Concept for an Electron Ion Collider detector at eRHIC

● Physics goals ● detector design ● performance studies

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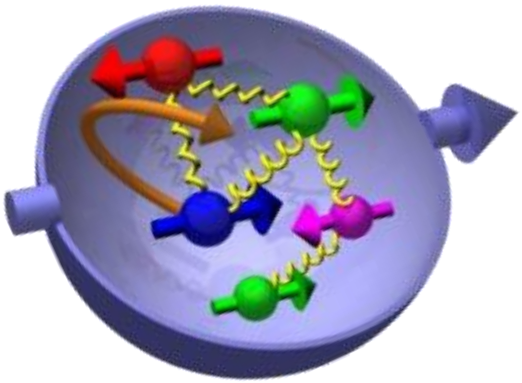
for the PHENIX collaboration

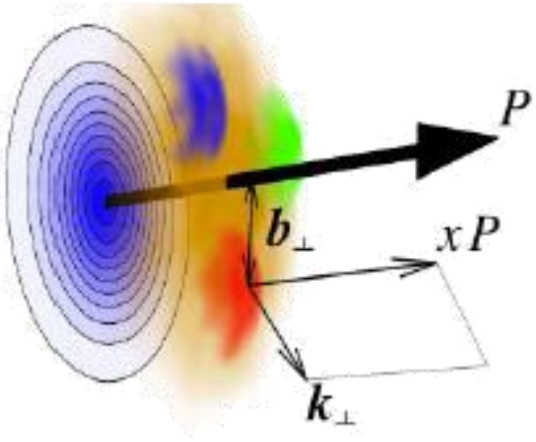
Based on the ePHENIX Letter of Intent, arXiv:1402.1209 [nucl-ex]

Physics goals: nucleon as a laboratory for QCD

Outlined in EIC white paper, arXiv:1212.1701

- The compelling question:
  How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- Deliverable measurement using polarized electron-proton collisions
  - The longitudinal spin of the proton, through Deep-Inelastic Scattering (DIS)
  - Transverse motion of quarks and gluons in the proton, through Semi-Inclusive Deep-Inelastic Scattering (SIDIS)
  - Tomographic imaging of the proton, through Deeply Virtual Compton Scattering (DVCS)
- Leading detector requirement:
  - Good detection of DIS electrons
  - Momentum measurement and PID of hadrons
  - Detection of exclusive production of photon/vector mesons and scattered proton

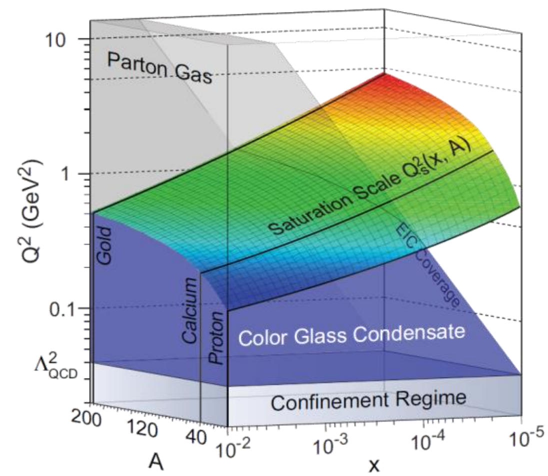


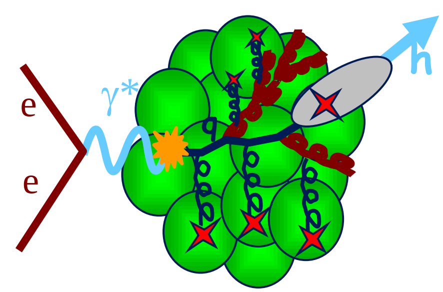


Physics goals: nucleus as a laboratory for QCD

Outlined in EIC white paper, arXiv:1212.1701

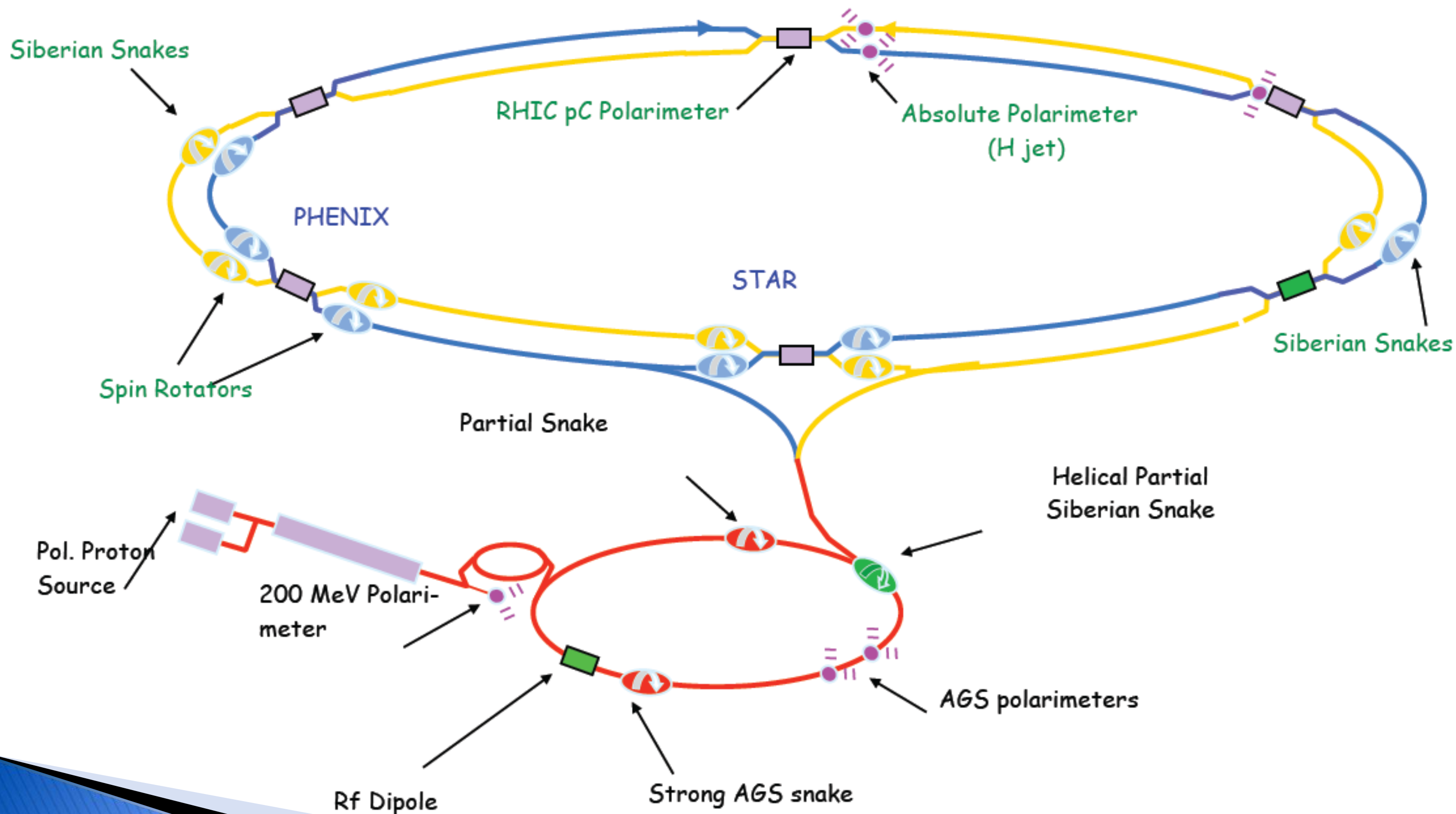
- The compelling questions:
  - Where does the saturation of gluon densities set in?
  - How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?
- Deliverable measurement using electron-ion collisions
  - Probing saturation of gluon using diffractive process
  - Nuclear modification for hadron and heavy flavor production in DIS events
- Leading detector requirement:
  - Large calorimeter coverage to ID diffractive events
  - ID of hadron and heavy flavor production





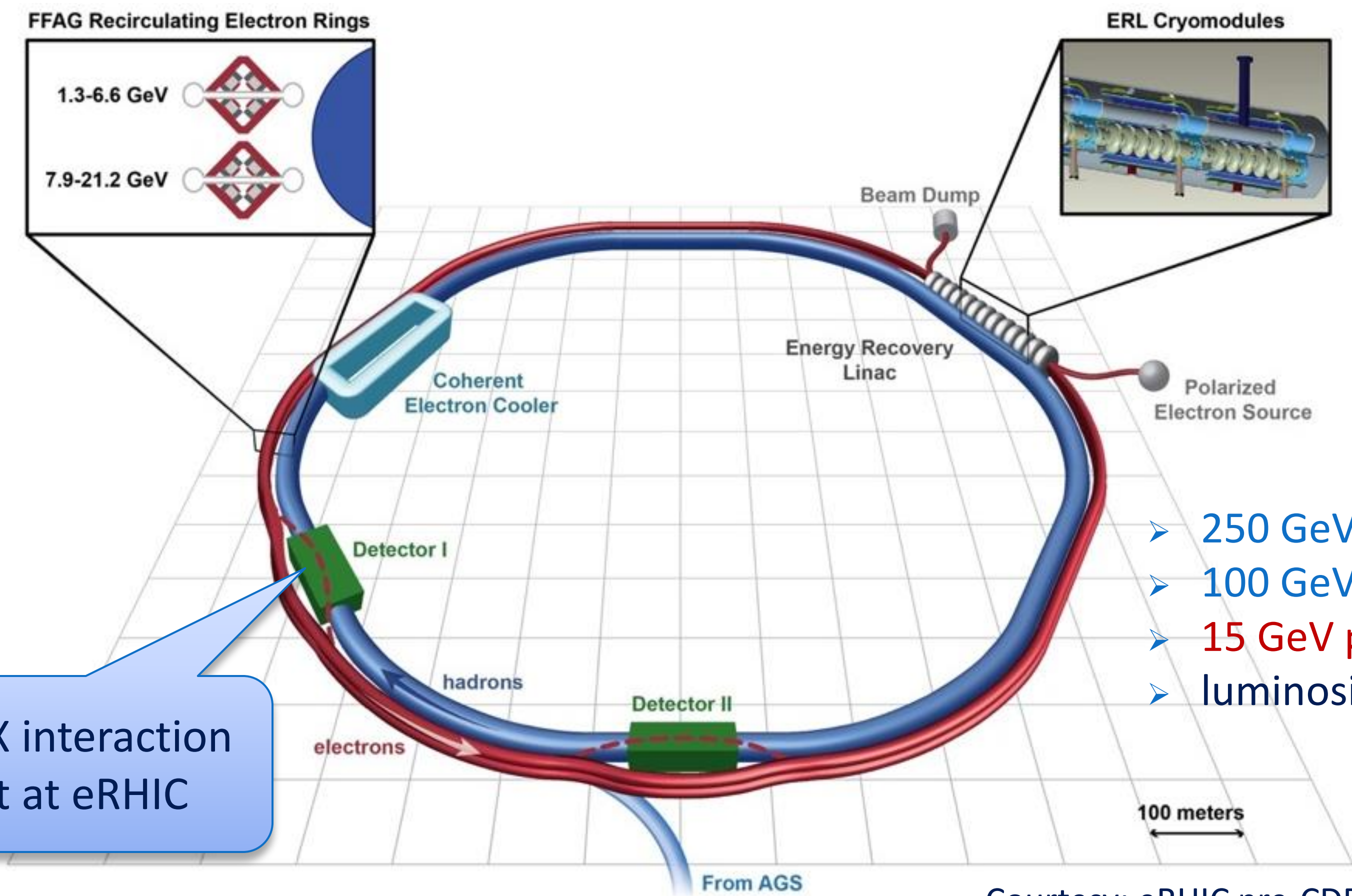
One realization of electron ion collider: RHIC → eRHIC at Brookhaven National Lab

