Search for the 'Ridge' in $d+Au$ Collisions at RHIC by STAR

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Overview

• Motivation

• Dihadron Correlations
  – High-multiplicity vs low-multiplicity
  – TPC-TPC ($\Delta \eta \sim 1.5$) and TPC-FTPC ($\Delta \eta \sim -3$)

• Summary
Ridge in p+p, p+Pb at LHC

- Ridge observed in high-multiplicity pp and pPb events
- High-multi. → low-multi. (for jets) → double ridge in pPb
Ridge in d+Au at RHIC?

PHENIX d+Au Double Ridge

Physics mechanisms
• Hydro?
• CGC?

PHENIX d+Au Finite $v_2$

STAR d+Au vs p+p $\left\{ \sum \cos \left( 2 \left( \varphi_{p_i} - \varphi_i \right) \right) \right\}$

PRL 111 (2013) 212301

PRC 72 (2005) 014904

arXiv 1404.7461v1
STAR Detector

- Large STAR acceptance
  TPC: $-1 < \eta < 1$
  FTPC: $2.8 < |\eta| < 3.8$

<table>
<thead>
<tr>
<th>Centrality</th>
<th>TPC</th>
<th>FTPC-Au</th>
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<tr>
<td>0-20%</td>
<td>$N_{ch} \geq 29$</td>
<td>$N_{ch} \geq 17$</td>
<td>$ADC \geq 128$</td>
</tr>
<tr>
<td>40-100%</td>
<td>$N_{ch} \leq 19$</td>
<td>$N_{ch} \leq 9$</td>
<td>$ADC \leq 116$</td>
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</tbody>
</table>
Dihadron $\Delta \eta - \Delta \phi$ Correlations

**d+Au@200 GeV  Run3**

**Trigger-Associate**

Normalized by number of trigger particles

- **TPC-FTPC (Au-going)**
  - $-4.5 < \Delta \eta < -2$
  - ZDC Energy

- **TPC-FTPC (d-going)**
  - $2 < \Delta \eta < 4.5$
  - ZDC Energy

- **TPC-TPC**
  - $-2 < \Delta \eta < 2$
  - FTPC Multiplicity

- **$p_T$: $[1,3] \times [1,3]$ GeV/c**

- **Background subtracted by $\Delta \eta$-dependent Zero-Yield-At-Minimum (ZYAM) method**
TPC-TPC $\Delta\phi$ Correlations High- vs Low-mult.

$d+Au@200$ GeV

$p_T: [1,3]\times[1,3]$ GeV/c

FTPC Multiplicity

\begin{itemize}
  \item high-mult. (cent.) > low-mult. (peri.) on both near-side and away-side.
  \item central - peripheral = “double ridge”
\end{itemize}
Near-side Ridge in High-multiplicity

d+Au@200 GeV

Finite pedestal → Near-side Ridge
Different jet shapes and yields between cent. and peri.
→ Multiplicity selection bias? Jet energy, fragmentation?

$Y = 0.0459(10)$
$\sigma = 0.336(6)$
$\text{Ped} = 0.0019(4)$
$\chi^2/\text{ndf} = 19/25$

$Y = 0.0594(18)$
$\sigma = 0.382(9)$
$\text{Ped} = 0.0070(8)$
$\chi^2/\text{ndf} = 19/25$

$\Delta \eta$

$\Delta \phi$
Away-side Ridge?

\( d+Au @ 200 \text{ GeV} \)

- Cent. - peri. \( \neq \) Cent. - Jets
- residual of jets

\( p_T : [1,3] \times [1,3] \text{ GeV/c} \)

FTPC Multiplicity

\((0-20\%) - (40-100\%)\)

[Graph showing distribution of \( 1/N_{\text{trg}} \frac{d^2N}{d\eta d\Delta\eta} \) for Near-side and Away-side with \( \Delta\eta \) on the x-axis and \( 1/N_{\text{trg}} \frac{d^2N}{d\eta d\Delta\eta} \) on the y-axis.]
Away-side Ridge?

d+Au@200 GeV

- Cent. - peri. ≠ Cent. - Jets residual of jets

$|\Delta \eta|$ used in PHENIX’s paper
Same near-side and away-side
PRL 111 (2013) 212301

$\vec{p}_T$: [1,3]x[1,3] GeV/c
FTPC Multiplicity

(0-20%) - (40-100%)
No Away-side Ridge

d+Au@200 GeV

Do first-order correction: same jet yield

Assume:
• Peri. correlation has jets only.
• Away-side jet yield $\propto$ near-side jet yield

$Y_{\text{Cent.}}, Y_{\text{Peri.}}$: near-side jet yields

$R = Y_{\text{Cent.}} / Y_{\text{Peri.}} = 1.29 \pm 0.05$

(Away-side ratio: $1.32 \pm 0.02$)

Cent. - $R \times \text{Peri} \approx$ Cent. - Jets

• Away-side $\sim 0 \rightarrow$ No Double Ridge in d+Au@200GeV
d+Au@200 GeV

$0 < \Delta \eta < 0.3$
- 0-20%
- 40-100%

$0.5 < |\Delta \eta| < 0.7$
- 1.29x(40-100%)

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$1.2 < |\Delta \eta| < 1.8$

$p_{T}$: [1,3]x[1,3] GeV/c

FTPC Multiplicity

$\Delta \phi$
- Cent.-Peri.
- Cent.-RxPeri.

