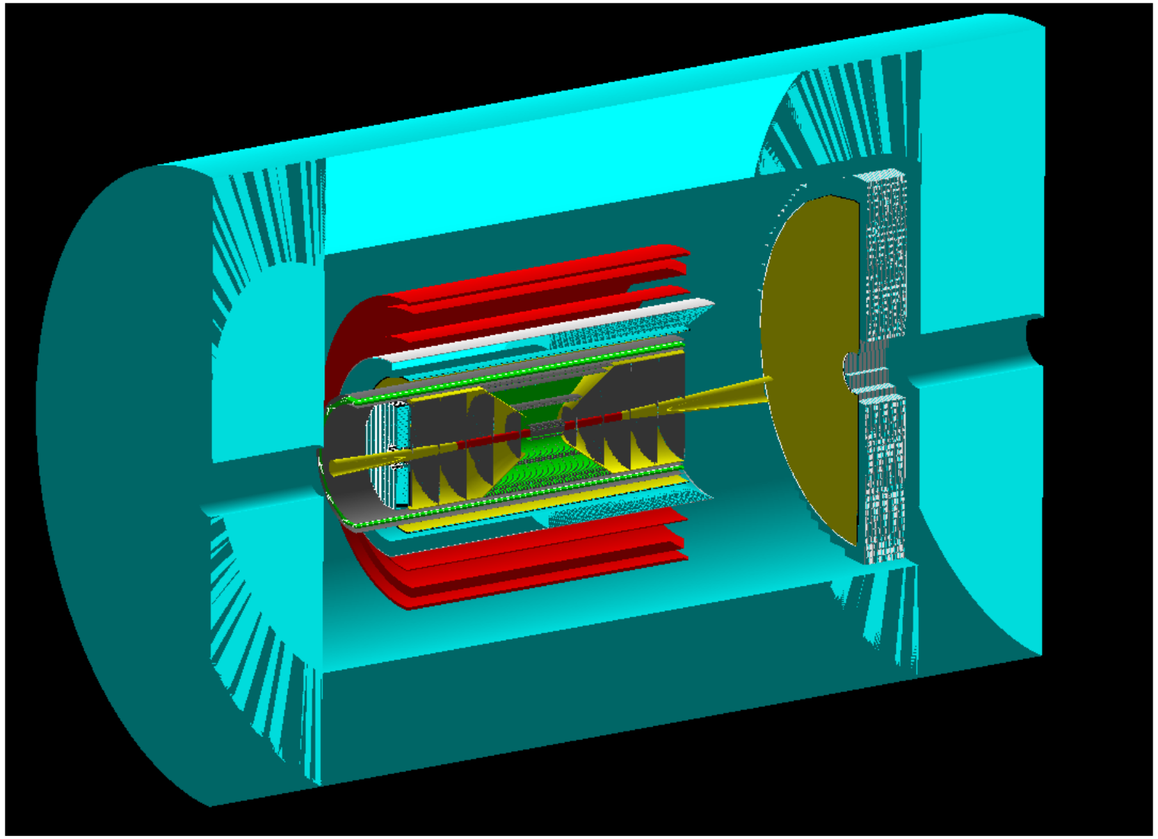
CORE: a COmpact detectoR for the EIC

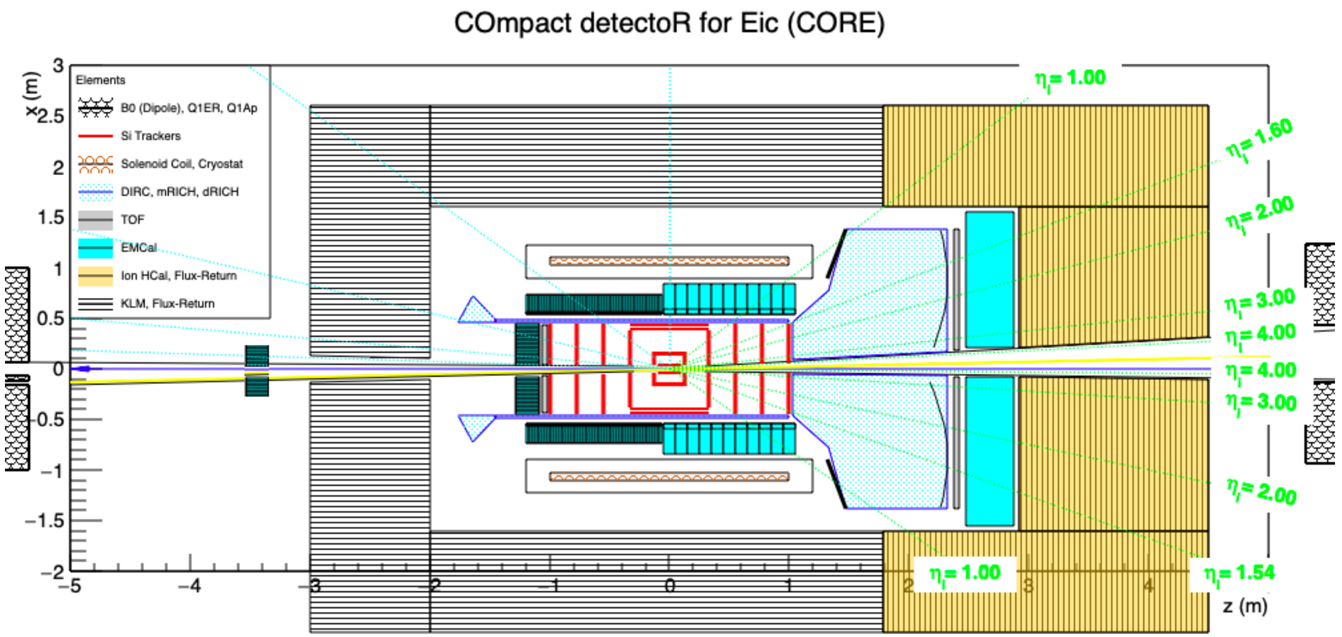


Pawel Nadel-Turonski

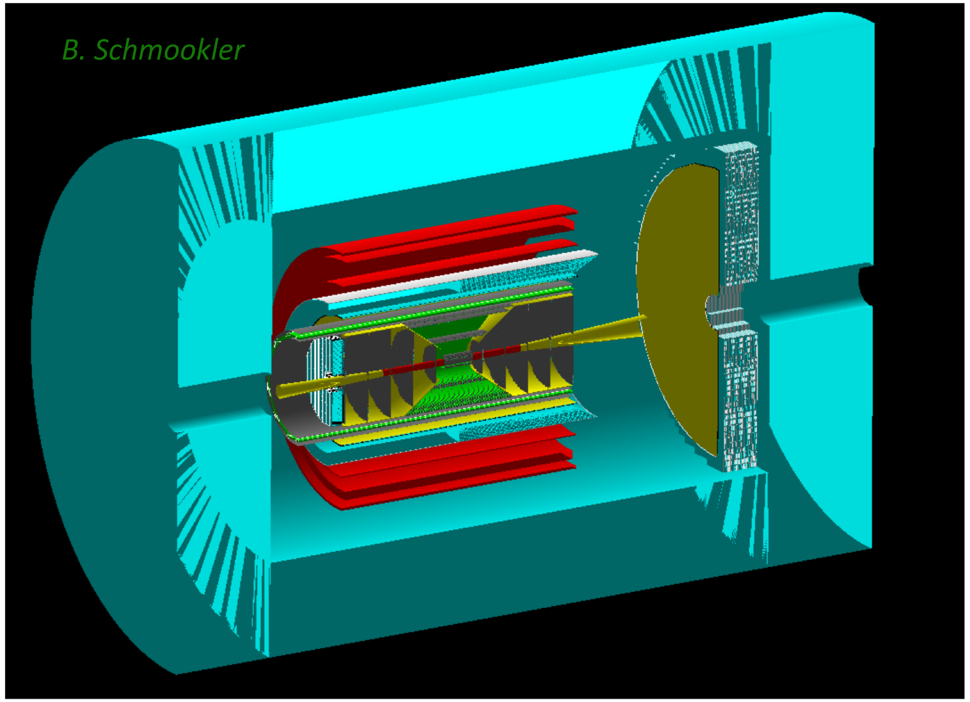
Stony Brook University

CFNS CORE workshop, March 29-30, 2021

a COmpact detectoR for the Eic (CORE)



CORE in Geant (fun4all)

