Measurement of electroweak-boson production in p-Pb and Pb-Pb collisions at the LHC with ALICE

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Electroweak Bosons in Heavy-Ion Collisions

Produced in the hard processes at the initial stages of the collisions

Insensitive to the presence of the strongly-interacting medium

A good way to access Parton Distribution Functions (in the proton) and their nuclear modification (nPDFs, in nuclei)

Flavour-dependent modifications of quark densities in nuclei accessible by studying $W^+/W^-$ asymmetry

Such initial stage effects can be studied in pA collisions

Reference for hot-matter effects on other probes
Z and W bosons with the ALICE Detector

Looking for muons from

\[ Z \rightarrow \mu^+ \mu^- \quad W^\pm \rightarrow \mu^\pm \nu_\mu \]

Muon spectrometer coverage:

\[ -4 < \eta < -2.5 \]

Pb-p and p-Pb asymmetry → access to different \textbf{rapidity} and \textbf{Bjorken-}x \textbf{ranges:}

Pb-Pb: \[ 2.5 < y_{\text{cms}} < 4 \]

“p-going”: \[ 2.03 < y_{\text{cms}} < 3.53 \]

“Pb-going”: \[ -4.46 < y_{\text{cms}} < -2.96 \]
Z and W bosons with the ALICE Detector

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Pb-p and p-Pb asymmetry \( \to \) access to different \textit{rapidity} and \textit{Bjorken-x} ranges:

<table>
<thead>
<tr>
<th>collision system</th>
<th>( \sqrt{s_{\text{NN}}} )</th>
<th>( L_{\text{int}} )</th>
<th>collected in</th>
<th>presented here</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb-Pb</td>
<td>5.02 TeV</td>
<td>( \sim 225 , \mu b^{-1} )</td>
<td>2015</td>
<td>Z boson</td>
</tr>
<tr>
<td>p-Pb Pb-p</td>
<td>5.02 TeV</td>
<td>( 5.03 \pm 0.18 , nb^{-1} ) ( 5.81 \pm 0.20 , nb^{-1} )</td>
<td>2013</td>
<td>Z, W bosons</td>
</tr>
<tr>
<td>p-Pb Pb-p</td>
<td>8.16 TeV</td>
<td>( 8.47 \pm 0.18 , nb^{-1} ) ( 12.75 \pm 0.25 , nb^{-1} )</td>
<td>2016</td>
<td>Z boson</td>
</tr>
</tbody>
</table>

Z-boson Signal Extraction

Opposite-sign muon pairs reconstructed in the spectrometer

Only high-$p_T$ muons are used

$$p_{T,\mu} > 20 \text{ GeV/c}$$

Signal extraction by counting candidates in

$$60 < m_{\mu\mu} < 120 \text{ GeV/c}^2$$

Residual background from

$$Z/\gamma^* \rightarrow \tau\tau \rightarrow \mu\mu \quad t\bar{t} \rightarrow \mu\mu$$

$$\rightarrow \sim 1\% \text{ of the yield (POWHEG and PYTHIA)}$$

Combinatorial background $\rightarrow$ small

Acceptance and efficiency are estimated with POWHEG simulations (embedding for centrality dependence)
W-boson Signal Extraction

Monte-Carlo template fit of the $p_T$ distribution of single muons

High $p_T$:

- Heavy-flavoured hadrons (FONLL pQCD calculations [1])
- Z-bosons and Drell-Yan
- Semi-leptonic decays of W

(POWHEG)

Isospin effects taken into account by simulating pp, pn, np, nn separately

Acceptance and efficiency are estimated with POWHEEG simulations
Results
Z-boson in Pb-Pb collisions, $\sqrt{s_{NN}} = 5.02$ TeV


$$R_{AA} = \frac{dN/dy}{\langle T_{AA} \rangle \sigma_{pp}}$$

Nuclear overlap function $T_{AA}$ by Glauber model

CT14 calculations\[^1\] are used for $\sigma_{pp}$

Yield and $R_{AA}$ measured as a function of rapidity and centrality

Comparison with different theoretical calculations at NLO, with free PDFs and nPDFs\[^{[1-4]}\]

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\[^{[1]}\] Phys.Rev. D93 (2016) no.3, 033006
\[^{[2]}\] JHEP 0904 (2009) 065
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Free PDFs calculations deviate from experiment, up to $3\sigma$
W and Z bosons in p-Pb collisions, $\sqrt{s_{NN}} = 5.02$ TeV

Results compared with NLO (based on CT10 PDFs$^{[1]}$) and NNLO (with FEWZ, based on MSTW2008 PDFs$^{[2-3]}$) predictions

EPS09 nPDF$^{[4]}$ for the nuclear modification

Here the precision of the data does not allow to draw conclusions on PDF modifications

**W and Z bosons in p-Pb collisions, \(\sqrt{s_{NN}} = 5.02\) TeV**

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Uncertainties reduced when measuring \(W^+ / W^-\) asymmetry

Within the uncertainties the production cross-section scales with the number of binary collisions

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Z-boson in p-Pb collisions, $\sqrt{s_{\text{NN}}} = 8.16$ TeV

**NEW**

**First measurement of Z in p-Pb collisions at 8.16 TeV**

Increased luminosity (almost 2 times greater) with respect to p-Pb at 5.02 TeV

**Cross section** measured at forward and backward rapidity

Comparison with different theoretical calculations at NLO, with free PDFs (CT14\[1\]) and nPDFs (from EPPS and nCTEQ groups\[2-3\])

With this precision (on both experimental data and models) no firm conclusions on PDF modifications
Summary

The measurements at large rapidities provide data in a kinematic region where the nPDFs are less constrained.

The results from Pb-Pb data are better described by calculations including nuclear modification of PDFs.

p-Pb results are still statistically limited but these new measurements can be included in nPDFs global fits.

Analyses ongoing on Z and W bosons production in Pb-Pb at 5.02 TeV, and on W-boson production at 8.16 TeV.
Extra Images
Z signal extraction - centrality

ALICE, 0-20% Pb-Pb \( s_{NN} = 5.02 \) TeV
2.5 < \( y < 4.0 \)
- Opposite charge
- Same charge

ALICE, 20-90% Pb-Pb \( s_{NN} = 5.02 \) TeV
2.5 < \( y < 4.0 \)
- Opposite charge
- Same charge
Comparison with other experiments

p-Pb $s_{NN} = 5.02$ TeV, $\sigma(Z \rightarrow l^+l^-)$

* Data/theory

** pQCD+CT10+EPS09

- ALICE ($p_T > 20$ GeV/c, $-4 < \eta < 2.5$)
- LHCb ($p_T > 20$ GeV/c, $2 < \eta < 4.5$)
- CMS ($p_T > 20$ GeV/c, $|\eta| < 2.4$)
- ATLAS (full lepton phase space)