

Measuring electroweak boson production in p-Pb and Pb-Pb collisions at $\sqrt{s}_{\text{NN}} = 5.02 \text{ TeV}$ with ALICE at the LHC

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For the ALICE collaboration

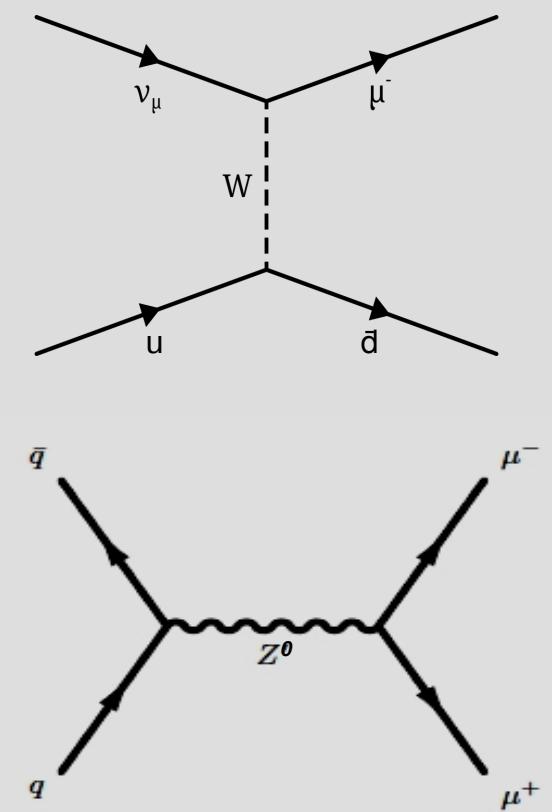


Hard Probes 2018
Aix-Les-Bains, Savoie, France
30 Sept - 5 Oct, 2018

Motivation

- ❖ **W & Z bosons:** massive force carriers of the electroweak interaction
- ❖ Produced in **initial hard processes** before the **QGP** is formed and either decay before the **QGP** is formed or during its formation
 - ⇒ can be used to study the **initial** conditions of the **interaction**
- Dominant process **LO** approximation:

$$u\bar{d} \rightarrow W^+, \quad \bar{u}d \rightarrow W^-, \quad \bar{u}u, \bar{d}d \rightarrow Z^0$$
- **Colourless probes** → not affected by the **strong interaction**
 - ⇒ reference for **medium-induced effects**
 - ⇒ in heavy-ion collisions they will be sensitive to **nuclear PDFs**
- Sensitive to **(valence) quark** and **(sea) antiquark** content of the nucleus



Motivation

❖ In heavy-ion collisions:

- Test the **scaling of hard processes** with the number of binary nucleon-nucleon collisions
- Investigate **initial-state effects**
- Sensitive to the nuclear modification of the **PDFs**
- Good probe to access **shadowing** and **anti-shadowing**

where,

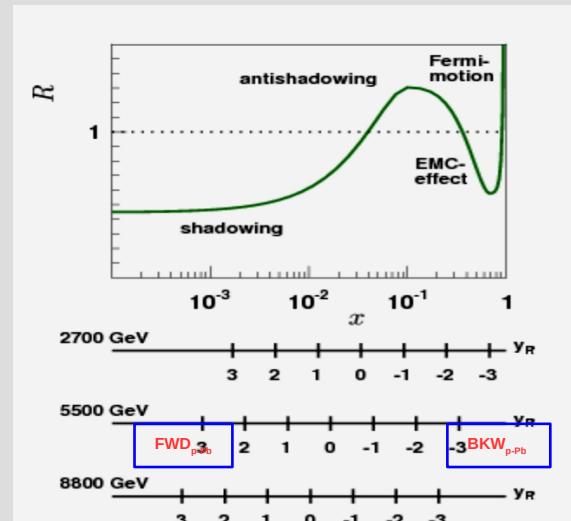
$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \times \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

❖ Production depends on the **flavour of the quark**

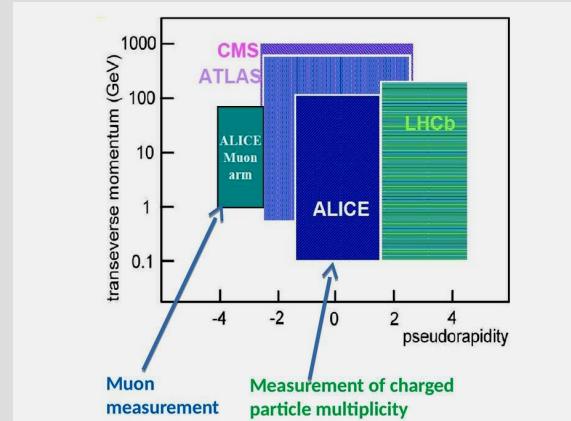
❖ Isospin asymmetries of the colliding systems induce **charge asymmetries** on the W-boson production cross section

❖ Measurement in ALICE:

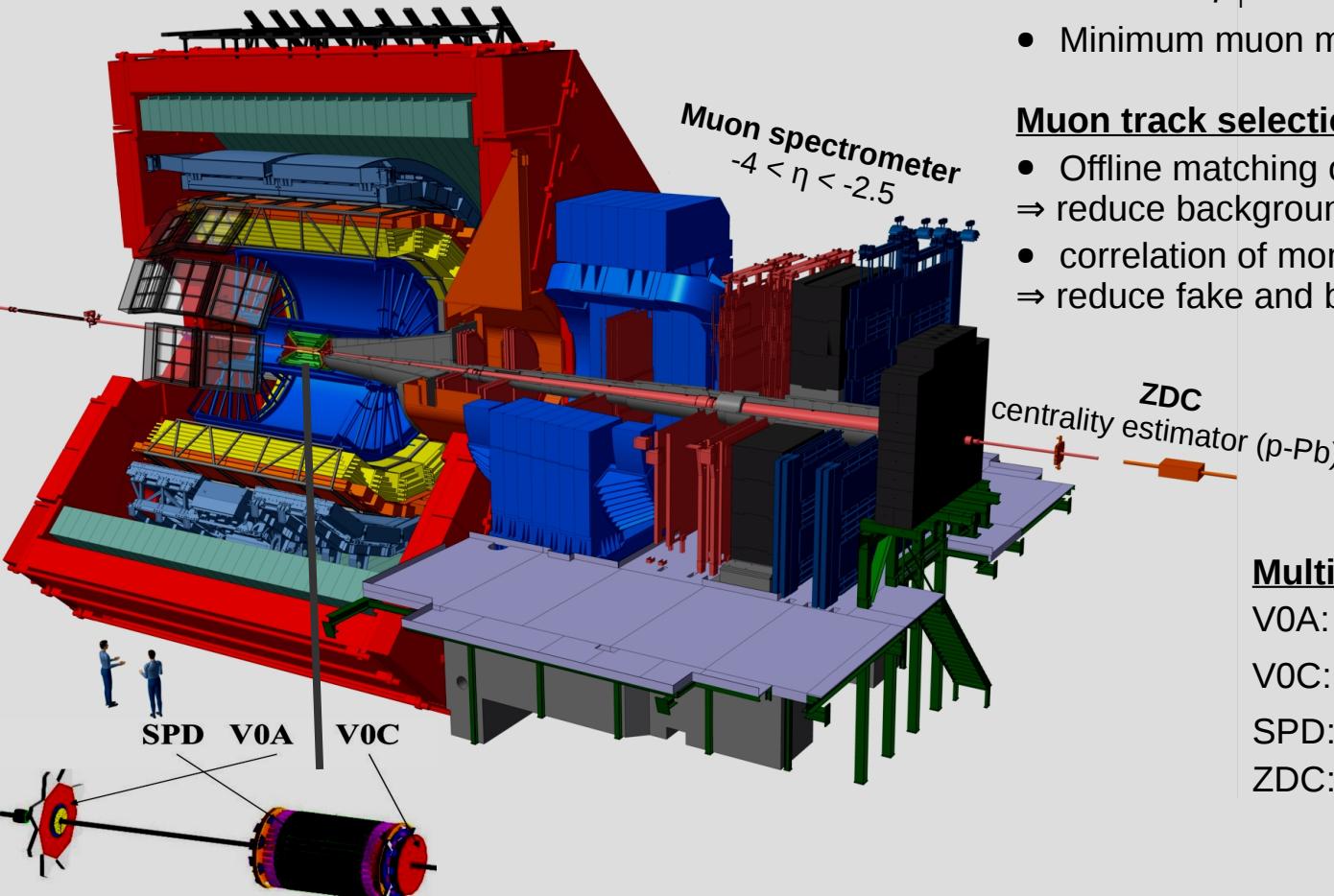
- Muon Spectrometer covers the kinematic region
 $-4 < \eta < -2.5 \Rightarrow$ (anti-) shadowing is more pronounced
- **Complementary** to other LHC experiments



