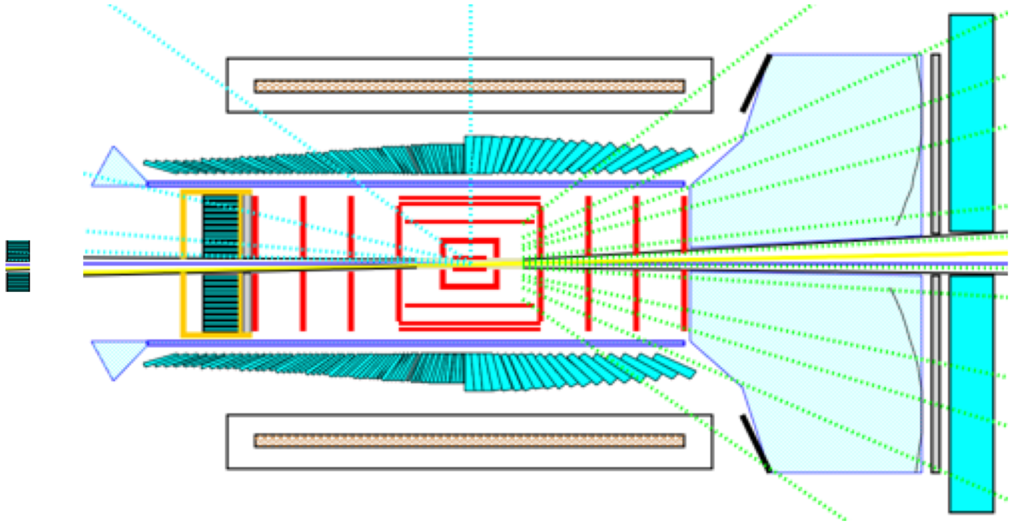
- An IR with a second focus (IR8) offers exceptional acceptance for protons, light ions, and ion fragments.

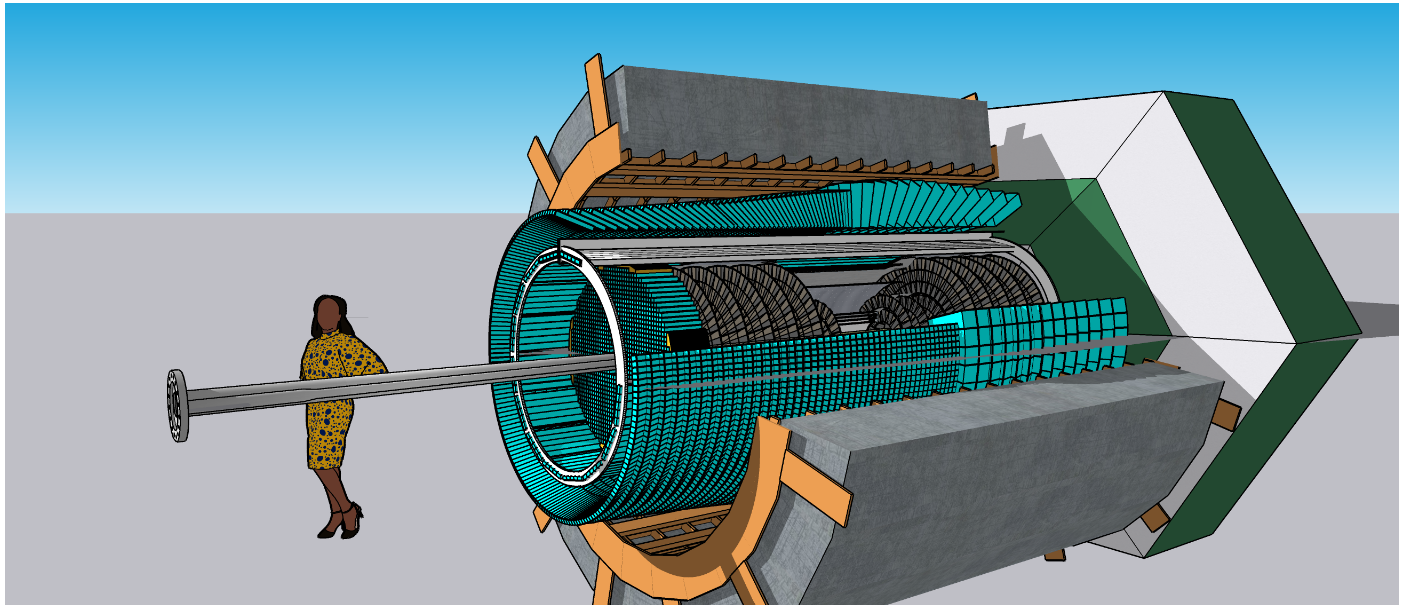
- To take full advantage of this, the central detector should be able to reconstruct the transverse momentum distribution with comparable resolution for production of mesons and photons (DVCS).
  - Tracking and EM calorimetry both at the %-level
  - No sensitivity to “beam effects.”
  - Helpful for protons – essential for ions.





