Electroweak boson production in p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE

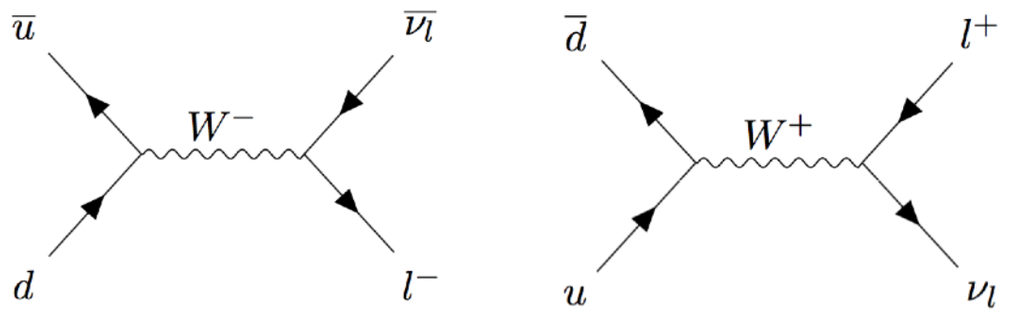
Diego Stocco
for the ALICE Collaboration

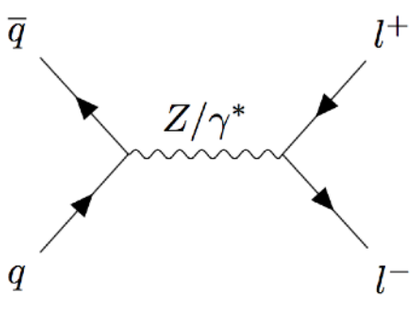
Subatech

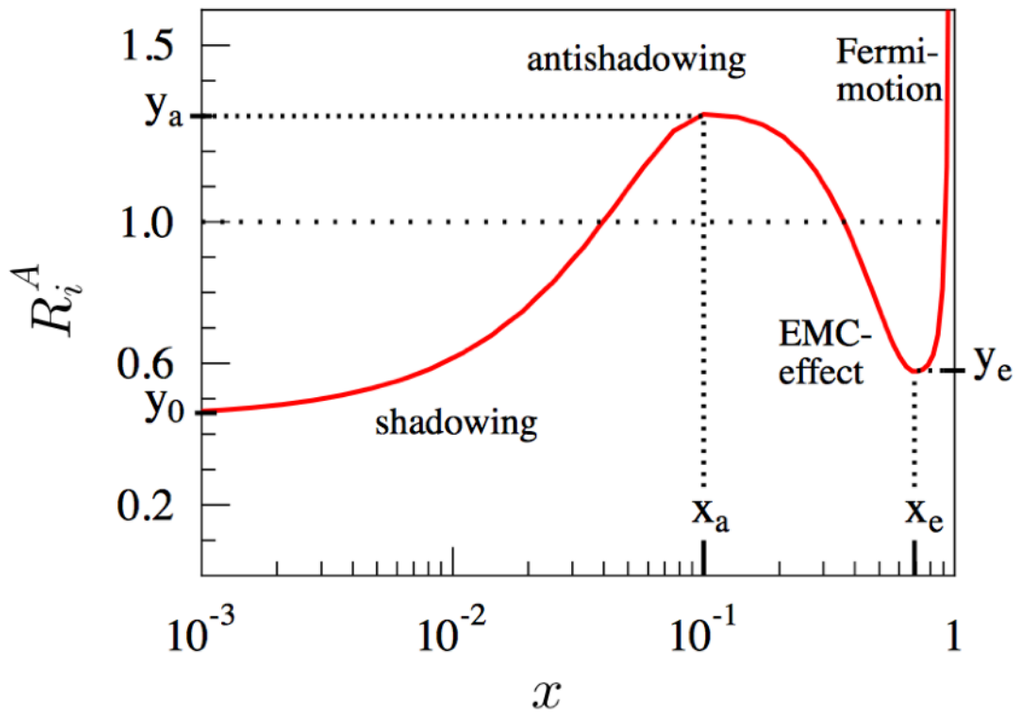
cnrs Institut Mines-Télécom UNIVERSITÉ DE NANTES

Motivation

- W/Z bosons in heavy-ion collisions:
  - produced in the initial hard scattering
  - unaffected by the strong interaction
  - production theoretically well-understood:
    - dependence on quark flavour (in particular for W)





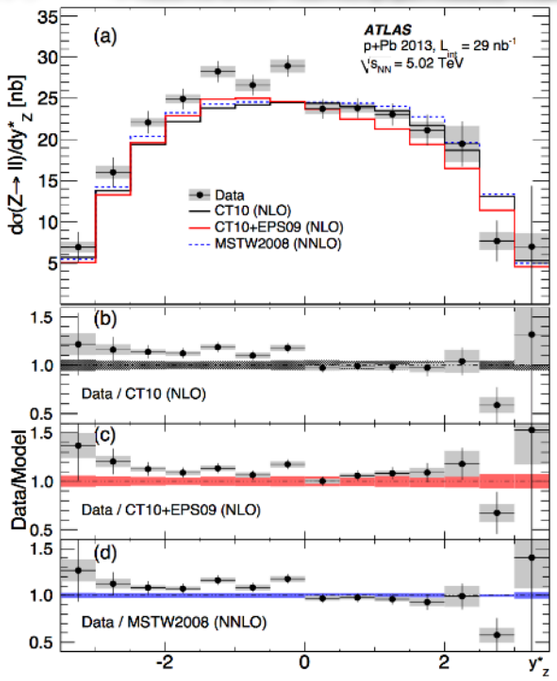


K.J.Eskola, H.Paukkunen, C.A.Salgado, JHEP 0904, 065 (2009)

- Sensitive to the nuclear modification of the PDFs
- Reference for hard probes measurements

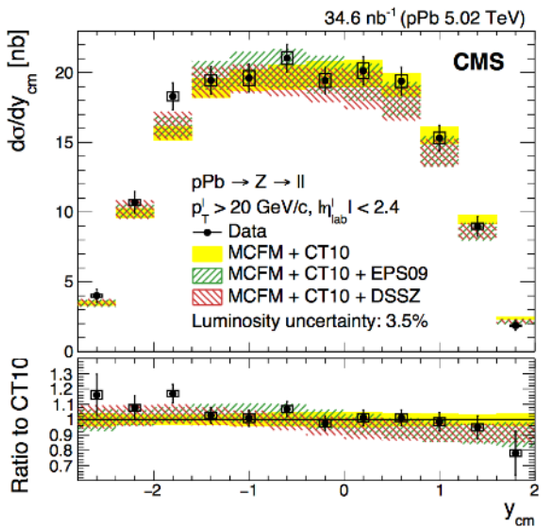
W/Z bosons in HI collisions at the LHC

- W/Z boson production measured in p-Pb and Pb-Pb collisions at the LHC

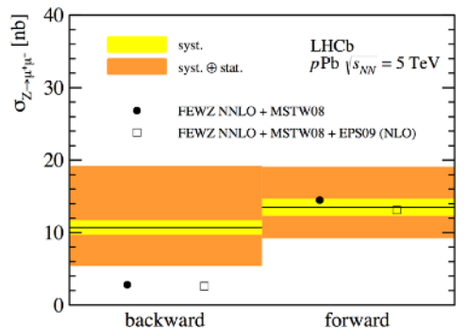


ATLAS, Phys.Rev.C 92, 044915 (2015)

Z p-Pb@5.02 TeV

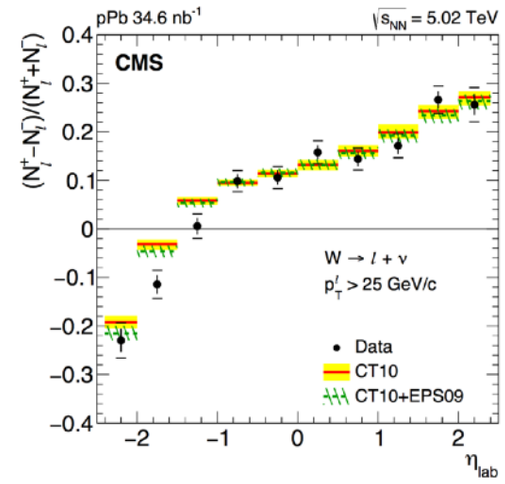


CMS, Phys.Lett.B 759, 36 (2016)



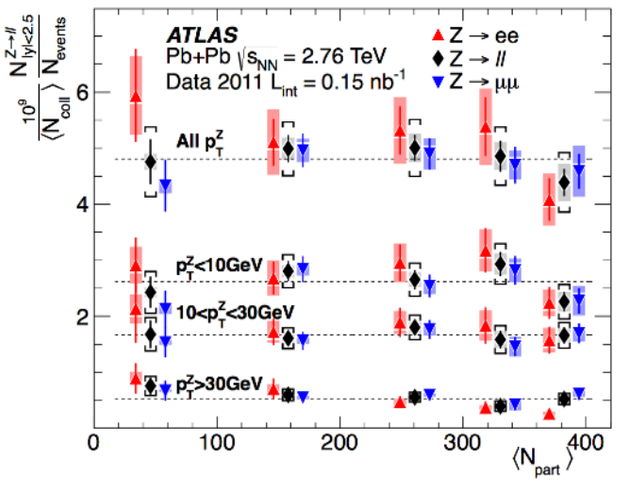
LHCb, JHEP 1409, 030 (2014)

W p-Pb@5.02 TeV

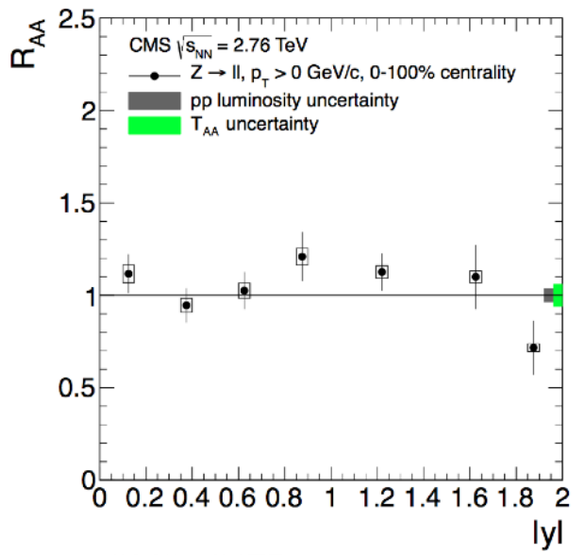


CMS, Phys.Lett.B 750, 565 (2015)

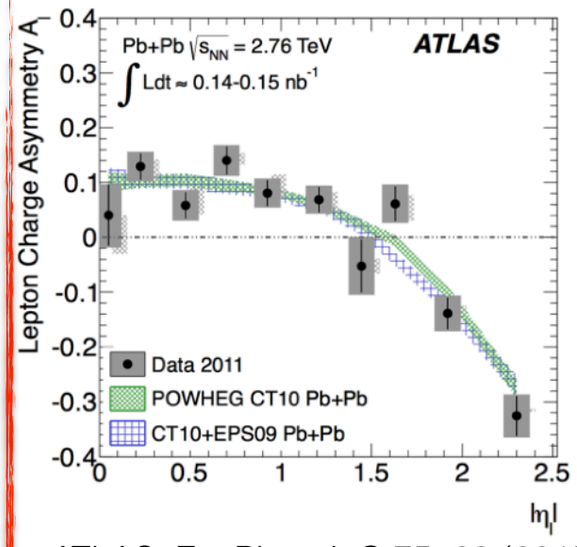
Z Pb-Pb@2.76 TeV



ATLAS, Phys.Rev.Lett. 110, 022301 (2013)

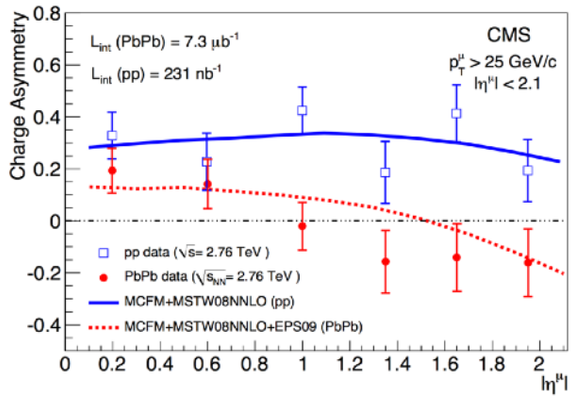


CMS, JHEP 1503, 022 (2015)



ATLAS, Eur.Phys.J. C 75, 23 (2015)

W Pb-Pb@2.76 TeV



CMS, Phys.Lett.B 715, 66 (2012)

