Correlations in small systems with ALICE

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on behalf of the ALICE Collaboration

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Outline

- ALICE overview
- Ridges in small systems
- LR-correlations in p-Pb
- Muon $v_2$ in p-Pb
- MPI in pp and p-Pb
- Summary and outlook
ALICE apparatus

Central Barrel Tracking, PID $|\eta| < 0.9$

Muon Arm $-4 < \eta < -2.5$
Two-particle correlations

Near-side jet peak, $\Delta \eta \approx \Delta \varphi \approx 0$
Away-side jet, $\Delta \varphi \approx \pi$ along $\Delta \eta$
Nuclear matter effects

- Elementary collision
  No nuclear matter effects

- Cold nuclear matter (CNM)
  effects, no Quark-Gluon Plasma

- CNM effects
  + Hot nuclear matter effects
  (related to QGP formation)
Near-side ridge seen in small systems at high multiplicity similar to the well-known feature from Pb-Pb (anisotropic flow).

- What is the origin of this ridge in small systems? Initial or final state effects?
No near-side ridge seen in 60-100% and similar to pp.
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Subtraction is done to “isolate” ridge from jet.
Double-ridge in p-Pb

- No near-side ridge seen in 60-100% and similar to pp.
- Subtraction is done to “isolate” ridge from jet.

- Quantified in terms of $v_n$ coefficients.
- Clear indication of mass ordering for $v_2$ in p-Pb.
- Resembles Pb-Pb.
- Collective effects in p-Pb?
Long-range correlations (LRC) in p-Pb

LHC beam asymmetry ($E_{Pb} = 1.58 \cdot A \text{ TeV}, E_p = 4 \text{ TeV}$) \implies $|\Delta y|_{\text{cms}} = 0.5 \log \left( \frac{Z_{Pb} A_p}{Z_p A_{Pb}} \right) = 0.465$

- p-going direction
- Pb-going direction

$y_{\text{lab}} = 0$
$y_{\text{cms}} = 0$

- Trigger particles from Muon Spectrometer.
  - Composition of parent particles of reconstructed muons varies as a function of $p_T$.
  - Dominated by Heavy Flavour (HF) at high $p_T$. 

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ALICE, PLB753 (2016) 126

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Long-range correlations (LRC) in p-Pb

LHC beam asymmetry \( (E_{\text{Pb}}=1.58\cdot A\,\text{TeV}, E_p=4\,\text{TeV}) \Rightarrow |\Delta y|_{\text{cms}} = 0.5 \log\left(\frac{Z_{\text{Pb}}A_p}{Z_pA_{\text{Pb}}}\right) = 0.465 \)

- p-going direction

\[ p_{-}\text{Pb} \rightarrow \text{Pb}_{-}\text{Pb} \rightarrow p_{-}\text{Pb} \]

\[ y_{\text{lab}} = 0 \quad y_{\text{cms}} = 0 \]

- Pb-going direction

\[ p_{+}\text{Pb} \rightarrow \text{Pb}_{+}\text{Pb} \rightarrow p_{+}\text{Pb} \]

\[ y_{\text{lab}} = 0 \quad y_{\text{cms}} = 0 \]

- Trigger particles from Muon Spectrometer.
- Composition of parent particles of reconstructed muons varies as a function of \( p_T \).
- Dominated by Heavy Flavour (HF) at high \( p_T \).

- Associated particles from central barrel.
- Tracklets: pair of hits on two SPD layers pointing to the primary vertex.
Long-range correlations (LRC) in p-Pb

LHC beam asymmetry ($E_{\text{Pb}}=1.58\text{ A TeV}, E_p=4 \text{ TeV}) \Rightarrow |\Delta y|_{\text{cms}} = 0.5 \log(Z_{\text{Pb}}A_p/Z_pA_{\text{Pb}}) = 0.465

- Trigger particles from Muon Spectrometer.
  - Composition of parent particles of reconstructed muons varies as a function of $p_T$.
  - Dominated by Heavy Flavour (HF) at high $p_T$.
- Associated particles from central barrel.
  - Tracklets: pair of hits on two SPD layers pointing to the primary vertex.
  - Selection uses azimuthal and polar angle differences of the hits.

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LRC in p-Pb: double ridge

p-going

Pb-going

projection

triggers: forward muons
associated: mid-y tracklets
[0-20%] - [60-100%] to isolate LRC

Double-ridge seen in both directions.
It extends to large rapidity, \( \eta \) up to \( \pm 4 \)

2\textsuperscript{nd} order dominates

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Sizable inclusive muon $v_2$

$v_2^\mu$ is larger for Pb-going

AMPT agrees with p-going at low $p_T$.

