Non-identical particle correlations in STAR as a probe of emission asymmetries and radial flow

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Outline

- Non-identical particle correlations
  - Measuring emission asymmetry
  - Connection to flow
- Data analysis at STAR
  - Pion-Kaon
  - Pion-Proton
  - Preliminary Kaon-Proton
- Fitting procedure
- Modeling emission asymmetry
  - Blast-wave – the flow baseline
  - Rescattering models
- Comparing with data
- Summary
The asymmetry analysis

Catching up
• Interaction time larger
• Stronger correlation

Moving away
• Interaction time smaller
• Weaker correlation

“Double” ratio
• Sensitive to the space-time asymmetry in the emission process

Kinematics selection on any variable
e.g. $k_{Out}$, $k_{Side}$, $\cos(v,k)$

Double ratio definitions

\[ 2k^* = p_1 - p_2 \]
\[ P = p_1 + p_2 \]

**Correlation functions**

**Double ratios**

\[ k_{\text{long}} \text{ is the z component of the momentum of first particle in LCMS} \]

**k_{\text{side}} sign selection arbitrary**

**k_{\text{out}} sign selection determined by the direction of the pair momentum \( P \)**

\[ k_{\text{out}} > 0 \]
What to expect from double ratios

- Initial separation in Pair Rest Frame (measured) can come from time shift and/or space shift in Source Frame (what we want to obtain)

\[
\langle \Delta x^* \rangle = \langle \Delta x \rangle + v_T \langle \Delta t \rangle \\
\langle x \rangle \equiv \langle \vec{r} \cdot \hat{x} \rangle \approx \left\langle r \frac{\beta^F + \beta_T^\perp \cos(\phi)}{\beta^\perp} \right\rangle \\
\approx \left\langle r \frac{\beta^F}{(\beta^F + \beta_T^\perp)^{1/2}} \right\rangle \\
\langle y \rangle = \langle \vec{r} \cdot \hat{y} \rangle = \left\langle r \frac{\beta_T^\perp \sin(\phi)}{\beta^\perp} \right\rangle = 0 \\
\langle z \rangle = \langle \tau_S \sinh(y_S) \rangle \approx \langle \sinh(y_S) \rangle \langle \tau_S \rangle = 0
\]

- We are directly sensitive to time shift, the space shift arises from radial flow – possibility of a new radial flow measurement

\[
\langle y \rangle \equiv \langle \vec{r} \cdot \hat{y} \rangle = \left\langle r \frac{\beta_T^\perp \sin(\phi)}{\beta^\perp} \right\rangle = 0 \\
\langle z \rangle = \langle \tau_S \sinh(y_S) \rangle \approx \langle \sinh(y_S) \rangle \langle \tau_S \rangle = 0
\]
Blast wave: a flow model

Pion
\( p_t = 0.15 \text{ GeV/c} \)
\( \beta_t = 0.73 \)

Kaon
\( p_t = 0.5 \text{ GeV/c} \)
\( \beta_t = 0.71 \)

Proton
\( p_t = 1. \text{ GeV/c} \)
\( \beta_t = 0.73 \)

Spatial shifts (\( \Delta r \))

Particle momentum
Non-identical particle correlations at STAR

- We present data from Year1 – 130 AGeV
- Central events – 13% of total cross-section
- Mid-rapidity particles from the TPC (|y| < 0.5)
- Particles identified by the dE/dx information
Technical Issues

- Particle purity must be carefully studied

- We use dE/dx PID probability
  - Pair cuts: $\pi$-K or $\pi$-P pair probability > 0.6
  - Removal of correlated pairs from $\gamma$ decay: probability of $e^+e^- < 0.01$

- Detector issues corrections
  - Two-track effects:
    - elimination of tracks with possible shared hits in the TPC
  - Particle purity
    - PID probability for kaons
    - PID probabilty + estimation of weak decay products for pions
  - Momentum resolution
Correlation functions

- The correlation functions are dominated by Coulomb – identical for the same charge combinations.
- The agreement within the charge combination points to a very similar $K^+$ and $K^-$ emission mechanism.

\[ \text{nucl-ex/0307025} \]

\[ 130 \text{ AGeV} \]

\[ k^* = |k_{\pi}^*| = |k_{K}^*| \text{ (GeV/c)} \]

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Double ratios

- Clear deviation from unity for Out – sign of asymmetry
- Side and Long – flat as expected (cross-check)

\[ \frac{C_+^{(k^*)}}{C_{+}(k)} \]

\[ \frac{C_+^{(k^*)}}{C_{+}(k)} \]

\[ \pi^+ - K^+ \]

\[ \pi^+ - K^- \]

\[ \pi^- - K^- \]

\[ \pi^- - K^+ \]

\[ k^* = |k_\pi^*| = |k_K^*| \text{ (GeV/c)} \]

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130 AGeV

nucl-ex/0307025
Results for Pion-Proton

- Similar preliminary analysis done for pion-proton
- We observe Lambda peaks at $k^* \sim m_{inv}$ of $\Lambda$
- Good agreement for identical and non-identical charge combinations
Preliminary results for Kaon-Proton

- Using data from Year2 (200 AGeV) – sufficient statistics
- No corrections for purity and/or momentum resolution done
- No error estimation yet – fit indicates theoretical expectations
Fitting procedure

- No analytic form of correlation function
- Need to generate correlation functions using experimental momentum distributions, Monte-Carlo methods and Lednicky's pair weights
- Best fit parameters are taken at the minimum $\chi^2$ value
Modeling the emission asymmetry

- Need models producing strong transverse radial flow:
  - Blast-wave as a baseline
  - RQMD
  - UrQMD
  - T. Humanic's rescattering model

- What do we measure and how to compare it to the models?
- Is our fitting method working? And if yes, what does it tell us?
- Need to disentangle flow and time shift
1D relativistic view

What can be probed?

