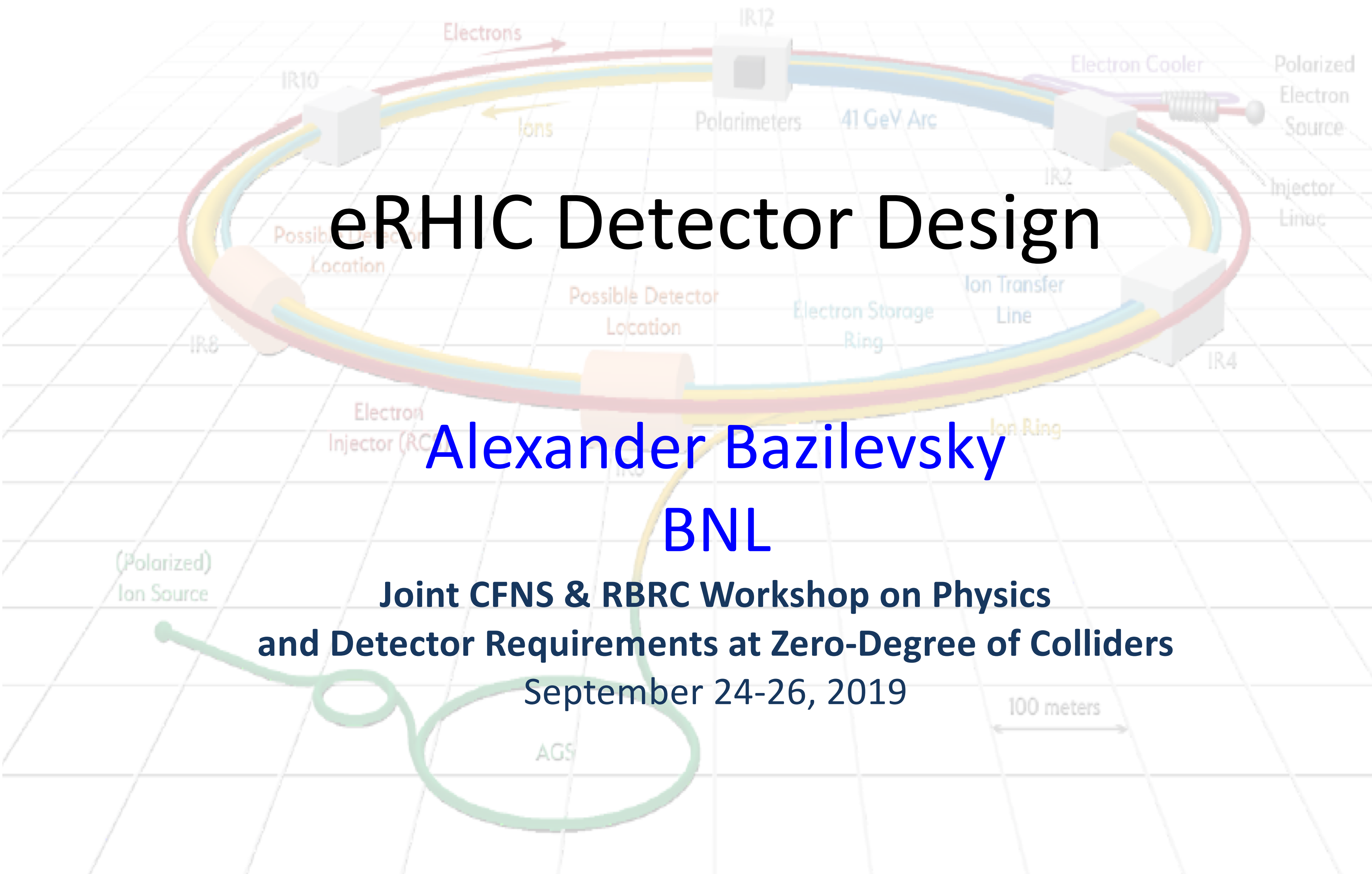


eRHIC Detector Design

Alexander Bazilevsky
BNL

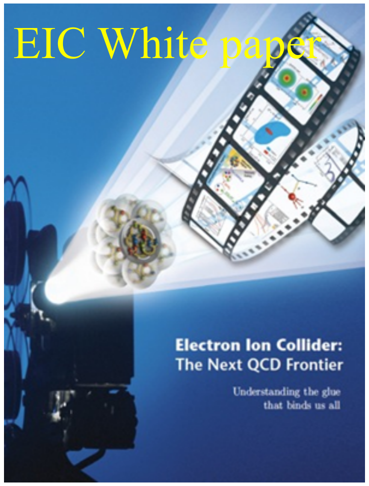
Joint CFNS & RBRC Workshop on Physics and Detector Requirements at Zero-Degree of Colliders

September 24-26, 2019

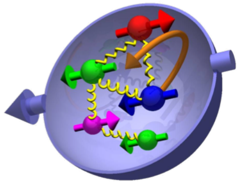
Outline

- EIC Physics Highlights
- Detector Concept
- Detector Performance

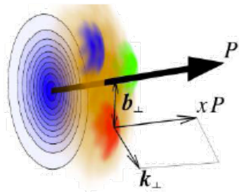
EIC Physics



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

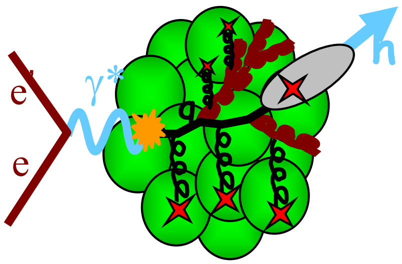


Nucleon helicity structure
Parton transverse motion in the nucleon
Spatial distribution of partons and parton orbital angular momentum



