W, Z and γ Production

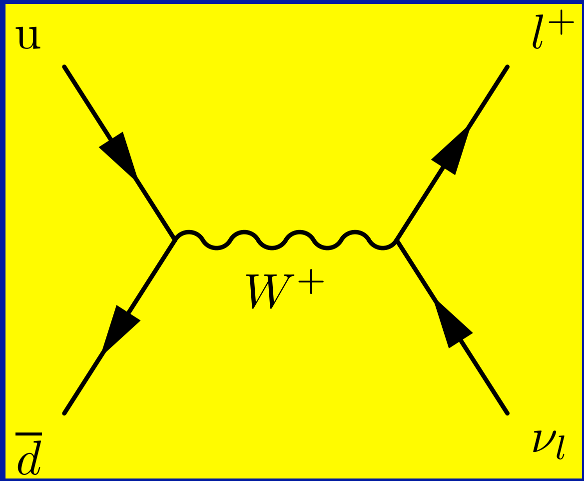
Alexander A. Savin
University of Wisconsin-Madison, USA
for ATLAS, CDF, CMS, D0, LHCb

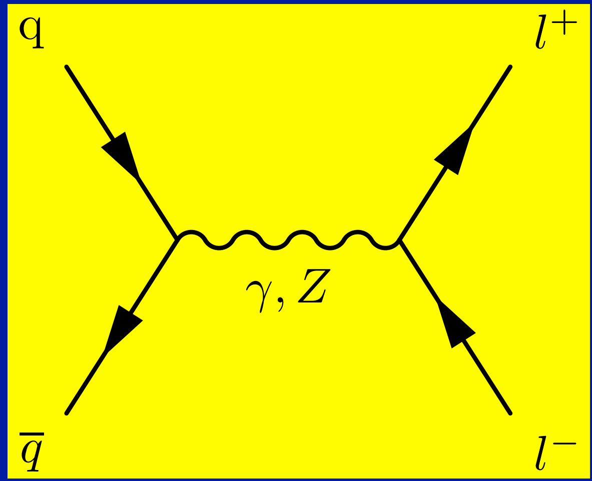
XXXII Physics in Collisions, September 12 – 15, 2012
Strbske Pleso, Slovakia

Outline

- Introduction
- W, Z and γ production
  - Drell-Yan production
  - Inclusive cross sections
  - Differential cross sections
  - W charge asymmetry
  - W and τ polarization
  - Z forward-backward asymmetry
  - Effective weak mixing angle
- Diboson production
  - Cross sections measurements
  - Anomalous triple gauge coupling
- Summary and outlook

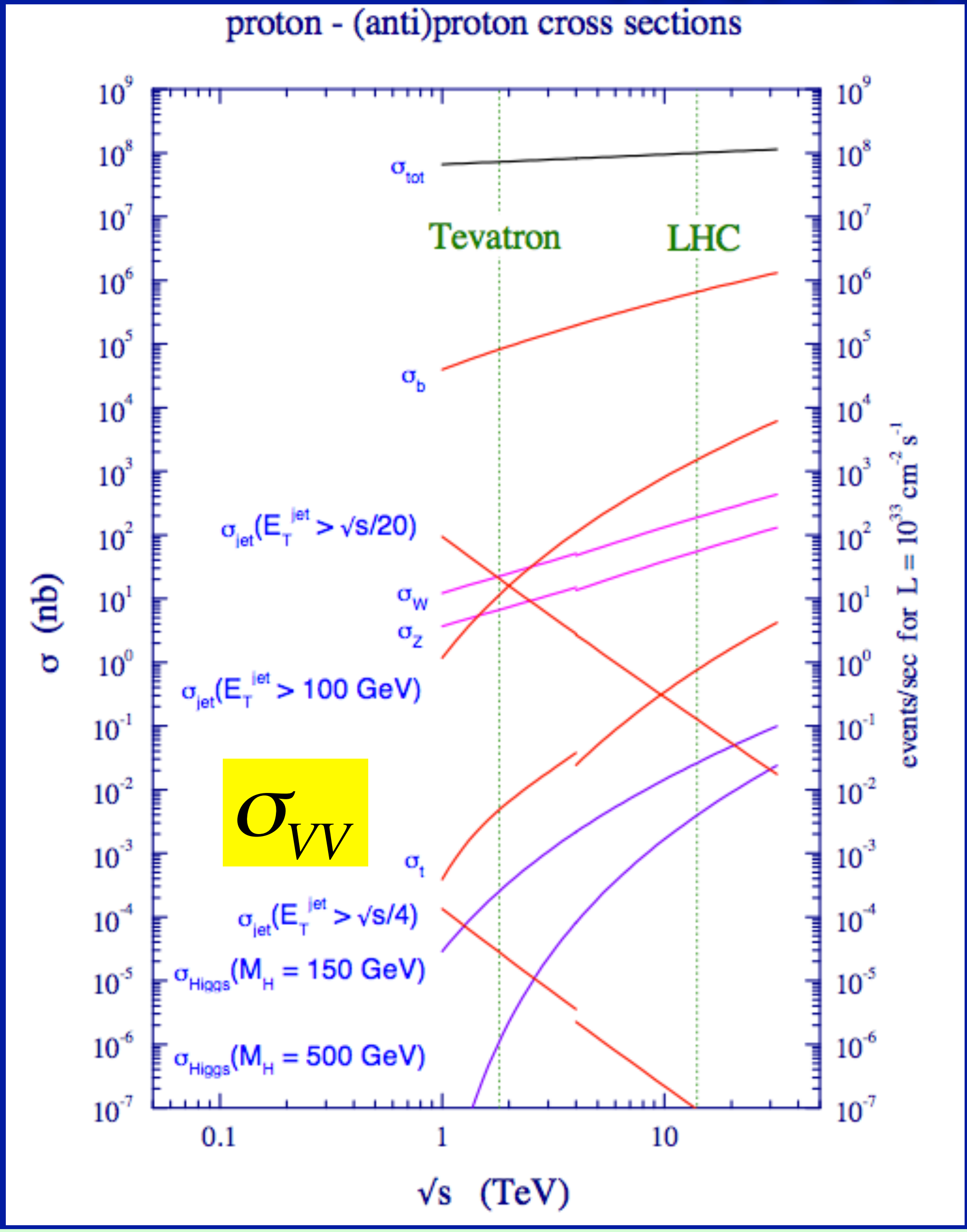
Introduction





- Theoretically well established picture
- PDF from deep inelastic scattering
- Well identifiable final states
- Corrections: QCD, EWK, including radiation, line shape, spin-correlations …

Introduction



J.M.Cambel, J.W.Huston, W.J.Stirling arXiv:hep-ph/0611148v1

Need to cover a wide region of cross sections

Tevatron Run II

2002-11 1.96 TeV 10.5 fb^{-1}

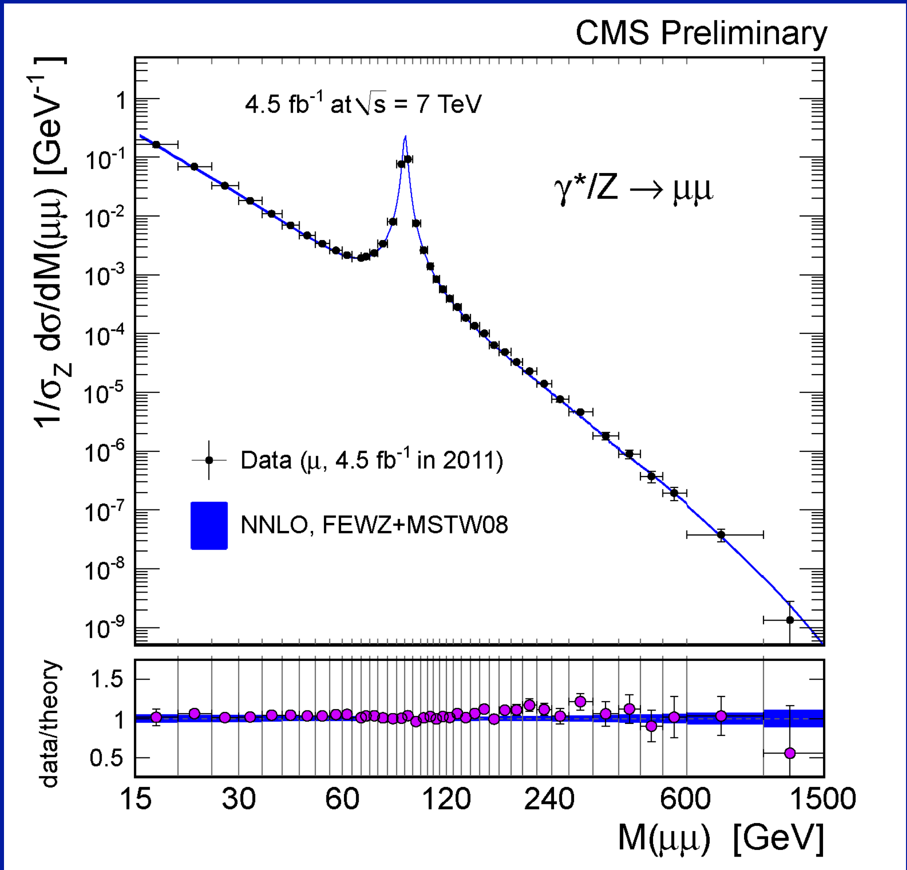
LHC

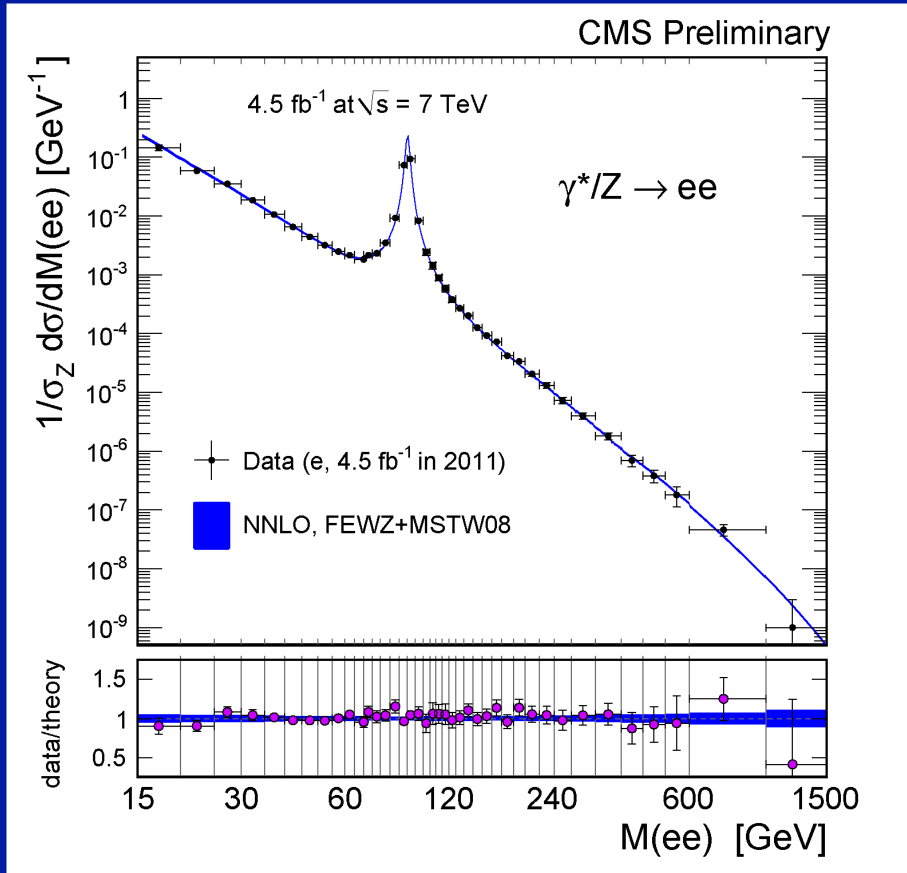
2010	7 TeV	36 pb^{-1}
2011	7 TeV	5 fb^{-1}
2012A+B	8 TeV	5 fb^{-1}
2012C	8 TeV	…

Due to natural limitations of this talk only most recent measurements will be presented

Drell-Yan Production

CMS-PAS-EWK-11-007



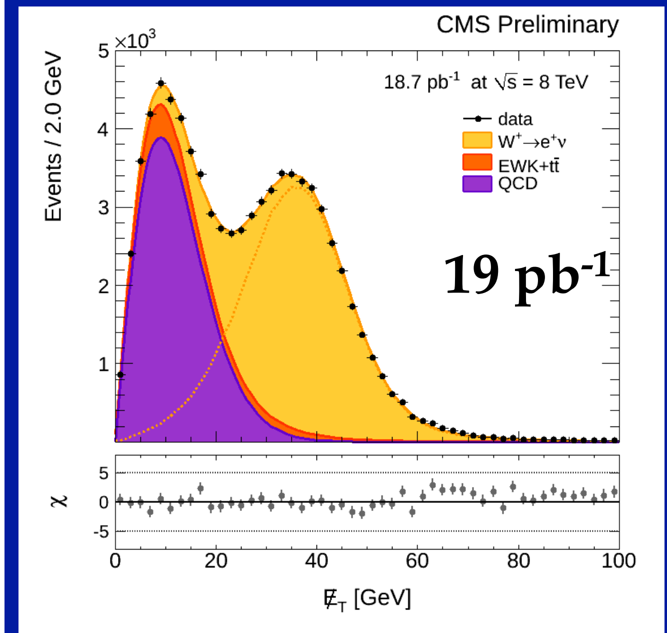


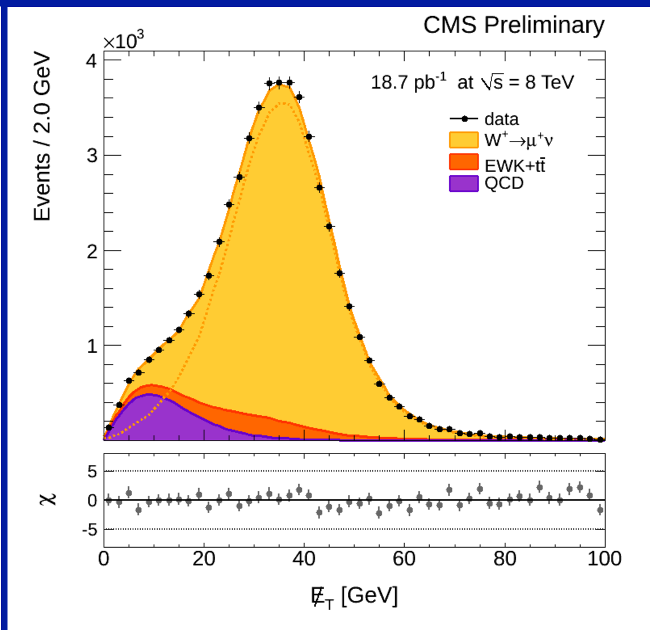
Few Millions of events, NNLO describes the data well

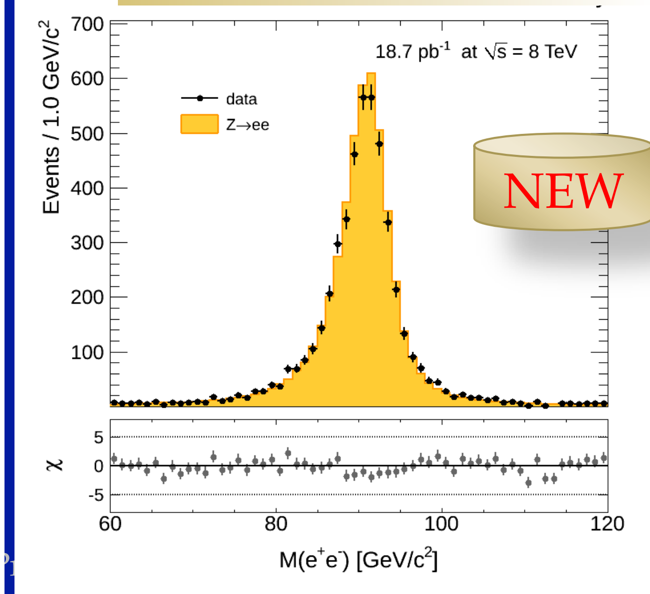
W , Z cross section measurement

- LHC luminosity is increasing – $2x10^{31}$ in 2010 to $7x10^{33}$ 2012
- Average number of inelastic pp interaction (pileup) increased from 2 to 20
- Precise measurement of inclusive cross section requires low pileup and low P_T trigger thresholds