RHIC as today: world's only polarized proton collider and support large variety of HI beam



One realization of electron ion collider: RHIC → eRHIC at Brookhaven National Lab

eRHIC: reuse one of the RHIC rings + high intensity electron beam



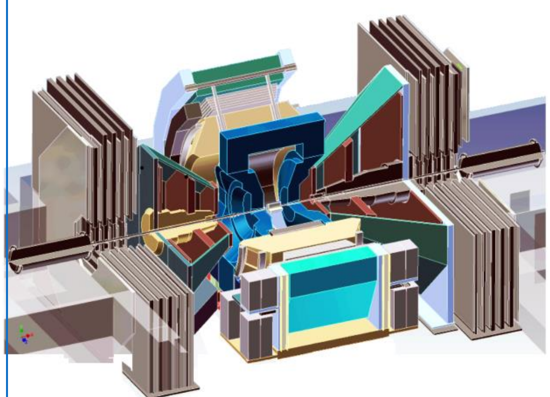
PHENIX interaction point at eRHIC

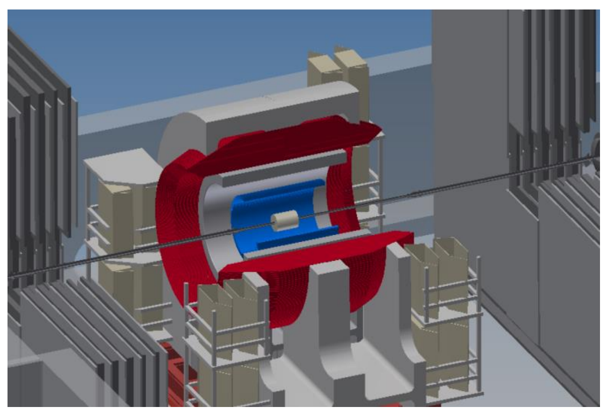
- 250 GeV polarized proton
- 100 GeV/N heavy nuclei
- 15 GeV polarized electron
- luminosity ≥ 10^{33} cm^{-2}s^{-1}

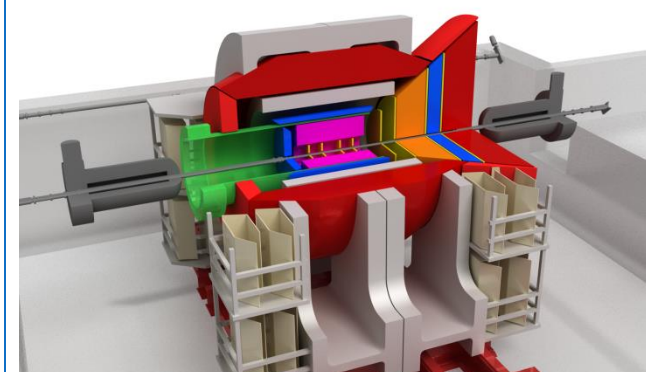
Courtesy: eRHIC pre-CDR

PHENIX upgrade plan

Current PHENIX	sPHENIX	ePHENIX
• Two sets of spectrometer for central and forward, respectively • Operating for ~10 years • 130+ published papers to date	• Comprehensive upgrade • Central rapidity: Calorimetry and tracking optimized for probing QGP using jets • Forward : new opportunity	• A capable EIC detector based on PHENIX upgrade • New collaboration will be formed



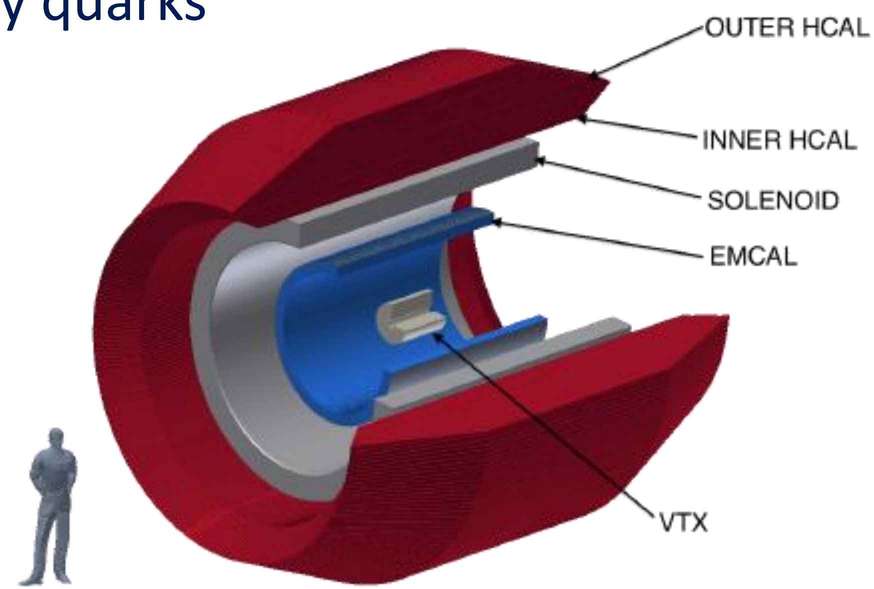




~2000 ~2020 ~2025 Time

The sPHENIX detector

- sPHENIX: major upgrade to the PHENIX experiment
- Baseline consists of new large acceptance EMCal+HCal built around recently acquired BaBar magnet. Additional tracking also planned
- Study QGP using jets and heavy quarks at RHIC energy region
- MIE submitted to DOE
  Strong support from BNL
- Serve as a good foundation for eRHIC detector



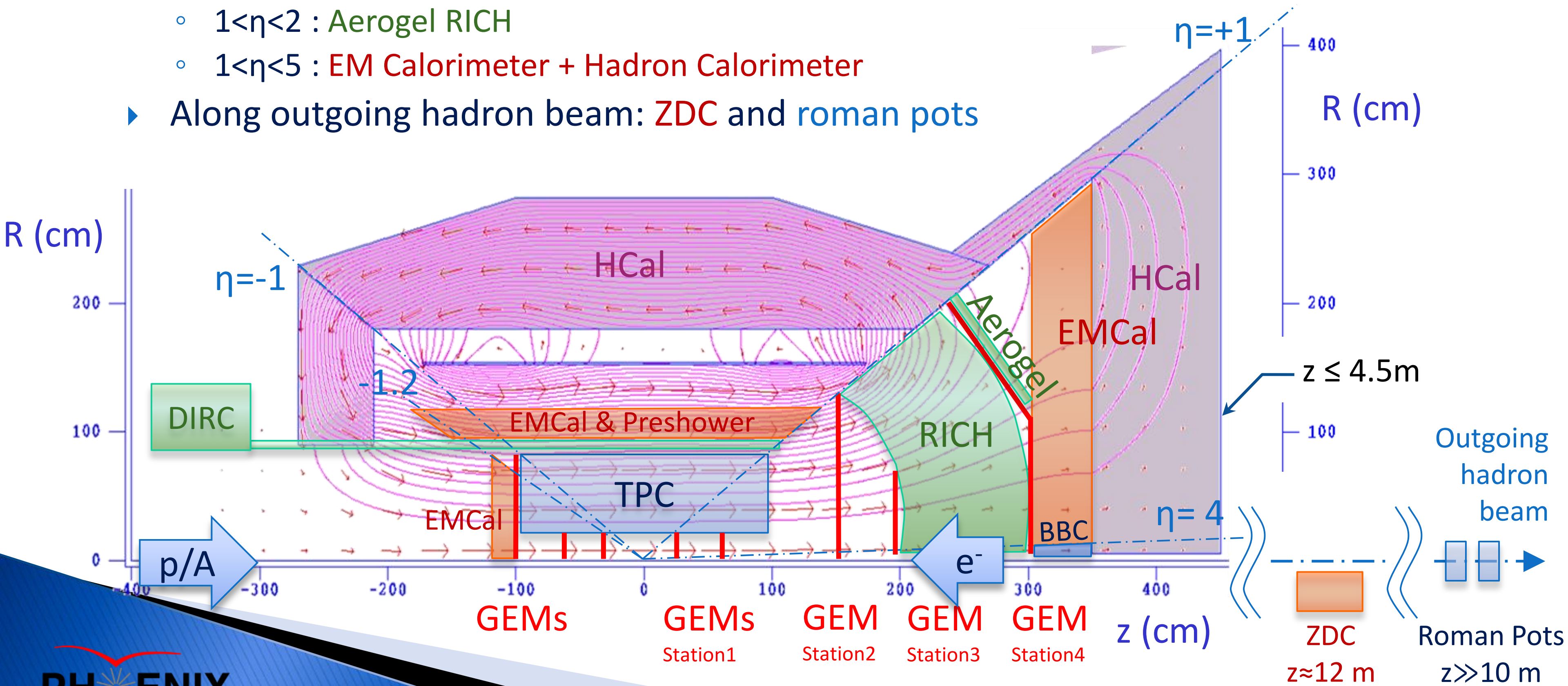
Baseline detectors for sPHENIX

sPHENIX MIE, http://www.phenix.bnl.gov/plans.html

ePHENIX Detector Concept

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

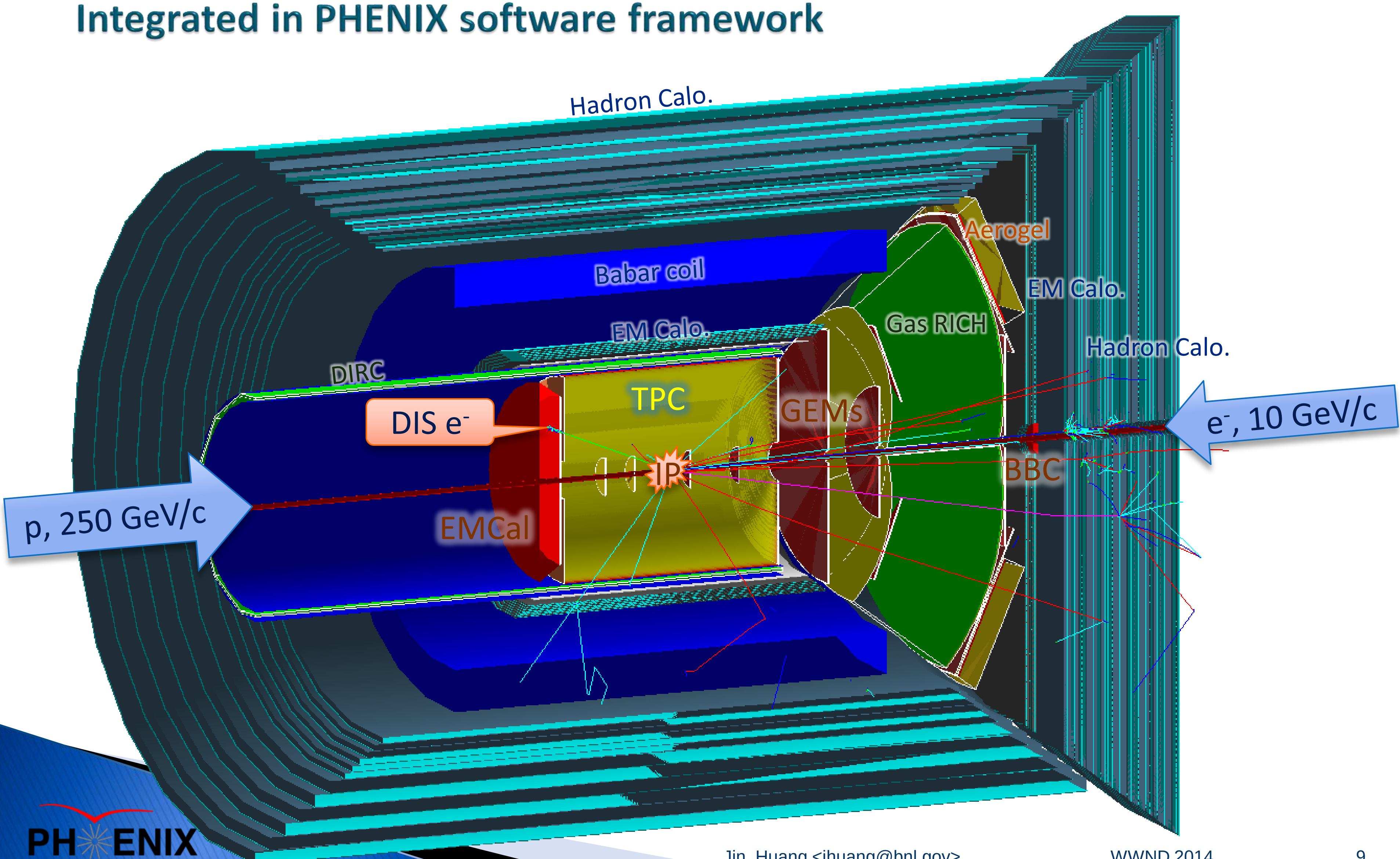
Costed: sPHENIX MIE + 75M$
(including overhead + contingency)



