EIC Physics and ‘ePHENIX’

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Inaugural 'SPhenix/New RHIC Detector' Collaboration meeting

Rutgers University

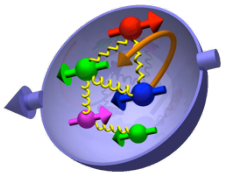
Outline

- EIC Physics Highlights
- Detector Concept
- Detector Performance
- From 10 GeV to 20 GeV electron beam

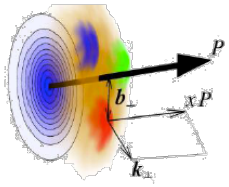
EIC Physics

Well developed and summarized in:
- INT EIC report: arXiv:1108.1713
- EIC White Paper: arXiv:1212.1701
- eRHIC Design Study: arXiv:1409.1633

Distribution of quarks and gluons and their spins in space and momentum inside the nucleon

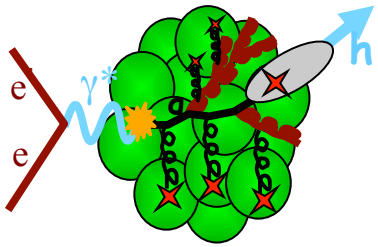


- Nucleon helicity structure
- Parton transverse motion in the nucleon
- Spatial distribution of partons and parton orbital angular momentum



QCD in nuclei

- Gluon saturation
- Nuclear modification of parton distributions
- Propagation/Hadronization in nuclear matter

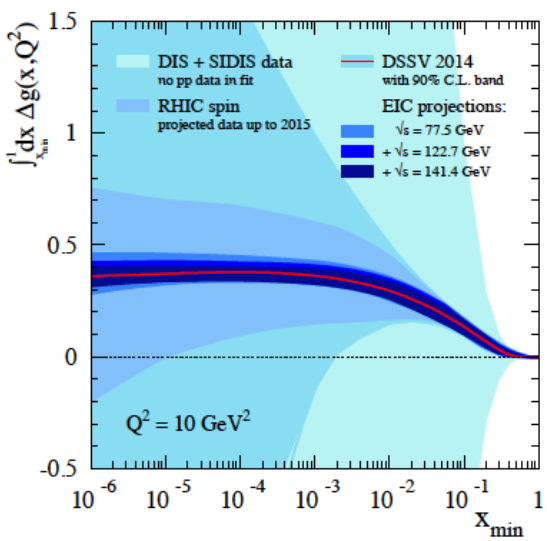


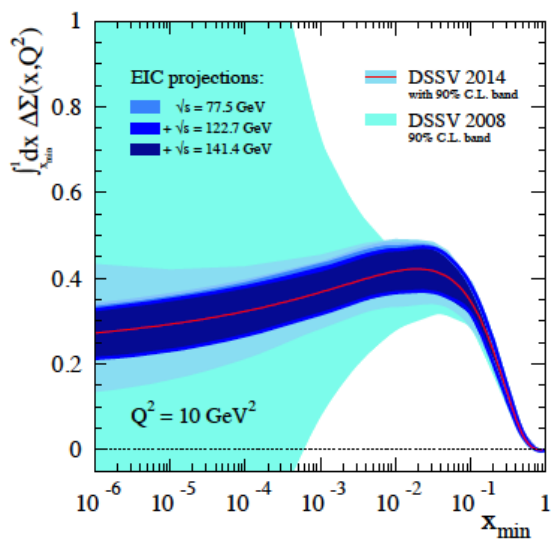
Nucleon Helicity Structure

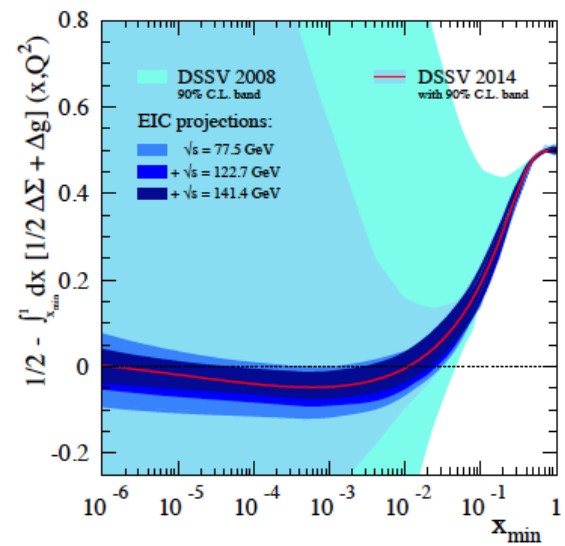
Inclusive DIS
Semi-Inclusive DIS

$$\frac{1}{2} = \frac{1}{2}\sum_q \left[\Delta q + \Delta \bar{q}\right] + \Delta g + L$$

arXiv: 1509.06489





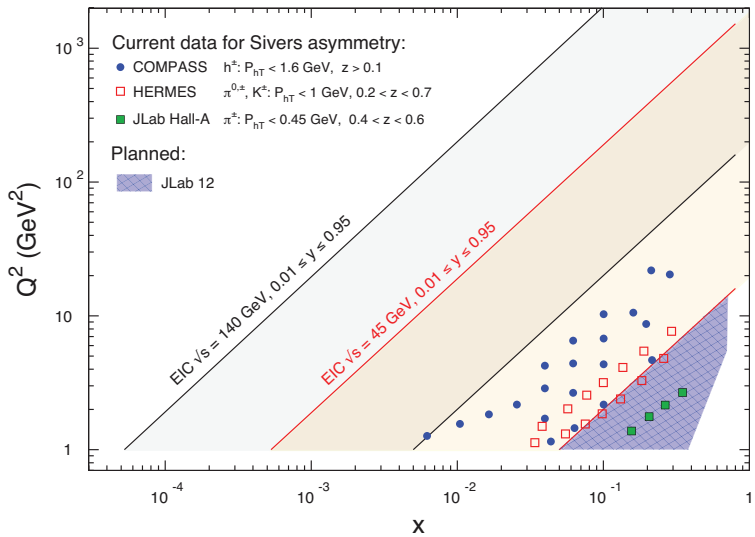


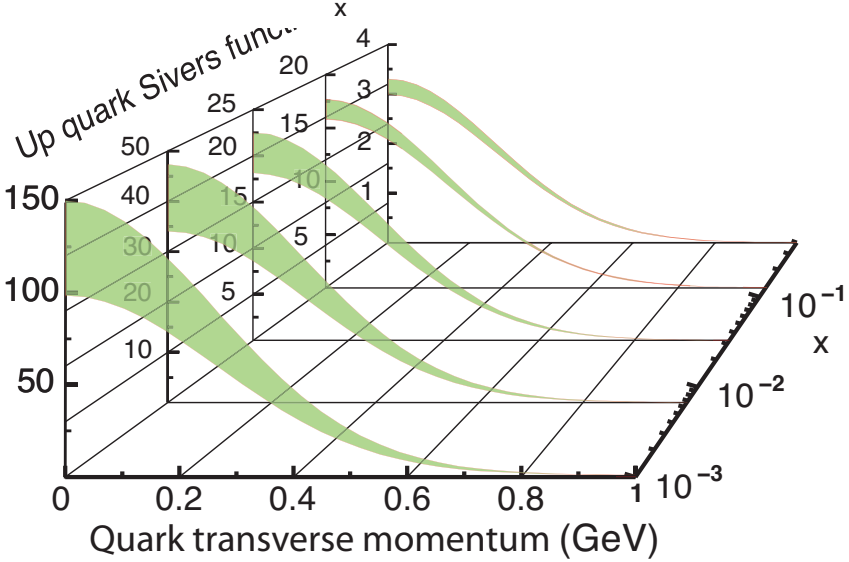
1/2 - Gluon - Quarks = Orbital angular momentum

Spin puzzle will be solved

Parton transverse motion in the nucleon

Semi-Inclusive DIS



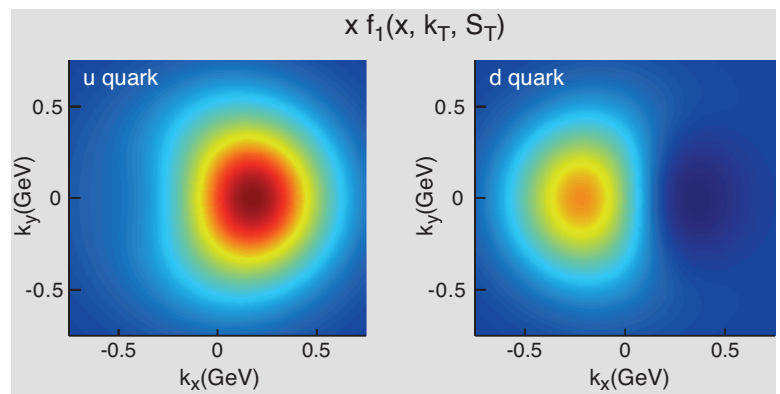


Transverse Momentum Dependent PDF

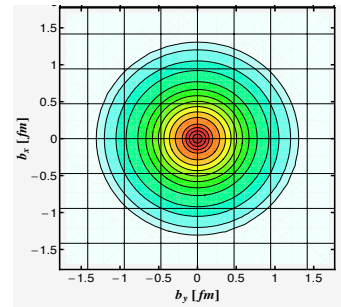
Sivers: links parton's intrinsic motion to the spin of the proton => connection to the parton orbital motion

