Electroweak and Top Results from ATLAS

Lynn Marx
University of Manchester
On behalf of the ATLAS Collaboration

LISHEP 2013, Rio de Janeiro, Brazil
March 20, 2013

ATLAS EXPERIMENT

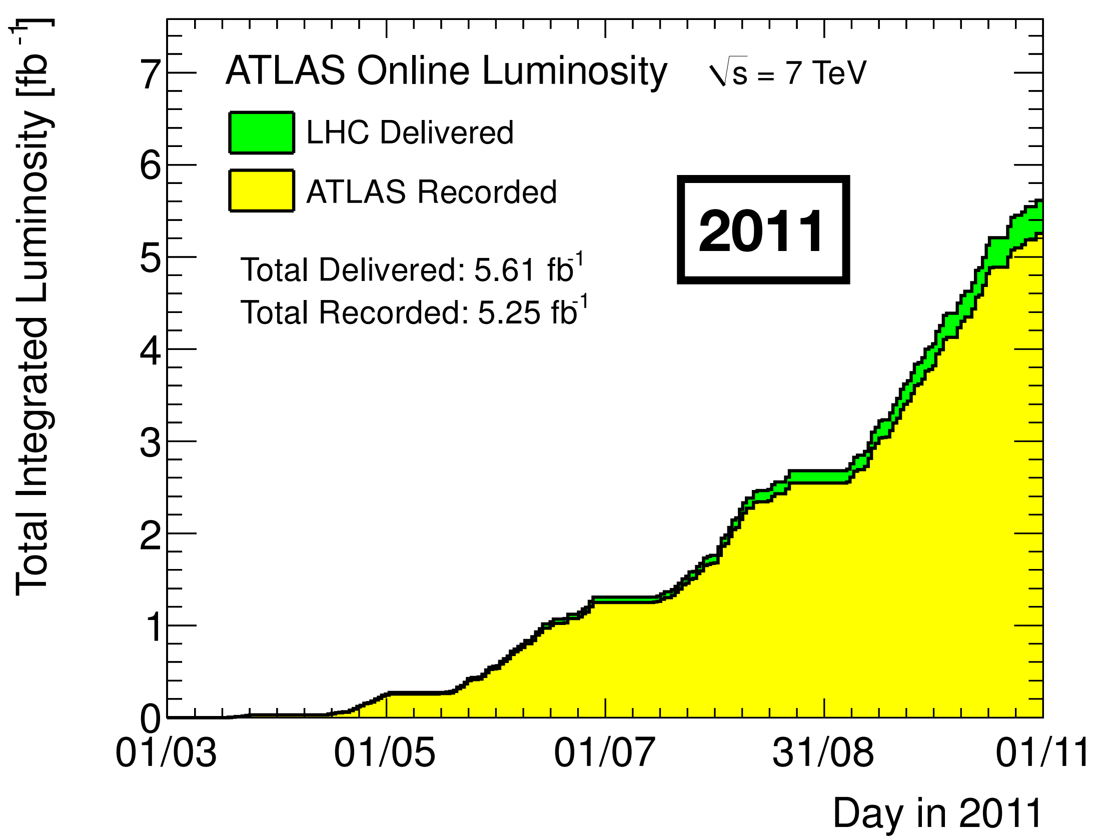
MANCHESTER 1824

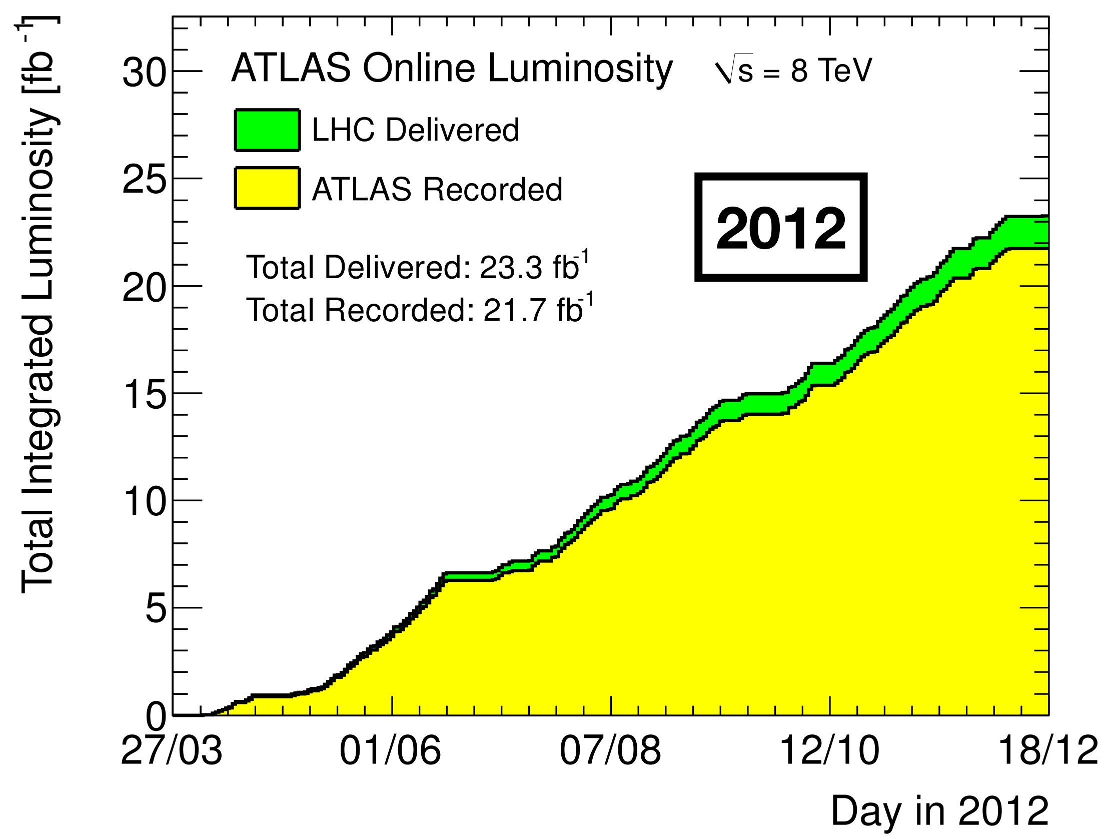
Overview

Electroweak Results

Diboson Production

- inclusive and differential cross sections
  - **W**(→lν)γ and **Z**(→ll)γ
  - **WW**→lνlν
  - **WZ**→lνll
  - **ZZ**→llll and **ZZ**→llνν
  - **WW/WZ**→lνjj
- triple gauge coupling limits





Overview

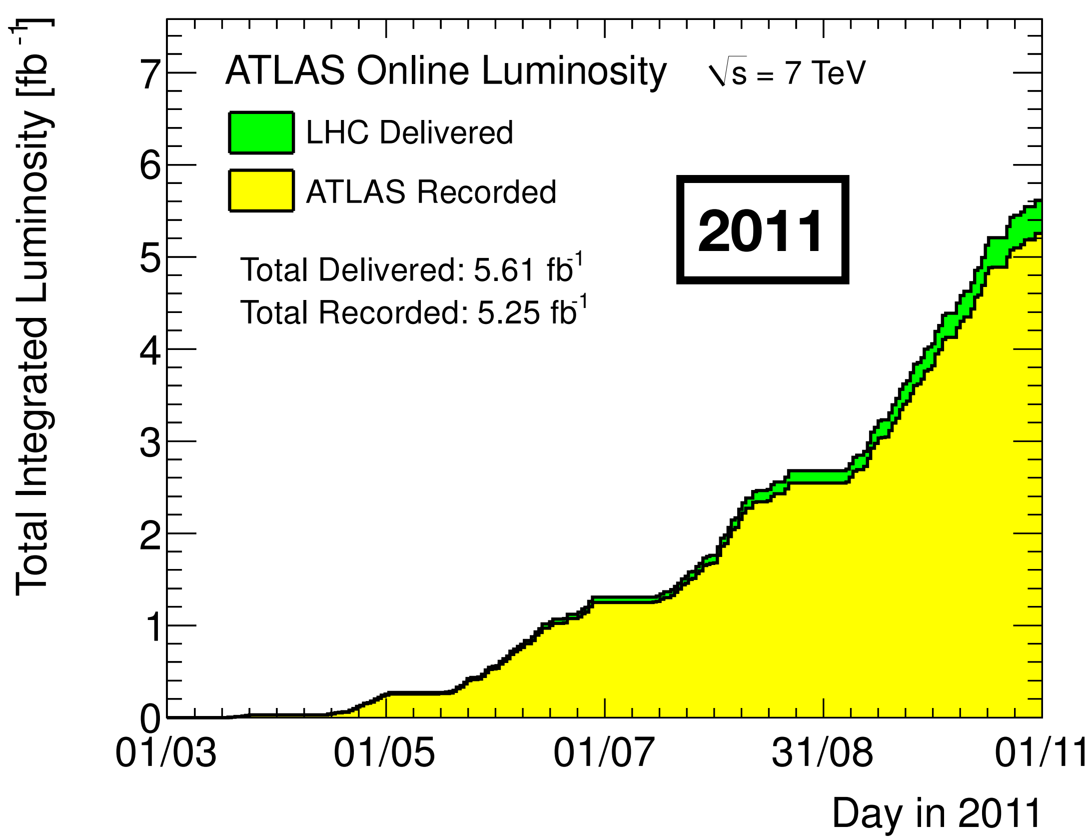
Electroweak Results

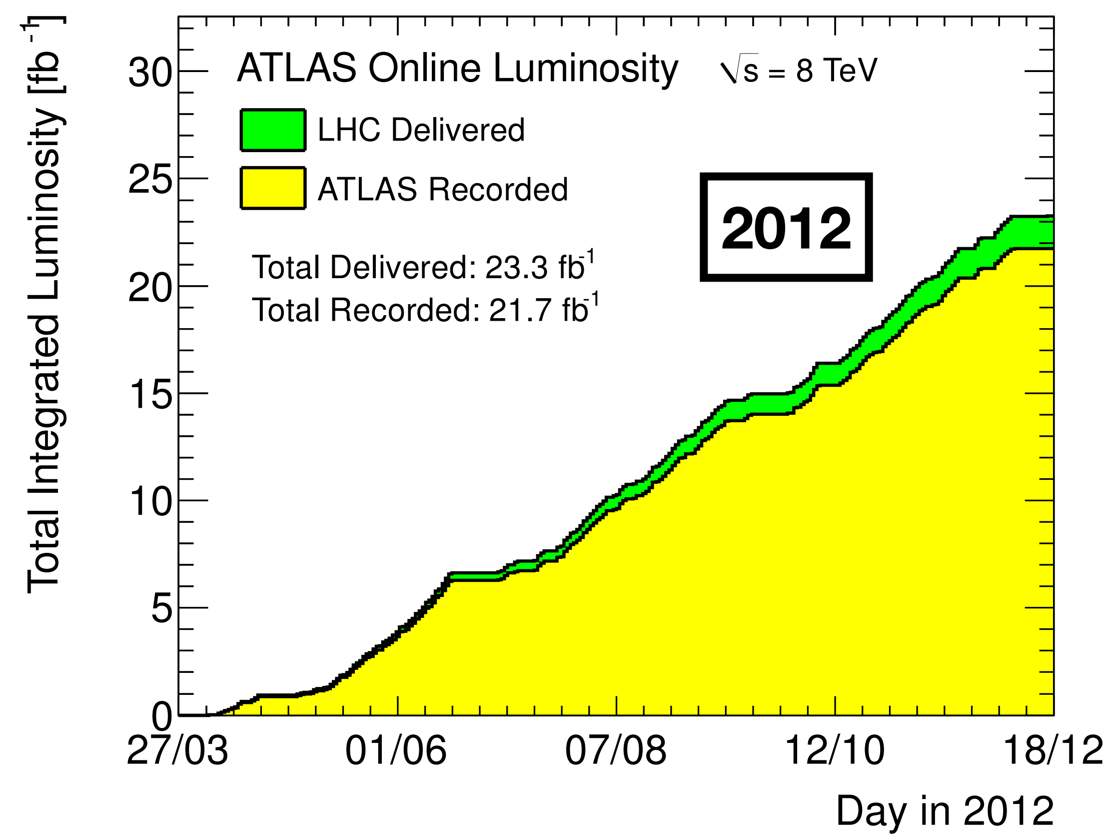
Diboson Production

- inclusive and differential cross sections
  - **W**(→lν)γ and **Z**(→ll)γ
  - **WW**→lνlν
  - **WZ**→lνll
  - **ZZ**→llll and **ZZ**→llνν
  - **WW/WZ**→lνjj
- triple gauge coupling limits

Top Results

- single top cross section
- top pair production
  - cross section
  - differential distributions
- properties
  - charge asymmetry
  - top quark polarisation
  - W polarisation in top decays
  - Wtb vertex and CP violation

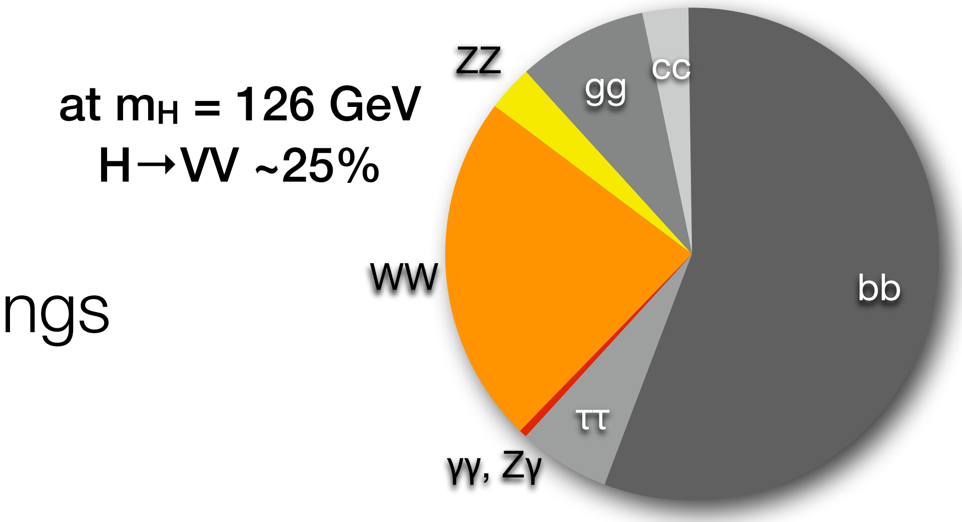




Why Diboson Production?

Background to Higgs Production

- significant and irreducible
- need precise understanding to constrain Higgs couplings

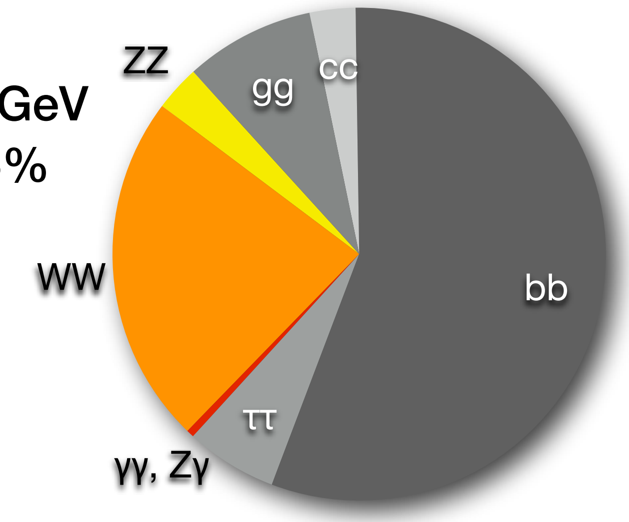


Why Diboson Production?

Background to Higgs Production

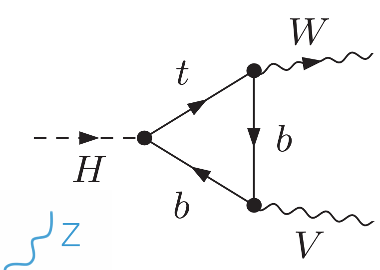
- significant and irreducible
- need precise understanding to constrain Higgs couplings

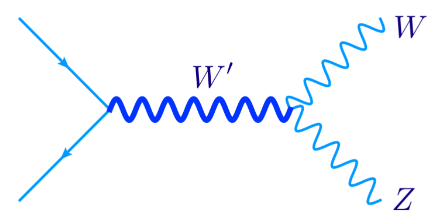
at m_H = 126 GeV
H→VV ~25%

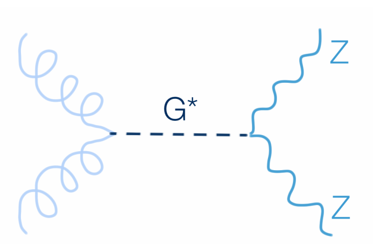


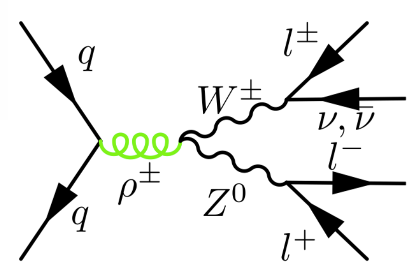
New Physics Searches

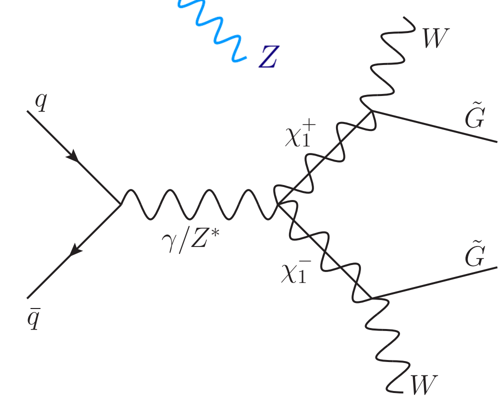
- extended Higgs sector
- extra vector bosons
- extra dimensions
- Supersymmetry
- Technicolor







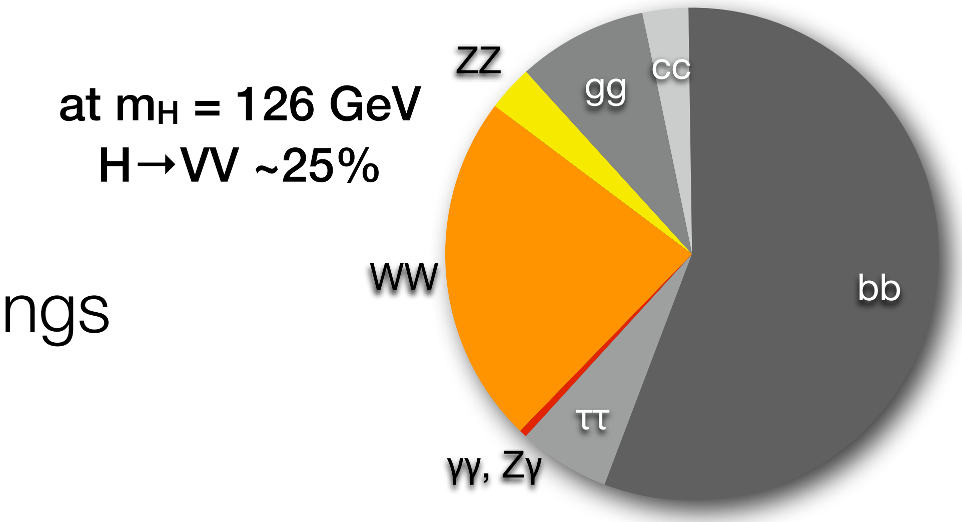




Why Diboson Production?

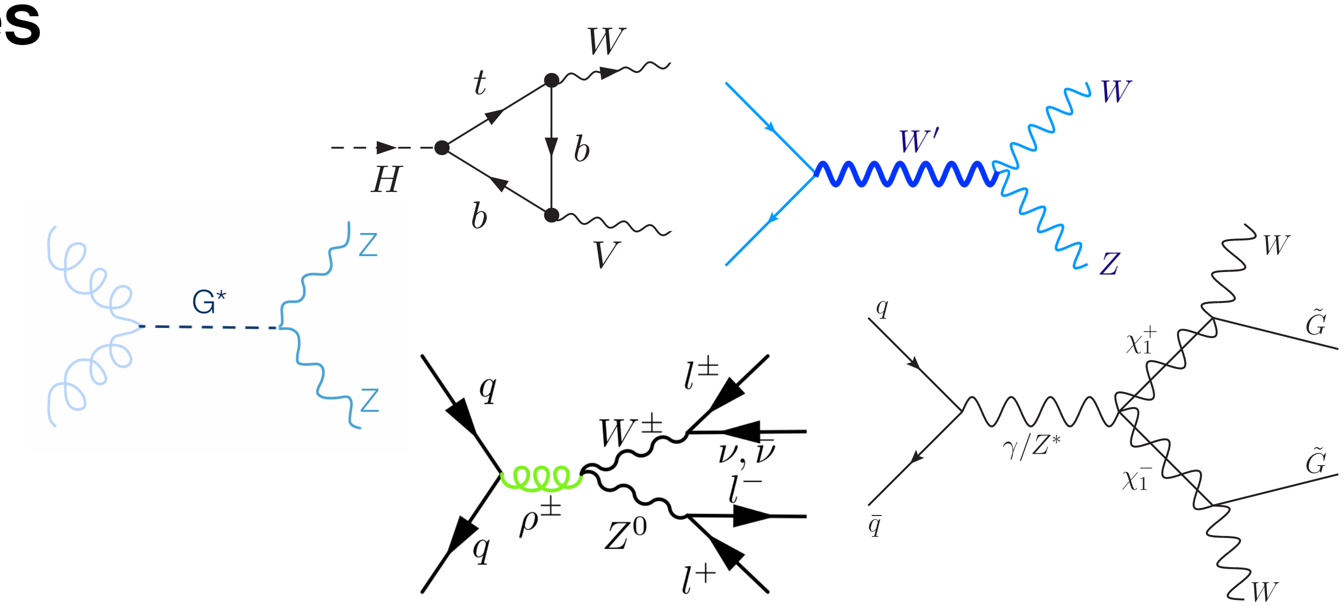
Background to Higgs Production

- significant and irreducible
- need precise understanding to constrain Higgs couplings



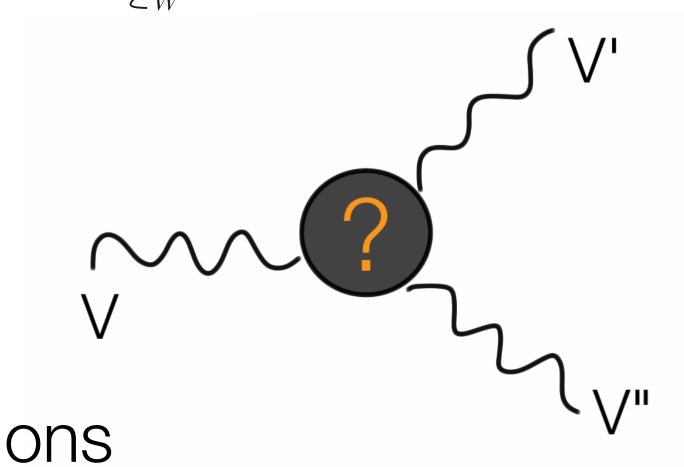
New Physics Searches

- extended Higgs sector
- extra vector bosons
- extra dimensions
- Supersymmetry
- Technicolor

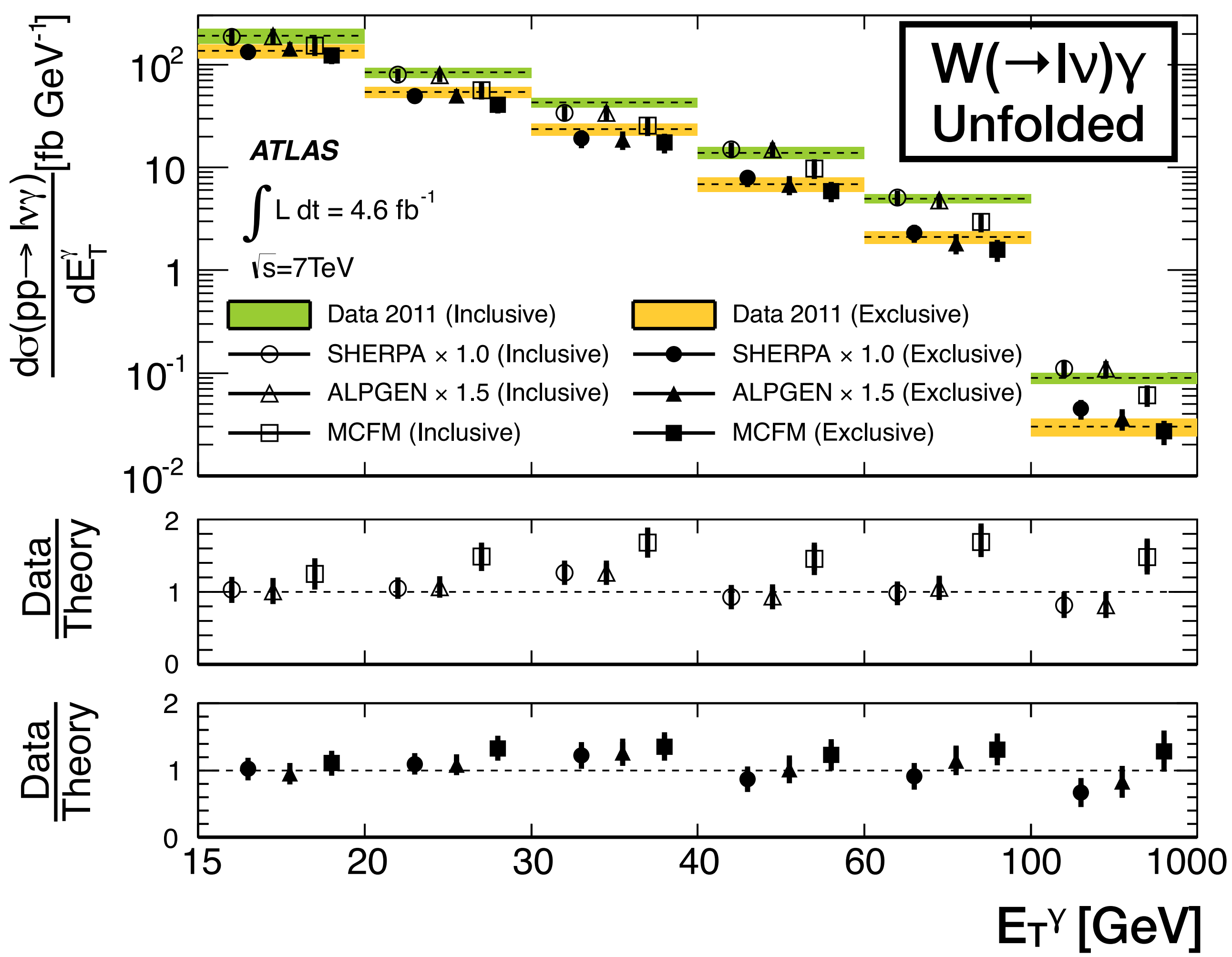


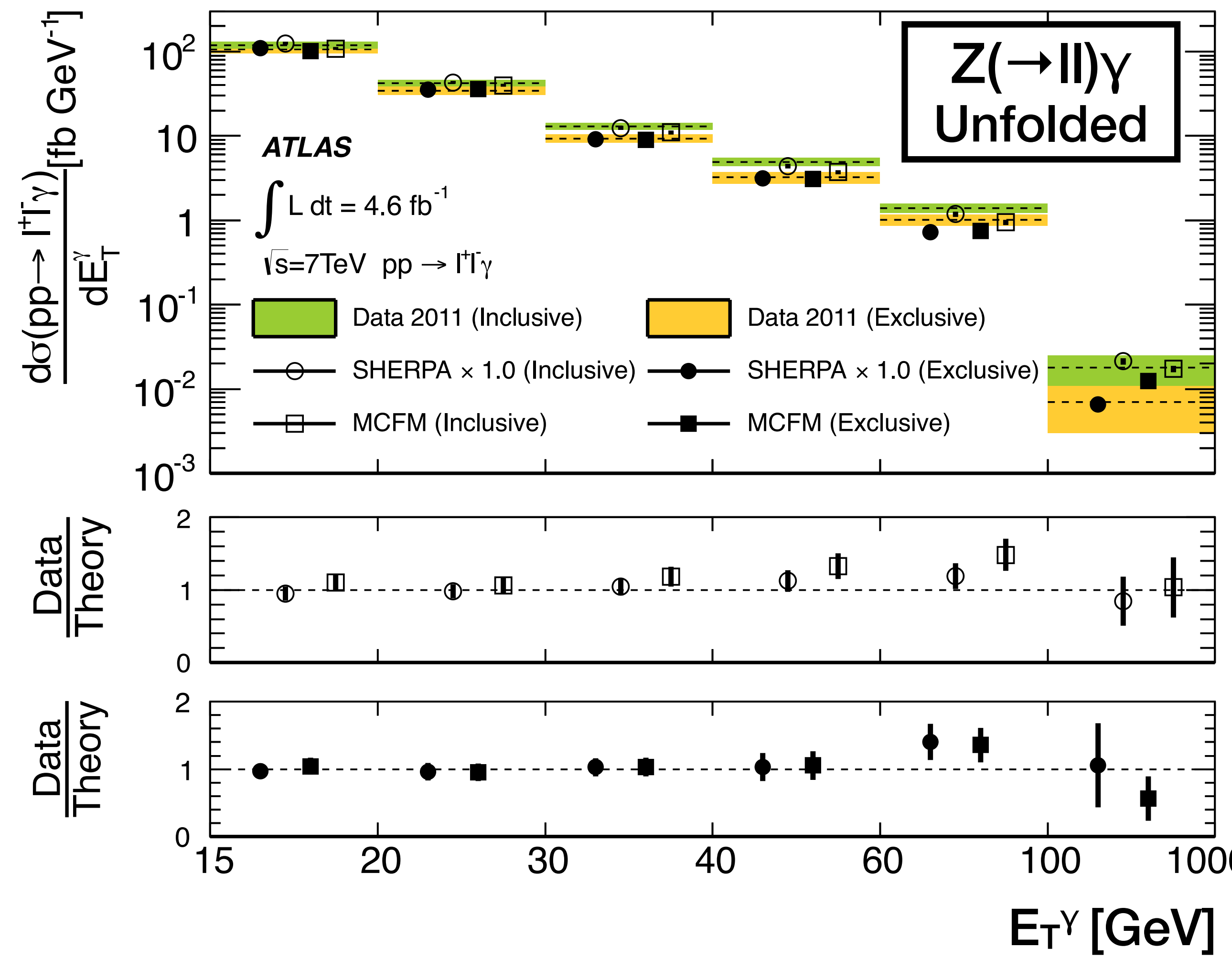
Gauge Boson Couplings

- fundamental prediction of non-abelian SU(2)×U(1)
- model-independent probe of high energy scale physics
- not as well measured as boson masses or couplings to fermions



