Electroweak boson results from CMS

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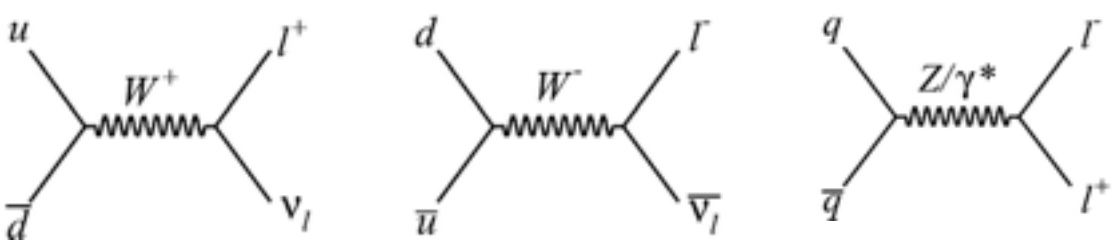
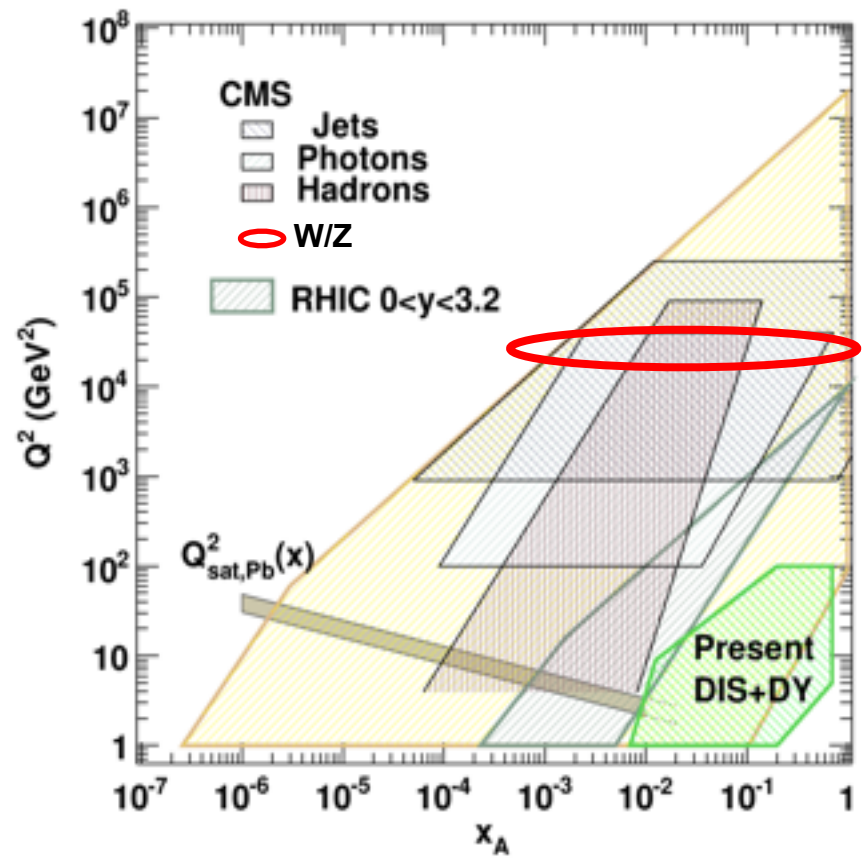
Introduction

- LHC energies allow first measurement of Z and W bosons in heavy ion collisions
- Electroweak bosons do not participate in strong interaction and their leptonic decays are medium-blind
- W and Z bosons are sensitive to valence quark and sea antiquark content in the nucleus
- W/Z constrain nuclear parton distribution functions (nPDFs) in unexplored region of Q^2-x phase space.
- Provide insights into the PDF of neutrons.



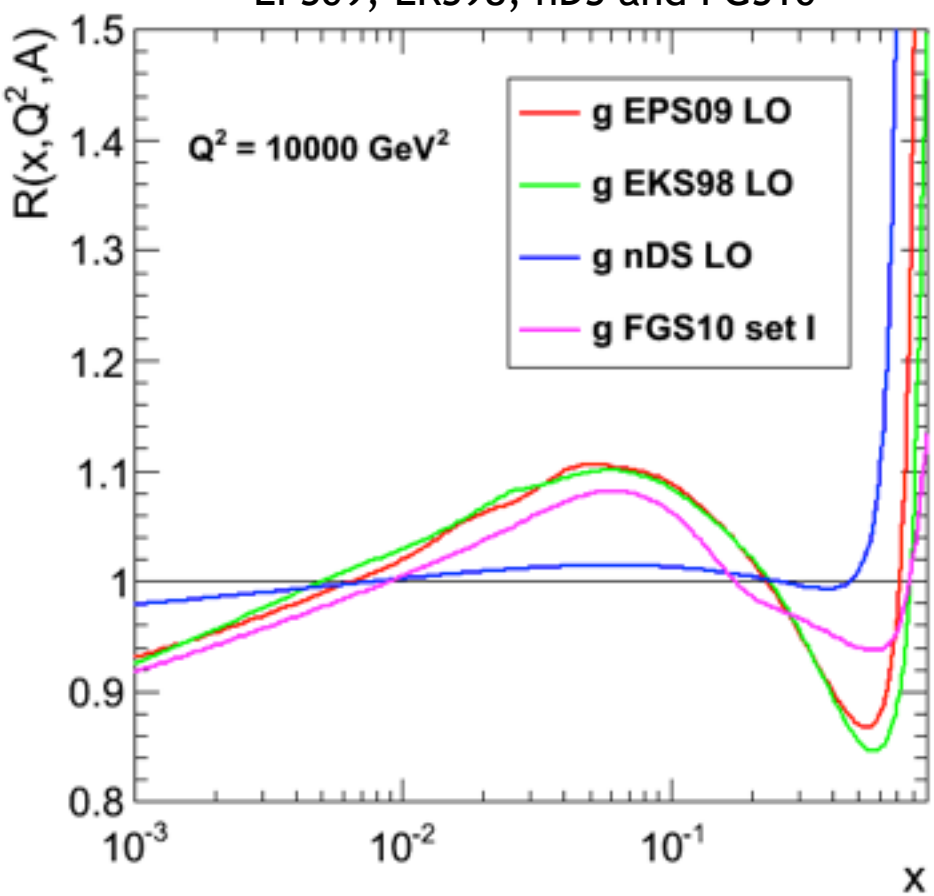


Nuclear parton distribution functions

Nuclear parton distribution functions (nPDFs):

$$f_i^A(x, Q^2) = R_i^A(x, Q^2) f_i^p(x, Q^2)$$

Gluon nPDF/PDF comparison between EPS09, EKS98, nDS and FGS10

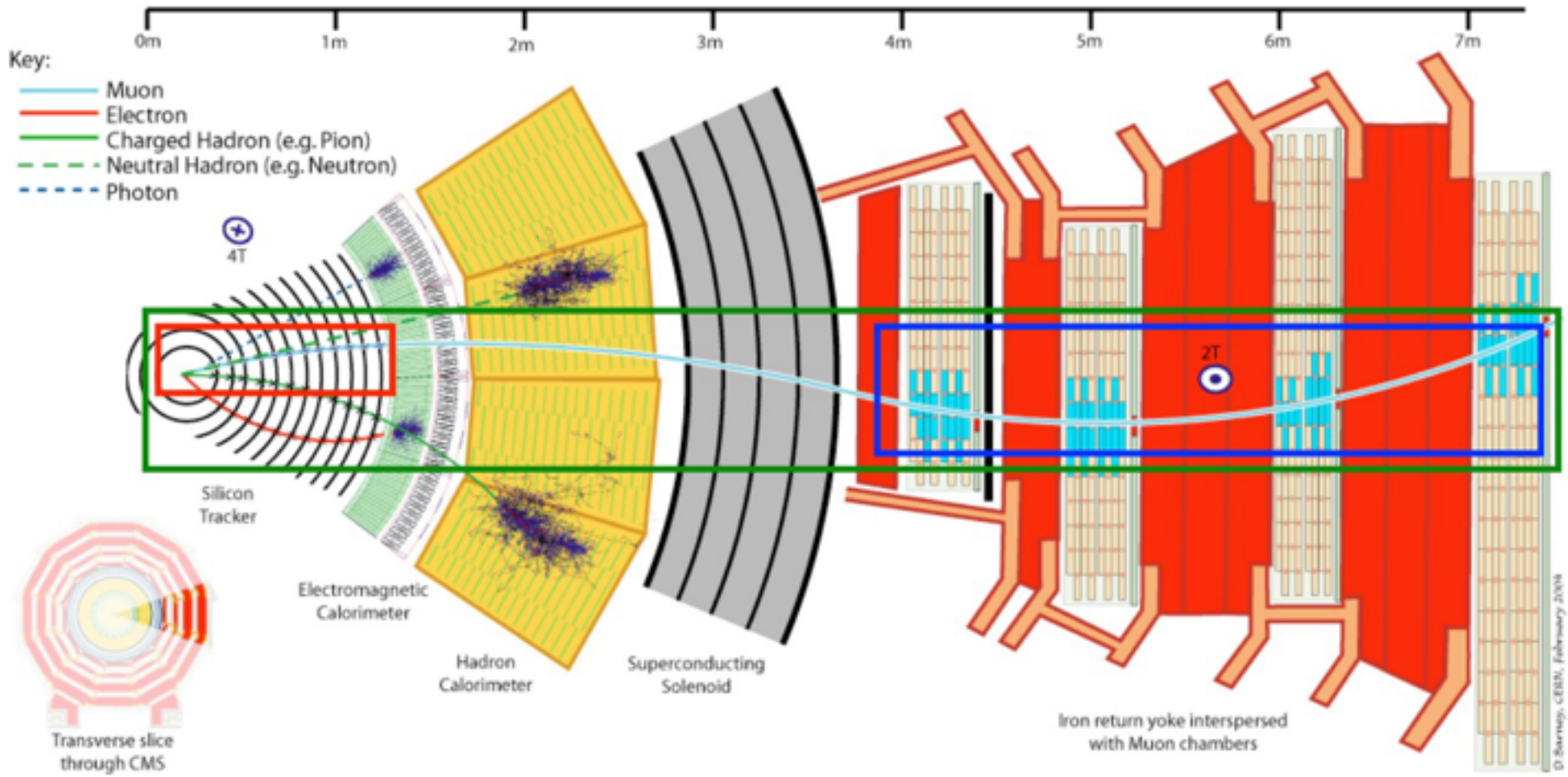


CMS Electroweak boson results

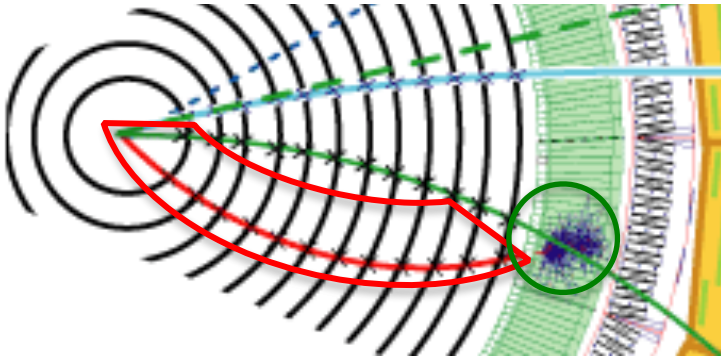
	PbPb & pp 2.76 TeV	pPb 5.02 TeV
Z	PRL 106 (2011) 212301 JHEP 03 (2015) 237	CMS-PAS-HIN-15-002
W	PLB 715 (2012) 66	arXiv:1503.05825
Isolated photons	PLB 710 (2012) 256	

presented today

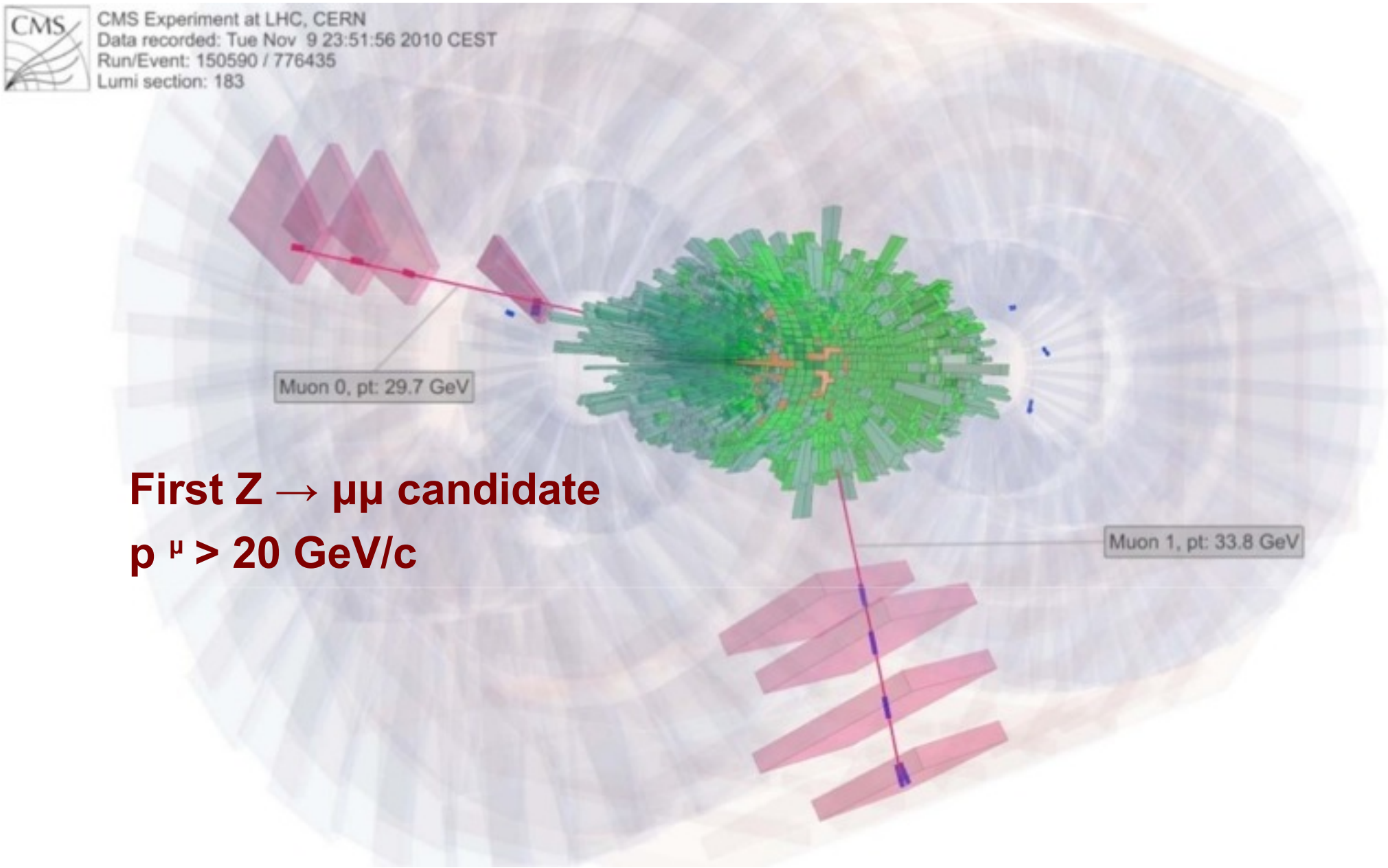
Muon/Electron reconstructions in CMS



- Muons: Si tracker + muon detectors
  - p_T resolution: 1-2% up to p_T ~ 100 GeV/c
- Electrons: Si tracker + ECAL dectector
  - p_T resolution: 1-2% for p_T ~ 45 GeV/c



