Electroweak boson production with ALICE

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for the ALICE Collaboration

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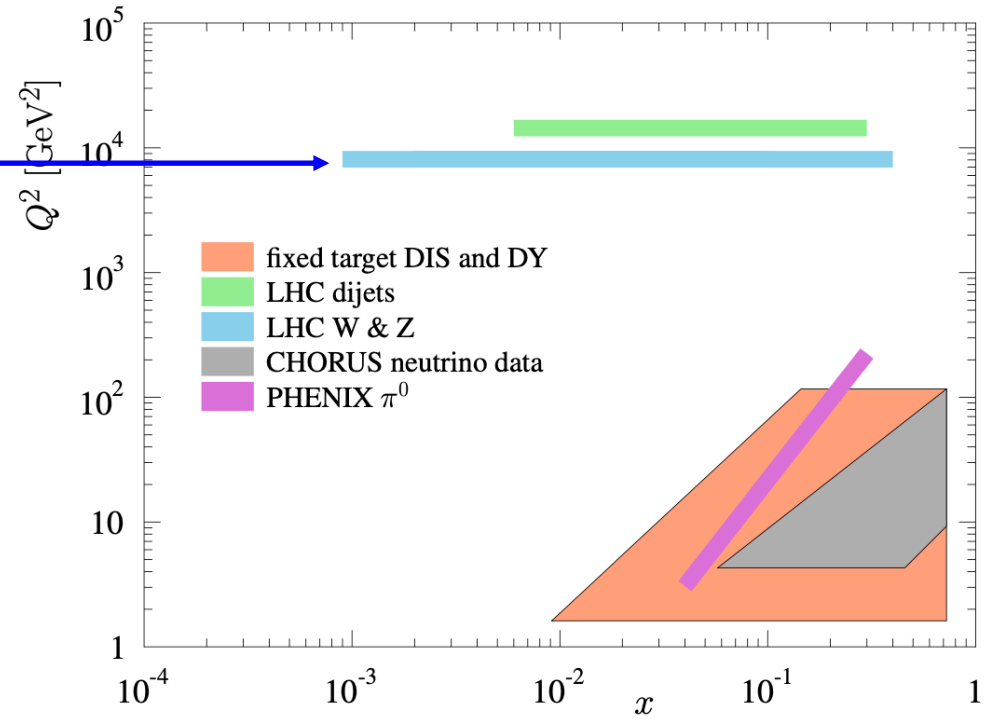
Motivation

- $W^{\pm}$ and Z^0 are **heavy electroweak** bosons
  - theoretically well known

- Ideal probes to constrain (nuclear) parton distribution functions (PDFs)
  - access to large Q^2 and wide Bjorken-x range
  - leptonic decay not affected by strongly-interacting medium
  - mainly produced via: $u\bar{d} \rightarrow W^+$, $\bar{u}d \rightarrow W^-$, $q\bar{q} \rightarrow Z^0$ => sensitive to the flavour dependence

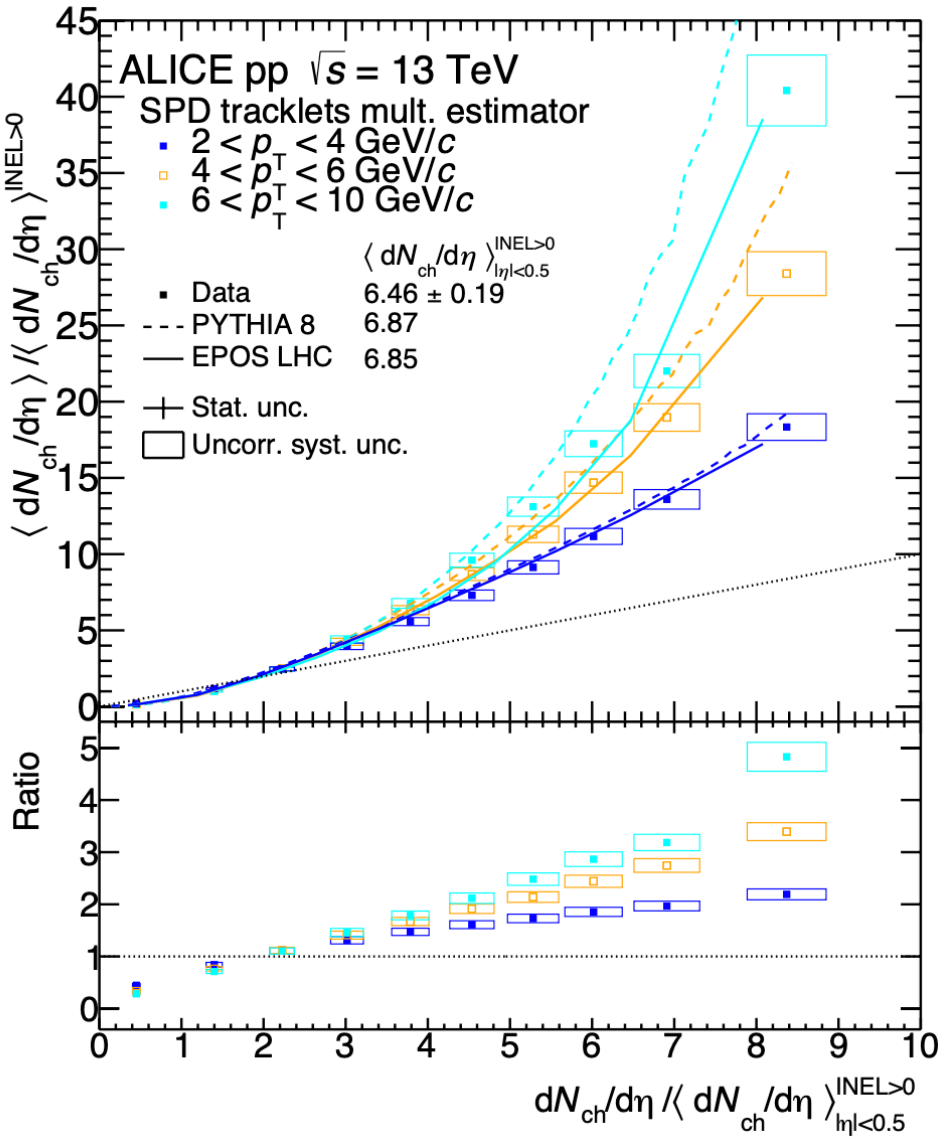
Eskola *et al.*, Eur. Phys. J. C77 (2017) 163



Reference for hadron production

- Non-trivial scaling of the intermediate/high-p_T charged-particle multiplicity vs INEL>0 observed

- $W^{\pm}$ and Z^0 bosons are electroweak probes =>
  - different sensitivity to underlying QCD mechanism compared to hadronic probes
  - unique insight



ALICE detector (Run 2)

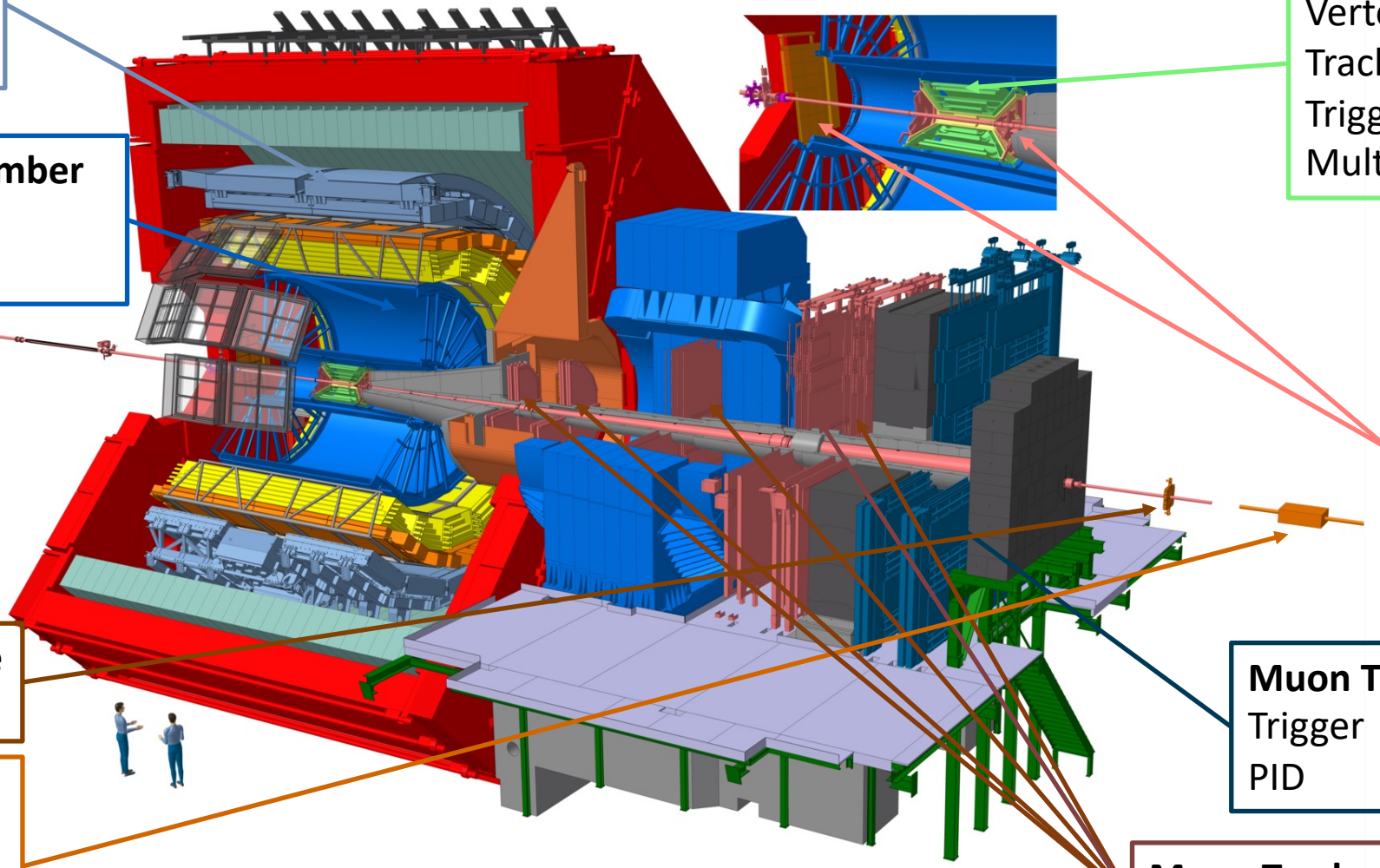
$|y| < 0.6$
$W^{\pm} \rightarrow e^{\pm} + X$
$Z^0 \rightarrow e^+e^-$

