WW+WZ cross section & anomalous gauge couplings using semileptonic final state ($l\nu jj$)

Kalanand Mishra

Fermilab

On behalf of the WW→ ℓ νjj analysis team

☆ = Plot/table seeking approval

SMP approval Meeting, July 31, 2012

The team

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Acknowledgements

- **We sincerely thank our ARC members for their time and effort getting our analysis to this point.**
    - **Dimitri Bourilkov**
    - **Vitaliano Ciulli**
    - **Helen Heath**
    - **Mayda Velasco (chair)**

- **We would also like to thank our conveners for their support.**

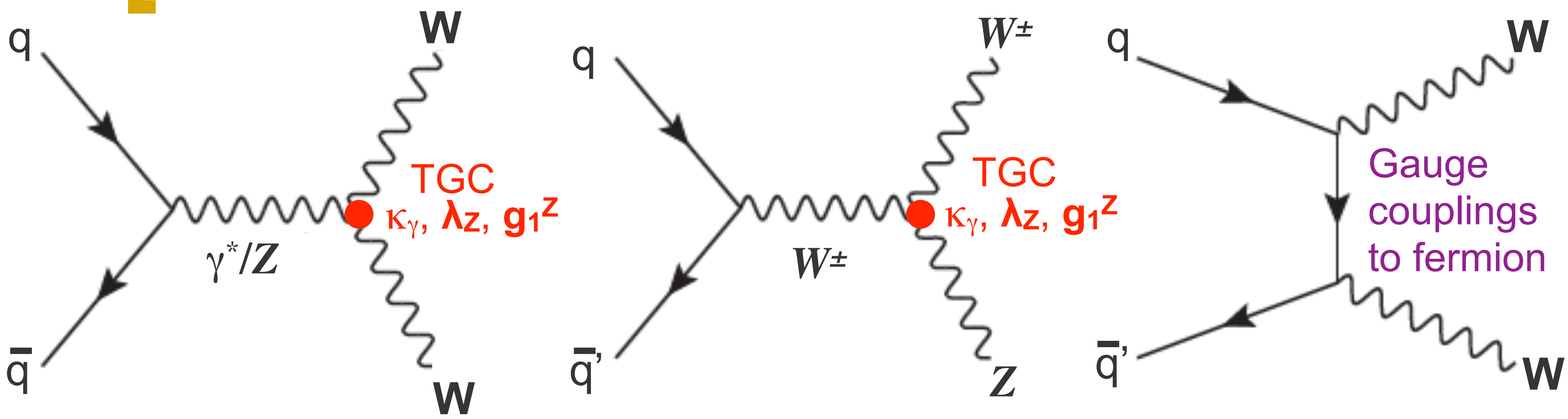
The analysis

- **Cadi/Paper**
  - http://cms.cern.ch/iCMS/analysisadmin/cadi?ancode=SMP-12-015
- **Hypernews**
  - https://hypernews.cern.ch/HyperNews/CMS/get/SMP-12-015.html
- **Twiki**
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP12015
- **Analysis note:**

  AN-2012/224
- **Review Q &A**
  - https://twiki.cern.ch/twiki/bin/viewauth/CMS/SMP-12-015-ARC

Measurement of Diboson Cross-section

Diboson production at LHC at Leading Order in α_s



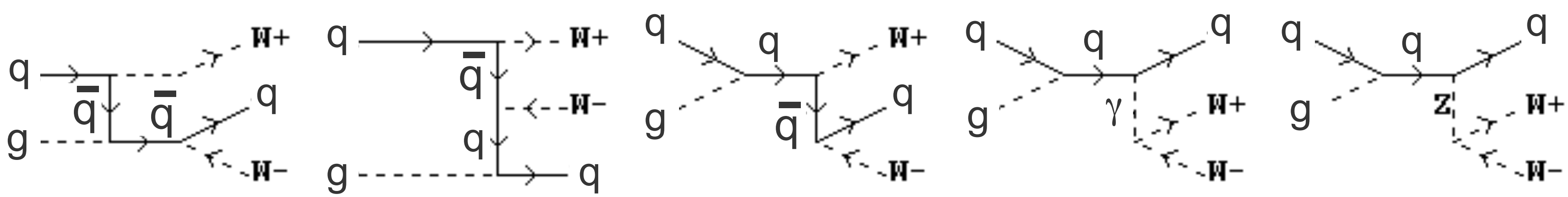
s-channel WW

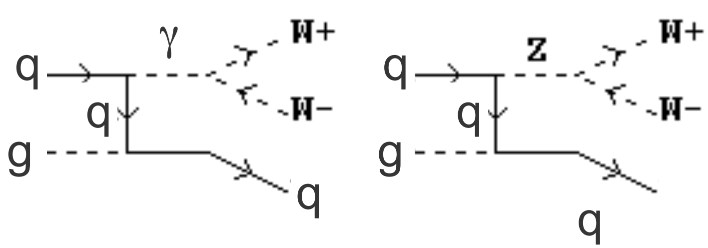
s-channel WZ

t-channel WW (similar diagrams for WZ, ZZ)

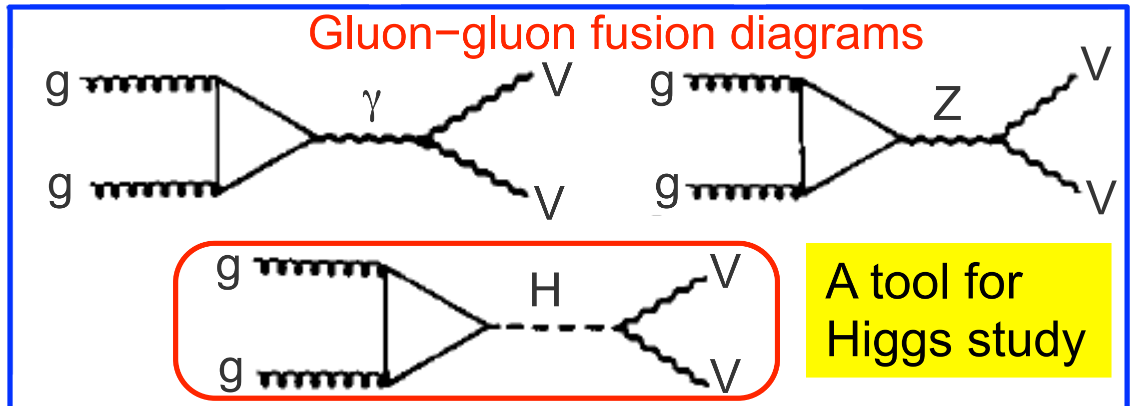
- ✦In SM, the s- and t-channel WW diagrams are divergent but their sum is not. Important milestone for LHC physics program.
- ✦Allow test of triple−gauge couplings (TGC).
- ✦Background to Higgs.

