Heavy Flavor & Quarkonia Measurements at sPHENIX

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for sPHENIX Collaboration
sPHENIX Mission

- A state-of-the-art jet detector; the first new detector at RHIC in >20 years.
- Completing the scientific mission of RHIC, as prioritized in DOE/NSF NSAC 2015 Nuclear Physics Long Range Plan.
- Complementarity in kinematics and medium property to LHC, also confirmed by ECFA WG5 (Heavy Ion group).
- sPHENIX as the highest priority for Runs 2023-2025 (PAC Report, Sep. 2020)
4 pillar physics topics, making use of very high statistics of jets & open/hidden heavy flavors over unprecedented kinematic range
- Scientific mission of sPHENIX can be achieved with 3 years of running.
- Consistent with the currently envisioned EIC schedule.
- If opportunity arises, additional runs can fully utilize the potential of the detector.
sPHENIX Detector

- High data rates: 15 kHz for all subdetectors
- 1.4 T Solenoid from BaBar
- Hermetic coverage: |η|<1.1
- Trigger capability also for pp with streaming readout
- High resolution vertexing with MVTX
- Large acceptance hadronic calorimetry for jets
  → brings first b-jet tagging at RHIC w/ MVTX!!
sPHENIX Tracking Detectors

Inner tracker:
- **MVTX**: Monolithic Active Pixel Sensors (3 layers)
  - Procurement copies of ALICE ITS IB staves integrated into sPHENIX
  - Precision vertexing
- **INTT**: strip pattern recognition, timing silicon sensors (2 layers)
- **DCA(\(r\phi\) or \(z\))** resolution < 50\(\mu\)m for \(p_T\) > 1 GeV/c

Outer tracker:
- **TPC**: 48 layers with gateless and continuous readout
  - Main tracking device; provide momentum measurement
- \(\delta p/p < 2\%\) for \(p_T < 10\) GeV/c
Impact of MVTX on Tracking

- Tracking efficiency above 90% at $p_T>1$ GeV/c. → promising to measure rare processes such as $\Upsilon(nS)$ production.
- DCA pointing resolutions in $r\phi$ & $z \sim 40\mu m$ at $p_T=0.5-1$ GeV/c. → crucial for open heavy-flavor programs.
- Momentum resolution < 2% for $p_T < 10$ GeV/c. → Important for $\Upsilon(nS)$ separation; $\delta M < 125$ MeV required.
sPHENIX EMCAL & Electron ID

- Tungsten/scintillating-fiber SPACAL. Radiation length ~7mm. Fits inside solenoid.
- Tower size $\Delta \eta \times \Delta \phi = 0.025 \times 0.025$. Resolution $\sim 16\% / \sqrt{E} \oplus 5\%$.
- Promising hadron (K/\pi/p) rejection factor with E/\rho requirement.

Electron ID @ 90% eff.
Upsilon $R_{AA}$

- sPHENIX can reconstruct Upsilon with excellent mass resolution.
- Measuring centrality & $p_T$ dependence of $R_{AA}$ is critical to compare with LHC.
- Measuring $\Upsilon(3S)$ modification will be challenging due to the large suppression.
  Feasibility checks ongoing for $\Upsilon(3S)$ modification.
QGP with Open Heavy-Flavor Quarks

• Comprehensive coverage in $p_T$ range:
  • $p_T \lesssim m_b$: diffusion of HQ (diffusion coeff. $D_s$)
  • $m_b \lesssim p_T \lesssim 10$ GeV: differential sensitivity to collisional energy loss, good probe for hadronization.
  • $p_T \gtrsim 10$ GeV: transition from collisional to radiative energy loss.

• sPHENIX brings precision measurements of $b$-quark sector to RHIC!
Streaming Readout & pp Program

- **Streaming readout**: triggerless configuration recording 10% of collisions. → increases amount of Run-24 data by orders of magnitude
  - Commended by PAC 2020 for this effort.

