KYUNGPOOK NATIONAL UNIVERSITY

W & Z boson Production @ CMS

SangEun Lee

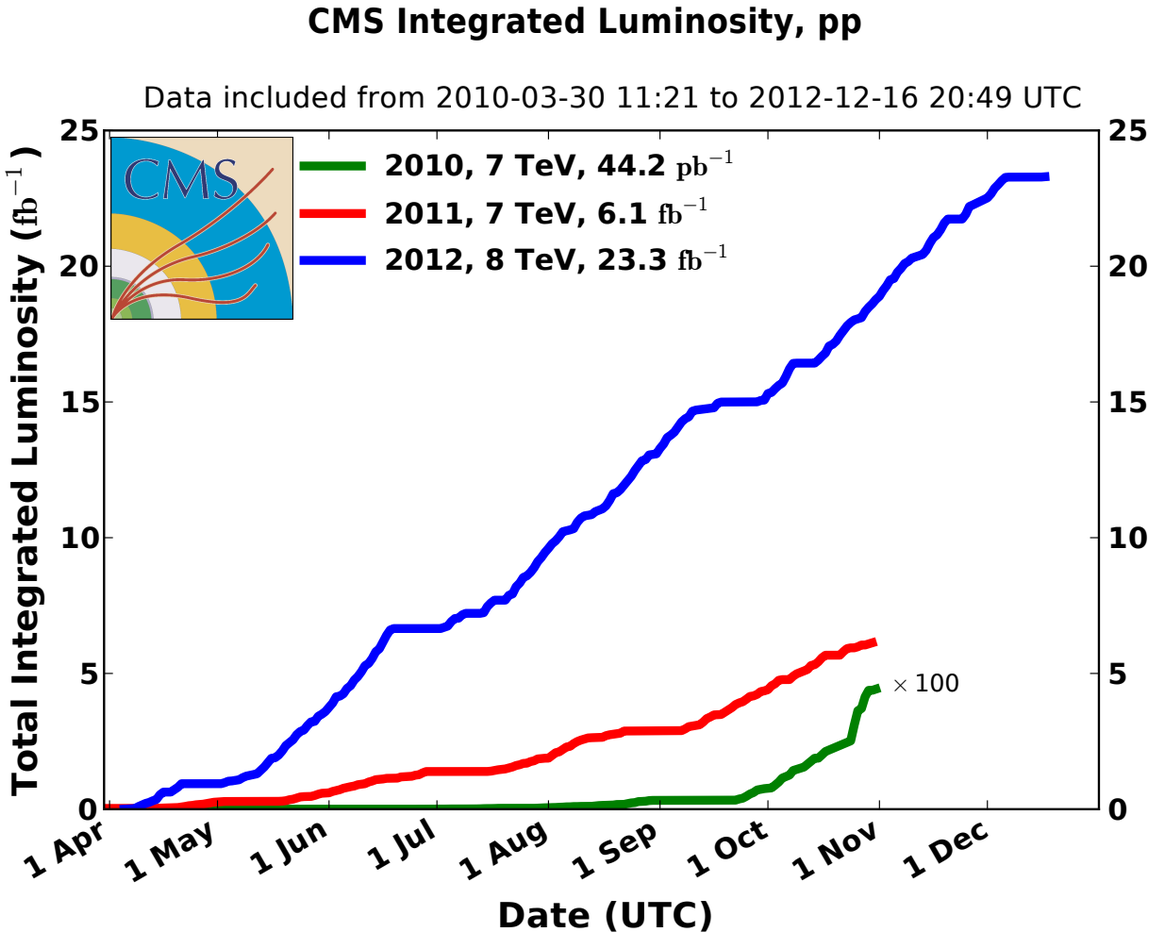
Kyoungpook National University

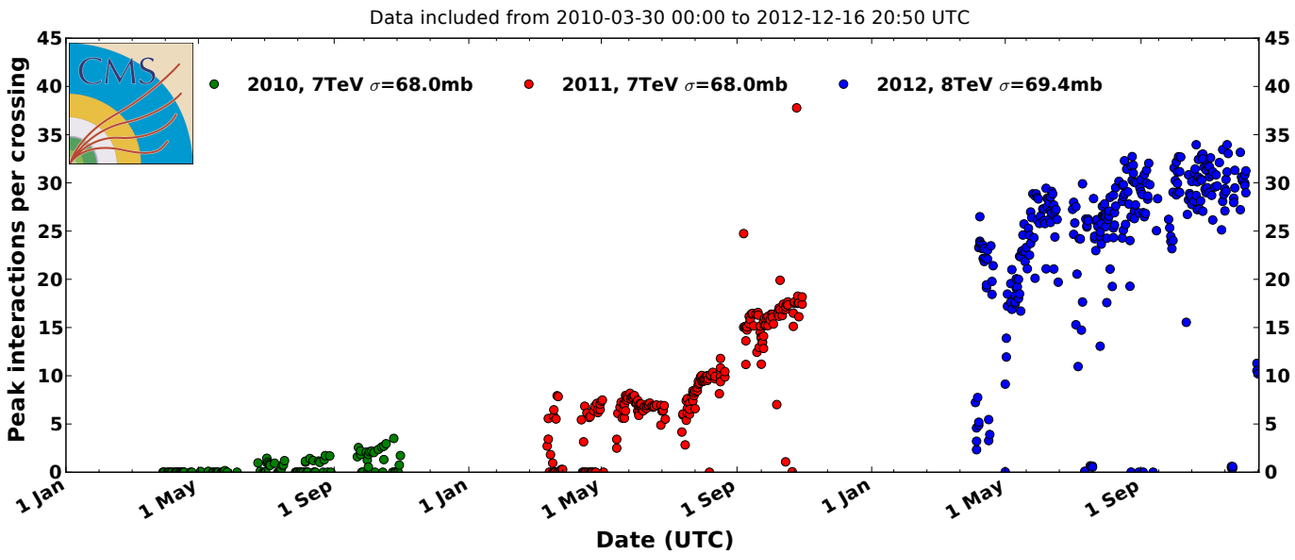
on behalf of the **CMS Collaboration**

EPS HEP 2013, Stockholm, Sweden

CMS Data taking

- Total 29.4/fb delivered to CMS detector
- 7 TeV analysis
  - ➡ **New result from Muon Q Asymm. 4.7/fb full data 2011**
  - ➡ DY differential: 4.5(Mu), 4.8(Ele)/fb full 2011 data
  - ➡ Electron Q Asymm. 840/pb data 2011
- Low Pile Up (Av. 3 bunch crossing) 8 TeV Special run:
  - ➡ 19/pb in the beginning of 2012 data taking
  - ➡ W/Z cross section
  - ➡ DY (muon) pT differential cross section





Measurement of the Muon Charge Asymmetry in inclusive W production at 7 TeV

Motivation

- Overall excess of W+ over W- due to the presence of two valence u-quarks in the proton
- Muon Charge Asymmetry on eta

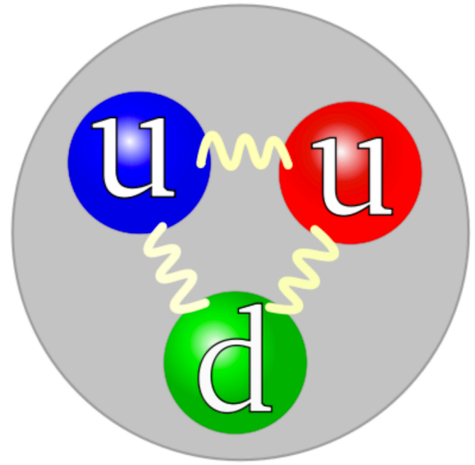
$$\mathcal{A}_{exp}(\eta) = \frac{P(\eta) - E(\eta)}{P(\eta) + E(\eta)}$$

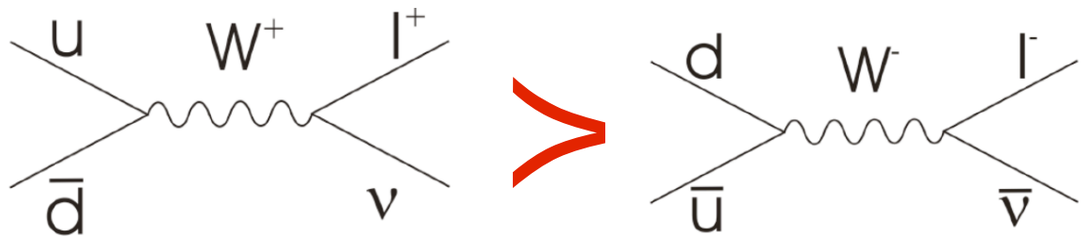
➡ High precision than boson

- **Full 2011 7 TeV dataset** amount to 4.7/fb

➡ Measurement with 20 M W bosons

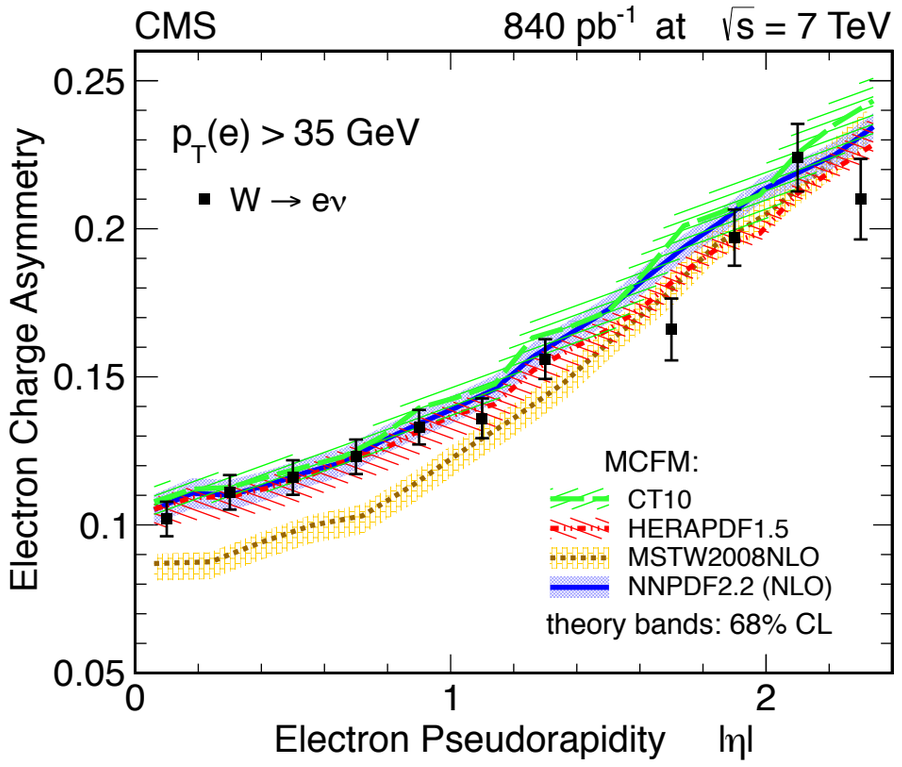
- **high precision than previous measurement**