A SIDIS event in ePHENIX

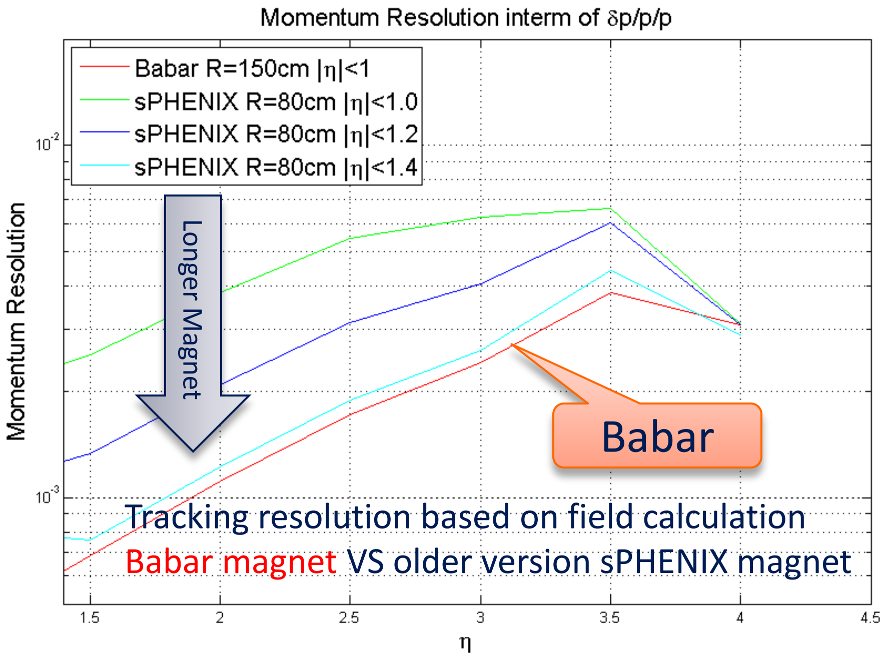
GEANT4 event display for SIDIS @ $x \approx 5\times10^{-3}$ and $Q^2=10\ (\mathrm{GeV}/c)^2$

Integrated in PHENIX software framework

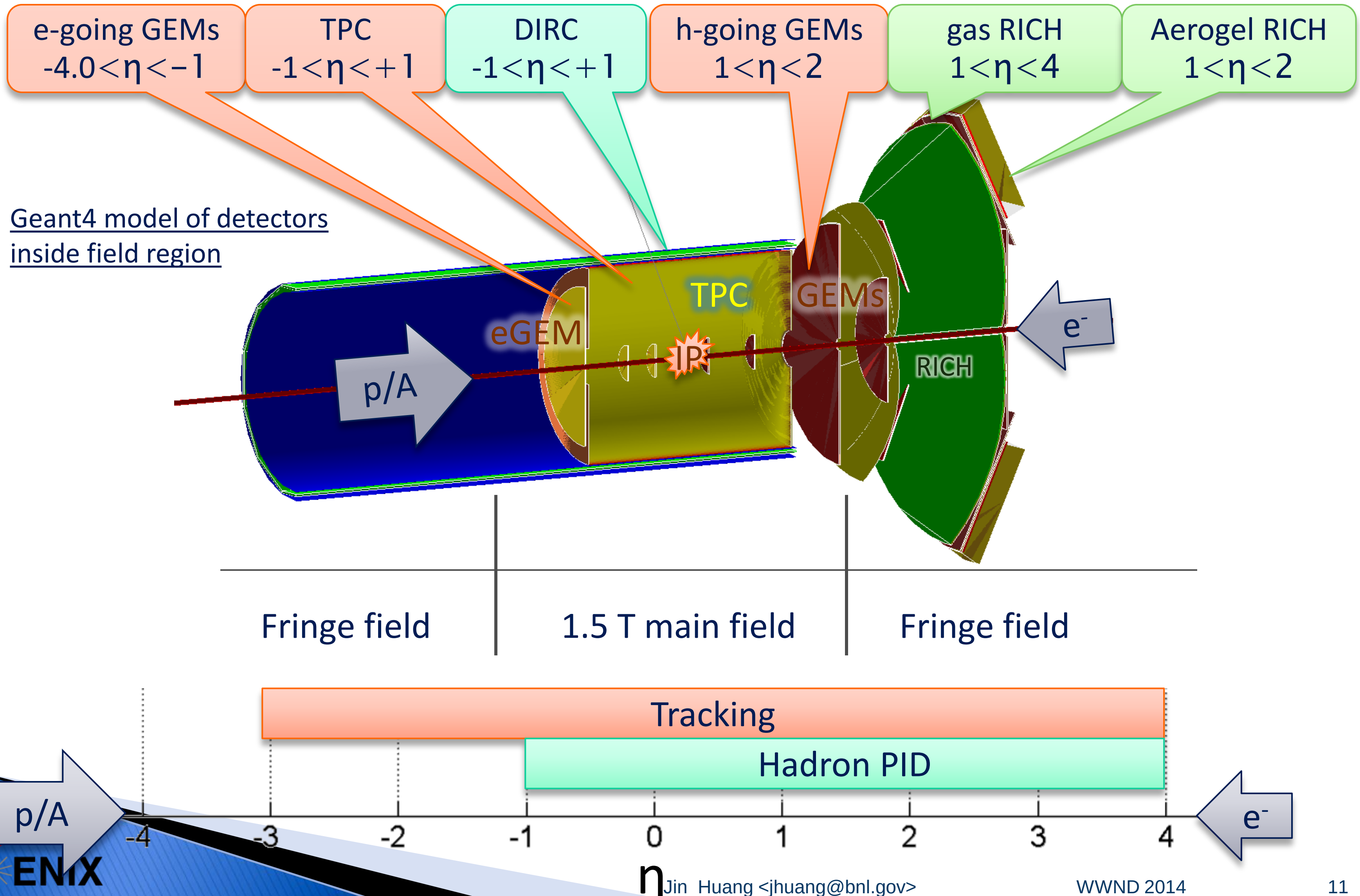


Magnet and field

- Went through ~10 types of forward field magnet design over few years
- BaBar superconducting magnet became available
  - Built by Ansaldo → SLAC ~1999
  - Nominal field: 1.5T
  - Radius : 140-173 cm
  - Length: 385 cm
- Field calculation and yoke tuning
  - Three field calculator cross checked: POISSION, FEM and OPERA
- Favor for ePHENIX 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 ePHENIX yoke: Forward & central Hcal + Steel lampshade
- Ownership officially transferred to BNL

