ELECTROWEAK-BOSON PRODUCTION IN pp, p-Pb and Pb-Pb COLLISIONS WITH ALICE

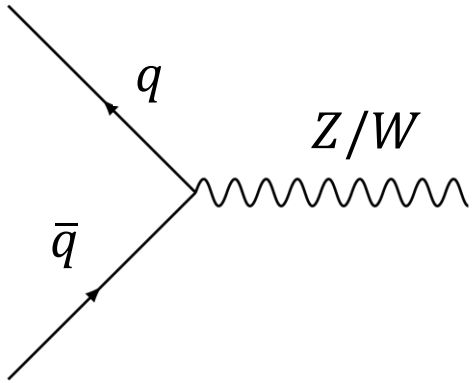
N.Valle* for the ALICE Collaboration
*University and INFN, Pavia (IT)

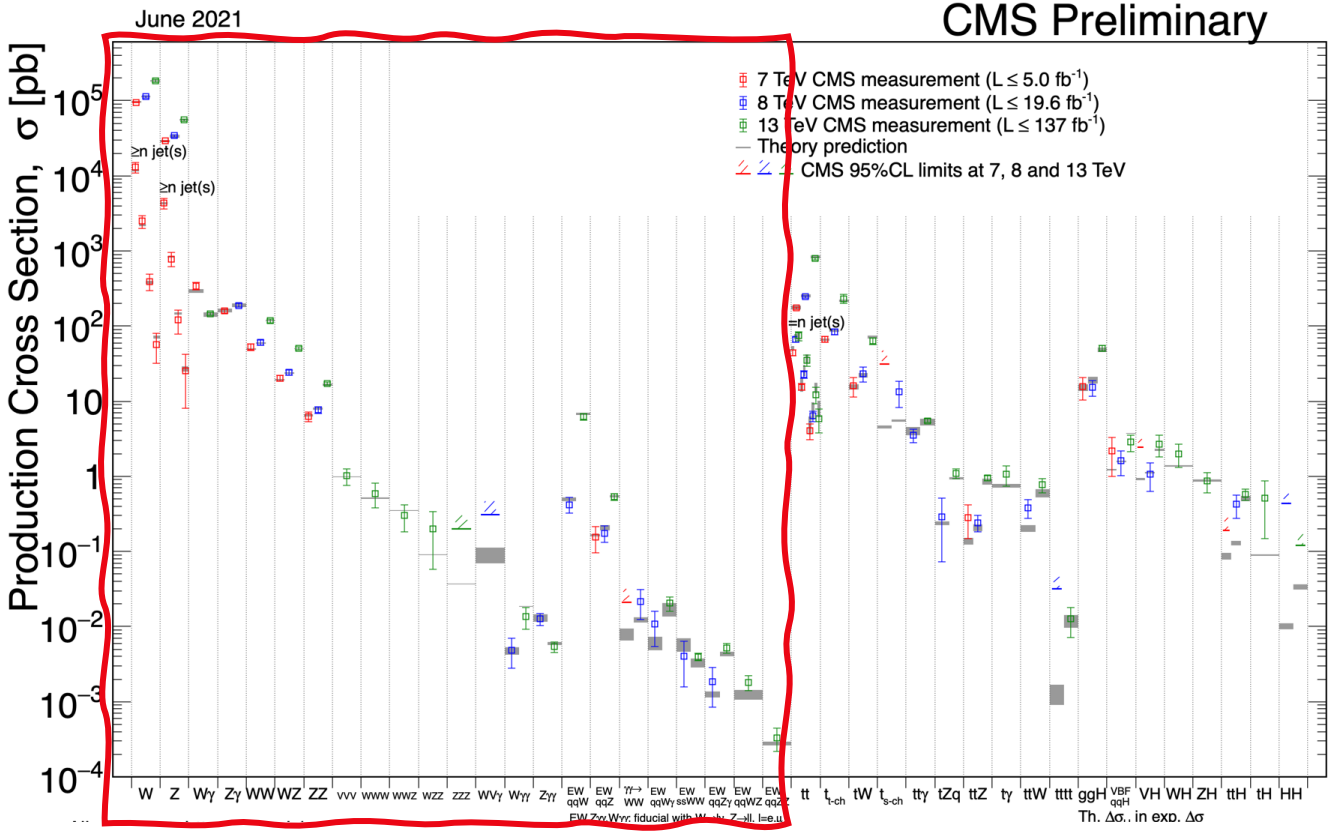
8th September 2021

W and Z bosons production

in pp collisions is:

- ✓ well described by perturbative QCD and EW theory
- ✓ measured with good precision at the LHC
- ✓ an effective handle to constrain Parton Distribution Functions





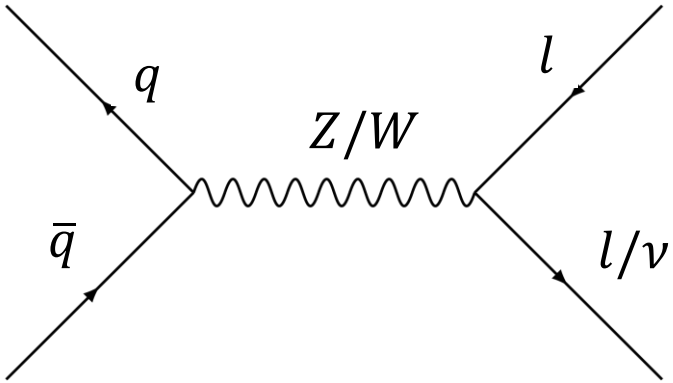
Standard Model summary:
CMS: http://cern.ch/go/pNj7
ATLAS: CERN CDS, ATL-PHYS-PUB-2020-010

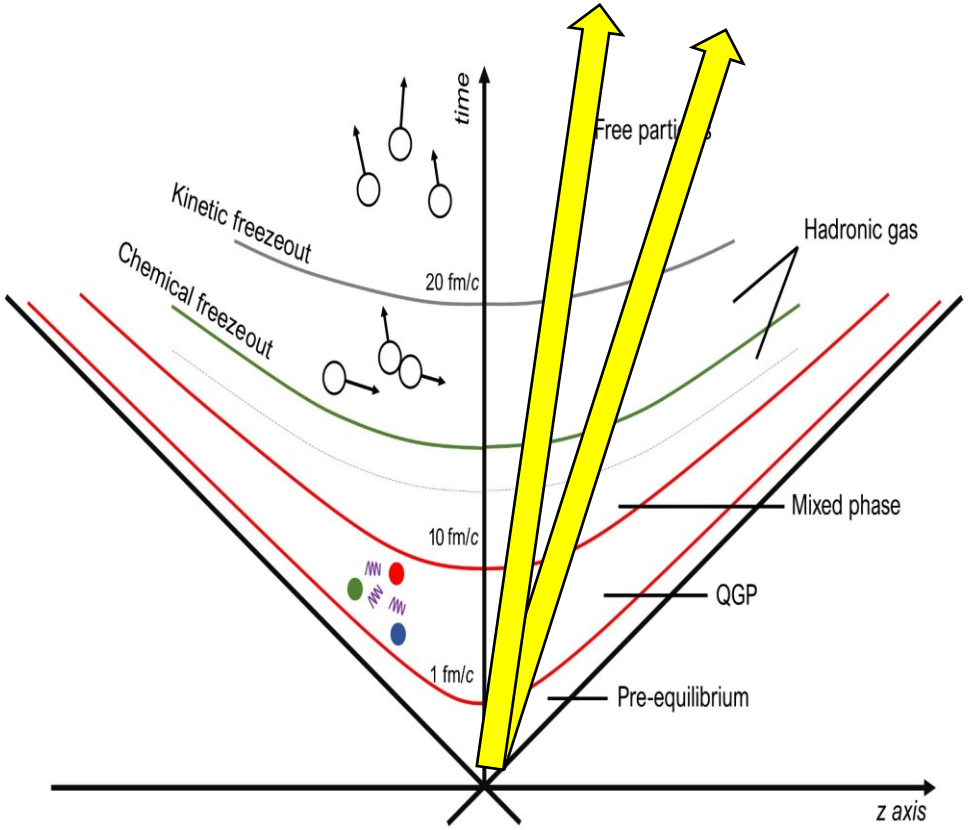
W and Z bosons production

in heavy-ion collisions:

- ✓ well described by perturbative QCD and EW theory
- ✓ takes place in the early stages of the collision
- ✓ an effective handle to constrain nuclear Parton Distribution Functions

➢ The leptonic decays are medium-blind processes





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Nuclear PDFs (nPDFs)

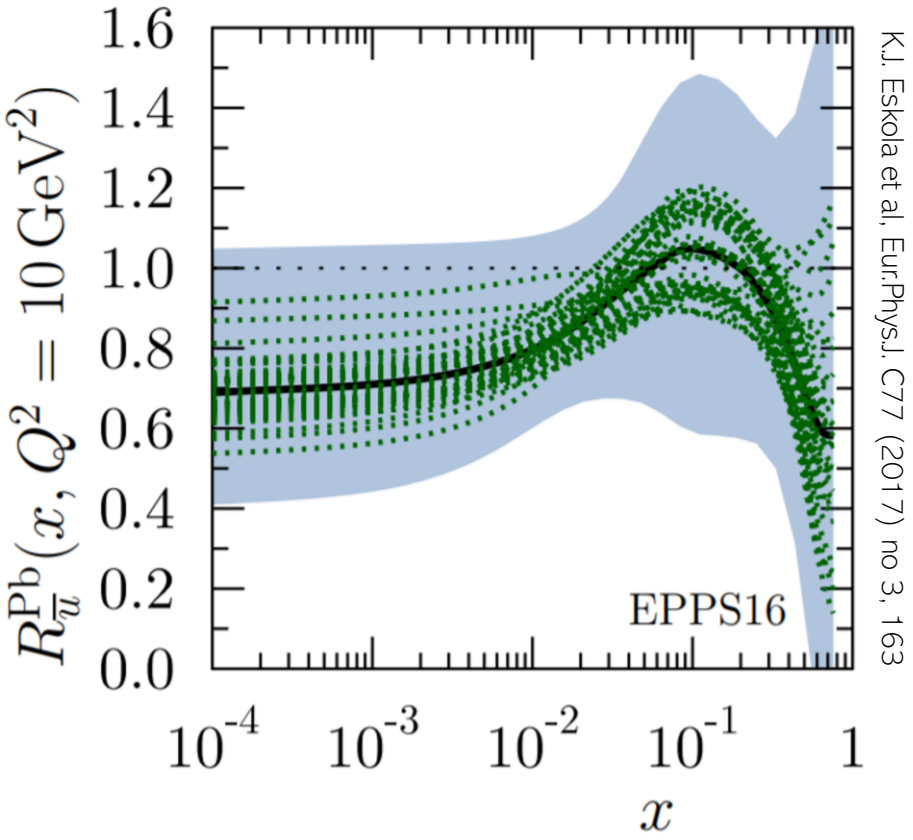
Different from free-nucleon PDFs

Extracted from global fits to data… but still less constrained than PDFs

- Need of observables not interacting strongly with QGP (no final state effects)
- Data from DIS, DY… (small Q^2, high Bjorken-x) + new LHC data on di-jets and electroweak bosons (wide x range)

