Plans and Prospects for fsPHENIX and an EIC detector

Jin Huang (BNL)

for the PHENIX collaboration

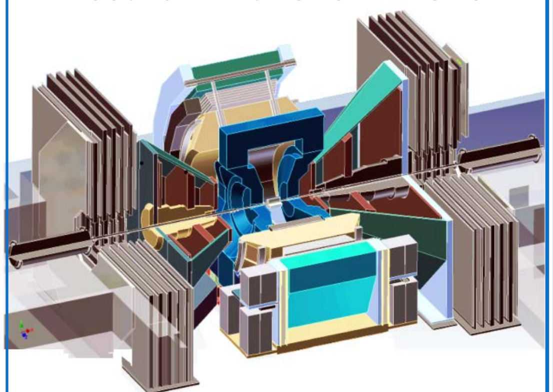
PHENIX

Overview

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

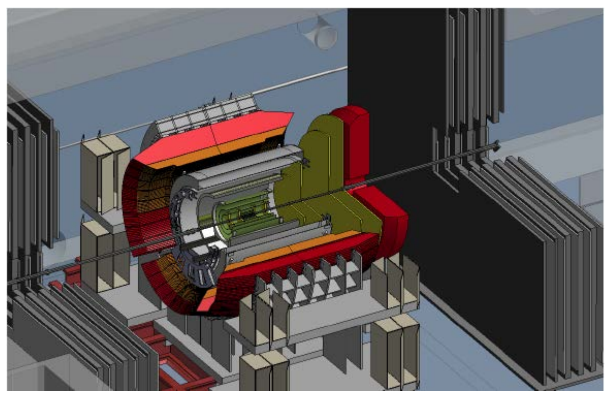
Current PHENIX

- Current PHENIX as discussed in many previous talks
- 14y+ work
  100+M$ investment
- 130+ published papers to date
- Last run in this form 2016



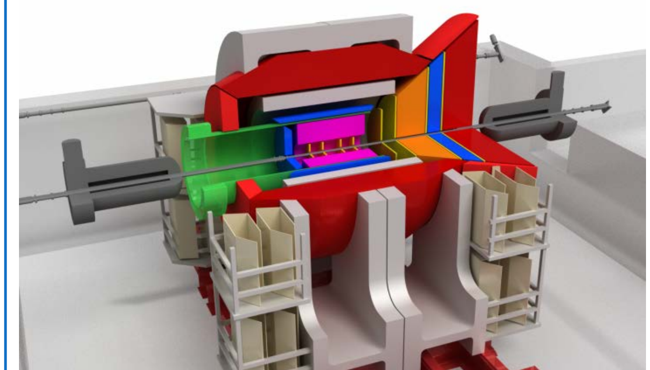
*f/s*PHENIX

- Comprehensive central upgrade base on BaBar magnet
- fsPHENIX : forward tracking, Hcal and muon ID
- Key tests of theoretical frameworks for transverse spin



An EIC detector

- Path of PHENIX upgrade leads to a capable EIC detector
- Large coverage of tracking, calorimetry and PID
- Open for new collaboration/new ideas



~2000 | 2017→2020 | ~2025 | Time

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

eRHIC: e+p, e+A

- **Unified forward spectrometer design**

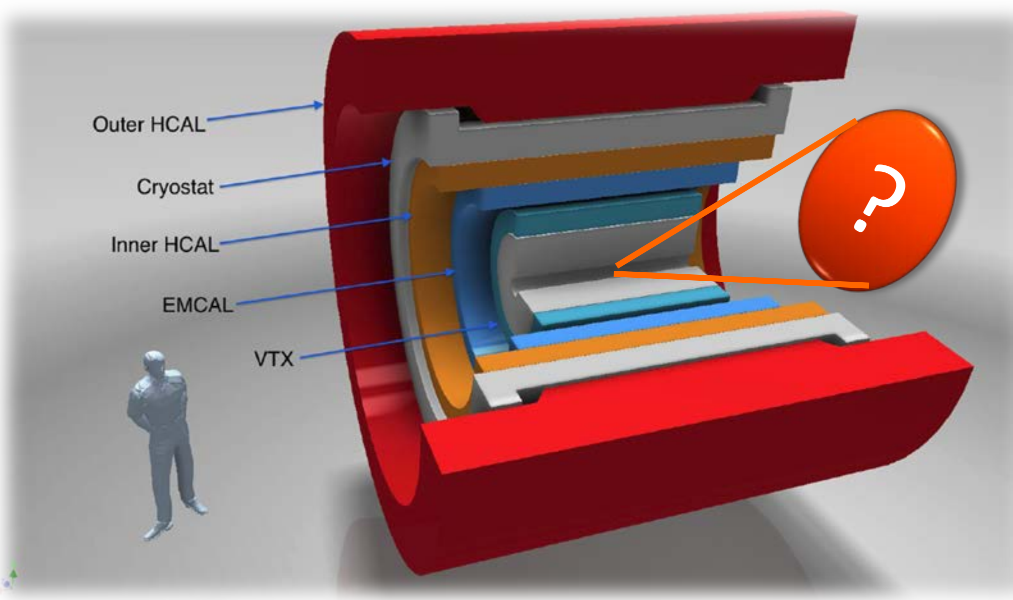
fsPHENIX in RHIC

An EIC detector concept for eRHIC

The sPHENIX detector

Details in talk: Upgrades for the Future Program/ Michael McCumber, LANL

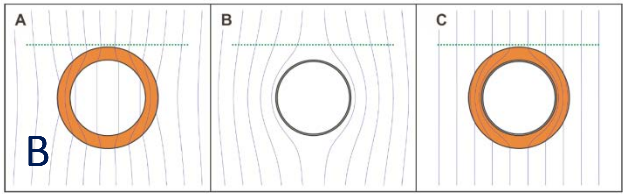
- sPHENIX: major upgrade to the PHENIX experiment aim for data @ 2020
- Physics Goals: detailed study QGP using jets and heavy quarks at RHIC energy region
- Baseline consists of new large acceptance EMCal+HCal built around recently acquired BaBar magnet. Additional tracking also planned
- MIE submitted to DOE
  Strong support from BNL
  DOE scientific review in two weeks
- A good foundation
  for future detector upgrade



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

What field shall we add in the forward? - Brain storm in the past few years

Design Family	Example
Piston	• Passive piston (C. L. da Silva) • Super conducting piston (Y. Goto)
Dipole	• Forward dipole (Y. Goto, A. Deshpande, et. al.) • Redirect magnetic flux of solenoid (T. Hemmick) • Use less-magnetic material for a azimuthal portion of central H-Cal (E. Kistenev)
Toroid	• Air core toroid (E. Kistenev) • Six fold toroid (J. Huang)
Other axial symmetric Field shaper	• Large field solenoidal extension (C. L. da Silva) • Pancake field pusher (T. Hemmick)

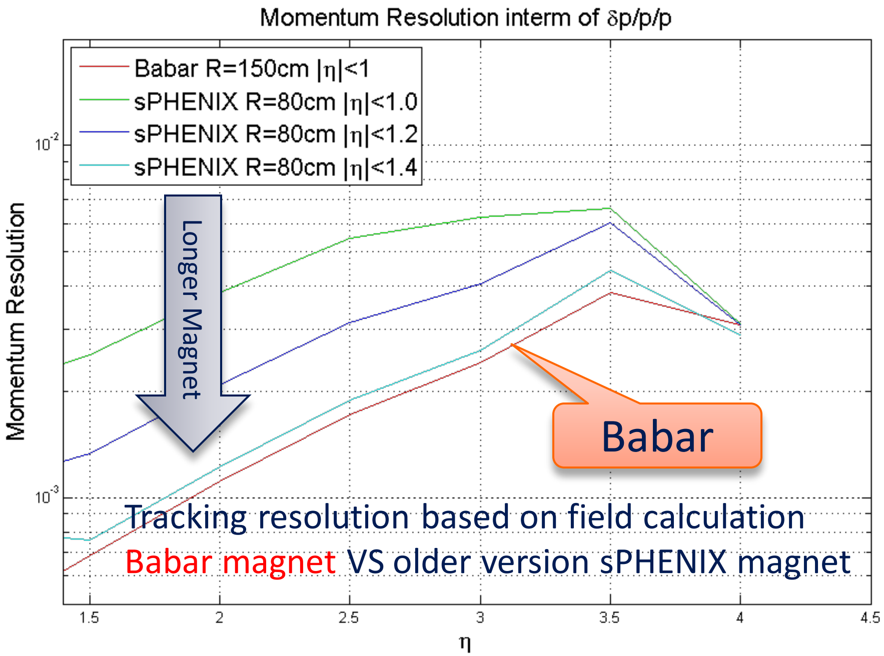


Beam line magnetic field shielding, based on superconducting pipe. From Nils F.