Electron Charge Asymmetry

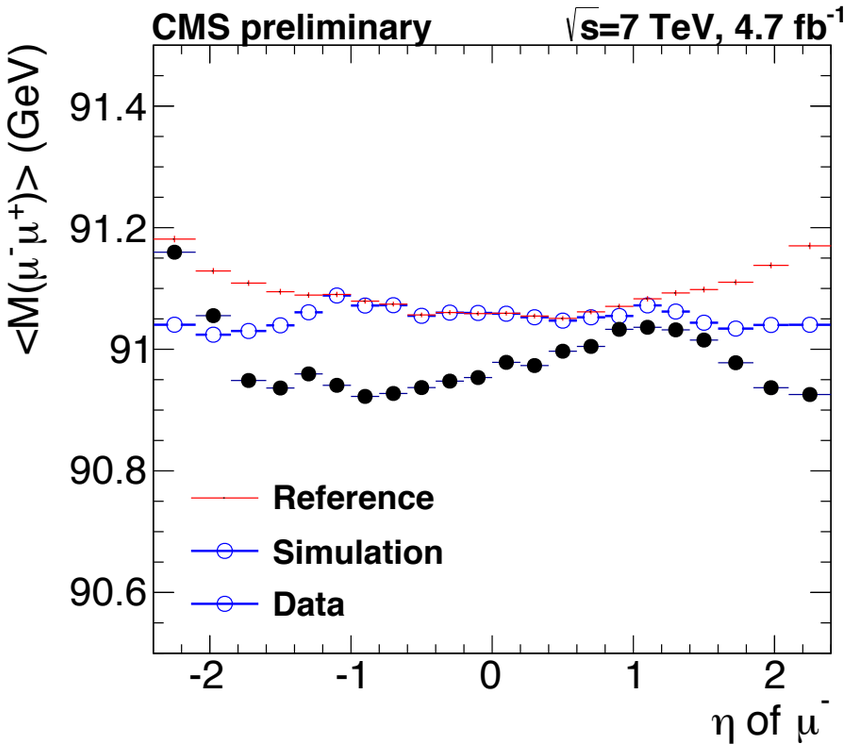
- **PRL 109 (2012) 111806**
- 840/pb at 7 TeV
- pT >35 GeV/c, 11 Bins of |η|<2.4
- very precise (4-5%) to theory predictions



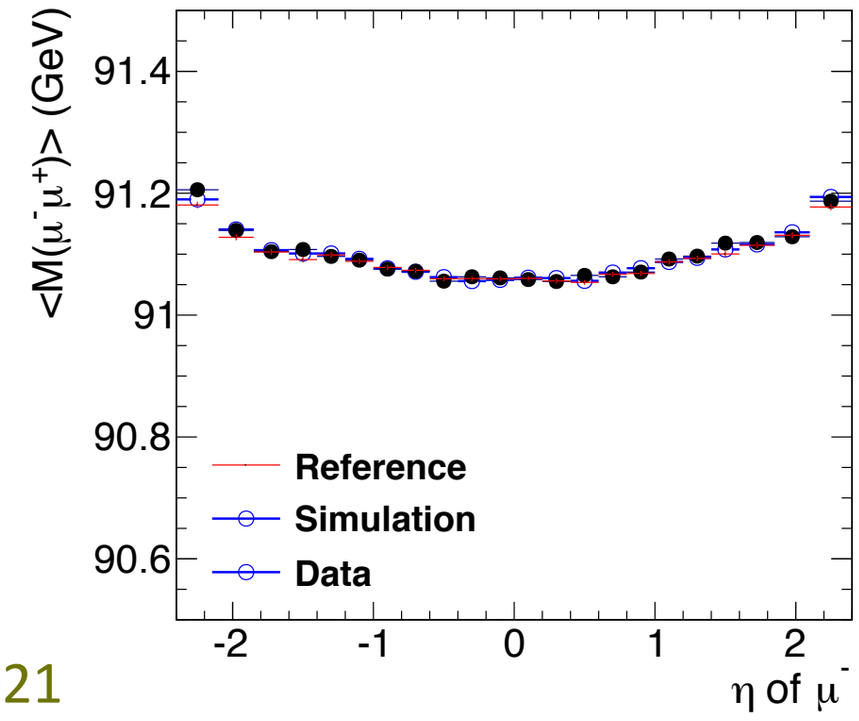
Muon Q Analysis

- For better resolution for MET distributions, several correction techniques are applied
- Muon **momentum scale correction**:
  - ➡ Due to misalignment and mis-modeling of magnetic field
  - ➡ The correction is derived from <1/pT> in (η,ϕ,Q) using Z events
  - ➡ Effect on: acceptance region, missing transverse energy (MET)
  - ➡ Corrections applied to data and MC
- Drell-Yan sample Normalization correction
  - ➡ Mass dependent k-factor derived to match data normalization in DY control region

Before



After



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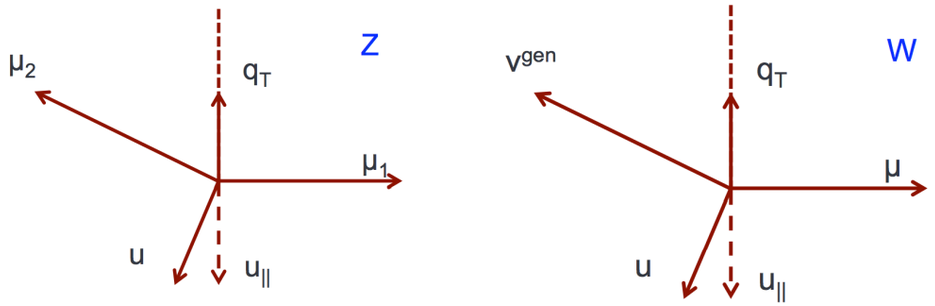
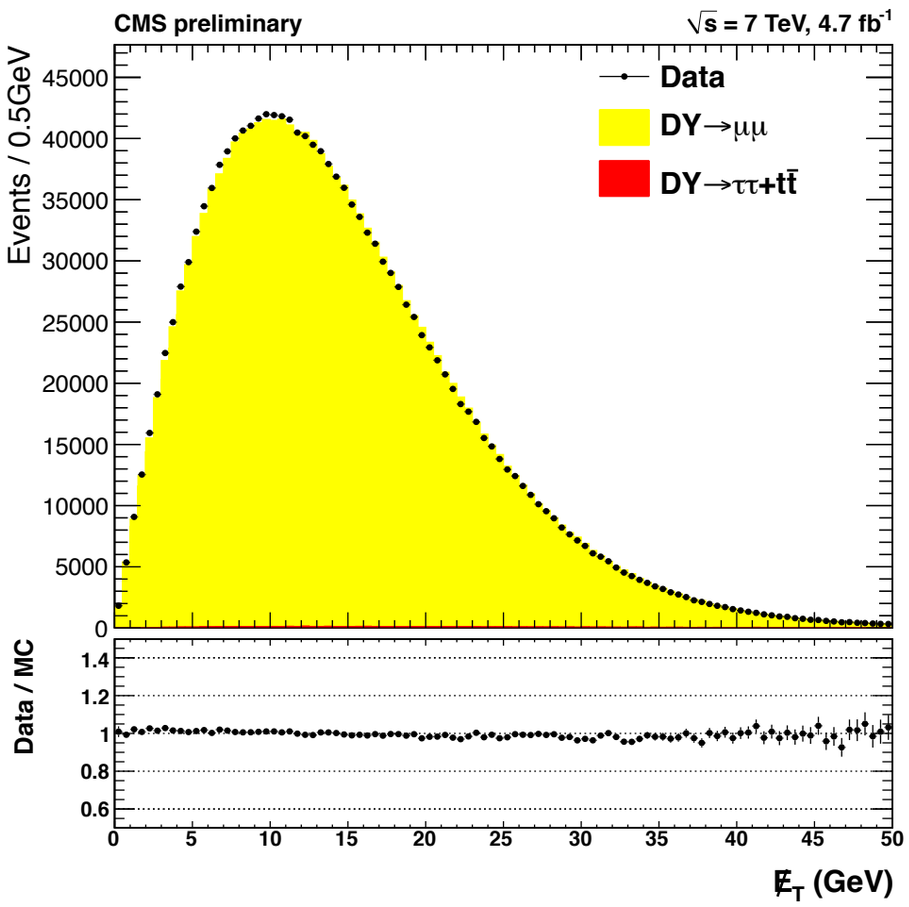
MET corrections

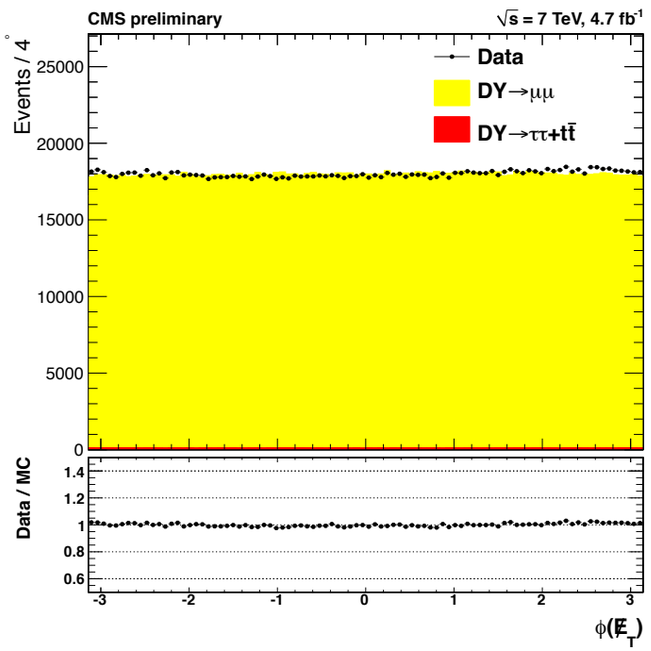
Define **Hadronic Recoil** to study MET taking advantage of well defined lepton

$$u = -MET - \sum p_T$$





- **Φ modulation correction** in data and MC
  - ➡ Caused by deviation b.t.w. interaction point and detector coordinates
  - ➡ To make **Φ (MET) flat**
  - ➡ Fit on $u_{||}$ and $u\perp$ with $A(n)\cos(\phi-\phi_0(n))$
- **Hadronic Recoil correction** in MC
  - ➡ To **match recoil and resolution to data**
  - ➡ Parallel recoil estimated for each of 4 |η| bins from a leading jet
  - ➡ Parallel & Perpendicular resolution in each n-vertices



Parameterization, for recoil w/ 1st order, for resolution w/ sqrt ftn

$$-\tilde{u_{||}}(q_T) = (c_0 + c_1 q_T)\left(1 + erf(\alpha q_T^{\beta})\right)$$

$$\sigma(q_T; n) = \sqrt{N_n^2 + S_n^2 q_T},$$

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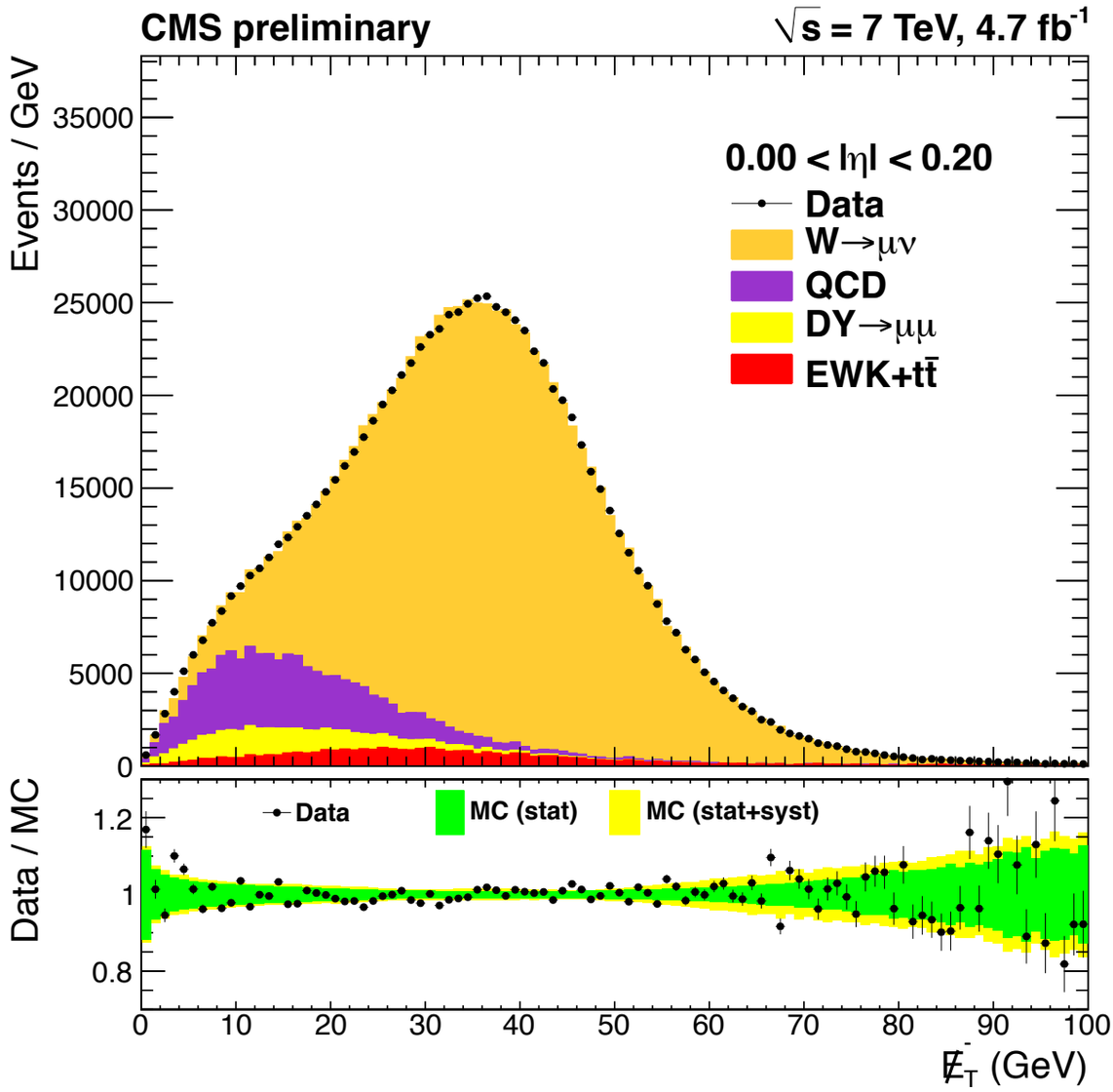
Signal Extraction

