Measurement of electroweak boson production in pp and PbPb collisions with CMS

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-Heavy Ion Collisions in the LHC Era-
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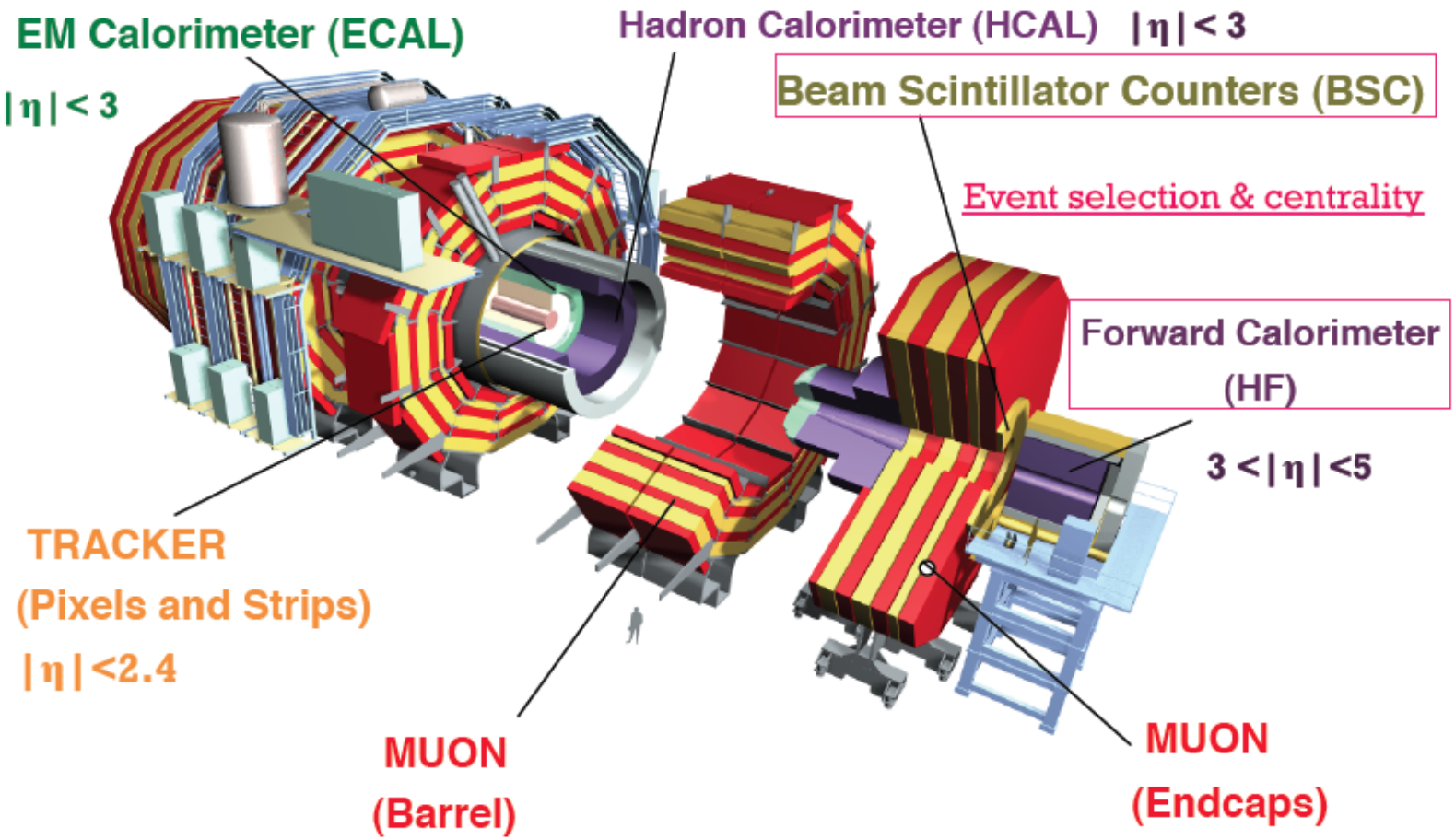
Outlook

1. Introduction
2. CMS
3. Z and W results in pp and PbPb collisions
   - 2010 PbPb data :
     - $\int Ldt \sim 7\ \mu b^{-1}$ at $\sqrt{s} = 2.76\,TeV$
   - 2011 pp data :
     - $\int Ldt \sim 18.7\ pb^{-1}$ at $\sqrt{s} = 8\,TeV$
     - $\int Ldt \sim 840\ pb^{-1}$ at $\sqrt{s} = 7\,TeV$
     - $\int Ldt \sim 4.5\ fb^{-1}$ at $\sqrt{s} = 7\,TeV$
     - $\int Ldt \sim 231\ nb^{-1}$ at $\sqrt{s} = 2.76\,TeV$
4. Conclusion

Motivation

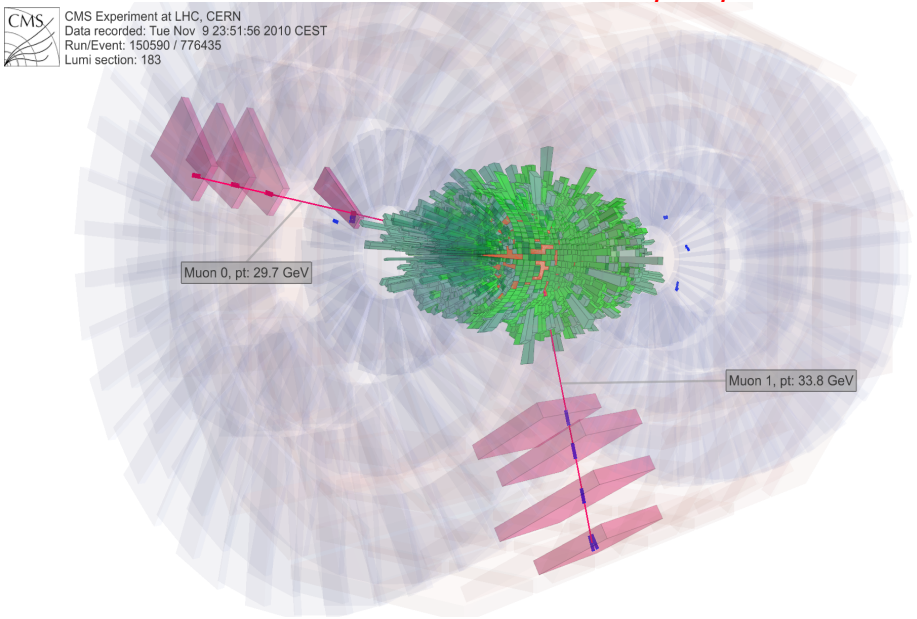
1. in PbPb
   - LHC allowed first observation and measurement of Z and W bosons in PbPb collisions
   - W and Z signals are essentially predicted to be unaffected by the strongly interacting medium produced in PbPb collisions
   - They are studied through their leptonic decay $Z \rightarrow \mu^+ \mu^-$, $W^{\pm} \rightarrow \mu^{\pm} \nu$
   - Precise measurement of W and Z production in heavy ion can help to constrain nuclear PDFs
2. in pp
   - Precision on Standard Model measurements at TeV scale
   - Background for new physics searches and Higgs studies
   - Constrain proton PDFs
   - Calibration of the detectors, improve lepton reconstruction