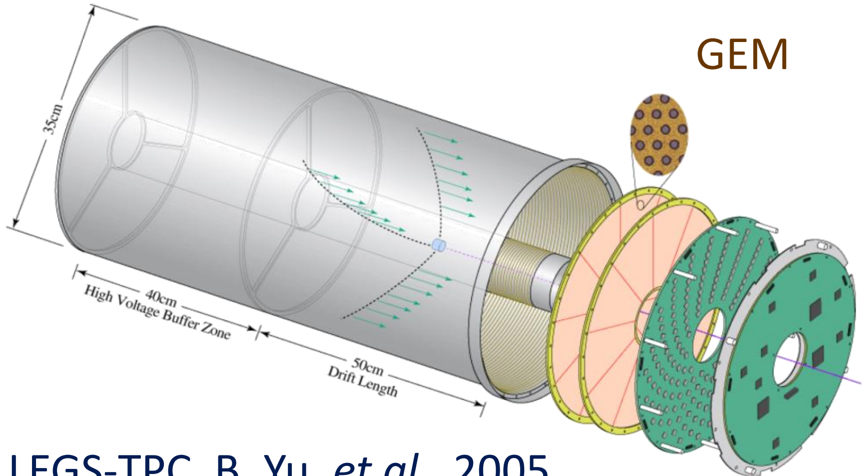


Tracking and PID detector overview

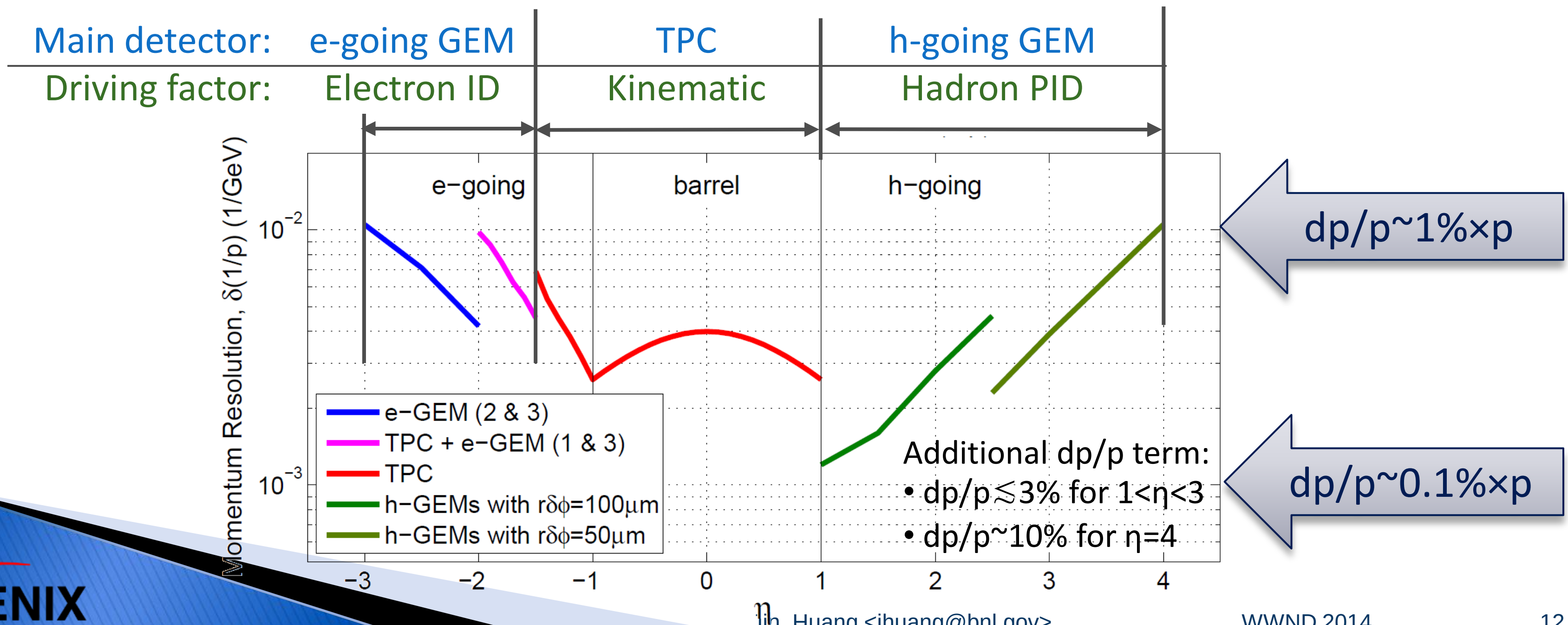


Tracking system

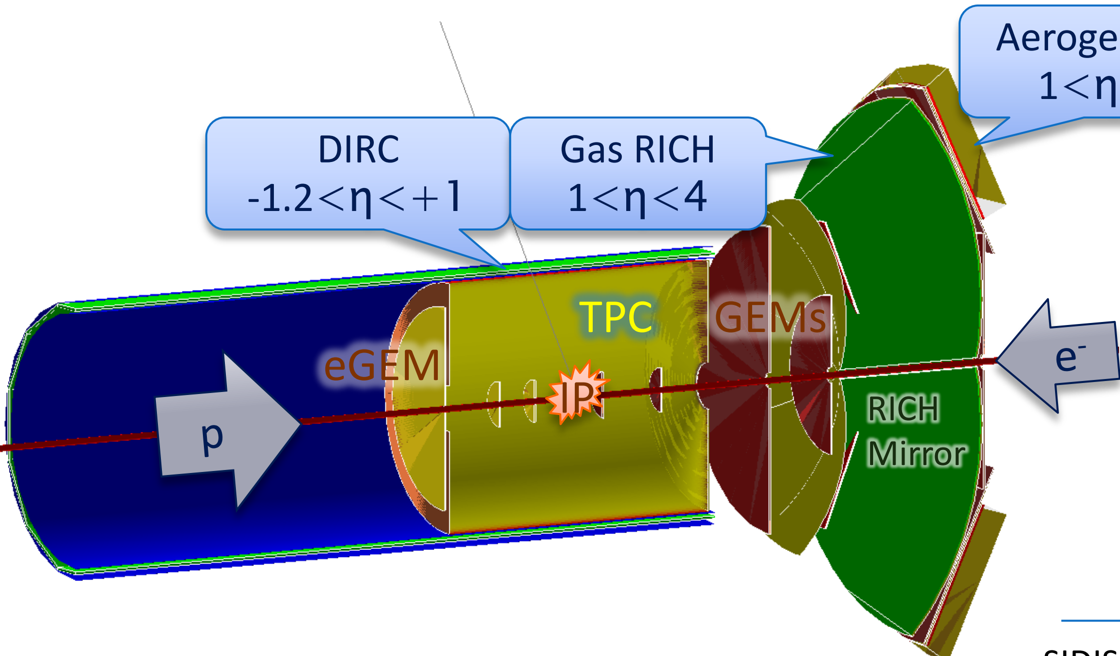
- Good momentum resolution over wide range, -3<η<+4
- GEM tracker for forward region
  - d(rϕ) = 100 μm; 50 μm for very forward region
- GEM-based TPC for barrel region
  - 10μs max drift time and no-gate needed
  - Thin support structure, e.g. fibre-reinforced polymer
- Space available for inner silicon tracker upgrade

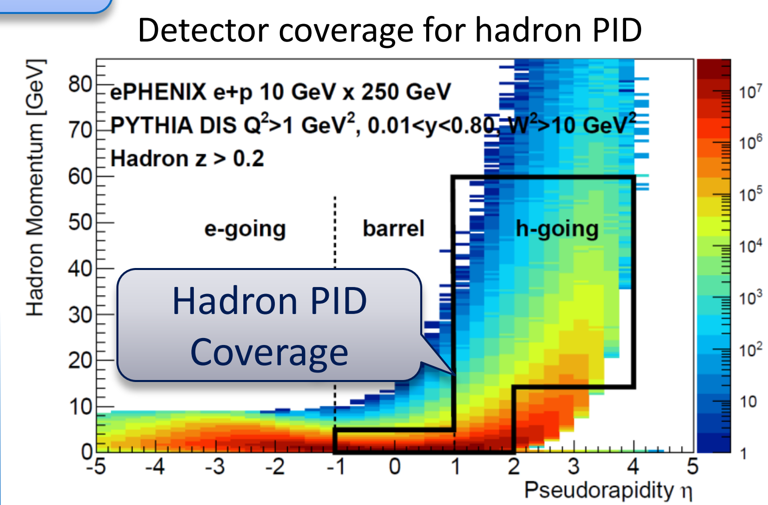


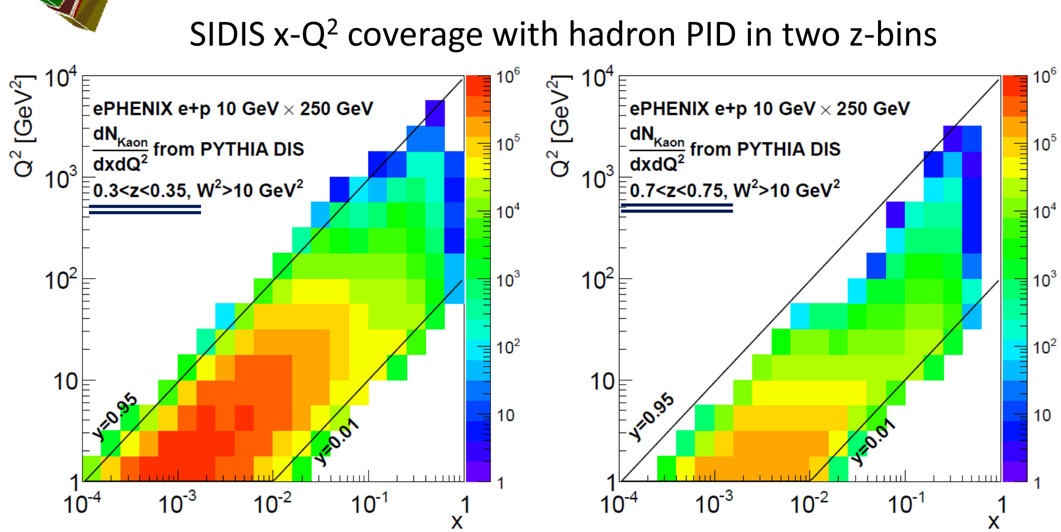
LEGS-TPC, B. Yu, *et al.*, 2005



Hadron PID Overview



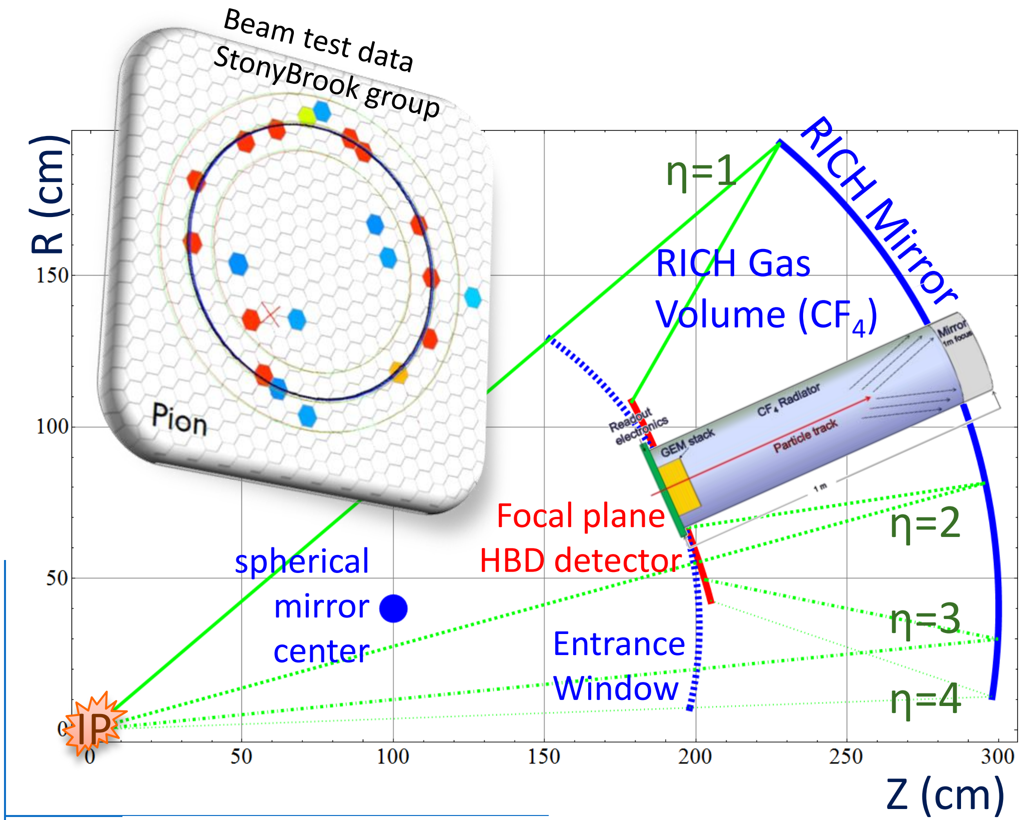




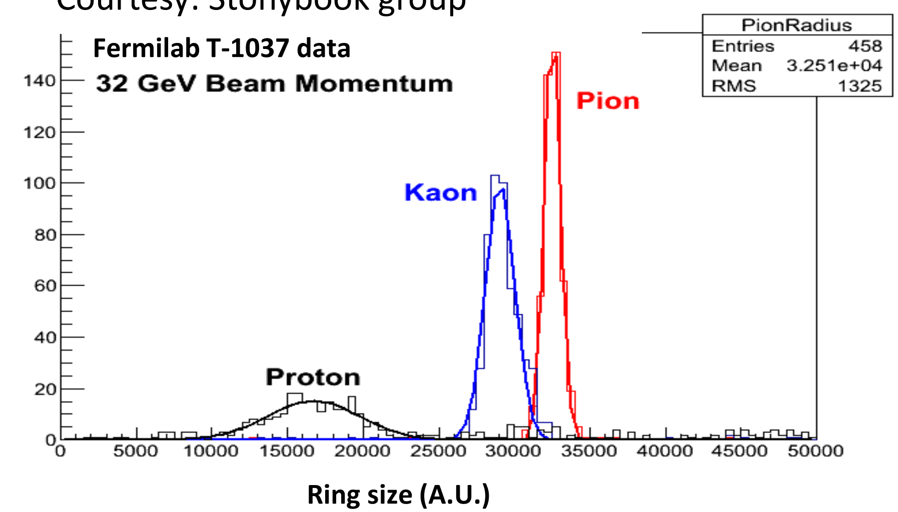
- DIRC
  - Based on BaBar DIRC design plus compact readout
  - Collaborate with TPC dE/dx for hadron ID in central barrel
- Aerogel RICH
  - Approximate focusing design as proposed by Belle-II
  - Collaborate with gas RICH to cover 1<η<2
- Gas RICH: next slides
- Possible upgrade in electron-going direction

