Anisotropic flow of identified particles in Pb-Pb collisions at 2.76 TeV with the ALICE detector

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Anisotropic flow signals the presence of multiple interactions between the constituents of the medium created in the collision, its magnitude therefore is a detailed probe of the level of thermalization.

**Anisotropic flow:**
- quantified as the coefficients of the Fourier expansion of azimuthal transverse momentum distribution

\[
E \frac{d^3 N}{d^3 p} = \frac{1}{2\pi} \frac{d^2 N}{dp_T d\eta} \left(1 + \sum_{n=1}^{\infty} 2v_n(p_T, \eta) \cos[n(\varphi - \Psi_n)]\right)
\]
- \(v_2\) : elliptic flow; \(v_3\) : triangular flow; \(v_4, v_5, \ldots\)

Anisotropic flow of identified particles allows to probe the freeze-out conditions of the system (temperature, radial flow, \ldots)
- test with \(\pi, K, p\) \(v_2\) and \(v_3\)
- describe all particles \(v_2\) simultaneously (strange, multi-strange particles)?

Identified particles \(v_2\) (\(v_3\)) allow us to check the baryon meson scaling
- indication of partonic collectivity?
Data sample:
- Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV,
- ~ 10 M Pb-Pb events,
- minimum bias trigger,
- acceptance: -0.8 < $\eta$ < 0.8.

Detectors used:
- Inner Tracking System (tracking and vertexing).
- Time Projection Chamber (tracking & particle identification),
- Time-Of-Flight (particle identification),
- VZERO detectors ( -3.7 < $\eta$ < -1.7, 2.8 < $\eta$ < 5.1, centrality / event plane)
Particle identification with TOF & TPC:
- asymmetric $\beta$-cut in TOF and $2\sigma$ cut in the TPC $dE/dx$ to select a high purity sample of $\pi$, $K$ and $p$.
- $p_T$ range (in GeV/c):
  - $\pi$: $0.3 < p_T < 3.5$
  - $K$: $0.4 < p_T < 2.5$
  - $p$: $0.5 < p_T < 4.0$
- purity > 90%

Identification at high $p_T$ with TPC:
- purity cut on the TPC $dE/dx$ signal:
- $p_T$ range (in GeV/c):
  - $\pi$ and $p$: $3 < p_T < 16$
- purity: pions > 90%, protons > 80%
Topological reconstruction

arXiv:1307.5530
Today
See Talk:
L. HANRATTY
25 Jul 2013, 18:10-18:30

arXiv:1307.5543
Today
See Talk:
D. COLELLA
25 Jul 2013, 17:50-18:10

- Topological reconstructions for strange and multi-strange particles
Flow Methodology

- Anisotropic flow of π, K, p is directly measured by Q-cumulant, Scalar Product and Event Plane method.
- We extract $v_2$ of $K_S^0$, Λ, Ξ and Ω, with $v_2$ vs. invariant mass method:
  $$v_2^T(m_{inv}) = v_2^S \frac{N^S}{N^T}(m_{inv}) + v_2^B \frac{N^B}{N^T}(m_{inv})$$
  - the yields $N^S, N^B$ are obtained from the fits of the invariant mass distributions.
  - the $v_2^T(m_{inv})$ is measured by Scalar Product and Event Plane method
  - the $v_2^B(m_{inv})$ is parameterized with the polynomial function
  - all necessary information to extract $v_2^S$ is available
\[ v_2 \text{ of } \pi, K, p, K_S^0, \Lambda \]

- \( v_2 \) is measured for a number of particles with light and strange quark contents.
- The mass ordering is stronger in most central collisions.
  - indicative of stronger radial flow in more central collisions
- The \( v_2 \) of \( p \) is significantly different from that of \( \pi \) at higher \( p_T \) region.
Comparison with hydrodynamic calculations

- hydrodynamic calculation, VISH2+1 (w/o afterburner) reproduces the main features of $v_2$ at low $p_T$ range,
  - it describes the measurements better in peripheral than central collisions
  - it overestimates the $p$ $v_2$ in central collisions.
  - the hadronic interactions might play an important role in reproducing $p$ $v_2$
Multi-strange particles $v_2$

We also observe clear mass ordering in $\bar{\Xi}$ and $\Omega$ $v_2$.
NCQ scaling serves a test for the particle production via quark coalescence.
The ratio of $v_2/n_q$ for identified particle and $v_2/n_q$ of $\pi$ vs $p_T/n_q$ have been shown.