CMS-PAS-SMP-12-011





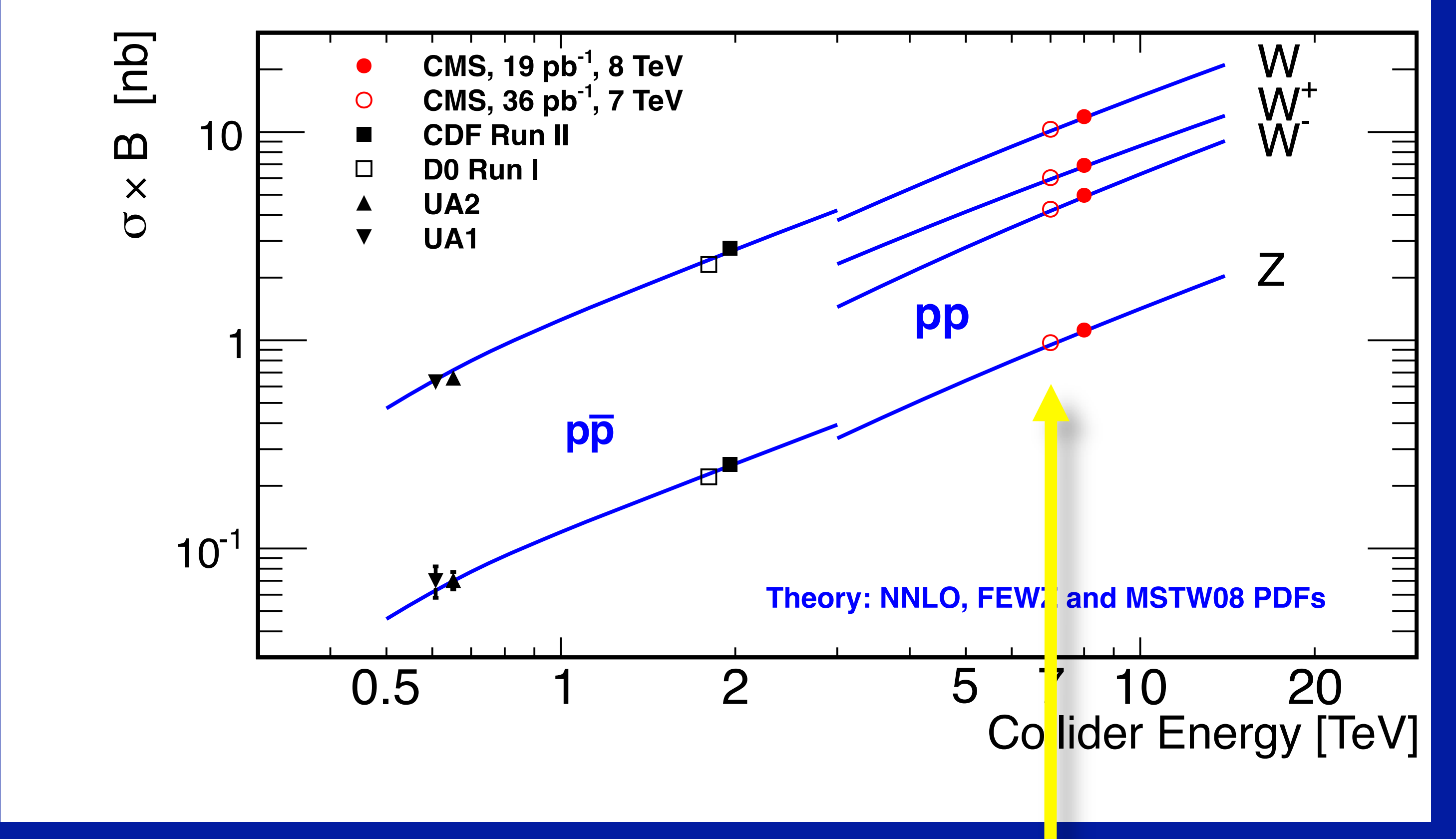


NEW

W , Z cross section measurement

JHEP 10 (2011) 132

CMS-PAS-SMP-12-011



NEW

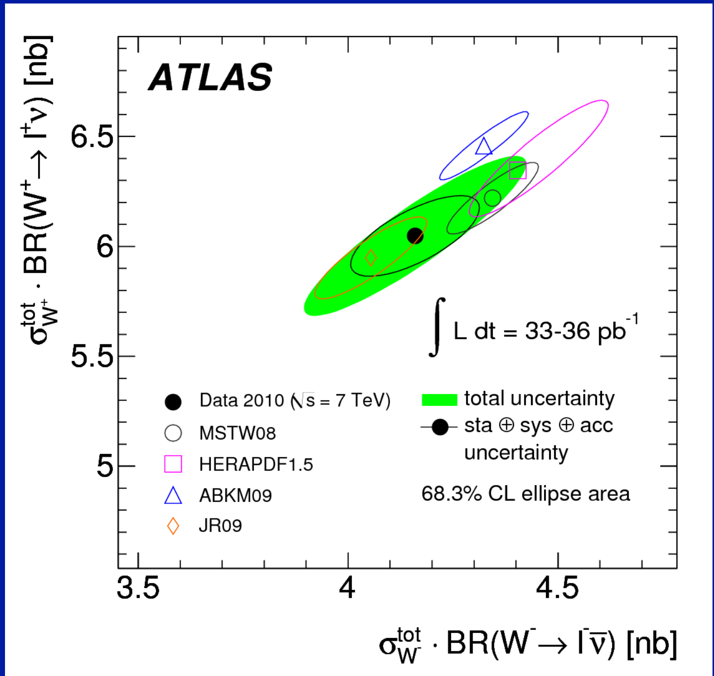
Phys.Rev. D85 (2012) 072004

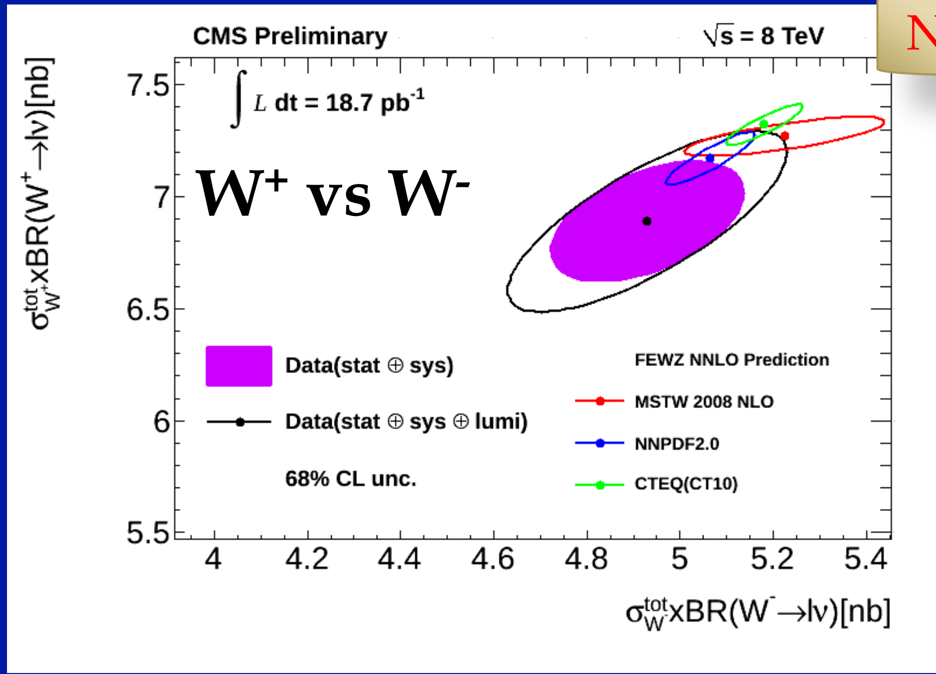
ATLAS 7 TeV
almost the same as CMS

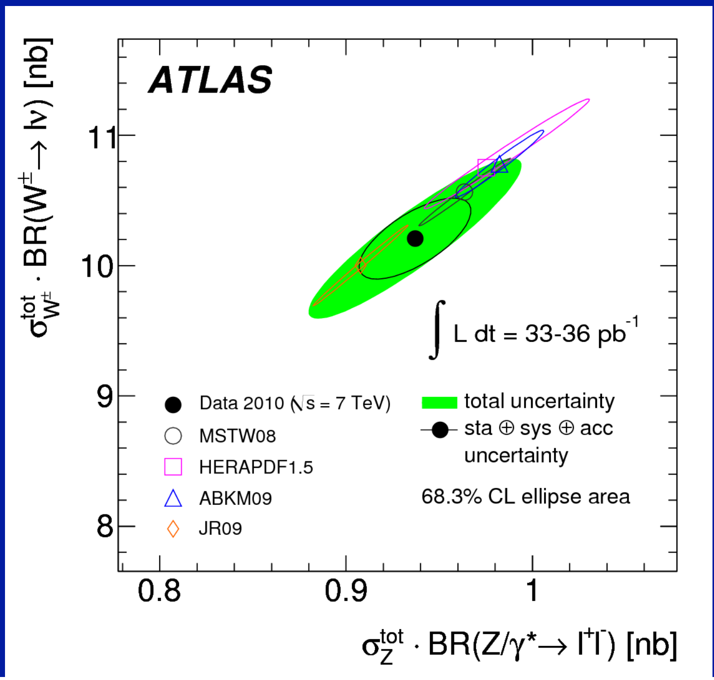
Phys.Rev. D85 (2012) 072004

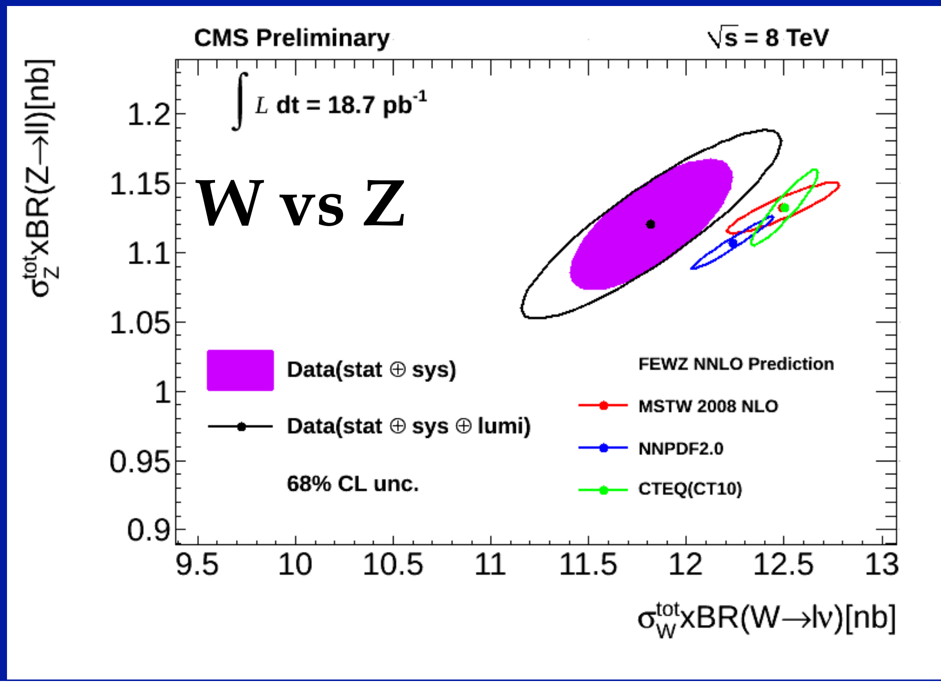
CMS-PAS-SMP-12-011

NEW





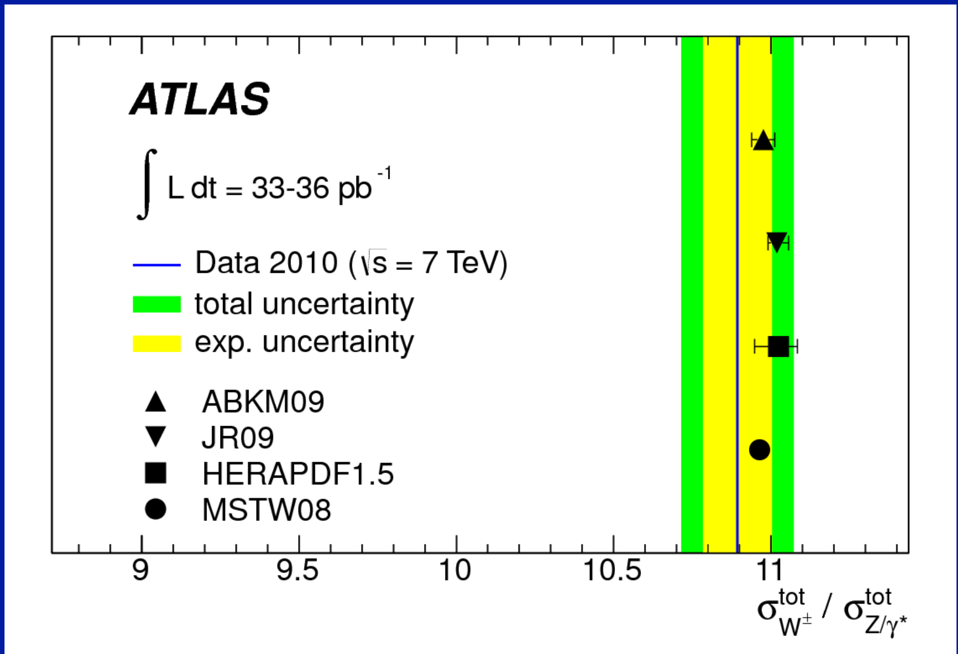


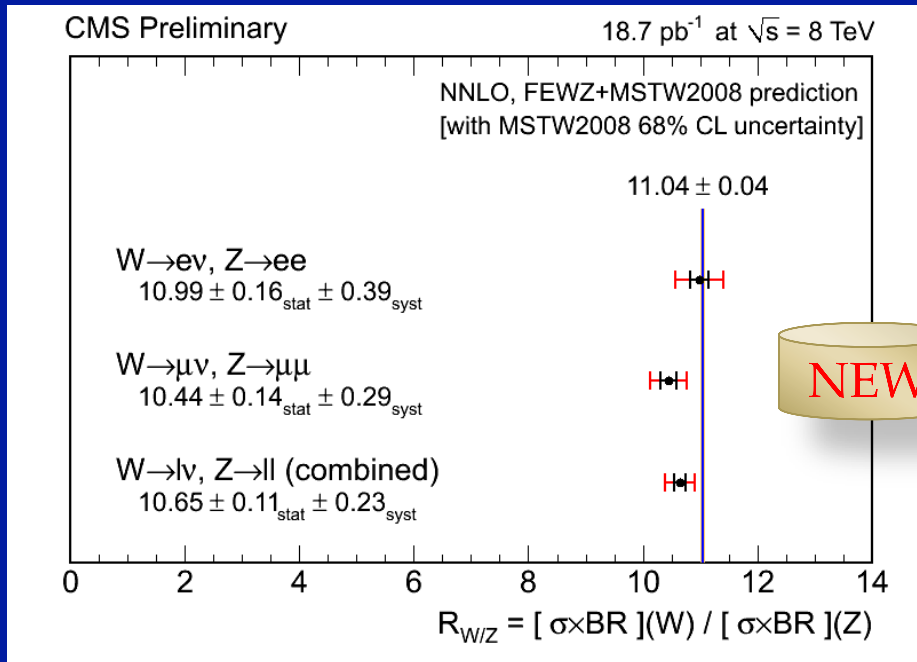


Cross-section ratios W/Z

Phys.Rev. D85 (2012) 072004

CMS-PAS-SMP-12-011



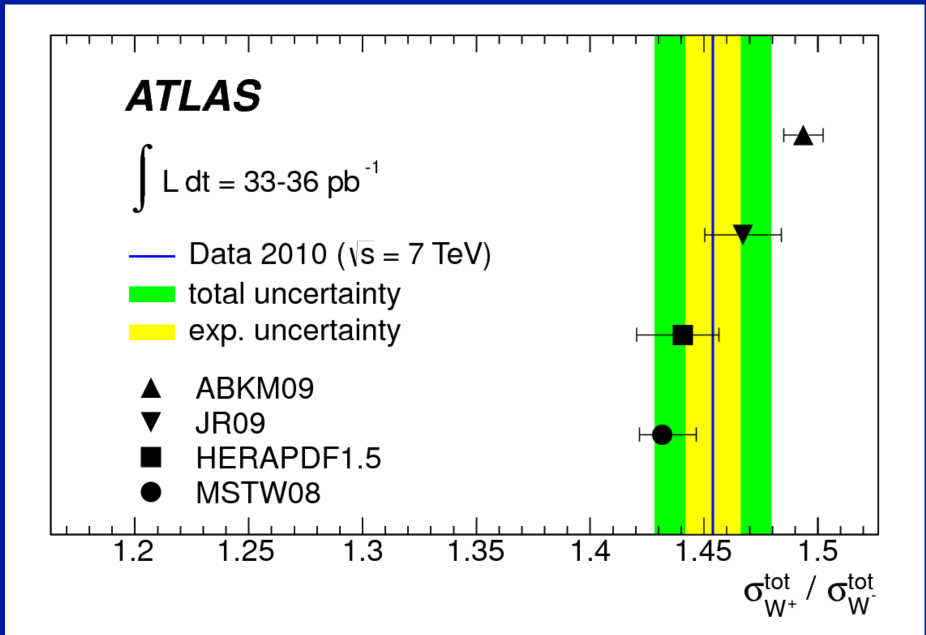


NEW

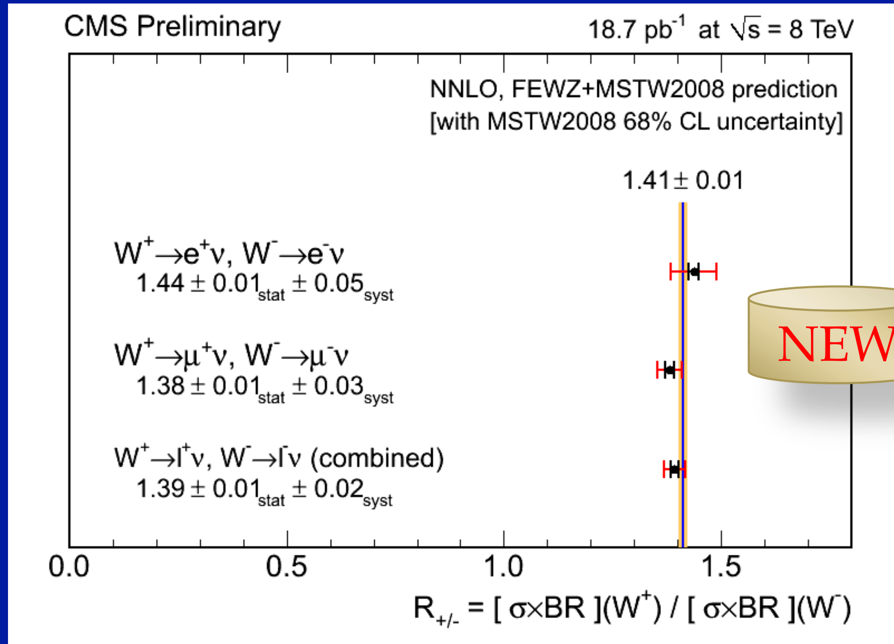
ATLAS	**7 TeV**	**10.893 +/- 0.079 (stat.) +/- 0.110 (syst.) +/- 0.116 (acc)**
CMS	7 TeV	10.54 +/- 0.07 (stat.) +/-0.08 (syst.) +/- 0.16 (th.)
CMS	8 TeV	10.65 +/- 0.11 (stat.) +/- 0.23 (syst.)

Cross-section ratios W^+/W^-

Phys.Rev. D85 (2012) 072004



CMS-PAS-SMP-12-011



NEW

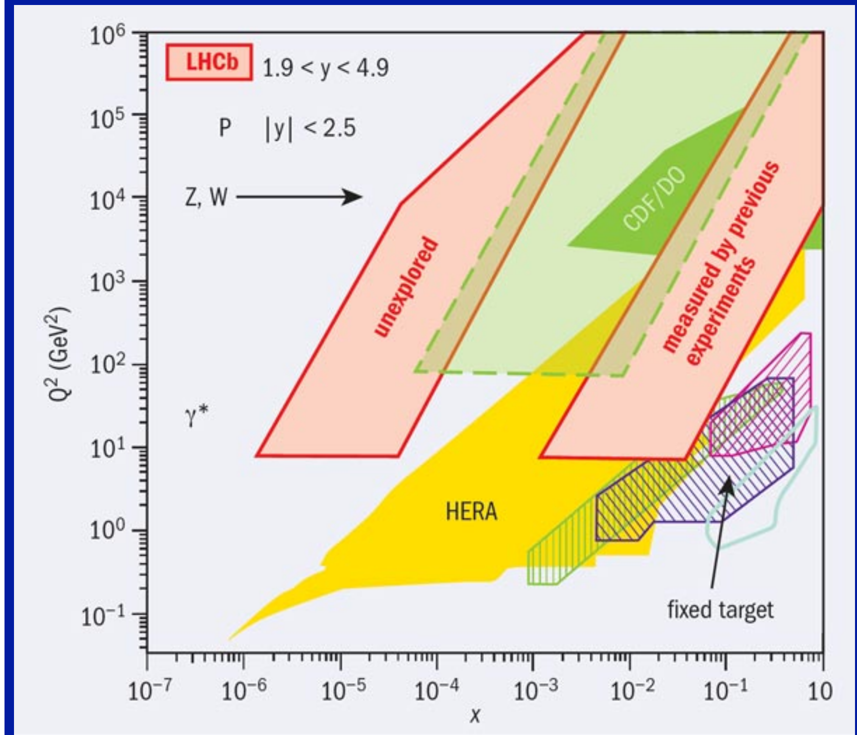
ATLAS	**7 TeV**	**1.454 +/- 0.006 (stat.) +/- 0.012 (syst.) +/- 0.022 (acc.)**
CMS	7 TeV	1.421 +/- 0.006 (stat.) +/- 0.014 (syst.) +/- 0.029 (th.)
CMS	8 TeV	1.39 +/- 0.01 (stat.) +/- 0.02 (syst.)

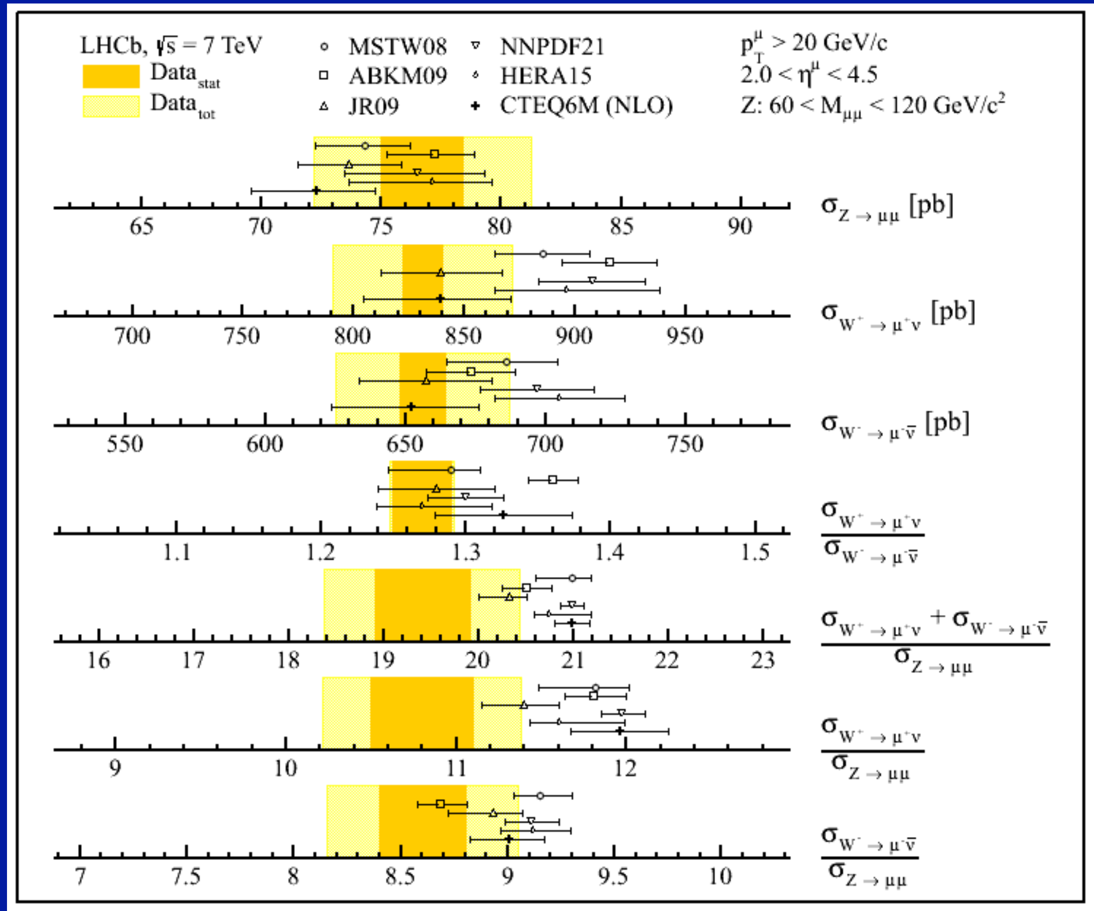
W and Z from LHCb

2.0 < η < 4.5

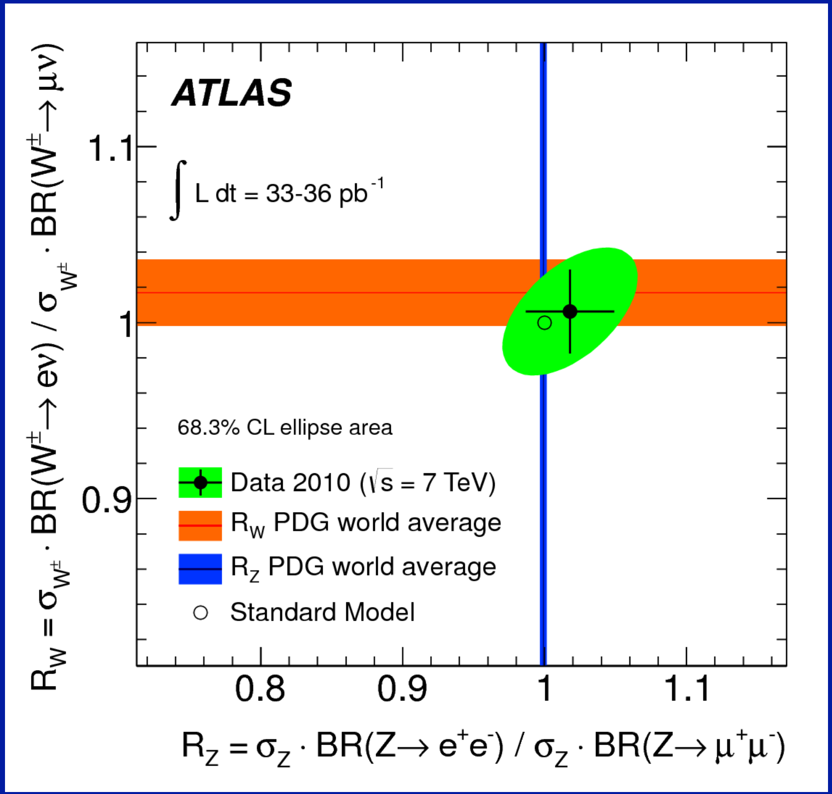
JHEP 06 (2012) 058 (mumu), LHCb-CONF-2012-011 (ee)

LHC





Lepton universality



Phys.Rev. D85 (2012) 072004

World average

R_W=1.017 +/- 0.019

R_Z=0.9991+/-0.0024

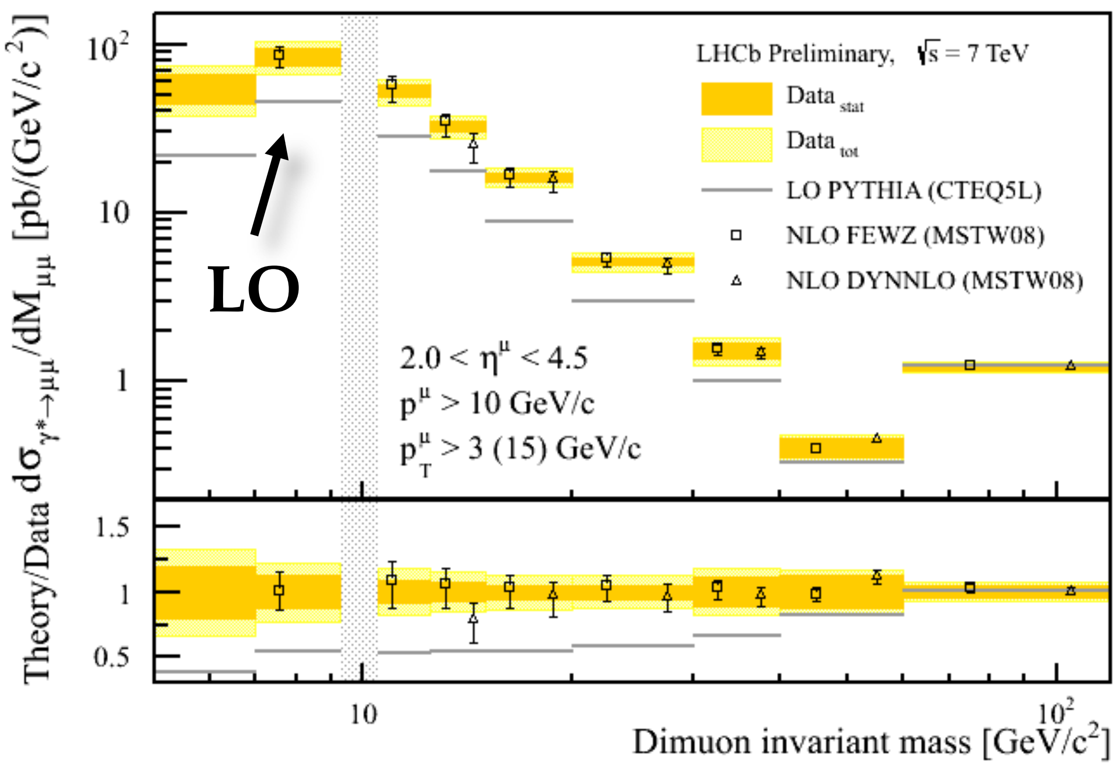
$$R_W = \frac{\sigma_W^e}{\sigma_W^\mu} = \frac{Br(W \to e\nu)}{Br(W \to \mu\nu)} = 1.006 \pm 0.004(stat.) \pm 0.006(unc.) \pm 0.022(corr.)$$

