Experimental Electroweak Results

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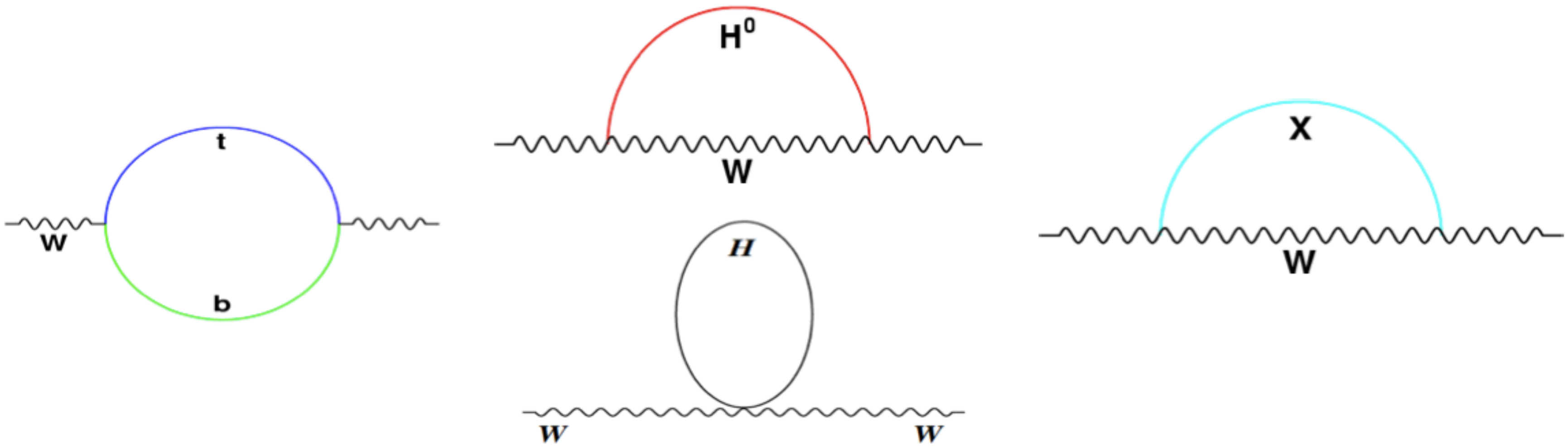
Outline

- Precision electroweak measurements
  - W mass measurement
  - Weinberg angle measurement
- Diboson measurements
  - Triple Gauge boson Couplings
- New frontiers in electroweak physics at the LHC
  - Quartic Gauge boson Couplings
  - VBF/VBS signatures

W mass measurement: motivation



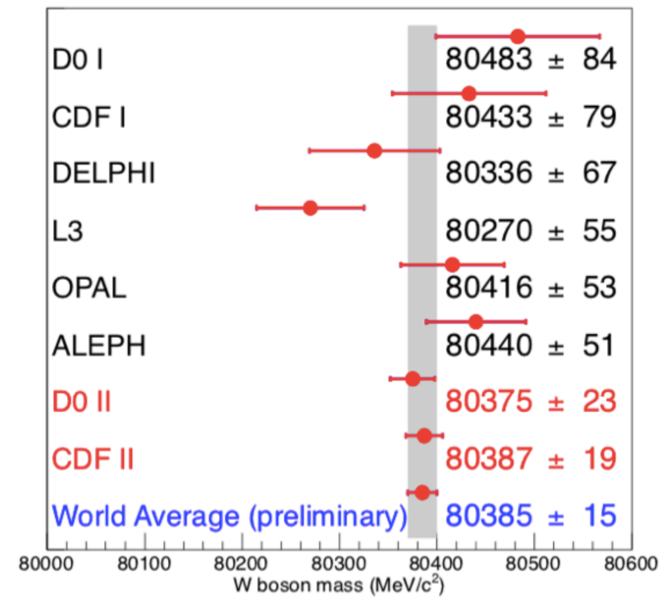
- Radiative corrections due to Higgs loops, heavy quark and exotica.
  - W mass and top mass constrain the mass of the Higgs boson, and possibly new particles beyond the standard model.
- Current top mass uncertainty is 0.5%

-> equivalent to 5 MeV on ΔM_W

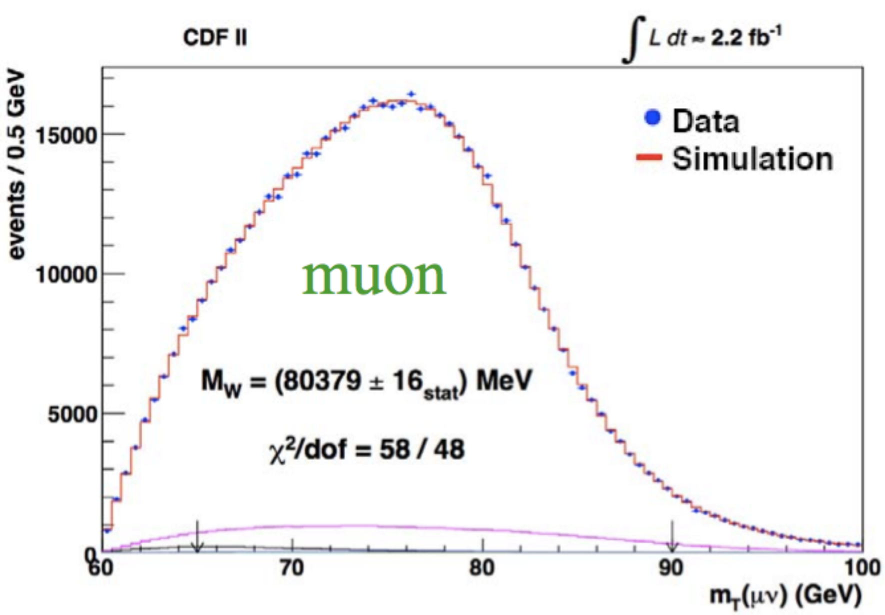
- Precision of W mass measurement is still much larger than 5MeV

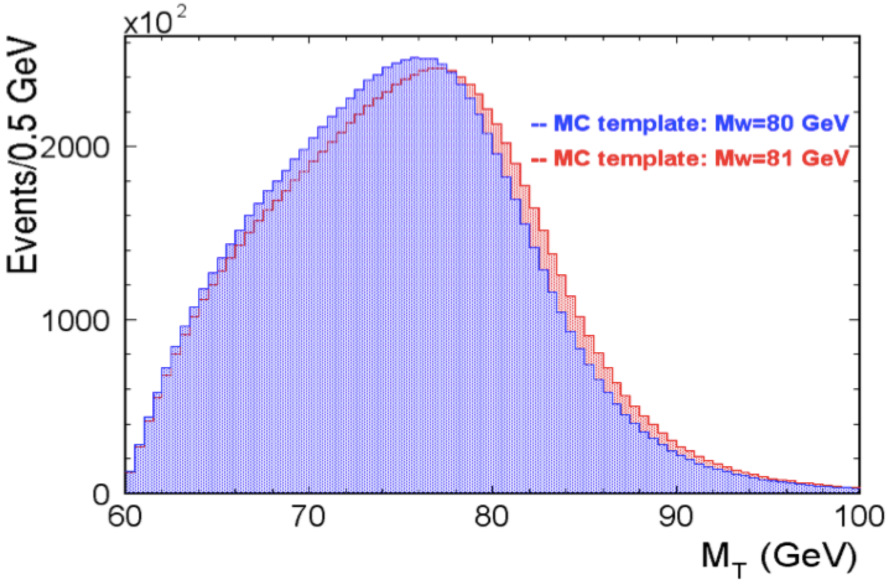
W mass measurement techniques

- Extract the W mass from fit to:
  - m_T, p_T and E^T_{miss}
- Reach 15MeV precision by combining CDF and D0 results.



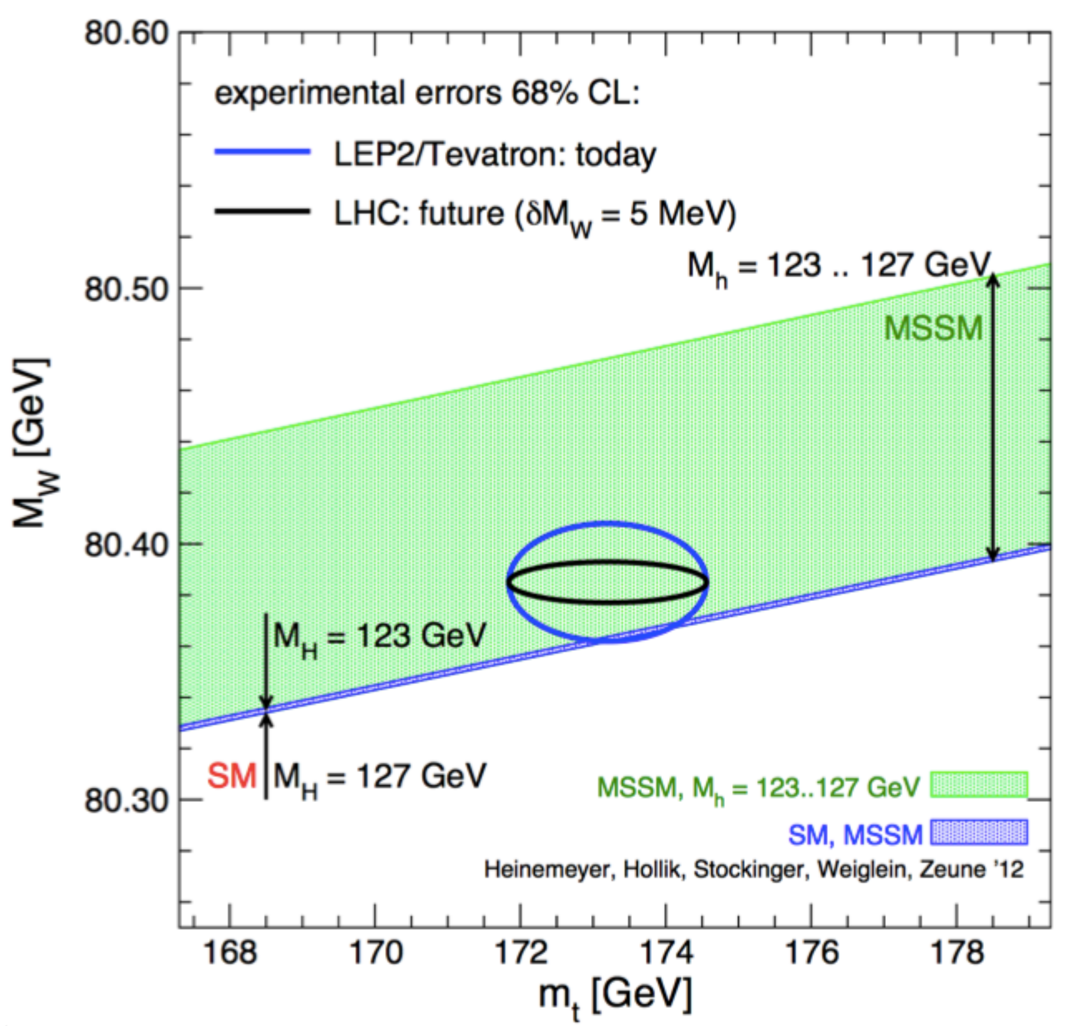
CDF: PRL 108, 151803 (2012)
D0: Phys. Rev. Lett. 108, 151804





W mass measurement: interpretation

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



[hep-ph/0604147]
[hep-ph/0412214]

Weinberg angle measurement

- Reminder of Weinberg angle definition:

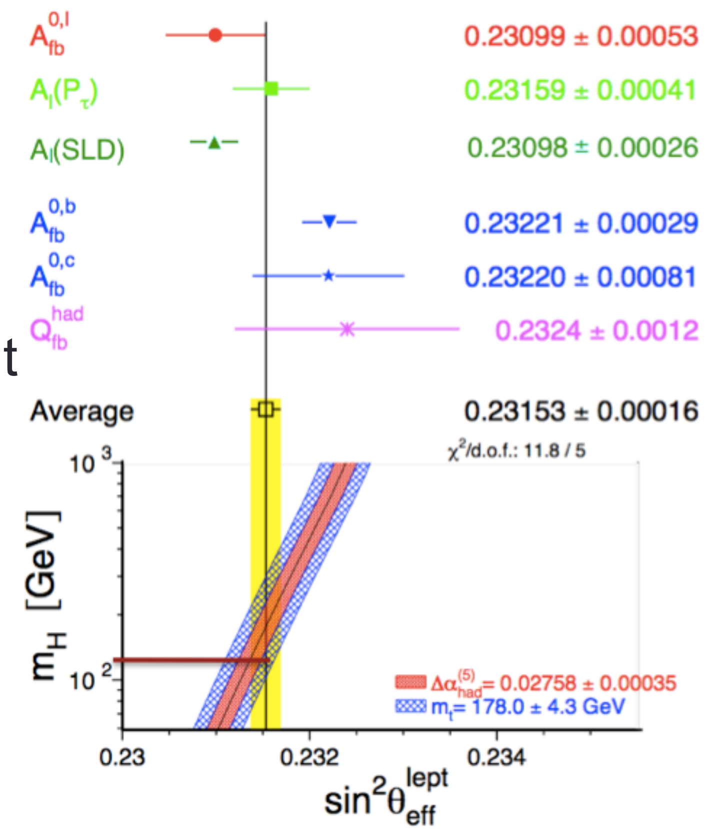
$$\sin^2(\theta_W) = 1 - \frac{m_W^2}{m_Z^2}$$

Experimental observable:

Backward –forward asymmetry in Z

- Precise Weinberg angle measurement constrains the mass of the Higgs boson.

