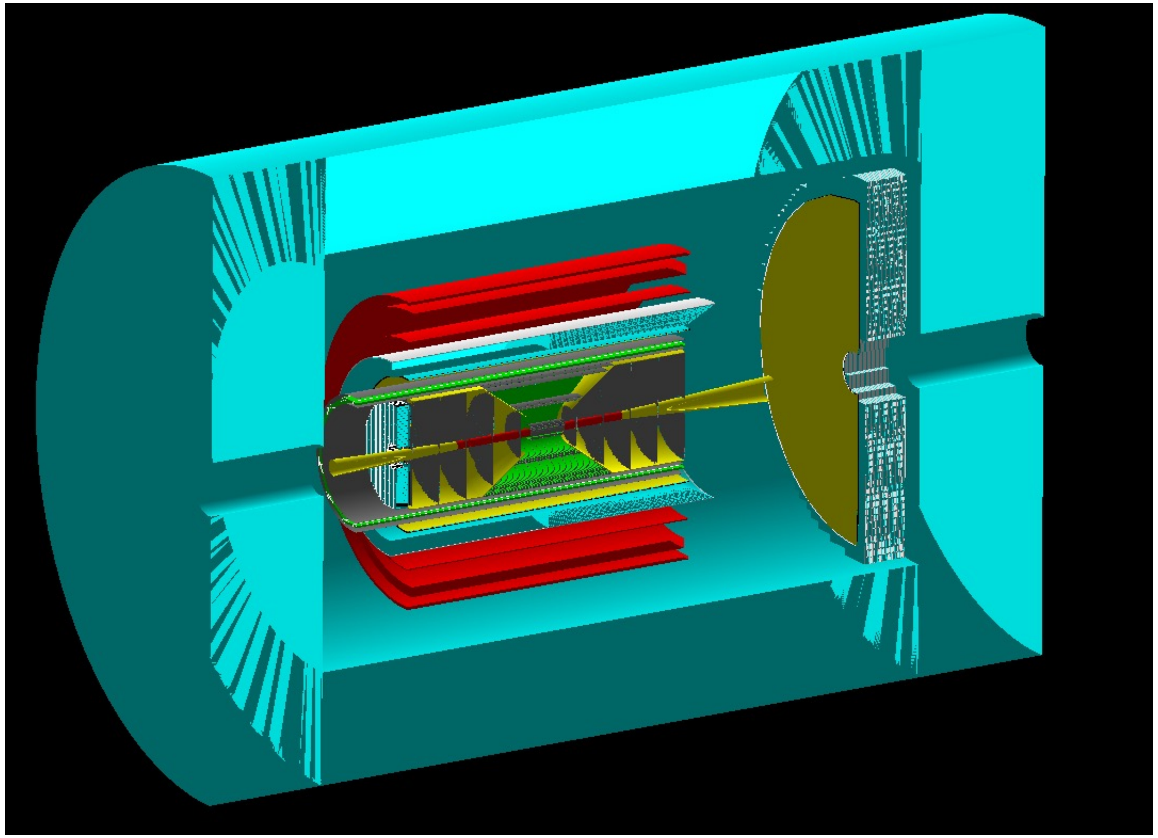
CORE: a COmpact detectoR for the EIC

- a Detector 2 (IP8) proposal



Charles Hyde

Old Dominion University

Pawel Nadel-Turonski

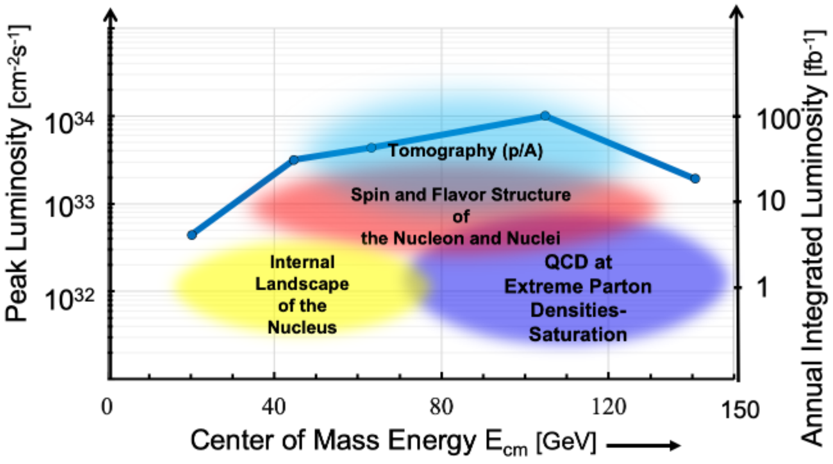
Stony Brook University

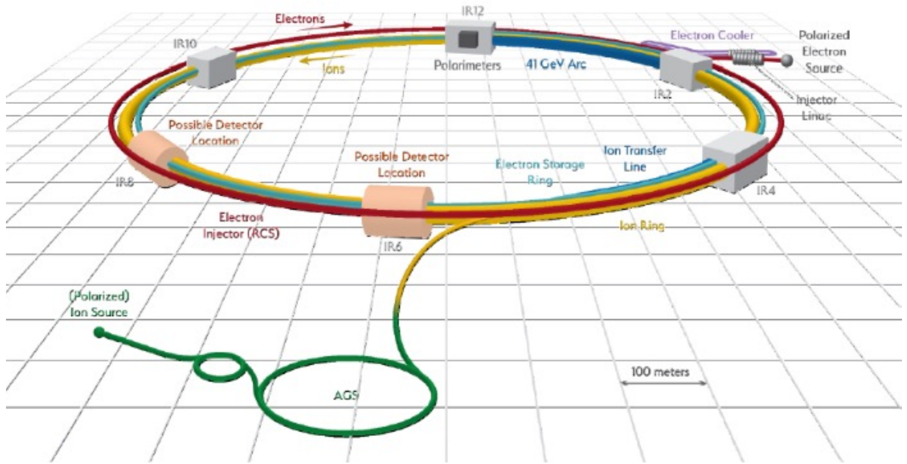
and the CORE pre-collaboration

(open to all users)

RIKEN Seminar, 02 June 2021

EIC Machine Parameters





Double Ring Design Based on Existing RHIC Facilities	
Hadron Storage Ring: 40 - 275 GeV	**Electron Storage Ring: 2.5 - 18 GeV**
• RHIC Yellow Ring and Injector Complex	• Many Bunches, Large Beam Current - 2.5 A
• Many Bunches, 1160 @ 1A Beam Current	• 9 MW Synchrotron Radiation
• Bright Beam Emittance ε_{xp}= 9 nm	• Superconducting RF Cavities , 10MW Power
• Flat Beam, Requires Strong Cooling	
High Luminosity Interaction Region(s)	**Electron Rapid Cycling Synchrotron**
• 25 mrad Crossing Angle with Crab Cavities	• Spin Transparent Due to High Periodicity

DOE Total Project Cost
$2,249M

Includes
1 Interaction Region,
1 Detector
“6:00 O’Clock” position
Requires
~$70M “In-kind” contribution to detector

Second IR + Detector
100% “off-project”
“8:00 O’Clock” position

Call for Detector Collaboration Proposals

www.bnl.gov/eic/CFC.php
Proposals due 1 Dec 2021

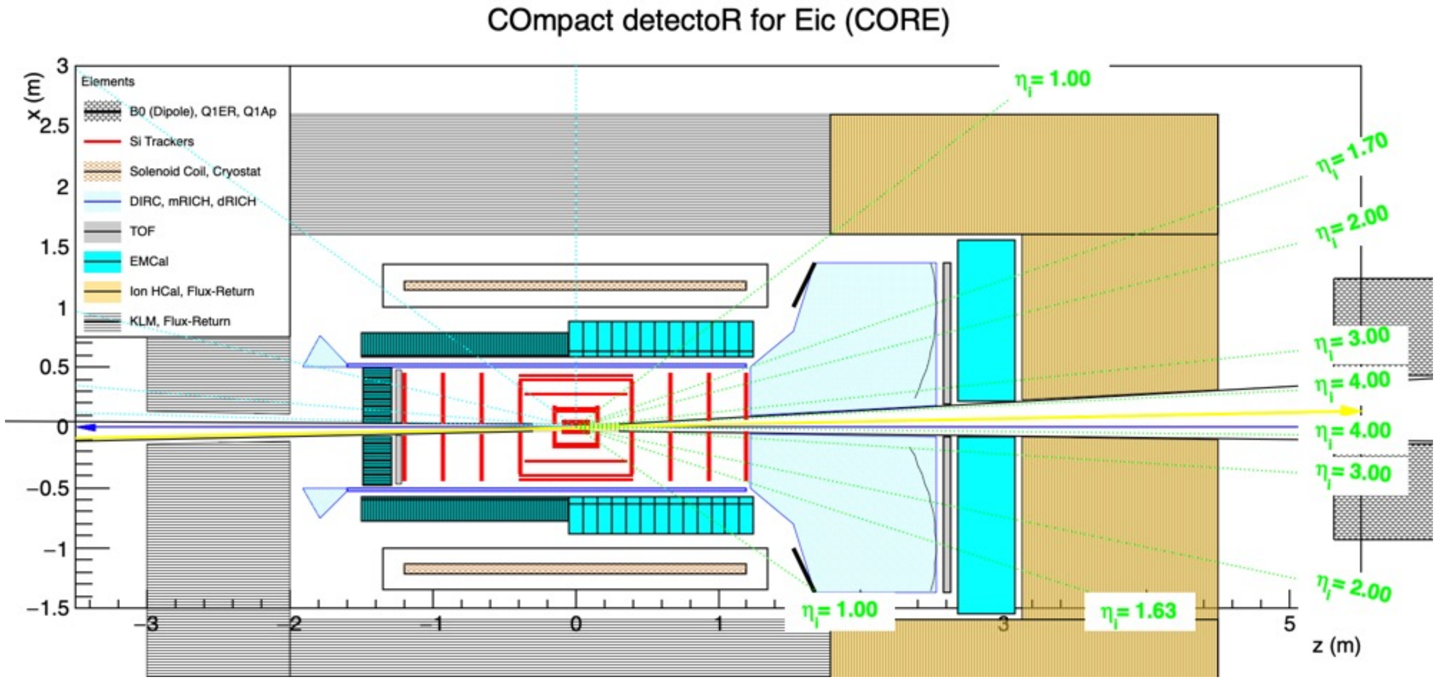
The Proposals should include two parts:

