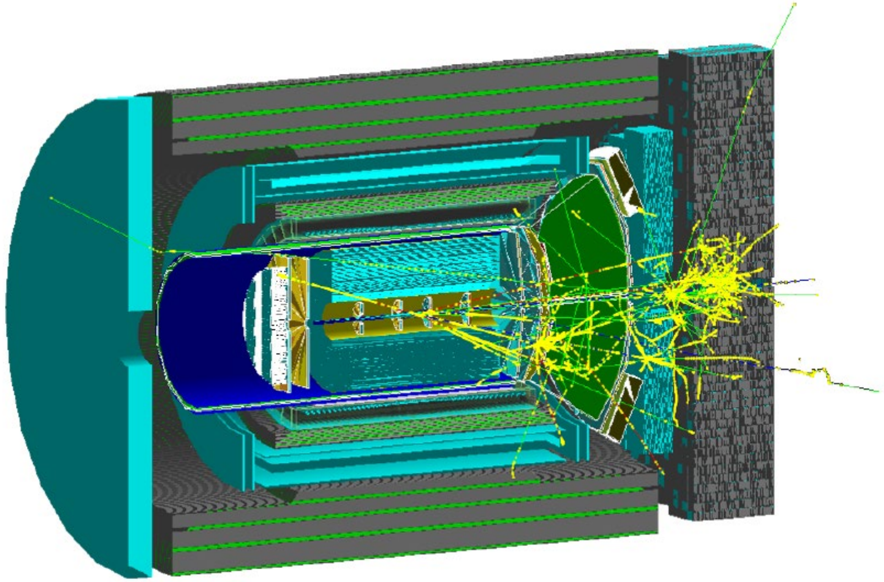
2018 Study for an EIC Detector with the BaBar Solenoid



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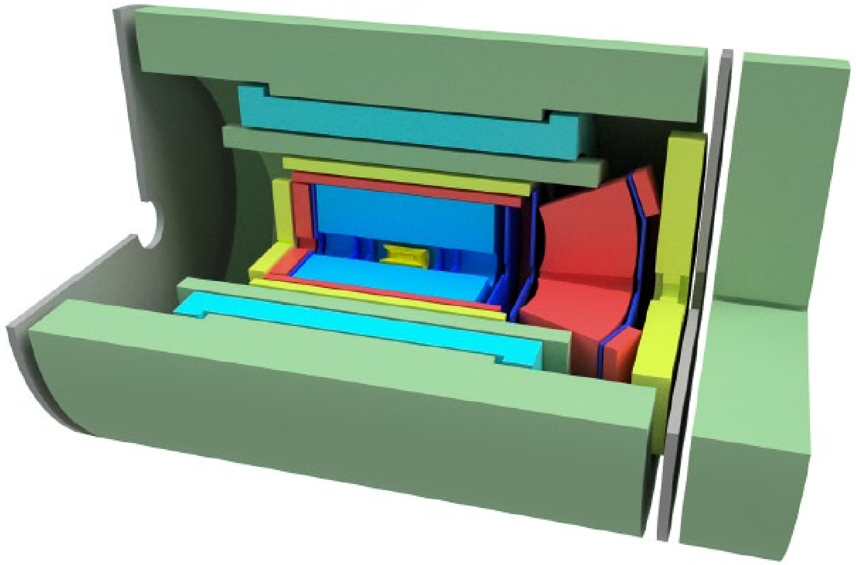
ECCE Workshop

February 11, 2021

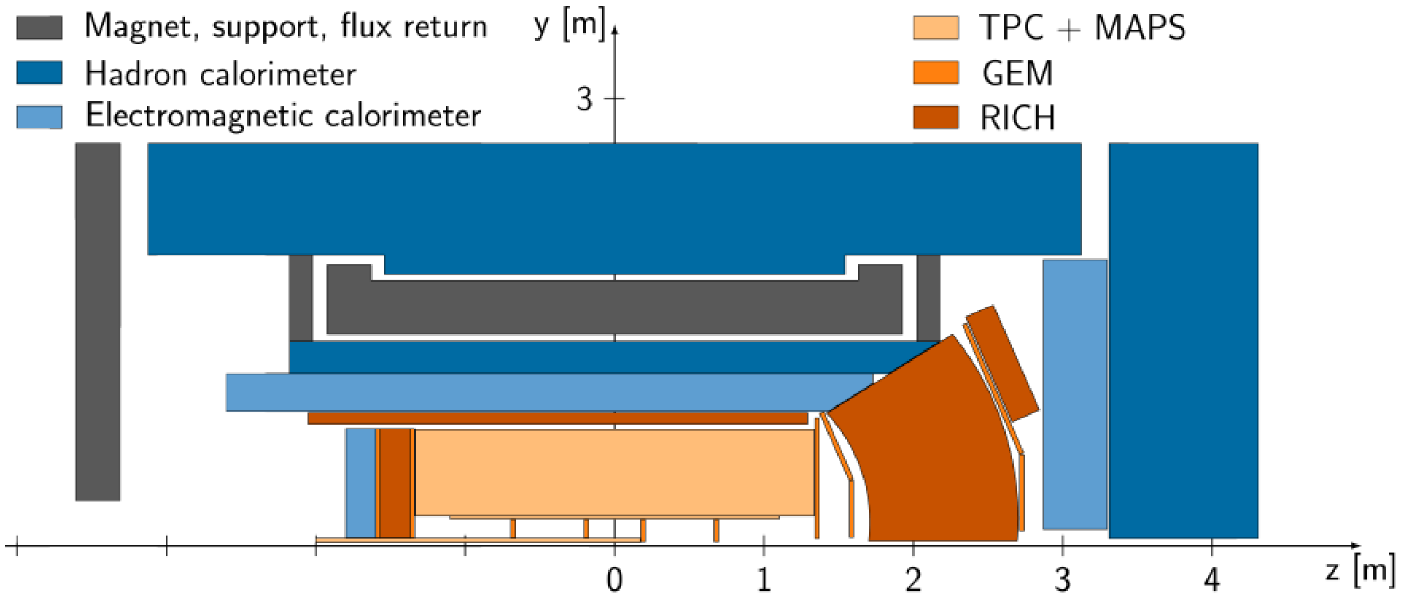


sPHENIX Note sPH-cQCD-2018-001, available at:
https://indico.bnl.gov/event/5283/attachments/20546/27556/eic-sphenix-dds-final-2018-10-30.pdf

Basic geometry considered for these studies

Table 2.1: EIC-sPHENIX Detector Coverage

Detector	pseudorapidity	Type
TPC + MAPS + GEM	(-4, 4)	Tracking
barrel EMCAL	(-1.55, 1.24)	Calorimetry
barrel inner HCAL	(-1.1, 1.1)	Calorimetry
barrel outer HCAL	(-1.1, 1.1)	Calorimetry
e-side EMCAL	(-4, -1.55)	Calorimetry
h-side EMCAL	(1.24, 4)	Calorimetry
h-side HCAL	(1.24, 4)	Calorimetry
DIRC	(-1.4, 1.24)	PID
gas RICH	(1.24, 3.95)	PID
h-side mRICH	(1.10, 1.85)	PID
e-side mRICH	(-3.9, -1.4)	PID



