Highlights on Standard Model Physics Results from ATLAS

João Guimarães da Costa
Harvard University

Particle Physics in the LHC Era

Zurich Phenomenology Workshop

Zurich, January 7-9, 2013

Re-establishing the SM at LHC

Tevatron timeline

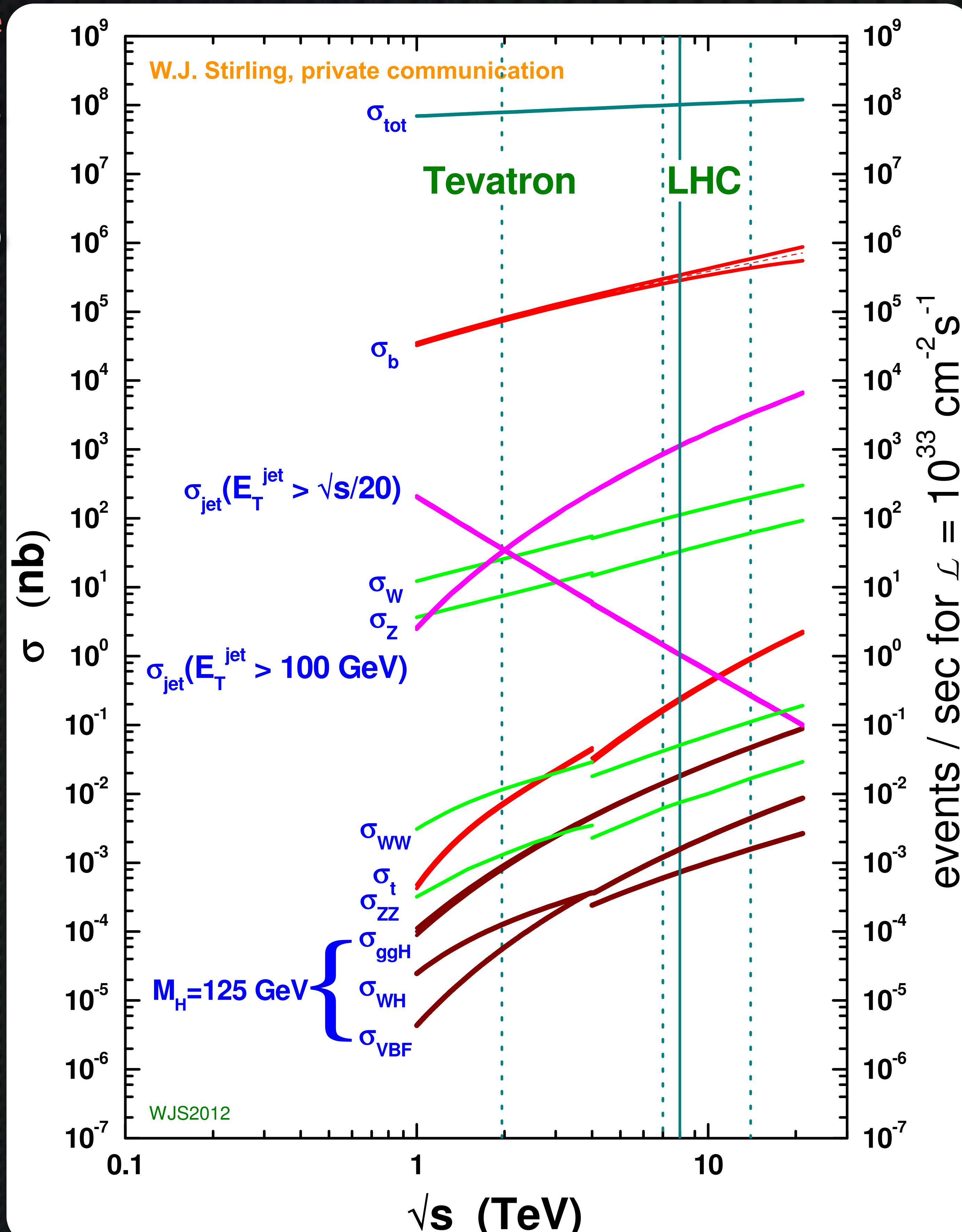
Particles$_{charged}$: 1988

jets$_{inclusive}$: 1989

(*) **W**: 1988
Z: 1988

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

(*) Discovered at CERN in 1983 by UA1 and UA2



LHC timeline

Apr 2010

jets: Sep 2010

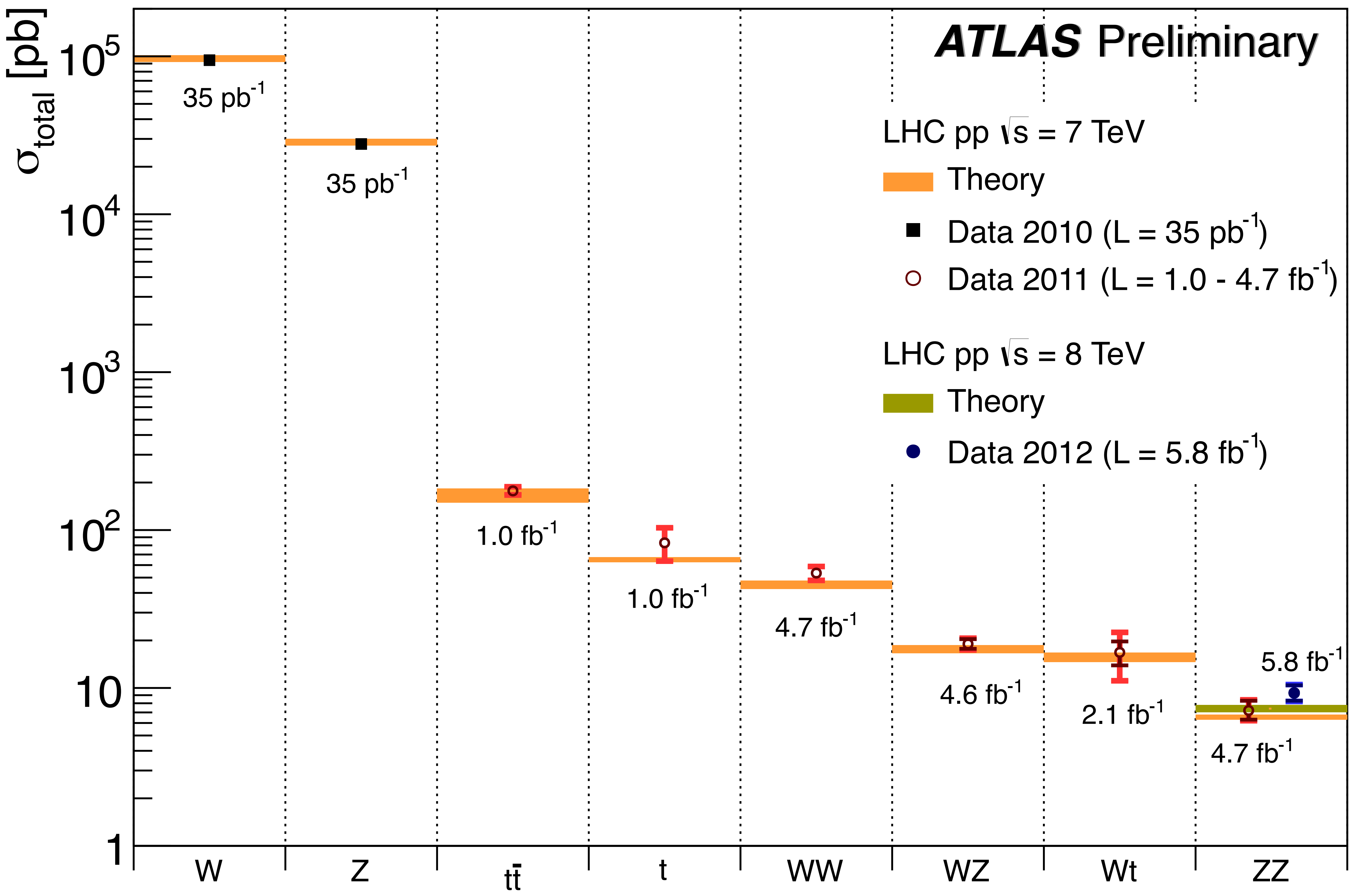
W: May 2010
Z: Jun 2010

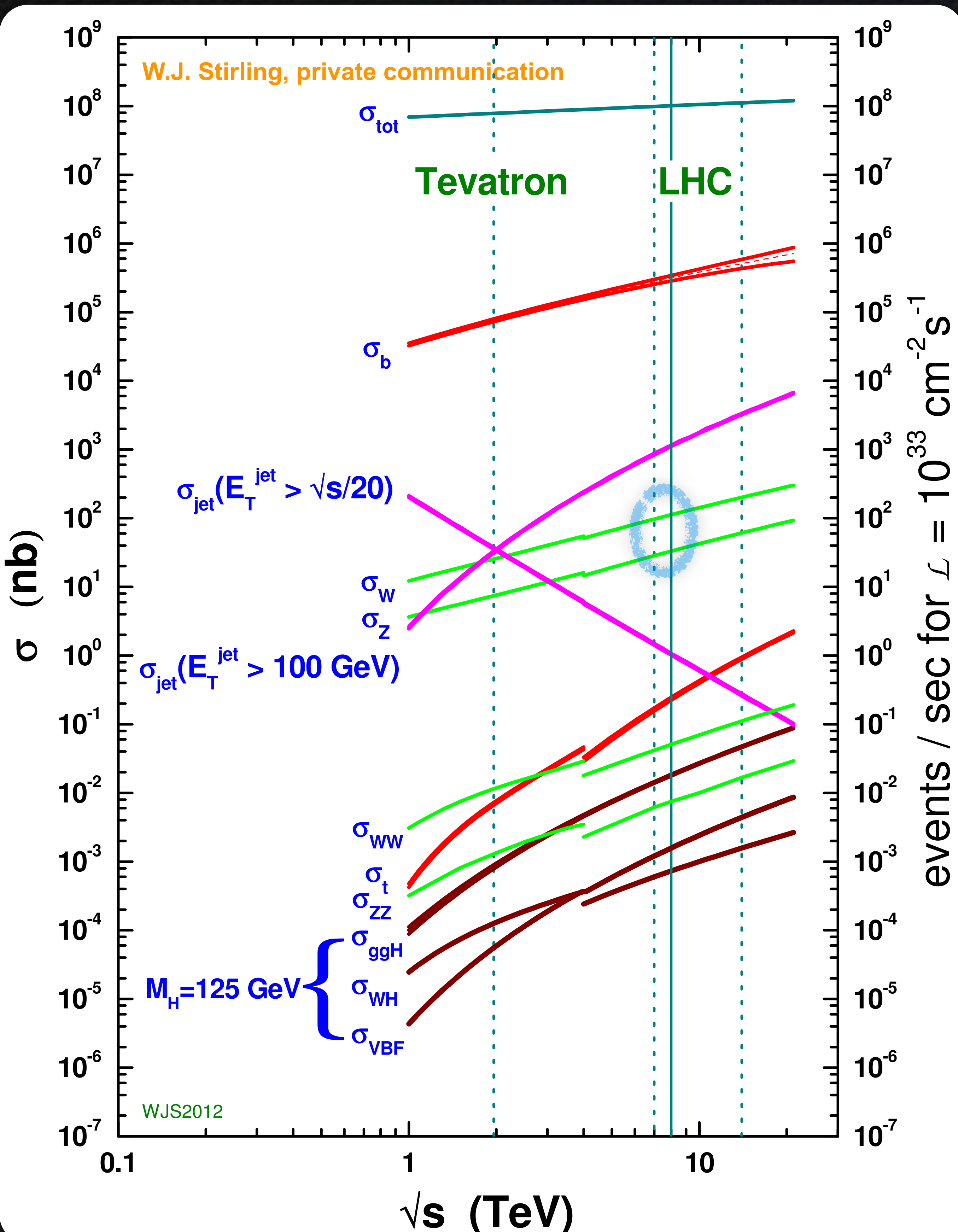
Top: Jul 2010

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

H: July 4, 2012?

Production cross sections in ATLAS





$e\nu$

$\mu\nu$

ee

$\mu\mu$

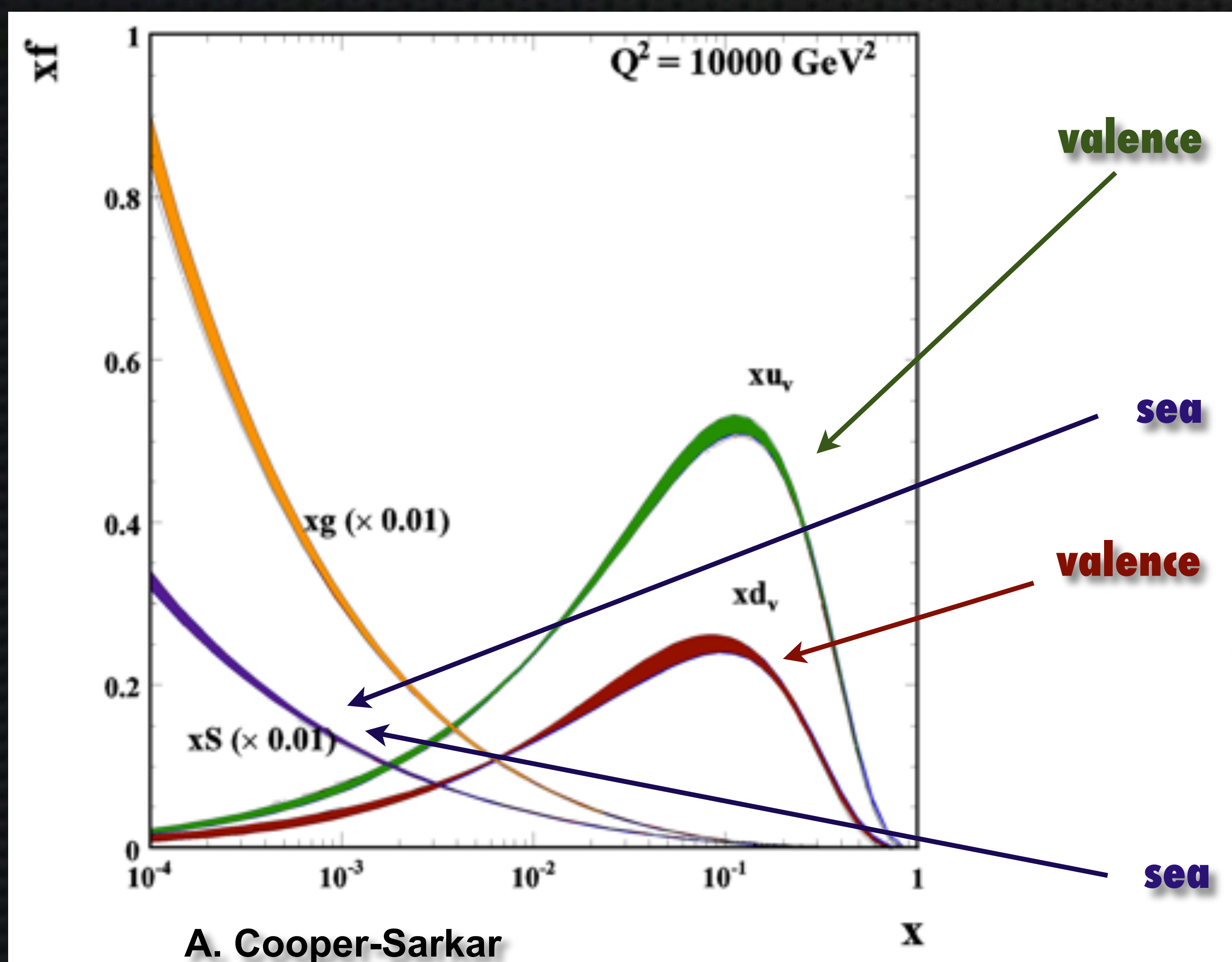
W and Z Production

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

Hadronic W Production

$$\sigma_W = \Sigma_q \int dx_1 dx_2 f_q(x_1) f_{\bar{q}}(x_2) \times \hat{\sigma}_{q\bar{q}}$$

total x-sec — parton distribution functions — parton x-sec

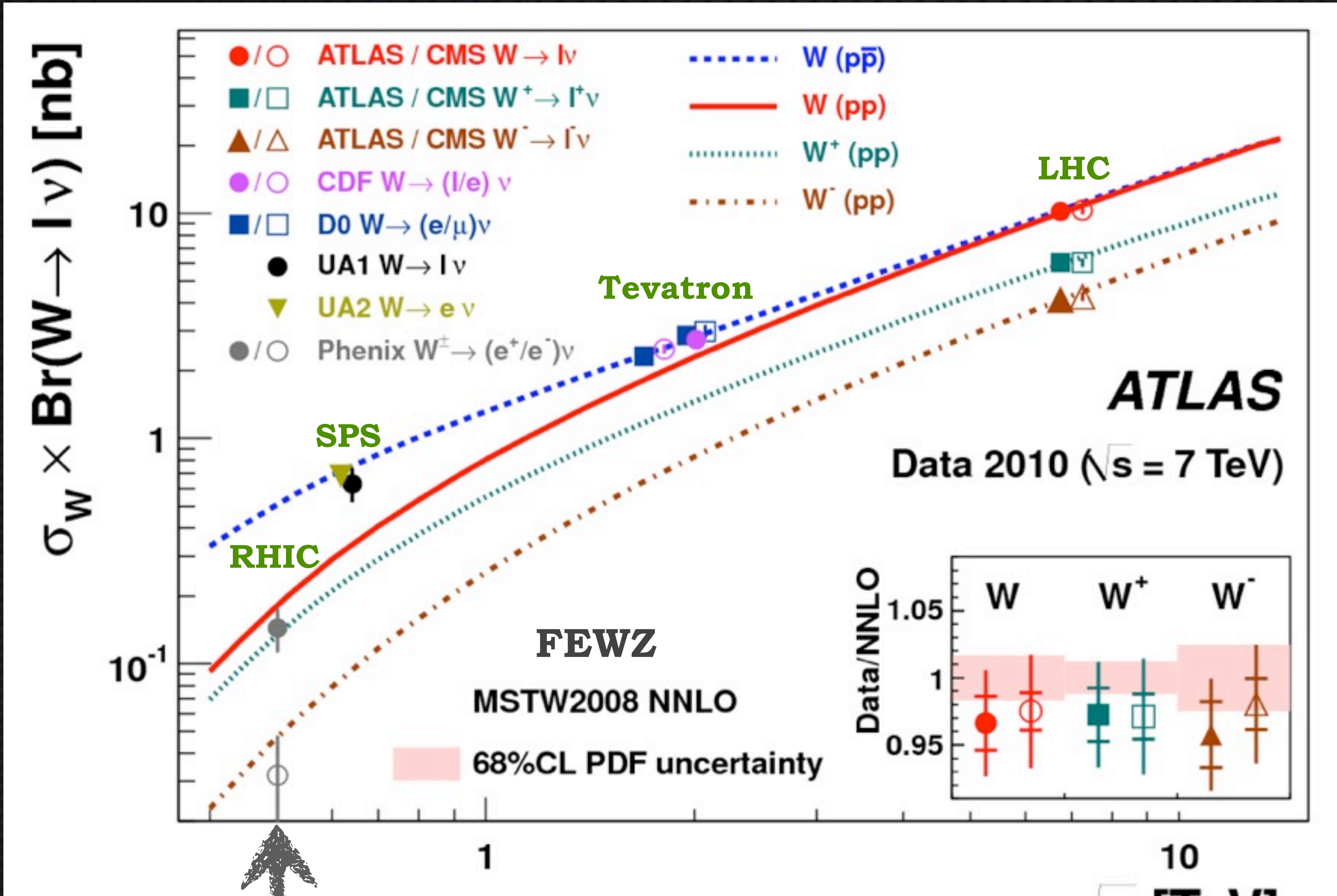


$$M_W^2 = x_1 x_2 s$$

Additional valence **u** compared to **d** => **W^+** production favored over **W^-**

W inclusive cross section

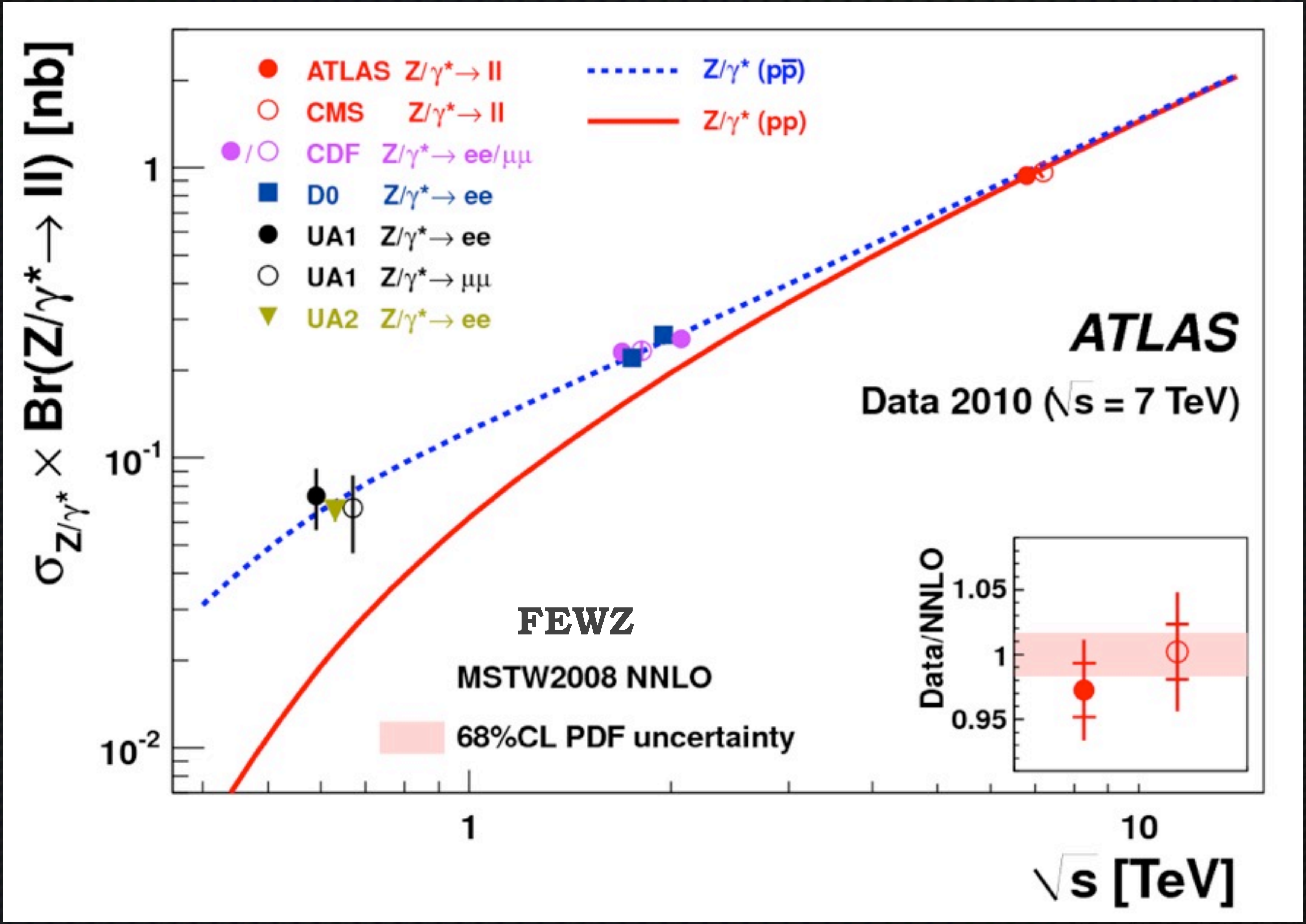
Phys. Rev. D85 (2012) 072004



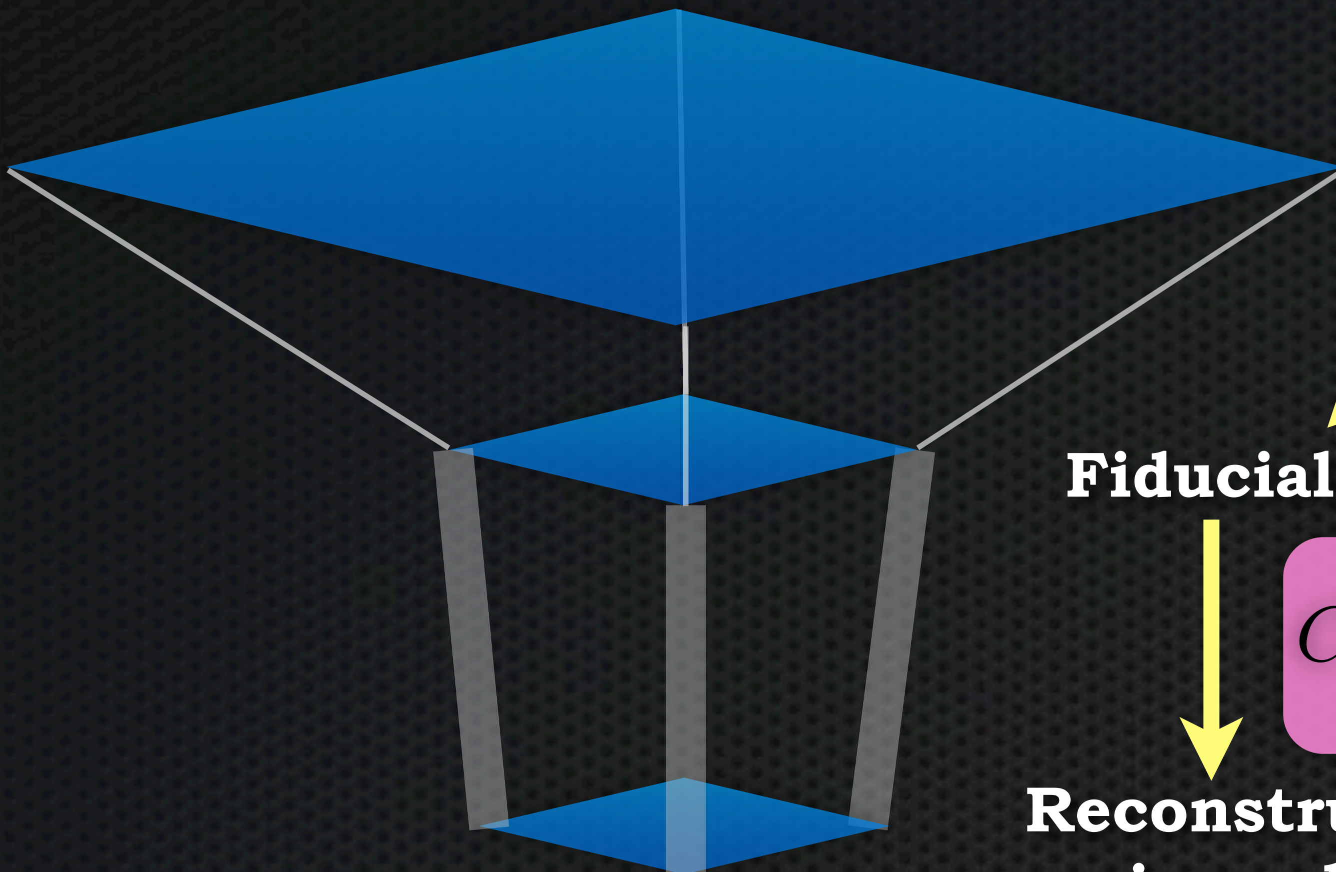
(First measurement in pp collisions)

Z inclusive cross section

Phys. Rev. D85 (2012) 072004



Fiducial cross section



Generated phase-space

$$A_{W/Z} = \frac{N_{\mathrm{MC,gen,cut}}}{N_{\mathrm{MC,gen,all}}}$$

Fiducial

$$C_{W/Z} = \frac{N_{\mathrm{MC,rec}}}{N_{\mathrm{MC,gen,cut}}}$$

Detector effects

Reconstructed passing selection

$$\sigma_{\mathrm{fid}} = \frac{N - B}{C_{W/Z} \cdot L_{\mathrm{int}}}$$

No theoretical uncertainty from extrapolation outside experimental acceptance

$$\sigma_{\mathrm{tot}} = \sigma_{W/Z} \times BR(W/Z \to \ell\nu/\ell\ell) = \frac{\sigma_{\mathrm{fid}}}{A_{W/Z}}$$

Fiducial phase space

$W \to e\nu$: $p_{T,e} > 20$ GeV, $|\eta_e| < 2.47$,
excluding $1.37 < |\eta_e| < 1.52$,
$p_{T,\nu} > 25$ GeV, $m_T > 40$ GeV;

$W \to \mu\nu$: $p_{T,\mu} > 20$ GeV, $|\eta_\mu| < 2.4$,
$p_{T,\nu} > 25$ GeV, $m_T > 40$ GeV;

$Z \to ee$: $p_{T,e} > 20$ GeV, both $|\eta_e| < 2.47$,
excluding $1.37 < |\eta_e| < 1.52$,
$66 < m_{ee} < 116$ GeV;

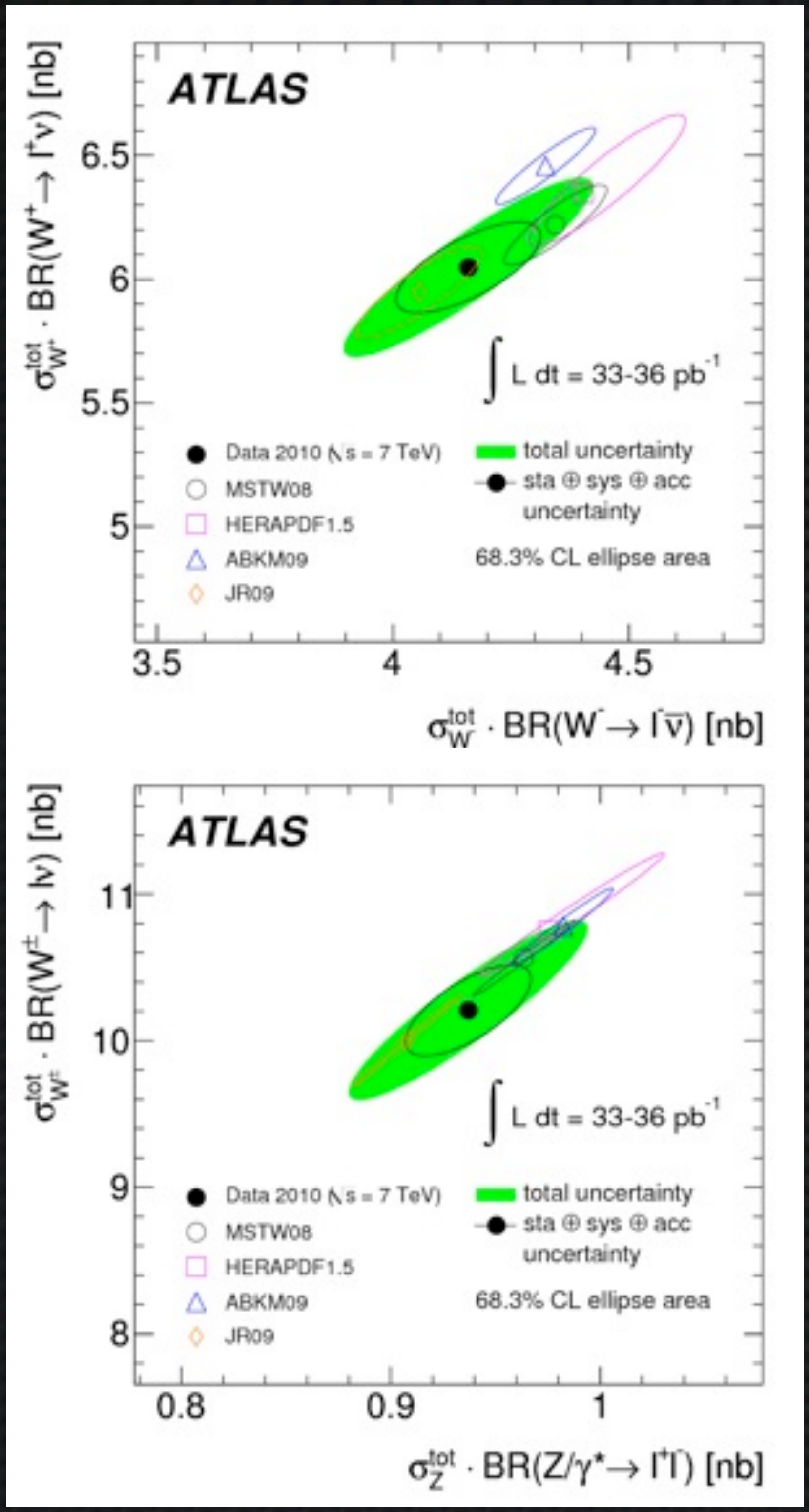
Forward $Z \to ee$: $p_{T,e} > 20$ GeV, one $|\eta_e| < 2.47$,
excluding $1.37 < |\eta_e| < 1.52$,
other $2.5 < |\eta_e| < 4.9$,
$66 < m_{ee} < 116$ GeV;

$Z \to \mu\mu$: $p_{T,\mu} > 20$ GeV, both $|\eta_\mu| < 2.4$,
$66 < m_{\mu\mu} < 116$ GeV.

Fiducial W and Z Cross Sections

Phys. Rev. D85 (2012) 072004

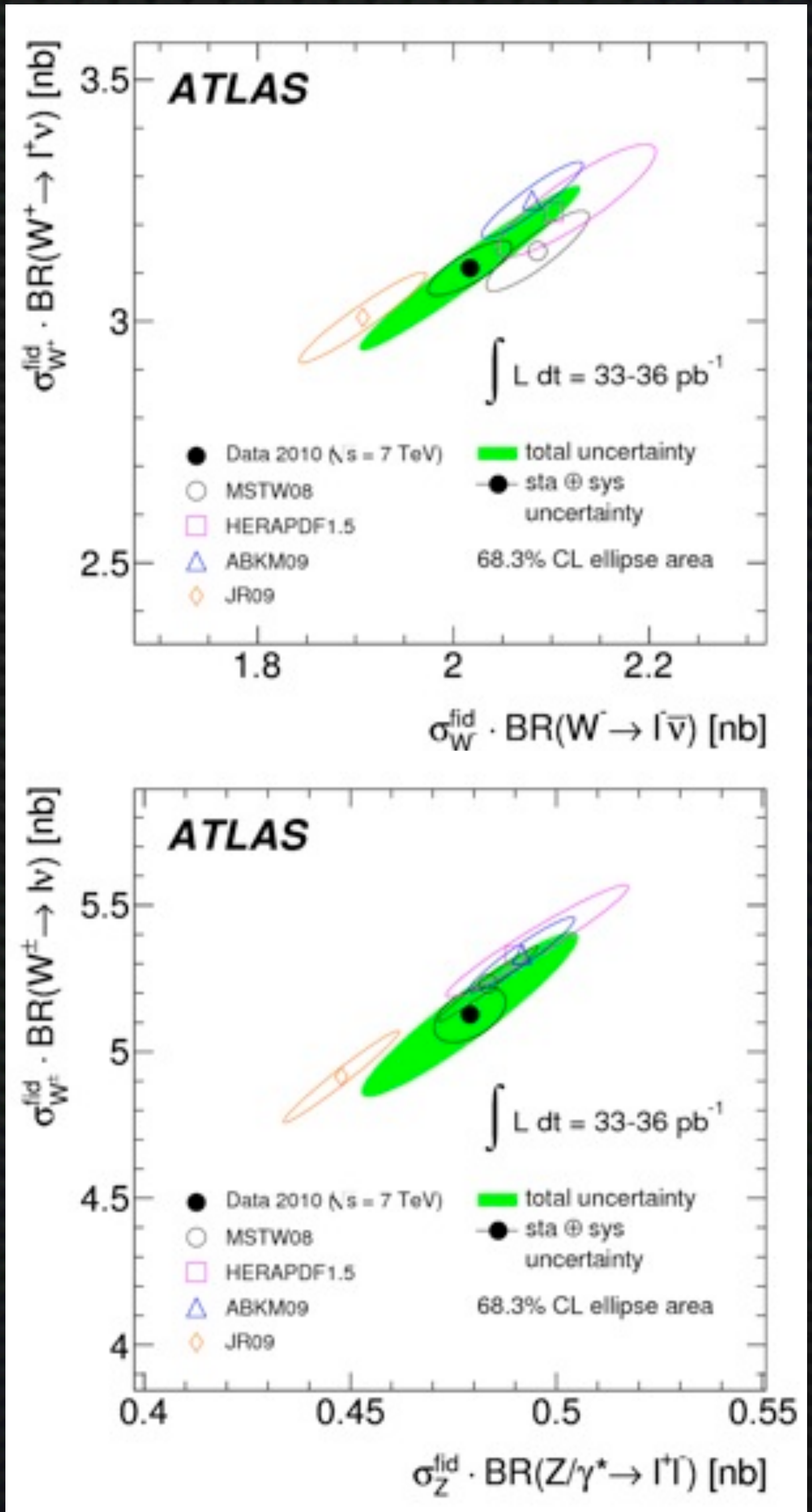
σ_{Total}



W⁺ versus W⁻

W± versus Z

$\sigma_{Fiducial}$



Luminosity 3.4%

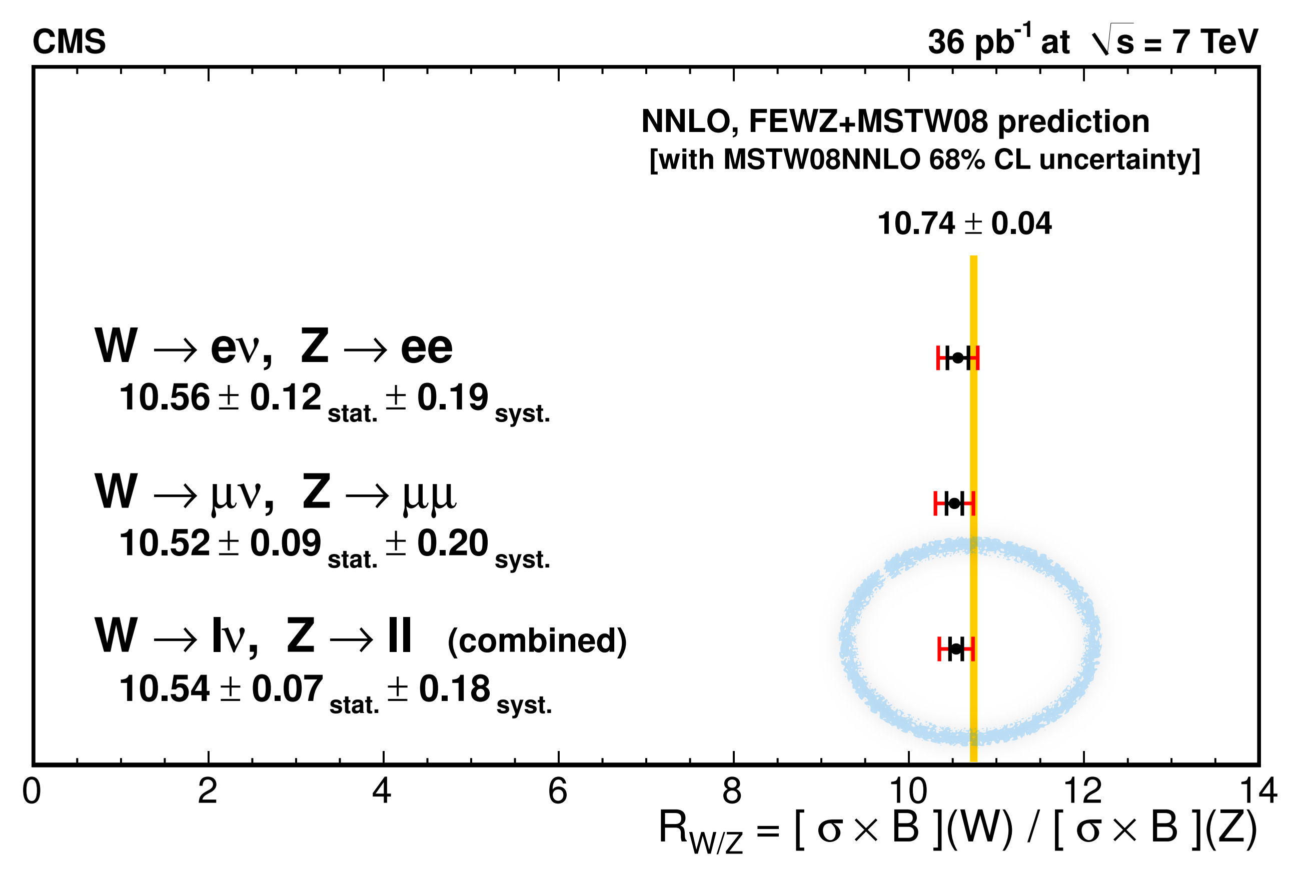
Some differentiation between PDF sets already observed

JR09 seems to be the most discrepant

Ratio W and Z Cross Sections

Benefits from experimental and theoretical systematics cancellation

JHEP 10 (2011) 132



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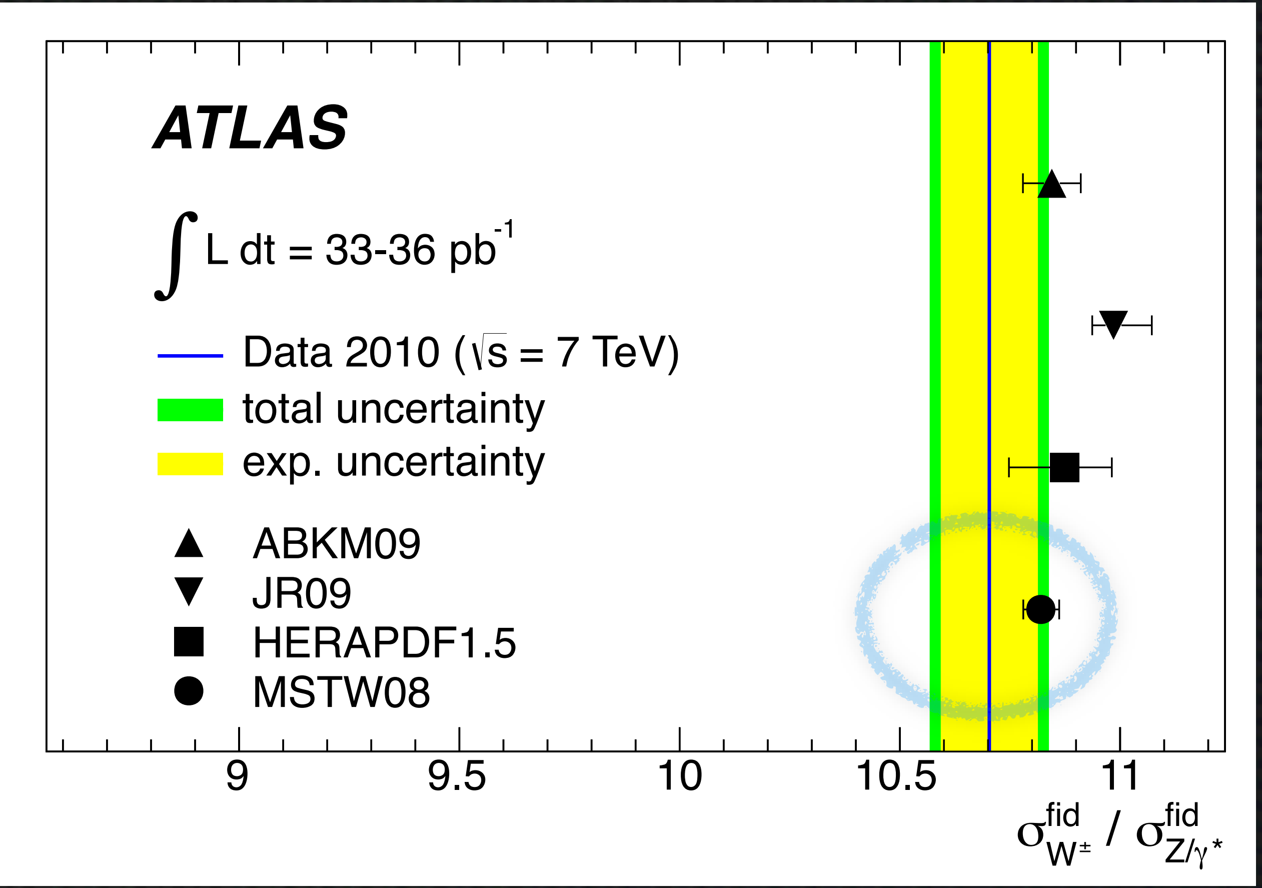
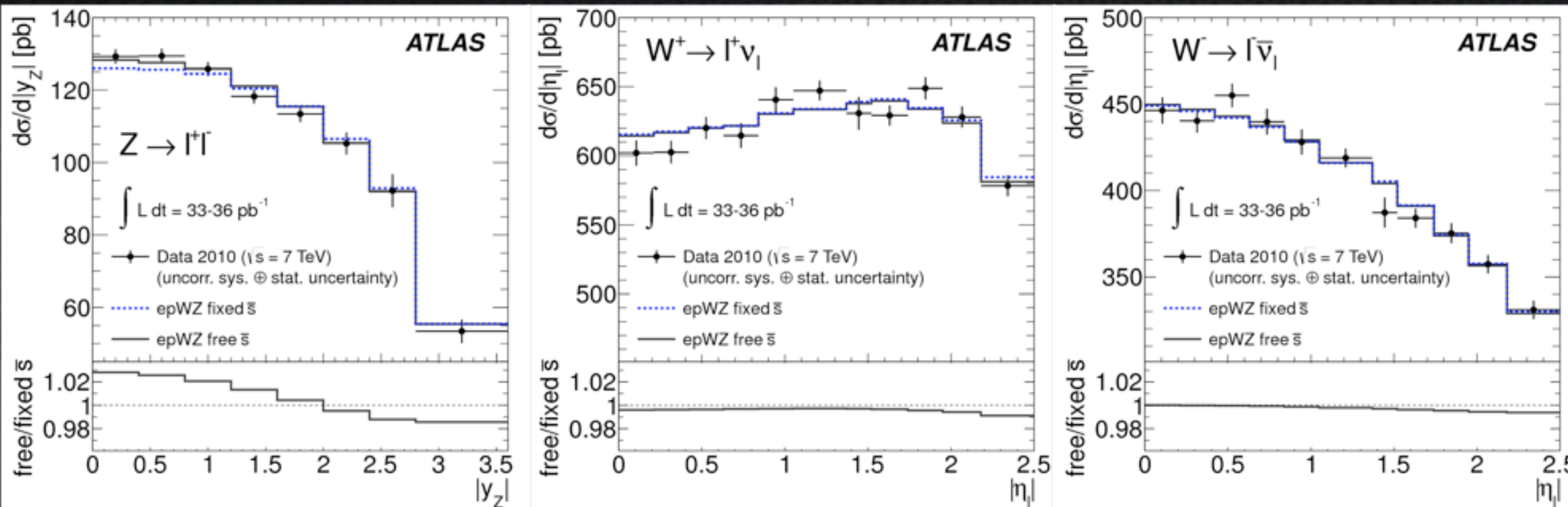


$\sigma^{tot}\times\mathcal{B}$	$W^{\pm}/Z$	
CMS	10.54 ± 0.07 (sta) ± 0.08 (sys) ± 0.16 (theo)	
ATLAS	10.893 ± 0.079 (sta) ± 0.110 (sys) ± 0.116 (acc)	1.6%
ATLAS $\sigma_{fiducial}$	10.703 ± 0.078 (sta) ± 0.110 (sys) ± 0.008 (acc)	1.3%

Strangeness in the Proton (from W and Z data)

Phys.Rev.Lett. 109 (2012) 012001



- **QCD fit of ATLAS differential distributions for W^+, W^- and Z with HERA $e^{\pm}p$ DIS data**
  - **NNLO pQCD analysis**
    - **HERAFitter framework with MCFM+APPLGRID NLO QCD**
    - **Corrected to NNLO QCD using k factors**

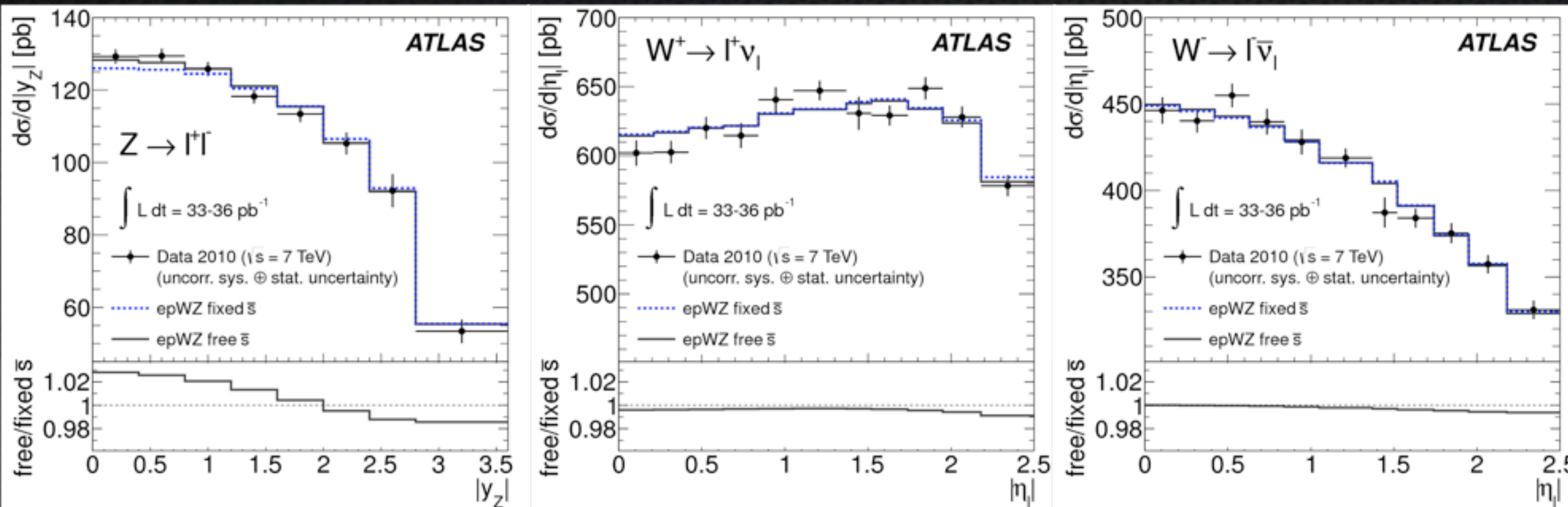
$$r_s = \frac{0.5(s+\bar{s})}{\bar{d}}$$

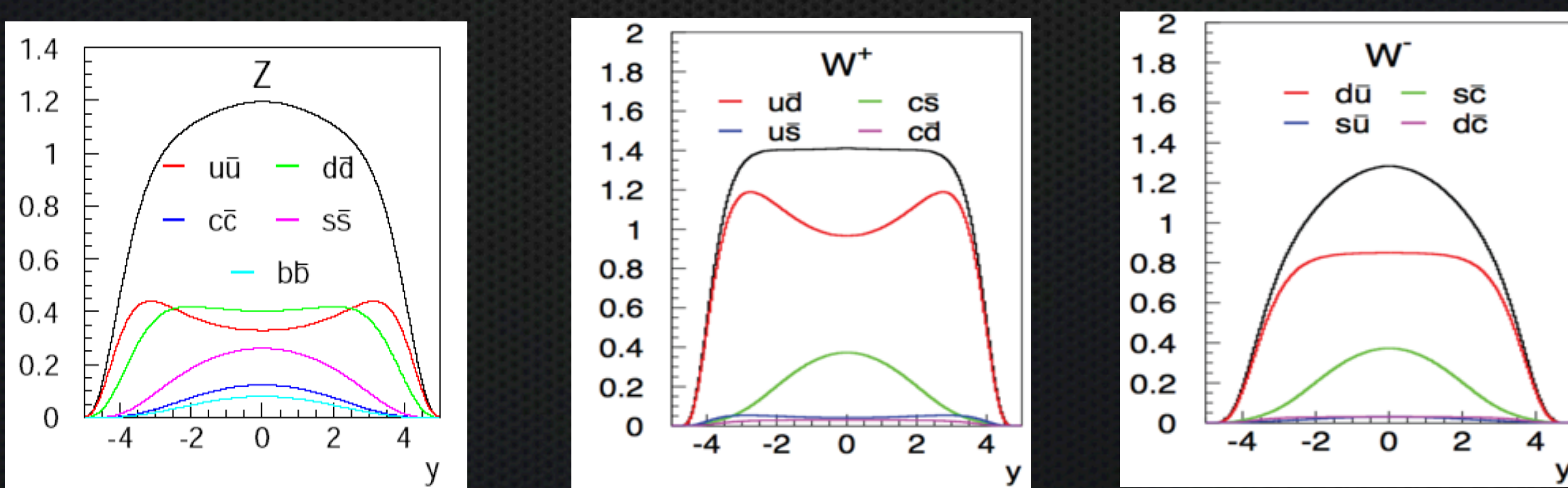
r_s = 0.5 fixed: χ^2/ndf = 44.5/30

r_s free: χ^2/ndf = 33.9/30

Strangeness in the Proton (from W and Z data)

Phys.Rev.Lett. 109 (2012) 012001

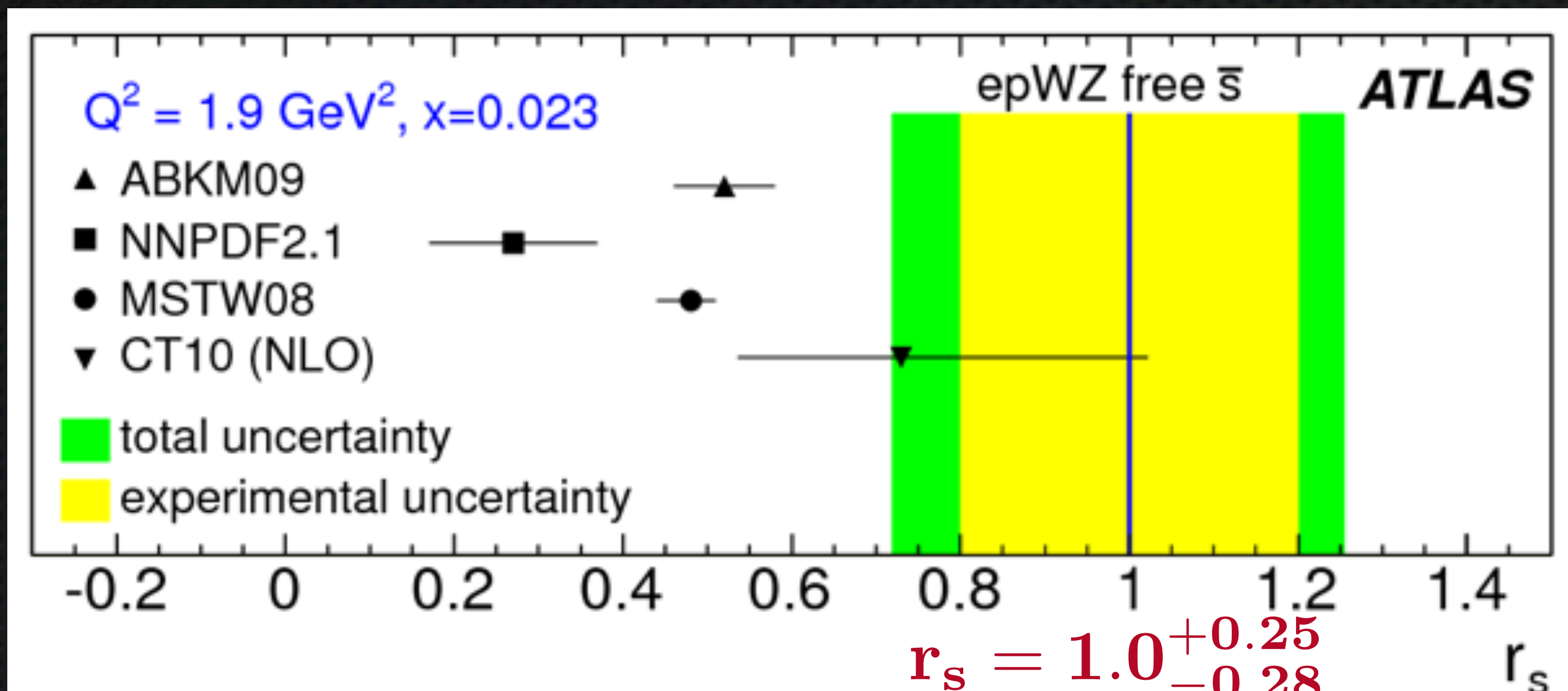




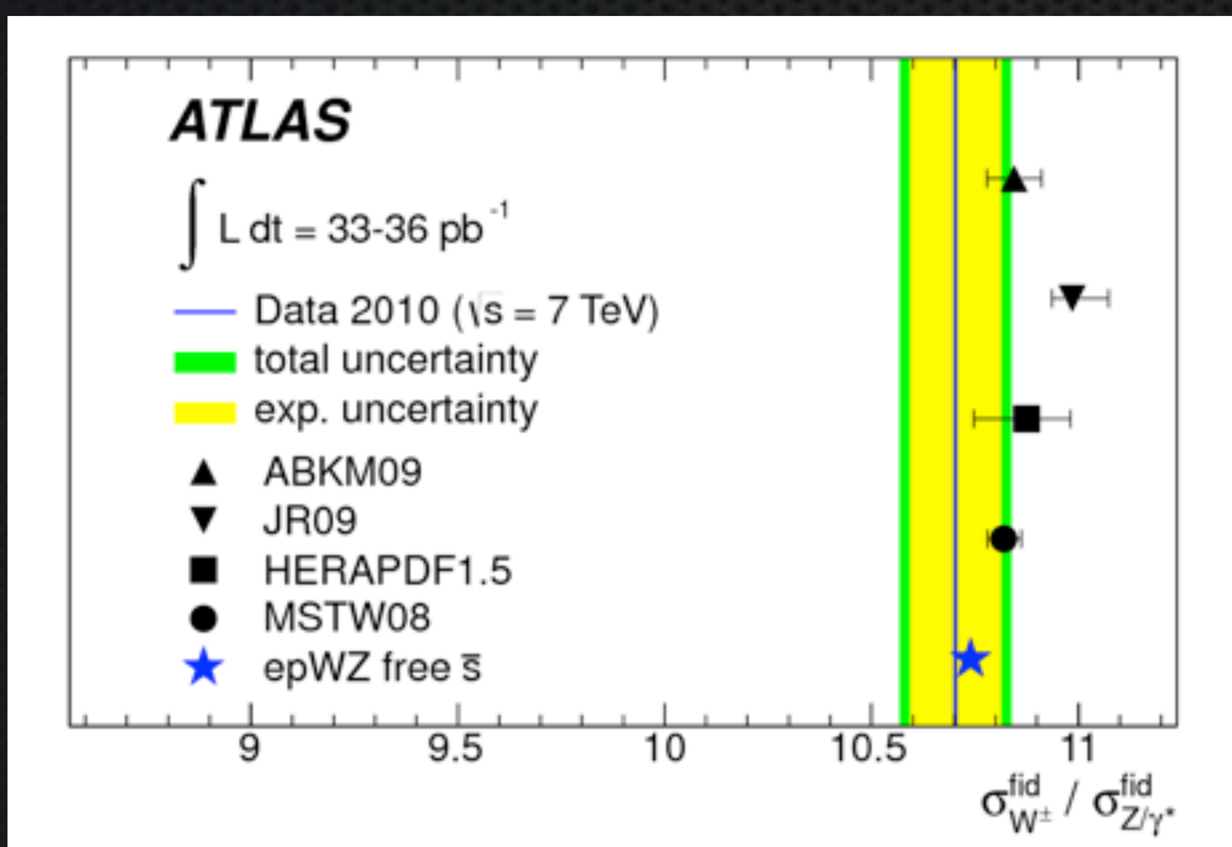
Strangeness in the Proton

Phys.Rev.Lett. 109 (2012) 012001

- **No strange sea suppression observed**



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



Fit results:

- **Light quark sea at low *x* is flavor symmetric** (x ~0.023, Q^2 = 1.9 GeV^2)

Strangeness in the Proton

Phys.Rev.Lett. 109 (2012) 012001

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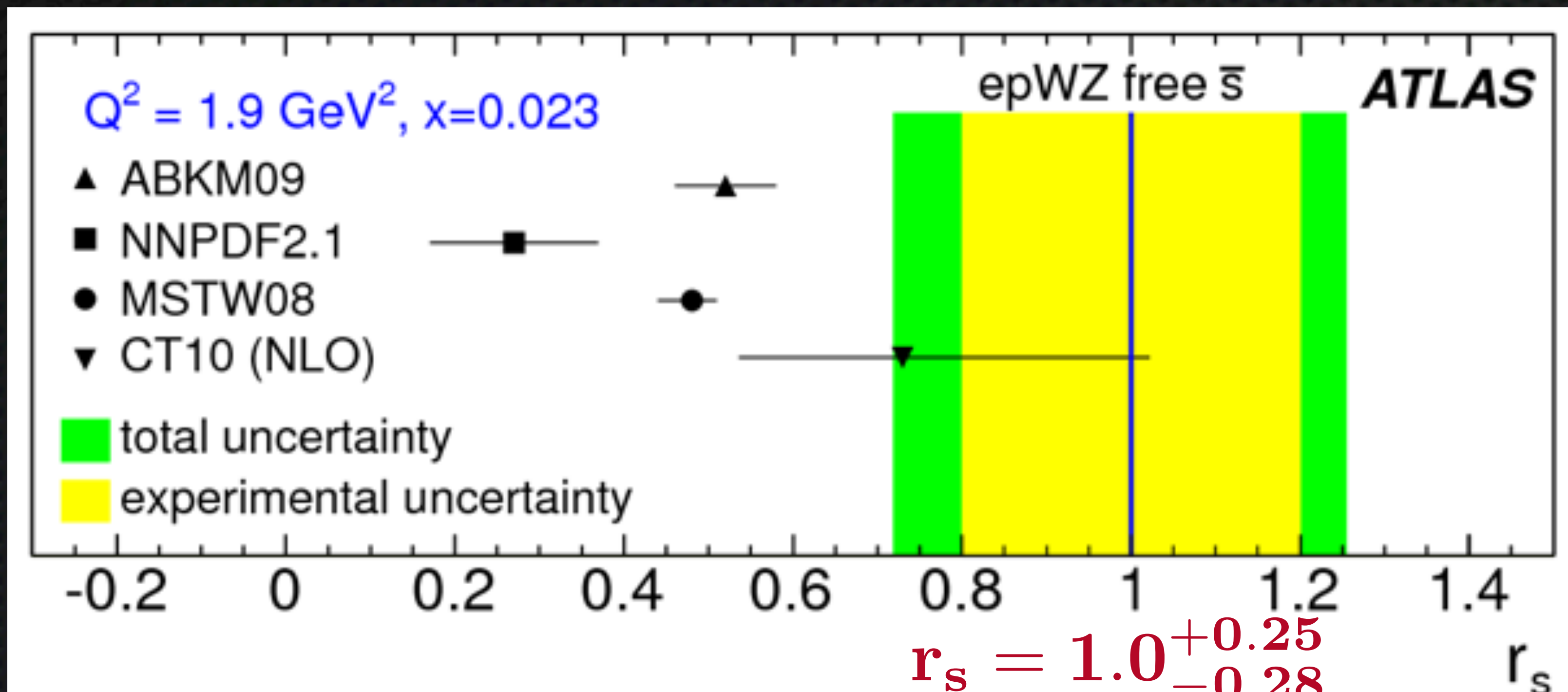