Gas RICH
- The Design

- High momentum hadron ID require gas Cherenkov
  - CF_4 gas used, similar to LHC_b RICH
- Beautiful optics using spherical mirrors
- Photon detection using CsI–coated GEM in hadron blind mode
  - thin and magnetic field resistant
- Active R&D:
  - Generic EIC R&D program
  - recent beam tests by the stony brook group

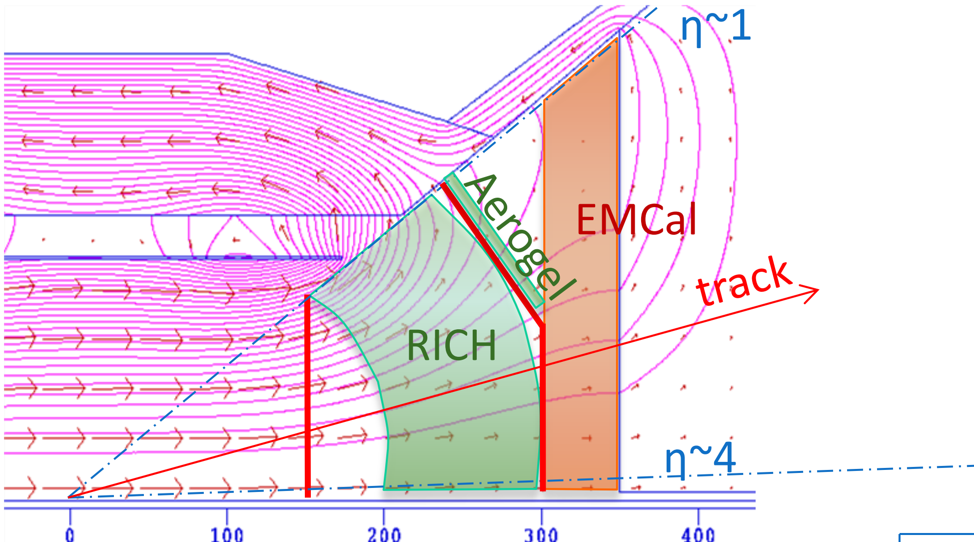


Courtesy: Stonybook group

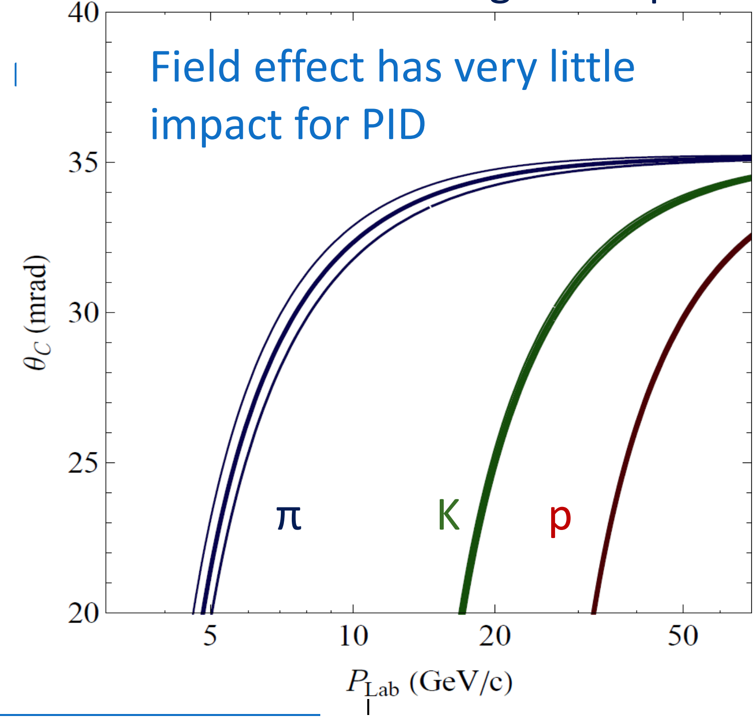


PHENIX

Gas RICH
- performance in ePHENIX

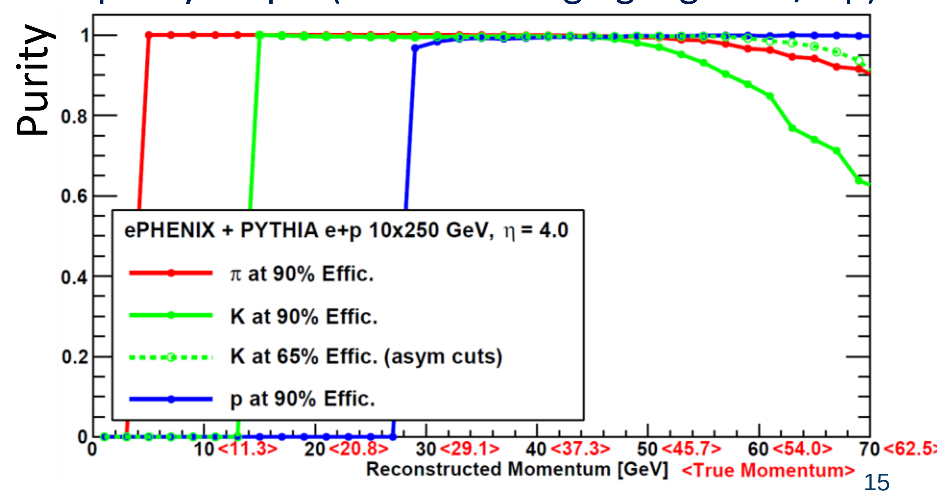


Ring radius ± 1σ field effect
for worst-case region at η~+1



- Strong fringe field unavoidable
  Tuned yoke → magnetic field line most along track within the RICH volume
  → very minor ring smearing due to track bending
- Reached good hadron ID to high energy

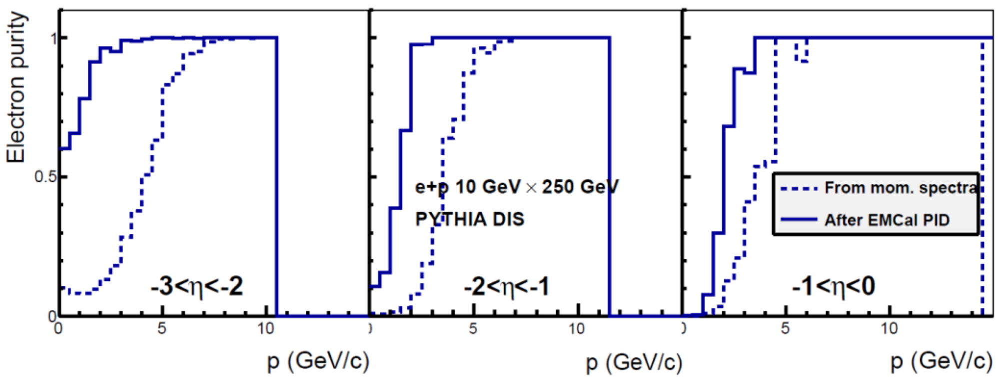
PID purity at η=4 (most challenging region w/ δp)



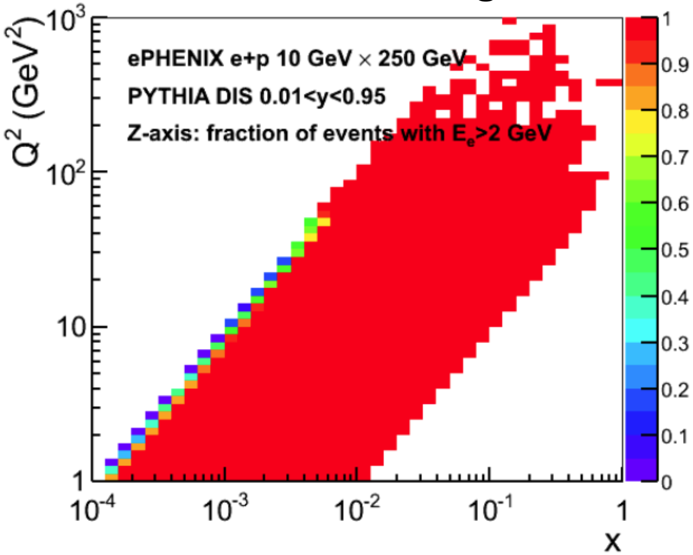
Calorimeters

- EM Calorimeter
  - Measure electrons and photons
  - e-going: $PbWO_4$ crystal calorimeter, dE/E~1.5%/√E
  - Barrel and h-going: W- and Pb-scint. sampling calorimeter, dE/E~12%/√E
  - GEANT simulation show electron background of photon conversion is negligible
- Hadron Calorimeter
  - Cover -1<η<+5, great for ID diffractive events
  - Also serve as magnetic field return