CMS Detector

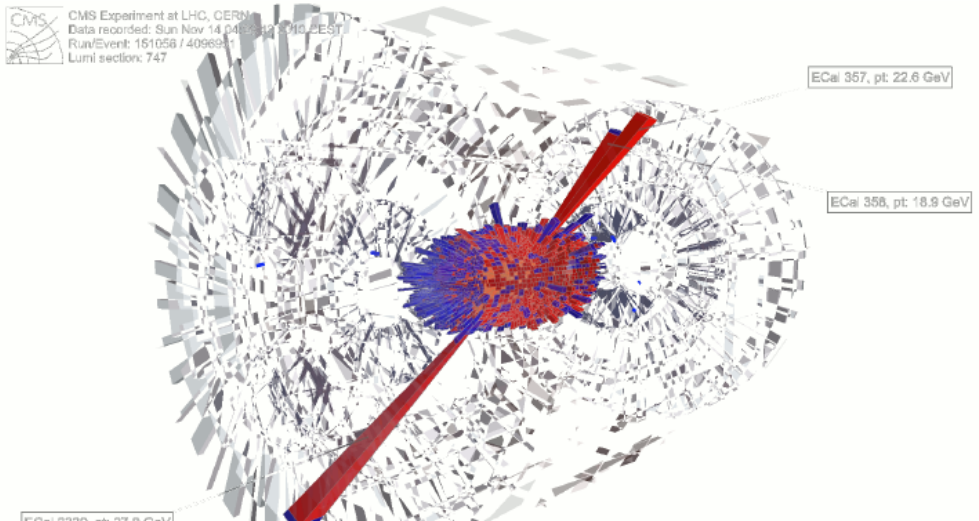


$Z \to \mu^+ \mu^-$ and $Z \to e^+ e^-$ candidates

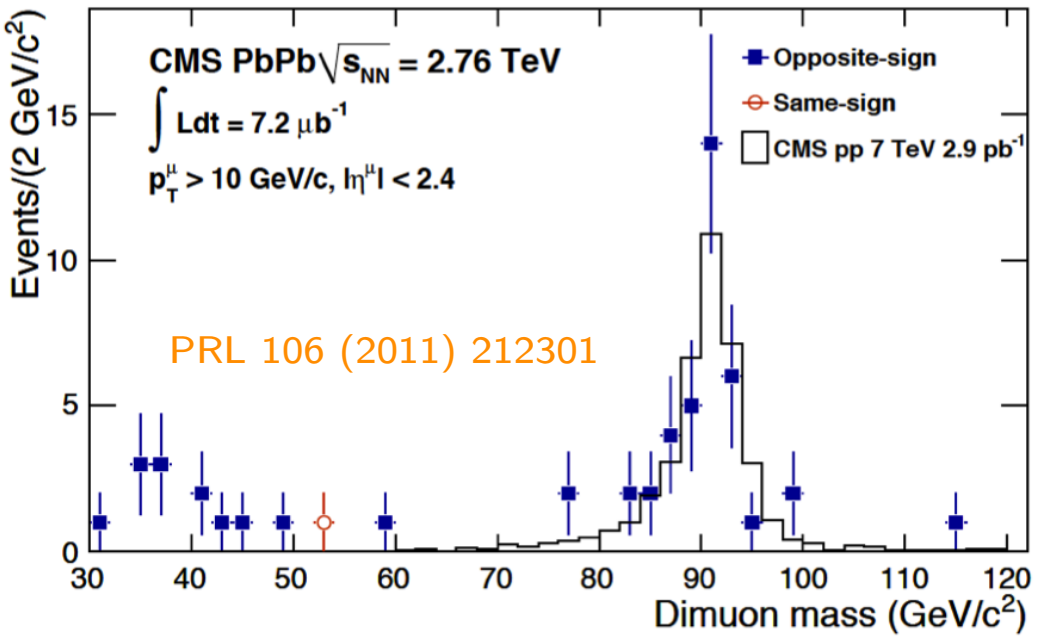
$Z \to \mu^+ \mu^-$



$Z \to e^+ e^-$



$Z \rightarrow \mu^+ \mu^-$

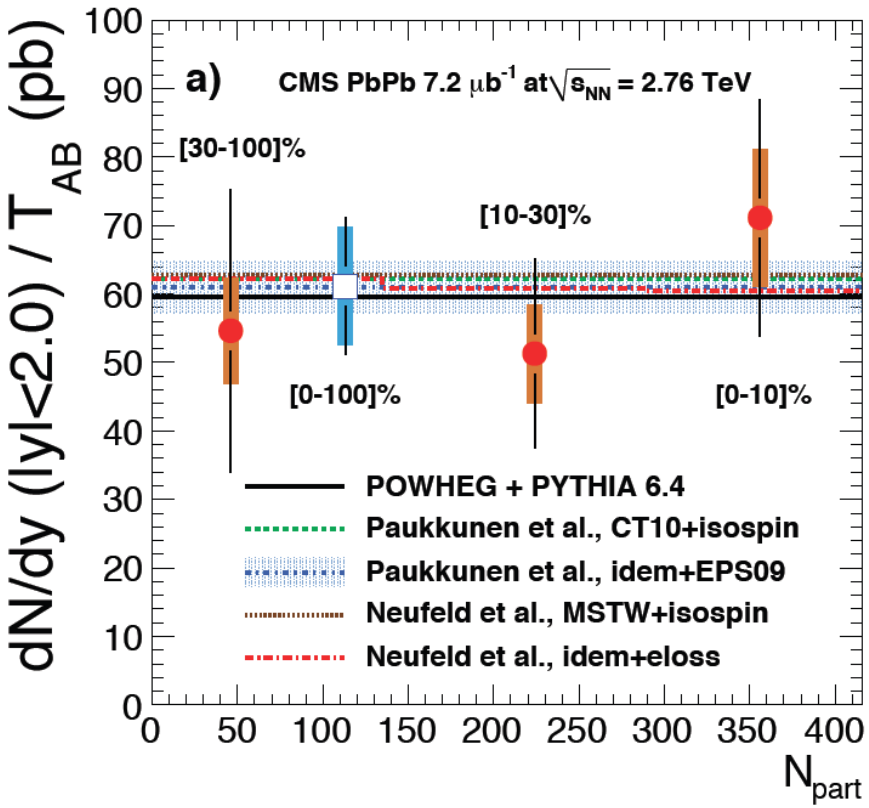


- 39 Z candidates counted in a di-muon invariant mass window [60,120 GeV/c^2]
- No background just with loose quality cuts, only one same-sign event in [30,120 GeV/c^2]
- Z mass resolution comparable to p-p

Normalized Z yield vs. N_{part}

- Z production scales with T_{AB}, i.e. with the number of NN collisions
- Comparison to different theoretical predictions
  - POWHEG: pp $\rightarrow$ Z $\rightarrow \mu^+ \mu^-$
  - Paukkunen: shadowing + isospin
  - Neufeld: isospin + energy loss
- Uncertainties: 16% statistical, 14% systematic

PRL 106 (2011) 212301

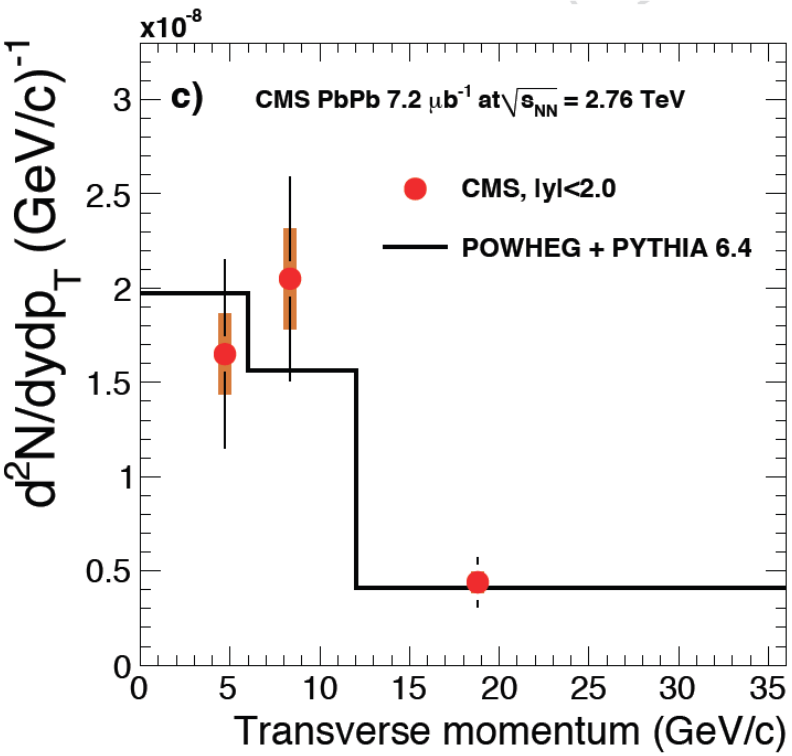


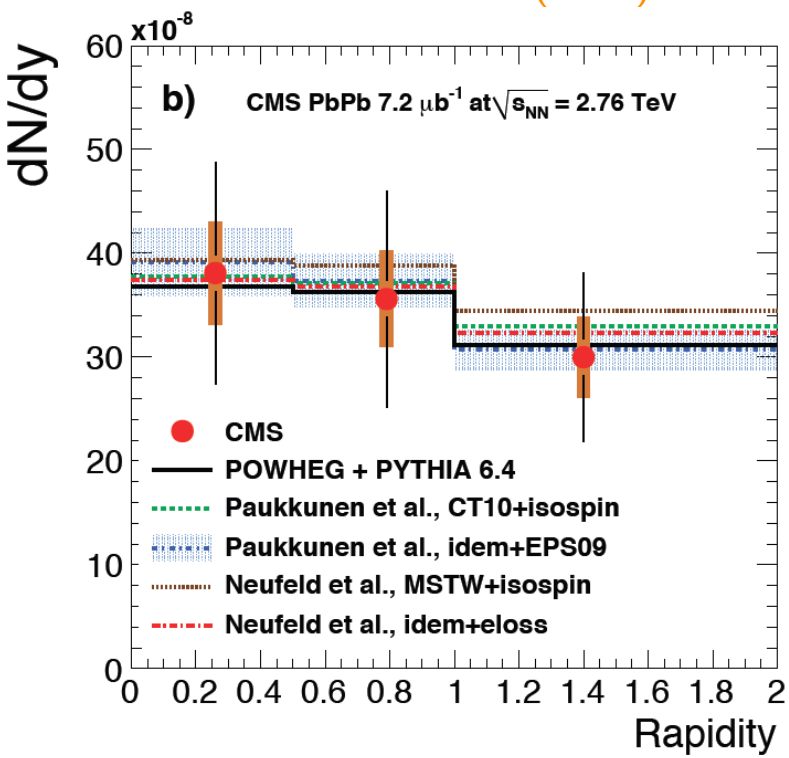
- Assuming from POWHEG $\frac{d\sigma_{pp}}{dy} = 59.6\ pb\ in\ |y| < 2$
  - $\mapsto R_{AA} = \frac{dN_{AA}}{T_{AB} d\sigma_{pp}} = 1.00 \pm 0.16 \pm 0.14$ (MinBias)

