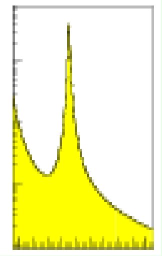
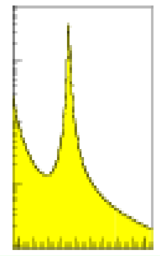


Event 4

Measurements of Drell-Yan Differential Cross Sections and W Charge Asymmetry in pp Collisions at 7 TeV with the CMS Detector



Dimitri Bourilkov

University of Florida

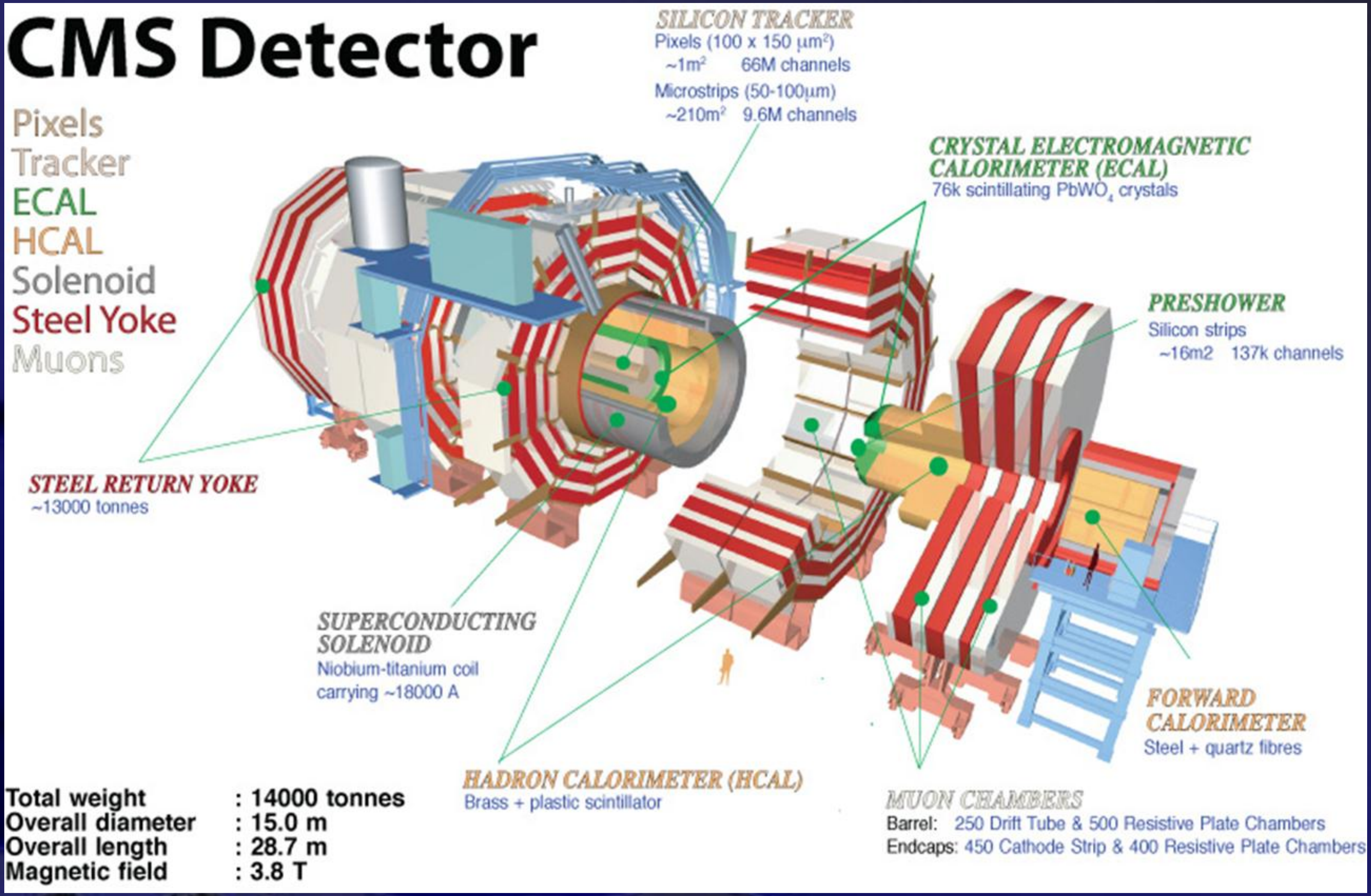
On behalf of the CMS Collaboration

EPS-HEP 2011: EPS High Energy Physics Conference, 21-27 July 2011, Grenoble, France

CMS & LHC @ 7 TeV

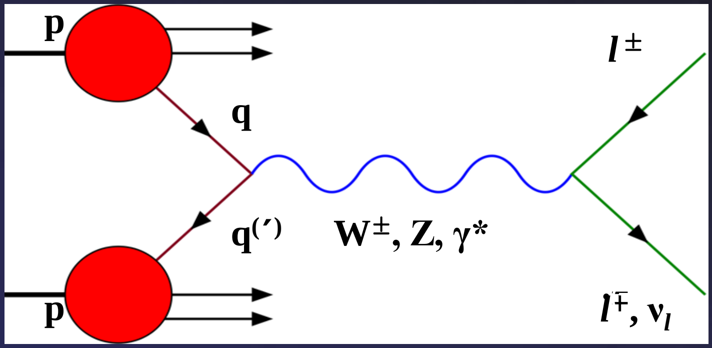
36 pb^{-1}, 2010 data @ 7 TeV

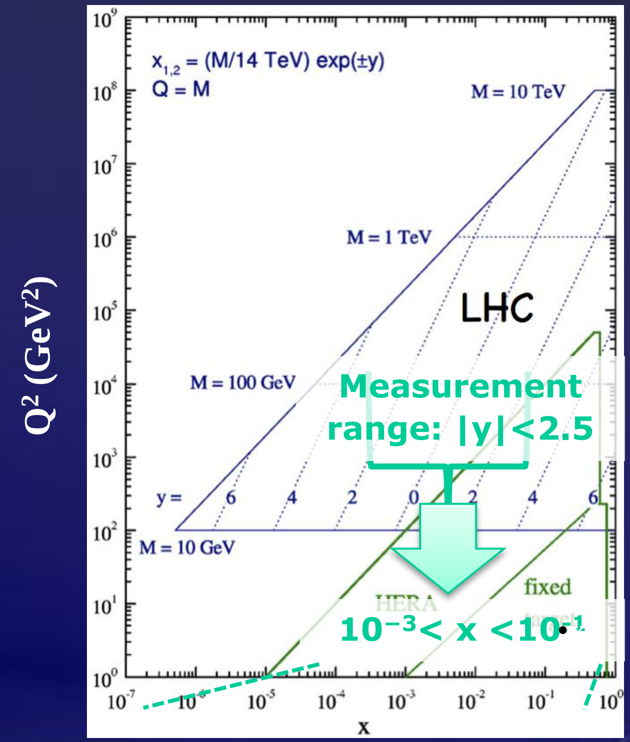
CMS PAS EWK-10-005, JHEP 04 (2011) 050, CMS PAS EWK-10-007



W & Z Production at the LHC

- The LHC is a Heavy Gauge Boson Factory
- Precision tests of the Standard Model at highest momentum transfers
  - W and Z productions are calculated to NNLO in QCD
  - Constrain Parton Density Functions (PDFs)
- W/Z events are standard candles:
  - High event rates at the LHC
  - Leptonic decays $W \rightarrow l\nu_l$ $Z \rightarrow l^+l^-$ to electrons and muons provide clean signals
  - Understand and calibrate the detector response: trigger, identification, resolution, efficiencies
- Important background in many early searches: W′, Z′ …





Cross Section & Charge Asymmetry

Cross Section

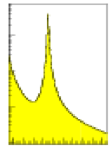
$$\sigma = \frac{\mathrm{N}^{\mathrm{observed}} - \mathrm{N}^{\mathrm{background}}}{\mathrm{Acceptance} \cdot \mathrm{Efficiency} \cdot \mathrm{Correction} \cdot \mathrm{Luminosity}}$$

- Number of events observed from data ($\mathrm{N}^{\mathrm{observed}}$)
- Number of estimated background events ($\mathrm{N}^{\mathrm{background}}$)
- Determine from simulation (Acceptance, Efficiency)
- Scale factor using the difference between data and MC simulation (Correction)
- 2010: 36 pb^{-1} ~4% uncertainty (Luminosity)

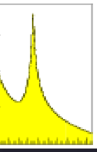
Charge Asymmetry

$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to l^+\nu) - \frac{d\sigma}{d\eta}(W^- \to l^-\nu)}{\frac{d\sigma}{d\eta}(W^+ \to l^+\nu) + \frac{d\sigma}{d\eta}(W^- \to l^-\nu)}$$