- A description of the science addressed and performance estimated through simulation including, but not limited to, e/γ, jets, π/K/p separation, vertex, and tracking, and how the simulated performance compares to the requirements detailed in the YR. The realization of the conceptual detector design given the technology choices, the R&D needs, risks, and, if applicable, adoption of emerging new technologies. (< 40 pages)
- A collaboration roster and structure, timescale and cost (including potential sources of funding sources and assumptions), and potential upgrade paths. (<20 Pages)

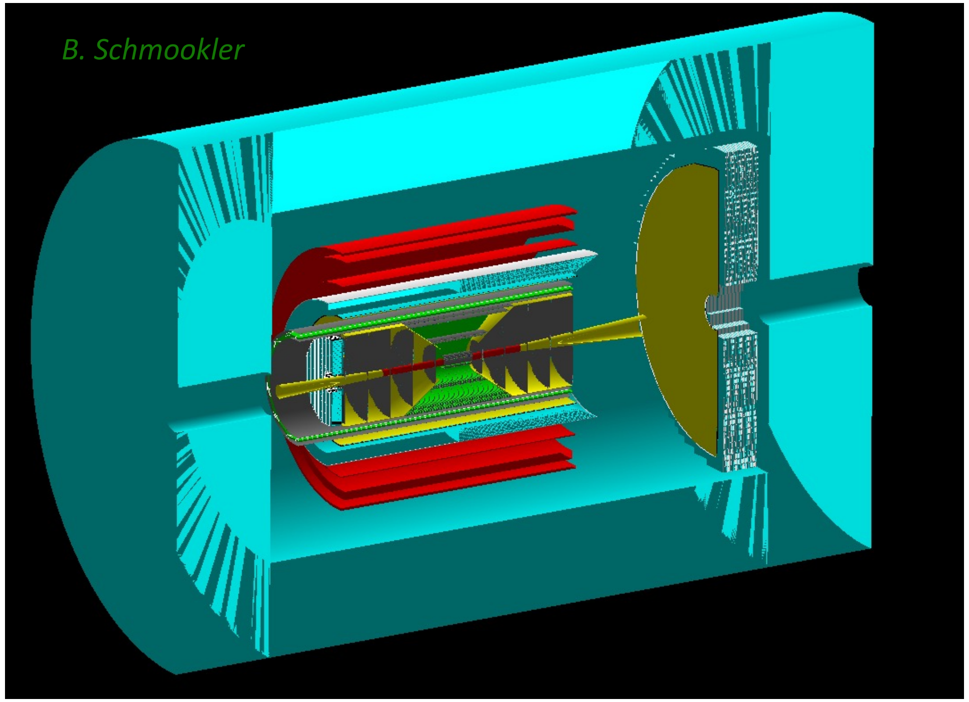
Three Detector "proto-Collaborations"

- ATHENA: https://sites.temple.edu/eicatip6/
- ECCE: https://www.jlab.org/ecce-eic-collider-experiment-consortium-remote
- CORE: https://indico.jlab.org/event/444/
  - Wiki page to be released soon: https://eic.jlab.org/core/index.php/Main_Page
  - Mailing lists:
    - eic-core@jlab.org
    - eic-core-det@jlab.org
    - eic-core-phys@jlab.org
  - Everyone welcome (theorists too)!

a COmpact detectoR for the Eic (CORE)

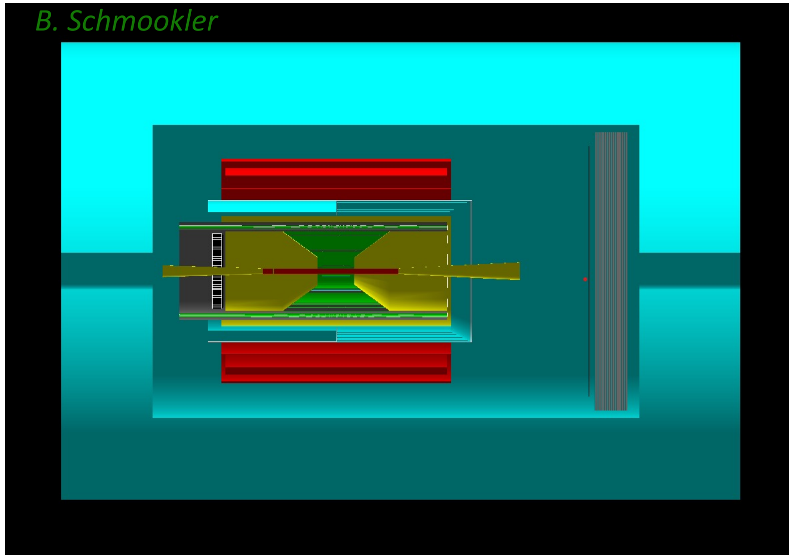


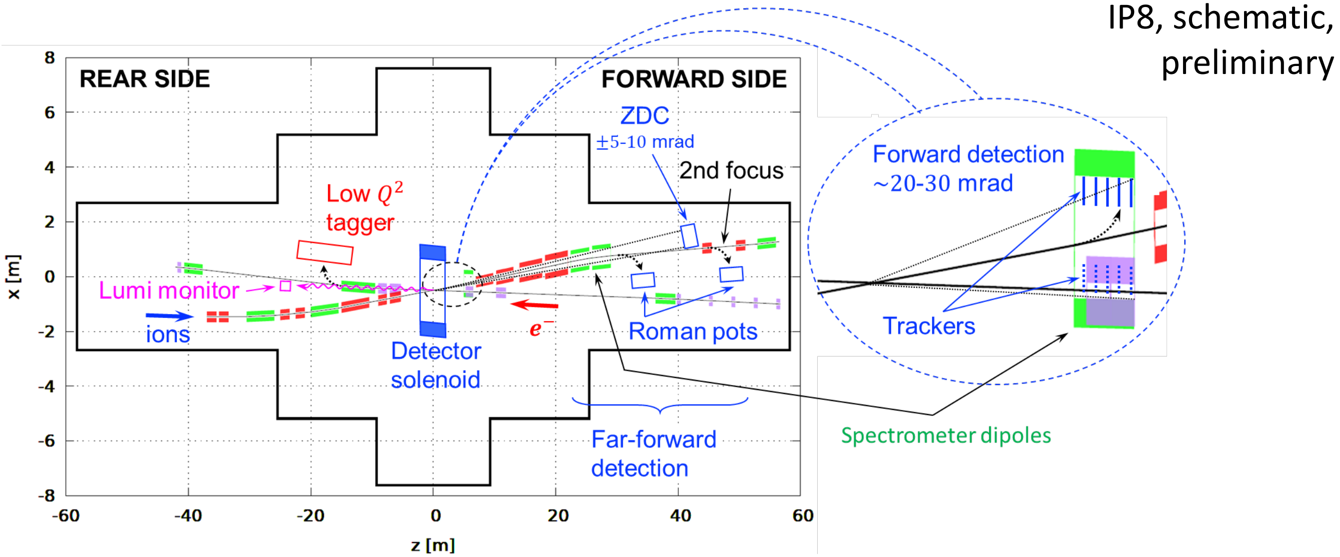
CORE in Geant (fun4all)



- Hermetic general-purpose detector that fulfills the EIC physics requirements
- Compact size reduces cost while allowing investment in critical components
- Small central core leaves plenty of space within the flux return for support and services

