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

Nicolò Valle[1], Guillaume Taillepied[2] for the ALICE Collaboration

[1]University and INFN, Pavia, Italy

[2]Laboratoire de Physique de Clermont, Clermont-Ferrand, France

ELECTROWEAK BOSONS IN HEAVY-ION COLLISIONS

Thanks to LHC large luminosities and collision energies, the measurement of electroweak bosons in heavy-ion collisions is now possible. Z and W bosons are produced in the hard scattering processes during the initial stages of the collisions and they are insensitive to the presence of the strongly-interacting medium. This makes them a clean probe of initial stage effects, and a good tool to extract information on the nuclear modificaton of Parton Distribution Functions (nPDFs), providing a reference for hot-matter effects on other probes.

DATA SAMPLES

Exploiting the ALICE muon spectrometer, data from proton-lead and lead-lead collisions at different nucleon-nucleon center-of-mass energies have been collected:

collision system	$\sqrt{s_{NN}}$	L_{int}	*data collected in*	*analyses here presented*	
Pb-Pb	5.02 TeV	$\sim 225\ \mu b^{-1}$	2015	Z boson	[1]
p-Pb Pb-p	5.02 TeV	$5.03 \pm 0.18\ nb^{-1}$ $5.81 \pm 0.20\ nb^{-1}$	2013	Z , W bosons	[2]
p-Pb Pb-p	8.16 TeV	$8.47 \pm 0.18\ nb^{-1}$ $12.75 \pm 0.25\ nb^{-1}$	2016	Z boson	New

ANALYSIS STRATEGY

In Pb-Pb collisions the centrality is estimated by fitting the V0 amplitude with a Monte Carlo (MC) implementation of the Glauber model. Only events with centrality < 90% are used.

The muon rapidity coverage in the laboratory frame is $-4 < y_{\rm lab} < -2.5$. The asymmetry of p-Pb and Pb-p collisions provides access to forward and backward center-of-mass rapidities, allowing us to probe various Bjorken-x ranges.

$$2.5 < y_{\rm cms} < 4 \ \text{(Pb-Pb)} \qquad 2.03 < y_{\rm cms} < 3.53 \ \text{(p-Pb)} \qquad -4.46 < y_{\rm cms} < -2.96 \ \text{(Pb-p)}$$

Z-boson signal extraction

Z candidates are selected by combining opposite-sign muon pairs reconstructed in the spectrometer. Only high $p_{\rm T}$ muons are used to reject background from the decay of low mass quarkonia. Tracks not pointing to the interaction vertex are suppressed by cutting on the momentum and the distance of closest approach to the vertex. The result of offline cuts is a nearly background-free sample and the signal is extracted by counting the number of muon pairs with invariant mass between 60 and 120 GeV/c^2. The results are presented in the fiducial region

$$-4 < \eta_\mu < -2.5 \qquad p_{\rm T,\mu} > 20 \text{ GeV}/c \qquad 60 < m_{\mu\mu} < 120 \text{ GeV}/c^2$$

