Plans and Prospects for fsPHENIX and an EIC detector

Jin Huang (BNL) for the PHENIX collaboration
# Overview


<table>
<thead>
<tr>
<th>Current PHENIX</th>
<th>fsPHENIX</th>
<th>An EIC detector</th>
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<tbody>
<tr>
<td>▶ Current PHENIX as discussed in many previous talks</td>
<td>▶ Comprehensive central upgrade base on BaBar magnet</td>
<td>▶ Path of PHENIX upgrade leads to a capable EIC detector</td>
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<tr>
<td>▶ 14y+ work 100+M$ investment</td>
<td>▶ fsPHENIX : forward tracking, Hcal and muon ID</td>
<td>▶ Large coverage of tracking, calorimetry and PID</td>
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<td>▶ 130+ published papers to date</td>
<td>▶ Key tests of theoretical frameworks for transverse spin</td>
<td>▶ Open for new collaboration/new ideas</td>
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<td>▶ Last run in this form 2016</td>
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~2000  | 2017→2020  | ~2025  |

**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

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

<table>
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<tr>
<th>Design Family</th>
<th>Example</th>
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<tr>
<td>Piston</td>
<td>• Passive piston (C. L. da Silva)</td>
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<td></td>
<td>• Super conducting piston (Y. Goto)</td>
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<tr>
<td>Dipole</td>
<td>• Forward dipole (Y. Goto, A. Deshpande, et. al.)</td>
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<td>• Redirect magnetic flux of solenoid (T. Hemmick)</td>
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<td></td>
<td>• Use less-magnetic material for a azimuthal portion of central H-Cal (E. Kistenev)</td>
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<tr>
<td>Toroid</td>
<td>• Air core toroid (E. Kistenev)</td>
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<td></td>
<td>• Six fold toroid (J. Huang)</td>
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<tr>
<td>Other axial symmetric Field shaper</td>
<td>• Large field solenoidal extension (C. L. da Silva)</td>
</tr>
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<td></td>
<td>• Pancake field pusher (T. Hemmick)</td>
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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
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 \(|z|<4.5\text{m}\) limit (eRHIC machine/detector t”ruce” line)

- **Baseline forward tracking**
  - Central + forward yoke (hadron calo.)
  - Last tracking station at \(z=3.0\text{m}\)

- Can be further enhanced for fsPHENIX DY

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**Momentum Resolution at high momentum limit**

- **fsPHENIX (EIC detector + passive piston)**
- **EIC detector concept [arXiv:1402.1209]**
- **Babar w/ central HCal only**
- **Above w/ constant coil current density**
- **Above w/ last station @ 1.2 m**

\[ r_0 \phi = 100 \mu\text{m} \rightarrow r_0 \phi = 50 \mu\text{m} \]
Unified forward spectrometer design

fsPHENIX at RHIC

An EIC detector concept for eRHIC
Forward spectrometer of sPHENIX: \textit{fsPHENIX}

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

**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

Single jet in GEANT4
\[ p_T = 4.1 \text{ GeV/c}, \, \eta = 3 \]
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

**Twist-3 framework**

- High $P_T$
- Low $P_T$

More details: Session I/ Z. Kang

**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

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<thead>
<tr>
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<th>Tracking</th>
<th>Calorimetry</th>
<th>Lepton PID</th>
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<tbody>
<tr>
<td>Jet Sivers</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Jet Collins</td>
<td>√</td>
<td>√</td>
<td></td>
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<tr>
<td>DY</td>
<td>√</td>
<td>√</td>
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### 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 $\rightarrow k_T$ 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

Jet + h $^{+/−}$ Collins Asymmetry: $A_N$ vs $Z$

10 GeV < Jet E < 100 GeV

$A_N^+$ > $A_N$ No Cut > $A_N^−$

$A_N^+$ < $A_N$ No Cut < $A_N^−$

Hadron Asymmetry in Jets

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RHIC/AGS AUM 2014
Sivers in SIDIS VS Polarized Drell-Yan and test the TMD picture

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

\[ f_{1T}^\perp (DY) = ? - f_{1T}^\perp (SIDIS) \]

Courtesy to M. Burkardt

FSI in SIDIS is attractive
apply to eRHIC measurement

ISI in Drell-Yan is repulsive
apply to RHIC pp measurements
\textbf{fsPHENIX DY – challenging but attractive}

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 $\rightarrow$ eRHIC around year 2025

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

- Beams of eRHIC
  - 250 GeV polarized proton
  - 100 GeV/N heavy nuclei
  - 15 GeV polarized electron
  - Luminosity $\geq 10^{33}$ cm$^{-2}$s$^{-1}$
  - Also, 20 GeV electron beam with reduced lumi.
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

- 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

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

**Geant4 model of detectors inside field region**

- e-going GEMs: $-4.0 < \eta < -1$
- TPC: $-1 < \eta < +1$
- DIRC: $-1 < \eta < +1$
- h-going GEMs: $1 < \eta < 2$
- gas RICH: $1 < \eta < 4$
- Aerogel RICH: $1 < \eta < 2$

**Fringe field**
**1.5 T main field**
**Fringe field**

**Tracking**

**Hadron PID**

**Calorimeters (H-Cal cover $\eta > -1$)**
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 $1 < \eta < 2$

- **Gas RICH**: next slides
- Possible upgrade in electron-going direction

Detector coverage for hadron PID

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

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RHIC/AGS AUM 2014
Gas RICH - The Design

- Hadron ID for $p>10\text{GeV/c}$ require gas Cherenkov
  - $\text{CF}_4$ 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

![Diagram of Gas RICH setup](image)

- 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

Field effect has very little impact for PID

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

Purity

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

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Physics performance:
longitudinal and transverse structure of proton

- This detector will significantly 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.

High $x$ and $Q^2$ 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

\[ f_{1T}^{\perp \text{(SIDIS)}} = - f_{1T}^{\perp \text{(DY)}} \]
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<\(\eta\)<+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 v VS Q2 coverage
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