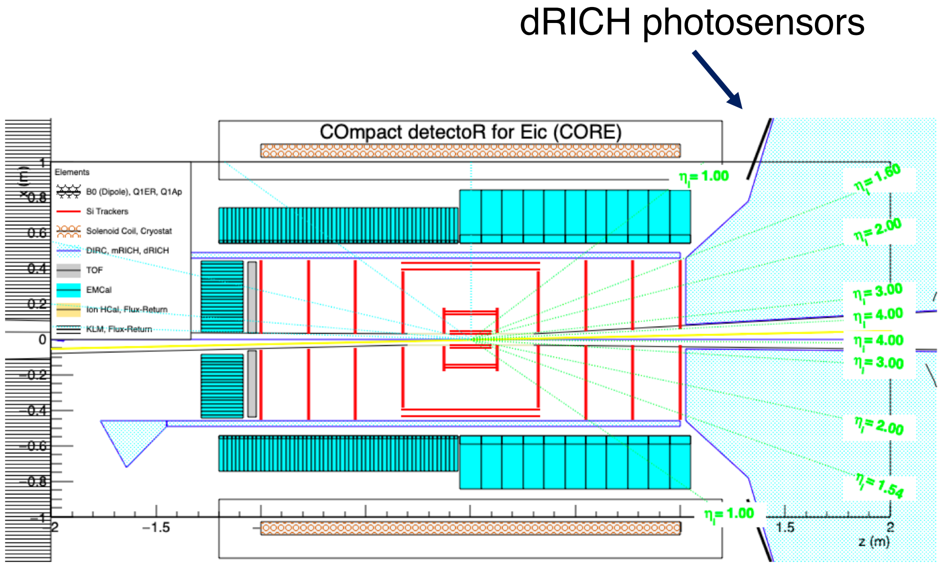


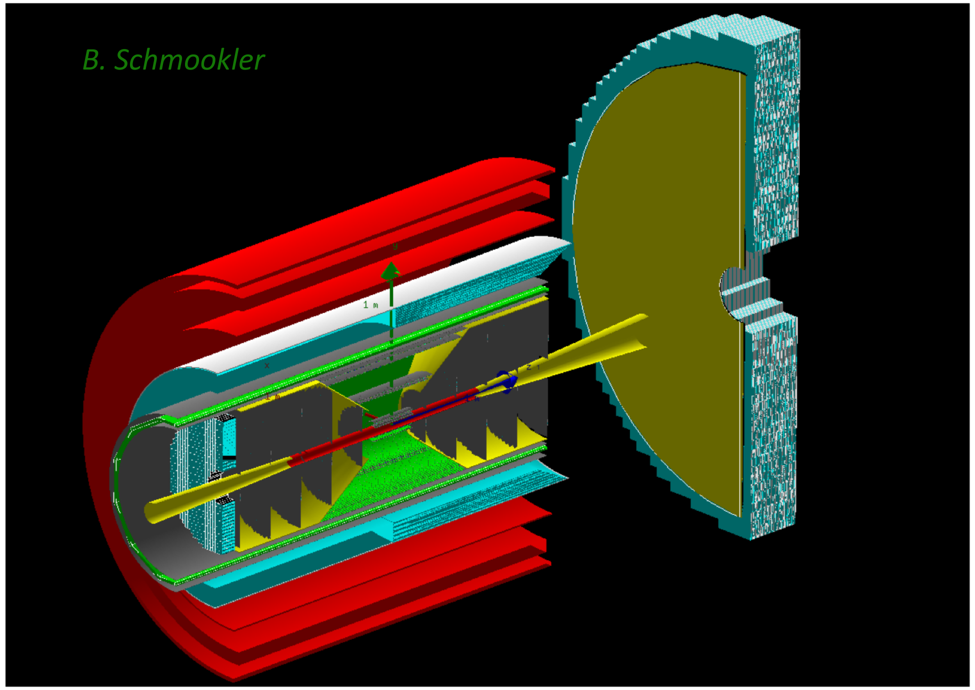
- A (nearly) hermetic general-purpose detector that fulfills the EIC physics requirements
- A small size, in particular of the inner systems, is cost-effective and allows:
  1. An overall reduction in cost without performance loss
  2. Improved performance in critical areas without large additional cost

  Balance can be different in a Detector 1 or 2 proposal
- Risk is minimized by utilizing subsystems from the Generic EIC R&D program

The core of CORE

inner CORE in Geant (fun4all)

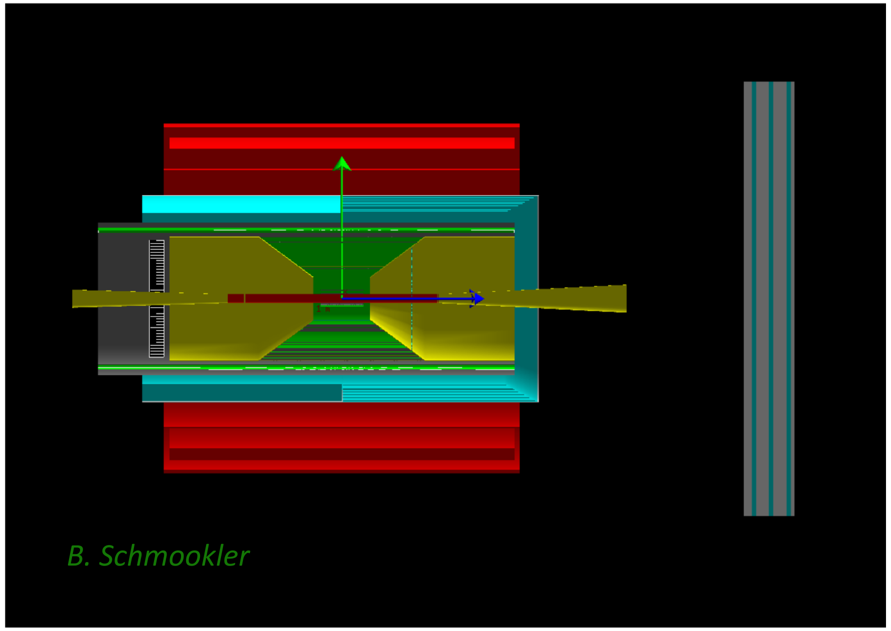




- Small solenoid (2.5 m long, 0.9 m inner radius)
  - could be new, but compatible with ZEUS
- Small central all-Si tracker (eRD25)
- Radially compact, high-performance barrel DIRC Cherenkov (eRD14)
- Dual-radiator RICH with *outward-reflecting* mirrors in the hadron endcap (eRD14)
- Extended PWO_4 EMcal coverage (up to 2π, $\eta < 0$) on the electron side (eRD1)

Solenoid options

- The CORE solenoid is 2.5 m long with a 0.9 m inner radius
- CORE is compatible with any field in the 2-4 T range
- 4 T is affordable due to the small volume of CORE
  - Can be operated at 2 T (better acceptance, hID)
- 2 T is the current low-cost, low-risk baseline option
- Ultimately the choice of field will be a collaboration decision



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**

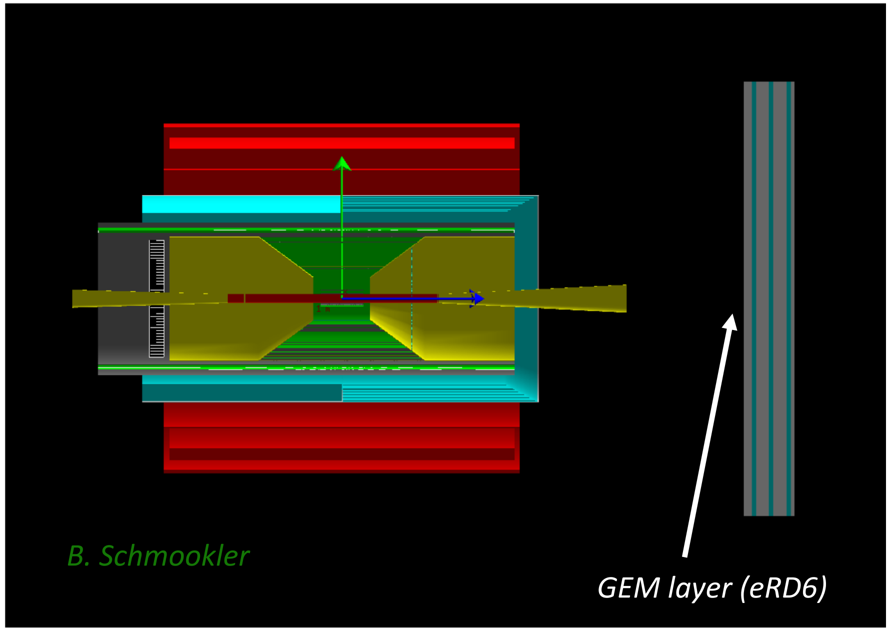
- The CORE and ZEUS solenoids have similar dimensions, and the latter could be used for CORE.
- However, the low cost of a new 2 T solenoid limits the benefits of re-use.