(Far-forward detectors considered not shown here)

Reuse of sPHENIX components

sPHENIX components that are reused in the EIC-sPHENIX reference design:

- Magnet.
- Barrel Flux Return / Outer HCal (including SiPMs).
- Endcap Flux Return Door on electron-going side.
- TPC. Replace inner 1/3 sector endcaps to extend instrumentation towards the inner field cage. Reason: space charge not as large an issue, so additional path length can be used for tracking.
- TPC Electronics. Expected that the TPC dE/dx resolution can be recovered by different working point without modifications.
- Data Acquisition. At 10^{34} can handle full minbias event rate. However, investigation needed on rejection of the 10 MHz beam-gas rate.
- Detector infrastructure in BNL experimental hall 1008. Racks, computers, etc.

sPHENIX components that are removed or replaced in the EIC-sPHENIX reference design:

- Endcap Flux Return Door on hadron-going side needs to be removed; use magnetic HCAL in that direction as flux return.
- INTT - will not be reused.
- MVTX - Both MAPS staves and mechanical structure need to be changed out. eRHIC will have a larger beam pipe radius in the IR than RHIC. In addition, EIC-sPHENIX requires signal readout to higher z to avoid interference with high-pseudorapidity tracking.
- SiPMs for EMCal - need to be replaced.
- Electronics - EMCal and HCal electronics need to be changed to handle higher readout and bunch crossing rate.

sPHENIX components that are included with modification in the EIC-sPHENIX reference design:

- Barrel EMCal needs to be either extended in pseudorapidity or replaced by a different calorimeter to ensure sufficient electromagnetic calorimeter coverage in pseudorapidity.
- Inner HCAL - since its purpose in sPHENIX (CD-1 configuration) is as a holding structure for the EMCal, depends on decision of EMCal reuse and engineering of modification to EMCal to extend coverage.

Tracking

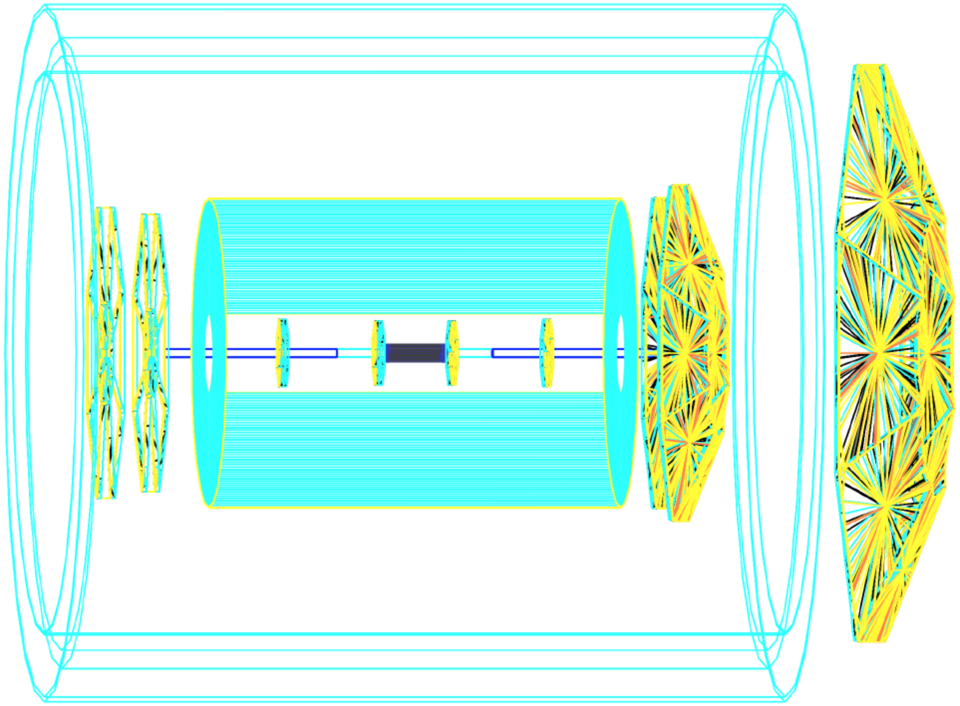


Figure 3.2: GEANT4 model of tracking detector setup. Yellow wire frames depict the forward/backward GEM stations. Light-blue volume represents the Time Projection Chamber. The black cylinder close to the interaction point shows the extension of the MVTX detector. In this drawing positive z is to the left side.

- Vertex tracker: MAPS staves, 3 layers silicon using ALICE's upgraded ITS stave station configuration using a realistic material budget. Sensitive pads considered fully efficient. Constant position smearing in $r\phi - z$ plane ($5 \times 5\ \mu m^2$) on the hit used to account for clusterization.

- TPC: Neon-based gas, 20 < r < 80 cm, |z|<105 cm. Inner and outer field cages included in material budget. Hits smeared 150 μm in $r\phi$ direction to account for pad segmentation; 0.5 mm in z direction to mimic time resolution from readout.

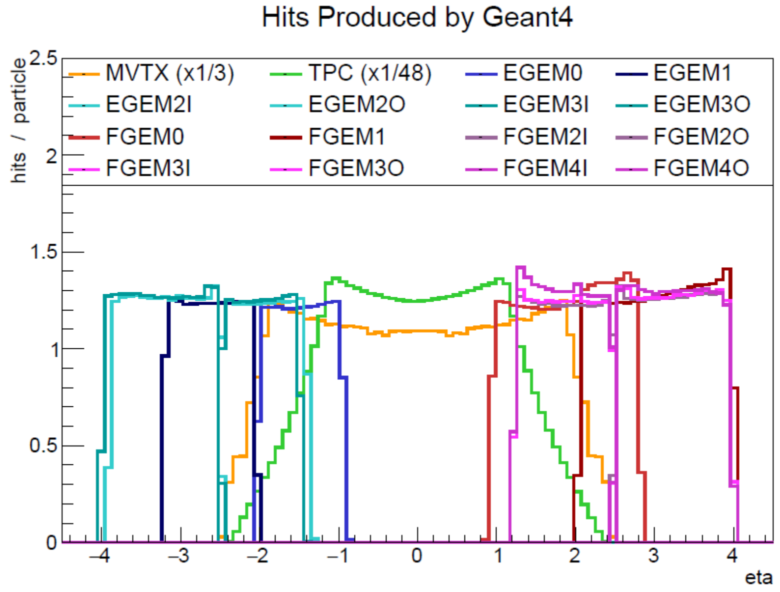
- Forward (FGEM) and backward (EGEM) tracking: Methane-GEM based tracking stations. Material budget for enclosure included in each station. EGEM – 4 stations. FGEM – 5 stations. Last two (E) or three (F) stations subdivided into inner and outer sections depending on pseudorapidity where pad segmentation changes to improve position resolution for $|\eta| > 2.5$.
  - Alternative technologies (silicon, MicroMegas, small-strip Thin Gap Chambers) for different layers also mentioned briefly in document but not studied in detail

- Track fitting using Kalman filter procedure from GenFit-2 package.
- Muons used in GEANT4 to study performance.

