Measurements of VV Boson Production And Self-Interactions in The Semileptonic Channel at CMS

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On behalf of the CMS Collaboration

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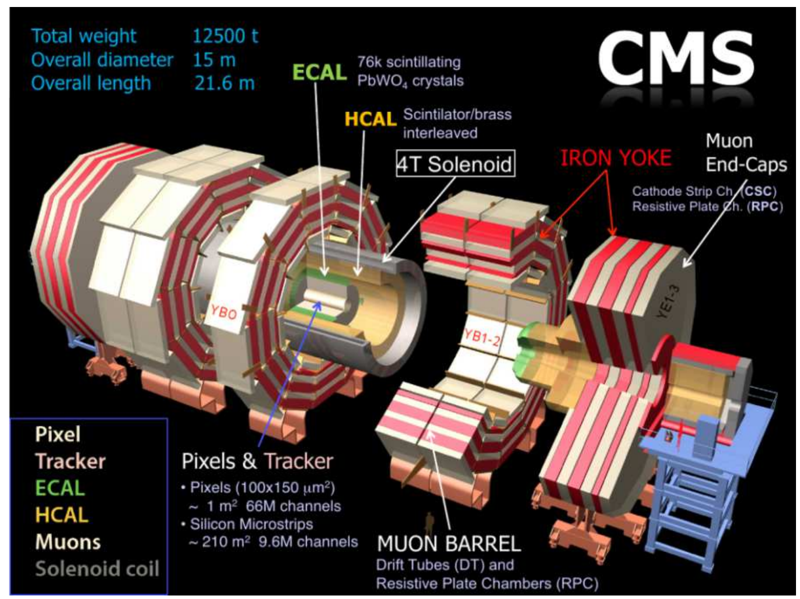
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP12015



Outline

- ❖ **Overview**
- ❖ **Challenges vs Advantages of the semileptonic channel**
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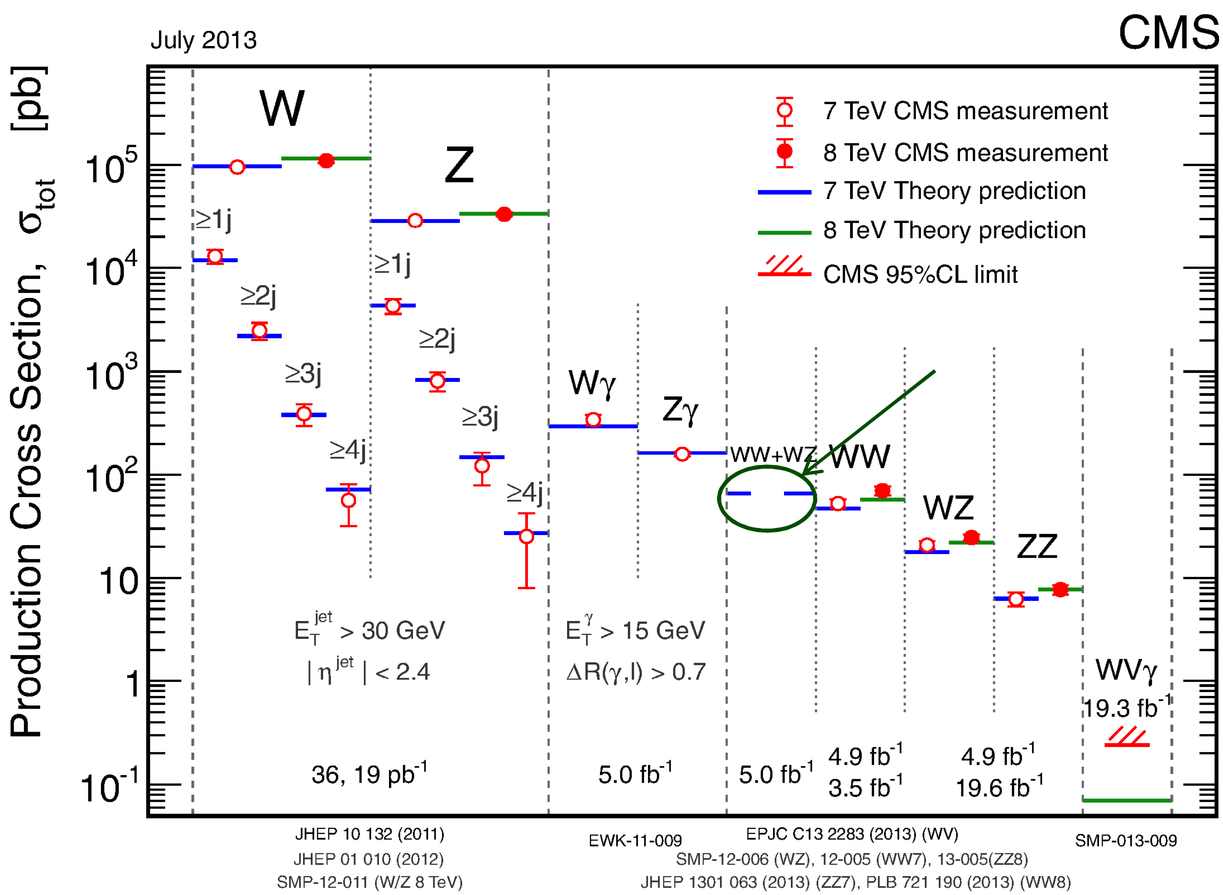
- ❖ **Conclusions**