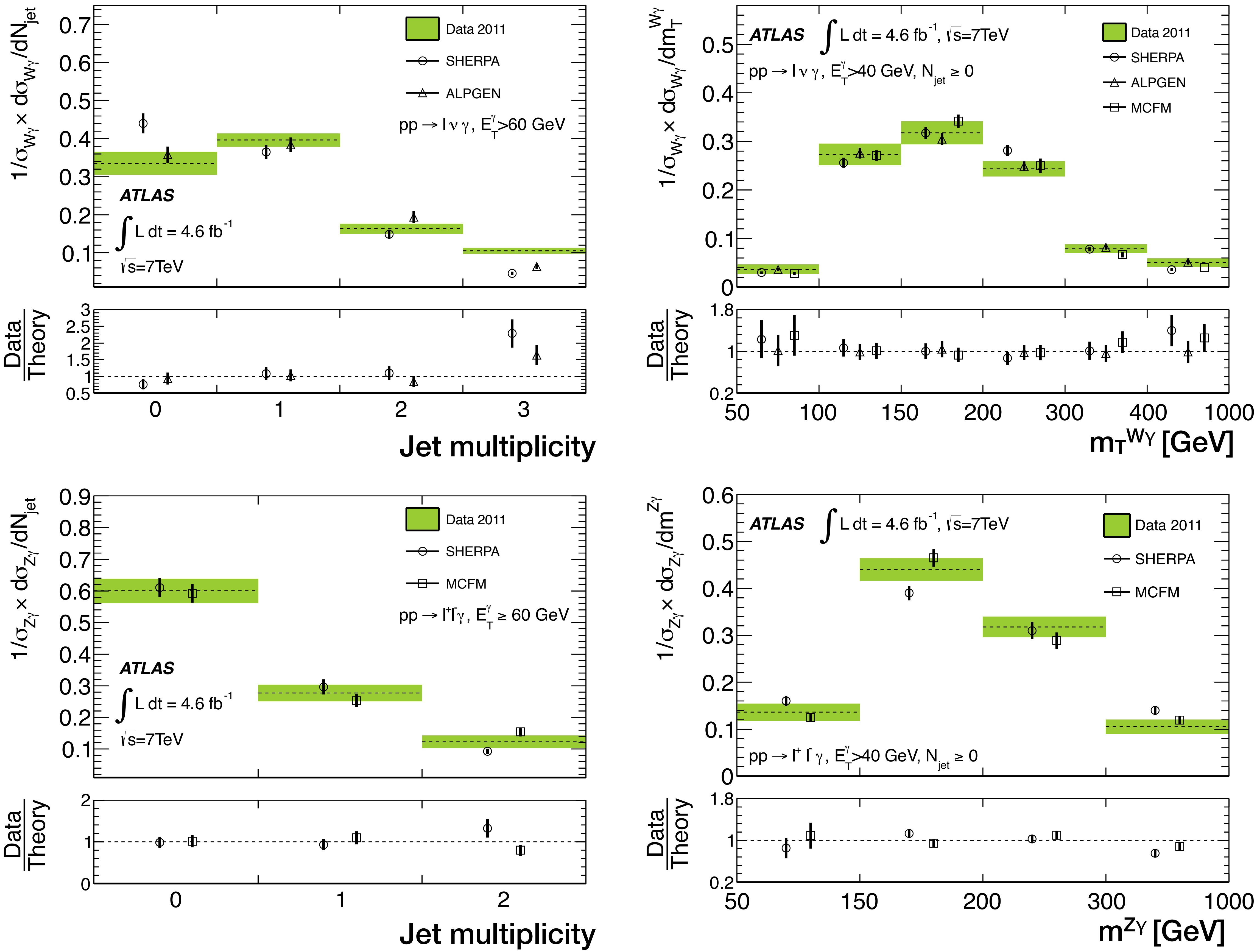
Wγ and Zγ Production





- **inclusive** and **exclusive** (n_{jet}=0) cross sections measured as a function of E_T^{γ}
- **unfold** data to determine **true value** of an observable
  → correct measured value for detector acceptance, efficiency, resolution
- multi-leg LO Sherpa and Alpgen give good inclusive and exclusive description
- NLO MCFM inclusive prediction low as multiple quark/gluon emission missing

Wγ and Zγ Production

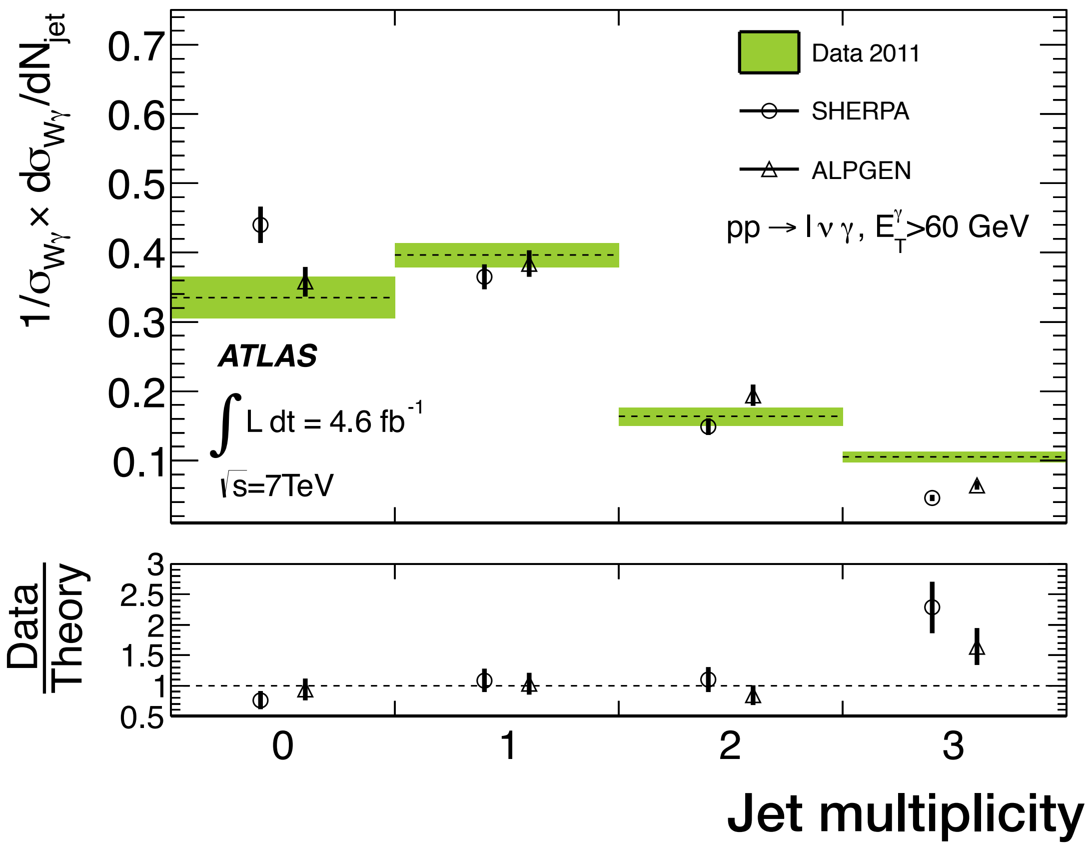


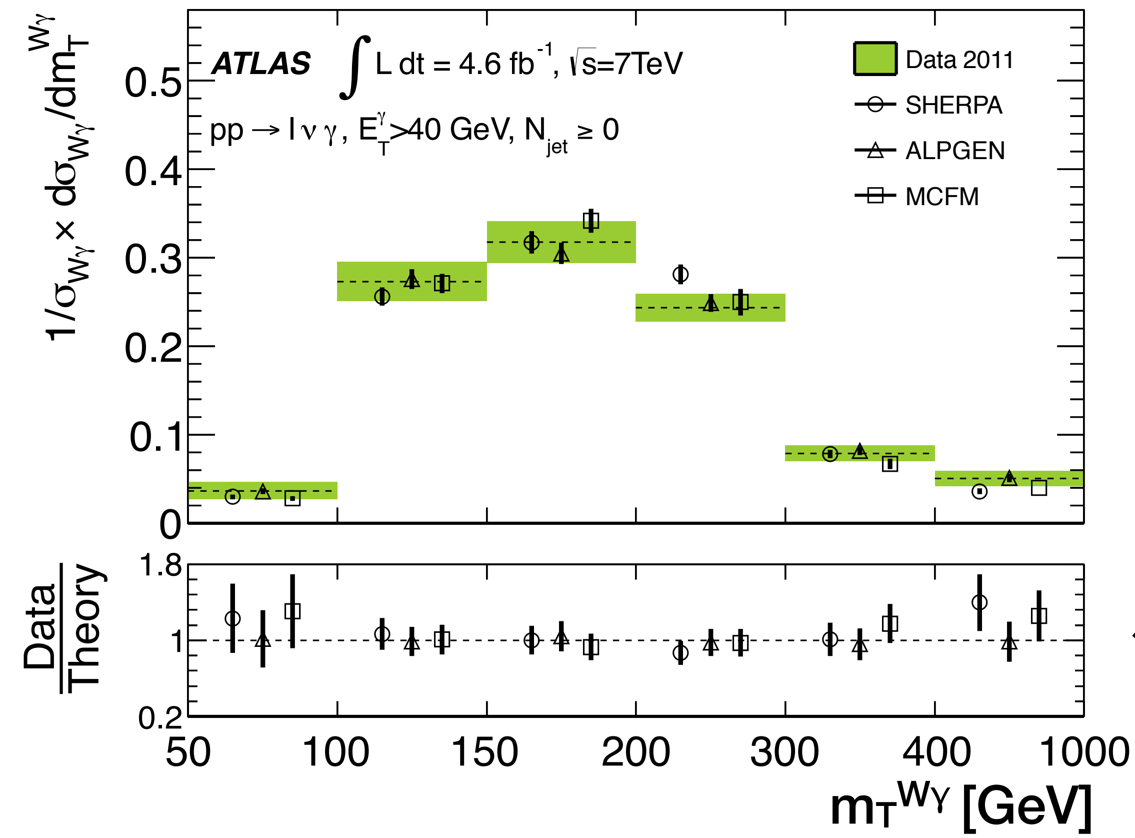
W(→lν)γ Unfolded

Z(→ll)γ Unfolded

Wγ and Zγ Production

CERN-PH-EP-2012-345

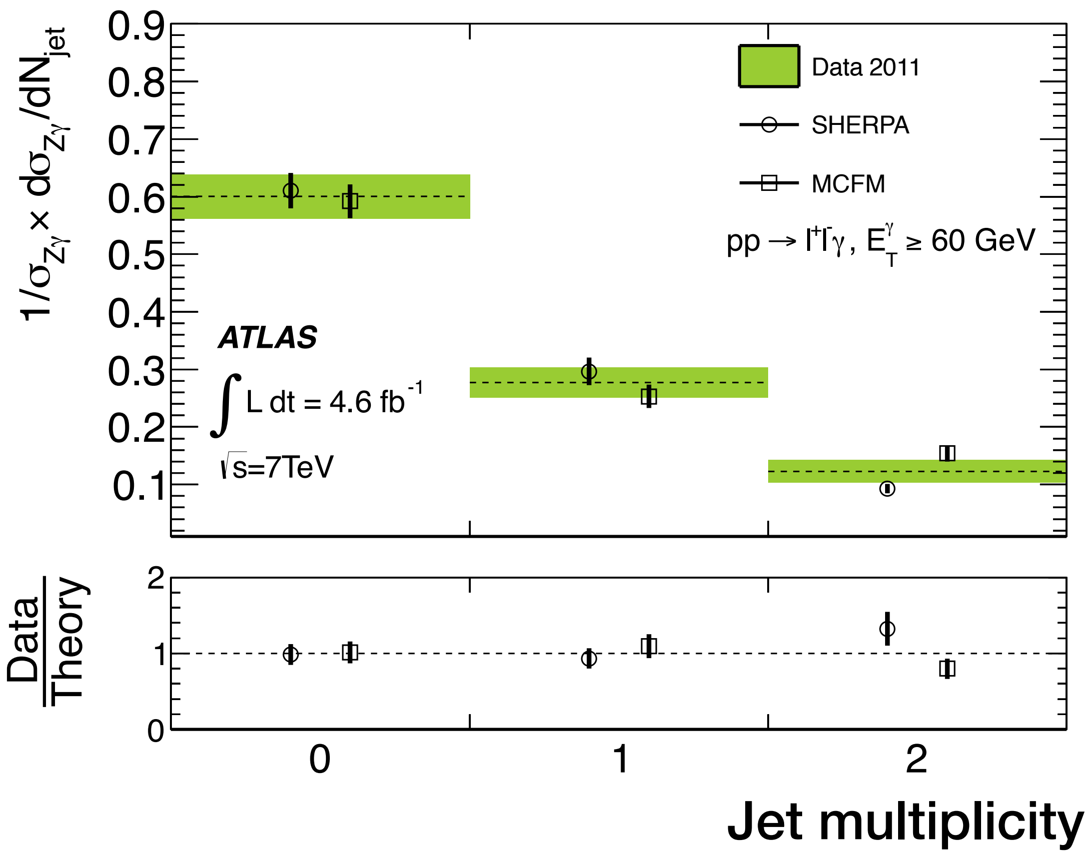


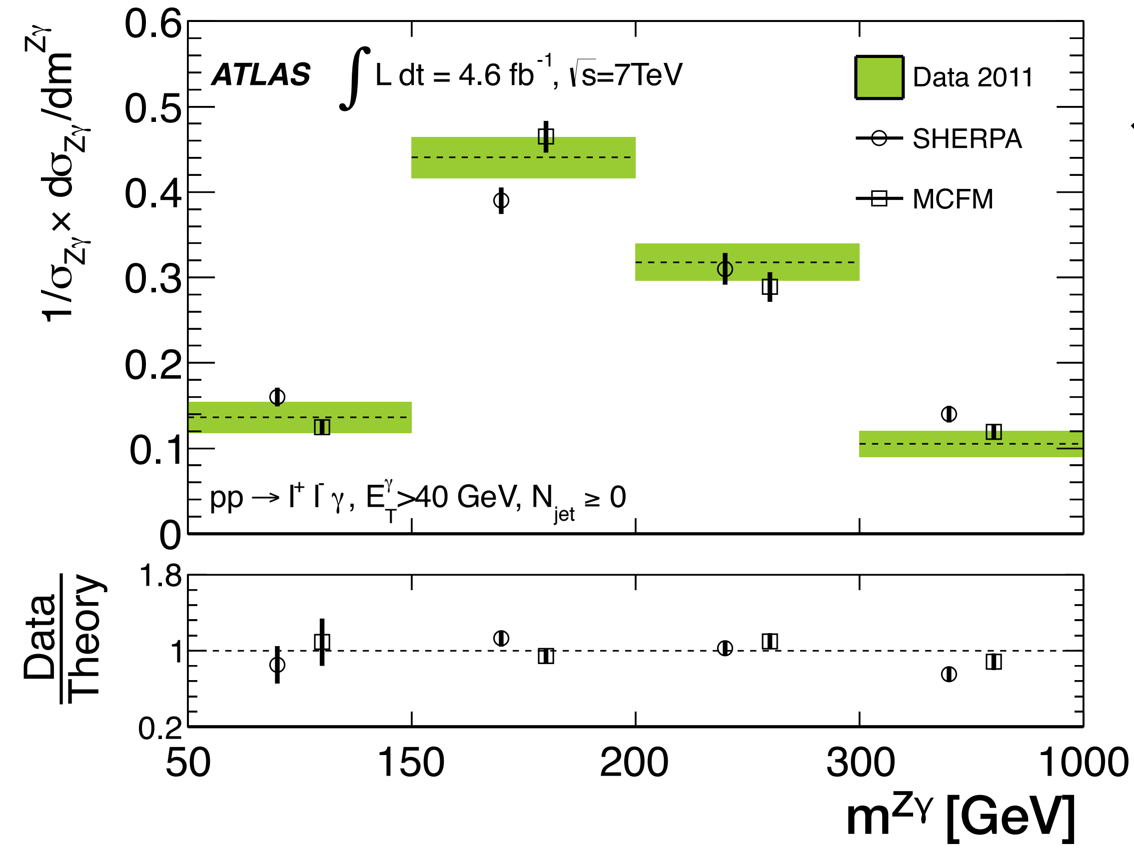


W(→lν)γ Unfolded

used to set technicolor limits

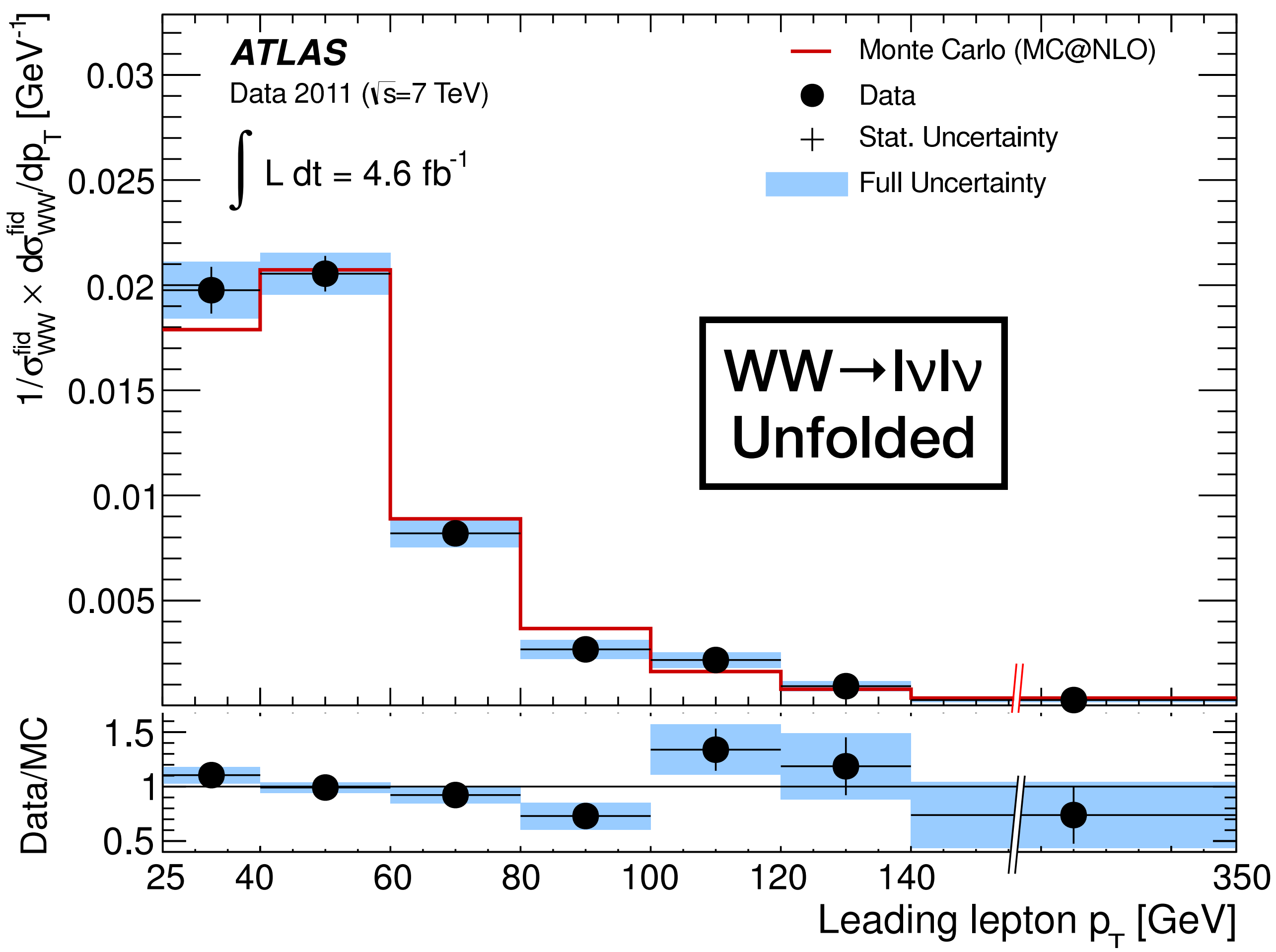
Z(→ll)γ Unfolded

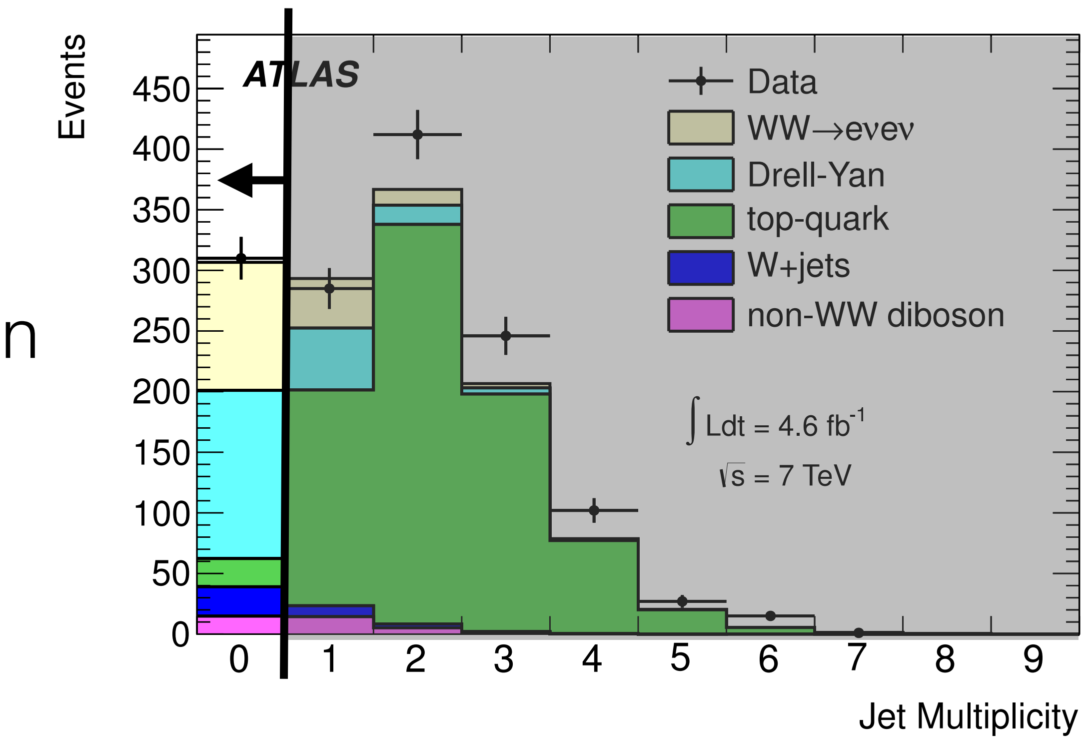


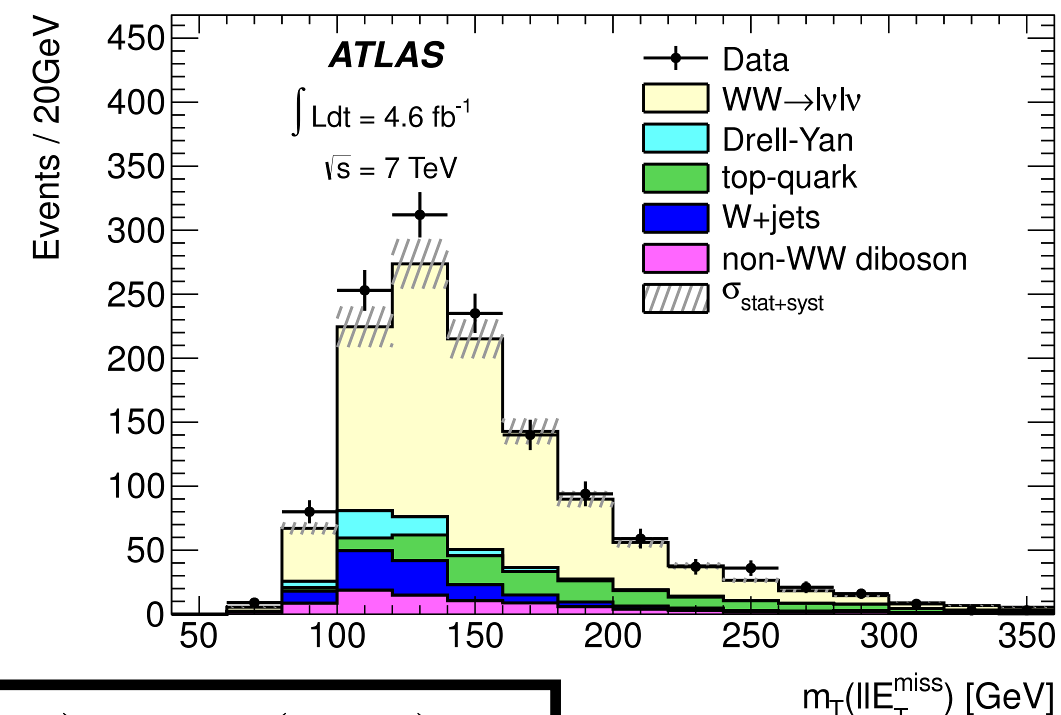


WW Production

- fully leptonic decays WW→lνlν
- largest backgrounds from **W/Z+jets** and **top**
- main systematic uncertainty from **jet veto**
- measure **inclusive** and **differential** cross section







$$\sigma_{WW} = 51.9 \pm 2.0\ (\text{stat}) \pm 3.9\ (\text{syst}) \pm 2.0\ (\text{lumi})\ \text{pb}$$