4π EM calorimetry





Electron hemisphere ($\eta < 0$)

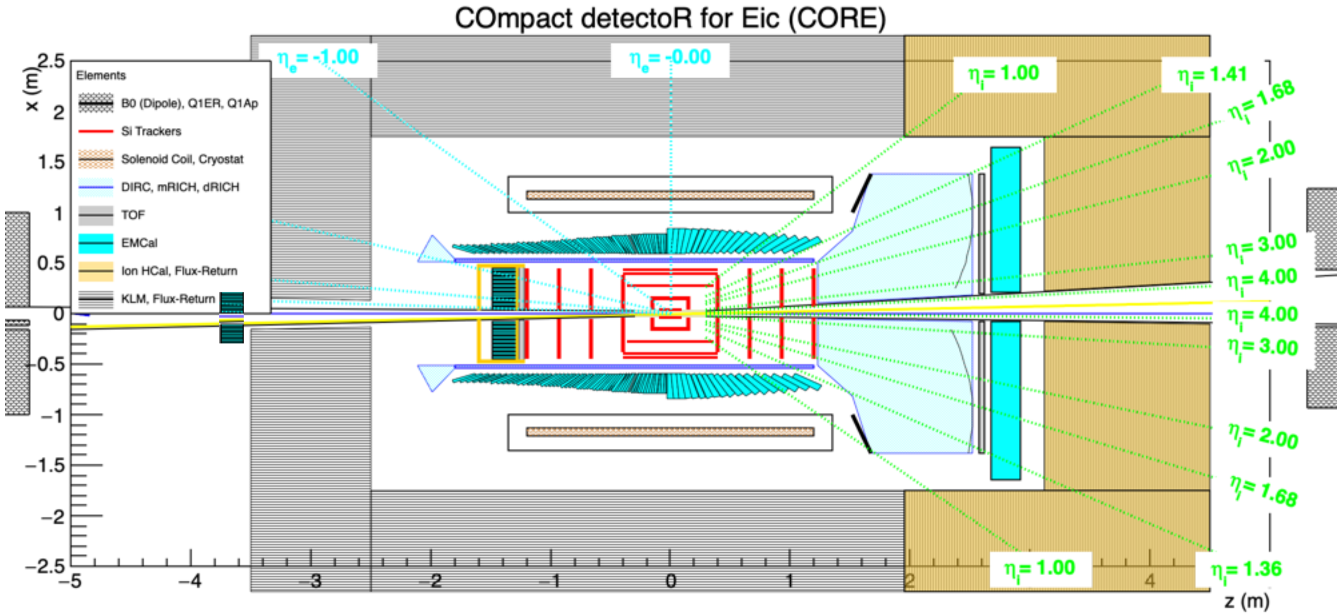
- PWO (1-2%) – temperature controlled
- Baseline coverage is $\eta < 0$, but $\eta < -0.5$ could be a cheaper fallback option
- But the PWO could also be extended to the full barrel like in the PANDA detector, which is about the same size as CORE
- Note the small-angle EMcal further back

Hadron hemisphere ($\eta > 0$)

- W-Shashlyk (6%) is an excellent option for a projective EMcal in the hadron endcap
- W-Shashlyk can also be a substitute for PWO in the forward part of the barrel
- The barrel-endcap transition minimizes partial showers in the edge of the barrel