Overview

❖ pp→W(→lν)+V(→ jj) @ √s = 7 TeV

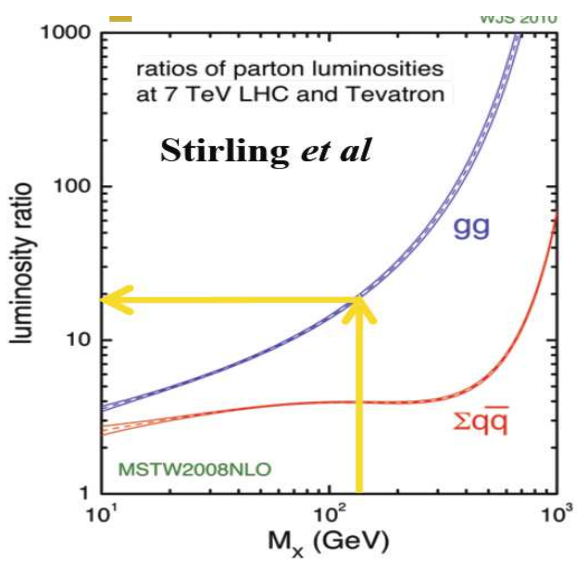


- **V = W or Z**
- **W vs Z mass difference ~resolution of the detector**
- **The reconstructed signal is WW+WZ**
- **Large backgrounds present for the semileptonic final state**

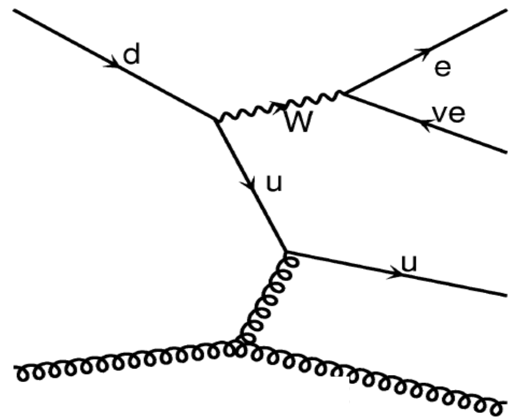
Challenges

❖ **Vast majority of events originate from the W+jets background**

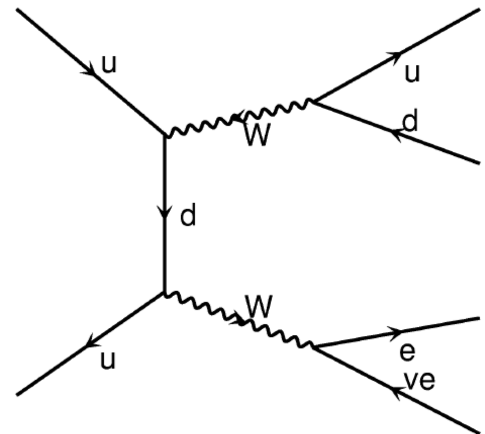
- **The production is dominated by quark-gluon scattering (vs. q-$\bar{q}$ at the Tevatron)**
- **σ_{W+jets}=3x10^{4}pb @NLO**



W+jj production via quark-gluon scattering



WW production via q-$\bar{q}$ annihilation



- **WW+WZ production is dominated by quark-antiquark collisions**
- **σ_{WW+WZ}≈70pb (mainly WW ~70%)**

❖ **The Signal to Background ratio is much worse at the LHC and stronger cuts as well as improved analysis techniques are needed**

Advantages

❖ **Why study the diboson production in the WW+WZ semileptonic channel ?**

Q. Why do you rob banks?

A. Because, that's where the money is.

- John Dillinger

❖ Higher Standard Model and Potential New Physics Signal Production Rates

- **Naturally extends to other diboson analyses with hadronic final states**
  - **Boosted topology and aTGC (Anomalous Triple Gauge Coupling) searches**
  - **Complimentary final states (e.g. W(→ jj)+γ, V(→ jj)+Z(→MET)).**
  - **Vector Boson Fusion studies**
- **Current Goals:**
  - **Confirm the WV signal in the semileptonic events at CMS**
  - **Set limits on Anomalous Triple Gauge couplings**
- **The work will serve as a benchmark for 8 and 13TeV measurements**

Object Selection

- Select μ, *e* , MET and reconstruct the W

Variable	Muons	Electrons
Single lepton trigger p_T threshold	24 GeV	25-32 GeV
offline p_T threshold	25 GeV	35 GeV
$\lvert\eta\rvert$	< 2.1	< 2.5, excluding 1.44 < $\lvert\eta\rvert$ < 1.57
W transverse mass (M_T)	> 30 GeV	> 50 GeV
Missing transverse energy (MET)	> 25 GeV	> 30 GeV
must be compatible with the primary vertex		
combined isolation $\Sigma_{\Delta R<0.3}$ ECAL+HCAL+tracker	< 10% muon p_T	< 5% electron p_T
secondary loose lepton veto, muon (electron) p_T > 10(20) GeV		