Analysis Procedures I



- For all results: common analysis procedures
  - Trigger, online/offline event selections
  - Unprescaled single lepton triggers
  - Acceptance and efficiency calculation using MC
  - Efficiency correction (scale factor) using data-driven methods (tag-and-probe technique)
- Z peak provides:
  - Data samples for tag-and-probe
  - Low backgrounds
  - Resolution estimates
  - Fixes momentum/energy scale



Analysis Procedures II

- **Signal extraction and background estimation: dominant backgrounds estimated using various data-driven methods**
- **Systematic uncertainty estimation**
- **Measurement of physics quantities**
  - **Inclusive or differential cross sections**
  - **Charge asymmetry**
- **Individual measurement can have additional analysis steps**
  - **Details given for each analysis**
  - **E.g. matrix unfolding method for Drell-Yan differential cross section measurements to correct for event migration between neighboring bins**

Inclusive W and Z Cross Sections

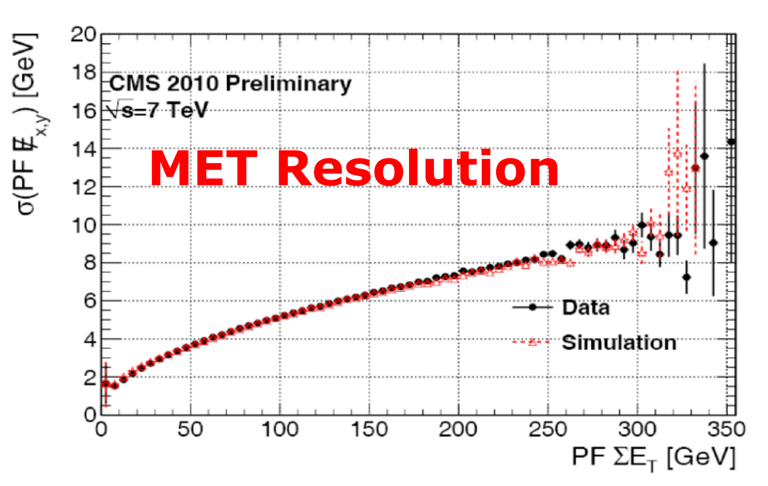
Lepton Selections

Electrons

- E_T (excludes Barrel-Endcap transition 1.44-1.57)
  - $E_T > 25$ GeV $|\eta|<2.5$
- High E_T super-cluster matched to a high p_T GSF track (accounts for hard Bremsstrahlung); match in η (tight) and φ
- Isolated; cuts on track, ECAL and HCAL energy in $\Delta R<0.3$ (reject QCD bkg)
- Limit HCAL energy deposits in cone $\Delta R < 0.15$
- Conversion rejection

Muons

- p_T
  - $P_T > 20$ GeV (Z)
  - $P_T > 25$ GeV (W) $|\eta|<2.1$
- At least 10 tracker, 1 pixel hits; $\chi^2/\mathrm{ndof} < 10$
- Distance from beamspot $d_{xy} < 0.2$ cm (reject cosmics)
- Isolated; relative combined isolation for W, tracks only for Z; in $\Delta R<0.3$ (reject QCD bkg)



Missing transverse energy MET from Particle Flow: tracks/energy deposits sorted into charged/neutral candidates

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

Acceptance & Efficiency

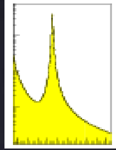
- **POWHEG Monte Carlo as baseline**
- **Tag-and-probe method on Z events**
- **Corrections for trigger, reconstruction, isolation and ID efficiencies from data**
- **Determined separately for W^+ and W^-**

Electrons

- **W**
  - **A = 0.4933 +- 0.0003**
  - **ε = 73.5 +- 0.9 %**
- **Z**
  - **A = 0.3876 +- 0.0005**
  - **ε = 60.9 +- 1.1 %**

Muons

- **W**
  - **A = 0.4543 +- 0.0003**
  - **ε = 84.8 +- 0.8 %**
- **Z: simultaneous fit for Z yield & efficiencies**
  - **A = 0.3978 +- 0.0005**



W Selection & Yield

- **W event signature**
  - **High p_T lepton**
  - **Missing transverse energy due to neutrino**
- **Background contributions**
  - **EWK (Drell-Yan, W $\rightarrow \tau\nu$, Di-boson: WW, WZ, ZZ)**
  - $t\bar{t}$
  - **QCD: multi-jet, γ+jet (electron), decay-in-flight (muon)**
- **Signal/background extraction**
  - **Signal from maximum likelihood fit to MET distributions**
  - **Signal shape: MC + Z $\rightarrow l^+l^-$ data for hadron recoil tuning**
  - **QCD: from data with lepton ID criteria reversed**

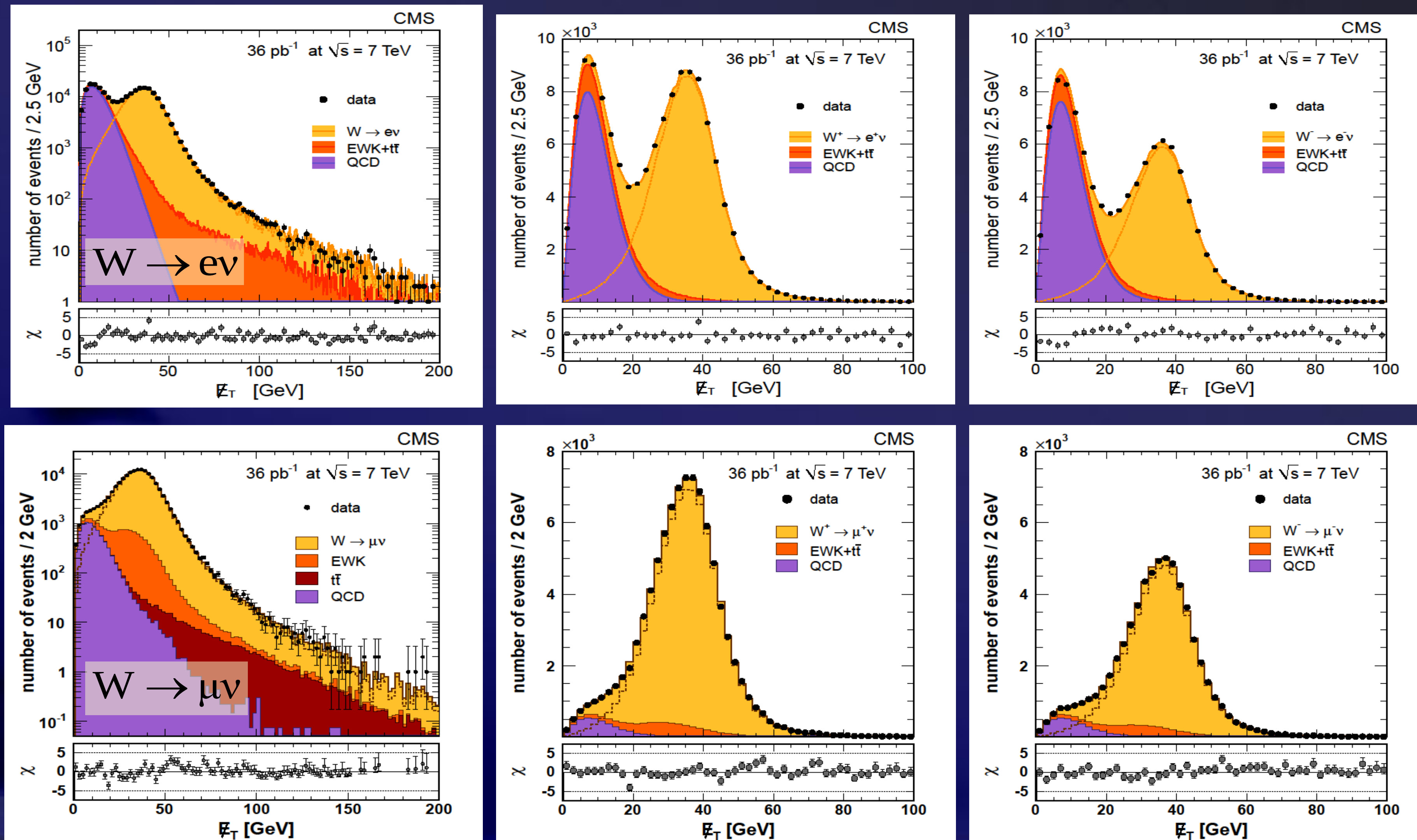
Background [%]	Electrons	Muons
Drell-Yan (ll, $\tau\tau$)	7.6	4.6
W $\rightarrow \tau\nu$	3.0	3.0
WW, WZ, ZZ	0.1	0.1
tt	0.4	0.4
cosmics	-	< 0.01
QCD	From fit	5.1

