Electroweak Physics Results

João Guimarães da Costa
Harvard University

On behalf of
ATLAS, CMS, LHCb, CDF and D0

ICHEP 2012

July 9, 2012

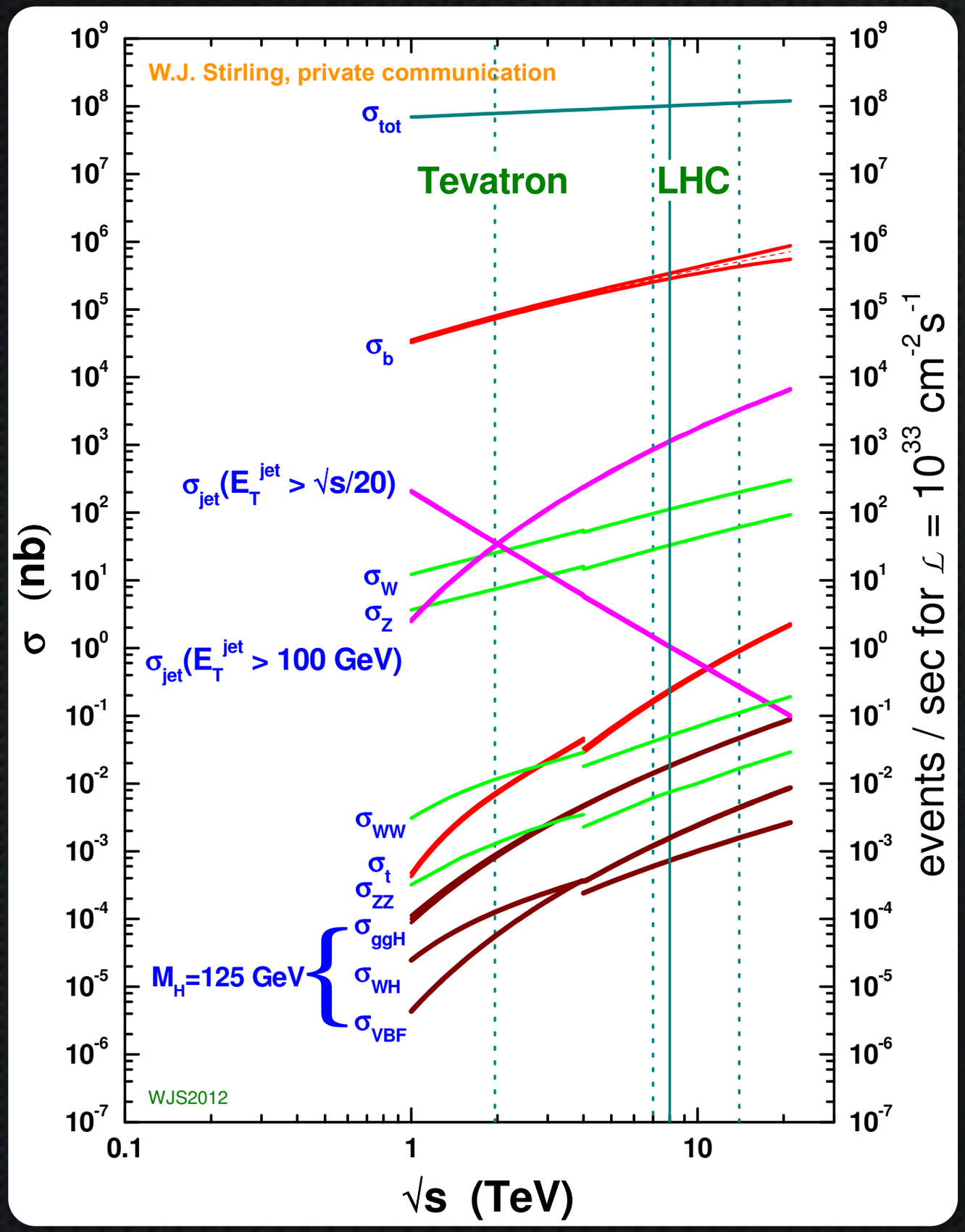
Outline

- **W and Z production at LHC**
  - Inclusive and differential cross sections
  - W charge asymmetry and impact on PDFs
  - Drell-Yan production
  - W and τ polarization
- **Diboson production at the Tevatron and LHC**
  - Anomalous Triple Gauge Couplings
- **Precision measurements at the Tevatron and LHC**
  - Z Forward-Backward Asymmetry
  - Effective weak mixing angle
- **Global electroweak fit**
  - Top quark mass
  - W mass
  - Higgs mass predictions

Production rates at Hadron Colliders

Tevatron timeline

LHC timeline



W: 1988
Z: 1988

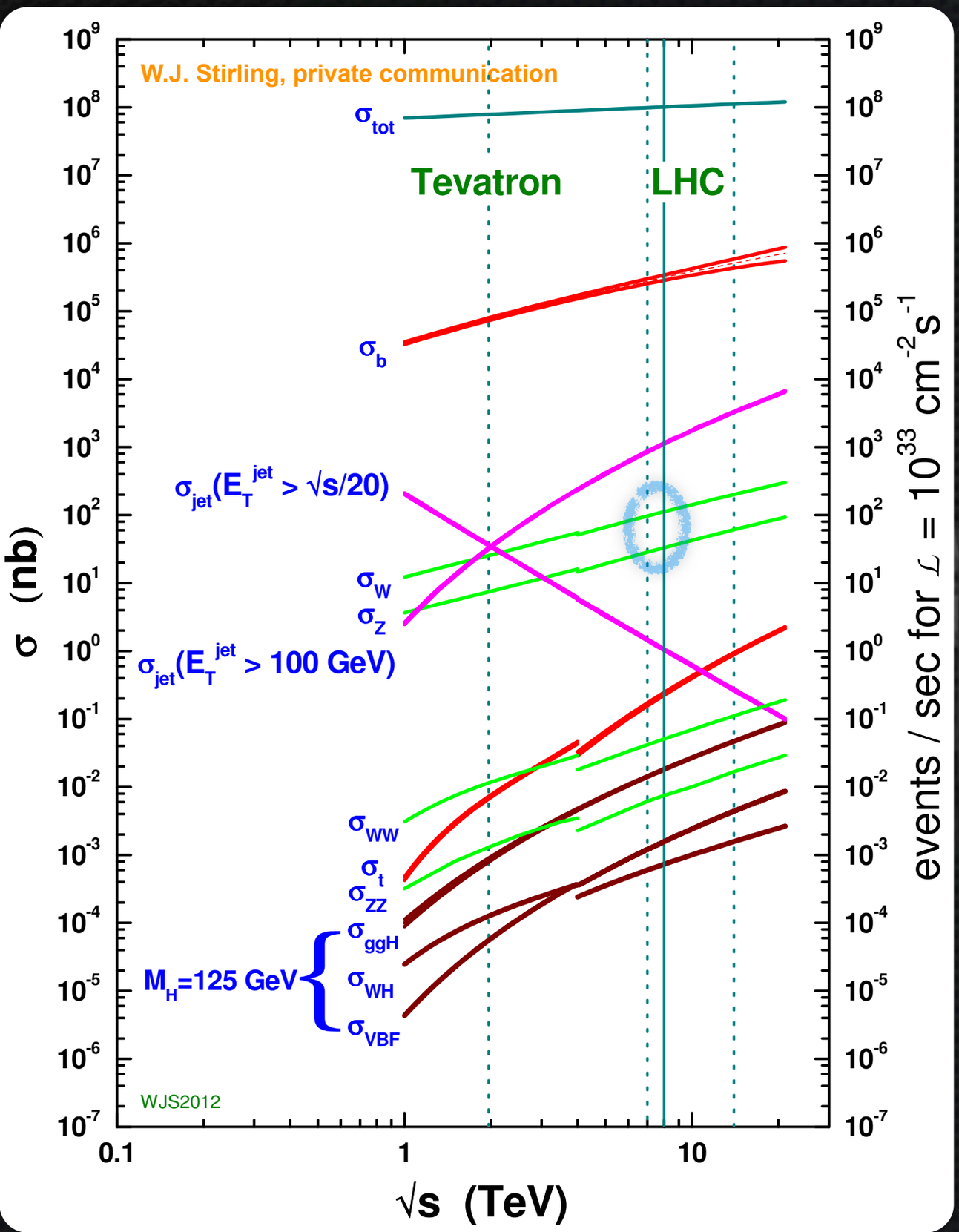
Top: 1994
WW: 2005
WZ: 2007
ZZ: 2008

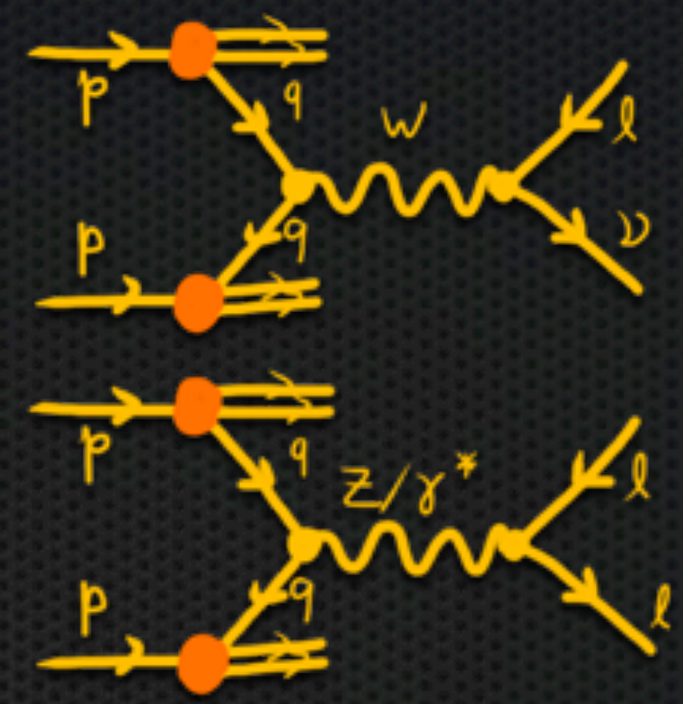
W: May 2010
Z: Jun 2010

Top: Jul 2010

WW: Dec 2010
WZ: Mar 2011
ZZ: Jul 2011

H: Last week?



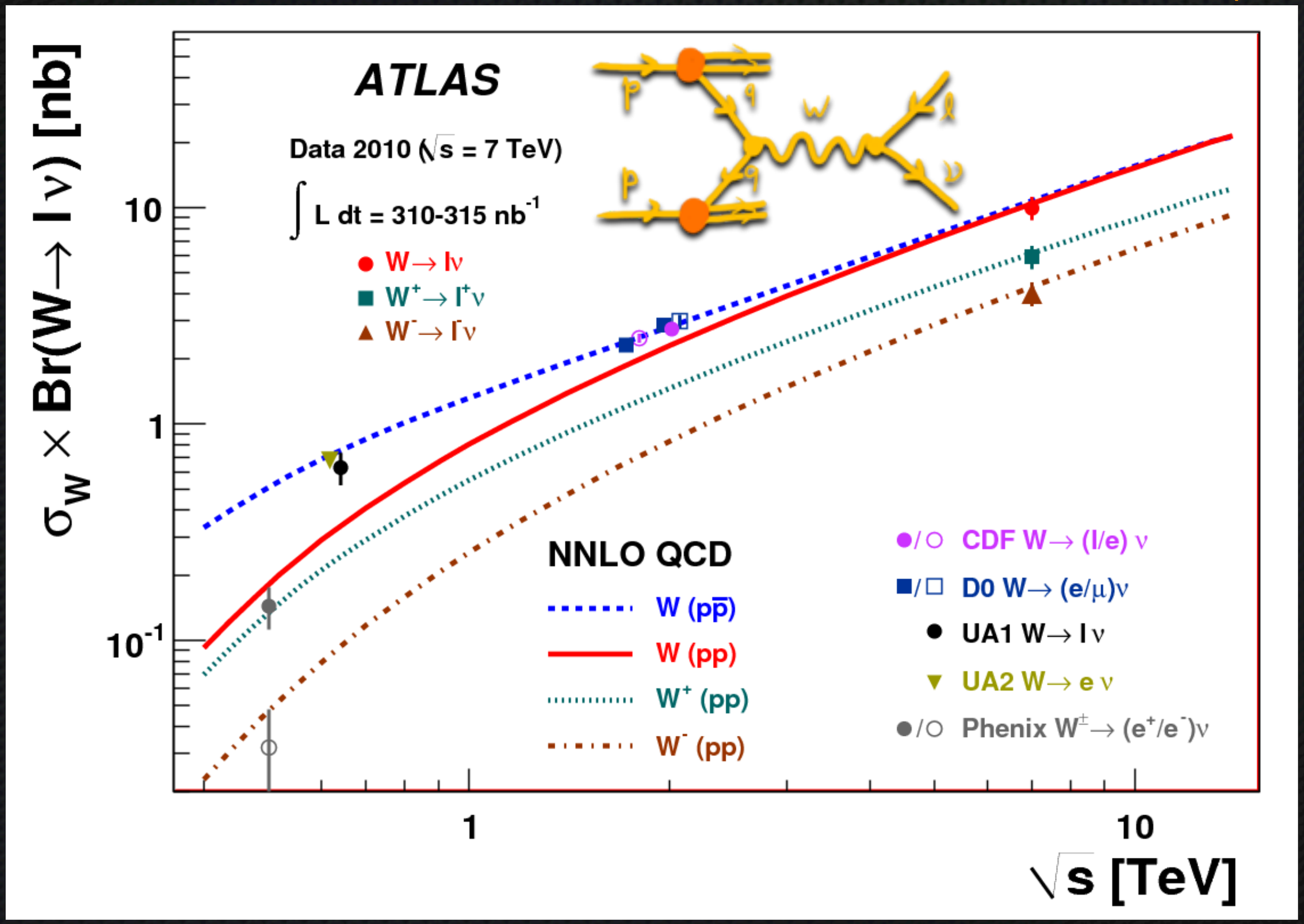


W and Z Production

- Performance measurements
- SM tests at TeV scale
- Proton PDFs
- Backgrounds for searches

First W/Z measurement at 7 TeV

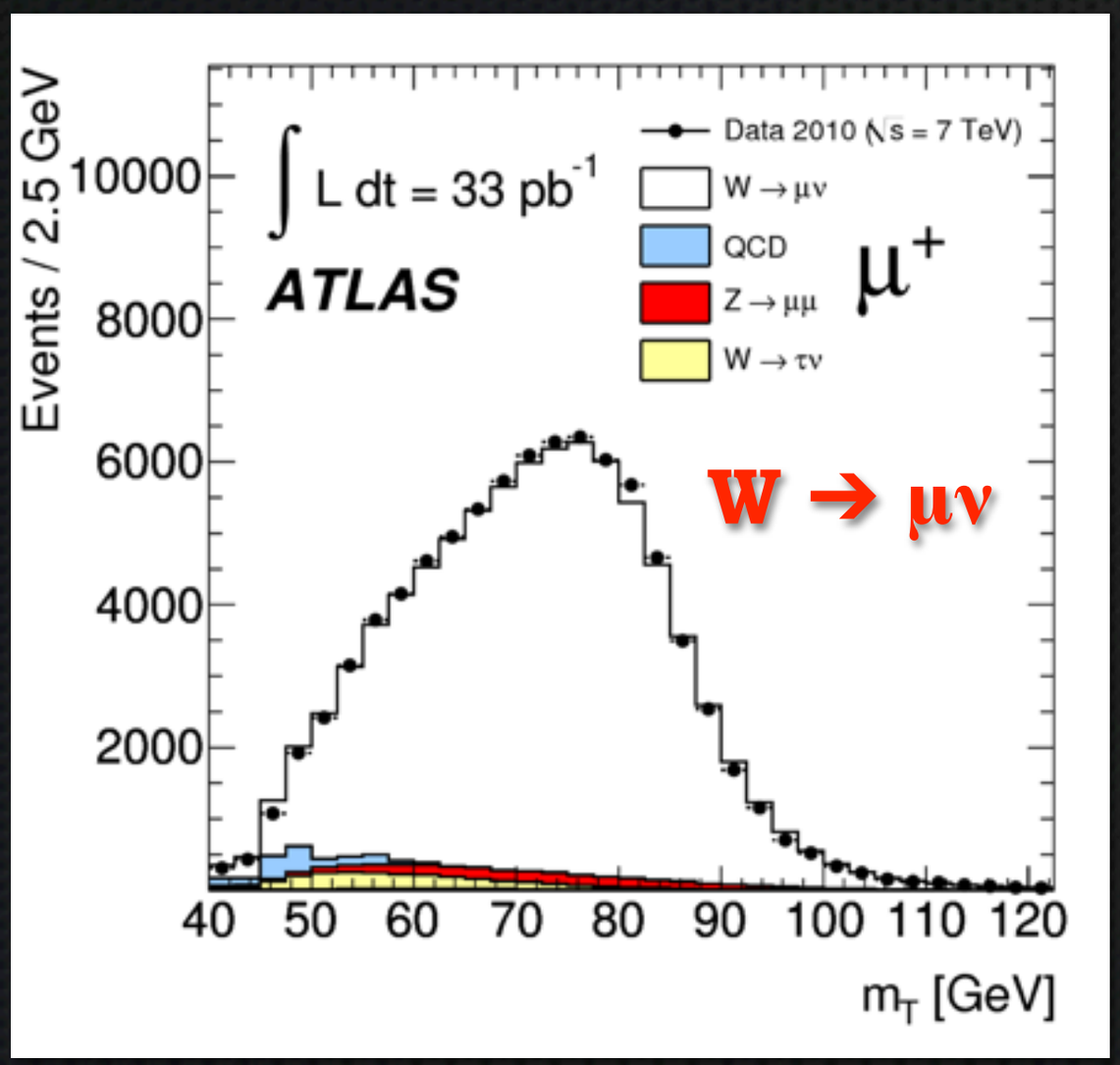
JHEP 12 (2010) 060



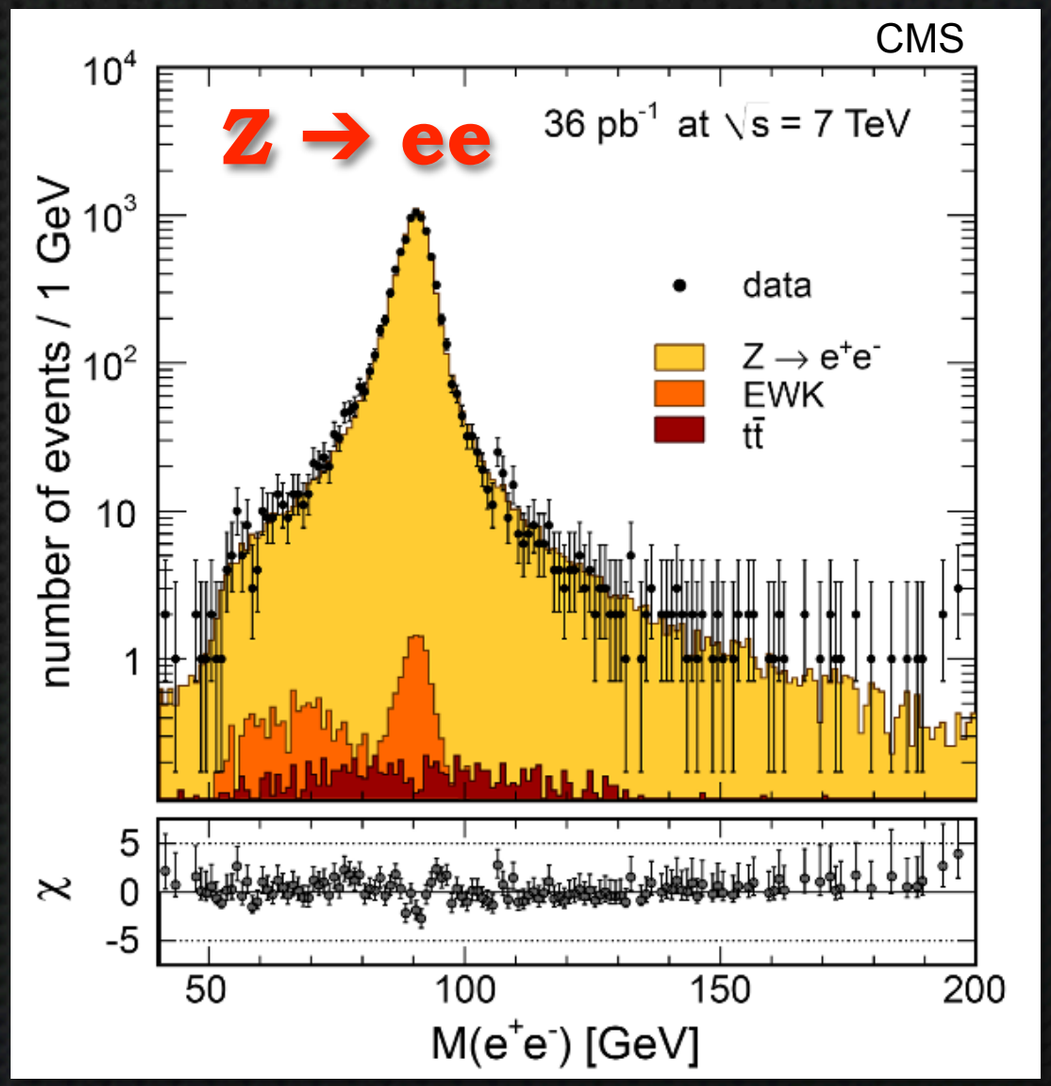
W/Z cross section measurements

- **ATLAS, CMS and LHCb published precision measurements with 2010 data --> relatively recent publications**

Phys. Rev. D85 (2012) 072004



JHEP 10 (2011) 132



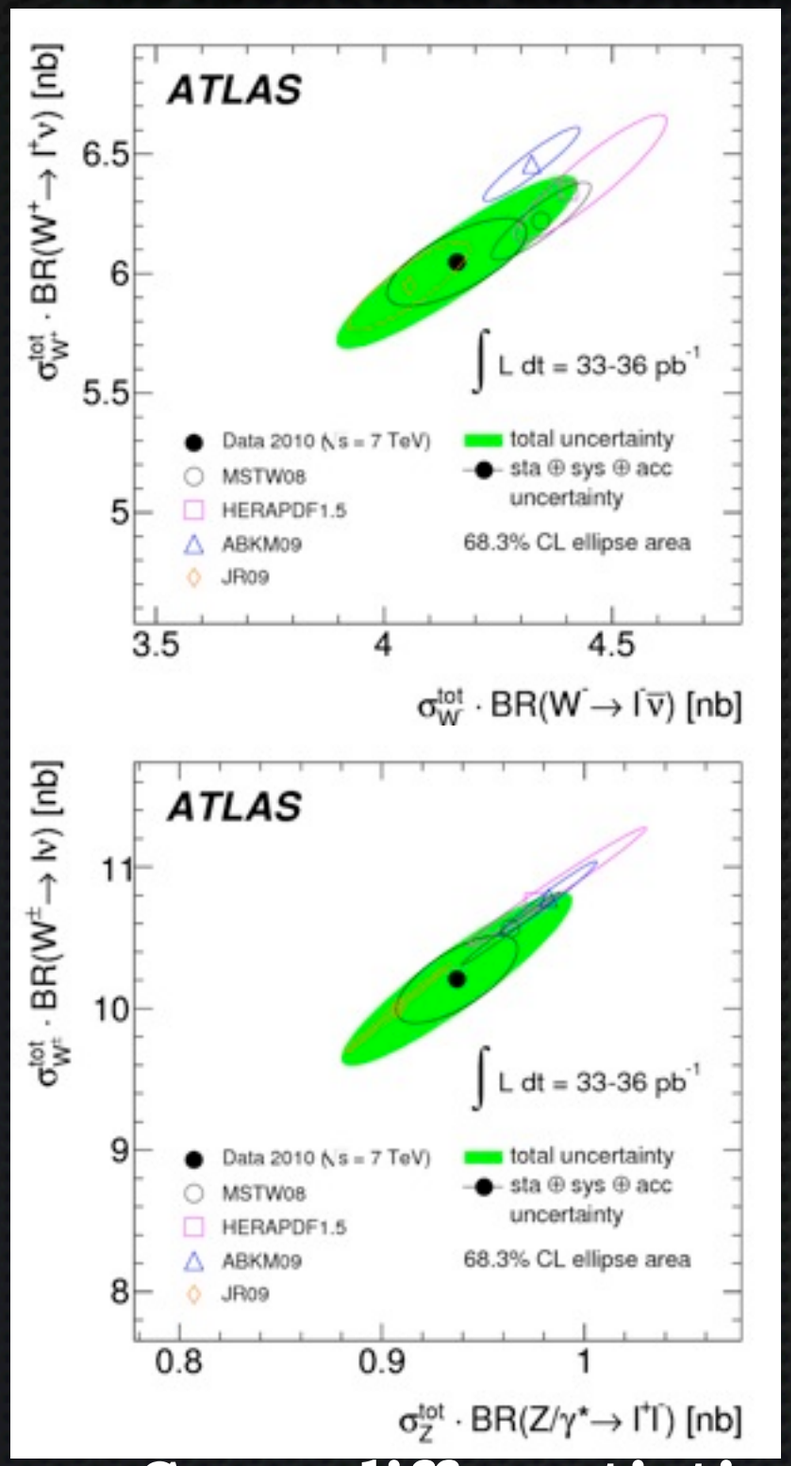
Much larger datasets are now available

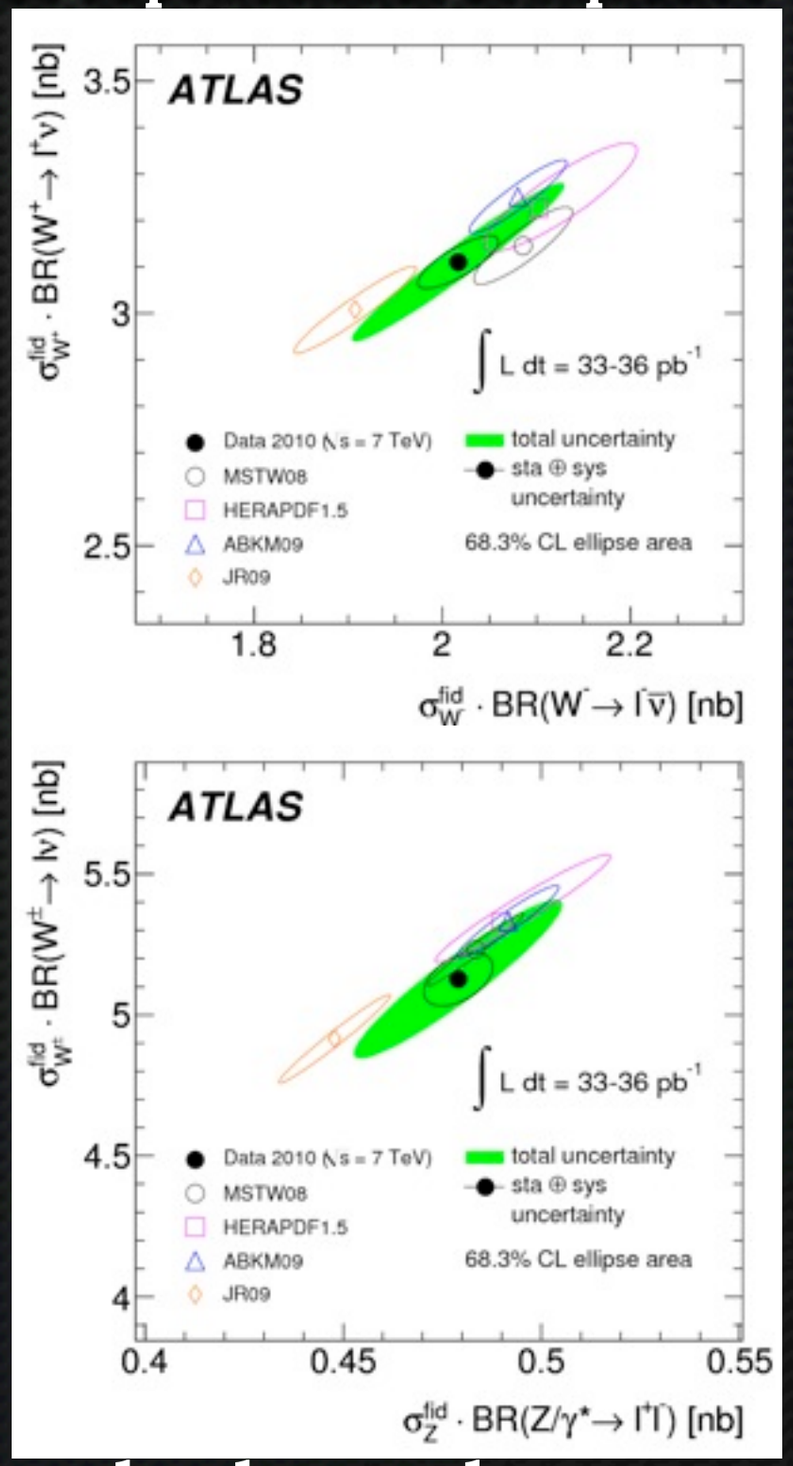
$\sqrt{s}$ = 7 TeV, 5 fb^{-1} { W → e/μ ν : ~ 25 Million; Z → ee/μμ : ~ 3 Million } + $\sqrt{s}$ = 8 TeV ~6 fb^{-1}

Fiducial W and Z Cross Sections

Phys. Rev. D85 (2012) 072004

- **ATLAS, CMS and LHCb measure fiducial cross sections**
  - **No theoretical uncertainty from extrapolation outside experimental acceptance**





Luminosity 3.4%

Some differentiation between PDF sets already observed now

JR09 seems to be the most discrepant

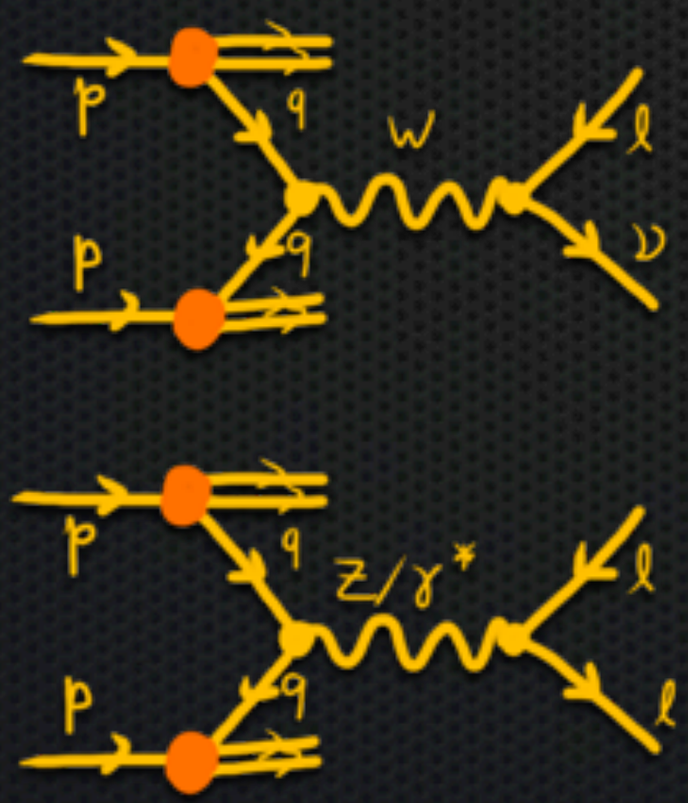
Lepton Universality

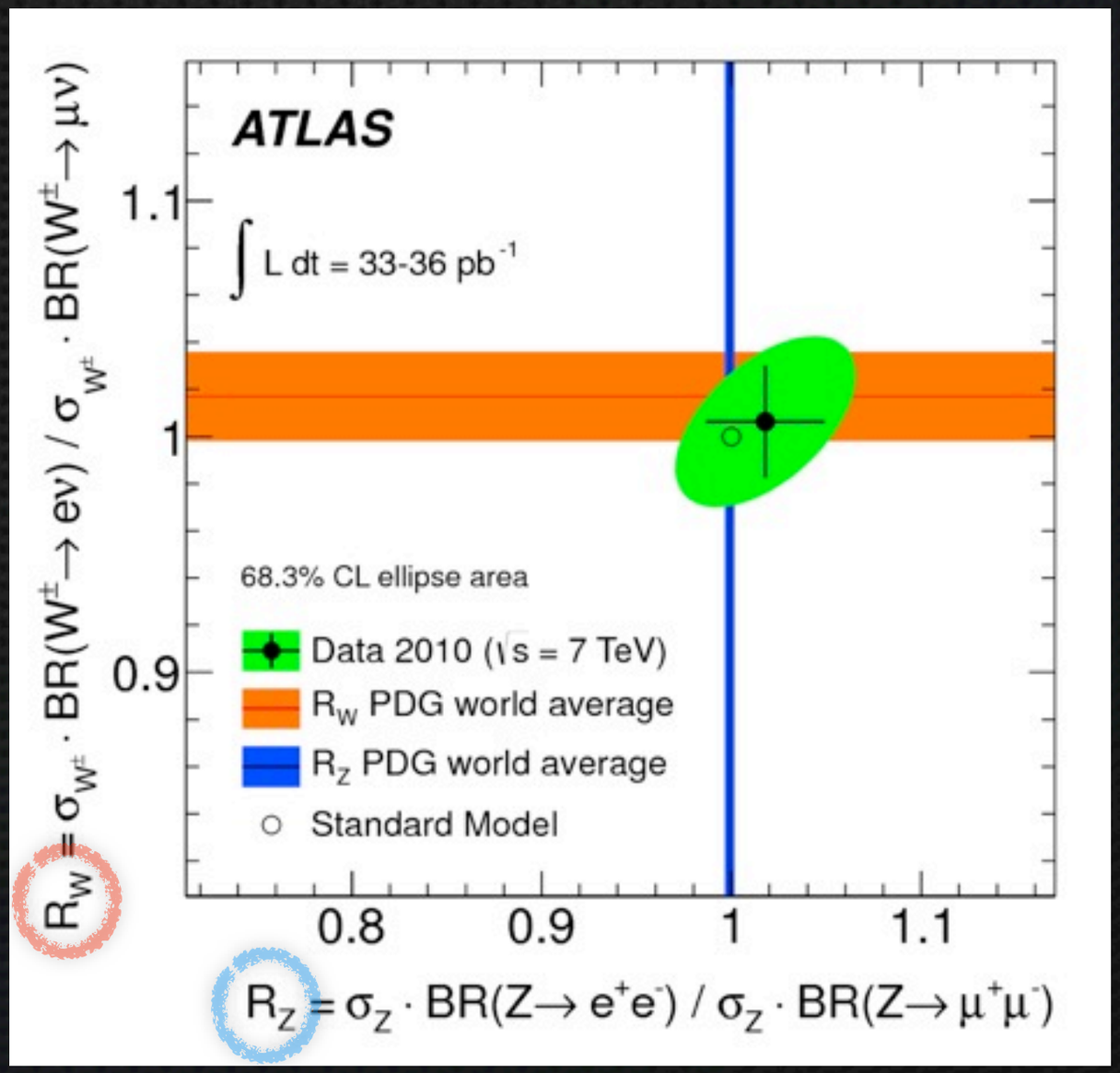
Phys. Rev. D85 (2012) 072004

$$R_W = \frac{\sigma_W^e}{\sigma_W^\mu} = \frac{Br(W \to e\nu)}{Br(W \to \mu\nu)} = 1.006 \pm 0.004\,(\text{sta}) \pm 0.006\,(\text{unc}) \pm 0.023\,(\text{cor}) = 1.006 \pm 0.024$$

$$R_Z = \frac{\sigma_Z^e}{\sigma_Z^\mu} = \frac{Br(Z \to ee)}{Br(Z \to \mu\mu)} = 1.018 \pm 0.014\,(\text{sta}) \pm 0.016\,(\text{unc}) \pm 0.028\,(\text{cor}) = 1.018 \pm 0.031$$

- **Result already close to best measurement (R_W)**
  - **PDG: 1.9%**
  - **This measurement: 2.4%**

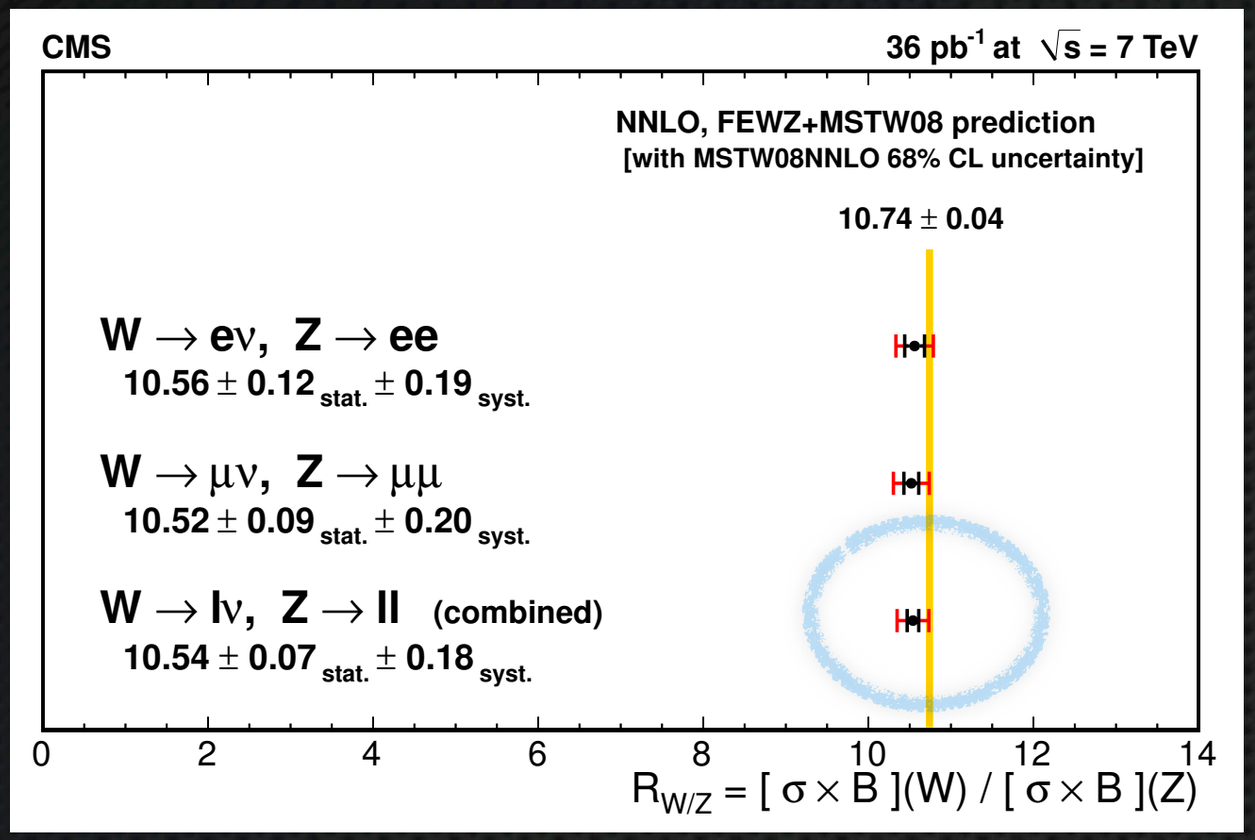




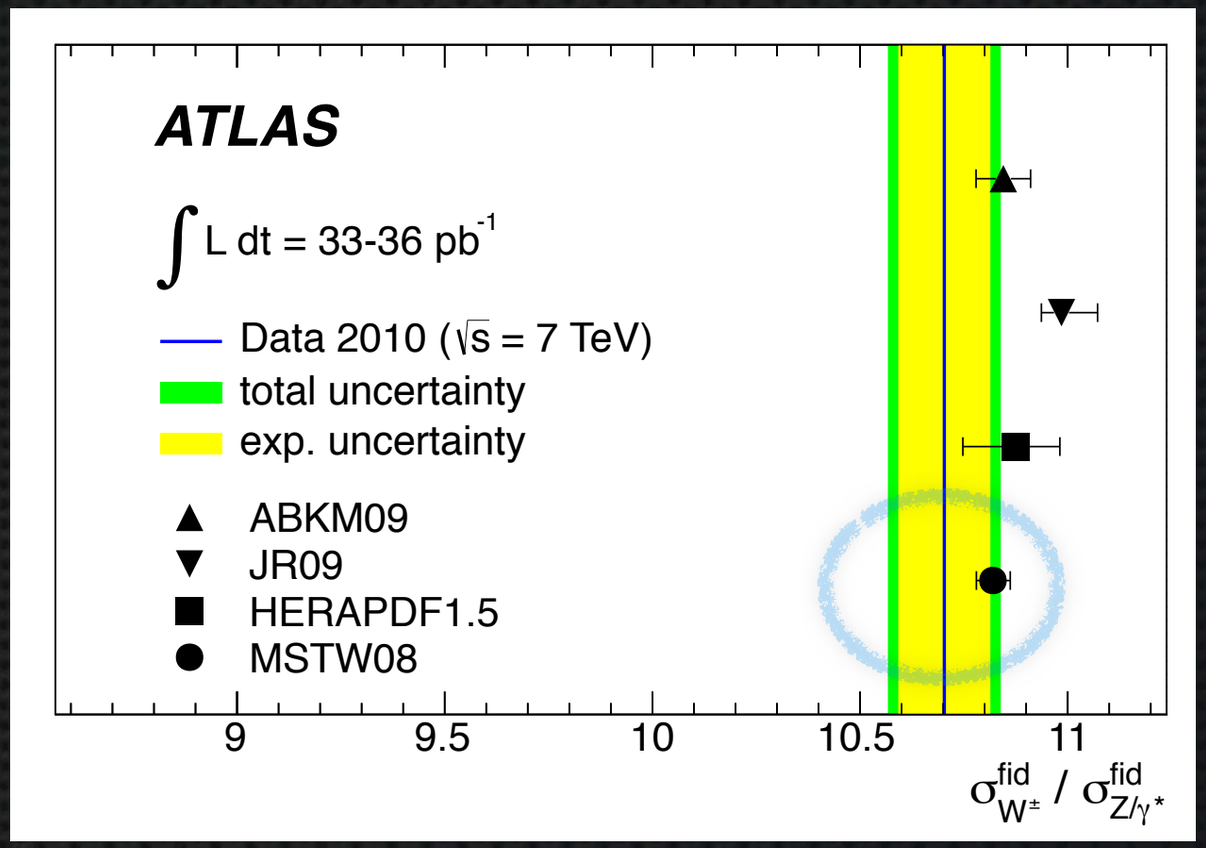
Ratio W and Z Cross Sections

Benefits from experimental and theoretical systematics cancellation

JHEP 10 (2011) 132



Phys. Rev. D85 (2012) 072004



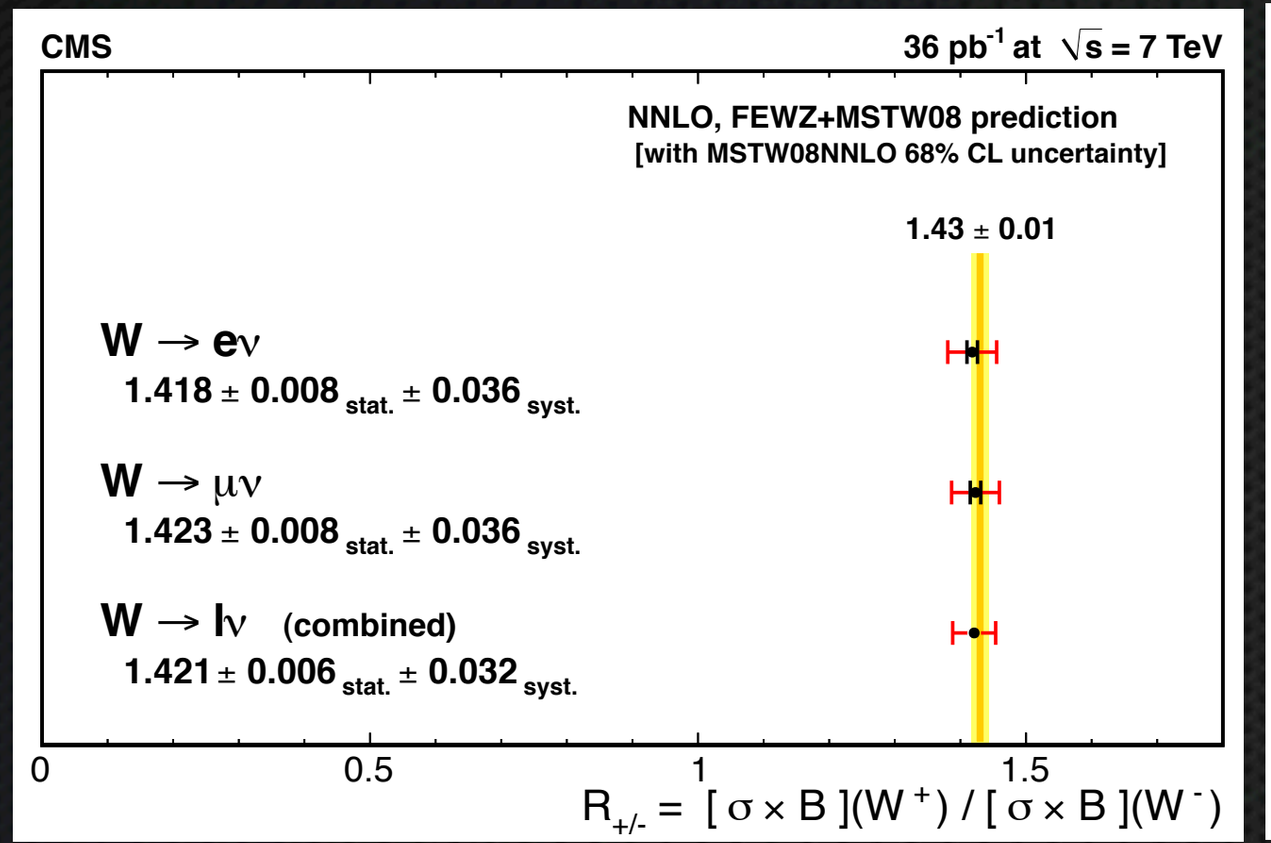
$\sigma^{tot} \times \mathcal{B}$	$W^\pm/Z$
CMS	10.54 ± 0.07 (sta) ± 0.08 (sys) ± 0.16 (theo)
ATLAS	10.893 ± 0.079 (sta) ± 0.110 (sys) ± 0.116 (acc)

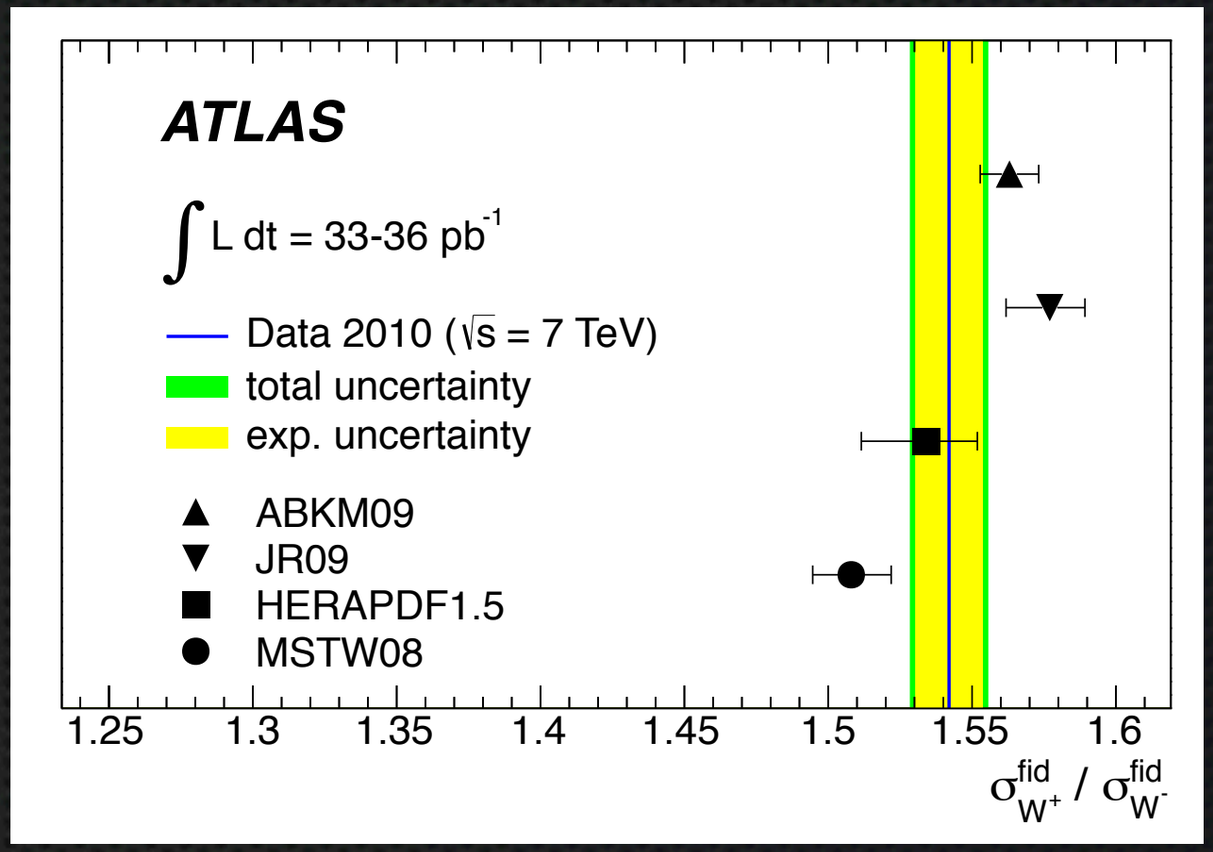
Cross Section Ratio W^+/W^-

Benefits from experimental and theoretical systematics cancellation

JHEP 10 (2011) 132

Phys. Rev. D85 (2012) 072004





$\sigma^{tot}\times\mathcal{B}$	W^+/W^-
CMS	1.421 ± 0.006 (sta) ± 0.014 (sys) ± 0.029 (the)
ATLAS	1.454 ± 0.006 (sta) ± 0.012 (sys) ± 0.022 (acc)