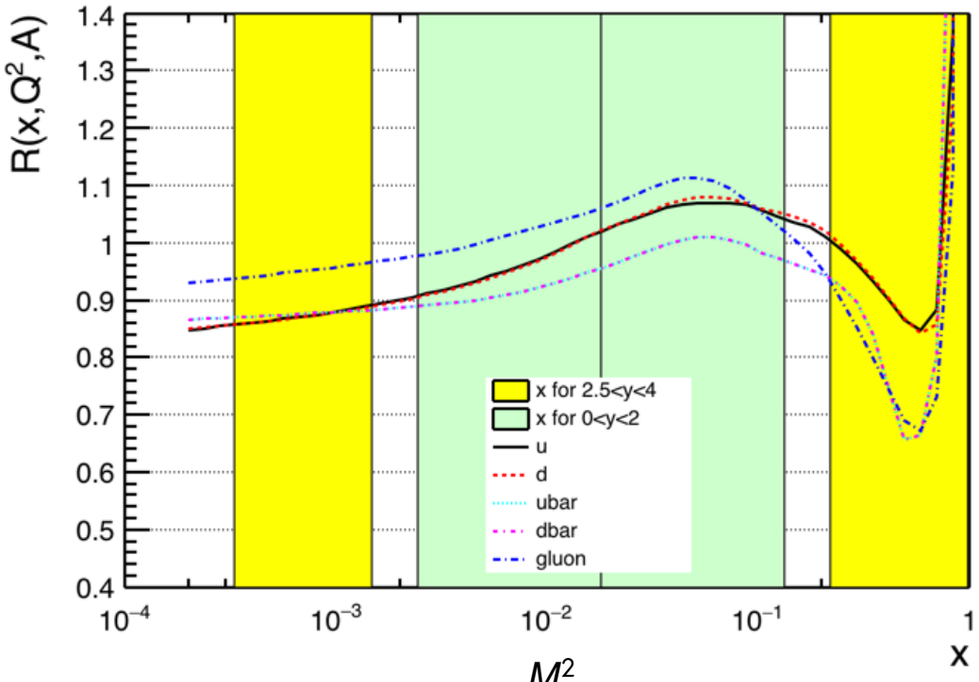
- Preference towards calculations including nPDF

Moving forward

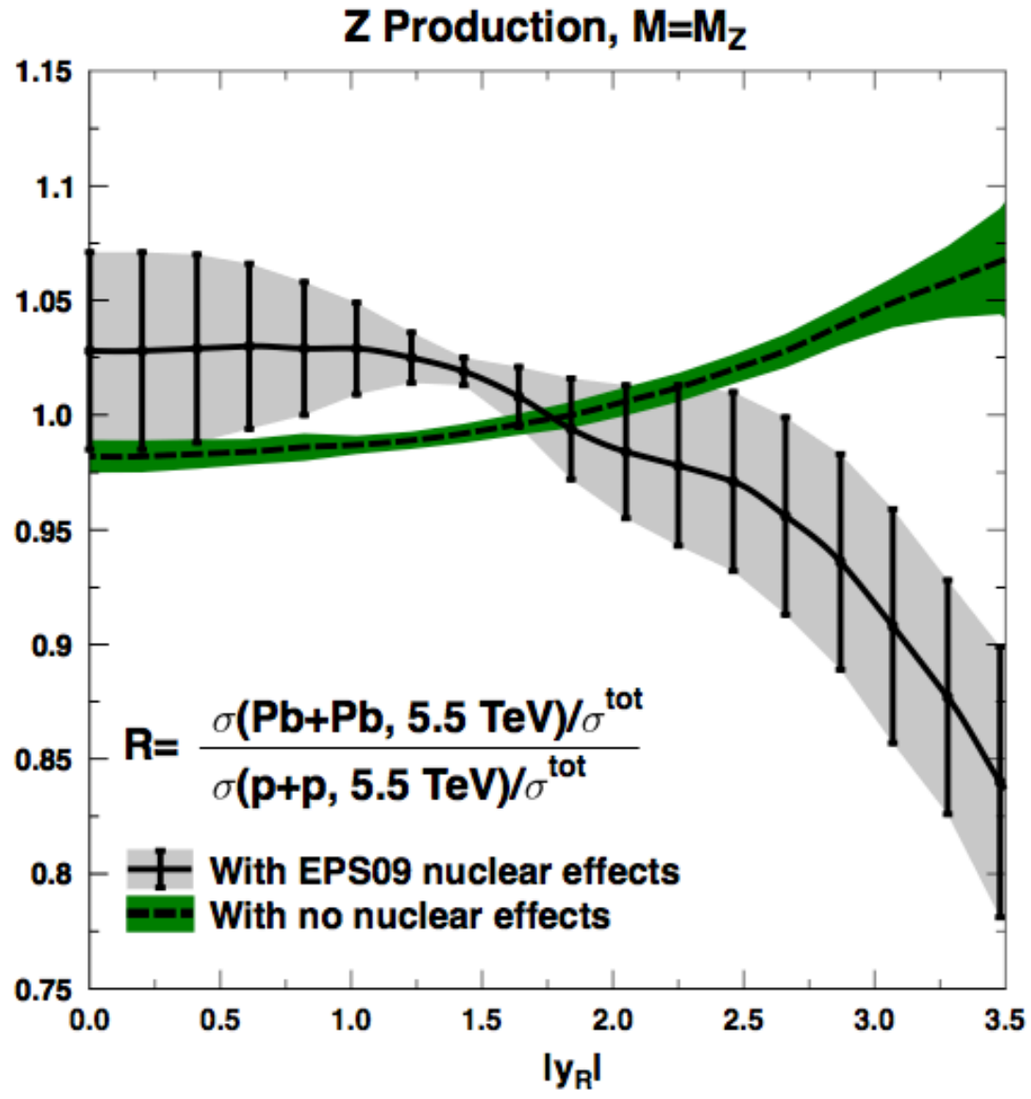
- The effect of nuclear modifications depends on rapidity (different Bjorken-*x* regions explored)

http://lapth.cnrs.fr/npdfgenerator/
$Q^2=M_Z^2$
nPDF=EPS09 NLO

EPS09: K.J.Eskola, H.Paukkunen, C.A.Salgado, JHEP 0904, 065 (2009)



$$x_{\pm} = \frac{M_Z^2}{\sqrt{s_{NN}}} e^{\pm y}$$



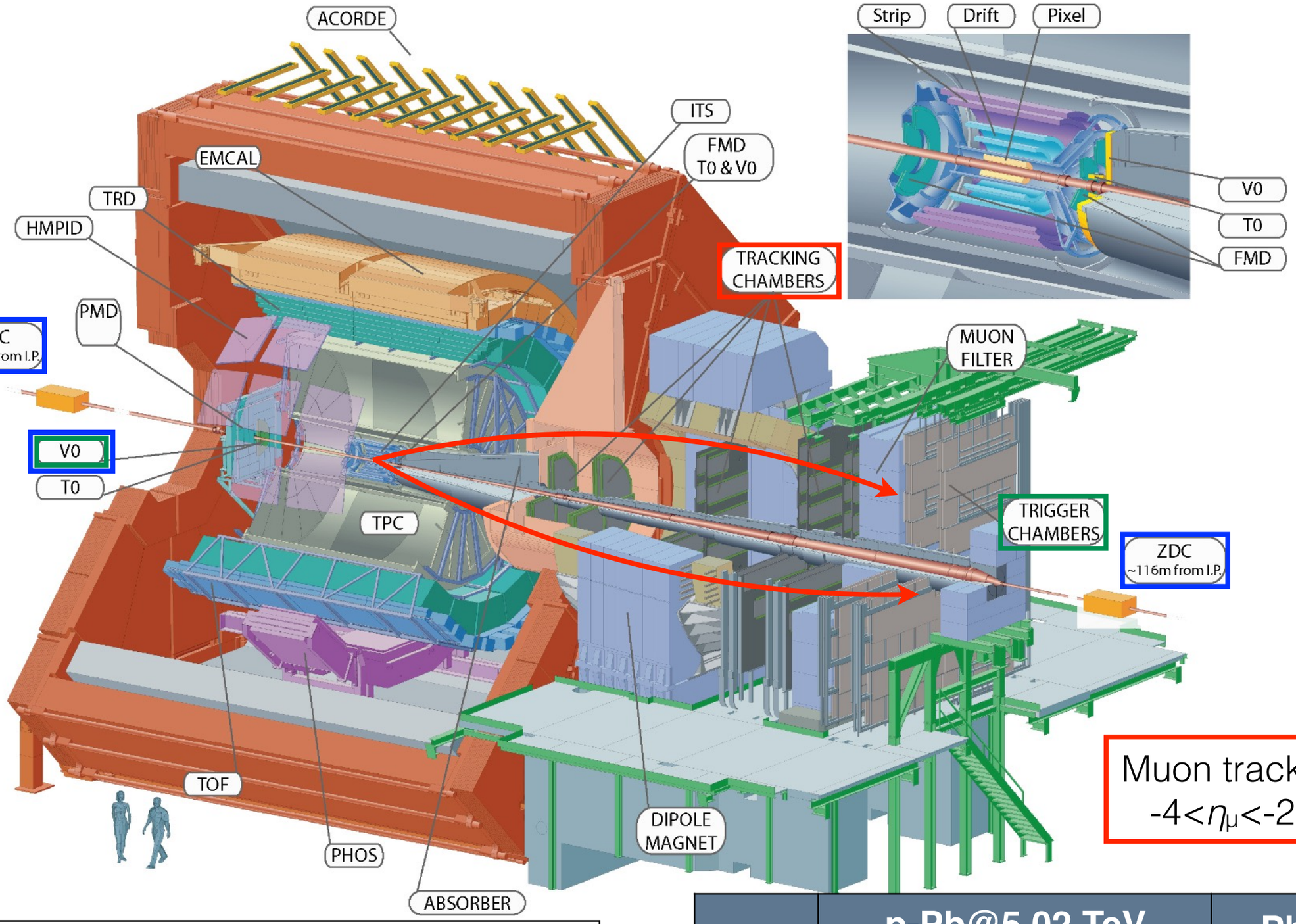
H.Paukkunen,C.A.Salgado,JHEP 1103, 071 (2011)

- ALICE can measure Z- and W-boson production at forward *y*, also in Pb-Pb collisions

The ALICE experiment

Centrality selection

Trigger



Muon tracking
$-4<\eta_\mu<-2.5$

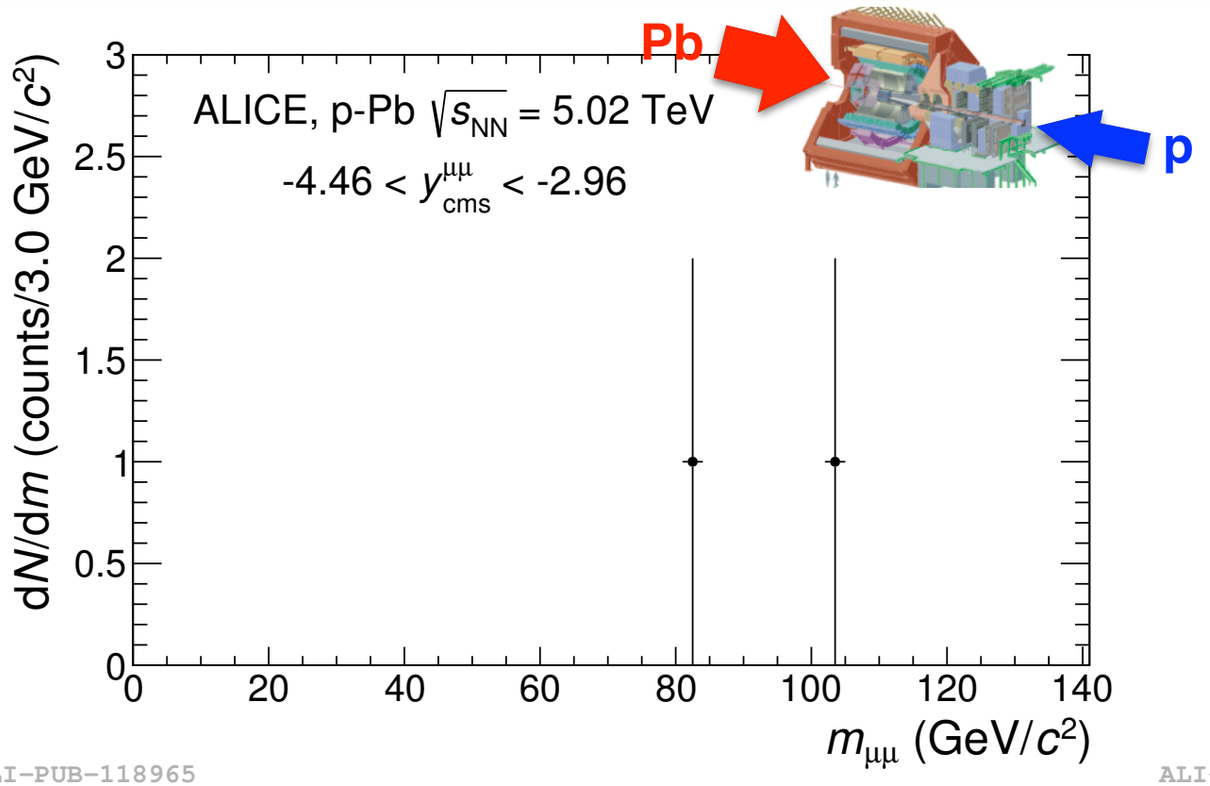
- Pb-going: Pb → ← p $-4.46<y_{CMS}<-2.96$
- p-going: p → ← Pb $2.03<y_{CMS}<3.53$