Correlation between MET and Isolation included in systematics

Events	Electrons	Muons
W^+	81568 +- 297	84091 +- 291
W^-	54760 +- 246	56666 +- 240

Signal Extraction: W, W⁺ and W⁻ Yields

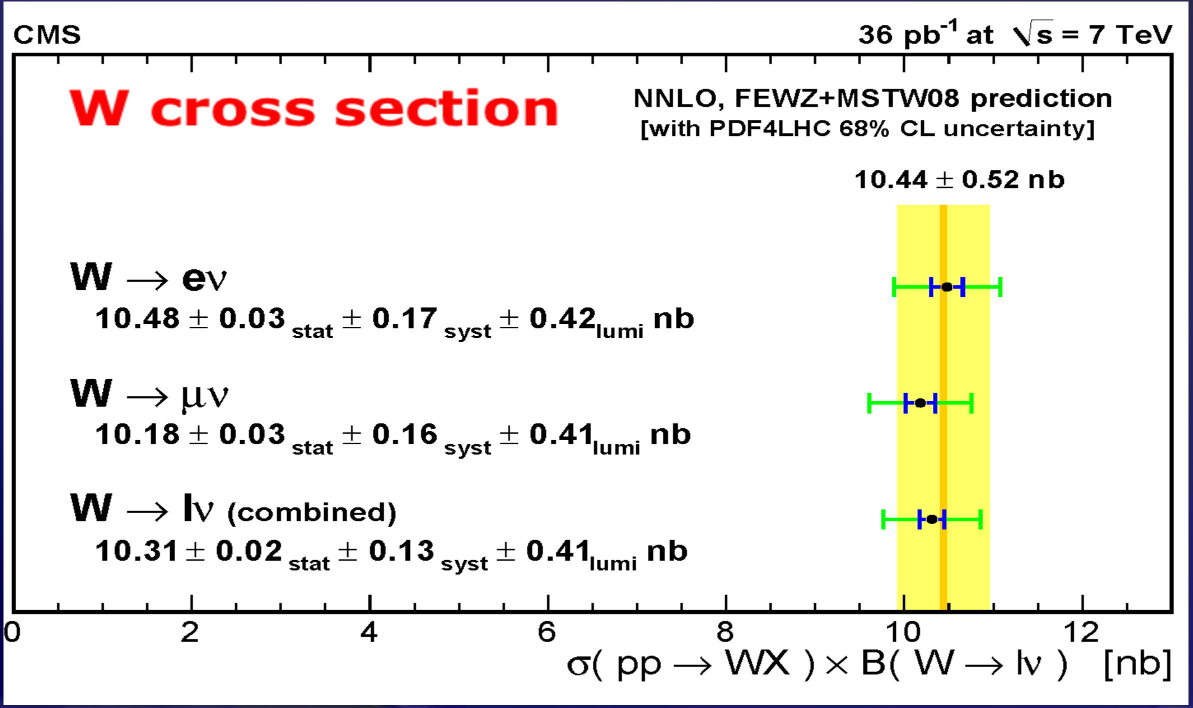
All W | **W⁺** | **W⁻**



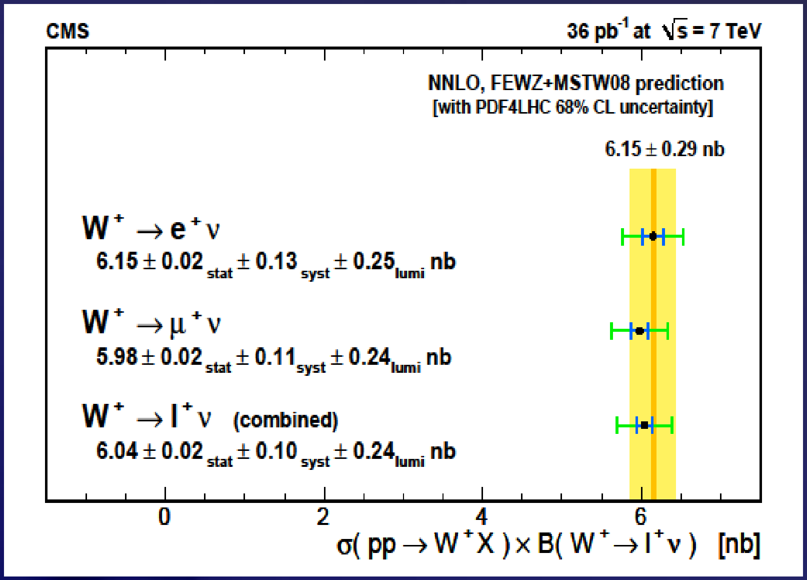
W Cross Sections

	$W \to e\nu$	$W \to \mu\nu$
Experimental	1.6%	1.1%
Theoretical	0.9%	1.1%
Total	1.8%	1.6%
Luminosity	4.0%	

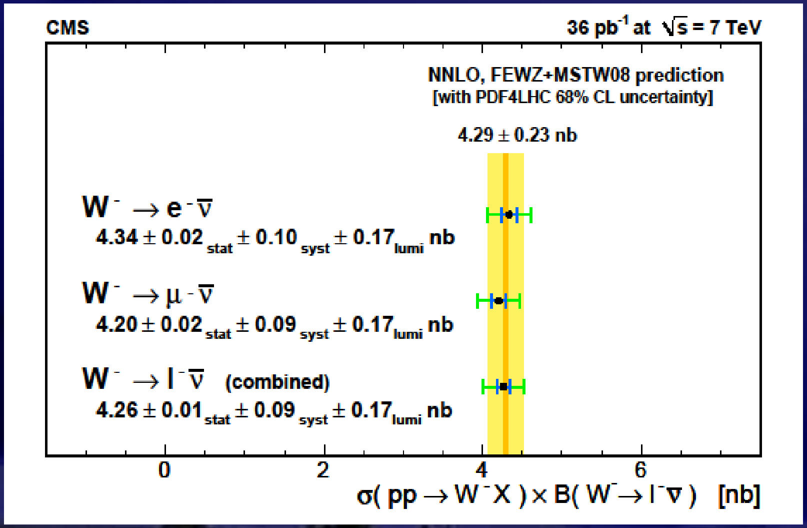
W results agree well with the NNLO FEWZ+MSTW08NNLO prediction