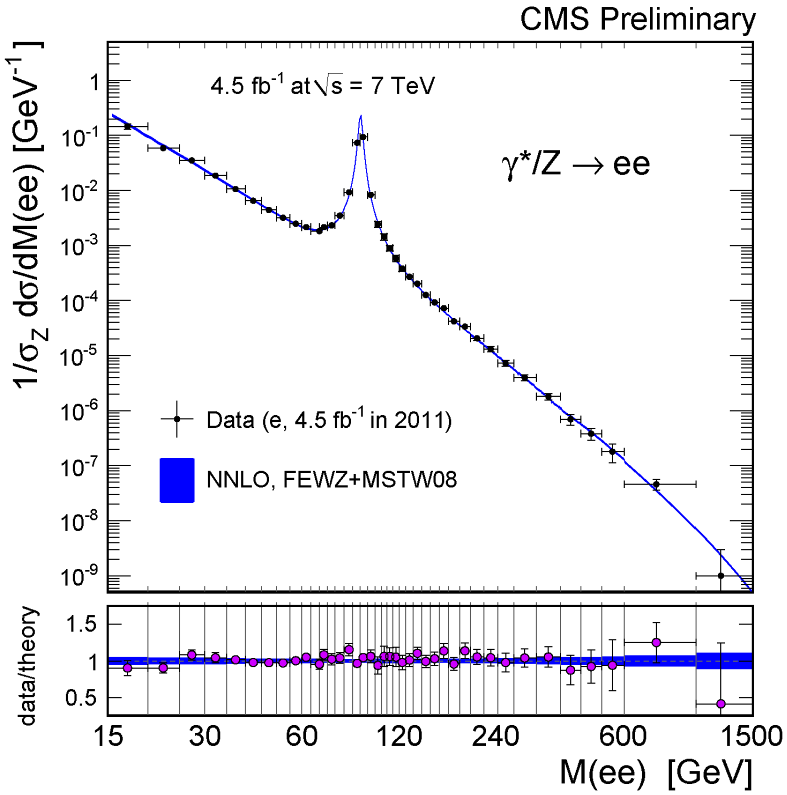
$$R_Z = \frac{\sigma_Z^e}{\sigma_Z^\mu} = \frac{Br(W \to ee)}{Br(W \to \mu\mu)} = 1.018 \pm 0.014(stat.) \pm 0.016(unc.) \pm 0.028(corr.)$$

Study of differential distributions

LHCb-CONF-2012-013

CMS-PAS-EWK-11-007

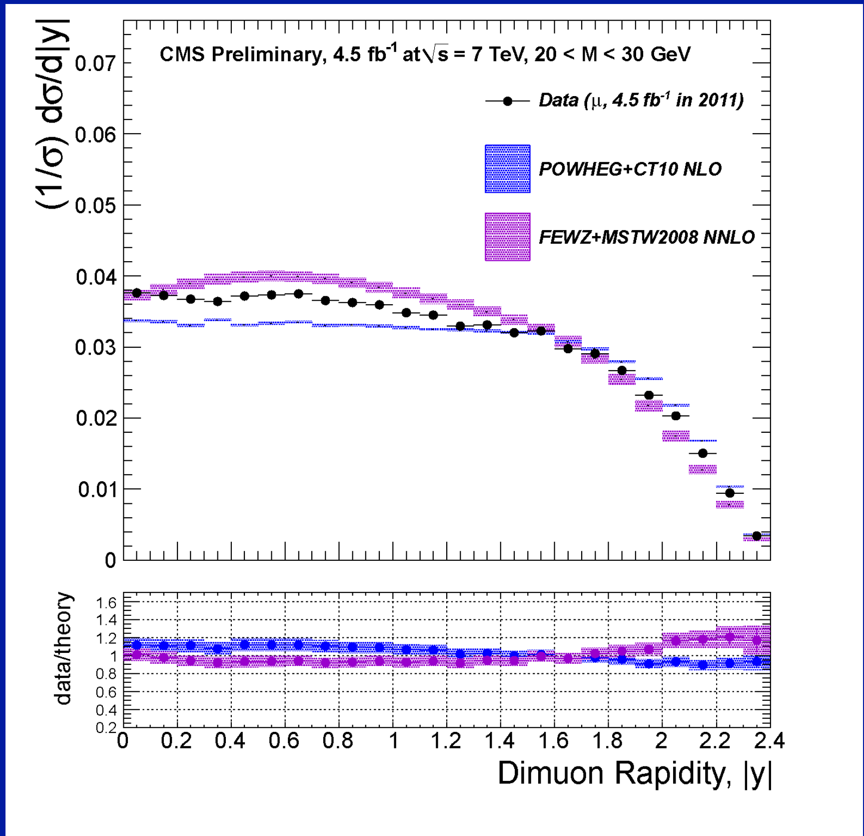


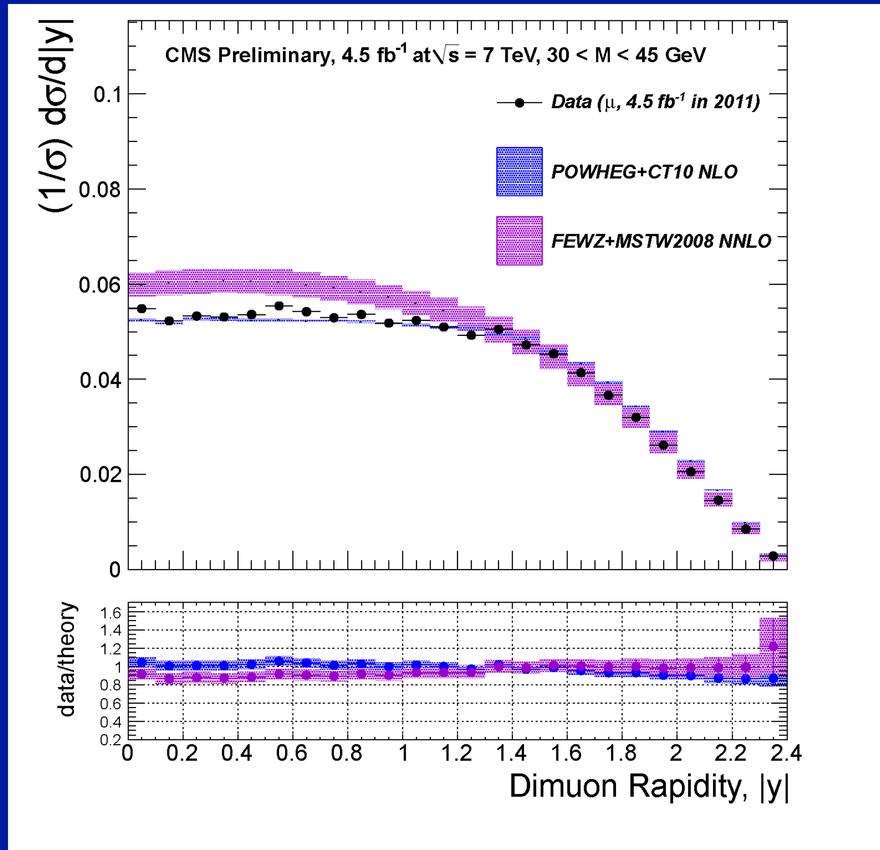


Theory well describes the invariant mass distributions

Differential distributions

CMS-PAS-EWK-11-007

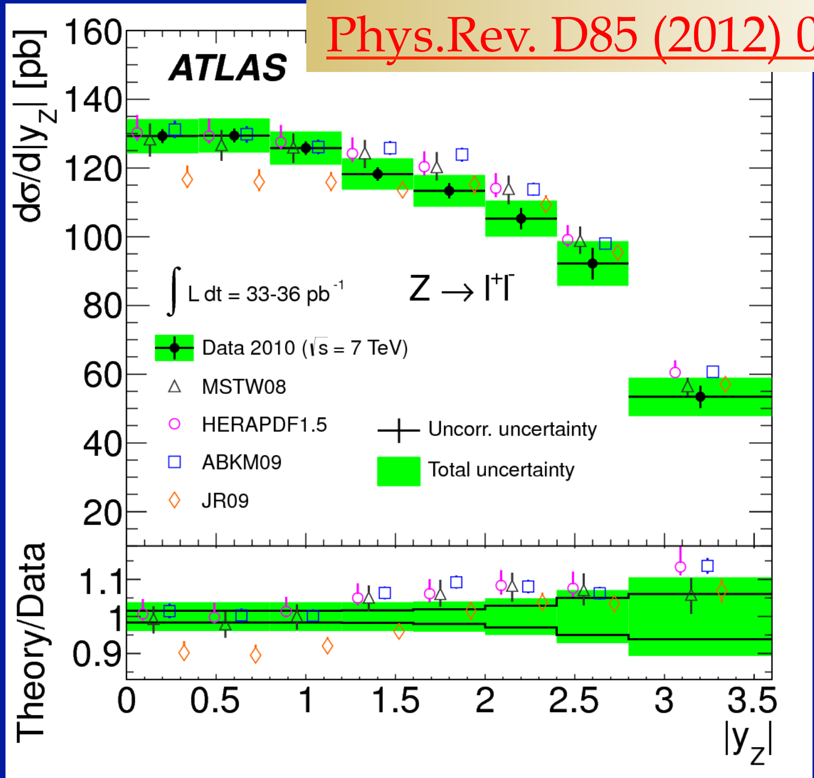




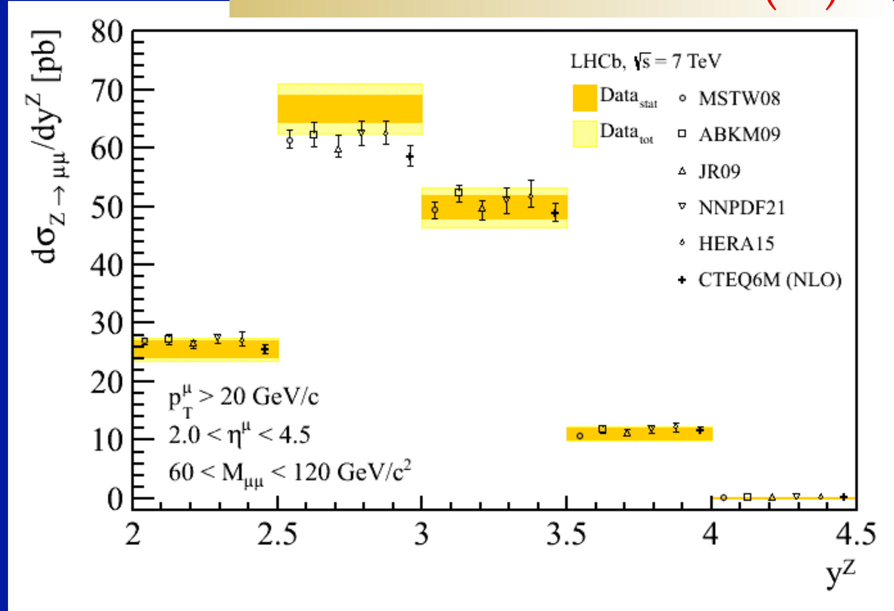
Significant differences between data and NLO/NNLO predictions at low masses

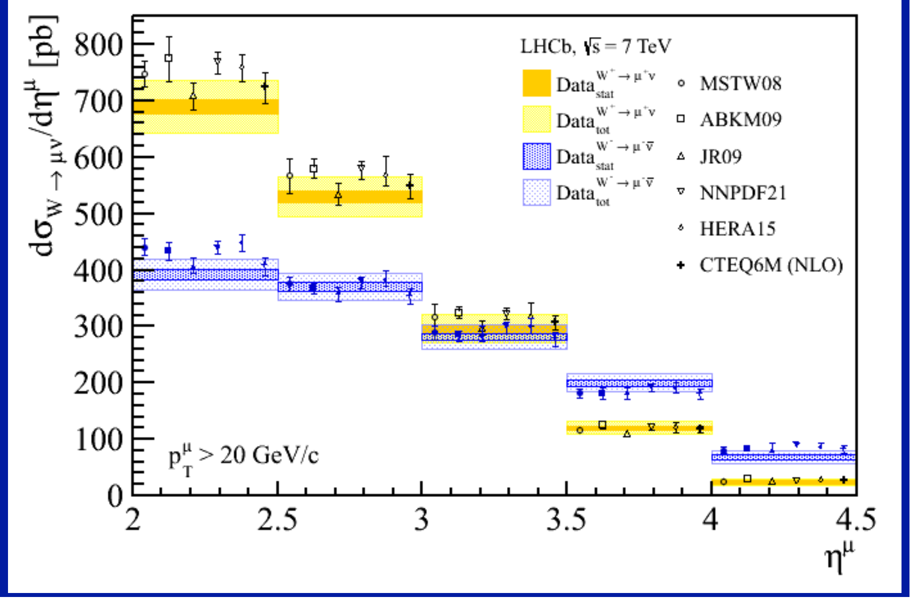
Study of differential distributions

Phys.Rev. D85 (2012) 072004



JHEP 06 (2012) 058 (mumu),
LHCb-CONF-2012-011 (ee)



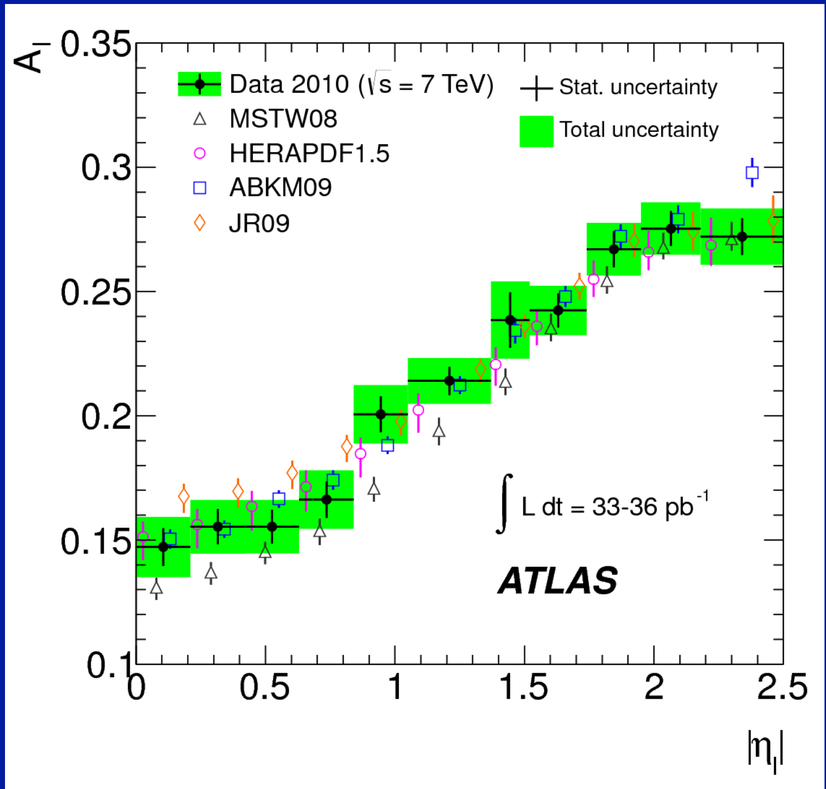


- NNLO predictions generally describe the data
- Differences due to PDFs are observed

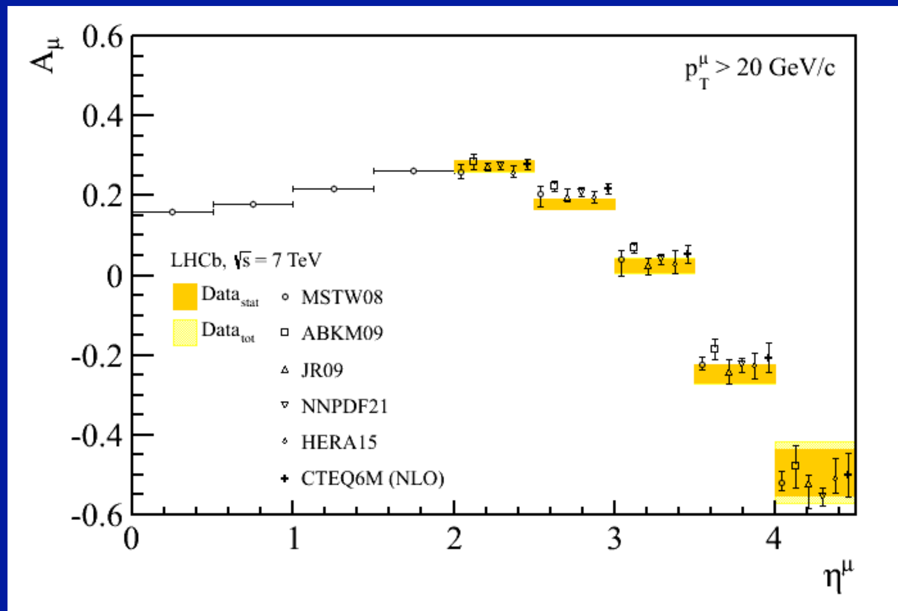
W charge asymmetry

- Charge Asymmetry, in pp access of *u*- over *d*- quarks
- Transverse Polarisation, $N_{qL} > N_{qR}$

Phys.Rev. D85 (2012) 072004



$$A_\ell(\eta_\ell) = \frac{d\sigma_{W^+}/d\eta_\ell - d\sigma_{W^-}/d\eta_\ell}{d\sigma_{W^+}/d\eta_\ell + d\sigma_{W^-}/d\eta_\ell}$$



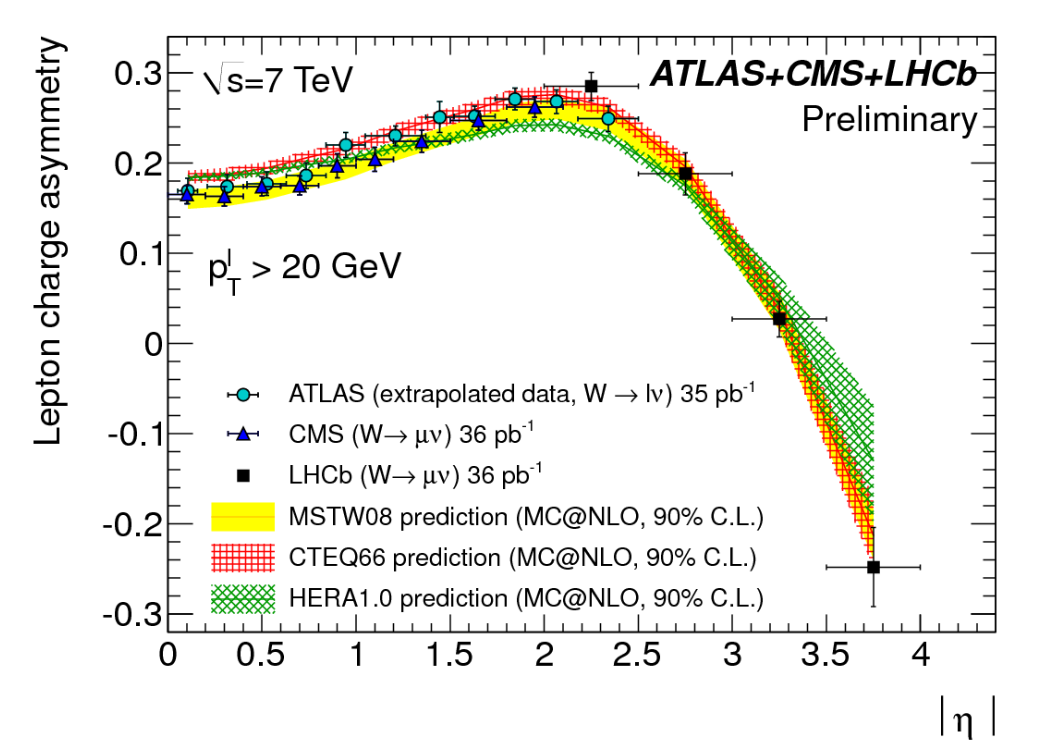
JHEP 06 (2012) 058

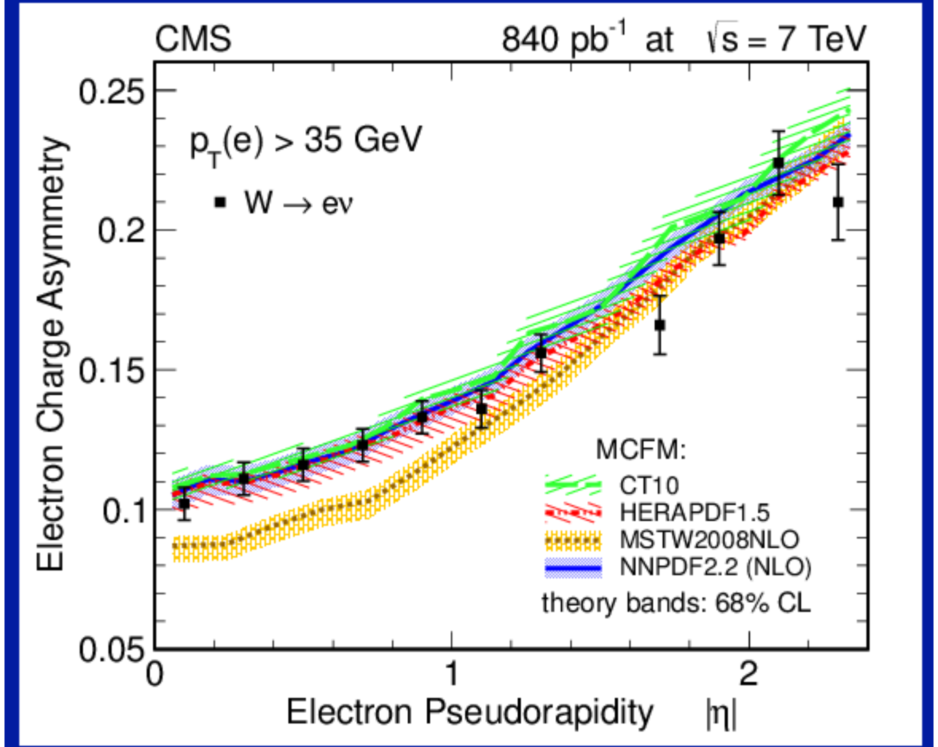
W charge asymmetry is reasonably well described by the NNLO, the deviations – individual XS measurements and correlations