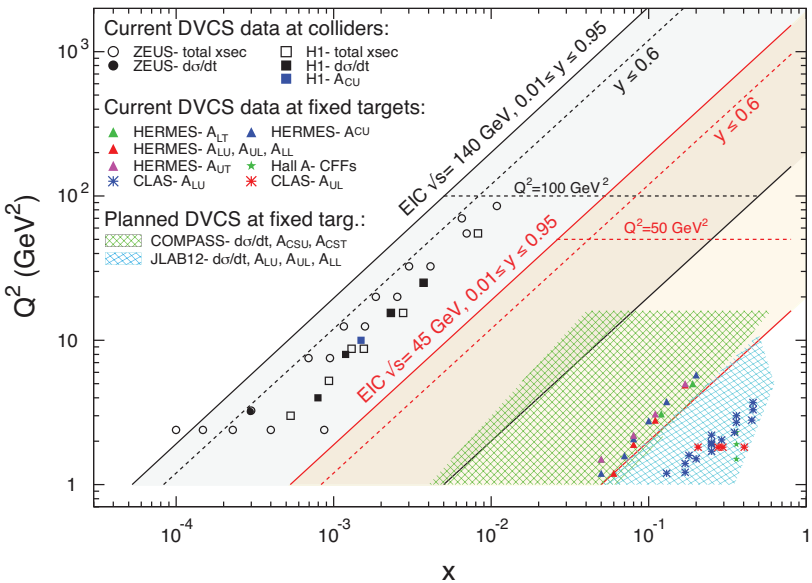
Greatly expand x&Q^2 coverage

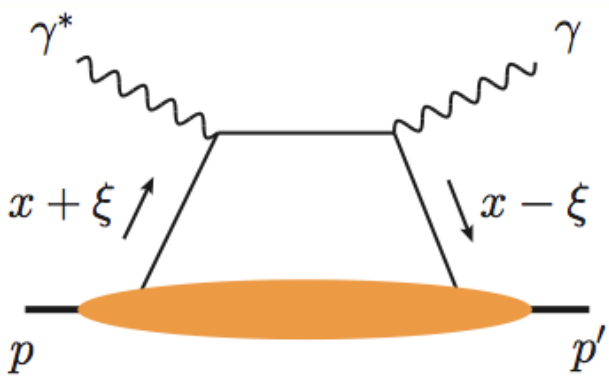
High luminosity => fully differential analysis over x, Q^2, z and P_{hT}



Parton spatial distribution: nucleon tomography







Exclusive DIS

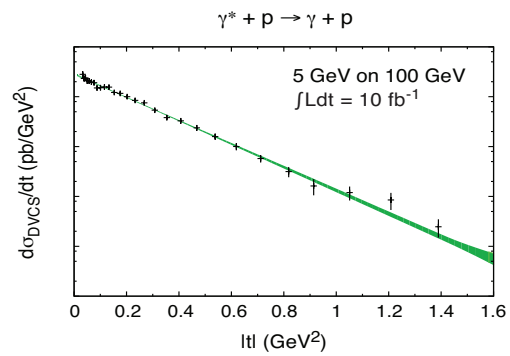
Generalized Parton Distributions (GPD)

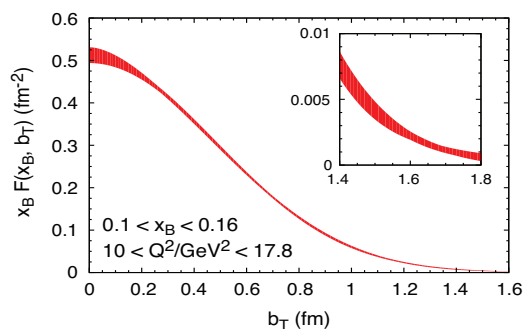
Connected to parton orbital angular momentum

Existing data are either at low Q^2 or have sizable stat. uncertainties

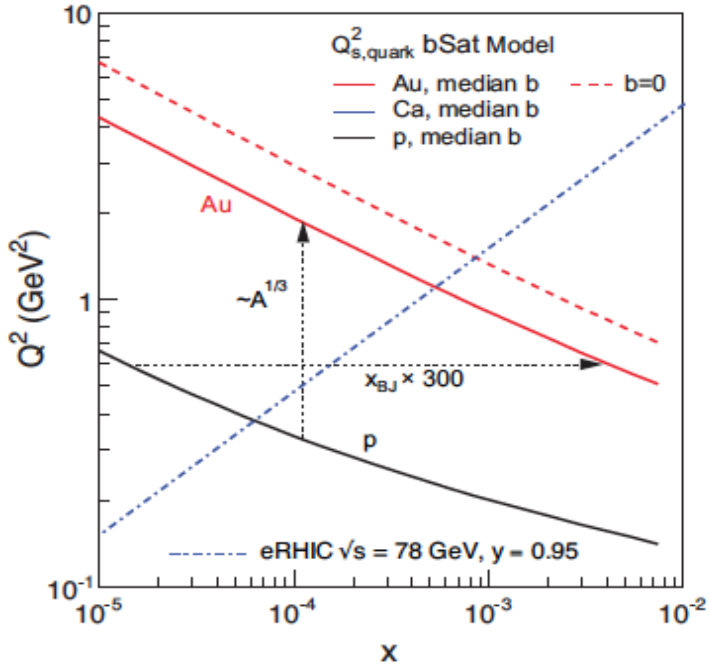
Provide data in wide x&Q^2

Precise imaging requires higher e-beam energy and luminosity





Gluon Saturation



$$Q_s^2(x) \propto \left(\frac{A}{x}\right)^{1/3}$$

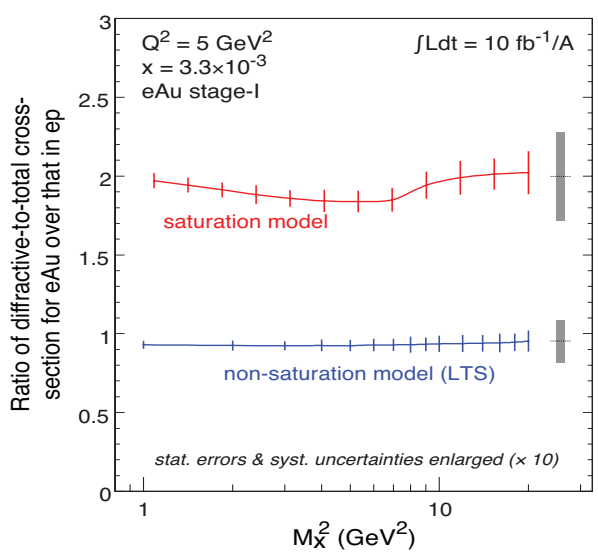
Color Glass Condensate (CGC)

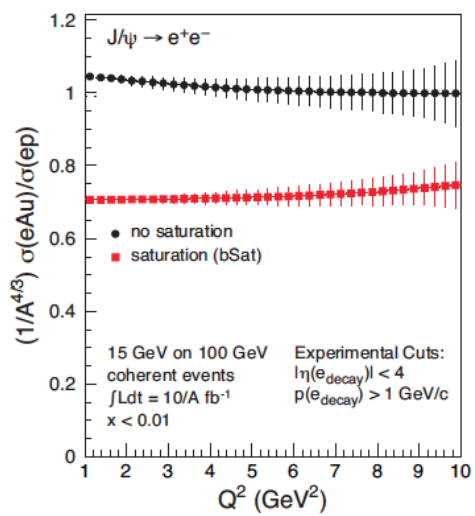
- High gluon density matter
- Direct consequence of gluon self-interaction in QCD

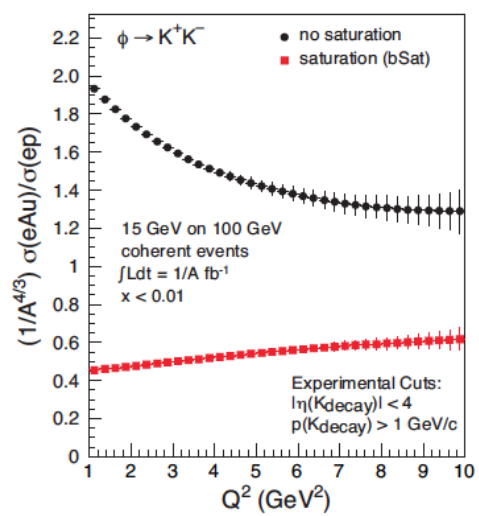
Saturation effects are greatly enhanced in eA collisions:

- Collider energy -> low x
- Heavy Ions -> high A

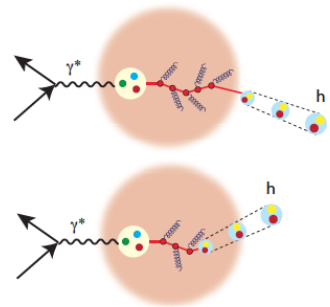
Diffractive: $\sigma_{diff} \sim (xG)^2$

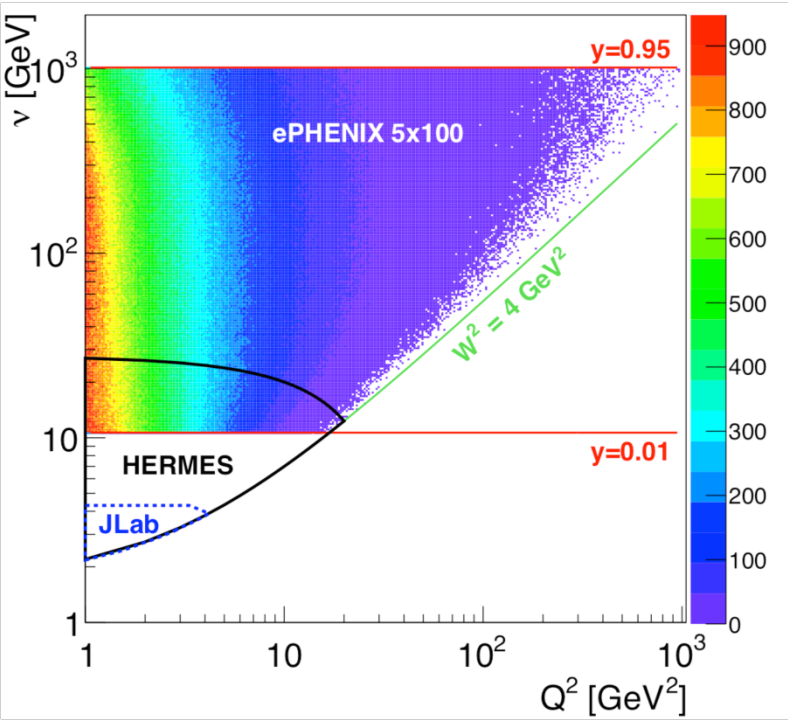






Color Propagation and Hadronization





Semi-inclusive eA

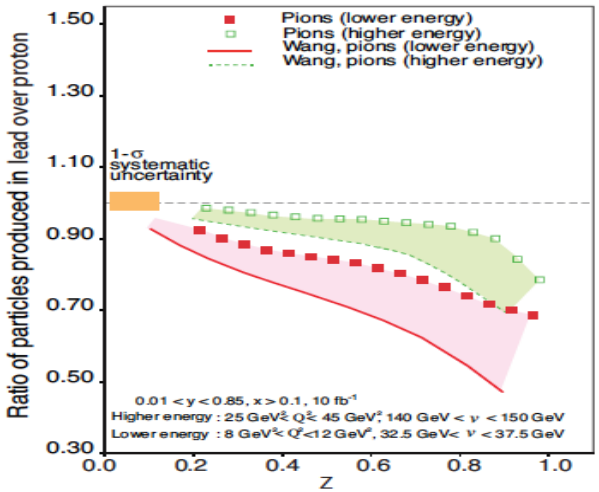
Probe color neutralization and hadronization

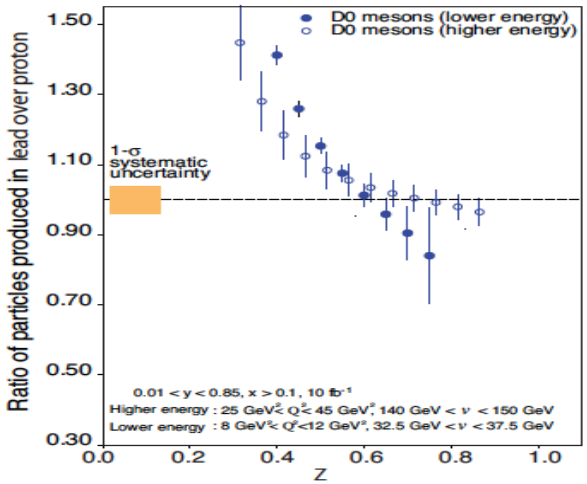
- Different time&distance probed by varying nuclear size and parton energy

Previous experiments are limited by low ν, Q^2

eRHIC:

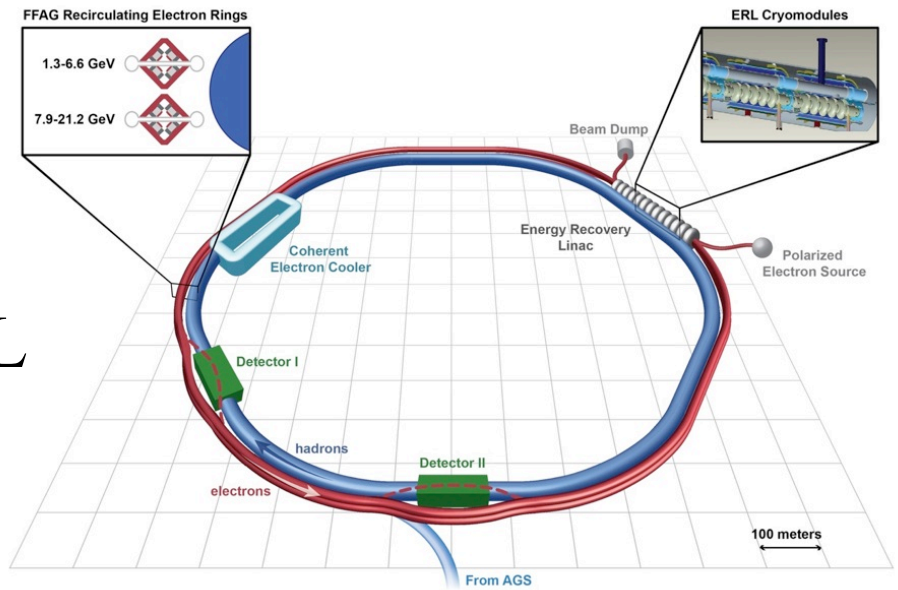
- Much larger range of ν, Q^2
- Wide range of nuclear size
- Excellent ePHENIX hadron PID up to 60 GeV