- Crucial for open heavy ion programs: i.e. enables to measure HF meson $R_{AA}$ instead of $R_{CP}$ as well as other qualitatively novel measurements

- Also brings other exciting opportunities for spin-dependent QCD; e.g. $D^0$ single spin asymmetry

![Graph](attachment:image.png)
B-meson Projections

• B mesons can be studied through their decay daughters (i.e. non-prompt D$^0$).
• Non-prompt D$^0$ suppression $\rightarrow$ collisional energy loss
• Determine b-quark flow $\rightarrow$ clean access to diffusion at RHIC
D^0 \nu_1 measurement

D^0 meson \nu_1 is sensitive to:

1. T-dependence of HQ diffusion coefficient
2. Geometrical tilt of QGP source
3. Initial magnetic field (from \( D^0/\bar{D}^0 \nu_1 \) difference)

1st observation of D^0 \nu_1 by STAR sPHENIX will provide high precision measurements
$\Lambda_c$ Hadronization

- $\Lambda_c/D^0$ significantly larger than the baseline Pythia calculation in pp, pA, AA. Important probe to understand the hadronization (coalescence model?).
- Charm baryons & charm-strange mesons give sizable contributions to the total charm xsec.
- sPHENIX will provide precision measurement at $p_T \sim 3-8$ GeV.
b-jet Identification

- The high-$p_T$ probe.
- RHIC has an advantage over LHC for having much less b-jets from gluon splitting ($g \to b\bar{b}$).

- Heavy flavor jets have distinct signatures with:
  - Tracks with large DCA
  - Presence of secondary vertex
  - Presence of displaced lepton

- Taggers making use of the first two features are investigated so far.
b-jet Identification

- Already compatible as CMS benchmark performance in Heavy Ion.
- Further studies ongoing to combine the two tagging schemes as well as making use of displaced leptons.
b-jet $R_{AA}$ & $v_2$ Projection

- sPHENIX brings precise inclusive b-jet $R_{AA}$ & $v_2$ measurements to RHIC.
- Strong constraints on the energy loss model.
b-jet Pairs

- Inclusive b-jets at RHIC are expected to originate from b-quarks (i.e. not from gluon splitting), but considering the correlation between two b-jets will further suppress those from the gluon splitting.

- Two ways to produce 1D integral of 2D di-jet distribution
  - Di-b-jet $p_T$ balance: sensitive to geometry fluctuation (our previous studies in the backup)
  - Di-b-jet mass: enhance sensitivity to transport property


Di-jet $2\sqrt{p_{T,1}p_{T,2}} \sim$ mass

Sensitivity is enhanced at RHIC!
**b-jet Pair Mass**

Inclusive b-jet

- Covers 35-70 GeV/c² in di-b-jet invariant mass.
- **Strong sensitivity to parton-QGP coupling.**
- x² effect against 10% variation on $g_{\text{med}}$!
b-jet Pair vs Light-jet Pair

- b-jet vs light-jet pair mass ratio has strong sensitivity to parton mass effect.
- Partial cancellation of experimental systematic uncertainties.
- 1-8 times enhancement on the mass effect against $g_{\text{med}}$ variations by taking this ratio.
- Will continue to be in close contact w/ theory community & look for more observables/strategies.
Summary

• sPHENIX brings precision measurements to b-quark sector at RHIC.
  • Upsilon to probe QGP with different size.
  • Comprehensively covers wide $p_T$ range for open heavy flavor
    → diffusion properties, hadronization, parton energy loss (collisional vs radiative)

• Beam Use Proposal submitted with the updated run program.

• PAC lists sPHENIX as the highest priority for Runs 23-25.

• Despite the challenges from COVID-19, the construction is progressing, targeting the first data in 2023.
Backup
sPHENIX Collaboration

- More than 320 members from 80 institutions in 13 countries (as of early 2020)
Schedule

Run plan updated in BUP 2020

Run 2026-2027, if opportunity arises

<table>
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<th>Year</th>
<th>Species</th>
<th>$\sqrt{s_{NN}}$ [GeV]</th>
<th>Cryo Weeks</th>
<th>Physics Weeks</th>
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<td>–</td>
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<td>30 nb$^{-1}$ [100%-str/DeMux]</td>
<td>30 nb$^{-1}$</td>
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Complementarity of RHIC & LHC
Tracking Performance

![Graph showing tracking performance vs. p_T (GeV/c)]
DCA Resolution

![Graphs showing DCA resolution vs. p_T (GeV/c) for 100 pion events with different conditions.](image-url)
Streaming Readout

The streaming data are recorded all the time, and broken up in chunks above threshold.

Only chunks correlated with triggered events are then kept.
Streaming Readout

Diagram showing the flow of data from various detectors and systems through a network switch, ending with buffer boxes and tape storage. The diagram includes Calorimeters, TPC, INT, MVTX, FEE, ROC, RU, DAM, EBDC, and SEB, with a structure indicating Trigger/Timing, Ethernet Switch, and Buffer Box.
b-jet Correlation – Early Studies

- Inclusive b-jets at RHIC are expected to originate from b-quarks (i.e. not from gluon splitting), but considering the correlation between two b-jets will further suppress those from the gluon splitting.

- Previous studies with truth. Studies to be updated & expanded with full simulation.