$v_2/n_q$ vs. $p_T/n_q$ ($n_q$: number of quarks per meson/baryon) shows that if such scaling exists it is only approximate (holds within 20%) at $p_T/n_q \sim 1.2$ GeV/c.
NCQ scaling vs transverse kinetic energy

- NCQ scaling vs KE_T/n_q provides additional checks (and w/o mass effect) if the particle production is due to the quark coalescence picture.
For low $KE_T/n_q$: $v_2/n_q$ together with $KE_T$ scaling is violated at LHC.

For $KE_T/n_q > 1$ GeV/c $v_2$ of p is lower than that of $\pi$. 
\( v_2 \) measured at the LHC is slightly above the RHIC \( v_2 \) for \( \pi \) and K

\( v_2 \) of \( p \) is lower at low \( p_T \) but higher at higher \( p_T \) at the LHC than at RHIC

- reflects effect of larger radial flow at LHC
Triangular flow of $\pi, K, p$

At low $p_T$, we see mass ordering as expected from the hydro picture.

$\nu_3$ of $\pi$ and $p$ cross at intermediate $p_T$ as expected from coalescence.

Further constrains for initial state models as well as the $\eta/s$. 
NCQ scaling of $v_3$ works better than for $v_2$ but it is still only approximate.
Elliptic flow and triangular flow at high $p_T$

- $v_2$ and $v_3$ of p are larger than that of $\pi$ out to $p_T = 8\text{ GeV}/c$
  - agree with the picture that particle production includes interactions of jet fragments with bulk matter in this $p_T$ region
- $\pi$ $v_2$ is compatible with $\pi^0$ measured by PHENIX and $\pi^0$ calculation reproduced by WHDG for LHC
- $\pi$ and p $v_2$ are consistent within uncertainties for $p_T > 10\text{ GeV}/c$. 

**ALICE:** PLB 719 (2013) 18

**Pb-Pb $\sqrt{s_{NN}}$=2.76 TeV**

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**PHENIX:** PRL 105 (2010) 142301

**WHDG:** Horowitz, Gyulassy, JPG 38, 124114 (2011)
Summary

- Anisotropic flow of identified particles (including $\pi$, $K$, $p$, $K_S^0$, $\Lambda$, $\Xi$ and $\Omega$) are measured in 2.76 TeV Pb-Pb collision.

- For $p_T < 3$ GeV/c:
  - observed mass dependence is reproduced by the hydrodynamic model calculations (VISH2+1)
  - The larger mass splitting of $v_2$ to higher $p_T$ observed by ALICE is consistent with stronger radial flow at the LHC
  - $v_3$ of $\pi$, $K$, and $p$ has a similar mass dependence and crossing point as that of $v_2$

- For $p_T \sim 3$-6 GeV/c:
  - number of constituent quark scaling holds only approximately for $v_2$
  - KE$_T$ scaling works better for $v_3$ than $v_2$

- For high $p_T$:
  - $v_2$ and $v_3$ of $p$ are finite, positive and higher than that of $\pi$ up to 8 GeV/c
  - $v_2$ of $\pi$ and $p$ are consistent within uncertainties for $p_T > 10$ GeV/c
ALICE contributions on PID Flow in SQM

- Heavy flavor decay $\mu \nu_2$ (talk from X. Zhang)
  - 23 Jul 2013, 16:20-16:40, Session: Heavy Flavour 1

- D-meson flow (talk from E. Bruna)

- PID $\nu_2\{2PC\}$ in pPb (talk from L. Milano)
  - 26 Jul 2013, 15:20-15:40, Session: p-A collisions

- Heavy flavor decay $e\nu_2$ (poster from A. Dubla)
  - 23 July 2013, 19:30-21:00, Session: poster

Thanks for your attention!