Electroweak-boson production in heavy-ion collisions with ALICE

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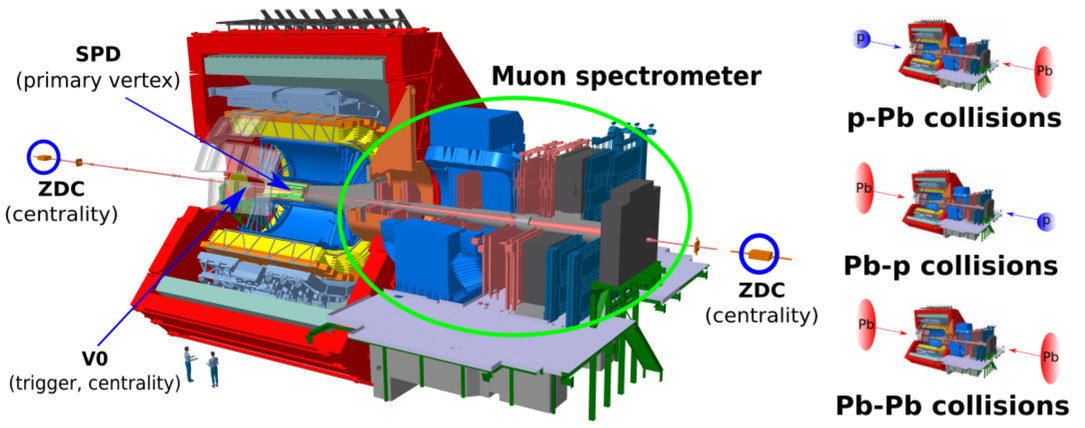
Physics motivation

Thanks to the unprecedented energies attained at the LHC, the measurement of electroweak bosons is now also possible in heavy-ion collisions. The W and Z bosons, produced in the hard scattering processes during the early stages of the collision, are sensitive probes of the initial state, and especially of the nuclear modifications of the Parton Distribution Functions (PDF). In the analyses presented here the bosons are reconstructed via their muonic decay. Since the bosons and muons are not sensitive to the strong force, the whole process is medium-blind, carrying the information from the initial stages, and providing inputs for the nuclear PDF (nPDF) determination from a global QCD analysis of data.

Data samples

System	$\sqrt{s_{NN}}$	$\mathcal{L}_{int}$
p–Pb	8.16 TeV	8.47 ± 0.18 nb^{-1}
Pb–p		12.77 ± 0.25 nb^{-1}
Pb–Pb	5.02 TeV	$\sim 750\ \mu$b^{-1}

The ALICE detector



Muons are reconstructed with the muon spectrometer of ALICE [1], covering the rapidity interval $-4 < y_{lab} < -2.5$, composed of:

- a tracking system (10 multiwire proportional chambers in five stations) with a dipole magnet for charge and momentum measurements,
- a triggering system (18 resistive plate chambers in two stations),
- a set of absorbers for background filtering.

In addition, the analysis requires information from:

- Silicon Pixel Detector (SPD) for vertex determination,
- V0 scintillators for Minimum Bias triggering and centrality in Pb–Pb,
- Zero Degree Calorimeter (ZDC) for centrality in p–Pb.

In p–Pb collisions, rapidity shift of $\Delta y_{cms/lab} \sim 0.47$:

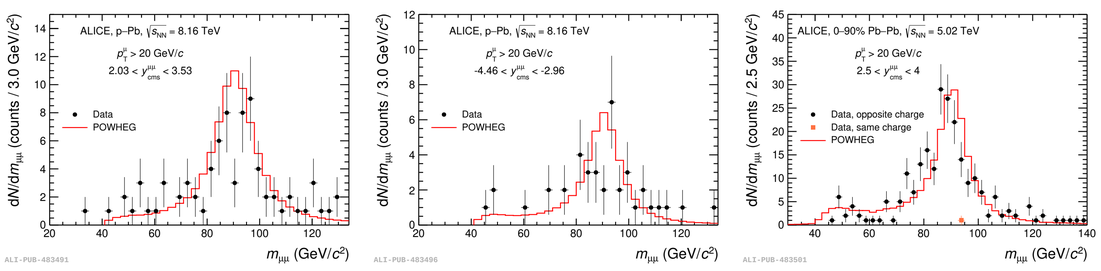
$$2.03 < y_{cms} < 3.53 \text{ (p–Pb)}, \qquad -4.46 < y_{cms} < 2.96 \text{ (Pb–p)}.$$

Analysis strategy

- **Z-boson signal extraction**

Z candidates selected by pairing high-p_T muons of opposite signs, from high-quality tracks pointing to the interaction vertex. Signal extraction done by counting the number of muon pairs with invariant mass between 60 and 120 GeV/c^2, measured in the fiducial region:

$$-4 < y^{\mu}_{lab} < -2.5, \qquad p^{\mu}_T > 20 \text{ GeV}/c, \qquad 60 < m_{\mu^+\mu^-} < 120 \text{ GeV}/c^2.$$