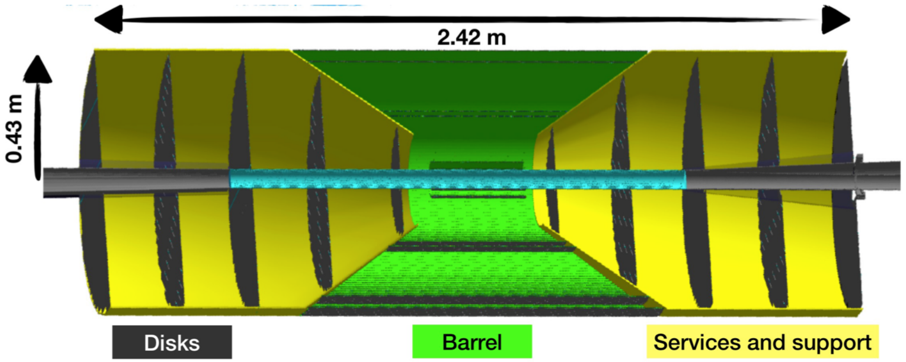
solenoid	field (T)	volume (m^3)	2020 cost (M$)	with 50% contingency
EIC-IP6	3	29	21	32
CORE	4	6.4	11	16
CORE	3	6.4	7	11
CORE	2	6.4	4	6

Central Si-tracker

--> talk by E. Sichtermann

- A silicon tracker is compact, has a high resolution, and offers opportunities for future upgrades.
- The tracker developed by eRD25 would utilize ALICE ITS3 technology and is designed for the angular resolution requirements of the DIRC, making it a good choice for CORE





eRD25 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

Note: modern microprocessors use 7 nm technology. The (unfair) comparison shows an opportunity for future improvements.

CORE in the context of the Yellow Report

- CORE systems are all designed to provide a cost or performance advantage, or be complementary to the YR reference detector

- A small DIRC, for instance, provides the same performance as a large one, but is cheaper.

- The small size makes CORE particularly suited for improving performance in two key areas: (e-side) electron ID and (h-side) hadronic calorimetry
  - highlighted in the YR “matrix”

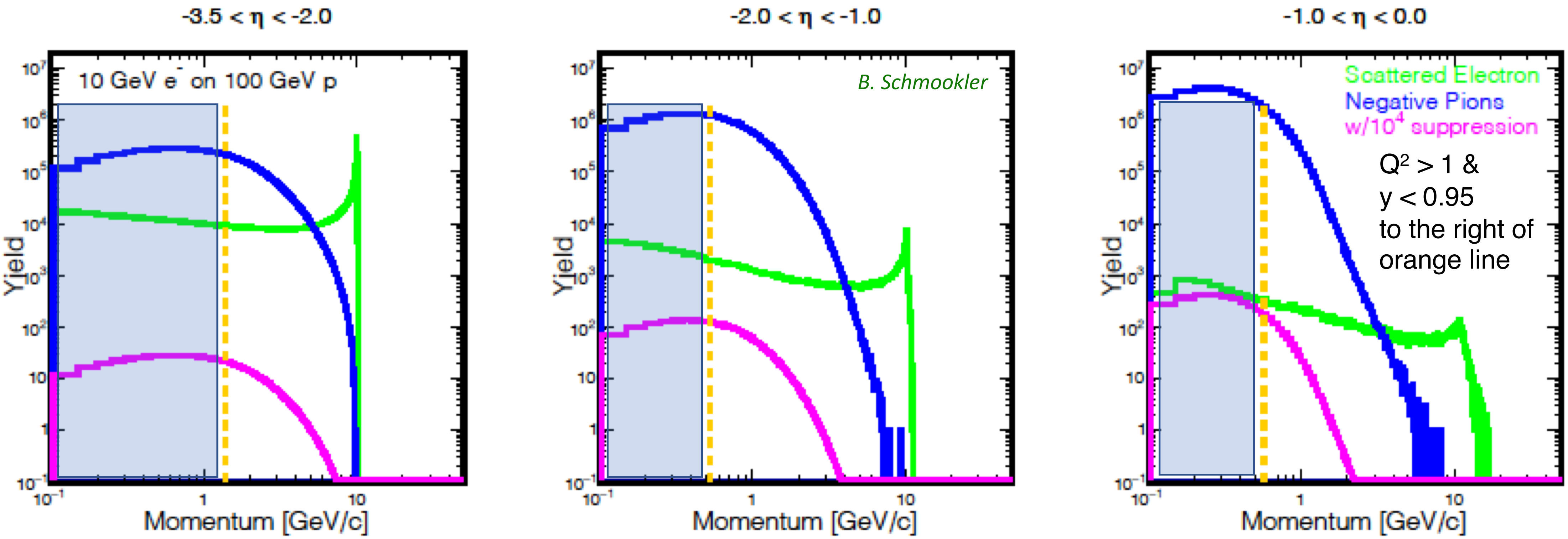
YR table 10.6
requirement matrix

η		Nomenclature		Tracking				Electrons and Photons			π/K/p		HCAL		Muons
				Resolution	Allowed	minimum-pT	Si-Vertex	Resolution σE/E	PID	min E	p-Range	Separati	Resolution σE/E	Energy	
-6.9 to -5.8			low-Q2 tagger	σθ/θ < 1.5%; 10-6 < Q2 < 10-2 GeV2											
-5.0 to -4.5						300 MeV pions									
-4.5 to -4.0			Instrumentation to separate charged particles from photons			300 MeV pions		2%/√E(+1-3%)		50 MeV					
-4.0 to -3.5	↓ p/A	Auxiliary De								50 MeV			~50%/√E + 6%		
-3.5 to -3.0										50 MeV					
-3.0 to -2.5			Backward Detector	σpT/pT ~ 0.1%⨁0.5%			σ_xy ~ 30/pT µm + 40 µm			50 MeV					
-2.5 to -2.0				σpT/pT			σ_xy ~ 30/pT µm + 20 µm	2%/√E(+1-3%)		50 MeV	≤ 7 GeV/c		~45%/√E+6%		
-2.0 to -1.5				σpT/pT 0.05%⨁0.5%				7%/√E(+1-3%)	π suppression up to 1:1E-4	50 MeV					muons useful for bkg, improve resolution
-1.5 to -1.0								7%/√E(+1-3%)		50 MeV					
-1.0 to -0.5							σxyz ~ 20 µm, d0(z) ~d0(rΦ) ~ 20/pTGeV µm + 5 µm			50 MeV			~85%/√E+7%		
-0.5 to 0.0		Central Detector	Barrel	σpT/pT ~0.05%×pT+0.5%	~5% or less X					50 MeV	≤ 10 GeV/c		~85%/√E+7%	~500 MeV	
0.0 to 0.5										50 MeV		≥ 3 σ	~85%/√E+7%		
0.5 to 1.0										50 MeV	≤ 15 GeV/c		~85%/√E+7%		
1.0 to 1.5				σpT/pT ~0.05%×pT+1.0%		<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT µm + 20 µm			50 MeV	≤ 30 GeV/c				
1.5 to 2.0										50 MeV	≤ 50 GeV/c				
2.0 to 2.5										50 MeV					
2.5 to 3.0			Forward Detectors	σpT/pT ~ 0.1%×pT+2.0%			σ_xy ~ 30/pT µm + 40 µm	(10-12)%/√E(+1-3%)	3σ e/π	50 MeV	≤ 30 GeV/c		35%/√E		
3.0 to 3.5							σ_xy ~ 30/pT µm + 60 µm			50 MeV	≤ 45 GeV/c				
3.5 to 4.0			Instrumentation to separate charged particles from photons	Tracking capabilities are desirable for forward tagging						50 MeV					
4.0 to 4.5	↑ e	Auxiliary Detectors								50 MeV			35%/√E (goal), <50%/√E (acceptable)*, 3mrad/√E (goal)		
4.5 to 5.0			Neutron Detection			300 MeV pions		4.5%/√E for photon energy > 20 GeV	<= 3 cm granularity	50 MeV					
>6.2			Proton Spectrometer	σintrinsic(|t|)/|t| < 1%; Acceptance: 0.2 < pt < 1.2 GeV/c											

- CORE also seeks complementarity with the reference detector by improving muon identification, which would be useful for, *e.g.,* charmonium production and GPD studies using timelike processes.