W charge asymmetry

ATLAS-CONF-2011-129

arXiv:1206.2598, submitted to PLB





First combination from all LHC experiments

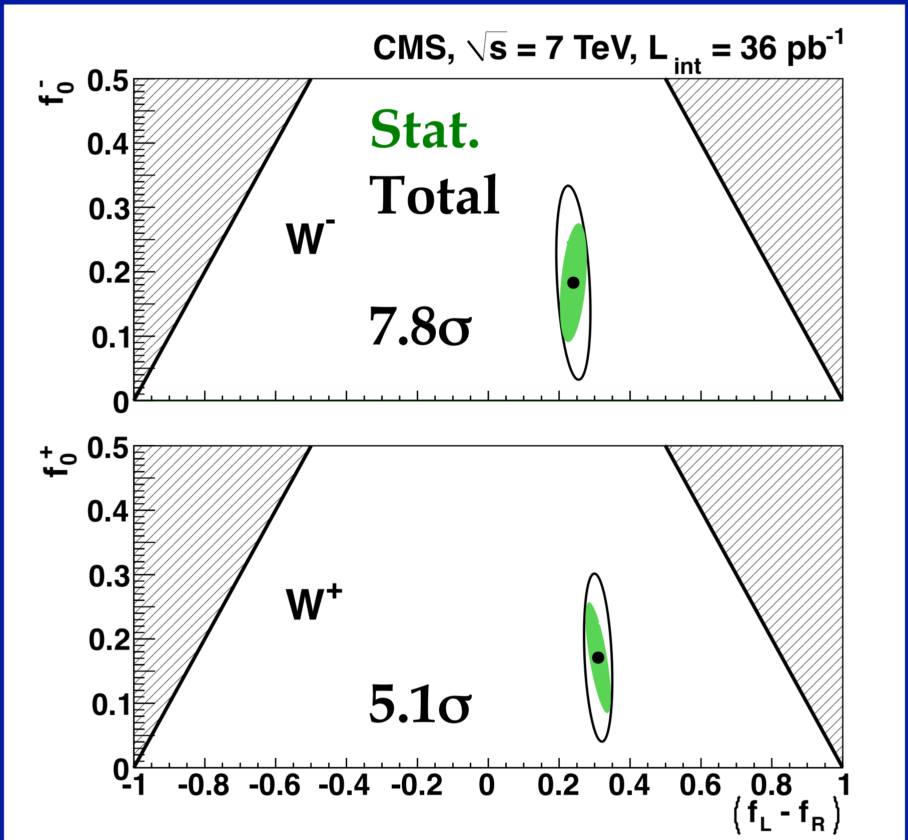
CMS measurement in electron channel

W polarization

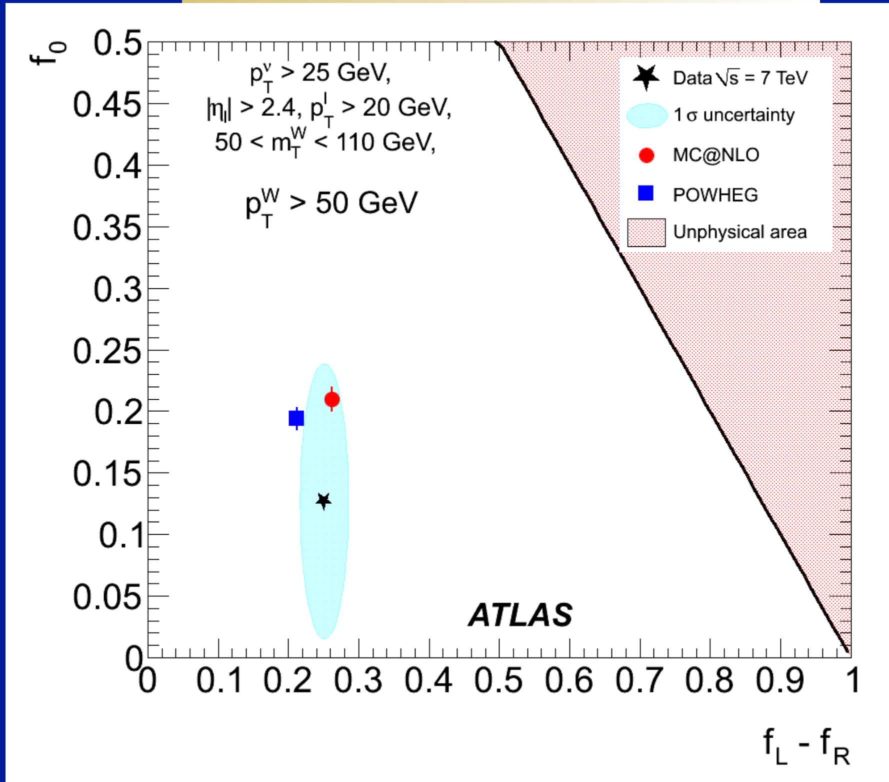
The left-handed, right-handed and longitudinal polarization fractions are measured using both muon and electron decays

$$W^+ : \sigma(\theta^*) \propto f_L \frac{(1-\cos\theta^*)^2}{4} + f_o \frac{\sin^2\theta^*}{2} + f_R \frac{(1+\cos\theta^*)^2}{4}$$

Phys.Rev.Lett. 107 (2011) 021802



Eur.Phys.J. C72 (2012) 2001



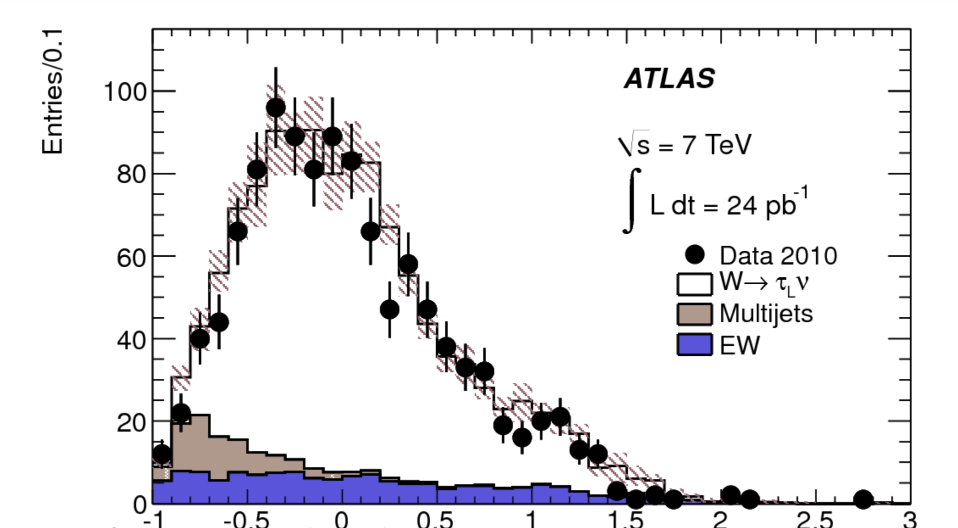
W at high-P_T in pp are left-handed, as expected by SM

Tau polarization

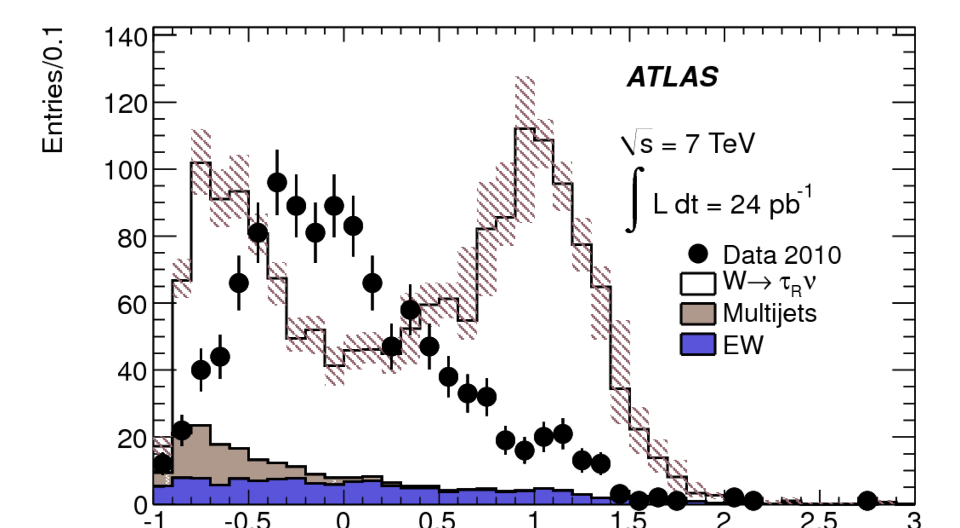
- Using $W \to \tau\nu$ $\quad \tau^{\mp} \to \pi^{\mp}\pi^{0}\nu$
  - W^- coupled to left-handed τ
  - W^+ coupled to right-handed τ
- $P_\tau = \sigma_R - \sigma_L / \sigma_R + \sigma_L$

$$\Upsilon = \frac{E_T^{\pi^{\mp}} - E_T^{\pi^0}}{p_T^{\tau}}$$

Eur.Phys.J. C72 (2012) 2062



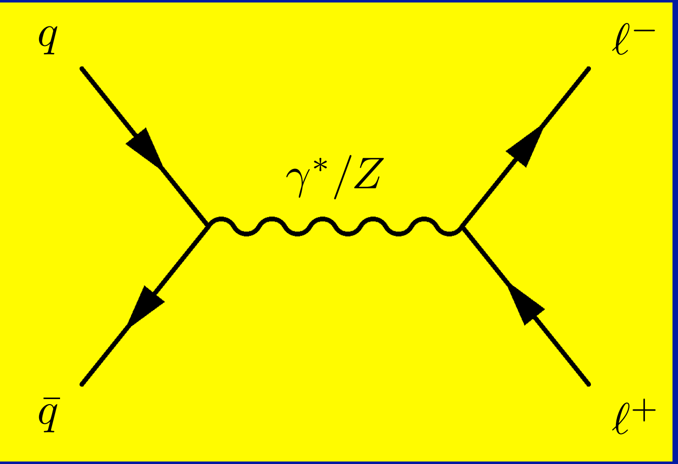
Left-handed



Right-handed

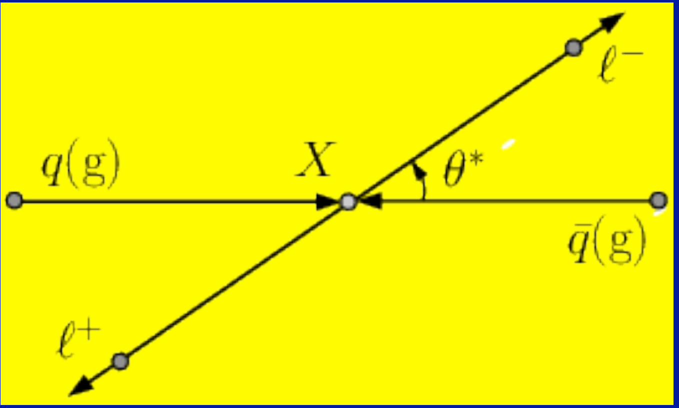
$$P_\tau = 1.06 \pm 0.04(stat.)^{+0.05}_{-0.07}(syst.)$$

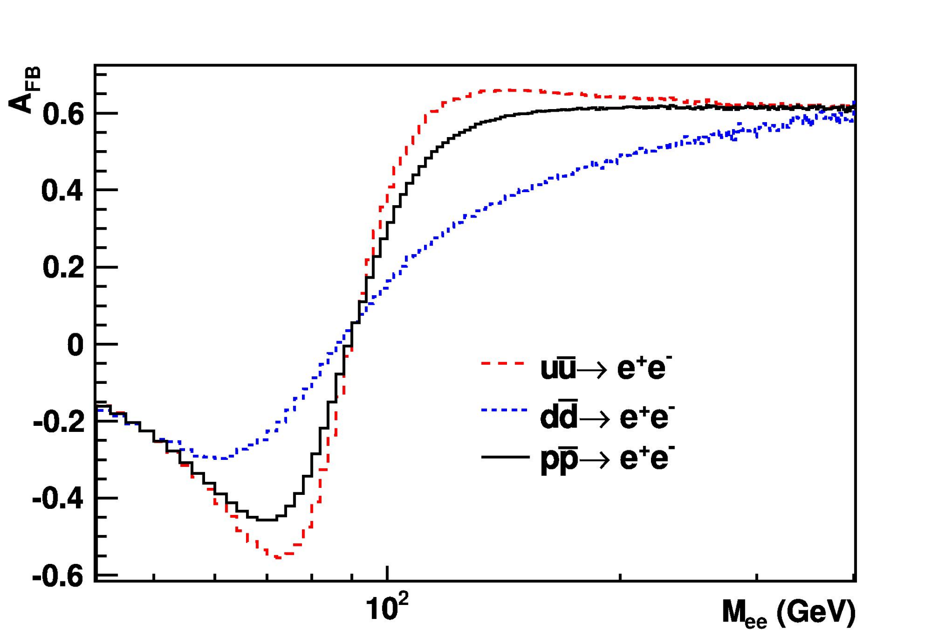
DY forward-backward asymmetry



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

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



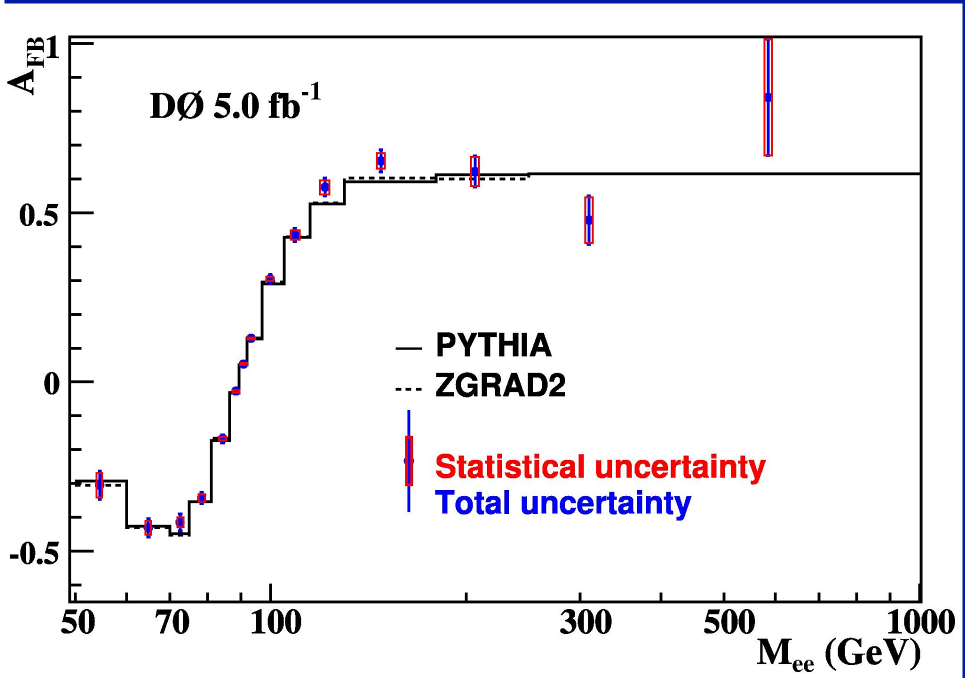


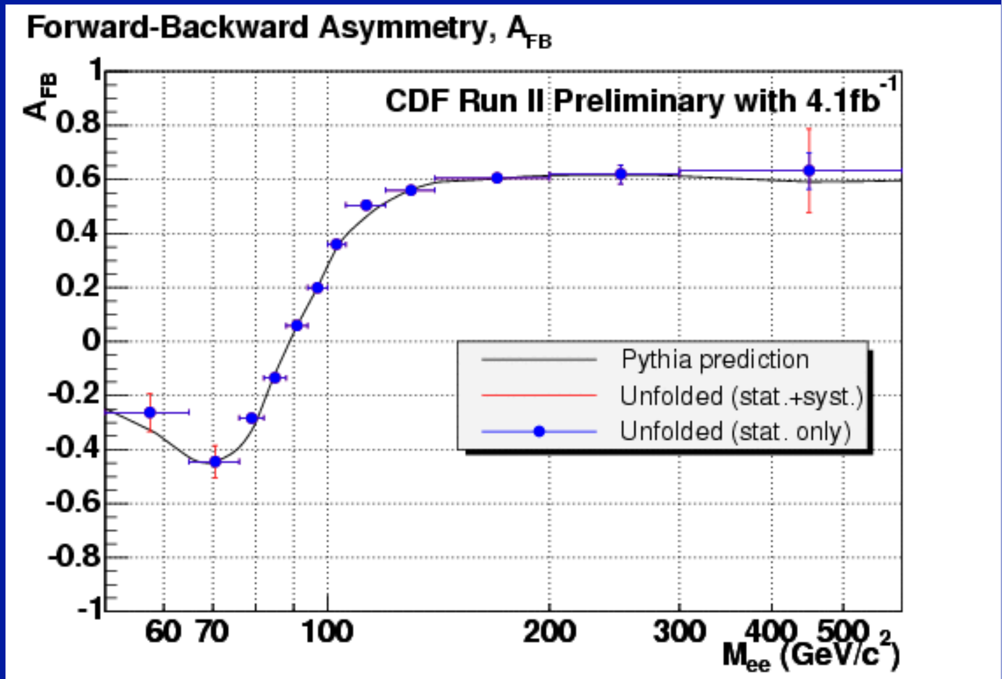
DY forward-backward asymmetry

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

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

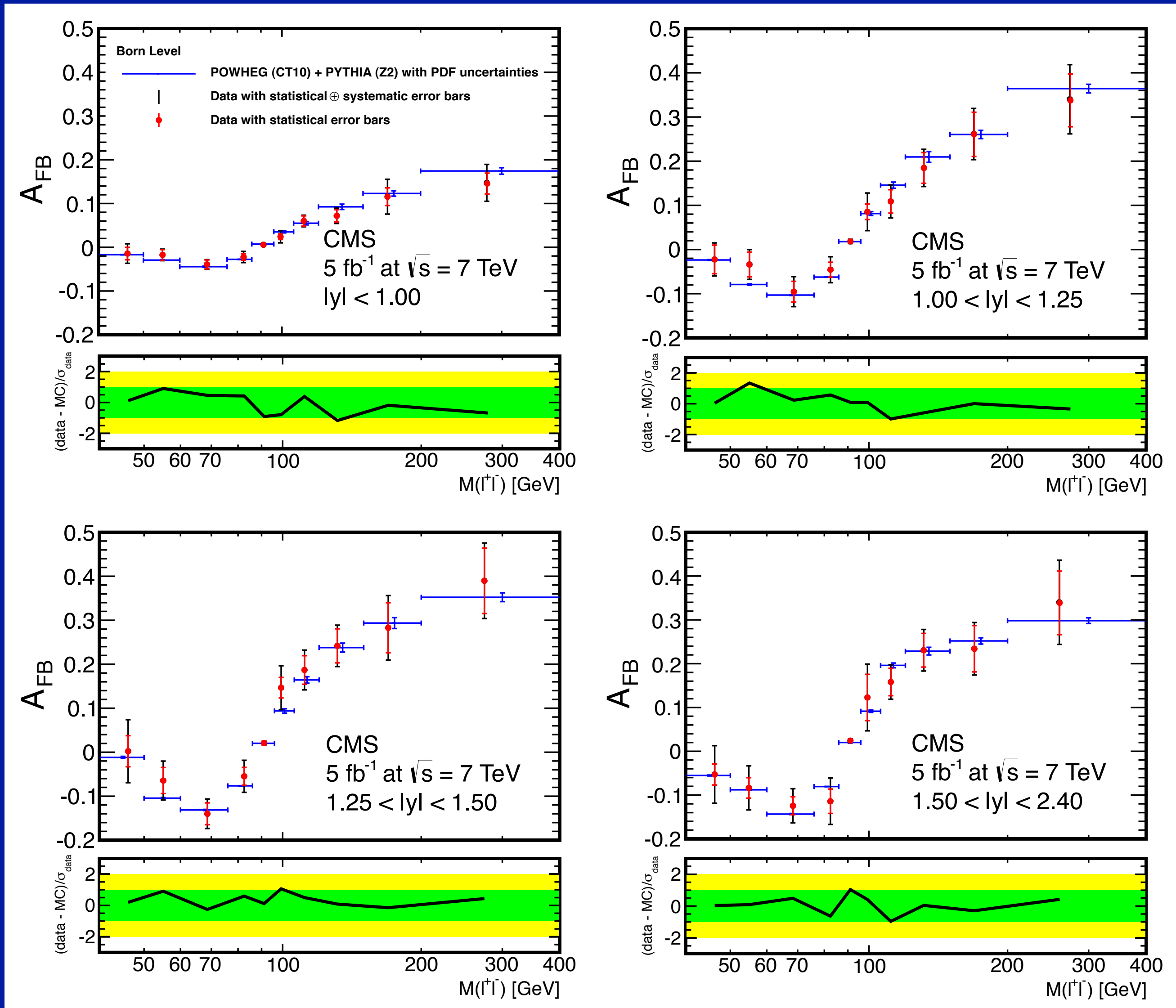
Phys.Rev.D84, 012007 (2011)





