Charged hadron multiplicity and transverse energy densities in PbPb collisions from CMS

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for the CMS Collaboration
CMS

• Compact Muon Solenoid
  – Large acceptance tracker, hermetic calorimetry, excellent muon spectrometer
Tracker and calorimeter systems

- **Tracker:** multiple layer silicon detector, $|\eta|<2.5$
  - Layers composed of pixels or strips cells
  - Pixels: 66M, each cell has a surface of 100x150 $\mu m^2$

- **Calorimeters:** $|\eta|<5.2$:
  - ECAL, HCAL
  - Used: $|\eta|<1.2$ and $3.2<|\eta|<4.9$
Data, simulation

- **Data:**
  - 100k minimum bias events recorded with $B=0$ T ($dN_{ch}/d\eta$)
  - 2M minimum bias events with $B=3.8$ T ($dE_T/d\eta$)

- **Simulations:**
  - 100k AMPT events, default tune
  - 100k HYDJET events, default tune

Event selection, centrality

• **Minimum bias data:**
  – Double sided HF or BSC, vertex
  – 99% hadronic efficiency (B=0 T)
  – 1% UPC contamination (B=0 T)

• **Collision centrality:**
  – determined via total transverse energy in HF

UPC: Djuvstrand and Nystrand, arXiv:1011.4908v2
\( \text{dN}_{\text{ch}}/\text{d}\eta \): Measurement methods

- **Two methods**
  - **Cluster counting:**
    - Determines multiplicity via single layer occupancy
  - **Tracklets:**
    - Uses all pairs of layers to create cluster-pairs
- **Vertexing:** done for each method separately
Cluster counting

- **Vertex:**
  - From the compatibility of cluster length with a primary vertex hypothesis

- **Cluster selection:**
  - Primary clusters:
    - $\text{cluster length } \sim |\sinh(\eta)|$
    - Not strictly true for clusters due to background

- **Further corrections:**
  - Background mimicking primaries
  - Layer 1: 10%, layer 2: 20%, layer 3: 30%
Tracklet method

• **Vertex:**
  – Clusterize tracklets along the beam line

• **Tracklet reconstruction:**
  – Input: clusters passing the cluster selection
  – Sort tracklets in $\Delta R$; cluster is matched multiple times, keep the tracklet with the smallest $\Delta R$

• **Typical correction:** <15%

• **Data-MC:** agreement over 5 orders of magnitude
dE_T/dη: Measurement method

- Uses the co-called particle flow objects
  Calorimeter information together with tracking
  See Matthew Nguyen’s talk (448, Friday)

- Non-linear calorimeter response at low energies
- The low-p_T particle spectra is not yet included
  → 0-2.5% centrality for |η|<1.2
  → 0-80% for |η|>3.2

- 50-100% of the transverse energy is captured

More details on Magdalena Malek’s poster (443)
Results
Measured $dN_{ch}/d\eta$

- The results from the two analysis methods agree within 1% → they are averaged
- $dN_{ch}/d\eta$ is ~flat over $|\eta|<2.5$ (<10% variation)

Measured \( \frac{dN_{\text{ch}}/d\eta}{(N_{\text{part}}/2)} \)

- Similar dependence for all \( \sqrt{s_{NN}} \)
- Provides constraints on soft+hard, parton saturation, Regge-Gribov approaches

In accordance with a power law dependence with exponents $s^{0.13}$ (PbPb) and $s^{0.09}$ (pp)
Measured $dE_T/d\eta$, 0-2.5%

- $E_T$: 2 TeV deposit for central pseudorapidities
  More than 3xRHIC (0.6 TeV)
- Yield falls by a factor of 2 from $\eta=0$ to $\eta=4$
Measured \( \frac{dE_T}{d\eta}/(N_{\text{part}}/2) \)

- Sideward S shape
- \( \sqrt{s_{NN}} \): More rapid rise than logarithmic
- Increase from 0.2 TeV:
  \[ 3.4 \pm 0.4 \text{ compared to } 2.2 \pm 0.1 \text{ for multiplicity} \]
Summary of the $dN_{ch}/d\eta$ distributions

- Charged hadron density in 0-5%: $1610 \pm 55$
- Small variation as a function of $\eta$ (<10%)
- No plateau in the $N_{\text{part}}$-normalised results
- Nice extrapolation to the pp values

- Very good description of the data by a parton saturation approach
- Collision energy dependence follows power law behaviour
Summary of the $dE_T/d\eta$ distributions

- **Central collisions**: $dE_T/d\eta$ reaches 2 TeV (more than 3xRHIC)
- Yield falls by a factor of 2 from $\eta=0$ to $\eta=4$
- $\sqrt{s_{NN}}$ dependence: stronger than predicted by earlier experiments assuming logarithmic scaling
- The increase of $(dE_T/d\eta)/(N_{\text{part}}/2)$ in central collisions from 0.2 to 2.76 TeV is $3.4 \pm 0.4$ compared to $2.2 \pm 0.1$ for multiplicity
Backup slides
Pixel clusters in PbPb collisions