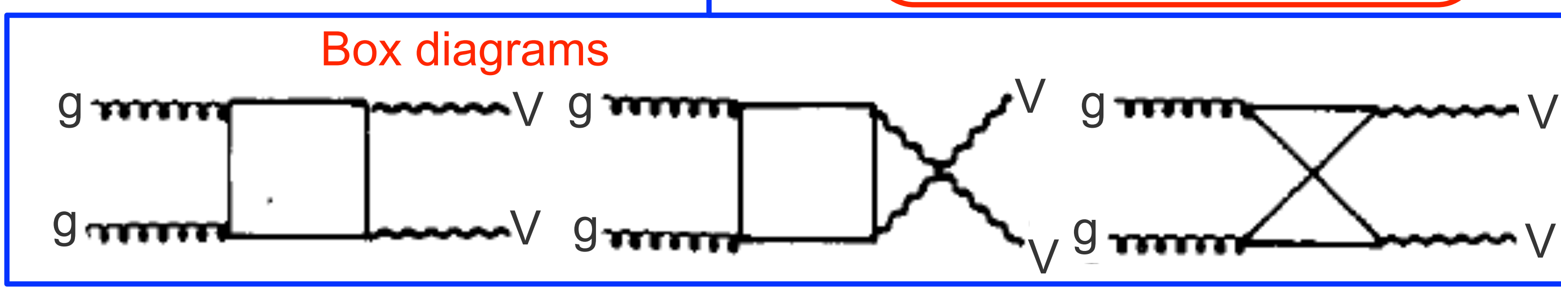
Significant contribution from NLO (≳50% of LO)





Quark−gluon diagrams





Plus vector boson fusion diagrams

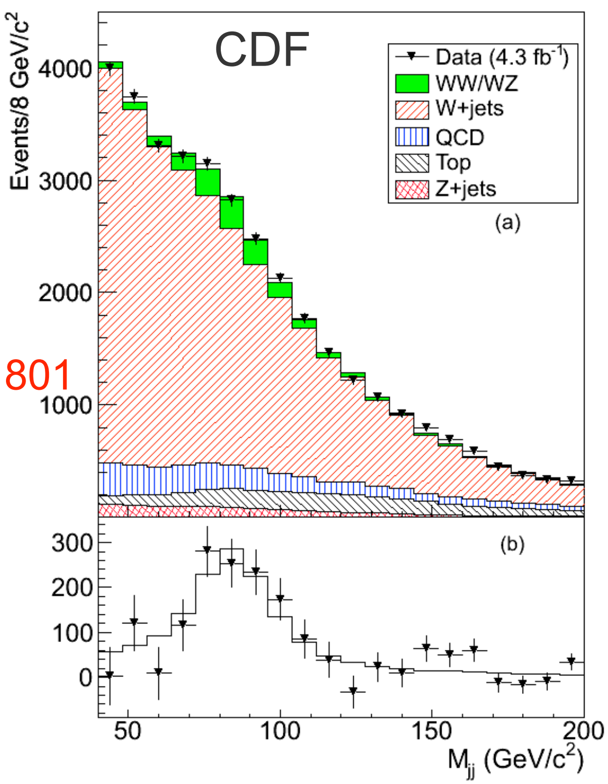
Previous measurements at hadron colliders

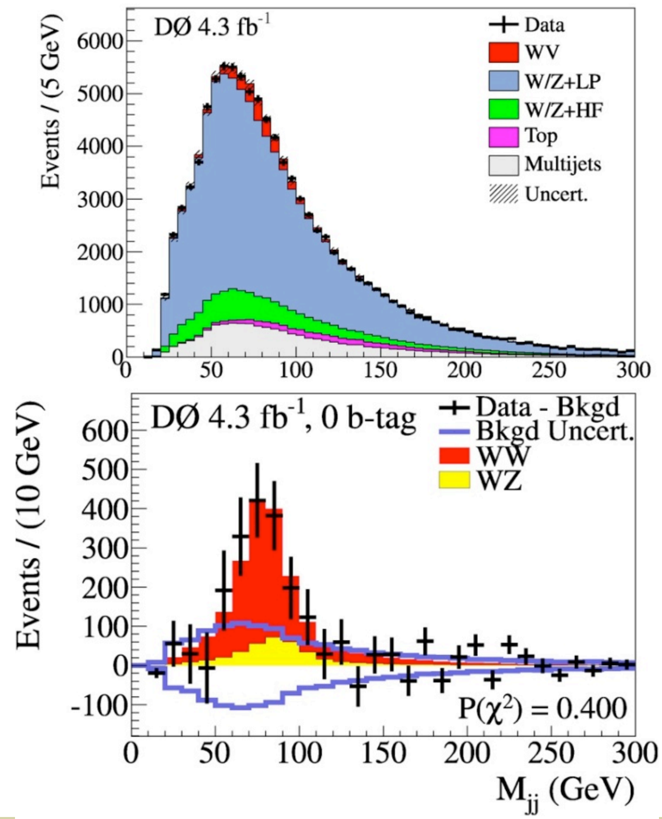
CDF and D0 have publications with 5σ significance in the last 1–2 years:

http://www-cdf.fnal.gov/physics/ewk/2010/WW_WZ/

http://www-d0.fnal.gov/Run2Physics/WWW/results/final/EW/E11E/

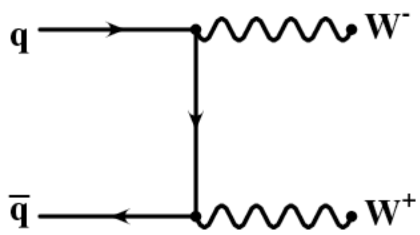
PRL 104, 101801 (2010), arXiv: 0911.4449

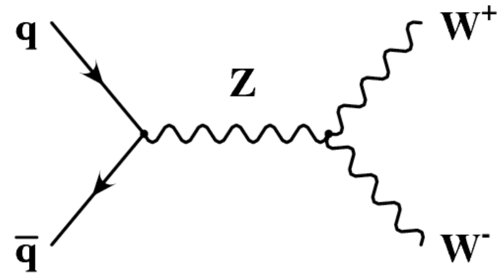


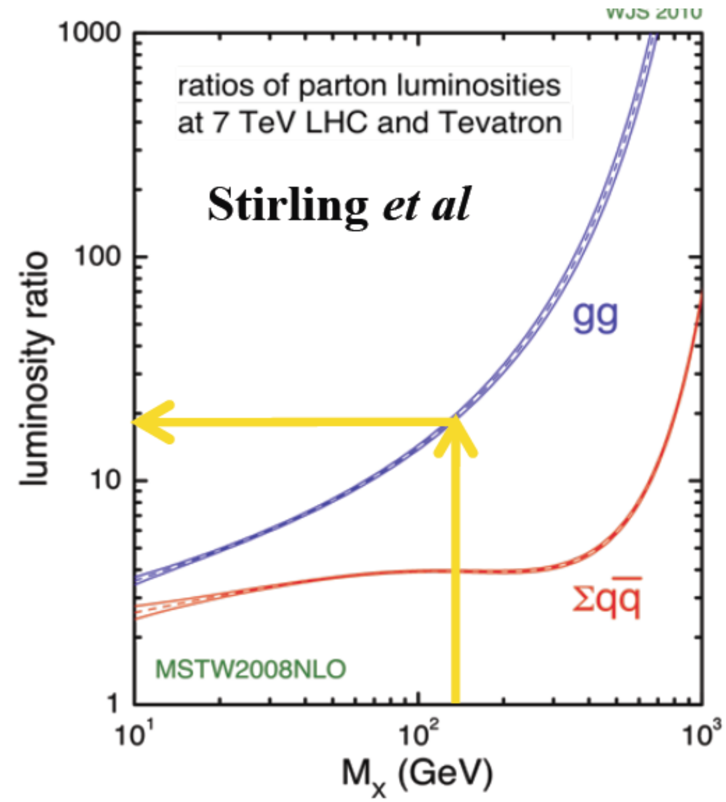


PRL 108,181803 (2012), arXiv: 1112.0536

Diboson in semi-leptonic channel







- **The WW+WZ Signal is dominated by qqbar diagrams and the luminosity ~3x higher at 7TeV (vs. 2TeV)**
- **The dominant background (W+Jets) increases 20x due to qg and gg processes**