CORE will be submitted as a Detector 2 (IP8) proposal



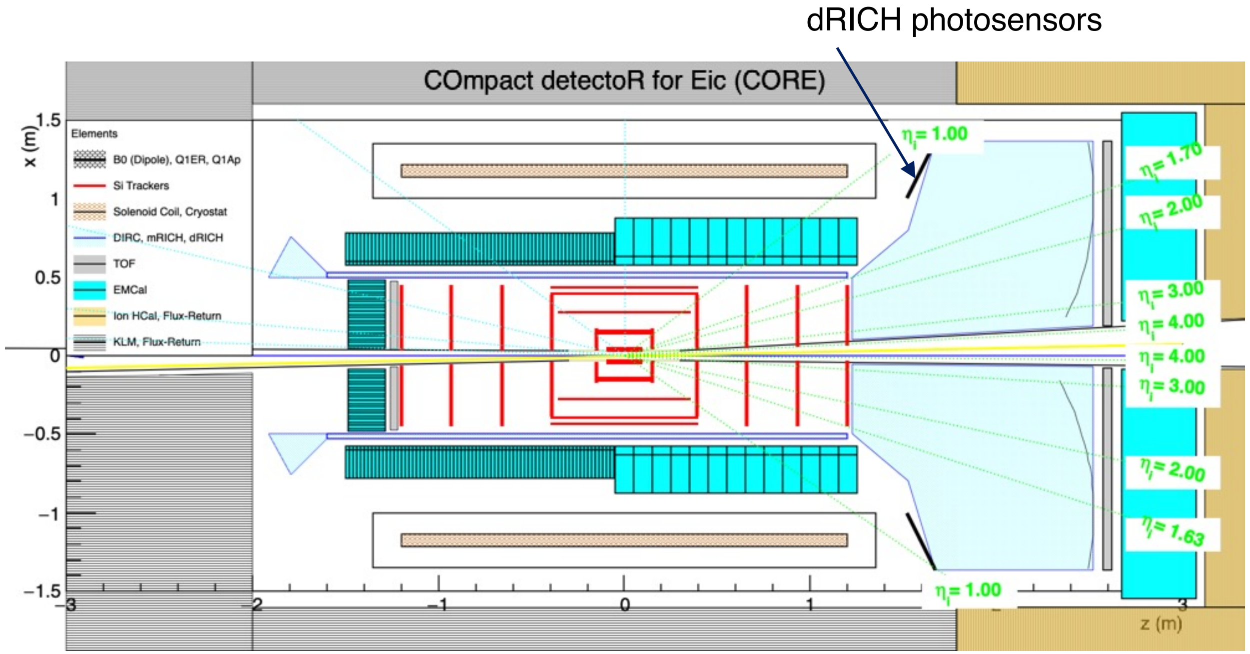


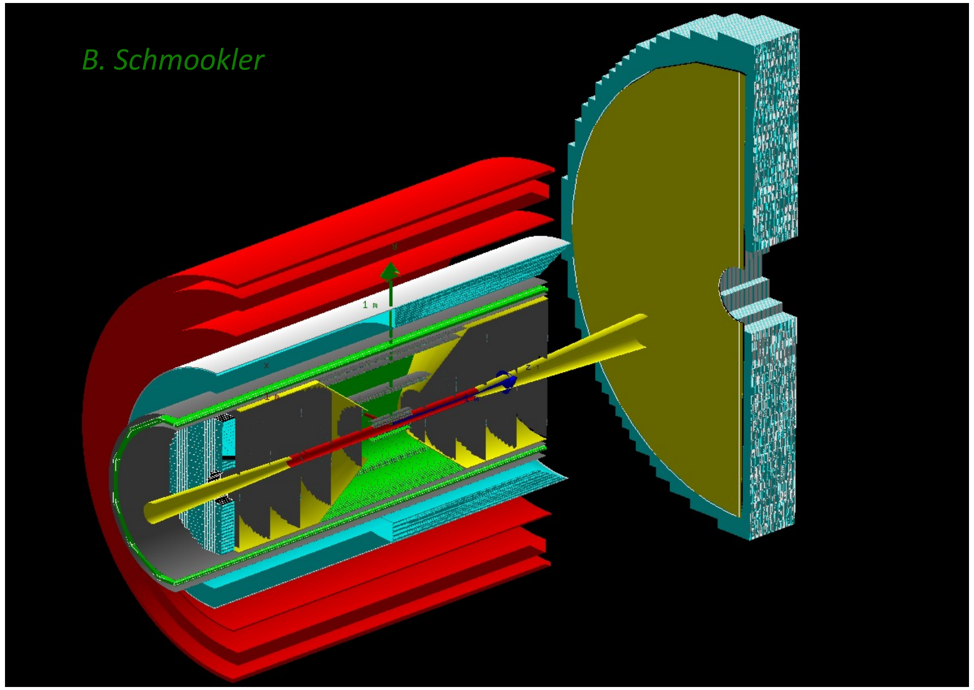
- Although CORE would also fit IP6 (Detector 1), the proposal will be submitted as a Detector 2 proposal for IP8 to take full advantage of the forward spectrometer.
  - The exceptional acceptance in rigidity (P'_A/Z') is particularly important for nuclei but also impacts protons
  - The interplay between CORE and the forward spectrometer will be part of the proposal
- CORE fits into a -3.5 m to +4.5 m IR space.
  - Simplifies IR integration and can offer a higher luminosity

The core of CORE:

There is no compelling requirement for a large magnet

inner CORE in Geant (fun4all)





- Small solenoid (2.5 m long, 1.0 m inner radius)
- Small central all-Si tracker (eRD25)
- Radially compact, high-performance barrel DIRC Cherenkov (eRD14)
- Dual-radiator RICH with *outward-reflecting* mirrors in the hadron endcap (eRD14)
- Extended PWO_4 EMcal coverage (up to 2π, $\eta < 0$) on the electron side (eRD1)
- TOF Si-LGAD electron-endcap (eRD29)

$$\eta = -\ln\left[tan\frac{\theta}{2}\right]$$

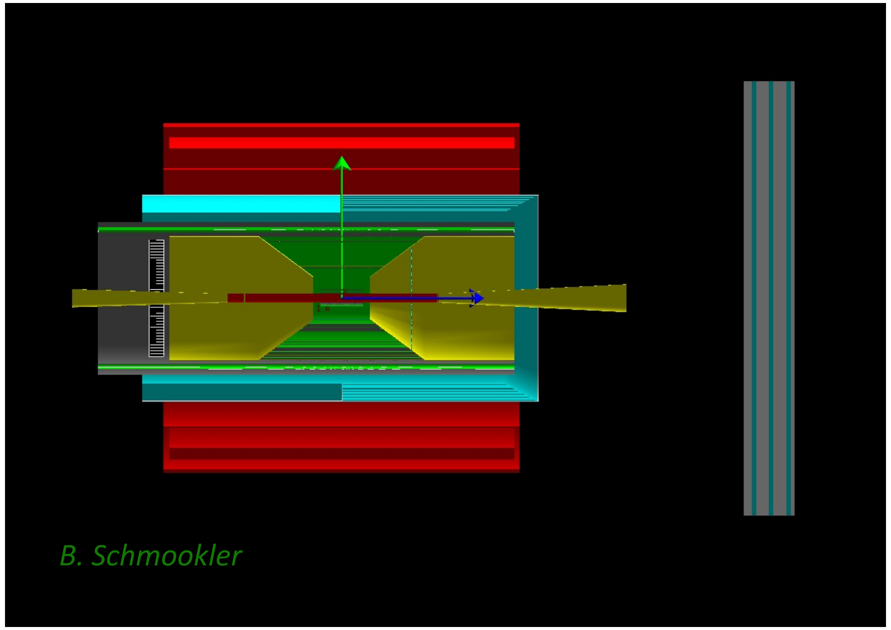
CORE solenoid

- The CORE solenoid is 2.5 m long with a 1 m inner radius
- CORE is compatible with any field in the 2 - 4 T range
- 2.5 T is the current baseline option

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**

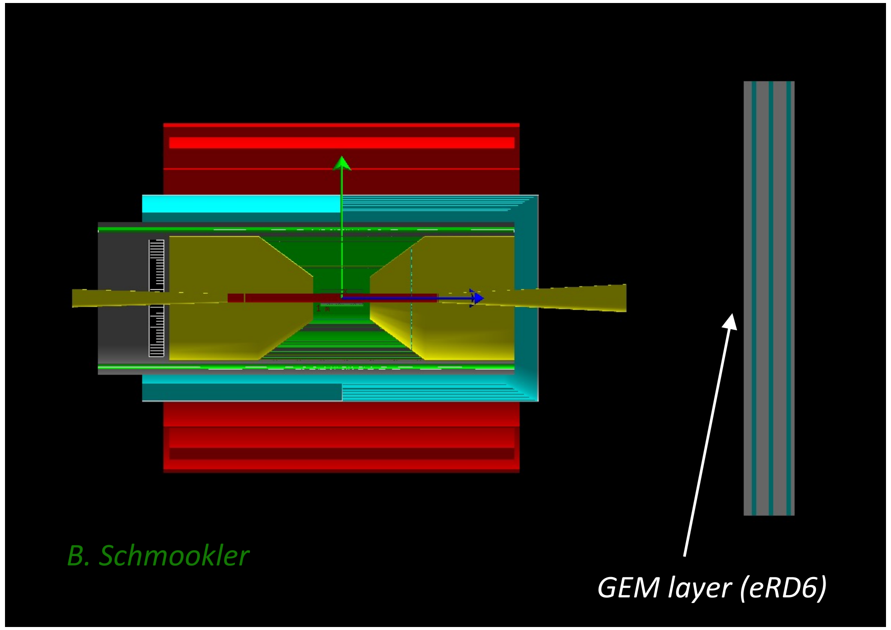
solenoid	field (T)	volume (m^3)	2020 cost (M$)
ATHENA	3	29	21
CORE	3	8	9
CORE	**2.5**	**8**	**7**
CORE	2	8	5



- A 1 m radius leaves 50 cm between the DIRC and solenoid
- First round of TOSCA studies showed excellent [approximately projective] B-field in the dual-radiator RICH and [~⊥] at the DIRC photosensors for a 2 T on-axis field.,
- A design and field map for the 2.5 T baseline option will be available soon.

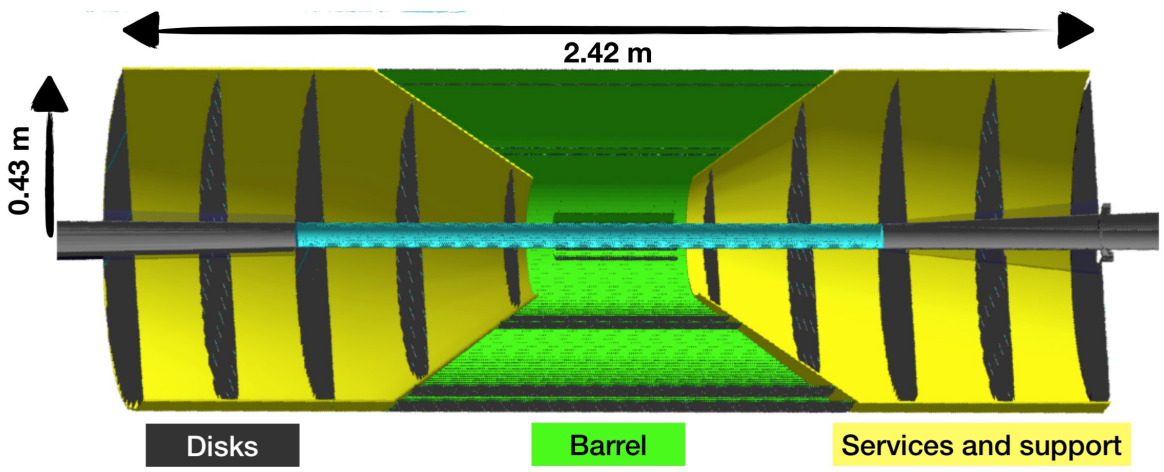
Central Si-tracker and h-endcap GEM

- A silicon tracker is compact, has a high resolution, and offers opportunities for future upgrades.
- The tracker developed by eRD25 will utilize ALICE ITS3 technology. The flexible ITS3 geometry in the vertex layers would allow to take full advantage of an elliptic beam pipe if this could be incorporated into IP8.
  - Fully digital "monolithic" technology