	p-Pb@5.02 TeV		Pb-Pb @5.02 TeV
	Pb-going	p-going	
Lum.	5.81/nb	5.03/nb	225/μb

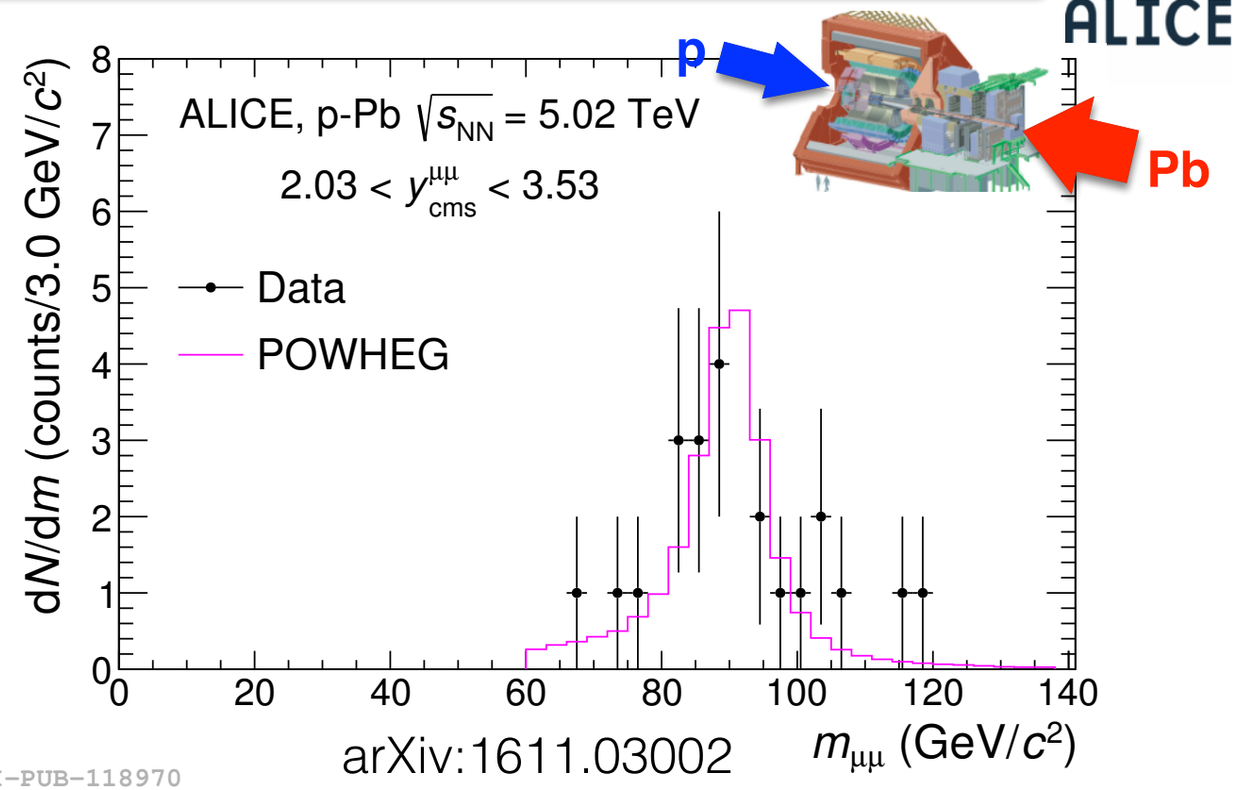
p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

arXiv:1611.03002

Z-boson measurement



ALI-PUB-118965



ALI-PUB-118970

arXiv:1611.03002

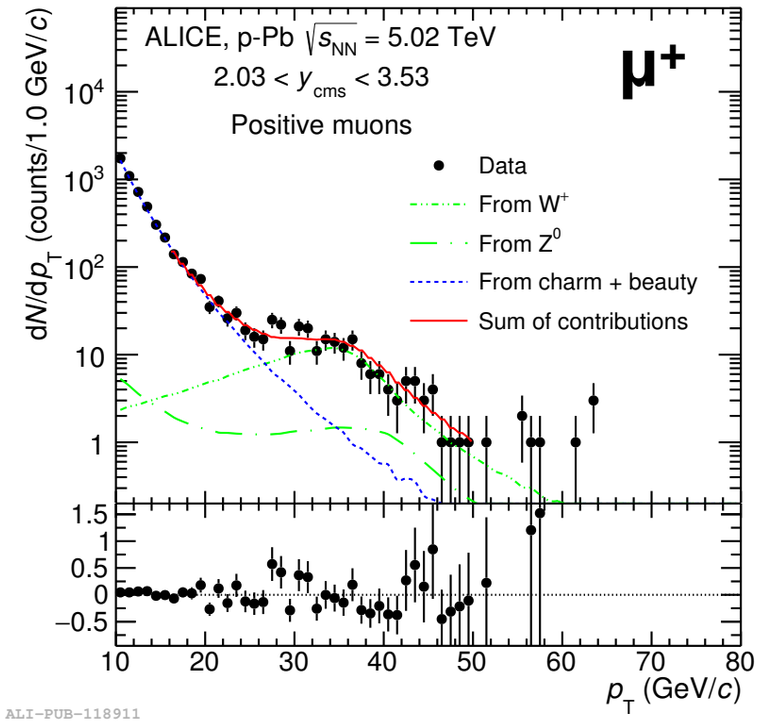
- Searching for candidates with:
  - $p_T(\mu)>20$ GeV/c
  - $60<m_{\mu\mu}<120$ GeV/c^2
- No observed candidate in the like-sign dimuon spectrum
- Expected contribution from $c\bar{c}$, $b\bar{b}$, $t\bar{t}$ and muonic decay of τ pairs:
  Pb-going: 0.7% p-going: 0.4%
- Signal extracted from a bin counting in $60<m_{\mu\mu}<120$ GeV/c^2 (results compatible with a gaussian fit)

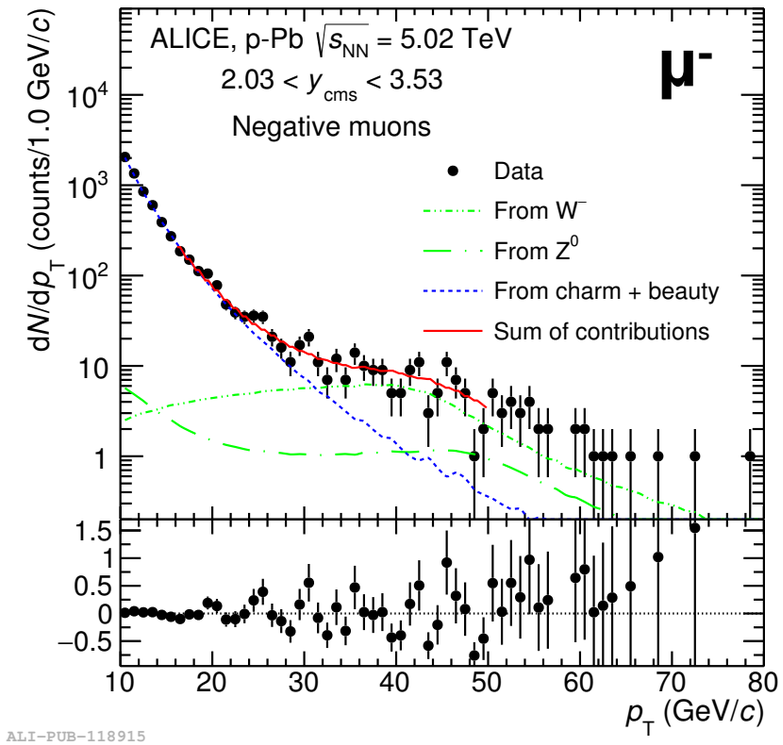
W-boson measurement

- Signal extracted through MC template fit of the single muon p_T distribution:

$$f(p_T) = N^{raw}_{bkg} f_{bkg}(p_T) + N^{raw}_{\mu \leftarrow W}\left(f_{\mu \leftarrow W}(p_T) + R f_{\mu \leftarrow Z}(p_T)\right)$$

Free parameters — MC templates — Fixed to POWHEG





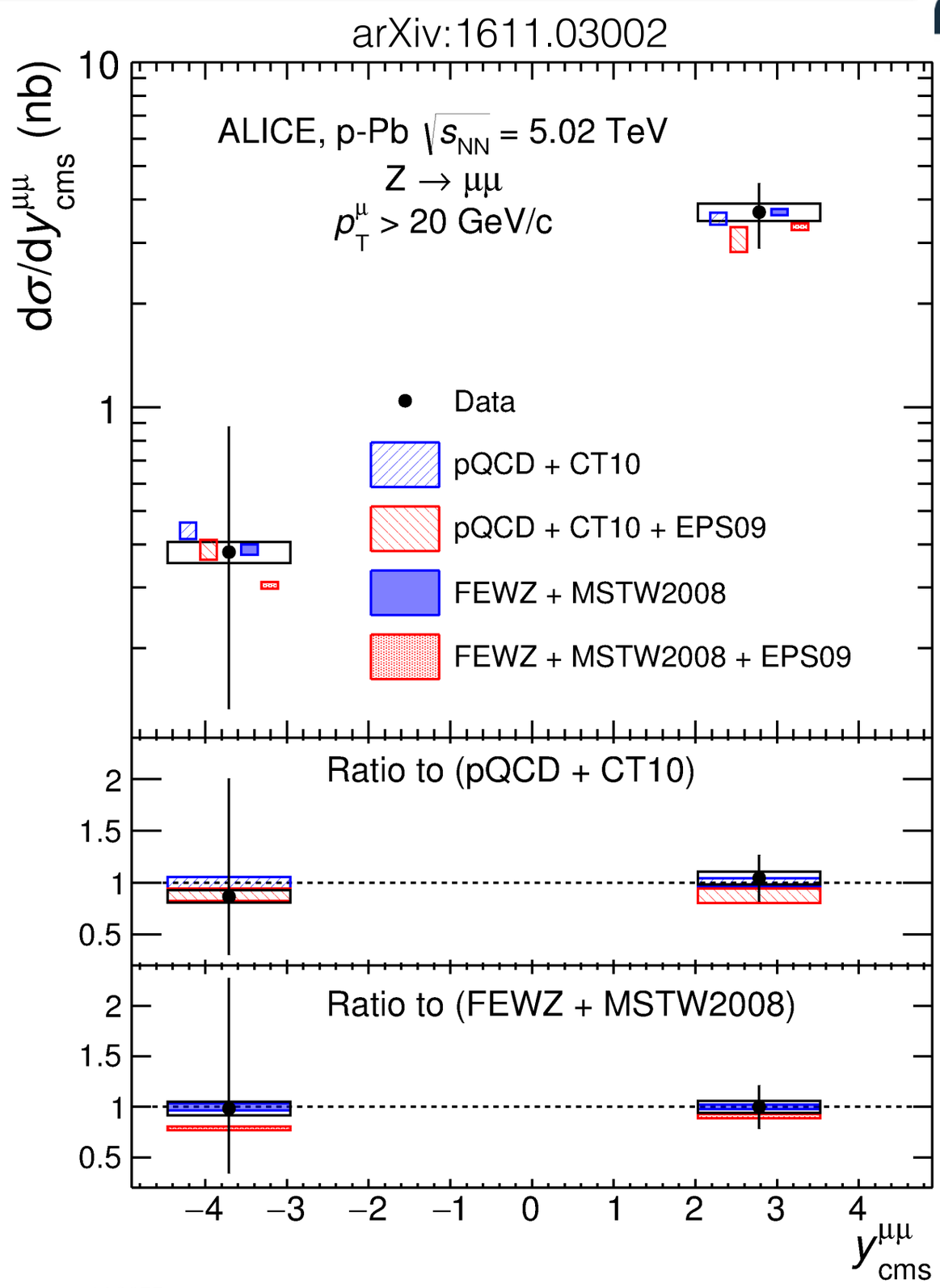
arXiv:1611.03002

- MC inputs: FONLL (HF), POWHEG (W,Z)
- Several fit iterations varying the shape of the templates accounting for: variation of inputs (scales, PDFs); uncertainties on momentum resolution
- Results obtained averaging over all fit results

FONLL: M.Cacciari et al., JHEP 10, 137, (2012)
POWHEG: S. Alioli et al., JHEP 07, 060 (2008)