H. Paukkunen & C. A. Salgado, JHEP 1103 (2011) 071



ALICE Detector



Muon Spectrometer ($-4.0 < \eta < -2.5$)

- Minimum p_T for trigger: $p_T > 0.5 \text{ GeV}/c$
- Minimum muon momentum: $p > 4 \text{ GeV}/c$

Muon track selection:

- Offline matching of the tracking & trigger
⇒ reduce background from punch-through hadrons
- correlation of momentum (p) and DCA
⇒ reduce fake and beam gas tracks

Multiplicity and trigger:

V0A: $2.8 < \eta_{\text{lab}} < 5.1$

V0C: $-3.7 < \eta_{\text{lab}} < -1.7$

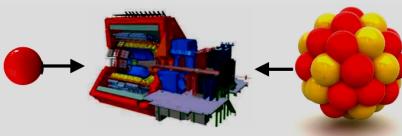
SPD: Primary vertex

ZDC: Used to determine the multiplicity

Data Sample

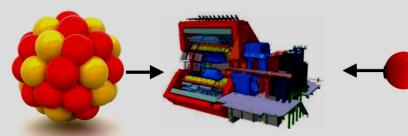
- p-Pb collisions at $\sqrt{s}_{NN} = 5.02$ ($E_p = 4$ & $E_{Pb} = 1.58$) TeV
- Two beam configurations with a rapidity shift ($\Delta y = 0.465$) in the proton direction

p-going (forward rapidity)



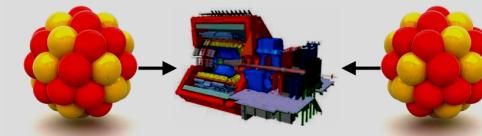
**p-Pb at $\sqrt{s}_{NN} = 5.02$ TeV
(p-going)**
 $2.03 < y_{cms} < 3.53$
 $L_{int} \sim 5.1 \text{ nb}^{-1}$

Pb-going (backward rapidity)



**p-Pb at $\sqrt{s}_{NN} = 5.02$ TeV
(Pb-going)**
 $-4.46 < y_{cms} < -2.96$
 $L_{int} \sim 5.8 \text{ nb}^{-1}$

Pb-Pb collisions at $\sqrt{s}_{NN} = 5.02$ TeV



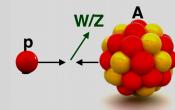
Pb-Pb at $\sqrt{s}_{NN} = 5.02$ TeV
 $2.5 < y < 4$
 $L_{int} \sim 225 \mu\text{b}^{-1}$

Triggers:

- high- p_T single muon triggered events (for **W-boson only**)
⇒ Minimum-Bias (MB, coincidence of V0A and V0C) & a single muon with $p_T \geq 4.0 \text{ GeV}/c$
- low- p_T di-muon triggered events (for **Z-boson only**)
⇒ Coincidence of MB and two muons with $p_T > 10 \text{ GeV}/c$

