W and Z studies at CMS

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on behalf of the CMS collaboration

XVII Rencontres de Physique de La Vallée d'Aoste

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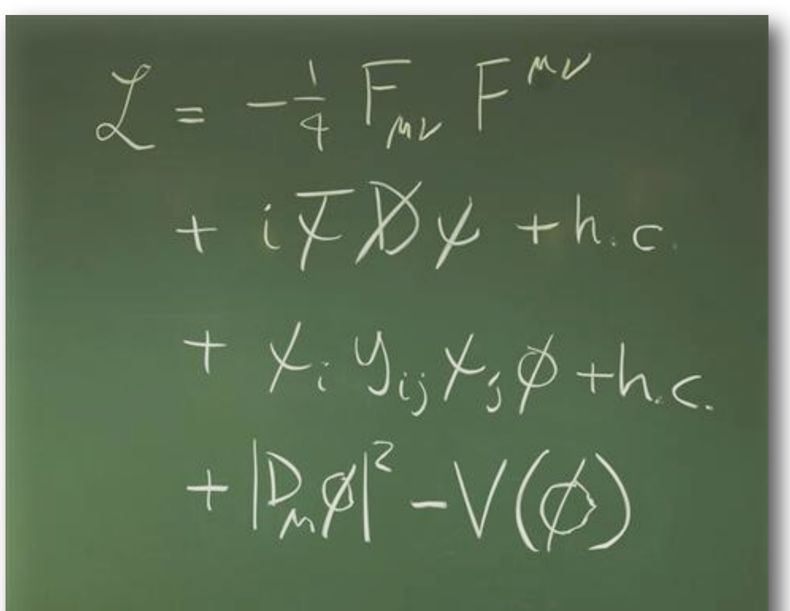
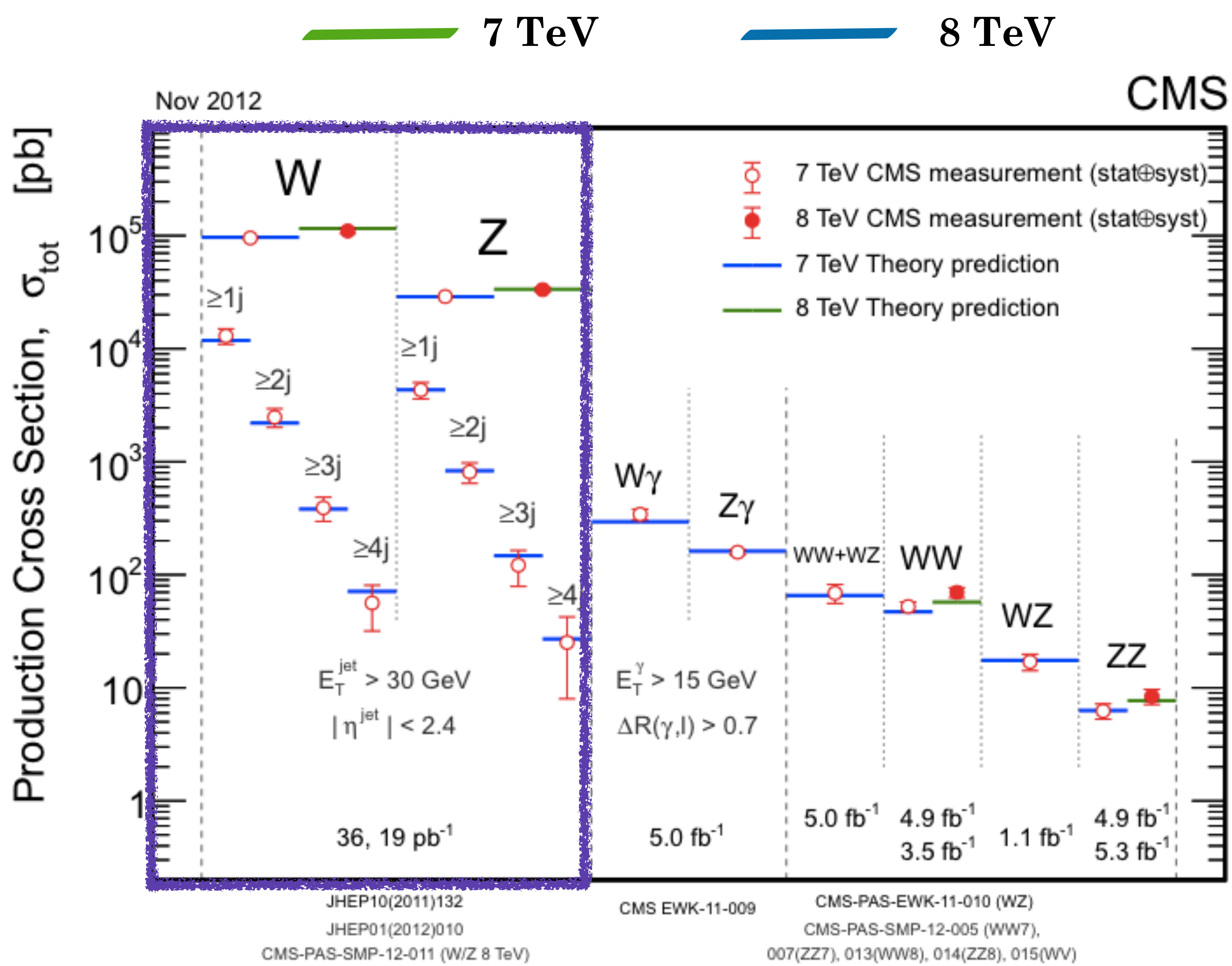
Introduction

- W and Z are precision tools for the SM physics
- Test perturbative QCD calculations and constrain PDFs
- Main background for SM and beyond processes

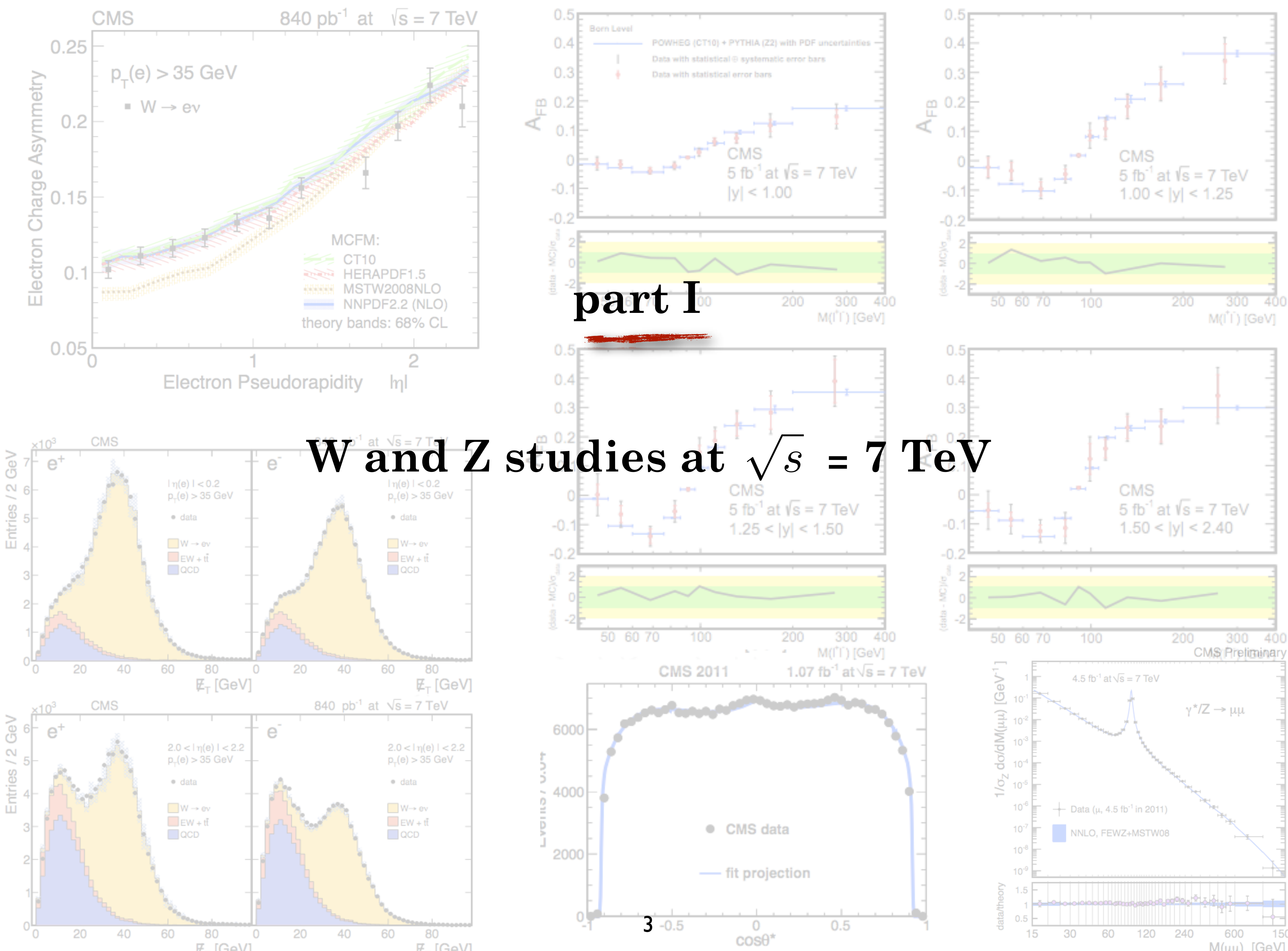




- Main background in Higgs studies
- Tool for physics calibration studies

part I

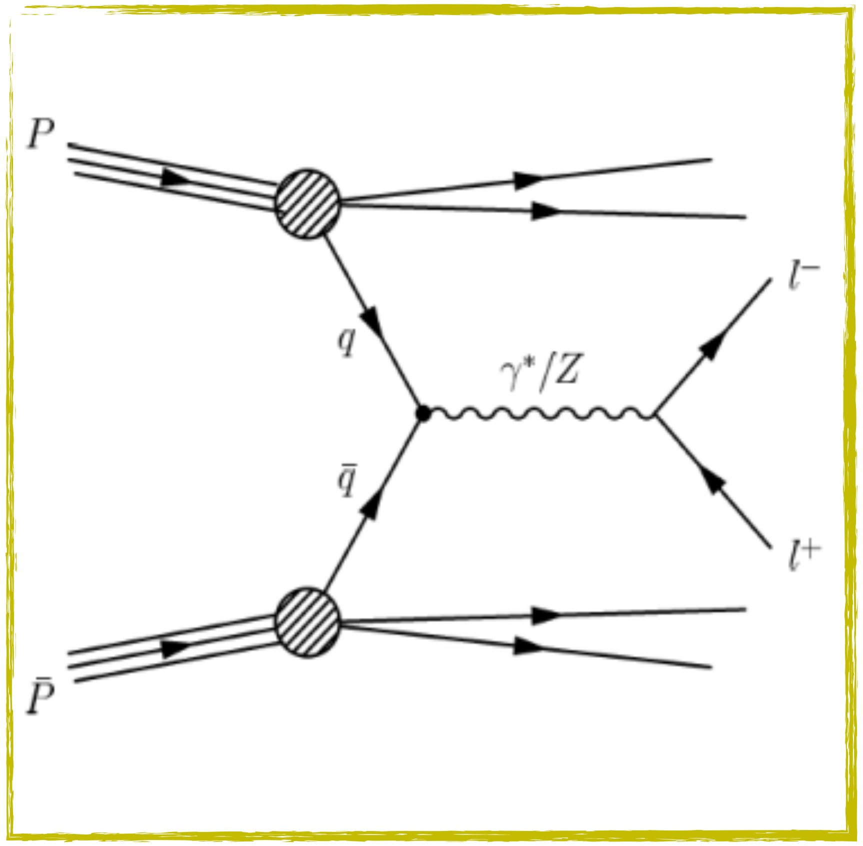
W and Z studies at $\sqrt{s}$ = 7 TeV



CMS-PAS-EWK-11-007

Drell-Yan cross section measurements

$$\frac{d^2\sigma}{dM\,dY}$$



- Theoretical $\boldsymbol{\sigma}$ known at NNLO $\longrightarrow$ test pQCD
- Use the double-differential $\boldsymbol{\sigma}$ to constrain the PDFs
- Normalized at the Z peak muons channel |Y|<2.4

