Dibosons production WW, WZ, ZZ in ATLAS

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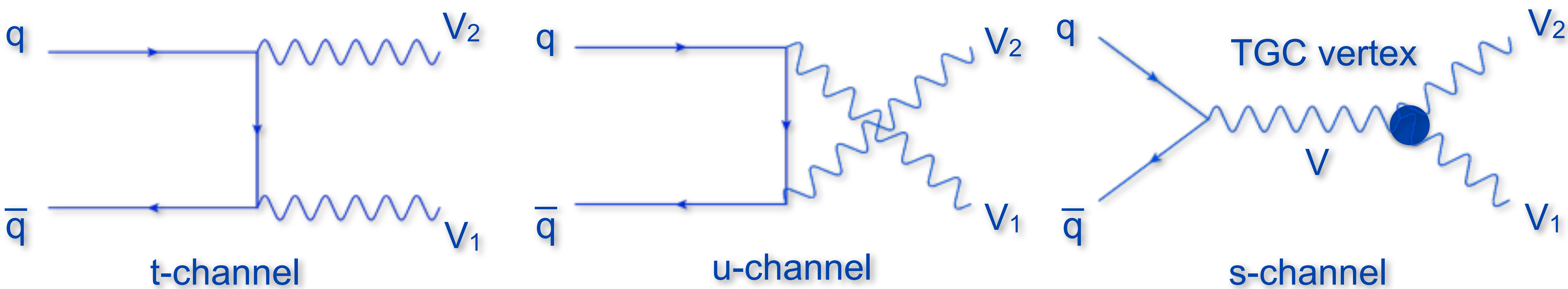
LHC France, Annecy 2013

3 April 2013

Outline

- Introduction and physics motivation
- Dibosons Analyses Overview
  - WZ $\longrightarrow \ell\nu\ \ell\ell$
  - WW $\longrightarrow \ell\nu\ \ell\nu$
  - ZZ $\longrightarrow \ell\ell\ \ell\ell$
- anomalous TGC measurements
- Conclusions and plans

Introduction and physics motivation



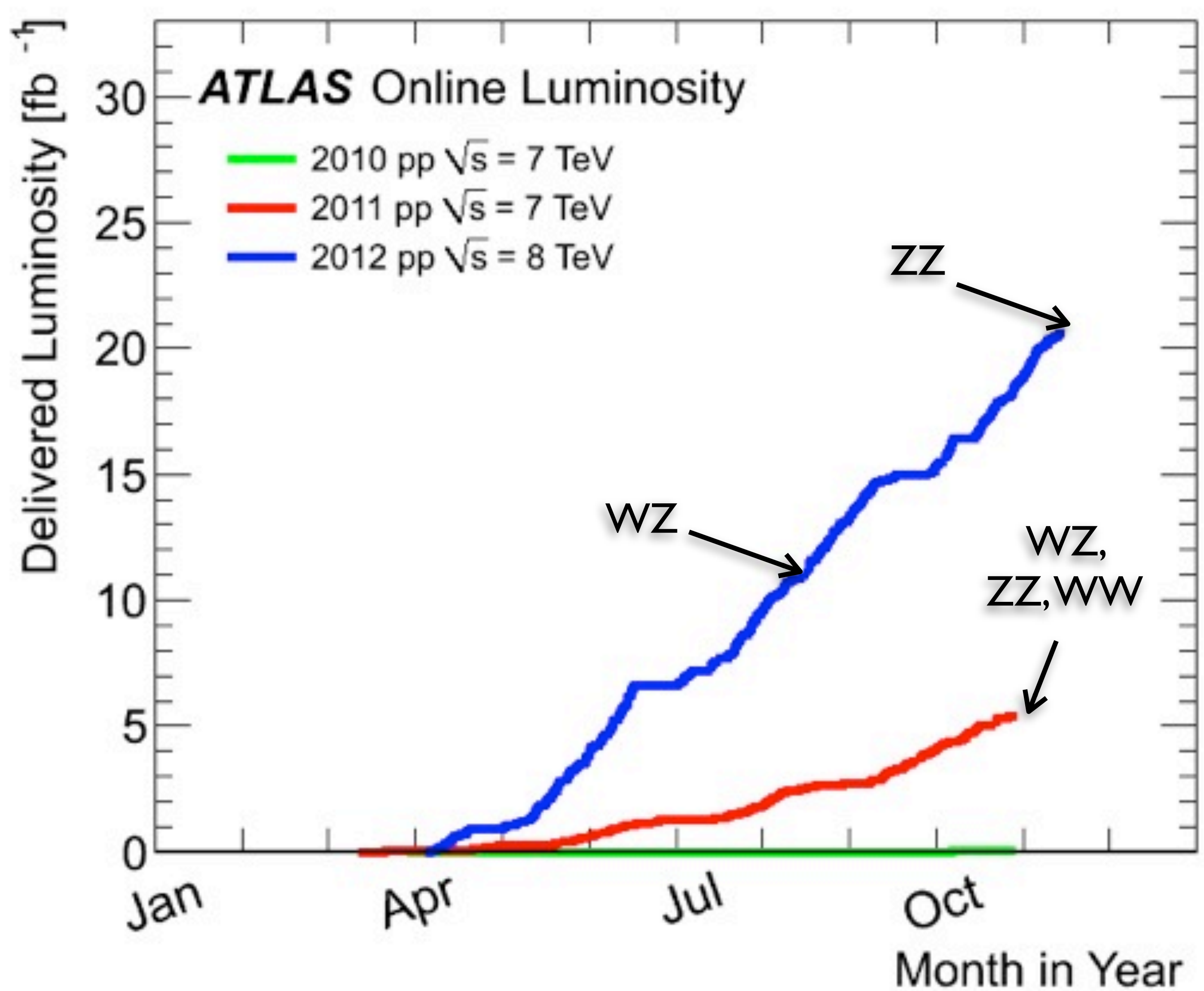
- Di-Boson production cross-sections and couplings at the triple gauge-boson vertices are precisely predicted by SM
  - WWγ and WWZ vertices are predicted and have been measured
  - ZZγ, Zγγ, γγγ and ZZZ vertices are forbidden (Henso's talk)
  - Provide direct test of SM predictions
- The presence of new physics :
  - anomalous Triple Gauge Couplings (aTGC) and exotics resonances.
  - Modify cross-sections and kinematic distributions
- Di-Bosons are also irreducible background to the Higgs boson measurements.

Introduction (I)

- Today's menu Dibosons measurements performed with :

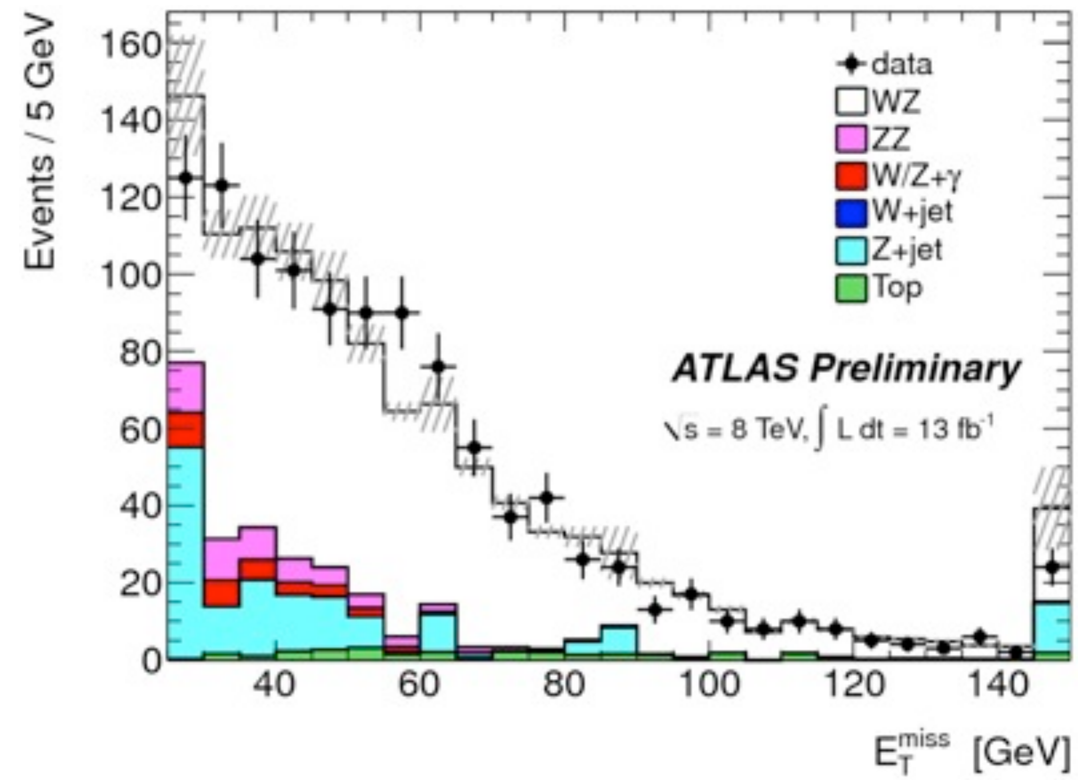
  7 TeV data (4.6 fb^{-1})
  - WW, WZ, ZZ

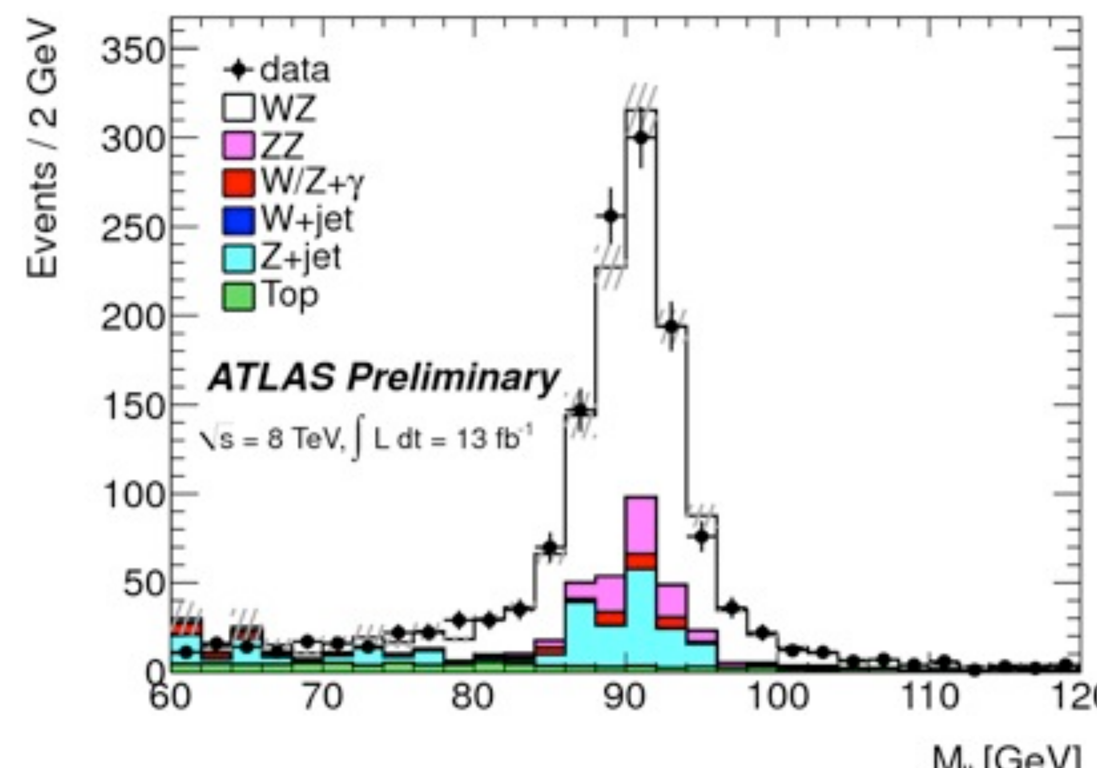
  8 TeV data
  - 13 fb^{-1} WZ
  - 20 fb^{-1} ZZ
- Fully leptonic decay channels allow
  - clean signal, small branching ratio
  - low background
- Common signature :
  - high p_T leptons,
  - missing energy (E_T^{miss}) when ν is present.



