Measurement of high-$p_T$ azimuthal anisotropy in charged hadron production from 2.76 TeV PbPb collisions at CMS

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Jet Quenching and Azimuthal Anisotropy

Path length ($L$) dependence of jet energy loss ($\Delta E$)

$$\Delta E \sim L^\alpha$$

Fourier decomposition of charged hadron yields:

$$\frac{d^3 N}{p_T dp_T d\eta d\phi} = \frac{1}{2\pi} \frac{d^2 N}{p_T dp_T d\eta} \left( 1 + \sum_{k=1}^{\infty} 2v_{n=km}(p_T, \eta) \cos[n(\phi - \Psi_m)] \right)$$

Azimuthal anisotropy ($v_2, v_3, v_4$) of high $p_T$ jets
Physics Motivation

ΔE~L^α

α = 1 for pQCD, collisional
α = 2 for pQCD, radiative
α = 3 for AdS/CFT

Initial Conditions:
- Glauber
- Color Glass Condensate

CMS Detector

Unprecedented kinematic range and acceptance
High $p_T$ Single Track Trigger

- Full 2011 HI Data set: $L_{\text{int}} = 150 \, \mu\text{b}^{-1}$
- Single-Track High-$p_T$ Triggers

(Total # of events: $\sim 1.55M$ with $p_T > 20$ GeV/c)

All triggers are at least 95% efficient (0-40%)
**Event Plane Formalism**

**Event Plane**
Experimentally observable, used to estimate the true participant plane.

\[ \Psi_n' = \frac{1}{n} \tan^{-1} \left( \frac{\sum w_i \sin(n\varphi_i)}{\sum w_i \cos(n\varphi_i)} \right) \]

**v² Coefficient**

\[ v^2_{ob} \{EP\} = \langle \cos 2(\varphi - \Psi_2) \rangle = \frac{1}{N_{ev}} \sum_j \left[ \frac{1}{M_j} \sum_i \cos 2(\varphi_i^j - \Psi_2^j) \right] \]

\[ v_n \{EP\} = \frac{v^2_{ob} \{EP\}}{R} \]

**Resolution Correction: (3-subevent method)**

Need to correct for \( \Psi_{EP} \) resolution (R).
To calculate $v_2$:
$v_2^+ \text{ with } EP^- \text{ and } v_2^- \text{ with } EP^+$

Particles from the positive $\eta$ region are correlated with the event plane calculated in the negative $\eta$ region.

Event Planes:
EP+ ($3<\eta<5$)  
EP- ($-5<\eta<-3$)

Hadronic Forward Calorimeters used for determining the Event Plane.

This minimizes systematic effects that result from back-to-back di-jets
Based on this study we conclude that the gap size of 3 is sufficient to suppress most of the back-to-back di-jet effects.
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$v_2$ as a function of $p_T \ (|\eta|<1)$

- First $v_2$ measurements for $p_T > 20\text{GeV}/c$
- Gradual decrease of $v_2$ above $p_T \sim 10 \text{ GeV}/c$

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$v_2$ as a function of $p_T$ ($1 < |\eta| < 2$)
Theory Comparison


Theory: B.Betz, M.Gyulassy; arXiv:1201.0281

-Data can constrain different theoretical scenarios
Higher Harmonics Results ($v_3$)

NEW RESULTS!!!
-Small $v_3$ signal above 20 GeV/c.

GLAUBER
Higher Harmonics Results ($v_4$)

NEW RESULTS!!!

GLAUBER
$v_2$ as a function of centrality

- Significant non-zero $v_2$ up to $p_T \sim 48$ GeV/c for all the centralities.
- For $p_T > 48$ GeV/c $v_2$ is consistent with 0 for all the centralities.

$\varepsilon_{\text{part}}$: 0.09 (0-10%) to 0.46 (50-60%)
Summary

- The $v_2$ azimuthal anisotropy coefficient is determined over a wide coverage in $p_T$: $1 < p_T < 60$ GeV/c as a function of collision centrality based on the 2011 data sample.

- The $v_3$ and $v_4$ coefficients are obtained up to $p_T \sim 40$ GeV/c.

- Above $p_T \sim 10$ GeV/c $v_2$ values show a gradual decrease with $p_T$, being consistent with zero only above $p_T \sim 48$ GeV/c for all the centralities. The $v_3$ and $v_4$ asymmetries are small above 20 GeV/c.

- Centrality dependence of $v_2$ is observed for both very low and high-$p_T$ particles. It is consistent with path-length-dependent energy loss observed at high-$p_T$ up to $p_T \sim 35$ GeV/c.
BACKUP
Di-hadron Correlations Formalism

Signal pair distribution:
\[ S(\Delta \eta, \Delta \phi) = \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{same}}}{d\Delta \eta d\Delta \phi} \]

Background pair distribution:
\[ B(\Delta \eta, \Delta \phi) = \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{mix}}}{d\Delta \eta d\Delta \phi} \]

Associated hadron yield per trigger:
\[ \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{pair}}}{d\Delta \eta d\Delta \phi} = B(0,0) \times \frac{S(\Delta \eta, \Delta \phi)}{B(\Delta \eta, \Delta \phi)} \]

\[ \Delta \eta = \eta^{\text{assoc}} - \eta^{\text{trig}} \]
\[ \Delta \phi = \phi^{\text{assoc}} - \phi^{\text{trig}} \]

(d) CMS N ≥ 110, 1 GeV/c < p_{T} < 3 GeV/c

back-to-back di-jet correlations

long-range near-side structure

jet peak
Azimuthal Correlations at High $p_T$

- Clear and significant long-range near-side structure is observed for the first time for $p_T^{\text{trig}} > 20$ GeV/c.