Knowing the nuclear initial state is important for the interpretation of the system evolution

ratio nPDF/PDF



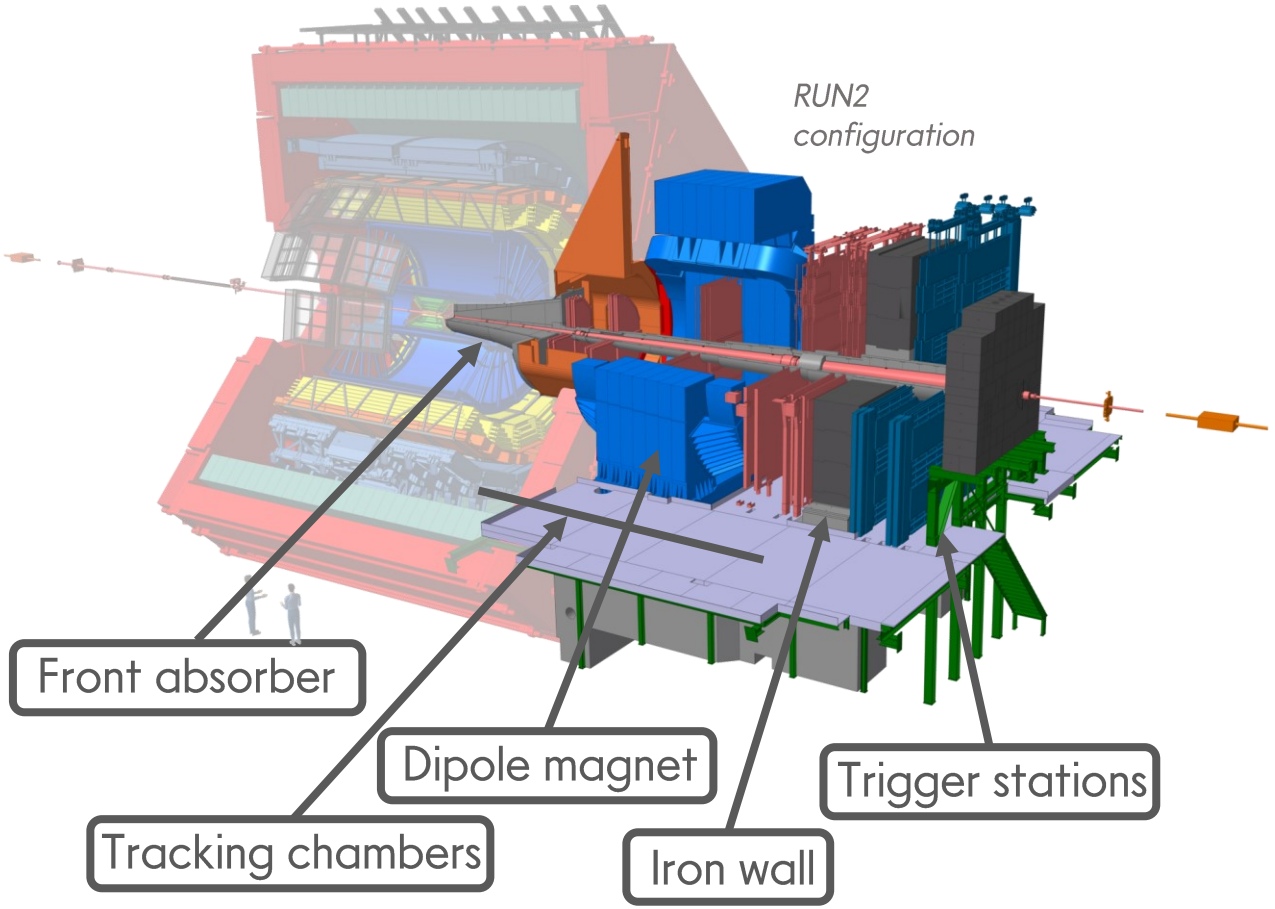
K.J. Eskola et al, Eur.Phys.J. C77 (2017) no 3, 163

EPPS16: EPJC (2017) 77:163

ALICE: p-Pb and Pb-Pb collisions

ALICE: W production in pp collisions

$Z \rightarrow \mu^+\mu^-$, $W \rightarrow \mu\nu_\mu$



The ALICE muon spectrometer

- $\mathbf{2.5 < y < 4}$ in the laboratory frame
- Shifted in the c.m.s. by $\Delta y = \pm 0.46$ when proton and lead nucleus collide
- Probing regions at **low** $(10^{-4} - 10^{-3})$ and **high** $(10^{-1} - 1)$ **Bjorken-x**, where the nPDFs are less constrained

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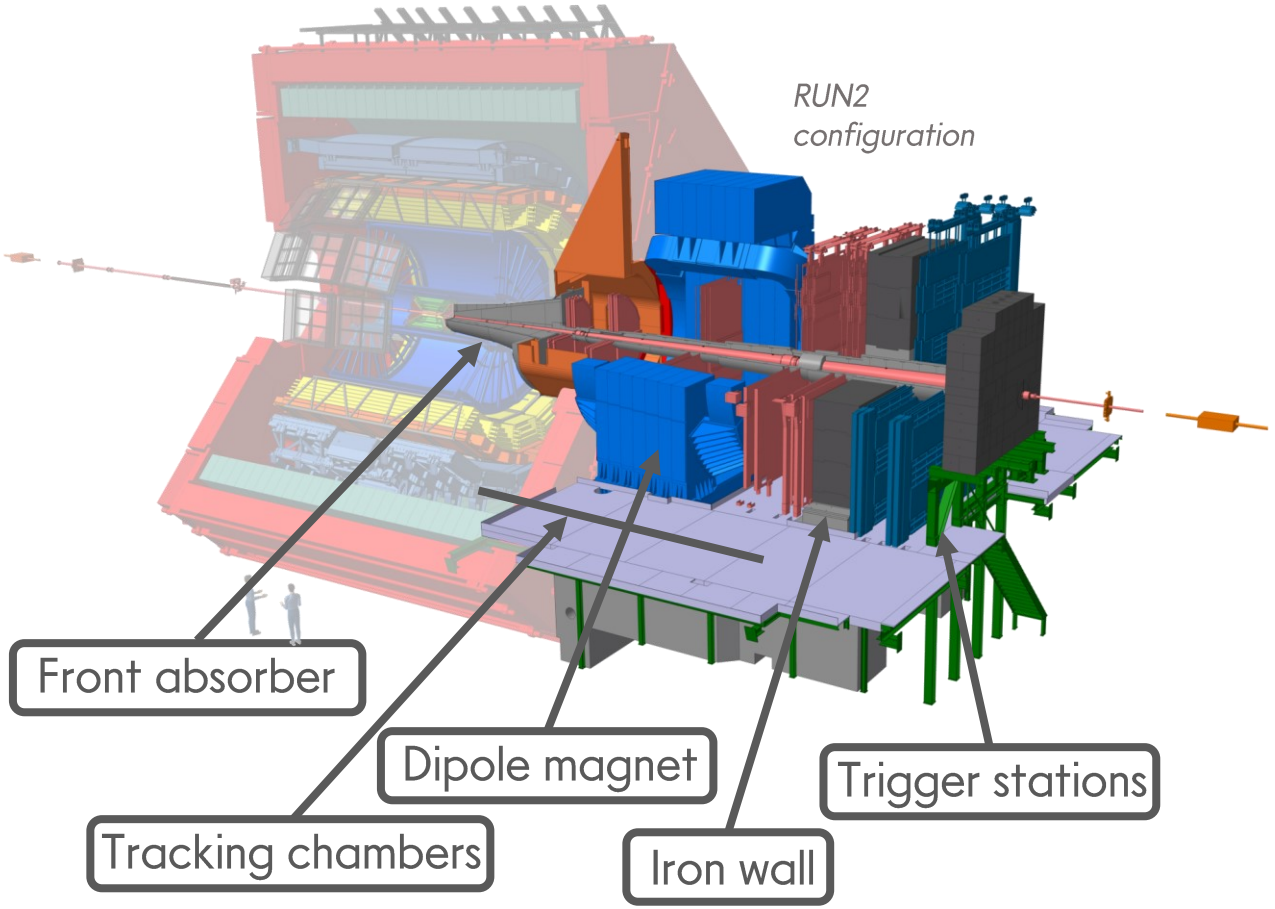

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ALICE results: Z and W; p–Pb and Pb–Pb

System, $\sqrt{s_{\mathrm{NN}}}$	L_{int}	
p–Pb, 8.16 TeV	~ 21.2 nb^{-1}	W: new!
p–Pb, 5.02 TeV	~ 10.8 nb^{-1}	
Pb–Pb, 5.02 TeV	~ 750 μb^{-1}	W: new!

W signal extraction

→ signal extracted by fitting single muon p_{T} distribution ←

$$f(p_{\mathrm{T}}) = N_{HF}\, f_{HF}(p_{\mathrm{T}}) + N_{\mu\leftarrow W}\left[f_{\mu\leftarrow W}(p_{\mathrm{T}}) + R\, f_{\mu\leftarrow Z}(p_{\mathrm{T}})\right]$$

Fitted parameters

MC templates (FONLL, POWHEG)

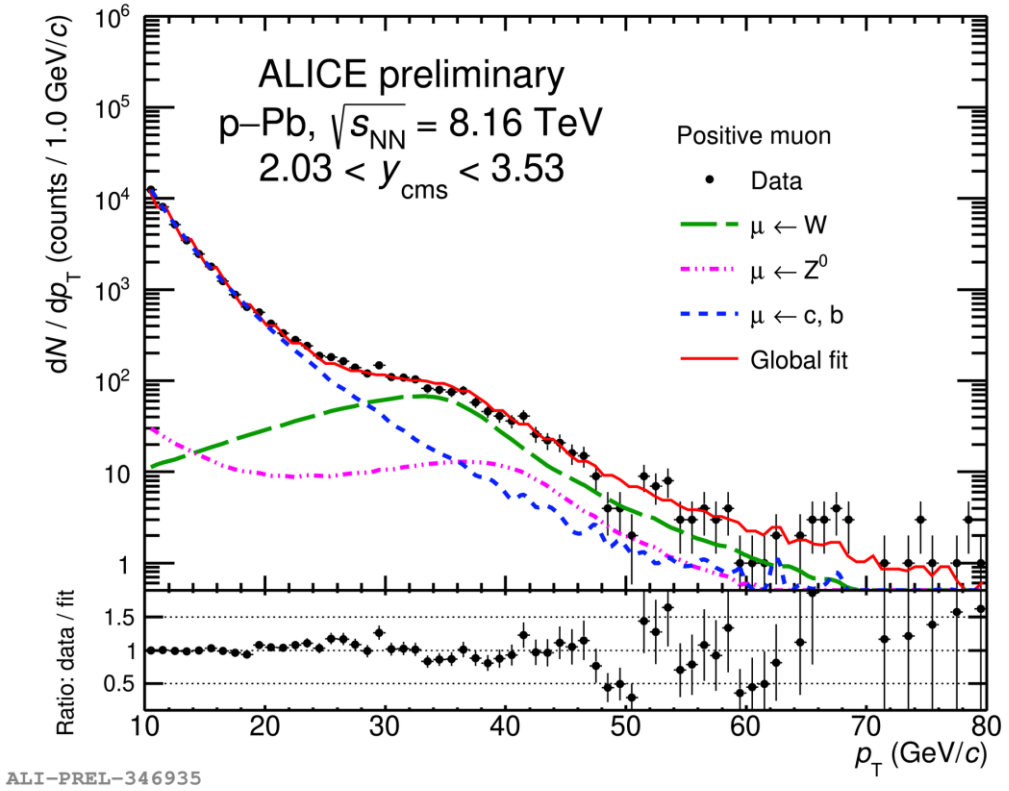
Fixed, from POWHEG

Fiducial region:

$2.5 < |\eta_\mu| < 4$

$p_{\mathrm{T},\mu} > 10\ \mathrm{GeV}/c$

Raw yield corrected for efficiency (POWHEG + Pythia, + embedding in Pb–Pb)



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

Z signal extraction

Opposite-sign muon pairs in the fiducial region:

$$2.5 < |\eta_\mu| < 4$$

$$p_{\mathrm{T},\mu} > 20\ \mathrm{GeV}/c$$

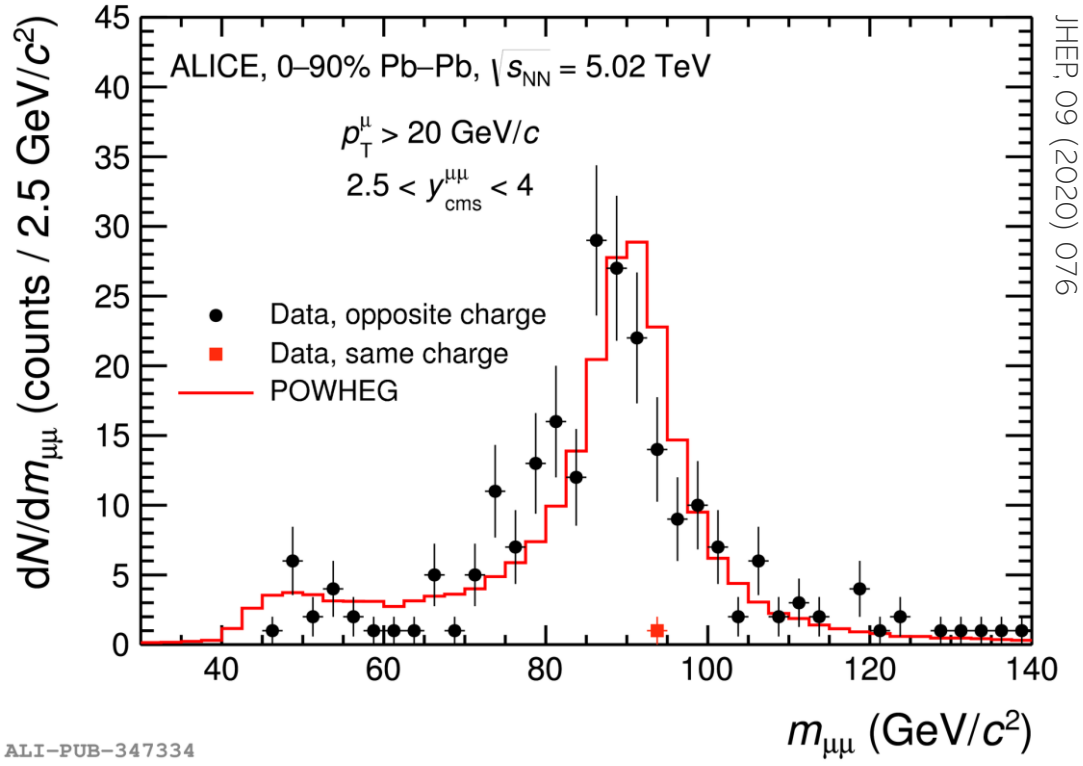
$$60 < m_{\mu\mu} < 120\ \mathrm{GeV}/c^2$$

Background from $b\bar{b}, c\bar{c}, t\bar{t}$ and $Z \to \tau\tau \to \mu\mu$: lower than ~1.5%

Combinatorial background (almost) negligible

→ signal extracted by bin counting ←

Raw yield corrected for efficiency (POWHEG + Pythia, + embedding in Pb–Pb)

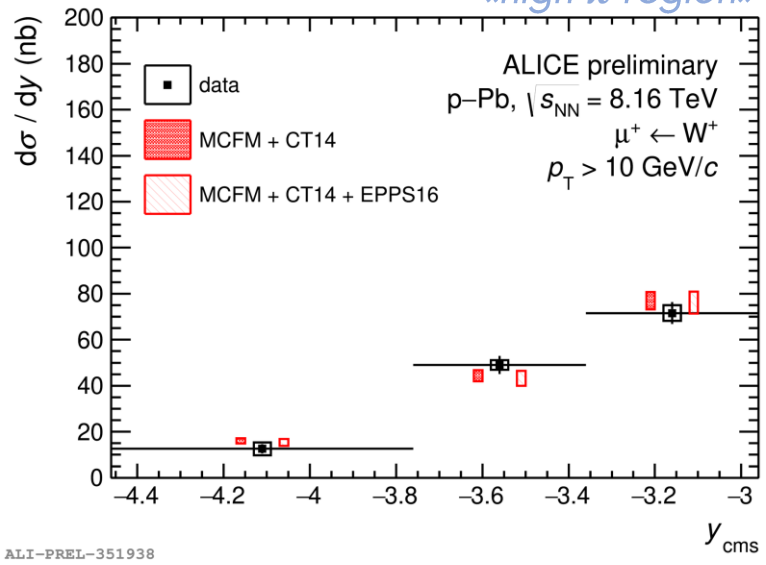


JHEP, 09 (2020) 076

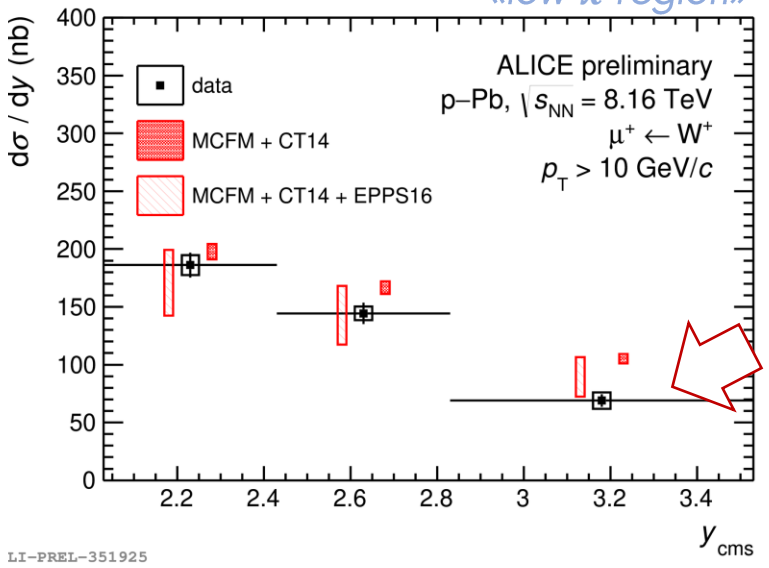
POWHEG: JHEP 07(2008)060

W± in p–Pb at 8.16 TeV

«high-x region»



«low-x region»



Probing a

- low-x (if $y > 0$, "p-going")

or a

- high-x (if $y < 0$, "Pb-going")

quark in the nucleus

Results compared with pQCD calculations with (CT14+EPPS16) and without (CT14) nuclear modification:

- Tension especially with free-nucleon predictions (**up to 3.7σ** at low-x, largest rapidities)

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CT14: Phys. Rev. D 93 (2016) 033006 EPPS16: EPJC (2017) 77:163

$W^{\pm}$ in p–Pb at 8.16 TeV

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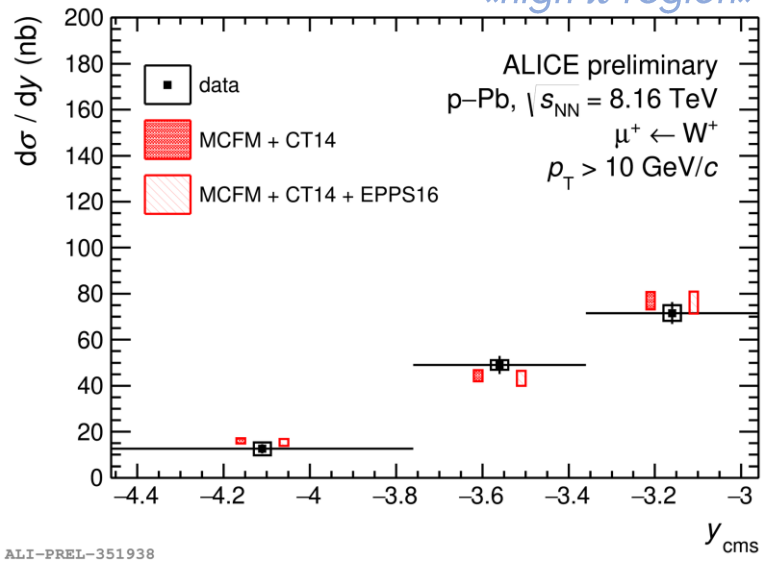

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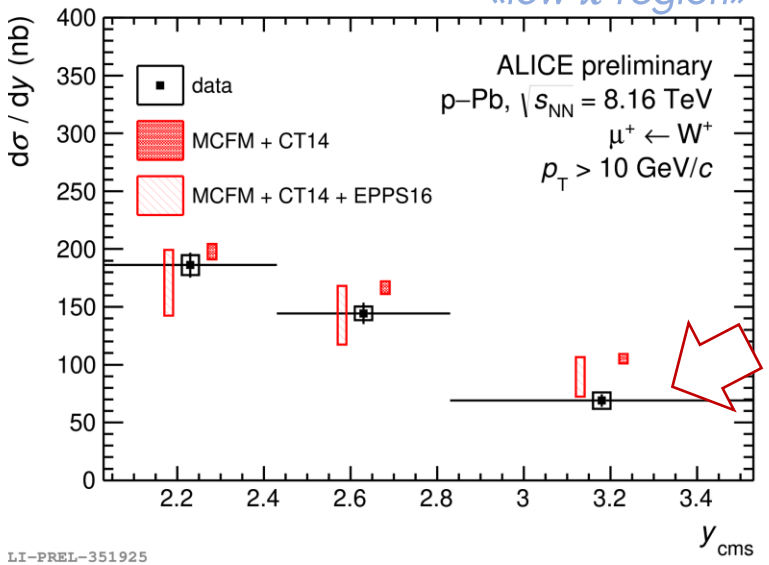