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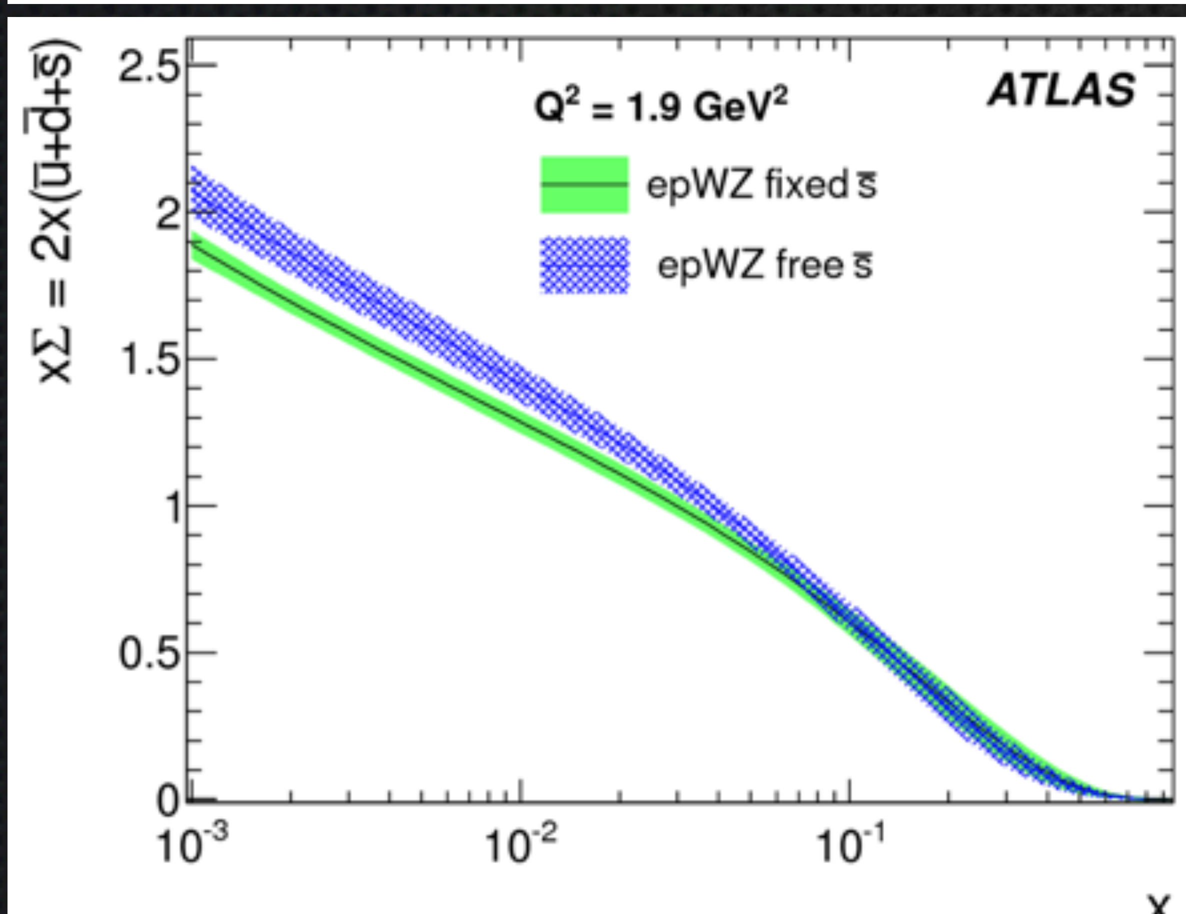


Fit results:

- **Light quark sea at low x is flavor symmetric** ($x \sim 0.023$, $Q^2 = 1.9$ GeV^2)
- **Total sea enhancement of 8%**

Transverse momentum distribution of Z/γ^* bosons

Predictions: FEWZ v2.0 + MSTW08

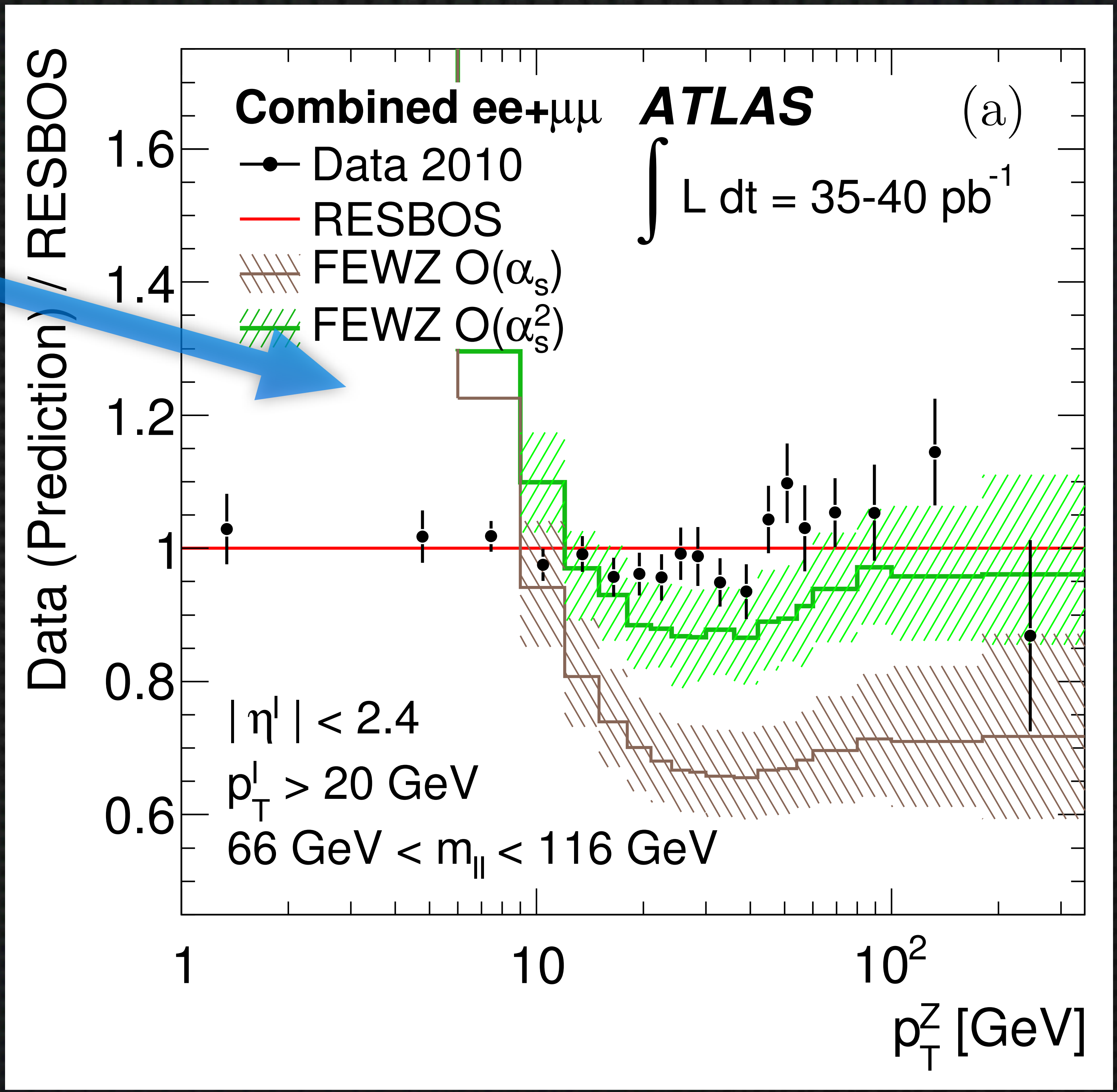
Fiducial measurement

FEWZ diverges at low p_T

(multiple soft gluon emissions)

RESBOS: Matches soft gluon resummation at low p_T with fixed order pQCD calculation

Ratio to RESBOS

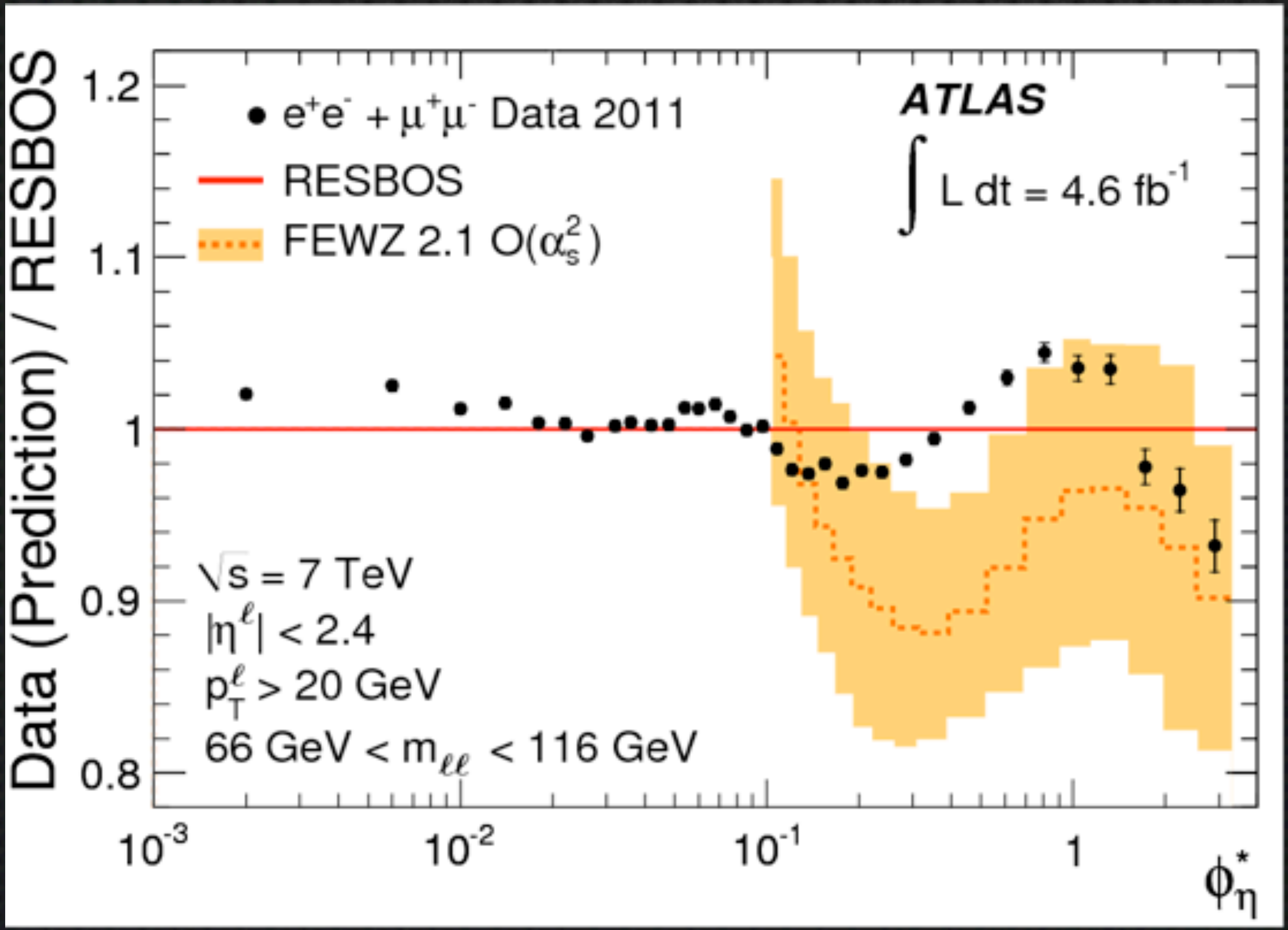


Measurement of the ϕ_η* distribution of Z/γ*

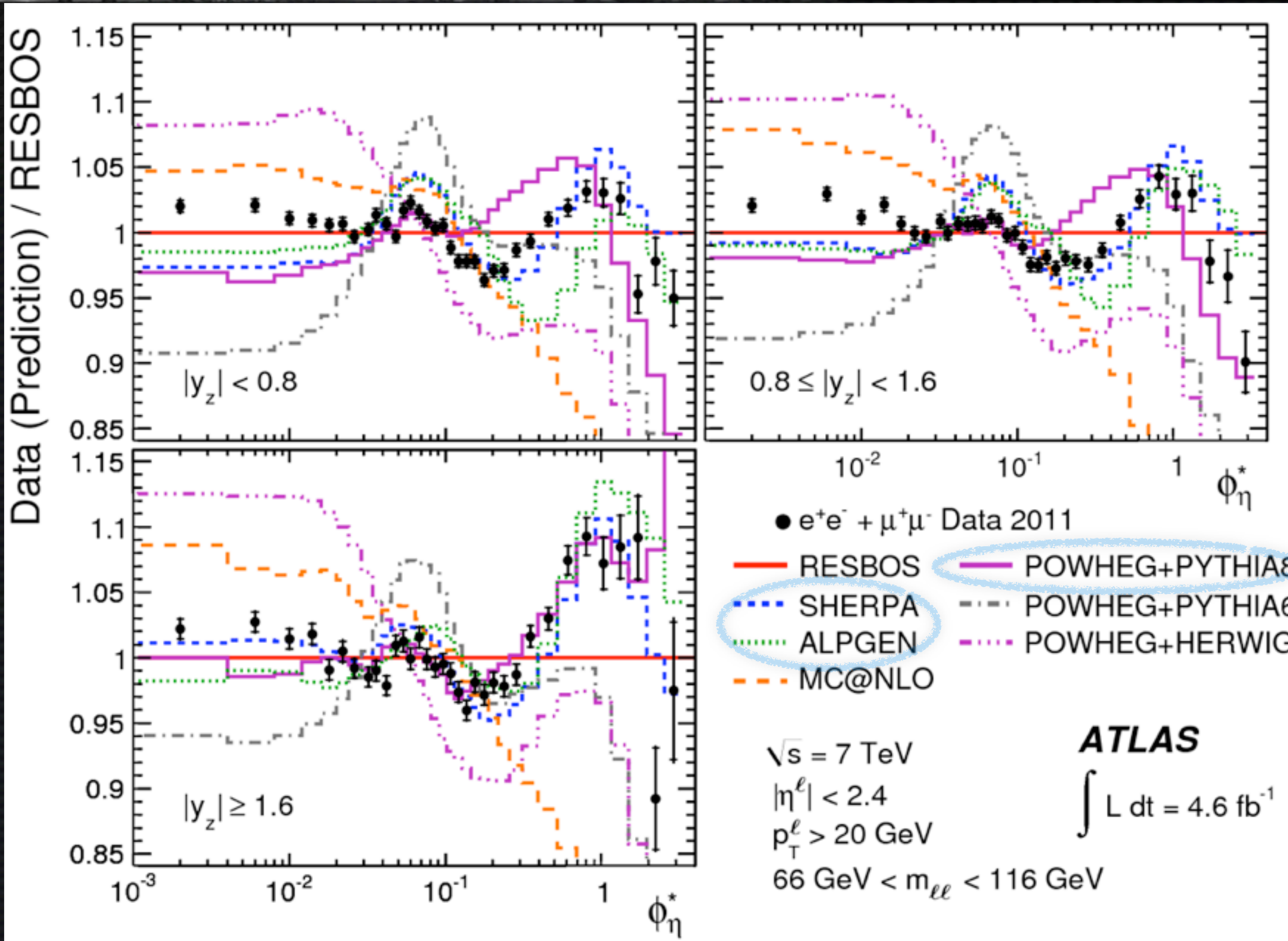
ϕ_η* is a measure of scattering angle of leptons relative to beam in Z/γ* rest frame

ϕ_η* is correlated to p_T(Z) and probes same physics

ϕ_η* depends on lepton angles only, more precisely measured than momenta

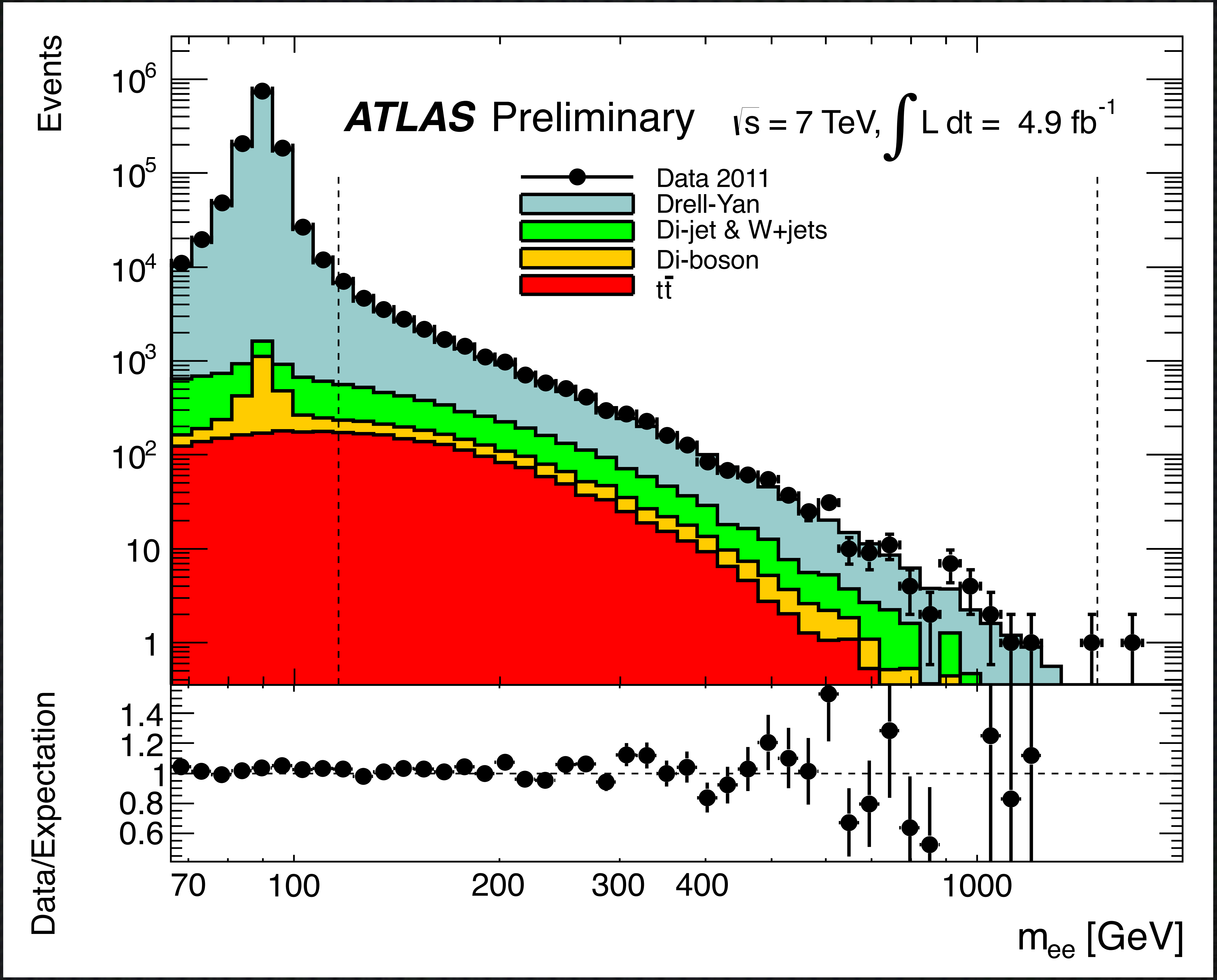


Measurement of the ϕ^* distribution of Z/γ^*

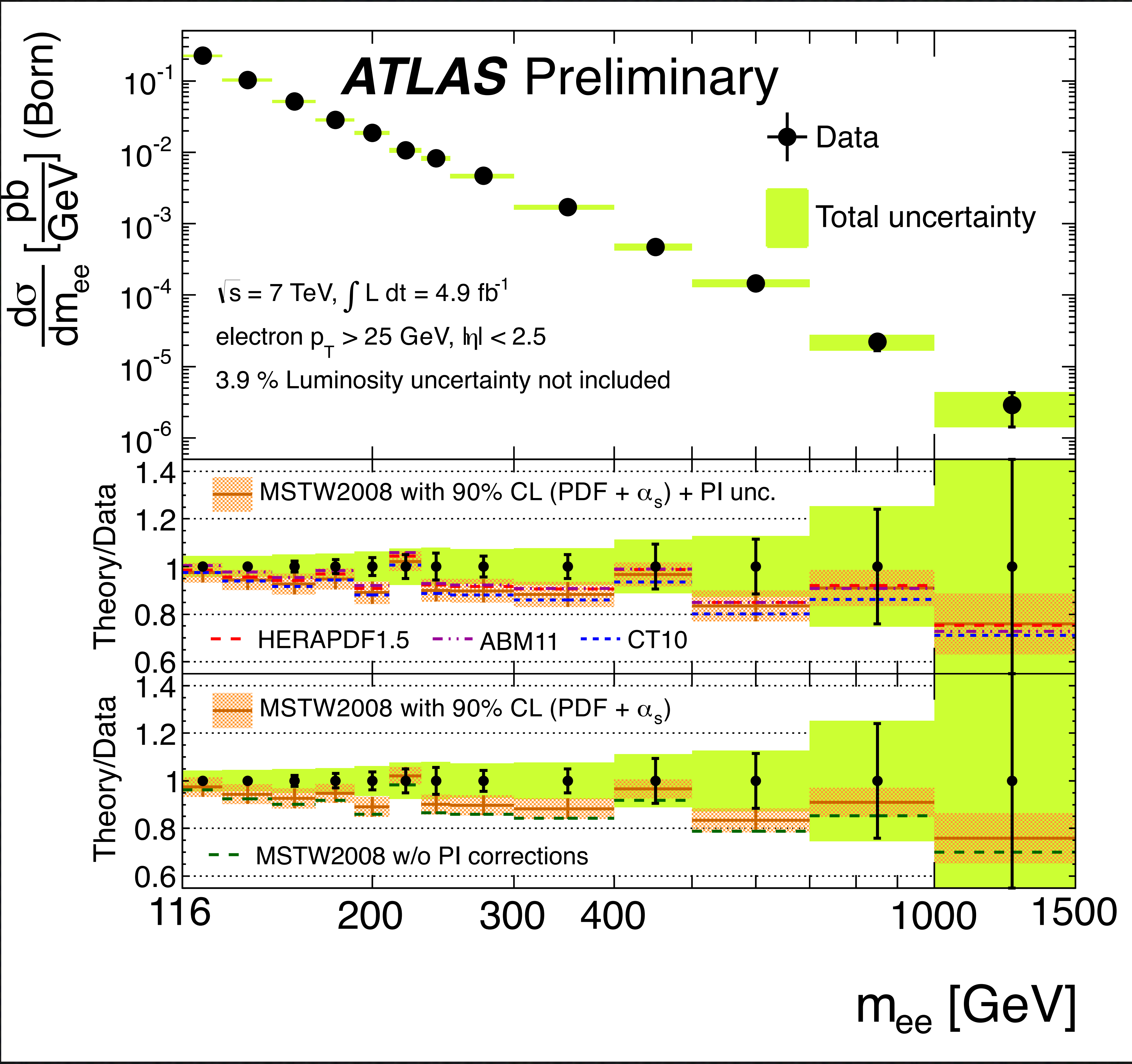


Similar situation to the Z p_T and W p_T measurements

High-mass Drell-Yan Production



High-mass Drell-Yan Production



Theory:
NNLO FEWZ 3.1

NNLO QCD calculation with NLO electroweak corrections (G_μ electroweak scheme)

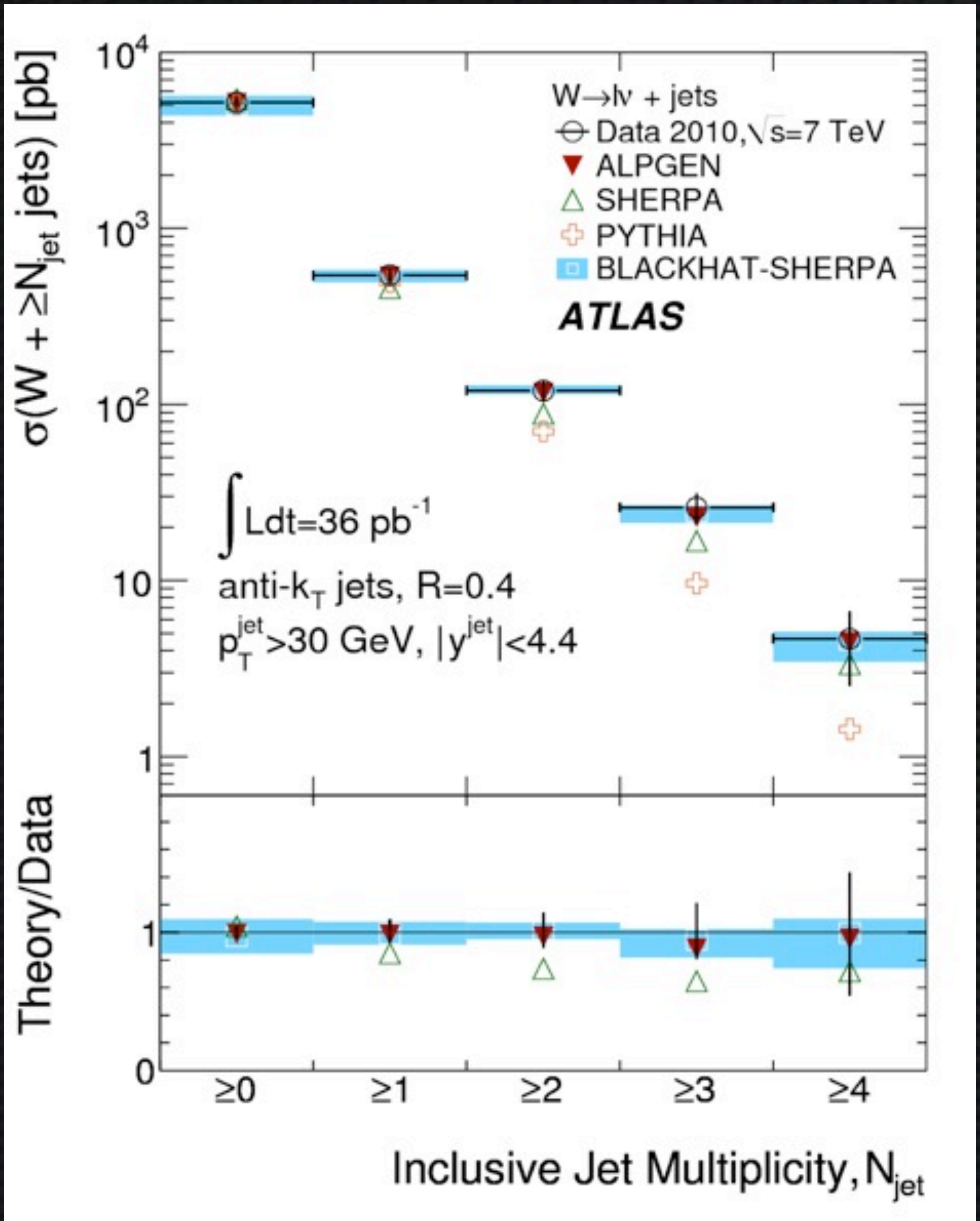
+

LO photon-induced correction $\gamma\gamma \rightarrow e^+e^-$

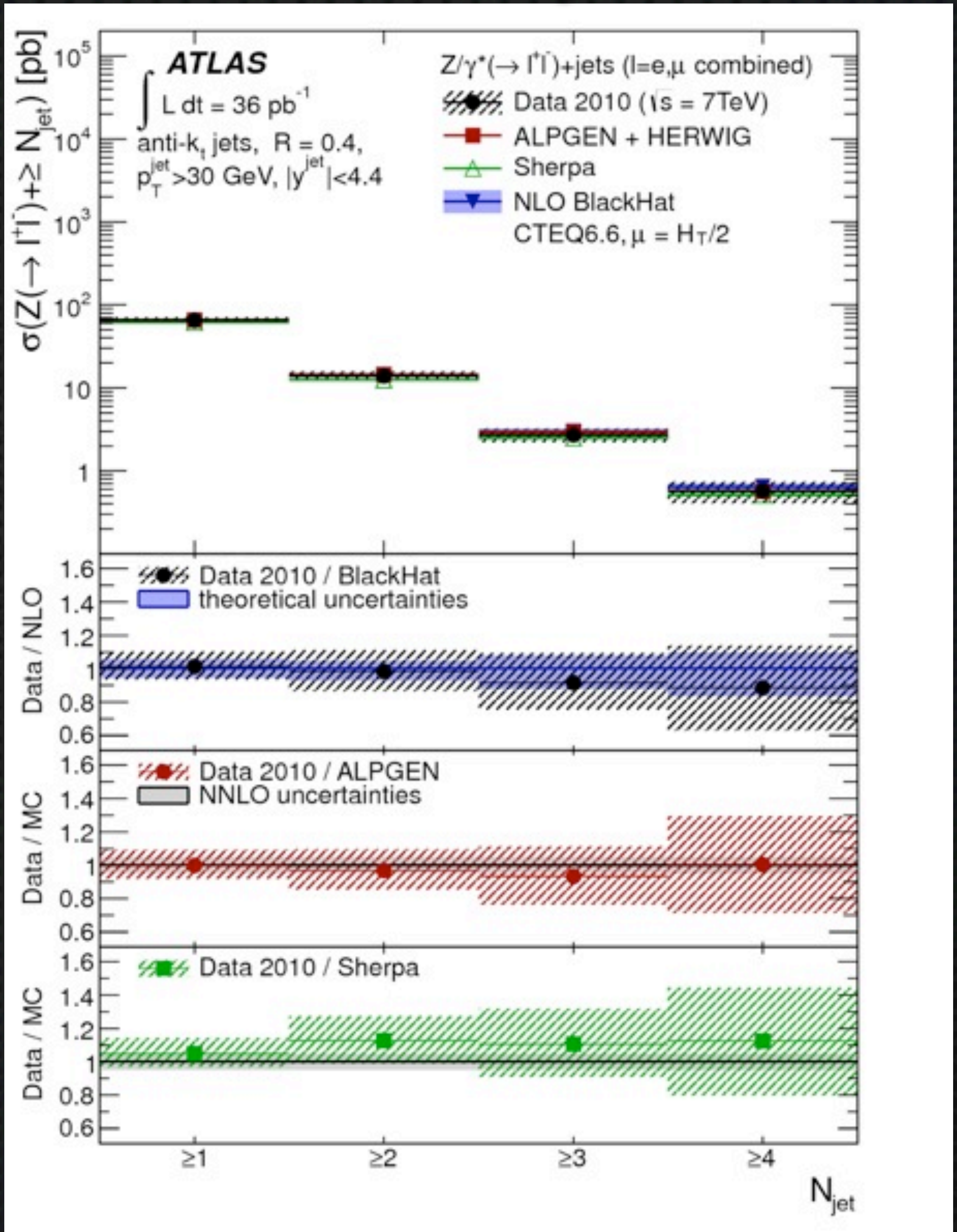
Results are consistent with all PDFs

W and Z plus jet production

W → lν + jets



Z → ll + jets



Phys. Rev. D85 (2012) 092002

Sherpa, Pythia, and Alpgen normalized to NNLO

Phys. Rev. D85 (2012) 032009

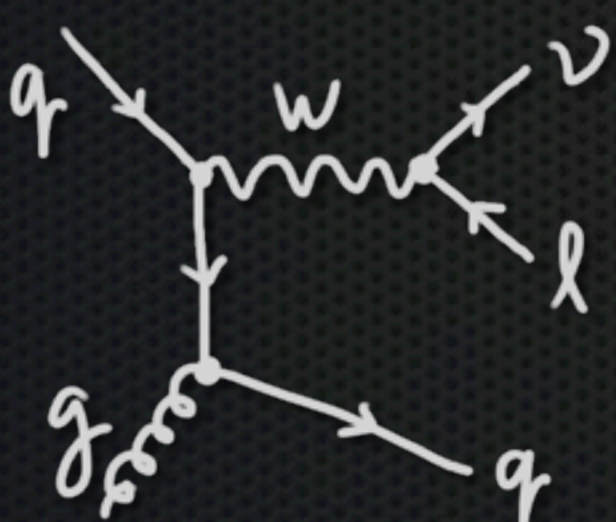
DPI in W+2 jets events

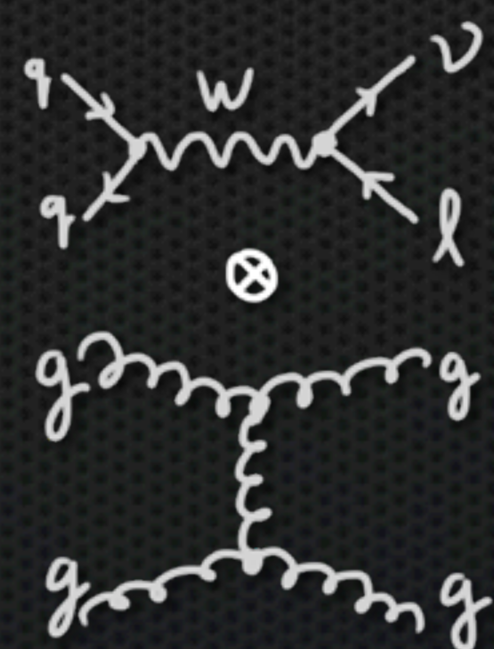
- **Double parton interactions**

cross section for the inclusive production of a combined Y + Z system

$$d\hat{\sigma}^{(\mathrm{MPI})}_{Y+Z}(s) = \frac{m}{2\sigma_{\mathrm{eff}}(s)} \int dx_1\, dy_1\, dx_2\, dy_2\, f(x_1, y_1, \mu_F) f(x_2, y_2, \mu_F)\, d\hat{\sigma}_Y(x_1, x_2, s)\, d\hat{\sigma}_Z(y_1, y_2, s),$$

double-parton distribution functions



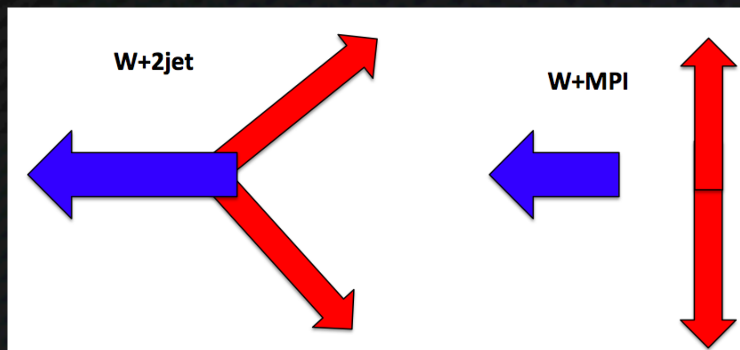


$$\sigma^{(\mathrm{DPI})}_{Y+Z} = \frac{\sigma_Y \cdot \sigma_Z}{\sigma_{\mathrm{eff}}}$$

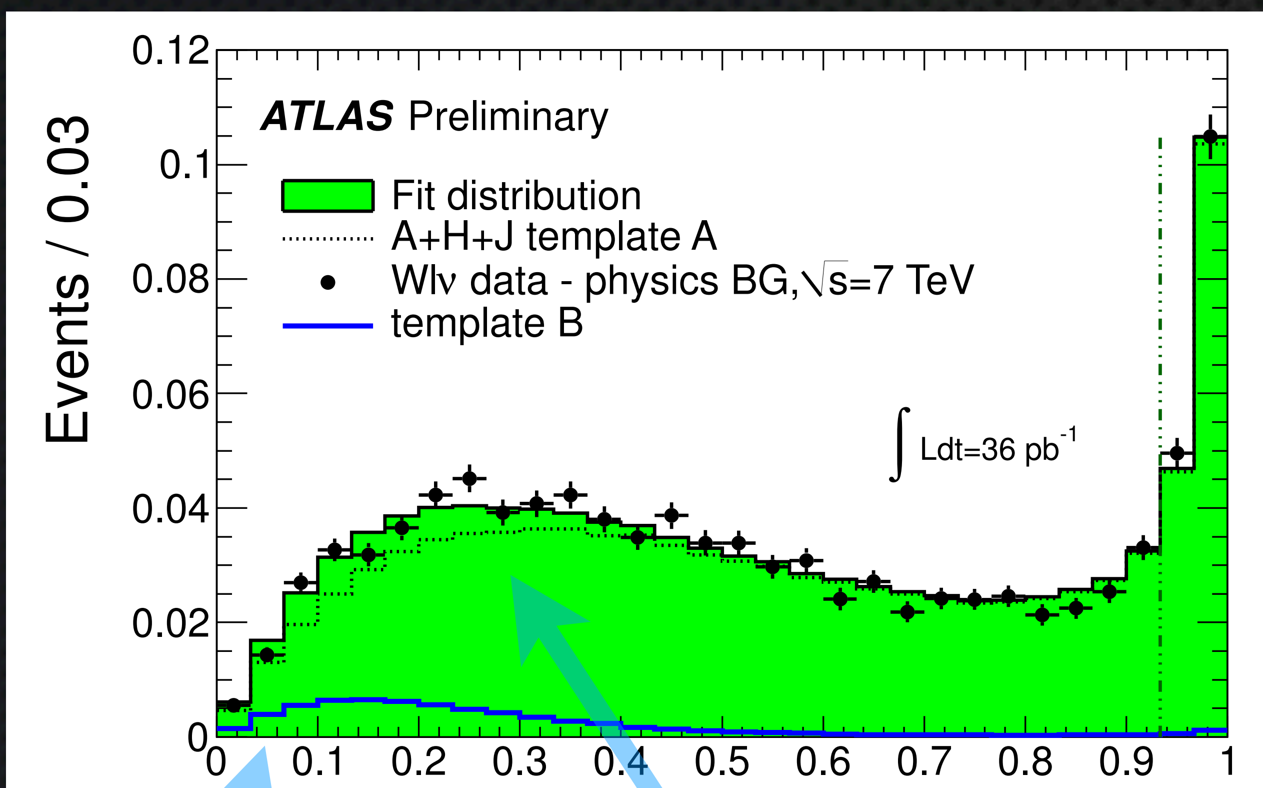
$$\sigma_{\mathrm{eff}} = \frac{\sigma_{W_{0j}} \cdot \sigma_{2j}}{\sigma_{W_{0j}+2j_{\mathrm{DPI}}}}$$

DPI in W+2 jets events

ATLAS-CONF-2011-160
(to be updated)



$$\Delta^{n}_{\mathrm{jets}} = \frac{|\vec{p}_{\mathrm{T}}^{\,J_1}+\vec{p}_{\mathrm{T}}^{\,J_2}|}{|\vec{p}_{\mathrm{T}}^{\,J_1}|+|\vec{p}_{\mathrm{T}}^{\,J_2}|}$$



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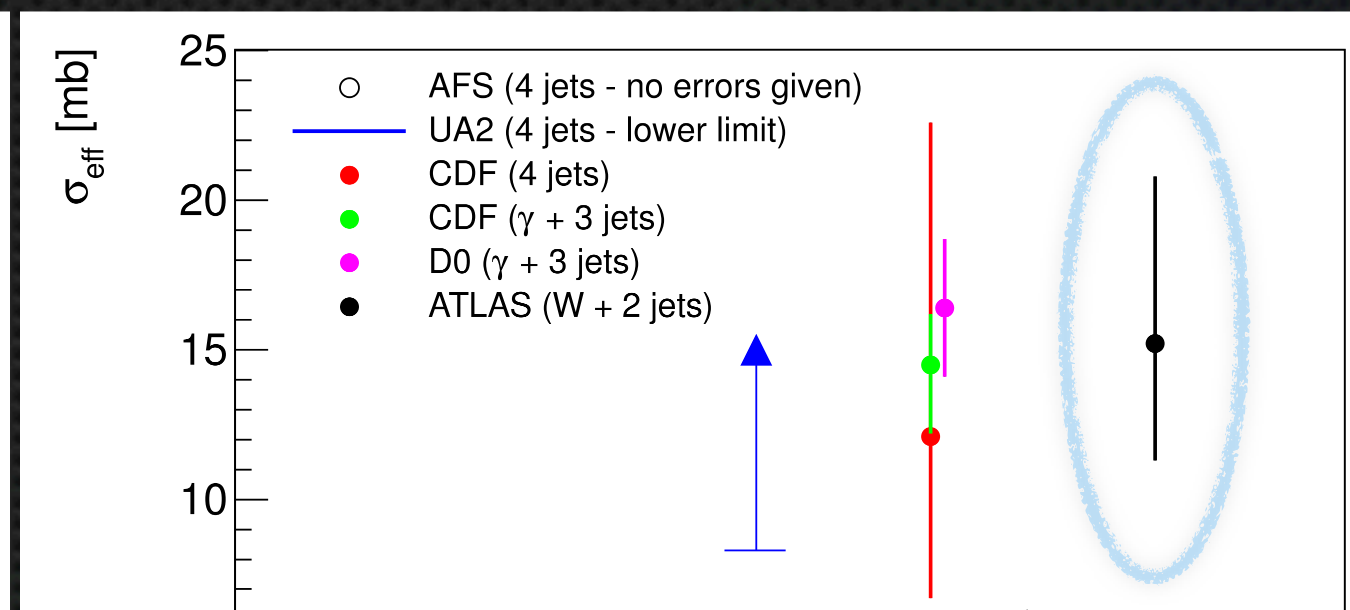
DPI template

W + 2 jets

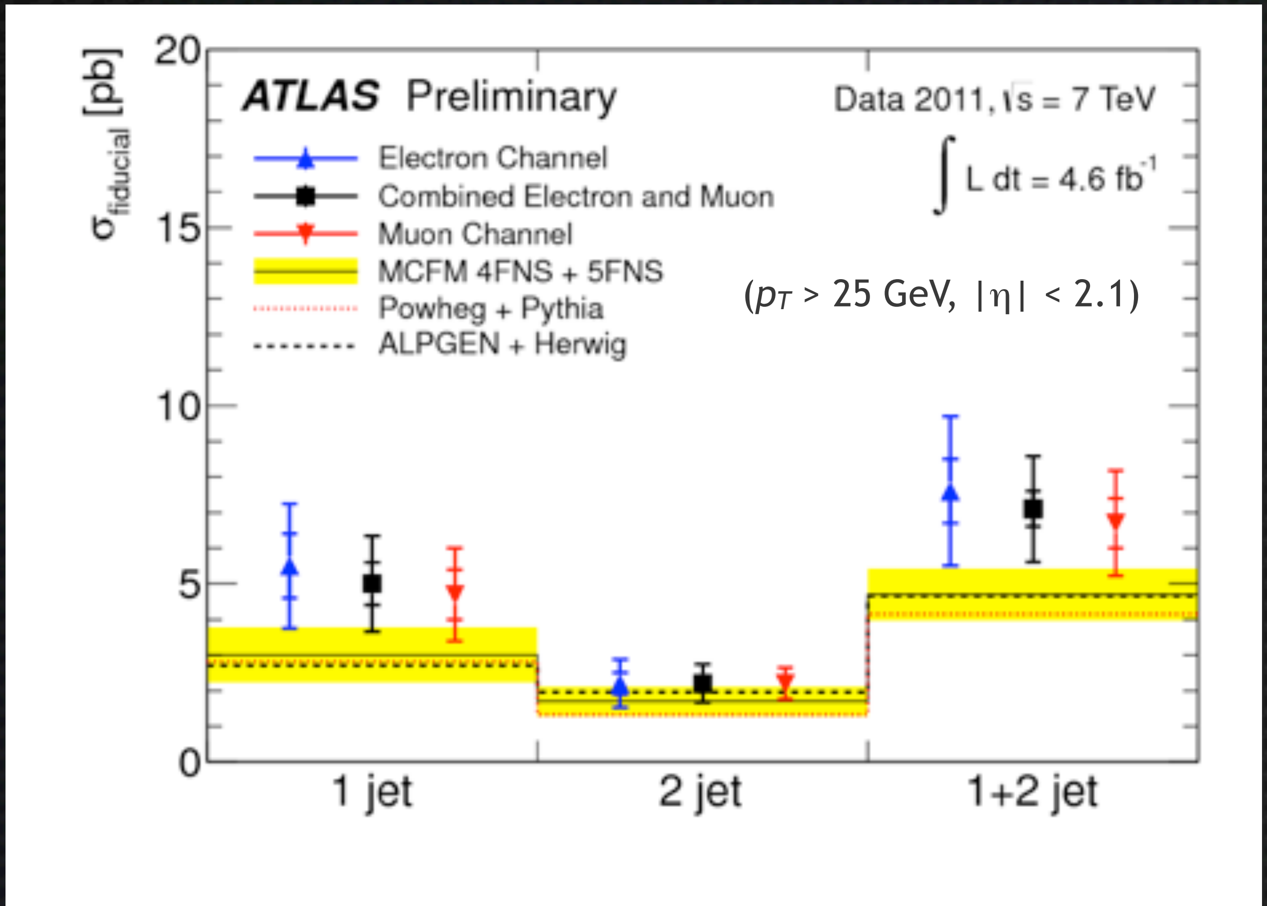


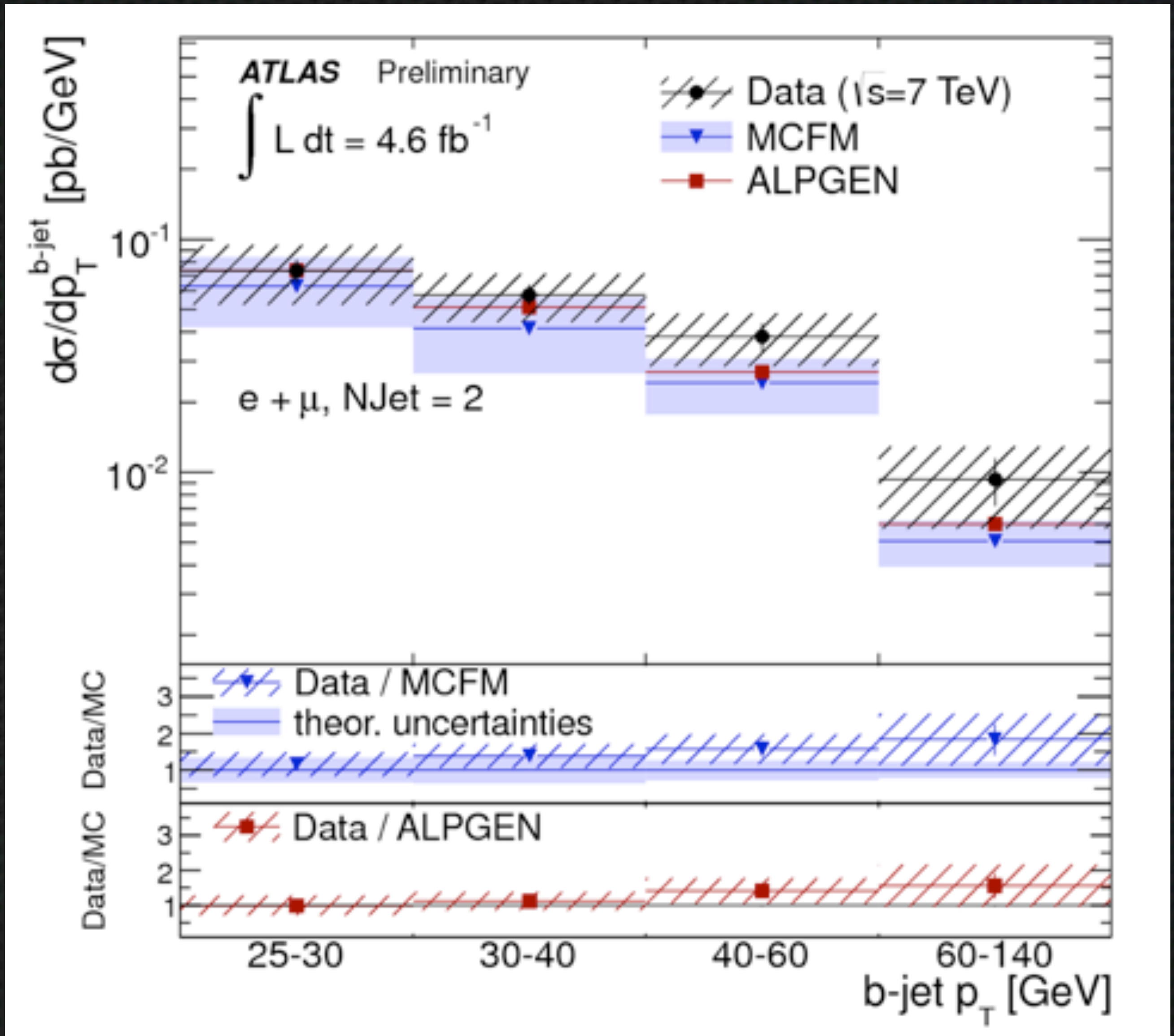
$\sigma_{\mathrm{eff}}(7\ \mathrm{TeV}) = 15 \pm 3\ (\mathrm{stat.})\ ^{+5}_{-3}\ (\mathrm{sys.})\ \mathrm{mb}$

$$f^{(\mathrm{D})}_{\mathrm{DP}} = 0.08 \pm 0.01\ (\mathrm{stat.}) \pm 0.02\ (\mathrm{sys.})$$

W + b-jet Fiducial Cross Section

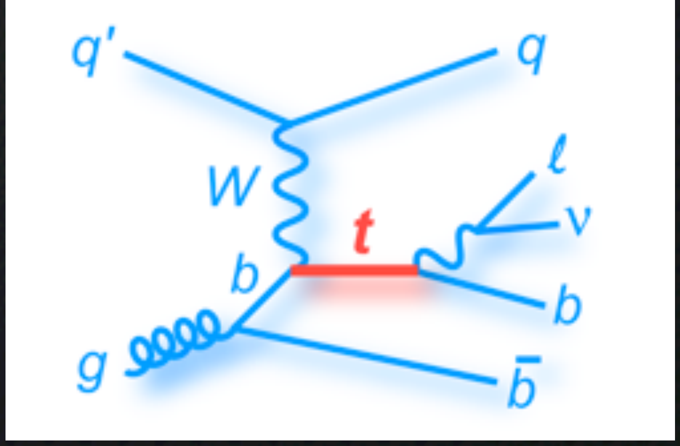
Important background for Higgs and top quark studies



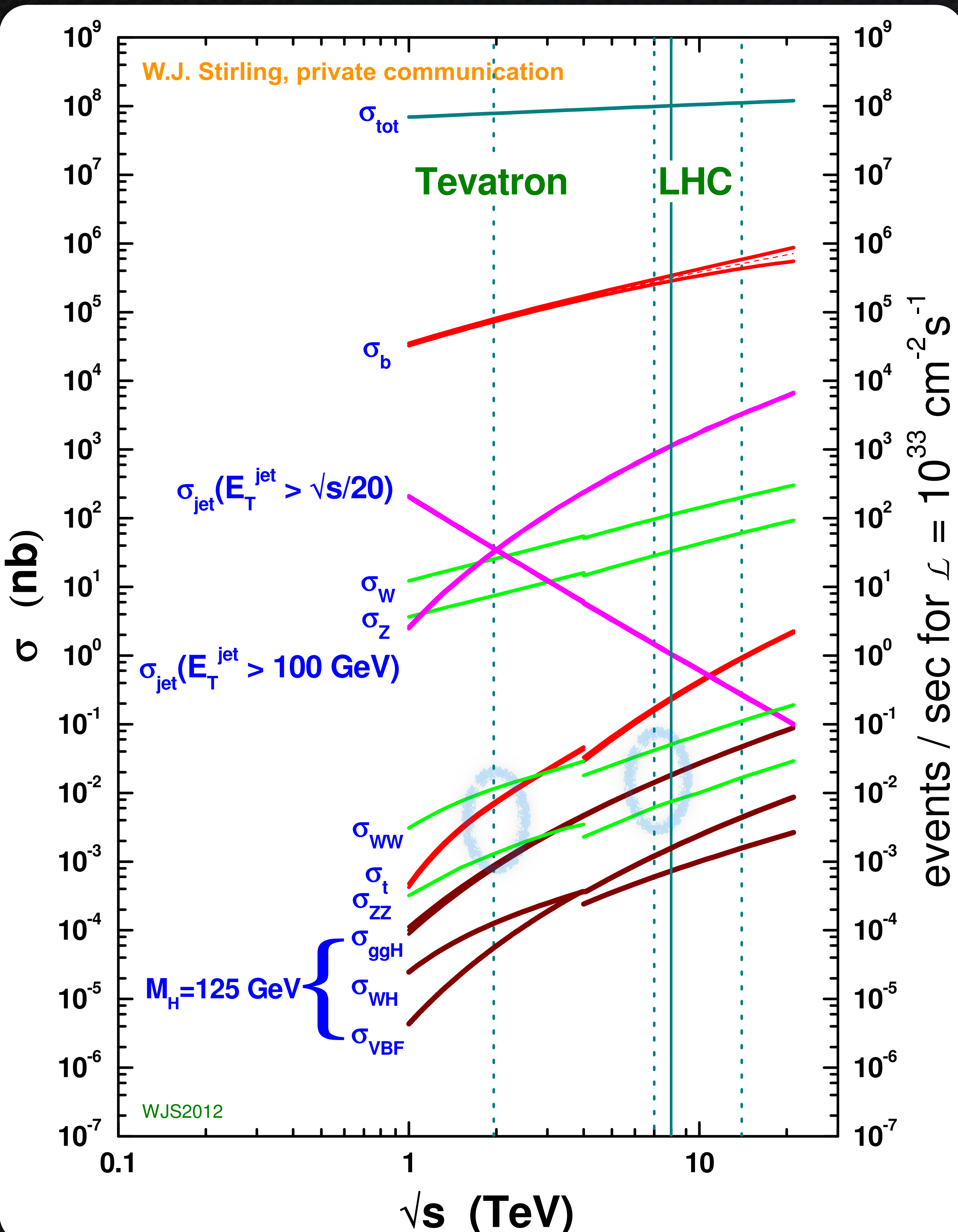


Agreement with theoretical expectations at 1 σ level

(includes a 25% effect due to DPI)



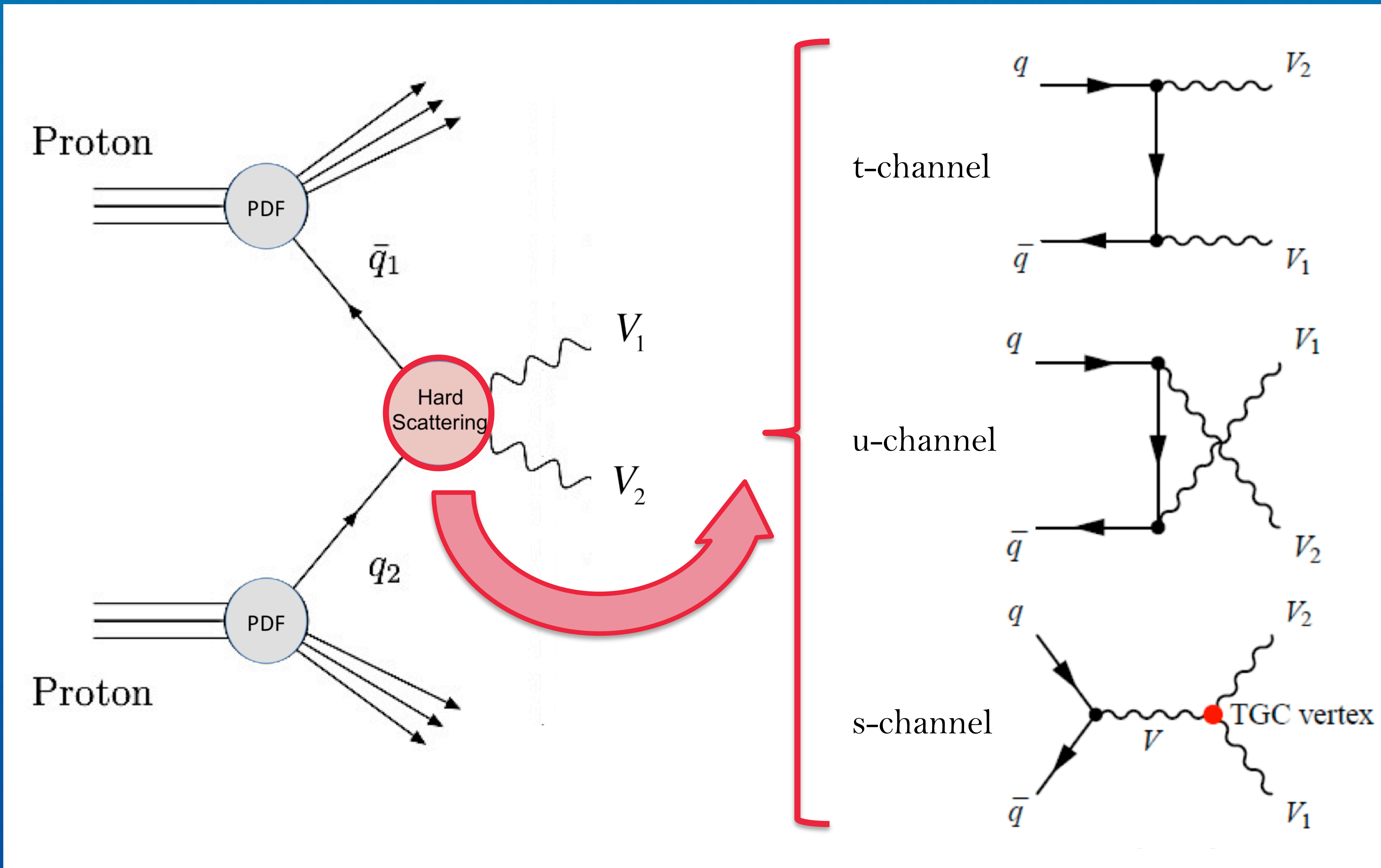
(measurement including single top production also available)



Diboson Production

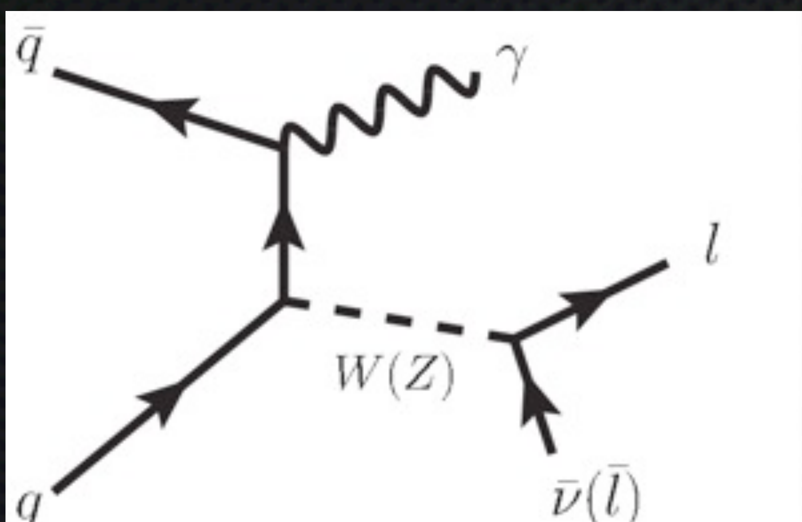
- Fundamental test of Standard Model
  - Triple gauge couplings (TGC)
  - Probe for new physics
    - Resonances with diboson final states
- Higgs hunting
  - Background to Higgs