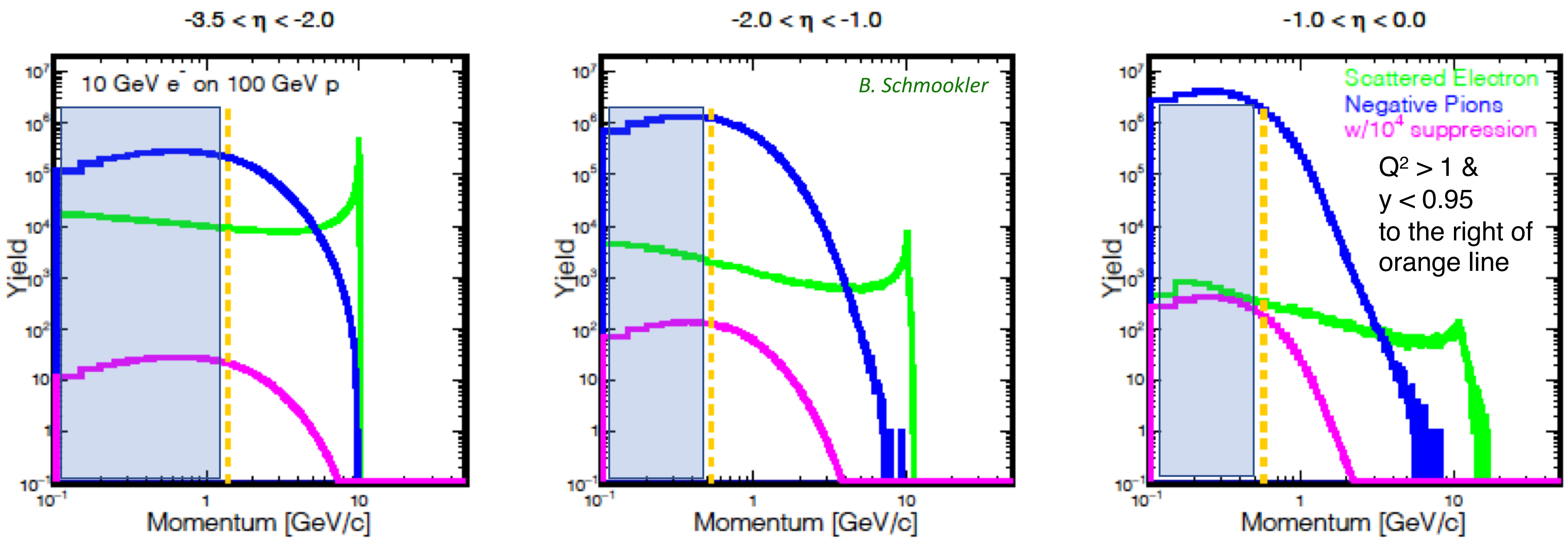
e/π identification in the electron hemisphere

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



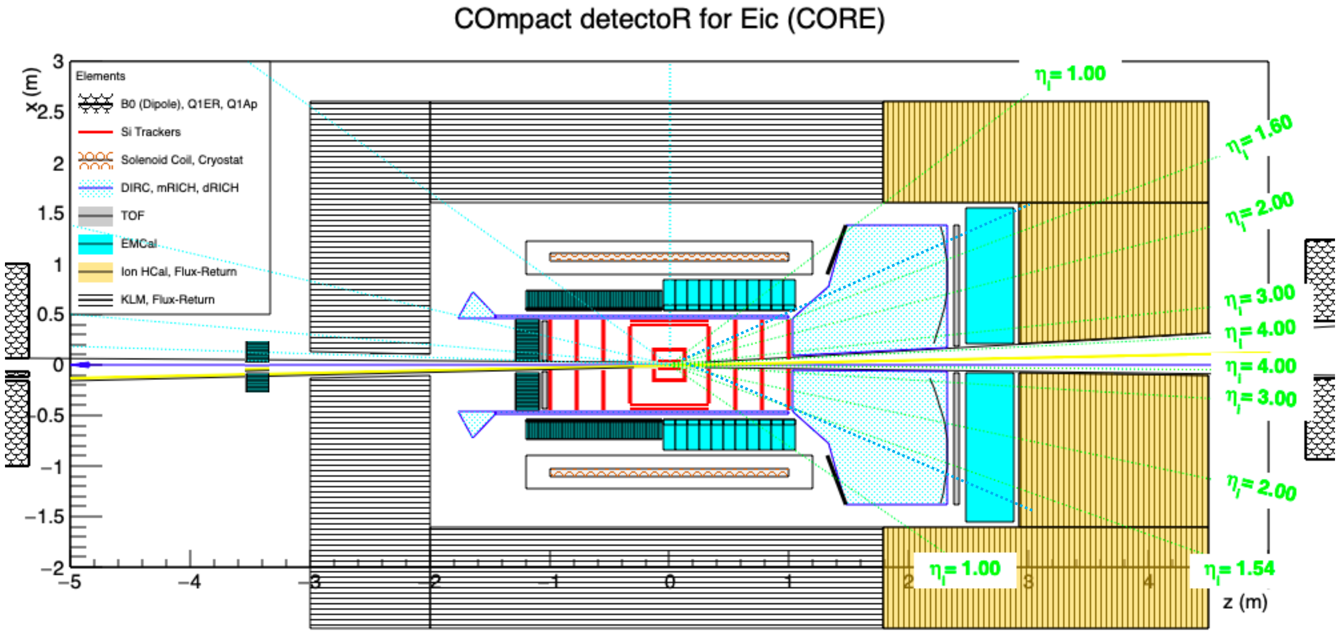
- For the EIC, a clean identification of the scattered electron is essential.
- The YR requirement matrix lists a pion suppression of up to 1:10^{-4} for the e-endcap and barrel.
- Since the relative pion background rises at larger (less negative) η, the barrel region poses the greatest challenge and requires the best electron ID.
- However, in the reference detector the best EMcal (PWO_4) only covers the inner endcap (η < -2).

CORE solution for e/π identification in the electron hemisphere

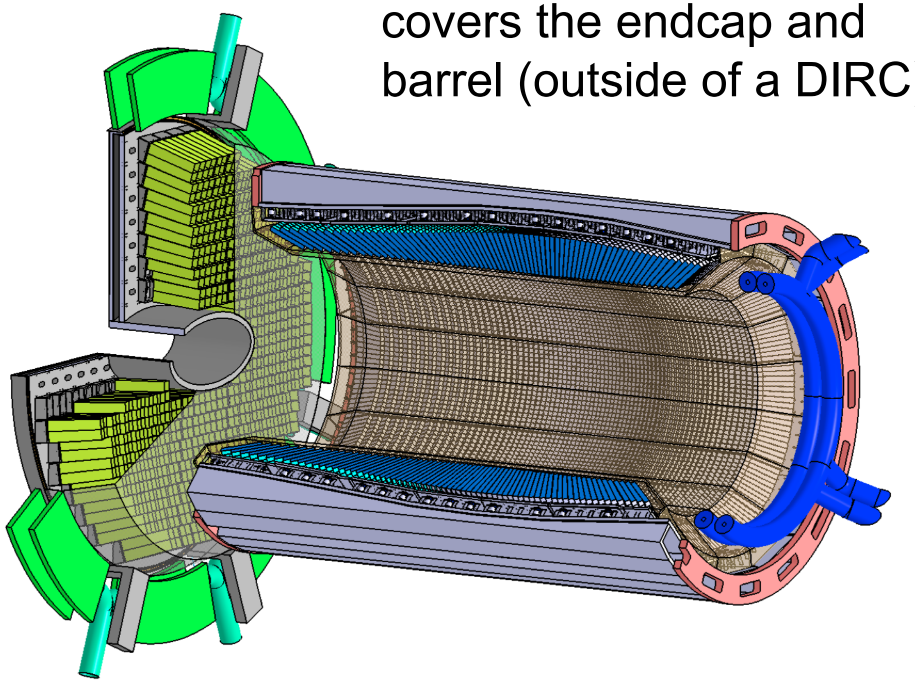


- CORE addresses the eID issue by extending the PWO_4 EMcal coverage up to $\eta < 0$.
- Additional e/π suppression (at least 1:10 up to 1.2 GeV) is also provided by the DIRC
- The result is a barrel eID configuration that can provide good pion suppression with a high electron efficiency (potentially enabling measurement of A_{PV}).
- A better energy resolution also improves photon detection in the electron hemisphere.

