Forward gaseous RICH performance in the EIC-sPHENIX solenoid fringe field

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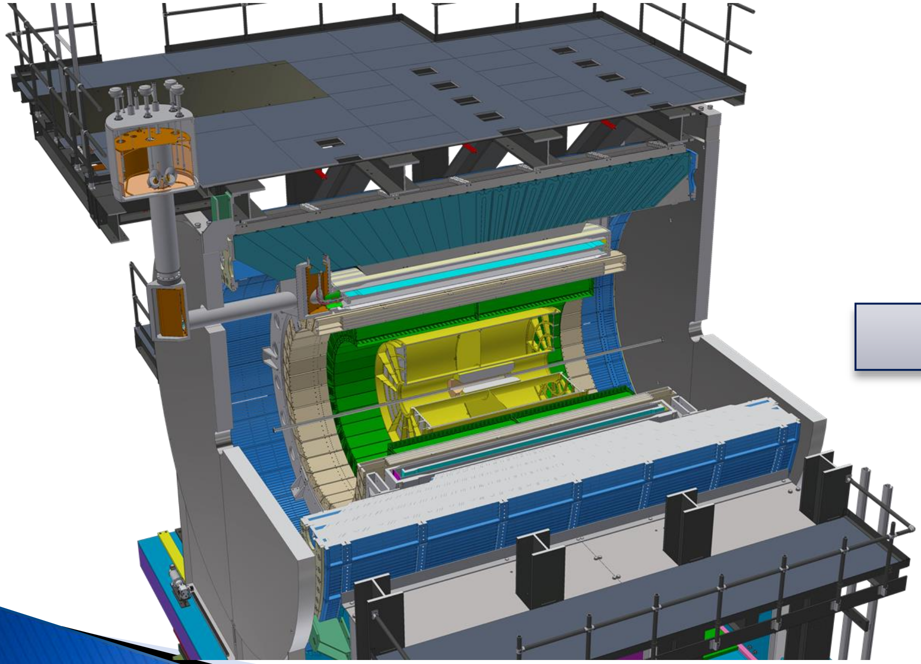
sPHENIX and sPHENIX-EIC concept

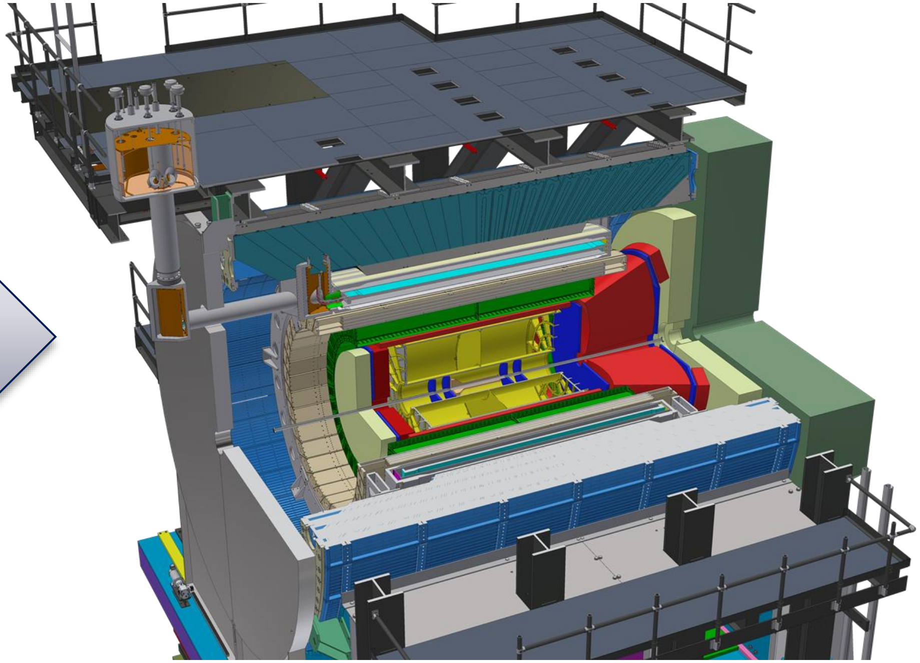
sPHENIX detector (start 2023)

- Under construction @ RHIC 8'clock
- Tracking, full calorimetry in central
- Former BaBar super conducting magnet

EIC-sPHENIX concept

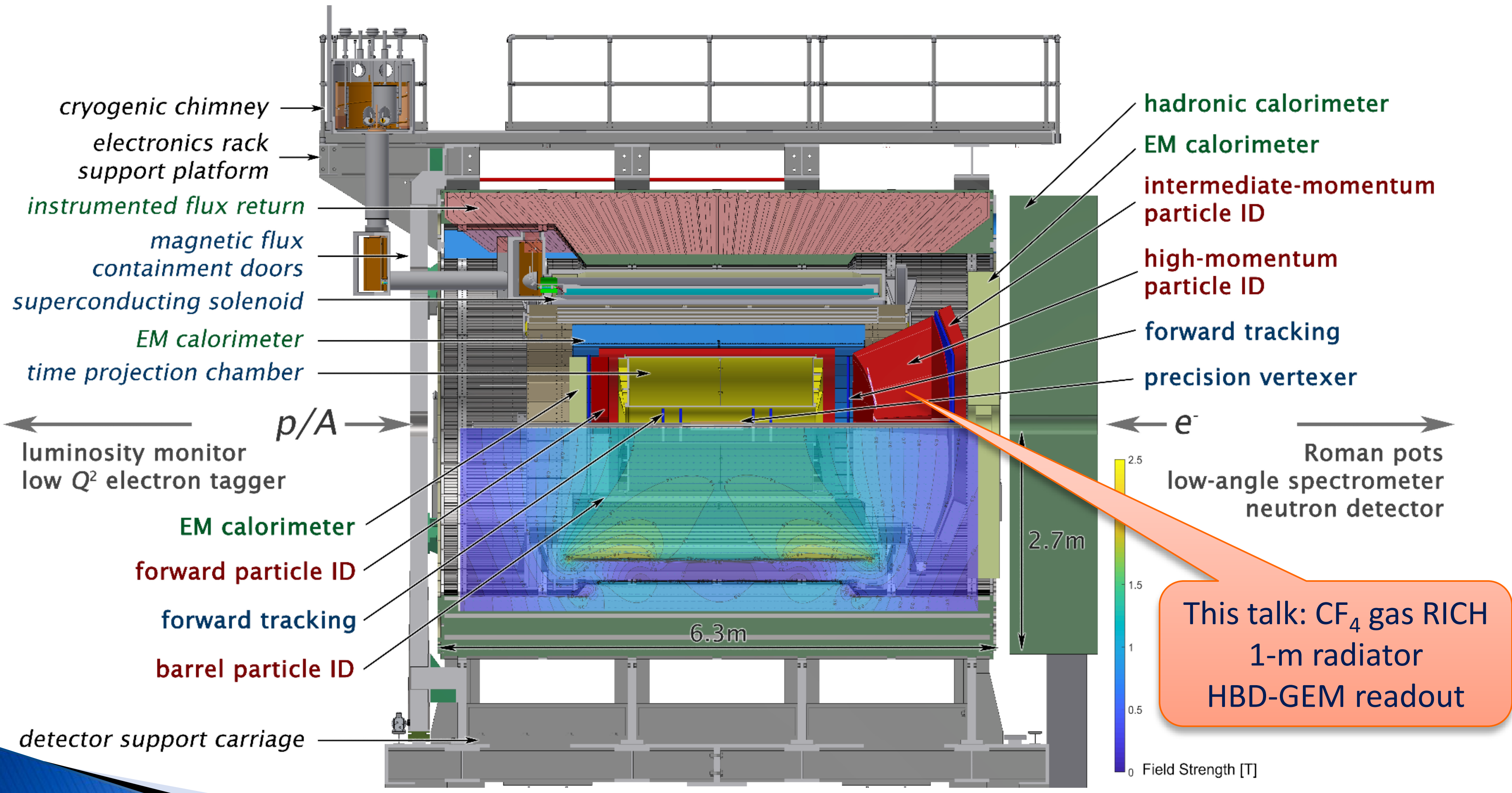
- One possible way to augment sPHENIX→EIC
- 2014 concept: arXiv:1402.1209 [nucl-ex]
- 2018 update: Note sPH-cQCD-2018-001
- New innovative use of sPHENIX in EIC YR?





sPHENIX-EIC concept

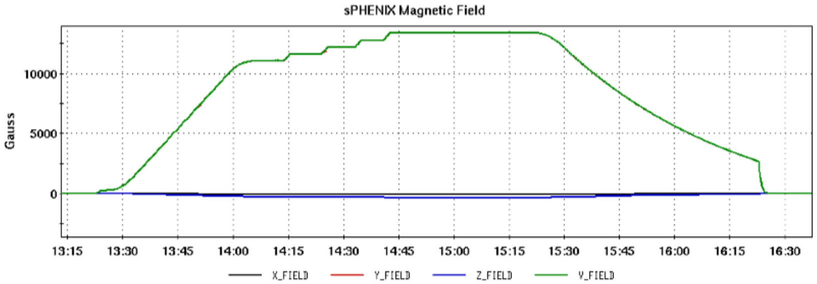
2014 concept: arXiv:1402.1209 [nucl-ex], 2018 update: sPH-cQCD-2018-001



sPHENIX (former BaBar) SC magnet

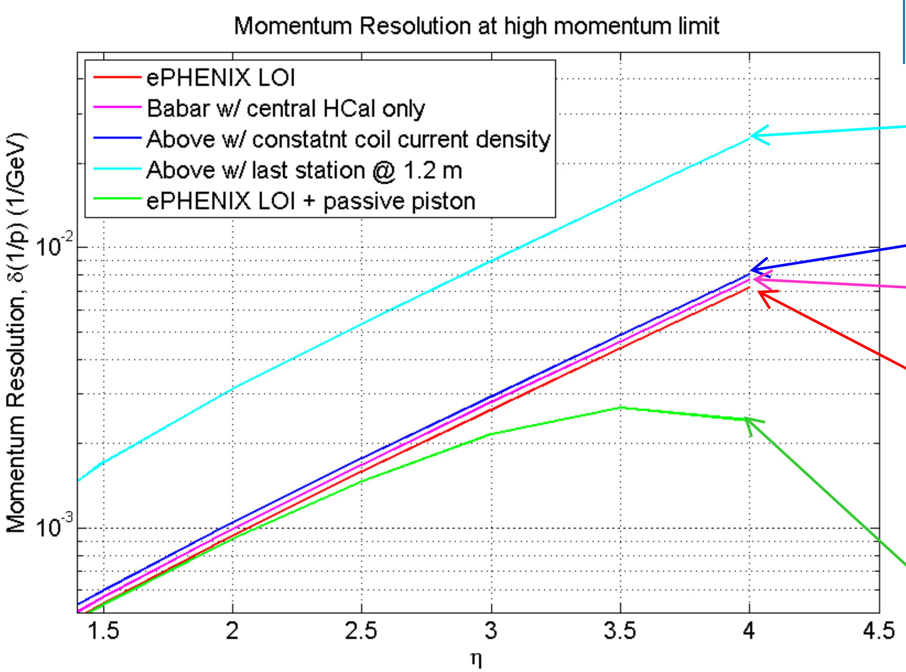
- History
  - Built by Ansaldo →
    SLAC ~1999 → BNL Feb 2015
  - Nominal field: 1.4-1.5T
  - Radius : 140-173 cm; Length: 385 cm
- Field calculation and yoke tuning
  - Three field calculator cross checked: POISSION, FEM and OPERA. Default loading for sPHENIX-EIC simulations
  - With sPHENIX field return, detailed 3D map is also available
- Benefit to EIC tracking
  - Designed for homogeneous B-field in central tracking
  - Longer field volume for forward tracking
  - Higher current density at end of the magnet -> better forward bending
  - Work well with RICH in forward yoke