$2.5 < y < 4$
$W^{\pm} \rightarrow \mu^{\pm} + X$
$Z^0 \rightarrow \mu^+\mu^-$

EMCal
Trigger
PID

Time Projection Chamber
Tracking
PID

Inner Tracking System
Vertexing
Tracking
Trigger
Multiplicity



VZERO
Trigger
Centrality
Background rejection
Veto activity
Multiplicity

ALICE Diffractive
Veto activity

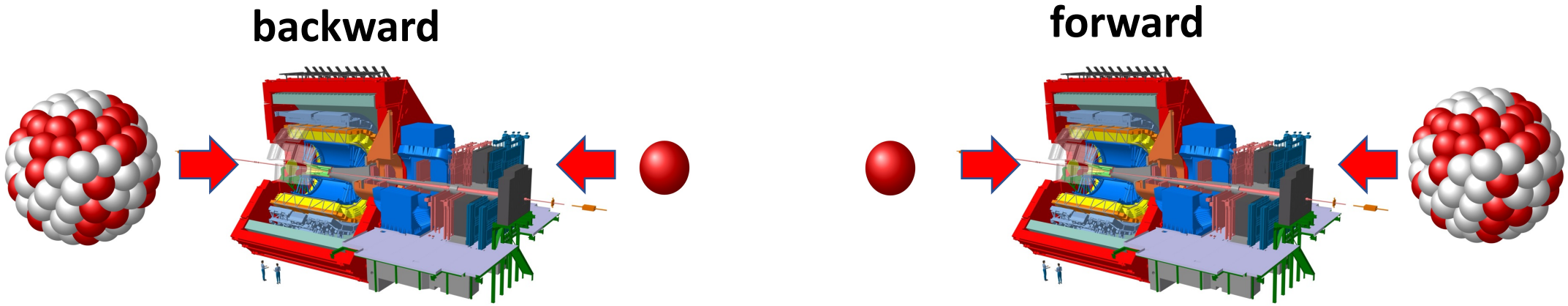
Muon Trigger
Trigger
PID

Zero Degree Calorimeter
Background rejection
Veto activity

Muon Tracker
Tracking

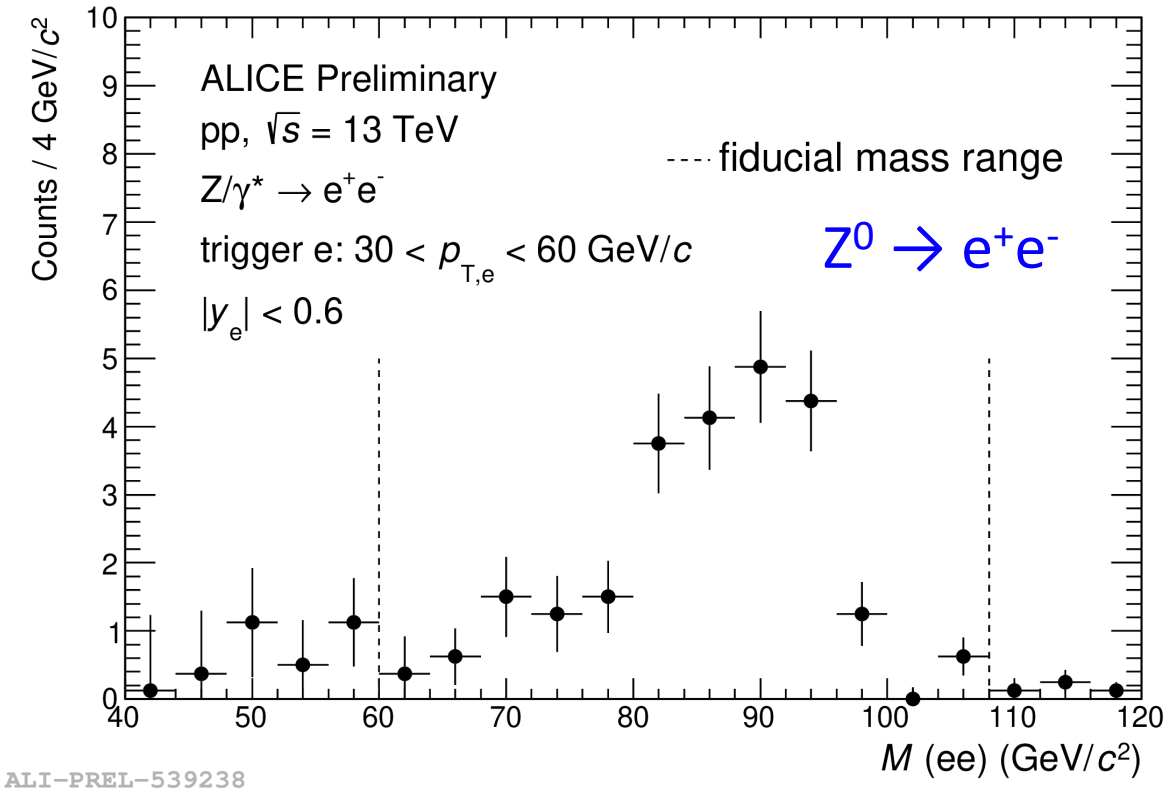
EW boson measurements

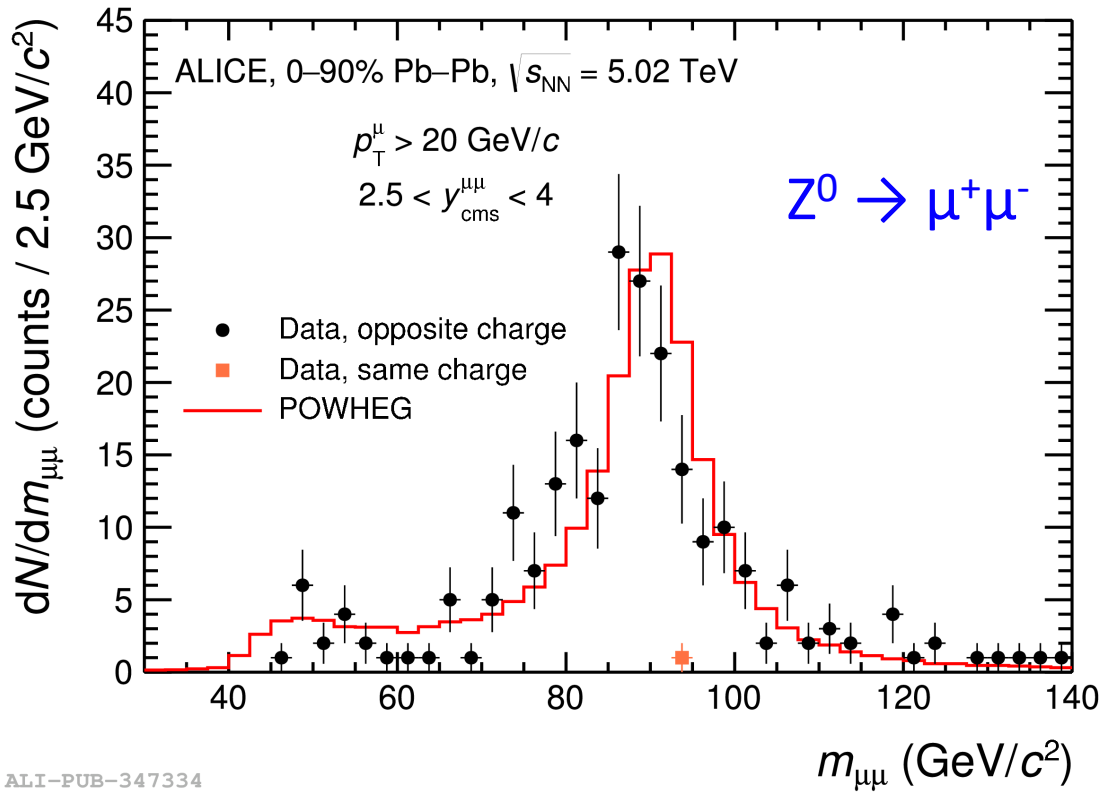
- For p-Pb collisions: different per-nucleon energy between p and Pb => CM boosted along proton direction (of 0.465 units)



Collision system	Energy	Luminosity	Rapidity	Publication
pp	13 TeV	~6.6 pb^{-1}	$\|y\| < 0.6$	
p-Pb	5.02 TeV	5.03 ± 0.18 nb^{-1} 5.8 ± 0.2 nb^{-1}	$2.03 < y_{CMS} < 3.53$ $-4.46 < y_{CMS} < -2.96$	JHEP 02 (2017) 077
p-Pb	8.16 TeV	6.73 ± 0.16 nb^{-1} 10.0 ± 0.2 nb^{-1}	$2.03 < y_{CMS} < 3.53$ $-4.46 < y_{CMS} < -2.96$	$W^{\pm}$: JHEP 05 (2022) 036 Z^0: JHEP 09 (2020) 076
Pb-Pb	5.02 TeV	663 ± 15 μb^{-1}	$2.5 < y < 4$	$W^{\pm}$: JHEP 05 (2022) 036 Z^0: JHEP 09 (2020) 076