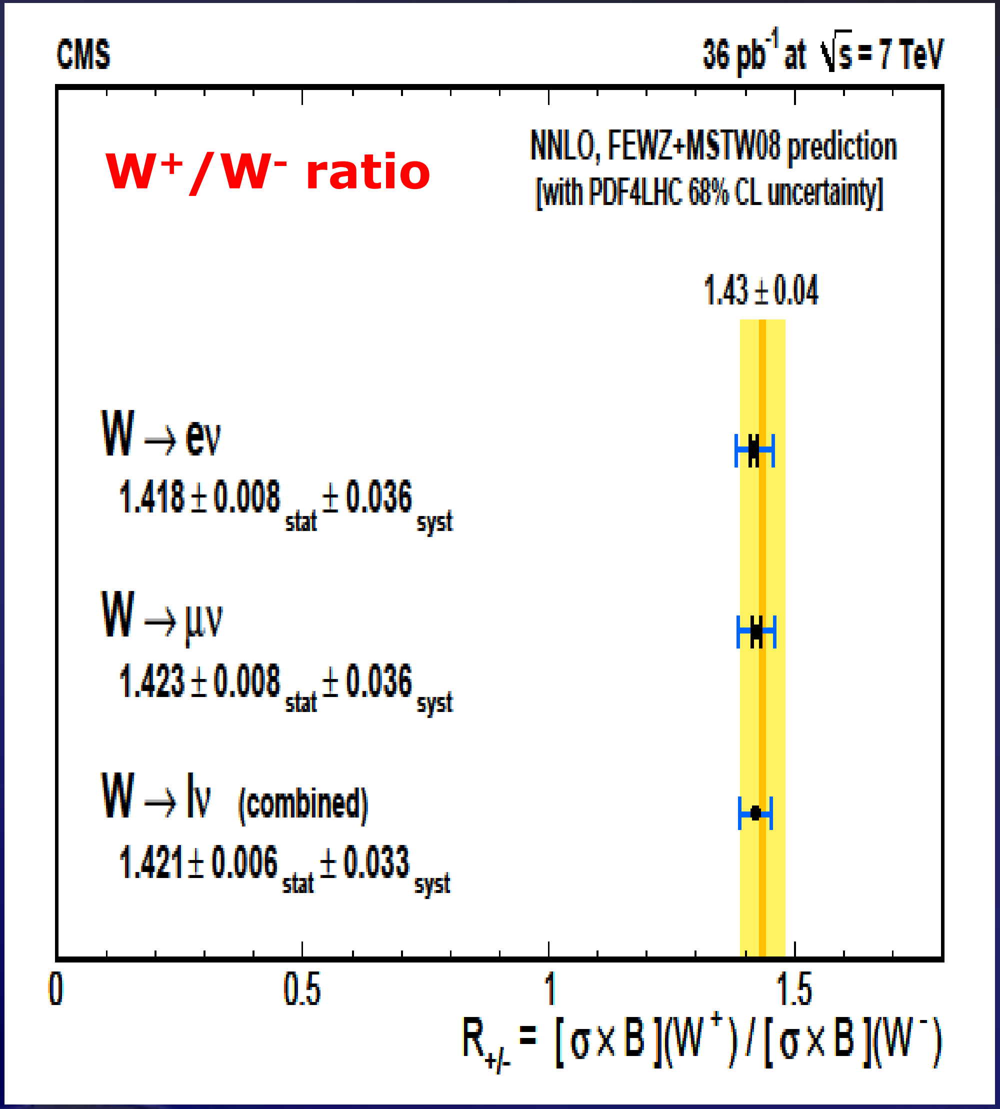
W^+/W^- Ratios



CMS
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
NNLO, FEWZ+MSTW08 prediction
[with PDF4LHC 68% CL uncertainty]
6.15 ± 0.29 nb
$W^+ \to e^+\nu$
$6.15 \pm 0.02_{stat} \pm 0.13_{syst} \pm 0.25_{lumi}$ nb
$W^+ \to \mu^+\nu$
$5.98 \pm 0.02_{stat} \pm 0.11_{syst} \pm 0.24_{lumi}$ nb
$W^+ \to l^+\nu$ (combined)
$6.04 \pm 0.02_{stat} \pm 0.10_{syst} \pm 0.24_{lumi}$ nb
0
2
4
6
$\sigma(pp \to W^+X) \times B(W^+ \to l^+\nu)$ [nb]



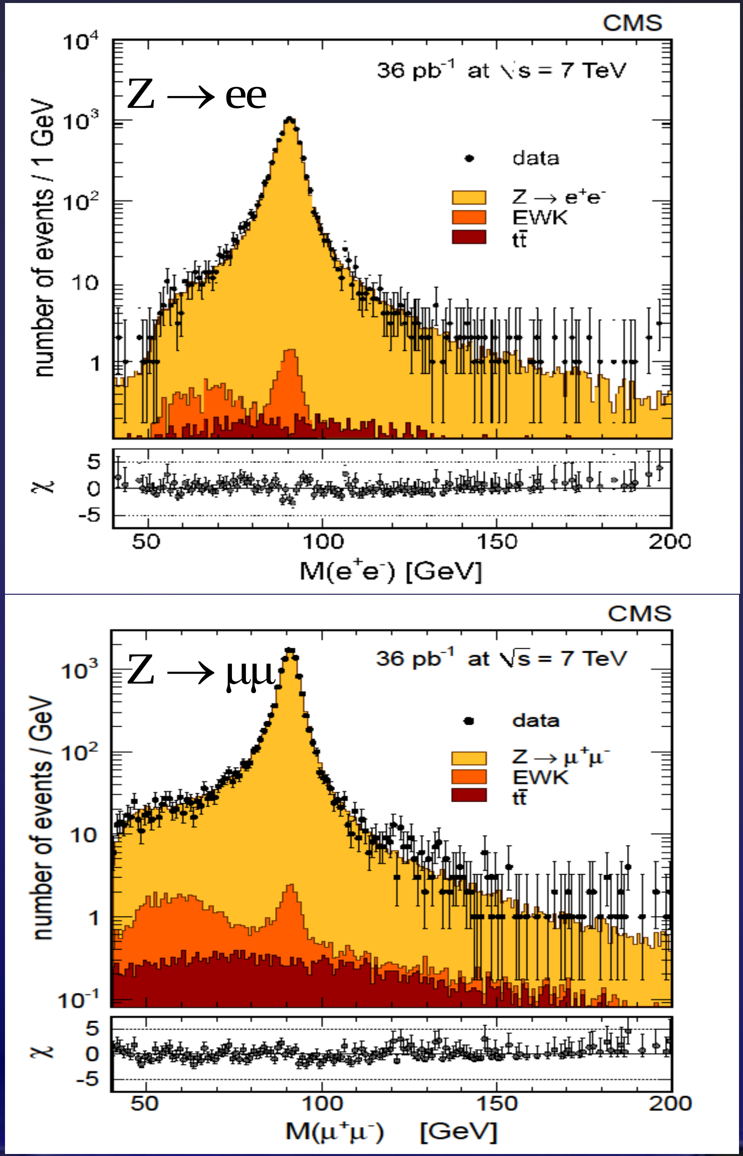
CMS
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
NNLO, FEWZ+MSTW08 prediction
[with PDF4LHC 68% CL uncertainty]
4.29 ± 0.23 nb
$W^- \to e^-\bar{\nu}$
$4.34 \pm 0.02_{stat} \pm 0.10_{syst} \pm 0.17_{lumi}$ nb
$W^- \to \mu^-\bar{\nu}$
$4.20 \pm 0.02_{stat} \pm 0.09_{syst} \pm 0.17_{lumi}$ nb
$W^- \to l^-\bar{\nu}$ (combined)
$4.26 \pm 0.01_{stat} \pm 0.09_{syst} \pm 0.17_{lumi}$ nb
0
2
4
6
$\sigma(pp \to W^-X) \times B(W^- \to l^-\bar{\nu})$ [nb]



CMS
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
W^+/W^- ratio
NNLO, FEWZ+MSTW08 prediction
[with PDF4LHC 68% CL uncertainty]
1.43 ± 0.04
$W \to e\nu$
$1.418 \pm 0.008_{stat} \pm 0.036_{syst}$
$W \to \mu\nu$
$1.423 \pm 0.008_{stat} \pm 0.036_{syst}$
$W \to l\nu$ (combined)
$1.421 \pm 0.006_{stat} \pm 0.033_{syst}$
0
0.5
1
1.5
$R_{+/-} = [\sigma \times B](W^+) / [\sigma \times B](W^-)$

Z Selection & Yield

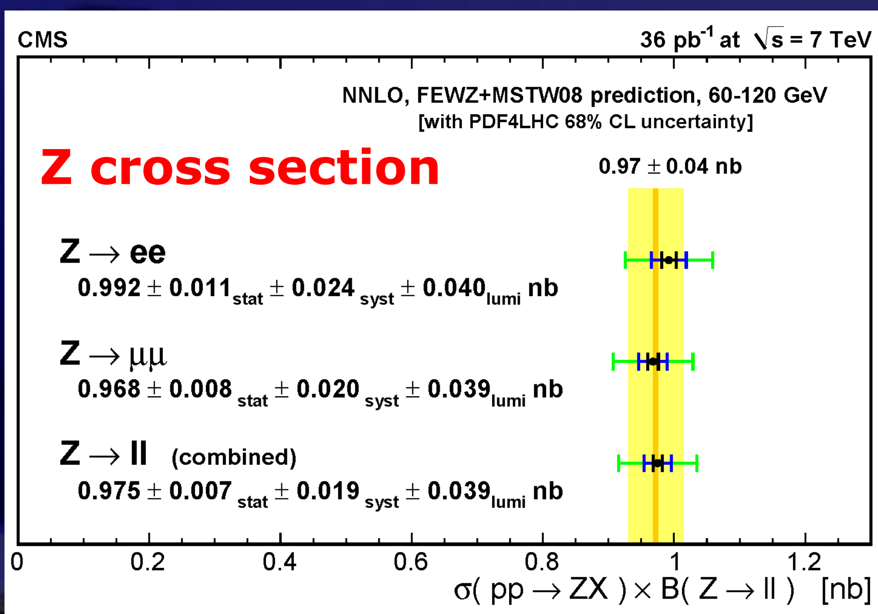
- **Z event signature**
  - Two isolated high p_T leptons
  - Mass: 60 < M(ll) < 120 GeV
- **Background contributions**
  - EWK (Z $\rightarrow\tau\tau$, Di-boson: ww, wz, wz)
  - $t\bar{t}$
  - QCD (multi-jet, γ+jet (electron))
- **Signal/background extraction**
  - Backgrounds almost negligible
  - Signal extracted by cut & count (electron channel)
  - 8442 events (36 +- 12 bkg)
  - Fits to M(ll) for signal yield and efficiencies simultaneously (muon channel)
  - 13728 +- 121 events
  - F_{bkg} = 0.44 +- 0.02%