QCD in nuclei

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

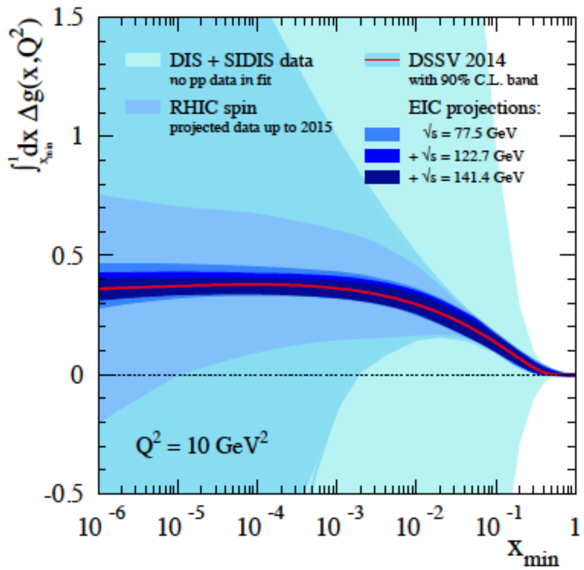


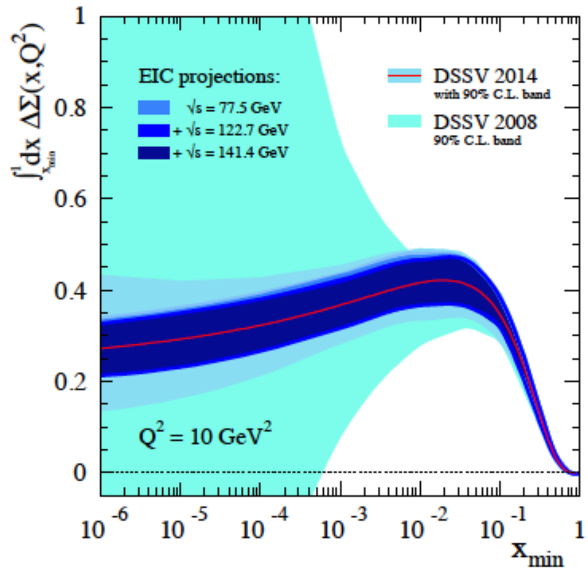
Nucleon Helicity Structure

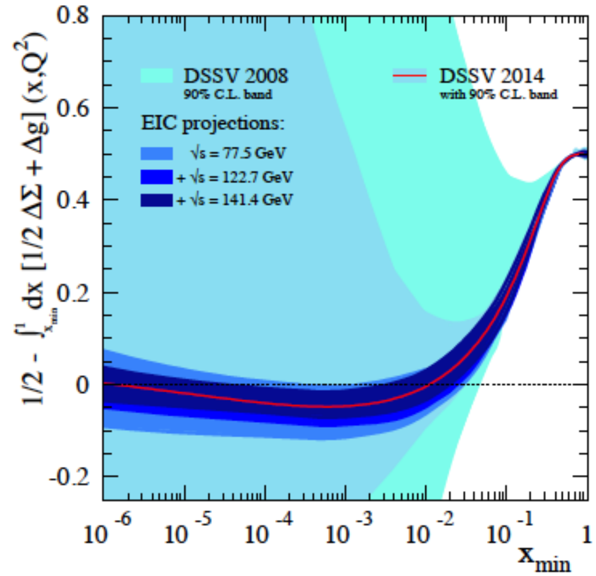
Inclusive DIS
Semi-Inclusive DIS

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

E.Aschenauer et al, PRD92, 094030





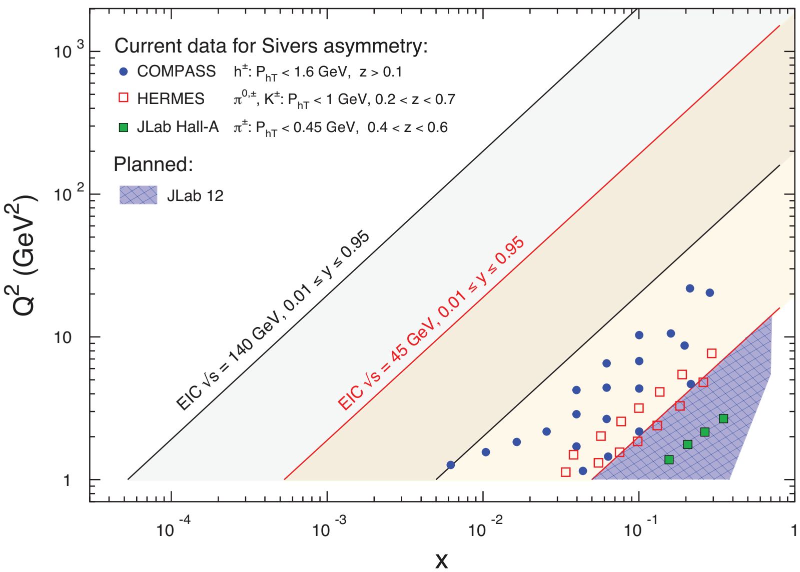


1/2 - Gluon - Quarks = Orbital angular momentum

Spin puzzle will be solved

Parton transverse motion in the nucleon

Semi-Inclusive DIS

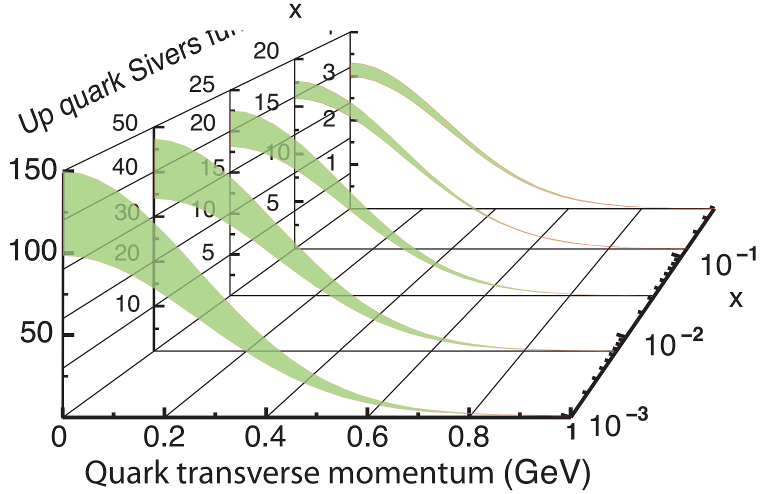


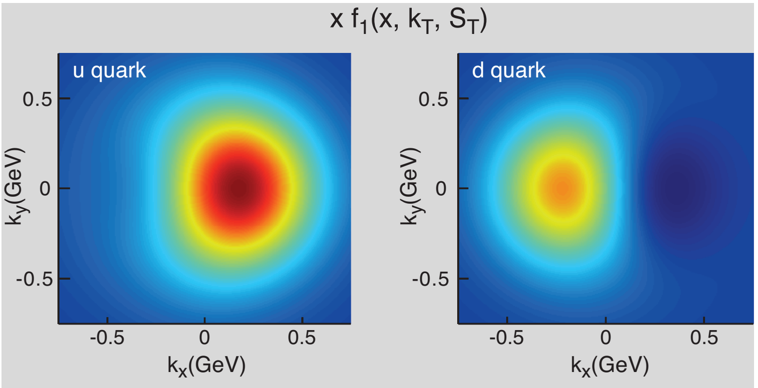
Transverse Momentum Dependent PDF

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

Greatly expand x&Q^2 coverage

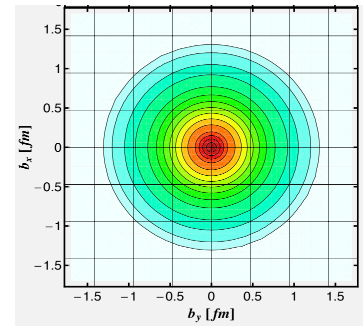
High luminosity => fully differential analysis over x, Q^2, z and P_{hT}





Also for gluon Sivers: L.Zheng et al, PRD98, 034011

Parton spatial distribution: nucleon tomography



Exclusive DIS

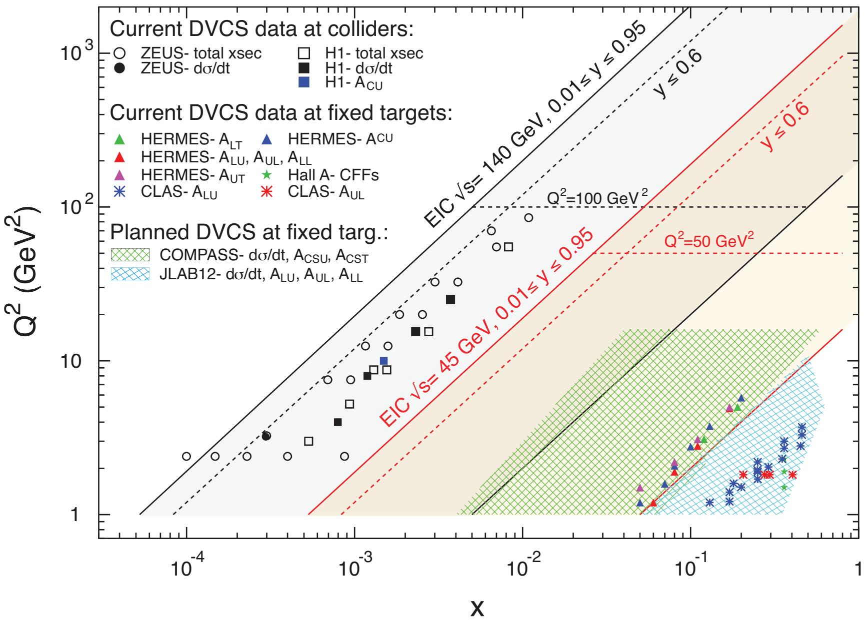
Generalized Parton Distributions (GPD)

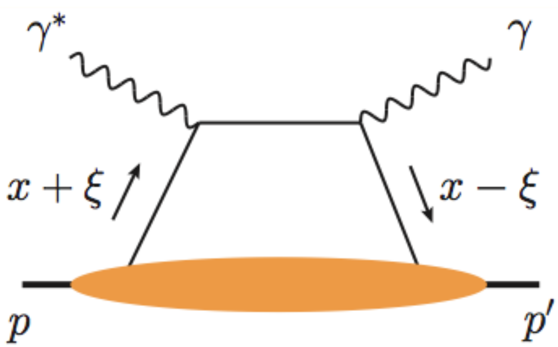
Connected to parton orbital angular momentum

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

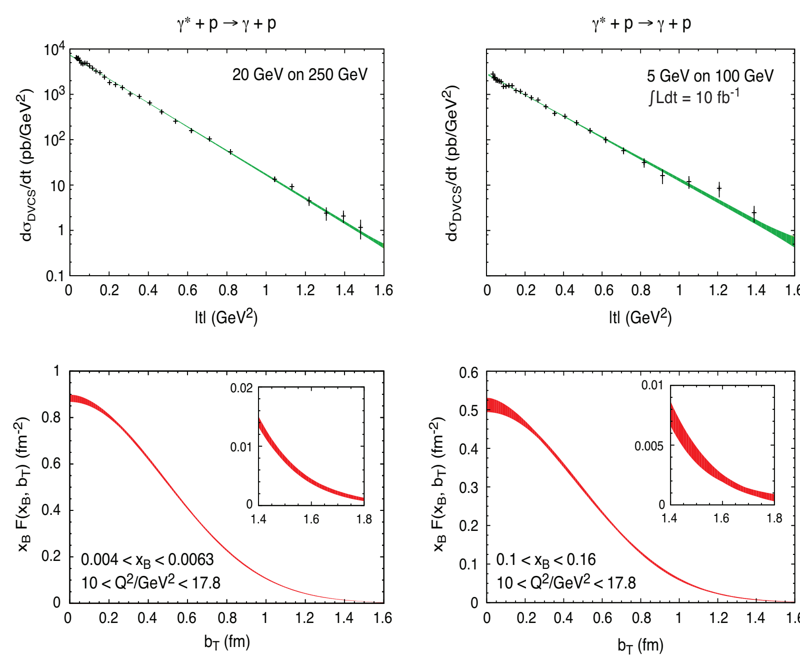
Provide data in wide x&Q^2

Precise imaging requires higher e-beam energy and luminosity

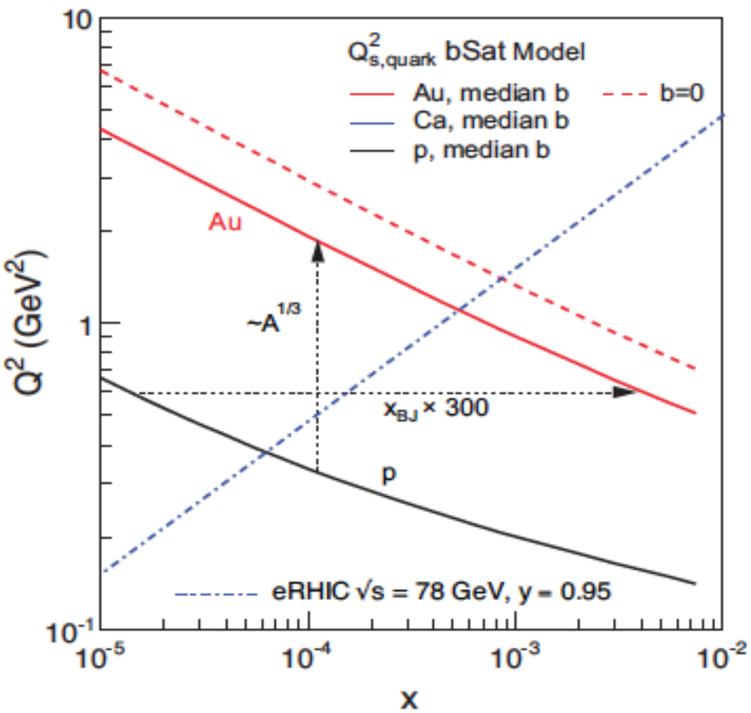




Also see talk by S. Fazio



Gluon Saturation



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

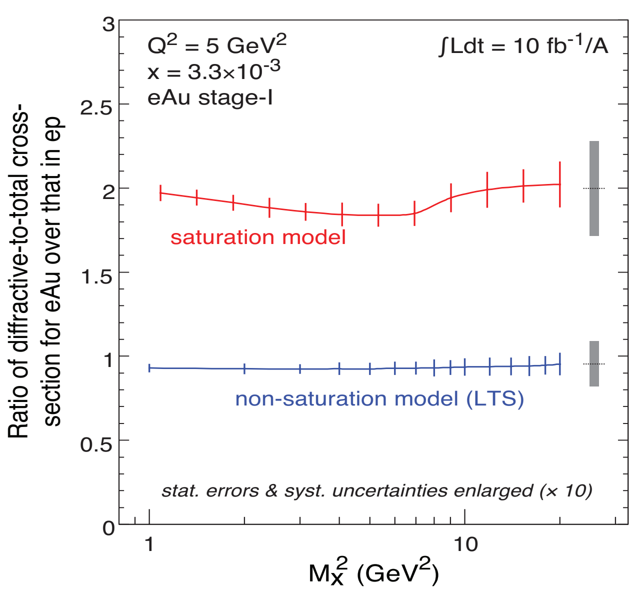
Color Glass Condensate (CGC)