Normalized Z yield vs. p_T and Rapidity

- 3 rapidity bins and 3 p_T bins
- $\frac{dN^z}{dy}$ is in a good agreement with different theoretical and MC predictions within statistical error bars and uncertainties
  - NLO calculation agrees with Z measurement in CMS

PRL 106 (2011) 212301





NEW

CMS-PAS-SMP-12-011

Z production in pp at 8 TeV

This analysis has been already done for 2010 data with low pile-up with L = 36 pb^{-1} at $\sqrt{s} = 7$TeV (J. High Energy Phys. 10 (2011) 132) and we redo it at $\sqrt{s} = 8$TeV

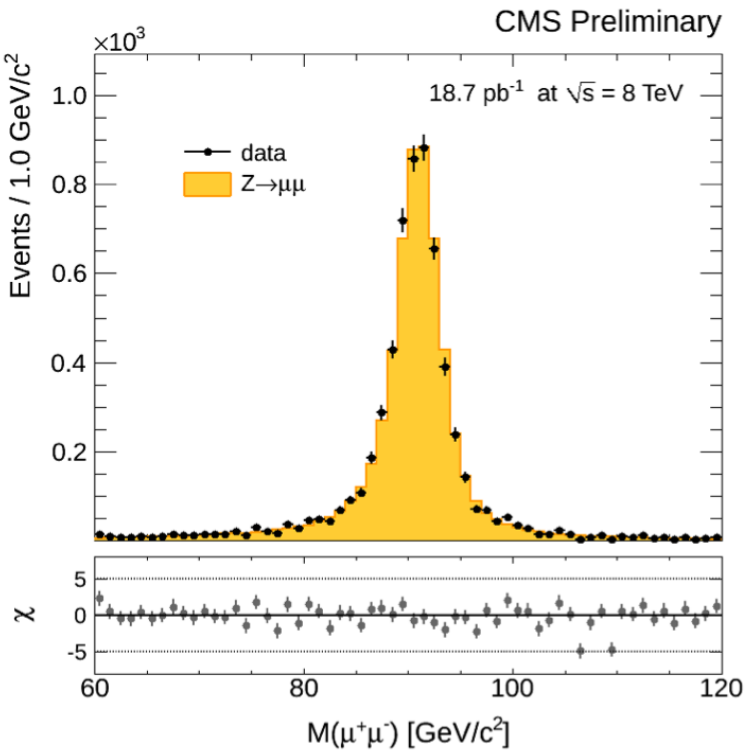
- CMS requested special LHC conditions during luminosity ramp up period to achieve low pile-up events (5) for good MET resolution at W:
  - LHC separate beams in transverse plane to reduce effective overlap
  - separation was periodically adjust to keep L_{inst} 3 10^{32} - 6 10^{32} cm^{-2} s^{-1}
  - Integrated L = 18.7 pb^{-1}
  - Special HLT menu with low E_T / p_T thresholds: 22 GeV for electrons and 15 GeV for muons

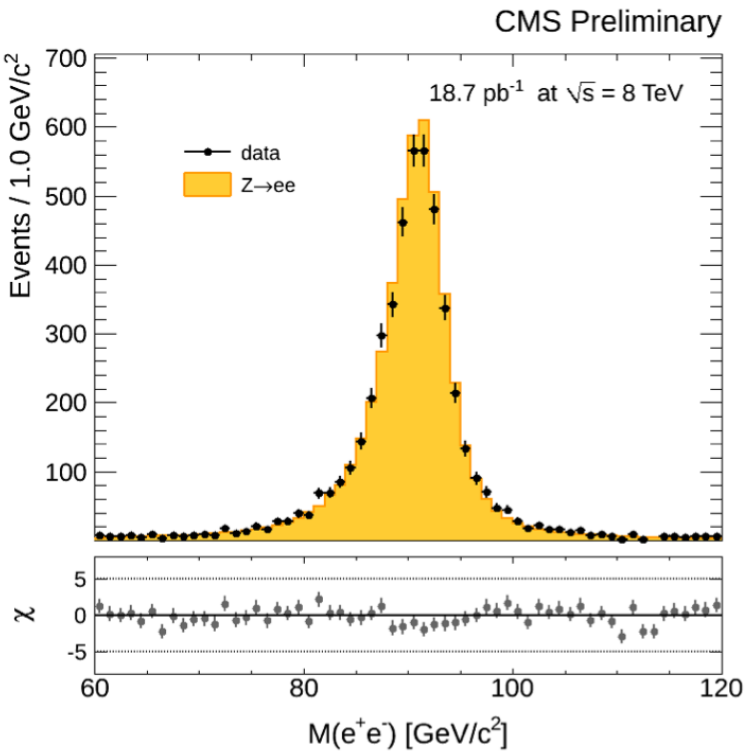
Analysis cuts used :

- Electron channel $E_T > 25$ GeV , $|\eta| < 2.5$ exclude barrel/forward transition $1.4442 < |\eta| < 1.566$
- Muon channel $p_T > 25$GeV/c, $|\eta| < 2.1$