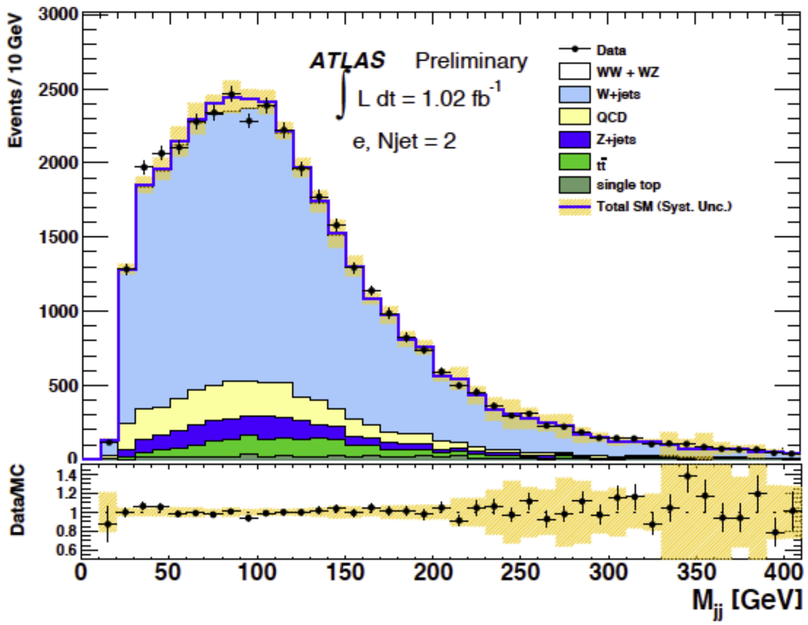
Compared to purely leptonic decay mode:

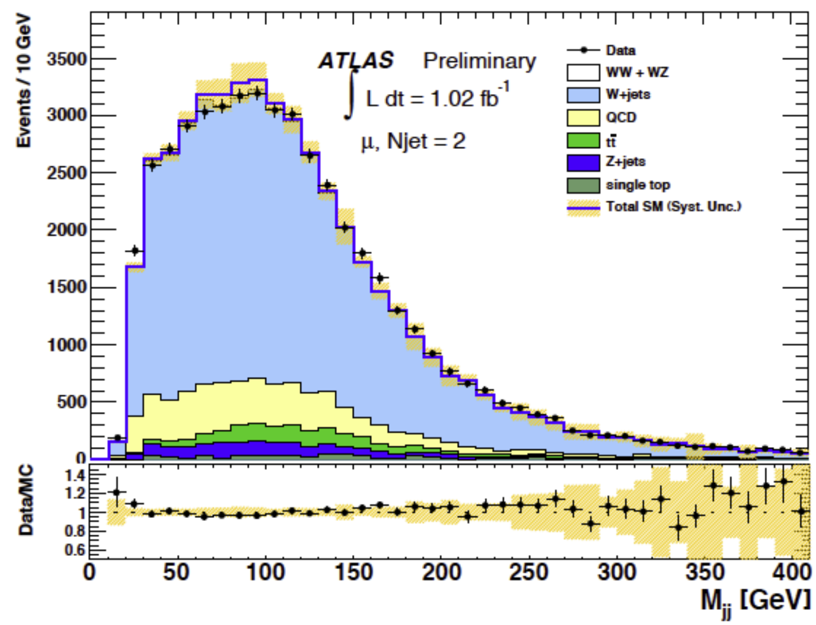
•S/B much worse → stronger cuts need to be applied to extract the signal
•Hard to generate as large a background MC sample as seen in data

But 6x larger branching ratio. Clear mass peak. Access to higher boson p_T and diboson mass.

ATLAS

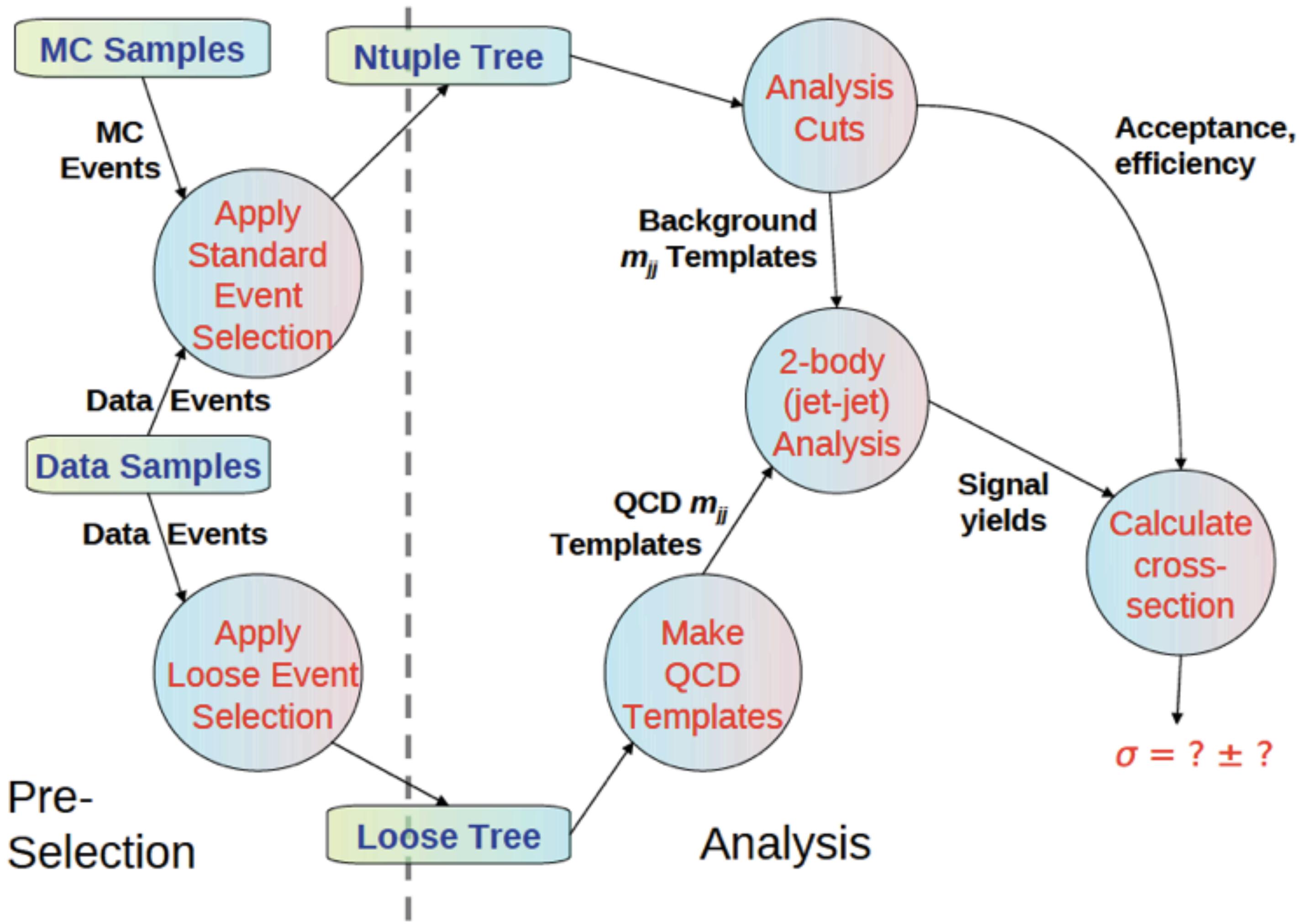
ATLAS doesn't yet have a paper/public result on this topic. The closest ones are:
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-097/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2011-09/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-018/





