Charged-particle multiplicity in Pb-Pb at 2.76 TeV with the displaced vertex technique with ALICE at LHC

Maxime GUILBAUD
On behalf of the ALICE collaboration
Overview

Motivations

The ALICE experiment

Analysis technique

Results

Conclusion
Motivations

- Global observable which reflects the initial conditions
- Investigate final-state distribution of available energy and underlying dynamics of particle production mechanisms
- $dN/d\eta$, over a wide pseudo-rapidity coverage, allows one to access the longitudinal scaling:
  - Violation vs conservation:
  - $dN/d\eta$ is related to:
    - Density of the system
    - Initial conditions, energy, entropy production in the early stage of heavy ion (HI) collisions
    - Background for hard-probes signals

VIOLATION

CONSERVATION
The ALICE detectors:

The relevant detectors for this talk are:

- The Silicon Pixel Detector (SPD): 2 first layers of the Inner Tracking System (ITS)
- The VZERO & The Forward Multiplicity Detector (FMD)
- The Zero Degree Calorimeter (ZDC)
  - ZNs (neutrons)+ZPs (protons) at 114m on both sides of the Interaction Point (IP)
  - Electromagnetic calorimeter (ZEM) on A side at 7.5m from the IP
Nominal collisions:

- SPD results using collisions at nominal vertex (light gray band)
  - $dN/d\eta$ SPD tracklet results are given in an extended range in $\eta$ ($|\eta|<2$) with respect to ALICE published results *PRL* 106, 032301 (2011)
  - To reach this pseudo-rapidity range, the analysis was performed in 3 bins along $Z$ axis to enlarge the acceptance of SPD:

<table>
<thead>
<tr>
<th>$Z_v$ Range</th>
<th>$\eta$ Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>-13 cm &lt; $Z_v$ &lt; -6 cm</td>
<td>-2.00 &lt; $\eta$ &lt; -0.75</td>
</tr>
<tr>
<td>-7 cm &lt; $Z_v$ &lt; 7 cm</td>
<td>-0.75 &lt; $\eta$ &lt; 0.75</td>
</tr>
<tr>
<td>6 cm &lt; $Z_v$ &lt; 13 cm</td>
<td>0.75 &lt; $\eta$ &lt; 2.00</td>
</tr>
</tbody>
</table>

![Diagram of ALICE detector and Z axis with vertex and SPD regions](attachment:image.png)
Satellite collisions:

- The LHC RF is 400 MHz, RF bucket separated by 2.5 ns:
  - **Nominal**, beam bunches filled in one out of ten buckets (separation by a multiple of 25 ns)
  - Small fraction of the beam captured in unwanted RF buckets → **satellite bunches**
  - Satellite bunches give satellite collisions by crossing nominal bunch every 37.5 cm

- Due to zero crossing angle, a large amount of satellite collisions was recorded by the ALICE experiment in 2010:
  - Low material budget between 75 to 337.5 cm
  - The pseudo-rapidity coverage of each detector changes with every vertex
Analysis technique: $\eta$ coverage

- VZERO-A $\eta$ coverage for collisions at main IP:

<table>
<thead>
<tr>
<th>Ring</th>
<th>$\eta$ range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.5 &lt; $\eta$ &lt; 5.1</td>
</tr>
<tr>
<td>1</td>
<td>3.9 &lt; $\eta$ &lt; 4.5</td>
</tr>
<tr>
<td>2</td>
<td>3.4 &lt; $\eta$ &lt; 3.9</td>
</tr>
<tr>
<td>3</td>
<td>2.8 &lt; $\eta$ &lt; 3.4</td>
</tr>
</tbody>
</table>

- FMD1 & FMD2 $\eta$ coverage at main IP:

<table>
<thead>
<tr>
<th>FMD</th>
<th>$\eta$ range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMD1</td>
<td>3.7 &lt; $\eta$ &lt; 5.0</td>
</tr>
<tr>
<td>FMD2</td>
<td>1.7 &lt; $\eta$ &lt; 3.7</td>
</tr>
</tbody>
</table>

Charged-particle multiplicity in Pb-Pb at 2.76 TeV with ALICE at LHC
Analysis technique: $\eta$ coverage

Large pseudo-rapidity coverage for both detectors thanks to satellite collisions:

- **VZERO**: $-3.0 < \eta < 5.25$
- **FMD**: $-5.0 < \eta < 5.5$
Analysis technique: VZERO

VZERO & SPD coverage overlap for several vertices

- VZERO signal calibrated on SPD measurement
- Charged-particle multiplicity is computed with:
  \[
  \frac{dN}{d\eta}(Z_m, i) = \frac{dN}{d\eta}(SPD, i) \cdot \frac{\alpha(\eta, Z_m, i) \cdot A_{VZERO}(Z_m, i)}{\alpha(\eta, Z_m, i) \cdot A_{VZERO}(Z_r, i)}
  \]

- \( A_{VZERO}(Z_r/m, i) \):
  - Signal amplitude for a given ring at a given vertex
  - \( \alpha_\eta \) are extracted from MC
  - HIJING + GEANT3 simulations with satellite vertices
  - Ratio between signal amplitude and the number of primary charged-particle generated at the collision
  - This ratio is given for each ring and each vertex

- Method features
  - Detector response, secondaries contribution are cancelled out in the ratio
  - Weakly MC dependent
  - Relative measurement

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FMD measurement was also performed with displaced vertex technique