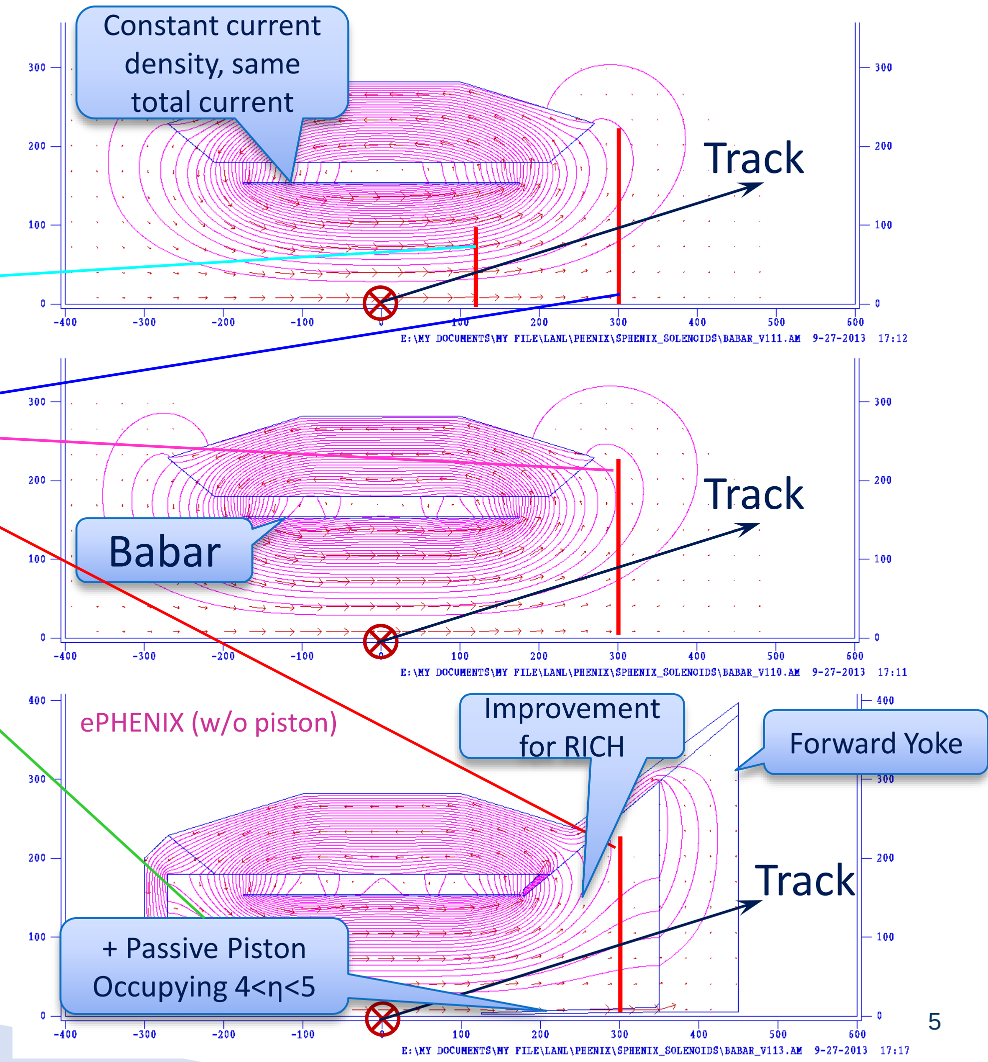
Full current test February 2018 @ BNL



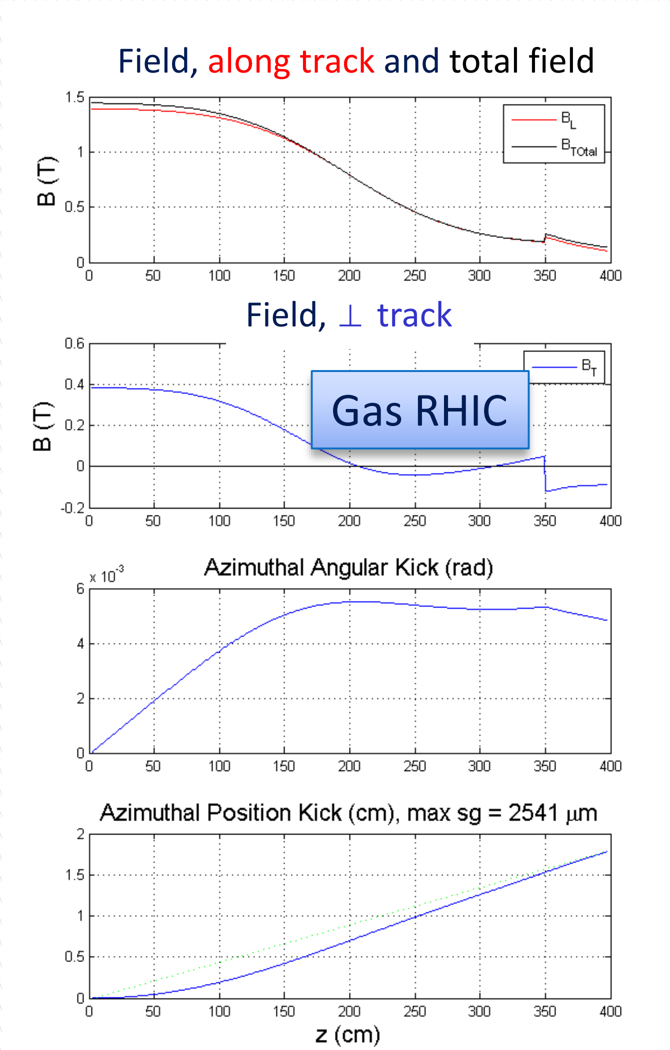
Considerations for yoke and tracking designs

- Optimal tracking configurations
  - Measure sagitta with vertex – optimal sagitta plane (not drawn) – last tracking station
  - Yoke after tracking space and conform with a |z|<4.5m limit
- sPHENIX-EIC concept:
  - Central + forward yoke (hadron calo.)
  - Last tracking station at z=3.0m