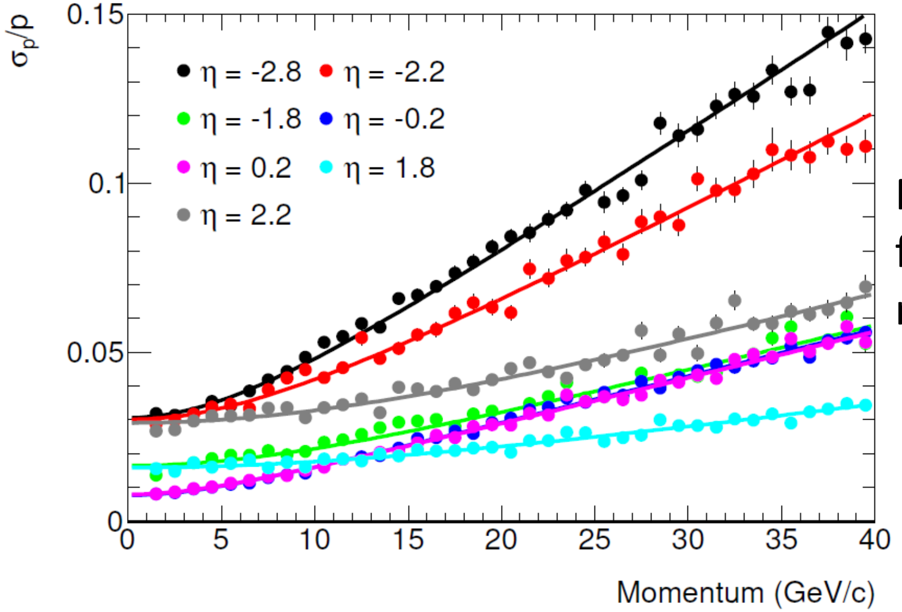
Tracking

	σ_R (mm)	$\sigma_{R\varphi}$ (μm)	σ_Z (μm)
MAPS	–	5	5
TPC	–	150	500
EGEM0	10	50	–
EGEM1	10	50	–
EGEM2 Inner	10	50	–
EGEM2 Outer	10	100	–
EGEM3 Inner	10	50	–
EGEM3 Outer	10	100	–
FGEM0	10	50	–
FGEM1	10	50	–
FGEM2 Inner	10	50	–
FGEM2 Outer	10	100	–
FGEM3 Inner	10	50	–
FGEM3 Outer	10	100	–
FGEM4 Inner	10	50	–
FGEM4 Outer	10	100	–

Table 3.1: Tracking detector properties used in the present studies.



Hits per particle produced by muons.

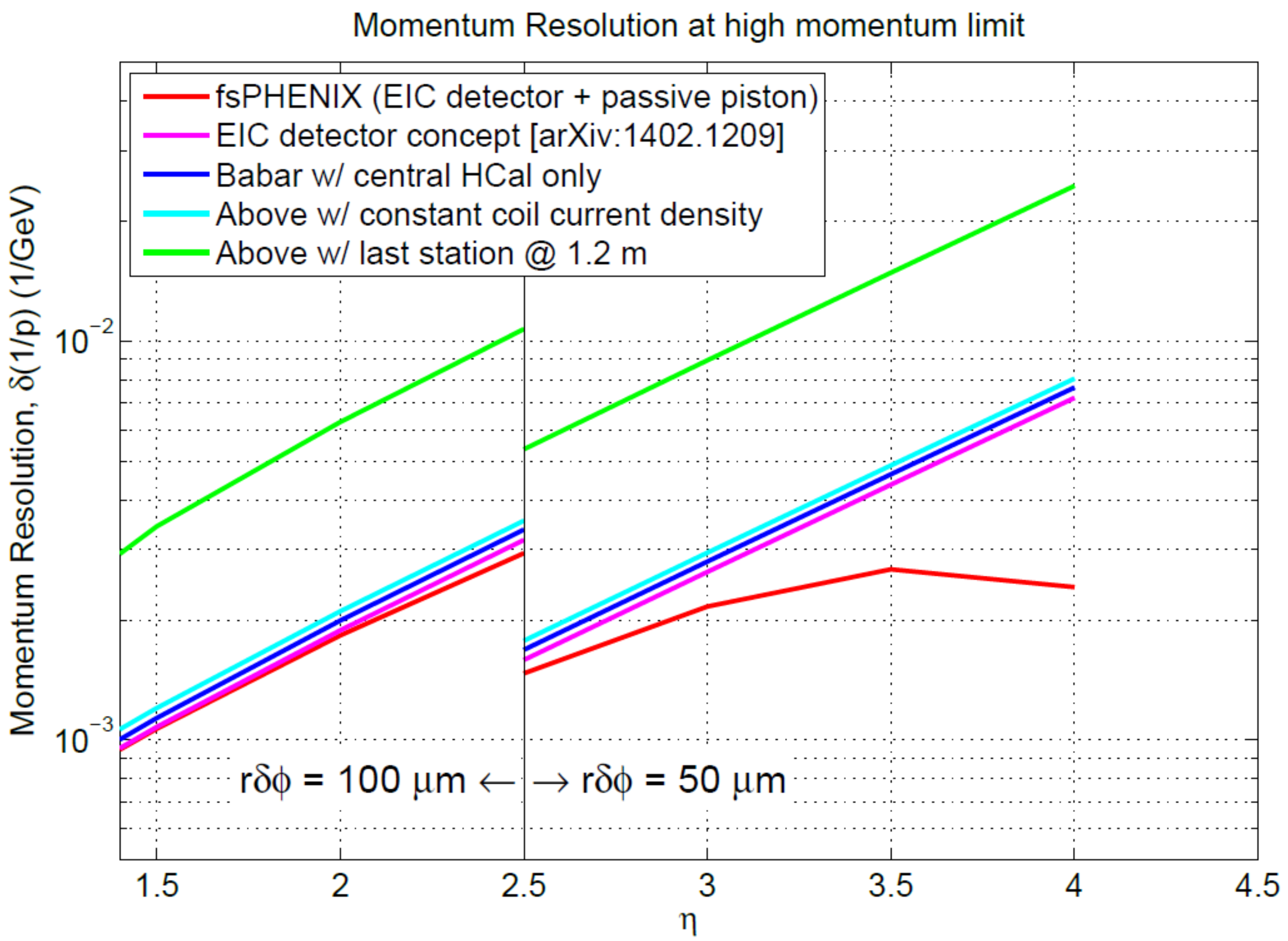


Momentum resolution from GEANT4, using muons.

Forward tracking
(previous slide only showed out to $\eta = 2.2$)

Fast optimization studies—not full GEANT here.

Considered a passive piston to help shape magnetic field in forward region.



Electromagnetic calorimetry

- Backward – $PbWO_4$. ~5000 crystals, similar size and shape to PANDA, projective geometry.
- Central EMCal – sPHENIX barrel EMCal (tungsten powder + scintillating fibers), with full design implemented in GEANT and resolutions matched to available test beam data at the time. 2D projective.
- Forward EMCal – assumed 788 refurbished PHENIX lead-scintillator towers. ~Circular disk of r ~ 170 cm at ~3 m from center of solenoid, just inside magnetic flux return.

