The Evolution Of PHENIX Into An Electron Ion Collider (EIC) Experiment

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“A Bridge Between Quarks / Gluons And Nuclei”

❖ How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

❖ Where does the saturation of gluon densities set in?

❖ How does the nuclear environment affect the distribution of quarks and gluons and their propagation?
e^+p / e^+A Collisions at RHIC

Alternative: MEIC at JLab
The Evolution Of PHENIX

By ~2021
sPHENIX
RHIC (p+p, p+A, A+A)

By ~2023
fsPHENIX

By ~2026
EIC Detector
eRHIC (e+p, e+A)
Putting The Pieces Together

- Nucleon spin and 3D structure
- Effects of ‘cold’ nuclear matter
- Color Glass Condensate

eRHIC (e+p, e+A)

- Quark-gluon plasma
- Effects of ‘hot’ nuclear matter

RHIC (p+p, p+A, A+A)

- Transverse spin
- Effects of ‘cold’ nuclear matter
The Central Element: The BaBar Coil

- Superconducting solenoid
- Field: 1.5 T
- Inner radius: 140 cm
- Outer radius: 173 cm
- Length: 385 cm

Inhomogeneity < 3%
sPHENIX

Tracking
• 2 layer Silicon vertex pixel
• 5 layer Silicon-strip (or TPC)

\[
\frac{\Delta p_T}{p_T} < (1.2\% + 0.03\% p_T)
\]

HCAL: Steel-scintillator (5 \( \lambda_{\text{int}} \))
100\%/\sqrt{E} energy resolution
\( \eta \times \varphi \sim 0.1 \times 0.1 \) segmentation

ECAL: Tungsten-scintillating fiber (18 \( X_0 \))
12\%/\sqrt{E} energy resolution
\( \eta \times \varphi \sim 0.024 \times 0.024 \) (2x2 cm\(^2\)) segmentation
Forward - sPHENIX (fsPhenix)

Tracking
- 2 layer Silicon vertex pixel
- Silicon-strip (or TPC)
- Forward vertex
- GEM ($r\delta\varphi$ resolution $\sim 100\mu\text{m}$)

Hadron Calorimeter
- Steel-scintillator ($5\lambda_{\text{int}}$)
  - 100%/\sqrt{E}$ energy resolution
  - $\sim 10 \times 10 \text{ cm}^2$ segmentation

Muon ID
Measuring DIS

- Measuring DIS
- e-going
- barrel
- h-going
- inclusive DIS
- semi-inclusive DIS
- exclusive DIS

- ePHENIX e+p 10 GeV x 250 GeV
- PYTHIA DIS $Q^2 > 1$ GeV$^2$, $0.01 < y < 0.80$, $W^2 > 10$ GeV$^2$
- Hadron $z > 0.2$
EIC Detector

Tracking
- TPC (300 μm position resolution)
  \[ \frac{\Delta p_T}{p_T} < (1\% + 0.4\% p_T) \]
- GEMs (50-100 μm resolution in \( r \Delta \varphi \))

Electromagnetic Calorimeter
- Lead-tungstate (20 \( X_0 \))
  1.5%/\( \sqrt{E} \) energy resolution
  3mm/\( \sqrt{E} \) position resolution
- Lead-scintillating Fibre (18 \( X_0 \))
  12%/\( \sqrt{E} \) energy resolution
  ~3x3 cm\(^2\) segmentation
RICH Detectors for Hadron ID

PID ~ 3–15 GeV/c

PID < 4 GeV/c

\[ \theta_c = \cos^{-1}\left(\frac{1}{\beta n}\right) \]

PID < 50 GeV/c
Electron ID via $E/p$ matching

-3 < $\eta$ < -2
-2 < $\eta$ < -1
-1 < $\eta$ < 0

Select only $E_e > 2$ GeV
\[
\frac{1}{2} = \frac{1}{2} \Delta \Sigma + L_q + \Delta G + L_g
\]

Valence to low-x physics
3D Imaging of Quarks and Gluons

momentum space

\[ f(x,k_T) \]

position space

\[ f(x,b_T) \]

Position \( r \)

Momentum \( p \)

Orbital motion of partons

\[ q(x=10^{-3}, b, Q^2 = 4 \text{ GeV}^2) \]

sea quark, unpolarized

fixed \( x, Q^2 \)

arXiv:1212.1701v3
Gluon Saturation from Diffraction

\[ \sigma_{\text{diff}} \propto [g(x, Q^2)]^2 \]

Fraction of diffractive events in eAu over that in ep

\[ Q_s^2(x) \sim \left( \frac{A}{x} \right)^{1/3} \]

\( x_{Bj} \times 300 \)

\( Q^2 = 5 \text{ GeV}^2 \)

\( x = 1 \times 10^{-3} \)

Mass squared of produced hadrons, \( M_X^2 \) (GeV^2)

arXiv:1212.1701v3
References

- sPHENIX - An Upgrade Proposal from the PHENIX Collaboration [arXiv:1207.6378v2]
- Future Opportunities in p+p and p+A Collisions at RHIC with the Forward sPHENIX Detector [http://tinyurl.com/lq6e9v3]
- Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid [arXiv:1402.1209v1]
Summary

The stages of this detector could make excellent use of the highly intriguing physics potential at RHIC:

- Quark Gluon Plasma
- Effects of hot and cold nuclear matter
- Transverse spin

and eRHIC (or the MEIC at JLab):

- Nucleon spin and 3D structure
- Effects of cold nuclear matter
- Color Glass Condensate
ADDITIONAL SLIDES
Parton Propagation in Nuclei

Fragmentation outside vs. inside of cold nuclear matter

Light vs. heavy quark propagation in cold nuclear matter

Ratio of particles produced in lead over proton

- Pions (model-I)
- Pions (model-II)
- D0 mesons

$x > 0.1$
$25 \text{ GeV}^2 < Q^2 < 45 \text{ GeV}^2$
$140 \text{ GeV} < \nu < 150 \text{ GeV}$
$fLdt = 10 \text{ fb}^{-1}$

Fraction of virtual photons energy carried by hadron, $z$
Deep Inelastic Scattering (DIS)

\[ s = \text{collision energy (squared)} \]

\[ Q^2 = -q^2 = - (k - k') = \text{momentum transfer / resolution} \]

\[ x = \text{momentum fraction of struck quark} \]

\[ y = \frac{(q \ p)}{(k \ p)} = \text{inelasticity} \]

Relation: \[ Q^2 = s \times y \]
Semi-inclusive DIS
Exclusive DIS

Deeply Virtual Compton Scattering (DVCS)

\[ \gamma^* \rightarrow \gamma \rightarrow x + \xi \quad x - \xi \]

\[ p \rightarrow p' \]
Hard Diffractive Scattering

\[ M_x^2 = (p - p' + k - k')^2 \]

\[ t = - (p - p')^2 = \text{momentum transfer} \]
EIC R&D: Gas RICH
Hadron ID Performance for EIC

\[ \theta_c (\text{mrad}) \]

\[ P_{\text{Lab}} \text{ (GeV/c)} \]

\[ e \]

\[ \mu \]

\[ K \]

\[ p \]

\[ \pi \]

\[ \text{AeroGel} \]

\[ \text{CF}_4 \]

\[ \text{DIRC} \]

(BaBar)