Directed flow at midrapidity in $\sqrt{s}=2.76\,\text{TeV}$ PbPb collisions

Ekaterina Retinskaya
Heavy-ion meeting
IPN Orsay
8 June 2012

* arxiv:1203.0931v1, to appear in PRL soon!
Outline:

- Dihadron correlations and factorisation
- Momentum conservation coefficient: fit parameter
- Momentum conservation coefficient: estimation
- Viscous hydro calculations: LHC and RHIC calculations
- Conclusions
Outline:

- Dihadron correlations and factorisation
- Momentum conservation coefficient: fit parameter
- Momentum conservation coefficient: estimation
- Viscous hydro calculations: LHC and RHIC calculations
- Conclusions
Measurements at ALICE

Distributions of angles $\Delta \phi$ and/or $\Delta \eta$ between:

- A “trigger” particle at transverse momentum $P_T^{\text{trigger}}$
- An “associated” partner at $P_T^{\text{partner}}$

Two-particle correlations:

$$V_{n\Delta} = \langle \cos n(\Delta \phi) \rangle$$
**ALICE analysis**

It was found recently, that two-particle correlation factorizes in long-range correlations with $|\Delta \eta| > 0.8$:

$$ V_{n\Delta} = V_n(p_T^t) * V_n(p_T^a) $$

**ALICE:** fit $N \times N$ matrix with $N$ parameters of $V_n$:

- $N$-number of $p_T$ bins

Fit is good for $n > 1$

---

arXiv:1109.2501v2
Factorization

\[ V_{n\Delta} = \nu_n(p_T^\uparrow) \nu_n(p_T^a) \]

How do we understand this?

**Particles are emitted independently with distribution:**

\[
\frac{dN}{d\phi} = \frac{N}{2\pi} \left(1 + 2 \sum \nu_n \cos(n\phi - n\psi_n)\right)
\]

**Where**

\[
\langle e^{i n \phi} \rangle = \nu_n e^{i n \psi_n}
\]

\[
V_{n\Delta} = \langle \cos n \Delta \phi \rangle = \langle e^{i n (\phi_1 - \phi_2)} \rangle = \langle e^{i n \phi_1} \rangle \langle e^{-i n \phi_2} \rangle = \nu_n^a \nu_n^\uparrow
\]
Momentum conservation

Factorization doesn’t work for n=1:

\[ \langle \cos(\Delta \phi) \rangle_{\text{mom. cons.}} = -k p_T^t p_T^a < 0 \]

We add one nonflow term due to global momentum conservation

\[ \sum \vec{p}_T = 0 \]

Two possibilities to find k:

- As fit parameter
- Calculate it as \( 1/\langle \Sigma p_T^2 \rangle \)

N. Borghini, M. Dinh, J.-Y. Ollitrault

arXiv:nucl-th/0004026v2
Outline:

- Dihadron correlations and factorisation
- Momentum conservation coefficient: fit parameter
- Momentum conservation coefficient: estimation
- Viscous hydro calculations: LHC and RHIC calculations
- Conclusion
Comparison of two fit functions:

Our fit with \( N + 1 \) parameters (\( v_1 + \kappa \)):

\[
V_{1\Delta} = v_1(p_T^t) v_1(p_T^a) - k p_T^t p_T^a
\]

ALICE fit with \( N \) parameters (\( v_1 \)):

\[
V_{1\Delta} = v_1(p_T^t) v_1(p_T^a)
\]

The quality of the fit is much better!

<table>
<thead>
<tr>
<th>Centrality</th>
<th>( \chi^2 / \text{d.o.f.}, k=0 )</th>
<th>( \chi^2 / \text{d.o.f.} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10%</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>10–20%</td>
<td>11</td>
<td>1.1</td>
</tr>
<tr>
<td>20–30%</td>
<td>45</td>
<td>2.2</td>
</tr>
<tr>
<td>30–40%</td>
<td>75</td>
<td>2.3</td>
</tr>
<tr>
<td>40–50%</td>
<td>126</td>
<td>2.5</td>
</tr>
</tbody>
</table>
First measurement of $v_1$ at the LHC

Extracted values from the fit give us the first measurement of $v_1$ at the LHC!

No net transverse momentum $\rightarrow$ low $p_T$ particles flow in the opposite direction to high $p_T$!
Outline:

- Dihadron correlations and factorisation
- Momentum conservation coefficient: fit parameter
- Momentum conservation coefficient: estimation
- Viscous hydro calculations: LHC and RHIC calculations
- Conclusion
How to estimate $k = 1/\langle \Sigma p_T^2 \rangle$?

What we know:
- $p_T$ spectra of $\pi, K, p$ at midrapidity in a limited $p_T$ range
- Total charged multiplicity $N_{ch}$: extrapolation made by ALICE

Sum runs over all the particles!