DY forward-backward asymmetry

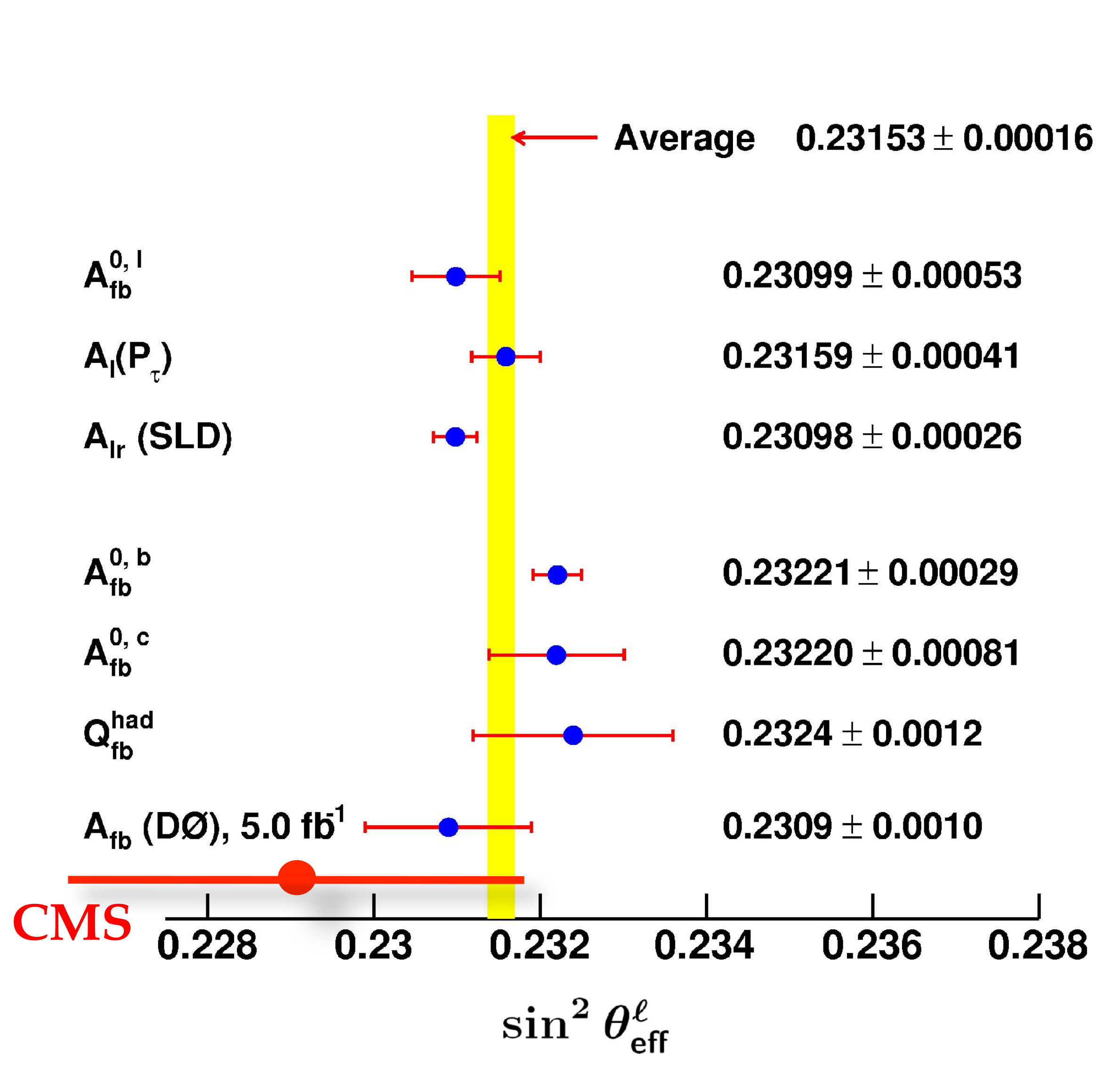
arXiv:12-7.3973, submitted to PLB



No evidence for new physics at high masses

Effective weak mixing angle

Phys.Rev.D84, 012007 (2011)

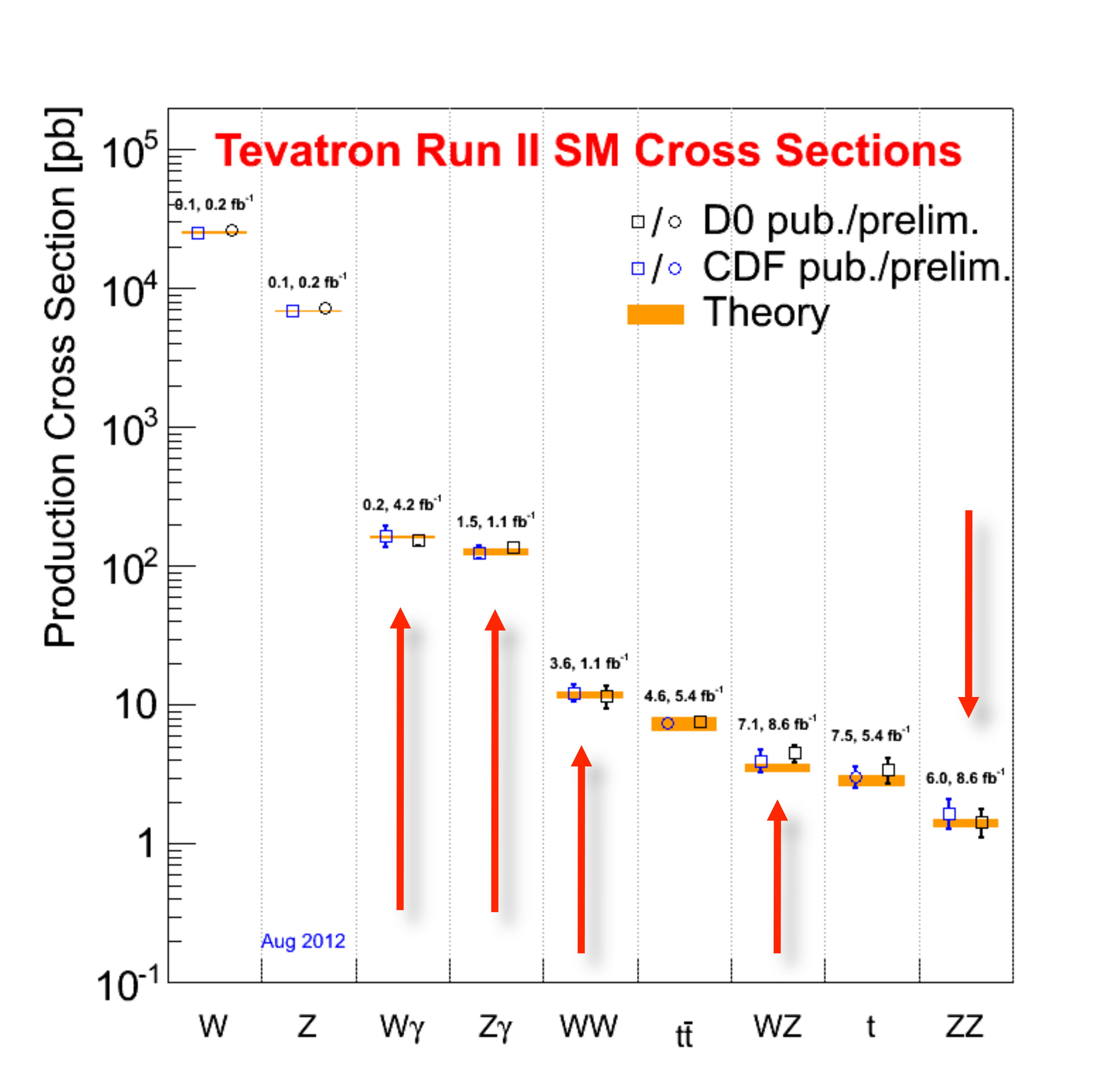


In the vicinity of the Z pole, A_{FB} is sensitive to the effective weak mixing angle

Phys.Rev.D84 (2011) 112002

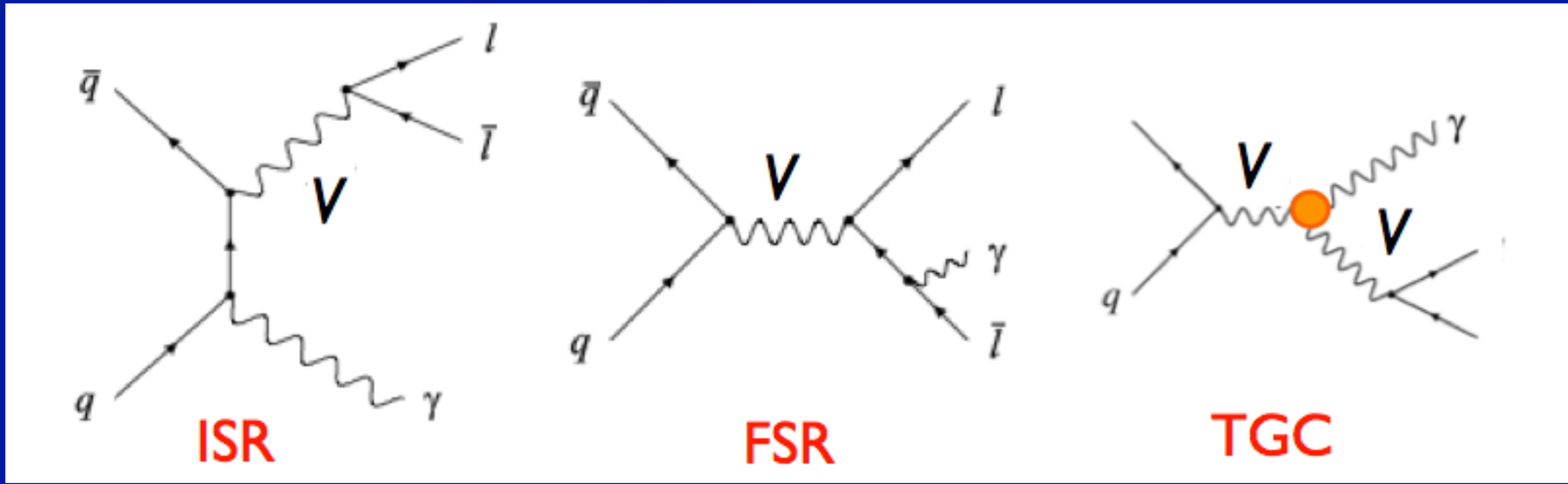
First measurement at LHC by CMS
0.229 +/-0.020+/-0.025 using 1 fb^{-1} of data

Diboson production

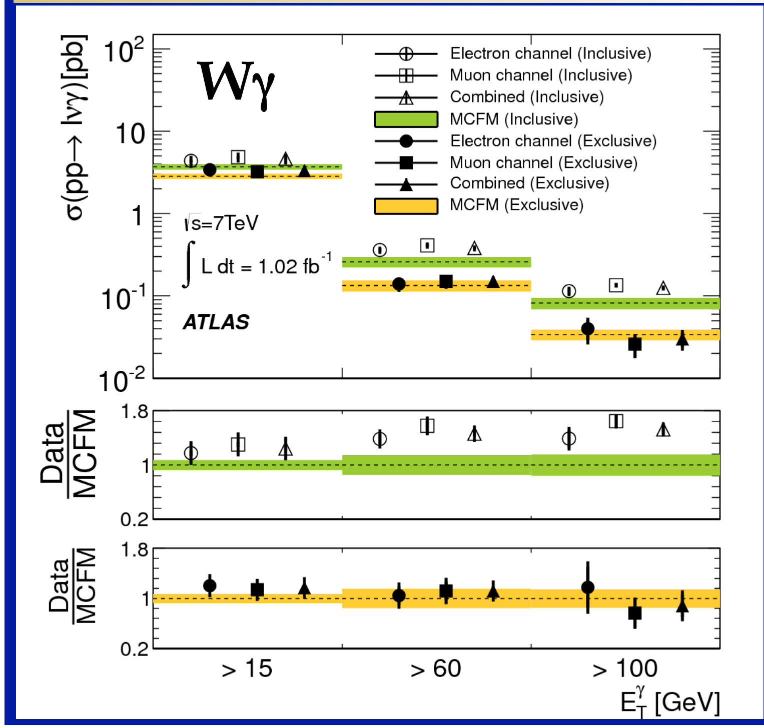


LHC provides an increasing luminosity at increased cross section – reduced statistical uncertainties, possibility to look into new decay channels

Wγ/Zγ production

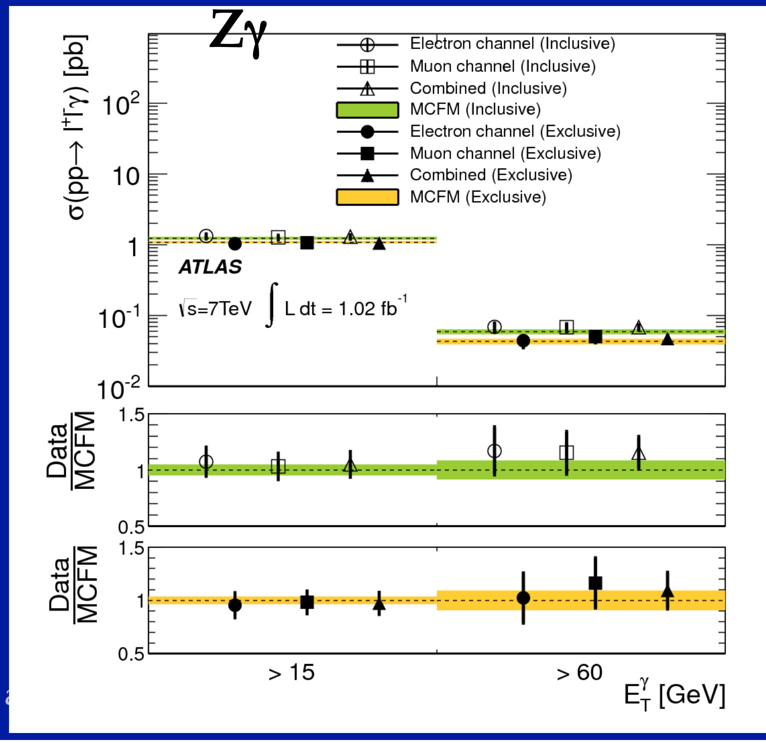


arXiv:1205.2531 , submitted to PLB



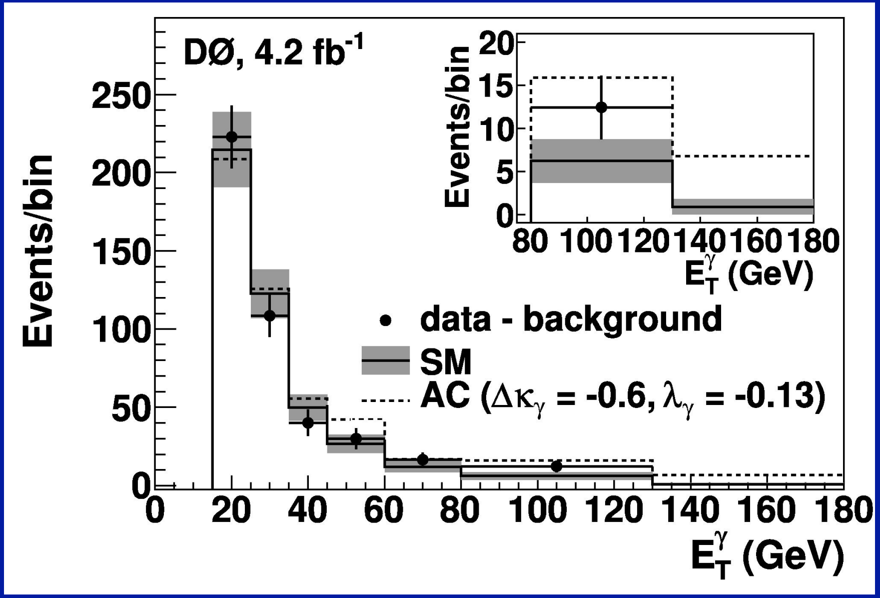
Pure agreement with MCFM for inclusive Wγ

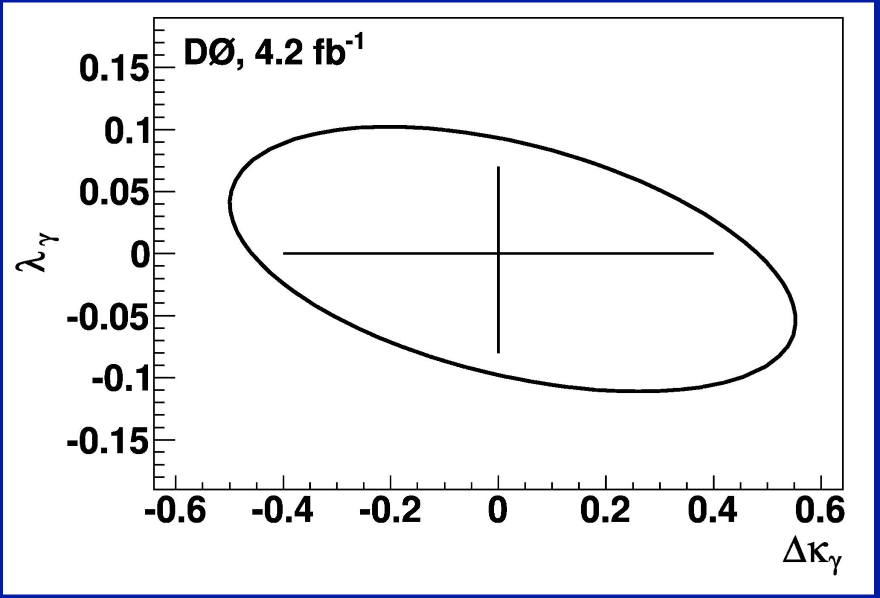
no jets >30 GeV



Anomalous WWγ coupling

Phys. Rev. Lett. **107, 241803 (2011)**





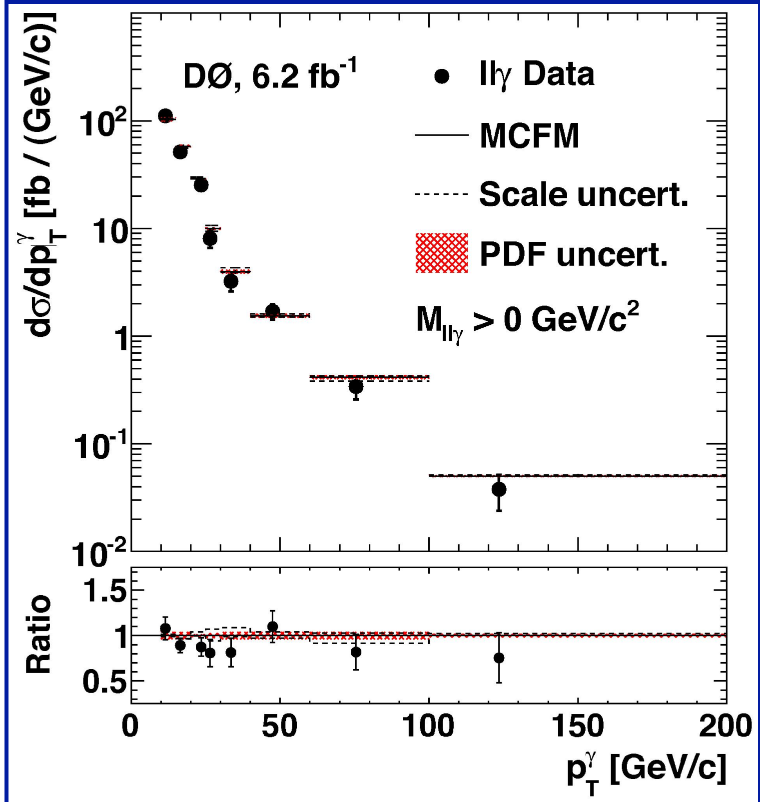
The most stringent limits on anomalous WWγ couplings for data from hadron colliders:

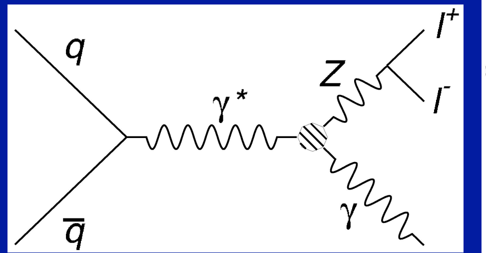
$-0.4 < \Delta\kappa_\gamma < 0.4$ and $-0.08 < \lambda_\gamma < 0.07$

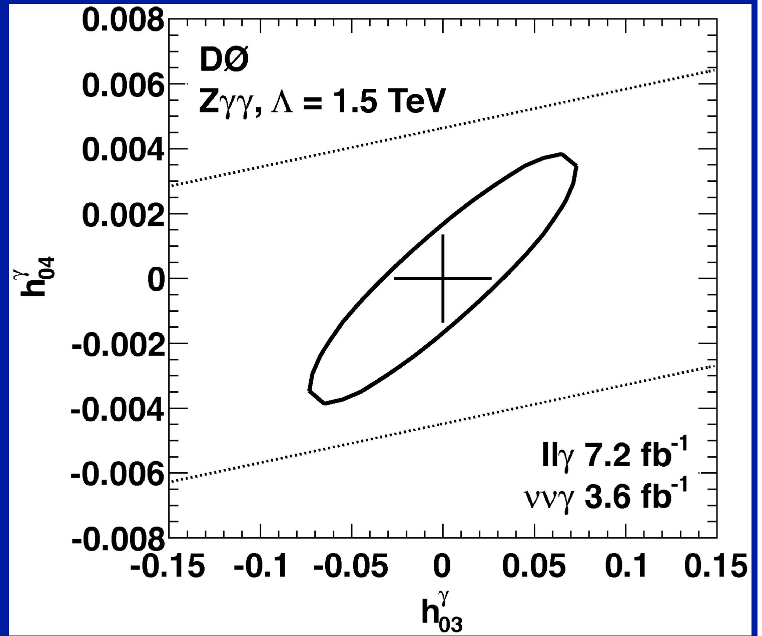
at the 95% C.L.