Hadronic calorimetry

- Central HCal – sPHENIX Outer HCal
- Forward HCal – 2,044 towers, energy resolution ~70%/$\sqrt{E}(GeV)$ for single hadrons. 64 layers of 10 mm iron absorbers, 2.5 mm plastic scintillators. Front face 3.5 m from interaction point. Serves as part of flux return, replacing sPHENIX plug door.

PID

Table 3.2: Momentum and pseudorapidity coverage for the EIC-sPHENIX reference design.

Detector	pseudorapidity	K/π 3σ separation (GeV/c)	e/π 3σ separation (GeV/c)
DIRC	(-1.4, 1.24)	$\lesssim$6	
gas RICH	(1.24, 3.95)	(15,50)	(5, 15)
h-side mRICH	(1.10, 1.85)	(3,9)	$\lesssim$2
e-side mRICH	(-3.9, -1.4)	(3,9)	$\lesssim$2

PID for Forward RICH: Dual-radiator vs. gas-only

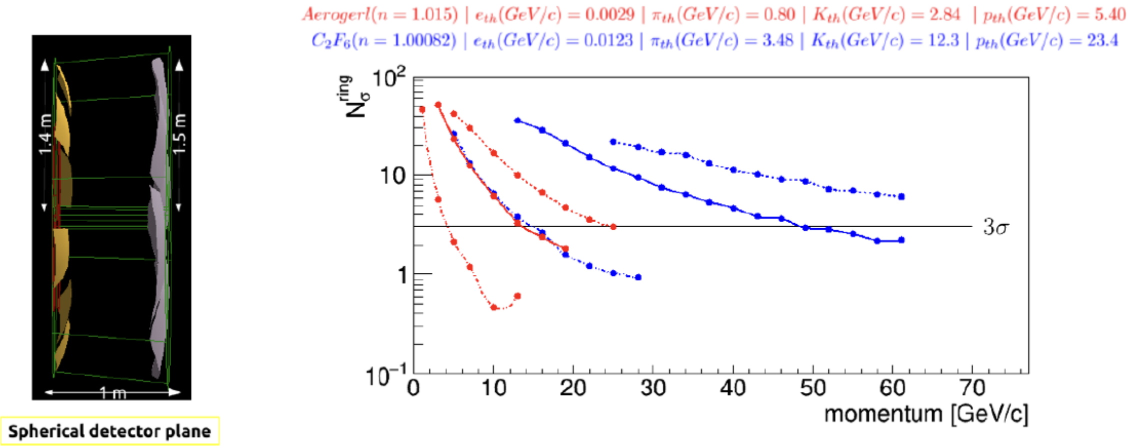


Figure 2.13: Dual-radiator RICH (dRICH) design and performance. Red curves from left to right show e/π, π/K, and K/p separation in standard deviations as a function of particle momentum, using information from the aerogel component of the dRICH. Blue curves show the separation using the C_2F_6.

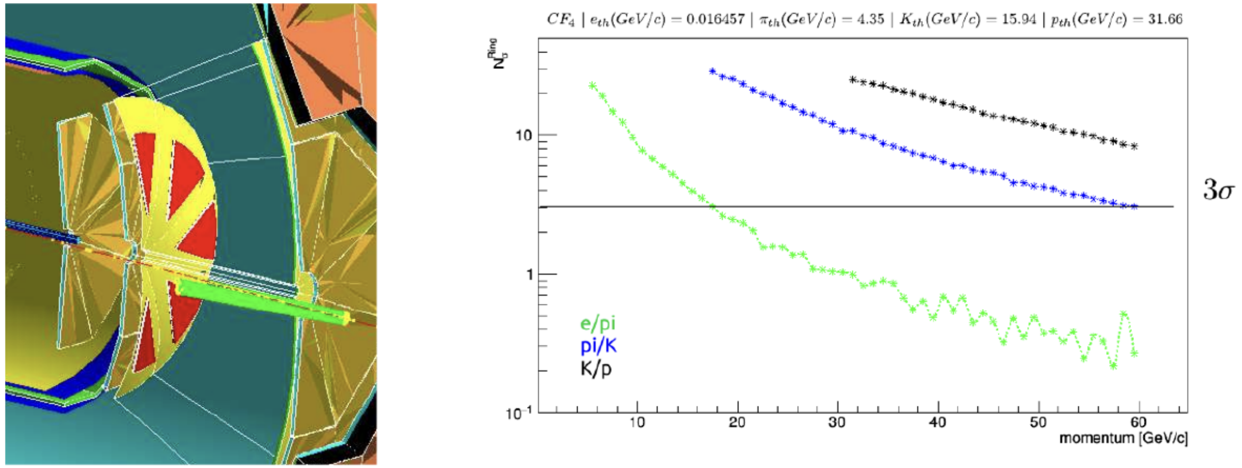
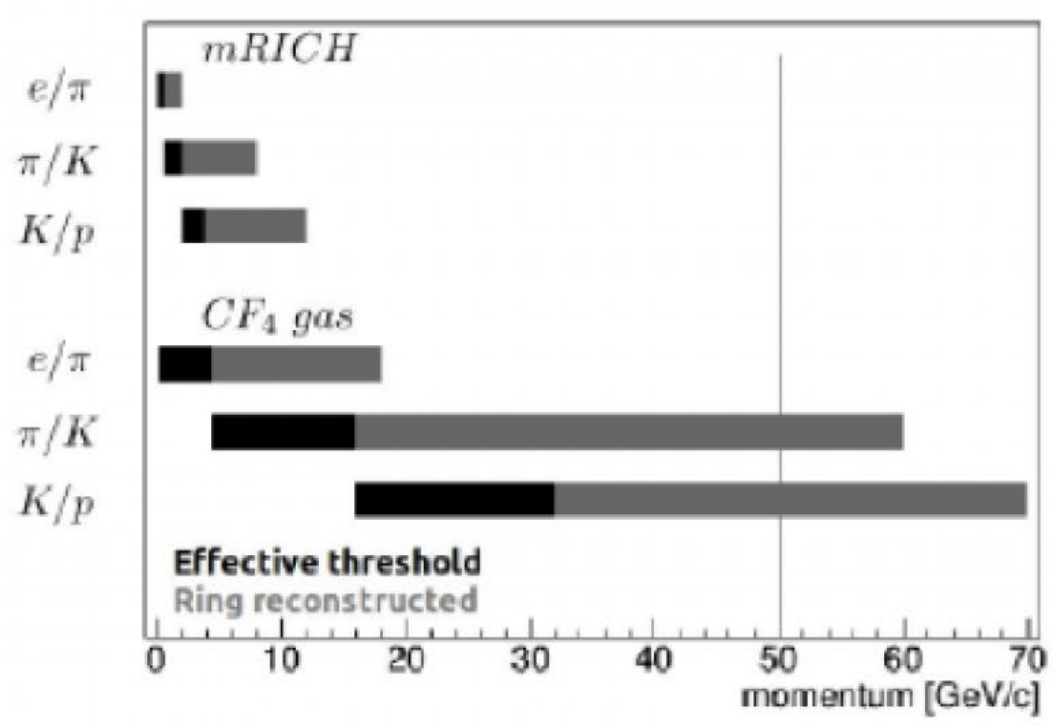
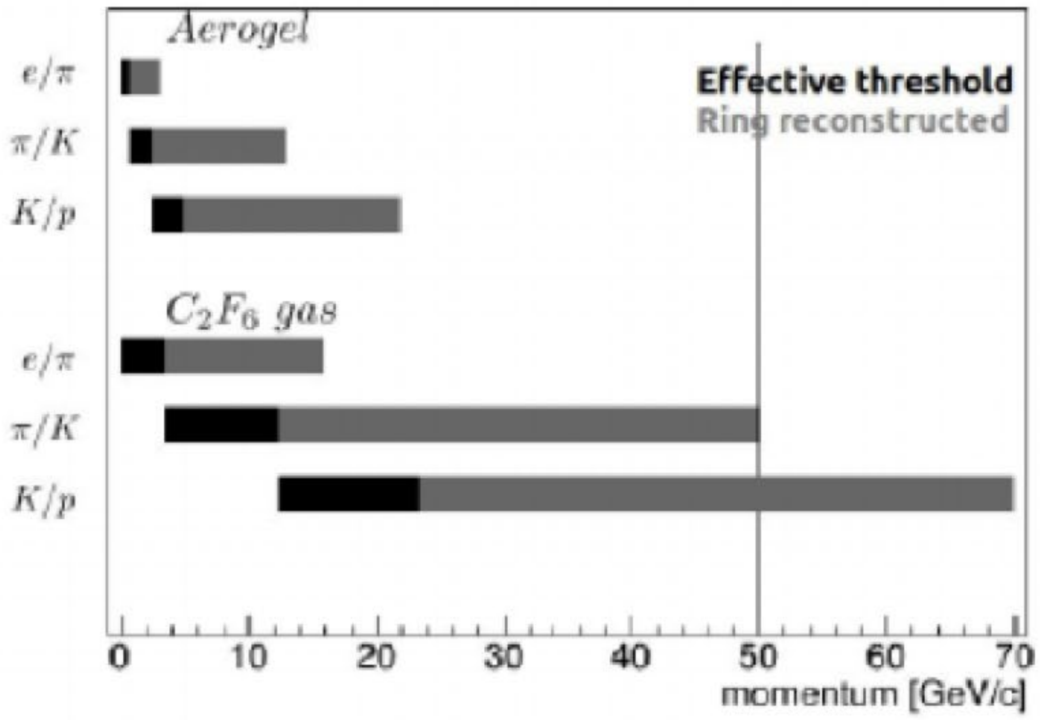


