Medium-energy Nuclear Physics at RHIC with sPHENIX and an sPHENIX Forward Upgrade

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Evolution of the PHENIX Interaction region

PHENIX experiment

- 16y+ operation
- Broad spectrum of physics (QGP, Hadron Physics, DM)
- 170+ physics papers with 24k citations
- Last run in this form 2016

An EIC detector

- Comprehensive central upgrade base on BaBar magnet
- Rich jet and beauty quarkonia physics program → nature of QGP
- Possible forward tracking, and calorimeter → Spin, CNM
- 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→2022, CD-0 @ 2016

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

>2025

EIC: e+p, e+A

Time
Ultimate Mission of sPHENIX

Completion of the QGP Study at RHIC!!

Jet and heavy flavor as proves
What's new about sPHENIX

Limited acceptance to measure Jet.

4π, but incomplete for jet without HCAL

4π & -1<η<1 with HCAL

Designed to be ideal detector for Jet
Detector Overview

- Central Tracking
  - TPC
  - INTT
  - MVTX

- Hadronic Calorimeter
  - Outer
  - Inner

- Electromagnetic Calorimeter

- Solenoid Magnet

- Full Azimuthal Coverage
- $|\eta| < 1.1$

15 kHz trigger
10 GB/s data logging
sPHENIX TimeLine

<table>
<thead>
<tr>
<th>Year</th>
<th>System</th>
<th>Weeks</th>
<th>Samp. Lum, All Z</th>
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</thead>
<tbody>
<tr>
<td>2022</td>
<td>Au+Au</td>
<td>16</td>
<td>34 nb⁻¹</td>
</tr>
<tr>
<td>2023</td>
<td>p+p</td>
<td>11.5</td>
<td>267 pb⁻¹</td>
</tr>
<tr>
<td>2023</td>
<td>p+Au</td>
<td>11.5</td>
<td>1.46 pb⁻¹</td>
</tr>
<tr>
<td>2024</td>
<td>Au+Au</td>
<td>23.5</td>
<td>88 nb⁻¹</td>
</tr>
<tr>
<td>2025</td>
<td>p+p</td>
<td>23.5</td>
<td>783 pb⁻¹</td>
</tr>
<tr>
<td>2026</td>
<td>Au+Au</td>
<td>23.5</td>
<td>92 nb⁻¹</td>
</tr>
</tbody>
</table>

Au+Au @ 200 GeV, |Z|<10 cm

Minimum Bias @ 15kHz
47B (2022) + 96B (2024) + 96B (2026) = 239 Billion Events

Level-1 Trigger (e.g. high pT photons)
550 Billion Events

Au+Au @ 15kHz, All Z
1.5 Trillion Events
**Quest for Gluon Spin**

**Drastic Improvement in statistics of Golden Probes**

**Jet**

**Direct -γ**

### STAR \( p+p \rightarrow \text{Jet+X} \)

- **2012 510 GeV \( \eta<0.9 \) Prelim.**
- **2009 200 GeV \( \eta<1.0 \)**
- Relative luminosity uncertainty
- LSS10p
- DSSV14
- NNPDF1.1

### sPHENIX proj.

- \( p+p \rightarrow \text{jet+X} \) \( \sqrt{s}=200 \text{ GeV} \)
- \( |\eta|<1.1 \)
- \( L=700 \text{ pb}^{-1} \) \( P=0.6 \)
- Theory curve: DSSV14

### PHENIX Run 6 PHENIX Preliminary

- GRSV max
- GRSV std
- GRSV g=0

8.3% scale uncertainty not included

### sPHENIX dir. \( \gamma \) proj.

- \( \sqrt{s}=200 \text{ GeV} \)
- \( |\eta|<1.1 \)
- \( L=700 \text{ pb}^{-1} \) \( P=0.6 \)
- Theory curve: DSSV14
Physics Goals From Cold QCD Plan

• **Key Physics Observables:**

  – **Jets in polarized p+p:**
    • Jet $A_N$: Sivers/Twist-3 for u/d quarks
    • Angular distribution in jets: transversity
    • Di-Jet $A_{LL}$: Dg at low-x

  – **nFF’s in p+A:**
    • Important measurement on the road to the EIC

  – **Drell-Yan and Direct Photons in p+A:**
    • Measurements of saturation, A-scan essential

  – **Diffraction in polarized p+p (200 GeV):**
    • $A_{UT}$ from single-diffractive events

  – **Ultraperipheral Collisions in p+Au:**
    • “p-shine”: gluon impact parameter distribution in Au nucleus via J/Y
    • “Au-shine”: access GPD $E_g$ in polarized p via J/Y production ($A_{UT}$)
      – Sets the scale for a program to measure GPD $E_g$ at the EIC!