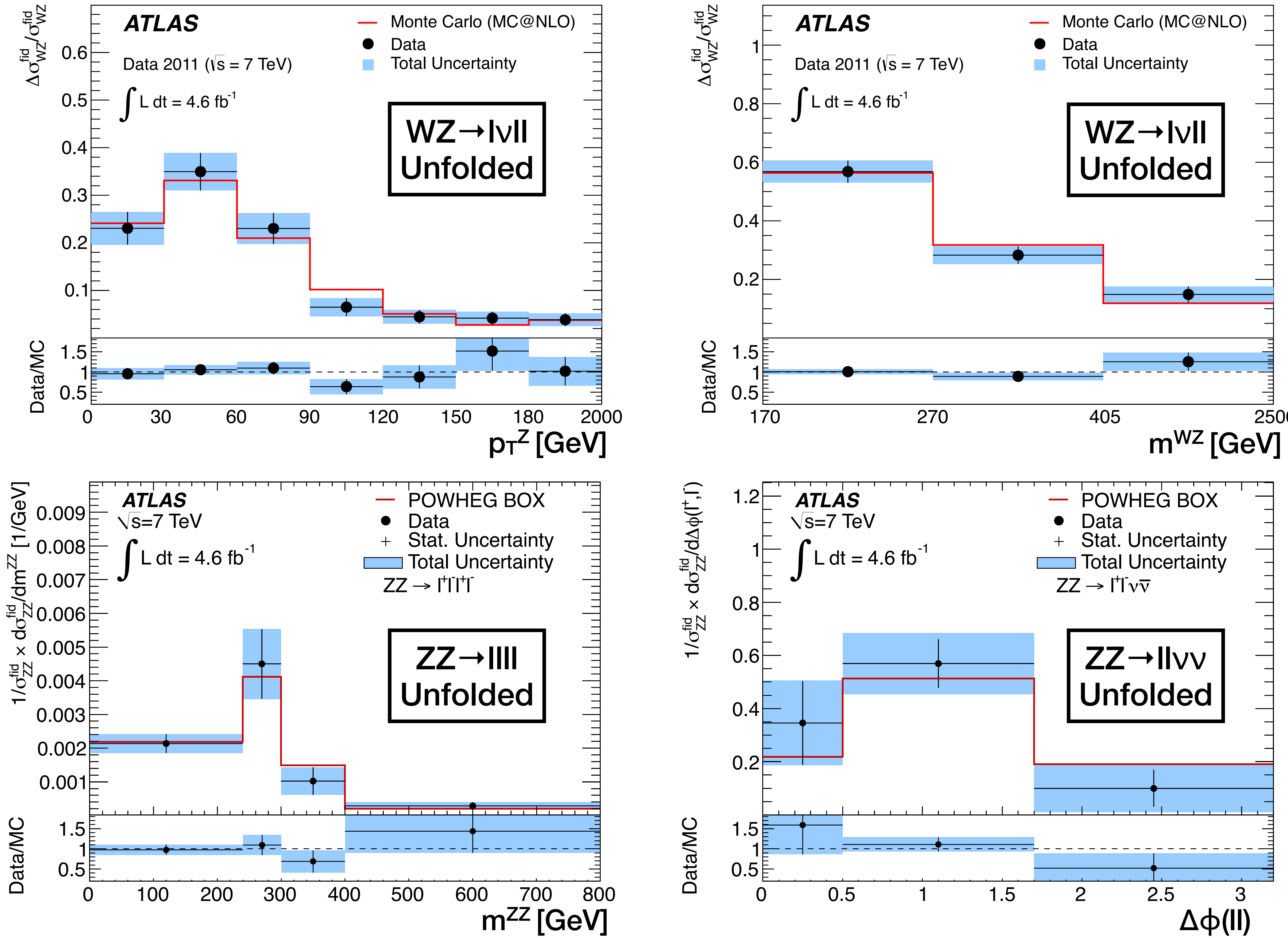
includes ~3% gg
but not ~3% H(126)

$$\sigma_{WW}^{\text{NLO}} = 44.7^{+2.1}_{-1.9}\ \text{pb}$$

(MCFM)

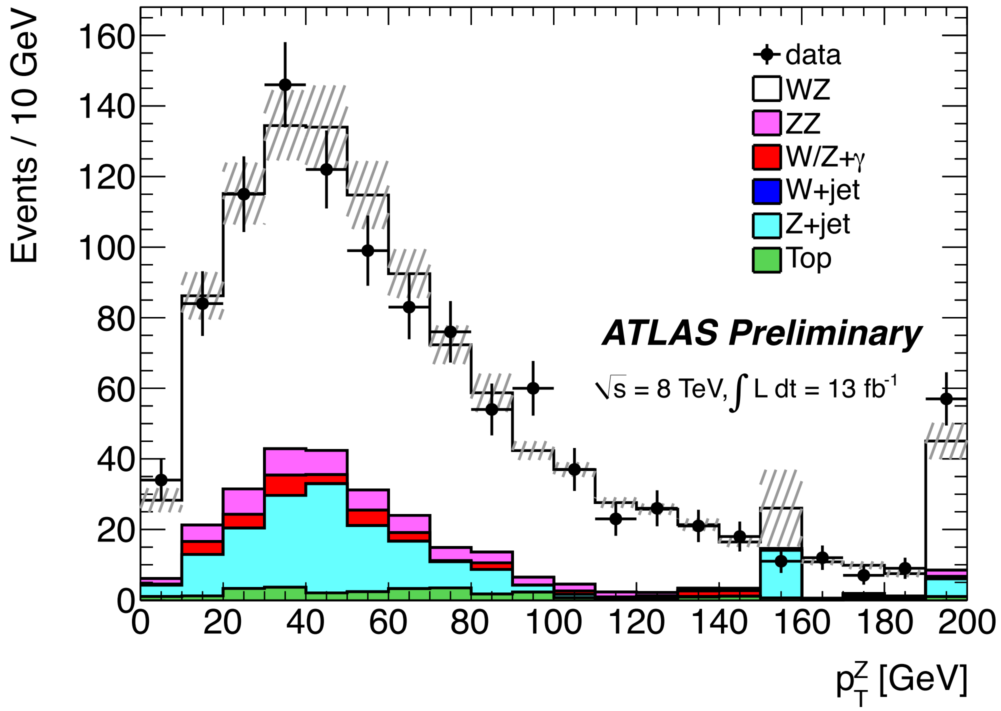
WZ and ZZ Production

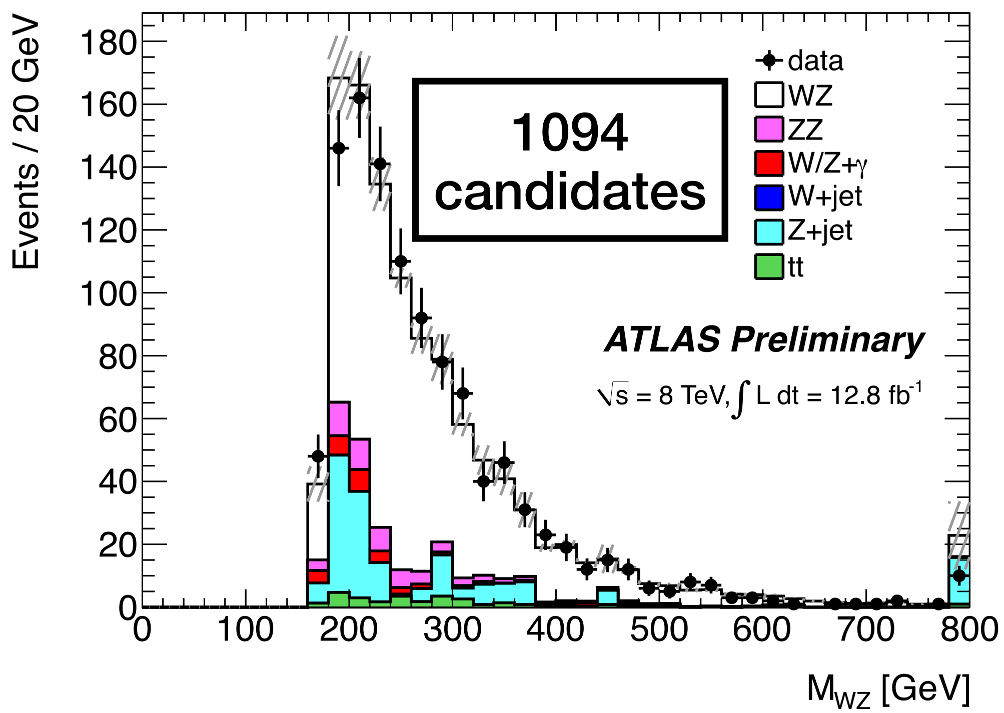
Eur. Phys. J. C (2012) 72:2173
CERN-PH-EP-2012-318



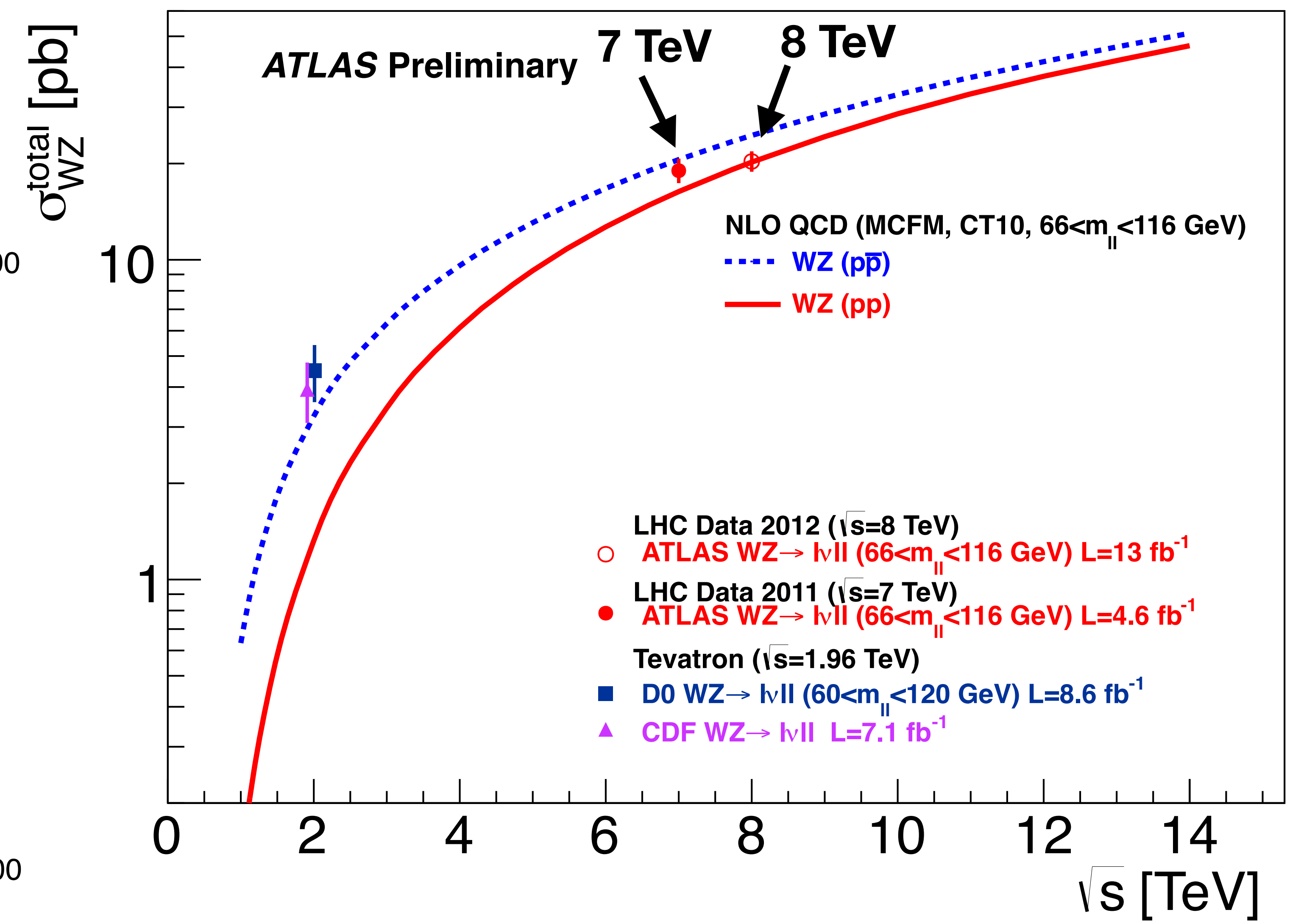
WZ Production

NEW ATLAS-CONF-2013-021





- WZ→lνll final states with 66 < m_{ll} < 116 GeV



$$\sigma_{WZ} = 20.3^{+0.8}_{-0.7}\ (\text{stat})^{+1.2}_{-1.1}\ (\text{syst})^{+0.7}_{-0.6}\ (\text{lumi})\ \text{pb}$$

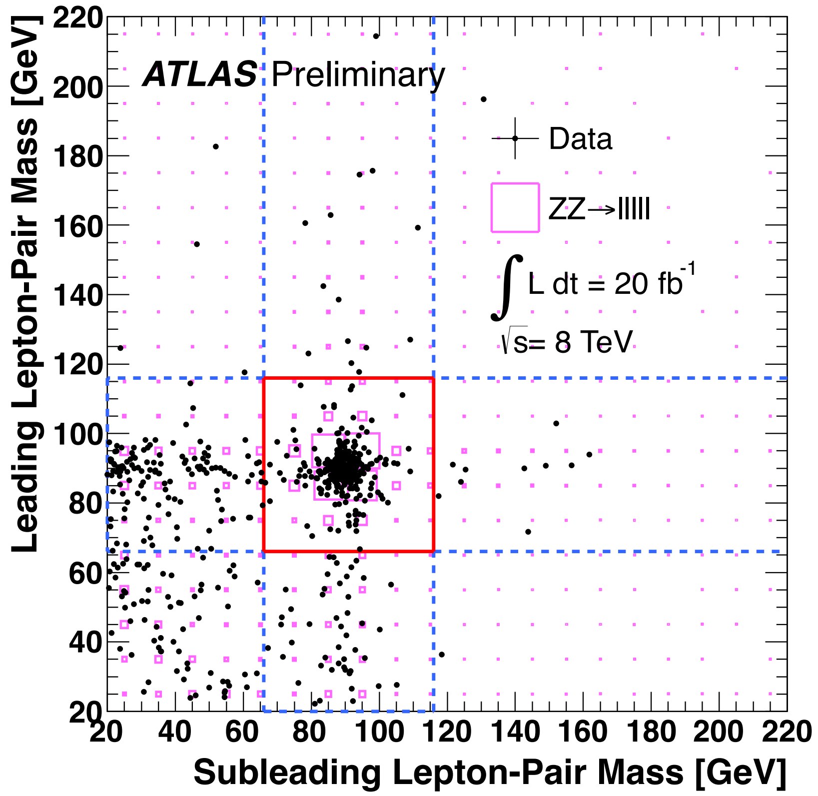
systematically dominated

$$\sigma^{\text{NLO}}_{WZ} = 20.3 \pm 0.8\ \text{pb}$$ (MCFM)

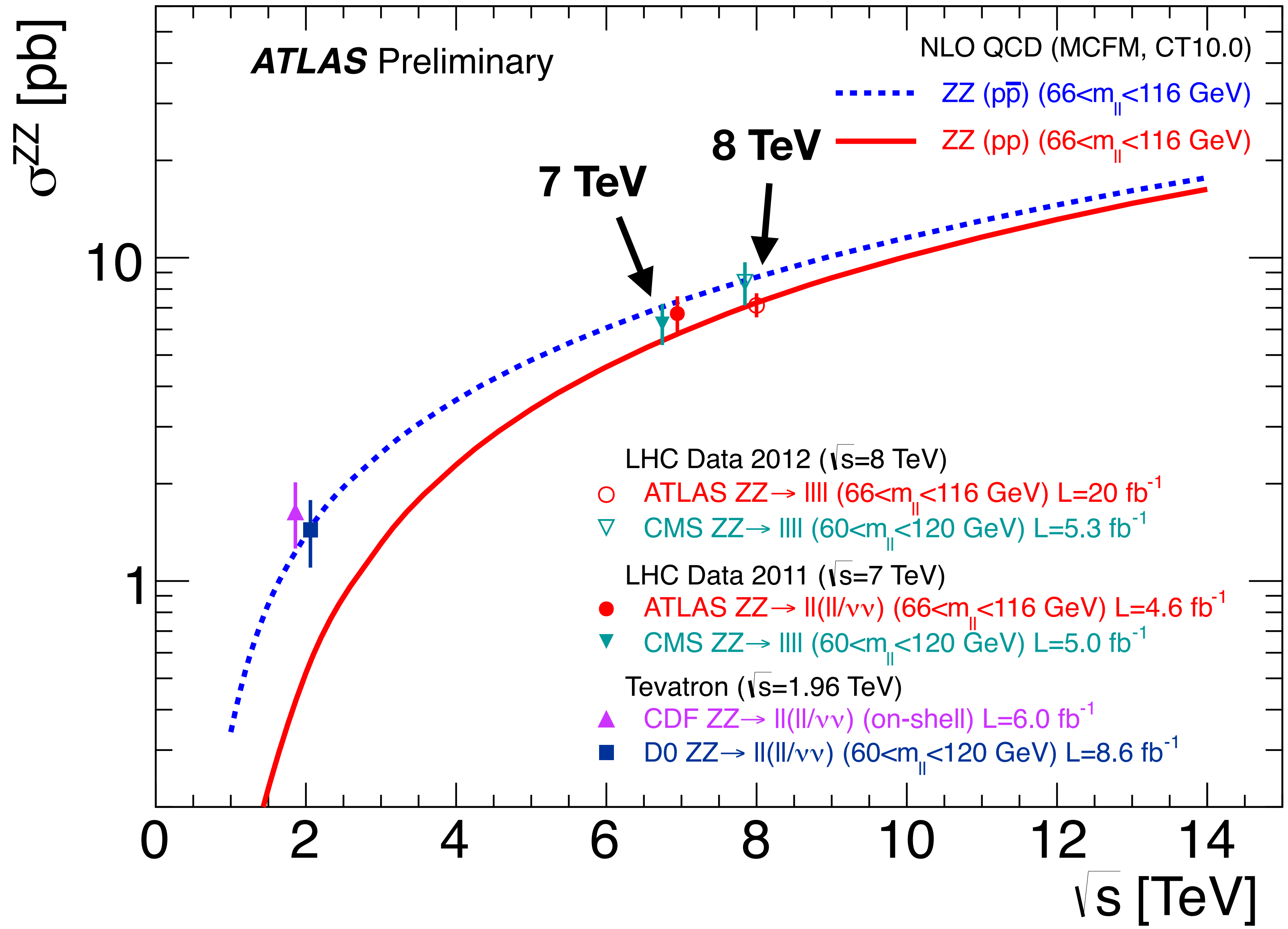
8 TeV

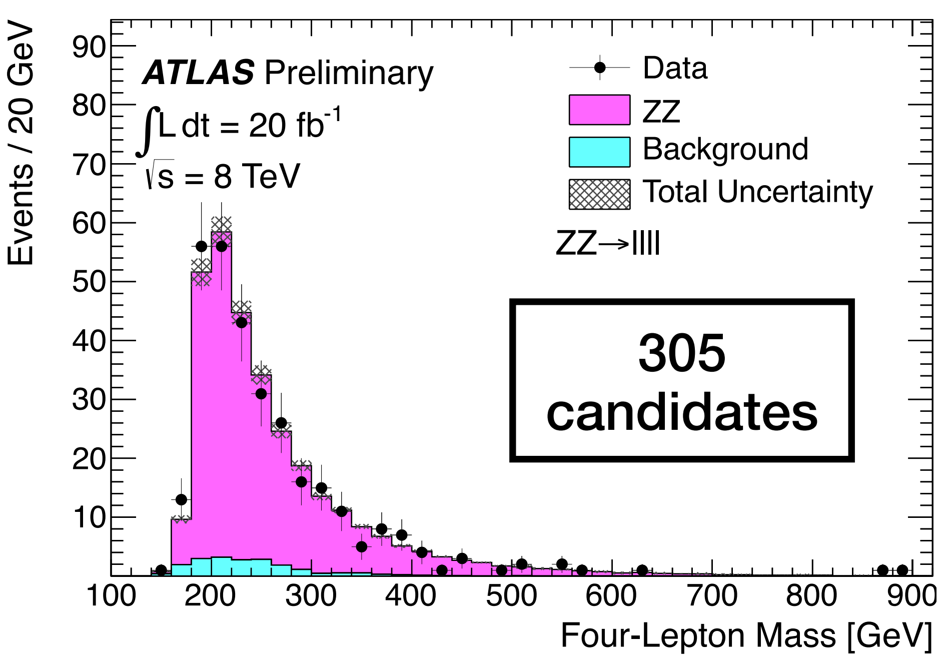
ZZ Production

NEW ATLAS-CONF-2013-020



- ZZ→llll final states with 66 < m_{ll} < 116 GeV





$$\sigma_{ZZ} = 7.1^{+0.5}_{-0.4}\ (\text{stat}) \pm 0.3\ (\text{syst}) \pm 0.2\ (\text{lumi})\ \text{pb}$$

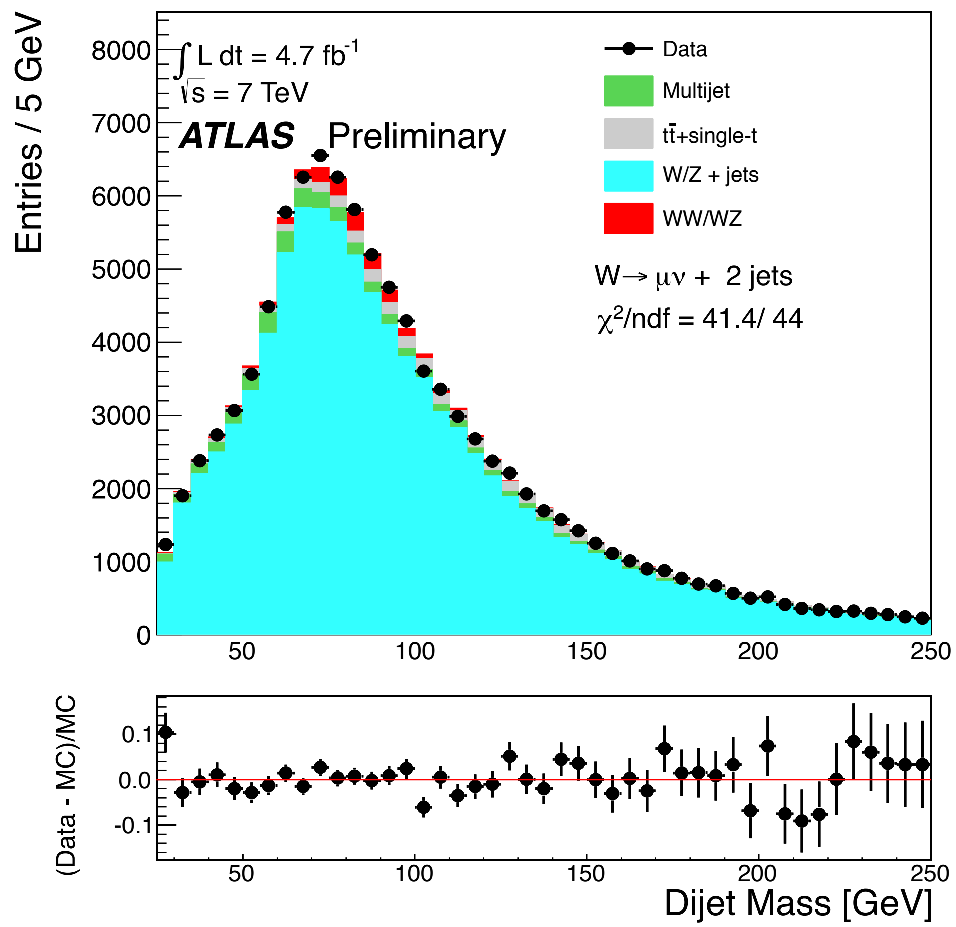
includes ~6% gg
but not ~3% H(126)