Z invariant mass at 8TeV

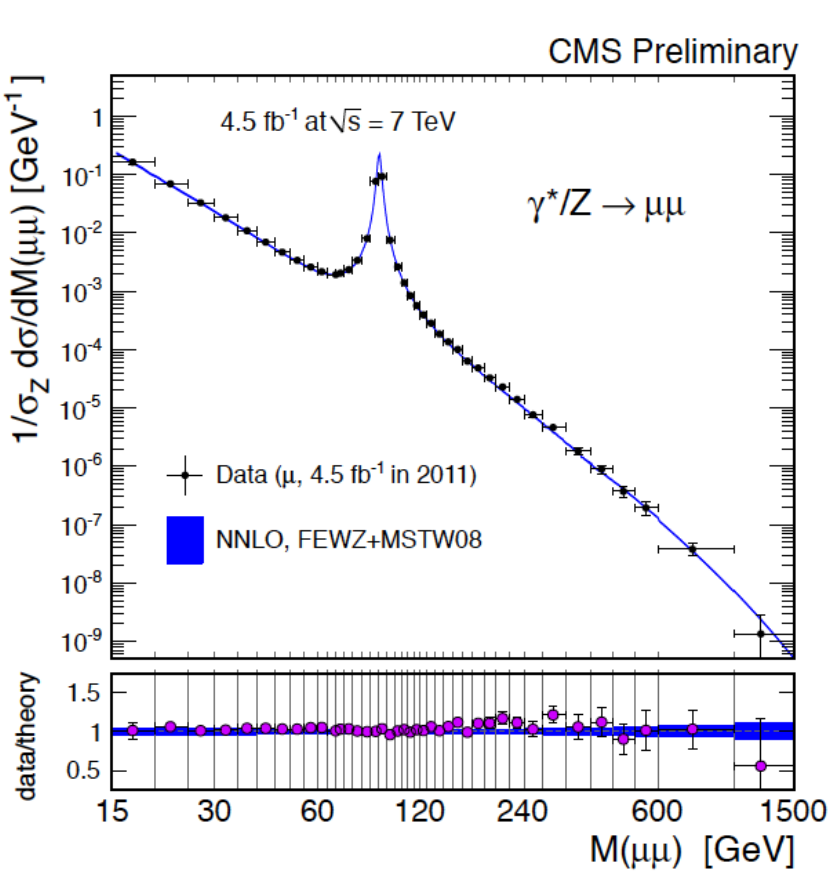
CMS-PAS-SMP-12-011

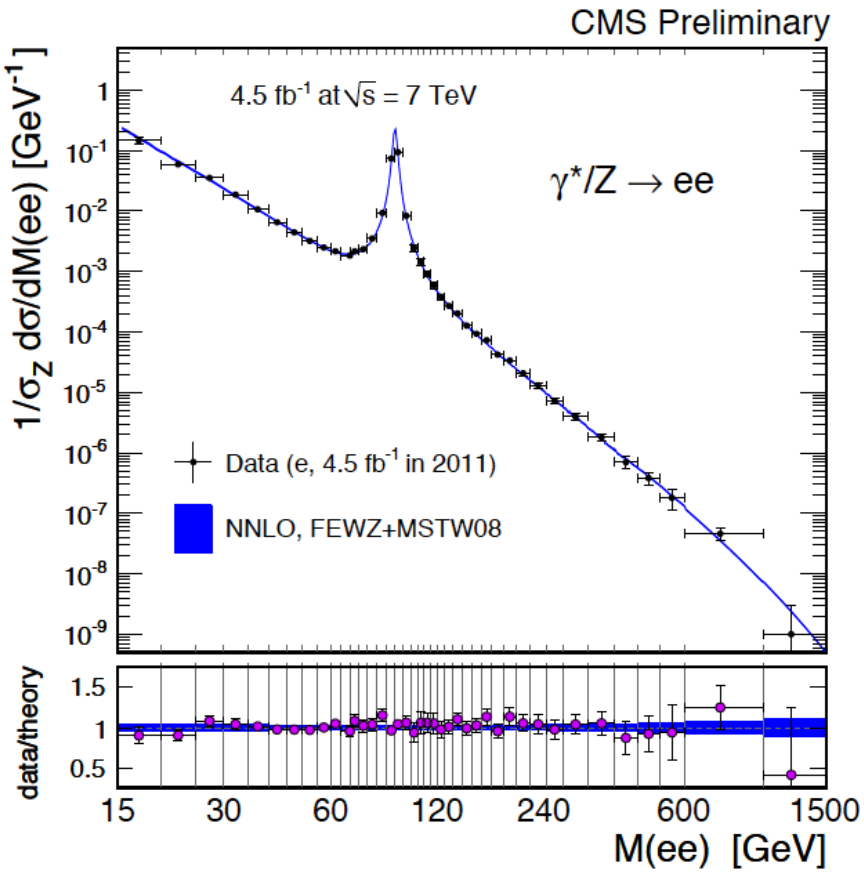




Drell Yann

CMS-PAS-EWK-11-007

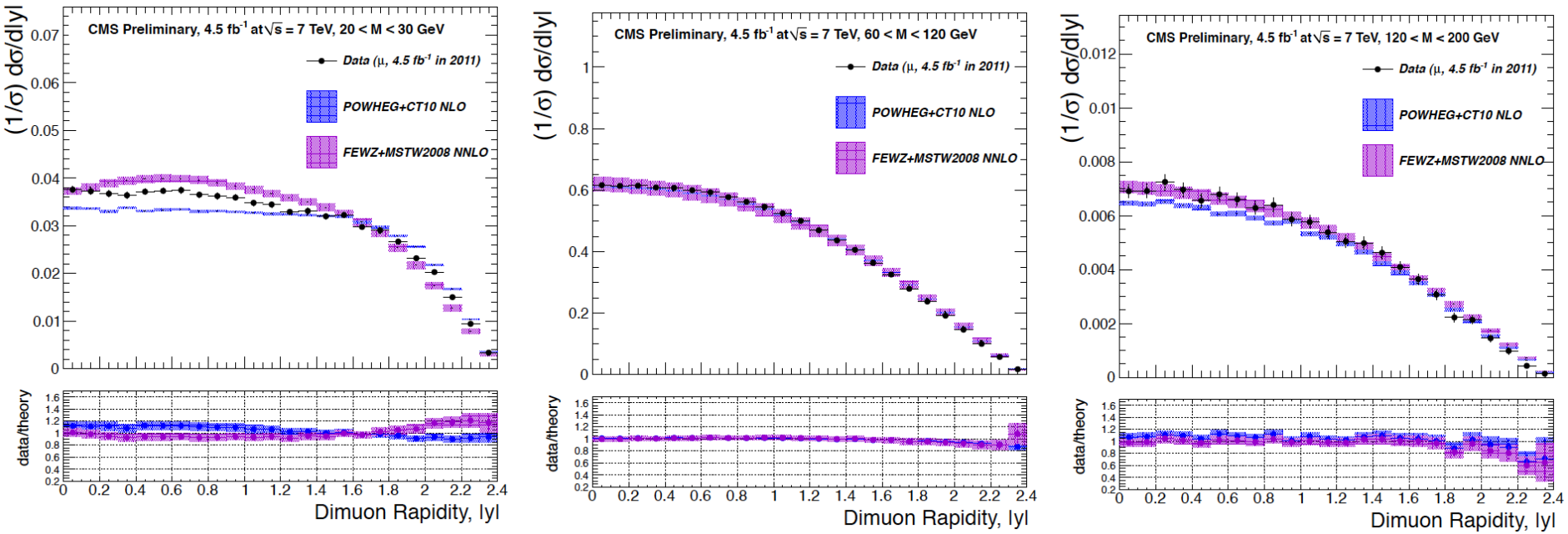




- $d\sigma/dM$ is calculated in the full phase space
- normalized to the cross section in the Z peak region ($60 < M < 120$ GeV) to reduce systematic uncertainties
- good agreement with NNLO theoretical prediction, computed with FEWZ using MSTW2008 PDFs

Drell Yann

CMS-PAS-EWK-11-007

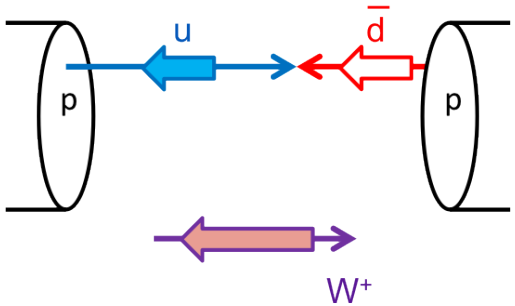


- 6 mass bins from 20 to 1500 GeV/c^2
- Drell-Yan rapidity-invariant mass spectrum in detector acceptance is normalized to the Z resonance region, r = $(1/\sigma_{ll} d\sigma/dMdY)$, as measured and as predicted by NLO POWHEG+CT10 PDF and NNLO FEWZ+MSTW2008 PDF calculations
- very important measurement for PDFs studies

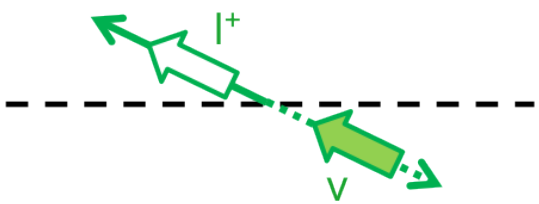
W $\rightarrow \mu^{\pm}\nu$

- $q\bar{q} \rightarrow W$
- $u\bar{d} \rightarrow W^+$
- $d\bar{u} \rightarrow W^-$

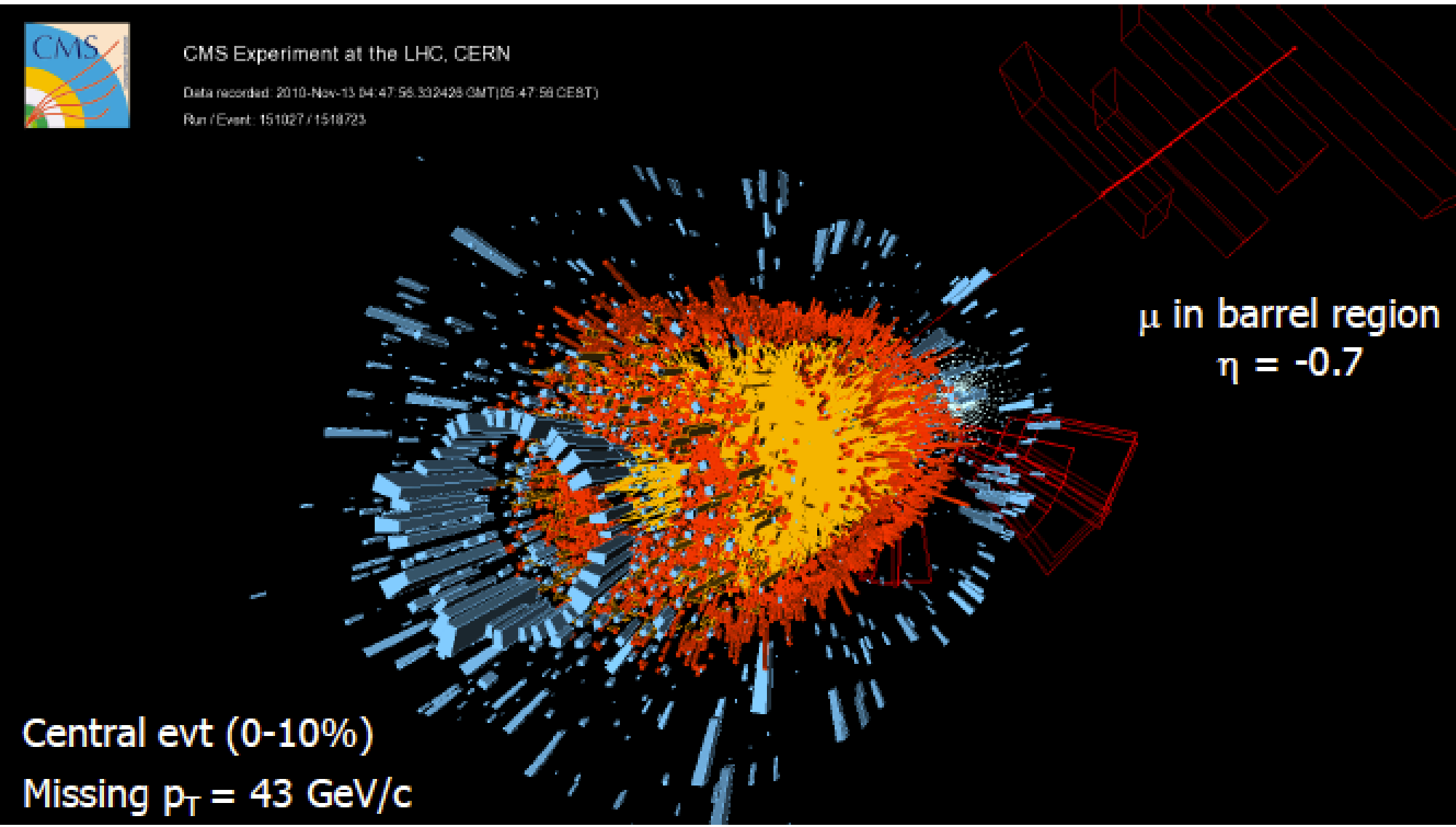
- W mostly produced via the fusion of a valence quark and a sea antiquark
  - More W^- (less W^+) in PbPb than in pp
    $\mapsto$ strong isospin effect
    (small when considering $W^+ + W^-$)
  - W are boosted in the valence quark direction
    (away from midrapidity)