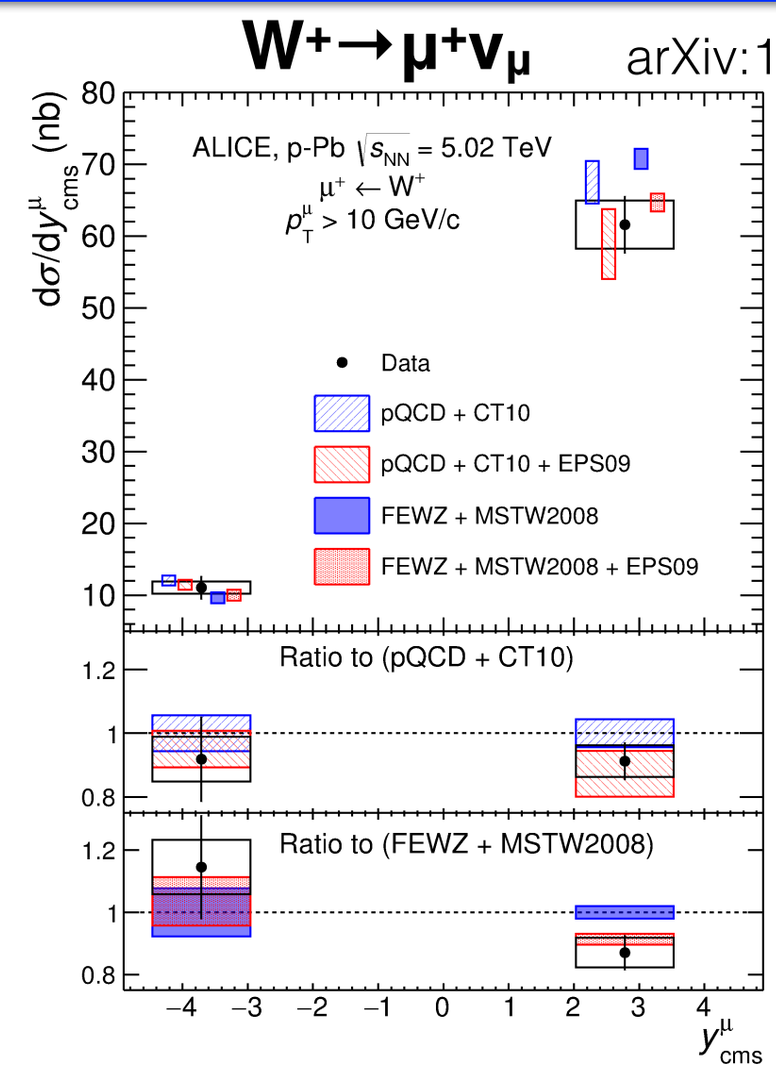
Z-boson cross section in p-Pb collisions

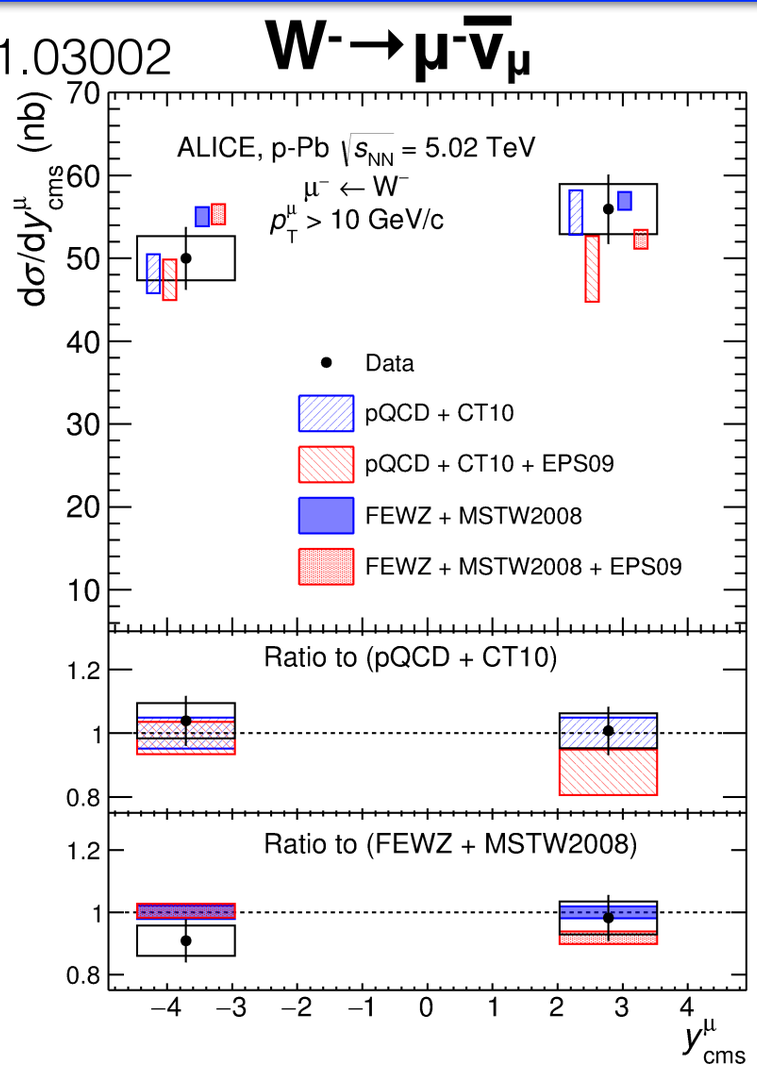
- Z-boson cross section compared with:
  - pQCD calculations (NLO)
  - FEWZ calculations (NNLO)
- Results in agreement with calculations with and without including nPDFs (EPS09)

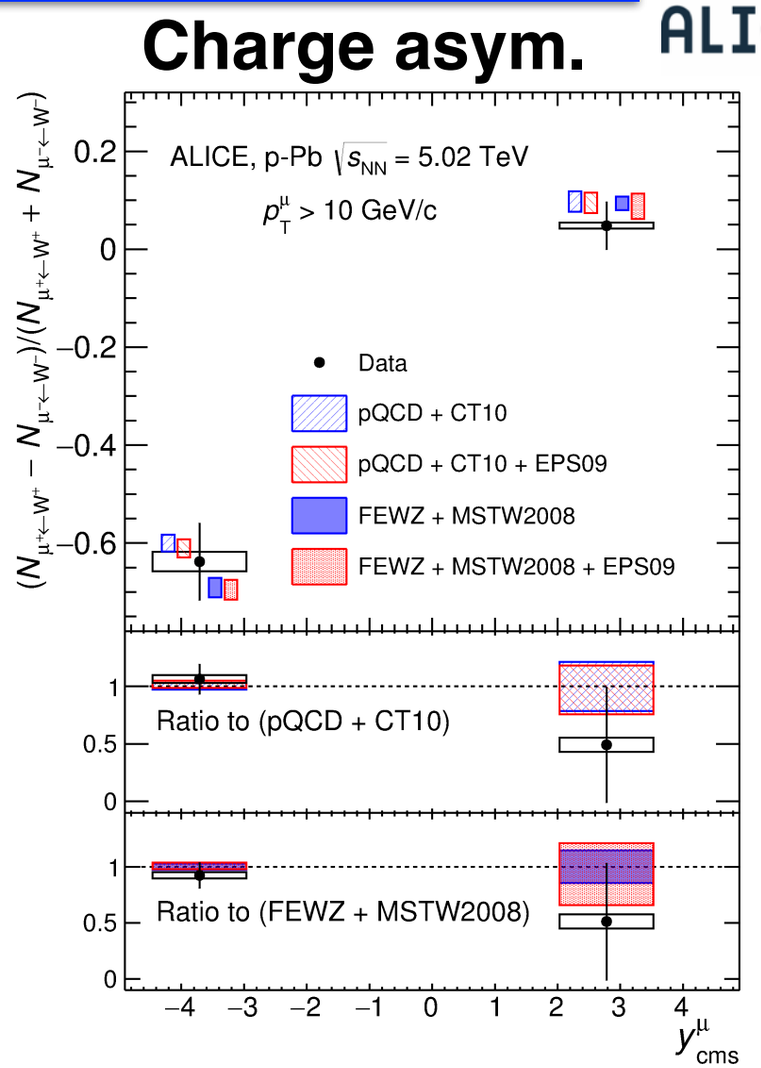


H.Paukkunen, C.Salgado, JHEP 1103, 071 (2011)
R.Gavin et al. Comput. Phys. Commun. 182, 2388 (2011)

W-boson results in p-Pb collisions



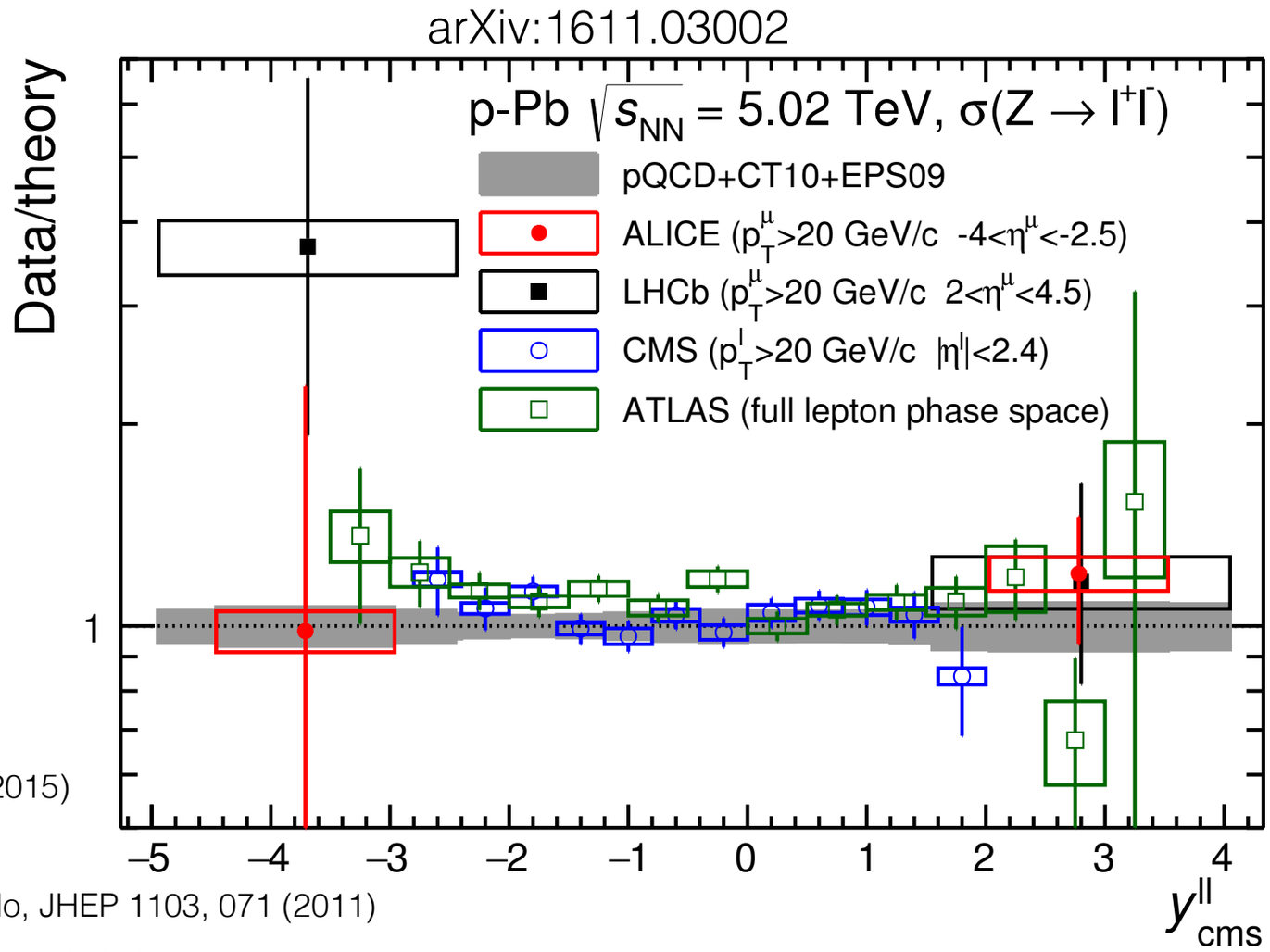




- Measurement of **cross section** of muons from W-boson decay with $p_T(\mu)>10$ GeV/c
- Measurement of **lepton charge asymmetry**: $\dfrac{N_{\mu^+\leftarrow W^+} - N_{\mu^-\leftarrow W^-}}{N_{\mu^+\leftarrow W^+} + N_{\mu^-\leftarrow W^-}}$
  - part of theoretical and experimental uncertainties cancel in the ratio
- Compared with pQCD and FEWZ:
  - in agreement with calculations with and without including nPDFs

Comparison with other experiments: Z boson

- Results not directly comparable (different kinematic cuts): compare the ratio over the corresponding pQCD predictions with nPDFs