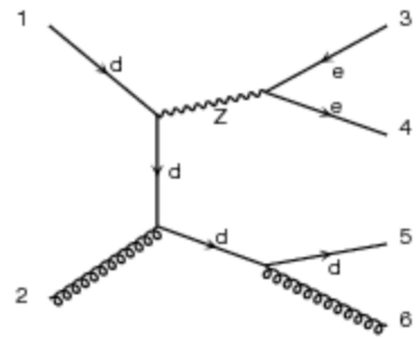
- Reconstruct (exactly) two jets and apply PileUp corrections

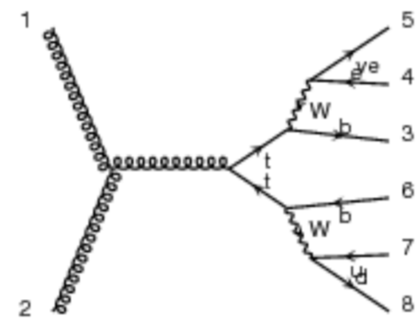
Variable	Value
Anti-k_T clustering distance parameter R	0.5
Jet Isolation from leptons Δ R	> 0.3
Jet p_T threshold	35 GeV
Jet $\lvert\eta\rvert$	< 2.6
Jet b-tag veto based on secondary vertex	

- Implement additional quality Cuts:
  - Designed to enhance S/B
  - Reduce the W+jets background by removing low p_T V candidates and jets with a high degree of separation
  - Dijet p_T^{jj}>20GeV, $\lvert\Delta\eta_{jj}\rvert$<1.5

Relevant Backgrounds

- **W+Jets (σ=3.1x10^{4}pb)**
  - **Dominant background**
  - **Significant effort made to reduce its contribution**
- **Z+Jets (σ=3.0x10^{3}pb)**
  - **Similar to W+Jets but smaller in amount**
  - **One of the leptons doesn't pass the selection requirements**
- **ttbar (σ=163pb)**
  - **Two real W's and two b-jets**
  - **Reduced by anti-btagging**
  - **Can identify the hadronic W and use as a control sample**
- **Single Top (σ=85pb)**
  - **One (leptonic) W and a b-jet**
  - **Reduced by anti-btagging**
- **QCD/Multijet**
  - **Taken from the Data sideband with inverted isolation**
  - **The yield is estimated based on MET fit**

