Quarkonium in sPHENIX

Marzia Rosati
Iowa State University
sPHENIX Physics Program

sPHENIX goal is to probe the QGP near $1\sim 2\ T_c$ and over a broad ranges of scales in the region of strongest coupling

- Jet inclusive spectra
- $\gamma$-jet correlations
- Heavy flavor jets & hadrons
- Separated
  $Y(1S), \ Y(2S), \ Y(3S)$ suppression

In this talk
sPHENIX Concept

- Uniform Acceptance \(|\eta| < 1\) \(\Delta \phi = 2\pi\)
- Superconducting magnet enabling high resolution tracking
- Compact electromagnetic calorimeter to allow fine segmentation at a small radius
- High data acquisition rate capability
- Hadronic calorimeter doubling as flux return
-1.1 < \eta < 1.1

2\pi azimuthal coverage

15 kHz MB trigger

Solenoidal magnetic field

B = 1.4 T
sPHENIX Tracking Detectors

Tracking currently consists of 4 sub-detectors; Pixel Vertex Detector (MVTX), Intermediate Silicon Tracker (INTT), Time Projection Chamber (TPC) and Time Projection Outer Tracker (TPOT)

- **MVTX** - precise track vertex
- **INTT** - timing & pattern recognition
- **TPC** - momentum measurement
- **TPOT** - calibration
sPHENIX Momentum Reconstruction

- **TPC**
  - Compact - 48 layers (30-78cm radius)
  - Gateless, continuous readout
  - Quad GEM electron multiplier + chevron readout pads
  - R-φ resolution ~ 150 μm
  - Δp/p~1% at 5 GeV/c

- **TPOT**
  - Uses micromegas for detection
  - Allows calibration of beam-induced space charge distortions

Momentum resolution of 100 MeV or better even in central collisions
sPHENIX Tracking

- Track finding in the TPC and silicon detectors is done separately.
- Track stubs are matched in $\eta$, $\phi$, position at the beamline.
- Multiple matches are resolved later, using fit quality.
- The reconstruction software goal: reconstruct Au+Au event in 10 seconds per event, including all calibrations.
- We have adopted the ACTS tracking package and final track fitting is done using ACTS Kalman Filter.
Simulated performance for minimum bias Hijing events with 50 KHz pileup rate + embedded 100 pions embedded 100 pions.

Y decay electrons region: efficiency ~94%
Simulated performance for minimum bias Hijing events with 50 KHz pileup rate + embedded 100 pions embedded 100 pions.

Y decay electrons region: resolution $\sim 1.2\%$
Electromagnetic Calorimeter

- Tungsten-scintillating fiber sampling calorimeter. 18 $X_0$, 1 $\lambda$
- $\Delta \eta \times \Delta \phi = 0.025 \times 0.025$
- Read out by silicon photomultipliers
- 2D projective geometry
- Small Moliere Radius, short radiation length


EMCAL block equipped with light guides and SiPMs
Electron/Pion Separation in EmCal

- Electrons/pions embedded in Min. Bias Au+Au HIjing events
- Electrons deposit most of the energy in EmCal (red) while pions (blue) only start showering in the inner HCal

![Graph showing energy deposition in EmCal and HCal for electrons and pions.](image)

- 90% electron efficiency

90% electron efficiency
Electron/Pion Separation in iHCal

- Electrons deposit most of the energy in EmCal and little deposited in iHCal (red) while pions (blue) start to shower in the iHCal.

- iHCal provides good rejection power, but overlaps with E/p rejection in EMCal, sophisticated multi-variable analysis study ongoing.
Trigger strategy

- The sPHENIX DAQ will record data at 15 KHZ.
  - Au+Au data will be recorded using minimum bias triggers.
  - p+p and p+Au data will be recorded using level 1 triggers.
    - The Y trigger will be an EMCal trigger based on the energy of the electrons and also pair invariant mass cut.

- Single cluster trigger efficiency and rejection in p+p simulations.
Upsilon Observables

- The observable we plan to measure $Y(1S), Y(2S), Y(3S)$ $R_{AA}$ as a function of collision centrality and $p_T$.

- Signal statistical precision that translates directly into $Y(1S), Y(2S), Y(3S)$ $R_{AA}$ and depends on
  - PID efficiency
  - Tracking efficiency and momentum resolution
  - Combinatorial and Correlated Backgrounds (semileptonic decays of $b,c$ hadrons and Drell Yan)
Opposite sign $e^+e^-$ invariant mass, signal only

$\gamma(1S,2S,3S) \rightarrow e^+e^-$
Simulated mass spectrum in 0-10% central Au+Au collisions.

- Before like-sign background subtraction.
Upsilon $R_{AuAu}$ vs $p_T$

$sPHENIX$ Projection 0-10% Au+Au, Years 1-3
- Y(1S) 62 pb$^{-1}$ samp. $p+p$
- Y(2S) 21 nb$^{-1}$ rec. Au+Au

Strickland, Bazow N.P. A879 (2012)25
Using expected luminosity from Au+Au runs in 2023 and 2025 and p+p run in 2024.

In the Strickland-Bazow model the Y(3S) state is so heavily suppressed that it is weaker than the estimated Drell Yan background.
Recently observed by CMS Y(3S) suppression < theory prediction: $R_{AA}(3S)/R_{AA}(2S) \approx 0.5$ at the LHC, we can project an observable yield for Y(3S)
This measurement serves as a baseline for the Au+Au measurement.
The modification of the Y yields in p+Au collisions is a measure of cold nuclear matter effects, not well constrained theoretically.

CNM effects include:
- Gluon shadowing (nPDF’s), CGC.
- Initial state parton energy loss
- Nuclear “absorption” i.e. collisions with target nucleons.
Summary

- The goal is for sPHENIX to provide precise measurements of the Y(1S) and Y(2S) invariant yields in Au+Au, p+Au and p+p collisions.

- If suppression is smaller than predicted, as at the LHC, we will be able to make the first measurement of the Y(3S) yield at RHIC.

- These measurements will be complementary to measurements by the LHC experiments at higher collision energies.
  - Different initial temperatures.
  - Different underlying bottom production cross sections.

- We are in the process of optimizing the reconstruction and electron identification analysis tools needed for this measurement.

- We will be ready for first beam in February!
Backup
Tracking System

Tracking system: MVTX + INTT + TPC + TPOT
Other Theory Comparison

See X. Yao, B. Mueller, arXiv:1811.09644
Run Plan

| 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) $pb^{-1}$ [5kHz] | 4.5 (6.2) $pb^{-1}$ [10%-str] |
| 2024 | $p^{+}$+Au | 200                   | –          | 5             | 0.003 $pb^{-1}$ [5kHz] | 0.02 $pb^{-1}$ [10%-str] |
| 2025 | Au+Au     | 200                   | 24 (28)    | 20.5 (24.5)   | 13 (15) $nb^{-1}$ | 21 (25) $nb^{-1}$ |

2023: Commissioning high multiplicity Au+Au run

2024: Commissioning $p+p$

$p^{+}p$, $p$+Au: HI reference set and cold QCD

2025: Very large Au+Au heavy-ion set for jet and heavy flavor physics

141 B events recorded in total