Brief introduction to fsPHENIX and its EIC evolution

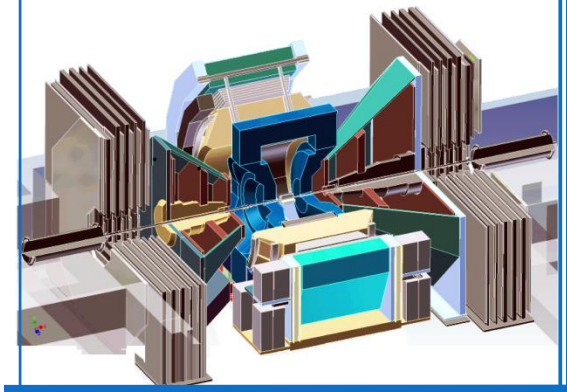
Jin Huang (BNL)

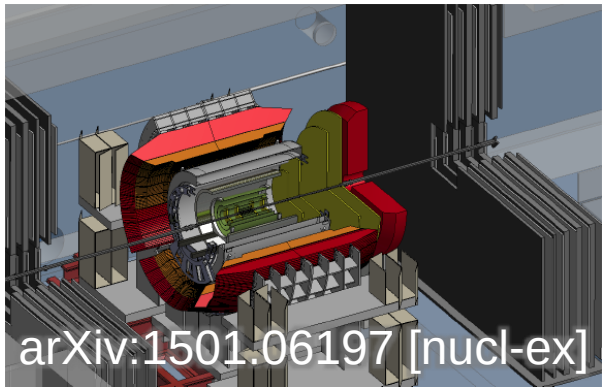
2016 PHENIX SpinFest @ UCR

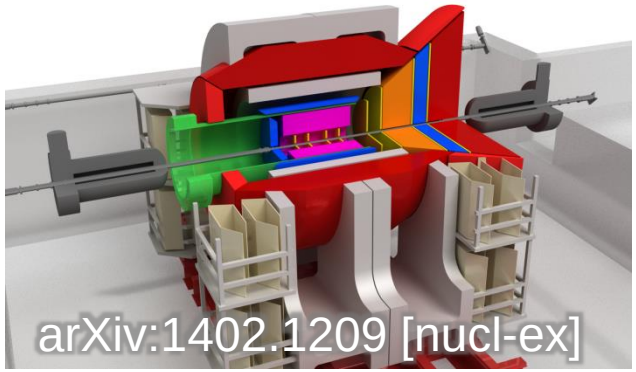
Evolution of the 8 o'clock IR @ RHIC

Documented: http://www.phenix.bnl.gov/plans.html

Current PHENIX	*s*PHENIX (+fsPHENIX)	An EIC detector
14y+ operation 100+M$ investment	Comprehensive central upgrade base on BaBar magnet	Path of PHENIX upgrade leads to a capable EIC detector
Broad spectrum of physics (QGP, Hadron Physics, DM)	Rich jet and beauty quarkonia physics program → nature of QGP	Large coverage of tracking, calorimetry and PID
140+ published papers to date	fsPHENIX : forward tracking, Hcal and muon ID → Spin, CNM	Open for new collaboration/new ideas
Completed last run 2016		







~2000 | 2016→2022 | ~2025 | Time

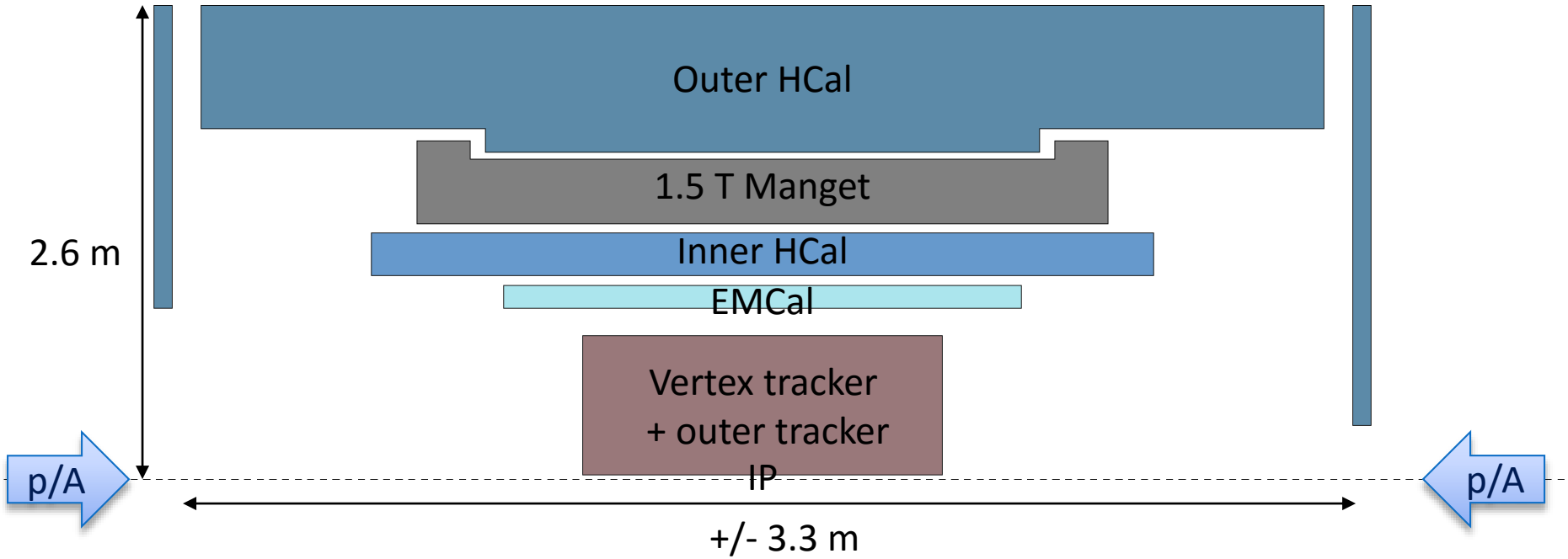
RHIC: A+A, spin-polarized p+p, spin-polarized p+A

EIC: e+p, e+A

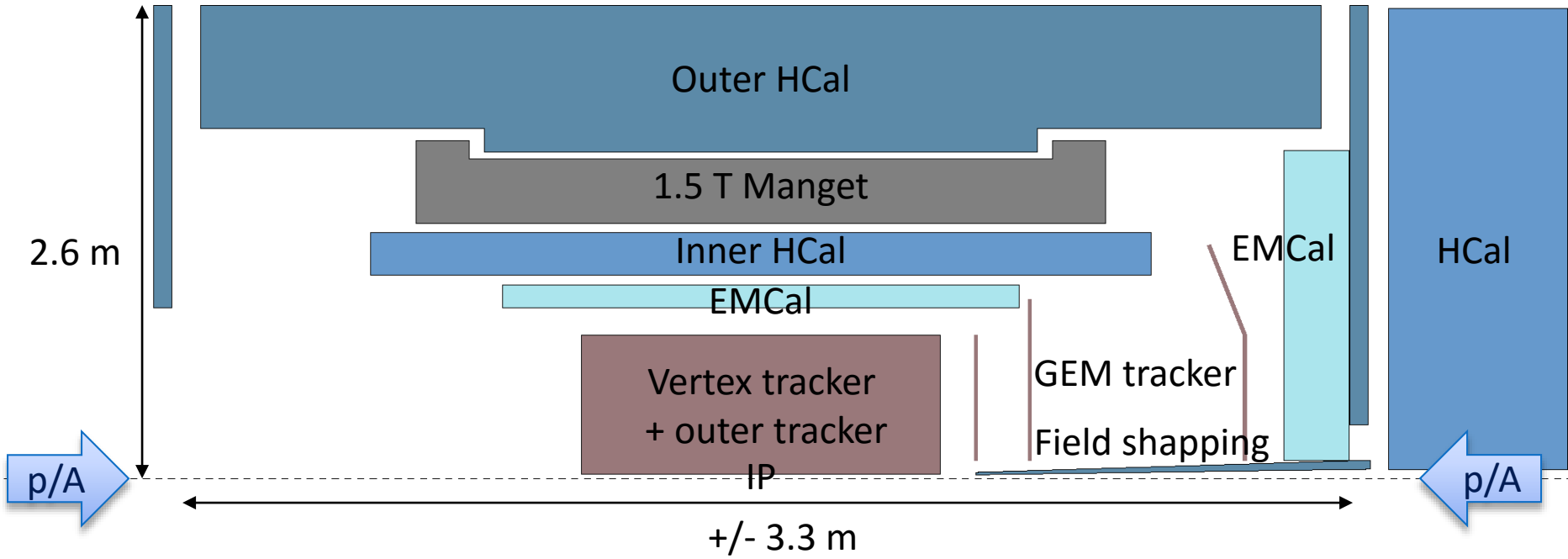
Recent documents / events

- An EIC detector Letter of Intent: arXiv:1402.1209 [nucl-ex]
- sPHENIX proposal: arXiv:1501.06197 [nucl-ex]
- fsPHENIX white paper: https://indico.bnl.gov/getFile.py/access?resId=0&materialId=5&confId=764
- eRHIC white paper: arXiv:1409.1633 [physics.acc-ph]
- Dec 2015: Formation of sPHENIX scientific collaboration
- RHIC cold-QCD white paper: https://indico.bnl.gov/getFile.py/access?resId=0&materialId=8&confId=1761
- **2016 fsPHENIX workshop: https://indico.bnl.gov/conferenceDisplay.py?confId=1796**
- **As of now: formation of cold-QCD topical group in sPHENIX collaboration**

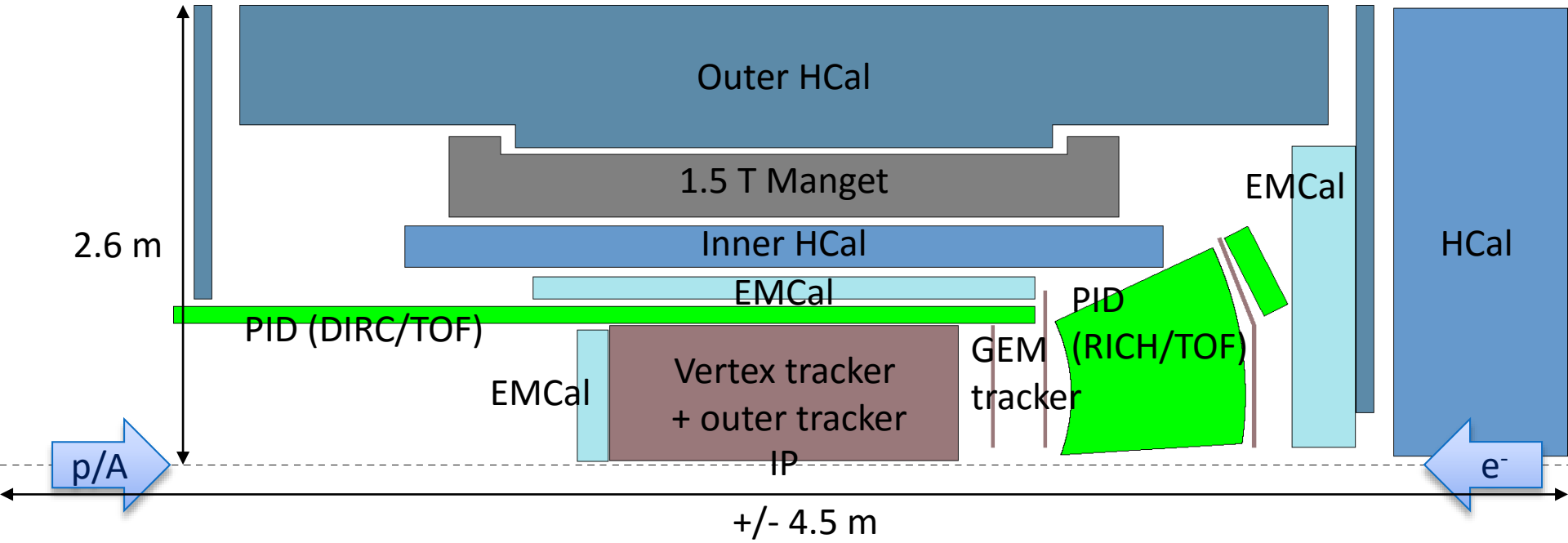
Detector evolution concept
sPHENIX, arXiv:1501.06197 [nucl-ex]



Detector evolution concept
sPHENIX + fsPHENIX



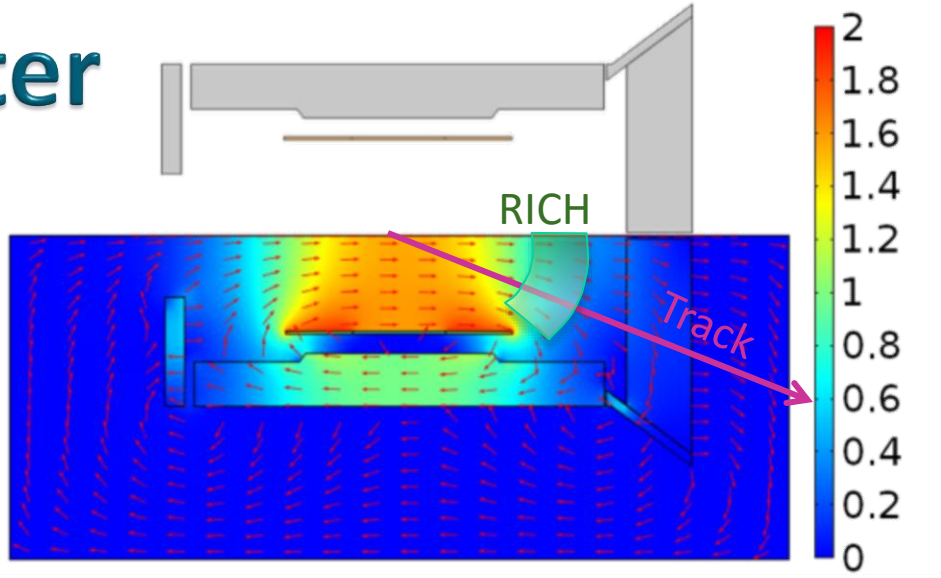
Detector evolution concept
sPHENIX + fsPHENIX
as foundation of an EIC detector