Electron purity after EMCal PID

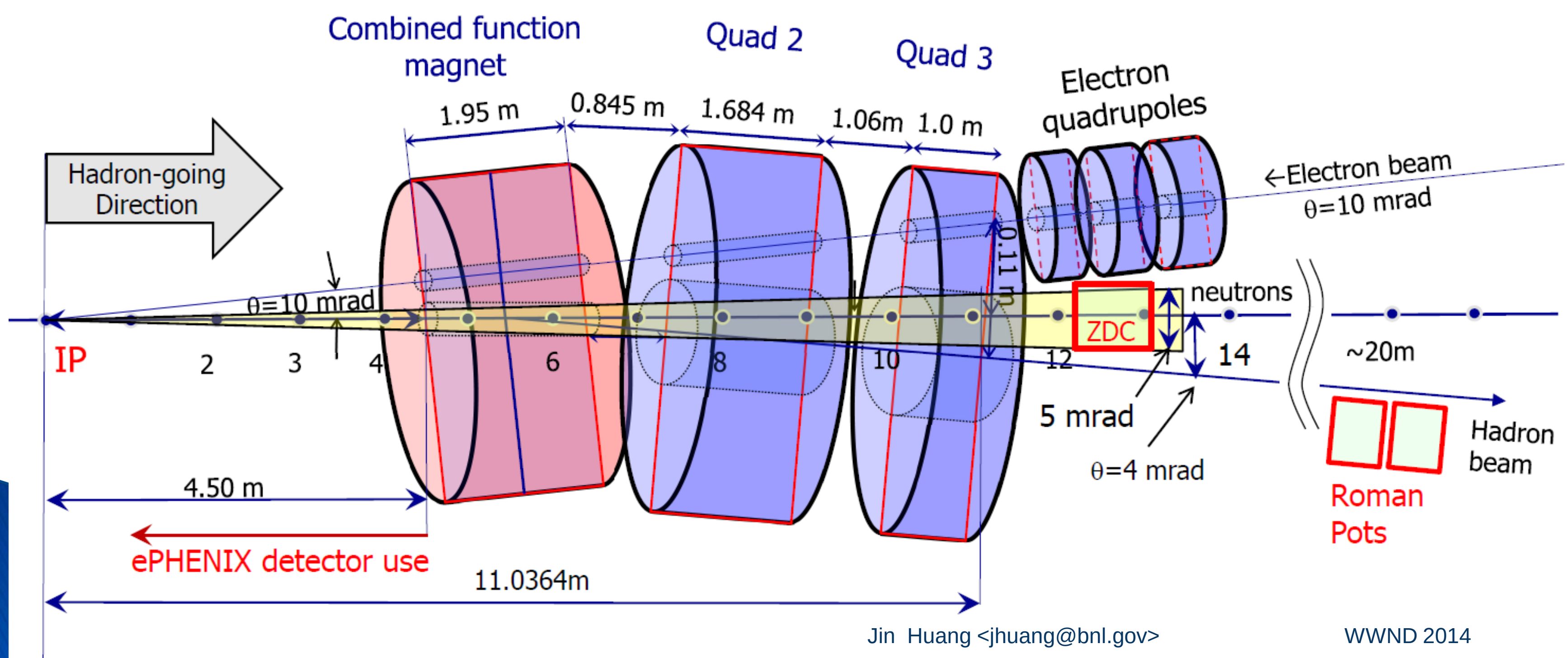


Fraction of DIS event with good electron ID



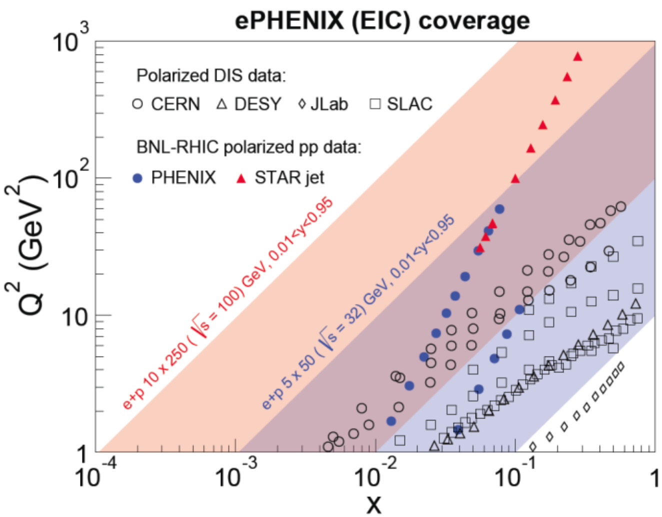
Beam line detector

- Beam line detector design is integrated to accelerator lattice
- ZDC -> detector neutron -> categorization of the eA collision type and geometry
- "Roman pots" → measure deflection of proton in exclusive productions → Kinematic determination for proton tomography
- One layout is shown here. More studies needed in iterations with accelerator

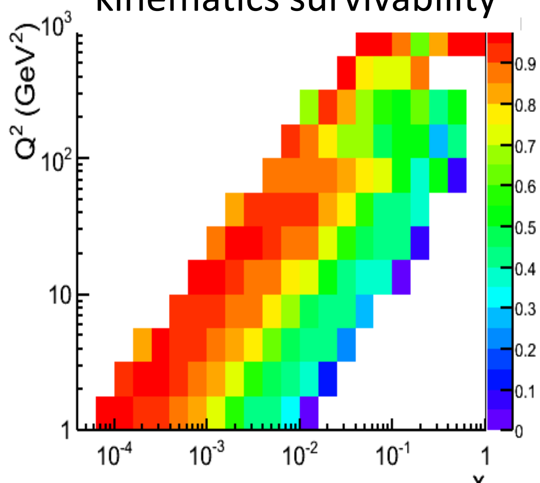


Physics performance: longitudinal spin structure of proton

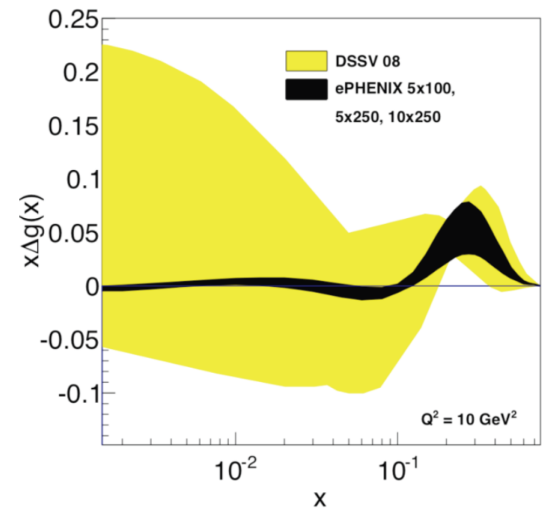
- ePHENIX will significant expand the x-Q^2 reach for longitudinal spin measurement
- EM calorimeter and tracking deliver good kinematic determination and particle ID
- Precise evaluation of gluon and sea quark spin



ePHENIX electron kinematics survivability



ePHENIX gluon helicity projection

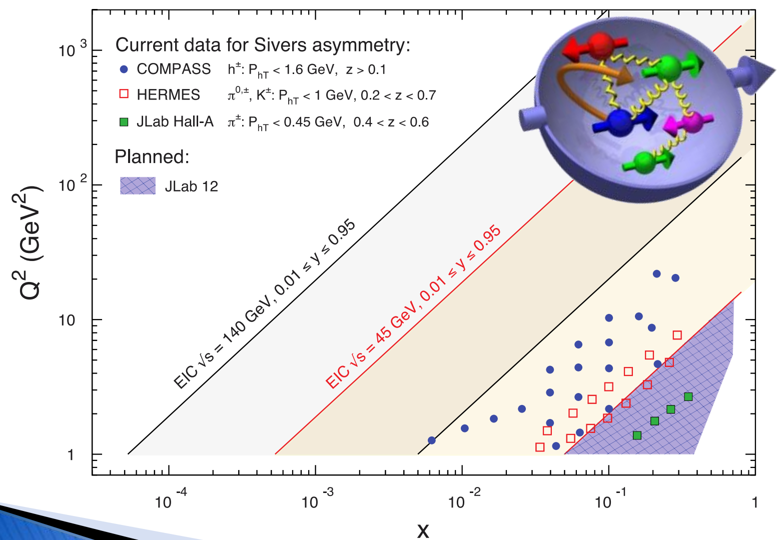


High x and Q2 region will be better determined using info from hadron final states

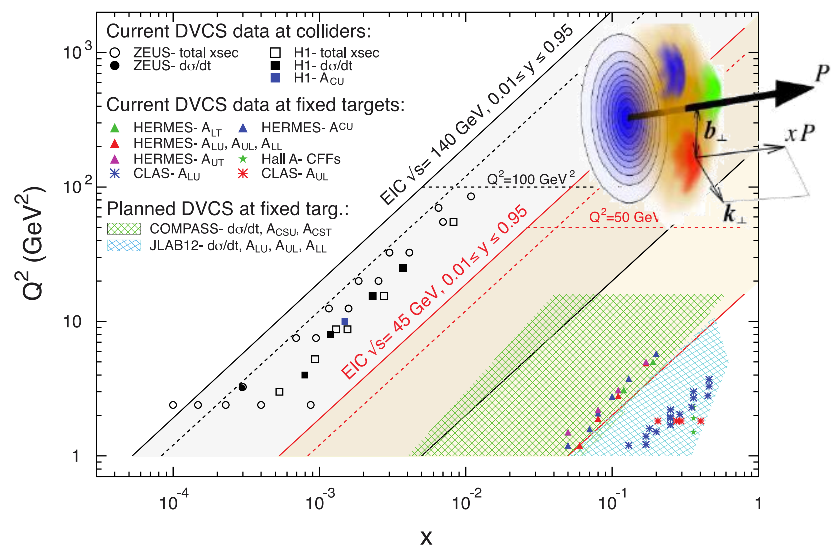
Physics performance: Transverse structure of nucleon

- 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



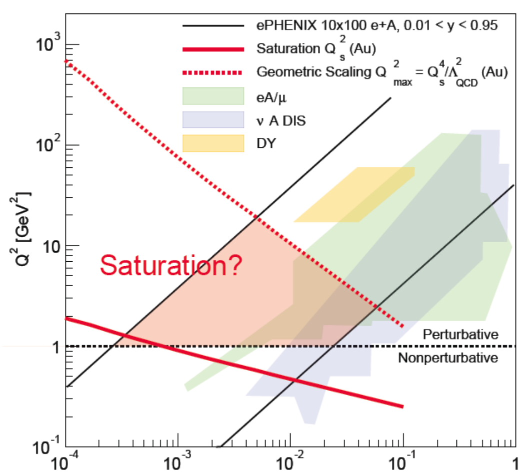
DVCS



Physics performance: Probing gluon saturation

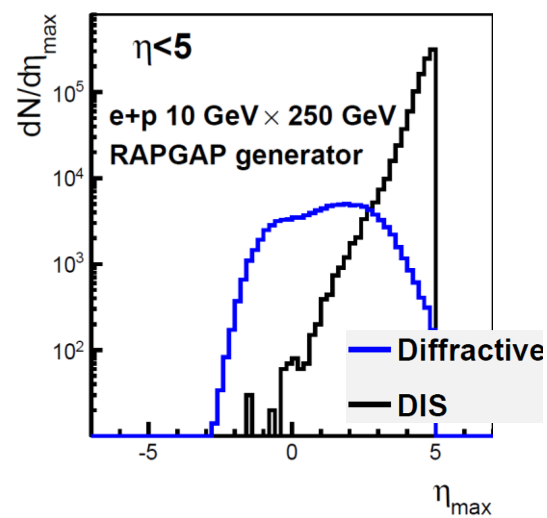
- ePHENIX is at the kinematic range to inspect the transition to gluon saturation region and their nuclear size dependent
- Large H-cal coverage (-1<η<+5) provide clean ID of diffractive events with reasonable efficiency through the rapidity gap method
- Delivering high precision diffractive-to-total cross section ratio measurement, which is very sensitive to the gluon saturation