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

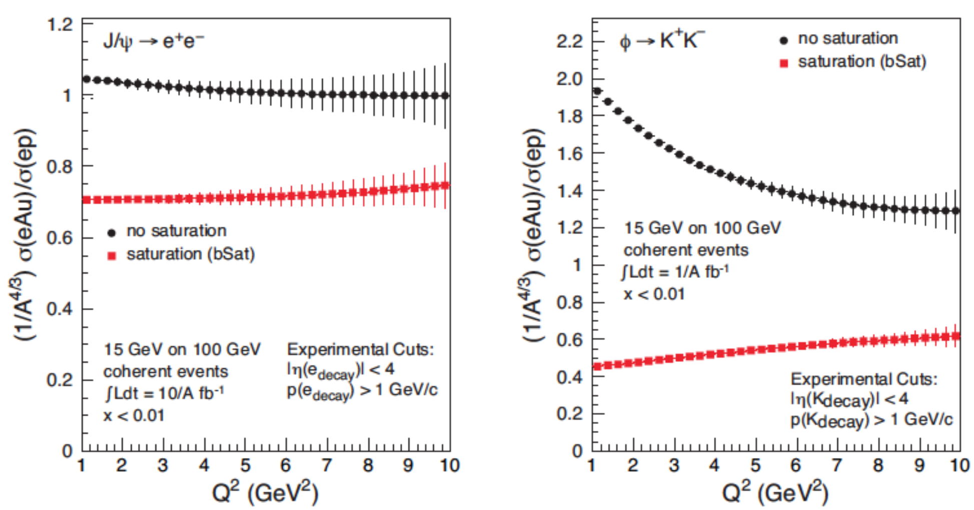
Saturation effects are greatly enhanced in eA collisions:

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

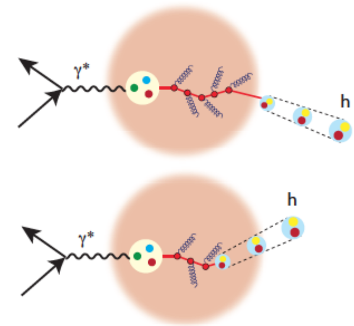
Diffractive: $\sigma_{diff} \sim (xG)^2$

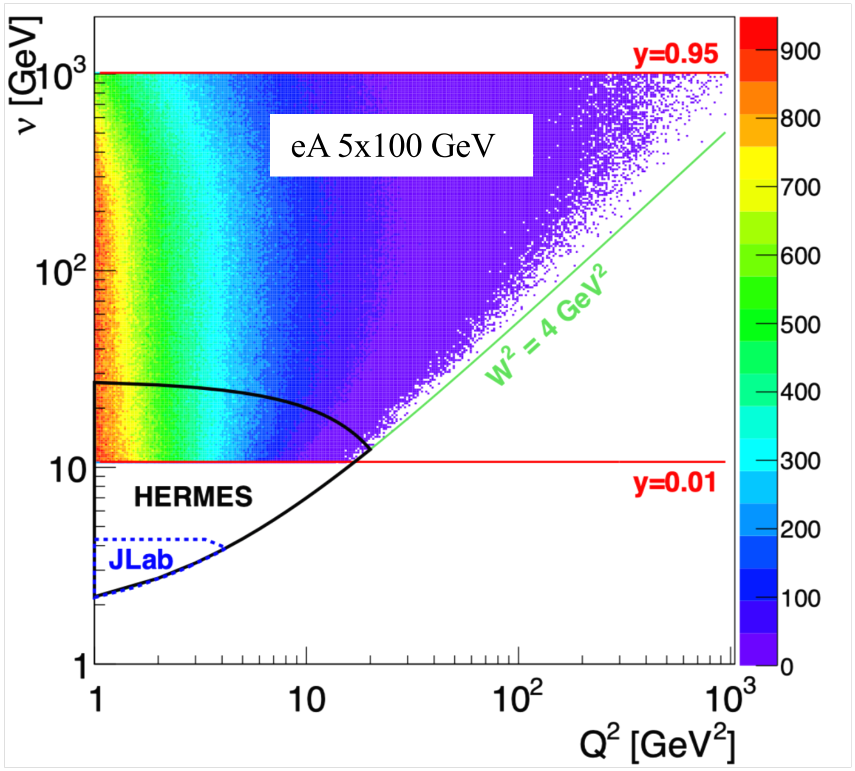


T.Toll and T.Ullrich, PRC87, 024913



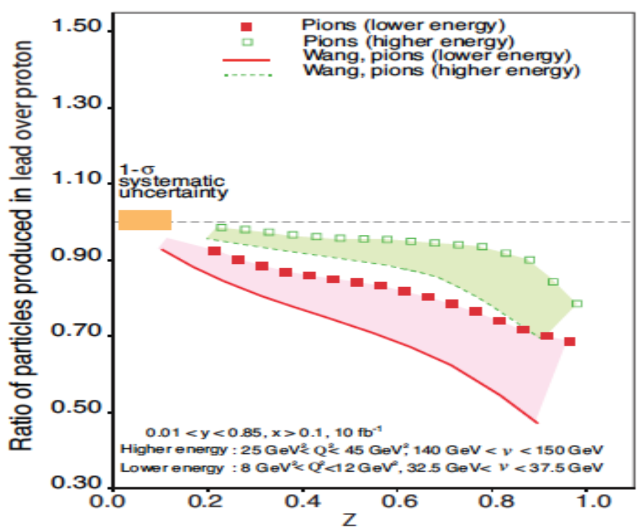
Color Propagation and Hadronization

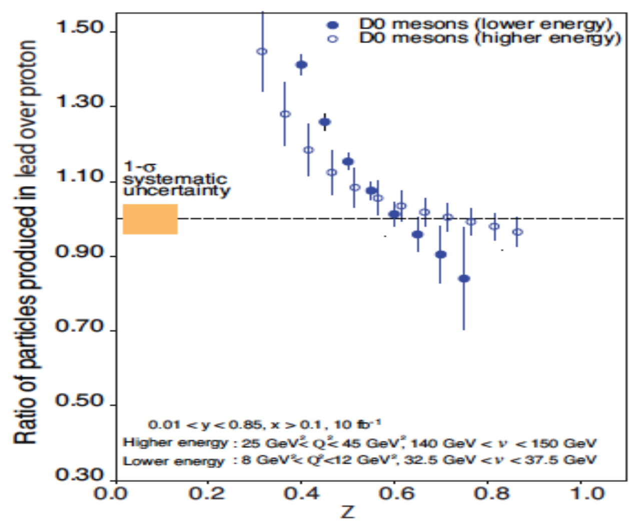




Semi-inclusive eA

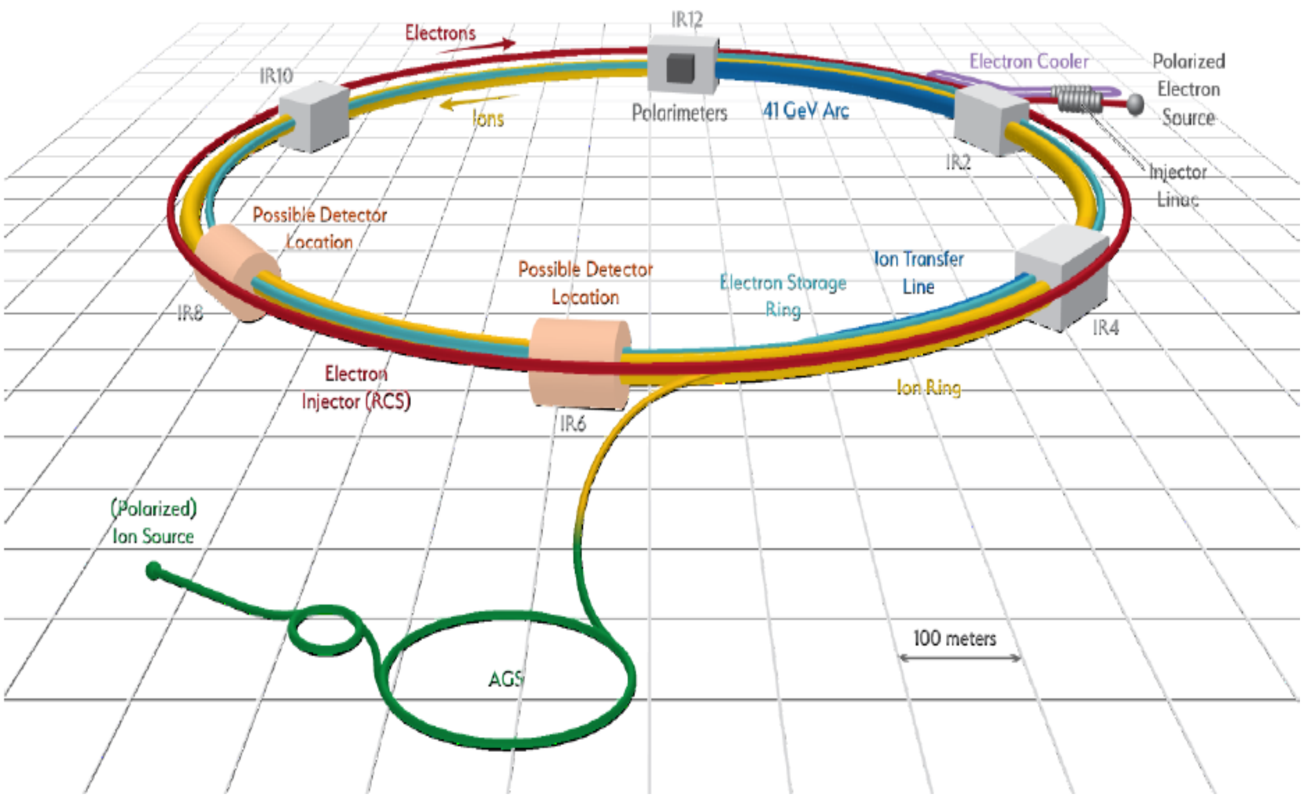
- Probe color neutralization and hadronization
  - Different time&distance probed by varying nuclear size and parton energy
- Previous experiments are limited by low ν, Q^2
- eRHIC:
  - Much larger range of ν, Q^2
  - Wide range of nuclear size