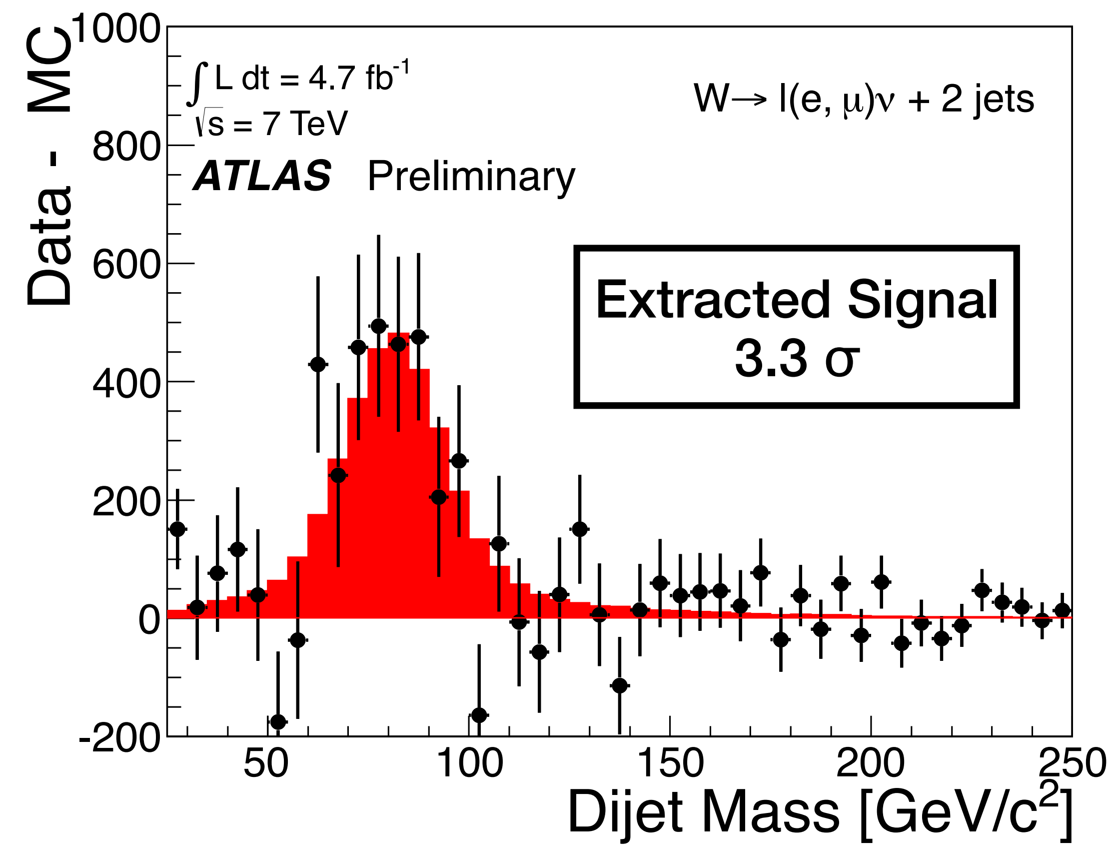
$$\sigma_{ZZ}^{\text{NLO}} = 7.2^{+0.3}_{-0.2}\ \text{pb}$$ (MCFM)

WW/WZ→lνjj Cross Section

ATLAS-CONF-2012-157

- larger branching fraction than fully leptonic channel
- dominated by **W/Z+jets backgrounds**
- more challenging at LHC than at Tevatron
- cross section extracted by binned maximum likelihood **fit of m_{jj} distribution**
- main uncertainties from background estimation and jet energy scale

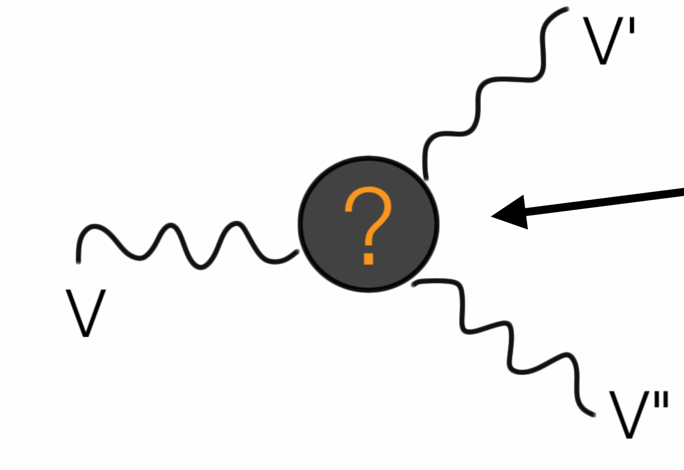




$$\sigma_{WW+WZ} = 72 \pm 9\ (\mathrm{stat}) \pm 15\ (\mathrm{syst}) \pm 13\ (\mathrm{MC\ stat})\ \mathrm{pb}$$

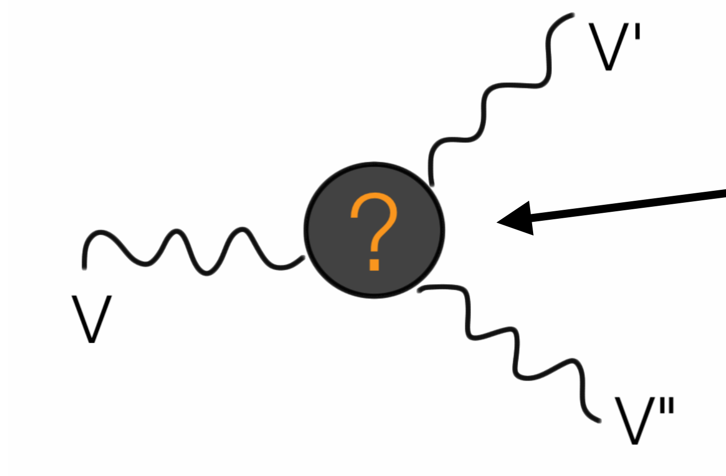
$$\sigma^{\mathrm{NLO}}_{WW+WZ} = 63.4 \pm 2.6\ \mathrm{pb}$$ (MCFM)

anomalous Triple Gauge Couplings



could be loops of new physics
W', Z', SUSY, Higgs...

anomalous Triple Gauge Couplings



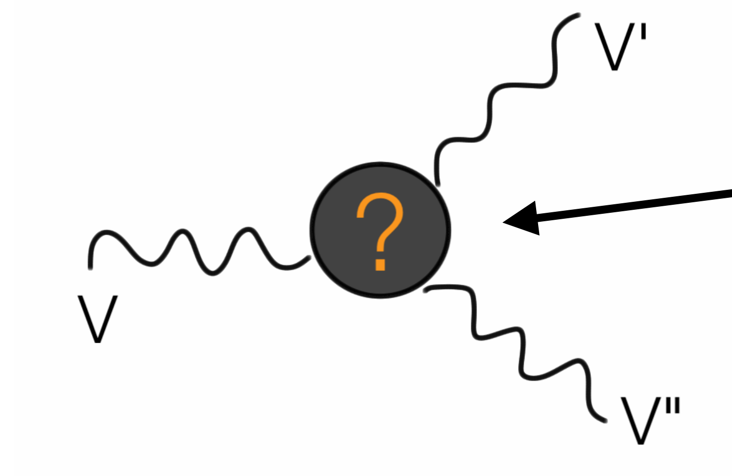
- The model-independent **effective TGC Lagrangian** can be expressed as

$$\mathcal{L}_{WWV} = ig_{WWV}\left[g_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{\dagger\mu}V^\nu) + \kappa^V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2}W^\dagger_{\rho\mu}W^\mu_\nu V^{\nu\rho}\right]$$ → **WW, WZ, Wγ**

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

$$\mathcal{L}_{Z\gamma V} = -ie\left[h_3^V\tilde{F}^{\mu\nu}Z_\mu\frac{(\Box + m_V^2)}{m_Z^2}V_\nu + h_4^V\tilde{F}^{\mu\nu}Z^\alpha\frac{(\Box + m_V^2)}{m_Z^4}\partial_\alpha\partial_\mu V_\nu\right]$$ → **Zγ**

anomalous Triple Gauge Couplings



- The model-independent **effective TGC Lagrangian** can be expressed as

$$\mathcal{L}_{WWV} = ig_{WWV}\left[g_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{\dagger\mu}V^\nu) + \kappa^V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2}W^\dagger_{\rho\mu}W^\mu_\nu V^{\nu\rho}\right]$$ → **WW, WZ, Wγ**

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

$$\mathcal{L}_{Z\gamma V} = -ie\left[h_3^V\tilde{F}^{\mu\nu}Z_\mu\frac{(\Box + m_V^2)}{m_Z^2}V_\nu + h_4^V\tilde{F}^{\mu\nu}Z^\alpha\frac{(\Box + m_V^2)}{m_Z^4}\partial_\alpha\partial_\mu V_\nu\right]$$ → **Zγ**

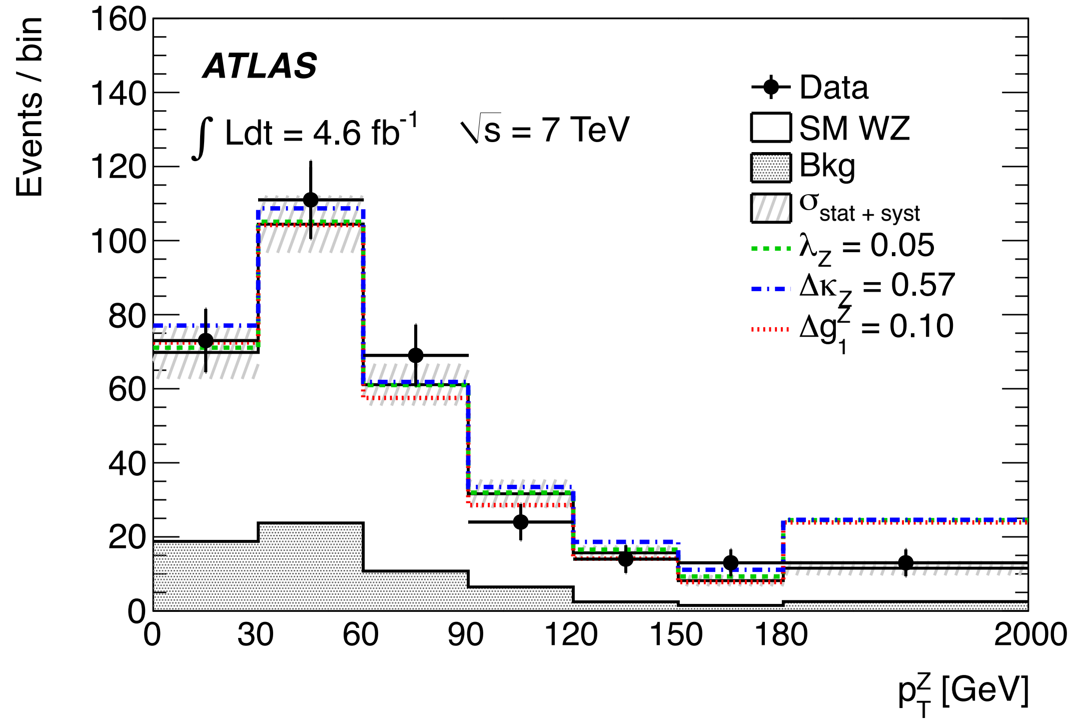
- In the Standard Model

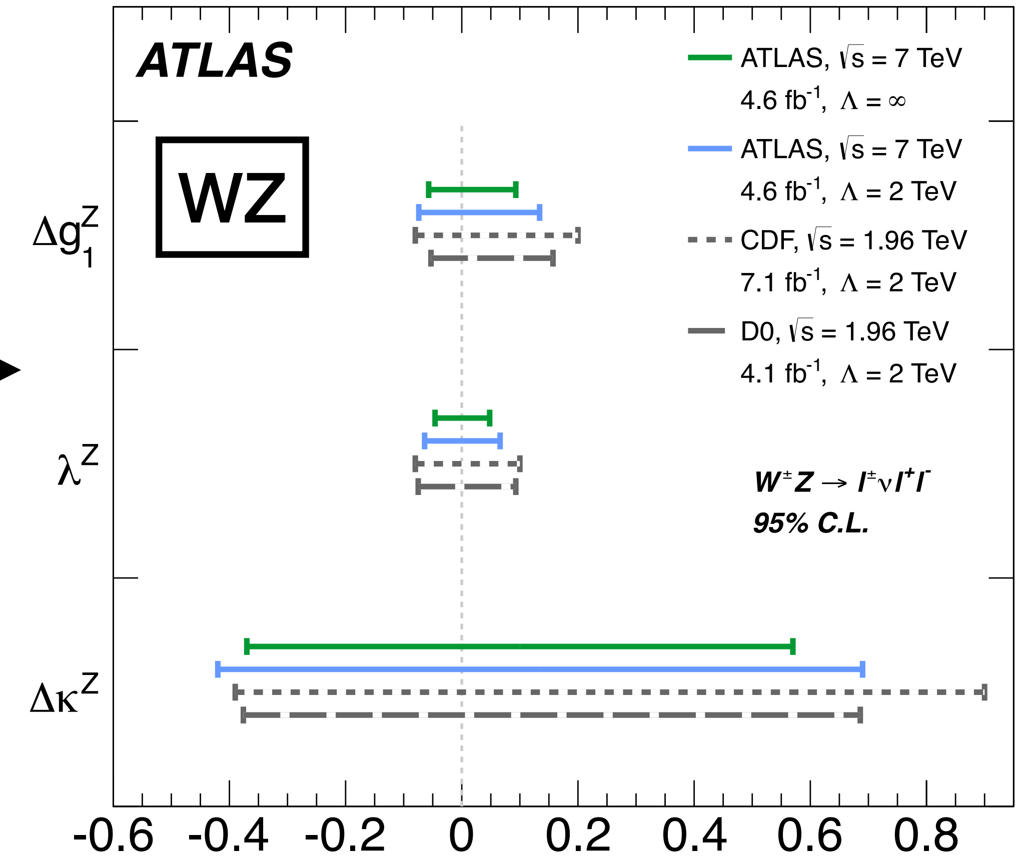
$$g_1^V = \kappa^V = 1 \qquad \lambda^V = f_4^V = f_5^V = h_3^V = h_4^V = 0$$

- In case of aTGCs, expect a change in **production rate** and **kinematic distributions**
- Gain sensitivity using shape distributions to set frequentist 1D + 2D limits on aTGCs

Charged aTGC Limits

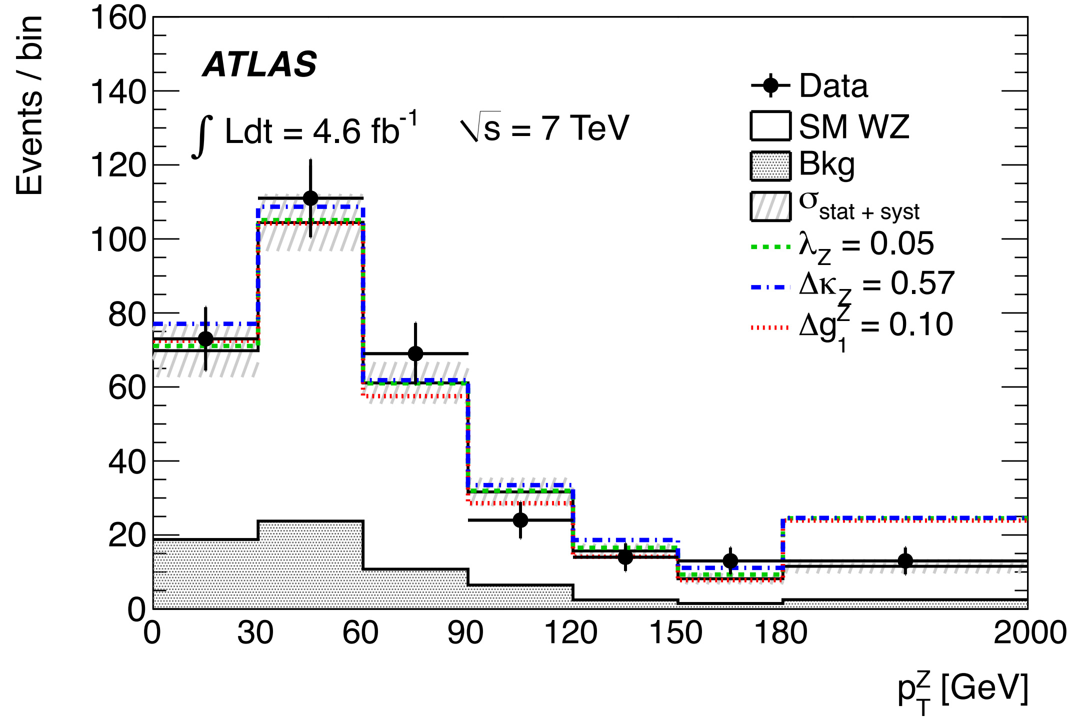
Eur. Phys. J. C (2012) 72:2173
CERN-PH-EP-2012-345
CERN-PH-EP-2012-242

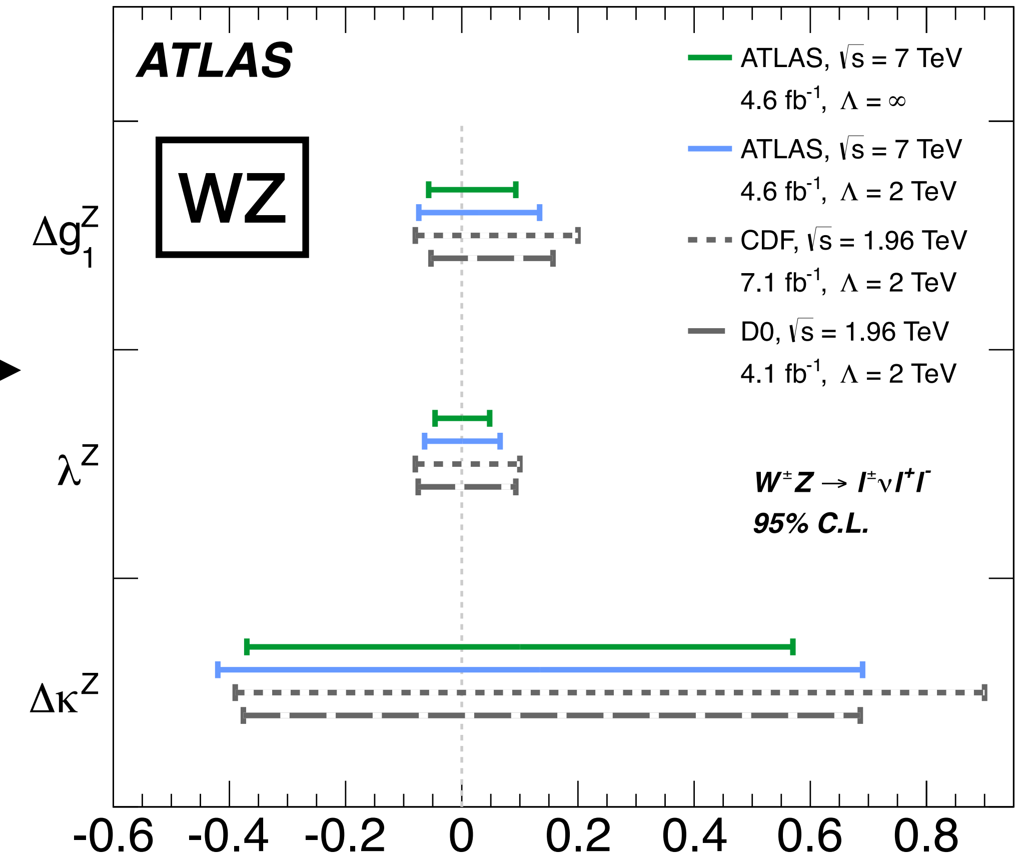


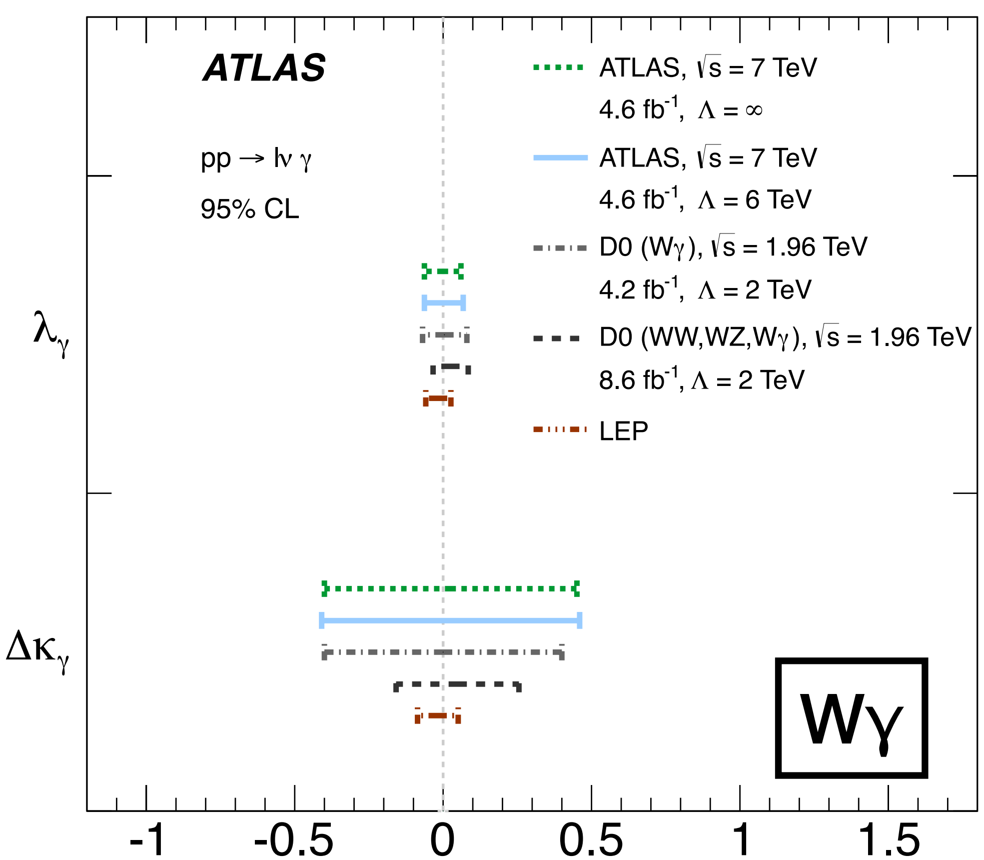


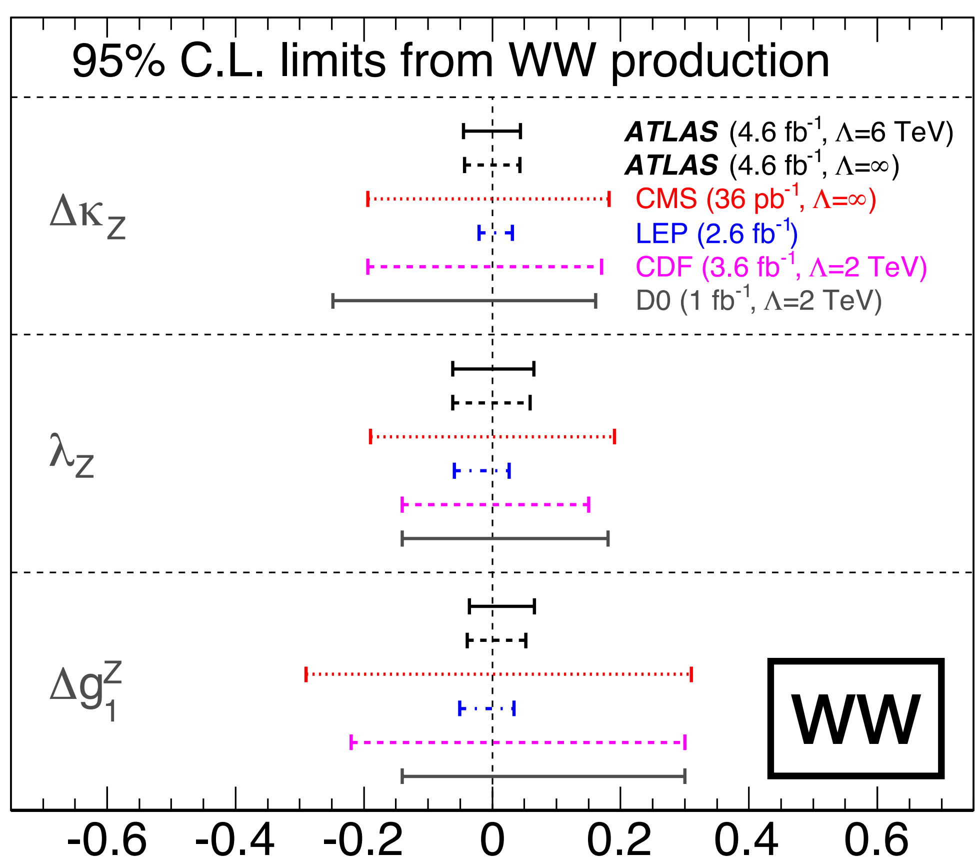
Charged aTGC Limits

Eur. Phys. J. C (2012) 72:2173
CERN-PH-EP-2012-345
CERN-PH-EP-2012-242





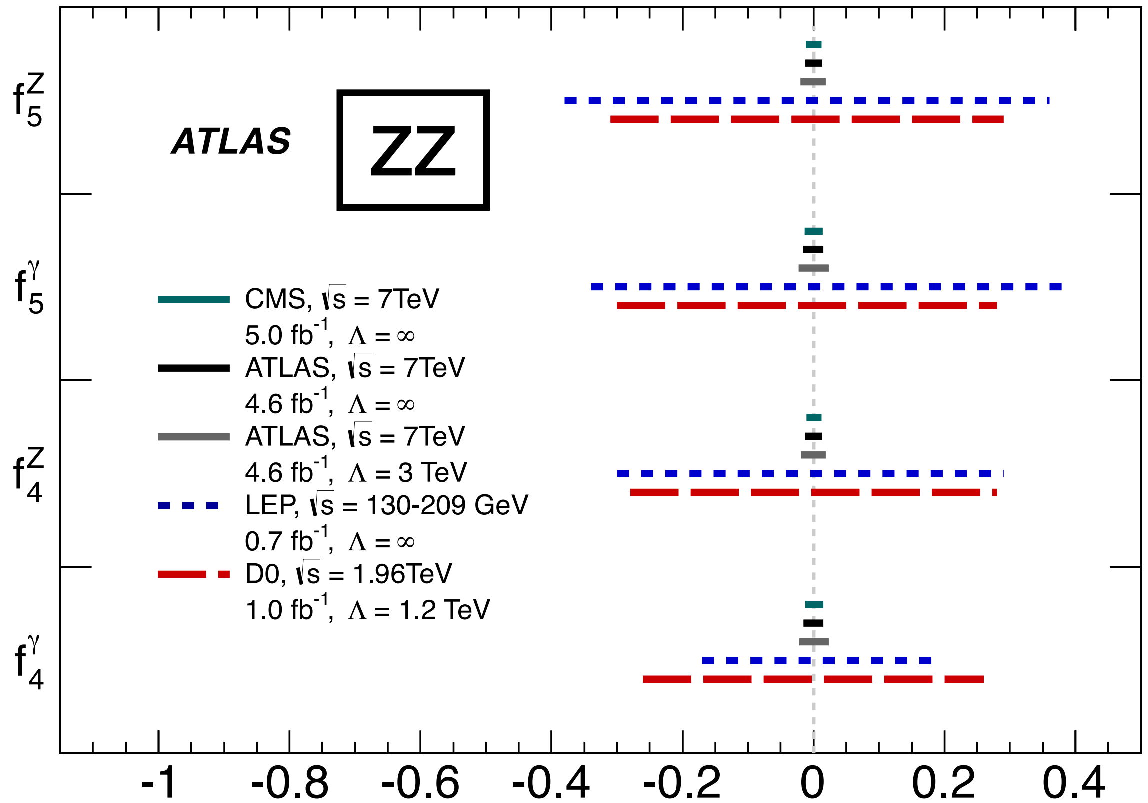




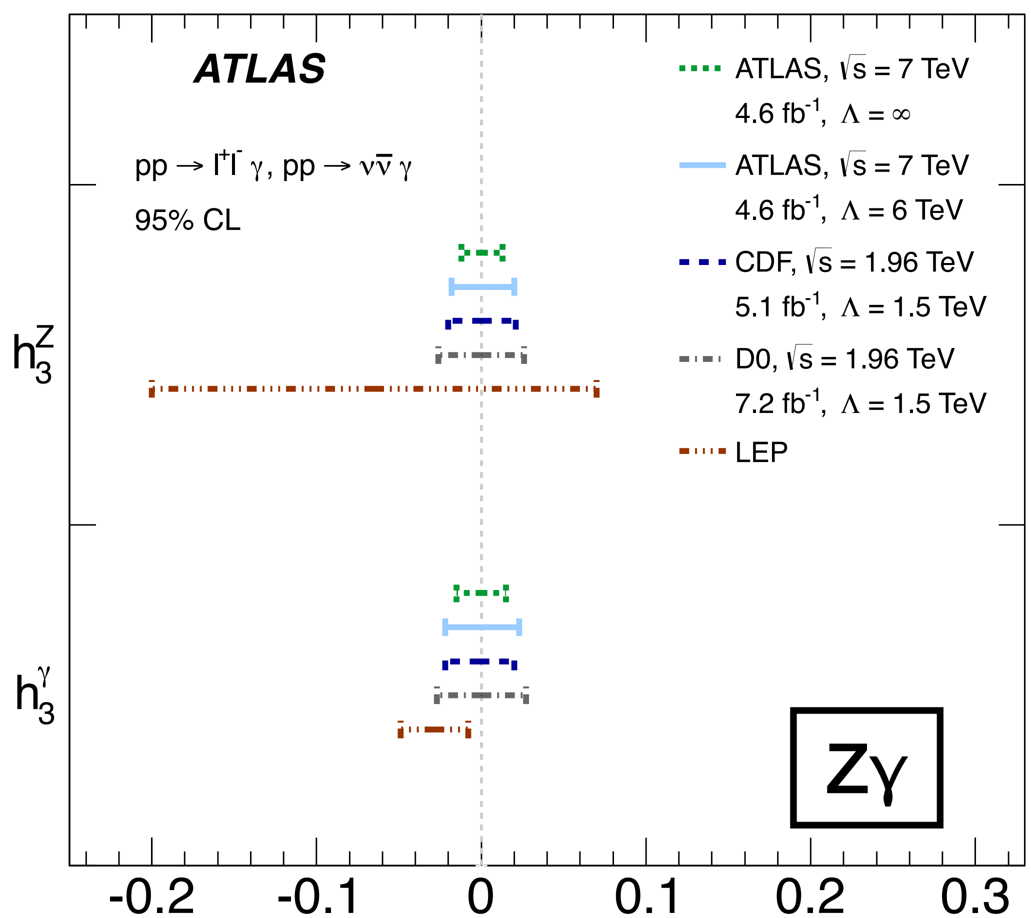
- limits set using
  - WZ: Z boson p_T
  - Wγ: photon E_T, $n_{jet}=0$
  - WW: leading lepton p_T
- **no deviations** from SM observed
- ATLAS limits comparable or tighter than Tevatron

