PHENIX results on elliptic and triangular flow at midrapidity in d+Au collisions from 19.6 to 200 GeV

Julia Velkovska

VANDERBILT UNIVERSITY

PHENIX

Quark Matter 2017
Collectivity in small systems at RHIC: geometry engineering at 200 GeV

- Hydrodynamics works!
- AMPT: weakly coupled partonic cascade+quark coallescence+hadronic cascade also works at low $p_T$. Why?
- What other knobs can we turn to understand the origin?
Why study small systems in a BES?

- The time spent in QGP is reduced with energy
- BES gives a good handle to understand the role of pre-equilibrium and hadronic flow
- Study of the pseudorapidity dependence
  - to gain insight in the longitudinal dynamics
  - discriminate between initial state models
- Run 16 d+Au: 200, 62, 39, 20 GeV
Experimental methods in PHENIX

Event plane: determined at large backward pseudorapidity
Particles: tracked over a large pseudorapidity range

Or

2-particle correlations comprised of:
1) particle at midrapidity
2) energy cluster in BBC
3) tracks in FVTX

pair amplitude modulation

\[ c_n = v_n^a \times v_n^b \]
d+Au at 200 GeV: 2-particle correlations

Central Arms

FVTX-South

FVTX-North

BBC-South

BBC-North

Julia Velkovska, QM 2017
d+Au at 200 GeV: 2-particle correlations

Central Arms

<table>
<thead>
<tr>
<th>关键技术点1</th>
<th>关键技术点2</th>
<th>关键技术点3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVTX-South</td>
<td>FVTX-North</td>
<td>Central Arms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>关键技术点1</th>
<th>关键技术点2</th>
<th>关键技术点3</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.9 &lt; η &lt; -3.1</td>
<td>3.1 &lt; η &lt; 3.9</td>
<td>1 &lt; η &lt; 3</td>
</tr>
</tbody>
</table>

Julia Velkovska, QM 2017
d+Au at 200 GeV: 2-particle correlations

Central Arms

FVTX-South

FVTX-North

BBC-South

BBC-North

Julia Velkovska, QM 2017
A clear ridge is seen with all detector combinations, even for $\Delta \eta > 6.2$. 

**d+Au at 200 GeV: 2-particle correlations**

Central Arms

- $|\eta| < 0.35$
- $-3 < \eta < -1$
- $1 < \eta < 3$
- $-3.9 < \eta < -3.1$
- $3.1 < \eta < 3.9$

**Detector Combinations**
- FVTX-South
- FVTX-North
- BBC-South
- BBC-North
Energy dependence of ridge in d+Au

200 GeV  62 GeV  39 GeV  20 GeV

Central Arms

FVTX-South

BBC-South

FVTX-North

BBC-North

Julia Velkovska, QM 2017
Energy dependence of ridge in d+Au

The $c_2$ amplitude decreases with energy, but so do multiplicity and resolution.
We use this detector to measure the event plane.

To optimize Resolution, we use:
- Central Arms
- FVTX-South
- BBC-South
Midrapidity event-plane measurements of $v_2$

200 GeV  

62 GeV  

39 GeV  

20 GeV

Nearly identical  

Increase at high $p_T$?
Event plane measurements of $v_2$

Nearly identical
Well described by hydro
No clear trend with preflow

Increase at high $p_T$ ?
Nonflow ?

Julia Velkovska, QM 2017
Triangular flow at 200 GeV in different systems: insights about the role of preflow

\( v_2 \) in \( d/^{3}\text{He}+ \text{Au} \)

Nearly identical

\( v_3 \) smaller in \( d+\text{Au} \)

See talk by Qiao Xu: Wed 11:20, Session 6.1
Triangular flow at 200 GeV in different systems: insights about the role of preflow

\( v_2 \) in \( d/^{3}\text{He}+ \text{Au} \)
Nearly identical

\( v_3 \) smaller in \( d+ \text{Au} \)

- Trends well described with hydro without preflow
Is there pre-equilibrium flow?

Preflow seems not important at 200 GeV

Julia Velkovska, QM 2017
Nonflow correlations: insights from AMPT

- Evidence for collective effects down to 39 GeV
- Nonflow correlations at 20 GeV require further studies
\(v_2\) vs \(\eta\): analysis method

- We want to measure integrated \(v_2\) (\(0 < p_T < \infty\))
- No \(p_T\) information available from FVTX
- Devise a correction based on AMPT
\( v_2 \text{ vs } \eta \)

- **Forward:** similar values at all \( \sqrt{s_{NN}} \)
- **Backward:** decrease with \( \sqrt{s_{NN}} \)

**200 GeV**

\[
\text{d+Au } \sqrt{s_{NN}} = 200 \text{ GeV 0-5\%} \quad (a)
\]

**62.4 GeV**

\[
\text{d+Au } \sqrt{s_{NN}} = 62.4 \text{ GeV 0-5\%} \quad (b)
\]

**39 GeV**

\[
\text{d+Au } \sqrt{s_{NN}} = 39 \text{ GeV 0-10\%} \quad (c)
\]