BaBar + Field shaping

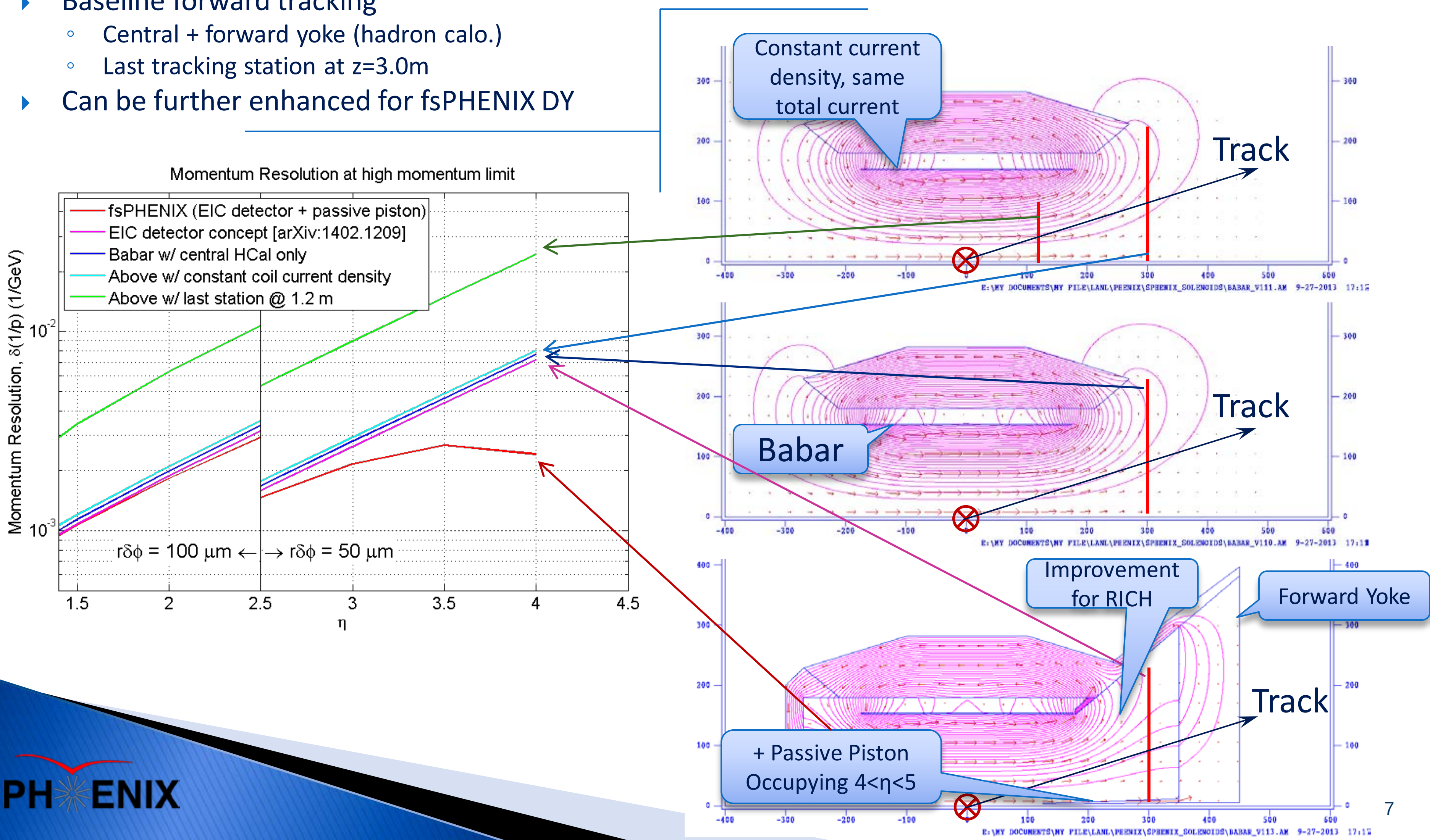
- BaBar superconducting magnet became available
  - Built by Ansaldo → SLAC ~1999
  - Nominal field: 1.5T
  - Radius : 140-173 cm
  - Length: 385 cm
- Field calculation and yoke tuning
  - Three field calculator cross checked: POISSION, FEM and OPERA
- Favor for forward spectrometer
  - Designed for 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 with field-shaping yoke: Forward & central Hcal + Steel lampshade
- Ownership officially transferred to BNL


BaBar solenoid packed for shipping, May 17 2013



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 (eRHIC machine/detector t"ruce" line)
- Baseline forward tracking
  - Central + forward yoke (hadron calo.)
  - Last tracking station at z=3.0m
- Can be further enhanced for fsPHENIX DY



PHENIX

Unified forward spectrometer design

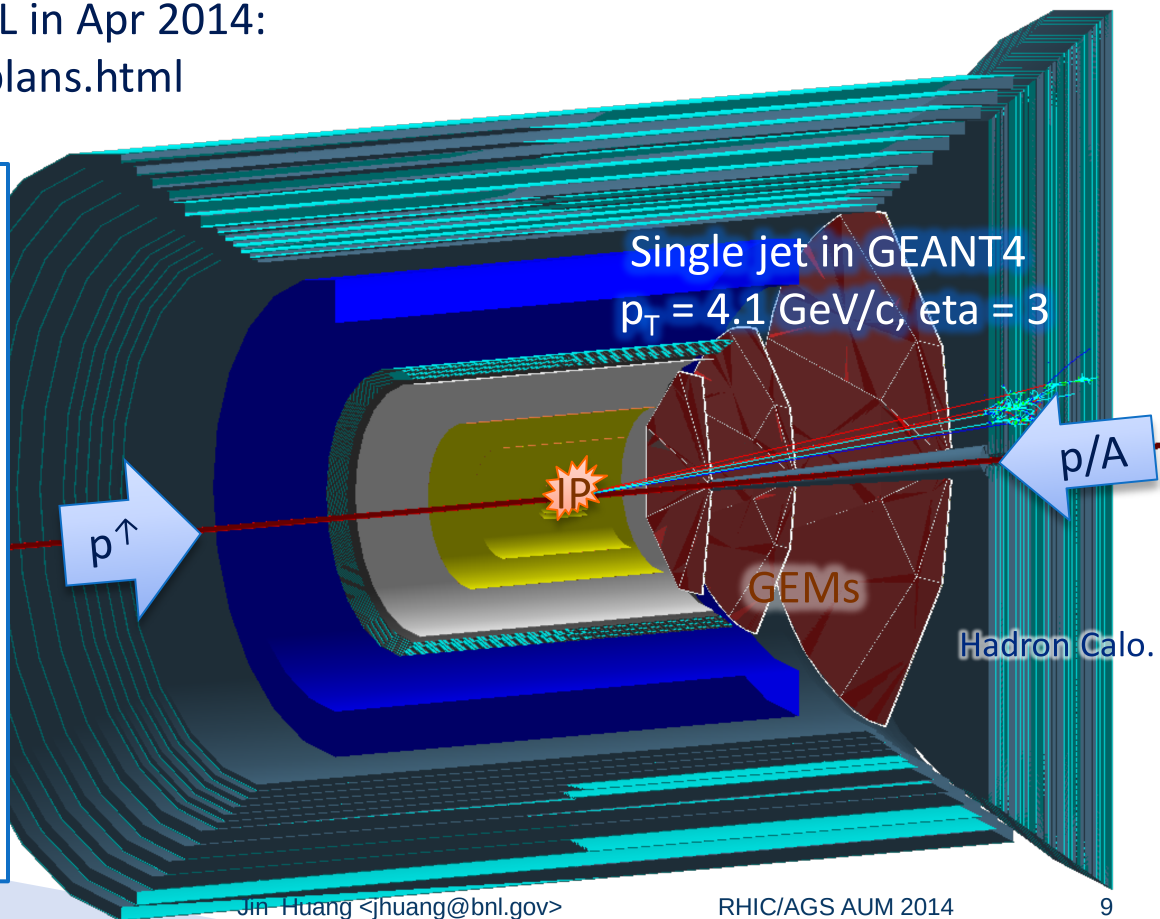
fsPHENIX at RHIC

An EIC detector concept for eRHIC

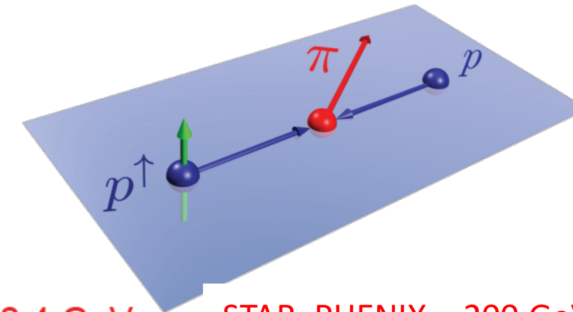
Forward spectrometer of sPHENIX: *fs*PHENIX
For forward detection in RHIC pp/pA collisions

- Shared detector with future eRHIC program and deliver an unique forward program with RHIC's pp/pA collision, which would otherwise lost in eRHIC
- white paper submitted to BNL in Apr 2014: http://www.phenix.bnl.gov/plans.html

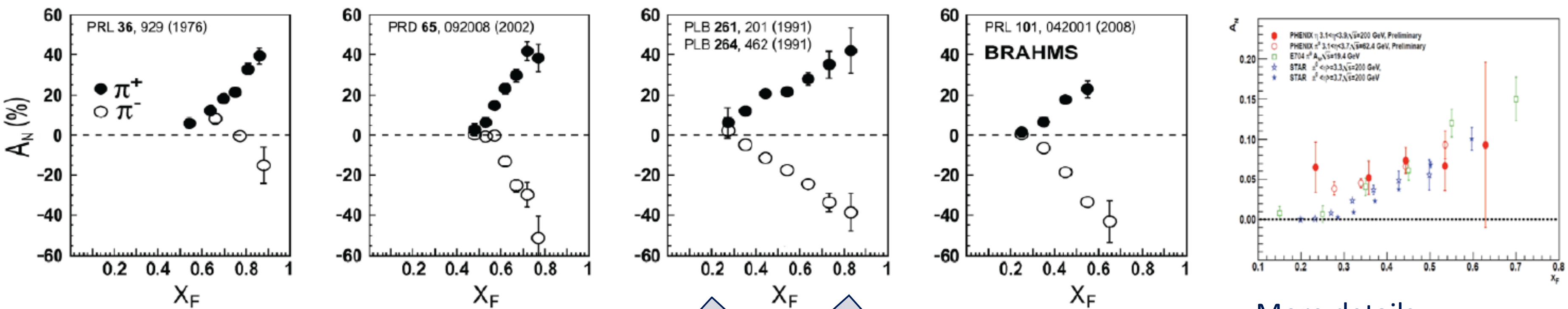
EIC detector GEM + H-Cal
→ Forward jet with charge sign tagging
→ Unlock secrets of large A_N in hadron collisions
+ reuse current silicon tracker & Muon ID detector
→ polarized Drell-Yan with muons
→ Critical test of TMD framework
+ central detector (sPHENIX)
→ Forward-central correlations
→ Study cold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