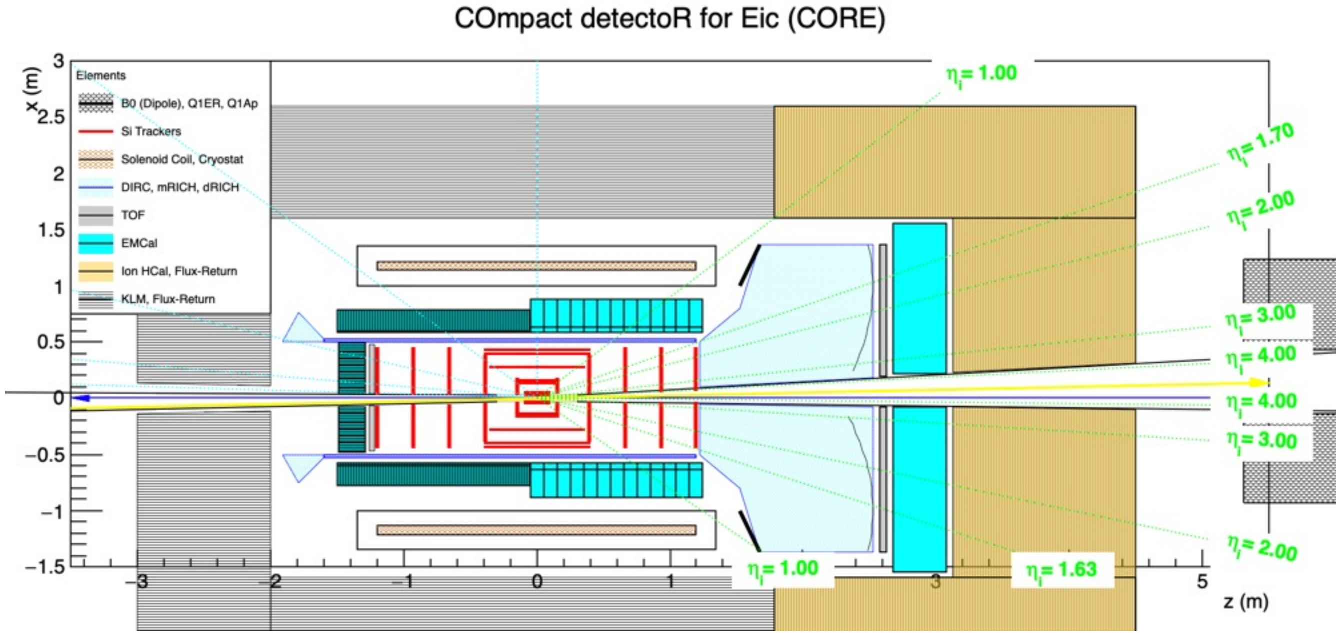
- In addition to the h-endcap GEM, MPGDs could also be used for post-DIRC tracking (if needed)

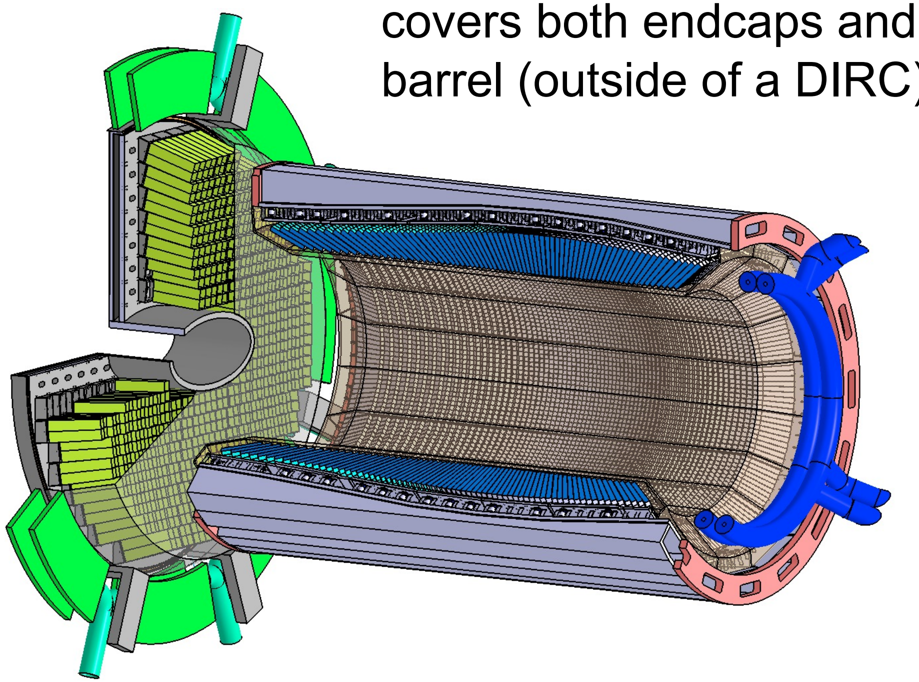
eRD25 Si-tracker



	ITS2/ALPIDE	ITS3
technology	180 nm	65 nm
pixel-size	27 x 29 μm	10 x 10 μm
thickness	50 μm	20-40 μm

4π EMcal





The PANDA PWO_4 EMcal covers both endcaps and barrel (outside of a DIRC)

PWO $\frac{\sigma(E)}{E} \sim (2\%)\sqrt{\frac{1\ GeV}{E}}$ for electron hemisphere: (up to 2π, $\eta < 0$ coverage)

- Both the endcap and barrel would be projective (*cf.* PANDA)
- The small-angle EMcal behind the main detector could be SciGlass.

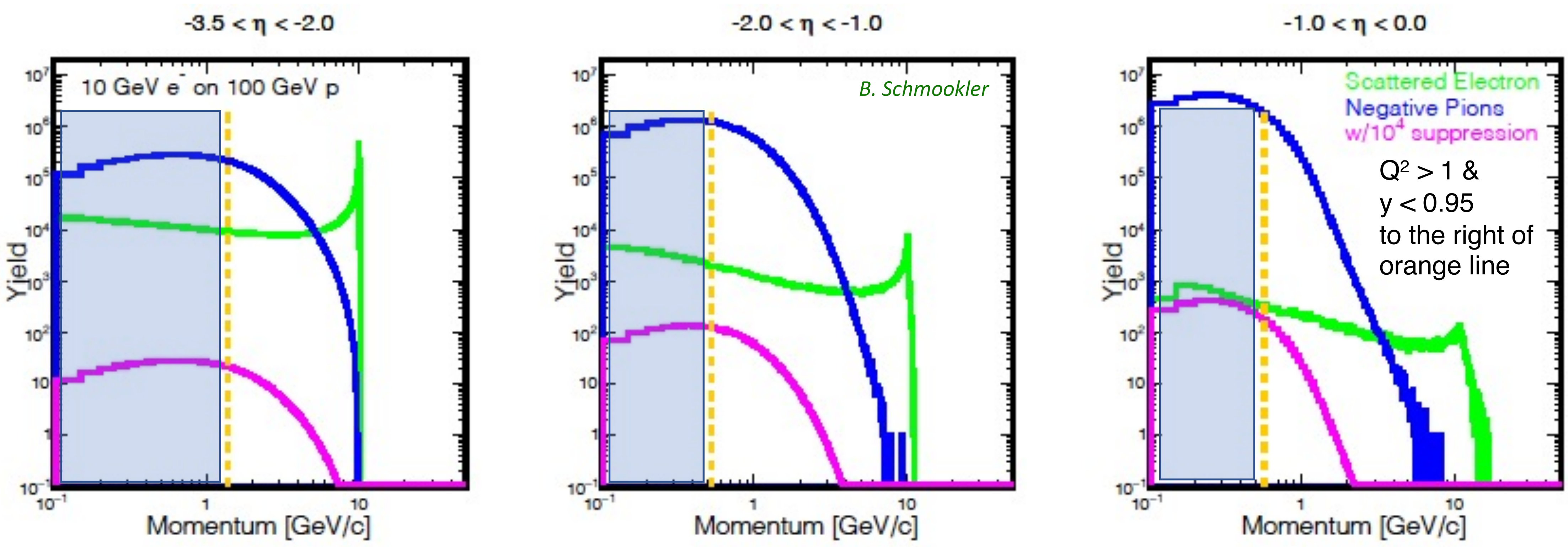
W-Shashlyk $\frac{\sigma(E)}{E} \sim (6\%)\sqrt{\frac{1\ GeV}{E}}$ for hadron hemisphere: ($\eta > 0$ coverage)

- Projective modules in the barrel
- Non-projective modules in the endcap

A PWO barrel Emcal:
- $e/\pi/\gamma$ ID
- Track reconstruction.
- $P_\perp$ resolution for
  $ep \rightarrow ep\gamma$
  $ep \rightarrow ep\pi^0$

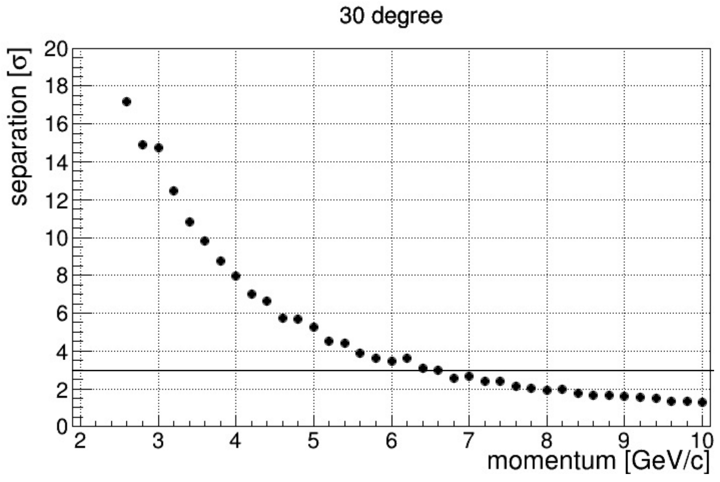
e/π identification in the electron hemisphere

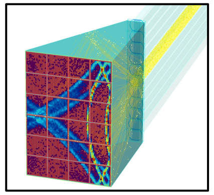
η = -ln(tan(θ/2))

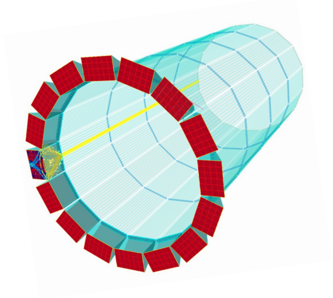


- For the EIC, a clean identification of the scattered electron is essential.
- The barrel region poses the greatest challenge and requires the best electron ID.\
- CORE addresses this issue by extending the PWO EMcal coverage up to η < 0 (or possibly -0.5)
- Additional e/π suppression (at least 1:10 up to 1.2 GeV) is also provided by the DIRC.