Julia Velkovska, QM 2017
Insights from AMPT

- Forward: well described at all $\sqrt{s_{NN}}$
- Backward: AMPT deviates from data at low energy

Julia Velkovska, QM 2017
Insights from AMPT

- Flow dominates at forward and middle pseudorapidity

Julia Velkovska, QM 2017
Summary

• In d+Au BES clear collective effects are observed in central collisions down to 39 GeV
• Interesting interplay between flow and nonflow correlations at 39 and 20 GeV d+Au
• Indication of flow in 20 GeV d+Au from $v_2\{4\}$
• At 200 GeV in d/$^3$He+Au collisions elliptic and triangular flow are well described with viscous hydrodynamics with small $\eta/s$
  – preflow contributions seem insignificant
• Stay tuned for more results at the lower energies
BACKUP
Run 16 d+Au BES: Event Sample Size

<table>
<thead>
<tr>
<th>Energy</th>
<th>Number of Central Events Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 GeV</td>
<td>15 Million</td>
</tr>
<tr>
<td>39 GeV</td>
<td>137 Million</td>
</tr>
<tr>
<td>62.4 GeV</td>
<td>131 Million</td>
</tr>
<tr>
<td>200 GeV</td>
<td>636 Million</td>
</tr>
</tbody>
</table>

Julia Velkovska, QM 2017
Nonflow correlations: insights from AMPT

200 GeV
62 GeV
39 GeV
20 GeV

Julia Velkovska, QM 2017
Pure Flow
With Non-Flow
All Non-Flow

Julia Velkovska, QM 2017
$v_2$ vs $\eta$: analysis method

We use this detector to measure the event plane

- $-3 < \eta < -1$
- $1 < \eta < 3$
- $|\eta| < 0.35$

1. d+Au collisions generated with AMPT
   - Determine parton-plane angle, "true" $\psi_2$
   - Use all final-state charged particles to determine "true" $v_2(\eta)$

2. reconstruct events with full GEANT simulation in PHENIX
   - Analyze using final-state particles in the PHENIX acceptance to get $v_2(\eta)$

Correction factor = $v_2$ from step (2)/ (1)

- Apply correction to data $v_2(\eta)$
- Change the AMPT input parton cross section (and resulting $v_2$) → repeat
- Change the input $p_T$ spectra → repeat

Julia Velkovska, QM 2017
Table 6: Summary of the systematic uncertainties on the $v_2$ vs $p_T$ measurements at 200, 62.4, and 39 GeV.

<table>
<thead>
<tr>
<th>Sys</th>
<th>200</th>
<th>62.4</th>
<th>39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double interactions</td>
<td>$+9.4%$</td>
<td>$&lt; 1%$</td>
<td>$&lt; 1%$</td>
</tr>
<tr>
<td>Event Plane</td>
<td>$4.5%$</td>
<td>$4.5%$</td>
<td>$4.5%$</td>
</tr>
<tr>
<td>East vs West</td>
<td>$1.6%$</td>
<td>$3.6%$</td>
<td>$5.9%$</td>
</tr>
<tr>
<td>PC3 Match</td>
<td>$1%$</td>
<td>$1%$</td>
<td>$1%$</td>
</tr>
<tr>
<td>$\phi$ shift</td>
<td>$1%$</td>
<td>$1%$</td>
<td>$10% \ p_T &lt; 1 \text{ and } 5% \ p_T &gt; 1$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$+10.6%$</td>
<td>$\pm 5.8%$</td>
<td>$\pm 7.5%$</td>
</tr>
</tbody>
</table>

Table 8: A summary of the systematic uncertainties applied to the measurement of $v_2$ vs $\eta$ in 200, 62.4, and 39 GeV $d+Au$ collisions.

<table>
<thead>
<tr>
<th>Sys</th>
<th>Type</th>
<th>200</th>
<th>62</th>
<th>39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Interactions</td>
<td>B</td>
<td>$+2%$</td>
<td>$&lt; 1%$</td>
<td>$&lt; 1%$</td>
</tr>
<tr>
<td>Event Plane</td>
<td>B</td>
<td>$4.8%$</td>
<td>$4.8%$</td>
<td>$4.8%$</td>
</tr>
<tr>
<td>Fake Tracks</td>
<td>B</td>
<td>$3.3%$</td>
<td>$3.3%$</td>
<td>$3.3%$</td>
</tr>
<tr>
<td>E vs W</td>
<td>B</td>
<td>$1.6%$</td>
<td>$3.6%$</td>
<td>$5.9%$</td>
</tr>
<tr>
<td>AMPT correction</td>
<td>B</td>
<td>$\sim 0 - 3%$</td>
<td>$\sim 0 - 3%$</td>
<td>$\sim 0 - 3%$</td>
</tr>
<tr>
<td><strong>Total (approx.)</strong></td>
<td>B</td>
<td>$+8%$</td>
<td>$\pm 8%$</td>
<td>$\pm 9%$</td>
</tr>
</tbody>
</table>