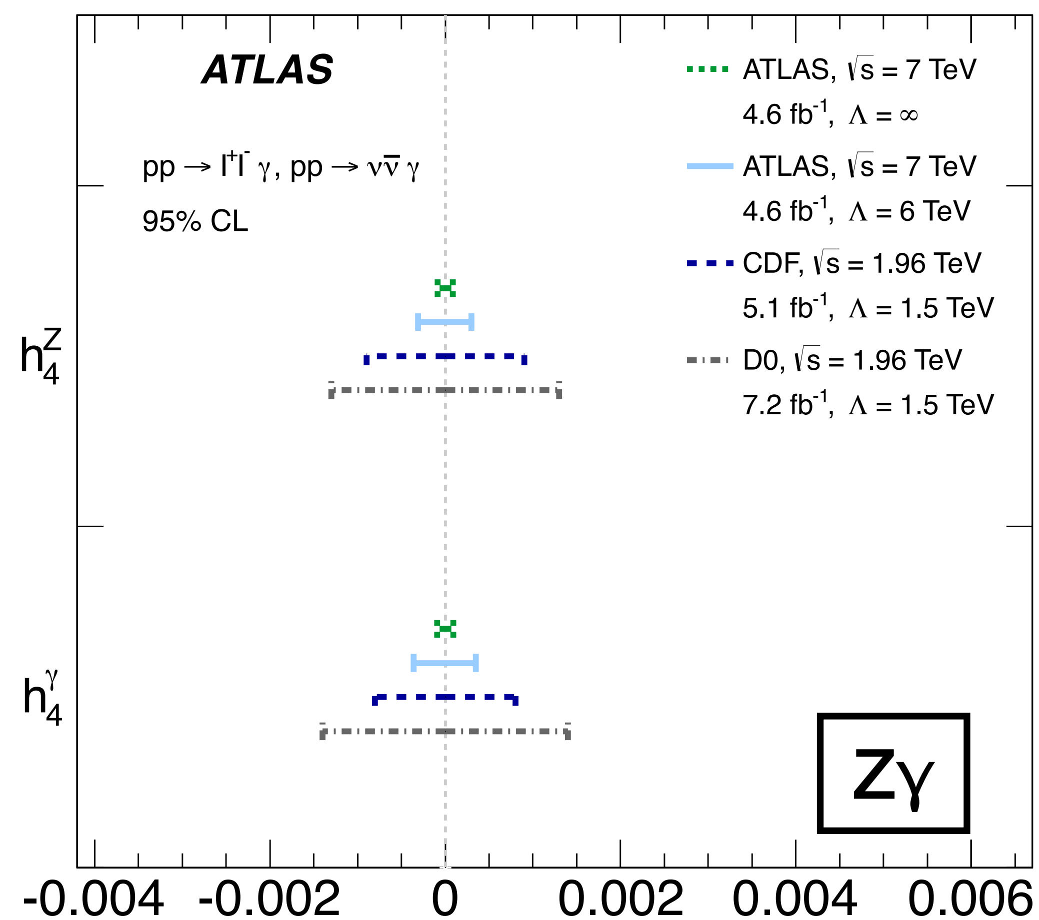
Neutral aTGC Limits

CERN-PH-EP-2012-318
CERN-PH-EP-2012-345



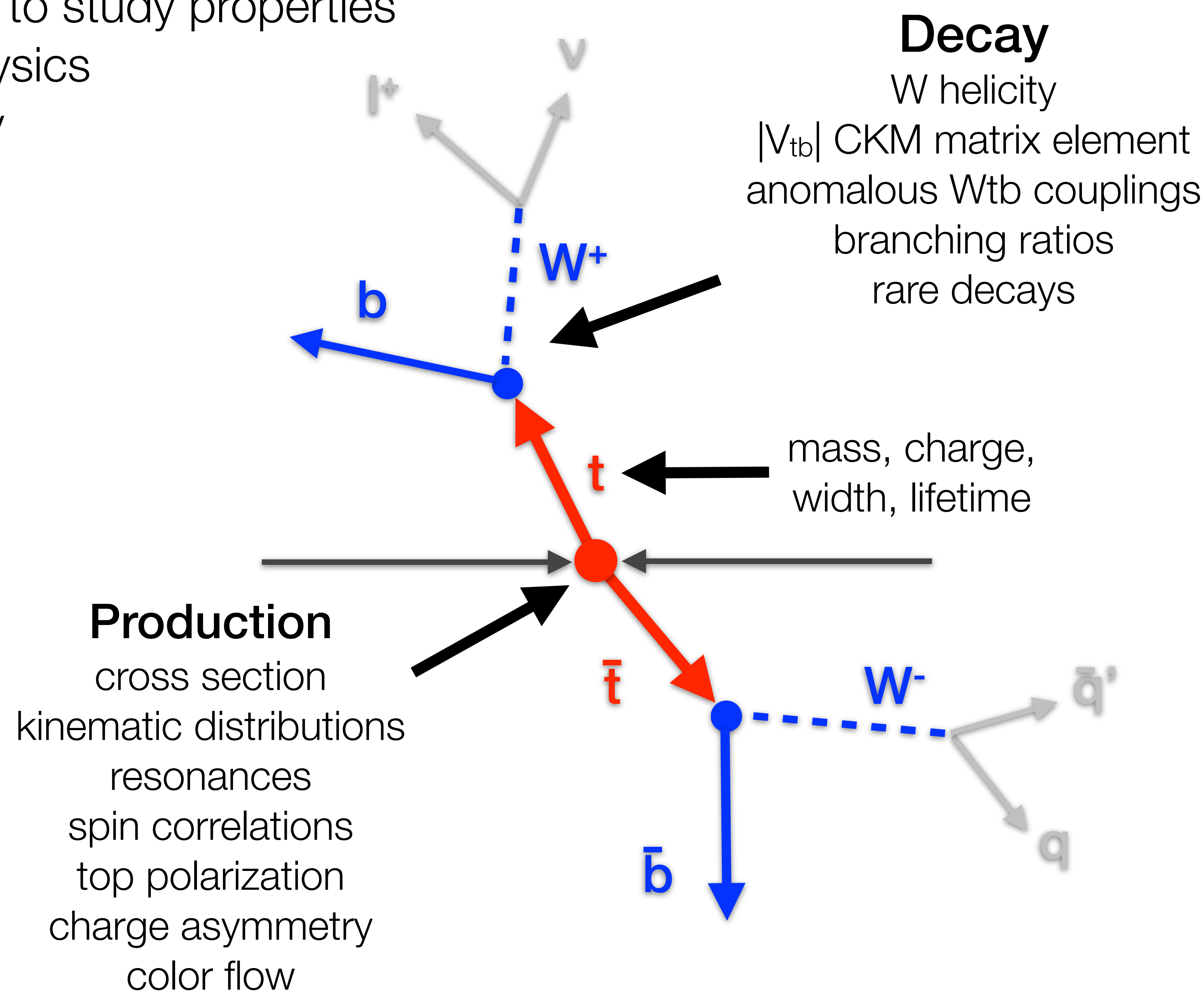
- limits set using
  - ZZ: leading Z boson p_T
  - Zγ: photon E_T, n_{jet}=0
- **no deviations** from SM observed
- ATLAS limits tighter than LEP and Tevatron





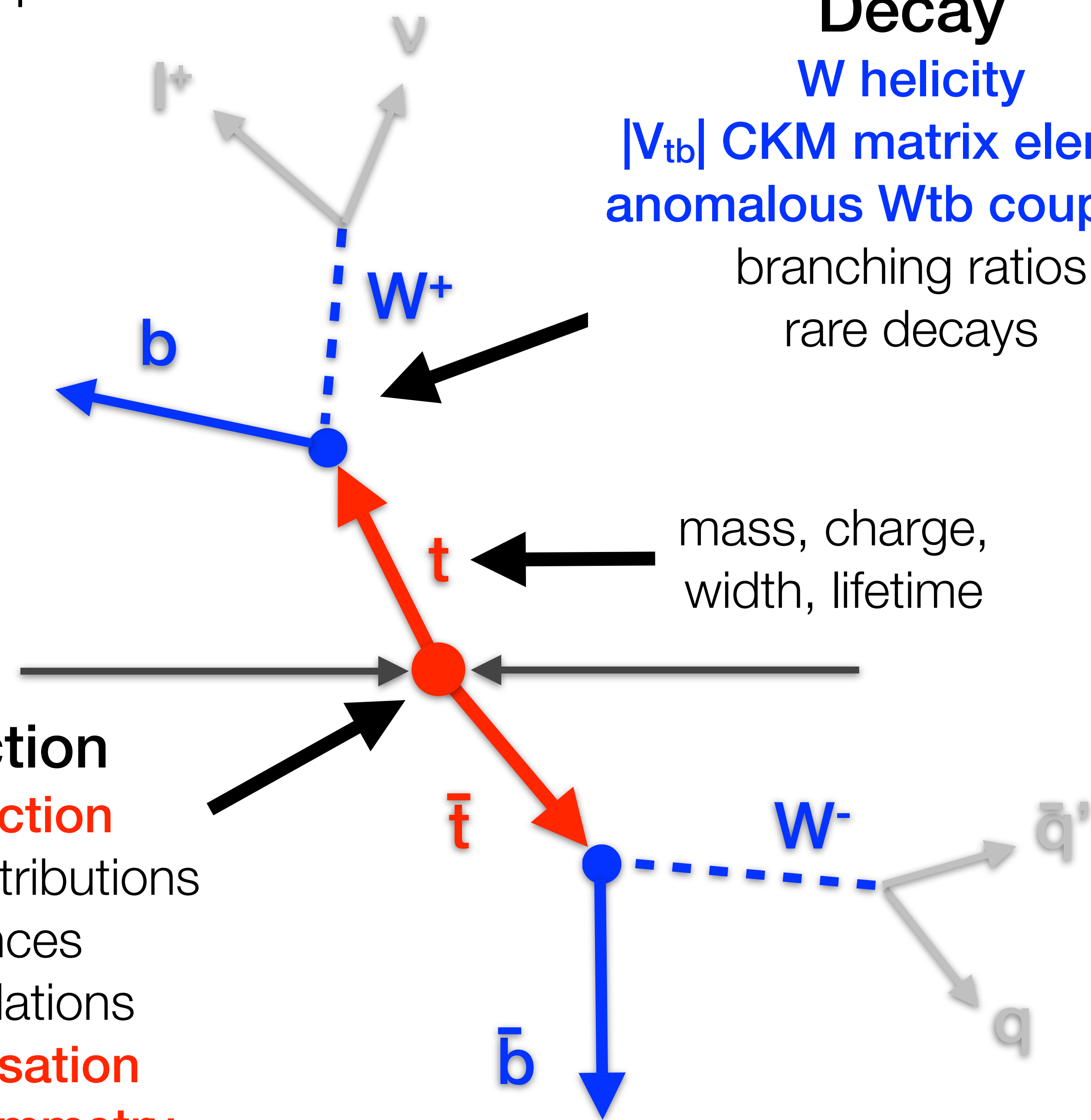
Why Top Production?

- heaviest fundamental particle
- large coupling to Higgs boson
- probe of electroweak symmetry breaking
- short lifetime allows to study properties
- sensitive to new physics
- LHC is a top factory



Why Top Production?

- heaviest fundamental particle
- large coupling to Higgs boson
- probe of electroweak symmetry breaking
- short lifetime allows to study properties
- sensitive to new physics
- LHC is a top factory



Decay

W helicity

$|V_{tb}|$ CKM matrix element

anomalous Wtb couplings

branching ratios

rare decays

mass, charge,
width, lifetime

Production

cross section

kinematic distributions

resonances

spin correlations

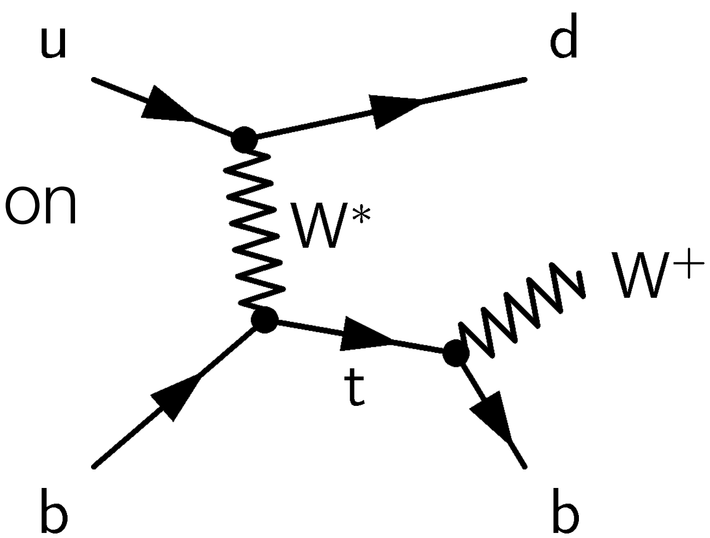
top polarisation

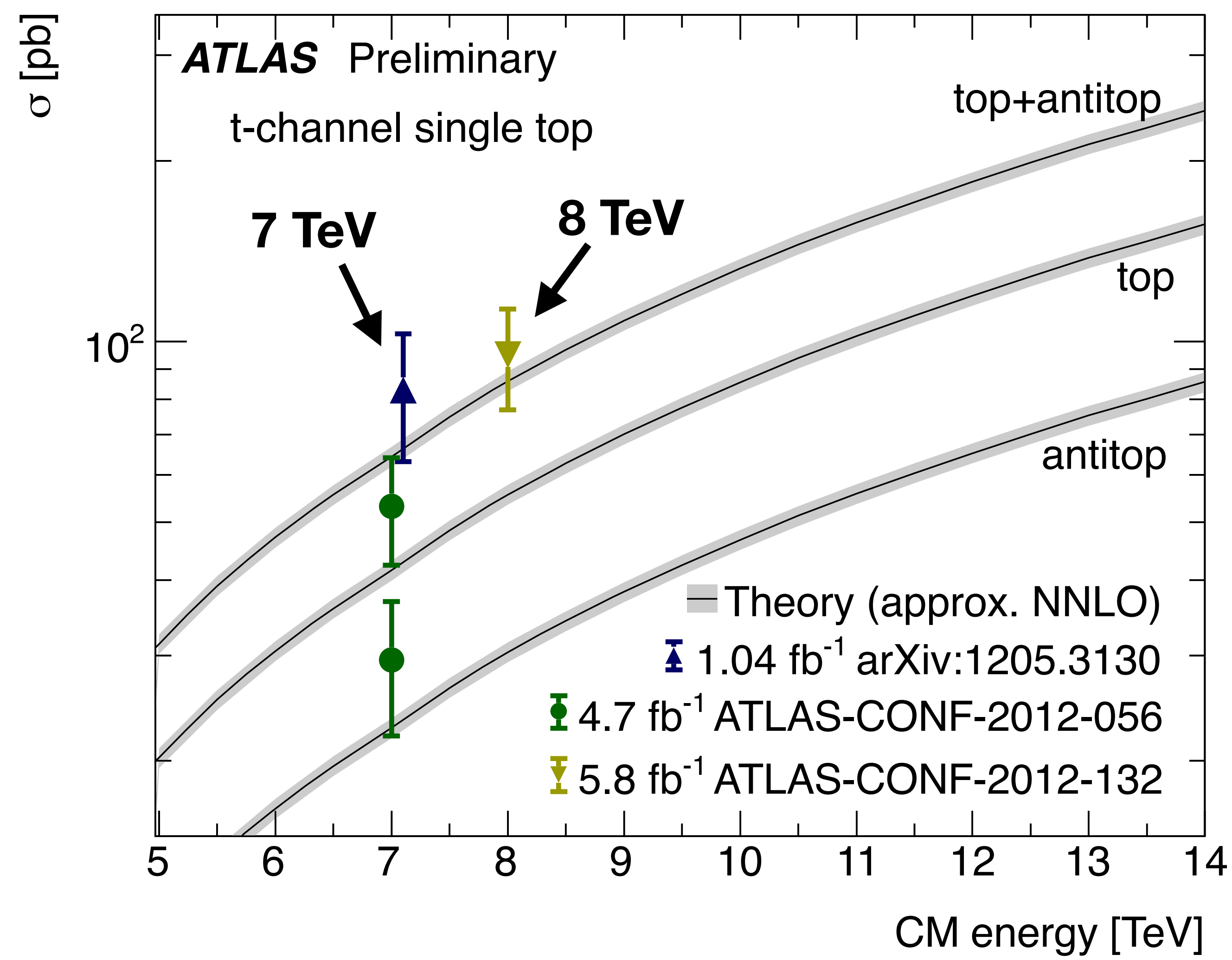
charge asymmetry

colour flow

Single Top Cross Section

- measurement in the lepton+jets **t-channel**
- neural network based discriminant in 2 and 3 jet bins
- backgrounds from W+jets, QCD multijet and other top production



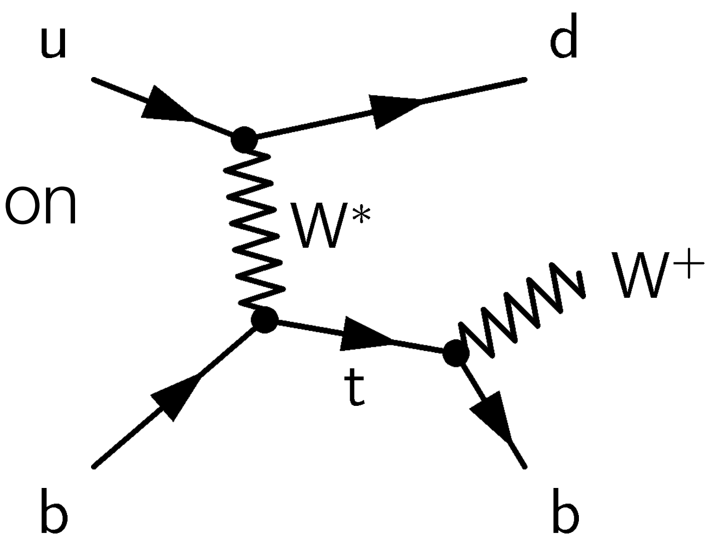


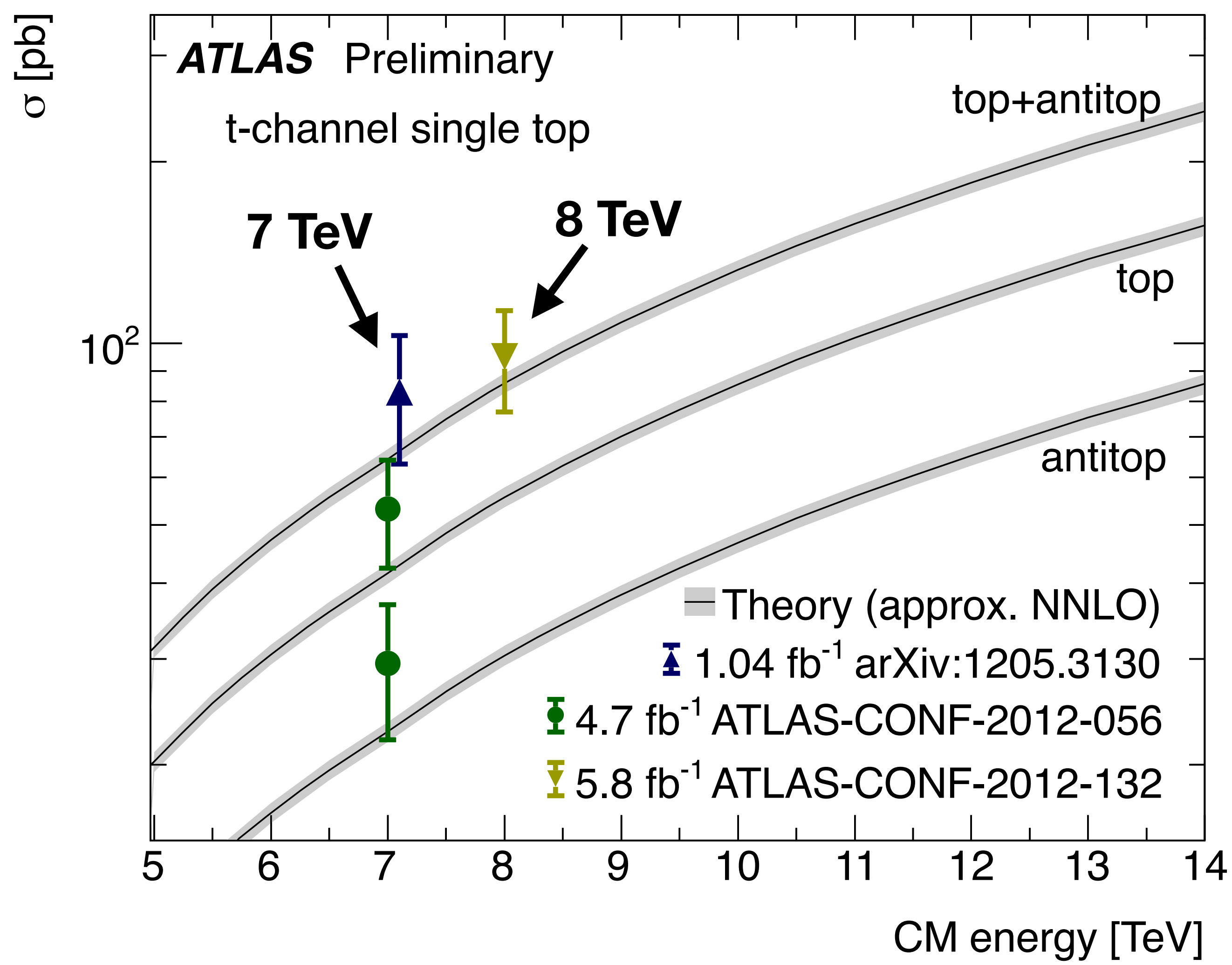
$$\sigma_t = 95 \pm 2\ (\mathrm{stat}) \pm 18\ (\mathrm{syst})\ \mathrm{pb}$$

$$\sigma_t^{\mathrm{NNLO}} = 87.8^{+3.4}_{-1.9}\ \mathrm{pb}$$

Single Top Cross Section

- measurement in the lepton+jets **t-channel**
- neural network based discriminant in 2 and 3 jet bins
- backgrounds from W+jets, QCD multijet and other top production





$$\sigma_t = 95 \pm 2\ (\text{stat}) \pm 18\ (\text{syst})\ \text{pb}$$

$$\sigma_t^{\text{NNLO}} = 87.8^{+3.4}_{-1.9}\ \text{pb}$$

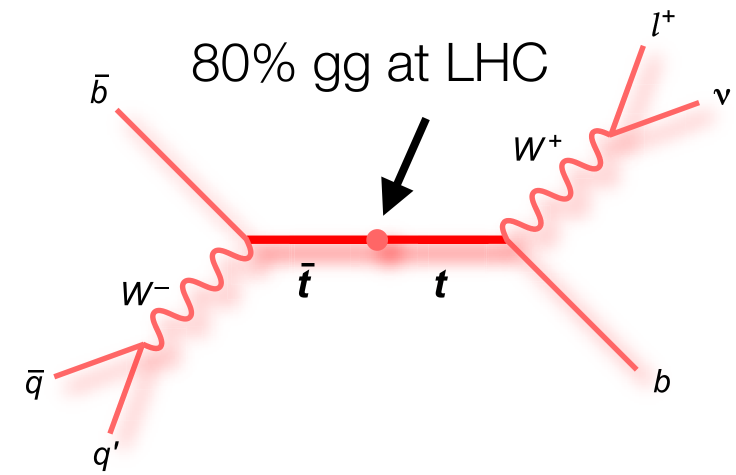
- direct probe of **Wtb coupling vertex**
- cross section measurement provides constraint on **CKM** matrix element

$$|V_{tb}| = 1.04^{+0.10}_{-0.11} \text{ assuming } |V_{tb}| \gg |V_{ts}|, |V_{td}|$$