The cross section

$$\sigma_{ij} = \frac{N^u_{ij}}{A_{ij}\epsilon_{ij}C_{ij}\int L dt}$$

i = mass bin
j = rapidity bin

Unfolded and bkg subtracted yield

full 2011 dataset
4.7 fb^{-1}

acceptance

efficiency

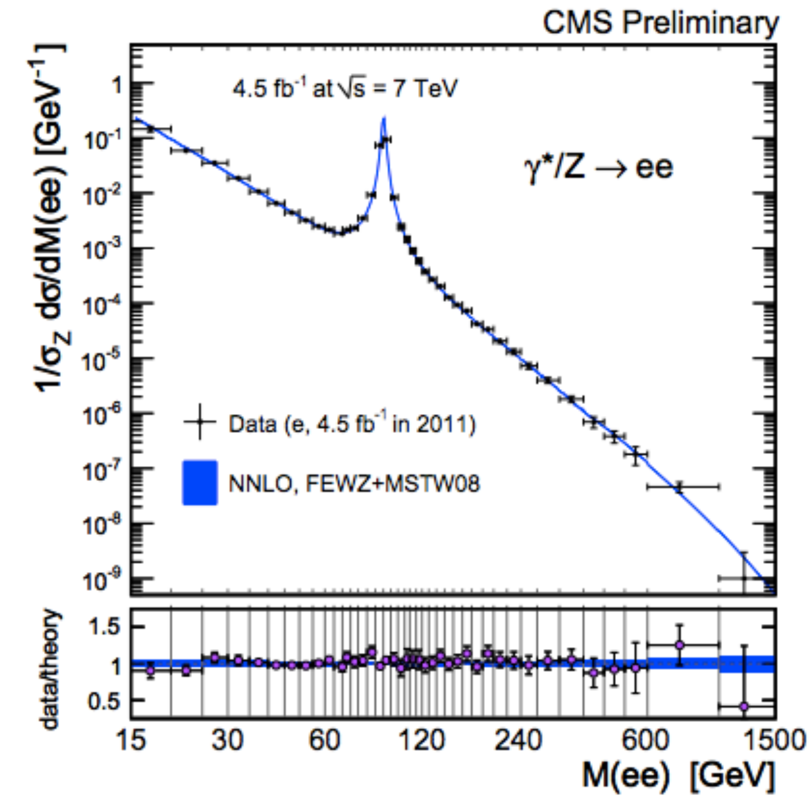
FSR correction

CMS-PAS-EWK-11-007

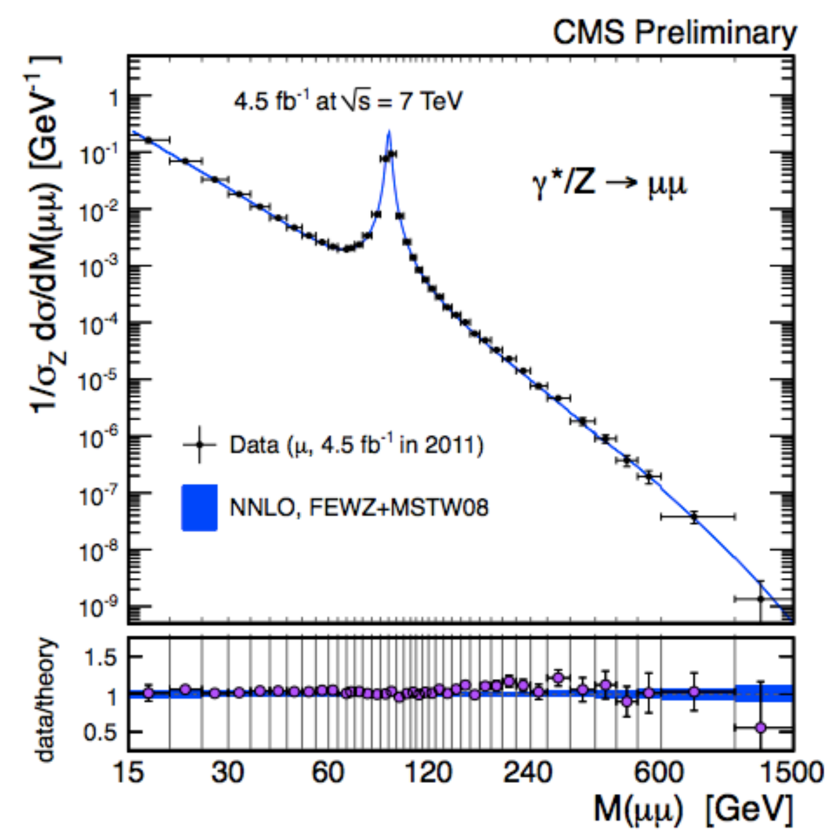
Drell-Yan differential cross section

Leptons selection

- 2 muons/electrons with opposite charge, p_T> 14, 9 GeV, $|\eta|$ < 2.4
- Muon track quality cuts, relative
- ParticleFlow isolation for leptons
- Un-prescaled double lepton trigger



- The *QED* FSR modeling in the generators to derive the corrections bin by bin
- Efficiency evaluated by data-driven methods scale factors to correct the data/MC



Systematic uncertainties

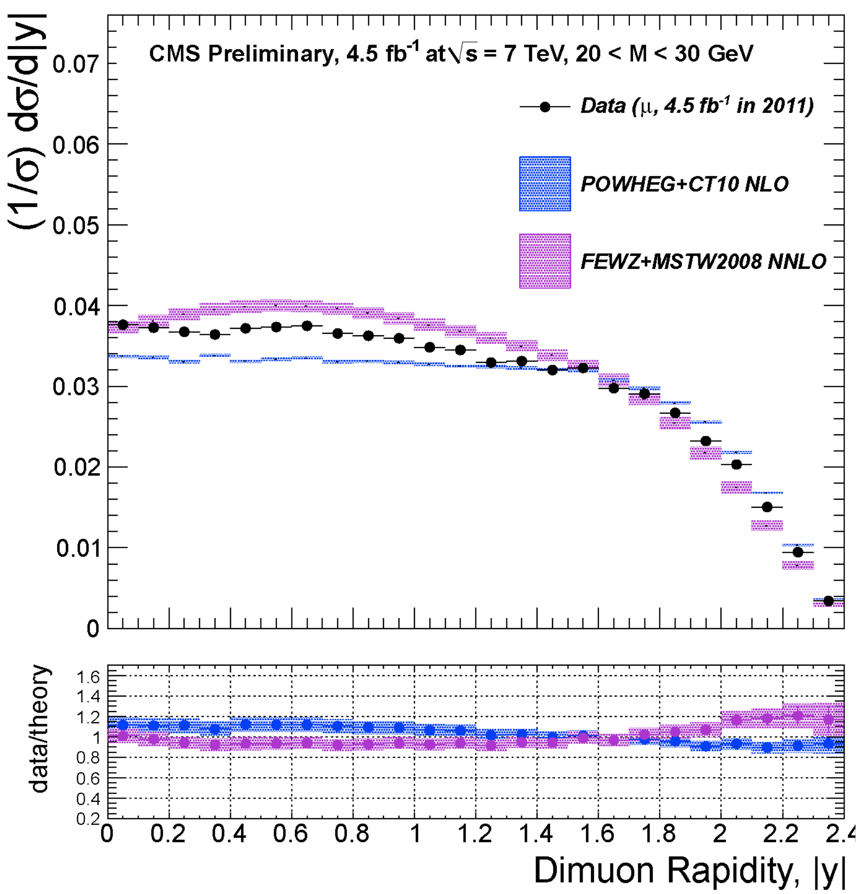
- Energy Scale 1-6 %
- Unfolding 0.5-28%
- PDFs ~ 3%
- Bkg estimation 0.5 - 23%
- Efficiency 0.5 -3.5 %
- Luminosity vanishes in the ratio

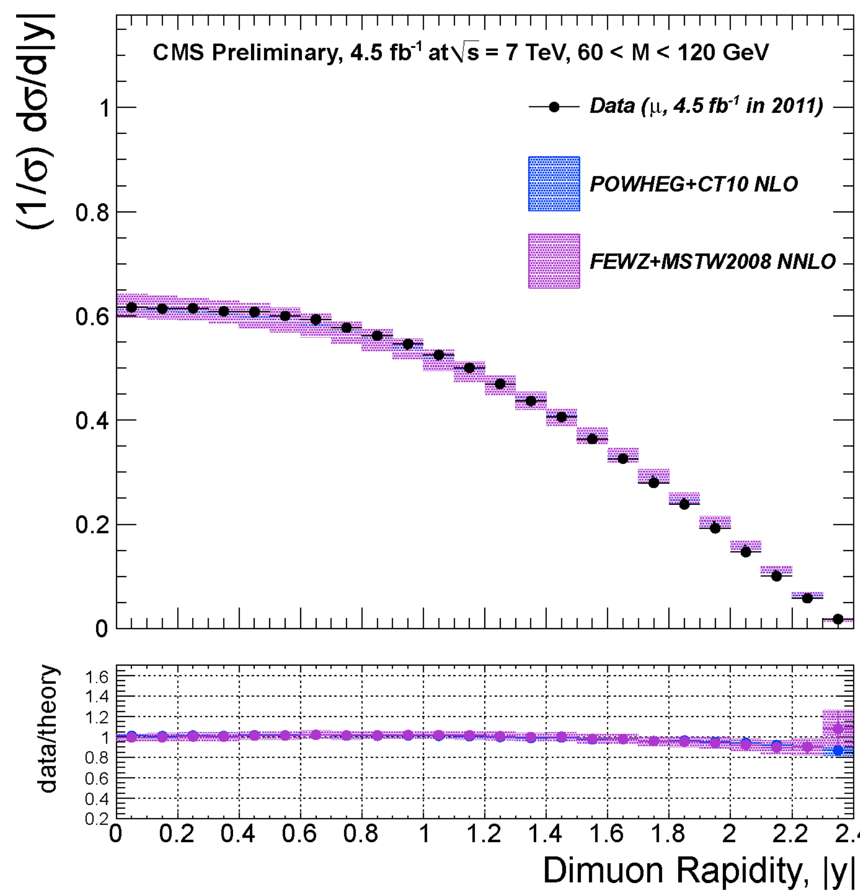
CMS-PAS-EWK-11-007

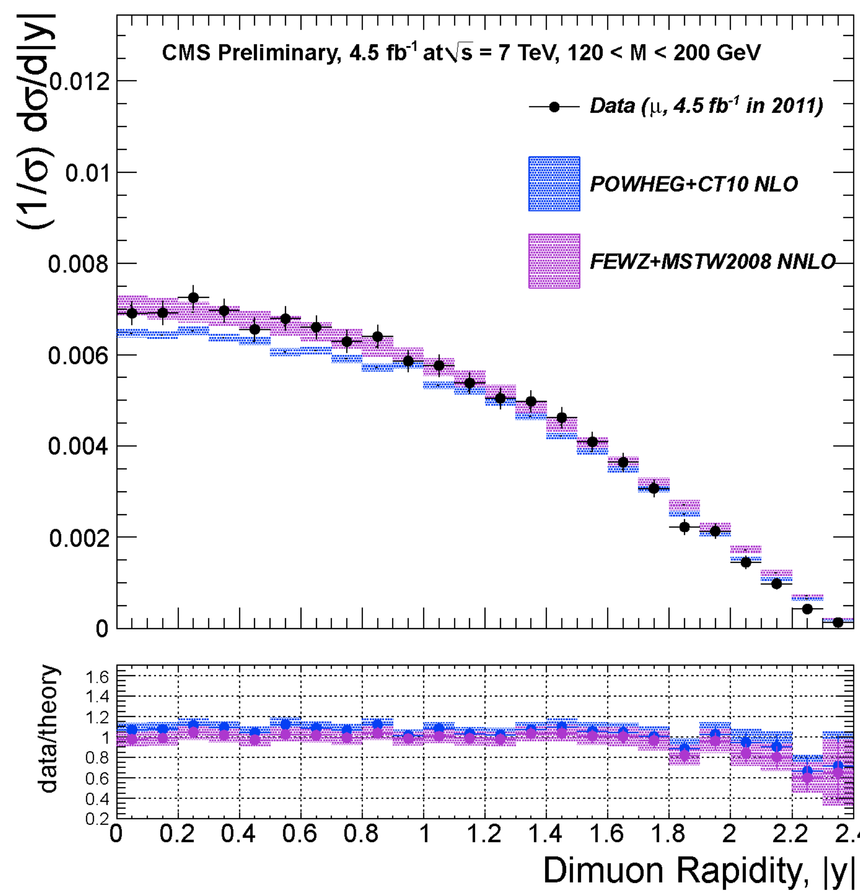
Drell-Yan double-differential cross section

- rapidity spectrum in 6 mass ranges
- measures within detector acceptance (to reduce model dependence)
- low mass very sensitive to PDF uncertainties

Results







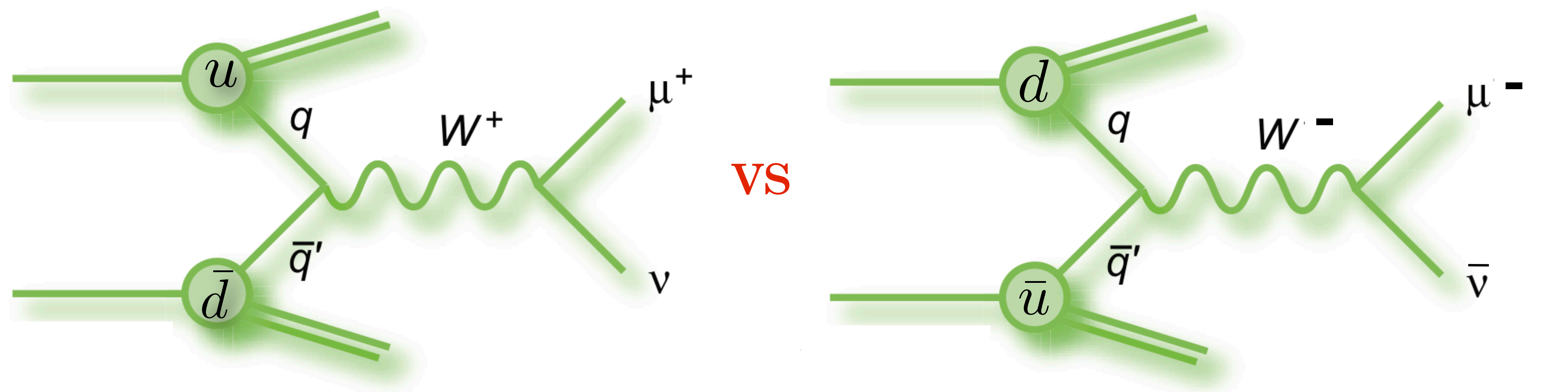
20 GeV< Mμμ < 30 GeV

120 GeV < Mμμ < 200 GeV

200 GeV < Mμμ < 1.5 TeV

Charge asymmetry in inclusive W decay

at LHC it's easier to produce W+ since protons have 2 u-quarks !