- Spin conservation
  - $\mapsto$ μ^+ (μ^-) are boosted
    back to (away from) midrapidity
  - $\mapsto$ Asymmetric μ^+ and μ^- distributions,
    varying with pseudorapidity
  - $\mapsto$ different acceptances for W^+ and W^-



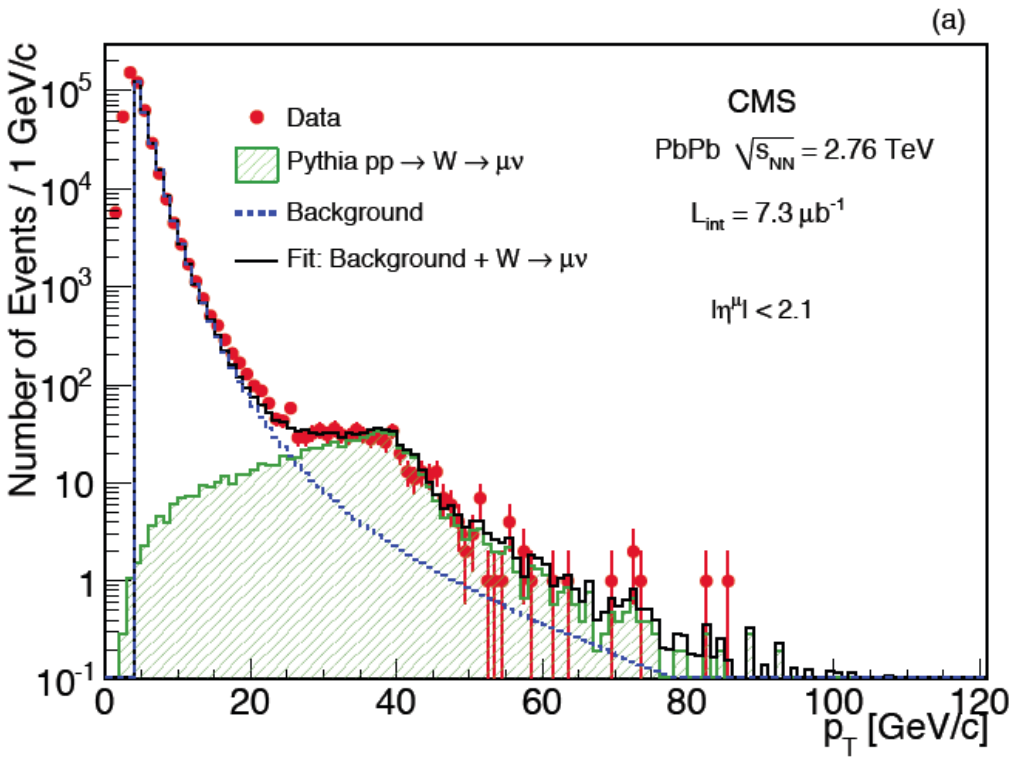
$W^{\pm} \rightarrow \mu^{\pm}\nu$



arXiv:1205.6334
CERN-PH-EP-2012-144

Muon p_T spectrum

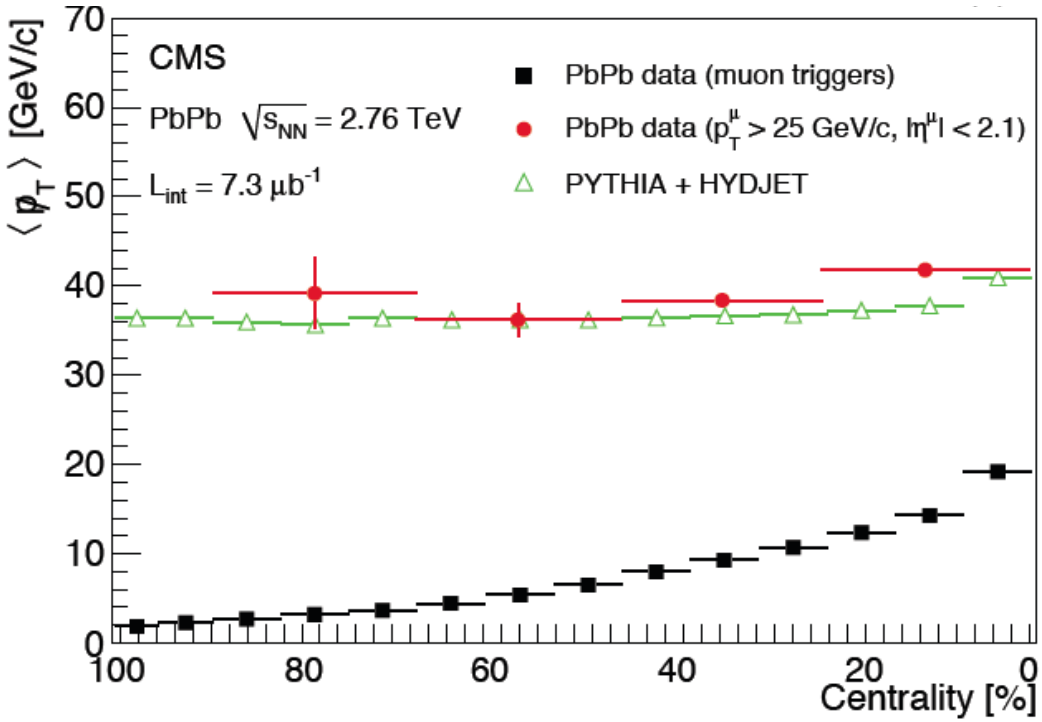
- Trigger and selection cuts on $\mu^{\pm}$
  - Single muon triggers $p_T \geq$ 2-3 GeV/c
  - Number of hits in the tracker > 10
  - Compatibility with primary vertex (< 0.3 mm)
  - χ^2/ndf < 10
- Veto on Z candidates



- PYTHIA simulation : $W\pm \rightarrow \mu^{\pm}\nu$ in pp collisions at $\sqrt{s} = 2.76\ TeV$
- Bump in the region $p_T^{\mu} > 30$ GeV/c where W decay product are expected
- At high p_T muons from W dominate
- For the analysis we require $p_T^{\mu} > 25$ GeV/c

Missing p_T

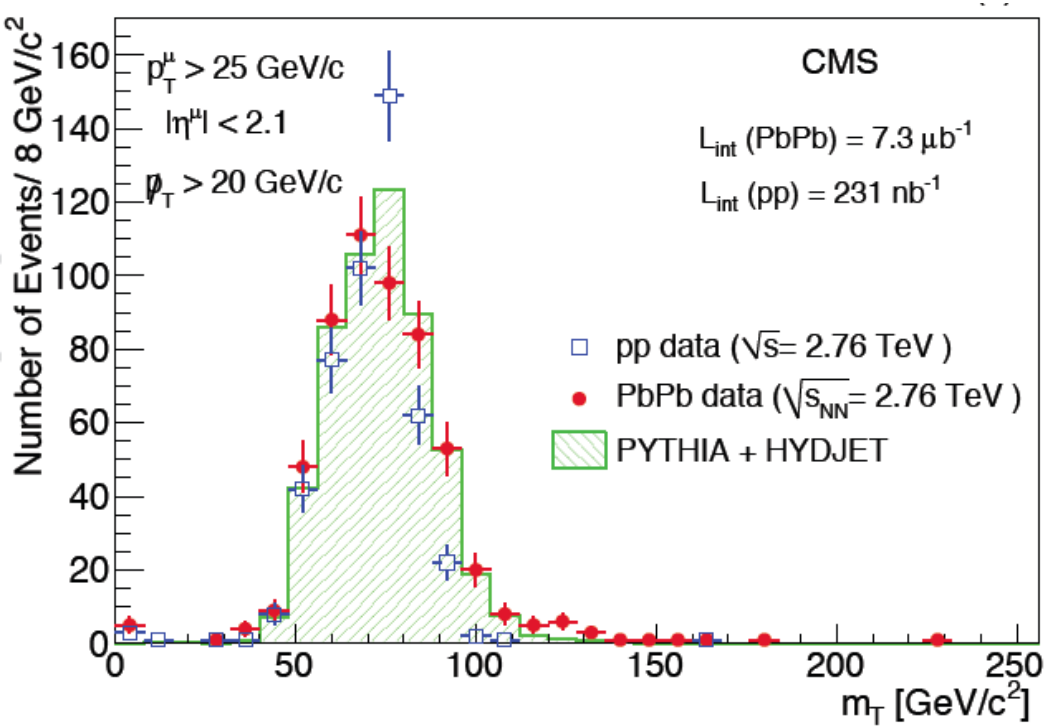
- $\not{p}_T = -\Sigma \vec{p_T}$ of all tracker tracks with $p_T > p_T^{thresh}$, $p_T^{thresh} = 3$ GeV/c



