Two–particle correlations and balance functions in $p$–$Pb$ and $Pb$–$Pb$ collisions at LHC energies with ALICE

Michael Weber (University of Houston) on behalf of the ALICE collaboration

EPS HEP 2013 - Stockholm, Sweden – 18.07.2013
Motivation

Heavy Ion collisions (Pb-Pb) → Hot QCD matter (Quark Gluon Plasma)

$p$-Pb collisions: as a reference for cold nuclear matter effects
Two-particle correlations

Study the underlying mechanism and dynamics of particle production
• For each trigger particle with $p_T$ count number of associated particles with $p_T$, $\Delta \varphi$, $\Delta \eta$

Example: jets

$\Delta \varphi = \pi$

$\Delta \varphi = 0$

$\Delta \eta = \eta_1 - \eta_2$
VZERO-A (2.8 < \eta < 5.1):
- Multiplicity determination
- Correlation between geometry/centrality and multiplicity is not trivial in p-Pb collisions

Time Projection Chamber:
- Vertex
- Tracking: |\eta| < 0.8
- PID (dE/dx)

Time Of Flight:
- PID (beta)

Inner Tracking System:
- Tracking
- Vertex (|V_z| < 10 cm)
Two-particle correlations (Pb-Pb)

Particle pairs in same event:

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

Corrected for single particle efficiency and contamination

Particle pairs in mixed events:

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

"Bulk-dominated" \( p_T \) region:
- double ridge structure
- long range in \( \Delta \eta \)

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Two-particle correlations (p-Pb)

High multiplicity events
\(<dN_{ch}/d\eta>|_{|\Delta\eta|<0.5}=35.84 \pm 0.78\)

Low multiplicity events
\(<dN_{ch}/d\eta>|_{|\Delta\eta|<0.5}=6.83 \pm 0.55\)

Double “Ridge”

Interpretation:
- Initial state (color glass condensate)?
- Final state (hydrodynamics)?

Identified Particles

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Correlations:

- Trigger particle = hadron
- Associated particle = pion, kaon, proton
- Symmetric $p_T$ bins
- PID: Combine TOF (beta) and TPC (dE/dx) information
- Low (<15%) contamination from wrongly identified particles
- Cuts:

\[
N_{\sigma,PID}^2 = N_{\sigma,TPC}^2 + N_{\sigma,TOF}^2, \quad N_{\sigma,PID}(p_T < 0.5\text{GeV} / c) = N_{\sigma,TPC}
\]

\[
N_{\sigma,PID} < 3
\]
Subtraction procedure

- Subtraction of Jet component via multiplicity classes: (0-20%) - (60-100%)
- Residual jet peak on near side excluded:
- Harmonic decomposition of $\Delta \varphi$ distribution:

$$a_0 + \sum_{n=1}^{3} 2a_n \cdot \cos(n \cdot \Delta \varphi)$$

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arXiv:1307.3237 [nucl-ex]
$v_2$ from two-particle correlations (2PC)

- Extract $v_2$
  
  $V^{h-i\{2PC\}}_{2\Delta} = a^{h-1}_2 / a^{h-1}_0, i = \pi, K, p$

  $v^{i\{2PC\}}_2 = V^{h-i}_{2\Delta} / \sqrt{V^{h-h}_{2\Delta}}$

- $v_2\{2PC, sub\}$: from subtraction procedure
- $p_T$ dependence shows a mass ordering
- Qualitatively similar to Pb-Pb
- Can be described by hydrodynamic models

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Balance function

**Definition:**

\[
B(\Delta \eta, \Delta \varphi) = \frac{S(\Delta \eta, \Delta \varphi)_{US}}{B(\Delta \eta, \Delta \varphi)_{US}} - \frac{S(\Delta \eta, \Delta \varphi)_{LS}}{B(\Delta \eta, \Delta \varphi)_{LS}}
\]

\[US = ++ / -- \]
\[LS = +-- / --+ \]

**Motivation:**

- Creation of balancing charges in rapidly expanding medium
- Questions:
  - What is the time ordering of the collision?
  - Can we detect different stages where charges are created?
- **Early stage creation:** larger final separation, wider balance functions
- **Late stage creation:** pairs more correlated, narrower balance functions
- **BUT:** stronger flow \( \rightarrow \) pairs also more correlated, **narrower balance functions**

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Example: Pb-Pb

- **Centrality 0-5%**
  - $0.3 < p_T (\text{GeV/c}) < 1.5$
  - $|\eta| < 0.8$

- **Centrality 30-40%**

- **Centrality 70-80%**
  - Pb-Pb @ $\sqrt{s_{NN}} = 2.76 \text{ TeV}$

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**Glauber model** - a description of heavy-ion collisions

- **Central collisions**:
  - Small impact parameter $b$
  - High number of participants
  - High energy density
  - Large volume
  - Large number of produced particles

- **Peripheral collisions**:
  - Large impact parameter $b$
  - Low number of participants
  - Low multiplicity

**Impact parameter $b$** is measured as:

- Fraction of cross section "centrality"
- Number of participants
- Number of nucleon-nucleon collisions

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**Peripheral Collision**

**Central Collision**

**Semi-Central Collision**
Centrality dependence
- Narrowing in $\Delta \eta$ and $\Delta \phi$ for peripheral $\rightarrow$ central
- Suggests expanding/flowing medium
- Description by hydrodynamical models
Charge dependent correlations from EbyE, 3+1 D, viscous hydro without charge balancing

Bozek, Broniowski, PRL, 109 (2012), 062301
Bozek, Broniowski, PLB, 718 (2013) 1557
Hydro calculations