Challenges and opportunities in understanding transverse spin

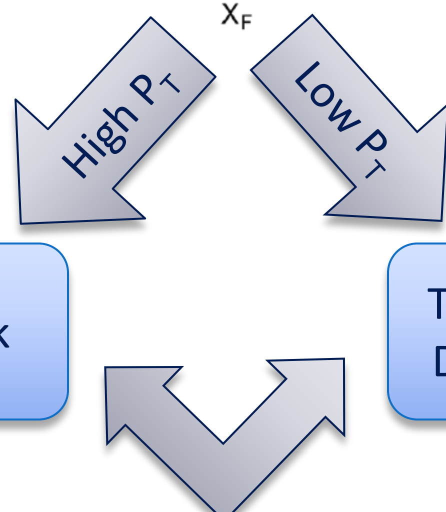


ANL – 4.9 GeV | BNL – 6.6 GeV | FNAL – 20 GeV | BNL – 62.4 GeV | STAR, PHENIX – 200 GeV



More details:
Session I/ W. Feng
Session I/ N. Namdara

More details: Session I/ Z. Kang



Twist-3 framework

Transverse Momentum Dependent (TMD) PDF

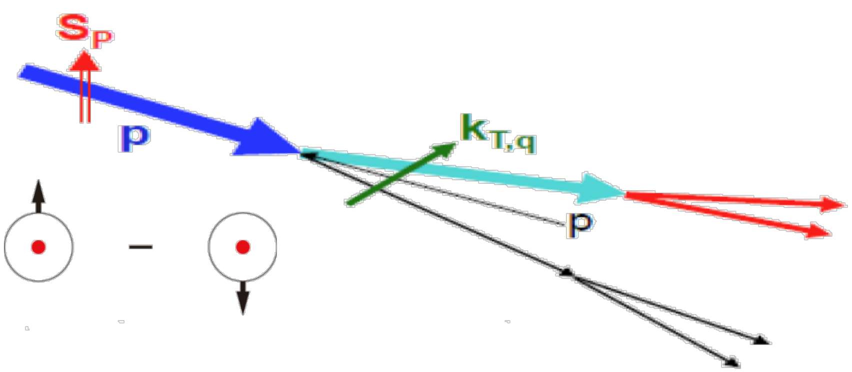
Connected in intermediate region

- Sign mismatch? → More complex system than simplified assumptions, separation of DF/FF
- Process dependency → Important to understand in pp (at RHIC) and in ep (at eRHIC)
- Evolution → probe at large scale range in PHENIX and STAR (see also next talk O. Eyser)

Hunting origin of transverse asymmetry using - fsPHENIX

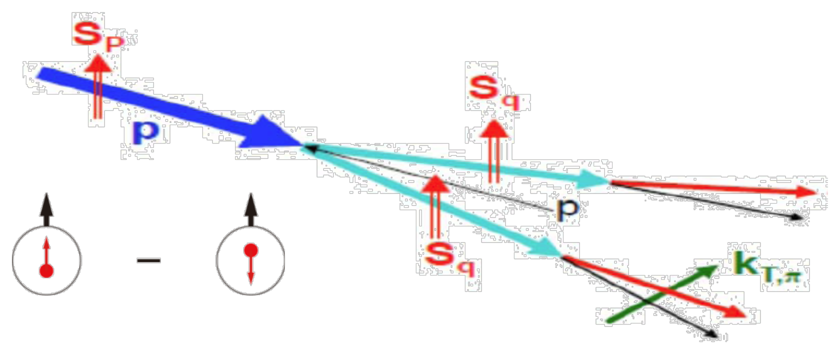
√	Required
	Great to have
	NOT required

	Tracking	Calorimetry	Lepton PID
Jet Sivers		√	
Jet Collins	√	√	
DY	√	√	√



Jet left-right asymmetry

- Probes Sivers effect: parton level correlation between spin and transverse momentum
- Detector: require good jet reconstruction
- Charge track tagging to differentiate parton contributions with different signs



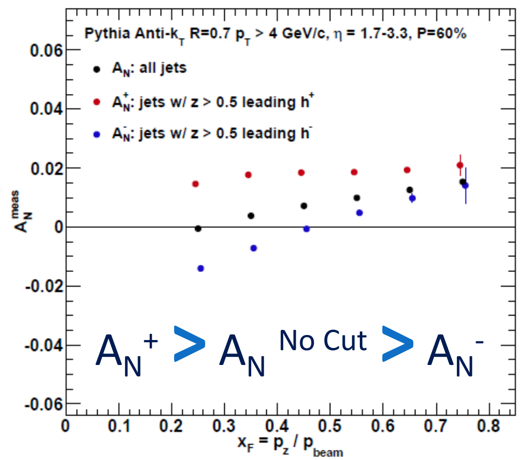
Left-right asymmetry of hadron inside jets

- Collins fragmentation: transverse quark spin → k_T of hadron
- Forward jets probes: quark transversity at high-x range (reach x = 0.5-0.6)
- Not include but possible for upgrade: PID inside the jet to probe s through $K^{\pm}$

Jet asymmetry projections in fsPHENIX

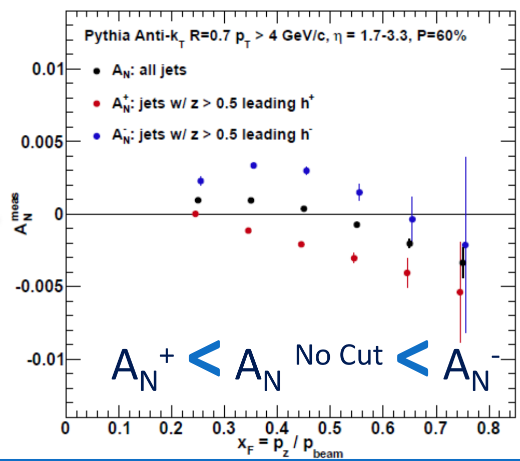
TMD [Anselmino, et. al.]

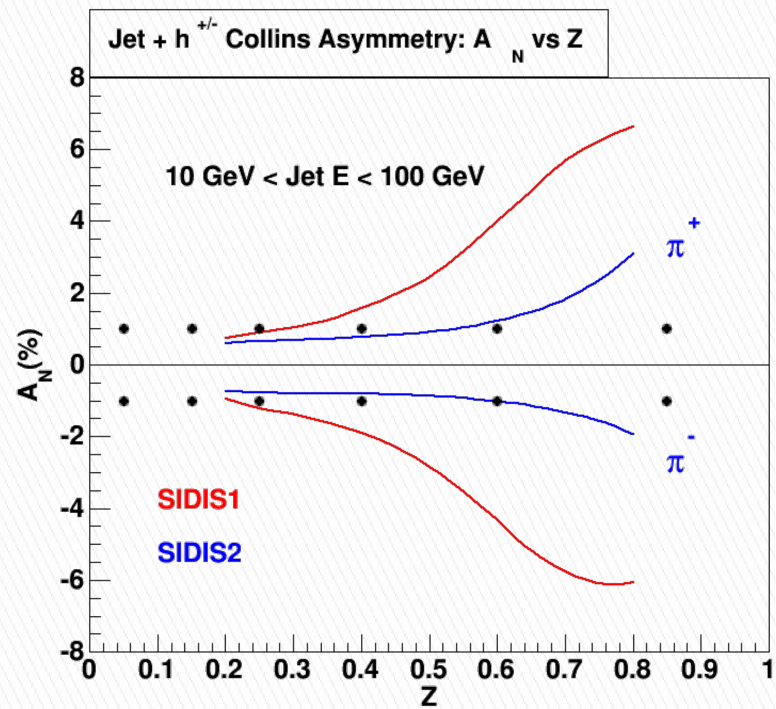
SIDIS Result
→ High P_T region



Twist-3 [Gamberg, Kang, Prokudin]

QS function fit of high p_T data



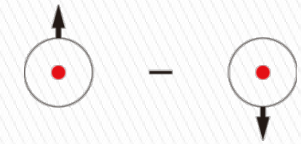


Jet left-right asymmetry with leading charge sign tagging

Hadron Asymmetry in Jets

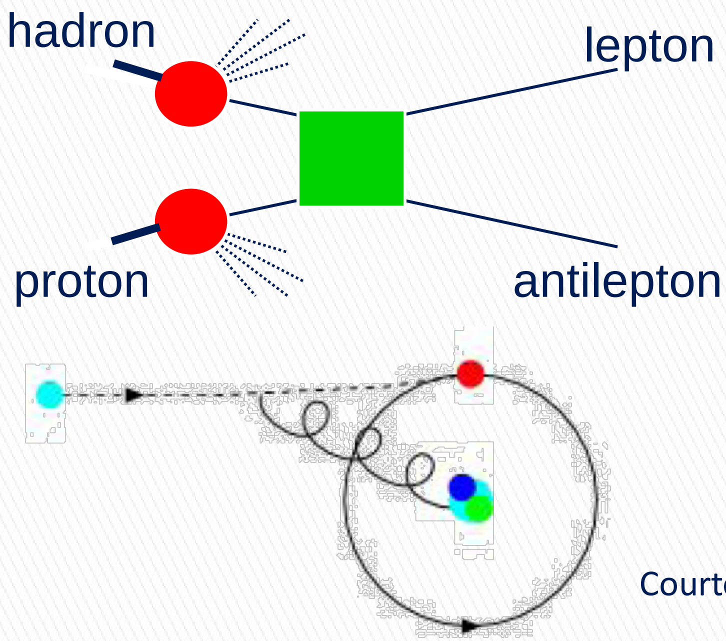
Sivers in SIDIS VS Polarized Drell-Yan and test the TMD picture

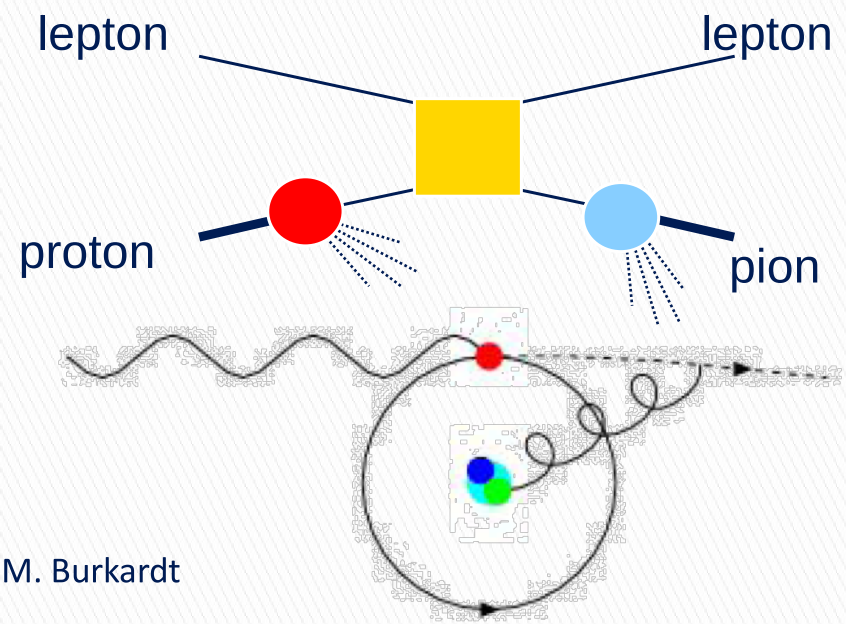
$f_{1T}^{\perp}$ =



- Test of sign reversal of Sivers function in SIDIS VS Drell-Yan is critical for the TMD factorization approach.