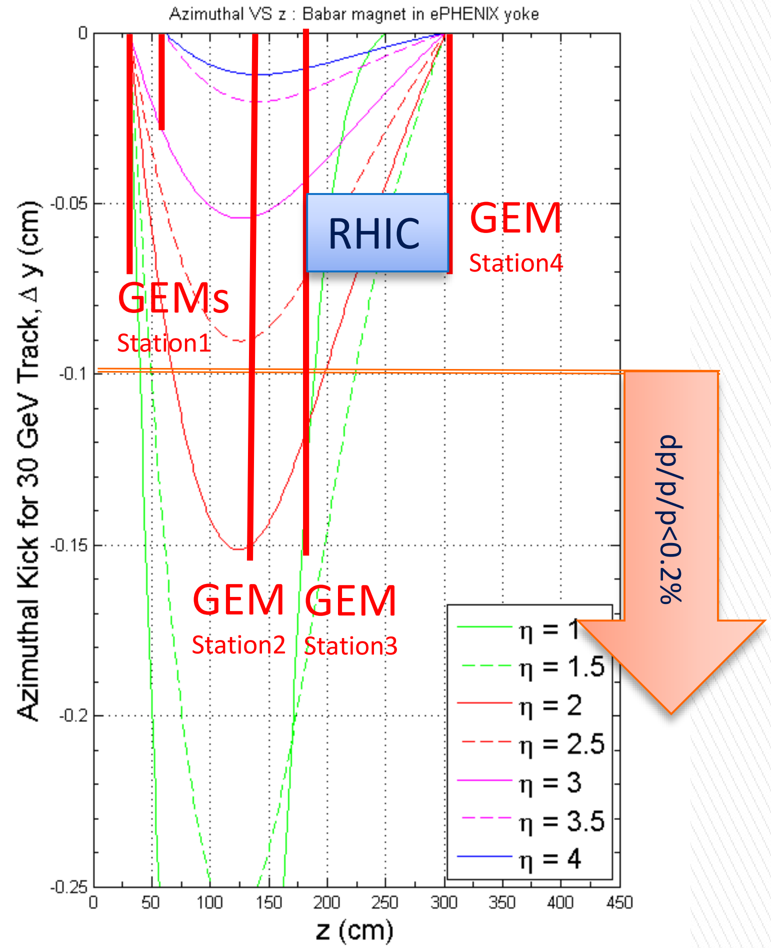




Forward tracking optimization



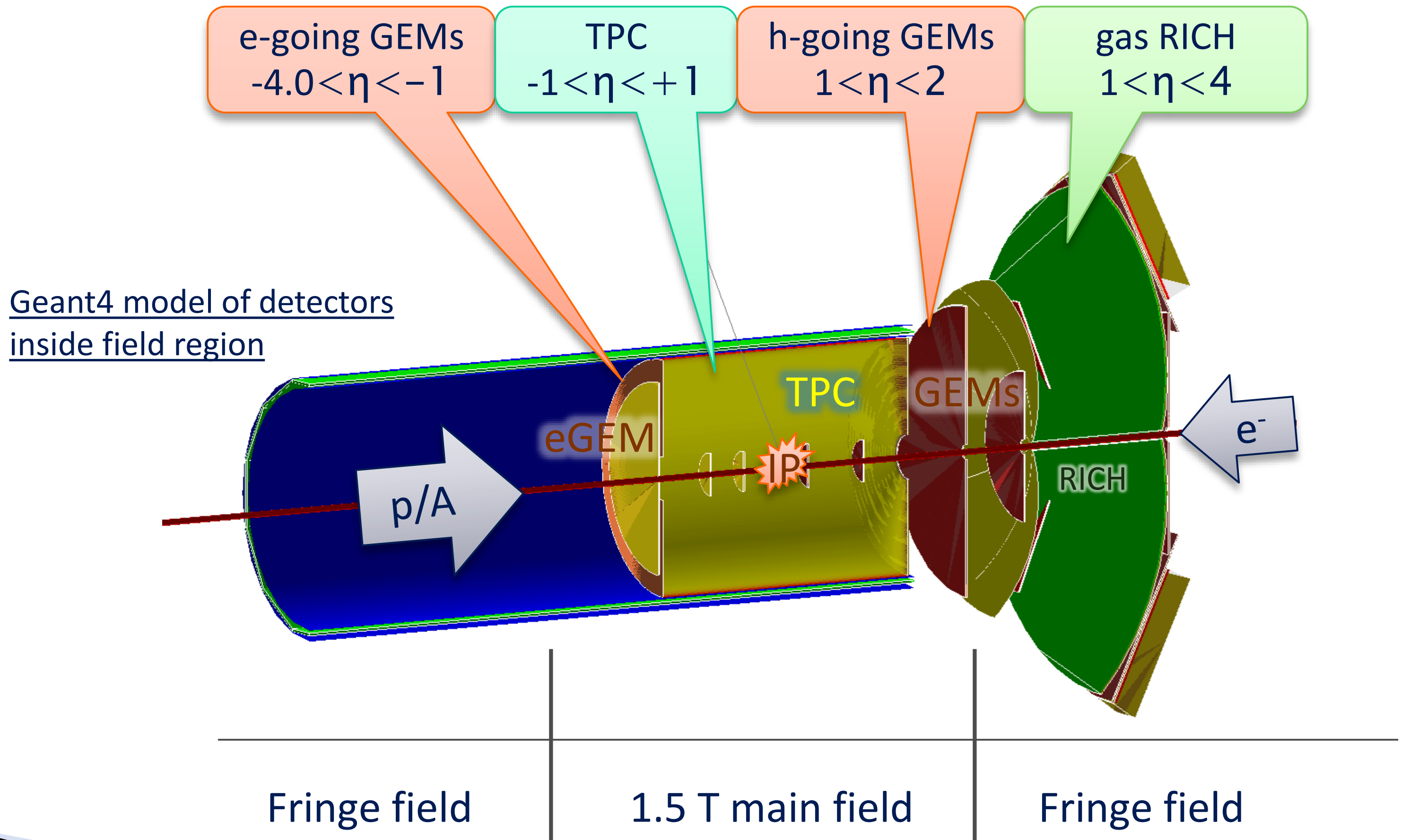
Using ϕ segmented GEM
with resolution of R Δϕ = 50μm



Magnetic bending
Track of η=2.0, p=30 GeV

Tracker layout for max sensitivity
Track of p=30 GeV

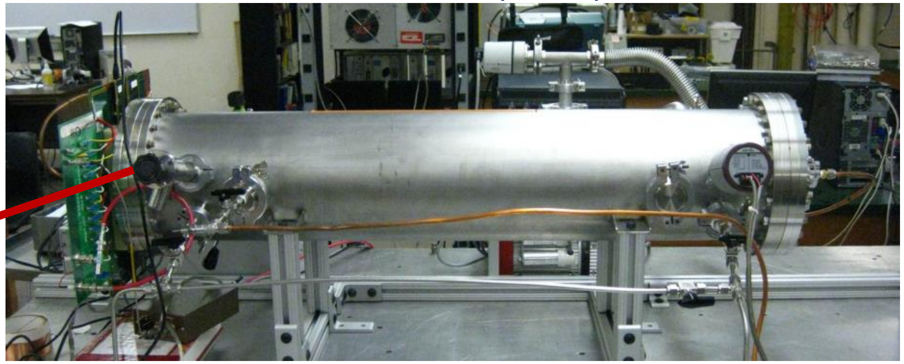
Detectors use/sensitive to magnetic field Tracking and Cherenkov detectors

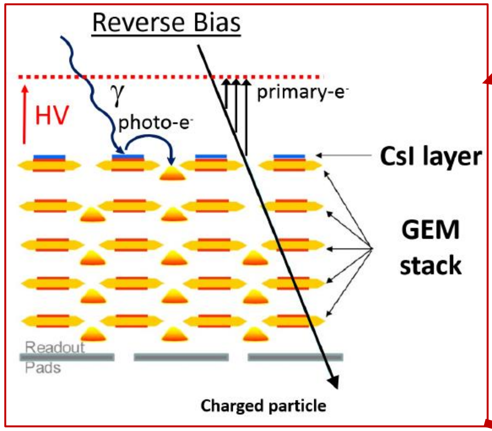


HBD-GEM gas RICH

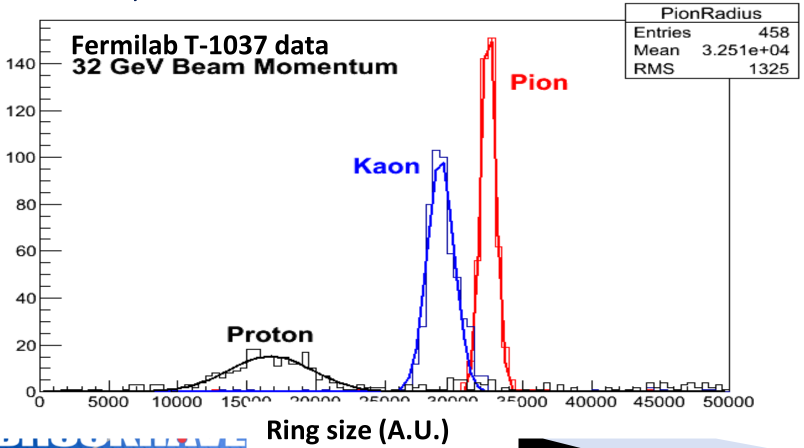
- Thin readout with CsI-coated Q-GEM
- Magnetic field resistant
- No gas window needed (UV photon)

