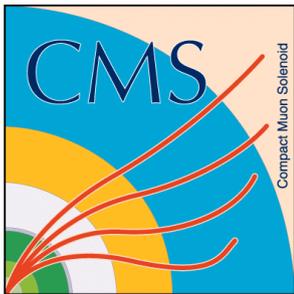


Z and W boson production in pPb collisions with CMS



Anna Julia Zsigmond
Wigner RCP

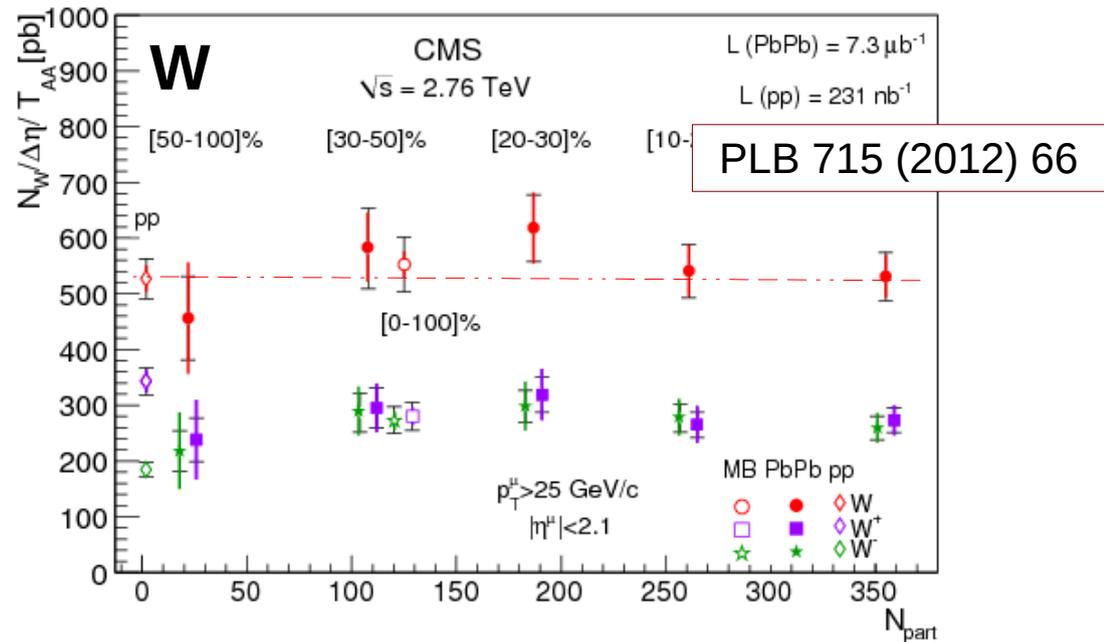
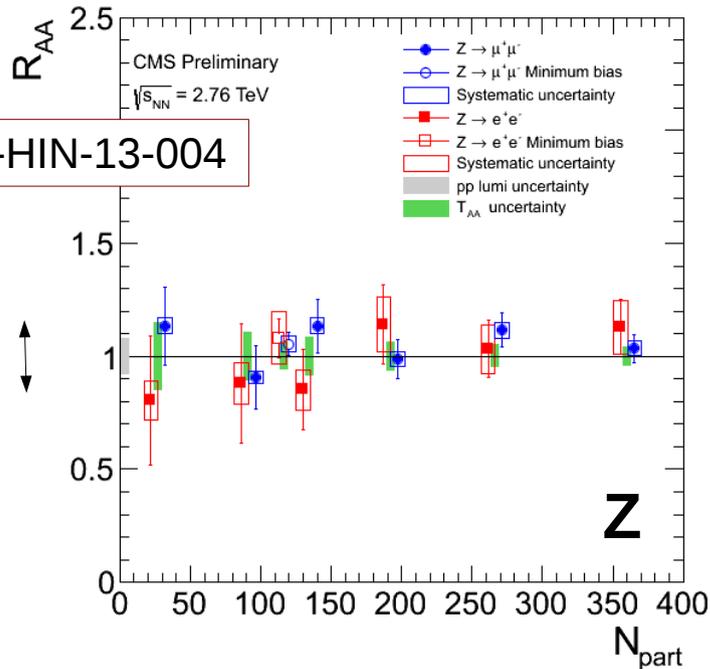


for the CMS Collaboration

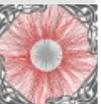
Quark Matter conference, Darmstadt
19th May 2014

Introduction

- LHC energies allow first measurements of Z and W bosons in heavy ion collisions
- Electroweak bosons are essentially not perturbed by the QCD medium \rightarrow observed binary scaling in PbPb collisions



- Constrain nuclear PDFs with pPb data **new**
 - CMS-PAS-HIN-14-003 \rightarrow Z in pPb 2013
 - CMS-PAS-HIN-13-007 \rightarrow W in pPb 2013



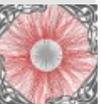
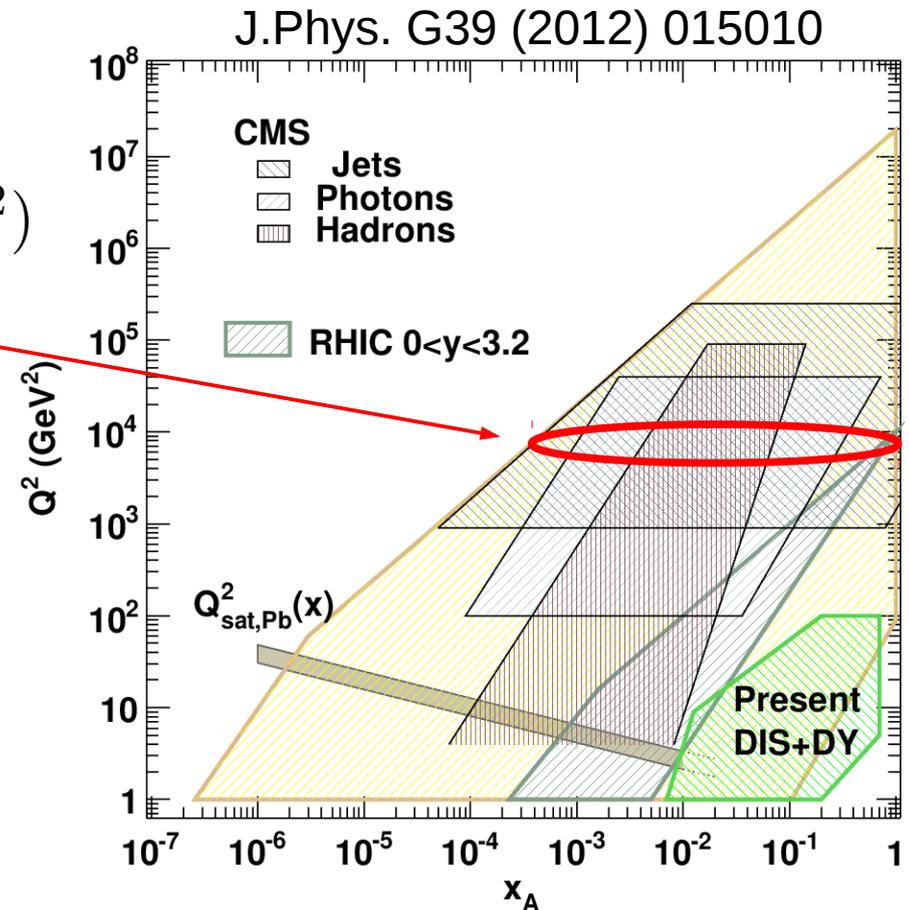
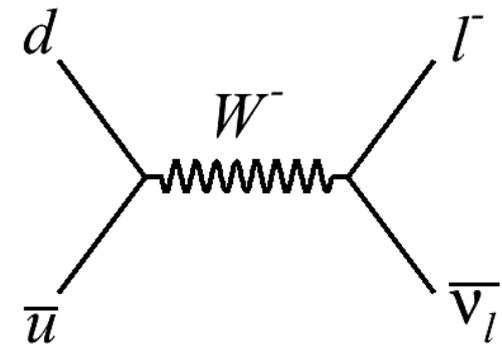
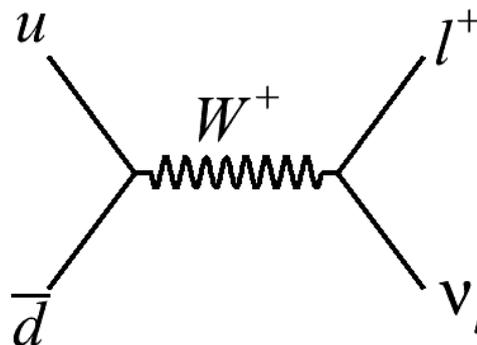
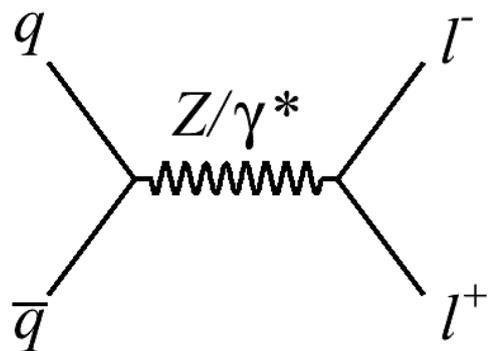
Nuclear parton distribution functions (nPDFs)

- Nuclear PDF parametrizations

$$f^{\text{proton},A} = R_f(x, Q^2) f^{\text{free proton}}(x, Q^2)$$

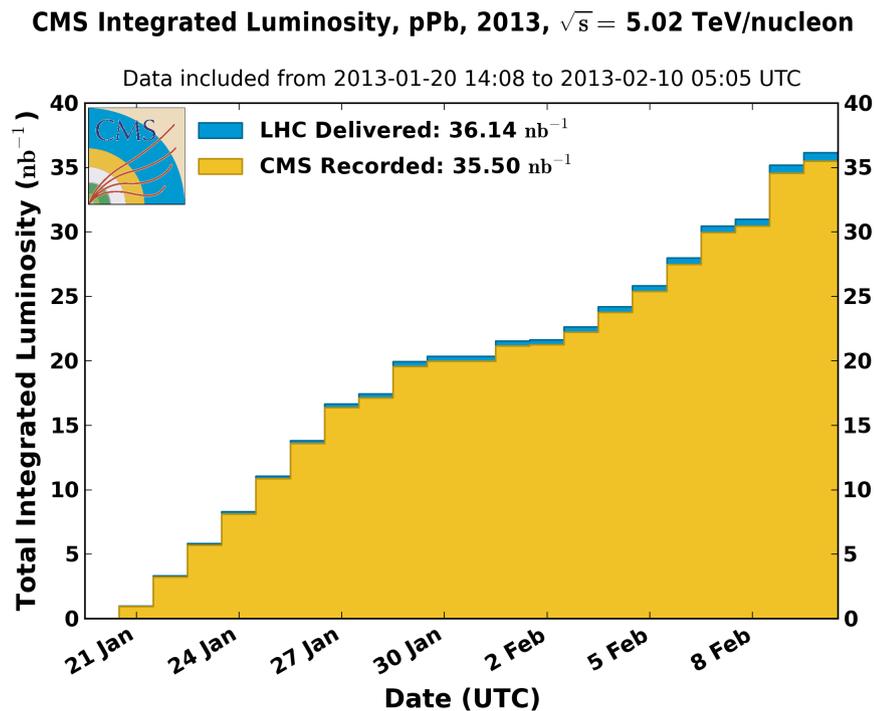
$$Q^2 \approx m_{W/Z}^2 \quad x \approx 10^{-3} - 10^{-1}$$

- Z and W bosons are sensitive to (valence) quark and (sea) antiquark content of the nucleus
- Dominant processes (LO)