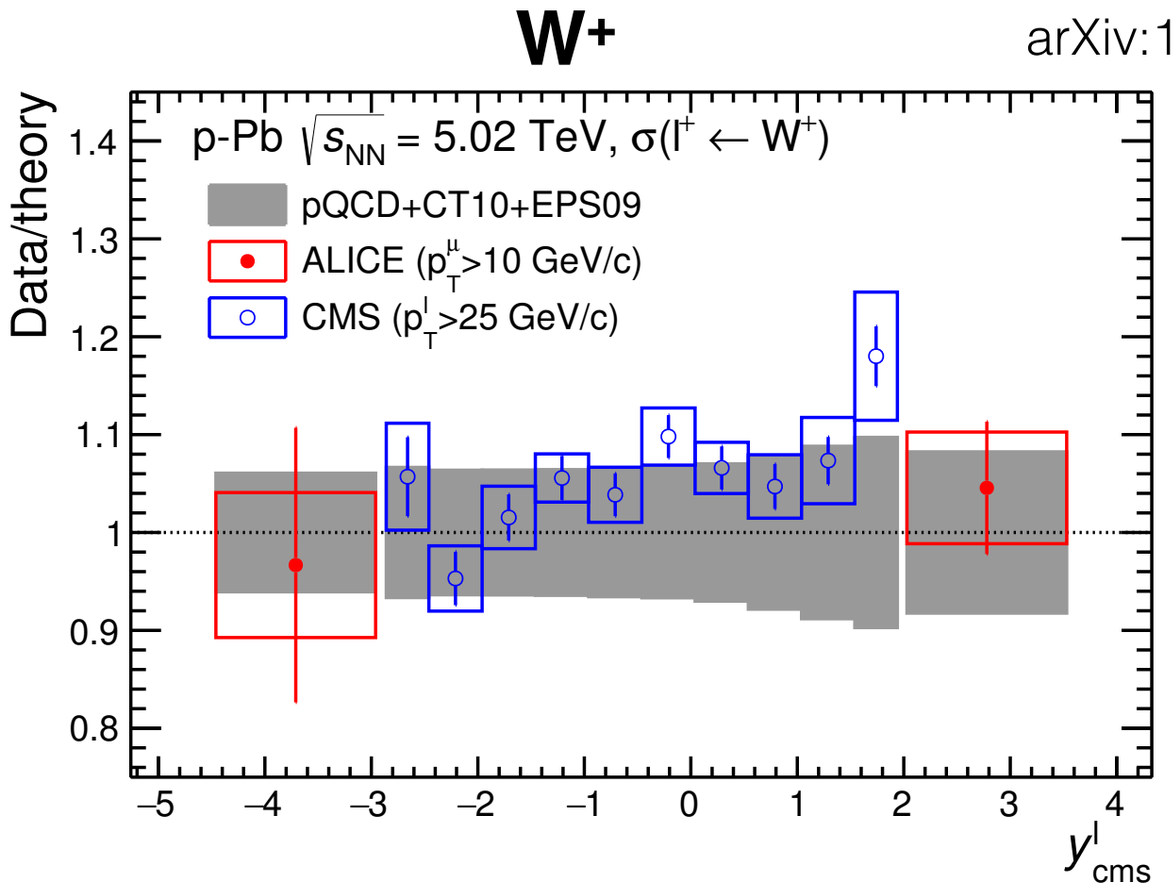
ATLAS, Phys.Rev.C 92, 044915 (2015)
CMS, Phys.Lett.B 759, 36 (2016)
LHCb, JHEP 1409, 030 (2014)
pQCD: H.Paukkunen, C.A.Salgado, JHEP 1103, 071 (2011)

ALI-PUB-118985

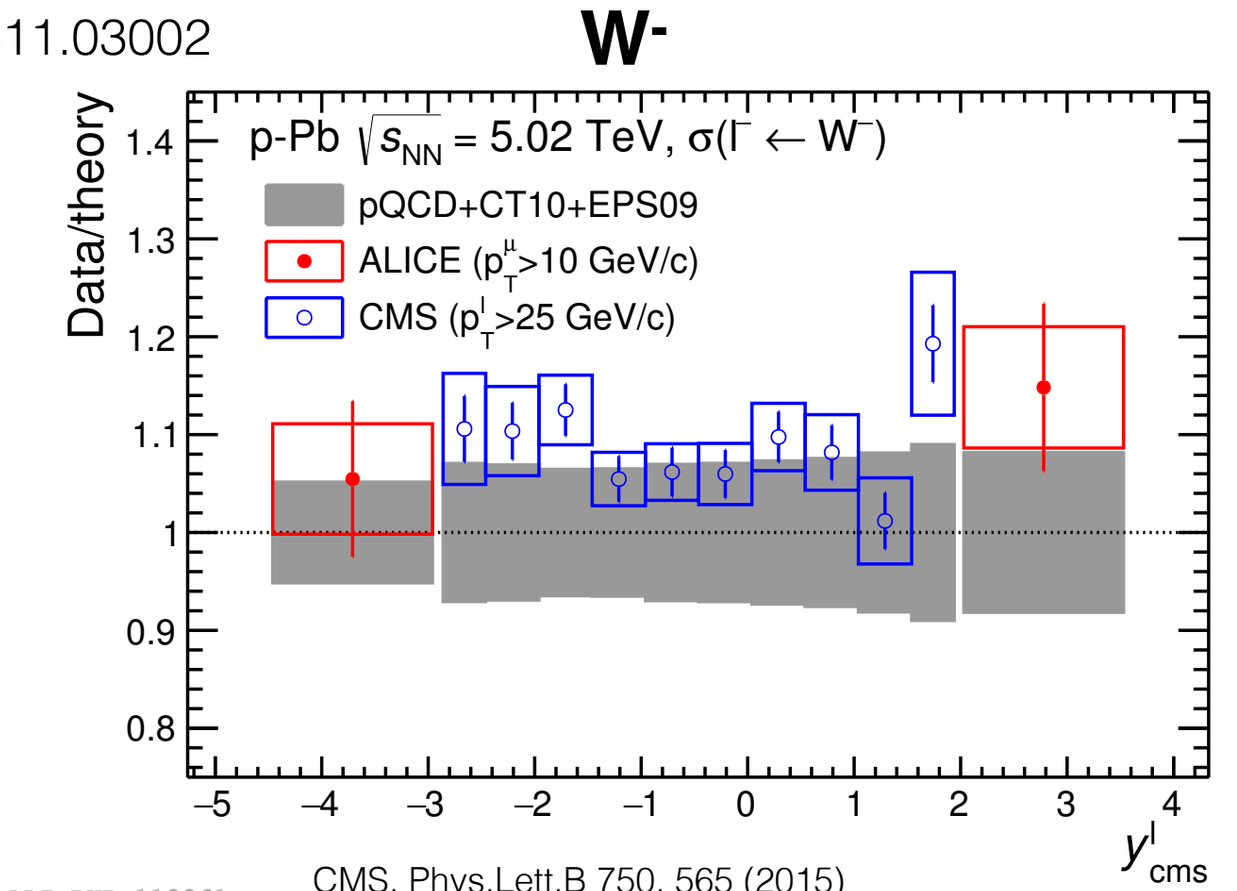
- ALICE measurement in a rapidity region complementary to CMS and ATLAS. Slightly better precision than LHCb

- Calculations can describe data over the full rapidity interval

Comparison with other experiments: W boson



arXiv:1611.03002

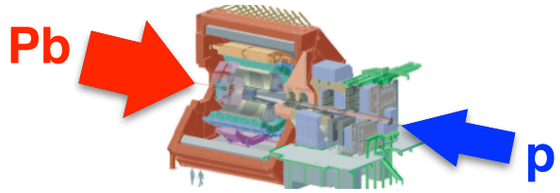


CMS, Phys.Lett.B 750, 565 (2015)
pQCD: H.Paukkunen, C.A.Salgado, JHEP 1103, 071 (2011)

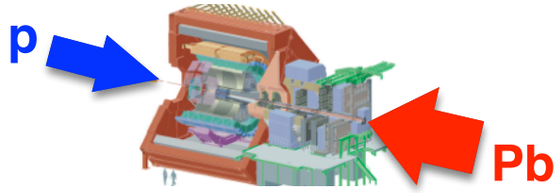
- Comparison with CMS data:
  - results divided by predictions from pQCD calculations with nPDFs
- Calculations can describe data over the full rapidity interval explored

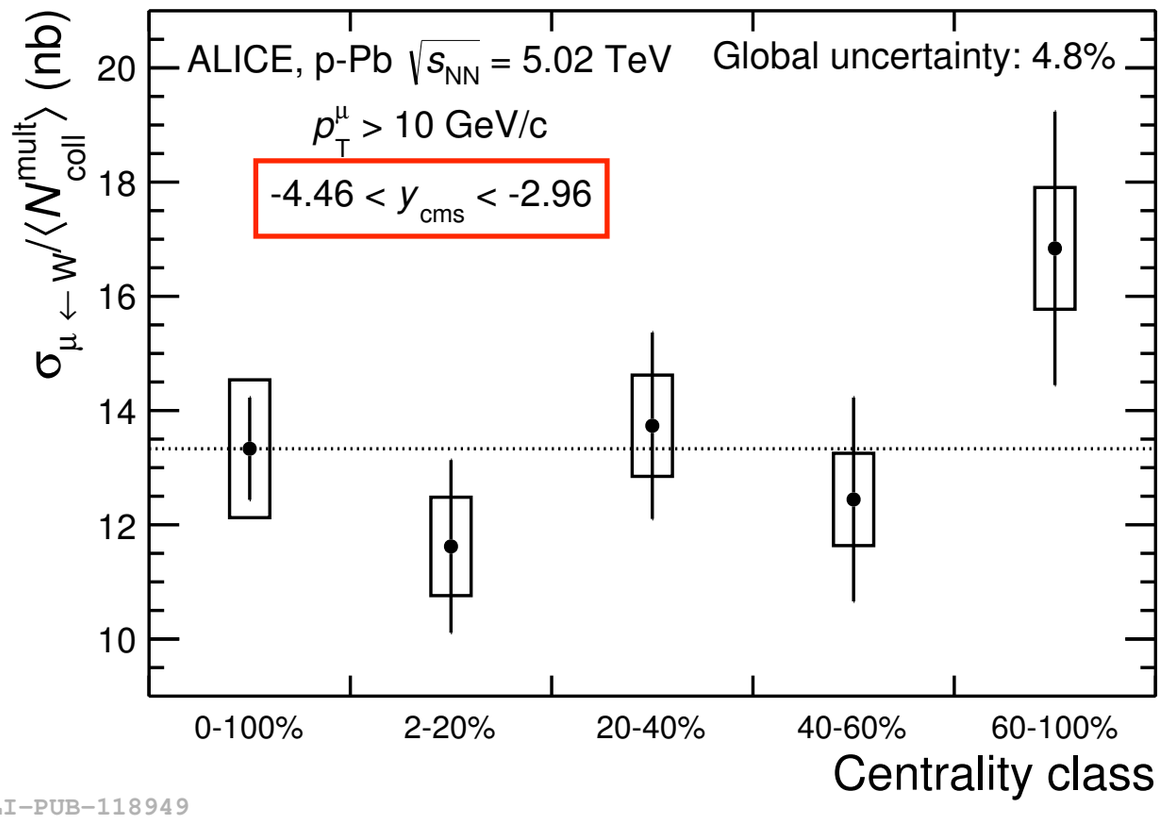
W boson: centrality dependence

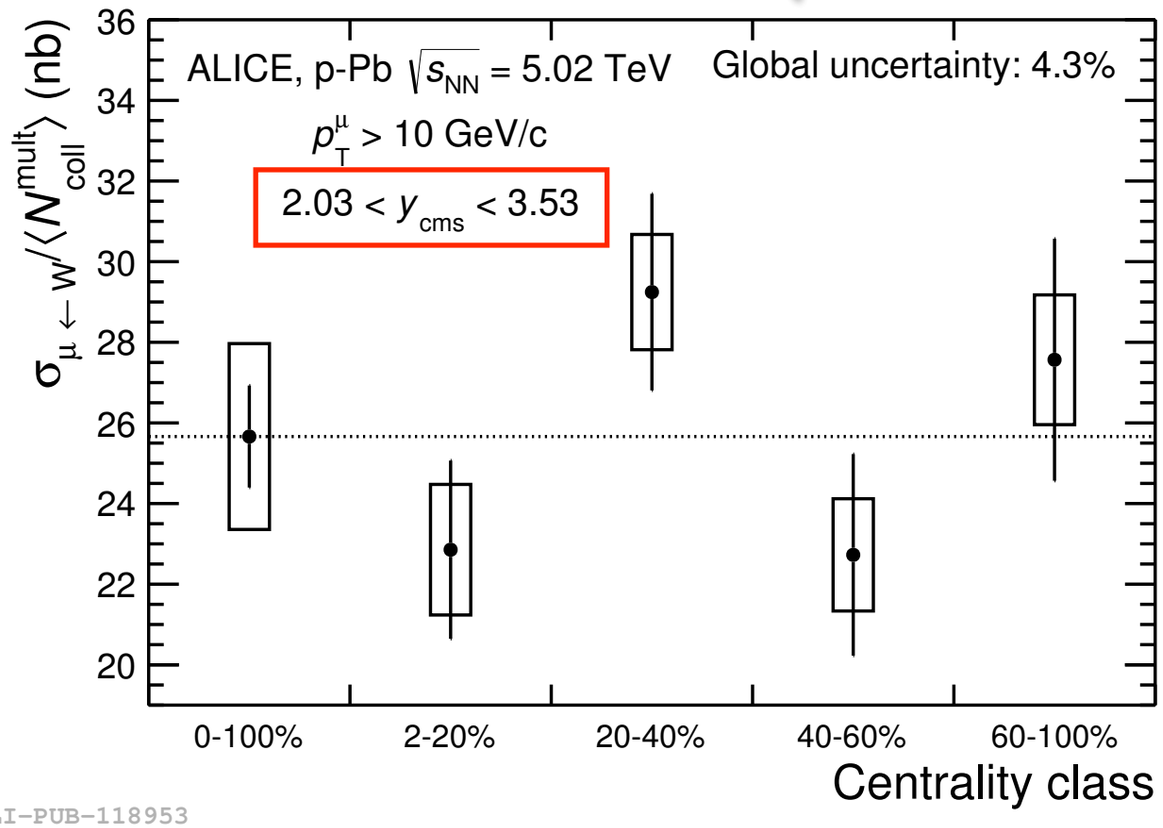
- Centrality dependence of W-boson production measured at forward (p-going) and backward (Pb-going) rapidities



arXiv:1611.03002







- Centrality dependence compatible with constant within uncertainties
- New data with $\sqrt{s_{NN}}$ = 8.16 TeV with larger statistics collected in 2016