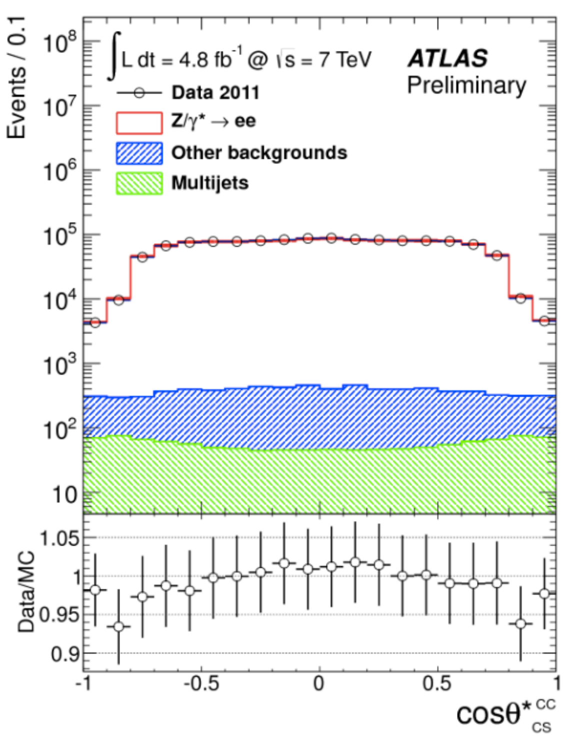
- The largest deviation between the best EWK fit vs. data
  - Tension between LEP and SLD results: ~3σ

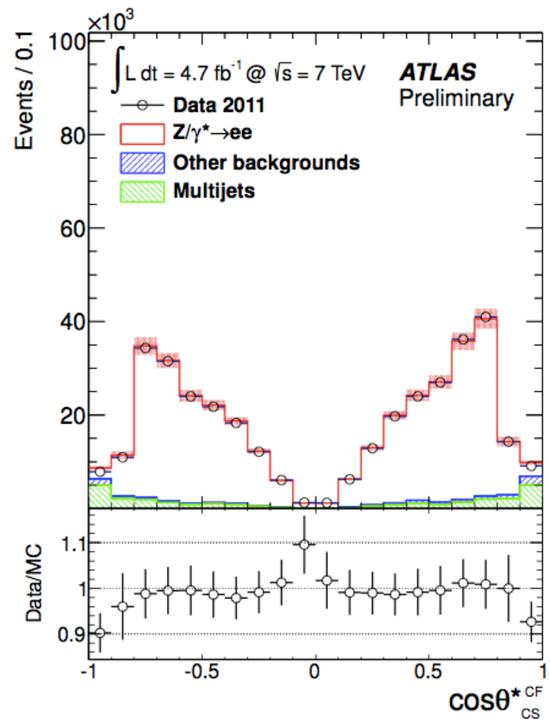


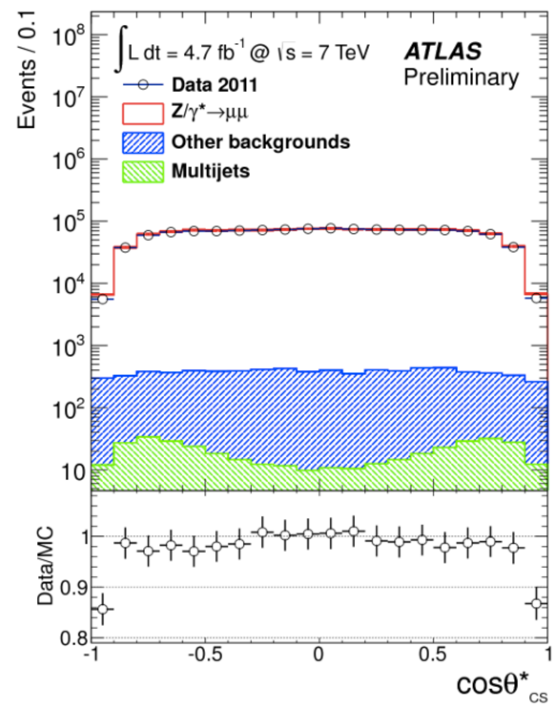
Backward-forward asymmetry in Z

ATLAS-CONF-2013-043

- Central-Central
  Electron channel
- Central-forward
  Electron channel
- Central-Central
  Muon channel







- Central lepton : |η|<2.5
- forward e: 2.5<|η|<4.9

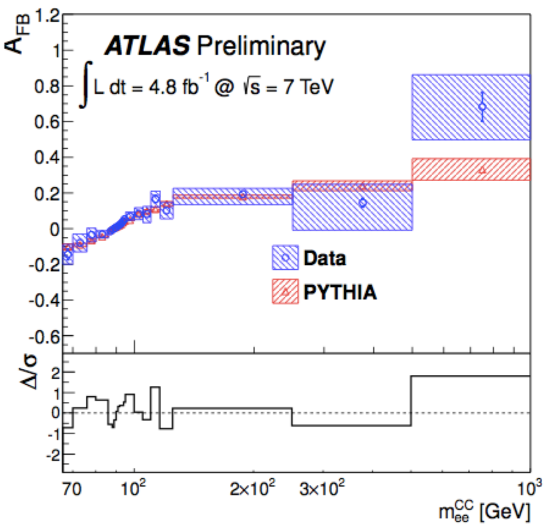
$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

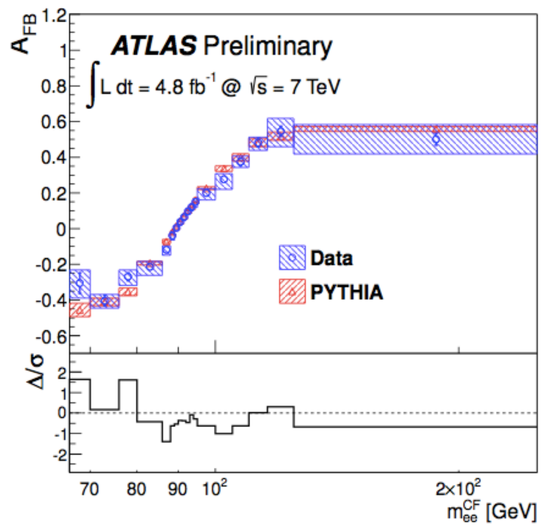
cos(θ)>0 → Forward (N_F)
cos(θ)<0 → Backward (N_B)

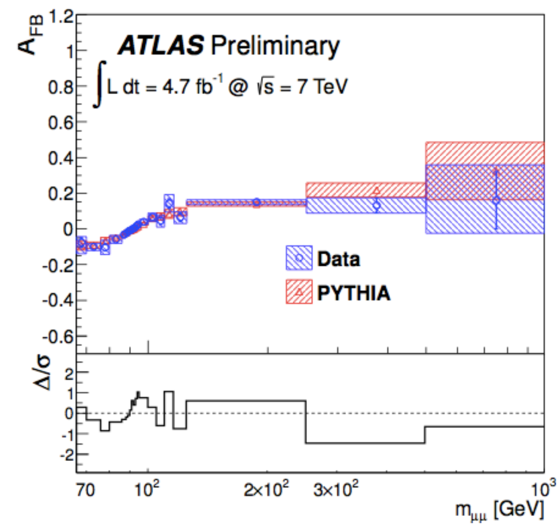
- Asymmetry is more visible in central-forward channel
- less dilution due to unknown incoming quark direction

Unfolded the AFB Spectra

- Central-Central Electron channel
- Central-forward Electron channel
- Central-Central Muon channel







- Unfolded to born level.
  - Compared to LO Pythia prediction
- Correcting for mass bin migration effect.
  - big impact from mass-bin- migration in low mass region
- Not included correction from dilution

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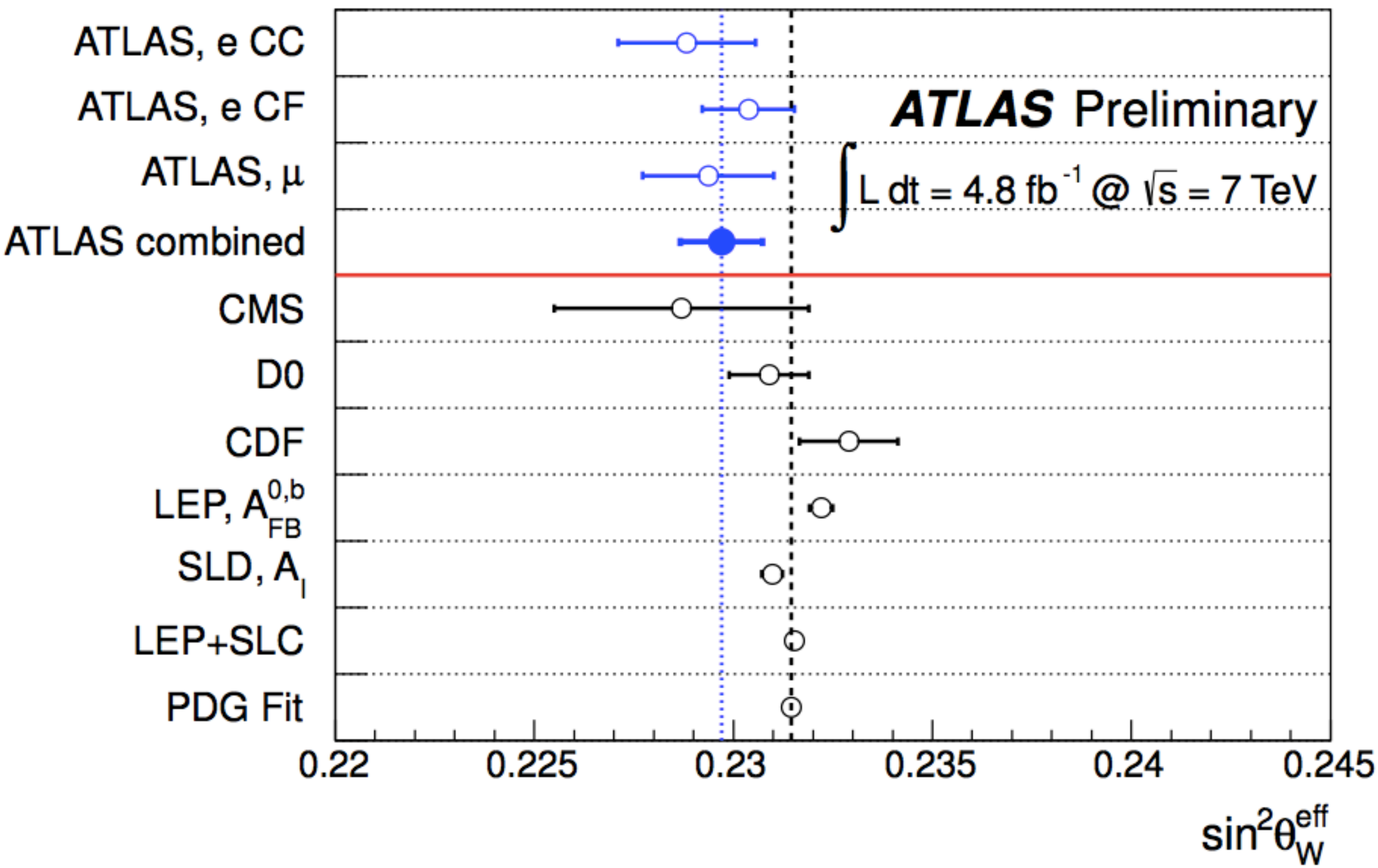
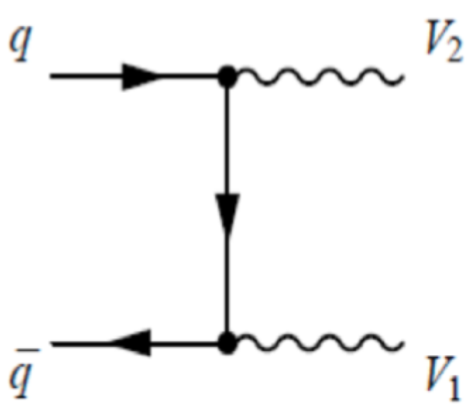
ATLAS Results and World Averages