Figure 2.14: Gas RICH design and performance. The e/π (green), π/K (blue), and K/p (black) separation in standard deviations as a function of particle momentum is shown.

The different geometries these two implementations would involve are also discussed in the document.

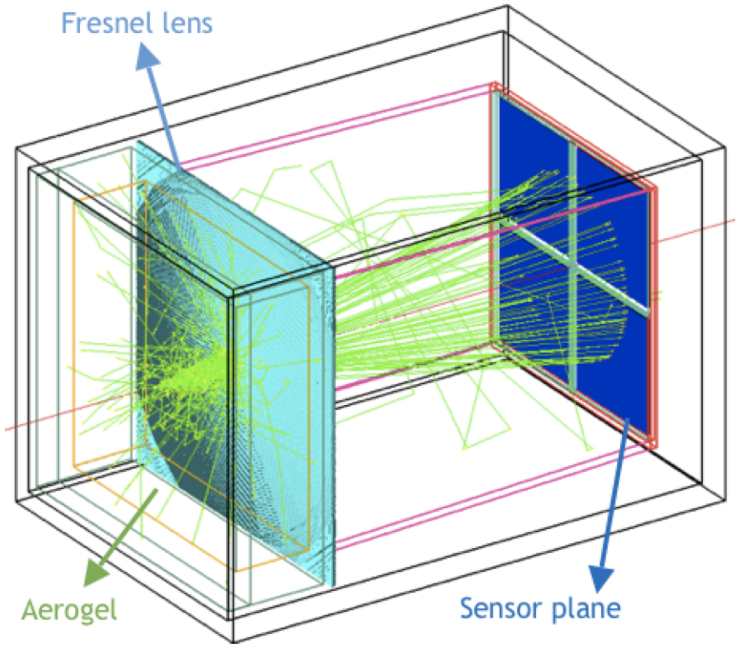
PID: Comparisons





An initial comparison carried out indicated a comparable momentum reach using CF_4 in the gas-only (bottom part of left figure) and C_2F_6 + aerogel (right figure) in the dual-radiator RICH.
"mRICH" – modular aerogel RICH – see next slide.

PID: Modular RICH



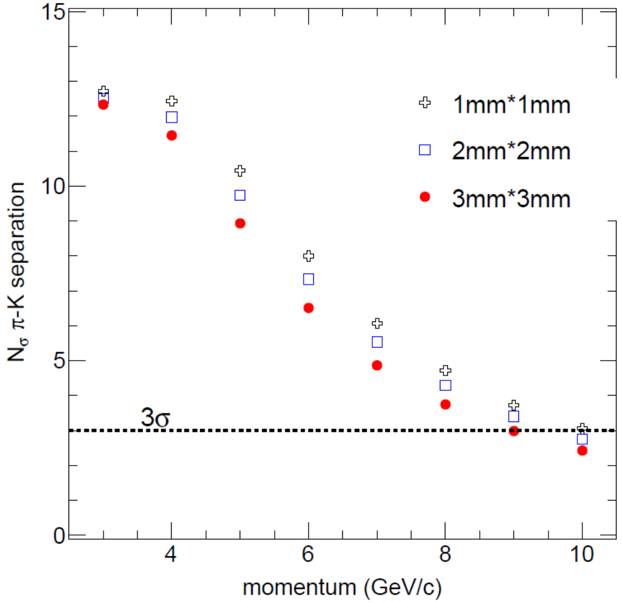
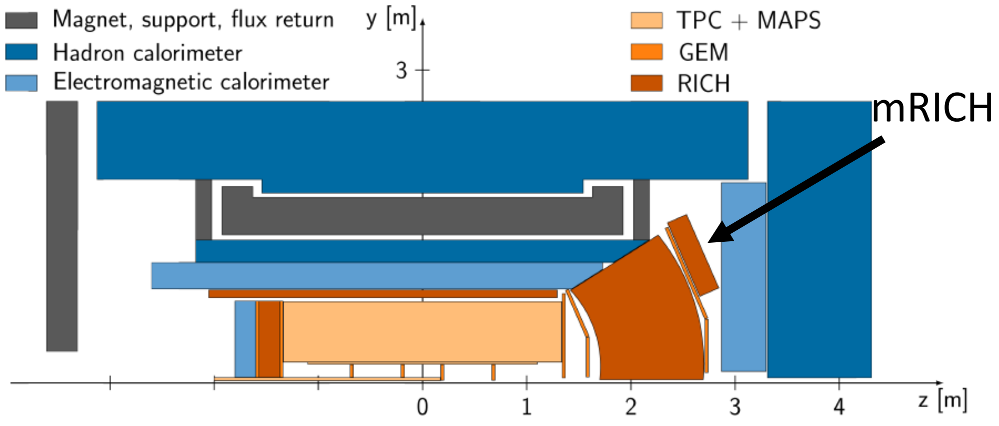
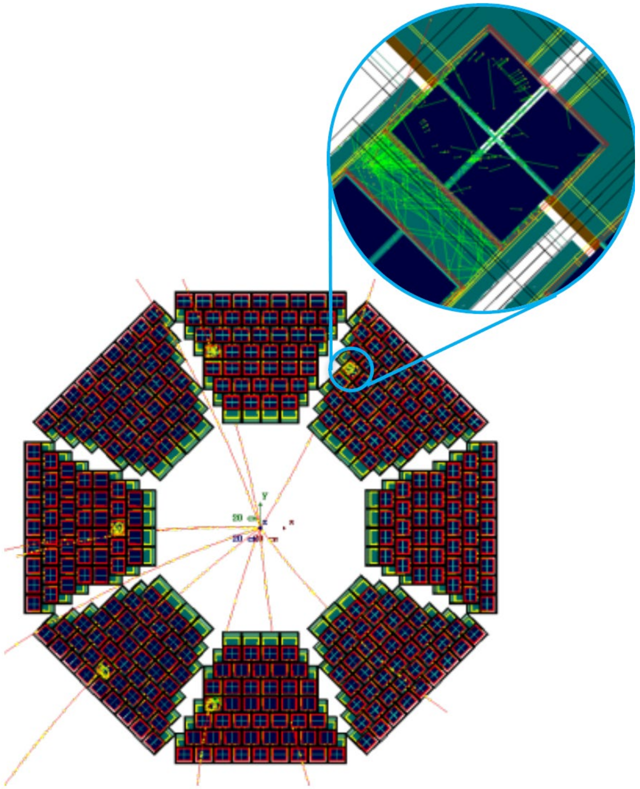


