Dihadron Correlations in PbPb Collisions at 2.76 TeV with CMS

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for the CMS Collaboration
Dihadron Correlations

• Features found in AA collisions at RHIC:
  – Broadened away side
  – Disappearance of back-to-back correlations
  – Near-side ridge

• Explanations of ridge include:
  – Connections to jet quenching
  – Higher order flow components ($v_n \mid n>2$)

• LHC and CMS provide:
  – Higher density system
  – Unprecedented pseudorapidity and $p_T$ reach
Very large coverage ($|\Delta \eta|$ up to 5.0)!
Dihadron correlations in CMS

Signal distribution:

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

Particle 1: trigger
Particle 2: associated

Background distribution:

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

Event 1

Event 2

Associated hadron yield per trigger:

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

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

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Heavy-ion “ridge” at LHC

Ridge-like structure extends out to $|\Delta \eta| = 4$

Associated hadron yield per trigger:

$$\frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{pair}}}{d\Delta \eta d\Delta \phi} = B(0,0) \times \frac{S(\Delta \eta,\Delta \phi)}{B(\Delta \eta,\Delta \phi)}$$

Particle triggers:

- $p_T^{\text{trig}} : 4 \sim 6 \text{ GeV/c}$
- $p_T^{\text{assoc}} : 2 \sim 4 \text{ GeV/c}$

$\text{ CMS } \int L \, dt = 3.1 \mu \text{b}^{-1}$

$\text{PbPb } \sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$, 0-5% centrality
Ridge in central PbPb collisions tends to diminish at high $p_T$. 

$v_2$ not subtracted

Ridge region ($2<|\Delta \eta|<4$)
Centrality dependence in PbPb

Centrality dependence in PbPb

PbPb 2.76 TeV

CMS Preliminary

$p_T^{\text{trig}}$: 4 - 6 GeV/c
$p_T^{\text{assoc}}$: 2 - 4 GeV/c

$\cos(2\Delta\phi)$
PbPb \sqrt{s_{NN}} = 2.76 \text{ TeV}

\nu_2 \text{ modulation} \\
(EP + \text{Cum}\{4\}) / 2

\nu_2 \text{ uncertainty} \\
EP \text{ method} = \text{upper limit} \\
Cum\{4\} = \text{lower limit}

\int L \, dt = 3.1 \mu b^{-1}

4 < p_T^{\text{trig}} < 6 \\
2 < p_T^{\text{assoc}} < 4 \\
2 < |\Delta \eta| < 4
$v_2$ subtracted
PbPb $\sqrt{s_{NN}} = 2.76$ TeV

Uncertainty from $v_2$

4 < $p_T^{\text{trig}}$ < 6
2 < $p_T^{\text{assoc}}$ < 4
2 < $|\Delta \eta|$ < 4

$\int L dt = 3.1 \mu b^{-1}$
4.0 < $p_T^{\text{trig}}$ < 6.0 GeV/c
2.0 < $p_T^{\text{assoc}}$ < 4.0 GeV/c
2 < $|\Delta \eta|$ < 4

CMS PAS HIN-11-006
PbPb $\sqrt{s_{NN}} = 2.76$ TeV

$v_2$ modulation
$(EP + \text{Cum}{4}) / 2$

$v_2$ uncertainty

$EP$ method = upper limit
Cum{4} = lower limit

$\int L \, dt = 3.1 \mu b^{-1}$

$4 < p_T^{\text{trig}} < 6$

$2 < p_T^{\text{assoc}} < 4$

$0 < |\Delta\eta| < 1$
$v_2$ subtracted
\(PbPb \sqrt{s_{NN}} = 2.76\) TeV

Uncertainty from $v_2$

- $4 < p_T^{\text{trig}} < 6$
- $2 < p_T^{\text{assoc}} < 4$
- $0 < |\Delta \eta| < 1$
Comparison with RHIC

Qualitatively, similar trend in centrality to RHIC results
Ridge from higher-order flow harmonics

Long range rapidity correlations $\rightarrow$ early time dynamics

Elliptic flow ($v_2$)

Initial condition fluctuations $\rightarrow$ higher order odd flow harmonics (e.g., triangle flow, $v_3$)

Add $V_{2\Delta}$ and $V_{3\Delta}$

~ $V_{2\Delta} \cos(2\Delta\phi)$

~ $V_{3\Delta} \cos(3\Delta\phi)$

Fourier analysis of $\Delta \phi$ correlations

**Fourier decomposition:**

$$\frac{1}{N_{\text{trig}}} \frac{dN_{\text{pair}}}{d\Delta \phi} = \frac{N_{\text{assoc}}}{2\pi} (1 + 2 \sum_{n=1}^{\infty} V_{n\Delta} \cos(n\Delta \phi))$$