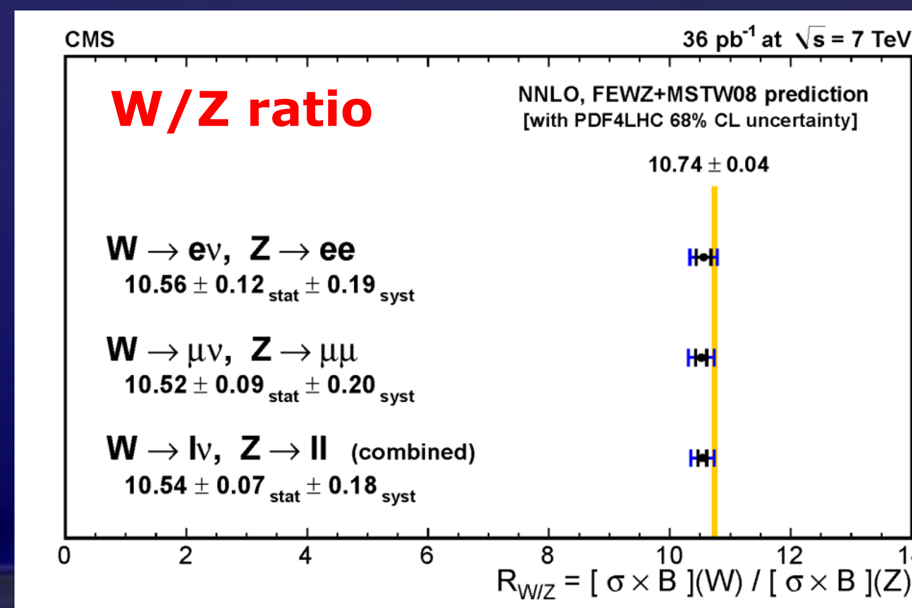


Z Cross Sections & W/Z ratio

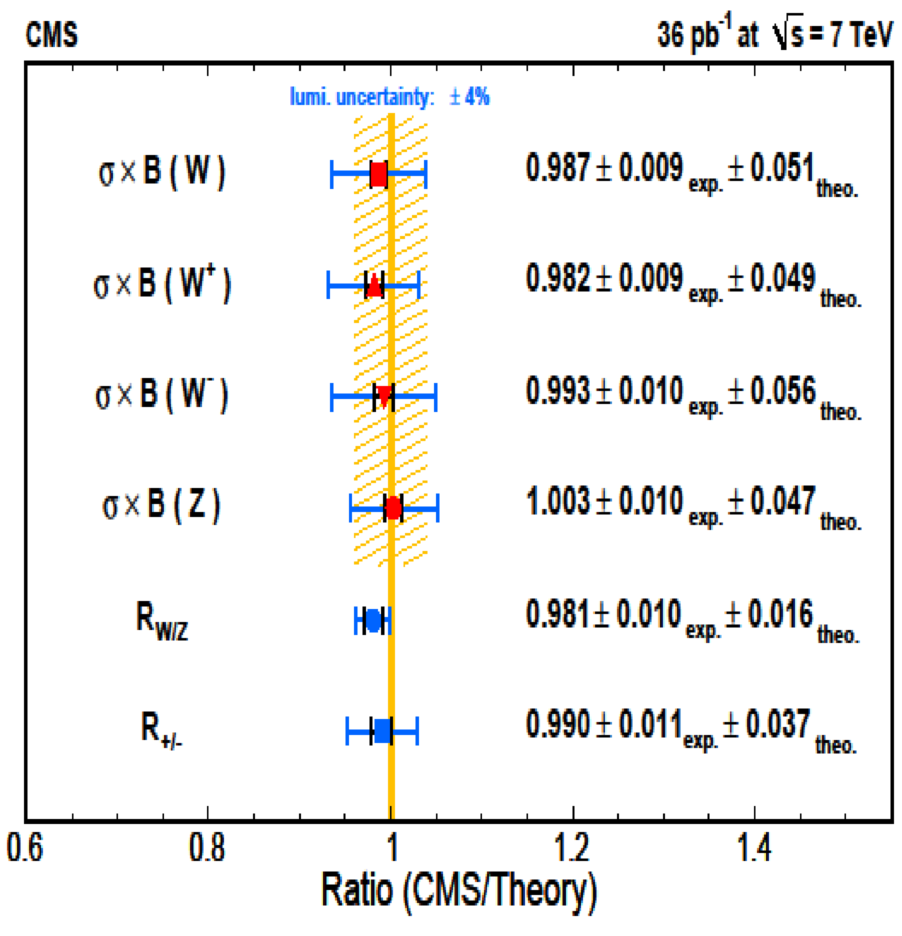
- Z inclusive cross sections are measured precisely
  - We collect 22k Z candidates
- Measurements start to be limited by theory systematic uncertainty
- W/Z ratio agrees well with the NNLO FEWZ+MSTW08NNLO prediction

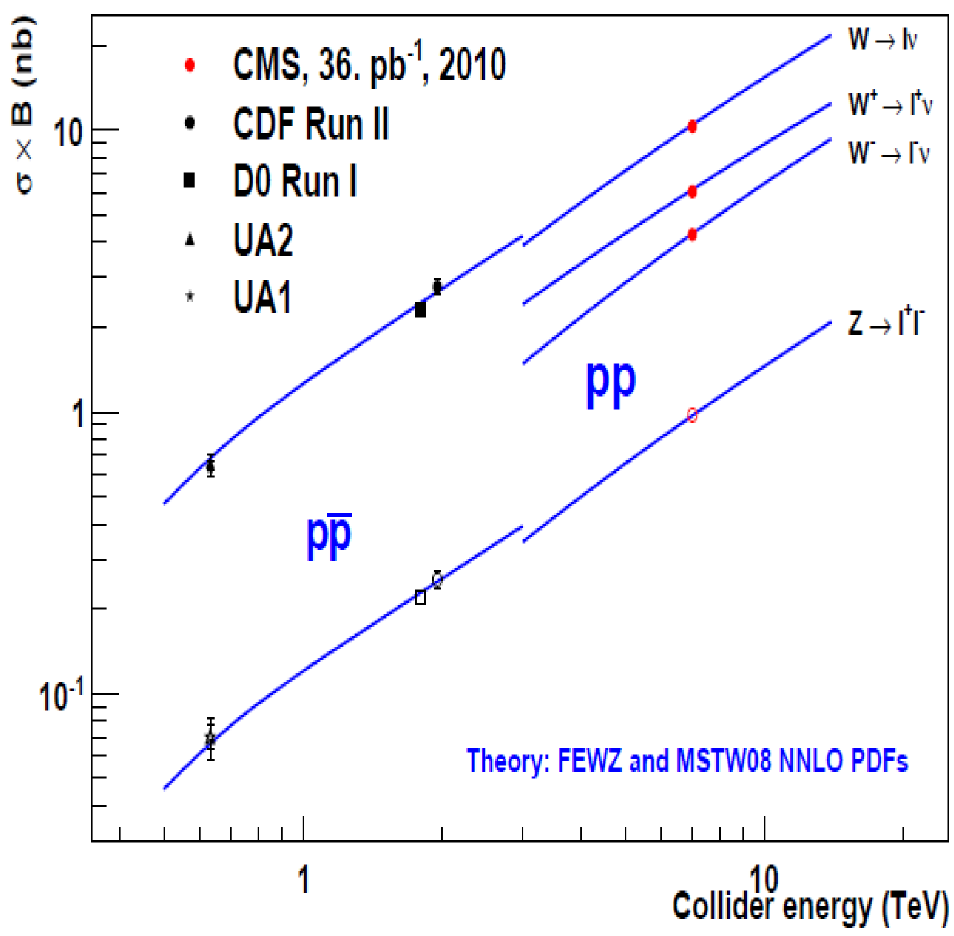
	$Z \to ee$	$Z \to \mu\mu$
Exp.	1.8%	0.7%
Theor.	1.6%	1.9%
Total	2.4%	2.0%
Lumi.	4.0%	