W-Boson Production in p-Pb

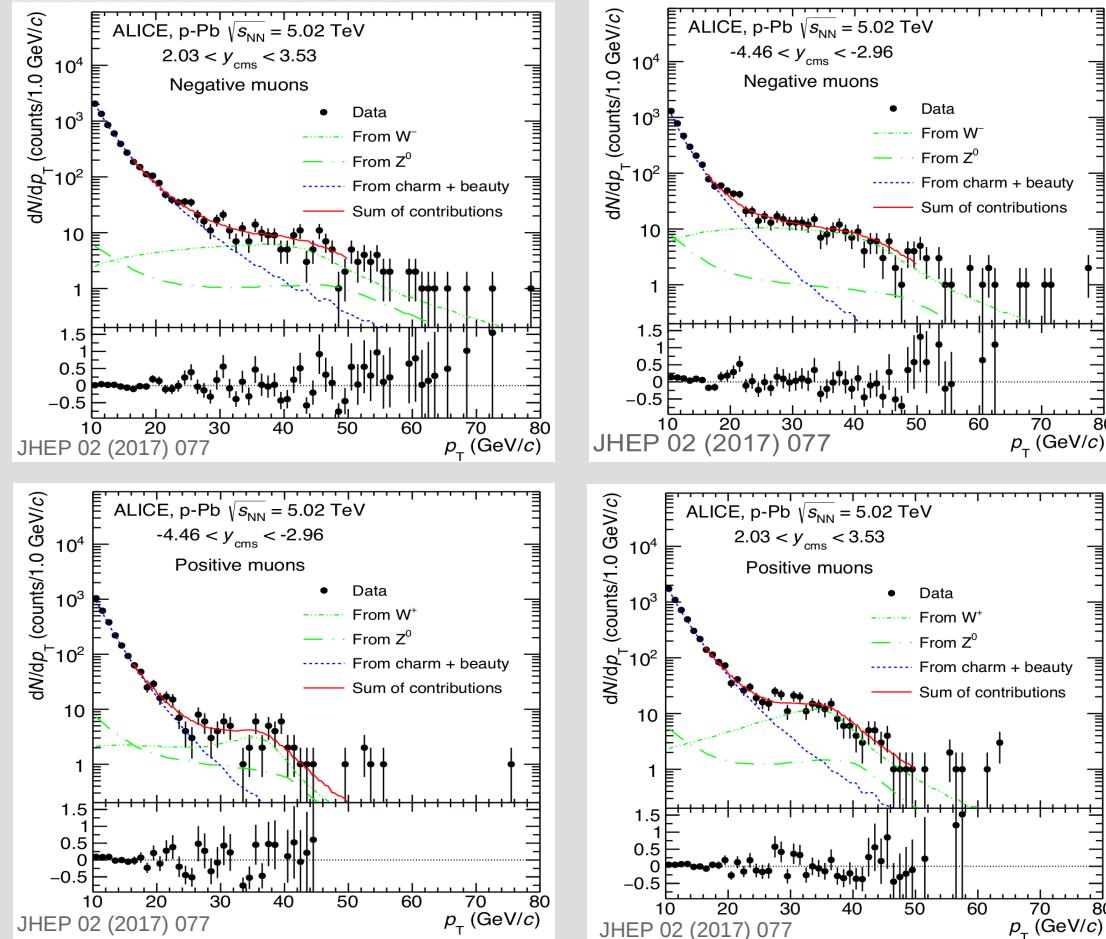
Signal Extraction W Boson



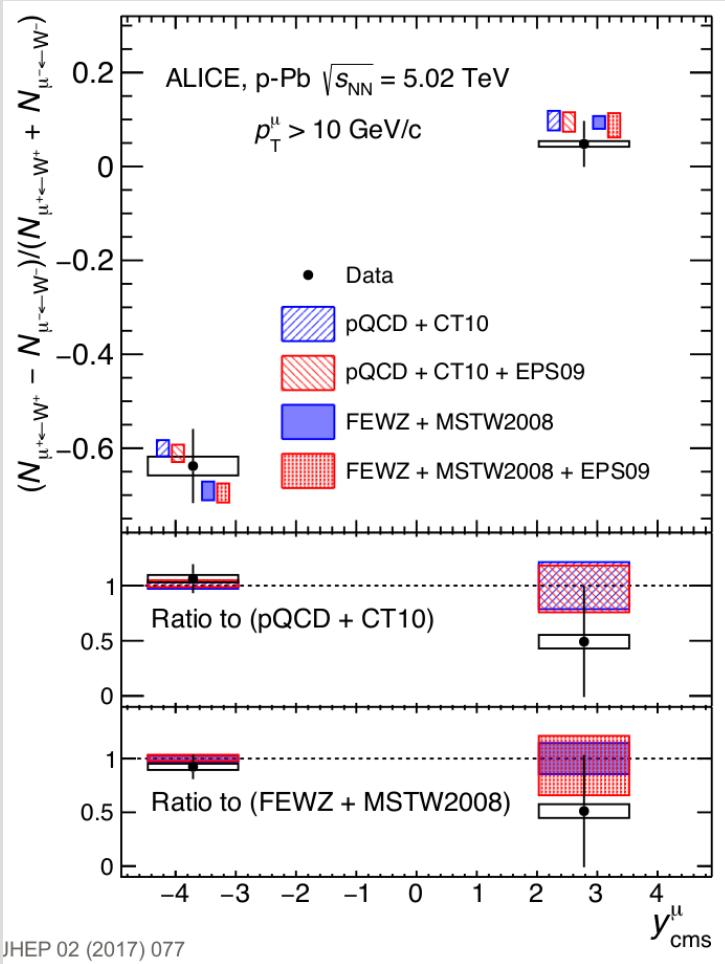
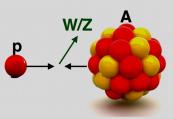
- ❖ $W^+ \rightarrow \mu^+ + \nu_\mu$ (BR $\sim 10.57 \pm 0.15\%$)
- ❖ $W^- \rightarrow \mu^- + \nu'_\mu$ (BR $\sim 10.57 \pm 0.15\%$)
- ❖ Jacobean peak at $p_T \sim M_W/2 \sim 40$ GeV/c, over heavy flavour and Z^0/y^* background
- ❖ Dominant at $p_T > 30$ GeV/c in the total single muon p_T distribution
- ❖ Number of $\mu^\pm \leftarrow W^\pm$ estimated from the p_T distribution through fit function obtained from MC simulation

Observables:

- Ratio and charge asymmetry
- Cross section: to constrain PDFs
- $\langle N_{\text{coll}} \rangle$ normalised yield: test binary scaling of hard probes



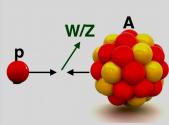
Charge Asymmetry W Boson



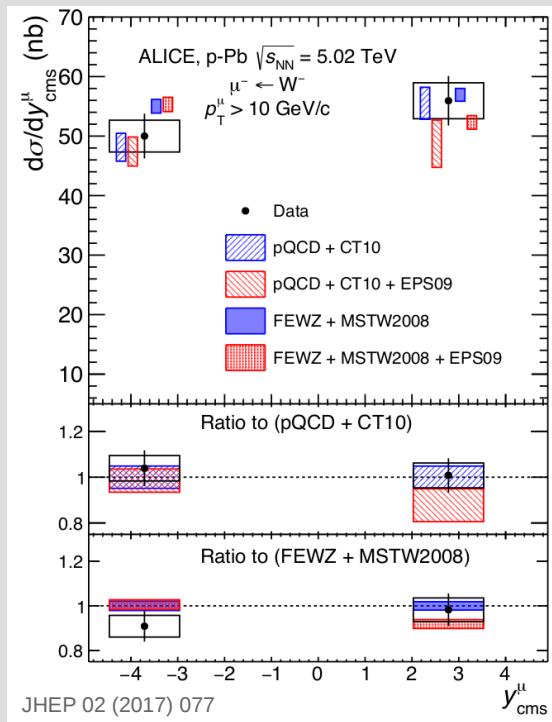
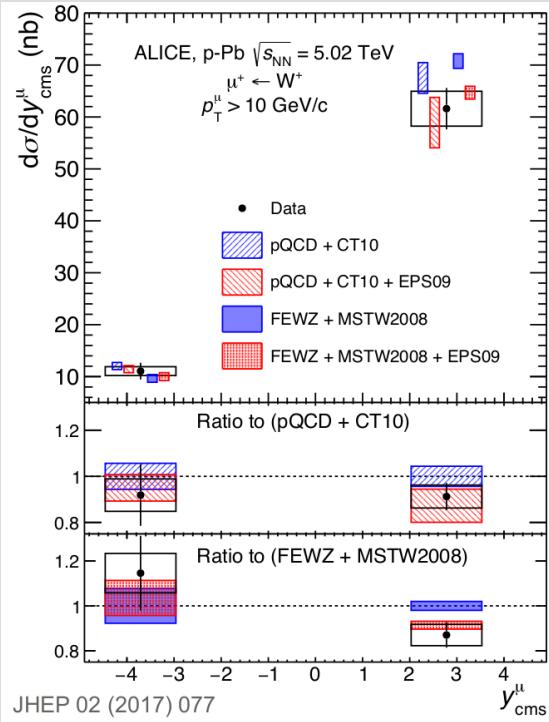
- ❖ The measured charge asymmetry is close to zero at forward rapidity and negative at backward rapidity
- ❖ The results are compared with pQCD at NLO and NNLO theoretical calculations both with and without including the nuclear modification of the parton distribution functions
- ❖ The model results with and without nuclear modification are very similar in this kinematic range, and the measurement cannot discriminate between them