Test this asymmetry by measuring the observable A

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

η = -ln(tg $\theta/2$)

- new insights on the u / d ratio
- sea antiquarks densities in a range of the Bjorken x
- significant contribution to PDFs

W to electrons final state using **0.234 fb $^{-1}$**

W to muons final state using **0.840 fb $^{-1}$**

CMS PAS-EWK-11-005

Charge asymmetry in inclusive $W \rightarrow \mu\nu$

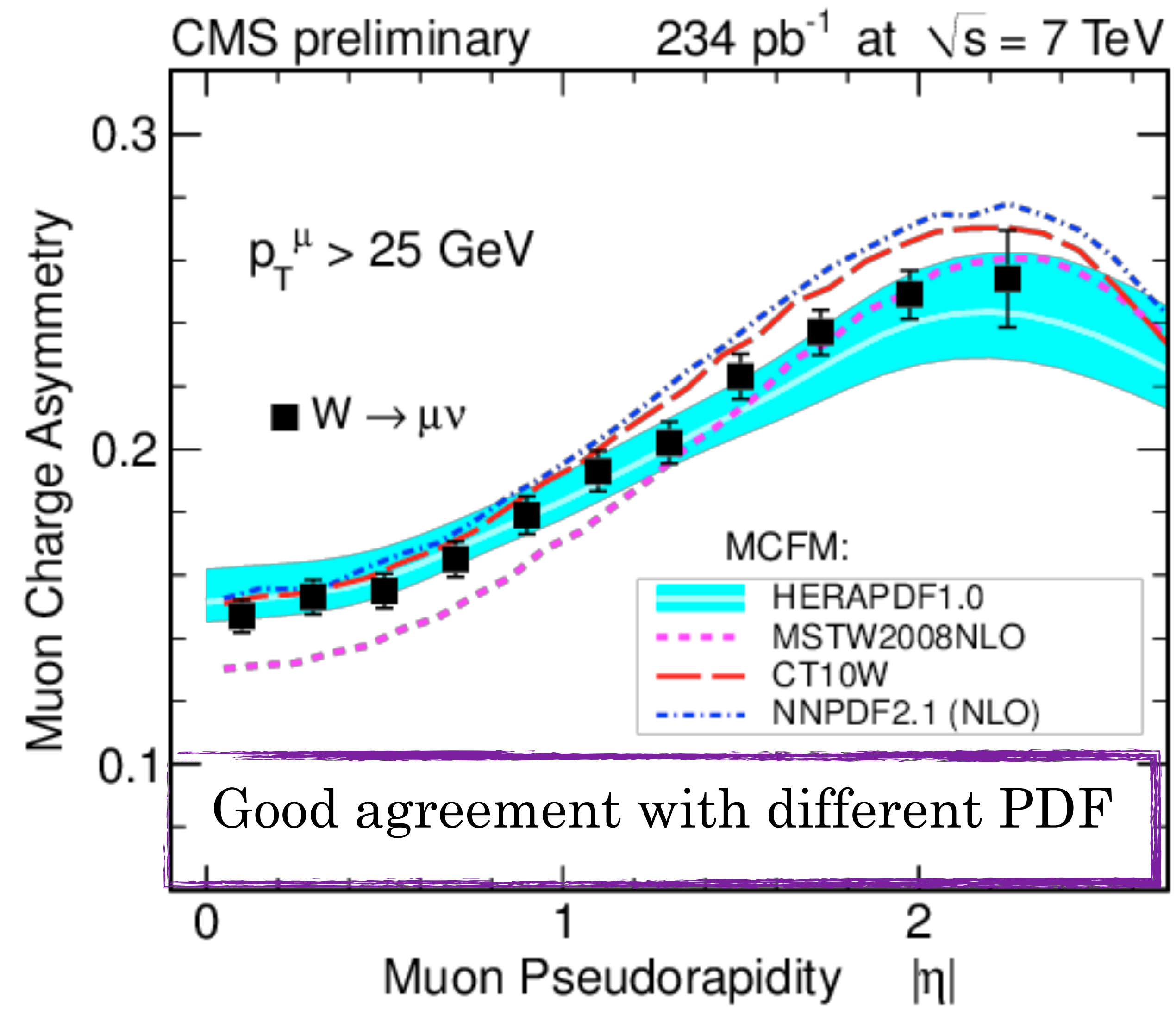
Muon selection

- Isolated muons with $p_T > 25$ GeV matching the trigger object
- Asymmetry in bins of $|\eta|$
- Isolation reconstruction and id efficiency

→ Tag&Probe in Z to μμ events in η bins

- Signal yield extracted by fitting the MET

$\boxed{W^+ (N^+) \text{ and } W^- (N^-)}$



Good agreement with different PDF

Understanding MET

- disagreement arises in Data/MC comparison due to PU, misalignment of sub-detectors, detector response

- Parametrize MET mis-modeling by correcting for the *hadronic recoil* (evaluated in the simulation)

$$u_T = -\not{E}_T - p_T^{\mu\mu}$$

<u // > ~ < (μμ) momenta> representing the detector response to the hadronic activity against the Z

Phys. Rev. Lett. 109 (2012) 111806

Charge asymmetry in inclusive $W \longrightarrow e\nu$ (1)

- Asymmetry rising with energy: *u* quarks involved in W+ production have higher *x* of the proton than *d* quarks to W-
- constraints PDFs in the range $10^{-3} < x < 10^{-4}$

Electron selection

- high p_T triggered electrons $p_T > 35$ GeV, $|\eta| < 2.4$
- missing transverse energy for neutrino presence

$$\not{E}_T = -\sum p_T$$

to separate signal from background

↓

binned maximum-likelihood fit

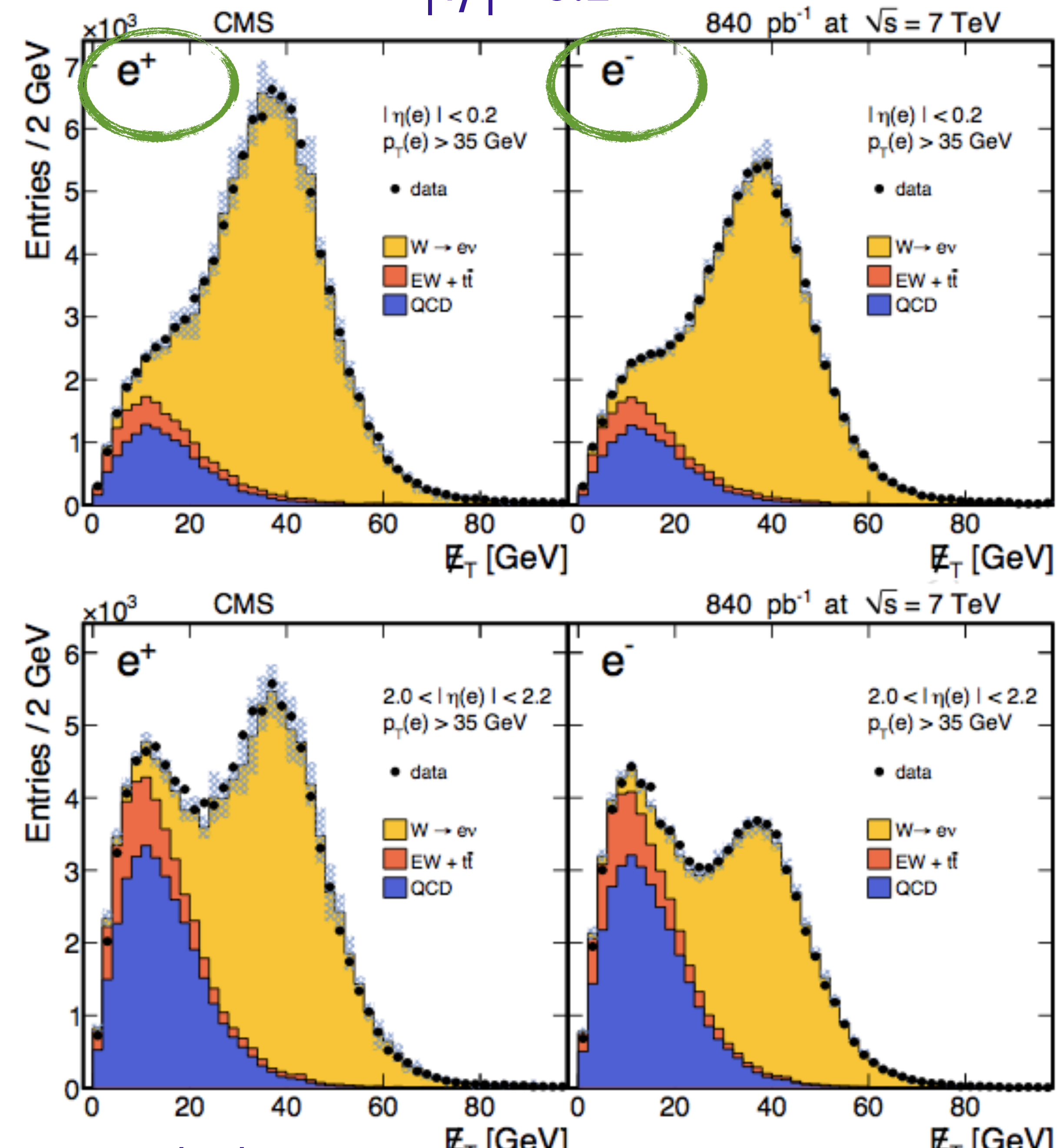
↓

electron (N^-) and positron (N^+) signal

asymmetry = (N^+ - N^-) / (N^+ + N^-)

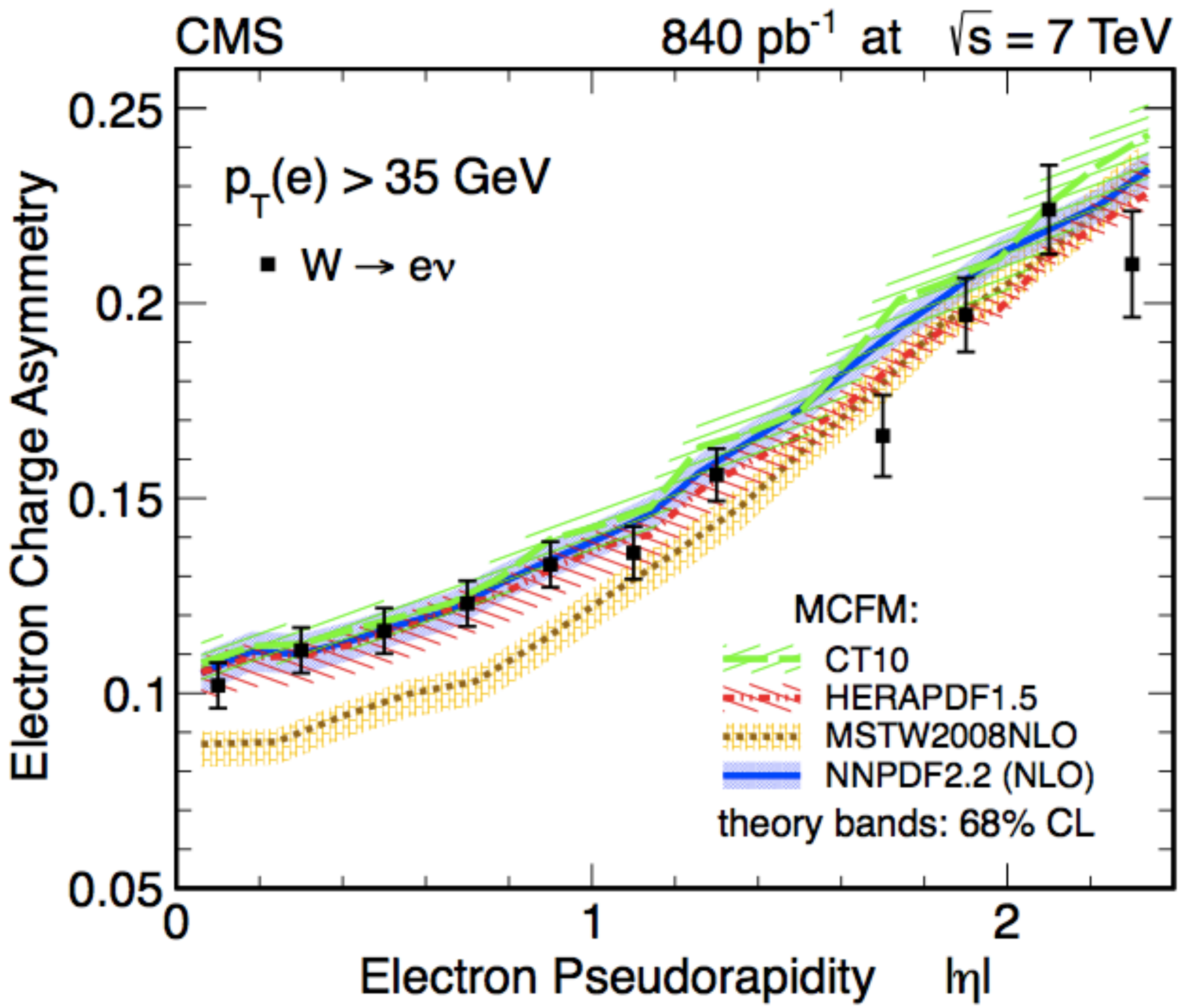
MET signal shape from MC
[corrected for *hadronic recoil*]

$|\eta|<0.2$



$2<|\eta|<0.2$

Charge asymmetry in inclusive $W \rightarrow e\nu$ (2)



Results

$\lvert\eta\rvert$ bin	Measured Asymmetry $\mathcal{A}$	Theoretical Predictions CT10	HERAPDF	MSTW	NNPDF
[0.0, 0.2]	$102 \pm 3 \pm 5$	109 ± 5	106^{+4}_{-8}	87^{+3}_{-5}	107 ± 5
[0.2, 0.4]	$111 \pm 3 \pm 5$	114 ± 5	110^{+4}_{-8}	89^{+3}_{-5}	110 ± 5
[0.4, 0.6]	$116 \pm 3 \pm 5$	119 ± 5	115^{+4}_{-8}	98^{+3}_{-5}	116 ± 5
[0.6, 0.8]	$123 \pm 3 \pm 5$	126 ± 5	122^{+4}_{-8}	103^{+3}_{-5}	123 ± 5
[0.8, 1.0]	$133 \pm 3 \pm 5$	138^{+5}_{-6}	132^{+4}_{-8}	115^{+4}_{-5}	134 ± 5
[1.0, 1.2]	$136 \pm 3 \pm 6$	146 ± 6	140^{+5}_{-8}	128^{+4}_{-5}	145 ± 5
[1.2, 1.4]	$156 \pm 3 \pm 6$	164^{+6}_{-7}	153^{+5}_{-7}	144 ± 5	158 ± 5
[1.6, 1.8]	$166 \pm 3 \pm 10$	195^{+8}_{-9}	181 ± 5	179 ± 5	190 ± 4
[1.8, 2.0]	$197 \pm 3 \pm 9$	207^{+8}_{-10}	196^{+4}_{-3}	200^{+6}_{-5}	206 ± 4
[2.0, 2.2]	$224 \pm 3 \pm 11$	224^{+8}_{-11}	211^{+5}_{-3}	213^{+6}_{-5}	219 ± 4
[2.2, 2.4]	$210 \pm 4 \pm 13$	241^{+8}_{-12}	225^{+9}_{-4}	231^{+6}_{-5}	231 ± 5