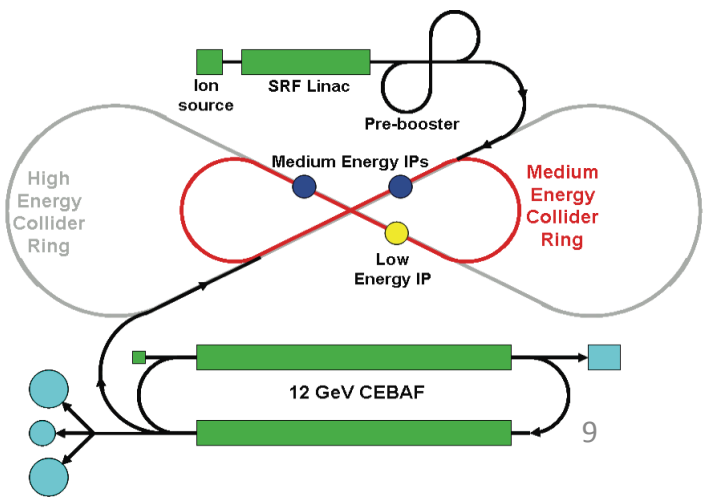


EIC: ep/eA

BNL



JLab

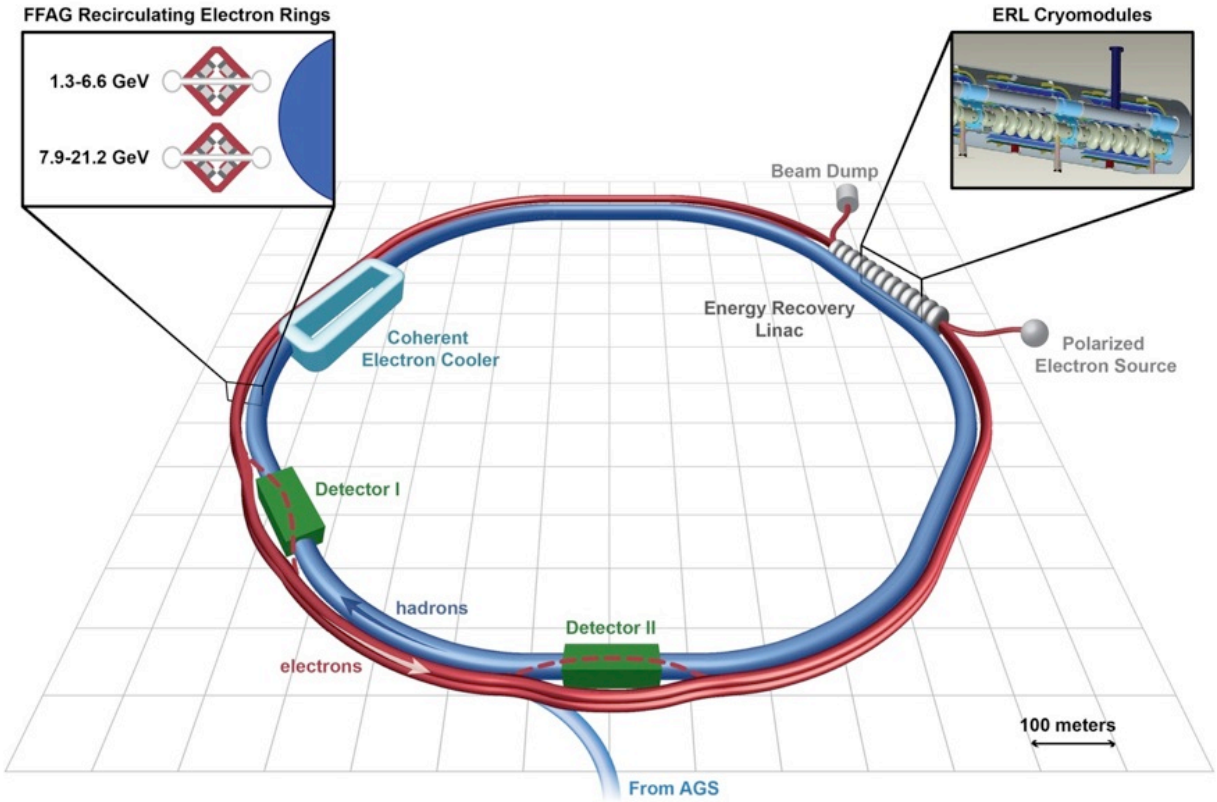


2015 Long Range Plan

We recommend a high-energy high-luminosity polarized **Electron Ion Collider** as the highest priority for new facility construction following the completion of FRIB.

eRHIC

ep/eA



In current design:

Energy:

Electron: 6.6–21.2 GeV
Proton: 25–250 GeV
Ions: 10–100 GeV
√s: up to 145 GeV

Polarization:

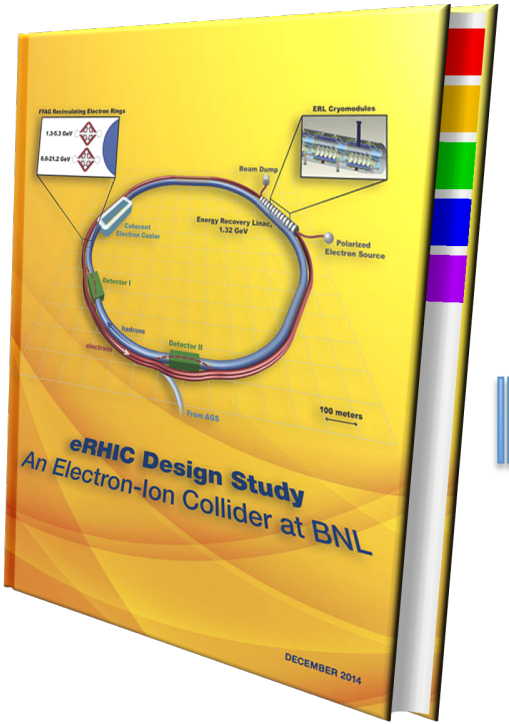
Electrons: 80%
Protons and He3: 70%

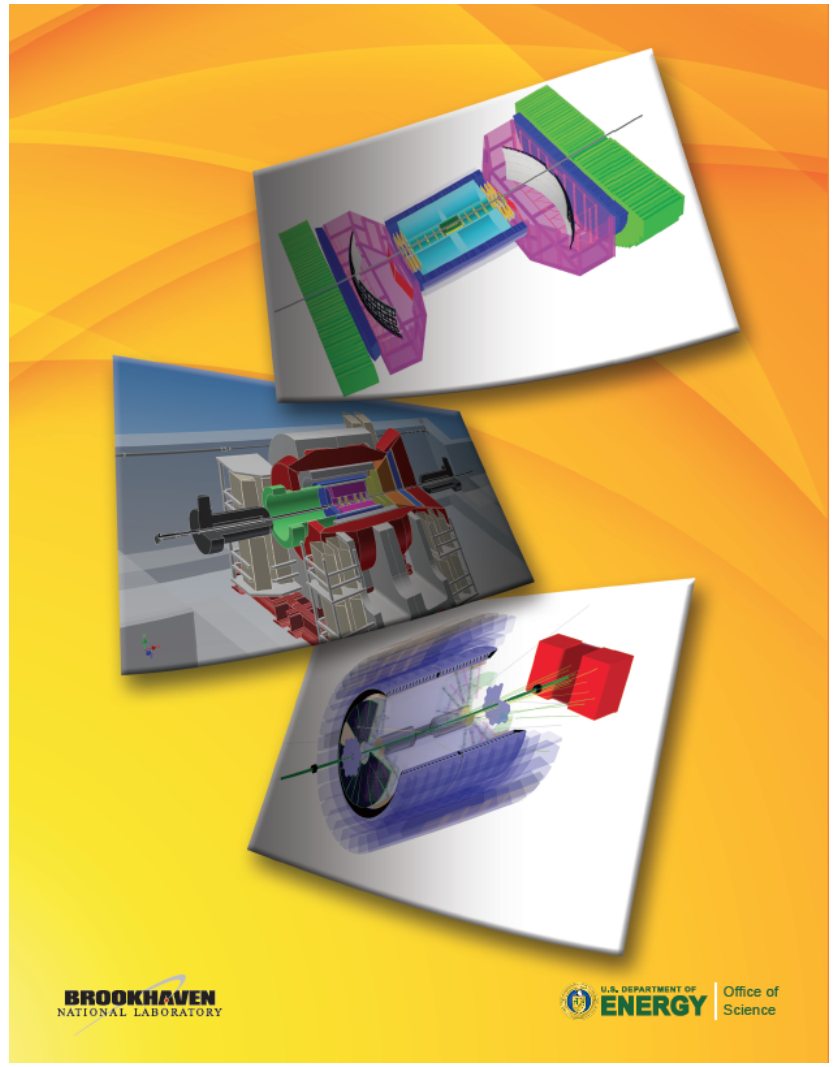
Luminocity:

$>10^{33}$ cm^{-2} s^{-1}

… Still evolving

eRHIC Detector Considerations



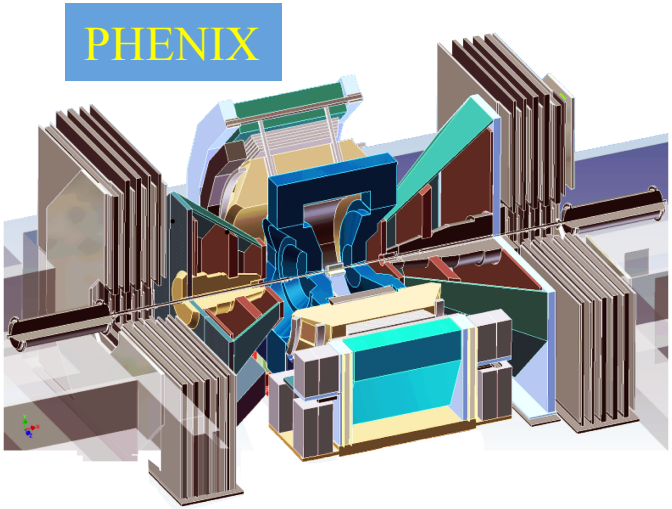


BeAST
(Dedicated Detector)

