The sPHENIX Experiment

Anthony D Frawley
Florida State University

For the sPHENIX Collaboration

RHIC/AGS User’s Meeting
June 12-15, 2018
RHIC and LHC Measurements are Complementary

Initial conditions and QGP evolution at RHIC and LHC are different!

- Use combined data to extract \( T \) dependence

The QGP spends more time near \( T_c \) at RHIC energy


The structure of the QGP is expected to depend on temperature
Complementary Kinematic Reach

Low pT at RHIC

High pT at LHC

- RHIC Today
- RHIC Tomorrow
- LHC Today
- LHC Tomorrow

R_{AA}

- Hadrons
- Jets
- D Mesons
- B Mesons
- b Jets

X+Jet

- Envelope-based measurements
- x+hadron correlations
- add low p_T reach

- Dijets (p_T,1)
- γ+Jets (p_Tγ)
- Z^0+Jets (p_TZ)
- Double b-Tag (p_T,1)
Overlaps $\rightarrow$ same probe, different QGP evolution

Low pT at RHIC

High pT at LHC

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**RHIC Today**

**RHIC Tomorrow**

**LHC Today**

**LHC Tomorrow**

- **R_AA**
  - **Hadrons**
  - **Jets**
  - **D Mesons**
  - **B Mesons**
  - **b Jets**

- **X+Jet**
  - **Dijets ($p_T$)**
  - **γ+Jets ($p_T^\gamma$)**
  - **Z^0+Jets ($p_T^Z$)**
  - **Double b-Tag ($p_T^{b\bar{b}}$)**

**$p_T$ [GeV/c]**

- 10
- 10^2
- 10^3

**Ensemble-based measurements and x+hadron correlations add low p_T reach**
The sPHENIX Physics Program

The sPHENIX physics program has three major legs with the goal of studying these in p+p, p+Au and Au+Au collisions:

- **Jets**
- **Upsilon**s
- **Heavy flavor**

sPHENIX Collaboration
sPHENIX

- outer HCal
- inner HCal
- INTT & MVTX
- solenoid
- EMCaCal
- TPC
-1.1 < η < 1.1
2π azimuthal coverage
15 kHz MB trigger

Solenoidal magnetic field
B = 1.4 T
Timeline
CD0 Review - Sep 2016
CD1 Review - May 2018
Installation complete - 2022
Running - 2023
The Tracking detectors

**Functions:**

**TPC** - momentum measurement

**MVTX** - precise track vertex

**INTT** - timing & pattern recognition
The Tracking detectors

**TPC** - Gateless, continuous readout
- 90:10 Ne-CF4 gas - low diffusion + high ion mobility
- Electron drift velocity 8 cm/μs - 13.2 μs maximum drift time
- Quad GEM electron multiplier + chevron readout pads
- 40 layer readout covering 30 - 78 cm radius
- R-φ resolution ~ 150 μm
- Δp/p ~ 1% at 5 GeV/c

**INTT** - Silicon strips with 80 μm pitch
- 4 layers 6 < R < 12 cm
- Pitch 78 μm
- Fast - can resolve one beam crossing

**MVTX** - 30 μm pitch MAPS pixels
- 3 layers 2.3 < R < 3.9 cm
- ~ 5 μm space point precision each
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Integration windows / events:

<table>
<thead>
<tr>
<th></th>
<th>Window</th>
<th>Au+Au</th>
<th>p+p</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC</td>
<td>± 13.2</td>
<td>5</td>
<td>343</td>
</tr>
<tr>
<td>MVTX</td>
<td>± 5</td>
<td>2</td>
<td>130</td>
</tr>
<tr>
<td>INTT</td>
<td>-.02 +.08</td>
<td>1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

This event “pileup” is properly included in all simulations

The INTT’s main function is to resolve ambiguities due to pileup
Tracking Performance

Simulated performance for
• Low occupancy events (100 pions)
• 0-4 fm Hijing Au+Au + 200 kHz event rate
  • (0-7% central, 100 pions embedded)

Have not yet implemented clustering designed to handle overlaps
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• 0-4 fm Hijing Au+Au + 200 kHz event rate
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designed to handle overlaps
Calorimeters

**EMCal**
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
Energy resolution $\leq 16\%/\sqrt{E}$ @ 5%

**HCal**
Sampling calorimeter
Magnet steel plates / scintillator tiles
3.8 $\lambda$
$\Delta \eta \times \Delta \phi = 0.1 \times 0.1$
Read out by silicon photomultipliers
Doubles as the flux return for the solenoid
Jet Physics Motivation

Broad goal
- understand coupling of the medium, origin of the coupling, and mechanism of rapid equilibration

sPHENIX will provide strong complementarity with the jet program at LHC:

Smaller underlying event activity
- Jets can be reconstructed to lower $p_T$
  - Probes longer distance scales
  - Smaller virtuality

Jets evolve in a QGP that is closer to $T_C$ at RHIC
- More sensitivity to 1-2 $T_C$

Different admixture of quark and gluon jets at RHIC
Jet Measurements

Di-jet asymmetry
• Sensitive to jet quenching in QGP

Photon-jet correlations
• How much energy is lost from the jet cone?
• Photon provides good access to parent parton of associated jet

Jet fragmentation functions
• How is the parton shower modified in the medium?
Photon Reconstruction Performance

Full GEANT 4 simulation of photons in 2D projective EMCal

$E_{\text{reco}}/E_{\text{true}}$

$E_{\text{reco}}$ vs $E_{\text{true}}$ for single photons vs photons embedded in $b=0$-4 fm Au+Au events

32 GeV $\gamma$, single
32 GeV $\gamma$, in central HI, $E_{\text{cl}}$
32 GeV $\gamma$, in central HI, $E_{\text{core}}$

Energy resolution for photons in Hijing events
• Constrained by beam test measurements

Joe Osborn (UM)
Jet Reconstruction Performance

Full GEANT 4 simulation of jets embedded in central Hijing events
- Test of underlying event estimations and background subtraction

Jet $p_T$ resolution in $b=0$-4 fm Au+Au events for different cone sizes
- Anti-kT algorithm with FastJet package

Truth level and reconstructed photon-jet $p_T$ ratio
Heavy Flavor Physics Motivation

Heavy quarks are sensitive to different energy loss mechanisms

Also sensitive to momentum

We want to measure bottom from low to high momentum
  • Precise measurement of track origin
  • High luminosity
Tagging $b$ - Jets

Two methods provide complementarity and cross checks

**Large DCA:**
Count tracks with DCA outside a cut relative to the event vertex

**Secondary Vertex:**
Reconstruct secondary vertex within jet
Heavy Flavor Measurements

Measure B hadrons through displaced vertex secondaries, or through complete reconstruction.

<table>
<thead>
<tr>
<th>Hadron</th>
<th>Abundance</th>
<th>ct (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0$</td>
<td>61%</td>
<td>123</td>
</tr>
<tr>
<td>$D^+$</td>
<td>24%</td>
<td>312</td>
</tr>
<tr>
<td>$D_s$</td>
<td>8%</td>
<td>150</td>
</tr>
<tr>
<td>$\Lambda_c$</td>
<td>6%</td>
<td>60</td>
</tr>
<tr>
<td>$B^+$</td>
<td>40%</td>
<td>491</td>
</tr>
<tr>
<td>$B^0$</td>
<td>40%</td>
<td>455</td>
</tr>
<tr>
<td>$B_s$</td>
<td>10%</td>
<td>453</td>
</tr>
<tr>
<td>$\Lambda_b$</td>
<td>10%</td>
<td>435</td>
</tr>
</tbody>
</table>

$$B \rightarrow \bar{D}^0 + X$$

$$B^+ \rightarrow \bar{D}^0 \pi^+$$

<table>
<thead>
<tr>
<th>Hadron</th>
<th>Decay Channel</th>
<th>B.R.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$-hadron admixture</td>
<td>$D^0$ + anything</td>
<td>$(59.5 \pm 2.9)$ %</td>
</tr>
<tr>
<td></td>
<td>$J/\psi$ + anything</td>
<td>$(1.16 \pm 0.10)$ %</td>
</tr>
<tr>
<td></td>
<td>$e^-$ + anything</td>
<td>$(10.86 \pm 0.35)$ %</td>
</tr>
<tr>
<td>$B^+$</td>
<td>$\bar{D}^0 + \pi^+$</td>
<td>$(0.480 \pm 0.015)$ %</td>
</tr>
<tr>
<td></td>
<td>$J/\psi + K^+$</td>
<td>$(0.103 \pm 0.003)$ %</td>
</tr>
</tbody>
</table>
Heavy flavor Measurements

Non-prompt $D^0$

$B^+$ reconstruction
Performance for heavy flavor

Full GEANT 4 simulation of HF decays embedded in central Hijing events

(Left) Precision of $R_{CP}$ for non-prompt and prompt $D^0$

(Right) Precision of $R_{AA}$ for b-jets

(Left) Precision of $v_2$ for non-prompt and prompt $D^0$

(Right) for reconstructed b-jets
Upsilon Physics Motivation

Three states with very different binding energy and radii
  • All with experimentally observable dilepton decay yields
  • Different sensitivity to QGP conditions

Complementary to LHC:
  • Samples QGP in different temperature region
  • Underlying b+b yield is very different
    • ~ 0.05 / Au+Au event at RHIC
    • ~ 5 / Pb+Pb event at LHC
  • Minimal coalescence at hadronization at RHIC
Upsilon Measurements

Simulated mass spectrum in p+p collisions (left).

