Energy dependence of the freeze out eccentricity from azimuthal dependence of HBT at STAR

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Outline

• Introduction and motivation
• Analysis methods
• Results
• Model Comparisons
• Summary and outlook
**Time evolution of the collision geometry**

- Initial out-of-plane eccentricity
- Stronger in-plane pressure gradients drive preferential in-plane expansion
- Longer lifetimes or stronger pressure gradients cause more expansion and more spherical freeze-out shape
- We want to measure the eccentricity at freeze out, $\varepsilon_F$, as a function of energy using azimuthal HBT:

\[
\varepsilon_F = \frac{R_y^2 - R_x^2}{R_y^2 + R_x^2}
\]

- Non-monotonic behavior could indicate a soft point in the equation of state.

<table>
<thead>
<tr>
<th>Spatial eccentricity</th>
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</thead>
<tbody>
<tr>
<td>0 fm/c</td>
</tr>
<tr>
<td>2 fm/c</td>
</tr>
<tr>
<td>4 fm/c</td>
</tr>
<tr>
<td>6 fm/c</td>
</tr>
<tr>
<td>8 fm/c</td>
</tr>
</tbody>
</table>

With 1\textsuperscript{st} order P.T.  Without 1\textsuperscript{st} Order P.T.

Reference: Kolb and Heinz, 2003, nucl-th/0305084
Motivation

Excitation function for freeze out eccentricity, $\varepsilon_f$

- Non-monotonic behavior may indicate interesting physics.
- Excitation function can constrain models.

Coordinate system (out-side-long)

- Particles from similar source region tend to have similar momentum.

- Project $\vec{q}$ onto out-side-long coordinates.

- The same event distribution, $N(\vec{q})$, has enhancement near $q = 0$.

- The mixed event distribution, $D(q)$, has no enhancement.

- The correlation function is

$$C(q_o, q_s, q_l) = \frac{N(\vec{q})}{D(\vec{q})}$$

$$\vec{k}_t = \frac{1}{2} (\vec{p}_{t1} + \vec{p}_{t2})$$

$$\vec{q} = \vec{p}_1 - \vec{p}_2$$
Event plane resolution and finite angular bins

Oscillations reduced by
• reaction plane resolution
  \[ \langle \cos \left[ 2 (\Psi_m - \Psi_R) \right] \rangle \]
• and finite angular bins
  \[ \sin \left( n \frac{\Delta}{2} \right) \]

\[ n \frac{\Delta}{2} \]

Reaction plane resolution vs. Centrality

\[ R^2_{\text{out}} \]

\[ N(\vec{q}) \]

\[ 0 \quad 45 \quad 90 \quad 135 \quad 180 \]

\[ 0 \quad 1 \]

\[ 0 \quad 200 \text{ GeV} \]
\[ 62.4 \text{ GeV} \]
\[ 39 \text{ GeV} \]
\[ 11 \text{ GeV} \]
\[ 7.7 \text{ GeV} \]
Fitting procedure

\[ C(q_o, q_s, q_l) = \frac{N(\vec{q})}{D(\vec{q})} = (1 - \lambda) + \lambda K_{\text{Coul}}(q_{inv})(1 + e^{-q_o^2 R_o^2 - q_s^2 R_s^2 - q_l^2 R_l^2 - 2q_o q_s R_{os}}) \]

Centrality = 30-80%  \quad Kt = 0

Au+Au 200 GeV

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\[ C_{\text{out}}(\Phi) \]

\[ C_{\text{side}}(\Phi) \]

\[ C_{\text{long}}(\Phi) \]

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Computing Fourier Coefficients

Fourier coefficients computed from radii:

\[ R_{0,i}^2 = \frac{1}{N_{\text{bins}}} \sum_{j=1}^{N_{\text{bins}}} R_i^2(\Phi_j) \quad i = o, s, l, os \]

\[ R_{2,i}^2 = \frac{1}{N_{\text{bins}}} \sum_{j=1}^{N_{\text{bins}}} R_i^2(\Phi_j) \cos(2 \Phi_j) \quad i = o, s, l \]

\[ R_{2,i}^2 = \frac{1}{N_{\text{bins}}} \sum_{j=1}^{N_{\text{bins}}} R_i^2(\Phi_j) \sin(2 \Phi_j) \quad i = os \]

\[ \varepsilon_F = \frac{R_y^2 - R_x^2}{R_y^2 + R_x^2} \approx 2 \frac{R_{2,s}^2}{R_{0,s}^2} \]