IEEE Trans.Nucl.Sci. 62 (2015) no.6, 3256-3264

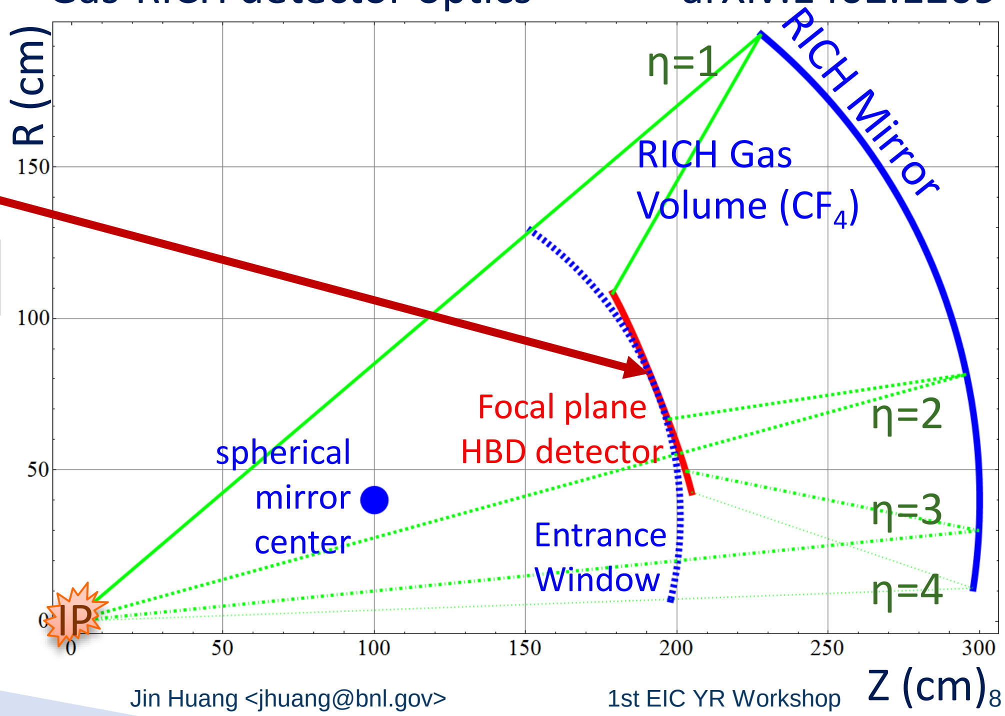




Courtesy : EIC eRD6 TRACKING & PID CONSORTIUM

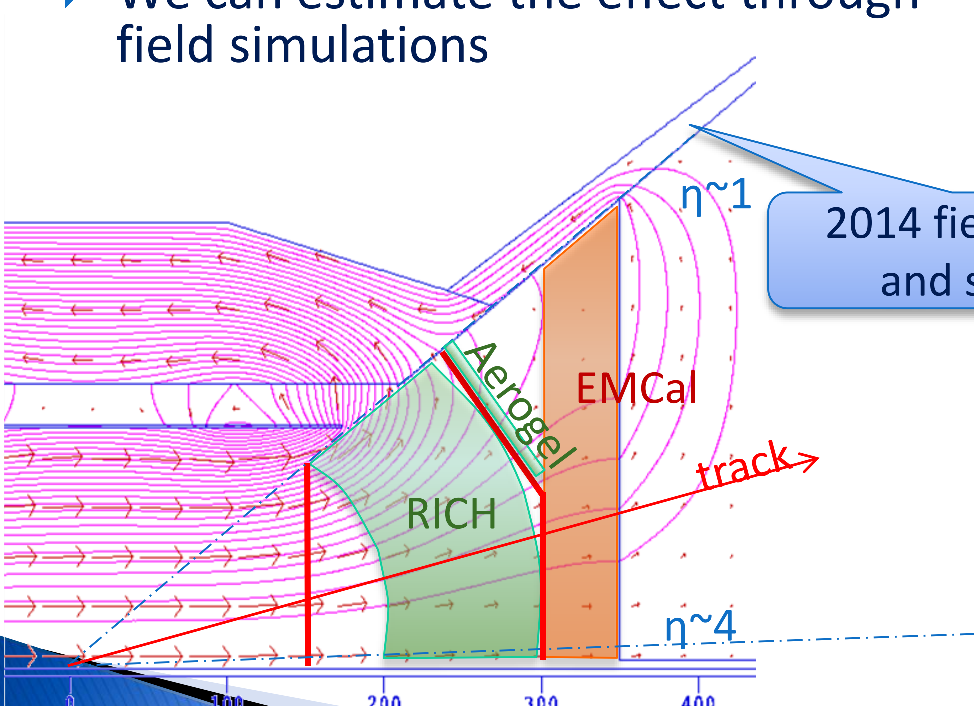


Gas-RICH detector optics arXiv:1402.1209

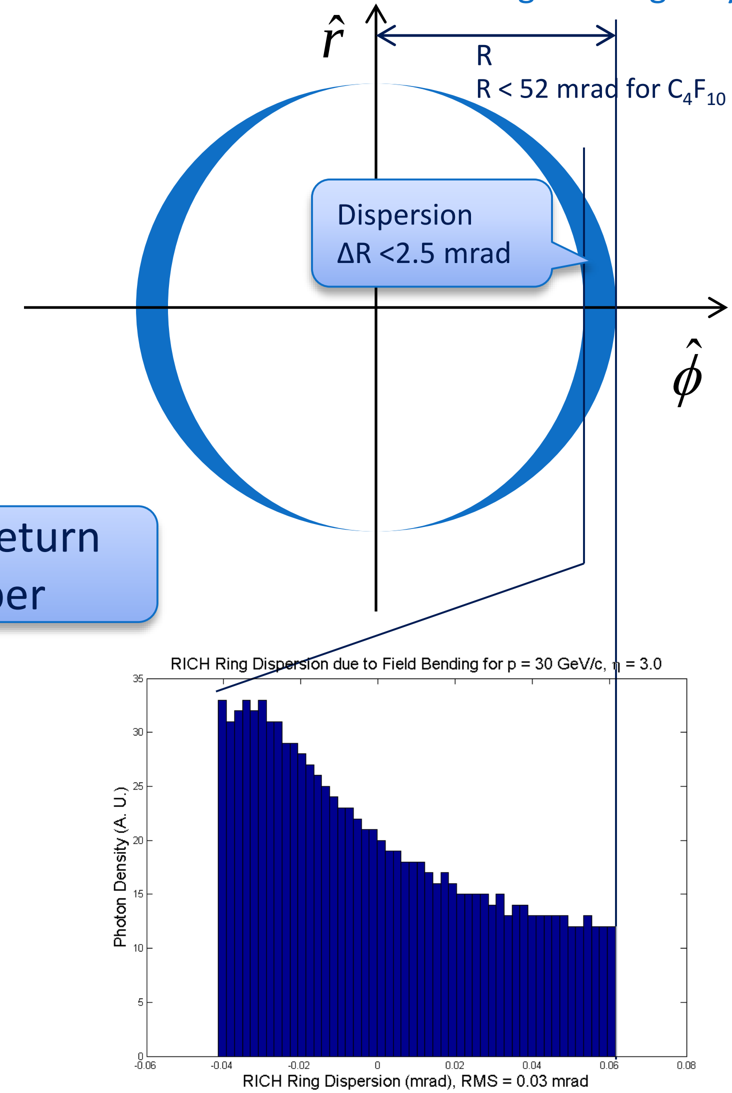


Field effect - distortion for RICH

- Field calculated numerically with field return
- Field lines mostly parallel to tracks in the RICH volume with the yoke
- We can estimate the effect through field simulations

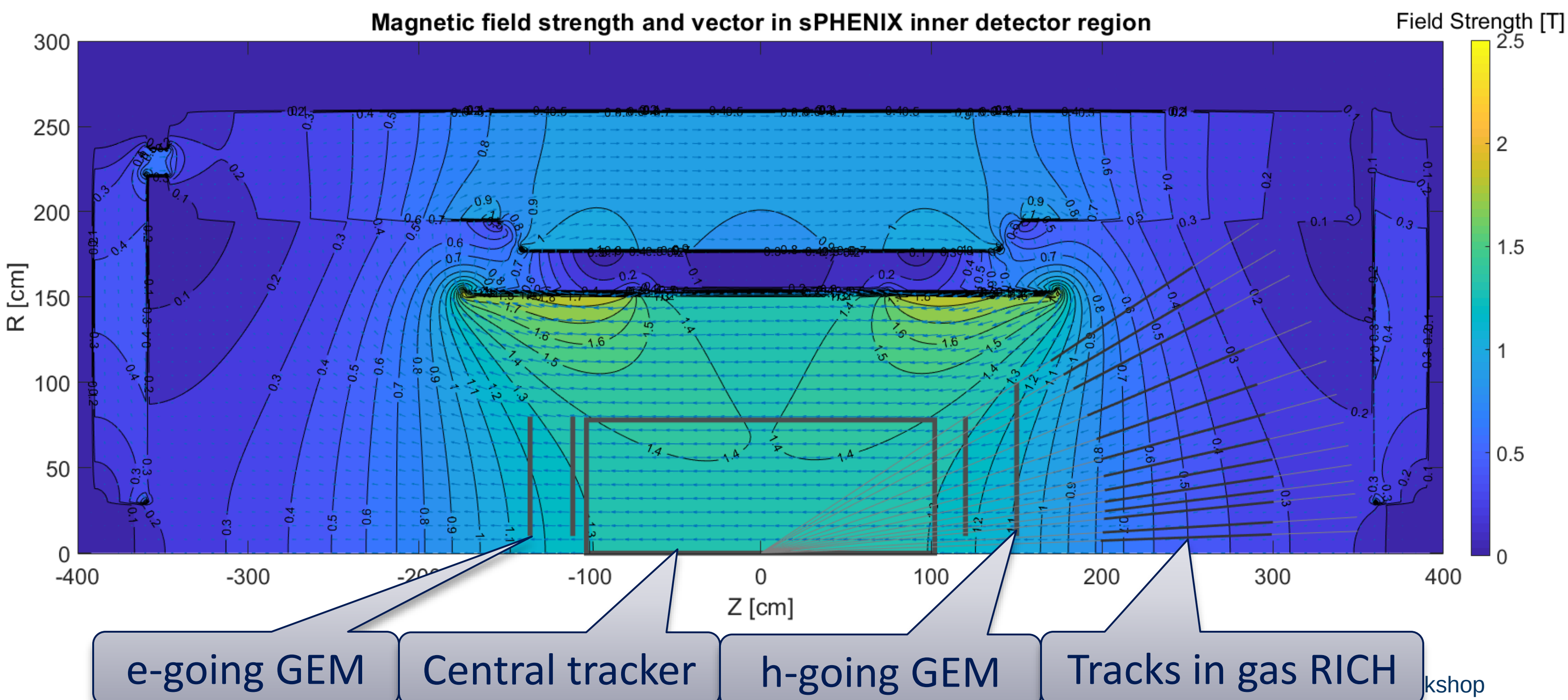


A RICH Ring :
Photon distribution due to tracking bending only

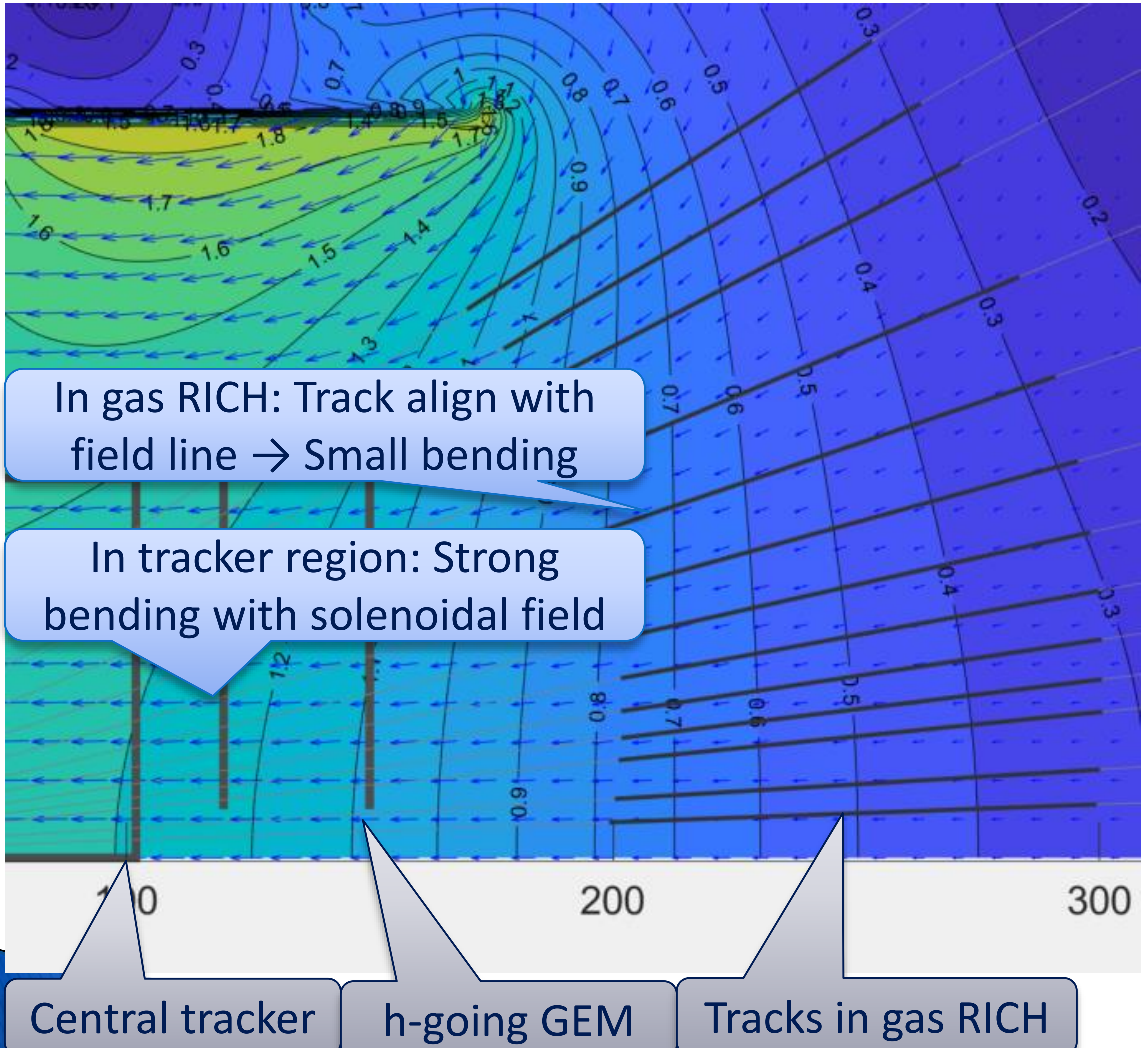


Now: new field return for sPHENIX and sPHENIX-EIC concept

- After arXiv:1402.1209, field return and HCal design for sPHENIX was updated
  - [sPHENIX CDR]: https://indico.bnl.gov/event/6145/
- Updated field map and conceptual EIC layout: sPH-cQCD-2018-001
  - Using Hcal to return field at the same location as the sPHENIX field return door
  - Field map : https://github.com/sPHENIX-Collaboration/calibrations/tree/master/Field/Map