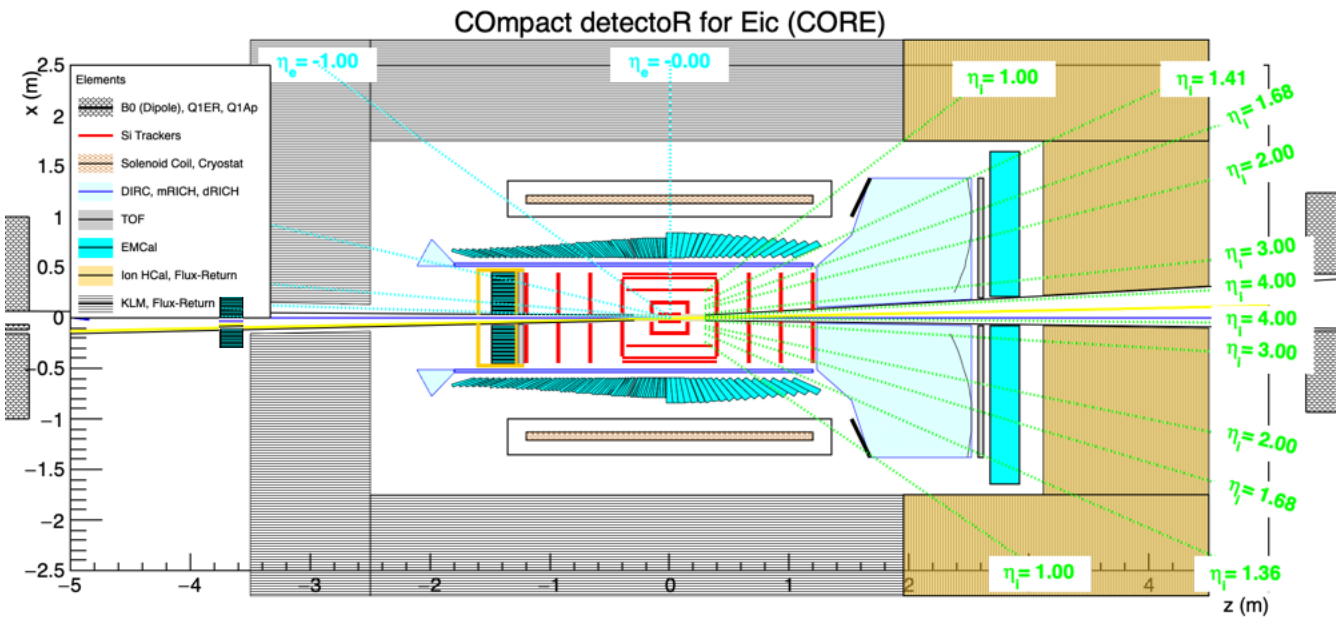
EM calorimetry and TOF in the electron endcap

- The inner electron endcap of CORE is designed to be small and light
  - PWO and LGAD TOF only
  - Can be cantilevered from behind rather than supported from the barrel in order to reduce supports and improve hermeticity.
- LGADs from ATLAS and CMS are being adapted for the EIC by eRD29
  - 30 ps and 55% fill factor per layer
  - The CORE endcap can support 2-3 layers within a 10 cm depth (z) at a distance of 130 cm from the IP
  - t0 can be obtained from the electron
  - R&D on LGADs with a higher fill factor is ongoing (trench-Isolated & AC)