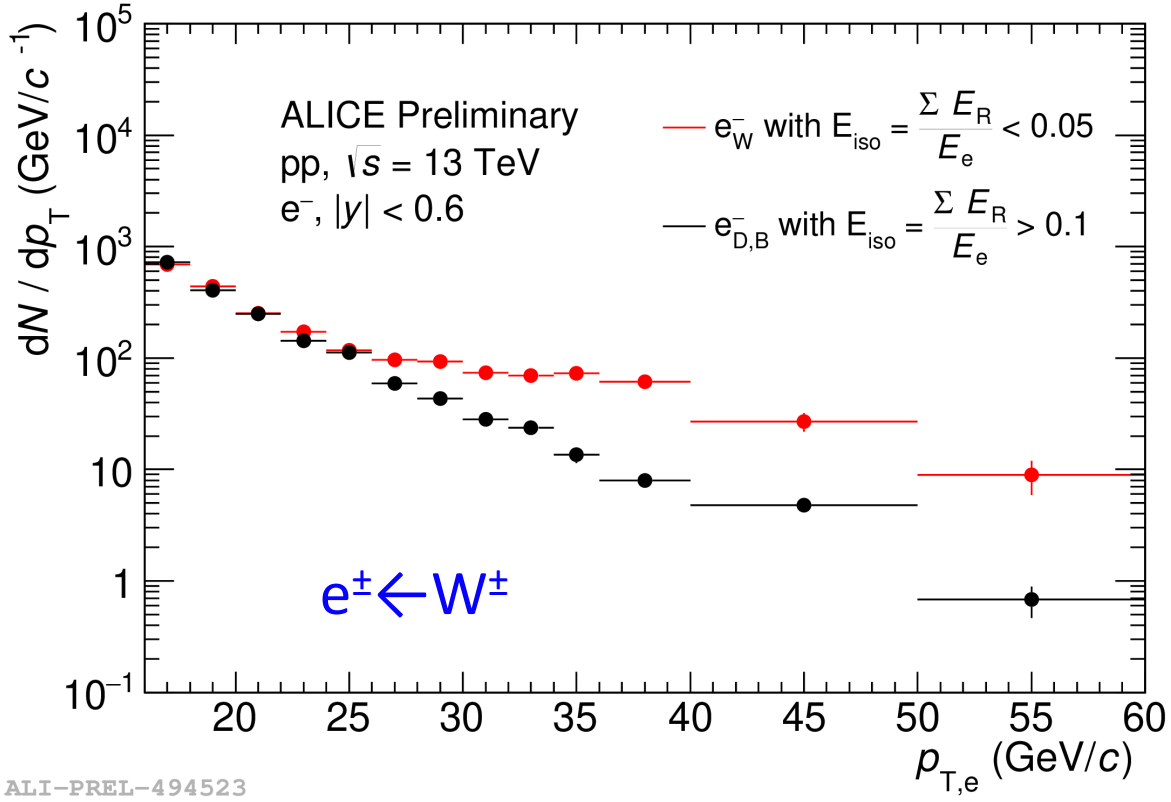
Analysis strategy: Z^0

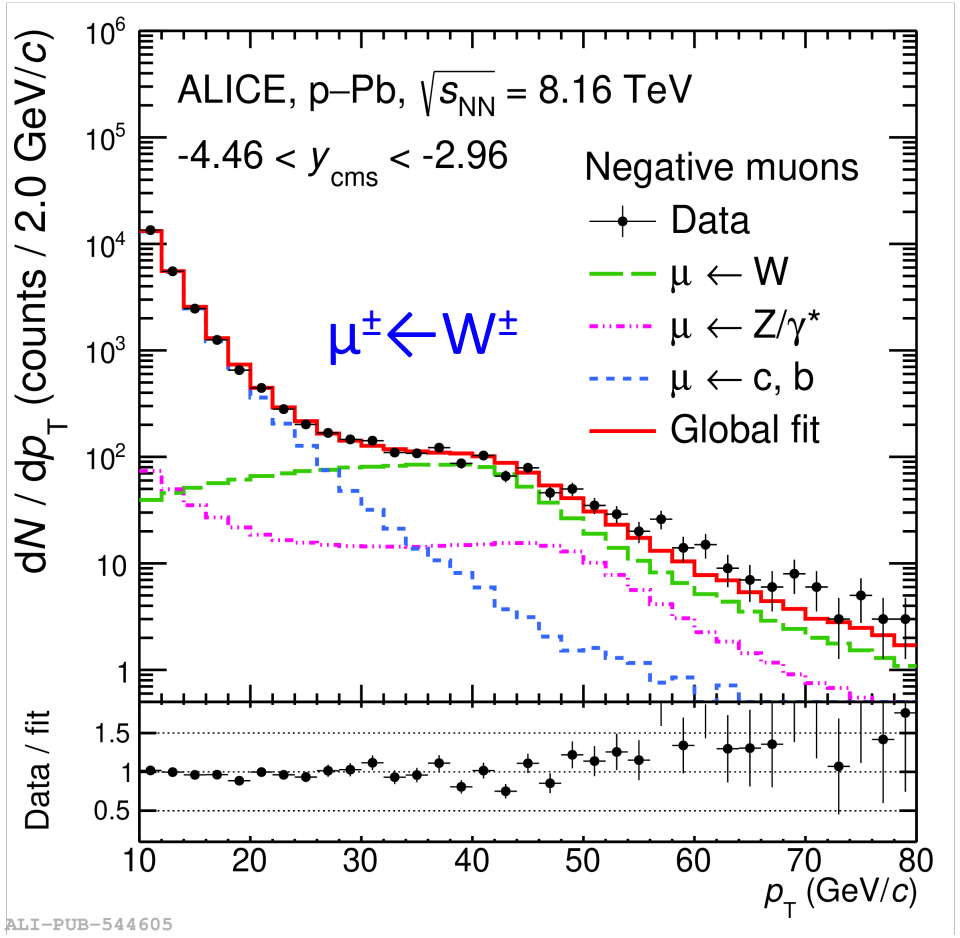




- Invariant mass of the lepton pairs
- PID and kinematic cuts on leptons
  - Isolation criteria for electrons
- Background estimated with like-sign pairs and subtracted

Analysis strategy: W±





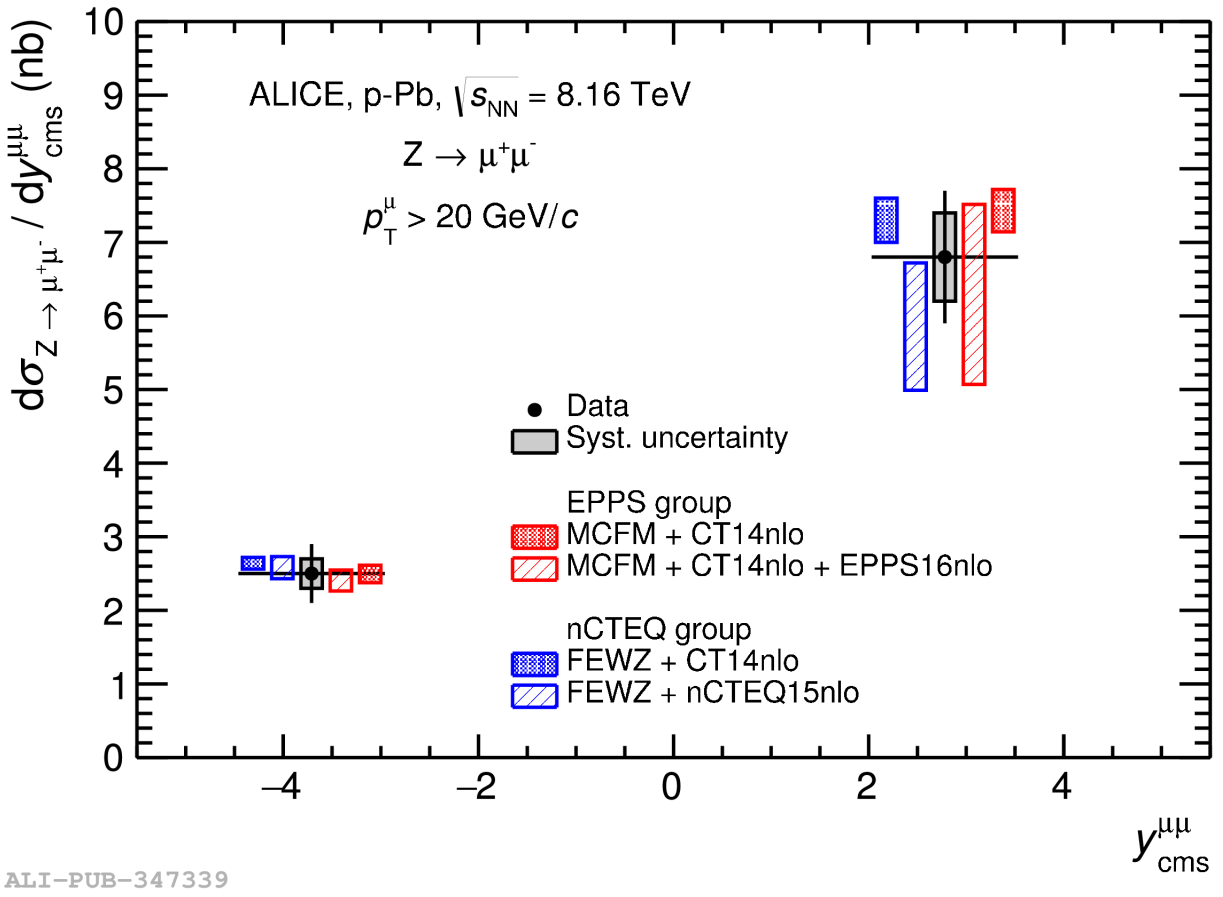
- Isolation cuts on energy
- Data-driven estimation and subtraction of the e←c,b contribution

- MC template fit of single-muon p_T distribution
- First analysis from a **joint China-France** PhD supervision

Z^0 production in p-Pb collisions at 8.16 TeV

- Small difference between free and nuclear PDFs in calculations: all in agreement with data