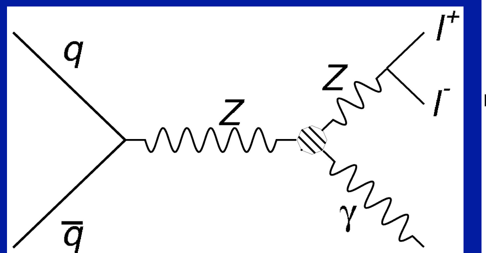
Anomalous ZZγ and Zγγ couplings

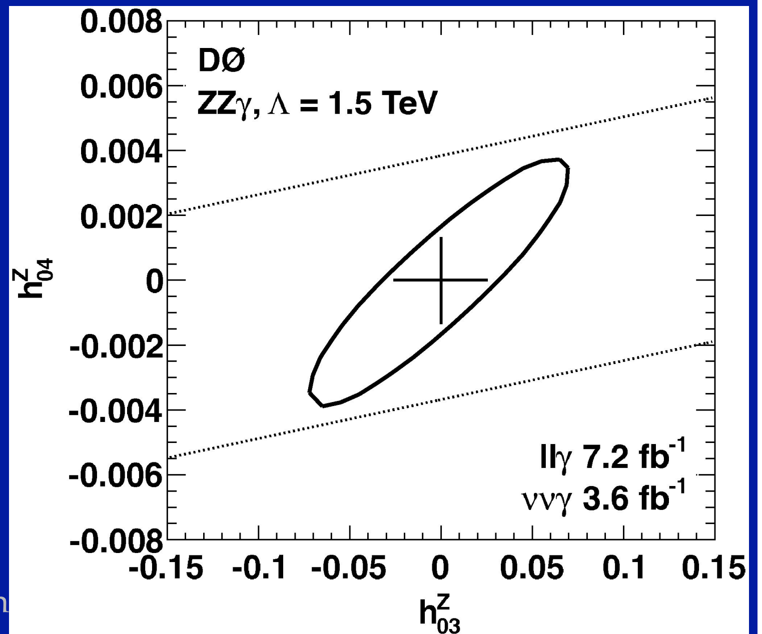
Phys. Rev. D85, **052001 (2012)**





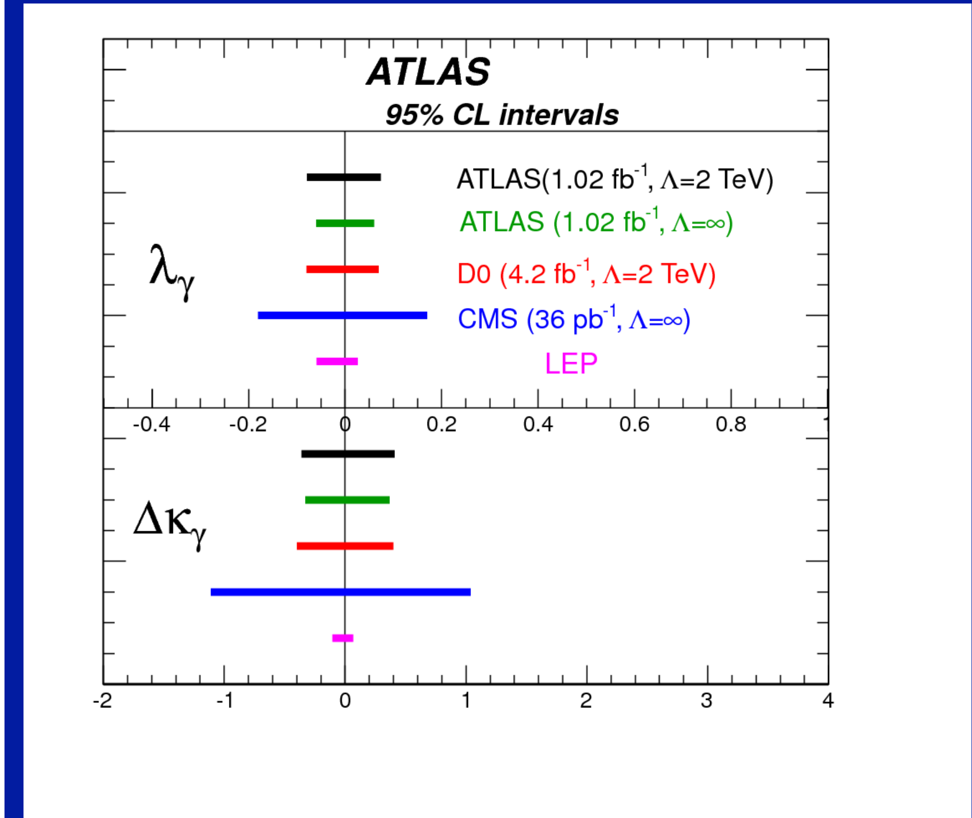


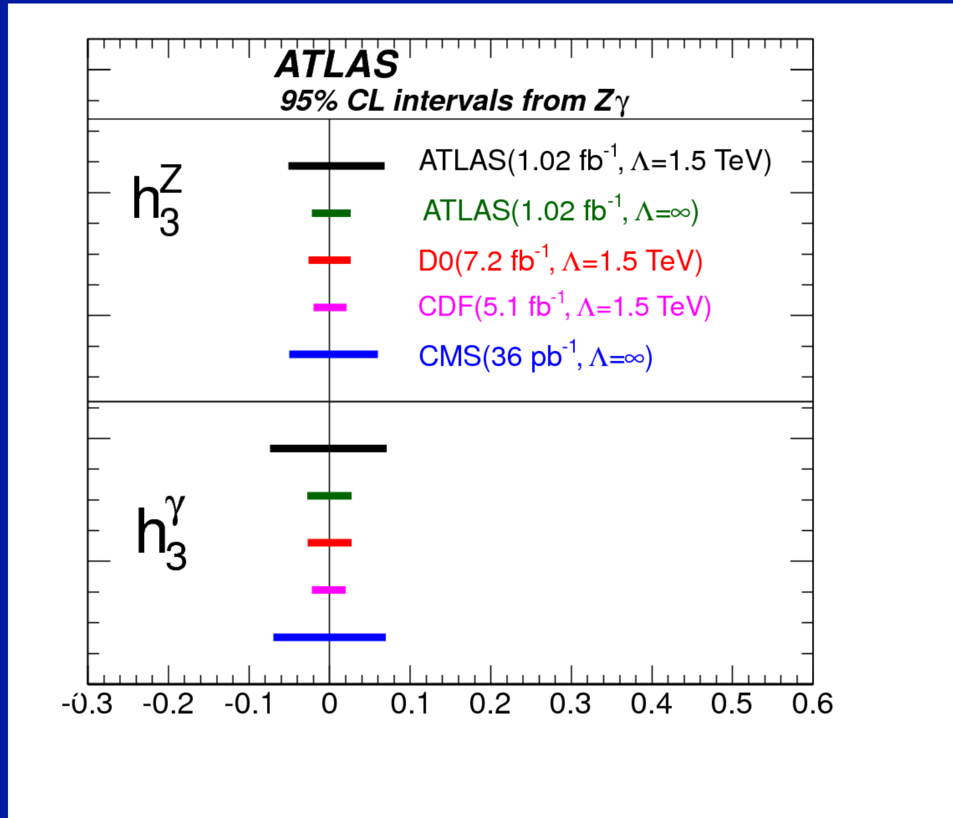




CDF: Phys. Rev. Lett. 107, **051802 (2011)**

WWγ, ZZγ and Zγγ aTGCs

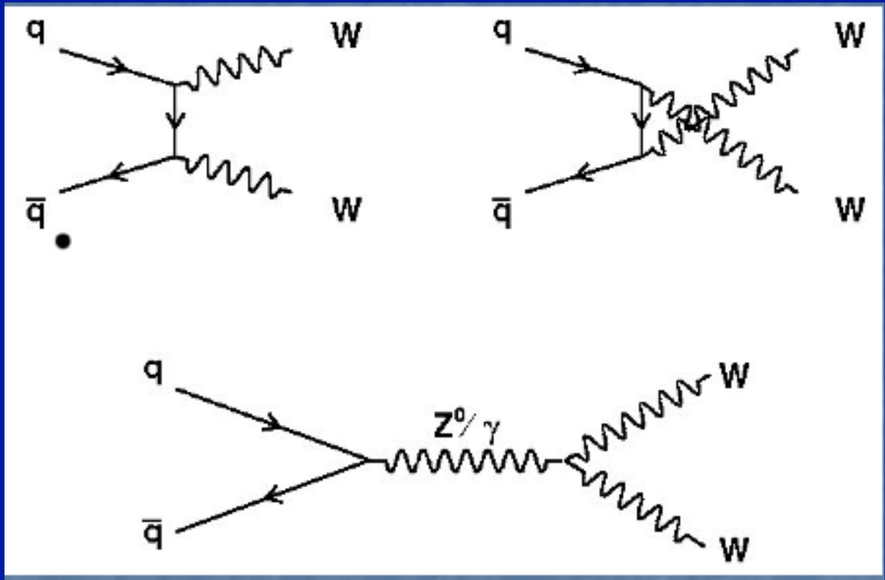


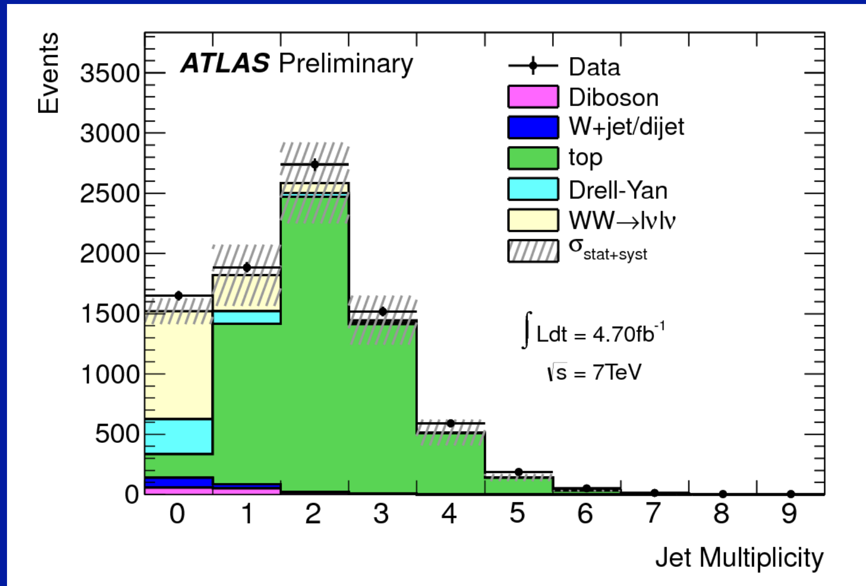


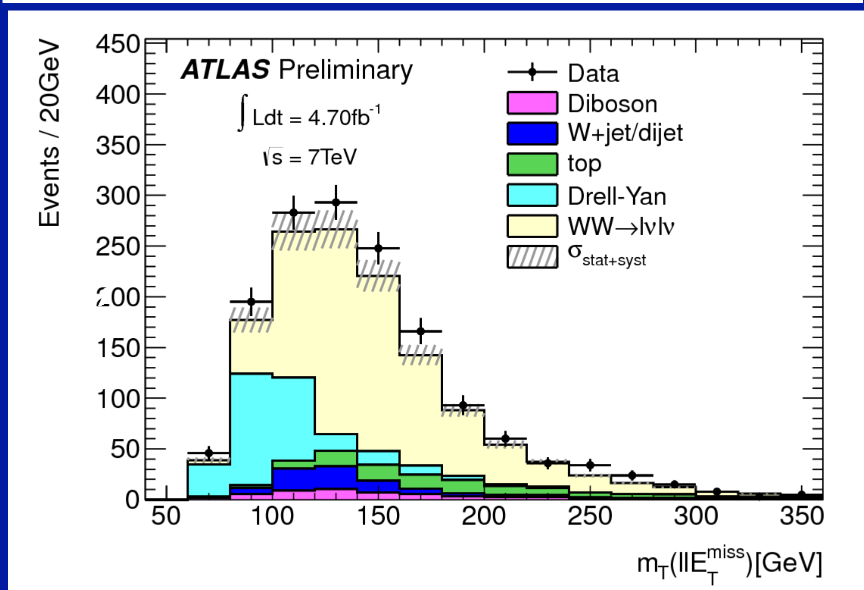
Comparison between different experiments

WW production

ATLAS-CONF-2012-025





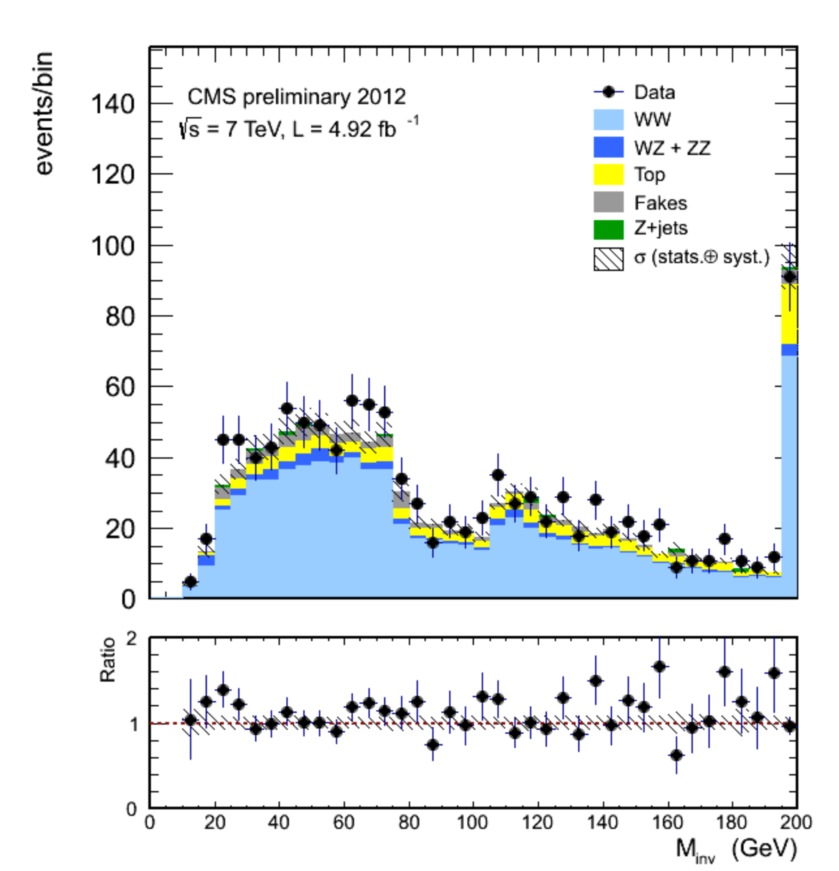


1524 observed events
background 531 ± 51 events
53.4 ±2.1(stat) ±4.5(syst) ±2.1(lumi)
NLO : 45.1 ± 2.8 pb

Background is under control, good MET reconstruction

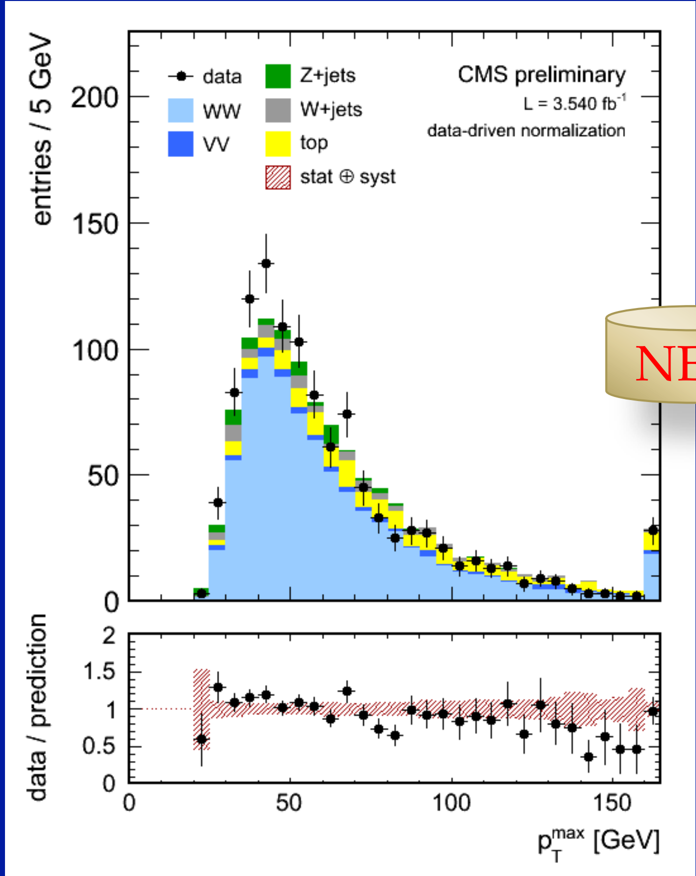
WW production

PAS-CMS-SMP-12-005



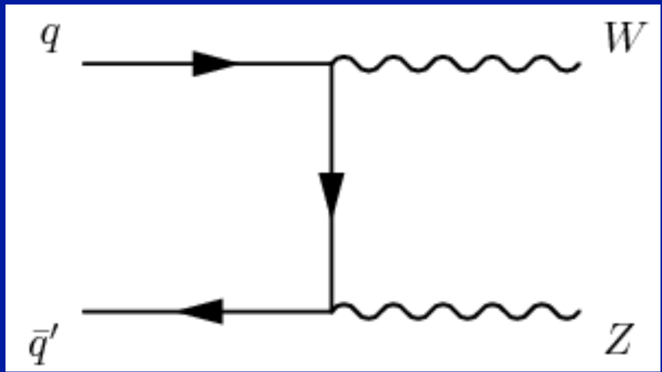
PAS-CMS-SMP-12-013

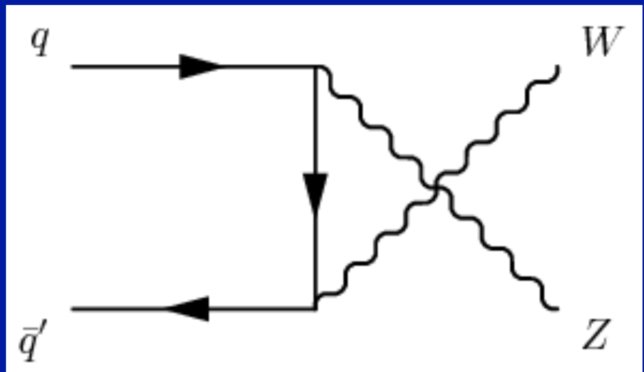
NEW



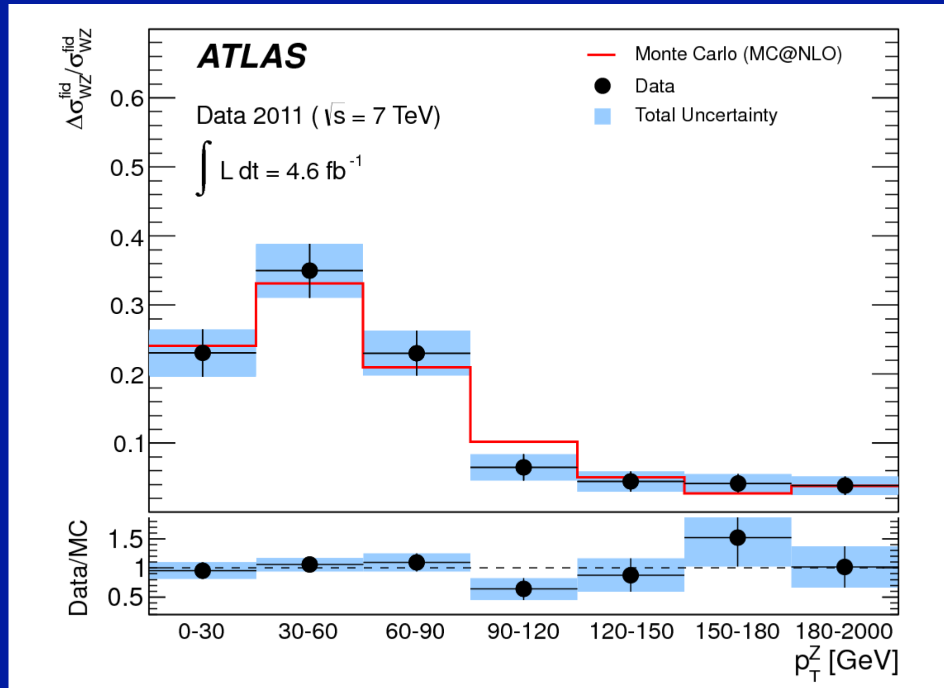
Energy	Events	Backgr.	Cross section, pb	NLO, pb
7 TeV	1134	247 ± 33	52.4 ±2.0(stat) ±4.5(syst) ±1.2(lumi)	45.1 ± 2.8
8 TeV	1111	275 ± 34	69.9 ±2.8(stat) ±5.6(syst) ±3.1(lumi)	57.3 +2.4 -1.6

WZ production LHC



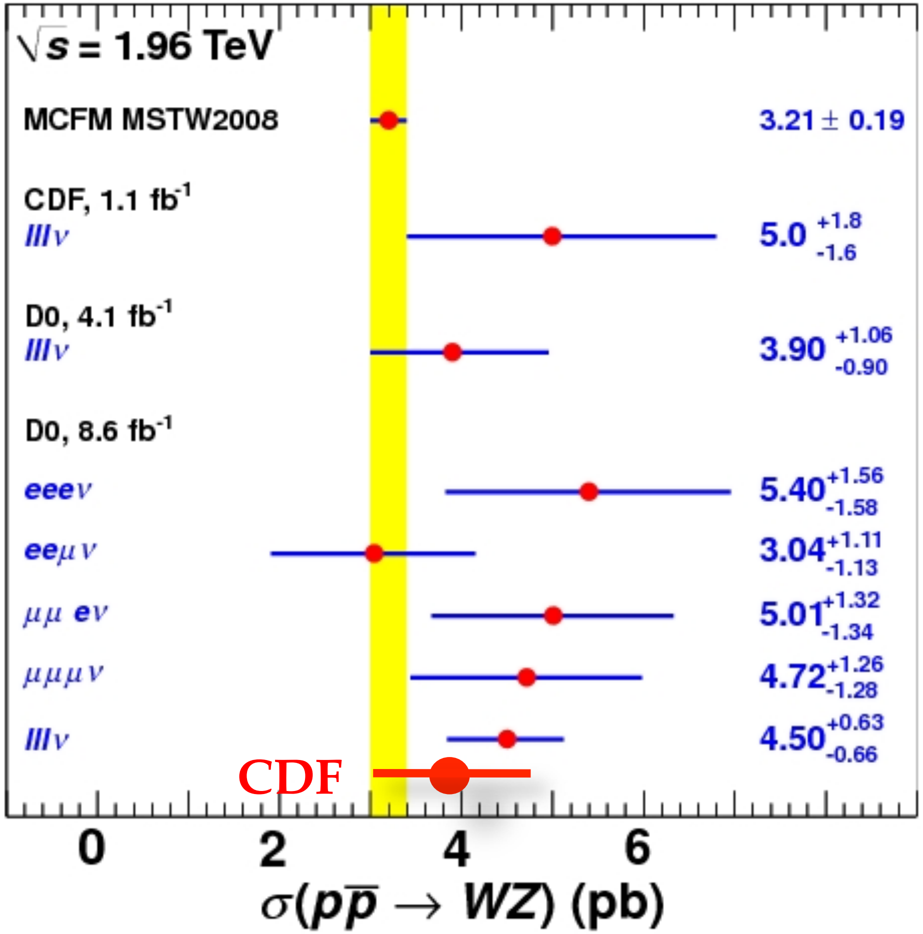


arXiv:1208.1390 , submitted to EPJC



	Ecms	Evt.	Bckg.	Measured cross section, pb	Theory
ATLAS	7 TeV	317	68 ± 10	$19.0^{+1.4}_{-1.3}(stat) \pm 0.9(syst) \pm 0.4(lumi)$	$17.6^{+1.1}_{-1.0}$
CMS	7 TeV	75	9.1	$17.0 \pm 2.4(stat) \pm 1.1(syst) \pm 1.0(lumi)$	17.6 ± 0.6

WZ production Tevatron



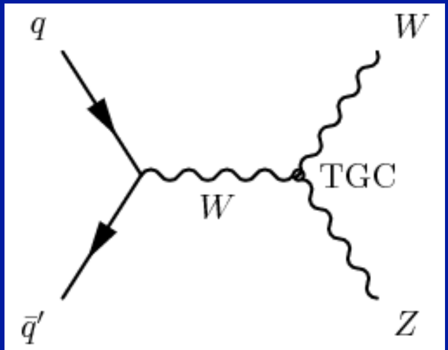
Phys.Rev.D85, 112005(2012)