eRHIC

ep/eA



Existing RHIC complex for p/A with added electron ring

Energy:

Electron: up tp 18 GeV
Proton: up to 275 GeV
Ions: up to 110 GeV
$\sqrt{s}$: 20–140 GeV

Polarization:

Electrons: 80%
Protons and d/^{3}He: up to 80%

Luminosity:

Up to 10^{34} cm^{-2} s^{-1}

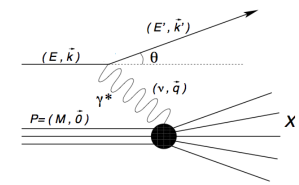
Detector Concept

Inclusive DIS and scattered electron measurements

With focus in e-going direction and barrel

High resolution EMCal and tracking; minimal material budget

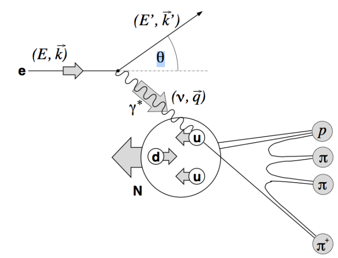
Additional eID with RICH and/or HCal



Semi-inclusive DIS and hadron ID

Needed in the whole rapidity range -4<η<4

Different detector technologies in different kin. regions

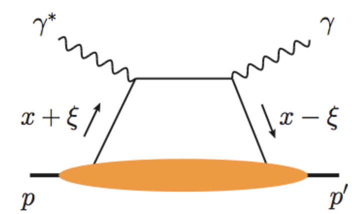


Exclusive DIS (DVCS etc.)

EMCal and tracking coverage in -4<η<4

High granularity EMCal in e-going direction

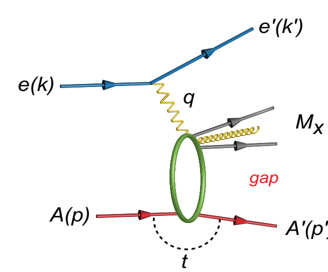
Roman Pots in h-going direction



Diffractive

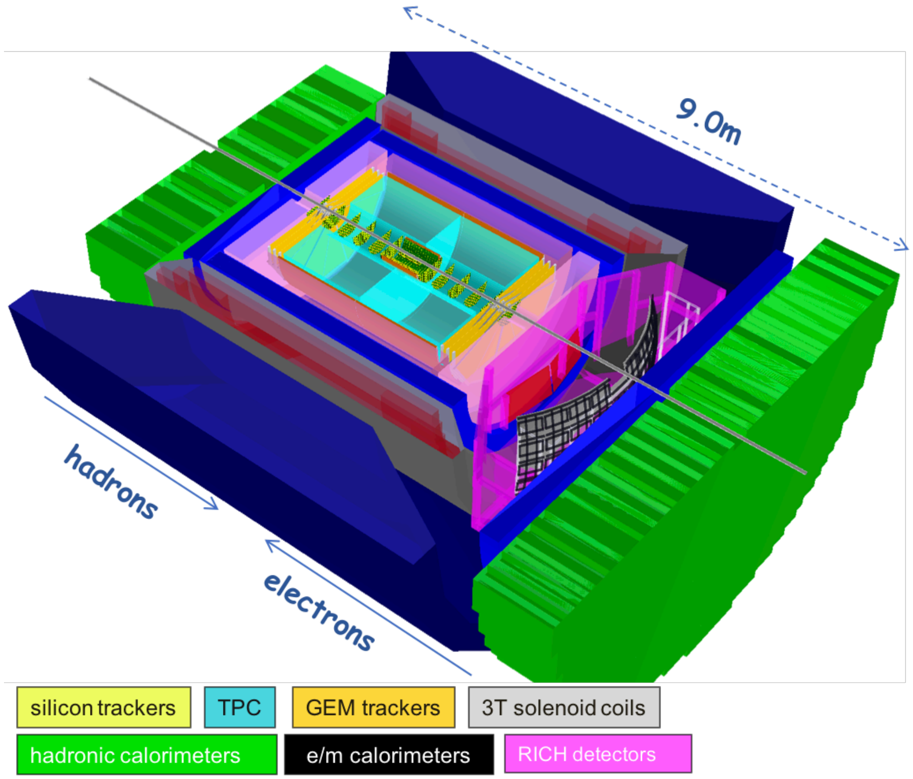
Rapidity gap measurements: HCal h-going direction

ZDC in h-going direction



eRHIC Detector: BEAST

A general purpose EIC detector

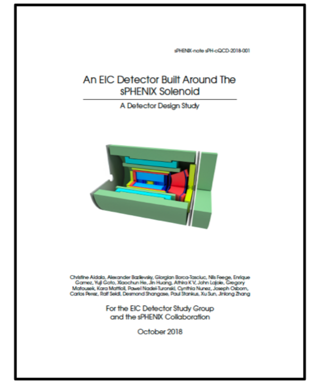


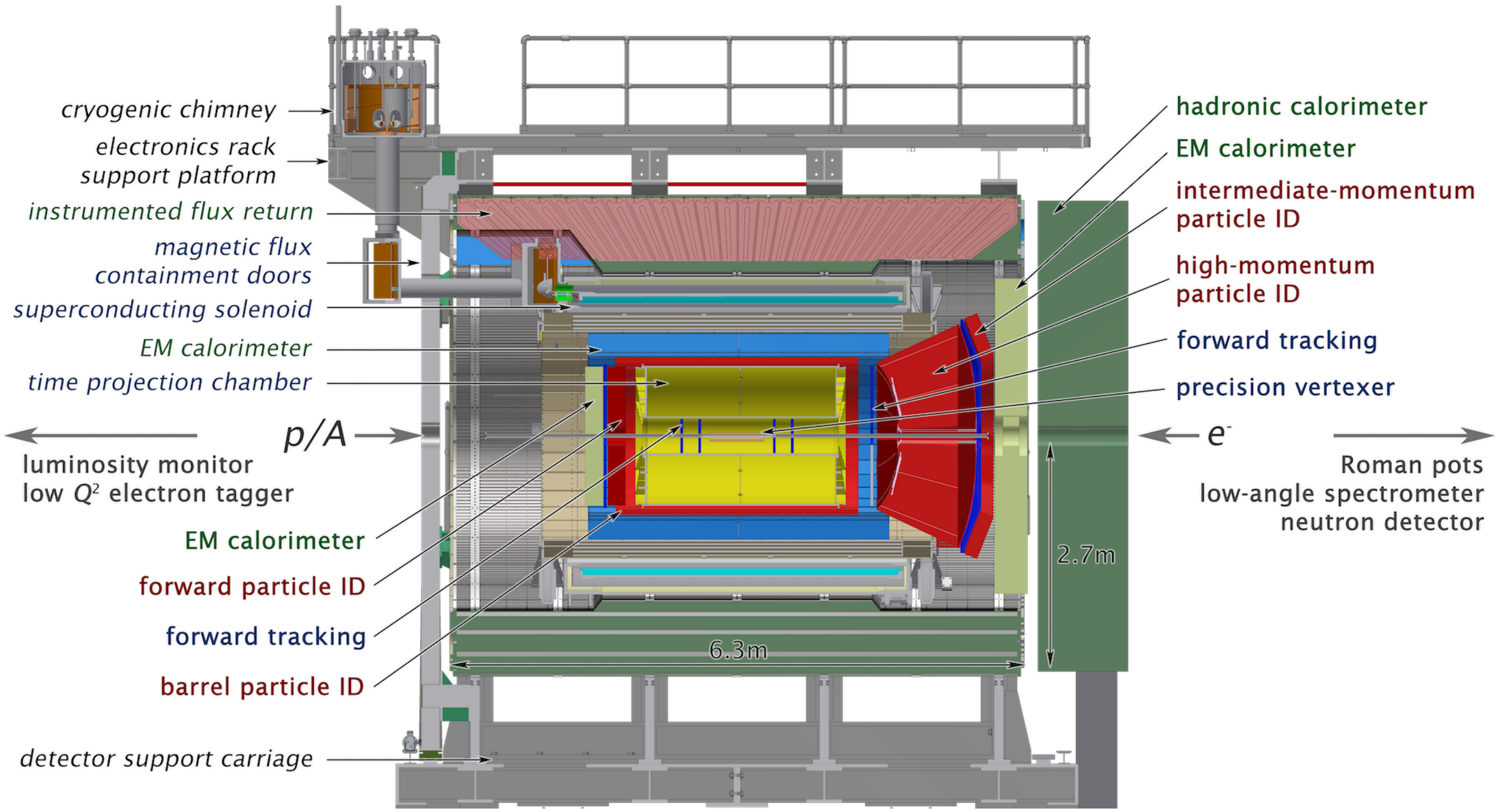
- The more close to 4π acceptance the better
- Pseudo-rapidity coverage of +/-4 or so
- Low material budget
- Reasonably high momentum resolution
- Reliable electron ID
- Good p/K/p separation
- High spatial resolution of primary vertex

