Two-particle correlations in p-Pb collisions at the LHC with ALICE

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On behalf of the ALICE Collaboration
- **Long range correlations**
  - the ridge structure in pp, Pb-Pb and p-Pb collisions

- **A Large Ion Collider Experiment (ALICE)**
  - Particle identification in ALICE

- **Two-particle correlations (2PC)**
  - event multiplicity selection in p-Pb
  - associated yield per trigger particle
  - $v_2$ from 2PC in high and low multiplicity events

- **Reduction of the jet component using the subtraction procedure**
  - the subtraction procedure
  - $v_2$ from 2PC after the subtraction procedure

- **Summary**
Long range correlations

$\eta, \phi$ correlation between trigger and associated particle in a given $p_T$ interval
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Minimum-bias pp:
- jet peak on the near side (+ resonances)
- recoil jet on the away side

CMS JHEP 09 (2010) 091
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In Pb-Pb there is more...

“Bulk-dominated” \( p_T \) region:
- near side ridge structure, typical of collective systems
- **long range** in \( \Delta \eta \)
- reproduced by hydro models

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**Minimum-bias** pp:
- **jet peak** on the near side (+ resonances)
- **recoil jet** on the away side

**High multiplicity** (0.0005% of MB)
- near side ridge
- origin still to be fully understood

CMS JHEP 09 (2010) 091

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The double ridge in p-Pb

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Initial state effects
- Color Glass Condensate (CGC)
- Color connections in the longitudinal direction

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  - Multiparton interactions
  - Collective effects

K. Werner, I. Karpenko, and T. Pierog, P.R.L. 106 (2011) 122004


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Does it flow or not?

Particle identification could say something
PID in ALICE: detectors and techniques
Detector description
In this analysis:
- **Inner Tracking System (ITS)**
  - tracking at low $p_T$
  - vertexing
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  - tracks extrapolated from ITS-TPC
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- **VZERO**
  - VZERO A (2.8<η<5.1)
  - VZERO C (-3.7<η<-1.7)
  - trigger, multiplicity selection
Particle identification

\[ N^2_{\sigma,\text{PID}} = N^2_{\sigma,\text{TPC}} + N^2_{\sigma,\text{TOF}} \]
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\[ N_{\sigma, \text{PID}} < 3 \]

\[ N_{\sigma, \text{PID}} = N_{\sigma, \text{TPC}} \quad \text{below } p_T = 0.5 \text{ GeV/c} \]
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high (> 85%) purity in the considered \( p_T \) range
2PC, event selection

- not easy to define centrality in p-A because of biases

see Andreas Morsch, 25 Jul 2013 at 11:30
2PC, event selection

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- Multiplicity in the VZERO A (2.8 < η < 5.1) to define the event classes
  - VZERO A in the flight direction of the Pb beam (fragmentation of the nucleus)

ALICE p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

0-5%  5-10%  10-20%  20-40%  40-60%  60-80%  80-100%

see Andreas Morsch, 25 Jul 2013 at 11:30
2PC, event selection

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- Multiplicity in the VZERO A (2.8 < \( \eta \) < 5.1) to define the event classes
- VZERO A in the flight direction of the Pb beam (fragmentation of the nucleus)
- large \( \eta \) gap between multiplicity determination and track selection
2PC, associated yield

Associated yield per trigger particle

\[
\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}
\]
Associated yield per trigger particle

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

- \(S(\Delta\eta, \Delta\Phi)\) from same events
Associated yield per trigger particle

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\[ B(\Delta \eta, \Delta \varphi) = \alpha \frac{d^2 N_{\text{mixed}}}{d \Delta \eta d \Delta \varphi} \]

- \( S(\Delta \eta, \Delta \varphi) \) from same events
- \( B(\Delta \eta, \Delta \varphi) \) from mixed events
  (normalized such that \( B(0,0)=1 \))
2PC, associated yield

Associated yield per trigger particle

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

- tracking efficiency and contamination from secondary particles as single particle weights
- data driven correction for misidentification:

\[ Y^K_{\text{corrected}}(\Delta \eta, \Delta \phi) = Y^K_{\text{measured}}(\Delta \eta, \Delta \phi) - \alpha_{\pi \to K} Y^\pi_{\text{measured}}(\Delta \eta, \Delta \phi) \]

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2PC, Fourier coefficients

trigger particle: unidentified hadron
associated particle: identified particle

same $p_T$ interval
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ALICE
$p$-Pb $\sqrt{s_{NN}} = 5.02$ TeV

Near side jet peak
Away side recoil-jet peak
2PC, Fourier coefficients

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same $p_T$ interval
2PC, Fourier coefficients

- Trigger particle: unidentified hadron
- Associated particle: identified particle
- Same $p_T$ interval

Jet peak in the near side excluded ($\Delta \eta < 0.8$)

Good fit with 3 components:
- First component large due to recoil jet
- $a_2$ given by jet+ridge
- $a_3$ much smaller than the other coefficients
2PC, $v_2$ coefficients

From $a_2$ we get $v_2$:

$$V^{h-i}_{n\Delta} \{2PC\} = \frac{a^{h-i}_{n}}{a^{h-i}_{0}}$$

$$v^{i}_{n} \{2PC\} = \frac{V^{h-i}_{n\Delta}}{\sqrt{V^{h-h}_{n\Delta}}}$$
From $a_2$ we get $v_2$:

$$v_n^{h-i} \{2PC\} = \frac{a_n^{h-i}}{a_0^{h-i}}$$

- No significant mass ordering in low multiplicity class
From $a_2$ we get $v_2$: \[ V_{n\Delta}^{h-i}\{2PC\} = a_{n}^{h-i}/a_0^{h-i} \quad v_{n}^{i}\{2PC\} = V_{n\Delta}^{h-i}/\sqrt{V_{n\Delta}^{h-h}} \]