- Selecting a high p_T muon $\mapsto < \not{p}_T > \sim 40$ GeV/c, and almost no dependence vs. centrality
- Good agreement between MC (W $\rightarrow \mu^{\pm}\ \nu$ signal embedded in HYDJET PbPb) and PbPb Data for missing p_T calculation

W transverse mass m_T

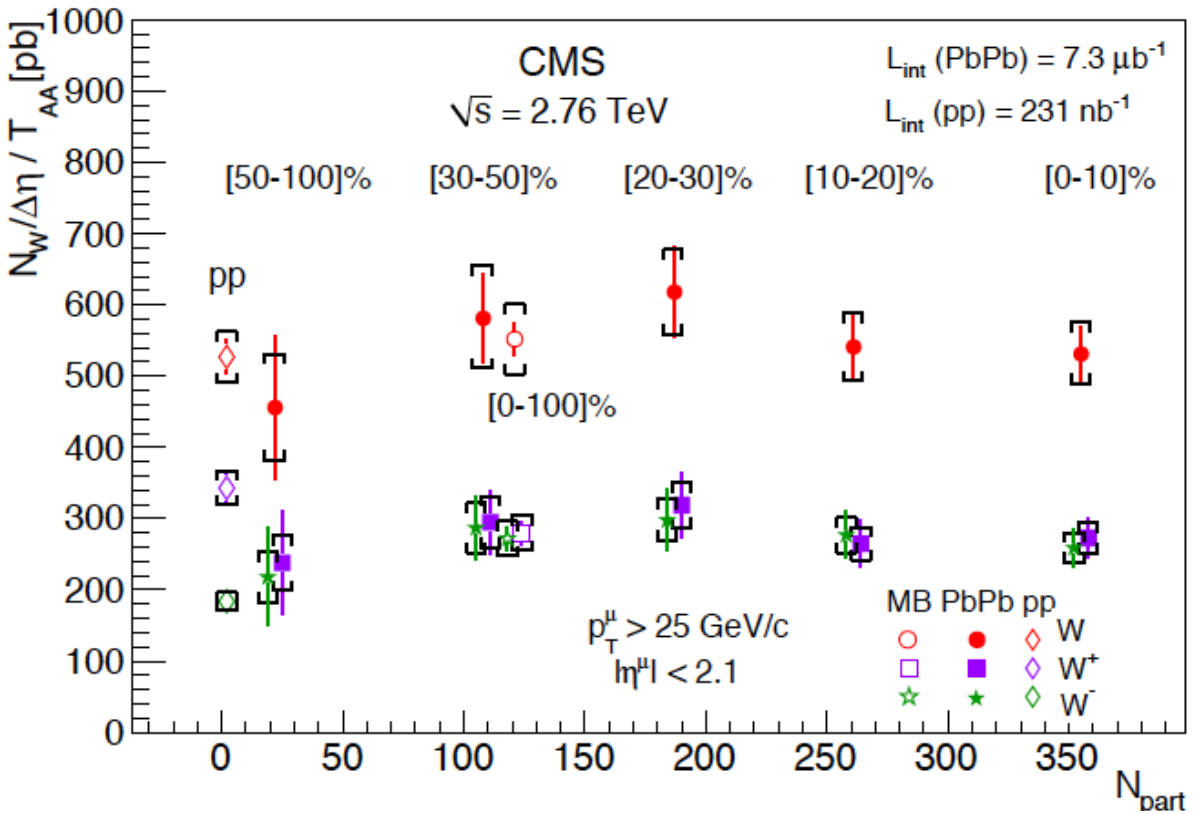
- We calculate the W transverse mass $m_T = \sqrt{2p_T^{\mu}\not{p}_T(1 - cos\phi)}$ where $\phi = \phi(\mu)$ - $\phi(\not{p}_T)$



- Sharp Jacobian peak at m_T=m_W , smeared by detector resolution
- pp data at $\sqrt{s} = 2.76$ TeV analyzed with the same procedure

- Better m_T resolution in pp than in PbPb
- Residual contamination (Z $\rightarrow \mu^+\mu^-$, W$\rightarrow \tau\nu$) subtracted (2%); QCD (<1%) included in systematic uncertainty for both pp and PbPb

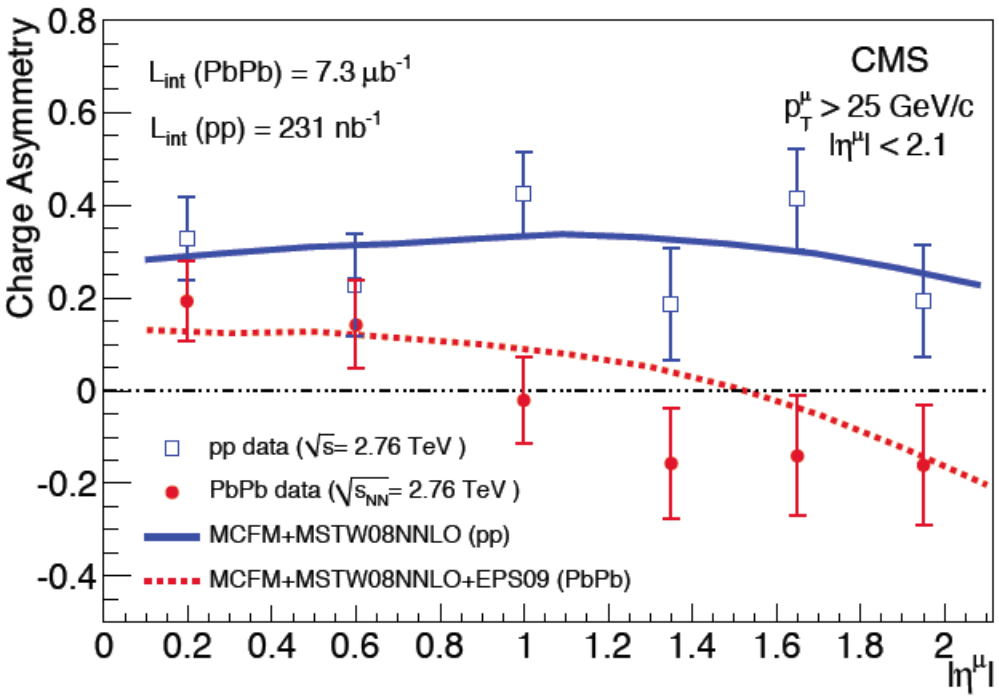
Centrality dependance



- Significant change in W^+ and W^- cross sections between pp and PbPb systems $\rightarrow$ isospin effect
  - PbPb(W^+) reduced with respect to $\sigma_{pp}(W^+)$ $R_{AA}(W^+) = 0.82 \pm 0.07 \pm 0.09$
  - PbPb(W^-) enhanced with respect to $\sigma_{pp}(W^-)$ $R_{AA}(W^-) = 1.46 \pm 0.14 \pm 0.16$
- No dependence on centrality within uncertainties
- Once summed W^+ and W^- is consistent with pp

Muon charge asymmetry at $\sqrt{s} = 2.76$ TeV

- Muon charge asymmetry : $\frac{dN(W^+) - dN(W^-)}{dN(W^+) + dN(W^-)}$

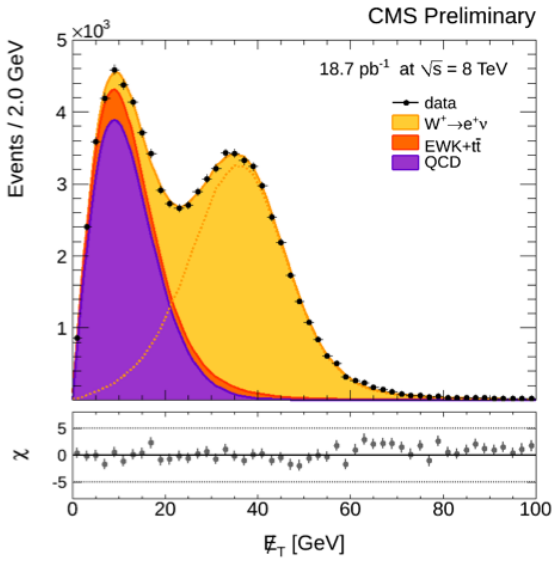


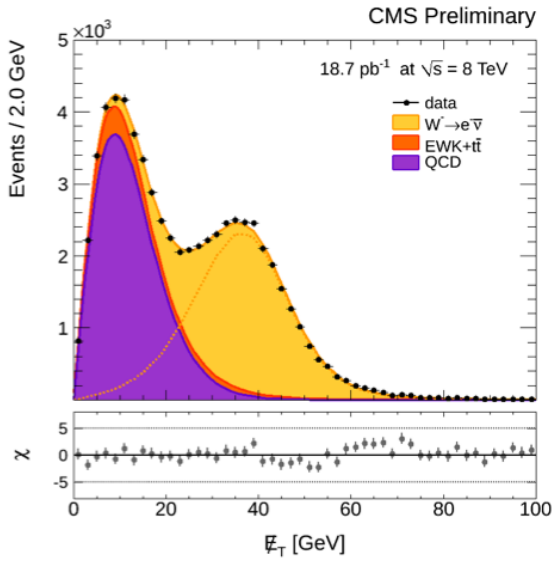
- PbPb: Predominance of W^- production for large muon rapidities
- pp: W^+ production higher than W^-
- Measured values of asymmetry compatible with theoretical predictions (MCFM + CTEQ6.6 + EPS09 (nuclear PDFs))