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

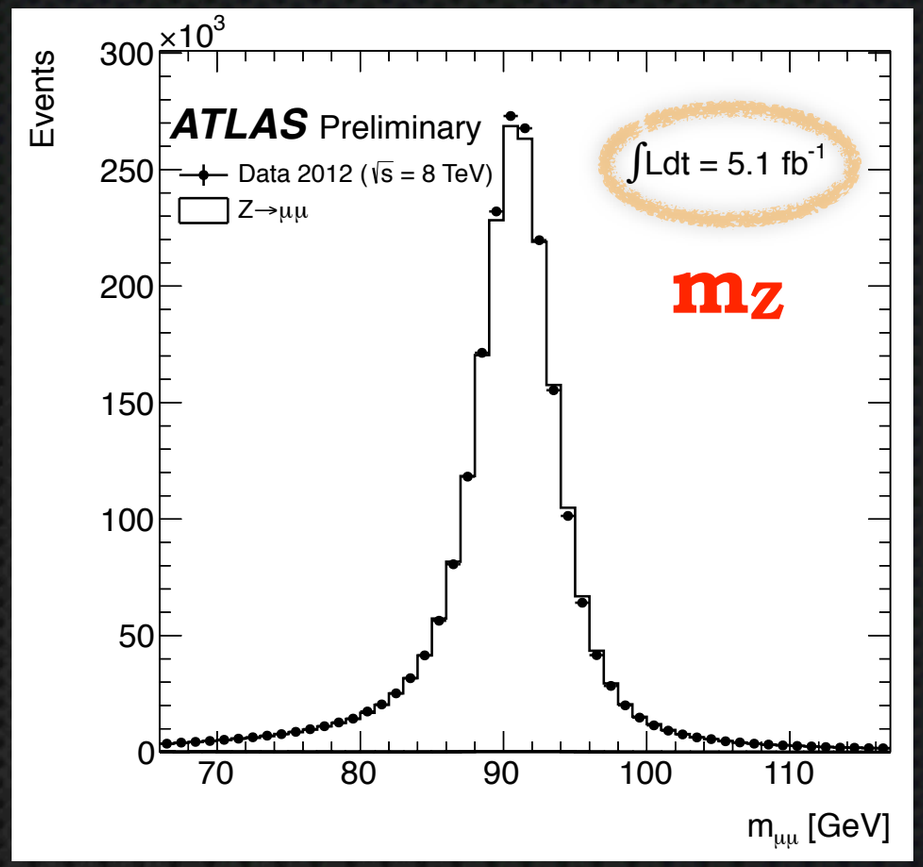
New

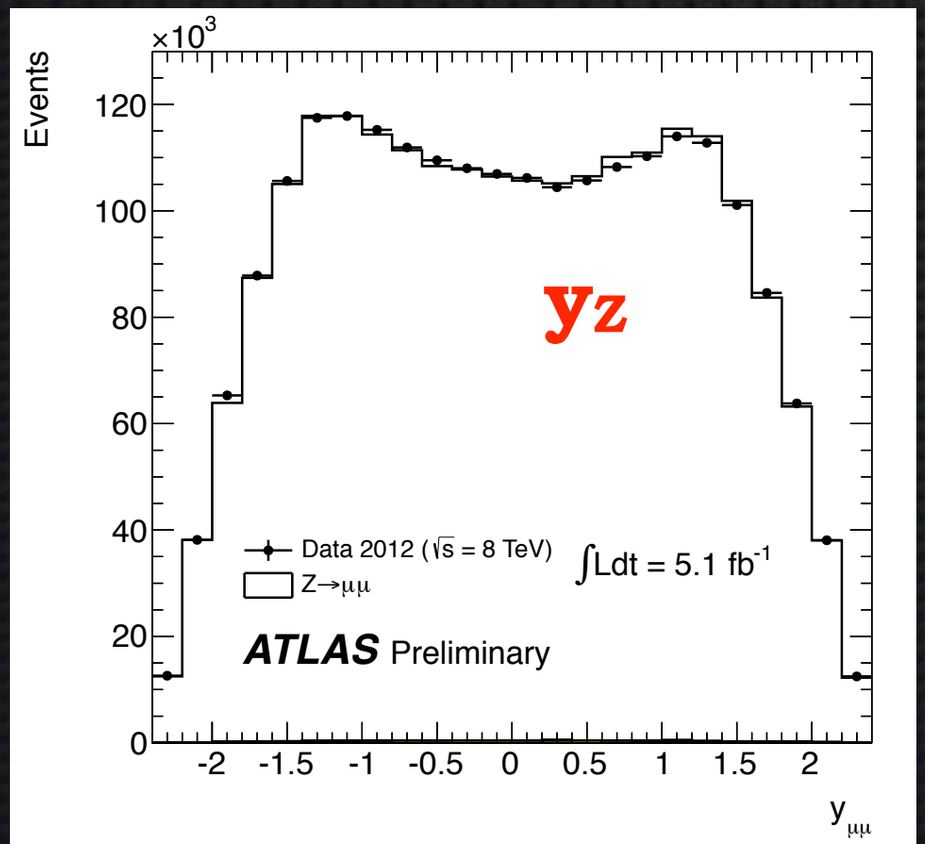
Z boson observation at $\sqrt{s}$ = 8 TeV

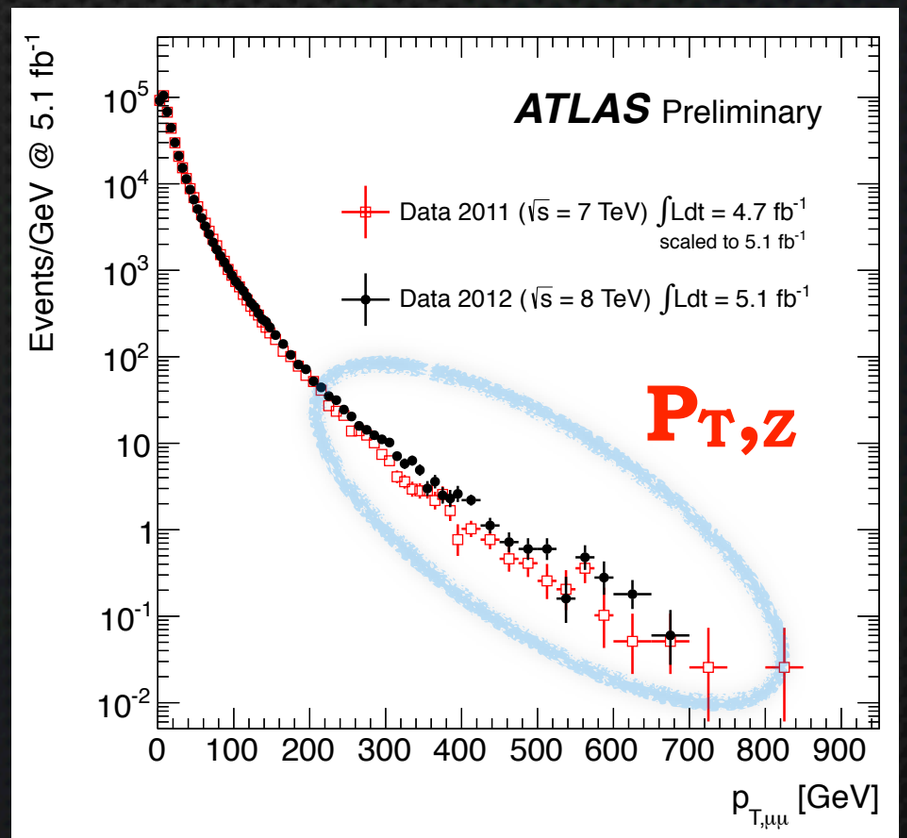
$Z \rightarrow \mu\mu$

POWHEG+PYTHIA 8 MC
CT 10.0

Distributions normalized to data



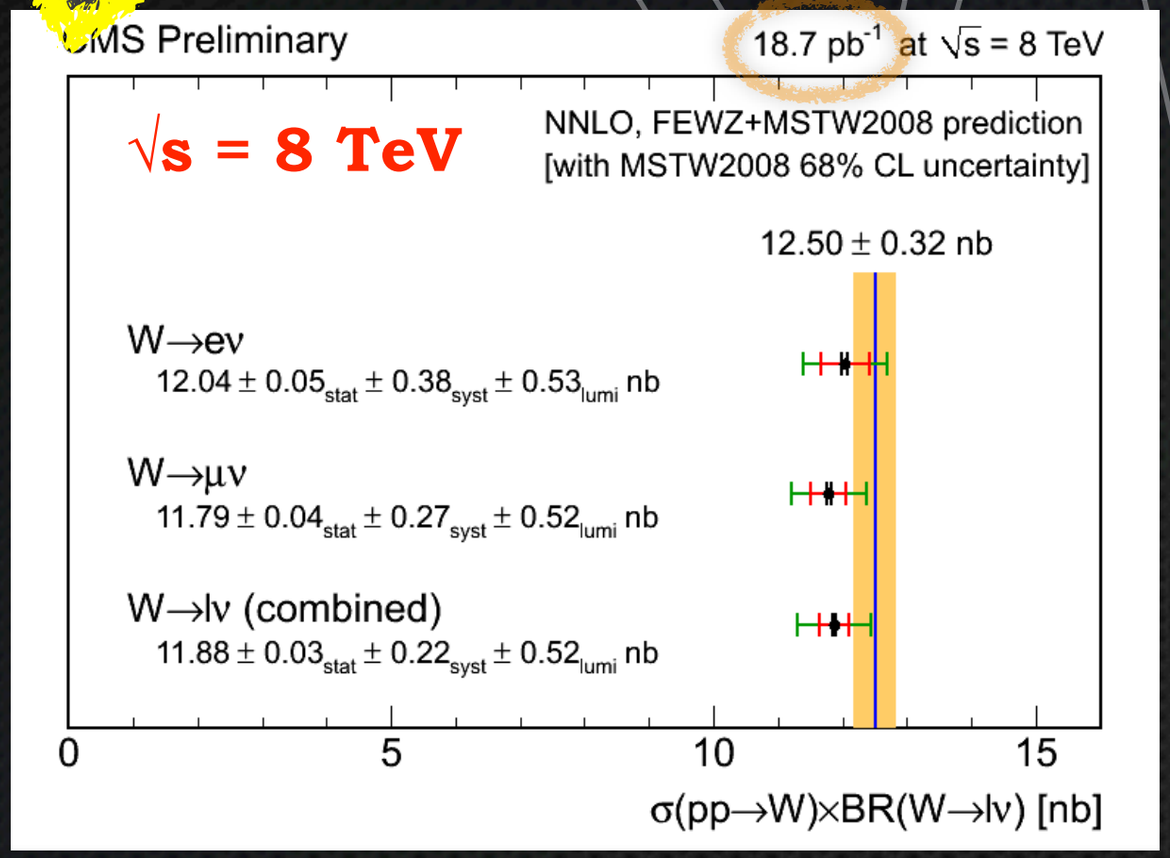


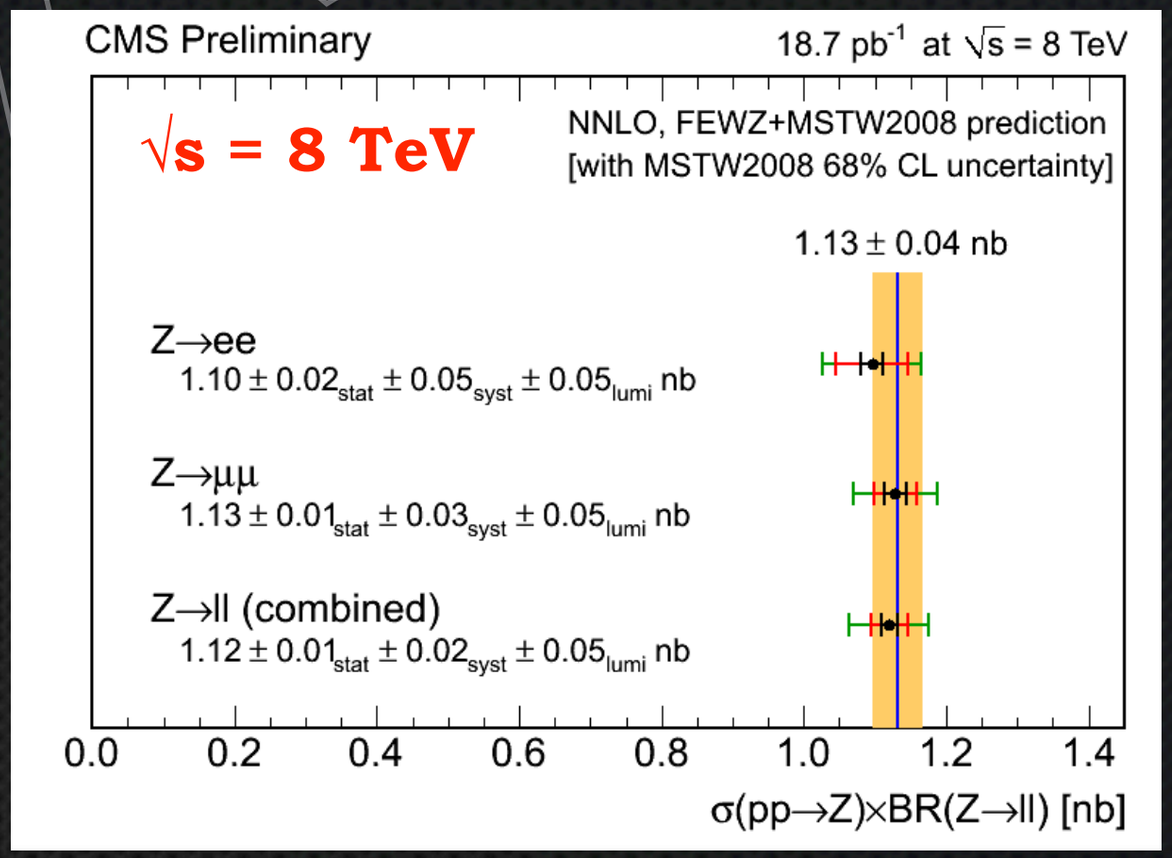


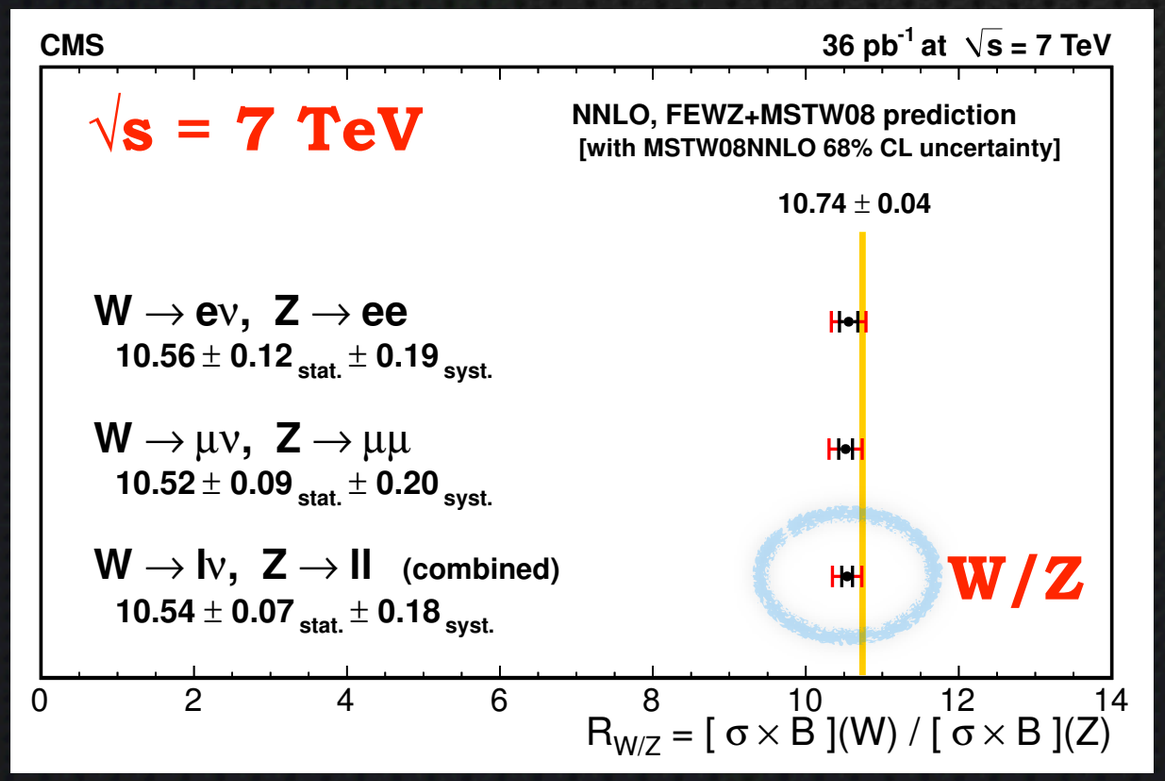
W and Z production at $\sqrt{s}$ = 8 TeV

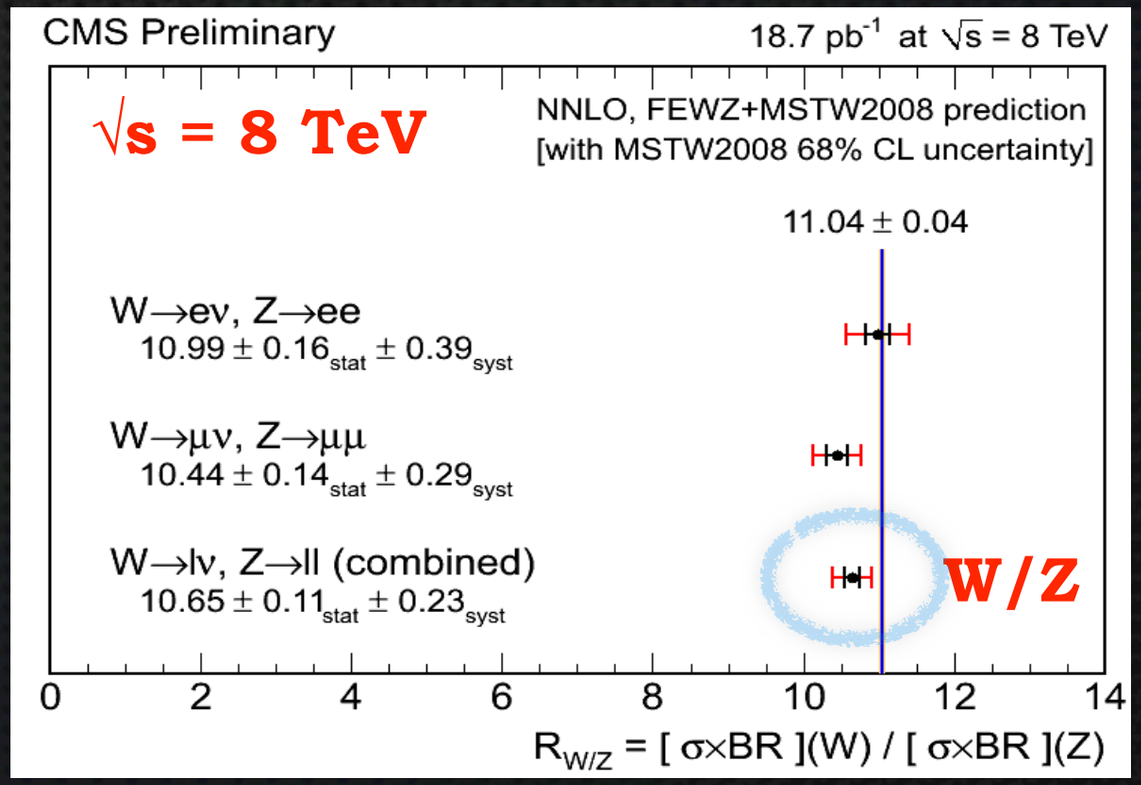
New

CMS-PAS-12-011



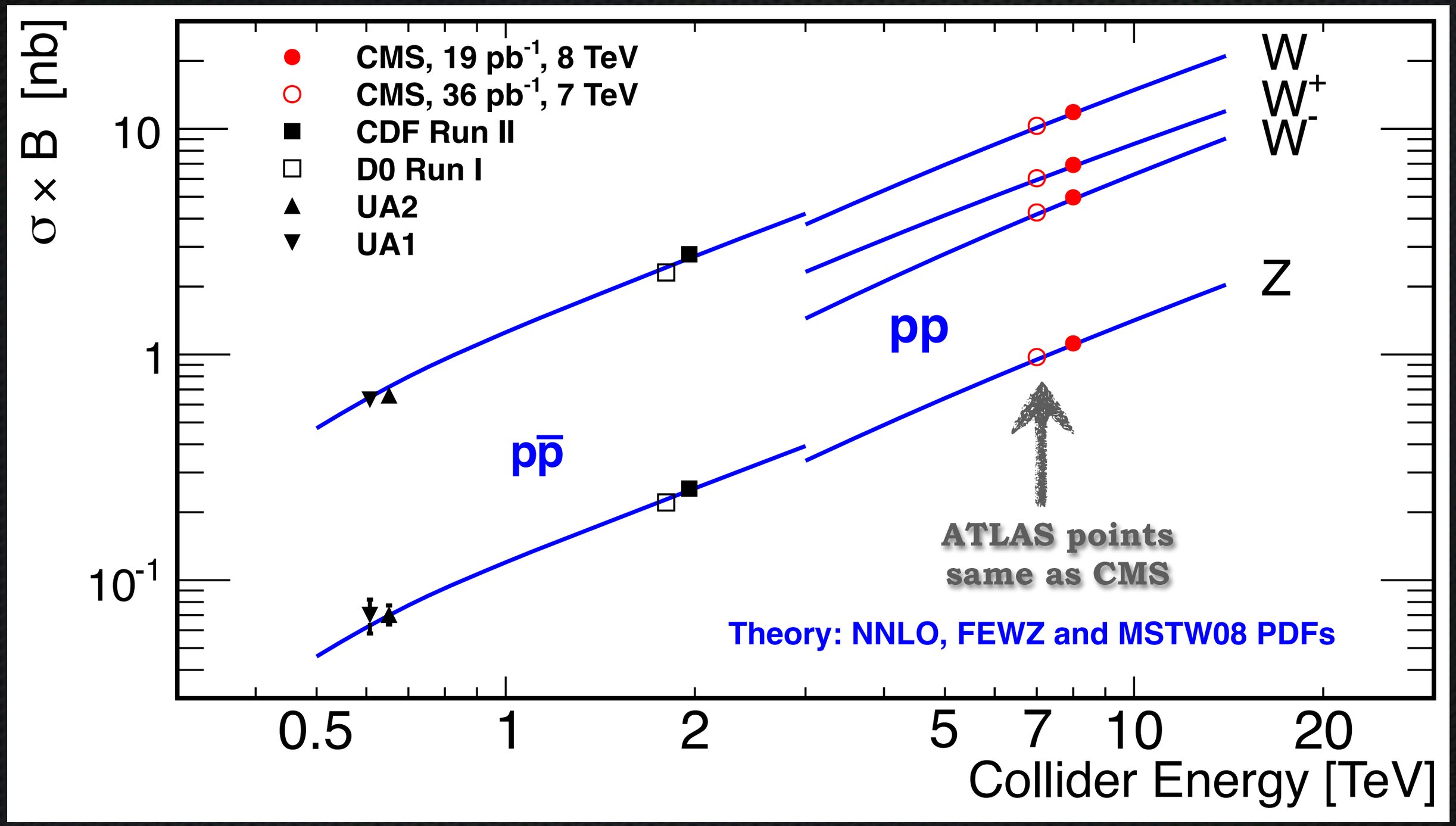






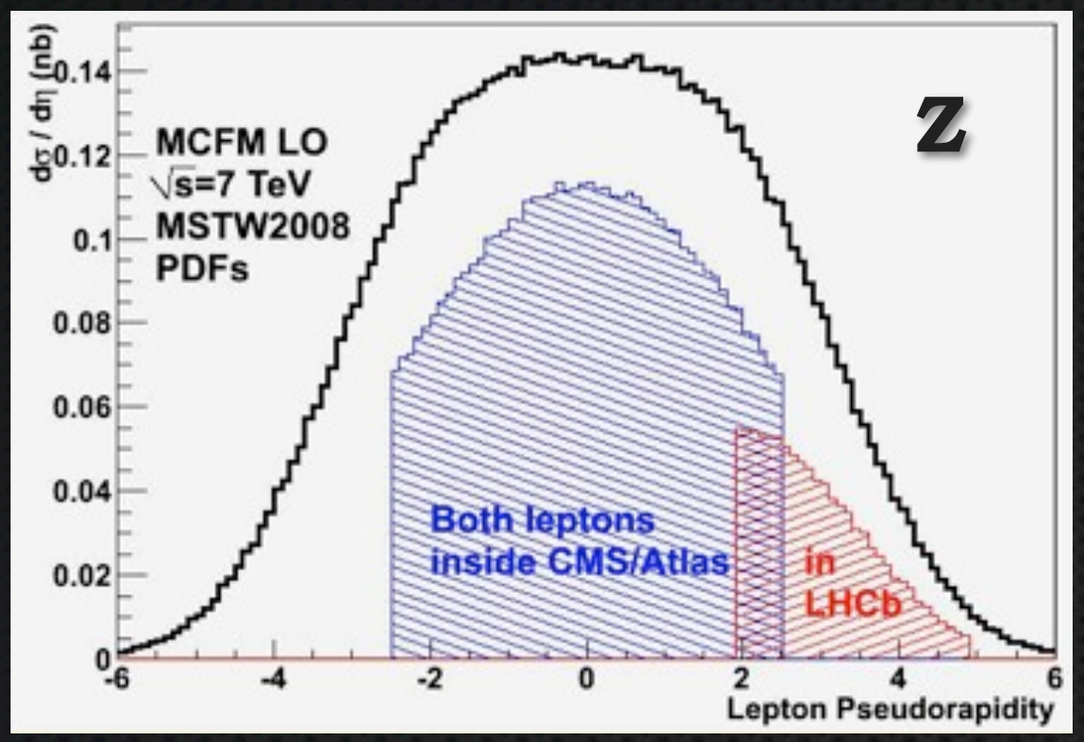
W and Z Inclusive Cross Sections

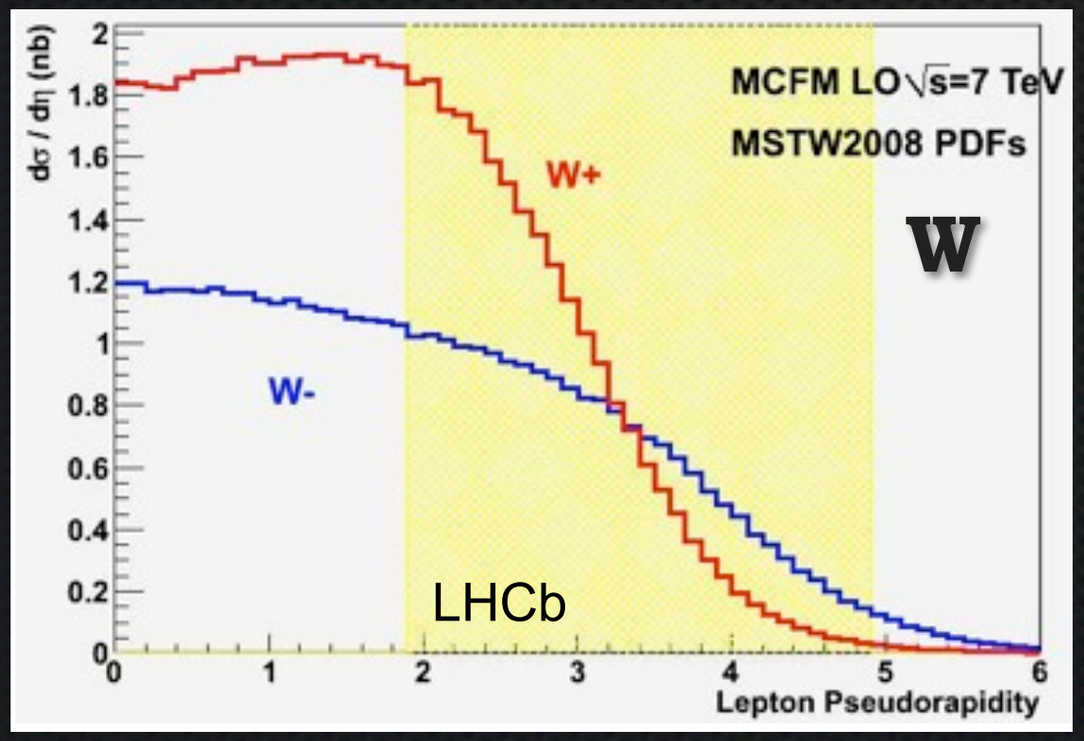
CMS-PAS-12-011

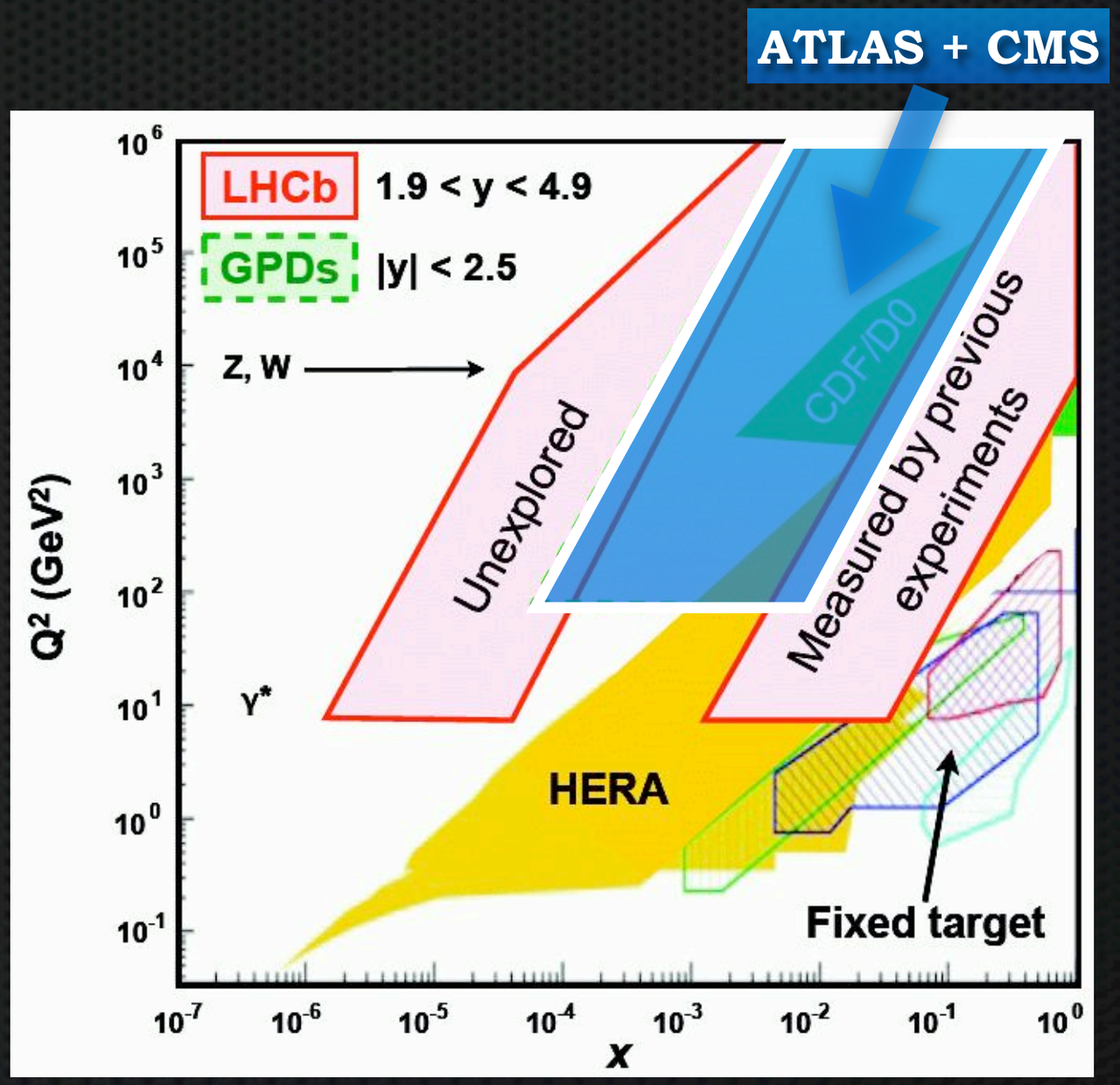


W and Z Production at LHCb

LHCb: Measurements extended up to $|\eta_l| = 4.9$



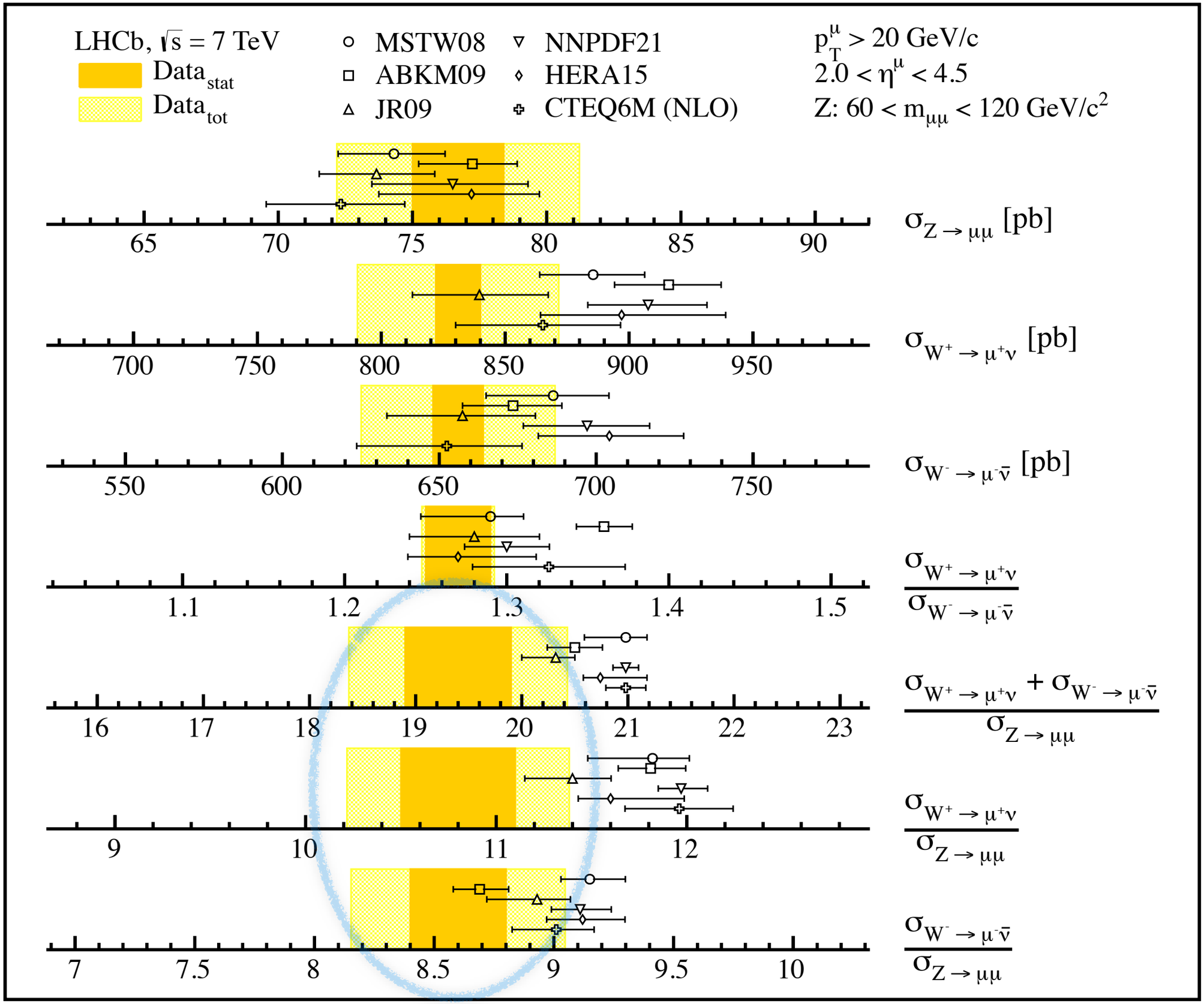




Important for PDF constraints

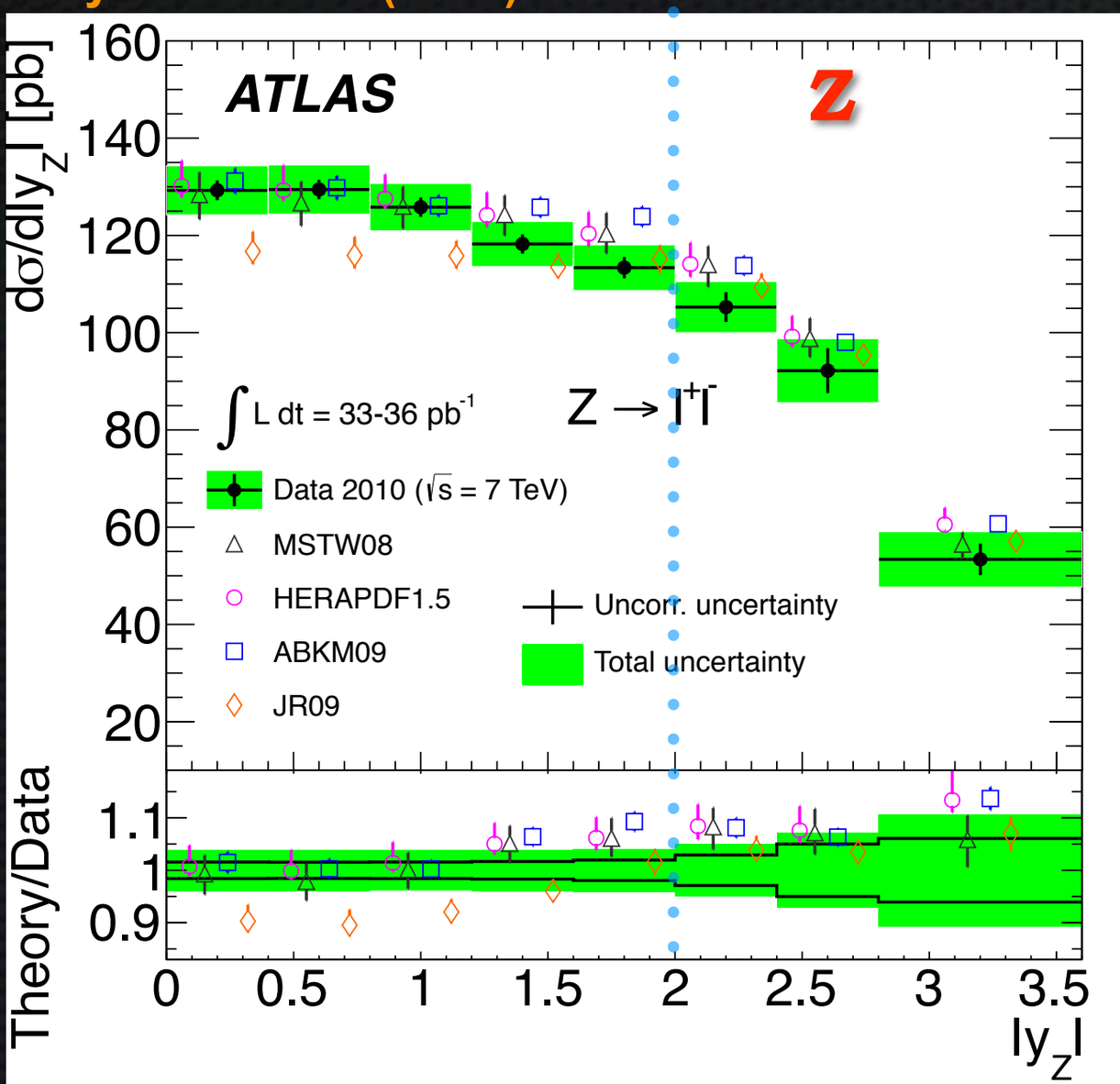
W and Z Production at LHCb

JHEP 06 (2012) 058

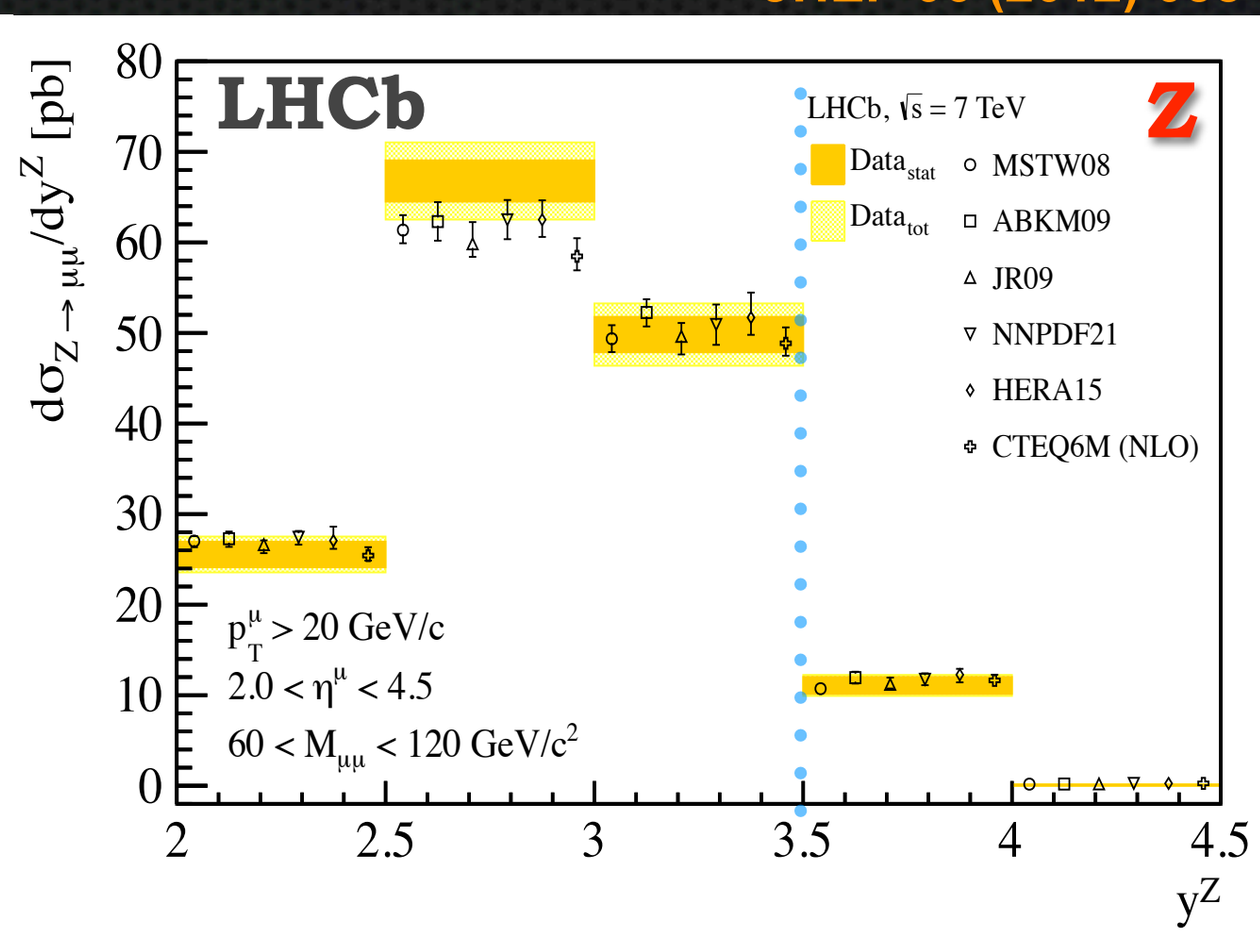


$d\sigma_Z/dy_Z$ versus NNLO PDF predictions

Phys. Rev. D85 (2012) 072004



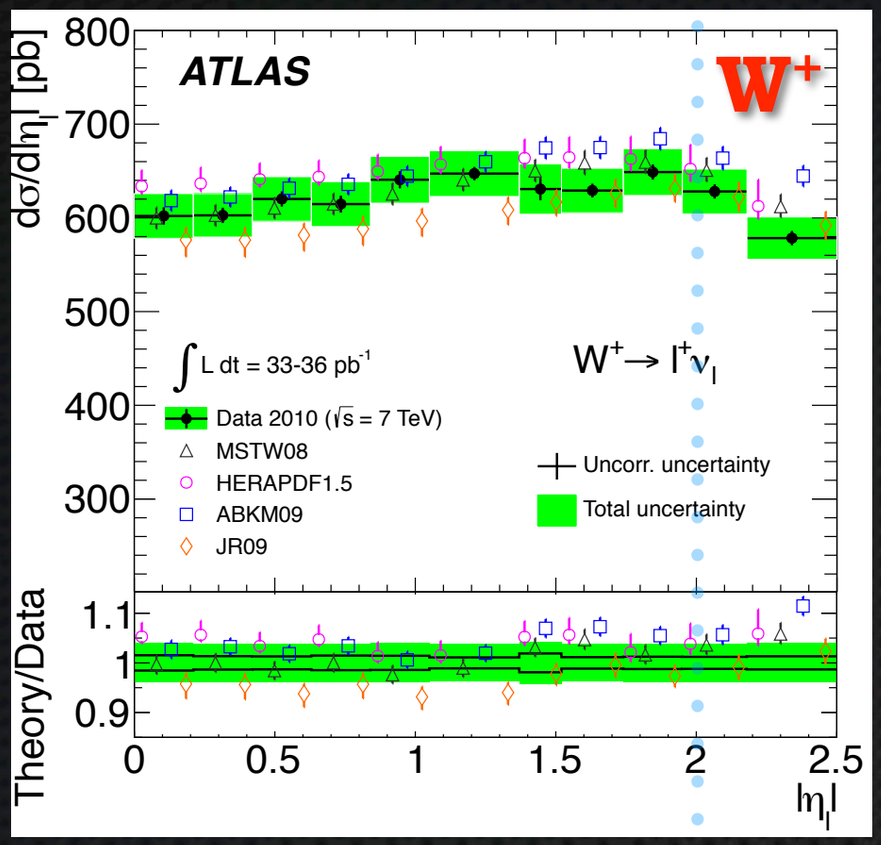
JHEP 06 (2012) 058

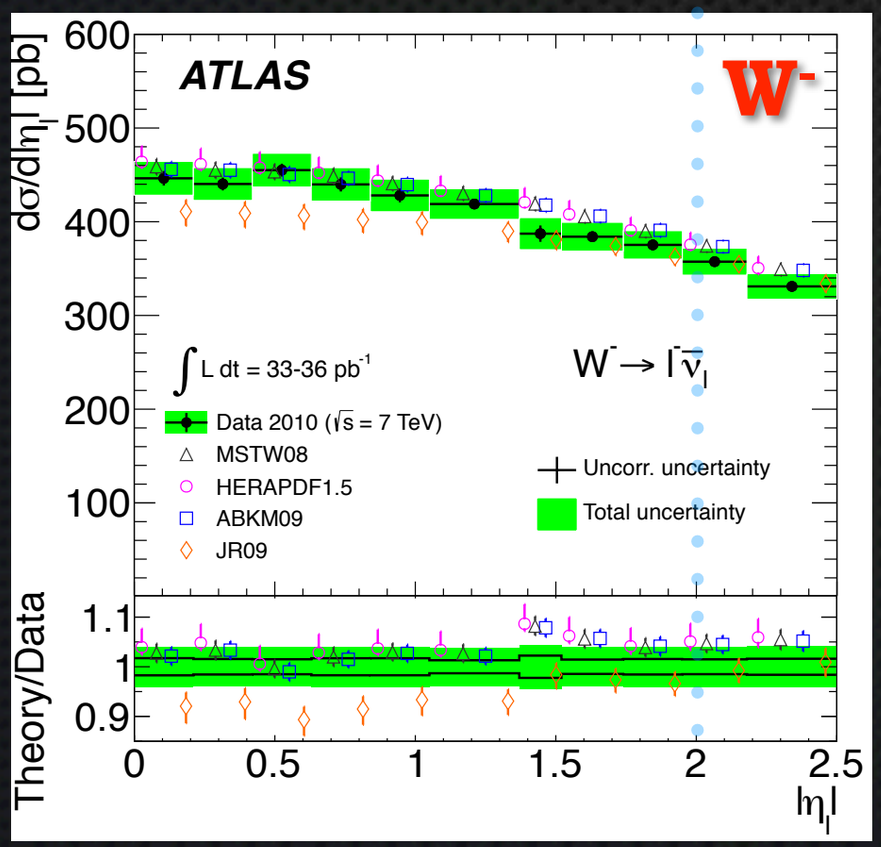


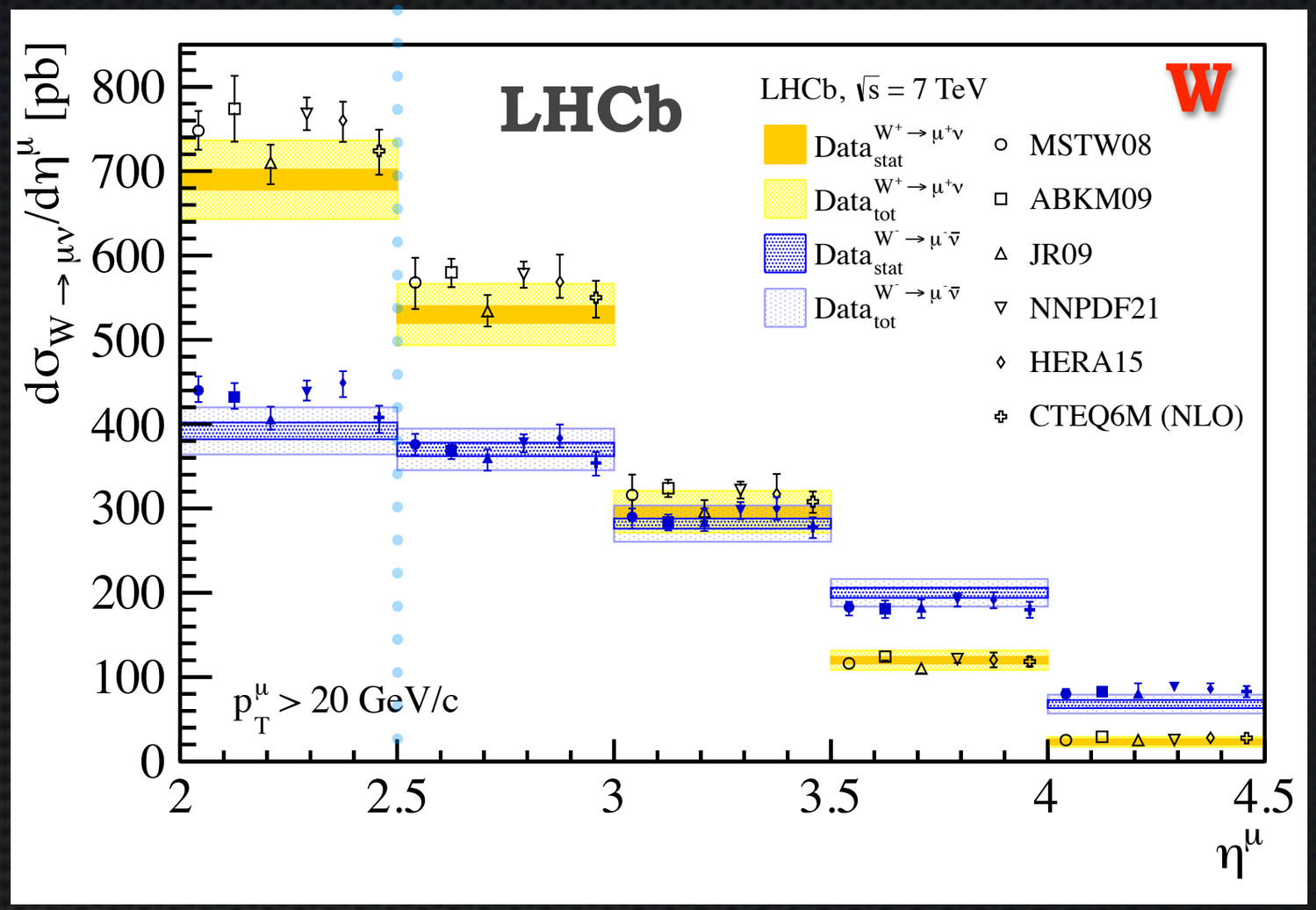
CMS Z rapidity measurement:
Phys. Rev. D 85 (2012) 032002