$$|V_{tb}| > 0.80 \text{ at } 95\% \text{ C.L. assuming } |V_{tb}| \leq 1$$

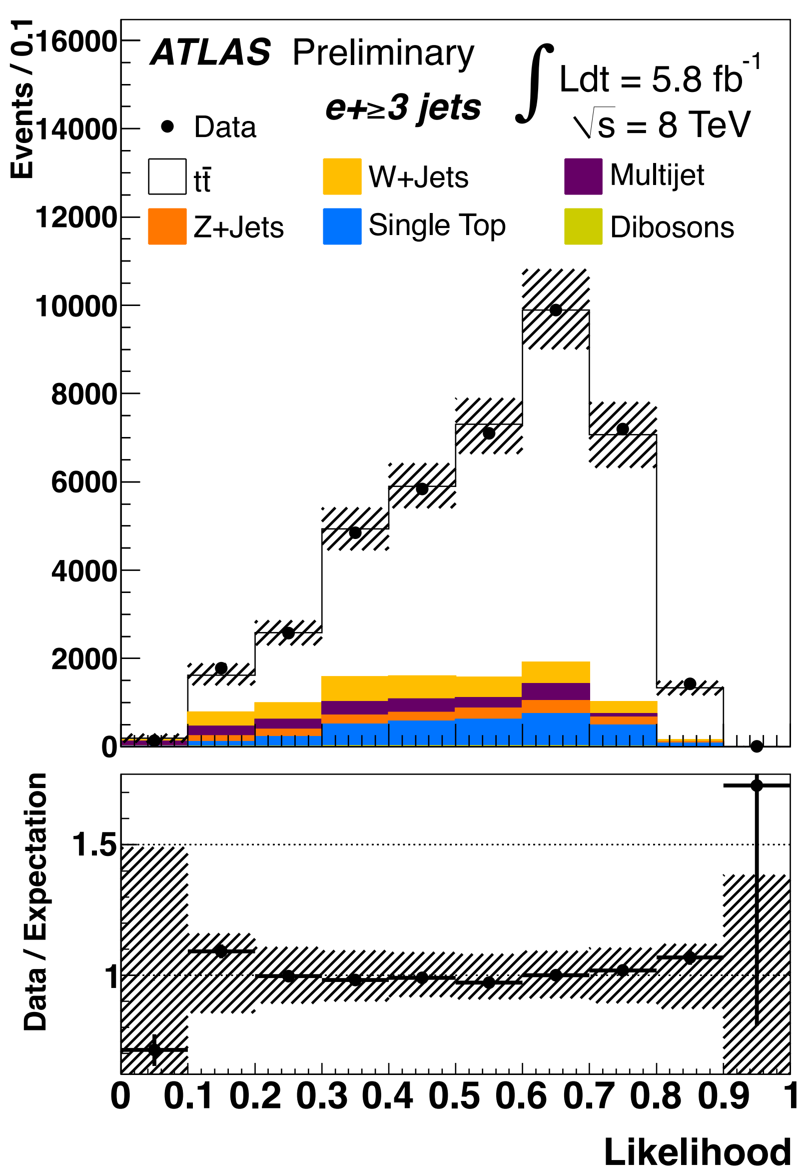
$t\bar{t}$ Cross Section

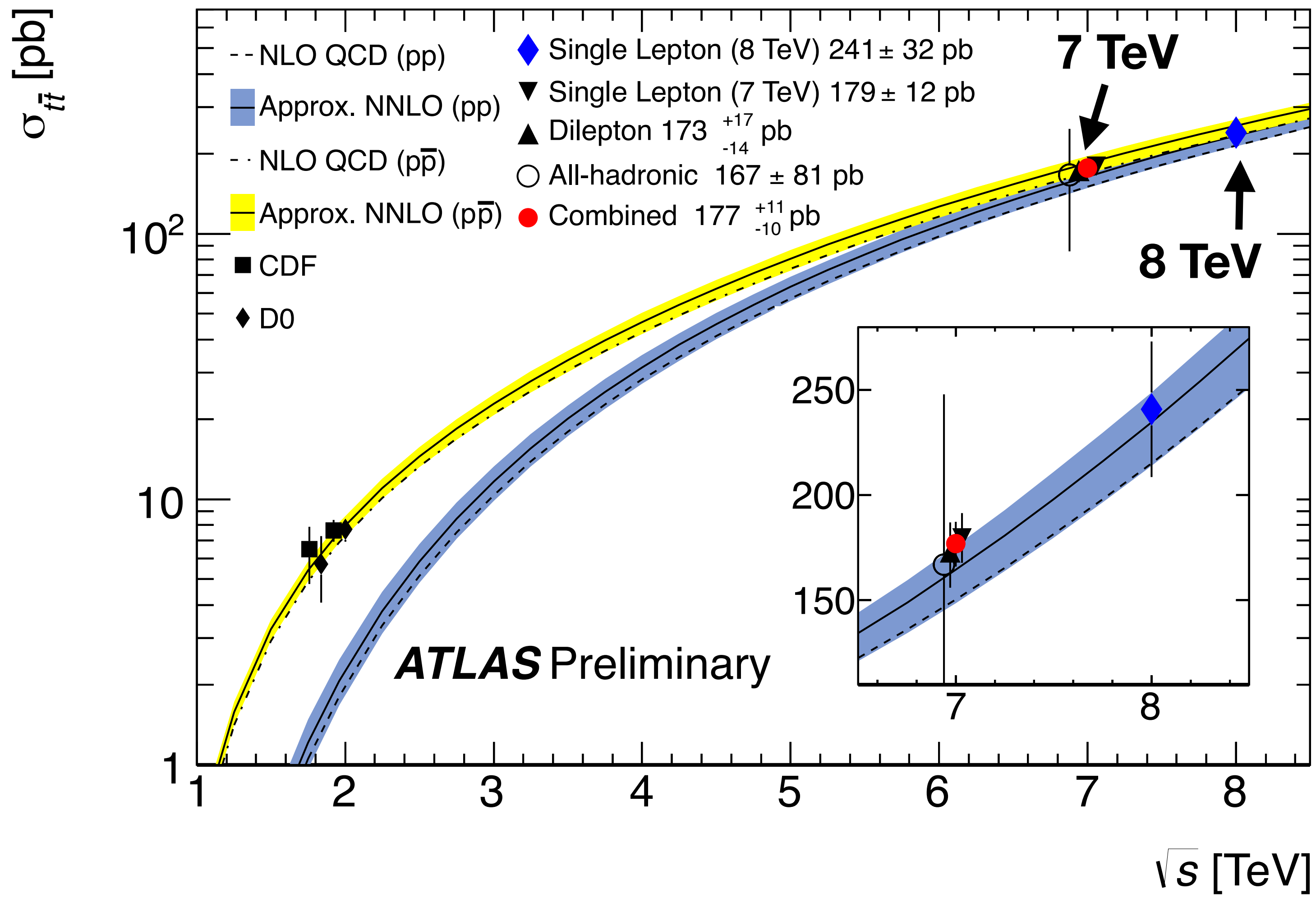
- **lepton+jets channel** measurement
- require 3 or more jets with at least one b-tag
- multivariate likelihood template fit
- less aggressive MC modelling uncertainty gives larger systematic uncertainty compared to 7 TeV combination



$$\sigma_{t\bar{t}} = 241 \pm 2\ (\text{stat}) \pm 31\ (\text{syst}) \pm 9\ (\text{lumi})\ \text{pb}$$

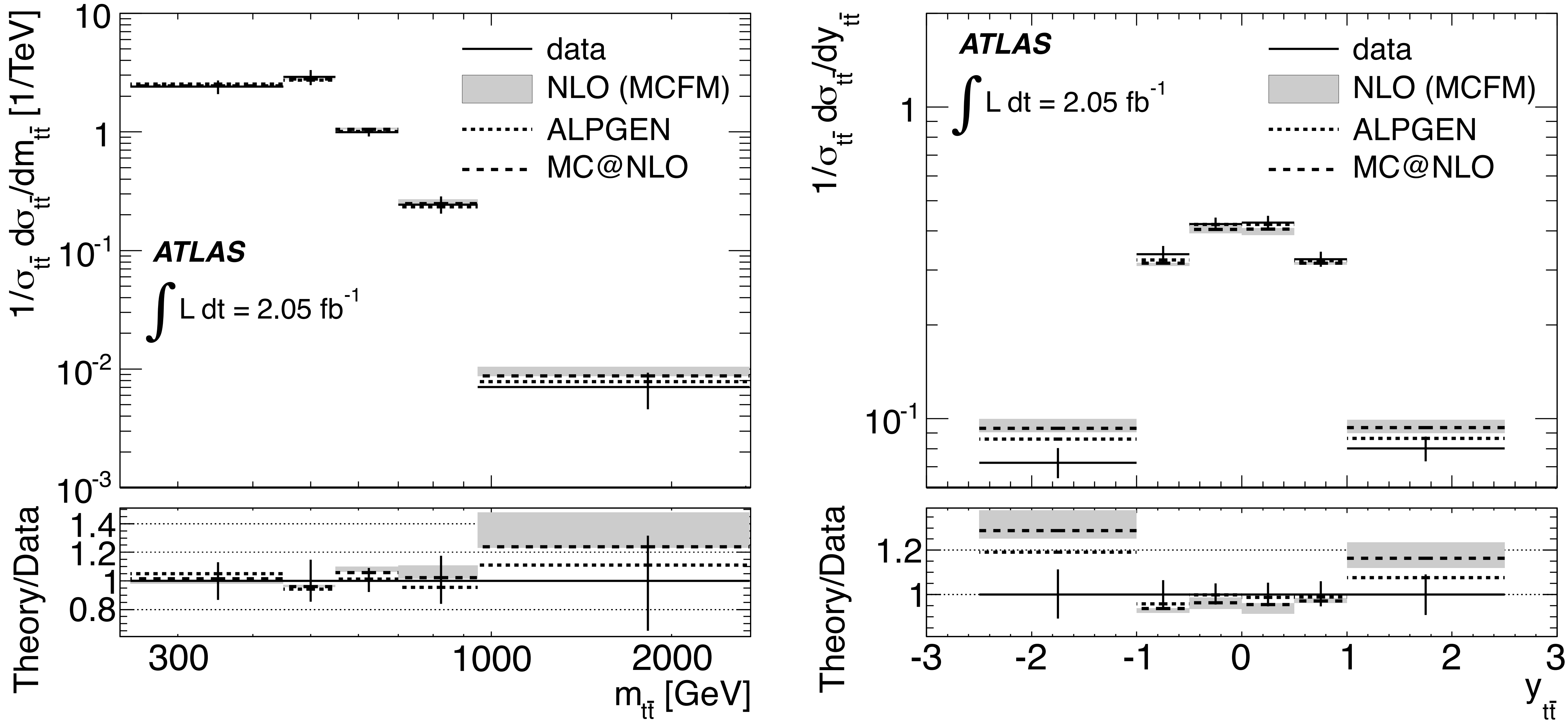
$$\sigma_{t\bar{t}}^{\text{NNLO}} = 238^{+22}_{-24}\ \text{pb}$$





$t\bar{t}$ Differential Distributions

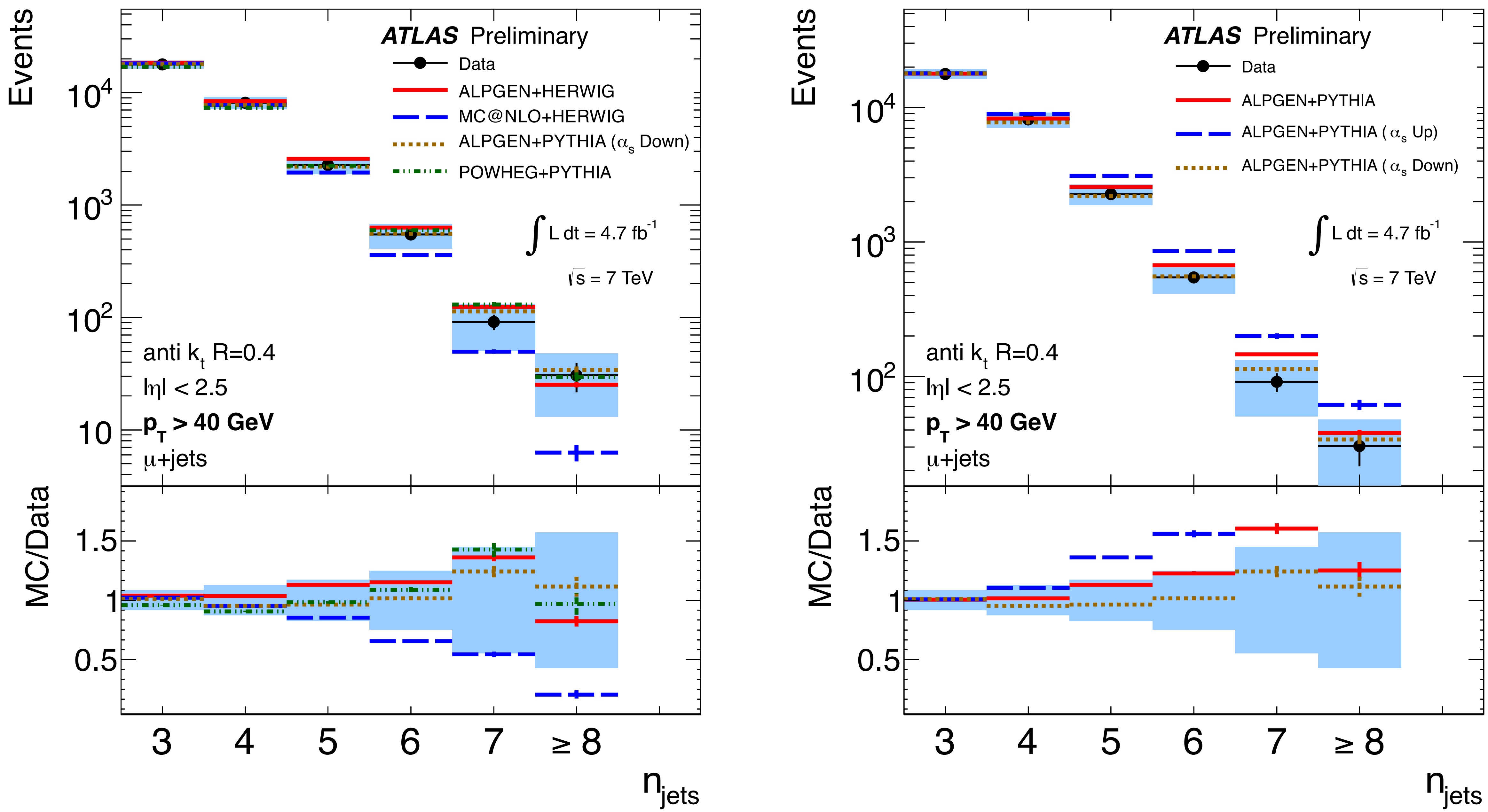
Eur. Phys. J. C (2013) 73:2261



- unfolded relative **differential cross sections**
- systematics dominated
- sensitive to
  - wide resonances
  - QCD radiation
- important background for new searches

$$\frac{1}{\sigma}\frac{d\sigma}{dx}$$

$t\bar{t}$ Differential Distributions



- unfolded **jet multiplicity**
- systematics dominated
- constrain ISR/FSR models
- test pQCD at LHC

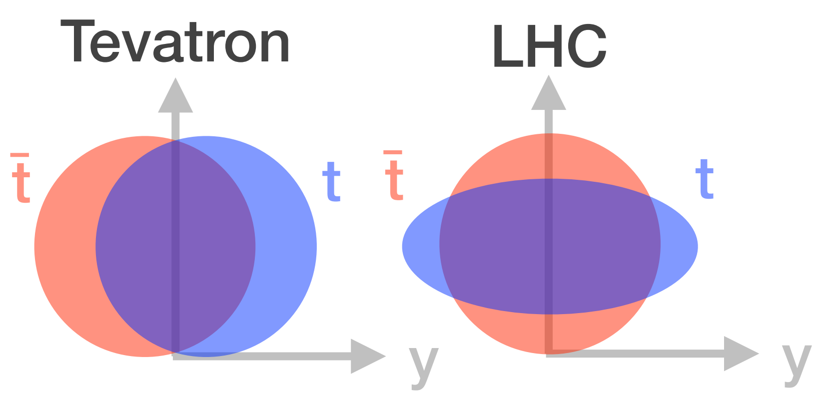
Top Properties

- **charge asymmetry** in top quark pairs
- NLO corrections in $q\bar{q} \to t\bar{t}$ introduce small y asymmetries

t ($\bar{t}$) preferentially emitted along p ($\bar{p}$) direction

- initial state $p\bar{p}$
  → forward-backward
- observed shift > prediction

  PRD 83 (2011) 112003
  PRD 84 (2011) 112005



- initial state symmetric
  → no overall y shift
- q more momentum than $\bar{q}$ in p
  → t more forward
- without specific cuts
  → sensitive to width not mean

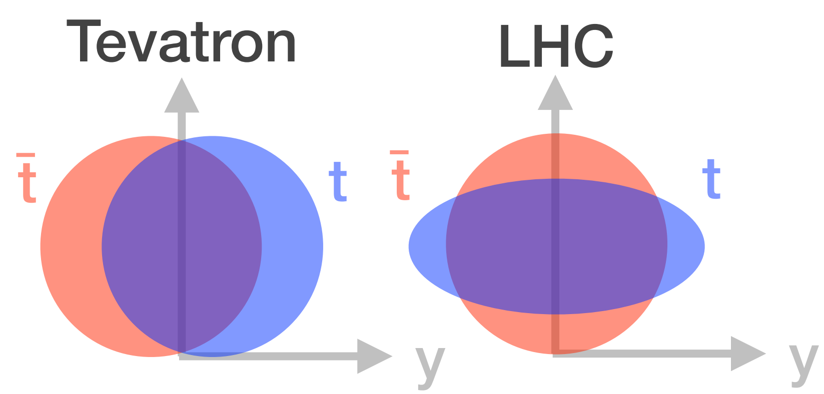
Top Properties

- **charge asymmetry** in top quark pairs
- NLO corrections in $q\bar{q}\rightarrow t\bar{t}$ introduce small y asymmetries

t ($\bar{t}$) preferentially emitted along p ($\bar{p}$) direction

- initial state $p\bar{p}$
  → forward-backward
- observed shift > prediction

PRD 83 (2011) 112003
PRD 84 (2011) 112005



- initial state symmetric
  → no overall y shift
- q more momentum than $\bar{q}$ in p
  → t more forward
- without specific cuts
  → sensitive to width not mean

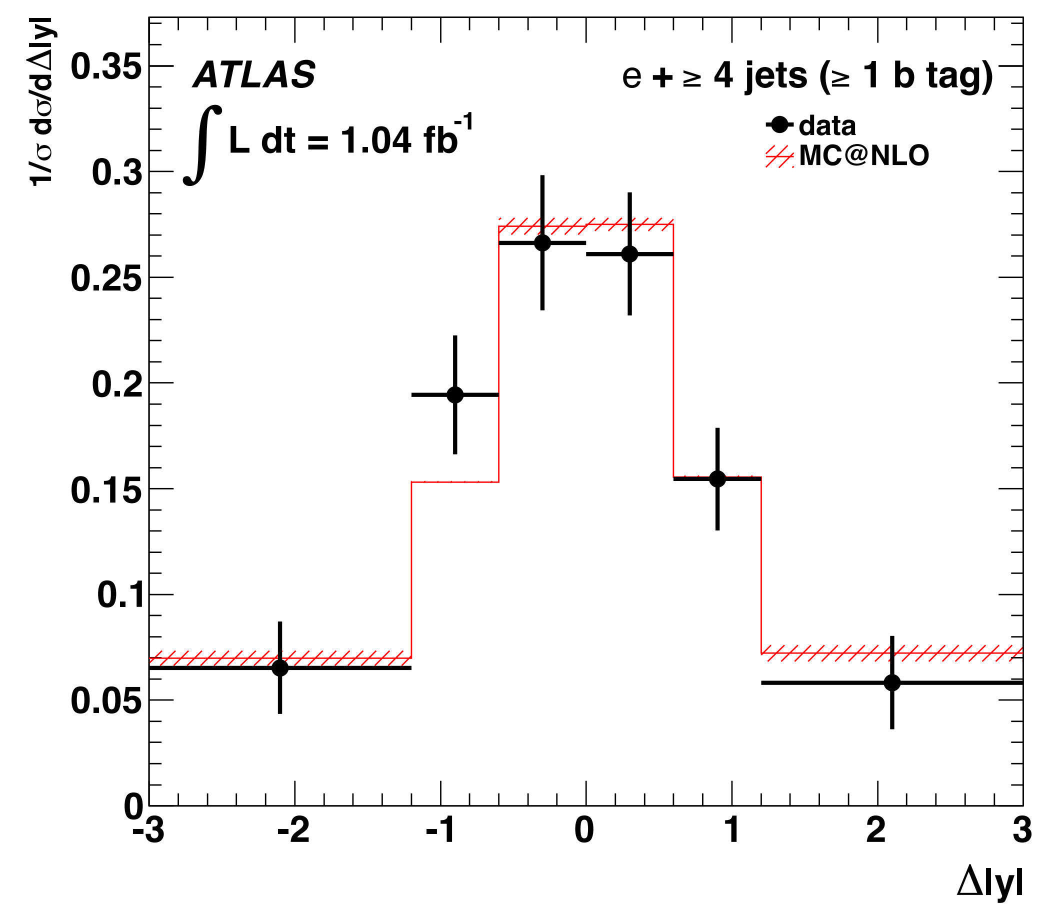
$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

$$= |y_t| - |y_{\bar{t}}|$$

$$A_C = 0.029 \pm 0.018\ (\mathrm{stat}) \pm 0.014\ (\mathrm{syst})$$

$$A_C = 0.006 \pm 0.002$$ (MC@NLO)

combination of single and dilepton channels

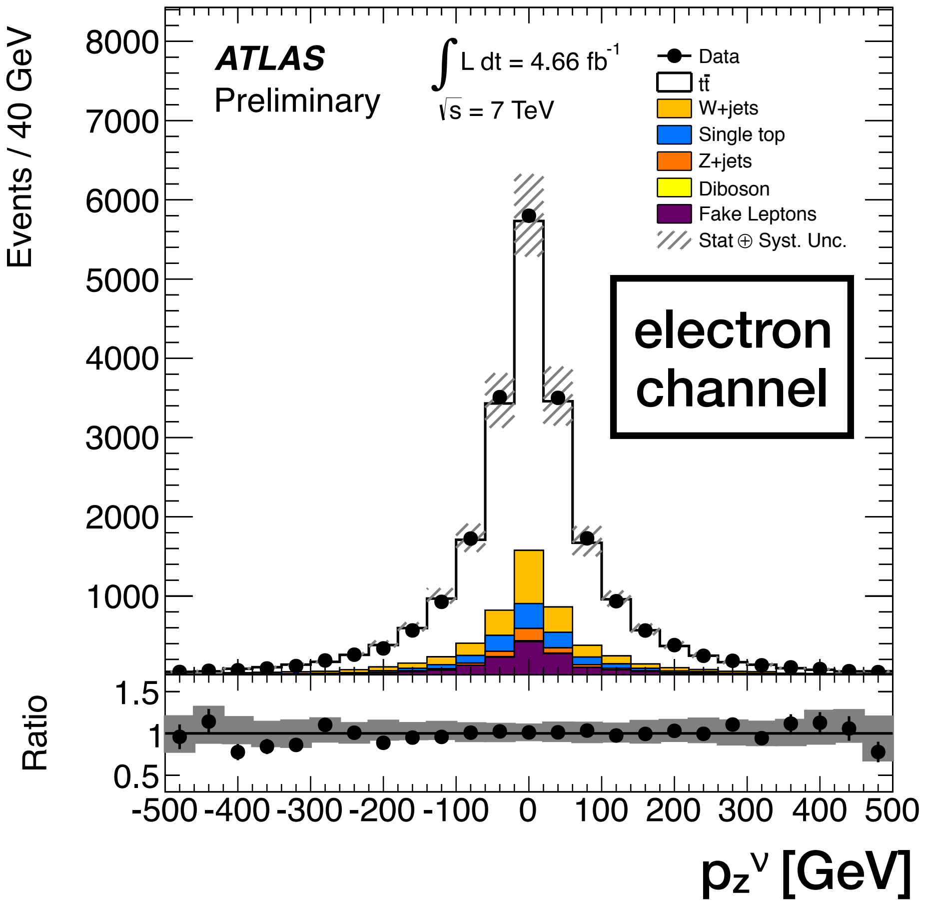


Top Properties

- **top polarization** in lepton+jets top quark pairs
- full reconstruction of top pair using likelihood method
- $\cos\theta_l$ template fit to extract **polarization fraction**