Probing saturation region in electron kinematics

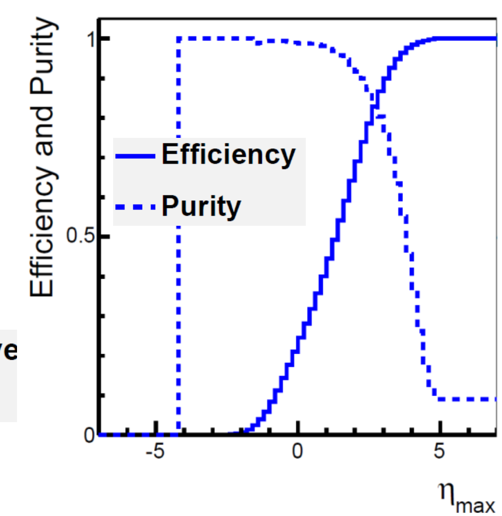


ID diffractive events using ePHENIX calorimeters

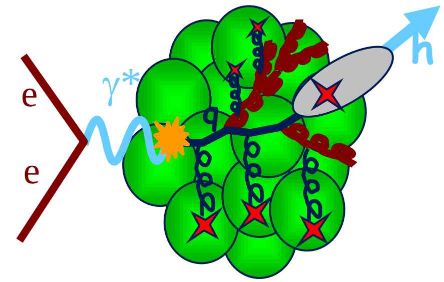
η of most forward going particle



Eff./Purity with η_{MAX} cut

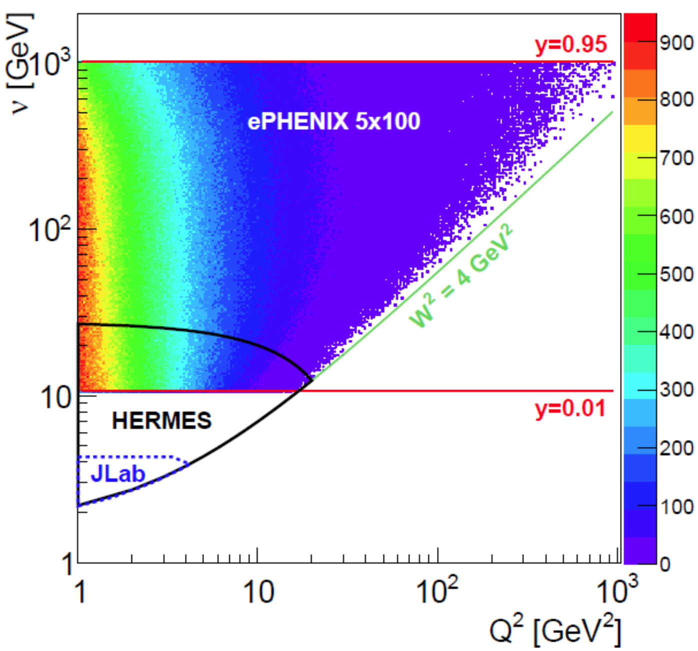


Physics performance:
parton propagation through nuclear matter

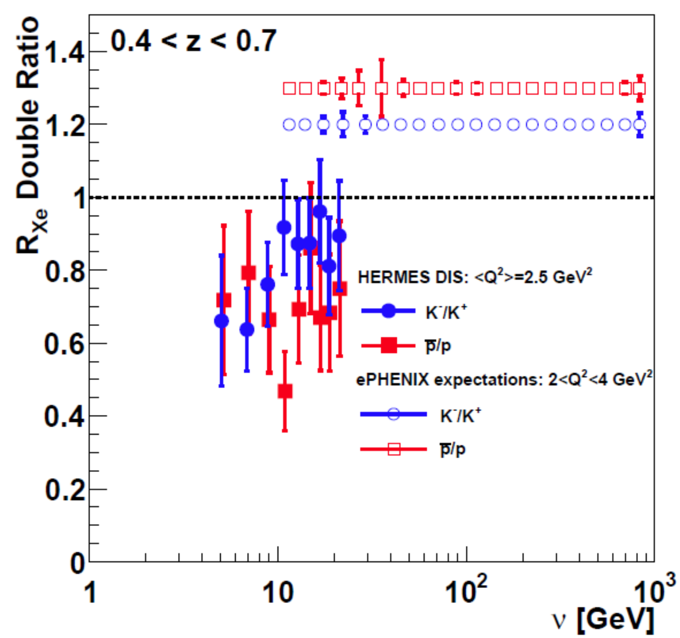


- SIDIS in e-A collisions probe color neutralization and harmonization as it propagate through nuclear matters
- ePHENIX provide a set of flexible handles : struck quark's energy and flavor, virtuality of DIS, geometry of the collision, specie of nuclei.
- Also possible for D-meson production through kinematical reconstruction of identified decay products

Energy transfer ν VS Q2 coverage



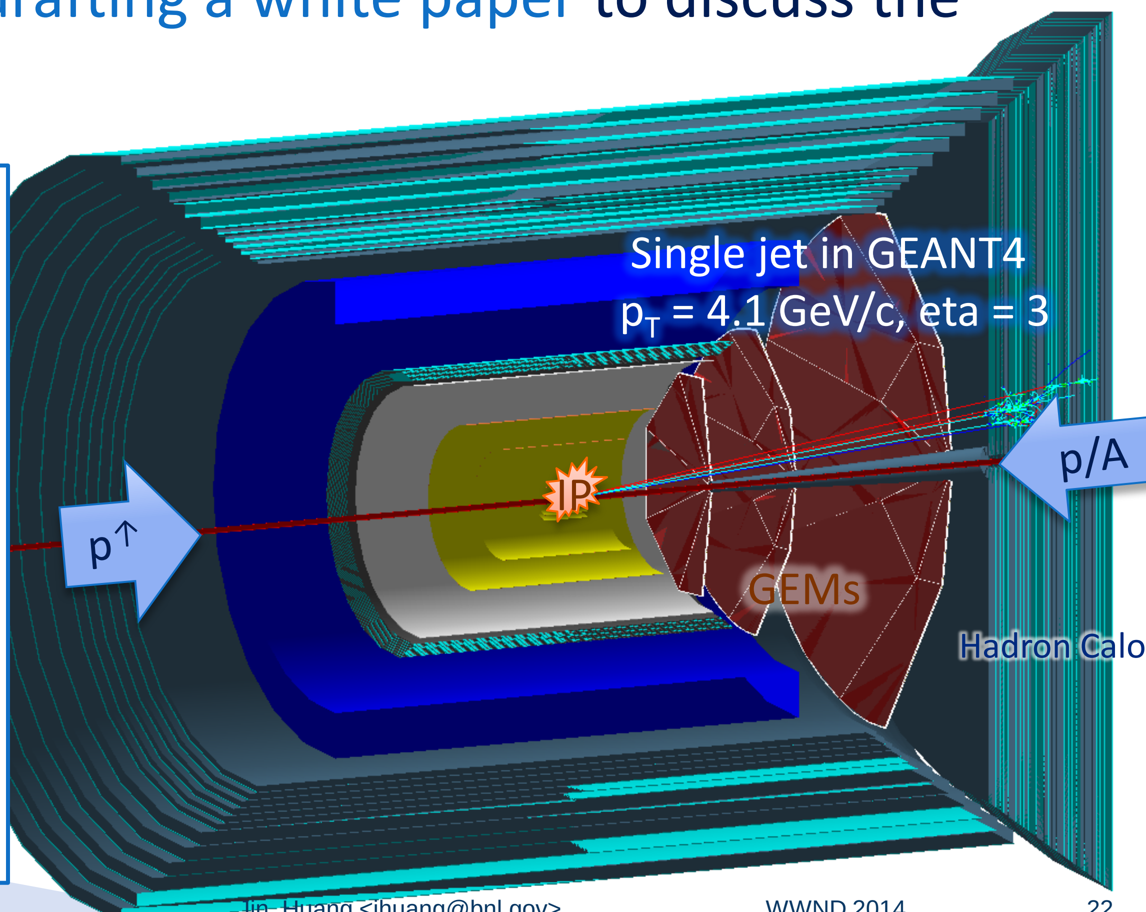
ePHENIX projection for nuclear modification ratio



Physics before the EIC era:
Use as forward detector in RHIC pp/pA collisions

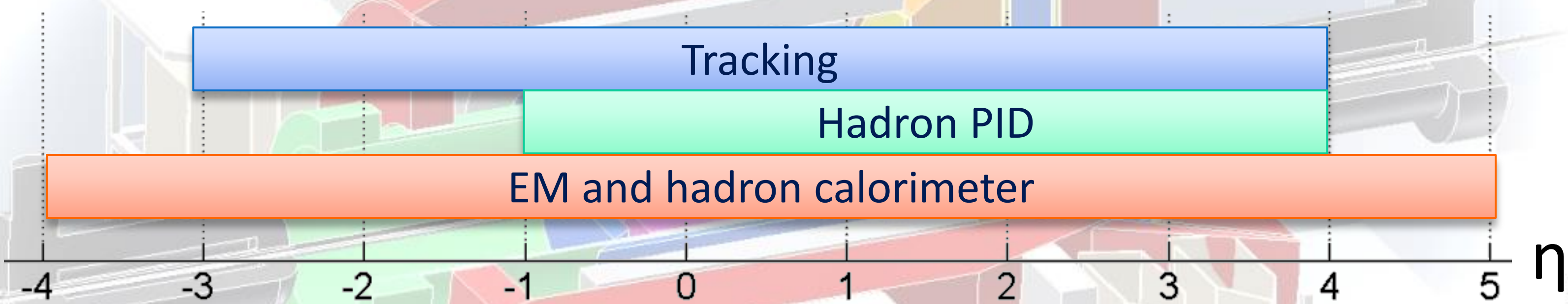
- The ePHENIX forward detector can be constructed earlier → a unique forward program with RHIC's pp/pA collision
- The collaboration is drafting a white paper to discuss the physics program

ePHENIX GEM + H-Cal
→ Forward jet with charge sign tagging
→ Unlock secrets of large A_N in hadron collisions
+ reuse current silicon tracker & Muon ID detector
→ polarized Drell-Yan with muons
→ Critical test of TMD framework
+ central detector (sPHENIX)
→ Forward-central correlations
→ Study cold nuclear matter in pA



Summary

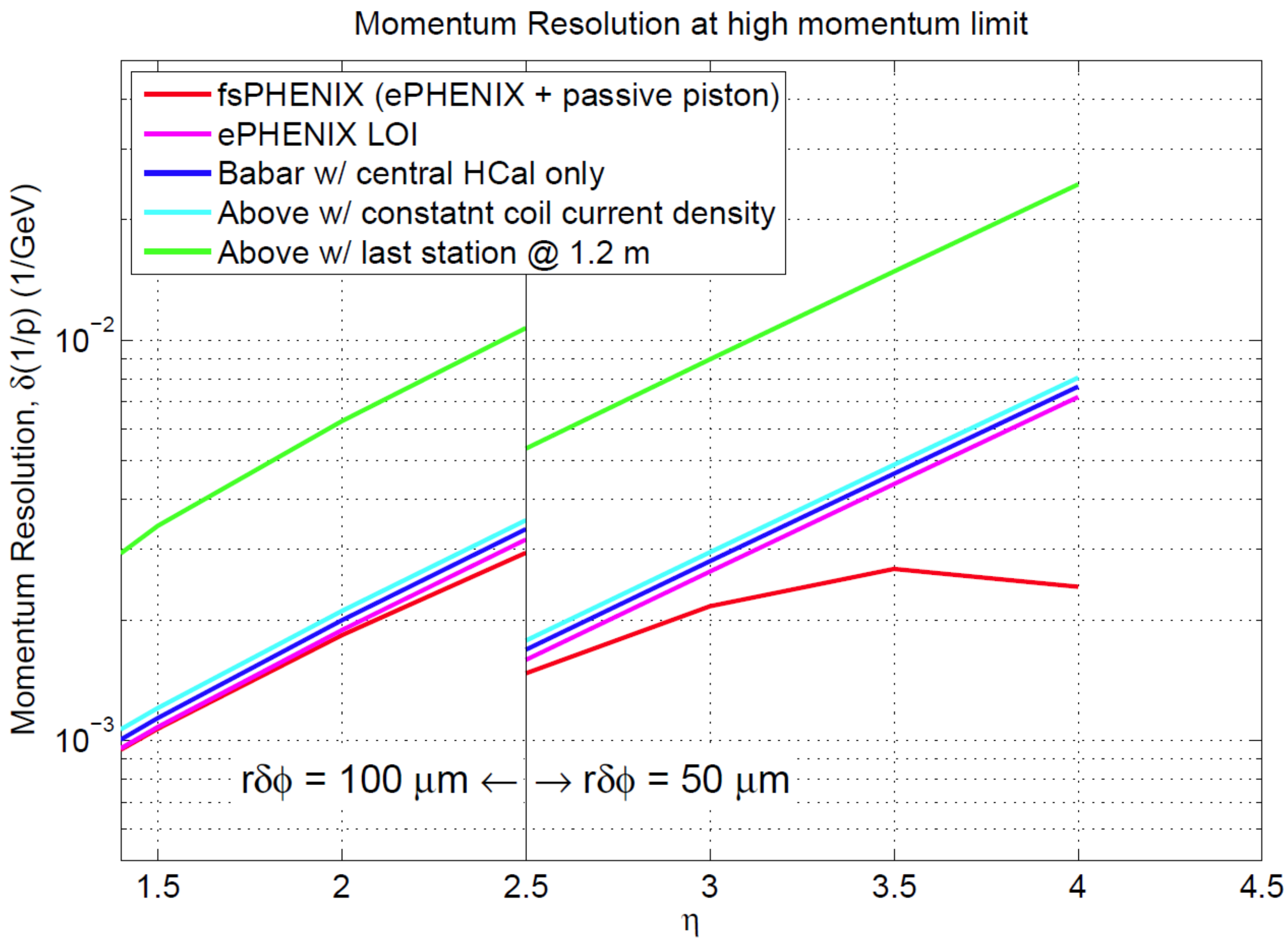
- Plan: PHENIX → sPHENIX → ePHENIX
- ePHENIX : a comprehensive detector concept for PHENIX interaction point at eRHIC