JHEP 09 (2020) 076

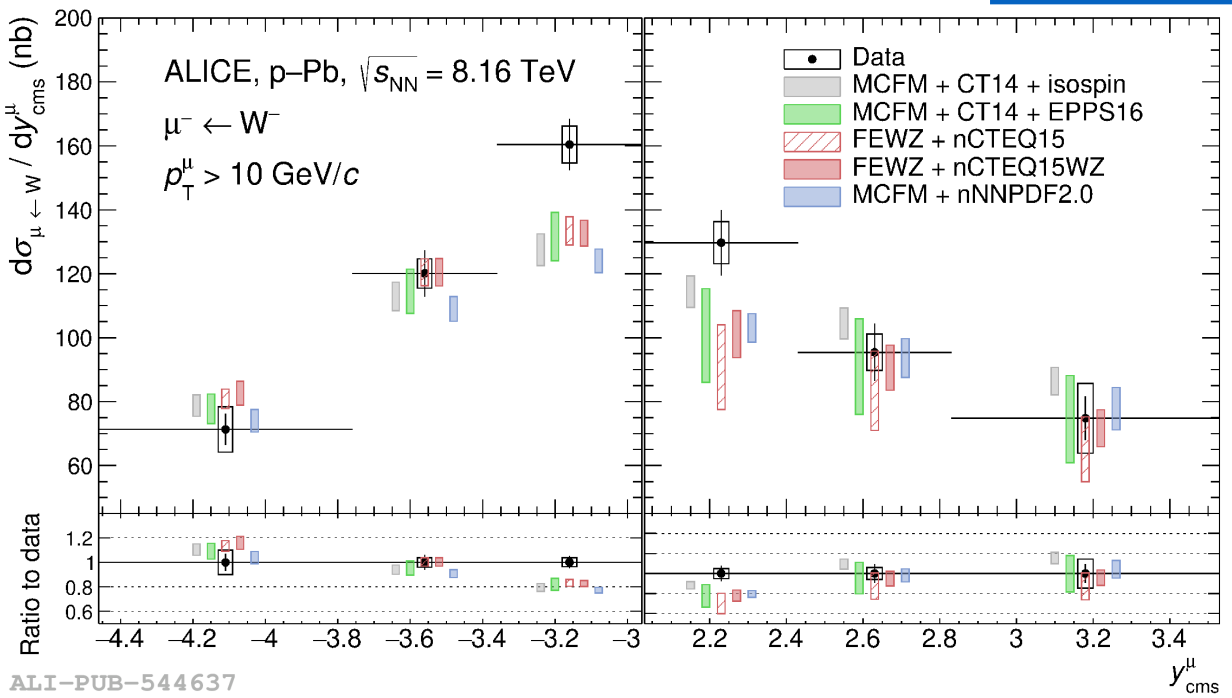


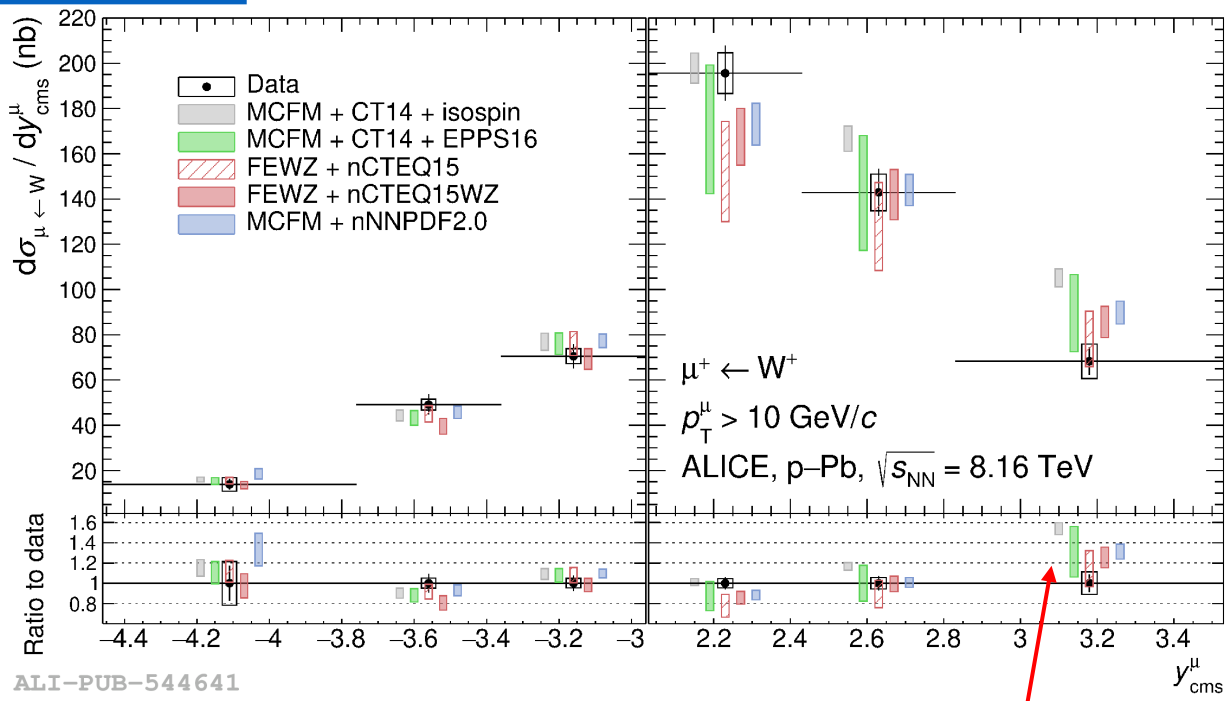
MCFM: Campbell, Neumann, JHEP 12 (2019) 034
CT14: Dular et. al., PRD 93 (2016) 033006
nCTEQ15: Kovarik et. al., PRD 93 (2016) 085037

FEWZ: Gavin, Petriello, S. Quackenbush, CPC 182 (2011) 2388-2403
CT14+EPPS16: Eskola et. al., EPJ C77 (2017) 163
nCT15WZ: A. Kusina et. al., EPJC 80 (2020) 968

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

W^- JHEP 05 (2022) 036 **W^+**



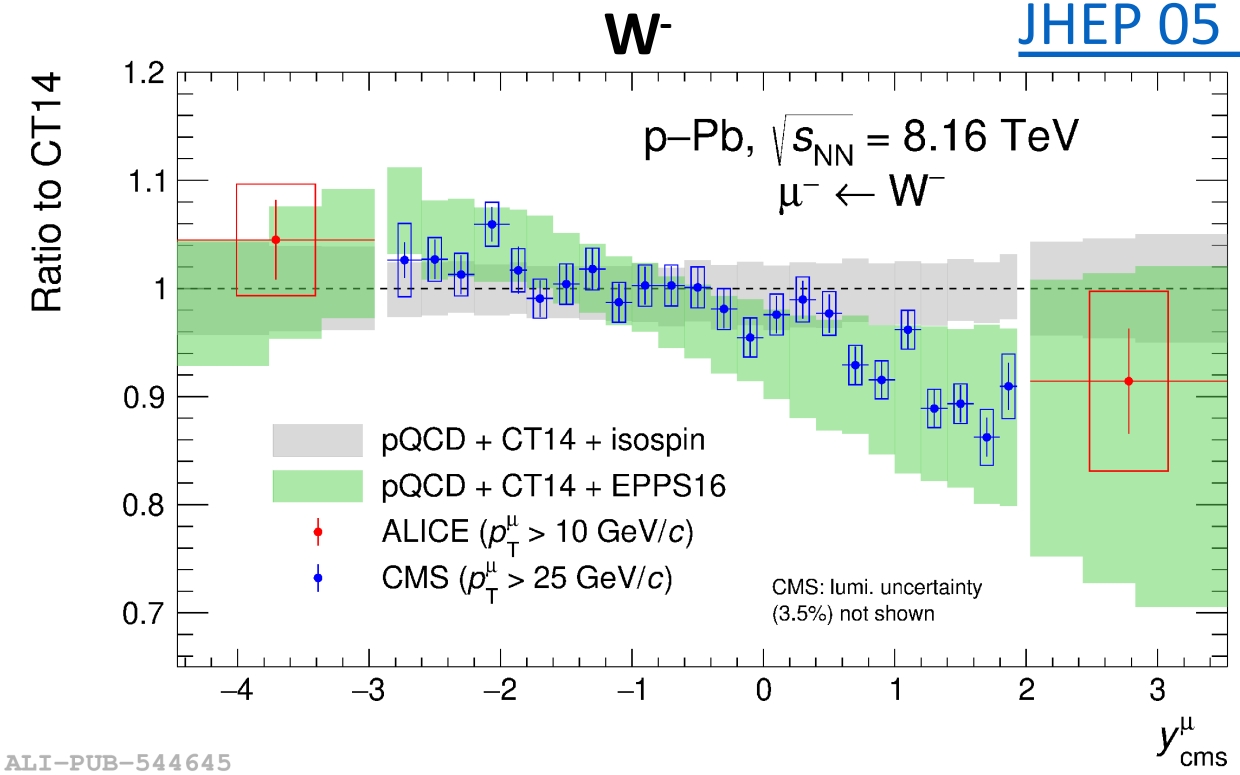


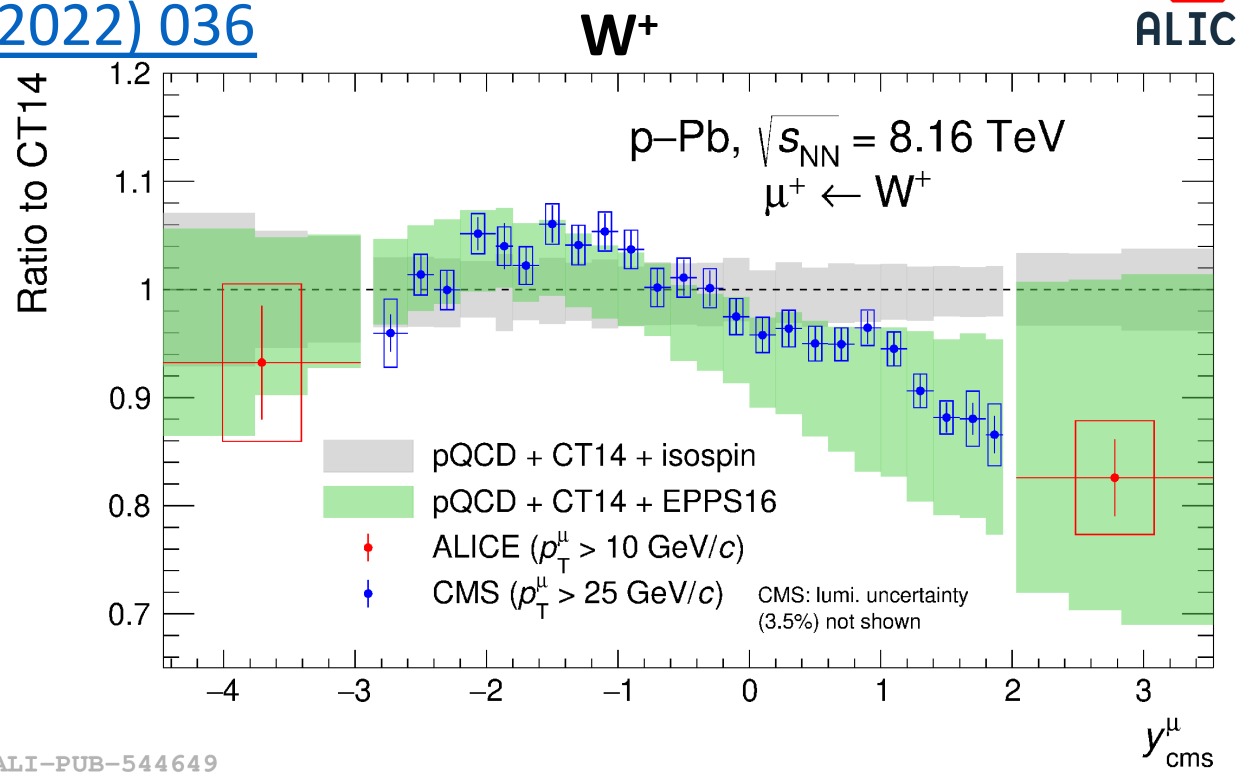
- Calculations underestimate data at smaller rapidity values both at forward and backward rapidities
- 3.5σ deviations from free-PDF calculation (MCFM+CT14) at the largest positive rapidity

MCFM: Campbell, Neumann, JHEP 12 (2019) 034 FEWZ: Gavin, Petriello, S. Quackenbush, CPC 182 (2011) 2388-2403
CT14: Dular et. al., PRD 93 (2016) 033006 CT14+EPPS16: Eskola et. al., EPJ C77 (2017) 163
nCTEQ15: Kovarik et. al., PRD 93 (2016) 085037 nCT15WZ: A. Kusina et. al., EPJC 80 (2020) 968 nNNPDF: Khalek et al., JHEP 09 (2020) 183