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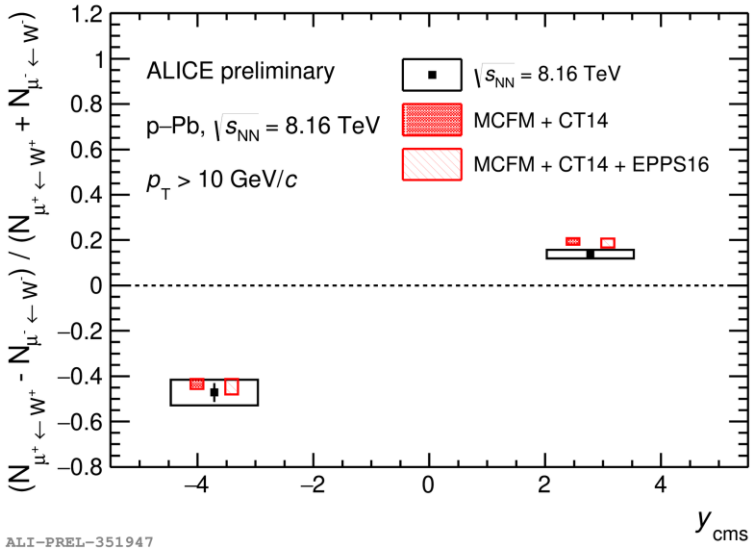
$$\frac{W^+ - W^-}{W^+ + W^-}$$

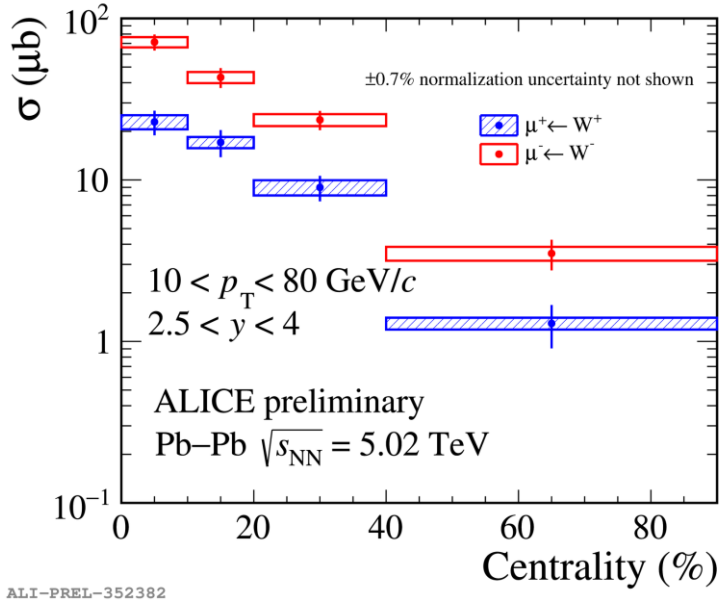


Lepton-charge asymmetry:

- Sensitive to down-to-up ratio in the nucleus
- Theoretical and experimental uncertainties partially cancelled out
  - ➢ Results compatible with both free-nucleon and EPPS16 PDFs

CT14: Phys. Rev. D 93 (2016) 033006 EPPS16: EPJC (2017) 77:163

W± in Pb–Pb at 5.02 TeV



Low and high x regions probed simultaneously

Sensitivity to valence quarks (u, d):

- Isospin differentiates W^+ and W^- production

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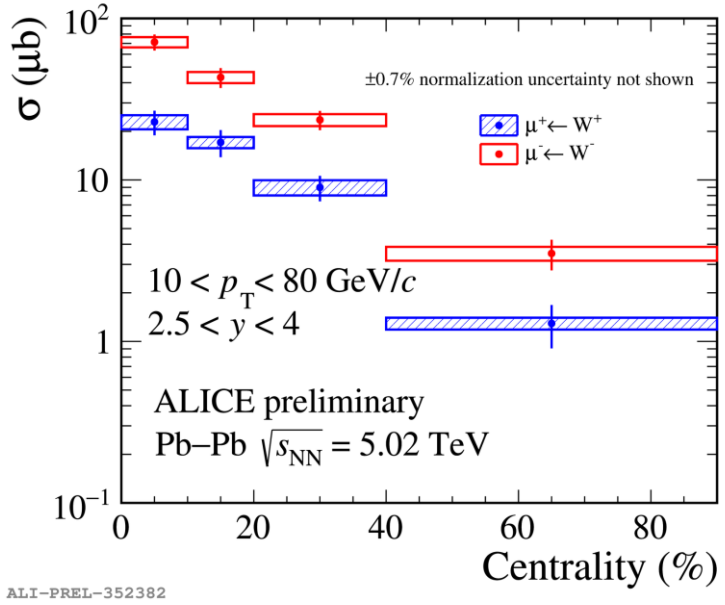

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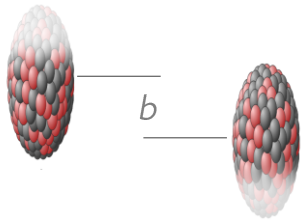
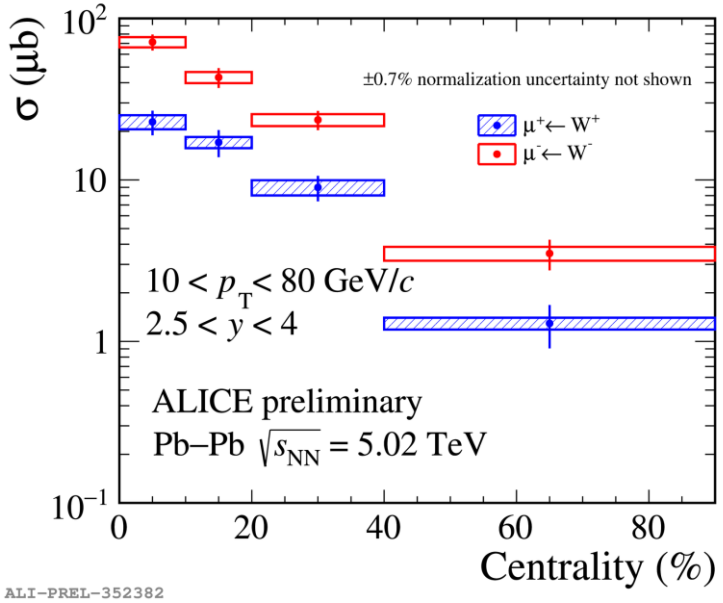


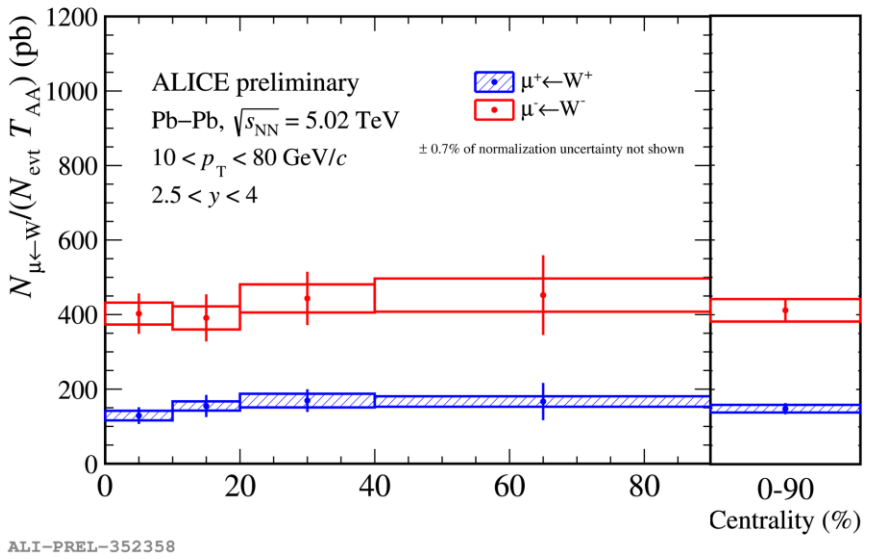
The number of participant nucleons and the number of nucleon-nucleon binary collisions N_{coll} depends on the centrality

- Nuclear overlap function T_{AA}, computed with Glauber model.

$$T_{AA} \sim N_{coll} \,/\, \sigma^{nucleon-nucleon}$$

$W^{\pm}$ in Pb–Pb at 5.02 TeV





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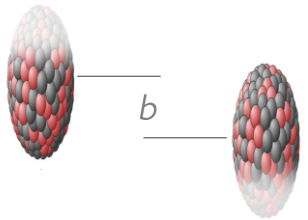

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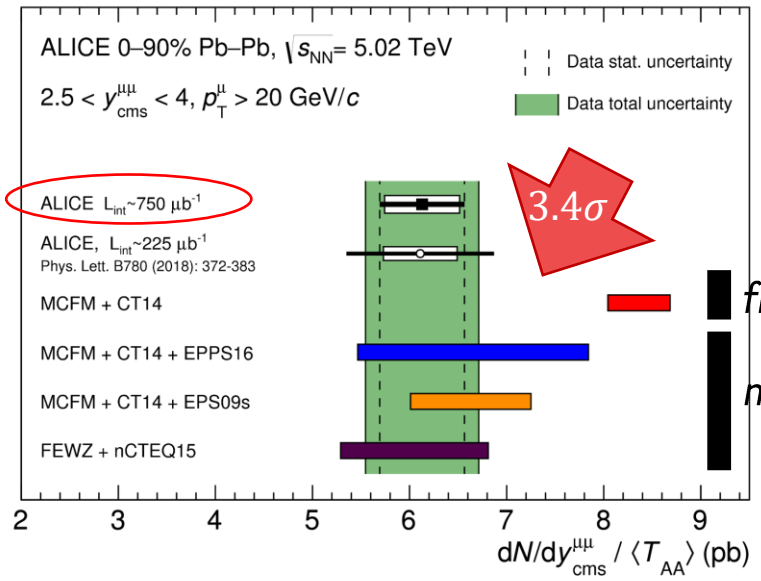
- Nuclear overlap function T_{AA}, computed with Glauber model.

$$T_{\mathrm{AA}} \sim N_{coll} \,/\, \sigma^{nucleon-nucleon}$$

✓ Expected scaling of hard processes with the number of nucleon-nuclon collisions