$$f_{1T}^{\perp}\,(DY) \overset{?}{=} - f_{1T}^{\perp}\,(SIDIS)$$



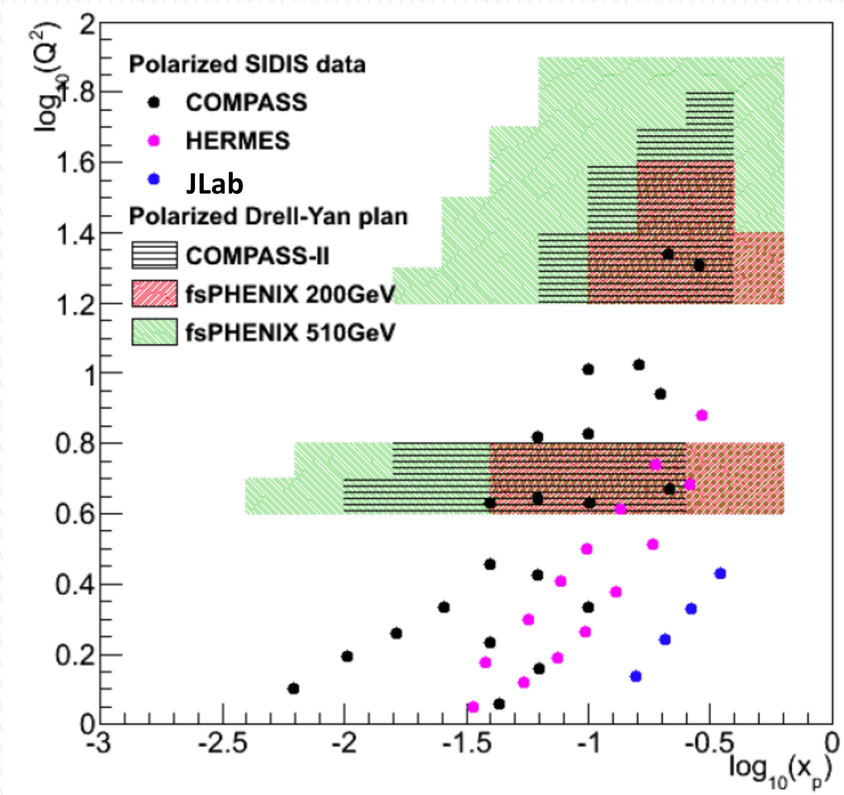


Courtesy to M. Burkardt

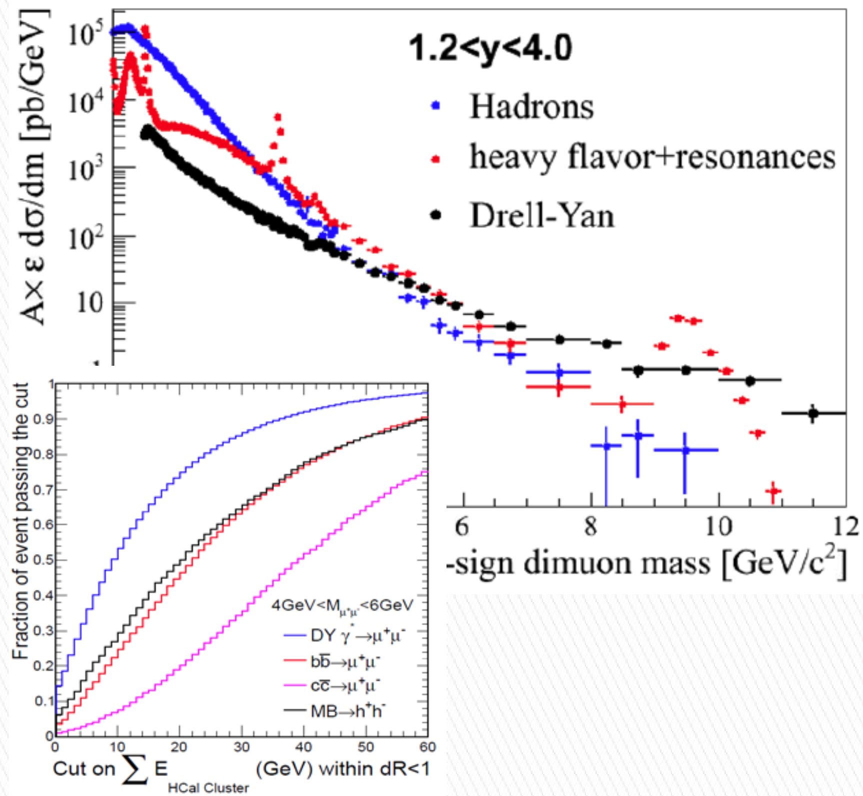
ISI in Drell-Yan is repulsive
apply to **RHIC** pp measurements

FSI in SIDIS is attractive
apply to **eRHIC** measurement

*fs*PHENIX DY – challenging but attractive



Shaded regions deliniate $\delta A_T^{\sin\phi_S} < 0.1$



Statistics-kinematic coverage comparisons

Major challenge on background and potential improvement

Also measure DY against large pT range from TMD-applied region to Twist-3

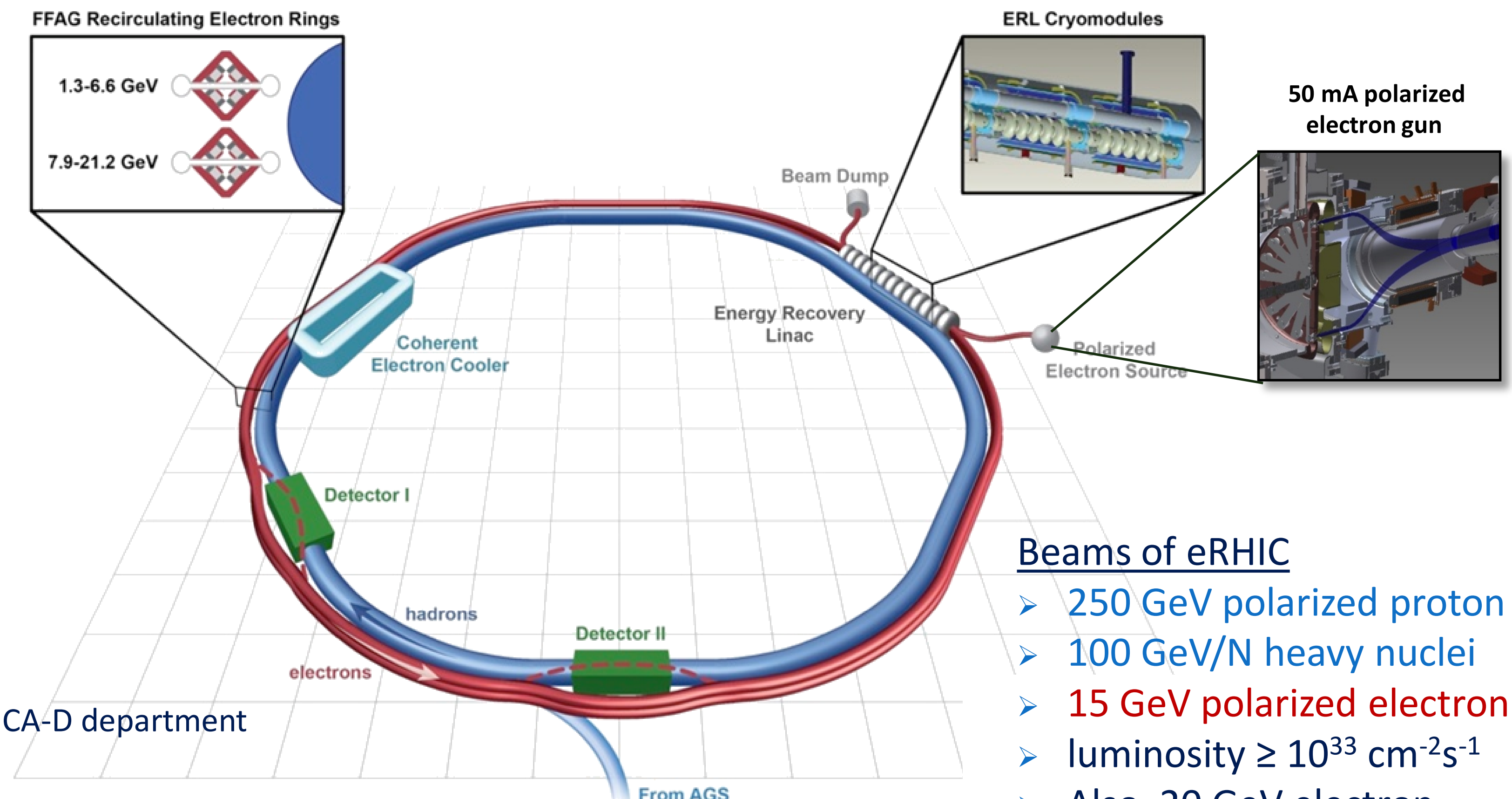
Unified forward spectrometer design

fsPHENIX in RHIC

An EIC detector concept for eRHIC

A realization of electron ion collider: RHIC → eRHIC around year 2025

eRHIC: reuse one of the RHIC rings + high intensity electron energy recovery linearc



