Overview of recent ATLAS results

Dominik Derendarz on behalf of the ATLAS collaboration
Hard Probes 2020
somewhere on the Zoom servers - 1/06/2020
Ultra Peripheral Collisions (UPC)

➡ better understanding of QED
➡ better understanding of backgrounds in the peripheral heavy ion collisions
➡ sensitive to new physics
Light-by-Light scattering

Full 5.02 TeV Pb+Pb dataset has been used to measure differential cross sections for $\gamma\gamma \to \gamma\gamma$

ATLAS-CONF-2020-010

ATLAS Preliminary
Pb+Pb $\sqrt{s_{NN}} = 5.02$ TeV
- Data, 2.2 nb$^{-1}$
- Syst. $\oplus$ Stat.
- Superchic 3.0

World best limit for axion like particles

Existing constraints from JHEP 1712 (2017) 044

ATLAS Preliminary

CDF

LEP

LHC

CMS $\gamma\gamma \to \gamma\gamma$ [PLB 797 (2019) 134826]

ATLAS $\gamma\gamma \to \gamma\gamma$ (this work)
Non UPC di-muons

UPC di-muons may probe EM degrees of freedom of QGP if they are produced on top of the heavy ion collisions.

Centrality dependent, shift of the distribution going from UPC to peripheral to central events.
Colorless probes - electroweak bosons (W/Z) in Pb+Pb
➡ how can we handle geometry of the collisions?
➡ what is the structure of the nucleon?
Electroweak bosons (W/Z) in Pb+Pb

Best agreement seen with free proton PDF including the isospin effect (CT14)


Iwona Grabowska Bold
Monday 11:00
(A2 - Electroweak Probes I)
Electroweak bosons (W/Z) in Pb+Pb

$R_{AA}$ in centrality overall constant for $W$ and $Z$, but …. 

…. indication of excess in peripheral collisions


➡ analysis with those data suggest suppression of $\sigma^{\text{inel}}_{pp}$
Colored probes - heavy flavour

- how is QGP affecting quarkonia states formation?
- how is open heavy flavour interacting with the medium?
Suppression of $\Upsilon(nS)$ states in Pb+Pb

**ATLAS Preliminary**

$pp$, $\sqrt{s} = 5.02$ TeV, $L = 0.26$ fb$^{-1}$

$Pb+Pb$, $\sqrt{s_{NN}} = 5.02$ TeV, $L = 1.38$ nb$^{-1}$

$p_T < 30$ GeV

$|y|<1.5$

Clear signal of sequential melting of $\Upsilon$ states
Heavy flavour flow in Pb+Pb

Non-zero $v_2$ of muons from charm and beauty decays

Model with energy loss (DREENA-B) better describe the data
Colored probes - jets

- precise measurement of jet quenching
- how does the jet suppression depend on jet structure?
Fresh look at the fragmentation

\[ I_{AA} = \text{PbPb/pp of per-Z yields} \]

**ATLAS** Preliminary

*pp, \( \sqrt{s} = 5.02 \text{ TeV, 260 pb}^{-1} \)*

*Pb+Pb, \( \sqrt{s_{NN}} = 5.02, 1.4-1.7 \text{ nb}^{-1} \)*

\[ \text{ATLAS-CONF-2019-052} \]

\[ p_{TZ} > 30 \text{ GeV} \]

**Z boson**

\[ p_{TH} > 1 \text{ GeV} \]

\[ \Delta\phi_{hZ} > 3\pi/4 \]

**Jeff Ouellette**

Thursday 13:30

(H1 - Jets and High-PT Hadrons XI)

Complementary information to jet fragmentation measurements - no explicit jet requirement
Di-jet asymmetry - reaching new precision

**ATLAS Preliminary**

- Pb+Pb 1.72 nb$^{-1}$
- $\sqrt{s_{NN}} = 5.02$ TeV
- $pp$ 260 pb$^{-1}$

**Significant modification of the momentum balance in central Pb+Pb with respect to pp**

General formula for di-jet asymmetry:

$$x_J = \frac{p_T^2}{p_T^1}$$
Jet $v_n$ in Pb+Pb

ATLAS Preliminary
Pb+Pb 1.72 nb$^{-1}$
$\sqrt{s_{NN}} = 5.02$ TeV
anti-$k_t$ $R = 0.2$, $|y| < 1.2$