Z in Pb–Pb at 5.02 TeV

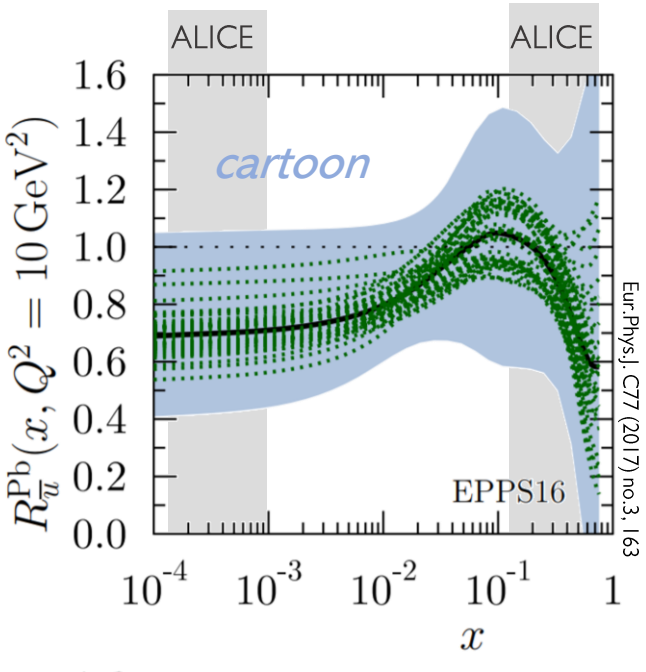


ALI-PUB-347344
JHEP, 09 (2020) 076

Low and high x regions probed simultaneously

- Both quarks are close to a region where PDFs are suppressed

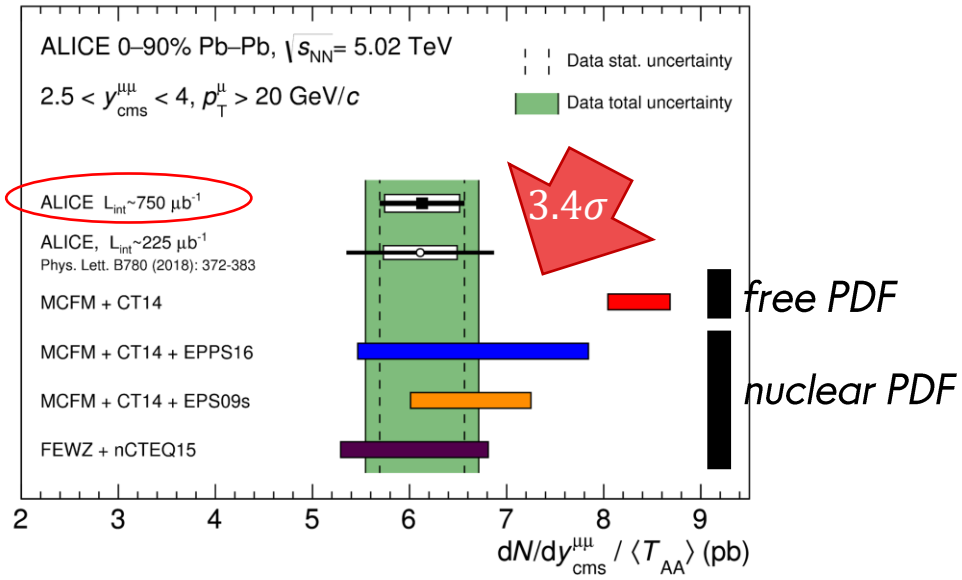
This result is a strong evidence of **nuclear modification**



Eur.Phys.J. C77 (2017) no.3, 163

CT14: Phys. Rev. D 93 (2016) 033006 EPPS16: EPJC (2017) 77:163 nCTEQ15: Phys. Rev. D 93 (2016) 085037

Z in Pb–Pb at 5.02 TeV



ALI-PUB-347344
JHEP, 09 (2020) 076

σ_{pp} from pQCD calculations

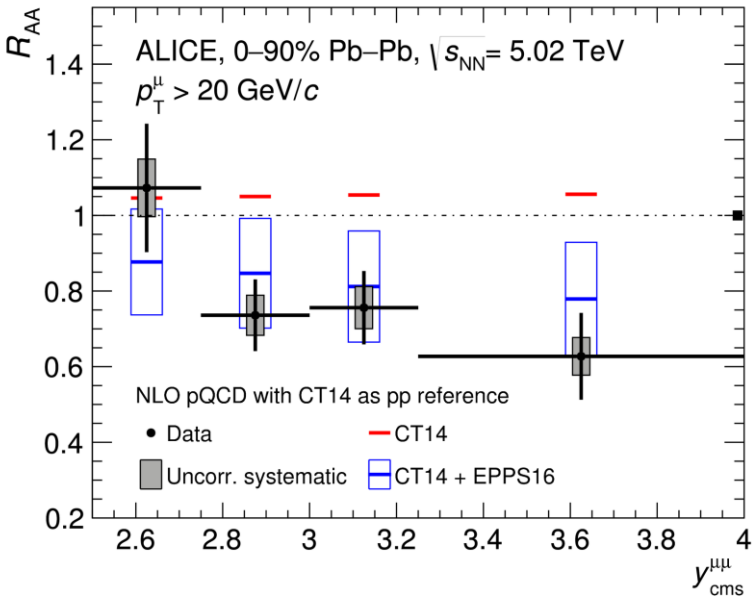
- suppression of theoretical uncertainties on free PDF (CT14) model

Larger deviation from free PDFs at the largest rapidities

Low and high x regions probed simultaneously

- Both quarks are close to a region where PDFs are suppressed

This result is a strong evidence of **nuclear modification**



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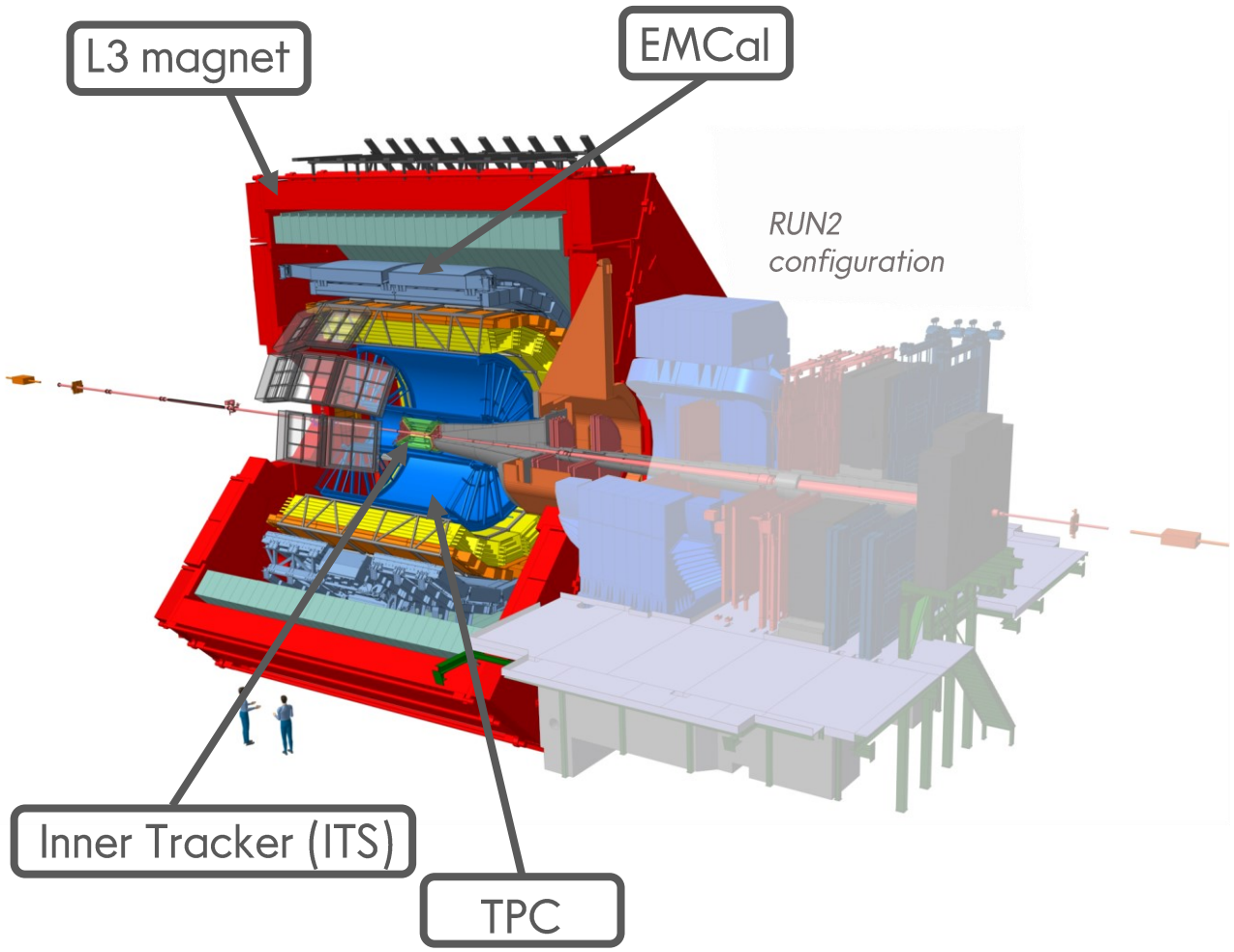
JHEP, 09 (2020) 076

$$R_{\mathrm{AA}} = \frac{yield_{\mathrm{AA}}}{T_{\mathrm{AA}}\,\sigma_{pp}}$$

ALICE: p-Pb and Pb-Pb collisions

ALICE: W production in pp collisions

$W \rightarrow e\nu_e$



W reconstructed in its **electronic decay** channel

Rapidity coverage:

- $|y| < 0.6$, to fit the EMCal fiducial region

Full Run 2 statistics, pp at $\sqrt{s} = 13$ TeV

- $L_{int} \simeq 6.6\ \mathrm{pb}^{-1}$

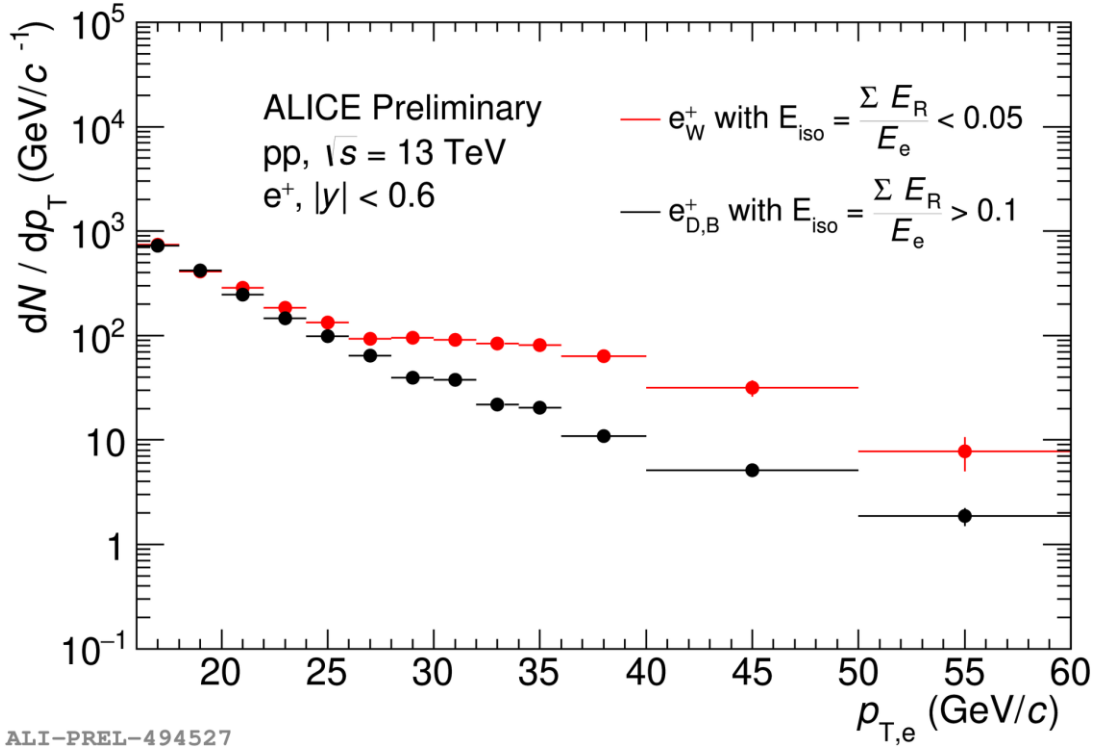
Signal extraction

The selection is based on **isolation cuts** on high-p_{T} electron candidates

- $30 < p_{\mathrm{T},e} < 60\ \mathrm{GeV}/c$
- ➢ $\dfrac{\text{Energy (R < 0.3)}}{\text{Electron energy}} < 0.05$