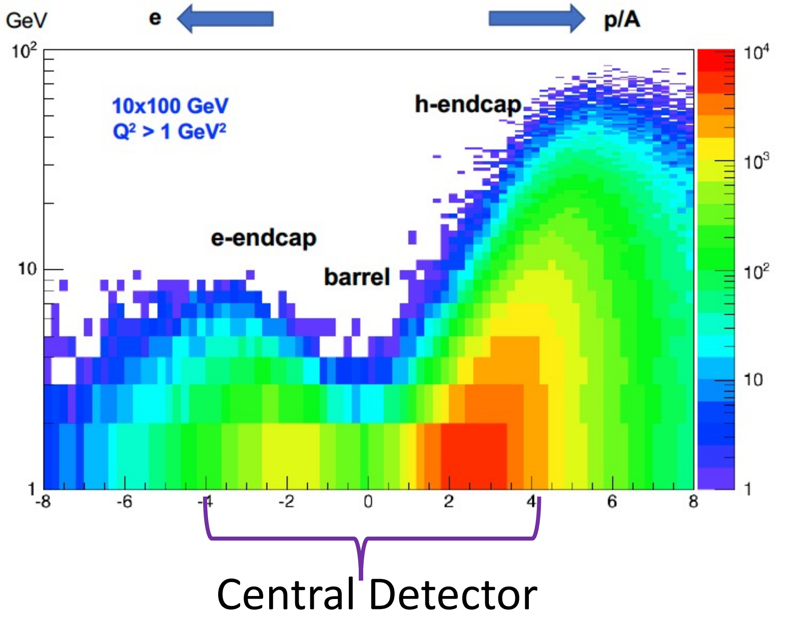
Hadron Identification in the barrel (hpDIRC) and hadron endcap (dRICH)

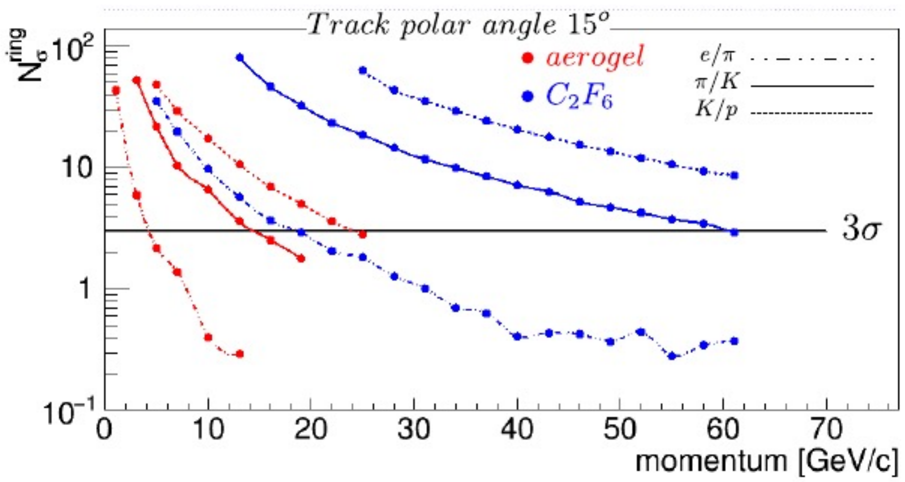


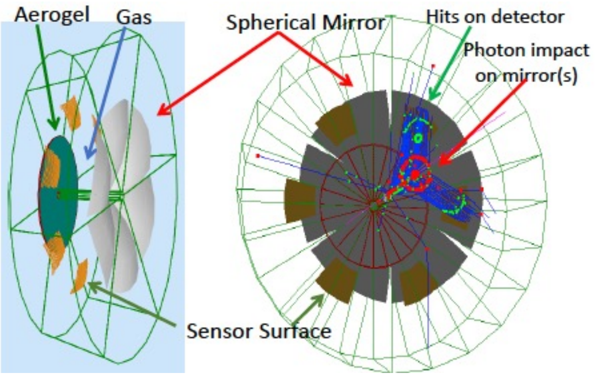




- The hpDIRC has a π/K separation of >4σ up to 6 GeV (and 2σ at 8 GeV).
- The minimum momentum for π/K ID in threshold mode is 0.2 GeV\



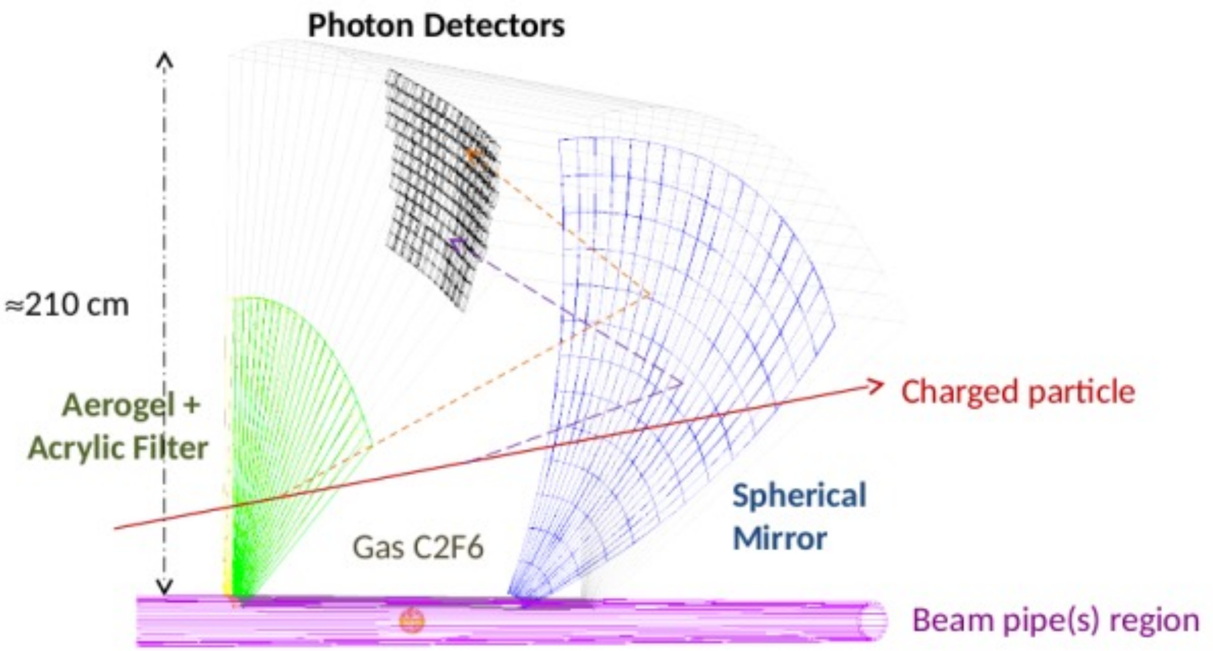


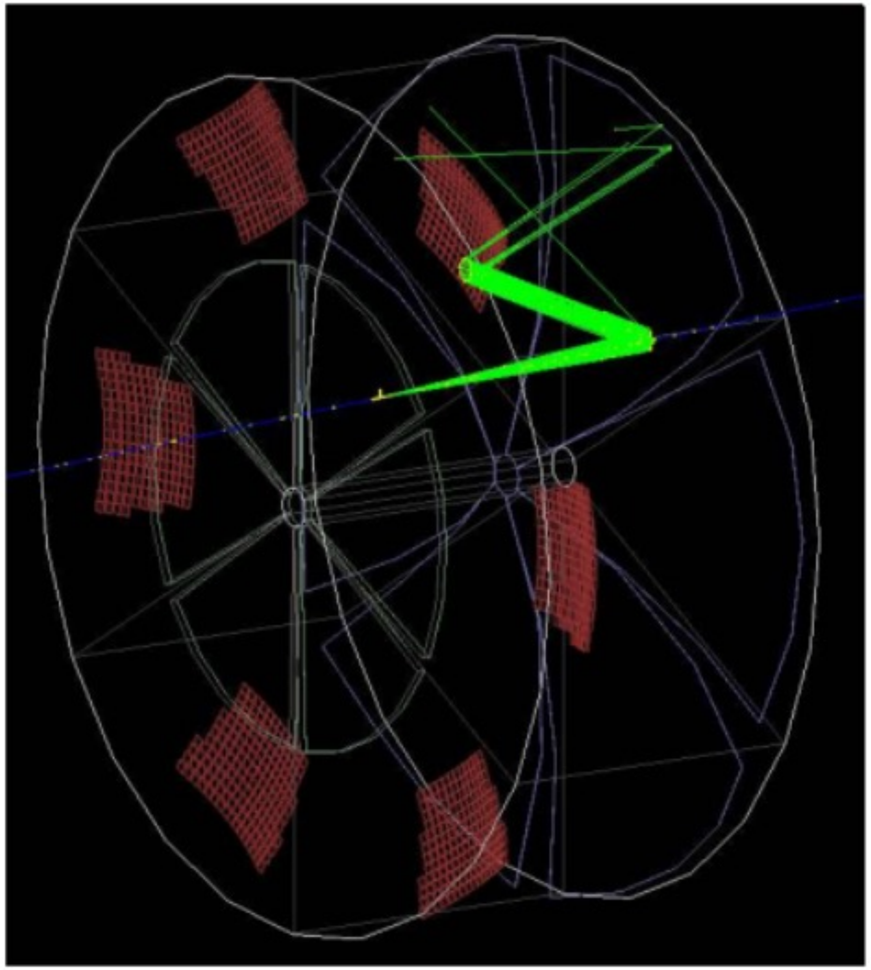


- Using aerogel and gas radiators with a single set of photosensors the dRICH provides *continuous* π/K separation of >3σ up to 60 GeV and an excellent e/π separation
  - e/π: 10σ at 10 GeV

The dual-RICH in Fun4All

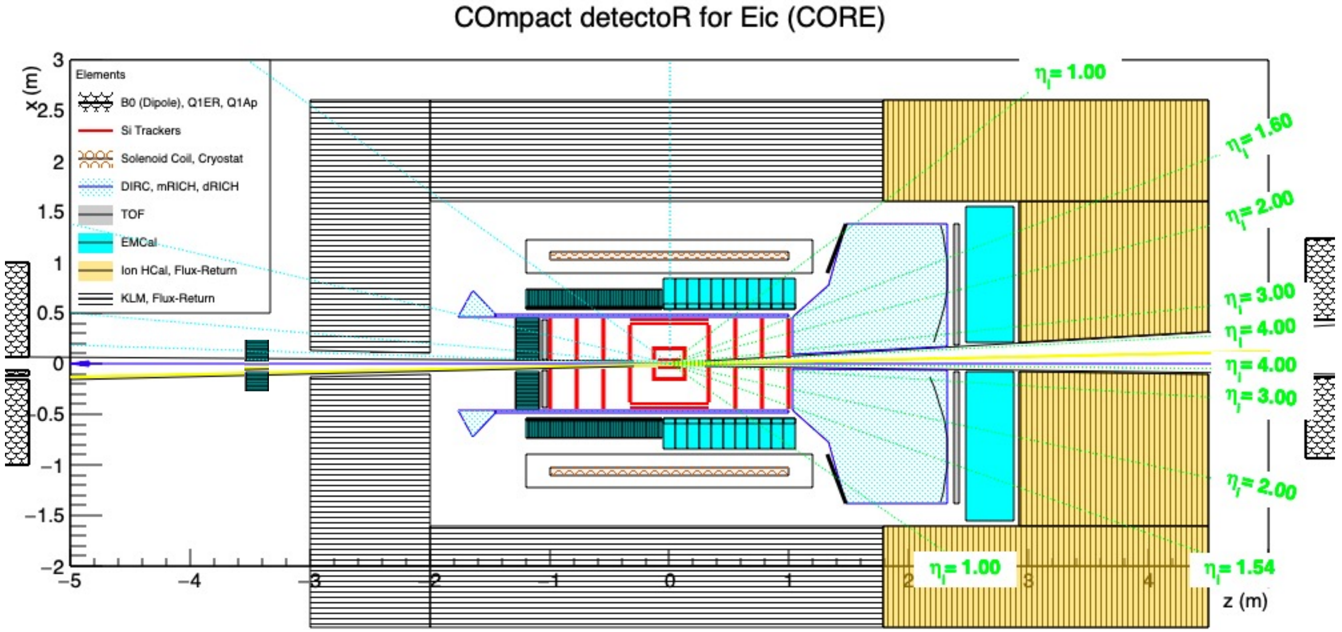
- Christopher Dilks, Duke U.