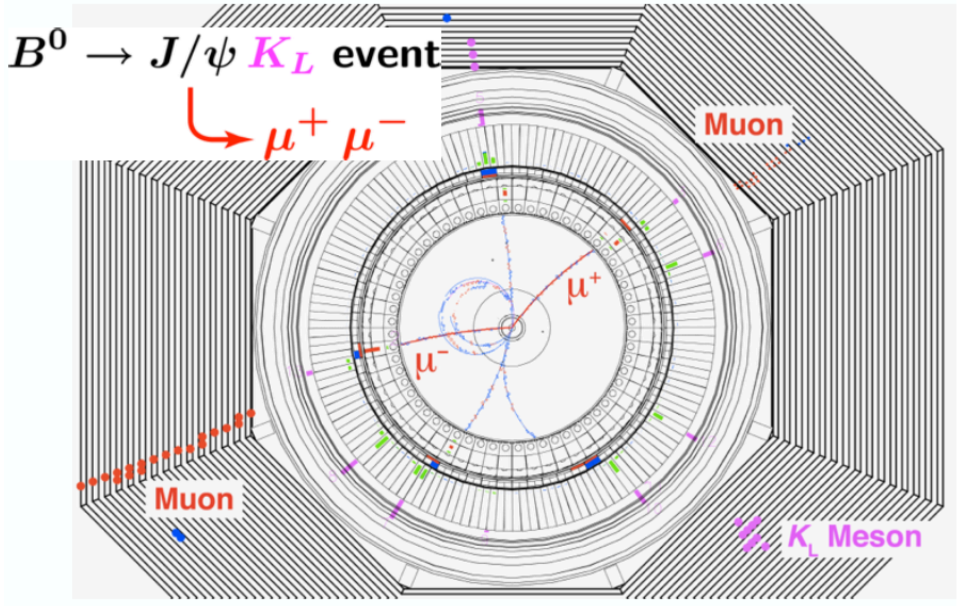


- Note that the small endcap means that the DIRC covers a larger η range
  - The endcap also coincides with the best range for K_S reconstruction