The NLO pQCD calculations (blue hatched boxes) are obtained using the CT10 PDF. NNLO calculations with FEWZ (blue filled boxes) use the MSTW2008 NNLO PDF set

CT10: H Paukkunen et. al., JHEP 1103 (2011) 071,
EPS09: K. J. Eskola et. al., JHEP 0904(2009)065,
FEWZ: R. Gavin et. al., Comput. Phys. Commun. 182 (2011) 2388–2403



Yield W Boson

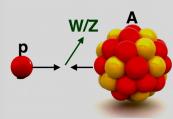


CT10: H Paukkunen et. al., JHEP 1103 (2011) 071,
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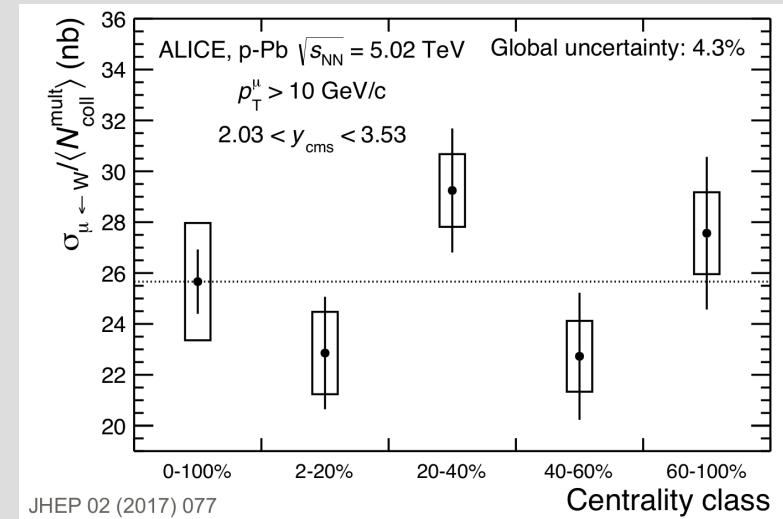
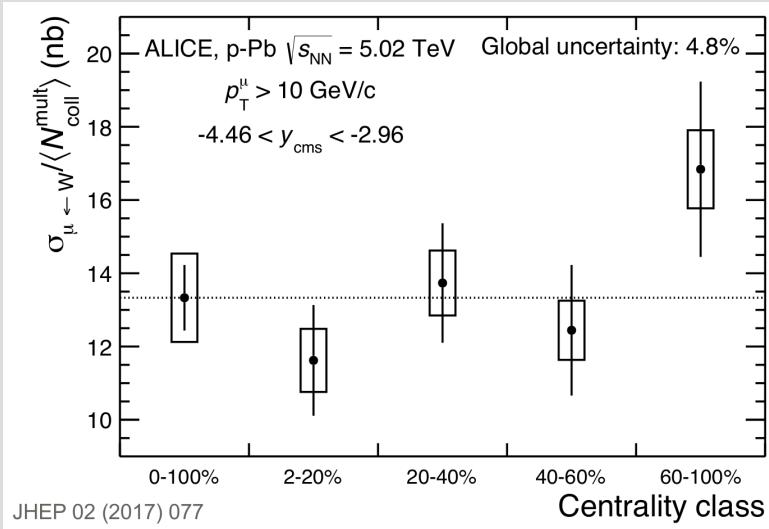
The pQCD calculations are obtained with CT10 NLO PDF set and with the EPS09NLO parameterisation of the nuclear modifications

- ❖ The measured production cross section of W^+ at forward rapidity is higher than that at backward rapidity by about a factor 6
- ❖ Within the uncertainties, the W^- production cross sections are similar at forward and backward rapidities
- ❖ Usage of EPS09 parameterisation of the nPDF in the calculations (red boxes) results in a slightly lower value of the cross section, especially at forward rapidity
- ❖ Both calculations **with** and **without** nPDF describe the data within uncertainties

Cross Section W boson



- ❖ Yield is normalized to $\langle N_{\text{coll}} \rangle$ to test binary scaling
- ❖ Signal extraction done separately for $\mu^+ \leftarrow W^+$ and $\mu^- \leftarrow W^-$ and then combined

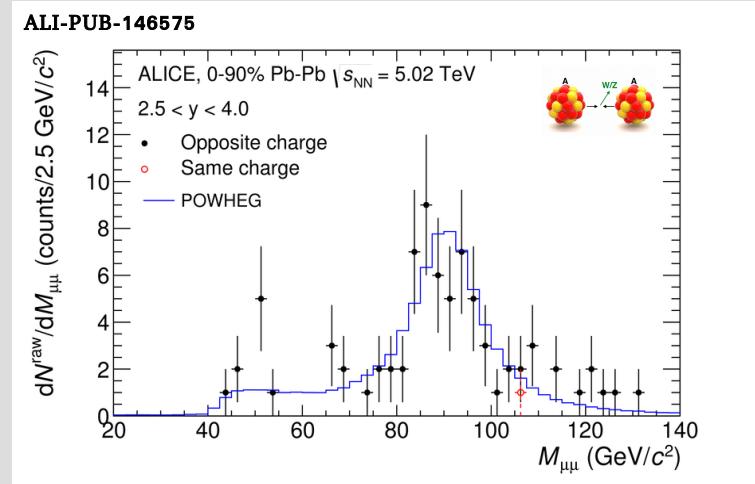
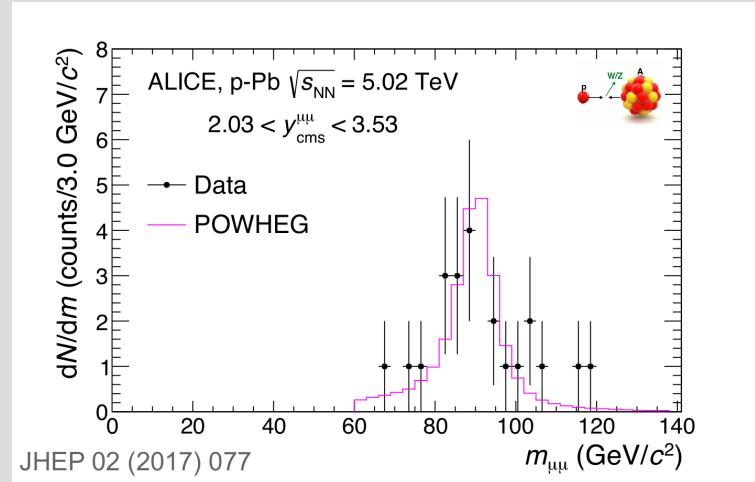


- ❖ W-boson production rate is consistent with geometric expectation
- ❖ The yield per binary collisions is independent of event activity within uncertainties
- ❖ Yield normalized to $\langle N_{\text{coll}} \rangle$ compatible within uncertainties among estimators
- ❖ The measured centrality dependence is found to be compatible with a constant within uncertainties
- ❖ Centrality in p-Pb: Phys. Rev. C 91 (2015) 064905