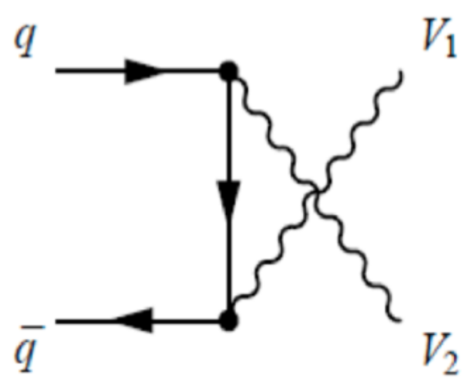


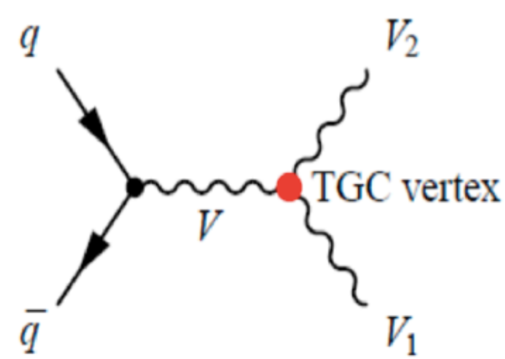
ATLAS-CONF-2013-043

Diboson physics

- Diboson production cross-section measurements
  - Test of SM electroweak theory and perturbative QCD at TeV scale
  - Irreducible SM background to Higgs (WW, ZZ, Zγ)
  - Sensitivity to new particles decaying to dibosons (Technicolor, Little Higgs, SUSY, etc...)
- Anomalous Triple Gauge Couplings (aTGCs)
  - Vector boson self-couplings fundamental prediction of the Electroweak Sector of SM
  - aTGC modify total cross sections and kinematics
  - neutral TGC not allowed in the SM (ZZZ, ZZγ) at tree level







Triple Gauge Couplings

- The s-channel diagrams contain the triple gauge coupling vertex
  - New physics may modify these couplings.

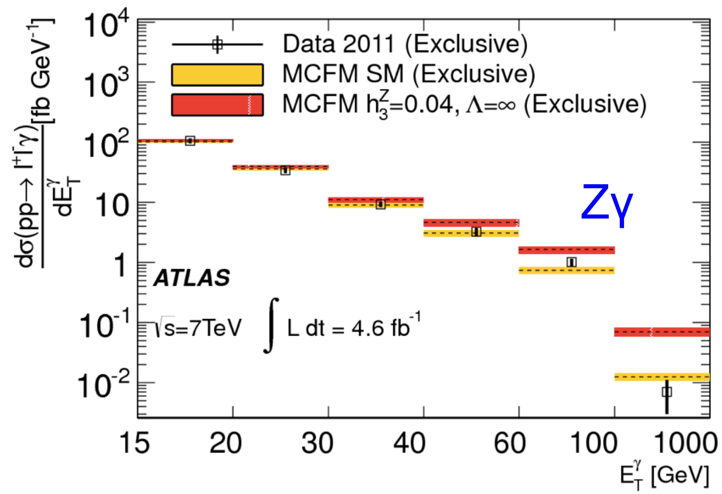
Coupling	Parameters	VV channel
$WW\gamma$	$\Delta\kappa_\gamma, \lambda_\gamma$	$WW, W\gamma$
WWZ	$\Delta g_1^Z, \Delta\kappa_Z, \lambda_Z$	WW, WZ
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma Z$	h_3^Z, h_4^Z	$Z\gamma$
$ZZ\gamma$	f_4^γ, f_5^γ	ZZ
ZZZ	f_4^Z, f_5^Z	ZZ

- aTGCs modify the event kinematics

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

- To avoid unitarity violation, an effective cutoff scale Λ is introduce
  - aTGCs are set with and without form factor
  - Unitarization treatments break model independence
- The meaning of aTGCs
  - One example is W-W-γ coupling
  - aTGCs study in W-W-γ is equivalent to
    - W's magnetic dipole moment measurement
    - W 's electric quadrupole moment measurement

$$\mu_W = \frac{e}{2M_W}(1+\kappa_\gamma+\lambda_\gamma)$$
$$Q_W^e = -\frac{e}{M_W^2}(\kappa_\gamma-\lambda_\gamma)$$

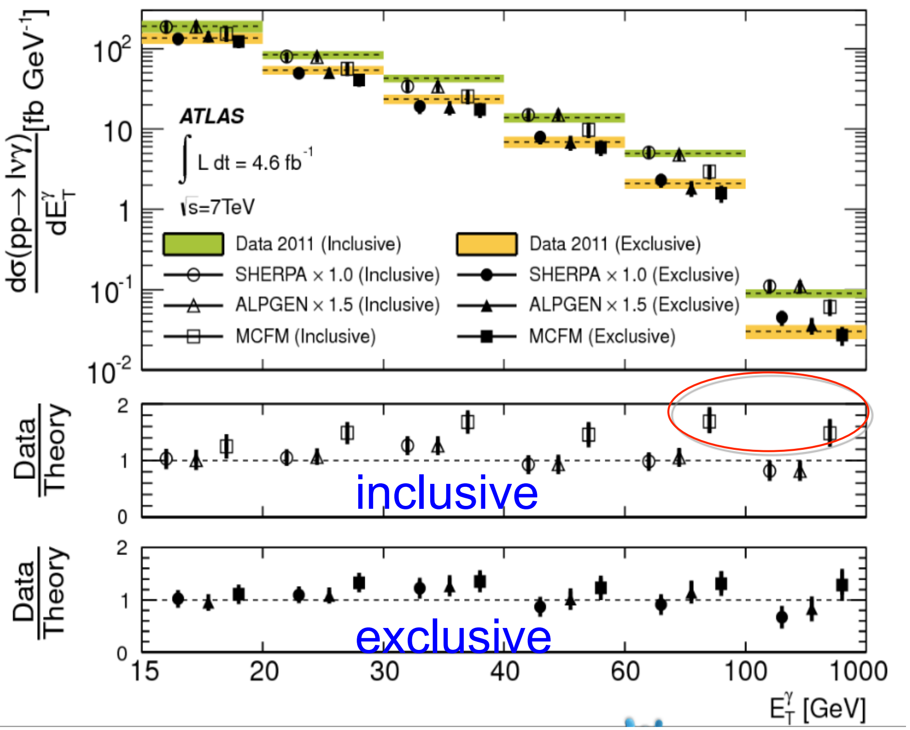


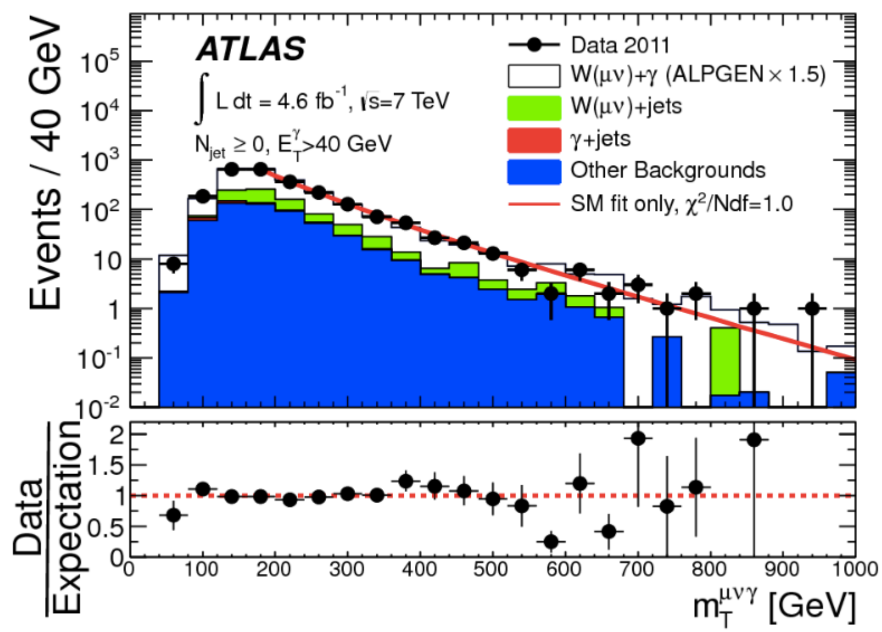
Wγ (lνγ) @ 7TeV

- Wγ/Zγ Paper (7TeV)

Phys. Rev. D 87, 112003 (2013)

  - First Wγ differential measurement.
  - First narrow resonance search using Wγ final state in all HEP experiments
  - Photon p_T shape is well described by Sherpa/Alpgen (LO multi-leg generator)
  - Photon p_T distribution measurement compared to MCFM NLO predictions
    - Discrepancy in high pT for inclusive measurement (without jet veto)
    - Agreement is improved for exclusive measurement (with jet veto)
    - Need NNLO calculations





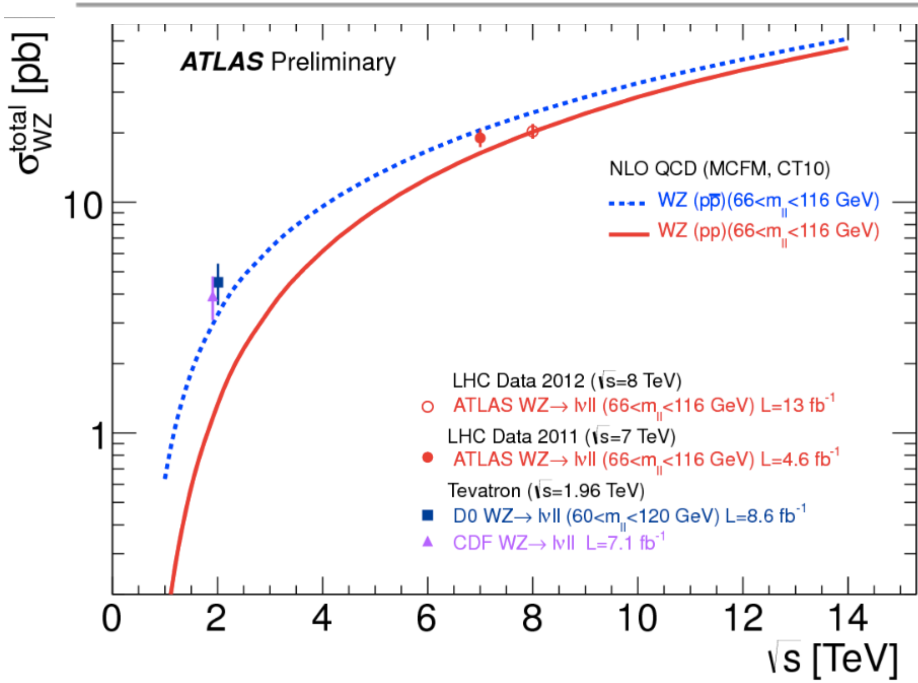
WZ @ 8TeV

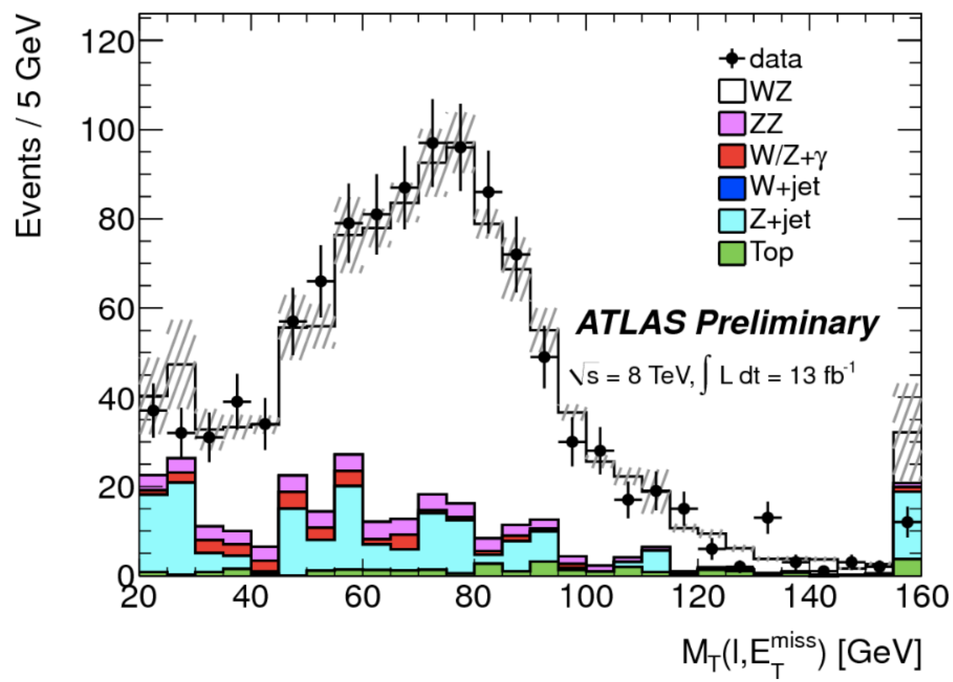
ATLAS-CONF-2013-021

- Moriond CONF note with $13 fb^{-1}$
  - First 8TeV WZ measurement from LHC experiments
    - in excellent agreement with theory