Common signatures and selections:

- **Leptons** (electrons, muons) :
  - Single lepton trigger.
  - High-p_T leptons > 7 - 20 GeV in a geometrical acceptance $|\eta| < 2.7(\mu), < 2.47(e)$
  - Calorimeter and track isolation used.
- When a $\boldsymbol{W \rightarrow l\nu}$ is involved :
  - Large E_T^{miss} cuts to account for the neutrino, cuts starting at $E_T^{miss} > 25$ GeV
- When a $\boldsymbol{Z \rightarrow ll}$ is involved :
  - Invariant mass close to the Z PDG mass within 10 to 25 GeV.





Common Backgrounds

- ☐ Dibosons processes make background to each other $\longrightarrow$ estimated mainly from MC (Powheg, Pythia, Sherpa, MC@NLO)
- ☐ Top (single top and $\bar{t}t$) or W/Z+jets mimics diboson final states:
  - Real leptons from Z or W decays
  - Lepton(s) from heavy flavor decays
  - Jet mis-identified as an electron or a photon
- Use data driven methods, since fragmentation functions are difficult to model.

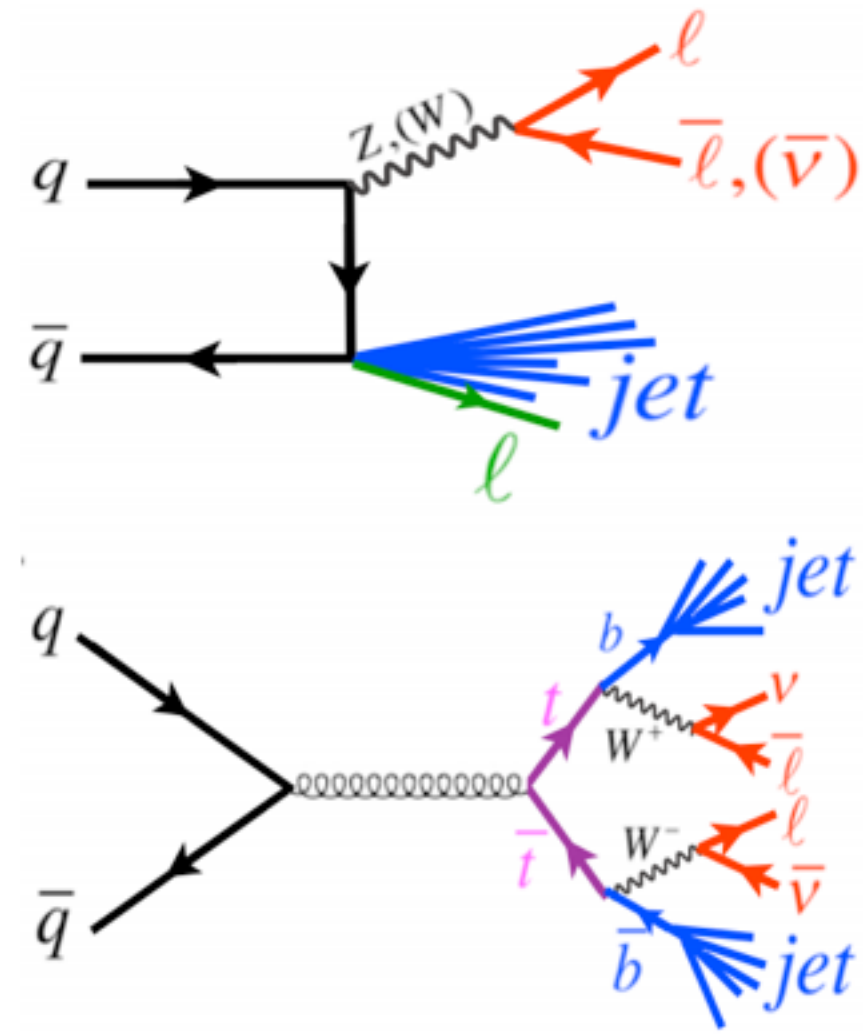


Figure : Feynman diagrams for Z/W+jets (top) and $\bar{t}t$ (bottom) decays

Data Driven Methods (I)

- Data-driven techniques are used for backgrounds containing jets.
- The concept is to build background enriched Control Regions (CR) by reversing analysis cuts (ex. isolation, E_T^{miss}, impact parameter significance)
- The background is extrapolated from the control region to the signal region using a transfer factor.
- Different methods (ABCD, Fake factor, Sideband fit, μeμ Control region, matrix method) and CR definitions depend on the analysis.

Example :

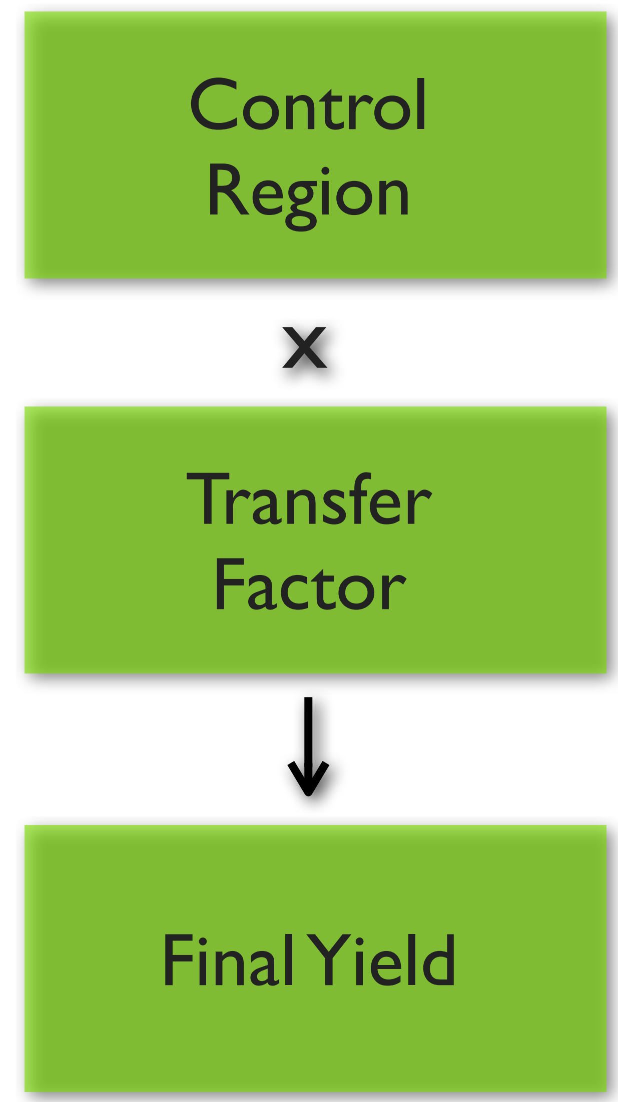


Figure : Data Driven principle. A Control Region enriched with background is built the amount of background in this region is estimated. Then Transfer Factor from the CR to the Signal Region is defined, and used to estimate the Final Yield.

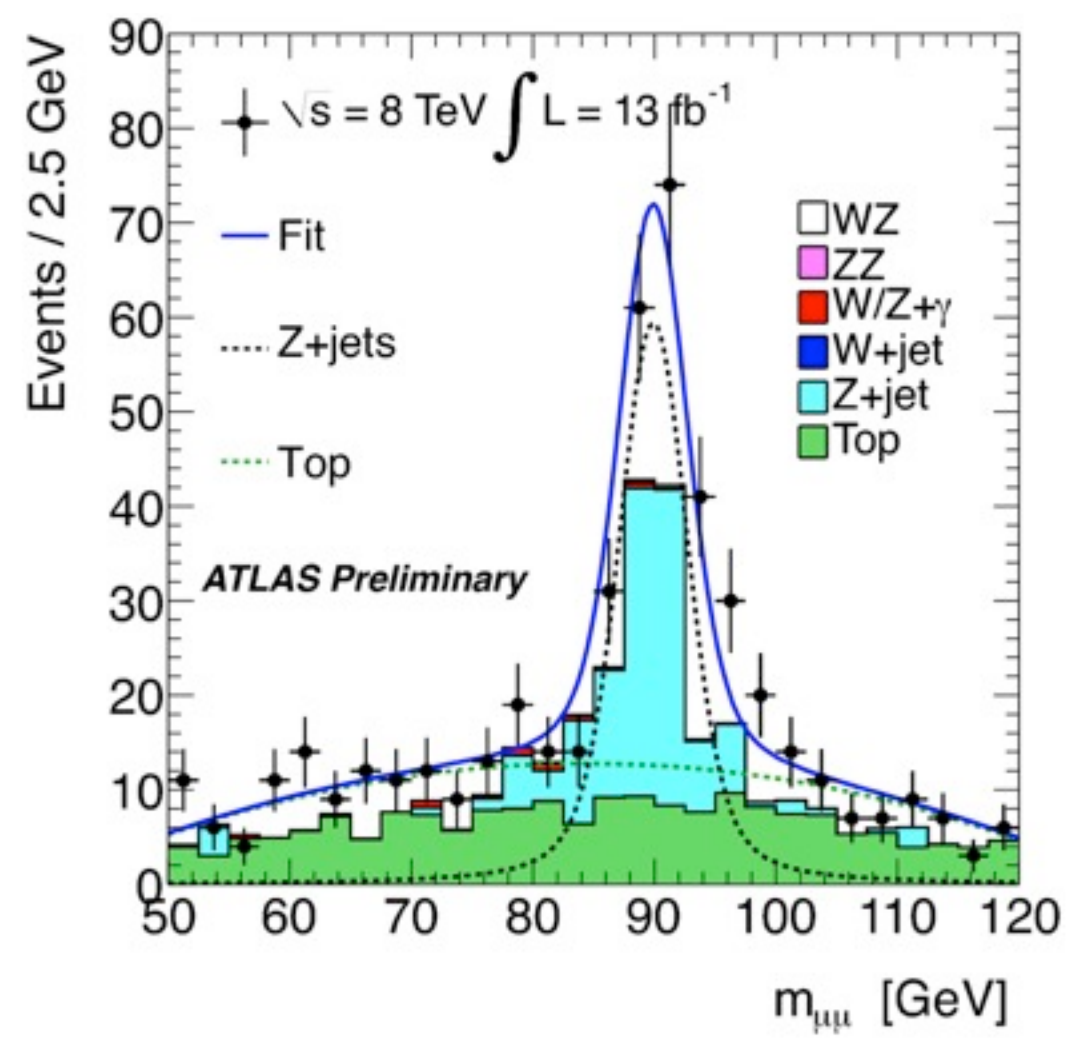
Data Driven Methods (II)

Sideband fit method example : For WZ analysis

- Define a **Control Region**, enriched with $\bar{t}t$ and Z+jets
  - Same Z requirement (except mass window cut).
  - On the W lepton no isolation cut, and reverse the d0 significance cut.
- On this region we will fit the data using :
  - for the $\bar{t}t$ a second order Chebychev polynomial.
  - For the Z+jet a BW line-shape convoluted with a Gaussian resolution.
- To extrapolate to the signal region we use, the **Transfer Factor** extracted from MC :

$$f_{\mathrm{transfer}} = \frac{N_{SR}}{N_{CR}}$$

$$f_{\mathrm{transfer}} = \frac{\epsilon_{iso} \times \epsilon_{d_0}}{(1 - \epsilon_{d_0})}$$



Cross Section

- Measure a cross section within the fiducial region.

$$\sigma^{fid} = \frac{N_{\rm data} - N_{\rm bg}}{C \cdot \int L dt}$$

efficiency corrections

N_{data} = Number of data events
N_{bg} = Number of background events either from MC or data driven methods
L = Luminosity
BR = Branching Ratio

$$C = \frac{N^{\rm MC\ Reconstructd}_{\rm evts\ passing\ the\ cuts}}{N^{\rm MC\ Fidutial\ volume}_{\rm evts\ generated}}$$

  - The fiducial volume is defined by the limited coverage of our detector (η cut) and is even more reduced when we apply our selection cuts (leptons p_T, dR(l,l)).