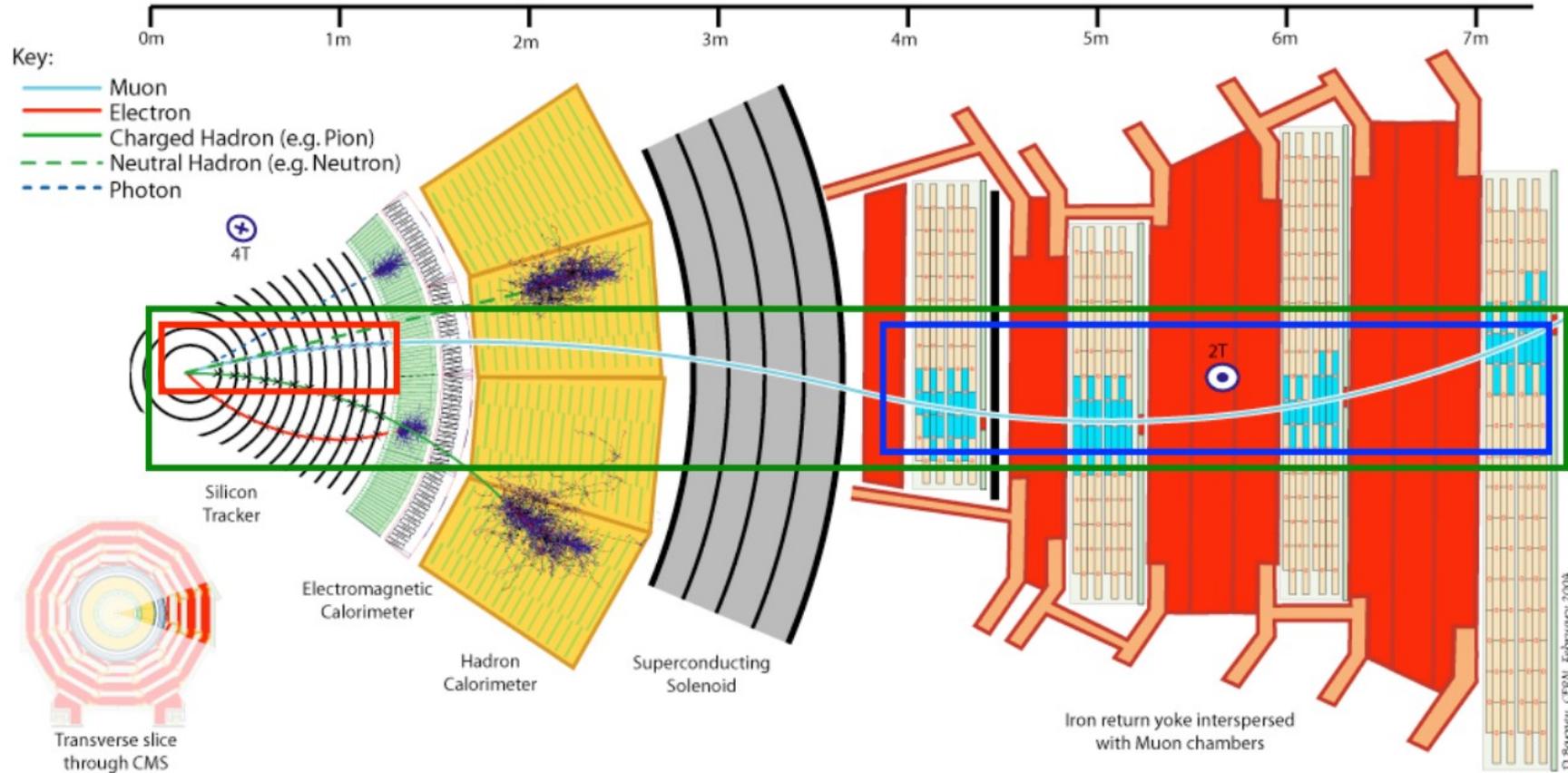


pPb collisions @ LHC

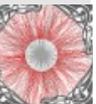
- Data taking in 2013
- Integrated luminosity
 - $34.6 \pm 1.2 \text{ nb}^{-1}$ (certified)
 - Calibrated by Van der Meer scans
- 5.02 TeV center-of-mass energy per nucleon pair
 - 4 TeV proton + 1.58 ATeV Pb
 - Rapidity boost of $\Delta y = (-)0.465$
- Data taking with both beam direction settings
- Results presented with proton fragmentation (forward) region probed at positive values of rapidity



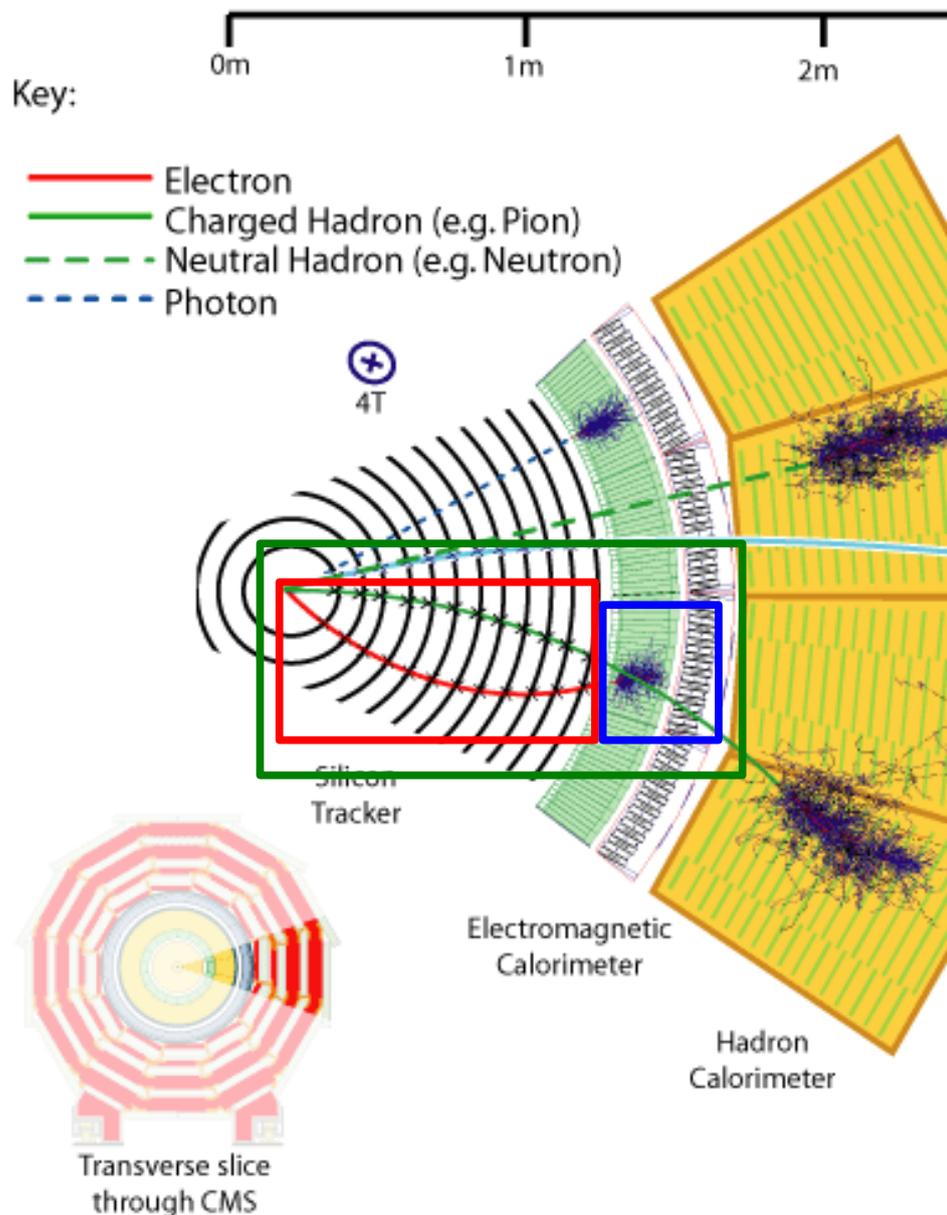
Muon reconstruction



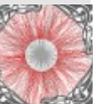
- **Global muons** reconstructed with information from **inner tracker** and **muon stations**
- 1-2% resolution up to muon $p_T \sim 100$ GeV/c



Electron reconstruction



- **Electron candidate** is a **supercluster** matched to an **inner track**
- Dedicated outside-in tracking to take into account radiation
- Resolution is 1-2% for high p_T (~ 45 GeV/c) electrons



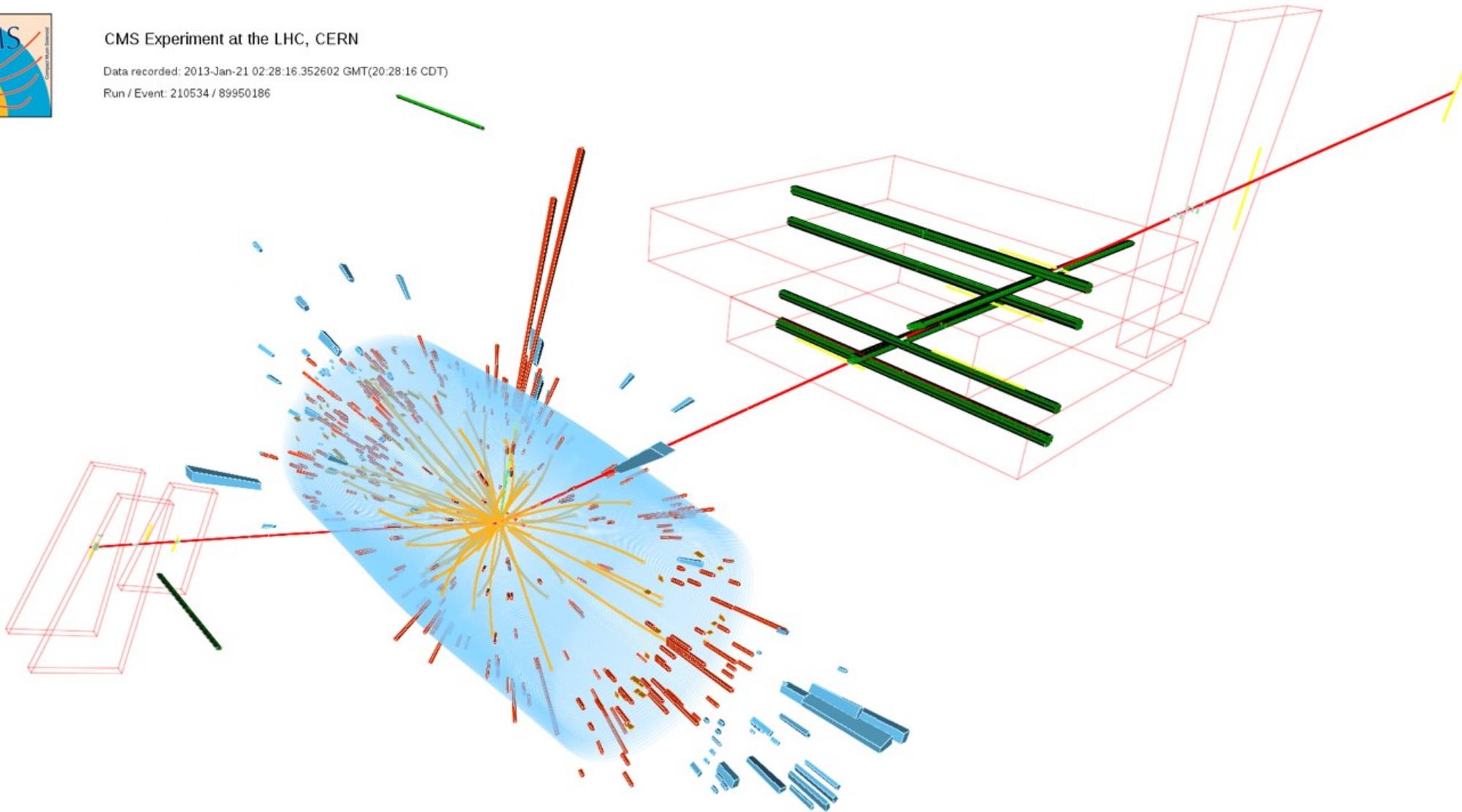
Z bosons in pPb @ 5.02 TeV



CMS Experiment at the LHC, CERN

Data recorded: 2013-Jan-21 02:28:16.352602 GMT(20:28:16 CDT)

Run / Event: 210534 / 89950186

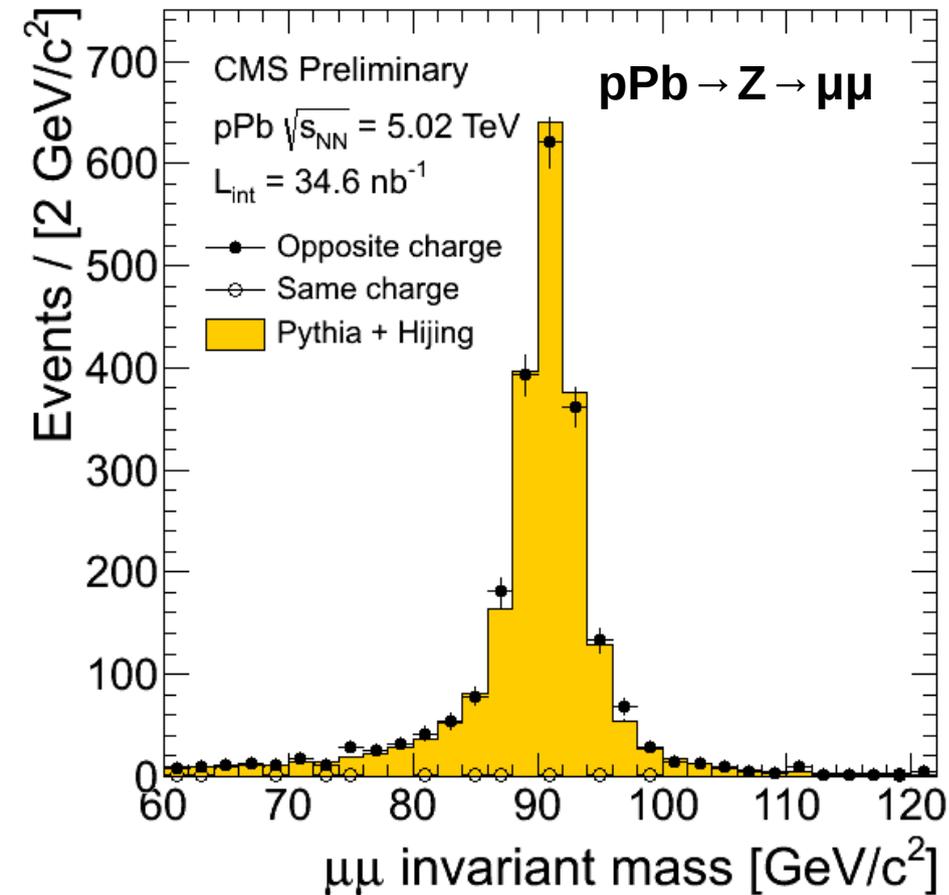


© CERN. All rights reserved.