Source of particle 1

Source of particle 2

Separation between source 1 and 2 in pair rest frame

Boost to pair rest frame

\[ \Delta r^* = \gamma_{\text{pair}} (\Delta r - \beta_{\text{pair}} \Delta t) \]

\[ \Delta r^* \text{ separation in pair rest frame} \]

Function of \( \gamma_{\text{pair}} (\beta_{\text{pair}}) \) which depend on the pair acceptance

\[ D_{r^*} = g_{\text{pair}} (D_{r} - \beta_{\text{pair}} D_{t}) \]

2 parameters
- Mean shift (\( <\Delta r^*> \))
- Sigma (\( \sigma_{r^*} \))
Fitting and quantitative comparisons

- Fits assume gaussian source in PRF
- $r^*$ distributions have non-gaussian tails
- Use the same fitting procedure for models and data - correlation functions constructed with “Lednicky's weights”

<table>
<thead>
<tr>
<th></th>
<th>$\sigma$ (fm)</th>
<th>$\langle \Delta r^*_{out} \rangle$ (fm)</th>
<th>$\chi^2$/dof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>$12.5 \pm 0.4^{+2.2}_{-3}$</td>
<td>$-5.6 \pm 0.6^{+1.9}_{-1.3}$</td>
<td>134.5/110</td>
</tr>
<tr>
<td>RQMD</td>
<td>$11.8 \pm 0.4$</td>
<td>$-8.0 \pm 0.6$</td>
<td>205/54</td>
</tr>
<tr>
<td>RQMD (no rescattering)</td>
<td>$5.8 \pm 0.1$</td>
<td>$-2.0 \pm 0.3$</td>
<td>940/54</td>
</tr>
<tr>
<td>BWP</td>
<td>$9.9 \pm 0.1$</td>
<td>$-6.9 \pm 0.3$</td>
<td>1020/118</td>
</tr>
</tbody>
</table>

Example of $r^*_{out}$ distribution from RQMD
Do we see time shifts, spatial shifts, or both?

The general formula:

$$\Delta r^* = \gamma_{\text{pair}} (\Delta r - \beta_{\text{pair}} \Delta t)$$

$r_{\text{out}}$ is a measure of flow

Turning off rescattering shuts down flow and decreases time shifts

We measure $r^*_{\text{out}}$, which combines time shifts and spatial shifts (from space-momentum $\phi$ correlations)
Rescattering models

- Both models produce significant flow
- Flow intensity scales with centrality
- RMQD w/o rescattering produced no flow
- pp collisions produce space-momentum correlations – jets?
Comparing models to data

- Rescattering models and blast-wave are able to reproduce the data
- Blast wave parameters constrained by other measurements from STAR
- In all models flow is required to reproduce the data
Summary and outlook

- Non-identical particle correlations give qualitatively new information: emission asymmetries, and an independent measurement of space-momentum correlations (transverse radial flow)

- Emission asymmetry was observed at STAR for pion-kaon and pion-proton pairs

- Rescattering models and blast-wave are consistent with the data, because they produce radial flow

- More systems (e.g. Proton-Lambda, Pion-Cascade), more statistics, higher collision energy data coming
Purity correction

Average pair purity = 0.75

\[ C_{\text{corrected}} = \frac{C_{\text{measured}} - (1 - P) \times 1.0}{P} \]
Momentum resolution

Momentum smearing and low $p_T$ shift

No change until resolution
4x worse than STAR
Hit sharing cut effect on Side ratio

Should be at 1.0 as there is no physics effect that can cause the asymmetry

Maximum number of shared hits between two tracks = 10%

Before the cut

After the cut
Static source - time shift can be the cause for asymmetry

Best fit:
6 fm/c

Best fit:
7.5 fm

Like-sign out ratio

Unlike-sign out ratio

Like-sign corr.fctn

Unlike-sign corr.fctn
Hydro + RQMD pure and scrambled can we disentangle time shift and flow

Out asymmetry comes from the combination of time shift and position-momentum correlations

Scrambling the positions removes some of the Out asymmetry

phi scrambling does not remove all momentum-position correlation
Hydro inspired parametrization - radial flow produces asymmetry

T = 110 MeV – spectra
trans. flow v = 0.6c - flow
radius = 13 fm

Unlike sign corr. Fctn

Like sign corr. fctn

Unlike sign out ratio

Like sign out ratio

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