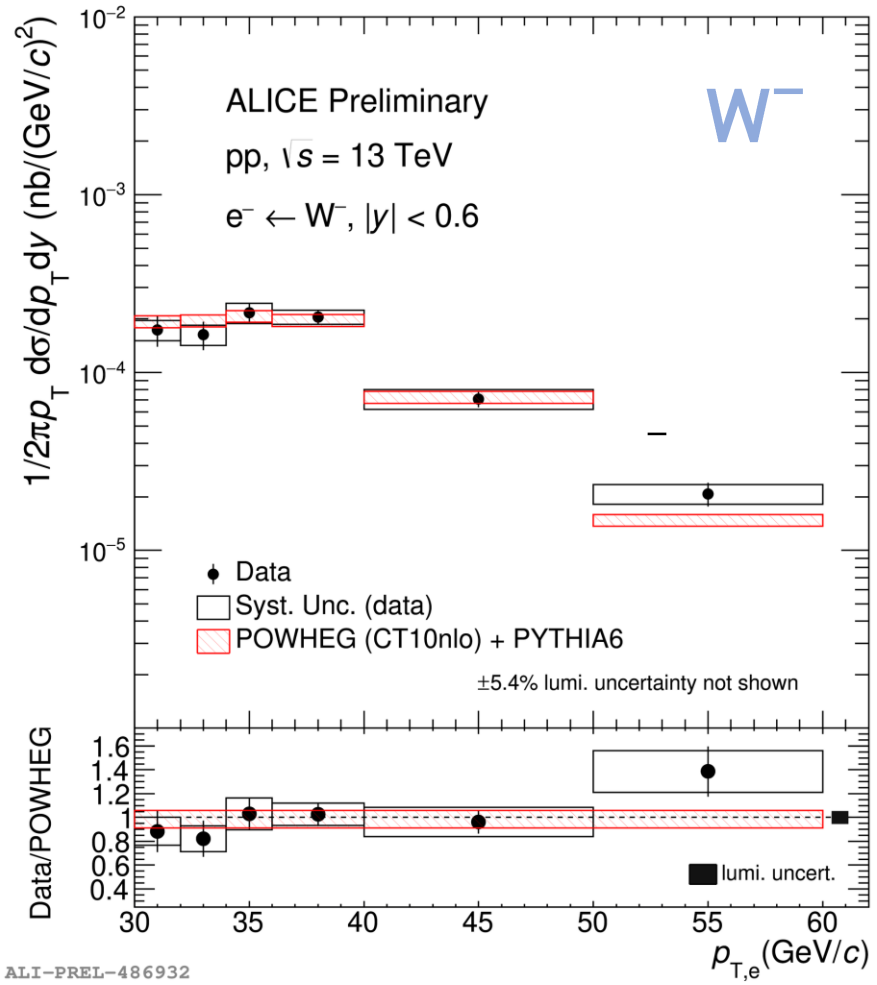
Main background from:

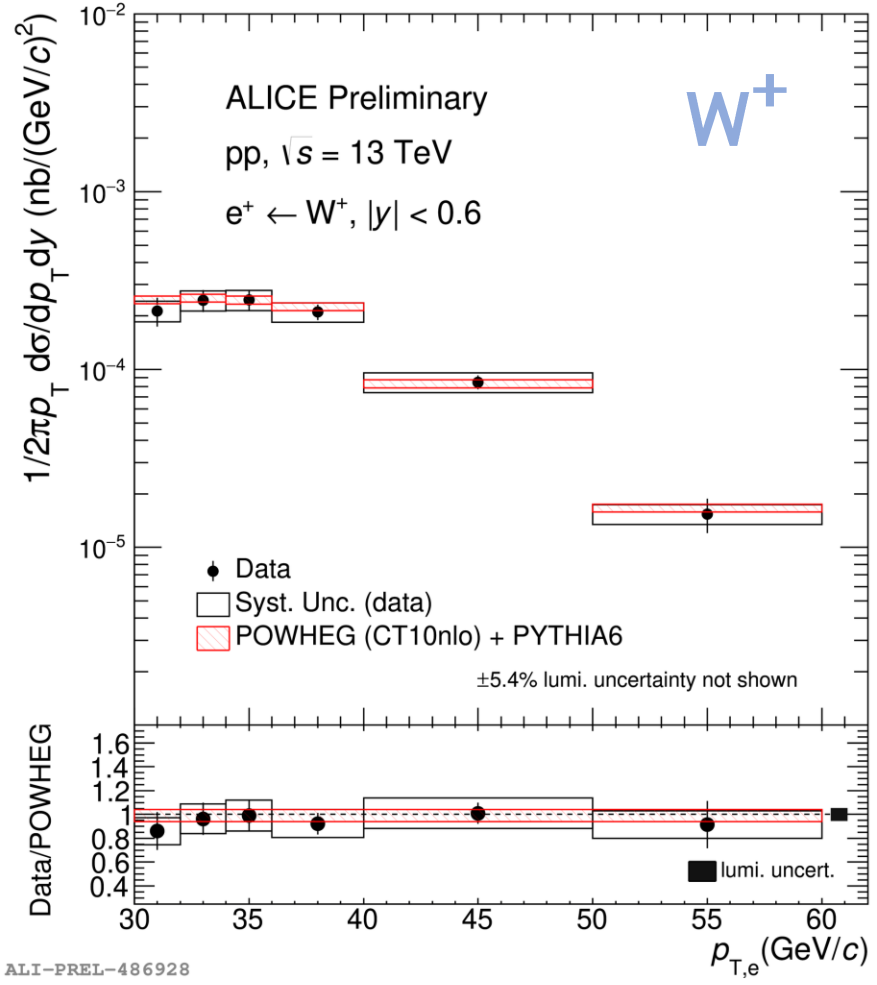
- heavy-flavour hadrons: data-driven estimation, by comparing p_{T} distributions with different isolation energy;
- Z boson: Z/W ratio estimated with POWHEG



POWHEG: JHEP 07(2008)060

W in pp at 13 TeV





- W⁻ and W⁺ cross sections (slightly) differ because of isospin

✓ Good agreement with calculations based on POWHEG+Pythia and CT10nlo PDFs

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POWHEG: JHEP 07(2008)060

ALICE measured electroweak-boson production in:

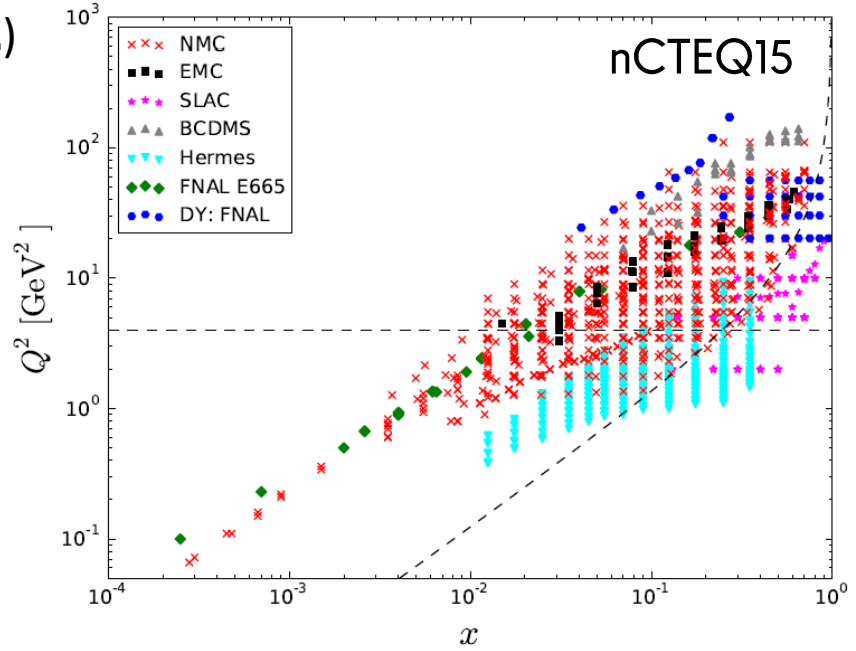
- **pp collisions at $\sqrt{s}$ = 13 TeV** (W boson)
  - ✓ Integrated and p_{T}-differential cross section; W^+/W^- ratio
  - ✓ Consistent with pQCD calculations
- **p-Pb and Pb-Pb collisions at different energies** (W and Z)
  - ✓ Large rapidities, where the nPDFs are less constrained
  - ✓ Integrated and y-differential cross sections and yields; centrality-dependent yield and R_{AA}
  - ✓ Results show evidence of nuclear suppression of the PDFs
  - ✓ **Sizable amount of new data points providing extra inputs for the nPDFs global fits**

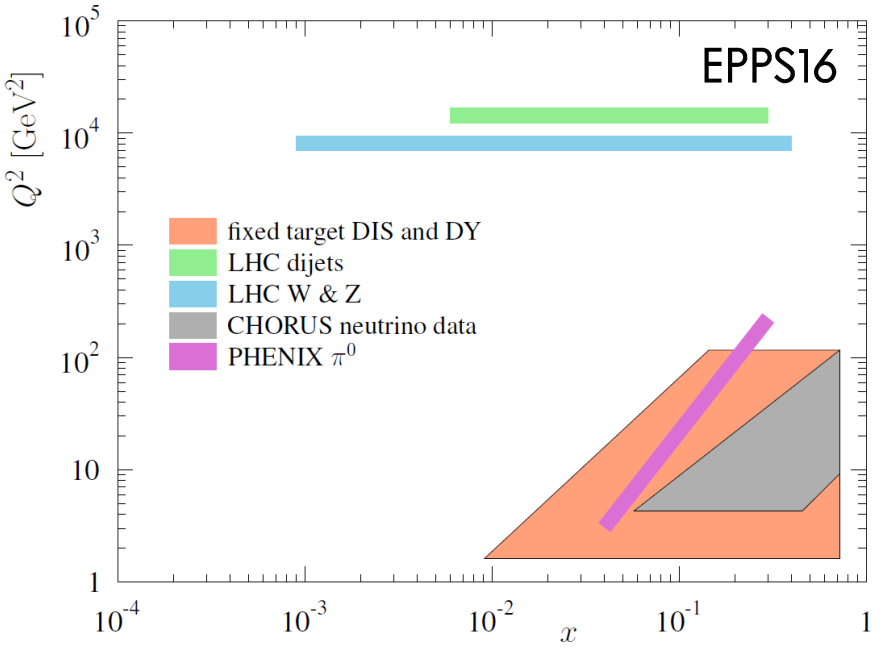
EXTRA SLIDES

nuclear PDFs

	nCTEQ15	EPPS16	nNNPDF2.0
Data points	~700	~1800	~1460
Accuracy	NLO	NLO	NNLO
Proton PDF	CTEQ6m	CT14nlo	NNPDF3.1
Flavour sep.	valence	yes	yes
EW meas.?	No	yes	yes