- **Broadly well described by predictions**
- **Can impact PDF central values and uncertainties**
  - **Full covariance matrix available from all experiments**

$d\sigma_W/d\eta_l$ versus NNLO PDF predictions





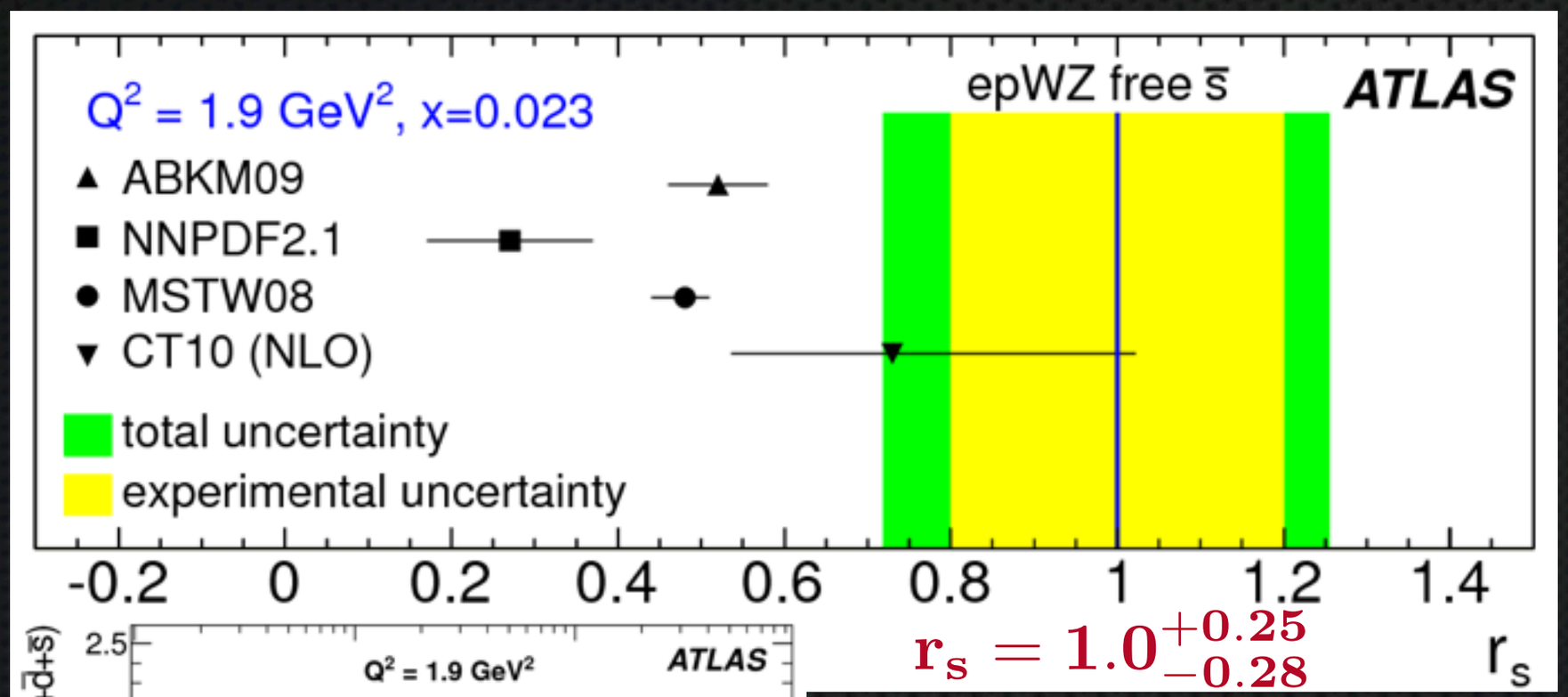


- **Broadly well described by predictions**
- **Can impact PDF central values and uncertainties**

Strangeness in the Proton

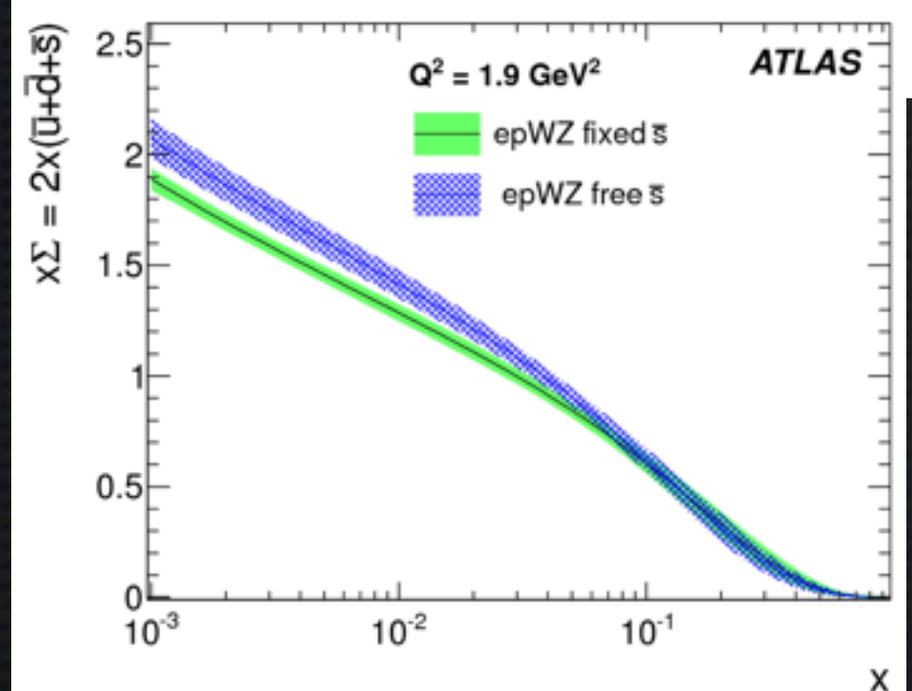
Phys.Rev.Lett. 109 (2012) 012001

- **Fit ATLAS differential distributions for W^+, W^- and Z with HERA $e^{\pm}p$ data**
  - **NNLO pQCD analysis**



$$r_s = 1.0^{+0.25}_{-0.28}$$

$$r_s = \frac{0.5(s+\bar{s})}{\bar{d}}$$



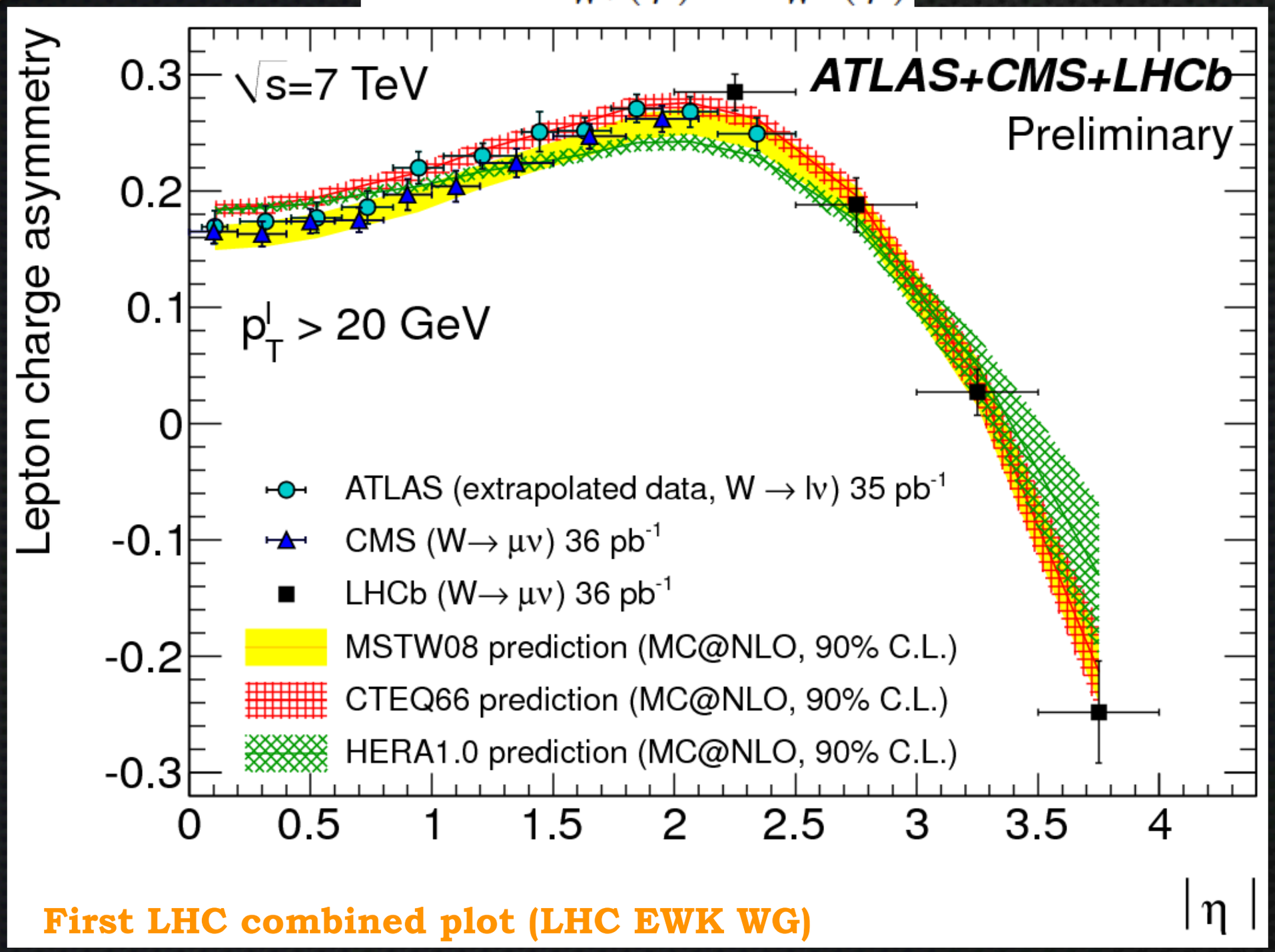
Fit results:

- **Light quark sea at low *x* is flavor symmetric**
- **Total sea enhancement of 8%**

W-Lepton Charge Asymmetry

ATLAS-CONF-2011-129

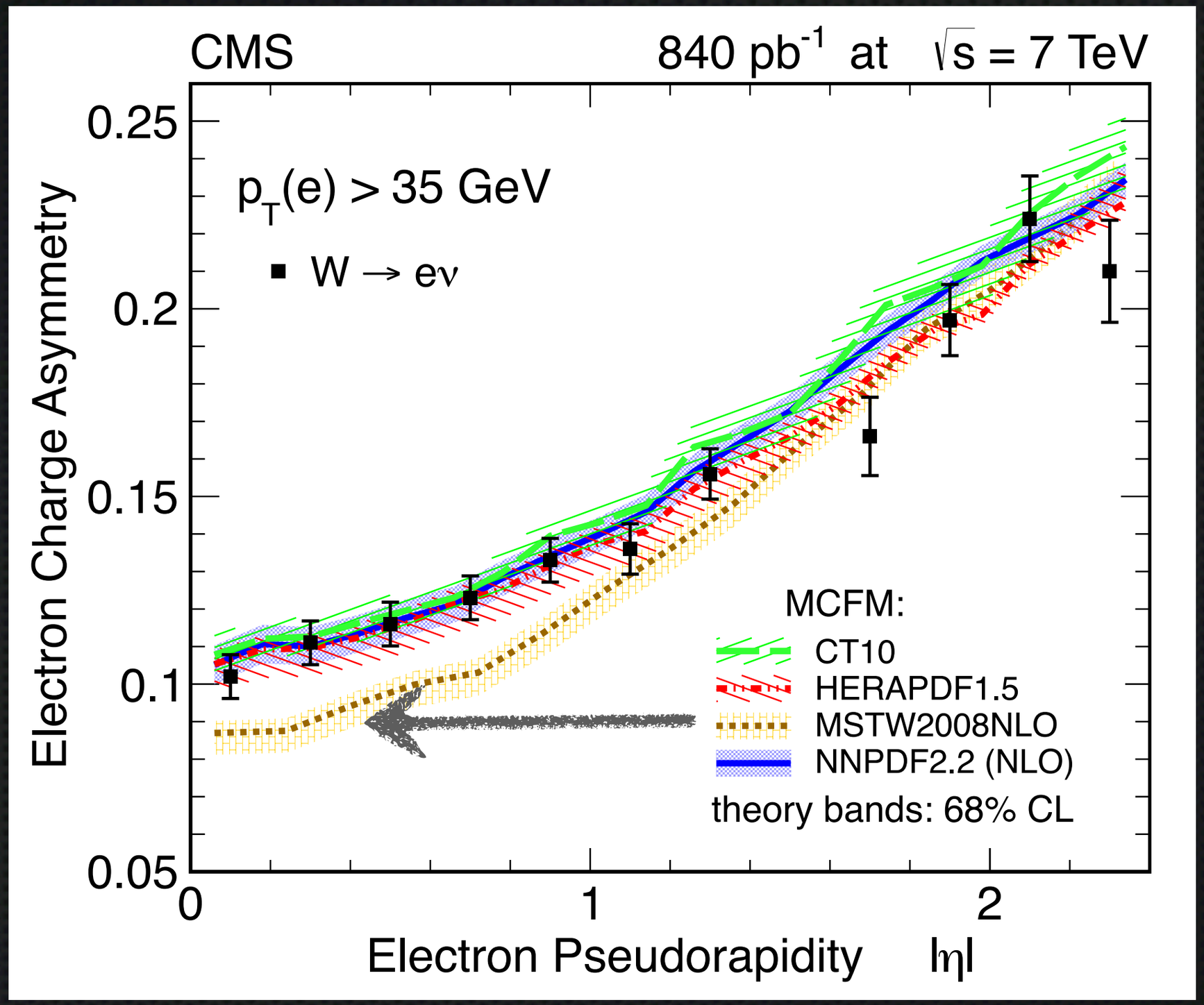
$$A(\eta_\ell) = \frac{d\sigma_{W^+}(\eta_\ell) - d\sigma_{W^-}(\eta_\ell)}{d\sigma_{W^+}(\eta_\ell) + d\sigma_{W^-}(\eta_\ell)}$$



First LHC combined plot (LHC EWK WG)

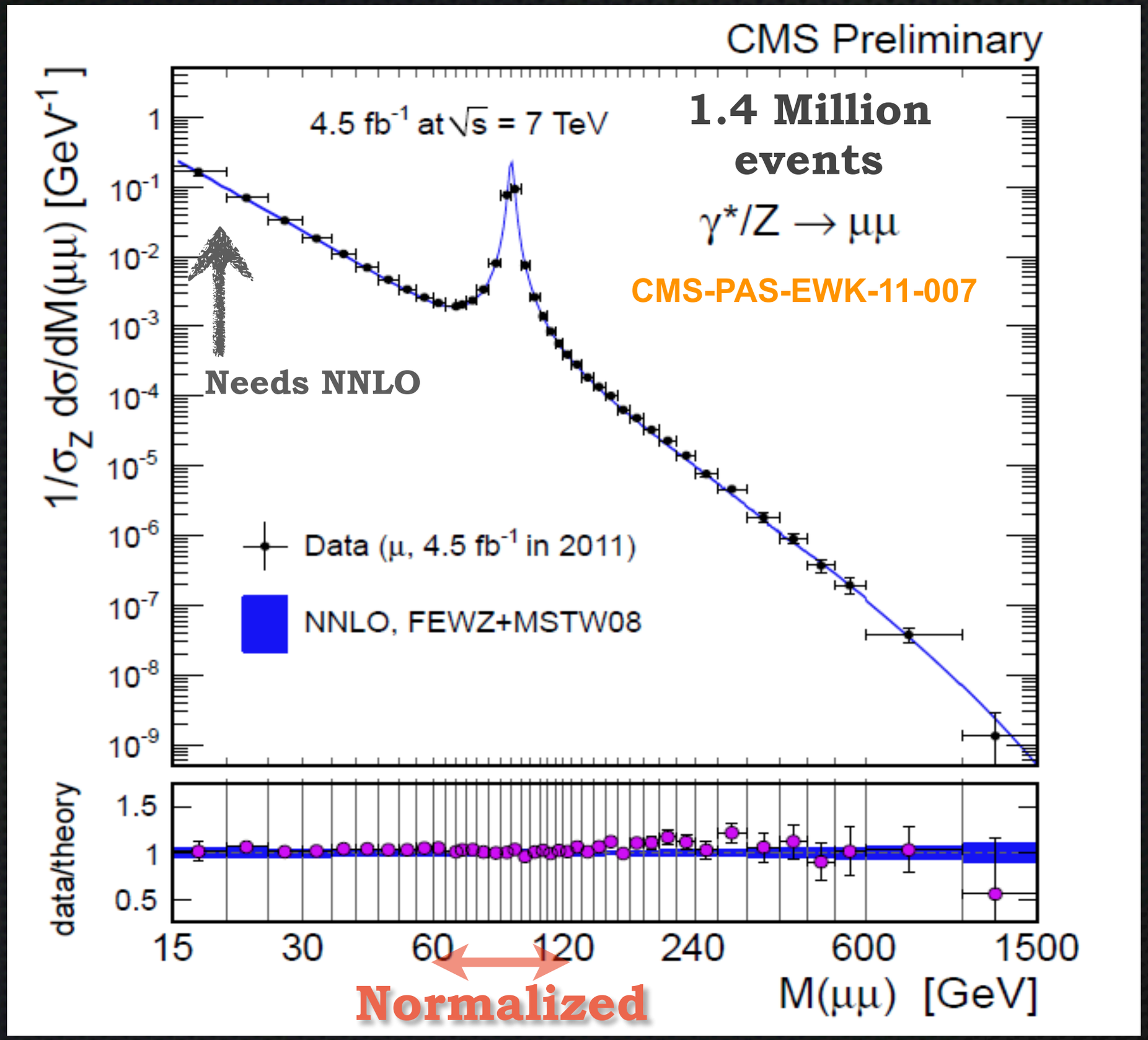
W charge asymmetry: update

arXiv:1206.2598



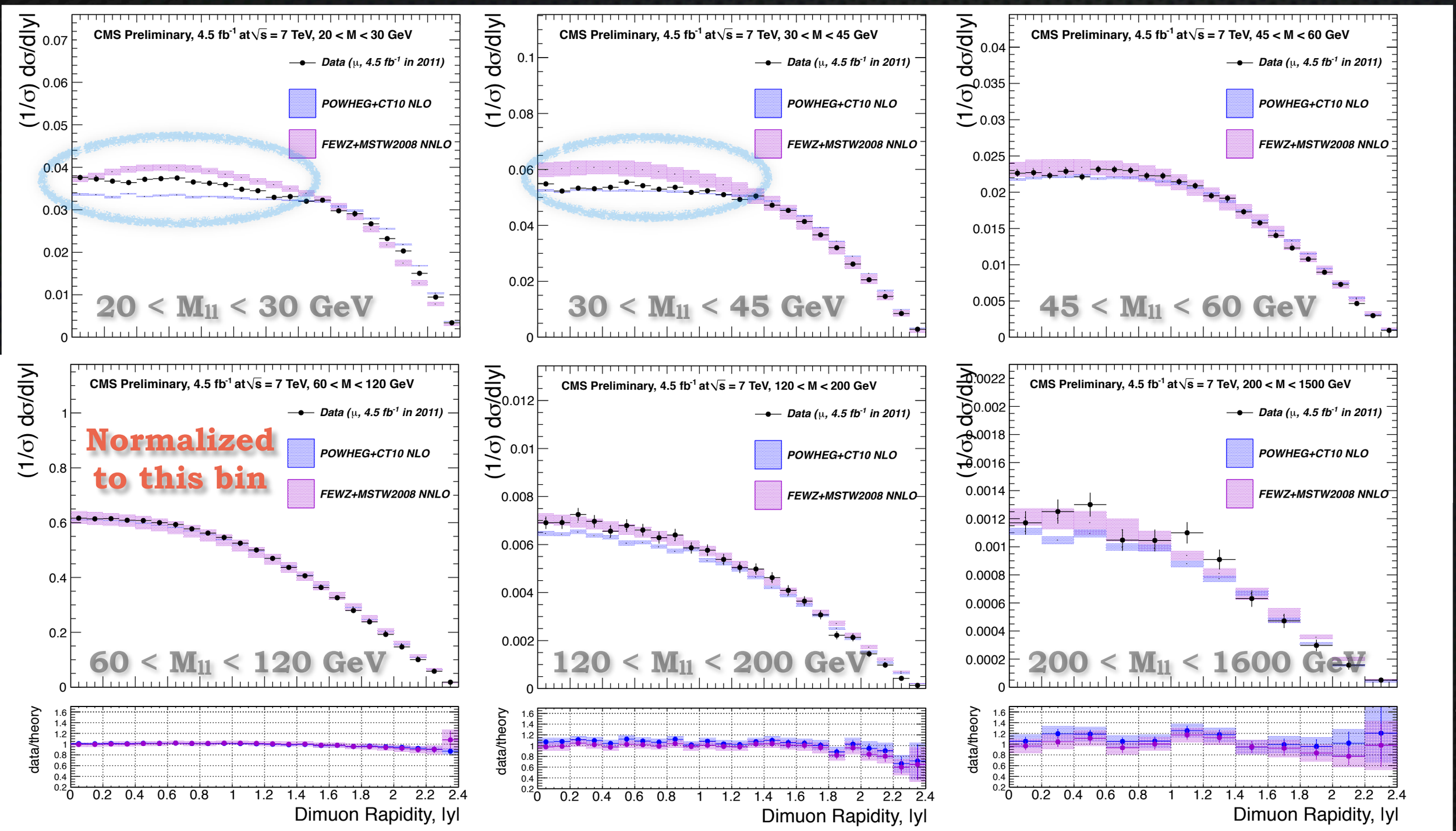
Discrimination between PDF at low |η|

Drell-Yan Production at LHC



DY double-differential cross section (CMS)

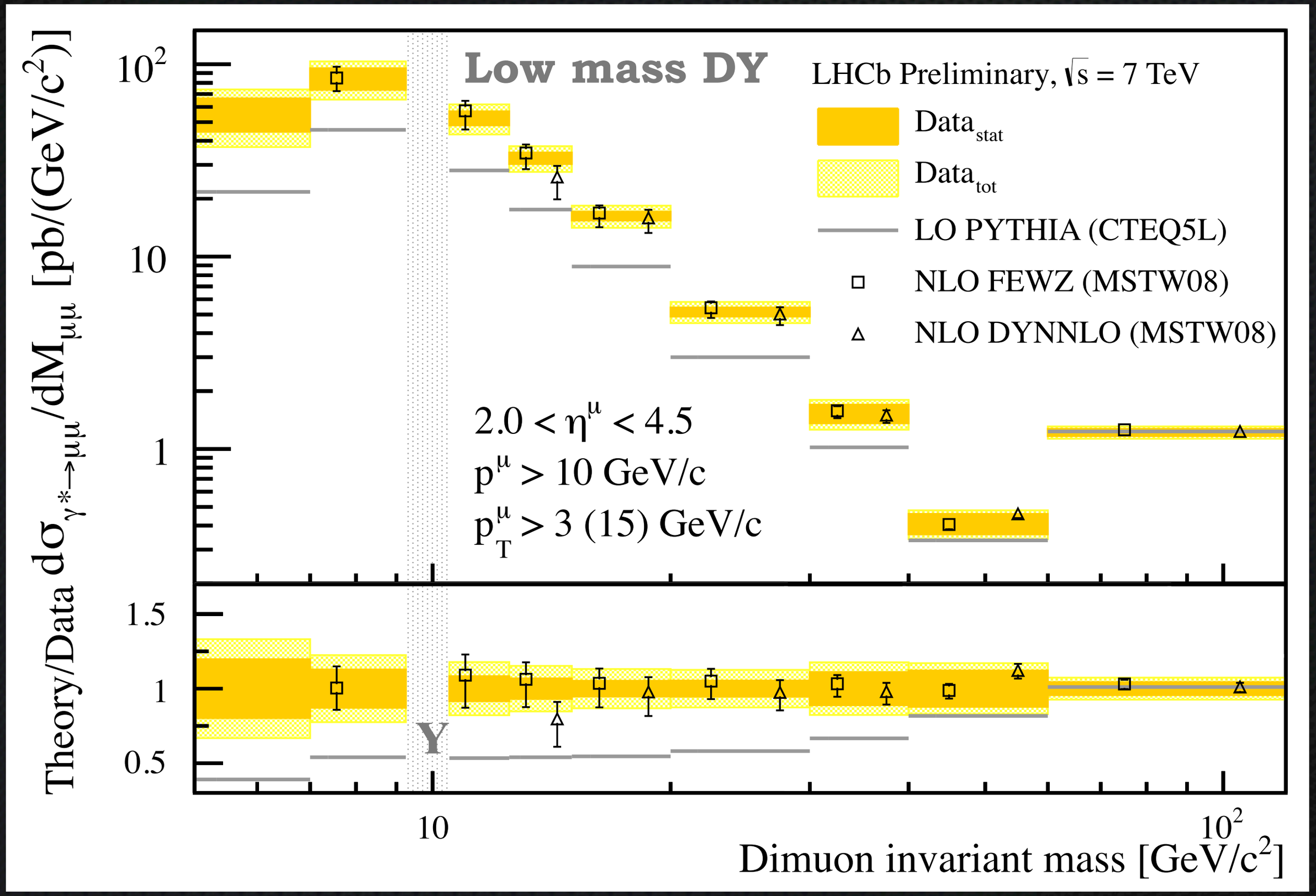
CMS-PAS-EWK-11-007



Significant differences between data, POWHEG NLO and FEWZ NNLO calculations at low mass

Drell-Yan production in forward region (LHCb)

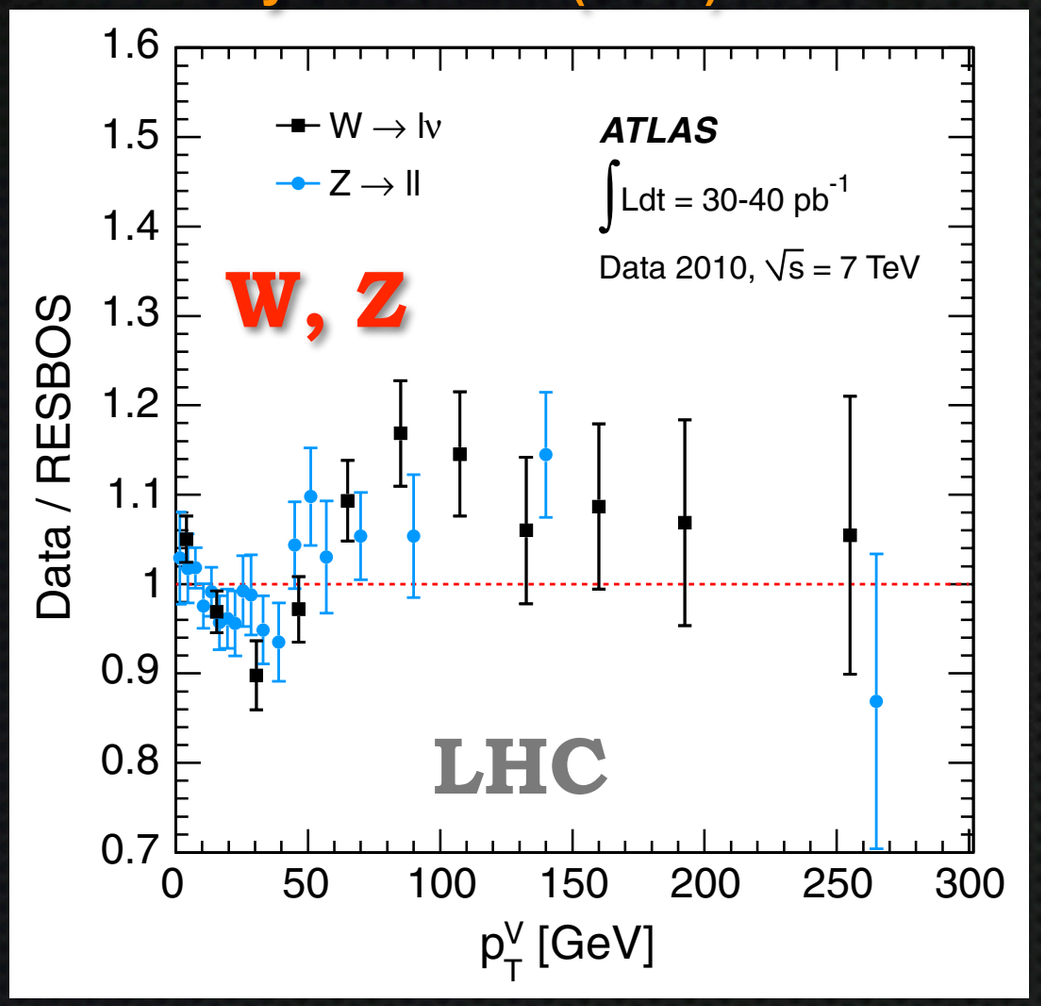
LHCb-CONF-2012-013



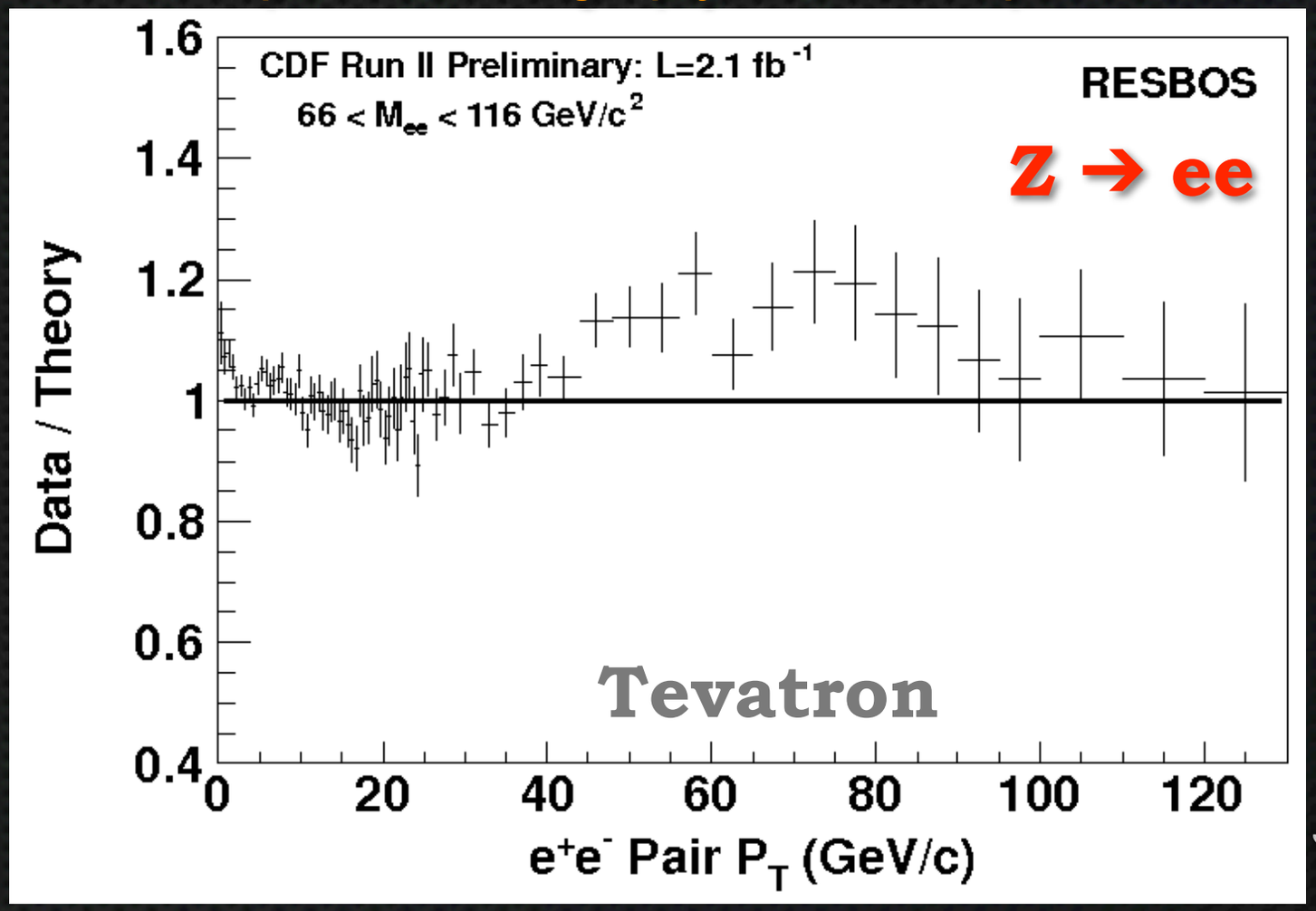
Measurement of Z and W P_T

- **Fully unfolded differential distributions**
  - **Comparison with RESBOS**

Phys.Rev. D85 (2012) 012005



http://www-cdf.fnal.gov/physics/ewk/2011/zpt21/cdf10699/

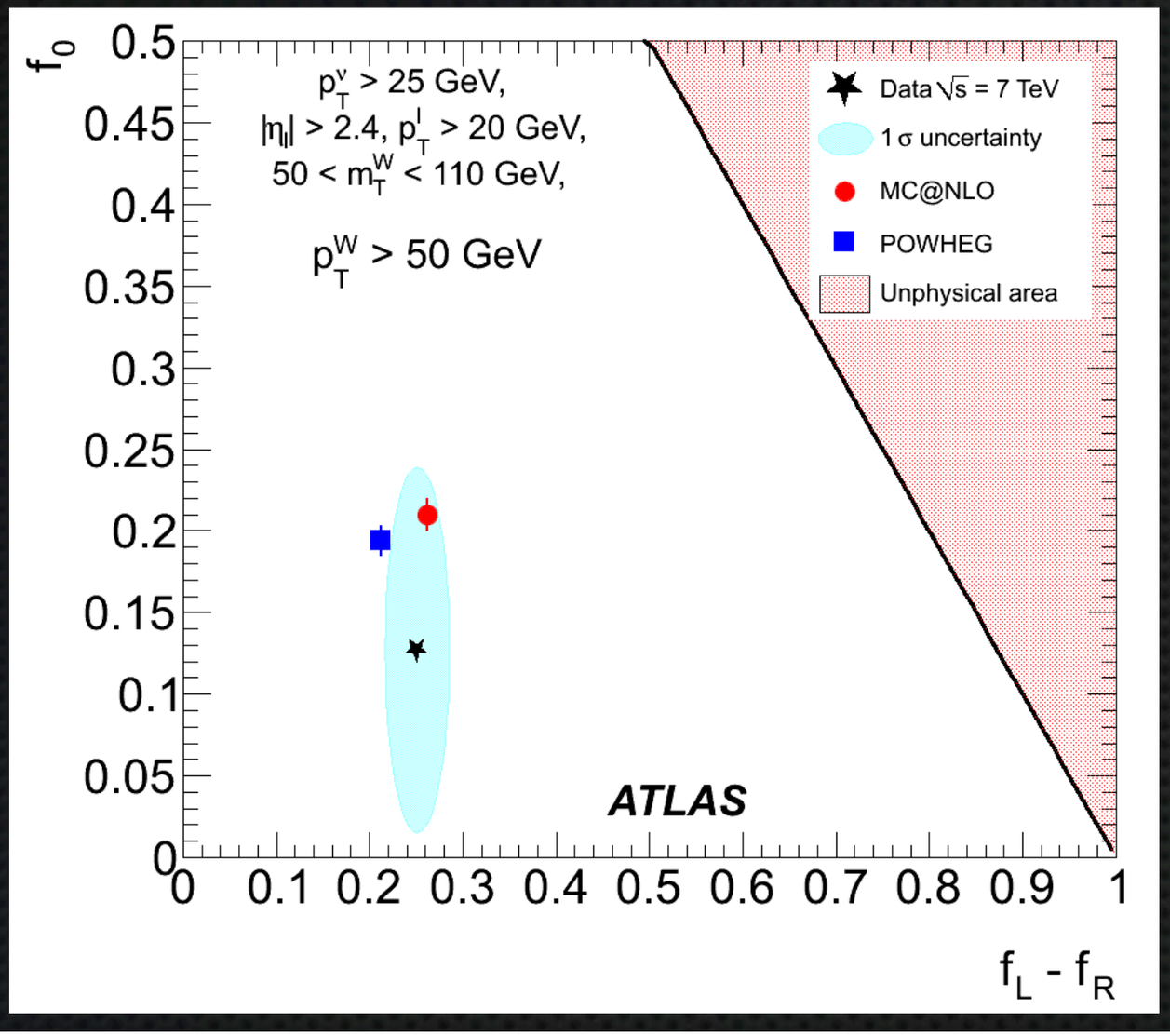


CMS Z P_T measurement:
Phys. Rev. D 85 (2012) 032002

RESBOS tuned to Tevatron data (but not to LHC yet)

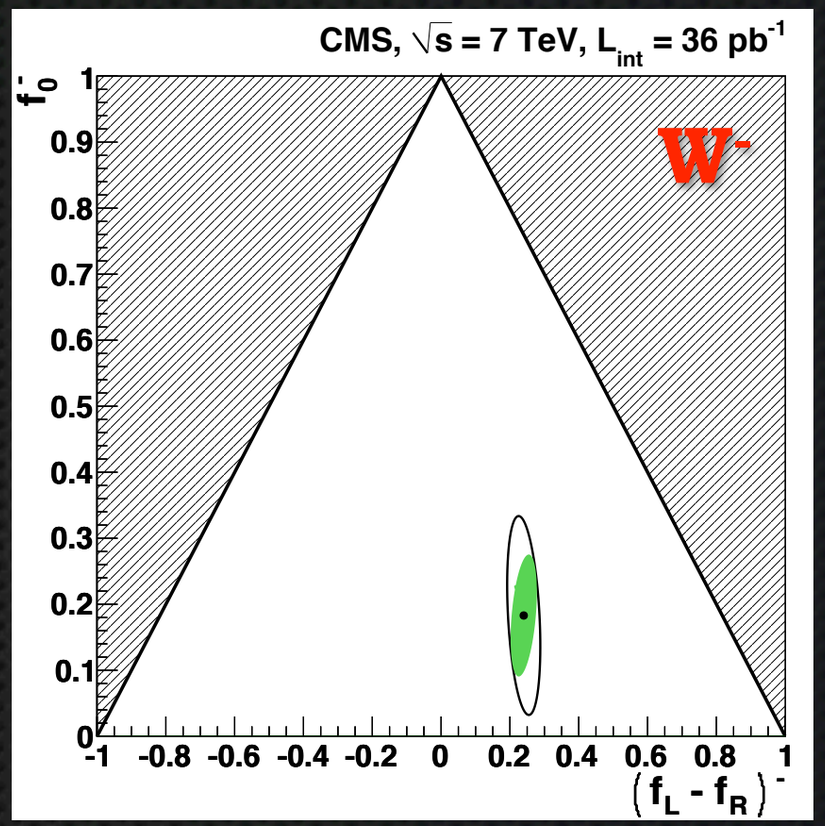
W Boson Polarization

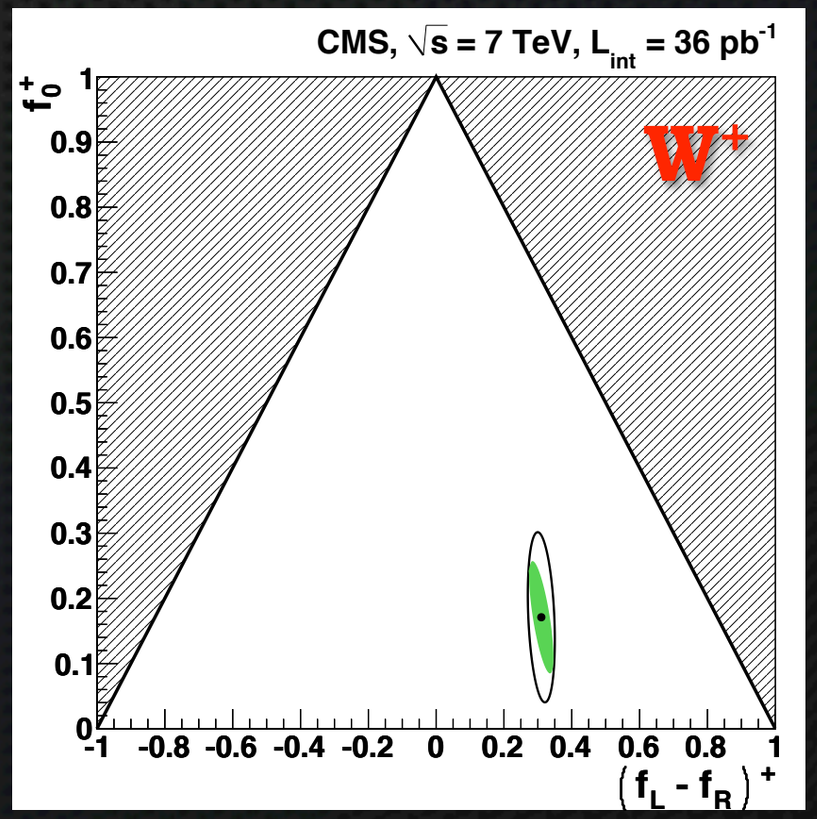
Eur. Phys. J. C72 (2012) 2001



	$f_L - f_R$ (%)	
	$35 < p_T^W < 50$ GeV	$p_T^W > 50$ GeV
Data	$23.8 \pm 2.0 \pm 3.4$	$25.2 \pm 1.7 \pm 3.0$
MC@NLO	27.1 ± 0.7	26.2 ± 0.5
POWHEG	19.9 ± 1.0	21.2 ± 0.8

Phys. Rev. Lett. 107 (2011) 021802





Tau Polarization

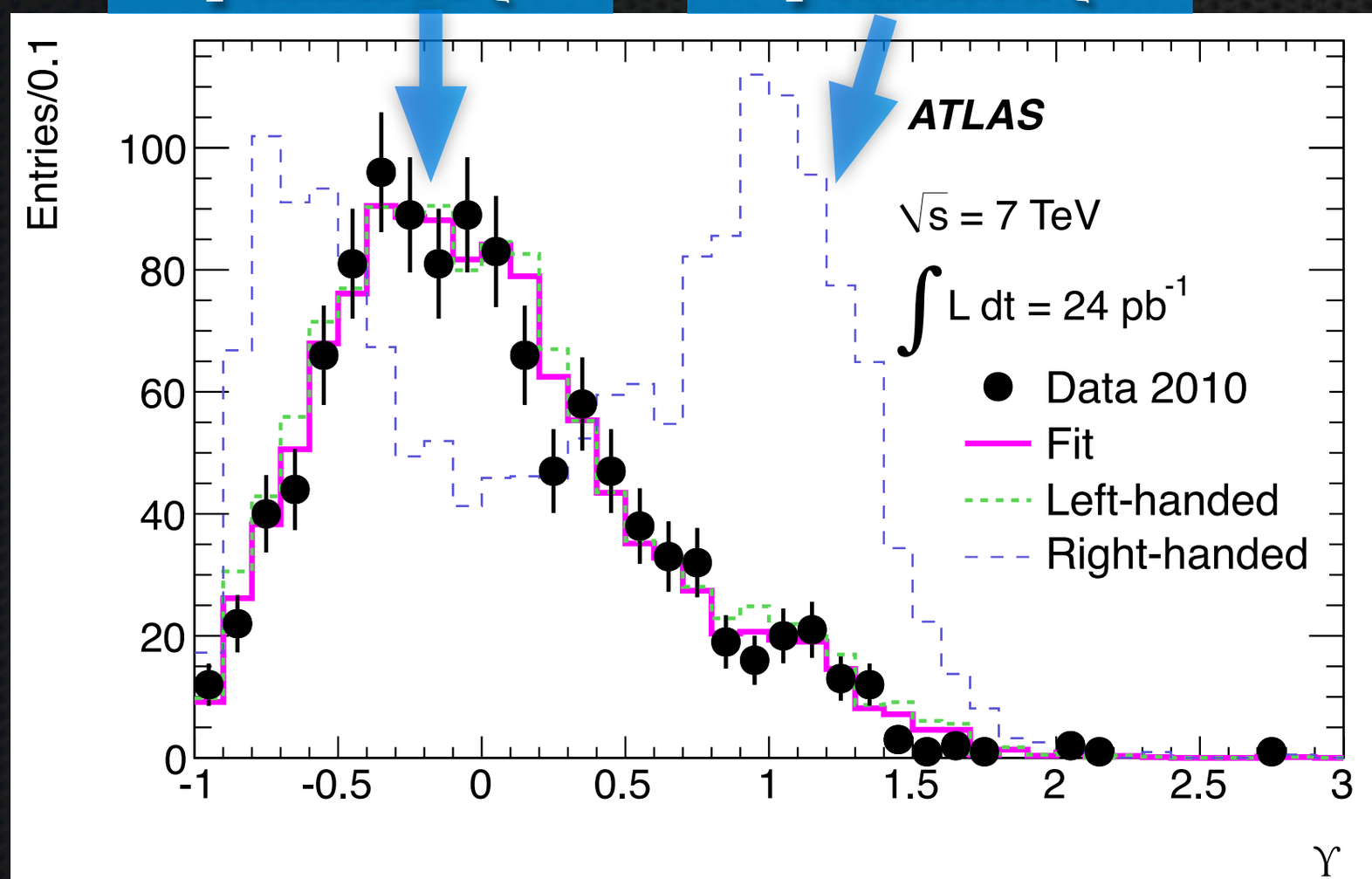
Eur.Phys.J. C72 (2012) 2062

$$P_\tau = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

Process	P_τ Prediction
$W^\pm \to \tau\nu$	-1
$H^\pm \to \tau\nu$	+1
$Z \to \tau\tau$	≈ -0.15
$H \to \tau\tau$	0

Transversely polarized ϱ

Longitudinally polarized ϱ

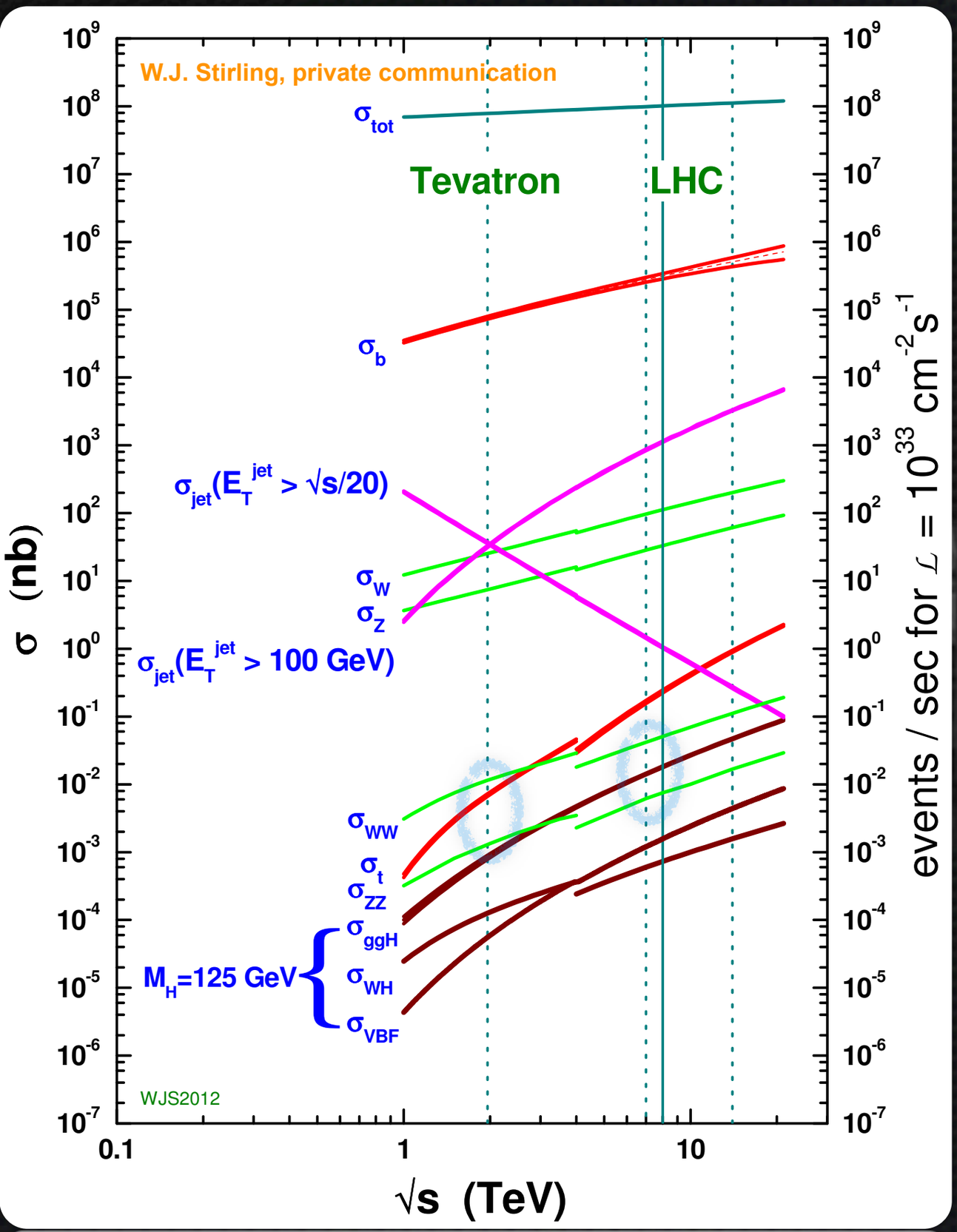


$$\tau \to \rho^- \nu_\tau \to \pi^- \pi^0 \nu_\tau$$

BR = 25.94 ± 0.09%

$$\Upsilon = \frac{2p_T^{trk}}{p_T^\tau} - 1 \approx \frac{E_T^{\pi^-} - E_T^{\pi^0}}{p_T}$$