Courtesy: BNL CA-D department

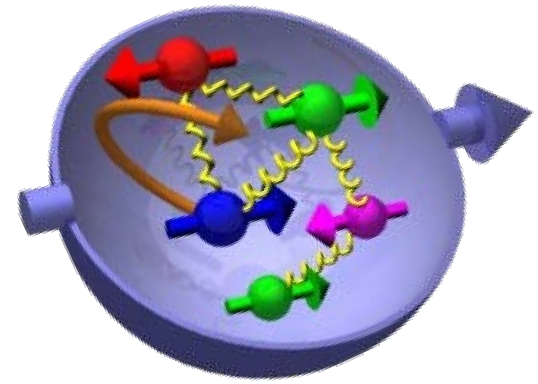
Beams of eRHIC

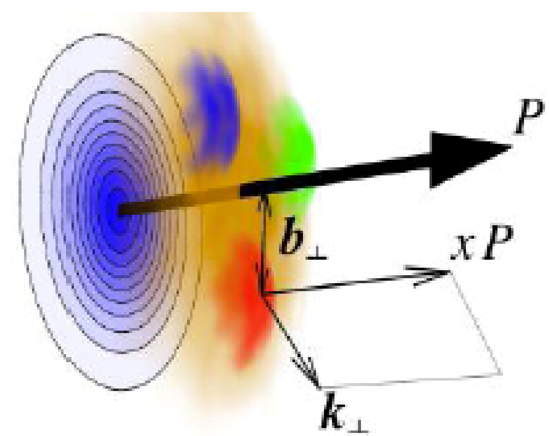
- 250 GeV polarized proton
- 100 GeV/N heavy nuclei
- 15 GeV polarized electron
- luminosity ≥ 10^{33} $cm^{-2}s^{-1}$
- Also, 20 GeV electron beam with reduced lumi.

Physics goals: nucleon as a laboratory for QCD

Outlined in EIC white paper, arXiv:1212.1701
See also: next two talks (O. Eyser, A. Deshpande)

- 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 and kinematic determination of DIS electrons
  - Momentum measurement and PID of hadrons
  - Detection of exclusive production of photon/vector mesons and scattered proton
  - Beam polarimetry and luminosity measurements

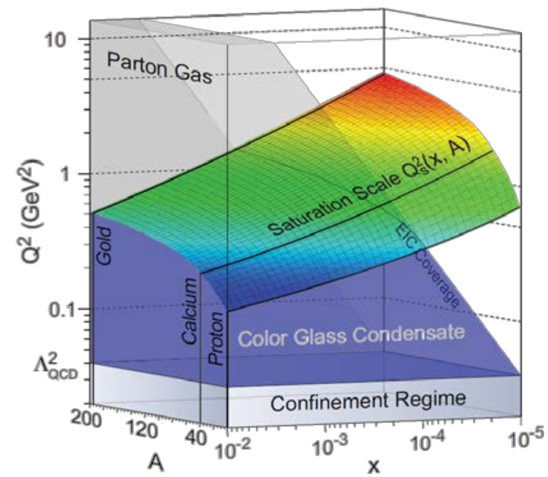


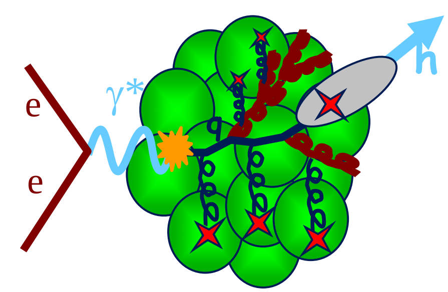


Physics goals: nucleus as a laboratory for QCD

Outlined in EIC white paper, arXiv:1212.1701
See also: next two talks (O. Eyser, A. Deshpande)

- 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 and correlation measurements
  - Nuclear modification for hadron and heavy flavor production in DIS events; probe of nPDF
  - Exclusive vector-meson production in eA
- Leading detector requirement:
  - ID of hadron and heavy flavor production
  - Large calorimeter coverage to ID diffractive events
  - Detection/rejection of break-up neutron production in eA collisions





In eRHIC era: concept for an EIC Detector

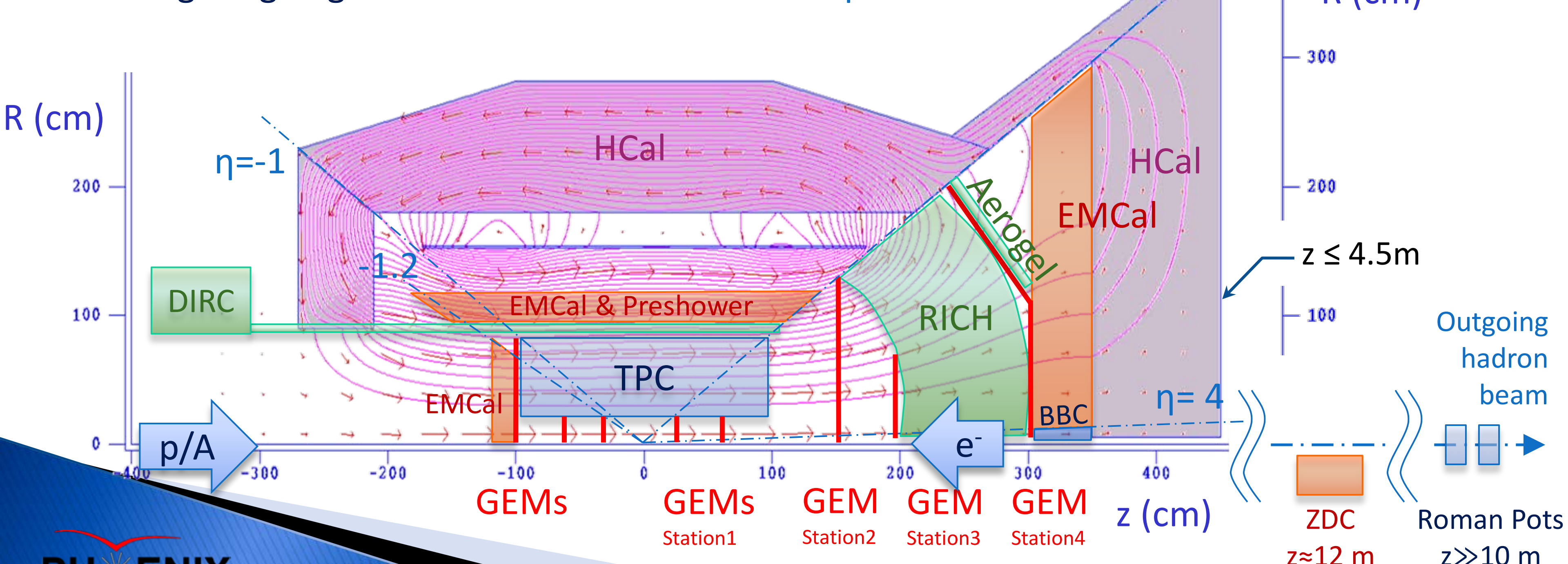
- $-1<\eta<+1$ (barrel) : sPHENIX + Compact-TPC + DIRC
- $-4<\eta<-1$ (e-going) :
  High resolution calorimeter + GEM trackers
- $+1<\eta<+4$ (h-going) :
  - $1<\eta<4$: GEM tracker + Gas RICH
  - $1<\eta<2$: Aerogel RICH
  - $1<\eta<5$: EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: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

Working title: "ePHENIX"

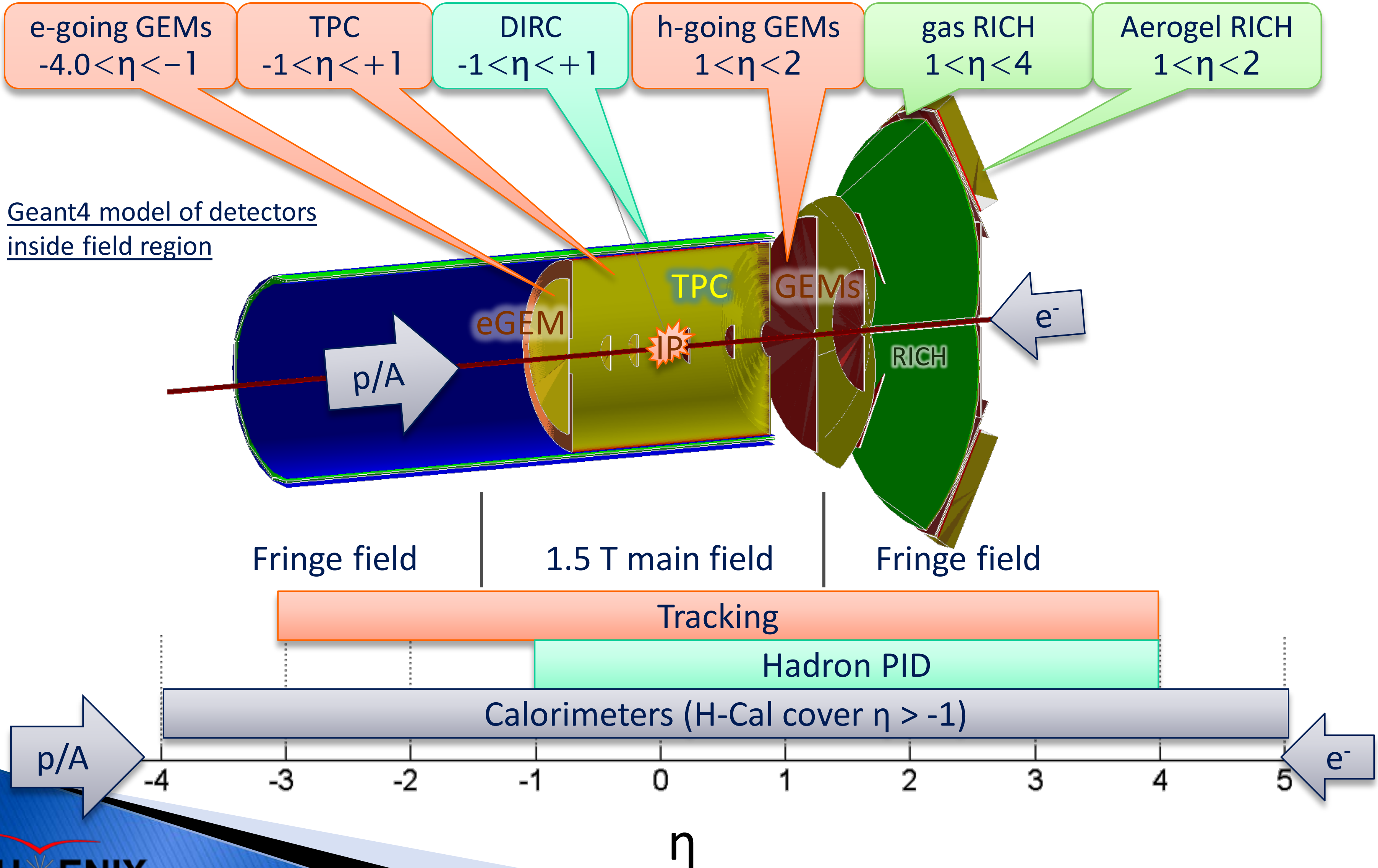
LOI: arXiv:1402.1209

Review: "good day-one detector"