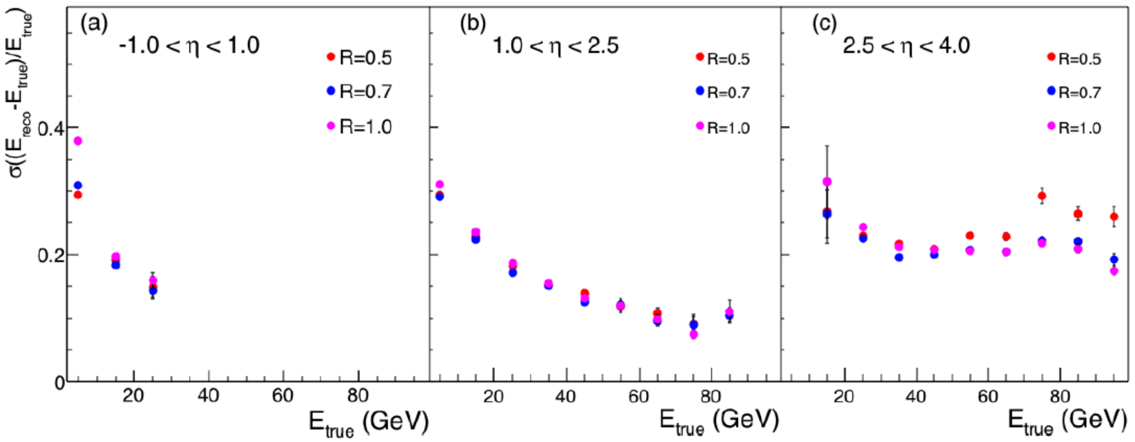
Figure 2.16: mRICH design and performance. The plot shows π/K separation in standard deviations as a function of particle momentum, for different pixel sizes.



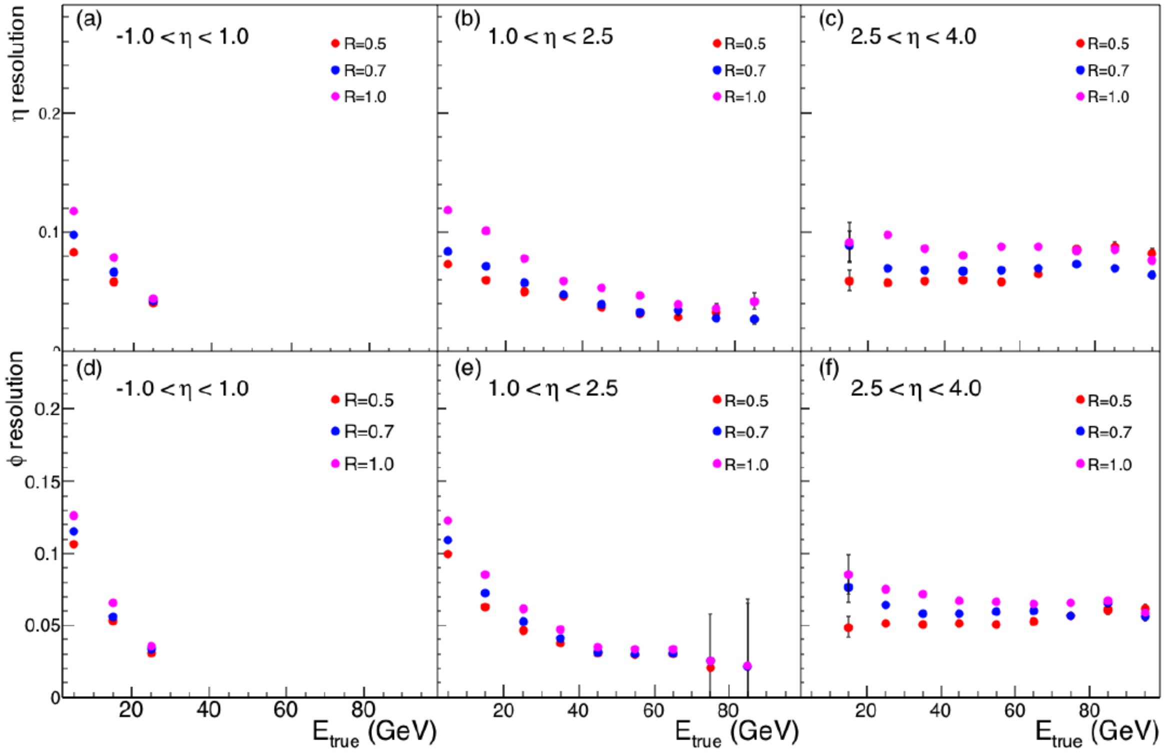


Proximity-focusing with a Fresnel lens. Reasonable performance in a small/flexible footprint.