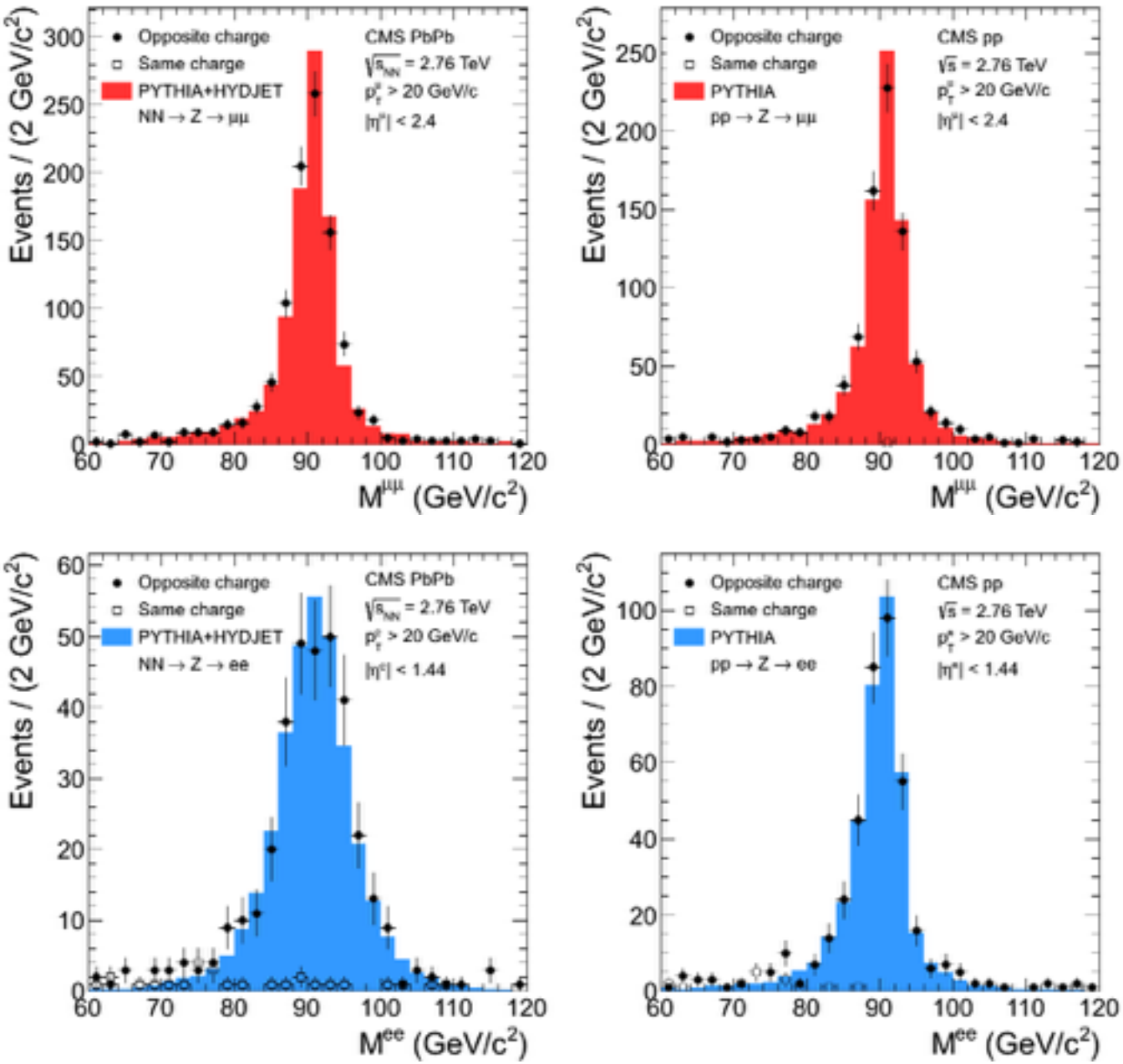
Z boson in PbPb and pp @ 2.76 TeV



First Z → μμ candidate

p^{μ} > 20 GeV/c

Z boson in PbPb and pp @ 2.76 TeV



- 2011 PbPb data
- 2013 pp data
- Both electron and muon channels analyzed
- Lepton selection:
  - p_T > 20 GeV/c
  - $|\eta^{\mu(e)}|$ < 2.4 (1.44)
  - Dilepton mass in [60 - 120] GeV/c^2
- Signal shapes agree with simulation in both channels and both collision systems

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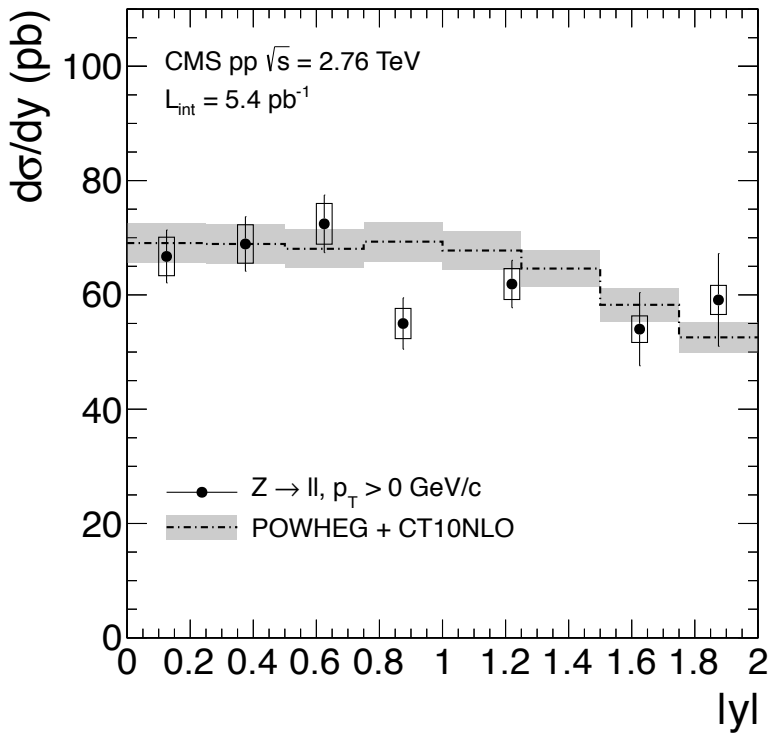
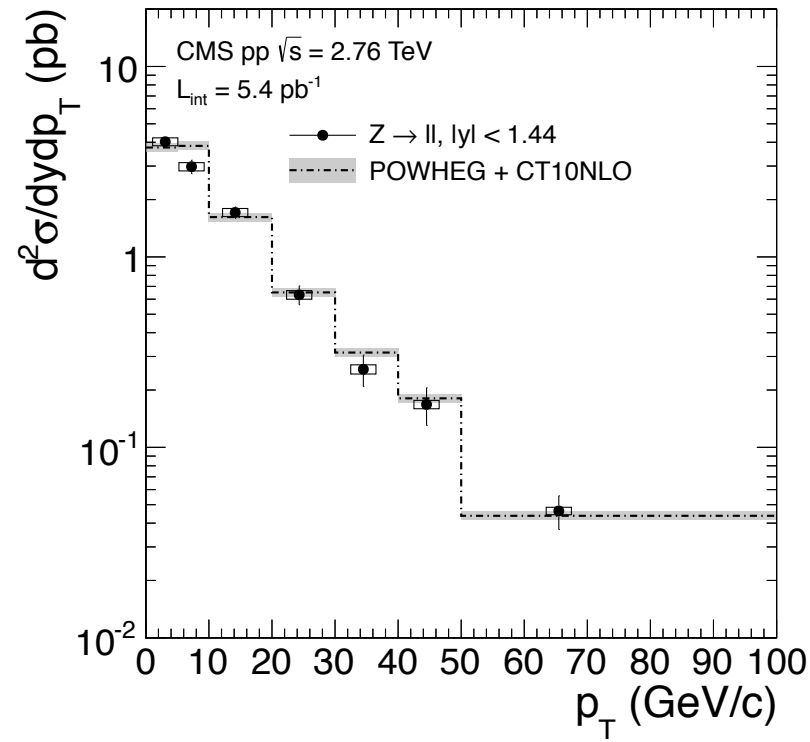
Z boson yield in pp @ 2.76 TeV





- Rapidity and transverse momentum dependence
- Agrees with scaled NLO POWHEG prediction within uncertainties

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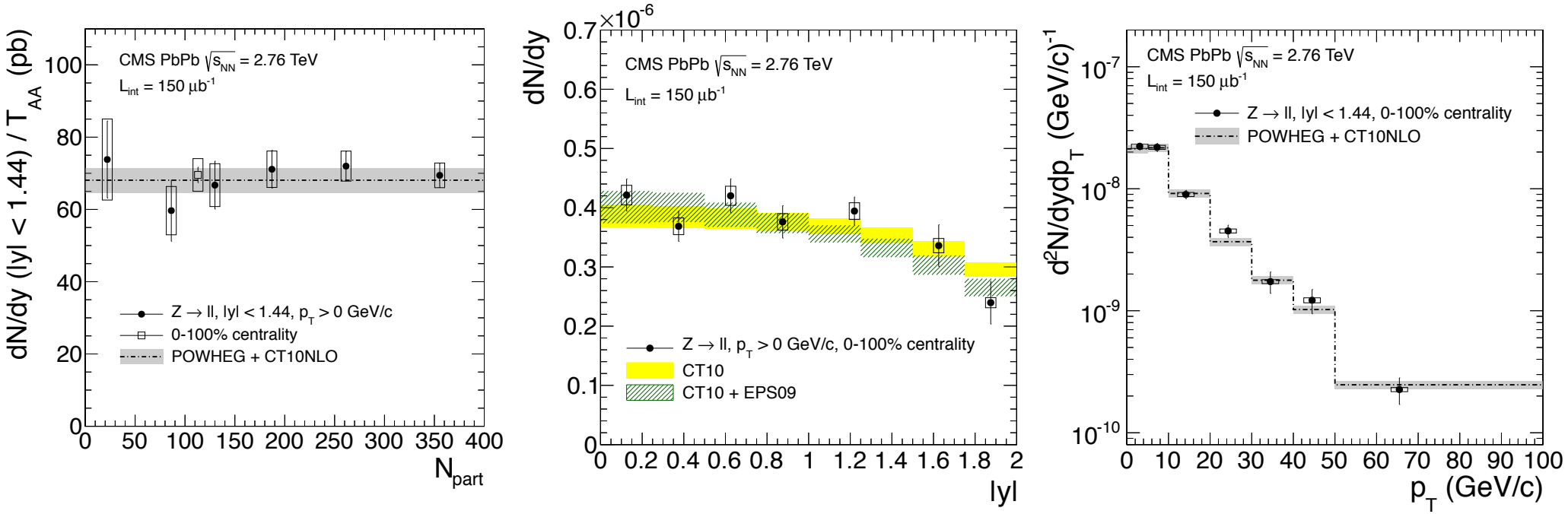
Z boson yield in PbPb @ 2.76 TeV



- Z boson yield scales with N_{coll}
- N_{part} distribution shows no dependence
- Rapidity distribution is sensitive to nPDFs but we need more data
- p_T spectrum agrees with scaled NLO POWHEG calculation within uncertainties

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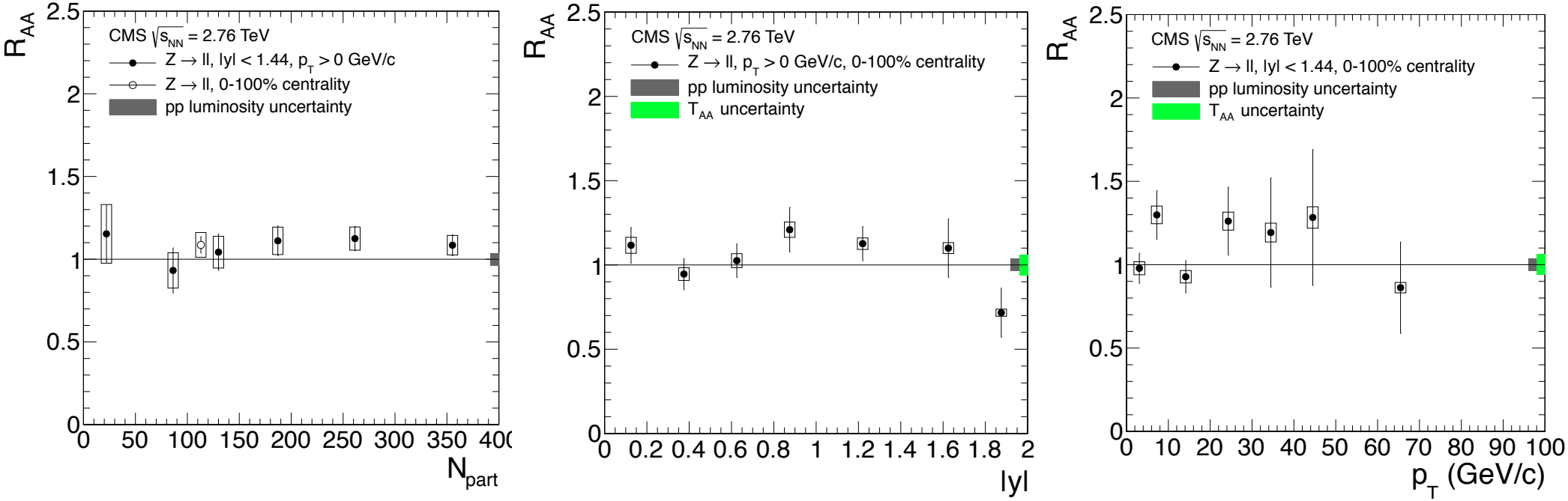
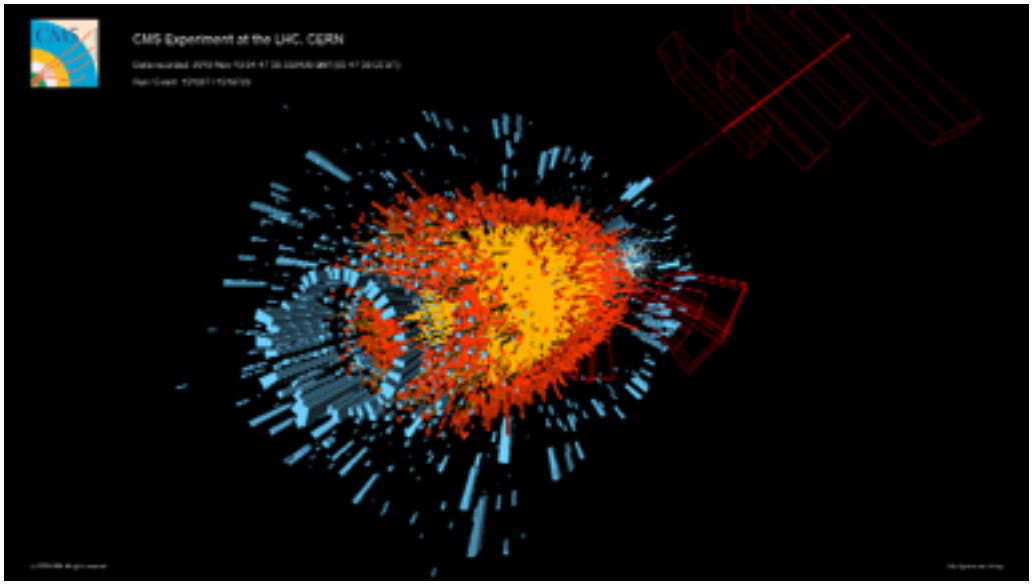
Z boson yield in PbPb @ 2.76 TeV