Method features

- Absolute measurement
- Symmetrical coverage: symmetry check
- Corrections from secondaries are MC dependent

MC:

- HIJING + GEANT3 simulation with satellite vertices

Low material density between 112.5 cm & 375 cm

- Lower secondary particle contribution to the signal
- Smaller syst. uncertainties
Satellite collisions every 2.5 ns

ZDC time resolution allows to separate collisions coming from different satellite bunches:

- Collision between nominal bunches (black circle)
- Satellite bunch from A side + nominal bunch from C side (red circles)
- Satellite bunch from C side + nominal bunch from A side (blue circles)
ZDC energy $\sim < N_{\text{spect}} >$

ZEM amplitude $\sim < N_{\text{part}} >$

Estimator calibrated on VZERO at nominal IP

- ZDC response weakly dependent on the vertex position (far from the IP) with respect to VZERO

- This estimator works only for the most central events (0-30%) due to nuclear fragment production in peripheral events
Results: FMD and VZERO comparison

- Comparison between SPD, FMD and VZERO:
  - SPD: $-2 < \eta < 2$
  - FMD: $-5 < \eta < 5.5$
  - VZERO: $-3 < \eta < 5.25$

- Good agreement between FMD and VZERO
Both FMD & VZERO are consistent with SPD in the overlapping region

Results are combined:

- Mean weighted by each detectors syst. errors
- Common sources of syst. errors are then summed in quadrature

The ratio shows a stronger contribution from FMD to the mean due to its smaller error
The ALICE combined distribution is given in 4 centrality bins

- Stat. error smaller than marker size
- Syst. error: 2-6%

Each distribution is symmetrized

A double gaussian function fits well the data:

\[
\frac{dN_{ch}}{d\eta} = A_1 e^{-\eta^2 / 2\sigma_1^2} - A_2 e^{-\eta^2 / 2\sigma_2^2}
\]
Three models are compared with ALICE results

- Color Glass Condensate (CGC) based model
  - J. L. Albacete, A. Dumitru, Y. Nara

- UrQMD model

- AMPT

CGC: reproduces the shape & the amplitude, but for a restricted $\eta$ range

UrQMD/AMPT: fails to reproduce the overall amplitude and shape of the pseudo-rapidity density
The $dN/d\eta$ scaling as a function of $<N_{\text{part}}>$ is given in 5 pseudo-rapidity bins:

- Complementary results to those published

The primary charged particle density normalized by the number of participant pairs increases for the most central events

The trend in each pseudo-rapidity bin is the same:

- These results are compared to the ALICE published* results in the central region

- The ratio is flat for all centrality bins

The longitudinal scaling is given for the most central bin:

- dN/dη distribution is normalized by the number of participant pairs & shifted by the beam rapidity

- Results are compared to BRAHMS & PHOBOS Au-Au data at 62 and 200 GeV at RHIC

- Tail not expected to be gaussian and the very high rapidity region is extrapolated with a linear function
The linear extrapolation shows that ALICE, BRAHMS and PHOBOS data are consistent.

Scaling validity is confirmed within the errors at LHC.

Also seen for $v_2$ longitudinal scaling:

- See Alexander Hansen's talk (#417) on Friday:
  - Pseudo-rapidity dependence of the anisotropic flow with ALICE at LHC
\( N_{\text{ch}} \) is estimated with the double gaussian fit function and a linear extrapolation at high rapidity for each centrality bin.

- Stat. error is smaller than the marker size.
- Syst. errors included the uncertainty on the extrapolation: 2-3 %.

The total number of charged particles increases with the number of participants:

- Fraction of extrapolation: 13%.

Comparison with PHOBOS data:

- PHOBOS data scaled by a factor 2.87.

\[
\left( \frac{N_{\text{ch}}}{N_{\text{part}}} \right)_{LHC} = 2.87 \cdot \left( \frac{N_{\text{ch}}}{N_{\text{part}}} \right)_{RHIC}
\]
The charged particle multiplicity was shown in 10 pseudo-rapidity units and 4 centrality bins (0-30%).

The dN/dη distribution scaled by the number of participant pairs increases as a function of N_{part} with a similar trend in all pseudo-rapidity bins.

The longitudinal scaling shows that ALICE results are consistent with PHOBOS and BRAHMS ones over a large range of energies and confirm the scaling validity.

ALICE and PHOBOS (scaled) N_{ch} are consistent within errors even if the trend of ALICE data looks a bit different.
Back up
Analysis technique: Simple Material Budget

Charged-particle multiplicity in Pb-Pb at 2.76 TeV with ALICE at LHC

FMD2  FMD1  VZERO-A
These plots are fitted with a linear function for each rings and several vertices.

The resulting slopes give $\alpha_\eta$ values.
Results: Longitudinal scaling in several centrality bins

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Charged-particle multiplicity in Pb-Pb at 2.76 TeV with ALICE at LHC
\( N_{\text{ch}} \) is fitted with a linear and a 2\textsuperscript{nd} order polynomial function

- The \( \chi^2 \) is better for the 2\textsuperscript{nd} order polynomial function for ALICE data

- PHOBOS are well fitted by a linear function
Results: Total number of charged particles $N_{ch}$

The PHOBOS scaling factor is extracted from this plot:

$$\left\langle \frac{N_{ch}}{N_{part}} \right\rangle_{LHC} = 2.87$$

The ALICE and PHOBOS measurements are consistent within errors.

The trend between both measurements looks a bit different.