Clear signal of path length dependent energy loss

Virginia Bailey
Monday 11:00
(A1 - Jets and High-PT Hadrons I)
Clear signal of path length dependent energy loss
Large R-jets - quenching and jet structure

Large R jets - ATLAS way

“Conventional” jet

Re-clustered jet

Splitting scale

$$\sqrt{d_{12}} = \min(p_{T1}, p_{T2}) \times \Delta R_{12}$$

Anne Sickles
Wednesday 10:30
(E1 - Jets and High-PT Hadrons V)

Poster by Wenkai Zou

SSJ jets less suppressed with respect to those with higher sub-jet multiplicity
Flow in small systems

- is the azimuthal anisotropy at high pT consistent with energy loss?
- how the flow in pp collision is affected by hard processes?
- can we constrain the geometry of the pp collision?
Flow of high pT hadrons in p+Pb

Associated charged particles close (|Δη|<1) to the jet (jet with $p_T > 15$ GeV) removed from the 2PC

Model able to reproduce the flow but …
Flow of high pT hadrons in p+Pb

Model able to reproduce the flow but ... requires significant modification of charged hadrons spectra

Associated charged particles close (|Δη|<1) to the jet (jet with p_T > 15 GeV) removed from the 2PC
Flow in pp with jet particle rejection

Charged particles close ($|\Delta\eta|<1$) to the jet (track jet with $p_T > 10$ GeV) removed from the 2PC (both trigger and associated)

The $v_2$ integrated over the 0.5–5 GeV $p_T$ range decreases only marginally (2-5%) when applying jet particle rejection

**ATLAS** Preliminary

$pp \sqrt{s}=13$ TeV, $64 \text{ nb}^{-1}$

$0.5<p_T^{a,b}<5$ GeV

$2<|\Delta\eta|<5 \quad 0\leq N_{\text{ch}}^\text{periph} < 20$

- Inclusive
- All Events
- NoJet
- WithJet

Ratio to the Inclusive Case
Flow in pp with jet particle rejection

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Blair Seidlitz
Tuesday 12:00
(C4 - Initial State III)

ATLAS
Preliminary

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$0.5<p_T^{a,b}<5$ GeV

$2<|\Delta \eta|<5$, $0 \leq N_{ch}^{\text{periph}} < 20$
Flow in Z tagged pp collisions

Large Q^2-process (Z) select pp events with smaller impact parameter

v_2 in Z-tagged events shows only a slight increase if any
Observed significant $v_2$, but smaller than $p+Pb$ and $pp$.
Heavy flavour flow in pp

$\nu_2$ of muons from charm decays consistent with light hadrons flow

$v_2$ of muons from beauty decays consistent with 0
Role of the initial state

$\langle p_T \rangle$ - $\langle \Gamma \rangle$ correlation


Tomasz Bold
Monday 12:20
(A4 - Initial State I)

System size dependence of flow harmonics decorrelation


Arabinda Behera
Wednesday 10:30
(E4 - Initial State V)

Poster by Arabinda Behera
Ultra Peripheral Collisions (UPC)
- limit for axion like particles production

W/Z bosons in Pb+Pb
- better description of data without nuclear PDFs

Heavy flavour probes
- observed sequential suppression of $\Upsilon$(nS) states
- interplay of hydro expansion and energy loss in open heavy flavour

Jet quenching
- new high precision measurement give better constrain on energy loss
- single isolated jets experience less energy loss than jets with more complicated structure

Flow in small systems
- no sing of impact parameter dependence of flow in pp
- flow in pp decreases only by few percent (2–5%) if jet particles rejection is applied
What have we learned

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ATLAS talks

Monday 11:00  Single jet and dijet measurements of jet quenching with the ATLAS detector
Monday 11:00  Electroweak probes in heavy-ion collisions with ATLAS
Monday 12:20  Measurements of $v_n$ at high-$p_T$ and correlation between $v_n$ and mean-$p_T$ in $p+Pb$ collisions with the ATLAS detector
Monday 13:15  Quarkonium production in $Pb+Pb$ collisions with ATLAS
Tuesday 12:00  ATLAS measurement of azimuthal anisotropies in Z-boson tagged $pp$ collisions at 8 and 13 TeV and in ultra-peripheral $Pb+Pb$ collisions at 5.02 TeV
Wednesday 10:30  Non-UPC production of di-muons from two-photon scattering in $Pb+Pb$ collisions with the ATLAS detector
Wednesday 10:30  Measurement of jet structure and substructure in heavy ion collisions with ATLAS
Wednesday 10:30  ATLAS measurements of transverse and longitudinal flow decorrelations in $Xe+Xe$, $Pb+Pb$, and $p+Pb$ collisions
Thursday 10:35  Production and azimuthal anisotropy of muons from heavy flavor decays in small and large systems with ATLAS
Thursday 13:30  Measurements of photon- and Z-tagged jet quenching by ATLAS

Thank you for attention!