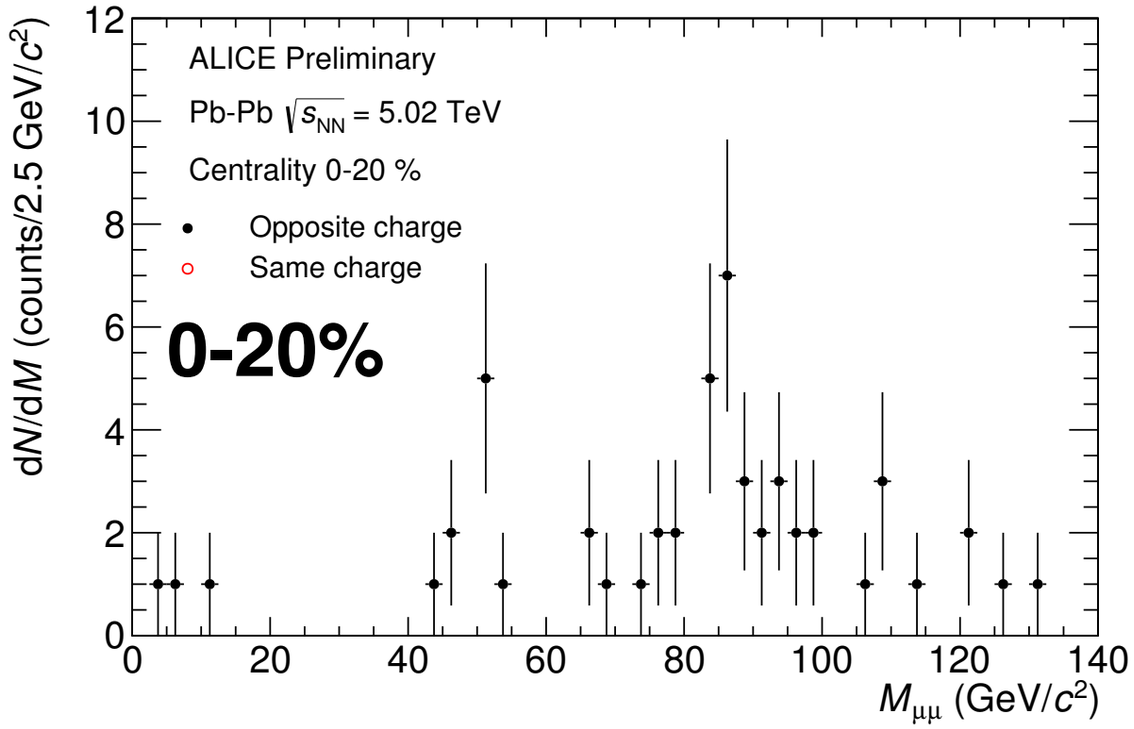
New

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

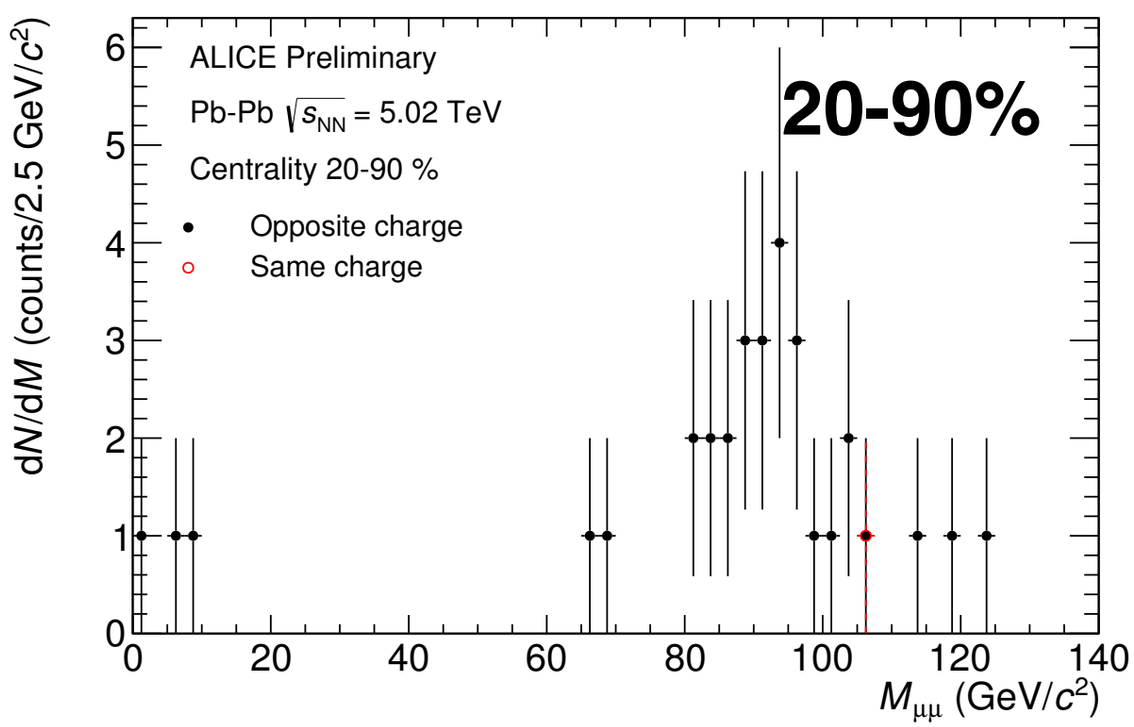
Z-boson measurement in Pb-Pb collisions

- First measurement of Z-boson production at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- Same analysis strategy as for p-Pb



ALI-PREL-124470



ALI-PREL-124482

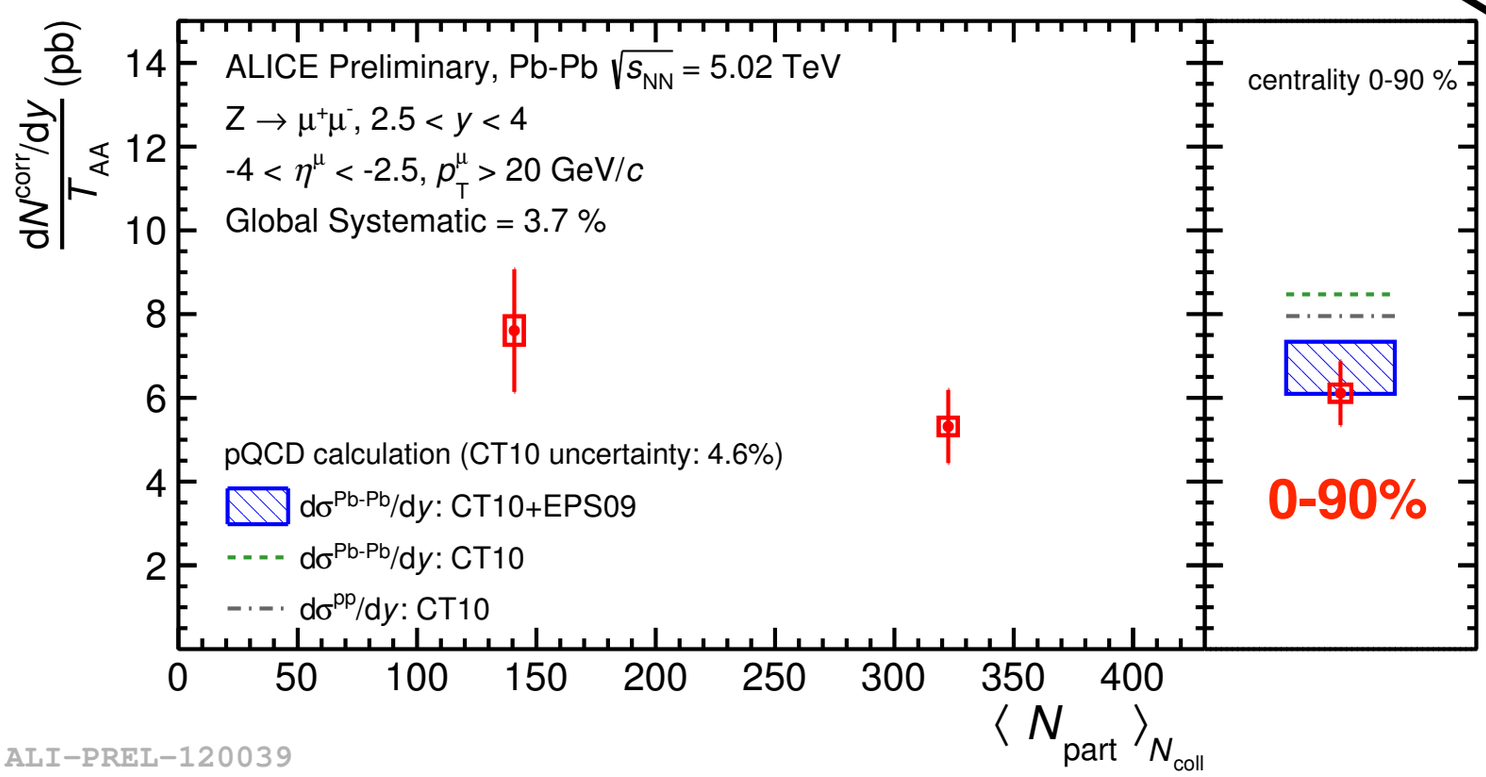
- Z-boson signal in (60<$m_{\mu\mu}$<120 GeV/c^2)

- Low invariant masses (<15 GeV/c^2): high-p_T $c\bar{c}$, $b\bar{b}$ pairs and resonances