<http://cms.cern>

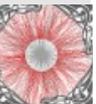


Z bosons in pPb @ 5.02 TeV



- Dimuon invariant mass in [60, 120] GeV/c 2
- Muon selection
 - $p_T^\mu > 20$ GeV/c
 - $|\eta_{lab}^\mu| < 2.4$
(muon detector coverage)
- Asymmetric acceptance in rapidity in the center-of-mass frame due to the boost
- 2183 Z candidates

CMS-PAS-HIN-14-003

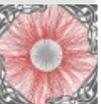


Z bosons in pPb @ 5.02 TeV

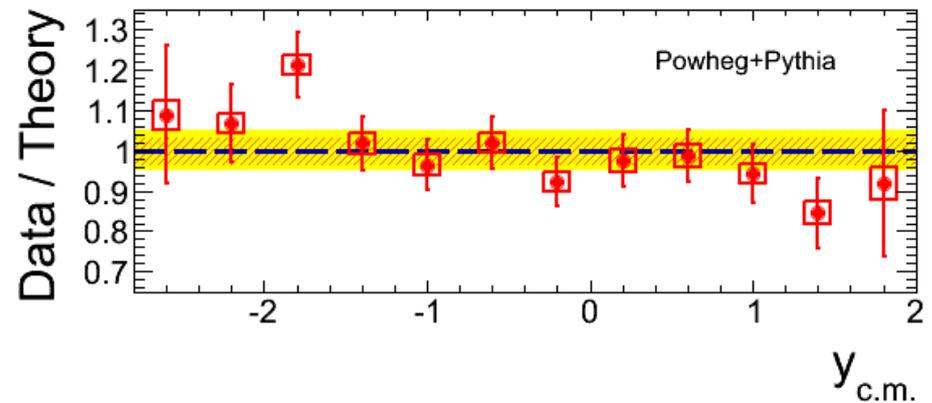
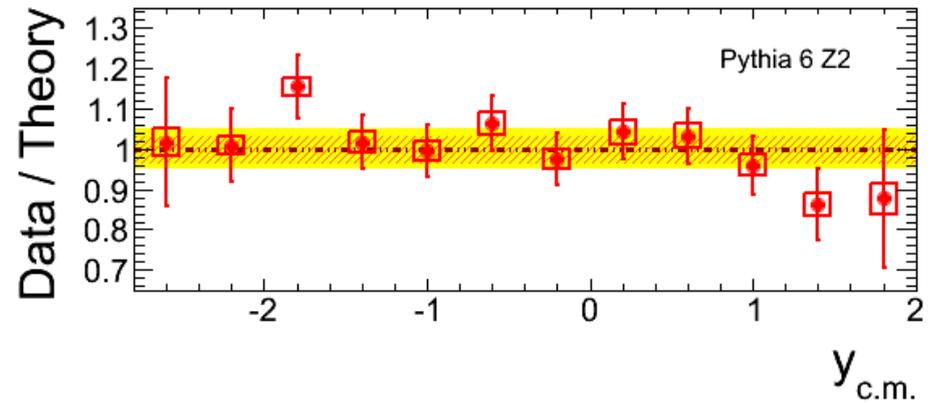
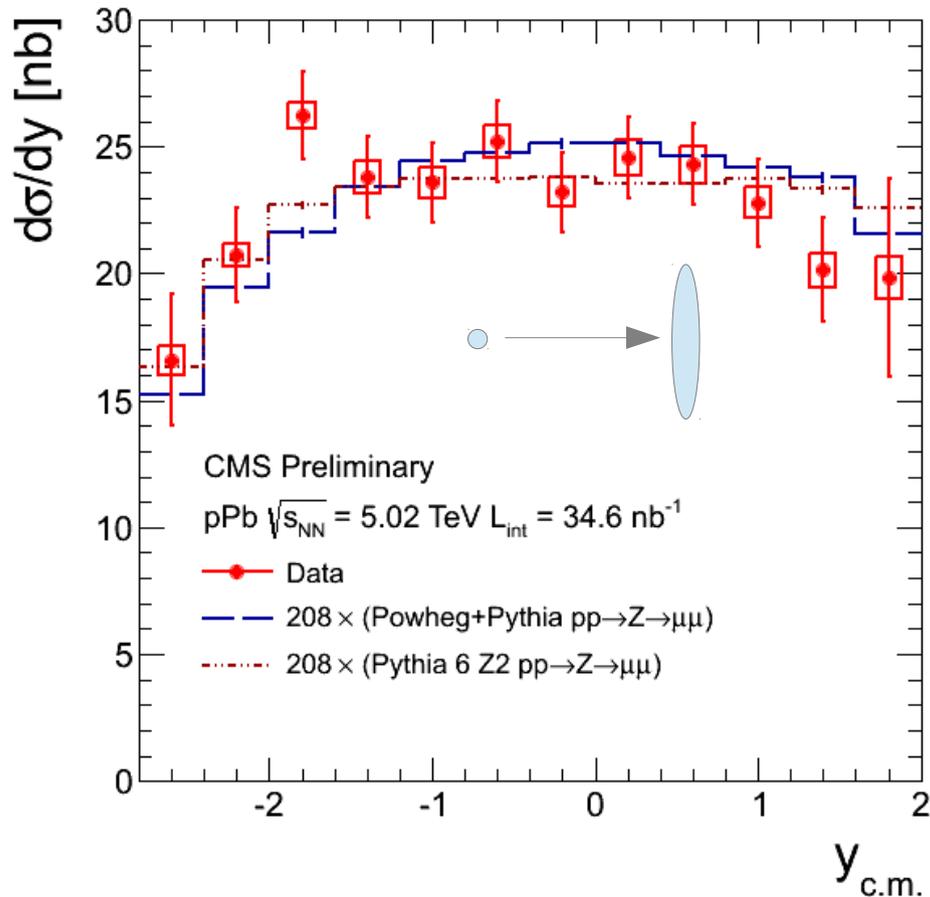
- Inclusive Z production cross section in pPb collisions
- Compared to NLO POWHEG calculation scaled by $A=208$

$\sigma(\text{pPb} \rightarrow Z \rightarrow \mu\mu)$	Measured $\sigma \pm \text{stat.} \pm \text{syst.} \pm \text{lumi.}$	$\sigma^{\text{NLO POWHEG}} \times A$
Full phase space	$134.4 \pm 2.9 \pm 7.1 \pm 4.7 \text{ nb}$	$134 \pm 7 \text{ nb}$
$-2.5 < y_{\text{c.m.}} < 1.5$	$94.1 \pm 2.1 \pm 2.4 \pm 3.3 \text{ nb}$	$94.0 \pm 4.7 \text{ nb}$

- Restricted rapidity range to reduce uncertainties on the acceptance correction
- Results consistent with $\sigma^{\text{pp}} \times A$

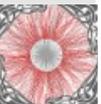


Z bosons in pPb @ 5.02 TeV

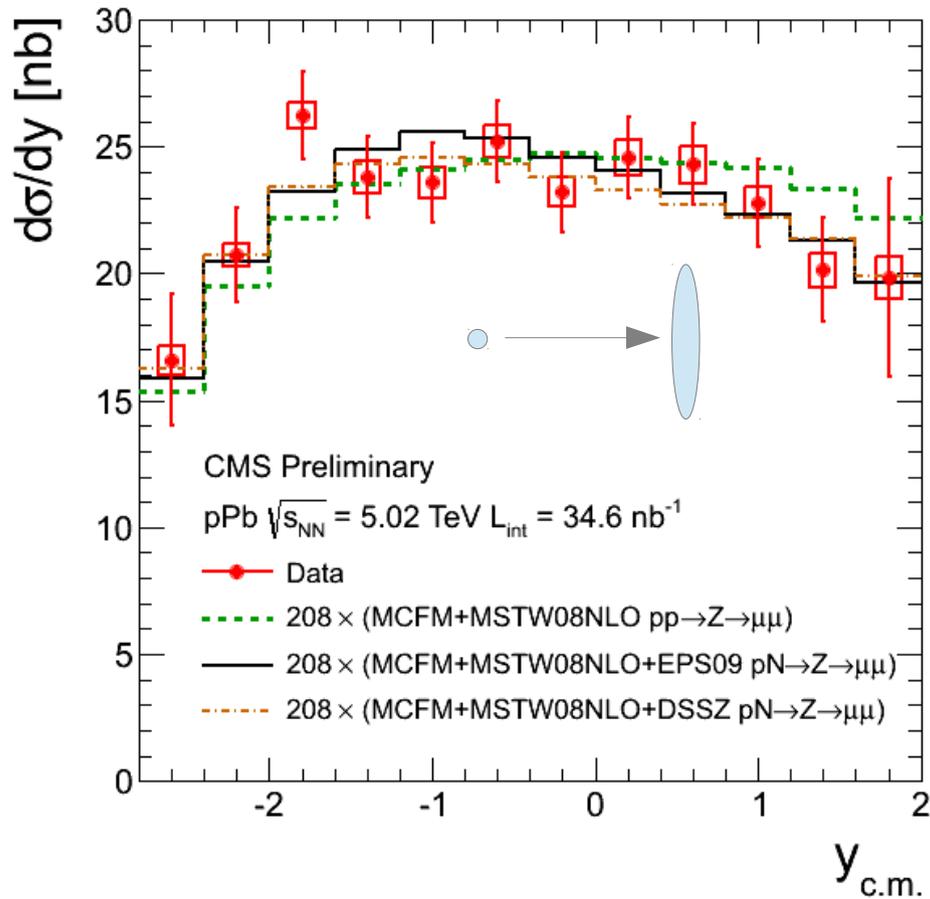


- $d\sigma/dy$ shifted to center-of-mass frame
- Uncertainties dominated by statistical uncertainties
- Consistent with scaled pp predictions

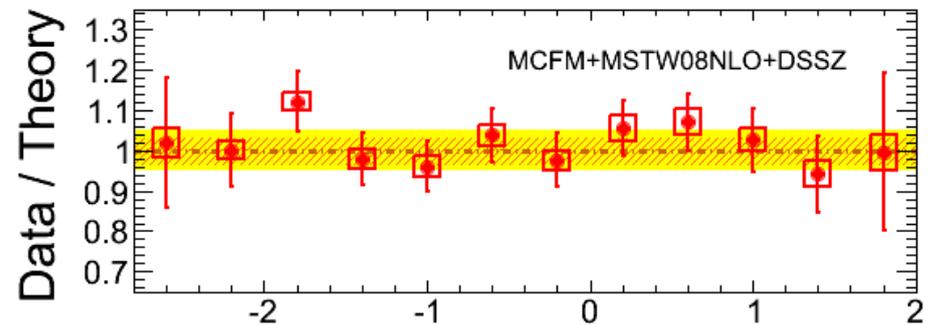
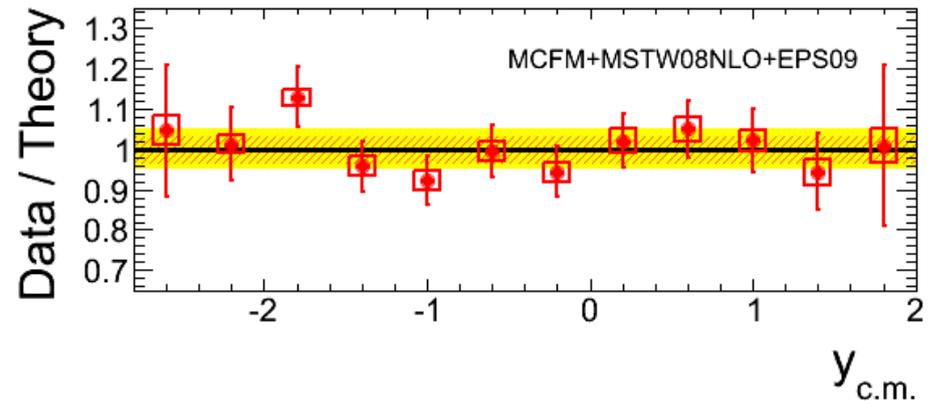
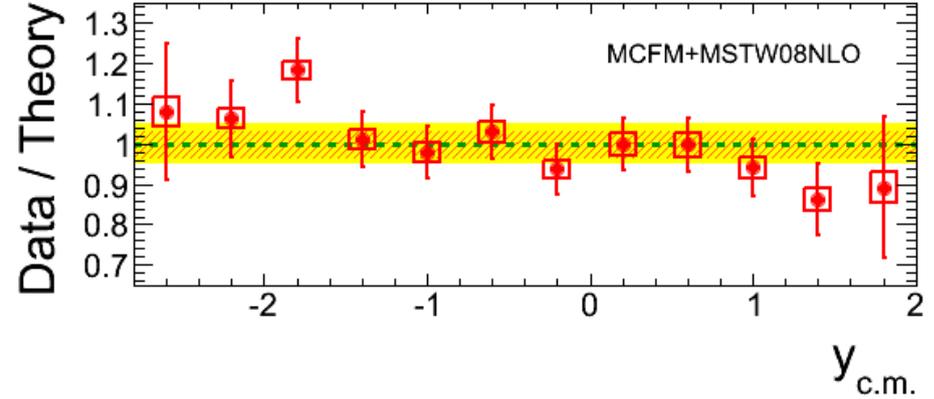
CMS-PAS-HIN-14-003