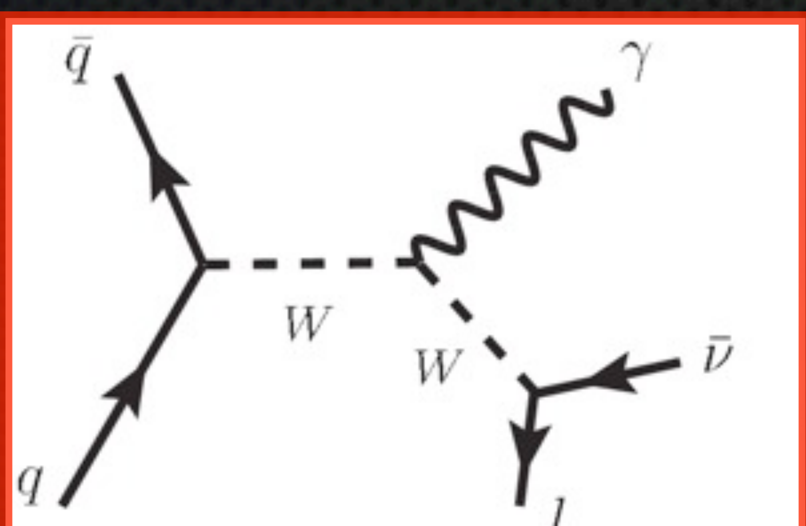
Diboson Production



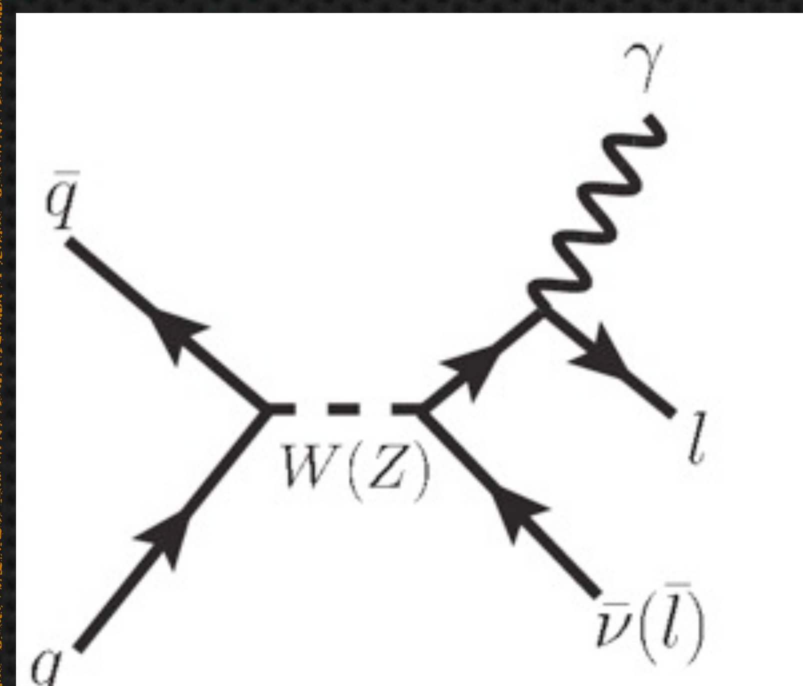
Dibosons: Wγ/Zγ

Initial State Radiation





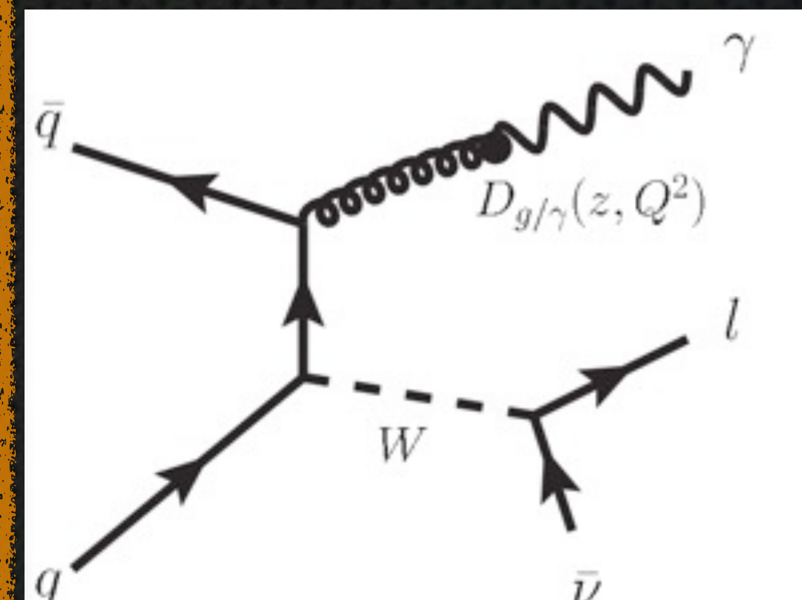
Final State Radiation

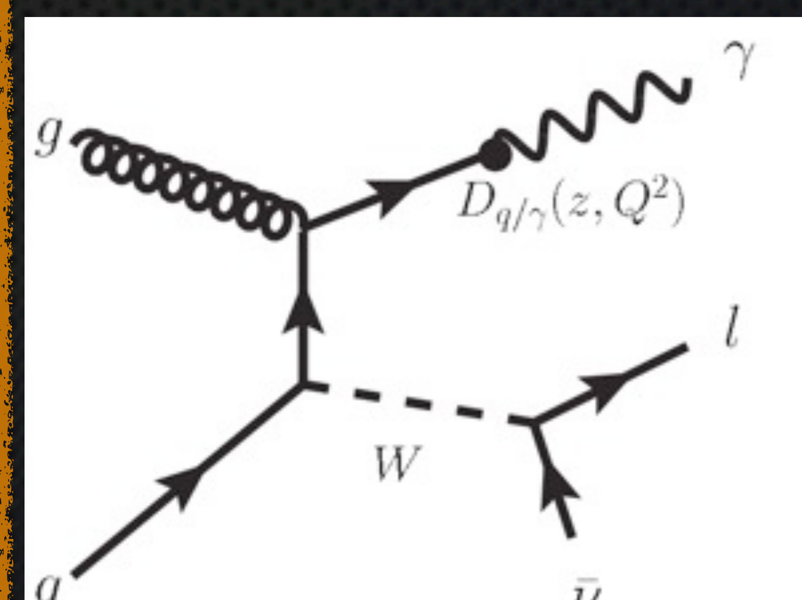


Suppress

ΔR(l, γ) > 0.7

Fragmentation

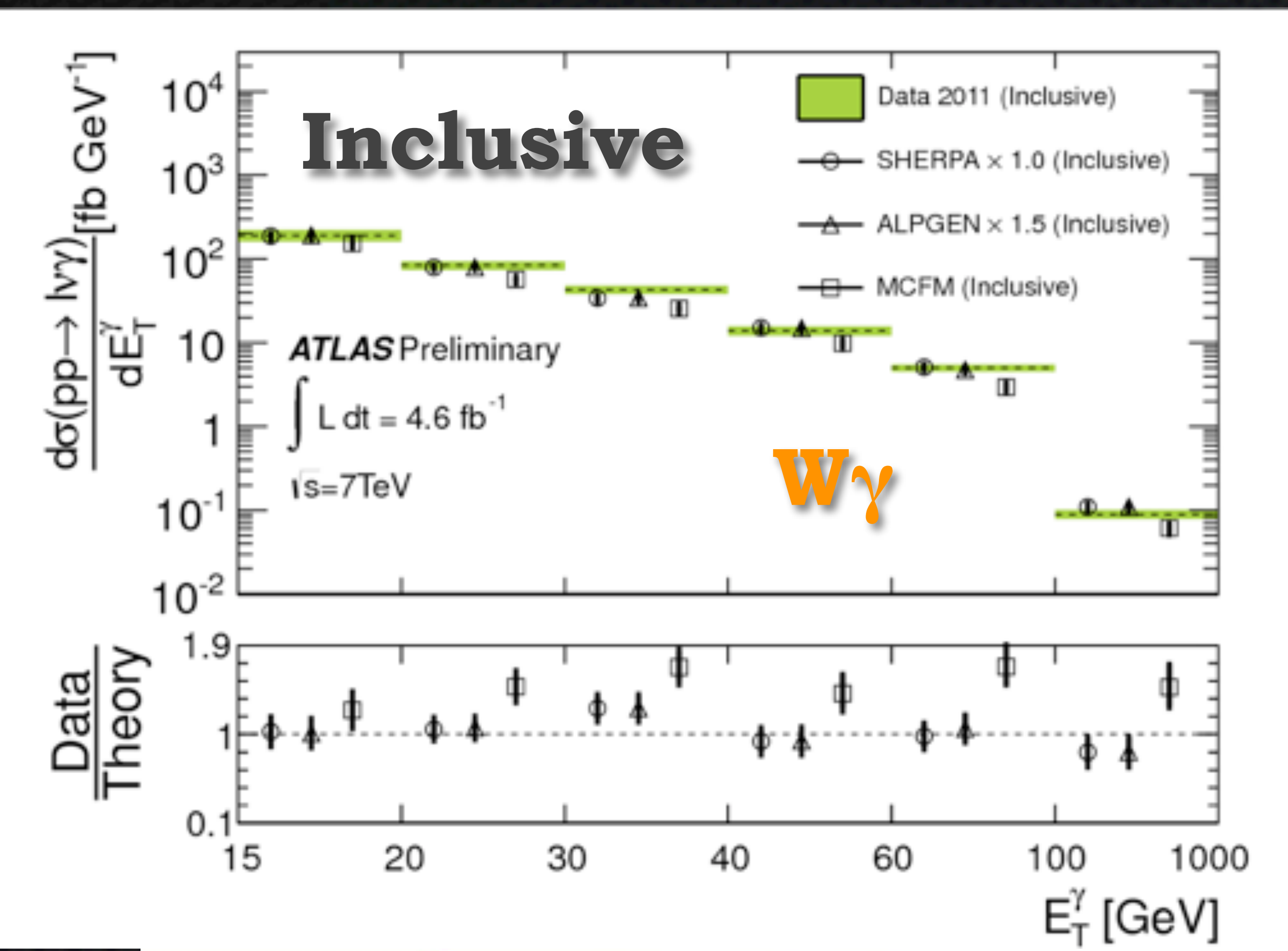


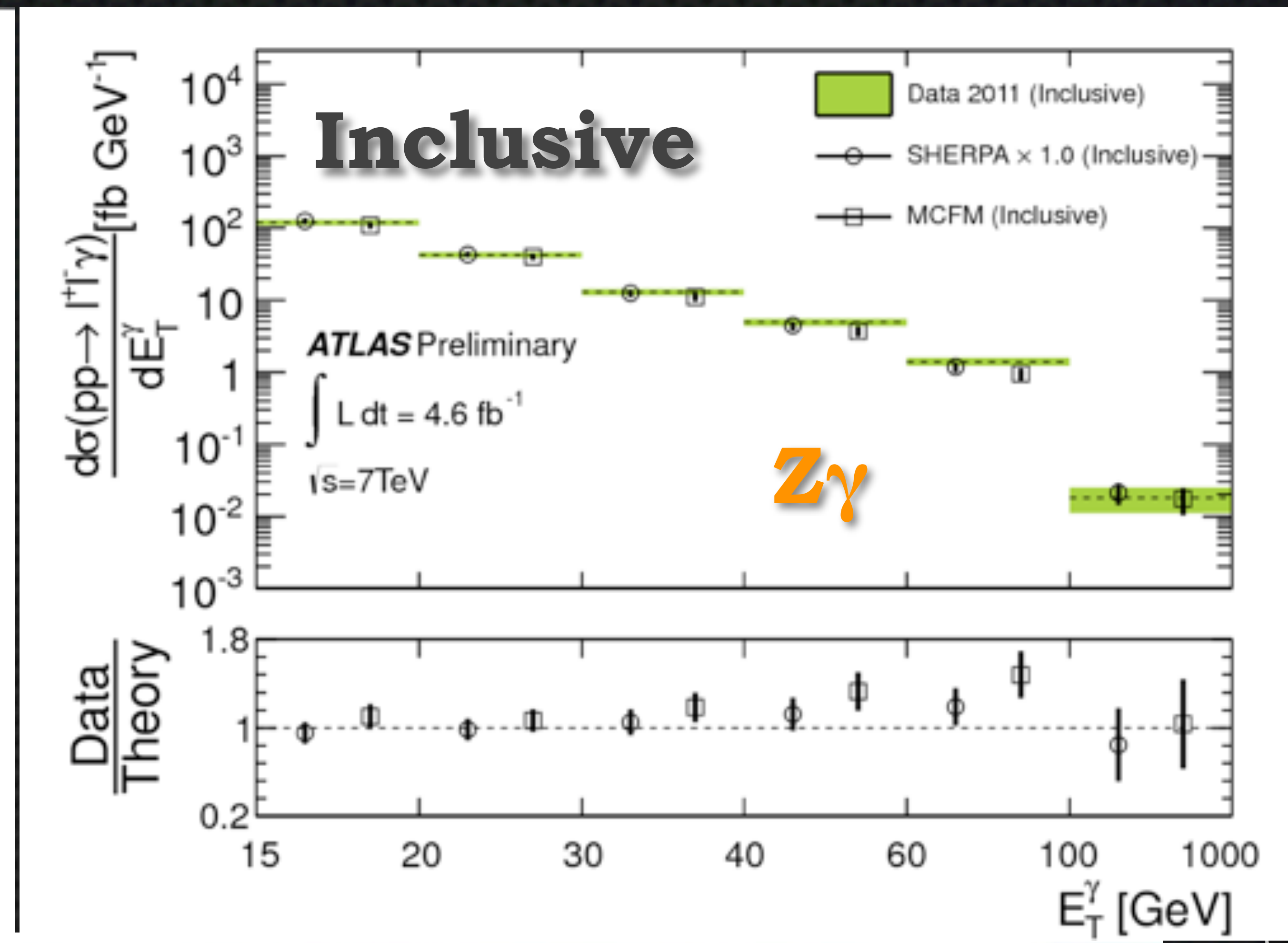


Suppress

Isolation requirement

Dibosons: Wγ and Zγ @ 7 TeV





	Measurement pb	NLO (MCFM) pb
lνγ	2.77 ± 0.03 (stat) ± 0.33 (syst) ± 0.14 (lumi)	1.96 ± 0.17
llγ	1.31 ± 0.02 (stat) ± 0.11 (syst) ± 0.05 (lumi)	1.18 ± 0.05
ννγ	0.133 ± 0.013 (stat) ± 0.020 (syst) ± 0.005 (lumi)	0.156 ± 0.012

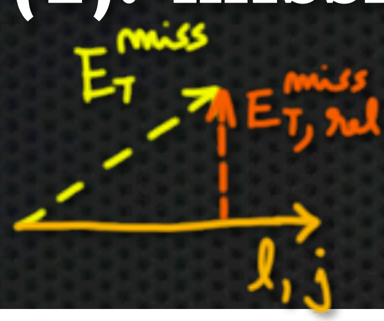
Wγ: Agreement with NLO MCFM calculation is not great
Exclusive calculation (N_{jet} =0) is good

Zγ: Better agreement with NLO MCFM calculation

Similar observations at CMS

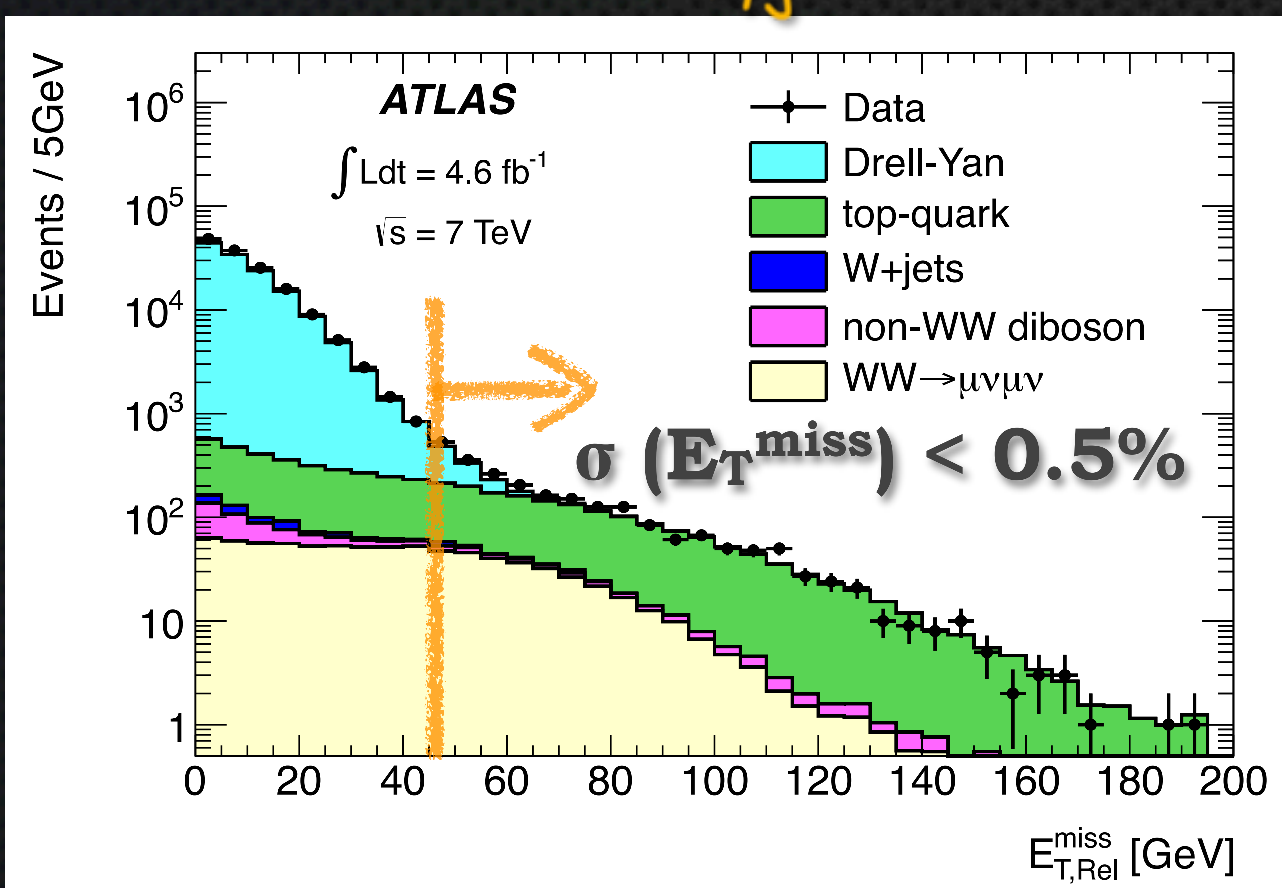
Dibosons: WW

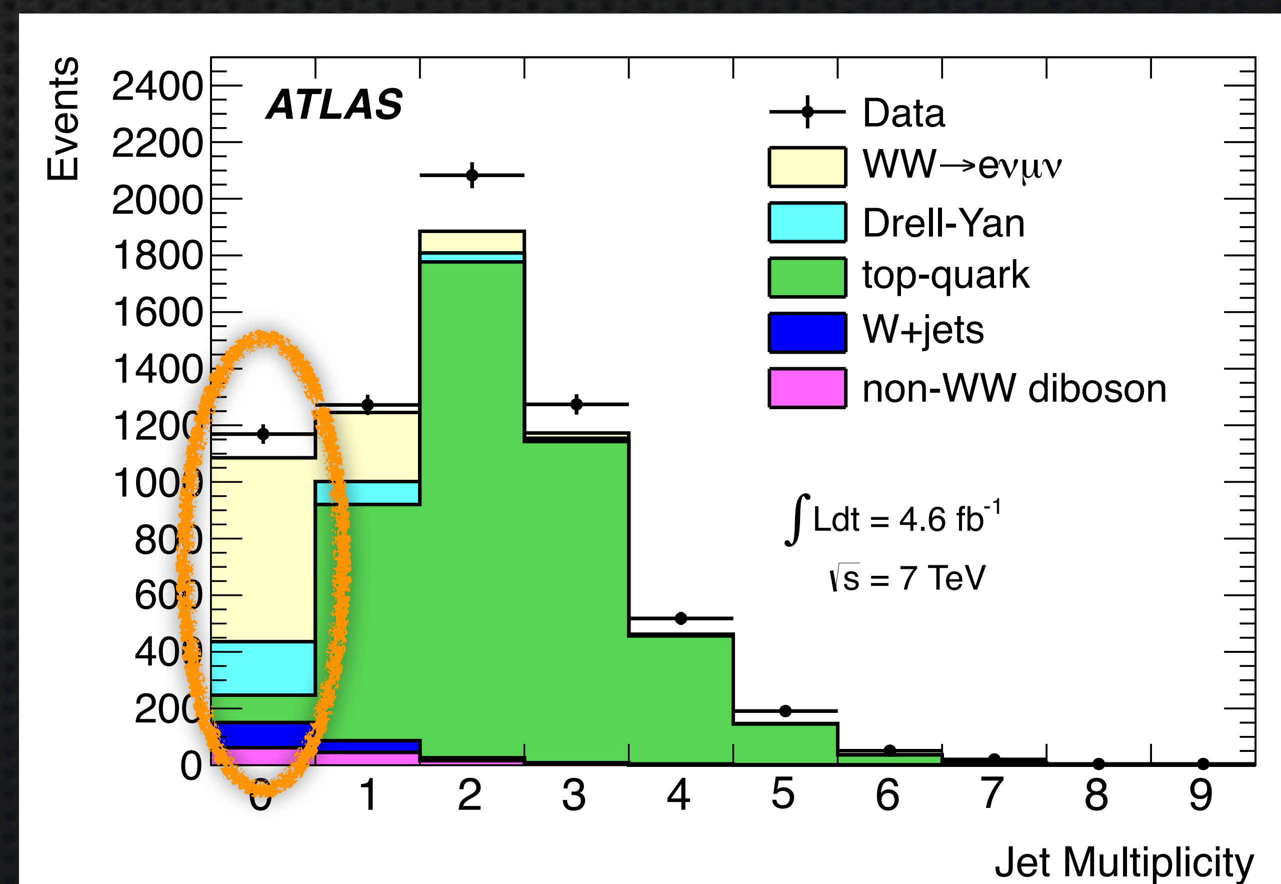
Challenge (1): missing energy



Challenge (2): Jet veto

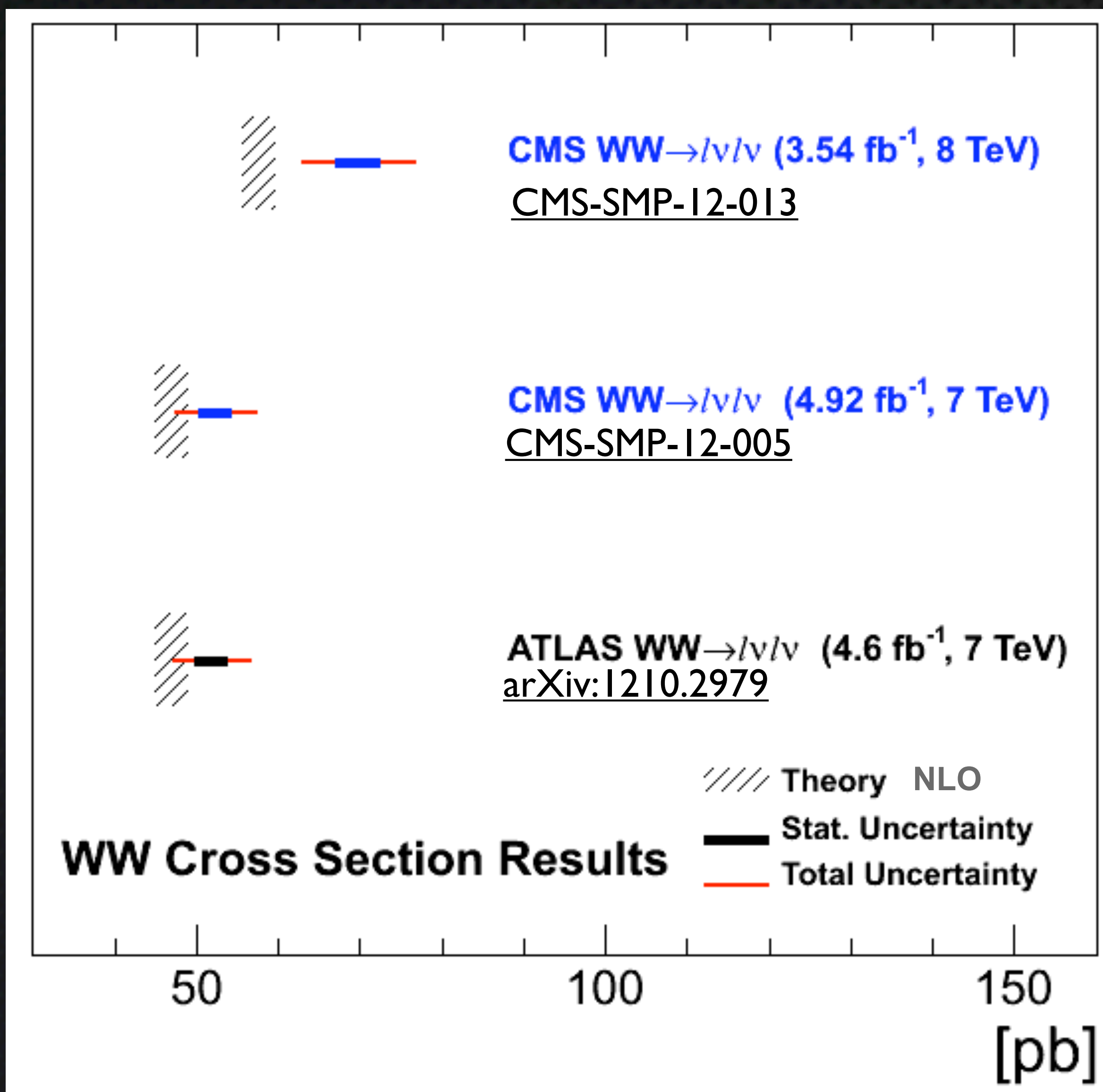
(reduce overwhelming top background)



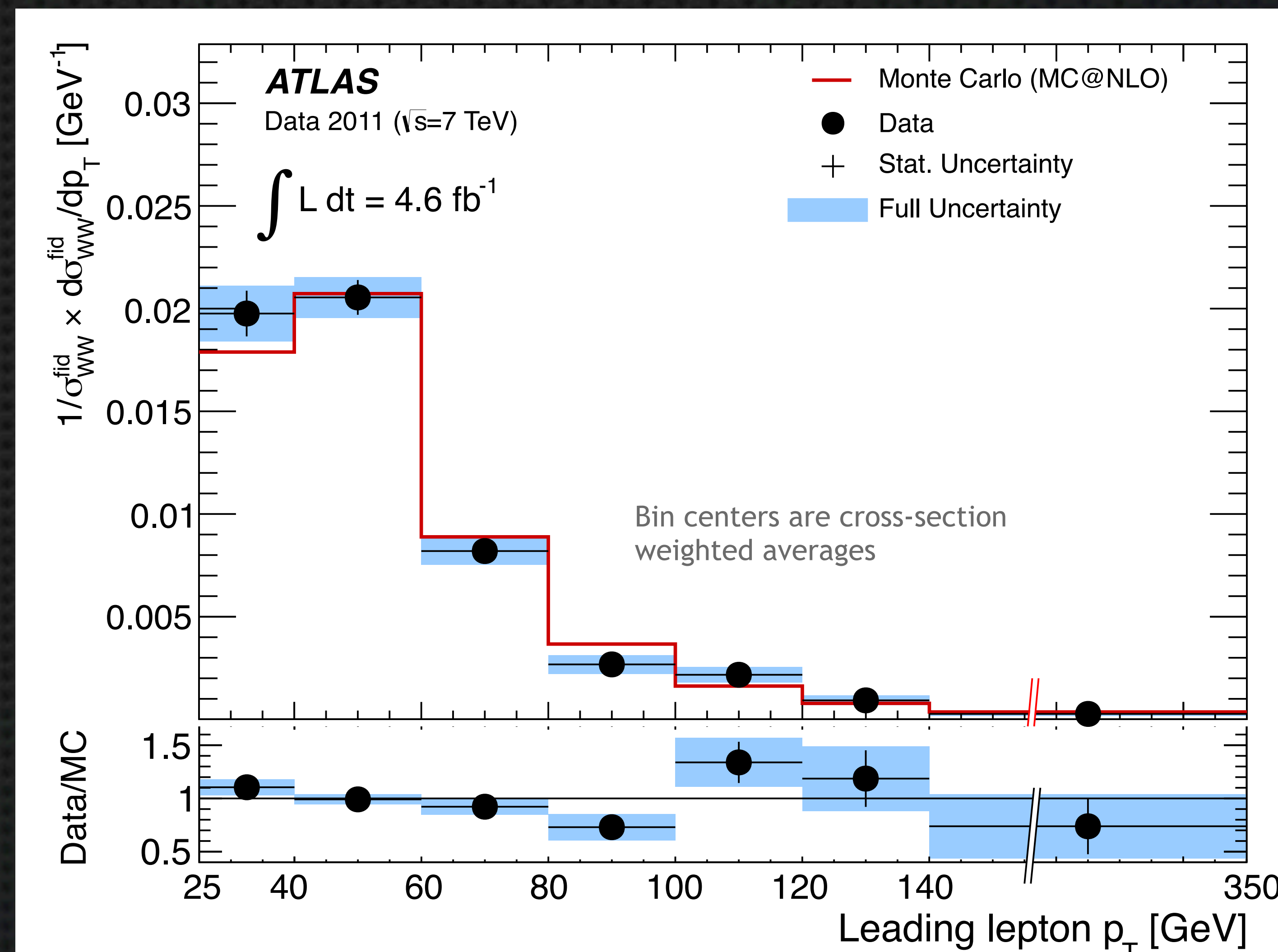


Dibosons: WW @ 7 TeV

Total cross section

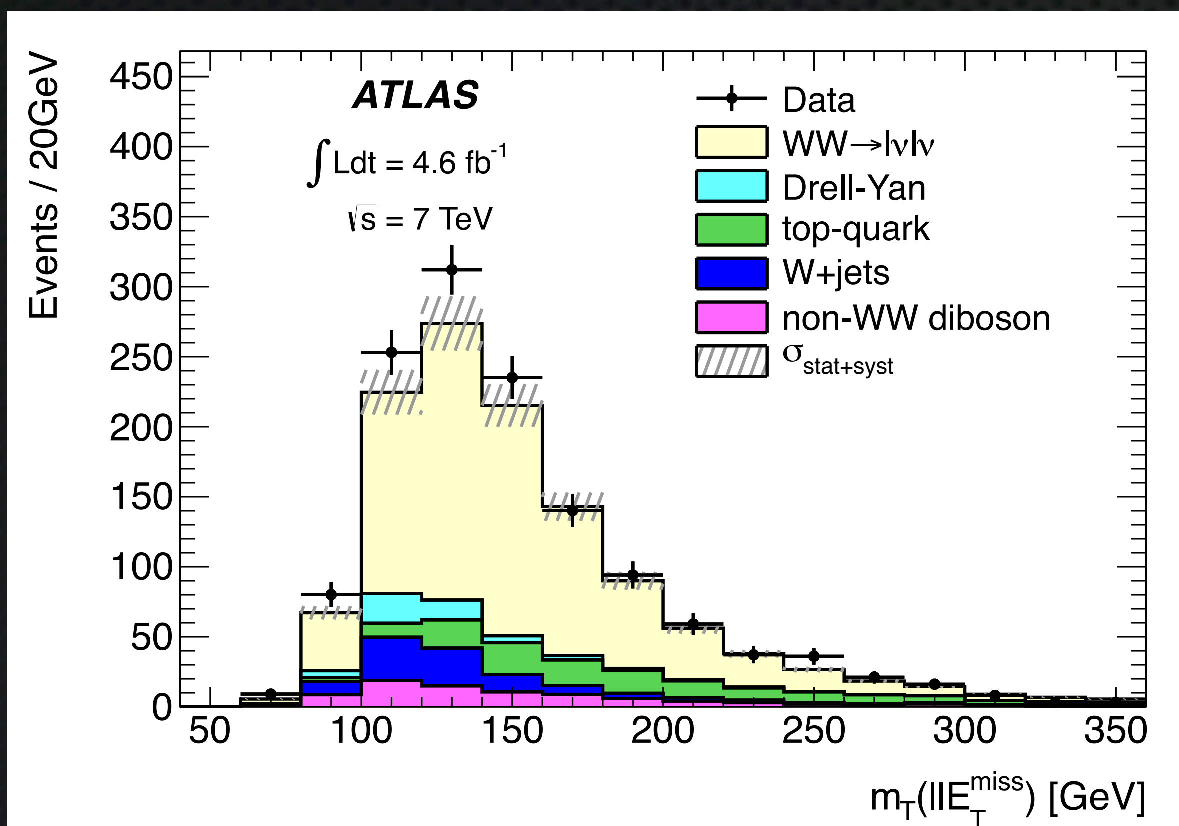


Normalized fiducial differential cross section

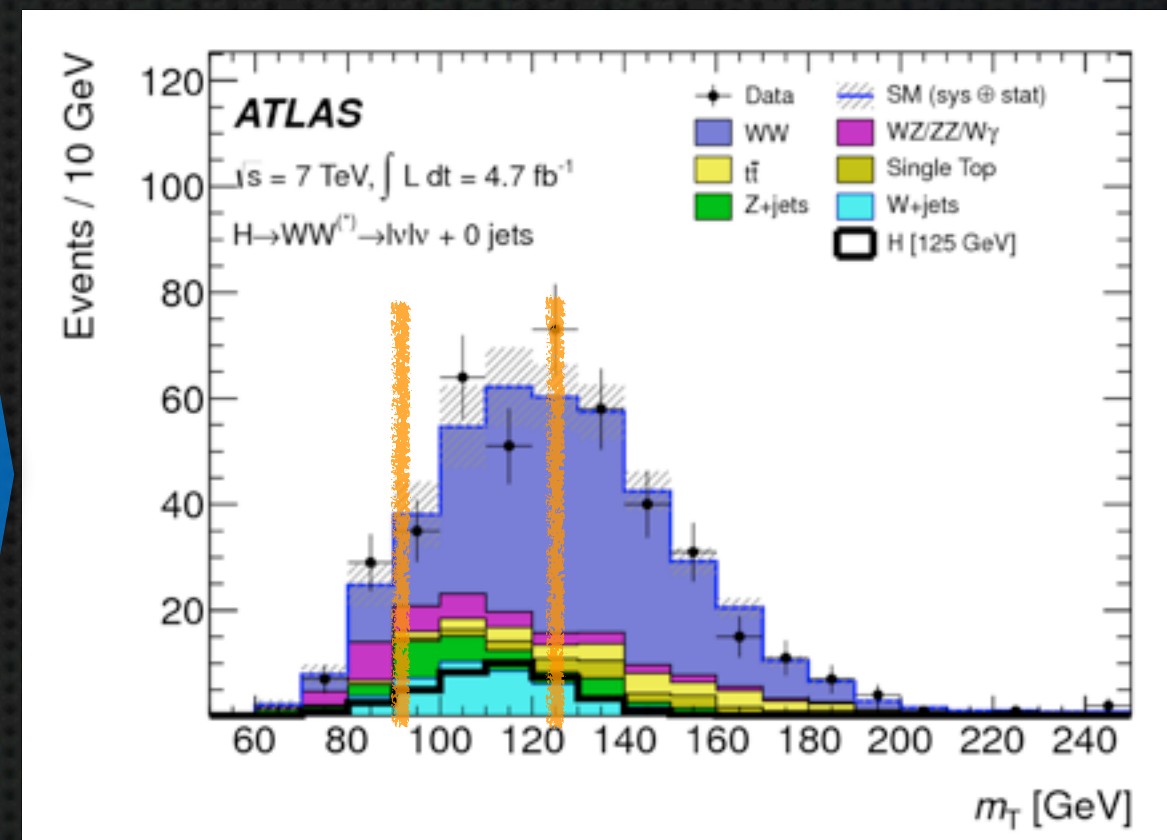


(several differential cross sections have been measured for all diboson channels)

From here to the Higgs



Higgs contribution: 3%



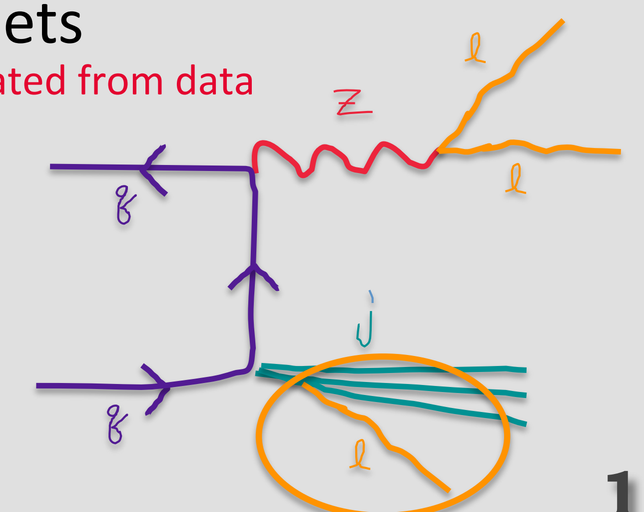
(note: 7 TeV Higgs analysis for proper comparison)

Further kinematic cuts

Dibosons: WZ Production

Z + jets

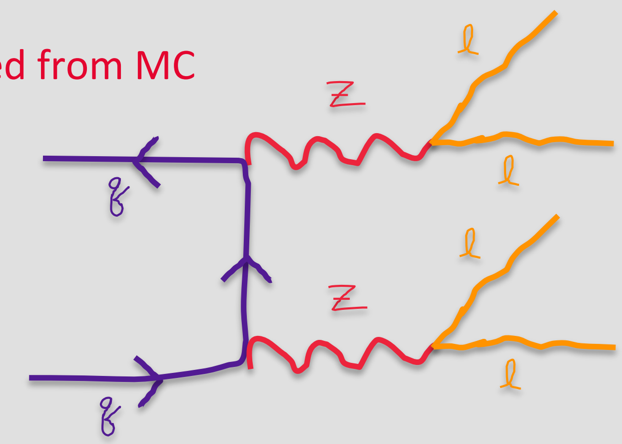
estimated from data



11%

ZZ

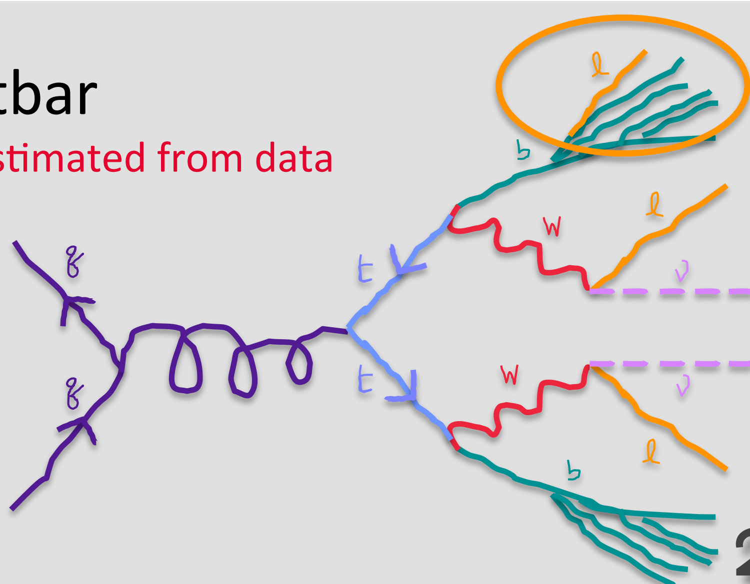
estimated from MC



7%

ttbar

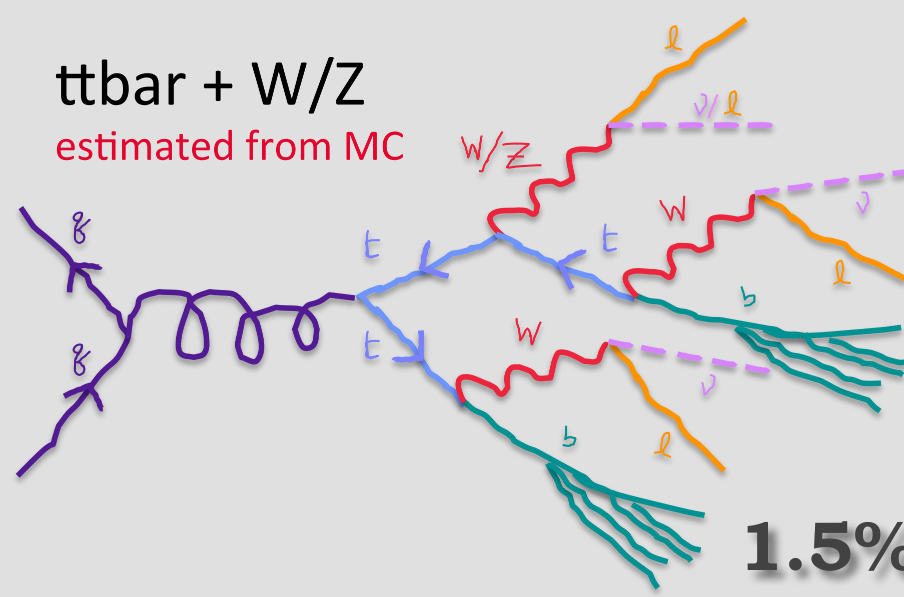
estimated from data



2%

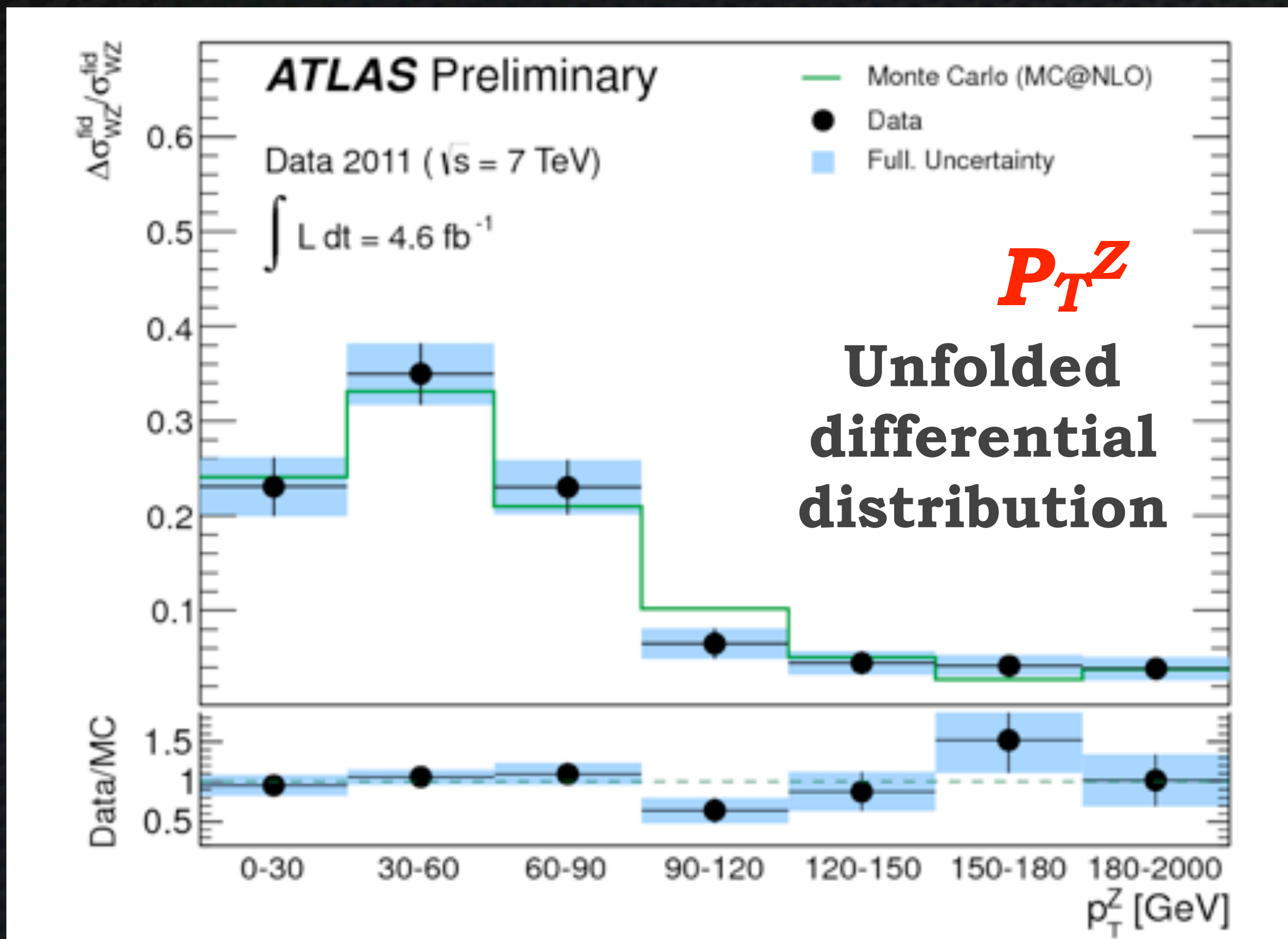
ttbar + W/Z

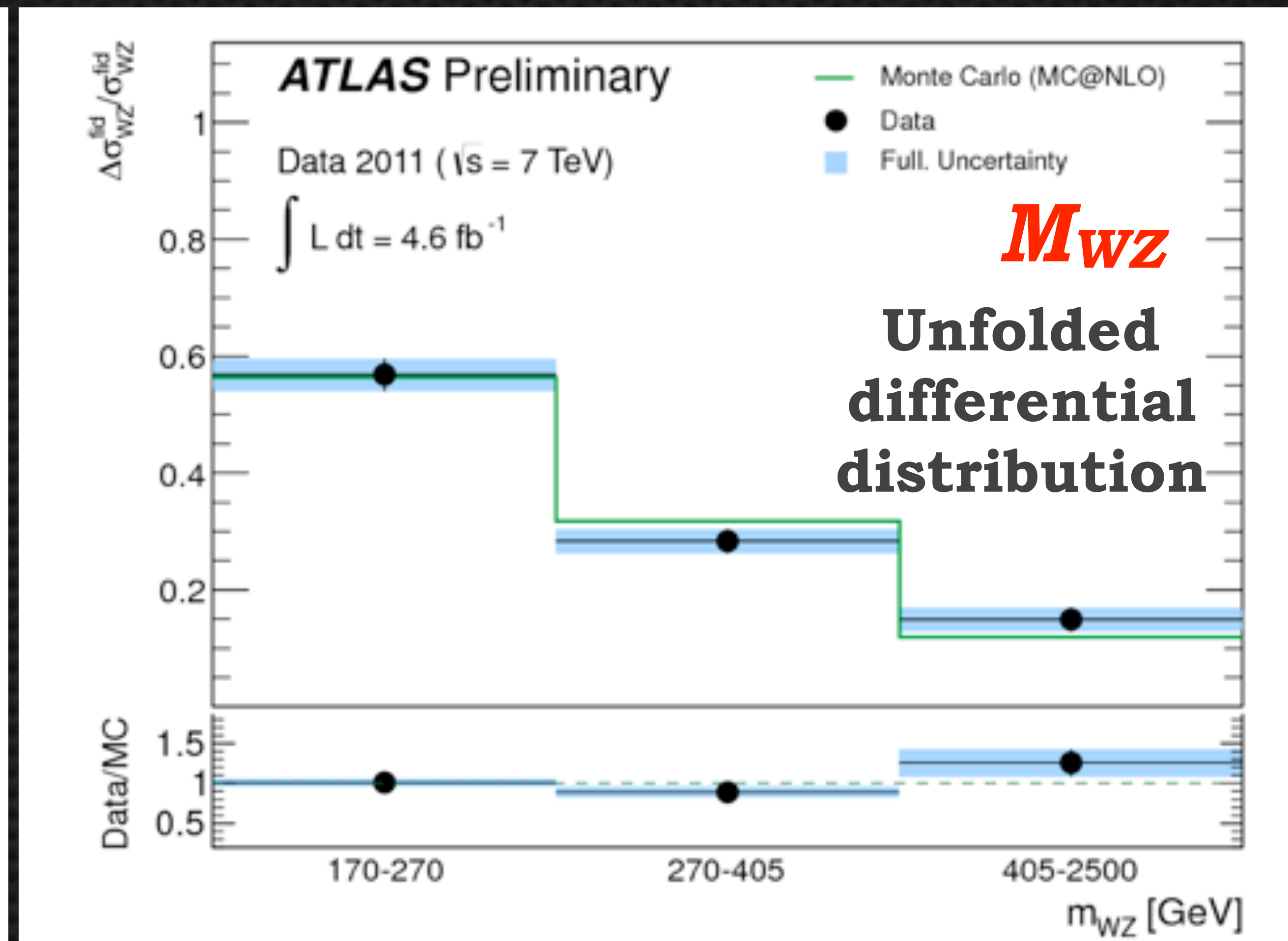
estimated from MC



1.5%

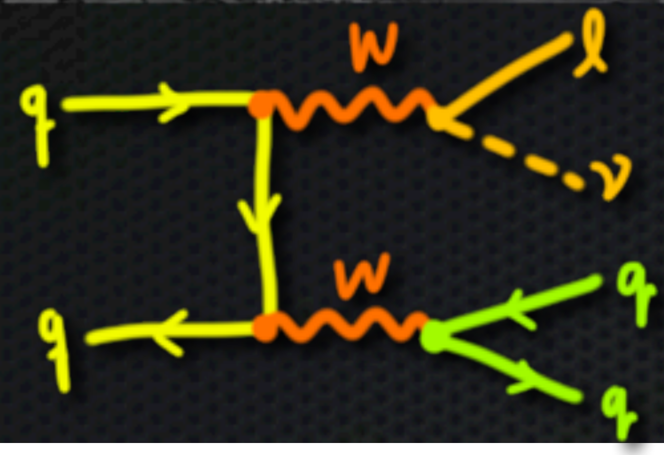
Dibosons: WZ @ 7 TeV



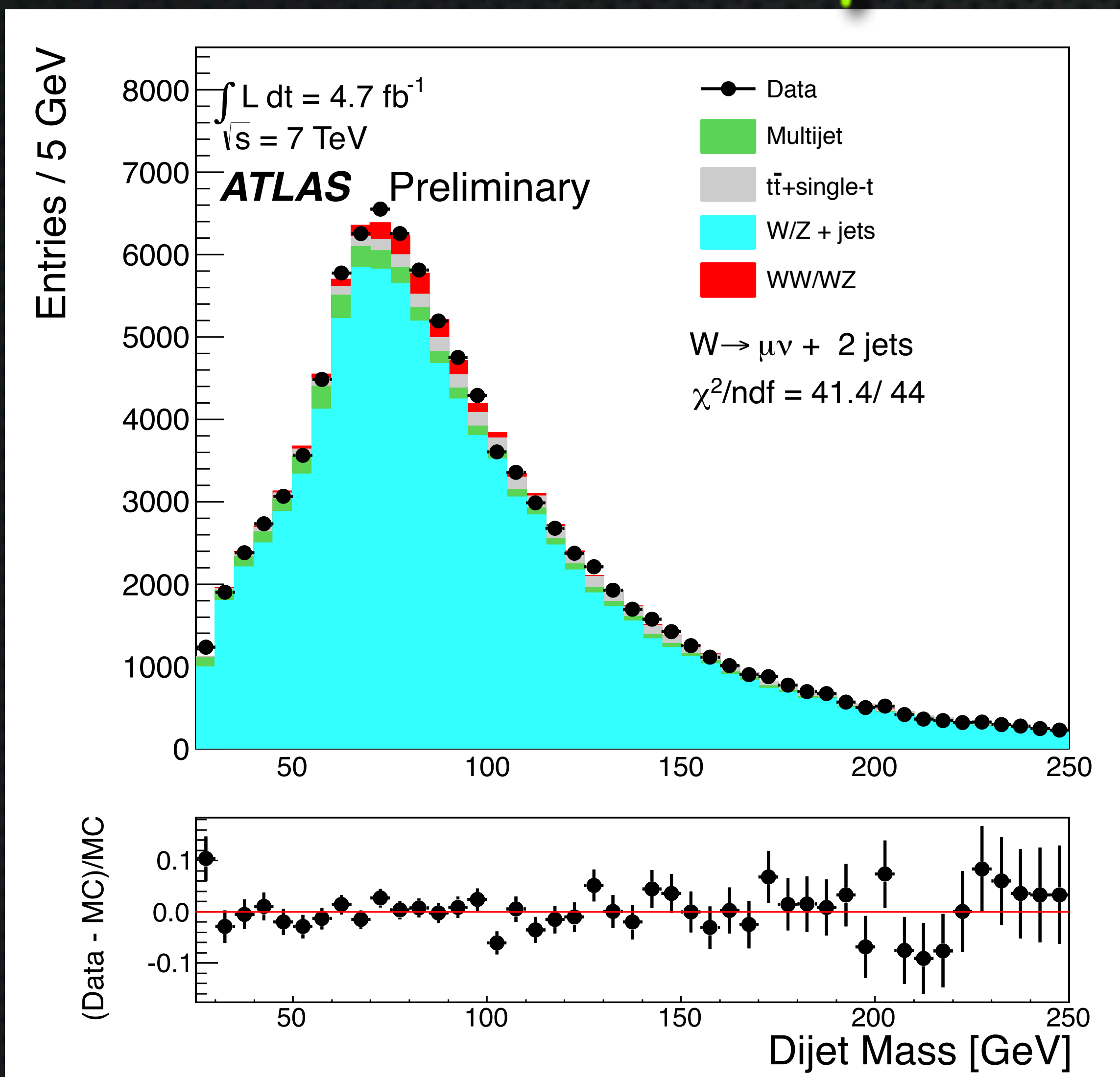


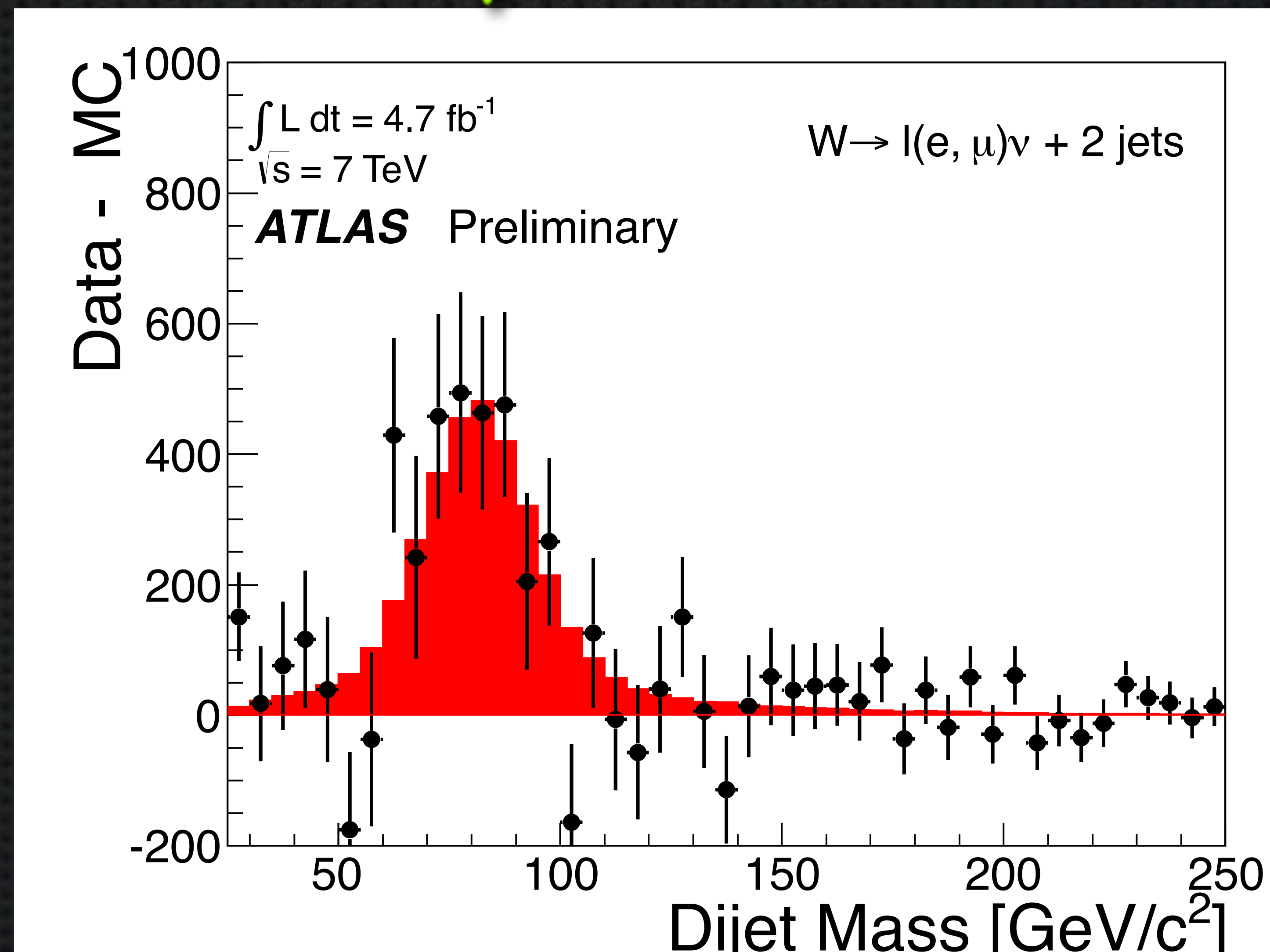
WZ	$N_{observed}$	N_{bkg}	$\sigma_{measured}$ (pb)	σ_{NLO} (pb)
ATLAS	317	68 ± 8	$19.0^{+1.4}_{-1.3} \pm 0.8 \pm 0.4$	$17.6^{+1.1}_{-1.0}$

Dibosons: WW+WZ → lν + jj @ 7 TeV



S/B < 1%

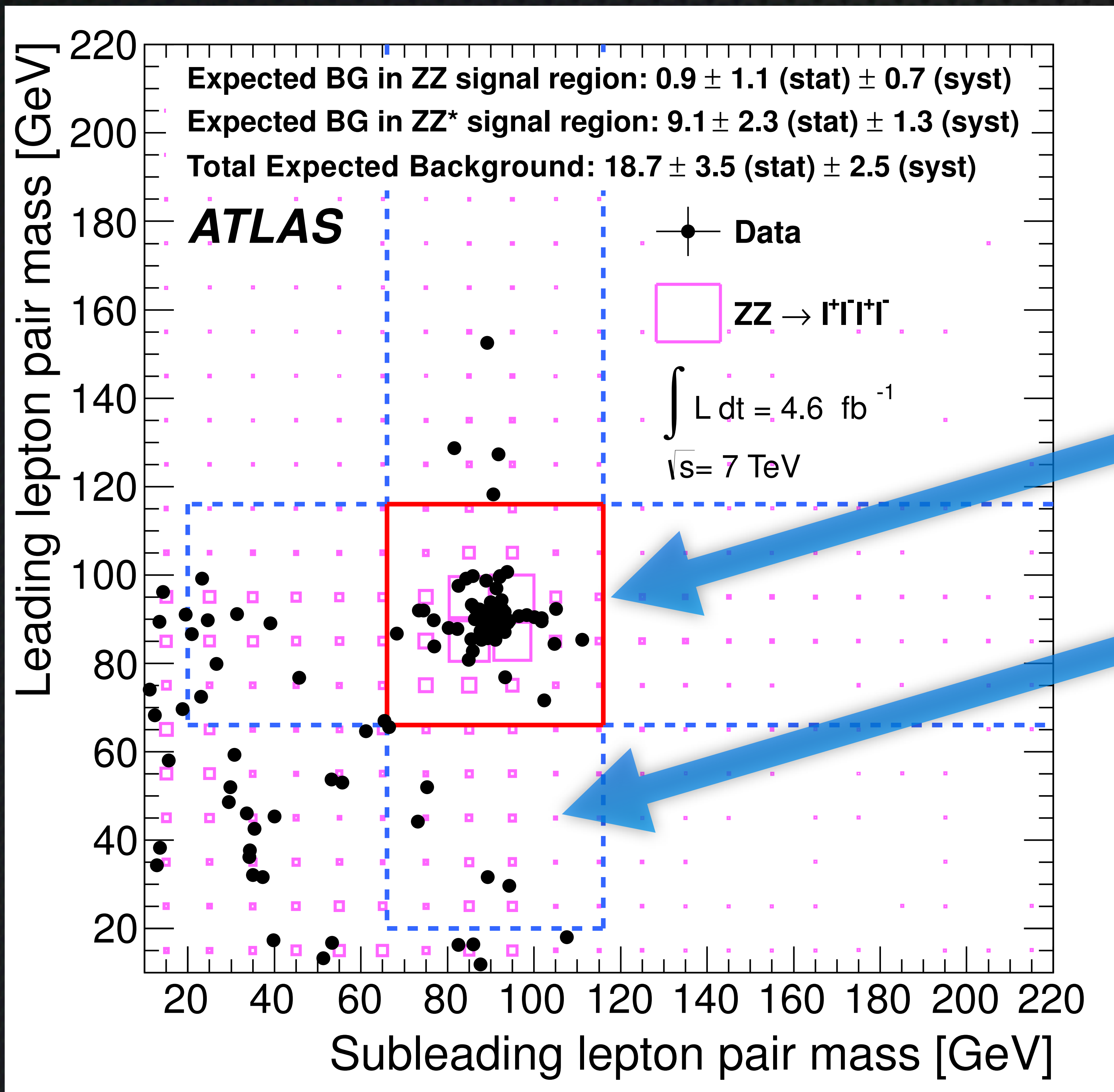




WW+WZ	$\sigma_{measured}$ (pb)	σ_{NLO} (pb)
ATLAS	72 ± 9 ± 15 ± 13 (MC stat)	63.4 ± 2.6

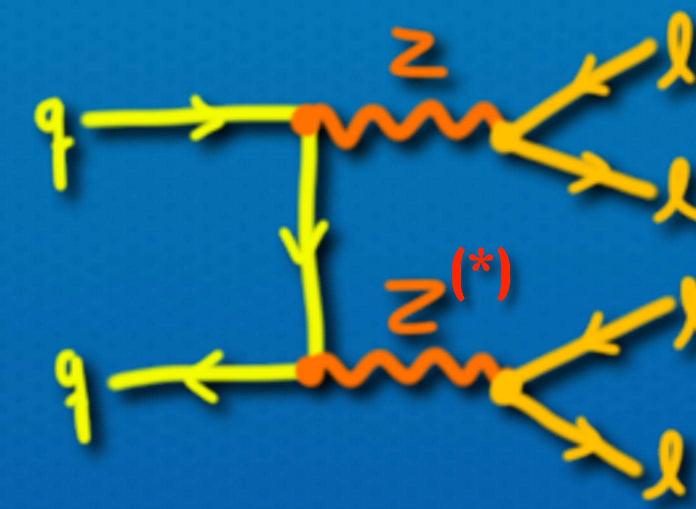
Dibosons: ZZ Production

ZZ → 4 leptons (eeee, μμμμ, eeμμ)



$66 < M_{Z1} < 116$ GeV

$66 < M_{Z2} < 116$ GeV

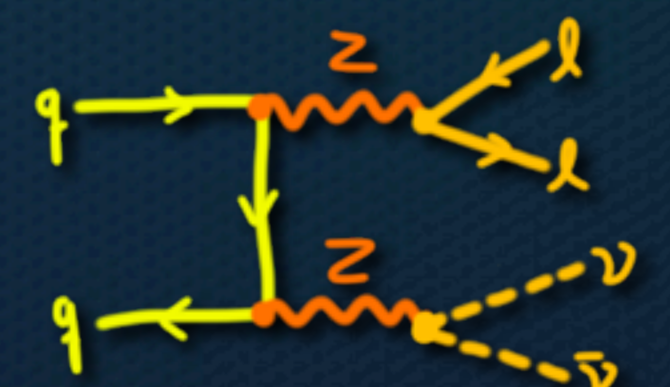


Two Z bosons on-shell

or

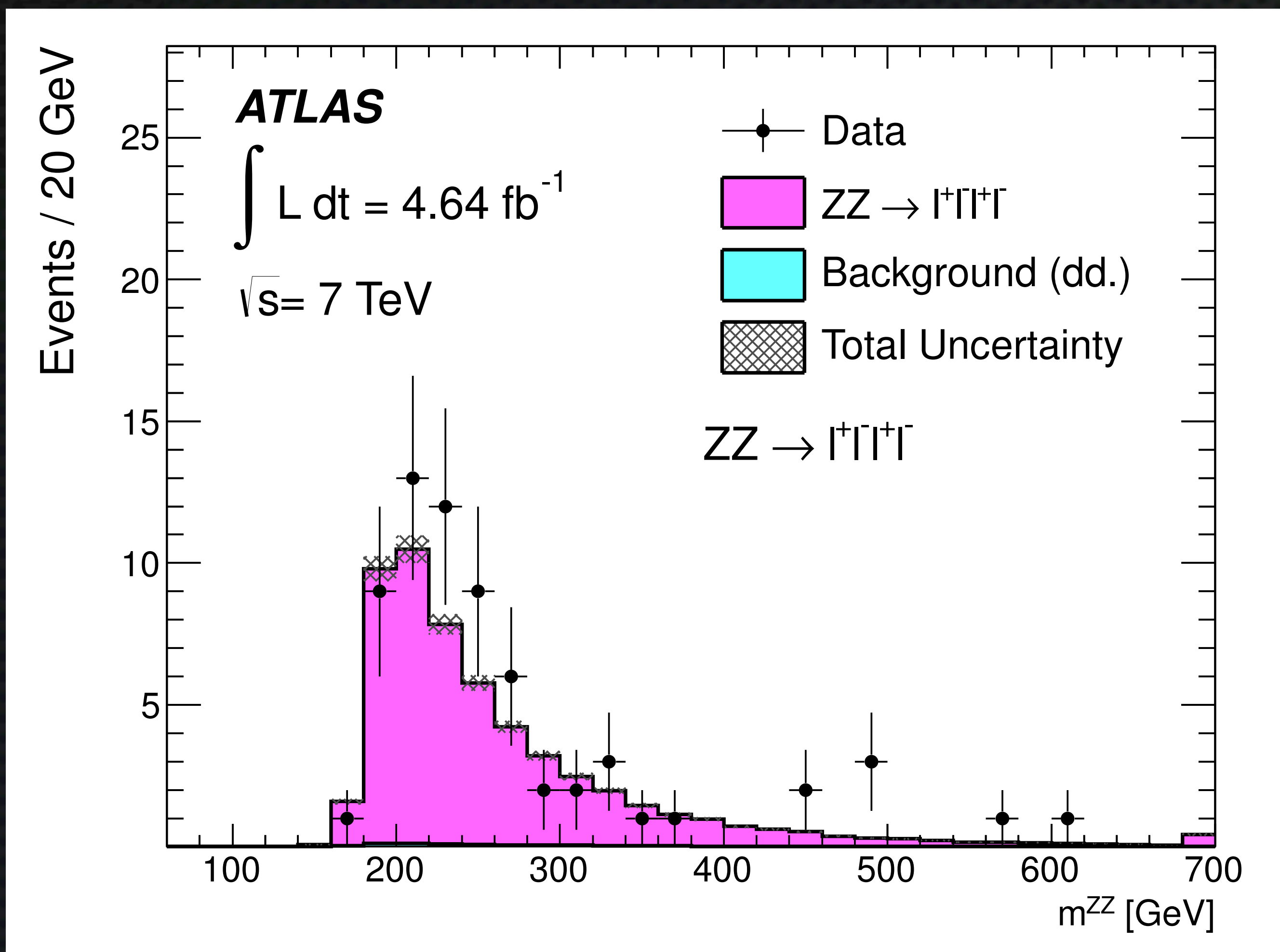
One Z boson on-shell and the other off-shell