- Intermediate masses (40<$m_{\mu\mu}$<60 GeV/c^2): compatible with Drell-Yan

Z-boson normalised yields

- Z-boson yield per MB event divided by T_{AA}



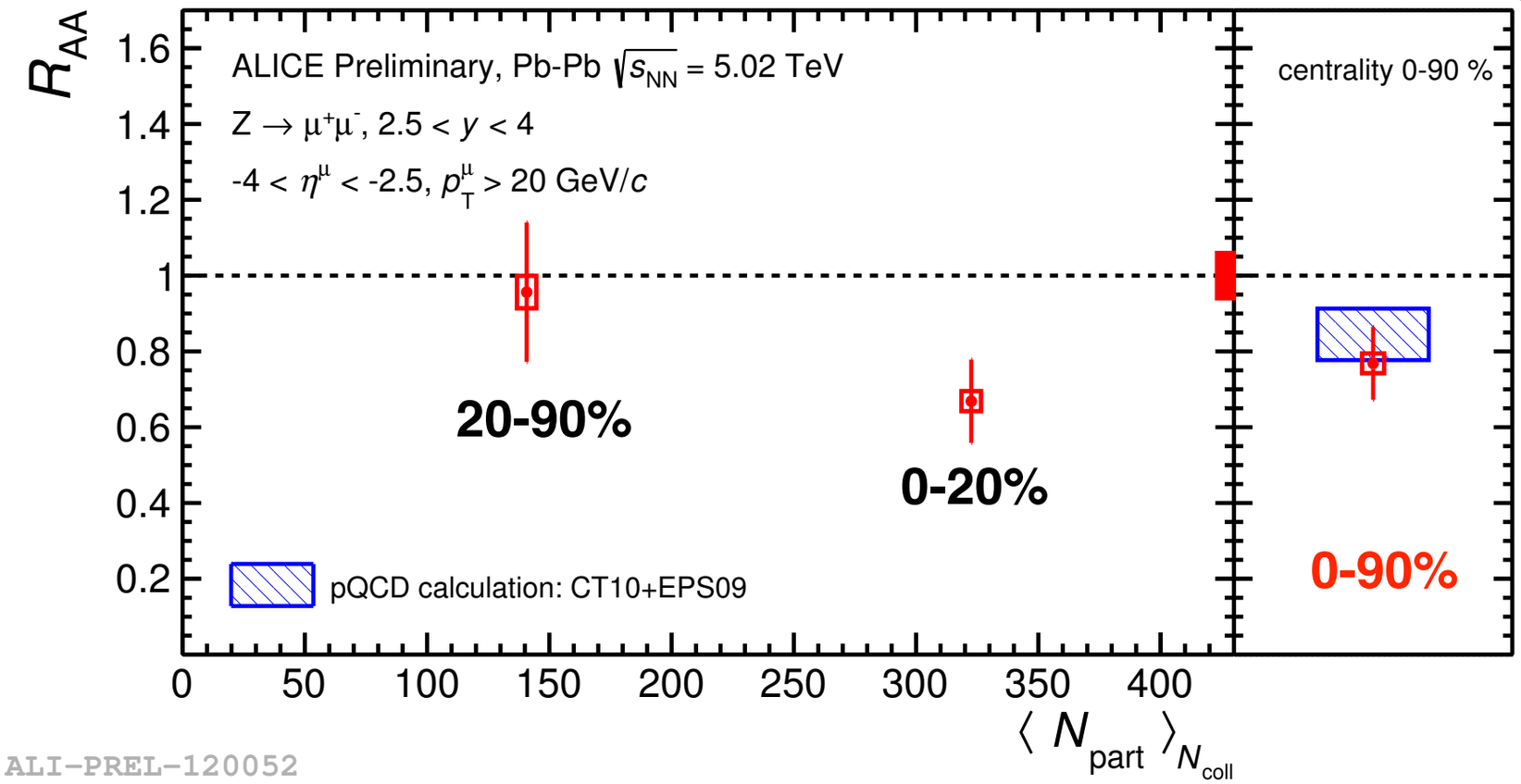
- Centrality integrated results compared with pQCD calculations with CT10:
  - expected Pb-Pb yields w/o nPDF (accounts for pp,pn,np,nn collisions) larger than expected yields in pp collisions
  - expected Pb-Pb yields w/ nPDF smaller than expected yields in pp collisions
- Results compatible with calculations including nPDFs (integrated results differs from expectations w/o nPDF by 2.6 σ)

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

Z-boson R_{AA}

- First measurement of Z-boson R_{AA} in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV at forward rapidities
  - pp reference: pQCD calculations with CT10 (compatible results obtained with FEWZ with MSTW2008)

New



- R_{AA} smaller than unity by 2.76 σ (stat.+syst.+global syst.) in the 0-20% most central collisions
- In agreement with calculations including nPDFs

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

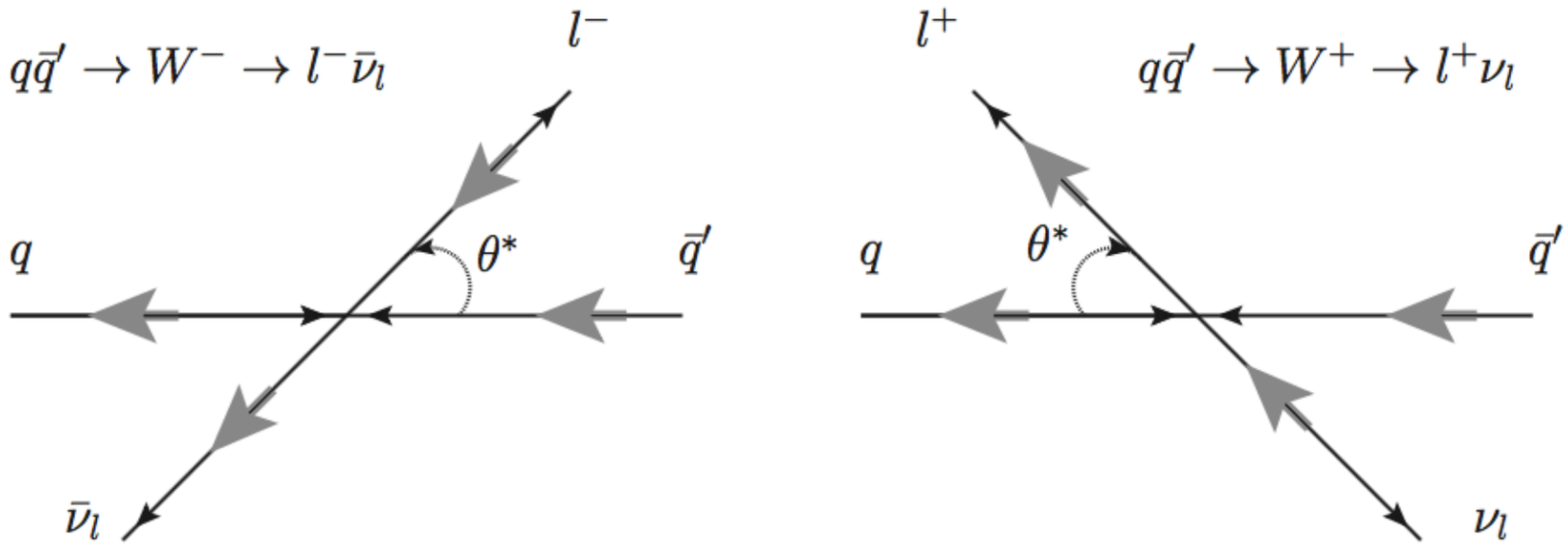
Conclusions

- W- and Z-boson production measured at **forward rapidity** in **p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV**
  - W boson measured in a complementary *y* range w.r.t. CMS
  - Z boson measured with slightly better precision than LHCb
- Results compared with NLO and NNLO calculations:
  - calculations describe data within uncertainties, but not enough precision to conclude on nPDFs
- W-boson production measured as a function of centrality: no dependence observed within uncertainties
- **First measurement** of **Z-boson** production at **forward rapidity** in **Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV**
  - yields smaller than expectations w/o nPDFs
  - nuclear modification factor smaller than unity: described by pQCD calculations including nPDFs

Extra slides

W boson kinematics

- W/Z boson mainly produced by valence quarks (carry more momentum than sea quarks)
- Electroweak interaction couples left-handed fermions with right-handed anti-fermions
- Helicity is conserved at high energies



- This implies:
  - μ^- mainly emitted in the direction of the incoming quark
  - μ^+ mainly emitted in the opposite direction of the incoming quark

p-Pb collisions: systematics

Z boson	Pb-going	p-going
Bkg. contamination	<1%	
Tracking efficiency	6%	4%
Trigger efficiency	2%	
Tracker/trigger matching	1%	
Alignment	2%	1%
Normalisation factor	1%	
MB cross section	3%	

W boson	Pb-going	p-going
Signal extraction	2 - 6%	
vs centrality	5 - 15%	
Tracking efficiency (*)	3%	2%
Trigger efficiency (*)	1%	
Tracker/trigger matching (*)	1%	
Alignment (*)	2%	1%
Normalisation factor (*)	1%	
MB cross section (*)	3%	
Pile-up	1 - 3%	
$\langle N_{coll}^{mult} \rangle$	2 - 8%	

(*) = correlated vs centrality

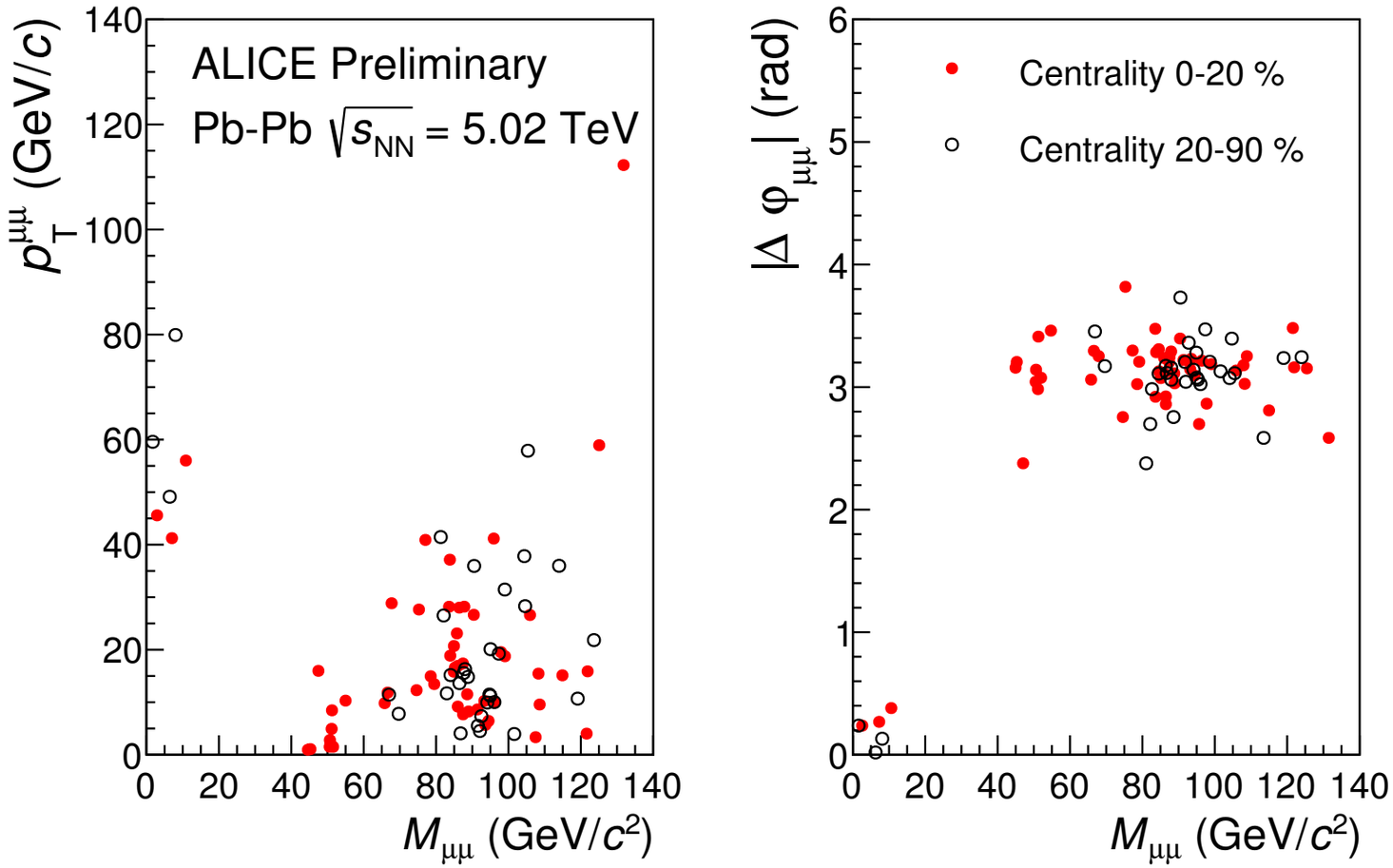
Pb-Pb collisions: systematics

Z boson	
Signal extraction	1%
Tracking efficiency (*)	3%
Trigger efficiency (*)	1.5%
Tracker/trigger matching (*)	1%
Normalisation factor (*)	0.5%
pp cross section (*)	4.6%
Centrality limits	1.5 - 2.3%
$\langle T_{AA} \rangle$	3.2 - 3.6%

(*) = correlated vs centrality

Dimuon kinematics in Pb-Pb collisions

- Distribution of dimuons passing analysis cuts and with: $p_T(\mu)>20$ GeV/c



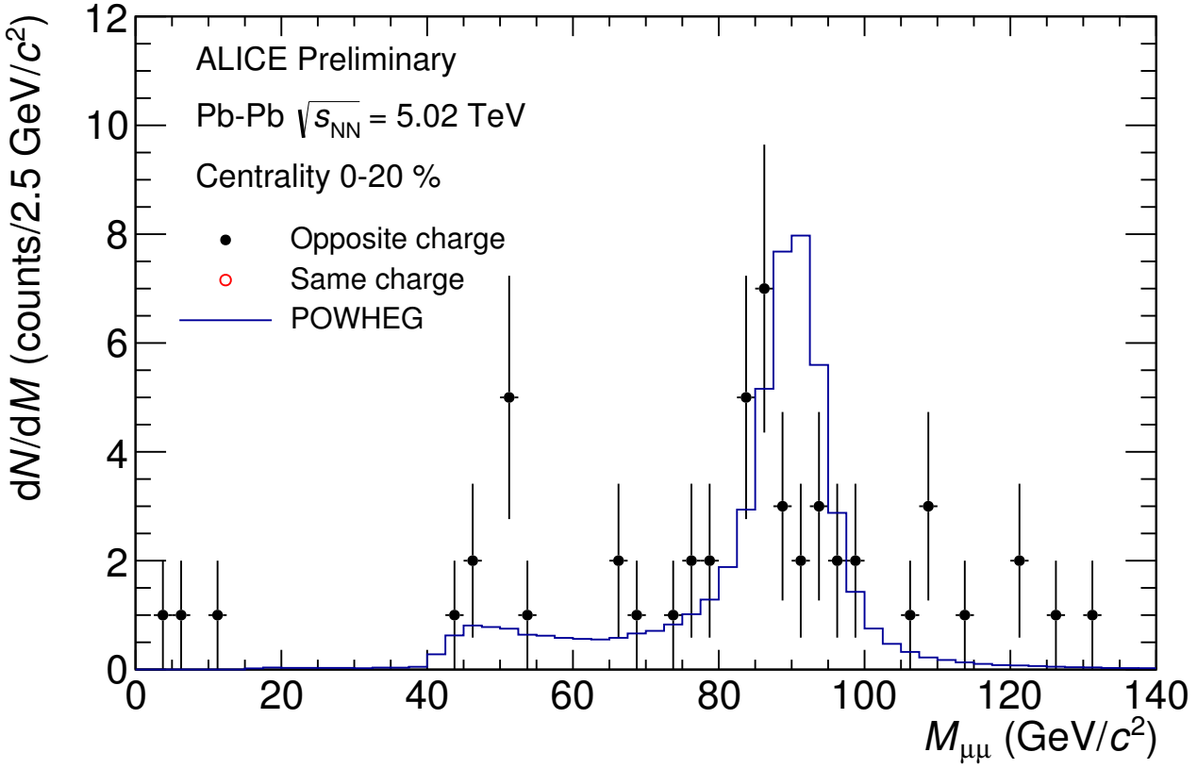
ALI-PREL-124498

- Dimuons at low invariant masses have:
  - large p_T (>2 × $p_T(\mu)$ cut)
  - small opening angle
- Compatible with large p_T resonances (J/psi,Upsilon,ϕ,…) + $c\bar{c}$ and $b\bar{b}$ pairs