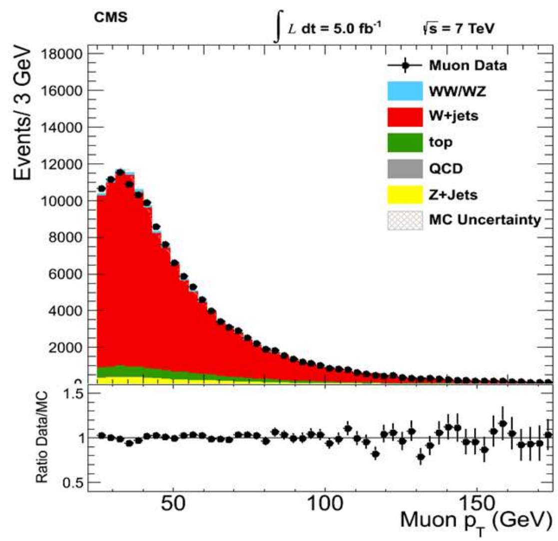


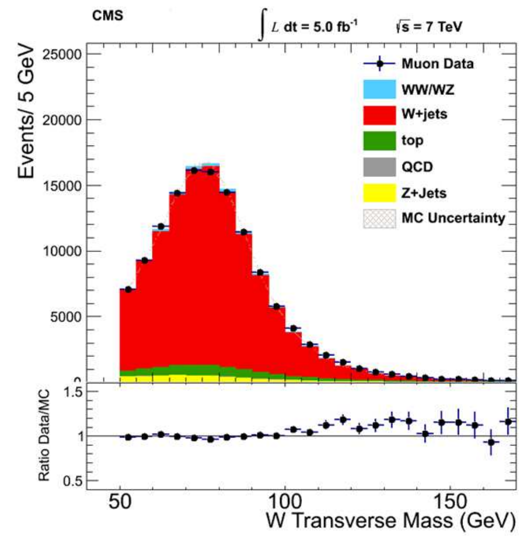


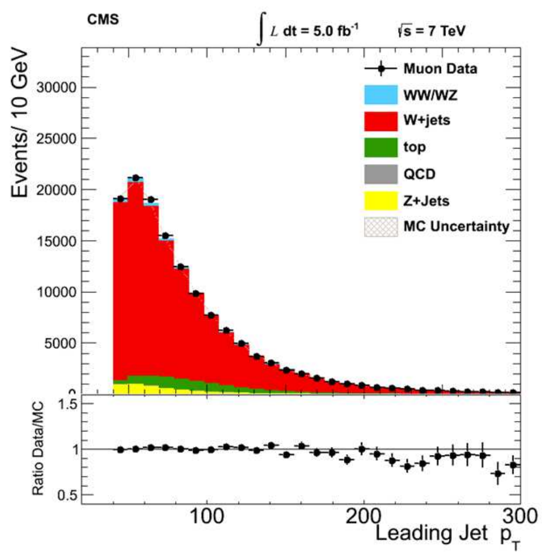
Data vs MC: Muon Channel

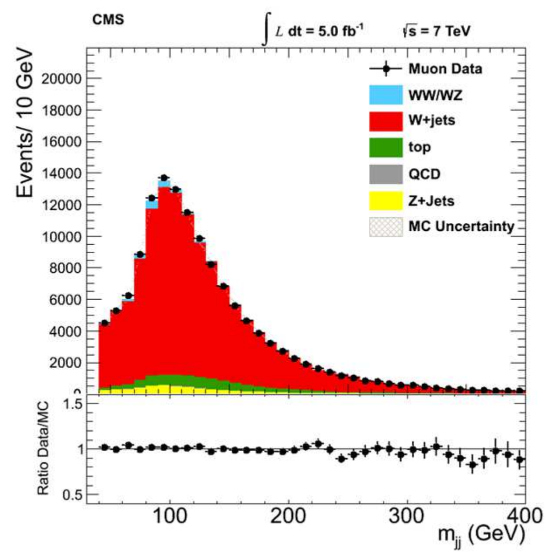
- **Overlay the relevant background simulation and scale the total yield to the data expectation**

- **Reasonable agreement between data and MC**





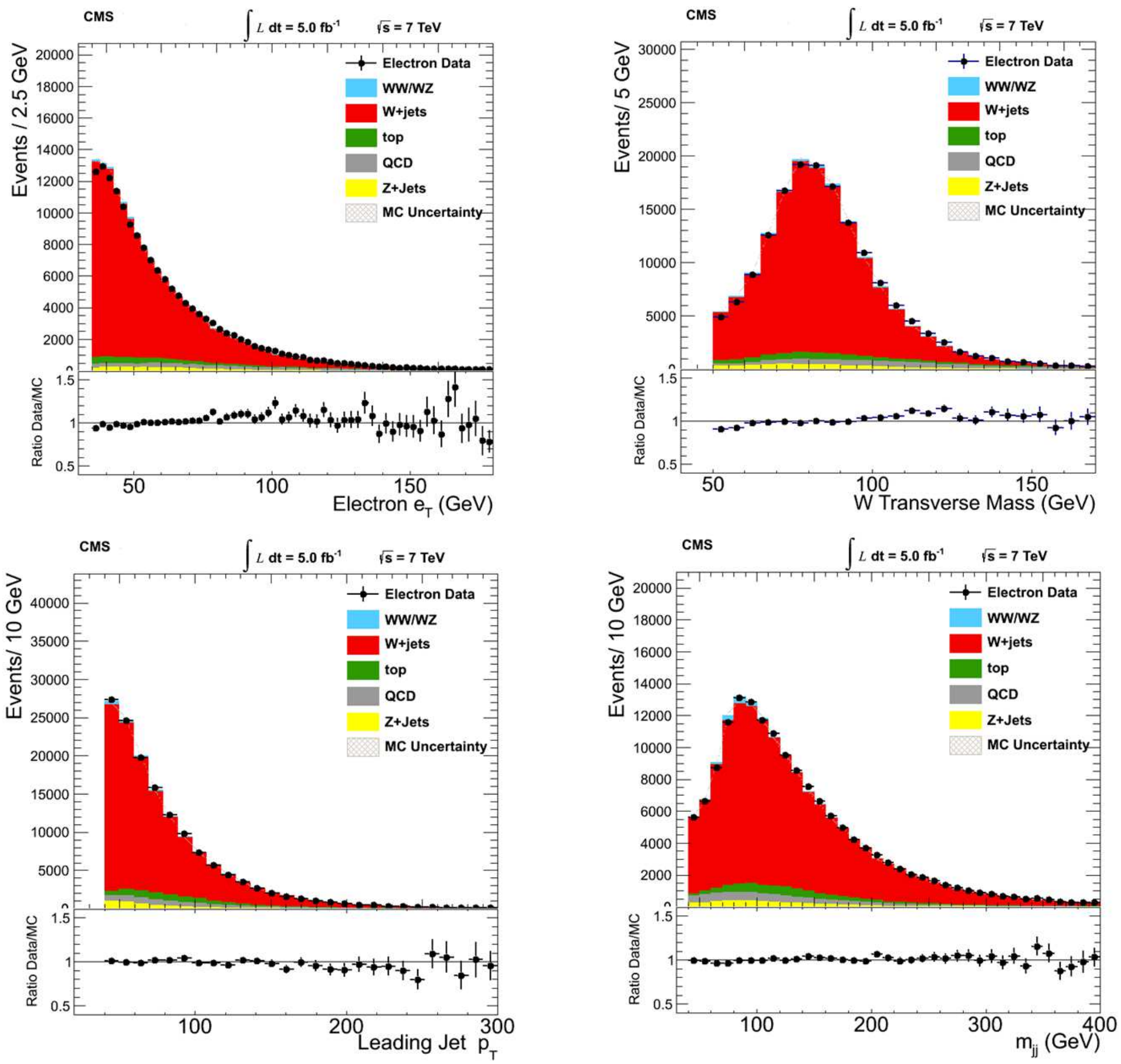




Data vs MC: Electron Channel

- **Overlay the relevant background simulation and scale the total yield to the data expectation**