Summary of W/Z Results

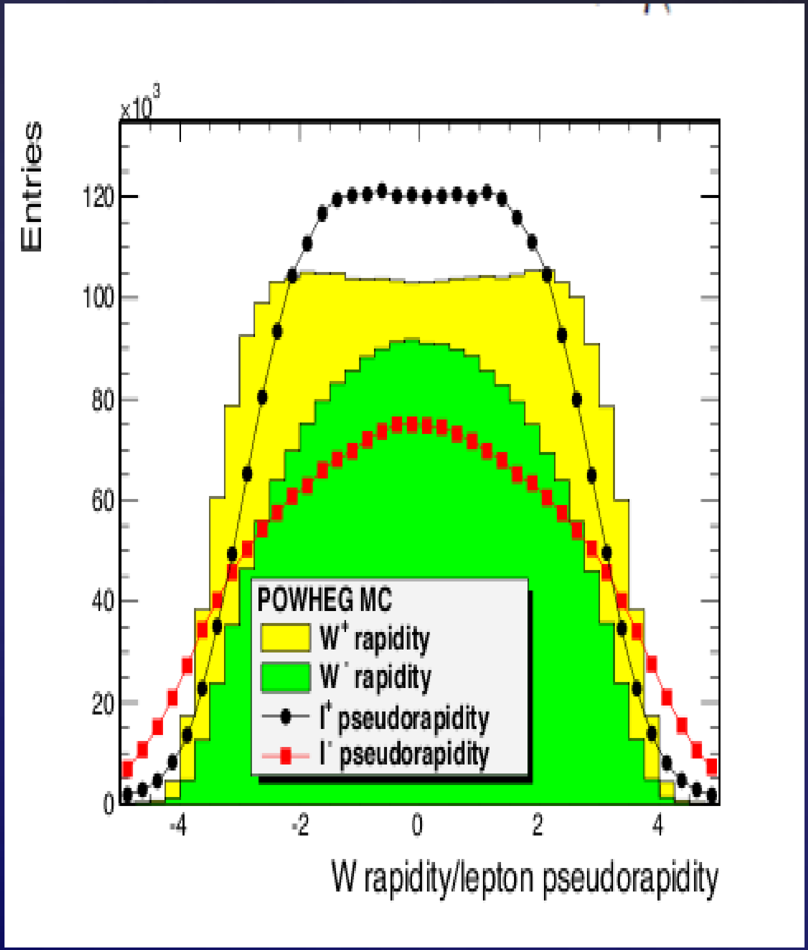




W Charge Asymmetry

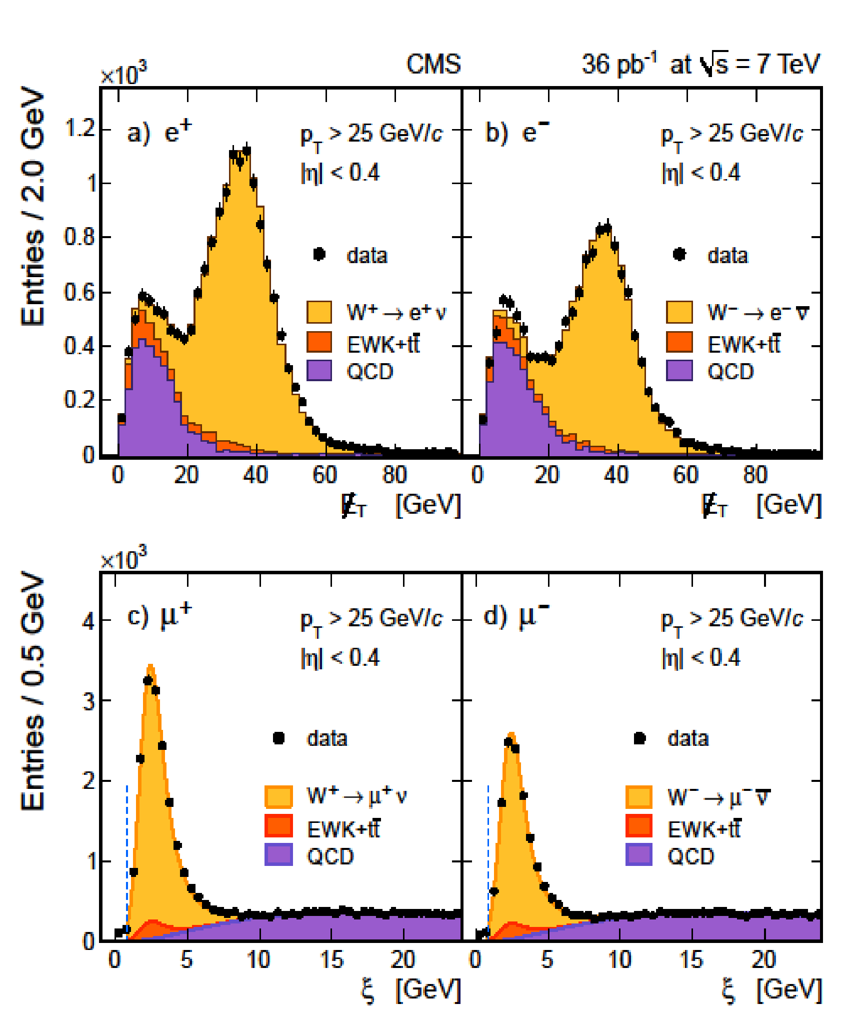
W Charge Asymmetry

- Difference in u/d valence quark distributions in the proton results in rate difference between W^+ and W^- bosons in pp collisions
- An asymmetry measurement as a function of boson rapidity can be used to constrain PDFs
- Lepton pseudorapidities "follow" W rapidities



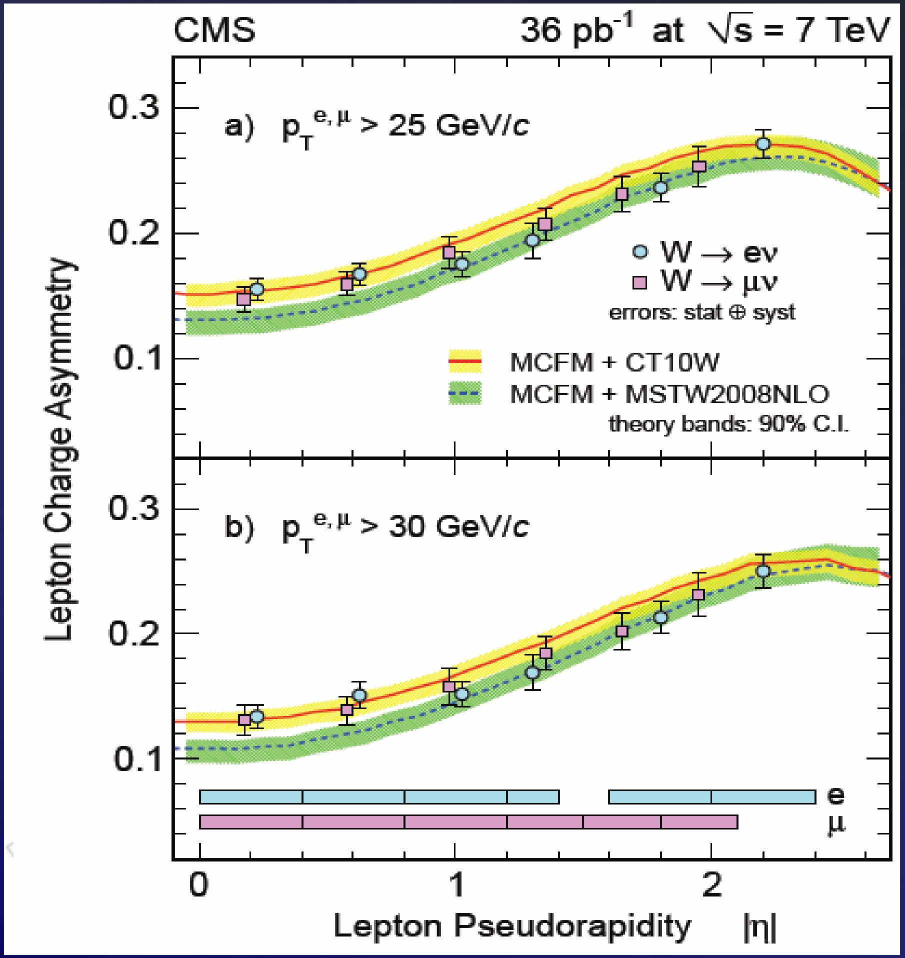
W Yield in Pseudorapidity Bins

- **Analysis procedure same as W cross section measurement**
  - For signal extraction, muon channel uses a fit to modified isolation variable, not MET
- **Fit performed in six pseudorapidity bins:**
  - for electrons: [0.0, 0.4], [0.4, 0.8], [0.8, 1.2], [1.2, 1.4], [1.6, 2.0], [2.0, 2.4]
  - for muons: [0.0, 0.4], [0.4, 0.8], [0.8, 1.2], [1.2, 1.5], [1.5, 1.8], [1.8, 2.1]

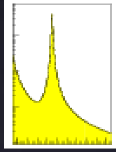


W Charge Asymmetry

- Charge asymmetries for electrons and muons agree with each other
- The precision is < 1.1 % (statistical), < 1.5 % (total) for all bins
  - New inputs to PDF global fits