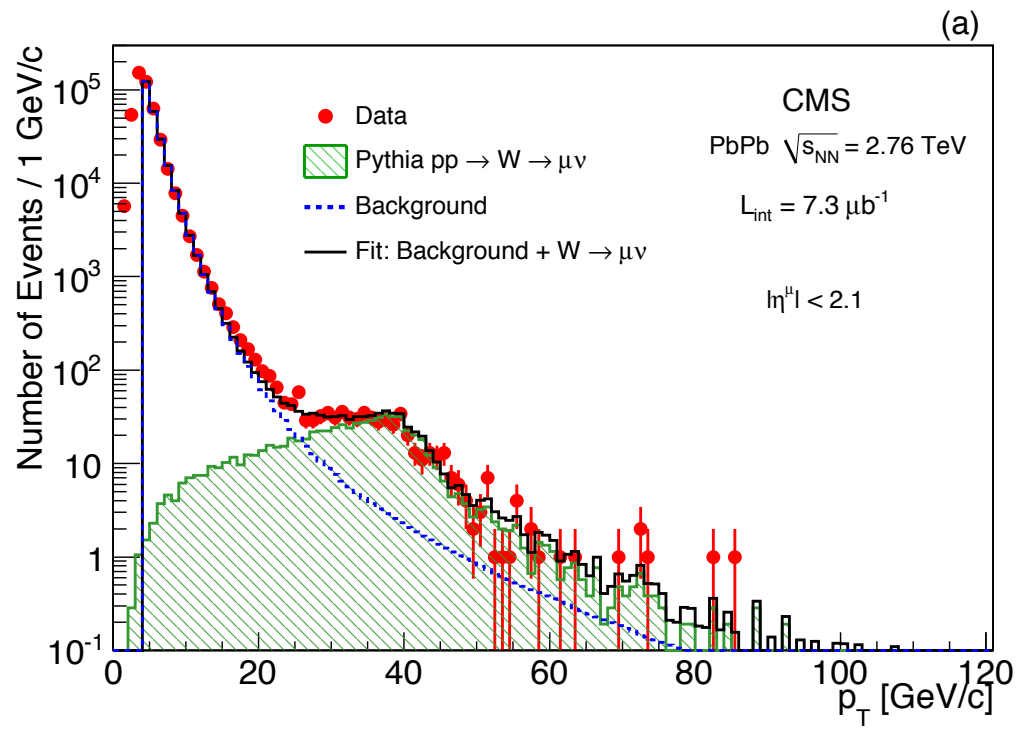
$$R_{AA} = \frac{1}{N_{coll}} \frac{d\sigma^{PbPb}}{d\sigma^{pp}}$$

- R_{AA} results consistent with unity
- Possible nuclear effect on p_T and y spectrum are within the uncertainties of the measurement

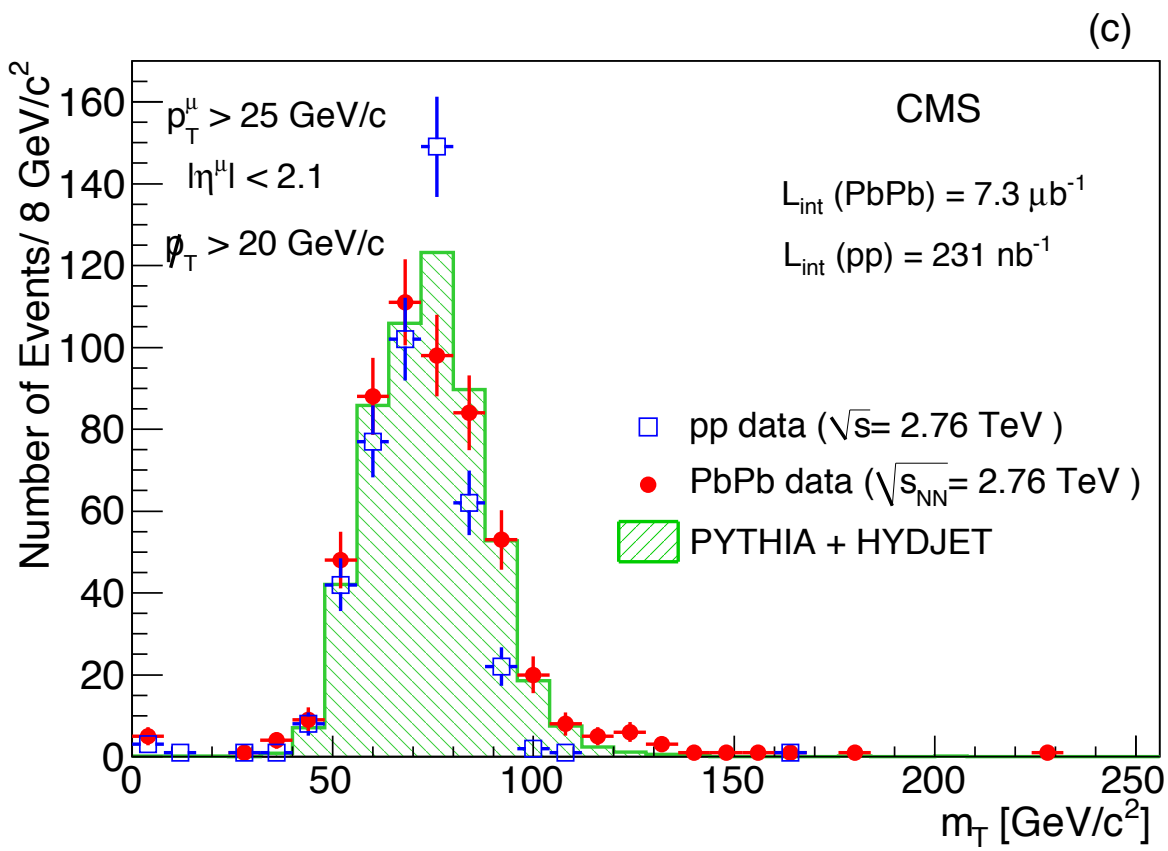
W boson in PbPb @ 2.76 TeV



- Muon selection:
  - pT > 25 GeV/c
  - pT_miss > 20 GeV/c
  - |η| < 2.1

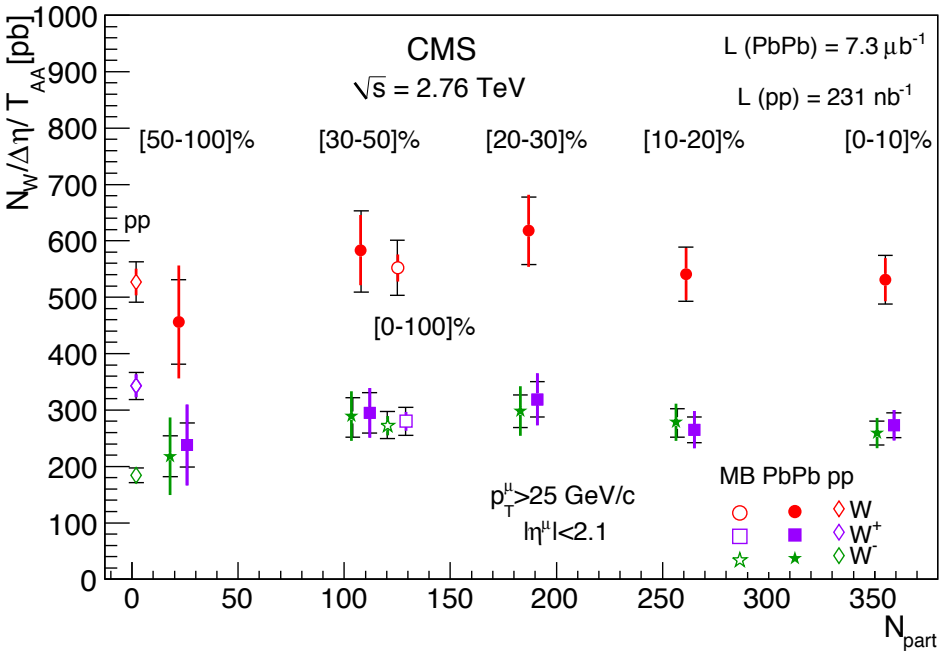


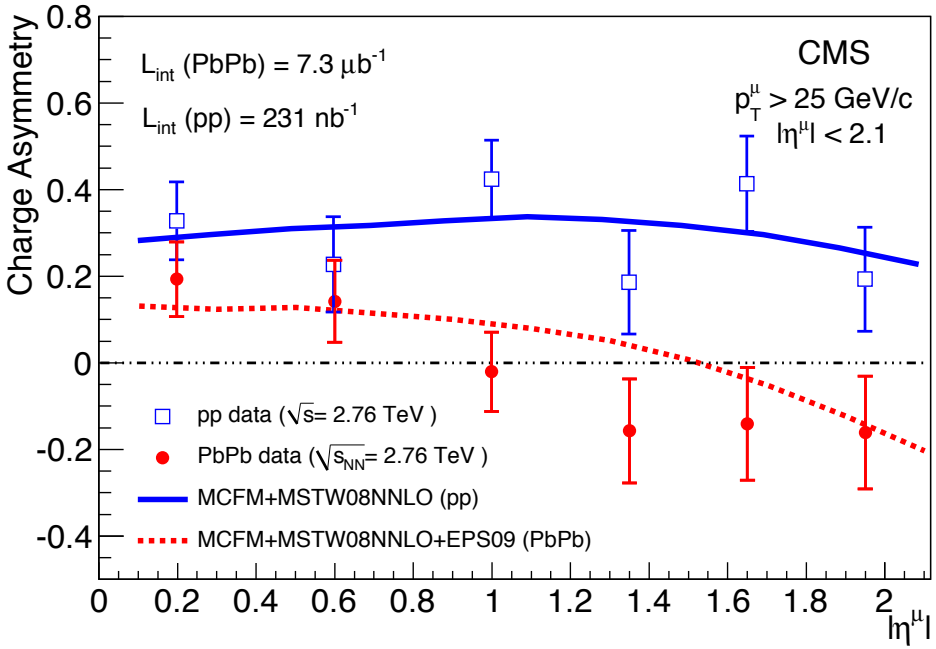
W boson in PbPb @ 2.76 TeV



- Distribution from PbPb data consistent with simulation
- Signal observed from pp data is similar from PbPb, slightly narrower
- Used fitting to get signal yield then calculated charge asymmetry

W boson in PbPb @ 2.76 TeV

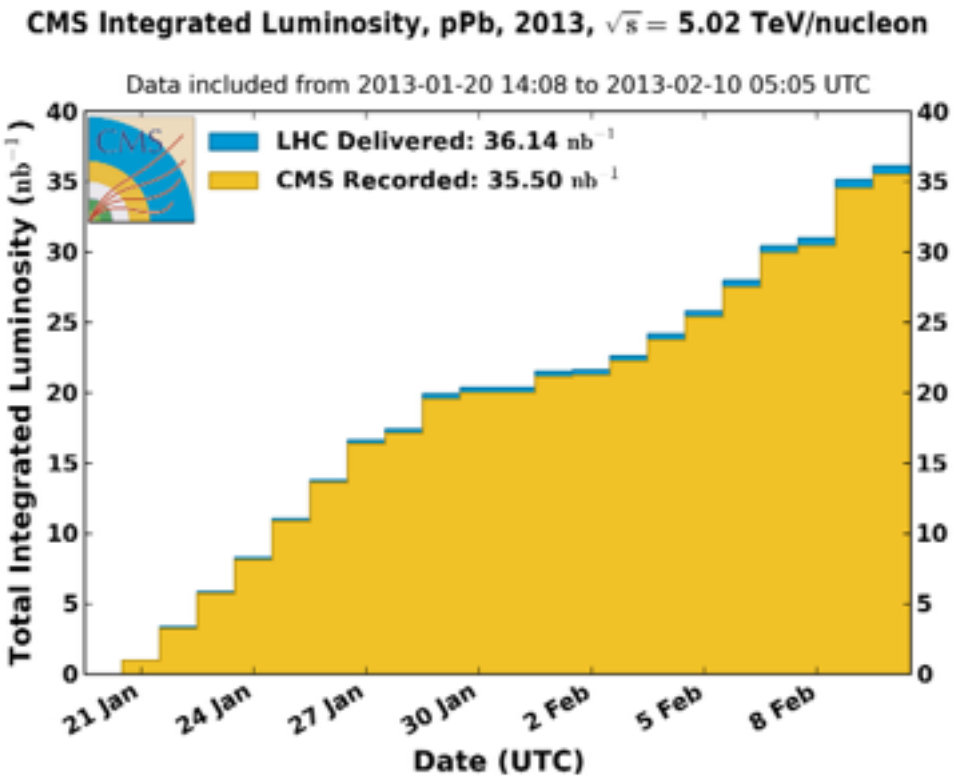


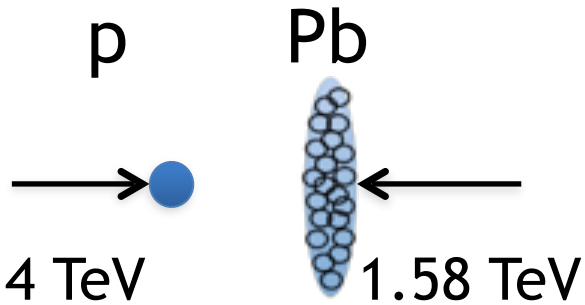


- Within uncertainties, no centrality dependence is observed
- pp system:
  - little dependence of asymmetry on η
  - positive in whole η range
- PbPb system:
  - larger dependence on η
  - negative values for |η| > 1.1