- Selection highlights
- 3 high pT leptons
  - pT>15GeV
- Large E_T^{Miss}
- Tight Z mass window

	Measured σ^{tot} [pb]	Theoretical σ^{tot} [pb]
8 TeV	$20.3^{+0.8}_{-0.7}$(stat.)$^{+1.2}_{-1.1}$ (syst.) $^{+0.7}_{-0.6}$(lumi.)	20.3 ± 0.8
7 TeV	$19.0^{+1.4}_{-1.3}$(stat.)± 0.9 (syst.) ± 0.4(lumi.)	$17.6^{+1.1}_{-1.0}$





WW @ 7TeV

Phys. Rev. D 87, 112001 (2013)

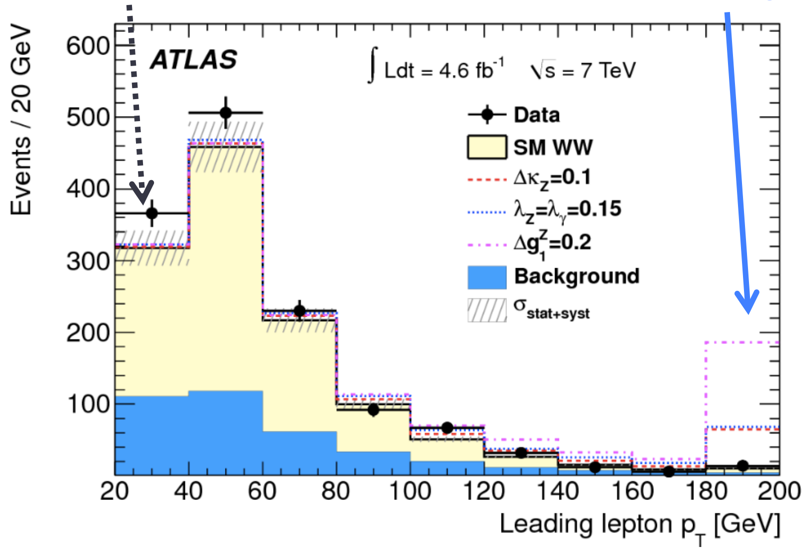
- Selection highlights
- Require exactly two isolated leptons
- ***Veto events with hard jets (reject top BG)***
- large E_T^{Miss}

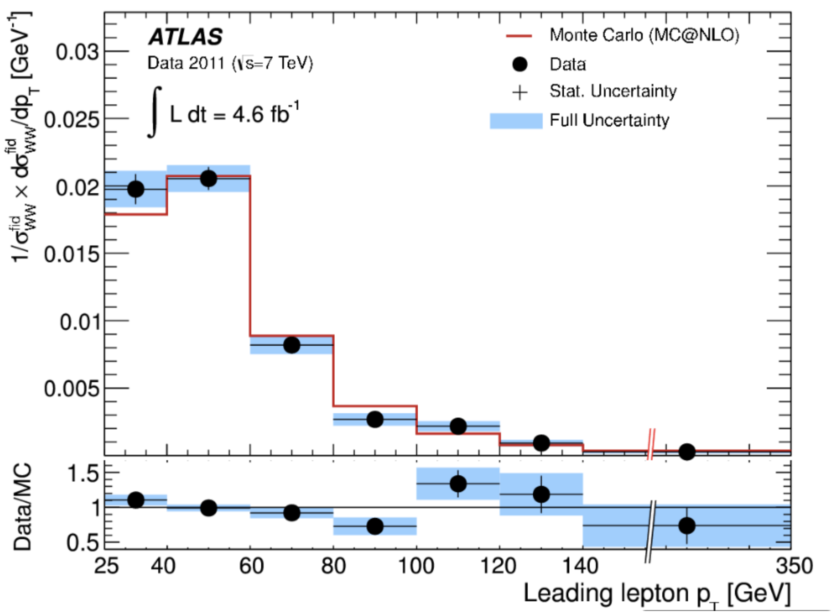
- First differential measurement of lepton p_T spectrum.
- Relative large uncertainty from jet veto
  - ~6% uncertainty due to jet veto in acceptance
  - will explore the measurement without jet veto cut in the future

	Measured σ^{tot} [pb]	Theoretical σ^{tot} [pb]
7 TeV	51.9 ± 2.0(stat.)±3.9 (syst.) ±2.0(lumi.)	44.7 ± 2.8

Excesses in data are at low pT

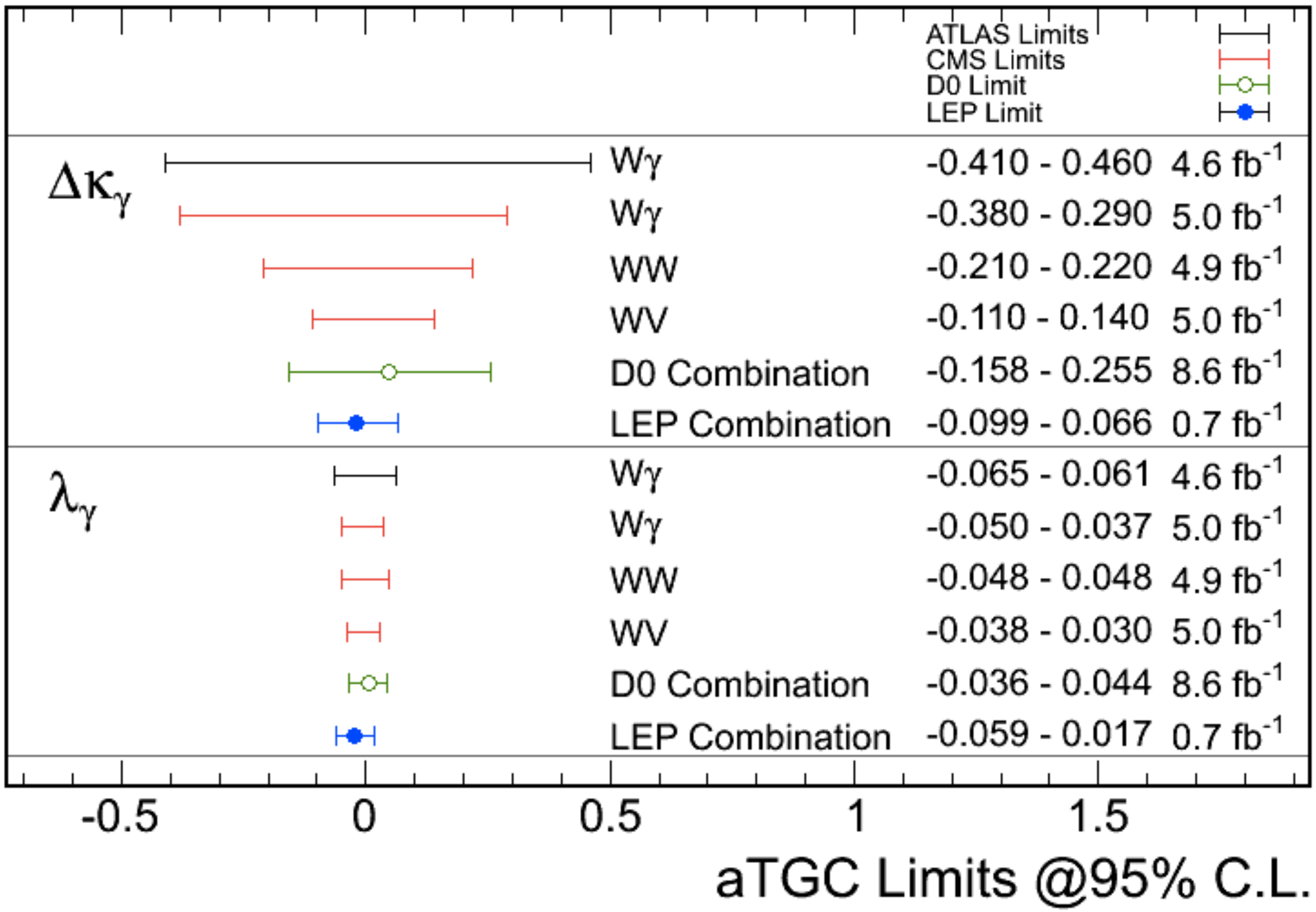
aTGCs contributions are at high pT





Charged aTGC results

- aTGC results summary
  - from Wγ,WZ,WW and WV

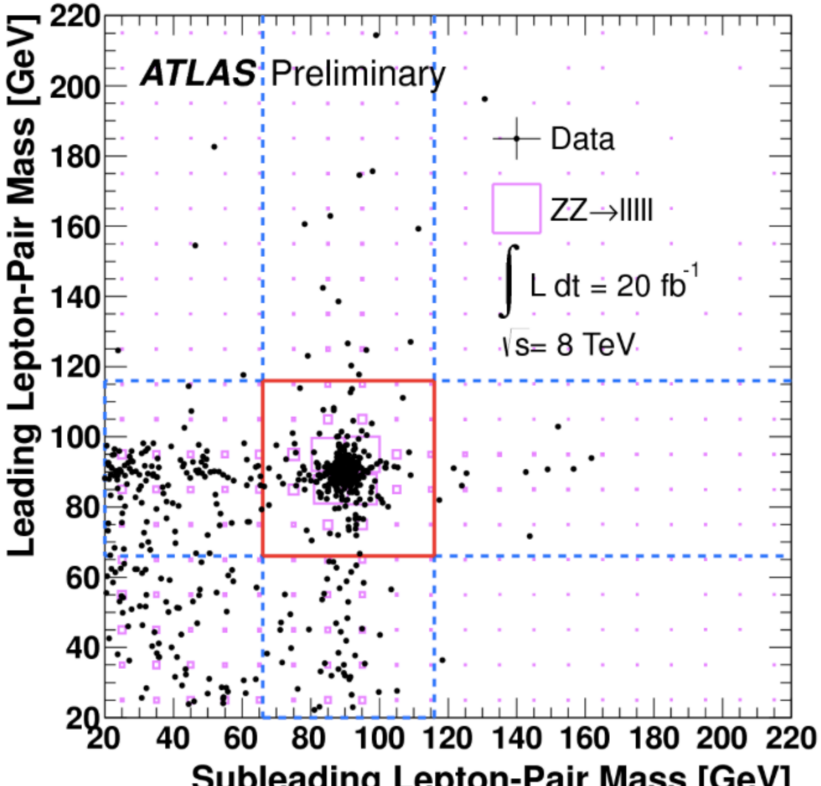


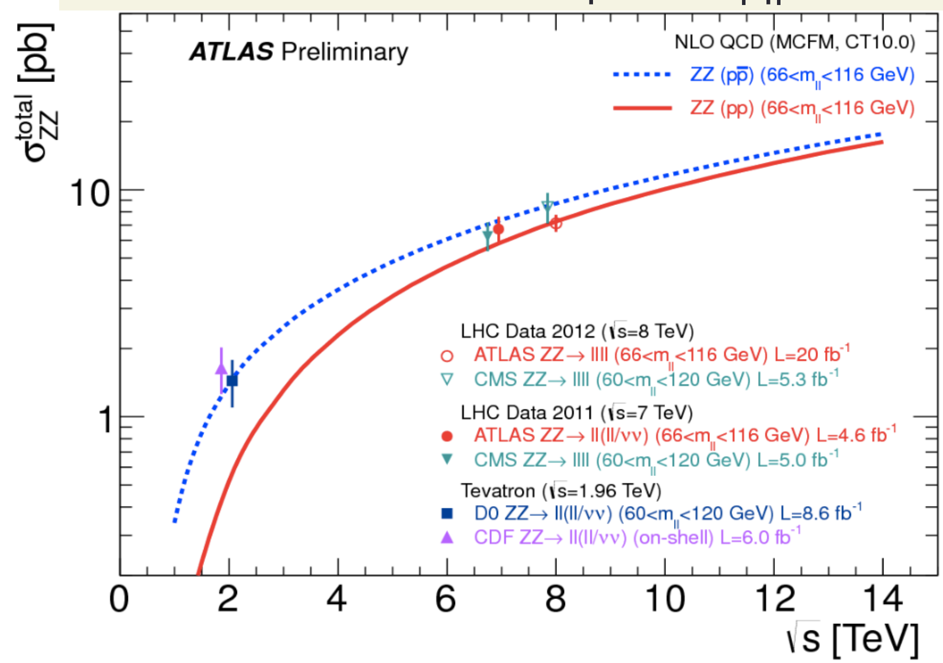
ZZ @ 8TeV

ATLAS-CONF-2013-020

- Moriond CONF note with full 8TeV dataset
  - 8TeV 20fb^{-1} results improved accuracy compared to 7TeV
  - Good agreement with SM expectation

