Event shape engineering with ALICE
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- Anisotropic flow
- The ALICE experiment
- Event shape selection
  - Unidentified charged particle $v_2$
  - Identified particle $v_2$
- Summary
Anisotropic flow

- Particle azimuthal distribution measured with respect to the symmetry planes is not isotropic

\[
E \frac{d^3 N}{d^3 p} = \frac{1}{2\pi} \frac{d^2 N}{p_T dp_T dy} \left( 1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_n)) \right)
\]

\[
v_n = \langle \cos(n(\phi_i - \Psi_n)) \rangle
\]

- \( \Psi_n \) – n-th harmonic symmetry plane
- \( v_n \) quantify the event anisotropy
  - \( v_2 \) elliptic flow

- Issues:
  - Non-flow
  - Flow fluctuations
A Large Ion Collider Experiment

Time Projection Chamber (TPC): tracking and particle identification

Two scintillators arrays (VZERO): trigger, determination of centrality and symmetry planes

- Segmented into 32 individual counters each arranged in four rings and eight sectors of 45°

Pseudo-rapidity ranges:
- TPC: $|\eta| < 0.8$
- VZERO-A: $2.8 < \eta < 5.1$
- VZERO-C: $-3.7 < \eta < -1.7$

~12M minimum-bias Pb-Pb events at $\sqrt{s_{NN}} = 2.76$ TeV (2010 run) used in this analysis

- TPC tracks (0.2<p_T<20 GeV/c)
Particle identification (PID)

- PID based on the ionization energy loss in the TPC
  - Calculate $\Delta_\pi = \frac{dE}{dx} - \langle \frac{dE}{dx} \rangle_\pi$
- Select ranges where the contamination is small:
  - Pions: contamination < 1 %
  - Protons: contamination < 15 %
Event shape selection: Idea

For fixed centrality, flow fluctuates. Can we select events with given flow value?

Yes, based on the length of flow vector

Flow vector $\rightarrow$ $q$-distributions

$$Q_{n,x} = \sum_i \cos(n\phi_i) \quad Q_n = \{Q_{n,x}, iQ_{n,y}\}$$

$$Q_{n,y} = \sum_i \sin(n\phi_i) \quad q_n = |Q_n|/\sqrt{M}$$

Cutting on $q_2$ in one pseudo-rapidity window and measure $v_2$ in another window:

- Width of $v_2$ distribution for shape engineered (SE) events smaller than unbiased results
- Variation of $v_2$ up to factor of 2-3
Event shape selection: Implementation

- **Tools:**
  - Cut on $q^2$ from one $\eta$ window of the TPC ($-0.8<\eta<0$ or $0<\eta<0.8$) and measure $v_2$ in the second window

![Graph showing event shape selection](image)

5% high $q^2$

10% low $q^2$
Event shape selection: Implementation

- **Tools:**
  - Cut on $q^2$ from one $\eta$ window of the TPC (-0.8<$\eta$<0 or 0<$\eta$<0.8) and measure $v_2$ in the second window
  - Cut on $q^2$ from VZERO-C (-3.7<$\eta$<-1.7) and measure $v_2$ in TPC (-0.8<$\eta$<0.8)
  - Cut on $q^2$ from VZERO-A (2.8<$\eta$<5.1) and measure $v_2$ in TPC (-0.8<$\eta$<0.8)

- **Systematics:**
  - Different $\eta$ gaps → different non-flow contributions
  - Different detector coverages → different flow and multiplicities → different method sensitivity

5% high $q^2$
10% low $q^2$
Event plane (EP) method

- Calculate the flow vectors: \( Q_{n,x} = \sum_i w_i \cos(n \phi_i) \) \( Q_{n,y} = \sum_i w_i \sin(n \phi_i) \)
- Determine the event plane angle: \( \psi_n = \text{atan2}(Q_{n,y}, Q_{n,x})/n \)
- The flow coefficients are given by: \( \nu_n = \langle \cos(n(\phi_i - \psi_n)) \rangle / R_n \)
- Resolution: assuming \( X_{VZERO-A(C)}/X_{TPC} \) and \( X_{VZERO-A}/X_{VZERO-C} \) in the unbiased sample to be the same as in the biased one (\( X = v^* \sqrt{M} \) – the parameter used to determine the event plane resolution)

\[
\begin{align*}
Q_n, x &= \sum_i w_i \cos(n \phi_i) \\
Q_n, y &= \sum_i w_i \sin(n \phi_i) \\
\psi_n &= \text{atan2}(Q_{n,y}, Q_{n,x})/n \\
\nu_n &= \langle \cos(n(\phi_i - \psi_n)) \rangle / R_n \\
R_n &= \langle \cos(n(\psi_n - \Psi_n)) \rangle
\end{align*}
\]
$v_2(p_T)$: SE ($q_2$ TPC) vs unbiased

Cutting on $q_2$ from half of the TPC (-0.8<\eta<0 or 0<\eta<0.8) and correlate tracks from the other half (0<\eta<0.8 or -0.8<\eta<0) with EP from VZERO

$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events

Ratio between SE (5% high, 10% low) and unbiased $v_2$

- Non flat ratios may indicate non-flow contributions

5% high $q_2$
10% low $q_2$
No $q_2$ selection
$v_2(p_T)$: SE ($q_2$ VZERO-A) vs unbiased

Cutting on $q_2$ from VZERO-A (2.8<\eta<5.1) and correlate tracks from TPC (-0.8<\eta<0.8) with EP from VZERO-C (-3.7<\eta<-1.7)