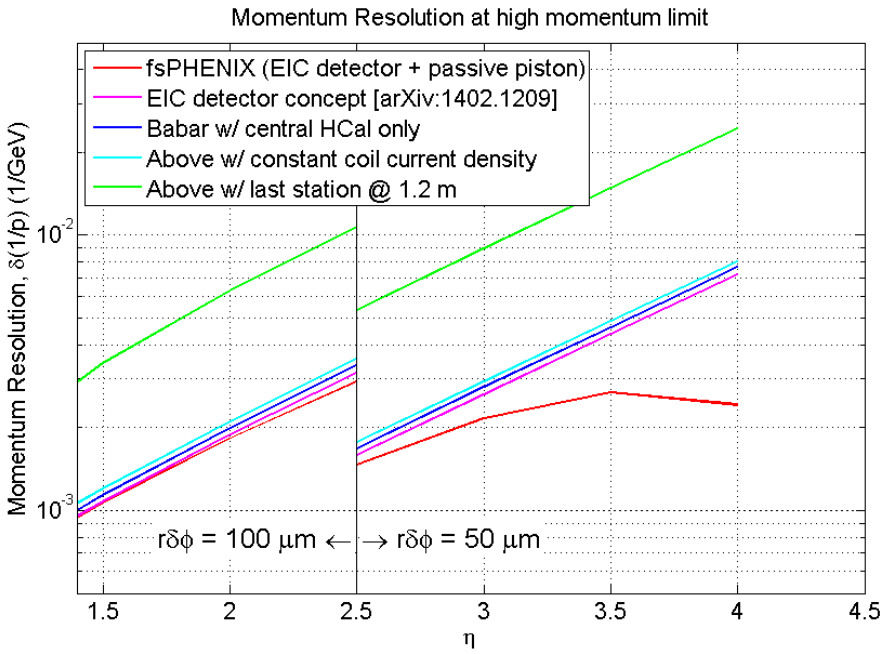


fsPHENIX and recent updates

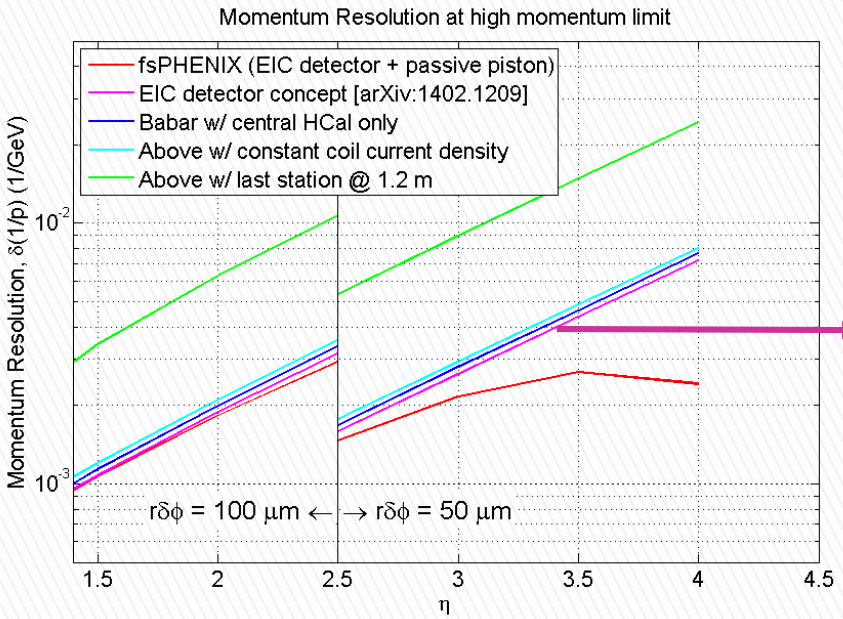
Forward spectrometer

- BaBar superconducting magnet is a power full and large magnet
  - Nominal field: 1.5T
  - Length: 385 cm
- Field calculation and yoke tuning
  - Preliminary field calculation in 2D : POISSION, FEM, OPERA and COMSOL
- Favor for forward spectrometer
  - Designed for homogeneous B-field in central tracking
  - Longer field volume for forward tracking
    - FOM (Position resolution) ~ $B*L^2$
    - FOM (multiple scattering) ~ $B*L$
  - Higher current density at end of the magnet -> better forward bending
  - Work well with RICH with field-shaping yoke: Forward & central Hcal + Steel lampshade
- Success super-conducting coil test





Recent update on tracking



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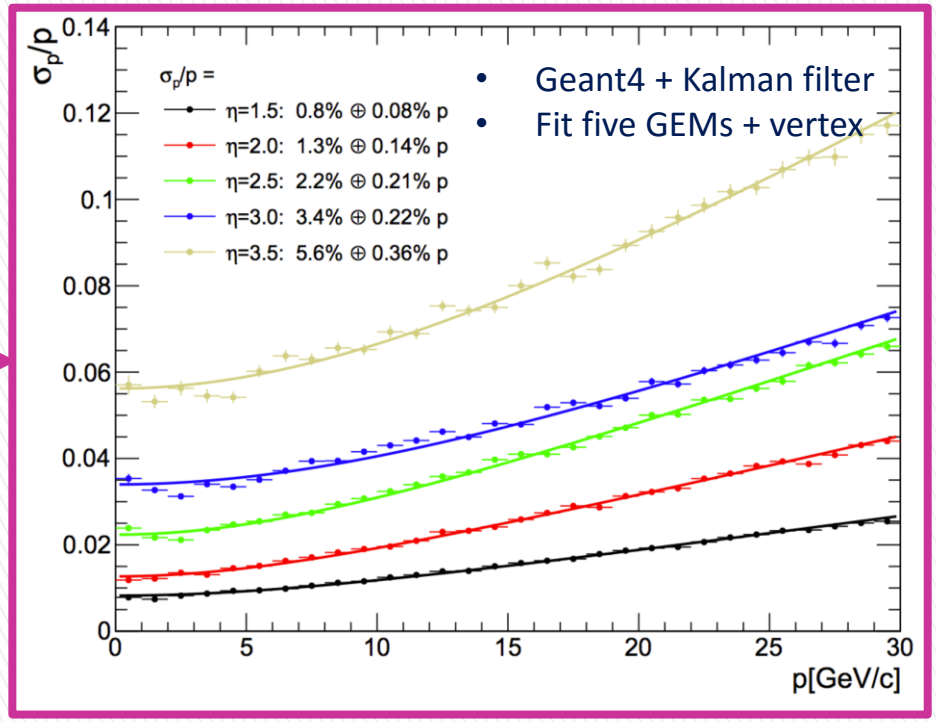


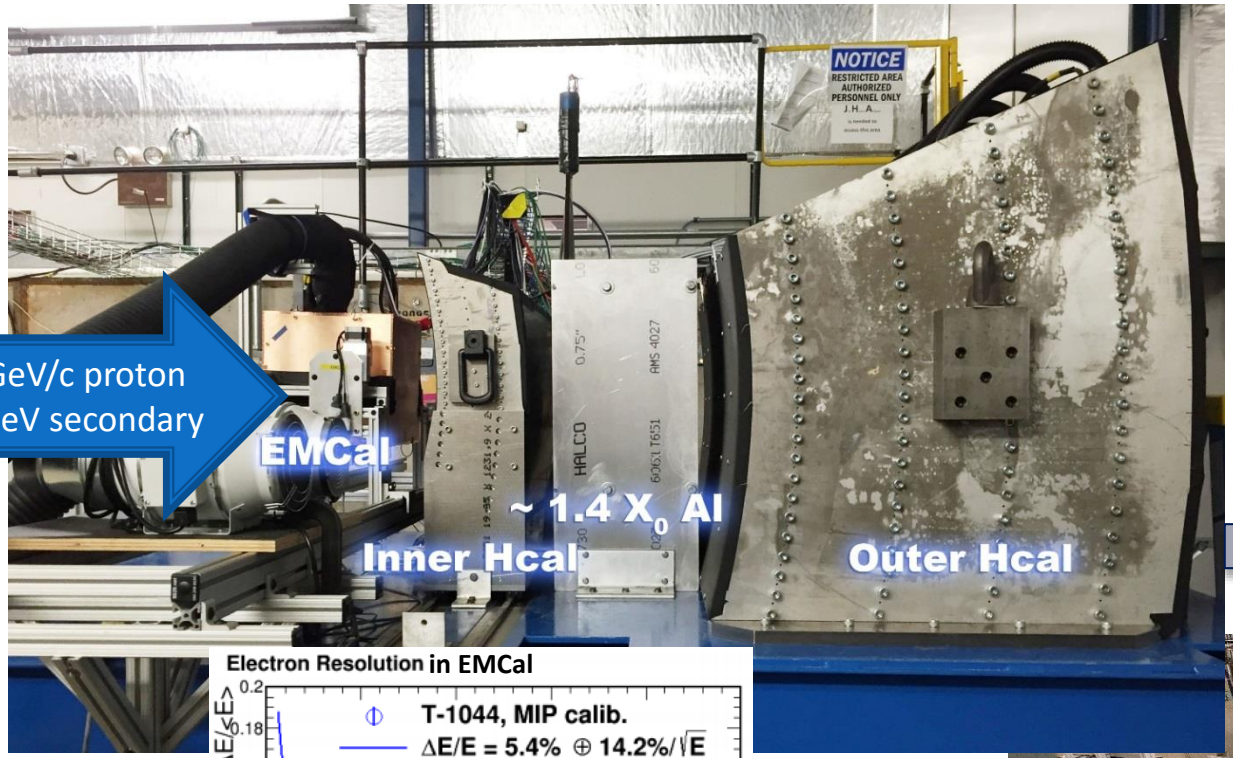
Analytical tracking resolution estimation in design stage

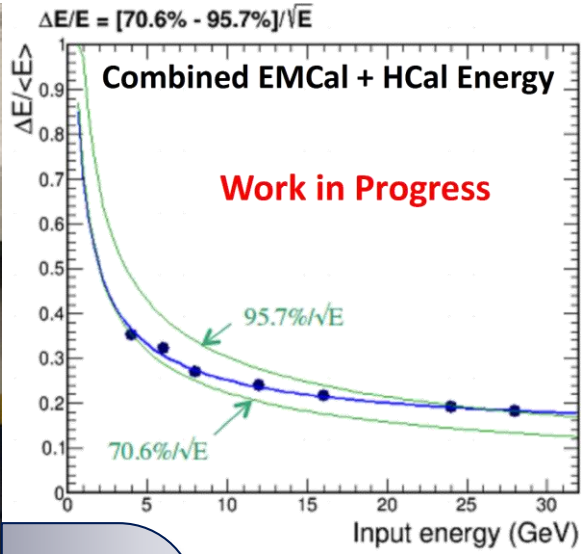
Geant4 simulation + Kalman Filter fit using GenFit2

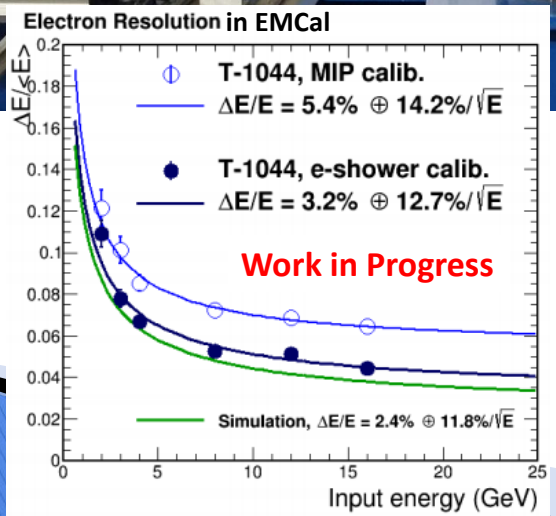
Tracking, next …

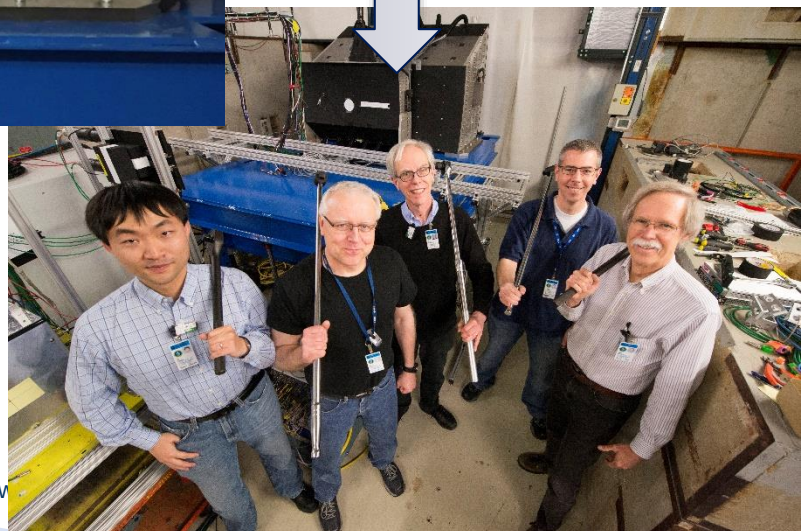
- Making the tracking output wider available in this workfest (Afternoon talk by Haiwang)
- Drell-Yan measurement
  - S/B: DY electron ID using track – calorimeter matching
  - John L. started Pythia background sample generation in sPHENIX framework
    - /gpfs02/sphenix/lajoie/user/fsPHENIX/events , electro triggered
  - HF background determination using e-μ correlations
  - DY pair pT resolution and azimuthal angle determination
- Upsilon in small collision system (Richard)
  - Calorimeter energy scale + track pointing to separate
- Direct heavy flavor tagging (Richard, LANL?)
  - Space point using central MAPS detector partially cover to $\eta<3$ for the forward track