Also beam line detectors (included in IR design) for:

- Recoil protons
- Low Q2 electrons
- Neutrons in h-going direction
- Luminosity and polarization measurements

eRHIC Detector: EIC-sPHENIX





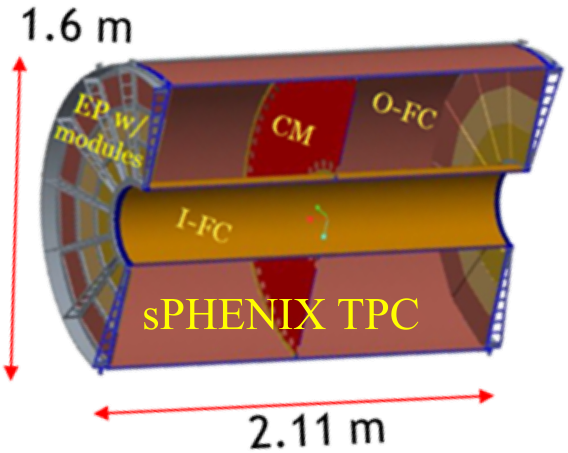
Based on sPHENIX (barrel solenoid, tracking and calorimetry)

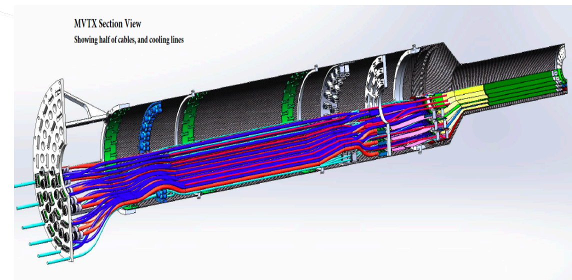
Augmented with central PID, and forward/backward tracking, calorimetry and PID

Detector design/performance studies below are presented for the EIC-sPHENIX case

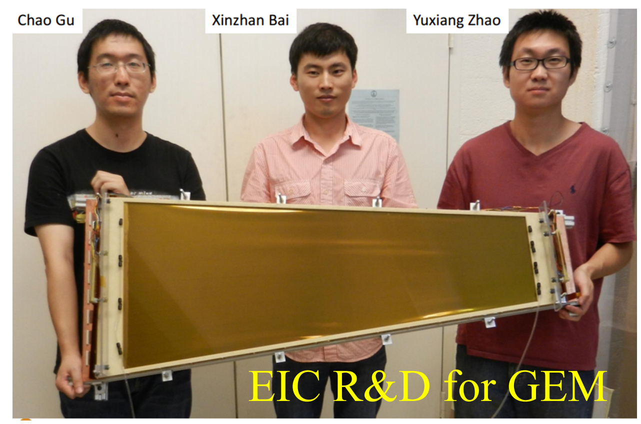
Magnetic Field and Tracking

-4<η<4





sPHENIX MAPS



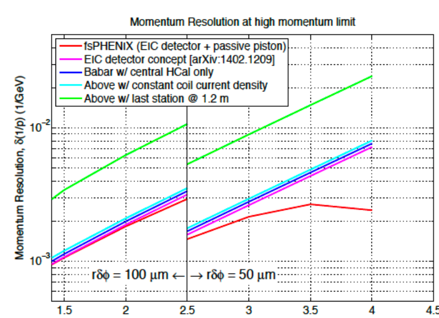
Trackers (-4<η<4):

- TPC and MAPS in barrel → A part of sPHENIX
- GEMs in forward and backward → Ongoing EIC R&D (eRD6)

e-going: electron ID (E/p) and $h^{\pm}$ tracking

Barrel: lower mom. tracking (<10 GeV/c)

h-going: $h^{\pm}$ tracking and ID



EM Calorimetry

$-4<\eta<4$

e-side EMCal:

$\sigma_E/E \sim 2\%/\sqrt{E}$

$\sigma_X < 3mm/\sqrt{E}$

$PbWO_4$ crystal

Similar to PANDA endcap design

Ongoing EIC R&D (eRD1)

Barrel EMCal:

$\sigma_E/E \sim 13\%/\sqrt{E}$

sPHENIX EMCal

Tungsten-fiber

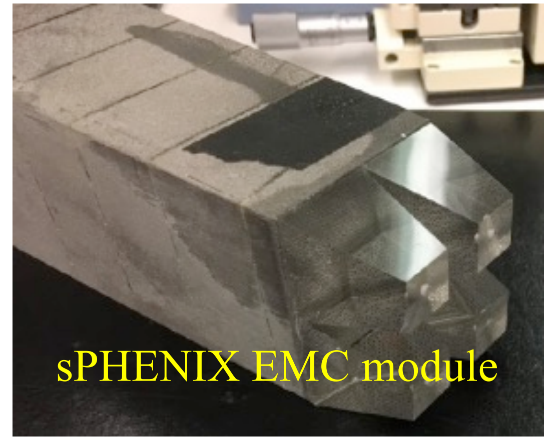
A part of sPHENIX

h-side EMCal:

$\sigma_E/E \sim 12\%/\sqrt{E}$

Pb-fiber

Ongoing EIC R&D (eRD1)


sPHENIX EMC module

EIC R&D for h-side EMC

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

Hadron Calorimetry

$-1<\eta<4$

Barrel HCal:

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

Steel & Scintillator

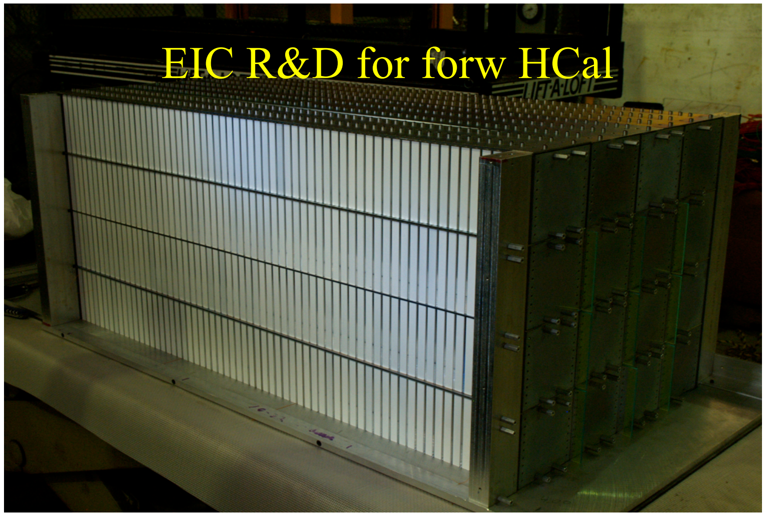
A part of sPHENIX

Forward HCal:

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

Steel & Scintillator

Ongoing EIC R&D (eRD1)

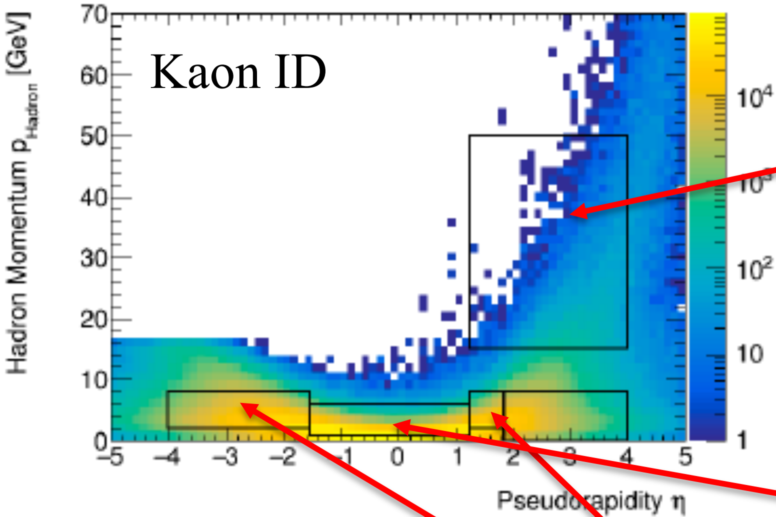


- Rapidity Gap for Diffractive
- Assist to PID and high momentum hadron measurements
- In BEAST, also for eID in e-side $-4<\eta<-1$

Hadron PID

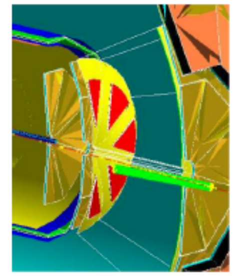
Active ongoing EIC R&D (eRD14) for all detector options

