Measurement of charged particle pseudorapidity density in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector

*Yujiao Chen*, for the ATLAS Collaboration

Physics department, Columbia university
Introduction

✦ Connection with energy/entropy production in early stages of heavy ion collisions.

✦ Past measurements exhibit interesting geometrical scaling properties.

➡ Multiplicity at mid-rapidity scales faster than \(<N_{\text{part}}\)\), but in a way that is energy independent.

➡ Total multiplicity scales with \(<N_{\text{part}}\).

✦ Hard to predict:

➡ Low momentum regime

➡ Non-perturbative QCD

➡ Multiple body interactions

➡ Different approaches: CGC, empirical scaling rules, Landau hydrodynamics etc
♦ High precision tracking device, very close to beam pipe.

♦ Three barrel layers (50.5, 88.5, 122.5 mm in radius), six disk layers, three on each side.

♦ Active area $\approx 1.8 \, \text{m}^2$ with $\approx 80 \times 10^6$ pixels arranged into 1744 modules.

♦ Placed in a 2 T solenoid field when turned on. B-field was off for this analysis.

♦ Pixel barrel used in this analysis, $|\eta| < 2.0$
Methods description

✦ Pixel tracking: ATLAS standard tracking algorithm, pixel detector only

✦ Two-point tracklet method:
  ❖ Select high quality clusters.
  ❖ Select cluster pairs aligned with primary vertex:

\[
\sqrt{\left(\frac{\Delta \eta}{\sigma \Delta \eta}\right)^2 + \left(\frac{\Delta \phi}{\sigma \Delta \phi}\right)^2} < 3 \times \sqrt{2}
\]
Two-point tracklet method

Two methods used to count tracklets.

- Method 1: multiple associations to layer-0 treated as one tracklet.
- Method 2: multiple associations to layer-0 treated as multiple tracklet candidates.

- Flipped event: $(z - Vz) \rightarrow - (z - Vz), \Phi \rightarrow \pi - \Phi$
- Subtract combinatorics using flipped events
Centrality definition

✦ Use Forward calorimeter transverse energy

\[ 3.2 < |\eta| < 4.9 \]

⇒ Sampling fraction: \( f = 100 \pm 2\% \)
MC samples $p_T$ re-weighting

✦ HIJING $p_T$ spectrum differs significantly from data.  
✦ HIJING spectrum much higher at low $p_T$.

✦ Re-weighting Procedure:

⇒ A re-weighting function is applied to HIJING sample to account for $p_T$ difference between data and MC, used only for corrections, not for $p_T$ measurement.  
⇒ Re-weighting function is obtained from pixels tracks from B-on data.  
⇒ The re-weighted HIJING spectrum agrees relatively well with data.
Correction procedure

✦ Pixel tracking:

Efficiency: \( \epsilon_{pt}(\eta) = \frac{N_{\text{match}}(\eta)}{N_{pr}(\eta)} \), Background: \( b_{pt}(\eta) = \frac{N_{\text{backg}}(\eta)}{N_{pt}(\eta)} \)

Correction factor:
\[ C_{pt}(\eta) = \frac{1 - b_{pt}(\eta)}{\epsilon_{pt}(\eta)} \]

✦ Tracklet methods:

Correction factor: \( C_{2pt}(\eta) = \frac{N_{pr}(\eta)}{N_{2pt}(\eta)} \)

✦ Correction factors are calculated in different occupancy intervals \((dN_{\text{clus}}^0/d\eta( |\eta| <1.0))\).
Comparison of three methods