Systematic uncertainties

- electron energy scale and resolution
- detection efficiency of positron/electron
- electron charge misidentification

Good agreement with NLO predictions *except* MSTW

Phys. Lett. B 718 (2013) 752

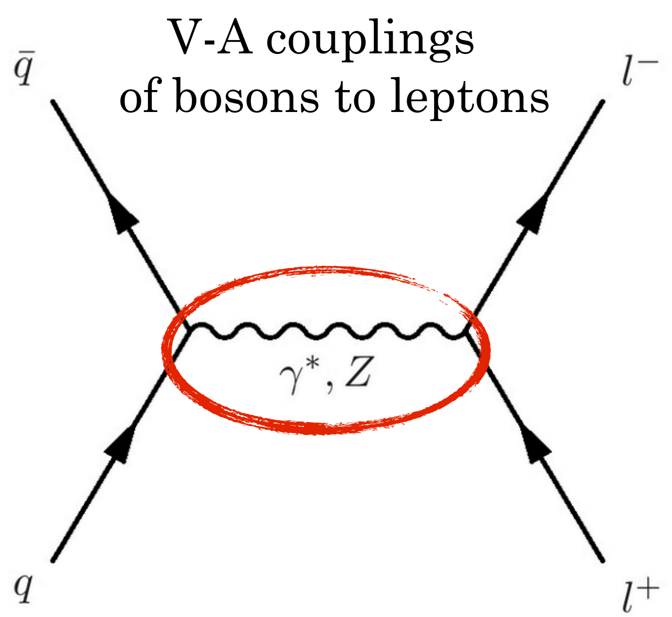
Forward-backward asymmetry in Z decay

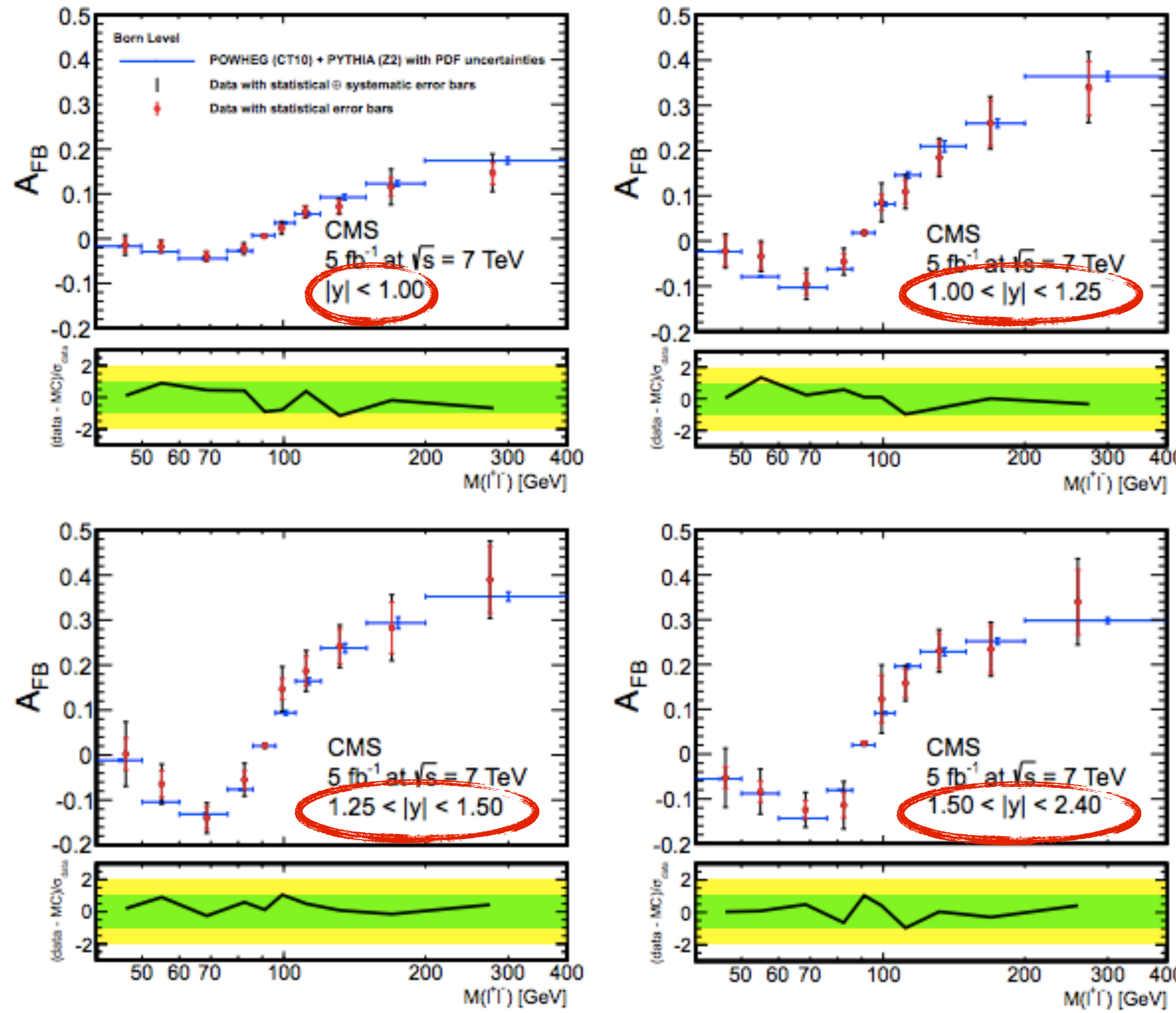
Submitted to Physics Letters B

5 fb^{-1}

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

$$\frac{d\sigma}{d\cos\theta^*} = C\left[\frac{3}{8}(1+\cos^2\theta^*) + A_{FB}\cos\theta^*\right]$$





- leptons $p_T > 20$ GeV, $|\,\eta\,| < 2.4$
- ee + μμ combined final state
- unfolded born level asymmetry in $|y|$ range
- ratio between Data/MC with 1σ, 2σ band

(POWHEG ct10 +Pythia Z2)

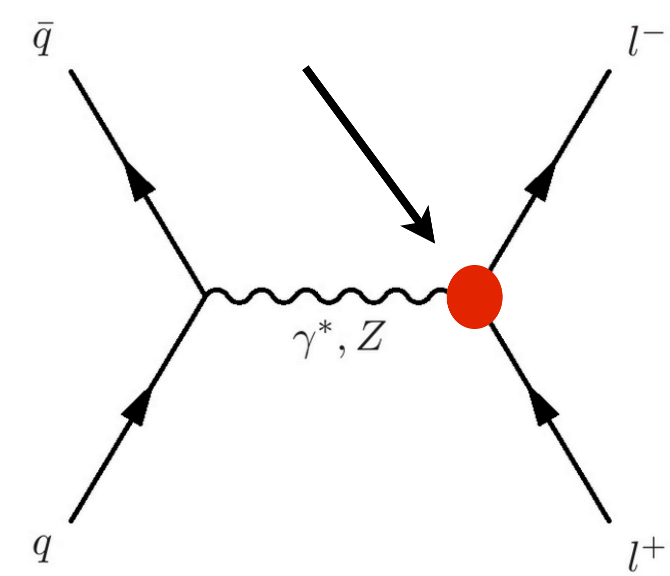
Phys.Rev. D84 (2011) 112002

Electroweak mixing angle measurement

$\boxed{sin^2\theta_W}$

- from EW spontaneous symmetry breaking:
  rotation of (W^0 , B^0) vectors into physical (Z, γ) bosons

- fixes couplings of Z, γ to fermions

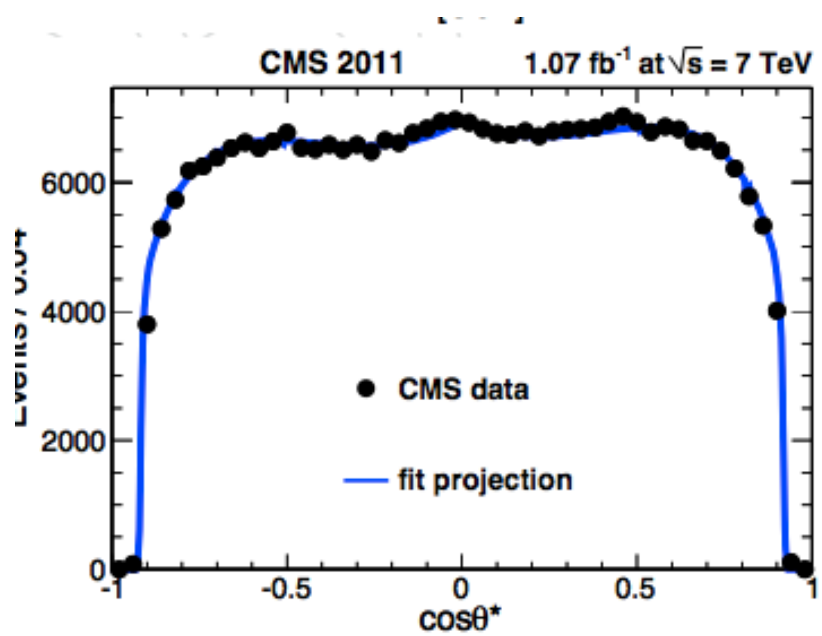


previous measurements
- LEP,SLC in lepton collider at 0.1%
- CDF, D0 in proton-antiproton collision at 1%

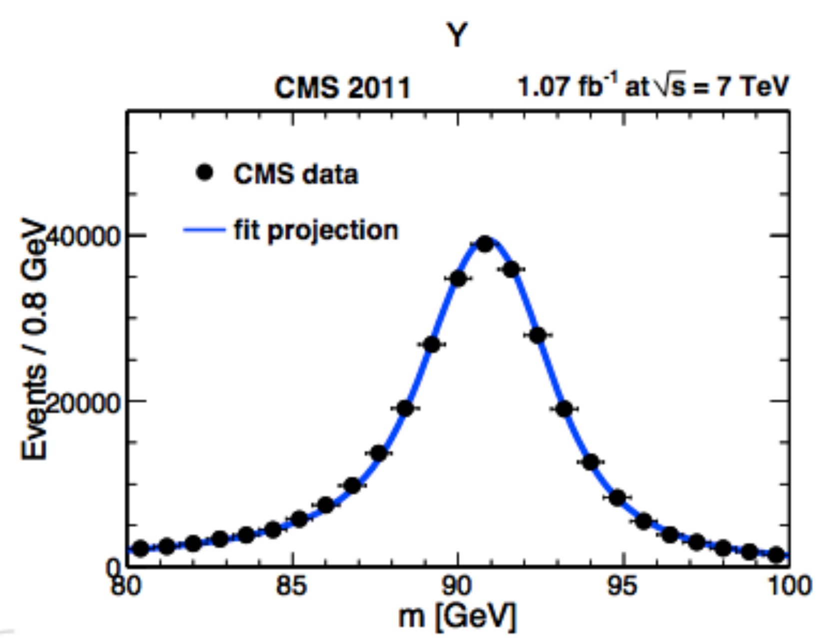
at LHC: in DY process to ***μμ***
extract the mixing angle by
a simultaneous unbinned ML fit to:

$$\boldsymbol{sin^2\theta_W = \ 0.2287 \pm 0.0020(stat.) \pm 0.0025}$$

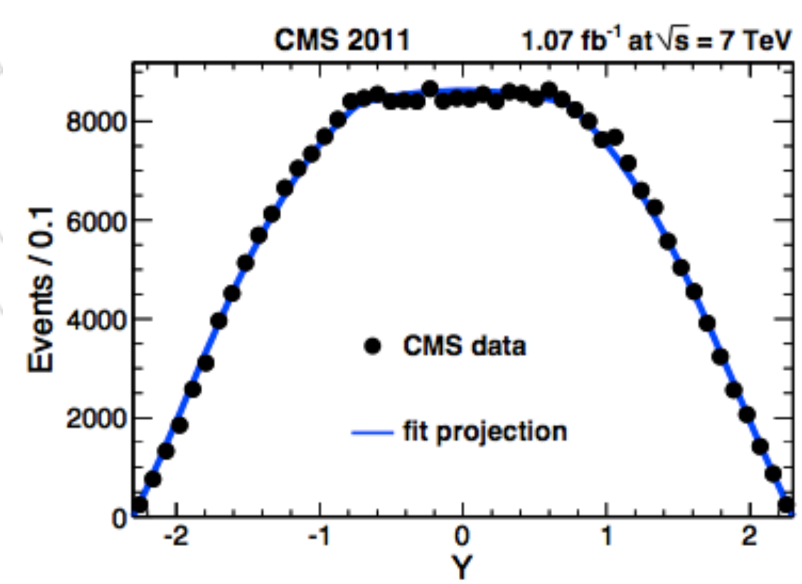
dimuon decay angle



dimuon invariant mass



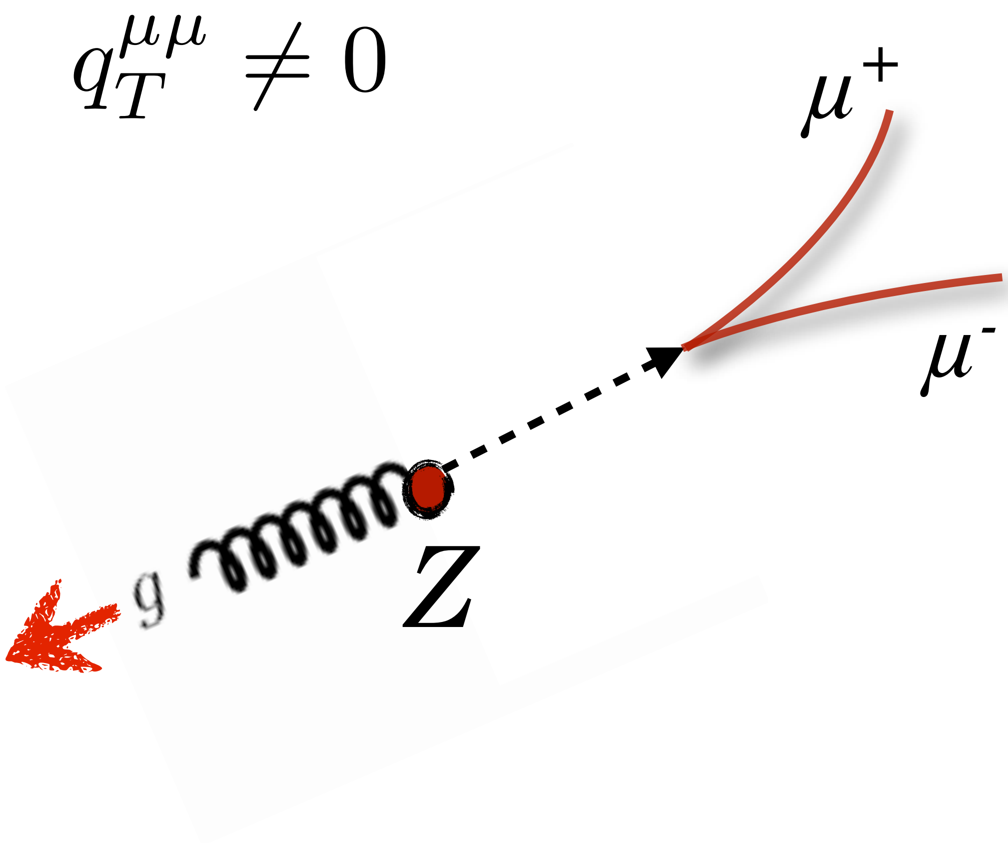
dimuon rapidity



Z q_T differential cross section

Phys. Rev. D 85 (2012) 032002 (1)