Jet shapes difference

- Away-side $\sim 0$
- Near-side: finite at $\Delta \eta \approx 1.5$

$\rightarrow$ How about even larger $|\Delta \eta| \approx 3$?
TPC-FTPC: High-\( \Delta \eta \) vs Low-multiplicity

d+Au@200 GeV

**Au-Going Side (\( \Delta \eta \approx -3 \))**
- 0-20%
- 40-100%

**Away-side:** enhanced at Au-going side; depleted at d-side.

**Near-side:** finite for FTPC Au-going side (\( \Delta \eta \approx 3 \)) in high-multiplicity collisions.

**d-Going Side (\( \Delta \eta \approx 3 \))**
- 2<\( \Delta \eta \)<4.5

\( p_T : [1,3]x[1,3] \) GeV/c

ZDC Energy

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Recap: Near-side in High-multiplicity

$d+Au@200$ GeV

$\Delta \eta \approx 1.5$

TPC-TPC
FTPC 0-20%

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$\Delta \eta \approx -3$

TPC-FTPC Au-going
ZDC 0-20%

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- Long-range near-side correlations are observed in both TPC-TPC and TPC-FTPC
- What could be the physics mechanism?
- Study charge combinations

$p_T: [1,3]\times[1,3]$ GeV/$c$
Unlike-sign vs Like-sign

\( \Delta \eta \approx 1.5 \) near-side: unlike-sign > like-sign
\( \rightarrow \) Jet-like feature?

\( \Delta \eta \approx -3 \): No difference.

\( p_T: [1,3] \times [1,3] \) GeV/c

\( d+Au@200 \) GeV

\( \Delta \eta \approx 1.5 \)

\( \Delta \eta \approx -3 \)

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\( \Delta \phi \)
Associated Particle: Positive vs Negative

\(d + Au @ 200 \text{ GeV}\)

\(\Delta \eta \approx 1.5\)

- Positive assoc
- Negative

\(\Delta \eta \approx -3\) near-side: positive associated particles only

→ Transport protons?

\(p_T : [1,3] \times [1,3] \text{ GeV}/c\)
$V_n$ for Pos. vs Neg. Associated Particles

d+Au@200 GeV

$$\frac{dN}{d\Delta \varphi} = N \left( 1 + 2V_1 \cos(\Delta \varphi) + 2V_2 \cos(2\Delta \varphi) \right)$$

for TPC-FTPC

No ZYAM background subtraction.

- $V_1$ are different for positive and negative associated particles despite similar multiplicity
- $V_2$ are somewhat different, but big difference in $V_1$
- $V_n$ may not be meaningful in d+Au collisions @200 GeV
Summary

- Jets yield and shape difference observed in low- and high-multiplicity d+Au@200 GeV
- Away-side $\sim 0$ after jet difference corrected - No double ridge
- Finite near-side long-range correlations – Ridge observed by STAR.
  - $\Delta\eta \sim 1.5$ : unlike-sign $>$ like-sign $\rightarrow$ jet-like?
  - $\Delta\eta \sim -3$: from positive associated particle only $\rightarrow$ transport protons?
- The near-side ridge may be due to physics mechanism other than flow. STAR does not observe elliptic flow in d+Au.
TPC-TPC $\Delta \phi$ Correlations Cent. vs Peri.

d+Au@200 GeV

**pT**: 1-3 x 1-3 GeV/c
FTPCMultiplicity

\[ 0 < |\Delta \eta| < 0.3 \]
- 0-20%
- 40-100%

\[ 0.5 < |\Delta \eta| < 0.7 \]
- 1.29x(40-100%)

\[ 1.2 < |\Delta \eta| < 1.8 \]

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\[ \frac{d^2N}{d\Delta \phi d|\Delta \eta|} \]

\[ \text{ZYAM}=0.3546(6) \]
\[ \text{ZYAM}=0.1578(4) \]

\[ \text{ZYAM}=0.3514(8) \]
\[ \text{ZYAM}=0.1471(6) \]

\[ \text{ZYAM}=0.3468(10) \]
\[ \text{ZYAM}=0.1324(7) \]

\[ \frac{d^2N}{d\Delta \phi d|\Delta \eta|} \]