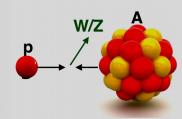
Signal Extraction Z boson

- ❖ $Z^0 \rightarrow \mu^+ + \mu^-$
- ❖ Combining opposite-charge pairs of muons with $p_T > 20 \text{ GeV}/c$
 → reduces the contribution of lower mass resonances (cc , bb) and those of heavy flavours
- ❖ Z boson signal : di-muon pair: $60 < m_{\mu\mu} < 120 \text{ GeV}/c^2$
- ❖ Minimum p_T of the muon to $10 \text{ GeV}/c$
 → to reduce additional unlike-sign di-muon pair with
 $m_{\mu\mu} > 40 \text{ GeV}/c^2$
 → contamination from background (cc , bb , $t\bar{t}$, $Z \rightarrow \tau\tau \rightarrow \mu\mu$) to the total $\mu^+ + \mu^-$ spectra estimated using PYTHIA and POWHEG simulations and found to be $< 1\%$

Observable: The cross section as a function of rapidity



Yield Z boson



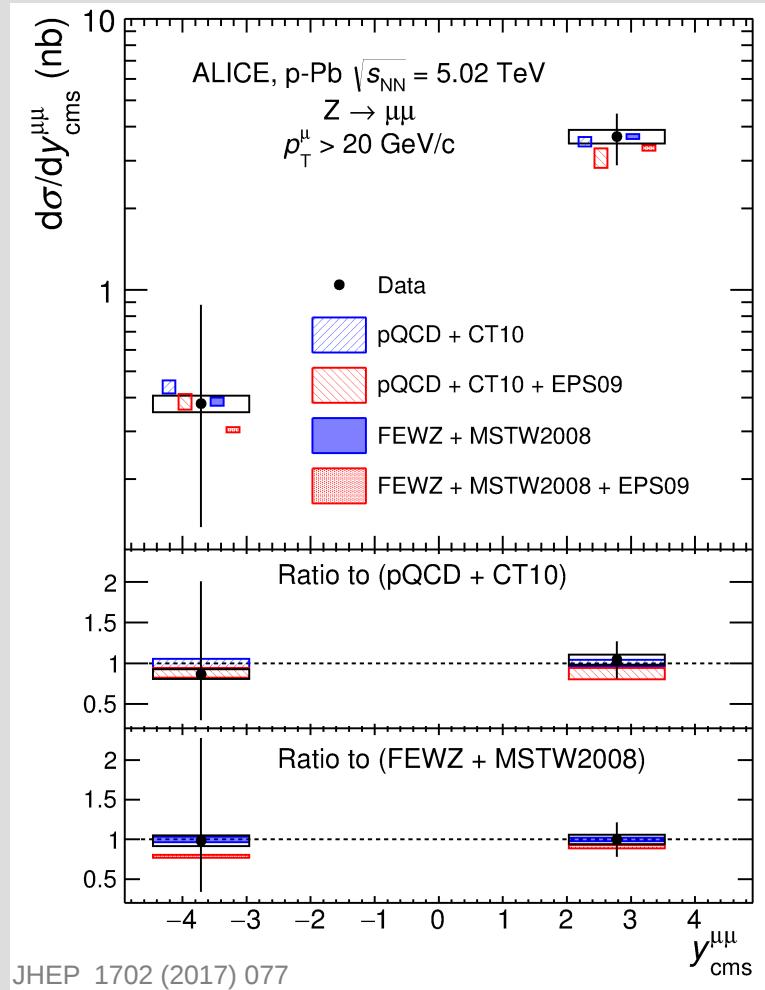
- ❖ First Z-boson measurement in ALICE

Cross section compared to:

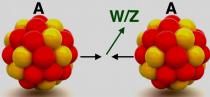
- pQCD calculations (NLO) [using CT10 NLO as PDF]
- FEWZ calculations (NNLO) [using MSTW2008 NNLO as PDF]

- ❖ Results in agreement with calculations **with** and **without** including nPDFs (EPS09)
- ❖ The measurement is compatible with the different calculations. More precision is needed to constrain nPDFs

CT10: H Paukkunen et. al., JHEP 1103 (2011) 071,
 EPS09: K. J. Eskola et. al., JHEP 0904(2009)065,
 FEWZ: R. Gavin et. al., Comput. Phys. Commun. 182 (2011) 2388–2403



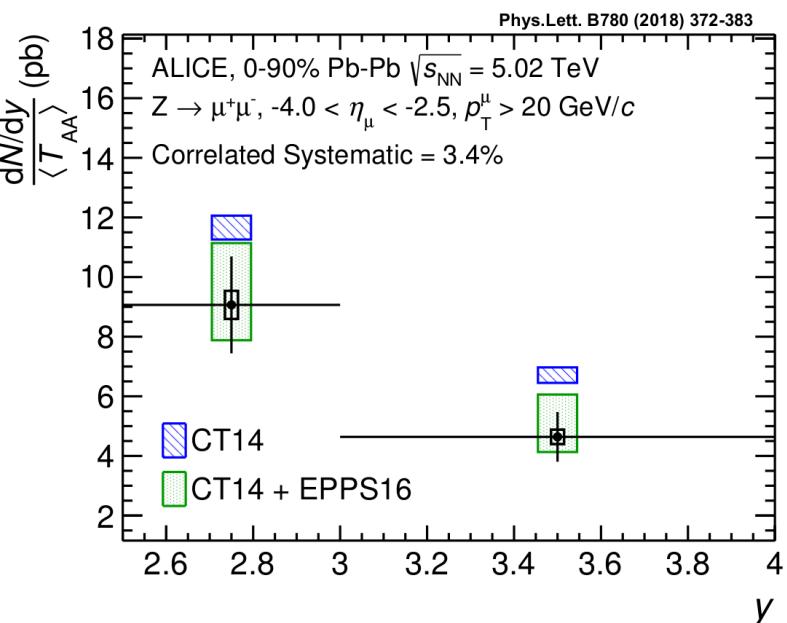
Z-Boson Production in Pb-Pb



Yield Z Boson

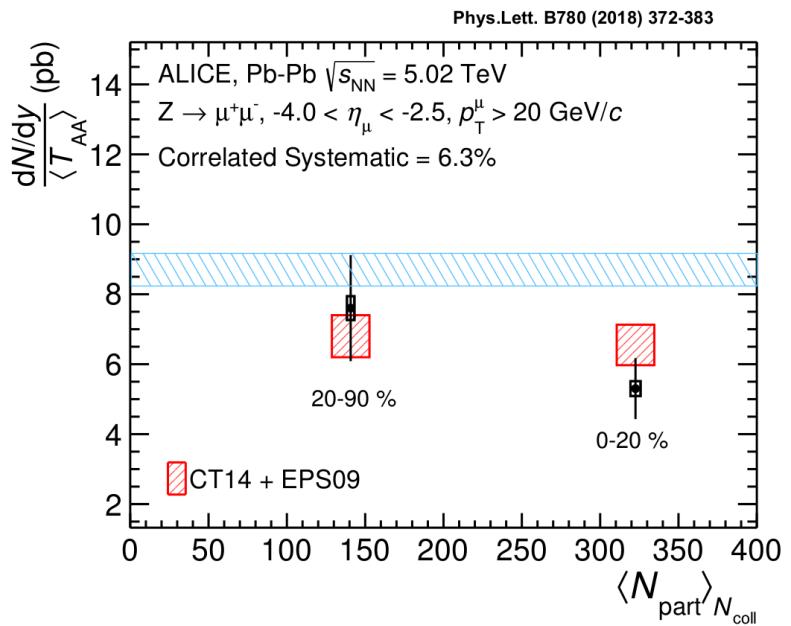
The PDFs modification depends on the rapidity