$q_T^{\mu\mu} \neq 0$

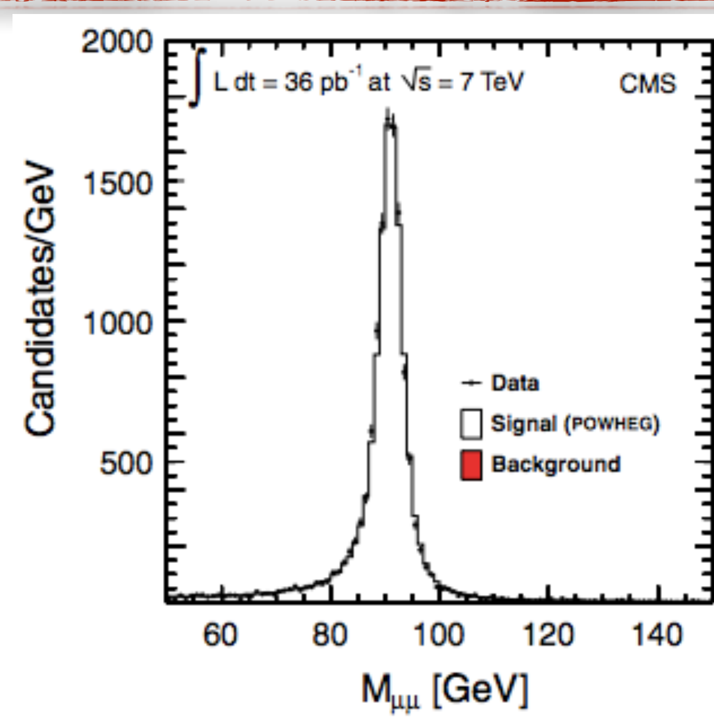


- at LHC energy, di-lepton pair can arise boosted from the Z because of:
  - QCD initial state radiation
  - underlying event activity
- information about the proton dynamics
- modeling the hard scattering in generators

36 pb^{-1}

same selection of Z μμ inclusive cross section to measure the Z momentum

Drell-Yan process
Z mass peak

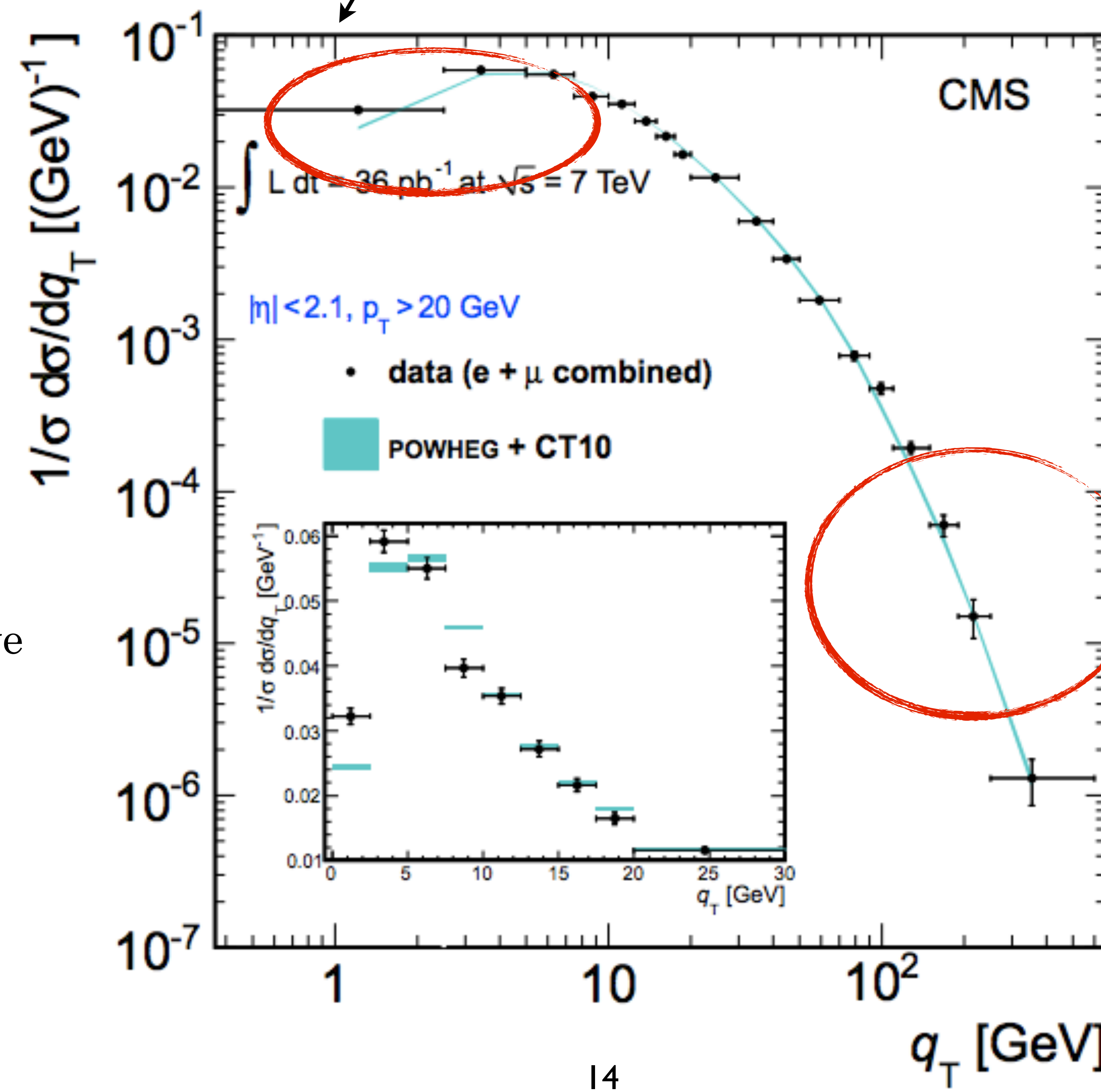


q_T Range	[2.5 GeV, 5.0 GeV]		[110 GeV, 150 GeV]	
Channel	Muon	Electron	Muon	Electron
Background Estimation	0.004	0.005	0.019	0.028
Efficiency Determination	0.010	0.002	0.010	0.008
Energy Scale	–	0.022	–	0.035
Tracker Alignment	0.015	0.013	0.023	0.020
Unfolding	0.006	0.004	0.017	0.001
PDF Acceptance Determination	0.002	0.002	0.001	0.001
Total	0.020	0.026	0.036	0.050

Systematics

Z q_T differential cross section (2)

multiple soft gluon radiation and non-perturbative effects

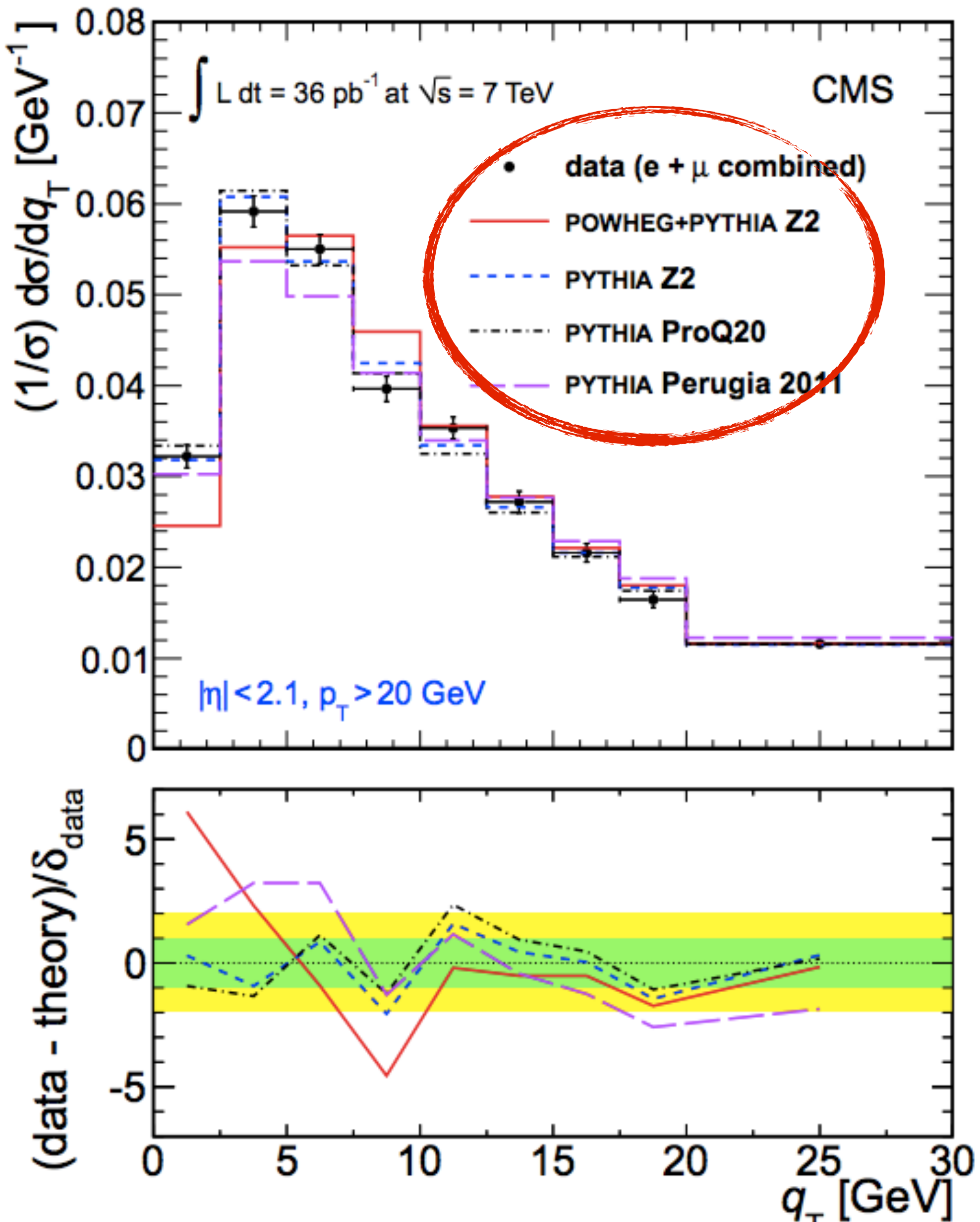


expect perturbative QCD calculations reliable from ~ 20 GeV/c (single hard gluon emission region)

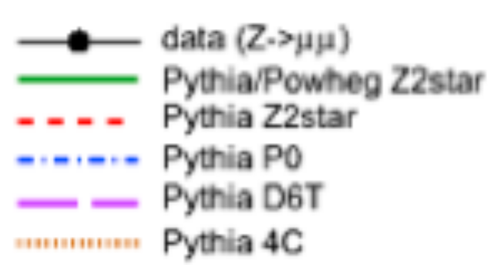
high q_T precision dominated by the order of α_S^2

Z q_T differential cross section (3)