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STAR Preliminary

\[ \frac{d^2N}{d\Delta \phi d|\Delta \eta|} \]

\[ \text{ZYAM}=0.3546(6) \]
\[ \text{ZYAM}=0.1578(4) \]
Away-side Ridge?

d+Au@200 GeV

- High. - Low. ≠ High. - Jets^{High} : jet residual
- Do first-order correction with jet yield → Next slide
No Away-side Ridge

d+Au@200 GeV

Assume:
• Peri. has jets only.
• Away-side jet yield $\propto$ near-side jet yield

$N^{\text{Cent.}}, N^{\text{Peri.}}$: near-side jet yields

$R = N^{\text{Cent.}} / N^{\text{Peri.}} = 1.29\pm0.05$

Cent. - $R\times\text{Peri.} \approx \text{Cent.} - \text{Jets}^{\text{Cent}}$

• Away-side $\sim 0$ $\rightarrow$ No Double Ridge in d+Au@200GeV
• Near-side: finite at $\Delta\eta \approx 1.5$
  $\rightarrow$ How about even larger $|\Delta\eta| \approx 3$?
Jet Difference in Central and Peripheral

$\text{d+Au@200 GeV}$

$\Delta\phi$:
- Near-side $|\Delta\phi|<\pi/3$ - $|\Delta\phi - \Delta\phi_{\text{min}}|<\pi/16$
- Away-side $|\Delta\phi - \pi|<\pi/3$ - $|\Delta\phi - \Delta\phi_{\text{min}}|<\pi/16$

40-100%

$\text{pT: 1-3 x 1-3 GeV/c}$

0-20%

$(0-20\%) - (40-100\%)$

$\text{pT: 1-3 x 1-3 GeV/c}$

$(0-20\%) - 1.29 \times (40-100\%)$
FTPC vs ZDC Energy

TPC-TPC $1.2 < |\Delta \eta| < 1.8$

FTPC Multiplicity
- 0-20%
- 40-100%
- $1.29 \pm 0.05 \times (40-100\%)$

ZDC Energy
- 0-20%
- 40-100%
- $1.13 \pm 0.05 \times (40-100\%)$
FTPC vs ZDC Energy

TPC-TPC 1.2<|Δη|<1.8

FTPC Multiplicity
- Unlike-sign
- Like-sign

ZDC Energy

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Fourier Coefficients vs. Multiplicity

d+Au@200 GeV

\[
\frac{dN}{d \Delta \phi} = N \left( 1 + 2 V_1 \cos(\Delta \phi) + 2 V_2 \cos(2 \Delta \phi) \right)
\]

for TPC-TPC and TPC-FTPC

No ZYAM background subtraction.

\[ V_1 \approx \frac{1}{\text{Multiplicity}} \]

• Peripheral dihadron \( \Delta \phi \) cannot see \( V_2 \) modulation because of large \( V_1 \).

\[ V_2 \text{ is constant over multiplicity} \]

pT: 1-3 x 1-3 GeV/c

\[ dN \]
Different Charges Combinations

d+Au@200 GeV

\[ p_T: 1-3 \times 1-3 \text{ GeV/c} \]

FTPC Multiplicity

\[ (\frac{dN}{d\Delta\phi})\frac{dN}{d\eta} \]

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\[ 1 < p_T < 3 \text{ GeV/c}, -4.5 < \Delta\eta < 2 \]

(1N_{ang}) dN/d\Delta\phi d\eta

FTPC 0-20% ZYAM=0.1086(3)

FTPC 40-100% ZYAM=0.0217(1)

(PP) 1 < p_T < 3 \text{ GeV/c}, -4.5 < \Delta\eta < 2

FTPC 0-20% ZYAM=0.1160(3)

FTPC 40-100% ZYAM=0.0230(1)

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Single Particle Dh Distribution

PHOBOS PRC 72 (2005)

![Graph showing dN/dη for d + Au collisions at 200 GeV for different collision centrality](image)
Associated Particle: Positive vs Negative

\( \Delta \eta \approx 1.5 \)
- Positive assoc
- Negative

\( \Delta \eta \approx -3 \) near-side: positive asso
→ Transport protons?

\( p_T: [1,3] \times [1,3] \ \text{GeV/c} \)

\[
\frac{dN_{\text{trig}}}{d\eta d\phi} [\text{Counts} / \text{GeV} / \text{rad}]
\]

Near-side yield
- Pos: \( 24 \pm 5 \pm 6 \times 10^{-4} \)
- Neg: \( 23 \pm 5 \pm 8 \times 10^{-4} \)

\[
\frac{dN}{d\eta d\phi} [\text{Counts} / \text{GeV} / \text{rad}]
\]

Near-side yield
- Pos: \( 12.5 \pm 1.6 \pm 2.4 \times 10^{-4} \)
- Neg: \( 2.4 \pm 1.5 \pm 1.0 \times 10^{-4} \)