- Then we extrapolate to the full phase space so we have a total cross section

$$\sigma^{tot} = \frac{N_{\rm data} - N_{\rm bg}}{A \cdot C \cdot \int L dt \cdot BR}$$

acceptance

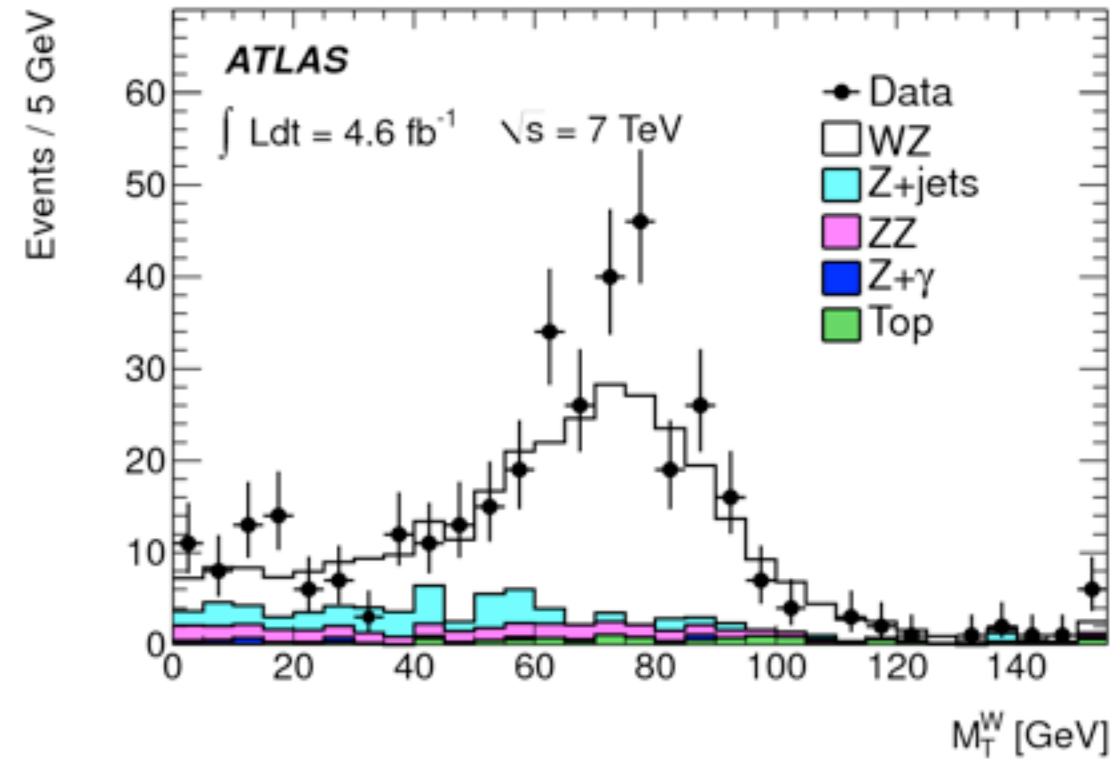
$$A = \frac{N^{\rm MC\ Fidutial\ Volume}_{\rm evts\ generated}}{N^{\rm MC\ All}_{\rm evts\ generated}}$$

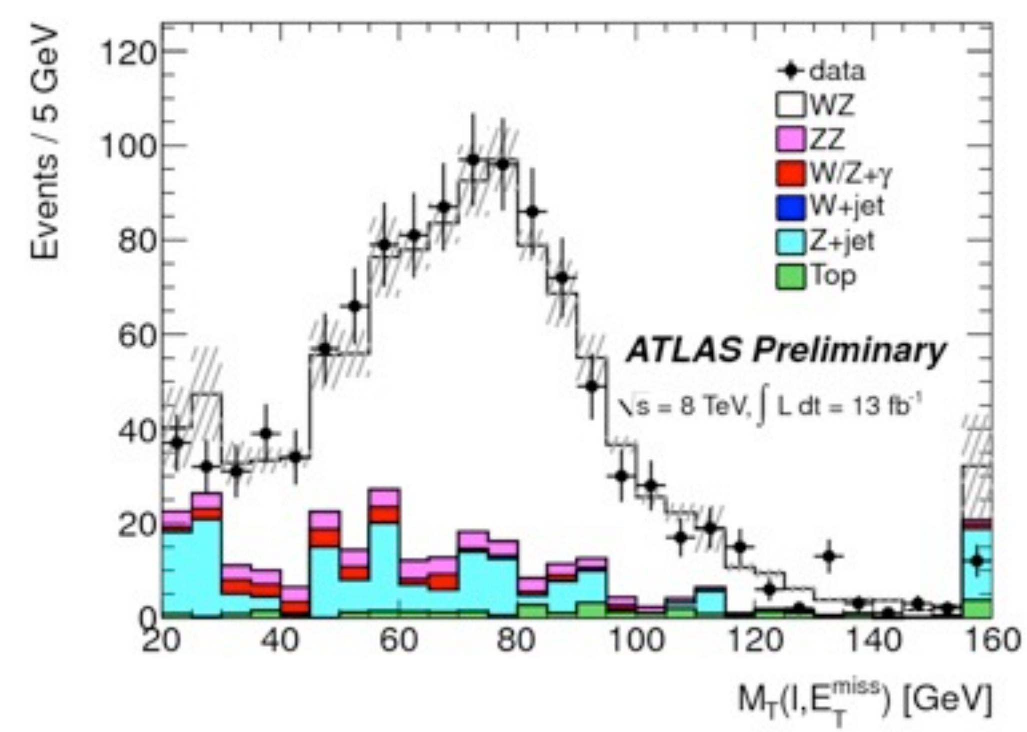
- We also provided unfolded distributions.

$WZ \longrightarrow \ell\nu\ \ell\ell$

4.6 fb^{-1} @7 TeV
13 fb^{-1} @8 TeV

- Two data samples 4.6 fb^{-1} of data at 7 TeV and 13 fb^{-1} of data at 8 TeV
- Selection :
  - 3 isolated leptons, $p_T(l)$ > 15 GeV,
  - Tight Z mass window $|m_{ll} - m_Z|$<10 GeV
  - Tight W lepton ID and isolation requirements
  - W m_T > 20 GeV, large E_T^{miss} > 25 GeV
- Major backgrounds :
  - Z+jets, ZZ, W/Z γ, Top.
  - Z+jets, and Top backgrounds are estimated using data driven methods.
  - ZZ and W/Z γ using MC.





ATLAS-CONF-2013-021
arXiv:1208.1390

$WZ \longrightarrow \ell\nu\ell\ell$ results

4.6 fb^{-1} @7 TeV
13 fb^{-1} @8 TeV

- Measured total cross section at 7 TeV

σ_{WZ} = 19.0 ±1.4(stat) ±0.8(sys)±0.4(lumi) pb

  - Theory

    SM: $\sigma_{WZ} = 17.6^{+1.1}_{-1.0}$ pb

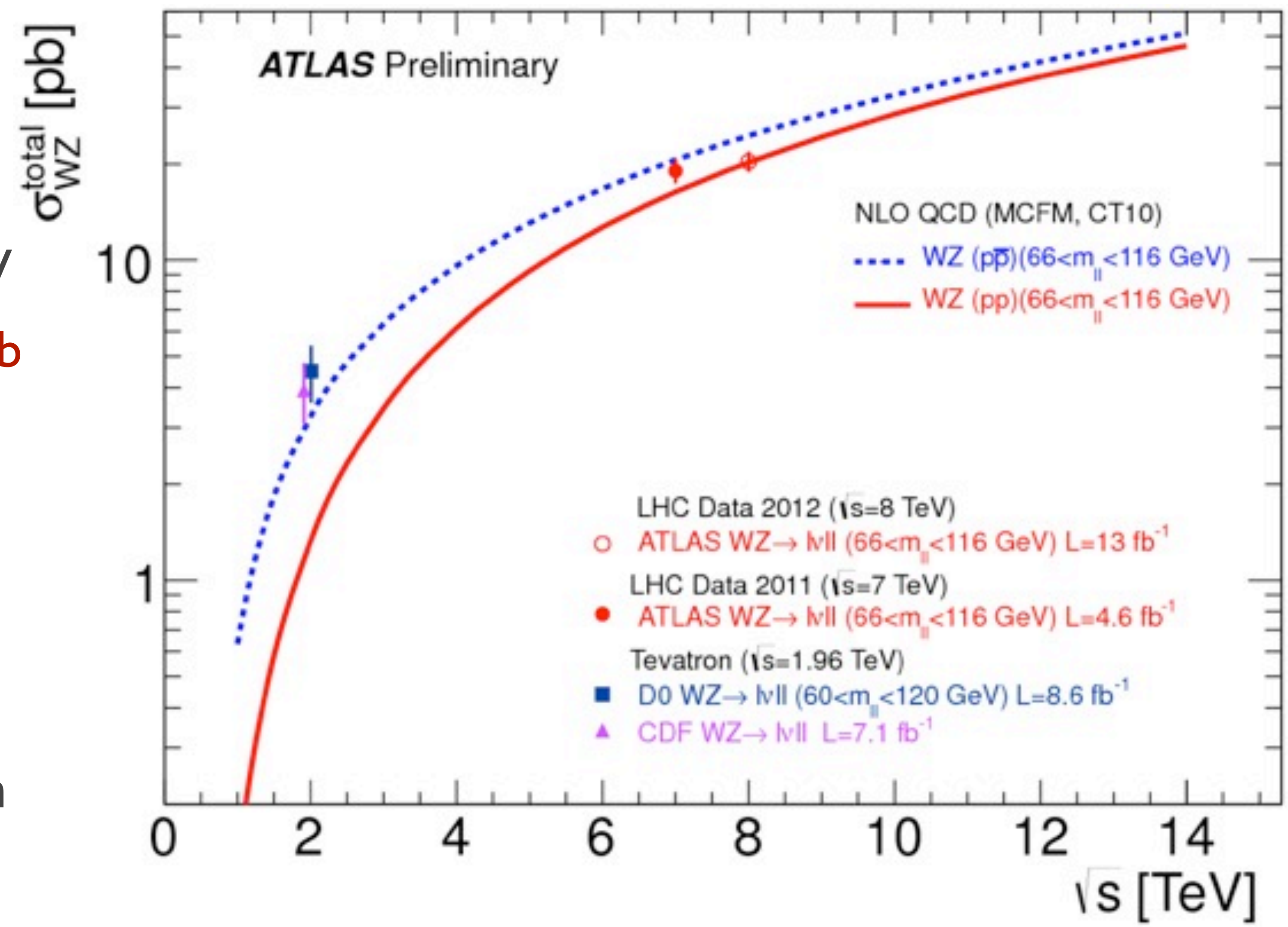
- Measured total cross section at 8 TeV

σ_{WZ} = 20.3 ±0.7(stat) ±1.1(sys)±0.6(lumi) pb

  - Theory

    SM: σ_{WZ} = 20.3 ± 0.8 pb

- Systematic uncertainties became dominant on the 8 TeV analysis. The dominant one is from the data driven background estimation.
- The results are compatible with the SM expectations.