- **Reasonable agreement between data and MC**



Fitting The M_{jj} Spectrum

- **Unbinned maximum likelihood for $40 < M_{jj} < 150$ GeV**
- **Shape templates taken from Monte Carlo (and multijet sideband)**
- **Two separate fits for muon and electron event yields (combine when evaluating the cross-section)**

Yield Constraints

Process	Shape	Constraint on normalization
Diboson (WW+WZ)	sim.	Unconstrained
W+jets	sim.	31314 pb ± 5% (NLO) [24]
$t\bar{t}$	sim.	163 pb ±7% (NLO) [25]
Single top	sim.	85 pb ±5% (NNLO) [26–28]
Drell-Yan+jets	sim.	3.05 nb ±4.3% (NNLO) [29]
Multijet	data	E_T^{miss} fit in data (see text)

- **The background contributions are free to float subject to Gaussian constraints.**

❖ **W+jets shape is a combination of:**
- **Default (MADGRAPH) MC**
- **Either Matrix Element - Parton Shower Matching Up ($\mu=2\mu_0$) or Matching Down ($\mu=0.5\mu_0$) MC**
- **Either Factorization Scale Up ($q'=2q_0$) or Scale Down ($q'=0.5q_0$) MC**

❖ **The choice of Up or Down Sample is based on the best fit to the Data**

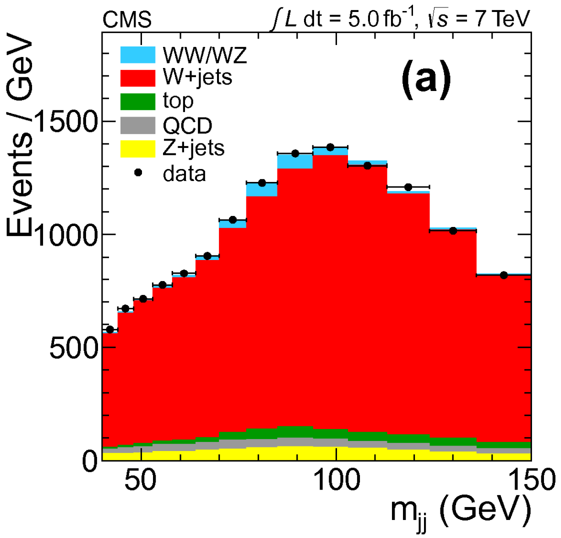
❖ **The relative fractions (α,β) are free to vary in the fit (empirical model):**

$$\mathcal{F}_{\mathrm{W+jets}} = \alpha \cdot \mathcal{F}_{\mathrm{W+jets}}(\mu_0^2, q'^2) + \beta \cdot \mathcal{F}_{\mathrm{W+jets}}(\mu'^2, q_0^2) + (1-\alpha-\beta)\cdot \mathcal{F}_{\mathrm{W+jets}}(\mu_0^2, q_0^2)$$

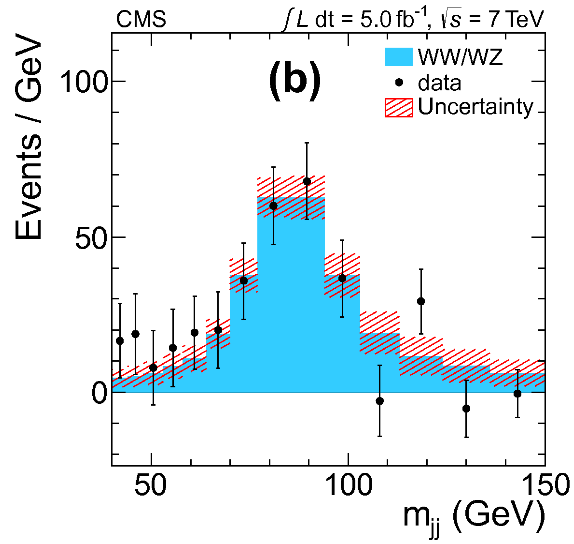
❖ **Diboson contribution is free to float during the fit**

Fit Output

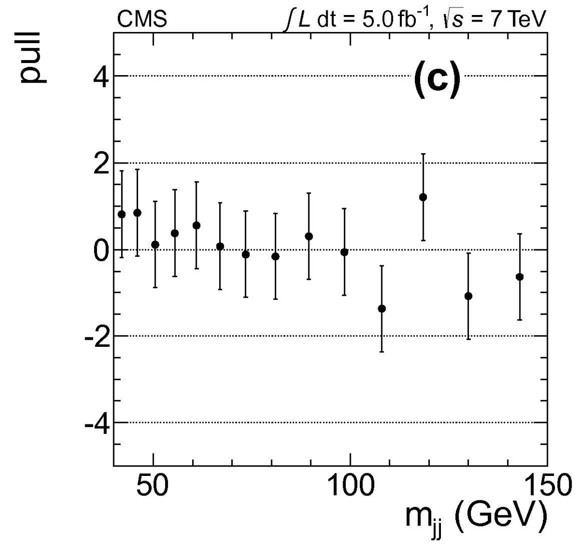
Mjj Fit Result



All SM backgrounds, except WW+WZ subtracted



Normalized Residual: [Data - Fit]/FitUncertainty



Process	Muon channel	Electron channel
Diboson (WW+WZ)	1899 ± 373	783 ± 306
W+jets	67384 ± 586	31644 ± 850
$t\bar{t}$	1662 ± 117	946 ± 67
Single top	650 ± 33	308 ± 17
Drell–Yan+jets	3609 ± 155	1408 ± 64
Multijet (QCD)	296 ± 317	4195 ± 867
Fit χ^2/dof (probability)	9.73/12 (0.64)	5.30/12 (0.95)
Total from fit	75420	39371
Data	75419	39365
Acceptance × efficiency ($\mathcal{A}\varepsilon$)	5.153×10^{-3}	2.633×10^{-3}
Expected WW+WZ yield from simulation	1697 ± 57	867 ± 29