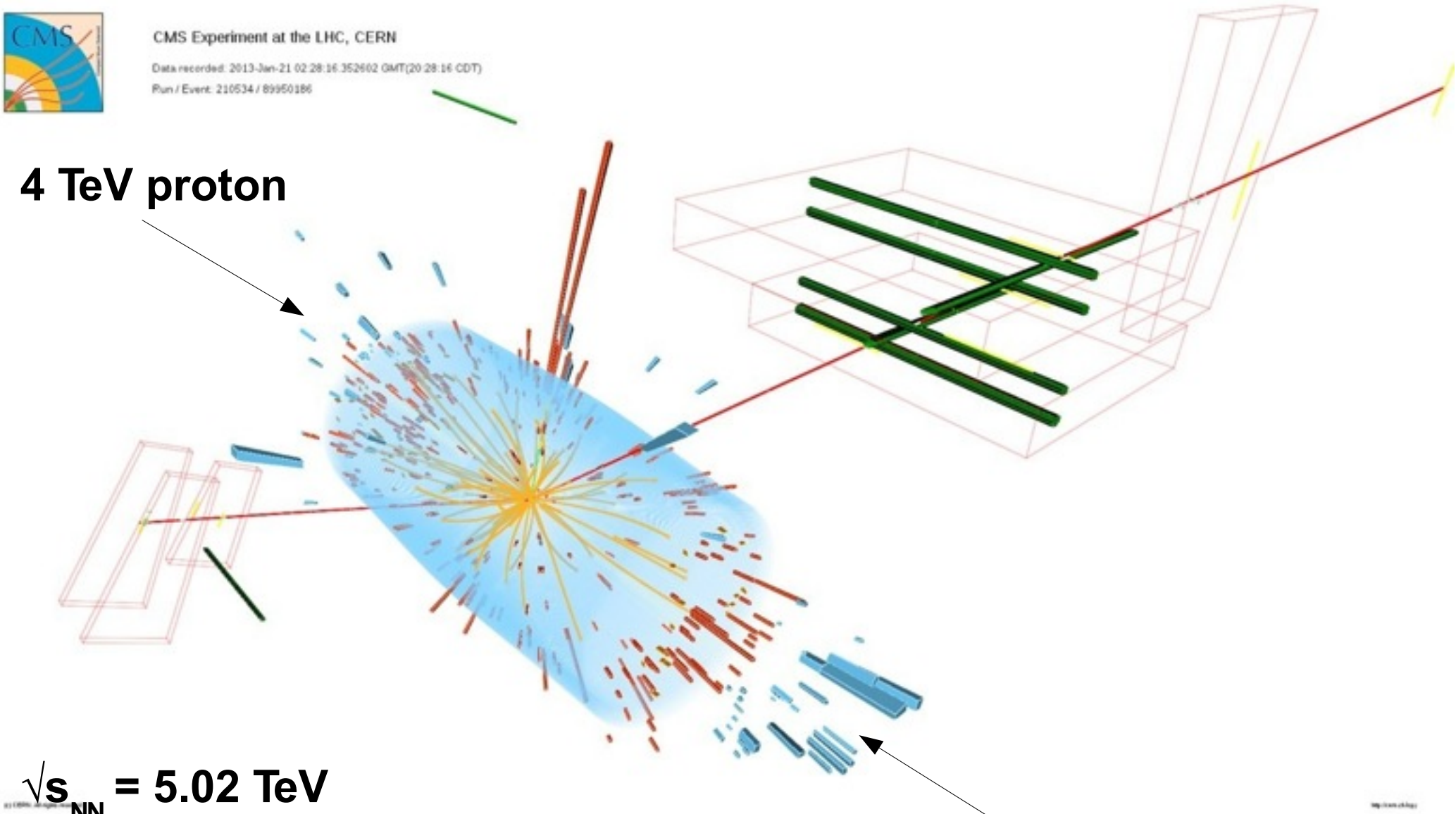
pPb collisions at LHC

- Data taken in 2013
- Integrated luminosity:
  - 34.6 ± 1.2 nb^{-1}
  - Calibrated by Van der Meer scans
  - Certified
- Data taking with both beam directions
- Results presented with proton fragmentation region





Z boson in pPb @ 5.02 TeV



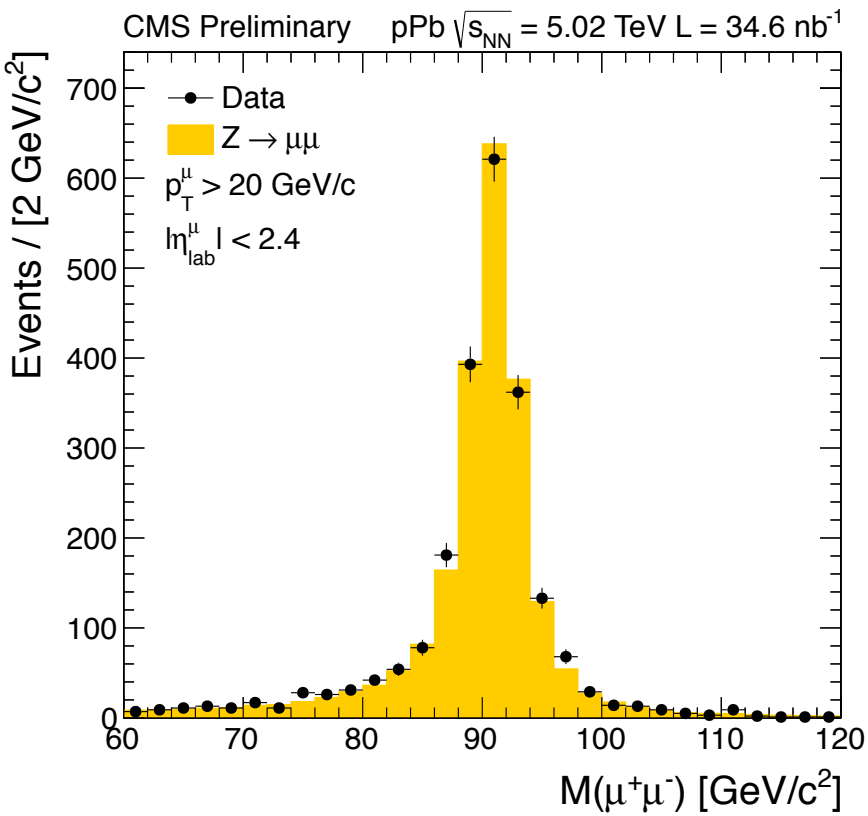
4 TeV proton

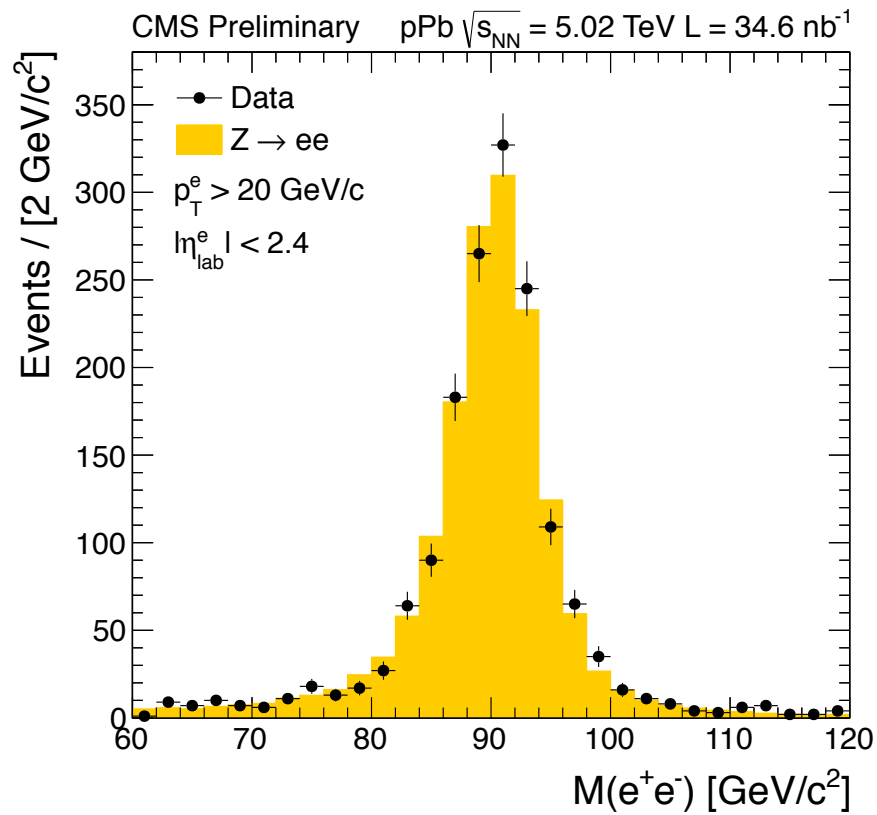
1.58 TeV Pb nucleus

$\sqrt{s_{NN}}$ = 5.02 TeV

Δy = (–)0.465 rapidity boost

Z boson in pPb @ 5.02 TeV





- Lepton cuts: pT > 20 GeV/c, $|\eta_{lab}| < 2.4$ → fiducial region
- Dilepton mass in [60 – 120] GeV/c^2
- 2183 dimuon & 1571 dielectron candidates

CMS-PAS-HIN-15-002

Z boson in pPb @ 5.02 TeV

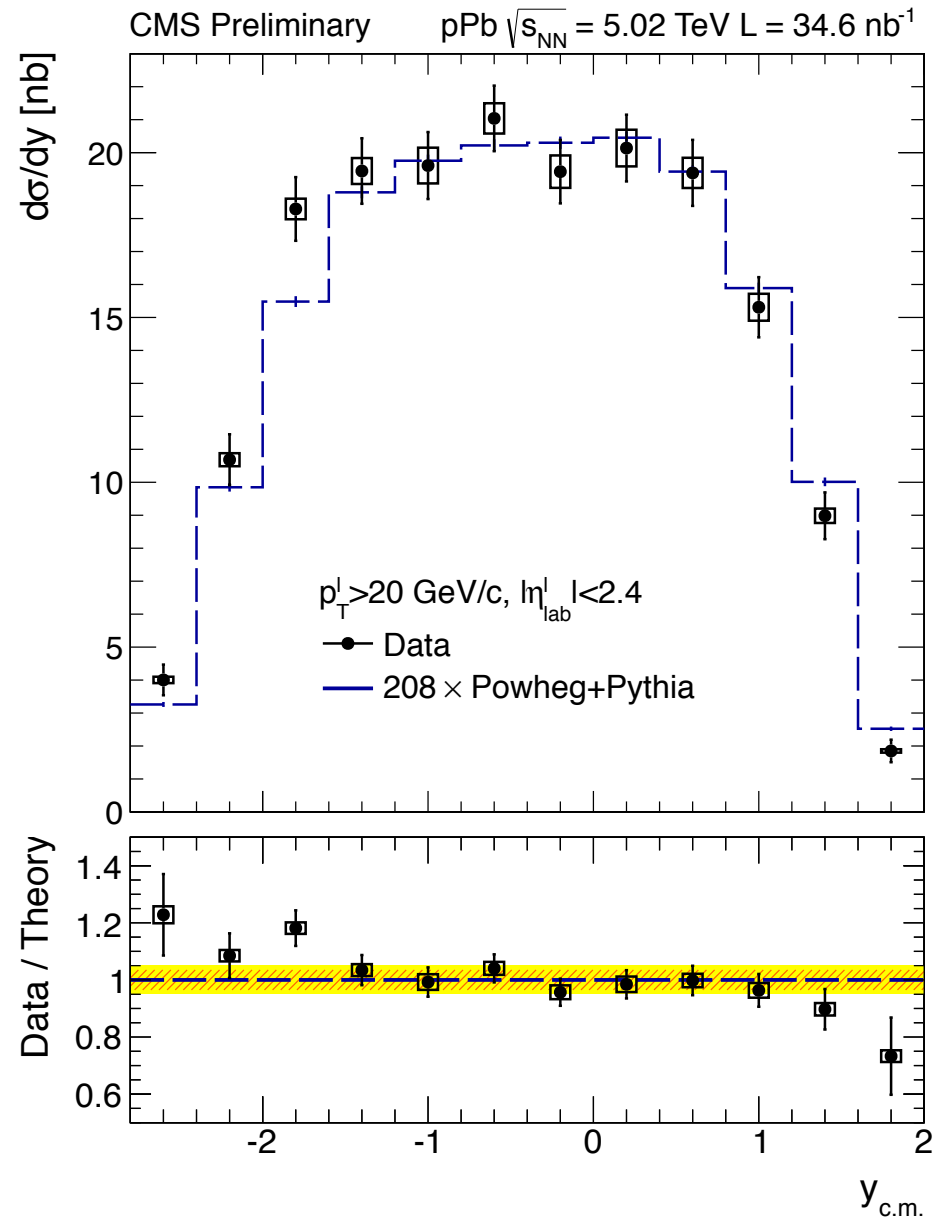
- Electron and muon results agree well and then combined to final results
- Inclusive cross section in fiducial region:

$$70.4 \pm 1.2\,(\text{stat.}) \pm 1.4\,(\text{syst.}) \pm 2.5\,(\text{lumi.})\,\text{nb}$$

