Recent results on electroweak probes in lead-lead and proton-lead collisions from the ATLAS Detector at the LHC

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The electroweak bosons can only interact with gluons at one loop and beyond, thus enabling:

• Estimation of effective *parton distribution functions* in collisions involving heavy ions

• Study of the *binary scaling* assumptions made in modeling ion-ion collisions

• Approximate calibration of *jet energies* in gamma-jet events
Reminder: geometric considerations

\[ T_A(s) = \int \rho_A(s, z_A) dz_A \]

probability/area of nucleon at \( s \)

\[ T_{AA}(b) = \int T_A(s) T_A(s - b) d^2s \]

Density overlap as a function of impact parameter \( b \)

\[ N_{Coll}(b) \sim T_{AA}(b) \cdot \sigma_{inel}^{NN} \]

Number of binary collisions as a function of impact parameter \( b \)

\( N_{Coll} \) can be estimated from experimental data via the “Glauber model”

Number of participants in the collision, \( N_{Part} \), ranges from 2 to 416.
Potential partonic in-medium effects

- Gluon saturation
- Gluon shadowing
- Partonic energy loss
- Modified parton distributions
- Modified fragmentation functions

- medium-modified PDFs
- NLO, constrained by DIS on nuclei, Drell-Yan in p+A, and inclusive pion production in d+Au and p+p
W bosons in lead-lead collisions

Combined signal from $e^{-}/e^{+}$ and $\mu^{+}/\mu^{-}$, measured with different ATLAS systems. Isolation cuts.
Analysis constrained by missing $p_T$ and transverse mass.
Parton distribution functions: W in lead-lead collisions

Models:
POWHEG with CT10 PDF set
EPS09 corrections: (anti)shadowing, EMC, Fermi [JHEP03:071 (2011)]
Within the existing uncertainties, no visible PDF modifications
The lepton charge asymmetry agrees well with theoretical predictions using QCD at NLO with CT10 PDF sets with and without EPS09 nuclear corrections corrected ± stat. ± syst.

<table>
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<th>$W \rightarrow \mu \nu_\mu$</th>
<th>$W \rightarrow e \nu_e$</th>
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<tbody>
<tr>
<td>$W^+ \rightarrow l^+ \nu$</td>
<td>$5870 \pm 100 \pm 90$</td>
<td>$5760 \pm 150 \pm 90$</td>
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<tr>
<td>$W^- \rightarrow l^- \nu$</td>
<td>$5680 \pm 100 \pm 80$</td>
<td>$5650 \pm 150 \pm 110$</td>
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<td>$W^+/W^-$</td>
<td>$1.03 \pm .03 \pm .02$</td>
<td>$1.02 \pm .04 \pm .01$</td>
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The basic pattern in pp is understood based on the nature of the interaction. This has been observed previously in pp, but for larger eta.
Z boson in lead-lead collisions

Combined signal from $e^-/e^+$ and $\mu^+/\mu^-$, measured with different ATLAS systems.

Lineshape, distributions well reproduced in simulation.
Parton distribution functions: 
Z in lead-lead collisions

PRL 110, 022301 (2013)  
H. Paukkunen, C. Salgado JHEP03:071 (2011)

Model: PYTHIA per-event yields using NNLO p+p calculations scaled by $<T_{AA}> = <N_{Coll}>/\sigma_{pp}$. Including p+n and n+n would increase the cross section by 3%.
Parton distribution functions: 
direct photons in lead-lead collisions

Models:
JETPHOX (NLO pQCD), CTEQ 6.6 pdfs, u/d quark reweighting
JETPHOX + EPS09 [JHEP 0904 (2009)]
Forward-central ratio
direct photons in lead-lead collisions

\(1.52 < |\eta| < 2.37\)
\(|\eta| < 1.37\)

Reduction of several experimental uncertainties in this ratio.

Isospin effects visible, particularly for central events.
Boson yields in PbPb scale with $\langle N_{\text{coll}} \rangle$

Direct photons show similarly consistent behavior.
Boson-jet correlations in Pb+Pb collisions

Clear centrality dependence measured with direct photons. Proof of principle using Z-jet events (36 events).
The momentum balance and the production rates change with centrality for direct photons; similar indication with Z – jet correlation.
Z boson in p+Pb collisions

Integrated cross section: value ± stat. ± sys. ± lumi [nb]

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<tr>
<td>y&lt;2.5</td>
<td>-3.5&lt;y&lt;4</td>
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<tr>
<td>Z→μμ</td>
<td>122.1 ± 3.4 ± 6.2 ± 4.2</td>
<td>122 ± 3 ± 13 ± 4</td>
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<tr>
<td>Z→ee</td>
<td>122 ± 3 ± 13 ± 4</td>
<td>144 ± 5 ± 17 ± 5</td>
</tr>
<tr>
<td>Z→ll</td>
<td>122.7 ± 2.4 ± 5.3 ± 4.2</td>
<td>144.1 ± 4.9 ± 8.3 ± 4.9</td>
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<tr>
<td>Model (*)</td>
<td>114.4</td>
<td>136.8</td>
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(*) NNLO pQCD, with CT10 & pp-pn-nn weighting

\[ \sqrt{s_{NN}} = 5.02 \text{ TeV} \]

\[ \text{L}_{\text{int}} = 29 \text{ nb}^{-1} \]

\[ y_{CM} \approx 0.465 \]

\[ 4 \text{ TeV} \quad 1.57 \text{ TeV/N} \]
Current statistics are insufficient to conclude if the measured spectra deviate from the model in different rapidity intervals in the center of momentum.
Z boson in p+Pb collisions - rapidity

Absolute amplitudes are different, depending on the Glauber model.

Similar effects are seen for dN_{ch}/d\eta and spectra ATLAS-CONF-2013-107

The shape of the rapidity distribution of Z-bosons in p+Pb changes with centrality measure.
Conclusions

- ATLAS measurements support binary scaling in Pb+Pb.
- Z in p+Pb measured in -3.5<y<4 shows a substantial deviation from calculations based on CTEQ10 parton distribution functions. The rapidity distribution is seen to depend on centrality measure.
- Boson – jet correlations provides very important information:
  - Photon – jets: strong modification
  - Z-boson – jets: proof of principle
  - W-boson – jets: future
- In LHC Run 2, with a factor of 10-30 more events, we will be able to make precision measurements with photons and with Z-bosons