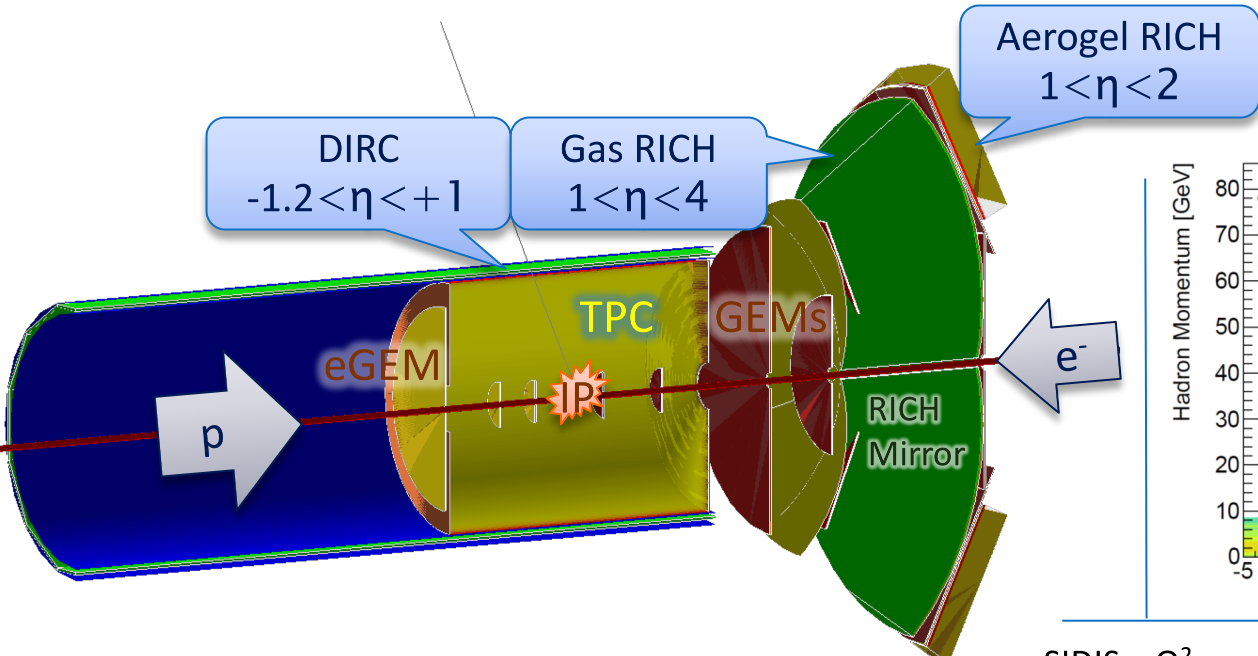
"solid foundation for future upgrades"



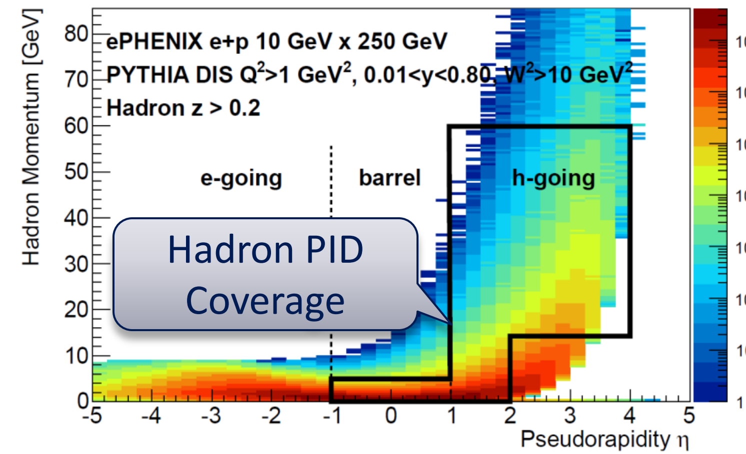
Tracking and PID detectors



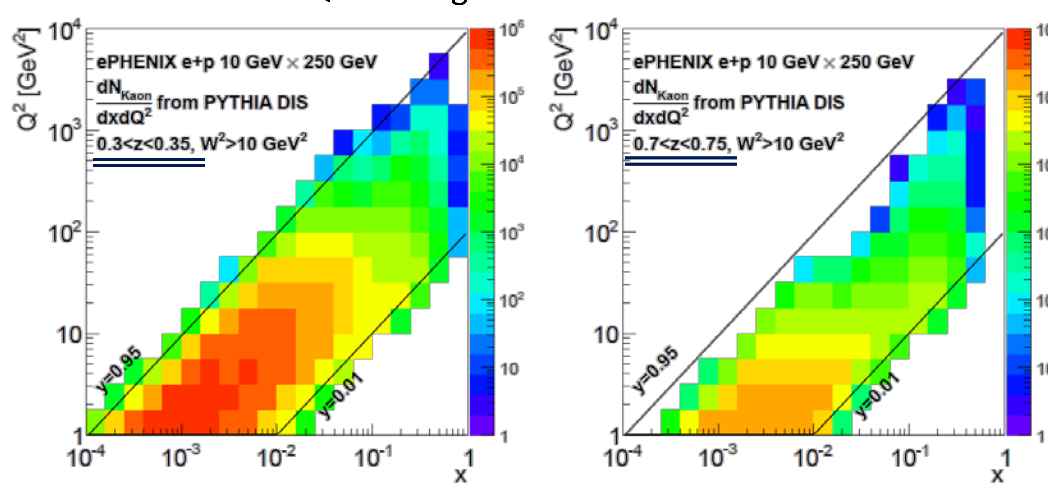
Hadron PID Overview



Detector coverage for hadron PID



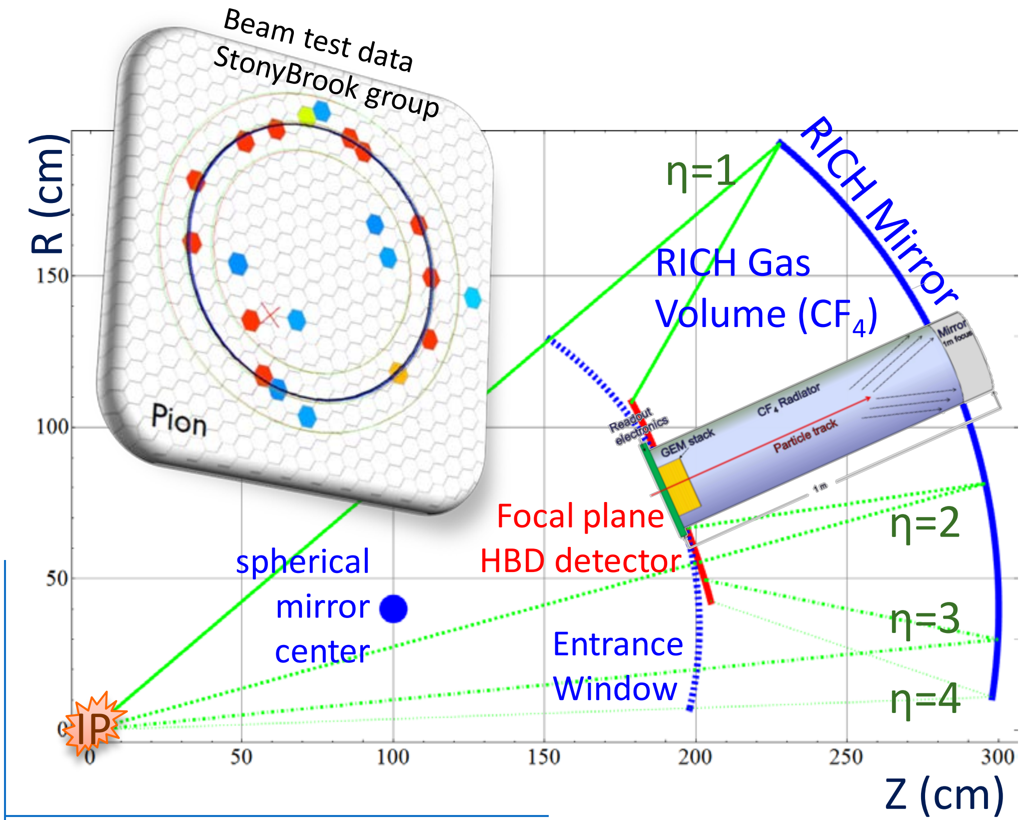
SIDIS x-Q^2 coverage with hadron PID in two z-bins