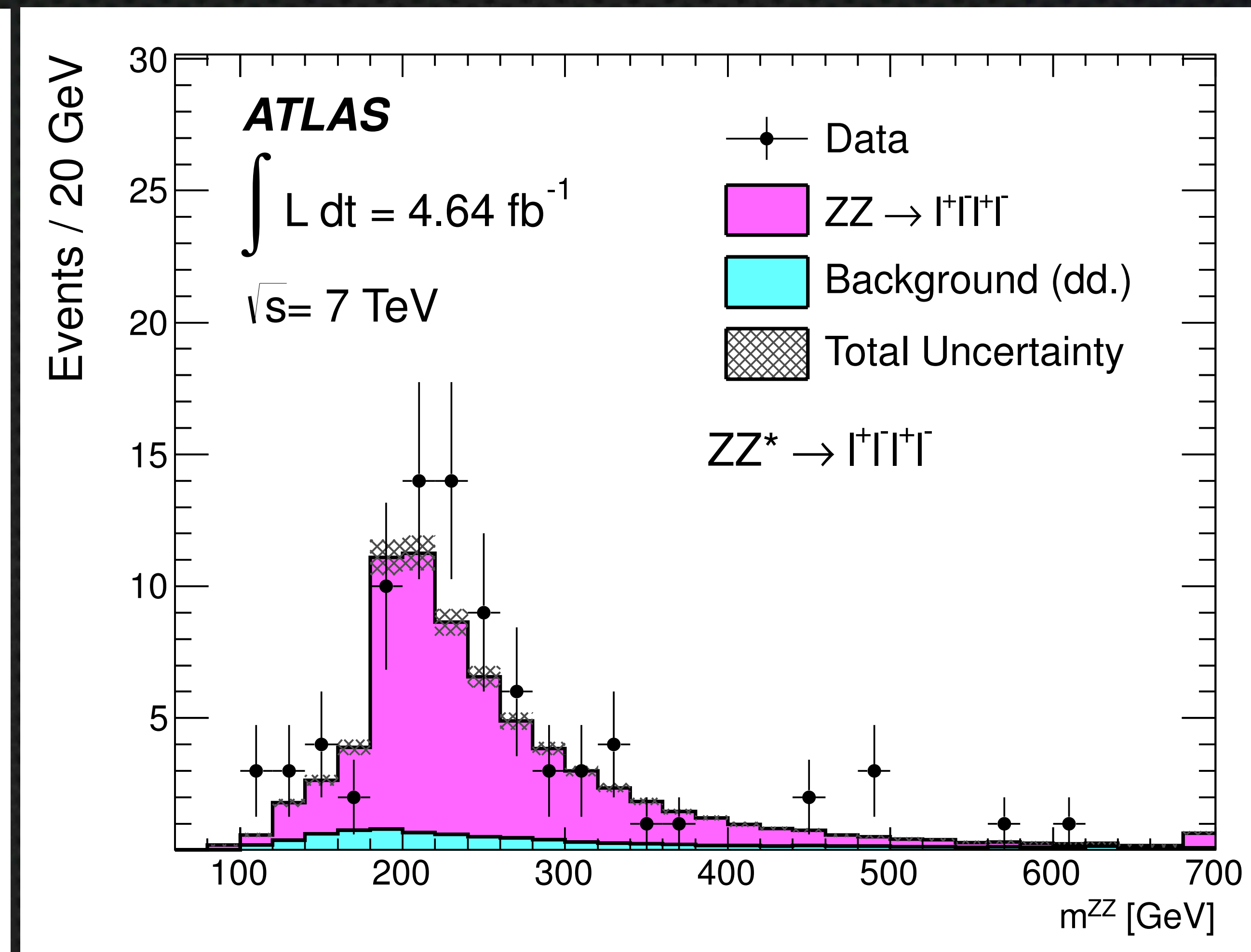
Also used:
Z → νν



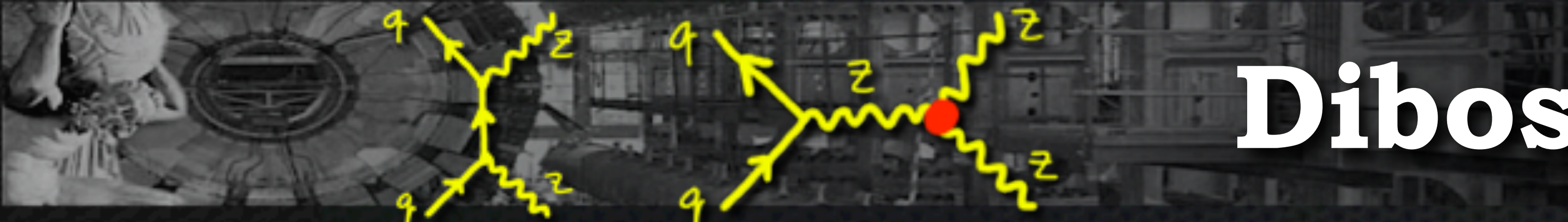
Dibosons: ZZ @ 7 TeV

ZZ → 4 leptons (eeee, μμμμ, eeμμ)



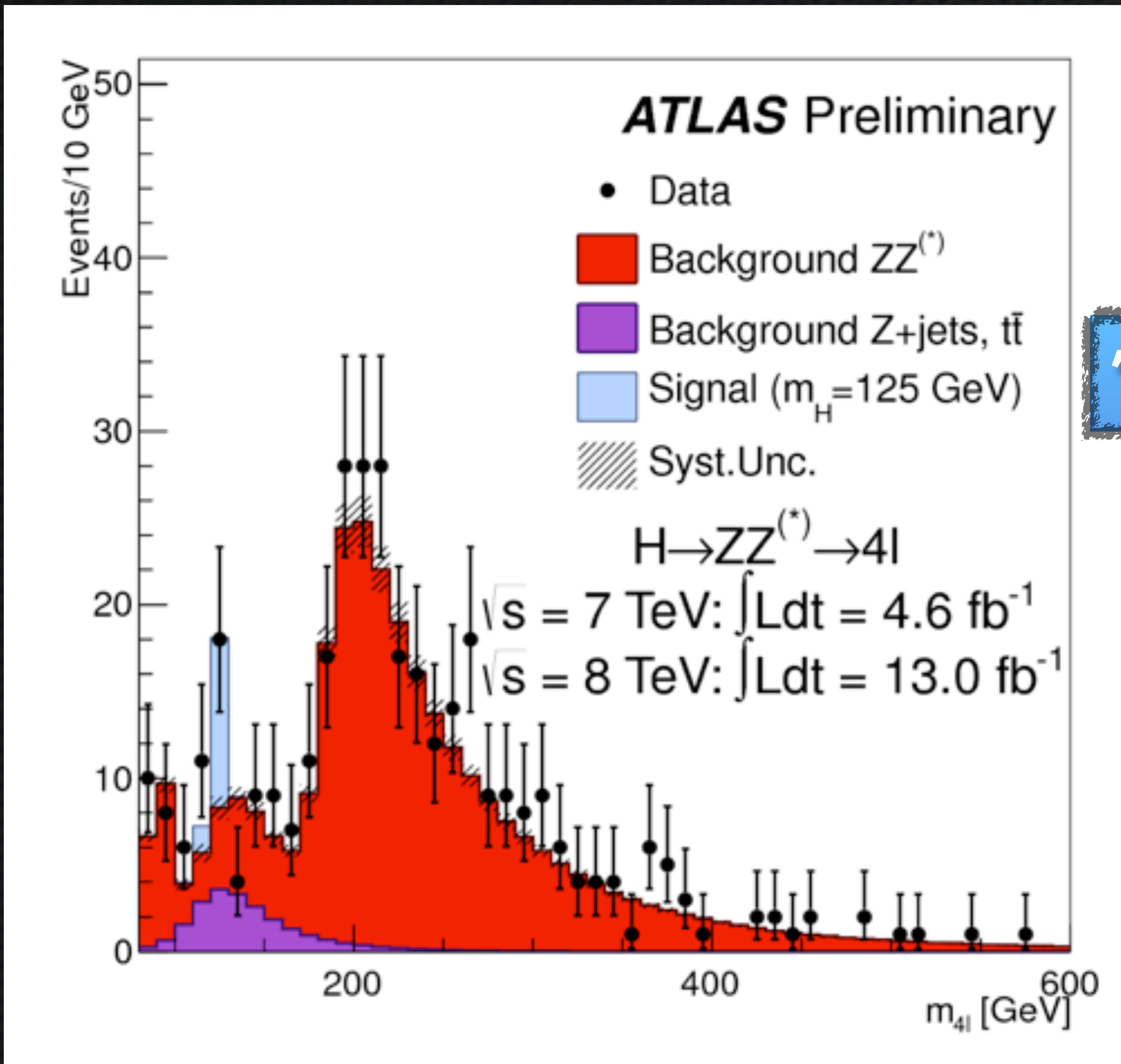


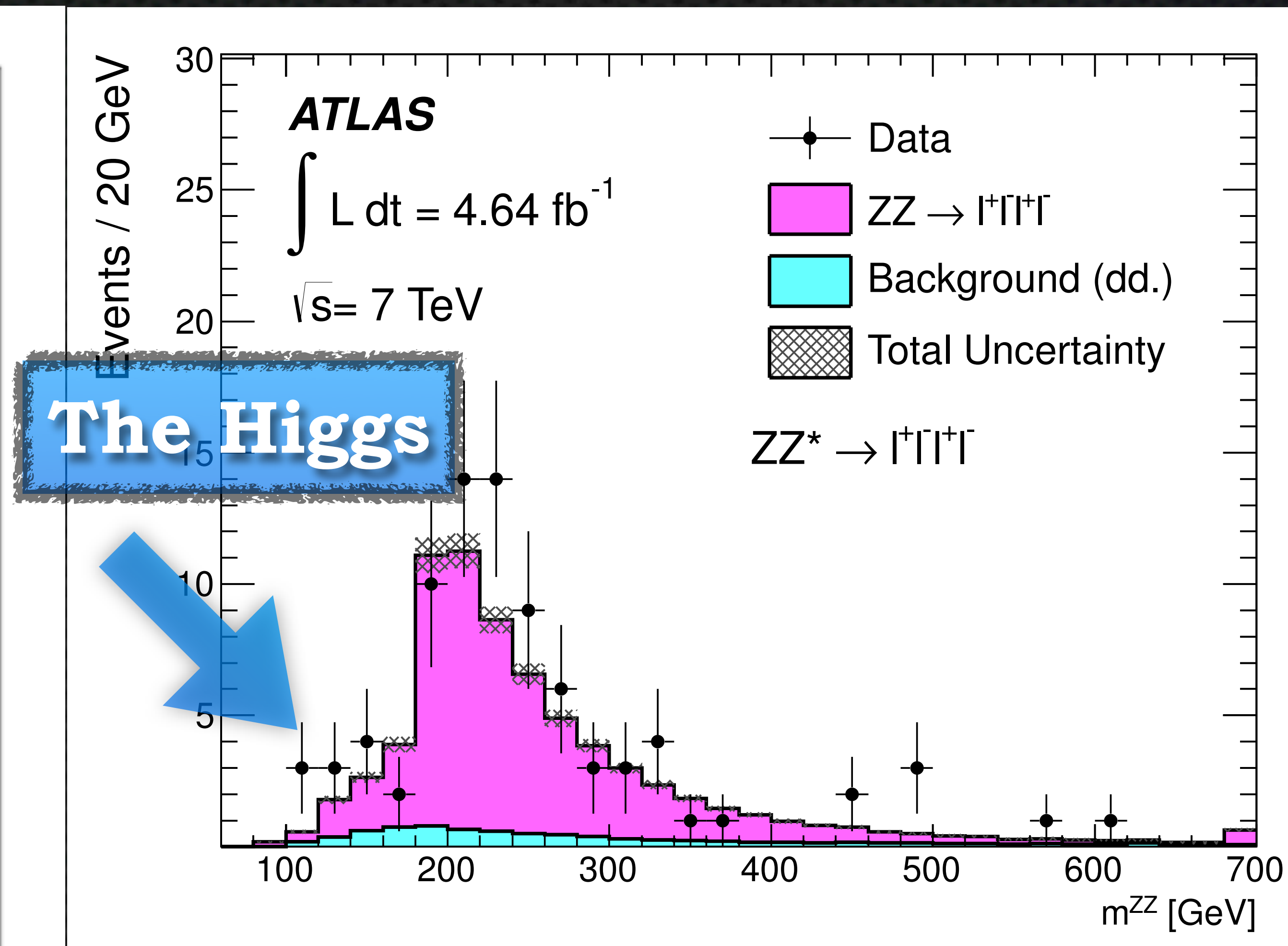
ZZ	$N_{obs(4l)}$	$N_{signal(4l)}$	$N_{bkg(4l)}$	$\sigma_{measured}$ (pb)	σ_{NLO} (pb)
ATLAS	150	117.8	10	$6.7 \pm 0.7 ^{+0.4}_{-0.3} \pm 0.3$	5.9 ± 0.2



Dibosons: ZZ @ 7 TeV

ZZ → 4 leptons (eeee, μμμμ, eeμμ)





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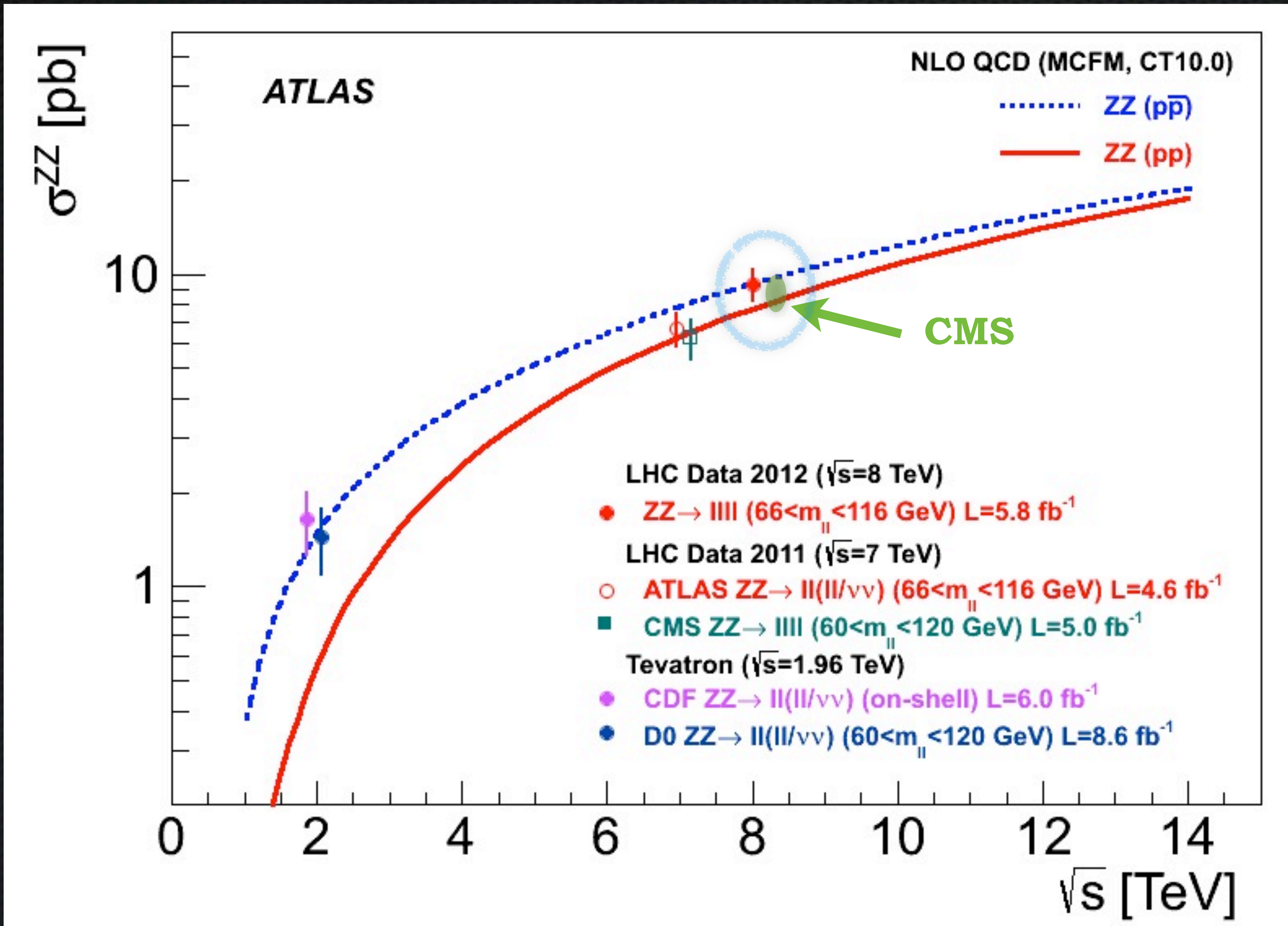
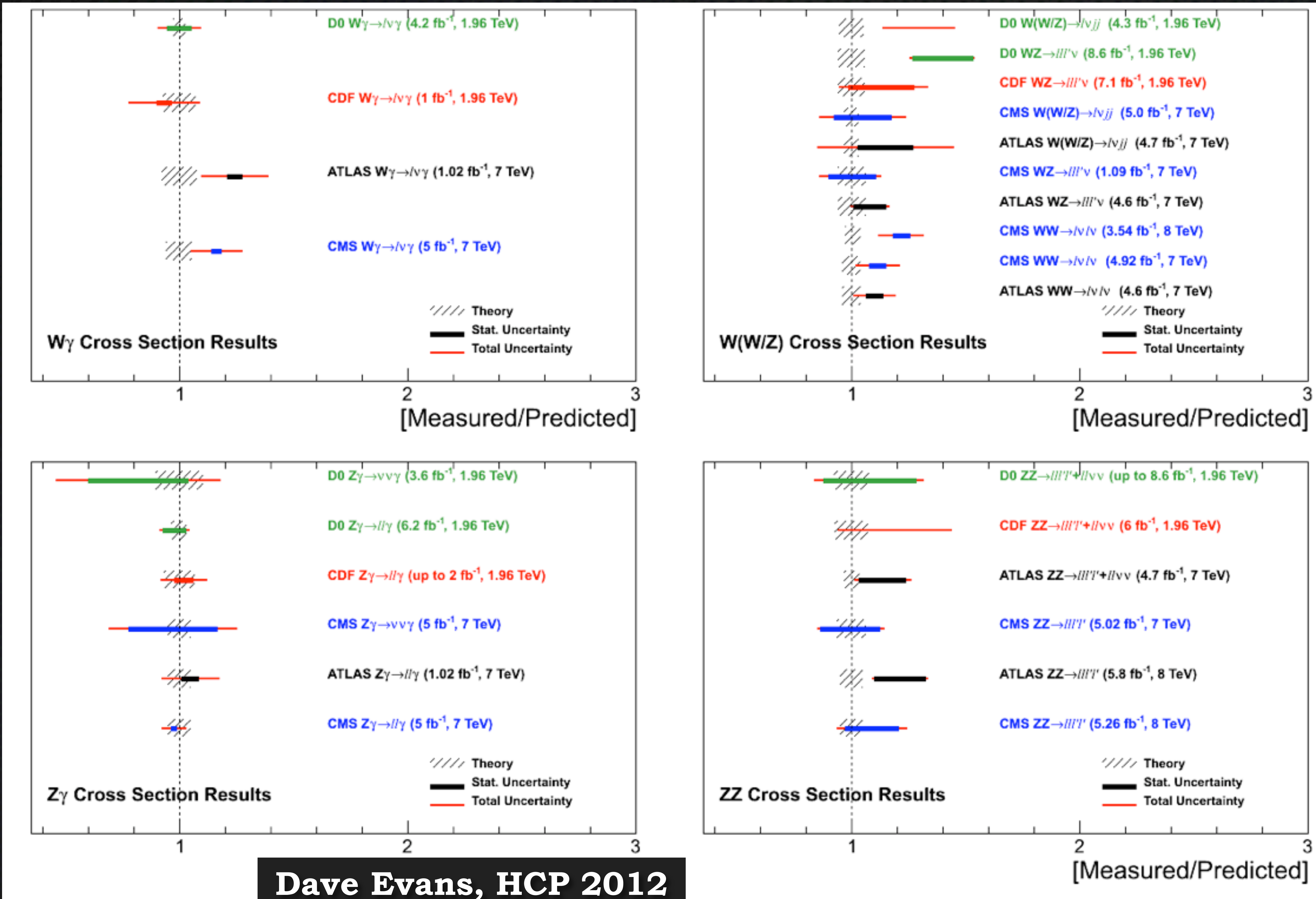
Dibosons: ZZ Overview

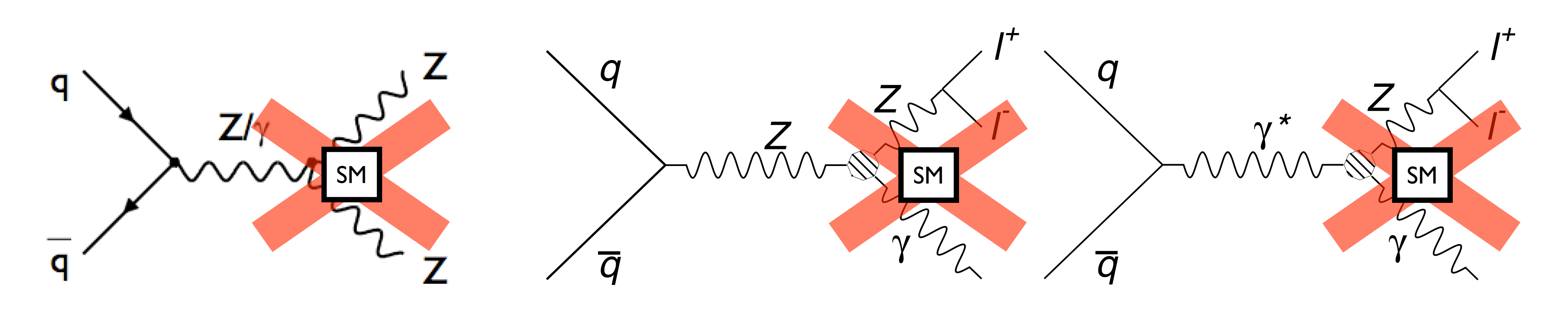


Summary of diboson cross section measurements



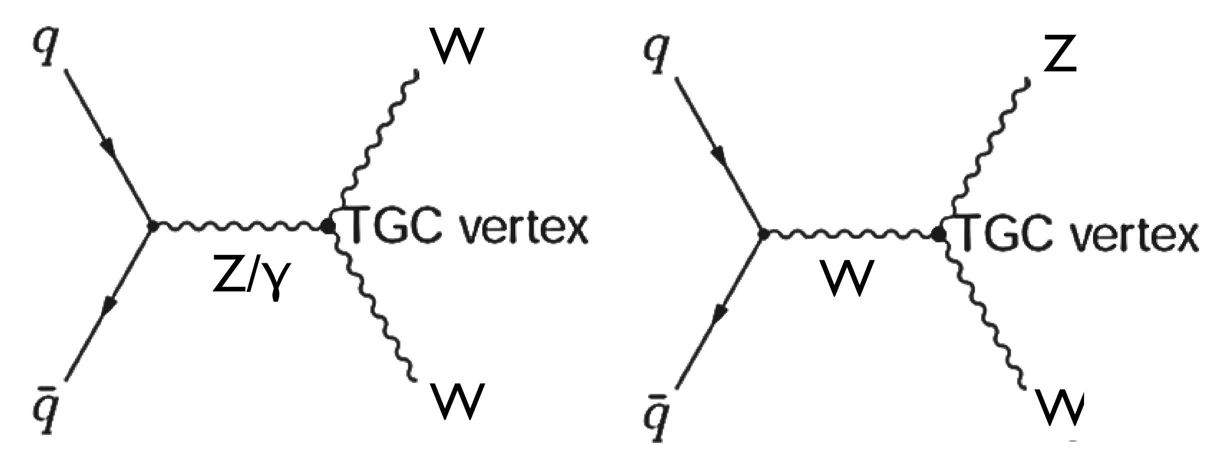
Dave Evans, HCP 2012

Limits on ZZZ, ZZγ , Zγγ aTGC



Anomalous Triple Gauge Couplings

Limits on WWZ, WWγ aTGC



Triple Gauge Couplings (WWZ and WWγ)

The effective Lagrangian for model-independent charged triple gauge couplings can be expressed as:

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

V = Z or γ, $g_{WW\gamma}$ = -e , and g_{WWZ} = -e cot(θ_W)

In the Standard Model: (g_1^V, k_V, λ^V) = $(1,1,0)_{SM}$

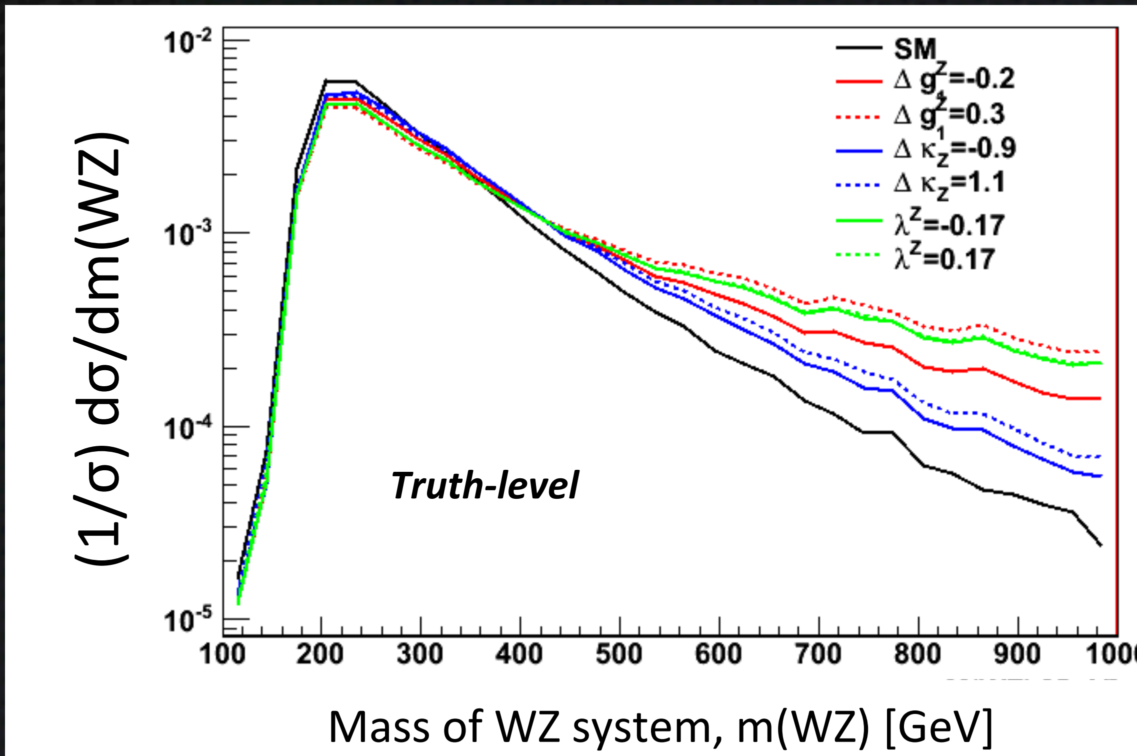
Set limits on: $\Delta g_1^V = g_1^V - 1$, $\Delta k^V = k_V - 1$, λ^V

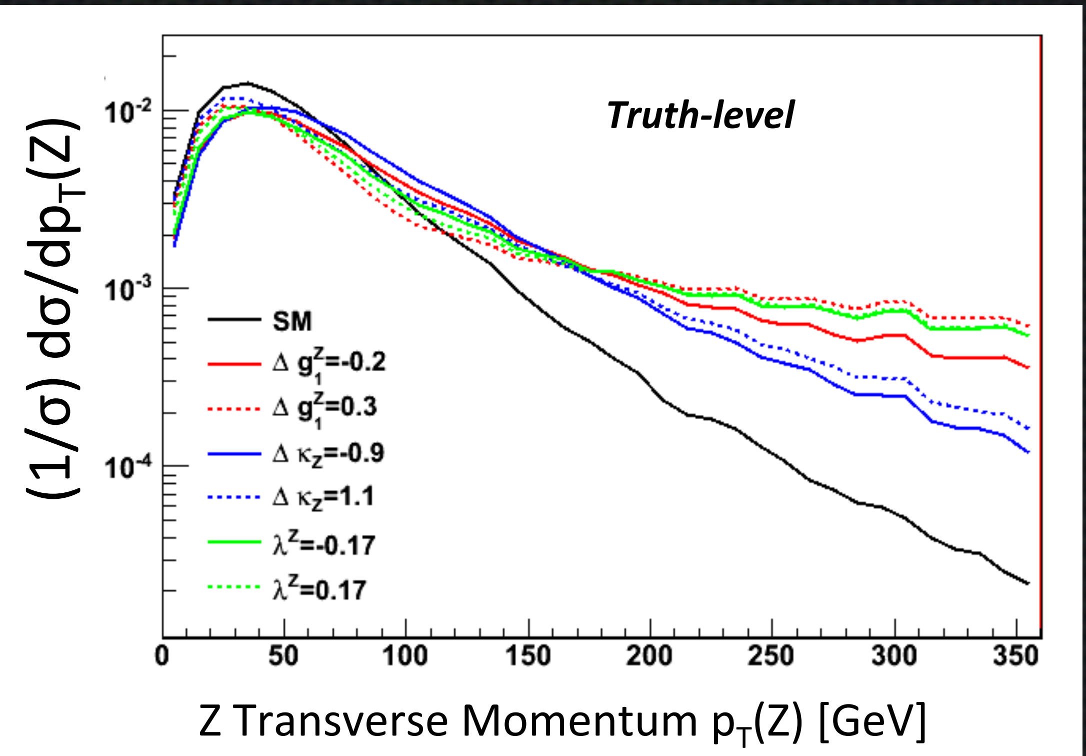
Introduce arbitrary cut-off scale Λ to enforce unitarity

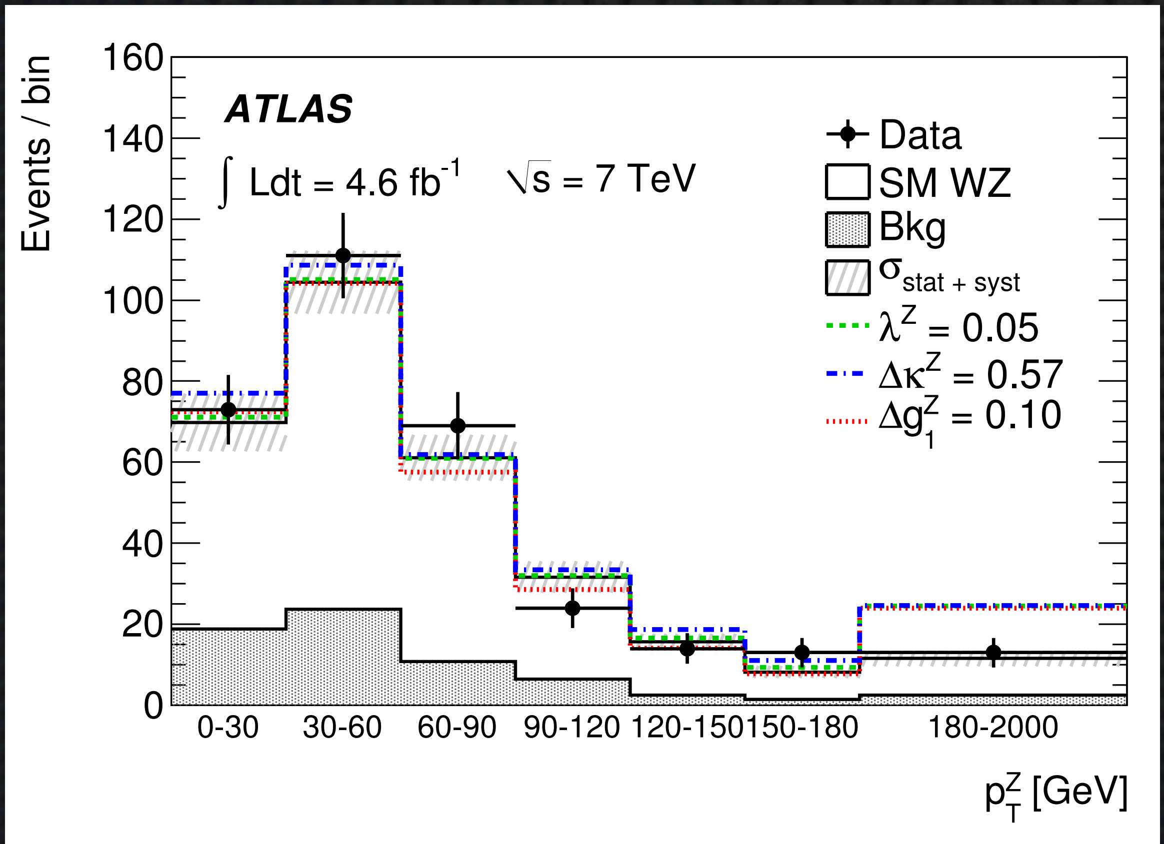
$$\alpha(\hat{s}) = \frac{\alpha_0}{(1+\hat{s}/\Lambda^2)^2}$$

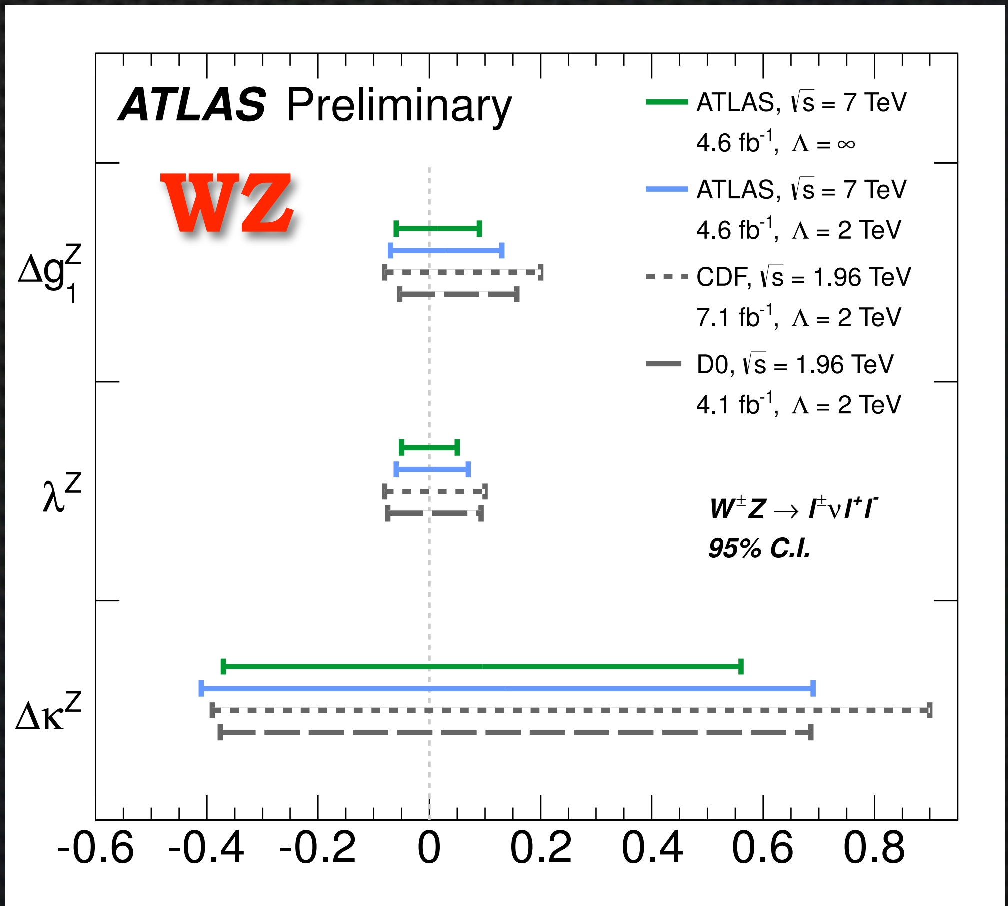
Cross section with aTGCs has strong energy dependence
- **k_Z proportional to $\sqrt{\hat{s}}$; g_1^Z and $\lambda^Z \sim \hat{s}$**
- **→ measure differential cross-section sensitive to $\sqrt{\hat{s}}$**

Anomalous TGC effect in WZ production



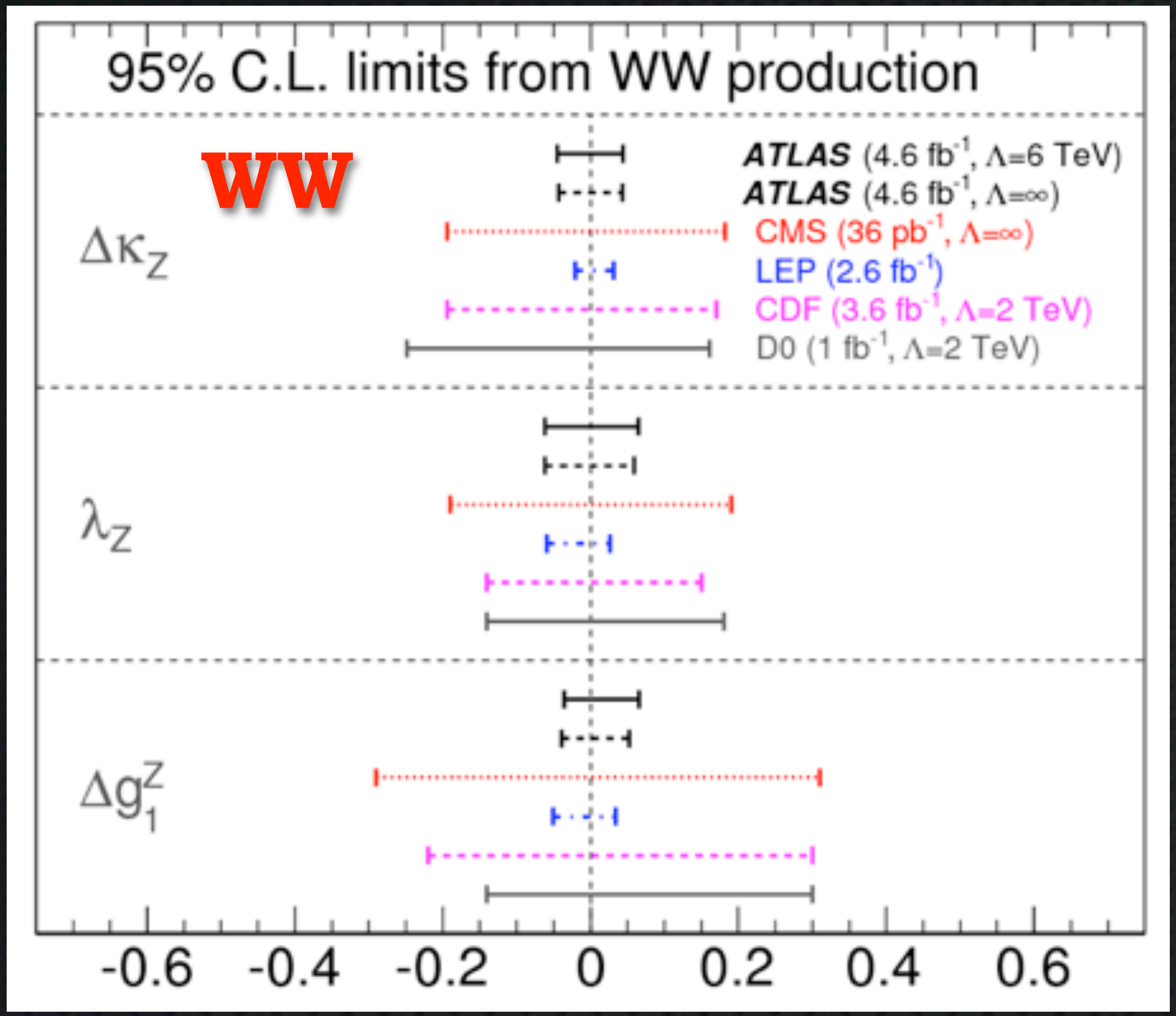




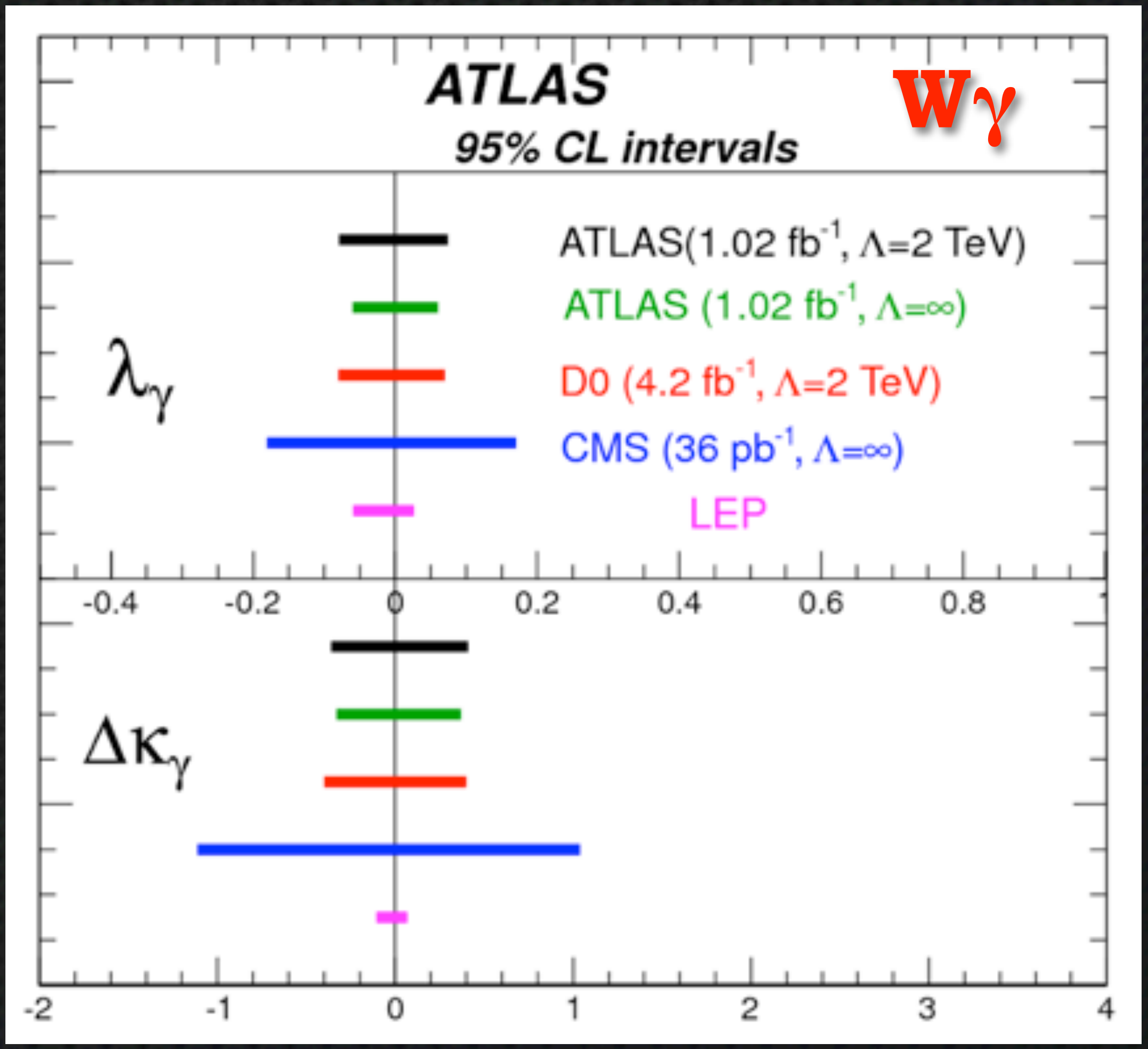


(using $P_T(Z)$ distribution)

Triple Gauge Couplings (WWZ and WWγ)



(using $P_T(l)$ distribution)



(from $P_T(\gamma)$ distribution)

neutral Triple Gauge Couplings (ZZZ and ZZγ)

- **Possible vertices using an effective Lagragian**

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

CP-violating **CP-conserving**

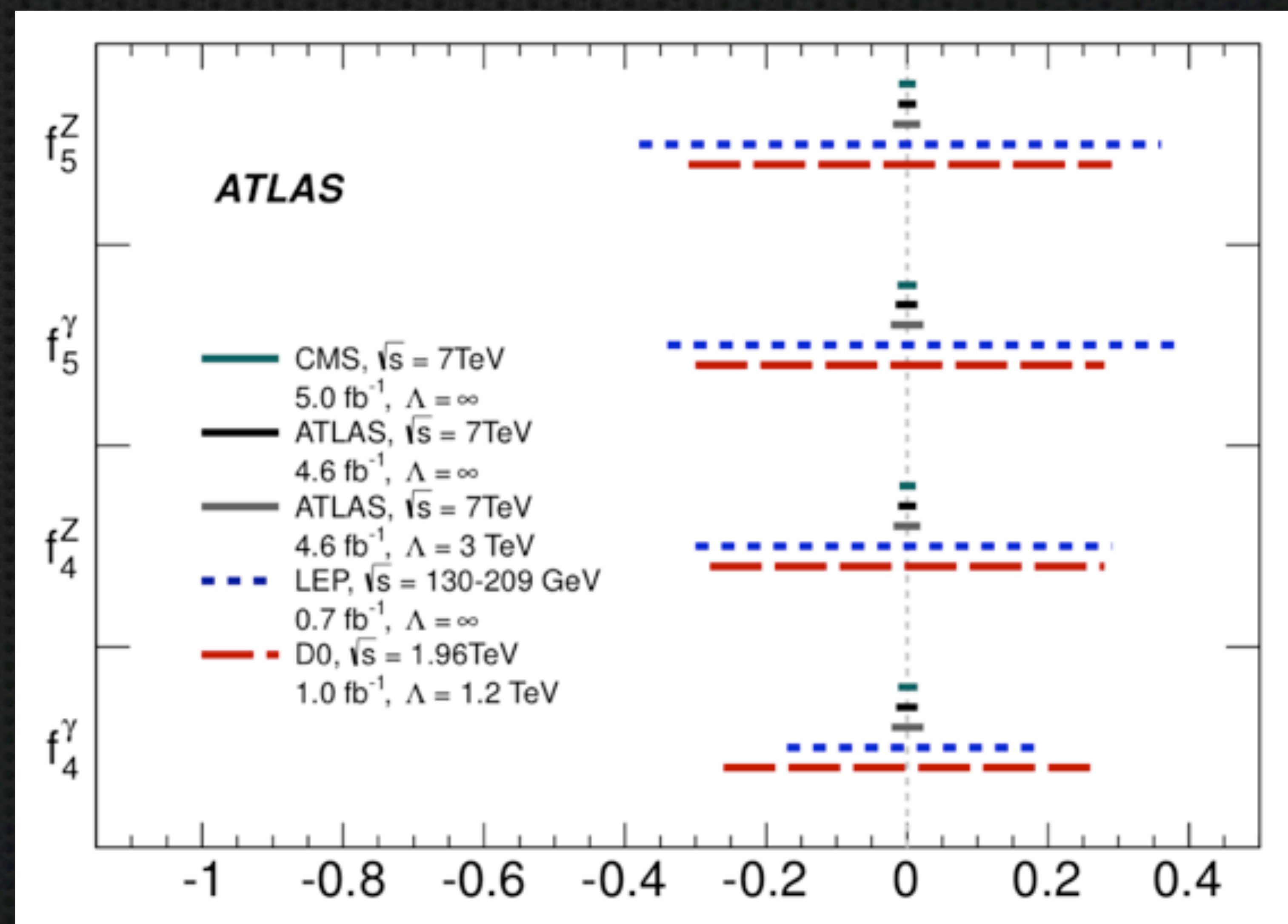
Scale dependent form-factors

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

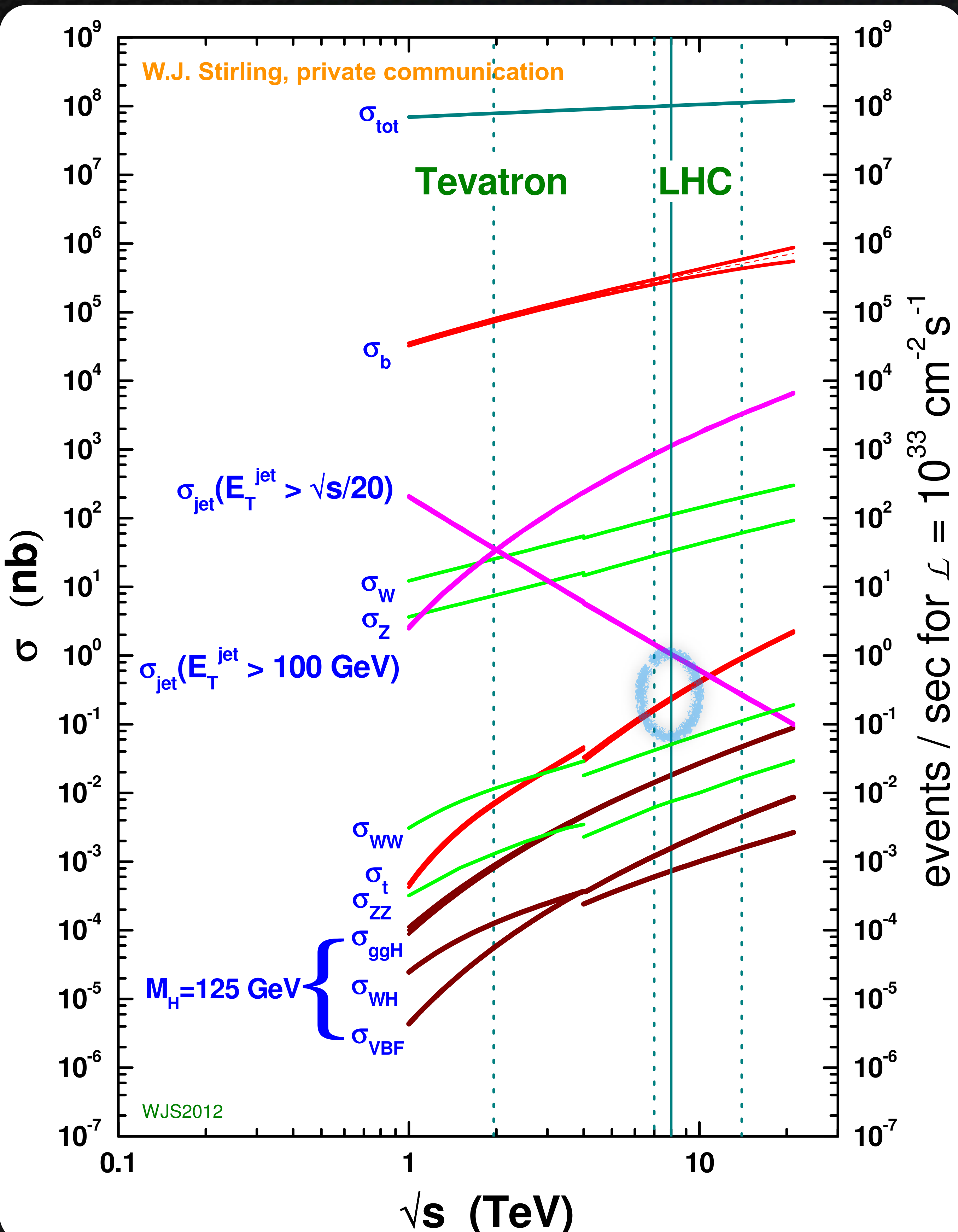
with cutoff scale Λ

ZZZ, ZZγ

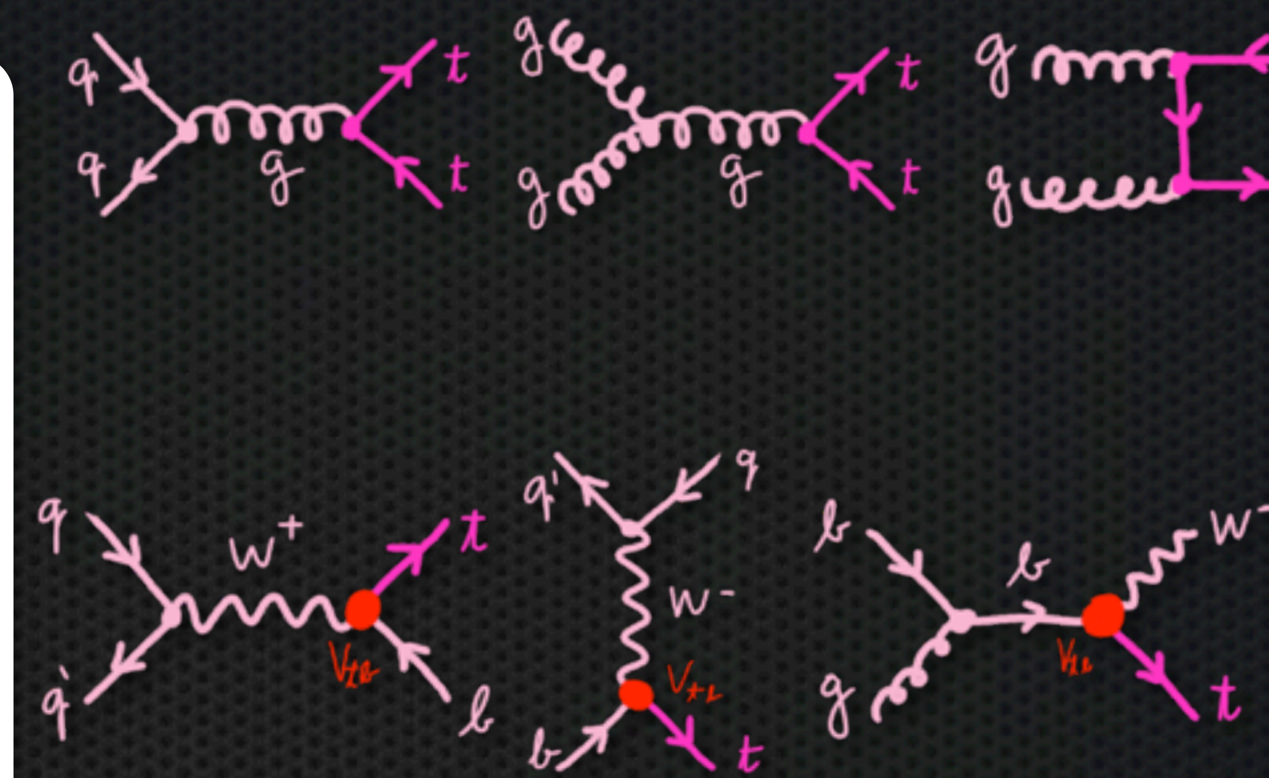
$(f_4^Z, f_4^\gamma, f_5^Z, f_5^\gamma) = (0,0,0,0)_{SM}$



(using $P_T(Z)$ distribution)



4 × more top pairs at LHC @ 7 TeV with 1 fb^{-1}, than at the Tevatron with 5 fb^{-1}

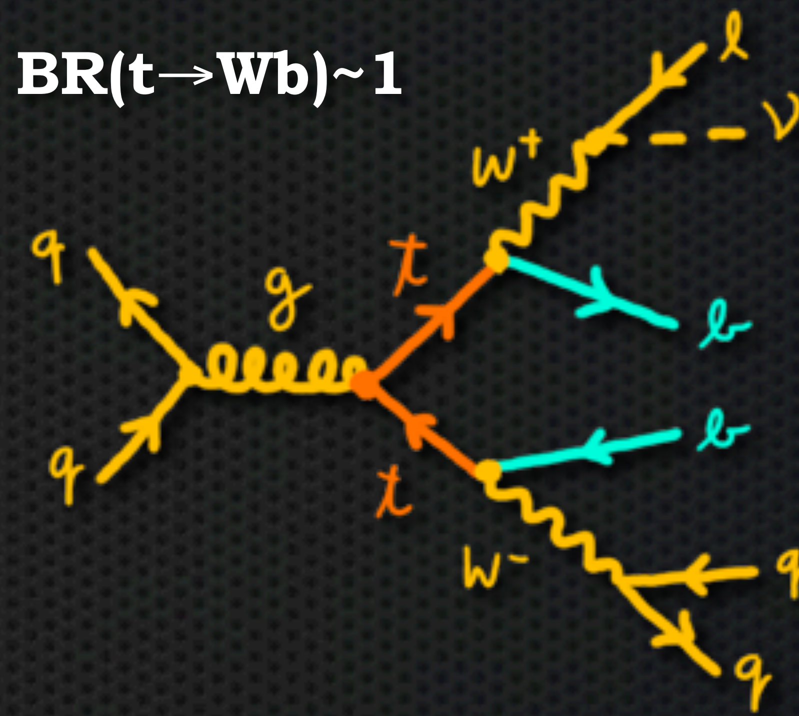


Top Quark Production

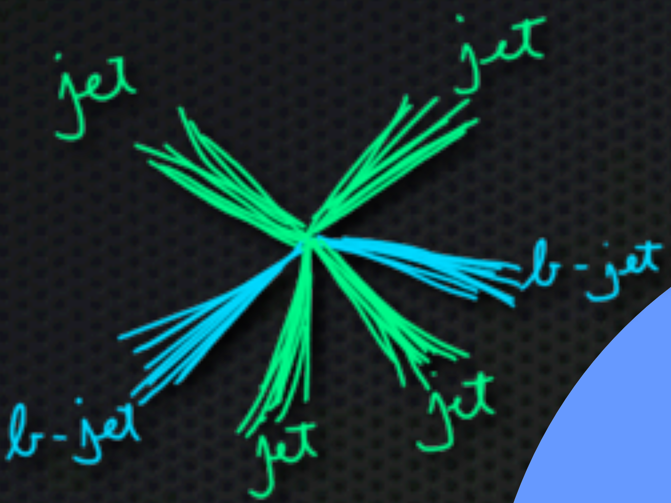
- Test QCD
- Study analysis techniques
  - b-tagging, JES
- Backgrounds for searches
- A good place to search for new physics