- **We extract 2682±482 WW+WZ events out of 1.15×10^5.**
- **Signal significance is 8.8σ using a simple likelihood ratio and 4.3σ using the profile likelihood ratio.**

WW+WZ Cross-Section

❖ **Systematic Uncertainties:**

➢ **We validate the fitter by performing pseudo-experiments (with correlations taken into account) and correct the yields & errors based on the resulting pull distributions. The procedure also covers the uncertainty due to limited MC.**

➢ **W+jets shape error, as well as uncertainties due to the choice of ME-PS matching and Factorization/Renormalization scale are covered by the empirical model**

➢ **Uncertainties due to JES, JER, MET resolution, trigger efficiency, lepton reconstruction & selection efficiency, choice of parton PDF, jet veto and luminosity are subsequently included.**

- Trigger Efficiency - 1%
- Lepton Reconstruction and selection efficiency - 2%
- Jet Energy scale - 0.6%
- Missing Transverse Energy Resolution - 0.5%
- Fit uncertainty - 0.2%
- Luminosity Determination - 2.2%
- Theory uncertainty on acceptance - 4%

❖ **$\sigma(pp \to WW+WZ) = 68.9 \pm 8.7$ (stat.) ± 9.7 (syst.) ± 1.5 (lum.) pb**

❖ **We measure the diboson cross-section consistent with the Standard Model expectation of 65.6 ± 2.2 pb.**

Anomalous Triple Gauge Couplings

❖ **Extend the Electro-Weak Lagrangian**

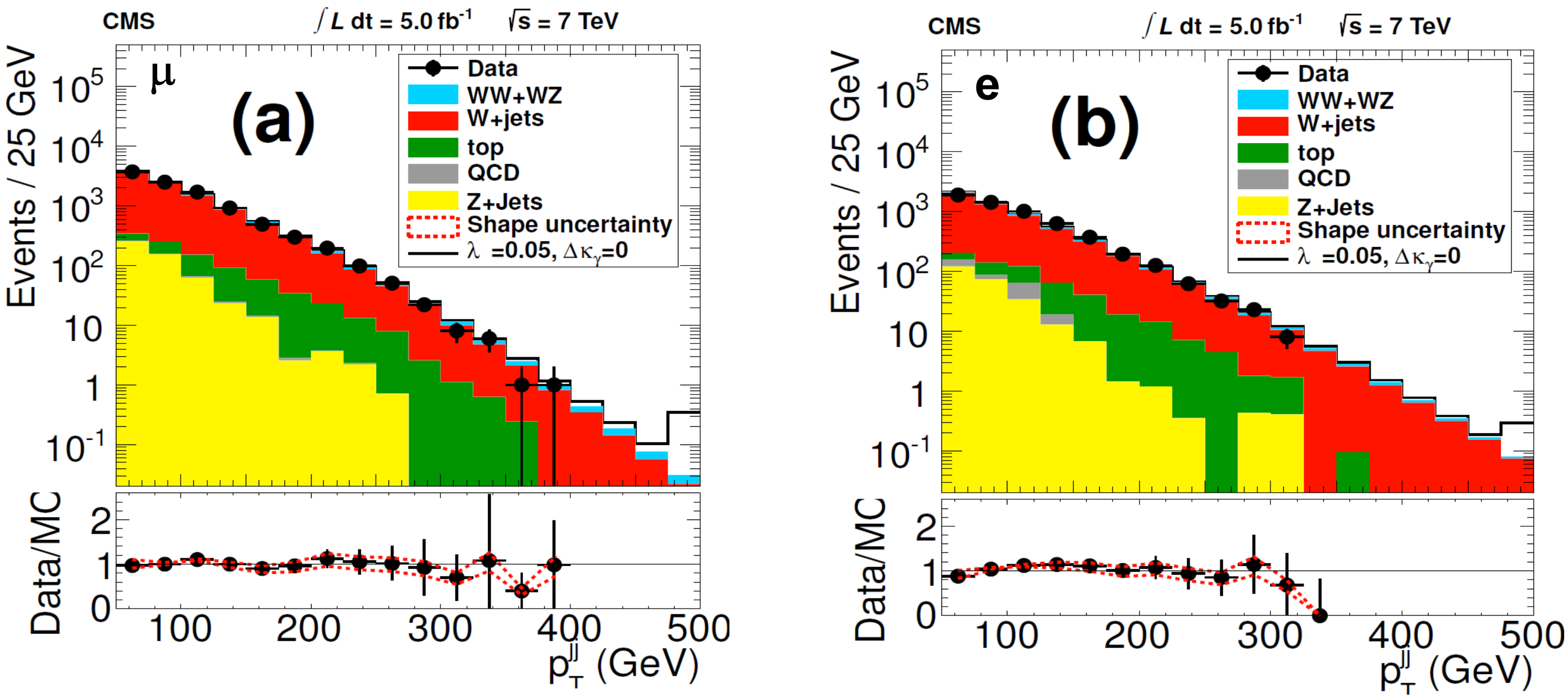
$$\frac{\mathcal{L}_{eff}^{VWW}}{g_{VWW}} = ig_1^V(W_{\mu\nu}^* W^\mu V^\nu - W_\mu^* V_\nu W^{\mu\nu}) + i\kappa_V W_\mu^* W_\nu V^{\mu\nu} + i\frac{\lambda_V}{M_W^2} W_{\lambda,\mu}^* W_\nu^\mu V^{\nu\lambda}$$
$$- g_4^V W_\mu^* W_\nu(\partial^\mu V^\nu + \partial^\nu V^\mu) + g_5^V \epsilon^{\mu\nu\lambda\rho}(W_\mu^*\partial_\lambda W_\nu - \partial_\lambda W_\mu^* W_\nu)V_\rho$$
$$+ i\tilde{\kappa}_V W_\mu^* W_\nu \tilde{V}^{\mu\nu} + i\frac{\lambda_V}{M_W^2} W_{\lambda\mu}^* W_\nu^\mu \tilde{V}^{\nu\lambda}$$