Beam test on the central calorimetry



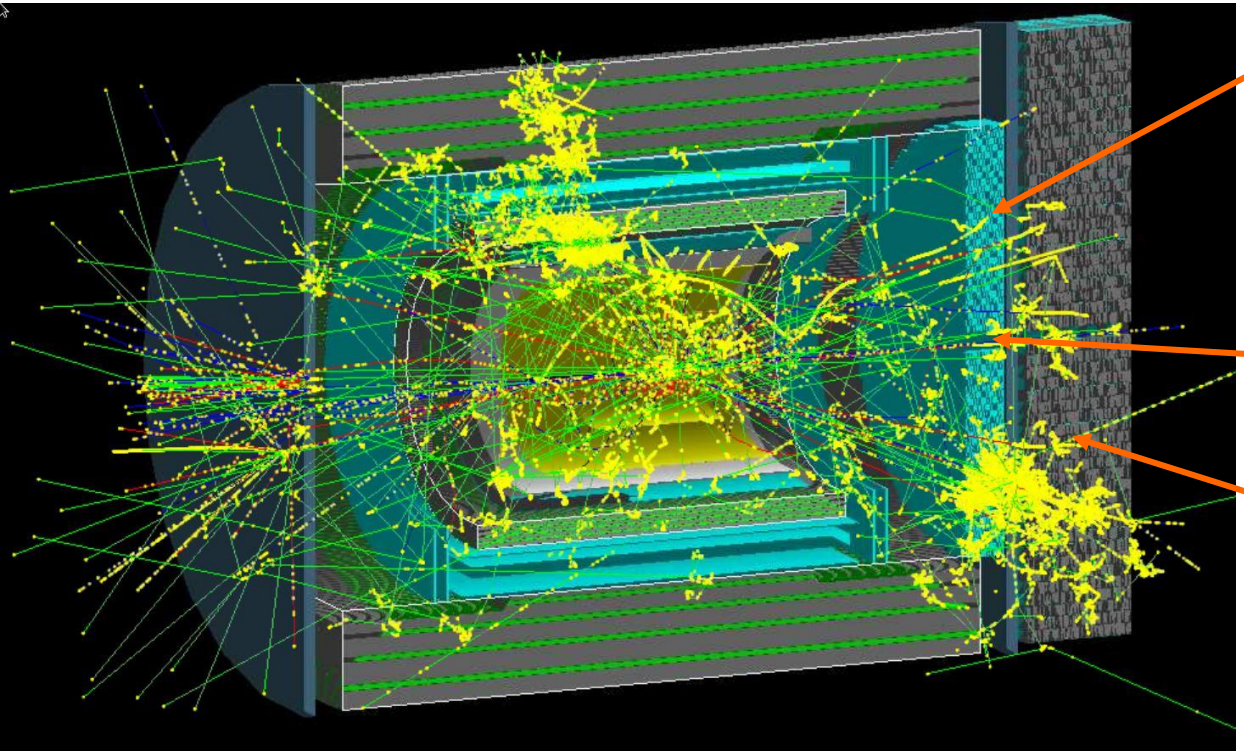






Spin w

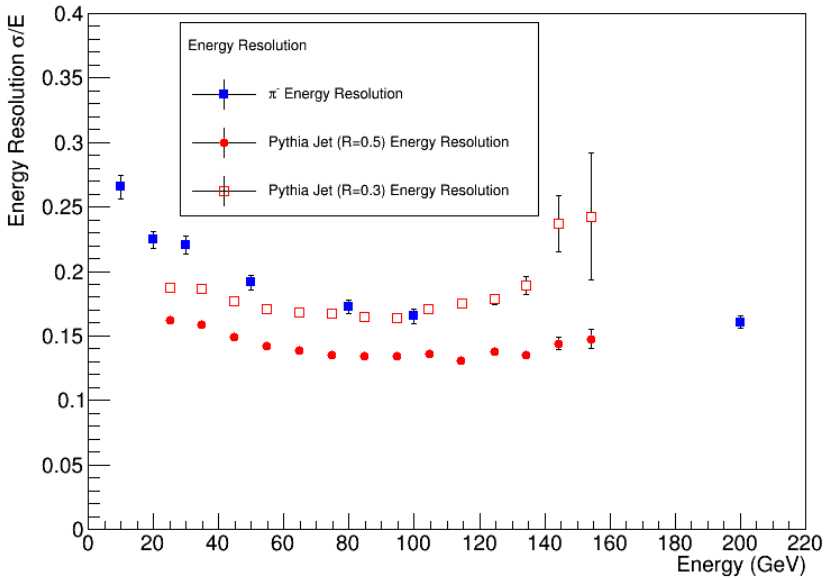
Recent update on forward calorimetry



- Outer EMCal: restack super module of PHENIX PbSc (Pb-shashlyk)
- Inner EMCal: restack PHENIX MPC (PWO_4)
- HCal: Tile-Cal with Iron absorber
- John produced layout and implemented in Geant4

Quantifying impact of inactive field return (~ 1 interaction length after EMCal)

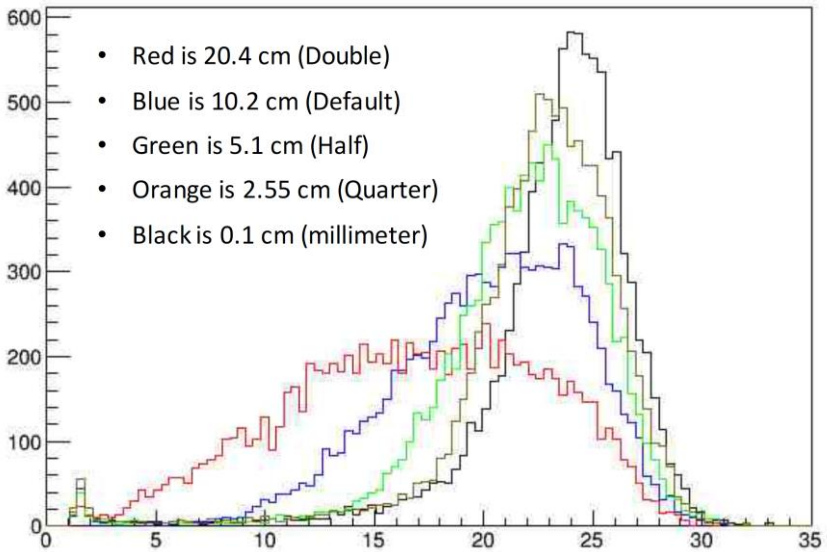
Magnet end door
-> 1 interaction length of inactive material
Limited to ~14% - large constant term



By John Lajore

Energy resolution

Hadron shower lineshape (30 GeV pion)
VS field return thickness (inactive iron)



EMCal + HCal (GeV, before energy scale correction)

By David Kapukchyan

Lineshape and low side tails

Calorimetry, next ...

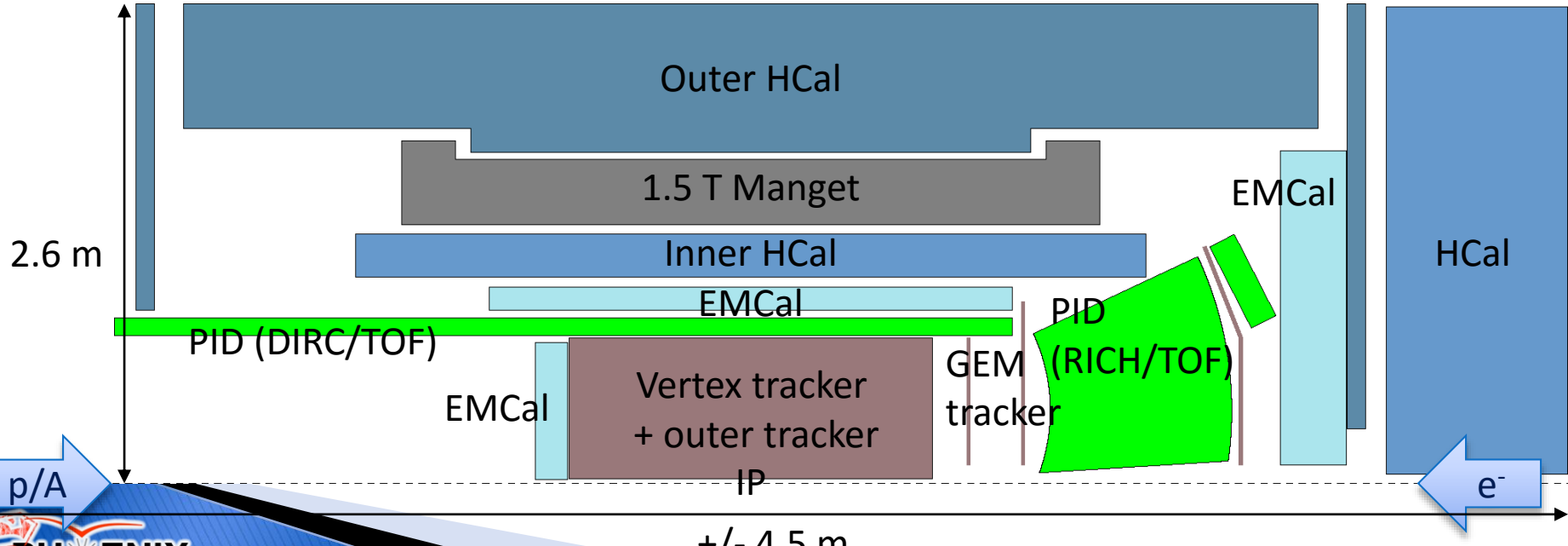
- Evolving the concept:
  - Readout, trigger
  - HCal as magnetic field return (iron based tile-cal?)
- Quantifying jet response (Chong, Dave)
- Sieves with charge tagging (update from white paper with unfolding?)
- Transversity measurement using track azimuthal A_N in jet (Ralf)

EIC concept and areas to be updated

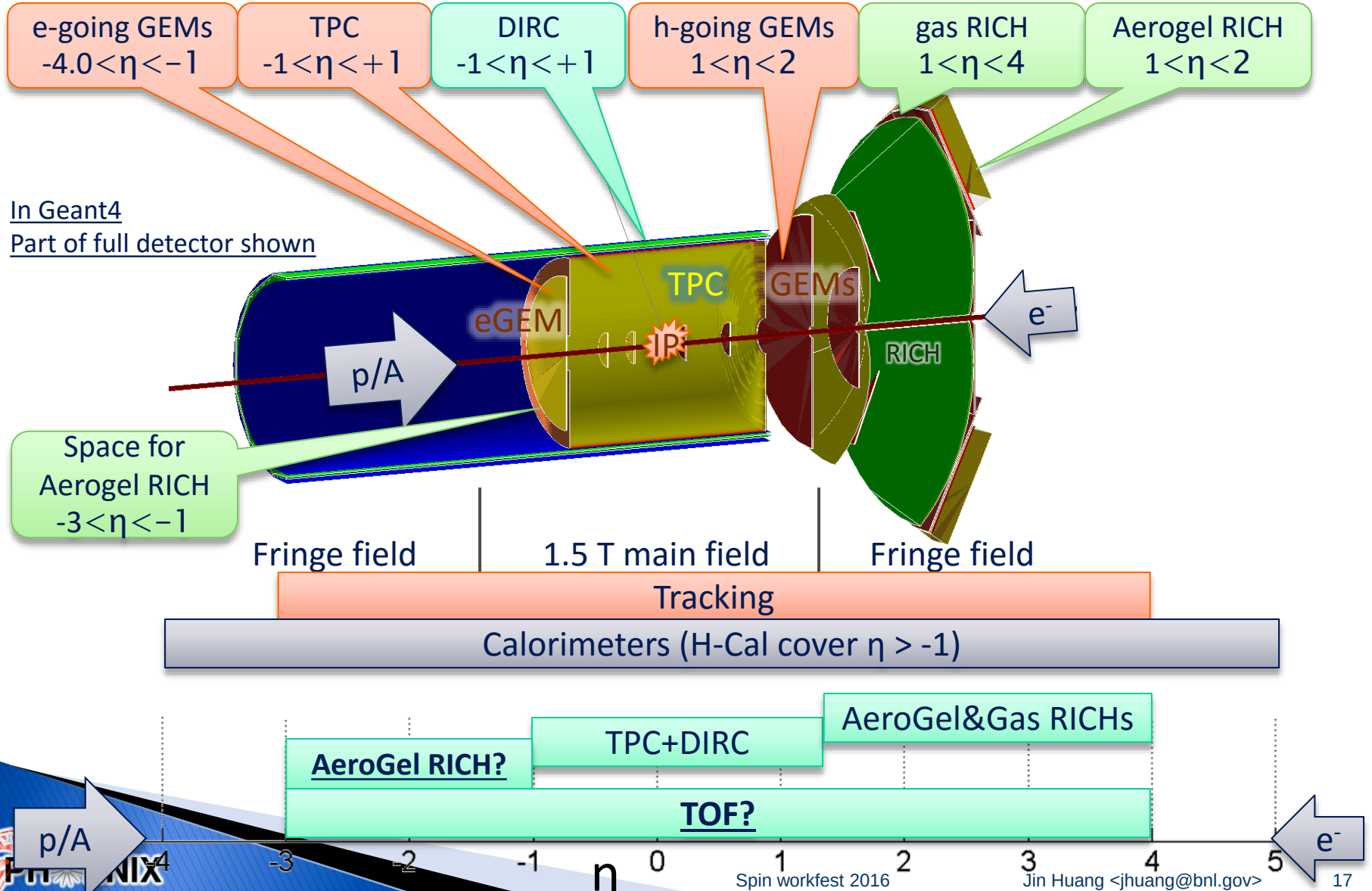
Next, in EIC era

- -1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC/TOF
- -4<η<-1 (e-going) :
  High resolution calorimeter + GEM trackers
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH/TOF
  - 1<η<2 : Aerogel RICH
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots

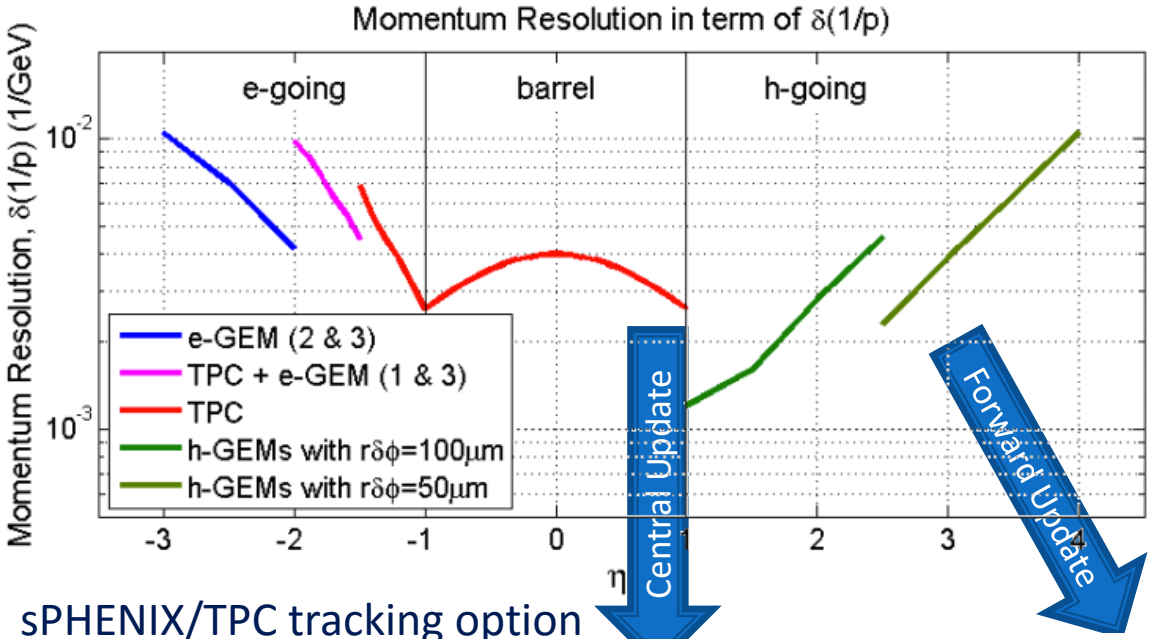
Working title: "ePHENIX"
LOI: arXiv:1402.1209