Cutting on $q_2$ from VZERO-C also investigated (see backup)

$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events

- Non-flow contributions significantly reduced using $\eta$ gap
- Smaller ratios due to smaller flow and multiplicity $\rightarrow$ method sensitivity to the event shape
- $v_2 \sim$ shape (ratio almost constant) at least up to $p_T=6$ GeV/c
- Effect of event shape fluctuations becomes small for $p_T > 6$ GeV/c

Cutting on $q_2$ from VZERO-A (2.8<\eta<5.1) and correlate tracks from TPC (-0.8<\eta<0.8) with EP from VZERO-C (-3.7<\eta<-1.7)

Cutting on $q_2$ from VZERO-C also investigated (see backup)

10-20% 30-40%

Ratio between SE (5% high, 10% low) and unbiased $v_2$

5% high $q_2$
10% low $q_2$
No $q_2$ selection
Integrated $v_2$: SE vs unbiased

Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV $|\eta|<0.8$ $0.2<p_t<20$ GeV/c

No $q_2$ selection

No $q_2$ selection
Integrated $v_2$: SE vs unbiased
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Integrated $v_2$: SE vs unbiased

- Method gives consistent results in the case of $q_2$ VZERO-A and VZERO-C
  - Non-flow contributions present in the case of $q_2$ TPC
- Method sensitivity to the event shape deteriorates for peripheral collisions
PID $v_2(p_T)$: SE ($q_2$ VZERO-A) vs unbiased

Cutting on $q_2$ from VZERO-A (2.8<\eta<5.1) and correlate tracks from TPC (-0.8<\eta<0.8) with EP from VZERO-C (-3.7<\eta<-1.7)

5% high $q_2$  

10% low $q_2$

Pions  

Protons
Summary

• Using q-distributions allows to select events with larger or smaller elliptic flow than the average
  – Effect of shape fluctuations extends at least up to $p_T=6$ GeV/c

• Method is sensitive to the pseudo-rapidity range used to determine the flow vector due to different multiplicities and flow

• Non-flow contributions are significant when no/small $\eta$ gap is employed between the region used to determine the flow vector and the one in which the elliptic flow is measured
New, promising tool

Plenty of reasons to use event shape selection:

- Anisotropic flow – shape evolution
- Identified particle flow – mass splitting
- Highly anisotropic events with large particle density – compare to hydrodynamic calculations
- Inclusive spectra and particle ratios – dependence on event shape
  - See talk by L. Milano, 5A, 14:00
- Two-particle correlations – check the presence of the away-side double bump in “no-triangularity” events
  - See poster 184 by A. Timmins
- Chiral magnetic effect study – background evaluation
- Evolution of eccentricities, dependence of the HBT radii on flow field
- ...
Backup
Select events based on the magnitude of flow vector → q-distributions (similar widths for different multiplicities)

\[ Q_{n,x} = \sum_i \cos(n\phi_i) \]
\[ Q_{n,y} = \sum_i \sin(n\phi_i) \]
\[ q_n = |Q_n|/\sqrt{M} \]

\[
\frac{dN}{dq} \propto \frac{1}{\sigma^2 q} \exp\left(\frac{-M\bar{v}^2 + q^2}{2\sigma^2}\right) I_0\left(\frac{q \bar{v} \sqrt{M}}{\sigma}\right) \propto BG\left(q; \bar{v} \sqrt{M}, \sigma\right)
\]
\[
\sigma \approx \left[1 + M(\delta + 2\sigma_v^2)\right]/2 \quad \langle q^2 \rangle = \bar{v}^2 M + 2\sigma^2
\]

Parameters:
- \(M\) – multiplicity
- \(\delta\) – non-flow
- \(\sigma_v\) – flow fluctuations width

q-distributions well understood; used to extract elliptic flow
Event plane resolution

- From the unbiased sample get $X_{\text{TPC}}$, $X_{\text{VZERO-C}}$, $X_{\text{VZERO-A}}$ ($X = v^* \sqrt{M} =$ the parameter used to determine the event plane resolution)
- Assume $X_{\text{VZERO-A(C)}}/X_{\text{TPC}}$ and $X_{\text{VZERO-A}}/X_{\text{VZERO-C}}$ in the unbiased sample to be the same as in the biased one
- From the TPC – VZERO-A(C) and VZERO-A – VZERO-C correlation in the biased sample determine $X_{\text{biased}}$
- From $X_{\text{biased}}$, $(X_{\text{VZERO-A(C)}}/X_{\text{TPC}})_{\text{unbiased}}$, $(X_{\text{VZERO-A}}/X_{\text{VZERO-C}})_{\text{unbiased}}$ calculate resolution for VZERO-A and VZERO-C
$v_2(p_T)$: SE ($q_2$ VZERO-C) vs unbiased

Cutting on $q_2$ from VZERO-C (-3.7<\eta<-1.7) and correlate tracks from TPC (-0.8<\eta<0.8) with EP from VZERO-A (2.8<\eta<5.1)

$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events

5% high $q_2$
10% low $q_2$
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Ratio between SE (5% high, 10% low) and unbiased $v_2$
PID $v_2(p_T)$:
SE ($q_2$ VZERO-C) vs unbiased

Cutting on $q_2$ from VZERO-C (-3.7<$\eta$<-1.7) and correlate tracks from TPC (-0.8<$\eta$<0.8) with EP from VZERO-A (2.8<$\eta$<5.1)

5% high $q_2$

10% low $q_2$

Pions

Protons