- **Lorentz invariant**
- **V=Z, γ**

- **Require that C and P be conserved separately: $g_4^V = g_5^V = \tilde{\kappa}_V = \tilde{\lambda}_V = 0$**
- **EM gauge invariance: $g_1^\gamma = 1$**
- **Redefine: $g_1^Z = 1 + \Delta g_1^Z$, $\kappa_V = 1 + \Delta\kappa_V$**
- **aTGCs: $\Delta g_1^Z \neq 0$, $\Delta\kappa_V \neq 0$, $\lambda_V \neq 0$ for any of the five couplings represents a deviation from the SM**
  - **New particles present at tree level**
  - **Loop effects of heavy particles**
  - **Non-abelian structure of the gauge sector**
- **Assuming the presence of a Higgs doublet, SU(2)xU(1) gauge invariance and considering up to dimension 6 operators:**
  - **$\lambda_Z = \lambda_\gamma = \lambda$**
  - **$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma * \tan^2\theta_w$**

aTGC Searches

❖ **Examine the hadronic V→jj p_T distributions**

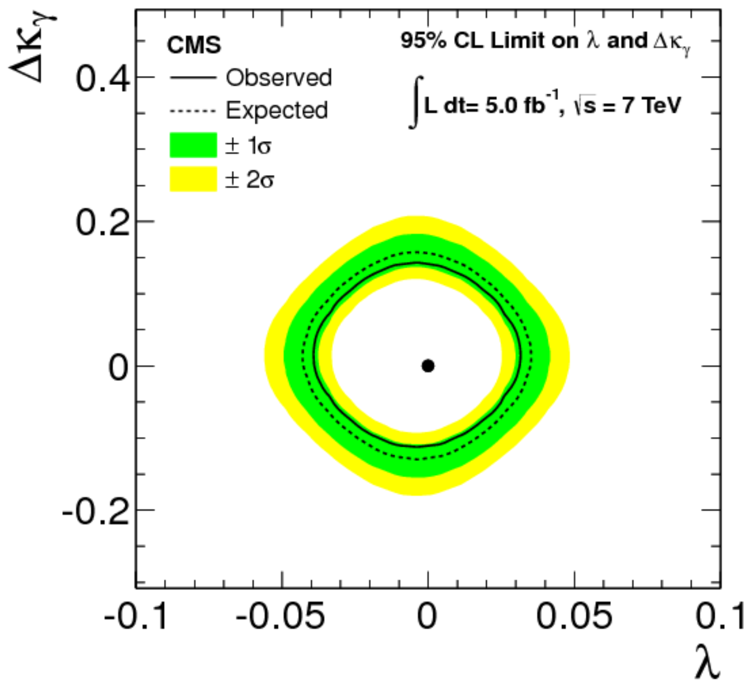


➢ **Place a 75 < m_{jj} < 95 GeV cut to enhance signal purity**

➢ **Normalize the backgrounds based on fit results**

➢ **The last bin includes overflow events**

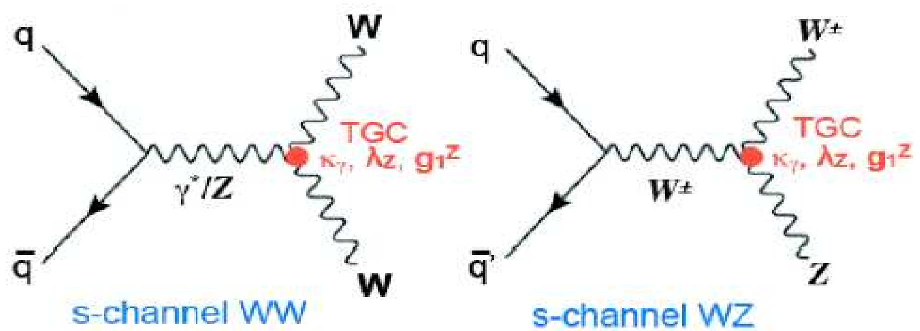
aTGC Limits



- aTGC dependence is modeled by reweighting SM Diboson MC to MCFM predictions
- Systematics due to luminosity, signal selection efficiency, signal shape, and from the normalization and shape of the SM processes are accounted for
- CLs (a modified frequentist construction) with profile likelihood as a test statistic is used to set limits
- Δg_1^Z is small and we take it to be 0