(yes: nCTEQWZ)





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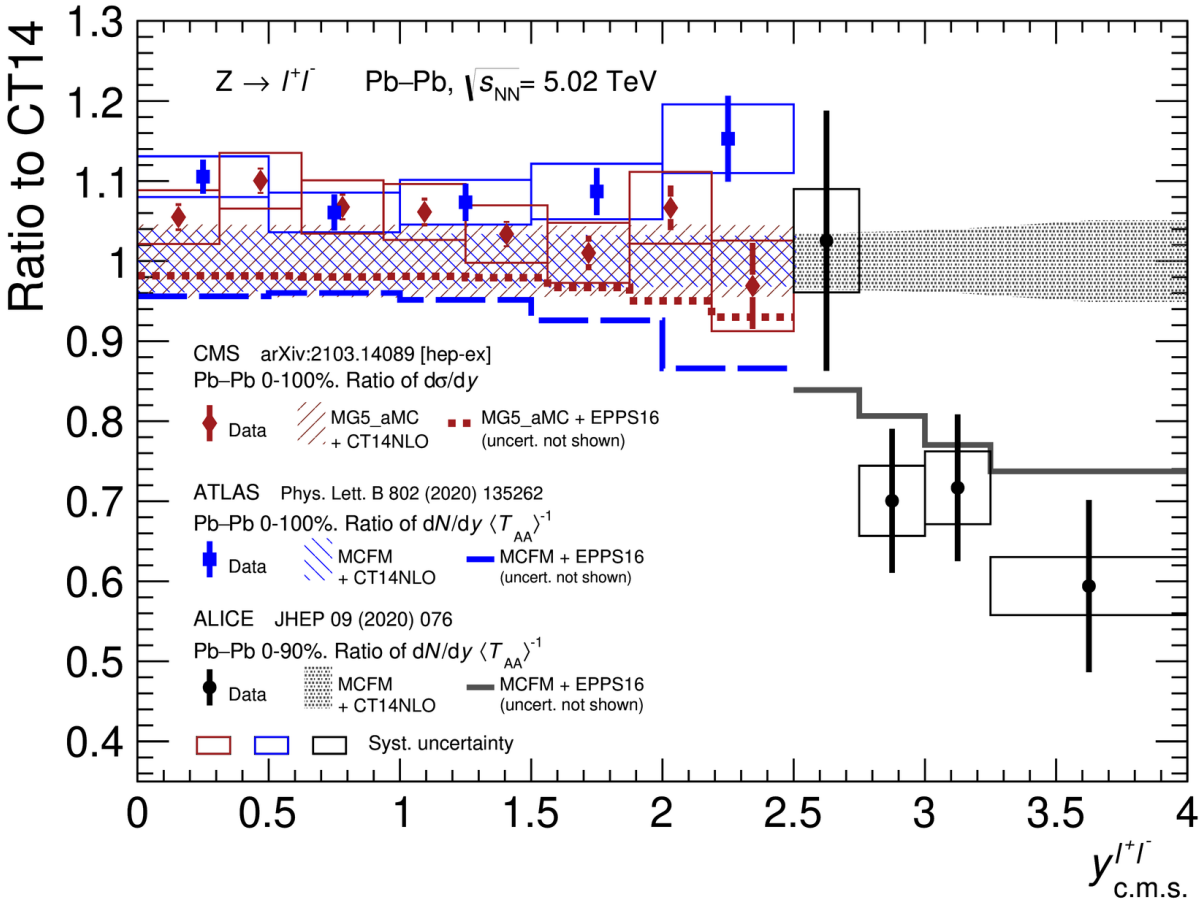
EPPS16: EPJC (2017) 77:163 nCTEQ15: Phys. Rev. D 93 (2016) 085037 nCTEQWZ: Eur. Phys. J. C 80, 968 (2020) nNNPDF2.0: J. High Energ. Phys. 2020, 183 (2020)

ATLAS / CMS / ALICE
Z-boson, Pb–Pb, 5 TeV

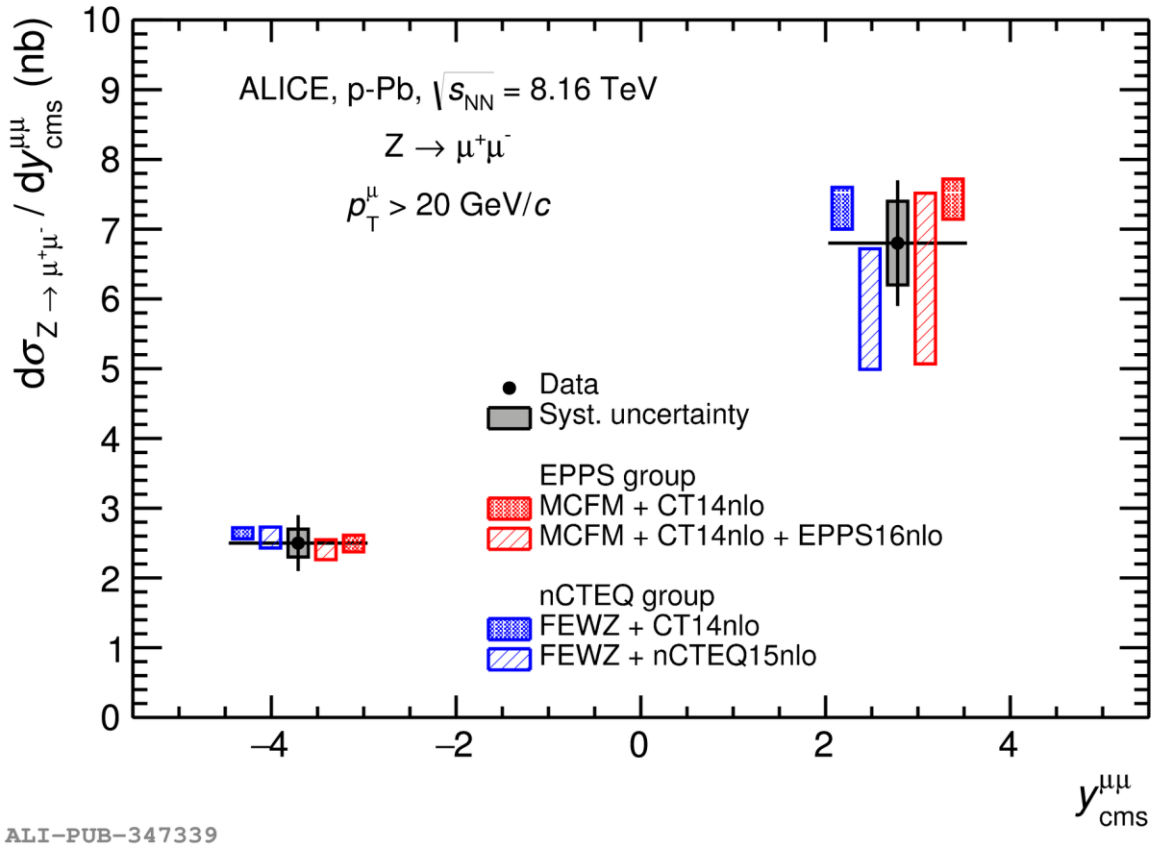


ALI-DER-494135

- Different fiducial regions, different decay channels and different yield normalizations (T_{AA} or luminosity)
  - Data/theory ratio to minimize the bias
  - pQCD calculations with CT14 NLO PDFs as reference

CT14: Phys. Rev. D 93 (2016) 033006 EPPS16: EPJC (2017) 77:163

ALICE
Z-boson, p–Pb, 8.16 TeV



Probing a
- low-x (if y>0 , "p-going")

or a
- high-x (if y<0, "Pb-going")

quark in the nucleus.

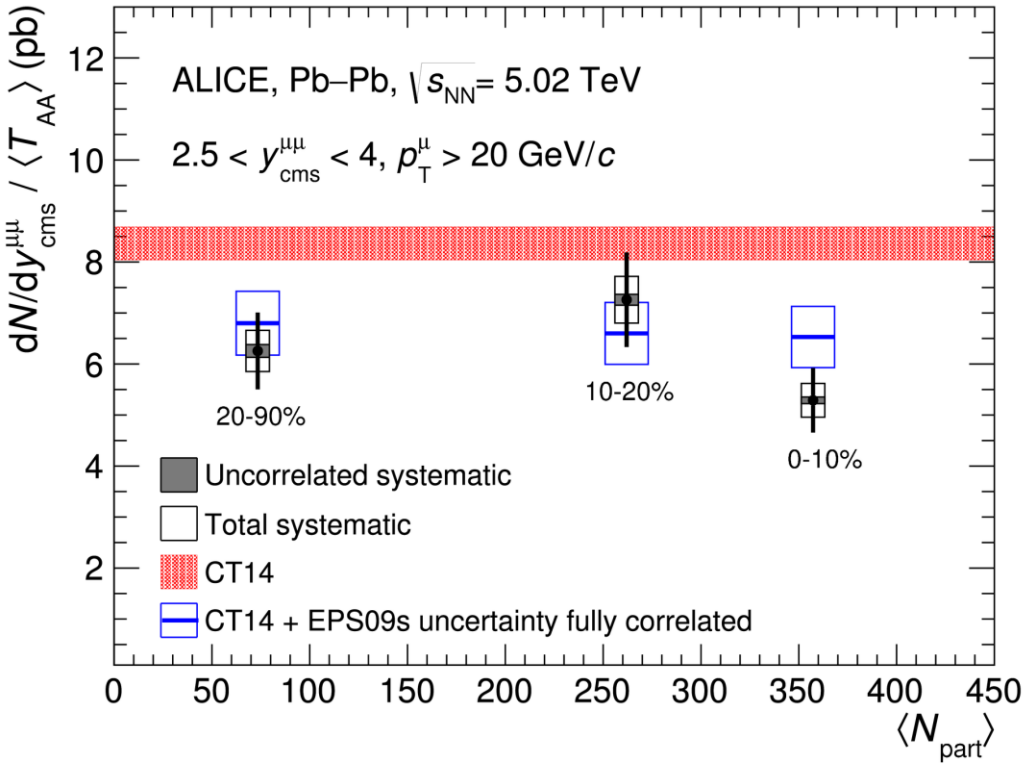
$$x_{1,2} \simeq \frac{M_Z}{\sqrt{s_{NN}}} e^{\pm y}$$

