ATLAS Perspective on O0 and p0

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first stable beams heavy-ion collisions

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aim of this talk

Michelangelo Mangano, opening talk of this workshop

Goals of the Workshop:

- review the scientific case, the technical challenges and the LHC performance projections
- highlight the scientific motivations to collect oxygen data during Run 3, and the potential returns as a function of delivered luminosity

within the context of a $O(1 \text{ week})$ run in Run 3, this talk will focus on flow measurements and jets

this is not the limit of what’s interesting but rarer probes would require more luminosity
big interest in small nuclei

- oxygen-oxygen collisions are really small compared to any symmetric system we’ve had at LHC or RHIC
- proton-oxygen collisions are really small compared to pPb collisions

Huss et al, 2007.13754
shrinking the QGP

from Pb-Pb collisions to pp hydrodynamic calculations can describe the data

the different role of geometry and fluctuations provides an opportunity to constrain the properties of the QGP

image: C. Shen (QM19)
size variation experimentally

ultra-central PbPb

photo-nuclear collisions

ATLAS has exploited the full versatility of the LHC with flow measurements
**XeXe has:**

- extra $v_2$ in central collisions → more fluctuations
- extra $v_3$ → more fluctuations
- smaller systems: stronger effect of viscosity to reduce $v_n$ values

**XeXe / PbPb**

**Xe: A = 129**

**Pb: A = 208**

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**Figure 16:** Comparisons of the $v_n$ measured in Xe+Xe collisions with those measured in Pb+Pb collisions at $p_{NN} = 5.02$ TeV. The results are plotted as a function of centrality, and obtained using the 2PC method. From top to bottom, each row corresponds to a different $n$. The right panels show the ratio of the Xe+Xe to the Pb+Pb $v_n$ values. The plots are for $0.5 < p_T < 5$ GeV. The error bars and bands represent statistical and systematic uncertainties, respectively. For the ratio plots, the correlated systematic uncertainties between the Xe+Xe and Pb+Pb results are taken into account.
clear differences for $N_{\text{ch}} < 100$ between measurements and calculations

clear motivation to explore small systems experimentally as much as possible
potential information from pO collisions

pO more sensitive to nucleon configuration (alpha clustering) in oxygen nucleus that OO

Lim, et al. 1812.08096
XeXe & PbPb correlations not reproduced by models
and we see differences in central and peripheral events based on how we classify the events
high $p_T$ anisotropies

\begin{align*}
\textbf{ATLAS} \text{ Preliminary} \\
\text{Pb+Pb } \sqrt{s_{NN}} = 5.02 \text{ TeV, 1.72 nb}^{-1} \\
\text{anti-}k_t \ R = 0.2, \ |y| < 1.2 \\
\text{20-40%} \\

v_2 \sim 2-4\% \ 50-250 \text{ GeV}
\end{align*}

understood to arise from path length dependence of jet energy loss
As described above, the physics interpretations of the results, the source of hadrons in this region should be considered. As detailed previously, in a highly space. For the high centrality range is selected because the spatial elliptic eccentricity is approximately the same as in overall multiplicity, which enables a stronger translation of spatial deformations into momentum.

The MBT events and the jet events with jet trends for 0–5% centrality are shown as narrow vertical lines on each point, and systematic uncertainties are presented as coloured boxes behind squares and orange diamonds, respectively, and those from measurements showing non-zero high deviations of all points. However, in the right panel of Figure 1910.13978, the dotted line gives the results of the 'size a' configuration and the dash-dotted line gives the results of the 'size b' configuration.

The ATLAS experiment uses the notation $(dashed)$ curves are nearly indistinguishable from each other. The right panel shows $Q_\text{pPb}$ for the same quantity to describe a bias that may exist due to differences in the overall behaviour of the results exhibit more of a plateau. Strikingly, the overall behaviour of the high-$v_2$ data from ATLAS is also shown in this panel; the 'size a' (dash-dotted) and 'size b' (dotted) curves are nearly indistinguishable from each other.