Presented at EPS : ATLAS-CONF-2011-097 (1.02fb^{-1}). Excessive Wjj background. No Visible Diboson Peak. Large Systematic Uncertainties.

Technical overview of CMS analysis



Dataset & MC samples: use full 2011 data

Data

Dataset name	Run range
/EG/Run2010A-Apr21ReReco-v1/AOD /Mu/Run2010A-Apr21ReReco-v1/AOD	136033 - 144114
/Electron/Run2010B-Apr21ReReco-v1/AOD /Mu/Run2010B-Apr21ReReco-v1/AOD	144919 - 149442
/SingleElectron/Run2011A-May10ReReco-v1/AOD /SingleMu/Run2011A-May10ReReco-v1/AOD	160431 - 163869
/SingleElectron/Run2011A-PromptReco-v4/AOD /SingleMu/Run2011A-PromptReco-v4/AOD	165088 - 167913
/SingleElectron/Run2011A-05Aug2011-v1/AOD /SingleMu/Run2011A-05Aug2011-v1/AOD	170826 - 172619
/SingleElectron/Run2011A-PromptReco-v6/AOD /SingleMu/Run2011A-PromptReco-v6/AOD	172620 - 173692
/SingleElectron/Run2011B-PromptReco-v1/AOD /SingleMu/Run2011B-PromptReco-v1/AOD	175832 - 180252

Triggers

For electron use:
Ele_25/32/35_WmT40/50

For muons:
IsoMu_24 || IsoMu_17 || Mu_20 || Mu30 || Mu40

Fall 11 MC: Processed in CMSSW 4_2_X

sample
/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/TTJets_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v2/AODSIM
/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/Tbar_TuneZ2_s-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/Tbar_TuneZ2_t-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/Tbar_TuneZ2_tW-channel-DS_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/T_TuneZ2_s-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/T_TuneZ2_t-channel_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/T_TuneZ2_tW-channel-DS_7TeV-powheg-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WW_TuneZ2_7TeV_pythia6_tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WZ_TuneZ2_7TeV_pythia6_tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM

Object selection: muons

- Trigger: IsoMu17, IsoMu20, IsoMu24, IsoMu30, Mu40.
- Reconstructed as both global & tracker muon
- p_T > 25 GeV, $|\eta|$ <2.1
- Quality Requirements: Standard VBTF Selection
  - Reconstructed as a Global and Tracker Muon
  - ≥10 tracker hits, ≥1 pixel hits (Tracker track)
  - ≥2 muon hits of the Global track
  - $\chi 2$/ndf < 10 global fit
  - Impact parameter |dxy|<0.02 cm (w.r.t. the beam spot)
- Combined Relative Isolation (R=0.3, PU density corrected) < 0.1
- W_{mT}>30GeV (PF MET > 25 GeV)

Object selection: electrons

- Trigger: Ele25, Ele27, Ele32 (with cut on W transverse mass).

- ECAL seeded gsf electrons
- E_T > 35 GeV, $|\eta|$ <2.5 (excluding 1.44 < $|\eta|$ <1.57)

- WP70 + Isolation Requirements: Standard VBTF Selection
- https://twiki.cern.ch/twiki/bin/view/CMS/SimpleCutBasedEleID

Conversion Rejection	
missing hits $\leq$	0
Dist	0.02
$\Delta cot\theta$	0.02

Combined Isolation		
Electron ID	EB	EE
$\sigma_{i\eta i\eta}$	0.01	0.03
$\Delta\phi$	0.03	0.02
$\Delta\eta$	0.004	0.005
		0.025

- W_{mT}>50GeV (PF MET > 30 GeV)

Object selection: jets/MET

- **Two or three anti-KT 0.5 PFJets after PfNoPU in each event**
- **p_T >35 GeV and |η| <2.4**
- **|ΔR(lepton,j)| > 0.3**
- **Standard CMS L2, L3, and residual corrections.**
- **JetMET official Loose Jet Id criteria:**
  - fraction of energy due to neutral hadrons < 0.99;
  - fraction of energy due to neutral EM deposits < 0.99;
  - number of constituents > 1;
  - number of charged hadrons candidates > 0;
  - fraction of energy due to charged hadrons candidates > 0;
  - fraction of energy due to charged EM deposits < 0.99.
- **PF MET > 25 (μ), 30 GeV (*e*)**

Event selection and quality cuts

Table 6: Summary of selection criteria.

$W \to \ell\nu$ selection	Jet selection
Single lepton trigger	$p_T^{jet} > 35$ GeV
High-quality lepton ID and isolation	$\Delta\eta_{jj} < 1.5$
Muon (electron) $p_T > 25(35)$ GeV	dijet $p_T > 20$ GeV
$\not{E}_T > 25(30)$ GeV for muon (electron) samples	$\Delta\phi(\not{E}_T, \text{lead jet}) > 0.4$
W transverse mass > 50 GeV (30 GeV for muons)	
Second lepton veto	

- Studied in detail
- Improve the signal to background ratio, reduce syst uncertainty
- Will show distribution of some of these variables later

Signal and background expectation

Signal Efficiency x Acceptance x BR

Signal	Cross section [4]	$A \times \varepsilon$ (ejj)	$A \times \varepsilon$ (ejj,b-tag)	$A \times \varepsilon$ (μjj)	$A \times \varepsilon$ (μjj,b-tag)
WW	47.0 ± 2.0	3.039×10^{-3}	3.163×10^{-4}	5.918×10^{-3}	5.864×10^{-4}
WZ	18.6 ± 1.0	1.608×10^{-3}	3.760×10^{-4}	3.220×10^{-3}	7.760×10^{-4}
Diboson	65.6 ± 2.2	2.633×10^{-3}	3.332×10^{-4}	5.153×10^{-3}	6.402×10^{-4}