Comparison with Pb–Pb at 5.02 TeV: similar x-regions are probed by the two collision systems. The shift in rapidity ($\Delta y = 0.456$) partially compensates the higher collision energy:

$$\frac{5.02\ \text{TeV}}{8.16\ \text{TeV}} e^{0.456} \simeq 1$$

CT14: Phys. Rev. D 93 (2016) 033006 EPPS16: EPJC (2017) 77:163

ALICE
Z-boson, Pb–Pb, 5.02 TeV vs centrality



ALI-PUB-347359

JHEP, 09 (2020) 076

This result is statistically compatible with the N_{coll} scaling hypothesis

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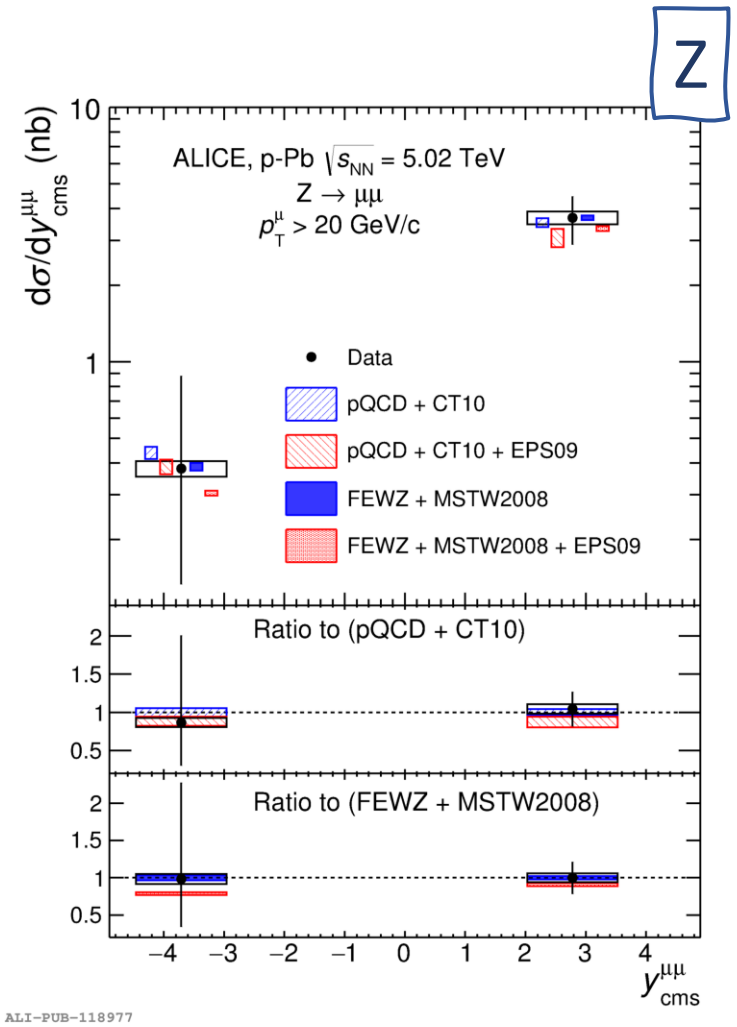
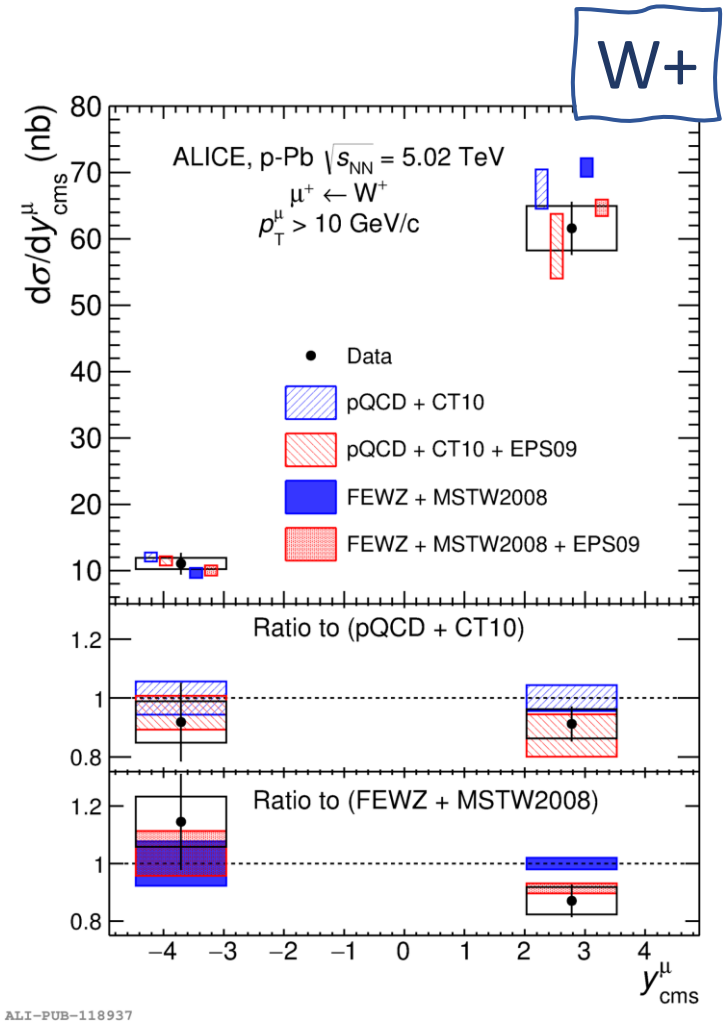
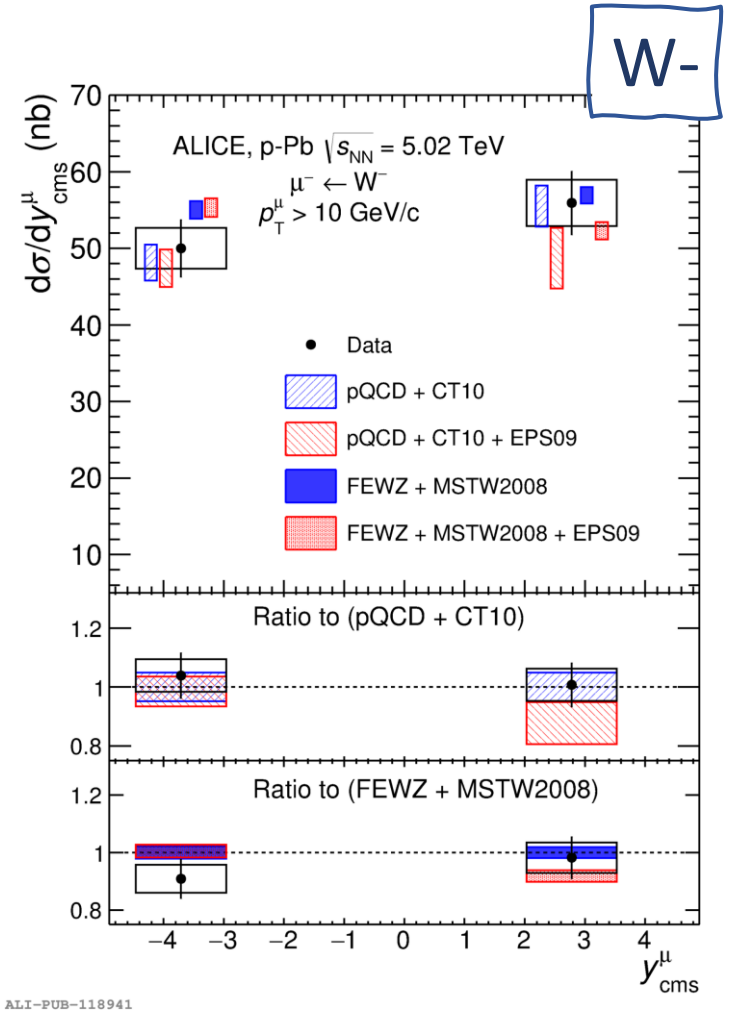
CT14: Phys. Rev. D 93 (2016) 033006 EPPS16: EPJC (2017) 77:163 EPS09s: Nucl. Phys. A 904-905 (2013) 999:1002.

ALICE
Z- and W-boson, p–Pb, 5.02 TeV

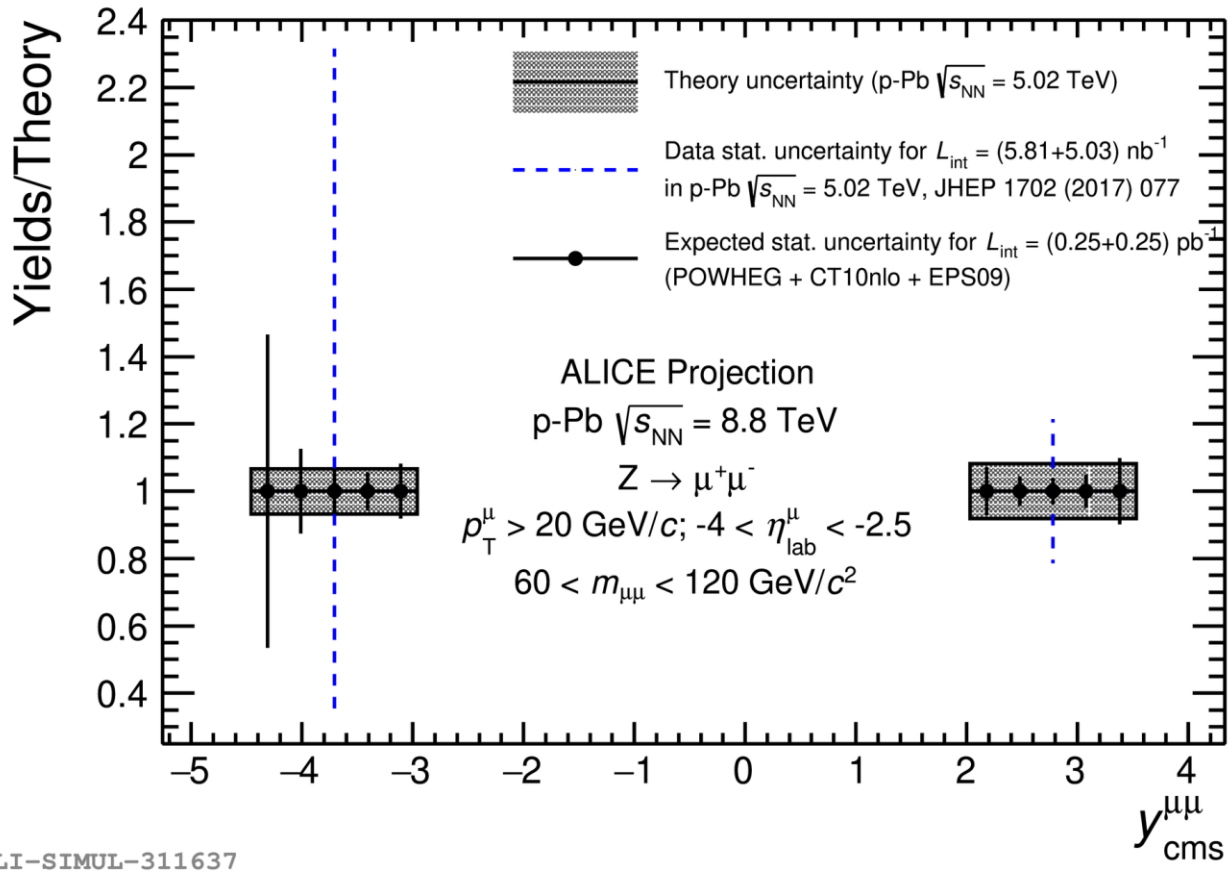






JHEP 02 (2017) 077

Z-boson in Run3



ALI-SIMUL-311637

Comparison between uncertainties in Run 2 and expectation in Run 3