Findings:
- Pb-Pb: Charge balancing leads to a difference for LS and US pairs
- p-Pb: double ridge

Balance function:
- Centrality dependence
- Sensitivity to input parameters
- To be measured with ALICE

Charge dependent correlations from EbyE, 3+1 D, viscous hydro with charge balancing

Balance function:
- 3+1 Viscous hydro
- $\eta/S = 0.08$
- $\tau_{\text{init}} = 0.6 \, \text{fm/c}$
- $p-Pb$ $s_{NN} = 5 \, \text{TeV}$
- 0.0-3.4%
- 3.4-7.8%
- 40-50%
Summary

Double “Ridge” in p-Pb correlations

Identified Particles:
- Mass ordering
- p-Pb is not just a reference, but shows new phenomena

Hydro with local charge conservation?
- Balance function to be measured
Particle identification

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**PID:**
- Combine TOF (beta) and TPC (dE/dx) information
- Cuts:
  
  $N_{\sigma,PID}^2 = N_{\sigma,TPC}^2 + N_{\sigma,TOF}^2$

  $N_{\sigma,PID}^2 < 3$

  $N_{\sigma,PID}(p_T < 0.5\,\text{GeV}/c) = N_{\sigma,TPC}$

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*arXiv:1307.3237 [nucl-ex]*
Misidentification

\[
p\text{-Pb } \sqrt{s_{NN}} = 5.02 \text{ TeV}
\]
DPMJET Monte Carlo simulation
   tuned on real data

\[
\text{misidentification fraction}
\]

\[
p_T (\text{GeV}/c)
\]

\[
\begin{align*}
\text{ID}_{\text{MC}} & \rightarrow \text{ID}_{\text{reco}} \\
\pi & \rightarrow K \\
\pi & \rightarrow p \\
K & \rightarrow \pi \\
K & \rightarrow p \\
p & \rightarrow \pi \\
p & \rightarrow K
\end{align*}
\]
h-h correlations

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

$1.5 < p_T < 2.0$ GeV/c

$\phi \Delta n \cos n \Delta \phi$ fit

Data $a_0 + \sum_{n=1}^{3} 2a_n \cos n \Delta \phi$

$|\Delta \eta| > 0.8$ (Near side only) Scale unc. = 3%

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arXiv:1307.3237 [nucl-ex]
h-π correlations

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

$1.5 < p_T < 2.0$ GeV/c

Data $a_0 + \sum_{n=1}^{3} 2a_n \cos n\Delta\varphi$ fit

$|\Delta\eta| > 0.8$ (Near side only) Scale unc. = 5%

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arXiv:1307.3237 [nucl-ex]
h-K correlations

\[ \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{assoc}}}{d\Delta\eta d\Delta\phi} \]

\[ \Delta\eta \]
\[ \Delta\phi \text{ (rad)} \]

\[ \begin{align*}
\text{ALICE} \\
p-Pb \quad \sqrt{s_{NN}} = 5.02 \text{ TeV} \\
(0-20\%)-(60-100\%) \\
1.5 < p_T < 2.0 \text{ GeV/c}
\end{align*} \]

\[ \text{Data} \quad a_0 + \sum_{n=1}^{3} 2a_n \cos n\Delta\phi \text{ fit} \]

\[ \text{n=1} \quad \text{n=2} \quad \text{n=3} \]

|\Delta\eta| > 0.8 (Near side only) \quad \text{Scale unc. = 5\%}
Hydro calculations

(a) $N_{\text{trk}} \geq 110, 1<p_{\text{T}}<3\text{GeV}$

(b) $90 \leq N_{\text{trk}} < 110, 1<p_{\text{T}}<3\text{GeV}$
HIJING:
- Charges produced early
  (mainly via string fragmentation)
- No collectivity e.g. radial flow

AMPT:
- HIJING: initial conditions
- ZPC: partonic evolution
- ART: hadronic rescattering
- Lund fragmentation
- Different flavours

Blast Wave
- Collective motion $U_{x,y}$ in/out of reaction plane and temperature $T$
- Local charge conservation
- Emission of pair with initial separation at freeze-out $\sigma_\eta$ and $\sigma_\phi$

HIJING:  
AMPT:  
Blastwave:  

PRC 61, (2000) 067901,  
PRC 84, (2011) 044907.
Centrality dependence

Measure:
- Weighted average: 
  \[ \langle \Delta \eta \rangle = \frac{\sum B(\Delta \eta_i) \Delta \eta_i}{\sum B(\Delta \eta_i)} \]

Data:
- Strong centrality dependence

HIJING:
- Charges produced early
  (mainly via string fragmentation)
- No collectivity e.g. radial flow
- Little or no centrality dependence
- Match data for most peripheral bin

AMPT:
- HIJING: initial conditions
- ZPC: partonic evolution
- ART: hadronic rescattering
- Lund fragmentation
- Different flavours
- \(\Delta \eta\): Little or no centrality dependence
- Can reproduce \(\Delta \varphi\)
Centrality dependence

Narrowing (peripheral to central):

\[ \langle \Delta \eta \rangle = \frac{\sum B(\Delta \eta_i)\Delta \eta_i}{\sum B(\Delta \eta_i)} \]

Consistent with idea of:

- Larger radial flow (RHIC → LHC)
- Longer–lived QGP phase and thus an even greater delayed creation of the detected charges.

BUT...

- Relative decrease:

\[ \langle \Delta \eta \rangle_{CP} = \frac{\langle \Delta \eta \rangle}{\langle \Delta \eta \rangle_{\text{peripheral}}} \]

- \( \langle \Delta \eta \rangle_{CP} \): seems to fall (unexpectedly?) on the same curve
- Hard to explain it in terms of late stage creation of charges