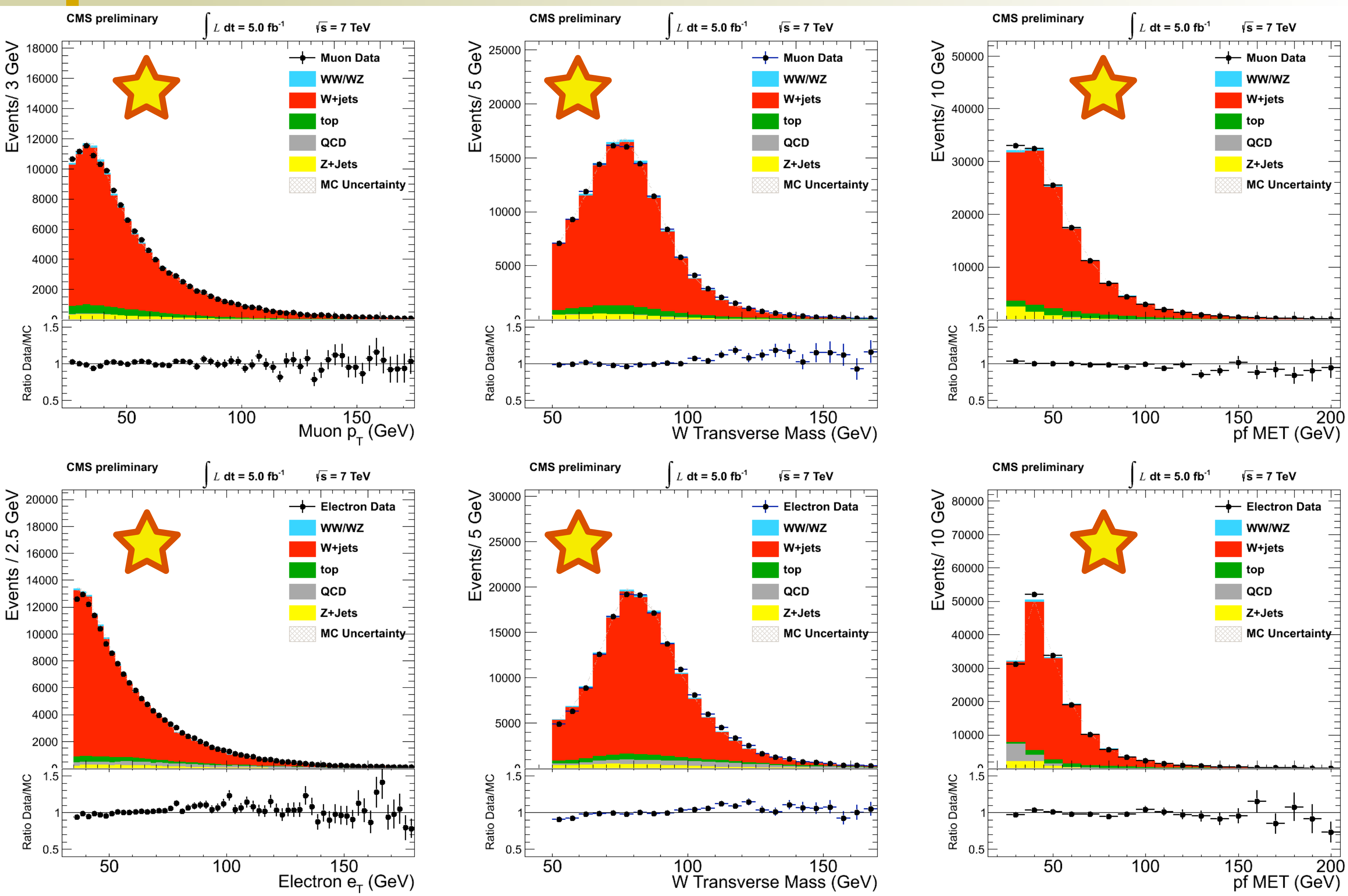
total = 0.88% including the BR (~11% for each lepton, 67% jj)

Back-of-the-envelope calculation: expect 65 pb x 5 fb^{-1} x 0.88% ≈ 2800 diboson events