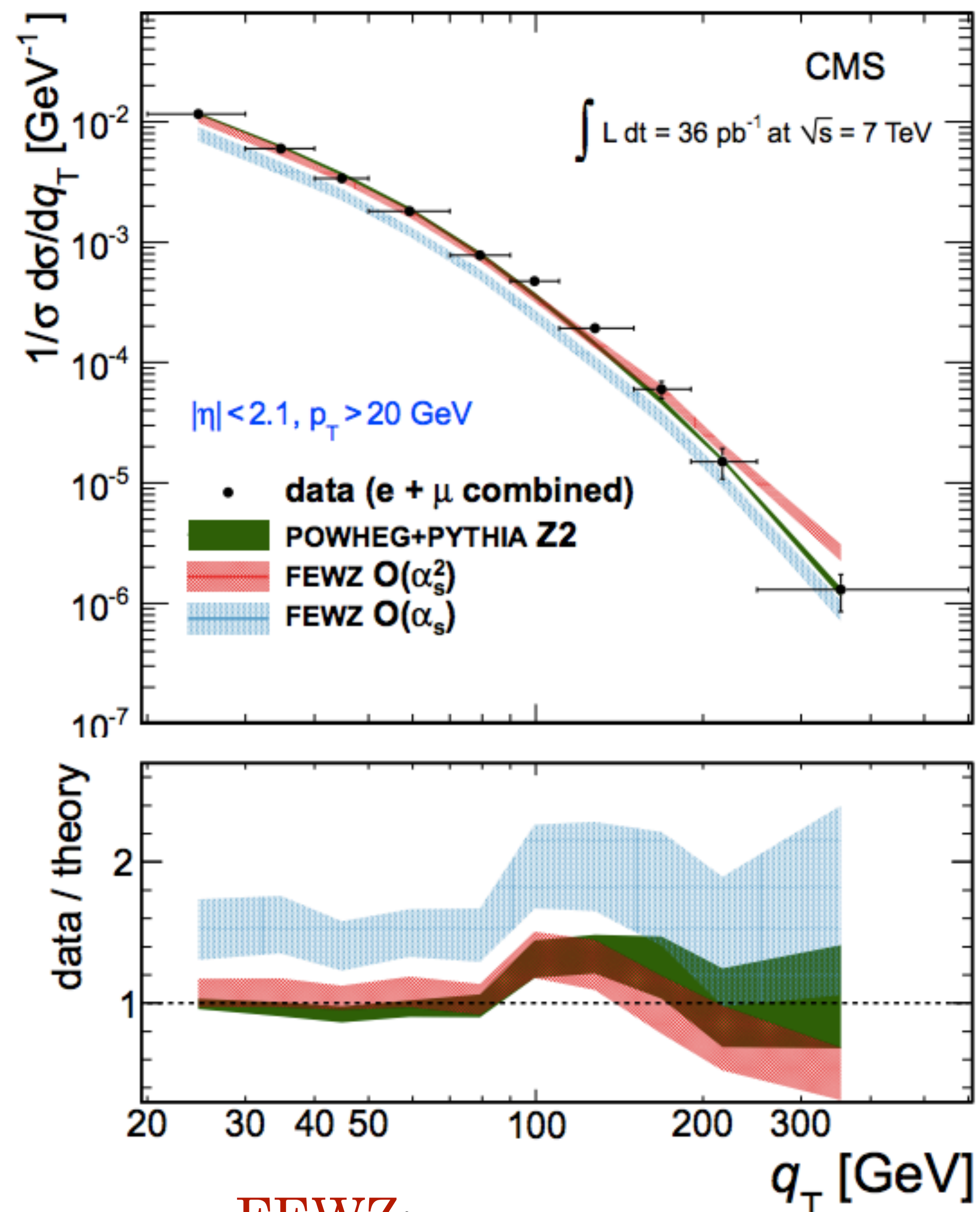
low Z boson q_T



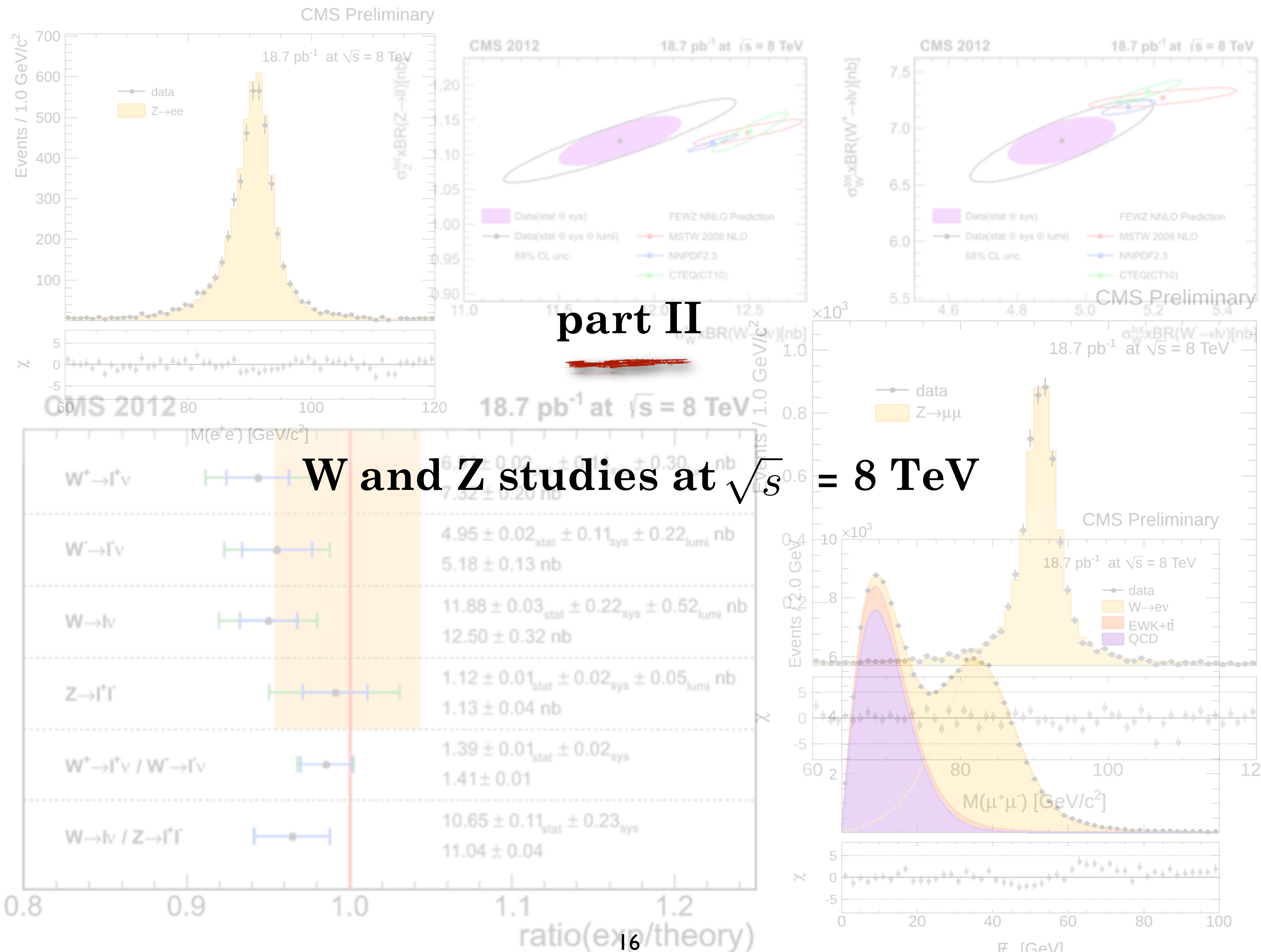
Pythia:
different tunes to account the non-perturbative QCD processes



high Z boson q_T



FEWZ:
$O(\alpha_S^2)$ calculation of W/Z exclusive production at NNLO



part II

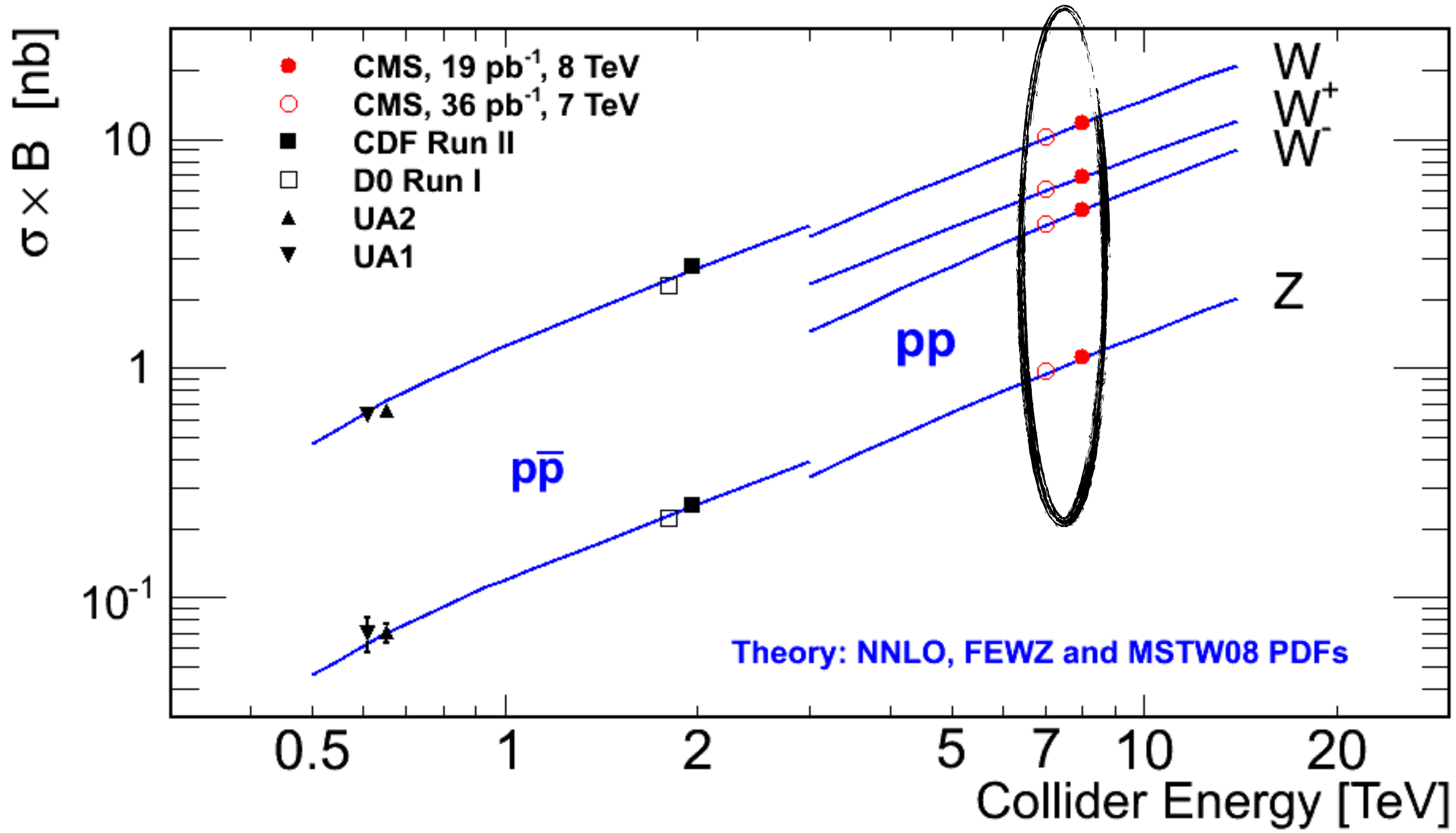
W and Z studies at $\sqrt{s}$ = 8 TeV

W and Z cross sections at $\sqrt{s} = 8$ TeV

PRL - CMS PAS SMP-12-011

from pQCD prediction we expect an increase of the cross section of 15 - 20 % from 7 to 8 TeV

- 7 TeV cross sections measured in CMS with 1% precision (with 36 pb^{-1})
- important to measure the W/Z, W^+/W^- ratio and the 7/8 TeV ratio for pQCD tests
- important as a starting point for 8 TeV measurements



LHC collisions requirements

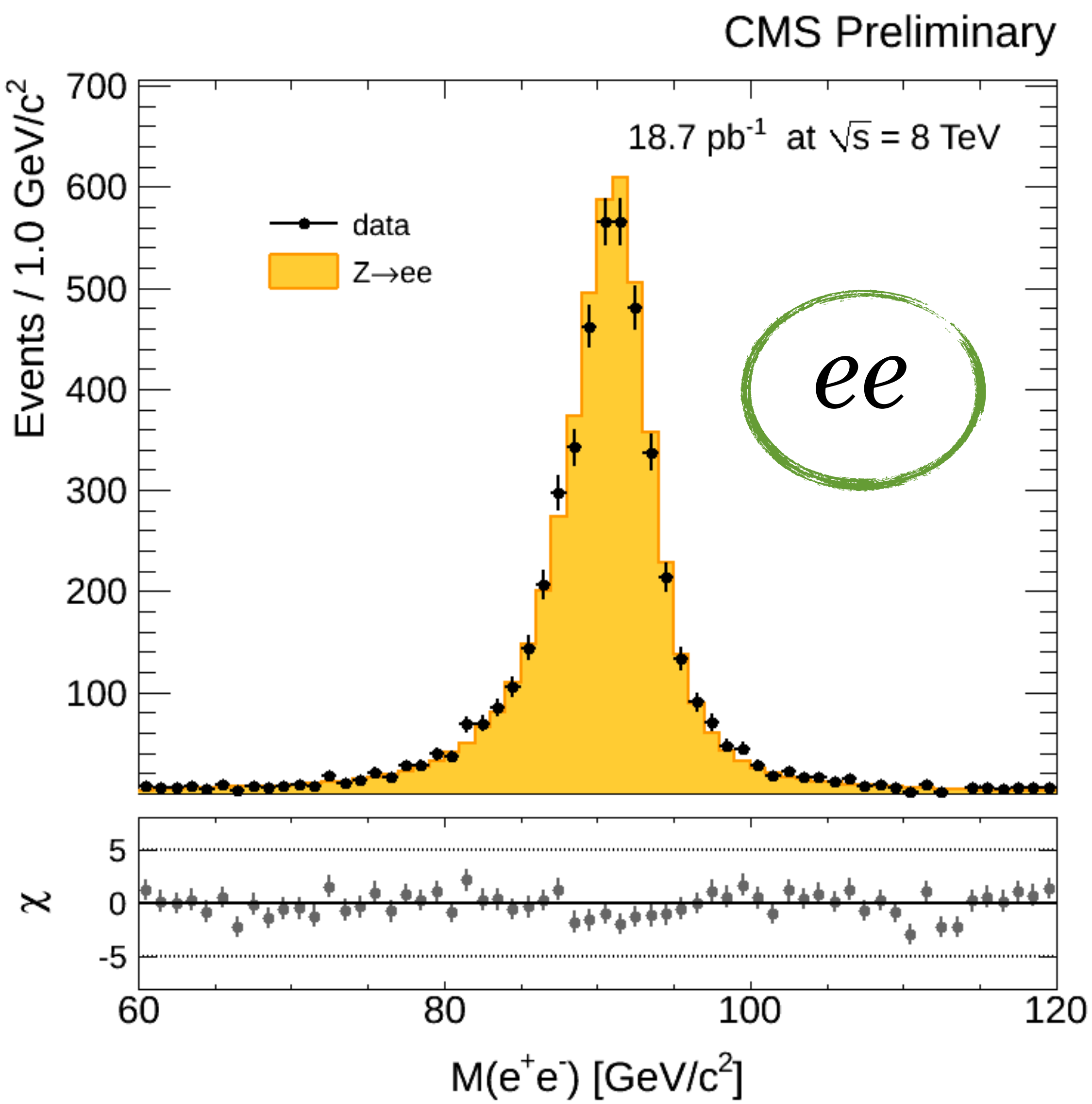
x need to reproduce the 2010 condition of pile-up and triggers !