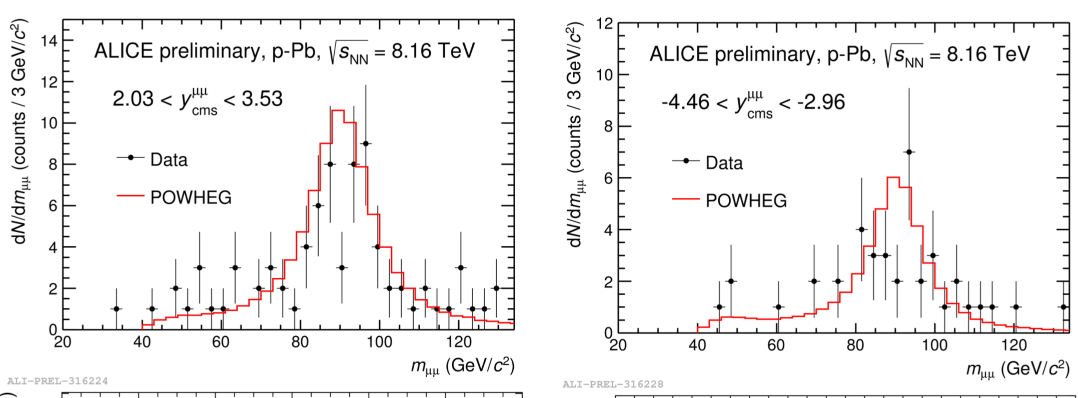


Fig 2: Invariant mass distribution of μμ from p-Pb (left) and Pb-p (right) collisions at 8.16 TeV. POWHEG predictions including both Z and γ contributions are superimposed. No like-sign muon pairs have been found in the region of interest.*

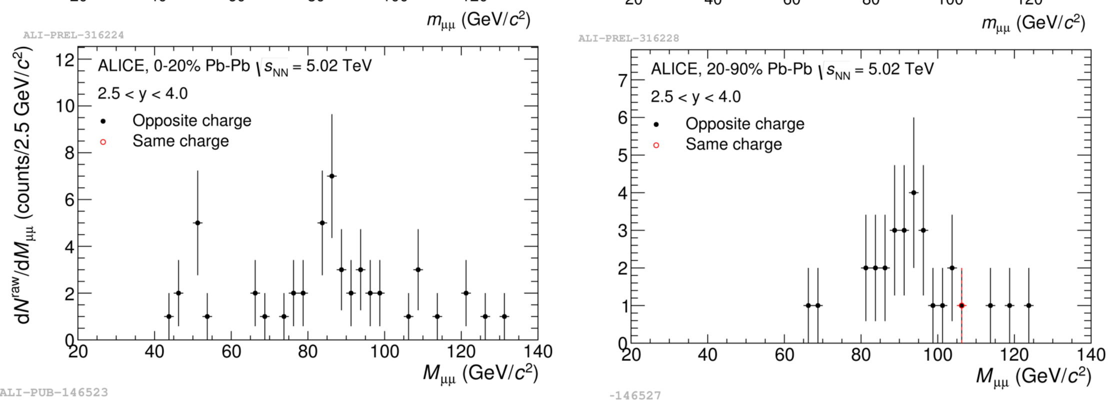


Fig 3: Invariant mass distribution of μμ (with like-sign reported in red) from Pb-Pb data sample, in 0-20% centrality (left) and 20-90% centrality (right).

The residual background contribution in the mass region of interest coming from $Z/\gamma^* \to \tau\tau \to \mu\mu$ and $t\bar{t} \to \mu\mu$, estimated through MC simulations (using POWHEG [3] and PYTHIA-6 [4]), is equal to 1% of the signal yield (smaller than 0.5% in Pb-Pb analysis) and treated as systematic uncertainty.

The combinatorial background is evaluated by counting the number of like-sign muon pairs (small or negligible: see Figs. 2 and 3).

The raw yields are then corrected for the detector acceptance-times-efficiency computed with POWHEG MC simulations. To account for detector occupancy in Pb-Pb collisions, Z signal is embedded in real data. Isospin effects are taken into account by simulating pp, pn and nn binary collisions.

W-boson signal extraction

The W$^\pm$ signal is extracted from a Monte Carlo template fit of the transverse momentum distribution of single muons, which above 10 GeV/c is dominated by:

- the semi-muonic decays of heavy-flavoured hadrons, simulated using FONLL pQCD calculations [5];
- the semi-leptonic decays of W$^\pm$ and the di-muon decays of Z^0/γ^*. Templates based on POWHEG simulations are used for these processes.

The normalizations of $p_{\rm T}$-spectra from heavy-flavour and W-boson decays are used as free parameters, while the ratio between the number of muons from Z and from W is fixed with POWHEG.