Hadronic calorimetry and muon ID



The Belle II K_L-μ (KLM) system

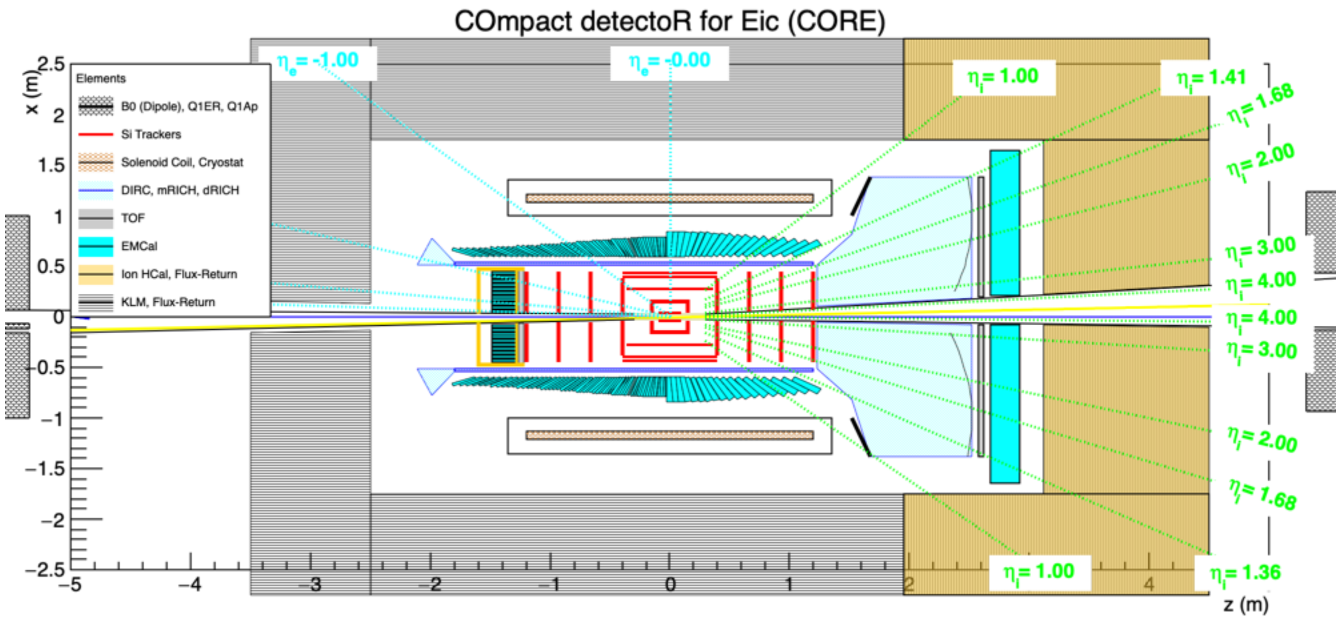


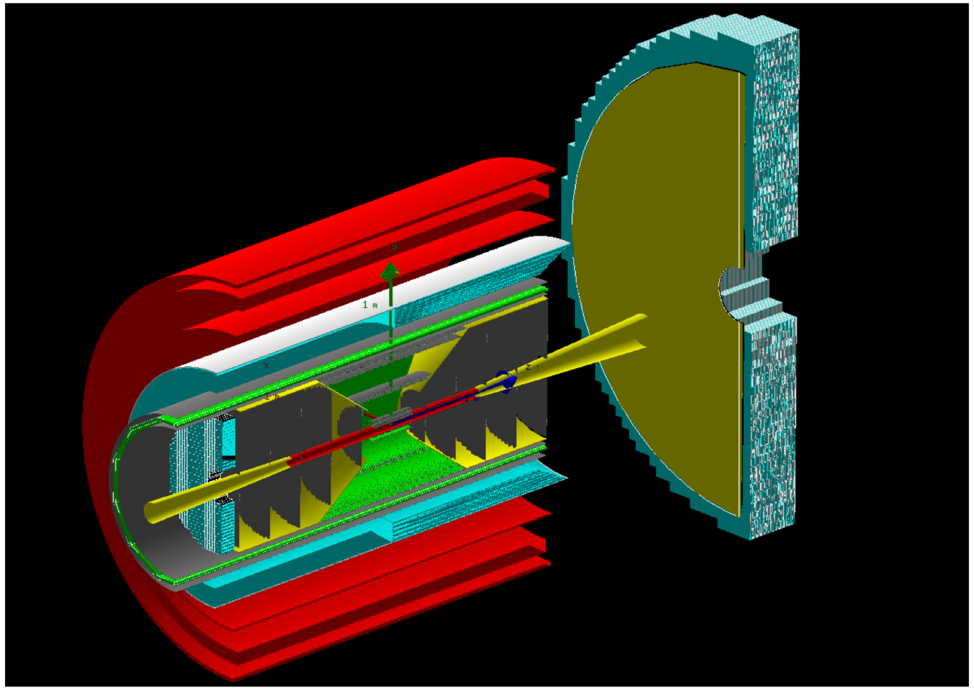
- High-resolution Hcal in hadron endcap (yellow) – *cf.* STAR FCS
  - Important for high-x jets, J-B and DA methods for reconstruction of event kinematics, etc.
- Low-resolution Hcal with excellent muon ID elsewhere – *cf.* Belle II KLM

Talk by W. Jacobs

  - Integrated with magnetic flux return
  - Neutral hadrons for mid-rapidity jets (which are best reconstructed from individual tracks)
  - Muon ID down to 0.6 GeV/c for, *e.g.*, exclusive di-lepton production
  - Energy resolution can be optimized for EIC requirements

CORE systems





- New 3 T solenoid (2.5 m long, 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: LGADs in e-endcap (eRD29) and a simple TOF behind the dRICH
- Hcal / K_L-μ (KLM) detector integrated with the magnetic flux return

Thank you!

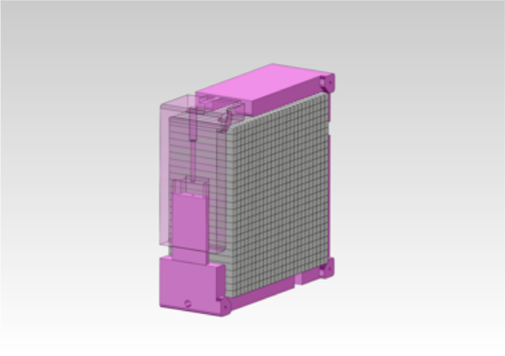
Pre-showers for γ/π^0 separation

- W-Shashlyk may be have sufficient intrinsic position sensitivity not to require a separate pre-shower

- PWO crystals can provide γ/π^0 separation at lower energies, but a pre-shower will improve separation and increase the energy range
  - Is PWO alone sufficient for the EIC?

- Several PWO pre-shower options exist:

A LYSO pre-shower from the RD2012-13 proposal with fiber readout could be an interesting option.



The CMS PWO pre-shower uses cooled 6 mm Si-strip detectors in-between an initial layer and the main PWO blocks