Top quark signatures

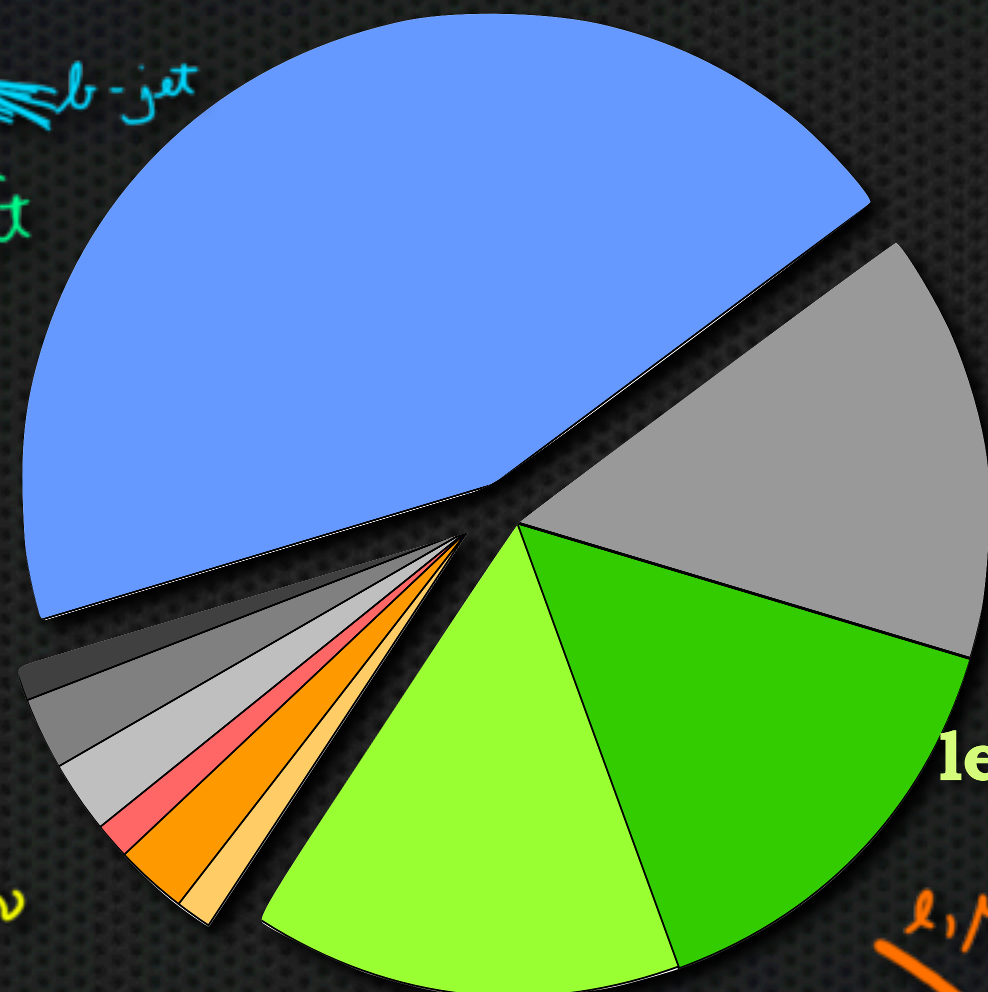
BR(t→Wb)~1



all jets: 46%



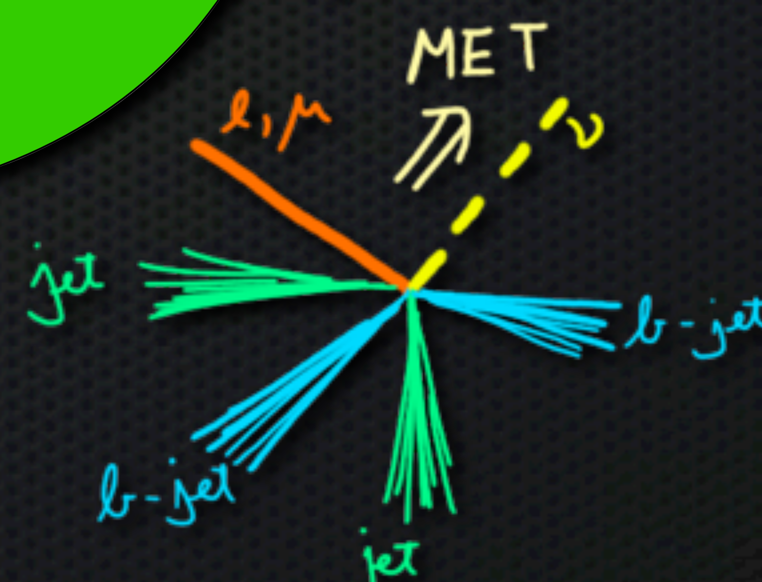
Large background (main bkg: multijets)



dileptons(e,μ): 4%

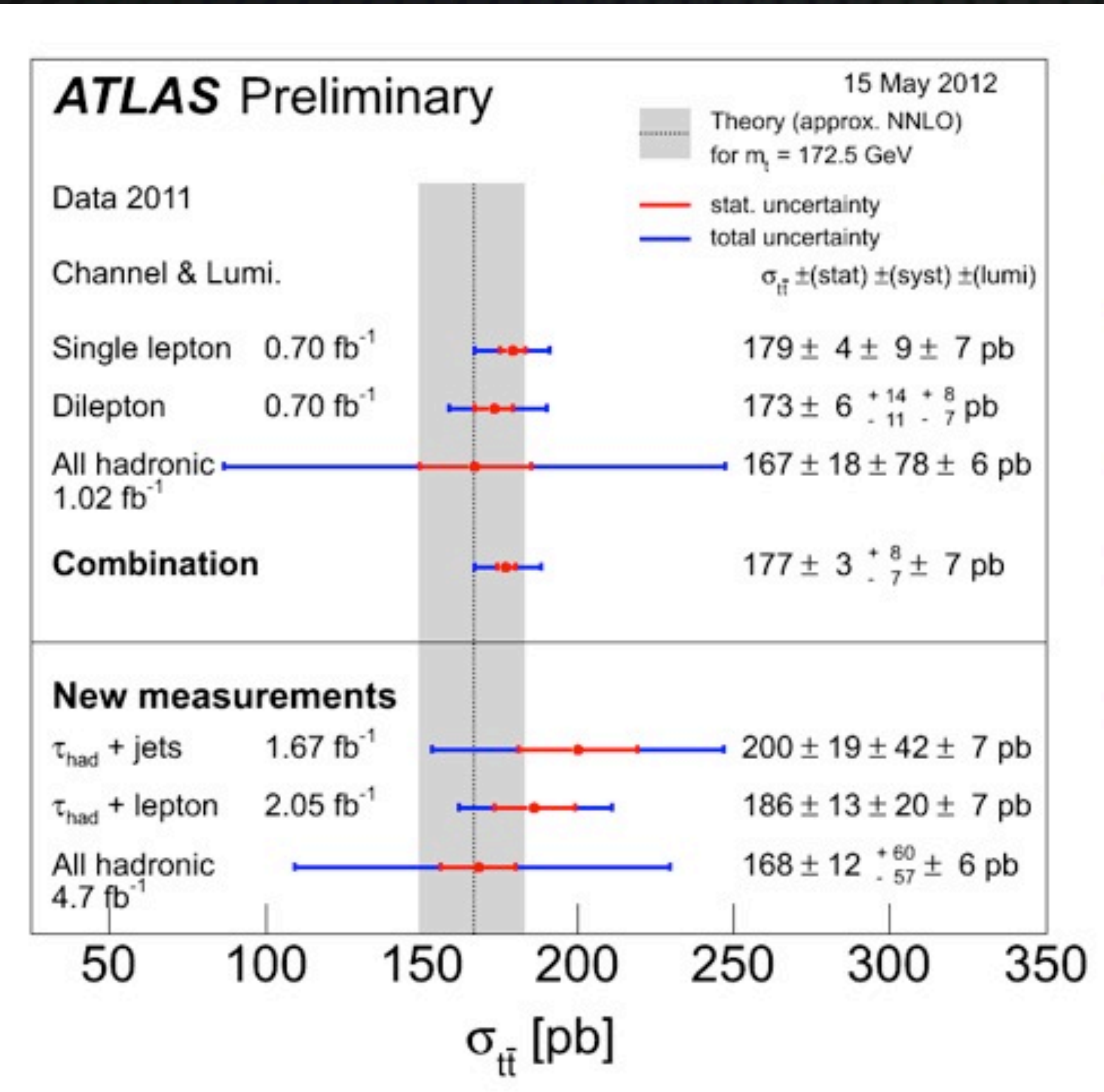
Small background, but small rate (main bkg: Drell-Yan and electroweak)

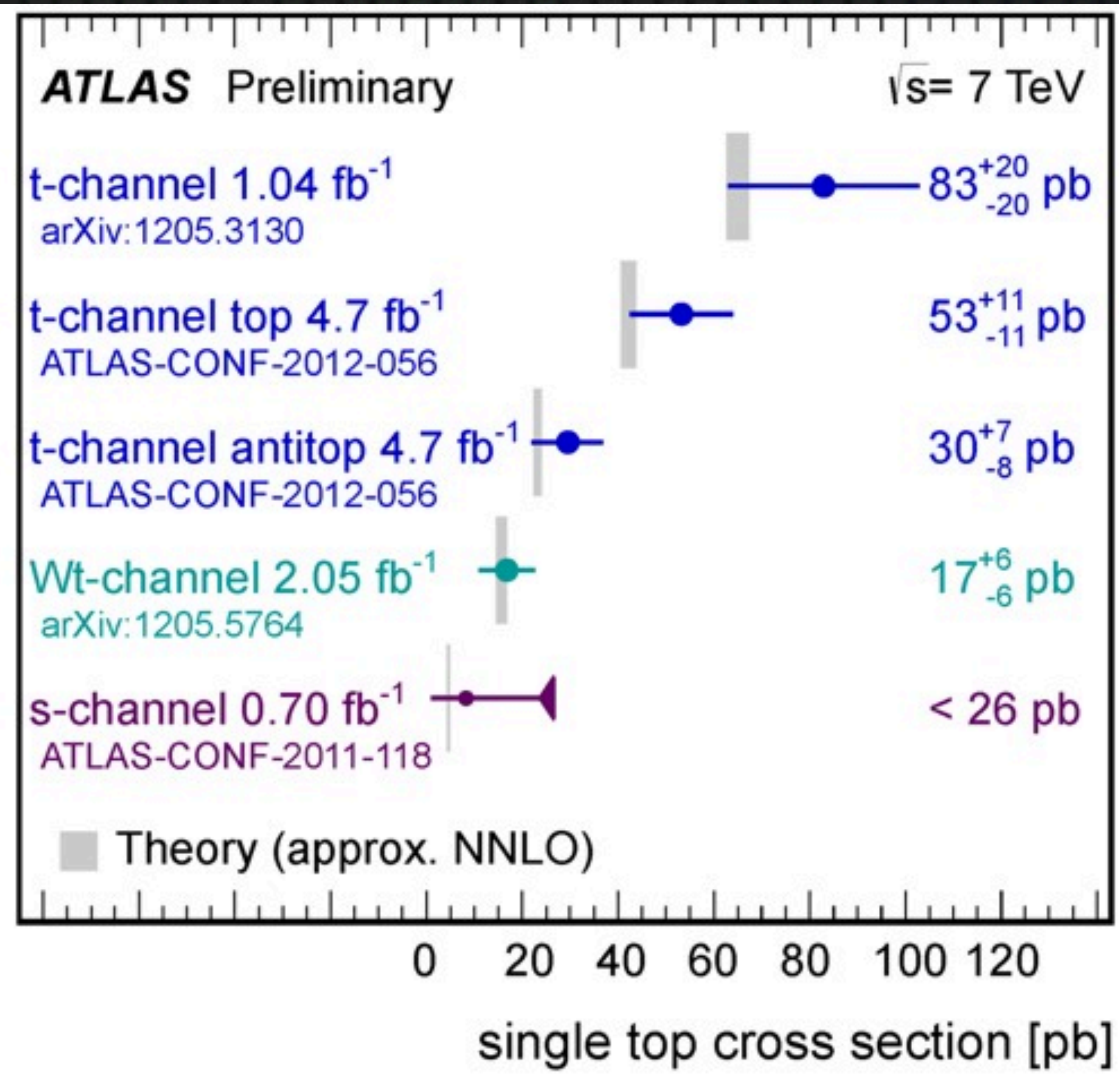
lepton+jets: 30%



Reasonable background (main bkg: W+jets and multijets)

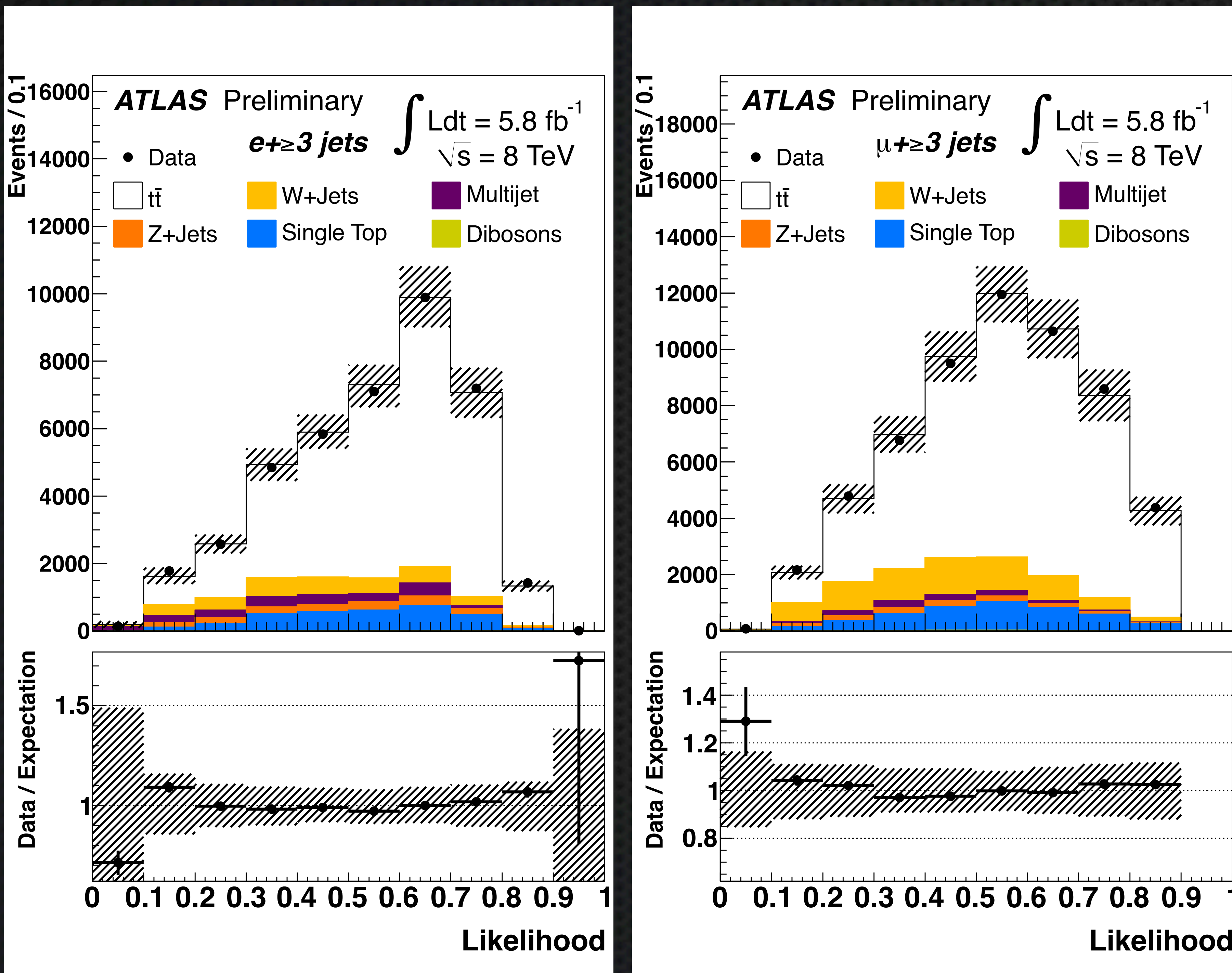
Top Quark Cross Section Measurements @ 7 TeV





Top Quark Pair Cross Section Measurement @ 8 TeV

1-lepton channel (5.8 fb^{-1}) using likelihood template fit



Inclusive tt cross section (using m(t) = 172.5 GeV:

σ = 241 ± 2 (stat)
± 31 (syst)
± 9 (lumi) pb

Syst. dominated by MC signal modeling (ISR/FSR, generator, parton shower, PDF)

Theory:

$\sigma = 238^{+22}_{-24}$ pb
(HATHOR, approx. NNLO)

Top Quark Pair Cross Section Measurement @ 8 TeV

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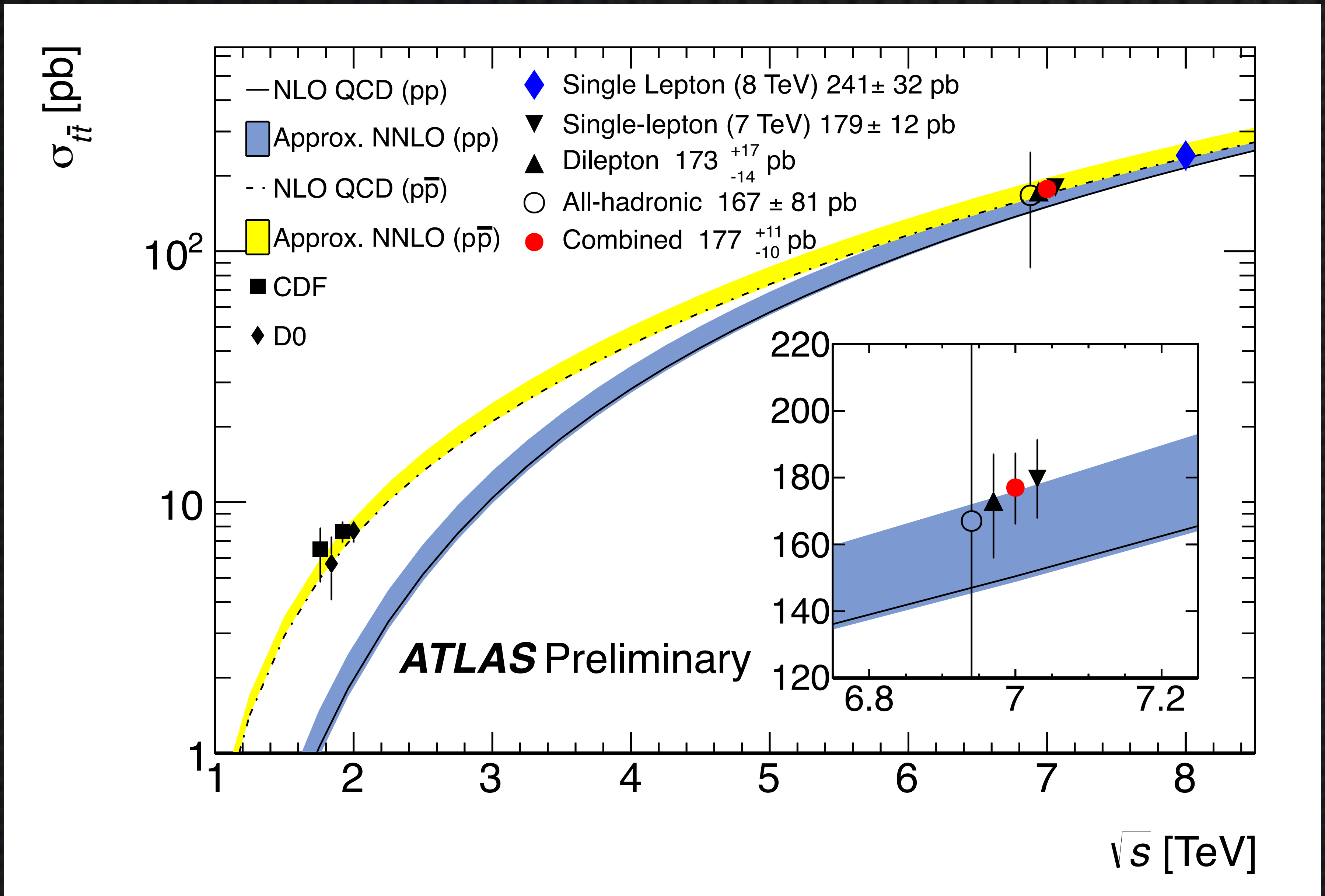

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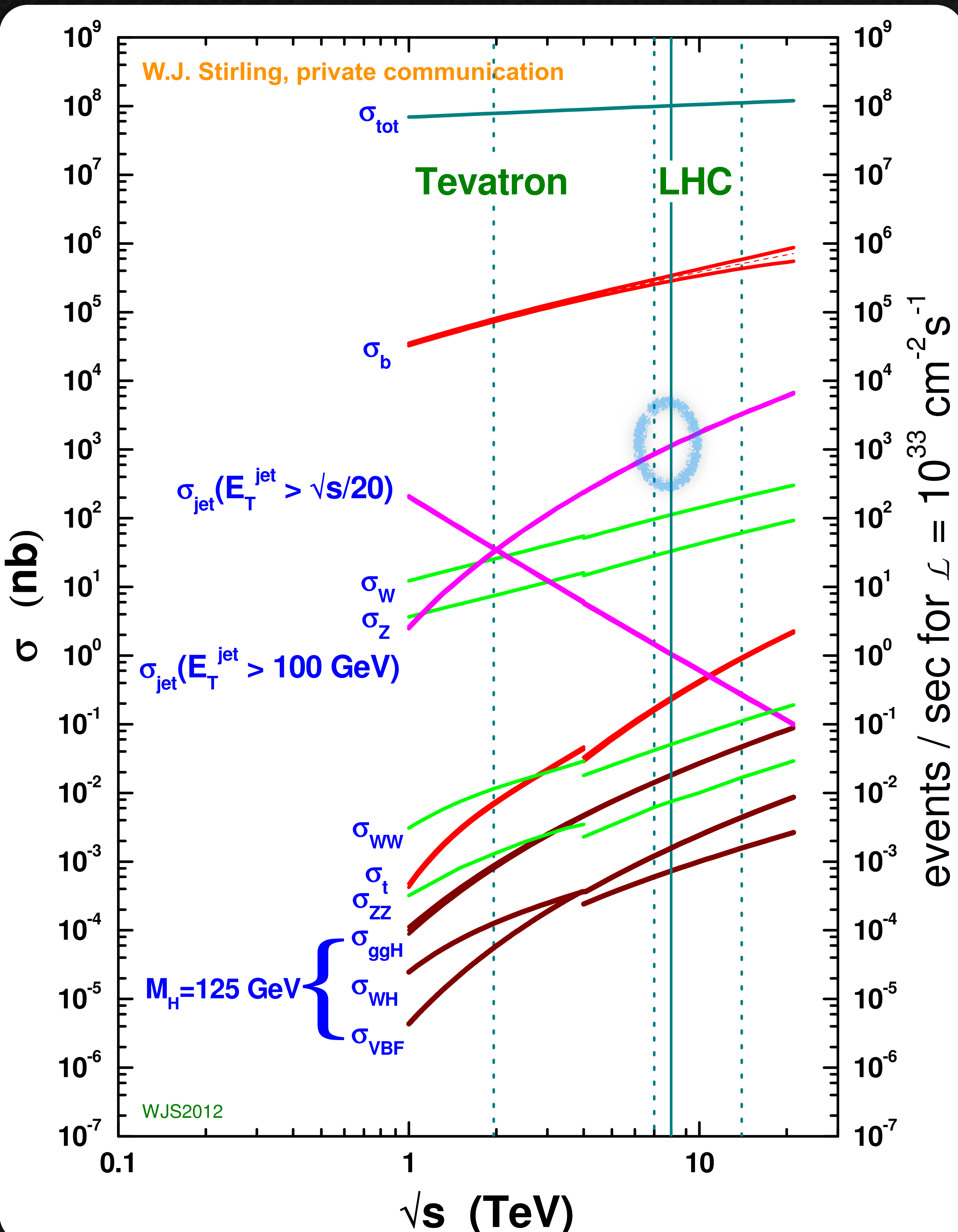
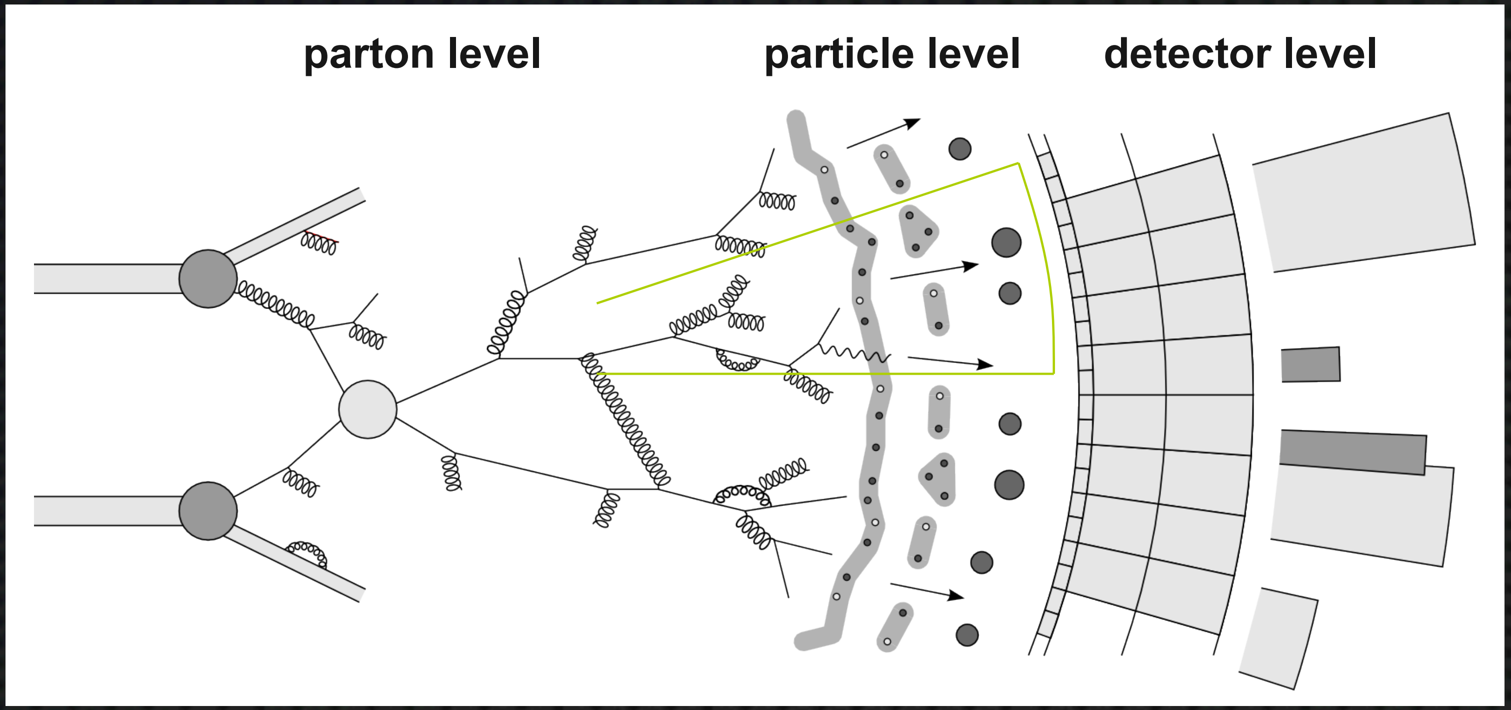


Jet Production

- NLO QCD tests at TeV scale
- Proton PDFs
- Performance measurements
- Backgrounds for NP searches

Jet Measurements

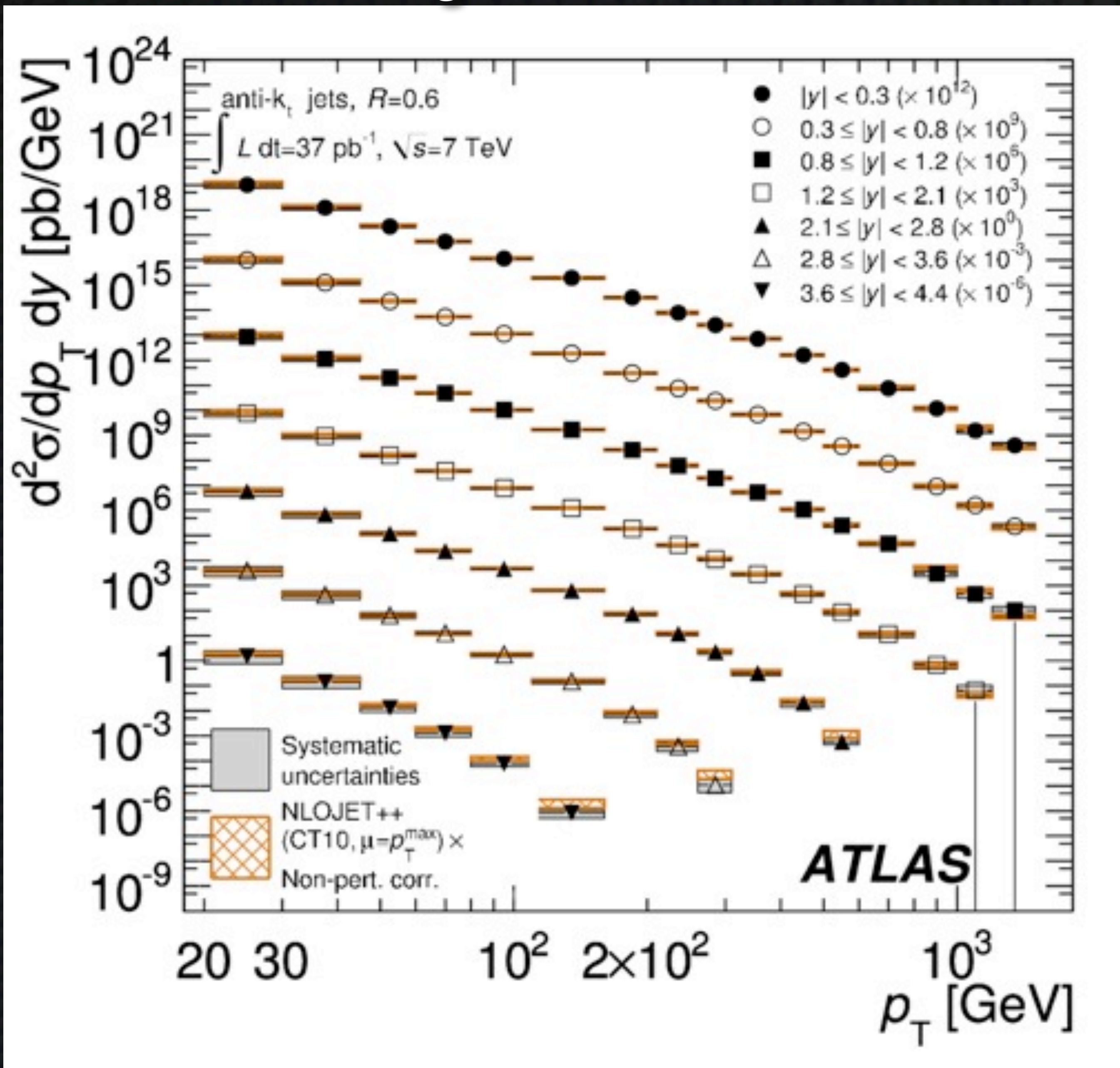


- **Jet algorithm:**
  - anti-k_t with distance parameter R=0.4 and R=0.6
    - Defined at parton, particle and detector lever (FASTJET)
  - Measurement
    - Unfolding data from detector effect ==> **particle level**
  - Predictions:
    - NLO pQCD with non-perturbative corrections
    - Compare different generators, tunes and PDFs

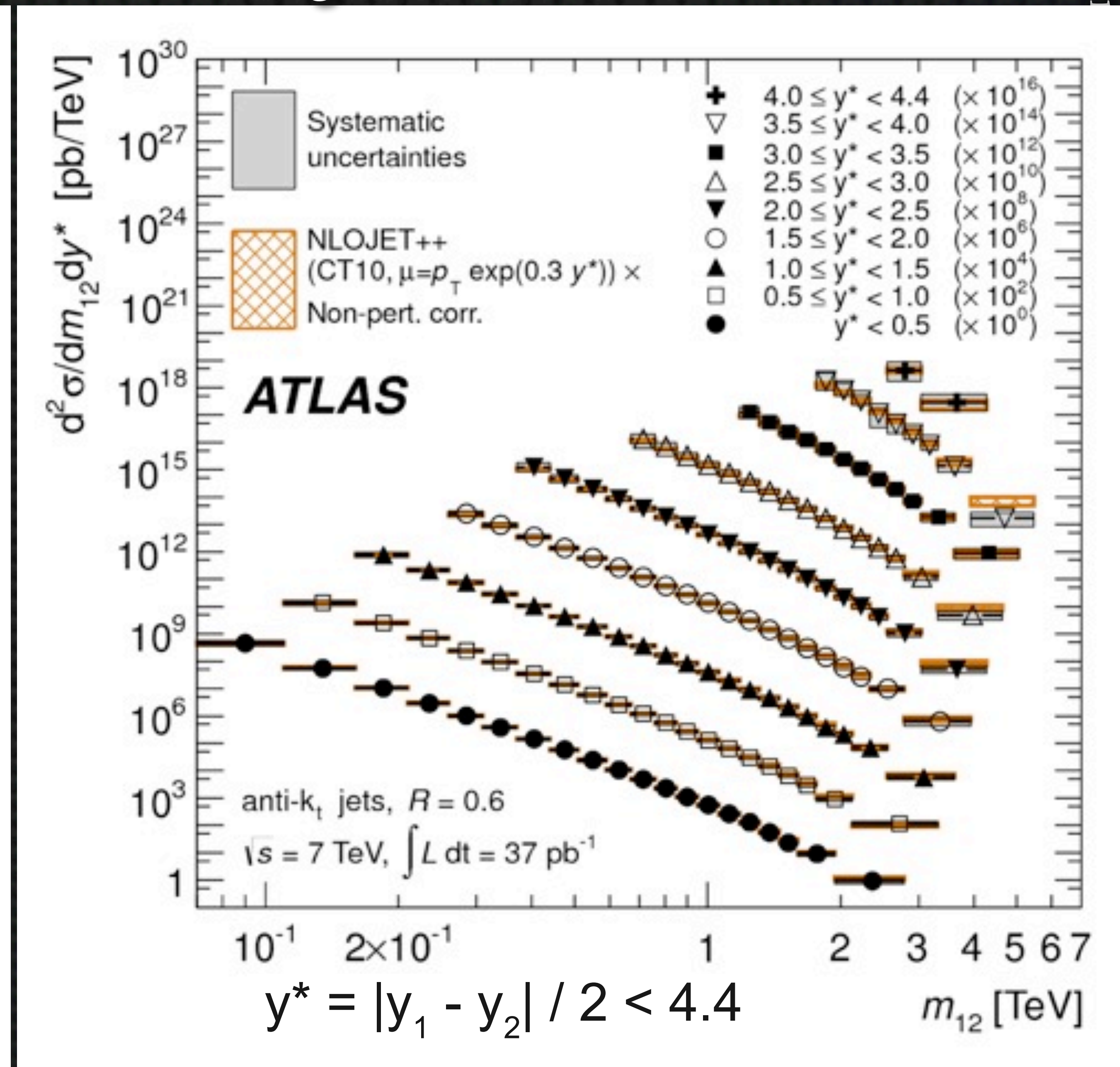
Inclusive Jet and Dijet Cross Sections at 7 TeV

L = 37 pb^{-1}

Inclusive jet cross section



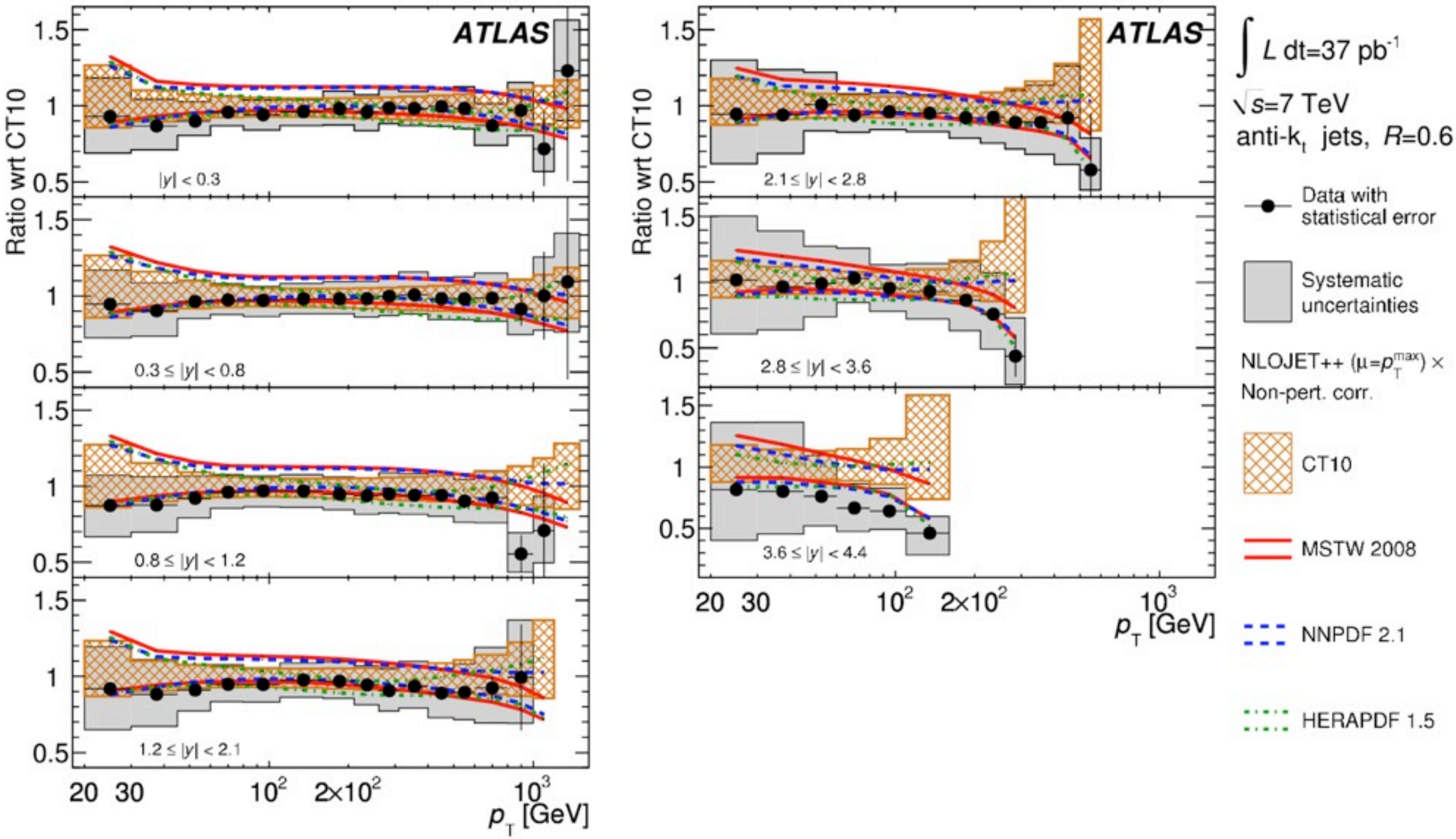
Dijet cross section



NLOJET++ prediction with CT10

Inclusive Jet Cross Sections at 7 TeV

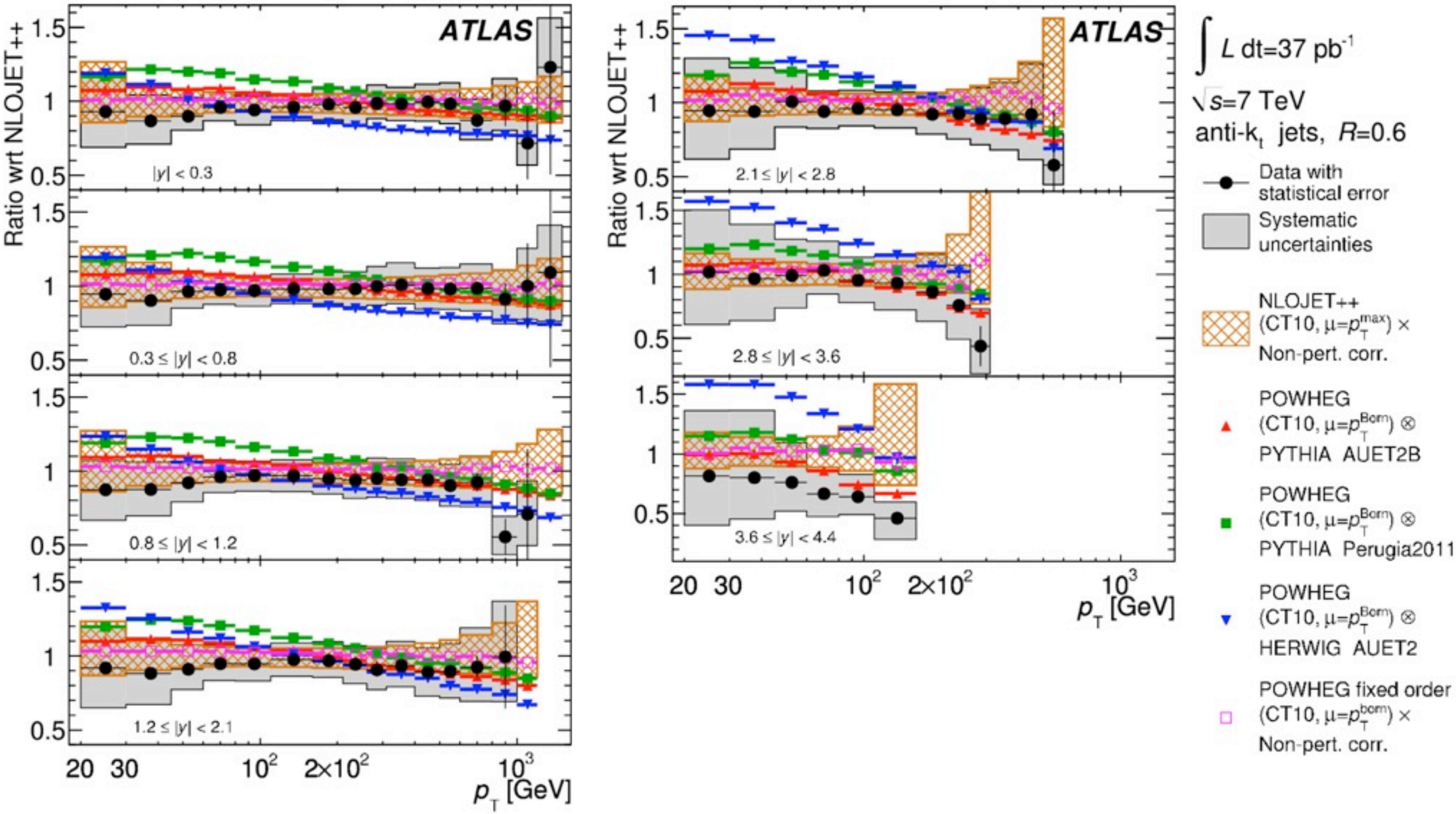
Comparison with different Parton Distribution Functions



Good general agreement

Inclusive Jet Cross Sections at 7 TeV

Comparison with different shower/underlying event models



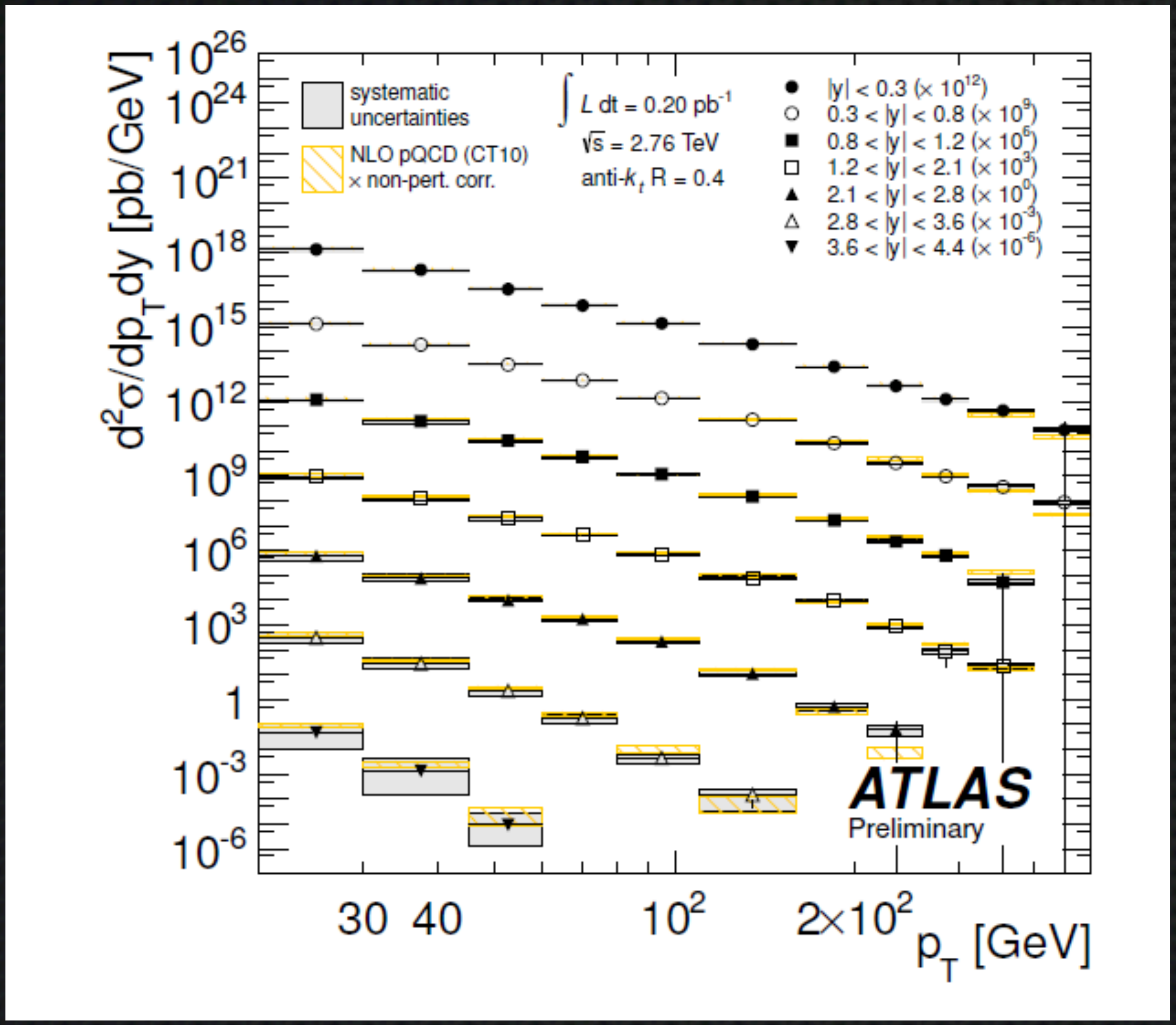
Inclusive jet cross section at 2.76 TeV

ATLAS-CONF-2012-128

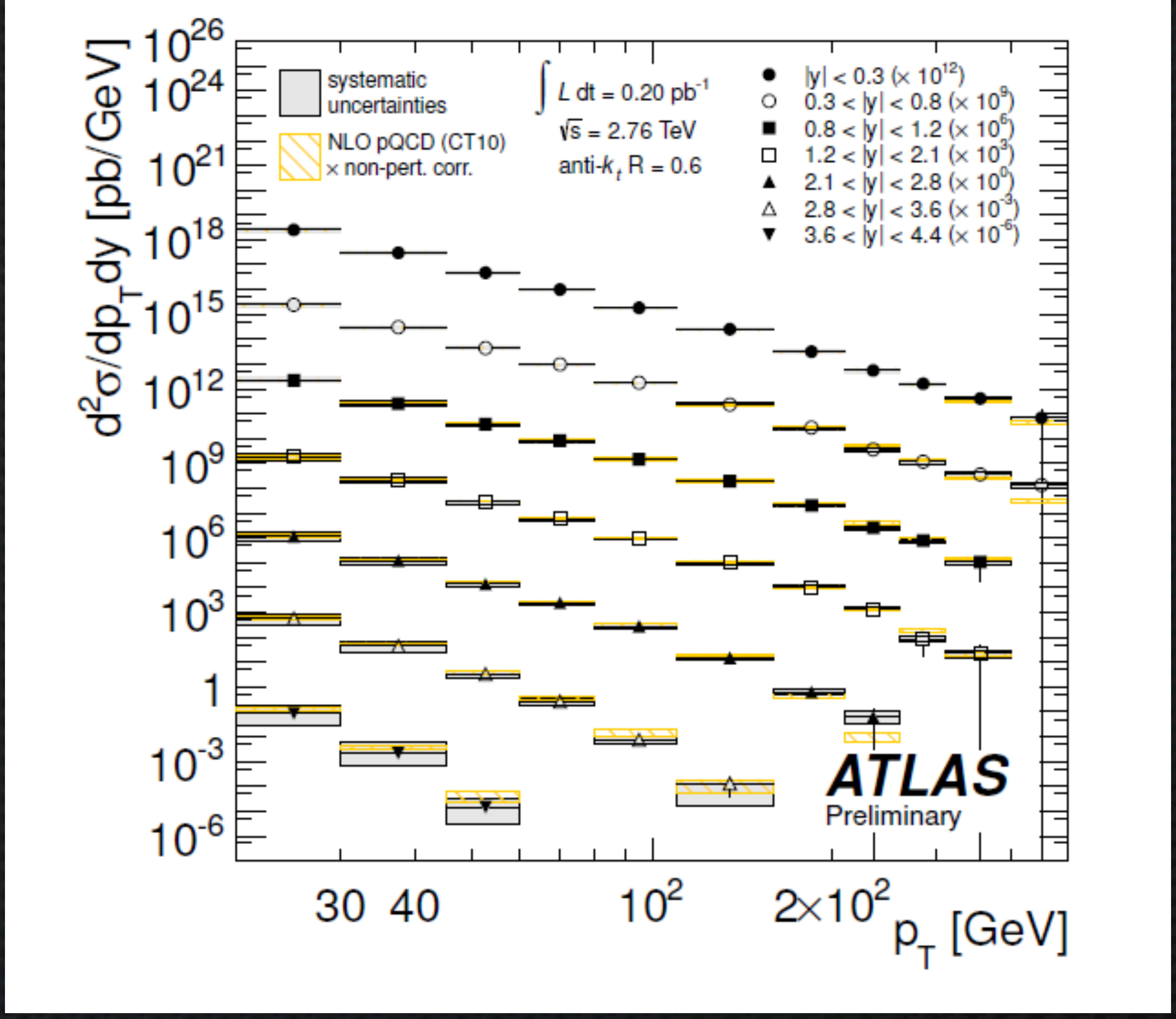
L = 0.20 pb^{-1}

Measurement made in the kinematic regions:
$20 \le p_T < 430$ GeV and $|y| < 4.4$

R=0.4



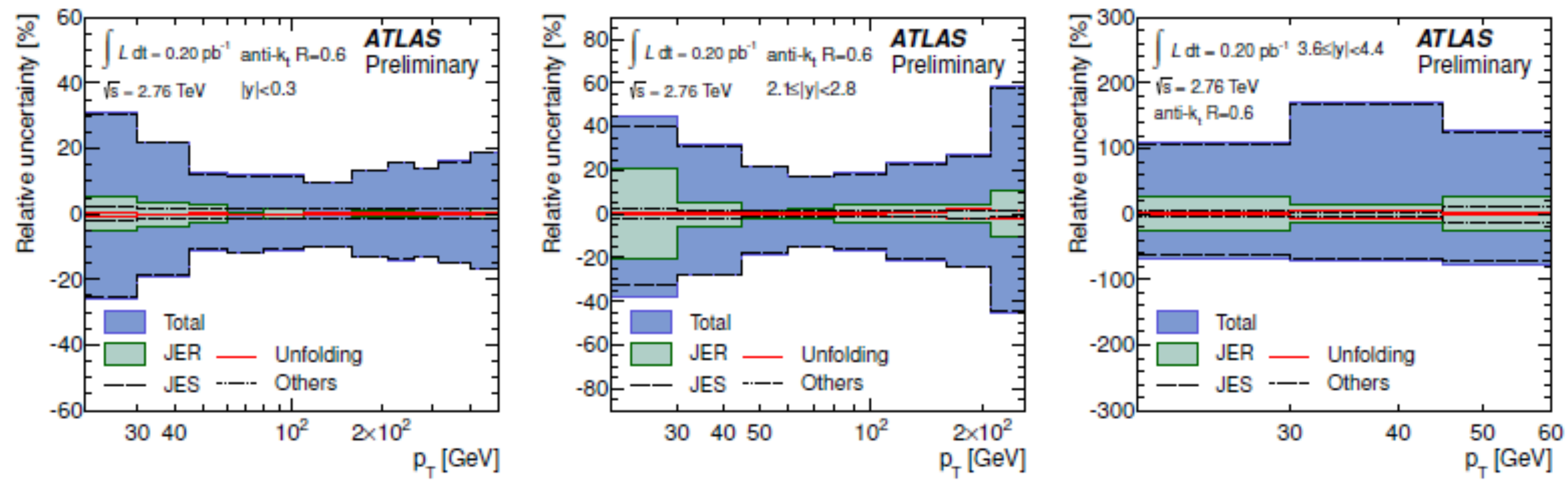
R=0.6



Luminosity uncertainty: 2.8%

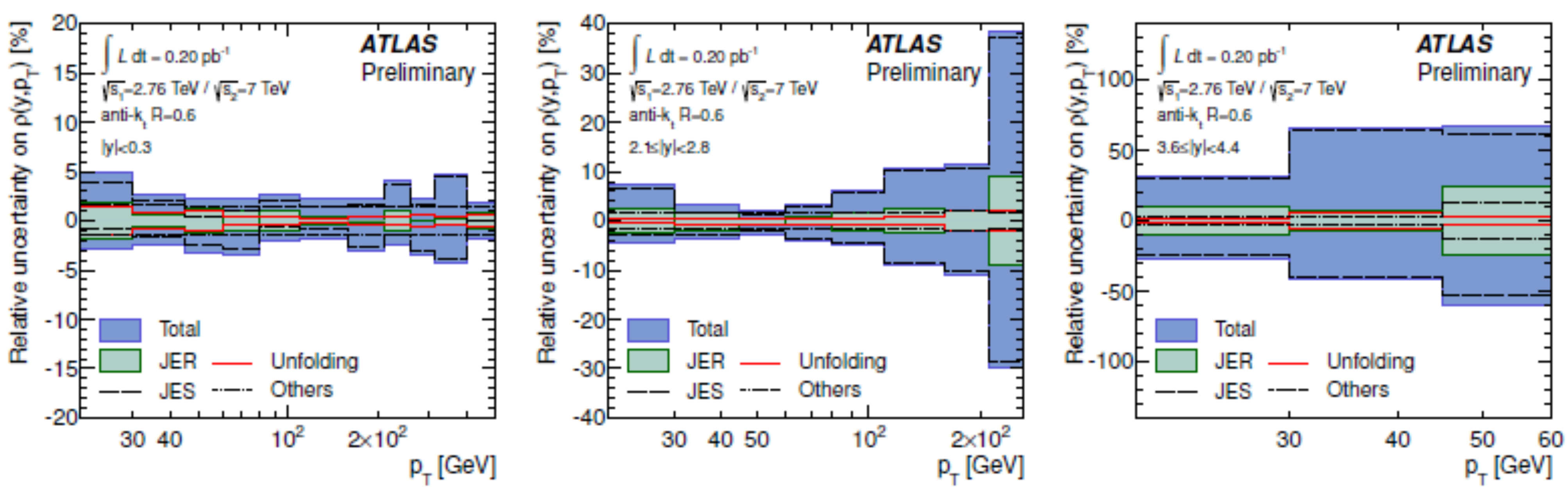
Inclusive jet cross section at 2.76 TeV

Uncertainties on 2.76TeV jet cross section



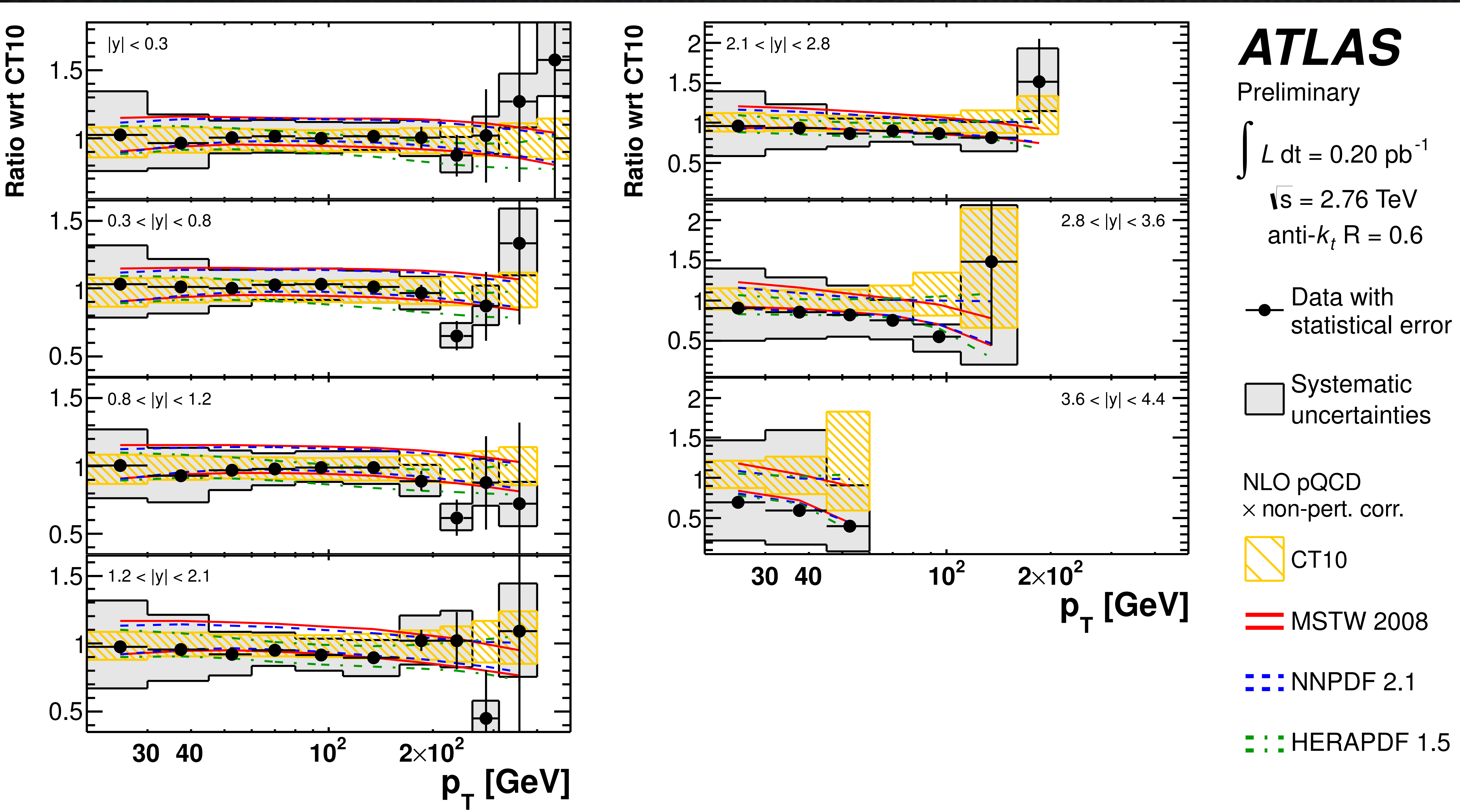
(a) $|y| < 0.3$ (b) $2.1 \leq |y| < 2.8$ (c) $3.6 \leq |y| < 4.4$

Uncertainties on the ratio 2.76 TeV to 7 TeV jet cross sections



(d) $\rho(y, p_{\mathrm{T}}), |y| < 0.3$ (e) $\rho(y, p_{\mathrm{T}}), 2.1 \leq |y| < 2.8$ (f) $\rho(y, p_{\mathrm{T}}), 3.6 \leq |y| < 4.4$

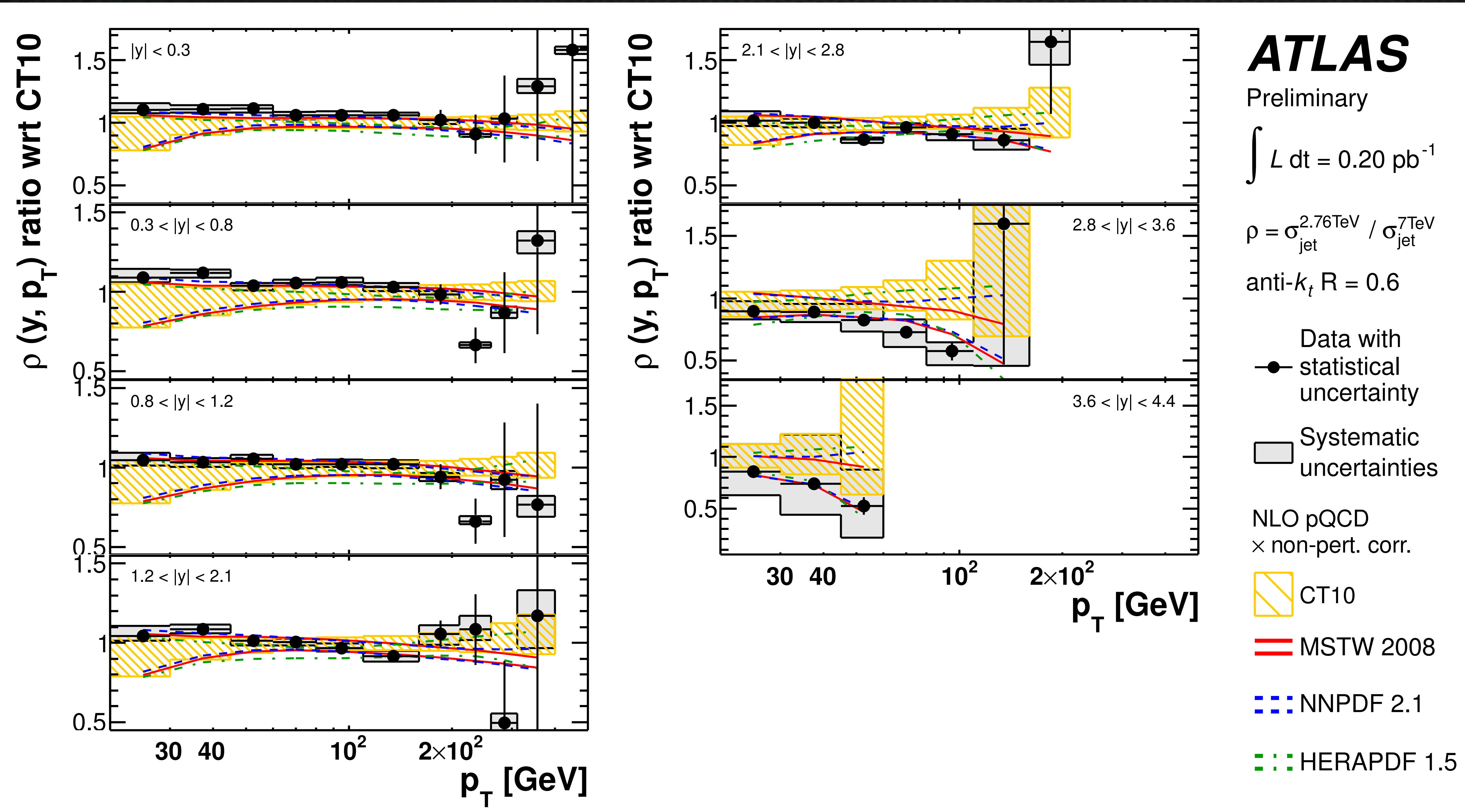
Inclusive jet cross section at 2.76 TeV



Systematic uncertainties are large ==> not easy to assess PDF impact

Cross section ratio 2.76 TeV/7 TeV

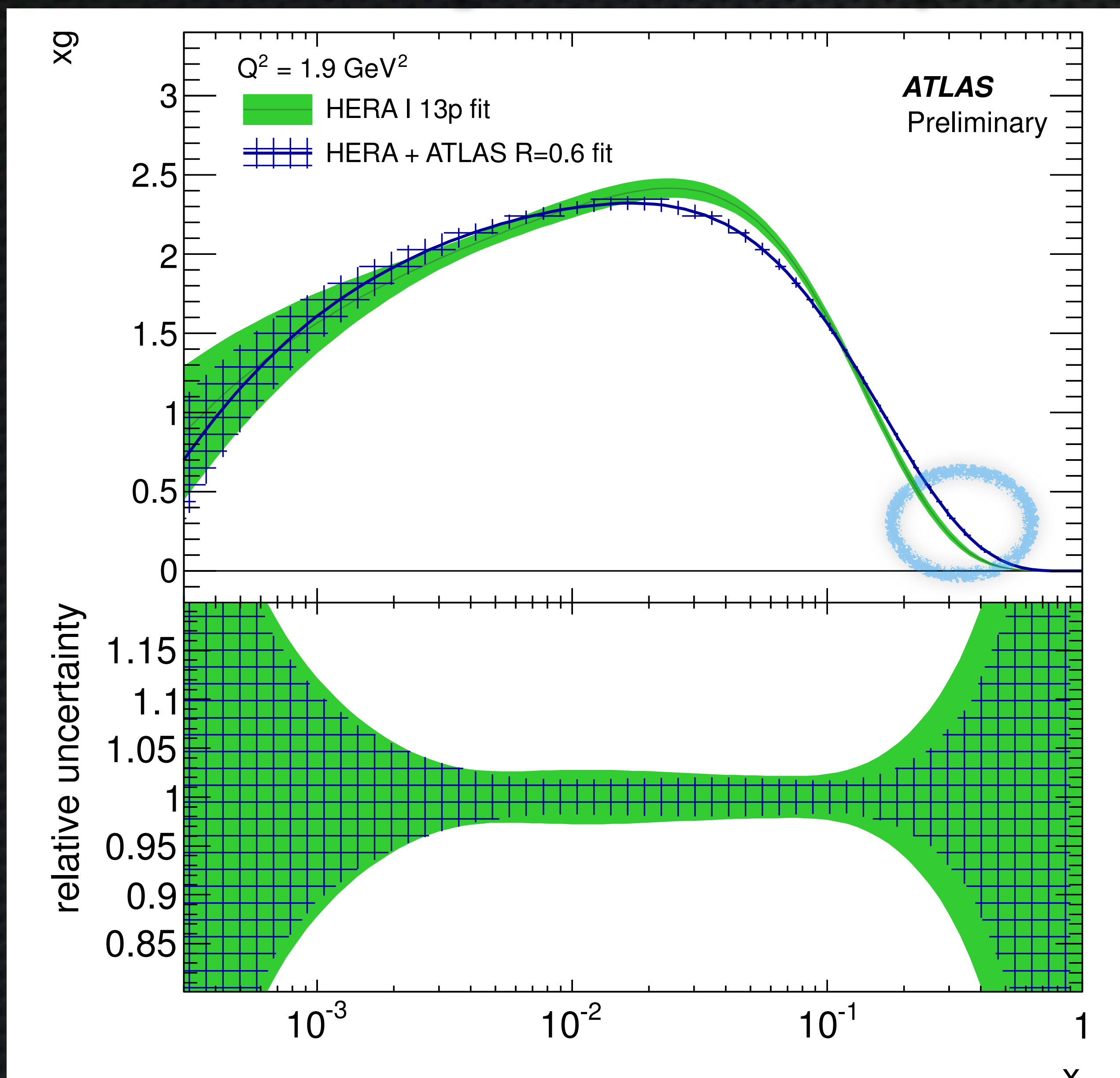
- **Ratio of experimental uncertainties is reduced and generally smaller than theory uncertainty**