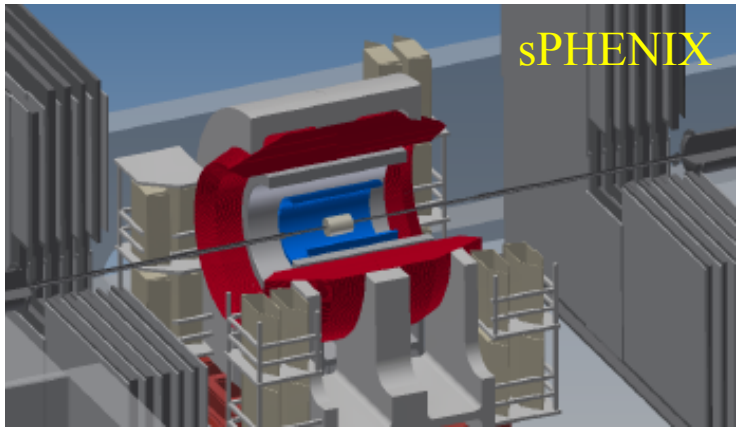
ePHENIX

eSTAR

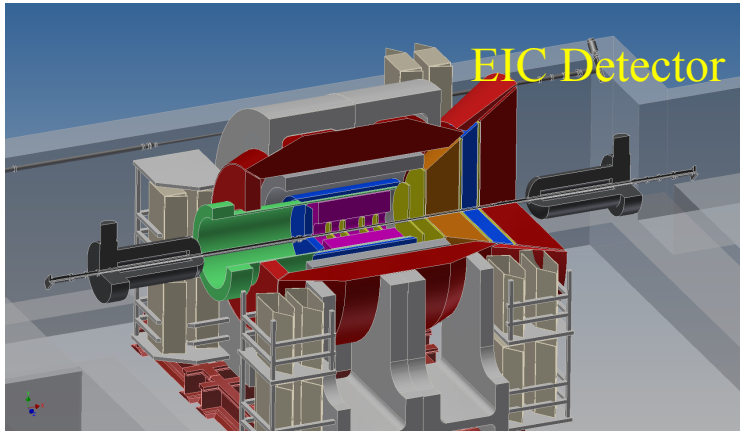
PHENIX -> EIC Detector Path



~2021-22



By ~2025

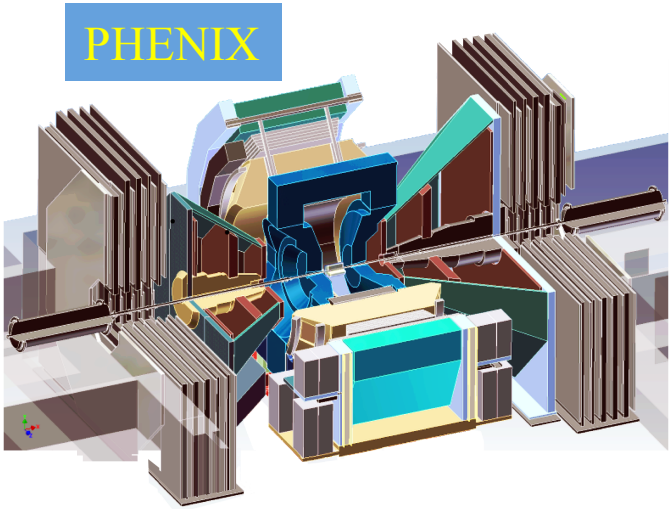


ePHENIX LoI: arXiv:1402.1209

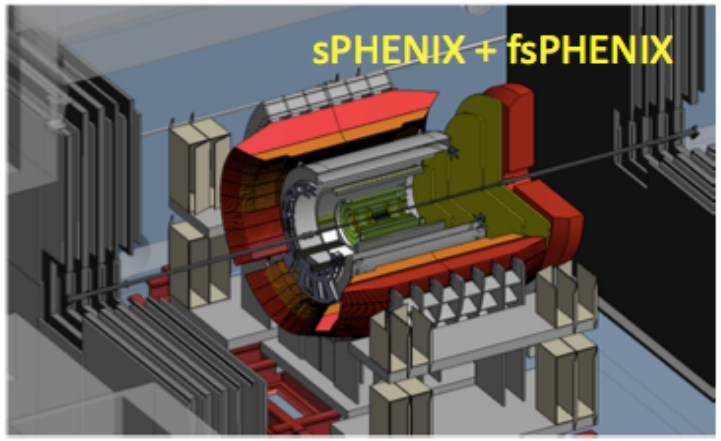
Evolve sPHENIX (pp and HI detector) to EIC Detector (ep and eA detector)

- To utilize e and p (A) beams at eRHIC with *e*-energy up to 10 GeV and *p*(*A*)-energy up to 250 GeV (100 GeV/n)
- *e*, *p*, *He*3 polarized
- Stage-1 luminosity ~10^{33} cm^{-2} s^{-1} (~1fb^{-1} /month)

PHENIX -> EIC Detector Path



~2021-22



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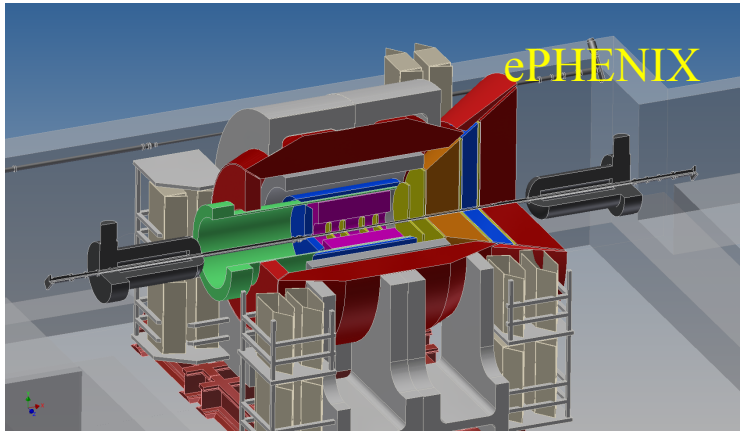

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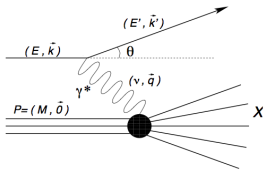
Detector Concept

Inclusive DIS and scattered electron measurements

With focus in e-going direction and barrel

High resolution EMCal and tracking; minimal material budget

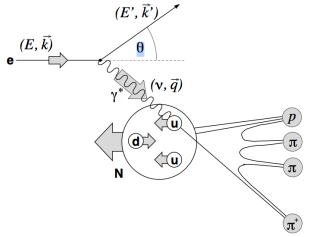


Semi-inclusive DIS and hadron ID

With focus in h-going direction and barrel

Barrel: DIRC for p_h<4 GeV/c

h-going direction: aerogel for lower p_h and gas RICH for higher p_h

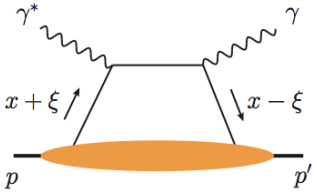


Exclusive DIS (DVCS etc.)

EMCal and tracking coverage in -4<η<4

High granularity EMCal in e-going direction

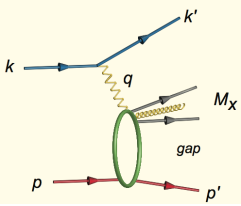
Roman Pots in h-going direction



Diffractive

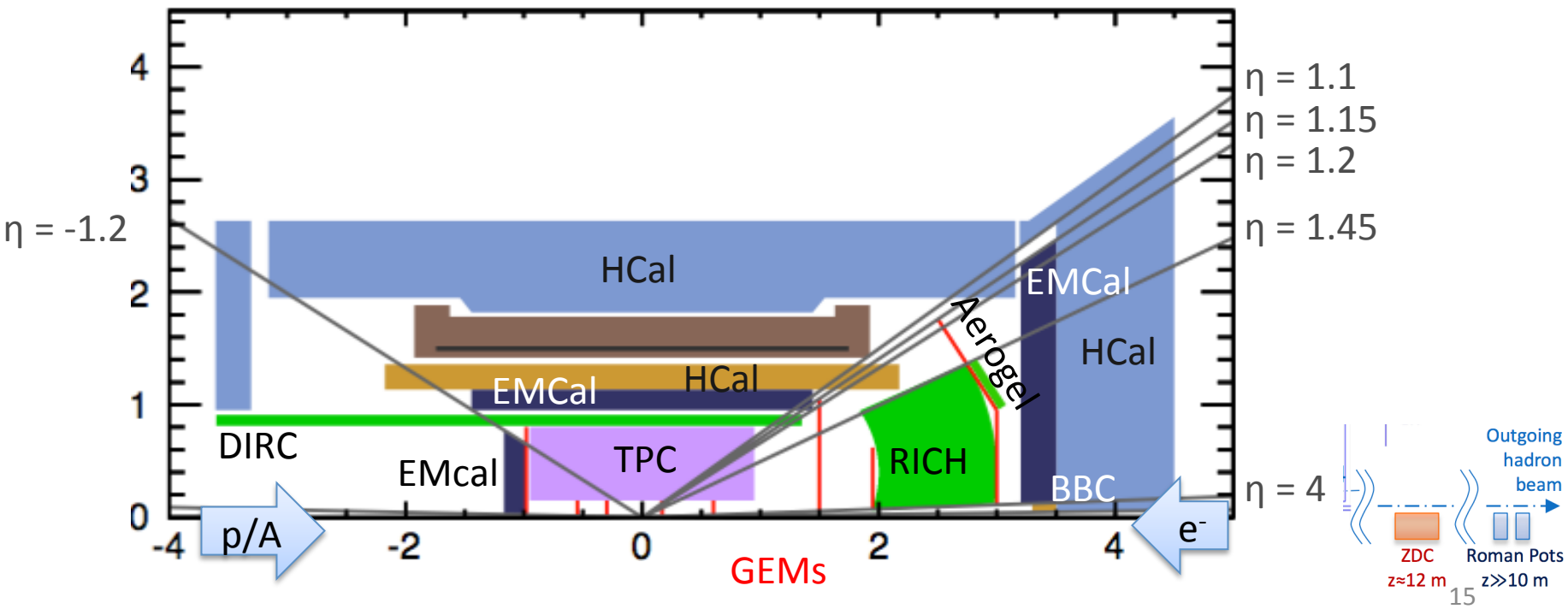
Rapidity gap measurements: HCal in -1<η<5; EMCal in -4<η<4