- Prediction from POWHEG:

$$\sigma^{pp} \times A = 70.4 \pm 3.5\,\text{nb}$$

- Some differences in forward and backward region compared to POWHEG



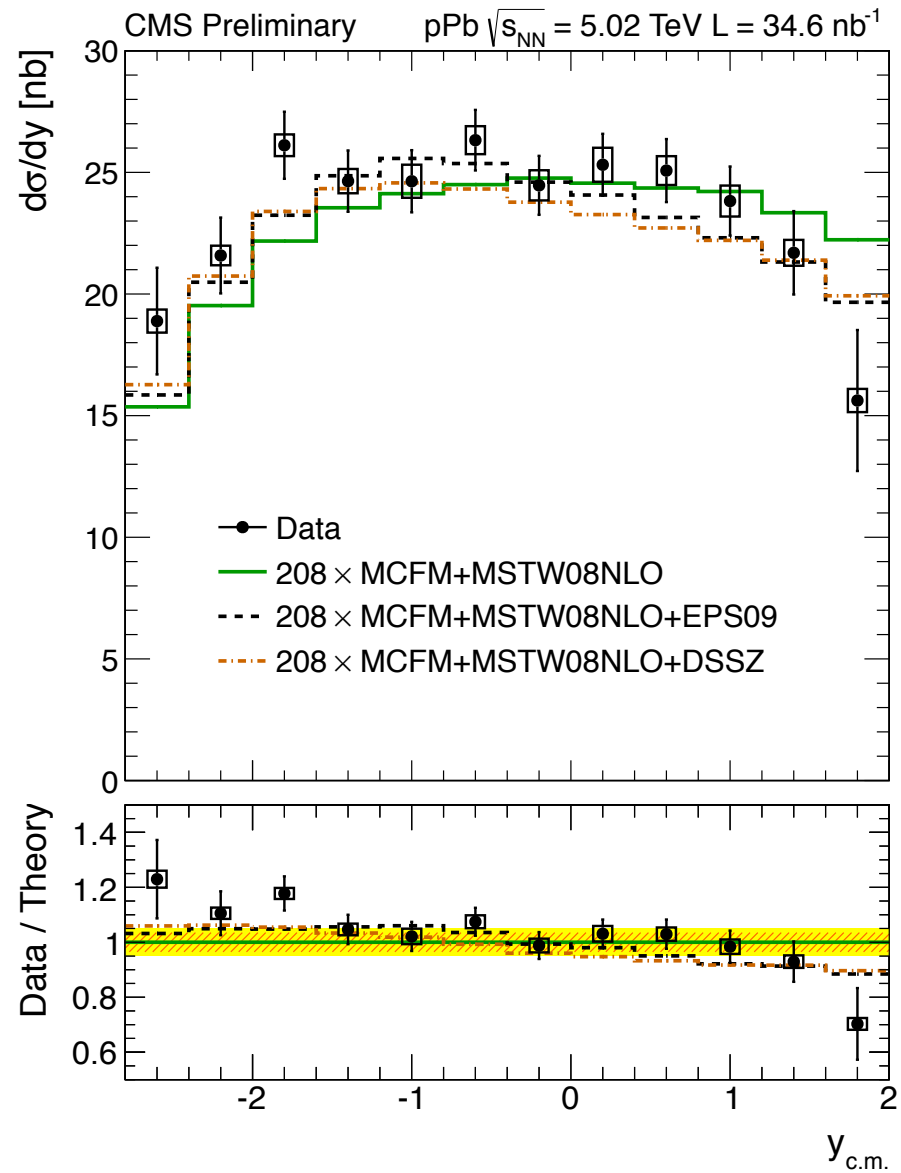
CMS-PAS-HIN-15-002

Z boson in pPb @ 5.02 TeV

- Total inclusive cross section:

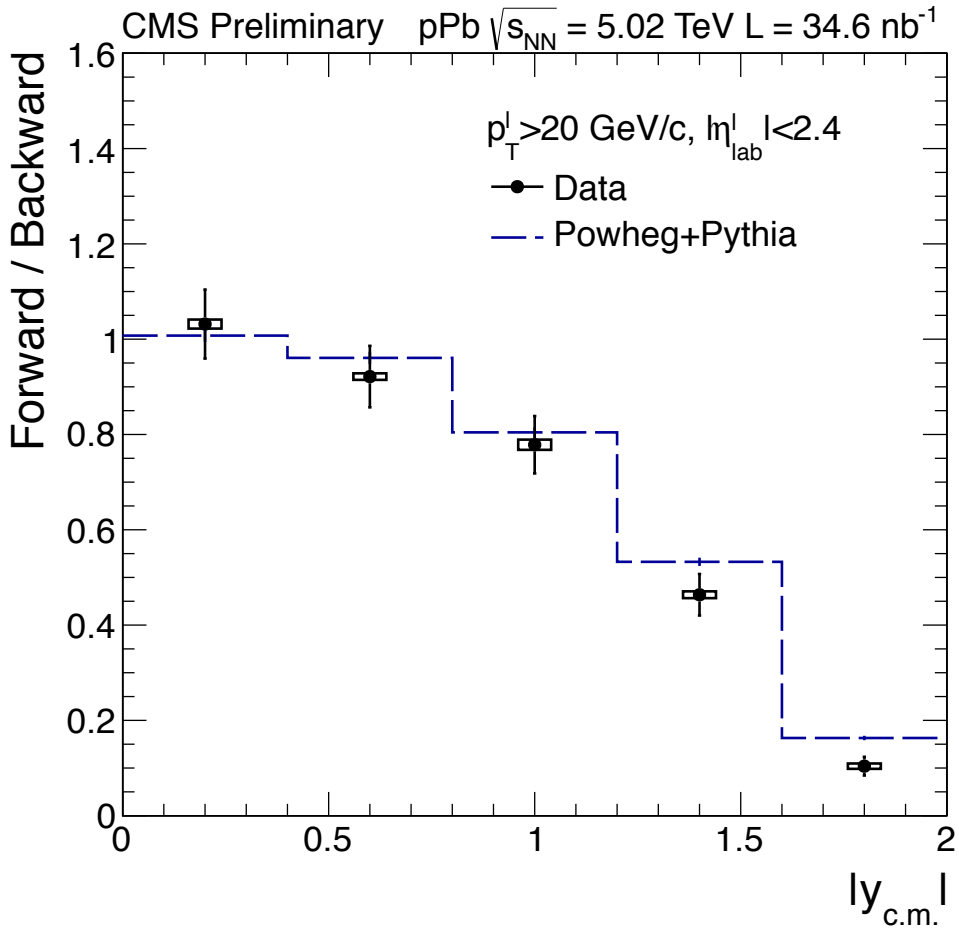
136.4 ± 2.3 (stat.) ± 8.5 (syst.) ± 4.8 (lumi) nb

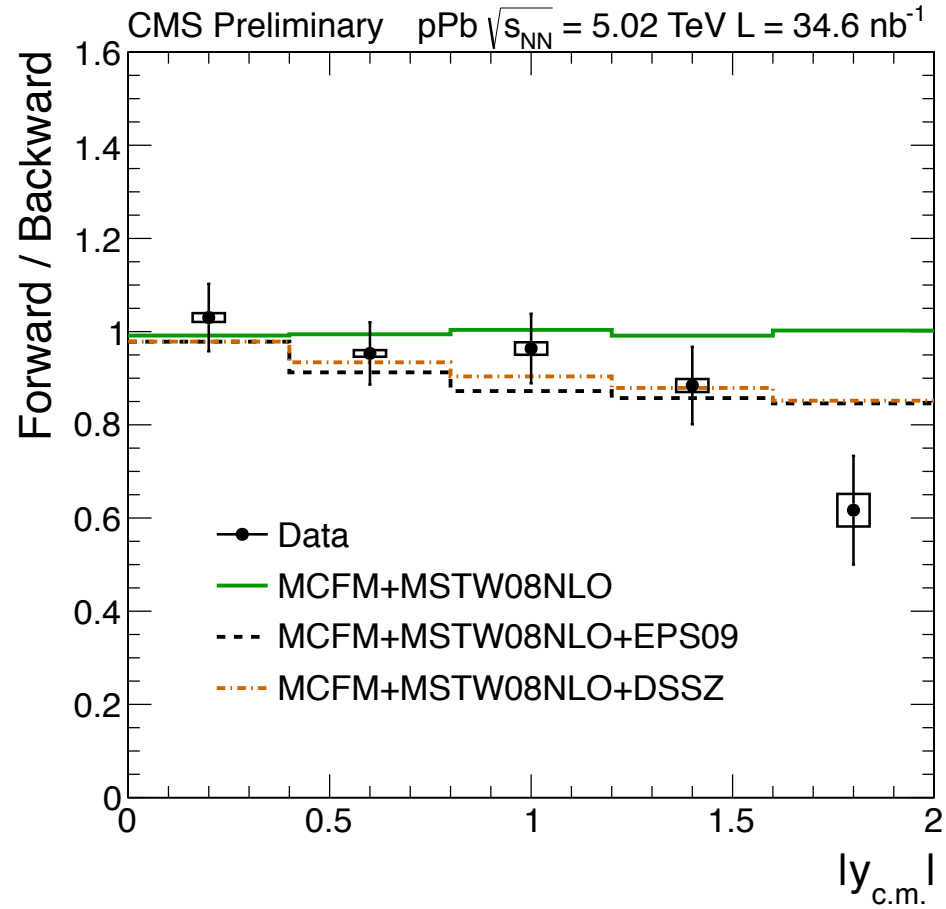
- Acceptance corrected rapidity differential cross section
- Compared to MCFM with and without nPDFs
- Dominated by statistical uncertainties
- Nuclear effects expected in forward and backward regions



CMS-PAS-HIN-15-002

Z boson in pPb @ 5.02 TeV



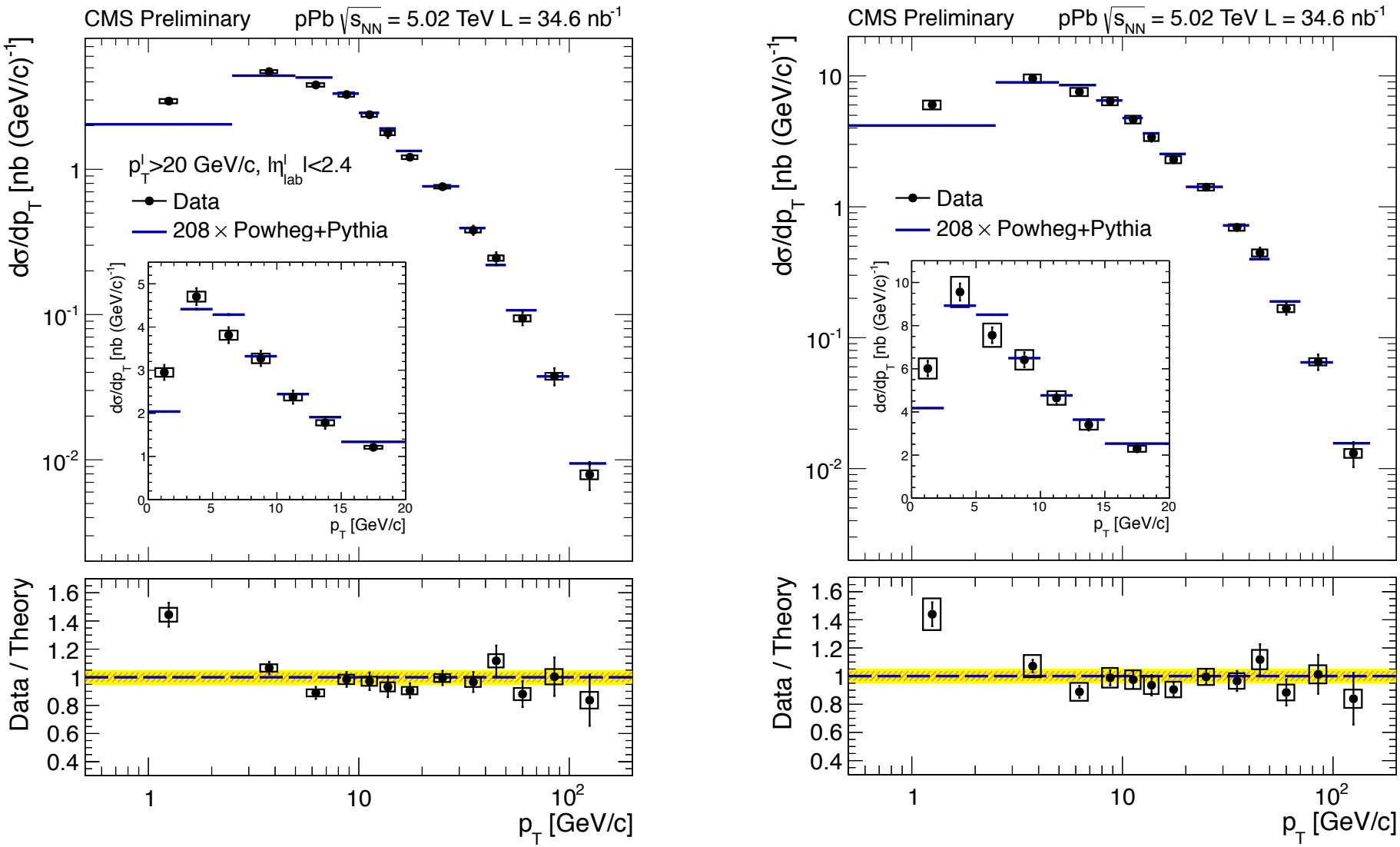


- Forward-backward ratio $R_{FB} = \frac{d\sigma(+y_{\mathrm{c.m.}})/dy}{d\sigma(-y_{\mathrm{c.m.}})/dy}$
- Compared to NLO predictions