$W^{\pm}$: comparison with other experiments

JHEP 05 (2022) 036





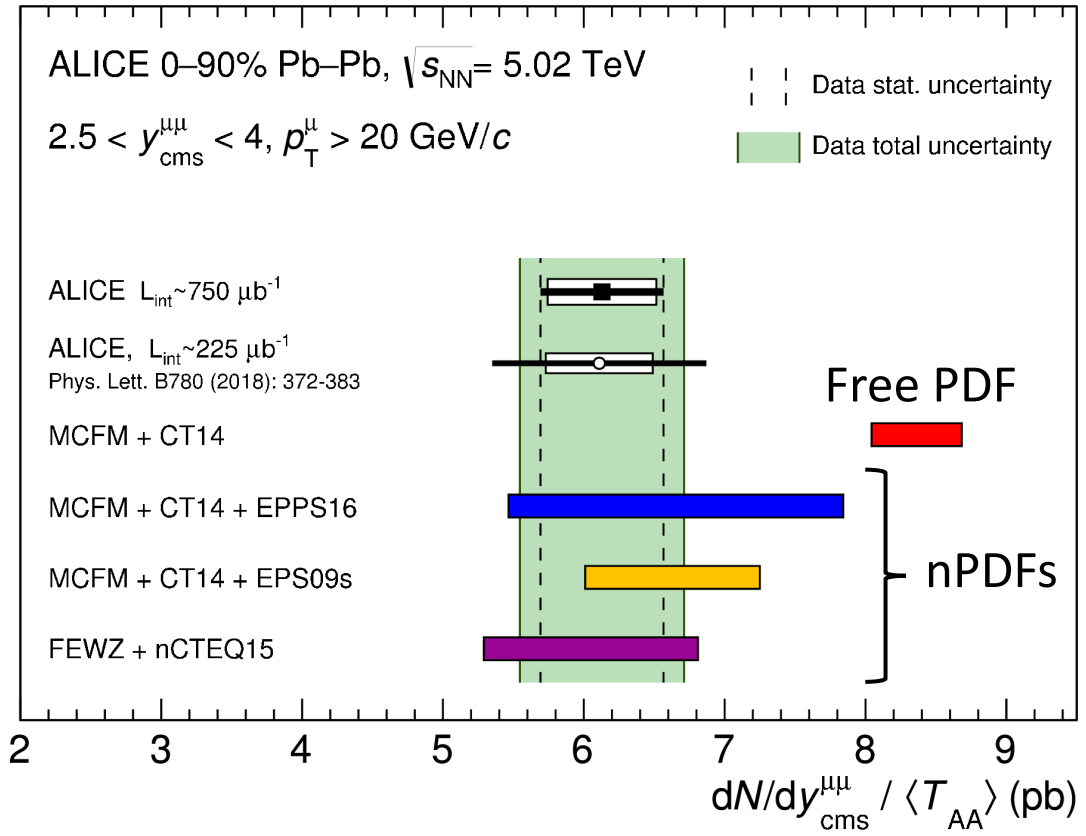
- Complementarity between ALICE and CMS PLB 800 (2020) 135048
  - ALICE reaches largest *y* region, exploring Bjorken-*x* region down to $x \sim 10^{-4}$ at forward rapidities
- Suppression of W^+ production at forward rapidity, consistent with pQCD calculations with nPDFs

CT14+EPPS16: Eskola et. al., EPJ C77 (2017) 163

Z^0 production in Pb-Pb collisions at 5.02 TeV

JHEP 09 (2020) 076

- Data well described by calculations with nPDFs
- 3.5σ discrepancy w.r.t. calculations with free PDF

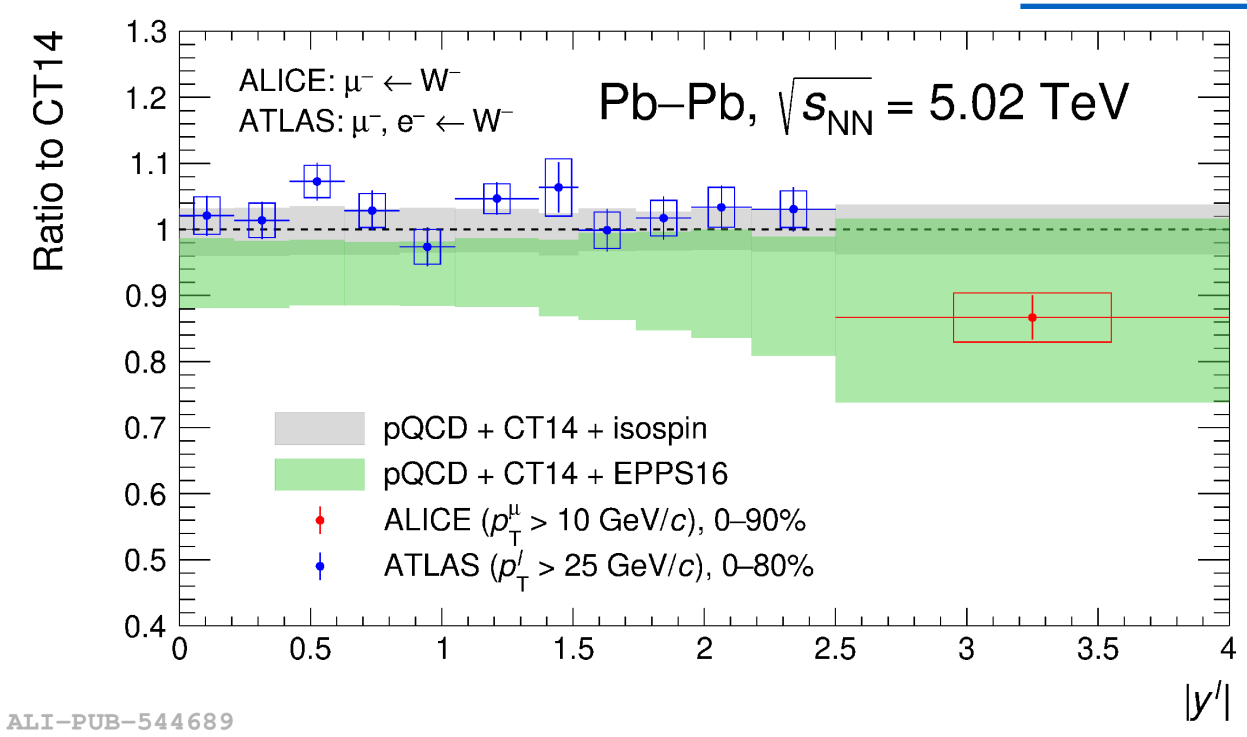


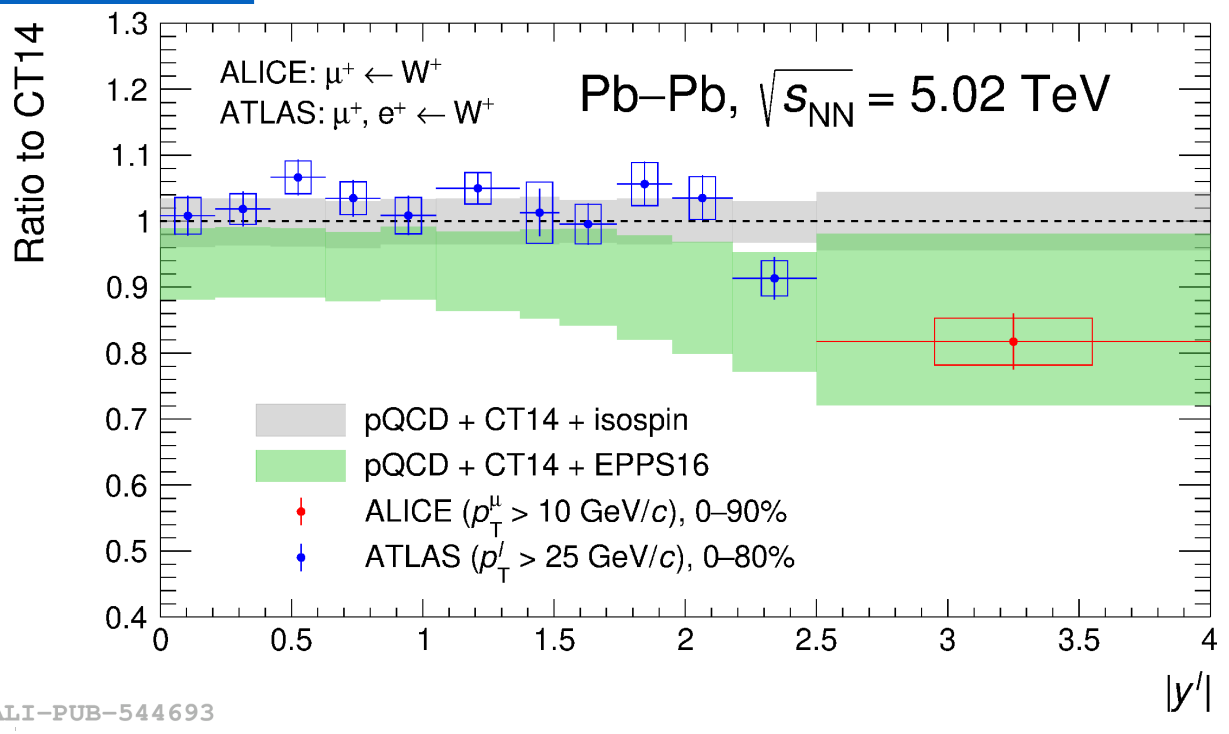
ALI-PUB-347344

MCFM: Campbell, Neumann, JHEP 12 (2019) 034
CT14: Dular et. al., PRD 93 (2016) 033006
CT14+EPPS16: Eskola et. al., EPJ C77 (2017) 163
FEWZ: Gavin, Petriello, S. Quackenbush, CPC 182 (2011) 2388-2403
nCTEQ15: Kovarik et. al., PRD 93 (2016) 085037
CT14+ EPS09: Helenius et al., JHEP 07 (2012) 073