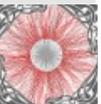
Z bosons in pPb @ 5.02 TeV



- Nuclear effects expected in the forward and backward regions



CMS-PAS-HIN-14-003

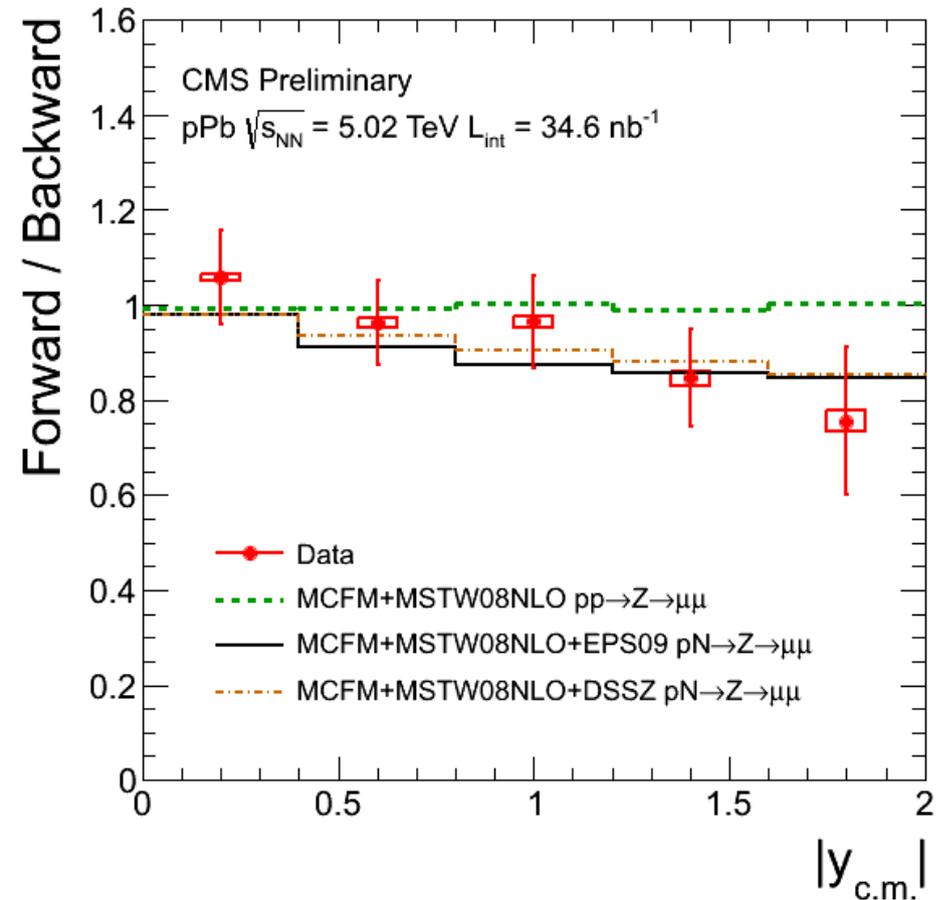


Z bosons in pPb @ 5.02 TeV

- Forward-backward ratio expected to be more sensitive to nuclear effects

$$R_{FB} = \frac{d\sigma(+y_{c.m.})/dy}{d\sigma(-y_{c.m.})/dy}$$

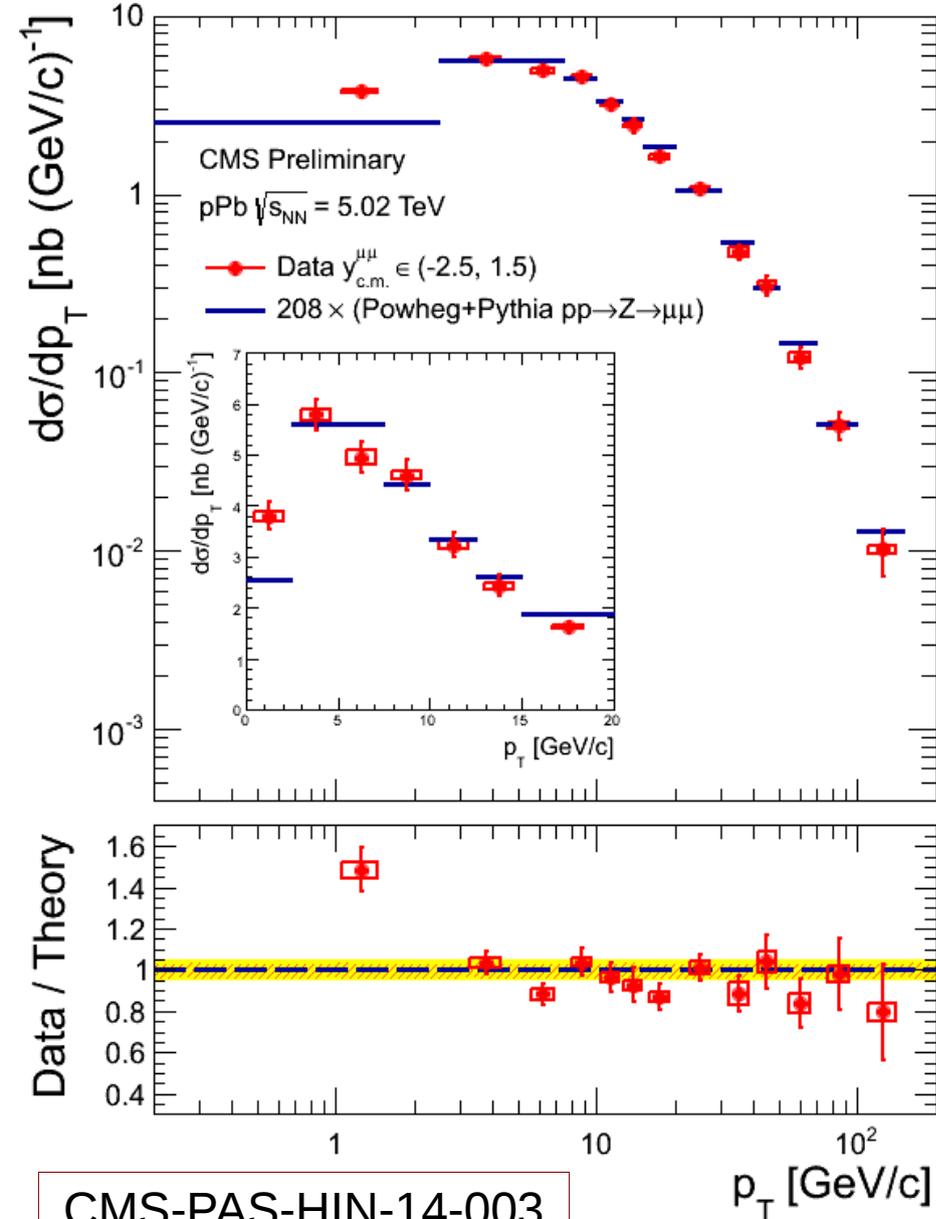
- Without nuclear effects should be 1
- Hint of nuclear effects visible
- Large uncertainties both on data and nuclear PDF central predictions



CMS-PAS-HIN-14-003

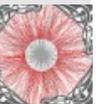


Z bosons in pPb @ 5.02 TeV

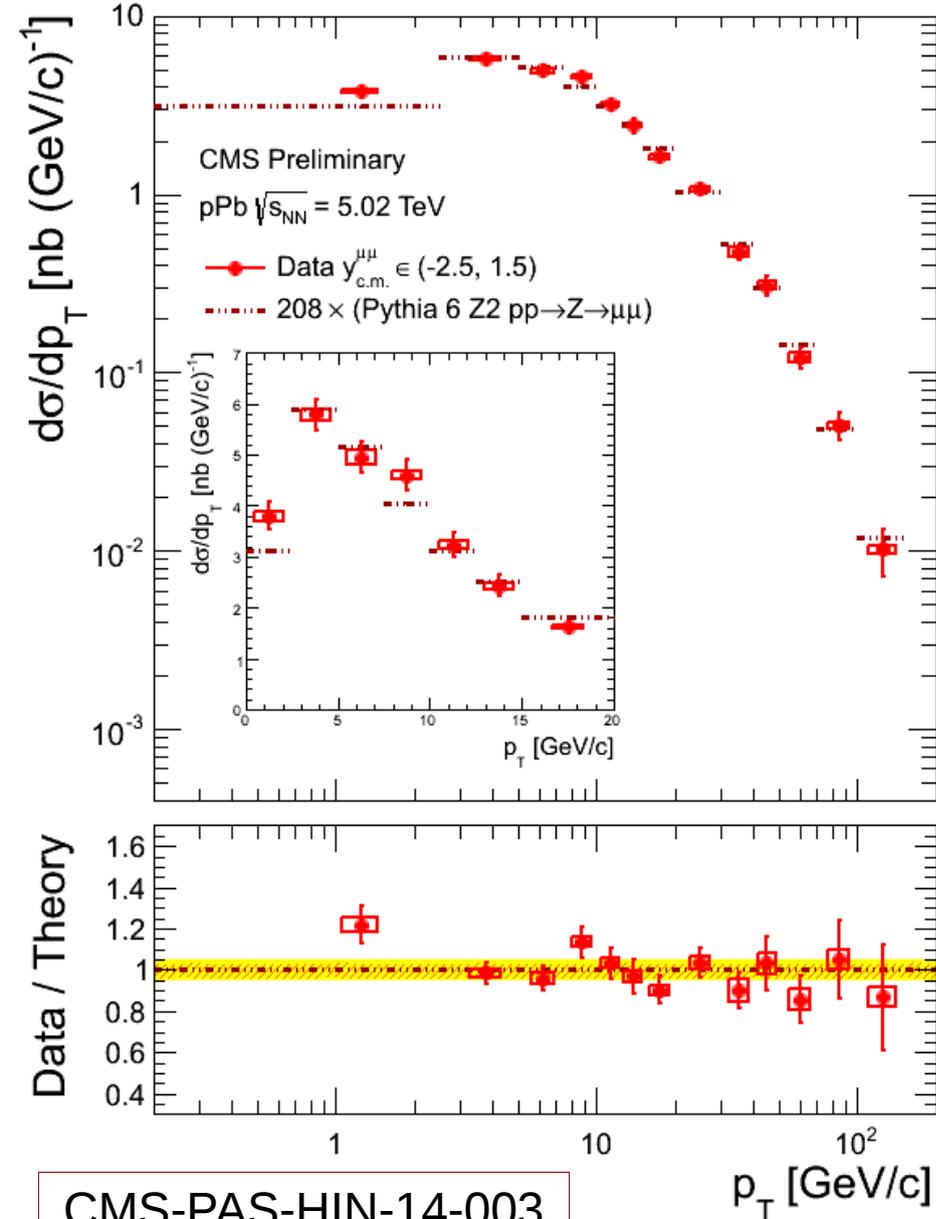


CMS-PAS-HIN-14-003

- p_T differential cross section
 - Wide range from 0 – 150 GeV/c
- Expected nuclear effects are small \rightarrow comparing only to pp
- Compared to POWHEG+PYTHIA
 - Deviations seen consistent with 7 & 8 TeV pp results

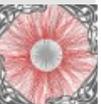


Z bosons in pPb @ 5.02 TeV



CMS-PAS-HIN-14-003

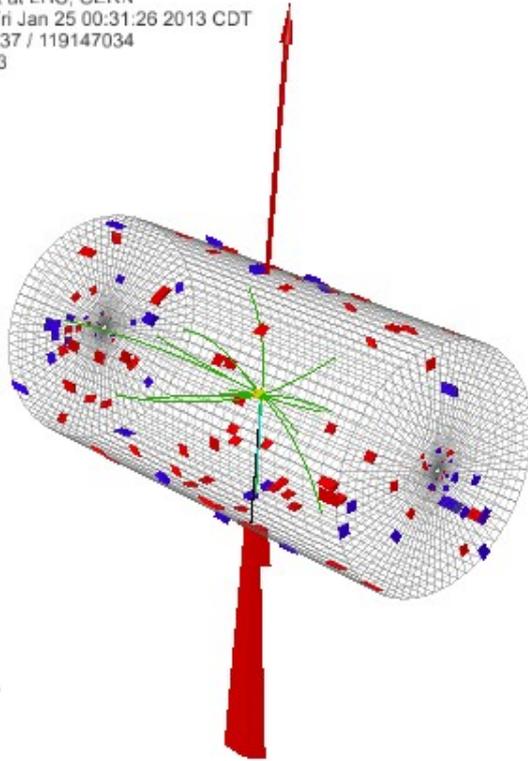
- p_T differential cross section
 - Wide range from 0 – 150 GeV/c
- Expected nuclear effects are small \rightarrow comparing only to pp
- Compared to POWHEG+PYTHIA
 - Deviations seen consistent with 7 & 8 TeV pp results
- Compared to PYTHIA
 - Better agreement in the low p_T region