- **Fitting MET distributions**
  - ➡ Binned Maximum likelihood for 11 bins, |η| <2.4
  - ➡ MC templates used
  - ➡ Floating: Number of W and QCD events
  - ➡ Fixing:
    - Ratio of QCD+ and QCD- to control region (CR) value
    - DY and ttbar normalization (+corrections to CR)
    - W->TauNu normalized to W->MuNu
- True charge asymmetry applying the charge dependent efficiency ratio ($r^{W+/W-}$)
  - ➡ Muon efficiency from Tag-and-Probe technique with Z control sample

$$A^{true} = A^{raw} - \frac{1-(A^{raw})^2}{2}\left(r^{W+/W-} - 1\right)$$



Green: statistical uncertainty in the shape of MC MET
Yellow band: total uncertainty

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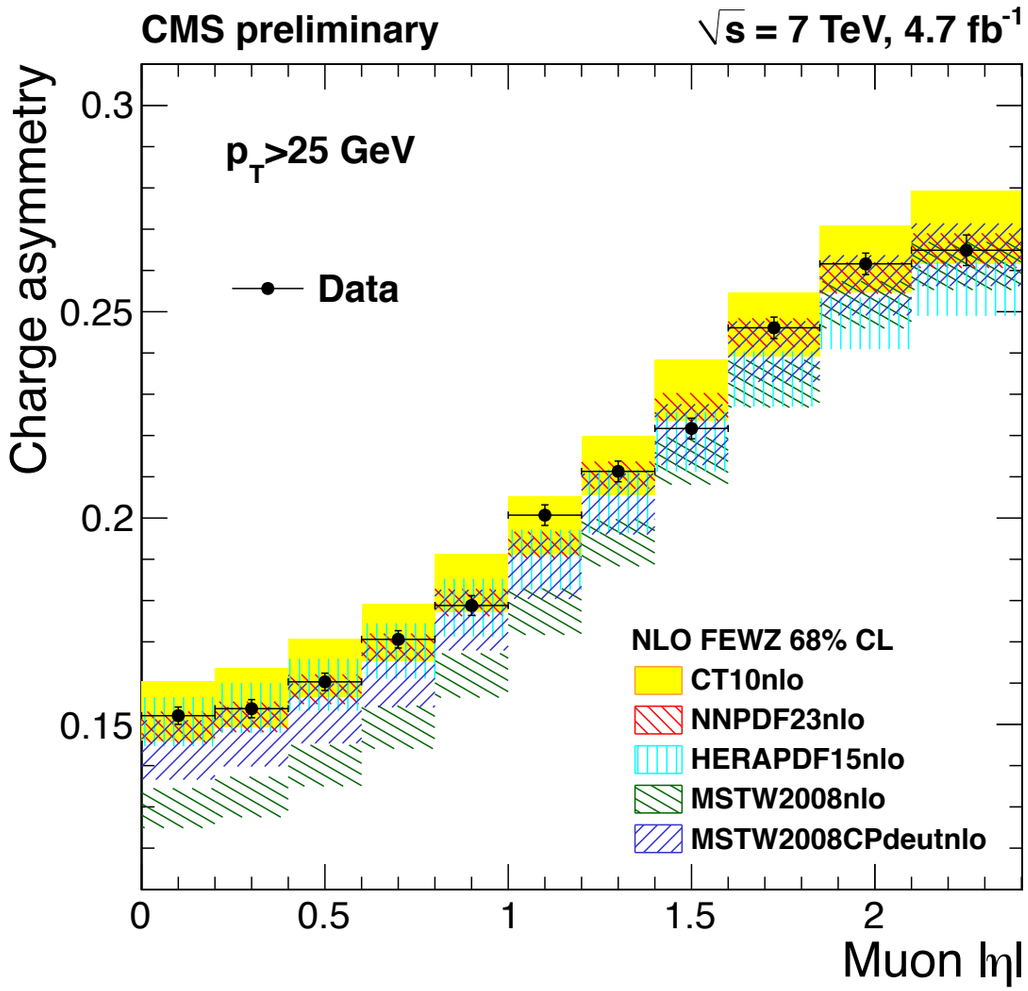
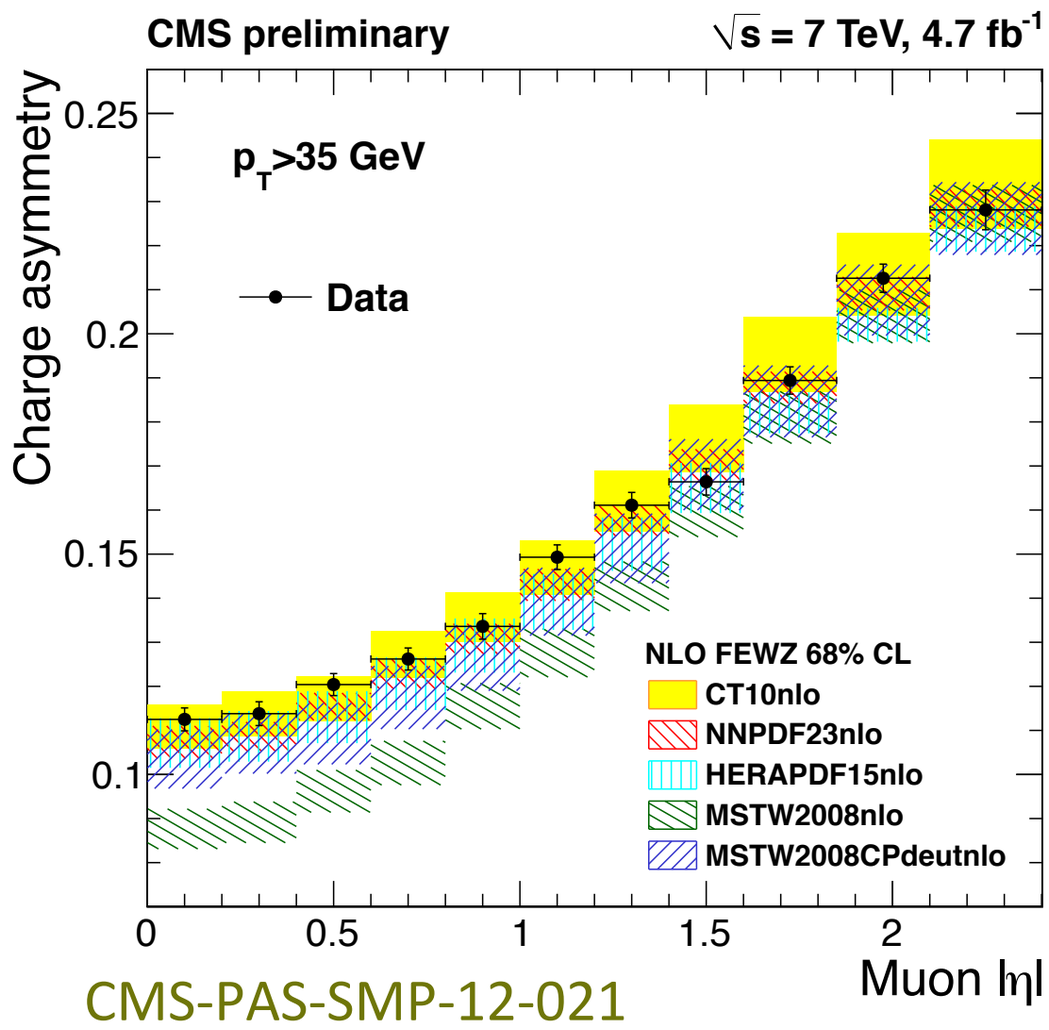
Muon Charge Asymmetry



- Measurement precision 0.2-0.4 % per bin
- Dominant systematics:
  - ➡ Efficiency ratio ϵ+/ϵ-
  - ➡ QCD Normalization
  - ➡ Muon Scale (for pT>35 analysis)

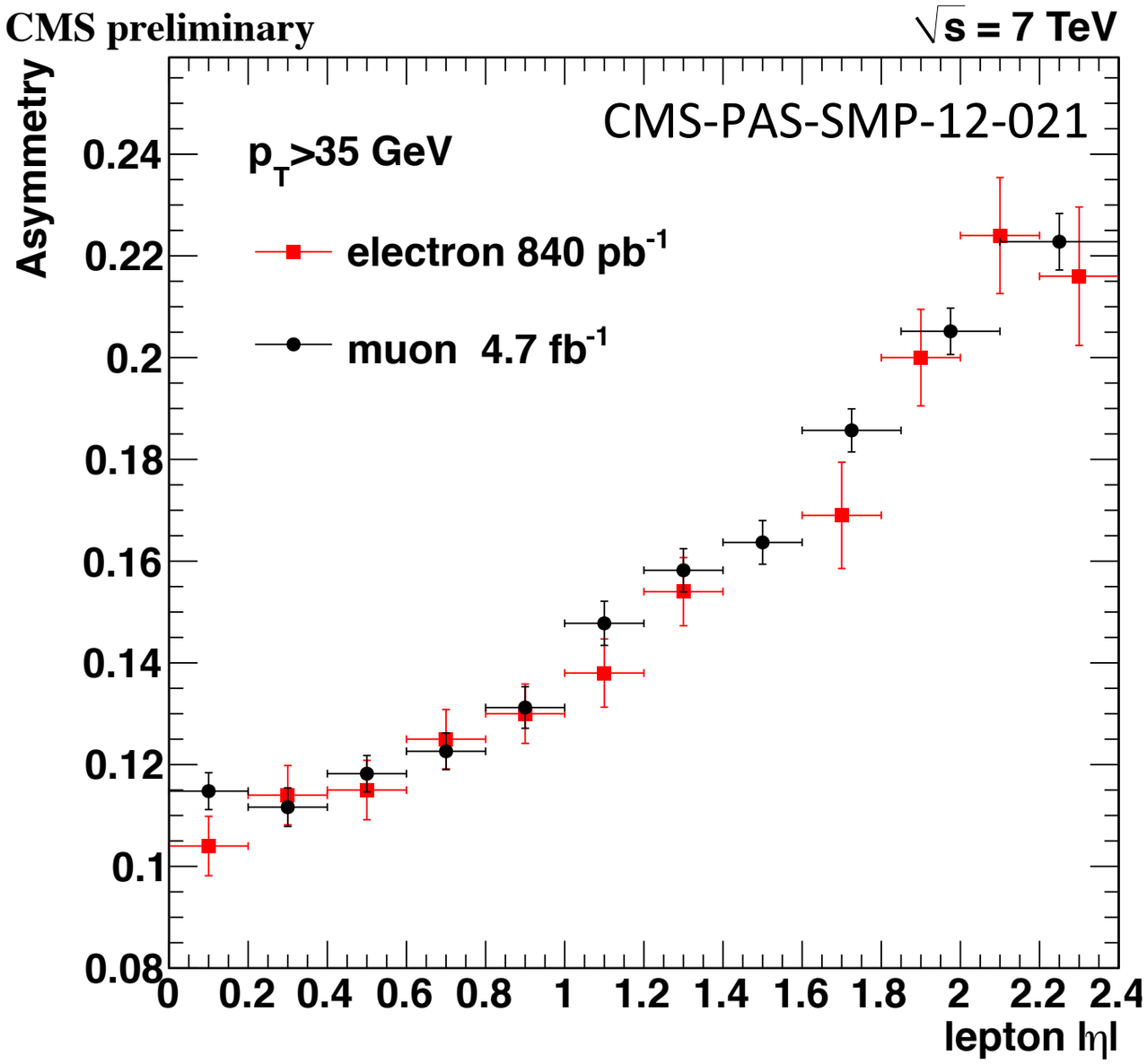


CMS-PAS-SMP-12-021

- Good agreement with CT10, NNPDF and HERA, worse with MSTW
- **New MSTW shows significant improvement**
  - ➡ Flexible input parameterisation
  - ➡ Deuteron correction
- **Data uncertainty** is much smaller than the PDF one