Tracking, PID and calorimetry coverage



Tracking



Analytical estimation of linear resolution term In 2012-concept [arXiv:1402.1209v1]

MS: < 1% (low η) to 3% (η = 3)

sPHENIX/TPC tracking option

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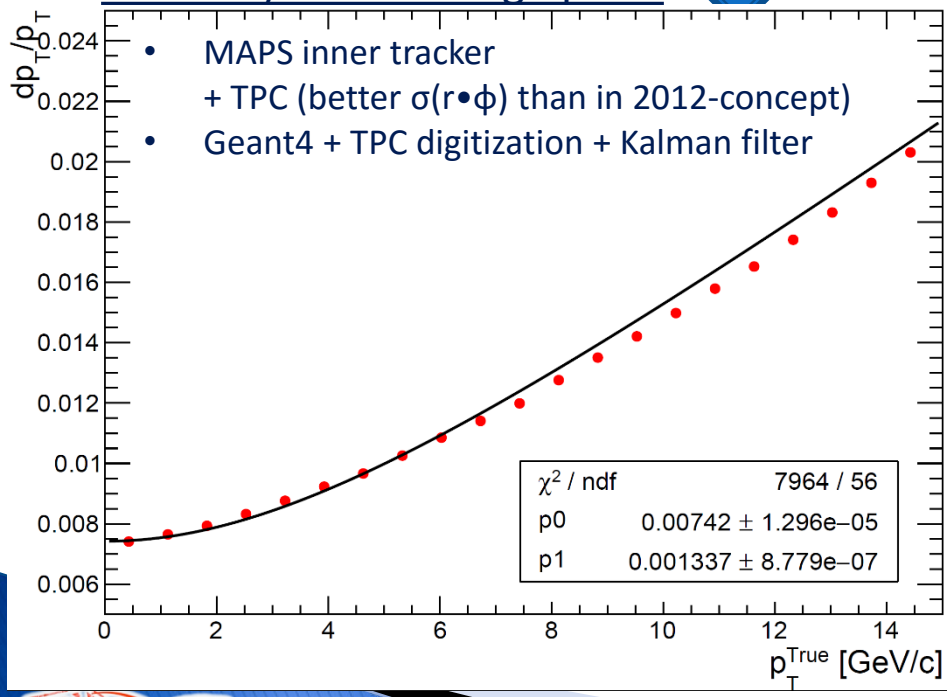
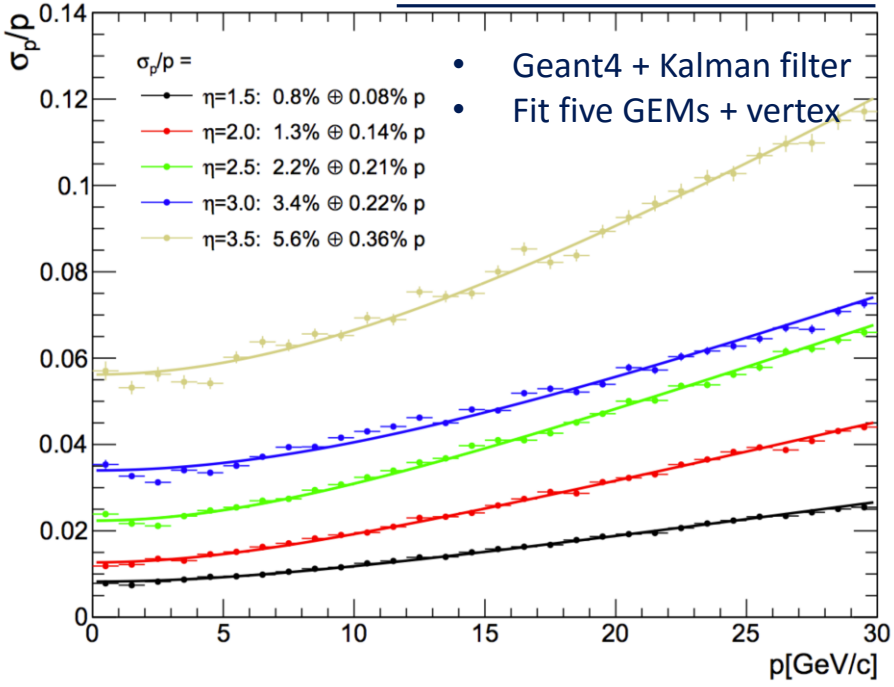


EIC GEM forward tracker

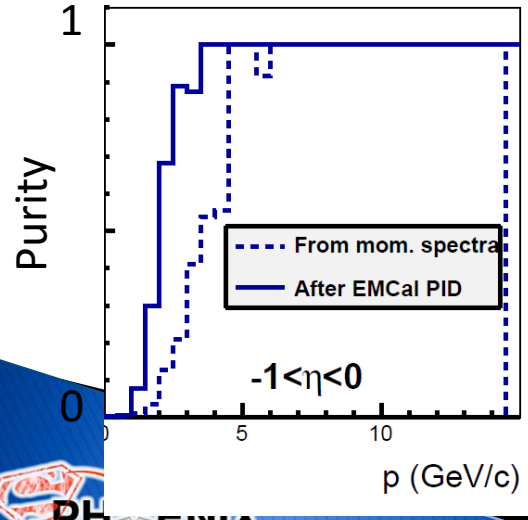
- Geant4 + Kalman filter
- Fit five GEMs + vertex



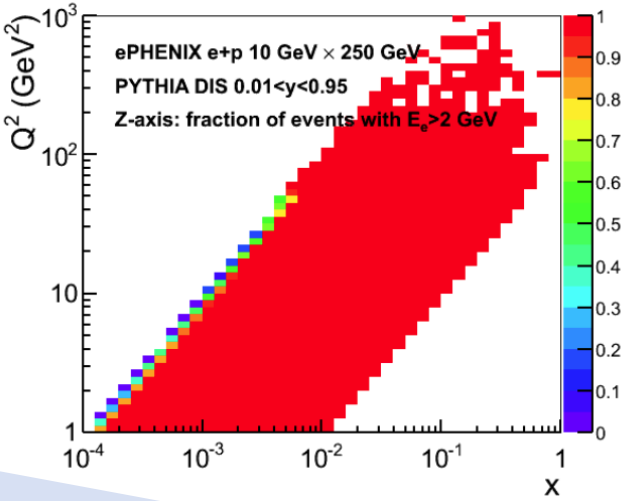
Calorimeter

- Electron identification (e-EMC, barrel EMC)
- Electron kinematics measurement (e-EMC, barrel EMC)
- DIS kinematics using hadron final states (barrel EMC/HCal, h-EMC/HCal)
- Photon ID for DVCS (All EMC)
- Diffractive ID (h-HCal)
- High momentum track energy measurement (h-HCal)

Electron purity after EMCal PID

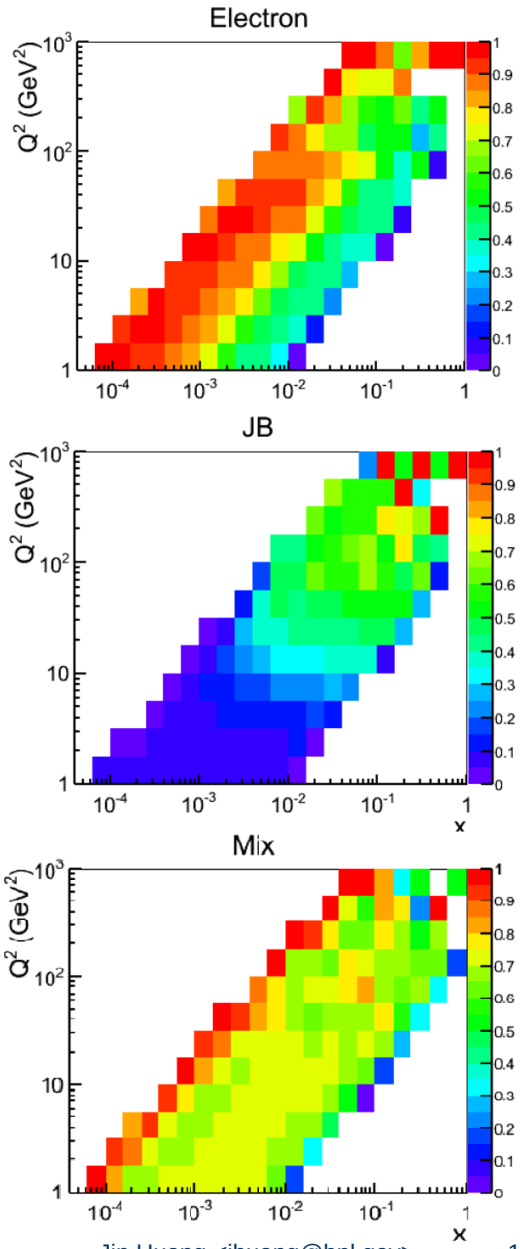


Fraction of DIS event with good electron ID

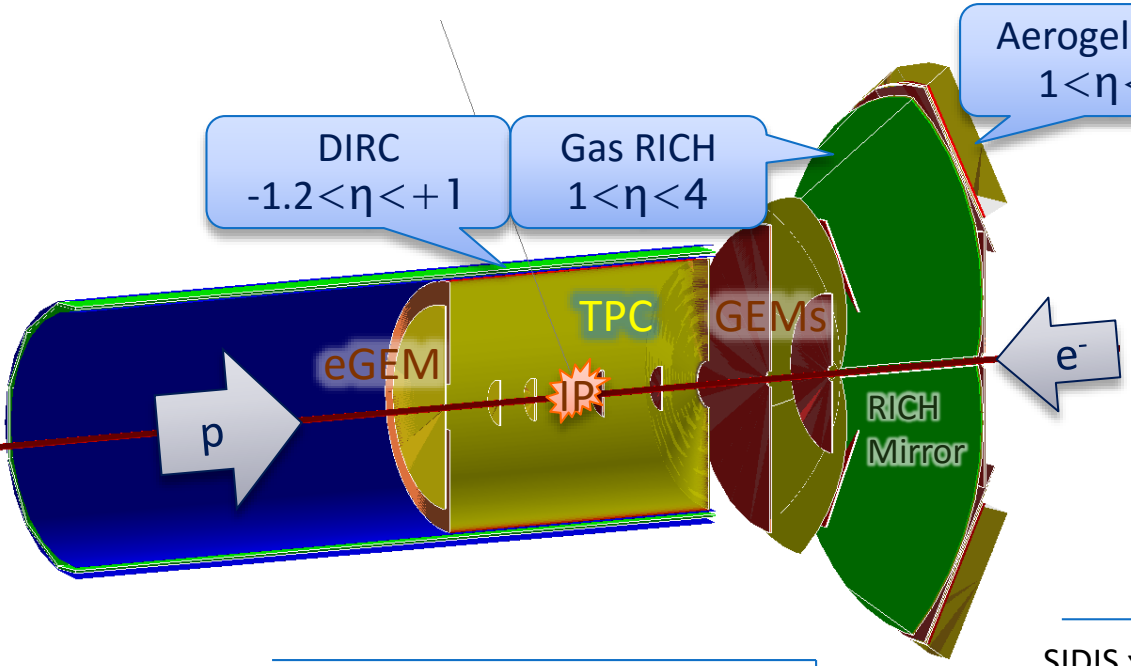


DIS kinematics survivability

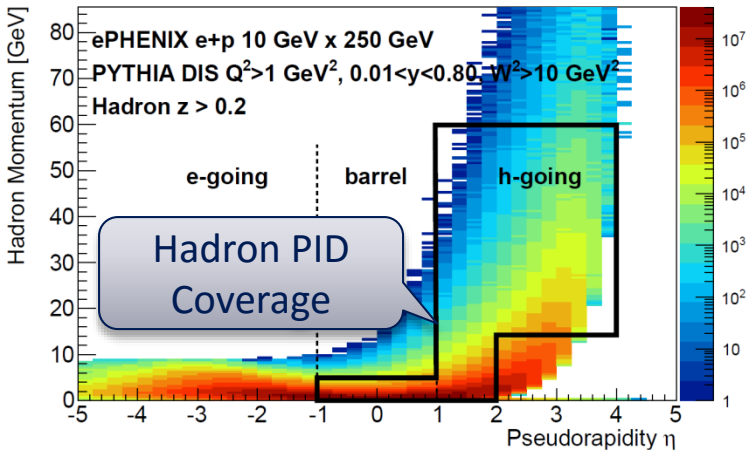
ePHENIX 15 x 250 GeV



Hadron Identification

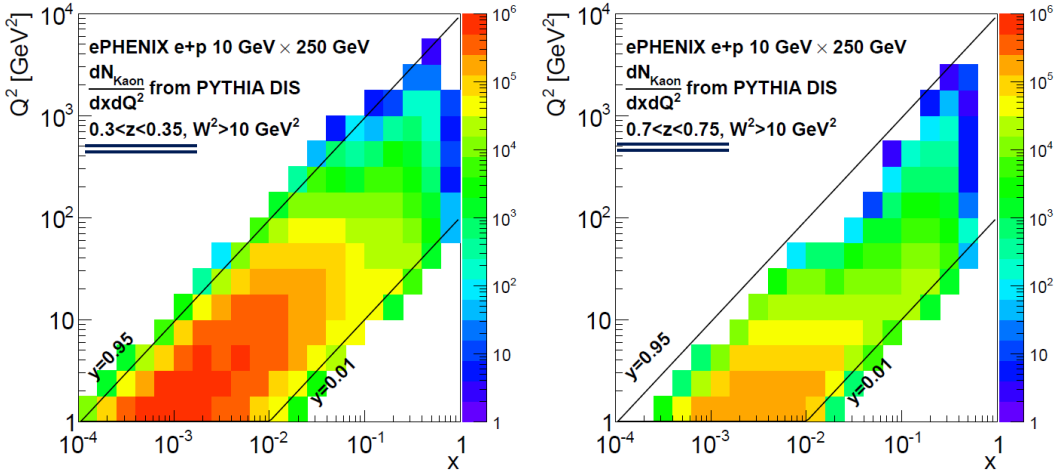


Detector coverage for hadron PID



- DIRC
  - Based on BaBar DIRC design plus compact readout
  - Collaborate with TPC dE/dx for hadron ID in central barrel
- Aerogel RICH
  - Approximate focusing design as proposed by Belle-II
  - Collaborate with gas RICH to cover 1<η<2
- Gas RICH: next slides
- Actively exploring ToF alternatives
- Considering hadron ID in en-going direction