ALI-PUB-146575



nPDF is expected to slightly depend on the centrality

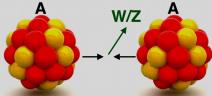
ALI-PUB-146575



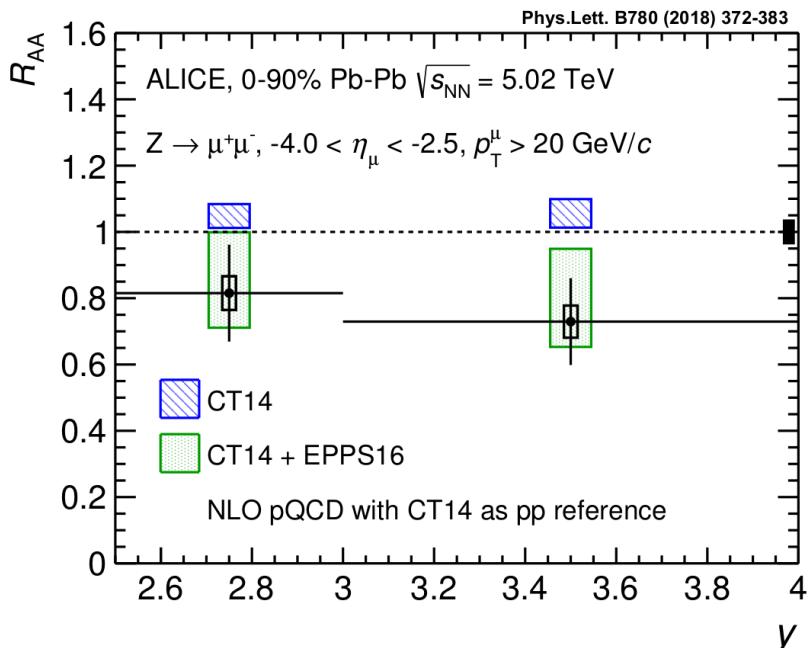
- ❖ The results are in a better agreement with the calculation that includes PDFs modification

- ❖ Free nucleon PDFs prediction overestimates the measurement by $\sim 3\sigma$ for 0-20% centrality
- ❖ Results are in agreement within uncertainties with calculations based on EPS09

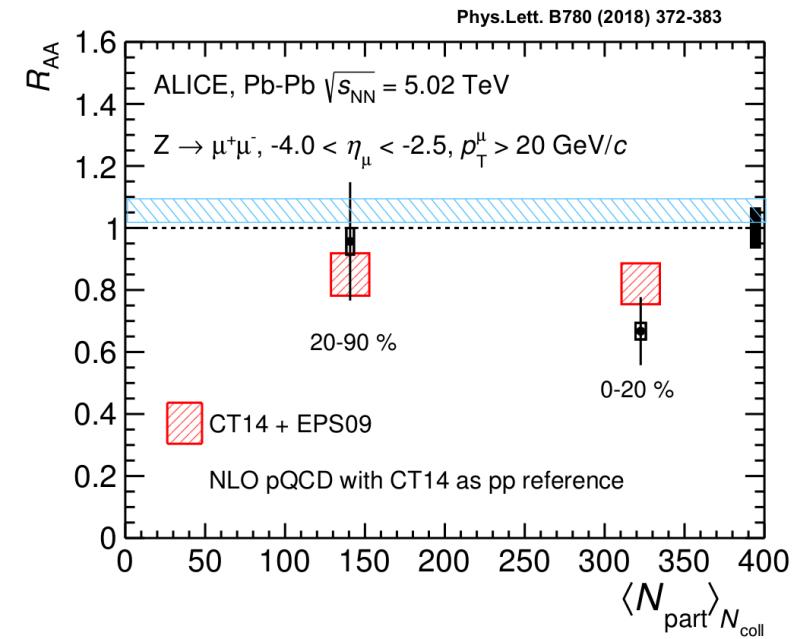
Z Boson R_{AA}



ALI-PUB-146575



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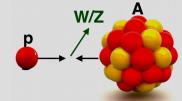


- The results are in a better agreement with the calculation that includes **PDFs** modification

- Free nucleon PDFs prediction overestimates the measurement by $\sim 3\sigma$ for 0-20% centrality
- Results are in agreement within uncertainties with calculations based on **EPS09**

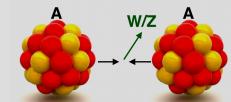
Summary & Outlook

❖ W/Z-boson production in p-Pb collisions at $\sqrt{s}_{NN} = 5.02$ TeV



- Results can be described by theoretical calculations within uncertainties
- Precision is not enough to conclude on the nPDFs
- Analysis of the $\sqrt{s}_{NN} = 8.16$ TeV data sample is ongoing: 4 (12) x more statistics expected in the p-going (Pb-going) direction

❖ Z-boson production in Pb-Pb collisions at $\sqrt{s}_{NN} = 5.02$ TeV



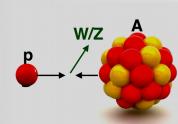
- Calculations with free PDFs overestimate the measurement by 2.3σ (3σ for the 0-20% most central collisions)
- Calculation with nPDF (EPS09) describe the data
- Larger Pb-Pb data sample is expected next month

❖ Measurement of the W-boson production in Pb-Pb collisions at $\sqrt{s}_{NN} = 5.02$ TeV is ongoing

Thank you for your attention

Extra Slides

W Boson Measurement

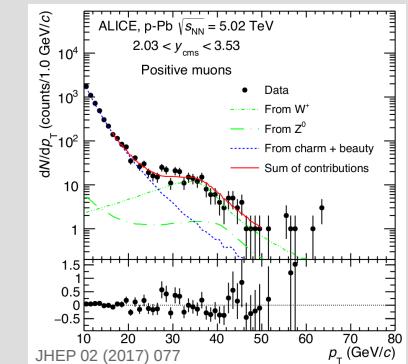
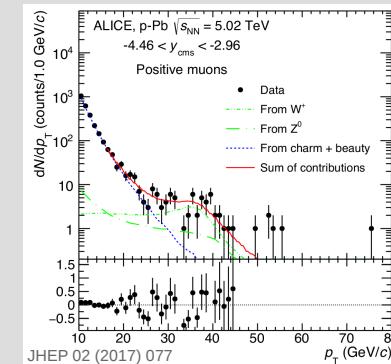
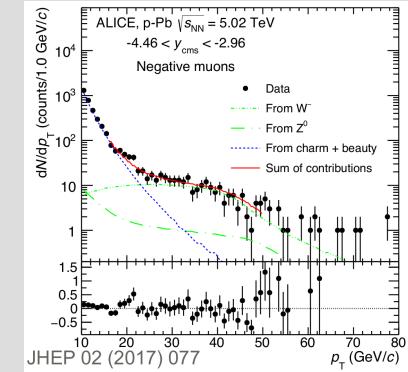
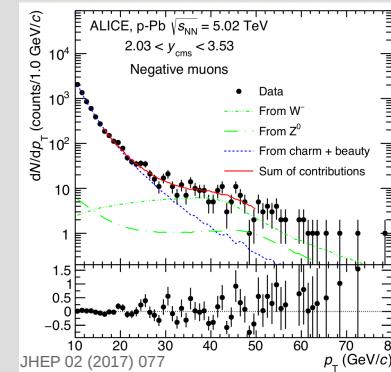