W bosons in pPb @ 5.02 TeV



CMS Experiment at LHC, CERN
Data recorded: Fri Jan 25 00:31:26 2013 CDT
Run/Event: 210737 / 119147034
Lumi section: 183

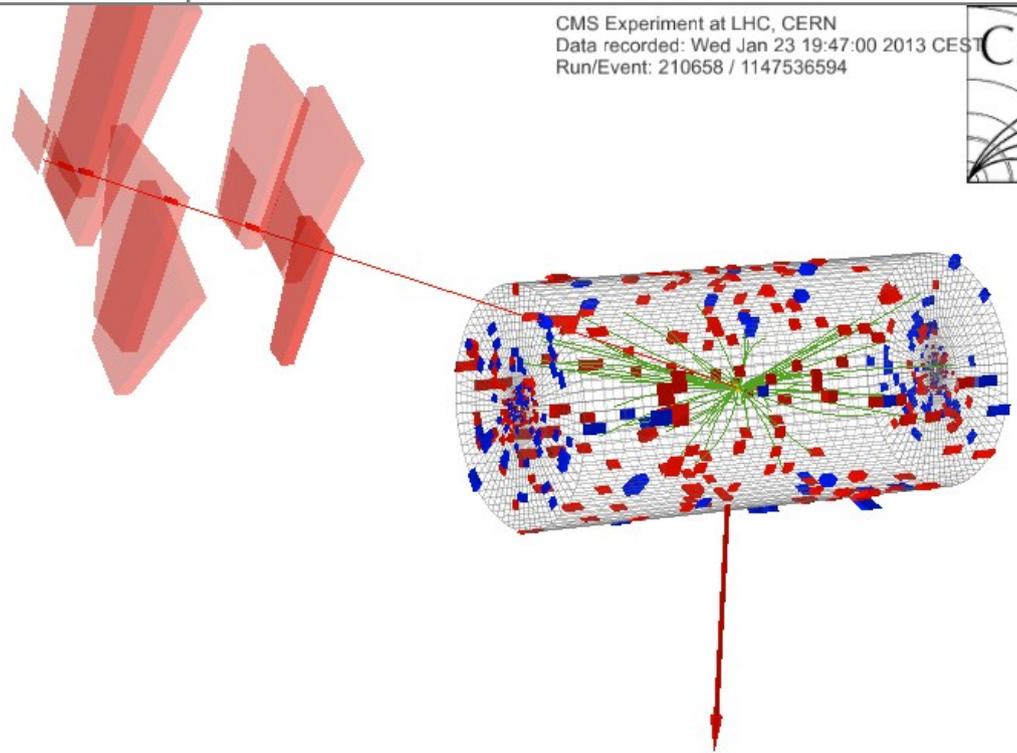


$W \rightarrow e\nu$

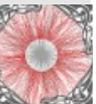
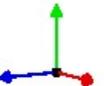
- ~20 000 candidates in both **electron** and **muon** channels

- More difficult to reconstruct but ten times more statistics than Z

CMS Experiment at LHC, CERN
Data recorded: Wed Jan 23 19:47:00 2013 CEST
Run/Event: 210658 / 1147536594

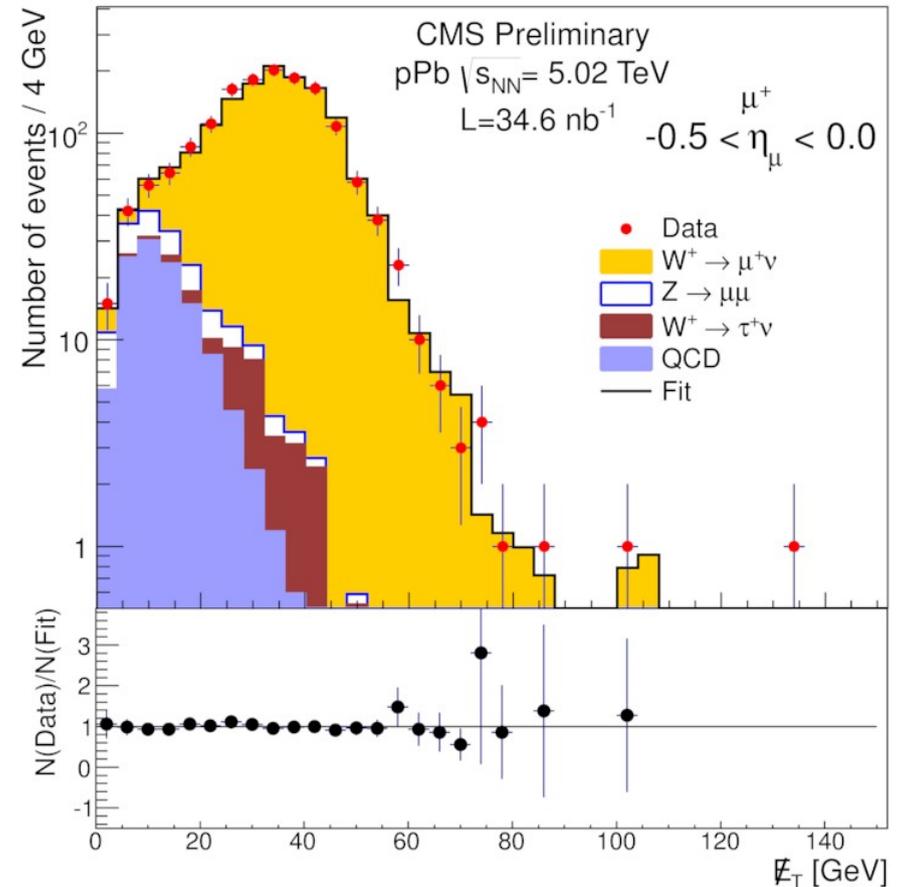


$W \rightarrow \mu\nu$

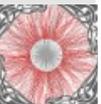


W bosons in pPb @ 5.02 TeV

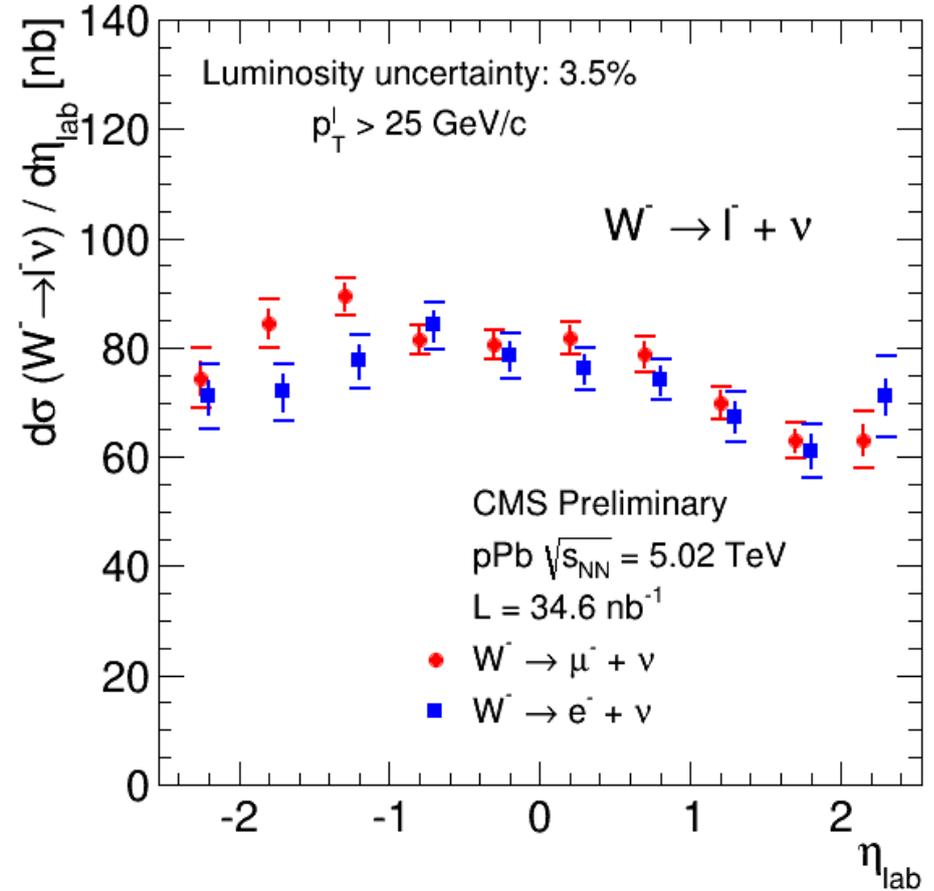
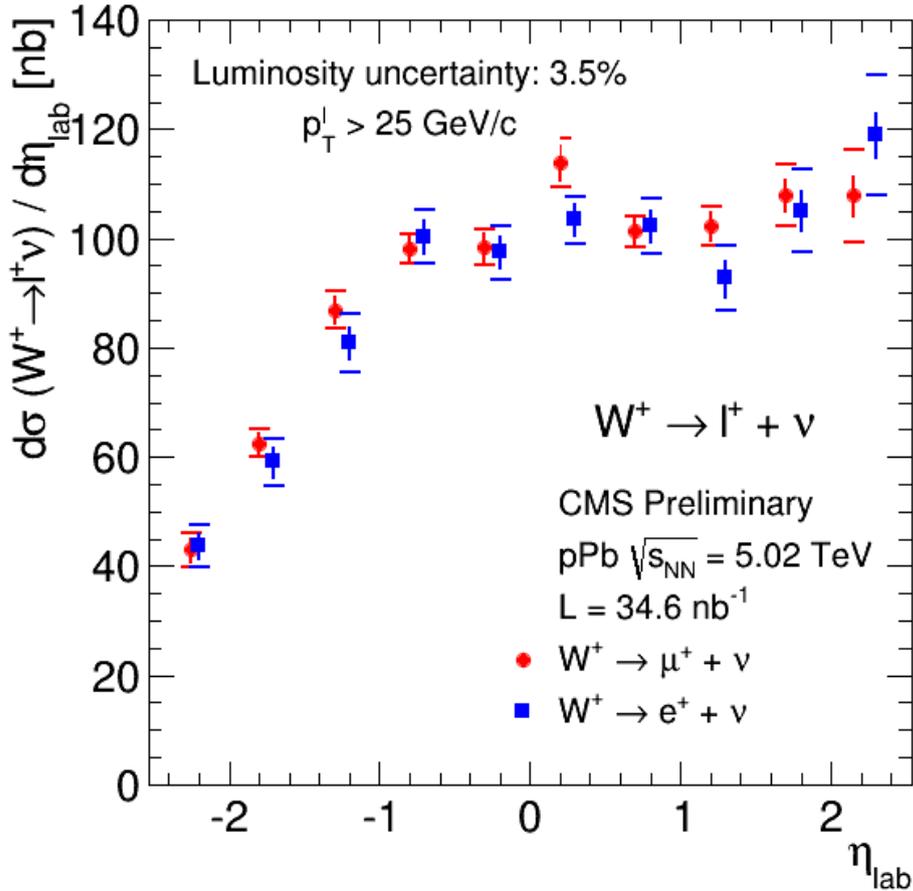
- Event selection
 - $p_T^{\mu/e} > 25 \text{ GeV}/c$
 - $|\eta^{\mu(e)}_{\text{lab}}| < 2.4 \text{ (2.5)}$
 - Quality and isolation requirements
 - Veto on dilepton events
- Fitting the missing transverse energy for both charges and every η bin
- Templates for QCD from data-based method and electroweak ($Z \rightarrow \mu\mu$ / ee , $W \rightarrow \tau\nu$) from simulation



