$W^{\pm}$ and Z bosons production in p–Pb and Pb–Pb collisions at ALICE

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Physics motivation

- Electroweak bosons are sensitive probes to nuclear modifications of the partion distribution functions (PDF):
  - Produced in hard processes before QGP is formed.
  - Their production is well described by perturbative QCD and electroweak theory.
  - Production is sensitive to initial state which can provide input on nuclear PDF(nPDF).
  - Their leptonic decay channels are insensitive to the medium
- Help constraining the nuclear PDF

Key concepts

- Nuclear modification factor

  Modify the suppression or enhancement of the production due to the nuclear effects compared to pp collision

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \cdot \frac{\frac{\mathrm{d}N_{AA}}{\mathrm{d}y}}{\frac{\mathrm{d}\sigma_{pp}}{\mathrm{d}y}}, \qquad R_{pA} = \frac{1}{A} \cdot \frac{\frac{\mathrm{d}\sigma_{AA}}{\mathrm{d}y}}{\frac{\mathrm{d}\sigma_{pp}}{\mathrm{d}y}}$$

  T_{AA}: nuclear overlap function from Glauber model. A: Nucleon number.

- W charge asymmetry

  Defined as:

$$A = \frac{N_{\mu^+ \leftarrow W^+} - N_{\mu^- \leftarrow W^-}}{N_{\mu^+ \leftarrow W^+} + N_{\mu^- \leftarrow W^-}}$$

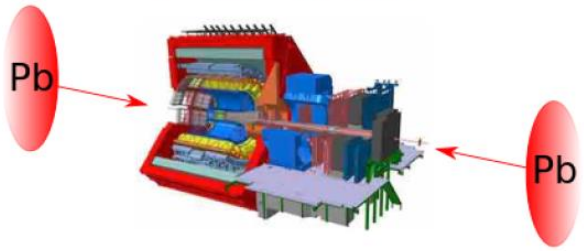
  Represents the difference between W^+ and W^- yields

  Directly constrains the PDF of the up and down quarks

The ALICE detector

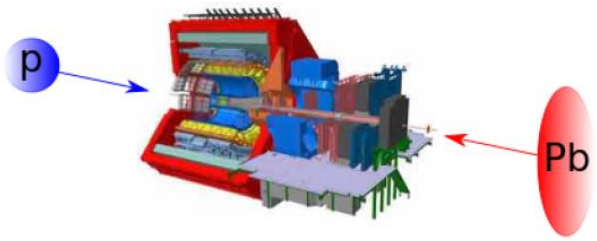
Large rapidity region

Pb–Pb:



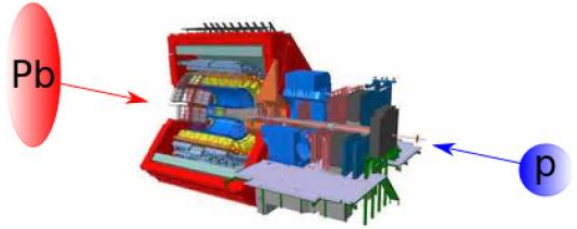
$2.5 < y_{\mathrm{cms}} < 4$

p–Pb, p-going:



$2.03 < y_{\mathrm{cms}} < 3.53$

p–Pb, Pb-going:

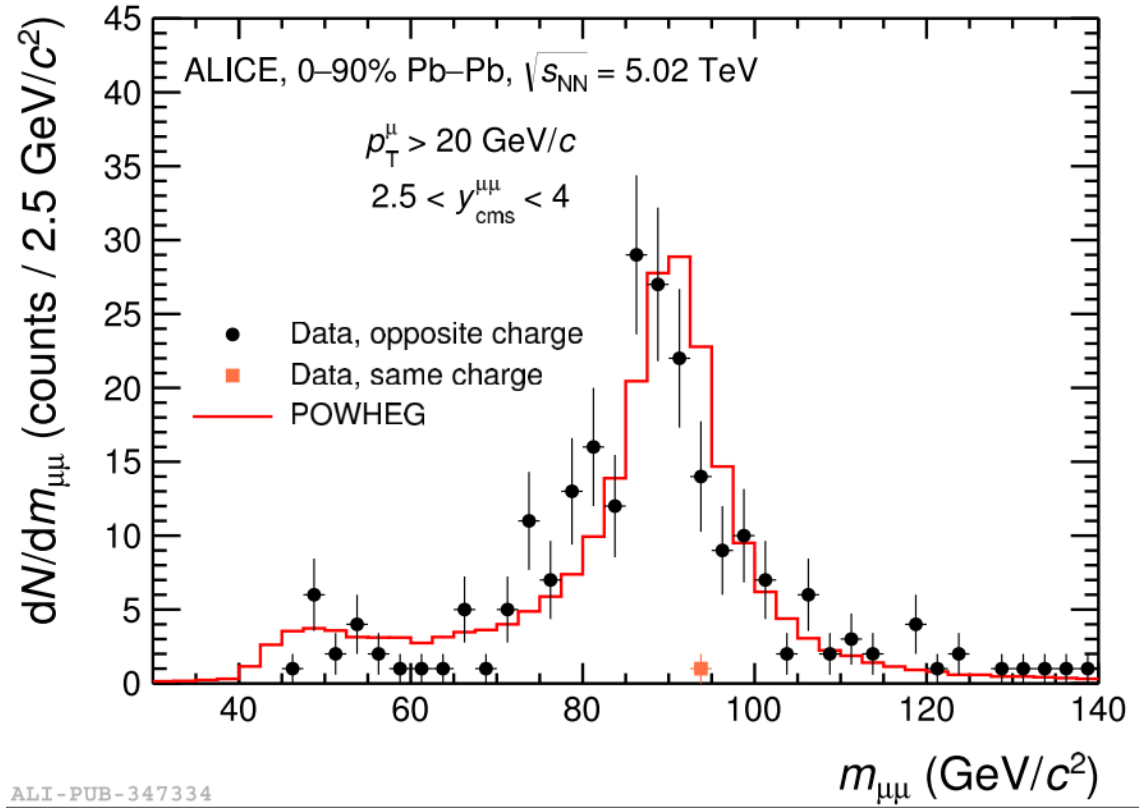


$-4.46 < y_{\mathrm{cms}} < -2.96$

Z extraction

- Z candidates: opposite-sign muon pairs in the fiducial region

$$\begin{cases} -4 < \eta_\mu < -2.5 \\ p_T(\mu) > 20\ \mathrm{GeV}/c \\ 60 < m_{\mu^+\mu^-} < 120\ \mathrm{GeV}/c^2 \end{cases}$$