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Short-range non-flow effects excluded

Ridge structure exhausted by first 5 Fourier terms

Flow driven correlations:

$$V_{n\Delta} = V_n^{\text{trig}} \times V_n^{\text{assoc}}$$

(factorization relation can be tested directly!)
Fourier analysis of $\Delta \phi$ correlations

$2 < p_T^{\text{assoc}} < 4 \text{ GeV/c}$
Ridge region ($2 < |\Delta \eta| < 4$)

$0-5\%$ most central
Ridge persists to high $p_T$ but decreases in magnitude

Extracted Fourier coefficients $V_{n\Delta}$
If assume flow alone is responsible for the ridge and there is no away side jet contribution in the correlation,

\[ V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}}) = v_n(p_T^{\text{trig}}) \times v_n(p_T^{\text{assoc}}) \]

flow coefficients \( v_n \) could be extracted:

\[ v_n^{\text{trig}} = \frac{V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}})}{\sqrt{V_{n\Delta}(p_T^{\text{assoc}}, p_T^{\text{assoc}})}} \]

Keep low \( p_T^{\text{assoc}} \) (1 < \( p_T^{\text{assoc}} \) < 2 GeV/c) to minimize non-flow effects
$v_2$ from long-range correlations

$0-5\%$

$\int L \cdot dt = 3.1 \mu b^{-1}$

CMS Preliminary

PbPb $\sqrt{s_{NN}} = 2.76$ TeV

$v_2^f$

$v_2^{(2)}$

$v_2^{(4)}$

$1 < p_{T\text{assoc}} < 2$ GeV/c
$2 < |\Delta n| < 4$

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$v_3$ from long-range correlations

$1 < p_T^{assoc} < 2$ GeV/c
$2.0 < |\Delta\eta| < 4.0$

$\int L dt = 3.1 \mu b^{-1}$

CMS Preliminary
Flow coefficients \((v_{n}^{f})\) vs centrality

Centrality dependence of \(v_{n}\) follows expectation from hydrodynamics (initial geometry and its fluctuation)

Powerful constrains on the initial condition and viscous property

Further systematic checks of \(V_{n\Delta}(p_{T}^{\text{trig}}, p_{T}^{\text{assoc}})\) factorization

- Disentangle flow and non-flow correlations
- Study jet-medium interactions (after flow subtraction)
Summary

- Ridge-like structure extends out to $|\Delta \eta| < 4$ and tends to disappear with increasing $p_T$
- Standard $v_2$-subtracted ridge results are qualitatively consistent with RHIC
- Ridge can be described by higher order flow ($v_n$), which supports a picture of fluctuating initial condition
- Results of Fourier analysis of the ridge region are consistent with standard flow measurements
BACKUP
v$_2$-subtracted associated yield in PbPb

**Before v$_2$ subtraction**

Jet Region
$0<|\Delta\eta|<1$
PuPb $\sqrt{s_{_{NN}}}=2.76$ TeV

Ridge Region
$2<|\Delta\eta|<4$

Jet Minus Ridge Region

**After v$_2$ subtraction**

Jet Region ($v_2$ Subtracted)
$0<|\Delta\eta|<1$
PuPb $\sqrt{s_{_{NN}}}=2.76$ TeV

Ridge Region ($v_2$ Subtracted)
$2<|\Delta\eta|<4$

CMS Preliminary

$4 < p_T^{\text{trig}} < 6$ GeV/c

$2 < p_T^{\text{assoc}} < 4$ GeV/c
Jet and Ridge Regions

Jet Region: $0 < |\Delta \eta| < 1$

Ridge Region: $2 < |\Delta \eta| < 4$
$v_4$ from long-range correlations

- $v_4^f$
- $v_4\{3\}$
- $v_4\{5\}$

$\int L \, dt = 3.1 \mu b^{-1}$

$1 < p_T^{assoc} < 2$

$2 < |\Delta\eta| < 4$
$v_5$ from long-range correlations

$1 < p_T^{assoc} < 2 \text{ GeV}/c$

$2.0 < |\Delta\eta| < 4.0$

$\int L dt = 3.1 \mu b^{-1}$

CMS Preliminary

PbPb $\sqrt{s_{NN}} = 2.76 \text{ TeV}$

$\nu_5$

$0 - 5 \%$

$5 - 10 \%$

$10 - 15 \%$

$15 - 20 \%$

$20 - 25 \%$

$25 - 30 \%$

$30 - 35 \%$

$35 - 40 \%$

$40 - 50 \%$

$p_T^{\text{trig}}$ (GeV/c)