→ hint of nuclear effects visible

CMS-PAS-HIN-15-002

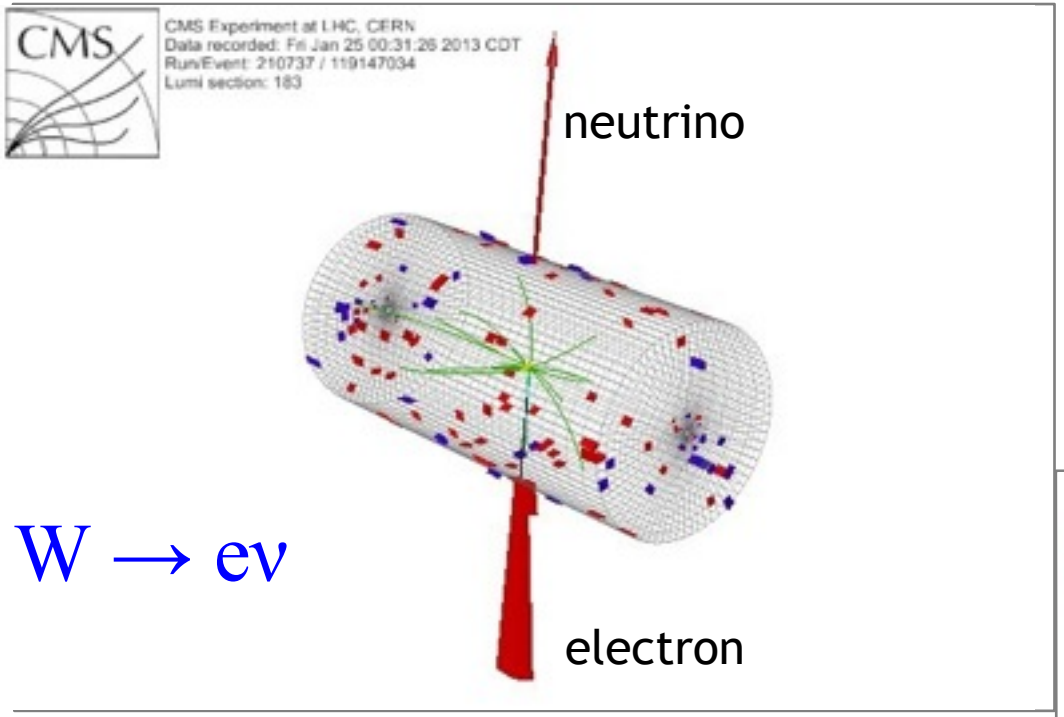
Z boson in pPb @ 5.02 TeV

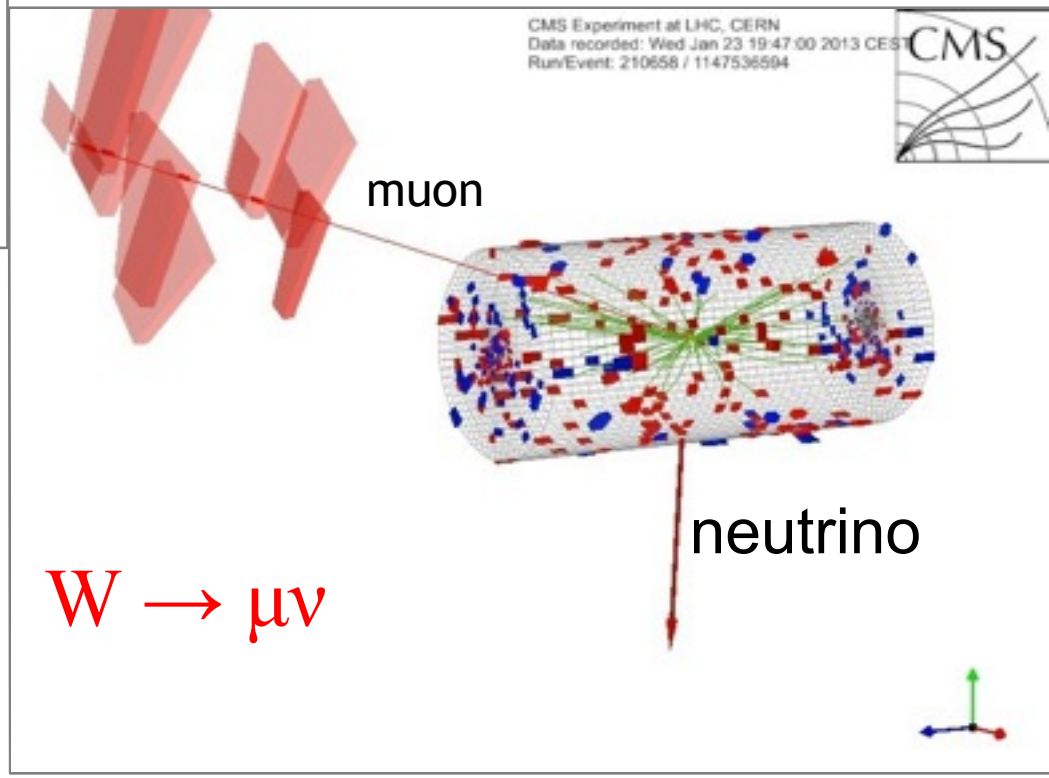


- p_T differential cross section wide range: 0 -150 GeV/c
- Compared to only pp prediction from POWHEG
- Deviation at low p_T region

CMS-PAS-HIN-15-002

W bosons in pPb @ 5.02 TeV

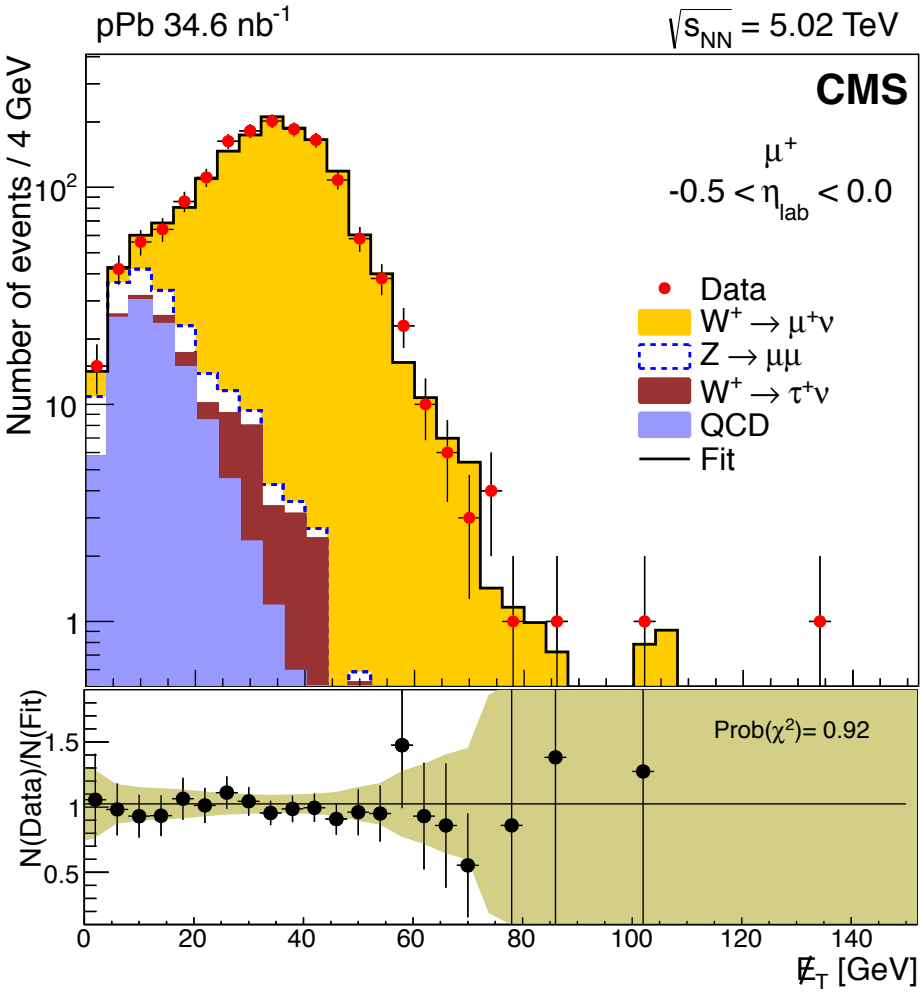




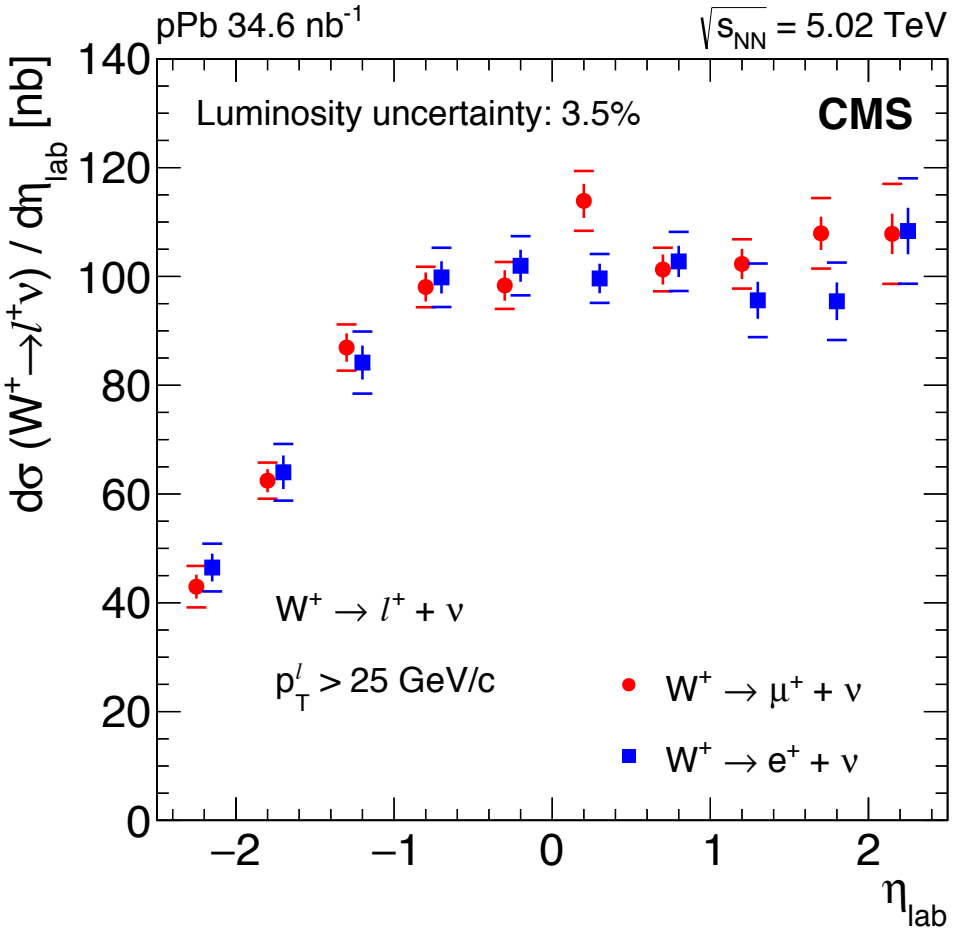
- ~20 000 candidates in both electron and muon channels

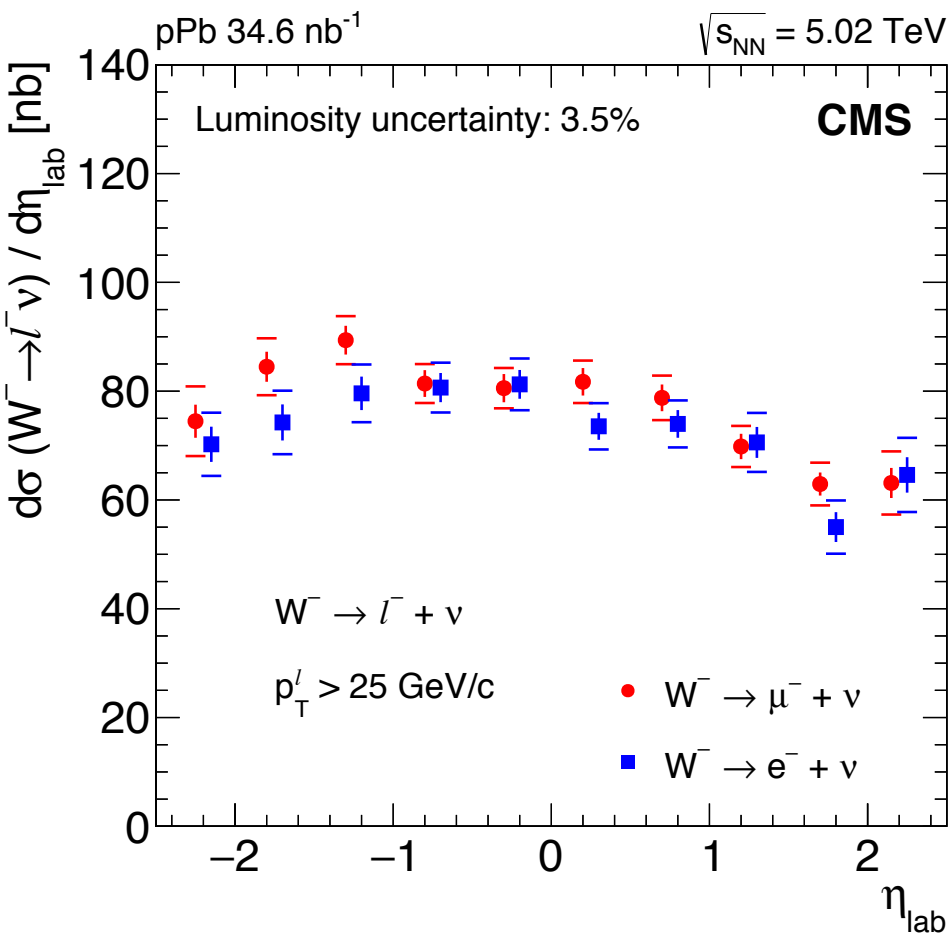
W bosons in pPb @ 5.02 TeV

- Event selection
  - $p_T^{\mu,e} > 25$ GeV/c
  - $|\eta_{lab}^{\mu,e}| < 2.4$
  - Good quality and isolation requirements
  - Veto on dilepton events
- Fitting on missing transverse energy to extract yield:
  - on both charges
  - each η bin separately.
- Templates for QCD background from data-based method, electroweak processes from simulations