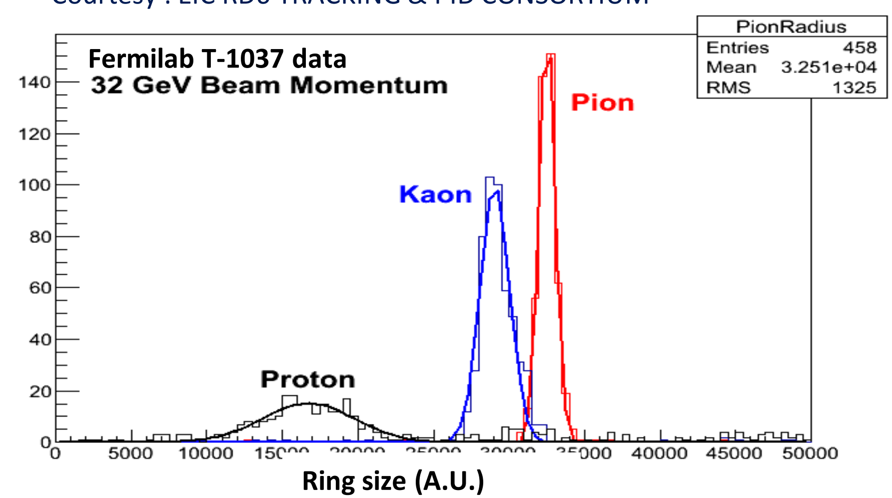
- DIRC
  - Based on BaBar DIRC design plus compact readout
  - Collaborate with TPC dE/dx for hadron ID in central barrel
- Aerogel RICH
  - Approximate focusing design as proposed by Belle-II
  - Collaborate with gas RICH to cover $1<\eta<2$
- Gas RICH: next slides
- Possible upgrade in electron-going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

Gas RICH
- The Design

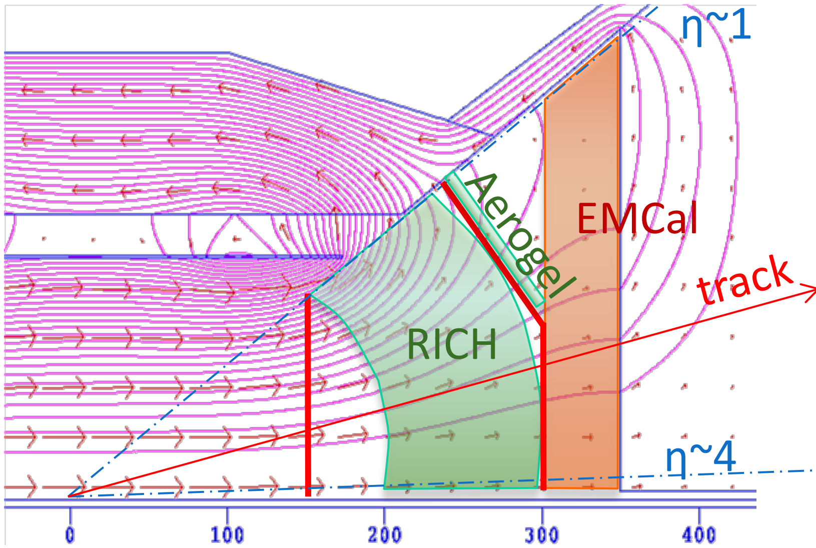
- Hadron ID for p>10GeV/c require gas Cherenkov
  - CF_4 gas used, similar to LHC_b RICH
- Beautiful optics using spherical mirrors
- Photon detection using CsI–coated GEM in hadron blind mode
  - thin and magnetic field resistant
- Active R&D:
  - Generic EIC R&D program
  - recent beam tests by the stony brook group



Courtesy : EIC RD6 TRACKING & PID CONSORTIUM

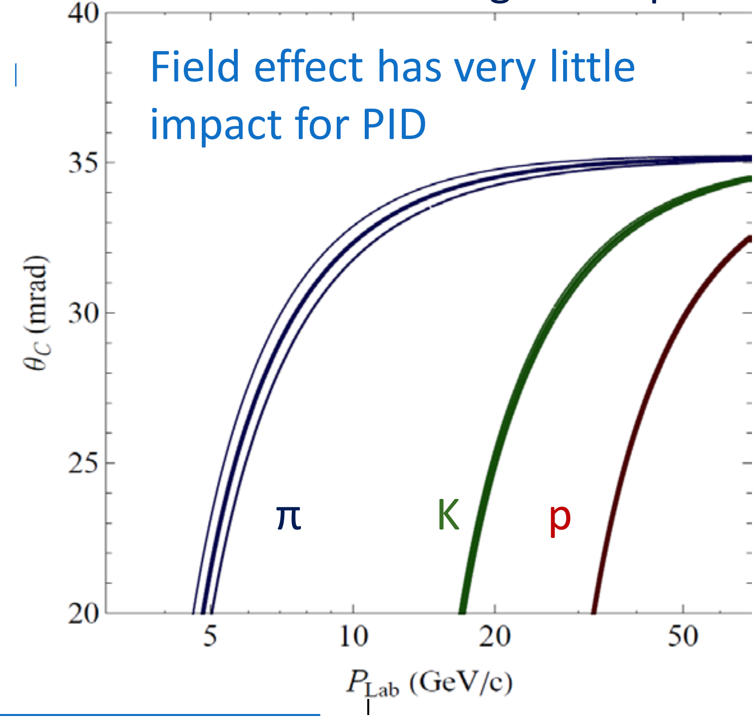


Gas RICH - performance

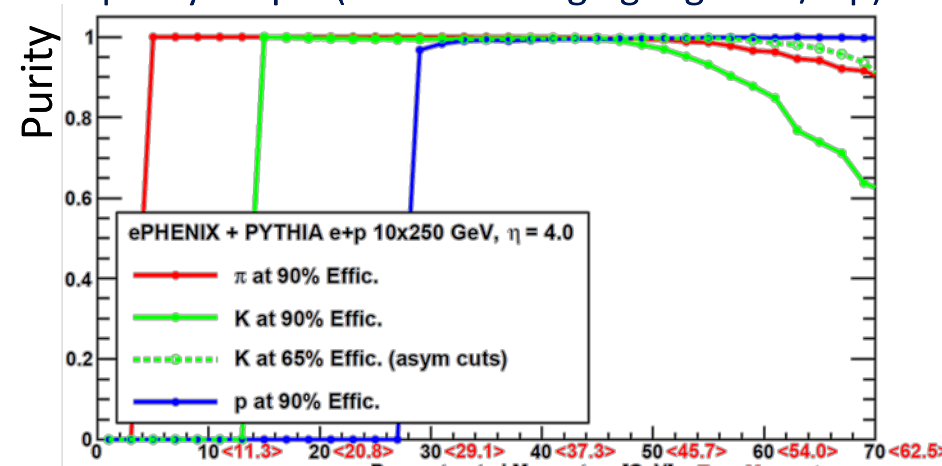


- Strong fringe field unavoidable
  Tuned yoke → magnetic field line most along track within the RICH volume
  → very minor ring smearing due to track bending
- Reached good hadron ID to high energy

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

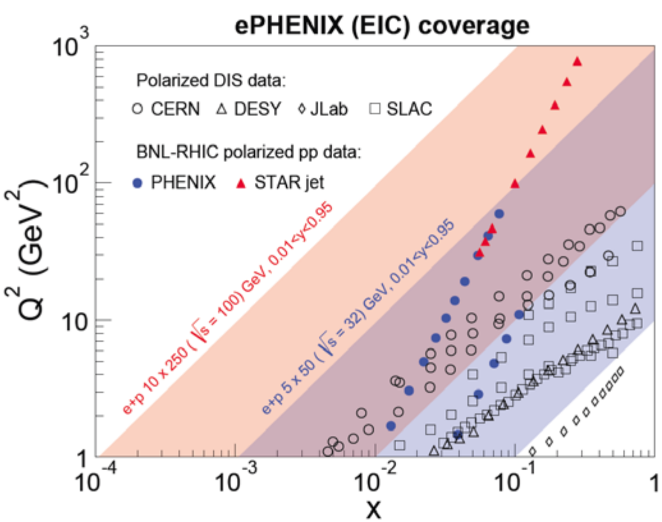


PID purity at η=4 (most challenging region w/ δp)

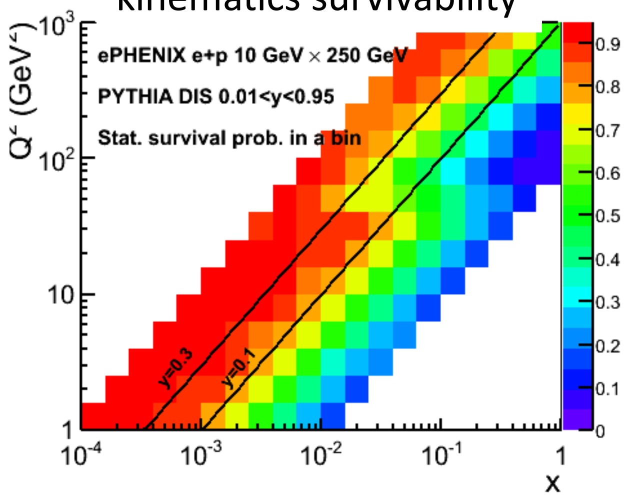


Physics performance: longitudinal and transverse structure of proton

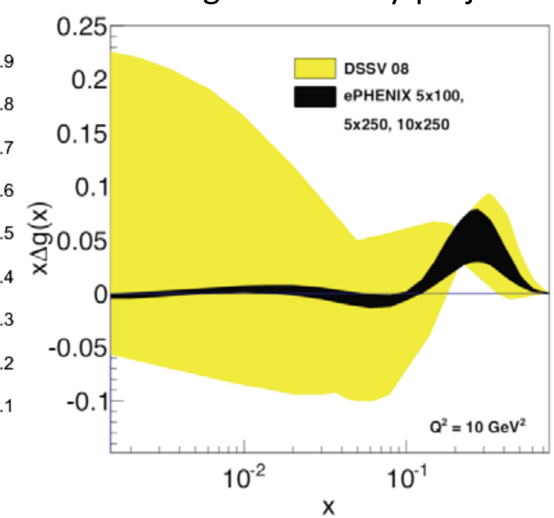
- This detector will significant expand the x-Q^2 reach for longitudinal spin measurements
- EM calorimeter and tracking deliver good kinematic determination and particle ID
- Precise evaluation of gluon and sea quark spin



ePHENIX electron kinematics survivability



ePHENIX gluon helicity projection

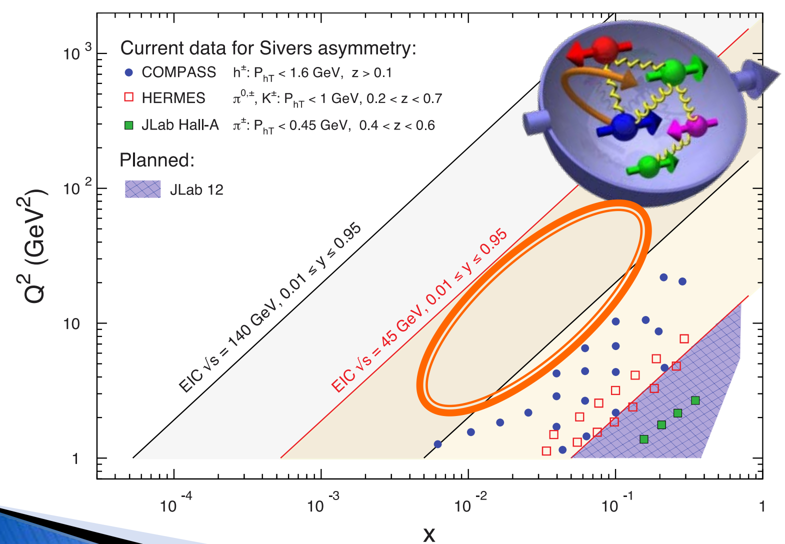


High x and Q2 region will be better determined using info from hadron final states