- Selection highlights
- ❑ 4 isolated leptons with pT>7GeV
  - Use forward muons
  - Enhanced muon acceptance: |η| < 2.7

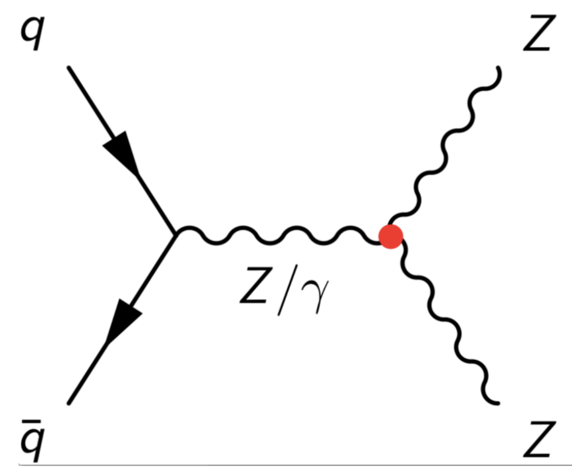


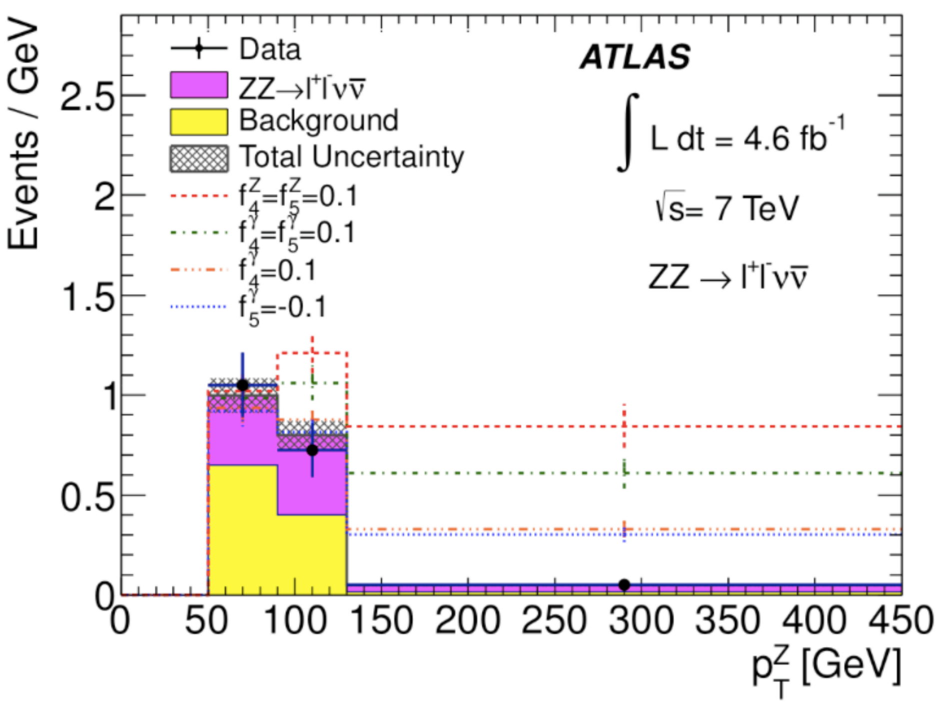


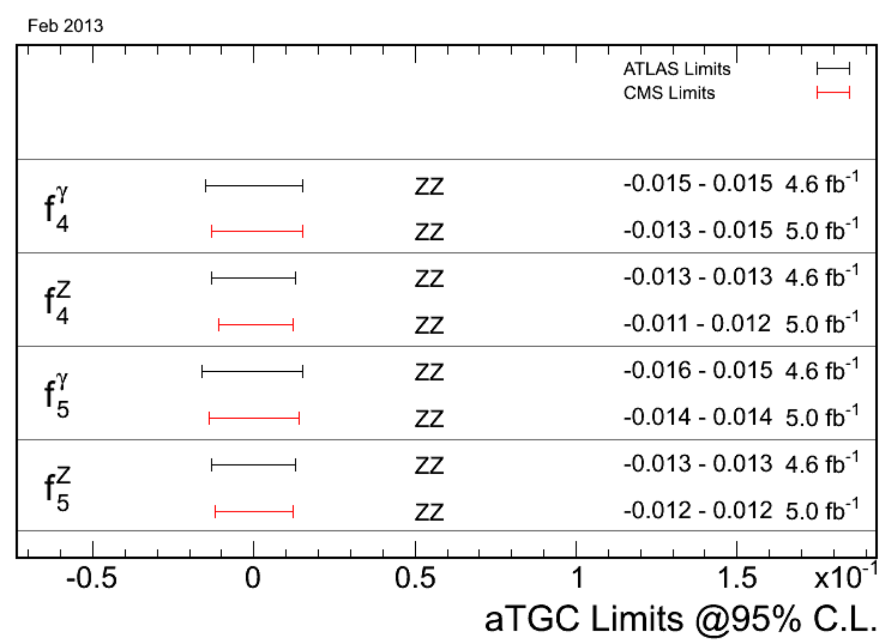
ZZ aTGCs

JHEP03(2013)128

- Z-Z-γ and Z-Z-Z coupling is forbidden in SM @ tree level.
  - Use $p_T(Z)$ spectrum to study aTGCs
  - 7TeV ZZ->4l and ZZ>2l2v events are used to probe aTGCs
  - Limits surpassing Tevatron and LEP!





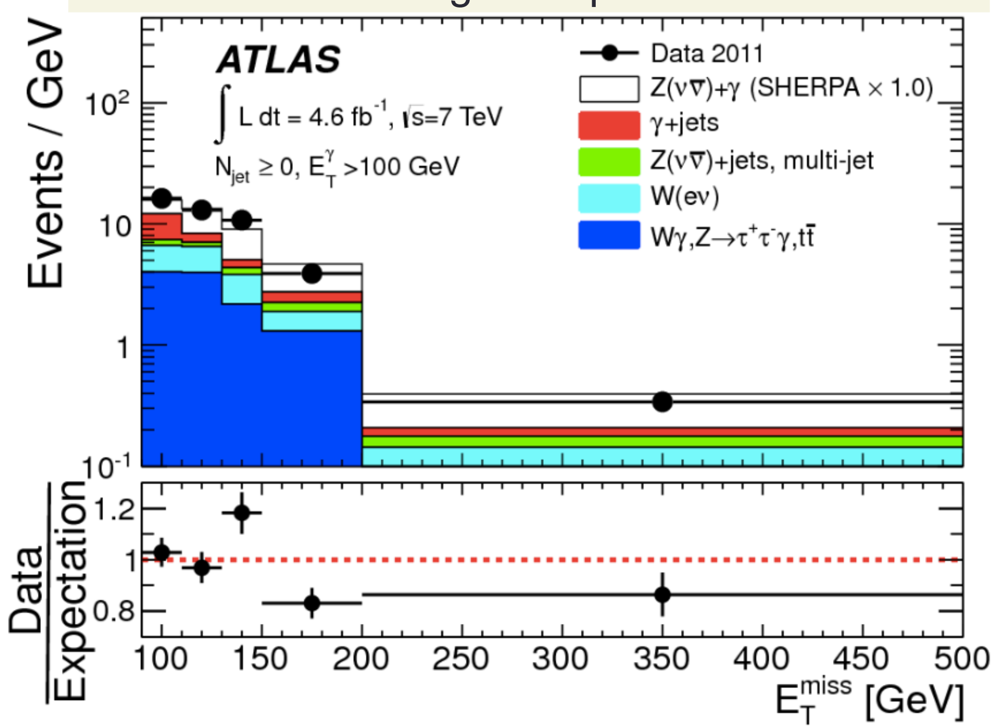


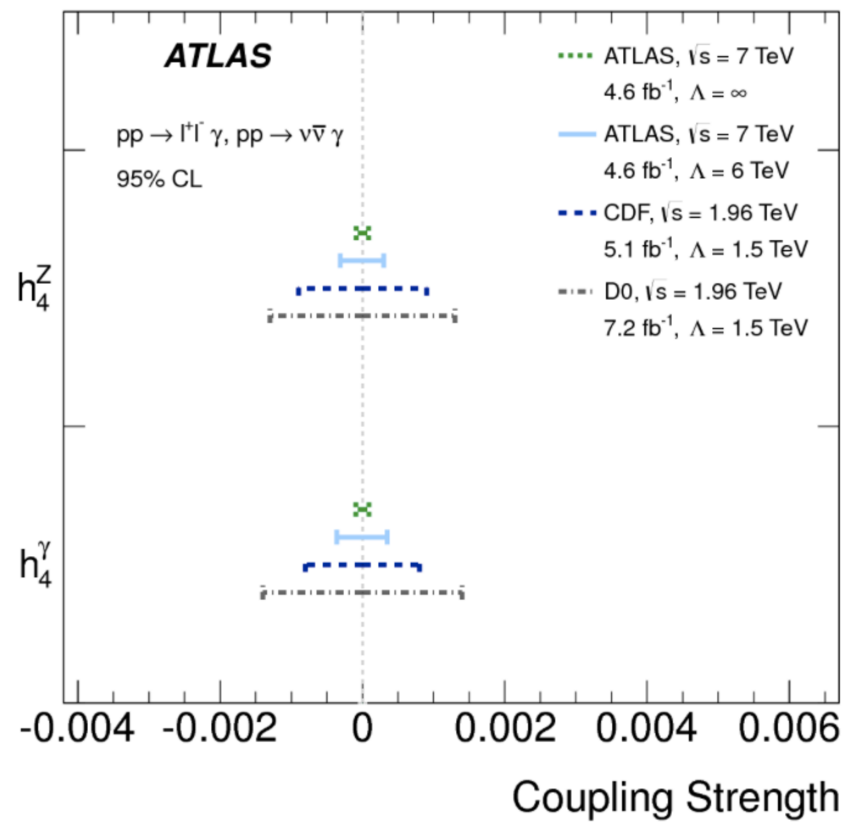
Zγ (ννγ) @ 7TeV

- measurement with neutrino decay channel in LHC (ννγ)
  - Sensitive to Z-Z-γ and Z-γ-γ aTGC.
  - Improve aTGC limit by combing ννγ with $l^+l^-γ$
  - Limits surpassing Tevatron and LEP!