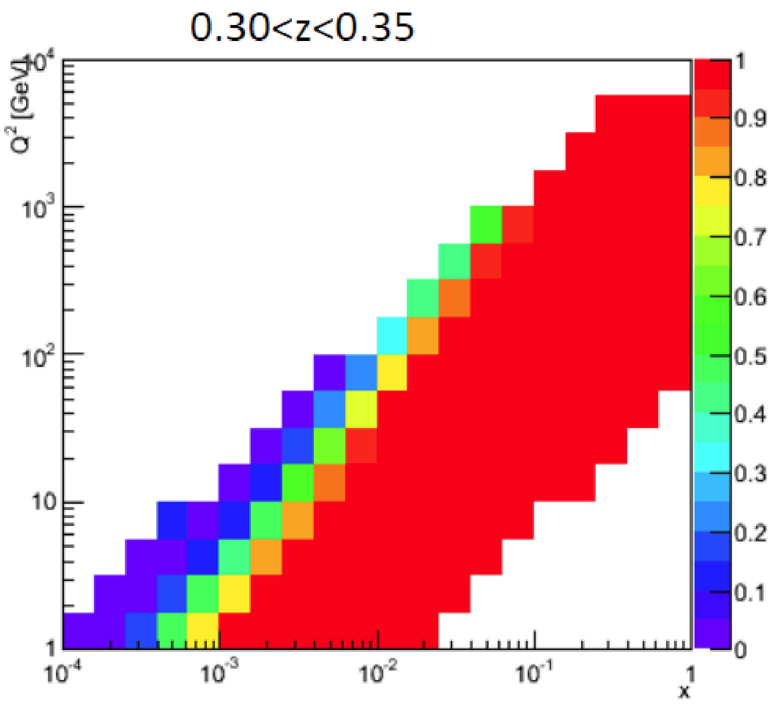
- A new collaboration will be formed for carrying out its construction and physics program. Abundant opportunities.
- Active study on going : successful review in Jan 2014, detector R&D, simulations
- Read more: arXiv:1402.1209 and https://www.phenix.bnl.gov/plans.html

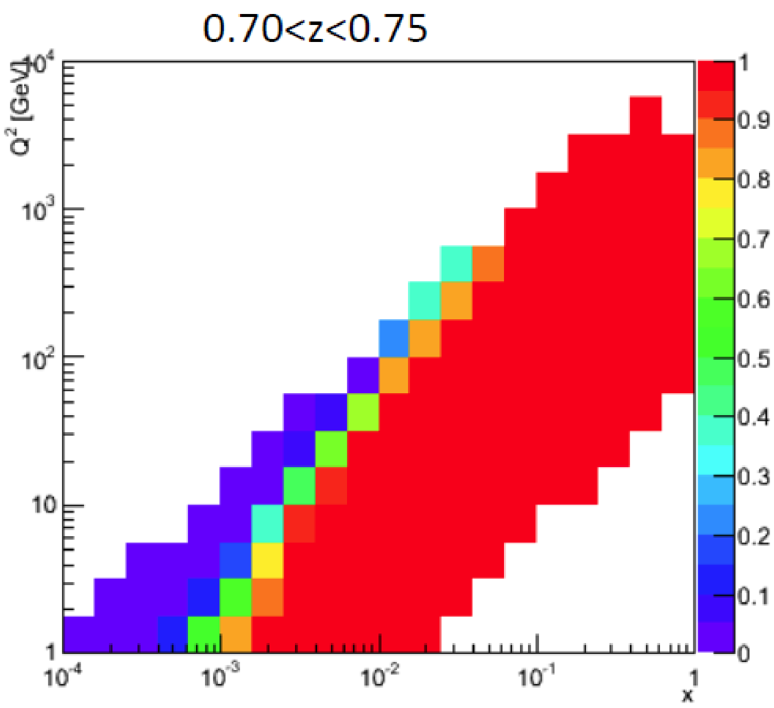
Backup

Forward tracking strategies



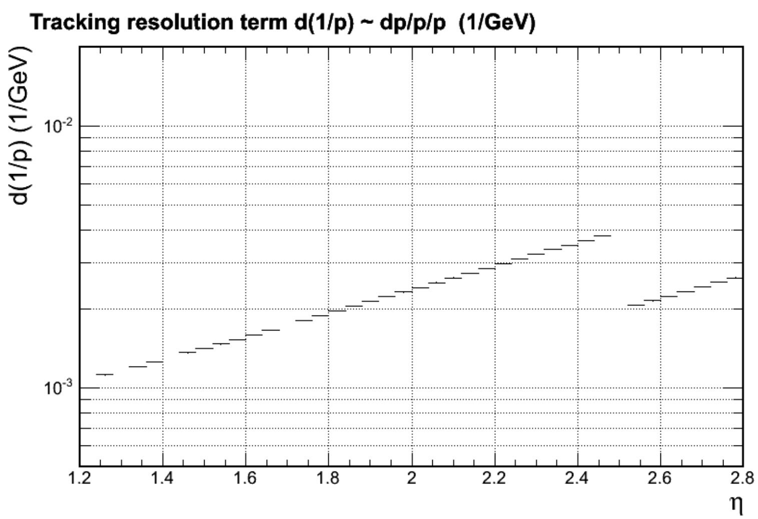
e-going hadron ID or what we missed

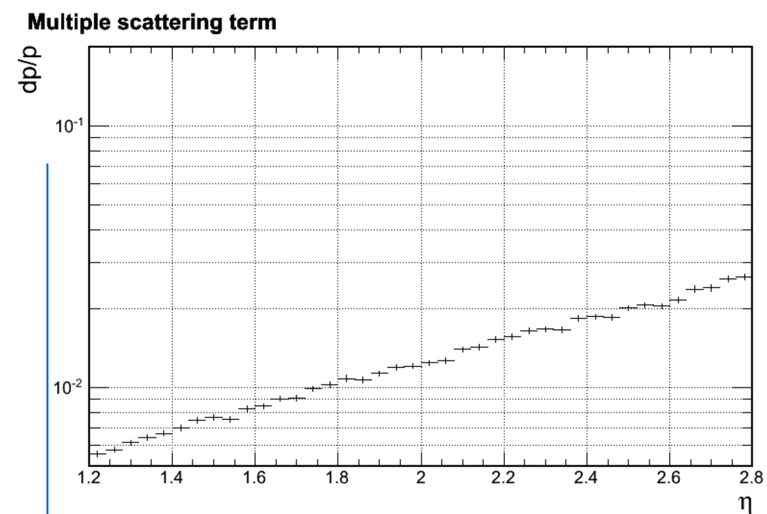




Geant Tracking resolution – 1<η<3

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

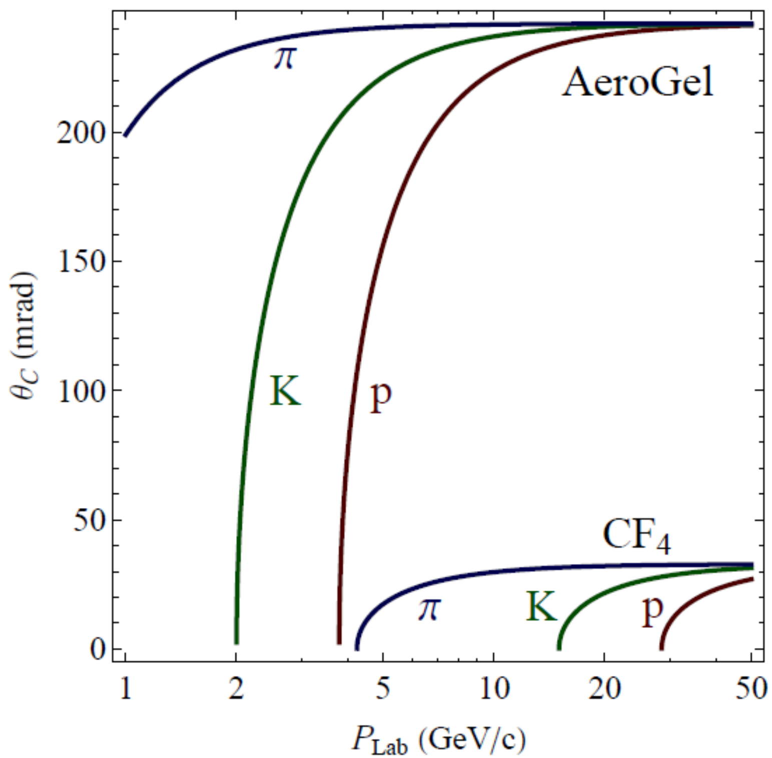
2.5< η <4: d($Sagitta_2$) = 60μm for 50 μm tracker resolution

Multiple scattering term

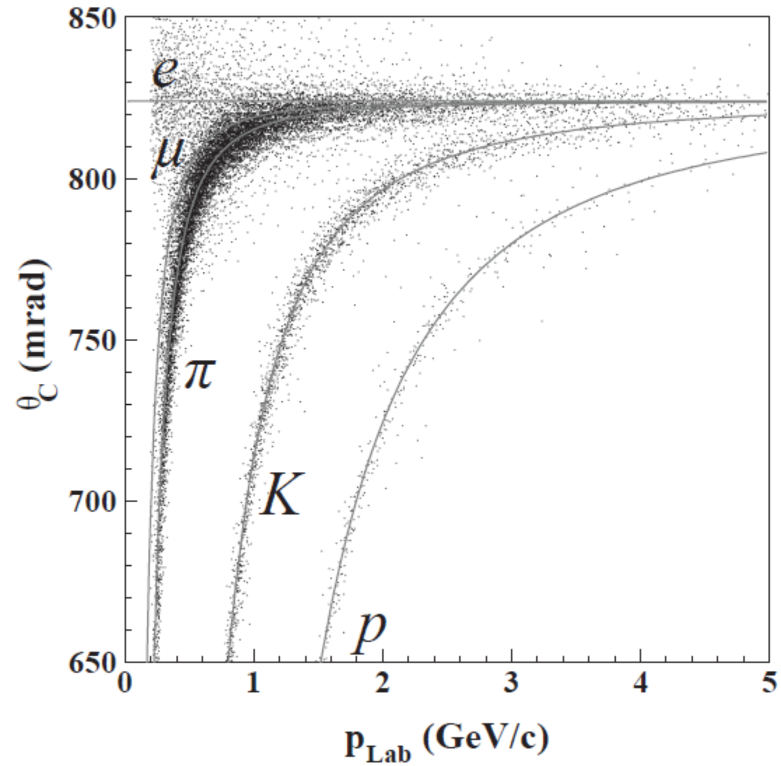
Displayed without RICH

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

Cherenkov angles choices



(a) Aerogel and RICH gas radiators for hadron-going direction



(b) Fused silica radiator for barrel DIRC detector. Data are measured by the BaBar DIRC [25]