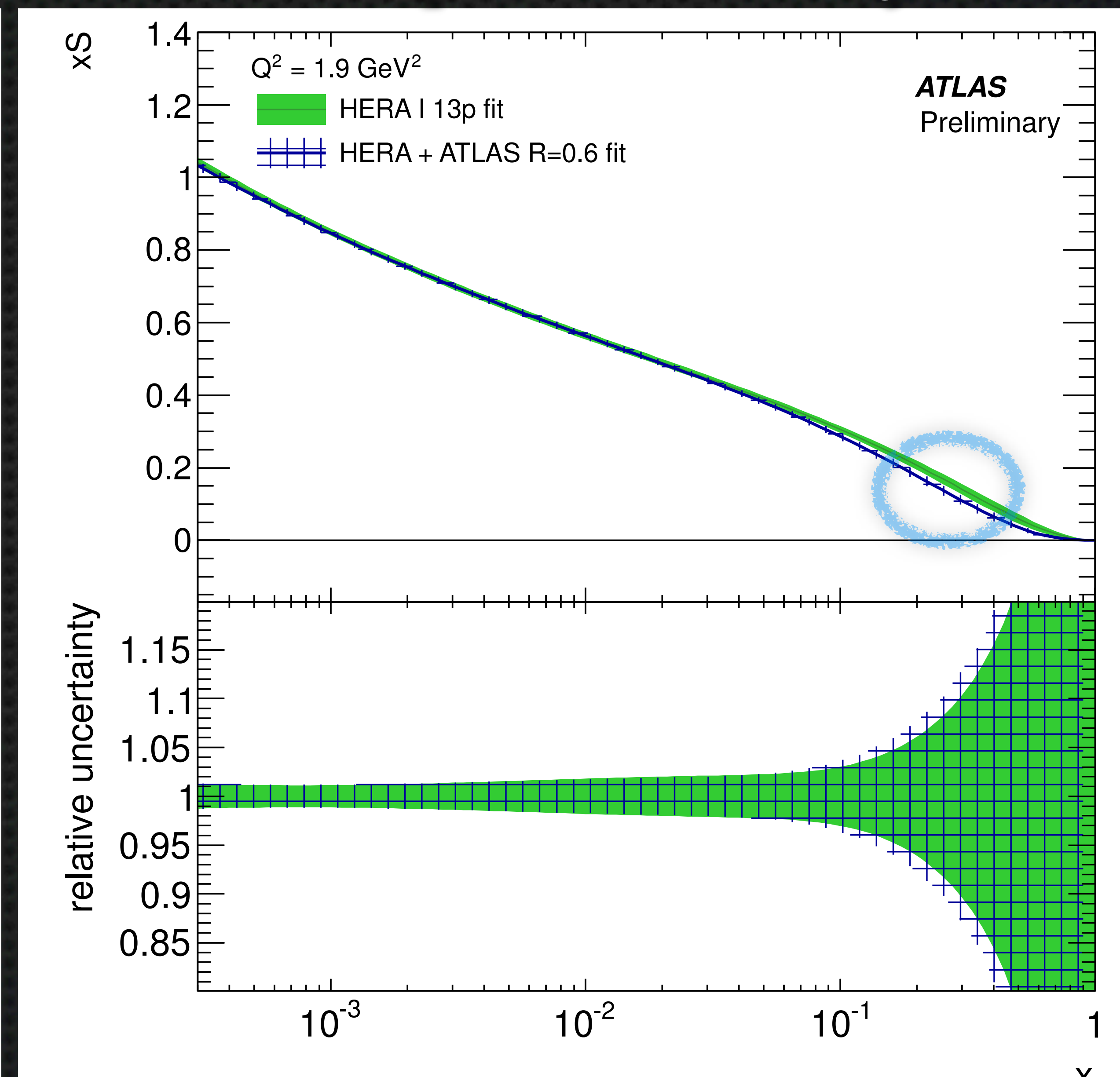
Assessment of effect on PDFs

Fit HERA data together with ATLAS 7 TeV and 2.76 TeV data

Gluon parton density

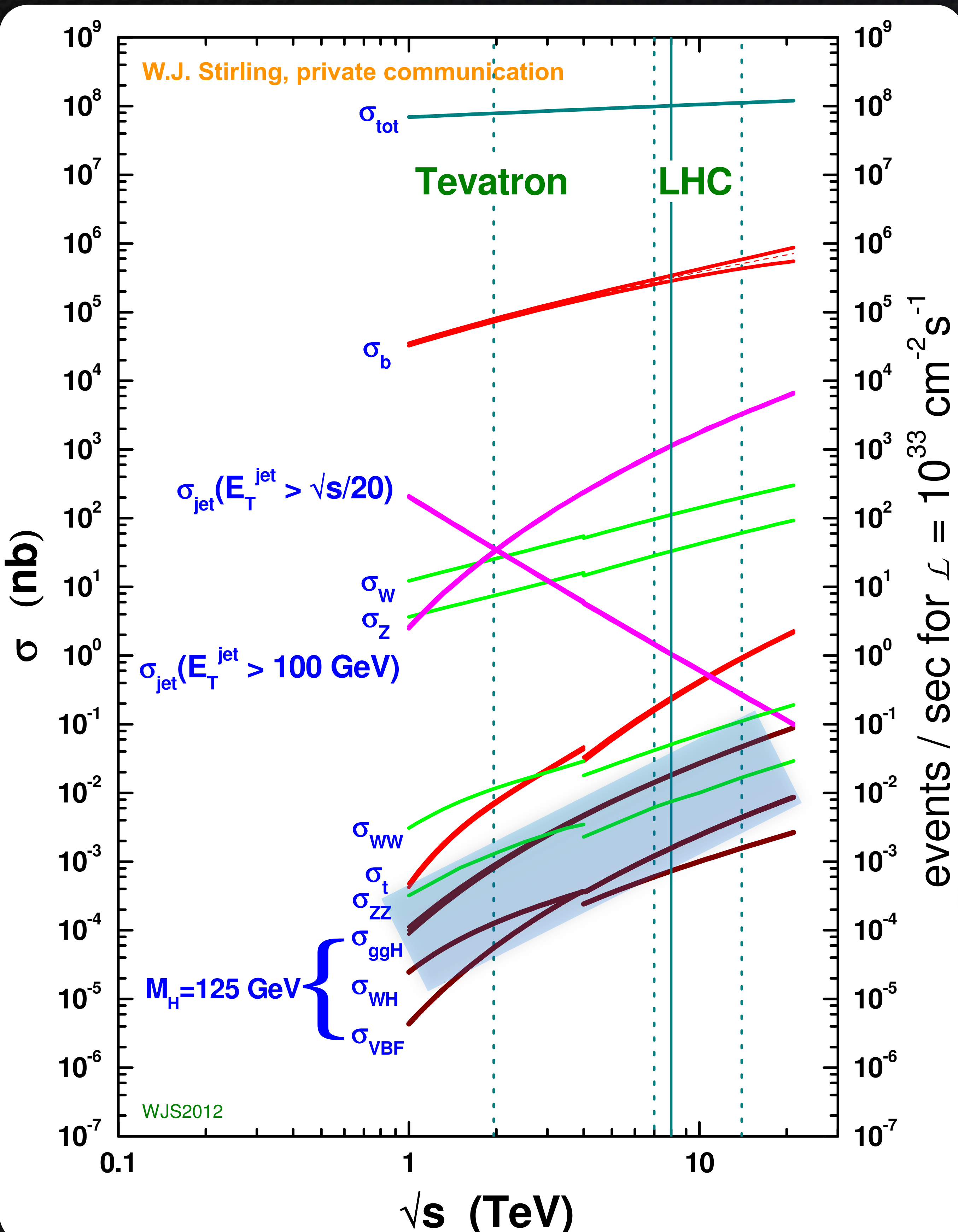


Sea parton density



NLO pQCD analysis using HERAFitter package

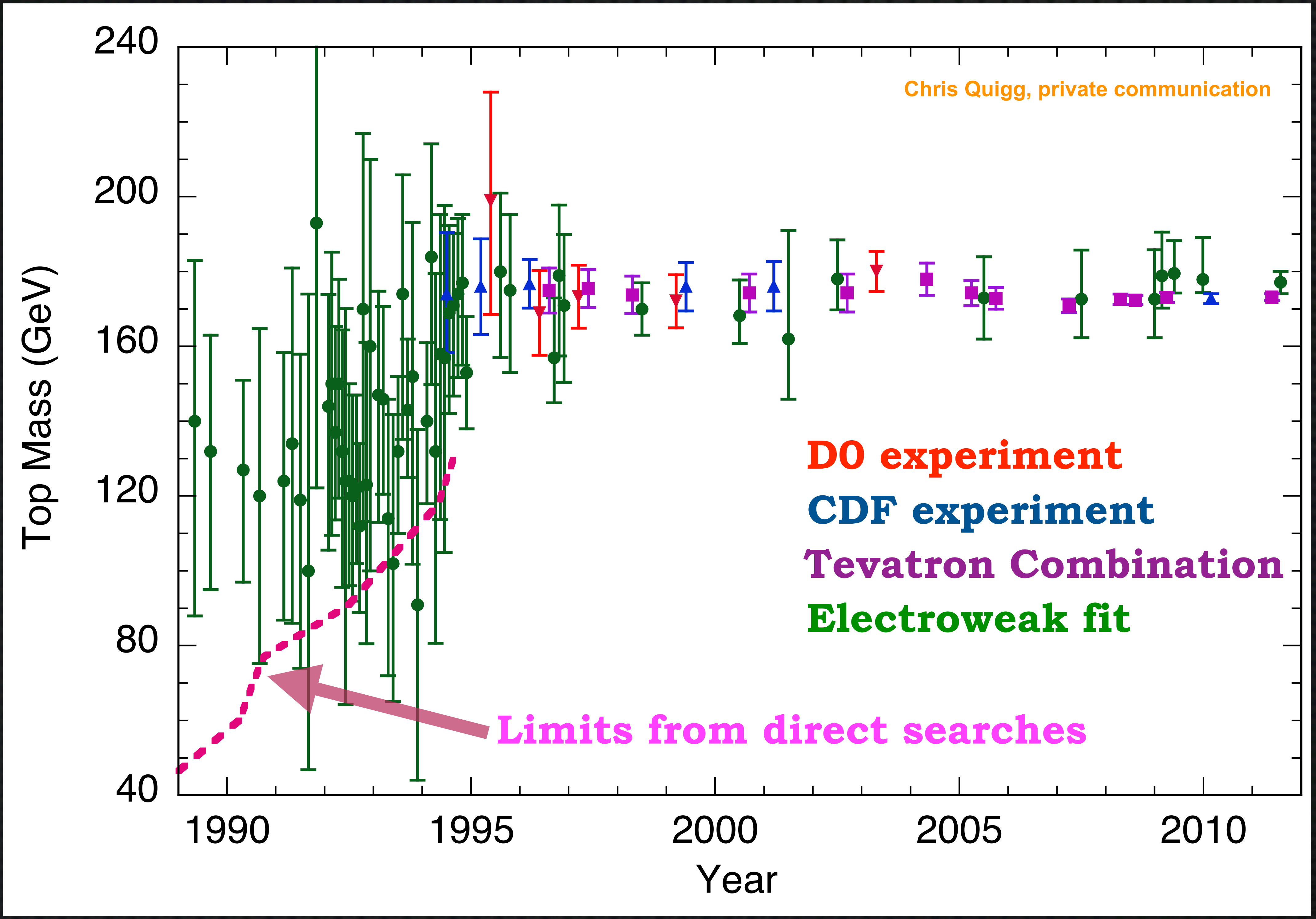
(impact of jet data is most visible in the forward region)



Electroweak Fit

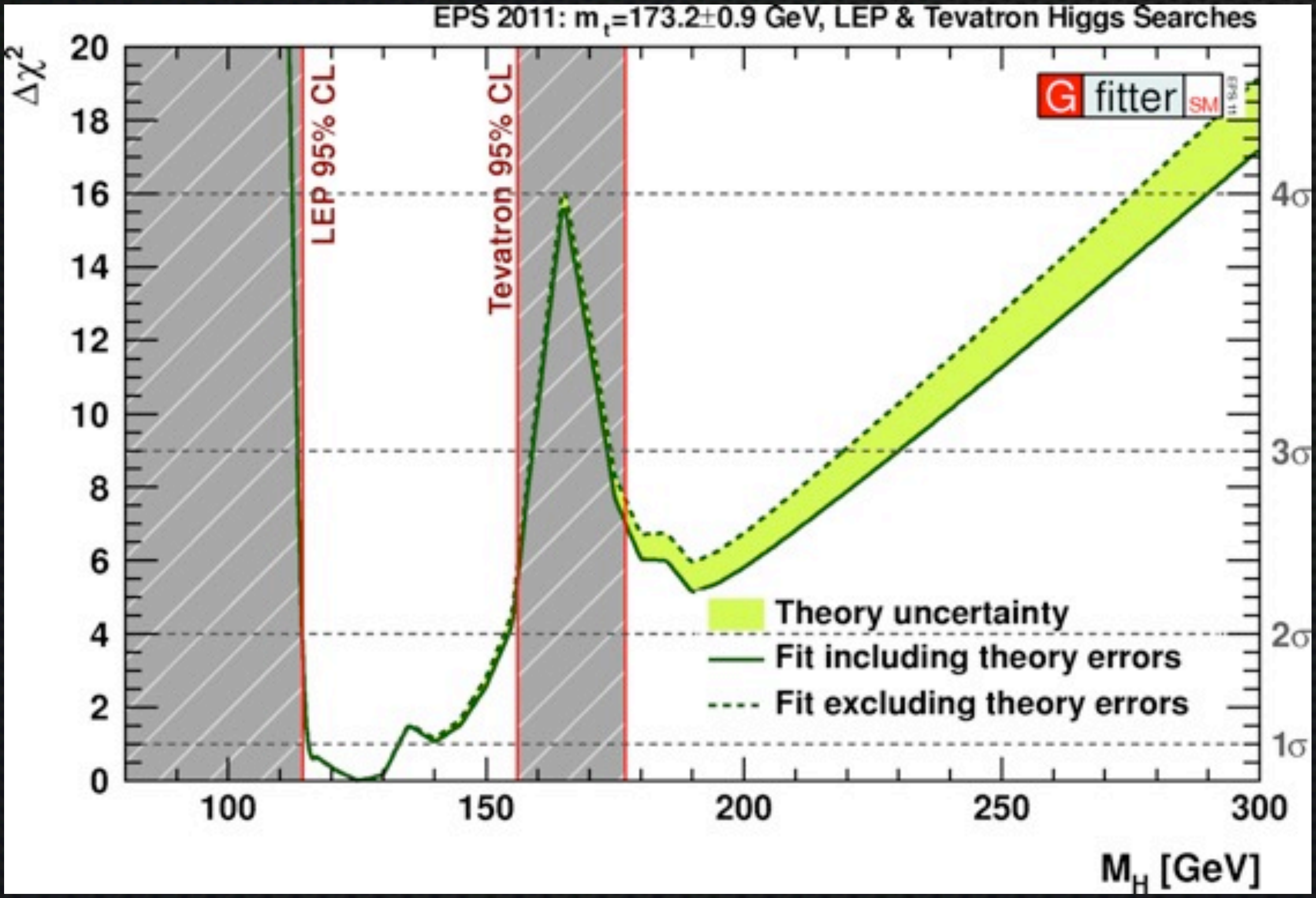
- Precise measurement of electroweak parameters constrains
  - New physics
  - The Higgs mass

Electroweak Theory and Top Mass



Electroweak Fit Status (September 2011)

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



Standard Fit

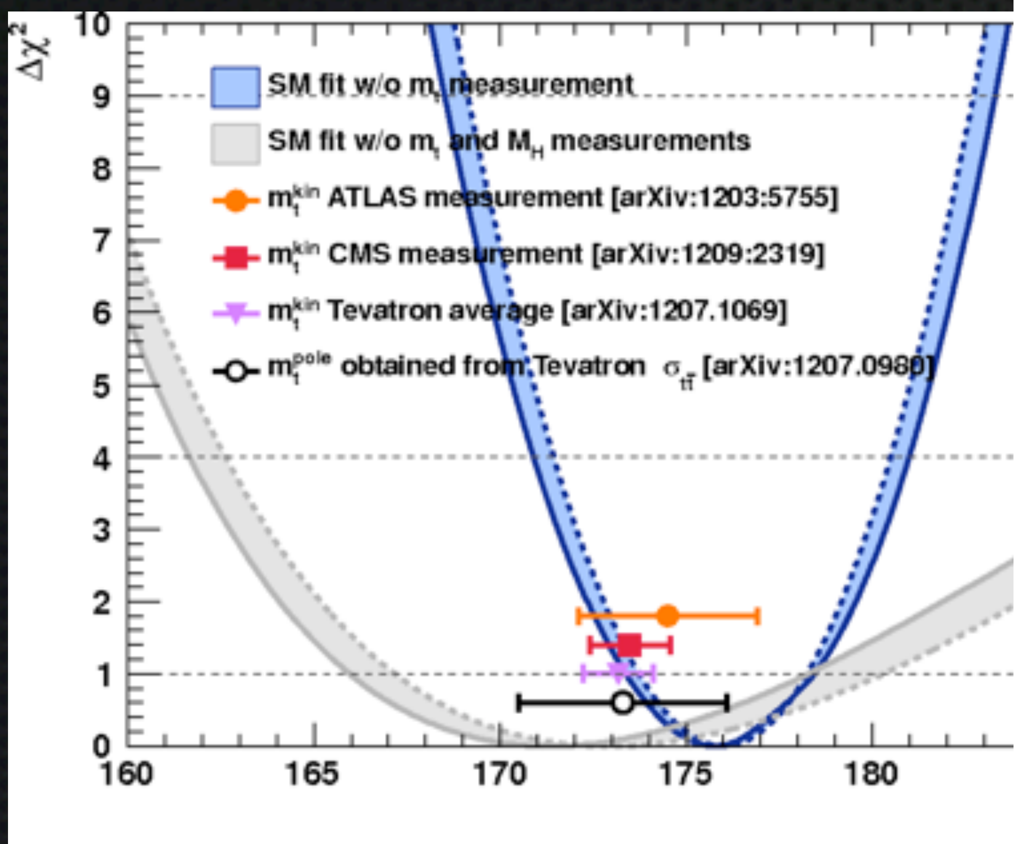
m_H = 94.5 GeV
Range m_H = [71, 124]
m_H (@ 95%) < 166.5 GeV

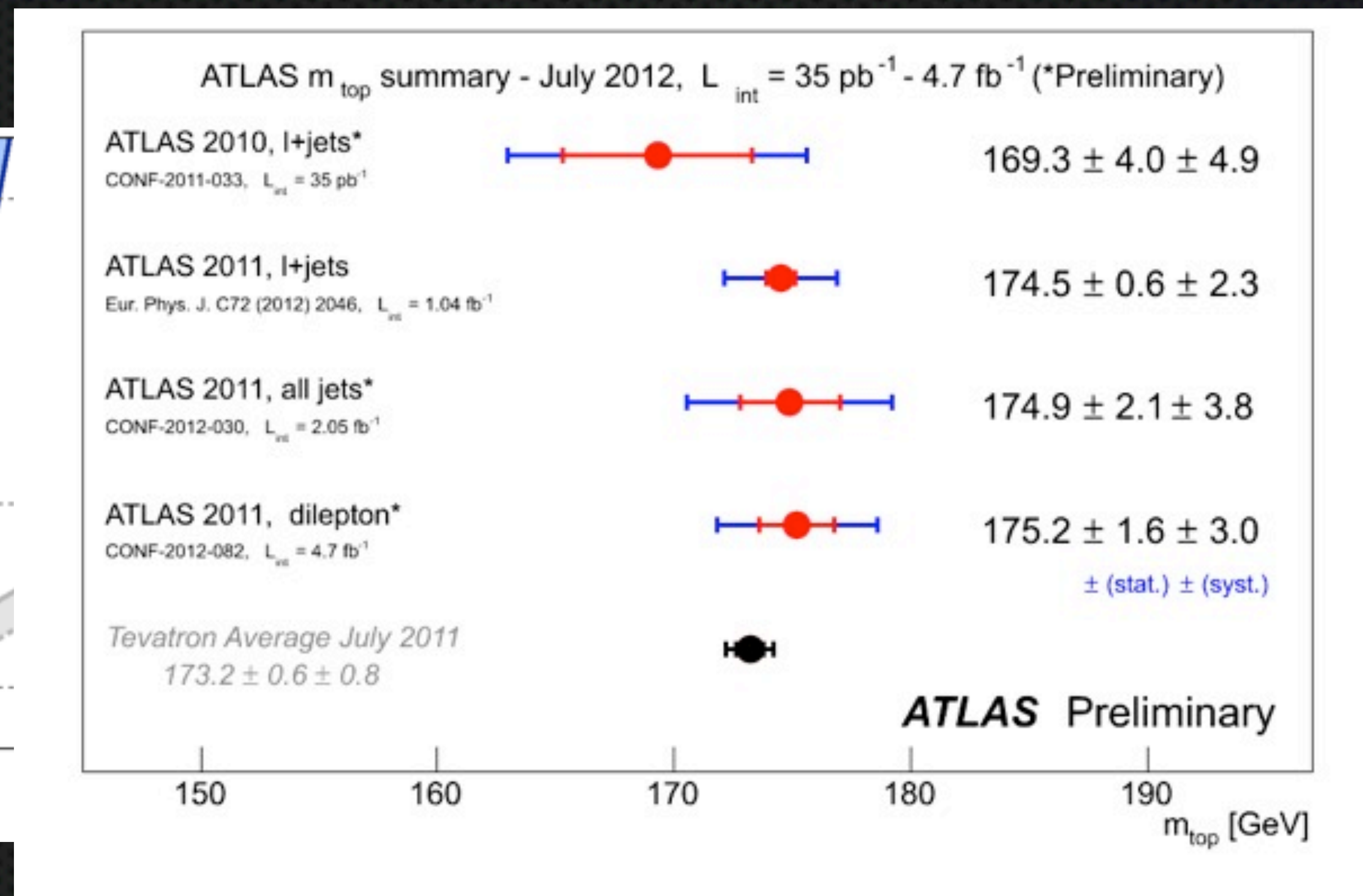
Complete Fit
(including direct limits on Higgs from LEP and Tevatron)

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

Includes results until September 2012

Top Mass

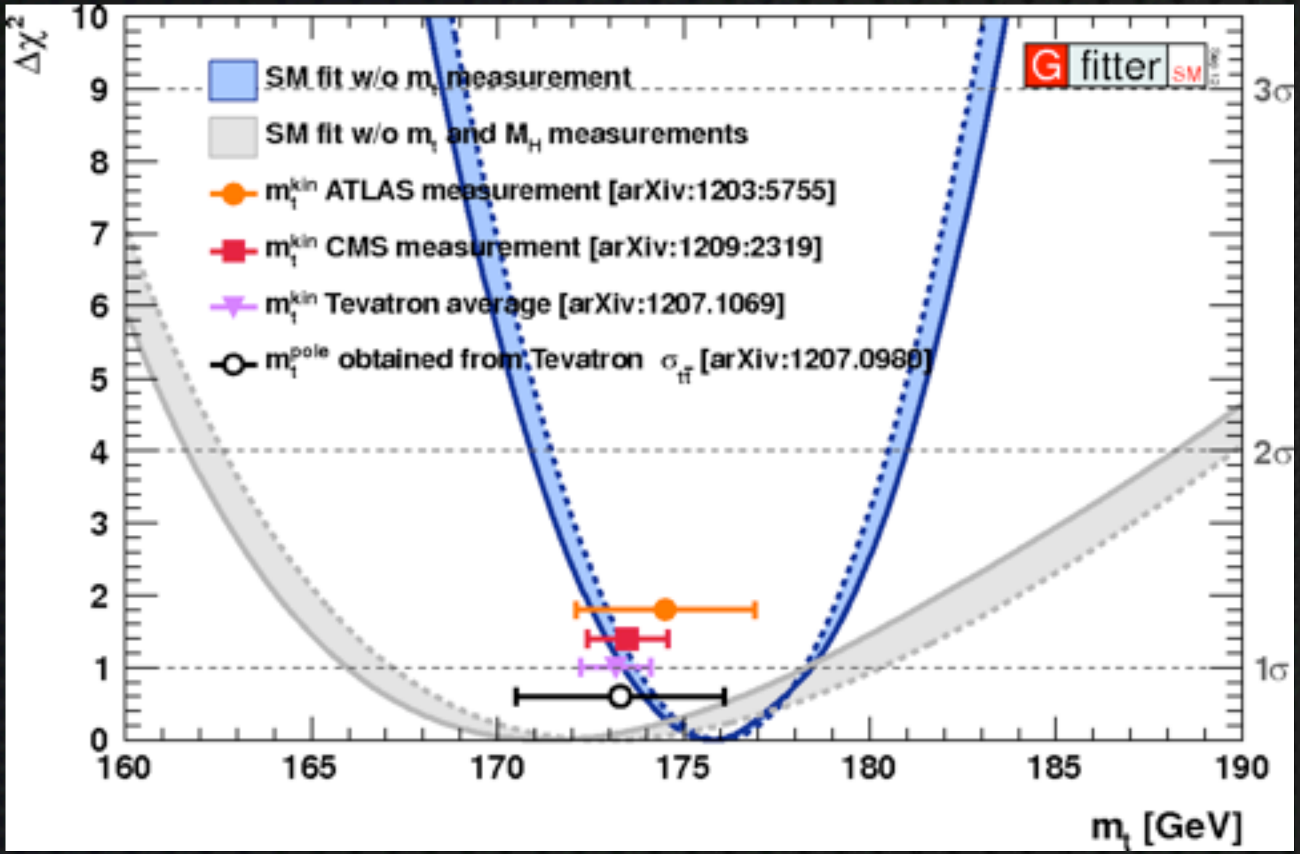




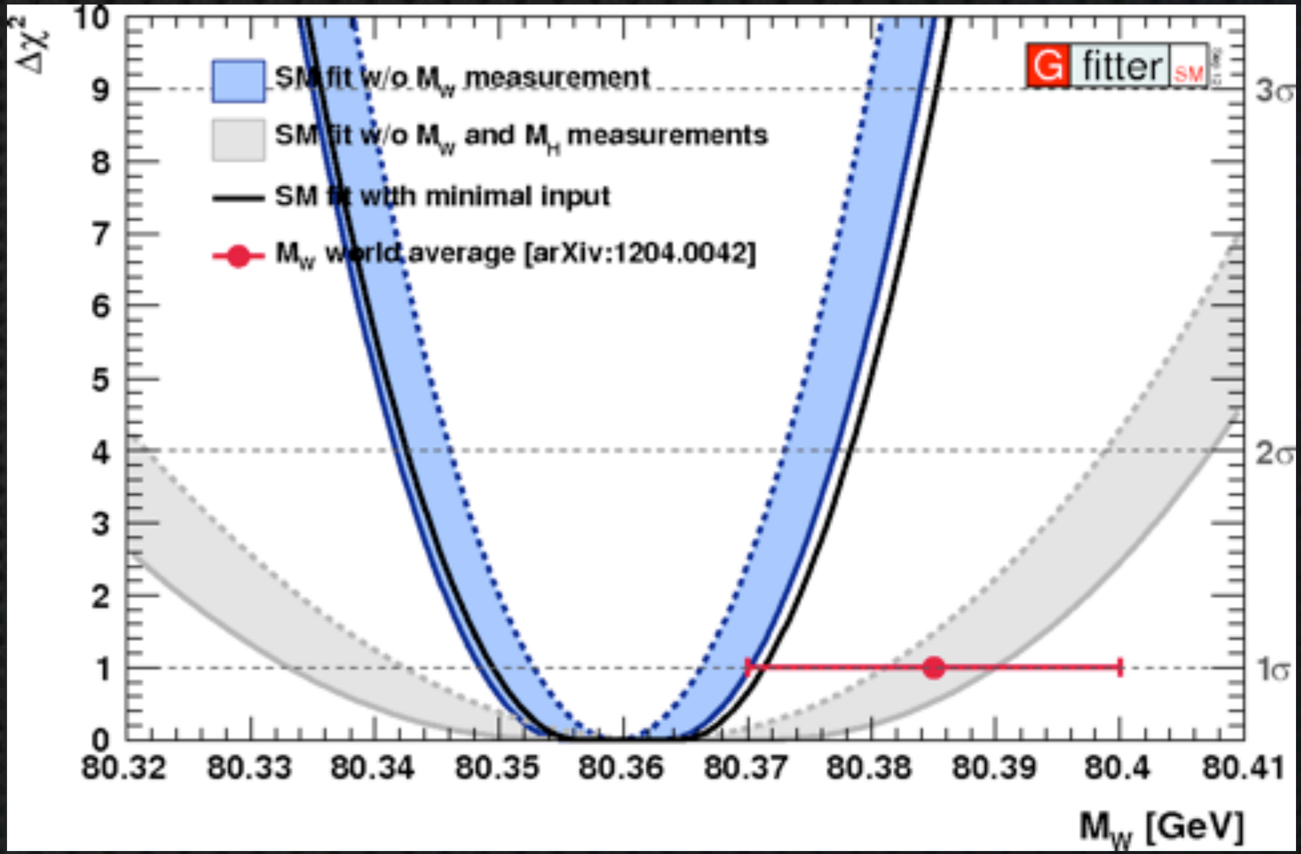
The electroweak fit

Includes results until September 2012

Top Mass

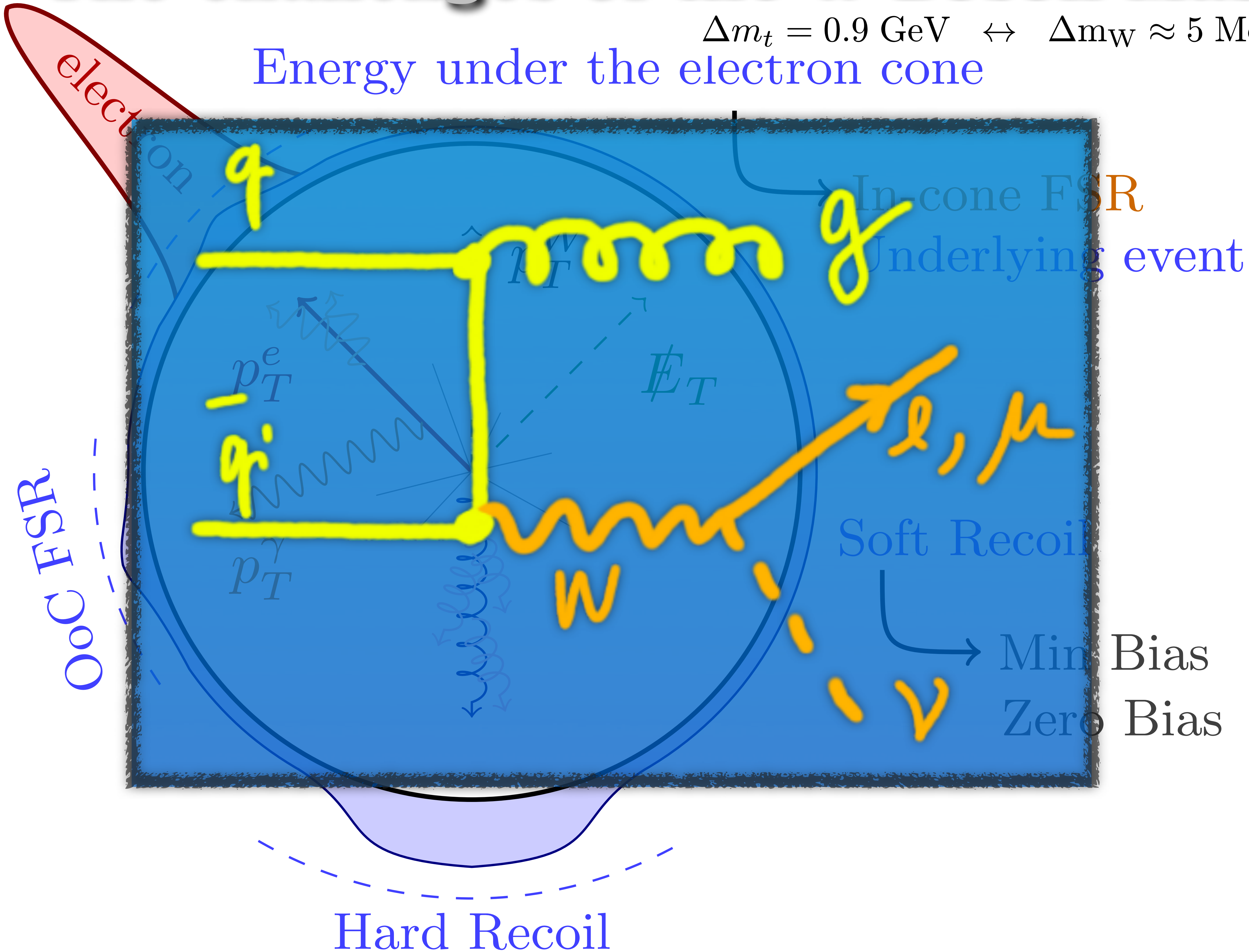


W Mass



The challenges of the W Boson Mass

$\Delta m_t = 0.9$ GeV $\leftrightarrow$ $\Delta m_W \approx 5$ MeV



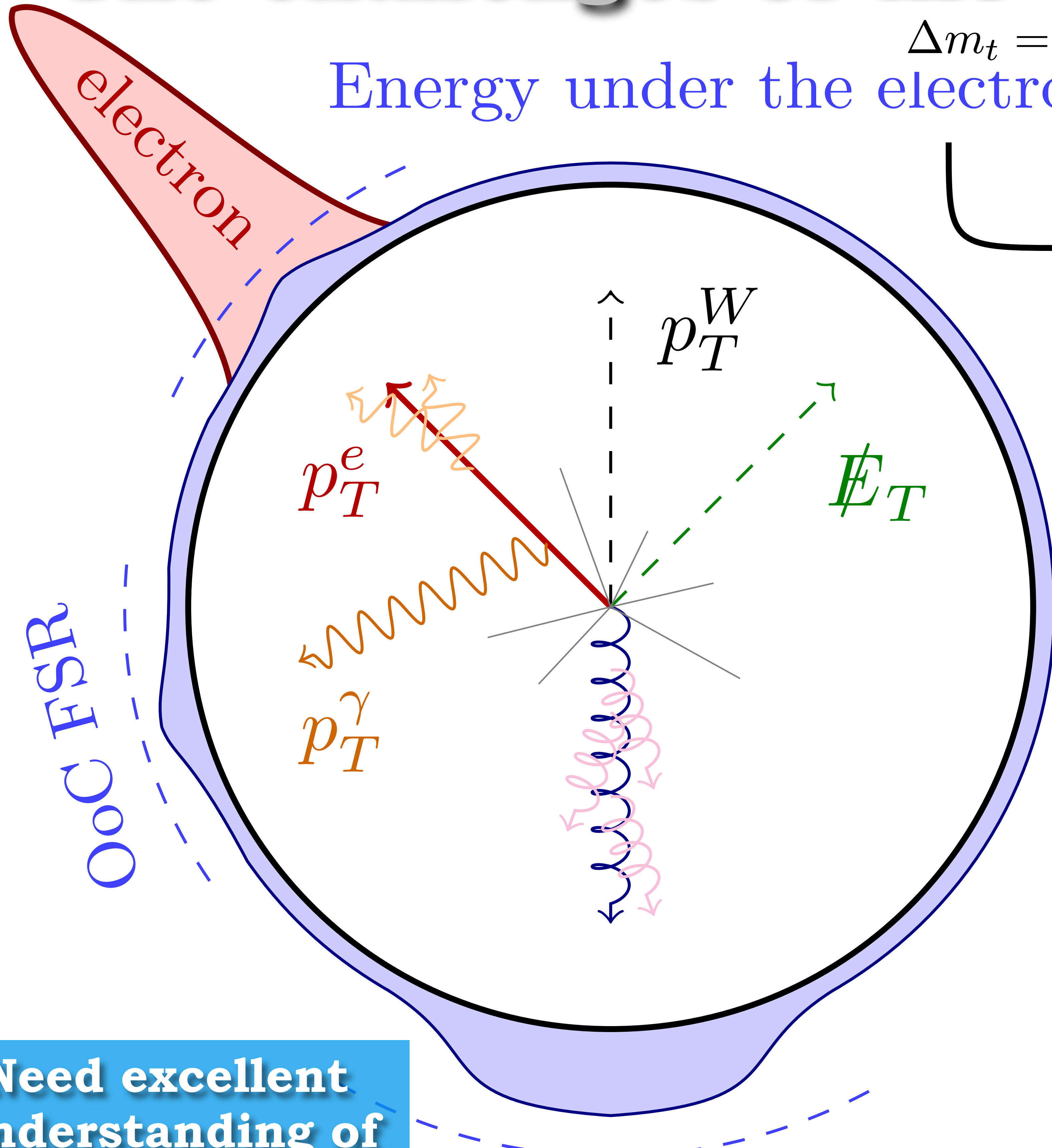
The challenges of the W Boson Mass

$\Delta m_t = 0.9$ GeV $\leftrightarrow$ $\Delta m_W \approx 5$ MeV

Energy under the electron cone

→ In-cone FSR

Underlying event



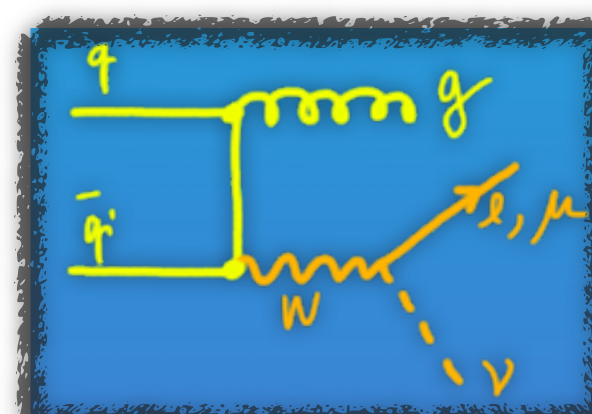
Soft Recoil

→ Min Bias

Zero Bias

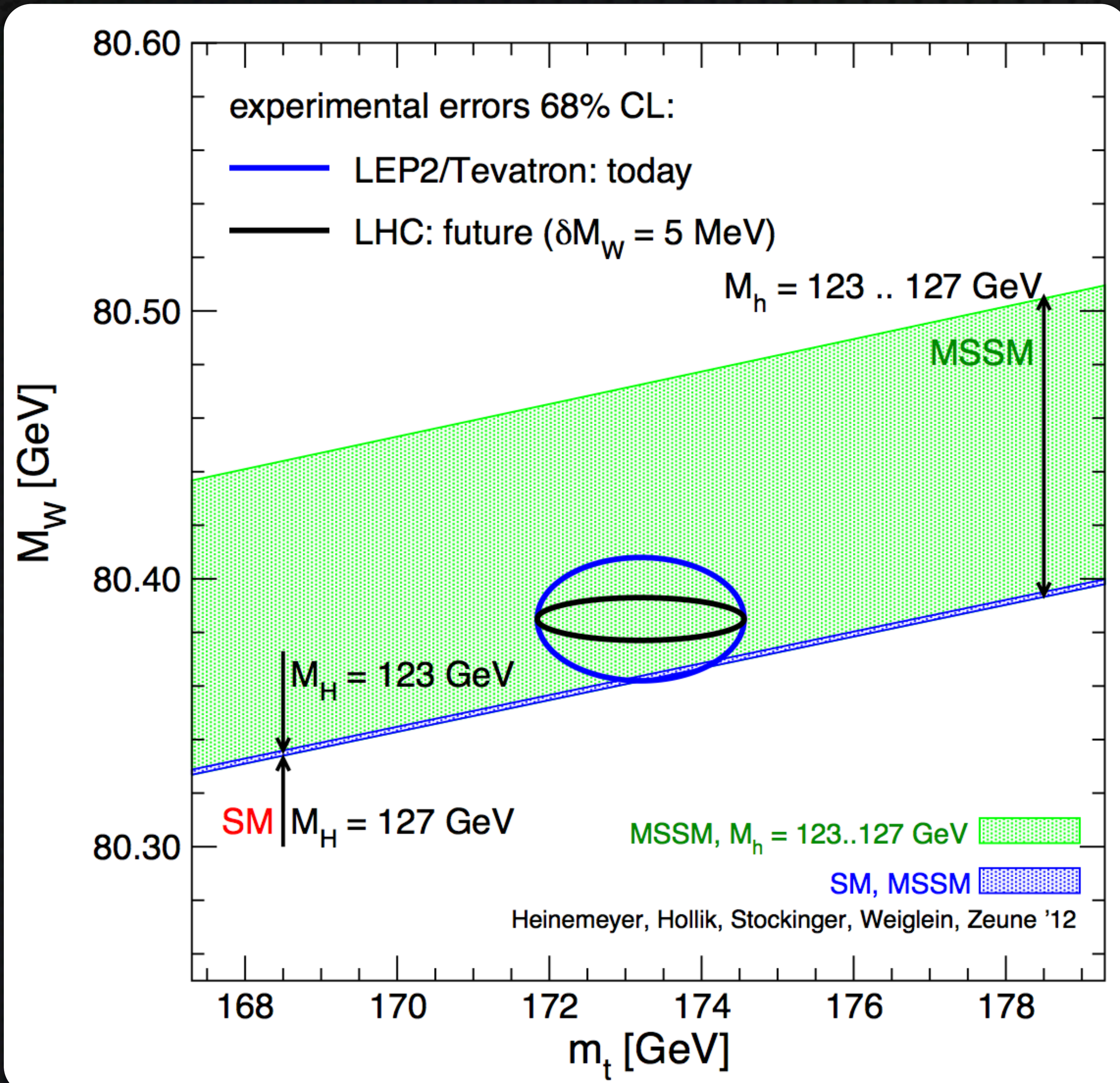
Hard Recoil

Need excellent understanding of detector and MC simulation



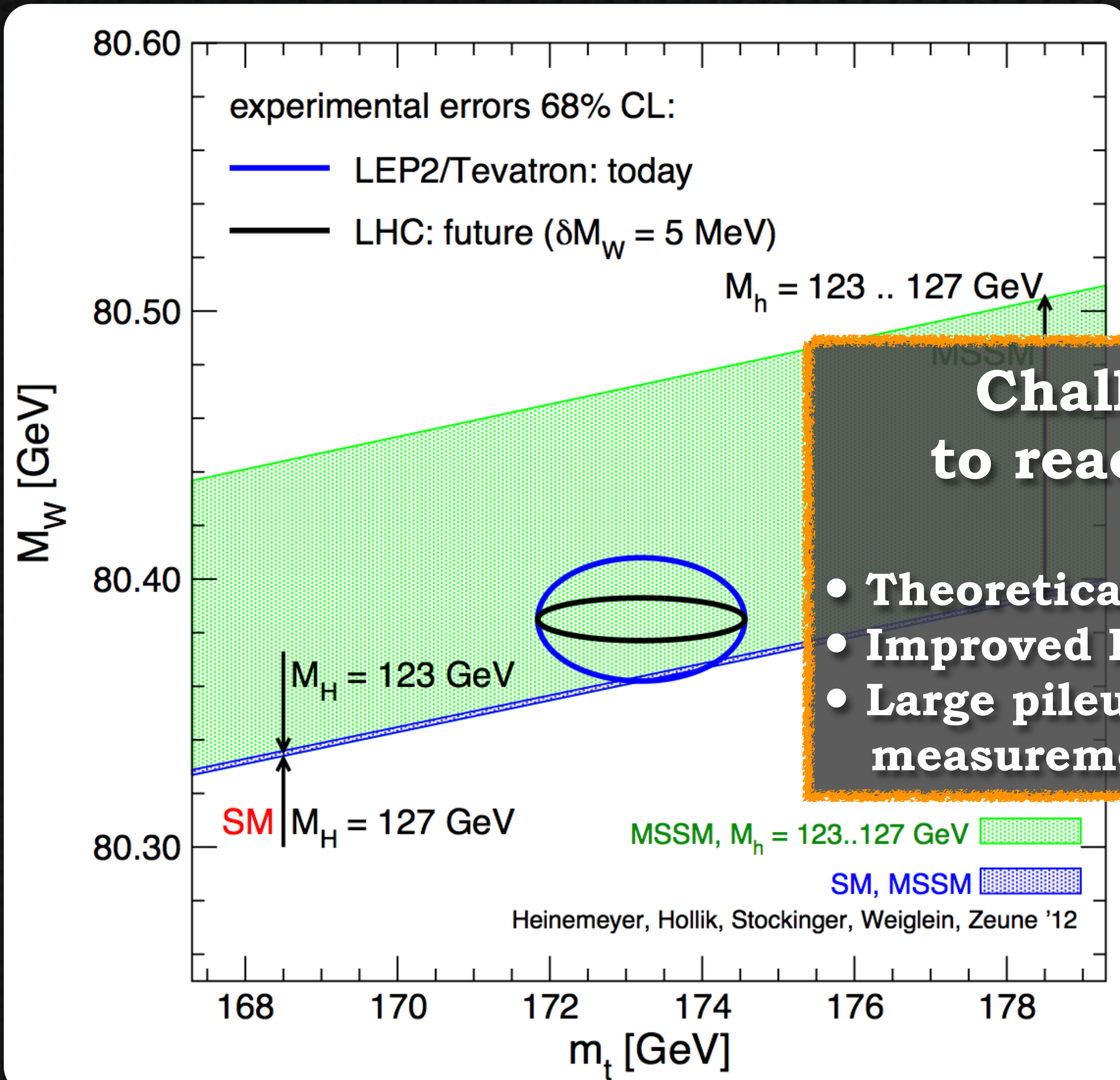
Precision Electroweak Constraints

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



Precision Electroweak Constraints

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



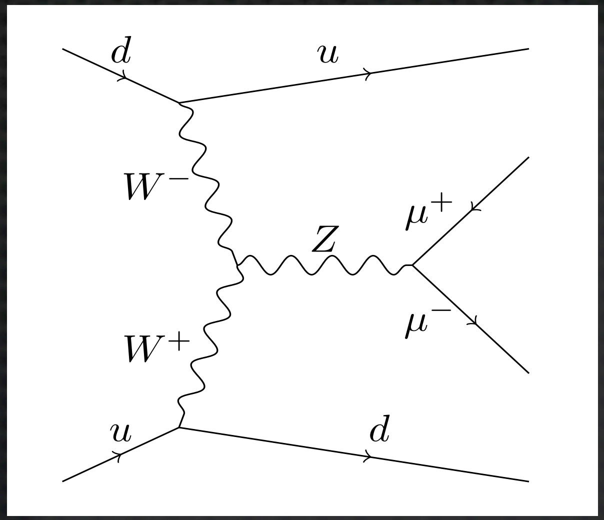
Challenges for LHC to reach $\Delta M_W = 5$ MeV

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

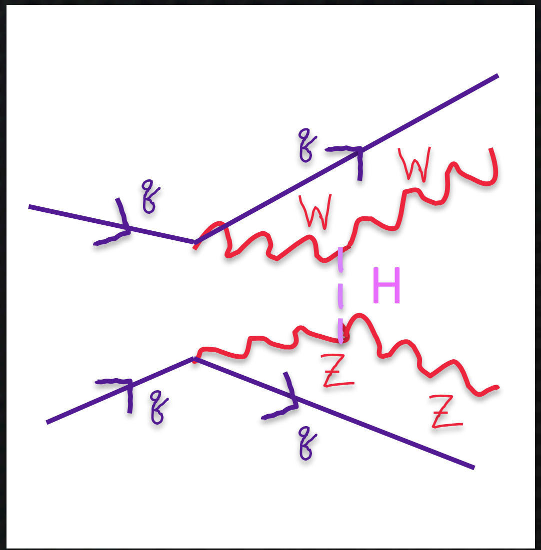
Conclusions

- **We have re-established the Standard Model at the LHC**
  - Impressive agreement with theory across orders of magnitude
    - But, exploring ever smaller cross sections
  - Stable ground for new physics searches
    - Still, deeper understanding is needed:
      - Parton distribution functions
      - NNLO calculations
- **EW precision measurements in a good agreement with a Higgs boson with mass of 125 GeV**
- **What's next?**

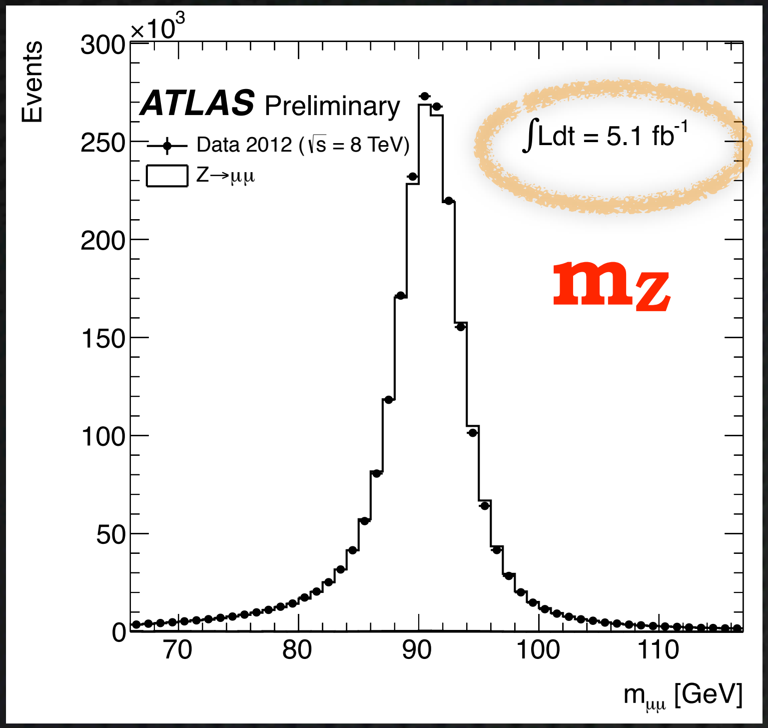
Vector Boson Fusion

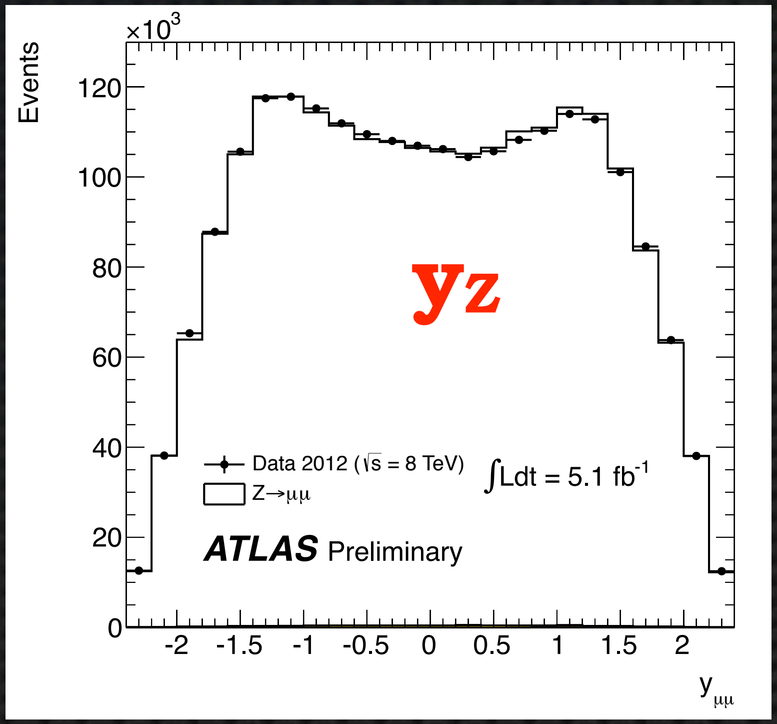


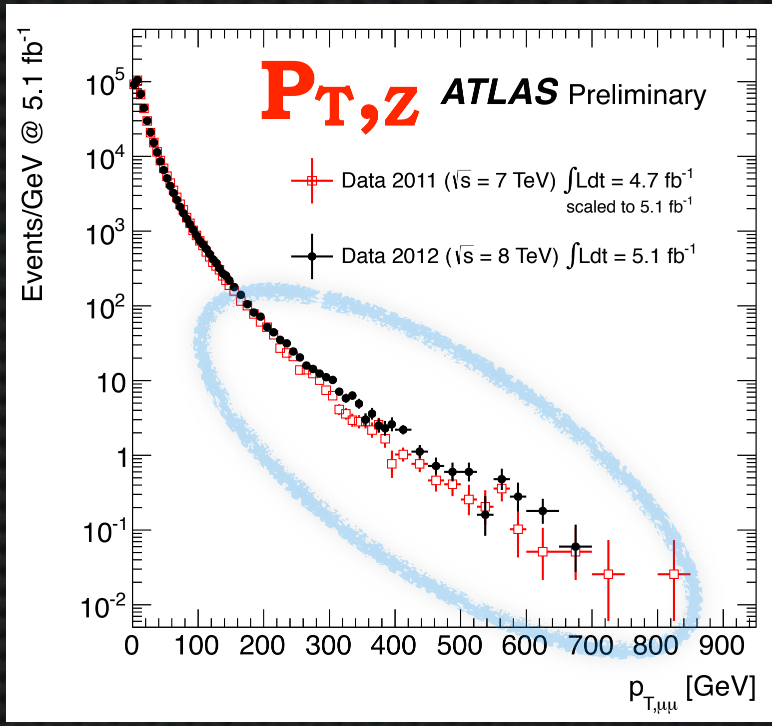
Vector Boson Scattering

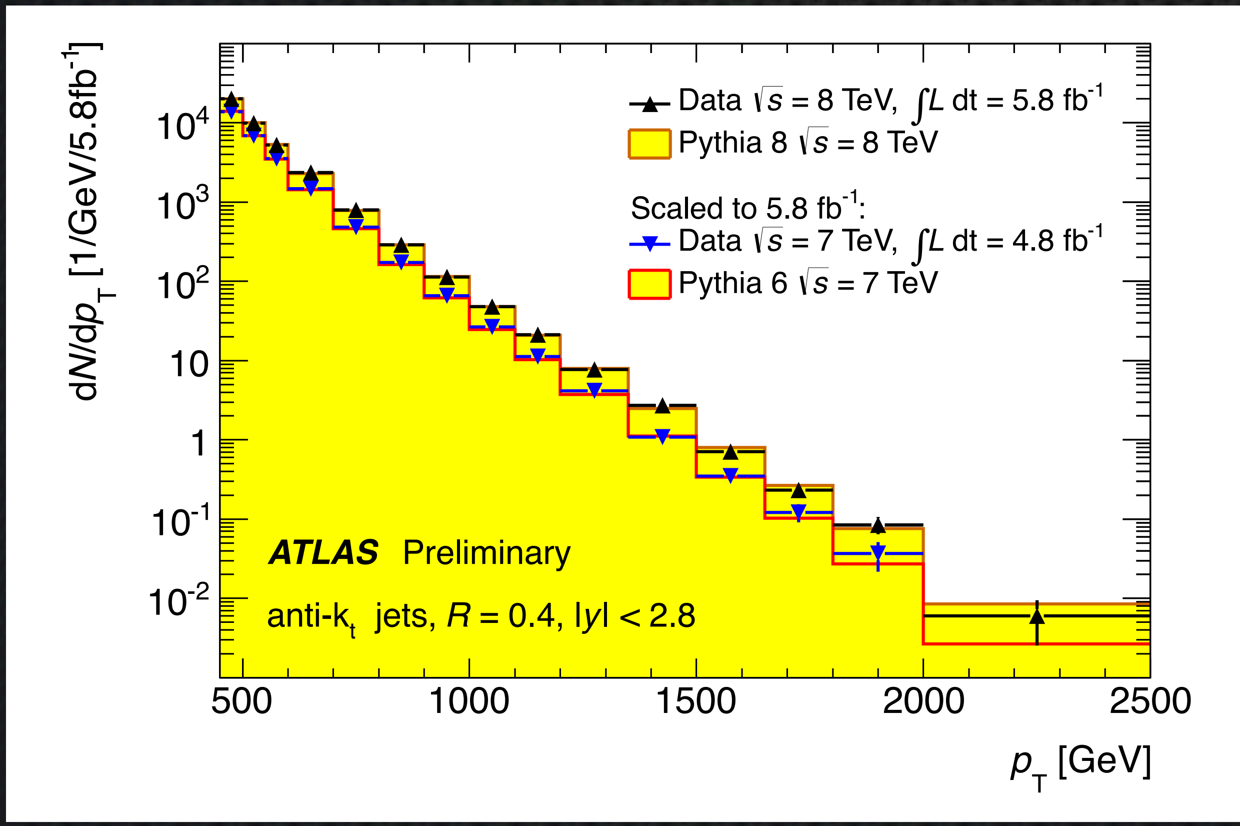


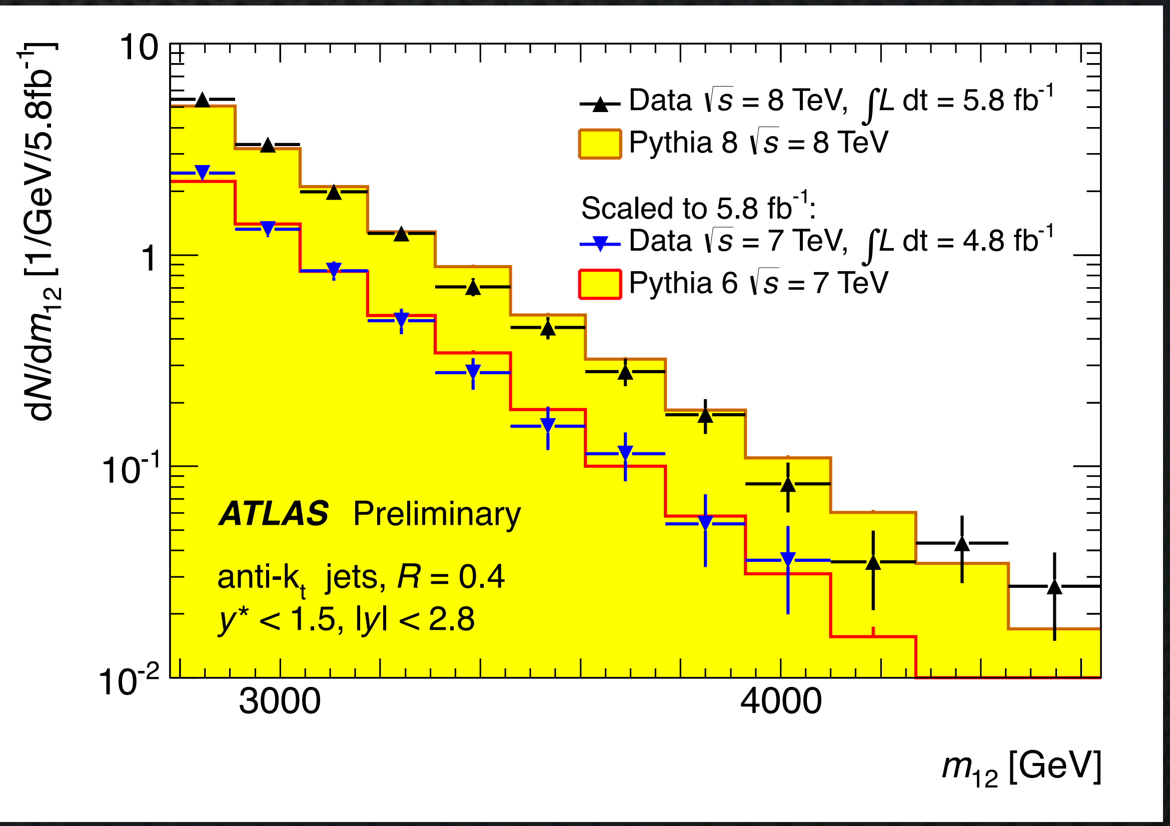
New results to come soon.... √s = 8 TeV









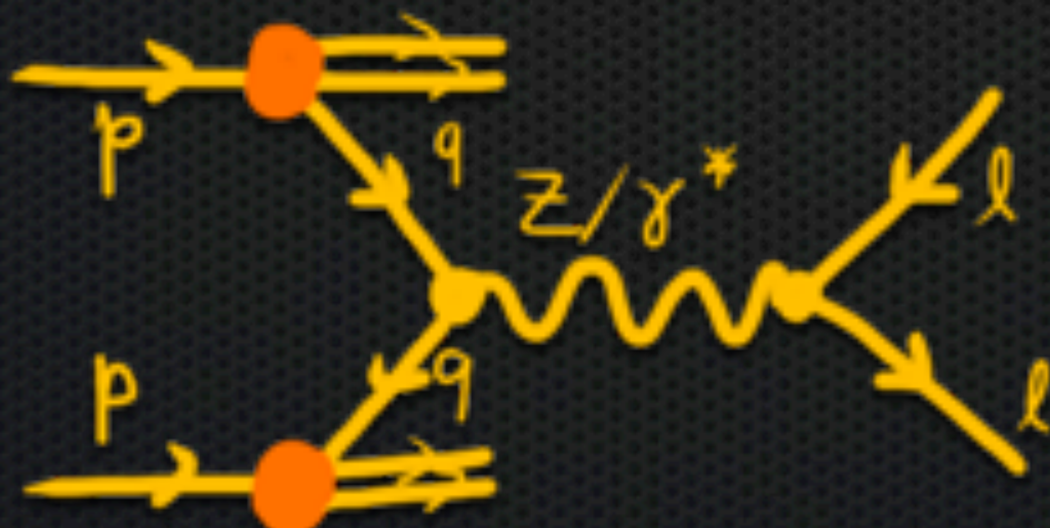


Particle Physics in the LHC Era -- Zurich 2013 -- Joao Guimaraes

$pp \rightarrow W + X$

- $\rightarrow e\nu$
- $\rightarrow \mu\nu$

W/Z inclusive production in e/μ channel

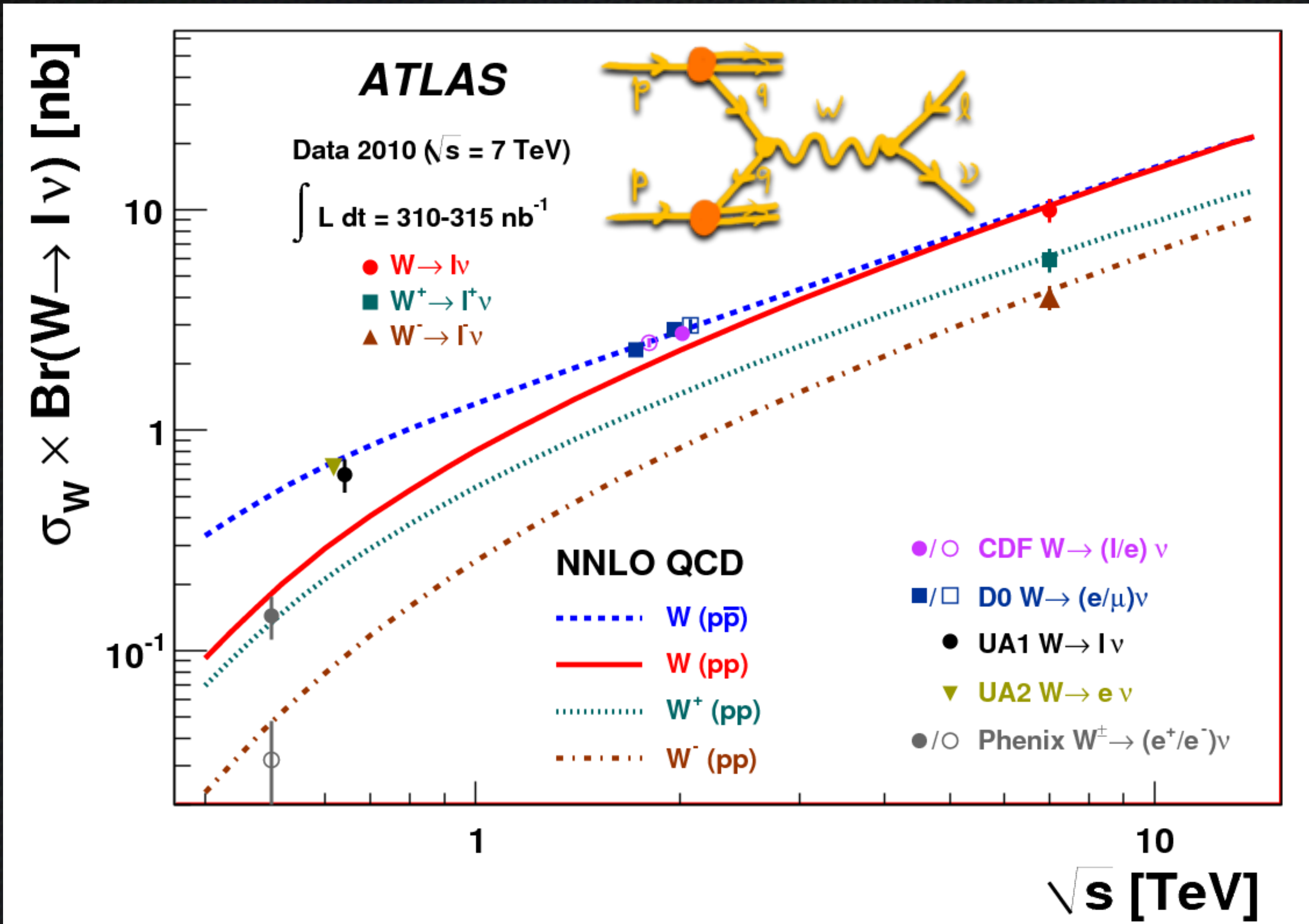


$pp \rightarrow Z + X$

- $\rightarrow ee$
- $\rightarrow \mu\mu$

First W/Z measurement at 7 TeV

JHEP 12 (2010) 060



Uncertainties: Electron channel

	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W^+}$	$\delta\sigma_{W^-}$	$\delta\sigma_Z$
Trigger	0.4	0.4	0.4	<0.1
Electron reconstruction	0.8	0.8	0.8	1.6
Electron identification	0.9	0.8	1.1	1.8
Electron isolation	0.3	0.3	0.3	—
Electron energy scale and resolution	0.5	0.5	0.5	0.2
Non-operational LAr channels	0.4	0.4	0.4	0.8
Charge misidentification	0.0	0.1	0.1	0.6
QCD background	0.4	0.4	0.4	0.7
Electroweak+$t\bar{t}$ background	0.2	0.2	0.2	<0.1
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution	0.8	0.7	1.0	—
Pile-up modeling	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
$C_{W/Z}$ theoretical uncertainty	0.6	0.6	0.6	0.3
Total experimental uncertainty	1.8	1.8	2.0	2.7
$A_{W/Z}$ theoretical uncertainty	1.5	1.7	2.0	2.0
Total excluding luminosity	2.3	2.4	2.8	3.3
Luminosity		3.4		