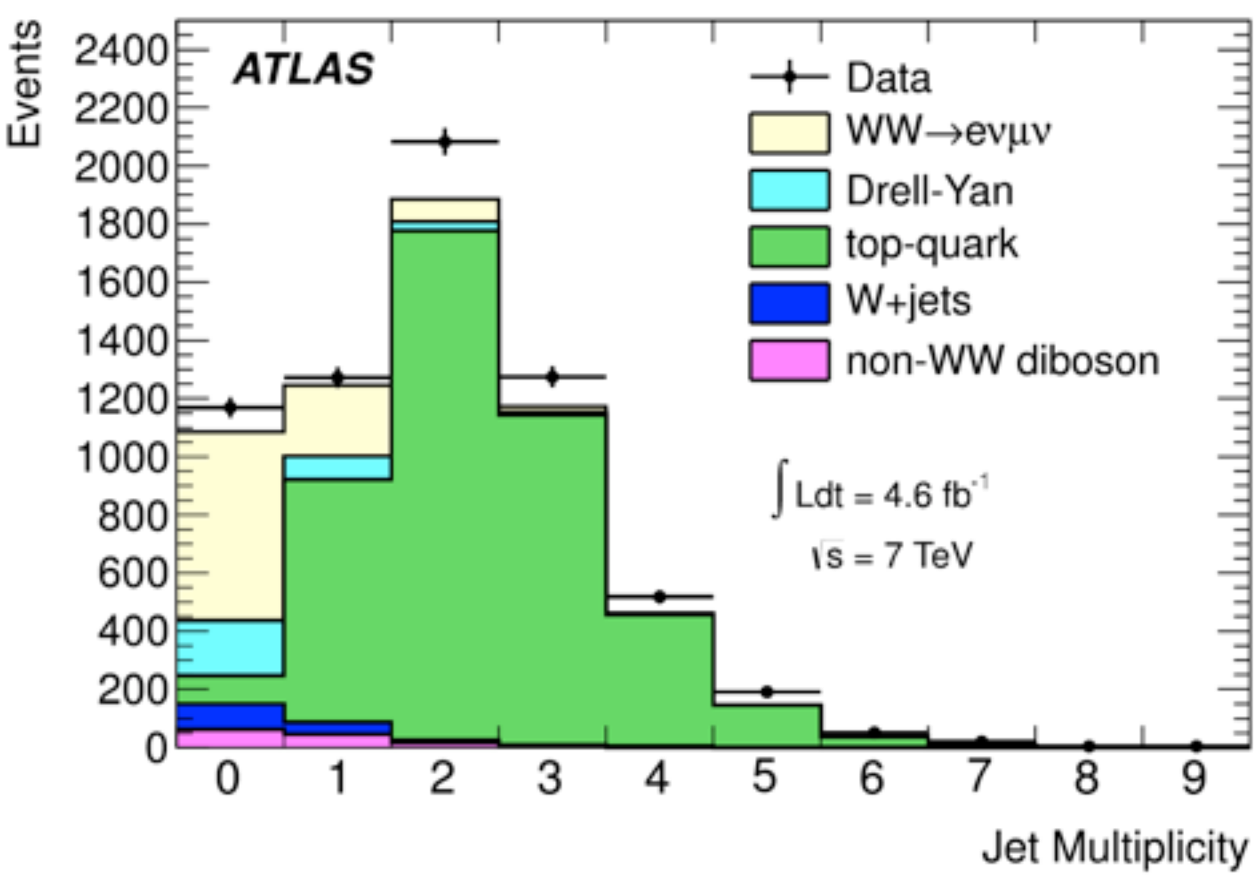
ATLAS-CONF-2013-021

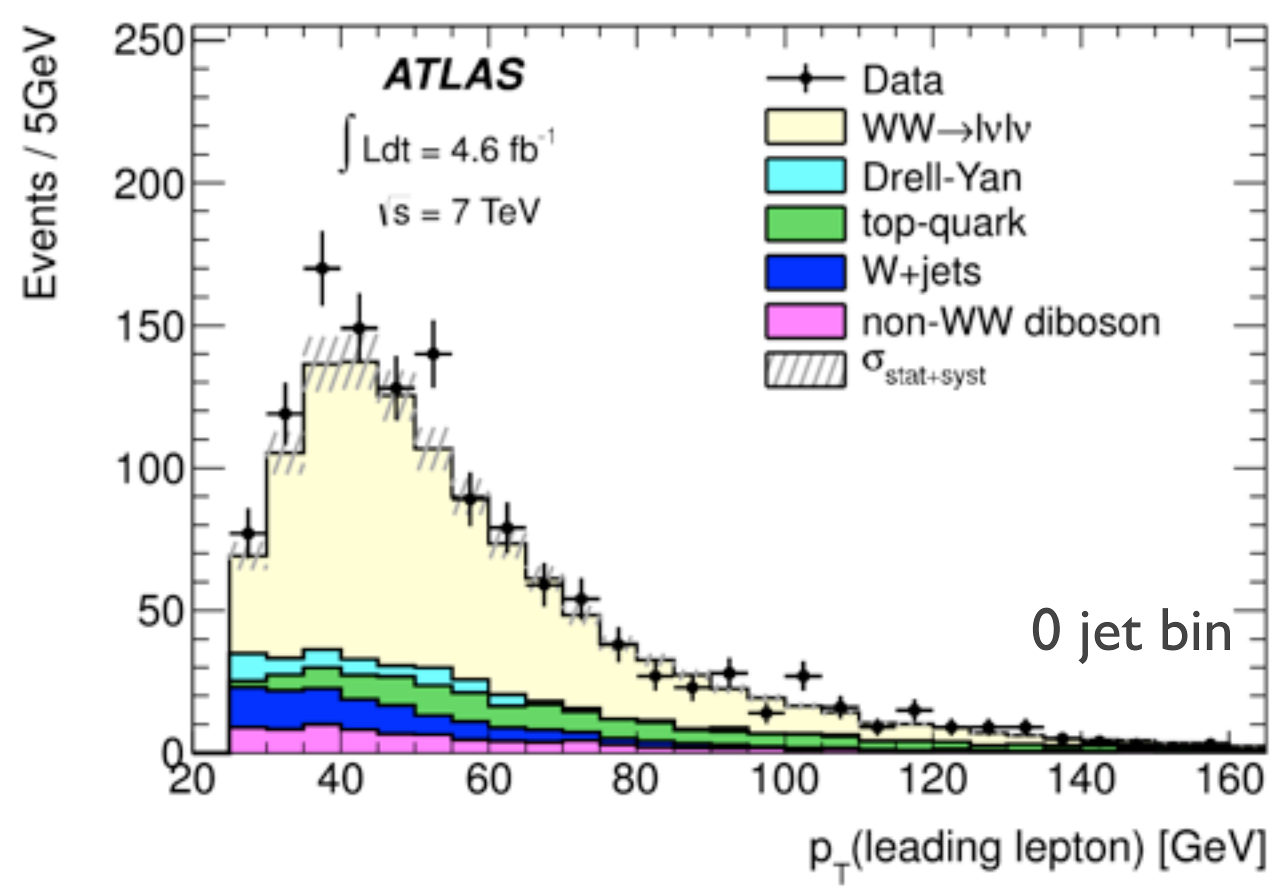
arXiv:1208.1390

$WW \longrightarrow \ell\nu\ \ell\nu$ 4.6 fb^{-1} @7 TeV

[arXiv:1104.5225]

- Selection :
  - Two isolated high p_T leptons.
  - Z veto to suppress Drell-Yan ($|m_Z - m_{ll}| > 15$ GeV)
  - Large E_T^{miss}
  - Jet veto : remove events with jet p_T>25 GeV to reject top-quark background.
- Major backgrounds :
  - Drell-Yan, W+jets, Top.