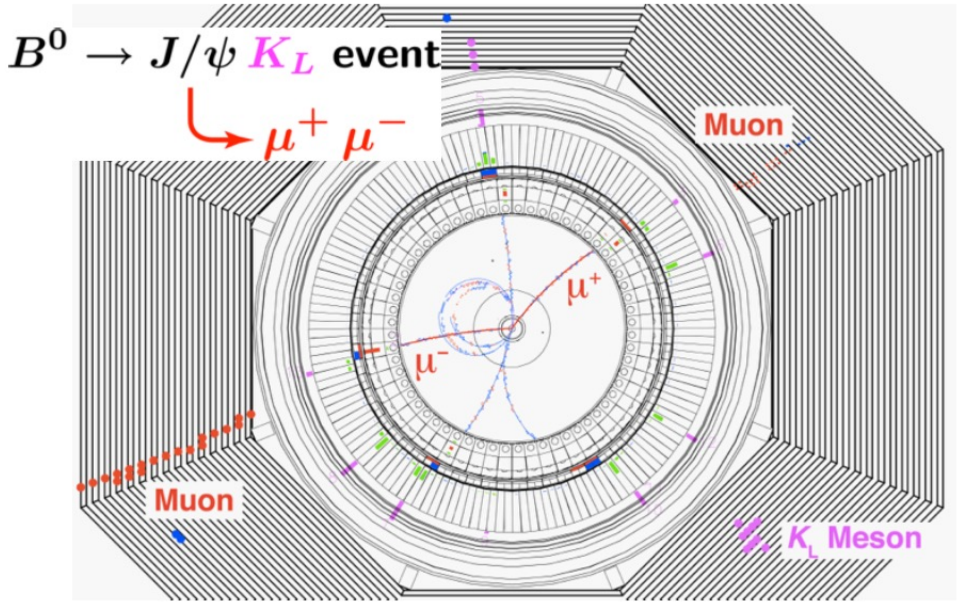


Geometry in Fun4All

Muon ID

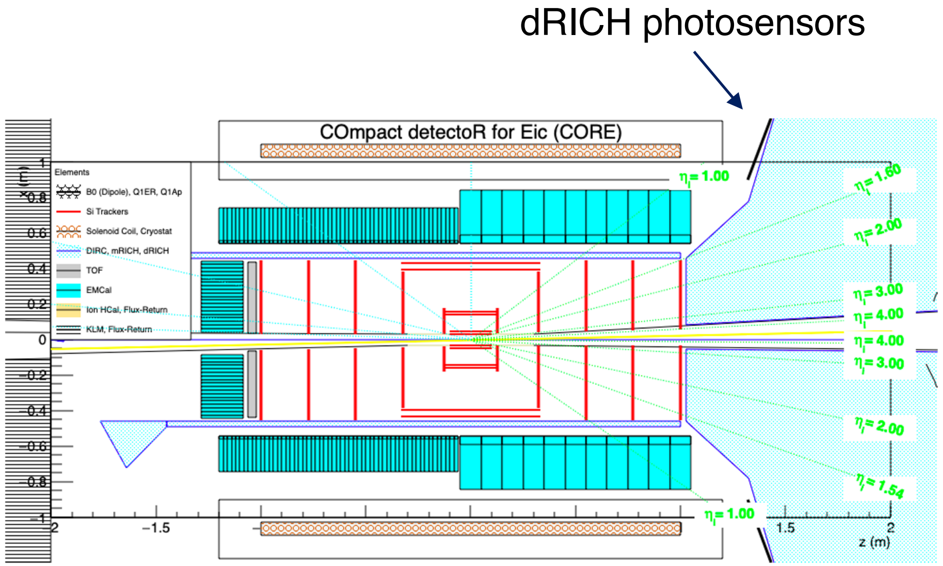


The Belle II K_L-μ (KLM) system

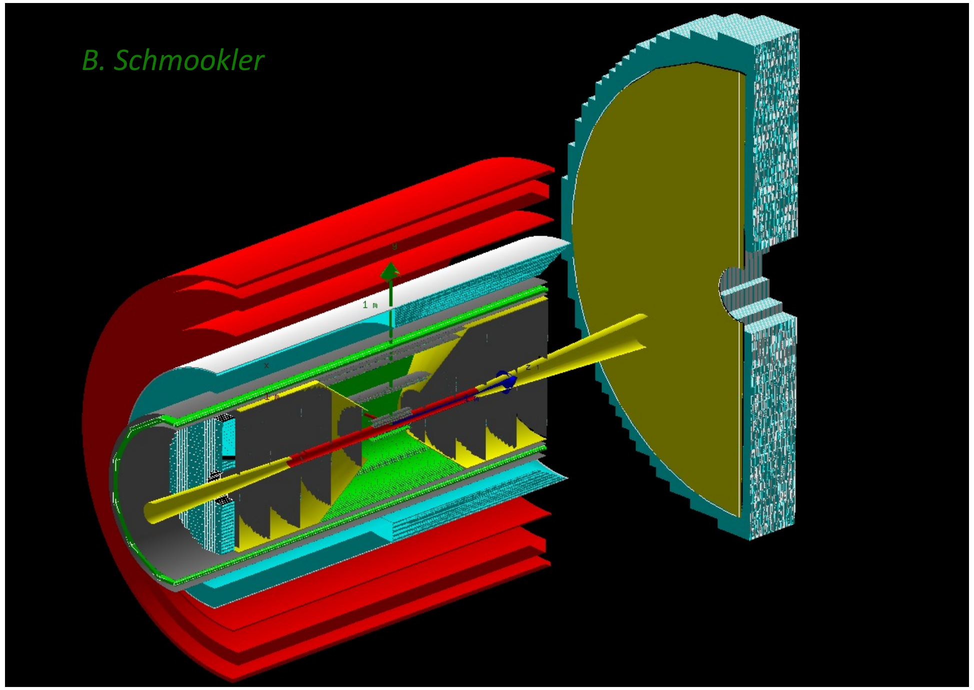


- At the EIC, mid-rapidity muons have relatively low momenta. The Belle KLM (K_L-μ) detector, which is integrated with the flux return, can ID muons down to 0.6 GeV.
- Since EIC mid-rapidity jets are best reconstructed from individual tracks, the KLM focus on measuring the neutral hadron angle rather than energy also fits the EIC needs well.
- In the hadron endcap, both jet and muon energies are large. Here, a high-resolution Hcal (yellow) is important, but a muon tracker can be placed behind it.

The core of CORE



inner CORE in Geant (fun4all)

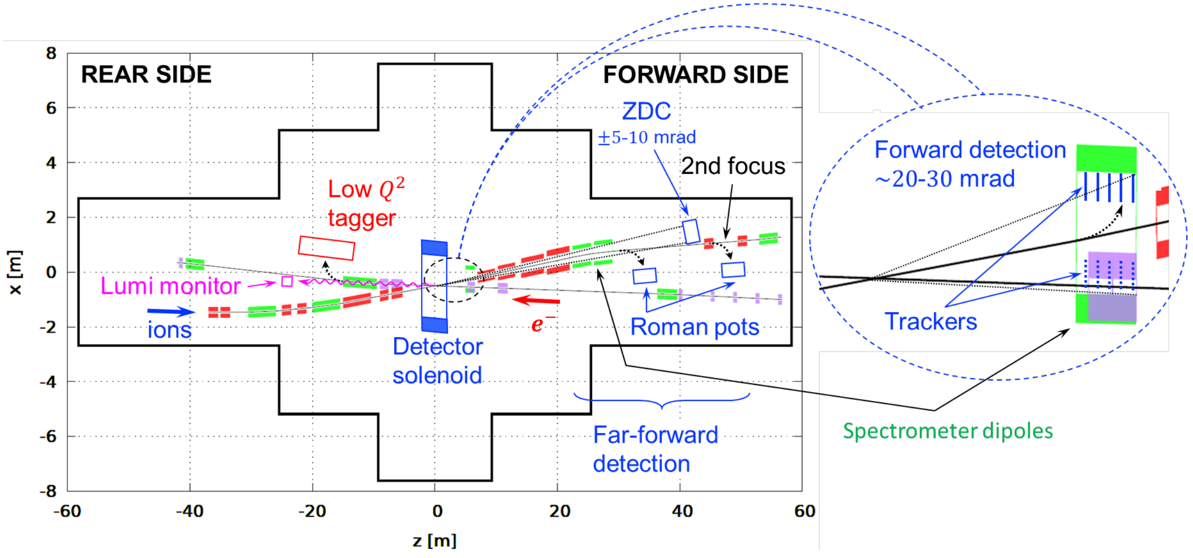


- New 2.5 T solenoid (2.5 m long, 1 m inner radius)
- Tracking: central all-Si tracker (eRD25) and h-endcap GEM tracker (eRD6)
- EMcal (eRD1): PWO for η < 0 and W-Shashlyk for η > 0
- Cherenkov PID (eRD14): DIRC (50 cm radius) in barrel and dual-radiator RICH with outward-reflecting mirrors at a moderate angle (minimizing aberrations) in h-endcap
- TOF: LGADs in e-endcap (eRD29) and a simple TOF behind the dRICH
- Forward HCal [1.5<η<4] and K_L / *muon [–4<* η*<1.5]* detectors integrated with flux return

$$\eta = -\ln\left[tan\frac{\theta}{2}\right]$$

Forward Detectors: The B0 Dipole

- Acceptance relative to ion beam line:
  - 5.5 mrad < θ < 13.5-20 mrad
  - 6 > η > 4