Backgrounds:

$Z \to \tau\tau \to \mu\mu$, $\mu^+\mu^-$ pairs from charm, bottom and top(FONLL, POWHEG) ~1%

Combinatorial background ($\mu^+\mu^+$, $\mu^-\mu^-$), negligible

Low Background means that signal extracted by counting the entries in the invariant mass distribution

Raw yield corrected for the acceptance × efficiency of the detector

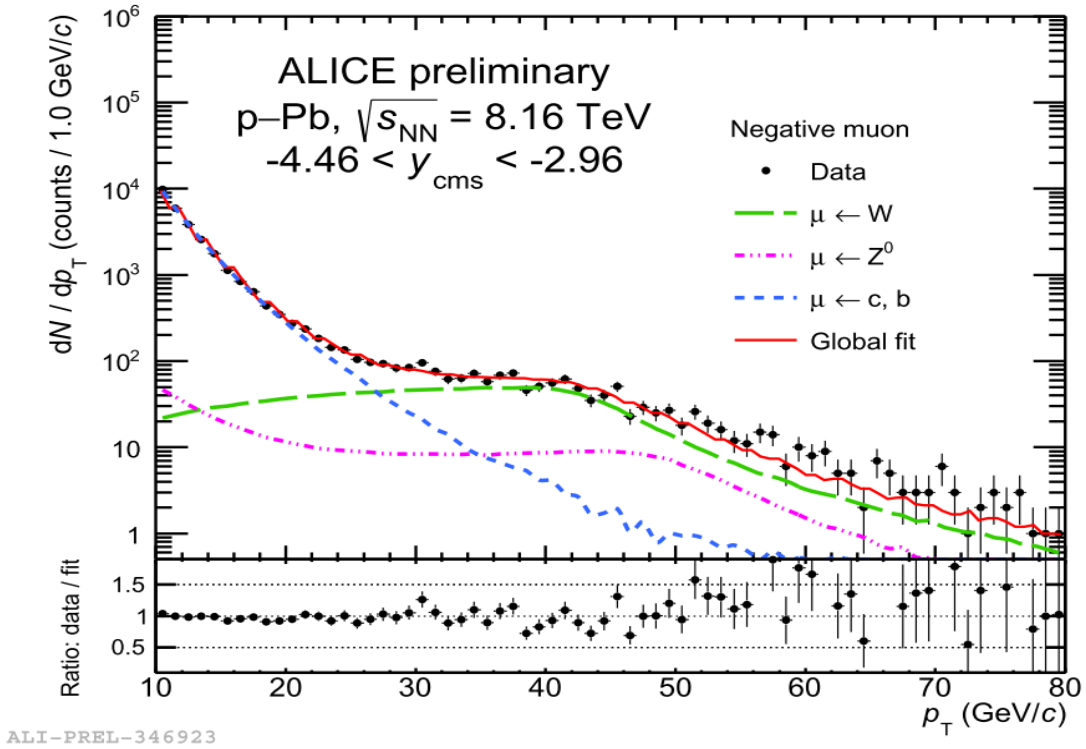
FONLL: JHEP 10(2012) 137
POWHEG: JHEP 07(2008)060

W extraction

- Decay channels: $W^+ \rightarrow \mu^+ + \overline{\nu_\mu},\ W^- \rightarrow \mu^- + \overline{\nu_\mu}$
- In the fiducial region:

$$\begin{cases} 2.5 < \eta_\mu < 4 \\ p_T(\mu) > 10\ \mathrm{GeV}/c \end{cases}$$

- Background:
  - $\mu^{\pm}$ from Z, heavy flavor hadron.



Single muon distribution:

$$f(p_T) = N_{HF} f_{HF}(p_T) + N_{\mu\leftarrow W}(f_{\mu\leftarrow W}(p_T) + R \cdot f_{\mu\leftarrow Z^0/\gamma^*}(p_T))$$

f_{HF}, $f_{\mu\leftarrow W}$, $f_{\mu\leftarrow Z^0/\gamma^*}$: MC templates.
N_{HF}, $N_{\mu\leftarrow W}$: free parameters.
R: ratio of the Z to W cross sections.

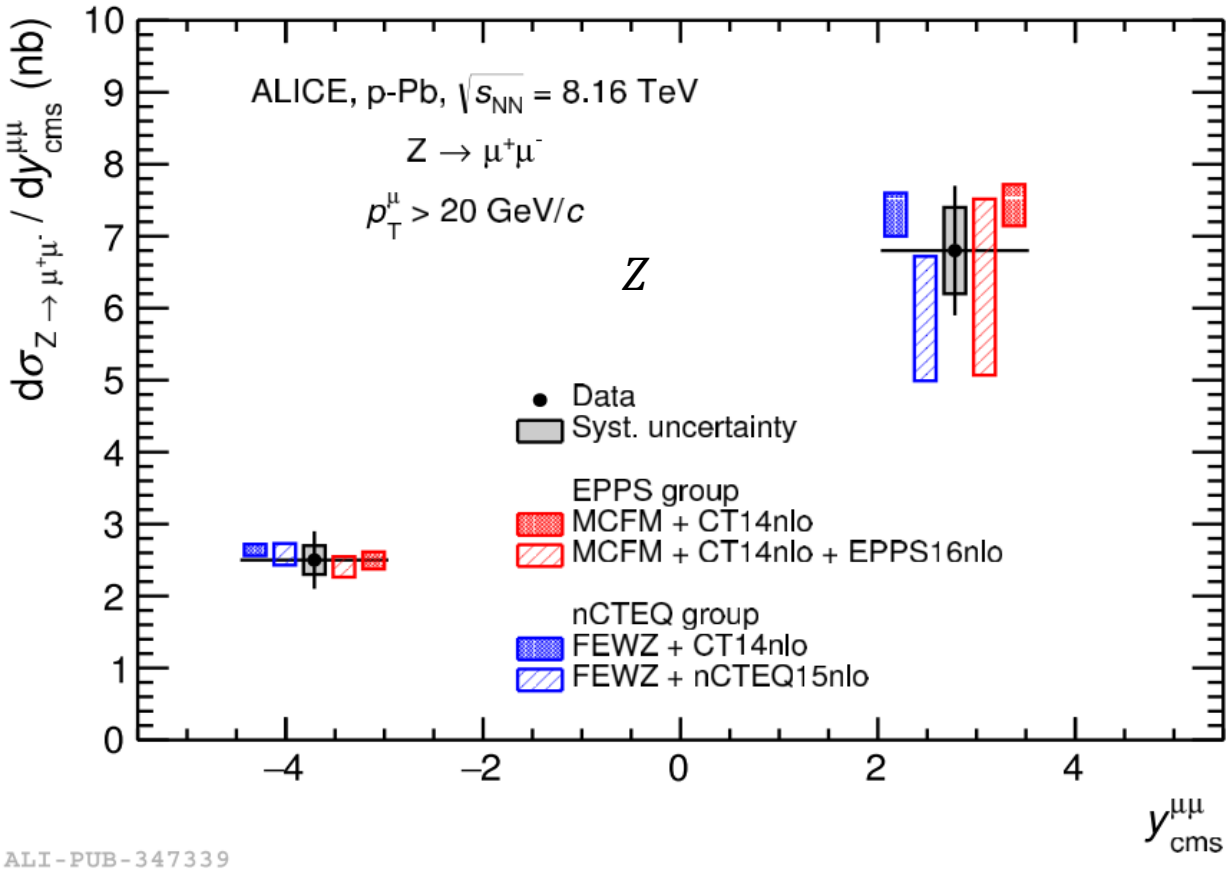
Raw yield corrected for the acceptance × efficiency of the detector.

Results

JHEP 2009 (2020) 076 (Z in p–Pb and Pb–Pb)

- Z in p-Pb at $\sqrt{s_{NN}} = 8.16$ TeV:
  - Increased statistics compared to p-Pb at 5.02 TeV.
  - 3 times more Z boson identified at forward rapidity.
  - 15 times more at backward rapidity.
- Z in Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV:
  - Combining the data from the 2015 and 2018.
  - Luminosity increased from 225 to 750 μb^{-1}, 3 times more Z bosons. Improvement of the precision of the measurement.
- W in p-Pb at $\sqrt{s_{NN}} = 8.16$ TeV:
  - Increased statistics: 2 to 7 times compared to 5.02 TeV data samples.
- W in Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV:
  - Preliminary results, first measurement at large rapidities.

Z in p-Pb at 8.16 TeV

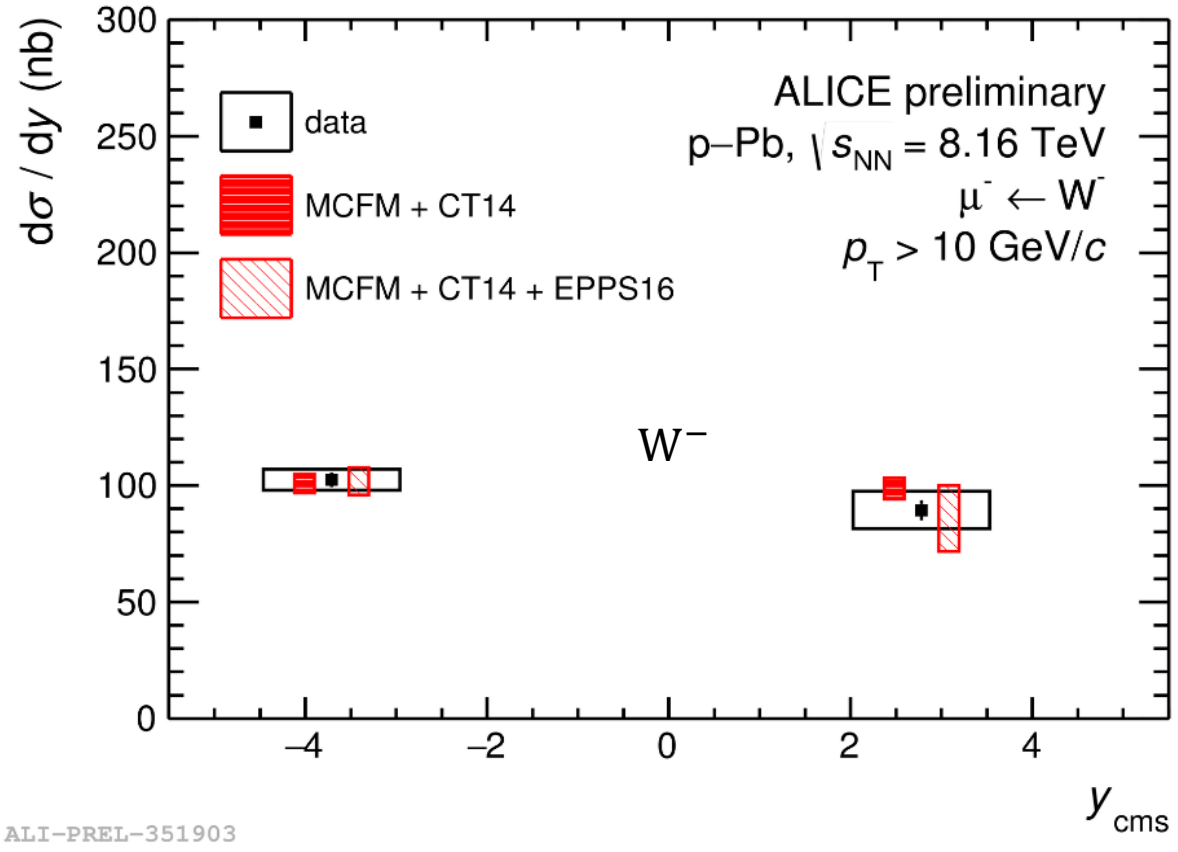


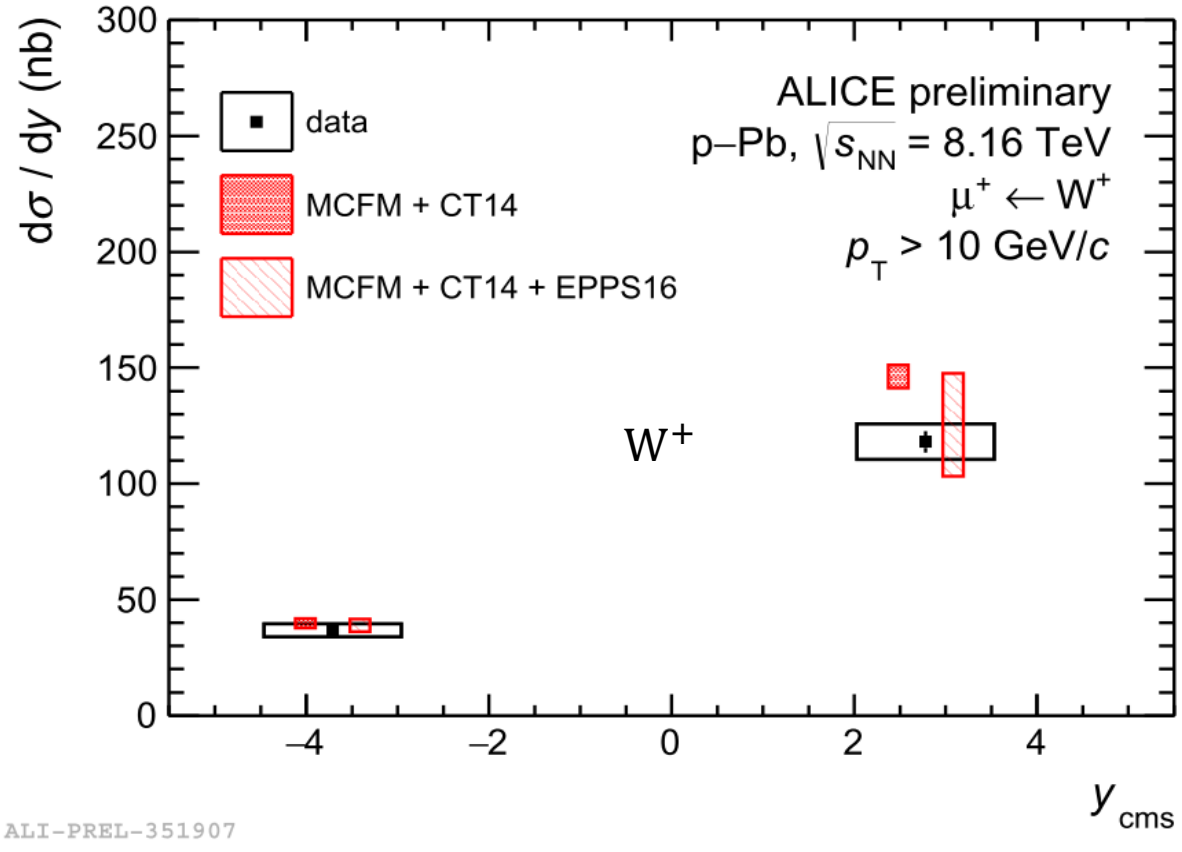
Measured cross section compared with predictions with and without nuclear modifications

Theory PDF:
CT14: Phys. Rev. D 93, 033006(2016)
MCFM: EPJC 77(2017)7
FEWZ: Comp. Phys. Comm. 182(2011)2388-2403
Nuclear modification factor R_{AA}:
EPPS16: EPJC(2017) 77:163
nCTEQ15: Phys. Rev. D 93, 0850037(2016)

The x-coordinates of theory points are shifted for eye. The same for the following plots.

$W^{\pm}$ in p-Pb at 8.16 TeV



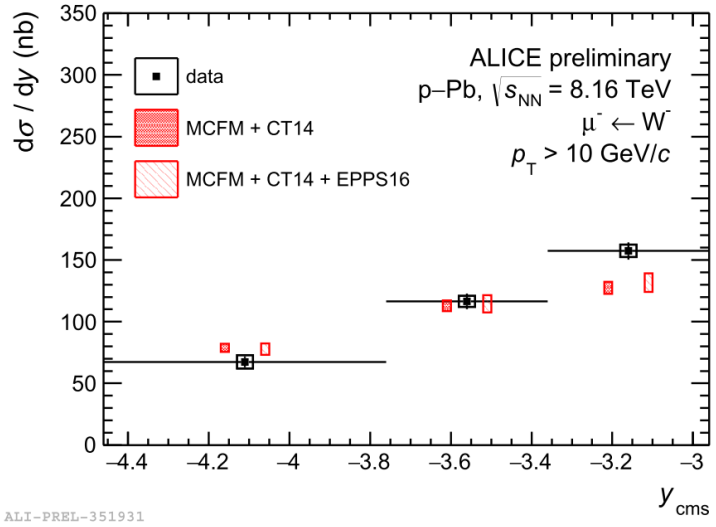


Deviation from free-PDF prediction by 2.7σ for W^+ at forward rapidity.

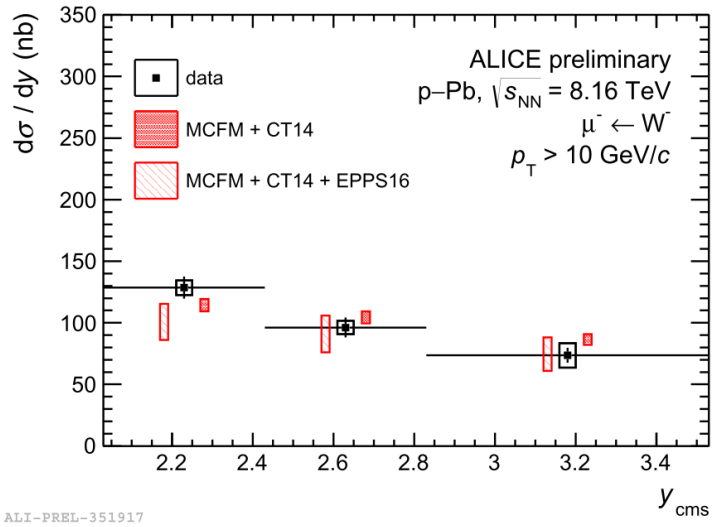
$W^{\pm}$ in p-Pb at 8.16 TeV

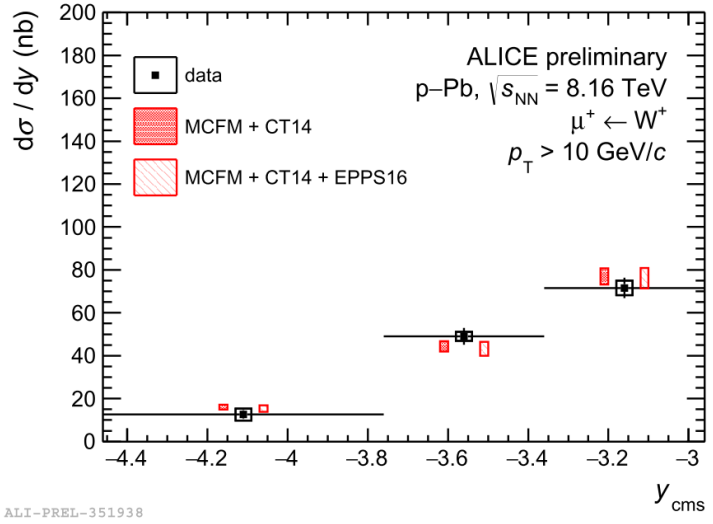
- Deviation from theory for W^{-} at backward rapidity in the most central bin.
- Deviation from free-PDF calculation for W^{+} at forward rapidity.

W^{-} Pb – going

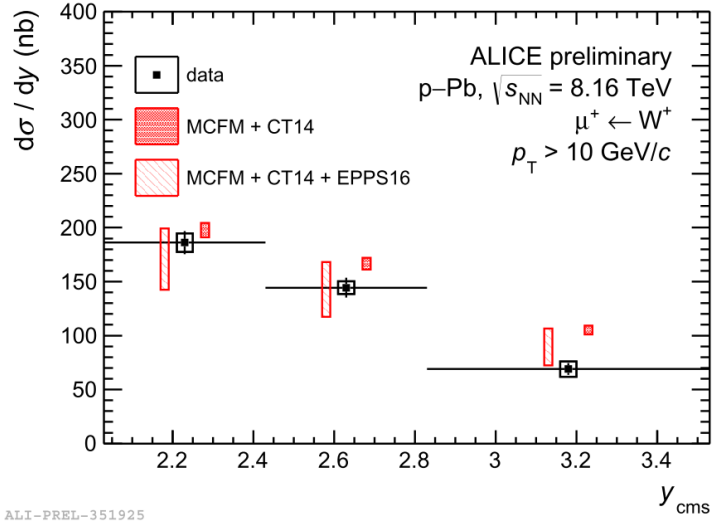


W^{-} p – going





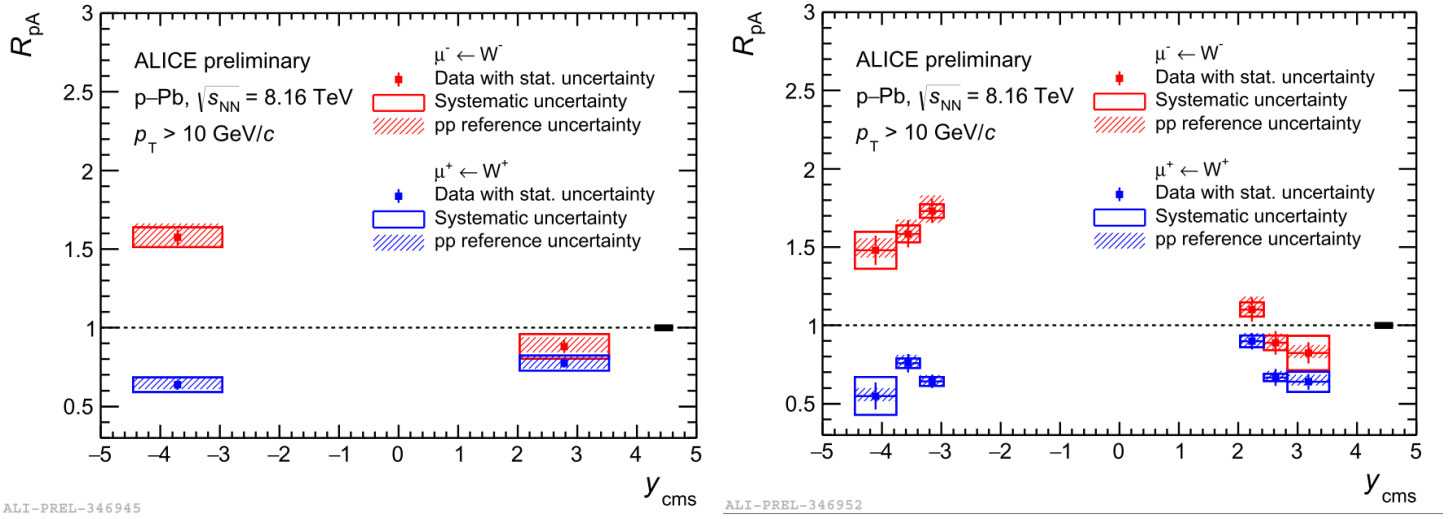
W^{+} Pb – going



W^{+} p – going

$W^{\pm}$ in p-Pb at 8.16 TeV

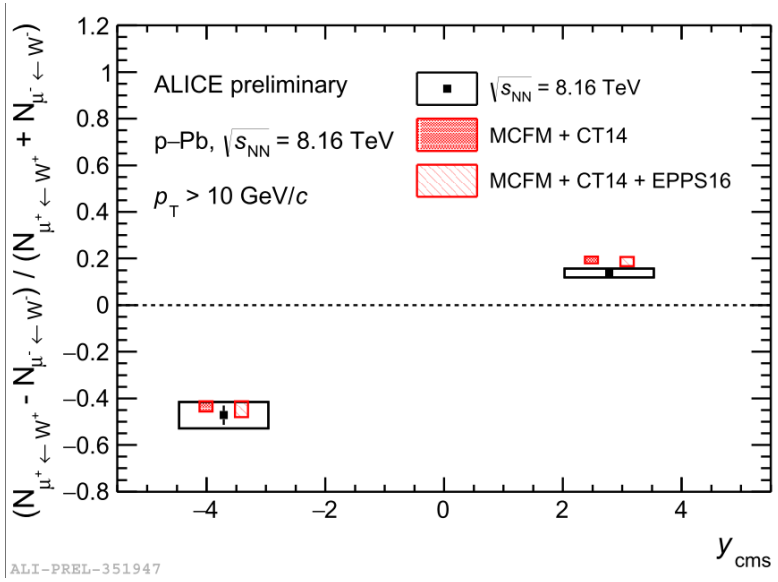
Nuclear modification factor R_{AA}



Deviation from 1 associated to isospin and nuclear effects.

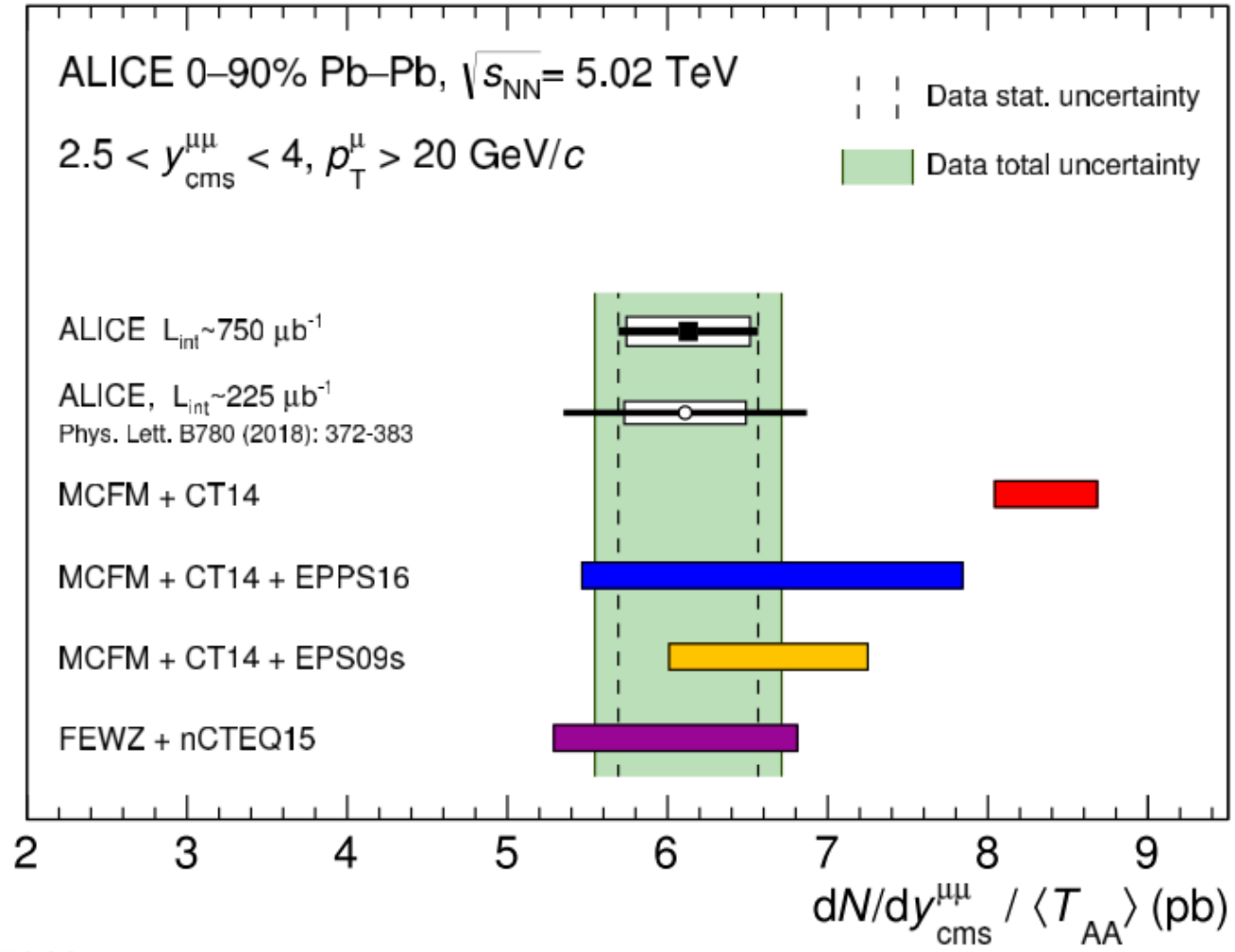
W charge asymmetry

$$A = \frac{N_{\mu^+ \leftarrow W^+} - N_{\mu^- \leftarrow W^-}}{N_{\mu^+ \leftarrow W^+} + N_{\mu^- \leftarrow W^-}}$$



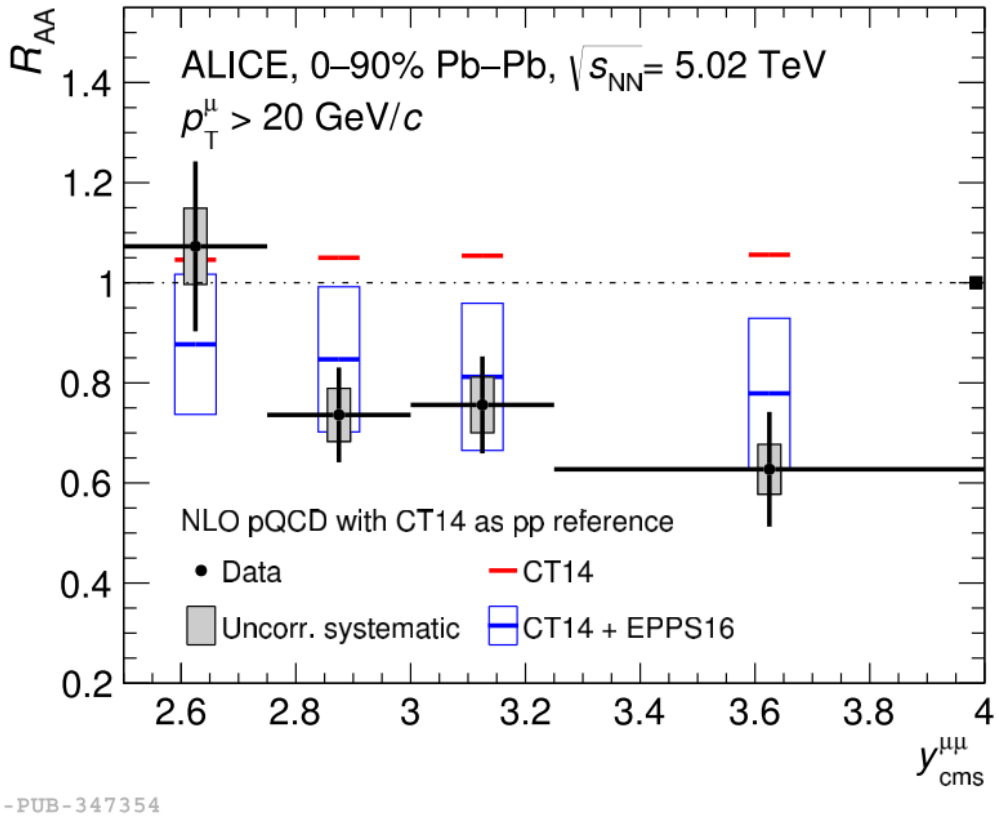
Results agree with theory.

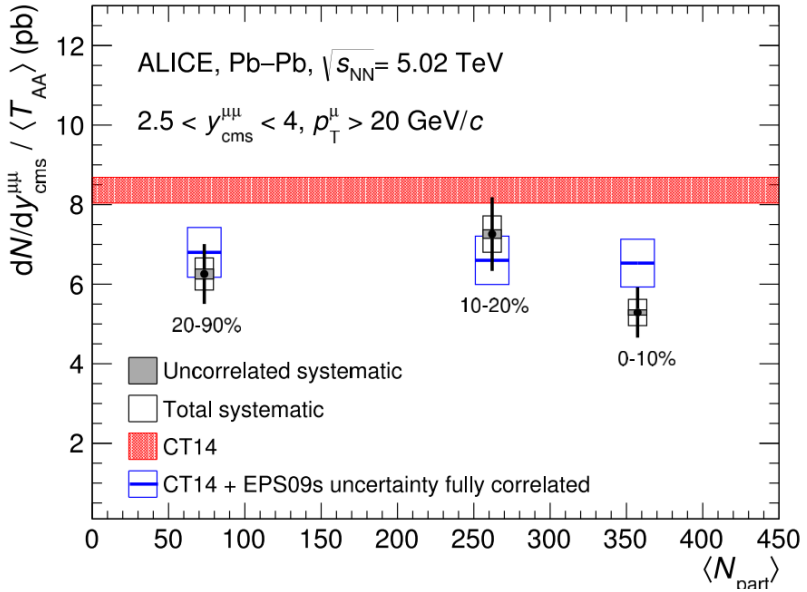
Z in Pb-Pb at 5.02 TeV

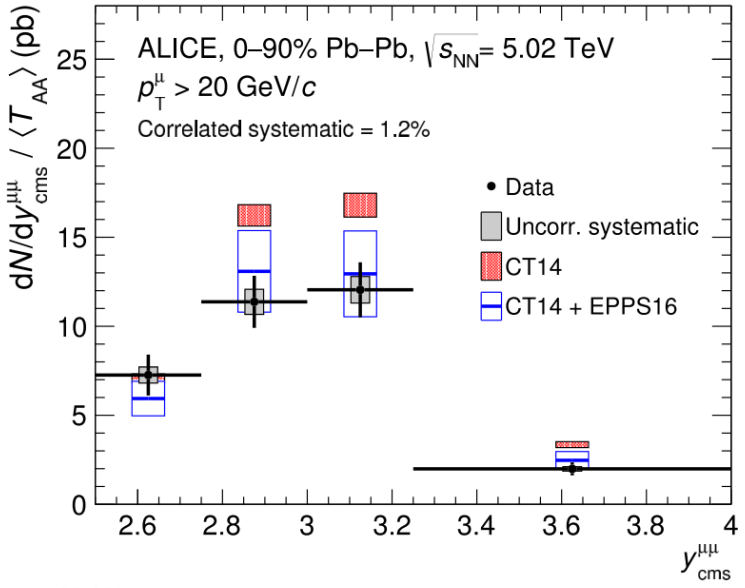


- Compatible with calculations including nPDFs using three different models.

Z in Pb-Pb at 5.02 TeV





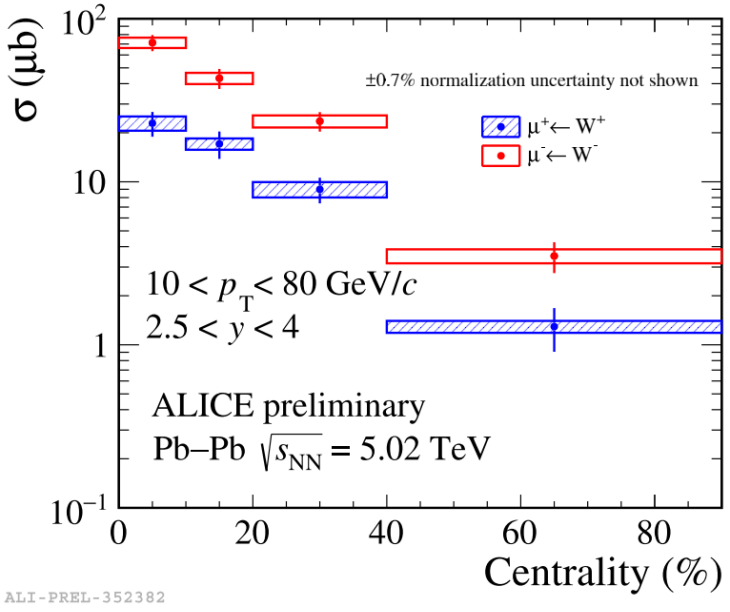


- Better agreement when including nuclear modifications.
- Larger deviation for the most central events and the largest rapidities.

$W^{\pm}$ in Pb-Pb at 5.02 TeV

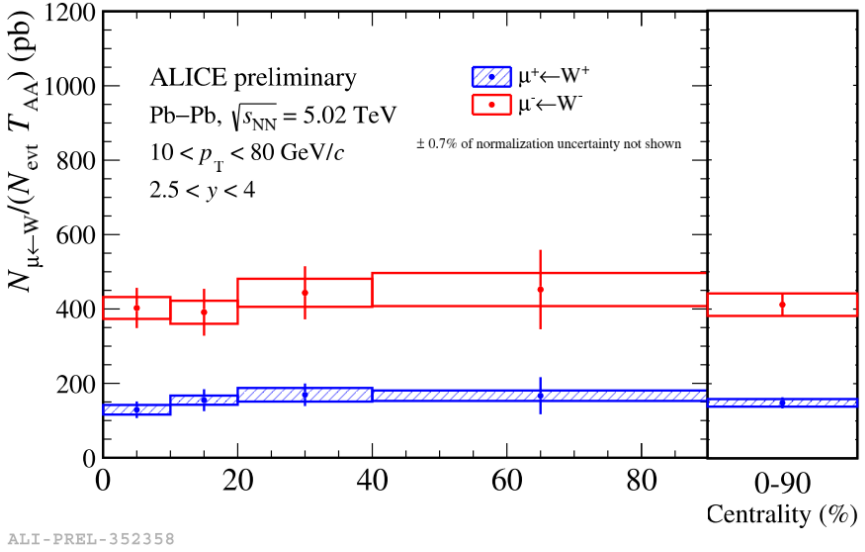
First measurement of W in Pb-Pb at large rapidities

σ v.s. Centrality:



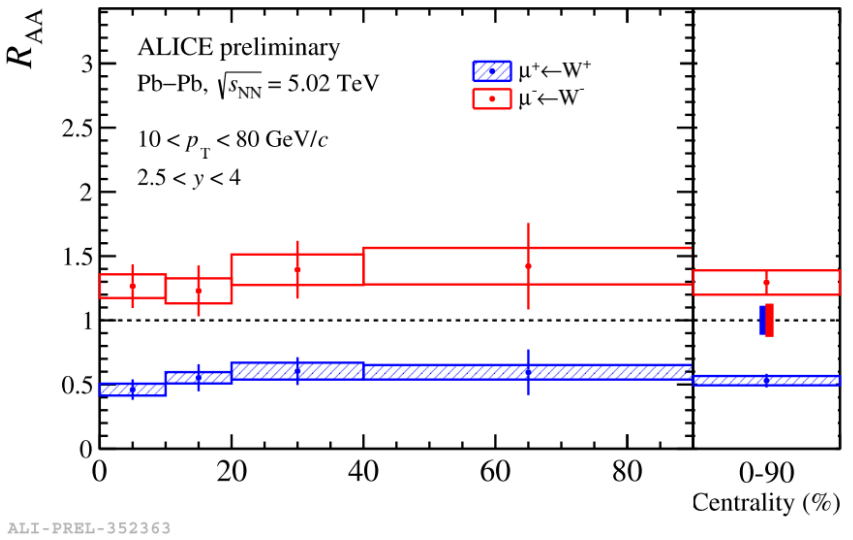
Decrease of the production for more peripheral events.

Normalized yield v.s. Centrality:



Weak centrality dependence.

Nuclear modification factor R_{AA} v. s. Centrality. Reference cross section: POWHEG + CT10nlo:



Deviation from 1 associated to isospin and nuclear effects. Weak centrality dependence.

Conclusions

- p-Pb:
  - Z: JHEP 2009 (2020) 076.
  - W: Preliminary results for W. Significant increase of statistics compared to analyses at 5.02 TeV: deviation of the measured W production from free-PDF at large rapidities.
- Pb-Pb:
  - W: Preliminary results for W. First measurement of the W production at forward rapidity. (Now with 2015 data samples, merging with the 2018 data.)
  - Z: Measurement results of Z with 2015 and 2018 data (JHEP 2009 (2020) 076). Significant deviation from free-PDF prediction for Z.
  - Statistic uncertainty dominates the results, which can be improved with Run3 and Run4.

Thank you for listening!