CT10 and MSTW2008 include full weight of TEVATRON W asymmetry



Drell-Yan Mass Spectrum

Drell-Yan Parton Kinematics

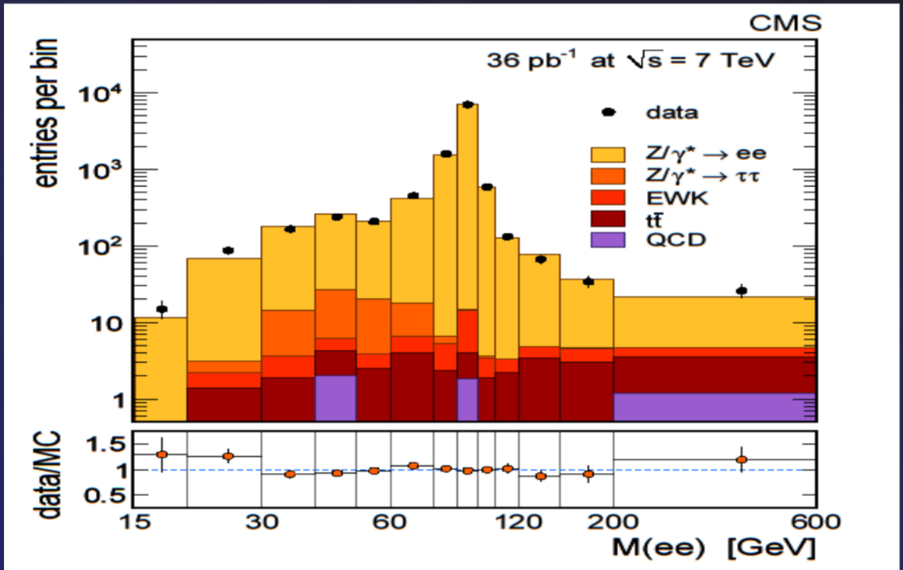
- Different X ranges probed for different masses; quite low X @ Z and below => HERA input is important
- Measuring PDFs is precision physics; at the start we will be constrained by PDFs; actually they are known quite well for DY@LHC
- The Drell-Yan spectrum is important background @ high mass

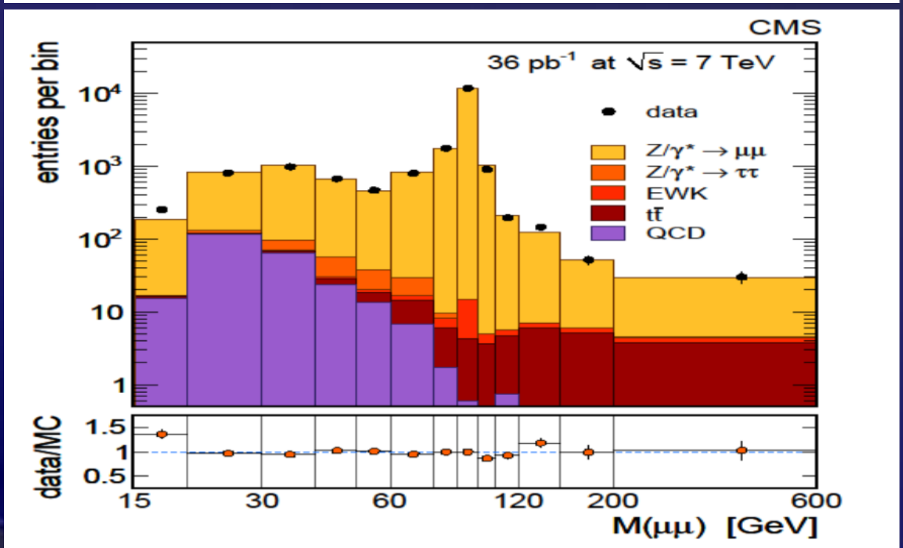
7 TeV

Y	0	1	2
M	15	GeV	
X1	0.00214	0.0058	0.0158
x2	0.00214	0.00079	0.00029
M	91	GeV	
x1	0.013	0.0353	0.096
x2	0.013	0.0048	0.00176
M	600	GeV	
x1	0.0857	0.233	0.633
x2	0.0857	0.0315	0.0116
M	1000	GeV	
x1	0.143	0.388	-
x2	0.143	0.0526	-

The Drell-Yan Mass Spectrum

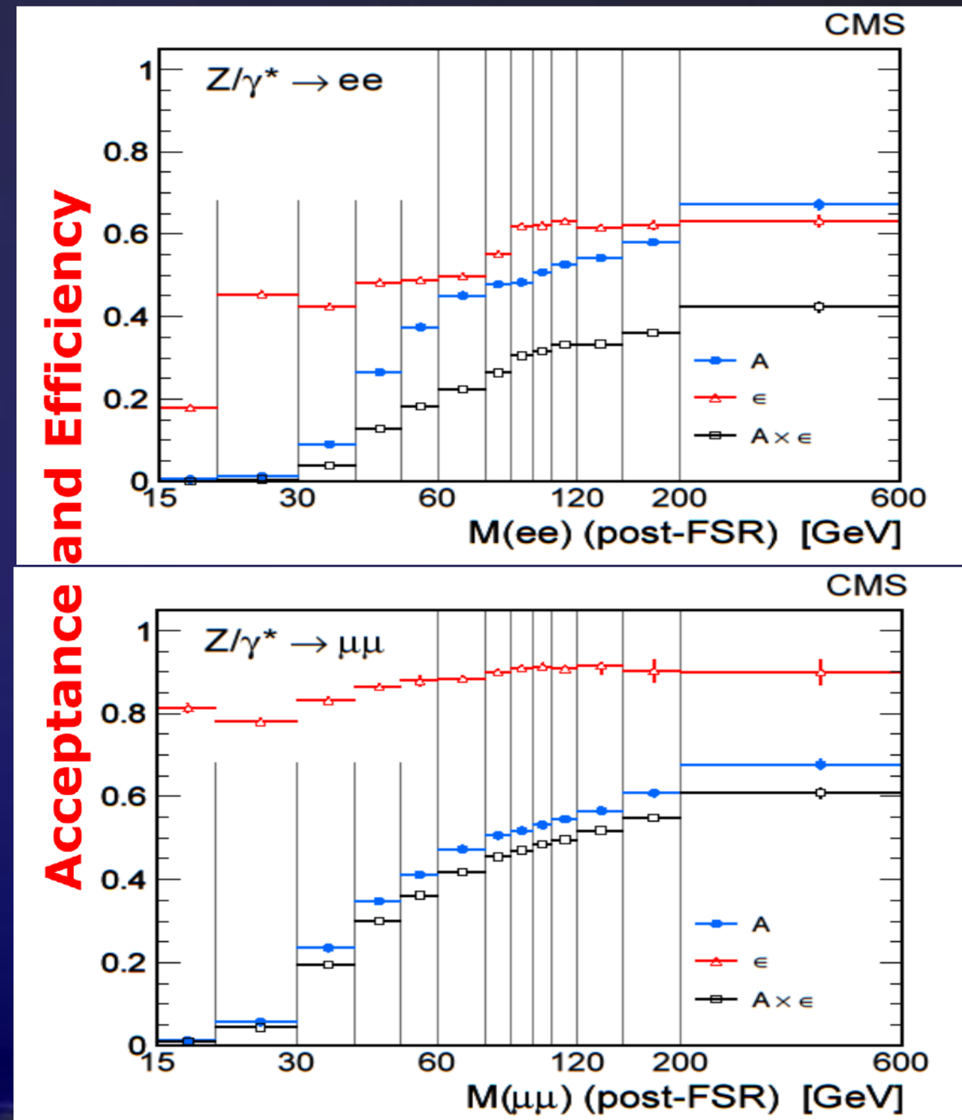
- The Drell-Yan mass spectrum contains information about:
  - QCD
  - Electroweak couplings
  - Parton Density Functions (PDFs)
- The "observed" DY mass spectrum adds detector effects
- Even after unfolding for detector effects and FSR the result will be cross sections folded with PDFs