Method 1
Method 2
Pixel tracks

ATLAS Preliminary
Pb+Pb $\sqrt{s_{NN}}=2.76$ TeV
Heavy Ion 2010 field-off data

Ratio
**Systematic uncertainties**

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty (0-10%)</th>
<th>Uncertainty (70-80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC detector description</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Extra material</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>$\Delta R$ cut</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>$p_T$ re-weighting</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Hadron flavor composition</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Enhanced $K_\pi$, $\Lambda$</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>HYDJet</td>
<td>0.5-7.5% vs. $\eta$</td>
<td>0%</td>
</tr>
<tr>
<td>Analysis Method</td>
<td>3.5%</td>
<td>1%</td>
</tr>
<tr>
<td>Combined ($\eta = 0$)</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Combined ($\eta = 2$)</td>
<td>8.5%</td>
<td>3%</td>
</tr>
</tbody>
</table>

5% increase of yield from $\eta \sim 0$ to $\eta \sim 1$ in peripheral events

(30-80% centrality class)
dN_{ch}/d\eta distribution

Ratio of central to peripheral

**dependence**

![Graph](attachment:image.png)

**ATLAS** Preliminary

Heavy Ion 2010 field-off data

- **AGS**
- **SPS**
- **PHOBOS**
- **p+p/p+p** (inel.)
- **p+p/p+p** (NSD)
- **CMS NSD p_{T}>0 MeV**
- **ALICE p+p**
- **ATLAS p_{T}>0 MeV**
- **ALICE Pb+Pb 0-5%**
- **ALICE power law s^{0.15}**
- **Landau**
- **Log extrapolation**
- **ATLAS Pb+Pb 0-6%**

**ALICE:** shifted along x-axis
**N_{part} dependence**

\[ \frac{1}{N_{\text{evt}}} \frac{dN_{\text{ch}}}{d\eta} \propto \langle N_{\text{part}} \rangle \]

**ATLAS** Preliminary

Pb+Pb $\sqrt{s_{NN}}=2.76$ TeV

Heavy Ion 2010 field-off data

- **ATLAS, Pb+Pb 2.76 TeV**
- **ALICE, Pb+Pb 2.76 TeV**
- **RHIC Au+Au 0.2 TeV, scaled up by a factor of 2.15**

RHIC result scaled up by a factor of 2.15 to match central ATLAS result.
$dN_{\text{ch}}/d\eta/<N_{\text{part}}/2> \text{ shape comparison}$

Extended measurement to high pseudorapidity region ($|\eta|<2.0$), but not yet able to address details of limiting fragmentation, which requires further forward region measurement.

Comparison with PHOBOS results, which extended over $|\eta|<5.4$

Shift one of the RHIC projectiles into rest frame of one of the LHC projectiles
Conclusions

✧ $dN_{ch}/d\eta$ over $|\eta|<2.0$ measured in different centrality bins.

➡ 5% increase from $\eta\sim0$ to $\eta\sim1$ in peripheral events (30-80% centrality class).

➡ No significant shape change in different centrality class.

✧ Energy and $N_{part}$ dependence of $dN_{ch}/d\eta$/
$<N_{part}/2>$ at mid-rapidity are compared with other experiments.

➡ Confirms RHIC $N_{part}$ dependence trend.

➡ Result is consistent with other experiments.

✧ $dN_{ch}/d\eta$ shape also compared with PHOBOS results.
Backup
Data-MC comparison

ATLAS Preliminary
Pb+Pb $\sqrt{s_{NN}}$=2.76 TeV

Data
Hijing

0-10%

ATLAS Preliminary
Pb+Pb $\sqrt{s_{NN}}$=2.76 TeV

Data
Hijing

0-10%

Δη distribution

ΔΦ distribution

MC sample with re-weighting procedure
The graph shows the dependence of $N_{\text{part}}$ on $1/N_{\text{evt}} dN_{\text{ch}}/d\eta / (\langle N_{\text{part}} \rangle / 2)$ for different experiments:

- **ATLAS**, Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV
- **ALICE**, Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV
- **RHIC** Au+Au $0.2$ TeV, scaled up by a factor of 2.15
- **PHOBOS** Au+Au $0.2$ TeV, scaled up by a factor of 2.15

The RHIC/PHOBOS result is scaled up by a factor of 2.15 to match the central ATLAS result.