0 jet bin

$WW \longrightarrow \ell\nu\ \ell\nu$ results 4.6 fb^{-1} @7 TeV

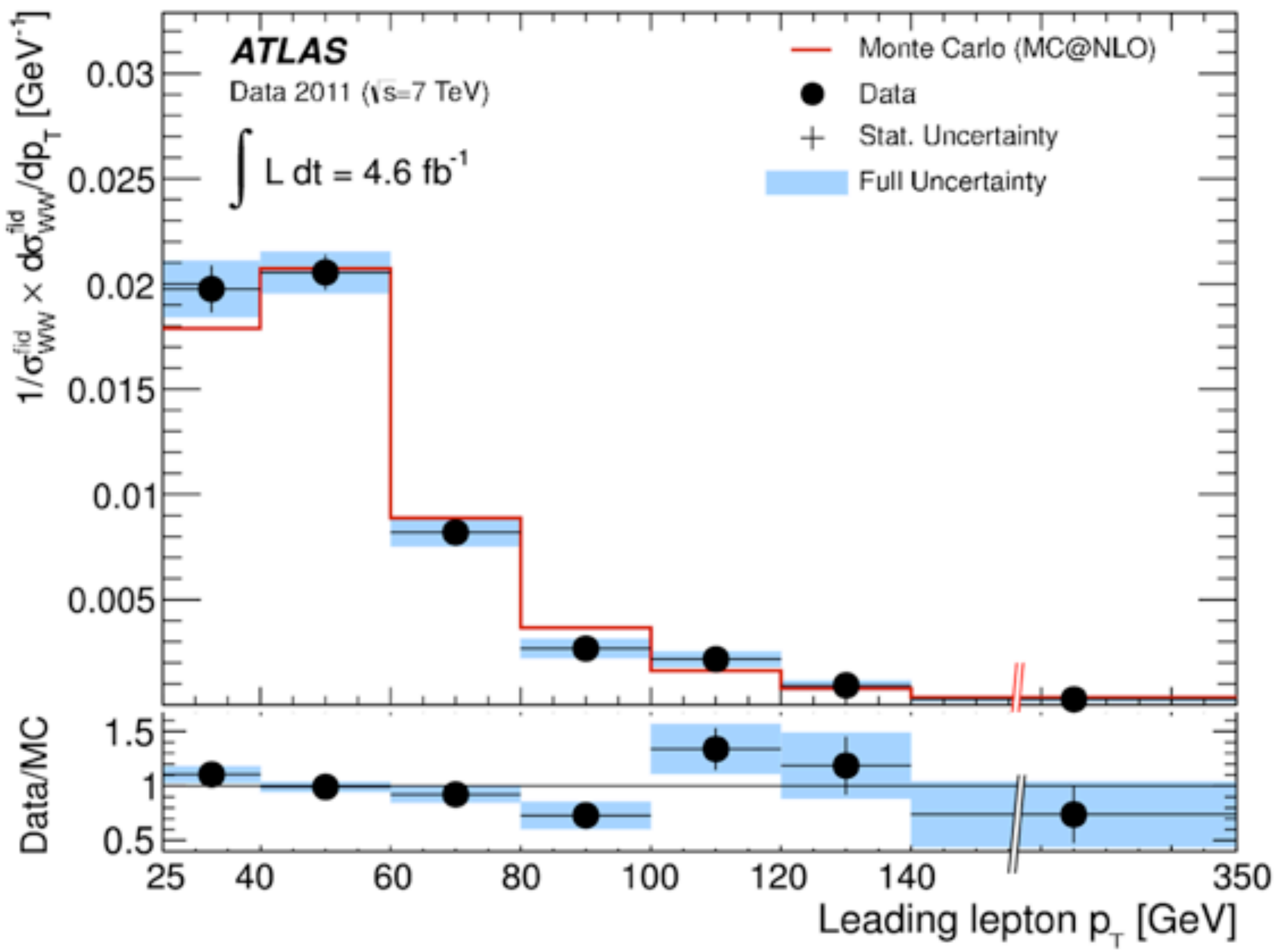
- Measured total cross section

σ_{WW} = 51.9±2.0(stat)±3.9(sys)±2.0(lumi) pb

- Theory

SM: $\sigma_{WW}(NLO) = 44.7^{+2.1}_{-1.9}$ pb

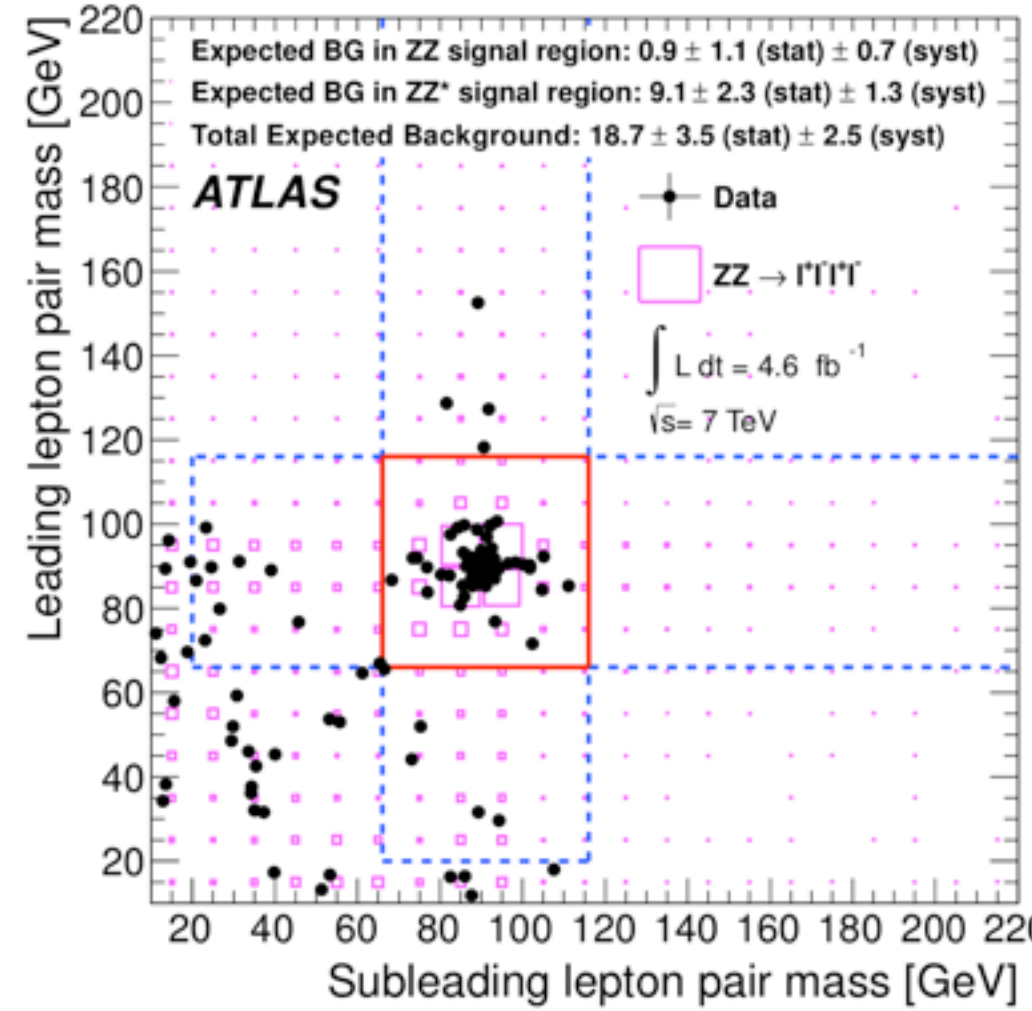
- Measurement slightly higher than theoretical prediction.
- Higgs contribution of the order of 3% (not subtracted in the unfolded distribution)
- Dominant uncertainty jet veto



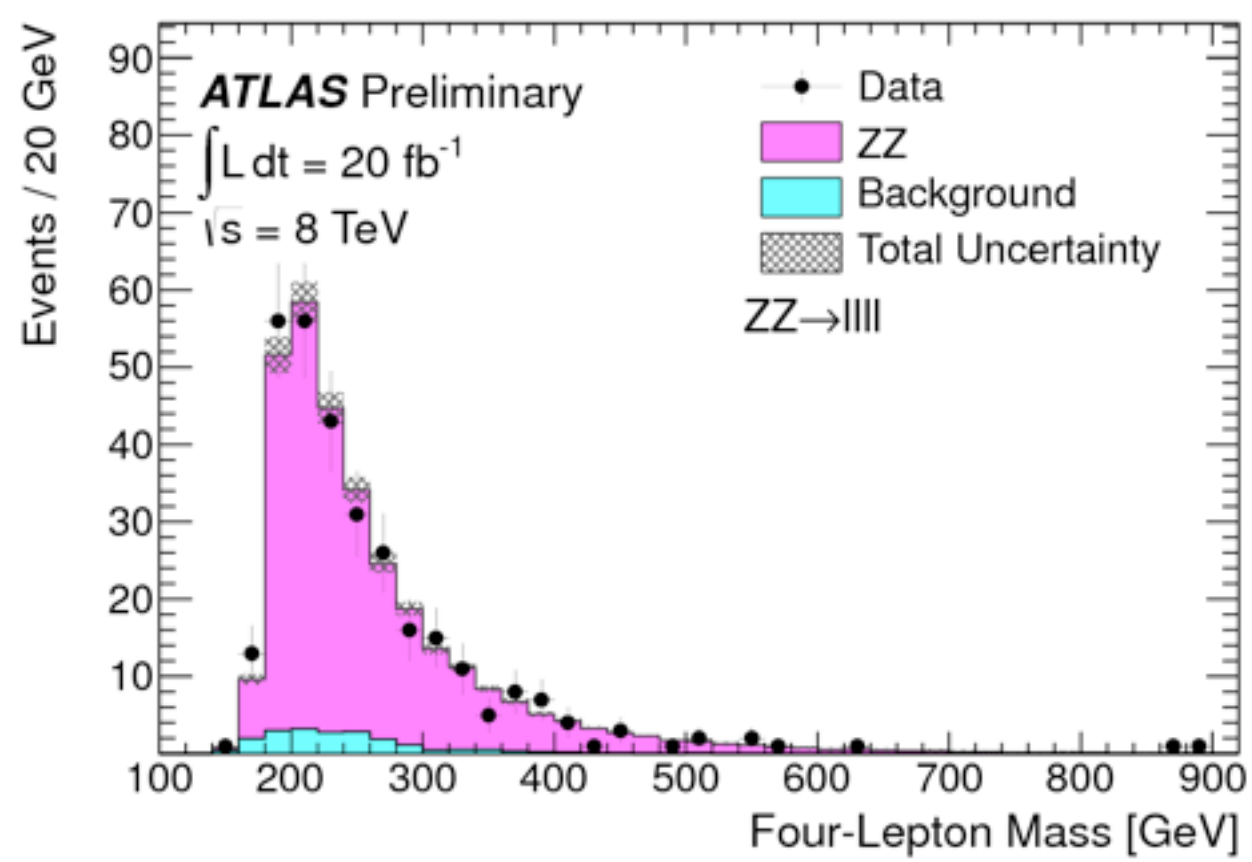
[arXiv:1104.5225]

$ZZ \to \ell\ell\ \ell\ell$

4.6 fb^{-1} @7 TeV
20 fb^{-1} @8 TeV



- Two data samples 4.6 fb^{-1} of data at 7 TeV and 20 fb^{-1} of data at 8 TeV
- Selection :
  - 4 isolated leptons, $p_T(l) > 7$ GeV,
  - leading lepton pT>25/20 GeV(e/μ)
  - $66 < m_{ll} < 116$GeV
- Major backgrounds :
  - Very clean signature backgrounds from W/Z+jets, Top, WW, WZ.
  - All backgrounds estimated using data driven methods.