- Selection highlights
- ❑ E_T^{Miss}>90GeV
- ❑ One isolated photon with pT>100GeV
- ❑ Veto events with good lepton

Phys. Rev. D 87, 112003 (2013)

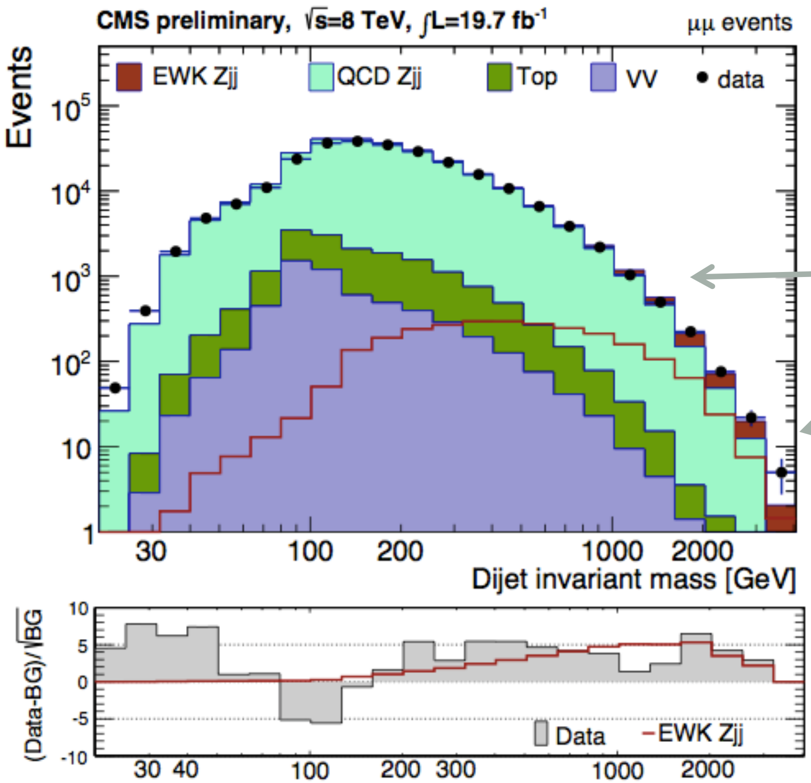


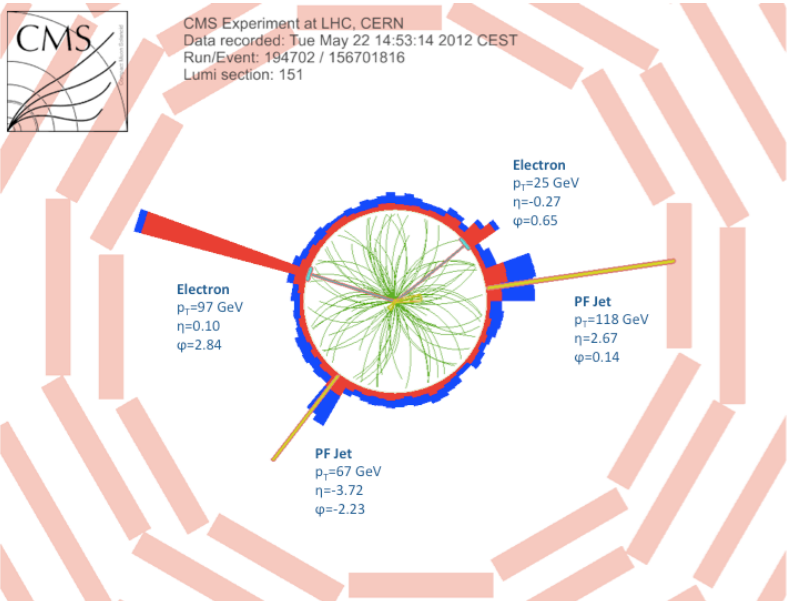


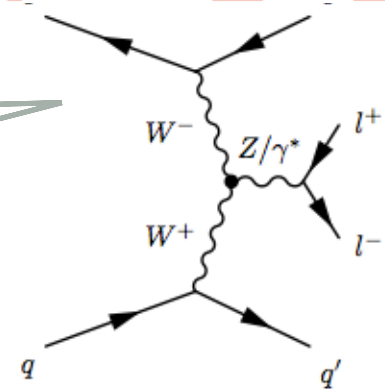
New frontiers in electroweak physics at the LHC

CMS VBF Z @ 8TeV

- Similar to VBF Higgs production
  - Probing WWZ TGC vertex
- Z+two jets signature
  - High dijet mass
  - Two jets are well separated







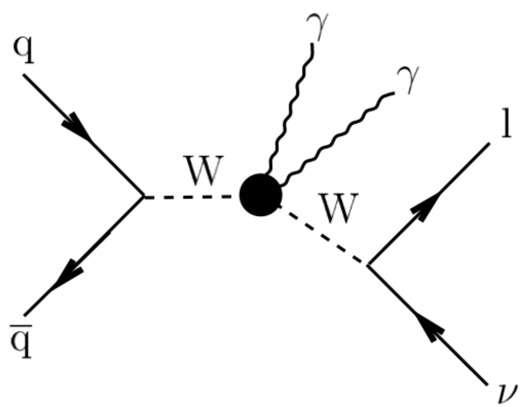
PAS-FSQ-12-35

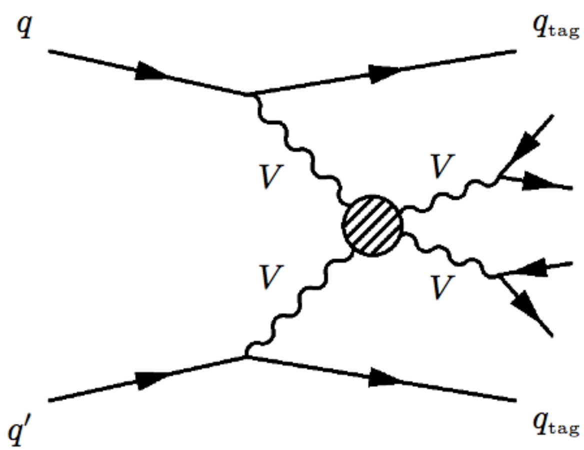
$$\sigma = 226 \pm 26_{stat} \pm 35_{syst}\ \text{fb}$$

Statistically limited measurement consistent with SM expectations

Quartic Gauge Boson Couplings

- Reminder of **Quartic Gauge Boson Couplings (QGCs)**
  - SM model predicts gauge boson self coupling
    - Four gauge boson vertex:
      - WWγγ , WWZγ , WWWW, WWZZ, ZZZZ …





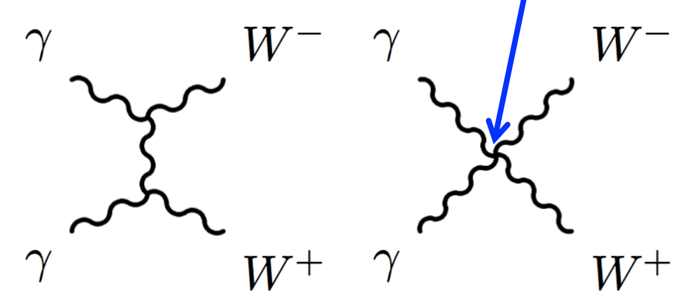
- Exclusive γγ->WW
  - Mainly probing WWγγ vertex
- Triboson Vγγ, WWW, WWγ …
  - Sensitive to WWγγ , WWZγ , WWWW
- Vector boson scattering WW->WW, WZ->WZ , ZZ->ZZ …
  - Sensitive to WWWW, WWZZ , ZZZZ vertex

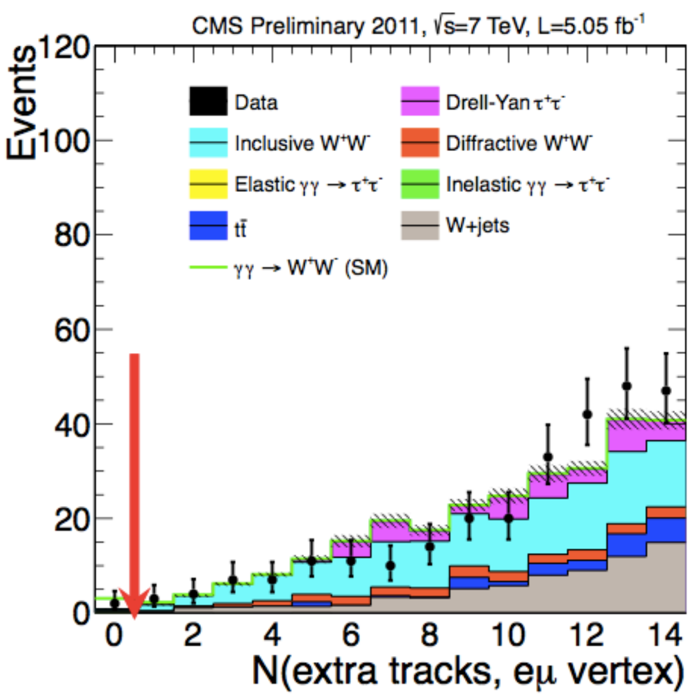
CMS γγ > W^+W^- 7TeV result

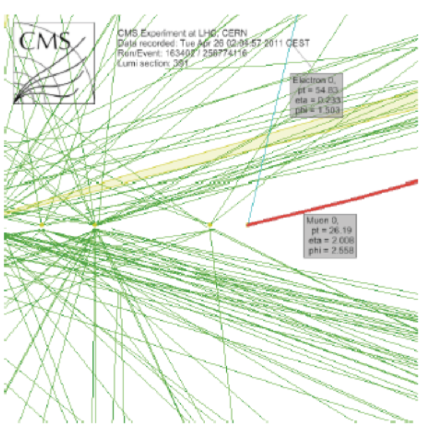
CMS PAS FSQ-12-010

- Aim to probe WWγγ quartic gauge coupling (QGCs)
- Event selection:
  - high pT isolated oppositely charged μe
  - no other tracks from primary vertex
  - Mass of di-lepton >20GeV
  - pT of di-lepton >30GeV
- 2 events observed
  - expected signal: 2.2 ± 0.5
  - expected bg: 0.84 ± 0.13