Reference: Lisa, Retiere, Phys. Rev. C, 70, 044907
Centrality dependence of $\epsilon_F$

- Peripheral events remain more out-of-plane extended than central events.
Evolution of participant zone shape

- The shape evolves more for higher energy in the 7 – 39 GeV range.
- Results remain similar to 39 GeV at higher energies.
- Central events evolve less than peripheral.
- Similar trend with centrality for all energies.
Energy dependence of $\varepsilon_F$

Excitation function for freeze out eccentricity, $\varepsilon_f$

- BES results exclude a gradual rise in $\varepsilon_F$ at higher energies.
- Any minimum near 17 GeV is constrained to be between 11.5 to 39 GeV.
- New 19.6 GeV data has been taken, 27 GeV is requested for 2012.
UrQMD generally predicts the trend seen in the STAR data.

Model Comparisons

Excitation function for freeze out eccentricity, $\varepsilon_f$

$K_t = 0.15-0.6$ GeV/c

*Model centralities correspond to data

- UrQMD appears to predict the STAR data most closely.
- All models predict monotonic decrease with energy.

Summary and outlook

- Azimuthal HBT searches for signals of a phase transition.

- The current Beam Energy Scan results do not show a gradual downward trend toward the CERES point on the excitation function but don't exclude a minimum.

- Taken alone, STAR results are consistent with a monotonic decrease in the freeze-out eccentricity with increasing collision energy.

- Any minimum is constrained to the range between 11.5 and 39 GeV.

- UrQMD appears to best describe the STAR results.

- STAR's new 19.6 GeV data set will provide data near the point at 17.3 GeV allowing to determine if a minimum is observed when the excitation function is measured using a single detector.

- A 27 GeV run is requested for 2012.
Backup slides
STAR 5-30% includes 10% more central + 5% more peripheral than CERES 15-25%. The error bar for CERES 15-25% is larger in this case. This is the case where no weights are applied to account for the centrality bin widths so the STAR values are the lowest of the possible cases.
## Data Sets and Cuts

<table>
<thead>
<tr>
<th>( \sqrt{s_{NN}} ) (GeV)</th>
<th>Event Cuts</th>
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<tr>
<td>7.7</td>
<td>(</td>
<td>V_z</td>
<td>&lt; 50 \text{ cm} )</td>
<td>( V_r &lt; 2.0 \text{ cm} )</td>
<td>( \frac{1}{2} \text{ TPC empty cut} )</td>
<td>11.5</td>
<td>(</td>
<td>V_z</td>
<td>&lt; 50 \text{ cm} )</td>
</tr>
</tbody>
</table>

### Track Cuts:

- Reaction Plane
  - \( 0.15 < P_t < 12.0 \text{ GeV/c} \)
  - \( |\eta| < 1.3 \)
  - \( 15 < \text{nFitPts} < 50 \)
  - \( 0.52 < \text{nFitOverMax} < 1.05 \)
- HBT analysis
  - \( 0.1 < P_t < 1.0 \text{ GeV/c} \)
  - \( |y| < 0.5 \)
  - \( \text{NHits} \geq 10 \)
  - \( 2D \text{ DCA} < 3.0 \text{ cm} \)
  - \( n\sigma \pi \leq 2 \)
  - \( n\sigma k, p, e > 2 \)

### Pair Cuts:

- HBT analysis
  - \( 0.15 < K_t < 0.6 \text{ GeV/c} \)
  - Fraction Merged Hits < 0.1
  - \(-0.5 < \text{Quality} < 0.6\)
The shape evolves more for higher energy in the 7 – 39 GeV range.

The 62.4 and 200 GeV results remain similar to 39 GeV.

\( \varepsilon_I \) was computed using a Monte Carlo Glauber model for 200 GeV collisions, same percent centrality binning is used for each energy.
A Quick Lambda Free Check

Conclusions:
Using the lambda Free results gives the same conclusion. The results are very similar for 39 and 200 GeV while the 62.4 GeV point is a little lower for lambda free. The Lambda Fixing is not responsible for the difference in STAR and CERES points.
Y4 62.4 GeV – Two correction schemes

- Y4 62.4 GeV, Kt Avg, Radii Corrected
- Y4 62.4 GeV, Kt Avg, Histos Corrected
- Y4 62.4 GeV, Kt Int, Radii Corrected
- Y4 62.4 GeV, Kt Int, Histos Corrected

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