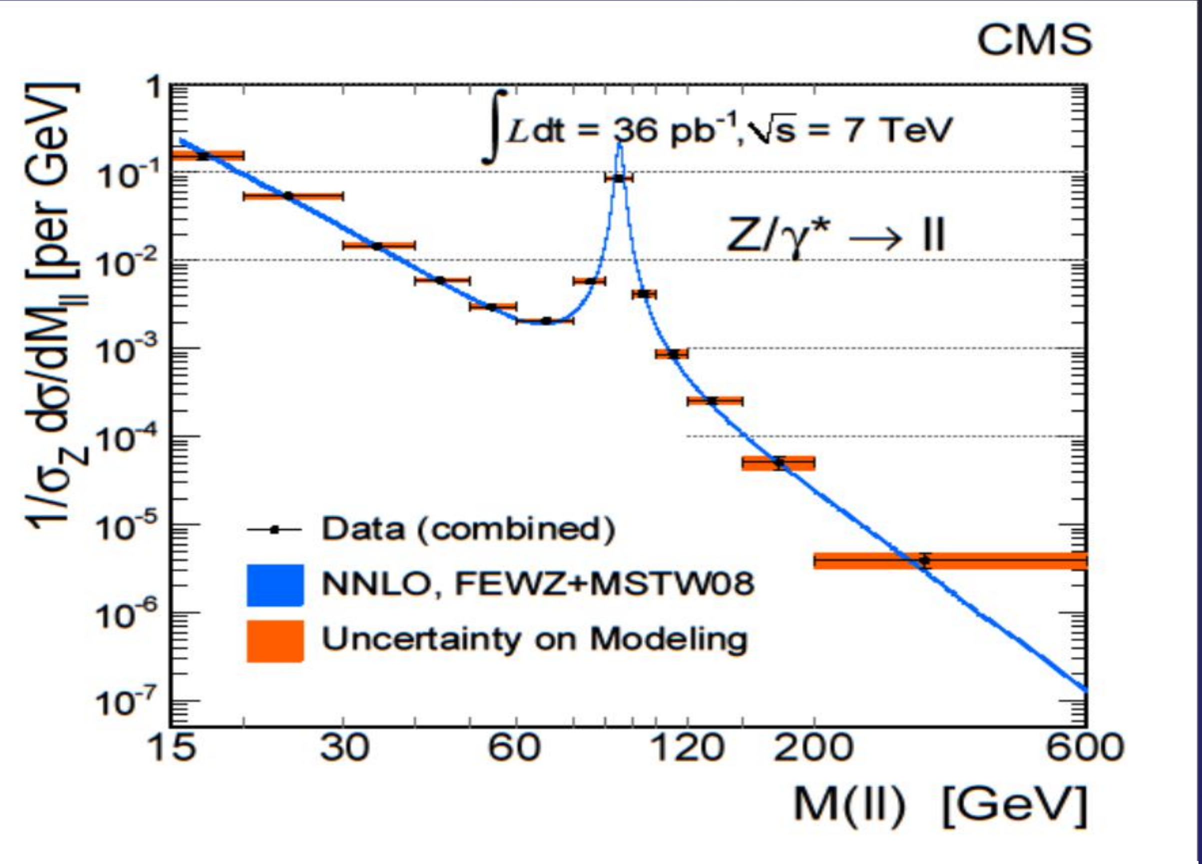
Drell-Yan Selections

- Analysis follows Z cross section measurements with modifications for low mass
- Asymmetric kinematic cuts on the **electrons and muons** to collect more data in the low mass region
- **Electrons:**
  - $E^1_T > 20$ GeV
  - $E^2_T > 10$ GeV
- **Muons:**
  - $p^1_T > 16$ GeV $|\eta| < 2.1$
  - $p^2_T > 7$ GeV $|\eta| < 2.4$
- **Unfolding correction** for detector resolution effects
  - FSR effects are corrected using simulation



Results for Drell-Yan

- We present a shape measurement normalized to the Z peak
- Good agreement between electron and muon channels
- Good agreement with NNLO FEWZ calculations using MSTW2008, CT10 and CTEQ66



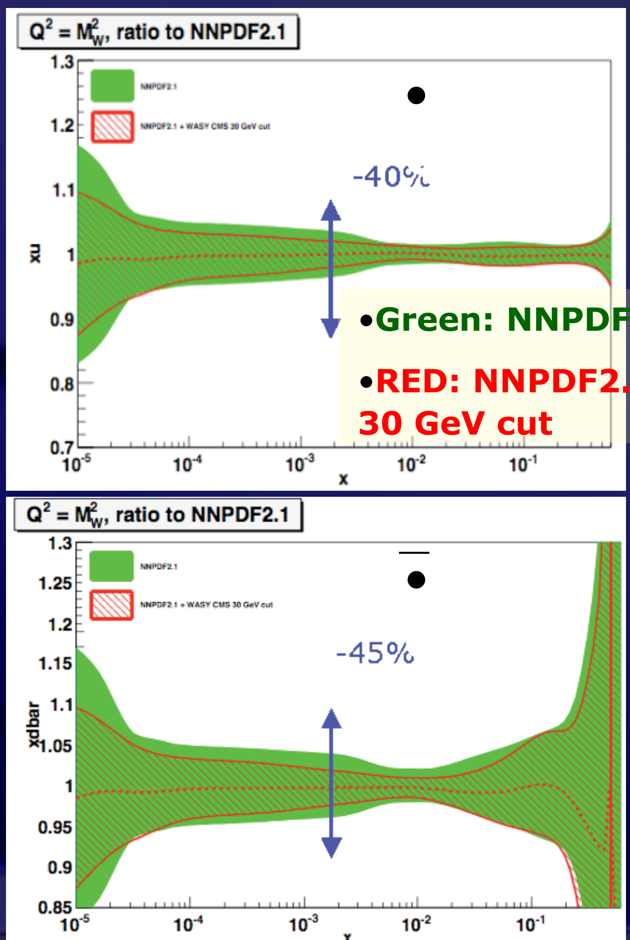
Normalized Drell-Yan mass spectrum, as measured (with statistical and systematic uncertainties summed in quadrature) and as predicted by NNLO calculations, for the full phase space. The band indicates the theory uncertainty resulting from the model-dependent kinematical distributions inside each (relatively large) bin

New PDF Constraints

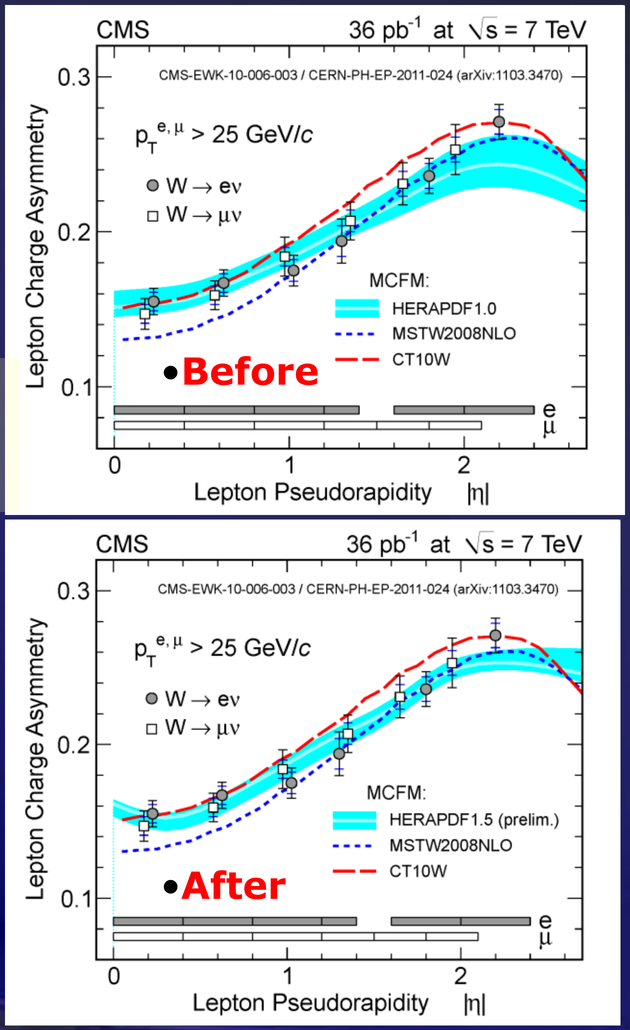
Reduction of PDF uncertainties (about 30-40%) for medium and small-x light (anti)quarks due to the CMS W charge asymmetry measurement

HERAPDF already incorporated the CMS measurement (by Katerina Lipka)

M. Ubiali, LHC EWK Workshop, Apr 2011



- Green: NNPDF2.1
- RED: NNPDF2.1+WASY CMS 30 GeV cut



Summary

- CMS has launched a broad program of electroweak measurements with the data from the first LHC run in 2010 at 7 TeV
- The standard W & Z candles provide excellent tools to understand and improve the detector performance
- W/Z and Drell-Yan results with electrons and muons in the final state:
  - Precise measurements of W & Z inclusive cross sections and ratios
    - Good agreement with NNLO QCD predictions
    - Good agreement between electron and muon channels
    - Good agreement with previous ATLAS and CMS results with lower statistics
  - Precise measurements of lepton charge asymmetries
  - Detailed studies of differential cross sections in Drell-Yan production (invariant mass)

Outlook

- All results show excellent agreement with the Standard Model predictions
- We have collected > 1 fb^{-1} in 2011
  - Stay tuned for more precise results from 2011 data

Terra incognita ahead!

Backup Slides

References

- Inclusive W and Z cross sections
  - CMS PAS EWK-10-005
- Lepton Charge Asymmetry
  - JHEP 04 (2011) 050
- Differential Drell-Yan Cross Section
  - CMS PAS EWK-10-007