4π EMcal



The PANDA PWO_4 EMcal covers the endcap and barrel (outside of a DIRC)



up to 2π ($\eta < 0$) PWO_4 coverage *--> talk by C. Munoz Camacho*

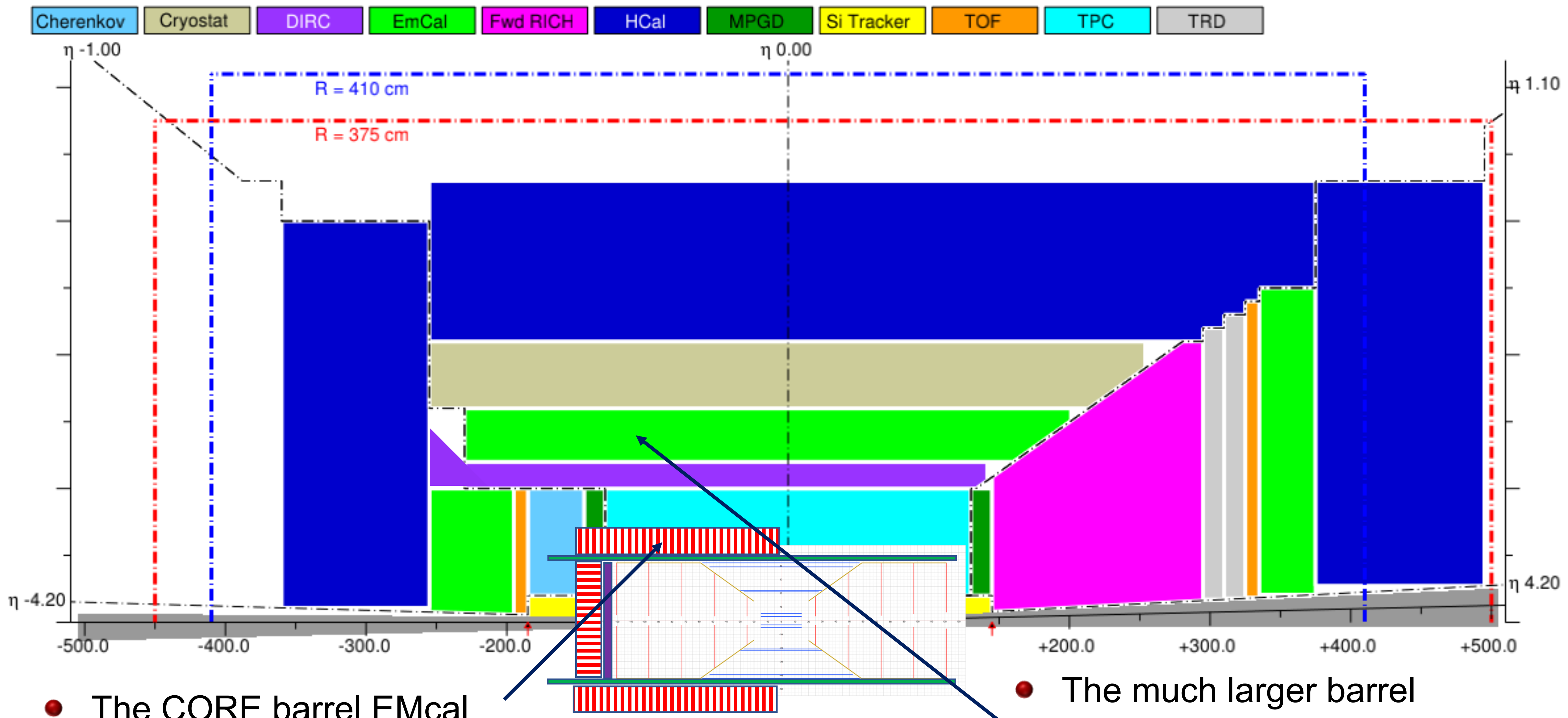
- The small size of CORE makes it affordable to extend the PWO_4 coverage up to 2π.
  - The PWO_4 area will be half or less of that planned for PANDA, which is similar in size to CORE
- An additional small-angle EMcal can be placed behind the main detector endcap

$\eta > 0$ coverage (several options – including pre-showers for γ/π^0)

--> talk by C. Woody

- The $\eta > 0$ barrel EMcal should be relatively compact and projective
- The endcap EMcal needs to be affordable and work well with a high-resolution Hcal

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.

Hadronic calorimetry

--> talk by O. Tsai

YR table 10.6 requirement matrix

- The inner part of CORE is independent of the Hcal configuration.
- But the smaller size of CORE makes a high-resolution Hcal in the hadron endcap (η > 2) a particularly interesting option.
- This would have a significant impact on measurements of jets where the energies are highest and tracking is least efficient

η		Nomenclature		Tracking: Resolution	Tracking: Allowed	Tracking: minimum-pT	Tracking: Si-Vertex	Electrons and Photons: Resolution σ_E/E	Electrons and Photons: PID	Electrons and Photons: min E	π/K/p: p-Range	π/K/p: Separation	HCAL: Resolution σ_E/E	HCAL: Energy	Muons
-6.9 to -5.8			low-Q2 tagger	σθ/θ < 1.5%; 10-6 < Q2 < 10-2 GeV2											
-5.0 to -4.5						300 MeV pions									
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-0.5 to 0.0		Central Detector			~5% or less X					50 MeV			~85%/√E+7%	~500 MeV	
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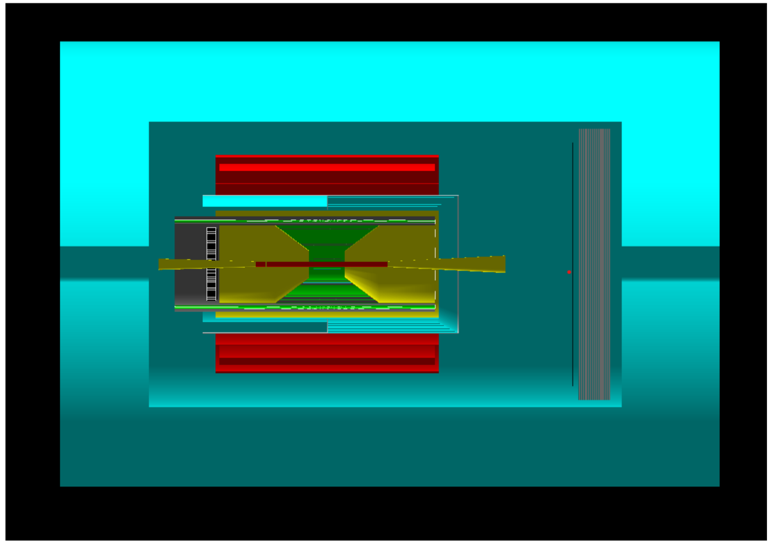
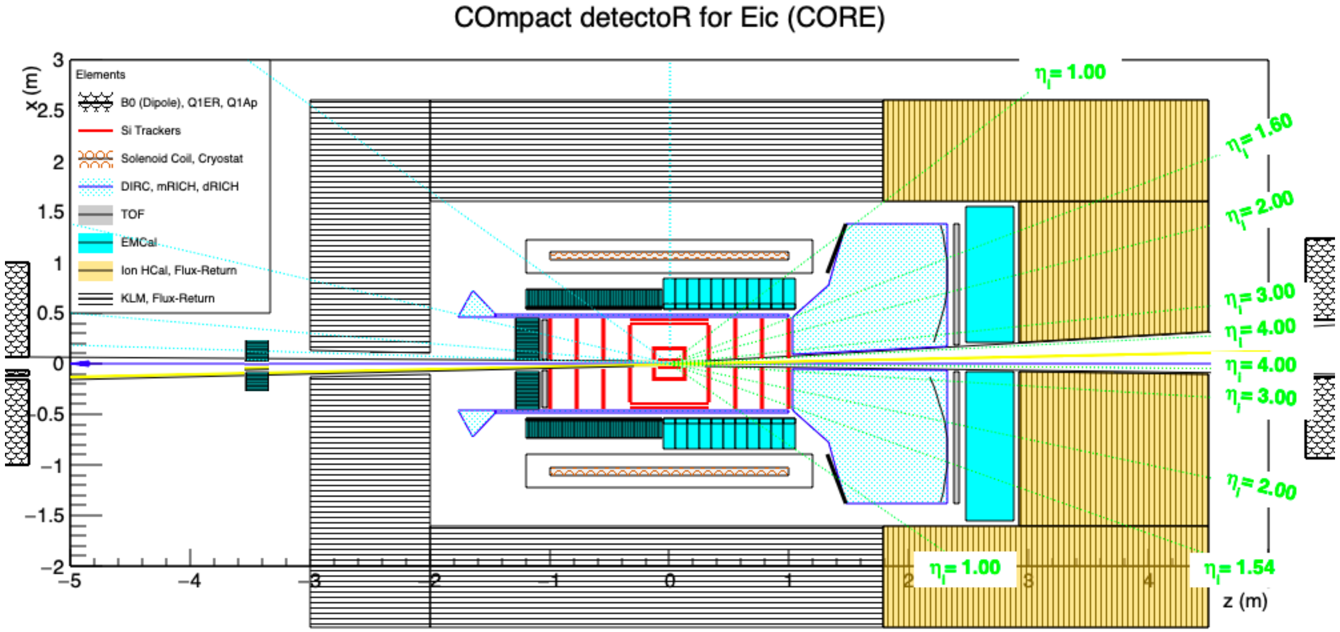
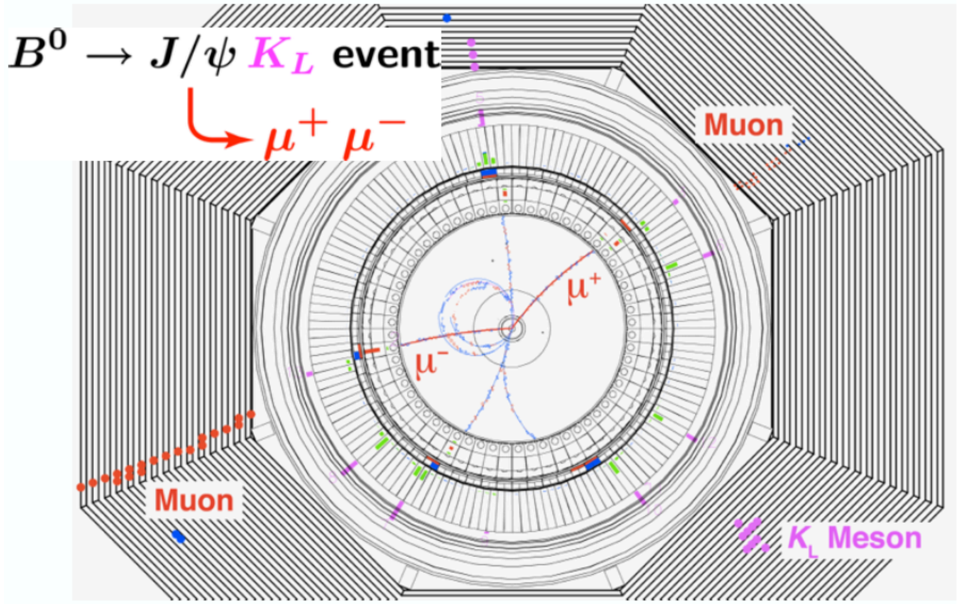