x special fills to reduce the mean pile-up to 5 interaction at L = 3 * 10^{32}

x dedicated low-threshold trigger menus

19 pb^{-1} recorded

Z cross sections at $\sqrt{s} = 8$ TeV



- opposite sign electrons with

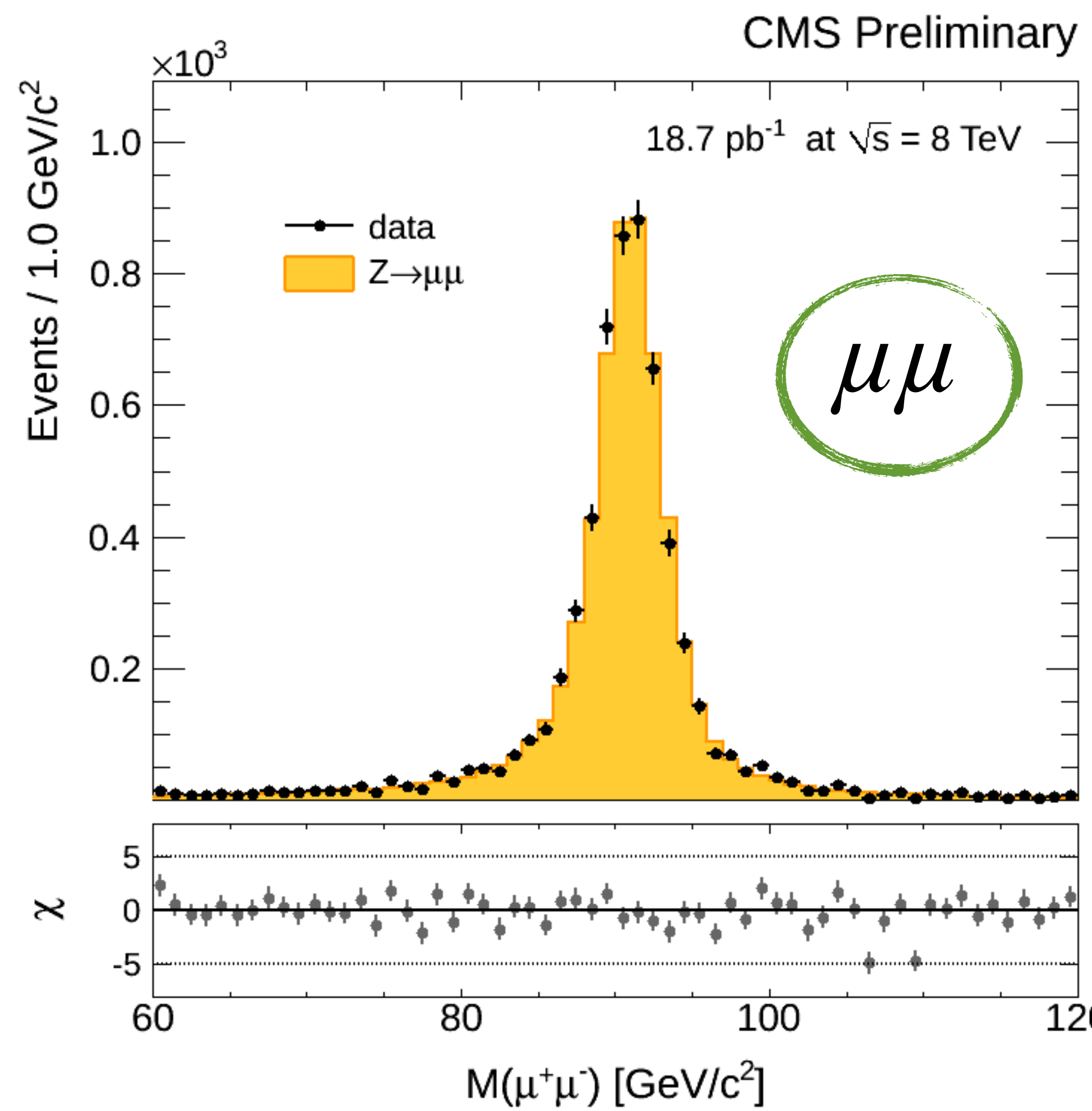
  $p_T > 25$ GeV, $|\ \eta\ | < 2.5$

- dielectron invariant mass in the range

  [60 ; 120] GeV

- Ele ID, isolation and reconstruction

  from Tag & Probe method 2.8% sys



- opposite sign muons with

  $p_T > 25$ GeV, $|\ \eta\ | < 2.1$

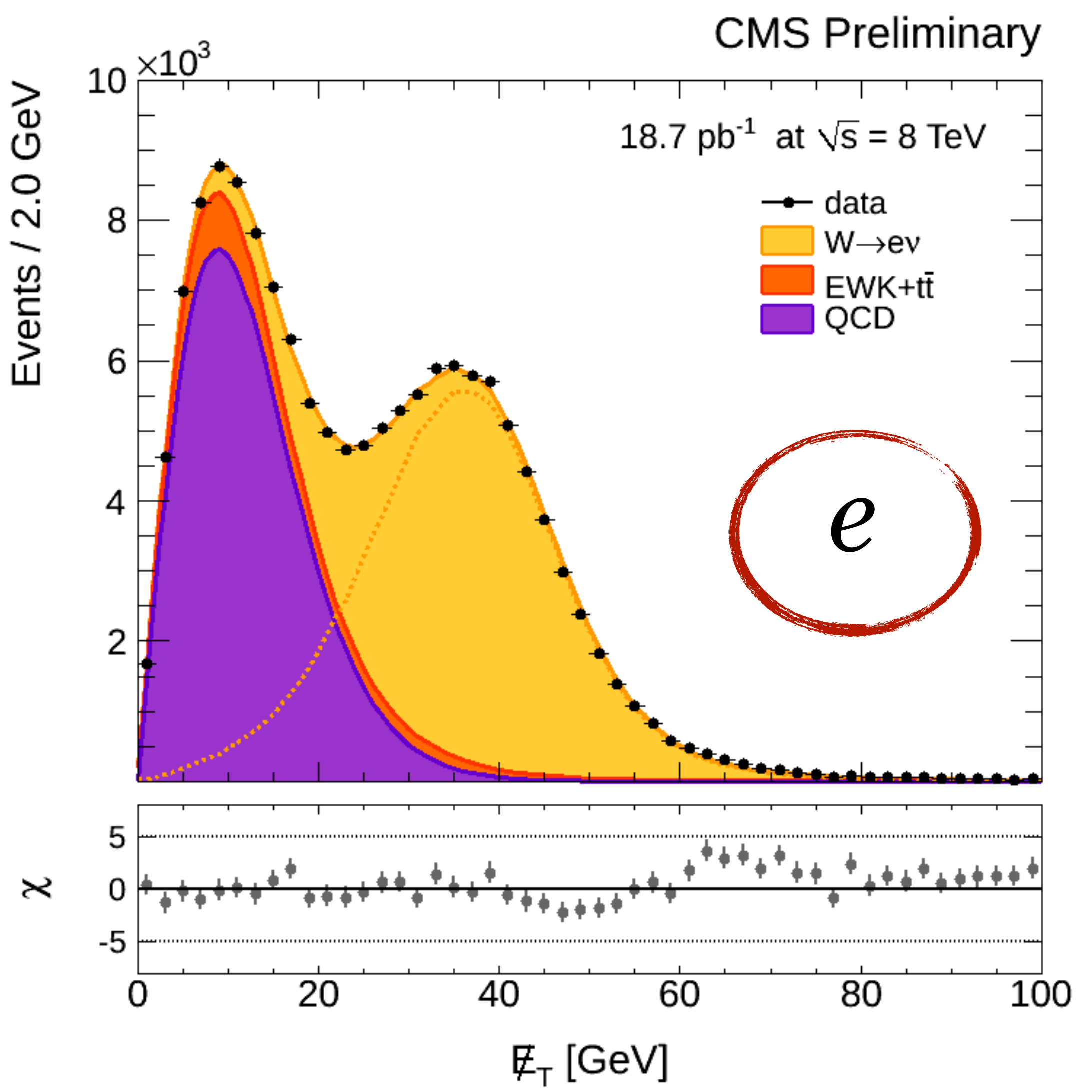
- dimuon invariant mass in the range

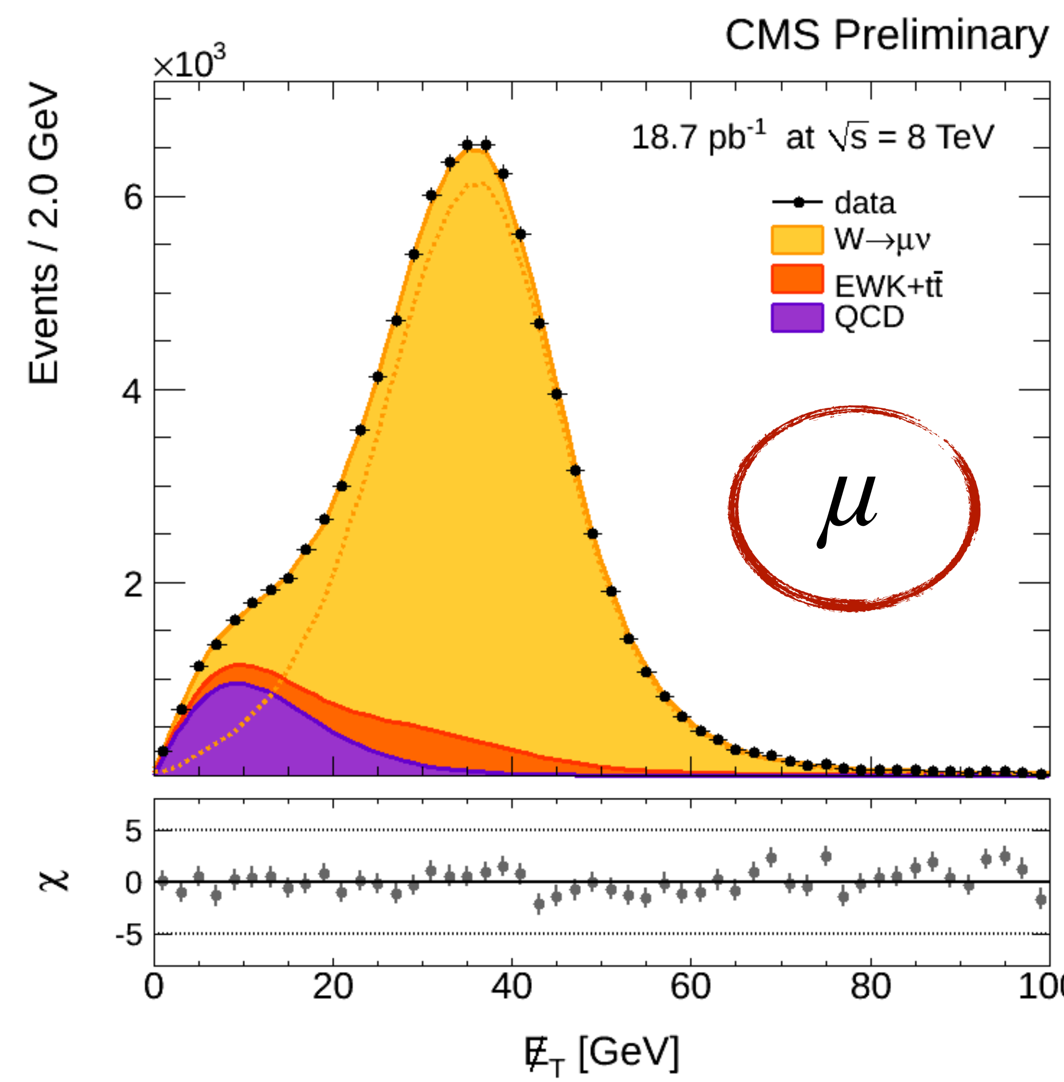
  [60 ; 120] GeV

- Muon ID, isolation and reconstruction

  from Tag & Probe method 1.1% sys

W cross sections at $\sqrt{s} = 8$ TeV





- single electron with

  $p_T > 25$ GeV, $|\eta| < 2.1$
- binned max.likelihood fit to MET

  extract signal+QCD shape parameters
- W MET modeling with recoil from Z event

  lepton efficiency dominated by 2.5% exp

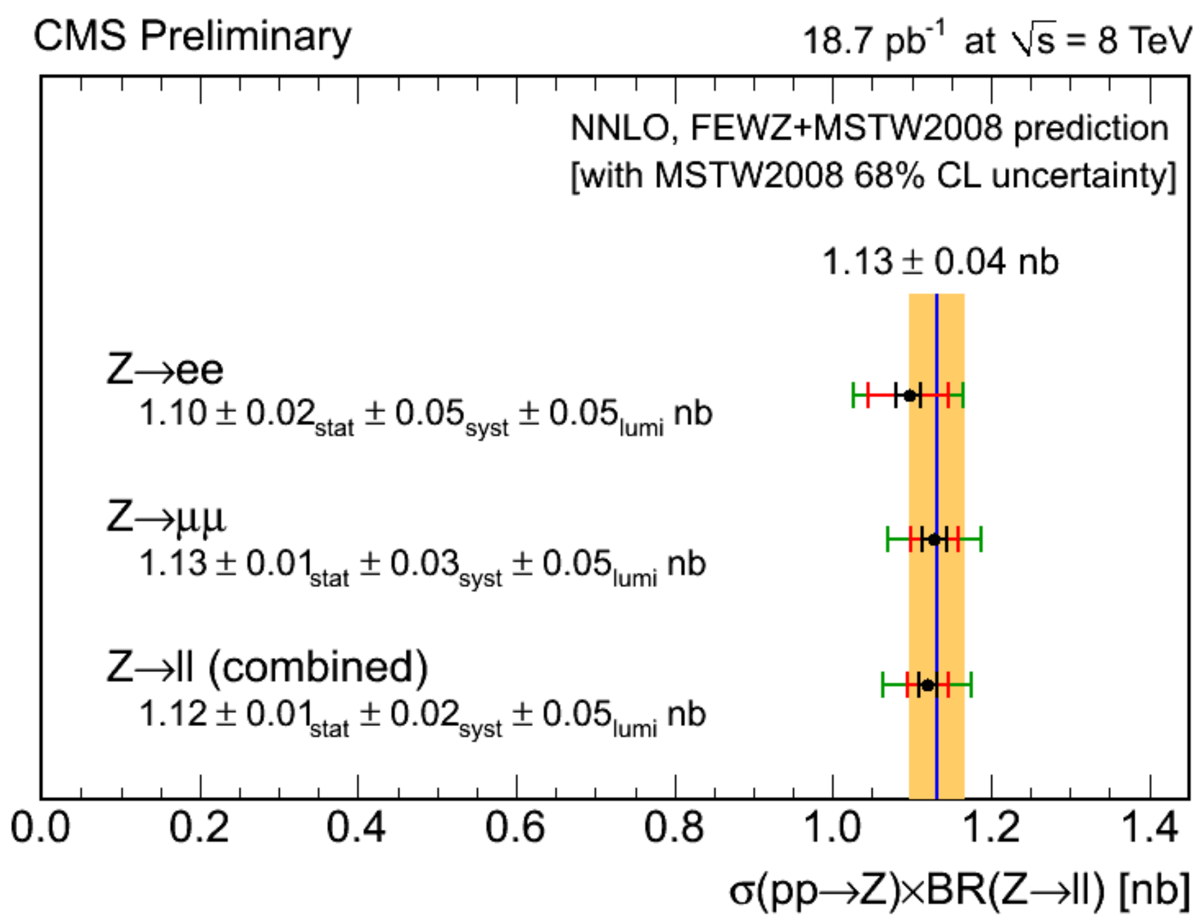
- single muon with

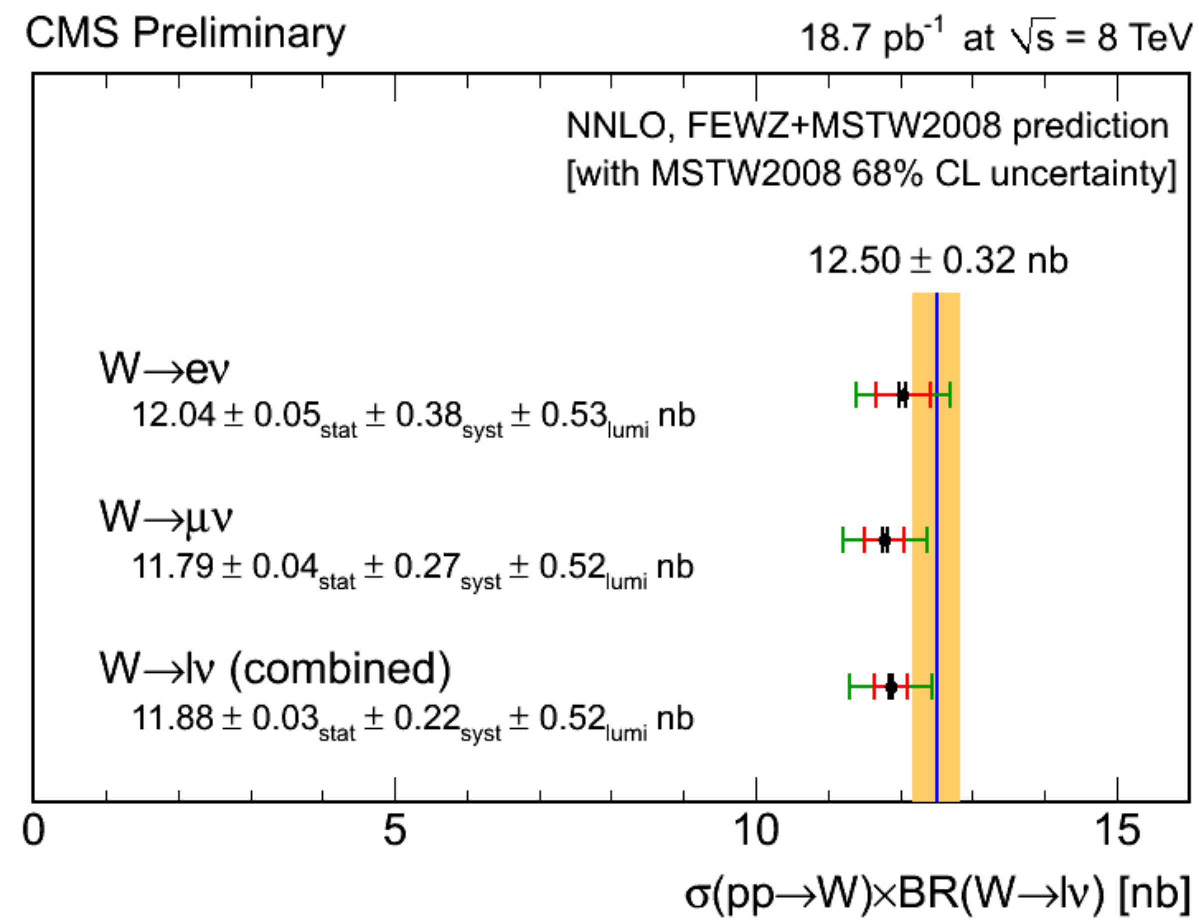
  $p_T > 25$ GeV, $|\eta| < 2.1$
- binned max.likelihood fit to MET

  extract signal+QCD shape parameters
- W MET modeling with recoil from Z event