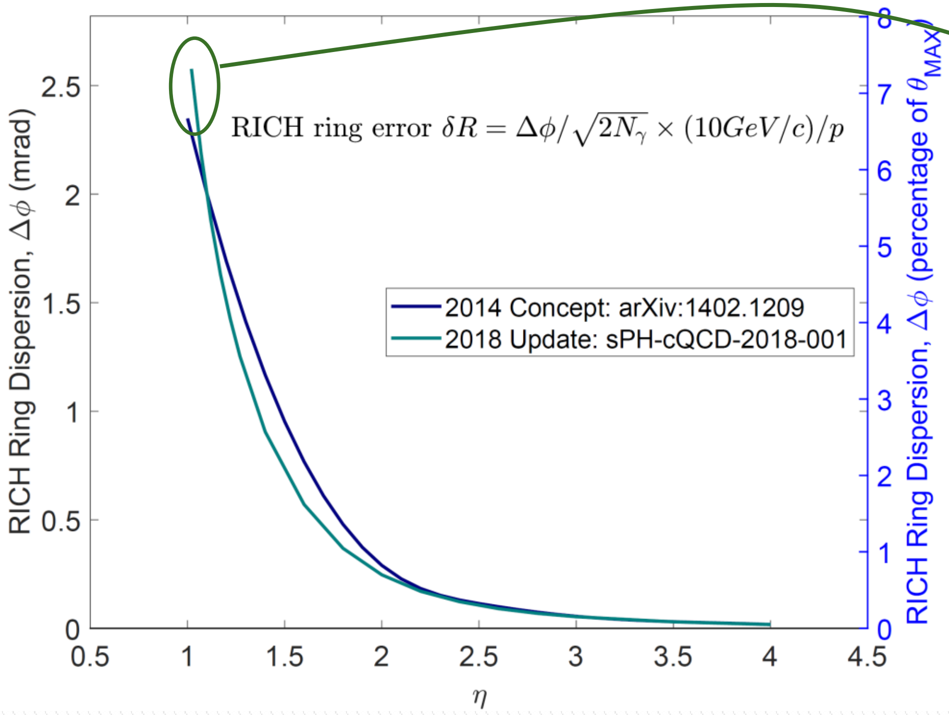


Zoom into gas RICH region

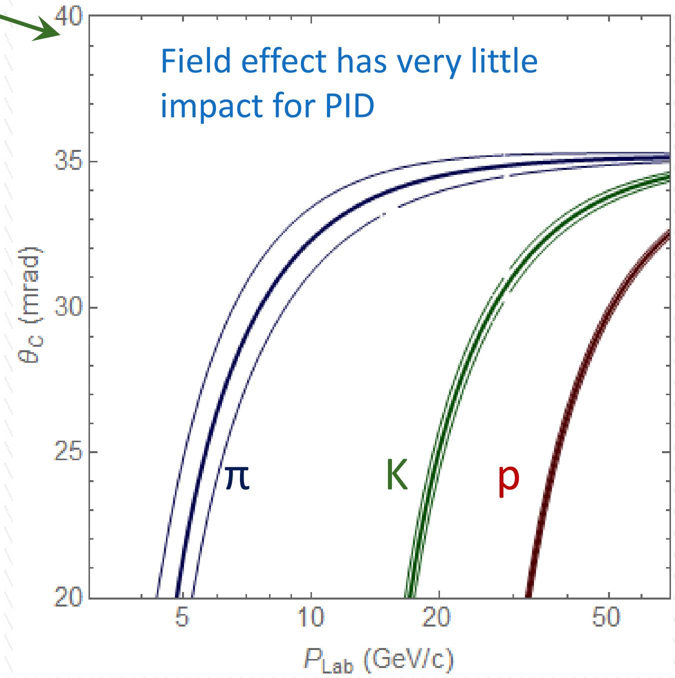


- In gas RICH region, track still align mostly along the field line → Small bending
- Larger bending field in low-eta, but max EIC collision track momentum is lower too
- More quantitative next page

Quantitative bending



Ring radius ± 1σ field effect (for worst η~1)



2014 & 2018 field maps

In the respect of PID: minor effect

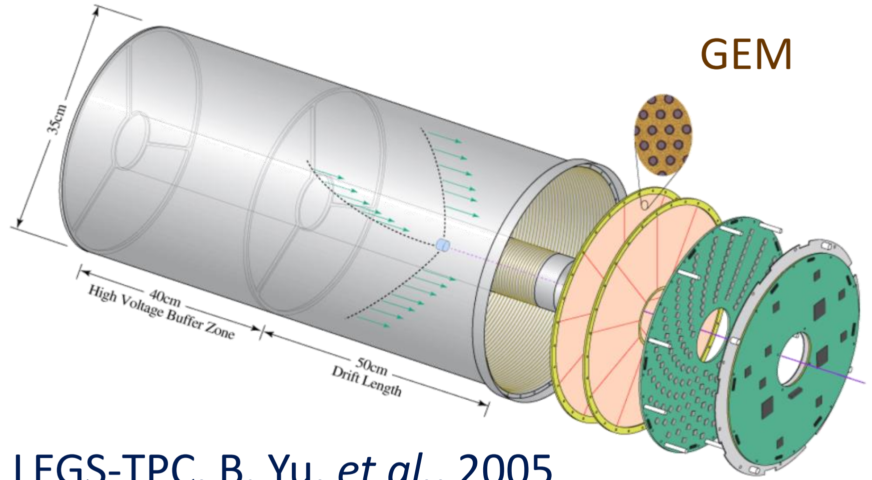
Summary

- sPHENIX under construction and are used as basis for an EIC detector concepts:
  - 2014 concept: arXiv:1402.1209 [nucl-ex]
  - 2018 update: sPH-cQCD-2018-001
  - Innovative concepts from YR studies welcomed!
- sPHENIX-EIC concept shows one way to use a 1-m CF4 gas RICH in fringe magnetic field region, integrated to a full detector design
  - The field line is mostly aligned with high-p tracks in RICH and the bending effect is small in both 2014 and the 2018 updated sPHENIX field map
- Open source code and field map
  - The source code used here: https://github.com/sPHENIX-Collaboration/analysis/blob/master/ForwardTracking/macros/ePHENIXFieldRICH.m
  - The field map: https://github.com/sPHENIX-Collaboration/calibrations/tree/master/Field/Map

Extra Information

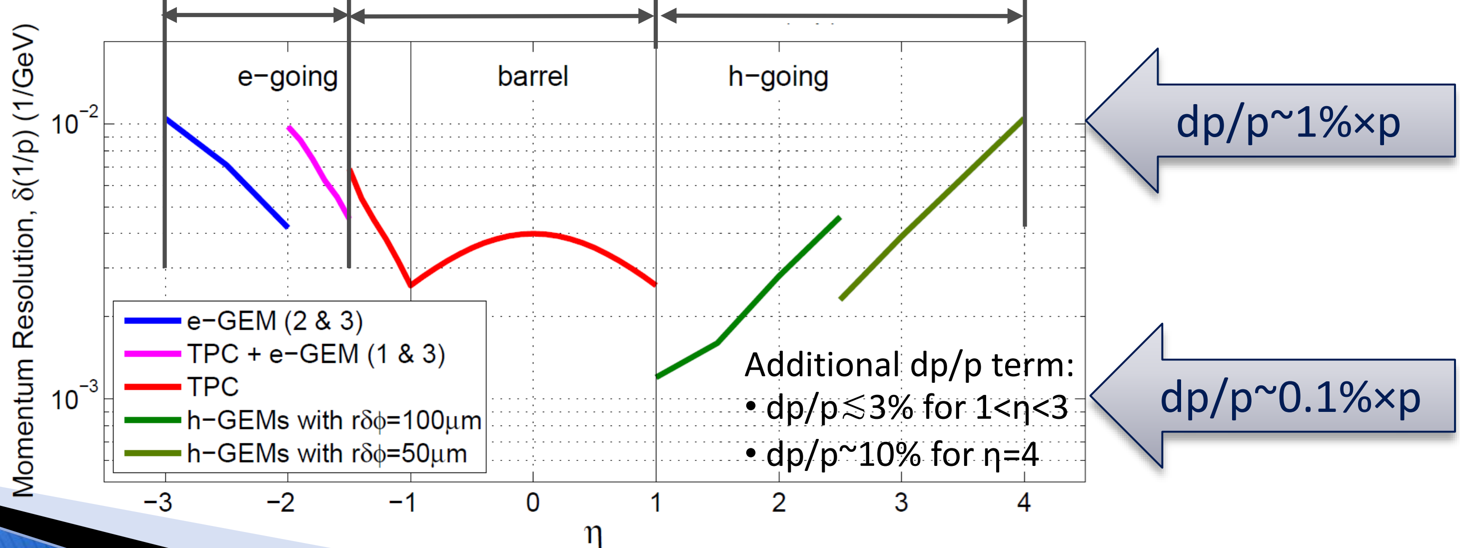
Tracking system

- Good momentum resolution over wide range, $-3<\eta<+4$
- GEM tracker for forward region
  - $d(r\phi)$ = 100 μm; 50 μm for very forward region
- GEM-based TPC for barrel region
  - 10μs max drift time and no-gate needed
  - Thin support structure, e.g. fibre-reinforced polymer