polar lepton angle in parent top frame

$$f_p = \frac{1}{2} + \frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$

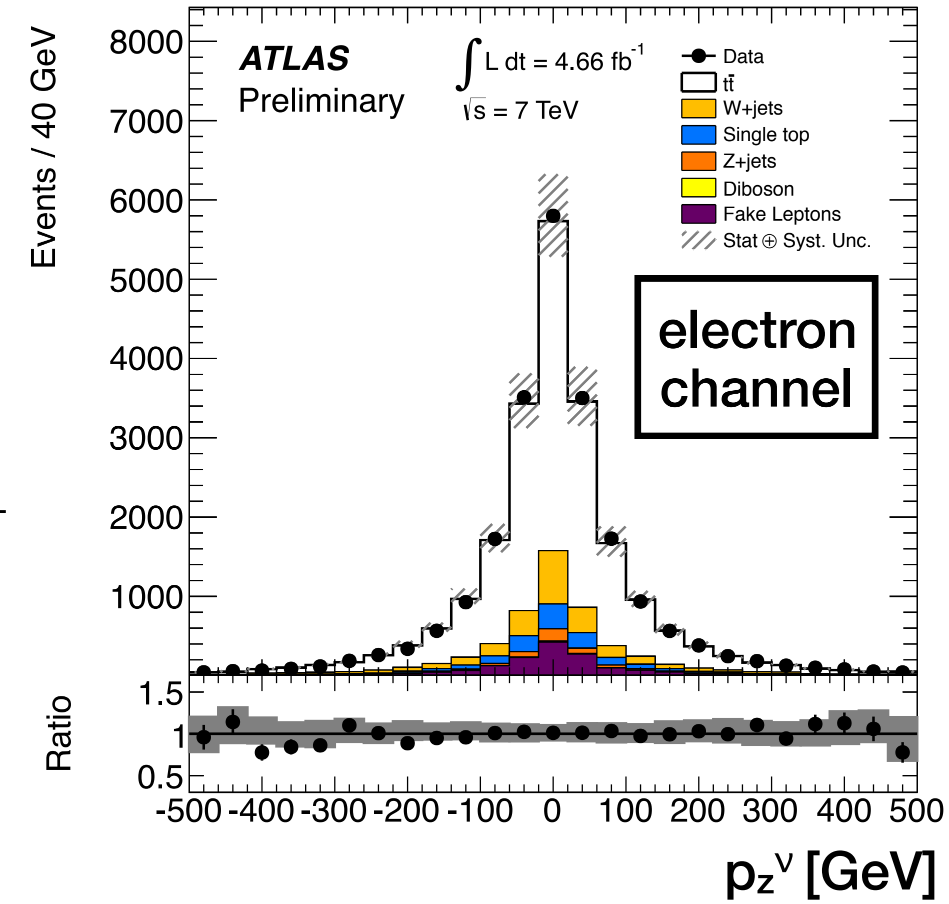


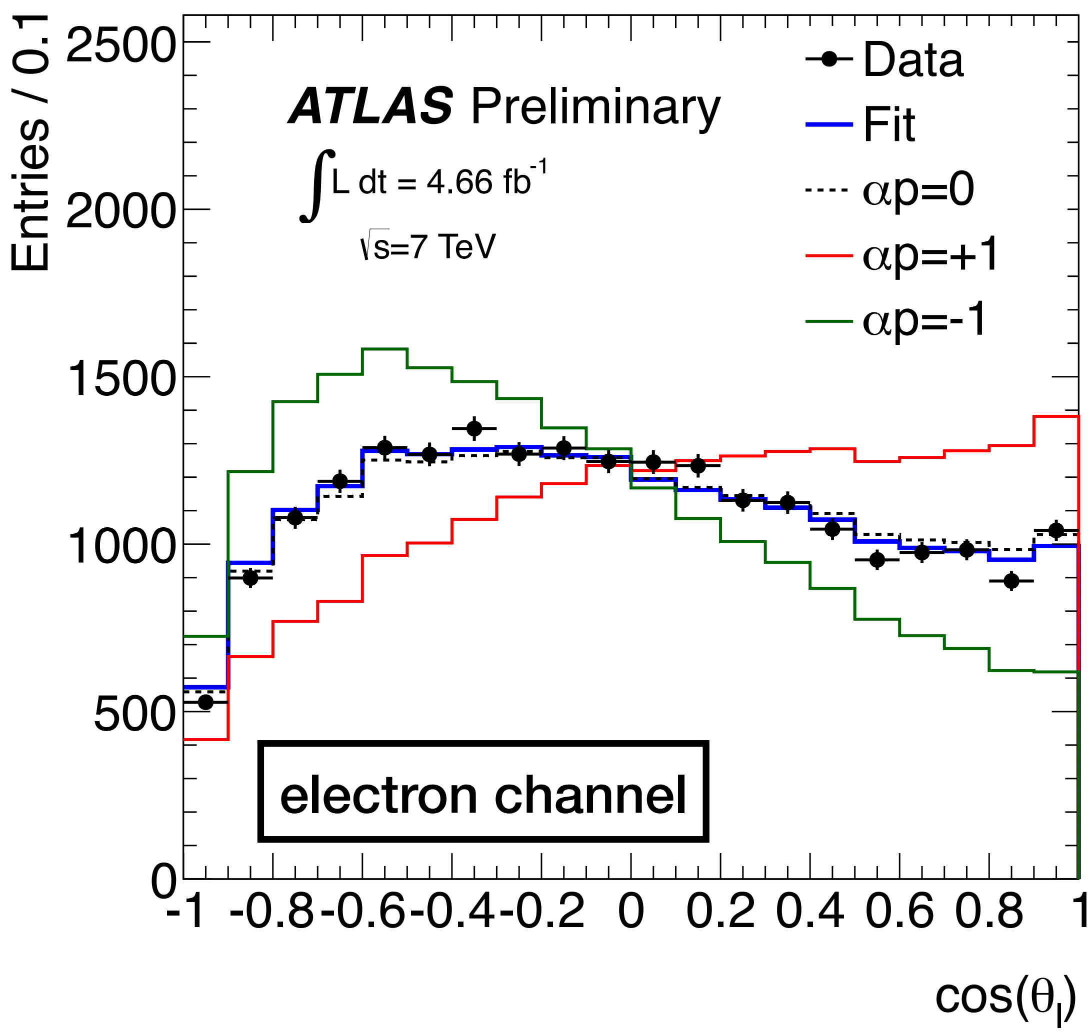
Top Properties

- **top polarization** in lepton+jets top quark pairs
- full reconstruction of top pair using likelihood method
- $\cos\theta_l$ template fit to extract **polarization fraction**

polar lepton angle in parent top frame

$$f_p = \frac{1}{2} + \frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$





$$f_p = 0.470 \pm 0.009\ (\mathrm{stat})^{+0.023}_{-0.032}\ (\mathrm{syst})$$

$$f_p = 0.5$$

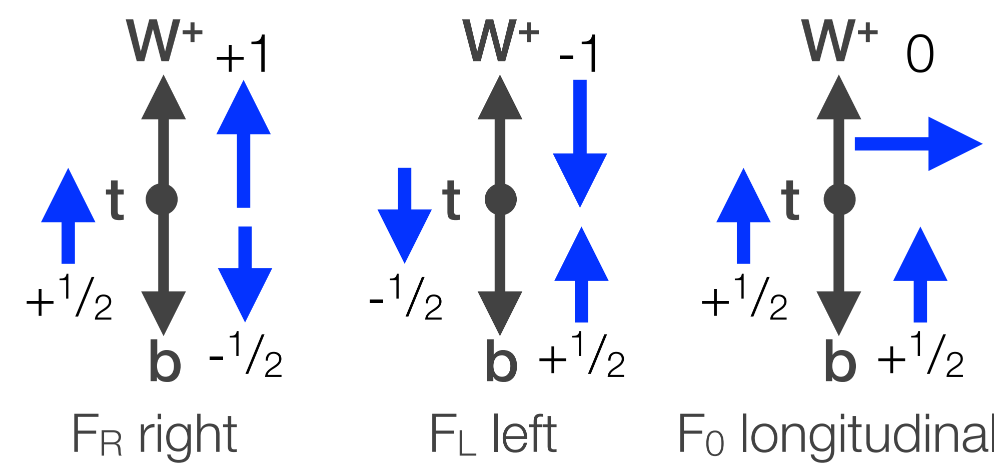
SM predicts unpolarized top quark

Top Properties

NEW

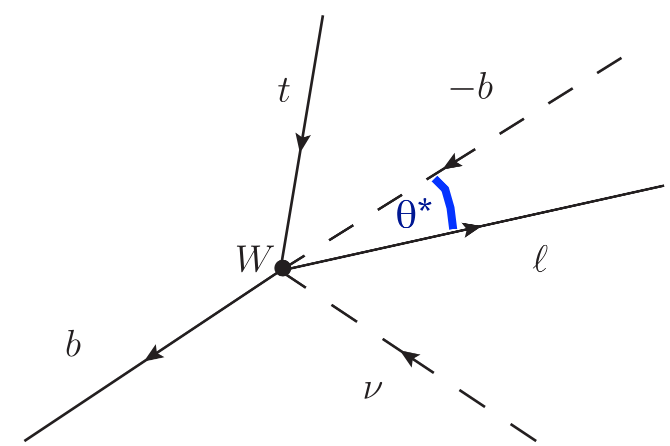
ATLAS-CONF-2013-033
JHEP 06 (2012) 088
CMS-PAS-TOP-11-020

- **W boson polarization** in top pair decays



- use cosθ* templates to measure different helicity fractions

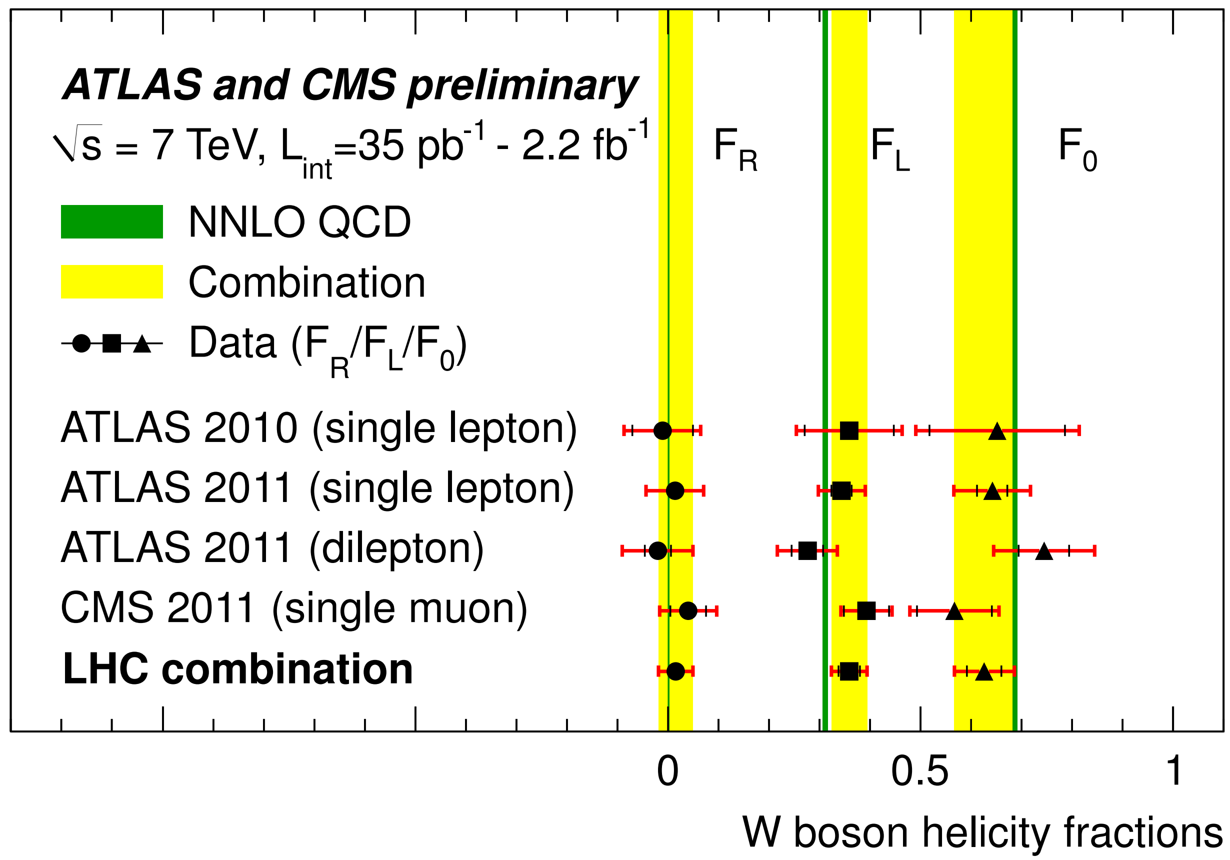
angle between lepton and reversed b direction in W rest frame



$$F_0 = 0.626 \pm 0.034\ (\mathrm{stat}) \pm 0.049\ (\mathrm{syst})$$
$$F_L = 0.359 \pm 0.021\ (\mathrm{stat}) \pm 0.028\ (\mathrm{syst})$$
$$F_R = 0.015 \pm 0.034\ (\mathrm{stat{+}syst})$$

$$F_0^{\mathrm{NNLO}} = 0.687 \pm 0.005$$
$$F_L^{\mathrm{NNLO}} = 0.311 \pm 0.005$$
$$F_R^{\mathrm{NNLO}} = 0.0017 \pm 0.0001$$

PRD 81 (2010) 111503



Top Properties

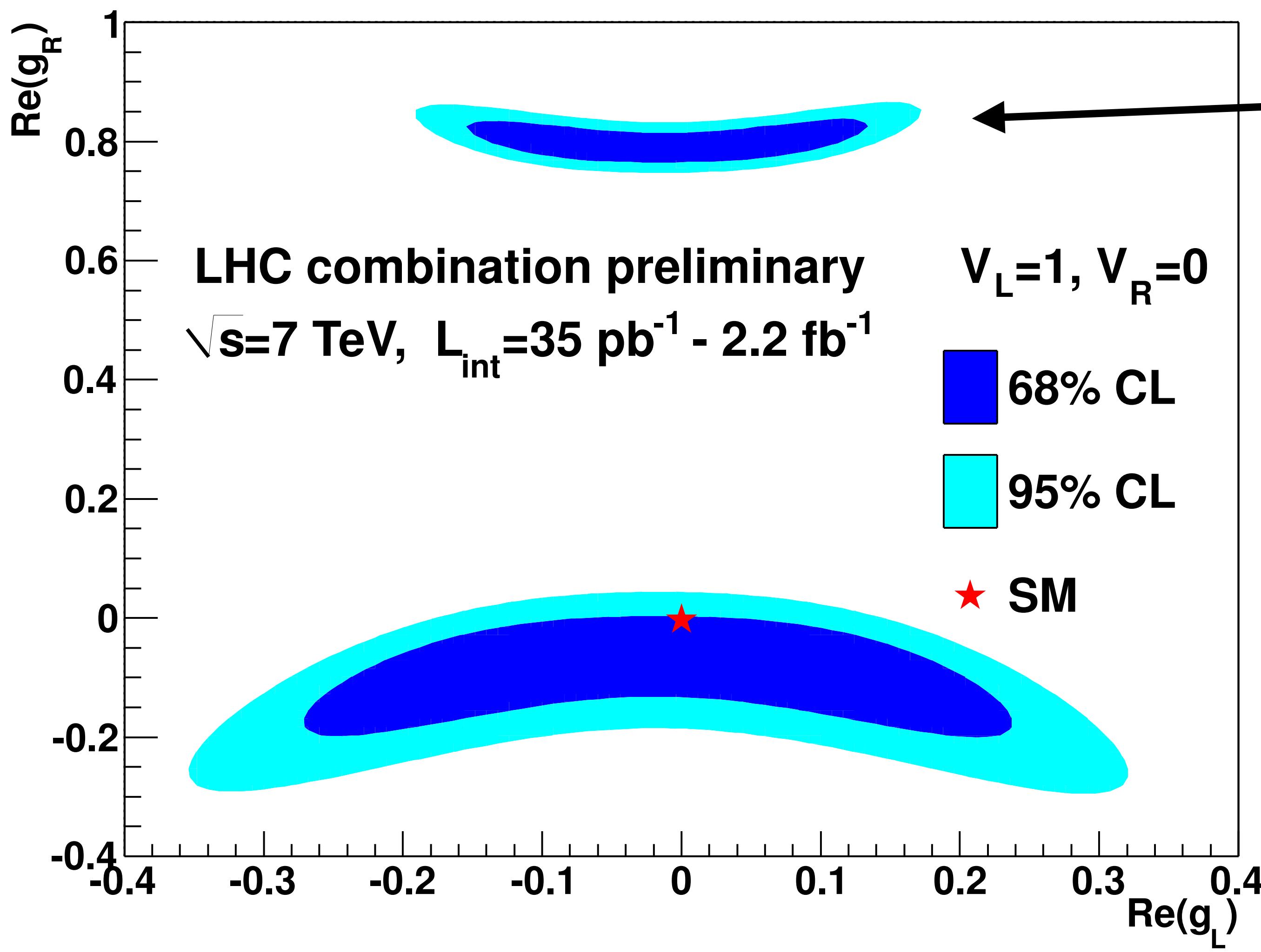
NEW

ATLAS-CONF-2013-033
JHEP 06 (2012) 088
CMS-PAS-TOP-11-020

- **W boson polarization** in top pair decays
- use to set limits on **anomalous Wtb couplings**
- effective Lagrangian approach

$$\mathcal{L}_{Wtb} = \frac{g}{\sqrt{2}}\bar{b}\left[\gamma^{\mu}\left(V_L P_L + V_R P_R\right) + \frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\left(g_L P_L + g_R P_R\right)\right] t W_{\mu}^{-} + \text{h.c.}$$

$V_L = V_{tb} \simeq 1$ (in SM), $V_R = 0$, $g_L = 0$, $g_R = 0$



region disfavoured by single top cross section measurements

Top Properties

NEW ATLAS-CONF-2013-032

- search for **CP violation** using **Wtb** vertex
- use lepton+jets t-channel single top
- expect highly polarised top quarks

forward-backward asymmetry w.r.t. normal to plane defined by W momentum and top polarization

$$A_{\rm FB} = 0.031 \pm 0.065\ ({\rm stat})^{+0.029}_{-0.031}\ ({\rm syst})$$

$$A_{\rm FB} = 0$$

consistent with CP invariance

Top Properties

NEW ATLAS-CONF-2013-032

- search for **CP violation** using **Wtb** vertex
- use lepton+jets t-channel single top
- expect highly polarised top quarks

forward-backward asymmetry w.r.t. normal to plane defined by W momentum and top polarization

$$A_{\mathrm{FB}} = 0.031 \pm 0.065\ (\mathrm{stat})^{+0.029}_{-0.031}\ (\mathrm{syst})$$

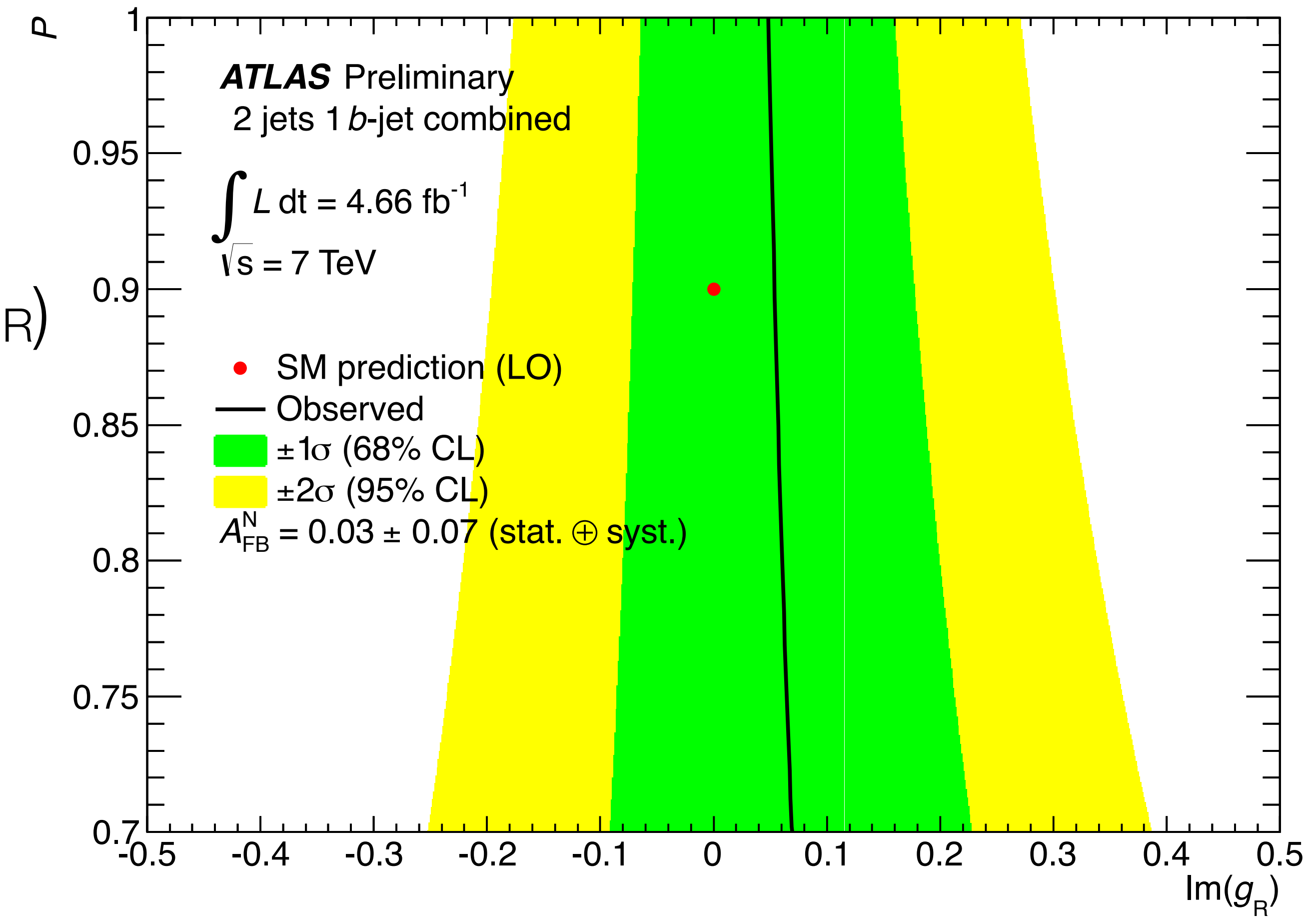
$$A_{\mathrm{FB}} = 0$$

consistent with CP invariance

- use to set first experimental limits on Im(g_R)

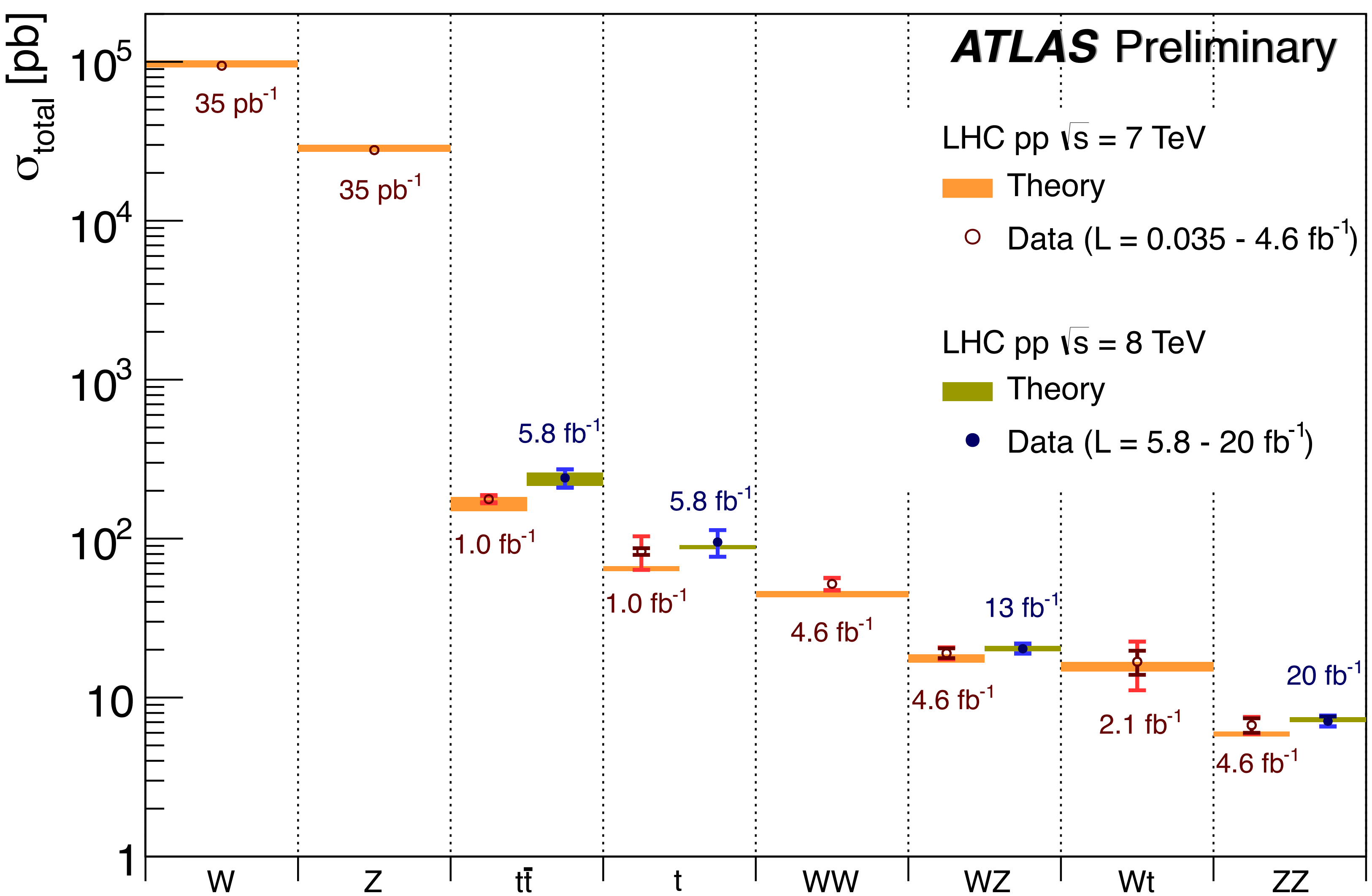
$$[-0.20, 0.30]\ \text{at}\ 95\%\ \text{C.L.}$$

assuming P = 0.9



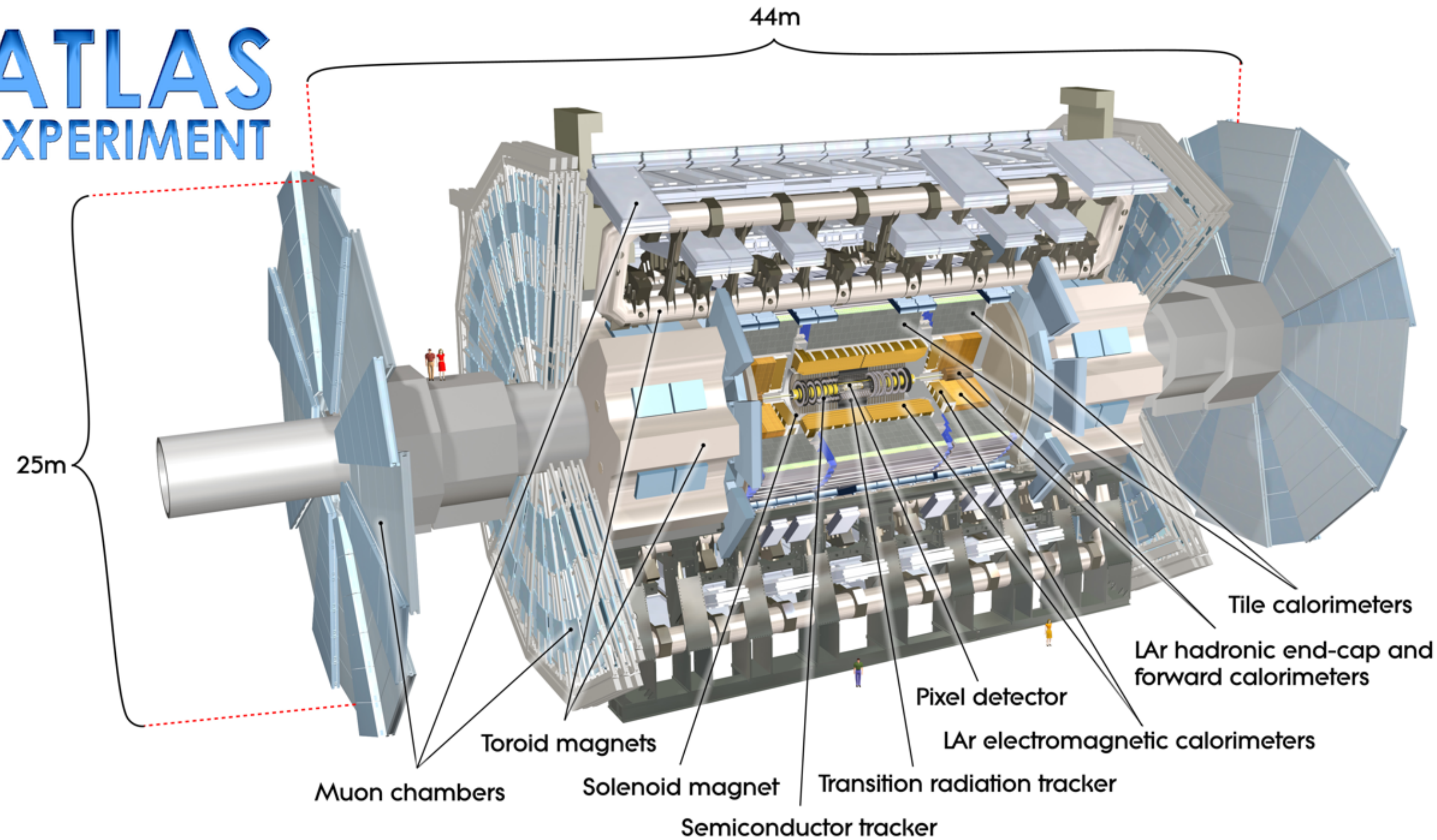
Summary

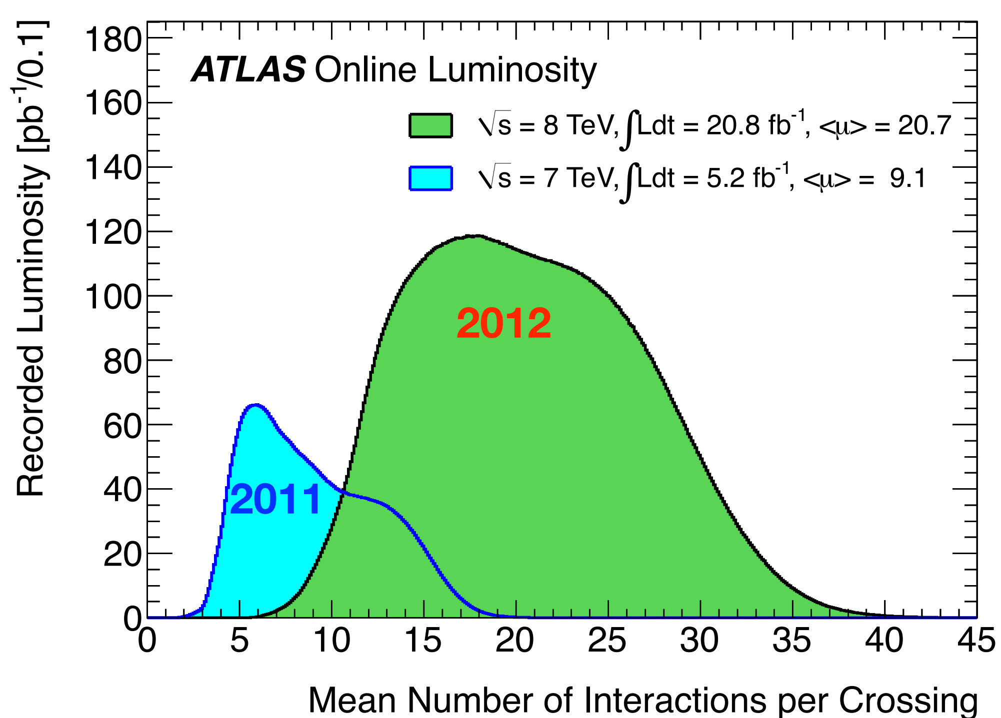
- recent **electroweak** and **top** results from ATLAS
  - diboson cross sections: inclusive systematically dominated, first differential
  - most stringent aTGC limits in many channels
  - top: precision measurements of cross sections and properties
- no significant deviations from Standard Model found
- many measurements yet to be repeated with 8 TeV dataset
- crucial milestones in understanding Higgs production