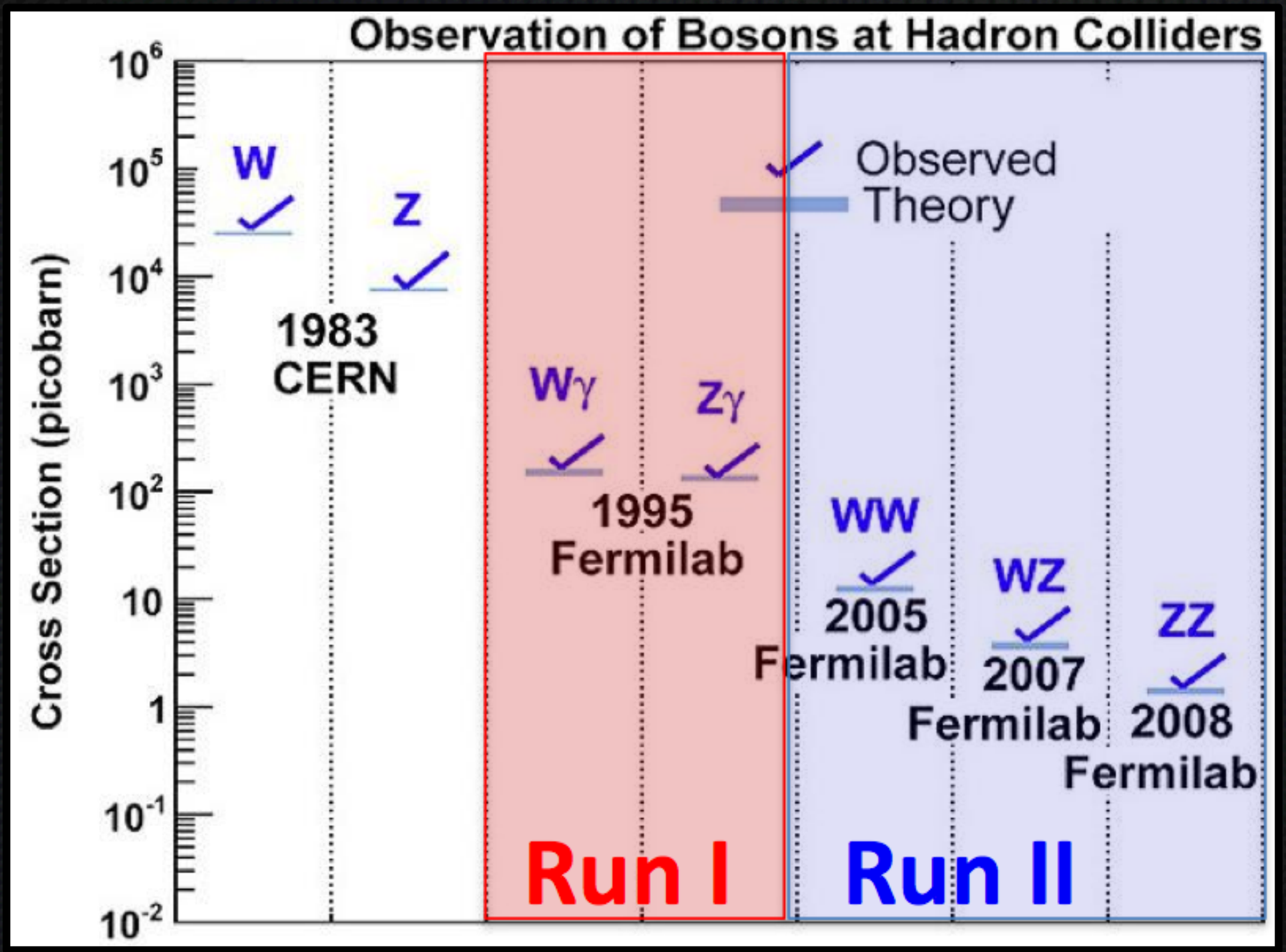
$$P_\tau = -1.06 \pm 0.04\ (\text{stat})^{+0.05}_{-0.07}\ (\text{syst})$$



Diboson Production

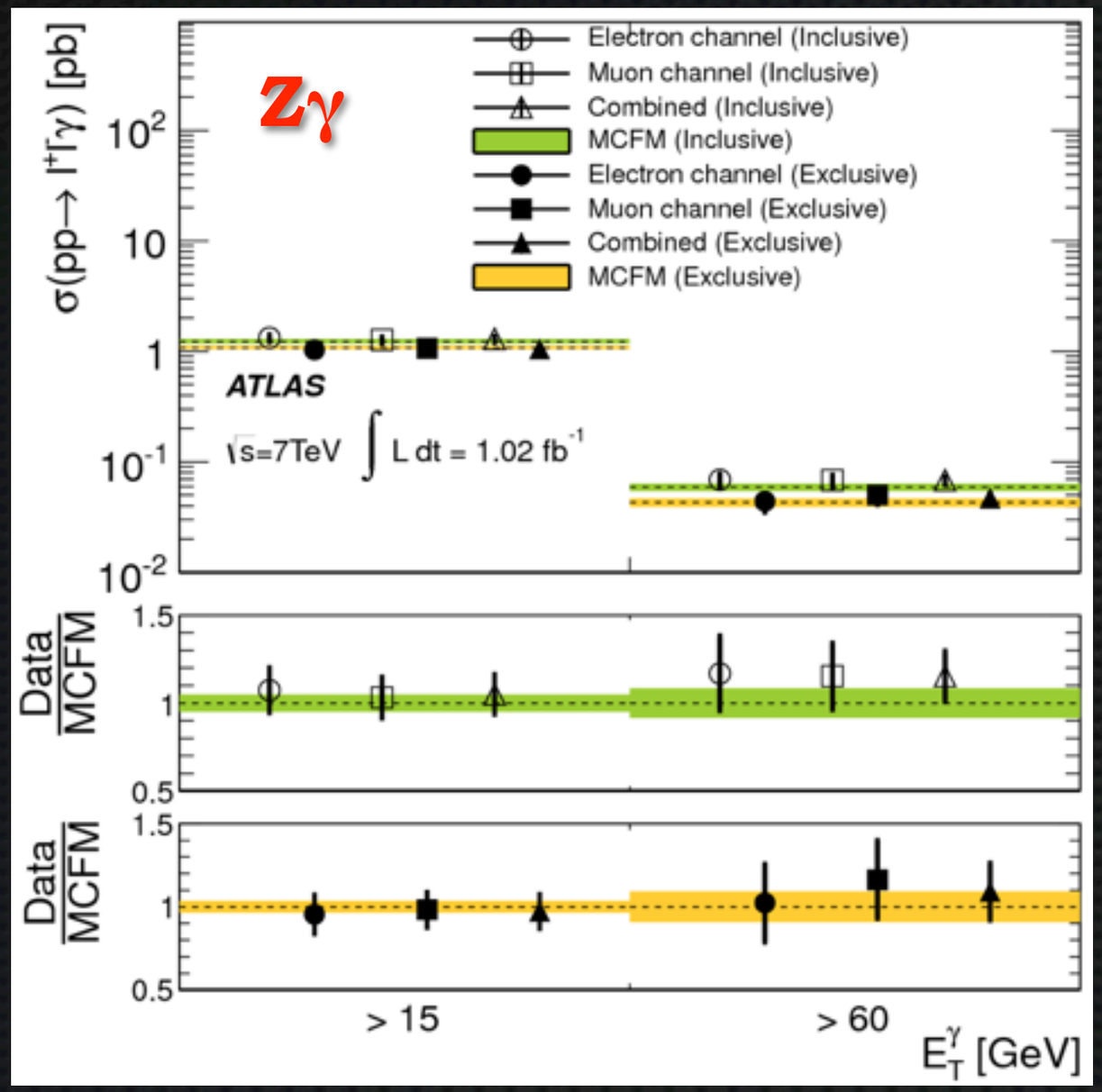
- Fundamental test of Standard Model
  - Triple gauge couplings (TGC)
  - Probe for new physics
    - Resonances with diboson final states
- Higgs hunting
  - Background to Higgs

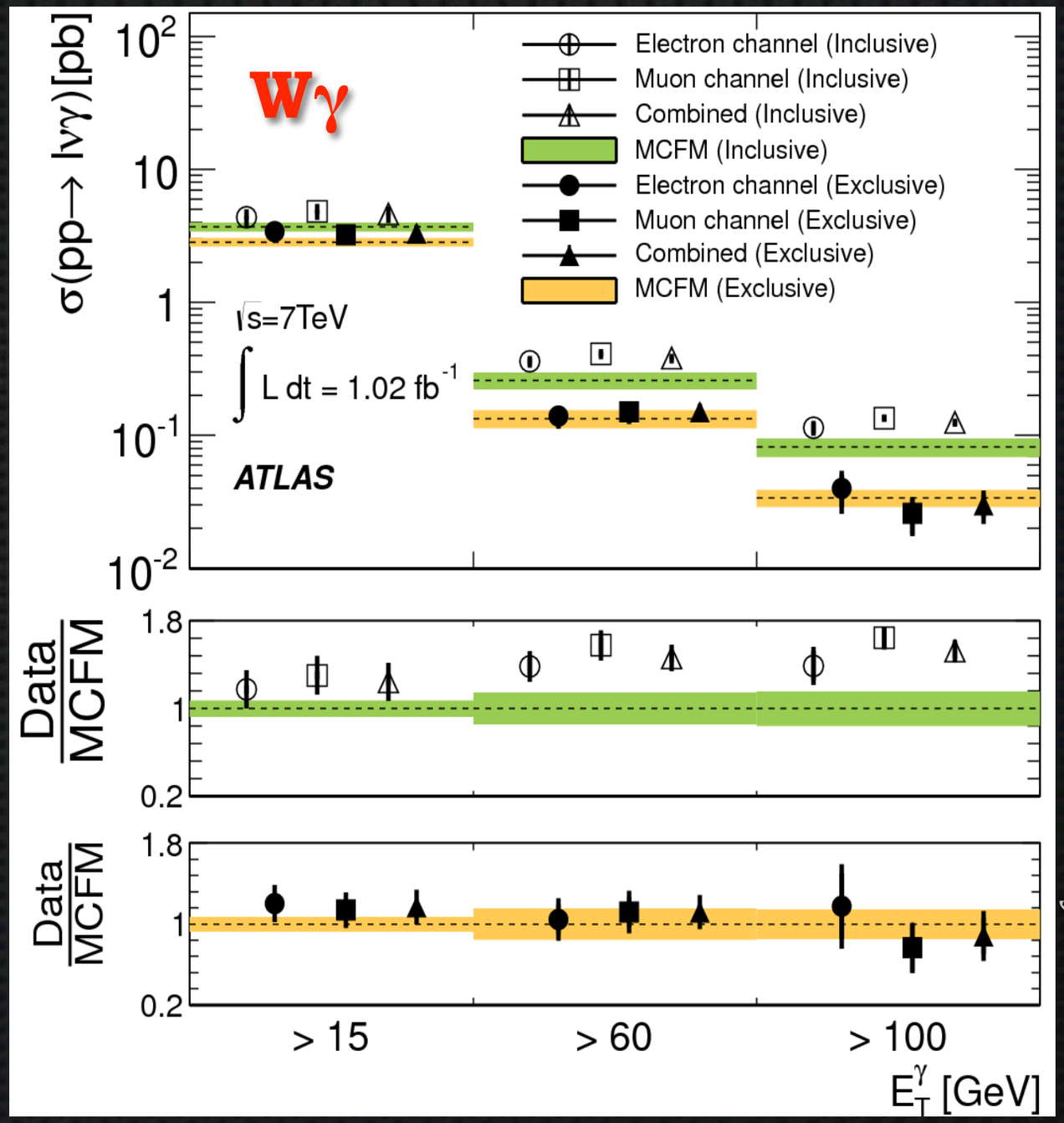
Electroweak measurements at the Tevatron



Dibosons: Wγ/Zγ

ATLAS: arXiv:1205.2531
CMS: PLB 701 (2011)

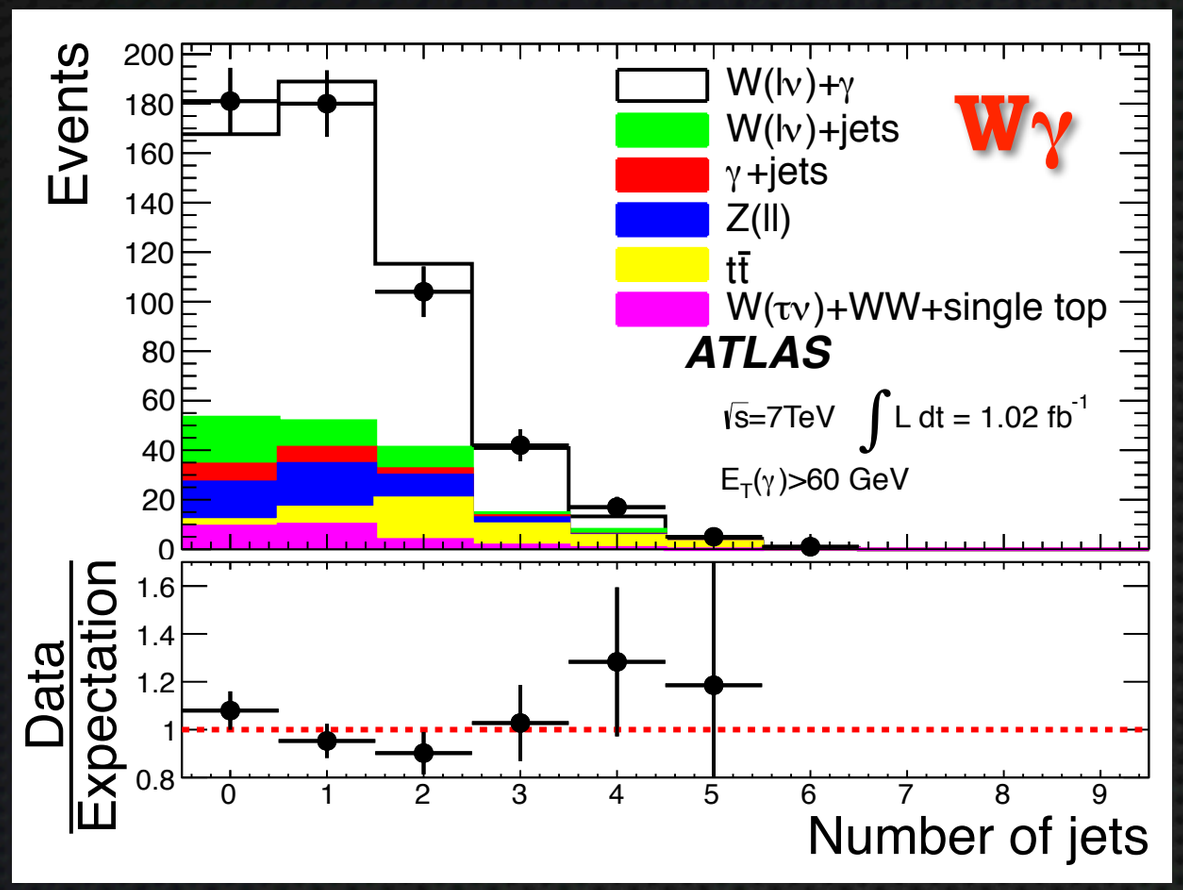


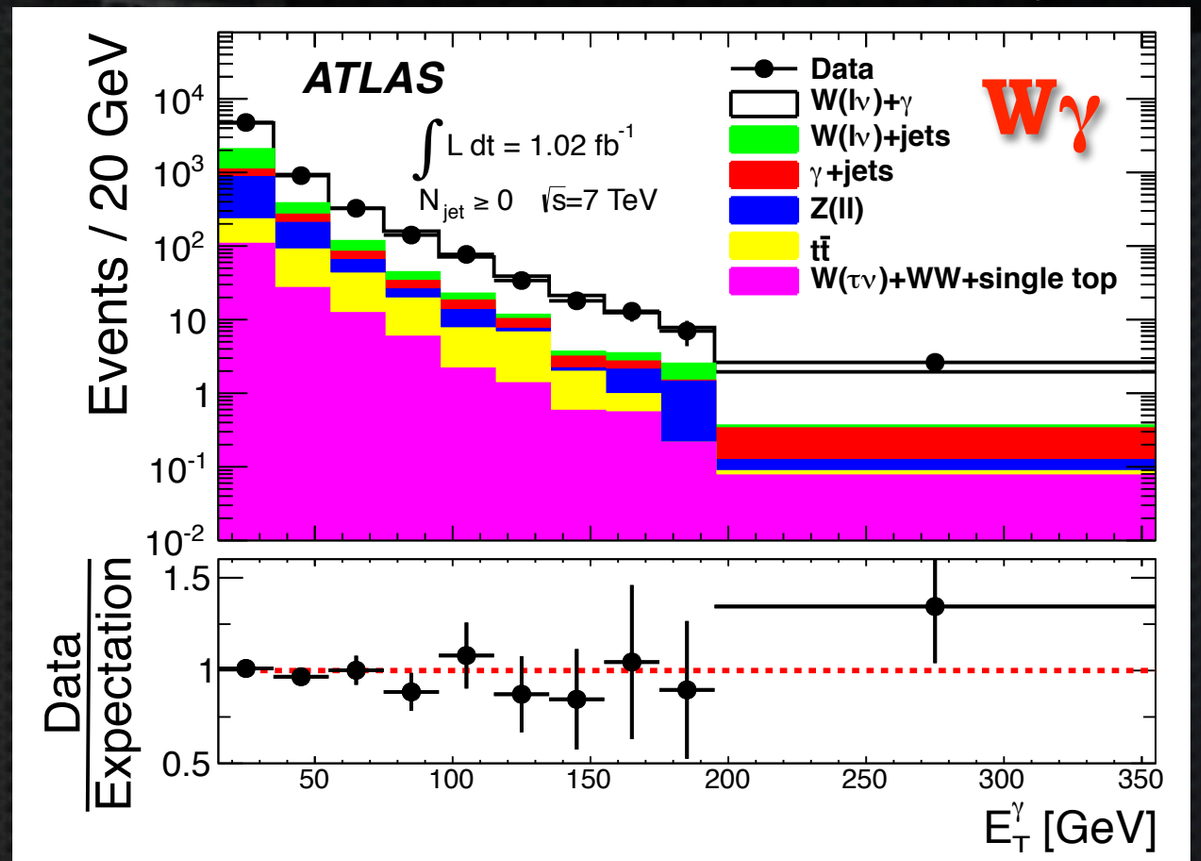


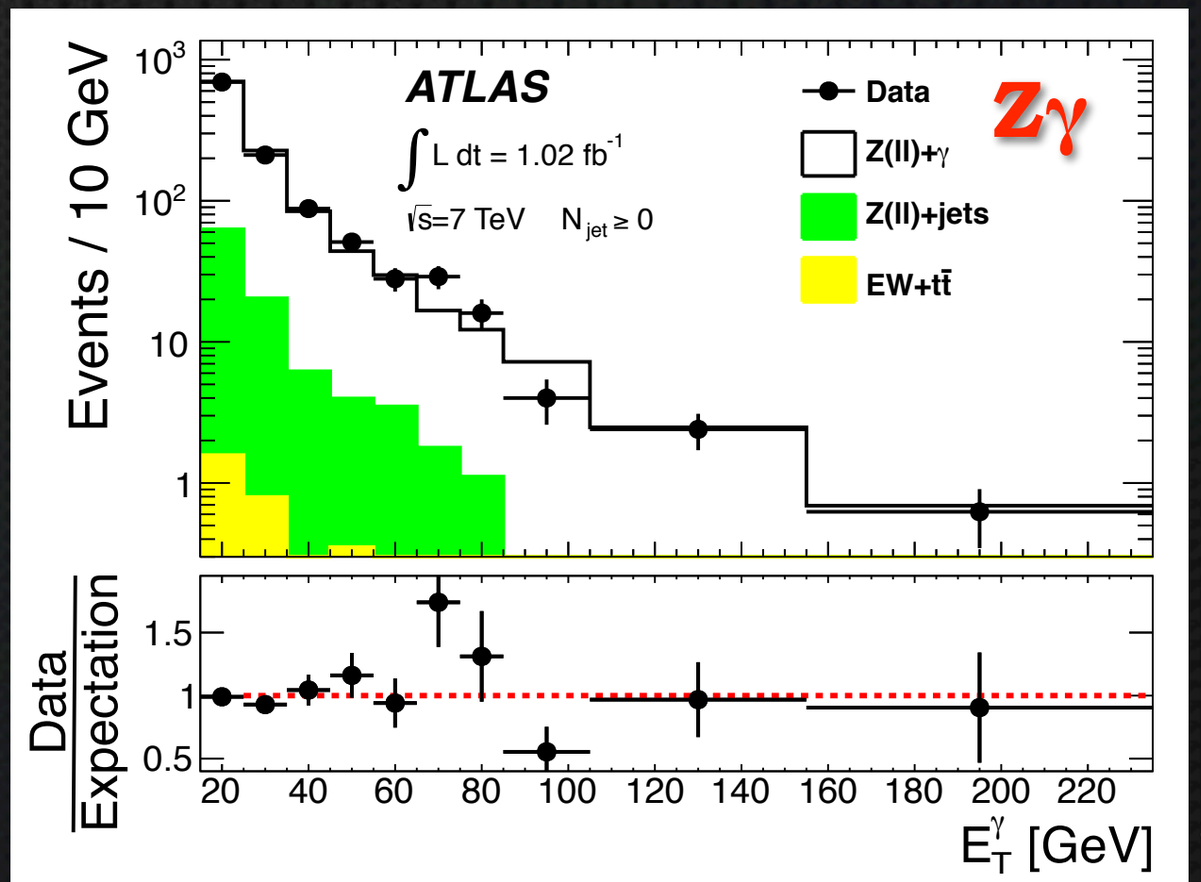
Wγ: Agreement with NLO MCFM calculation is poor
Exclusive calculation (N_{jet} =0) looks good

Dibosons: Wγ/Zγ

ATLAS: arXiv:1205.2531
CMS: PLB 701 (2011)

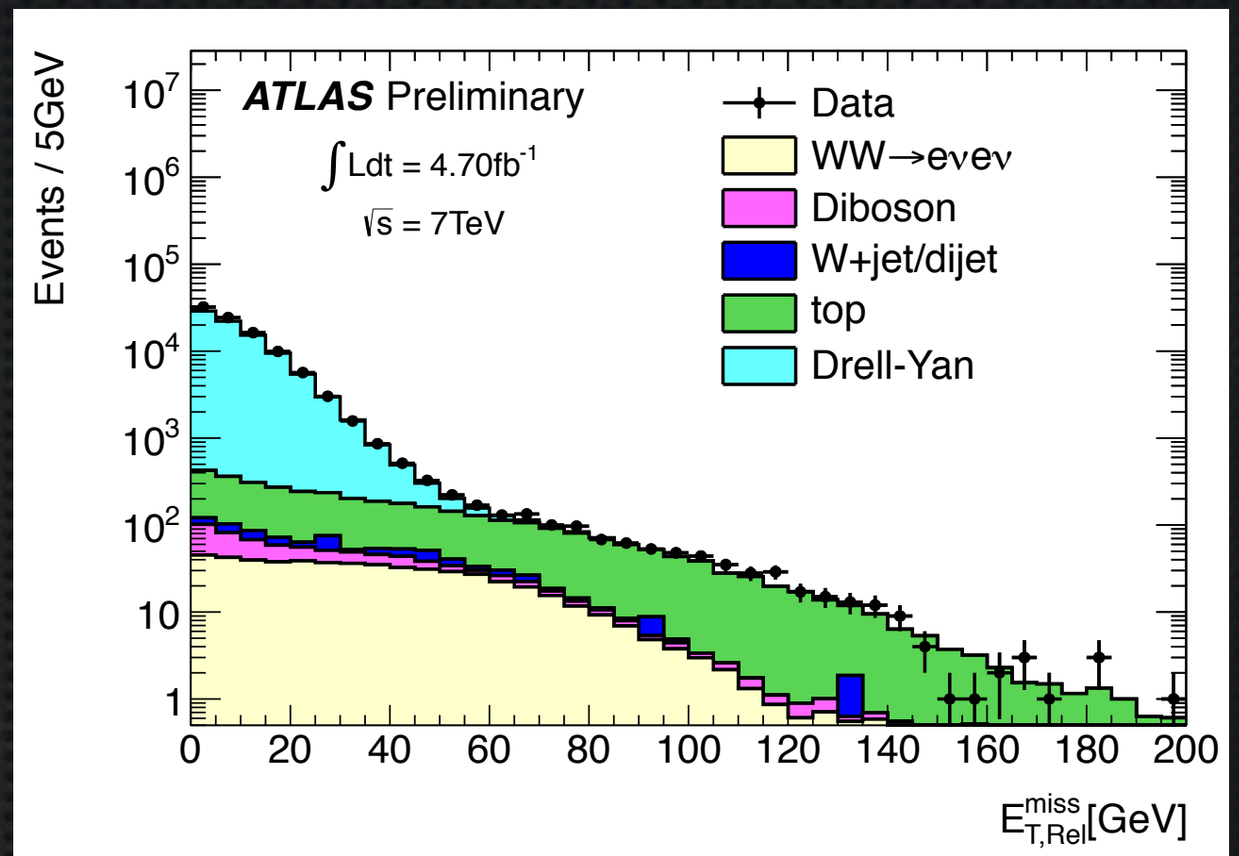


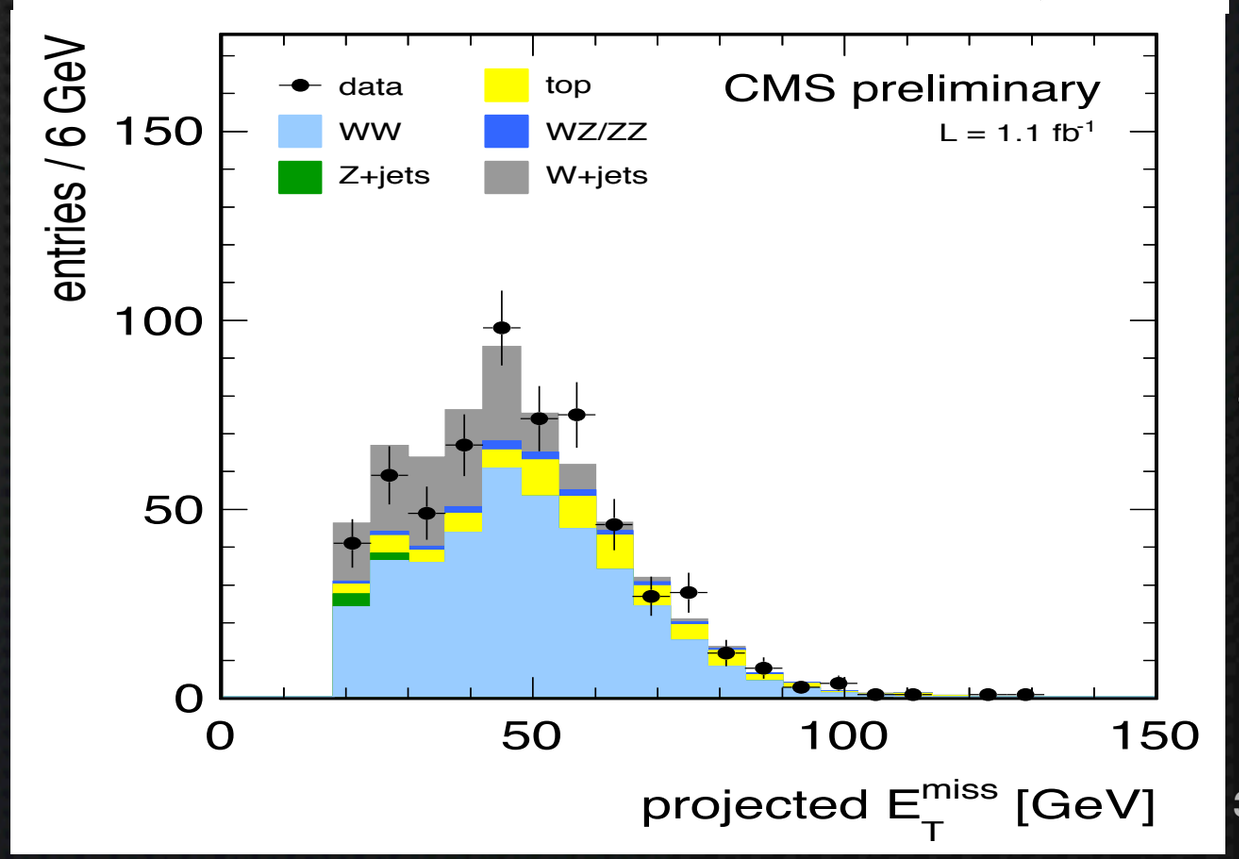




W+jets and Z+jets simulated with ALPGEN + 5 partons and SHERPA + 3 partons

Dibosons: WW





Challenge: missing energy

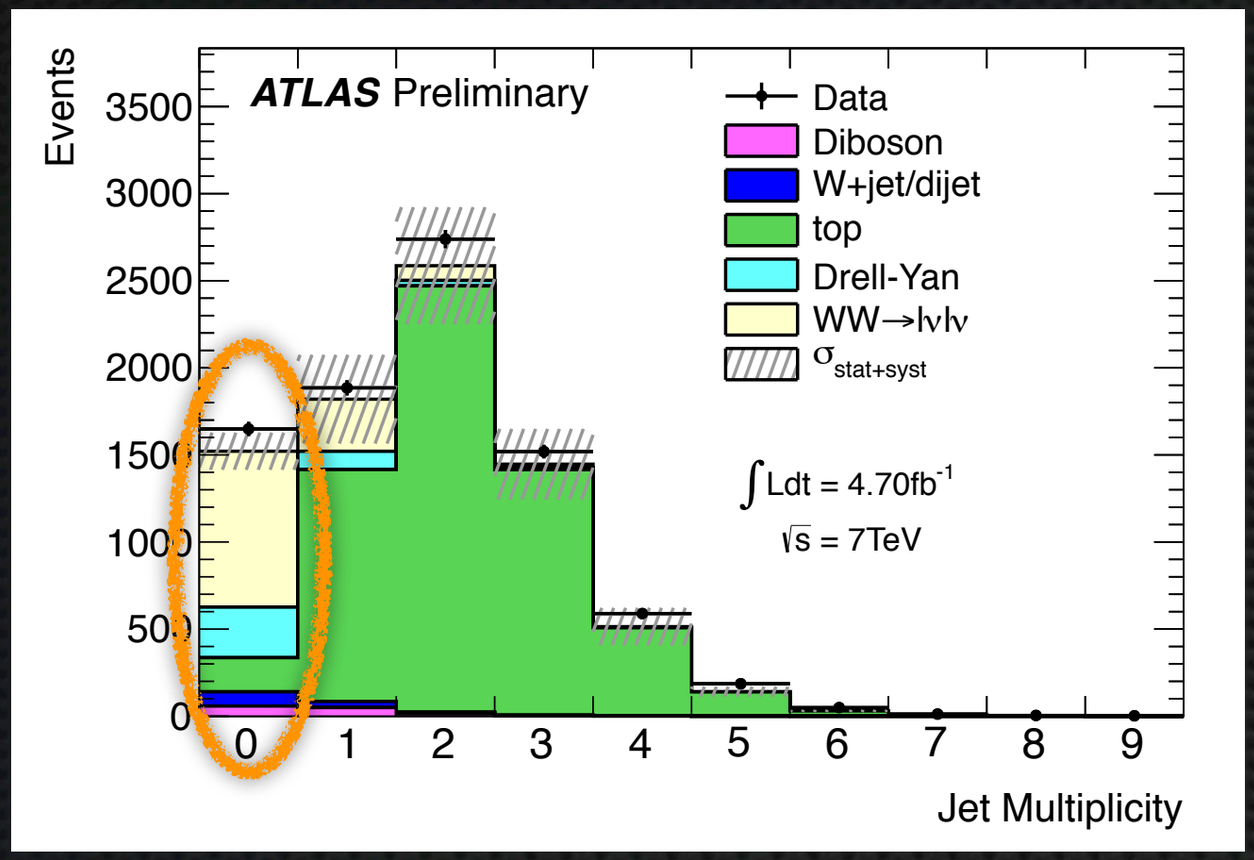
Both experiments have shown good ability to control missing energy in the 2011 dataset

ATLAS-CONF-2012-025
CMS PAS SMP-12-005
CMS PAS EWK-11-010

Dibosons: WW

ATLAS-CONF-2012-025

$\sqrt{s} = 7$ TeV



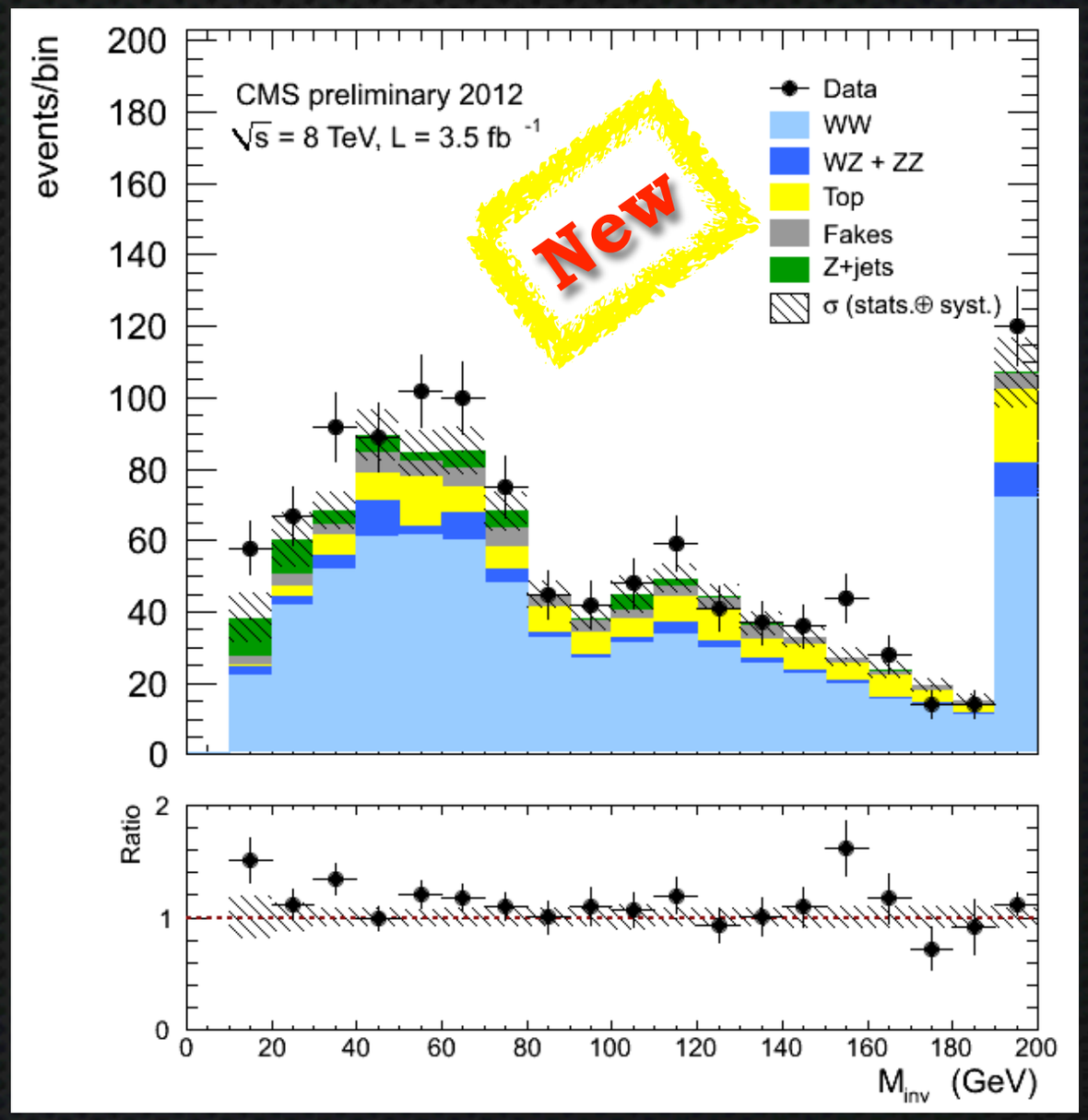
ATLAS:
$\sigma = 53.4 \pm 2.1 \pm 4.5 \pm 2.1$ pb

CMS:
$\sigma = 52.4 \pm 2.0 \pm 4.5 \pm 1.2$ pb

Theory:
$\sigma = 45.1 \pm 2.8$ pb

CMS PAS SMP-12-013

$\sqrt{s} = 8$ TeV

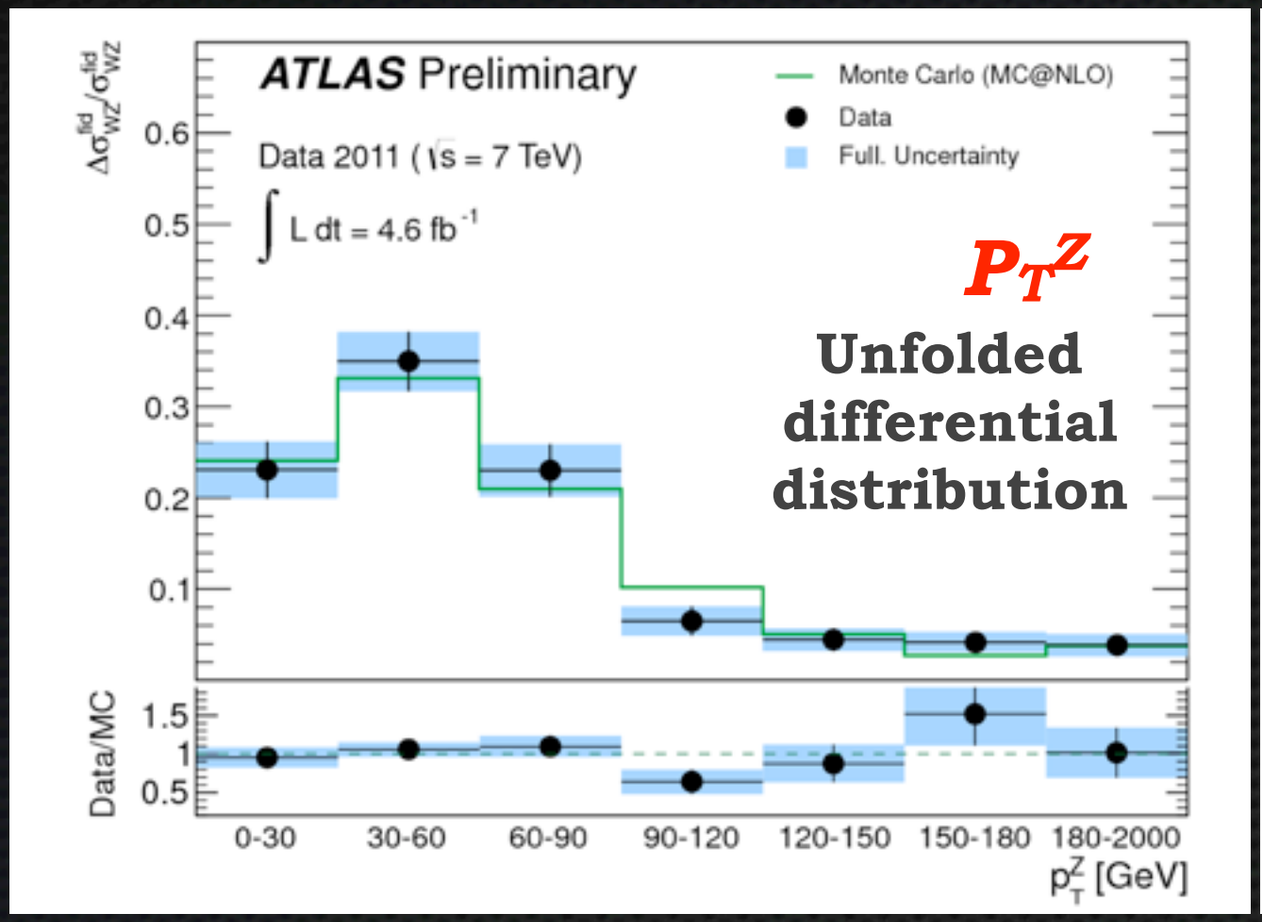


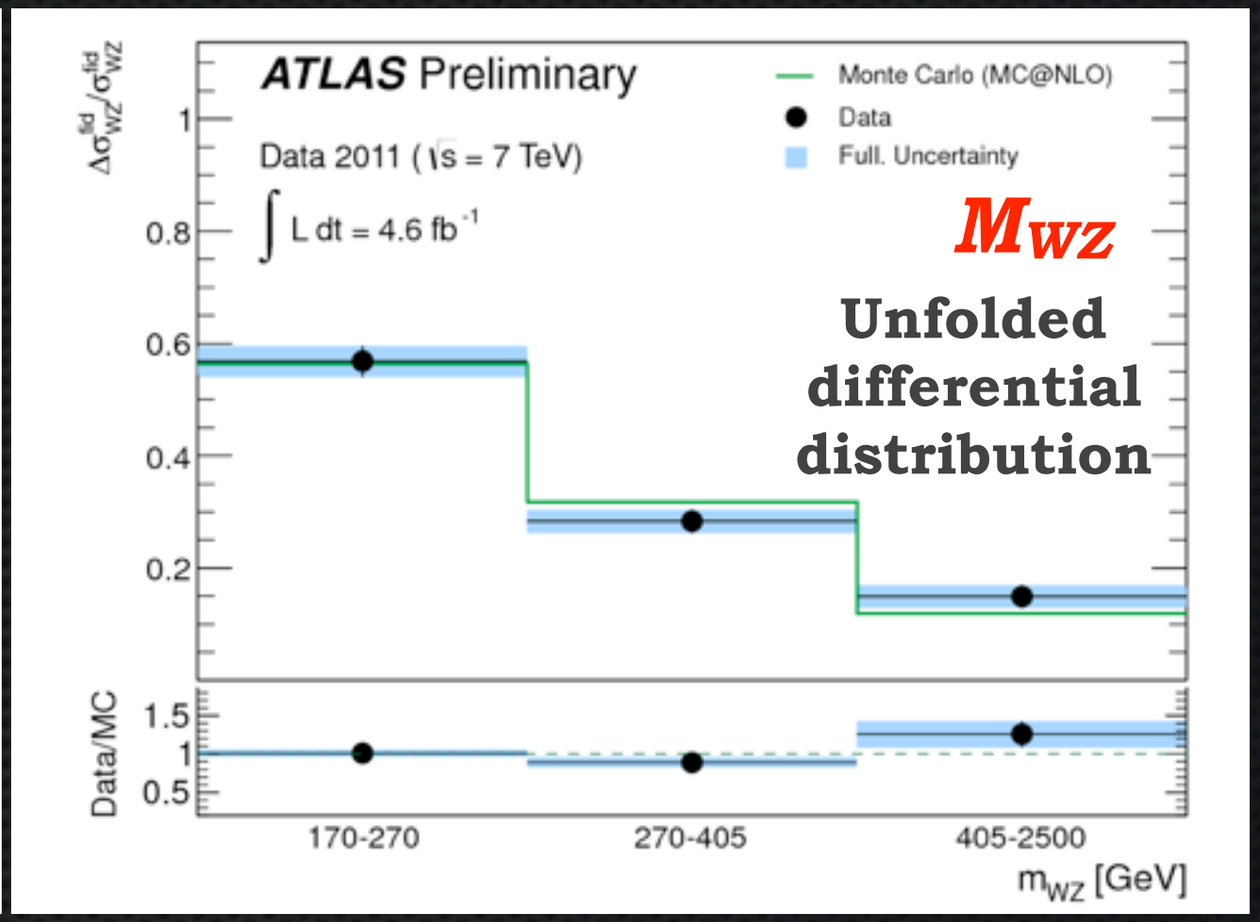
CMS:
$\sigma = 69.9 \pm 2.8 \pm 5.6 \pm 3.1$ pb

Theory:
$\sigma = 57.3^{+2.4}_{-1.6}$ pb

Dibosons: WZ @ 7 TeV

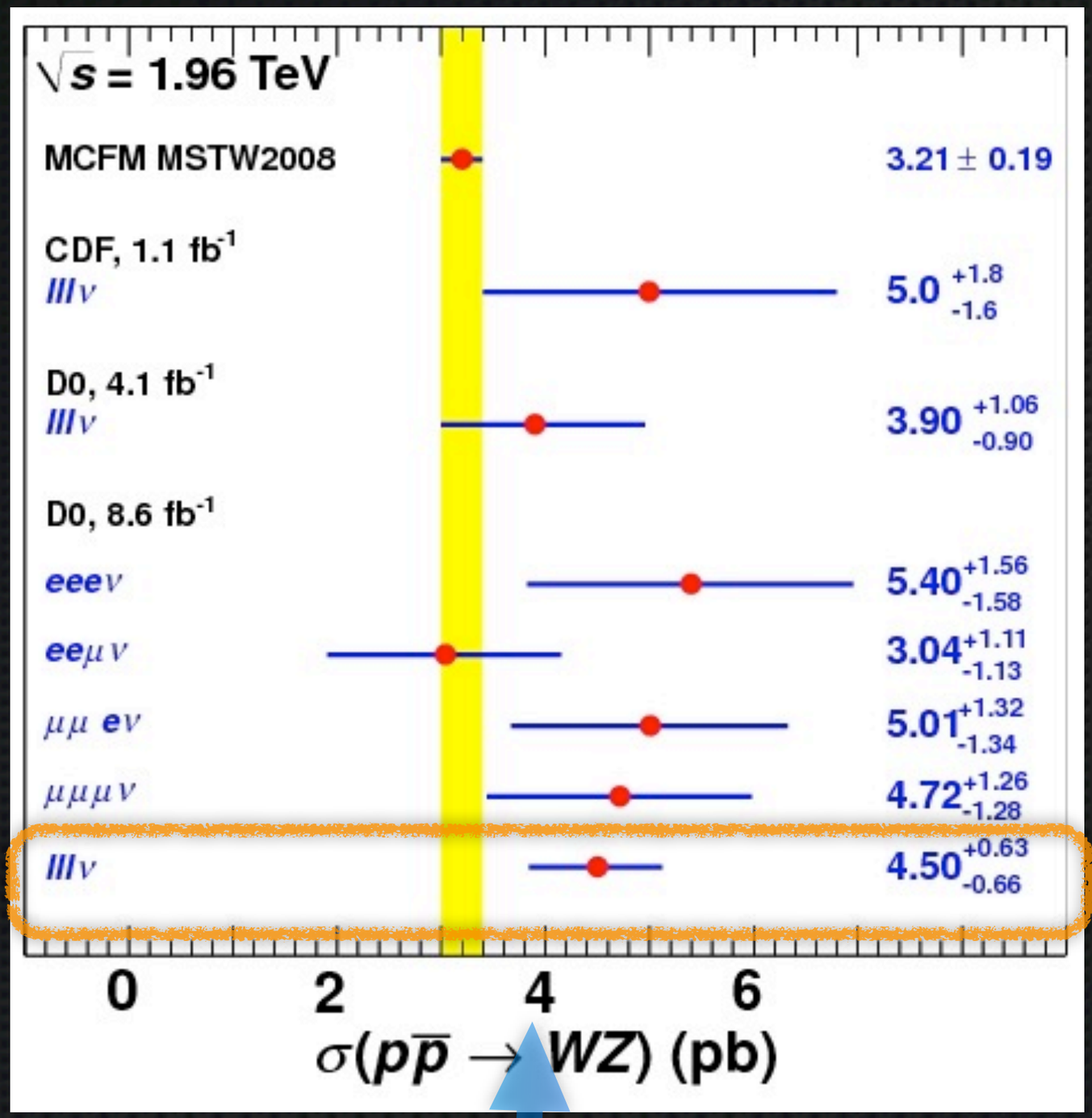
New

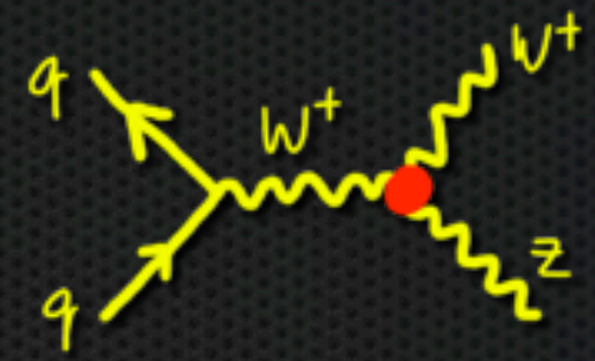




WZ	$N_{observed}$	N_{bkg}	$\sigma_{measured}$ (pb)	σ_{NLO} (pb)
ATLAS	317	68 ± 8	$19.0^{+1.4}_{-1.3} \pm 0.8 \pm 0.4$	$17.6^{+1.1}_{-1.0}$
CMS	75 (1.1 fb^{-1})	~9.1	17.0 ± 2.4 ± 1.1 ± 1.0	17.5 ± 0.6

Dibosons: WZ at Tevatron



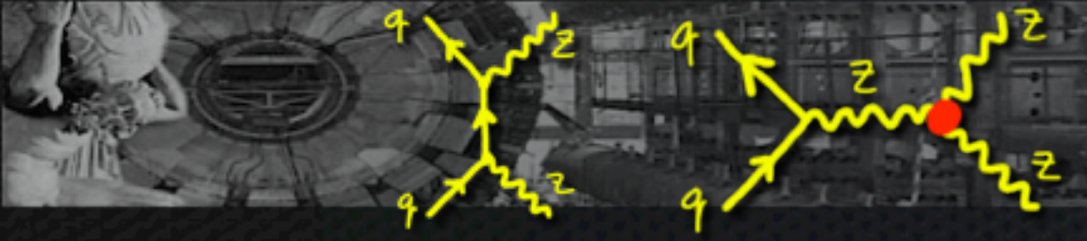


3l+ν

Phys. Rev. D 85, 112005 (2012)