ZDC in h-going direction



Detector Concept

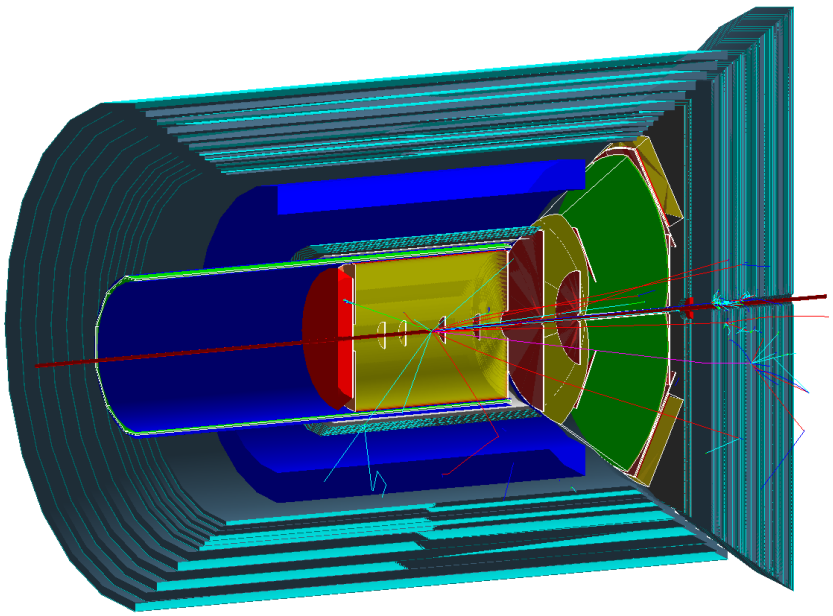
- -4<η<-1 (e-going):
  - Crystal calorimeter with high energy and position resolution
  - GEM Trackers
- -1<η<1 (barrel):
  - Add Compact-TPC and DIRC
- 1<η<4 (h-going):
  - HCal & EMCal (1<η<5)
  - GEM Trackers
  - Aerogel RICH (1<η<2)
  - Gas RICH
- Far Forward (h-going)
  - ZDC and Roman Pots



Detector performance evaluation

Generators:

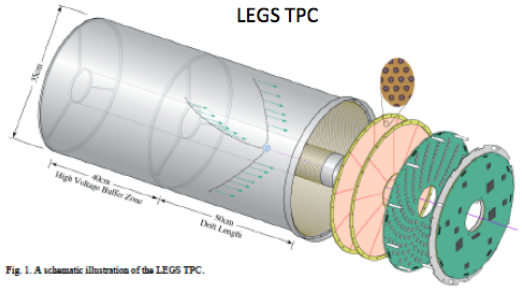
PYTHIA, MILOU (for DVCS), RAPGAP (diffractive), RADGEN (rad. effects)
Thanks to BNL EIC group for maintaining them at racf



GEANT4 description of ePHENIX

Simulation and analysis software common with sPHENIX and PHENIX

Magnetic Field and Tracking



Superconducting Solenoid: 1.5 T

Trackers (-3<η<4):

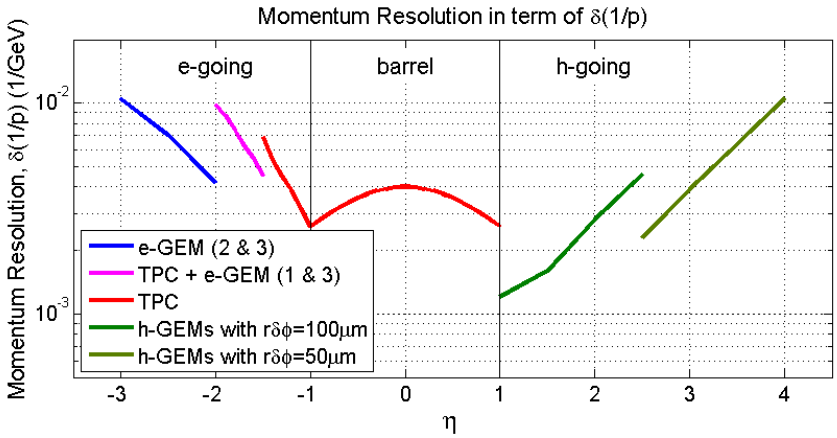
- TPC in barrel
- GEMs in forward and backward

Good resolution over full acceptance

e-going: electron ID (E/p)

Barrel: low mom. measurements (<10 GeV/c)

h-going: needed for PID

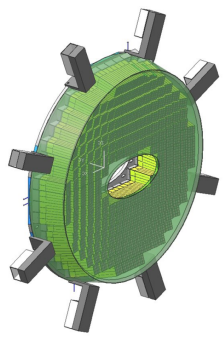


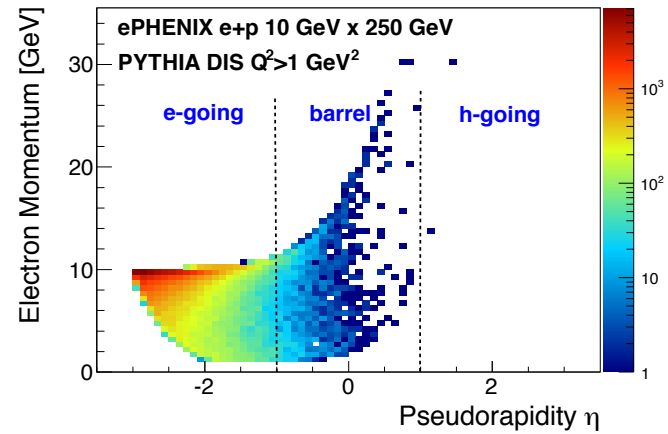
EM Calorimetry

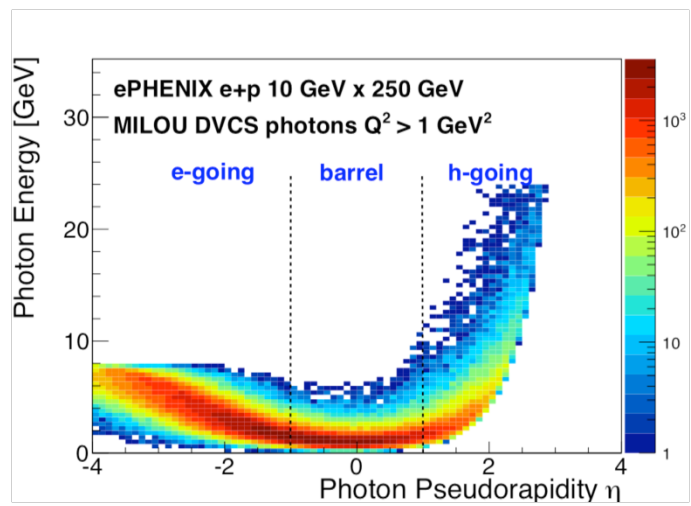
$-4<\eta<4$

Endcap EMCal:	Barrel EMCal:	Forward EMCal:
$\sigma_E/E \sim 1.5\%/\sqrt{E}$	$\sigma_E/E \sim 12\%/\sqrt{E}$	$\sigma_E/E \sim 12\%/\sqrt{E}$
$\sigma_X < 3mm/\sqrt{E}$	sPHENIX EMCal	Pb-fiber
$PbWO_4$ crystal	Tungsten-fiber	
Similar to PANDA endcap design		

TDR for PANDA
arXiv:0810.1216







- Scattered electron measurements
  High resolutions in e-going direction required
- Vector meson and photon measurements
  Wide coverage required

Hadron Calorimetry

$-1<\eta<5$

Barrel HCal:

$\sigma_E/E \sim 100\%/\sqrt{E}$

Steel & Scintillator

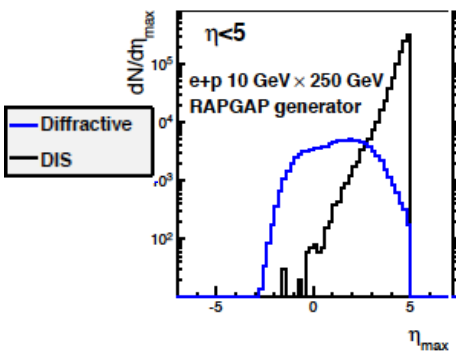
sPHENIX EMCal

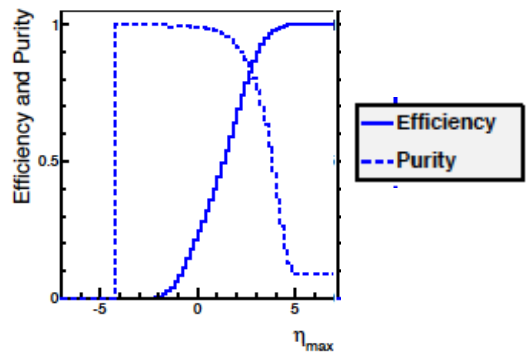
Forward HCal:

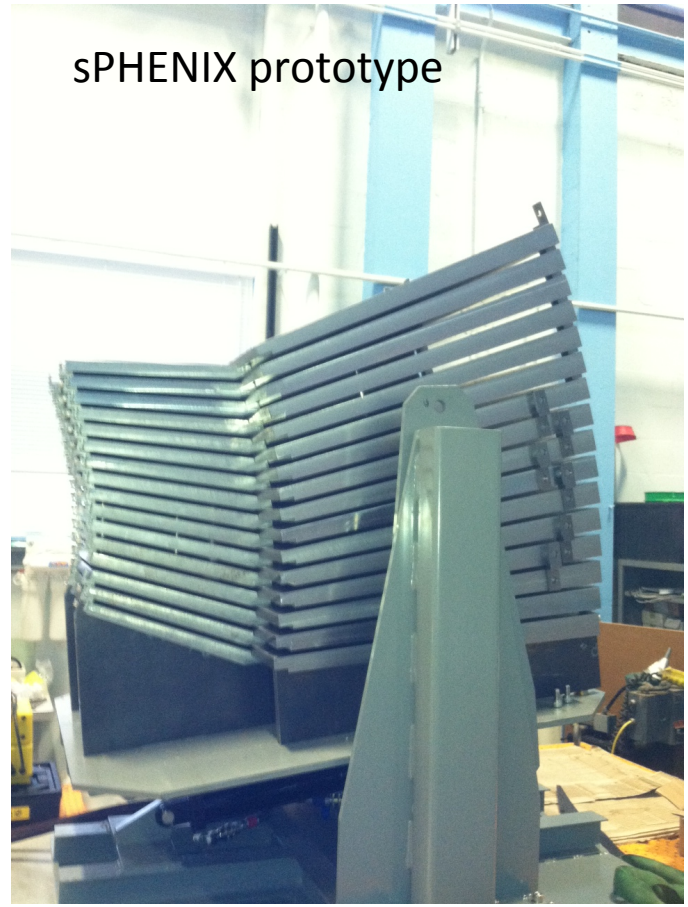
$\sigma_E/E \sim 100\%/\sqrt{E}$

Steel & Scintillator

Same as barrel



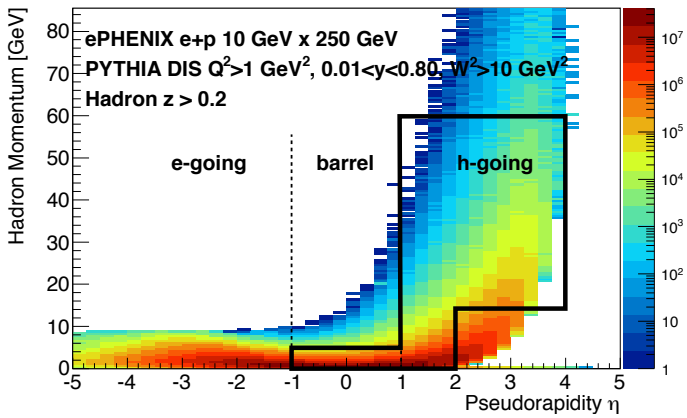




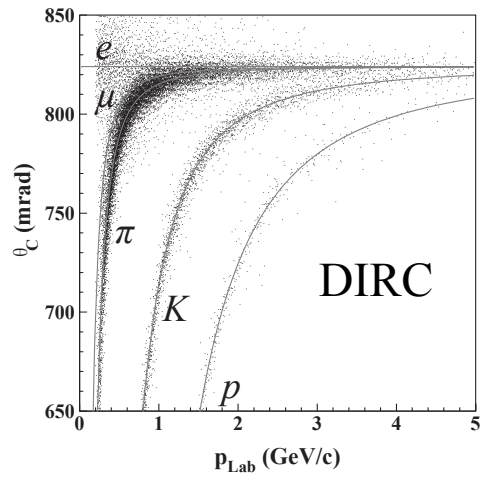
- Rapidity Gap for Diffractive
- Assist to PID and high momentum hadron measurements