- In the barrel and electron endcap, jet energies are lower and jets are best reconstructed from individual tracks (tracking, PID, EMcal).
- Here, the Hcal is mainly used for individual low-momentum neutral hadrons (mostly K_L). Resolution has a more limited impact.

Muon ID



The Belle II K_L-μ (KLM) system



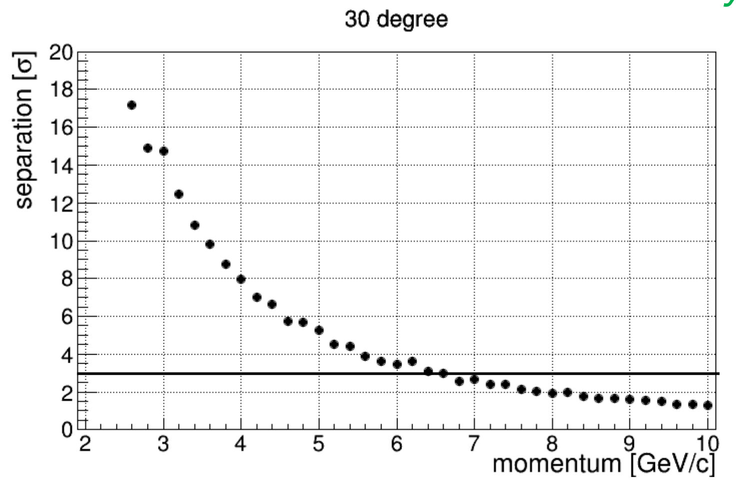
- At the EIC, mid-rapidity muons have relatively low momenta, and it is important to minimize multiple scattering (placing a muon detector behind an Hcal is not feasible).
- Since jets are best reconstructed from individual tracks, one approach is to trade energy resolution for better muon and neutral hadron (K_L) ID, and lower cost (*cf.* Belle II KLM)

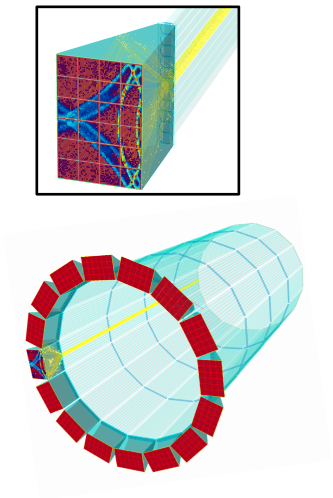
  --> talk by W. Jacobs
- One can also try to enhance the muon ID capability of a more conventional barrel Hcal, or improve the energy resolution of a KLM-inspired system

  --> talk by O. Tsai

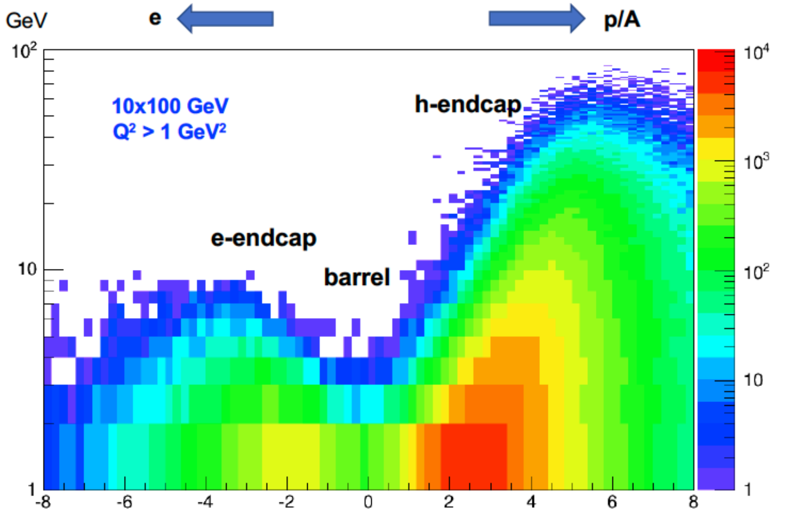
Hadron Identification in the barrel (hpDIRC) and hadron endcap (dRICH)

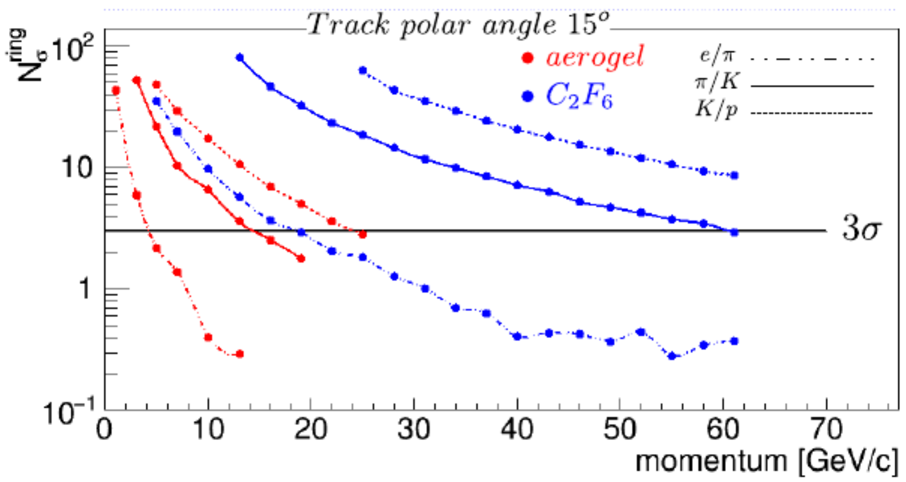
--> *talk by G. Kalicy*

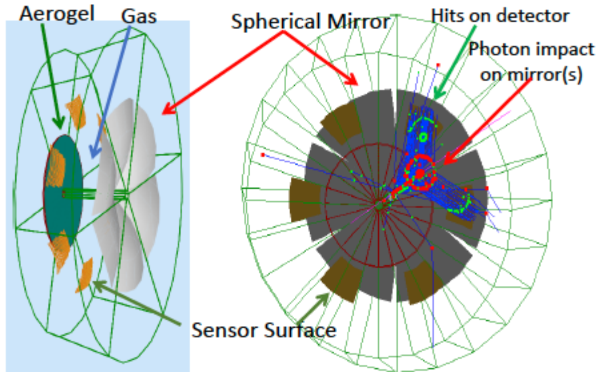




- The hpDIRC has a π/K separation of >4σ up to 6 GeV (and 2σ at 8 GeV).
- The minimum momentum for π/K ID in threshold mode is 0.2 GeV