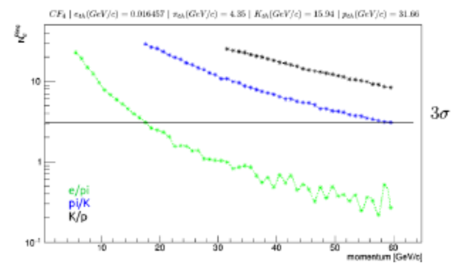
$-4<\eta<4$



Gas RICH

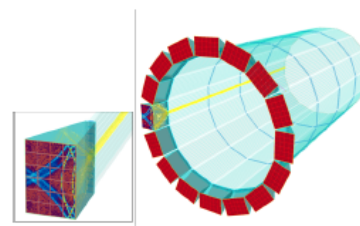
PID at <60 GeV/c

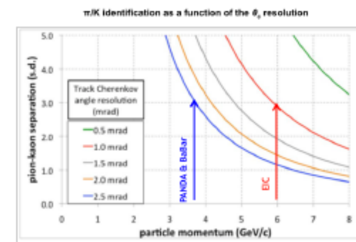




DIRC

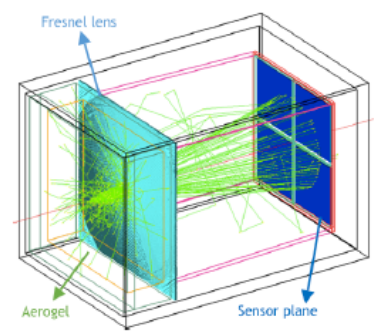
PID at <6 GeV/c

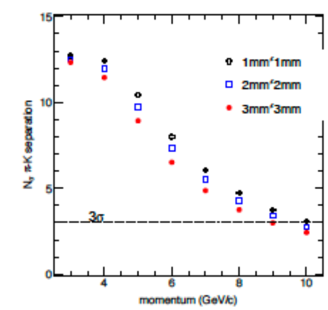




Aerogel RICH

PID at <15 GeV/c





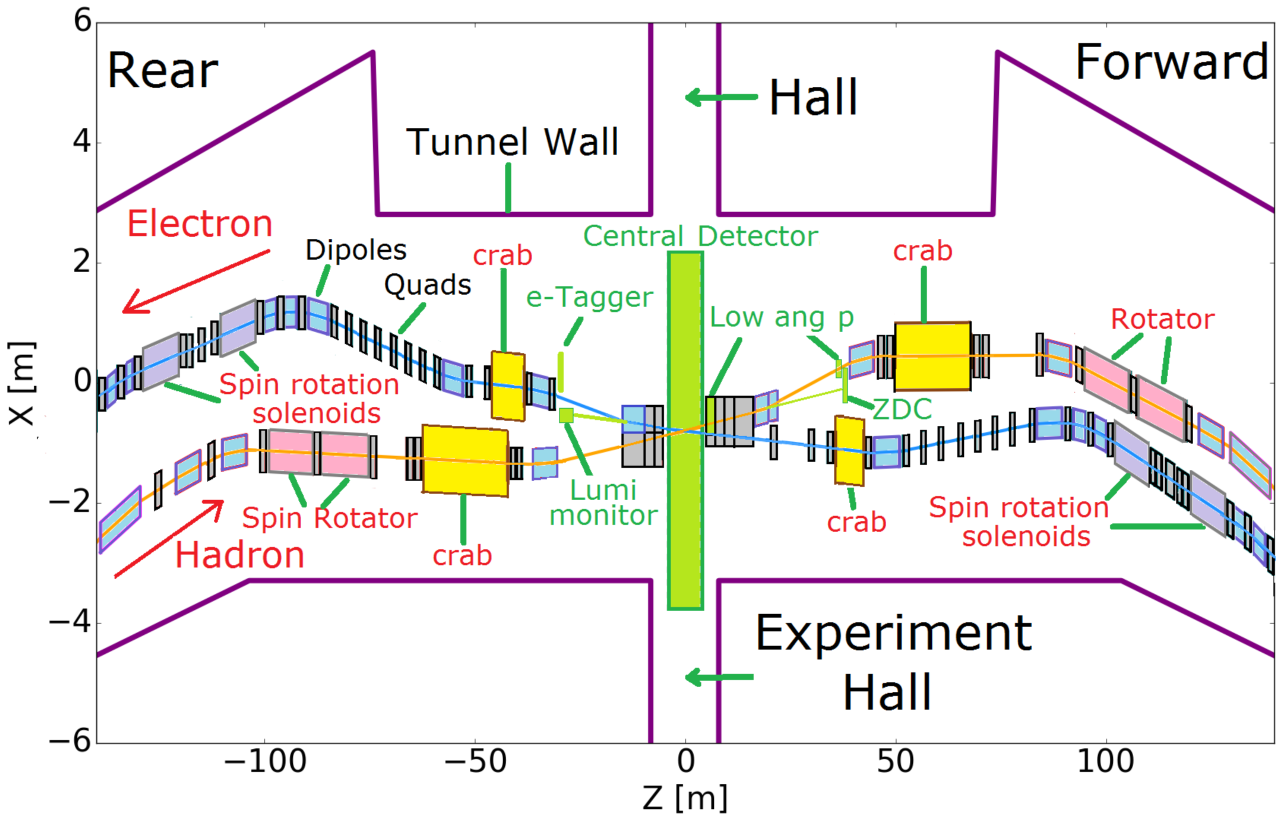
- Quark Helicity, TMDs, Hadronization

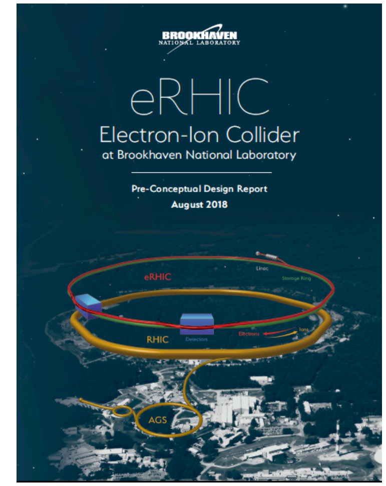
  Tightly coupled to high resolution momentum measurements in forward rapidity

See also talk by M.Chiu

Beamline Detectors

A part of IR design





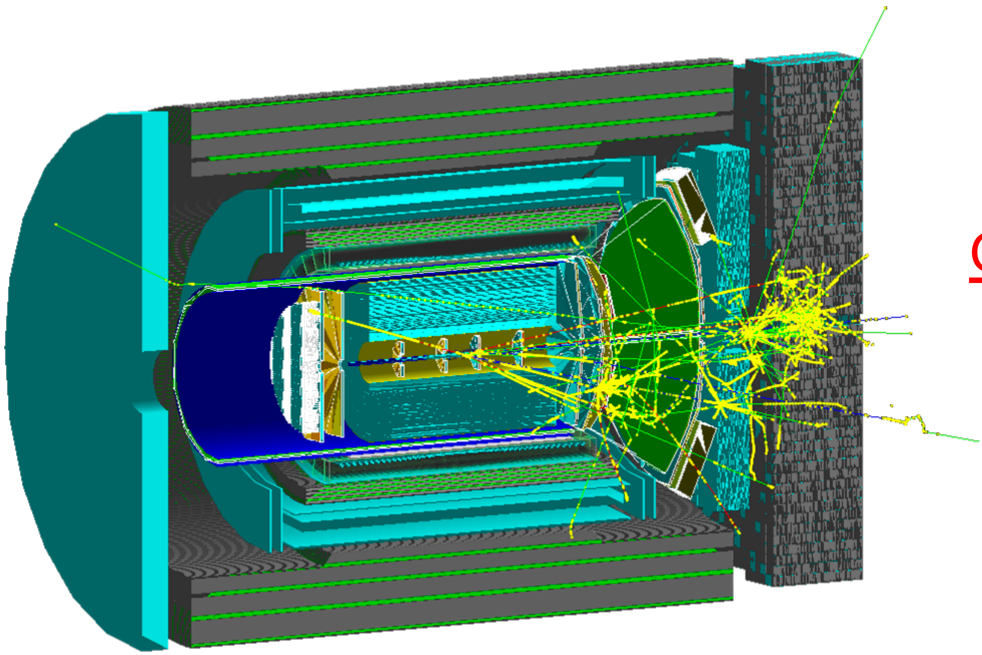
See talk
By C. Montag

- Recoil protons
- Low Q^2 electrons
- Neutrons in h-going direction
- Luminosity and polarization measurements

Detector performance evaluation

Generators:

PYTHIA, MILOU (for DVCS), RAPGAP (diffractive),
RADGEN (rad. effects), Sartre (diffractive ep/eA)



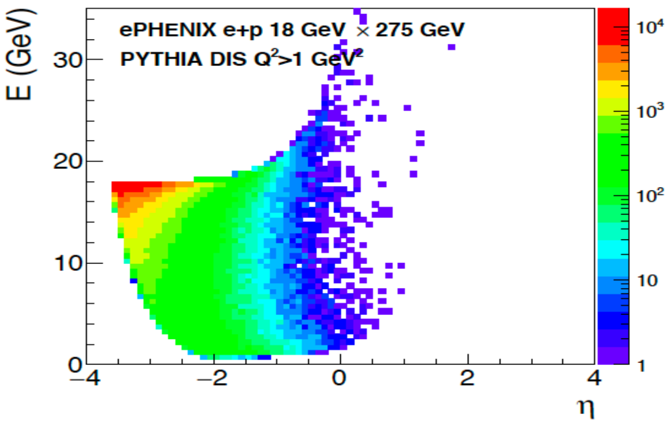
GEANT4 description of EIC-sPHENIX

Simulation and analysis software
common with sPHENIX

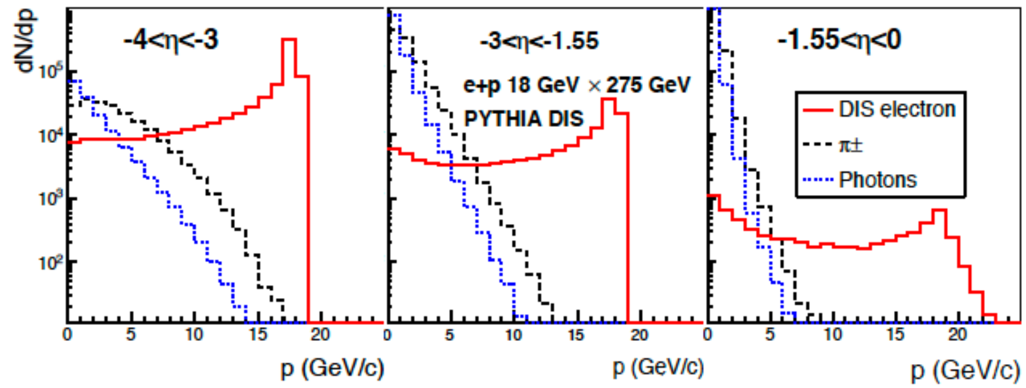
Experience from previous DIS experiments:

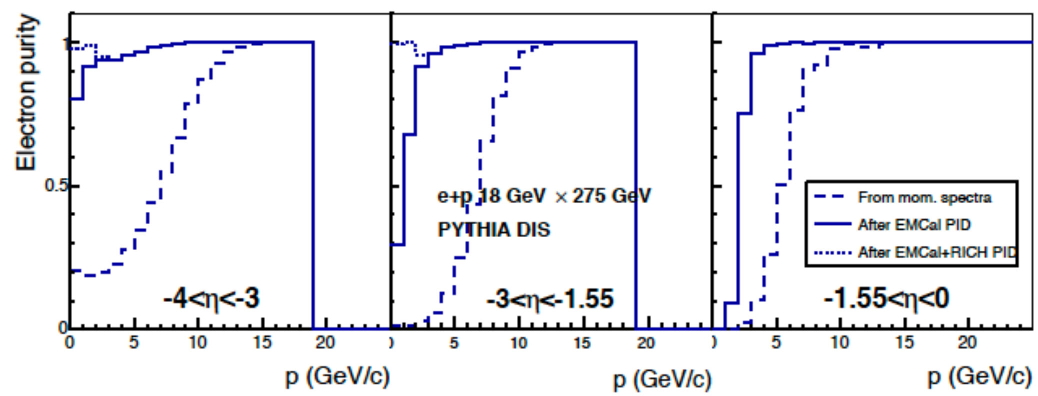
SLAC, CERN, DESY, Jlab

Inclusive DIS and Kinematics



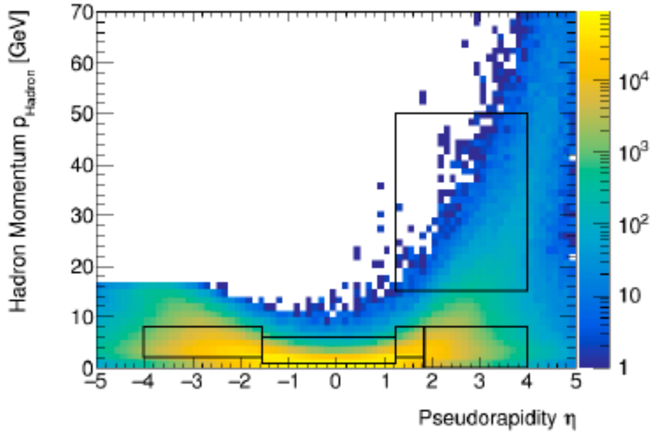
Scattering mainly in e-going direction and barrel





Reliable electron identification in the whole kin. range

SIDIS and Hadron PID



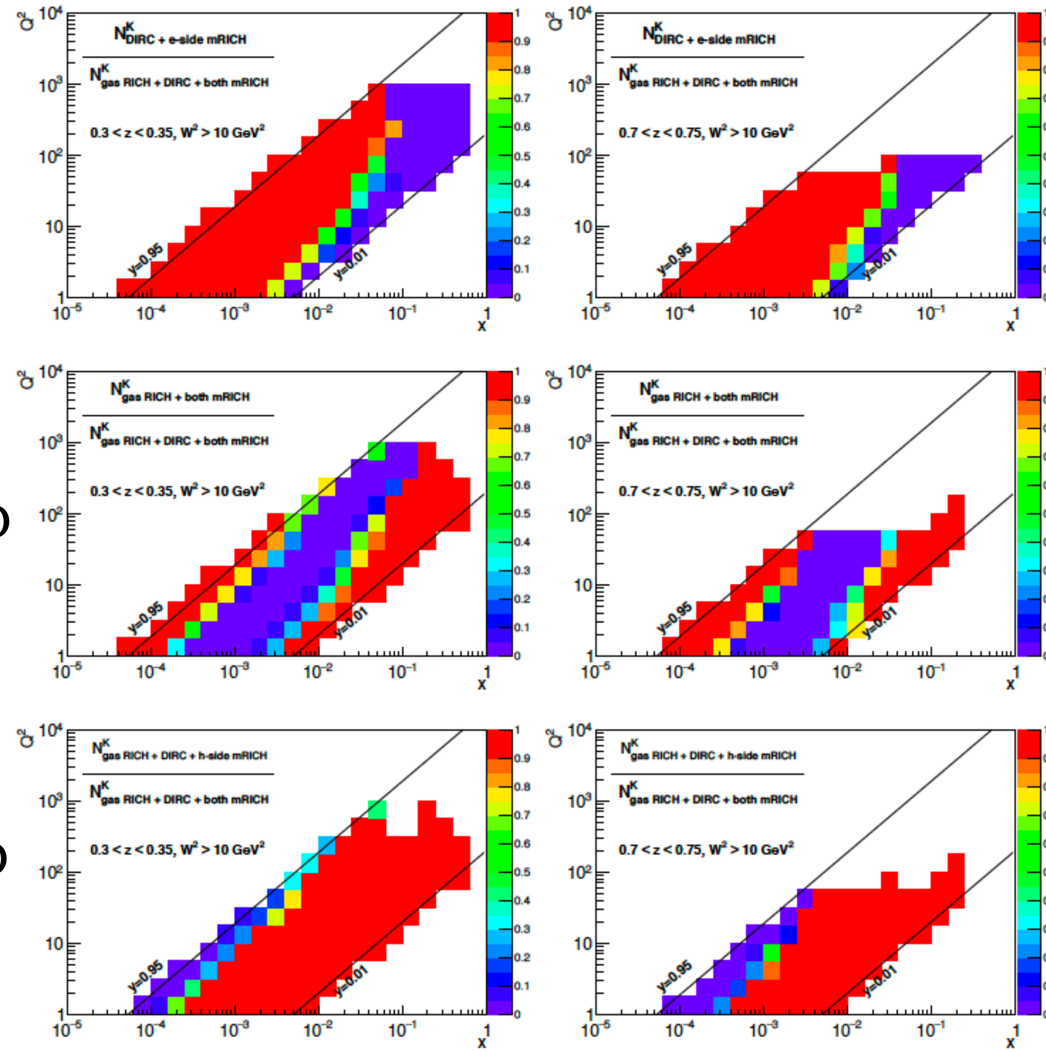
0.30<z<0.35

0.70<z<0.75

No h-side PID

No central PID

No e-side PID

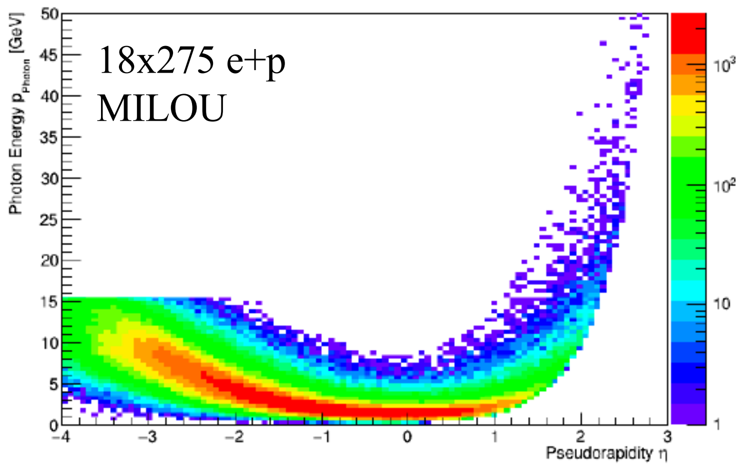


Important to provide PID coverage in wide kin. region

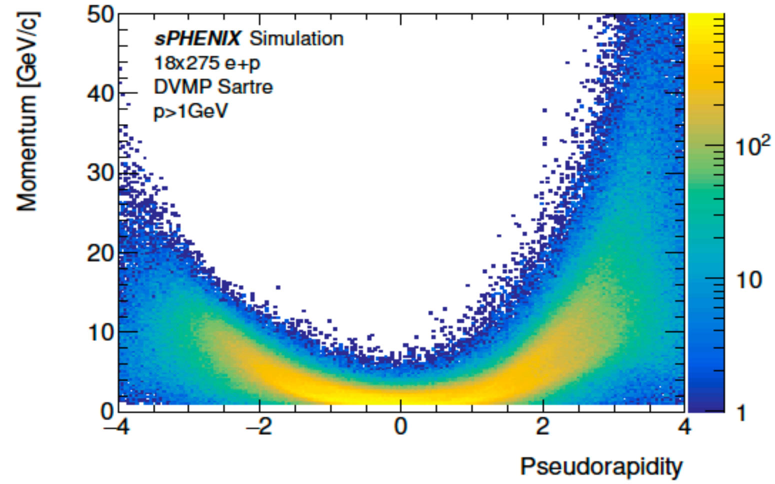
Exclusive DIS

See talk
by S. Fazio
and A. Jentsch

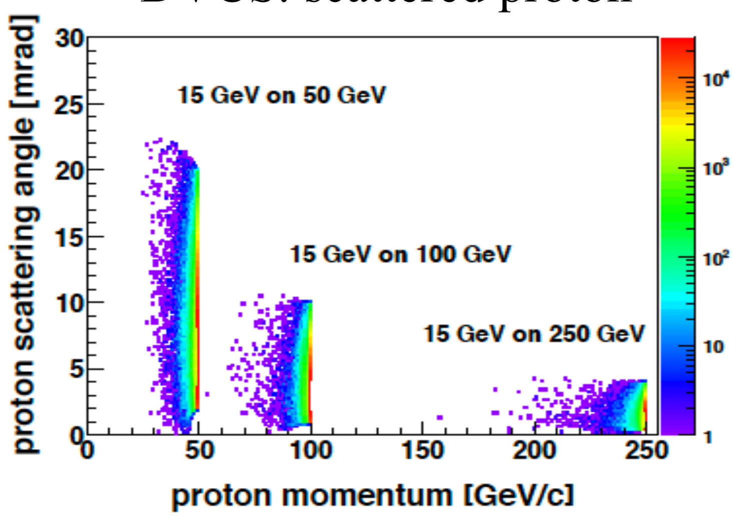
DVCS: photon



DVMP: J/ψ→ee



DVCS: scattered proton



Wide kin. coverage is crucial

Scattered proton misses the main detector

⇒ A dedicated detector close to the beam line is required (Roman Pots)

