Final state effects on charge asymmetry of pion elliptic flow in high-energy heavy-ion collisions

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Outline

• Introduction

• Charge dipole separation

• Charge quadrupole separation

• Summary
Dipole charge separation

- RHIC data are consistent with the CME expectation that charges could be distributed asymmetrically w.r.t reaction plane, i.e. charge separation.

\[
\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle = \left[ (v_{1,\alpha} v_{1,\beta}) + B_{in} \right] - \left[ (a_\alpha a_\beta) + B_{out} \right]
\]

- Directed flow: vanishes if measured in a symmetric rapidity range
- Non-flow/non-parity effects: largely cancel out
- P-even quantity: still sensitive to charge separation

PRL 103, 251601 (2009)
We include initial dipole charge separation mechanism into AMPT model. We switch the $p_y$ values of a percentage of the downward moving $u$ quarks with those of the upward moving $u$-bar quarks, and likewise for $d$-bar and $d$ quarks. (The percentage is a relative ratio with respect to the total number of quarks.)

We focus on final interaction effects on the charge separation, including parton cascade, hadronization, resonance decays.

Resonance decays are implemented to ensure charge conservation.
$<\cos(\varphi_\alpha + \varphi_\beta)>$ from AMPT with a global charge separation

- An initial charge separation $\sim 10\%$ can describe same-charge data in the presence of strong final state interactions.
- From a percentage of charge separation of $10\%$ in the beginning $\rightarrow 1-2\%$ percentage at the end.
A domain-based charge separation improves the description of opposite-charge correlation.

The size and number of metastable domains should be relatively small in the early stage of QGP.

TABLE I: The occupancy factors of the total volume of domains over the fireball volume as functions of centrality bin in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

<table>
<thead>
<tr>
<th>% Most Central</th>
<th>$r &lt; 0.3$ fm</th>
<th>$r &lt; 0.5$ fm</th>
<th>$r &lt; 1$ fm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>0.38 %</td>
<td>4.15 %</td>
<td>65.81 %</td>
</tr>
<tr>
<td>10-20</td>
<td>0.40 %</td>
<td>4.29 %</td>
<td>70.62 %</td>
</tr>
<tr>
<td>20-30</td>
<td>0.36 %</td>
<td>4.00 %</td>
<td>67.31 %</td>
</tr>
<tr>
<td>30-40</td>
<td>0.31 %</td>
<td>3.35 %</td>
<td>59.71 %</td>
</tr>
<tr>
<td>40-50</td>
<td>0.26 %</td>
<td>2.69 %</td>
<td>48.79 %</td>
</tr>
<tr>
<td>50-60</td>
<td>0.19 %</td>
<td>2.20 %</td>
<td>42.33 %</td>
</tr>
<tr>
<td>60-70</td>
<td>0.21 %</td>
<td>2.19 %</td>
<td>41.66 %</td>
</tr>
</tbody>
</table>
Quadrupole charge separation: charge asymmetry of pion $v_2$

\[ j_A = \frac{N_c e}{2\pi^2} \mu V B \]

Chiral Magnetic Effect

Chiral magnetic wave

Yannis Burnier, Dmitri Kharzeev, Jinfeng Liao, Ho-Ung Yee, PRL 107, 052303 (2011)

\[ v^+_2 = v_2 \pm \frac{r}{2} A_{ch} \]

\[ v^-_2 - v^+_2 = r A_{ch} \]

• RHIC-STAR preliminary data are consistent with the CMW expectation of charge asymmetry of pion elliptic flow.
Charge asymmetry slope $r$ of pion $v_2$

- RHIC-STAR preliminary data can be described by the CMW expectations with different CMW duration times.
- UrQMD cannot reproduce the slopes $r$. 
How to include initial quadrupole charge separation into the AMPT model:
I switch the positions (x,y,z) of a fraction of the small-|y| u quarks with those of large-|y| u-bar quarks, and likewise for d-bar and d quarks for Ach>-0.01 events; A contrary manner for Ach<-0.01 events. (The percentage is a relative ratio with respect to the total number of quarks.)

The goal is to learn some properties of chiral magnetic wave through how final charge asymmetry of pion $v_2$ depends on the quadrupole fraction without B and E.
(Note: only resonance decays are employed to ensure charge conservation, no hadron scatterings for hadronic phase here.)
Initial charge quadrupole distribution

- Initial partonic net charge distribution changes with quadrupole percentage.

G.-L. Ma, arXiv: 1401.6502

Yannis Burnier, Dmitri Kharzeev, Jinfeng Liao, Ho-Ung Yee, PRL 107, 052303 (2011)
The Ach dependences of pion $\pi^+/- v_2$ appear with a non-zero initial charge quadrupole.
• No charge asymmetry of pion $v_2$ for the initial quadrupole percentage of 0%.
• $\Delta v_2$ increases with $A_{ch}$ for non-zero initial quadrupole percentages.
• $\Delta v_2$ increases faster with larger initial quadrupole percentage.
Stage evolution for charge asymmetry of $v_2$

- The slope $r$ appears after parton cascade.
- The slope $r$ increases after coalescence.
- The slope $r$ is largely weaken due to resonance decays.

$r = 9.950 \pm 1.134$
$r = 5.898 \pm 0.577$
$r = 3.343 \pm 0.558$
$r = -0.690 \pm 0.718$

exp. data:
$r = 3.187 \pm 0.286$
A helpful constraint on CMW

It gives a constraint (<4%) to the centrality dependence of initial quadrupole percentage.

<table>
<thead>
<tr>
<th>centrality bin</th>
<th>0-10%</th>
<th>10-20%</th>
<th>20-30%</th>
<th>30-40%</th>
<th>40-50%</th>
<th>50-60%</th>
<th>60-70%</th>
<th>70-80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial quad. perc.</td>
<td>0%</td>
<td>&lt;1%</td>
<td>1-2%</td>
<td>1-2%</td>
<td>2-3%</td>
<td>2-3%</td>
<td>3-4%</td>
<td>?%</td>
</tr>
</tbody>
</table>
Summary

• Final interactions reduce charge azimuthal correlation \(<\cos(\phi_a + \phi_\beta)\)>, it indicates the percentage of initial dipole charge separation > 5%\(^1\).

• Domain-based AMPT results indicates that the size and number of metastable domains should be relatively small in the early stage of QGP\(^2\).

• The slope \(r\) of charge asymmetry of pion \(v_2\) is sensitive to the percentage of the initial charge quadrupole separation, which give a helpful constraint (<4%) to the CMW effect\(^3\).

References: