Vector Boson and Charmonium Production in pPb and PbPb Collisions with ATLAS at the LHC

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EW Bosons in Pb+Pb @ 2.76 TeV
EW Boson Signal Extraction

- Z bosons extracted from di-lepton peak
- W bosons extracted from templates using lepton $p_T$ and missing $p_T$

 EW Bosons Consistent with Expectations

pQCD calculations that work for pp collisions are scaled up to account for the number of binary collisions in PbPb ...

pQCD calculations describe the data (even without nuclear modification of the PDF)

EW Bosons Consistent with Expectations

Boson yield scales with number of binary collisions

ATLAS

Int. L = 0.14 - 0.15 nb^{-1} \ Pb+Pb \ |s_{NN}| = 2.76 TeV

\textbf{ATLAS}

Pb+Pb \ |s_{NN}| = 2.76 TeV

Data 2011 \ L_{int} = 0.15 nb^{-1}

\begin{align*}
W^\pm & \text{ Data} \\
W^+ & \text{ POWHEG CT10} \\
W^- & \text{ W} \\
\end{align*}

EW Bosons in p+Pb @ 5.02 TeV
Studying nPDF with EW Bosons

Rapidity differential Z boson cross section

- Asymmetric in $y$
- Shape matched only with inclusion of nuclear PDF modification
- (Models underestimate total cross-section)

4 TeV $\rightarrow$ 1.57 TeV

$p$ Pb

ATLAS $p$+Pb 2013, $L=29$ nb$^{-1}$
\(s_{NN}=5.02\) TeV

$\frac{d\sigma(Z\rightarrow l\bar{l})}{dy_Z}$ [nb]

$\frac{\text{Data}}{\text{CT10 (NLO)}}$
$\frac{\text{Data}}{\text{CT10+EPS09 (NLO)}}$
$\frac{\text{Data}}{\text{MSTW2008 (NNLO)}}$

PRC 92 (2015) 044915
Studying nPDF with EW Bosons

*x* differential Z boson cross section

- Asymmetric in *y*
- Shape matched only with inclusion of nuclear PDF modification
- (Models underestimate total cross-section)
- *x* to <10⁻³

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Studying nPDF with EW Bosons

Lepton $\eta$ differential W boson cross section

Similar trend as observed in Z bosons
Charge asymmetry gives added information on (n)PDF
Charmonium in p+Pb
Quarkonium Signal Extraction

Correct every event for acceptance and efficiencies. → Dominant source of uncertainty

Prompt $\psi(nS)$:
- Direct production
- Feed-down contribution

Non-prompt $\psi(nS)$:
- Decays from B hadrons

$Y(2S)$ and $Y(3S)$ are combined as $Y(2S+3S)$. 
Nuclear Modification Factor

\[ R_{pPb} = \frac{1}{A_{Pb}} \frac{d^2\sigma_{p+Pb}}{dy^* dp_T} \frac{d^2\sigma_{pp}}{dy dp_T}, \]

\( pp \) reference is constructed using interpolations

No significant suppression or enhancement for the kinematics range of \(|y^*| < 1.5\) and \(10 < p_T < 30 \text{ GeV}\)

ATLAS-CONF-2015-023
Nuclear Modification Factor

\[ R_{pPb} = \frac{1}{A_{Pb}} \frac{d^2\sigma_{\psi}^{p+Pb}}{dy^* dp_T} \frac{d^2\sigma_{\psi}^{pp}}{dy dp_T} \]

\( pp \) reference is constructed using interpolations

**Graphs:**
- **Left Panel:** ATLAS Preliminary, \( p+Pb, |y_{NN}| = 5.02 \) TeV
  - ATLAS \( \Upsilon(1S), -1.2 < y^* < 1.2 \)
  - ATLAS Prompt J/\( \psi \), \(-1.5 < y^* < 1.5 \)
  - ALICE inclusive J/\( \psi \), \(-1.37 < y^* < 0.43 \)