Need Forward Rapidity Coverage!
BNL ALD has called for LOI’s – June 2017
20x20 array of 2.2 x 2.2 x 18 cm³ PbW (PHENIX MPC) crystals with 10x10 square hole (300 crystals total) 3.0-3.3 < η < 4.0

PHENIX PbSc modules (5.5 x 5.5 x 33 cm³) organized in groups of four modules (3152 modules or 788 groups of 4) (1.4 < η < 3.0-3.3), energy resolution 8%/√E

Flux return door between FEMC and FHCAL (10.2 cm)

PHENIX PbSc modules (5.5 x 5.5 x 33 cm³) organized in groups of four modules (3152 modules or 788 groups of 4) (1.4 < η < 3.0-3.3), energy resolution 8%/√E

Field shaper piston

Pb/Sc sandwich hadronic calorimeter (NEW) 10 x 10 x 100 cm³ towers (1.2 < η < 4.0)

GEM/sTGC Tracking Stations (z = 120, 165, 275 cm, 50-100 mm in φ, 1 cm in r)
Forward jet $\rightarrow$ origin of transverse $A_N$

Charge-track tagged jet asymmetry $\rightarrow$ Access Sivers effect

Charge-track asymmetry in jet $\rightarrow$ Access Transversity @ large $x$

$sPHENIX$ simulation

$p^\uparrow + p \rightarrow \text{jet}(h^\pm) + X, \sqrt{s} = 510 \text{ GeV}$

$3.0 < P_{T\text{jet}} < 4.0$

Check universality of Transversity @ SIDIS
Forward DY

- DY in p+A provides clean access to sea quark distribution → gluon in nuclei
- fsPHENIX measure DY via di-electron final states
- Benefit from continuous and large calorimetry + tracking coverages
Due to causality, correlations that are widely separated in rapidity probe the earliest times. Adding forward capabilities to sPHENIX will enable a new, complementary physics program to study the initial conditions in HI collisions.

De-correlation of the event plane can result from quantum fluctuations in the initial state. Need to understand this to be able to extract $\eta/s(T)$ from hydrodynamic models.
Documentations

- sPHENIX CDR
- Medium-Energy Nuclear Physics Measurements with the sPHENIX Barrel
- sPHENIX Forward Instrumentation LOI
Summary

• sPHENIX: Study QGP with precision jet and beauty quarkonia @ RHIC
  – Completing scientific mission @ RHIC

• Hadronic physics opportunities in sPHENIX and proposed forward detector upgrade
  – Complementarity of hadronic collisions and DIS, e.g. JLab, COMPASS, EIC

• sPHENIX received CD-0 approved, in preparation for CD-1. Planned data taking start 2022.

• sPHENIX detector has advanced design.
  – Forward upgrade and EIC: many opportunities for joint detector R&D
BACKUP SLIDES
Detector Configuration

- EM & Hadron Calorimeters

- # of Tracking stations
  - MAPS: 3
  - INTT: 4
  - TPC: 60

- Momentum Resolution ~100 MeV/c

- 15 kHz trigger
- 10 GB/s data logging
Kinematic Coverage

Measurements with $A \geq 56$ (Fe)
$W, Z^0$ pPb $\sqrt{s} = 5$ TeV:
- LHCb
- CMS / ATLAS
- ALICE
- $vA$ DIS
- DY (E772, E866)
- E906
- fsPHENIX pA DY
- eA DIS
- JLab-12 GeV

EIC $\sqrt{s} = 90$ GeV, $0.01 \leq y \leq 0.95$
EIC $\sqrt{s} = 45$ GeV, $0.01 \leq y \leq 0.95$