Systematic uncertainties are derived varying FONLL calculation parameters and the PDF sets.

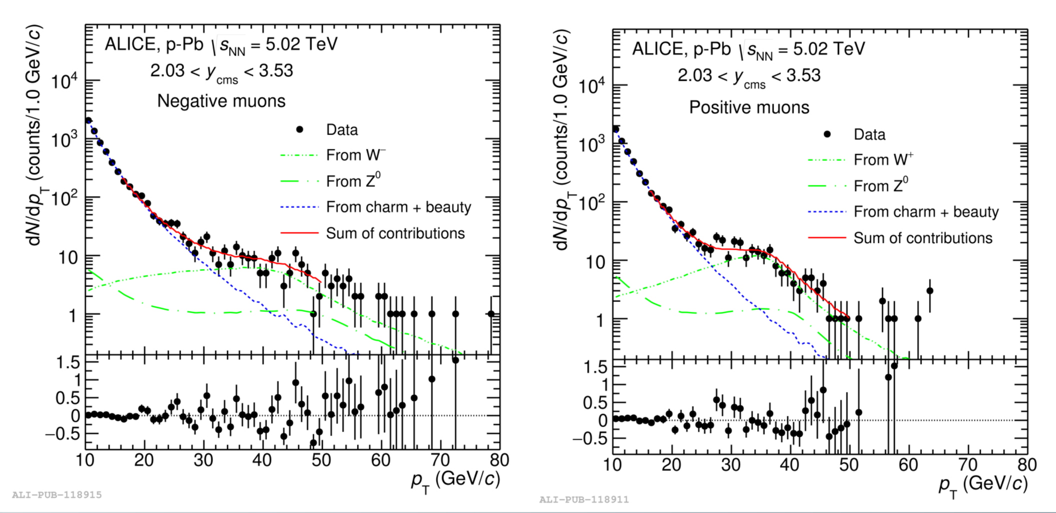


Fig 4: Left (right): Inclusive distribution of negative (positive) charge muon candidates measured in p-Pb data. The results of the MC templates fit for the extraction of the μ⁻⁽⁺⁾ ← W⁻⁽⁺⁾ signal are shown. Bottom panels: relative difference between data and the fit results.

THE ALICE DETECTOR

ALICE can measure W and Z bosons via their muon and dimuon decay channels respectively.