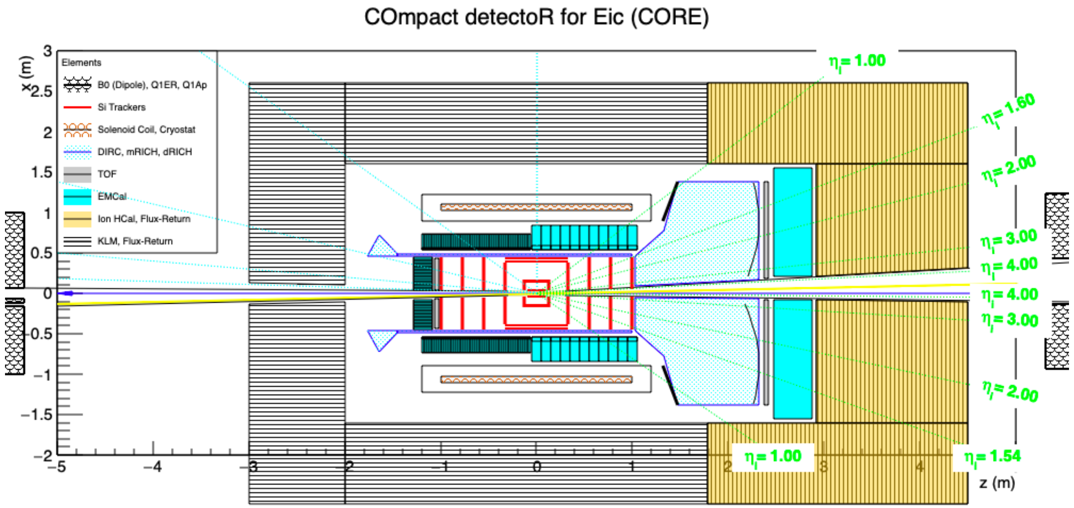




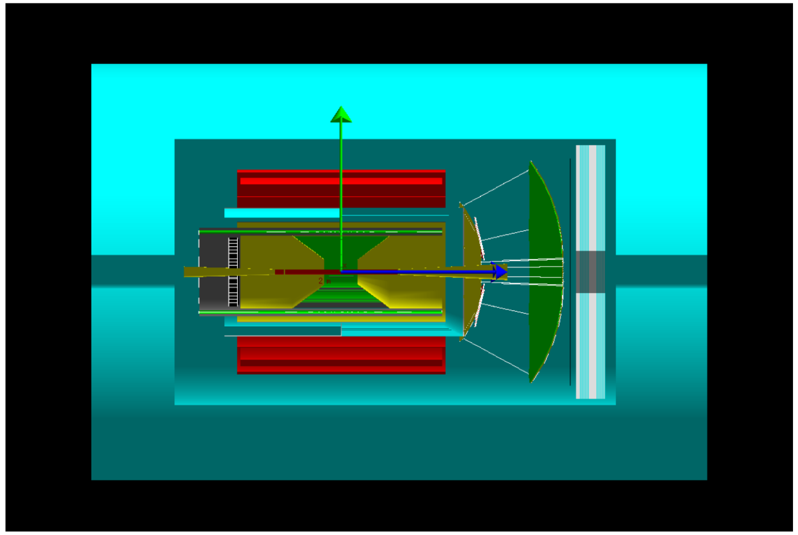
--> *talk by E. Cisbani, M. Contalbrigo*

- 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 (no TRD needed).
  - e/π: 10σ at 10 GeV

TOF in the hadron endcap



CORE with a dual-radiator RICH (eRD14)



CORE with a gas-only RICH (eRD6)
and LGAD-based TOF behind it

- The dual-radiator RICH (dRICH) is a cost-effective solution with continuous coverage over a wide momentum range, but a simple TOF system could provide PID for the lowest momenta below the aerogel thresholds.
- However, pending the implementation of the dRICH in fun4all, Geant simulations can start using a gas-only RICH in combination with high-resolution LGAD TOF, which is already implemented

Hadron Identification in the electron endcap

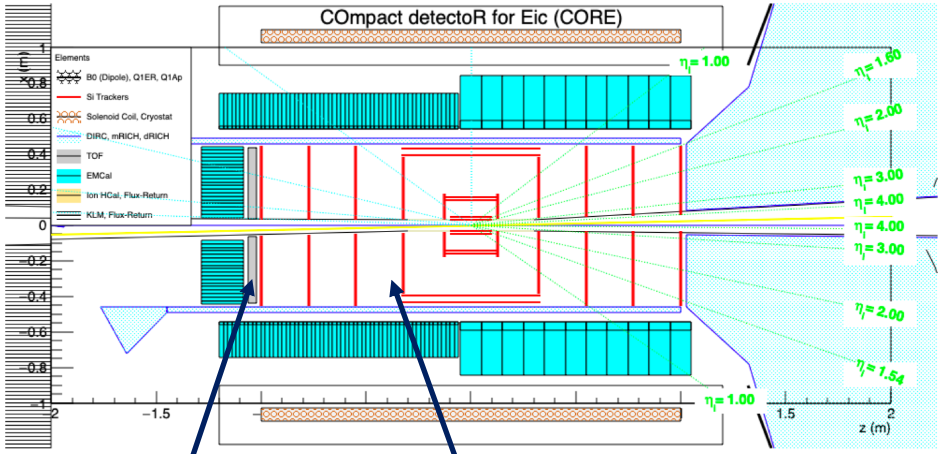
--> talk by G. Giacomini

- 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.

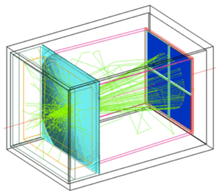
- The TOF installation is modest and resolution could improve through future upgrades.

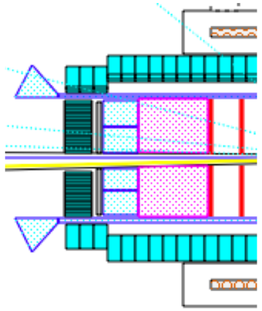
- Alternatively, CORE could also support an aerogel RICH (*e.g.*, the mRICH) by extending the endcap by 30 cm, for which there is plenty of space - although this would also extend the length of the PWO_4 EMcal.



A Si timing "start" layer (eRD29) could be added in-between disks

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





Complementarity?

Future upgrades – a few examples

- Rapidly evolving technologies create natural upgrade paths
  - Photosensors, Si-timing, S-tracking, optical meta materials, etc.

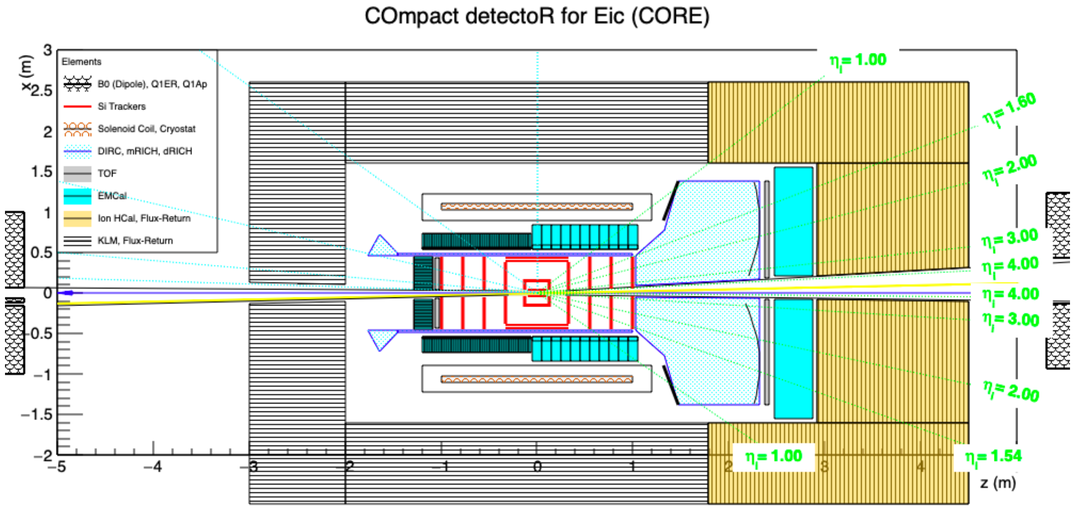
- Advances in photosensor timing beyond 100 ps rms can in the shorter term increase the momentum reach of the DIRC; SiPMs could provide tolerance to very high magnetic fields.