ATLAS-CONF-2012-026
ATLAS-CONF-2013-020

$ZZ \longrightarrow \ell\ell\ \ell\ell$ results

4.6 fb^{-1} @7 TeV
20 fb^{-1} @8 TeV

- Measured total cross section at 7 TeV

  $\sigma_{ZZ} = 6.7 \pm 0.7(stat)\ ^{+0.4}_{-0.3}(sys) \pm 0.3(lumi)$ pb

  - Theory

    SM: $\sigma_{ZZ} = 5.89^{+0.22}_{-0.18}$ pb

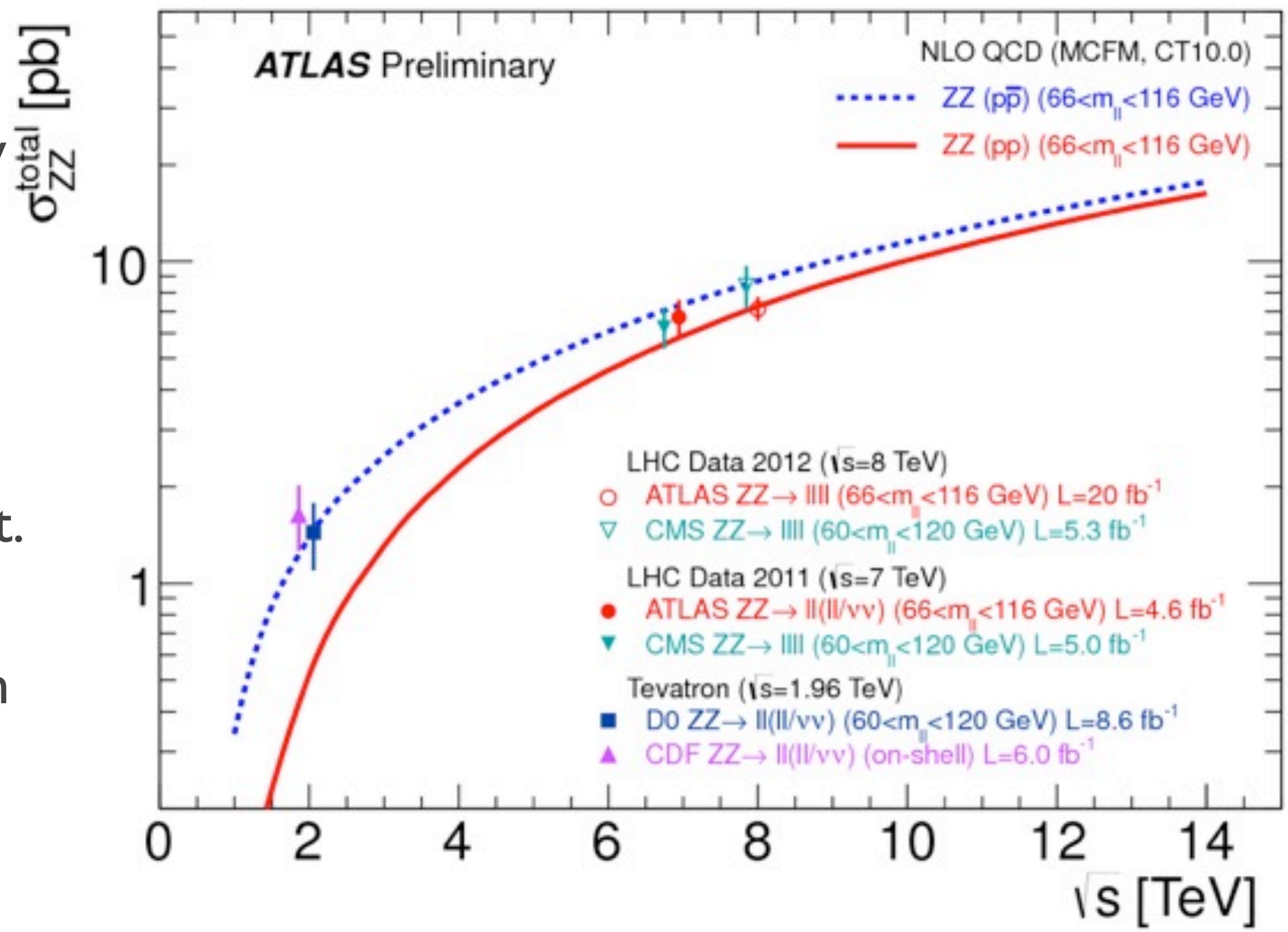
- Measured total cross section at 8 TeV

  $\sigma_{ZZ} = 7.1 \pm 0.4(stat) \pm 0.3(sys) \pm 0.2(lumi)$ pb

  - Theory

    SM: $\sigma_{ZZ} = 7.2 \pm 0.3$ pb

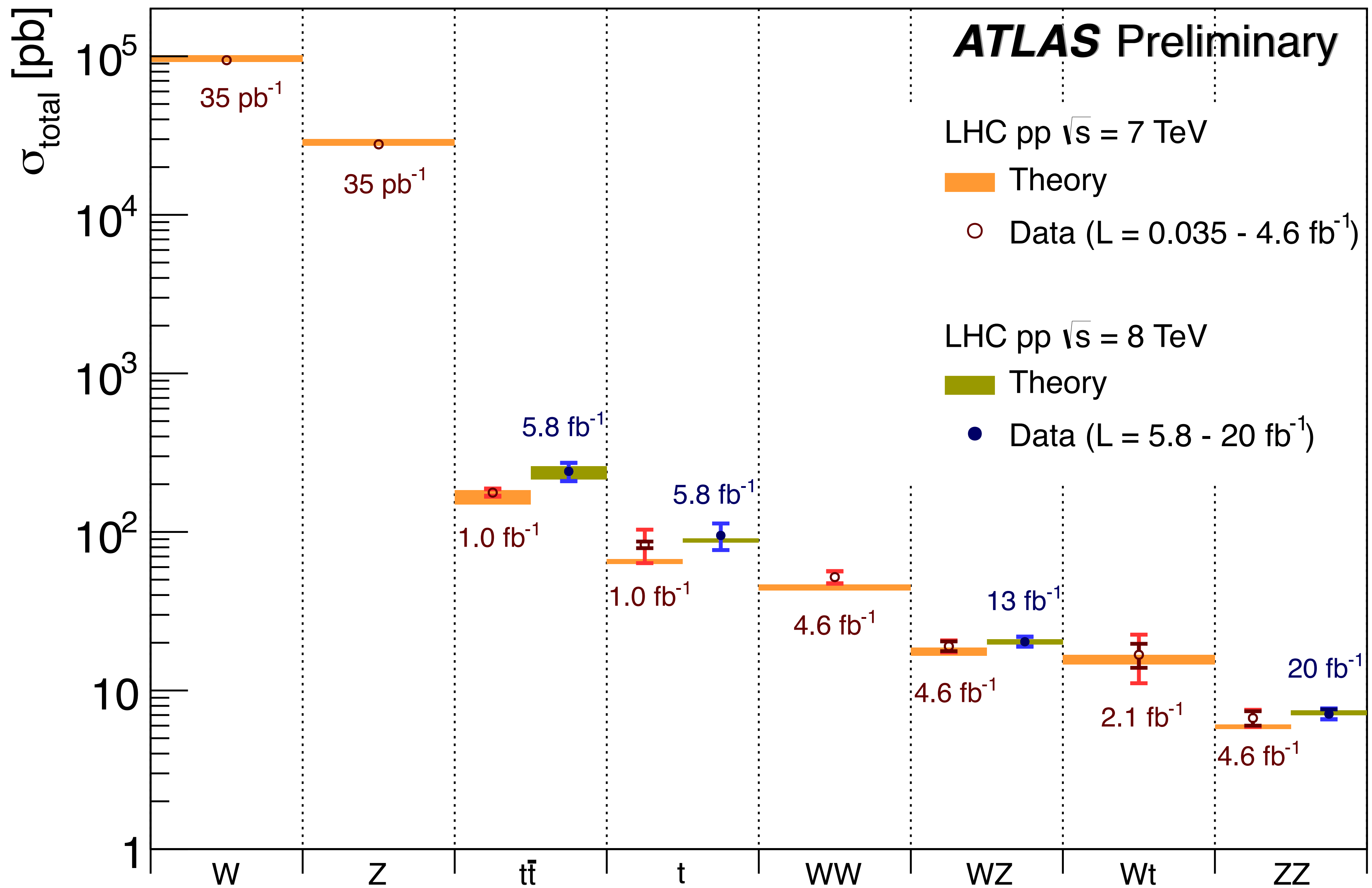
- Statistical uncertainty is still dominant.
- Dominant systematic uncertainty electron ID and muon reconstruction efficiency.
- The results are compatible with the SM expectations.



ATLAS-CONF-2012-026

ATLAS-CONF-2013-020

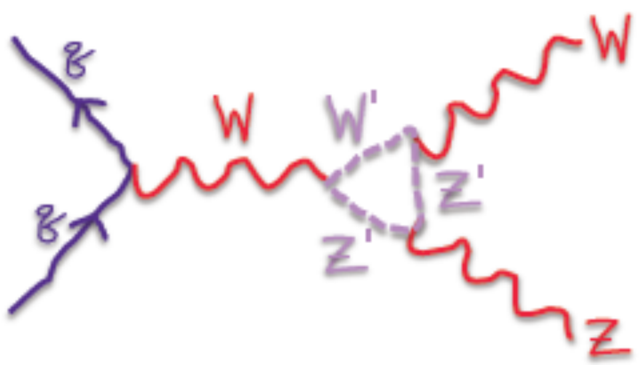
SM total production cross section measurements in Atlas ...



Anomalous couplings (I)

- The effective Lagrangian used to describe the effect of non-SM processes on TGCs depends on a number of parameters (only the ones conserving CP are listed):

coupling	parameters (All = 0 in SM)	channel
$WW\gamma$	λ_γ, $\Delta\kappa_\gamma$	WW, Wγ
WWZ	λ_Z, $\Delta\kappa_Z$, Δg_1^Z	WW, WZ
$Z\gamma Z$	f_{40}^Z, f_{50}^Z	ZZ
ZZZ	f_{40}^γ, f_{50}^γ	ZZ



Example: W', Z' could be SUSY, Technicolor, Higgs...

- In the SM κ_V, g_1^V =1, We look for deviations $\Delta\kappa$, Δg from 1 and λ =0.
- aTGCs modify total production rate as well as event kinematics. So we can use the cross section or kinematics to constrain aTGCs.

Anomalous couplings (II)

Experimentally:

- The aTGCs will modify the total production rate as well as event kinematics.
- We can write the expected number of signal events as a function of the standard model cross sections plus some other terms depending on the aTGC parameters.
- Example on the WZ case :

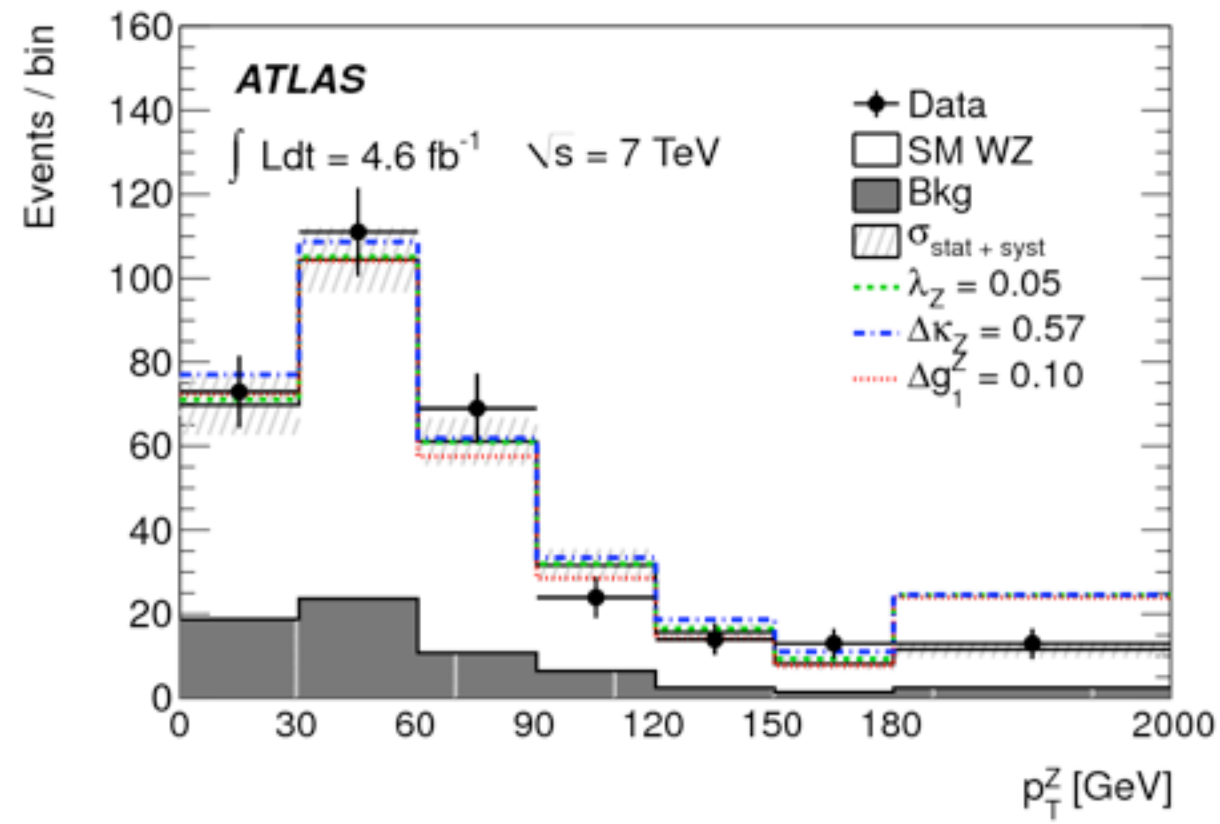
$$N_s^i(\Delta g_1^Z, \Delta\kappa^Z, \lambda^Z) = W_0^i \quad + \quad (\Delta g_1^Z)^2 W_1^i + (\Delta\kappa^Z)^2 W_2^i + (\lambda^Z)^2 W_3^i$$
$$+ \quad 2\Delta g_1^Z W_4^i + 2\Delta\kappa^Z W_5^i + 2\lambda^Z W_6^i$$
$$+ \quad 2\Delta g_1^Z \Delta\kappa^Z W_7^i + 2\Delta g_1^Z \lambda^Z W_8^i + 2\Delta\kappa^Z \lambda^Z W_9^i$$

SM cross section

- We make Maximum likelihood fit leaving some of the aTGC parameter free.
- We make the measurement on p_T^Z. Higher aTGC sensitivity at high p_T^Z (high mass or lepton p_T)
- Form factor defined like :

  $\Delta g(s) = \Delta g/(1+s/\Lambda^2)^2$

  used in old results and for recent we have $\Lambda=\infty$



WZ aTGC limits 4.6 fb^{-1} @7 TeV

- Measurement performed using the Z boson p_T.
- 30GeV bins, with larger last bin [180-2000] GeV
- No significant deviation wrt SM predictions is observed.
- Atlas results already competitive with Tevatron.