QGCs



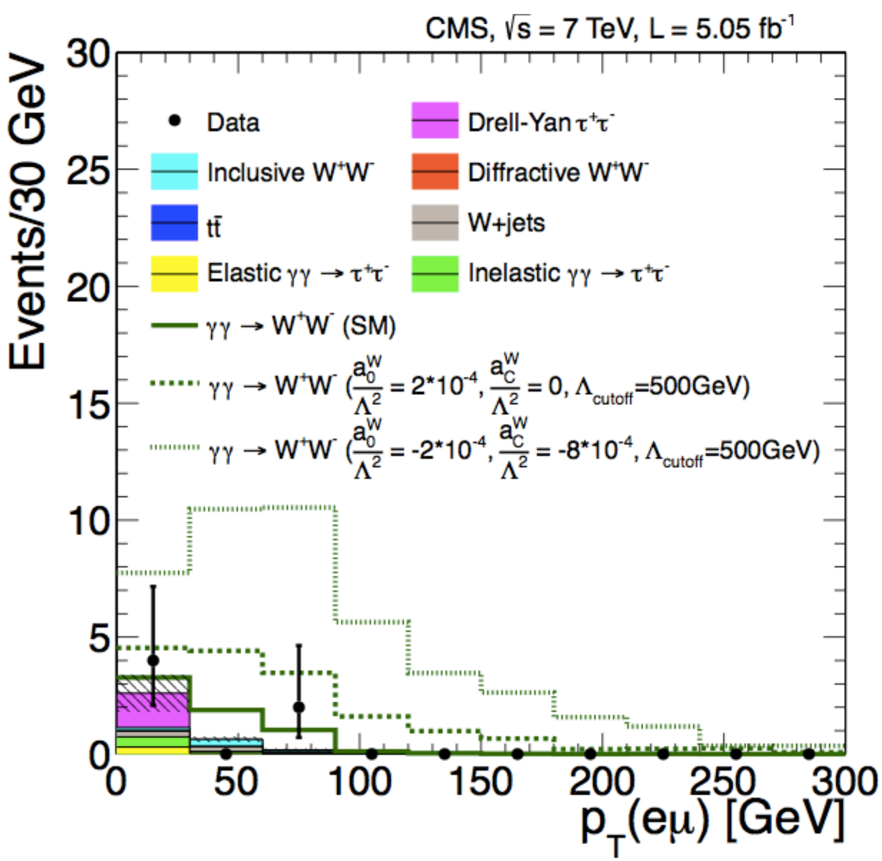


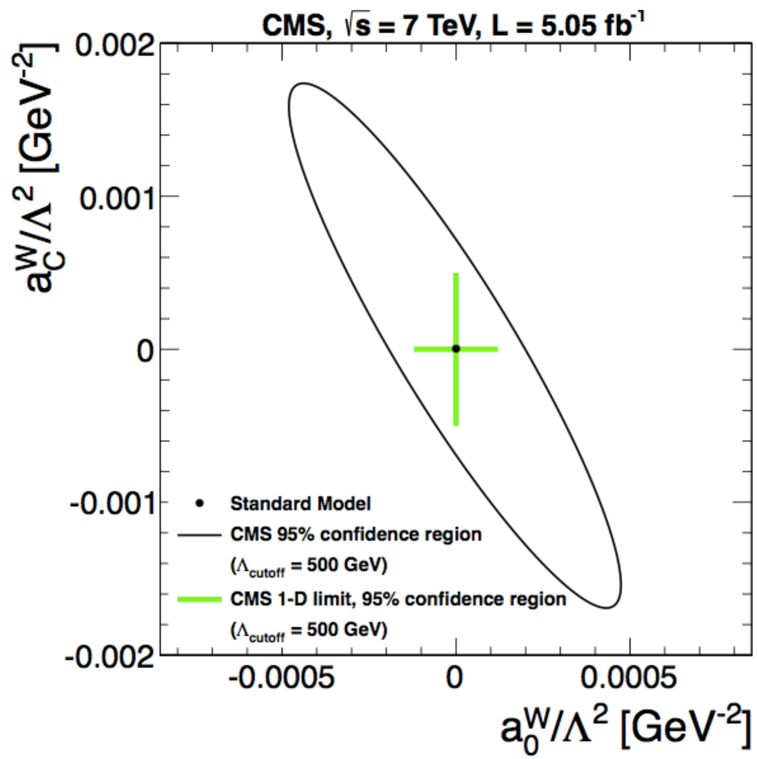


CMS $\gamma\gamma > W^+W^-$ 7TeV result

CMS PAS FSQ-12-010

- Not enough data for a significant xsec measurement
  - Set limits on anomalous WW$\gamma\gamma$ quartic gauge coupling (aQGCs): look in tail of pT(eμ) > 100 GeV
  - Improved aQGC limit from LEP by two orders of magnitude!

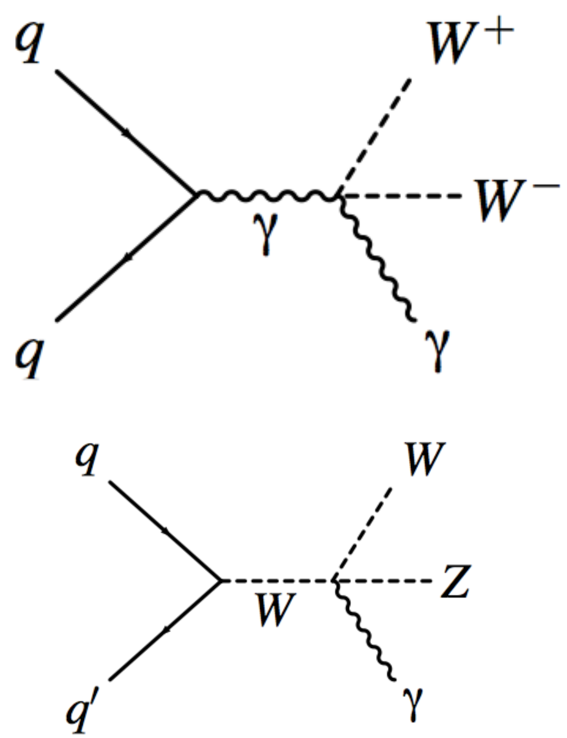


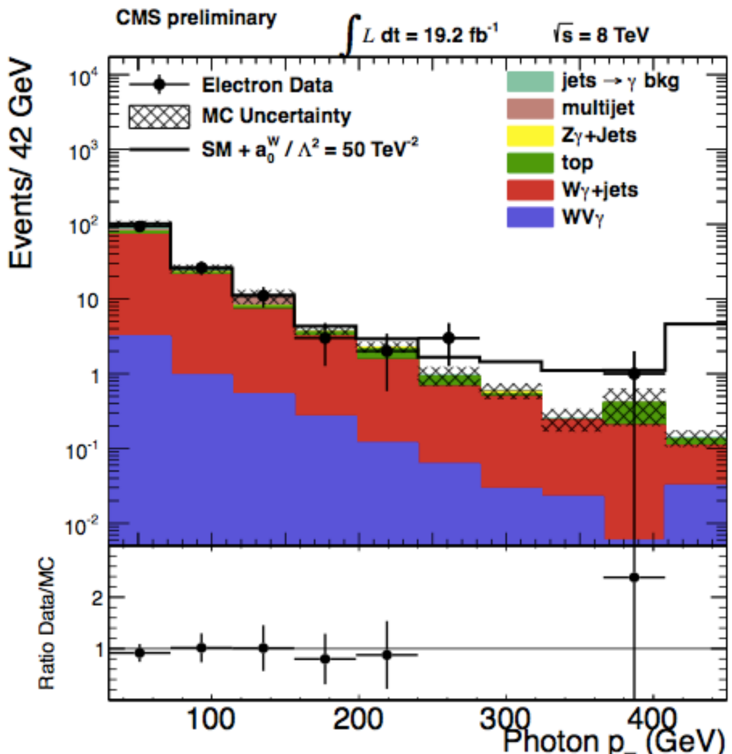


CMS WWγ @ 8TeV

CMS-PAS-SMP-13-009

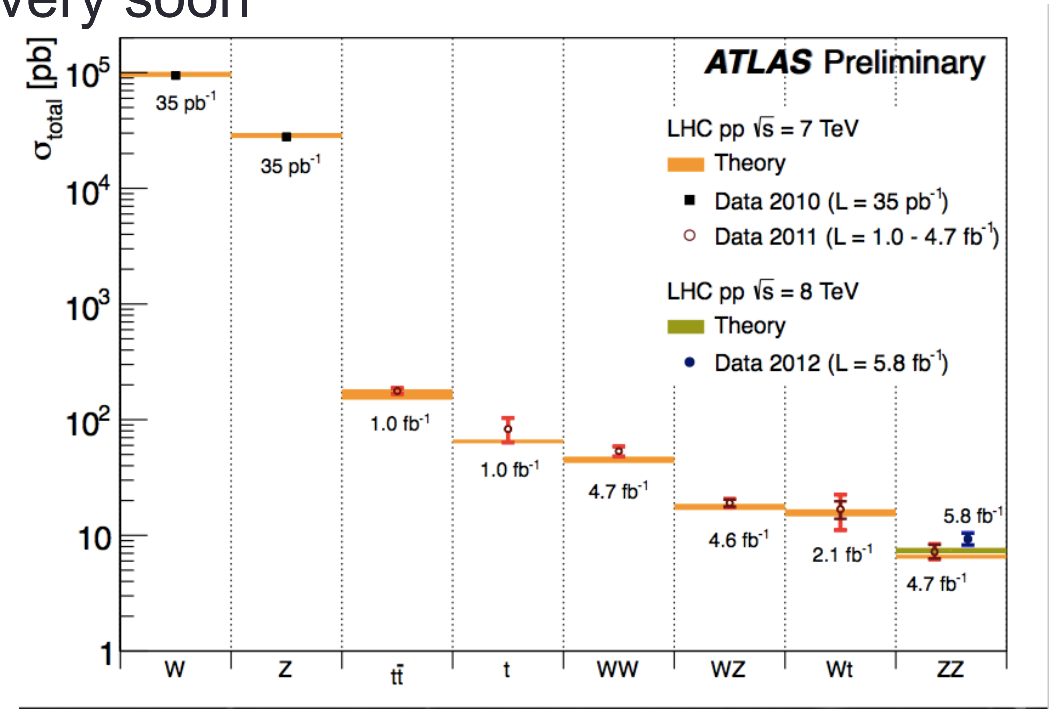
- Aim to probe WWγγ and WWZγ aQGCs
- Not enough data and too much background for a measurement
  - Set upper limit on cross section σ(WVγ) < 241 fb @ 95% C.L.
- No excess in data
  - Set limits on anoumalous WWγγ and WWZγ quartic gauge coupling





Summary

- LHC physics program provides
  - Precision tests of the Standard Model at TeV scale!
  - Stable ground for new physics searches!
- Triple Gauge Couplings have been measured in all the channels
  - no deviations from SM were observed
- Start looking at quartic gauge couplings
- More 8TeV results will come very soon



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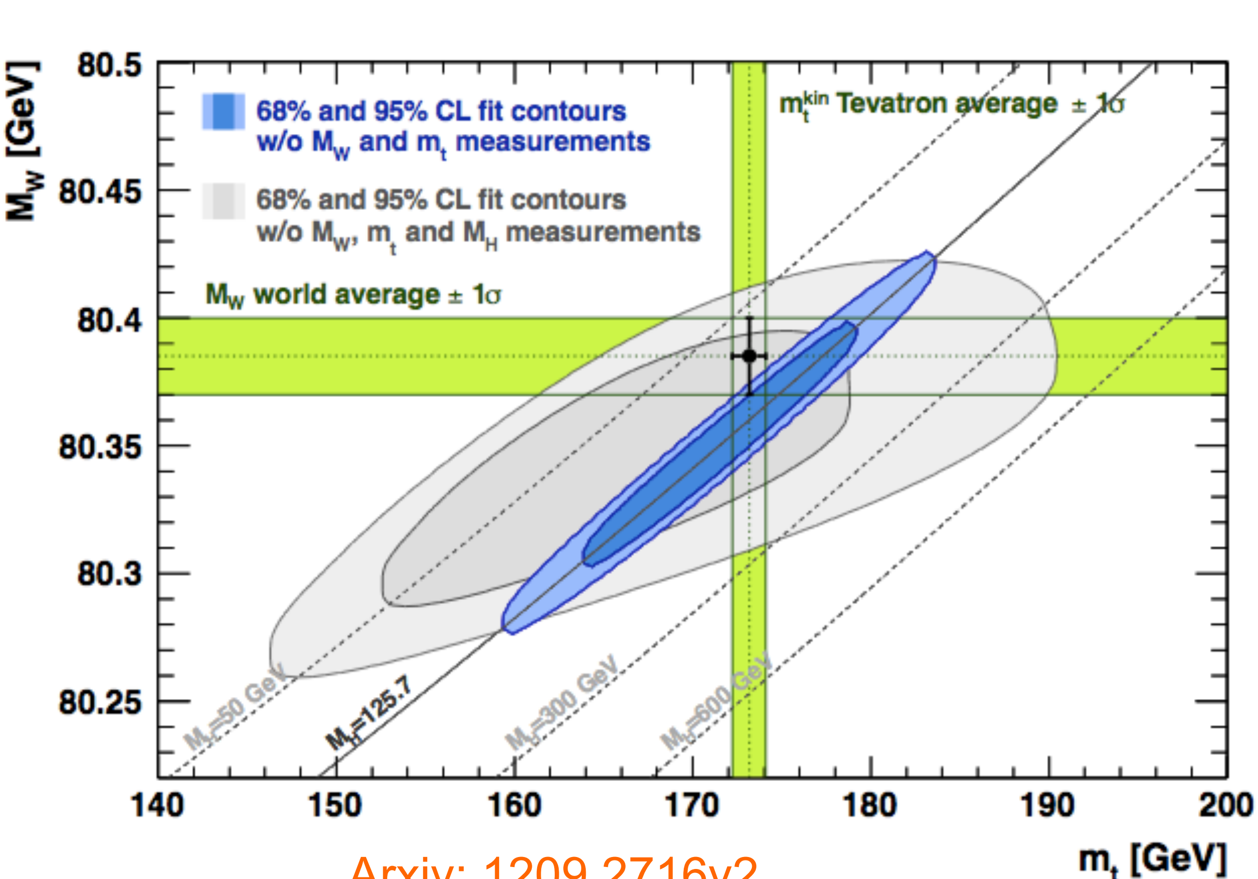
A Grand Success of Electroweak Theory

- Grey area: EWK fit excluding direct measurements of M_W , M_H and M_{top} .
- Green area: direct measurements of M_W and M_{top}.
- Blue area: EWK fit excluding measurements of M_W and M_{top} , including M_H
- Excellent agreement with theory