Jet reconstruction



Jet energy resolution



Jet η resolution

Jet ϕ resolution

GEANT4, anti-kT in FASTJET

$\sqrt{s} = 140$ GeV

Electron ID

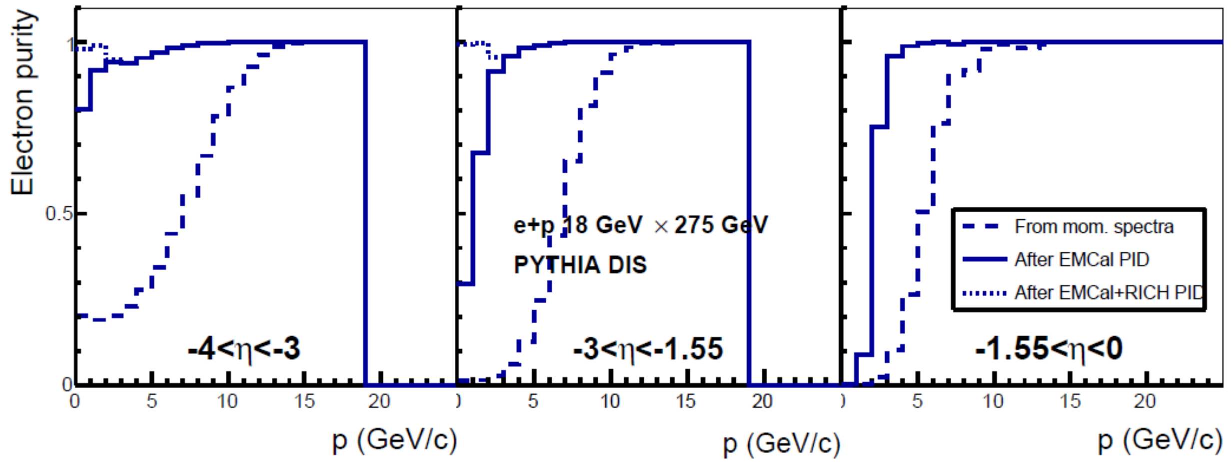
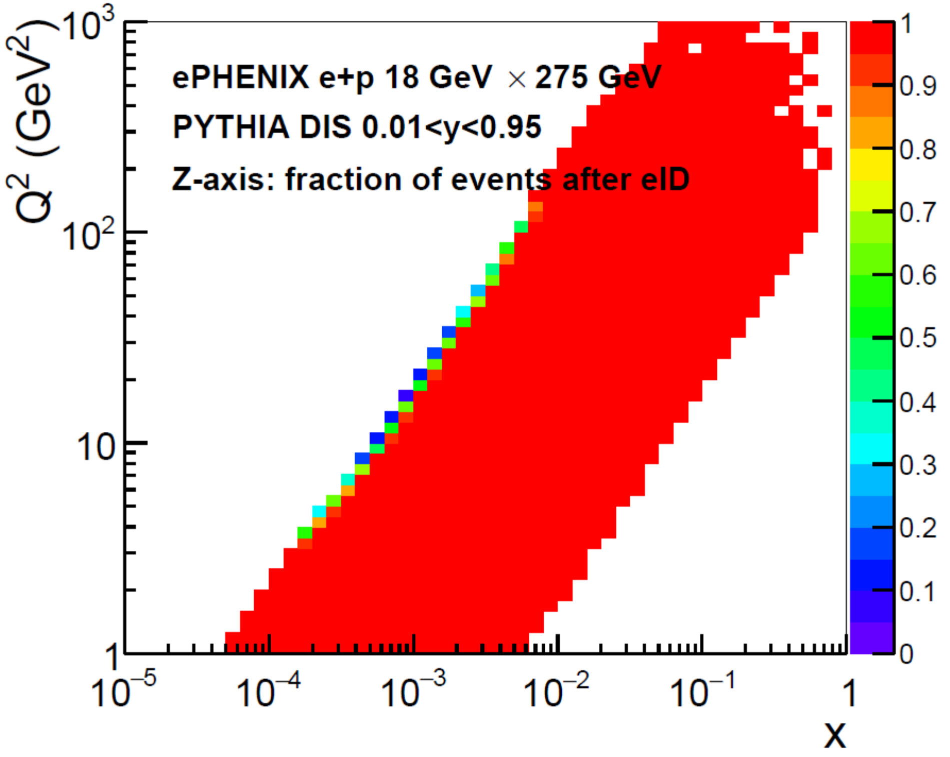
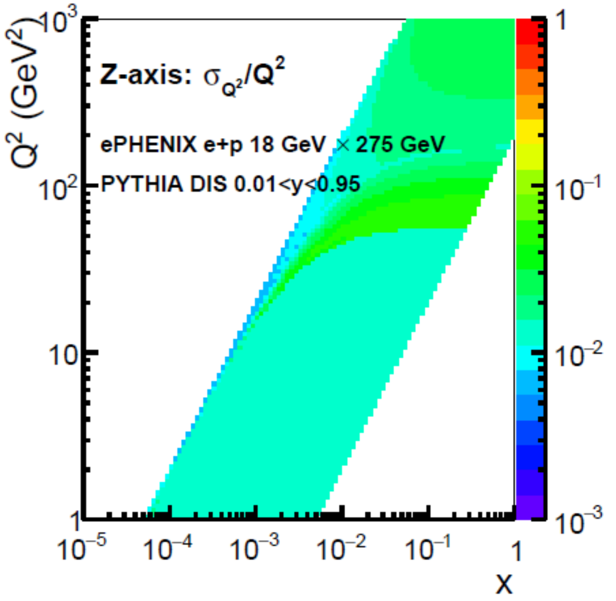


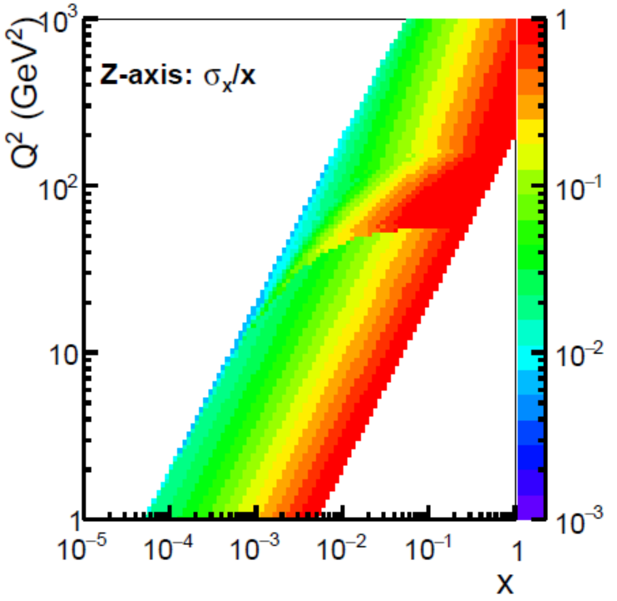
Figure 3.12: For 18 GeV × 275 GeV beam energy configuration: The fraction of DIS electrons in the reconstructed charged particle sample before electron identification (dashed), after identification with the EMCal+Tracking (solid), and after identification with EMCal+Tracking+RICH (dotted); the latter is estimated only for $-4 < \eta < -1.55$.