Comparison to Electron channel

- In good agreement
- Electron and current muon results are largely independent (common systematics are negligible)
  - ➡ Complementary input for global PDF analysis
- Can make significant contribution to global PDF analysis



CMS-PAS-SMP-12-021

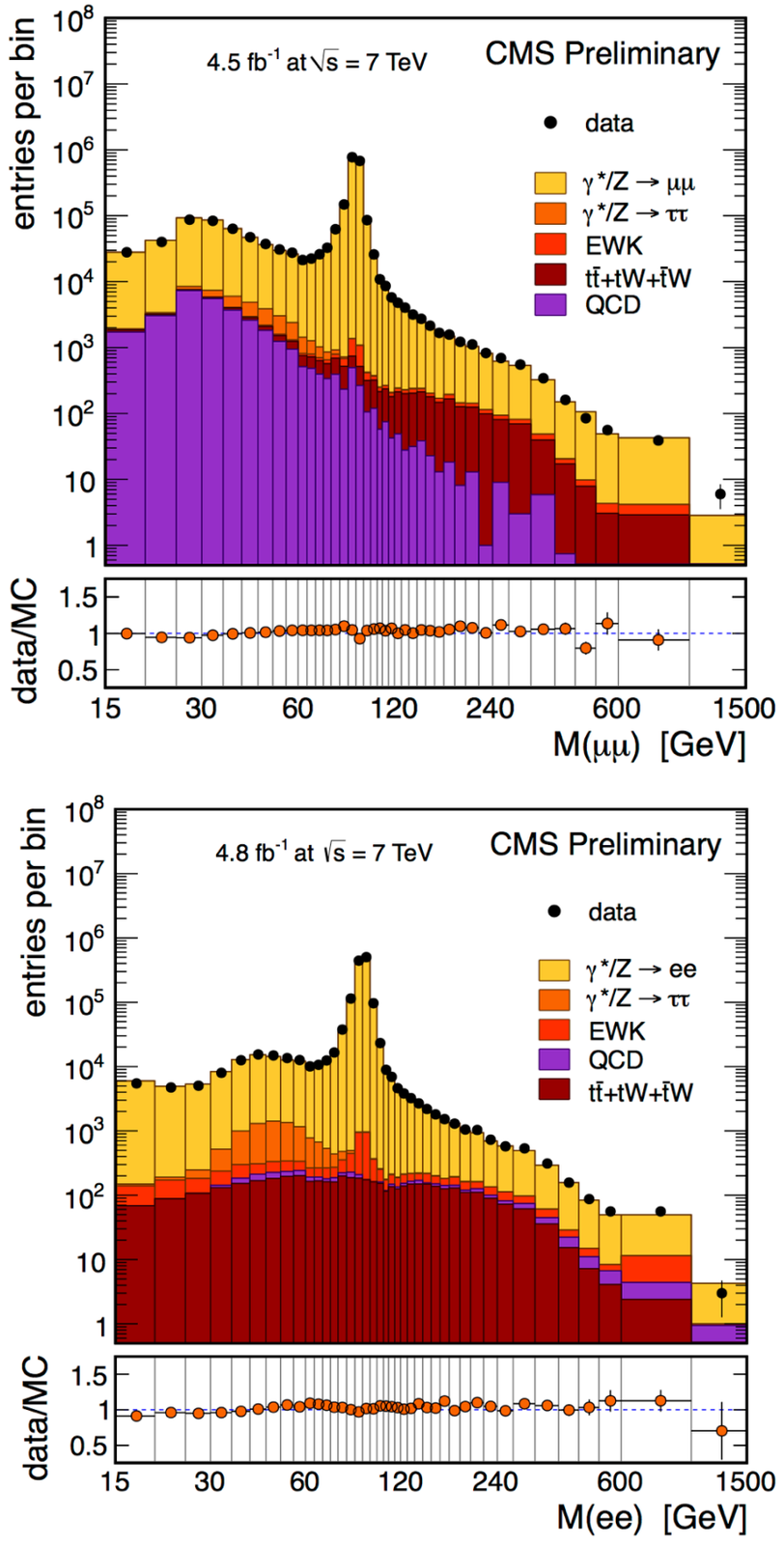
Measurements of Differential and Double Differential Drell-Yan Cross Sections in PP collisions at 7 TeV

$$\sigma = \frac{N}{A \cdot \epsilon \cdot \rho \cdot L}$$

Analysis

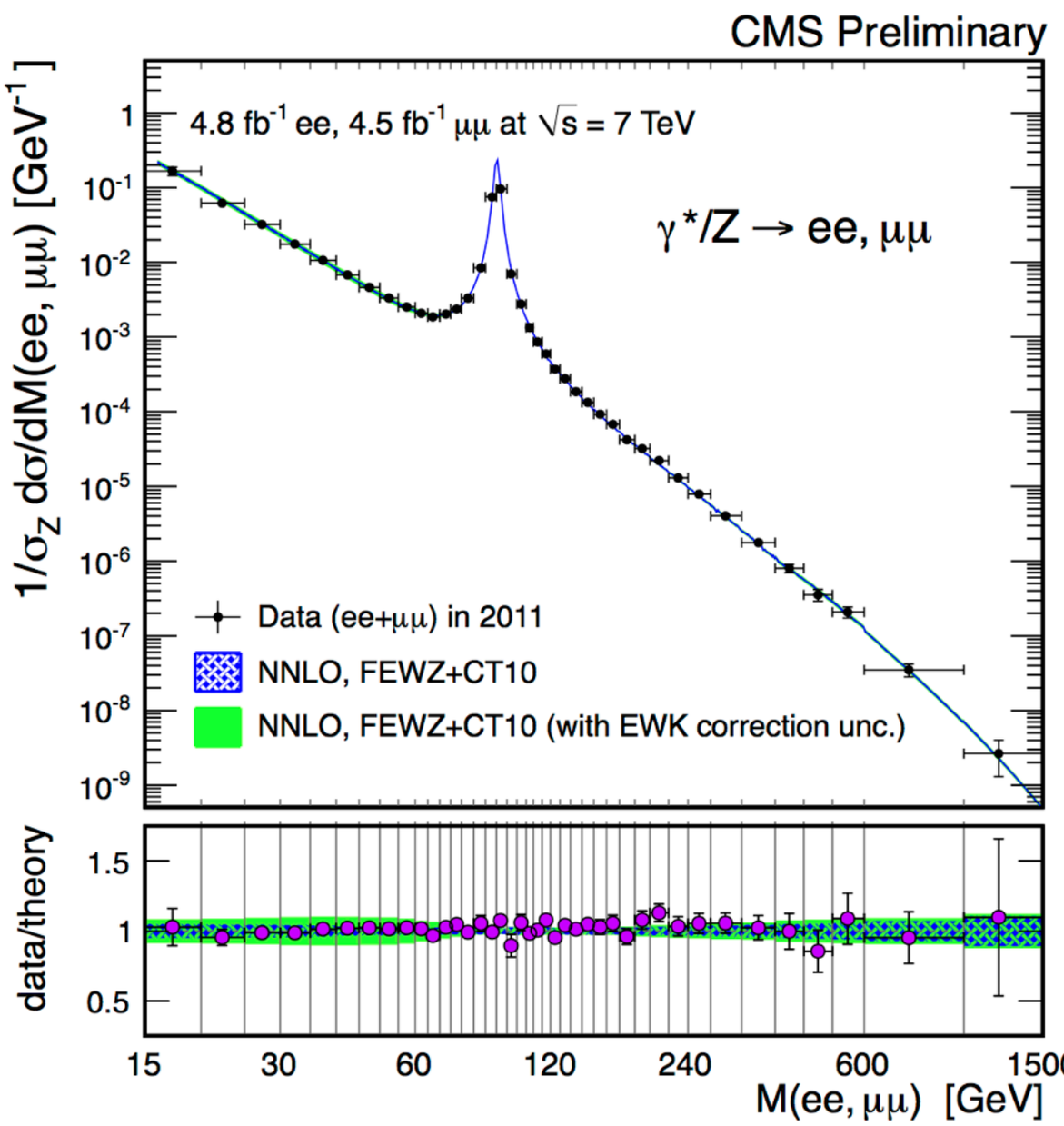
- Muon Channel
  - ➡ **Muon** in fiducial volume: pT >14, 9 GeV/c, |η| <2.4
  - ➡ Dominant backgrounds are estimated in data-driven ways, Top (e-μ), QCD (ABCD), others from MC
  - ➡ Muon momentum scale & resolution applied to data and MC
- Electron Channel
  - ➡ **Electron** in fiducial volume: pT > 20, 10 GeV/c, |η|<2.5
  - ➡ All Electron channel background from data-driven ways: QCD and W+Jets from fake rate, others from e-μ
  - ➡ Electron energy scale applied to Et and smearing to MC
- Efficiency correction using MC
  - ➡ Take into account the difference between data and MC using tag-and-probe method
- Correction for detector resolution and FSR effects:
  - ➡ Unfolding with matrix inversion technique

CMS-PAS-SMP-13-003



dσ/dM Results

- With full phase and within detector accep., at pre(post)-FSR
  - ➡ 40 mass bins (15-1500 GeV/c^2) taking advantage of the CMS detector
  - ➡ Test significant NNLO contribution below 40 GeV
- Combined (BLUE) DY invariant mass spectrum in full phase space
- Cross section normalized to the Z peak (60<Inv.M<120 GeV/c^2)
  - ➡ Cancel/reduce systematic uncertainties
- Statistical uncertainty: <2%, systematic uncertainty: <12% up to 200 GeV/c^2
- Dimuon and dielectron are compatible within uncertainties: χ^2/ndof = 1.1
- Good agreement with FEWZ NNLO expectation of CT10 PDF