CMS-PAS-HIN-13-007

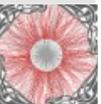


W bosons in pPb @ 5.02 TeV

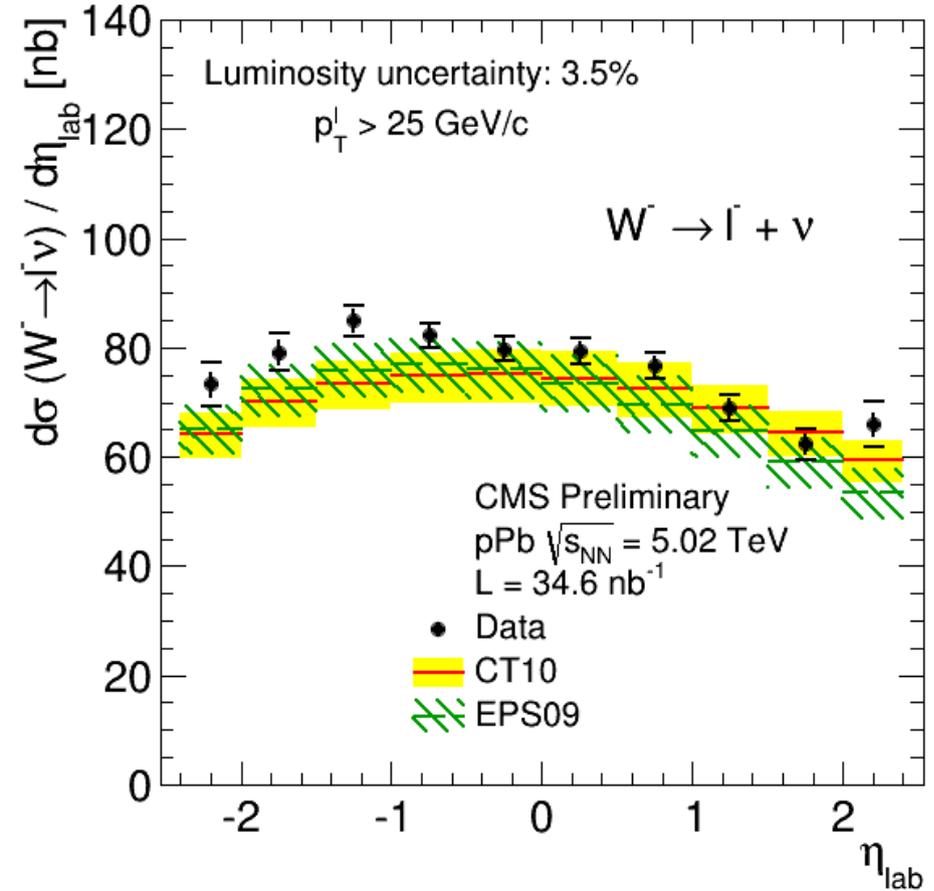
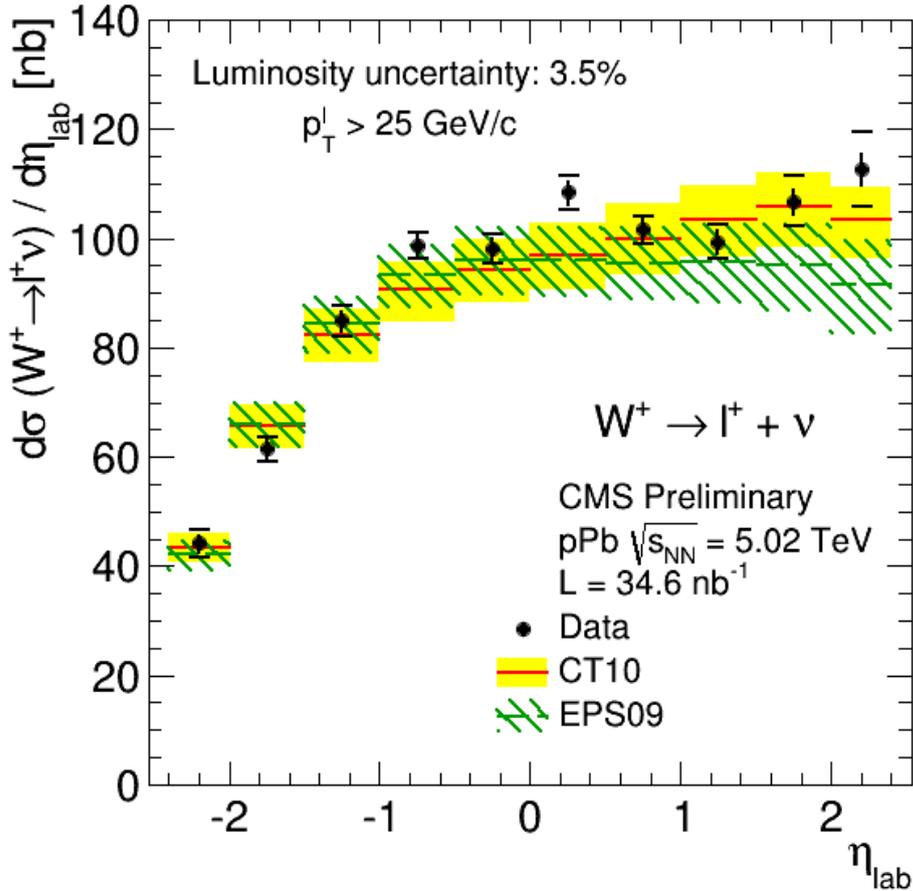


- Cross section as a function of η in laboratory frame
- Electron and muon results agree \rightarrow combination is performed

CMS-PAS-HIN-13-007



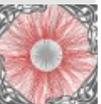
W bosons in pPb @ 5.02 TeV



- Combined cross section compared to NLO theory predictions with and without nuclear effects from EPS09
- New data to constrain the nPDFs

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

CMS-PAS-HIN-13-007



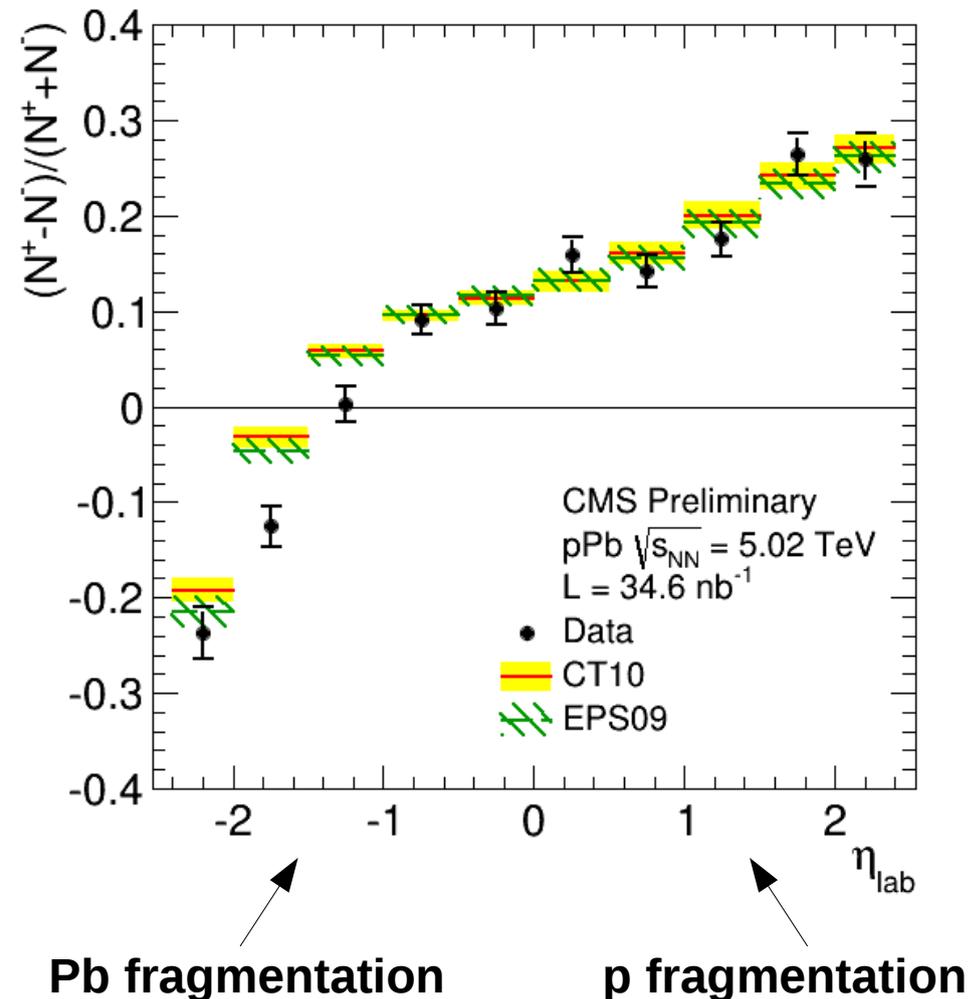
W bosons in pPb @ 5.02 TeV

- Luminosity (experimental) and scale (theory) uncertainties cancel in asymmetries

- Charge asymmetry

$$\frac{N^+(\eta_{\text{lab}}) - N^-(\eta_{\text{lab}})}{N^+(\eta_{\text{lab}}) + N^-(\eta_{\text{lab}})}$$

- Sensitive probe of the up to down quark PDF ratio
- Isospin symmetry ($R_u = R_d$) assumed in nPDF fits
- Assuming $R_d < R_u$ would decrease the charge asymmetry in negative η



CMS-PAS-HIN-13-007

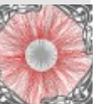
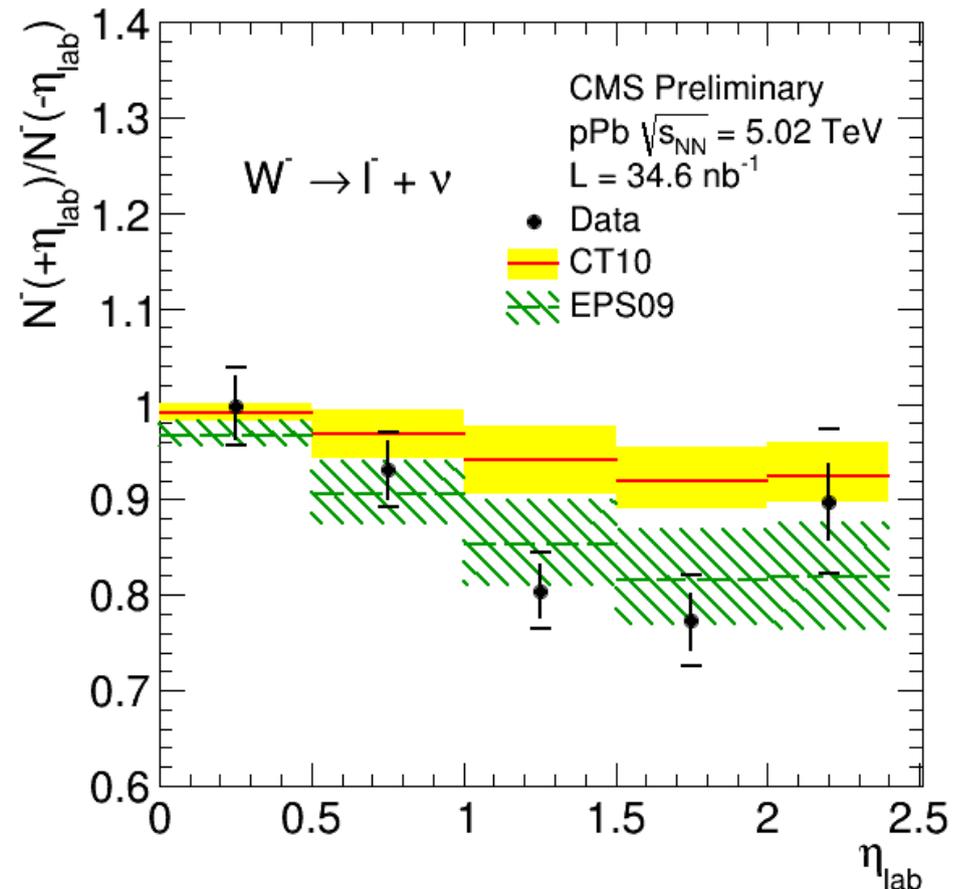
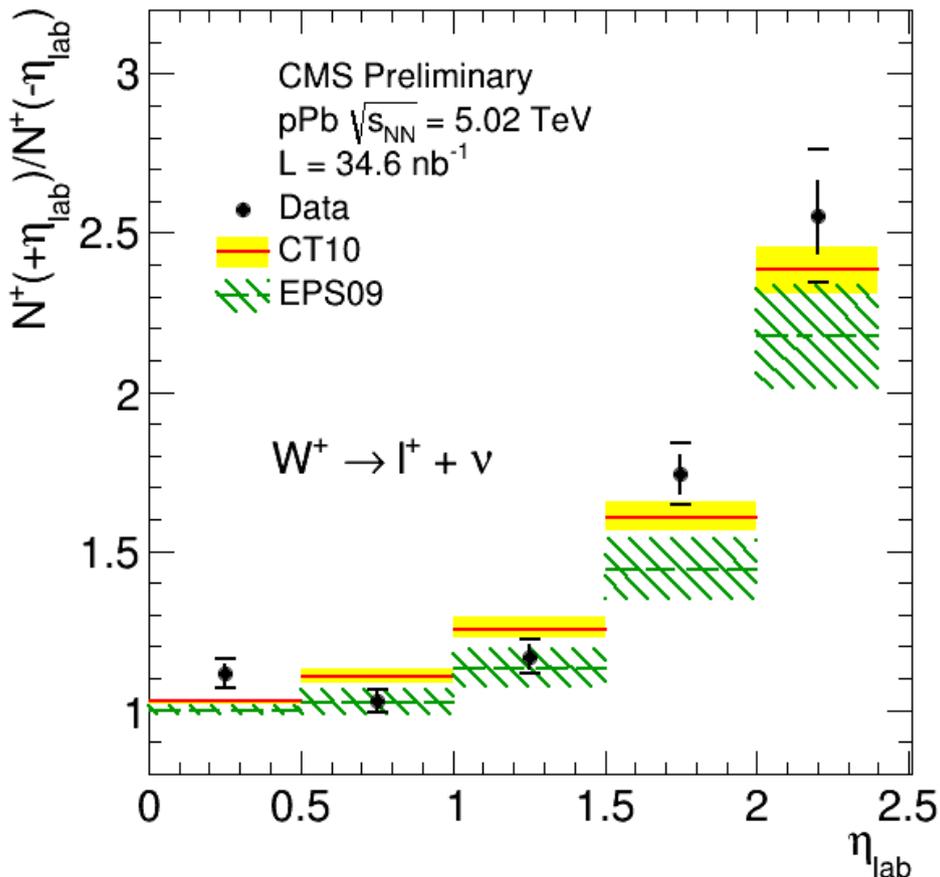