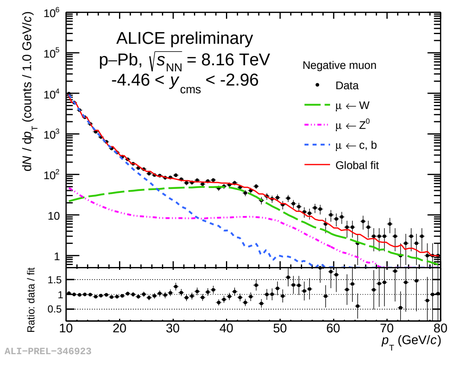


Combinatorial background evaluated by looking at the same-sign muon pairs. Residual background (muonic decay of HF hadrons, $t\bar{t} \to \mu^+\mu^-$ and $Z \to \tau^+\tau^- \to \mu^+\mu^-$ processes) evaluated with MC simulations using POWHEG [2] and Pythia 6 [3]. Total background amounts to 1% at most, taken as systematic uncertainty on the signal extraction.

- **W-boson signal extraction**

Signal extraction done by fitting the inclusive single-muon p_T spectrum with MC templates accounting for the various contributions (HF, W and Z decays) above 10 GeV/c with:

$$f(p_T) = N_{\mu^\pm \leftarrow HF} \cdot f_{\mu^\pm \leftarrow HF}(p_T) + N_{\mu^\pm \leftarrow W} \cdot \left(f_{\mu^\pm \leftarrow W}(p_T) + R \cdot f_{\mu^\pm \leftarrow Z}(p_T)\right)$$



where:

- f_i are the templates,
- $N_{\mu^\pm \leftarrow HF}$ and $N_{\mu^\pm \leftarrow W}$ are the numbers of muons from HF and W decays, free parameters of the fit,
- R is a fixed parameter, the ratio of the Z to W production cross section evaluated with POWHEG + Pythia 6 simulations.

Measured in the fiducial region:

$$-4 < y^{\mu}_{lab} < -2.5, \qquad p^{\mu}_T > 10 \text{ GeV}/c.$$

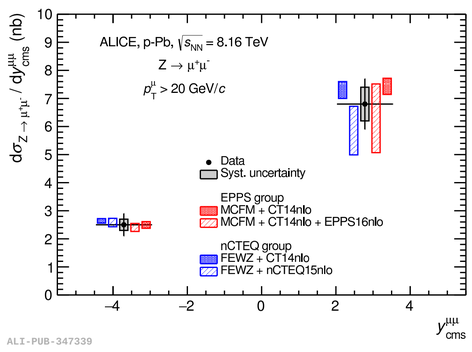
The raw yields are finally corrected for the efficiency of the detector, evaluated with POWHEG + Pythia 6 + GEANT3 [4] simulations. The occupancy in Pb–Pb is accounted for by embedding the simulated signal in real data.

Results

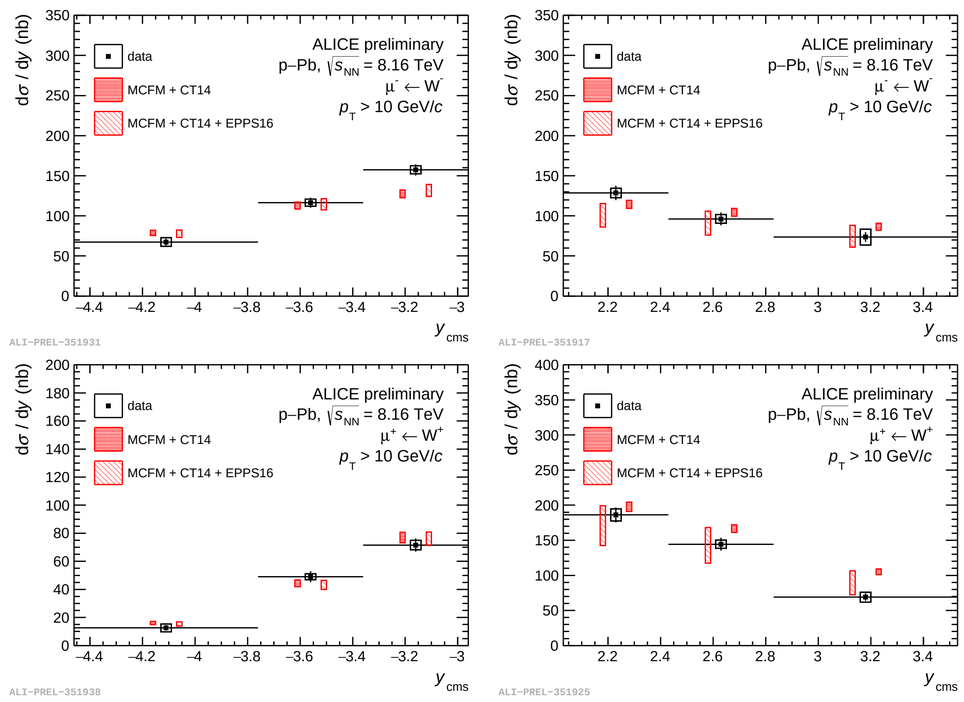
- **p–Pb collisions** at $\sqrt{s_{NN}} = 8.16$ TeV

Z-boson cross section [5] compared with predictions from CT14 + EPPS16 [6,7] and nCTEQ15 [8], as well as CT14 accounting for the isospin but without nuclear modifications for reference.