  lepton efficiency dominated by 1% exp

W and Z cross sections results





Systematics

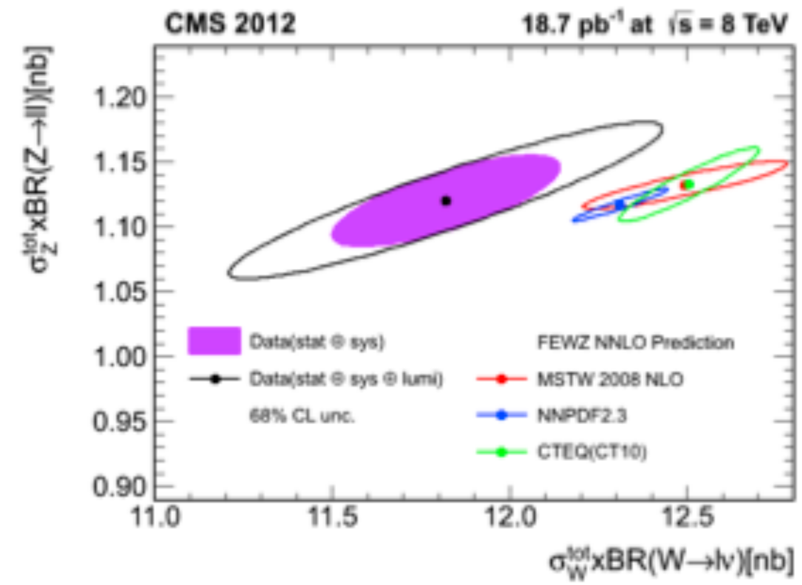
Source	W^+	W^-	W	W^+/W^-	Z	W/Z
Lepton reconstruction & identification	1.0%	0.9%	1.0%	1.2%	1.1%	1.5%
Momentum scale & resolution	0.3%	0.3%	0.3%	0.1%	-	0.3%
E_T^{miss} scale & resolution	0.5%	0.5%	0.5%	0.1%	-	0.5%
Background subtraction / modeling	0.2%	0.1%	0.1%	0.2%	0.4%	0.4%
Total experimental	1.2%	1.1%	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%

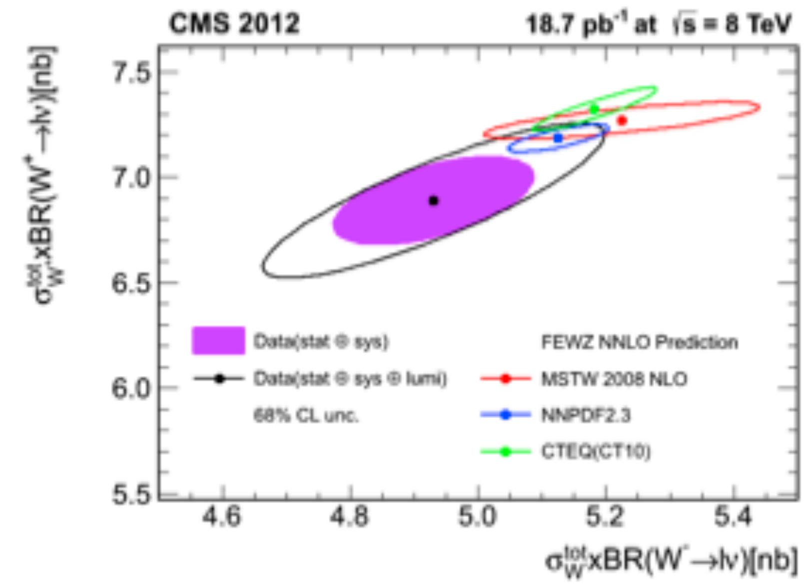
- luminosity
  ~ 4.4 %
- acceptance (theory)
  ~ 2-3 %

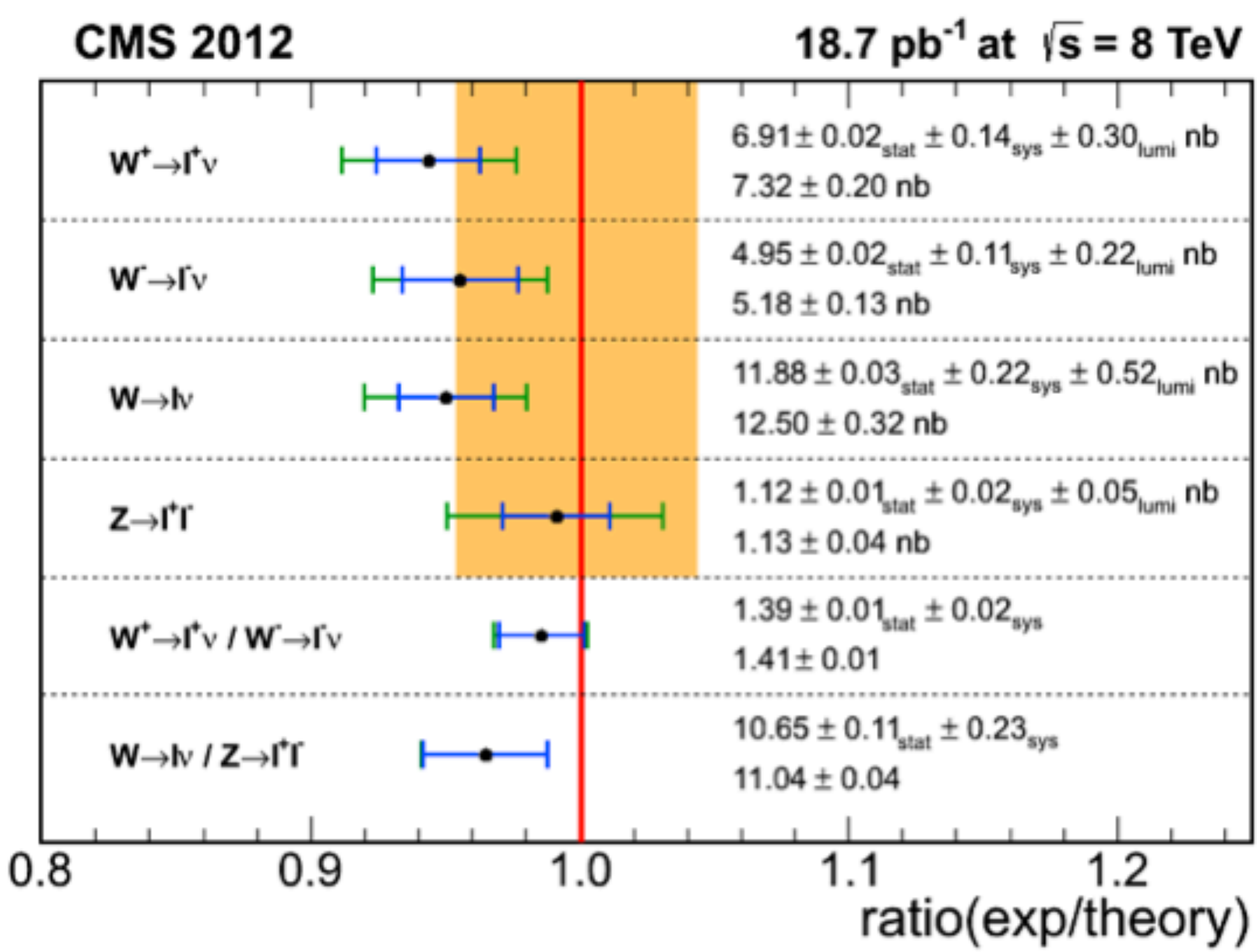
Good agreement with NNLO FEWZ+MSTW08

W / Z cross section ratio at $\sqrt{s}$ = 8 TeV

W / Z
ratio







agreement
within
1.5 sigma with
FEWZ+MSTW08

Conclusions

- Electroweak processes crucial to understand protons dynamics at LHC

- PDFs, generator tunings, (p-)QCD tests performed with 7 and 8 TeV

- Central role of Drell - Yan process (useful at high mass for new physics)

- Many other measurements already done:
  - *Z + jets / Z angular studies / b quark and c quark PDF extraction / W pT / Z rapidity ......*

Standard Model measurements have never been more alive !