- ❖ Contribution of $W^\pm \rightarrow \mu^\pm$ to the single- μ^\pm pT distribution at:
 - $p_T > 30 \text{ GeV}/c$
- ❖ The main background to the single- μ pT distribution are:
 - Heavy-flavour decay muons:
 $b \rightarrow \mu, c \rightarrow \mu$: $8 < p_T < 40 \text{ GeV}/c$
 - Di-muon decay from Z^0/γ^* :
 $Z^0/\gamma^* \rightarrow \mu^+ + \mu^-$: $p_T > 50 \text{ GeV}/c$
- ❖ Signal extraction:

$$f(p_T) = N_{\text{bkg}} f_{\text{bkg}}(p_T) + N_{\mu \leftarrow W} f_{\mu \leftarrow W}(p_T) + N_{\mu \leftarrow Z/\gamma^*} f_{\mu \leftarrow Z/\gamma^*}(p_T)$$

where,

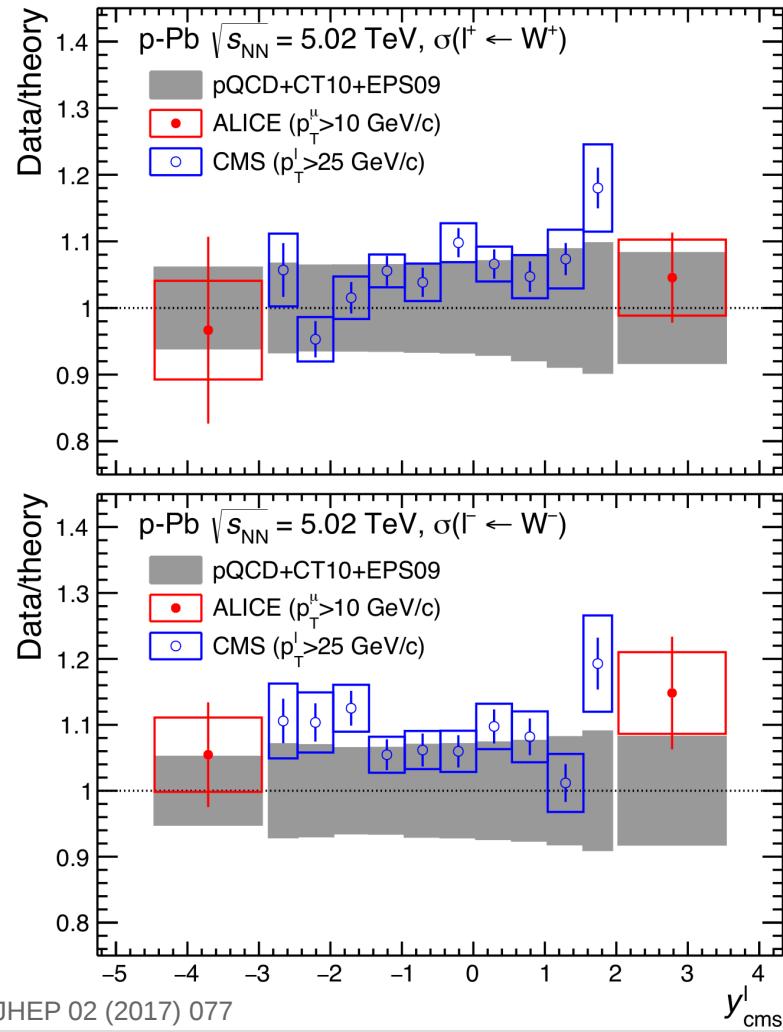
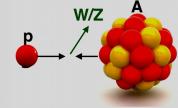
$f_{\text{bkg}}(p_T)$: FONLL based template $f_{\mu \leftarrow W(p_T)}$ & $f_{\mu \leftarrow Z/\gamma^*(p_T)}$:
Pythia6.4.25 Monte Carlo templates, N_{bkg} & $N_{\mu \leftarrow W}$:
free normalisation parameters, $N_{\mu \leftarrow Z/\gamma^*}$: fixed to $N_{\mu \leftarrow W}$



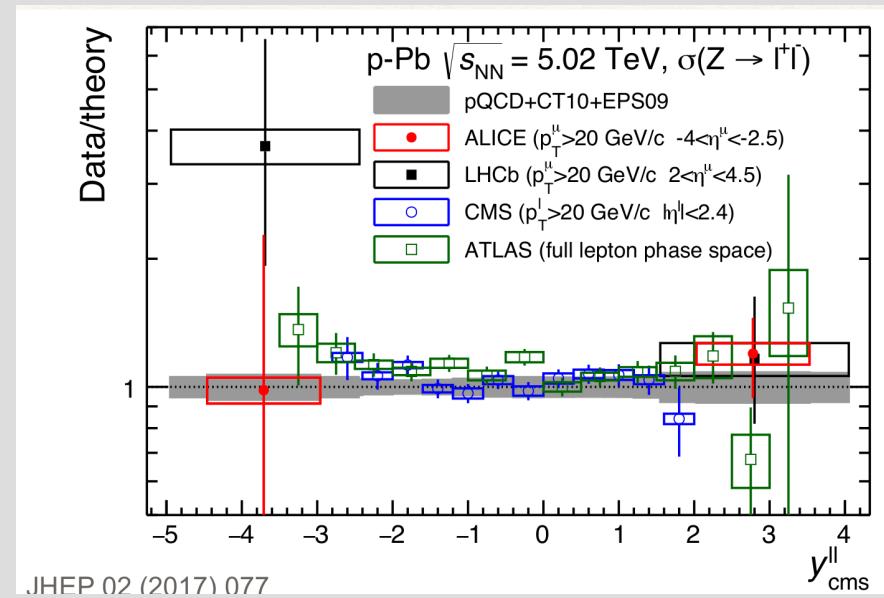
Trials include:

5000 MC template for bkg, different p T ranges: 10-20 (in step of 1) $< p_T < 50$ -80 (in step of 5), alignment files, resolution task , MC templates for signal and Z^0/γ^*