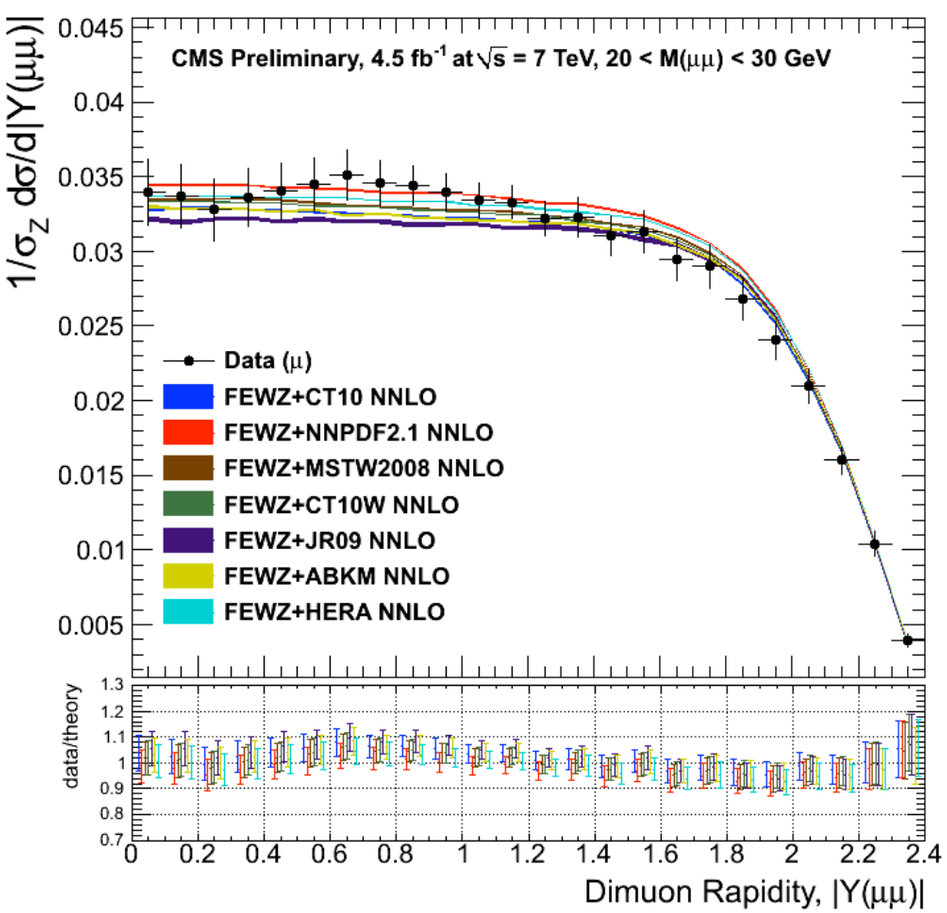
FEWZ calculation with stat+PDF (blue) , + EWK correction uncer. (green)

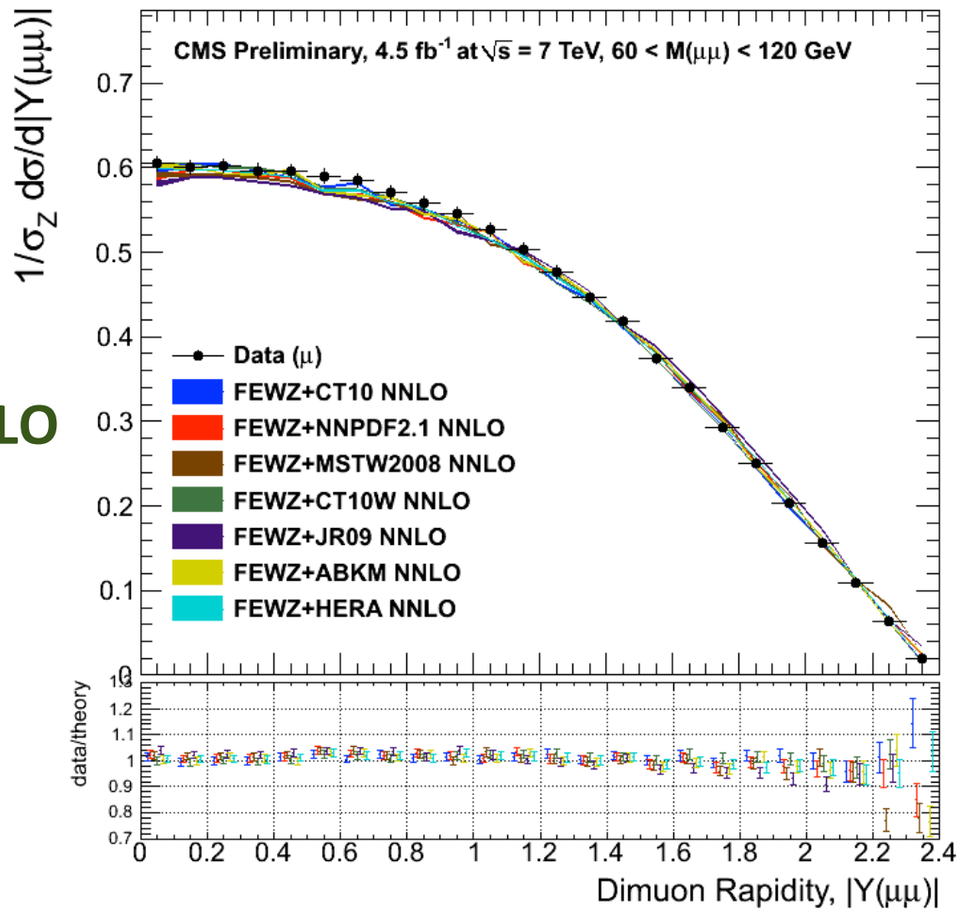
CMS-PAS-SMP-13-003

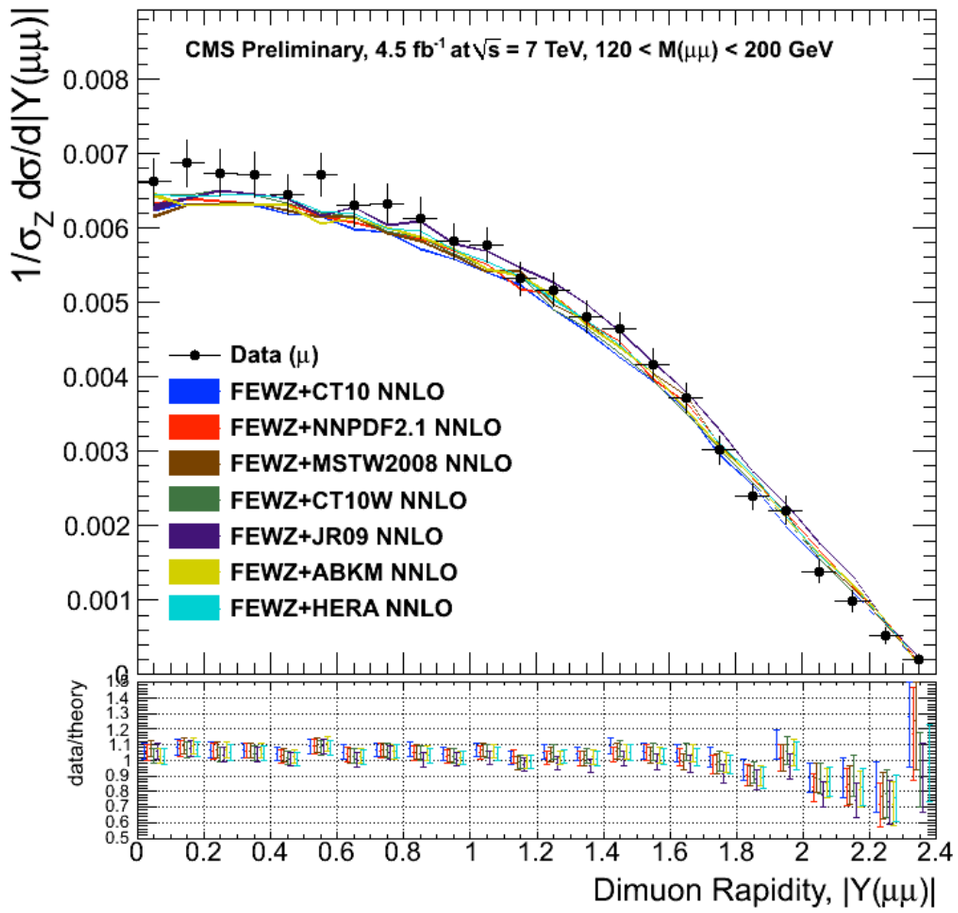
$d\sigma^2/dMdY$

- **Within the detector acceptance** to reduce the model dependence using **6×24=132 mass-rapidity** bins
- Interesting for PDF constraints, especially d quark and antiquark
- Good agreement with most of PDFs but deviations shown at low and high mass regions
  - ➡ Potential constraint to PDFs expected from the results

All of the existing NNLO PDFs







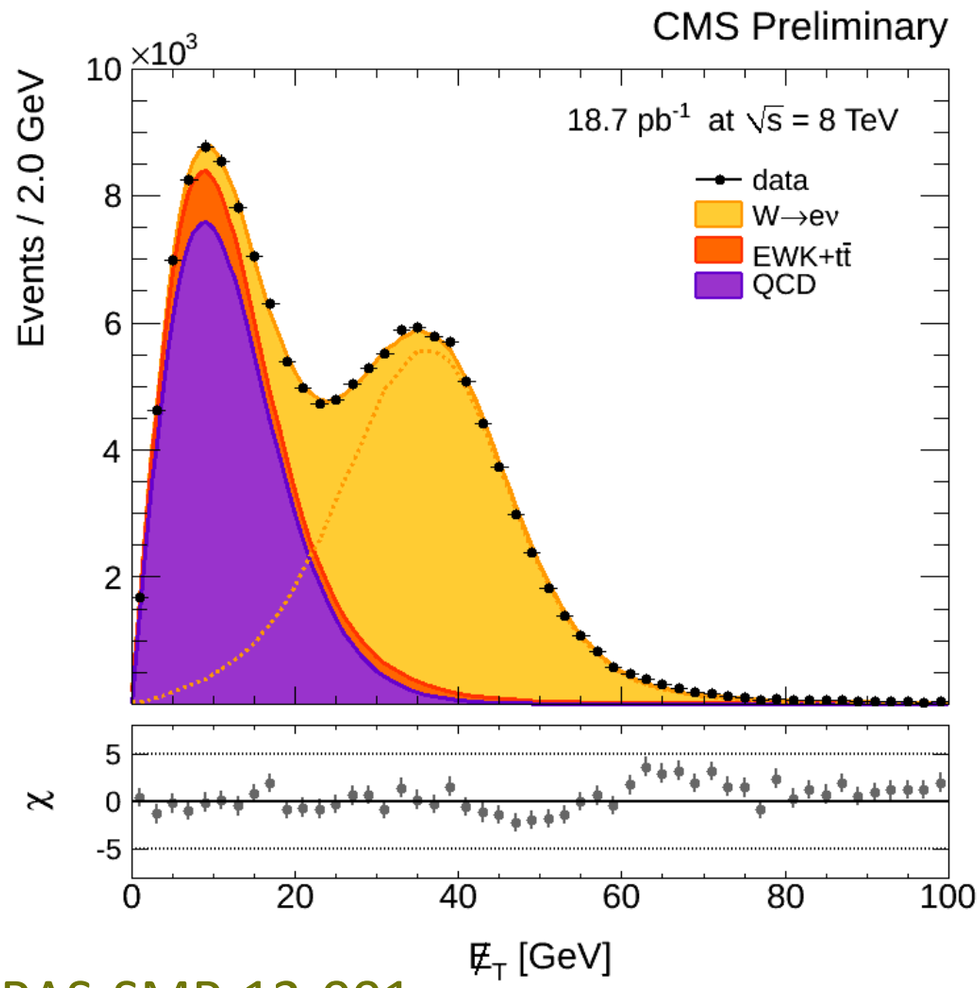
CMS-PAS-SMP-13-003

W and Z Cross Section at 8 TeV

Introduction

- Update to previous measurement with 36/pb at 7 TeV
- Using **special run with low pileup**(3) amount to 18.7±0.9/pb
  - ➡ Un-prescaled trigger with low pT thr.
  - ➡ Suitable MET resolution for data-driven QCD estimation
- Fiducial volume: pT > 25 GeV, |η|<2.1(mu), 2.5(e)
- Using Tag-and-Probe in Z sample for efficiency
- Electron energy, Muon momentum scale corrections
- Recoil method to correct for the MET
- Z→μμ(ee) boson yield extraction:
  - ➡ 4 categories from each muon (electron) ID
  - ➡ Add events from categories
- W boson extraction: template fitting
  - ➡ QCD template from QCD dominant region
- Acceptance: POWHEG NLO MC