CDF, 7.1 fb^{-1}: $\sigma_{WZ} = 3.93^{+0.60}_{-0.53}{}^{+0.59}_{-0.46}$ pb

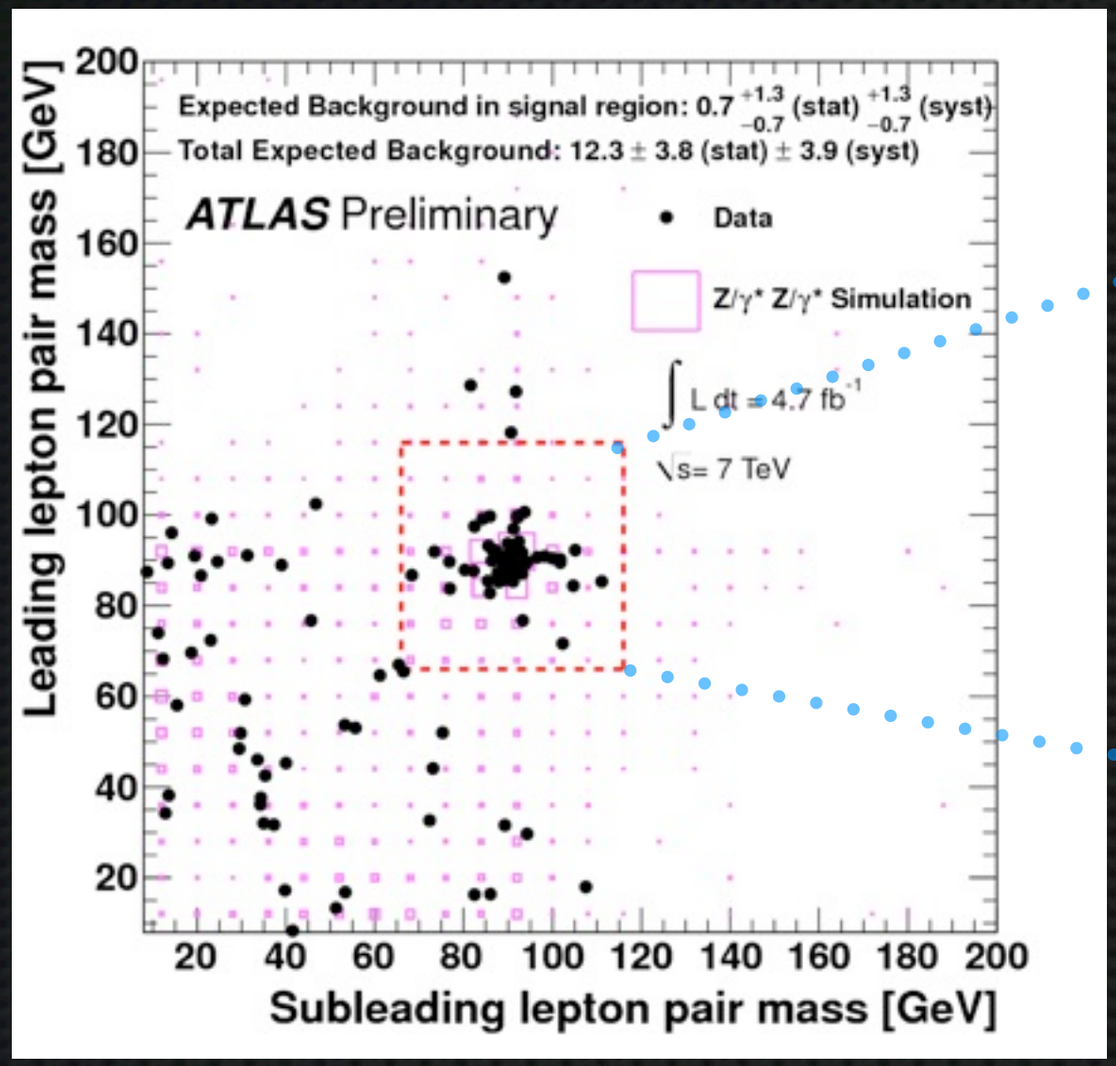
arXiv:1202.6629

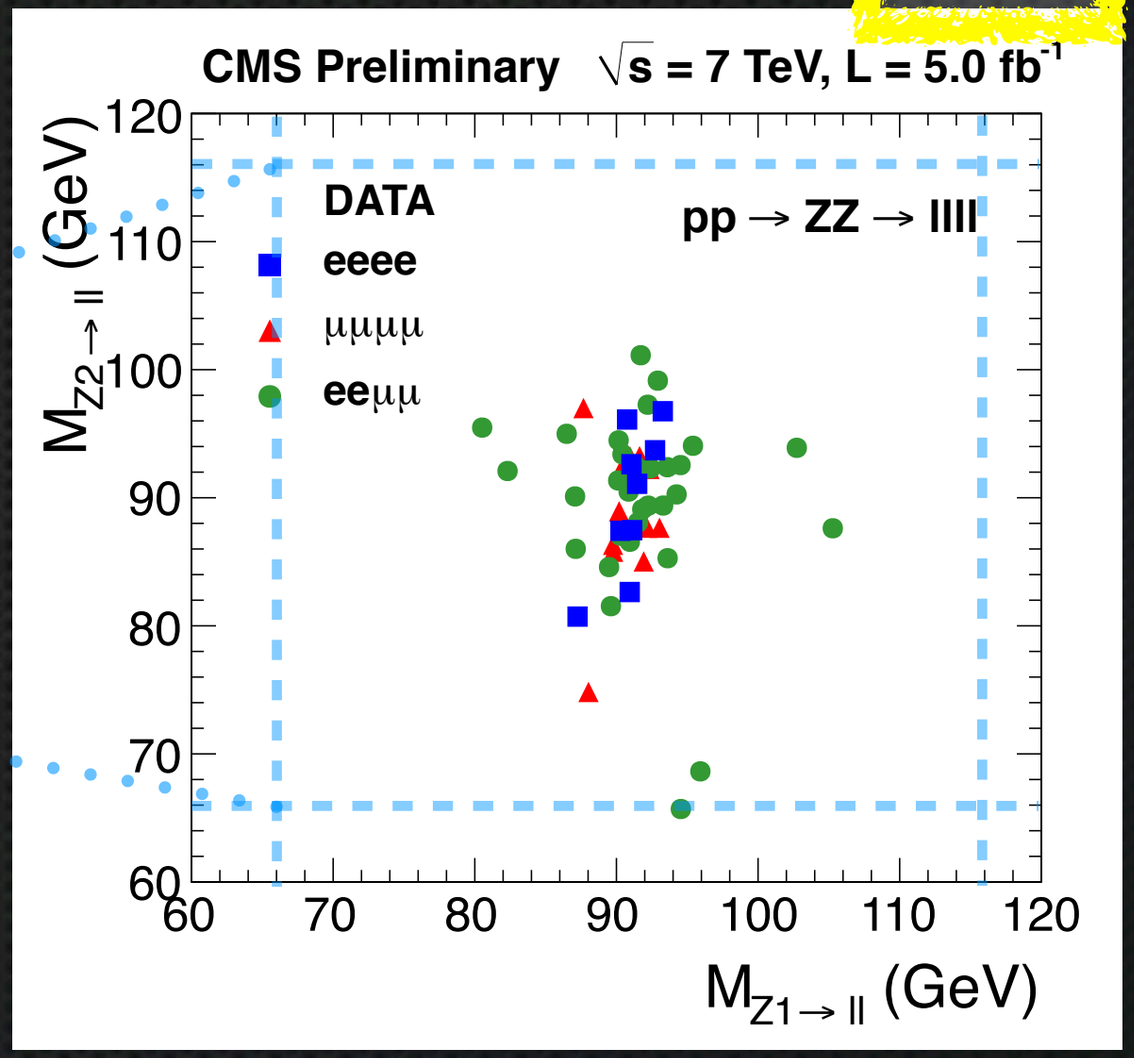


Dibosons: ZZ @ 7 TeV

ZZ → 4 leptons (eeee, μμμμ, eeμμ)

$$\sqrt{s} = 7\ \mathrm{TeV}$$





$66 < M_{Z1} < 116$ GeV
$66 < M_{Z2} < 116$ GeV

ATLAS-CONF-2012-027

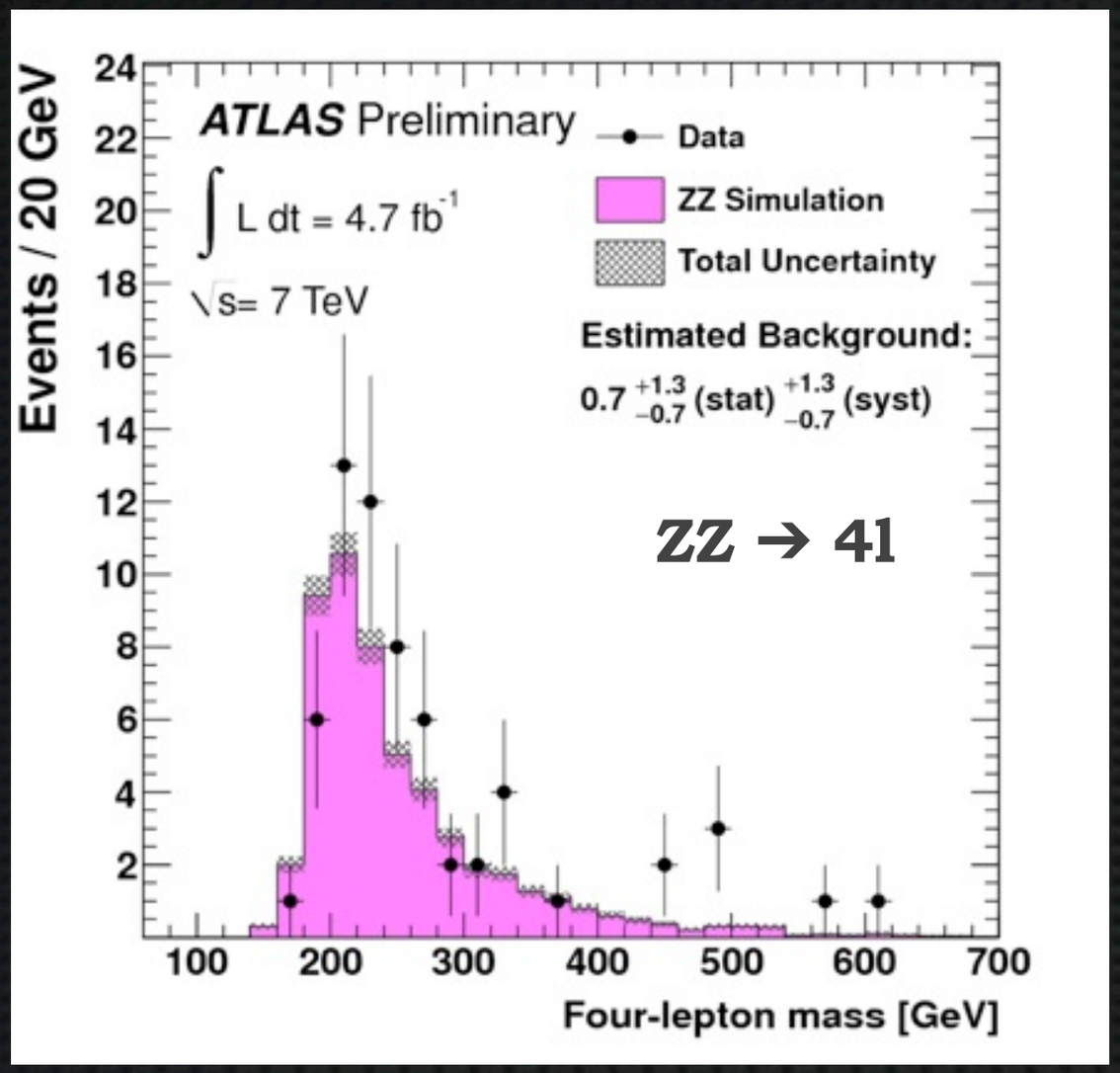
$60 < M_{Z1} < 120$ GeV
$60 < M_{Z2} < 120$ GeV

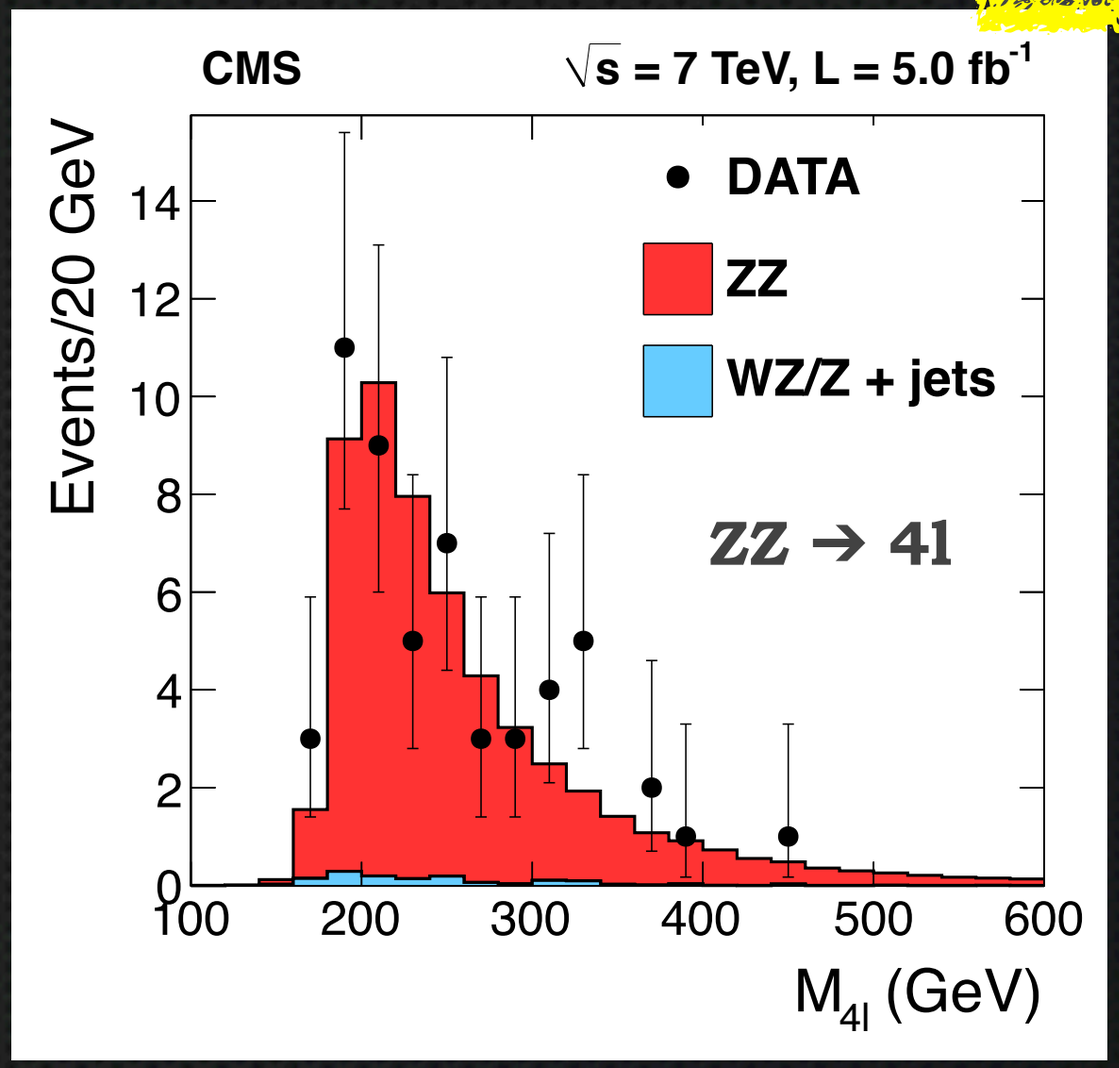
CMS PAPER SMP-12-007

Dibosons: ZZ @ 7 TeV

ZZ → 4 leptons (eeee, μμμμ, eeμμ)

New





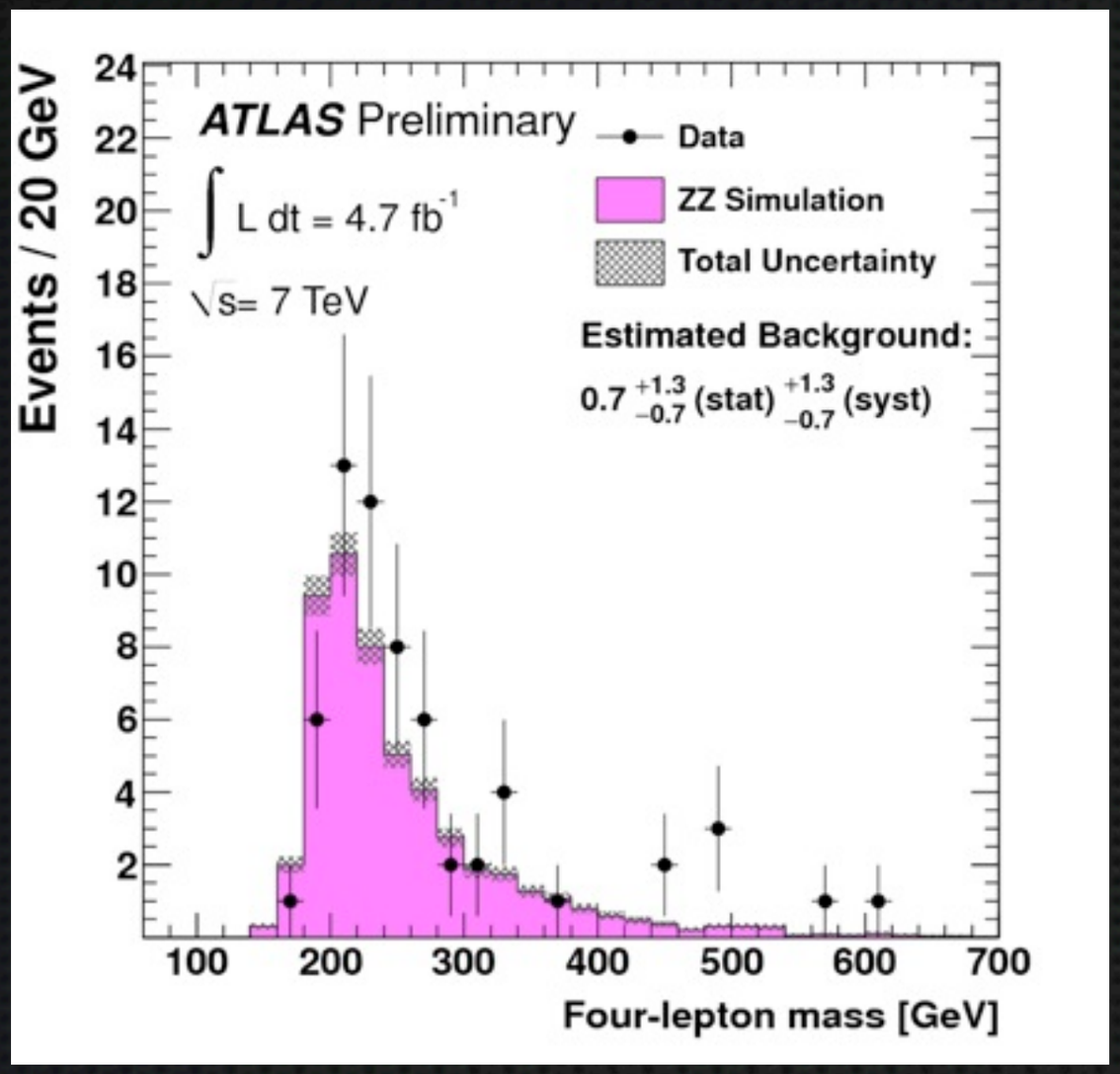
(*) includes ZZ → 2l2τ

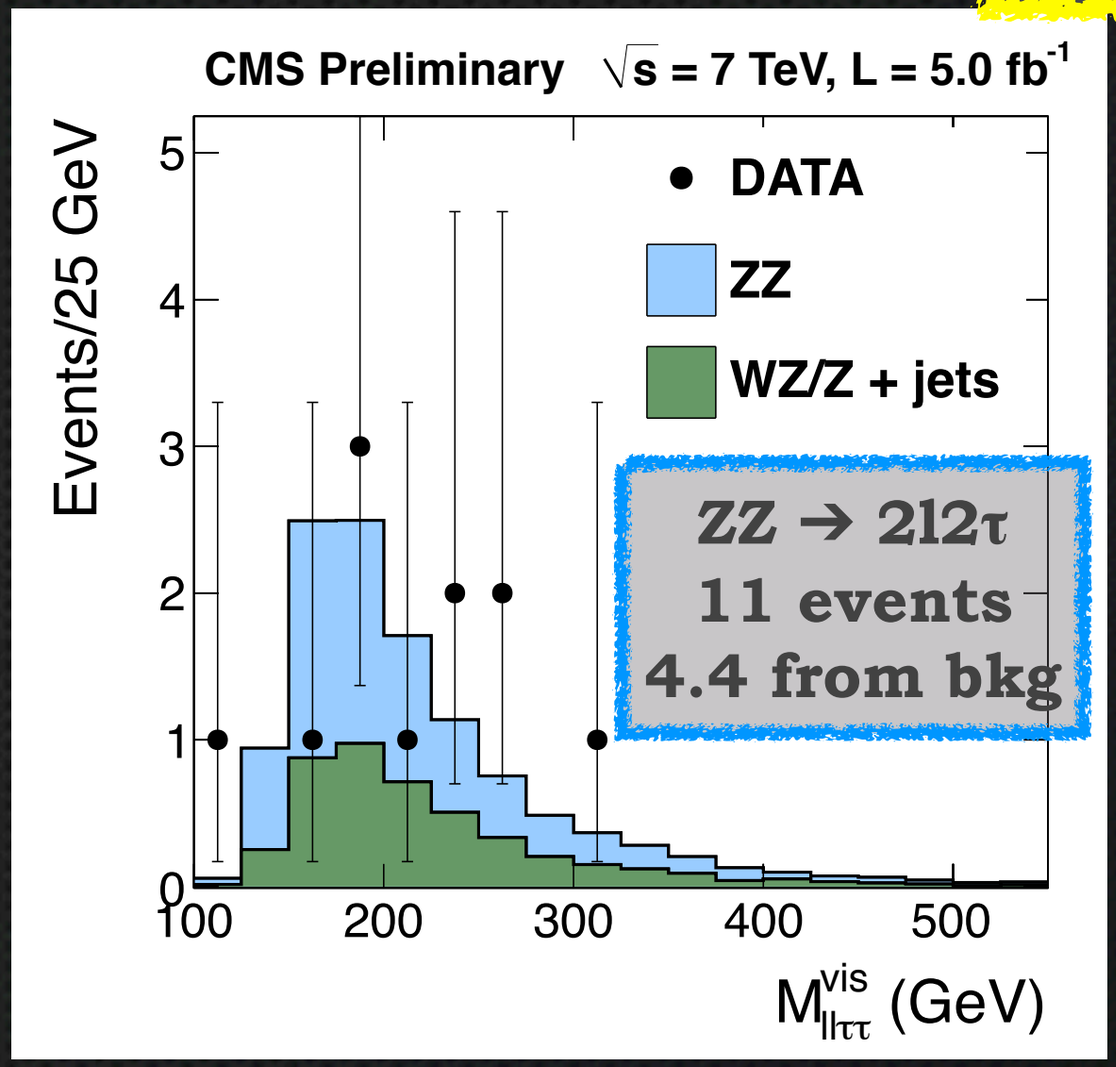
ZZ	$N_{obs(4l)}$	$N_{signal(4l)}$	$N_{bkg(4l)}$	$\sigma_{measured}$ (pb)	σ_{NLO} (pb)
ATLAS	62	53.2 ± 2.2	0.7± 2.1	$7.2^{+1.1}_{-0.9}{}^{+0.4}_{-0.3} \pm 0.3$	$6.5^{+0.3}_{-0.2}$
CMS	54	54.4 ± 4.8	1.4 ± 0.5	(*) $6.24^{+0.86}_{-0.80}{}^{+0.41}_{-0.32} \pm 0.14$	6.3 ± 0.4

Dibosons: ZZ @ 7 TeV

ZZ → 4 leptons (eeee, μμμμ, eeμμ) + ZZ → 2l2τ

New





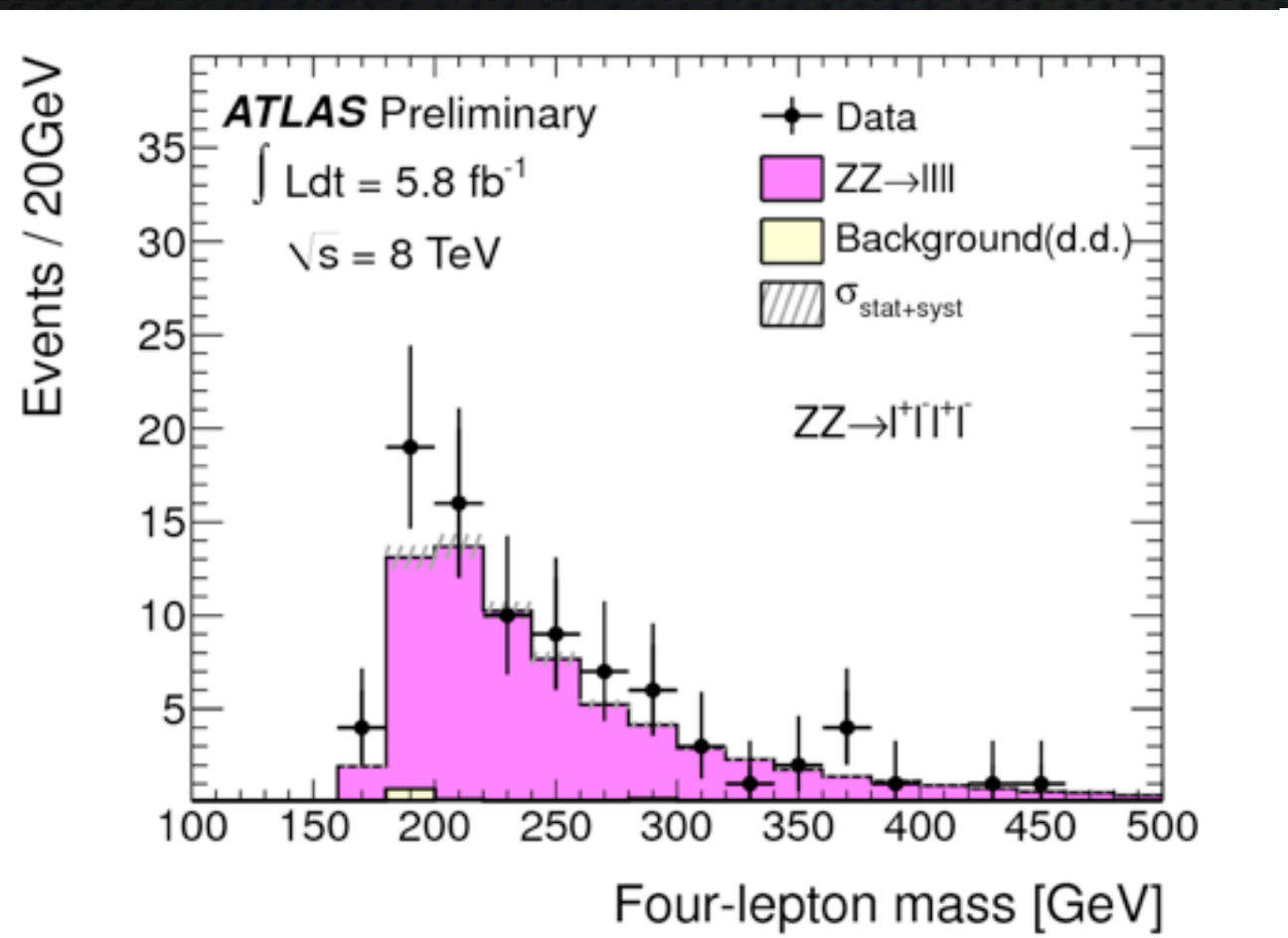
(*) includes ZZ → 2l2τ

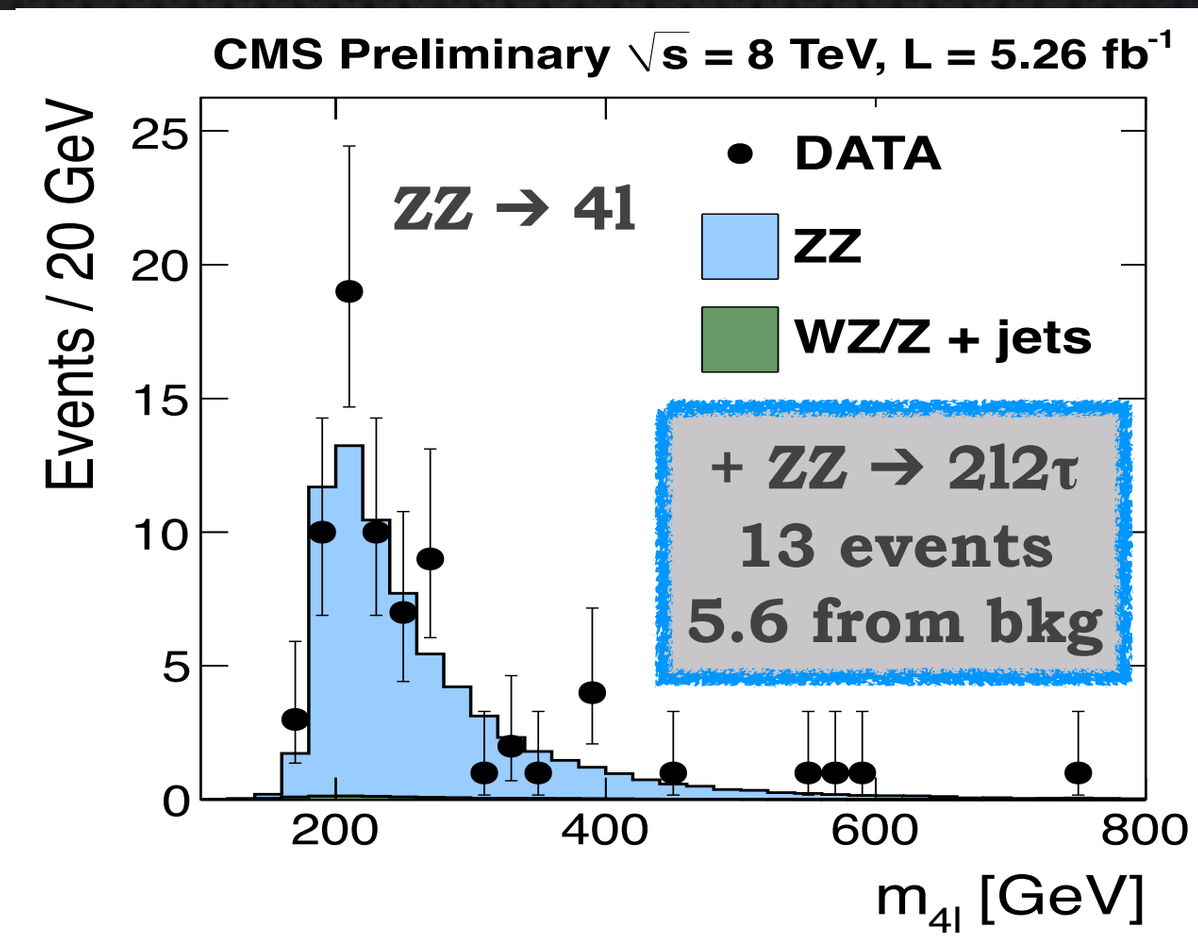
ZZ	$N_{obs(4l)}$	$N_{signal(4l)}$	$N_{bkg(4l)}$	$\sigma_{measured}$ (pb)	σ_{NLO} (pb)
ATLAS	62	53.2 ± 2.2	0.7± 2.1	$7.2^{+1.1}_{-0.9}{}^{+0.4}_{-0.3} \pm 0.3$	$6.5^{+0.3}_{-0.2}$
CMS	54	54.4 ± 4.8	1.4 ± 0.5	(*) $6.24^{+0.86}_{-0.80}{}^{+0.41}_{-0.32} \pm 0.14$	6.3 ± 0.4

Dibosons: ZZ @ 8 TeV

ZZ → 4 leptons (eeee, μμμμ, eeμμ) + ZZ → 2l2τ

CMS PAS SMP-12-014

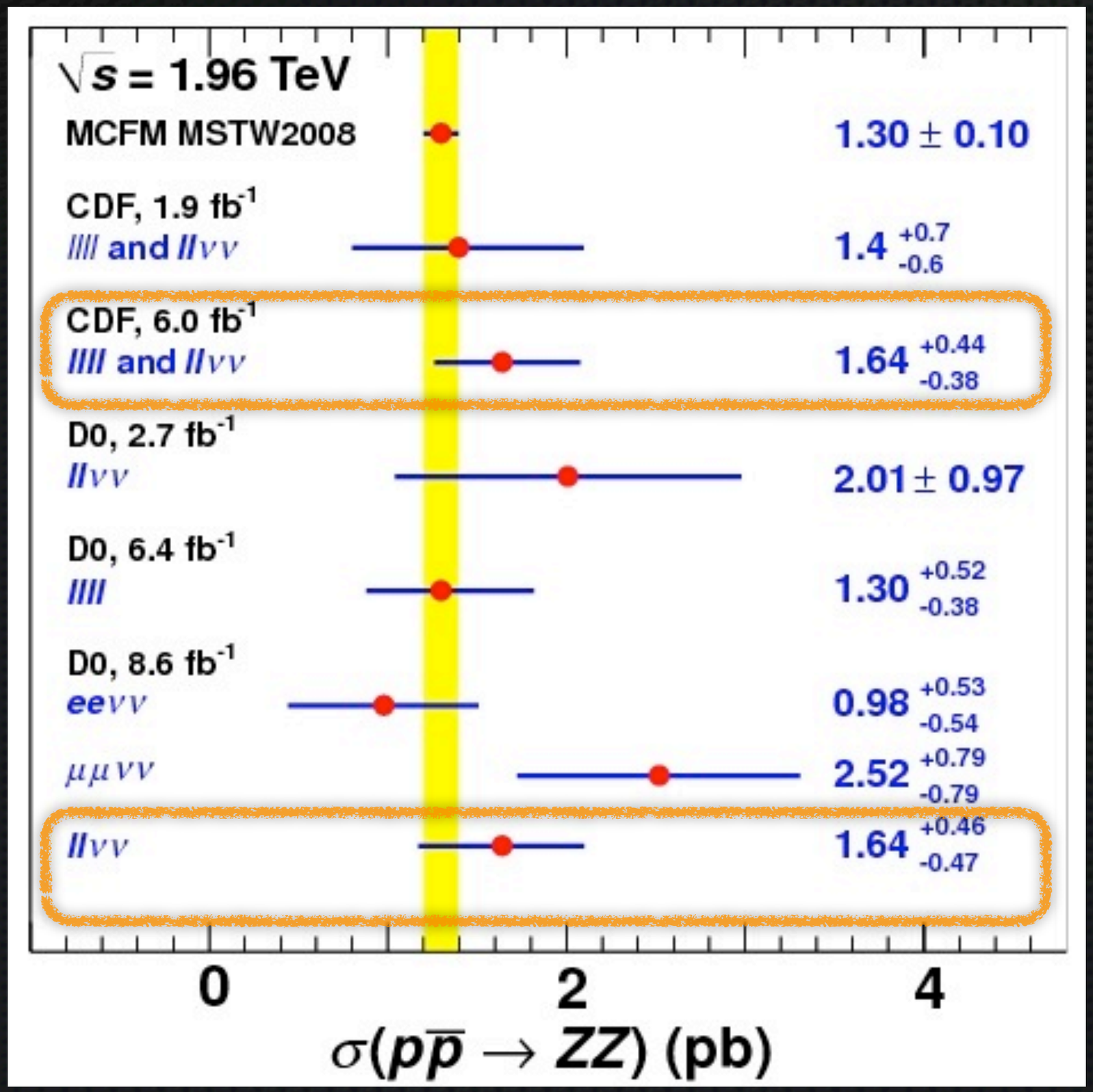


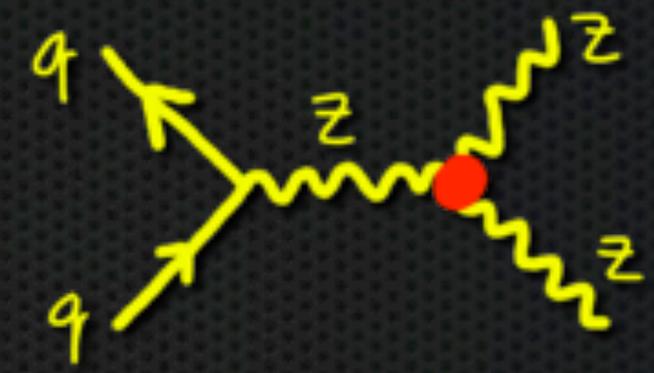


(*) includes ZZ → 2l2τ

ZZ	$N_{obs(4l)}$	$N_{signal(4l)}$	$N_{bkg(4l)}$	$\sigma_{measured}$ (pb)	σ_{NLO} (pb)
ATLAS	85	70.5 ± 1.7	1.5 ± 1.3	$9.3^{+1.1}_{-1.0}{}^{+0.4}_{-0.3} \pm 0.3$	7.4 ± 0.4
CMS	71	64.3 ± 4.4	1.3 ± 0.5	(*) 8.4 ± 1.0 ± 0.7 ± 0.4	7.7 ± 0.4

Dibosons: ZZ @ Tevatron

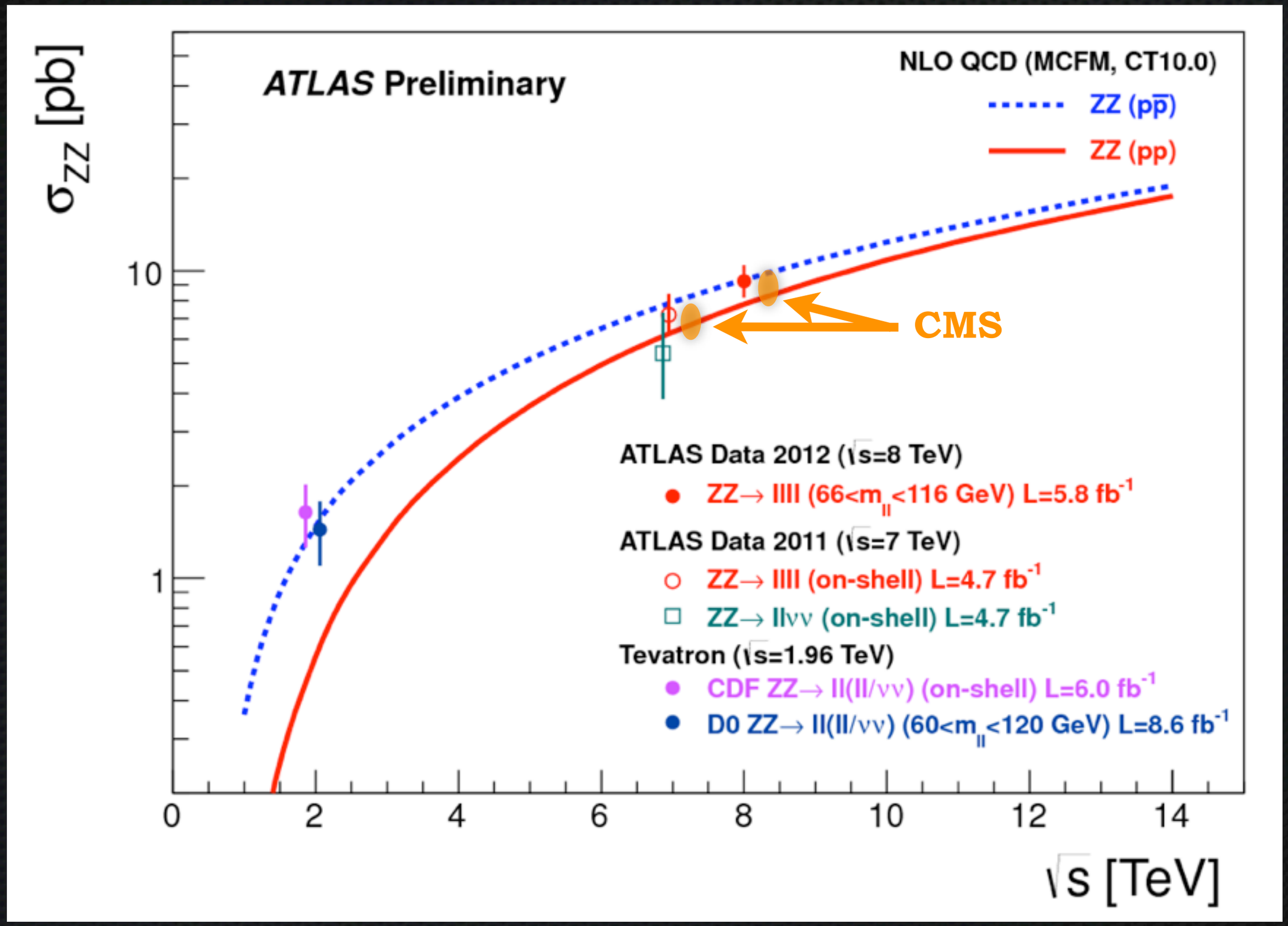




PRL 108, 101801 (2012)

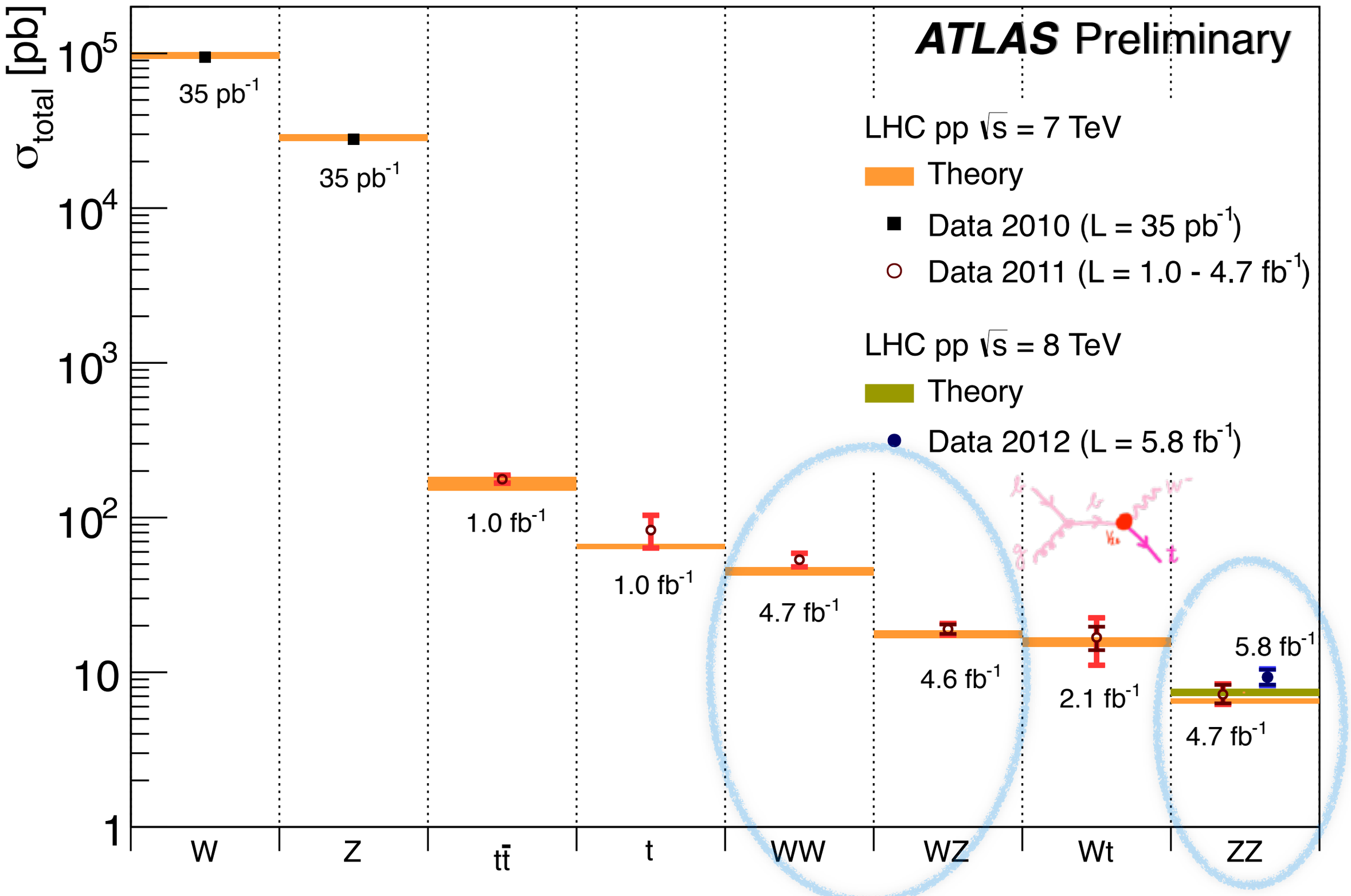
Phys. Rev. D 85, 112005 (2012)

Dibosons: ZZ Overview



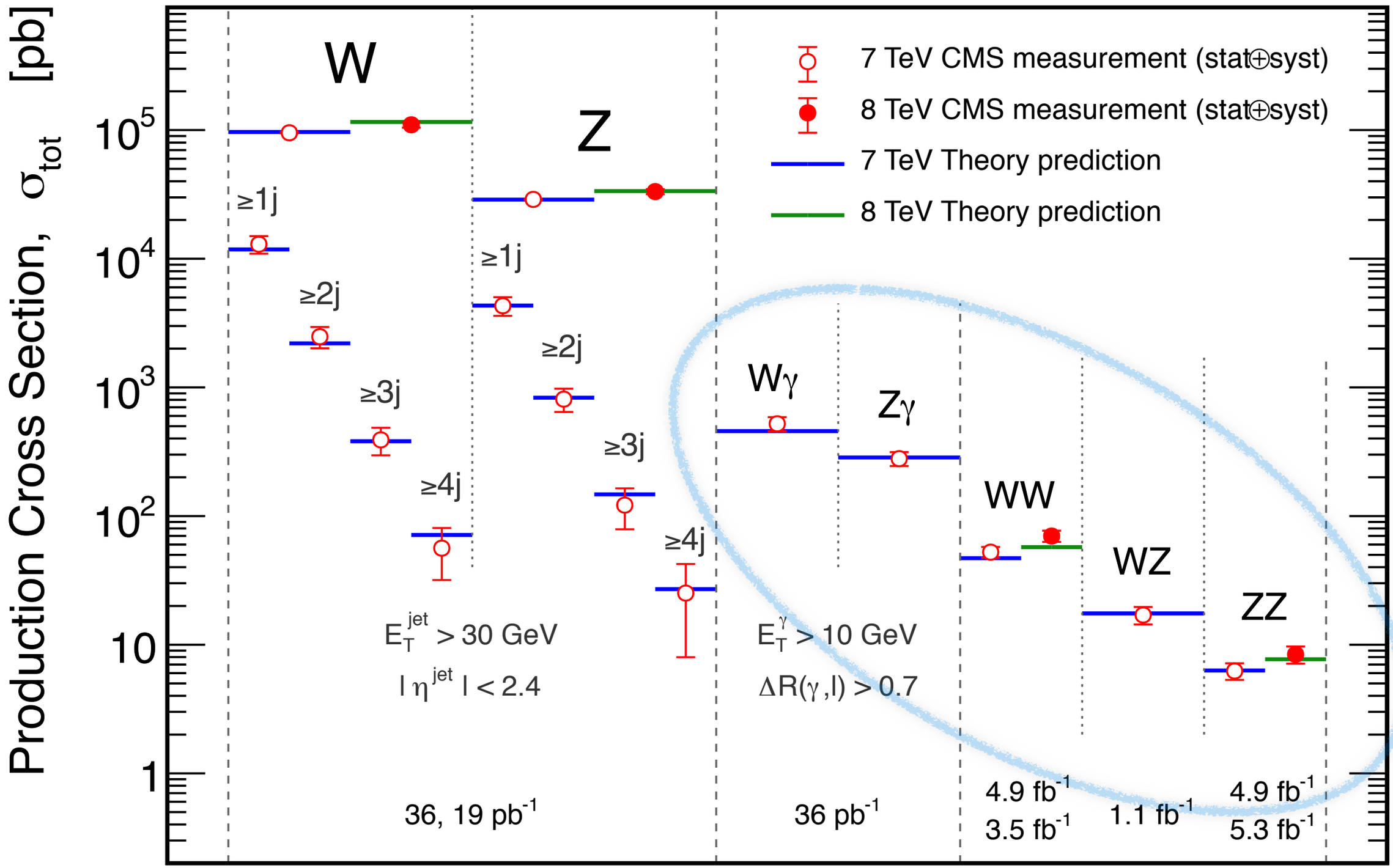
Production cross sections in ATLAS

New



Production cross sections in CMS

New



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)

Triple Gauge Couplings (ZZZ and ZZγ)

- **Possible vertices using an effective Lagragian**

$$\mathcal{L}_{VZZ} = -\frac{e}{M_Z^2}\left[f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) + f_5^V(\partial^\sigma V_{\sigma\mu})\tilde{Z}^{\mu\beta}Z_\beta\right]$$