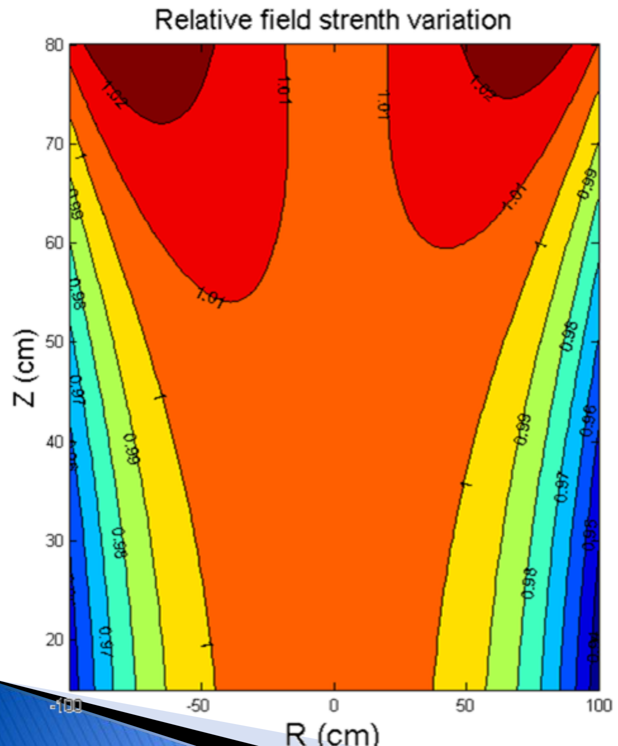
LEGS-TPC, B. Yu, *et al.*, 2005

Main detector:	e-going GEM	TPC	h-going GEM
Driving factor:	Electron ID	Kinematic	Hadron PID



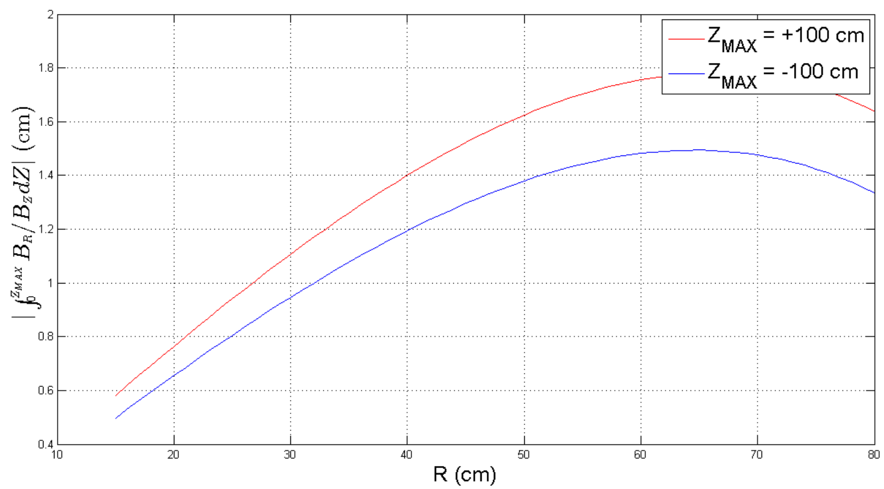
Field effect - TPC drift effect and Correction

- Ideally, magnetic field along z axis for TPCs. $B_{X/Y}$ terms → corrections
- Field map can reach quoted uniformity for Babar (±3% for central tracking volume) by some tuning on the yoke
- Residual distortion on Rϕ should be calibrated and corrected in Reco.



→ Field correction ≲ few mm in Rϕ

Will apply correction in offline analysis



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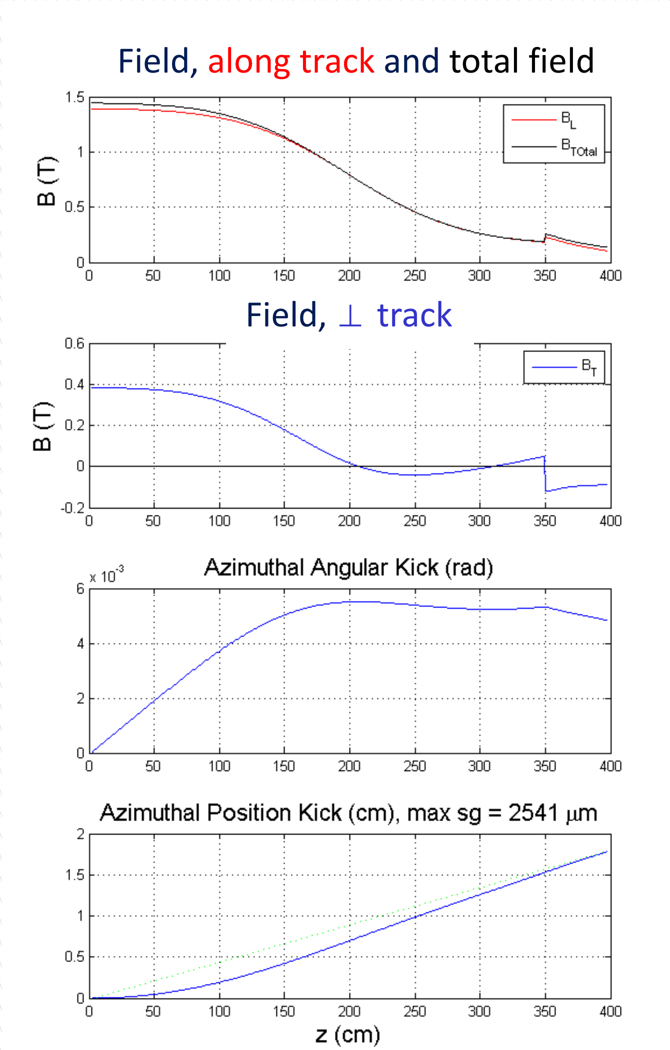

Using ϕ segmented GEM
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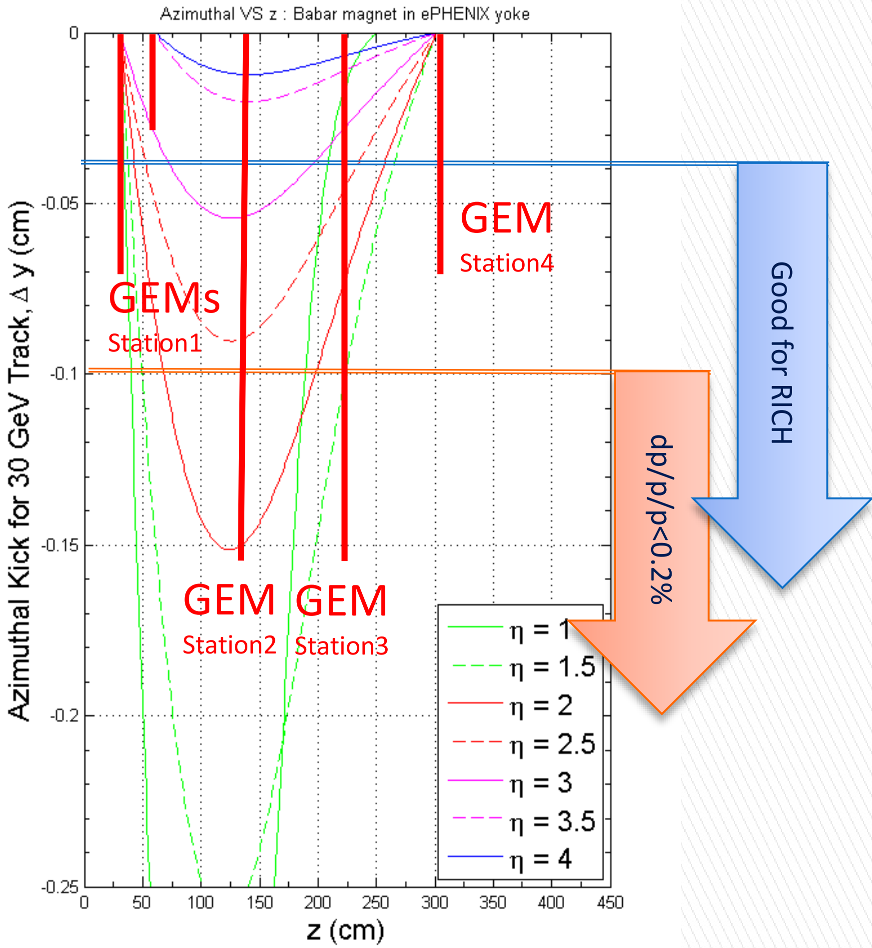