BACKUP

Data


44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker


ATLAS Online Luminosity
√s = 8 TeV, ∫Ldt = 20.8 fb⁻¹, <μ> = 20.7
√s = 7 TeV, ∫Ldt = 5.2 fb⁻¹, <μ> = 9.1
2012
2011
Recorded Luminosity [pb⁻¹/0.1]
Mean Number of Interactions per Crossing
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40
45

Fiducial and total cross sections

measure **fiducial** and **total** cross sections

$$\sigma_{fid} = \frac{N_{obs} - N_{bkgd}}{\mathbf{C} \times \int \mathcal{L}dt}$$

efficiency corrections
(reconstruction, trigger, ...)

$$\sigma_{tot} = \frac{\sigma_{fid}}{\mathbf{A} \times BR}$$

acceptance
(extrapolates to full phase space)

define **fiducial** cuts

- as close as possible to analysis cuts but using final state "truth" objects
- to reduce extrapolation to phase space regions with large theoretical uncertainties

$$C = \frac{N^{\text{Pass Reco Cuts}}_{\text{MC Reco}}}{N^{\text{Pass Fid Cuts}}_{\text{MC Truth}}}$$

corrects for efficiencies and geometric acceptance

- includes selection, trigger and reconstruction efficiency
- includes data/MC corrections
- defines fiducial cross section

$$A = \frac{N^{\text{Pass Fid Cuts}}_{\text{MC Truth}}}{N^{\text{All}}_{\text{MC Truth}}}$$

extrapolates from fiducial to full phase space

- extends kinematic cross section beyond kinematics selection
- defines inclusive cross section

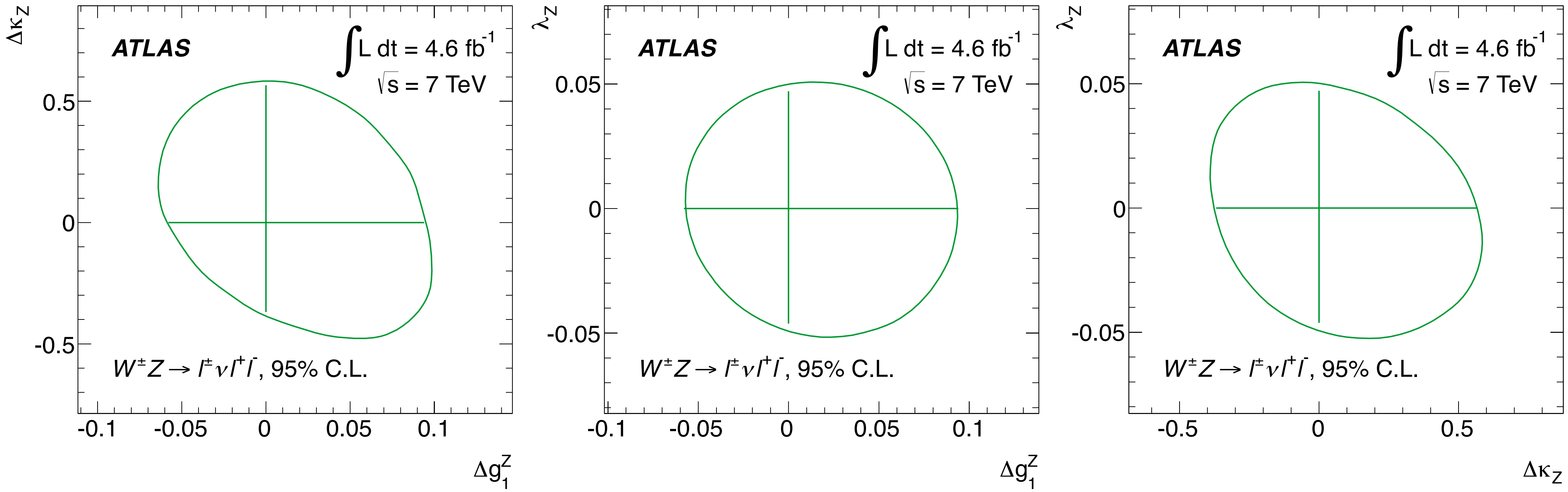
7 TeV diboson cross sections

Process	L [fb^{-1}]	σ^{tot} [pb]	δ stat	δ syst	δ lumi	σ^{NLO} [pb]	$\delta\sigma^{NLO}$
$W(\rightarrow l\nu)\gamma$	5	**2.77**	± 0.03	± 0.33	± 0.14	**1.96**	± 0.17
$Z(\rightarrow ll)\gamma$	5	**1.31**	± 0.02	± 0.11	± 0.05	**1.18**	± 0.05
$WW\rightarrow l\nu l\nu$	5	**51.9**	± 2.0	± 3.9	± 2.0	**44.7**	+2.1/-1.9
$WZ\rightarrow l\nu ll$	5	**19.0**	+1.4/-1.3	± 0.9	± 0.4	**17.6**	+1.1/-1.0
$ZZ^*\rightarrow llll$/ $ZZ\rightarrow ll\nu\nu$	5	**6.7**	± 0.7	+0.4/-0.3	± 0.3	**5.89**	+0.22/-0.18
$WW/WZ\rightarrow l\nu jj$	5	**72**	± 9	± 15	± 13 (MC stat)	**63.4**	± 2.6

Most cross sections seem to fluctuate ~1σ high but agree individually with SM predictions within uncertainties

More aTGC information

WZ

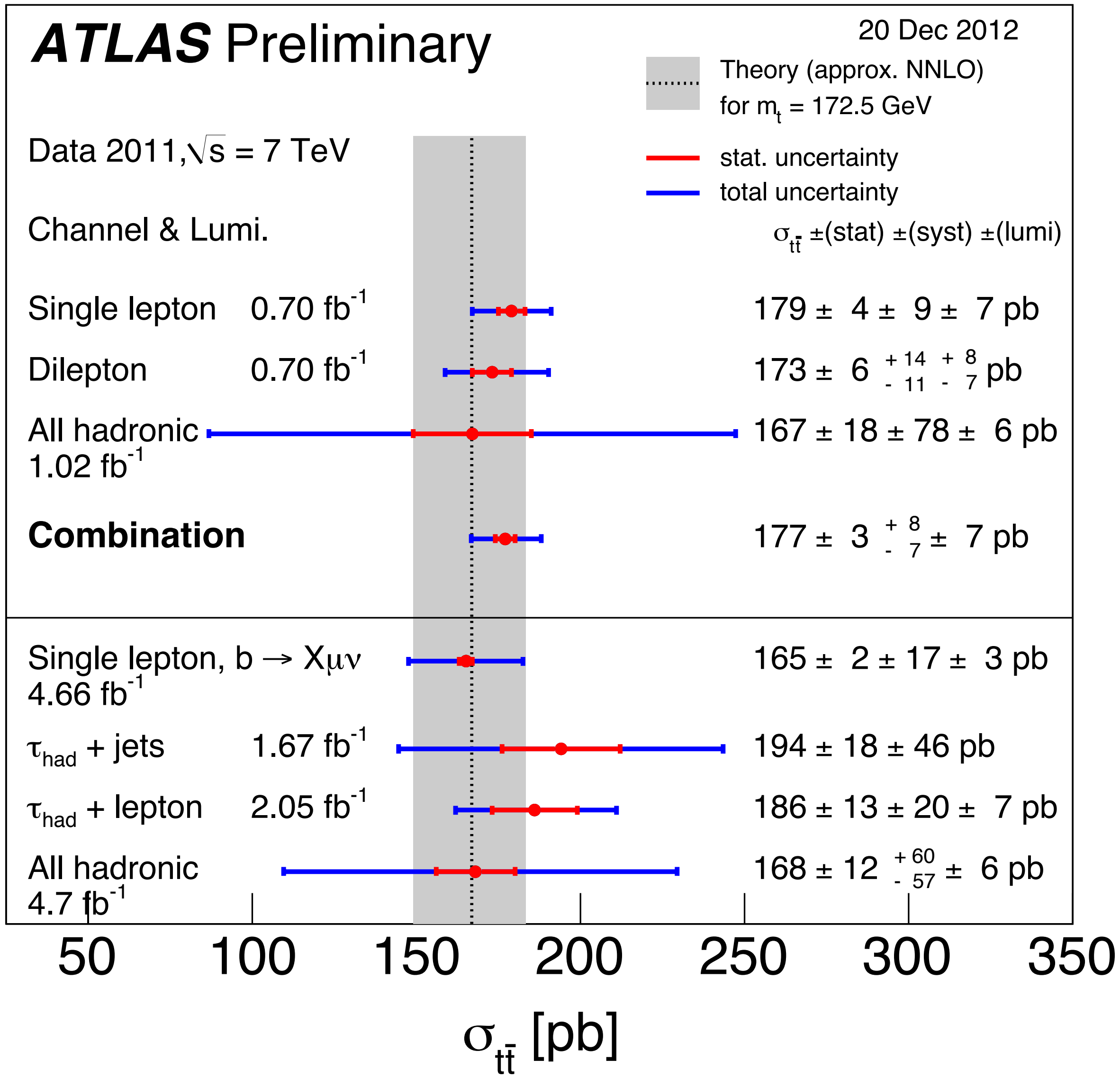


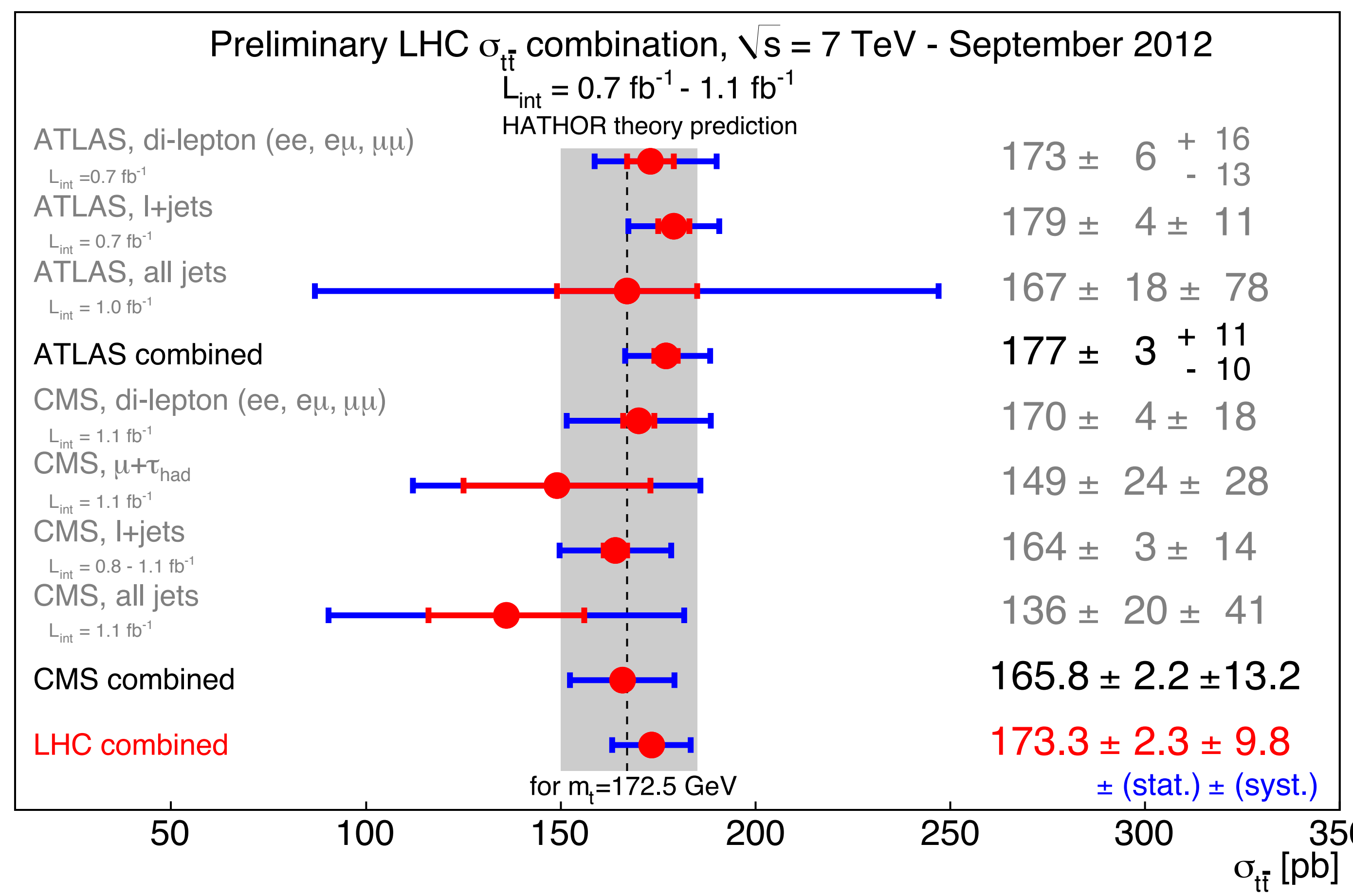
WZ

	Observed $\Lambda = 2$ TeV	Observed no form factor	Expected no form factor
Δg_1^Z	$[-0.074, 0.133]$	$[-0.057, 0.093]$	$[-0.046, 0.080]$
$\Delta \kappa_Z$	$[-0.42, 0.69]$	$[-0.37, 0.57]$	$[-0.33, 0.47]$
λ_Z	$[-0.064, 0.066]$	$[-0.046, 0.047]$	$[-0.041, 0.040]$

Coupling	C	P	CP
g^V_1	✔	✔	✔
κ^V	✔	✔	✔
λ^V	✔	✔	✔
f^V_4	✘	✔	✘
f^V_5	✘	✘	✔
h^V_3	✔	✔	✔
h^V_4	✔	✔	✔

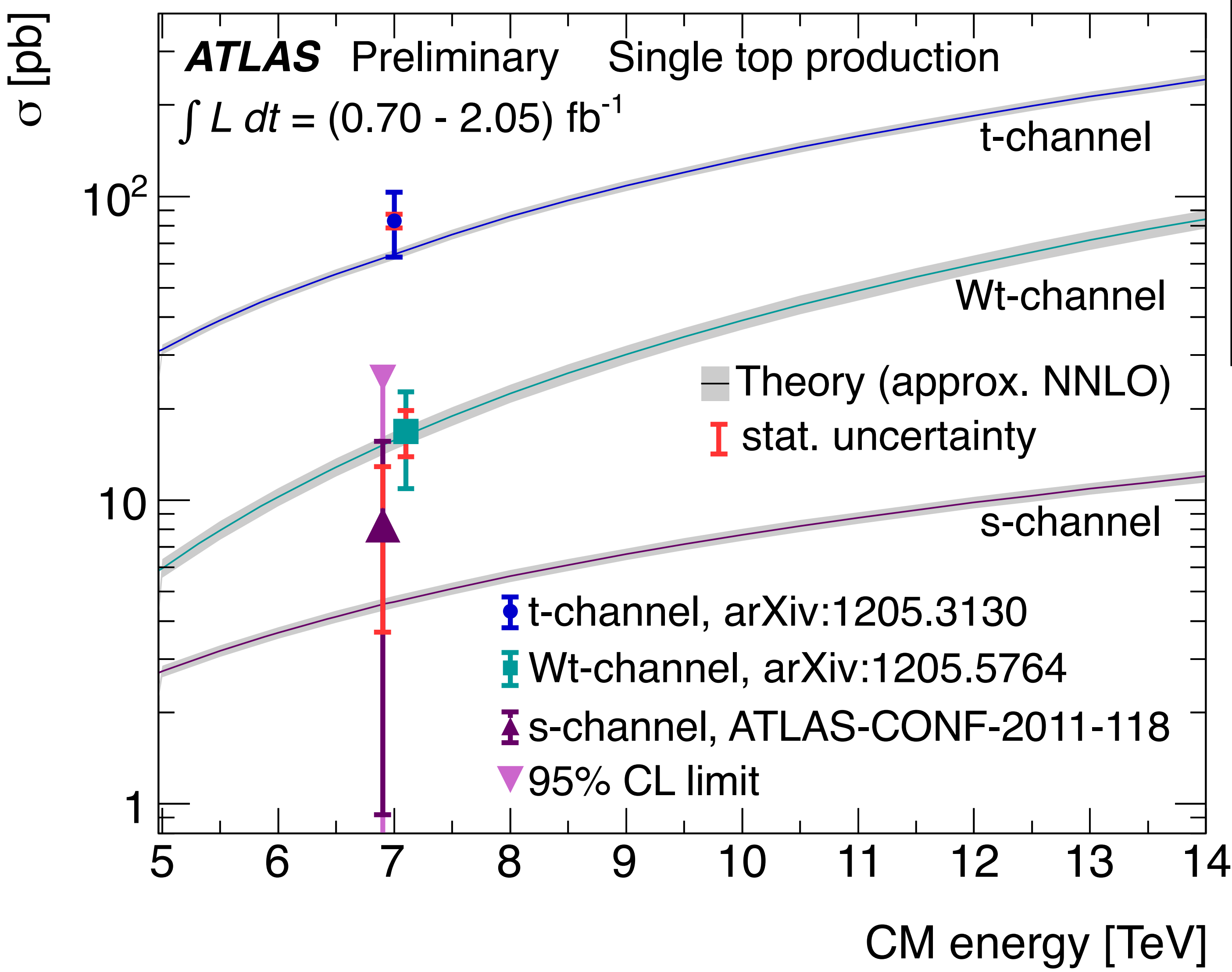
Top pair cross section

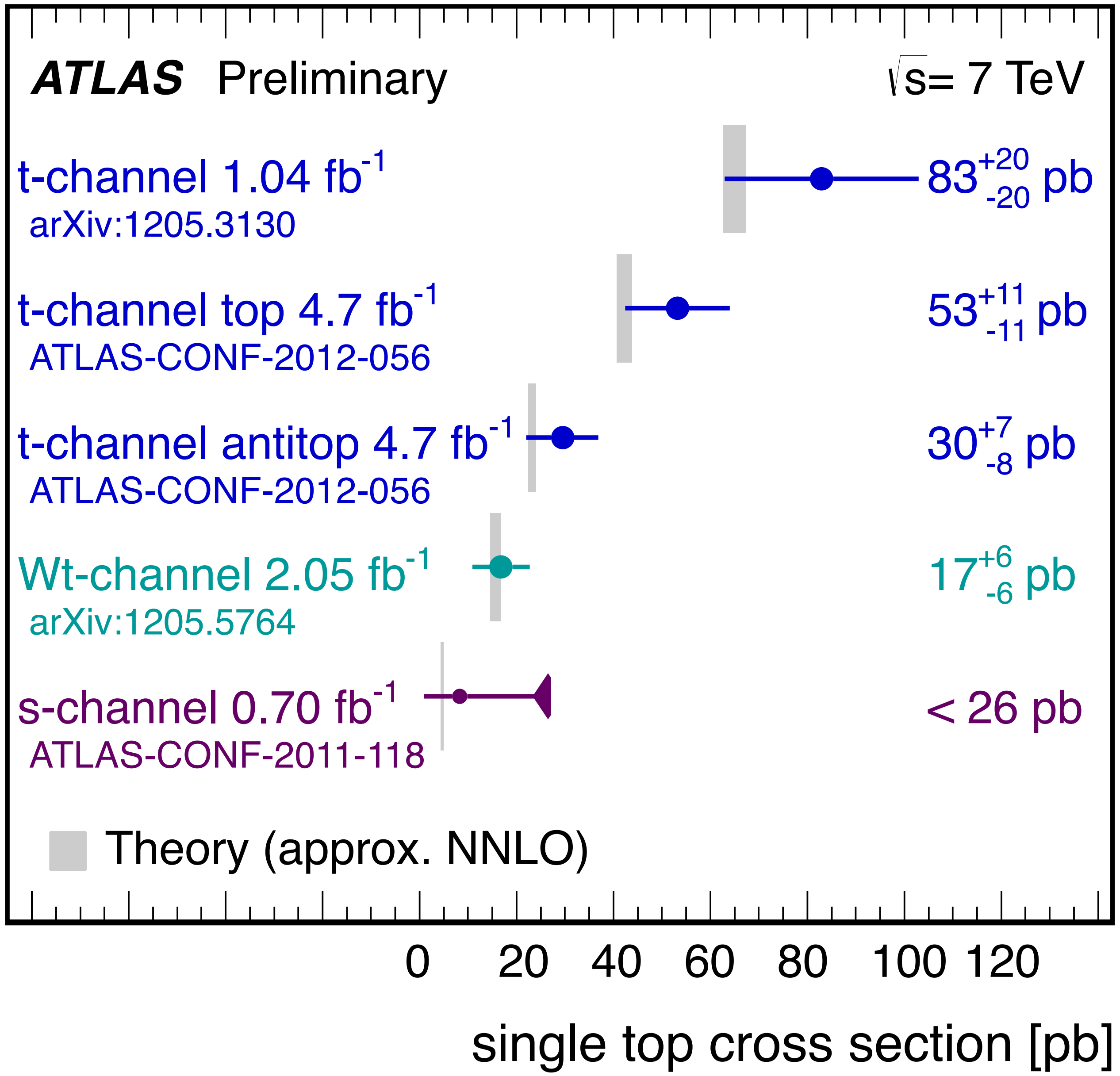




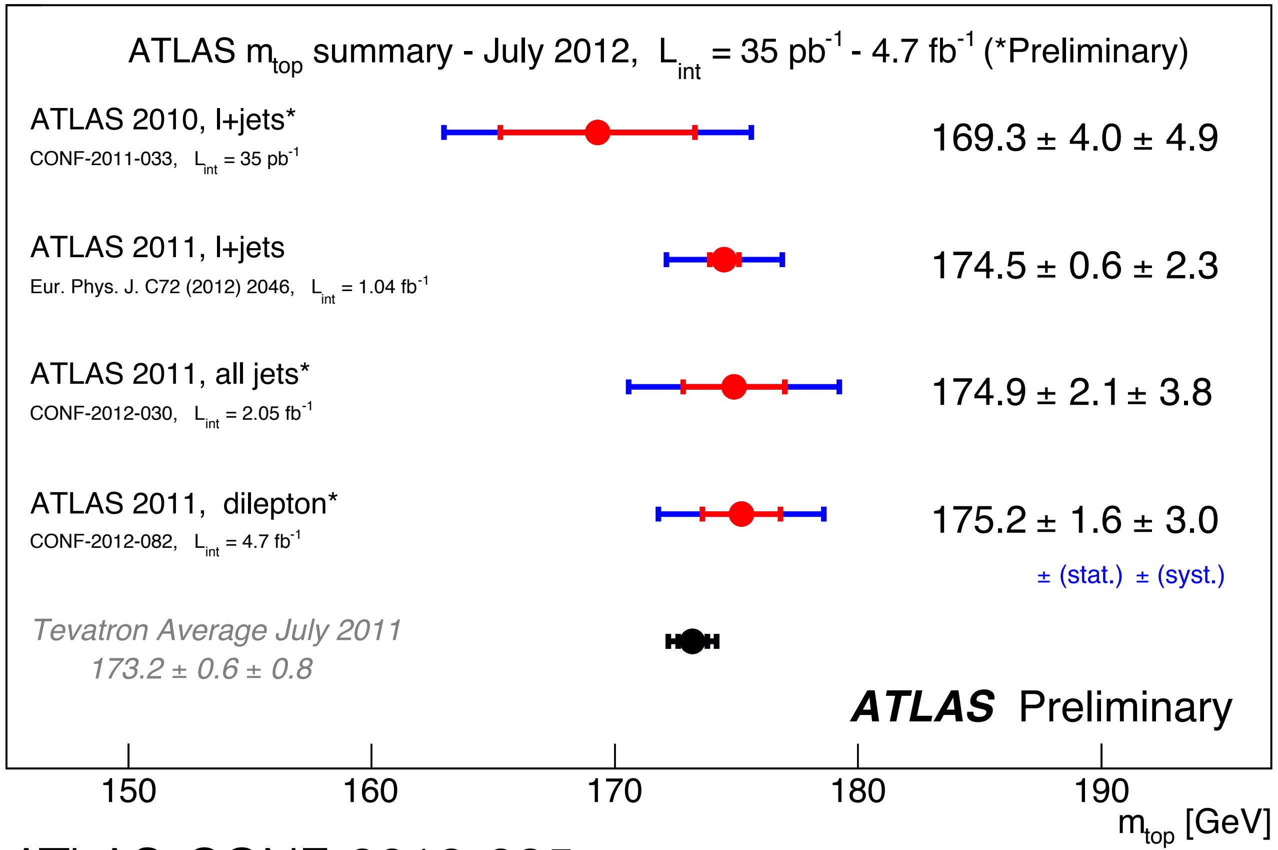
7 TeV

Single top cross section





Top mass



ATLAS-CONF-2012-095