- **Pixel detector:**
  - **Occupancy:** <1% even for the 0-5% collisions
  - **Efficiency:** exceptionally good, >99% just as in pp

- **Pixel clusters:**
  - Well understood behaviour
Cluster length in pp and PbPb

Pixel cluster length along z [pixel units]

B=4 T pp data

B=0 T PbPb data, slide 7

PbPb $s_{NN}=2.76$ TeV
Barrel layer 1
CMS Preliminary
Tracklets: data-MC comparison

- Signal peaks around $(\Delta \eta, \Delta \phi) = (0,0)$
- Agreement over 6 orders of magnitude
dN_{ch}/d\eta: pp and PbPb

CMS Preliminary
PbPb $\sqrt{s_{NN}}=2.76$ TeV

NSD pp data
### Systematic uncertainties: $dN_{\text{ch}}/d\eta$

- **Systematics for the two analysis methods**

<table>
<thead>
<tr>
<th>Source</th>
<th>Pixel Counting [%]</th>
<th>Tracklet [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction on event selection</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Centrality (0–5% – 85–90%)</td>
<td>0.5–15.6</td>
<td>0.5–15.6</td>
</tr>
<tr>
<td>Pixel hit efficiency</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Tracklet and cluster selection</td>
<td>3.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Acceptance uncertainty</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Correction of secondary particles</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Pixel cluster splitting</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Efficiency of the reconstruction</td>
<td>-</td>
<td>1.9</td>
</tr>
<tr>
<td>Misalignment, different scenarios</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Random hits</td>
<td>1.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Total non-correlated uncertainties</td>
<td>-</td>
<td>2.1</td>
</tr>
<tr>
<td>Total uncertainties</td>
<td>4.2–16.2</td>
<td>3.1–15.9</td>
</tr>
</tbody>
</table>
### Systematic uncertainties: $dE_T/d\eta$

<p>| Source                        | $|\eta| &lt; 0.6$ | $0.6 &lt; |\eta| &lt; 1.3$ | $3.2 &lt; |\eta| &lt; 4.2$ | $4.2 &lt; |\eta| &lt; 4.9$ |
|-------------------------------|-------------|----------------|----------------|----------------|
| Energy scale                  | 2%          | 2%             | 10%            | 10%            |
| MC correction factor          | 9%          | 9%             | 4%             | 4%             |
| HF noise                      | --          | --             | 2%             | 2%             |
| Vertex distribution           | 2%          | 2%             | 1%             | 2%             |
| $\eta$ symmetry               | 2%          | 2%             | 2%             | 2%             |
| Auto correlations             | 1.5%        | 1.5%           | 1%             | 1%             |
| PF/Calo difference            | 1%          | 1%             | 0.1%           | 0.1%           |
| <strong>Total</strong>                     | <strong>10%</strong>     | <strong>10%</strong>        | <strong>12%</strong>        | <strong>12%</strong>        |</p>
<table>
<thead>
<tr>
<th>Cent. bin</th>
<th>0–5%</th>
<th>5–10%</th>
<th>10–15%</th>
<th>15–20%</th>
<th>20–25%</th>
<th>25–30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\langle N_{\text{part}} \rangle$</td>
<td>381 ± 2</td>
<td>329 ± 3</td>
<td>283 ± 3</td>
<td>240 ± 3</td>
<td>203 ± 3</td>
<td>171 ± 3</td>
</tr>
<tr>
<td>Cent. bin</td>
<td>30–35%</td>
<td>35–40%</td>
<td>40–45%</td>
<td>45–50%</td>
<td>50–55%</td>
<td>55–60%</td>
</tr>
<tr>
<td>$\langle N_{\text{part}} \rangle$</td>
<td>142 ± 3</td>
<td>117 ± 3</td>
<td>95.8 ± 3.0</td>
<td>76.8 ± 2.7</td>
<td>60.4 ± 2.7</td>
<td>46.7 ± 2.3</td>
</tr>
<tr>
<td>Cent. bin</td>
<td>60–65%</td>
<td>65–70%</td>
<td>70–75%</td>
<td>75–80%</td>
<td>80–85%</td>
<td>85–90%</td>
</tr>
<tr>
<td>$\langle N_{\text{part}} \rangle$</td>
<td>35.3 ± 2.0</td>
<td>25.8 ± 1.6</td>
<td>18.5 ± 1.2</td>
<td>12.8 ± 0.9</td>
<td>8.64 ± 0.56</td>
<td>5.71 ± 0.24</td>
</tr>
</tbody>
</table>
Event selection efficiency

• Hadronic event selection efficiency:
  – Peripheral PbPb data
  – 2.76 TeV pp data
  – AMPT
  – Pythia Z2

• UPC study:
  – Based on Djuvstrand’s and Nystrand’s article: arXiv:1011.4908v2