$$\sigma = \frac{N}{A \cdot \epsilon \cdot \rho \cdot L}$$



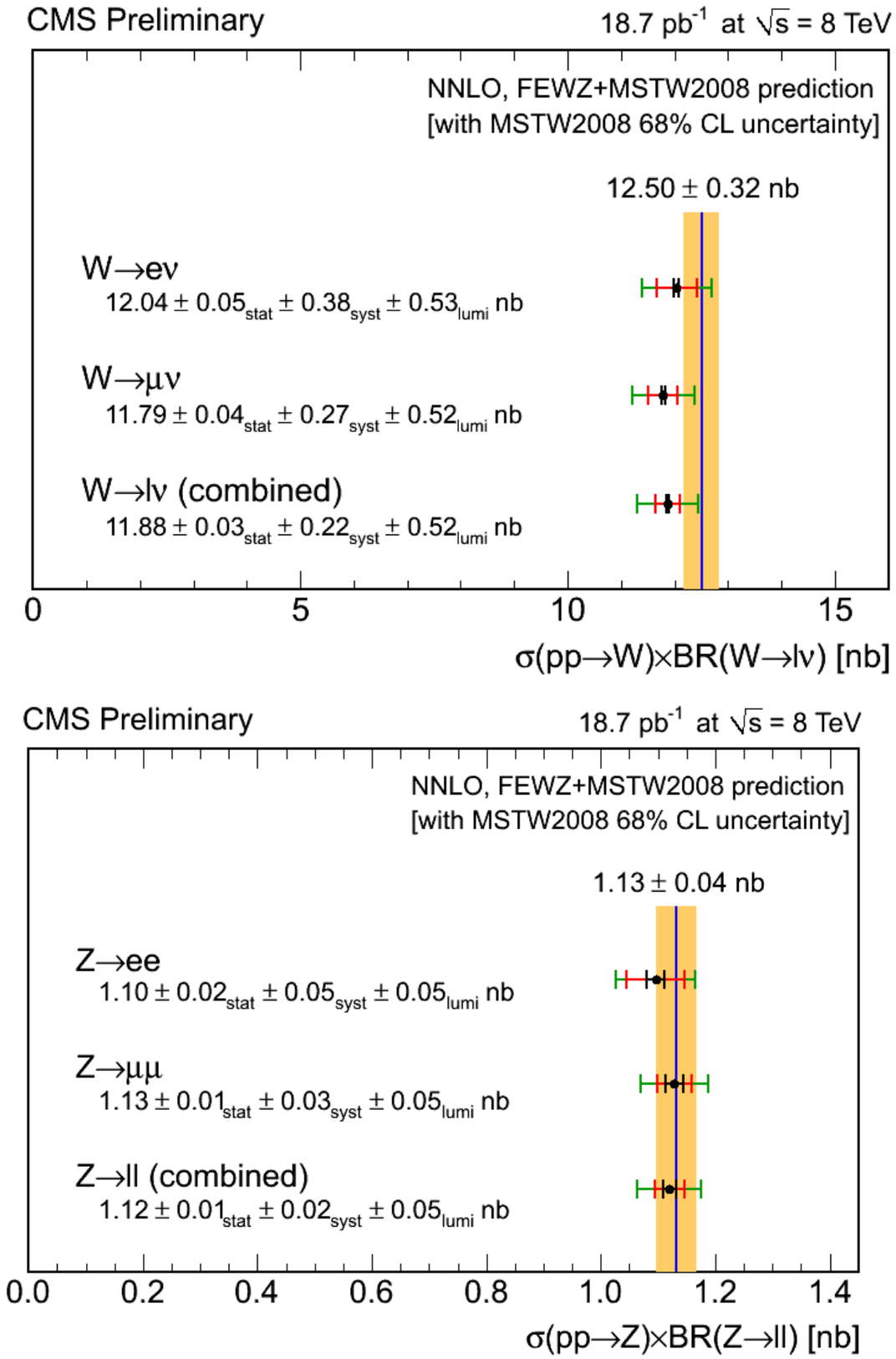
CMS-PAS-SMP-12-001

Results

- Theory uncertainty interpreted as a 68% CL
- Z cross section is limited to a dilepton mass range of 60 to 120 GeV/c^2
- Measurements are **consistent between the electron and muon channels**, and in agreement with NNLO cross section calculations
- Inclusive electron, muon, and combined cross section
- Theoretical prediction w/ FEWZ MSTW NNLO PDF

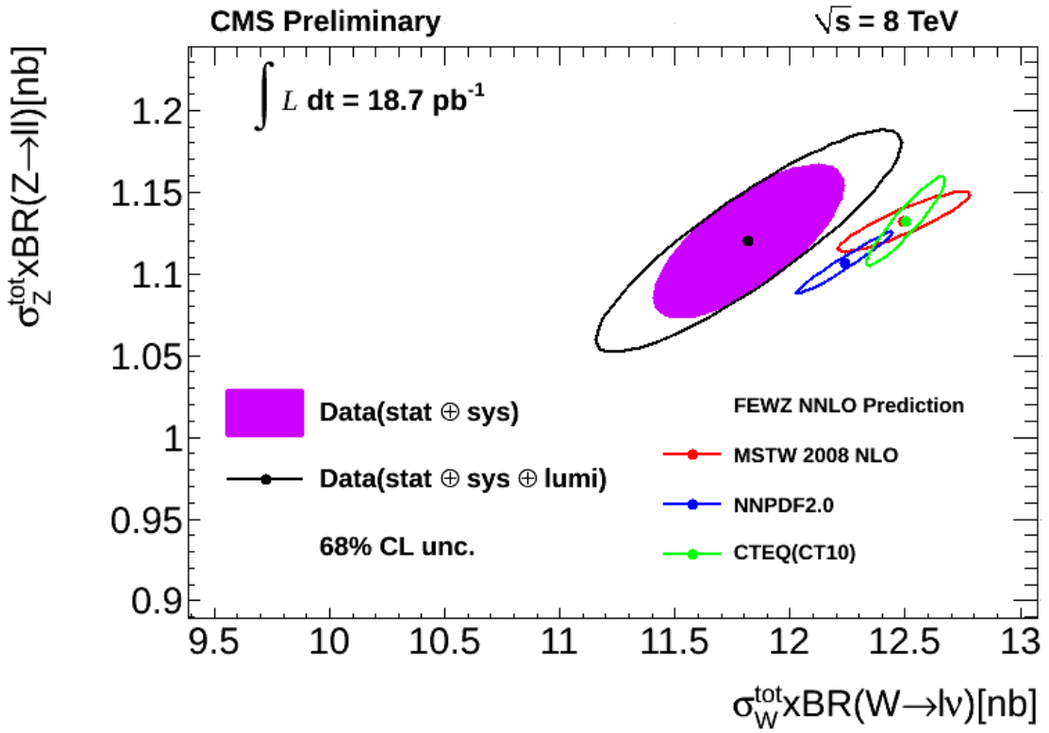
Stat. (back) +Syst. (red) + lum (green)

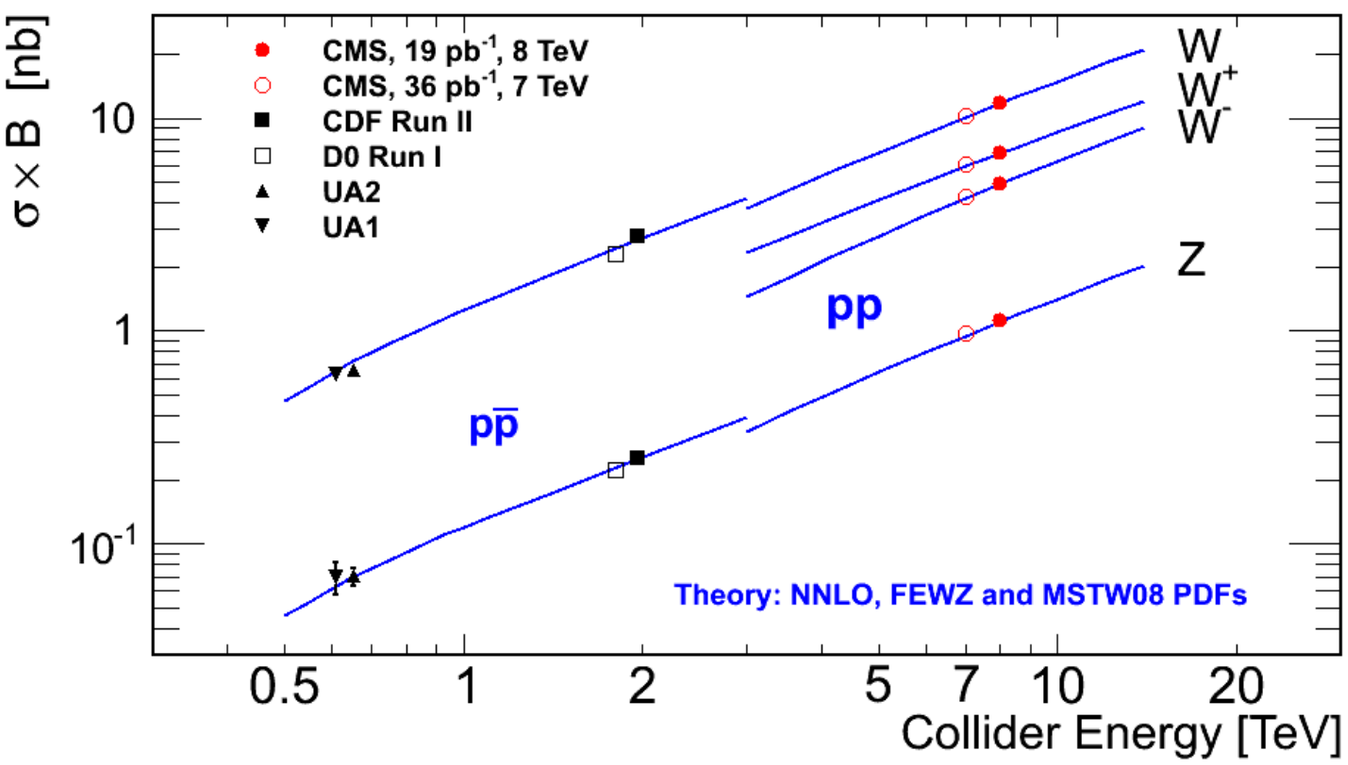
CMS-PAS-SMP-13-003

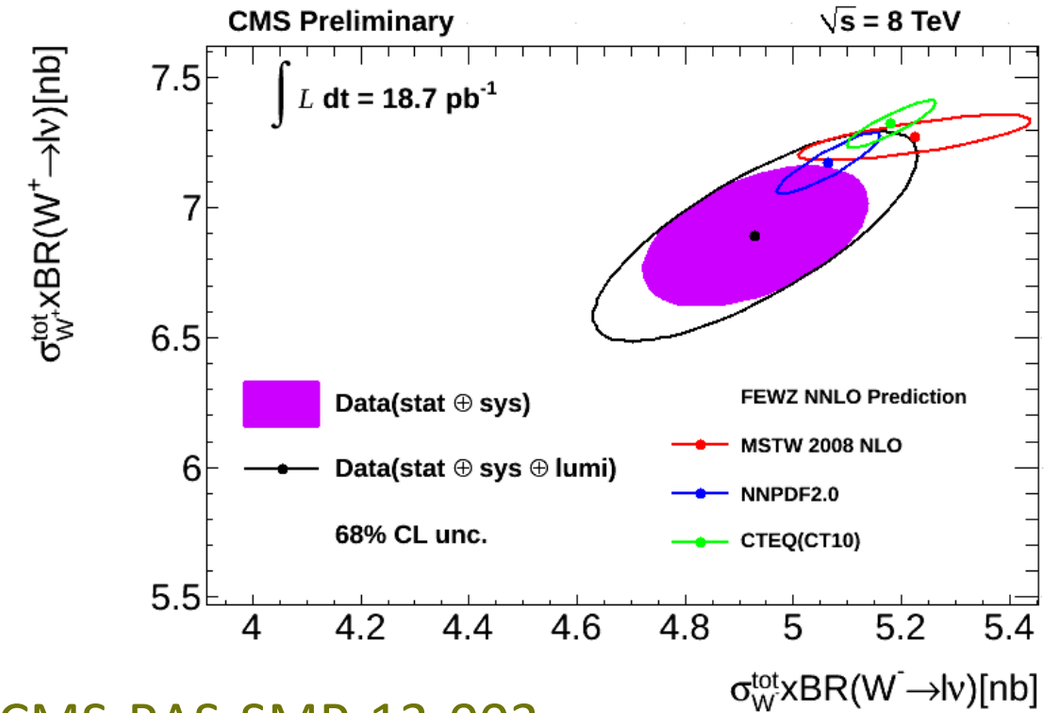


Results (cont'd)