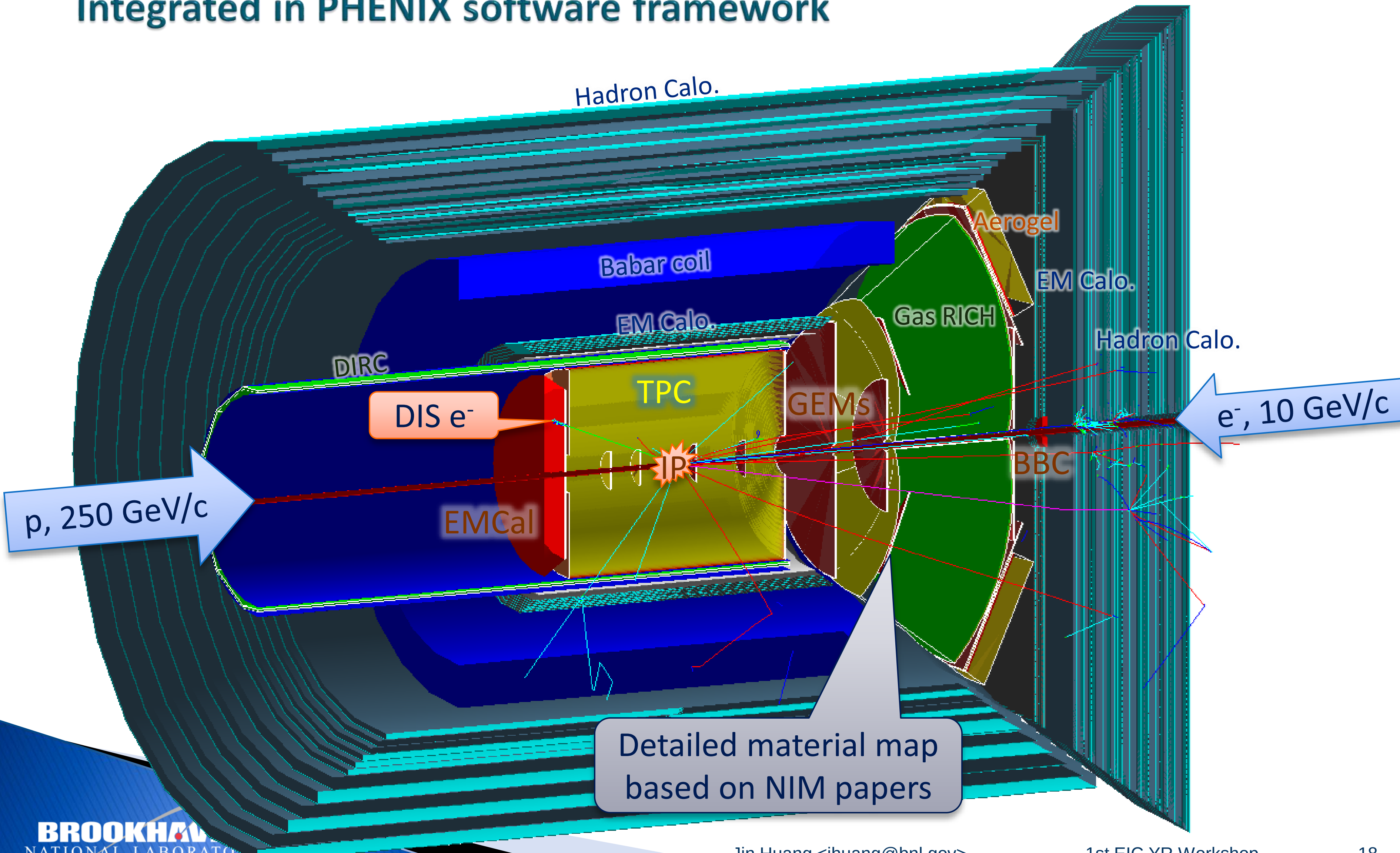
Magnetic bending
Track of η=2.0, p=30 GeV

Tracker layout for max sensitivity
Track of p=30 GeV

Tracking studied in Geant4 models

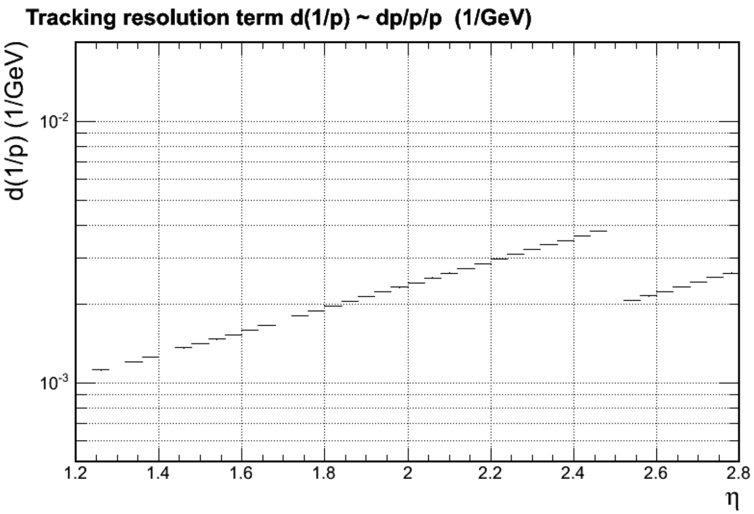
An event display for SIDIS @ $x \approx 5\times10^{-3}$ and $Q^2=10$ (GeV/c)^2

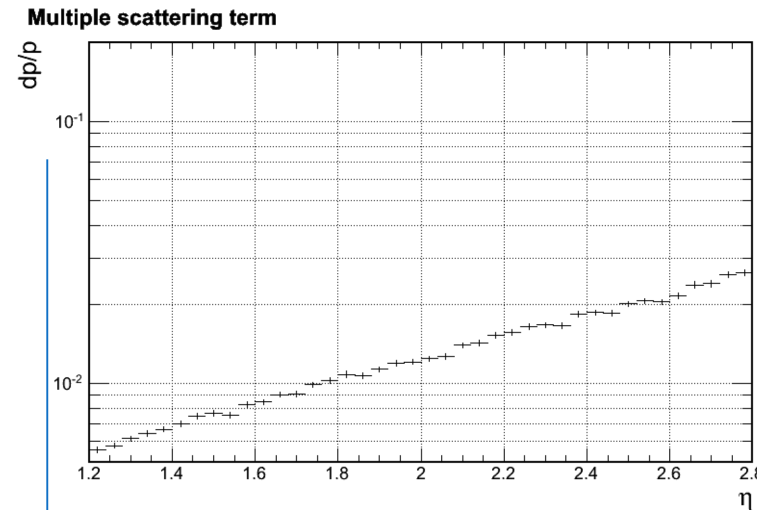
Integrated in PHENIX software framework



Geant Tracking resolution – 1<η<3

dp/p ~ (Multiple scattering term) + (Tracker resolution term)*p





Tracker resolution term,

1< η <2.5: d($Sagitta_2$) = 120µm for 100 µm tracker resolution

2.5< η <4: d($Sagitta_2$) = 60µm for 50 µm tracker resolution

Multiple scattering term

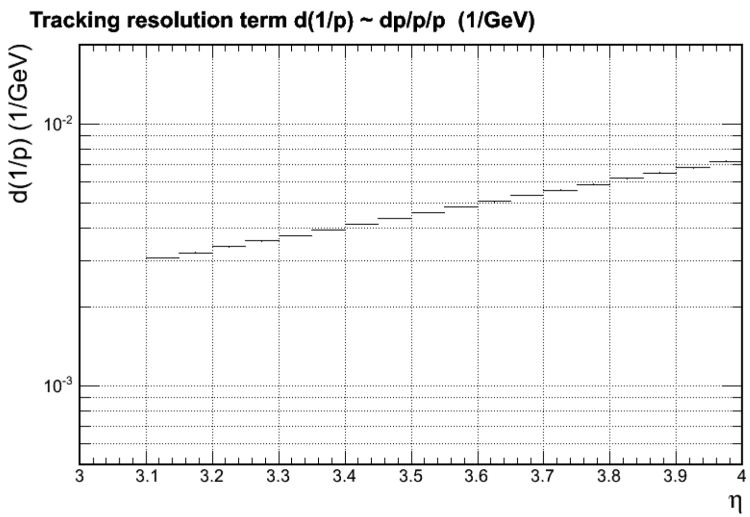
Displayed without RICH

- With RICH tank (2/3 of tracks): ~20% (rel.) worse
- With RICH tank + Readout (1/3 of tracks): ~50% (rel.) worse

Geant Tracking resolution – $3<\eta<4$

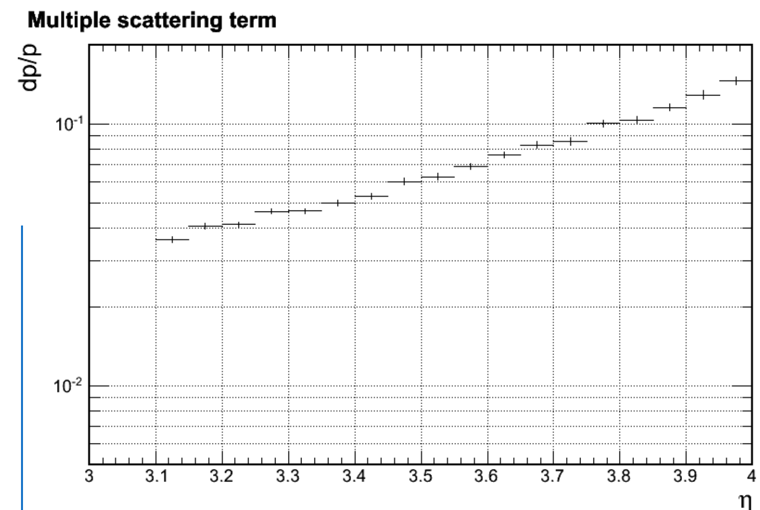
Using vertex as first tracking station

dp/p ~ (Multiple scattering term) + (Tracker resolution term)*p



Tracker resolution term

2.5< η <4: d(Sagitta$_2$) = 60µm for 50 µm tracker resolution



Multiple scattering term

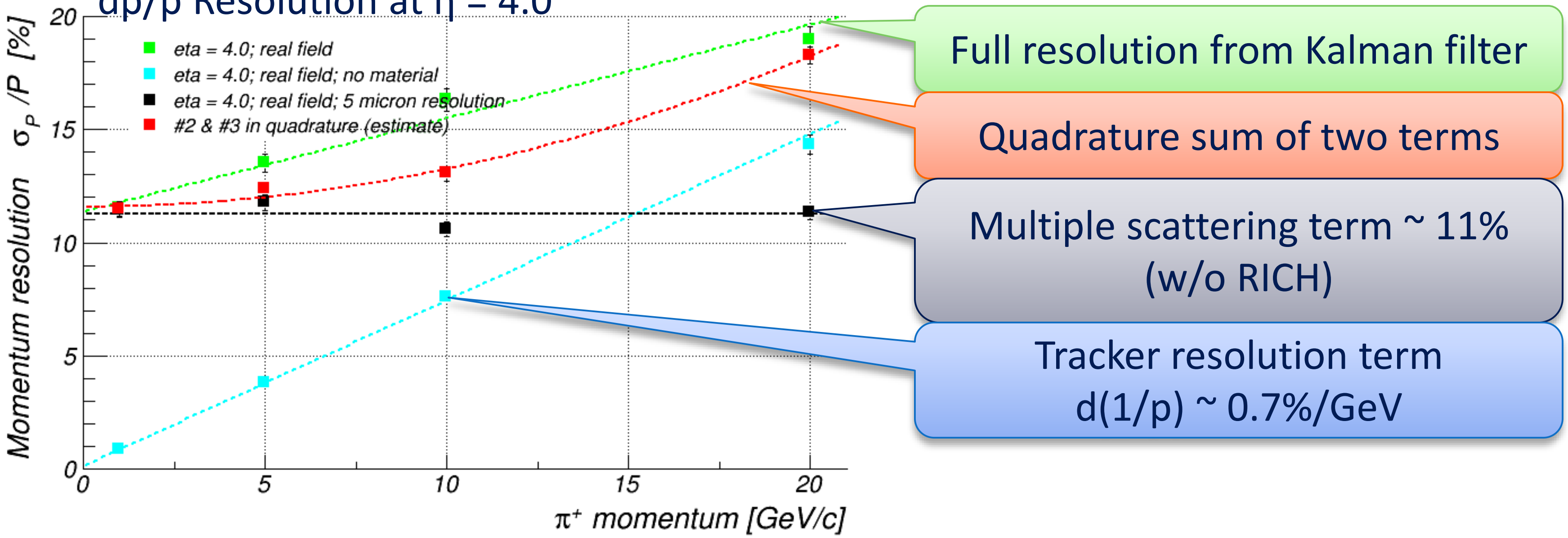
Without RICH

- 20% worse with RICH tank
- RICH readout is away from this region

Confirmed this study by BNL EIC task force using Kalman filter

- Evaluated using EICroot by EIC taskforce using ePHENIX tracking bare-bone setup and field
- Consistent with my study in general