What we don’t know:
- ALICE doesn’t measure number of neutral particles
- $p_T$ spectra outside midrapidity

What we don’t know:
- ALICE doesn’t measure number of neutral particles
- $p_T$ spectra outside midrapidity
Calculating $k$

- Fit $p_T$ spectra by Levy function to extrapolate from 0 to $\infty$

\[
\frac{dN}{dy dp_t} = \frac{dN}{dy} \frac{p_t (n-1) (n-2)}{(n \cdot C \cdot (n \cdot C + m (n-2)))} \left( \frac{\sqrt{p_t^2 + m^2 - m}}{n \cdot C} \right)^{-n}
\]

- Integrate function to get $dN/dy$, $\langle p_T^2 \rangle$

\[
\langle p_T^2 \rangle = \frac{\int p_T^2 \frac{dN}{dp_T dp_t} dp_t}{\int \frac{dN}{dp_T dp_t} dp_t}
\]

- Neutral particles are taken into account assuming to isospin symmetry

- FIT $p_T$ SPECTRA BY LEVY FUNCTION TO EXTRAPOLATE FROM 0 TO $\infty$

- INTEGRATE FUNCTION TO GET $dN/dy$, $\langle p_T^2 \rangle$

- NEUTRAL PARTICLES ARE TAKEN INTO ACCOUNT ASSUMING TO ISOSPIN SYMMETRY
## Comparison of $k$-coefficients

<table>
<thead>
<tr>
<th>Centrality</th>
<th>$k_{\text{fit}, \times 10^{-5}}$</th>
<th>$k_{\text{est}, \times 10^{-5}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10%</td>
<td>2.5</td>
<td>6.1</td>
</tr>
<tr>
<td>10–20%</td>
<td>4.7</td>
<td>8.8</td>
</tr>
<tr>
<td>20–30%</td>
<td>10.3</td>
<td>13</td>
</tr>
<tr>
<td>30–40%</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>40–50%</td>
<td>42</td>
<td>35</td>
</tr>
</tbody>
</table>
Outline:

✔ Dihadron correlations and factorisation
✔ Momentum conservation coefficient: fit parameter
✔ Momentum conservation coefficient: estimation
✔ Viscous hydro calculations: LHC and RHIC calculations
✔ Conclusion
Types of $v_1$

Corresponding to:
- event-plane method, odd in rapidity - already studied
- fluctuations in energy-density profile, even in rapidity - our study
Next step: viscous hydro

We use a smooth, symmetric density profile which we deform to introduce a dipole asymmetry $\varepsilon_1$ of the desired size and orientation.

$$
\varepsilon_1 = \begin{bmatrix} r^3 e^{i\varphi} \\ r^3 \end{bmatrix}
$$

Our calculation is a 2+1D viscous hydrodynamic uses as initial condition the transverse energy density ($\varepsilon(r, \phi)$) profile from an optical Glauber model:

$$
\varepsilon(r, \phi) \rightarrow \varepsilon(r\sqrt{1+\delta \cos(\phi - \Psi_1)}, \phi)
$$

$\delta \ll 1$ \quad $V_1 \sim \varepsilon_1 \sim \delta$
Dependence on viscosity of $v_n/\varepsilon_n$

$\nu_1/\varepsilon_1(p_T)$

$\nu_1$ has a weaker dependence on viscosity than $\nu_2$
Hydro+experimental data

Choose $\varepsilon_1$ to match the data from below or above

Comparison of Monte-Carlo models

With hydro+experimental data, we can constrain $\varepsilon_1$

Through $\varepsilon_1$, we constrain models of initial state fluctuations
RHIC prediction for $v_1$
Conclusions:

- first measurement of directed flow, $v_1$, at midrapidity at the LHC,
  
  similar analysis later by ATLAS: \texttt{arXiv:1203.3087v2}

- first viscous hydrodynamic calculation of directed flow

- $v_1$ depends less on viscosity than $v_2$ and $v_3$

- data on $v_1$ constrain the fluctuations of the early-time system $\rightarrow$ rule out certain current theoretical models

- first prediction made for directed flow at midrapidity in lower-energy collisions at RHIC
Backup slides
Estimated value of $k$

estimated value $k$: \[ k = \frac{1}{\langle \Sigma p_T^2 \rangle} \]

\[ \langle \sum p_t^2 \rangle = N_{ch} \cdot \left( \frac{3 \cdot \langle p_t^2 \rangle dN/ dy \text{ pion} + 4 \cdot \langle p_t^2 \rangle dN/ dy \text{ kaon} + 4 \cdot \langle p_t^2 \rangle dN/ dy \text{ proton}}{2 \cdot [dN/ dy] \text{ pion} + 2 \cdot [dN/ dy] \text{ kaon} + 2 \cdot [dN/ dy] \text{ proton}} \right) \]