- W vs. Z x-sec.: ellipses illustrate the 68% coverage for total uncertainties
- W^+ vs. W^- x-sec in agreement to theory within 1σ
- Cross section comparison to previous results from CMS and other experiment
  - ➡ Good agreement with theory predictions at NNLO for both at 7 and 8 TeV





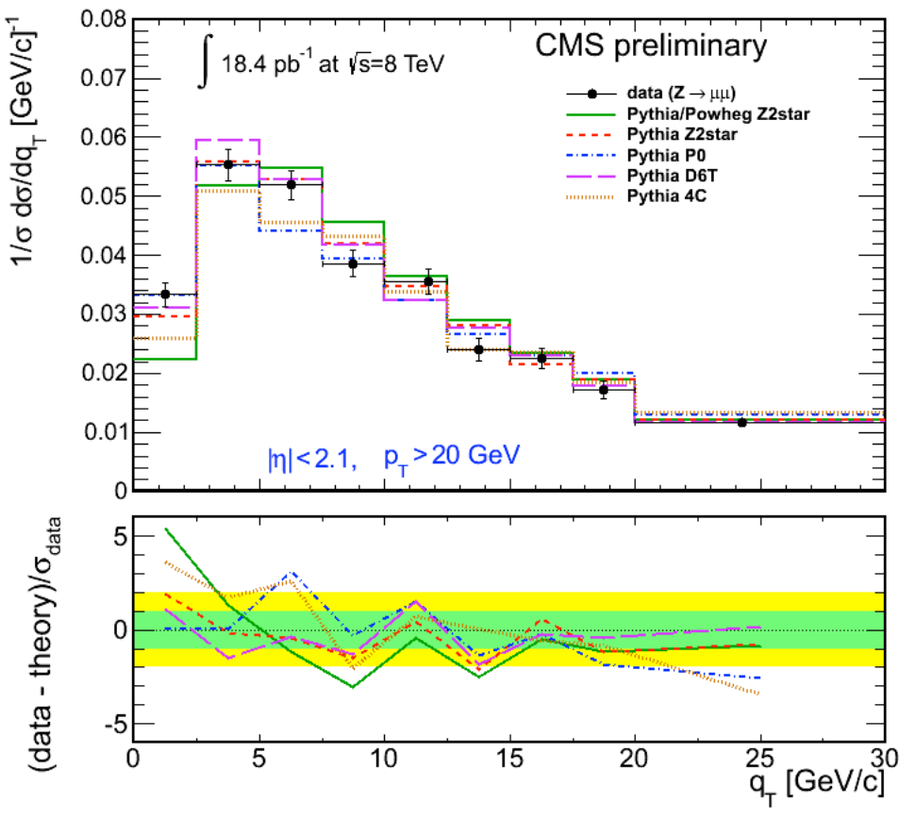


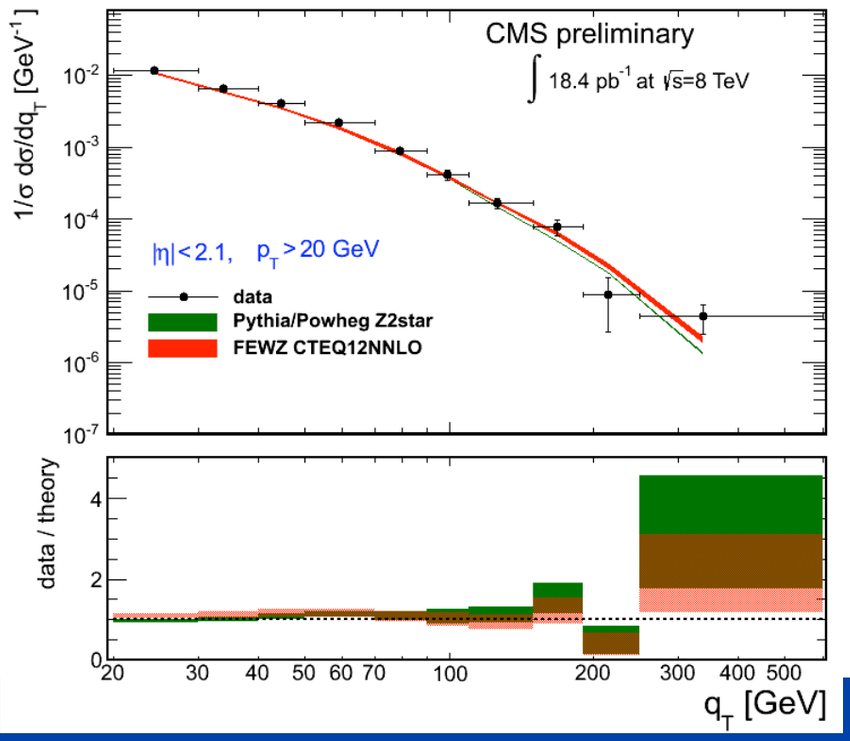
CMS-PAS-SMP-13-003

Measurement of the Transverse Momentum distribution of Z bosons decaying to dimuons in pp collisions at sqrt(s) = 8 TeV

Z pT differential cross-section

- Transverse momentum qT of dimuon system has important role
  - ➡ **Non perturbative** prediction of soft gluon emission in **low qT**
  - ➡ **Perturbative QCD prediction** for hard gluon radiation in the initial state in the **high qT range**
- Low PU data sample of pp collisions at 8 TeV in 2012, similar PU condition to 2010 analysis
- Similar methods used as DY dσ/dM
  - ➡ e-μ method, fake muon ratio from QCD
- Resolution & FSR Unfolding with inverse matrix technique
- Several **Pythia tunes tested** for the underlying events in the low qT





CMS-PAS-SMP-12-025

W & Z production Summary

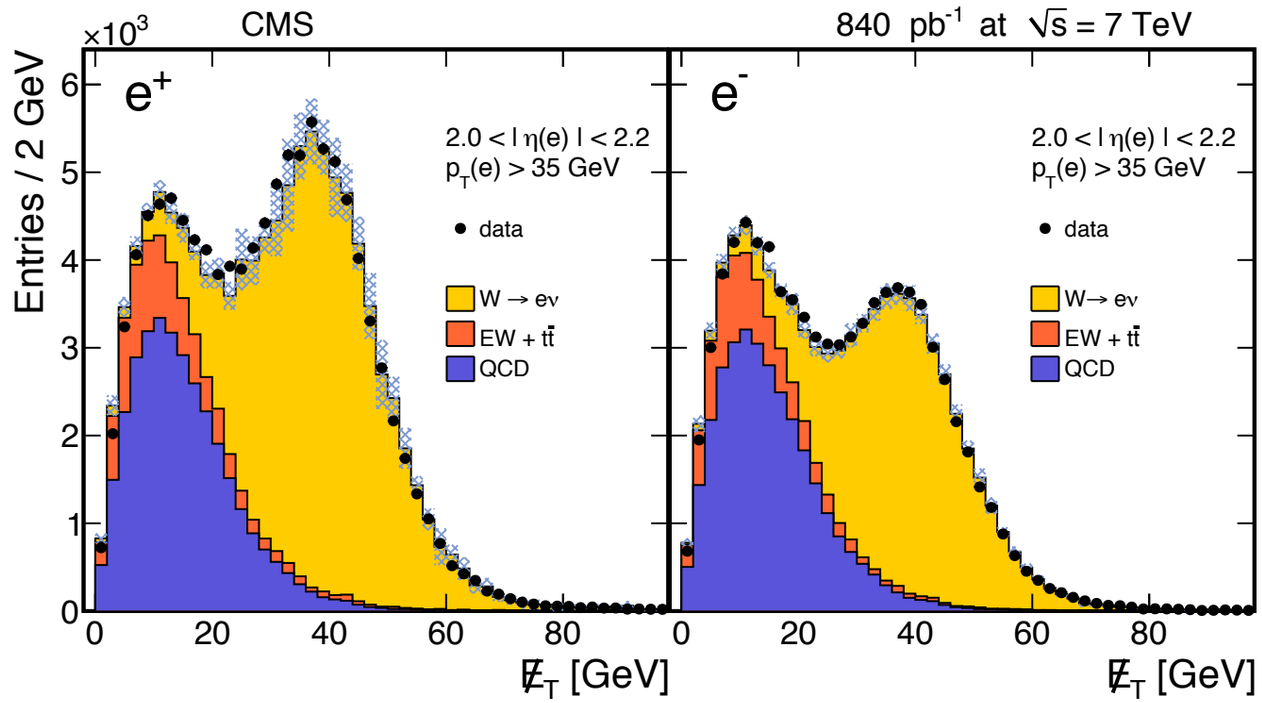
- Presented
  - ➡ **The first release of W Muon Charge Asymmetry** at 7 TeV with **4.7/fb full data** 2011 with high precision results 0.2-0.4 % per bin
  - ➡ W Electron Charge Asymmetry at 7TeV with 840/pb partial data 2011
  - ➡ DY mass, mass and rapidity differential cross section at 7 TeV with 4.5(Mu), 4.8(Ele)/fb full 2011 data
  - ➡ W/Z cross section at 8 TeV with 19/pb
  - ➡ DY (muon) pT differential cross section at 8 TeV with 19/pb
- With high precision, in good agreement to theory prediction within error.
  - ➡ high precision results contribute to theory calculations
- We are planning to get better results at 8 TeV data with more data 20/fb taken in 2012, cf. 5/fb in 2011

Back-UP Slides

Measurement of the Electron Charge Asymmetry in Inclusive W Production in pp Collision at sqrt(s) = 7 TeV

Analysis

- 840/pb partially collected in 2011
- Electron pT >35 GeV/c, 11 bin of|η| < 2.4
- Electron with same charges with three different algorithm to suppress systematic from mi-charge measurement