ATLAS posters

Timothy Rinn  Exploring jet quenching through the measurement of di-jet momentum balance with ATLAS
Klaudia Burka  Light-by-light scattering in ultra-peripheral $Pb+Pb$ collisions in the ATLAS experiment
Martin Krivos  Suppression of charmonia states in $Pb+Pb$ collisions at 5.02 TeV with the ATLAS detector
Arabinda Behera  Longitudinal flow decorrelation in $Xe+Xe$ and $p+Pb$ collisions with the ATLAS detector
Wenkai Zou  Measurement of suppression of large-radius jets and its dependence on substructure in $Pb+Pb$ with ATLAS
Benjamin Gilbert  Measurement of $\gamma\gamma\rightarrow\mu\mu$ pairs in non-ultra peripheral $Pb+Pb$ collisions with the ATLAS detector

All HI ATLAS public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults
Backup
Centrality in Heavy Ion collisions

Centrality is parametrized using the energy deposited in the Forward calorimeter ($|\eta|>3.2$)

$\Sigma E_T^{FCal}$ [TeV]

Peripheral collision

Central collision

Negligible pile-up!
Centrality intervals and their corresponding geometric quantities

<table>
<thead>
<tr>
<th>Centrality [%]</th>
<th>$\langle N_{\text{part}} \rangle$</th>
<th>$\langle T_{\text{AA}} \rangle$ [mb$^{-1}$]</th>
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<th>$\langle T_{\text{AA}} \rangle$ [mb$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2%</td>
<td>399.0 ± 1.6</td>
<td>28.30 ± 0.25</td>
<td>20–25%</td>
<td>205.6 ± 2.9</td>
<td>9.77 ± 0.18</td>
</tr>
<tr>
<td>2–4%</td>
<td>380.2 ± 2.0</td>
<td>25.47 ± 0.21</td>
<td>25–30%</td>
<td>172.8 ± 2.8</td>
<td>7.50 ± 0.17</td>
</tr>
<tr>
<td>4–6%</td>
<td>358.9 ± 2.4</td>
<td>23.07 ± 0.21</td>
<td>30–40%</td>
<td>131.4 ± 2.6</td>
<td>4.95 ± 0.15</td>
</tr>
<tr>
<td>6–8%</td>
<td>338.1 ± 2.7</td>
<td>20.93 ± 0.20</td>
<td>40–50%</td>
<td>87.0 ± 2.4</td>
<td>2.63 ± 0.11</td>
</tr>
<tr>
<td>8–10%</td>
<td>317.8 ± 2.9</td>
<td>18.99 ± 0.19</td>
<td>50–60%</td>
<td>53.9 ± 2.0</td>
<td>1.28 ± 0.07</td>
</tr>
<tr>
<td>10–15%</td>
<td>285.2 ± 2.9</td>
<td>16.08 ± 0.18</td>
<td>60–80%</td>
<td>23.0 ± 1.3</td>
<td>0.39 ± 0.03</td>
</tr>
<tr>
<td>15–20%</td>
<td>242.9 ± 2.9</td>
<td>12.59 ± 0.17</td>
<td>80–100%</td>
<td>4.80 ± 0.36</td>
<td>0.052 ± 0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0–100%</td>
<td>114.0 ± 1.1</td>
<td>5.61 ± 0.06</td>
</tr>
</tbody>
</table>
Large R jets - ATLAS way

Cal. towers & UE subtraction \[ \rightarrow \] \( R = 0.2 \) jets \( p_T > 35 \text{ GeV} \) \[ \rightarrow \] re-clustering with anti-\( k_t \) \( R = 1.0 \)