W bosons in pPb @ 5.02 TeV

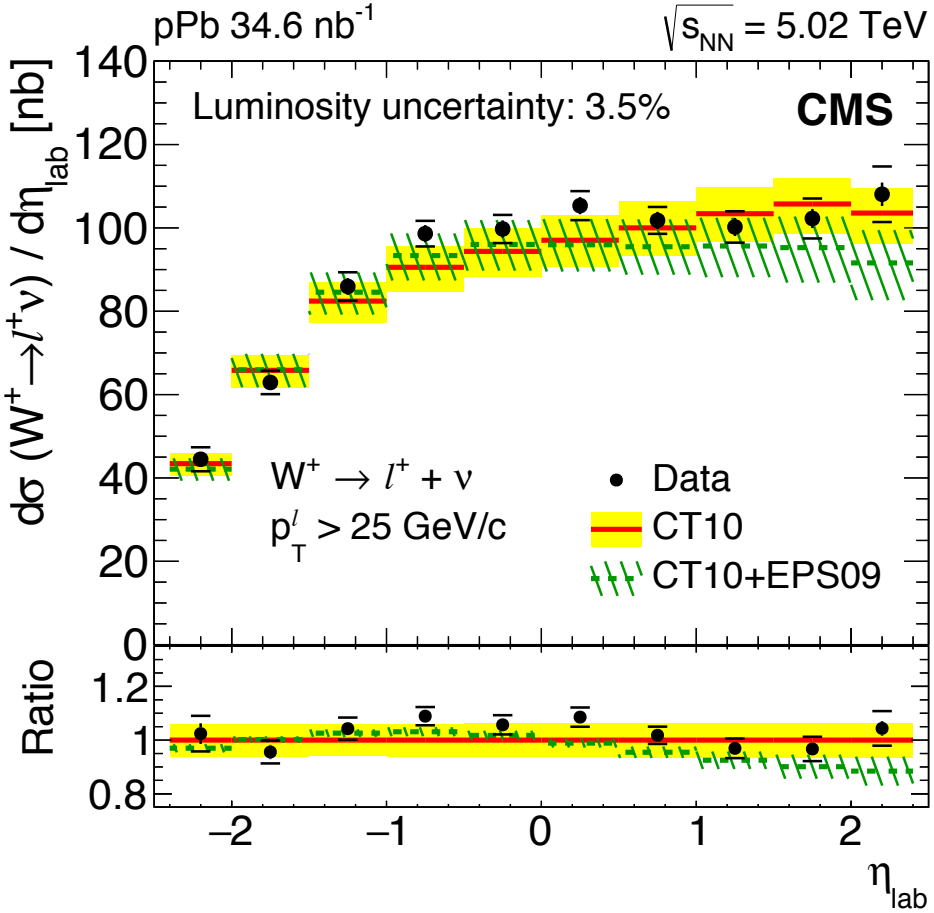


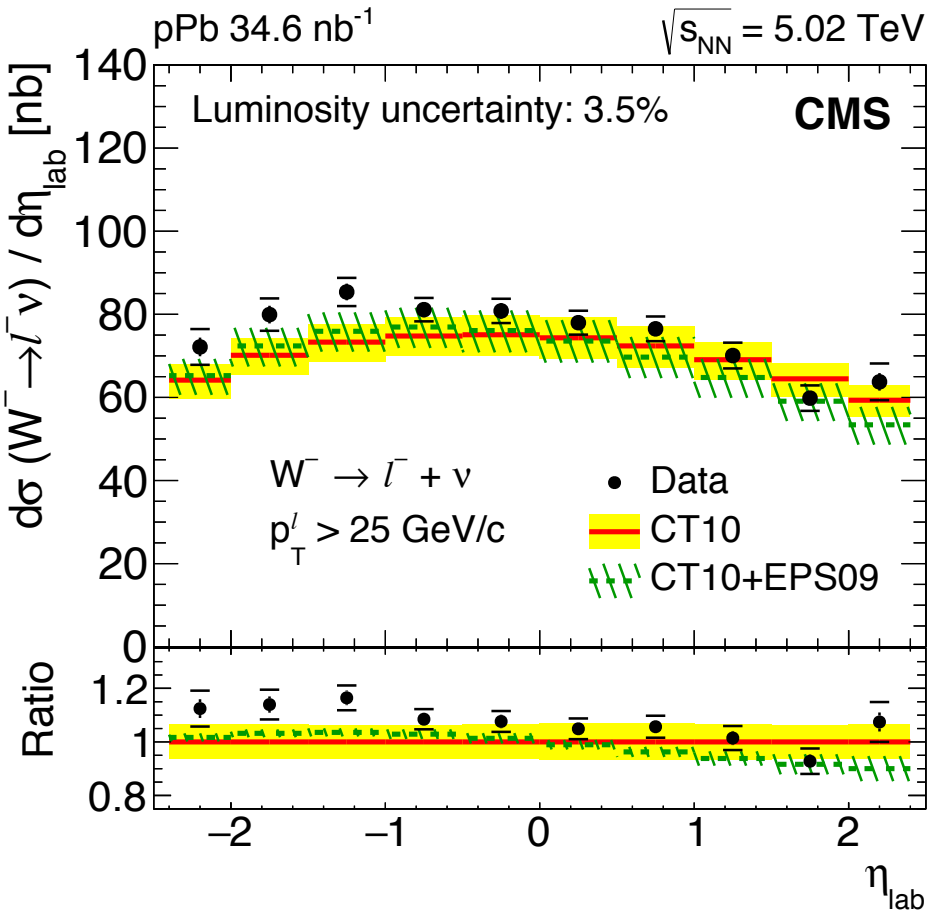


- Cross section as a function of η in laboratory frame
- Electron and muon results agree → combination is performed

arXiv:1503.05825

W bosons in pPb @ 5.02 TeV





- Combined cross section compared to NLO theory predictions with (CT10 + EPS09) and without nuclear effects (CT10)
- Displayed in lab frame
- Nuclear effects are not clear → use asymmetries

arXiv:1503.05825

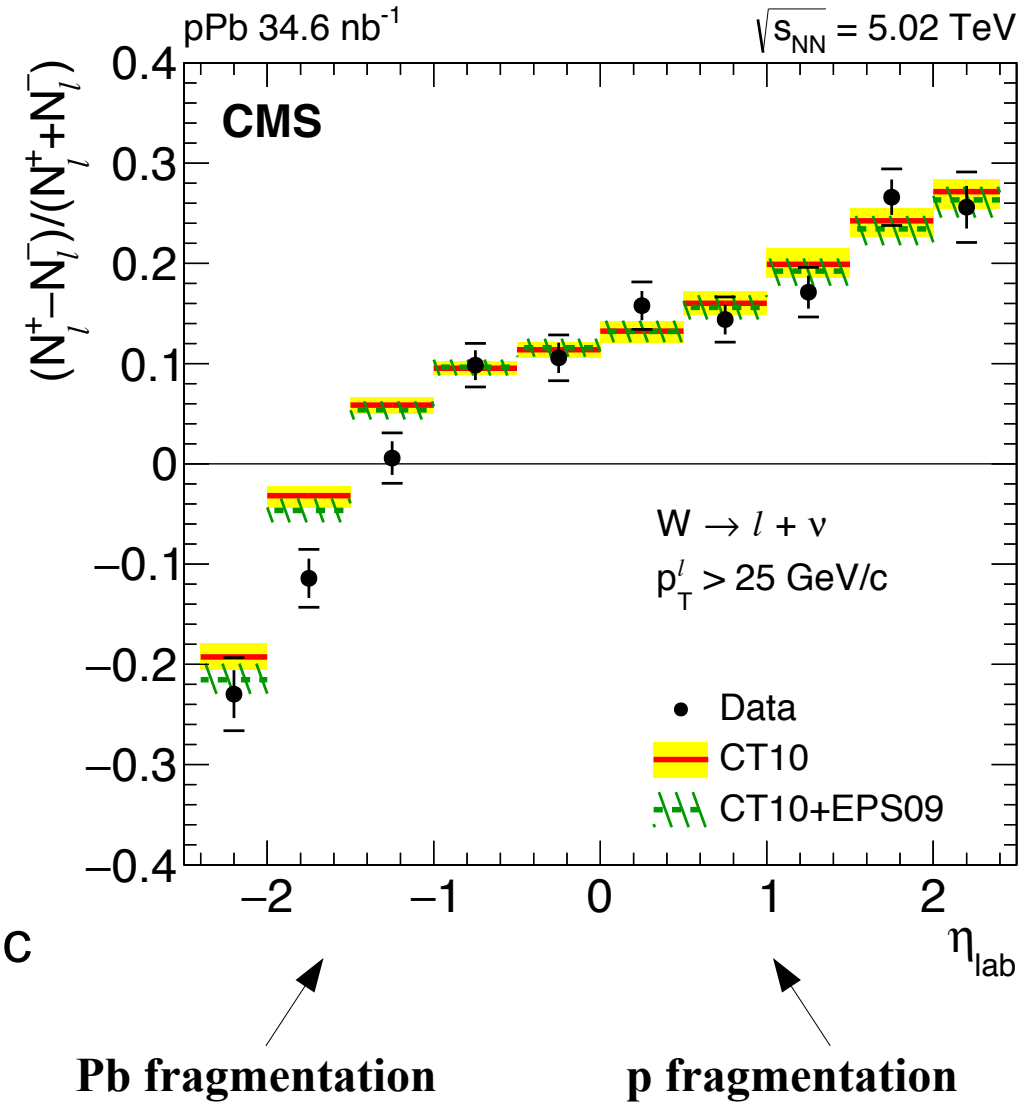
Predictions from H. Paukkunen, C. A. Salgado, JHEP 1103 (2011) 071

W bosons in pPb @ 5.02 TeV

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

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

- Sensitive probe of the up to down quark PDF ratio
- Disagreement from isospin symmetric PDFs at negative region



CMS-PAS-HIN-13-007

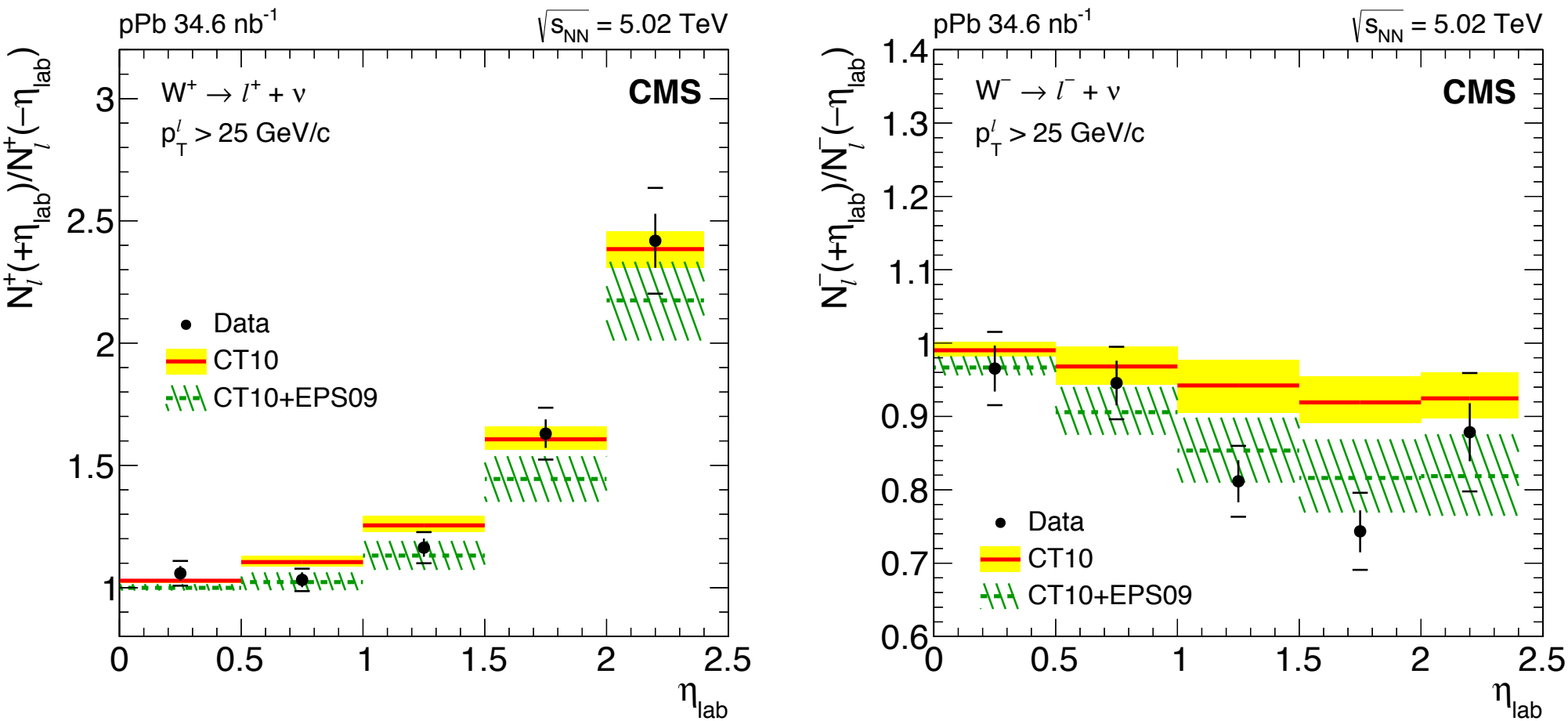
W bosons in pPb @ 5.02 TeV

- Forward-backward asymmetry
- More sensitive to nuclear modifications
- Different behavior of different charges

→ hint for different u and d quark modification ?

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

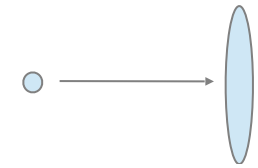
arXiv:1503.05825

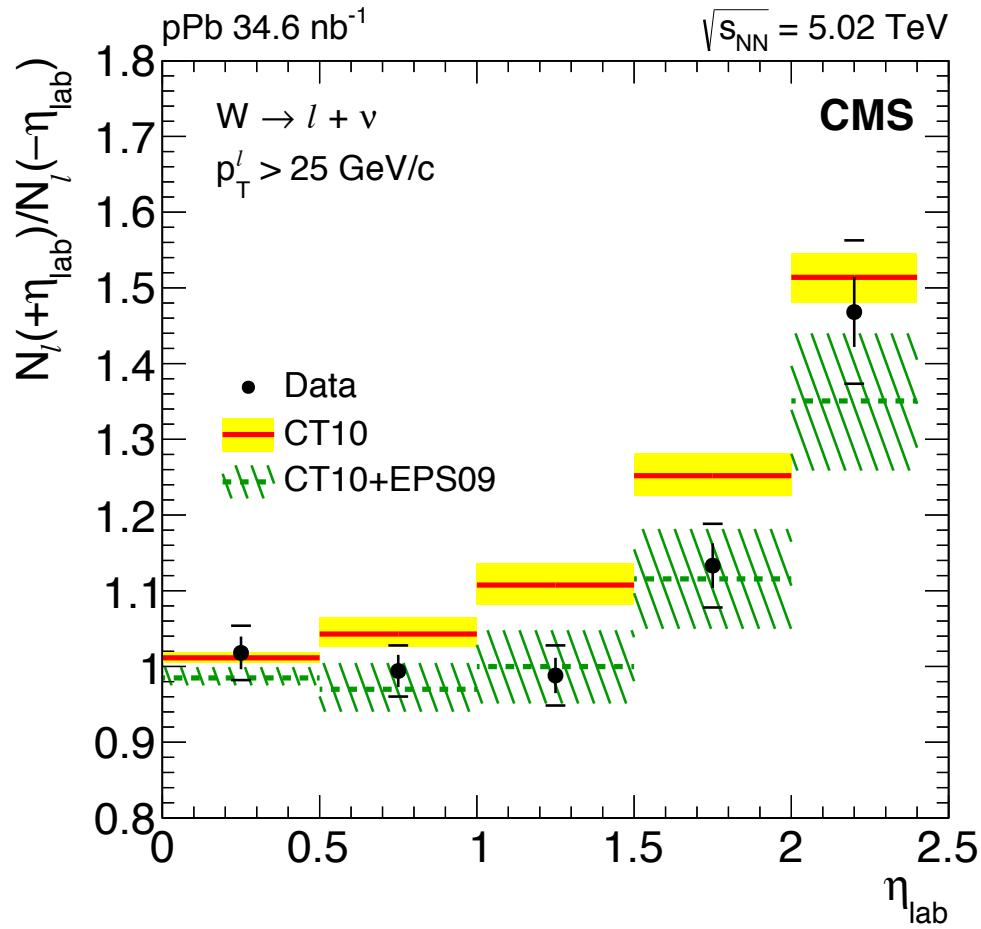


W bosons in pPb @ 5.02 TeV

- Forward-backward asymmetry of the charge-summed W bosons
- Good sensitivity for nuclear modification of parton distributions
- χ2 probabilities of 29% with CT10 and 83% including EPS09
- confirm the nuclear modification of nPDFs