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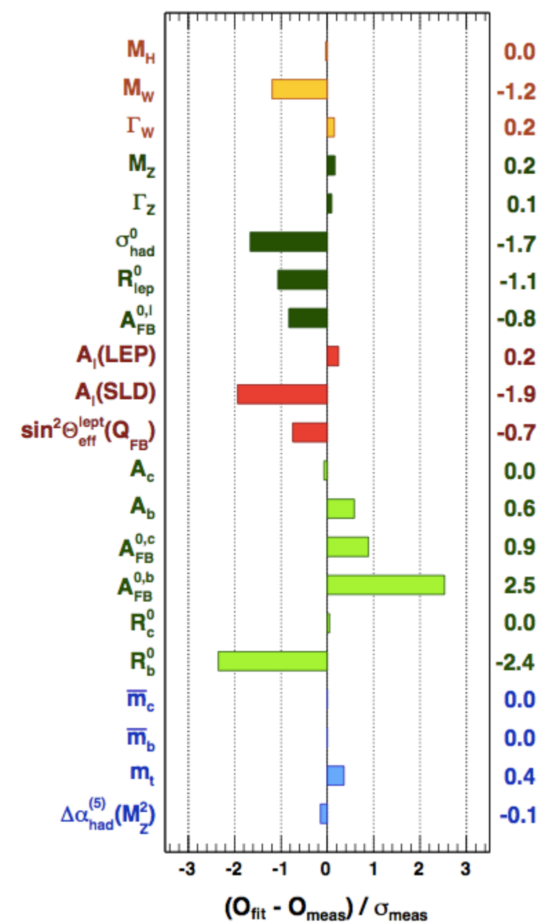


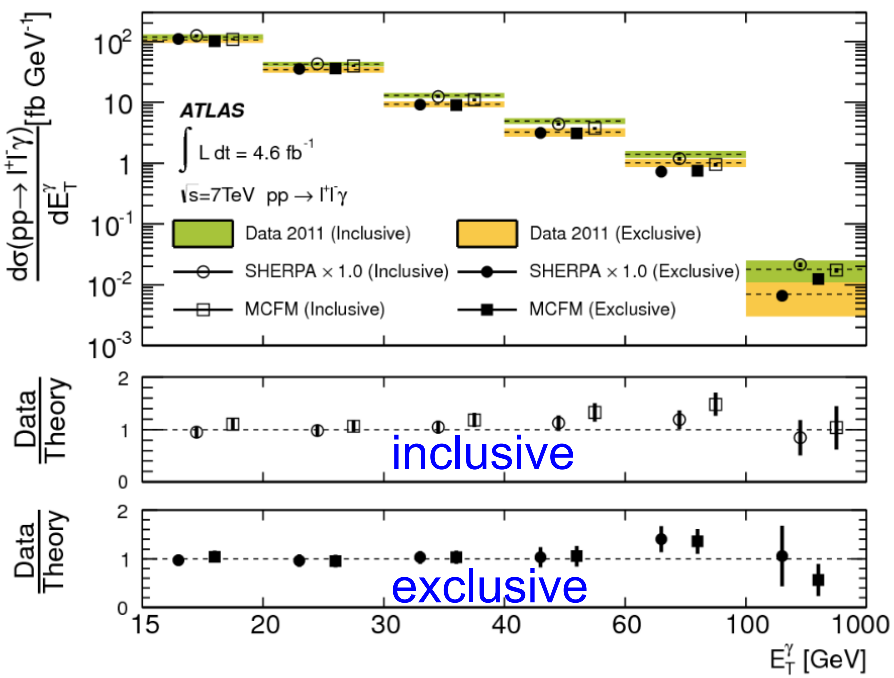
Zγ ($l^+l^-γ$) @ 7TeV

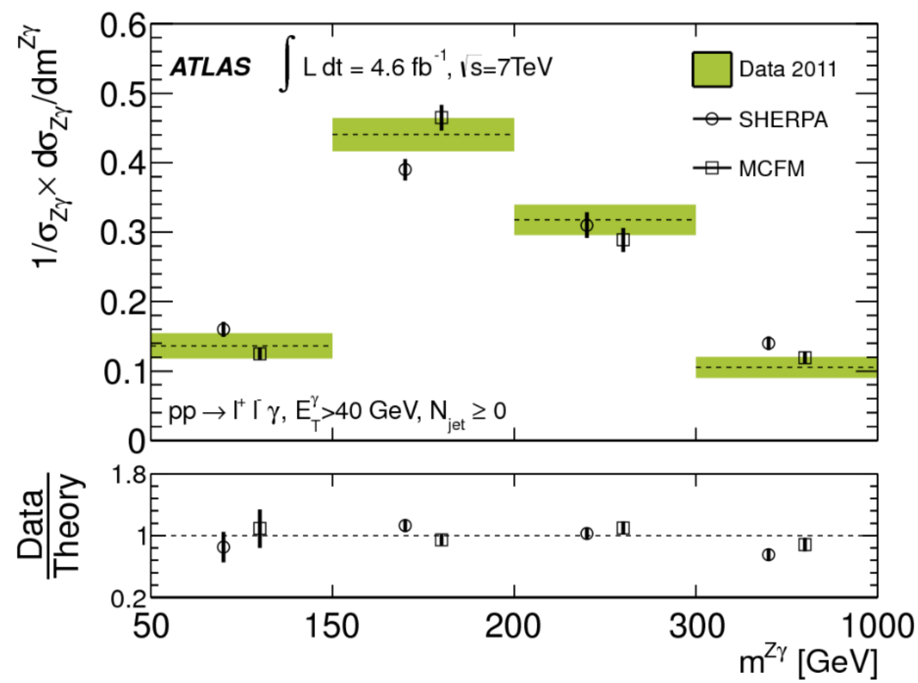
- First Zγ differential measurement:
  - Photon pT , jet multiplicity and Zγ mass spectrum
- Photon p_T measurements

Phys. Rev. D 87, 112003 (2013)

  - fair agreement with Sherpa and MCFM NLO predictions.

- Selection highlight
- ❑ 2 high pT lepton with pT>25GeV
- ❑ One isolated photon with pT>15GeV



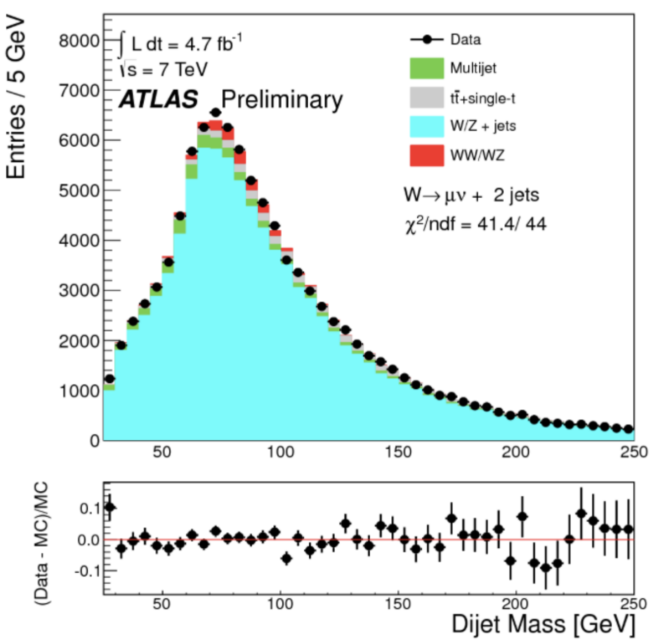


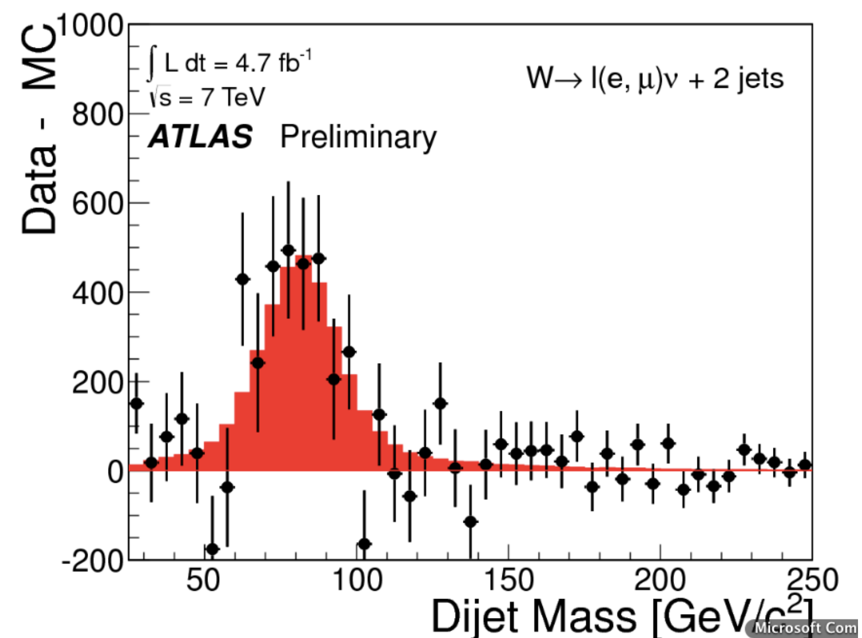
WW/WZ -> lvjj @7TeV

- Main backgrounds
  - W/Z + jets and ttbar
- Main systematics
  - Jet energy scale and resolution uncertainty
  - W+jet and ttbar dijet mass shape

- Selection highlights
  - ❑ One high pT lepton
  - ❑ large E_T^{Miss}
  - ❑ Exactly two jets

	dataset	Channel	Measured σ^{tot} [pb]	Theoretical σ^{tot} [pb]
7 TeV	4.6 fb^{-1}	$WW/WZ \to l\nu jj$	72 ± 9(stat.)±15 (syst.) ±13(MC stat.)	63.4 ± 2.6

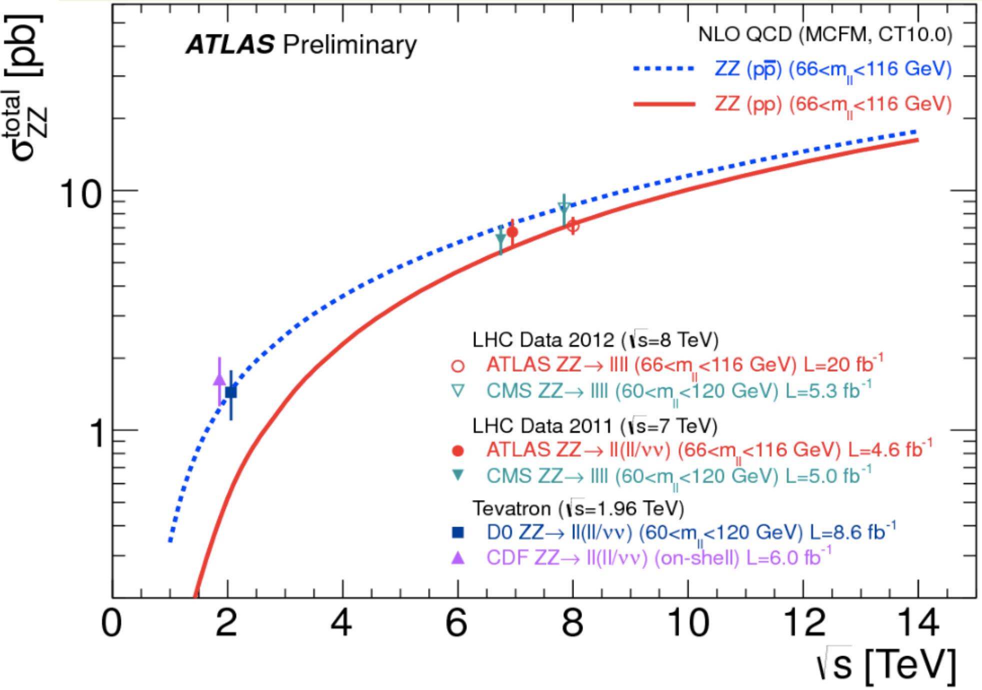




ZZ

- Latest 8TeV Moriond CONF note results and 7TeV results from ZZ paper

	dataset	Channel	Measured σ^{tot} [pb]	Theoretical σ^{tot} [pb]
7 TeV	4.6 fb^{-1}	$4l, 2l2\nu$	$6.7 \pm 0.7(\text{stat.})^{+0.4}_{-0.3}$ (syst.) ± 0.3(lumi.)	$5.89^{+0.22}_{-0.18}$
8 TeV	Moriond 2013 (20 fb^{-1})	$4l$	$7.1^{+0.5}_{-0.4}$(stat.)± 0.3 (syst.) ± 0.3(lumi.)	$7.2^{+0.3}_{-0.2}$



- ❑ Latest Moriond 8TeV CONF note results
  - ➢ Improved accuracy compared to 7TeV
  - ➢ Good agreement with SM expectation
  - ➢ Statistical uncertainty reduces compared to ICHEP 2012 results