SIDIS x-Q^2 coverage with hadron PID in two z-bins

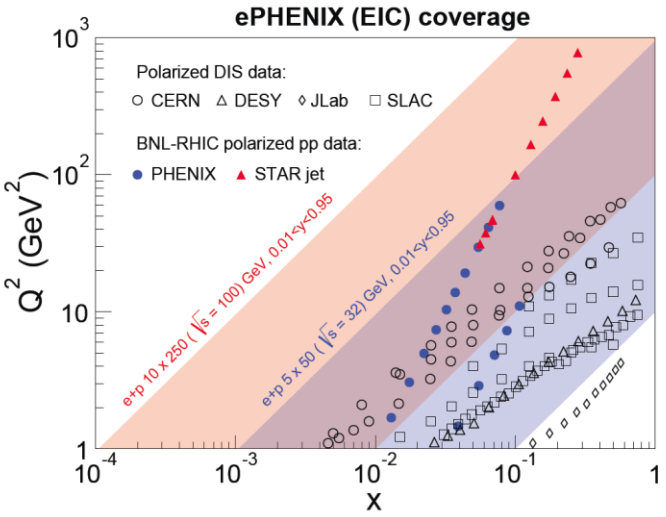


Target updates - ePHENIX

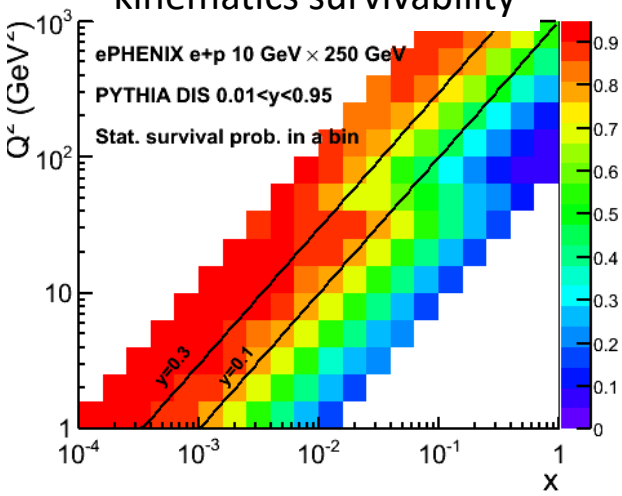
- Update with sPHENIX
- New detector that can be introduced to the concept:
  - ToF as part of eRD14
  - MAPS as part of sPHENIX ref. tracking design
  - TPC as SBU refining design for sPHENIX based on ALICE and ILC R&D
- Updated hadron ID in e-going direction
- Refresh performance plots
- New impact studies:
  - Parity violating NC exchange asymmetry projection and impact (SBU)

Physics performance to be updated: Example longitudinal structure of proton

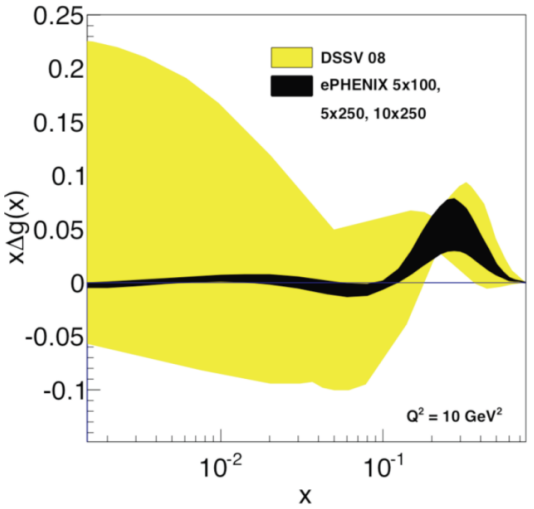
- Update with EM calorimeter and tracking simulation, → updates on DIS kinematic determination and e-ID
- Update with impact plot with updated PDF, RHIC projection and new projection curve



ePHENIX electron kinematics survivability



ePHENIX gluon helicity projection



High x and Q2 region will be better determined using info from hadron final states

Summary

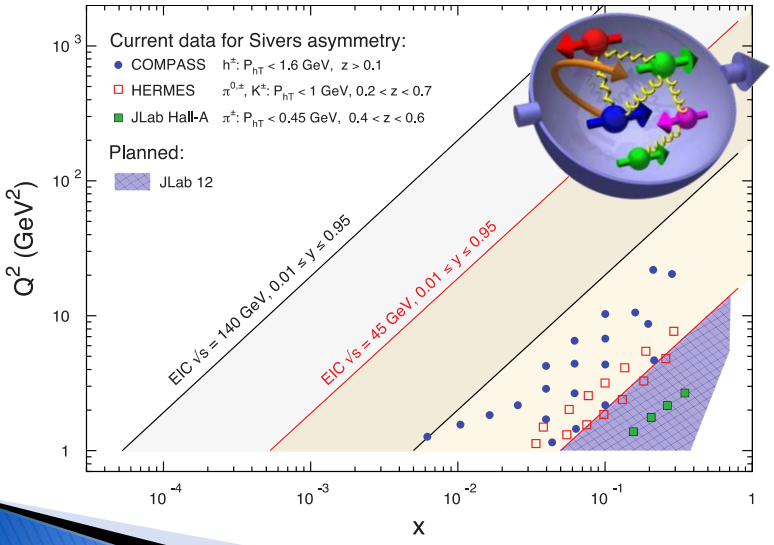
- Concepts evolve sPHENIX -> + fsPHENIX → a foundation of an EIC detector
- Concept developed in the past years, being updated/need to be updated as physics knowledge, detector technology evolves.
  - Abundant opportunities to contribute
  - Open agenda/software development to colleagues in the field
- Cold-QCD was recognized by the sPHENIX collaboration as one of four topical groups

Extra information

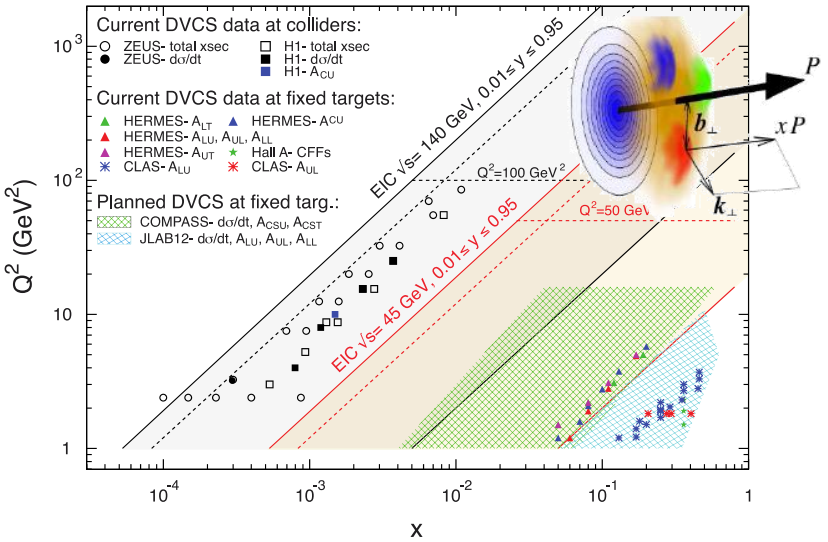
Physics performance: Transverse structure of nucleon

- Deliver clean measurement for SIDIS and DVCS
- Significantly expand x-Q^2 reach and precision for such measurements
- Extract sea quark and gluon's transverse motion and their tomographic imaging inside polarized nucleons
- Sensitive to the orbital motion of quark inside proton

SIDIS Sivers Asymmetries



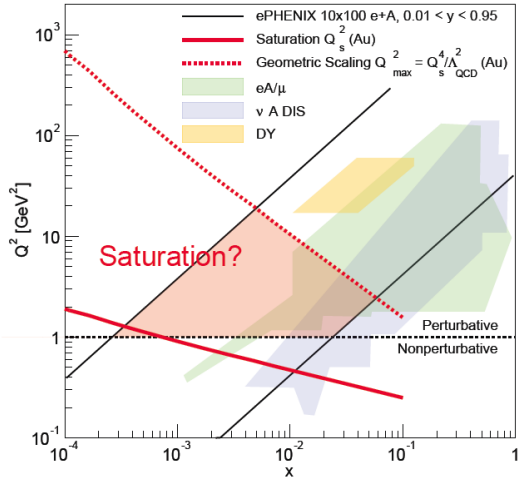
DVCS



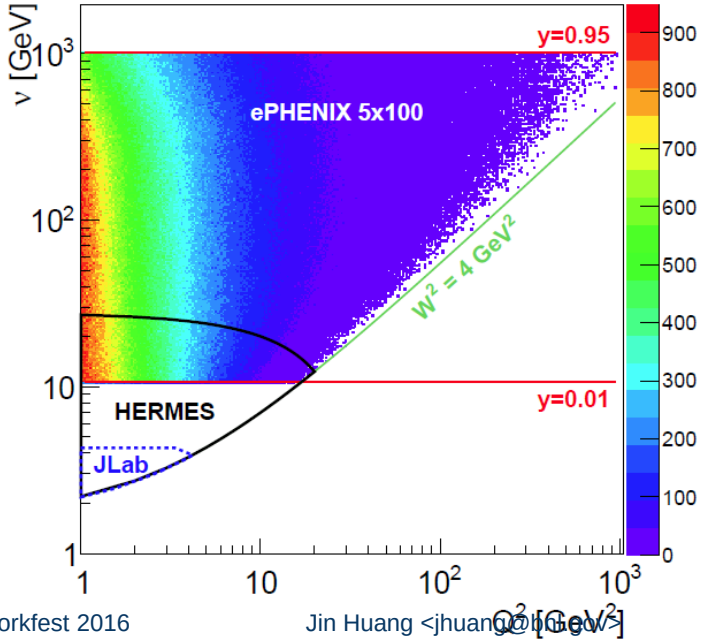
Physics performance: nucleus as a laboratory for QCD

- Probe the kinematic range to inspect the transition to gluon saturation region and their nuclear size dependent
  - Large H-cal coverage (-1<η<+5) provide clean ID of diffractive events with reasonable efficiency through the rapidity gap method
- SIDIS in e-A collisions probe color neutralization and harmonization as it propagate through nuclear matters
  - Provide a set of flexible handles : struck quark's energy and flavor, virtuality of DIS, geometry of the collision, specie of nuclei.

Probing saturation region in electron kinematics



Energy transfer ν VS Q2 coverage



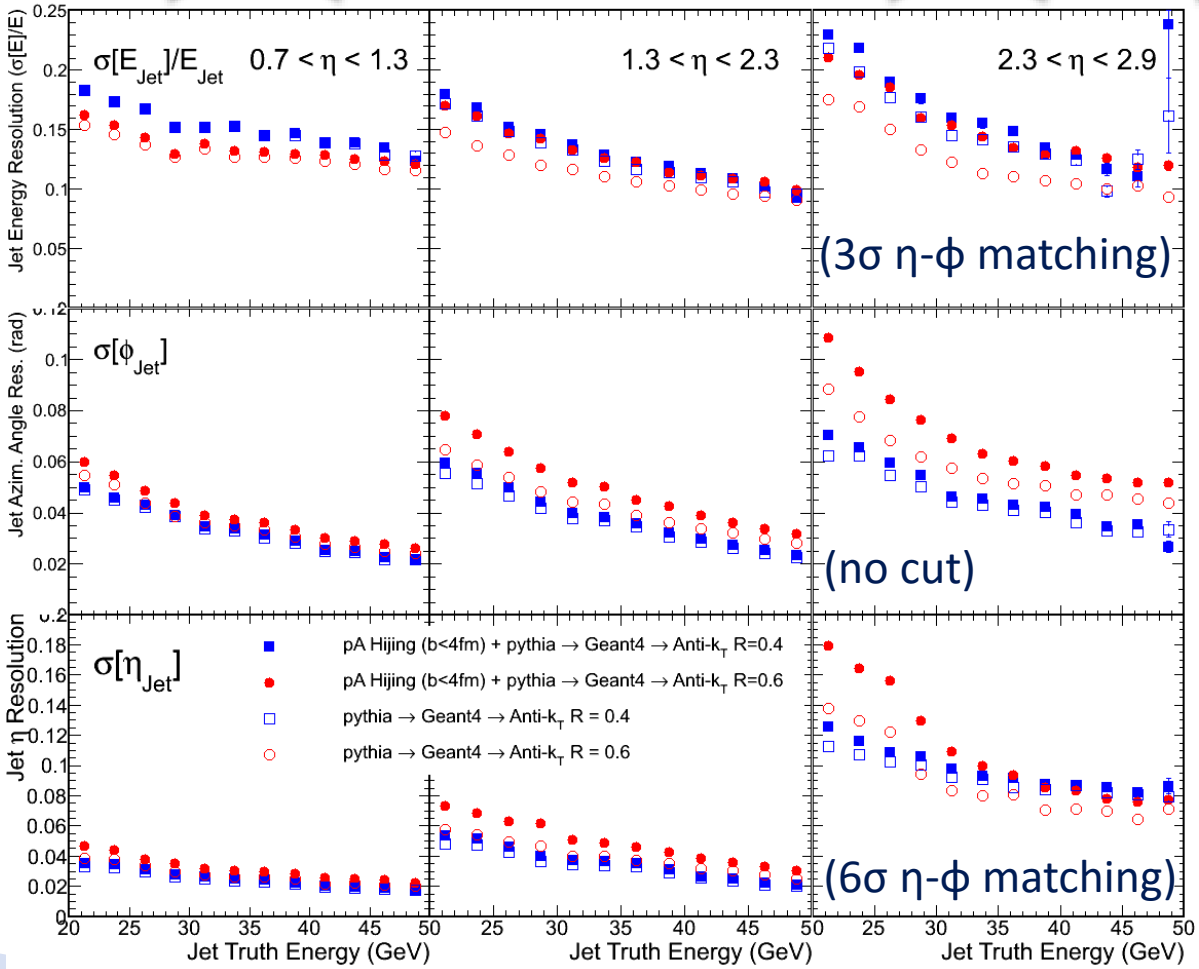
2.5m Hcal summary – need refresh for new calo, should do better