CMS data for p+p, Pb+Pb (right).

Simulated mass spectrum in 0-10% central Au+Au collisions.

- Suppression taken from Strickland & Bazow.
## Multi-year sPHENIX run plan

- Guidance from ALD to think in terms of a multi-year run plan
- Consistent with language in DOE CD-0 “mission need” document
- Based on BNL C-AD guidance on projected luminosity
- Incorporates commissioning time in first year
- Structured so that first three years delivers at least minimum science program

### Minimum bias Au+Au at 15 kHz for |z| < 10 cm:

47 billion (Year-1) + 96 billion (Year-2) + 96 billion (Year-3) = Total 239 billion events

For topics with Level-1 selective trigger (e.g. high \( p_T \) photons), one can sample within \( |z| < 10 \) cm a total of 550 billion events. One could sample events over a wider z-vertex for calorimeter only measurements, 1.5 trillion events.

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<tbody>
<tr>
<td>Year-1</td>
<td>Au+Au</td>
<td>200</td>
<td>16.0</td>
<td>7 nb(^{-1})</td>
<td>8.7 nb(^{-1})</td>
<td>34 nb(^{-1})</td>
</tr>
<tr>
<td>Year-2</td>
<td>p+p</td>
<td>200</td>
<td>11.5</td>
<td>—</td>
<td>48 pb(^{-1})</td>
<td>267 pb(^{-1})</td>
</tr>
<tr>
<td>Year-2</td>
<td>p+Au</td>
<td>200</td>
<td>11.5</td>
<td>—</td>
<td>0.33 pb(^{-1})</td>
<td>1.46 pb(^{-1})</td>
</tr>
<tr>
<td>Year-3</td>
<td>Au+Au</td>
<td>200</td>
<td>23.5</td>
<td>14 nb(^{-1})</td>
<td>26 nb(^{-1})</td>
<td>88 nb(^{-1})</td>
</tr>
<tr>
<td>Year-4</td>
<td>p+p</td>
<td>200</td>
<td>23.5</td>
<td>—</td>
<td>149 pb(^{-1})</td>
<td>783 pb(^{-1})</td>
</tr>
<tr>
<td>Year-5</td>
<td>Au+Au</td>
<td>200</td>
<td>23.5</td>
<td>14 nb(^{-1})</td>
<td>48 nb(^{-1})</td>
<td>92 nb(^{-1})</td>
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47 \text{ billion (Year-1)} + 96 \text{ billion (Year-3)} + 96 \text{ billion (Year-5)} = \text{Total 239 billion events}

For topics with Level-1 selective trigger (e.g. high \(p_T\) photons), one can sample within \(|z| < 10 \text{ cm}\) a total of 550 billion events. One could sample events over a wider \(z\)-vertex for calorimeter only measurements, 1.5 trillion events.
Marching toward reality

- Magnet successfully tested to full current
- Contract awarded for full order of oHCal steel
- Full chain tests of calorimeter stack, MVTX telescope, INTT telescope, readout electronics
- TPC prototype to see test beam next week
R&D well underway for all detectors

MVTX & INTT test beam at FNAL
- February, March 2018

MVTX 4 sensor telescope
+ full readout chain

INTT telescope

TPC chevron pad plane
R&D well underway for all detectors

*Block production begins this month for a pre-production EMCal sector*

Setup for Calorimeters beam test at FNAL Feb-March 2018

*Setup to be used for HCal tile testing during production*
From Christine Aidala’s PAC presentation on June 7

- Solenoid
- Flux return
- Central tracking
- Electromagnetic calorimeter
- Hadron calorimeter
Solenoid															Flux	return
Electromagnetic	calorimeter
Hadron	calorimeter
Central	tracking
Forward/backward	tracking
Particle	ID
Conclusions and outlook

• An EIC detector based on sPHENIX can address the full physics program of the facility, spanning inclusive, semi-inclusive, and exclusive measurements.

• Efforts have ramped up investigating realistic possible implementations—lots of technical progress since 2014 LOI.

• Delivery of LOI in September will mark a milestone within ongoing work toward an EIC detector based on sPHENIX.
Collaboration

Growing collaboration - number of institutions is now > 70

Collaboration meeting June 5-6 had > 50 participants

On May 23-25 we had a very positive DOE OPA CD1/3A review!
We welcome new collaborators! There are many opportunities to contribute to the physics program and to detector R&D and construction.