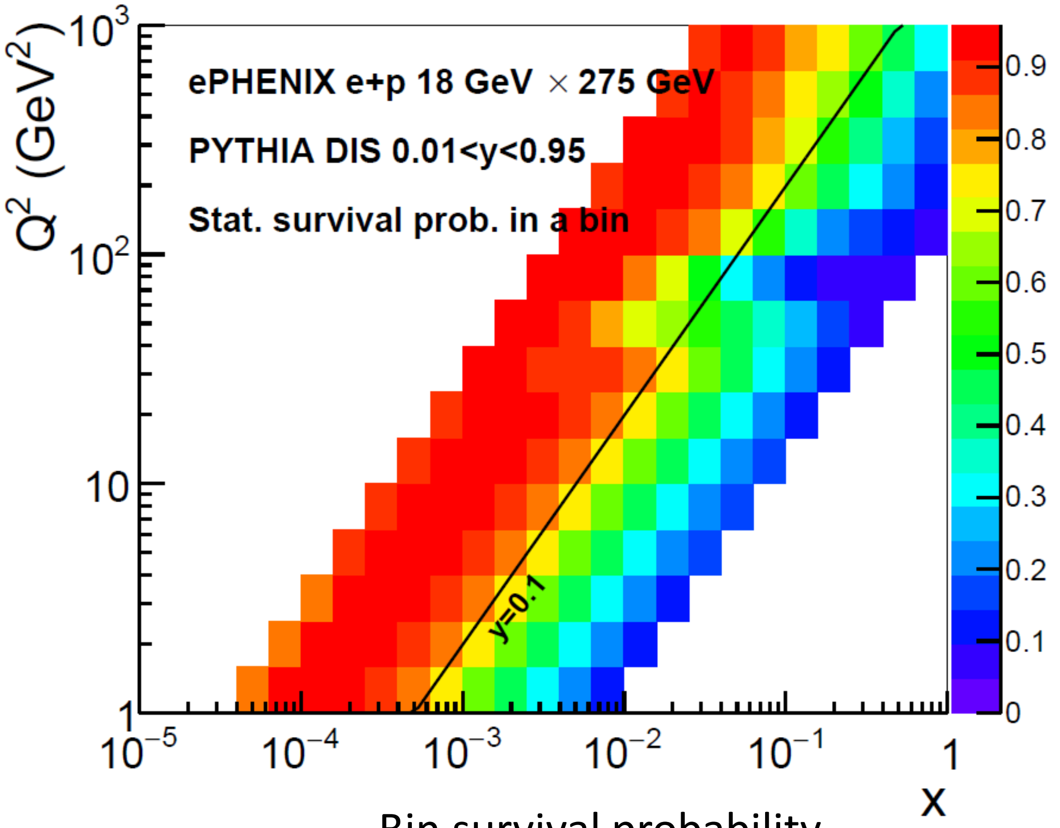
Event kinematics reconstruction



Relative Q^2 resolution



Relative *x* resolution



Bin survival probability

Streaming DAQ studies

Data rate estimates

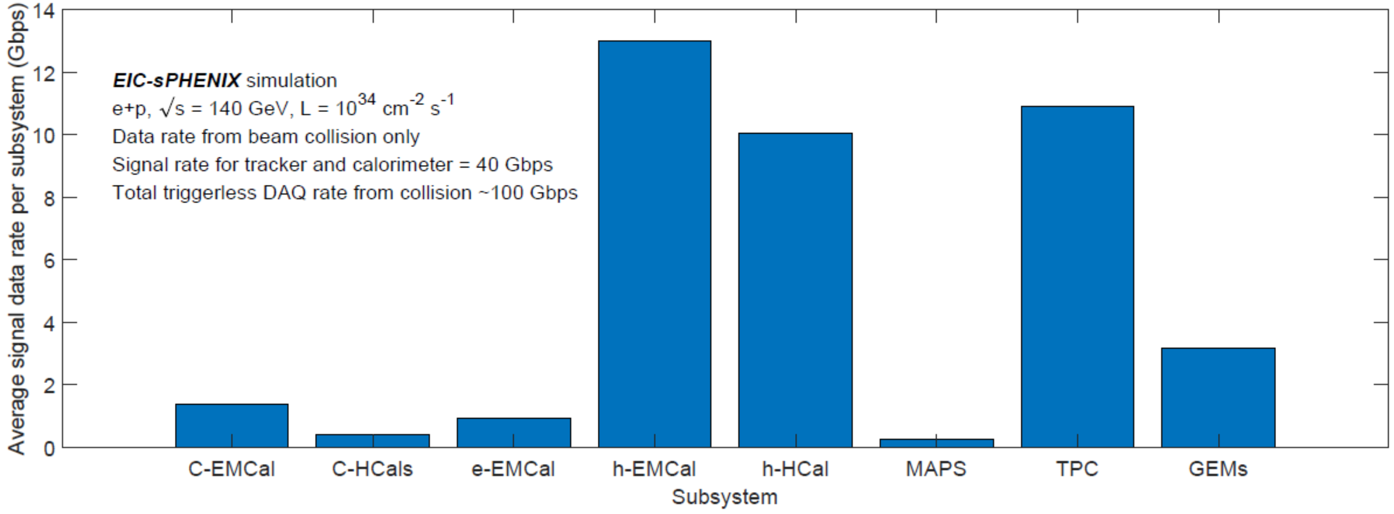


Figure 2.20: Triggerless DAQ data rate breakdown by subsystem originating from $e+p$ collisions at $\sqrt{s_{ep}} = 140$ GeV and instantaneous luminosity of 10^{34} cm^{-1}s^{-1}. The primary collision events are generated via eRHIC tune of PYTHIA6, which represents 50 μb of the $e+p$ collisions. All generated particles are then simulated via full detector GEANT4 simulation which is ten converted to streaming data rate. Only the tracking detectors and calorimeters are included in this simulation study, which sum to a collision-originated streaming data rate of 40 Gbps. With addition of the PID detectors, the overall collision-originated streaming data rate would be around 100 Gbps. Please note the background, e.g. beam gas collisions and detector noise, are not included in this study, which could be significant depending on the accelerator design.

Contributors to 2018 Detector Design Study

Large effort by few people/institutions!

- Christine Aidala (Michigan)
- Sasha Bazilevsky (BNL)
- Giorgian Borca-Tasciuc (Stony Brook)
- Nils Feege (Stony Brook)
- Enrique Gamez (Michigan)
- Yuji Goto (RIKEN)
- Xiaochun He (Georgia State)
- Jin Huang (BNL)
- Athira K V (Michigan)
- John Lajoie (Iowa State)
- Gregory Matousek (Stony Brook)
- Kara Mattioli (Michigan)
- Pawel Nadel-Turonski (SBU)
- Cynthia Nunez (Michigan)
- Joe Osborn (Michigan)
- Carlos Perez (Stony Brook)
- Ralf Seidl (RIKEN)
- Desmond Shangase (Michigan)
- Paul Stankus (ORNL)
- Xu Sun (Georgia State)
- Jinlong Zhang (Stony Brook)

Summary

- A set of studies was performed in 2018 to investigate possible EIC detector designs using the BaBar solenoid and various components of sPHENIX.
- Hopefully some aspects of these studies can provide useful input now as the community works toward EIC detector proposals!

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- Magnet.
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- Endcap Flux Return Door on electron-going side.
- TPC. Replace inner 1/3 sector endcaps to extend instrumentation towards the inner field cage. Reason: space charge not as large an issue, so additional path length can be used for tracking.
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https://indico.bnl.gov/event/5283/attachments/20546/27556/eic-sphenix-dds-final-2018-10-30.pdf

Backup

Solenoid magnetic field map