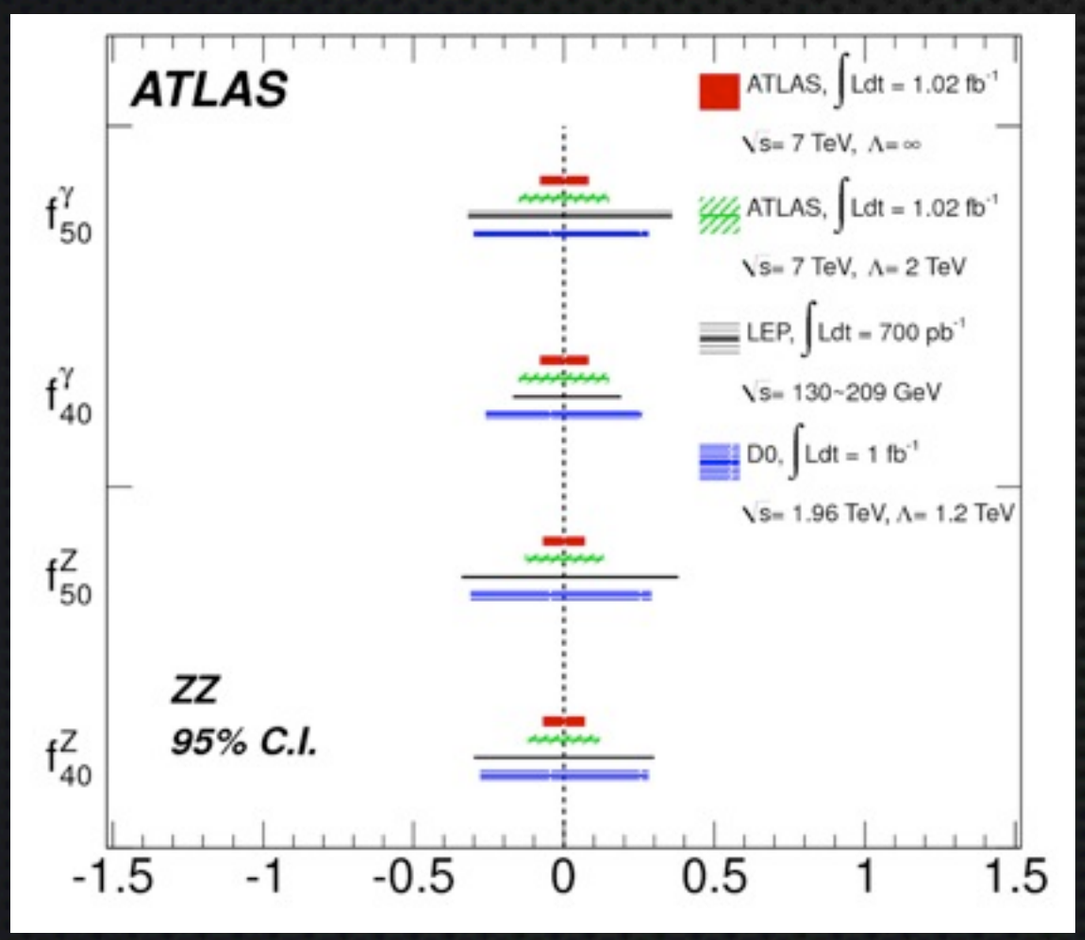
ZZZ, ZZγ

$(f_4^Z, f_4^\gamma, f_5^Z, f_5^\gamma) = (0,0,0,0)_{SM}$

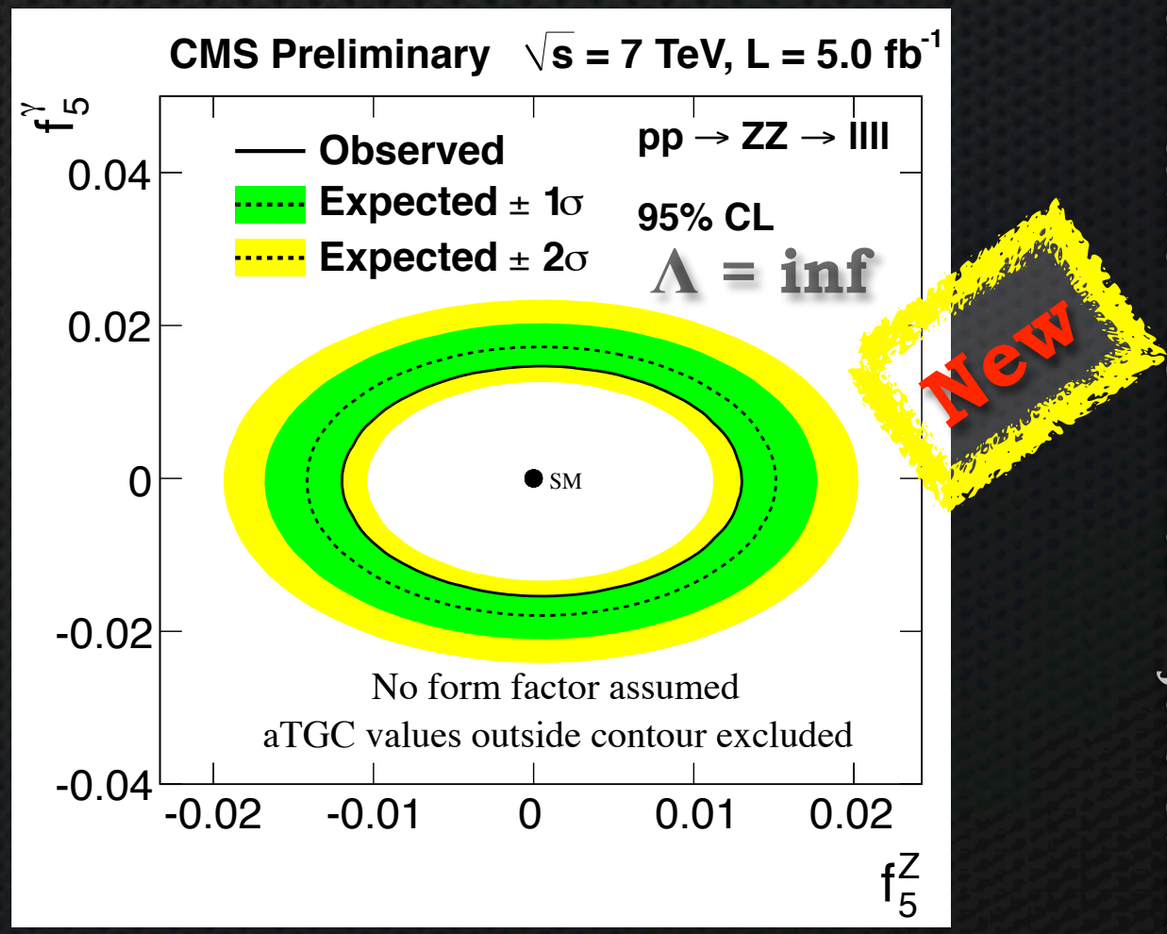
Scale dependent form-factors

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

with cutoff scale Λ



(using ZZ total cross section)



(from ZZ invariant mass)

Most powerful limit to date

Phys. Rev. Lett. 108 (2012) 041804

Triple Gauge Couplings (WWZ and WWγ)

- **Possible vertices using an effective Lagragian**

$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = i\left[g_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{\dagger\mu}V^\nu) + \kappa^V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2}W^\dagger_{\rho\mu}W^\mu_\nu V^{\nu\rho}\right]$$

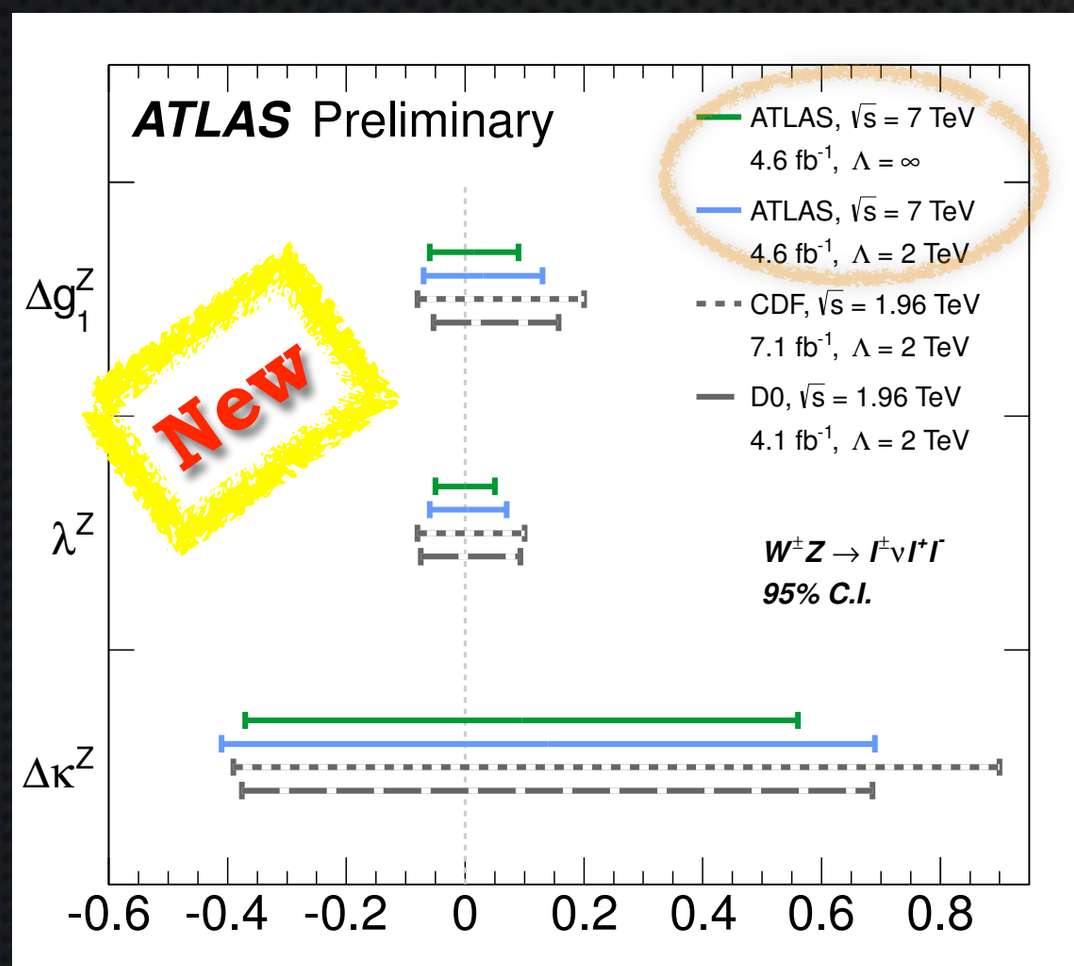
WWZ

$(g_1^Z, k^Z, \lambda) = (1,1,0)_{SM}$

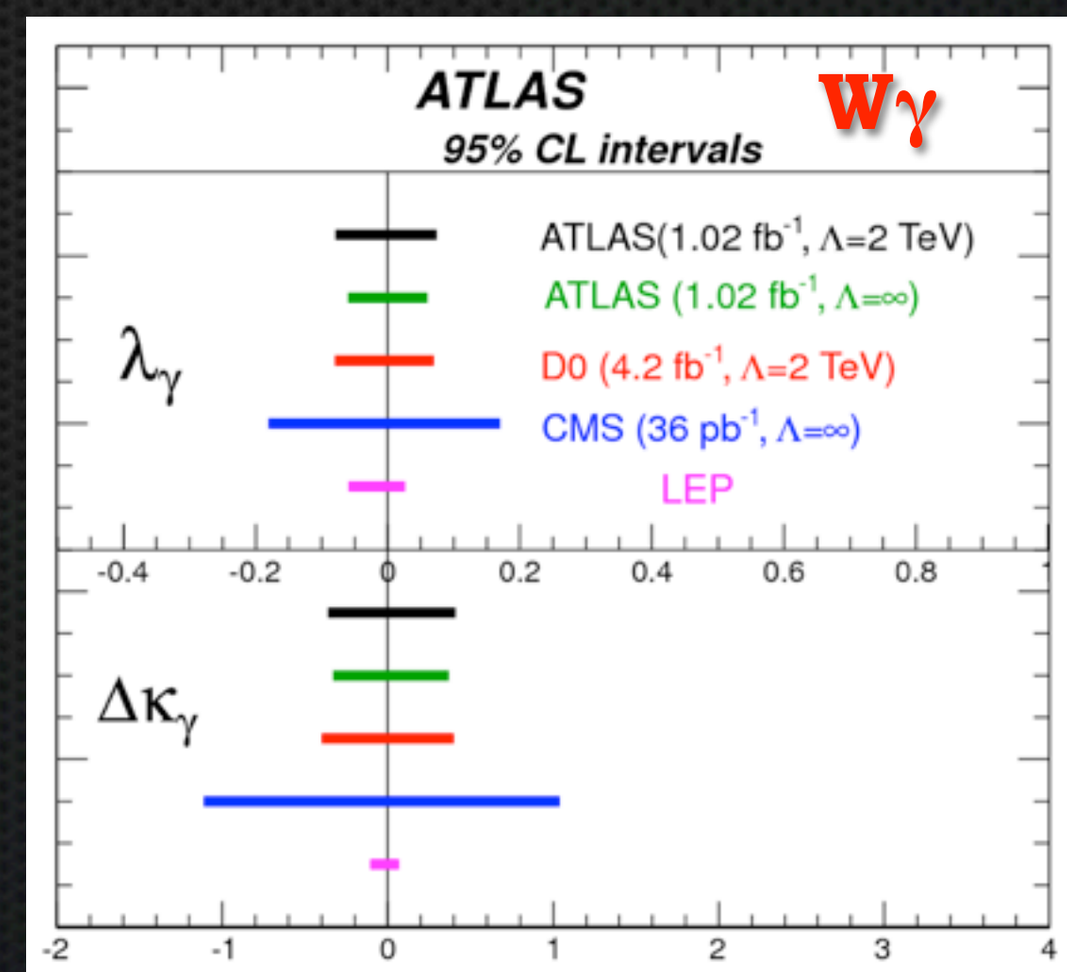
Scale dependent form-factors

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

with cutoff scale Λ

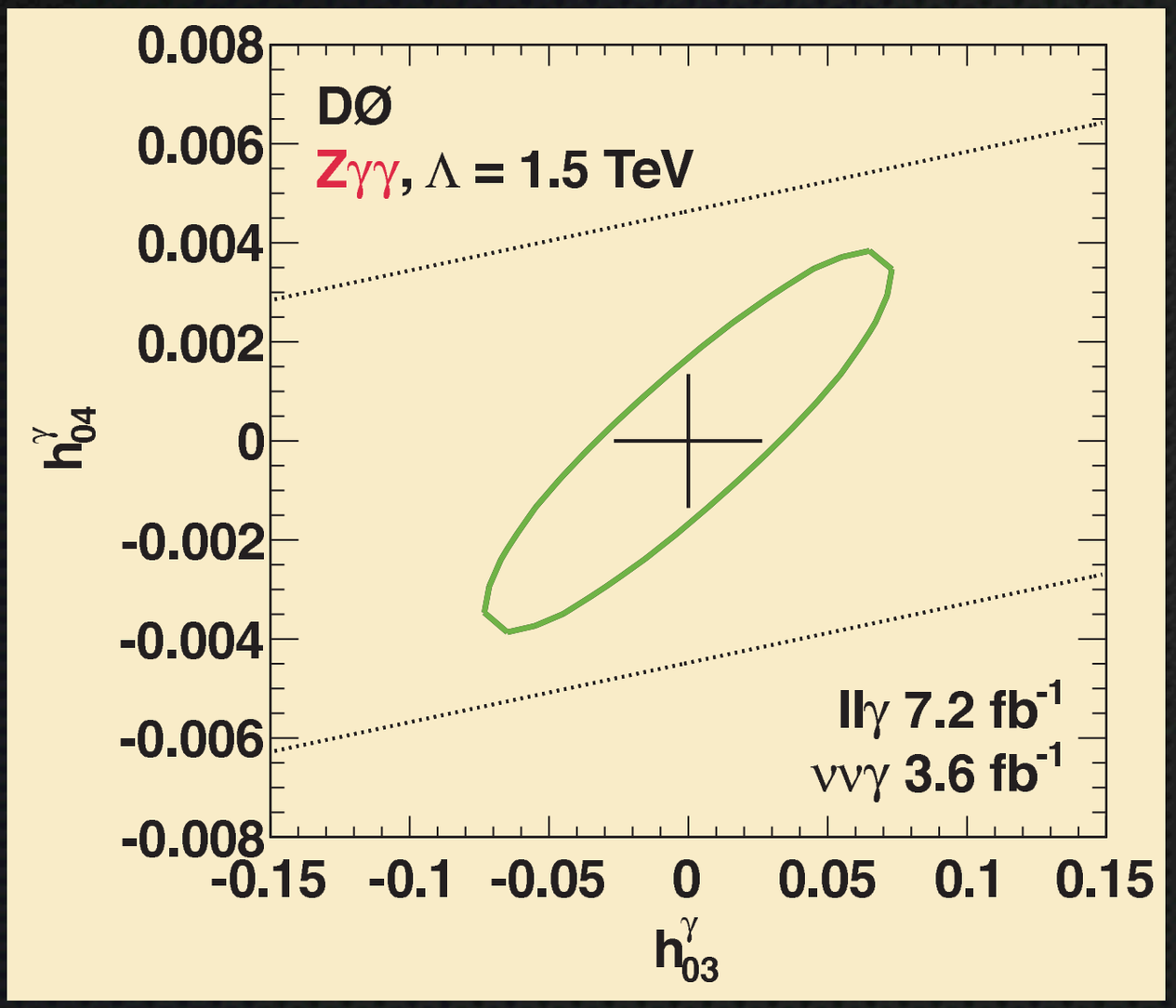


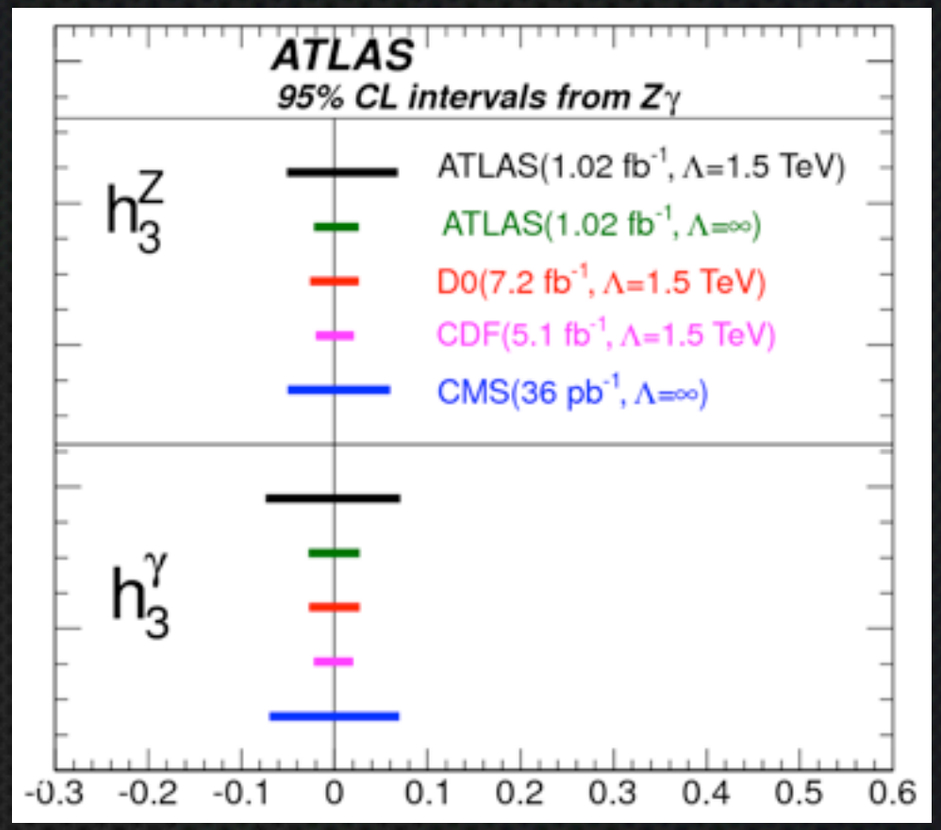
(using $P_T(Z)$ distribution)

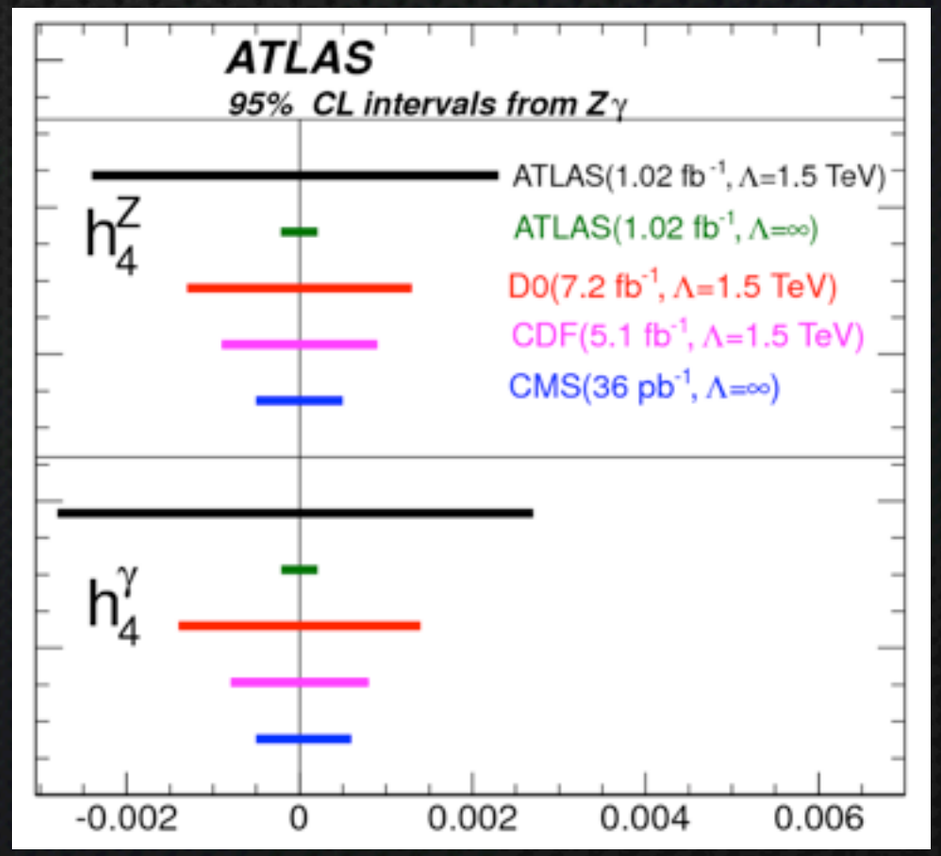


(from $P_T(\gamma)$ distribution)

Anomalous Triple Gauge Couplings





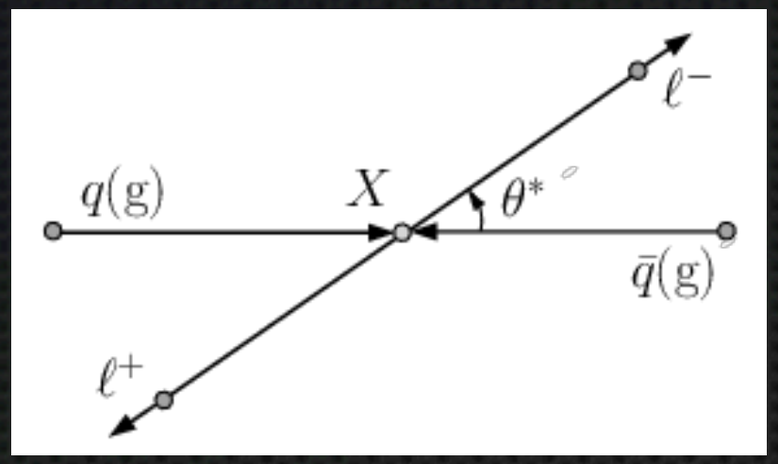


$$Z\gamma\gamma \quad |h_{03}^{\gamma}| < \mathbf{0.027}$$
$$|h_{04}^{\gamma}| < \mathbf{0.0014}$$

PRD 85, 052001 (2012)

Z forward-backward asymmetry

at Hadron Colliders



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

A_{FB}

0.6
0.4
0.2
0
-0.2
-0.4
-0.6

10^2

M_{ee} (GeV)

$u\bar{u} \to e^+e^-$

$d\bar{d} \to e^+e^-$

$p\bar{p} \to e^+e^-$

Sensitive to new physics
(new neutral bosons, LED)

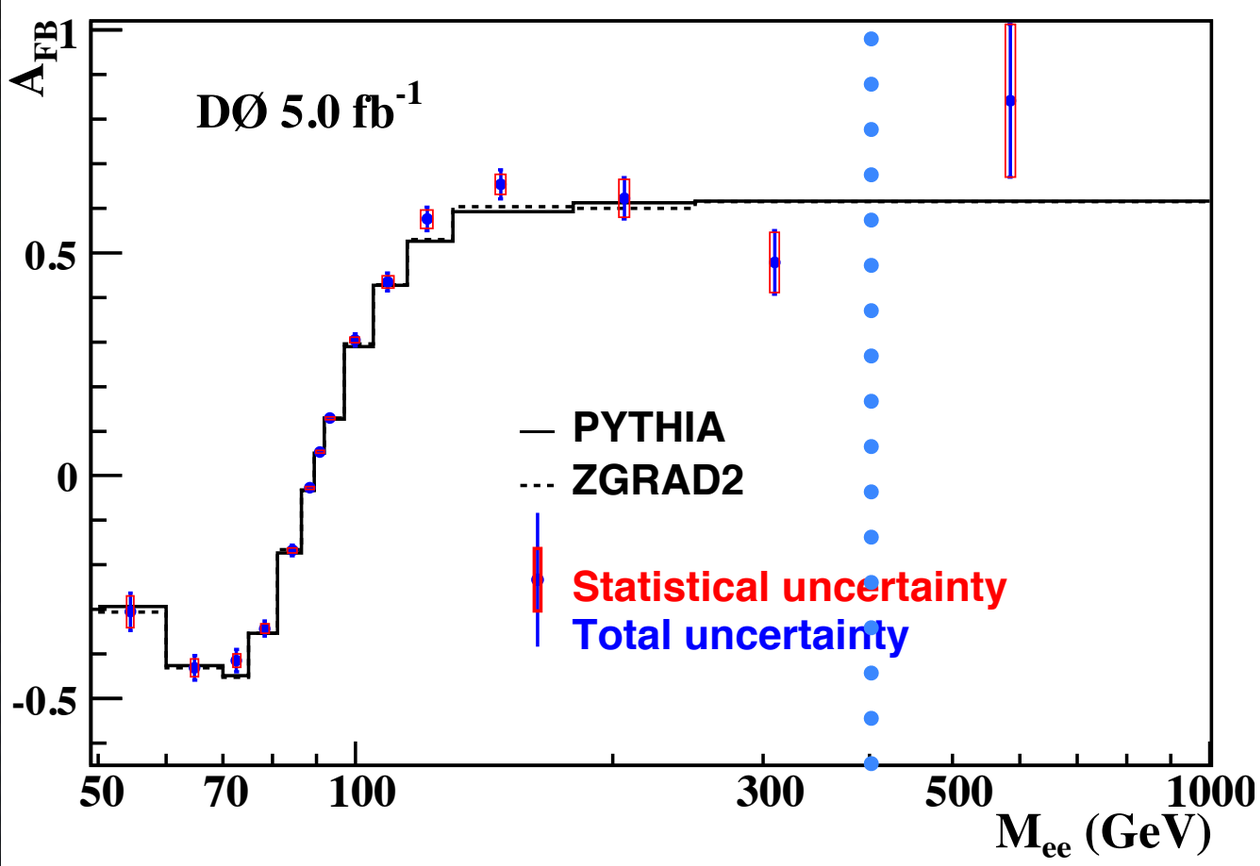
Sensitive to $\sin^2\theta_{eff}$

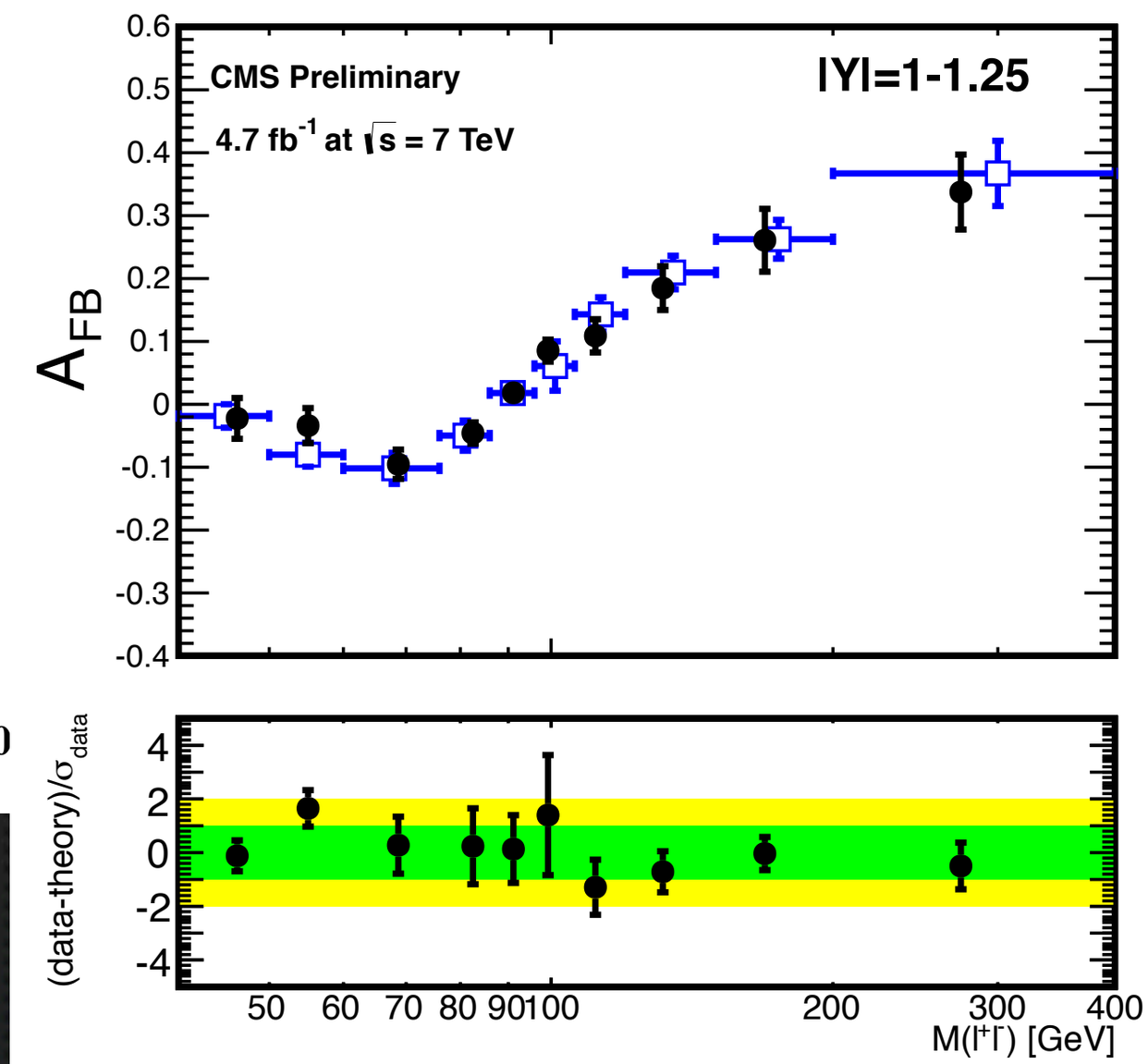
Z forward-backward asymmetry

at Hadron Colliders

Phys. Rev. D 84, 012007 (2011)

CMS PAS EWK-11-004



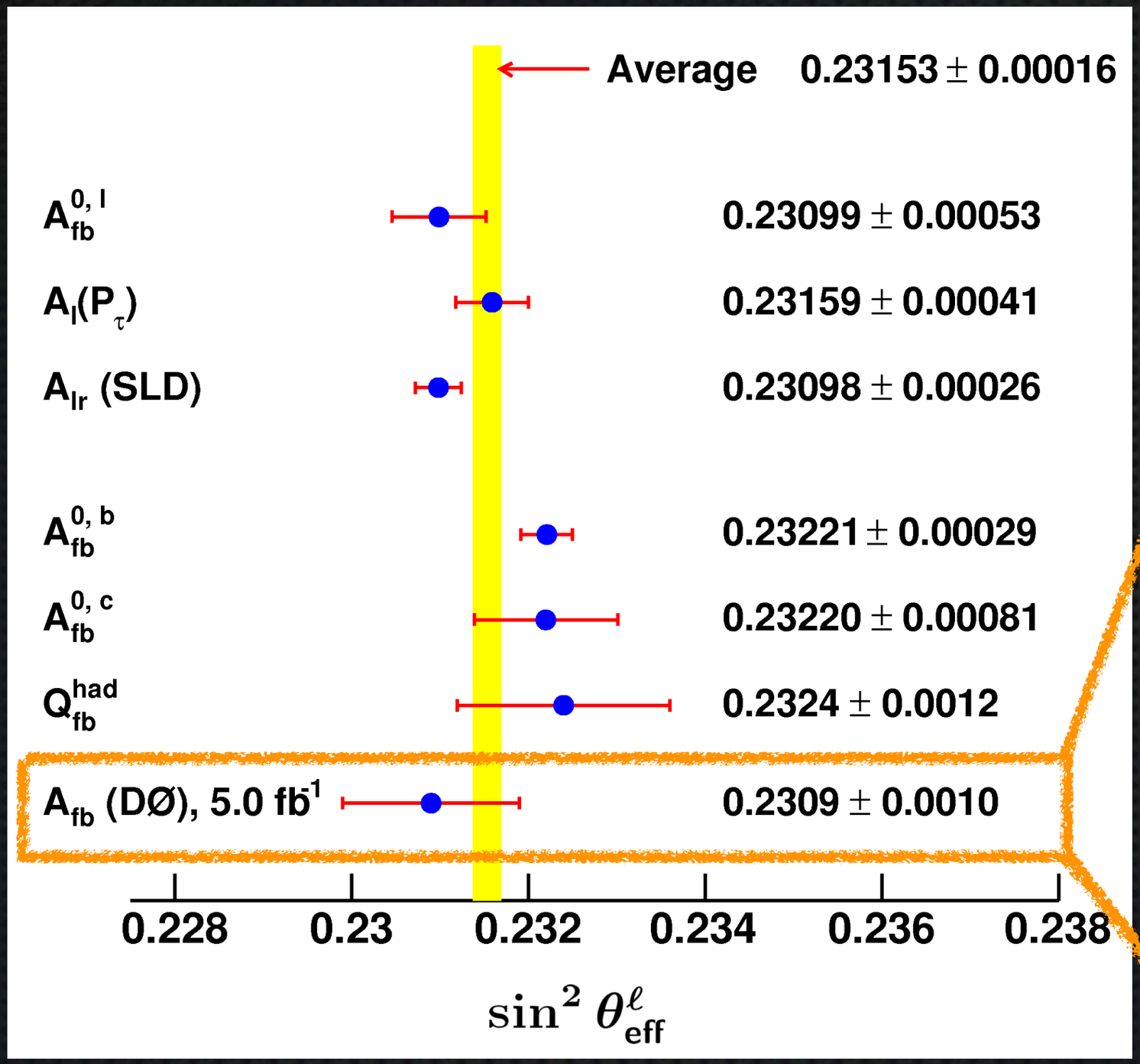


Unfolded AFB agrees well with theoretical predictions

No evidence for new physics at high-mass

Effective Weak Mixing Angle

D0



0.2309 ± 0.0008 (stat) ± 0.0006 (syst)

Most precise measurement from Z to light-quark coupling

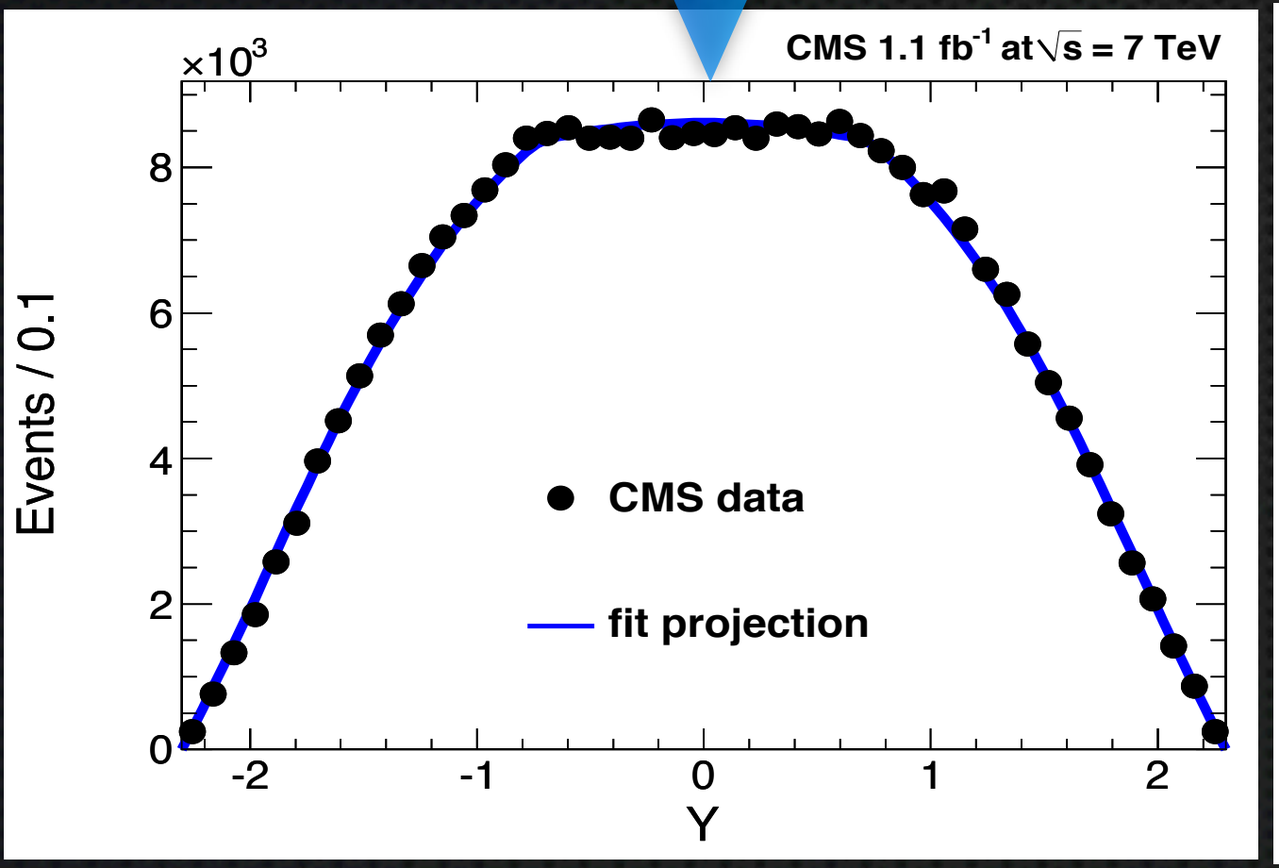
Statistical uncertainty still dominant

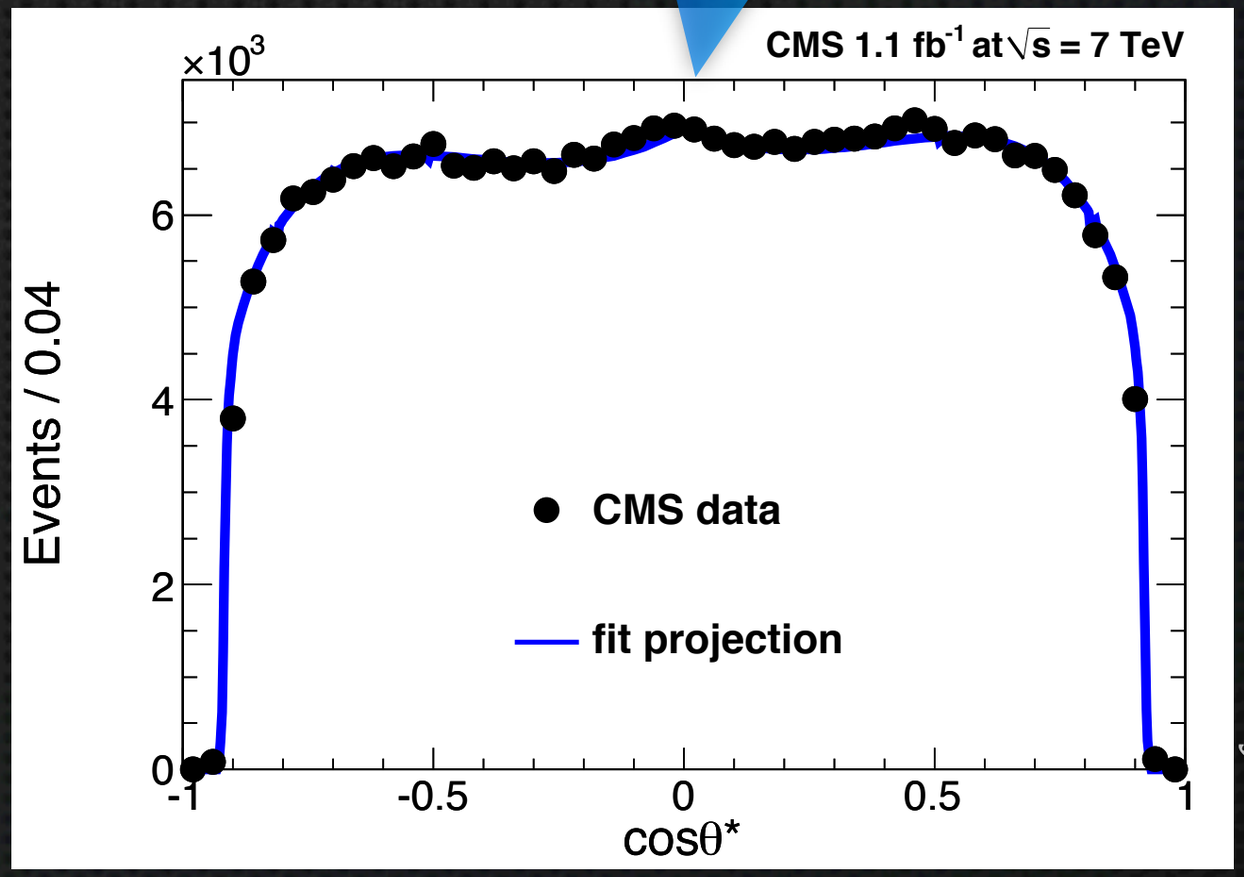
Dominant systematic uncertainty PDF uncertainty (0.00048)

Effective Weak Mixing Angle

CMS: First measurement at the LHC

Extracted from $Z/\gamma^* \rightarrow \mu\mu$ data using unbinned maximum likelihood fit: di-lepton rapidity, invariant mass and $\cos\theta^*_{CS}$





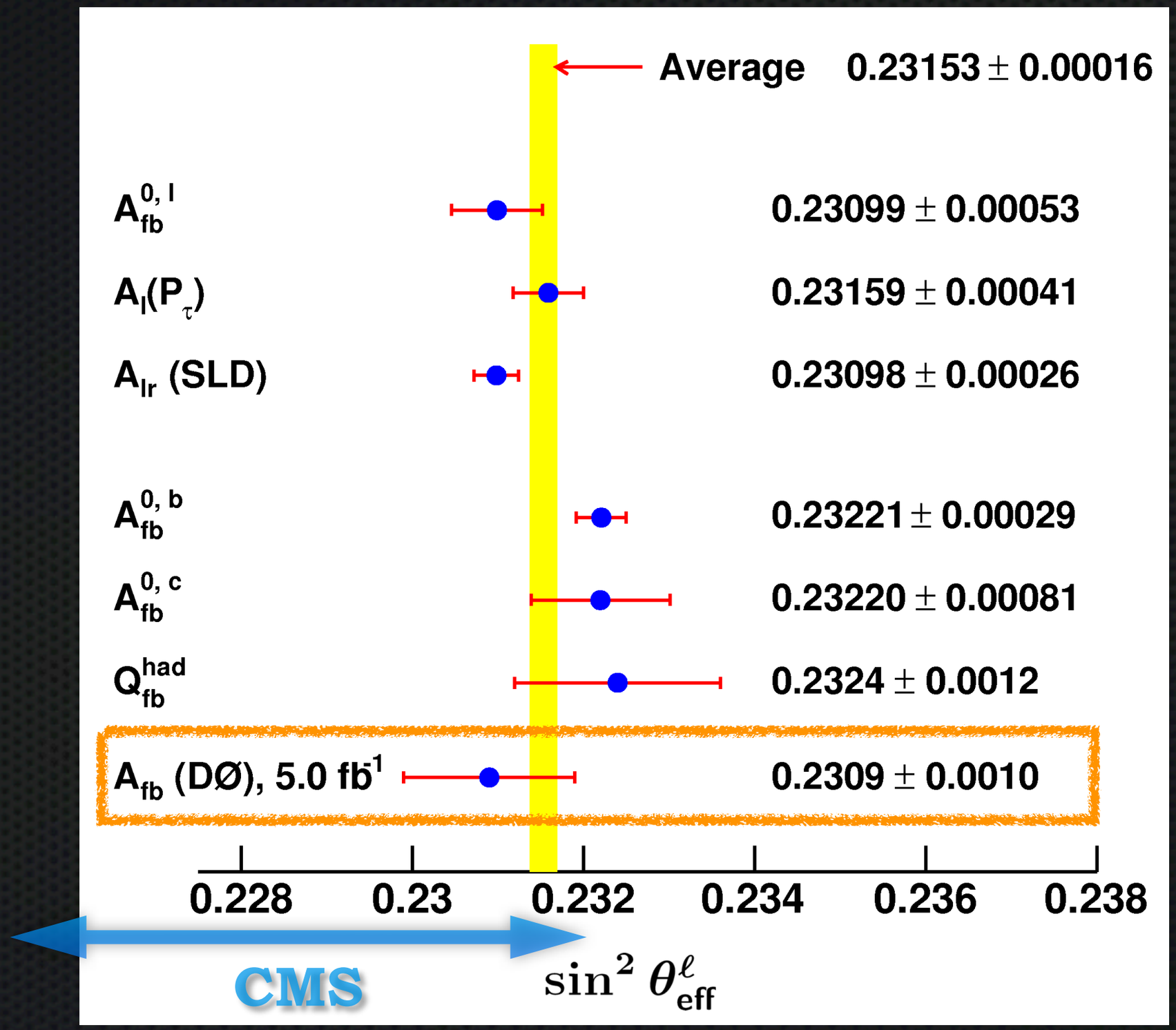
$$\sin^2\theta_{eff} = 0.2287 \pm 0.0020\ (stat) \pm 0.0025\ (syst)$$

Major systematics: PDF, FSR and detector alignment

Phys. Rev. D 84 (2011) 112002

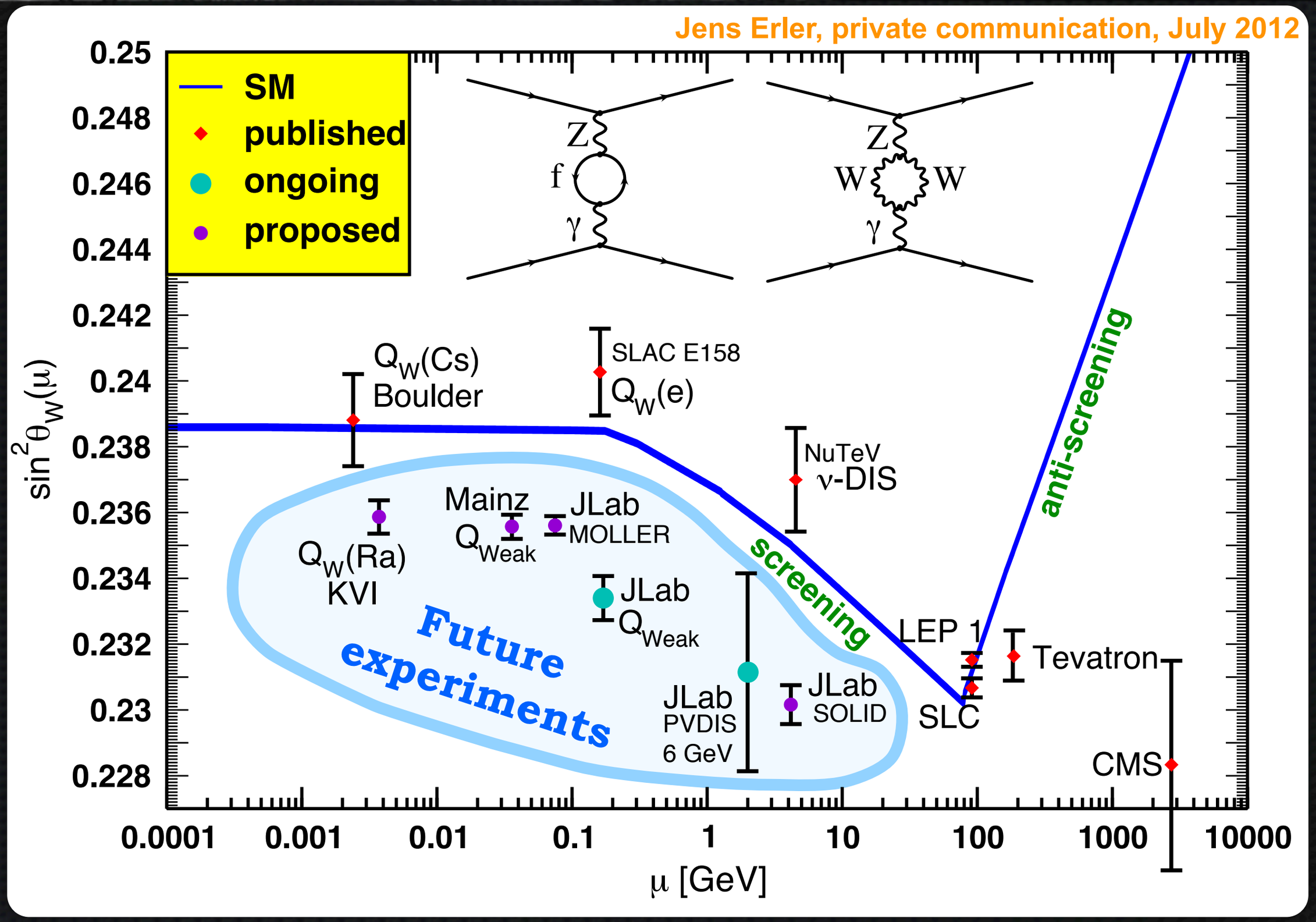
Effective Weak Mixing Angle

CMS: First measurement at the LHC

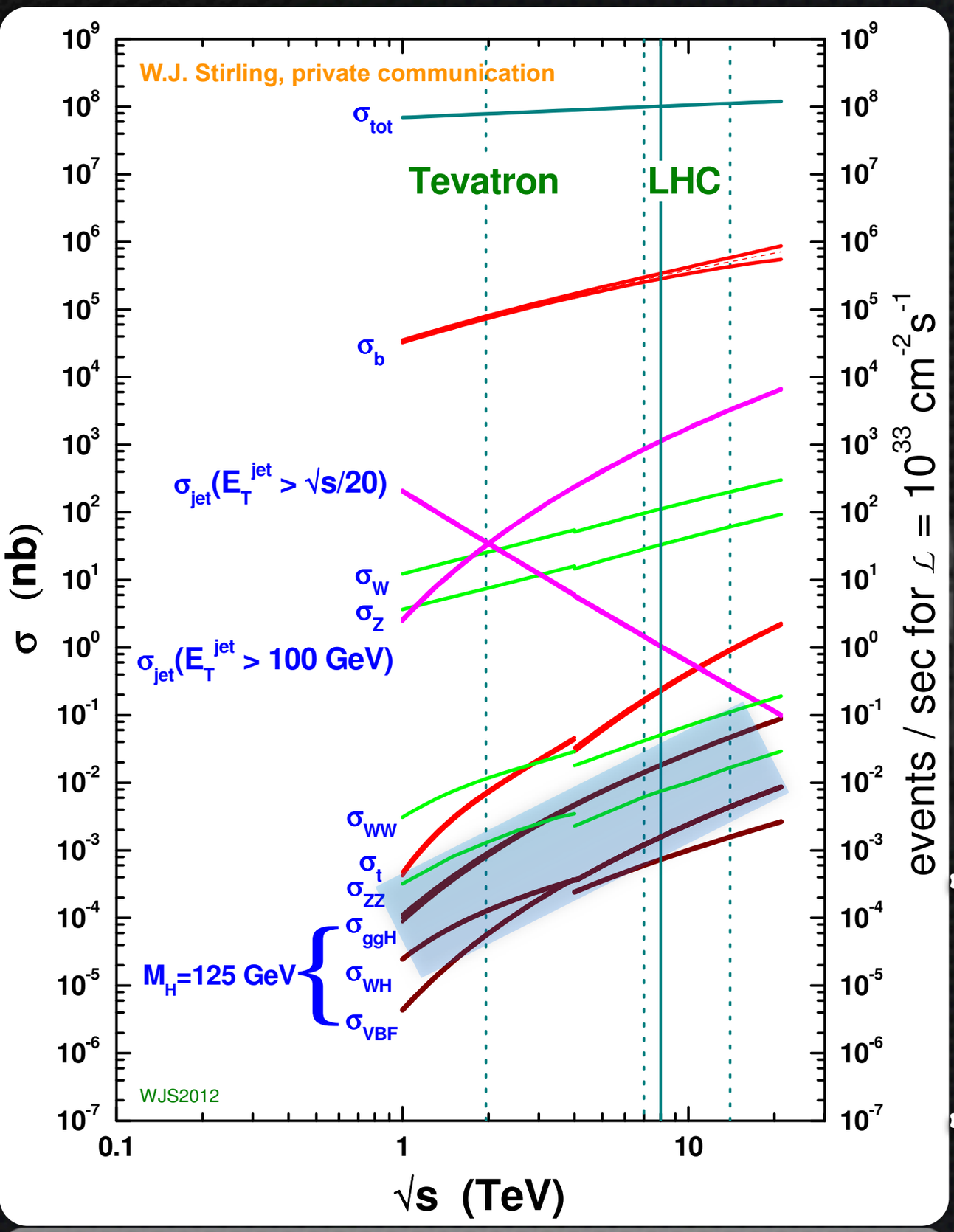


$\sin^2\theta_{eff}$ = 0.2287 ± 0.0020 (stat) ± 0.0025 (syst)