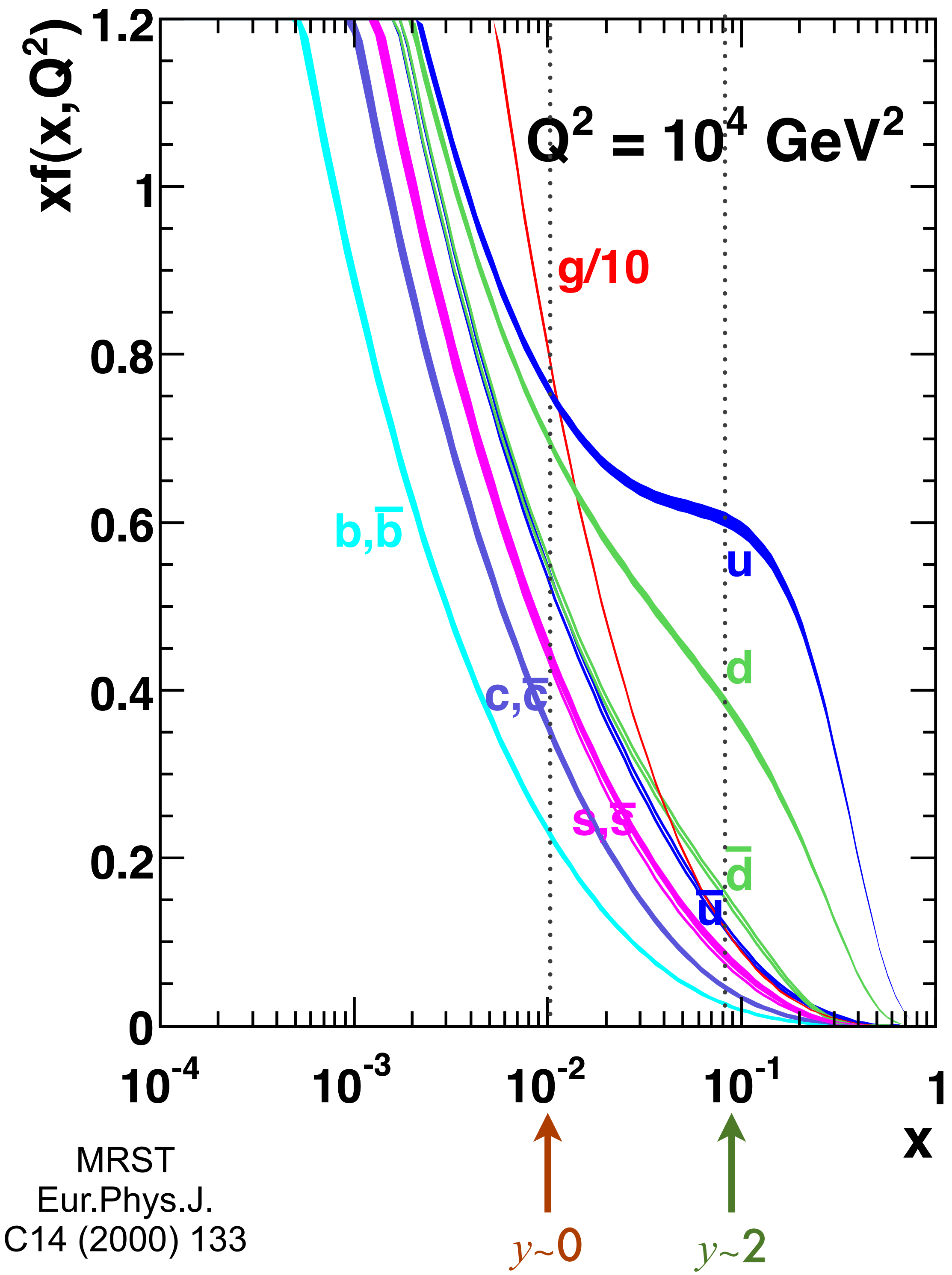
Extrapolation

Uncertainties: Muon channel

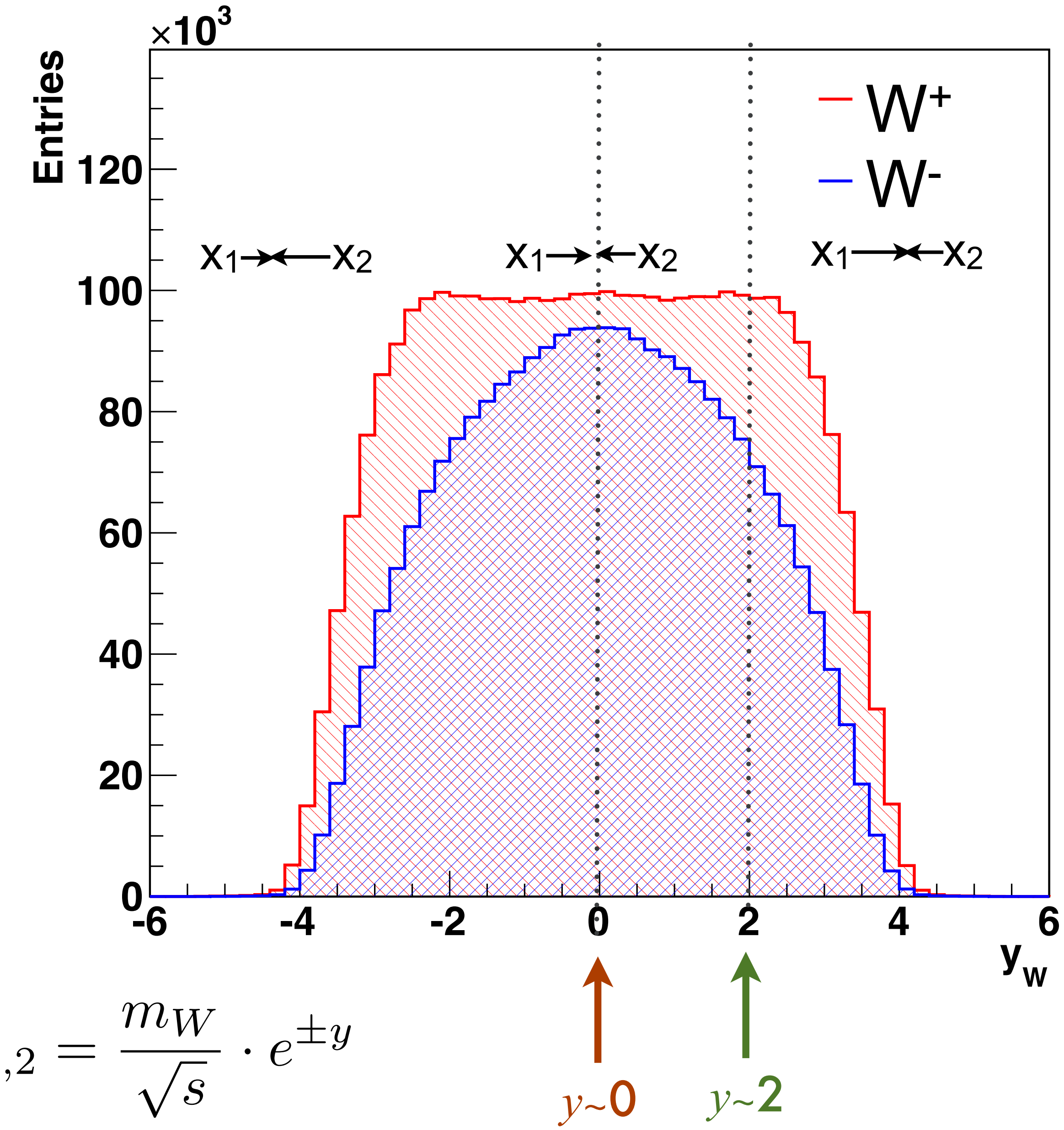
	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W^+}$	$\delta\sigma_{W^-}$	$\delta\sigma_Z$
Trigger	0.5	0.5	0.5	0.1
Muon reconstruction	0.3	0.3	0.3	0.6
Muon isolation	0.2	0.2	0.2	0.3
Muon p_{T} resolution	0.04	0.03	0.05	0.02
Muon p_{T} scale	0.4	0.6	0.6	0.2
QCD background	0.6	0.5	0.8	0.3
Electroweak+$t\bar{t}$ background	0.4	0.3	0.4	0.02
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution and scale	0.5	0.4	0.6	-
Pile-up modeling	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
$C_{W/Z}$ theoretical uncertainty	0.8	0.8	0.7	0.3
Total experimental uncertainty	1.6	1.7	1.7	0.9
$A_{W/Z}$ theoretical uncertainty	1.5	1.6	2.1	2.0
Total excluding luminosity	2.1	2.3	2.6	2.2
Luminosity	3.4			

Extrapolation

W^+ and W^- Rapidity



MRST
Eur.Phys.J.
C14 (2000) 133

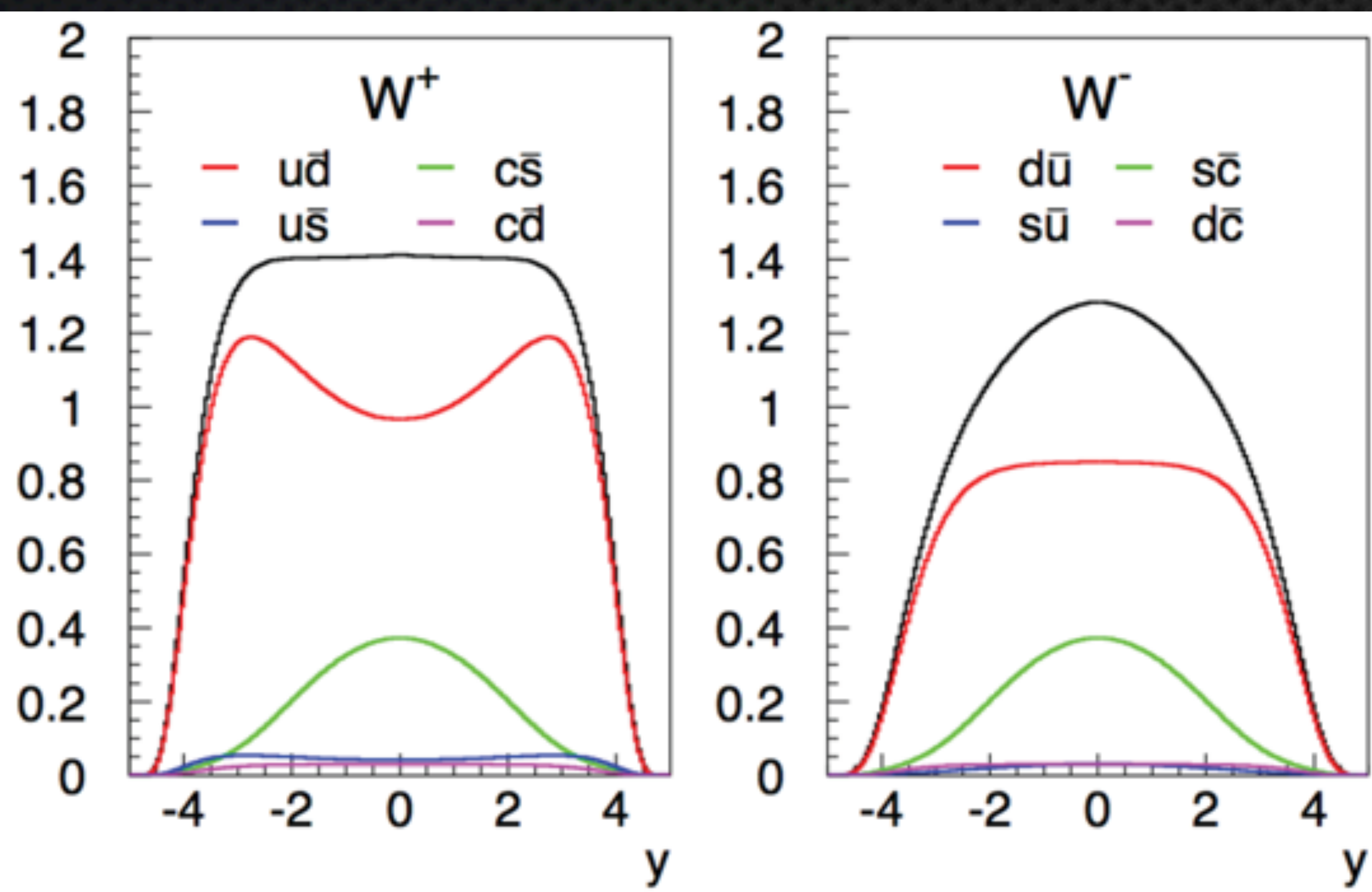


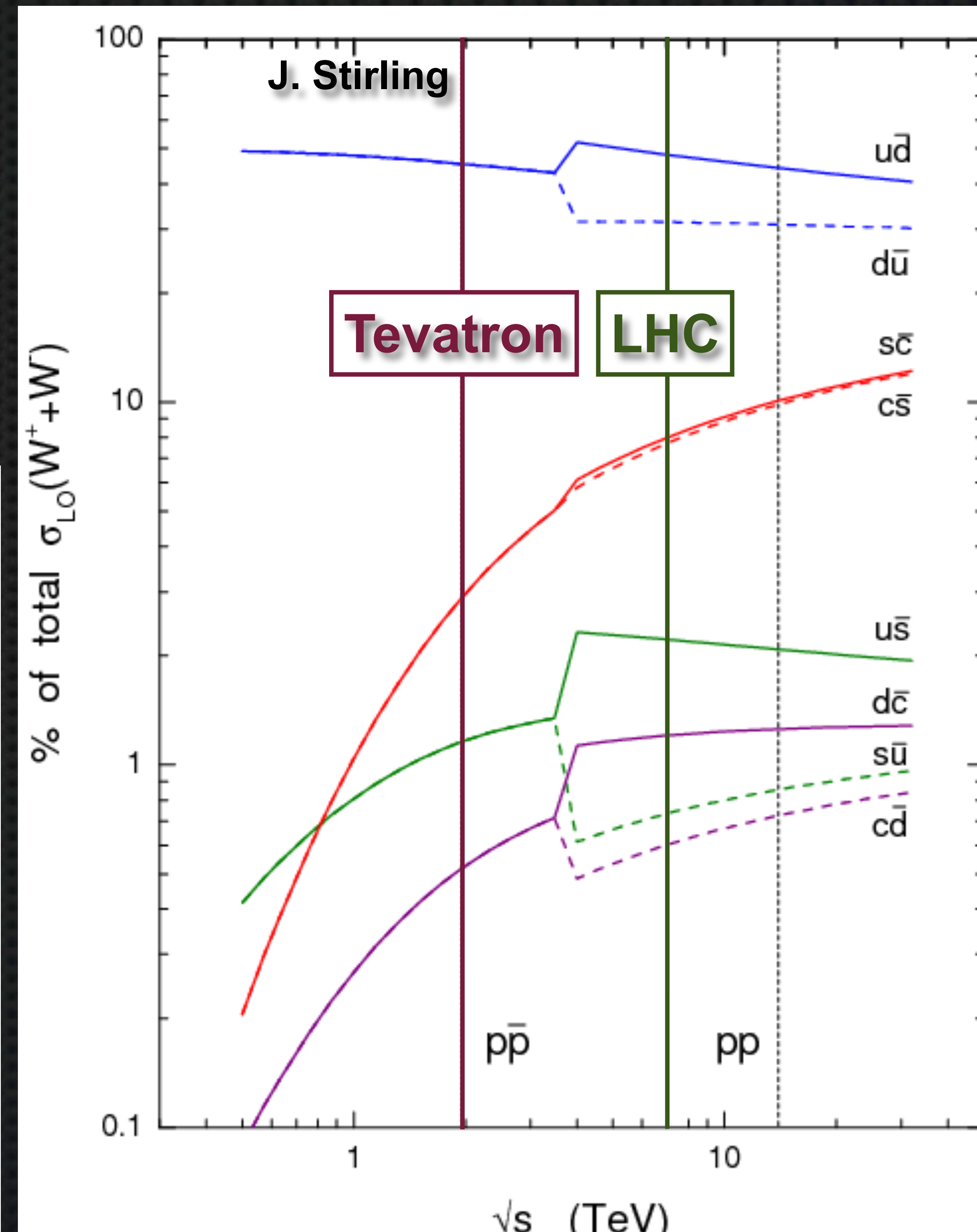
$$x_{1,2} = \frac{m_W}{\sqrt{s}} \cdot e^{\pm y}$$

Rapidity dependence of W^+/W^- production sensitive to differences in u and d

Flavor Decomposition

- **Dominant W production mode is *ud* quark annihilation**
  - Valence *u* gives broader structure in *y* for W^+
- **Significant contribution of sea quarks**
  - Total about 30%, particularly at low y

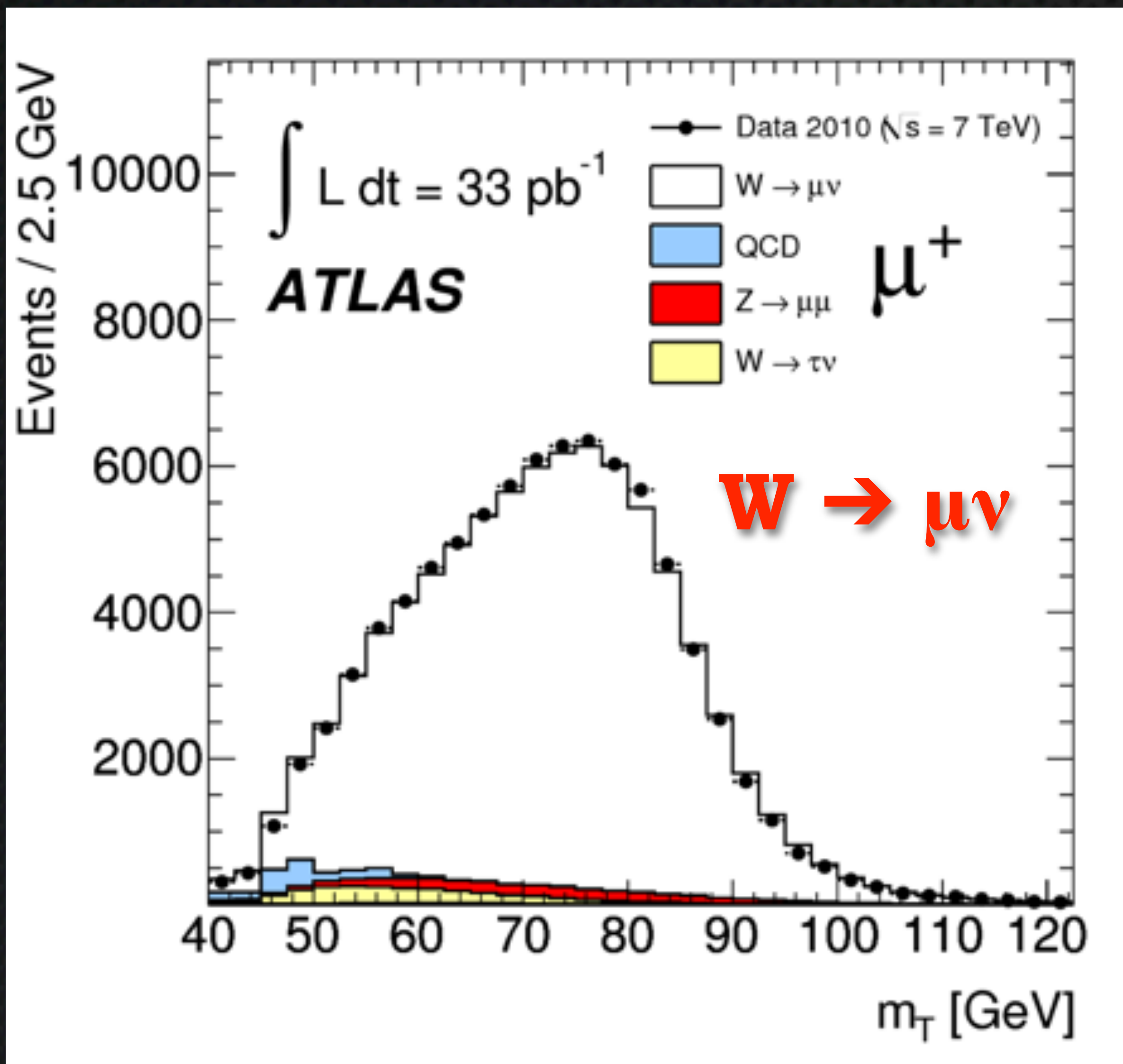




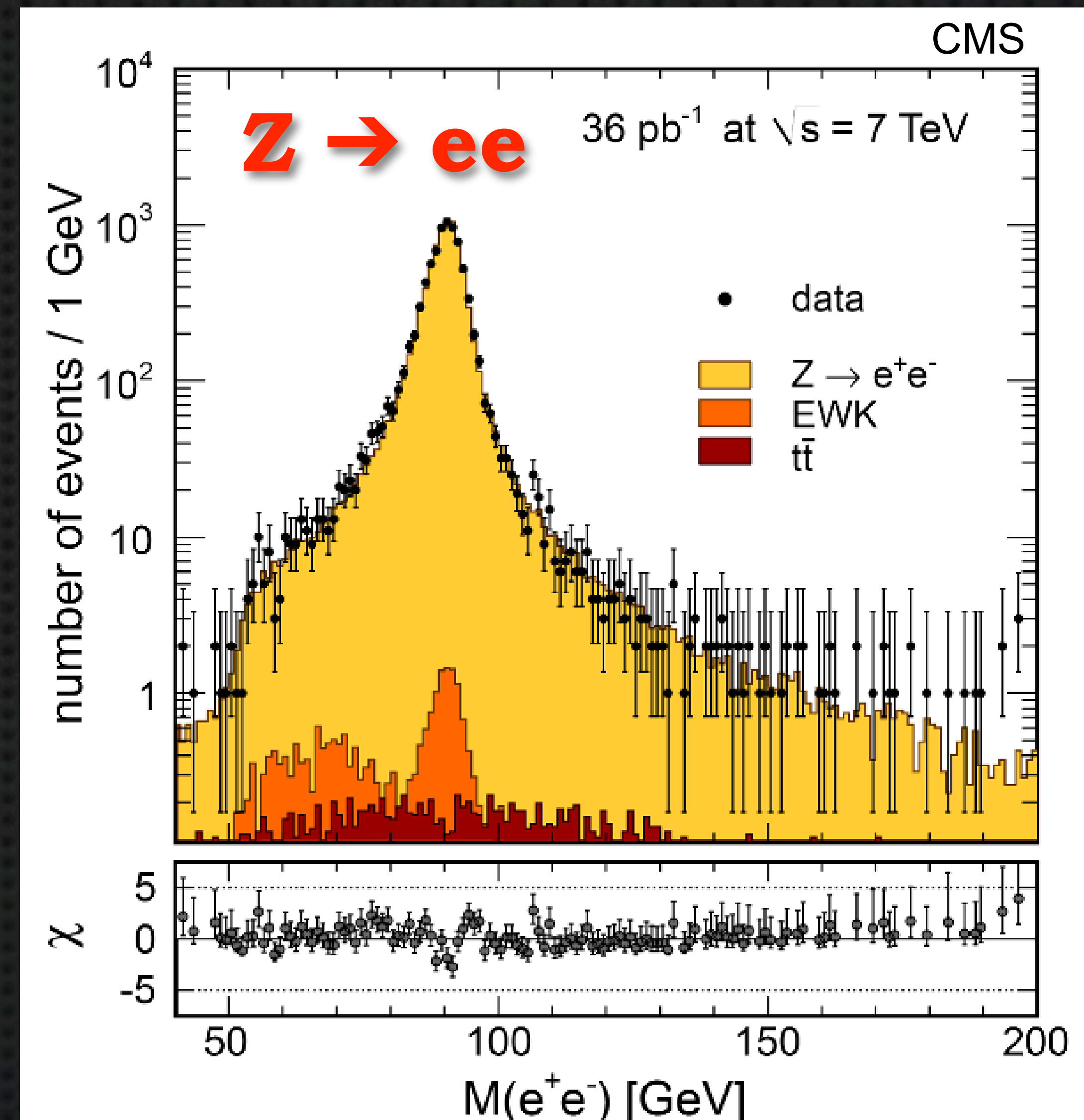
W/Z cross section measurements

- **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

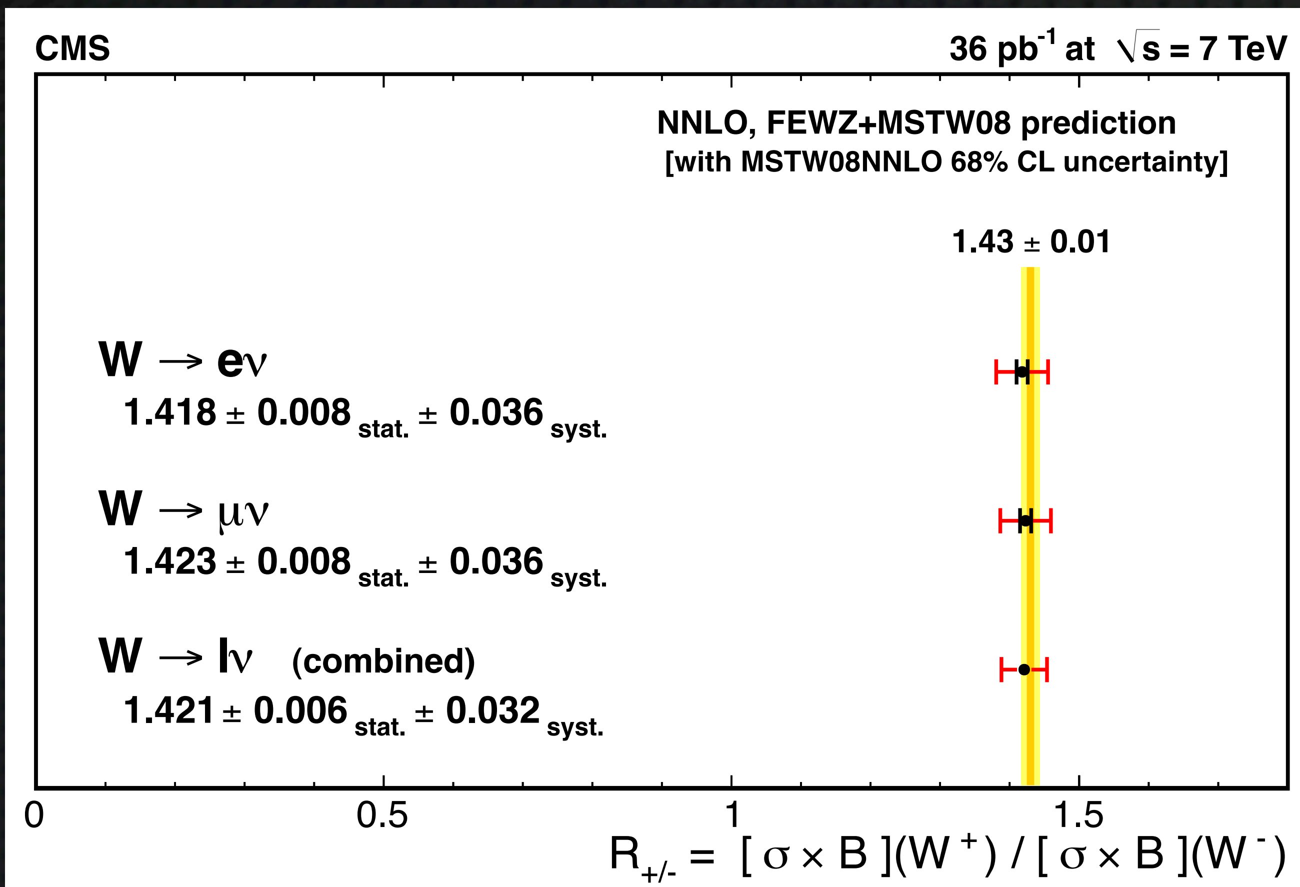
$\sqrt{s}$ = 7 TeV, 5 fb^{-1} { $W \to e/\mu\ \nu$: ~ 25 Million; $Z \to ee/\mu\mu$: ~ 3 Million } + $\sqrt{s}$ = 8 TeV ~23 fb^{-1}

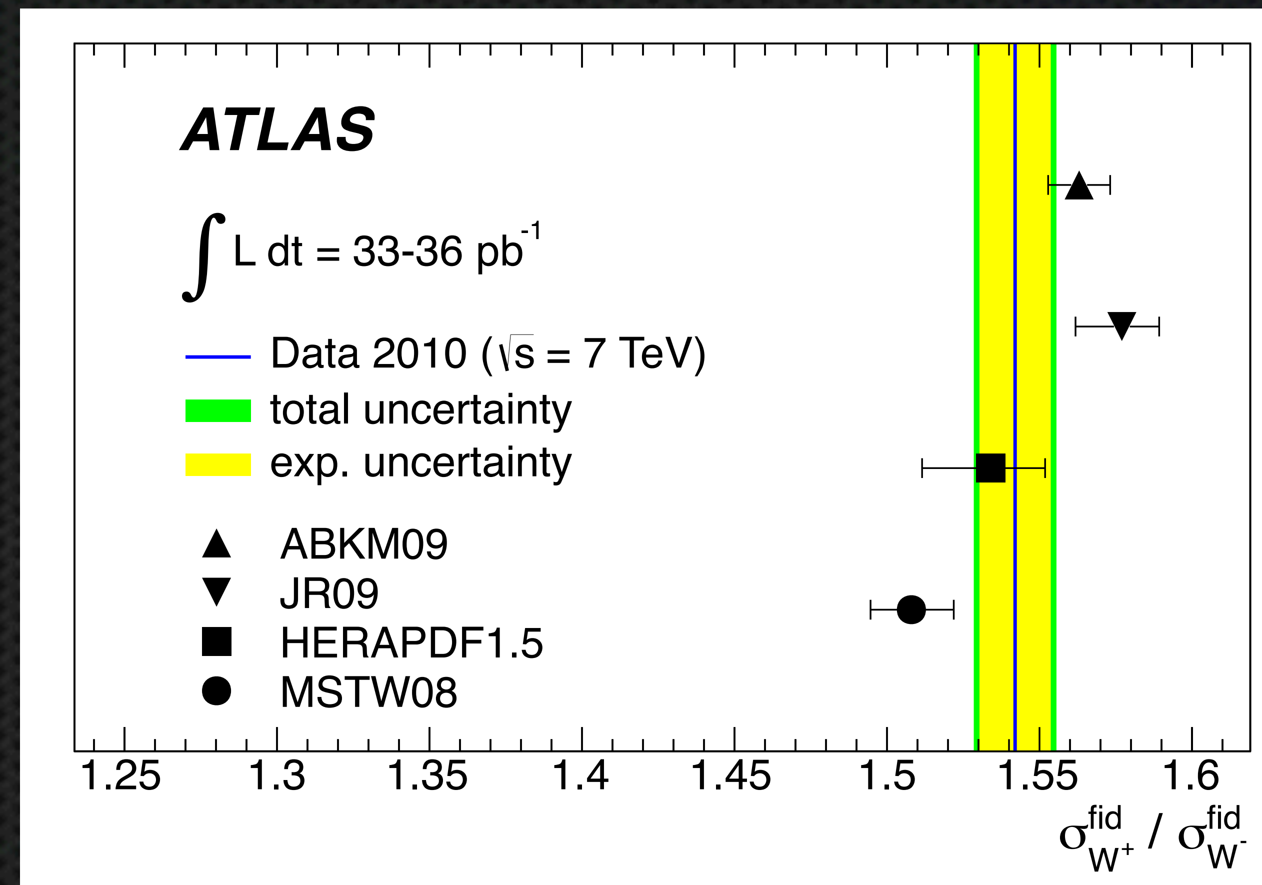
Cross Section Ratio W^+/W^-

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)	1.8%
ATLAS $\sigma_{fiducial}$	1.542 ± 0.007 (sta) ± 0.012 (sys) ± 0.001 (acc)	0.9%

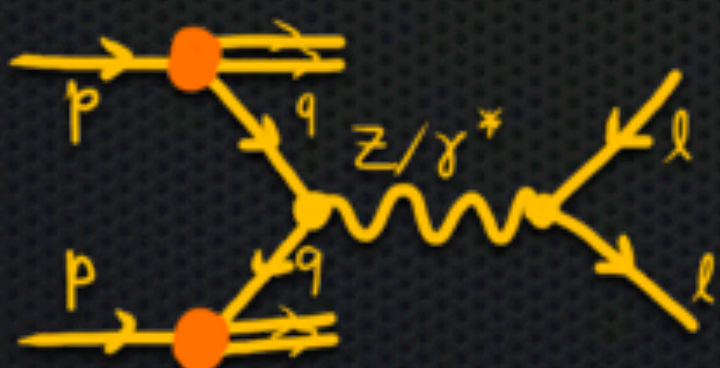
Lepton Universality

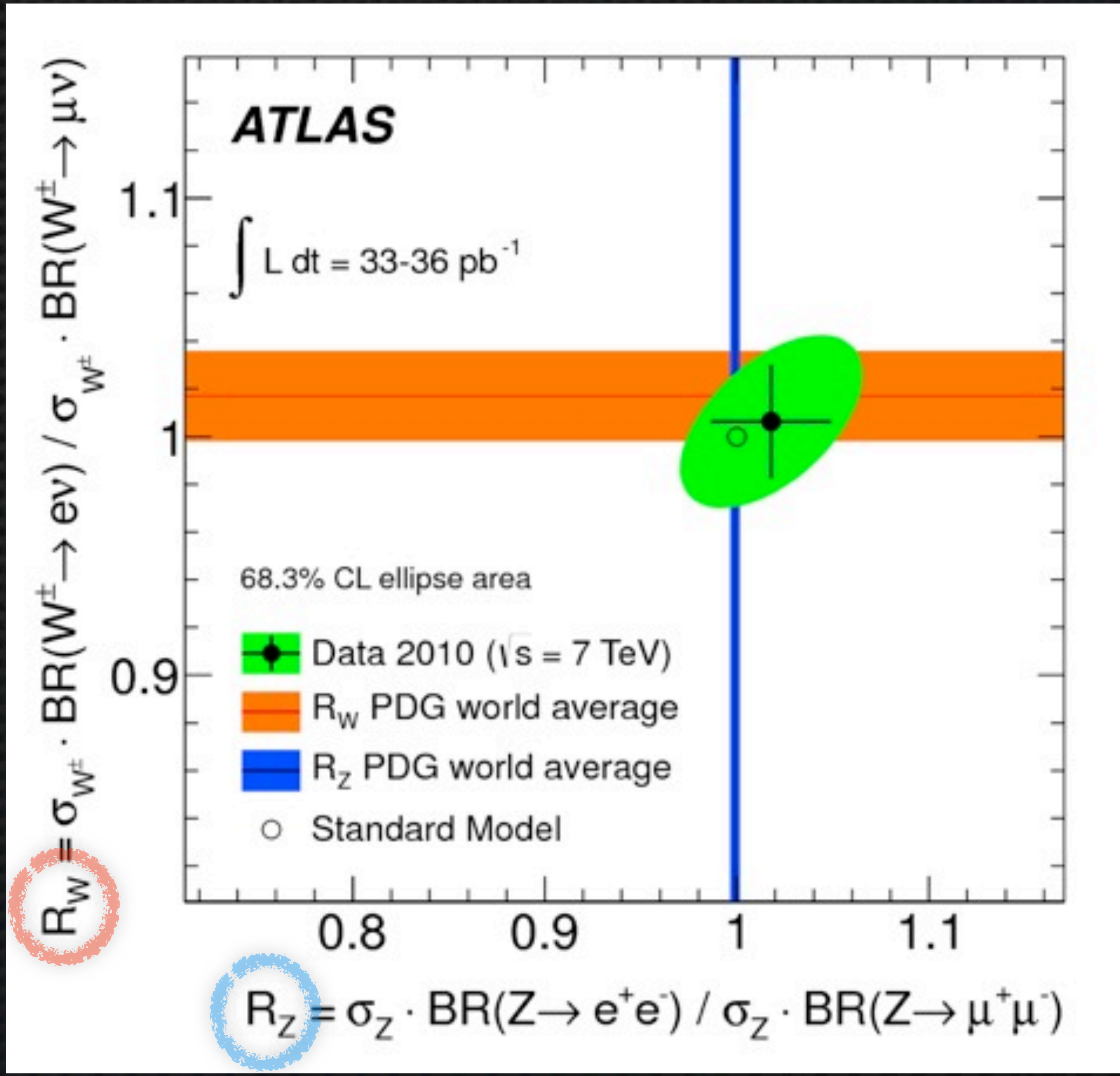
Phys. Rev. D85 (2012) 072004

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

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

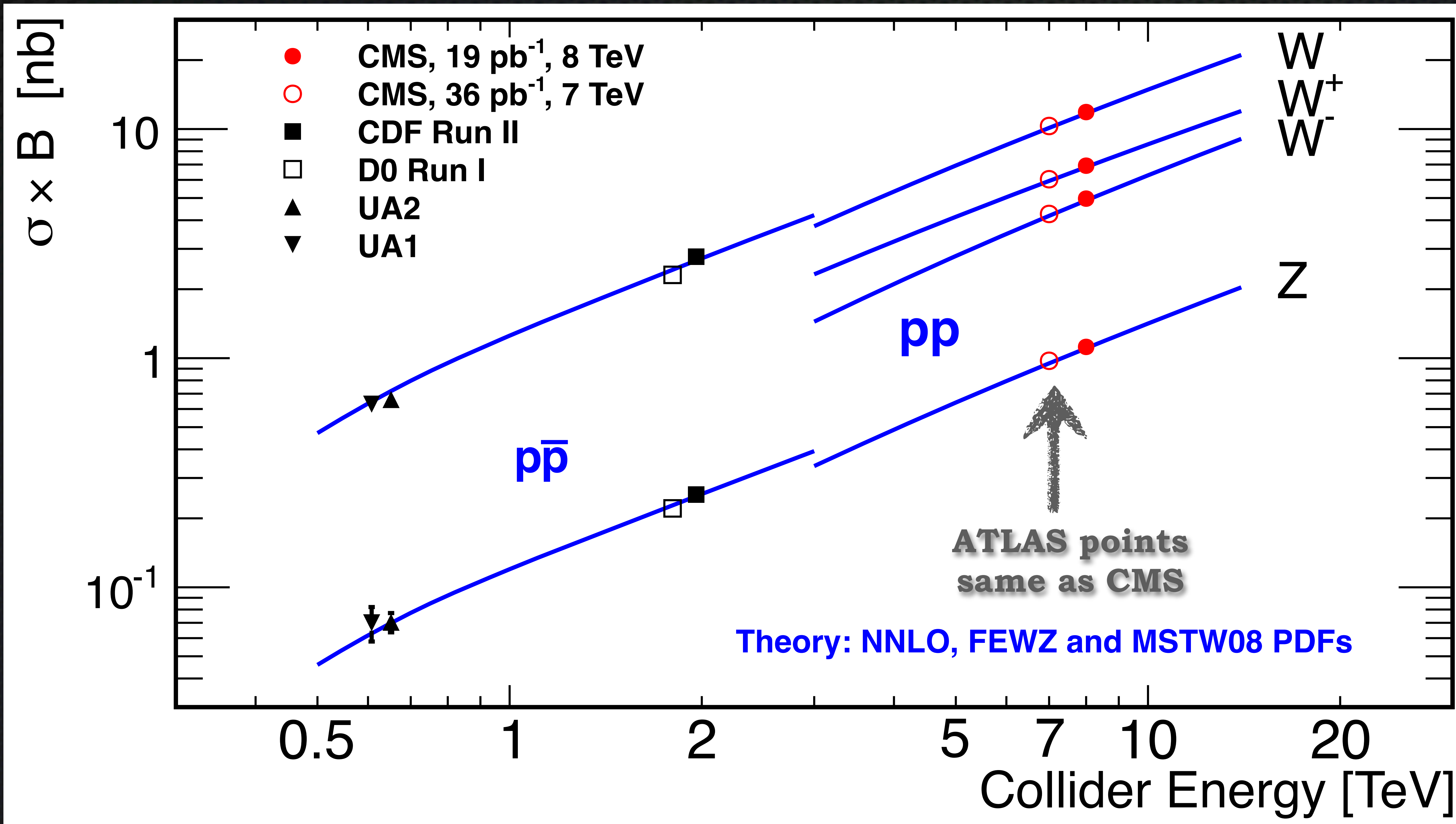
- **Result already close to best measurement (R_W)**
  - **PDG: 1.9%**
  - **This measurement: 2.4%**





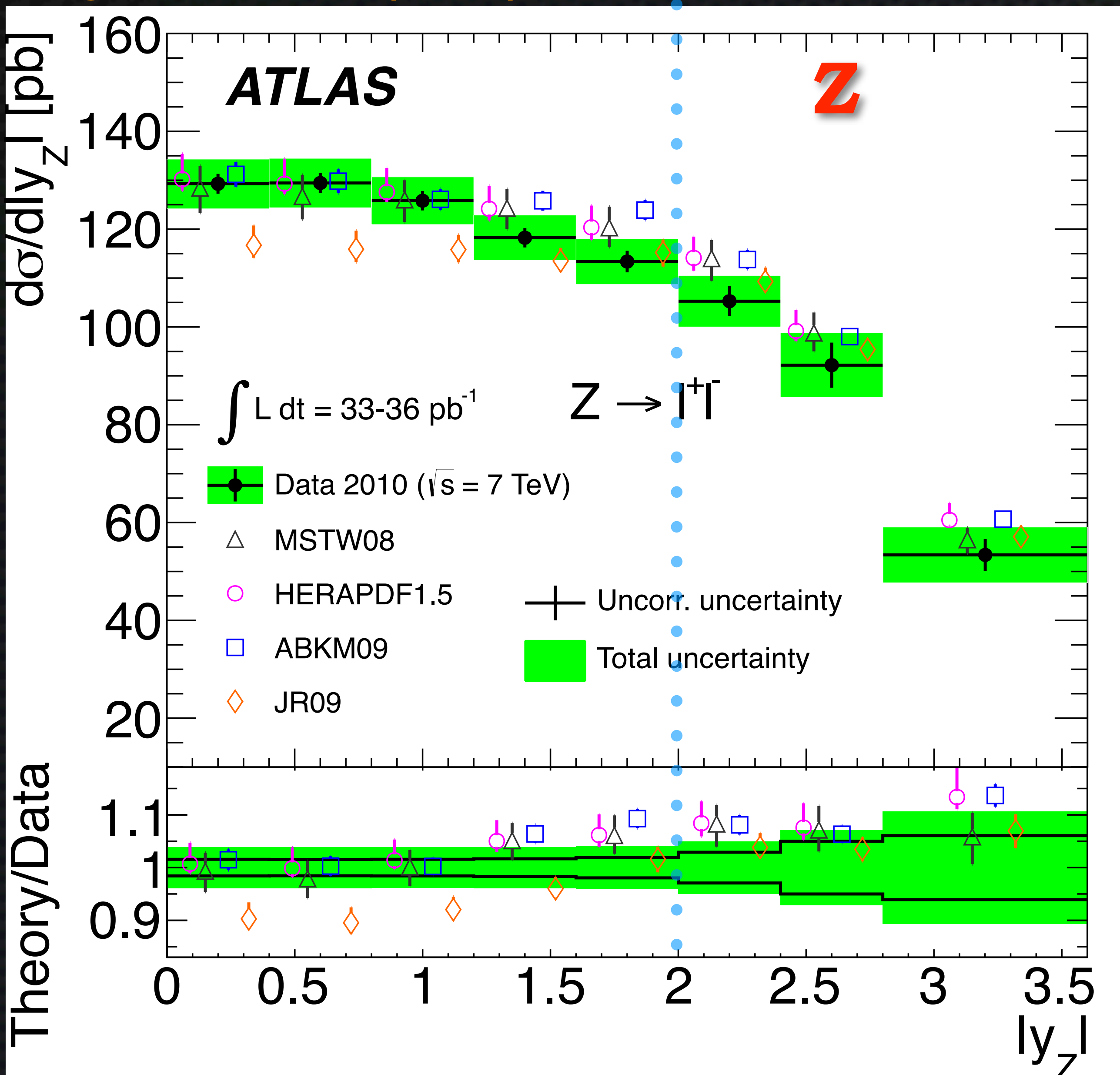
W and Z Inclusive Cross Sections

CMS-PAS-12-011

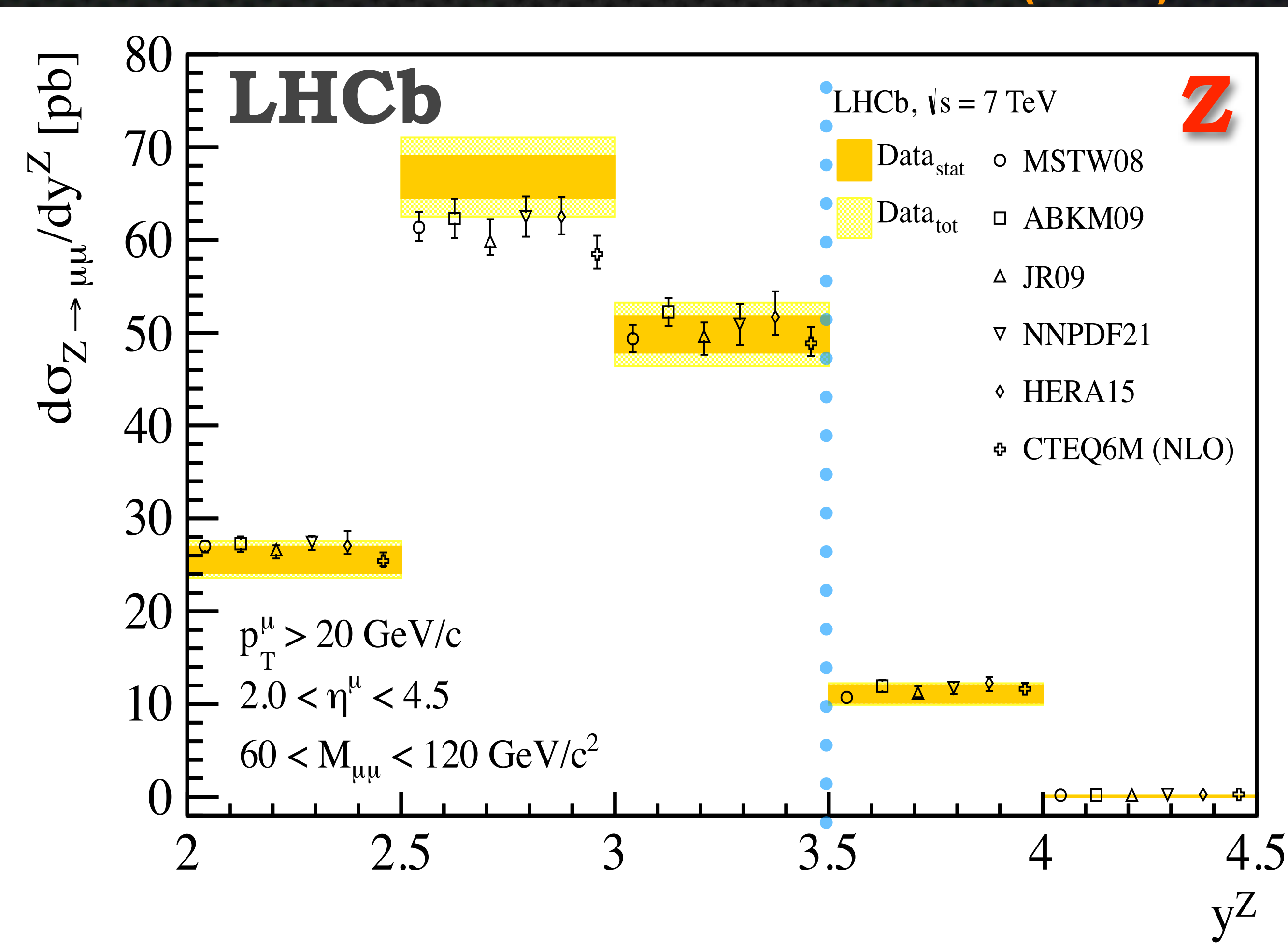


$d\sigma_Z/dy_Z$ versus NNLO PDF predictions

Phys. Rev. D85 (2012) 072004



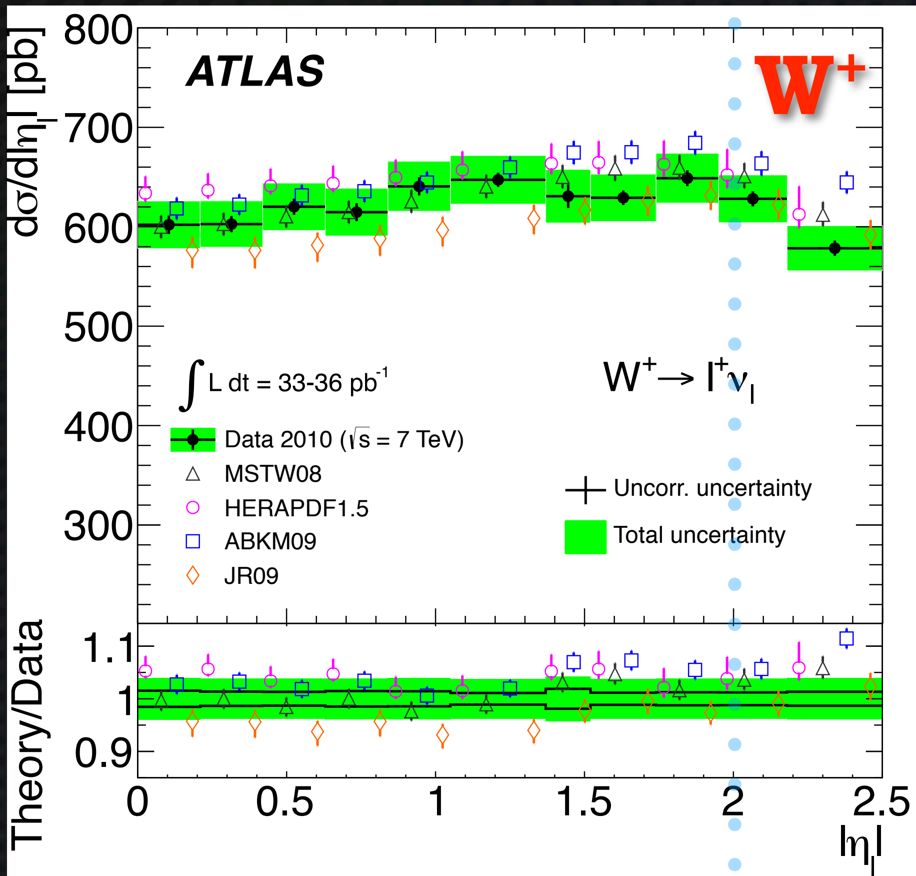
JHEP 06 (2012) 058

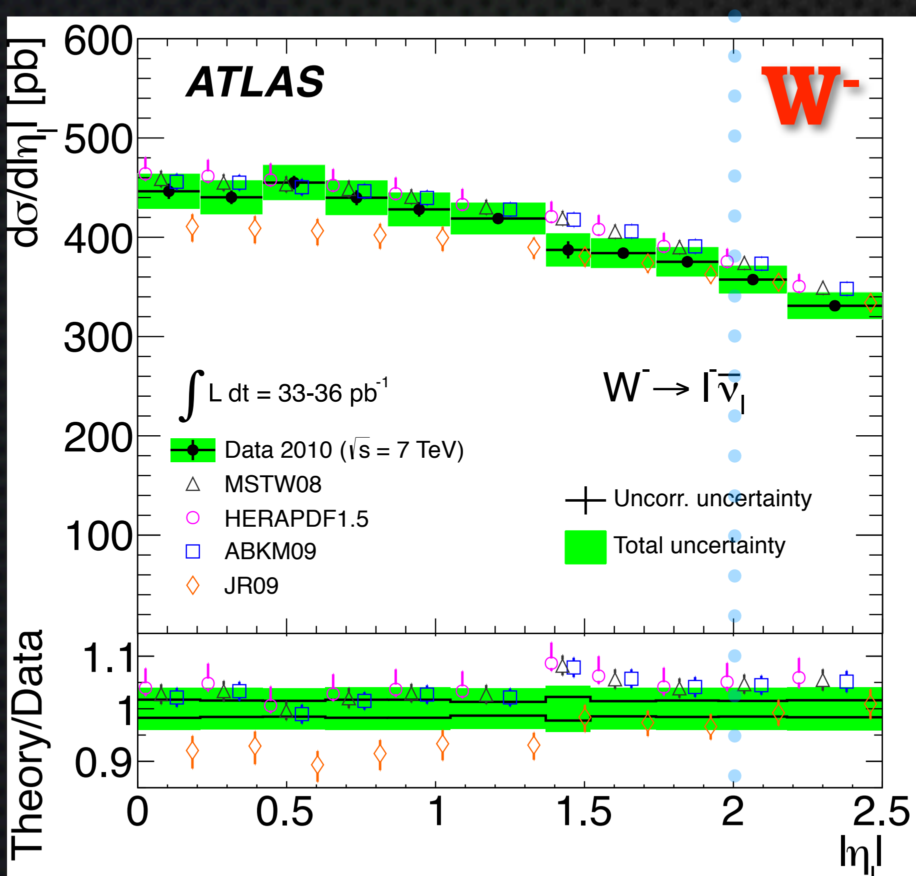


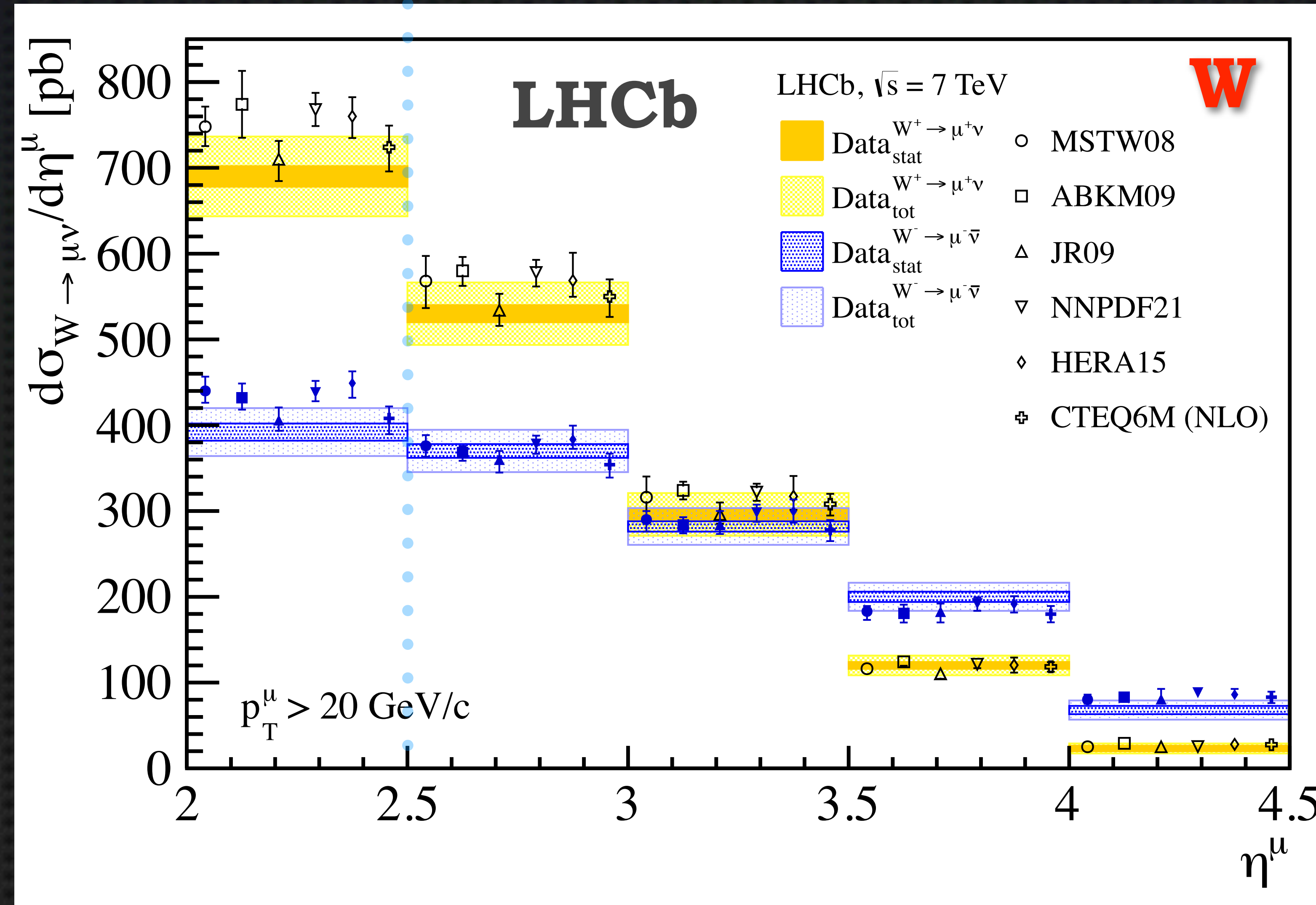
CMS *Z* rapidity measurement:
Phys. Rev. D 85 (2012) 032002