Comparison with MC

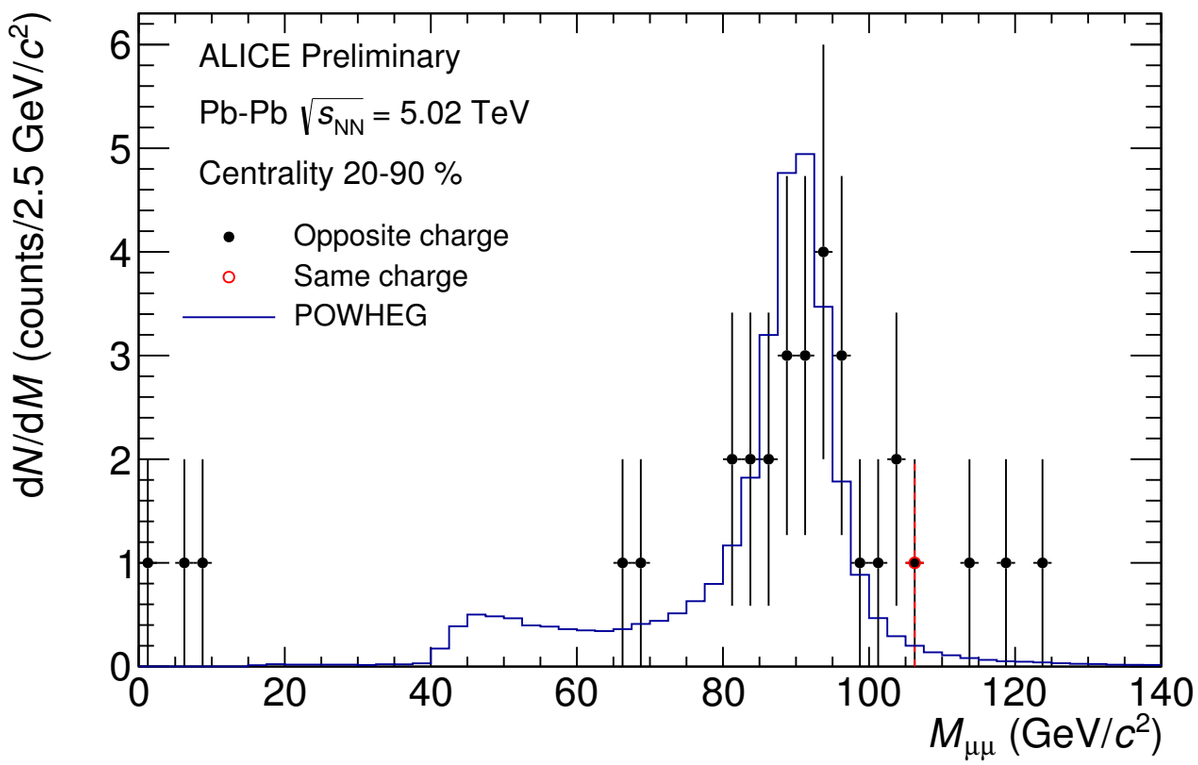
- Invariant mass distribution compared with MC simulations using POWHEG as input

0-20%



ALI-PREL-124486

20-90%



ALI-PREL-124490

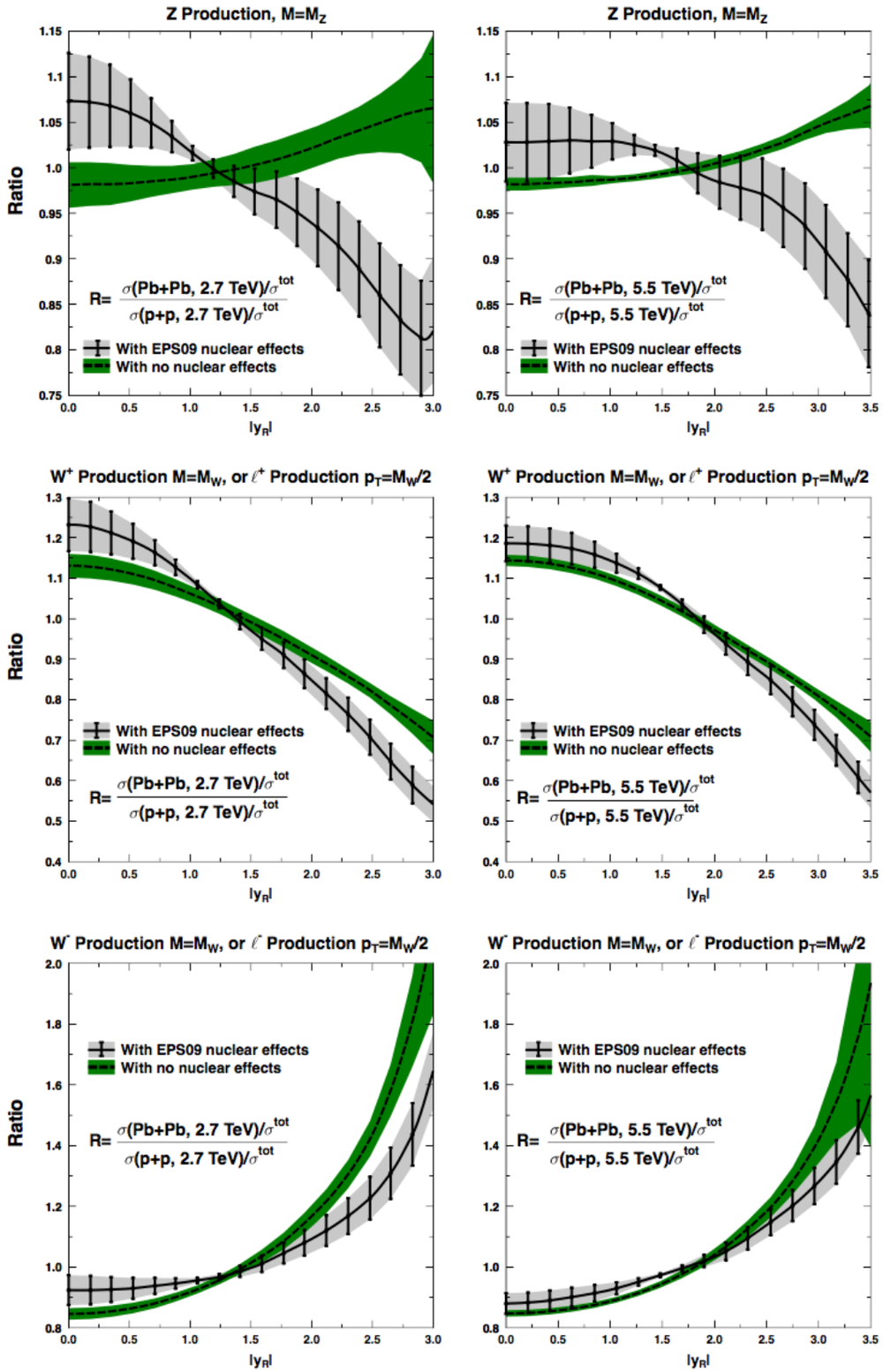
- Results described by POWHEG, implementing Z/γ* interference terms

POWHEG: S. Alioli et al., JHEP 07, 060 (2008)

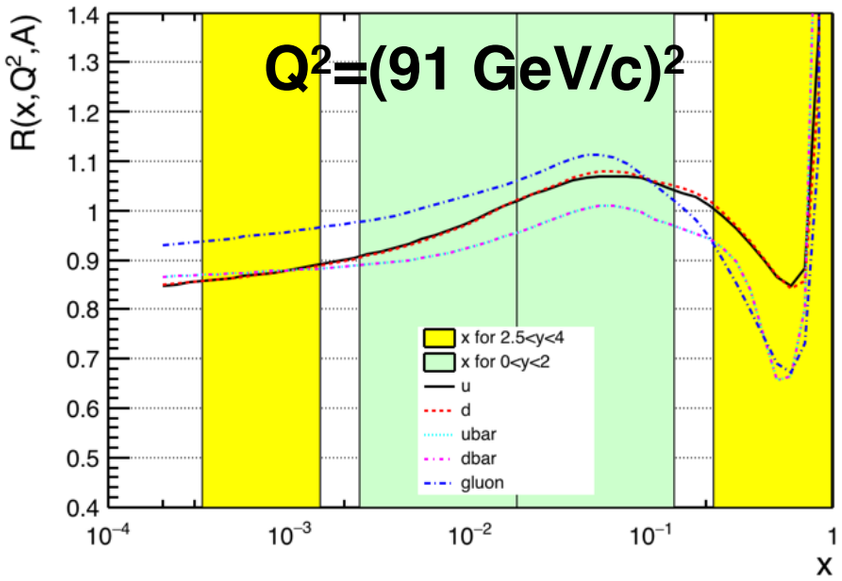
Rapidity dependence of isospin and nuclear effects

- Rapidity dependence of the ratio of normalised cross sections in Pb-Pb and pp collisions
  - w/o accounting for nPDF
  - accounting for nPDF
- Difference is mostly visible at forward rapidities

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

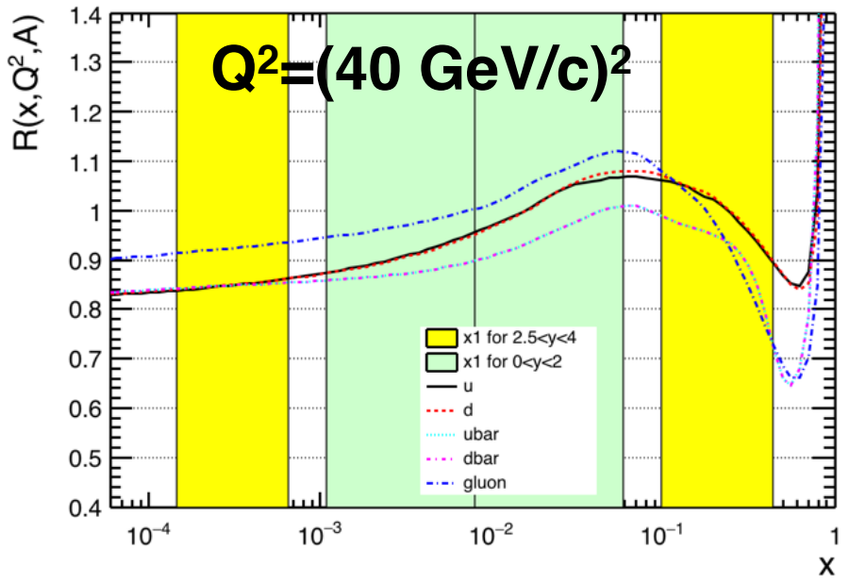


Rough calculations for sqrt(s_{NN})=5.02 TeV



y ->	0	3.25
$R_u \times R_{\bar{u}}$	0.98	0.77
$R_g \times R_g$	1.13	0.68

y ->	-0.46	2.79	-3.71
R_u	1.05		1.02
$R_{\bar{u}}$	0.98	0.88	
R_g	1.09	0.96	0.84



y ->	0	3.25
$R_u \times R_{\bar{u}}$	0.86	0.86
$R_g \times R_g$	1.01	0.89

y ->	-0.46	2.79	-3.71
R_u	0.98		0.95
$R_{\bar{u}}$	0.92	0.85	
R_g	1.03	0.93	0.84

- Showing R(x,Q^2) values and their product for:
  - $q\bar{q}$=> important for vector boson production
  - gg => important for HF production

$$x_{\pm} = \frac{Q^2}{\sqrt{s_{NN}}} e^{\pm y}$$

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