dp/p Resolution at η = 4.0



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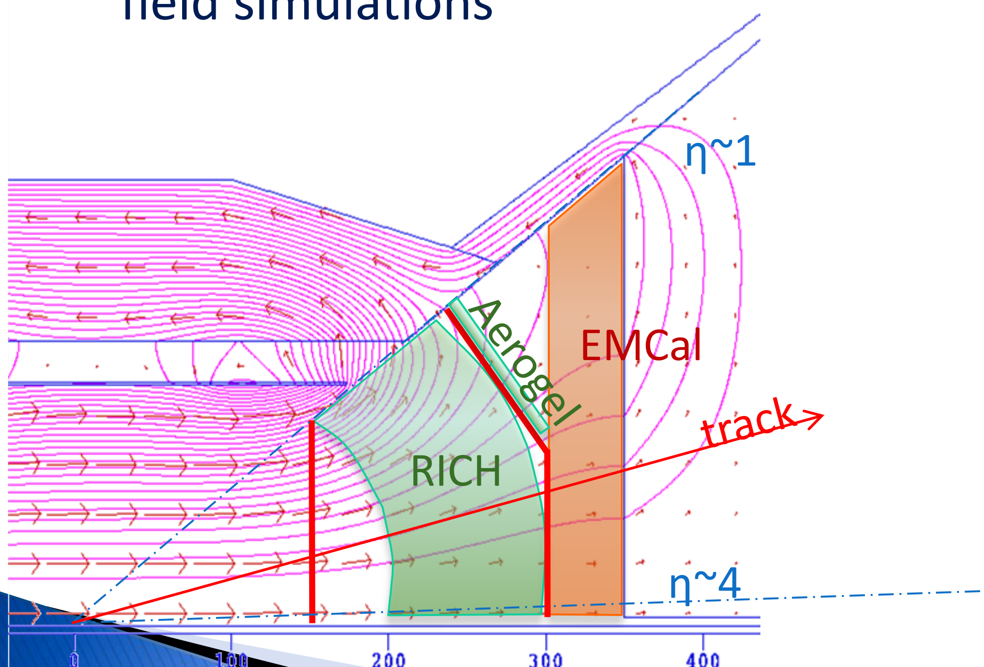
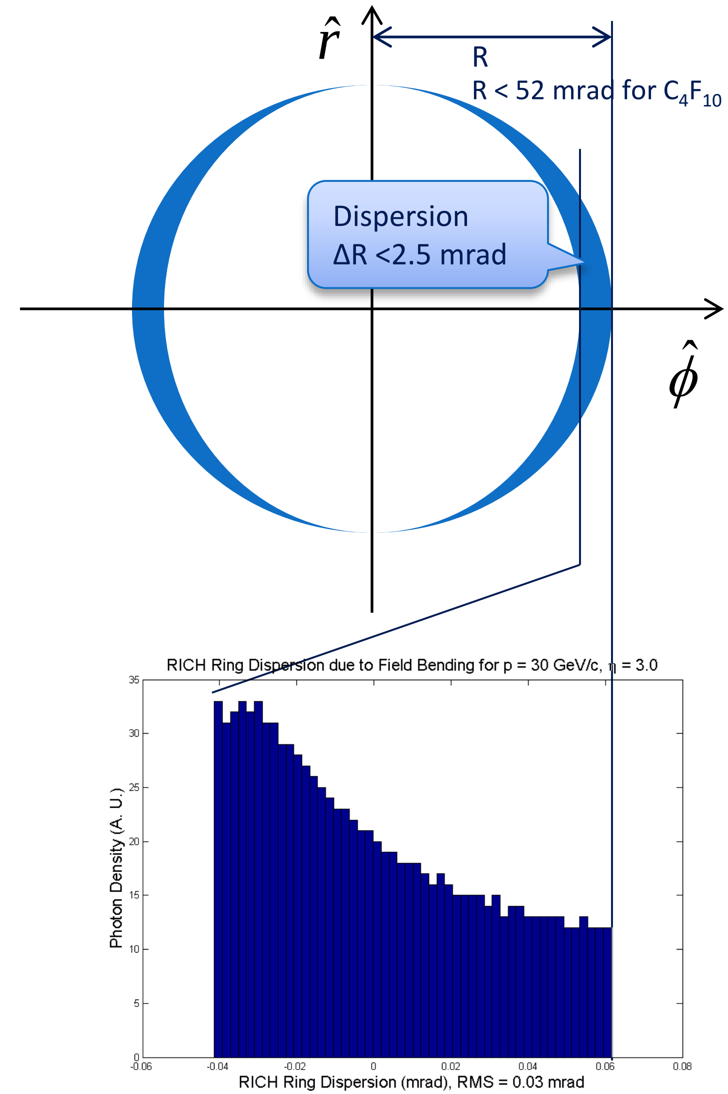
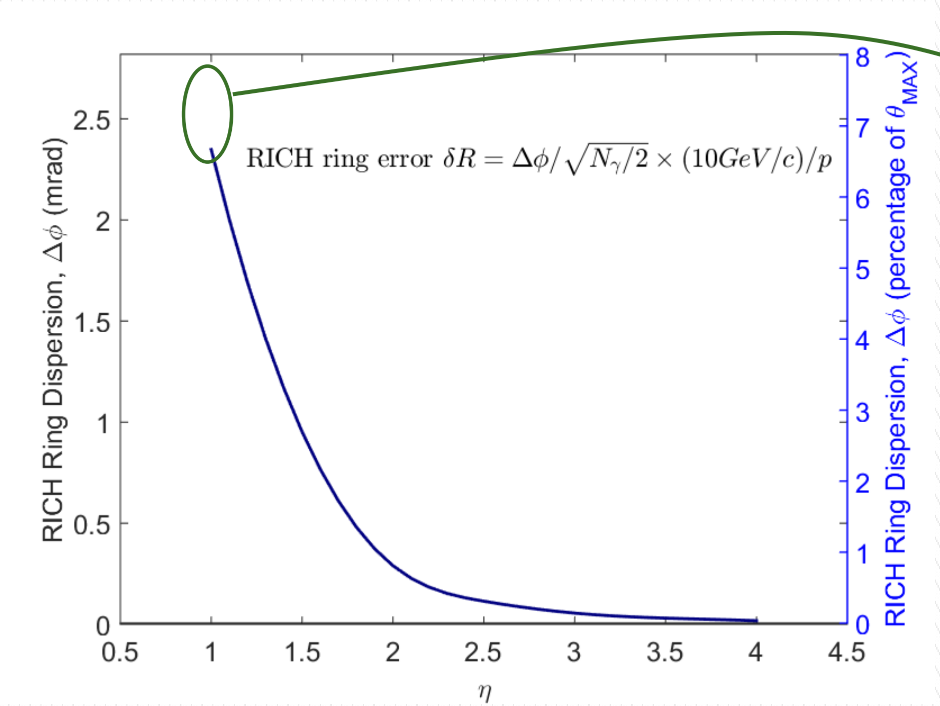


A RICH Ring:

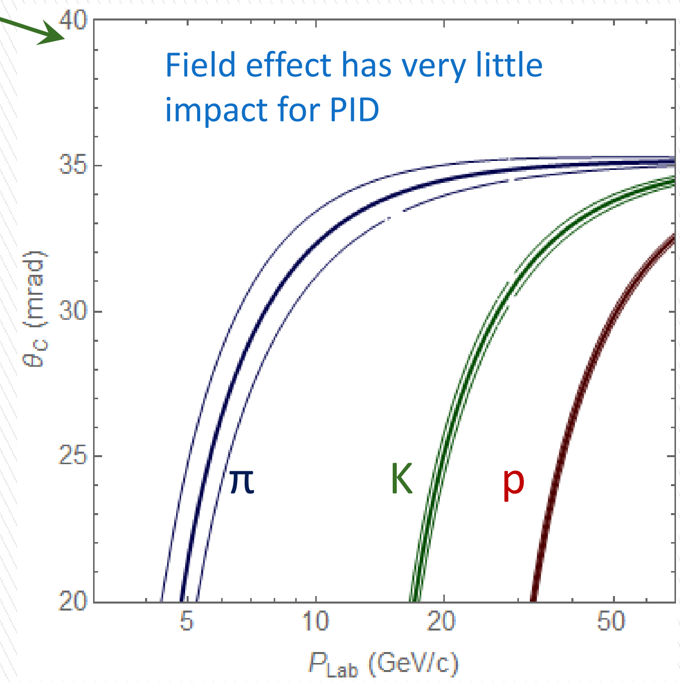
Photon distribution due to tracking bending only



Field effect –
Radius uncertianty of RICH Ring



Ring radius ± 1σ field effect (for worst η=1)



Quantify ring radius error

In the respect of PID: minor effect

Summary

- ePHENIX field design is based on BaBar coil
  - Benefit for forward tracking
  - Ownership officially transferred to BNL
- Yoke designed around the coil
  - Optimizing tracking resolution
  - Reducing field effect in RICH and TPC
  - Use iron-scintillator sample calorimeter as majority part of return yoke
- Detector performance studied with numerical field calculation
  - Tracking resolution : Good enough for ePHENIX physics
  - Field distortion to gas RICH is minor
  - Field distortion for TPC can be calibrated corrected