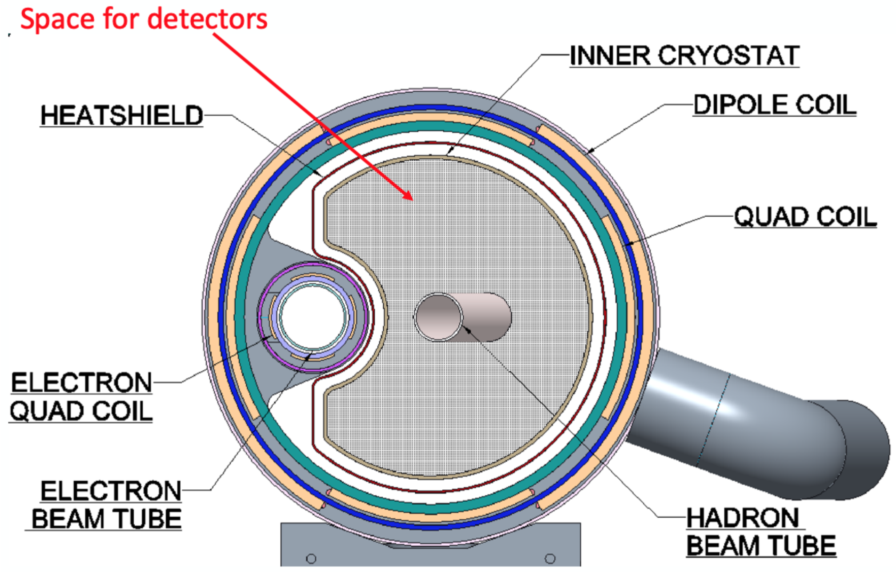
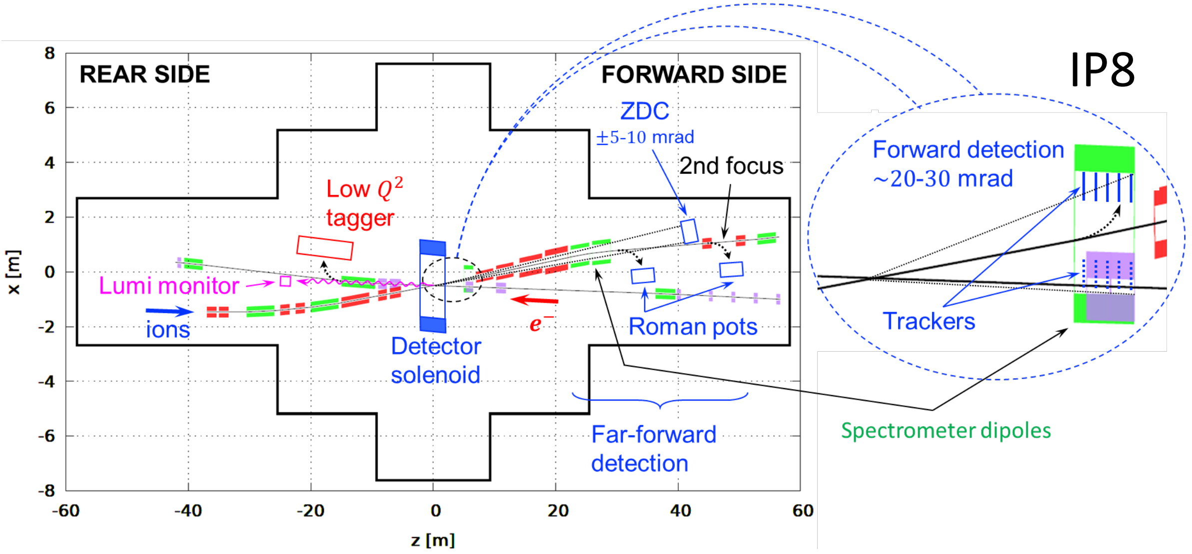


Figure 8.23: Closeup image of the B0pf magnet bore with both hadron and electron beam pipes and warm area for placement of detectors. The detector area allows for up to ~13 mrad of angular coverage between the two beam pipes, and up to ~20 mrad of angular coverage between the hadron beam pipe and the inner wall of the bore. Both silicon tracking detectors as well as compact electromagnetic calorimetry are under consideration for integration into the open space in the bore.

Far-Forward Detectors



- "Off-Momentum" θ<4.5 mr,
  - Rigidity K = P/Z $|K - K_0|/K_0 < 0.5$
- "Roman-Pot" Trackers
  - IP8, secondary focus at ~45 m $|K - K_0|/K_0 > 0.005$
- Zero Degree Calorimeter (ZDC)

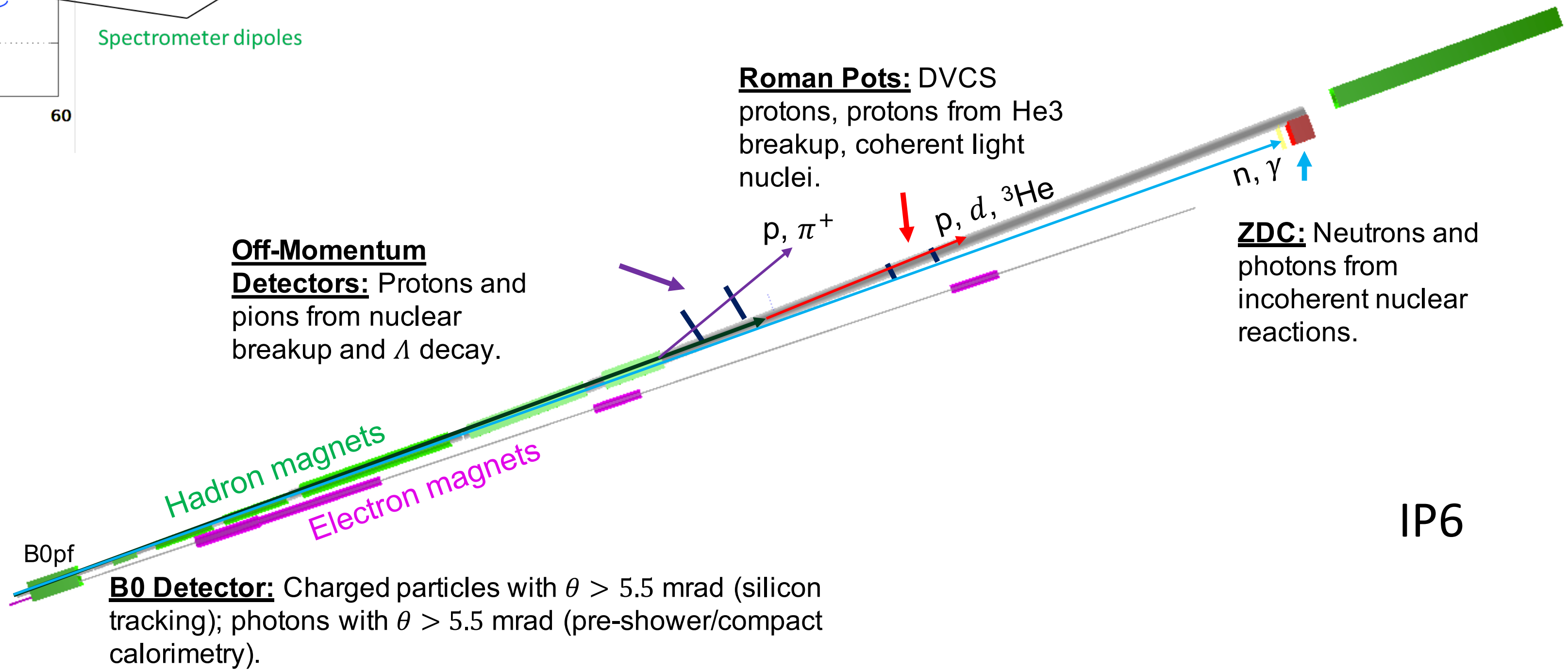
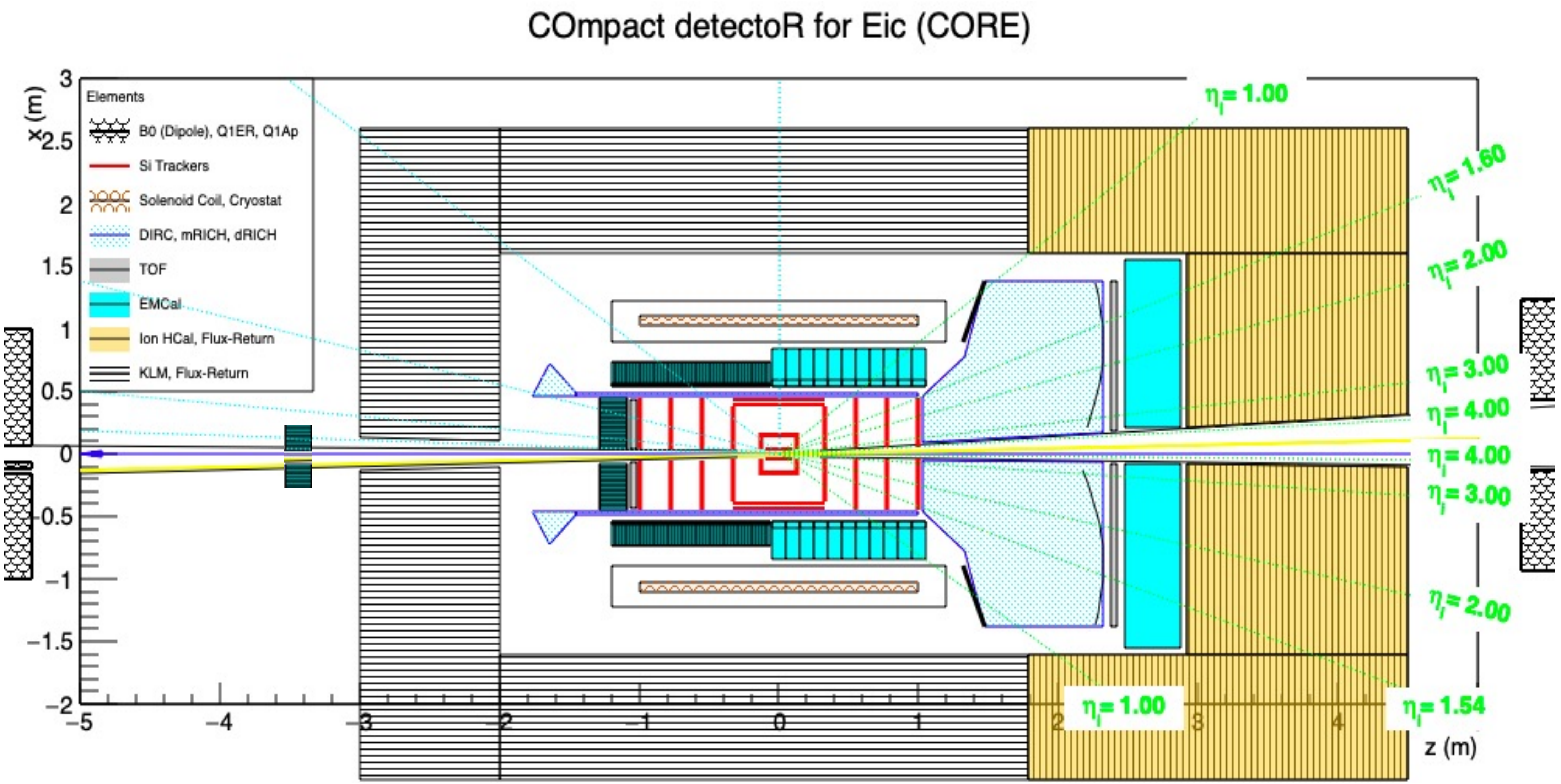