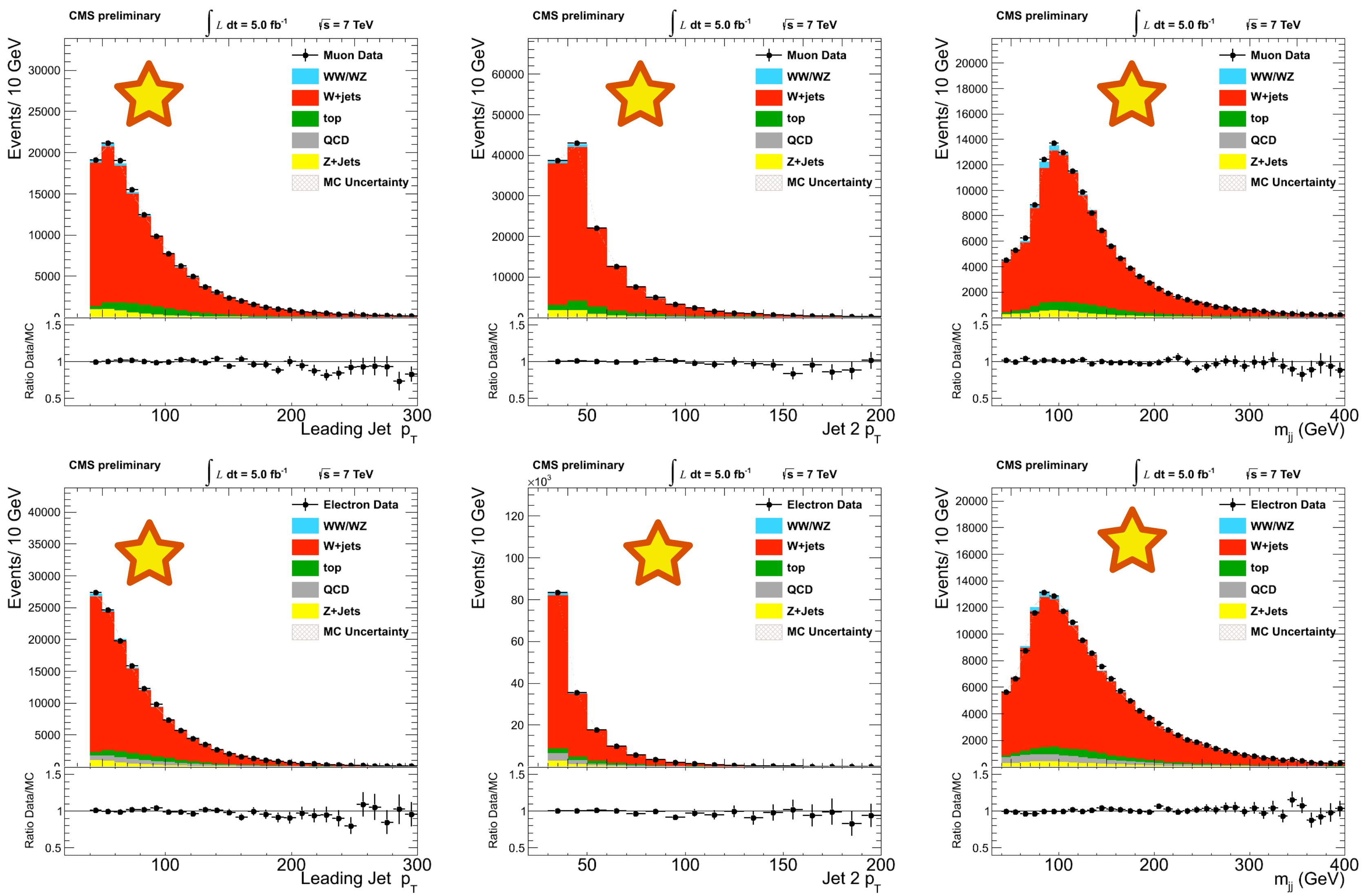
Background rate

Process	cross section
W plus jets	(NLO) 31314 pb ± 5% [23]
$t\bar{t}$	(NLO) 163 pb ±7% [24]
Single top	(NNLO) [25–27] ± 5%
Drell-Yan plus jets	(NLO, $m_{ll} > 50$ GeV) 3048 pb ± 4.3% [23]
Multijet	$\not{E}_T$ fit in data ± 50% (100%) for electron (muon)

Control plots: lepton+MET system

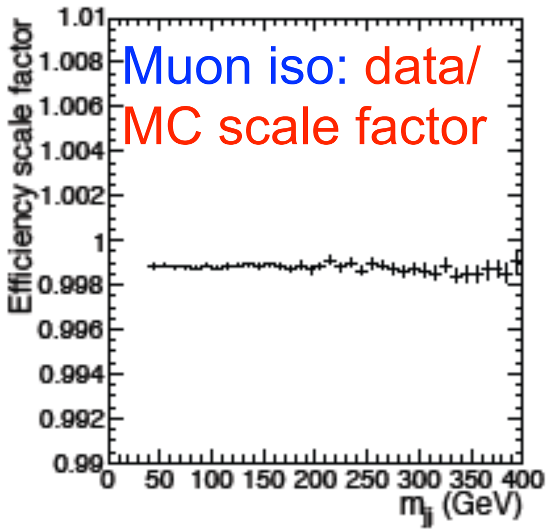


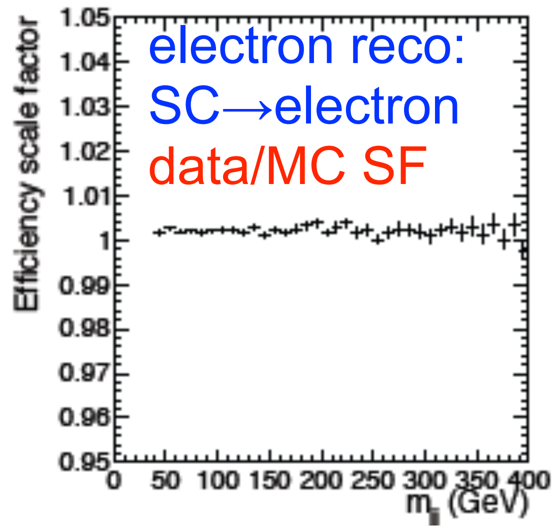
Control plots: dijet system

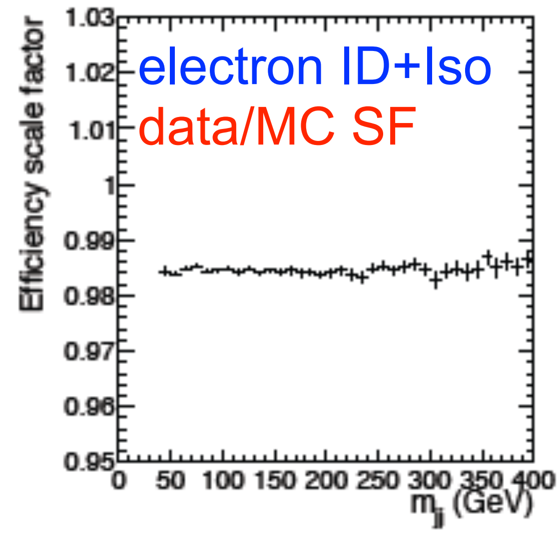


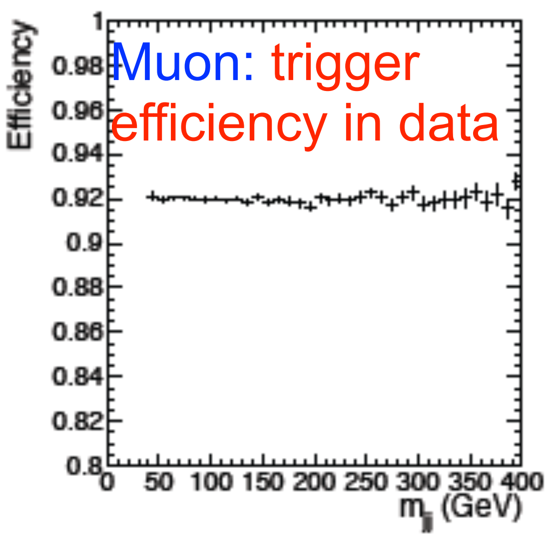
Lepton efficiency from tag & probe

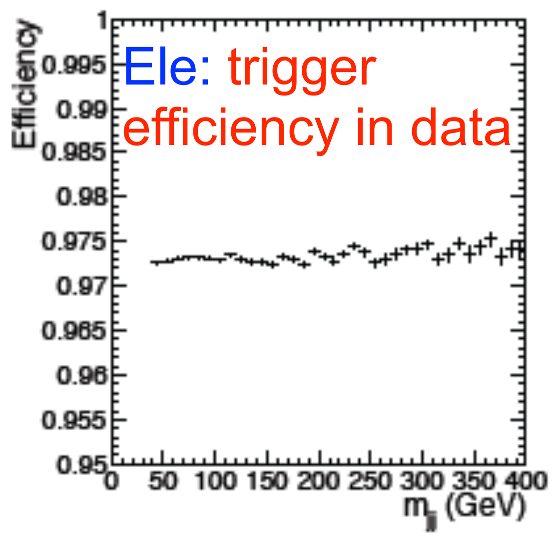
lumi-weighted average

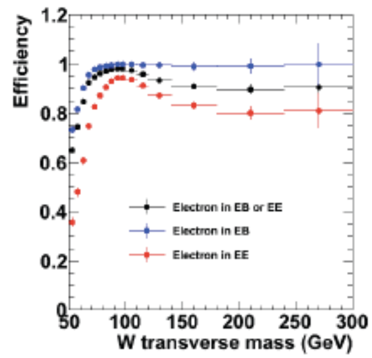


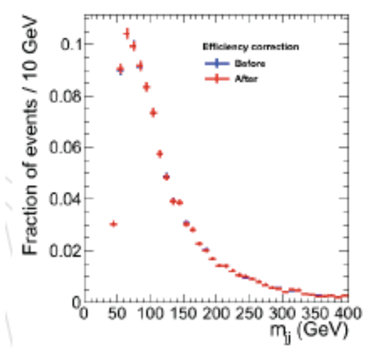












W m_T trigger turnon for electron

Maximum likelihood fit

- Unbinned maximum likelihood fit within 40 < Mjj < 150 GeV
- Divide data into 2 disjoint categories, separate fits for (μ or *e*)+jj
  Combine the two results when calculating cross-section / setting upper limits for anomalous TGC