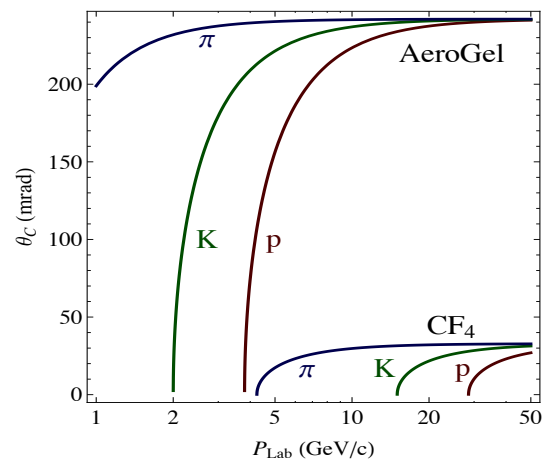
Hadron PID

$-1<\eta<4$



Focus on h-going direction and barrel





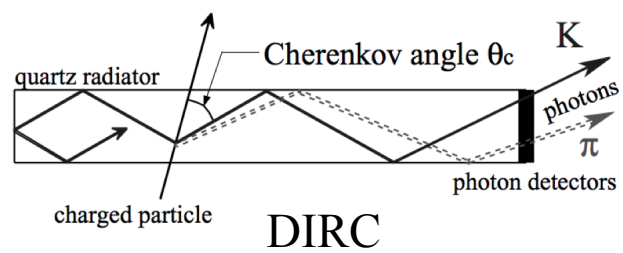
DIRC:
$-1<\eta<1$
PID at <4 GeV/c

Aerogel:
$1<\eta<2$
PID at <15 GeV/c

Gas RICH (CF4):
$1<\eta<4$
PID at <60 GeV/c

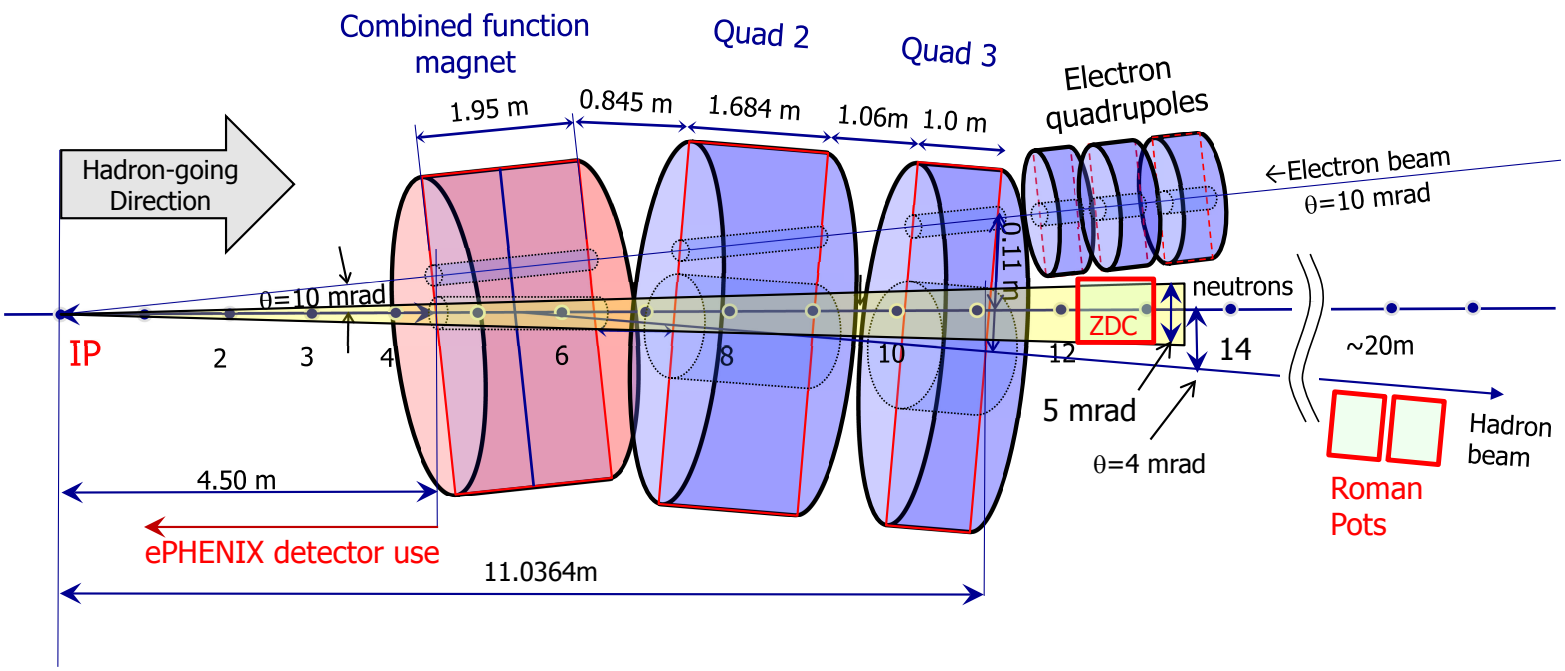
- Quark Helicity, TMDs, Hadronization

  Tightly coupled to high resolution momentum measurements in forward rapidity



Beamline Detectors

Similar to all eRHIC detectors, being designed in parallel with IR design



ZDC

12 m downstream

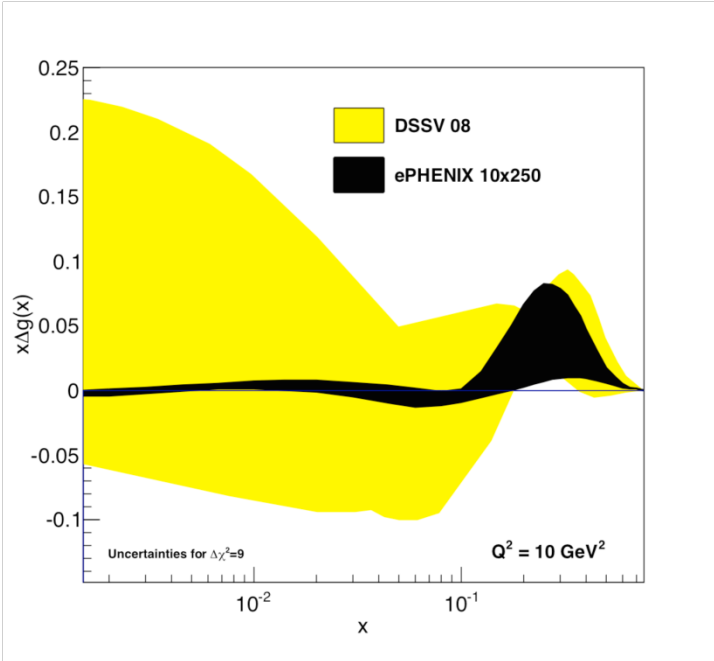
5 mrad cone opening of the IP is available from ePHENIX and IP design

Roman Pots

>20 m downstream

Similar to STAR design

Physics Expectations:
Quick exercises with 'ePHENIX'



Δg(x) from long. pol. ep:

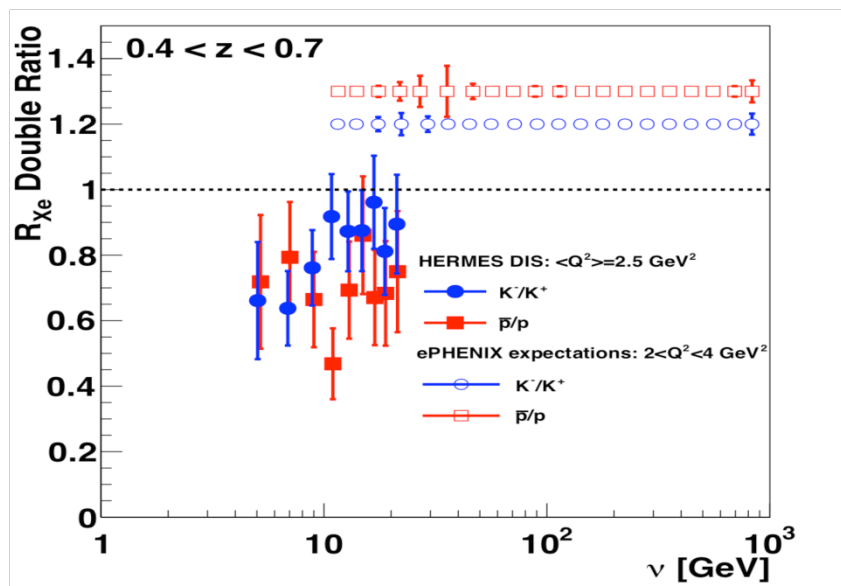
PHYTHIA generator and ePHENIX acceptance/efficiencies

10 fb^{-1} at 10GeV×250GeV

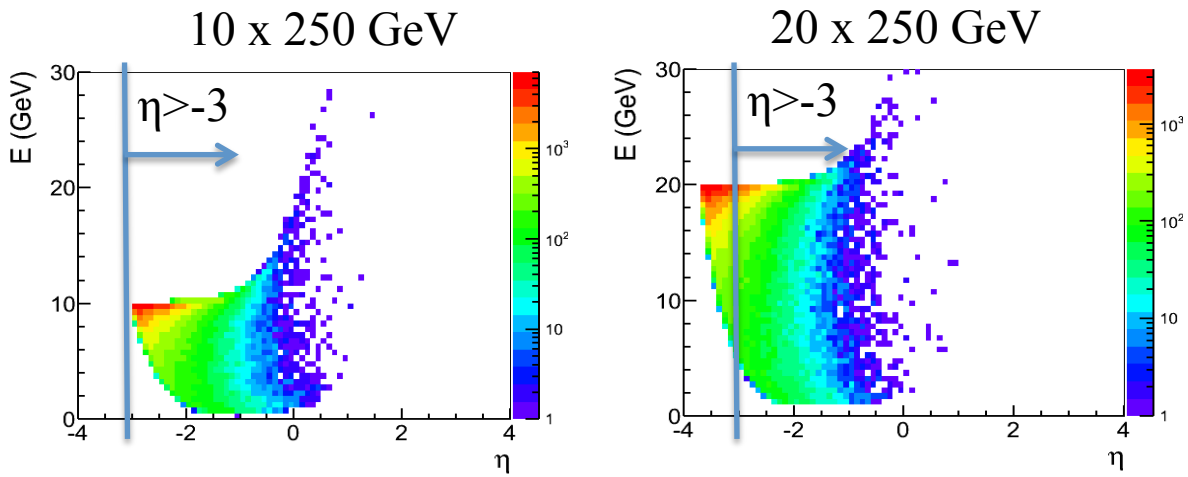
Parton hadronization – modified fragmentation

$2 < Q^2 < 4$ GeV^2

2 fb^{-1} at 5GeV×250GeV

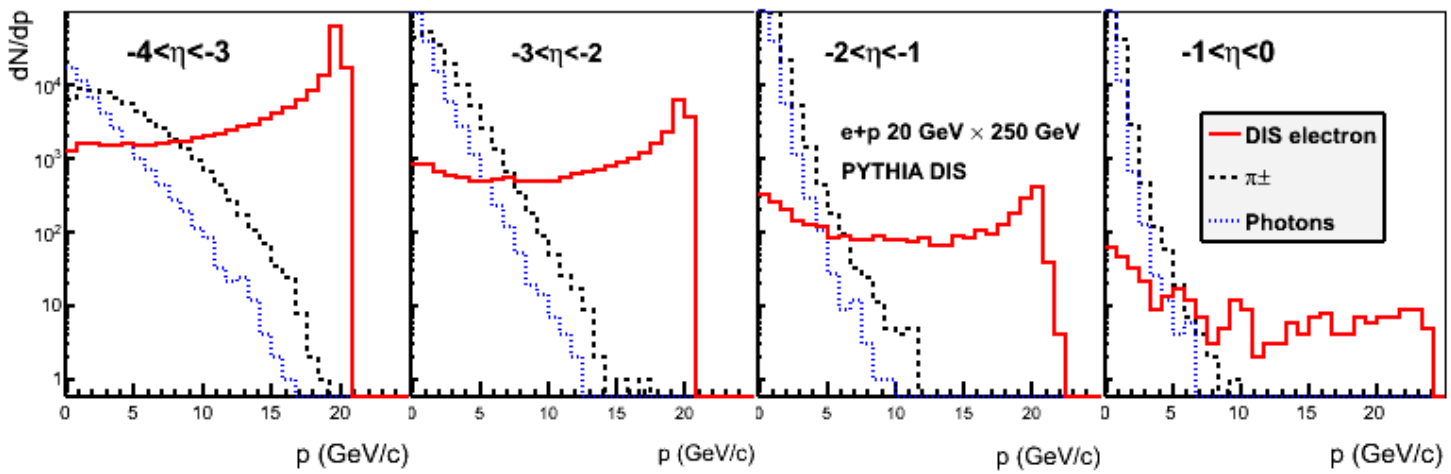


From 10 GeV to 20 GeV e beam



Need eID
down to η= -4

ePHENIX:
No tracking at η< -3



Summary

Backup