- No significant mass ordering in low multiplicity class
- Mild mass ordering at low transverse momenta in high multiplicity classes
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- No significant mass ordering in low multiplicity class
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...But we can do more...
jet contribution reduced assuming:

- Mostly jet contribution (i.e. no significant ridge) in low multiplicity p-Pb events
2PC, the subtraction procedure

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No significant ridge in 60-100%
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Not the case for 0-20%

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- per-trigger jet contribution independent of the event multiplicity

**ALICE, arXiv:1307.3237 [nucl-ex]**
2PC, the subtraction procedure

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high multiplicity (0-20%) - low multiplicity (60-100%)

2PC, the subtraction procedure
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\[ \frac{1}{N_{\text{coll}}} \frac{d^3N}{d\eta \cdot d\phi \cdot d\Omega} = \frac{1}{N_{\text{coll}}} \frac{d^3N}{d\eta \cdot d\phi \cdot d\Omega} \]

\[ \frac{1}{N_{\text{coll}}} \frac{d^3N}{d\eta \cdot d\phi \cdot d\Omega} \]
2PC, the subtraction procedure

residual of jet, particularly important for pions
- most likely event selection bias on jet fragmentation
- excluded on the near side (|Δη|>0.8)
- systematic on the away side taken into account
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residual of jet, particularly important for pions
- most likely event selection bias on jet fragmentation
- excluded on the near side ($|\Delta \eta| > 0.8$)
- systematic on the away side taken into account
Only significant contribution from second Fourier coefficient
First coefficient smaller w.r.t. the case without subtraction (up to ~10 times smaller)
Third coefficient still small
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Not only the jet is subtracted but also the baseline:

\[ V_{n\Delta}\{2\text{PC, sub}\} = \frac{a_n}{(a_0 + b)} \]

*b calculated in 60-100% class
2PC, v2 of π, K and p

ALICE

p-Pb $\sqrt{s_{NN}} = 5.02$ TeV
(0-20%) - (60-100%)

$|\Delta\eta| > 0.8$ (Near side only)

$v_2^{2PC, \text{sub}}$

$p_T$ (GeV/c)

- $v_{2,h}$ same as our earlier results ALICE, Phys.Lett. B719 (2013) 29–41
2PC, $v_2$ of $\pi$, K and p

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- $v_{2,\pi}$ similar to $v_{2,h}$
$2\text{PC, } v_2 \text{ of } \pi, K \text{ and } p$

$\text{p-Pb } \sqrt{s_{NN}} = 5.02 \text{ TeV}$

$(0-20\%) - (60-100\%)$

- $v_{2,h}$ same as our earlier results $ALICE, \text{Phys.Lett. B719 (2013) 29–41}$
- $v_{2,\pi}$ similar to $v_{2,h}$
- Hint of $v_{2,K}$ smaller than $v_{2,\pi}$ at low $p_T$
2PC, v2 of π, K and p

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- $v_{2,\pi}$ similar to $v_{2,h}$
- hint of $v_{2,K}$ smaller than $v_{2,\pi}$ at low $p_T$
- $v_{2,p}$ smaller than $v_{2,\pi}$ below 2 GeV/c and larger above
- crossing at about 2 GeV/c

2PC, v2 of $\pi$, K and p

- behavior similar to PbPb collisions  
(also seen in the $p_T$ spectra)

ALICE, arXiv:1307.6796 [nucl-ex]

see Jonas ANIELSKI on 26 Jul 2013 at 15:40
2PC, v2 of π, K and p

- behavior similar to PbPb collisions

(also seen in the $p_T$ spectra)

ALICE, arXiv:1307.6796 [nucl-ex]

see Jonas ANIELSKI on 26 Jul 2013 at 15:40

- Mass ordering at low $p_T$ qualitatively consistent with hydro models


Summary

ALICE has further characterized the double ridge structure from two particle correlations in p-Pb
- the jet contribution has to be subtracted to reveal the double ridge
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The double ridge can be studied using Fourier decomposition
- second Fourier coefficient much larger than the others
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The behavior of the $v_2$ parameter is similar to the one observed in Pb-Pb collisions
- different mechanisms to explain such structure
- the question “Does it flow or not?” still open
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Thank you for your attention!
THANKS
BACKUP
tracking efficiency

\[ p_{\text{T}} \text{ (GeV/c)} \]

\[ \begin{array}{c}
\text{tracking efficiency} \\
0.5 \ 1 \ 1.5 \ 2 \ 2.5 \ 3 \ 3.5 \ 4 \ 4.5 \ 5 \\
\end{array} \]

\[ \begin{array}{c}
\text{tracking efficiency} \\
0.1 \ 0.2 \ 0.3 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.9 \ 1 \\
\end{array} \]

\[ p \text{-Pb } s_{\text{NN}}=5.02 \text{ TeV} \]

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ALI-PERF-50609

Leonardo Milano, CERN
TOF matching efficiency

$\pi^+, \pi^-, K^+, K^-, p, \bar{p}$

$p_{T}$ (GeV/c)

$p$-Pb $\sqrt{s_{NN}}=5.02$ TeV

17/07/2013

ALI-PERF-56258