SPHERENIX Experiment Overview

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Measurements at RHIC & the LHC have shown: Quark-Gluon Plasma (QGP) behaves as an almost perfect fluid

- expansion governed by relativistic hydrodynamics
- lowest specific viscosity ($\eta/s$) of any known material!
larger pressure gradients in this direction

nearly frictionless expansion
Spatial anisotropies at time of QGP creation…

…momentum-space anisotropy in the final state

Flow magnitude
strongly-coupled, long-distance behavior

emergent near-perfect fluidity
short-distance, asymptotically free quarks and gluons

fundamental interaction & degrees of freedom exactly known

emergent near-perfect fluidity

QGP

strongly-coupled, long-distance behavior
How does the behavior of Quark-Gluon Plasma emerge from the microscopic QCD theory?
sPHENIX science

There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: (1) **Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales.** The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called **sPHENIX.** (2) **Map the phase diagram of QCD with experiments planned at RHIC.**

2015 US NP LRP

sPHENIX recognized by the U.S. Nuclear Physics community as an *essential* tool for QGP microscopy

→ new, unique capabilities not used before at RHIC!
Cold QCD study proton spin, transverse-momentum, and cold nuclear effects.

Jet structure vary momentum/angular scale of probe.

Parton energy loss vary mass/momentum of probe: u,d,s, c, gluon, b.

Quarkonium spectroscopy vary size of probe: \( \Upsilon(3s) \) 0.78fm, \( \Upsilon(2s) \) 0.56fm, \( \Upsilon(1s) \) 0.28fm.
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$\Upsilon(3s)\ 0.78\text{fm}$

$\Upsilon(2s)\ 0.56\text{fm}$

$\Upsilon(1s)\ 0.28\text{fm}$

Parton energy loss vary mass/momentum of probe:

- $u, d, s$
- $c$
- gluon
- $b$

Ejiro Umaka, 9/7, 1pm

Zhaozhong Shi, 9/8, 3:25pm
sPHENIX run plan (2023-2025)

Year-1

Commissioning the detector
First Au+Au collisions for physics!

Year-2

Transversely polarized $p+p$ and $p$+Au collisions:
vacuum baseline & reference for Au+Au physics
spin & “cold QCD” physics in their own right

Year-3

“Archival” high-luminosity Au+Au run

>140 billion fully min-bias Au+Au events(*) recorded to disk

(*) - $|z| < 10$cm, 28-cryoweek scenarios

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Table 1: Summary of the sPHENIX Beam Use Proposal for years 2023-2025, as requested in the charge. The values correspond to 24 cryo-week scenarios, while those in parentheses correspond to 28 cryo-week scenarios. The 10%-str values correspond to the modest streaming readout upgrade of the tracking detectors. Full details are provided in Chapter 2.

| Year  | Species | $\sqrt{s_{NN}}$ [GeV] | Cryo Weeks | Physics Weeks | Rec. Lum. $|z| <$10 cm | Samp. Lum. $|z| <$10 cm |
|-------|---------|------------------------|------------|--------------|-----------------|-----------------|
| 2023  | Au+Au   | 200                    | 24 (28)    | 9 (13)       | 3.7 (5.7) nb$^{-1}$ | 4.5 (6.9) nb$^{-1}$ |
| 2024  | $p^+p^+$ | 200                    | 24 (28)    | 12 (16)      | 0.3 (0.4) pb$^{-1}$ [5 kHz] | 45 (62) pb$^{-1}$ |
|       |         |                        |            |              | 4.5 (6.2) pb$^{-1}$ [10%-str] |                  |
| 2024  | $p^+Au$ | 200                    | –          | 5            | 0.003 pb$^{-1}$ [5 kHz] | 0.11 pb$^{-1}$ |
|       |         |                        |            |              | 0.01 pb$^{-1}$ [10%-str] |                  |
| 2025  | Au+Au   | 200                    | 24 (28)    | 20.5 (24.5)  | 13 (15) nb$^{-1}$  | 21 (25) nb$^{-1}$ |
sPHENIX detector

Key sPHENIX advantages for jet & HF probes at RHIC:
(1) large, hermetic acceptance, (2) huge data rate, (3) hadronic calorimeter, (4) precision tracking, (5) unbiased triggering in $p+p$

<table>
<thead>
<tr>
<th>First run year</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{S_{NN}}$ [GeV]</td>
<td>200</td>
</tr>
<tr>
<td>Trigger Rate [kHz]</td>
<td>15</td>
</tr>
<tr>
<td>Magnetic Field [T]</td>
<td>1.4</td>
</tr>
<tr>
<td>First active point [cm]</td>
<td>2.5</td>
</tr>
<tr>
<td>Outer radius [cm]</td>
<td>270</td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>$</td>
<td>z_{vtx}</td>
</tr>
<tr>
<td>N(AuAu) collisions*</td>
<td>$1.43 \times 10^{11}$</td>
</tr>
</tbody>
</table>