W bosons in pPb @ 5.02 TeV

- Forward-backward asymmetry
- More sensitive to nuclear modifications
- Different behavior of different charges
→ hint of $R_u \neq R_d$?

$$\frac{N^\pm(+\eta_{\text{lab}})}{N^\pm(-\eta_{\text{lab}})}$$

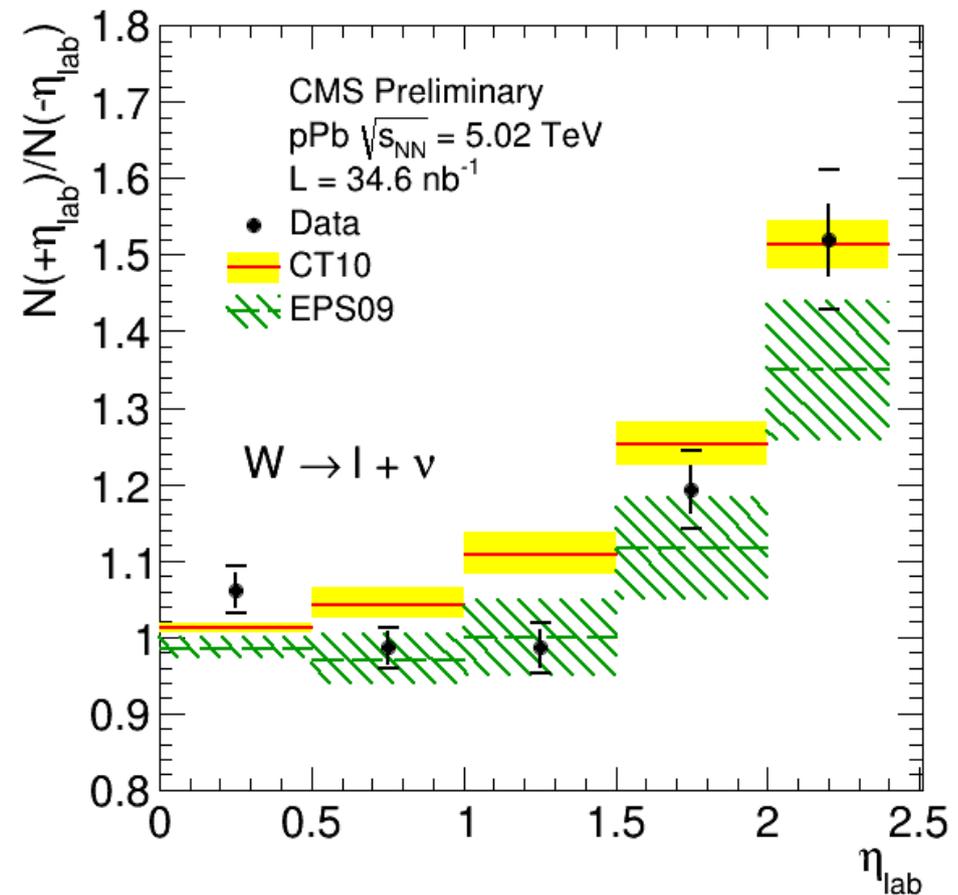
CMS-PAS-HIN-13-007



W bosons in pPb @ 5.02 TeV

- Forward-backward asymmetry of the charge-summed W bosons
- Good sensitivity for nuclear modification of parton distributions
- Probes the shadowing over anti-shadowing and/or EMC effect
- χ^2 probabilities of 10% with CT10 and 27% with including EPS09

$$\frac{N(+\eta_{\text{lab}})}{N(-\eta_{\text{lab}})}$$



CMS-PAS-HIN-13-007

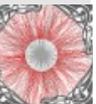


Summary

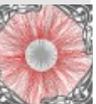
- Reported **first measurements of Z and W boson production in pPb collisions** with the CMS experiment
- At first order, the production cross section scales with number of binary nucleon-nucleon collisions
- Compared to NLO theory predictions with and without nuclear modification of the PDFs
- The measurements set **significant constraints for the global fits of nuclear parton distribution functions** in a previously unexplored phase space
- Hints of nuclear effects seen but more luminosity is needed to distinguish between nPDFs



<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN>

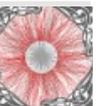


Backup



W bosons in pPb @ 5.02 TeV

Observable	No nuclear effects		Nuclear effects from EPS09	
	χ^2	probability	χ^2	probability
$d\sigma/d\eta(l^+)$	15.7	10.8%	14.2	16.5%
$d\sigma/d\eta(l^-)$	10.3	41.3%	6.24	79.5%
$(N^+ - N^-)/(N^+ + N^-)$	17.7	6.12%	12.8	23.5%
$N^+(+\eta)/N^+(-\eta)$	7.42	19.1%	8.62	12.5%
$N^- (+\eta)/N^- (-\eta)$	7.99	15.7%	2.88	71.9%
$N(+\eta)/N(-\eta)$	7.85	16.5%	6.00	30.6%



Systematic uncertainties

$$Z \rightarrow \mu\mu$$

Source	$\sigma(\text{inclusive})$	$\sigma(-2.5 < y_{\text{c.m.}} < 1.5)$	$d\sigma/dp_T$	$d\sigma/dy$
Acceptance	4.7%	0.9%	0.4 – 1.2%	0.1 – 1.1%
MC efficiency	0.2%	0.2%	0.1 – 0.3%	0.01 – 0.9%
Data/MC efficiencies	1.7%	1.7%	1.7%	1.7% – 3.4%
Background	1.7%	1.8%	0.3 – 5.4%	0.5 – 2.4%

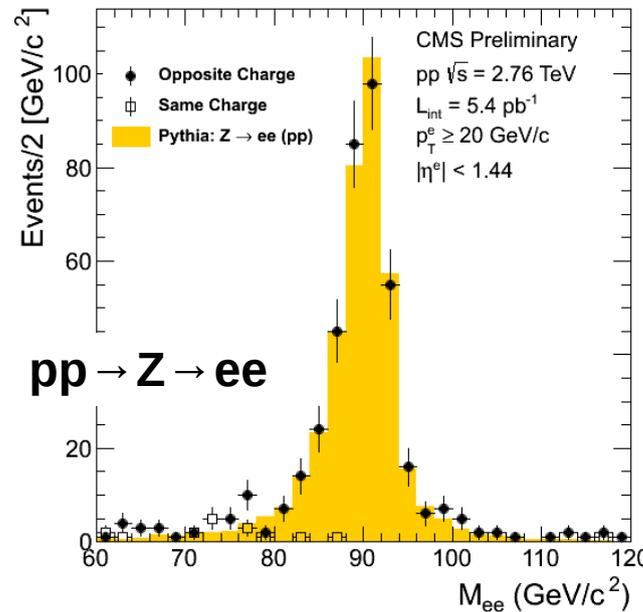
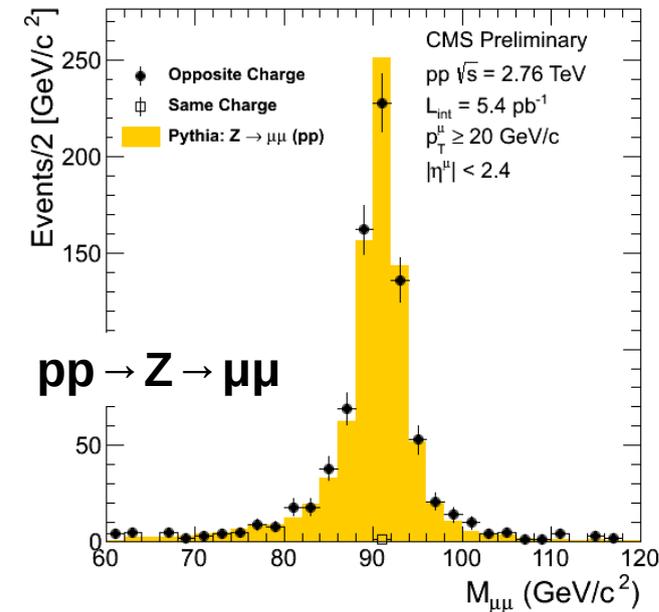
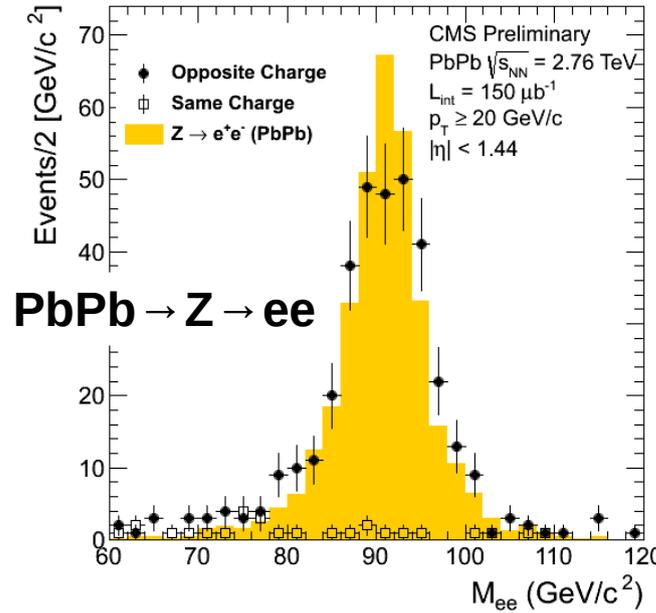
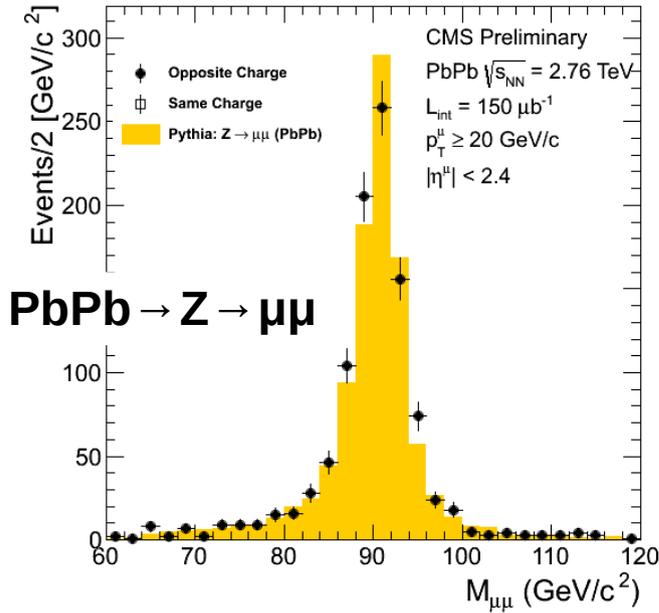
$$W \rightarrow l\nu$$

Source	$W \rightarrow \mu\nu$	$W \rightarrow e\nu$
EWK background normalization	1.1 – 3.2%	1.7 – 3.7%
QCD background template	0.1 – 2.0%	0.5 – 3.9%
Data/MC efficiencies	2.2 – 7.5%	3.4 – 12.7%
Electron energy scale	–	0.1 – 2.0%