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





arXiv:1503.05825

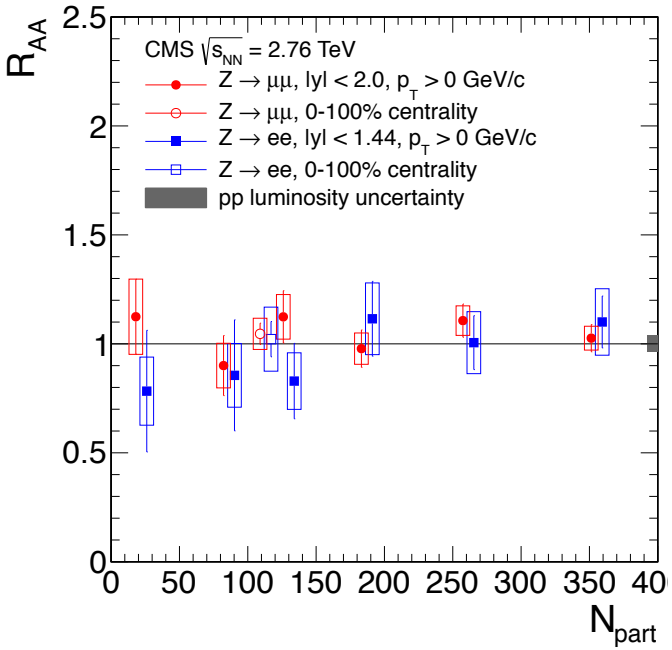
Summary

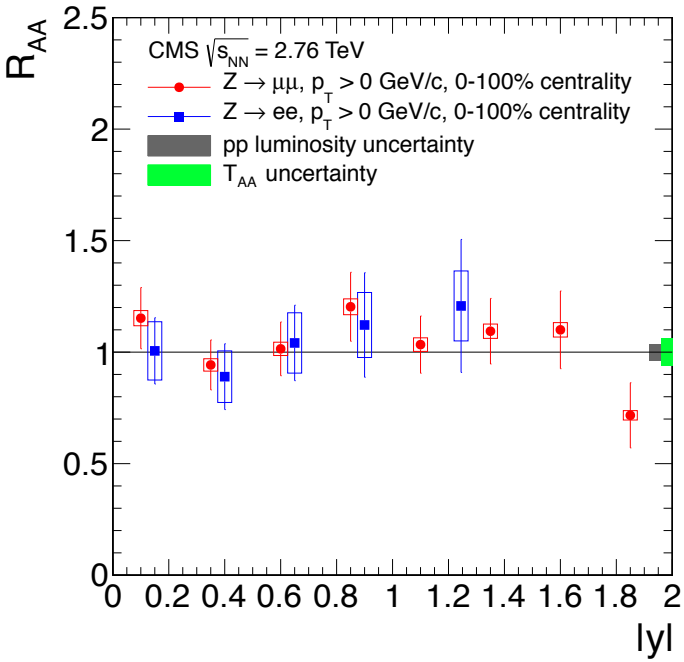
- Finalized results of Z and W bosons measurements in PbPb at 2.76 TeV, W boson in pPb, and updated the result of Z boson in pPb collisions are presented
- The production cross section of Z scales with the number of binary nucleon-nucleon collisions
- Results compared to prediction at NLO with and without nuclear modification
- Hint of nuclear effects seen in pPb data :
  - Asymmetries vs rapidity show sensitive to nuclear modification
  - More statistic would help distinguish between nPDFs

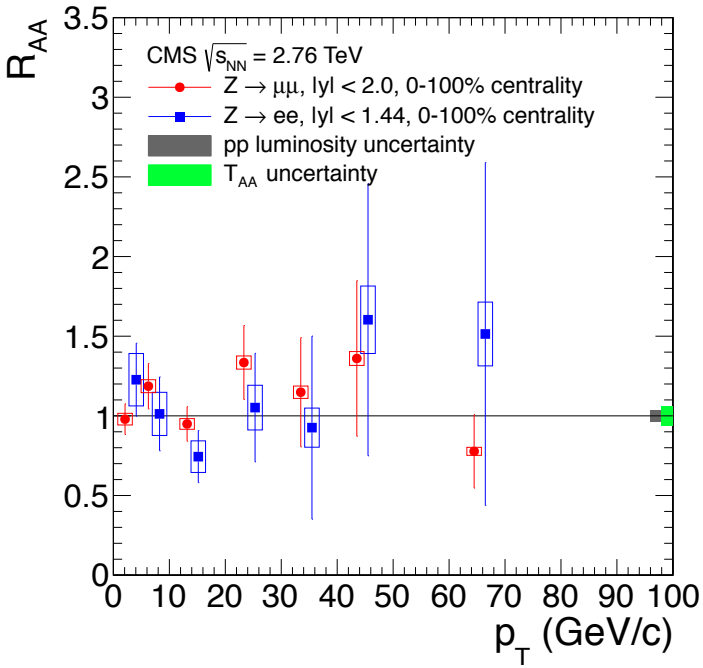
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Back up

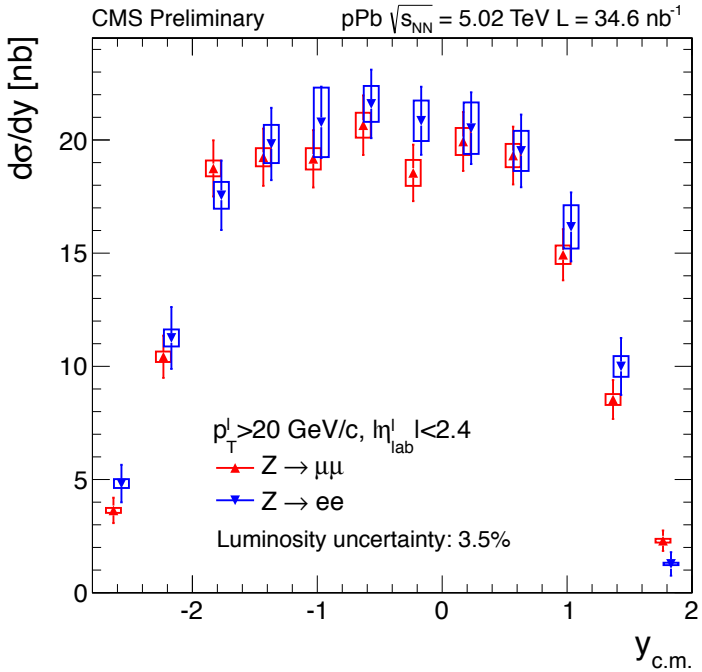
Z boson in PbPb @ 2.76 TeV

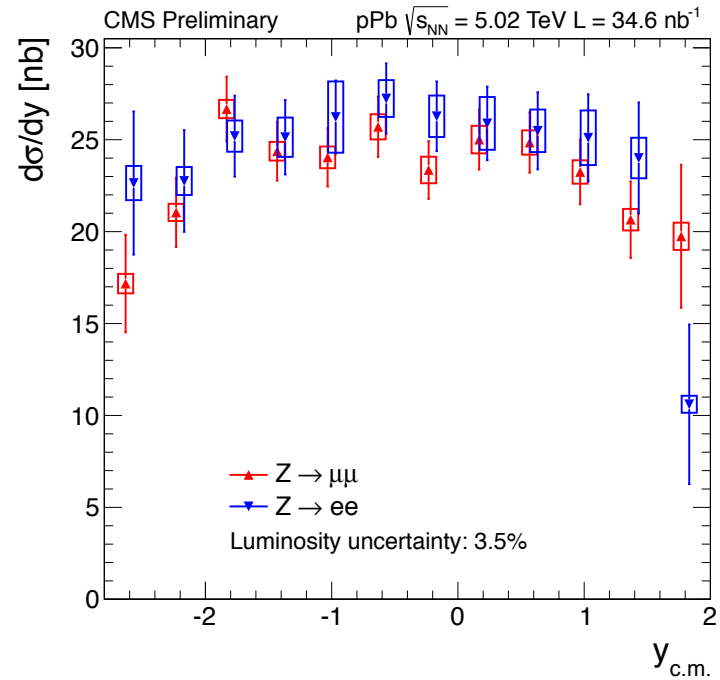


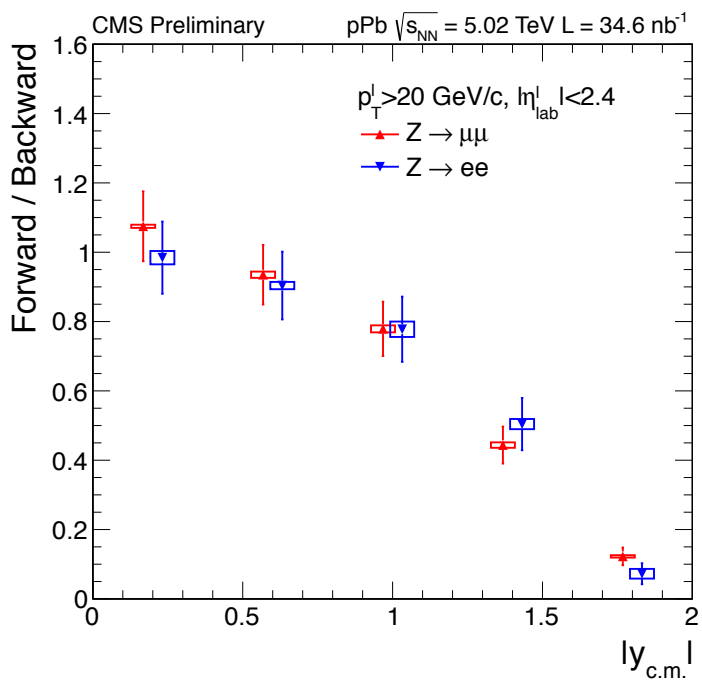


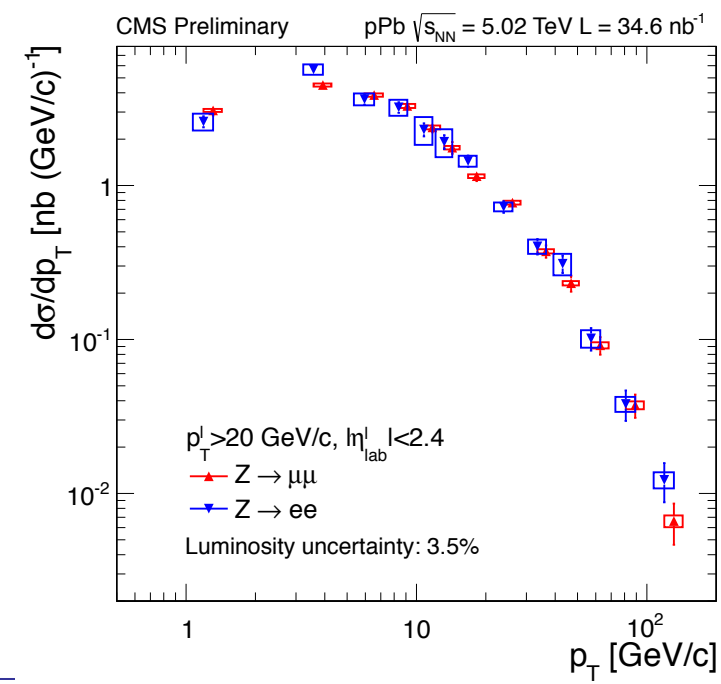


Z boson in pPb @ 5.02 TeV









W bosons in pPb @ 5.02 TeV

- Cross-section:

$$\sigma = \frac{N_{tot} - N_{background}}{\alpha \cdot \epsilon \cdot SF \cdot \int L}$$

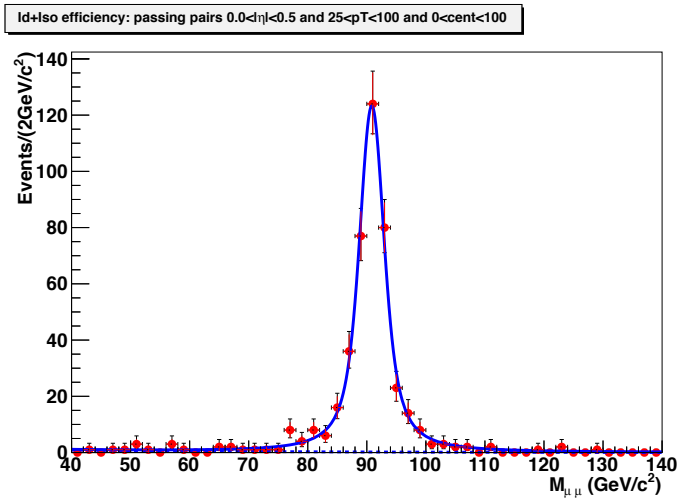
acceptance

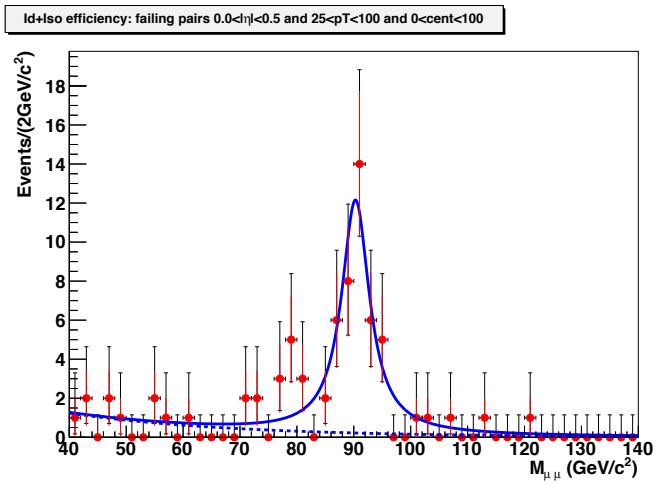
efficiency

efficiency ratio of data and MC

luminosity

- TnP fitting





$\chi 2$ values

Observable	No nuclear effects		Nuclear effects from EPS09	
	$\chi 2$	probability	$\chi 2$	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 uncertainty

Source	$W \to \mu\nu$	$W \to e\nu$
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%