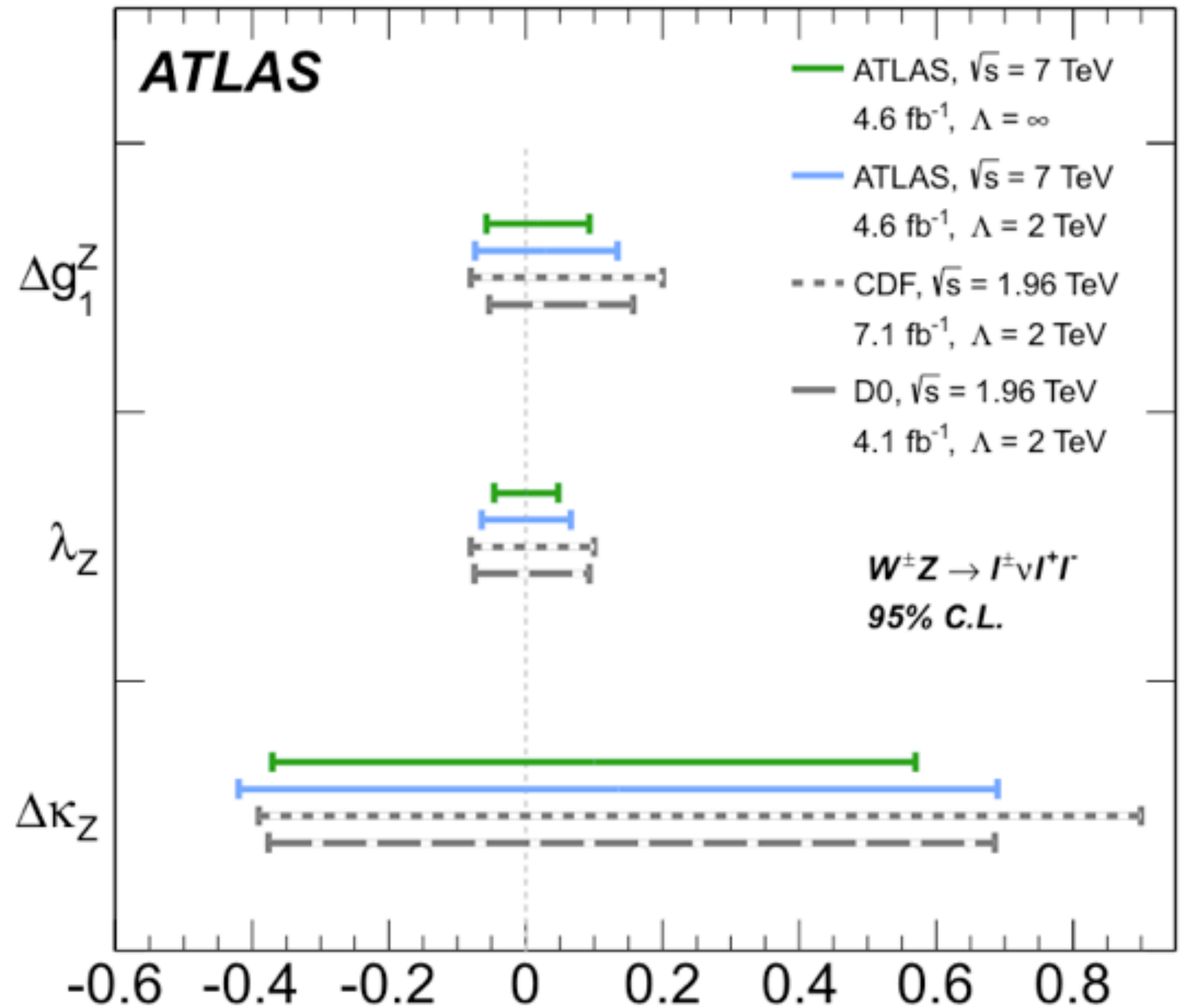
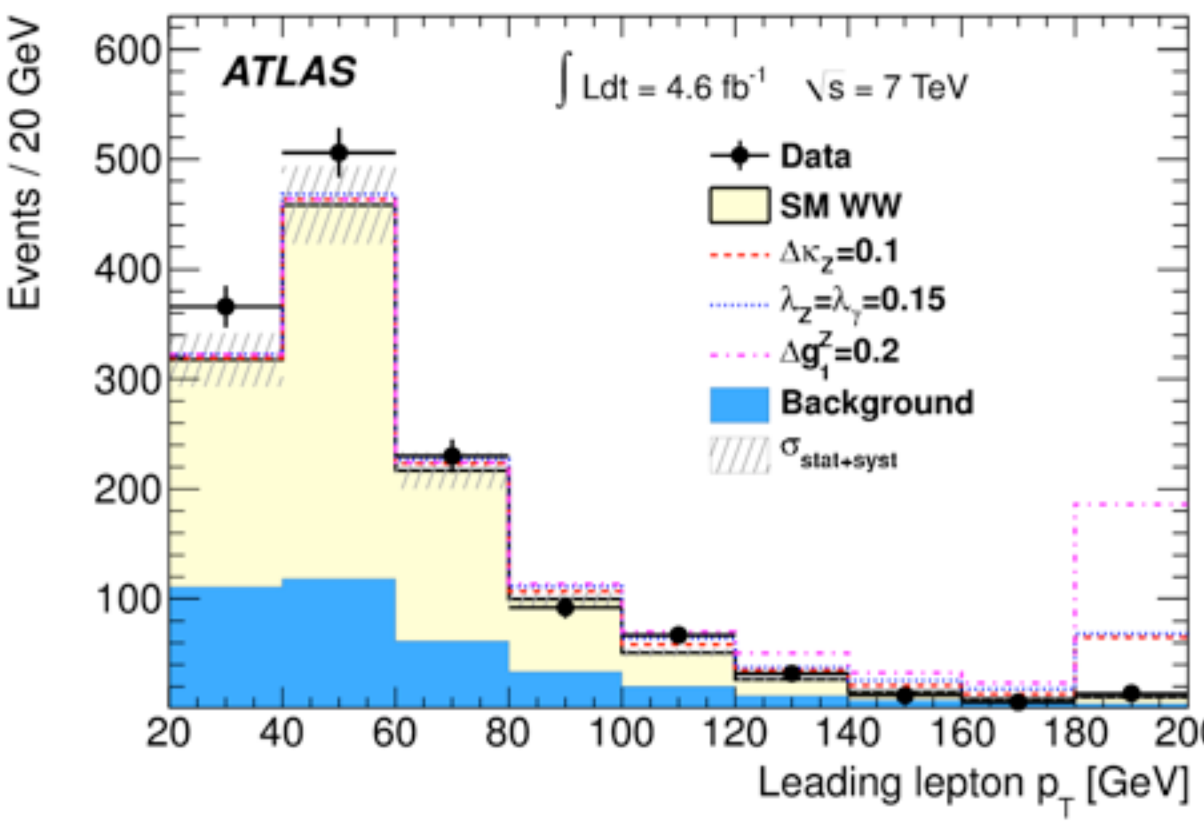
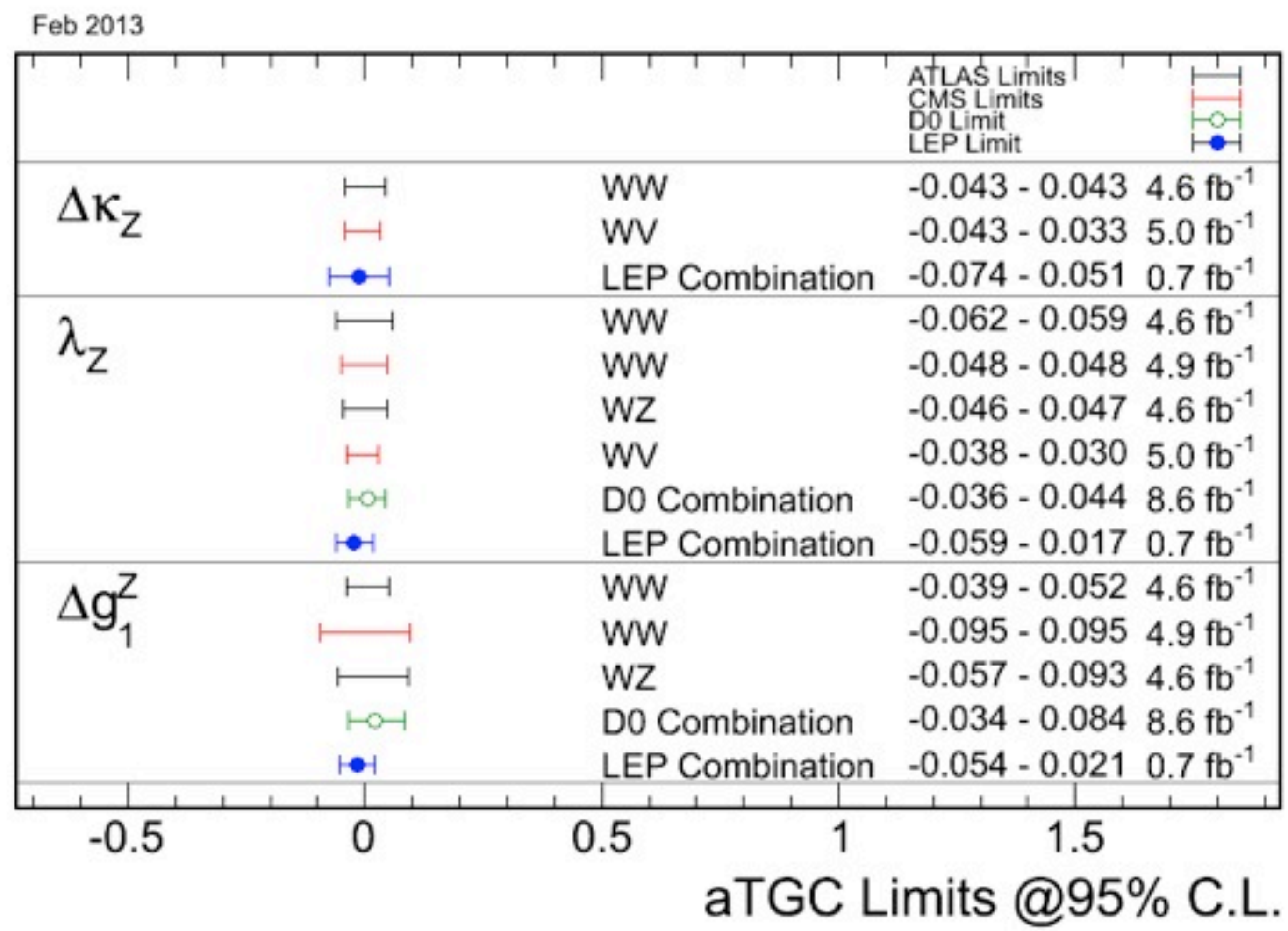


Figure : 95% confidence intervals for anomalous TGCs from ATLAS, CDF and D0. Integrated luminosity, center-of-mass energy and cut-off Λ for each experiment are shown

arXiv:1208.1390

WW aTGC limits 4.6 fb^{-1} @7 TeV





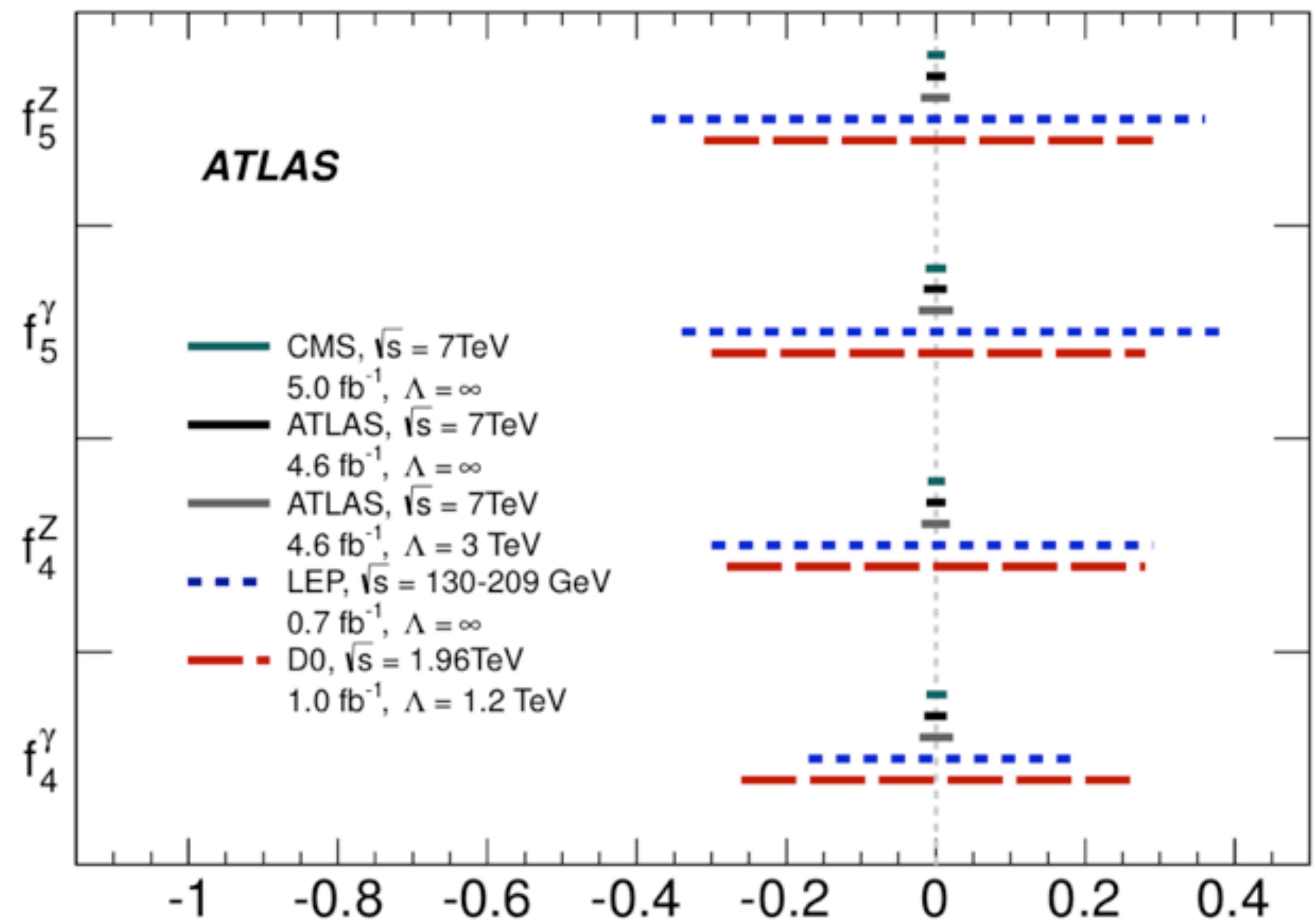
- Fit for anomalous couplings using distribution pf leading lepton p_T
- No significant deviation wrt the SM predictions is observed