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

W^- JHEP 05 (2022) 036 **W^+**

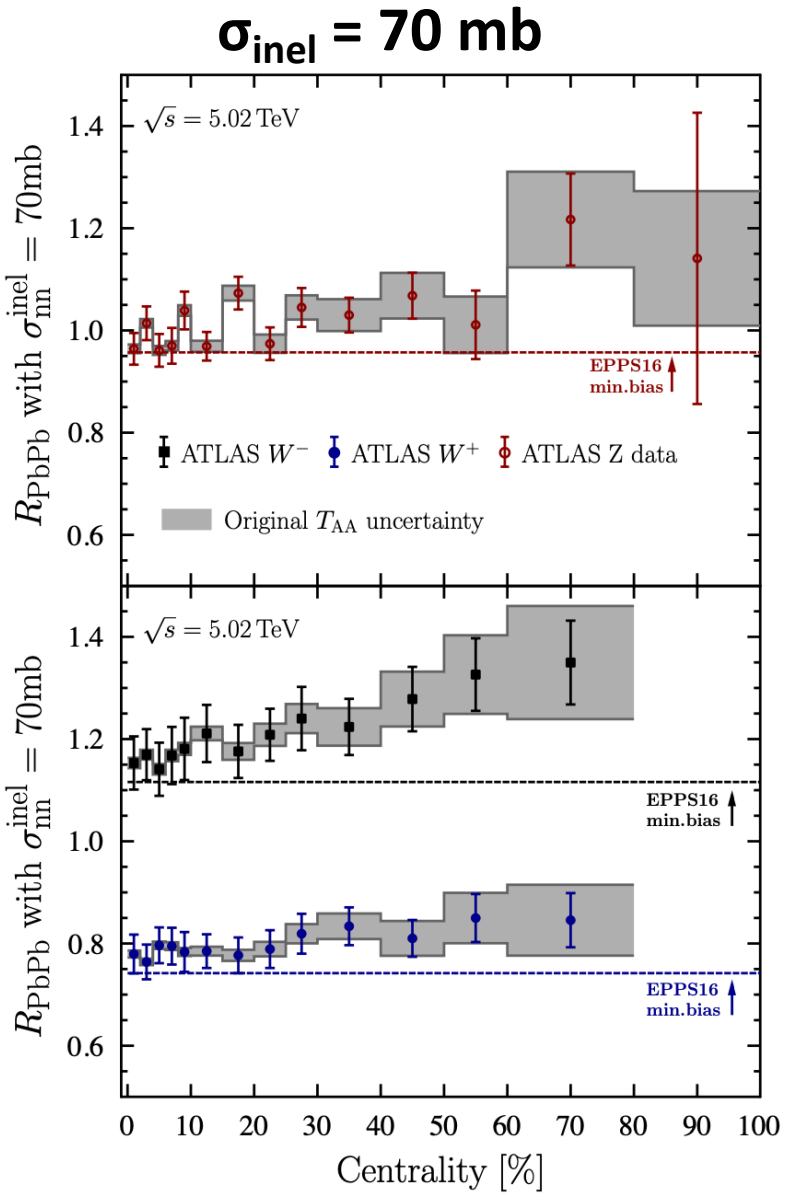


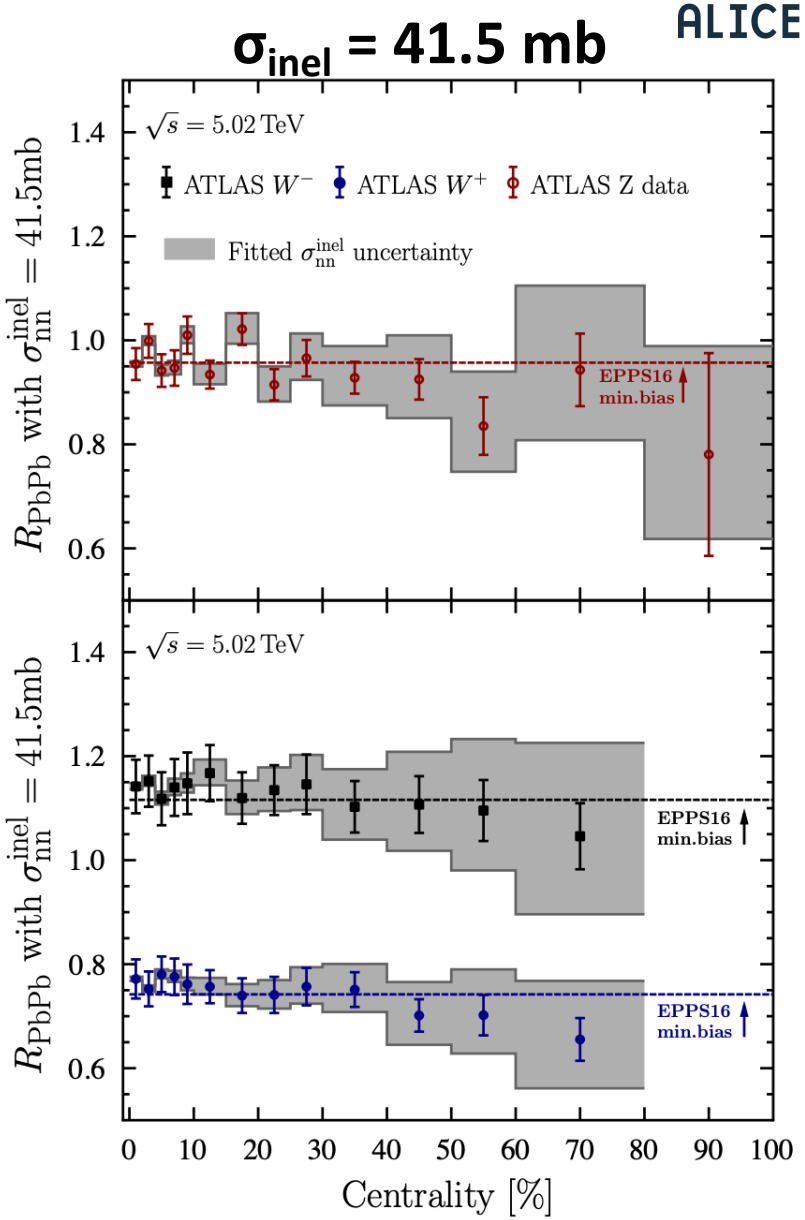


- Comparison between ALICE and ATLAS (EPJC 79 (2019) 935) in a complementary y region
  - EPPS16 (Eskola et. al., EPJ C77 (2017) 163) results in agreement with ALICE data but underestimate ATLAS data
- Suppression of W^+ production at forward rapidity, consistent with pQCD calculations with nPDFs

Shadowing in the σ_{inel} cross section?

- ATLAS data systematically above calculations
- Better agreement if inelastic nucleon-nucleon cross section for binary scaling is reduced due to shadowing





[Eskola et al., PRL 125 (2020) 21, 212301]

$W^{\pm}$ results as a function of centrality

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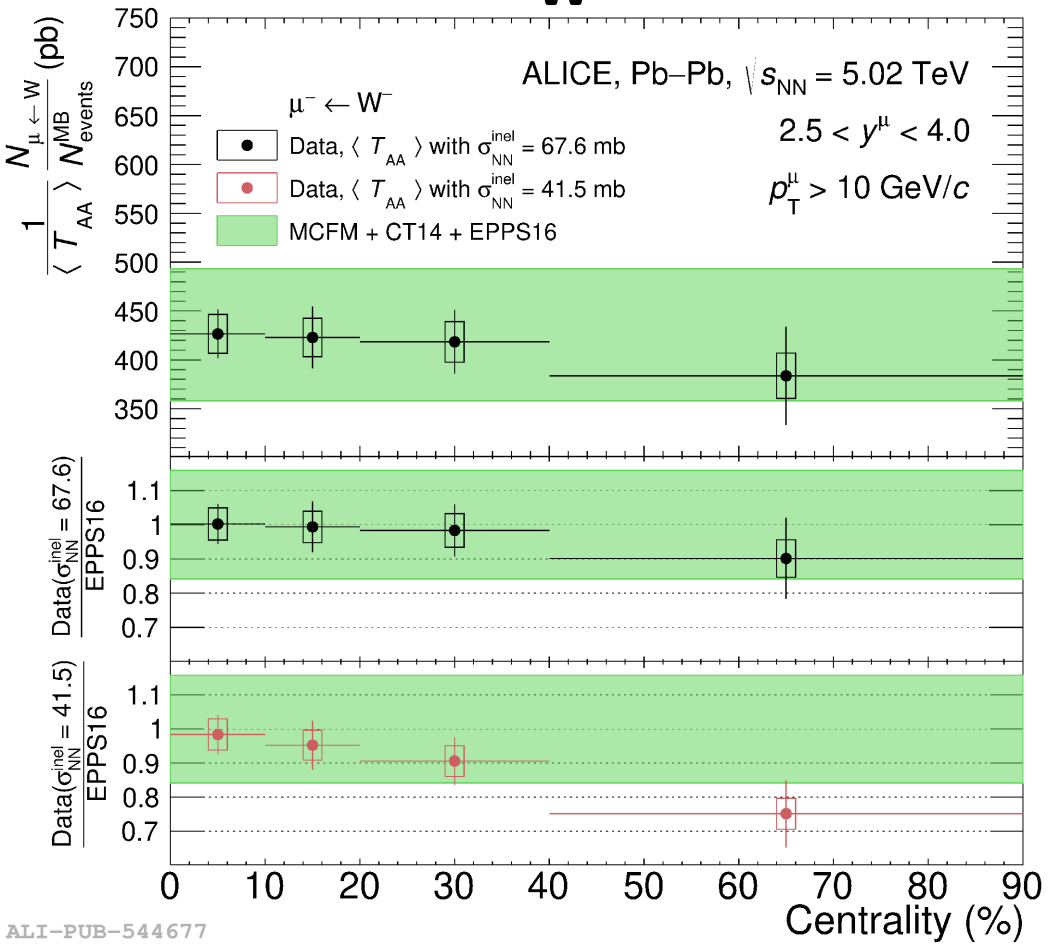
W^-



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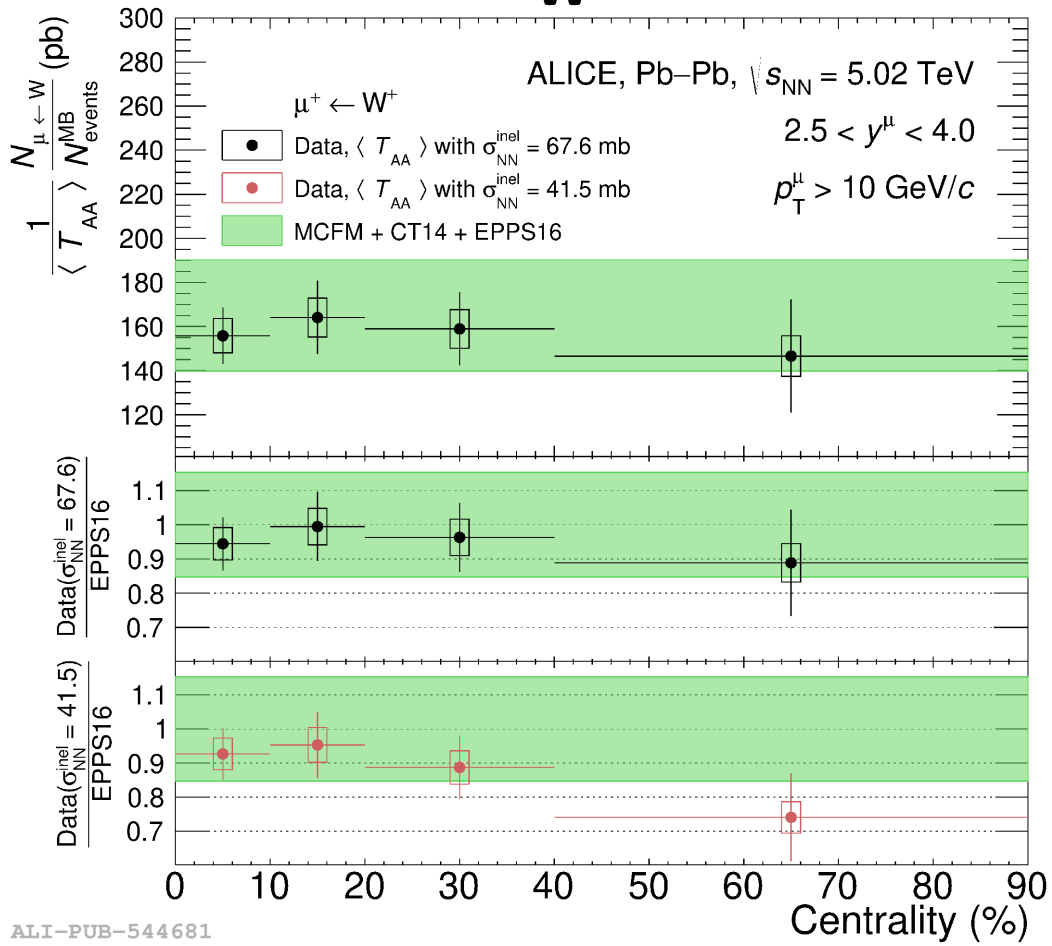
W^+



