



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

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# Motivation

## ■ W/Z boson productions

### ■ Predominantly via a quark – antiquark pair annihilation (Drell-Yan)

■  $u\bar{d} \rightarrow W^+, d\bar{u} \rightarrow W^-, \text{ and } q\bar{q} \rightarrow Z$

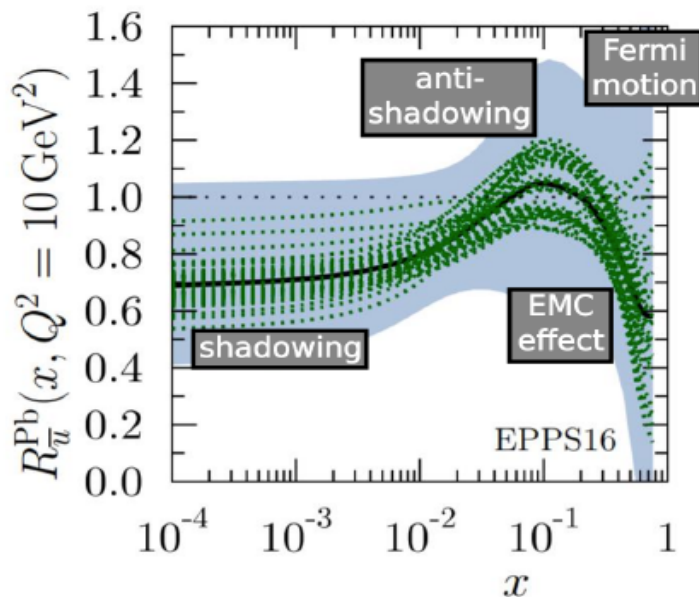
### ■ Sensitive to quark and antiquark content in nucleon / nucleus

■ Difference in pp & p-Pb (Pb-Pb) --- nuclear Parton Distribution Function (nPDF)

■ W charge asymmetry --- sensitive to the down / up ratio (isospin)

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### ■ Partons in nuclear (nPDF)

■ Enhance @  $x \sim 10^{-1}$

■ Suppress @  $x < 10^{-2}$

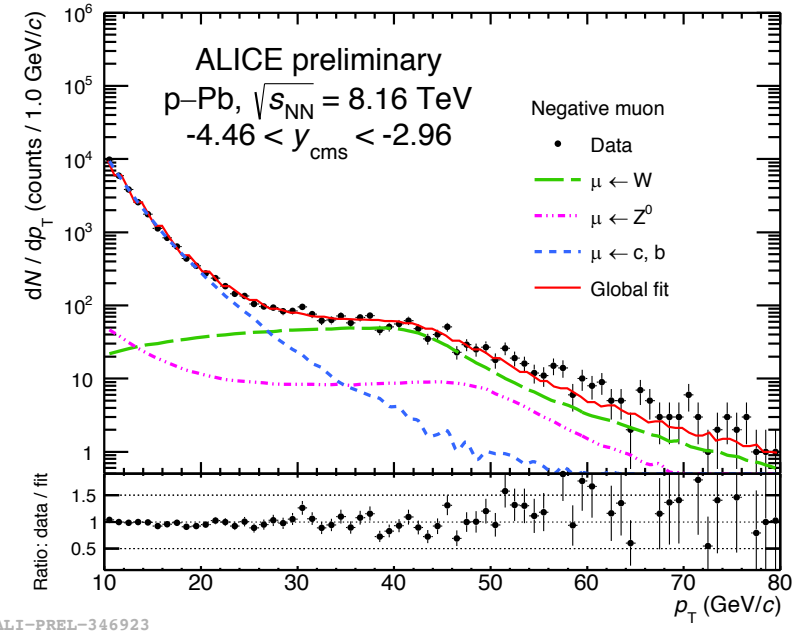
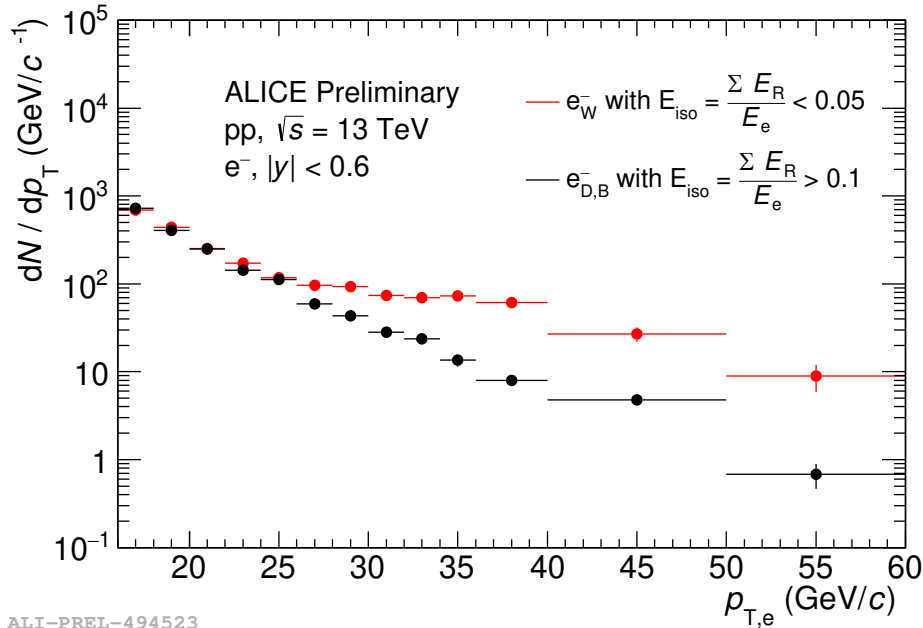
■ ALICE probe different x regimes, from  $x \sim 10^{-3} - 10^{-4}$  to  $x \sim 10^{-1}$

■ Several prediction in the market

■ with large theory uncertainties

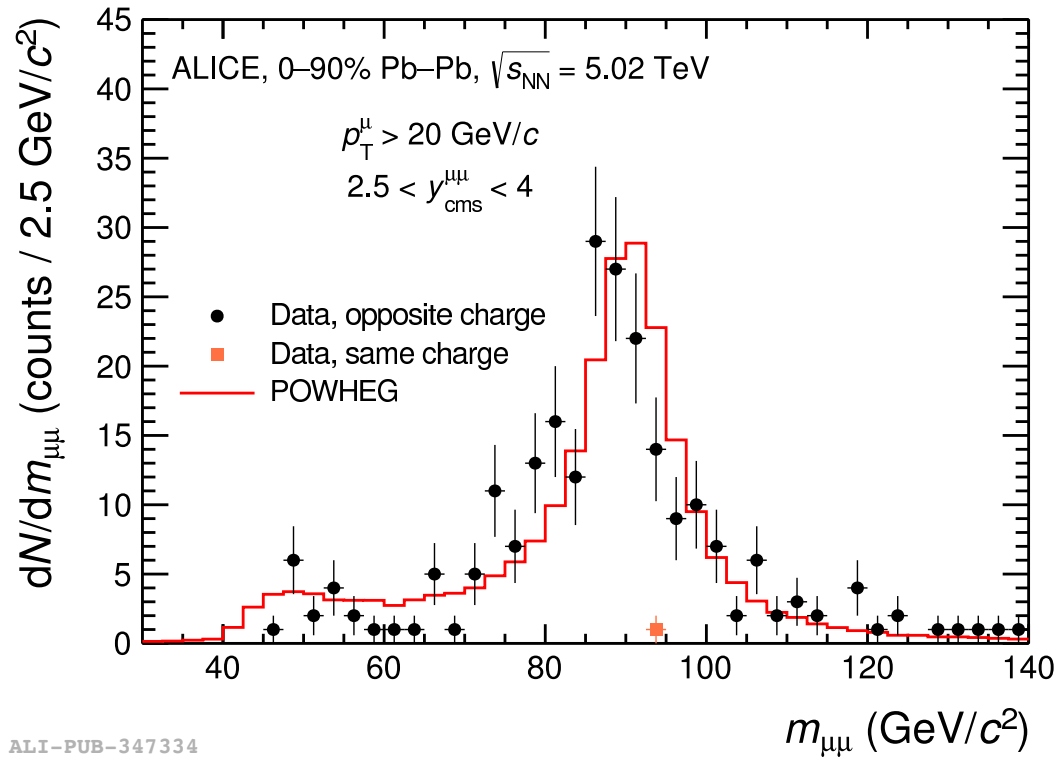
■ Important to understand the distribution to investigate the initial condition in QCD matter (QGP) in heavy-ion collisions

# W yields extraction in ALICE



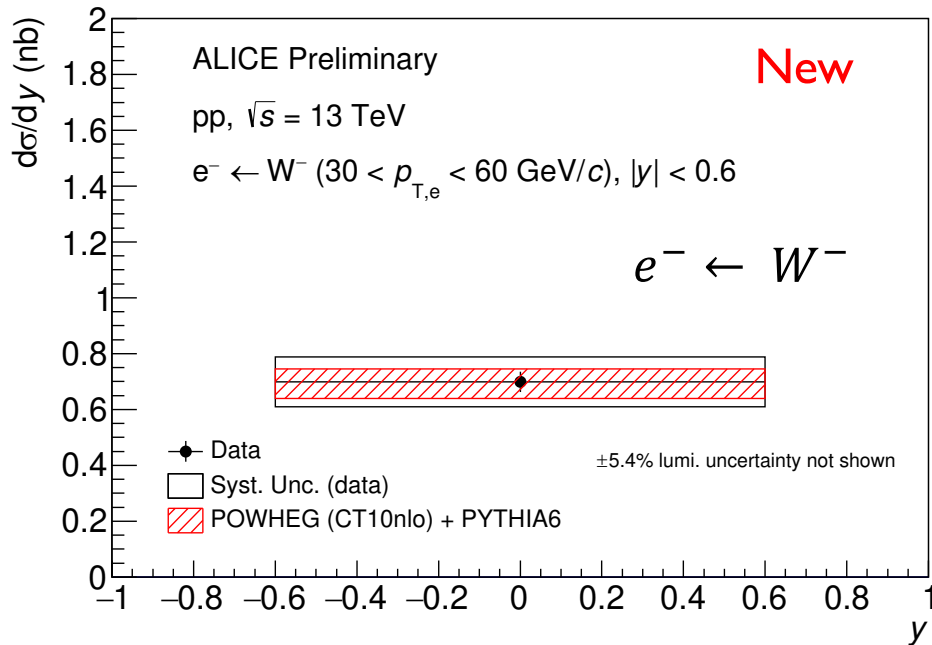
- $e^\pm \leftarrow W^\pm$  ( $|y| < 0.6, p_T > 30$  GeV/c) --- New
  - Based on isolation cuts on energy;  $E_{iso} = \frac{\sum E_R}{E_e} < 0.05$
  - $e^\pm \leftarrow c, b$  are obtained by data driven subtraction (large isolation energy)
- $\mu^\pm \leftarrow W^\pm$  ( $-4 < y_{lab} < -2.5, p_T > 10$  GeV/c)
  - Fit of the single muons  $p_T$  distribution via MC templates
    - $\mu^\pm \leftarrow c, b$  by FONLL,  $\mu^\pm \leftarrow W^\pm, Z$  by POWHEG

# Z yields extraction in ALICE

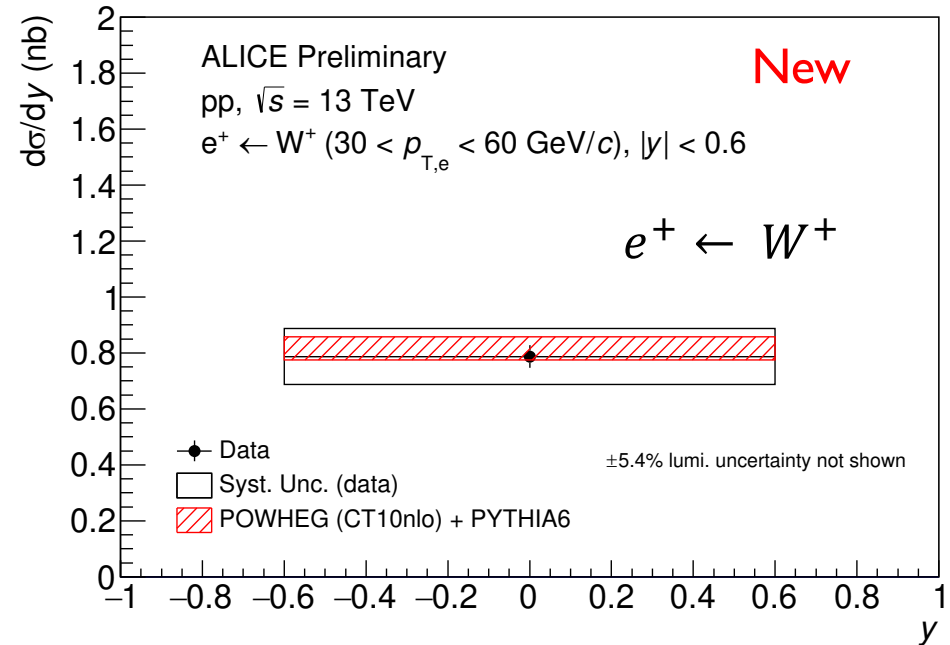


- $Z \rightarrow \mu^\pm$  ( $-4 < y_{lab} < -2.5$ ,  $p_T > 20$  GeV/c)
  - Invariant mass of opposite-sign muon pair
  - $Z \rightarrow \tau\tau \rightarrow \mu\mu$ , Paris from charm and bottom and top (FONLL, POWHEG)  $\sim 1\%$

# $W^\pm$ in pp collisions at 13 TeV (1)



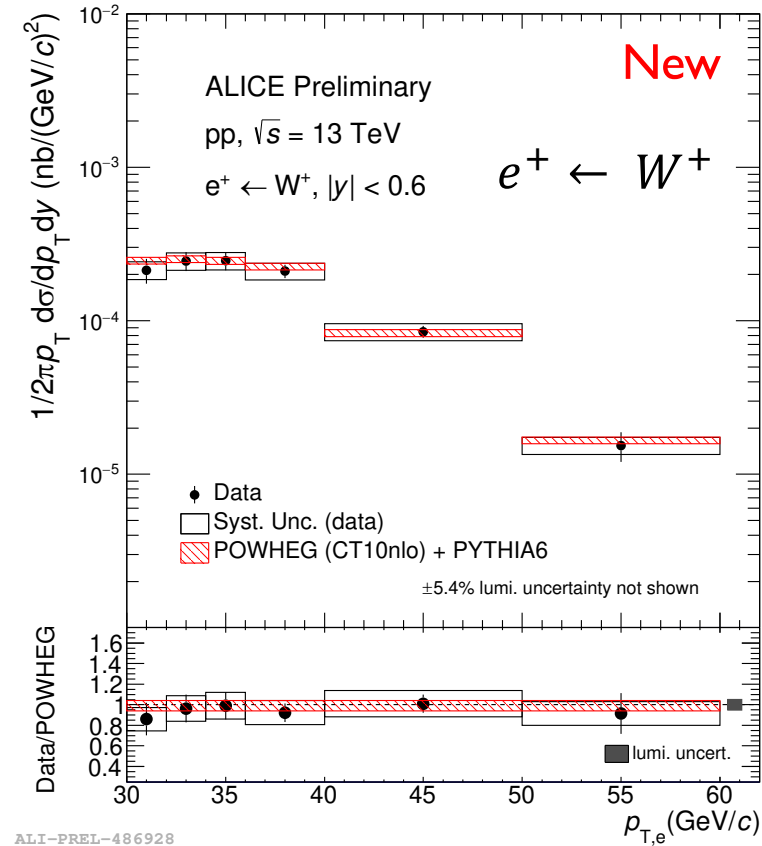
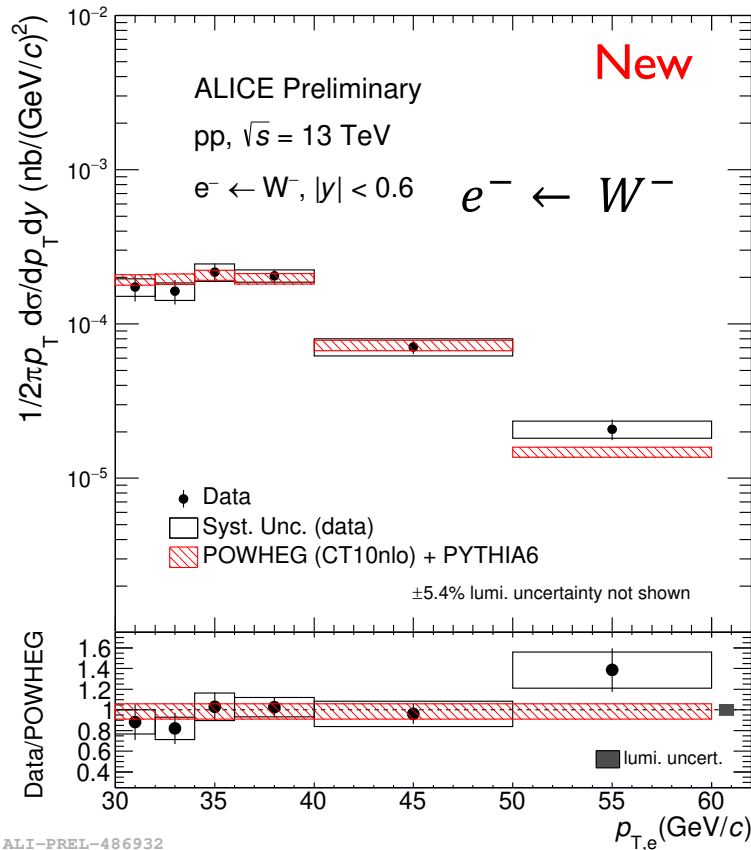
ALI-PREL-486940



ALI-PREL-486936

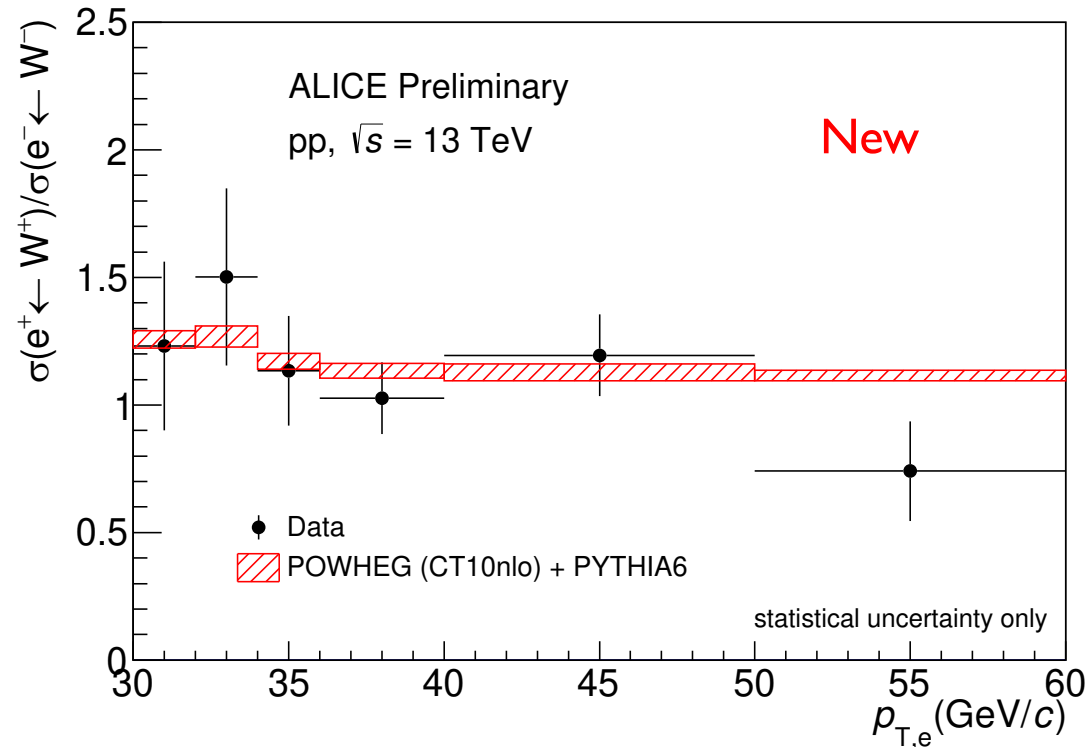
- Cross sections for  $e^\pm \leftarrow W^\pm$  in  $|y| < 0.6$ 
  - Electrons in  $30 < p_T < 60$  GeV/c
- Compared to a model including pQCD NLO (POWHEG) + CT10nlo
- Consistent with data in uncertainties

# $W^\pm$ in pp collisions at 13 TeV (2)



- $p_T$  differential cross sections for  $e^\pm \leftarrow W^\pm$  in  $|y| < 0.6$
- Compared to a model including pQCD NLO (POWHEG) + CT10nlo
  - Measurements and model are consistent within the uncertainties

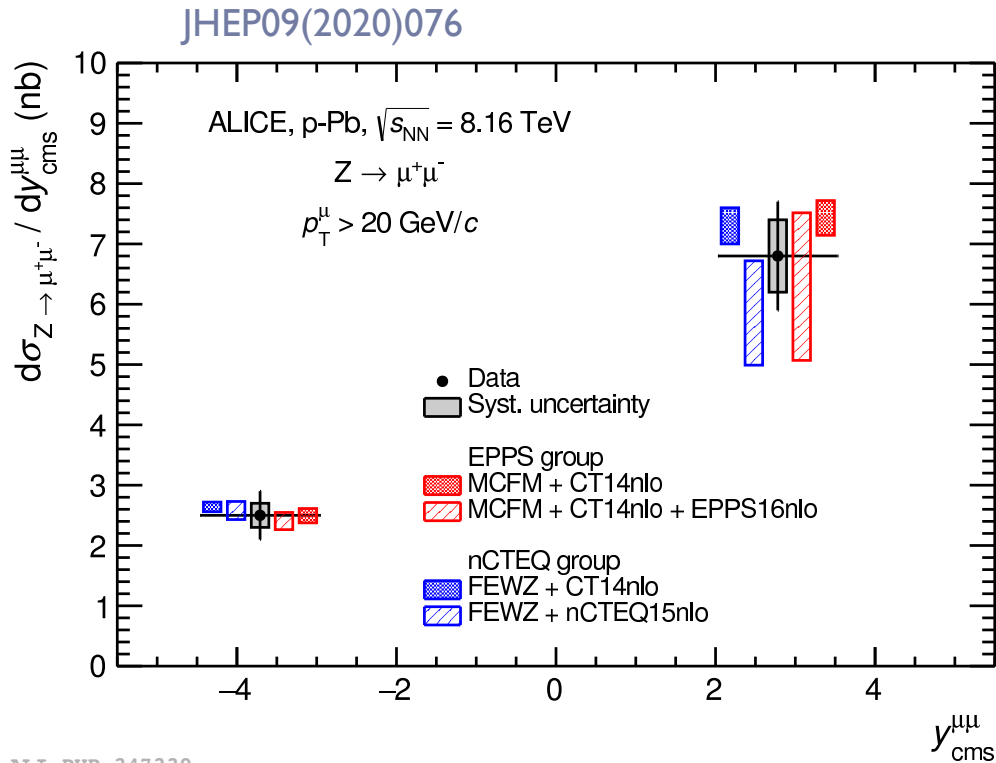
# $W^\pm$ in pp collisions at 13 TeV (3)



ALI-PREL-486951

- Ratio for  $e^+ \leftarrow W^+$  and  $e^- \leftarrow W^-$  as a function of electrons  $p_T$ 
  - reflect to isospin effect
- Hints of a larger cross section for  $e^+ \leftarrow W^+$  in data
  - Consistent with POWHEG + CT10nlo calculation

# Z production in p-Pb @ 8.16 TeV



- p-Pb collisions
  - $2.03 < y_{\text{cms}} < 3.53$  ( $x < 10^{-3}$ )
    - p going (forward)
  - $-4.46 < y_{\text{cms}} < -2.96$  ( $x \sim 10^{-1}$ )
    - Pb going (backward)

- Difference in measured cross section between two rapidities

- Model calculations
  - Based on pQCD
  - including isospin effects
  - With/without nPDF

- Within experimental and theoretical uncertainties, pQCD+isospin with/without nPDF are consistent with the measured cross section



# $W^\pm$ in p-Pb at 8.16 TeV (1)

- Cross section as a function of rapidity

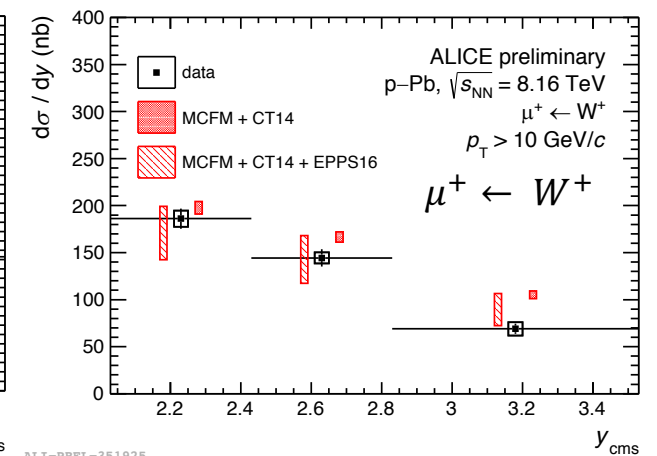
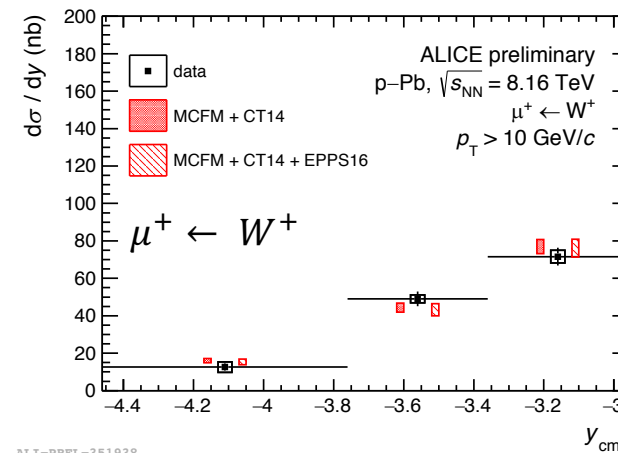
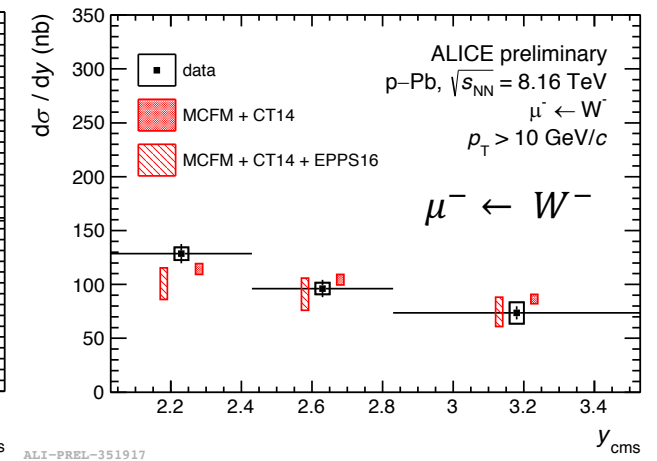
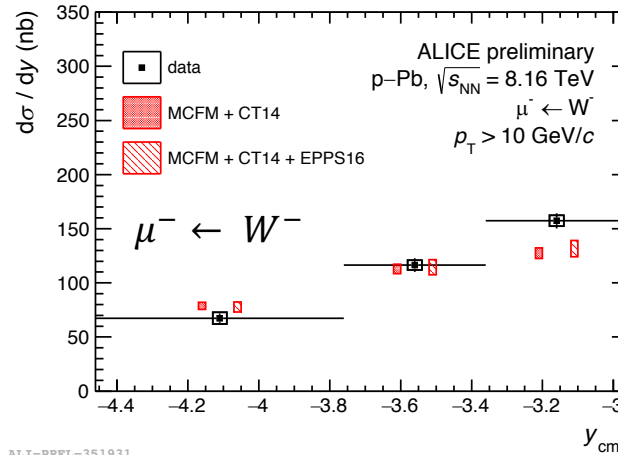
- $2.03 < y_{\text{cms}} < 3.53$

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

- Model calculations

- Based on pQCD

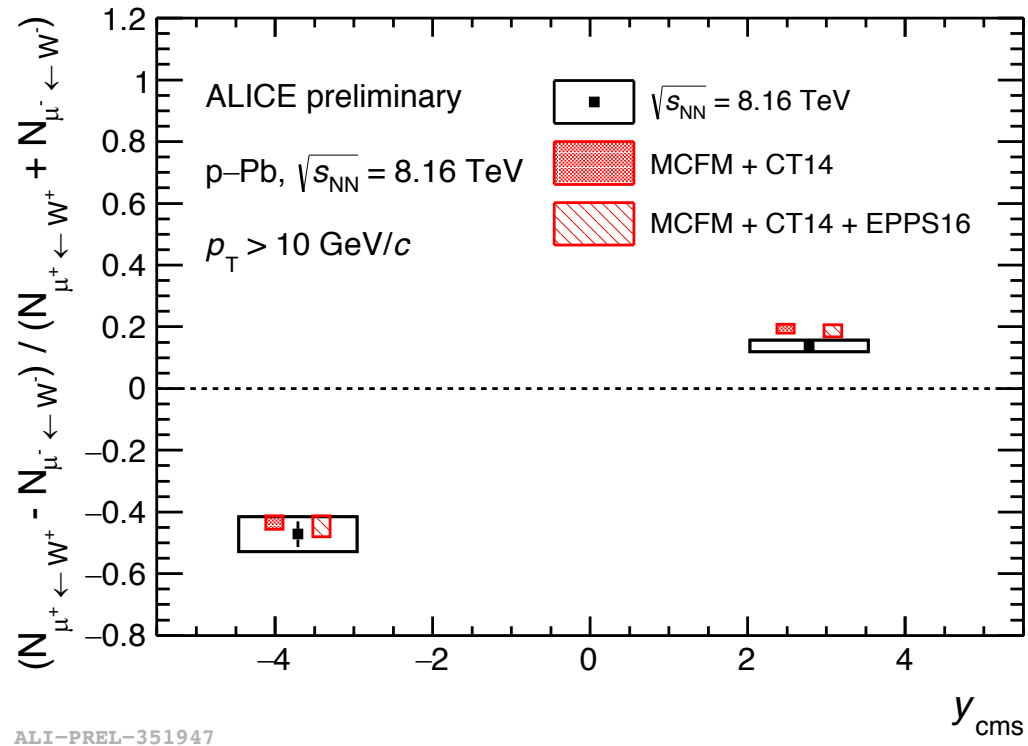
- including isospin effects with/without nPDF



- Within experimental and theoretical uncertainties, pQCD + isospin with/without nPDF are consistent with the measured cross section

- $3.7\sigma$  deviation from free-PDF calculation for  $W^+$  at forward rapidity for the bin at largest rapidity

# $W^\pm$ in p-Pb at 8.16 TeV (2)



## ■ Charge asymmetry

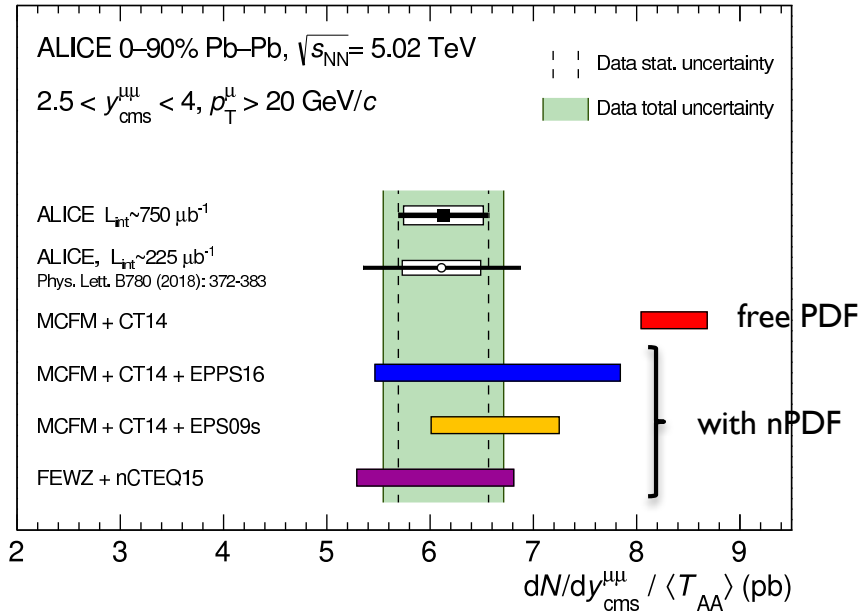
■  $-4.46 < y_{\text{cms}} < -2.96$  ;  $d\bar{u} \rightarrow W^-$  dominant

■  $2.03 < y_{\text{cms}} < 3.53$  ;  $u\bar{d} \rightarrow W^+$  dominant

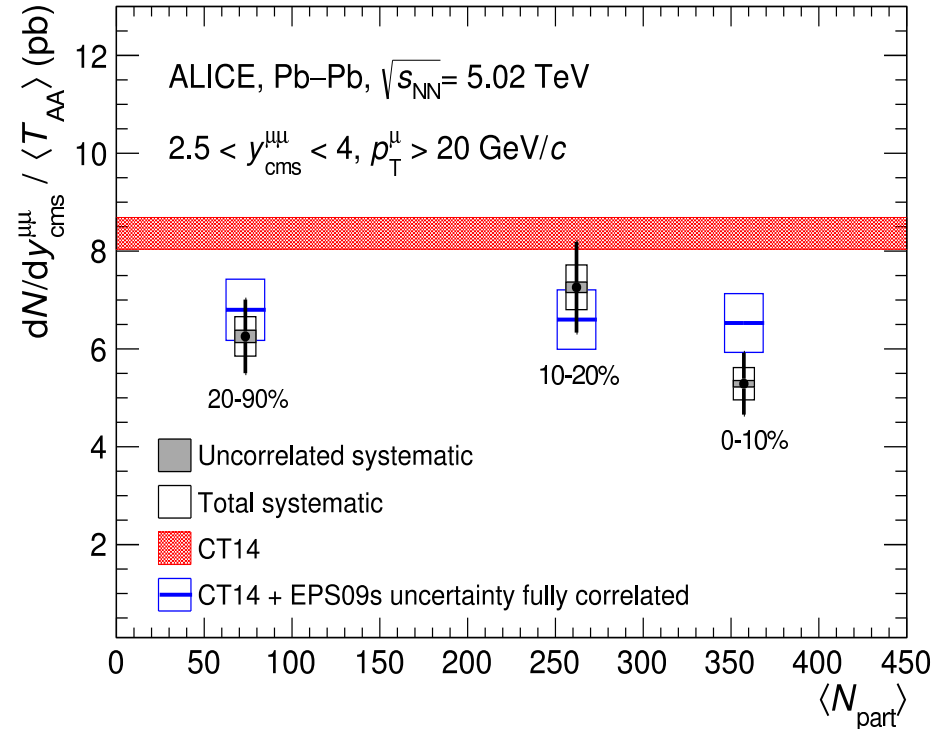
■ pQCD + isospin with/without nPDF reproduces the rapidity dependence

# Z in Pb-Pb at 5.02 TeV

JHEP09(2020)076



ALI-PUB-347344

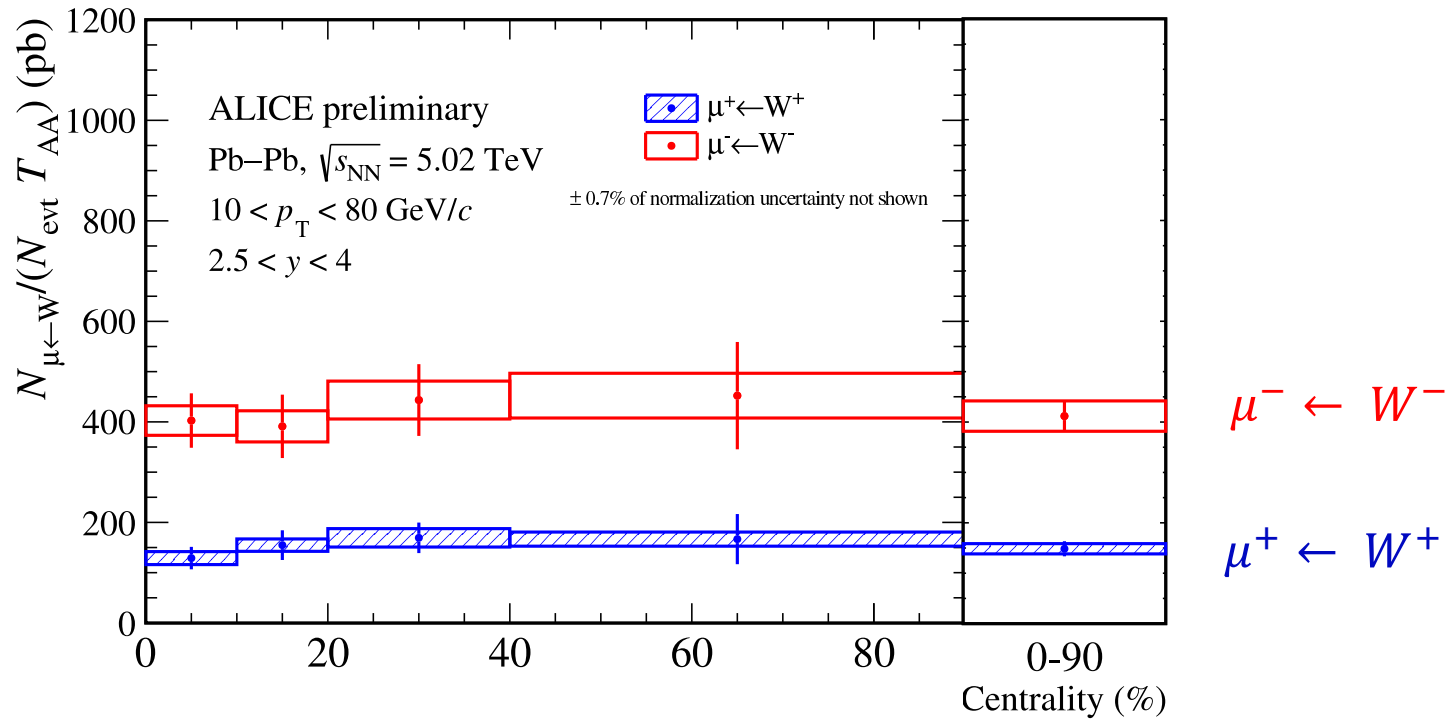


ALI-PUB-347359

EPS09: JHEP 04(2009) 065  
 EPS09s: JHEP 07 (2012) 073

- Z production in  $2.5 < y < 4$ 
  - $x < \sim 10^{-3}$  --- probing shadowing region
- Model with free PDF ---  $3.4 \sigma$  deviation w.r.t. measured Z cross section
- Models with nPDF --- well reproduced measured Z cross section
- Strong evidence of modification of Z production in Pb-Pb collisions

# $W^\pm$ in Pb-Pb at 5.02 TeV



ALI-PREL-352358

- $W^\pm$  production ( $2.5 < y < 4$ ) as a function of centrality in Pb-Pb collisions
  - followed by the # of binary NN collisions  $\langle T_{AA} \rangle$
  - Indicate there is no final state effect (i.e. energy loss) on W

# Summary

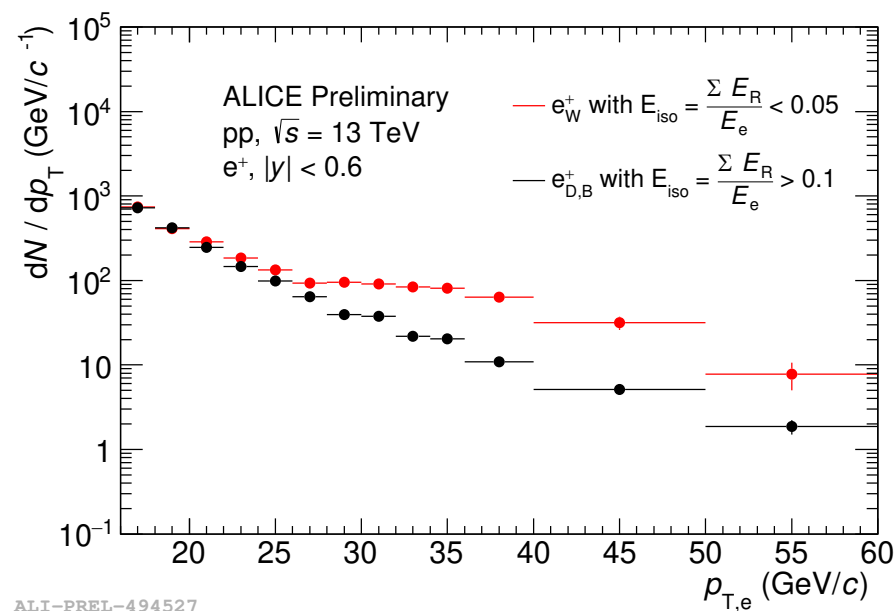
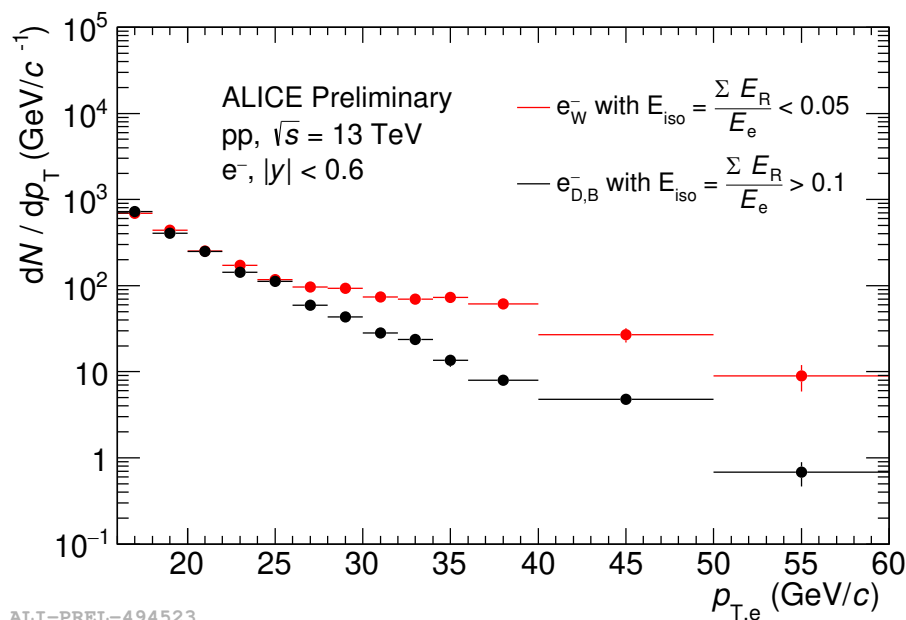
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- ▶ **W production in pp collisions (New)**
  - ▶ Consistent with POWHEG (NLO) + CT10nlo
    - ▶ Integrated &  $p_T$  differential cross section
    - ▶  $W^+ / W^-$  ratio
- ▶ **W/Z production in p-Pb**
  - ▶ Clear rapidity dependence of the productions
  - ▶ Models + isospin with/without nPDF are reproduced the data
- ▶ **W/Z production in Pb-Pb**
  - ▶ Both follow by # of binary NN collisions
    - ▶ Indicate no final state effects (no interaction with QGP)
  - ▶ Z productions are well reproduced by the model with nuclear PDF
- ▶ **Sizeable amount of new measurements at large rapidities, providing extra inputs for nPDFs global fits**

# Back up

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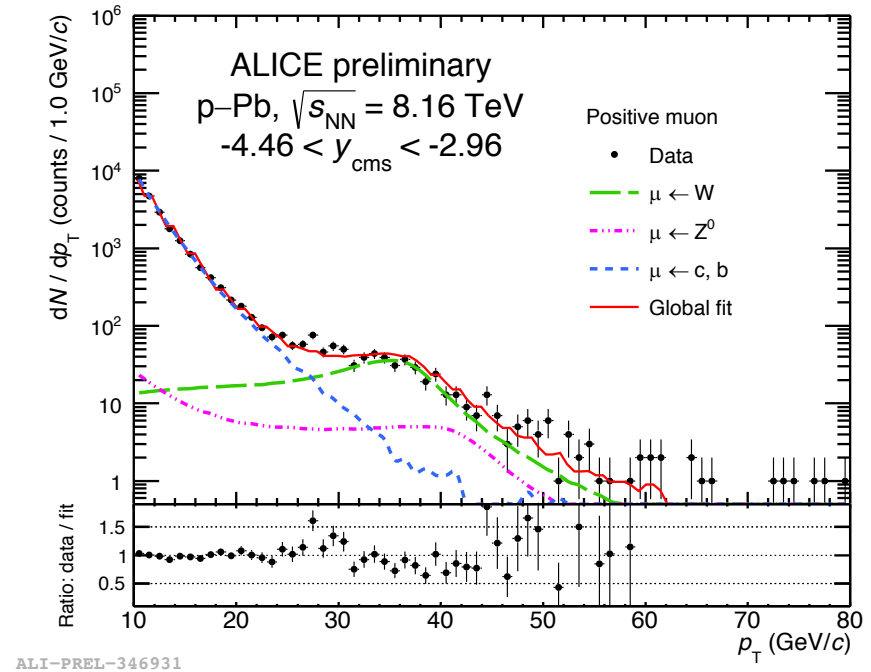
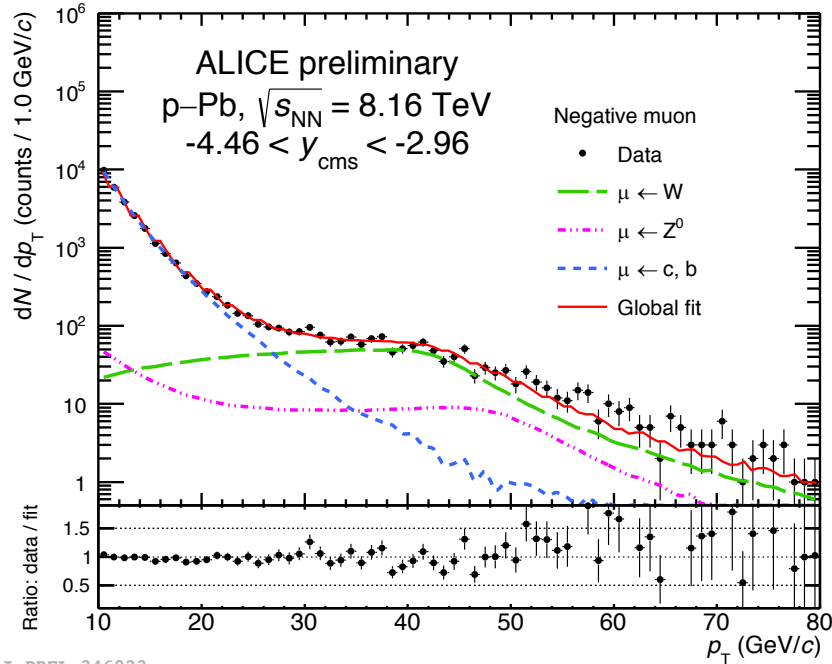
# W-boson yield extraction (1)



## ■ $e^\pm \leftarrow W^\pm$ ( $|y| < 0.6, p_T > 30$ GeV/c)

- Based on isolation cuts on energy;  $E_{iso} = \frac{\sum E_R}{E_e} < 0.05$
- $e^\pm \leftarrow c, b$  are obtained by data driven (large isolation energy)
- $e^\pm \leftarrow Z$  contribution was estimated by POWHEG
- Other backgrounds, electrons from conversion and neutral mesons decays are less than 3%

# W-boson yield extraction (2)

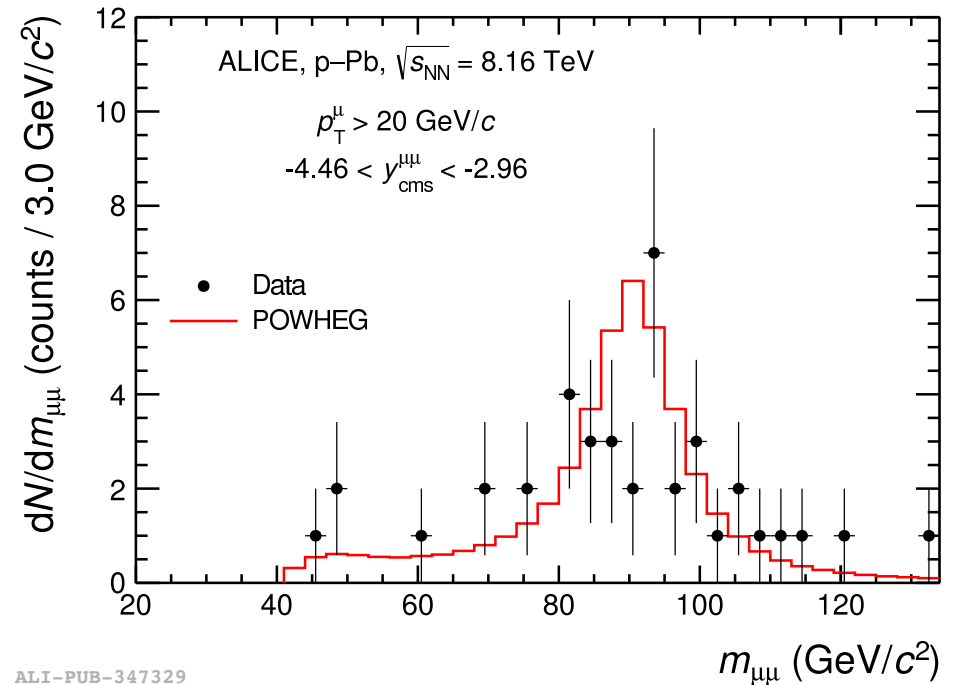
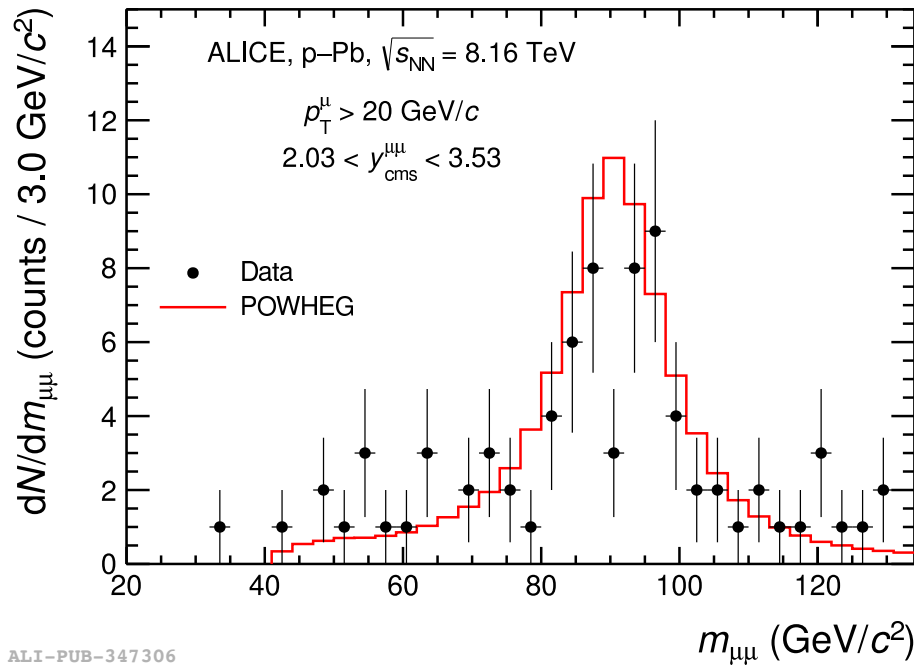


$$f(p_T) = N_{HF} \cdot f_{HF}(p_T) + N_{\mu \leftarrow W} \cdot (f_{\mu \leftarrow W}(p_T) + R \cdot f_{\mu \leftarrow Z}(p_T))$$

- $f_x(p_T)$  : MC templates (FONLL, POWHEG)
- $N_x$  : free parameters
- $R$  : ratio of the Z to W cross section from POWHEG



# Z-boson yield extraction



- $Z \rightarrow \tau\tau \rightarrow \mu\mu$ , paris from charm and bottom and top (FONLL, POWHEG)  $\sim 1\%$
- Combinatorial background (same-sign dimuon invariant mass), negligible

# W and Z at the ALICE

**p-Pb, p-going:**



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

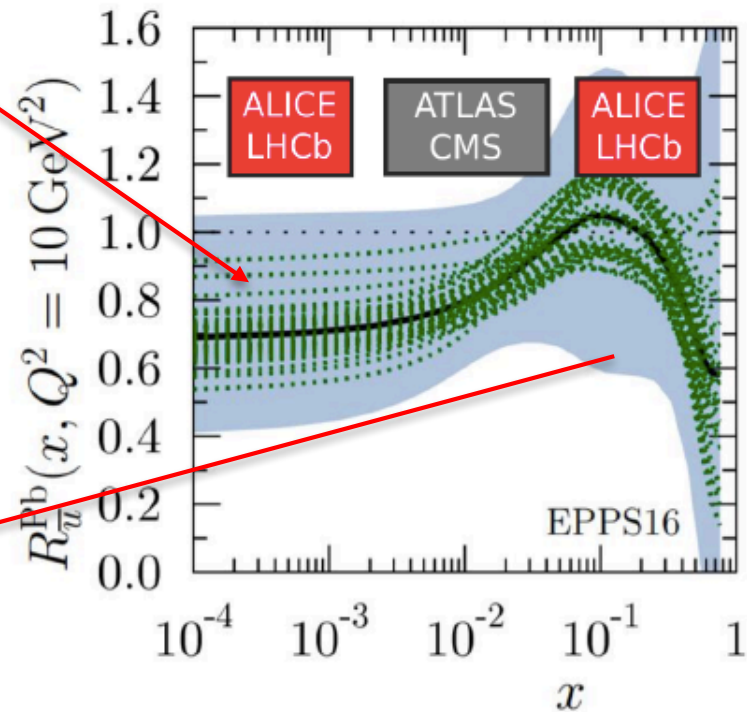
$$x \sim 10^{-3}$$

**p-Pb, Pb-going:**



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

$$x < 10^{-1}$$



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