$p+\text{Pb}$ $\sqrt{s_{\text{NN}}} = 8.16$ TeV, 165 nb$^{-1}$

$p+\text{Pb} 1.5 \times $ $\text{p+Pb MBT}$

$1.5 \times p+\text{Pb} p_T^{\text{jet}>100}$ GeV

$0-5\%$ central

$\text{pPb} \sqrt{s_{\text{NN}}} = 5.02$ TeV

$\text{PbPb} 20-30\%$ central

$p_T^A$ [GeV]

$p_T$ [GeV]

$p\text{Pb}: v_2 > 0 \& R_{p\text{Pb}} \approx 1$

is the picture of $\Delta E(L)$ in PbPb right?

light ion collisions with a different geometry but similar size as pPb could help clarify this
what happens to jet quenching in small systems?

no significant suppression for $N_{\text{part}} < 50$ at high $p_T$

measurement dominated by large statistical and systematic uncertainties
studying flow in small systems has been a huge focus of the field over the last several years—many important issues remain that OO and pO can help address

onset of jet quenching now rests on peripheral heavy-ions which is imprecise and pPb collisions which suggests tension with our understanding of jet quenching in PbPb; OO collisions are a straightforward way to address this
• ATLAS could not record every collision at the projected peak luminosities
  
  • for this program we could collect inclusive jets, unprescaled above some threshold using triggers we have

  • the rest of the bandwidth would likely be filled with minimum bias events for flow studies

  relative rates of jet and MB triggers would have to be optimized and would be enhanced toward minimum bias collisions at luminosities lower than the peak

experience in PbPb and pp running in Run 3 as well as updated luminosity guidance would be used to prepare...
pO: triggering

<table>
<thead>
<tr>
<th>IP parameters</th>
<th>IP1/5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta^*$ [m]</td>
<td>0.5</td>
</tr>
<tr>
<td>External half crossing [μrad]</td>
<td>170</td>
</tr>
<tr>
<td>Total half crossing [μrad]</td>
<td>170</td>
</tr>
<tr>
<td>N.o. collisions</td>
<td>24</td>
</tr>
<tr>
<td>Peak luminosity [$10^{27}$cm$^{-2}$s$^{-1}$]</td>
<td>45 (12*)</td>
</tr>
<tr>
<td>Peak pileup (no split, split)</td>
<td>0.075 (0.02*)</td>
</tr>
</tbody>
</table>

- **pO collisions:**
  - leveled rate low enough to record every collision @ $12 \times 10^{27}$/cm$^2$/s
  - given our interests in rare probes, *ATLAS would be interested to run at the highest possible luminosity given the machine and time constraints*
  - a triggering strategy as in OO collisions would also work here if increased luminosity were available
jet & charged particle projections

projections under the assumption that the pp reference has negligible statistical uncertainties

0.5/nb OO provides enough jets and charged particles at either collision energy to have a systematics limited $R_{AA}$ measurement over a big kinematic range

0.5/nb of OO is about 2.5 times the partonic luminosity of the XeXe running & about half of the 2010 PbPb
$
u_2$: jets & charged particles

given the tension in the pPb results, having a measurement of high $p_T \nu_2$ is key in O+O collisions

a $\nu_2$ of 2-3% would be observable in jets and charged particles over a wide kinematic range with 0.5/nb of O+O data
\[ R_{AA} \] measurements

**ATLAS**

anti-\(k_t\) \(R = 0.4\) jets, \(\sqrt{s_{NN}} = 5.02\) TeV

2015 data: Pb+Pb 0.49 nb\(^{-1}\), pp 25 pb\(^{-1}\)

\(\langle T_{AA} \rangle\) and luminosity uncer.

\(<4\%\) systematic uncertainty on \(R_{AA}\) due to nearly all uncertainties canceling because PbPb and pp data were measured under very similar conditions
uncertainty on pp cross section

uncertainty on PbPb yields

uncertainty on $R_{AA}$

1.9% pp luminosity uncertainty & 1% $T_{AA}$ uncertainty not shown in plots

uncertainty on $R_{AA}$ is much smaller than the uncertainty on the PbPb or pp spectra separately
missing references have lead to incorrect interpretations

original 5.02 TeV charged particle reference was interpolated between 2.76 TeV and 7 TeV before data was available

**interpolated reference gives a qualitatively different picture than the measured reference**
• jet measurement could serve as a reference but there are no inclusive charged particle measurements

• ATLAS detector & software have changed significantly since then so it is not trivial to reanalyze this data and it hasn’t been done

most or all of the systematics would not cancel with an OO measurement so any jet $R_{AA}$ using this as a reference would have at least 15% systematic uncertainties
• OO and pO do provide a great opportunity to extend the HI at the LHC
• even with the compressed Run 3 this is timely and provides a clear way to get important new information about hard and soft probes in heavy ion collisions
• ATLAS is well prepared to take the data and do physics with it
• it is essential for the energy loss program that there is a pp reference at the same energy
backups