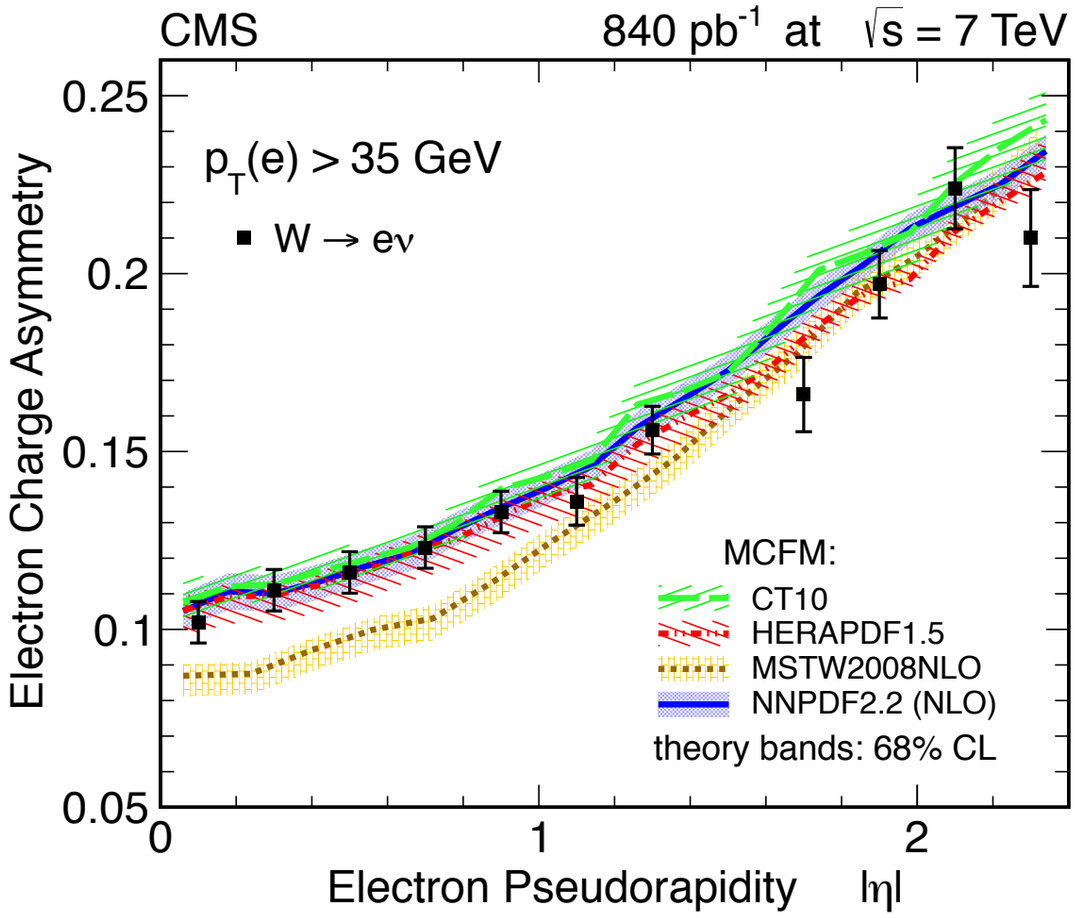


- corrections on Hadronic Recoil, energy scale and resolution
- Signal Extraction by Ext. binned Max. Likelihood fit with templates floating N(QCD) and N(Sig +EWK)
- QCD template from Anti-Selection of Data
- Charge misid(w) measured in data from same-sign/opposite-sign Z boson yield
- Relative efficiency from Tag-and-Probe using Z sample

$$\mathcal{A}_R = \frac{1}{1-2\omega}\frac{\mathcal{A}_M(R+1)-(R-1)}{(R+1)-\mathcal{A}_M(R-1)} \simeq \frac{1}{1-2\omega}\left(\mathcal{A}_M - \frac{(R-1)\left(1-\mathcal{A}_M^2\right)}{2}\right)$$

Results

- 11 bins result with factor 2 precision than previous 6 bins, error with stat.+syst
- PDF uncertainty using PDF reweighting technique corresponding 68% CL
- 4 PDFs interfaced to MCFM (NLO)
  - ➡ data are in good agreement with HeraPDF, CTEQ, and NNPDF while MSTW is systematically lower
- Very precise (4-5%) theory predictions
- Systematic errors from Efficiency ratio, Signal MET shape (CTEQ6.6), recoil corrections
- PU insensitive for using of data-driven MET templates



10^{-3}	Signal Yield	Energy Scale and Res.	Charge MisId.	Efficiency Ratio
$0.0 < \|\eta\| < 0.2$	1.8	0.6	0.0	4.5
$0.2 < \|\eta\| < 0.4$	2.5	0.6	0.0	4.4
$0.4 < \|\eta\| < 0.6$	2.7	0.3	0.0	4.4
$0.6 < \|\eta\| < 0.8$	2.5	0.3	0.0	4.4
$0.8 < \|\eta\| < 1.0$	1.9	0.6	0.1	4.4
$1.0 < \|\eta\| < 1.2$	2.4	1.0	0.1	4.9
$1.2 < \|\eta\| < 1.4$	2.6	0.8	0.1	5.4
$1.6 < \|\eta\| < 1.8$	3.1	0.8	0.1	9.2
$1.8 < \|\eta\| < 2.0$	2.0	1.6	0.2	8.7
$2.0 < \|\eta\| < 2.2$	2.0	2.6	0.3	10.0
$2.2 < \|\eta\| < 2.4$	2.9	2.4	0.3	12.5

Muon Charge Asymm. Syst. Err

- Units in Percent

$\|\eta\|$ bin	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	1.0-1.2	1.2-1.4	1.4-1.6	1.6-1.85	1.85-2.1	2.1-2.4
$p_T > 25$ GeV											
Stat. err.	0.096	0.098	0.094	0.093	0.098	0.099	0.099	0.099	0.093	0.094	0.106
Eff.	0.111	0.133	0.121	0.122	0.170	0.175	0.170	0.168	0.165	0.175	0.268
QCD +/-	0.120	0.113	0.110	0.105	0.102	0.103	0.097	0.104	0.108	0.094	0.183
QCD shape	0.070	0.065	0.065	0.067	0.068	0.069	0.078	0.082	0.092	0.083	0.087
Muon scale	0.045	0.050	0.050	0.049	0.051	0.054	0.054	0.058	0.054	0.054	0.055
PDF	0.028	0.026	0.023	0.025	0.018	0.020	0.027	0.031	0.042	0.050	0.069
Drell-Yan bkg.	0.002	0.001	0.002	0.003	0.000	0.007	0.001	0.013	0.019	0.038	0.046
$\not{E}_T$ Φ modul.	0.011	0.009	0.033	0.012	0.029	0.034	0.044	0.045	0.055	0.049	0.038
Recoil	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003
PU	0.017	0.013	0.011	0.005	0.014	0.025	0.022	0.031	0.019	0.028	0.000
Luminosity	0.002	0.003	0.004	0.004	0.006	0.009	0.012	0.017	0.024	0.033	0.040
$t\bar{t}$ bkg.	0.012	0.013	0.012	0.012	0.011	0.011	0.010	0.009	0.008	0.007	0.005
W $\rightarrow \tau\nu$ bkg.	0.026	0.026	0.026	0.026	0.026	0.025	0.025	0.025	0.025	0.025	0.024
W q_T	0.003	0.004	0.004	0.005	0.008	0.011	0.008	0.009	0.006	0.003	0.000
Tot. sys.	0.189	0.197	0.190	0.186	0.221	0.229	0.227	0.233	0.239	0.241	0.355
Tot. err.	0.212	0.220	0.212	0.208	0.242	0.249	0.248	0.253	0.256	0.259	0.371
$p_T > 35$ GeV											
Stat.err.	0.116	0.119	0.114	0.114	0.124	0.121	0.123	0.123	0.118	0.123	0.141
Eff.	0.120	0.138	0.116	0.107	0.159	0.164	0.171	0.176	0.186	0.194	0.325
QCD +/-	0.151	0.138	0.135	0.128	0.133	0.118	0.116	0.122	0.137	0.120	0.168
QCD shape	0.030	0.025	0.017	0.023	0.024	0.022	0.018	0.017	0.031	0.031	0.037
Muon scale	0.122	0.135	0.134	0.141	0.146	0.154	0.162	0.170	0.161	0.172	0.189
PDF	0.008	0.008	0.007	0.011	0.012	0.010	0.017	0.022	0.031	0.040	0.058
Drell-Yan bkg.	0.010	0.009	0.009	0.003	0.006	0.010	0.008	0.009	0.009	0.020	0.040
$\not{E}_T$ Φ modul.	0.002	0.009	0.010	0.003	0.008	0.028	0.037	0.035	0.022	0.022	0.001
Recoil	0.005	0.006	0.005	0.004	0.005	0.004	0.005	0.004	0.004	0.006	0.008
PU	0.015	0.003	0.005	0.018	0.019	0.002	0.007	0.003	0.013	0.014	0.032
Luminosity	0.001	0.002	0.000	0.000	0.000	0.001	0.004	0.010	0.016	0.025	0.039
$t\bar{t}$ bkg.	0.011	0.013	0.012	0.011	0.011	0.010	0.010	0.009	0.007	0.006	0.005
W $\rightarrow \tau\nu$ bkg.	0.013	0.012	0.013	0.012	0.012	0.012	0.011	0.012	0.011	0.011	0.011
W q_T	0.004	0.002	0.004	0.004	0.007	0.005	0.006	0.009	0.009	0.001	0.014
Tot. sys.	0.232	0.240	0.225	0.221	0.257	0.258	0.267	0.277	0.287	0.294	0.423
Tot. err.	0.260	0.268	0.252	0.248	0.285	0.285	0.294	0.303	0.311	0.318	0.446

DY 1/σ dσ/dM Syst. Err

unit (%)	Low mass		Peak region		High mass	
Luminosity	2.2					
	mu	ele	mu	ele	mu	ele
Energy Scale corr.	--	<2.5	--	<19	--	3-8
Backgrounds	<4	<7	0.1	0.1	15	33
Unfolding	<0.5	2-3	3	<13	0.5-3	3-6
Efficiency scale	2	2	<1.5	<1	2	1.5
FSR correction	0.5	<3	1.5	2-6	0.5	10-15
Modeling(MC NNLO rew.)	10		<0.5		2-3	
PDF	2.5-3	2-3	2-2.5	2	0.5-1.5	0.5-3

DY 1/σ $d^2\sigma/dMdY$ Systematic Err

- Backgrounds
  - ➡ 4-5% off the Z-peak, increasing up to 15% in the last mass bin
- Momentum scale correction and unfolding
  - ➡ within 1%
- Efficiency scale factors
  - ➡ 1.5-3%, up to 10% in the first mass bin
- FSR correction
  - ➡ within 1%, 2-6% in the FSR region growing at high rapidity

W/Z cross section Uncertainties

- Theory Uncertainty
  - ➡ determined as function of W boson pT, following the strength of the strong coupling: Non-perturbative, Resummed, Perturbative
- Affect of higher order perturbative terms
  - ➡ Calculate FEWZ (NNLO) Acceptance
- Affect of NNLO+higher order resummed terms
  - ➡ Compare Acc. difference for Resbos vs. Powheg
  - ➡ Resbos is an NNLO+NNNLL calculation
- PDF uncertainties comparing NNPDF/MSTW/CTEQ: dominant theoretical uncertainty
- FSR uncertainties+O(α) EWK uncertainties
  - ➡ Compare Horace w/ and w/o O(α) EWK corrections
  - ➡ Compare Horace FSR w/ Pythia FSR

Source	W^+	W^-	W	W^+/W^-	Z	W/Z
Lepton reconstruction & identification	2.8%	2.5%	2.5%	3.8%	2.8%	3.8%
Momentum scale & resolution	0.4%	0.7%	0.5%	0.3%	-	0.5%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale & resolution	0.8%	0.7%	0.8%	0.3%	-	0.8%
Background subtraction / modeling	0.2%	0.3%	0.3%	0.1%	0.4%	0.5%
Total experimental	3.0%	2.7%	2.7%	3.8%	2.8%	3.9%
Theoretical uncertainty	2.1%	2.6%	2.7%	1.5%	2.6%	2.0%
Lumi	4.4%	4.4%	4.4%	-	4.4%	-
Total	5.7%	5.8%	5.8%	4.1%	5.8%	4.4%

Source	W^+	W^-	W	W^+/W^-	Z	W/Z
Lepton reconstruction & identification	1.0%	0.9%	1.0%	1.2%	1.1%	1.5%
Momentum scale & resolution	0.3%	0.3%	0.3%	0.1%	-	0.3%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale & resolution	0.5%	0.5%	0.5%	0.1%	-	0.5%
Background subtraction / modeling	0.2%	0.1%	0.1%	0.2%	0.4%	0.4%
Total experimental	1.2%	1.1%	1.2%	1.2%	1.2%	1.7%
Theoretical uncertainty	2.0%	2.5%	2.2%	1.4%	1.9%	2.5%
Lumi	4.4%	4.4%	4.4%	-	4.4%	-
Total	5.0%	5.2%	5.1%	1.8%	4.9%	3.0%

DY pT differential xsection Error