* In 3 years of running
sPHENIX Tracking

1. MAPS Vertex Detector (MVTX)
   - High-precision vertexing

2. Intermediate Silicon Strip Tracker (INTT)
   - High-precision timing for beam crossing

3. Time Projection Chamber (TPC)
   - High-precision momentum measurement

4. Time Projection Outer Tracker (TPOT)
   - Correct for TPC space-charge distortions
sPHENIX Tracking

MAPS Vertex Detector (MVTX)

**Completed half-sector at LBNL**

3 Layers of Monolithic Active Pixels (MAPs), small material budget

- Distance of Closest Approach (DCA) resolved at $< 10 \, \mu m$ for $p_T > 2 \, GeV$
- Essential to heavy flavor program
**sPHENIX Tracking**

*Half-sectors at BNL*

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**Intermediate Silicon Strip Tracker (INTT)**

- 4 Layer (2-hit) Silicon Strip Detector
  - Timing resolution \(~100\text{ns}\)
  - Resolves single RHIC bunch crossing & connects closer/further trackers
sPHENIX Tracking

Compact design, active region $30 < r < 78$ cm

- Gateless, employs GEMs to minimize ion backflow, continuous streaming readout
- Provides lever arm for momentum resolution

Time Projection Chamber (TPC)

TPC under assembly at Stony Brook
sPHENIX Tracking

Micromegas-based detector with 8 sectors

- Situated between TPC and EMCal
- Correct for beam-induced space charge distortions of the TPC

**TPC Outer Tracker (TPOT)**

*TPOT panels at Stony Brook*
sPHENIX Calorimetry

1. Electromagnetic Calorimeter (EMCal)
   • Enables, jet, and $ee$

2. Inner Hadronic Calorimeter (IHCal)
   • Inducing hadronic shower pre-magnet for jet measurement

3. BaBar Superconducting Magnet
   • Not an active part of the system but defines inner/outer HCal

4. Outer Hadronic Calorimeter (OHCal)
   • Primary detector of hadronic shower for jets
sPHENIX Calorimetry

10/32 sectors installed

Electromagnetic Calorimeter (EMCal)

Tungsten & scintillating fiber, 2-D projective design

- 0.025x0.025 towers, \(\sim 20 \, X_0, |\eta| < 1.1\), \(2\pi\) azimuthal acceptance

- 16%/\(\sqrt{E}\) resolution for photons (\(\gamma\), jets), electrons (\(\Upsilon\) spectroscopy)
sPHENIX Calorimetry

IHCal installation into OHCal+magnet

Inner & Outer Hadronic Calorimeter (HCal)

Aluminum (IHCal) or Steel (OHCal) interleaved w/ scintillating tiles

- ~5 $\lambda_0$ total, IHCal catches start of hadronic showers before magnet
- 0.1x0.1 segmentation & excellent energy resolution for jet measurements
GEANT4 simulation of Au+Au event in sPHENIX

Jet, HF, Quarkonia measurements happening in a large, fluctuating background with huge dynamic variations event by event!
sPHENIX Collaboration

More than 360 members from 82 institutions in 14 countries as of 2022

- steady growth since collaboration formation with 40 institutions
- world-class expertise in physics, silicon, TPCs, calorimeter, electronics, computing, …
Cold QCD study proton spin, transverse-momentum, and cold nuclear effects.

Jet structure vary momentum/angular scale of probe.

Quarkonium spectroscopy vary size of probe.

Parton energy loss vary mass/momentum of probe.

<table>
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<th>Quark</th>
<th>Size (fm)</th>
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u,d,s, c, gluon, b
Jet probes of the QGP

- vary momentum/angular scale of probe

Jet structure

sPHENIX is a dedicated jet detector for detailed studies of the parton shower - QGP interaction

- Capabilities enable a rich physics program with many channels!
- One example above: jet suppression at large cone size $R$

Ejiro Umaka, 9/7, 1pm
Upsilon spectroscopy

Sequential Upsilon dissociation: systematic probe of QGP temperature profile

- Precise tracking system designed to separate 1S, 2S, and 3S states
- Unique opportunity to observe $\Upsilon(3S)$ at RHIC!
Heavy flavor physics

Parton energy loss
vary mass/momentum of probe
u,d,s
c
b
gluon

Zhaozhong Shi, 9/8, 3:25pm

Heavy flavor hadron & jet program enabled by vertex detector & streaming readout

- In-medium modification of $D/B$ hadrons, and HF-tagged jets
- One example above: explore hadronization in nuclear medium
Cold QCD
study proton spin, transverse-momentum, and cold nuclear effects

p+A physics program

Collective behavior in small systems - a revolutionary discovery in heavy ion physics

⇒ sPHENIX will have new tools to investigate these phenomena - e.g. heavy flavor “flow” at RHIC energies

Also a dedicated “Cold QCD” physics program taking advantage of transversely polarized p beams

⇒ measurements looking towards Electron-Ion Collider at BNL!
Conclusion

- sPHENIX is a dedicated jet & heavy flavor physics detector for QGP microscopy, with new, purpose-built capabilities never deployed at RHIC

→ Complementary to LHC Run 3 program, while also breaking new ground in regions unique to sPHENIX

→ Major priority for U.S. Nuclear Physics community - finish the scientific mission of RHIC!

- Looking forward to commissioning & first data-taking next year in 2023!