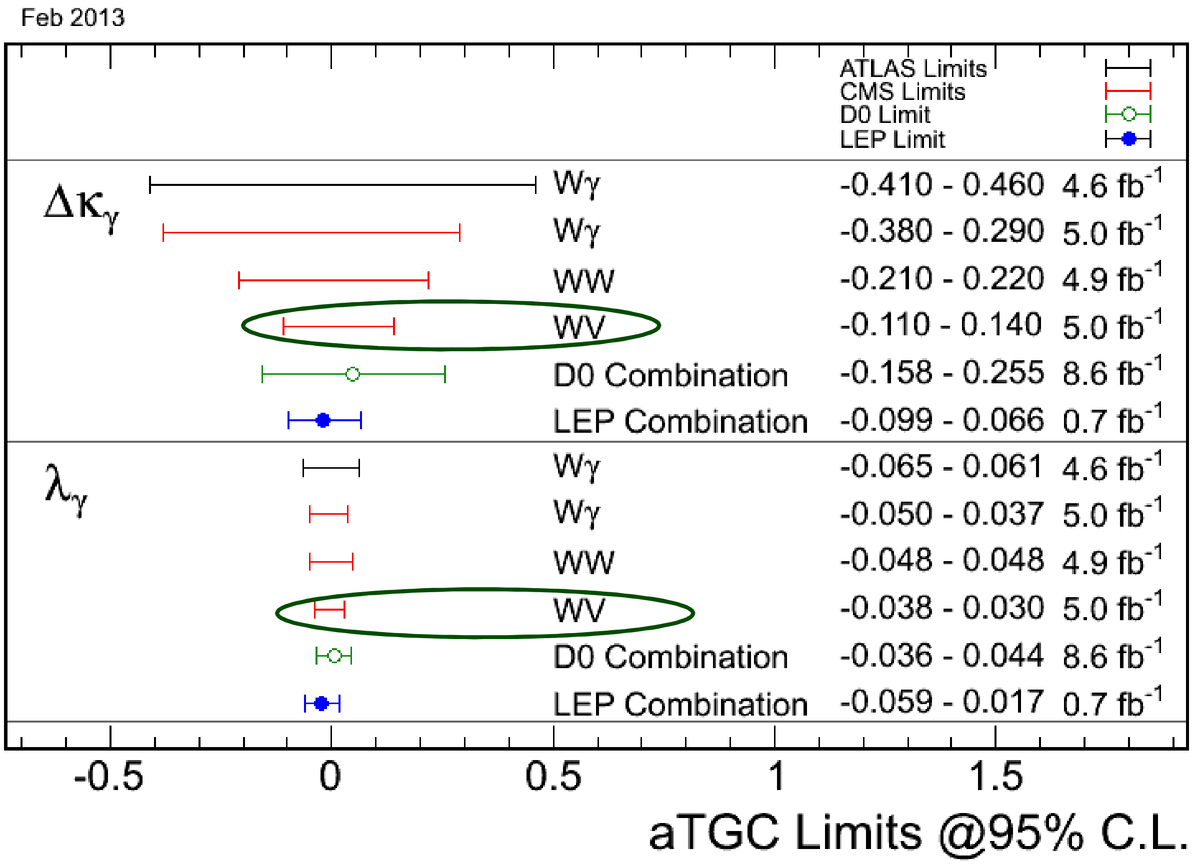
1D Limits:

- $-0.038 < \lambda_Z < 0.030$
- $-0.111 < \Delta\kappa_\gamma < 0.142$



aTGC Limits In Context

❖ Compare to other analyses and experiments



- Improve upon the limits from the fully leptonic channels due to a higher branching ratio
- Competitive with the LEP Combination

Conclusions

- **Studying the WV semileptonic final states gives us access to higher signal yields at the expense of dealing with much higher background rates**

- **WW+WZ cross-section measurement**
  - **Defined a set of cuts and made Data vs Monte Carlo Comparisons**
  - **Performed a template fit to the data**
  - **Extracted the signal yield and accounted for systematics**
  - **σ_{WW+WZ} = 68.9 ± 8.7 (stat.) ± 9.7 (syst.) ± 1.5 (lum.) pb, consistent with the Standard Model prediction**

- **Anomalous Triple Gauge Couplings**
  - **Reduced the number of aTGC couplings by assuming C, P, EM and SU(2)xU(1) invariance**
  - **Dijet p_T spectrum was used to compare the Standard Model to aTGC signal**
  - **No evidence for deviations from the SM is found**
  - **We set limits of $-0.038 < \lambda_Z < 0.030$, $-0.111 < \Delta\kappa_\gamma < 0.142$, an improvement upon the leptonic channels and competitive with LEP.**

- **Future versions of the analysis to include boosted topology and extension to similar diboson final states with hadronic decays**

Backup