W/Z-boson production at LHC

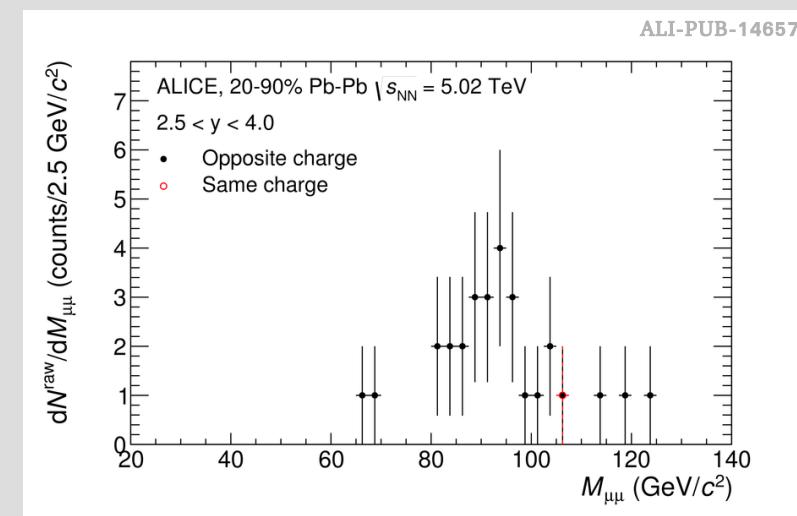
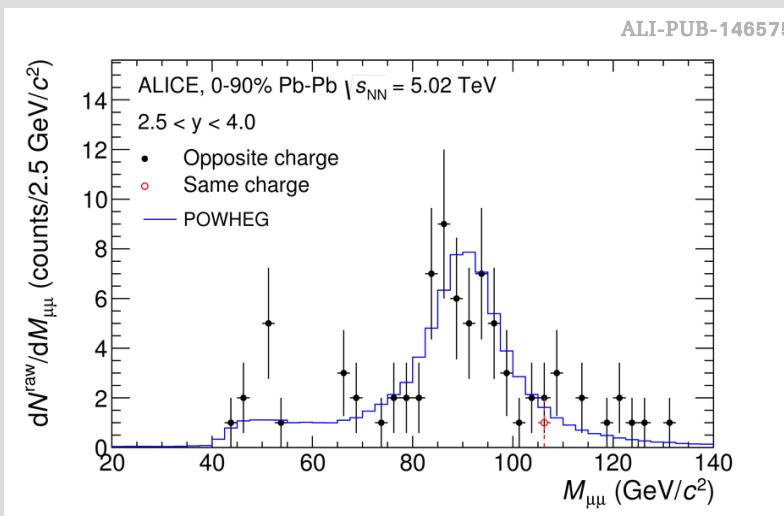
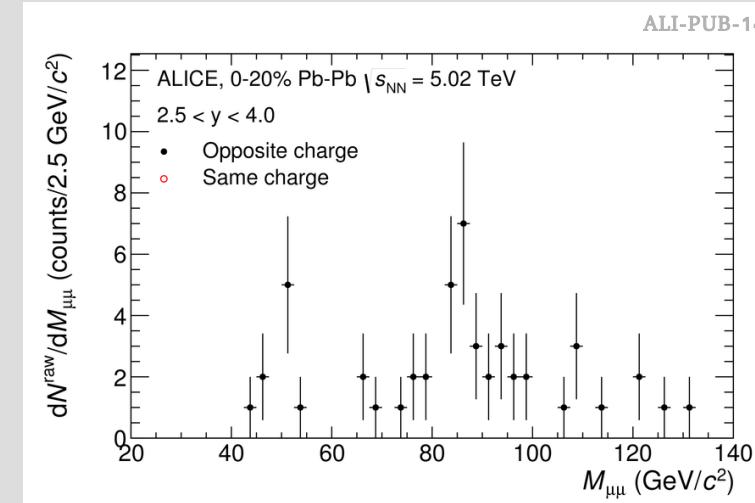
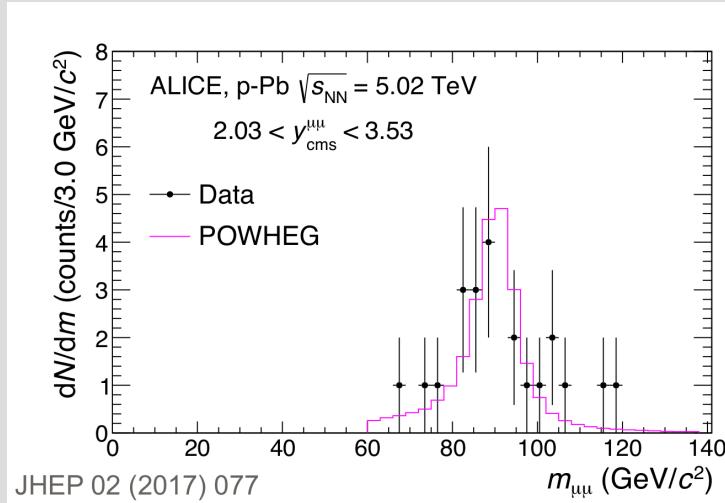


Results not directly comparable (different kinematic cuts) → compare the ratio data over the corresponding pQCD predictions

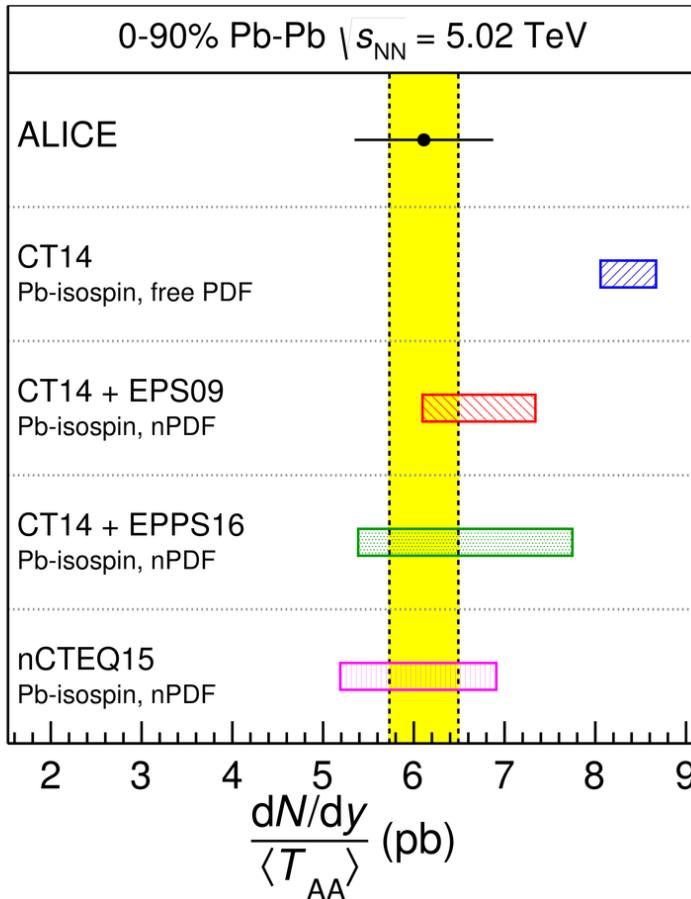
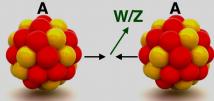


Calculations including EPS09 PDFs modification can describe data within uncertainties over the full rapidity interval

Z-boson Measurement



Z-boson Measurement



- ❖ Within uncertainties, the result is in agreement with the calculation using three different nPDFs
- ❖ 2.3 σ separation between the results and the calculations without including nPDF
- ❖ The R_{AA} is evaluated, dividing the normalised yield by CT14 pp cross section ($\sigma_{pp} = 11.92 \pm 0.43 \text{ pb}$)