- **Broadly well described by predictions**
- **Can impact PDF central values and uncertainties**
  - **Full covariance matrix available from all experiments**
  - **Information on *d*, *u* and *s* decomposition at $x \sim 0.01$**

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



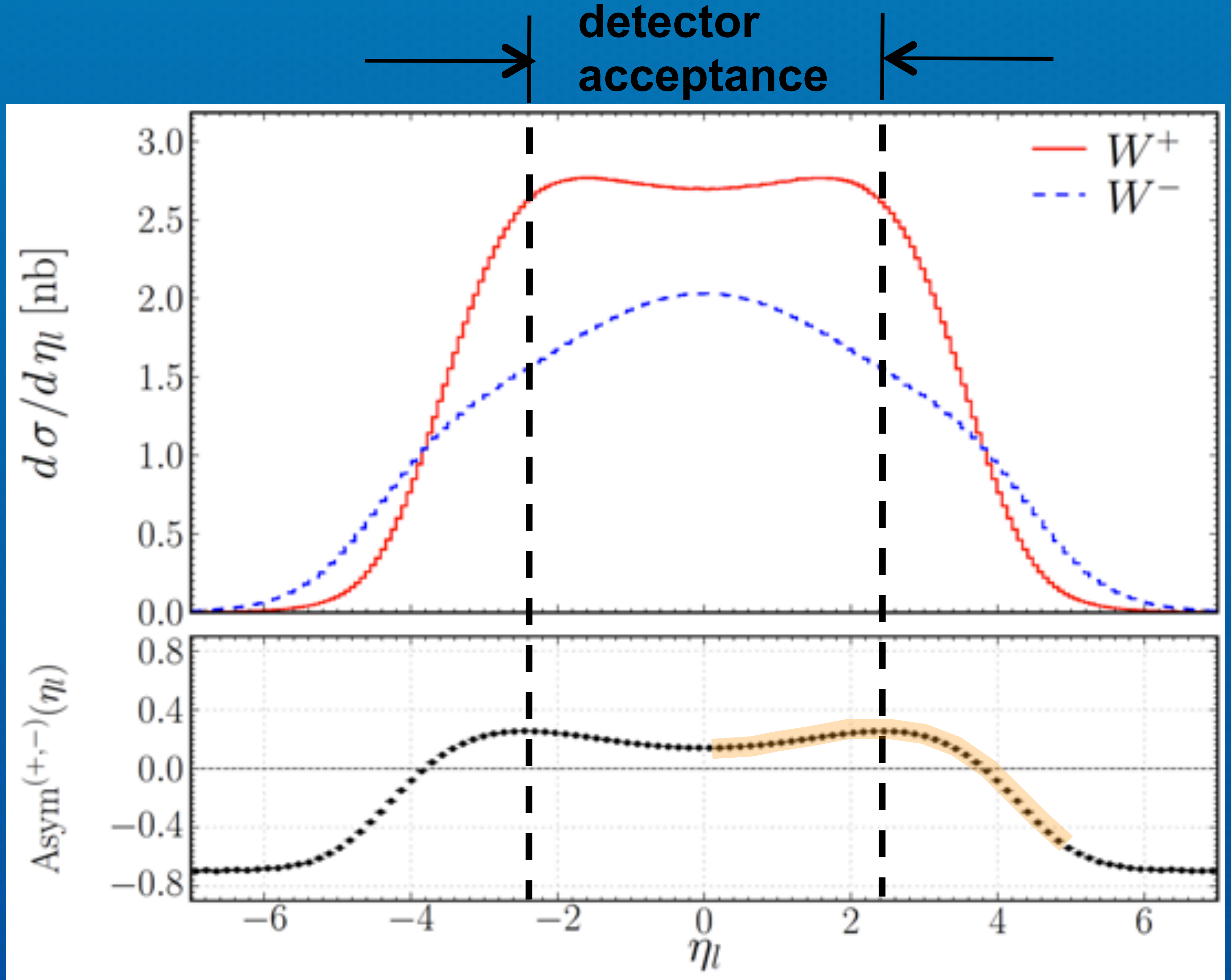




- Broadly well described by predictions
- Can impact PDF central values and uncertainties
  - Information on u_v and d_v PDFs

W-Lepton Charge Asymmetry

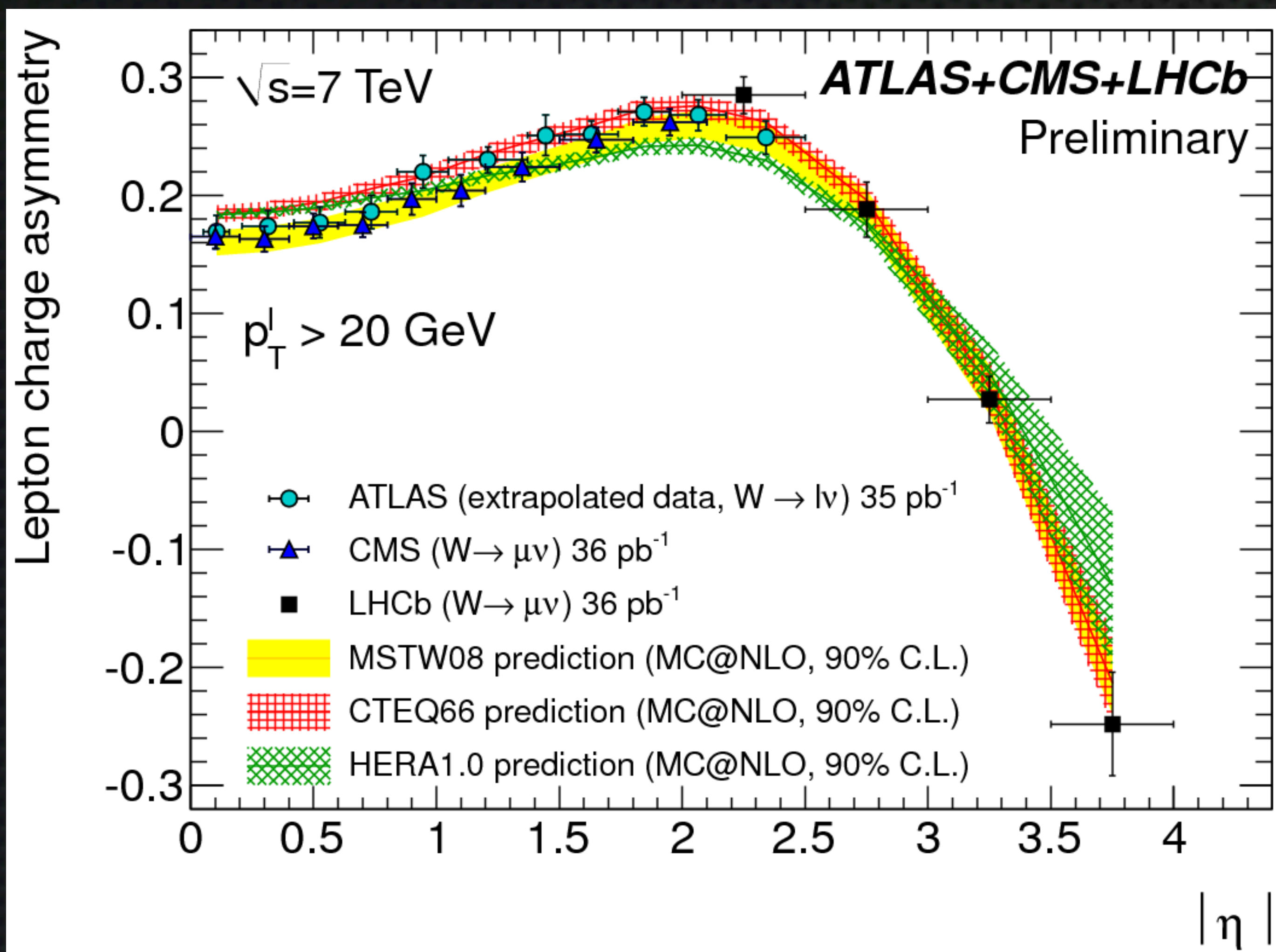
$$A(\eta_\ell) = \frac{d\sigma_{W+}(\eta_\ell) - d\sigma_{W-}(\eta_\ell)}{d\sigma_{W+}(\eta_\ell) + d\sigma_{W-}(\eta_\ell)}$$



W-Lepton Charge Asymmetry

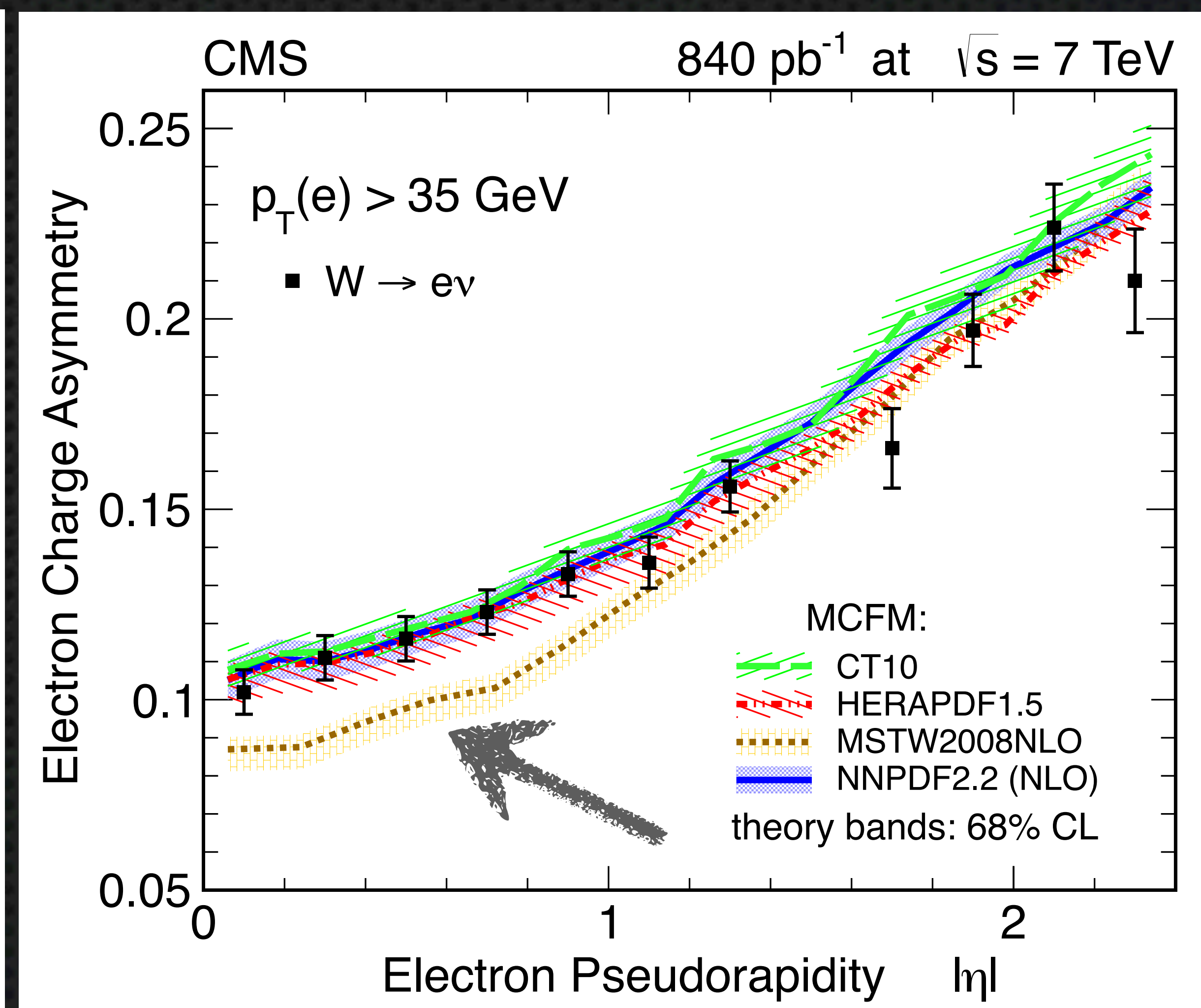
$$A(\eta_\ell) = \frac{d\sigma_{W+}(\eta_\ell) - d\sigma_{W-}(\eta_\ell)}{d\sigma_{W+}(\eta_\ell) + d\sigma_{W-}(\eta_\ell)}$$

ATLAS-CONF-2011-129



First LHC combined plot (LHC EWK WG)

arXiv:1206.2598



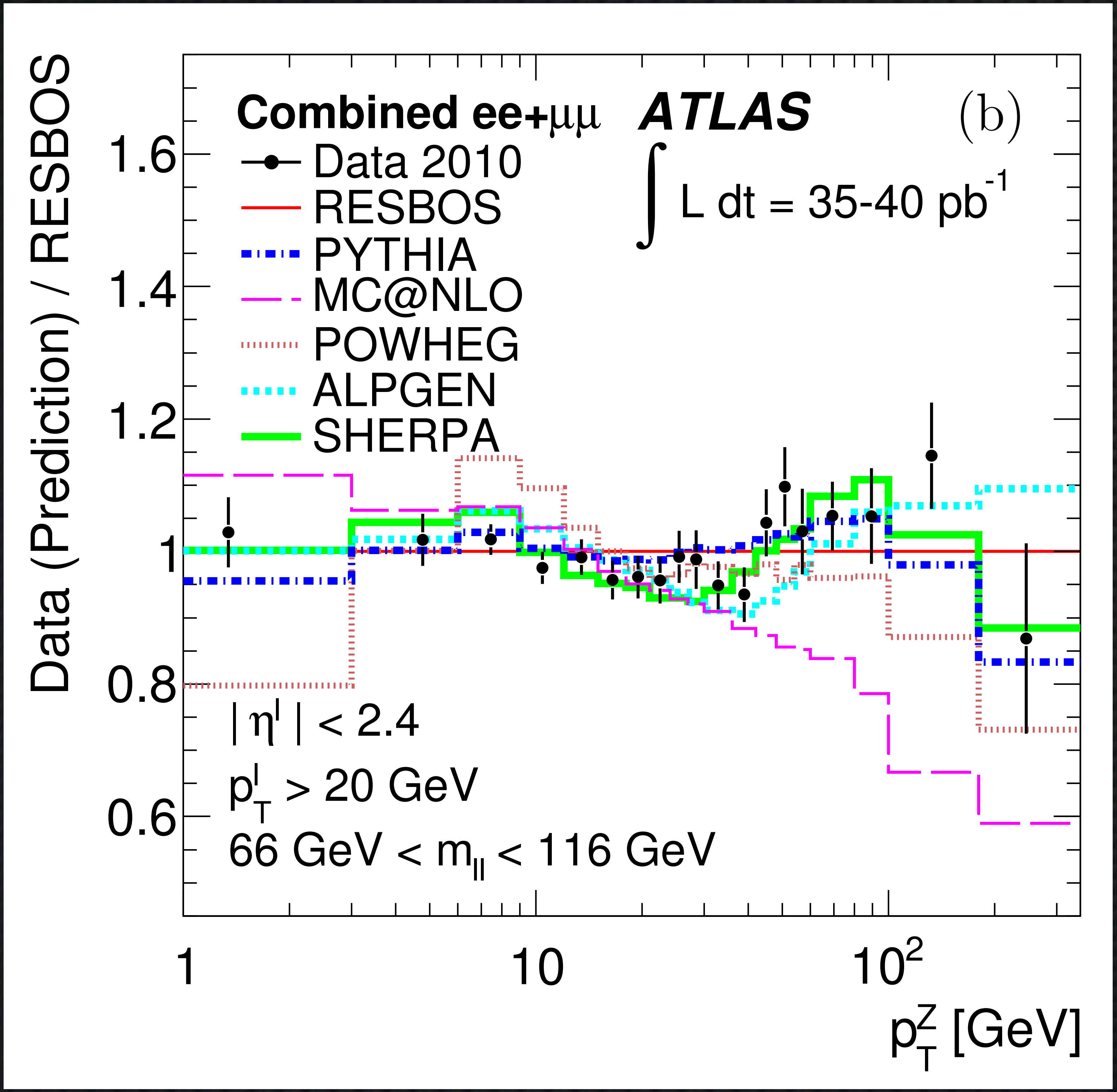
Discrimination between PDF at low |η|

Transverse momentum distribution of Z/γ* bosons

Predictions: Different event generators

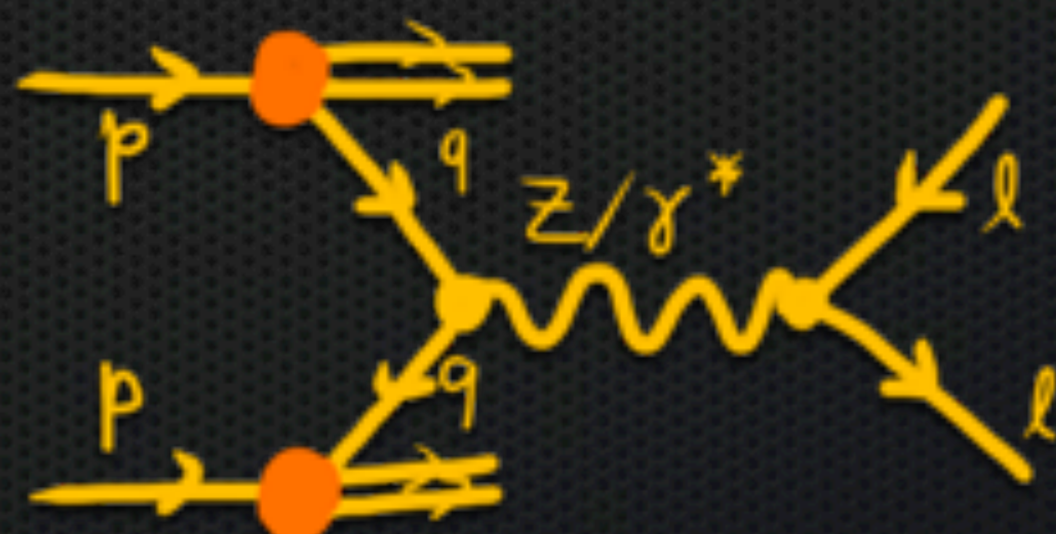
Fiducial measurement

Ratio to RESBOS

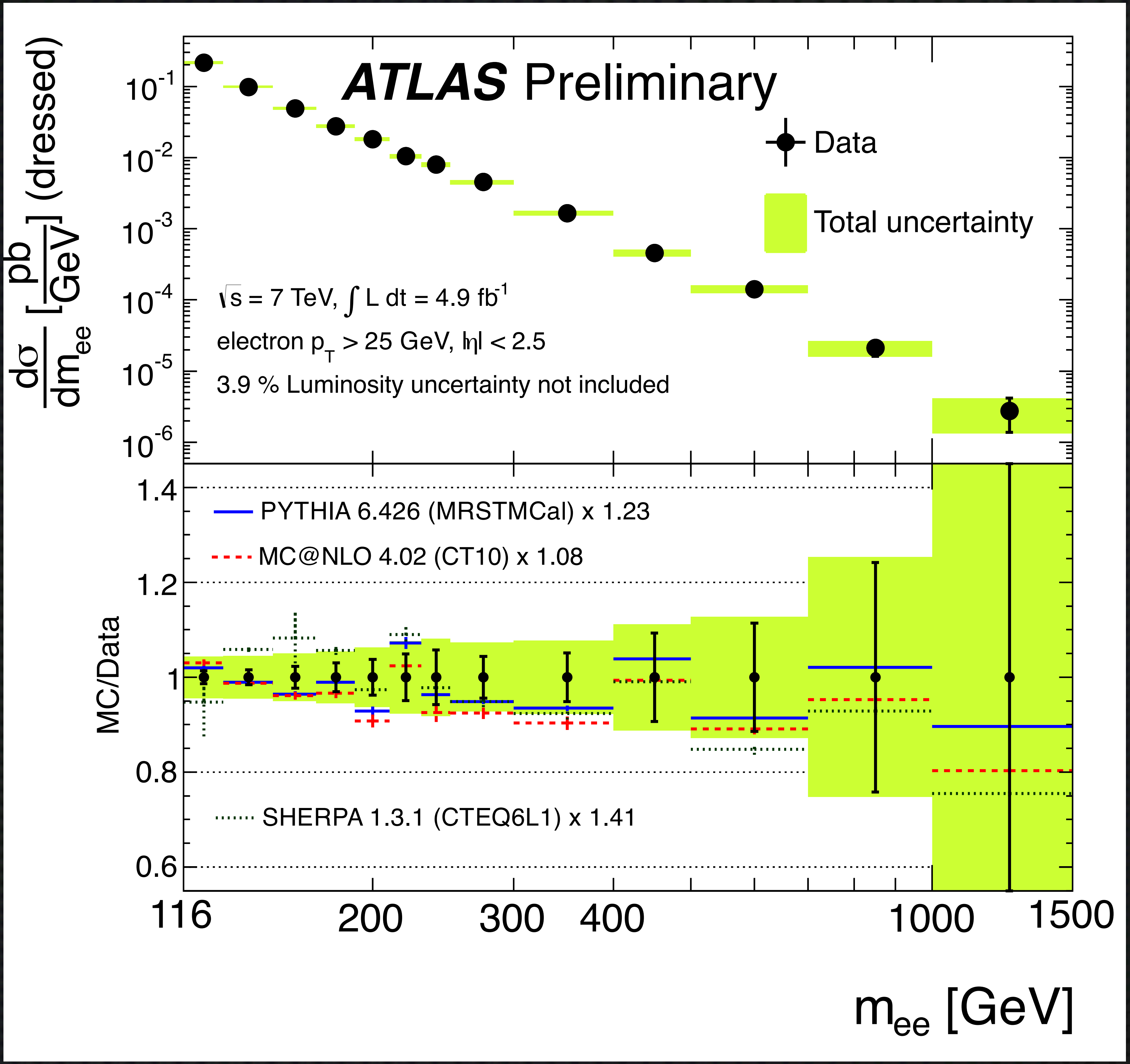


Similar situation with W p_T

Drell-Yan Production

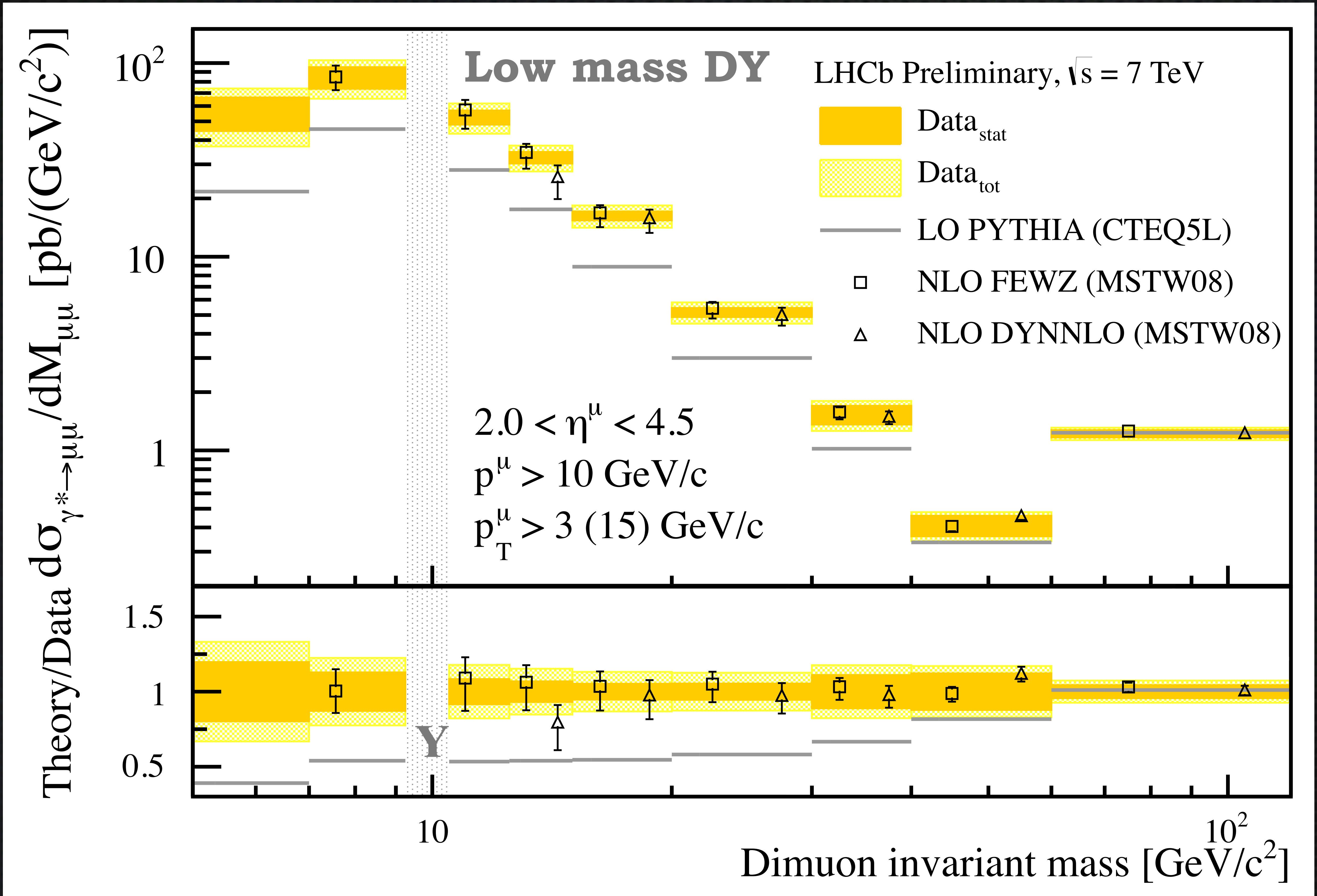


High-mass Drell-Yan Production

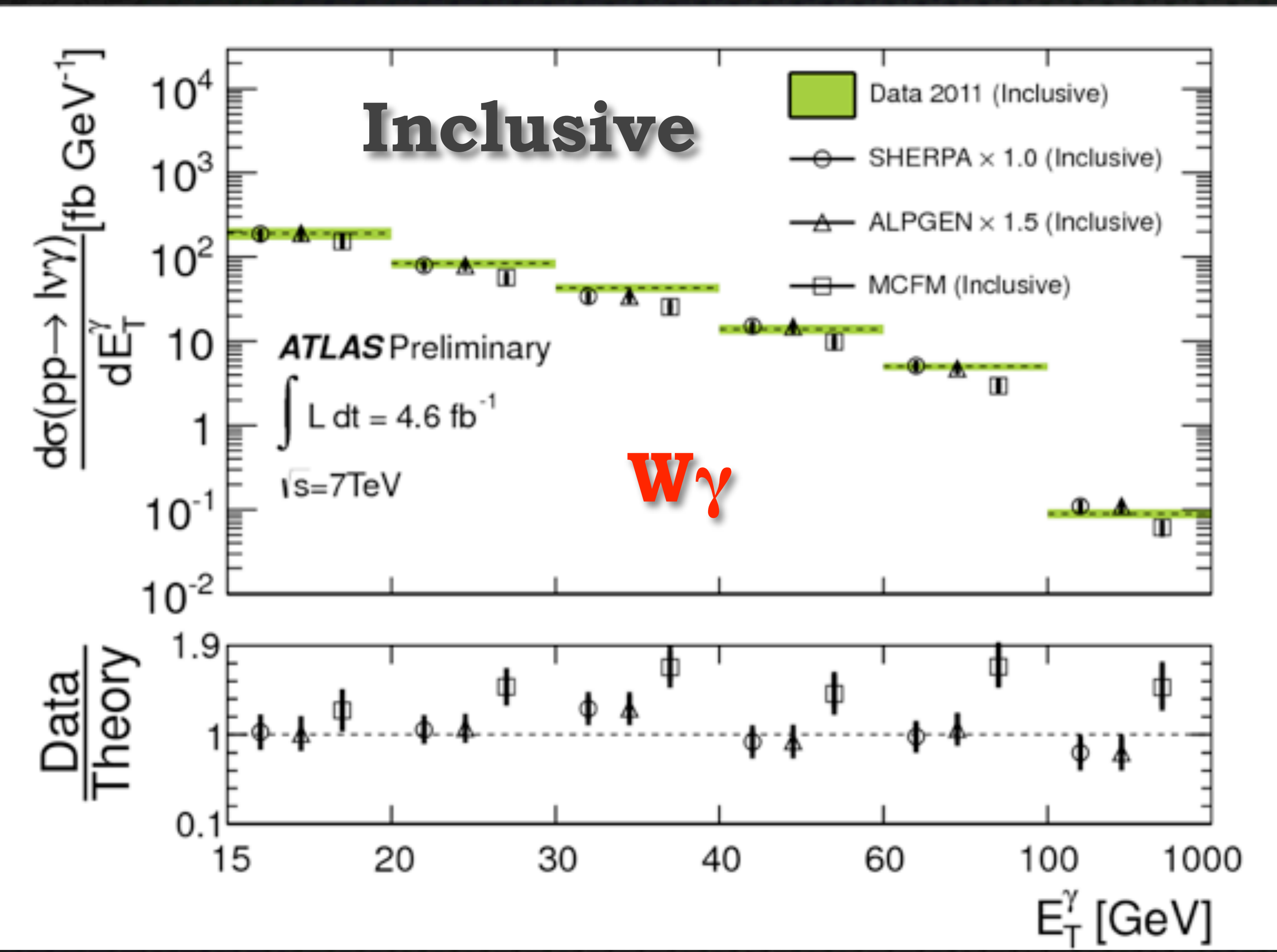


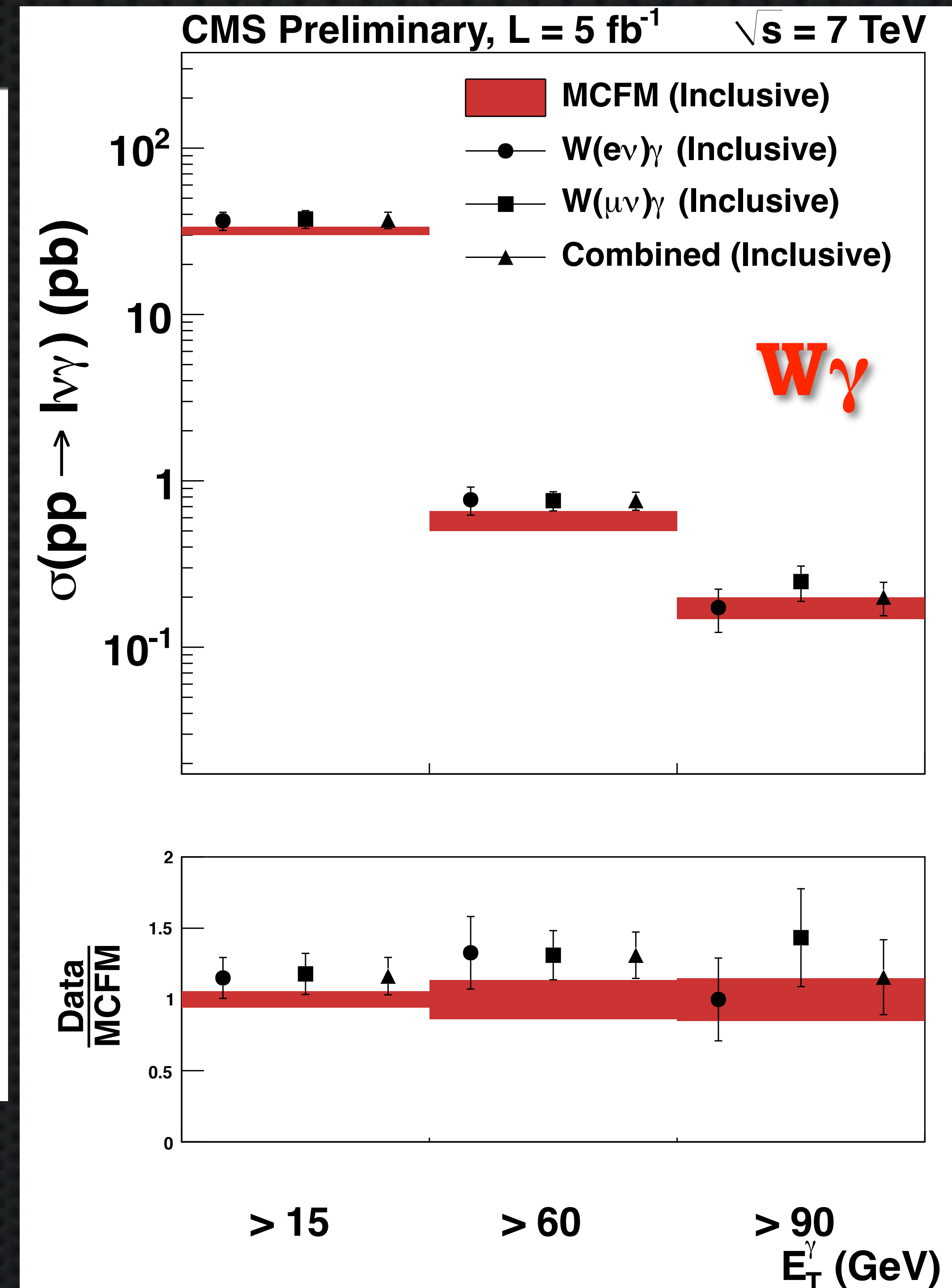
Drell-Yan production in forward region (LHCb)

LHCb-CONF-2012-013



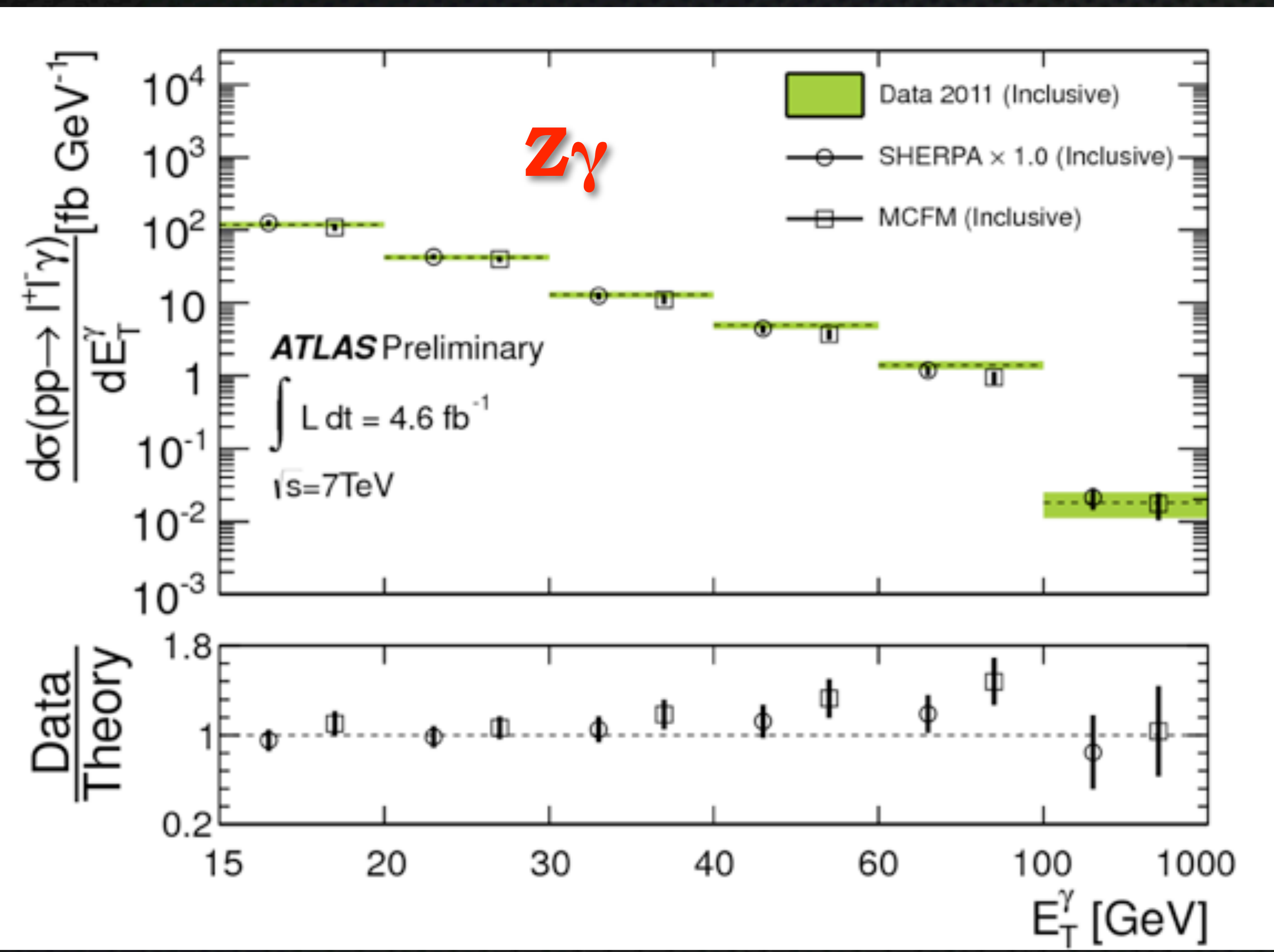
Dibosons: Wγ

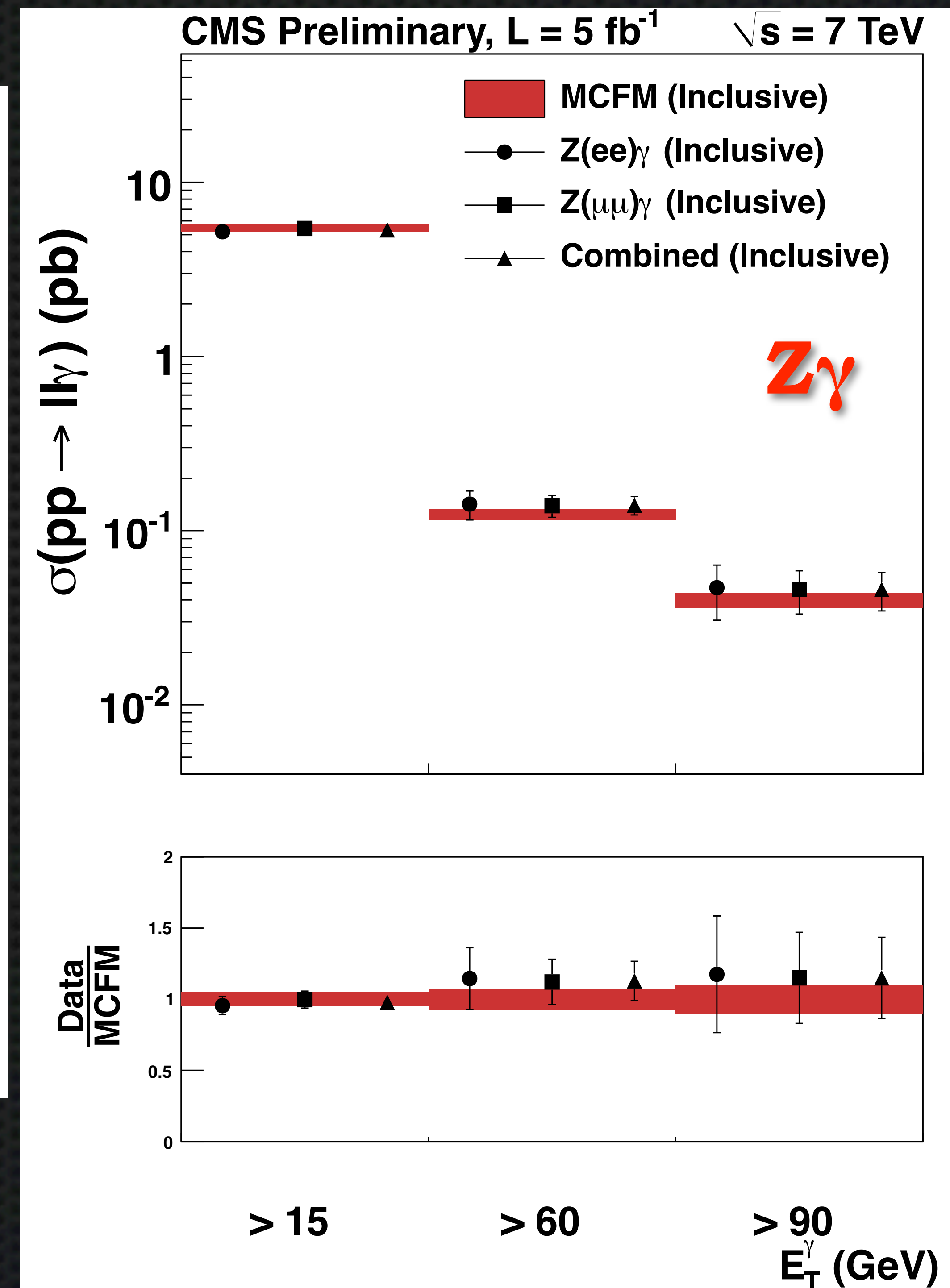




Wγ: Agreement with NLO MCFM calculation is not great
Exclusive calculation (N_{jet} =0) looks good

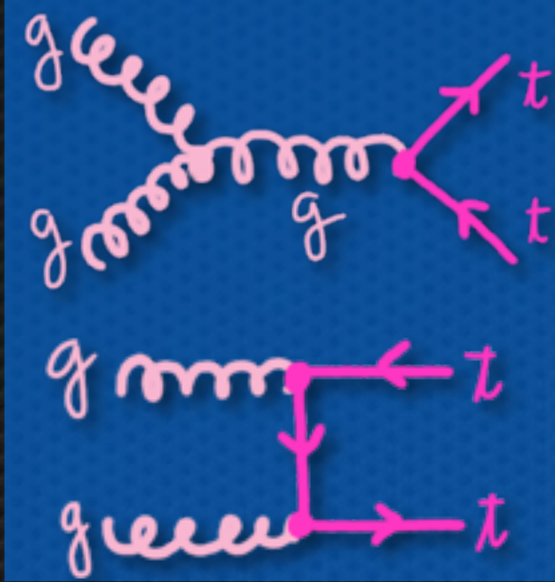
Dibosons: Zγ





Zγ: Good agreement with NLO MCFM calculation

Top Quark Pair Production at Hadron Colliders

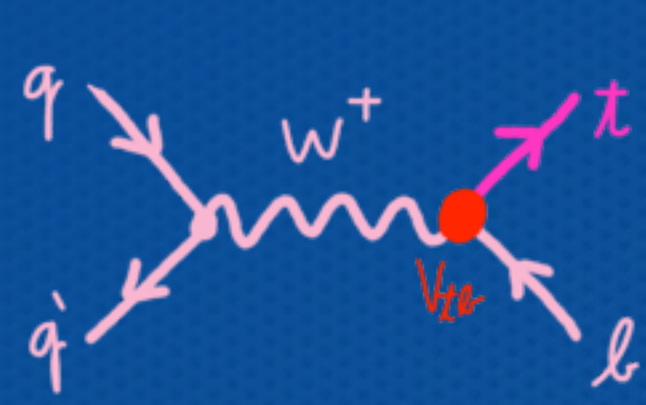
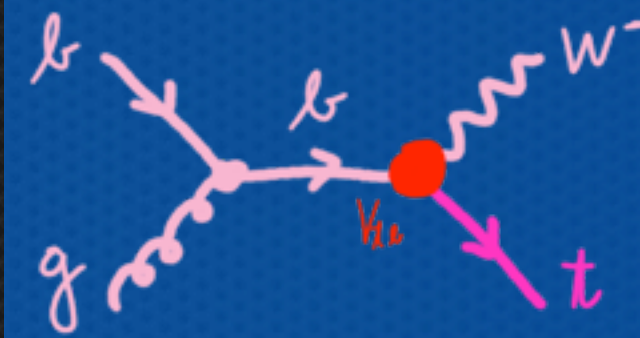
			σ(NNLO$_{approx}$) (pb) (m_{top} = 172.5 GeV)
Tevatron @ 1.96 TeV	85%	15%	$7.46^{+0.48}_{-0.67}$
LHC @ 7 TeV	15%	85%	$164.6^{+11.4}_{-15.7}$

×22

Langenfeld et al. PRD 80, 054009 (2009)
Aliev et al., Comput.Phys.Commun. 182, 1034 (2011)
Kidonakis, Phys.Rev. D82, 114030 (2010)
Ahrens et al., JHEP 1009, 097 (2010), arXiv:1105.5824

4 × more top pairs at LHC with 1 fb^{-1}, than at the Tevatron with 5 fb^{-1}

Electroweak Top Production at Hadron Colliders

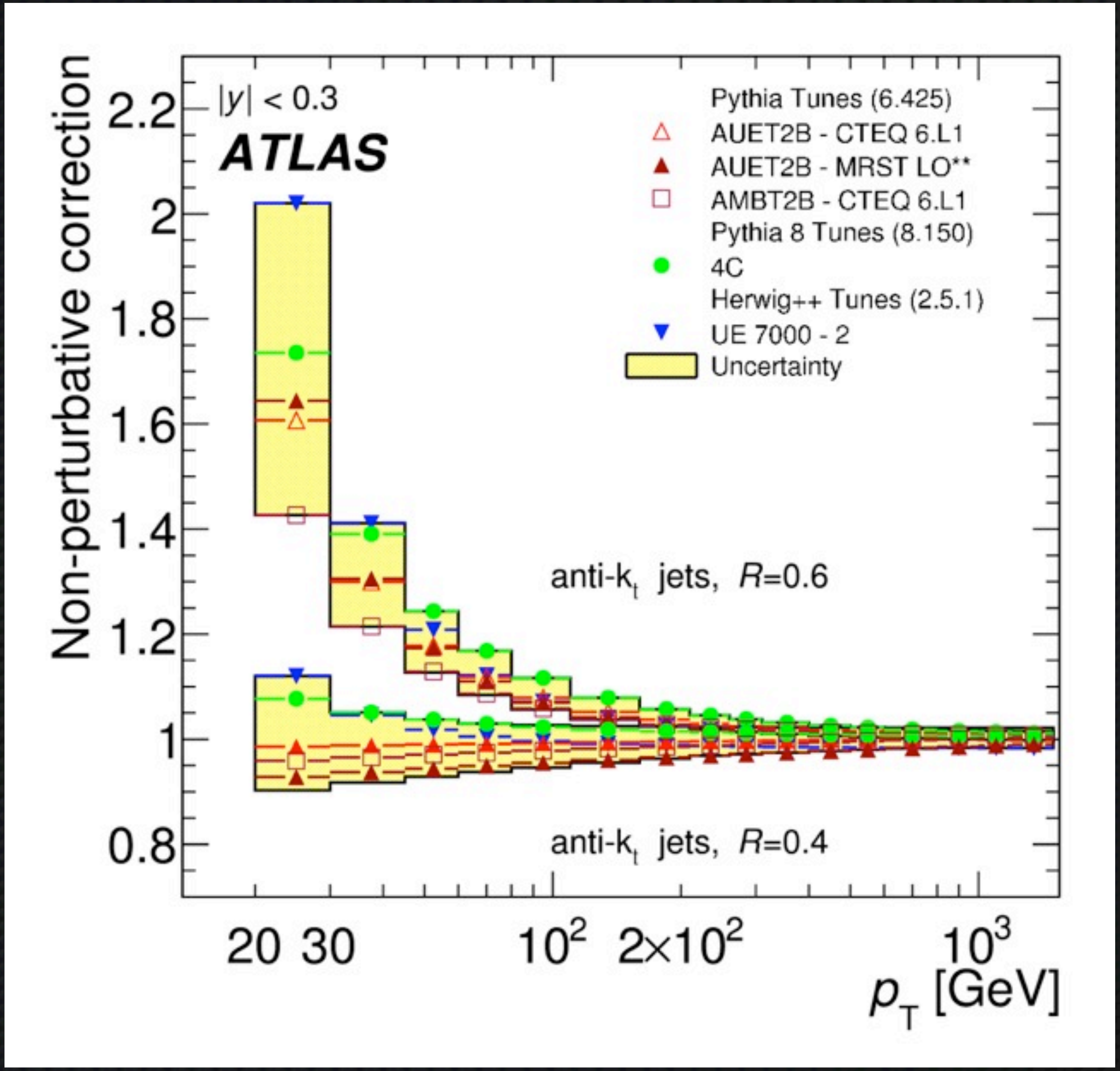
σ(NNLO) (pb) (m_{top} = 172.5 GeV)	s-channel	t-channel	Wt-channel
			
Tevatron @ 1.96 TeV	1.04 ± 0.4	2.26 ± 0.12	0.28 ± 0.06
LHC @ 7 TeV	4.6 ± 0.3	$64.6^{+3.3}_{-2.6}$	15.7 ± 1.4

Very difficult at LHC (s-channel)

Not possible at Tevatron (Wt-channel)

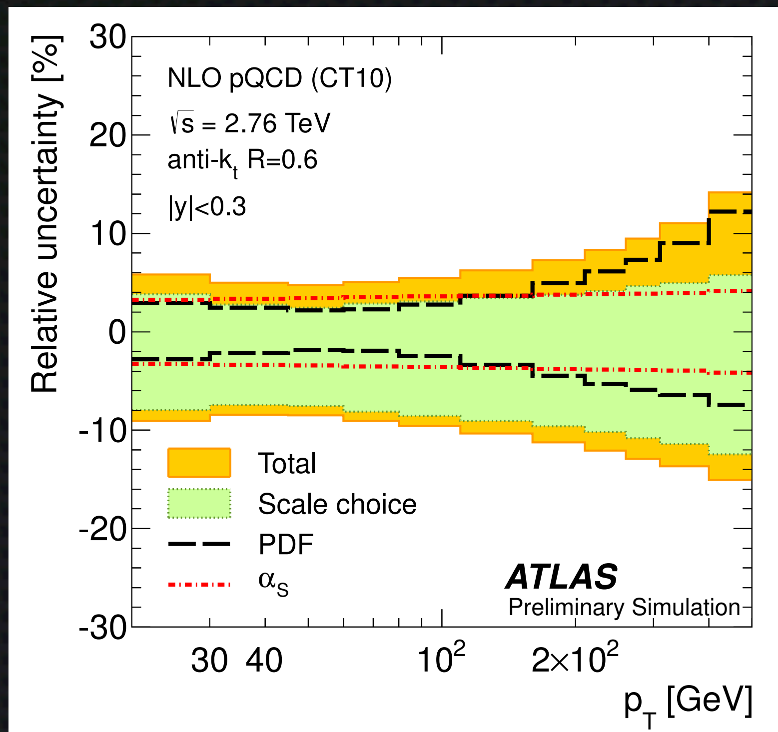
Inclusive Jet Cross Sections at 7 TeV

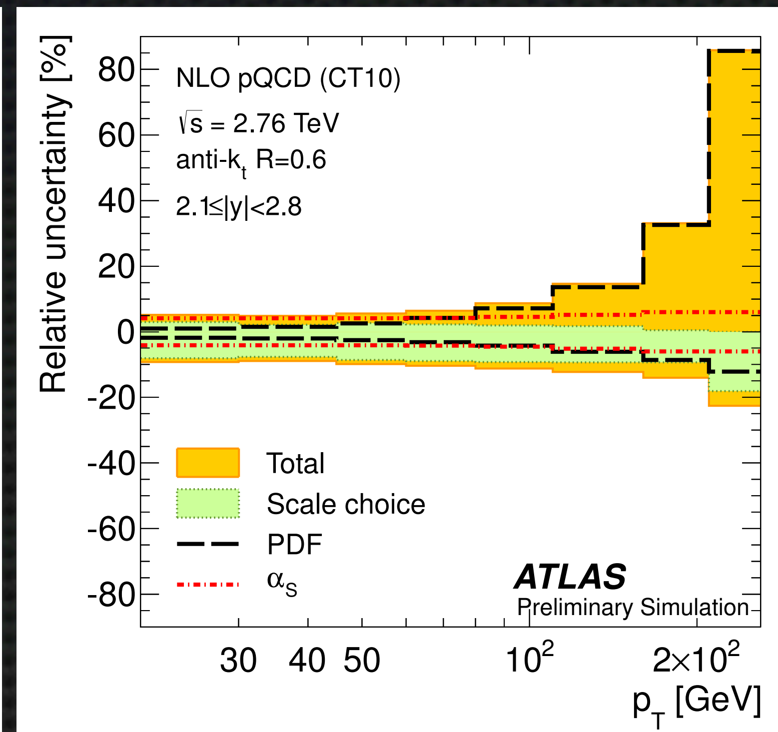
Non-perturbative corrections

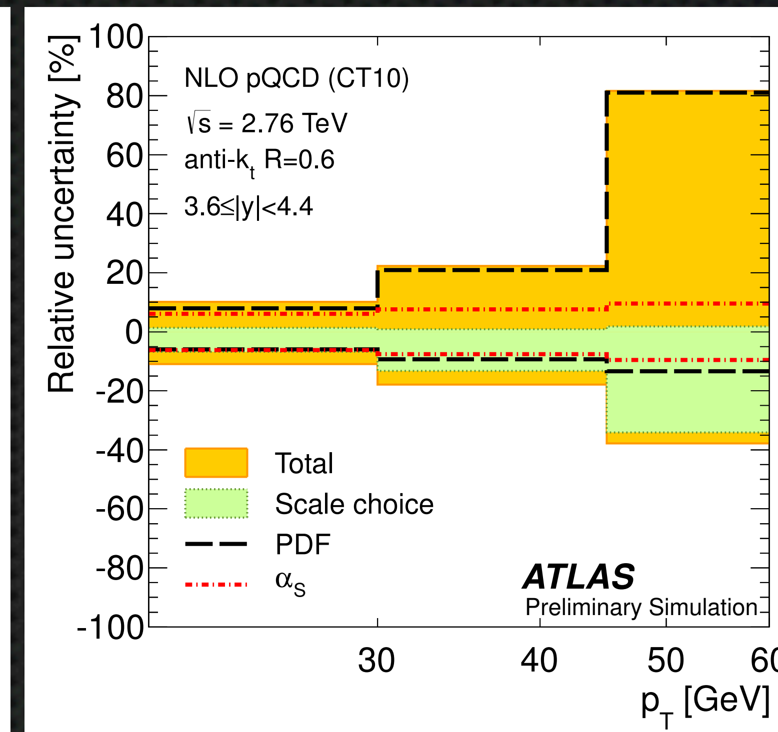


Inclusive jet cross section at 2.76 TeV

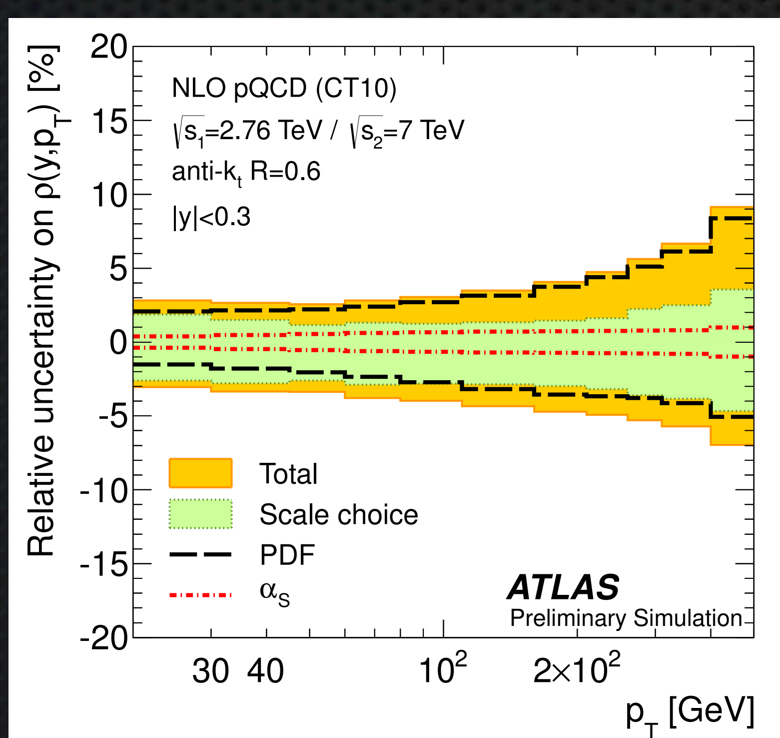
Uncertainties on NLO pQCD prediction of cross section

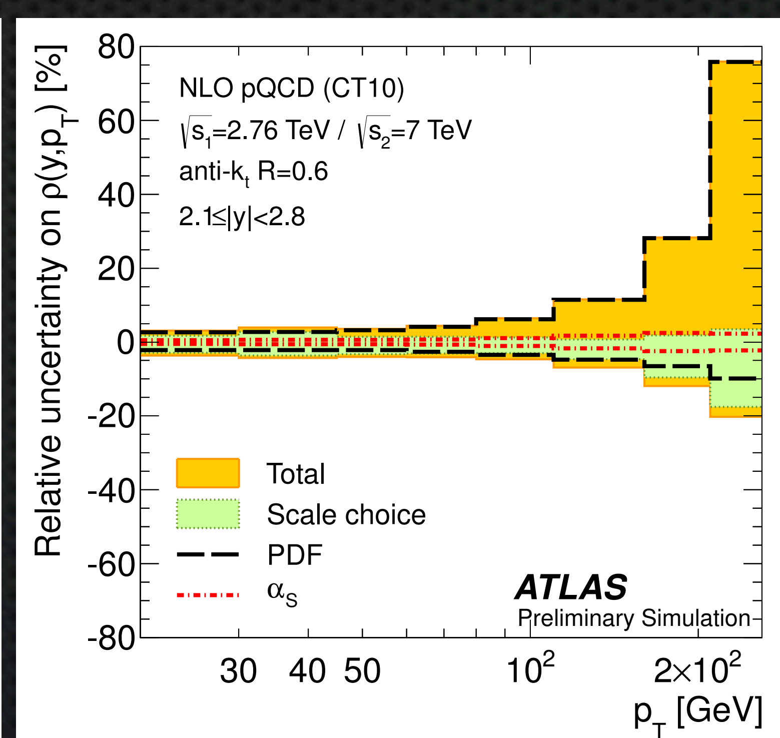


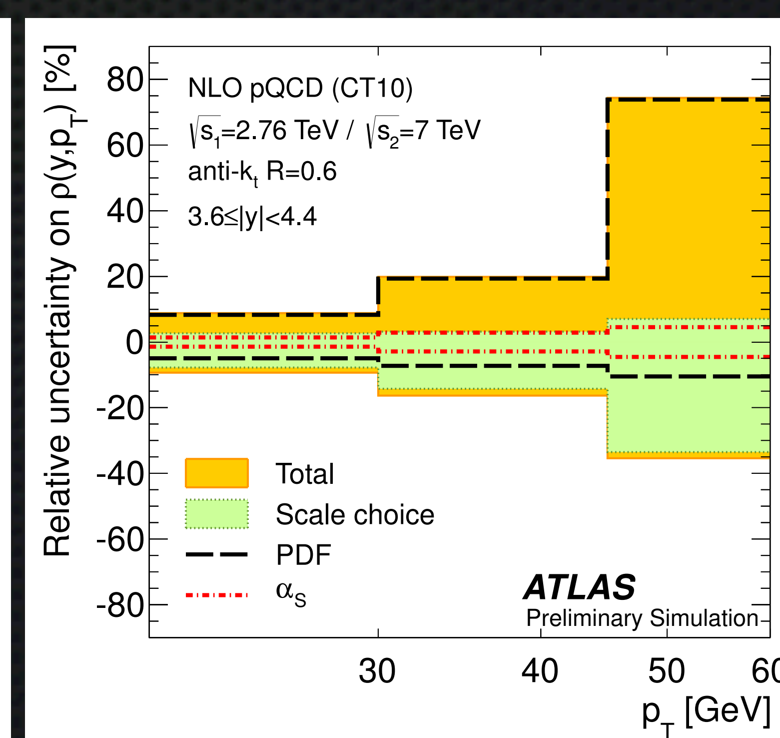




Uncertainties on NLO pQCD prediction of cross section ratio







Inclusive jet cross section at 2.76 TeV

ATLAS-CONF-2012-128

Systematic uncertainties

Uncertainty source	$\|y\|$ bins							Correlation to 7 TeV
	0-0.3	0.3-0.8	0.8-1.2	1.2-2.1	2.1-2.8	2.8-3.6	3.6-4.4	
Trigger efficiency	u_1	u_1	u_1	u_1	u_1	u_1	u_1	N
Jet reconstruction eff.	83	83	83	83	84	85	86	Y
Jet selection eff.	u_2	u_2	u_2	u_2	u_2	u_2	u_2	N
JES1: Noise thresholds	1	1	2	3	4	5	6	Y
JES2: Theory UE	7	7	8	9	10	11	12	Y
JES3: Theory showering	13	13	14	15	16	17	18	Y
JES4: Non-closure	19	19	20	21	22	23	24	Y
JES5: Dead material	25	25	26	27	28	29	30	Y
JES6: Forward JES generators	88	88	88	88	88	88	88	*
JES7: E/p response	32	32	33	34	35	36	37	Y
JES8: E/p selection	38	38	39	40	41	42	43	Y
JES9: EM + neutrals	44	44	45	46	47	48	49	Y
JES10: HAD E-scale	50	50	51	52	53	54	55	Y
JES11: High p_T	56	56	57	58	59	60	61	Y
JES12: E/p bias	62	62	63	64	65	66	67	Y
JES13: Test-beam bias	68	68	69	70	71	72	73	Y
JES15: Forward JES detector	89	89	89	89	89	89	89	*
Jet energy resolution	76	76	77	78	79	80	81	Y
Jet angle resolution	82	82	82	82	82	82	82	Y
Unfolding: Closure test	74	74	74	74	74	74	74	N
Unfolding: Jet matching	75	75	75	75	75	75	75	N
Luminosity	87	87	87	87	87	87	87	N

Calorimeter and jet reconstruction common to both analyses at 7 TeV and 2.76 TeV

Jet energy scale (JES) systematics are largely correlated between the two analyses