+ Luminosity uncertainty 3.5%

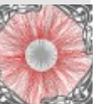


Z bosons in PbPb and pp @ 2.76 TeV

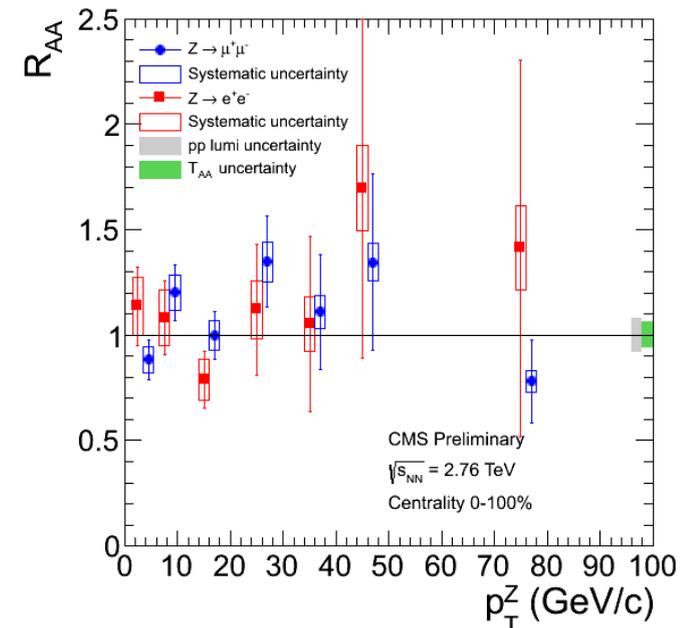
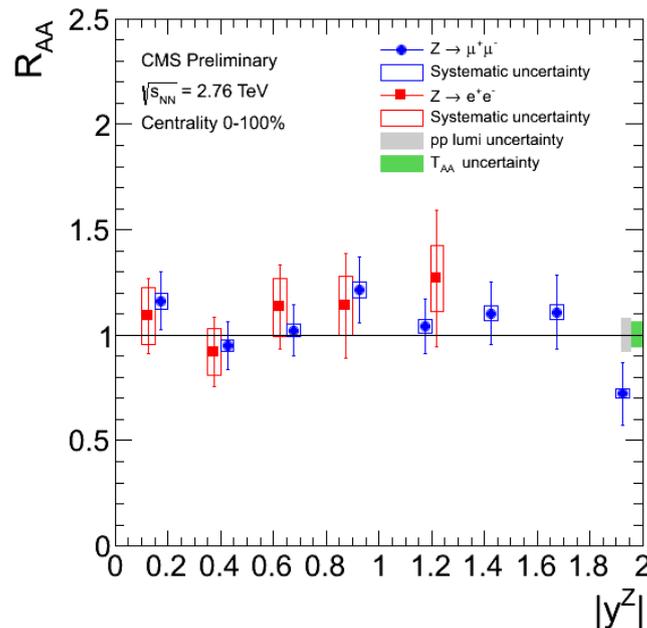
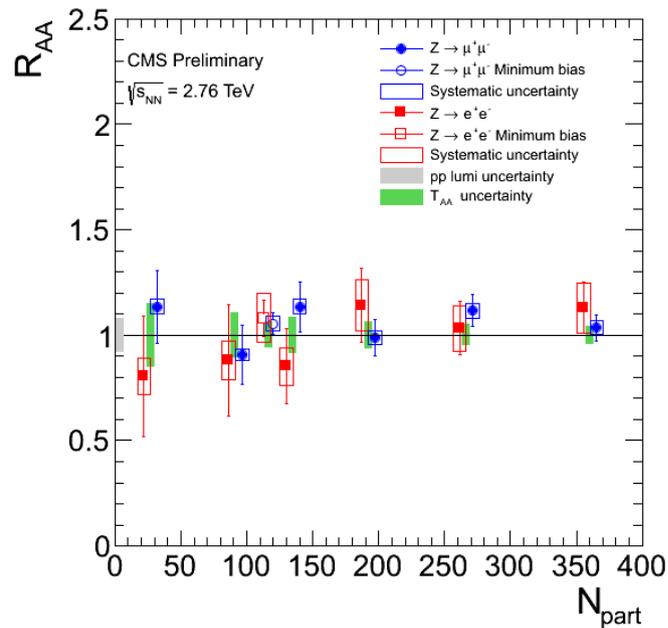


- 2011 PbPb data
- 2013 pp data
- Both muon and electron channels included
- Lepton selection:
 - $p_T > 20$ GeV/c
 - $|\eta^{\mu(e)}| < 2.4$ (1.44)
- Dilepton mass in [60, 120] GeV/c²

CMS-PAS-HIN-13-004

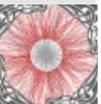


Z bosons in PbPb and pp @ 2.76 TeV



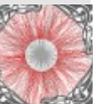
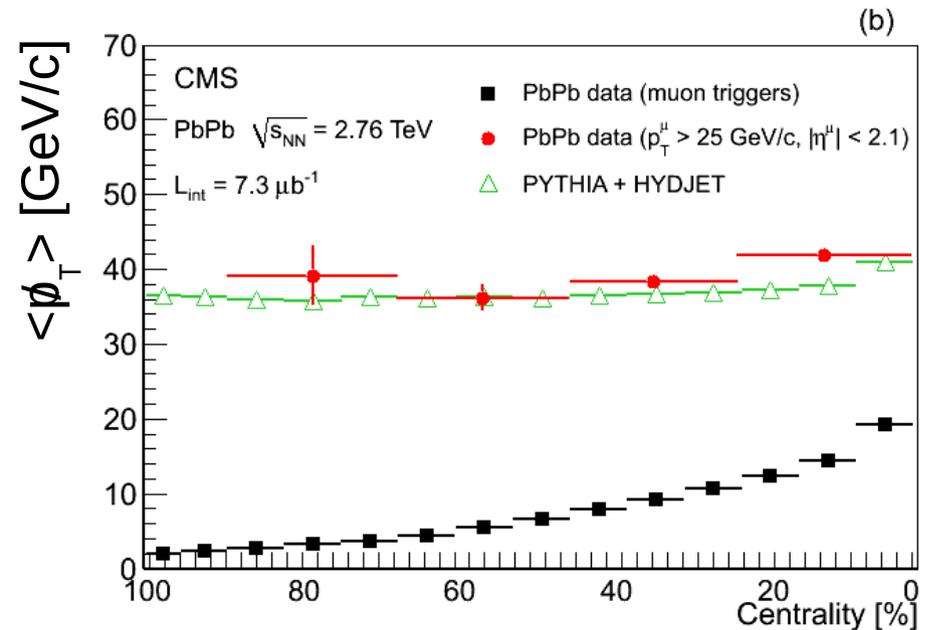
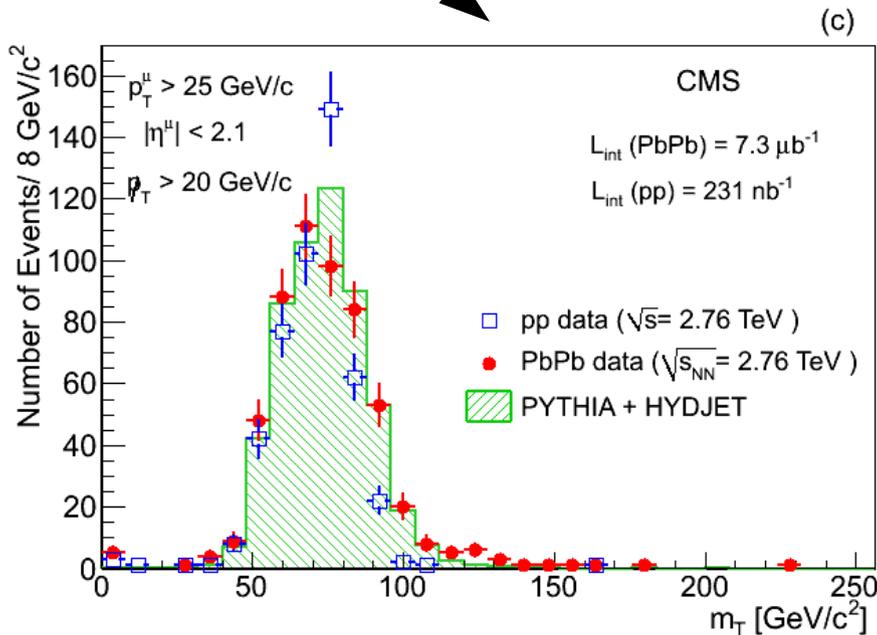
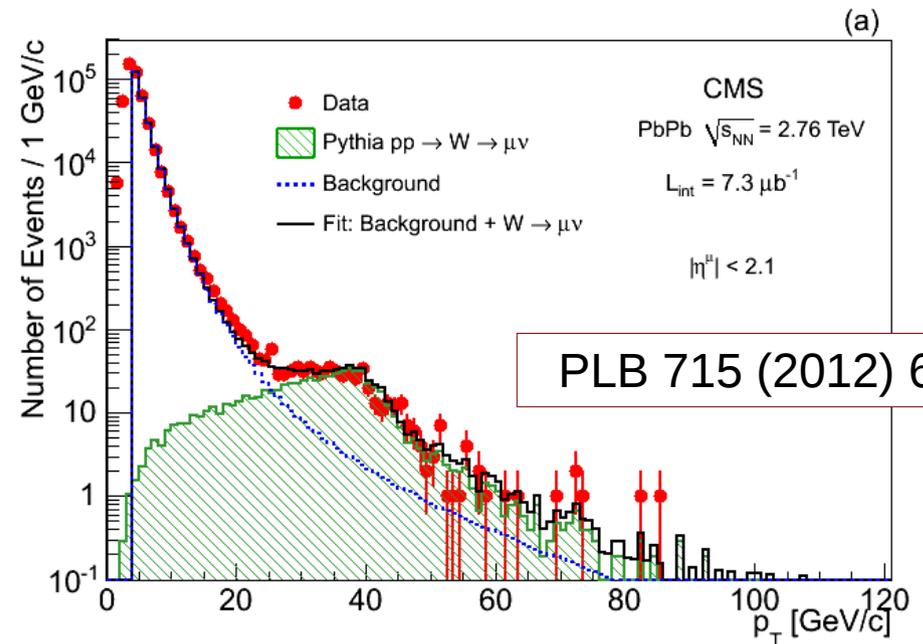
- Muon and electron results agree
- R_{AA} consistent with 1
- Scaling with number of binary collisions confirmed
- Possible nuclear effects on the p_T or rapidity spectrum are within the uncertainties of the measurement

CMS-PAS-HIN-13-004

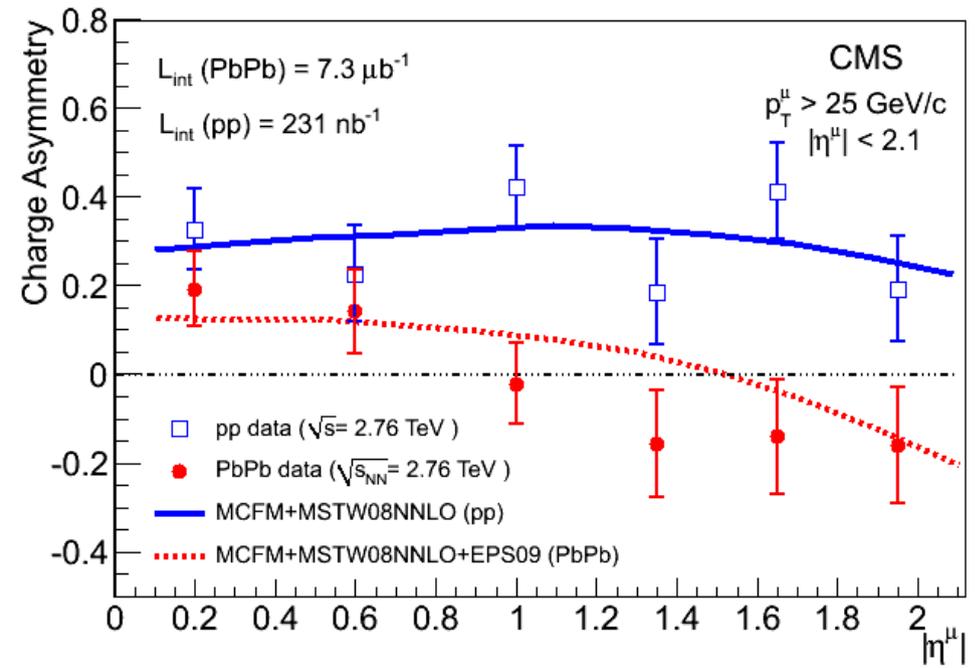
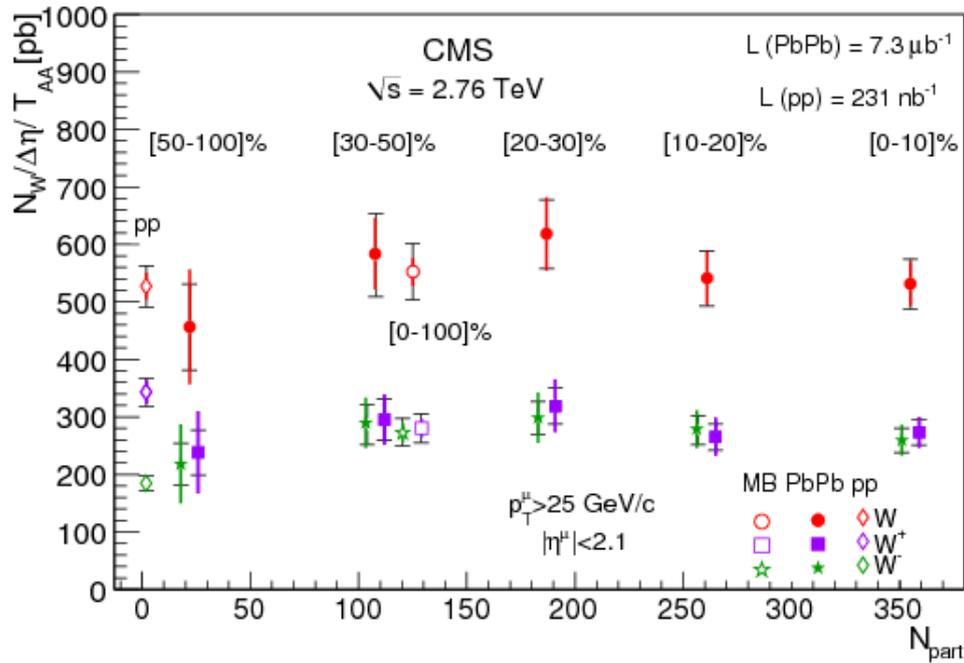


W bosons in PbPb & pp @ 2.76 TeV

- Signal already visible in muon p_T spectrum
- Simple missing p_T from tracks ($p_T^{\text{track}} > 3 \text{ GeV}/c$)
- Then transverse mass



W bosons in PbPb & pp @ 2.76 TeV



- $R_{AA}(W) = 1.04 \pm 0.07 \pm 0.12$
- $R_{AA}(W^+) = 0.82 \pm 0.07 \pm 0.09$
- $R_{AA}(W^-) = 1.46 \pm 0.14 \pm 0.16$
- Consistent with isospin effect

- Charge asymmetry in **pp** and **PbPb**
- Experimental values compatible with NLO pQCD predictions

PLB 715 (2012) 66