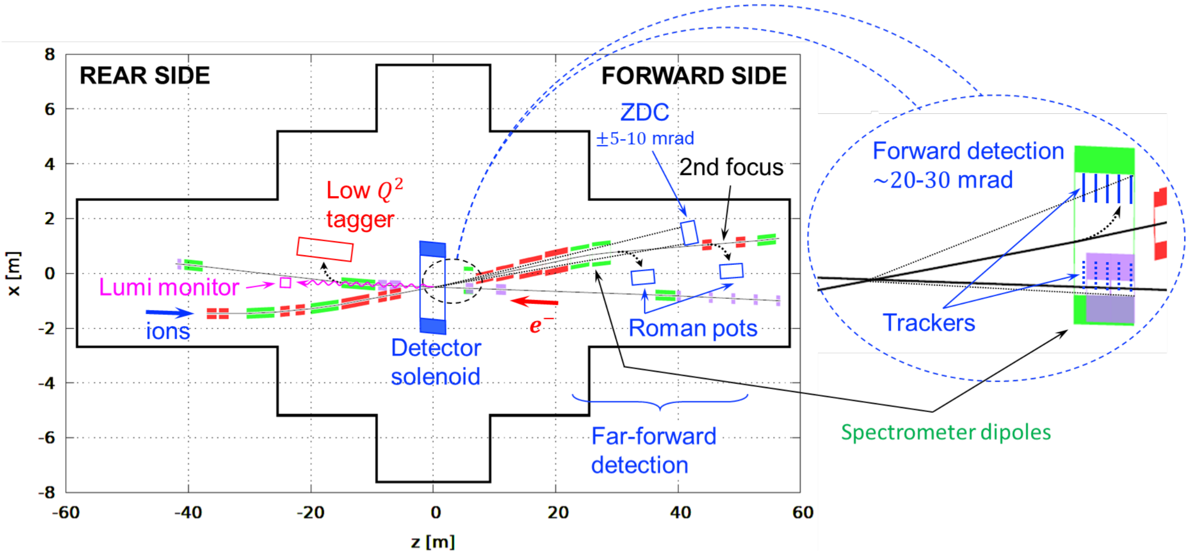
- The next generation of Si-trackers could improve position (momentum) resolution, readout speed, and further reduce mass.

- At the time of an EIC mid-life upgrade, optical metamaterials might be available for use as Cherenkov radiator, greatly improving momentum reach for compact PID systems.
  - Pioneering studies at SBU as part of eRD6

Thank you!

IR integration





- Despite its compact size, CORE has a lot of room available for supports and services

- In its nominal configuration, CORE fits into a -3 m to +4.5 m IR space.

YR requirement matrix

YR table 10.6

η	Nomenclature			Tracking				Electrons and Photons			π/K/p		HCAL		Muons
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-2.5 to -2.0				σpT/pT			σ_xy ~ 30/pT µm + 20 µm	2%/√E(+1-3%)		50 MeV					
-2.0 to -1.5				σpT/pT 0.05%⊕0.5%				7%/√E(+1-3%)	π suppression up to 1:1E-4	50 MeV					muons useful for bkg, improve resolution
-1.5 to -1.0								7%/√E(+1-3%)		50 MeV					
-1.0 to -0.5			Barrel	σpT/pT ~0.05%×pT+0.5%			σxyz ~ 20 µm, d0(z) ~d0(rΦ) ~ 20/pTGeV µm + 5 µm			50 MeV	≤ 10 GeV/c		~85%/√E+7%		
-0.5 to 0.0		Central Detector			~5% or less X					50 MeV		≥ 3 σ	~85%/√E+7%	~500 MeV	
0.0 to 0.5										50 MeV			~85%/√E+7%		
0.5 to 1.0										50 MeV	≤ 15 GeV/c		~85%/√E+7%		
1.0 to 1.5										50 MeV	≤ 30 GeV/c				
1.5 to 2.0				σpT/pT ~0.05%×pT+1.0%		<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT µm + 20 µm			50 MeV	≤ 50 GeV/c				
2.0 to 2.5										50 MeV					
2.5 to 3.0			Forward Detectors				σ_xy ~ 30/pT µm + 40 µm	(10-12)%/√E(+1-3%)	3σ e/π	50 MeV	≤ 30 GeV/c		35%/√E		
3.0 to 3.5				σpT/pT ~ 0.1%×pT+2.0%			σ_xy ~ 30/pT µm + 60 µm			50 MeV	≤ 45 GeV/c				
3.5 to 4.0			Instrumentation to separate charged particles from photons	Tracking capabilities are desirable for forward tagging						50 MeV					
4.0 to 4.5	↑ e	Auxiliary Detectors								50 MeV			35%/√E (goal), <50%/√E (acceptable)*, 3mrad/√E (goal)		
4.5 to 5.0			Neutron Detection			300 MeV pions		4.5%/√E for photon energy > 20 GeV	<= 3 cm granularity	50 MeV					
>6.2			Proton Spectrometer	σintrinsic(|t|)/|t| < 1%; Acceptance: 0.2 < pt < 1.2 GeV/c											

YR detector subsystem matrix

YR table 11.50

η	θ	Nomenclature			Tracking						Electrons and Photons			π/K/p		HCAL		Muons
					Resolution	Relative Momentum	Allowed X/X_0	Minimum-pT	Transverse Pointing Res.	Longitudinal Pointing Res.	Resolution σ_E/E	PID	Min E Photon	p-Range (GeV/c)	Separation	Resolution σ_E/E	Energy	
< -4.6			Far Backward Detectors	low-Q2 tagger														
-4.6 to -4.0		↓ p/A			Not Accessible													
-4.0 to -3.5						Reduced Performance												
-3.5 to -3.0						σp/p ~0.2%×p⊕5%												
-3.0 to -2.5											1%/E ⊕ 2.5%/√E ⊕ 1%	π suppression up to 1:1E-4	20 MeV					
-2.5 to -2.0				Backward Detector				70-150 MeV/c (B=1.5 T)						≤ 10 GeV/c		50%/√E⊕10%		
-2.0 to -1.5						σp/p~ 0.04%×p⊕2%			dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(z) ~ 100/pT µm ⊕ 20 µm	2%/E ⊕(4-8)%/√E ⊕ 2%	π suppression up to 1:(1E-3 - 1E-2)	50 MeV					Muons useful for bkg, improve resolution
-1.5 to -1.0																		
-1.0 to -0.5																		
-0.5 to 0.0			Central Detector	Barrel		σp/p ~0.04%×p⊕1%	~5% or less X	200 MeV/c	dca(xy) ~ 30/pT µm ⊕ 5 µm	dca(z) ~ 30/pT µm ⊕ 5 µm	2%/E ⊕(12-14)%/√E ⊕ (2-3)%	π suppression up to 1:1E-2	100 MeV	≤ 6 GeV/c	≥ 3 σ	100%/ √E+10%	~500MeV	
0.0 to 0.5																		
0.5 to 1.0																		
1.0 to 1.5									dca(xy) ~ 40/pT µm ⊕ 10 µm									
1.5 to 2.0						σp/p ~0.04%×p⊕2%				dca(z) ~ 100/pT µm ⊕ 20 µm								
2.0 to 2.5				Forward Detectors				70 - 150 MeV/c (B = 1.5 T)			2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		50%/ √E+10%		
2.5 to 3.0						σp/p ~0.2%×p⊕5%												
3.0 to 3.5																		
3.5 to 4.0				Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5		↑ e			Not Accessible													
> 4.6			Far Forward Detectors	Proton Spectrometer Zero Degree Neutral Detection														