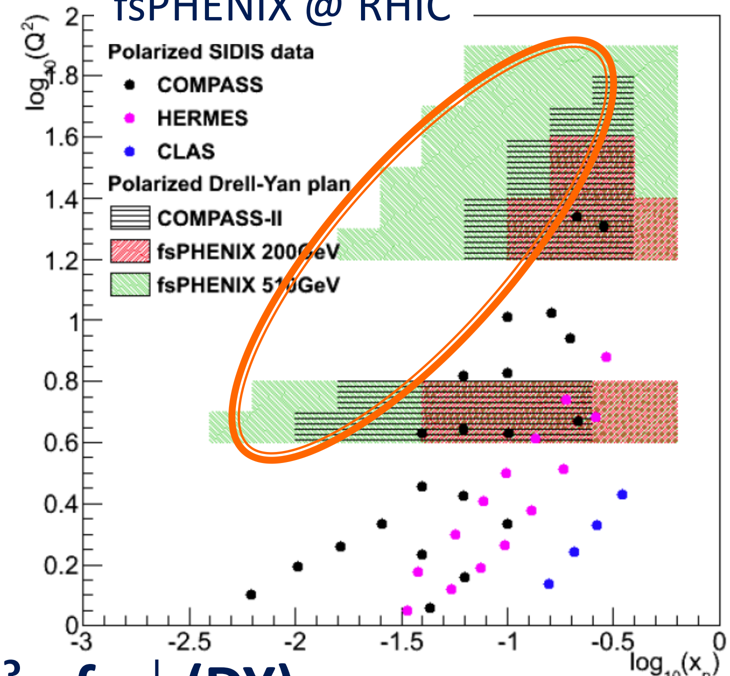
Physics performance: Transverse structure of nucleon

- 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



fsPHENIX @ RHIC

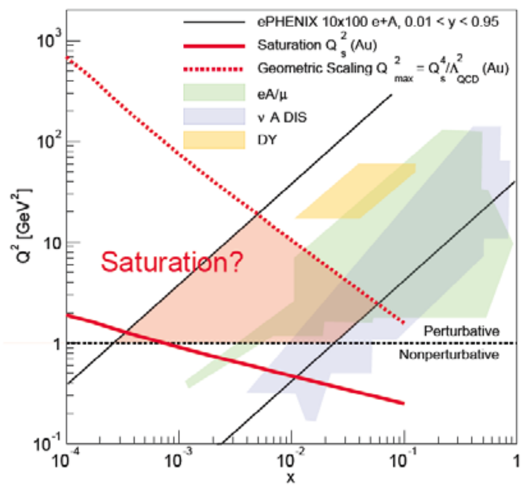


$f_{1T}^{\perp}$ (SIDIS) =? − $f_{1T}^{\perp}$ (DY)

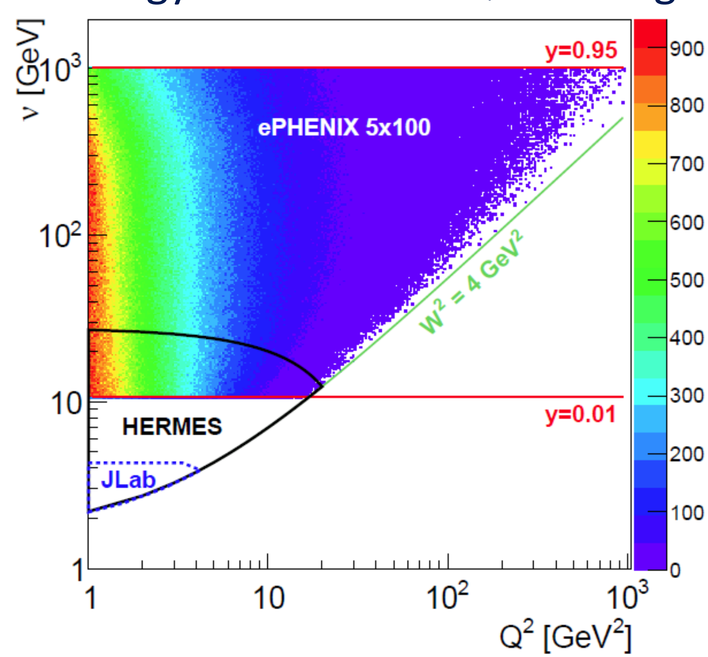
Physics performance: nucleus as a laboratory for QCD

- 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.

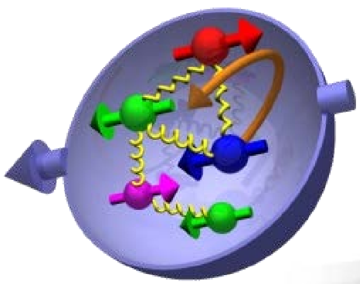
Probing saturation region in electron kinematics

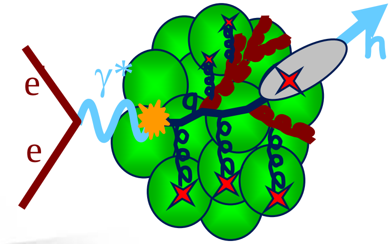


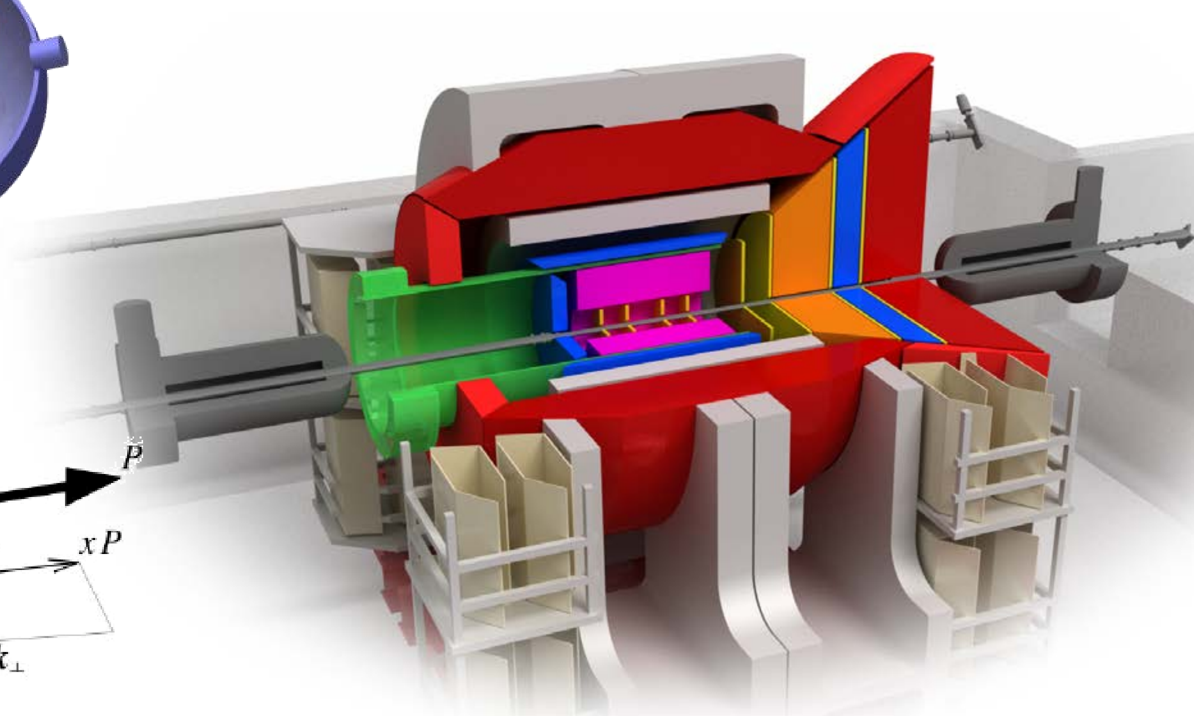
Energy transfer ν VS Q2 coverage

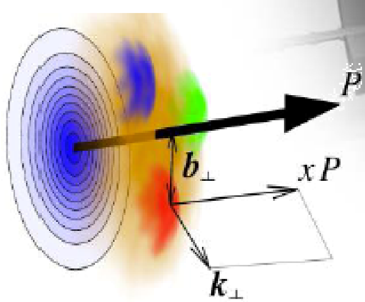


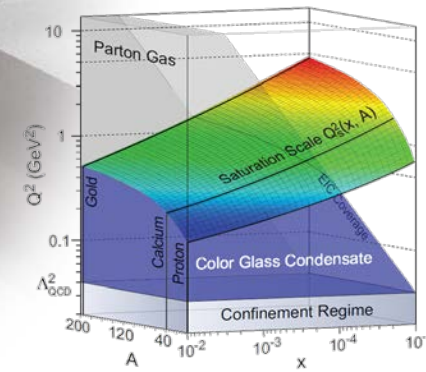
Summary











- An upgrade path that harvests **pp, pA and AA** physics and leads to an EIC era
- 2020-2025, fsPHENIX: unlocking for origin of single spin asymmetry
- 2025+ EIC detector: A comprehensive day-one eRHIC detector for studying nucleon structure and dense nuclear matter