Good agreement with models, but no possibility to conclude on nuclear modifications due to sizeable uncertainties.



W-boson cross section in rapidity bins compared with CT14+EPPS16 or CT14 standalone.

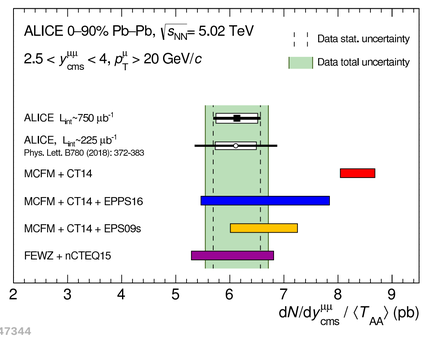


Deviation by 3.7 σ from CT14 for W^+ at large, positive rapidities, while in agreement with EPPS16. Some tensions with models observed in the evolution vs. rapidity.

- **Pb–Pb collisions** at $\sqrt{s_{NN}} = 5.02$ TeV

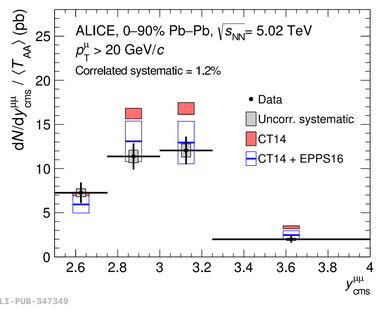
Z-boson yield [5] by merging the 2015 and 2018 data samples ($\sim$ 3 times more luminosity compared with 2015 data only [9]).

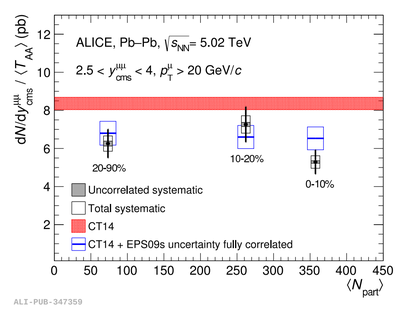
Comparison with calculations yields good agreement with nPDF models, and significant deviation of 3.4 σ from CT14 prediction.



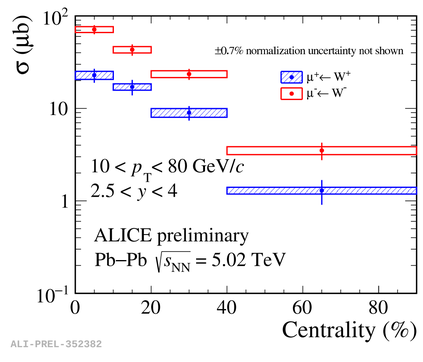
Differential evaluation:

Better agreement when including the nuclear modifications.
Larger deviations from CT14 in most central events and at largest rapidities.

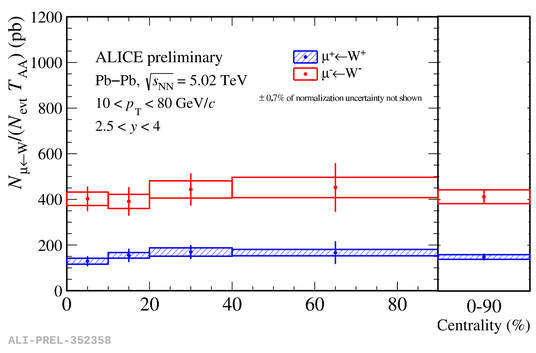




W-boson cross section vs rapidity, shows the decrease of the production towards more peripheral events.



W-boson yield normalised to the nuclear overlap T_{AA} exhibits a flat distribution, as expected for a hard process.



References

[1] **ALICE** Coll., J. Inst. 3(2008)S08002
[2] S. Alioli *et al.*, JHEP 06(2010)43
[3] T. Sjostrand *et al.*, JHEP 05(2006)026
[4] R. Brun *et al.*, CERN-W-5013
[5] **ALICE** Coll., JHEP 09(2020)076
[6] S. Dulat *et al.*, PRD 83(2016)033006
[7] K. Eskola *et al.*, EPJC 77(2017)163
[8] K. Kovarik *et al.*, PRD 93(2016)085037
[9] **ALICE** Coll., PLB 780(2018)372