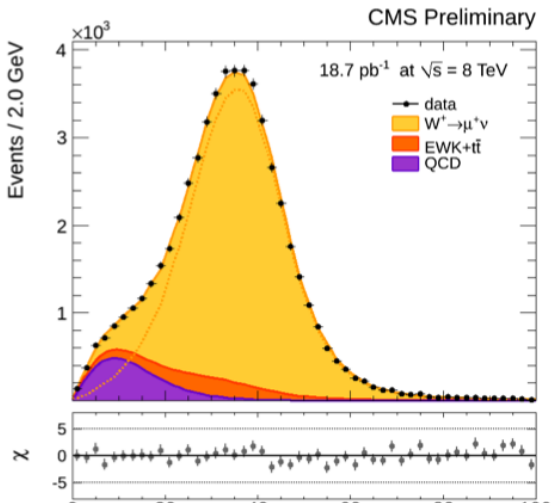
NEW

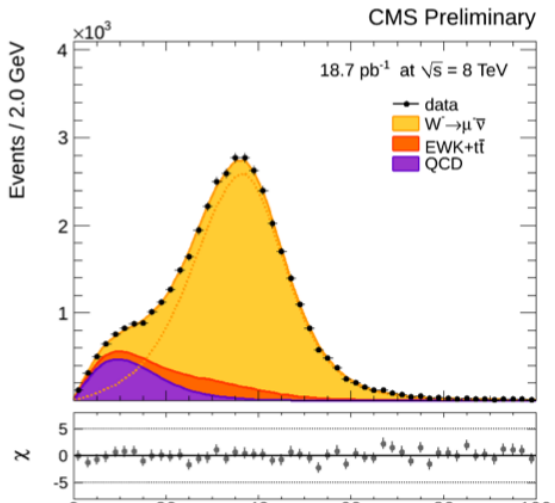
CMS-PAS-SMP-12-011

W results in pp





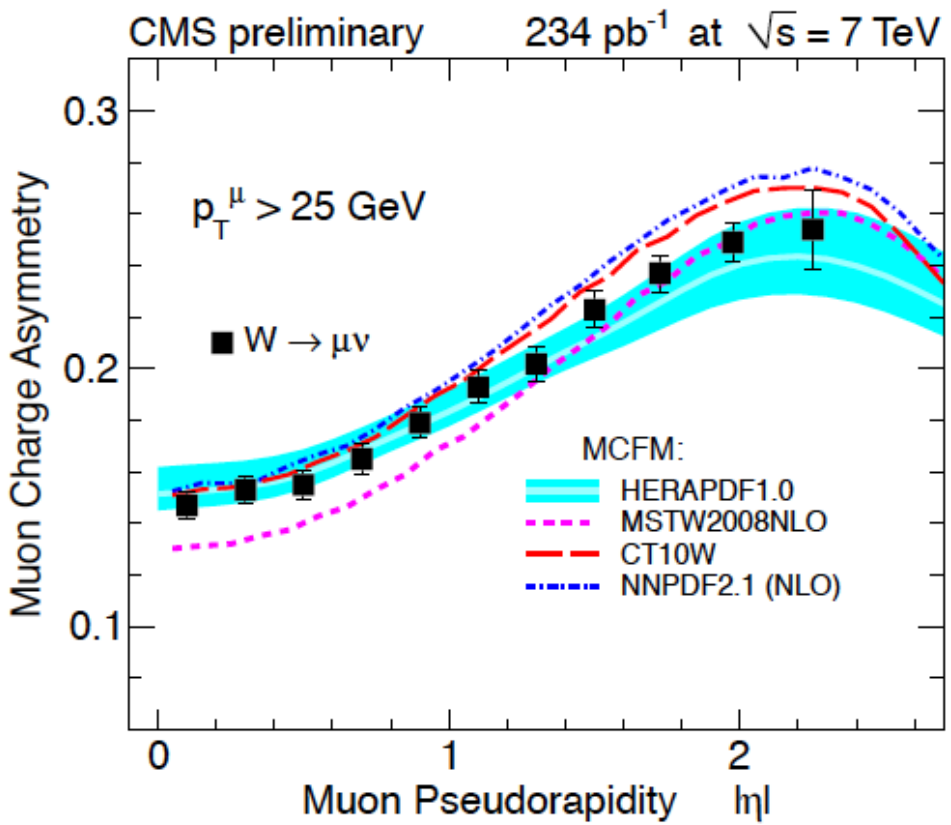




- Fit MET distribution W extraction:
- W: MC with recoil corrected to data
- QCD model: analytic function
- Other background: from MC with xsec fixed to W from theory

Charge asymmetry in inclusive $W^{\pm} \to \mu^{\pm} \nu$

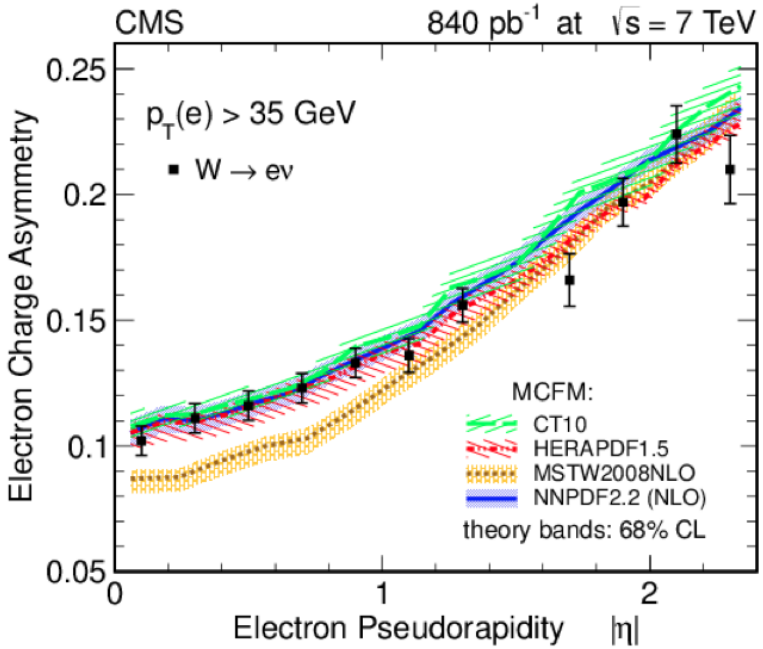
CMS-PAS-EWK-11-005



- Data has flatter variation of the asymmetry in η then predicted by MSTW2008NLO, CT10W and NNPDF2.1 (NLO)
- Will provide significant contribution to PDFs

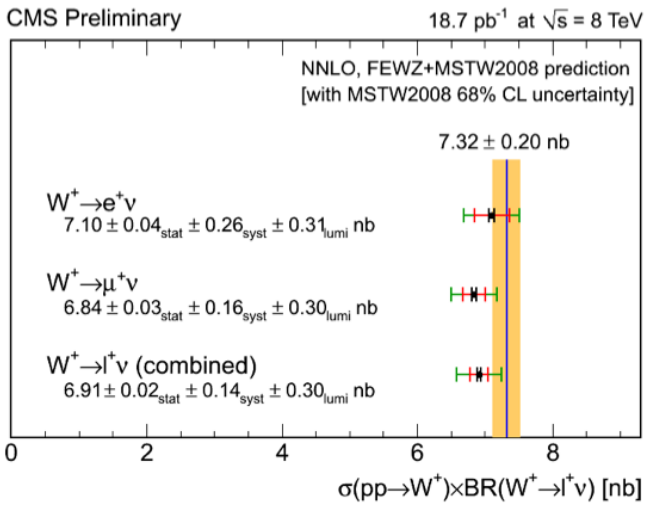
Charge asymmetry in inclusive $W^{\pm} \rightarrow e^{\pm} \nu$