- **Right Panel:** ATLAS Preliminary, \( p+Pb, |y_{NN}| = 5.02 \) TeV
  - ATLAS, \( \Upsilon(1S), p_T < 40 \) GeV
  - LHCb, \( \Upsilon(1S), p_T < 15 \) GeV
  - ALICE, \( \Upsilon(1S), p_T > 0 \) GeV
‘Double Ratio’ – (Excited/Ground) in p+Pb/pp

- **(Left)** Prompt charmonium double ratio
- **(Right)** Bottomonium double ratio

No obvious $p_T$ and rapidity dependence

\[
\frac{\frac{\Gamma(2S+3S)/\Gamma(1S)}{pp}}{\frac{\Gamma(2S+3S)/\Gamma(1S)}{ppb}}
\]

pp @ 2.76 TeV
Centrality in p+Pb
Unraveling centrality & nPDF effects

• Centrality is *difficult* in p+Pb collisions
  – Less overall activity and asymmetric system
  – Small *physics* effects that get averaged over in Pb+Pb may become significant

• ‘Centrality bias’ - hard processes are correlated with larger underlying event

• Glauber model may not be the full story: ‘Gribov’ color fluctuations may be at play which allow the nucleon-nucleon cross-section to fluctuate
Unraveling centrality & nPDF effects

Z boson $y$ distributions

W boson $\eta$ distributions

Modification of nPDF seen in both Z and W bosons looks centrality dependent

ICHEP 2016 Chicago, 5 August
Unraveling centrality & nPDF effects

- ‘Raw’ Z boson yield grows with centrality
- Centrality bias or Gribov color fluctuations can ‘restore’ binary scaling

\[10^9 n_Z \langle N_{\text{coll}} \rangle^{-1} N_{\text{evt}} \]

- Glauber \( \omega_s = 0 \)
- GGCF \( \omega_s = 0.11 \)
- GGCF \( \omega_s = 0.2 \)

\[ p+Pb 2013, L_{\text{int}} = 29 \text{ nb}^{-1} \]
\[ s_{NN} = 5.02 \text{ TeV} \]

PRC 92 (2015) 044915
Charmonium and Z Boson Yields

Sidestep centrality definitions, and use Z boson as reference for charmonium centrality dependence.
Unraveling centrality & nPDF effects
Unraveling centrality & nPDF effects
Unraveling centrality & nPDF effects

- Striking similarity between Z boson and charged particle yield
- Suggests centrality bias (inapplicable to charged particle yield) may not be the culprit
- Final conclusion remains elusive …
Summary

• EW Bosons in Pb+Pb demonstrate binary collisions scaling
  – Baseline for color sensitive QGP measurements
  – Relatively little sensitivity to nuclear effects

• EW bosons & charmonium probe nuclear effects in p+Pb collisions, inform our understanding of:
  – nPDF
  – Cold nuclear matter
  – Collision geometry
Looking Forward ...

- New pp data will provide reference for p+Pb at same energy
- New Pb+Pb measurements with higher precision coming soon!
Backup Information
We can measure the EW boson production in p+p collisions ...
We can measure the EW boson production in p+p collisions ...
Add the medium and measure the same thing – EW bosons won’t interact with the colored QCD medium any changes observed must be due to initial state effects
Forward to Backward Ratio

**PRC 92 (2015) 034904**

**ATLAS**  
2013 p+Pb, 28.1 nb\(^{-1}\)  
\(8 < p_T < 30\) GeV  
\(\sqrt{s_{NN}} = 5.02\) TeV

- **(Left) Prompt J/\(\psi\) \(R_{FB}\)**
- **(Right) Non-prompt J/\(\psi\) \(R_{FB}\)**

Prompt J/\(\psi\) \(R_{FB}\) is compatible with both EPS09 models.

\[
R_{FB}(p_T, y^*) = \frac{d^2\sigma(p_T, y^* > 0)/dp_T dy^*}{d^2\sigma(p_T, y^* < 0)/dp_T dy^*}.
\]

\(y^*\): CM rapidity being positive in forward (proton beam direction)