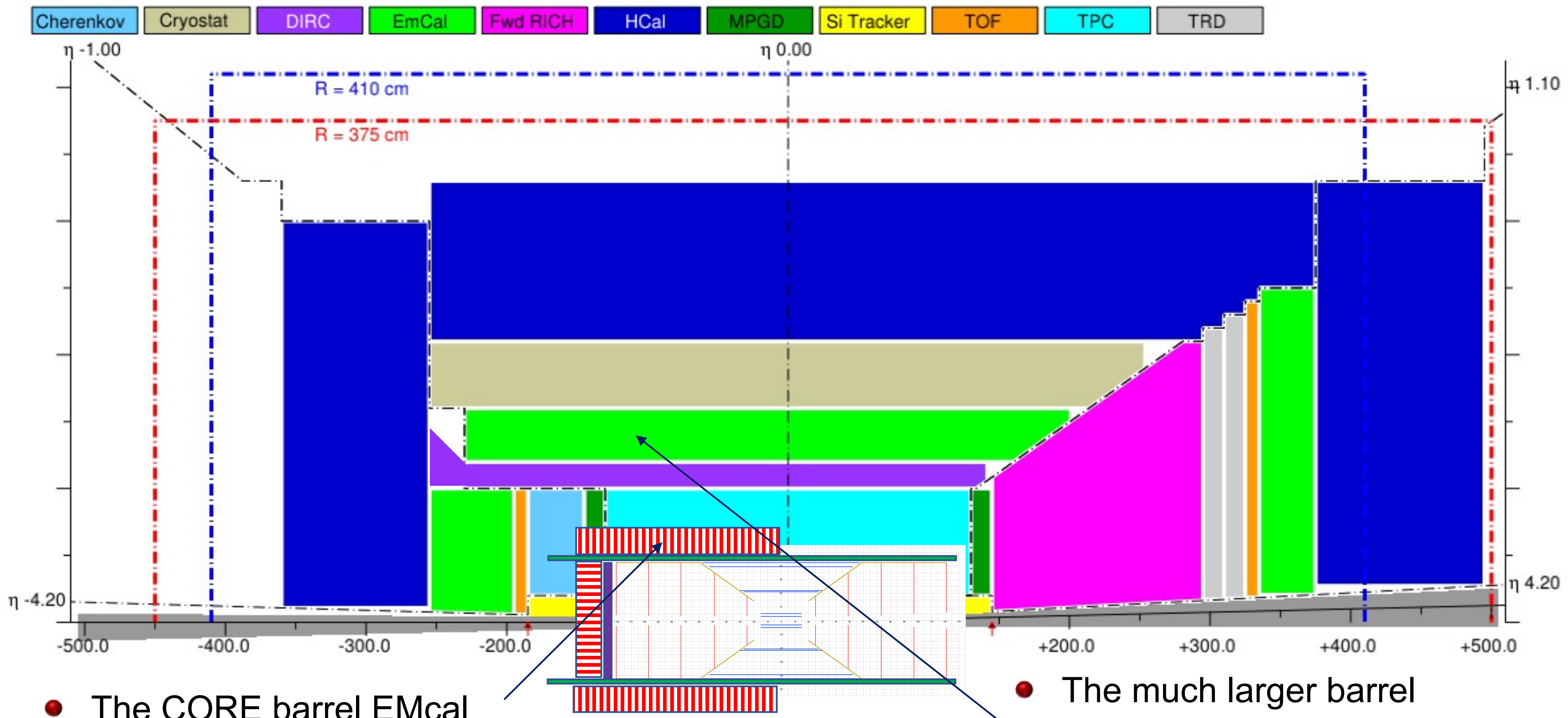
Figure 8.19: Top-down sketch of FF hadron and electron lattices and the four detector systems used for the detection of FF charged and neutral particles.

Thank you!



COmpact detectoR for Eic (CORE)
Elements
B0 (Dipole), Q1ER, Q1Ap
Si Trackers
Solenoid Coil, Cryostat
DIRC, mRICH, dRICH
TOF
EMCal
Ion HCal, Flux-Return
KLM, Flux-Return
x (m)
z (m)
η = 1.00
η = 1.60
η = 2.00
η = 3.00
η = 4.00
η = 4.00
η = 3.00
η = 2.00
η = 1.00
η = 1.54

CORE 2π PWO_4 EMcal superimposed on the YR reference detector



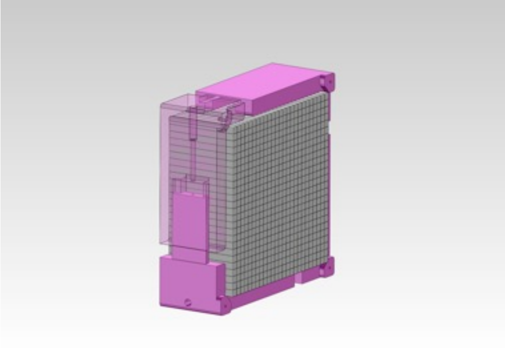
- The CORE barrel EMcal is shown in red/white
- The much larger barrel EMcal for the reference is shown in green.

Pre-showers for γ/π^0 separation

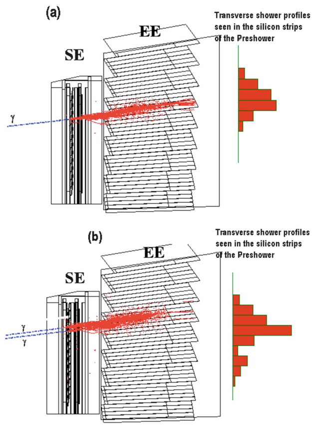
- W-Shashlyk may be have sufficient intrinsic position sensitivity not to require a separate pre-shower
  - R&D will determine optimal configuration.
  - No separate pre-shower needs to be implemented in simulation at this point

- PWO crystals can provide γ/π^0 separation at lower energies, but a pre-shower will improve separation and increase the energy range
  - Would PWO alone be sufficient for the EIC?
- Several PWO pre-shower options exist.
  - Simplified configuration in simulation?

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



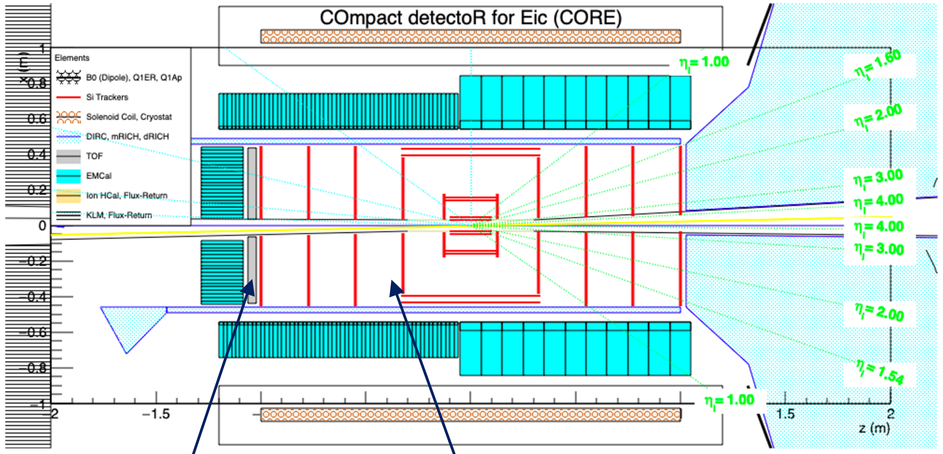
Hadron Identification in the electron endcap

- While high-resolution TOF is not competitive with Cherenkov detectors in the central barrel (small radius), it could be a good solution for the electron endcap.

- t_0 can be obtained using an electron scattered into the endcap and/or a separate ”start” layer integrated with the Si-tracker.

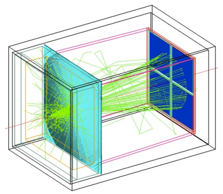
- The TOF installation is modest and resolution could improve through future upgrades.

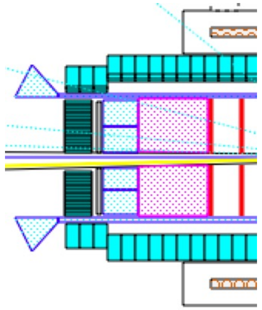
- Alternatively, CORE could also support an aerogel RICH (*e.g.*, the mRICH) by extending the endcap by 30 cm, for which there is plenty of space - although this would also extend the length of the PWO_4 EMcal.



A Si timing “start” layer could be added in-between disks

High-resolution TOF using LGADs (eRD29) or LAPPDs (which work up to 2 T)





Complementarity?