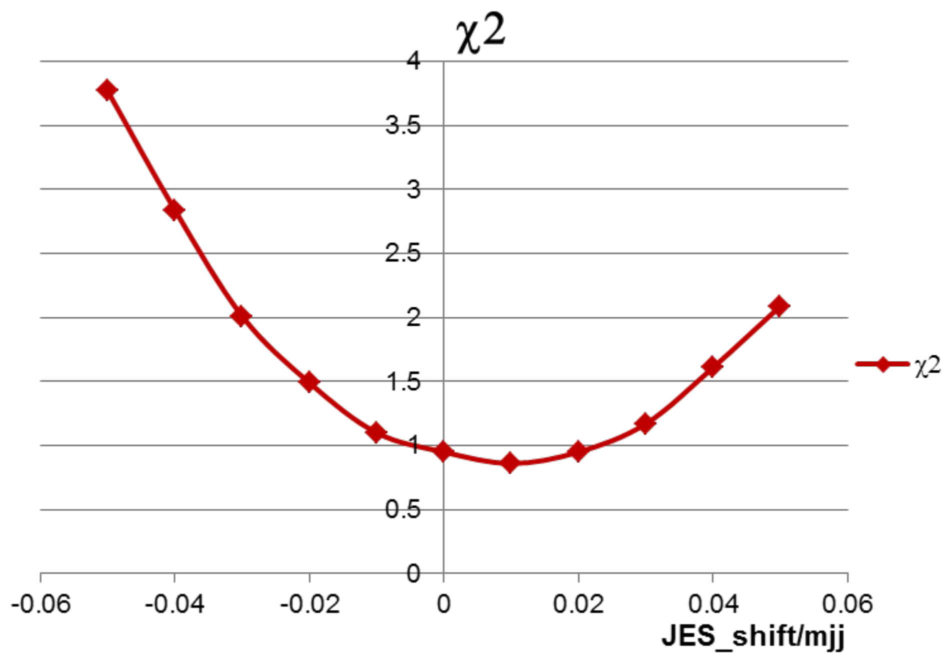
- Diboson normalization is completely floated/unconstrained
  Other components are constrained within NLO uncertainty

Process	Shape	External constraint on normalization
W plus jets	MC/data	Constrained: (NLO) 31314 pb ± 5% [23]
Diboson	MC	Unconstrained
$t\bar{t}$	MC	Constrained: (NLO) 163 pb ± 7% [24]
Single top	MC	Constrained: (NNLO) [25–27] ± 5%
Drell-Yan plus jets	MC	Constrained: (NLO, $m_{ll} > 50$ GeV) 3048 pb ± 4.3% [23]
Multijet	data	Constrained: $\not\!\!E_T$ fit in data ± 50% (100%) for electron (muon)

Jet Energy Scale Systematic

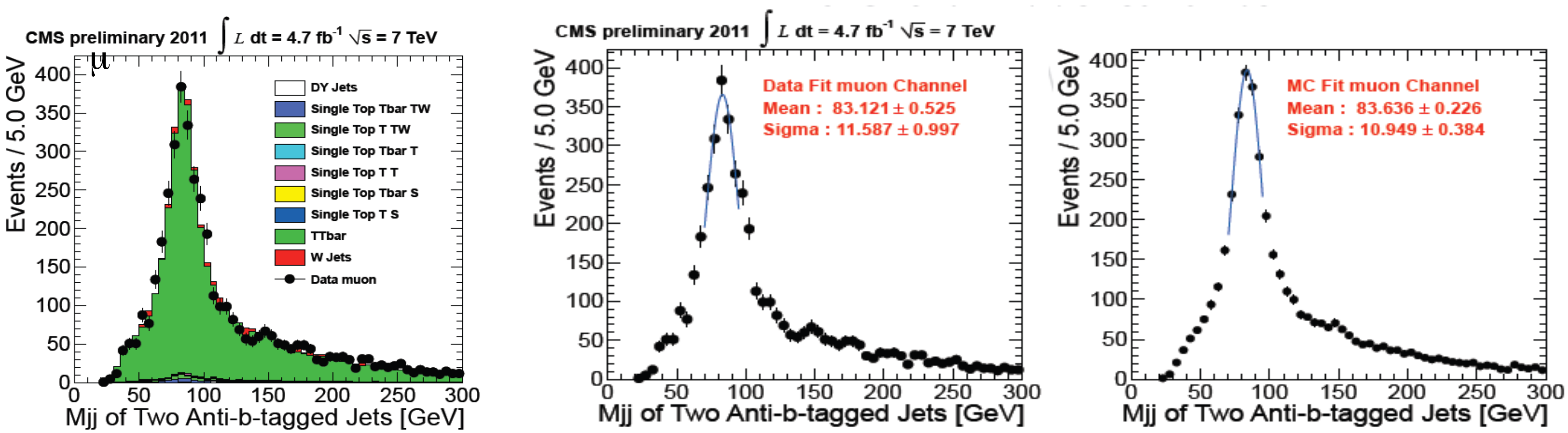
- JetMET POG already constrains JES uncertainty for <u>generic</u> PFJet to 3%
  - JINST 6, P11002 (2011), arxiv:0802,1189 [hep-ph]
  - For our jet topology standard JES uncertainty is ~1%
- We validate the JES uncertainty in two different ways:
  1. Perform a manual scan by fixing JES and repeat the fit
  2. Study JES MC/data agreement using top control sample (next slide)

The fit is stable and has a χ^2 minimum near 0.



Jet energy scale/resolution from top events

- **Compare to the (almost) pure ttbar control sample:**
  - **Exactly four jets - two b-tagged and two anti-b-tagged**
  - **Use the anti-b-tagged jets to reconstruct the hadronic W**
  - **Compare the fits of data vs MC**
  - **Similar approach and conclusions as TOP-11-015 (top mass measurement)**



❖ **The difference in JES (~1%) is propagated to our templates and makes a negligible impact**

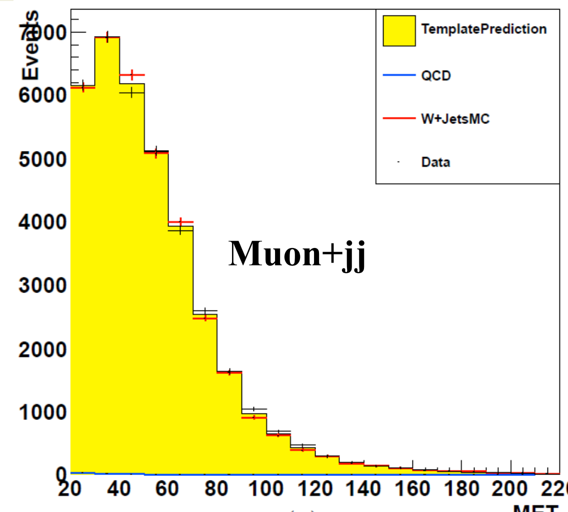
QCD template and normalization

- ❖Data-driven
- ❖Invert the lepton Isolation
- ❖2-component fit of MET distribution