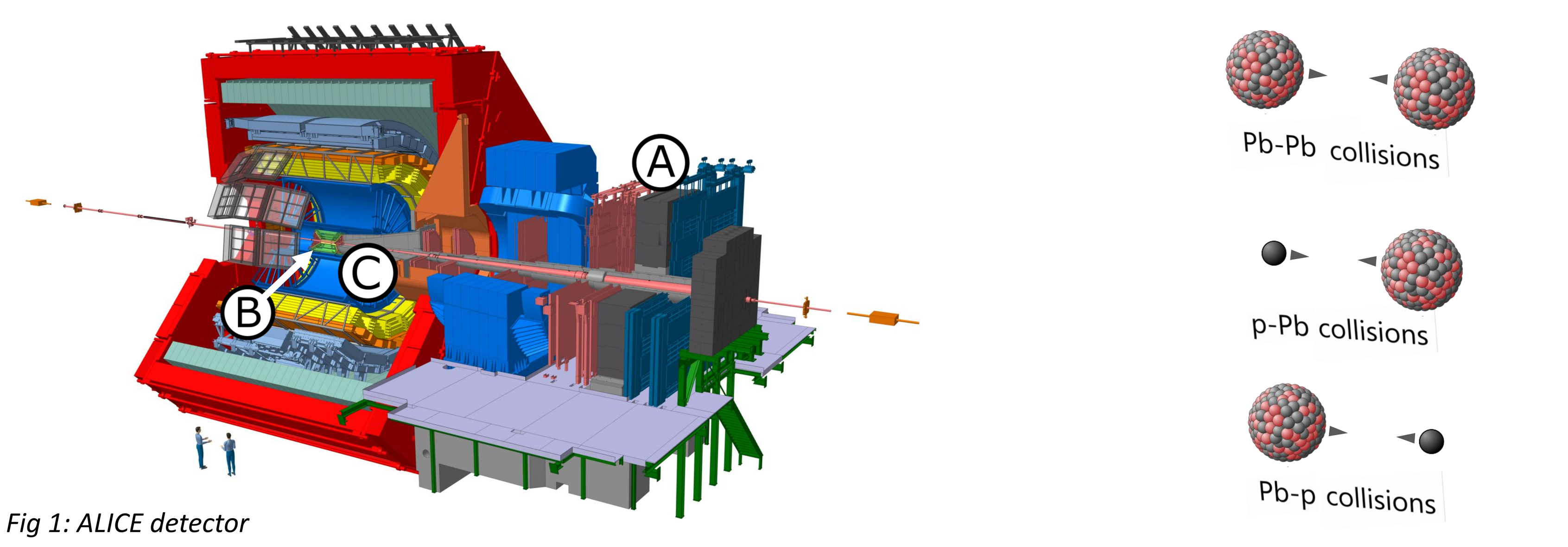


Fig 1: ALICE detector

A. Muons are reconstructed in the muon spectrometer, which covers the pseudorapidity range $-4 < \eta < -2.5$. It consists of a tracking system (10 Multi-Wire Proportional Chambers), a triggering system (18 Resistive Plate Chambers) and a set of absorbers. A dipole magnet provides a 3 Tm integrated magnetic field.
B. SPD (Silicon Pixel Detector) measures the primary vertex position.
C. V0 detectors provide the Minimum Bias trigger and are used as centrality estimator in Pb-Pb collisions.

RESULTS

LEAD-LEAD COLLISION RESULTS

The Z-boson invariant yield is normalized by the average nuclear overlap function $\langle T_{\rm AA}\rangle$. Dividing also by the cross section in pp collisions, the nuclear modification factor $R_{\rm AA}$ is computed. Results are presented as a function of centrality and rapidity and are compared to different theoretical calculations at NLO, with and without the nuclear modification of PDFs.

CT14 [6] free PDFs prediction for the invariant yield deviates from experiment by 2.3σ.