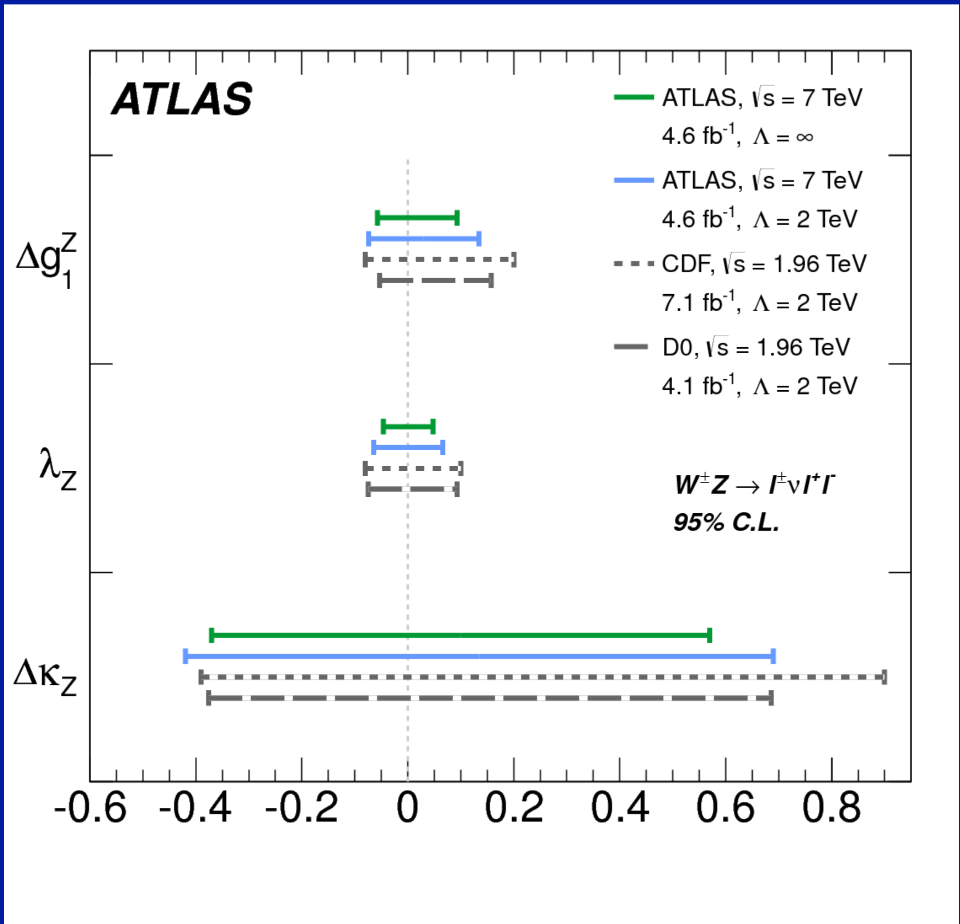
Most of the measurements are slightly above the SM prediction

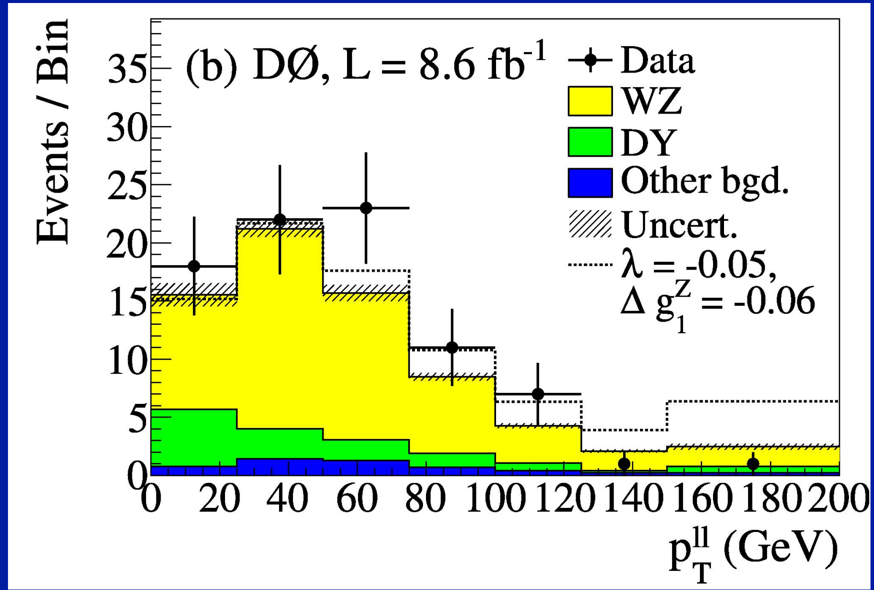
arXiv:1202.6629

$$3.93^{+0.60}_{-0.53}(stat)^{+0.59}_{-0.46}(syst)\,pb$$

WWZ aTGC







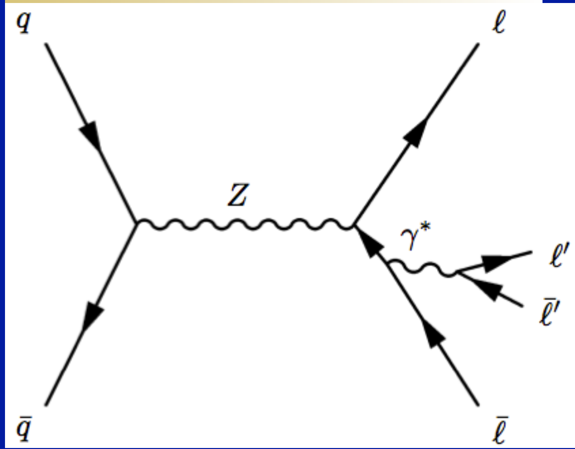
arXiv:1208.5458, submitted to PLB

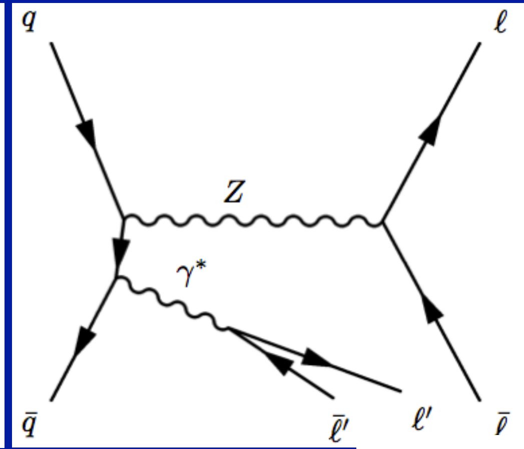
$$\alpha(\hat{s}) = \frac{\alpha_0}{\left(1 + \hat{s}/\Lambda^2\right)^2}$$

arXiv:1208.1390 , submitted to EPJC

ZZ production: Z to 4l

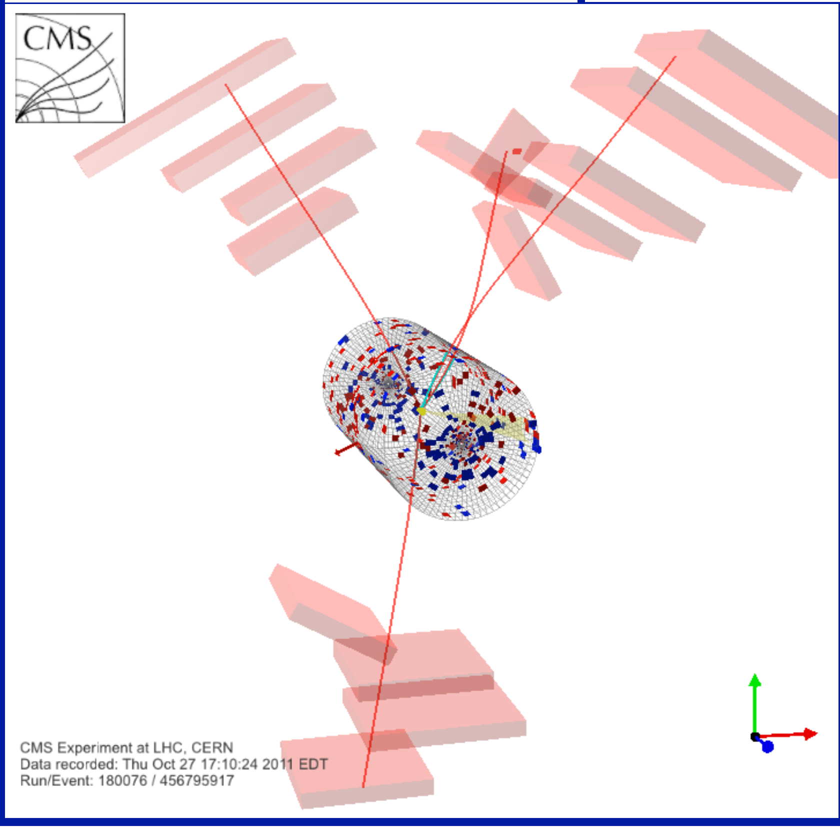
CMS-PAS-SMP-12-009

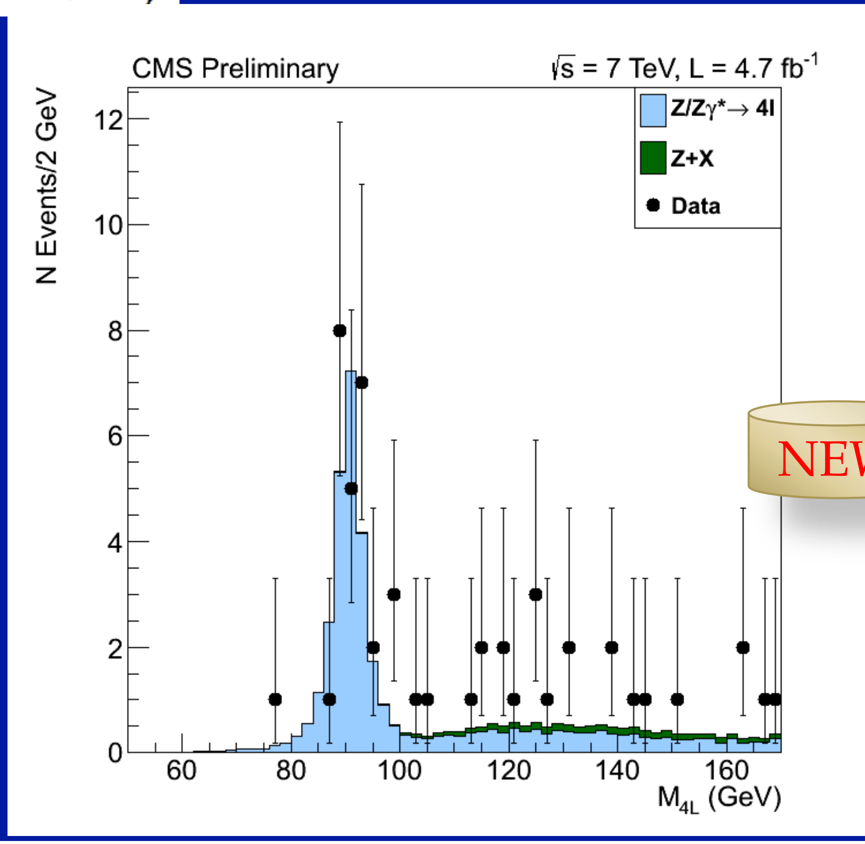




26 observed
25 expected in
80-100 GeV mass range
SM σ*Br=120 fb

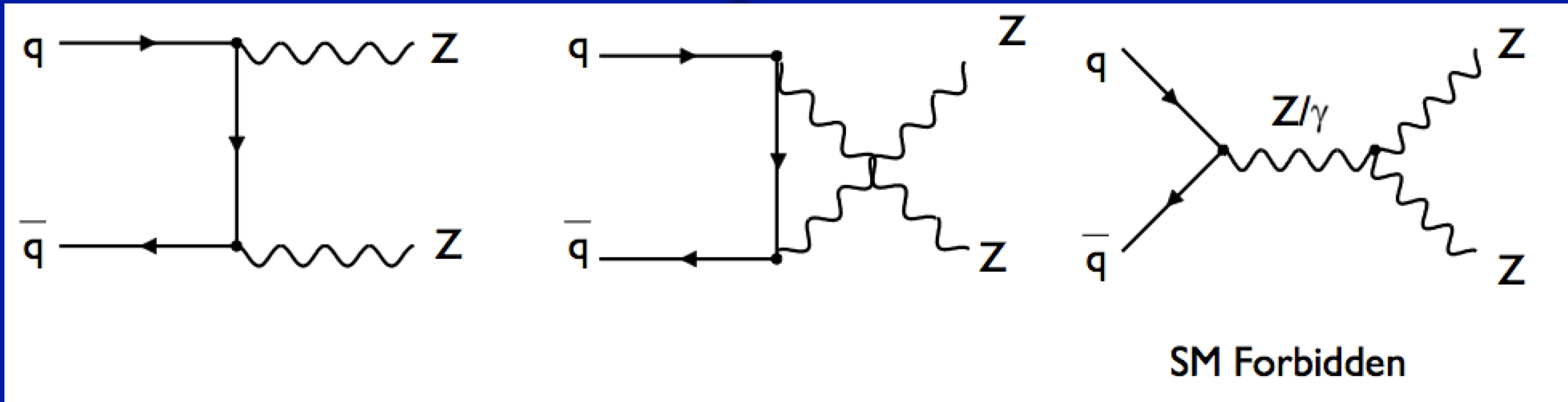
$$126^{+26}_{-23}(stat)^{+9}_{-6}(sys)^{+7}_{-5}(lumi)$$

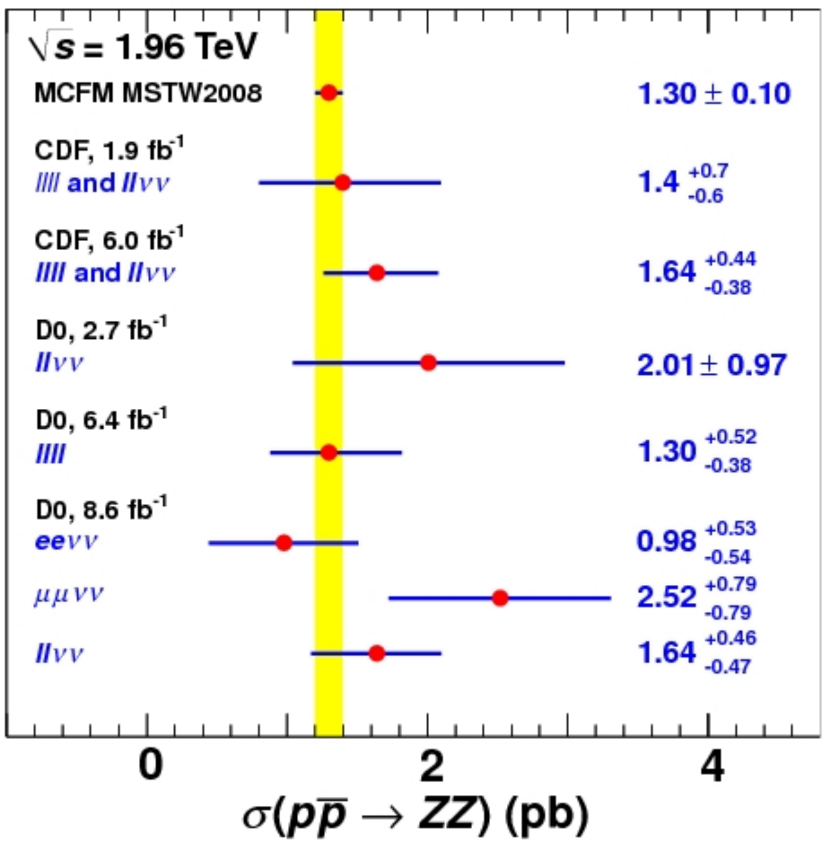




NEW

ZZ production



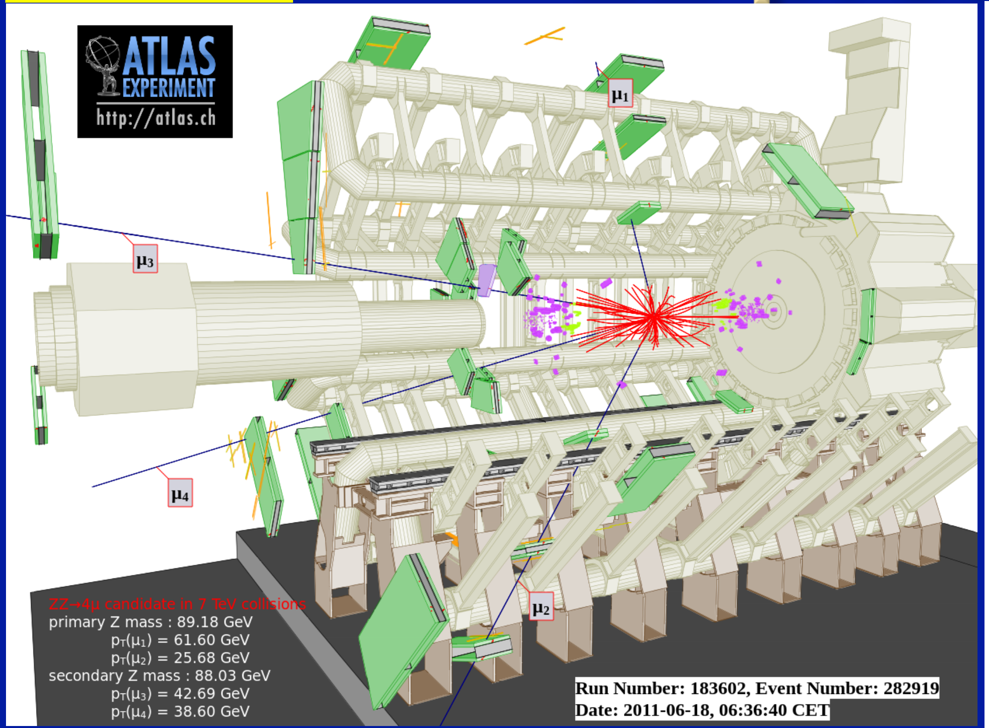


Phys.Rev. D85, 112005(2012)

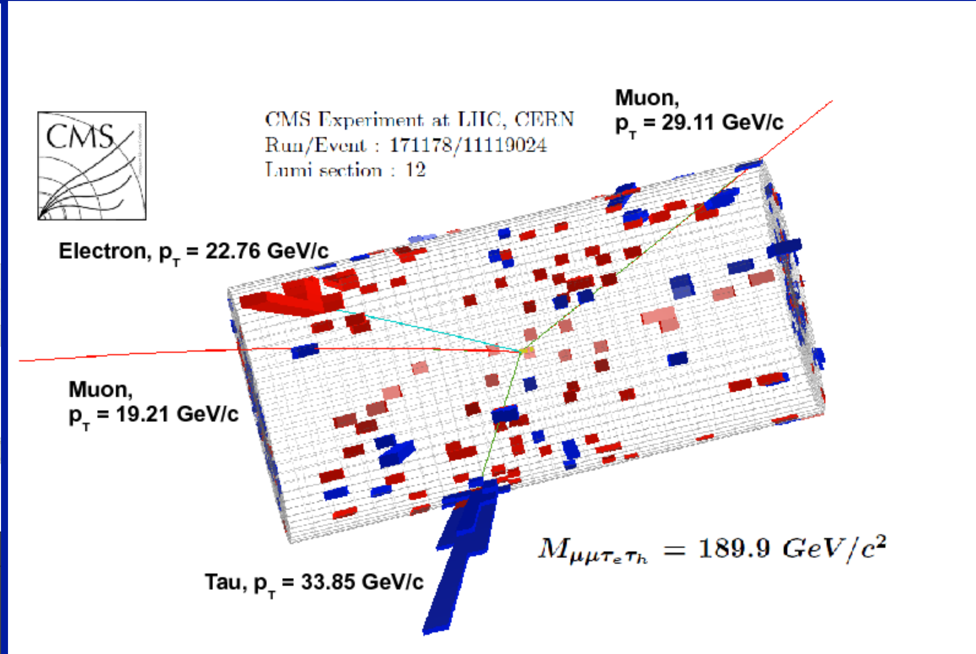
Big statistical uncertainties due to very low cross section

ZZ production

$ZZ \to 4\mu$



$ZZ \to 2l2\tau$

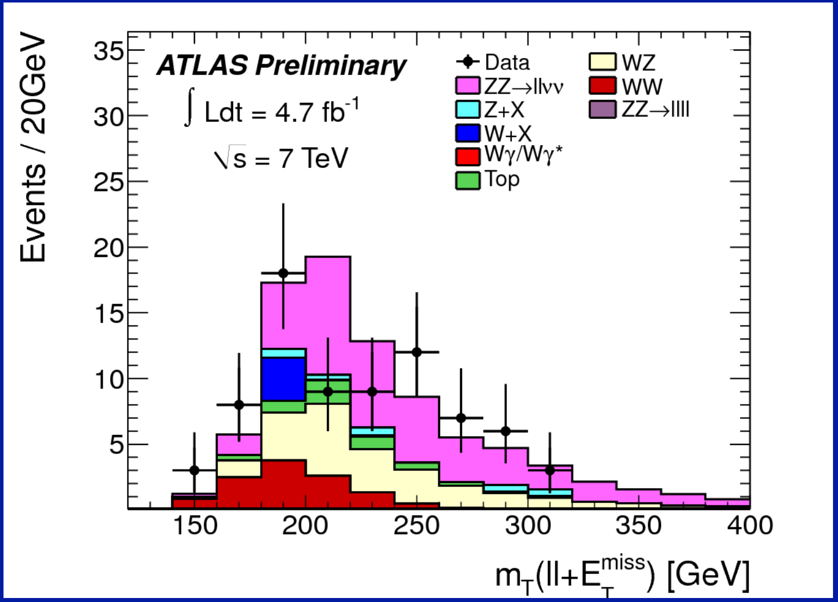


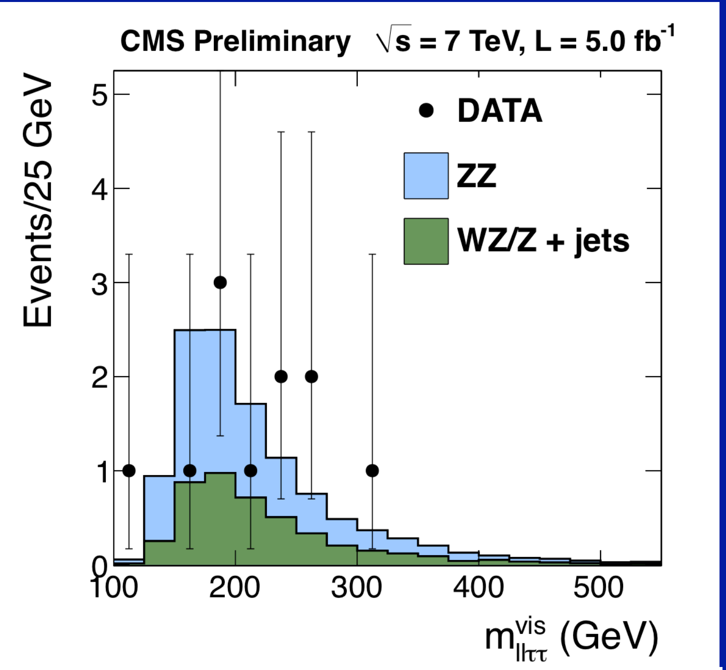
First time taus are used in this channel