2.5m FHCal results

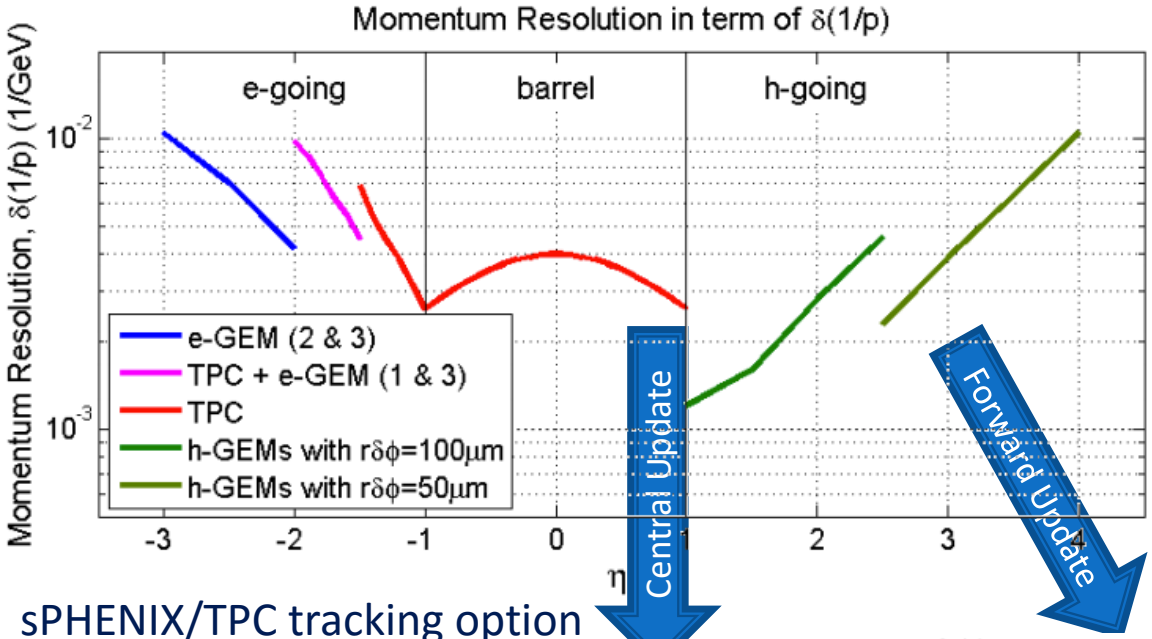
Presented: Appendix A, Nov-2014 sPHENIX proposal [arXiv:1501.06197]

Barrel calorimeter | Forward calorimeter | beam line

- R=0.6 is better for energy resolution
- R=0.4 is better for angular measurement and for pA
- Matching energy resolution in barrel for pp
- Good angular resolution
- Some complexity for
  - Energy matching barrel-forward join region
  - Angular resolution for very forward region



Tracking



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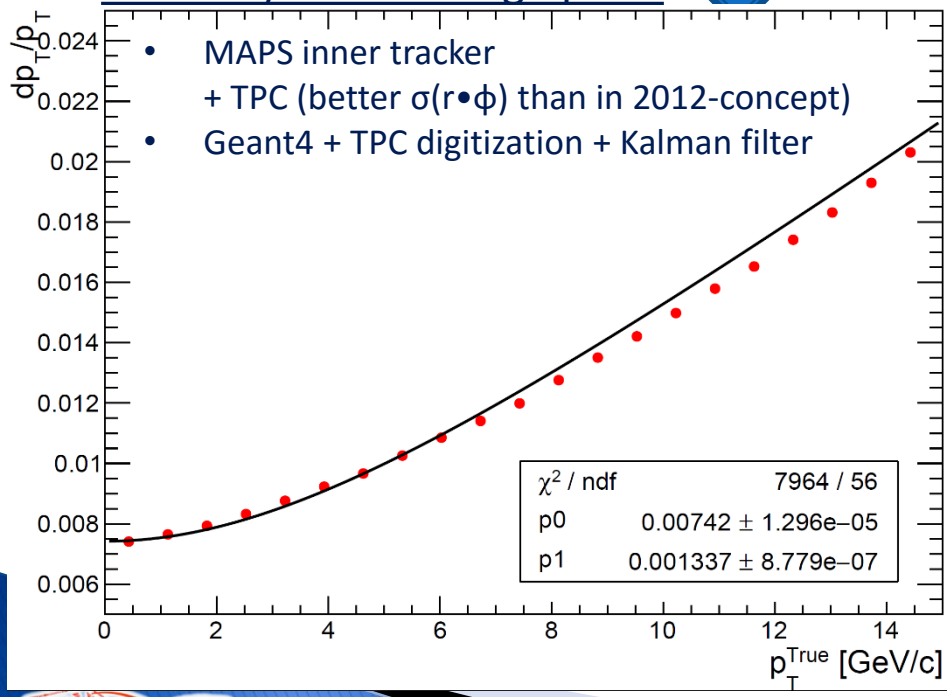

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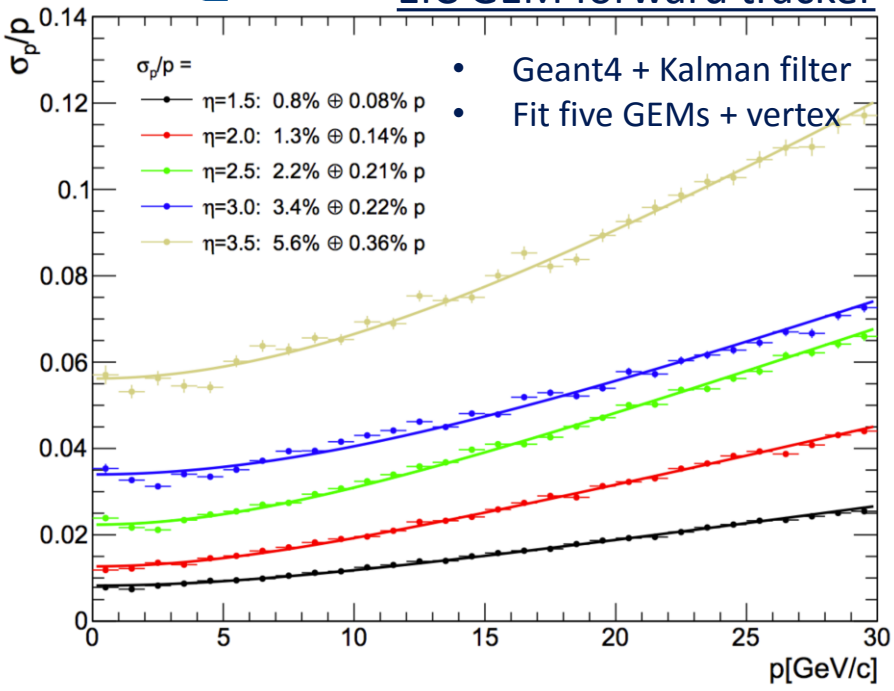
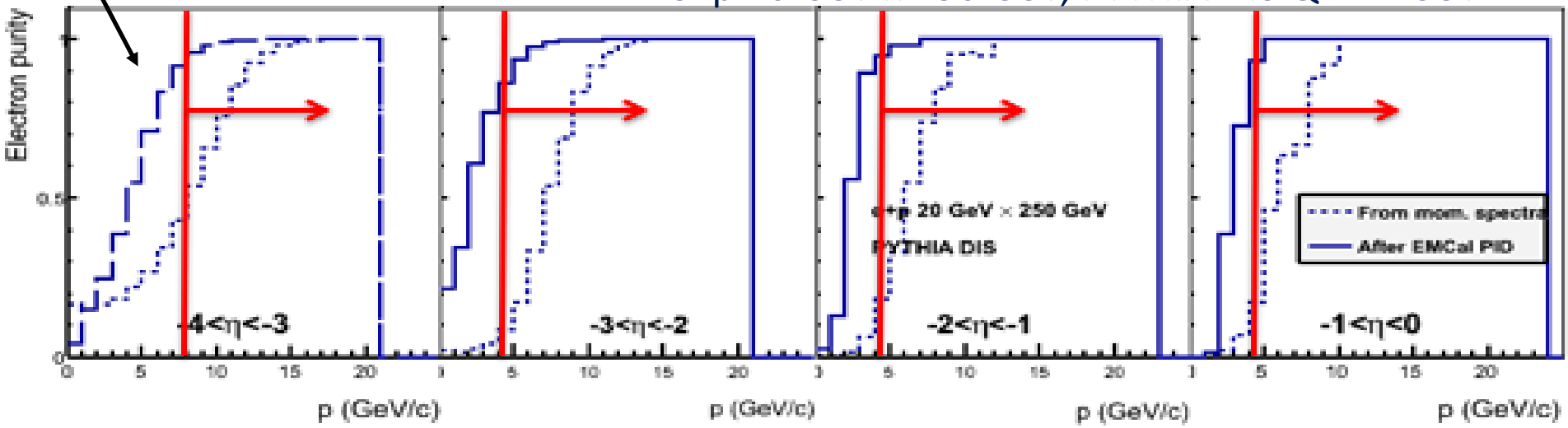
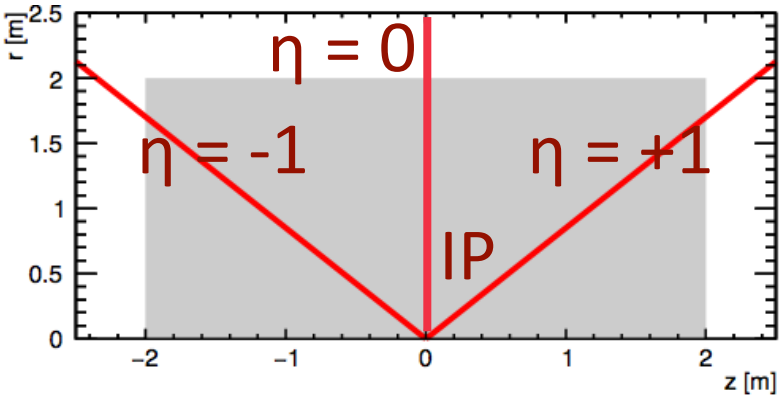


Electron Identification

No tracking or E/p

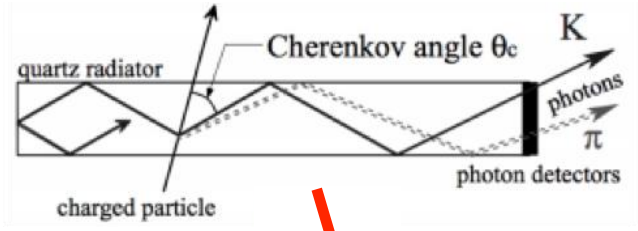
e+p 20 GeV x 250 GeV, PYTHIA DIS $Q^2 > 1$ GeV

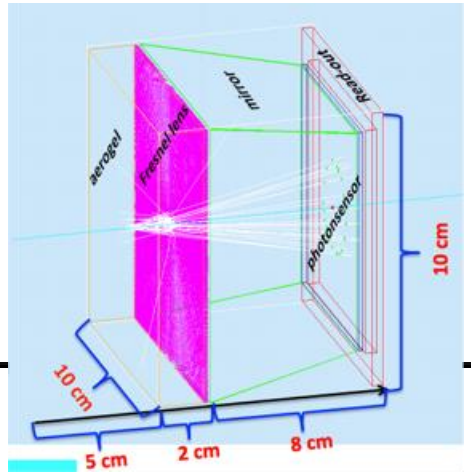


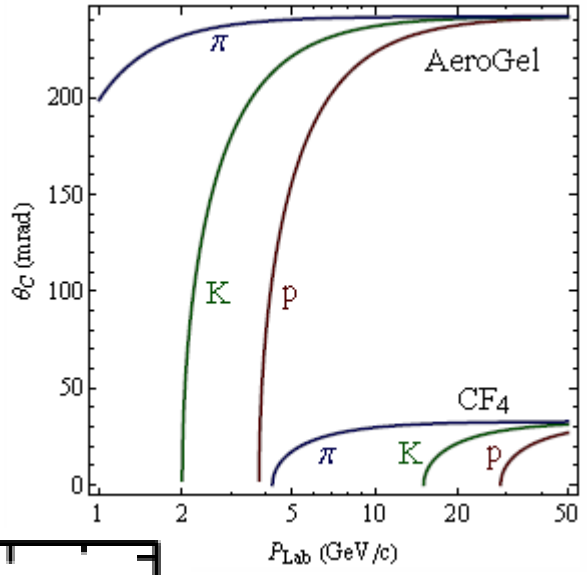


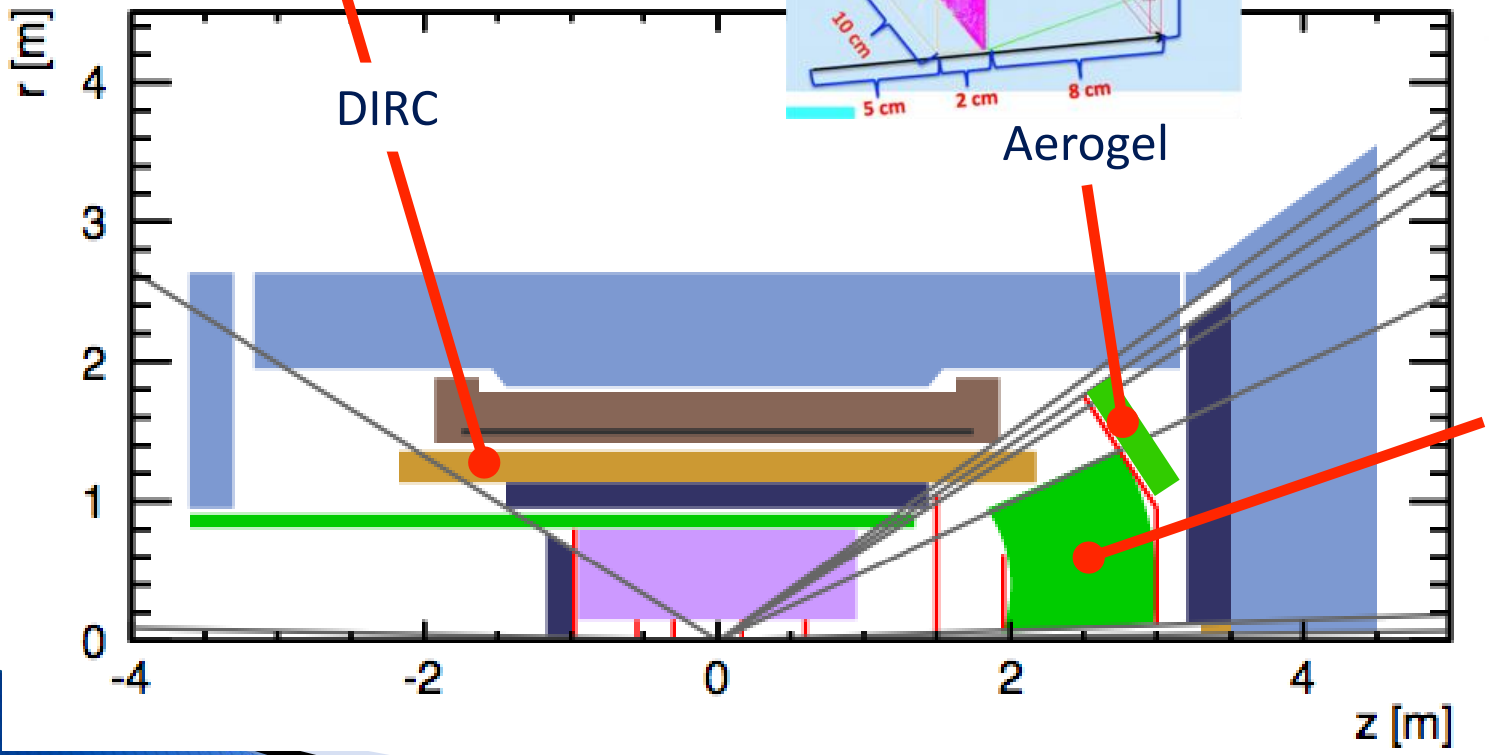
- Cut on electron energy only marginally reduces x-Q^2 coverage