Exclusive DIS

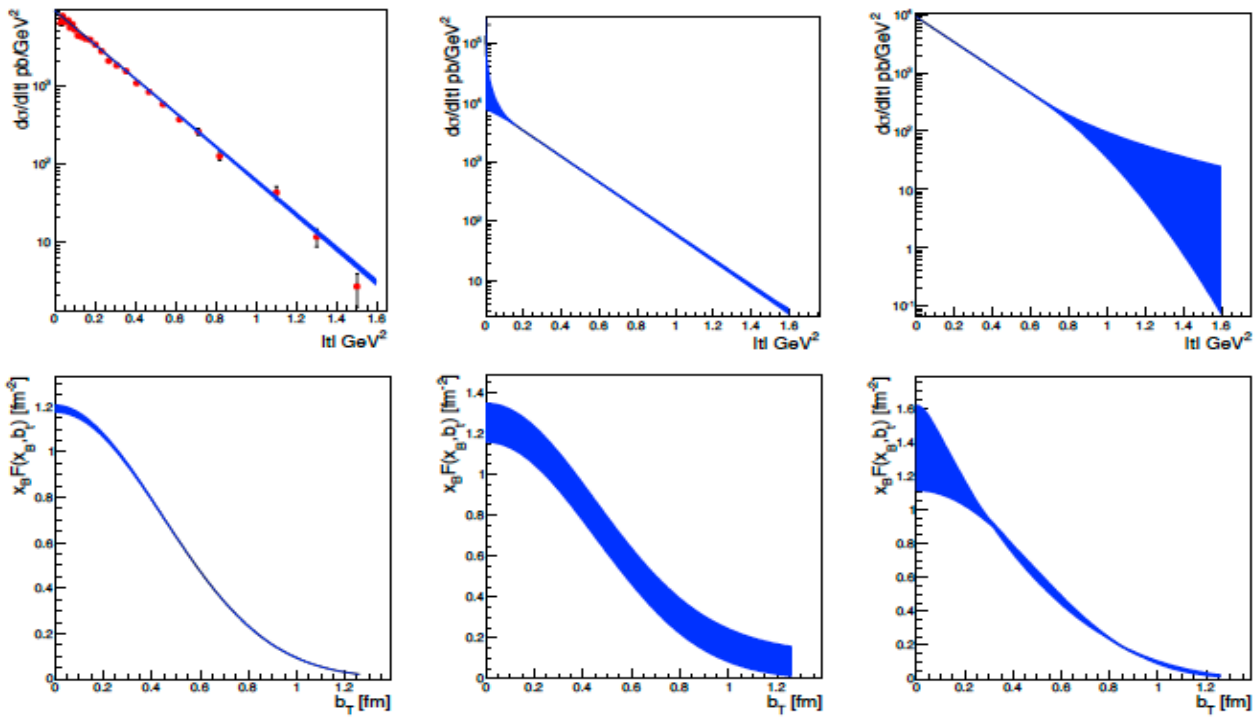
and far-forward proton detection

$\sqrt{s}$=141 GeV
L=10 /fb

$0.18<p_T<1.3$ GeV/c | $0.44<p_T<1.3$ GeV/c | $0.18<p_T<0.8$ GeV/c

DVCS $\sigma(t)$

PDF(b_T)



Need to cover at least $0.18<p_T<1.3$ GeV/c for far-forward scattered protons => Roman Pots

⇒ part of IR design requirements at eRHIC

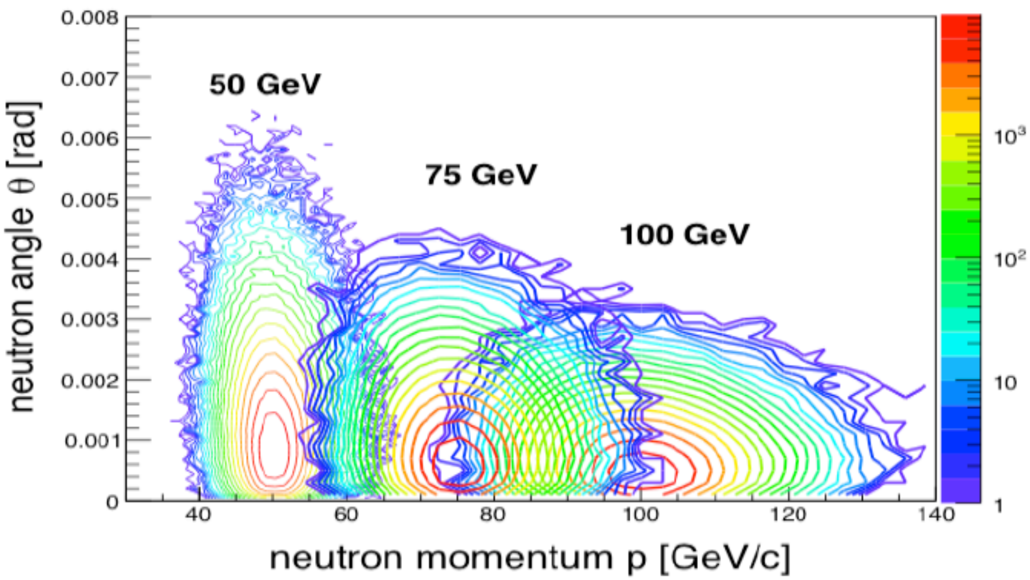
See talks by W. Guryn and A. Jentsch

eA measurements

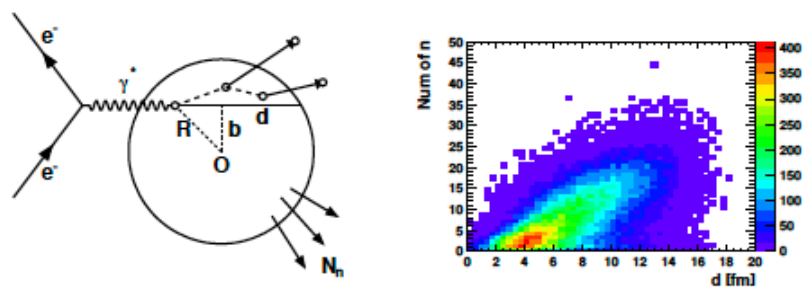
and far-forward neutron detection

See talk by W. Chang

Neutrons from nuclear breakup



Number of forward neutrons is sensitive to impact parameter and parton path length



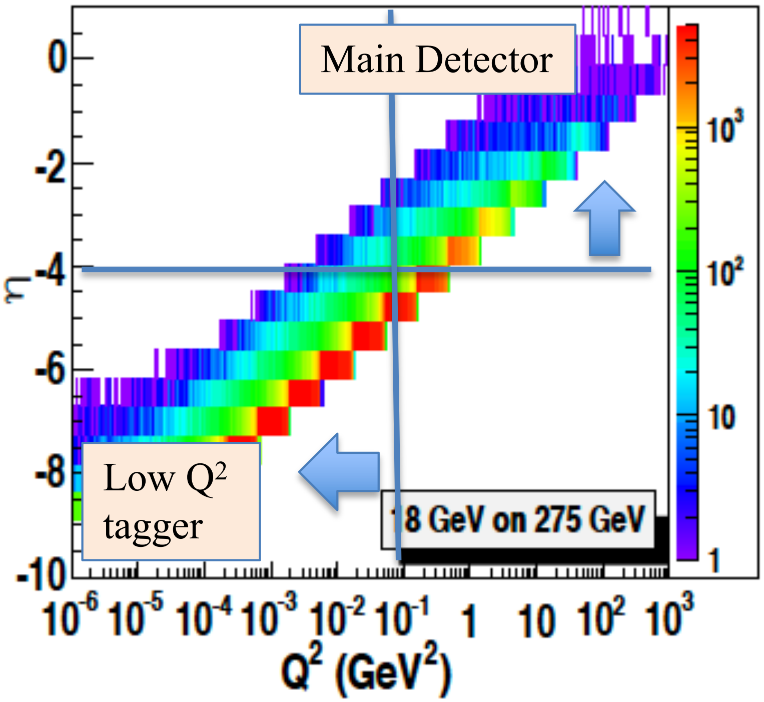
L. Zheng et al, Eur. Phys. J. A (2014) 50: 189

Need to cover up to θ = 4-6 mrad for far-forward scattered neutrons => ZDC

=> part of IR design requirements at eRHIC

Low Q^2

Scattered electron η vs Q^2



Low Q^2 events dominate the e+p cross section

Quasi-real photo-production

E.g. photon partonic structure

(X. Chu et al, PRD96, 0.74035)

Need dedicated scattered electron detector close to the beam line

$Q^2 = 4E_eE_e\text{'}\sin^2(\theta/2)$

Need to cover Q^2<0.1 GeV^2 => e.g. EMC and tracking planes

=> part of IR design requirements at eRHIC

Summary

Two eRHIC Detector design studies are on the table:

Closely follow the physics requirements as in the EIC White Paper

Based on proven/existing components or ongoing R&D

Implemented in full GEANT4 simulation

Beam line detectors are essential instruments for the EIC physics program

Backup