Charge Asymmetry Dependence of \( \pi/K \) Anisotropic Flow in UU and AuAu Collisions at RHIC

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Charge Separation in HIC

- Charge asymmetry w.r.t. reaction plane as a signature of Local Parity Violation
- Charge separation is believed as a consequence of chiral magnetic effect

More LPV results from STAR,
F. Zhao, \( \Lambda(K^0_s)\)-h Azimuthal Correlations with Respect to the Reaction Plane and Searches for CME and CVE

Chiral Magnetic Wave (CMW)

![Diagram of CMW and Chiral Separation Effect]

Measurements consistent with the expectation of CMW

CMW Draw Lots of Theoretical Attention

**Expanding QCD**

Signal is very small, but can be enhanced if early asymmetries in the axial charge distribution exists.

**Freezeout**

Condition is important. CMW effect is not small if calculated realistically.

**Hydro calculation**

The intercept, instead of the slope, is sensitive to anomalous transport effects (CMW).

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M. Hongo, Y. Hirono and T. Hirano, arxiv:1309.2823

S. F. Taghavi, U. A. Wiedemann, arxiv:1310.0193

H-U Yee, Y. Yin, arxiv 1311.2574
One Possible Explanation
Local Charge Conservation

- Hydro model + Local charge conservation at freeze-out
- \( \text{slope}(\Delta v_2) / \text{slope}(\Delta v_3) \sim 3 \)
- The \( \eta \) window depedence

What This Study Provides ...

Ingredients for various consistency checks:

• **The measurement in UU collisions**
  different geometry setup

• **The slope of $\Delta v_2(A_{ch})$ for kaons**
  other particle species with different $\Delta v_2$

• **The measurement of $\Delta v_3(\pi)$ as a function of $A_{ch}$**
  test for Hydro + Local charge conservation at freeze-out

RHIC-STAR

TPC and ToF are used for particle identification
Data Analysis
Flow Calculation

- Q-cumulant method
- $\Delta \eta$ between two correlated particles should be larger than 0.3 to suppress non-flow effect

Data Analysis
Charge Asymmetry

Each bin has the same number of events

\[ A_{ch} = \frac{N_+ - N_-}{N_+ + N_-} \]

Apply the same cuts in Monte-Carlo and real data calculation
Data Analysis

Slope Parameter

$\nu_3 \text{ vs } A_{ch}$

Slope($\Delta \nu_3$) < slope($\Delta \nu_2$) in mid-centrality
Result

$\Delta v_2(\pi)$ Slope vs. Centrality (Au vs. U)

Slope in UU collisions is consistent with that in AuAu collisions
Result

$\Delta v_2(K)$ Slope vs. Centrality

Slope of $\Delta v_2$ vs $A_{ch}$ for kaons could be different from slope for pions (flow difference are likely to be masked or reversed)

<table>
<thead>
<tr>
<th></th>
<th>Slope ($\pi$)</th>
<th>Slope (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.92±0.10 %</td>
<td>1.65±0.44 %</td>
</tr>
</tbody>
</table>
Result

$\Delta v_2(\pi), \Delta v_3(\pi)$ Slope vs. Centrality

In mid-centrality bins, the slope of $\Delta v_3(\pi)$ is much smaller than that of $\Delta v_2(\pi)$
Result

Comparison between slope($\Delta v_2$) and slope($\Delta v_3$)

Combining 20-60% centrality bins, slope($\Delta v_3$) value is 3.2σ away from 1/3 of slope($\Delta v_2$)

<table>
<thead>
<tr>
<th>Slope ($\Delta v$)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta v_2$</td>
<td>2.92±0.10 %</td>
</tr>
<tr>
<td>$\Delta v_3$</td>
<td>0.07±0.28 %</td>
</tr>
</tbody>
</table>
Result

$\Delta v_2(\pi), \Delta v_3(\pi)$ Slope vs. Centrality (Narrow $\eta$)

Results do not show $\eta$ dependence
• The same linear relationship between $\Delta v_2(\pi^{\pm})$ and $A_{ch}$ has been observed in both minimum bias AuAu and UU collisions

• The first attempt to study the slope for $\Delta v_2(K)$ $\Delta v_2(K^{\pm})$ results show consistency with CMW expectations

• $\Delta v_3(\pi)$ as a function of $A_{ch}$ studied in AuAu and UU collisions
  In mid-central collisions, the ratio of slope of $\Delta v_3(A_{ch})$ to that of $\Delta v_2(A_{ch})$, is 3.2$\sigma$ below the predicted value (1/3) from hydro + local charge conservation at freeze-out. This indicates that it is unlikely that such effect can have a significant contribution to the splitting of $v_2(\pi)$ as a function of $A_{ch}$

• Both $\Delta v_3(A_{ch})$ and $\Delta v_2(A_{ch})$ measurements do not show $\eta$ dependence

Thank you for your attention!
Backup
Data Analysis

Event, Track Selection

**Event**
- Run10 AuAu 200GeV
  ~328M MinBias
- Run11 AuAu 200GeV
  ~555M MinBias
- Run12 UU 193GeV
  ~643M MinBias
  - $|V_z| < 30$ cm
  - $|V_r| < 2$ cm

**Charge Asymmetry**
- All charged particles excluding (anti)proton with $p_T < 0.4$ GeV/c
  - $0.15 < p_T < 12$ GeV/c
  - $|\eta| < 1$

**Flow**
- Primary Tracks
  - DCA $< 1$ cm
- Pion PID
  - $|n\sigma_\pi| < 2$
  - $0 < m^2 < 0.1$
- Kaon PID
  - $|n\sigma_k| < 2$
  - $0.15 < m^2 < 0.35$
  - $0.15 < p_T < 0.5$ GeV/c
  - $|\eta| < 1$
1. Flow vectors:
   - Reference Particle (RP): \( Q_n = \sum_{i=1}^{M} e^{i n \phi_i} \)
   - Particle of Interest (POI): \( p_n = \sum_{i=1}^{m_p} e^{i n \psi_i} \)
   - RF & POI: \( q_n = \sum_{i=1}^{m_q} e^{i n \psi_i} \)

2. Two-particle Correlations:
   - \( \langle 2 \rangle = \frac{|Q_n|^2 - M}{M(M - 1)} \)
   - \( \langle 2' \rangle = \frac{p_n Q_n^* - m_q}{m_p M - m_q} \)

3. Cumulants:
   - \( c_n \{2\} = \langle 2 \rangle \)
   - \( d_n \{2\} = \langle 2' \rangle \)

4. Flow estimation:
   - Reference flow: \( v_n \{2\} = \sqrt{c_n \{2\}} \)
   - Differential flow: \( v'_n \{2\} = \frac{d_n \{2\}}{\sqrt{c_n \{2\}}} \)

Data Analysis
Flow Calculation - 2

- $\Delta \eta$ between two correlated particles should be larger than 0.3 to subtract non-flow effect
- Divide a given event into two sub-groups according to $\eta$ to guarantee the $\eta$ gap