Weak mixing angle: scale dependence



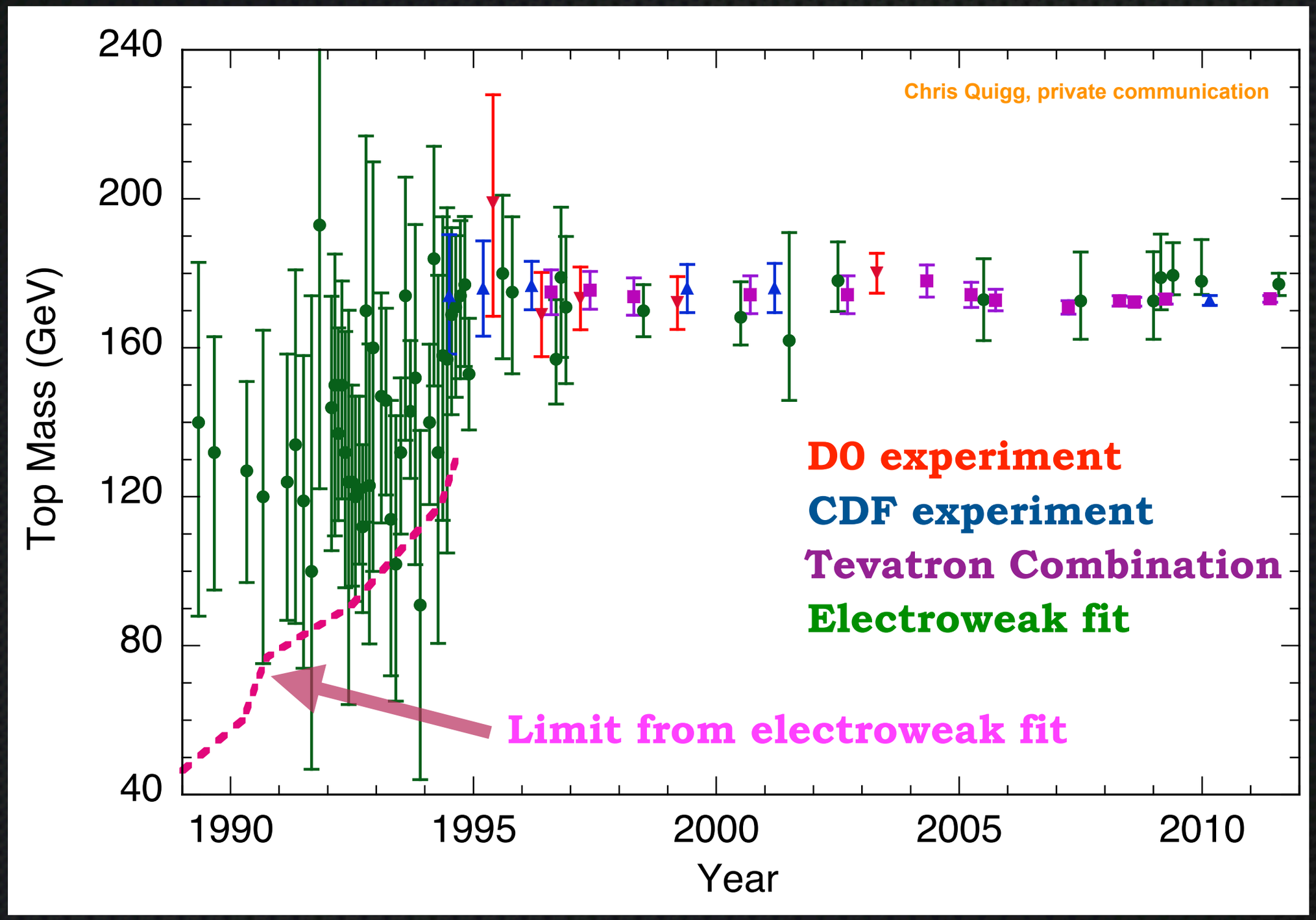
Scale dependence due to radiative effects



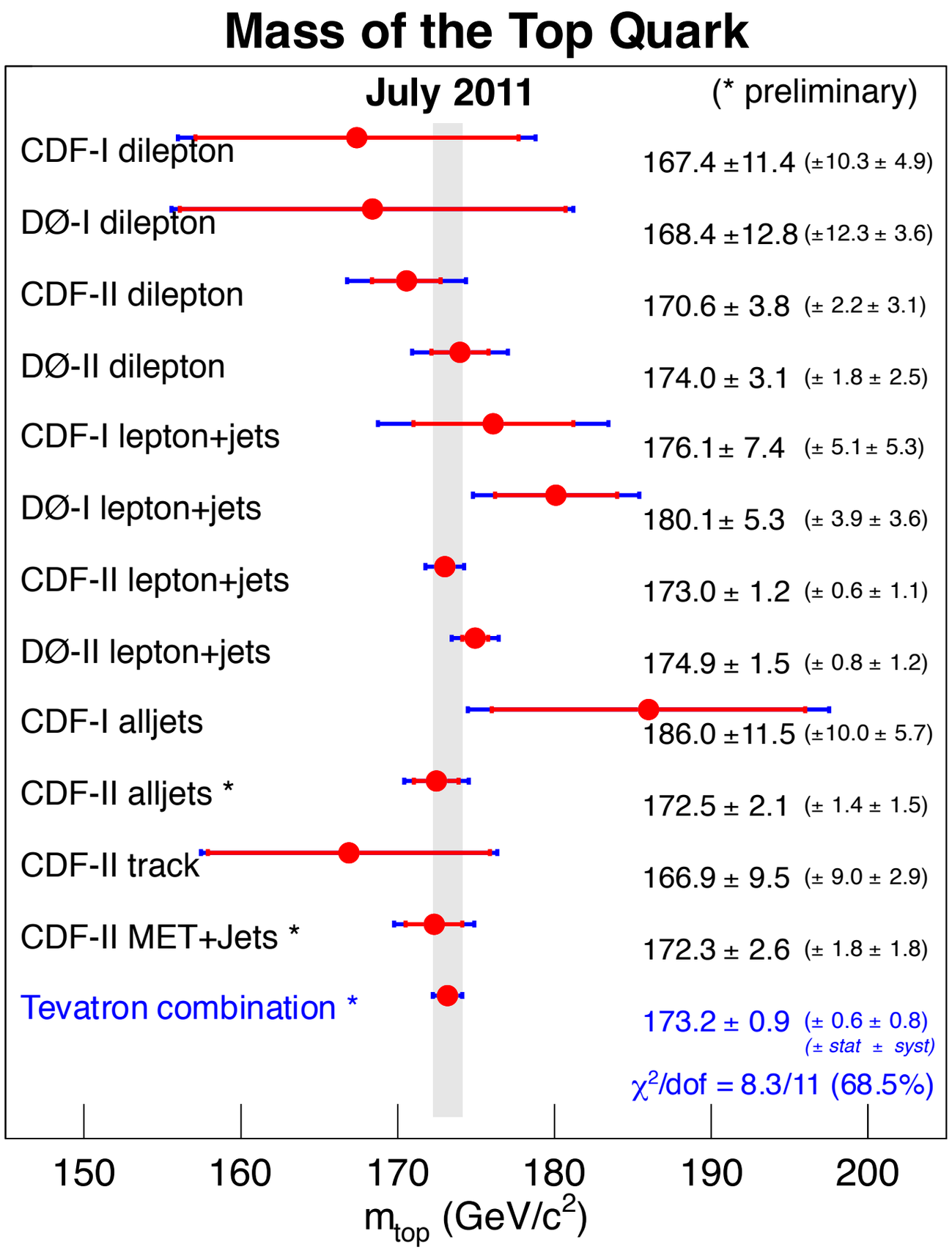
Electroweak Fit

- Precise measurement of electroweak parameters constrains
  - New physics
  - The Higgs mass
- Updated results from EPS'11

Electroweak Theory and Top Mass



Top Quark Mass Measurements

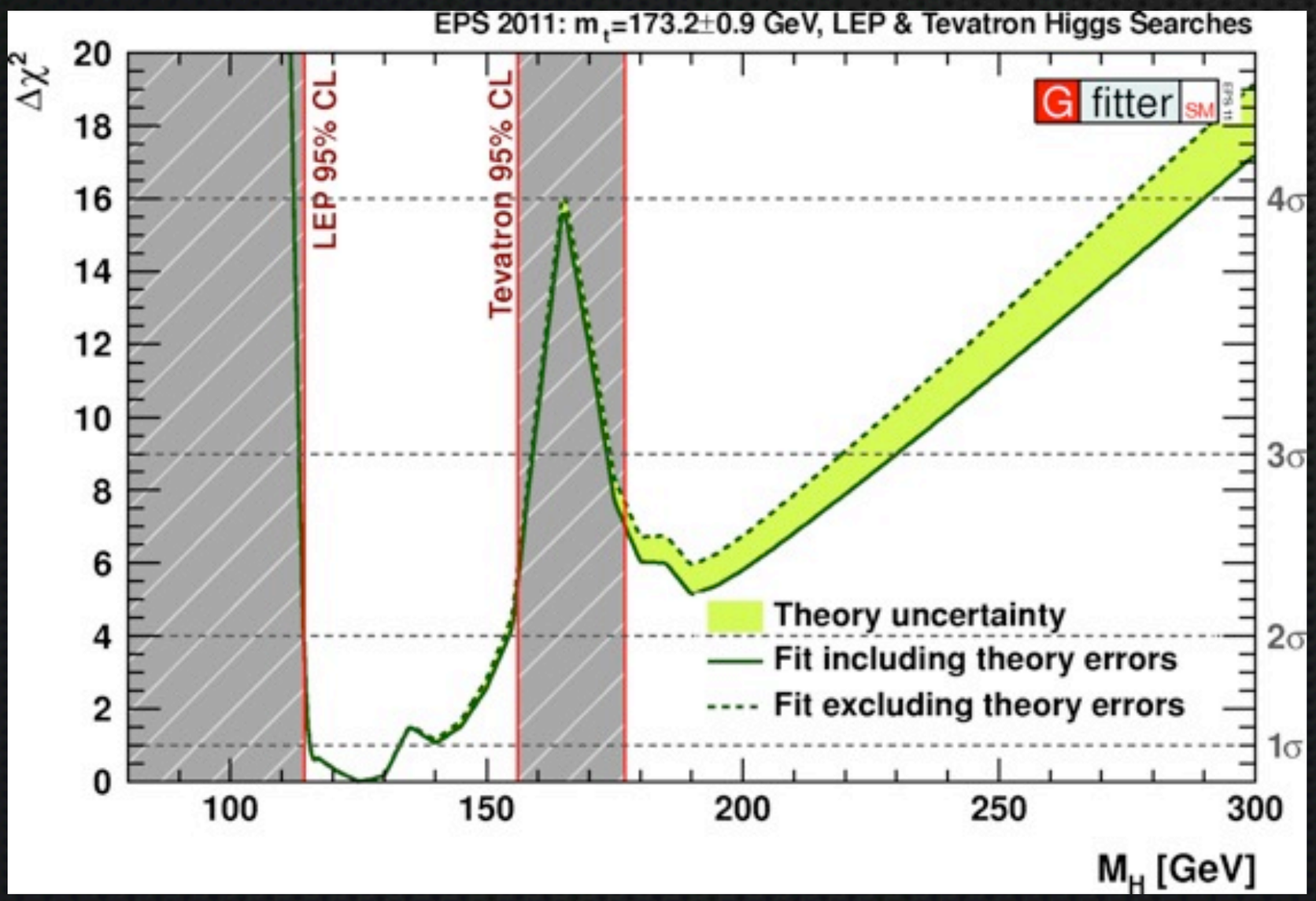


Tevatron:
M_t =173.2 ± 0.9 GeV

LHC:
M_t=173.3 ± 0.5 ± 1.3 GeV

Electroweak Fit Status (September 2011)

- **Updated with EPS'11 results**
  - **Excludes direct Higgs searches from ATLAS and CMS**



Standard Fit

m_H = 94.5 GeV
Range m_H = [71, 124]
m_H (@ 95%) < 166.5 GeV

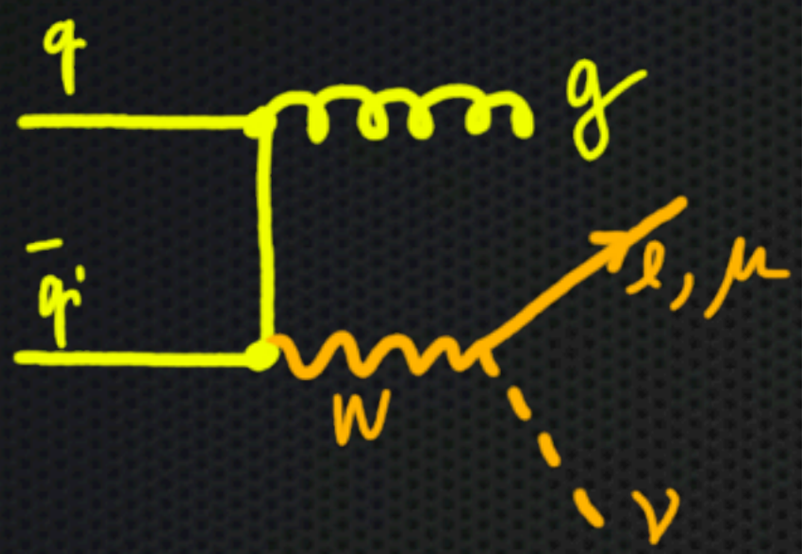
Complete Fit
(including direct limits on Higgs from LEP and Tevatron)

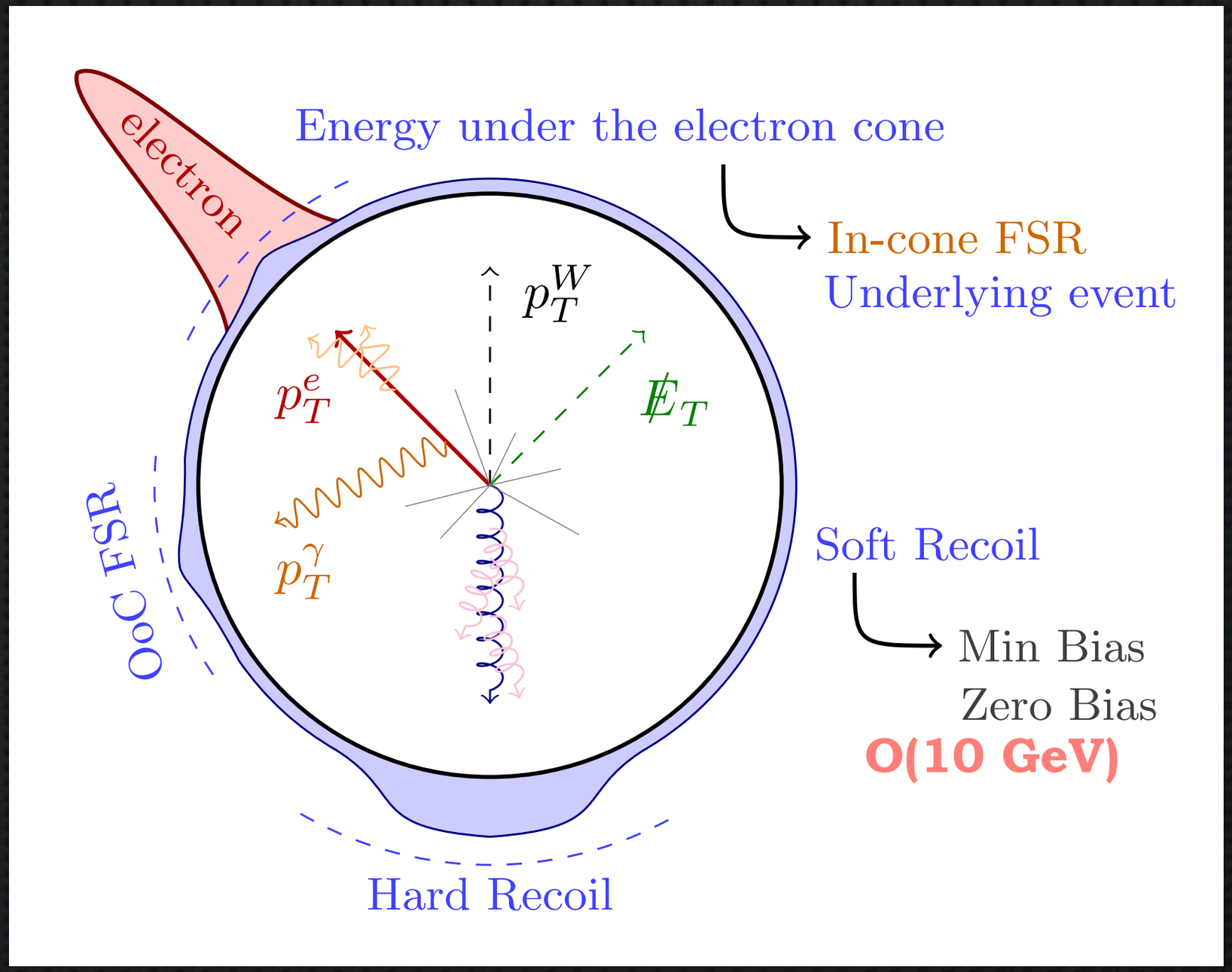
m_H = 125.2 GeV
Range m_H = [116, 133]
m_H (@ 95%) < 153.9 GeV

New W Boson Mass at the Tevatron

Constraints Higgs mass: $\Delta m_t = 0.9\ \mathrm{GeV} \quad \leftrightarrow \quad \Delta \mathrm{m_W} \approx 5\ \mathrm{MeV}$

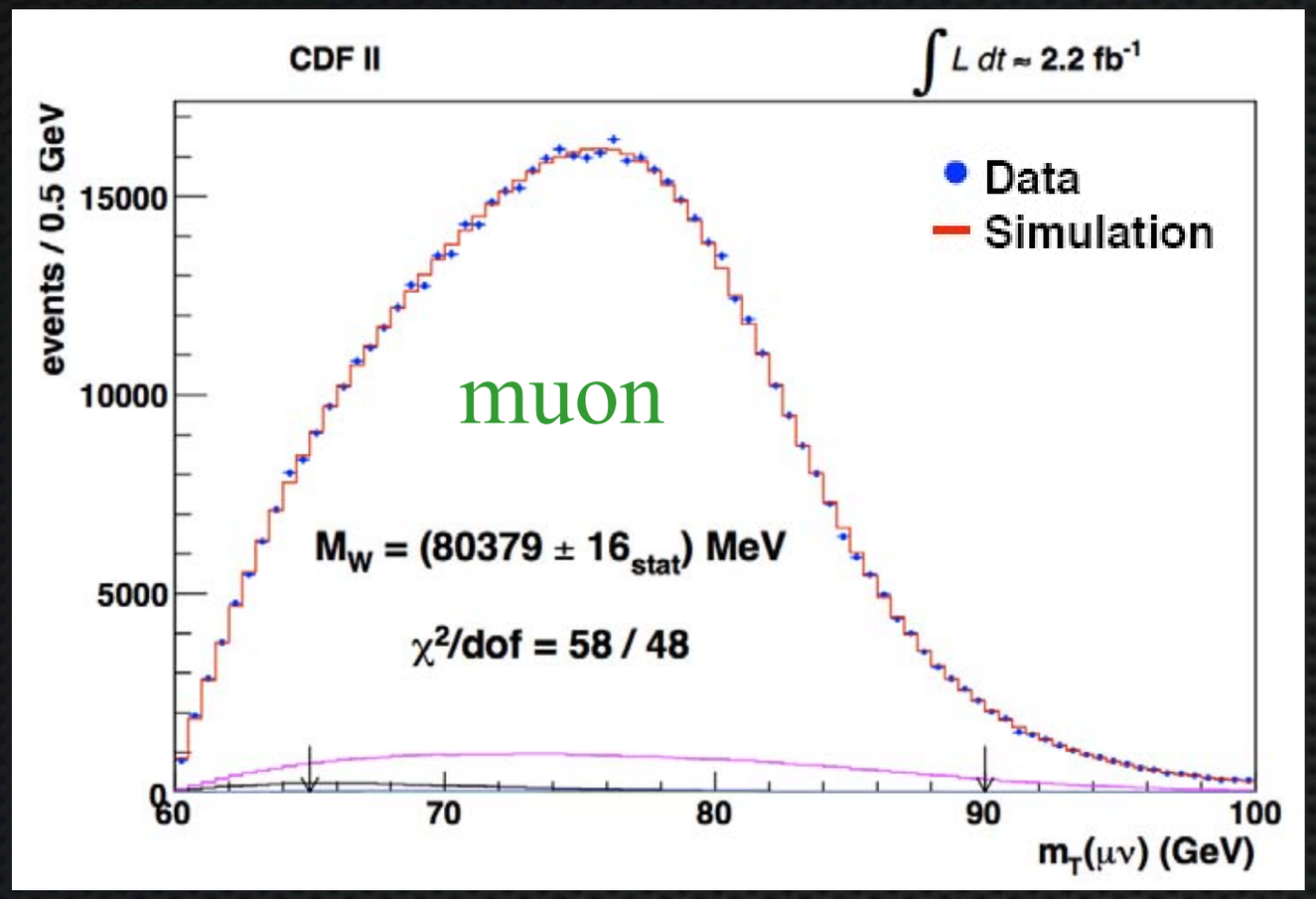
Need excellent understanding of detector and MC simulation



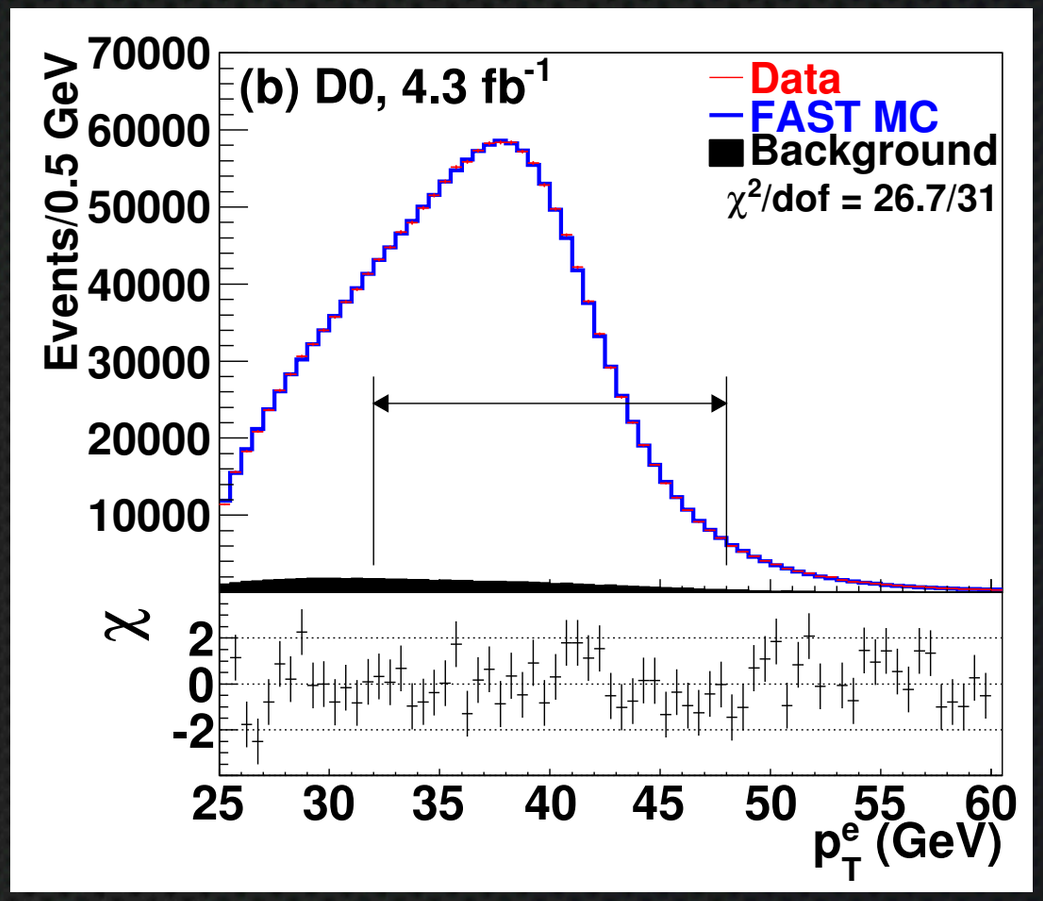


New W Boson Mass at the Tevatron

PRL 108, 151803 (2012)



Phys. Rev. Lett. 108, 151804 (2011)

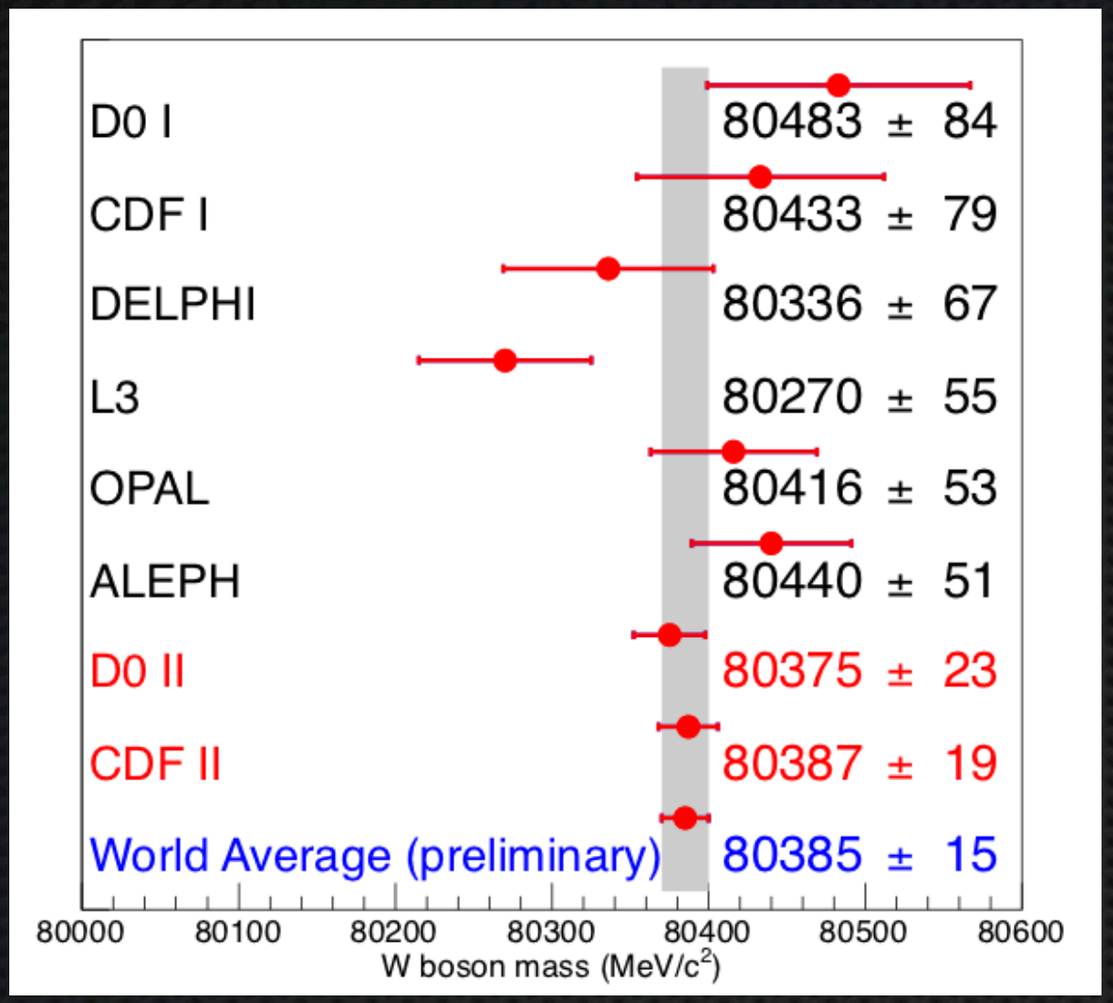


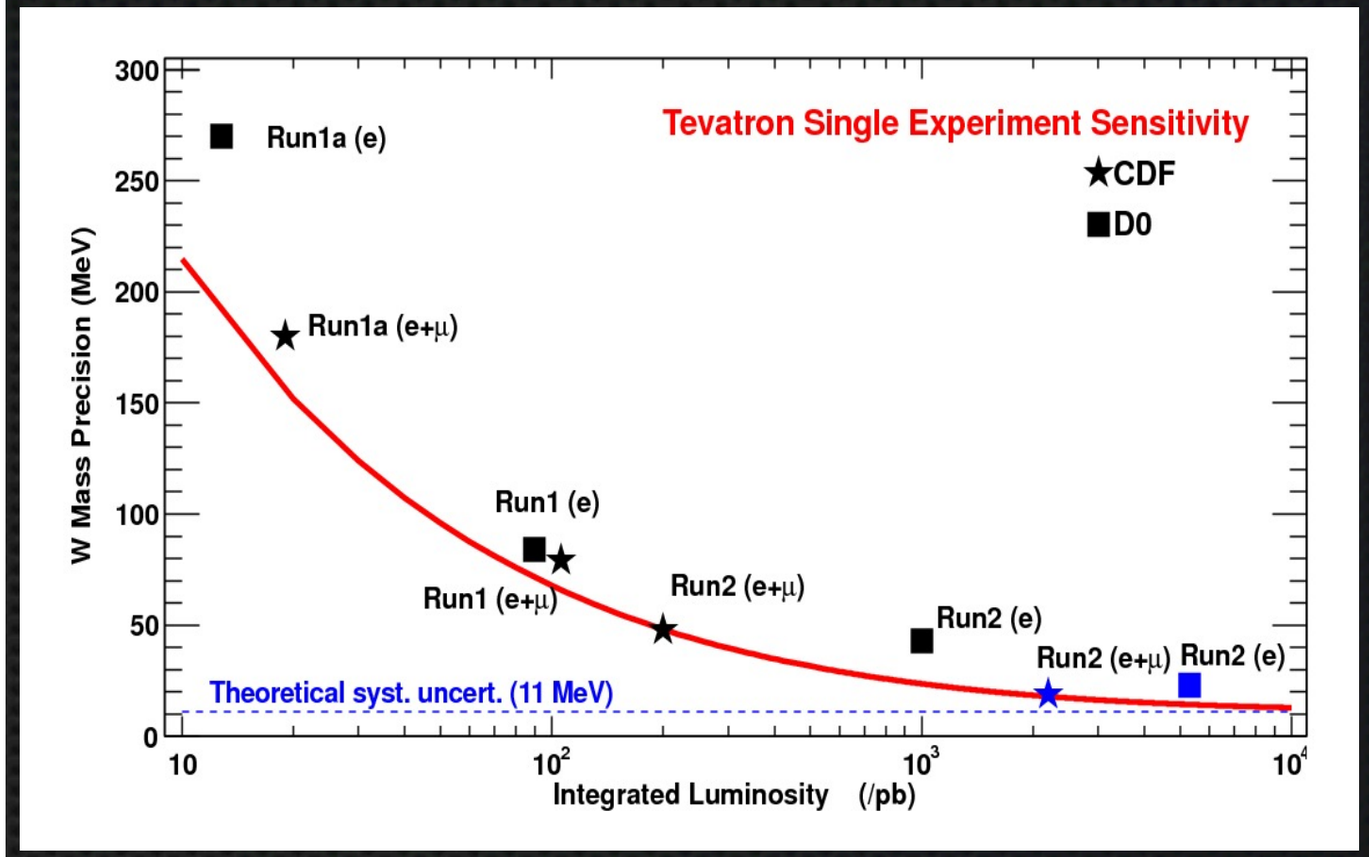
Fits transverse mass, lepton p_T and neutrino p_T

Uses both e and μ
2.2 fb^{-1}
1.1 M W events
Δm_W(sys) = 18 MeV (e)
Δm_W(sys) = 16 MeV (μ)

Uses only e
4 + 1 fb^{-1}
1.7 M W events
Δm_W(sys) = 22 MeV (e)

W Boson Mass





Dominant uncertainties:

Parton distribution functions: 10-14 MeV

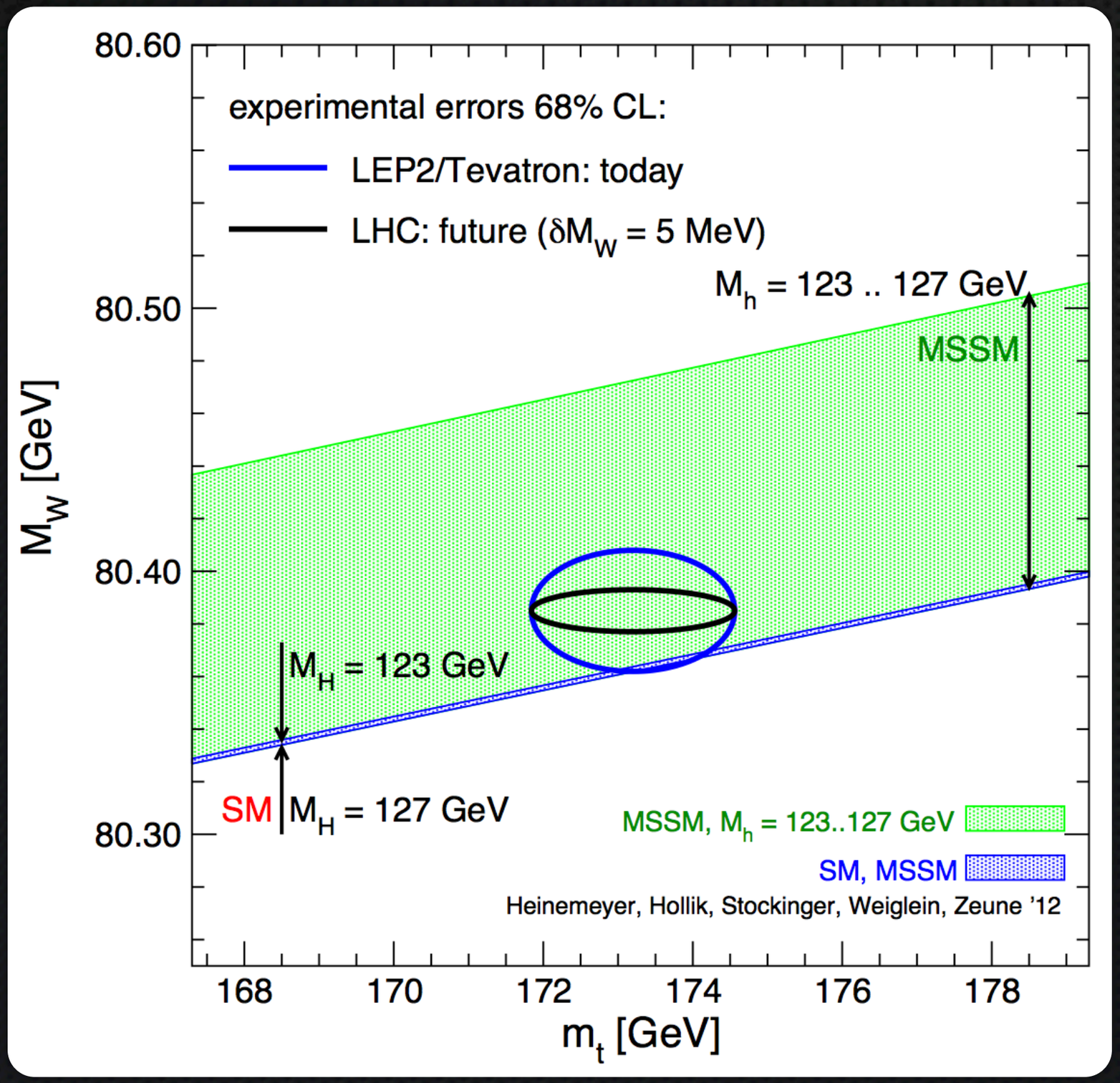
Lepton calibration: 16 MeV (D0) / 5 MeV (CDF)

Improvements still to come

More than double statistics with full run II dataset

Precision Electroweak Constraints

- **Disentangle if "observed" Higgs boson is SM or SUSY-like**



Precision Electroweak Constraints

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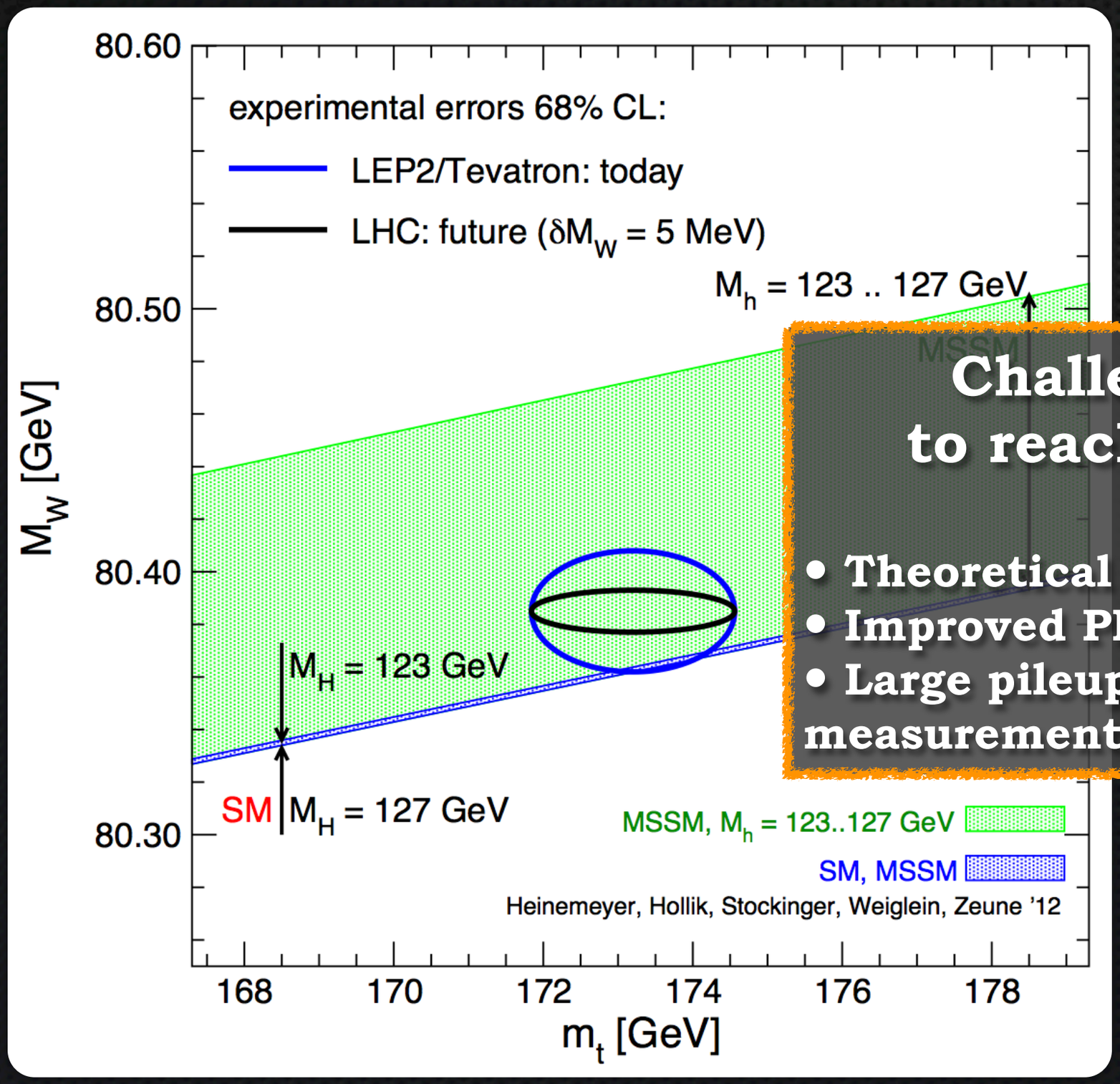


Challenges for LHC to reach ΔM_W =5 MeV

- **Theoretical understanding of $P_T(W)$**
- **Improved PDFs (strangeness)**
- **Large pileup affecting measurement of soft recoil**

Conclusions

- **Large Hadron Collider program well underway towards precision physics with W and Z bosons**
  - Stable ground for new physics searches
  - SM physics offers spin-offs into discoveries
- **Tevatron still putting out high quality results**
  - It will have the better hand on the W and top mass for a long time
- **Agreement with theory across orders of magnitude is impressive**
- **EW precision measurements in a fair agreement with a Higgs boson with mass of 125 GeV**
  - Future precision measurements should help disentangle possible new physics

Extra Slides

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

A. Kropivnitskaya

- 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 instantaneous $\mathcal{L}_{inst}$ ~ 3E32 – 6E32 $cm^{-2}s^{-1}$
  - ➔ Integrated $\mathcal{L}$ = 18.8 pb^{-1}
  - ➔ Special HLT menu with low thresholds: 22 GeV for e and 15 GeV for μ
  - ➔ minimal ID/Iso requirement to suppress background

Event Selection:

e-channel:
E_T > 25 GeV and |η|< 2.5, exclude 1.4442 < |η| < 1.566 (barrel/forward transition)
W ➔ eν: Reject events with 2nd e with E_T > 20 GeV

μ-channel:
p_T > 25 GeV and |η| < 2.1
W ➔ μν: Reject events with 2nd μ with p_T > 10 GeV

Z→ll: 60 GeV < M_{ll} < 120 GeV

The dominant source of systematic uncertainty:
- Experimental:
  - Luminosity (4.4%) for absolute cross sections
  - Lepton efficiency (1-3%)
  - Theoretical uncertainty in acceptance (2-3%)
- Theoretical:
  - PDFs
  - Higher order QCD corrections
  - Higher order electroweak corrections

Event selection in tau polarization analysis

- 24 pb-1 from 2010 data with tau (16 GeV) + Missing E_T (22 GeV) trigger
- Offline: single-track tau with p_T > 20 GeV and Missing ET greater than 30 GeV
- Reject events with jet activity in region between the central and endcap detectors
- Reject events with electron or muon greater than 15 GeV E_T
- Reject events with jet activity along direction of event Missing E_T
- Require Missing ET significance > 6

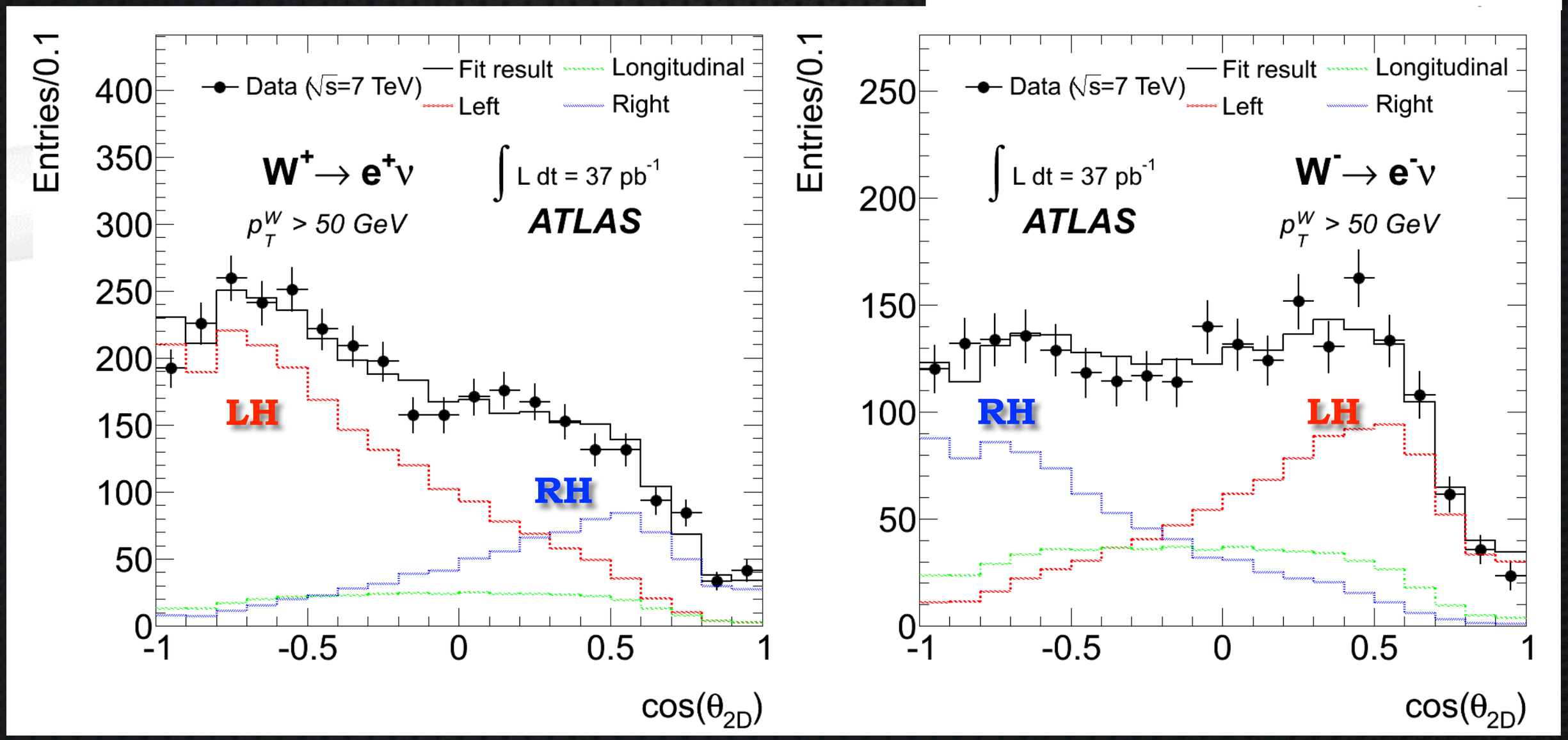
$$S_{E_{\mathrm{T}}^{\mathrm{miss}}} = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{\sigma(E_{\mathrm{T}}^{\mathrm{miss}})}$$

Based on ATLAS W-> τν cross section measurement: Phys. Lett. B 706, 276 (2012)

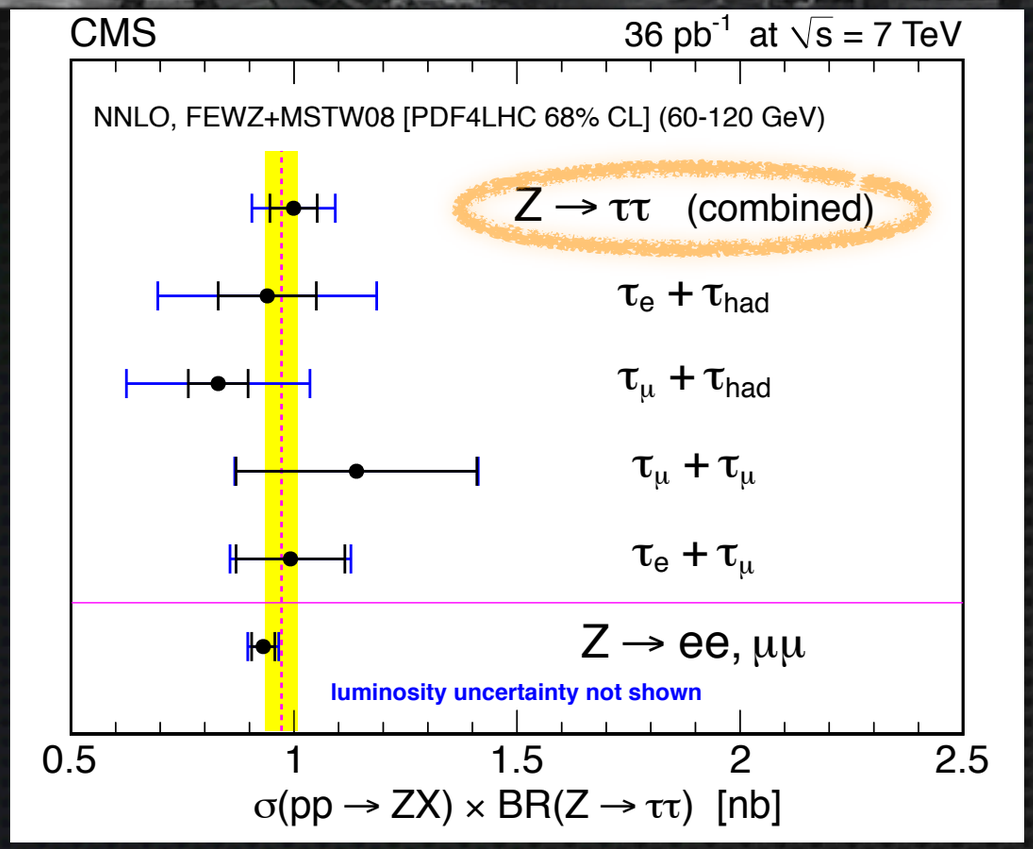
W Polarization

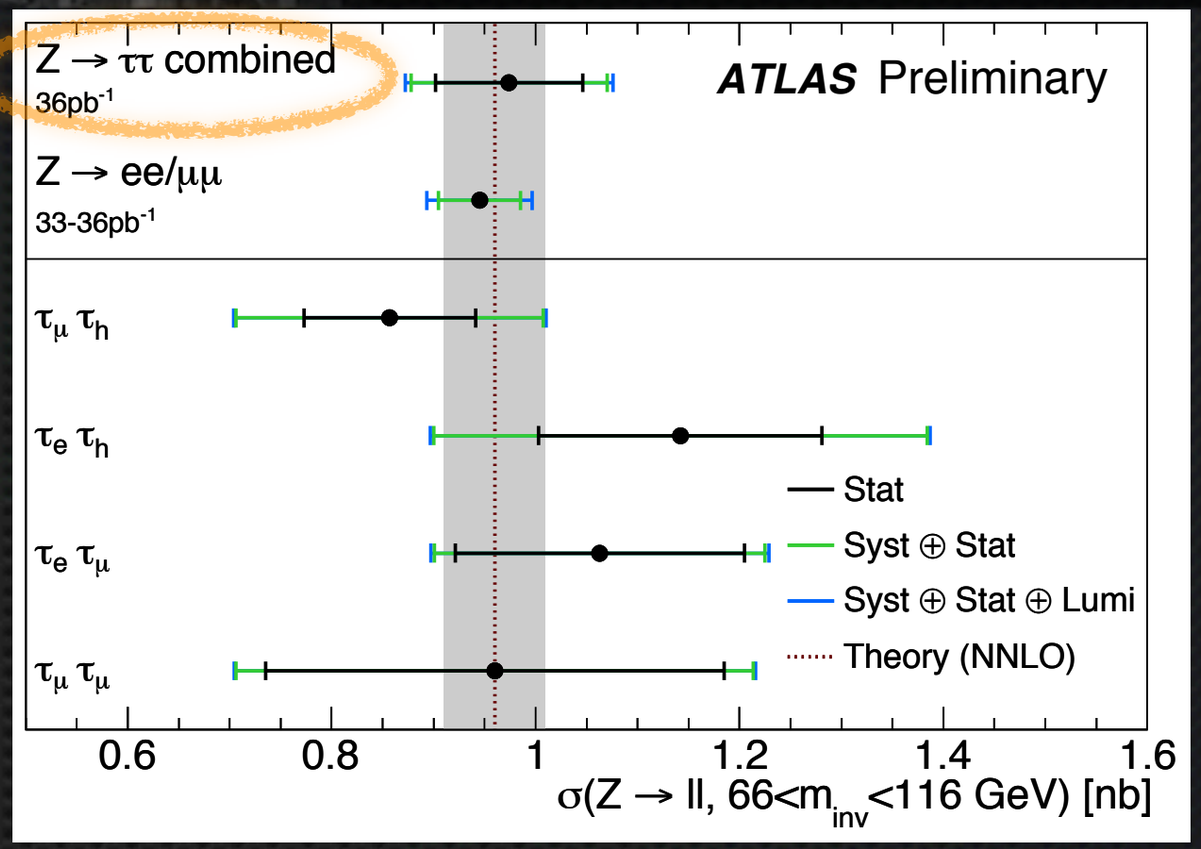
Eur. Phys. J. C72 (2012) 2001

$$\cos\theta_{2D} = \frac{\vec{p}_T^{\,\ell*} \cdot \vec{p}_T^{\,W}}{|\vec{p}_T^{\,\ell*}|\,|\vec{p}_T^{\,W}|}$$