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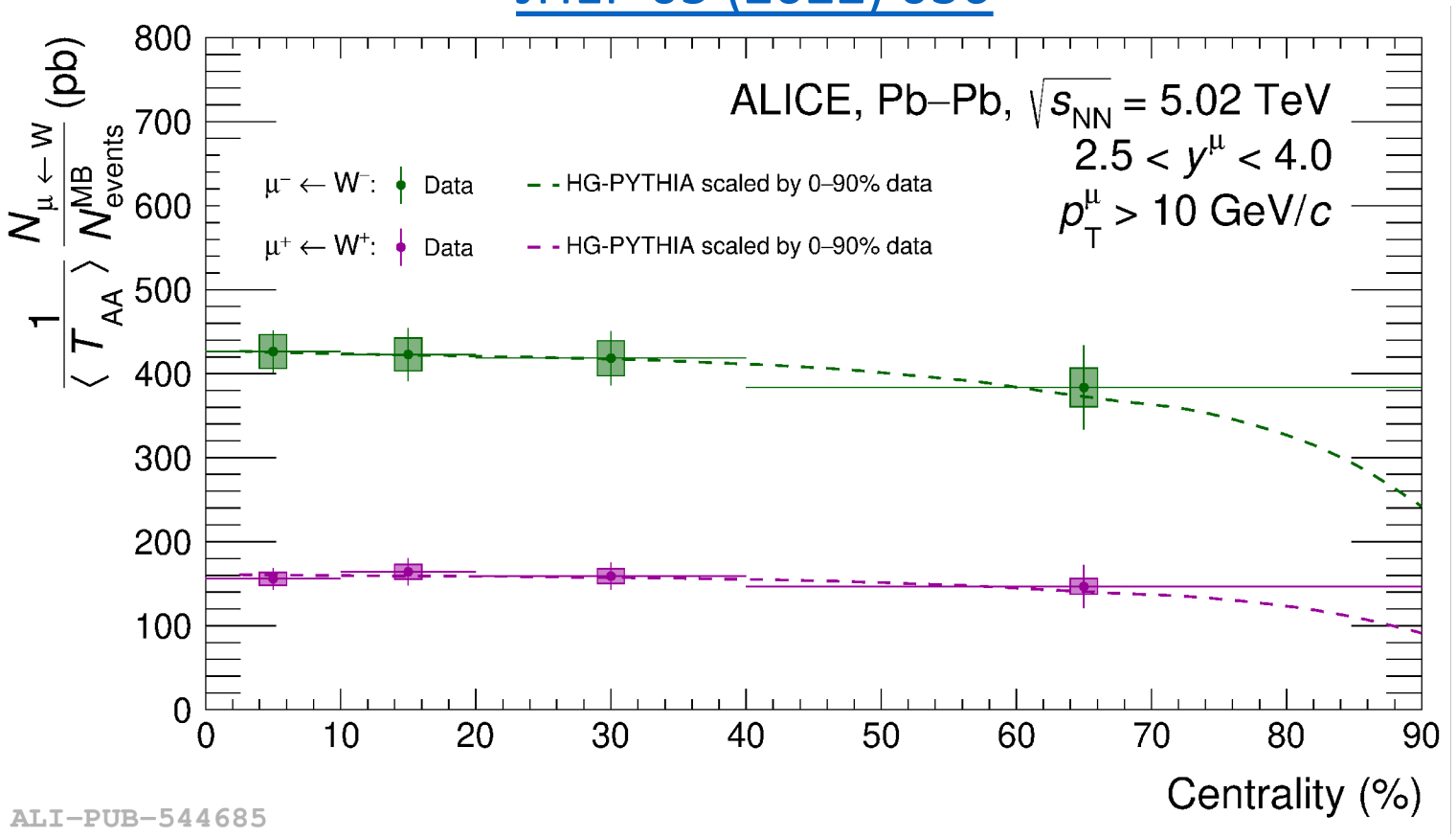
- Change of σ_{inel} cross section does not seem to improve the agreement, but larger statistics needed to conclude

Testing the centrality estimation

- Geometric bias expected in peripheral collisions

JHEP 05 (2022) 036

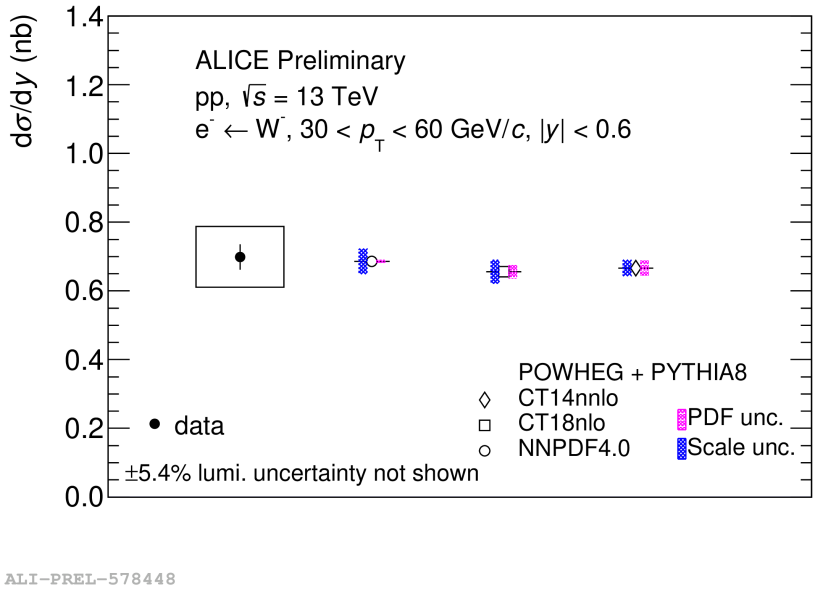


- Larger statistics needed to conclude

HG-PYTHIA: Loizides, Morsch, PLB 773 (2017) 408-411

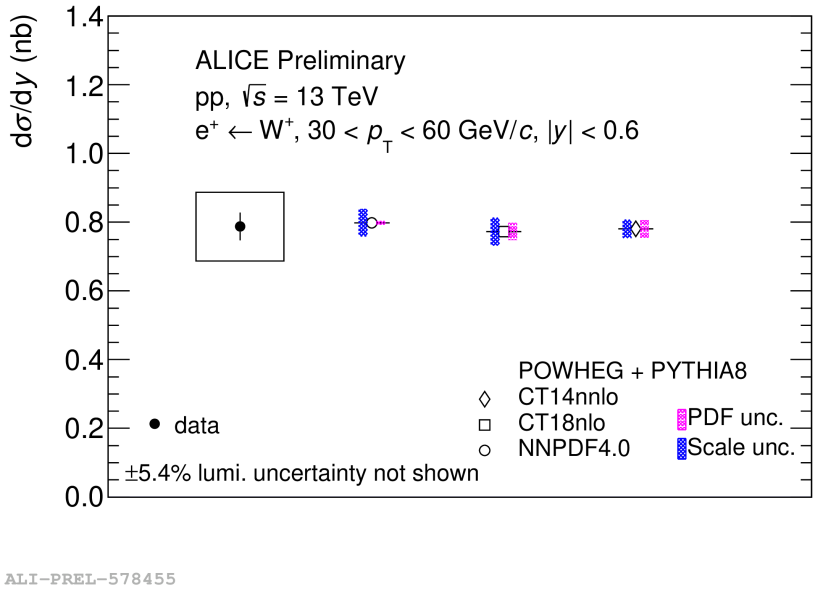
$W^{\pm}$ and Z^0 boson production in pp collisions at 13 TeV

W^-



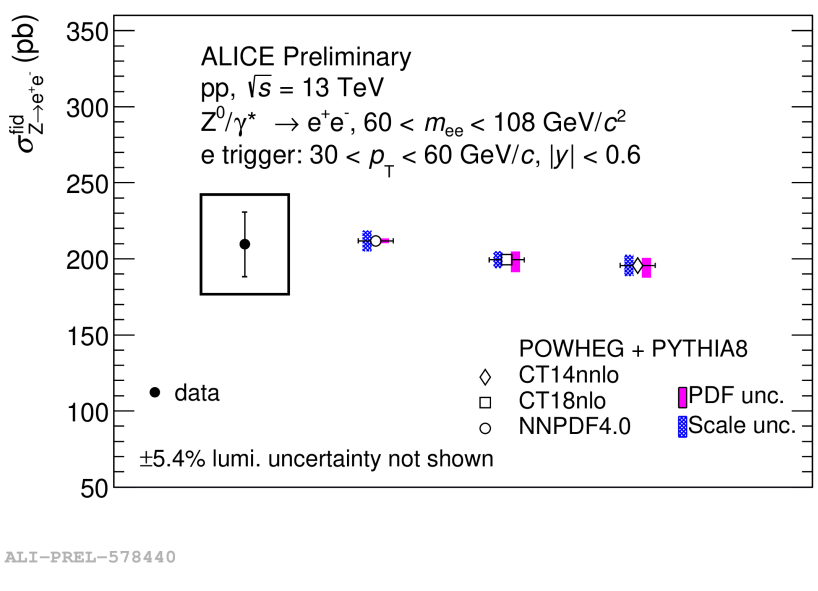
ALI-PREL-578448

W^+



ALI-PREL-578455

Z^0



ALI-PREL-578440

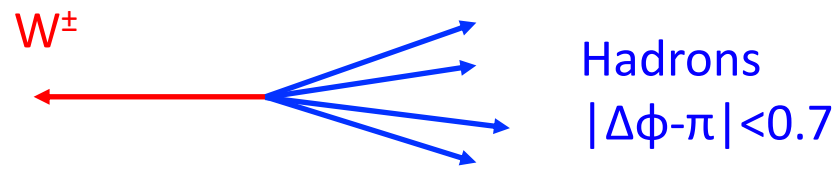
- First measurement in pp collisions at 13 TeV with ALICE
- In agreement with calculations within uncertainties