Particle ID: RICH Detectors

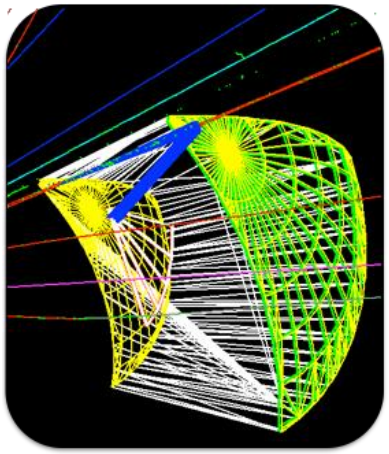




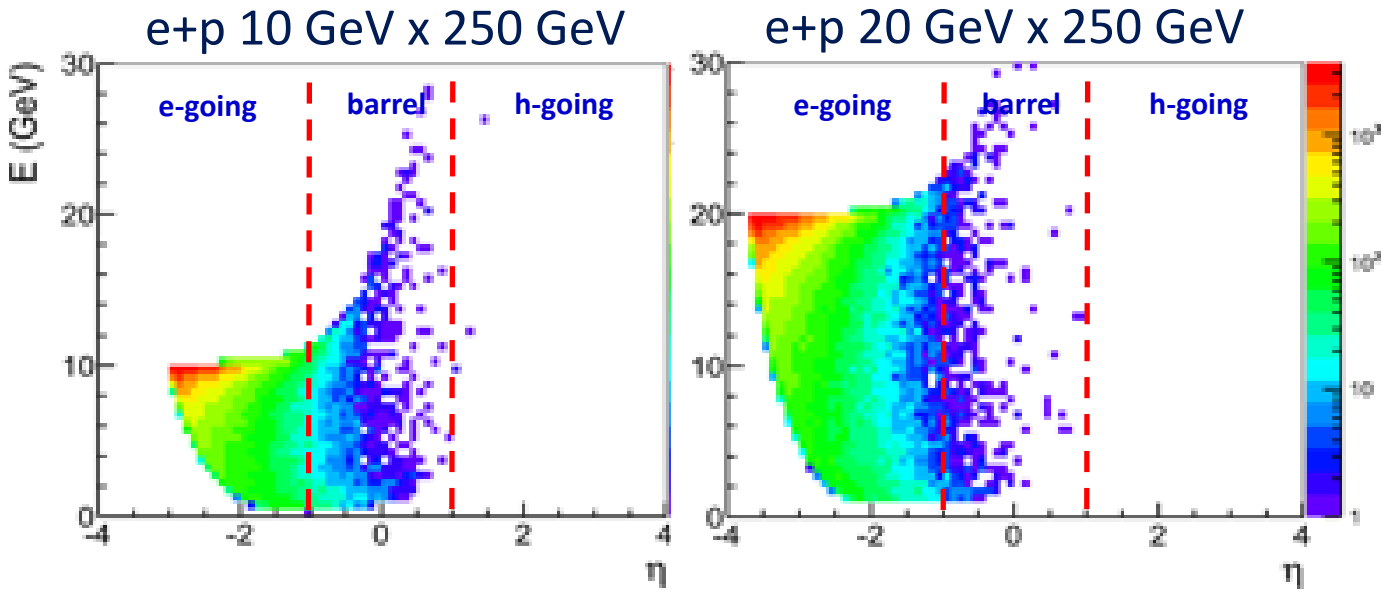


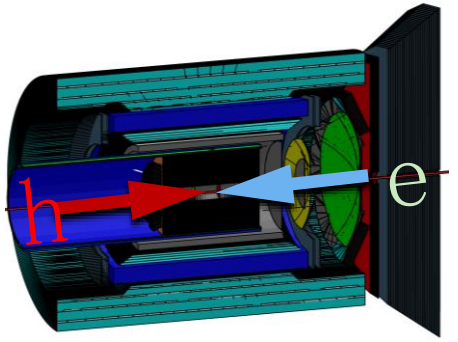


Gas (CF_4)



DIS: electron measurement





PYTHIA DIS with $Q^2 > 1$ GeV

Requirements (EIC task force):

- High purity electron ID (99%)
- Energy measurement
- Angle measurement
- High survival probability (80%) in each x,Q^2 bin
- e-going and barrel coverage

Solution (electron-going):

✓ High resolution GEM Tracking

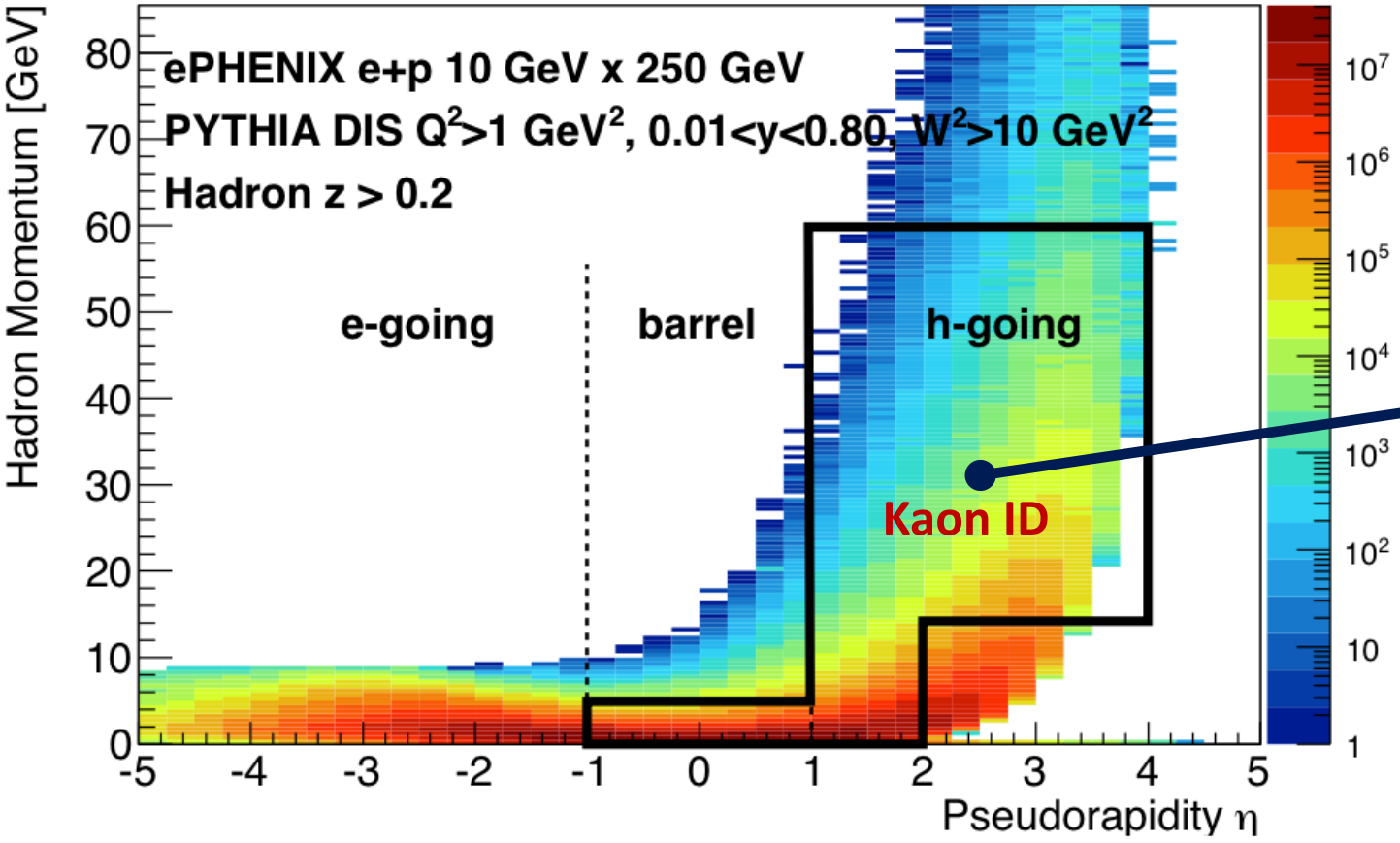
✓ High resolution Crystal EMCal

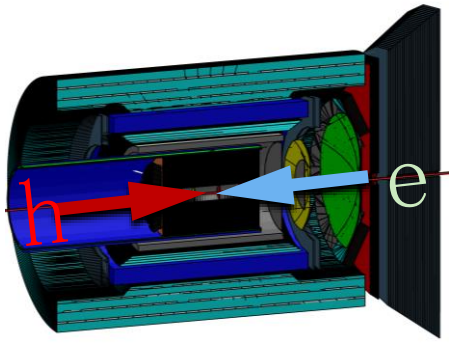
Solution (barrel):

✓ (sPHENIX?) Compact-TPC+(MAPS?)

✓ sPHENIX EMCal

SIDIS: Hadrons from DIS





Black outline: Identified Kaons in planned PID detectors

Requirements:

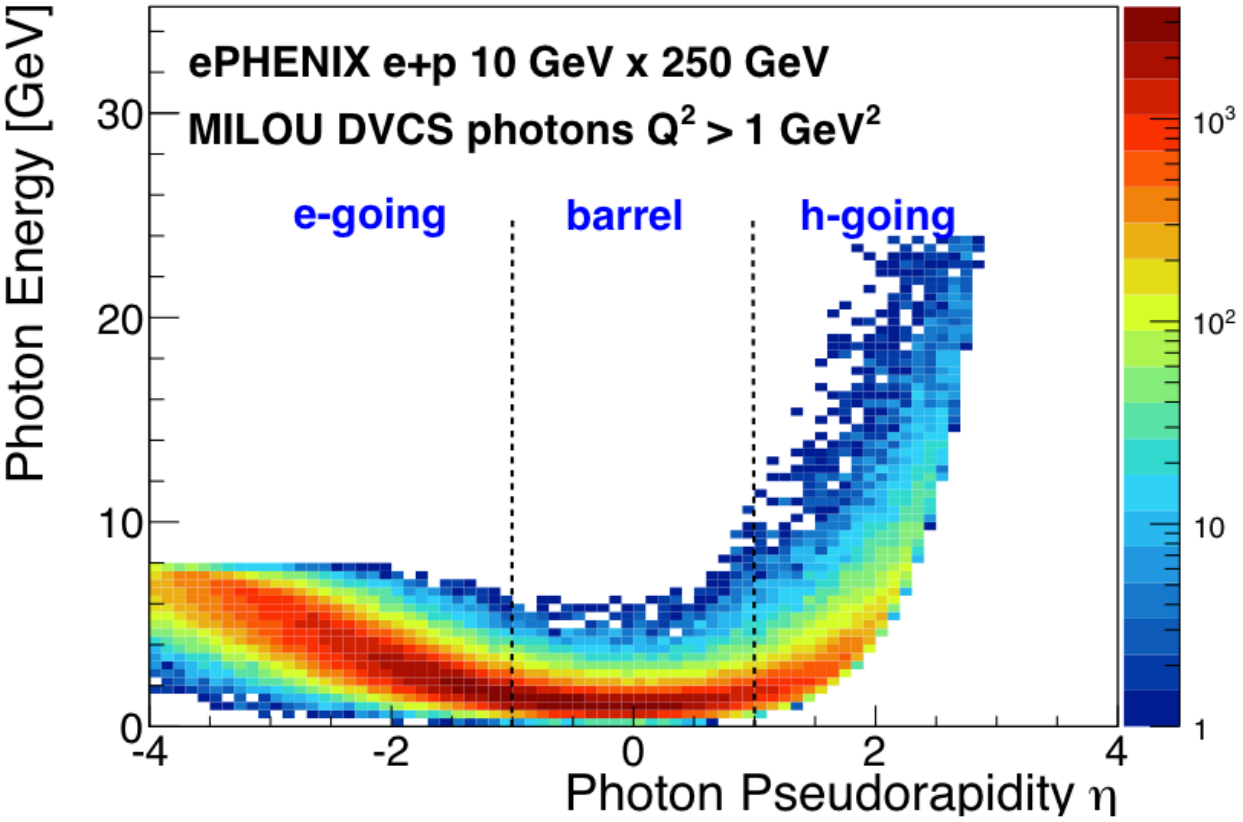
- Hadron ID
- 90% eff, 90% purity

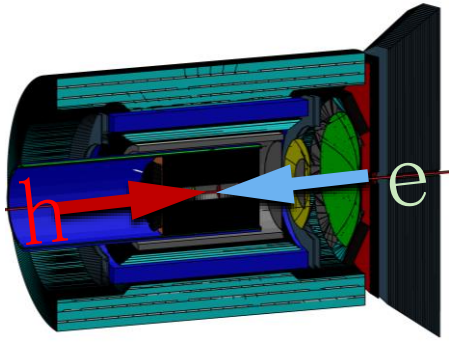
Solution: RICH

✓ Barrel: DIRC (+TPC dE/dX for low p)

✓ h-going: Gas RICH (high p)& Aerogel (low p)

Exclusive DIS: DVCS photons





Requirements:

- e/γ separation over large x,Q^2,t range
- Confirm exclusiveness

Solution:

✓ Granular EMCal and tracking from -4<η<4

✓ Roman Pots

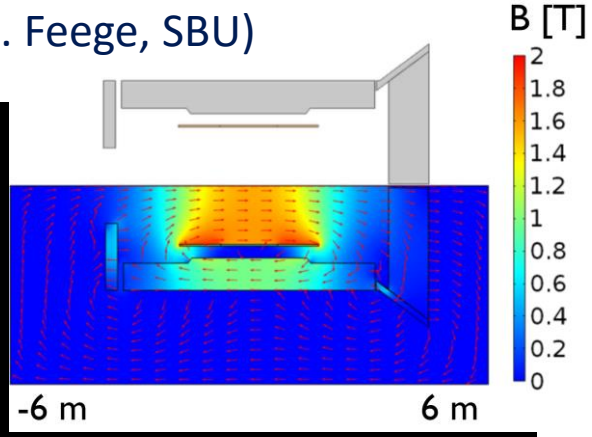
Active development from both sPHENIX and for EIC applications

- Software open in access:
  - sPHENIX software core: https://github.com/EIC-Detector/coresoftware
  - Macros to drive the software: https://github.com/EIC-Detector/coresoftware-eic
  - Virtual machine under test, available to run on your computer soon
- Software meeting series (in open access):
  - Application to sPHENIX: https://indico.bnl.gov/categoryDisplay.py?categId=93
  - Application to EIC: https://indico.bnl.gov/categoryDisplay.py?categId=88
  - Tutorial workshop: https://indico.bnl.gov/conferenceDisplay.py?confId=1237
- A few updates shown in the next section

Detector implemented in details under Fun4All

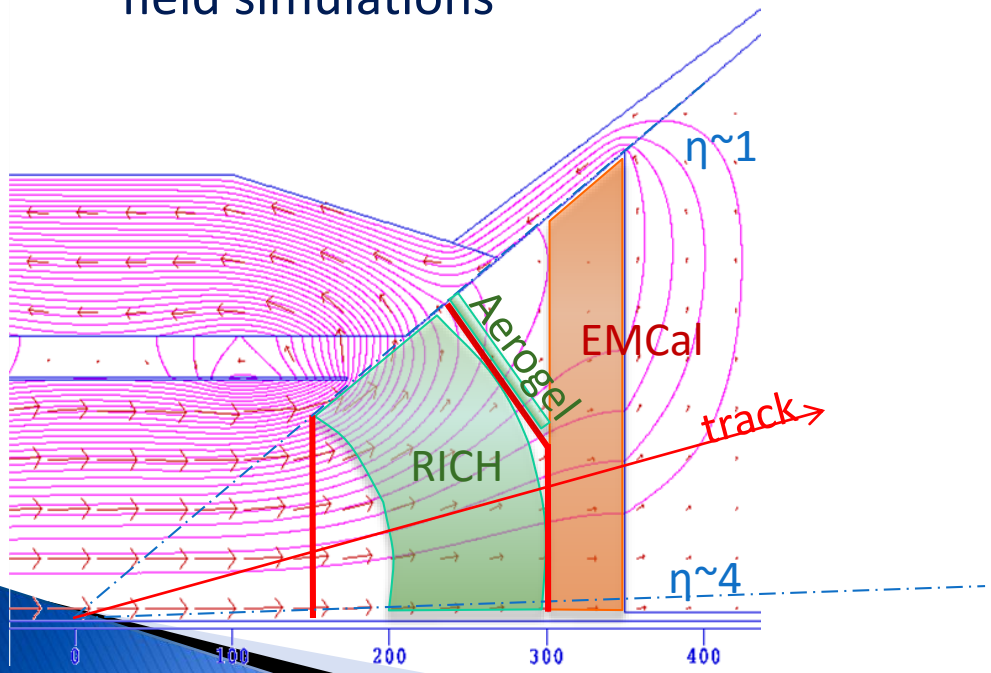
Available under GitHub/EIC-Detector:
coresoftware-eic/macros/Fun4All_G4_ePHENIX.C

Field map/balance in COMSOL
(N. Feege, SBU)



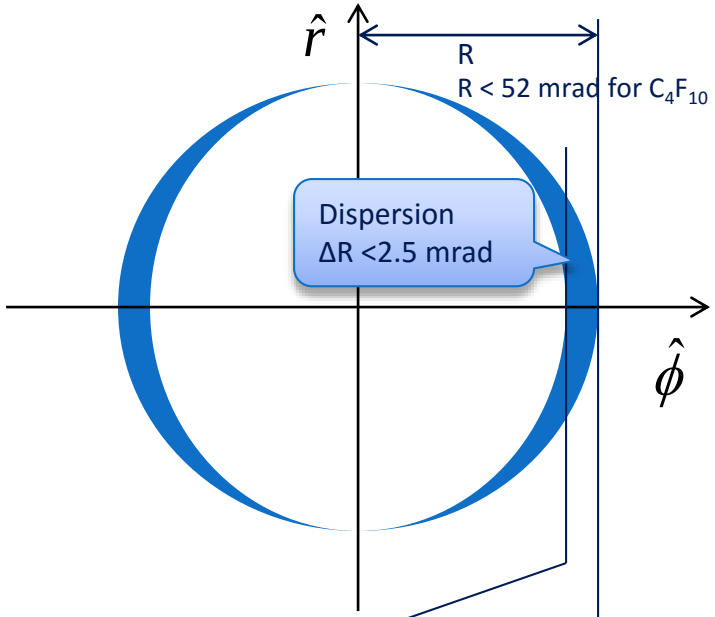
Field effect - distortion for RICH

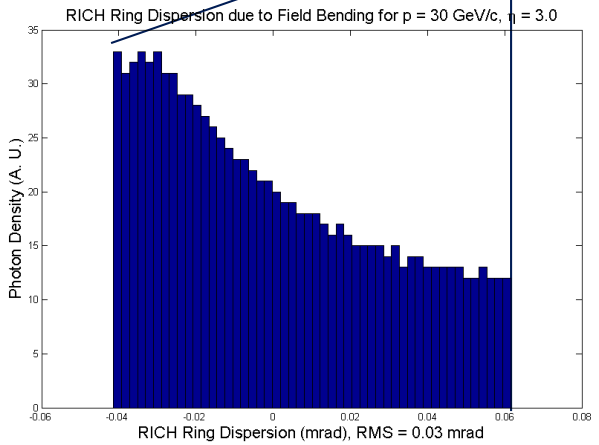
- Field calculated numerically with field return
- Field lines mostly parallel to tracks in the RICH volume with the yoke
- We can estimate the effect through field simulations



A RICH Ring:

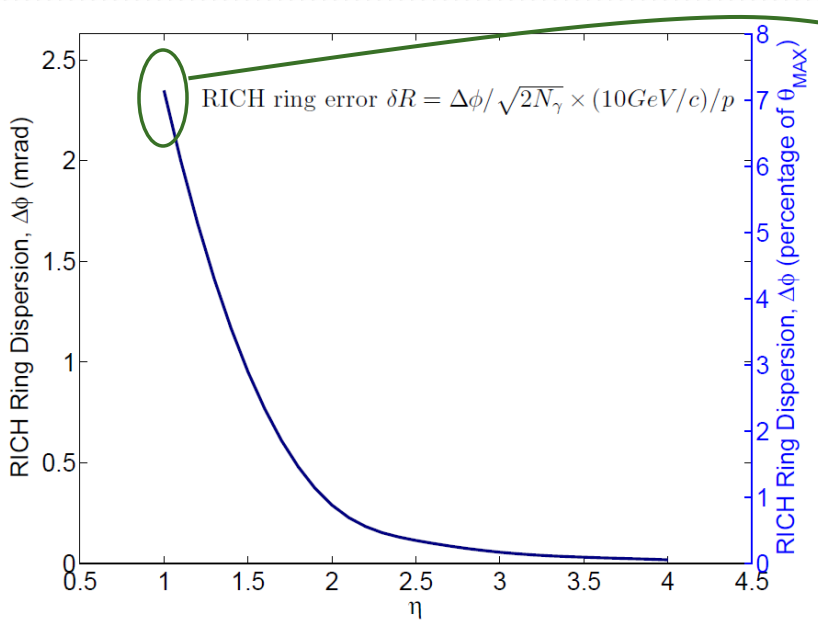
Photon distribution due to tracking bending only

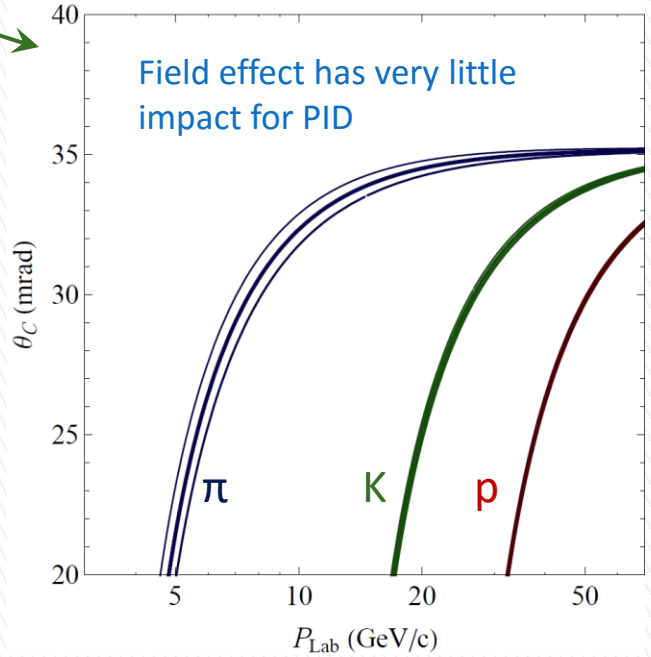




Field effect – Radius uncertianty of RICH Ring

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

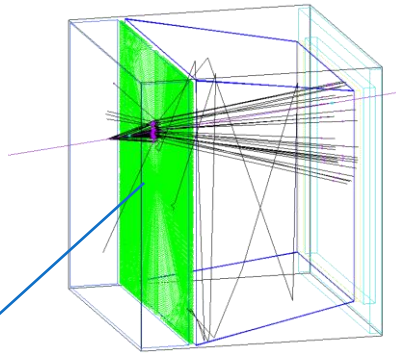


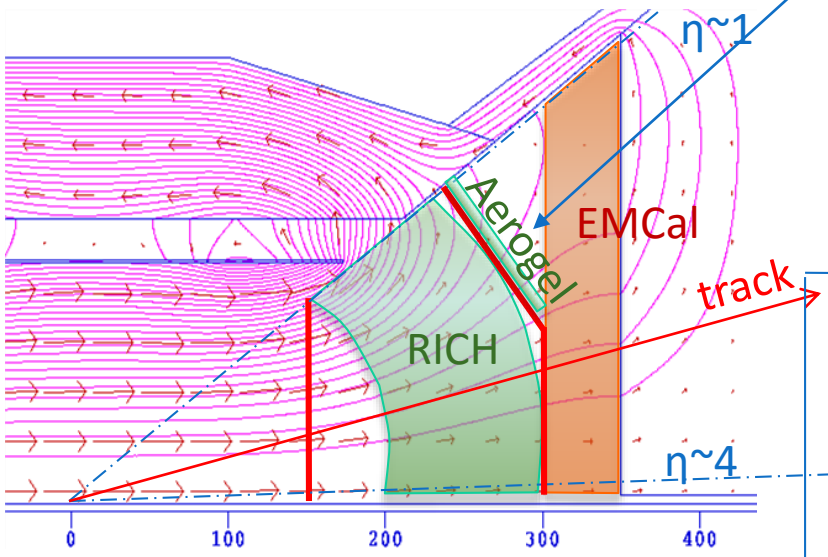


Quantify ring radius error

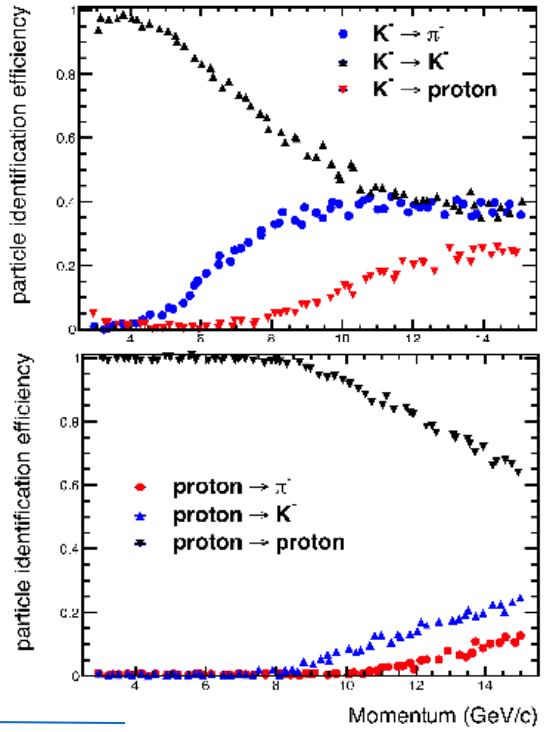
In the respect of PID: minor effect

H-going side - performance

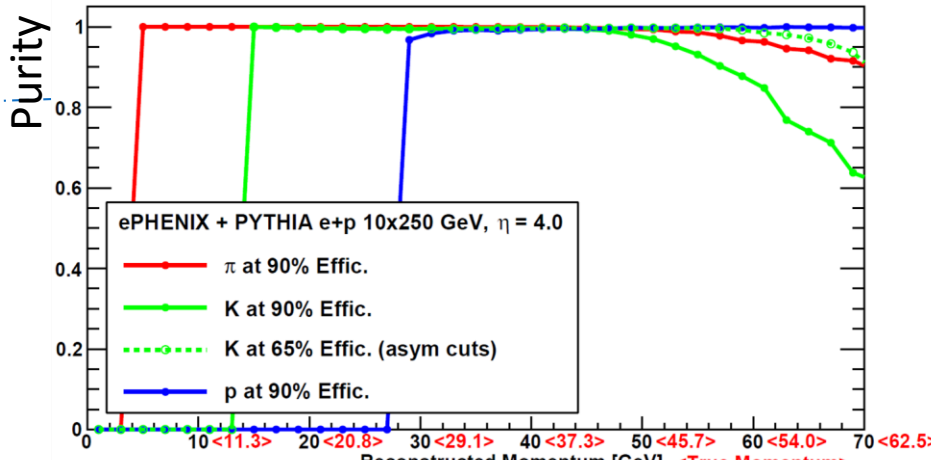




AeroGel RICH PID eff.



Gas RICH PID purity at η=4 (most challenging region w/ δp)



Central Barrel PID, DC + DIRC in BaBar