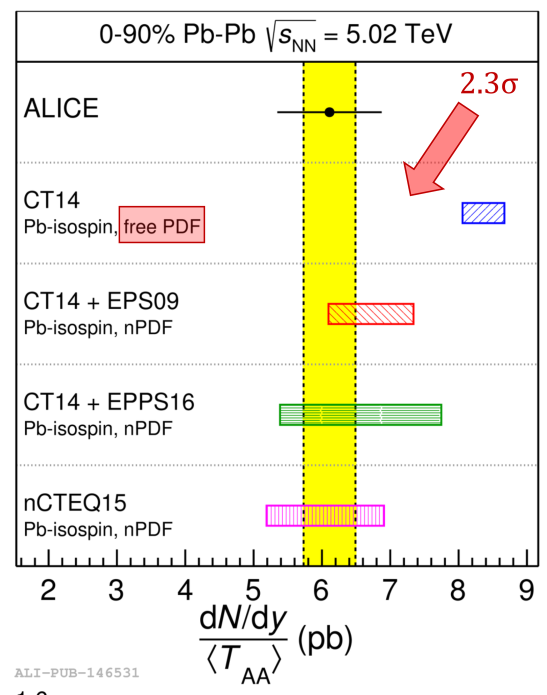
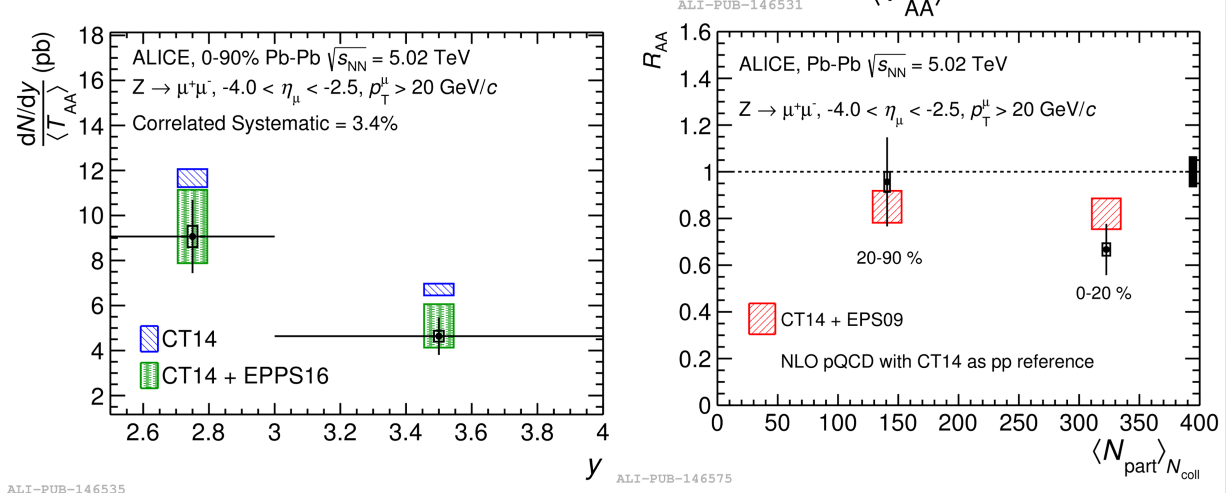


Fig 5: Comparison between ALICE result in 0-90% centrality and different PDF calculations and parametrizations [6-9] (yellow band for systematics).

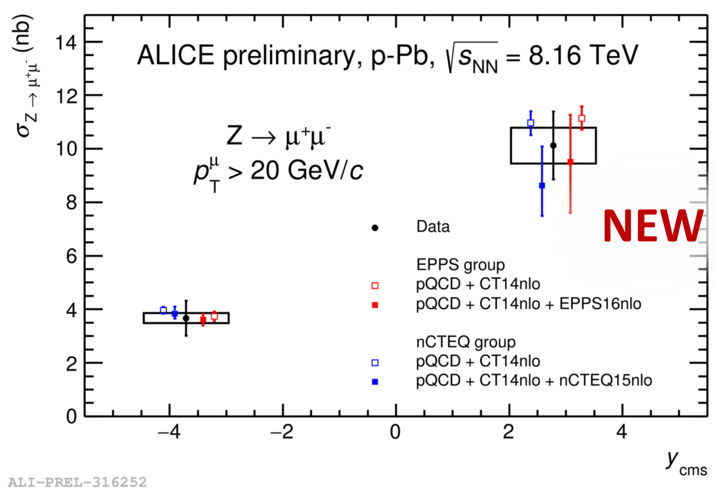
Fig 6: Left. Rapidity dependence of yield divided by ⟨T_AA⟩. CT14 predictions with and without EPPS16 nuclear modification are shown. Right: R_{AA} as a function of centrality, expressed in terms of participant nulceons.