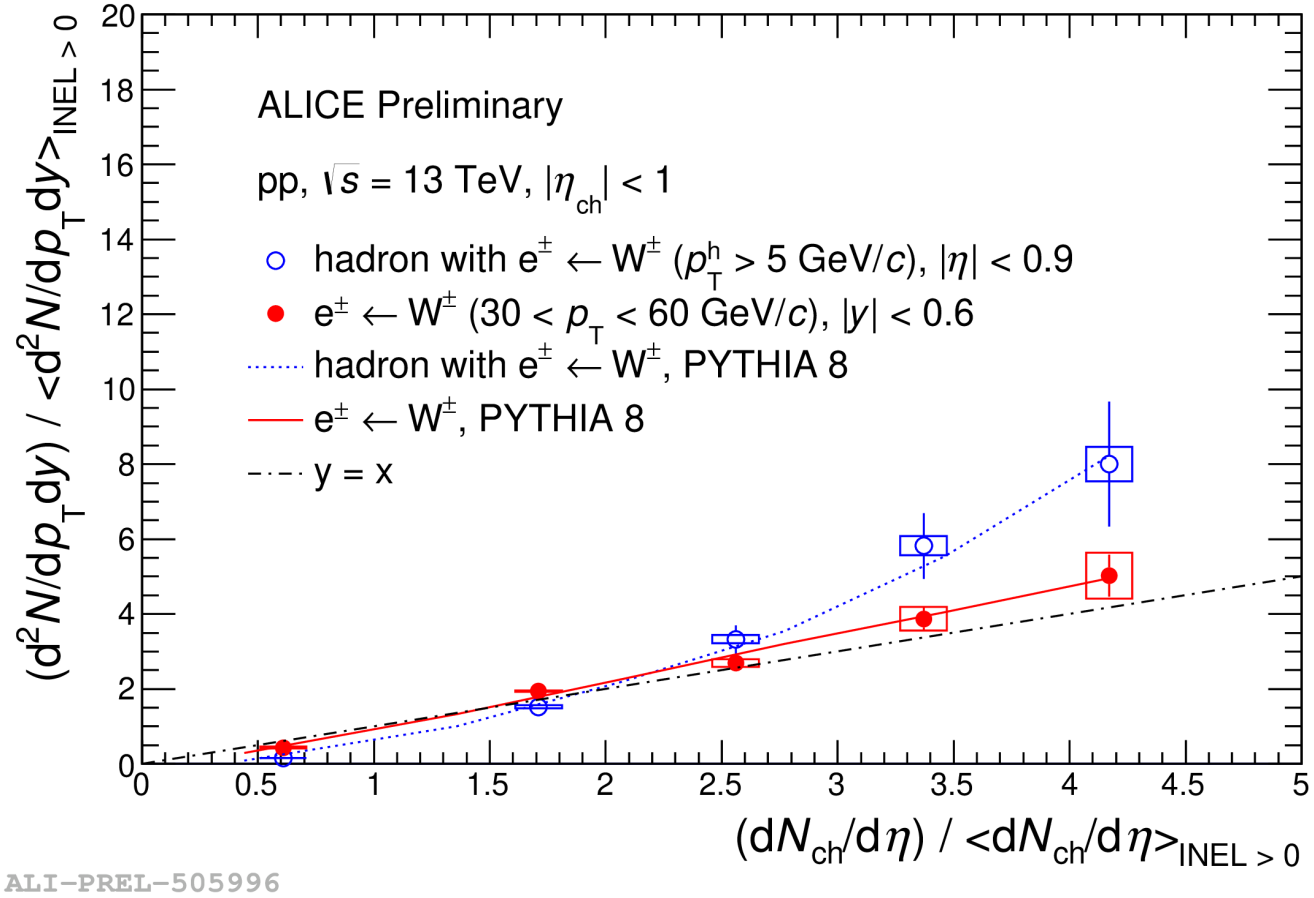
CT14nnlo: Dulat et al., PRD 93 (2016) 033006 CT18nlo: Yan et al., PRD 107 (2023) 116001 NNPDF4: Ball et al., EPJC 82 (2022) 428

Multiplicity dependence of $W^{\pm}$ and associated hadron

- $W^{\pm}$ boson production scales with charged particle multiplicity

- Faster-than linear increase of associated hadron production
  - Colour reconnection
    Christiansen, Skand, JHEP 08 (2015) 003
  - Auto-correlation in multiplicity estimation between jet-fragmentation products and hadrons
    Weber et al., EPJC 79 (2019) 1, 36





ALI-PREL-505996

Conclusions

- ALICE measured $W^{\pm}$ and Z^0 boson production in several collisions system and energies

p-Pb and Pb-Pb collisions:

- Study and constrain the nuclear parton distribution functions at large rapidities
  - Significant difference w.r.t. free PDFs observed

pp collisions:

- First EW boson measurement in pp collisions with ALICE
- $W^{\pm}$ production scales linearly with charged particle multiplicity; faster-than-linear increase observed for associated hadron production

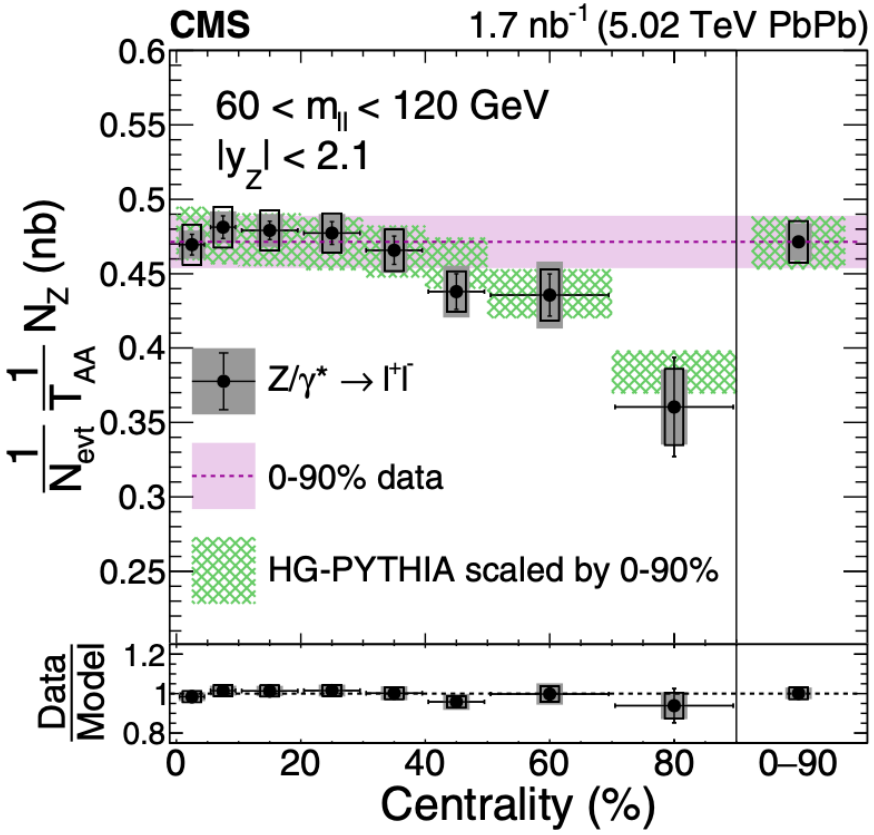
- Significant increase in luminosity expected in Run 3 => improve statistical precision!

Backup

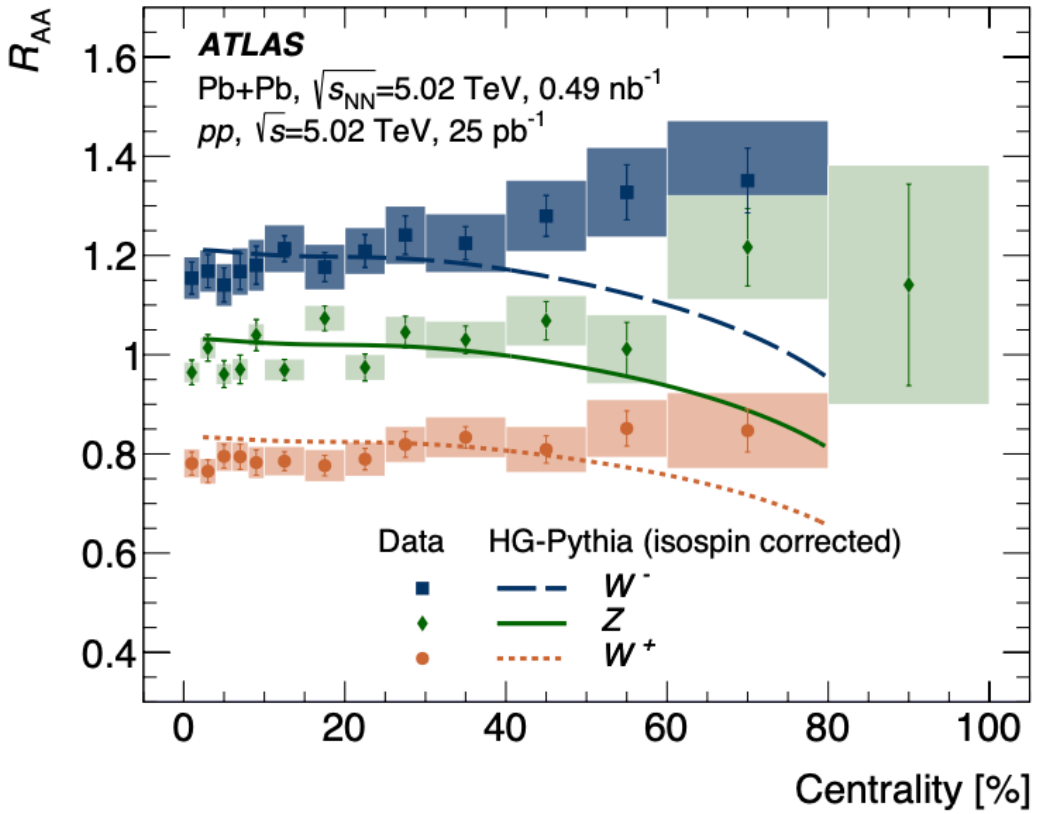
CMS and ATLAS

- Geometry and centrality selection effects visible in peripheral Pb-Pb collisions

PRL 127 (2021) 102002



PLB 802 (2020) 135262



- HG-PYTHIA describes CMS data but some tension with ATLAS data

HG-PYTHIA: Loizides, Morsch, PLB 773 (2017) 408-411