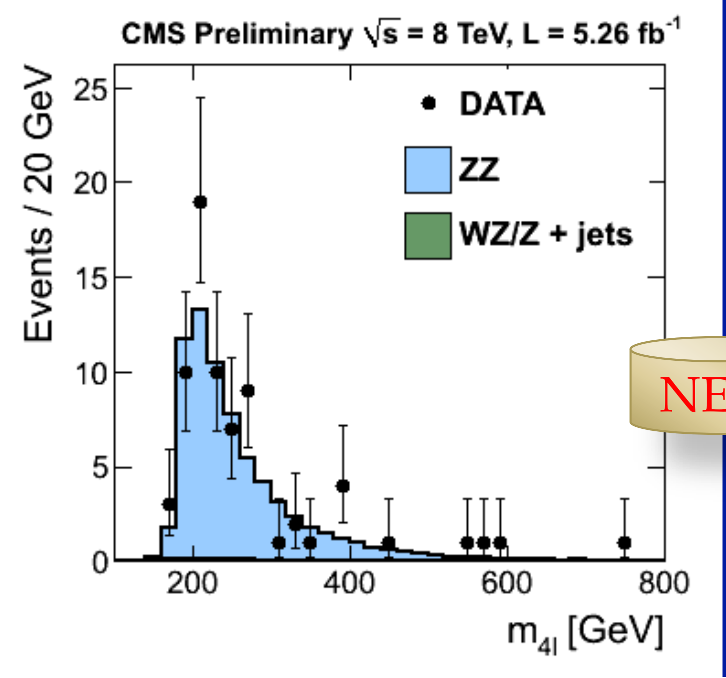
	Decay	Ecms	Measured cross section, pb	Theory
ATLAS	2l2ν	7 GeV	$5.4^{+1.3}_{-1.2}(stat)^{+1.4}_{-1.0}(syst) \pm 0.2(lumi)$	6.5 ± 0.3
ATLAS	4l	7 GeV	$7.2^{+1.1}_{-0.9}(stat)^{+0.4}_{-0.3}(syst) \pm 0.3(lumi)$	6.5 ± 0.3
CMS	4l+2l2τ	7 GeV	$6.24^{+0.86}_{-0.80}(stat)^{+0.41}_{-0.32}(syst) \pm 0.14(lumi)$	6.3 ± 0.4
ATLAS	4l	8 GeV	$9.3 \pm 1.1(stat) \pm 0.4(syst) \pm 0.3(lumi)$	7.4 ± 0.4
CMS	4l+2l2τ	8 GeV	$8.4 \pm 1.0(stat) \pm 0.7(syst) \pm 0.4(lumi)$	7.7 ± 0.4

ZZ production

ATLAS-CONF-2012-027 (2l2nu)







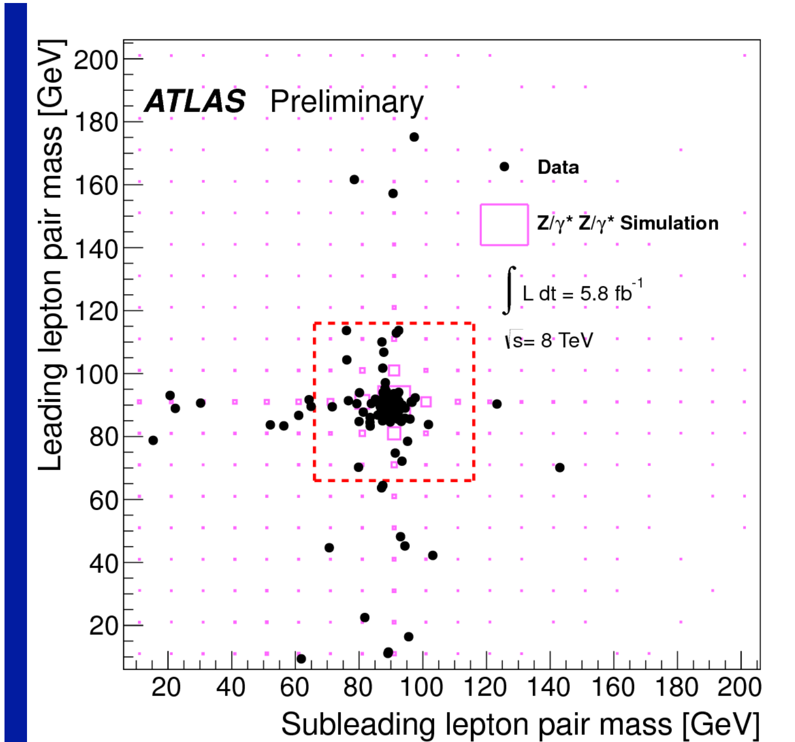
NEW

ATLAS-CONF-2012-026

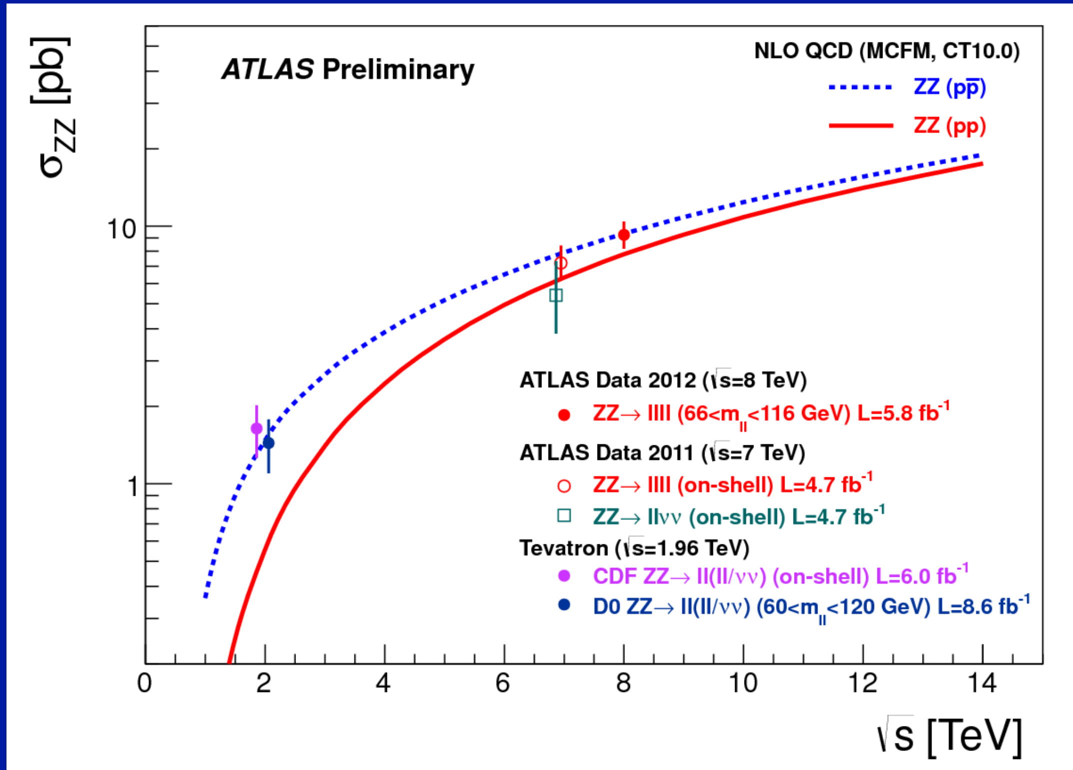
ATLAS-CONF-2012-090

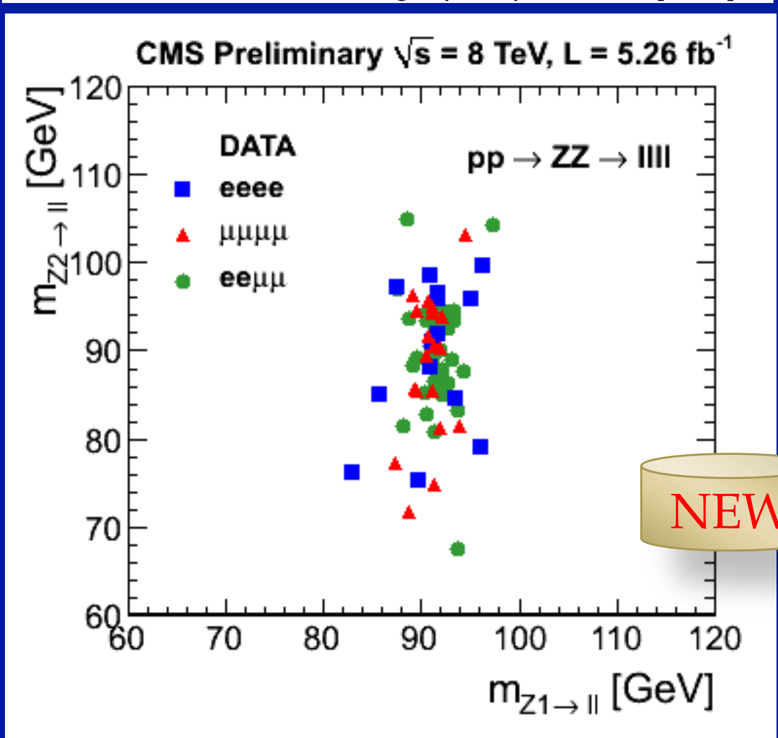
CMS-PAS-SMP-12-007

CMS-PAS-SMP-12-014



ATLAS-CONF-2012-090





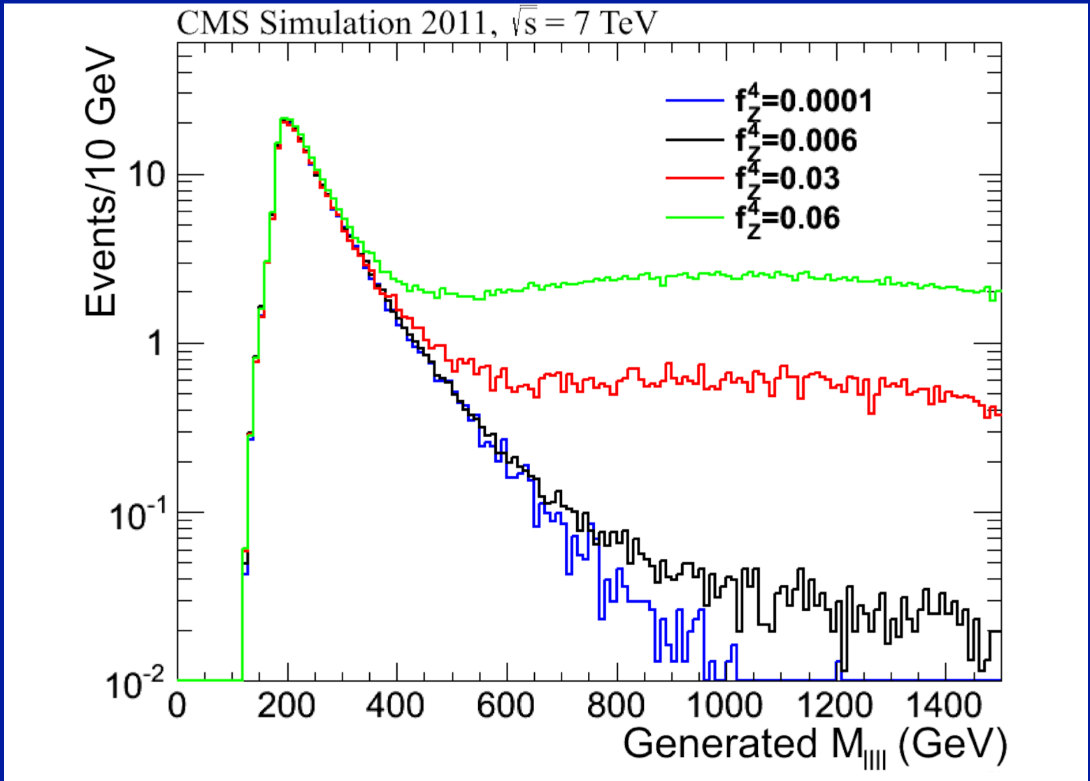
NEW

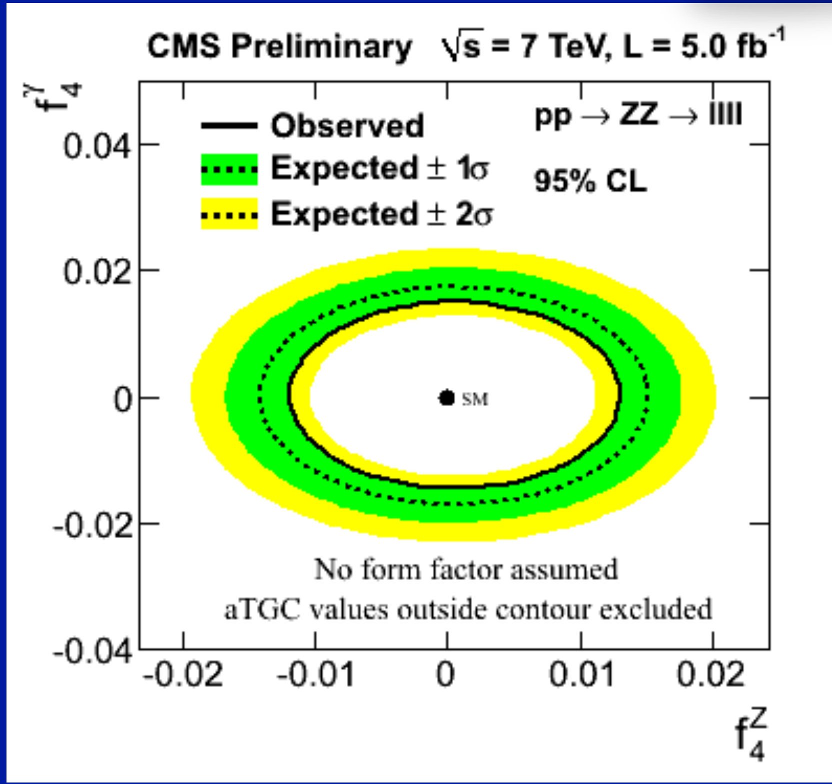
CMS-PAS-SMP-12-014

ZZZ and ZZγ aTGC

CMS-PAS-SMP-12-007

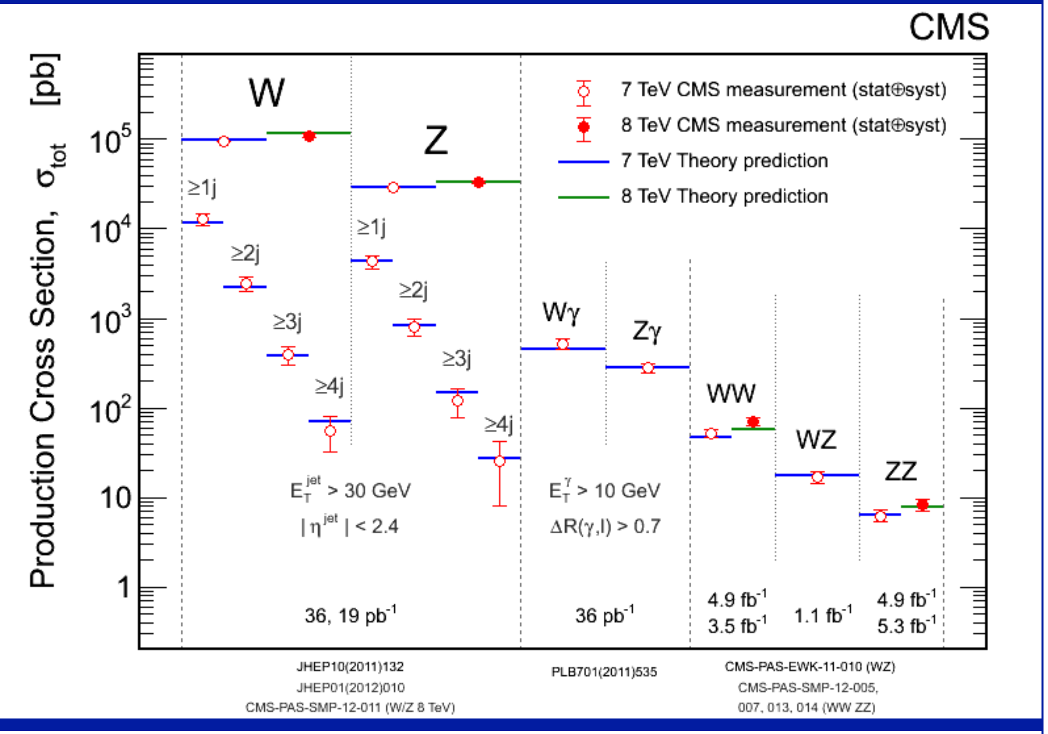
NEW



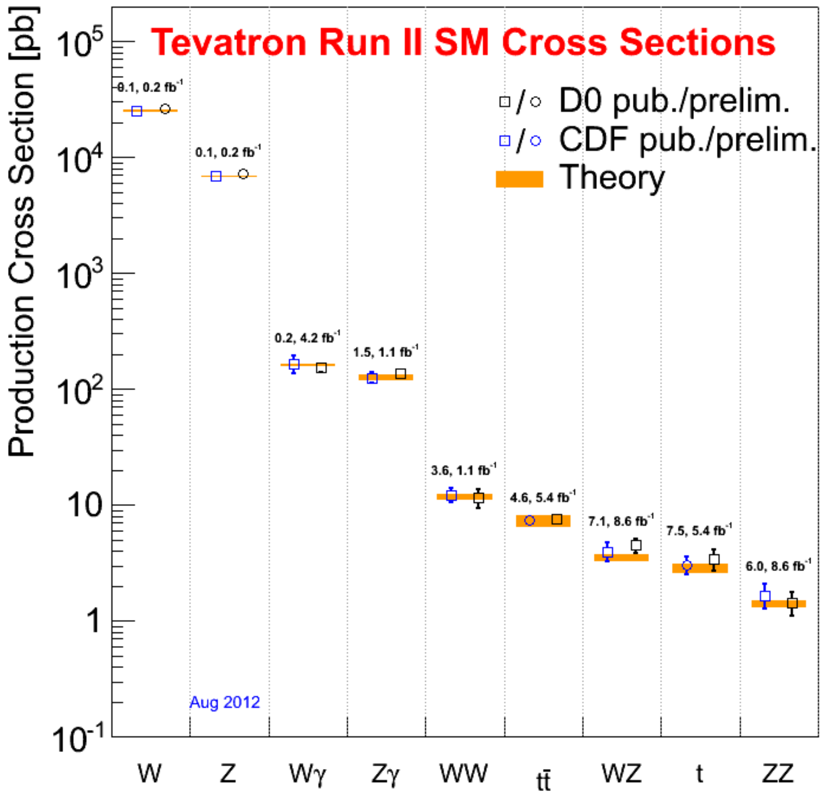


The most stringent limits on anomalous ZZZ and ZZ γ couplings using shape of the M_{4l} distribution

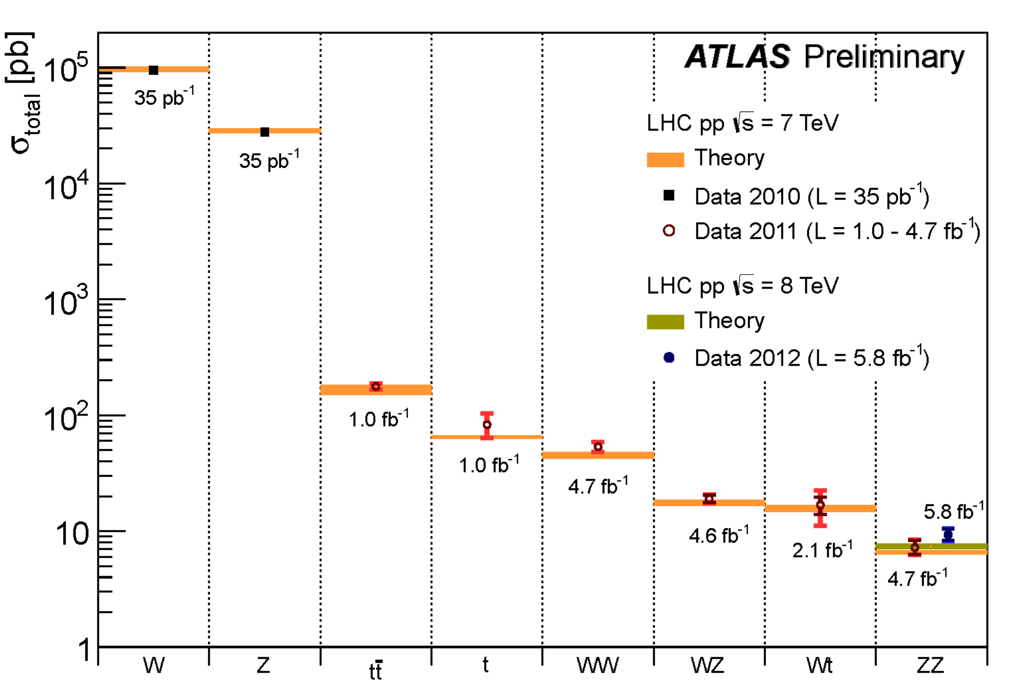
Summary



CMS
W
Z
≥1j
≥2j
≥3j
≥4j
Wγ
Zγ
WW
WZ
ZZ
7 TeV CMS measurement (stat⊕syst)
8 TeV CMS measurement (stat⊕syst)
7 TeV Theory prediction
8 TeV Theory prediction
Production Cross Section, σ_tot [pb]
E_T^jet > 30 GeV
|η^jet| < 2.4
E_T^γ > 10 GeV
ΔR(γ,l) > 0.7
36, 19 pb^-1
36 pb^-1
4.9 fb^-1
3.5 fb^-1
1.1 fb^-1
4.9 fb^-1
5.3 fb^-1
JHEP10(2011)132
JHEP01(2012)010
CMS-PAS-SMP-12-011 (W/Z 8 TeV)
PLB701(2011)535
CMS-PAS-EWK-11-010 (WZ)
CMS-PAS-SMP-12-005,
007, 013, 014 (WW ZZ)



Tevatron Run II SM Cross Sections
D0 pub./prelim.
CDF pub./prelim.
Theory
Production Cross Section [pb]
0.1, 0.2 fb^-1
0.1, 0.2 fb^-1
0.2, 4.2 fb^-1
1.5, 1.1 fb^-1
3.6, 1.1 fb^-1
4.6, 5.4 fb^-1
7.1, 8.6 fb^-1
7.5, 5.4 fb^-1
6.0, 8.6 fb^-1
Aug 2012
W
Z
Wγ
Zγ
WW
tt̄
WZ
t
ZZ



ATLAS Preliminary
LHC pp √s = 7 TeV
Theory
Data 2010 (L = 35 pb^-1)
Data 2011 (L = 1.0 - 4.7 fb^-1)
LHC pp √s = 8 TeV
Theory
Data 2012 (L = 5.8 fb^-1)
σ_total [pb]
35 pb^-1
35 pb^-1
1.0 fb^-1
1.0 fb^-1
4.7 fb^-1
4.6 fb^-1
2.1 fb^-1
5.8 fb^-1
4.7 fb^-1
W
Z
tt̄
t
WW
WZ
Wt
ZZ