High $p_T$: no agreement.

$p_T > 2$ GeV/c: yield is dominated by HF decays.

The ratio seems to be independent of $p_T$.

Constant fit: $1.16 \pm 0.06$, $\chi^2$/NDF=0.4.

Possible scenarios for $p_T > 2.0$ GeV/c:

- $v_2 > 0$ for HF muons (seen in Pb-Pb)
- Different composition of the parent distribution and $v_2$ in AMPT vs data
Uncorrelated seeds: yields calculation

\[
< N_{\text{uncorrelated seeds}} > = \frac{< N_{\text{trig}} >}{< N_{\text{correlated triggers}} >} = 1 + \frac{< N_{\text{trig}} >}{1 + < N_{\text{assoc,nearside}} > + < N_{\text{assoc,awayside}} >}
\]

- number of independent particle sources
- proportional to multiple parton interactions (MPI) in Pythia

![Graphs showing particle distributions](ALICE, JHEP 1309 (2013) 049 pp)

**pPb**

ALICE, PLB741 (2015) 038

- Near-side
- Away-side
- Background

- Double-ridge and small contribution from \( v_3 \) to be subtracted in p-Pb.

I. Lakomov, ICHEP 2016, 04 Aug 2016
Uncorrelated seeds: results

\[
\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trig}} \rangle}{\langle N_{\text{correlated triggers}} \rangle} = \frac{\langle N_{\text{trig}} \rangle}{1 + \langle N_{\text{assoc,nearside}} \rangle + \langle N_{\text{assoc,awayside}} \rangle}
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- number of independent particle sources
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\[\text{ALICE, JHEP 1309 (2013) 049}\]

\[\text{ALICE, PLB 741 (2015) 038}\]

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\begin{align*}
\text{pp} & \quad \text{ALICE p-Pb } \sqrt{s_{NN}} = 5.02 \text{ TeV} \\
& \quad \bullet 0.7 < p_{T,\text{assoc}} < p_{T,\text{trig}} < 5.0 \text{ GeV/c, data} \\
& \quad - \cdot 0.7 < p_{T,\text{assoc}} < p_{T,\text{trig}} < 5.0 \text{ GeV/c, fit} \\
& \quad \blackblacket 2.0 < p_{T,\text{assoc}} < p_{T,\text{trig}} < 5.0 \text{ GeV/c, data} \\
& \quad \ldots \quad 2.0 < p_{T,\text{assoc}} < p_{T,\text{trig}} < 5.0 \text{ GeV/c, fit} \\
\end{align*}

\[\langle N_{\text{charged}} \rangle_{\eta| < 0.9, p_T > 0.2 \text{ GeV/c}}
\]

\[\text{Ratio data/fit}
\]

\[\text{systematic uncertainties}
\]

\[\langle N_{\text{ch}} \rangle^{V_{OA}}_{\eta| < 0.9, p_T > 0.2 \text{ GeV/c}}
\]

- Number of uncorrelated seeds (MPI) scales linearly with the multiplicity in pp and p-Pb.
Summary

- Double ridge and mass ordering of the $v_2$ measured in p-Pb collisions might indicate some collective effects in p-Pb collisions.

- Muon-hadron correlations in p-Pb collisions:
  - Double ridge extends over 10 units of pseudorapidity.
  - Inclusive muon $v_2$ is larger on Pb-going side than p-going side.
  - AMPT comparison suggests HF $v_2 > 0$ or different particle composition.

- Number of uncorrelated seeds (MPI) scales linearly with the multiplicity both in pp and p-Pb.

- High-statistics data from Run 2 is required for more detailed studies, in particular for the MPI analysis and searches of double-ridge in pp if any?
First measurement of the D-h± correlations at the LHC.

Similar correlation functions for pp @ 7 TeV and p-Pb @ 5.02 TeV.

Larger statistic is needed for detailed studies (hope to have it in Run 2).
Thank you!
Backup slides
ALICE apparatus

Inner Tracker System (ITS)
✓ tracking at low $p_T$
✓ vertexing

Time Projection Chamber (TPC)
✓ main tracking system
✓ particle identification (PID) based on the energy loss

Time of Flight (TOF)
✓ PID based on the arrival time

V0
✓ V0A (2.8<$\eta<$5.1)
✓ V0C (-3.7<$\eta<$-1.7)
✓ trigger, multiplicity selection

Muon Spectrometer
✓ tracking chambers (-4<$\eta<$-2.5)
✓ trigger chambers