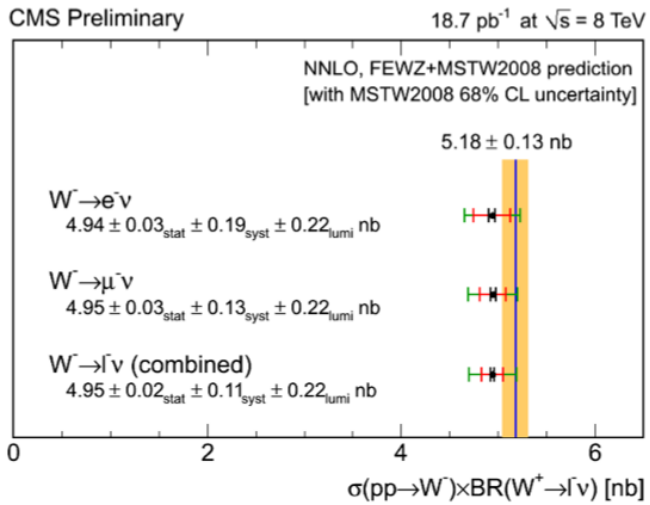
arXiv:1206.2598
CERN-PH-EP-2012-151

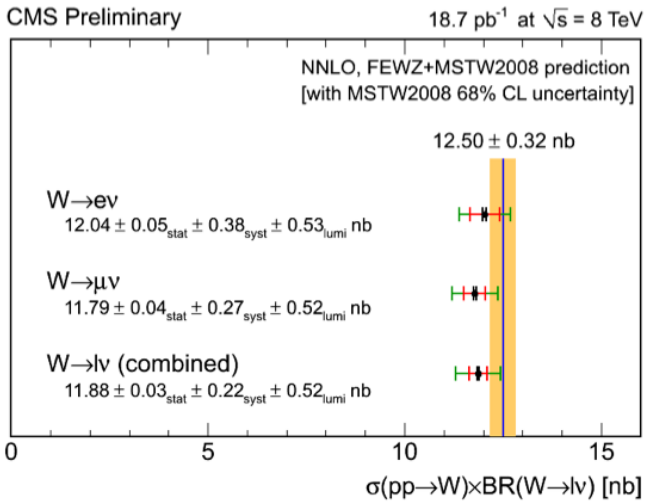


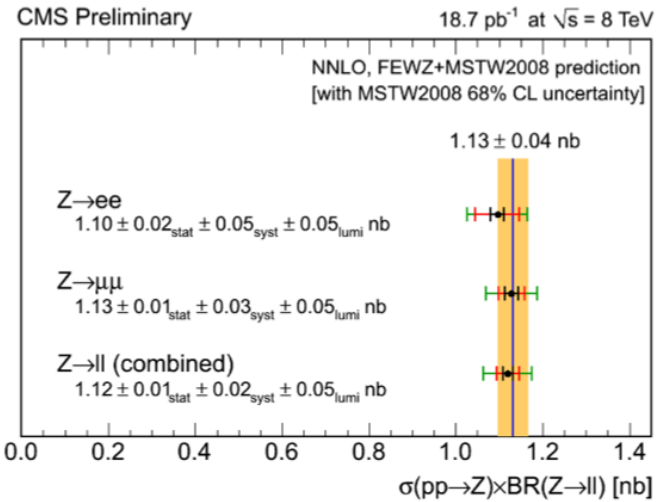
- Good agreement with NLO prediction except MSTW
- Background contribution increase with $|\eta|$
- Will provide significant contribution to PDFs

W and Z boson cross section at $\sqrt{s} = 8\,TeV$









- Good agreement with theoretical NNLO predition

W and Z boson cross section at $\sqrt{s} = 8\,TeV$

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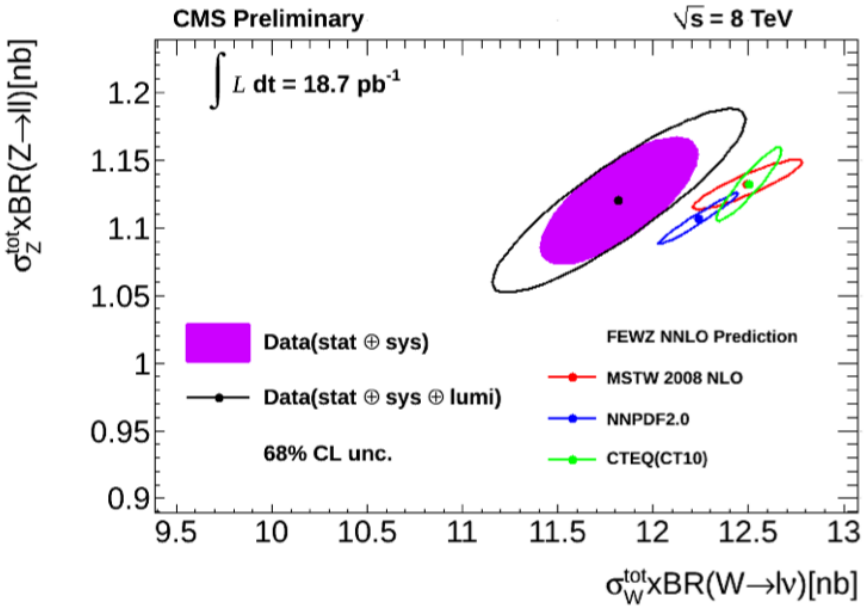
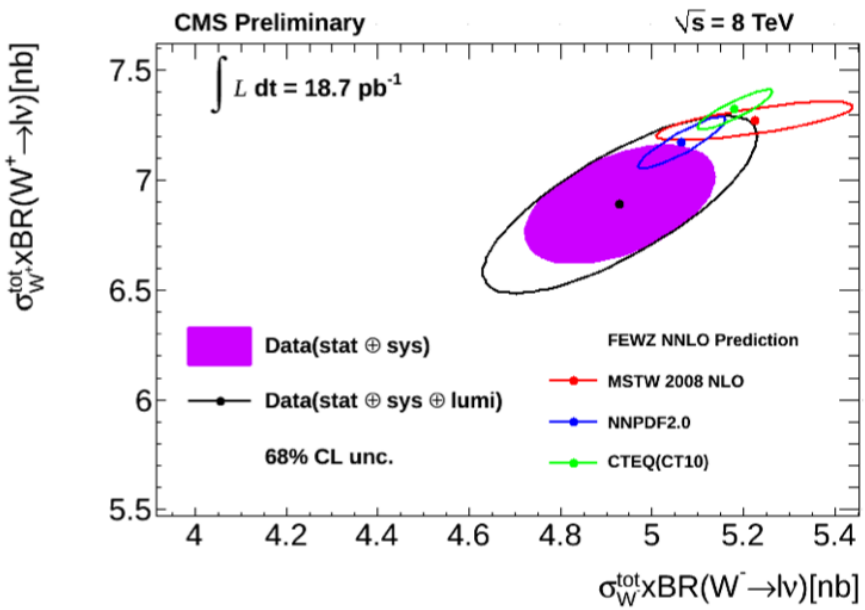
Z vs W cross section



W^+ vs W^- cross section



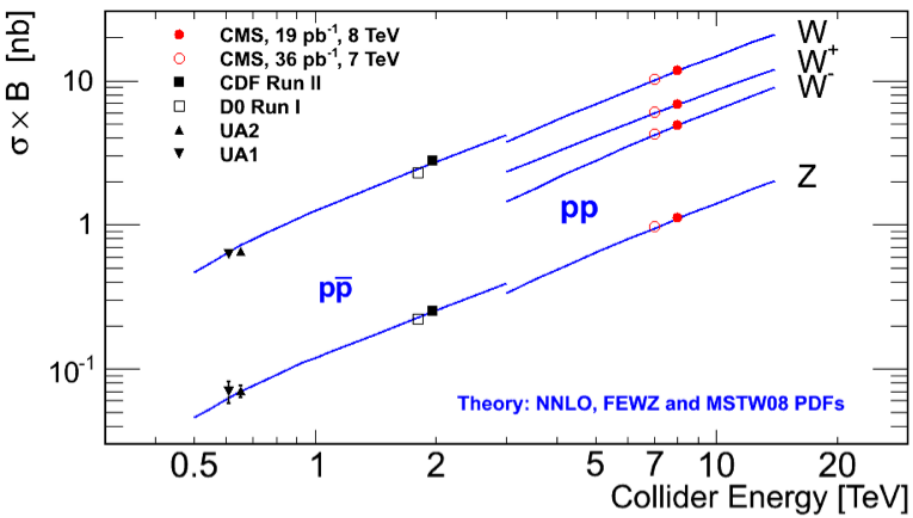
Good agreement with theoretical NNLO prediction

Conclusion (in PbPb)

- Within uncertainties no modification is observed with respect to theoretical NLO pQCD p-p cross sections scaled by elementary nucleon-nucleon collisions
- Confirm the validity of Glauber scaling in nucleus-nucleus collisions
- For the Z boson, expected shadowing (10-20%), Isospin effect (3%) and energy loss (3%) cannot be confirmed or excluded, one need more statistics
- Individual W^+ and W^- yields in PbPb interactions exhibit an isospin effect, enhancement for W^- production and reduction of W^+ with respect to that measured in pp collisions at same $\sqrt{s}$
- Muon charge asymmetry evaluated in PbPb and pp interacting systems. In agreement with expectations from NLO pQCD calculations
- Detailed and precise studies on the Z and W may help constrain PDFs

Conclusion (in pp)

- First results at $\sqrt{s} = 8$ TeV are presented: W and Z inclusive cross section
- W, Z and Drell-Yan are studied very detailed at $\sqrt{s} = 7$ TeV :
  - Precise test of Standard Model
  - Significant contribution to PDFs
- Looking forward for more 8 TeV results



The most recent public results always could be found at `https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP`

Back-up

$Z \rightarrow \mu^+ \mu^-$ and $Z \rightarrow e^+ e^-$ with 2011 data

Ongoing analysis on $Z \rightarrow \mu^+ \mu^-$, $Z \rightarrow e^+ e^-$ with 2011 PbPb data