Splitting scale \[ \sqrt{d_{12}} \] \[ \leftarrow \] re-clustering with \( k_t \) algorithm \[ \leftarrow \] Sub-jets

\[ \sqrt{d_{12}} = \min(p_{T1}, p_{T2}) \times \Delta R_{12} \]

Different jets than the conventional \( R = 1.0 \)
Trimming & 35 GeV threshold remove all the soft component
## Heavy ion datasets

<table>
<thead>
<tr>
<th>System</th>
<th>Year</th>
<th>$\sqrt{s_{NN}}$ [TeV]</th>
<th>$L_{\text{int}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb+Pb</td>
<td>2010</td>
<td>2.76</td>
<td>7 µb$^{-1}$</td>
</tr>
<tr>
<td>Pb+Pb</td>
<td>2011</td>
<td>2.76</td>
<td>0.14 nb$^{-1}$</td>
</tr>
<tr>
<td>pp</td>
<td>2012</td>
<td>8</td>
<td>19.4 fb$^{-1}$</td>
</tr>
<tr>
<td>pp</td>
<td>2013</td>
<td>2.76</td>
<td>4 pb$^{-1}$</td>
</tr>
<tr>
<td>p+Pb</td>
<td>2013</td>
<td>5.02</td>
<td>29 nb$^{-1}$</td>
</tr>
<tr>
<td>low $&lt;\mu&gt;$ pp</td>
<td>2015-16</td>
<td>13</td>
<td>0.9 pb$^{-1}$</td>
</tr>
<tr>
<td>pp</td>
<td>2015</td>
<td>5.02</td>
<td>28 pb$^{-1}$</td>
</tr>
<tr>
<td>Pb+Pb</td>
<td>2015</td>
<td>5.02</td>
<td>0.49 nb$^{-1}$</td>
</tr>
<tr>
<td>p+Pb</td>
<td>2016</td>
<td>5.02</td>
<td>0.5 nb$^{-1}$</td>
</tr>
<tr>
<td>p+Pb</td>
<td>2016</td>
<td>8.16</td>
<td>0.16 pb$^{-1}$</td>
</tr>
<tr>
<td>Xe+Xe</td>
<td>2017</td>
<td>5.44</td>
<td>3 µb$^{-1}$</td>
</tr>
<tr>
<td>pp</td>
<td>2017</td>
<td>5.02</td>
<td>270 pb$^{-1}$</td>
</tr>
<tr>
<td>Pb+Pb</td>
<td>2018</td>
<td>5.02</td>
<td>1.76 nb$^{-1}$</td>
</tr>
</tbody>
</table>
Heavy flavor muon versus heavy flavor meson flow

ATLAS
- charm muon
- bottom muon

DREENA-B
- D meson
- B meson
- $D \rightarrow \mu$
- $B \rightarrow \mu$

5.02 TeV Pb+Pb 0-10%
0.3 - 1.9 nb$^{-1}$, $|\eta^\mu| < 2
Events with and without track jet of certain threshold in pp

**ATLAS**

- Preliminary
- $\sqrt{s}=13$ TeV, 64 nb$^{-1}$
- Jet $p_T > 6$ GeV

- All Events
- No Jet
- With Jet

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**ATLAS**

- Preliminary
- $\sqrt{s}=13$ TeV, 64 nb$^{-1}$
- Jet $p_T > 8$ GeV

- All Events
- No Jet
- With Jet

---

**ATLAS**

- Preliminary
- $\sqrt{s}=13$ TeV, 64 nb$^{-1}$
- Jet $p_T > 10$ GeV

- All Events
- No Jet
- With Jet

---

**ATLAS**

- Preliminary
- $\sqrt{s}=13$ TeV, 64 nb$^{-1}$
- Jet $p_T > 12$ GeV

- All Events
- No Jet
- With Jet

---

ATLAS-CONF-2020-018
Flow in pp with jet particle rejection - $p_T$ dependence

ATLAS Preliminary

$pp \sqrt{s}=13$ TeV, 64 nb$^{-1}$

$2<|\Delta \eta|<5$, $0.5<p_T<5$ GeV

$60\leq N_{\text{ch}}^{\text{rec,corr}} < 150$, $0\leq N_{\text{ch}}^{\text{periph}} < 20$

• Inclusive  ○ AllEvents  □ NoJet

Ratio to the Inclusive Case

ATLAS-CONF-2020-018