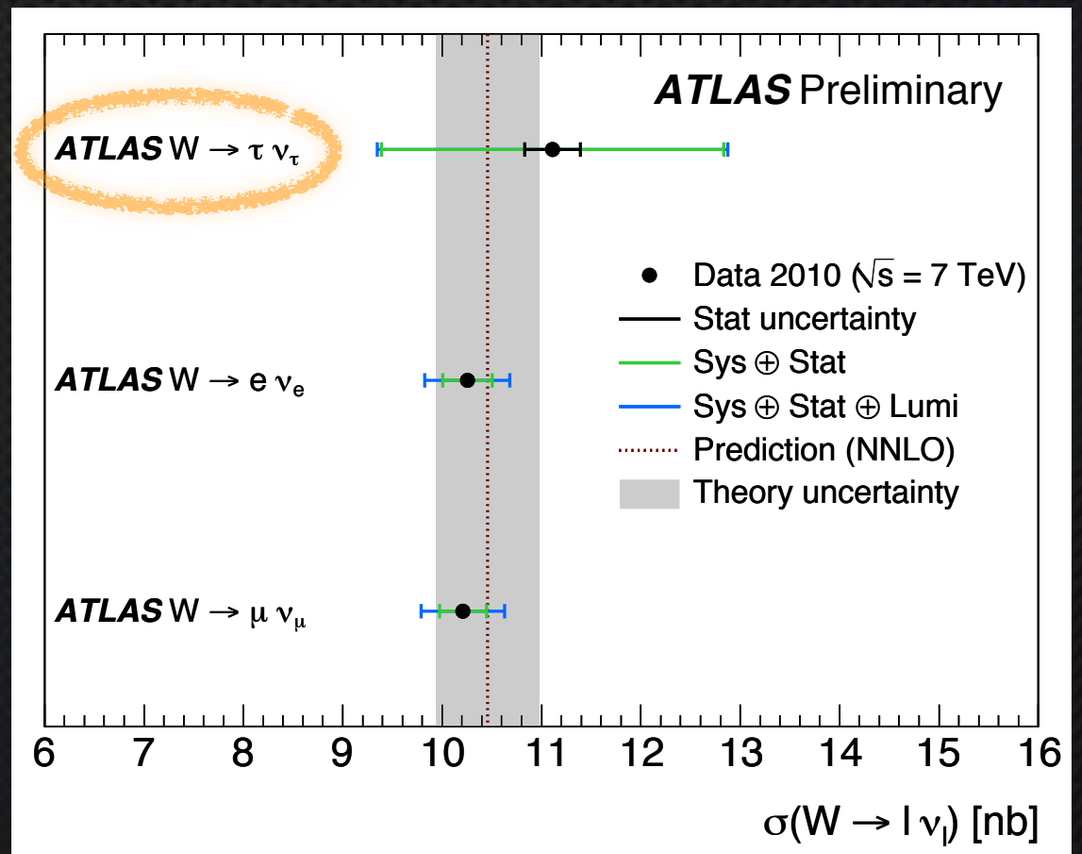


Z→ττ and W→τν Cross Section

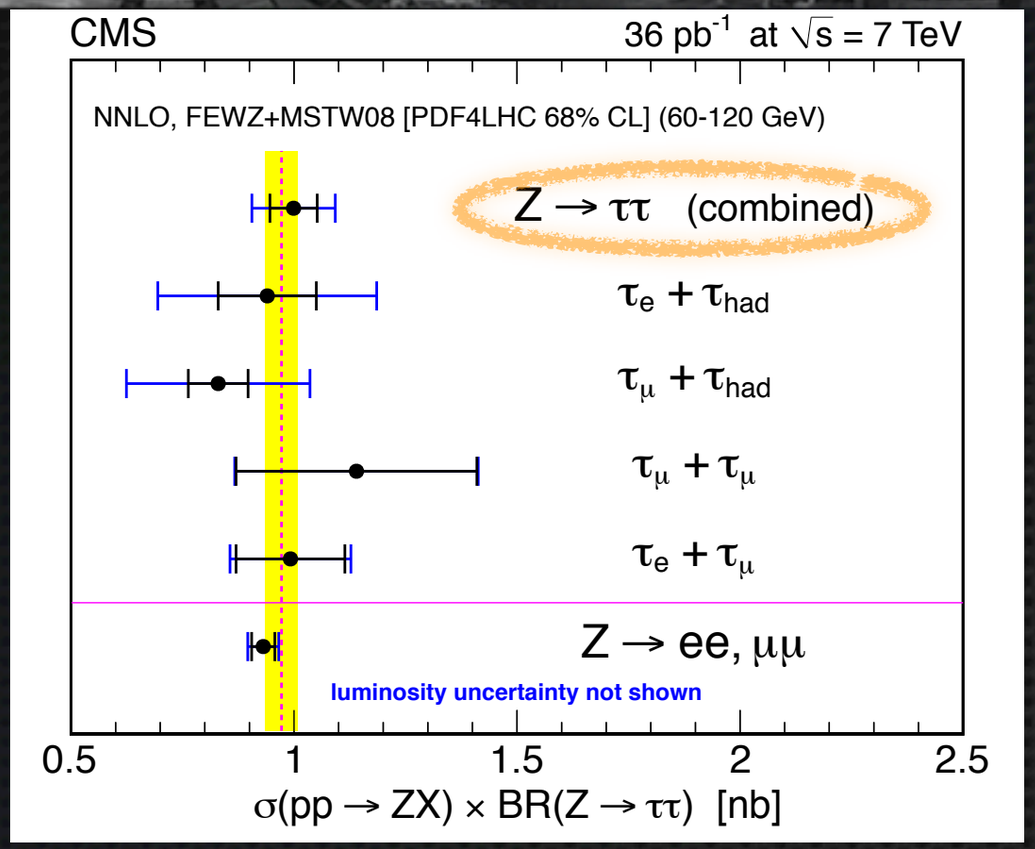


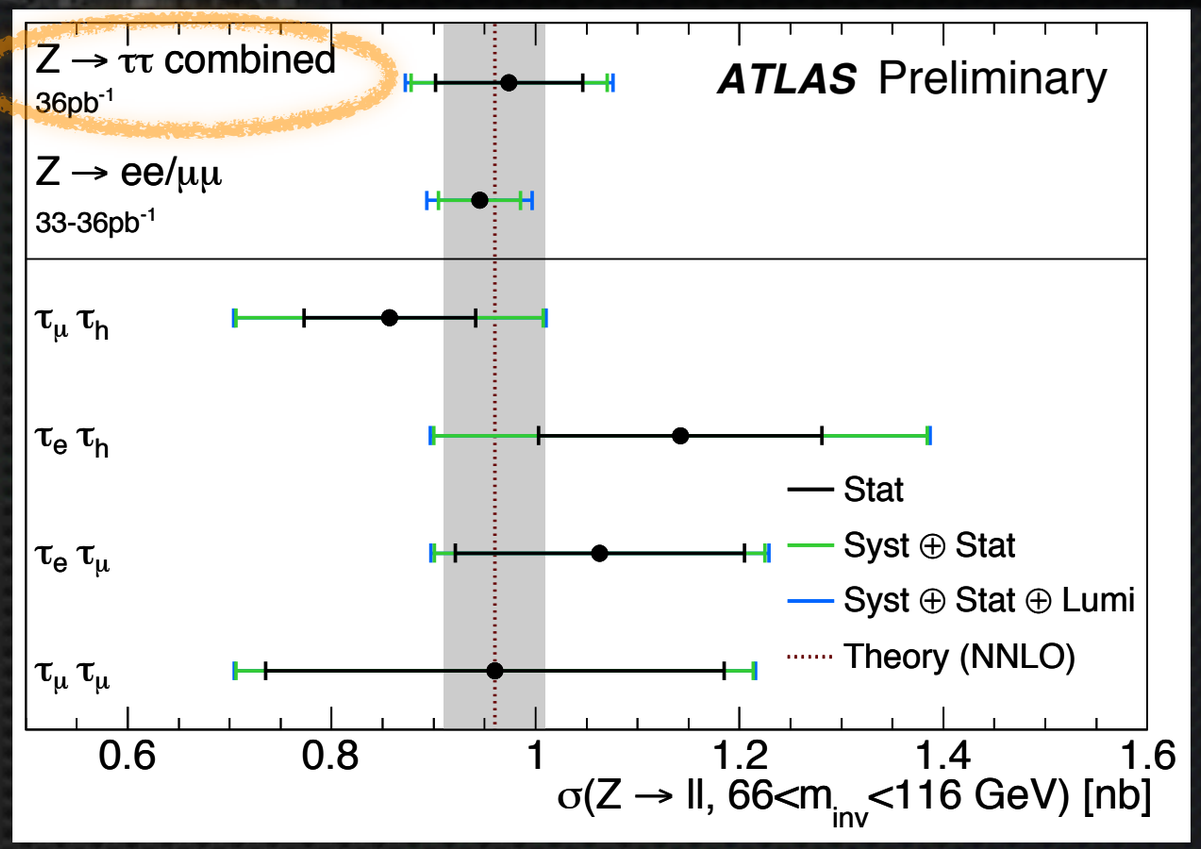


- **Excellent tau identification at LHC**
- **Z→ττ cross section**
  - **CMS: Published**
  - **ATLAS: New**
- **W→τν cross section**
  - **ATLAS: New**
- **Good prospects for new physics searches with taus**



Z→ττ and W→τν Cross Section





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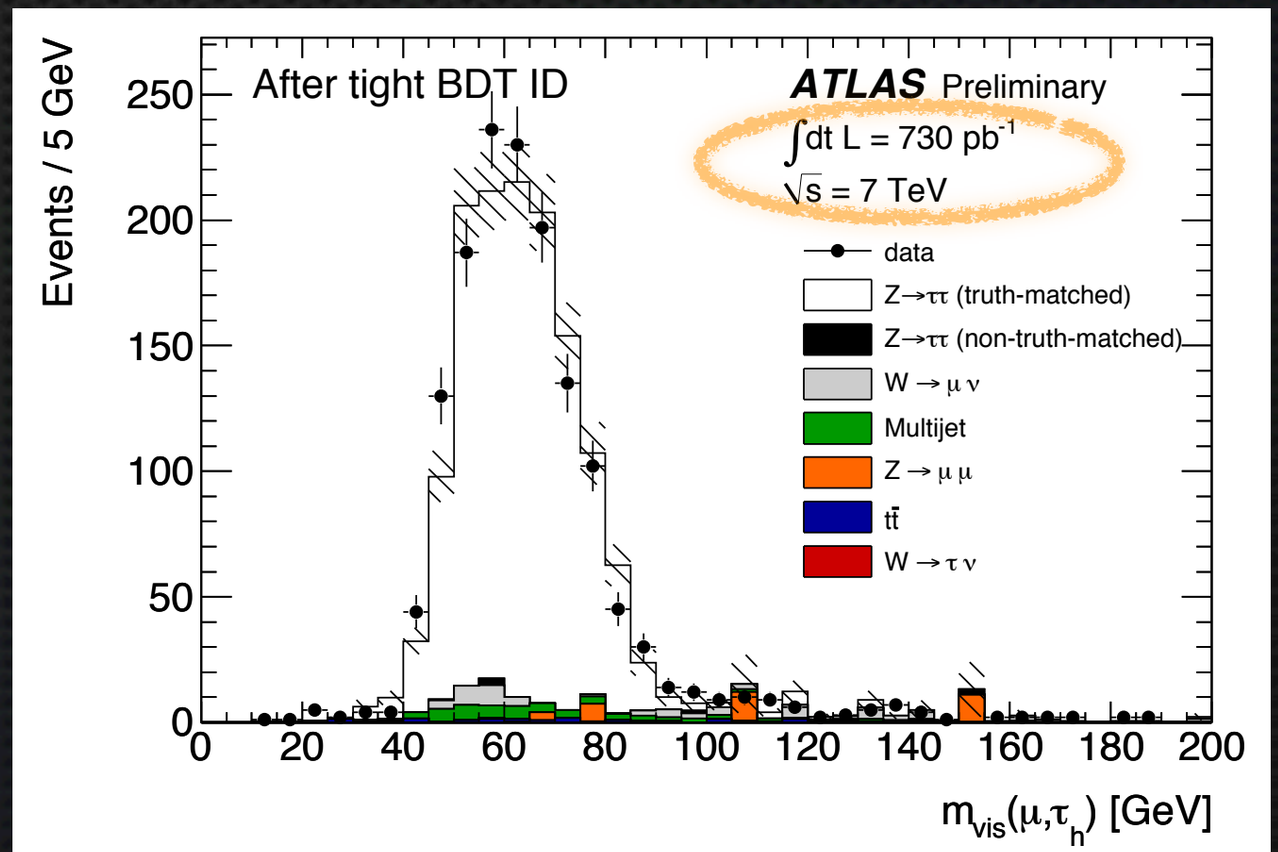
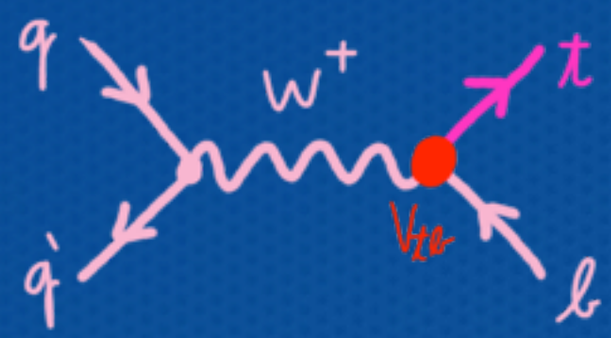
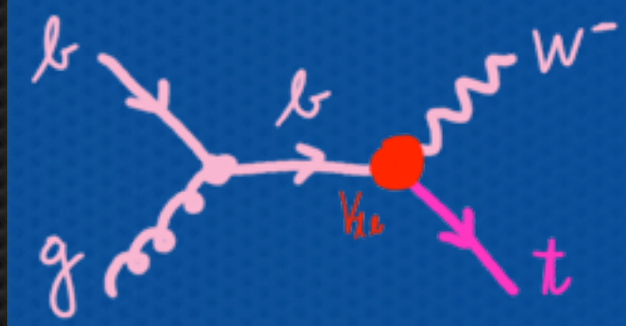


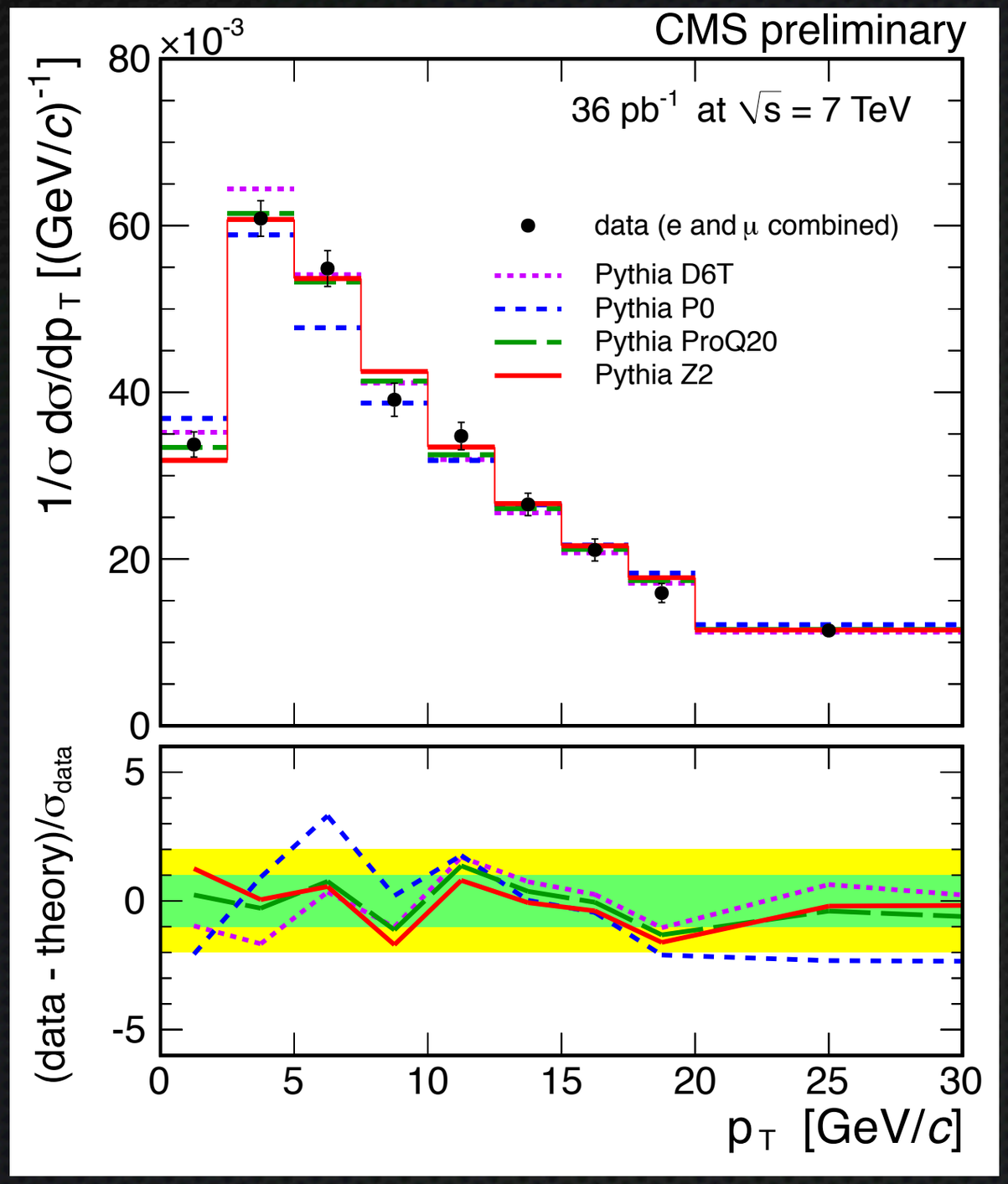
Electroweak Top Production at Hadron Colliders

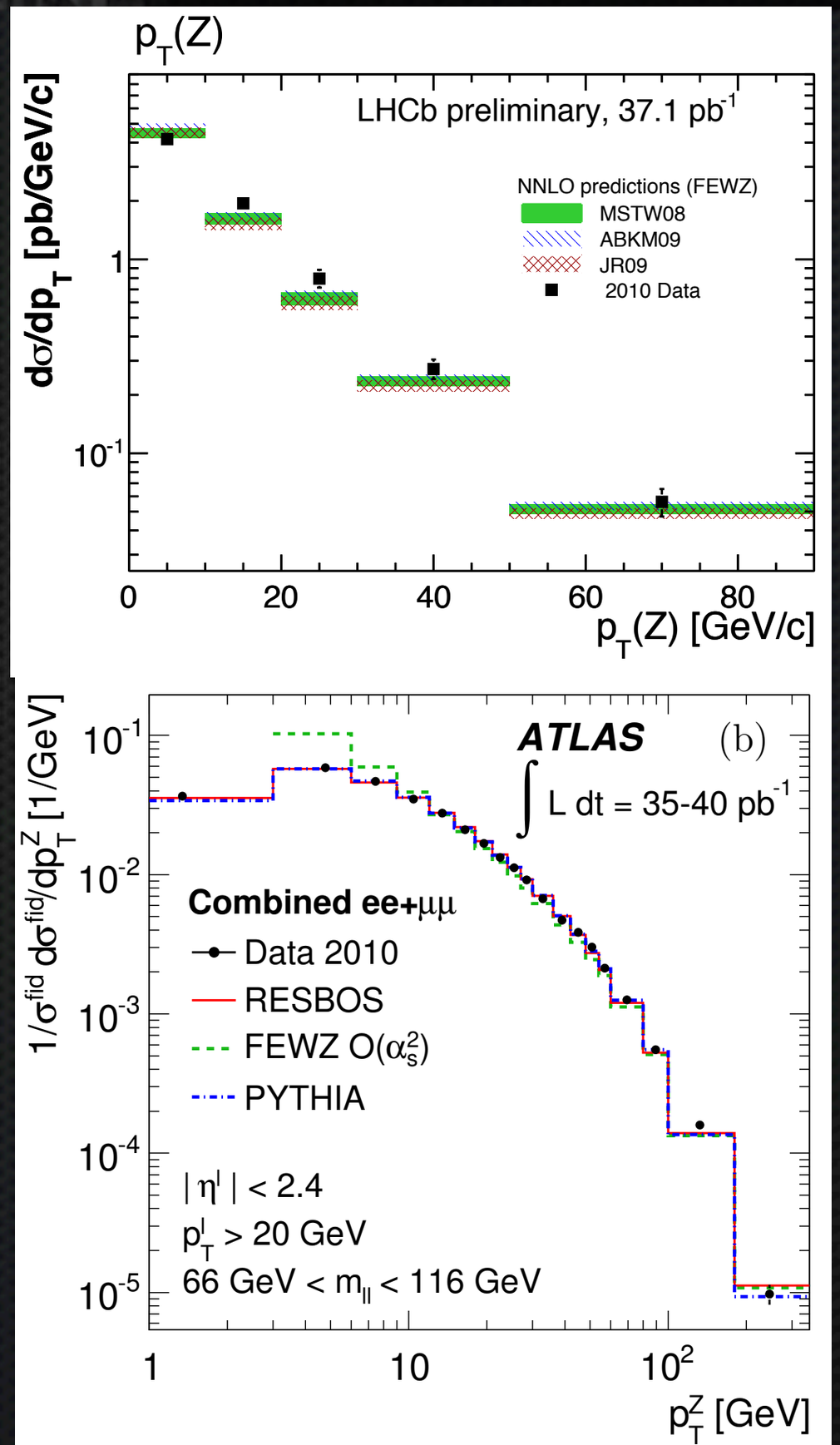
σ(NNLO) (pb) (m_{top} = 172.5 GeV)	s-channel	t-channel	Wt-channel
			
Tevatron @ 1.96 TeV	1.04 ± 0.4	2.26 ± 0.12	0.28 ± 0.06
LHC @ 7 TeV	4.6 ± 0.2	$64.6^{+2.7}_{-2.0}$	15.7 ± 1.1

Very difficult at LHC

Not possible at Tevatron

Z Transverse Momentum at LHC

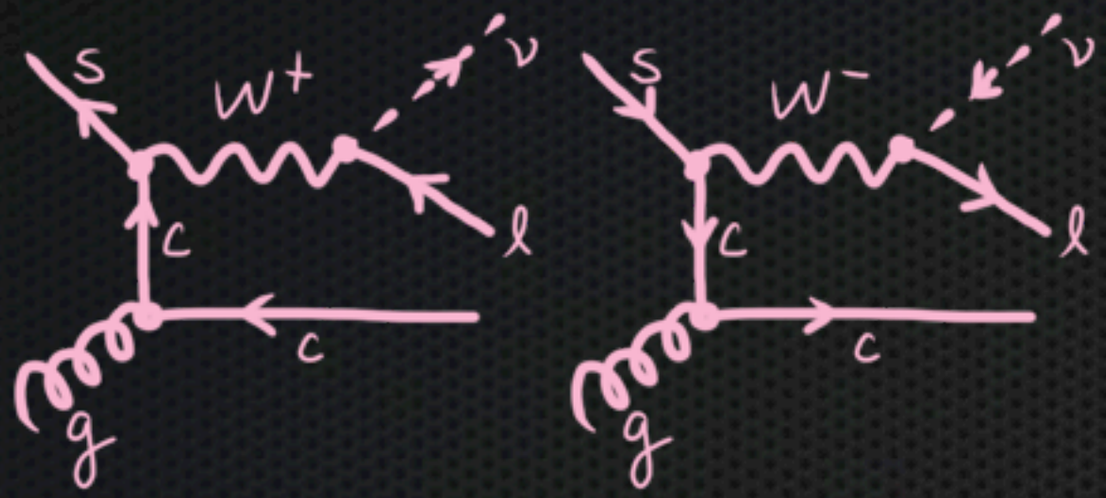


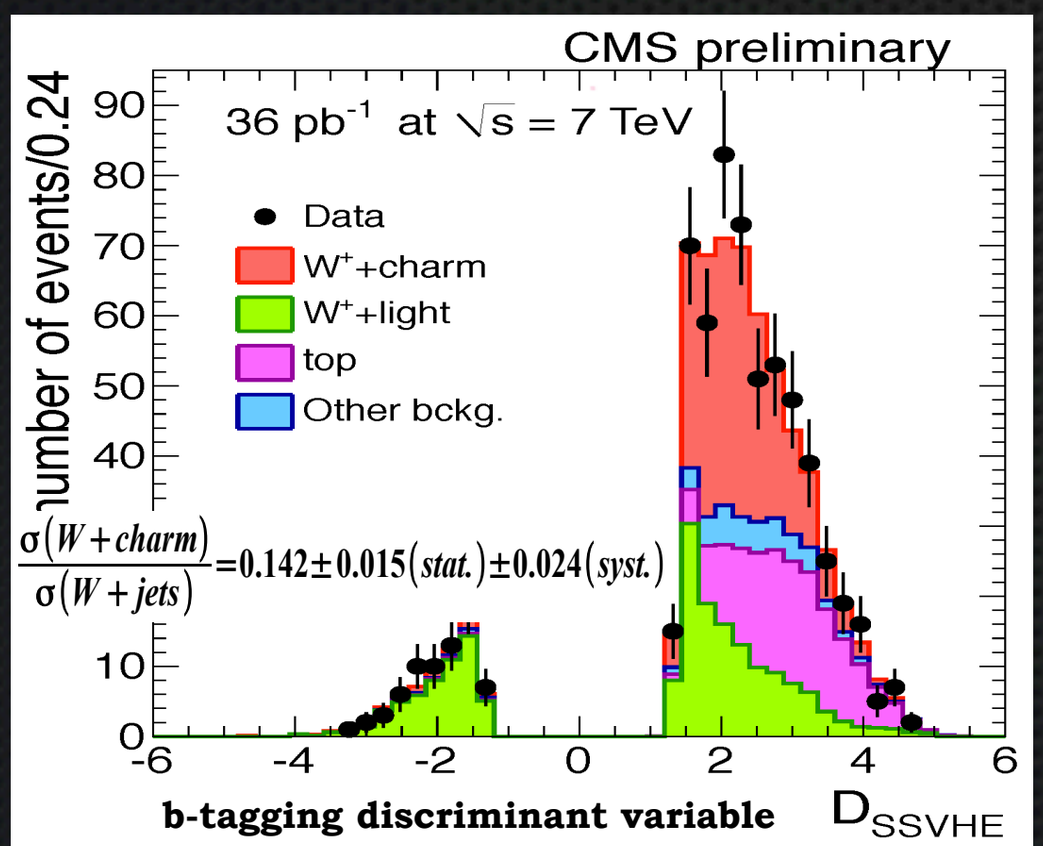


- **Predictions describe the data well in the full range**

W + HF-quark Production at LHC

CMS: Wc



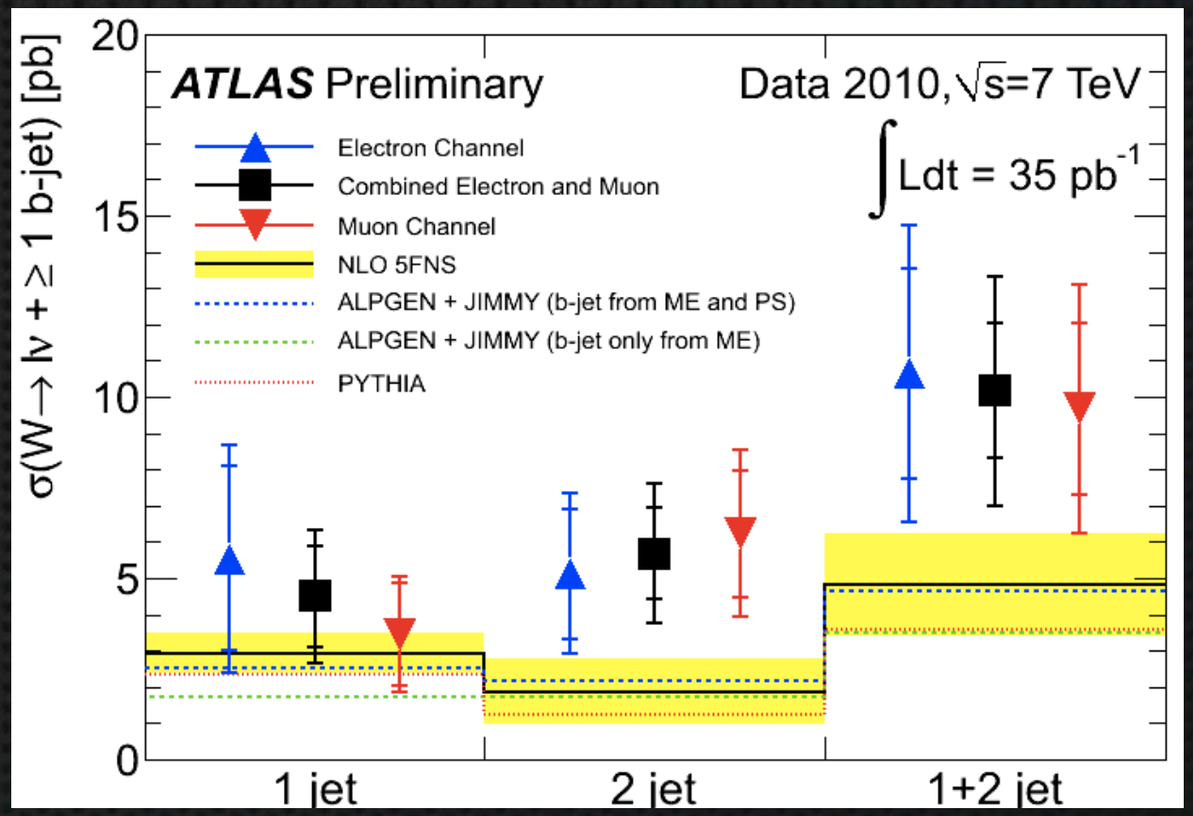


$$\frac{\sigma(W+charm)}{\sigma(W+jets)} = 0.142 \pm 0.015(stat.) \pm 0.024(syst.)$$

$$\frac{\sigma(W^{+}+charm)}{\sigma(W^{-}+charm)} = 0.92 \pm 0.19(stat.) \pm 0.04(syst.)$$

ATLAS: Wb

Important background for Higgs and top



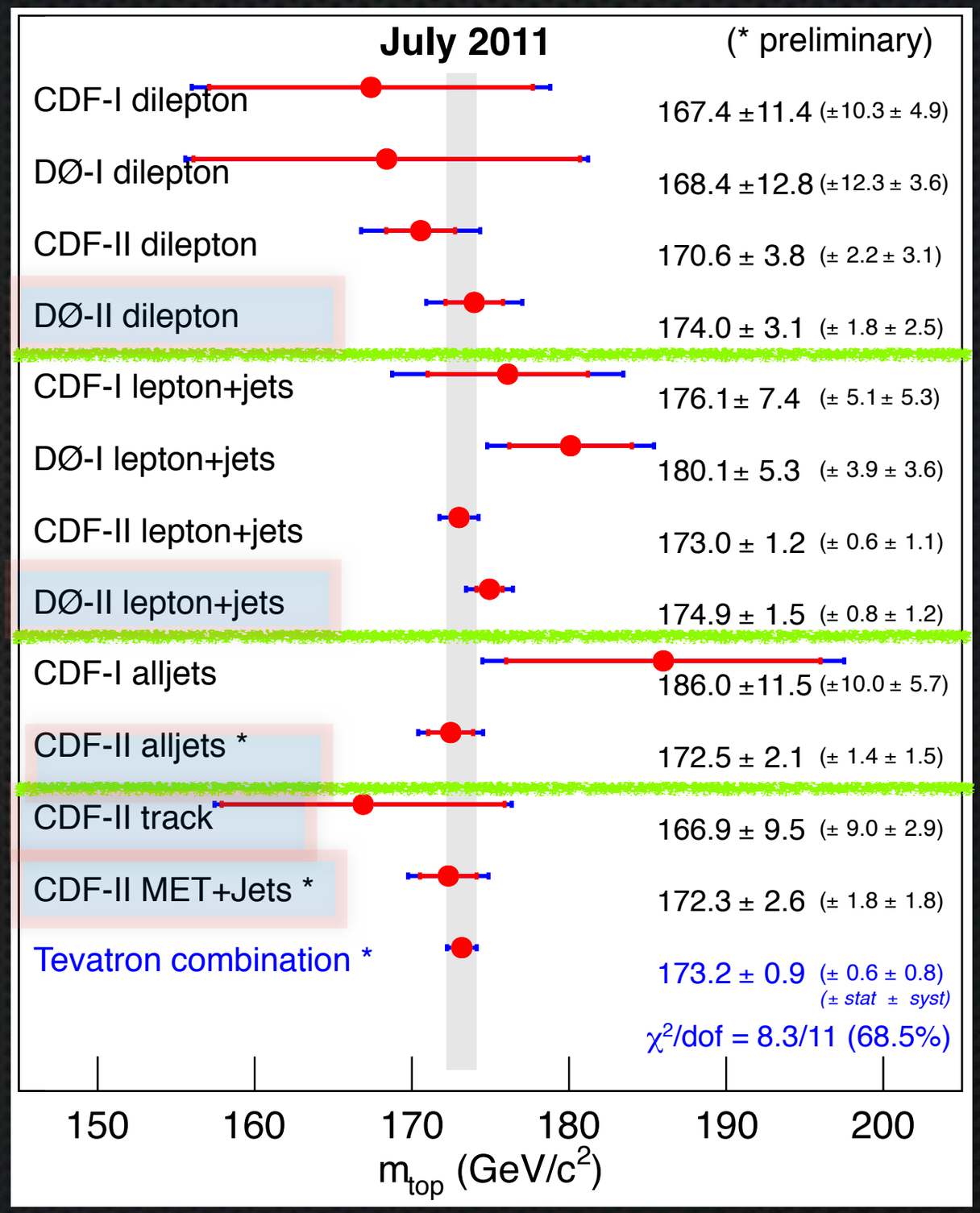
Agreement with theoretical expectations at 1.5 σ level

Top Quark Mass Summary

- **New Tevatron Combination**
  - Uncertainty below 1 GeV for the first time
  - Systematic uncertainties will decrease further with larger datasets
    - Dominated by JES
  - To improve:
    - b-jet modelling
    - uncertainties in signal and background simulations
- **LHC Experiments still far away**
  - CMS result in lepton+jets

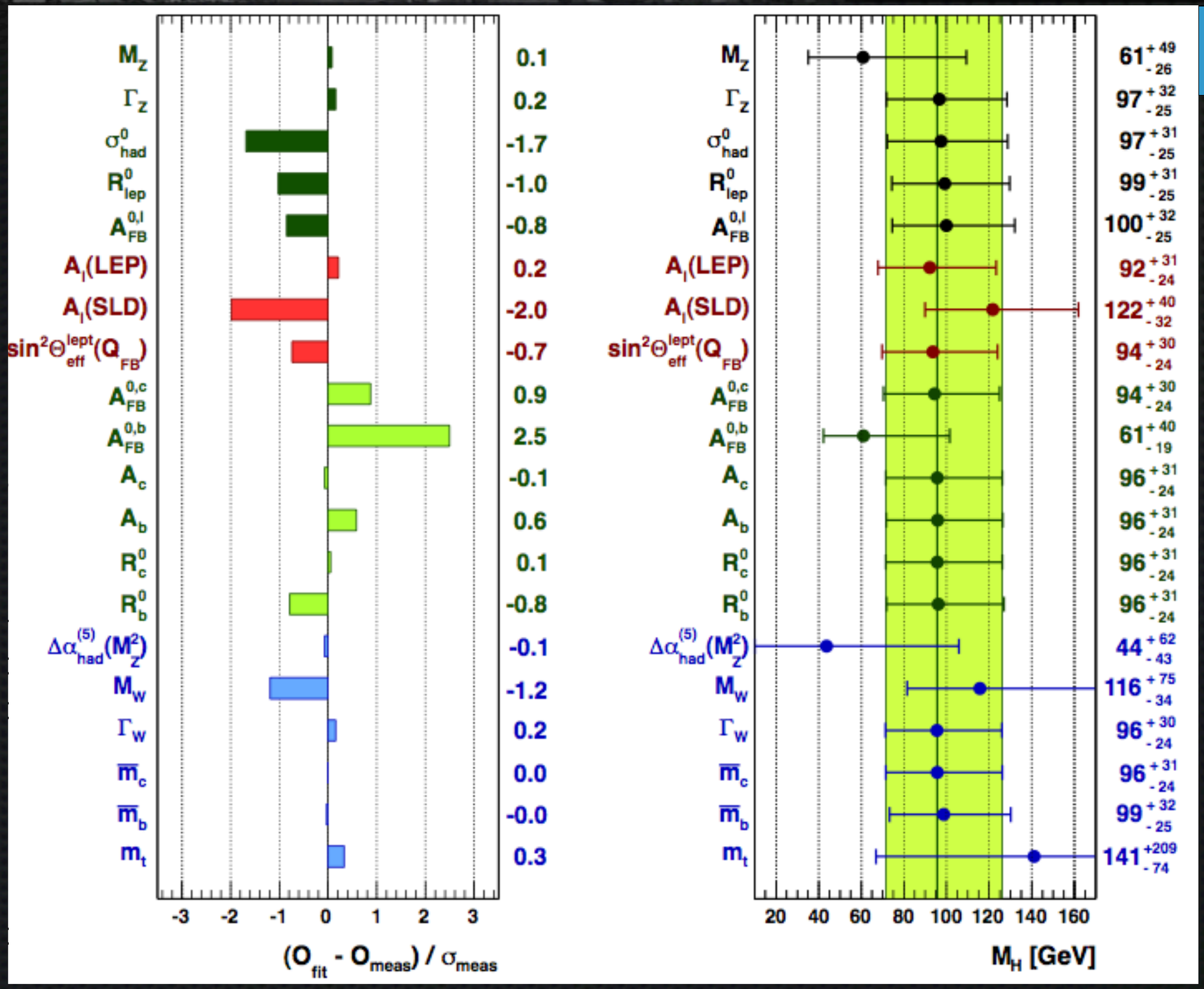
$$m_t = 173.1 \pm 2.1(\text{stat})^{+2.8}_{-2.5}(\text{syst})\ \text{GeV}$$

    - Dominant systematic: JES



M_{top} =173.2 ± 0.9 GeV

GFitter: The Global Electroweak Fit

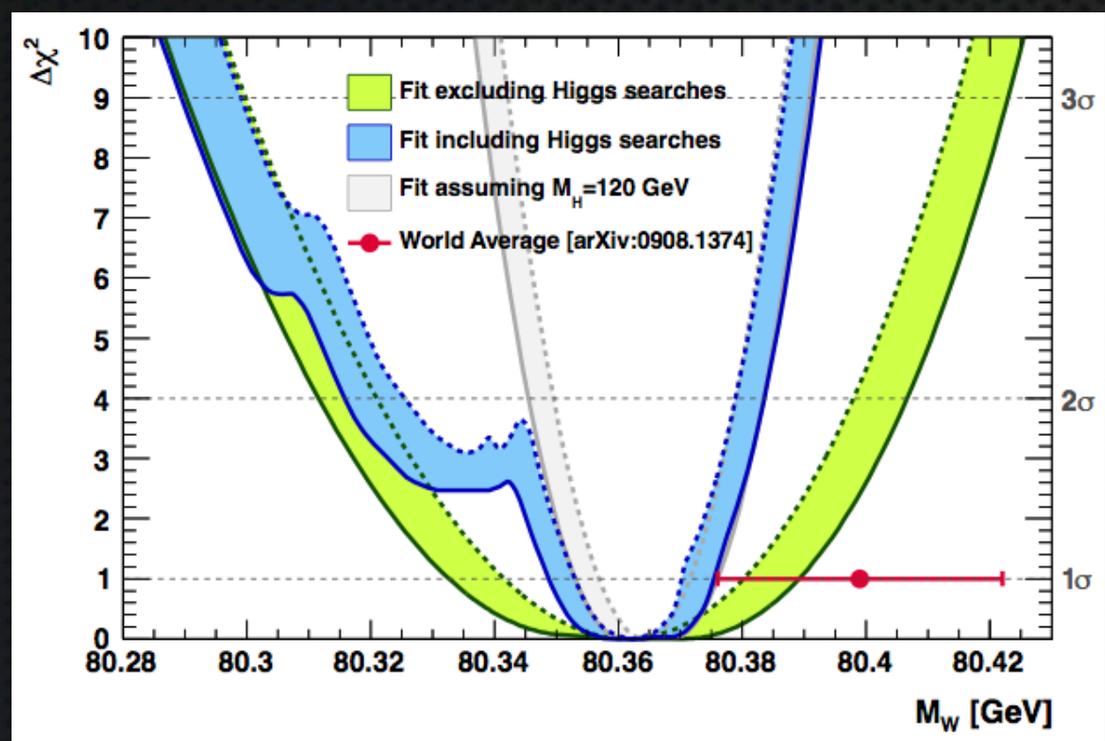


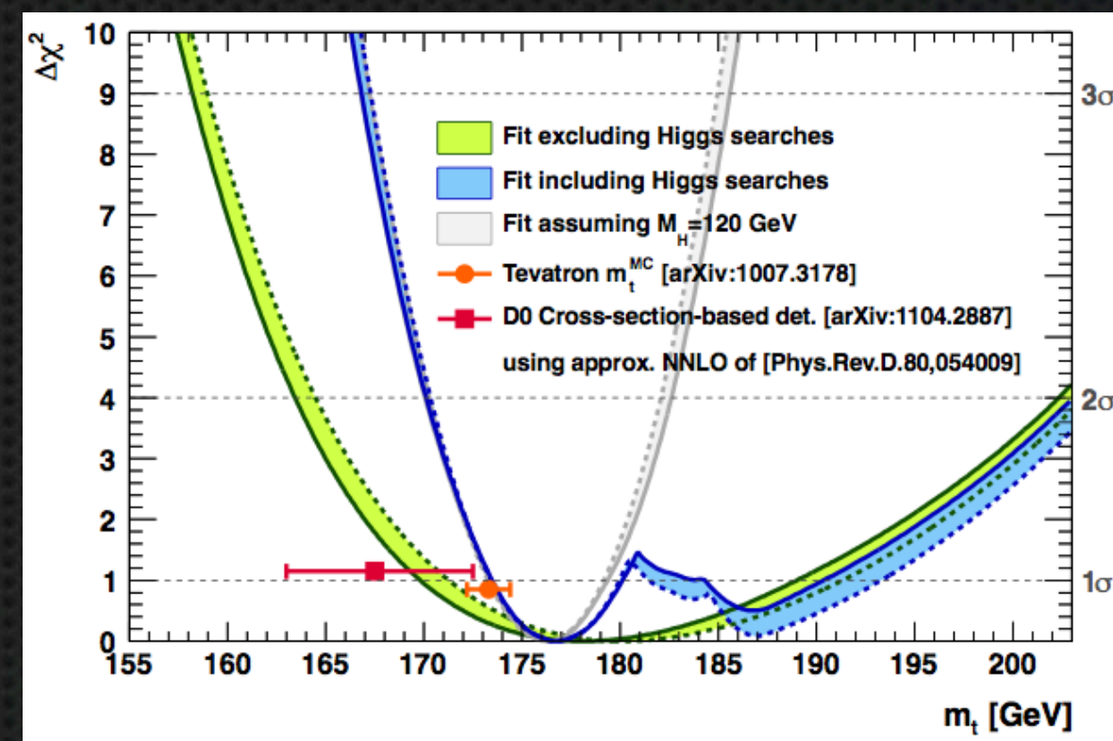
Gfitter/GSM sub-package used in the global EW fit of the SM

[Co-authored by Gfitter and ZFITTER groups] [H. Flaecher et al., Eur. Phys. J. C60 (2009) 543; Erratum in preparation] [A.B. Arbuzov et al., Comput. Phys. Commun. 174, 728 (2006)] [D.Y. Bardin et al., Comput. Phys. Commun. 133, 229 (2001)]

Indirect determination of m_t and m_W

- **Results prior to EPS'11**





$$M_W = 80.359\,^{+0.017}_{-0.010}\ \text{GeV}$$

1.6σ below measured value

$$m_t = [173.5, 181.1]\ \text{GeV} \quad \text{and} \quad [184.3, 190.3]\ \text{GeV}$$

GFitter Experimental Inputs

- Free fit parameters
  - M_Z, M_H, m_t, $Da_{had}^{(5)}(M_Z^2)$, $a_S(M_Z^2)$, m_c, m_b
  - Scale parameters for theoretical uncertainties on M_W, $sin^2\theta^l_{eff}$ (and the EW form factors r_Z^f, k_Z^f)

- Latest experimental input
  - Z-pole observables: LEP / SLC results
    [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
  - M_W and G_W latest from LEP/Tevatron (03/2010)
    [ADLO,CFD+D0: arXiv:0908.1374v1]
  - m_{top} : latest Tevatron average (07/2010)
    [CDF&D0: new combination ICHEP'10]
  - m_c, m_b world averages [PDG, J. Phys. G33,1 (2006)]
  - **$\Delta a_{had}^{(5)}(M_Z^2)$ including a_S dependency (10/2010)**
    [Davier et al., arXiv:1010.4180]
  - **Direct Higgs searches from LEP/Tevatron/LHC**
    (03/2011) [ADLO: Phys. Lett. B565, 61 (2003)], [CDF+D0: Moriond 2011]
    [ATLAS+CMS: Moriond 2011]
  - Not considered: $sin^2\theta_{eff}$ results from NuTeV. APV and polarized Möller scattering

Parameter	Input value	Free in fit
M_Z [GeV]	91.1875 ± 0.0021	yes
Γ_Z [GeV]	2.4952 ± 0.0023	–
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	–
R^0_ℓ	20.767 ± 0.025	–
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	–
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	–
A_c	0.670 ± 0.027	–
A_b	0.923 ± 0.020	–
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	–
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	–
R^0_c	0.1721 ± 0.0030	–
R^0_b	0.21629 ± 0.00066	–
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	–
M_H [GeV] $^{(\circ)}$	Likelihood ratios	yes
M_W [GeV]	80.399 ± 0.023	–
Γ_W [GeV]	2.085 ± 0.042	–
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	yes
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	yes
m_t [GeV]	173.3 ± 1.1	yes
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2749 ± 10	yes
$\alpha_s(M_Z^2)$	–	yes
$\delta_{\rm th} M_W$ [MeV]	$[-4, 4]_{\rm theo}$	yes
$\delta_{\rm th} \sin^2\theta^\ell_{\rm eff}$ $^{(\dagger)}$	$[-4.7, 4.7]_{\rm theo}$	yes
$\delta_{\rm th}\rho^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$	yes
$\delta_{\rm th}\kappa^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$	yes

W/Z Inclusive: ATLAS Systematics

- **Detailed systematic uncertainties**
  - **Luminosity: 3.4%**

Electron channels (%)	$W^{\pm}$	W^{+}	W^{-}	Z
Trigger	0.4	0.4	0.4	<0.1
Reconstruction	0.8	0.8	0.8	1.6
Identification	0.9	0.8	1.1	1.8
Isolation	0.3	0.3	0.3	—
Energy scale and resolution	0.5	0.5	0.5	0.2
Defective LAr channels	0.4	0.4	0.4	0.8
Charge misidentification	<0.1	0.1	0.1	0.6
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.8	0.7	1.0	—
Pile-up	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
QCD Background	0.4	0.4	0.4	0.7
EWK+$t\bar{t}$ Background	0.2	0.2	0.2	<0.1
$C_{W/Z}$ Theor. uncertainty	0.6	0.6	0.6	0.3
Total Exp. uncertainty	**1.8**	**1.8**	**2.0**	**2.7**
$A_{W/Z}$ Theor. uncertainty	1.4	1.6	1.9	1.9
Total excluding Luminosity	2.3	2.4	2.8	3.3

Muon channels (%)	$W^{\pm}$	W^{+}	W^{-}	Z
Trigger	0.5	0.5	0.5	0.1
Reconstruction	0.4	0.3	0.3	0.6
Isolation	0.2	0.1	0.2	0.3
p_{T} Resolution	0.04	0.03	0.05	0.02
p_{T} Scale	0.4	0.6	0.6	0.2
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.5	0.4	0.6	-
Pile-up	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
QCD Background	0.6	0.5	0.8	0.3
EWK+$t\bar{t}$ Background	0.4	0.3	0.4	0.02
$C_{W/Z}$ Theor. uncertainty	0.8	0.8	0.7	0.3
Total Exp. uncertainty	**1.6**	**1.7**	**1.7**	**0.9**
$A_{W/Z}$ Theor. uncertainty	1.4	1.6	2.0	2.0
Total excluding Luminosity	2.1	2.3	2.6	2.2

W/Z Inclusive: CMS Systematics

- **Detailed systematic uncertainties**
  - **Luminosity: 4%**

Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	1.4	0.9	1.8	n/a
Trigger prefiring	n/a	0.5	n/a	0.5
Energy/momentum scale & resolution	0.5	0.22	0.12	0.35
$\not{E}_T$ scale & resolution	0.3	0.2	n/a	n/a
Background subtraction / modeling	0.35	0.4	0.14	0.28
Trigger changes throughout 2010	n/a	n/a	n/a	0.1
Total experimental	1.6	1.1	1.8	0.7
PDF uncertainty for acceptance	0.6	0.8	0.9	1.1
Other theoretical uncertainties	0.7	0.8	1.4	1.6
Total theoretical	0.9	1.1	1.6	1.9
Total (excluding luminosity)	1.8	1.6	2.4	2.0

CMS Cross Section Measurements