arXiv:1210.2979

ZZ aTGC limits

4.6 fb^{-1} @7 TeV

arXiv:1211.6096



- No significant deviation wrt SM predictions is observed.
- ATLAS and CMS results are already more constraining than LEP and Tevatron

Conclusions

- Dibosons production cross-sections and aTGC parameters have been measured using 7 TeV data and for some channels at 8 TeV data.
- We have a good agreement with the SM predictions, within uncertainties.
- Most of the results are still dominated by the statistical uncertainties, but we have a lot of data to process.
- Still most of the LHC data at 8 TeV to be analysed … more results with improved precision expected soon

Backup

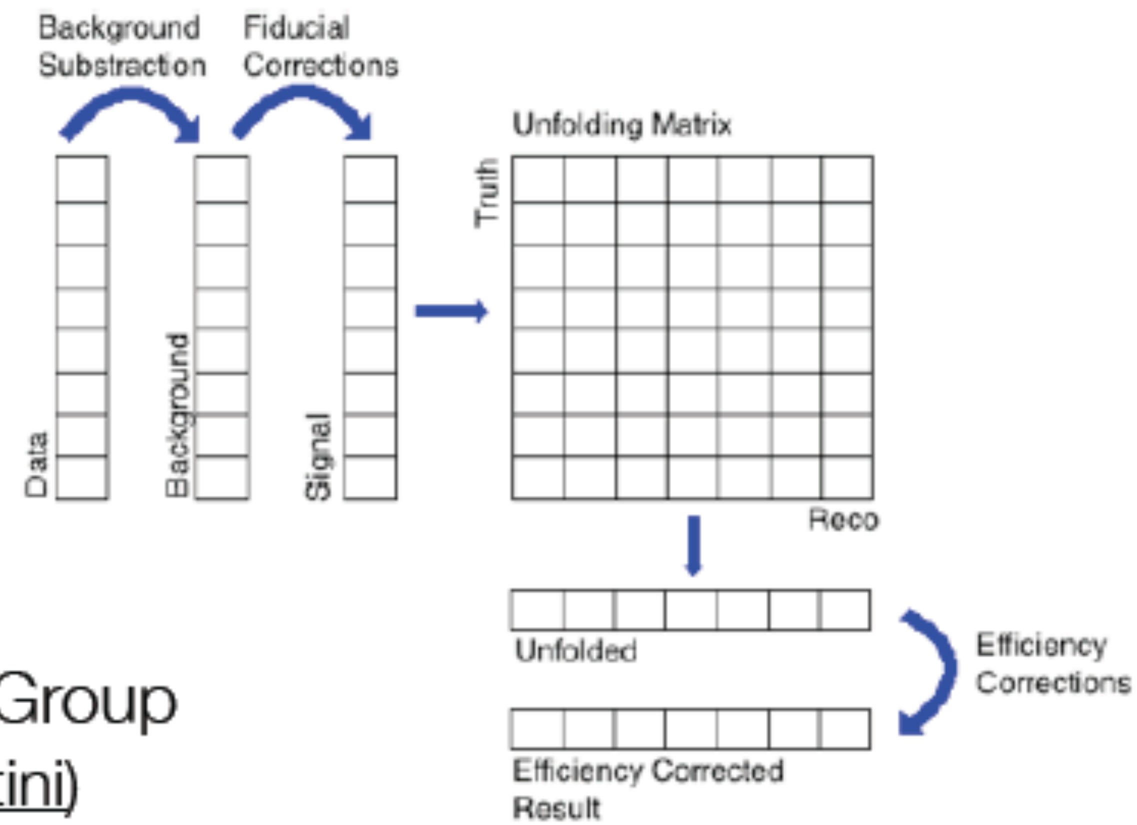
Unfolding methodology

Motivation

Determine **true value** of an observable

Measured value is distorted by detector's

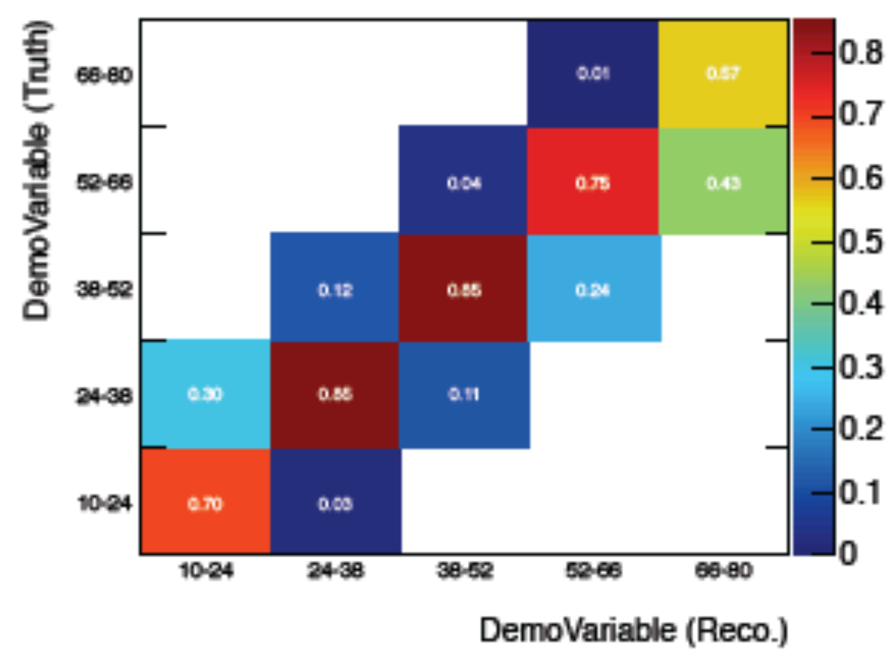
- limited acceptance
- imperfect efficiency
- finite resolution



Method

Common Framework among Electroweak Group

- use **iterative Bayesian unfolding** (d'Agostini)
- **normalized** unfolding within **fiducial region** only
- based on **RooUnfold** using **response matrix**



Published Results

Fractional, binned kinematic distributions

- $\Delta\sigma^{fid}(x)/\sigma^{fid}$

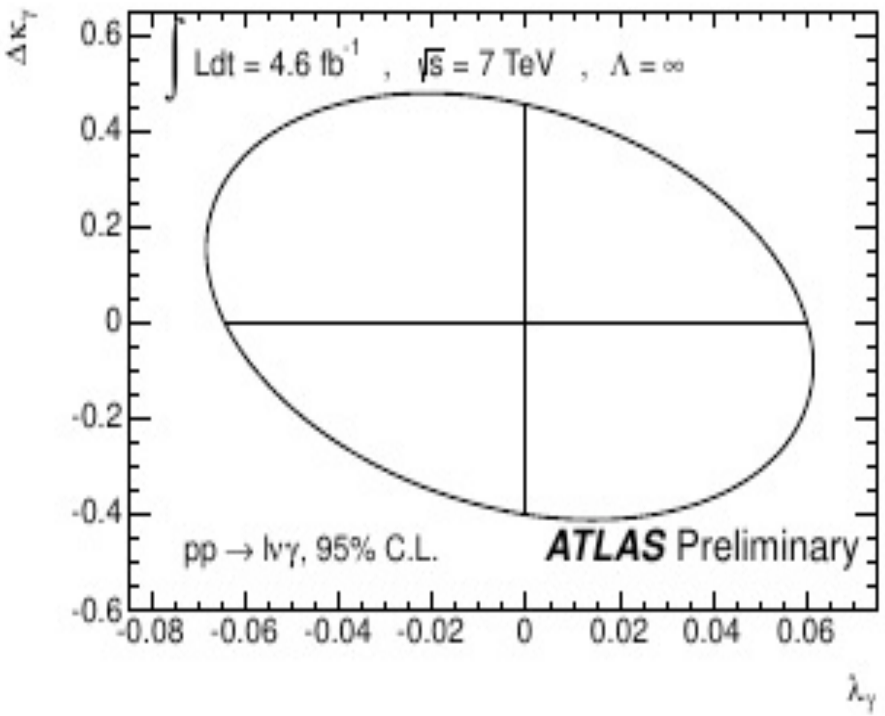
Full correlation matrices (on HEPDATA)

- combined stat, syst, background

Systematics uncertainties on

Channel	Main Uncertainties
WW→lνlν	jet veto (3.6%)
W(W/Z)→lνqq	jet energy scale (12%), W/Z+jets normalization (11%)
WZ→lνll	electron identification efficiency (3.5% for eee, 2.3% for eem) muon reconstruction efficiency (0.8% for μμμ, 0.5% for μμe)
Wγ	photon identification (11% for E_T>15GeV, 4.5% for E_T>60,100GeV)
ZZ→llll	electron identification efficiency (3.8% for eeee, 1.9% for eeμμ) muon reconstruction efficiency (1.0% for μμμμ, 0.5% for eeμμ)
ZZ→llνν	jet veto (5.3%)
Zγ	photon identification (11% for E_T>15GeV, 4.5% for E_T>60,100GeV)

Summary of aTGC



- All channels studied. No deviations from SM expectations
- But sensitivity still low :
  - Channel with highest statistics Wγ give $\Delta\kappa_\gamma < 0.4$ and $\lambda_\gamma < 0.05$
  - while the « interesting » range is rather $\Delta\kappa_\gamma \sim 0.01$ and $\lambda_\gamma \sim 0.001$
- Expected improvements soon with the full 2012 stat to be analysed (23 fb^{-1}) and combination of channels measuring the same couplings.
- The aTGC are proportional to s (or $\sqrt{s}$) it will be interesting to look at the 13 TeV data.
- Need to run at 13 TeV (higher sensitivity with increasing s) and 100 fb^{-1} (2 to 3 years)

Introduction (II)

- To detect a fully leptonic decay we use :
  - The muon spectrometer
  - The electromagnetic and hadronic calorimeters
  - The inner detector
- The missing energy (E_T^{miss}), is calculated all the detector informations.
- It is also important to know the acceptance of our detector for an accurate fiducial cross section measurement, as well as a total cross section extrapolation.

WW → μμνν event display