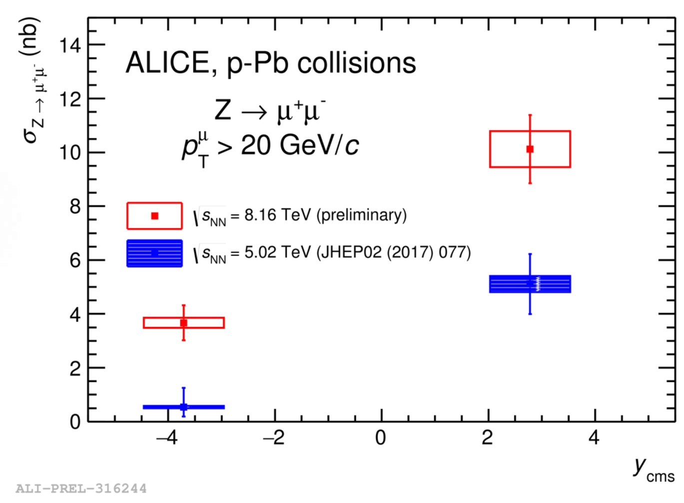


The $R_{\rm AA}$ result in the most central collisions is smaller than unity by 2.6 standard deviations and deviates from free PDFs prediction by 3σ (the greater enhancement with respect to scaled pp collision is expected because of isospin effects).

PROTON-LEAD COLLISION RESULTS

The measured cross sections are compared to NLO pQCD calculations.





First measurement of Z production in p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 8.16 TeV

Fig 7: Measured cross sections at forward and backward rapidities compared to different predictions. Full points include nuclear modification of PDFs (EPPS16 [8] and nCTEQ15 [9]).

Fig 8: Cross sections computed in proton-lead collisions at $\sqrt{s_{\rm NN}}$ = 8.16 TeV and $\sqrt{s_{\rm NN}}$ = 5.02 TeV

Theoretical uncertainties on the factorization and renormalization scales and some experimental uncertainties cancel out when measuring the relative yields of muons from W⁺ and W⁻ decays.

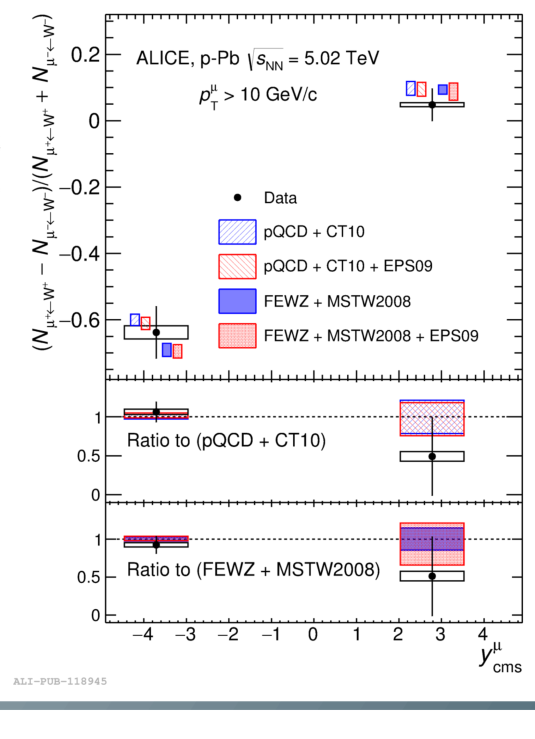


Fig 9: Charge asymmetry of muons from W boson in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV . The results are compared with theoretical calculations [10, 11] performed both with free and modified (EPS09 [7]) PDFs. The middle (bottom) panel shows the data and pQCD (FEWZ) calculations divided by the pQCD (FEWZ) calculations without nuclear modification of the PDFs.

CONCLUSIONS

- 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.
- These measurements of the rapidity and centrality dependence can help constraining nPDFs.

REFERENCES

[1] Phys. Lett. B780 (2018) 372-383
[2] JHEP 1702 (2017) 077
[3] JHEP 1006 (2010) 043
[4] JHEP 0605 (2006) 026
[5] JHEP 1210 (2012) 137
[6] Phys.Rev. D93 (2016) no.3, 033006
[7] JHEP 0904 (2009) 065
[8] Eur.Phys.J. C77 (2017) no.3, 163
[9] Eur.Phys.J. C77 (2017) no.7, 488
[10] JHEP 1103 (2011) 071
[11] Comput.Phys.Commun. 182 (2011) 2388-2403