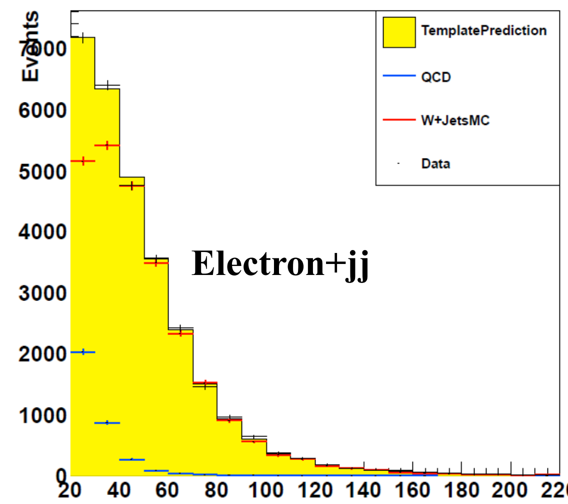
- Relative fractions of QCD in data (accounting for acceptances):
  - μ 2J : 0.0016 ± 0.0042
  - el 2J : 0.0617 ± 0.0038

- QCD Errors in the global template fit:

- μ : fractions listed above (i.e., >100%)
- el : 50% of the QCD event yield



(a)



(c)

W+jets shape and uncertainty

❖ **The simulation needs to describe the matrix elements for the hard processes as well as the subsequent development of the hard partons into jets of hadrons.**

Standard Approach:

- **Fit with the default MC: Matrix Element – Parton Shower matching threshold = 20GeV, Factorization Scale = 20 GeV**
- **Repeat the fit with alternate ME-PS matching (Factorization) samples where threshold and scale vary by a factor 2, and compute the systematics**
- **Overcovers the errors and can get into the non-perturbative regime**

We let these scales float:

- **Fit with the combination of Default MC, either Matching Up or Matching Down MC, and either Scale Up or Scale Down MC**
- **The relative fractions are free to vary in the fit**
- **Accounts for Matching and Factorization errors**
- **Accounts for W+Jets shape uncertainty**

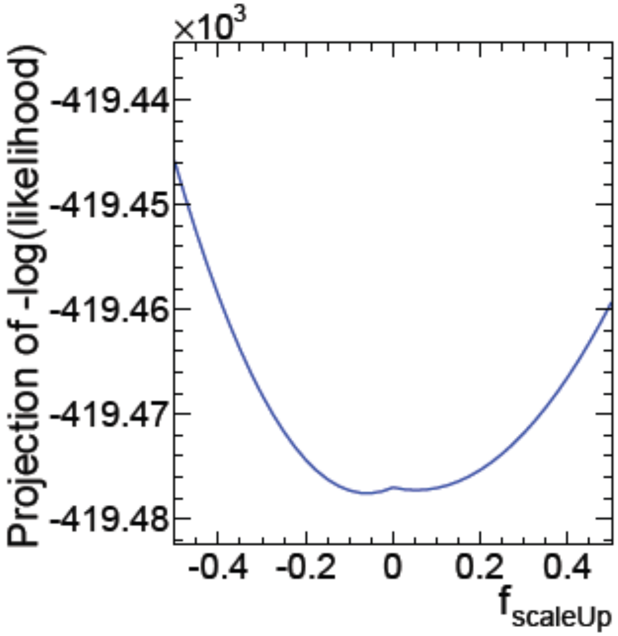
$$\mathcal{F}_{\mathrm{W+jets}} = \alpha \cdot \mathcal{F}_{\mathrm{W+jets}}(\mu_0^2, q'^2) + \beta \cdot \mathcal{F}_{\mathrm{W+jets}}(\mu'^2, q_0^2) + (1 - |\alpha| - |\beta|) \cdot \mathcal{F}_{\mathrm{W+jets}}(\mu_0^2, q_0^2),$$

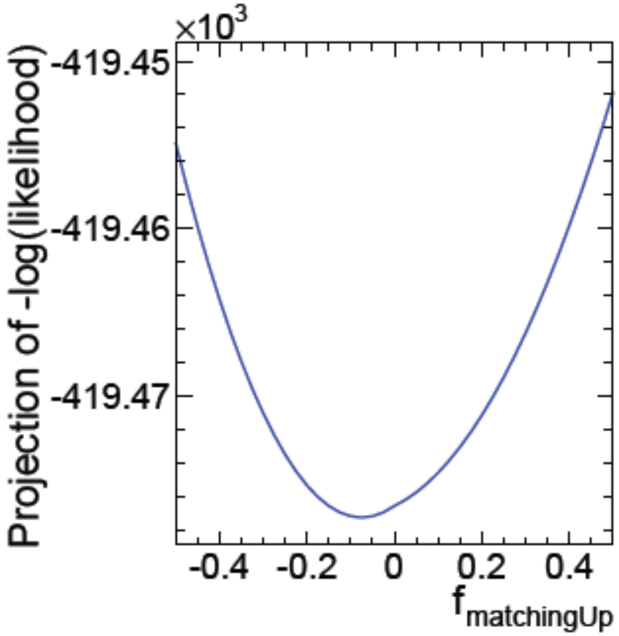
W+jets shape and uncertainty

- Fit results for α (scale up/down fraction) and β (matching up/down fraction) are consistent between electron and muon data

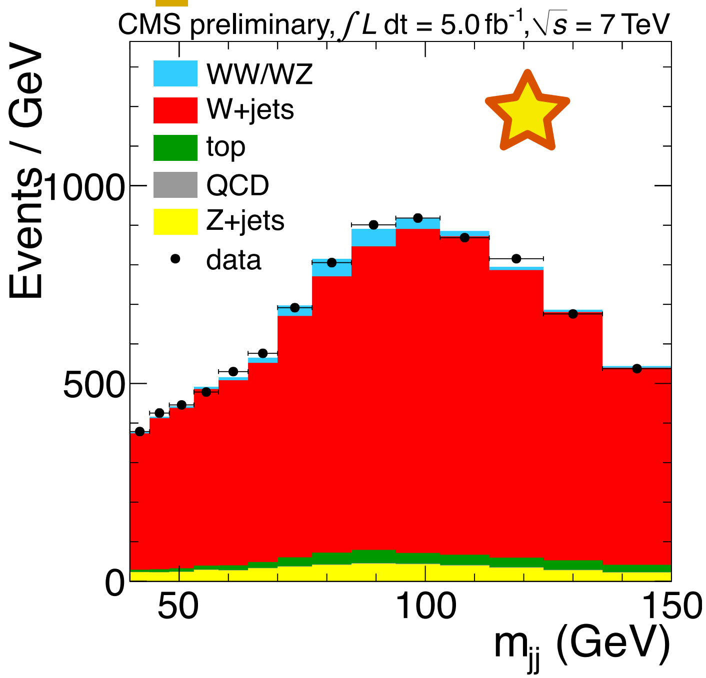
	α (fSU)	β (fMU)
Electron	-0.0027 ± 0.074	-0.136 ± 0.081
Muon	0.053 ± 0.078	-0.075 ± 0.065

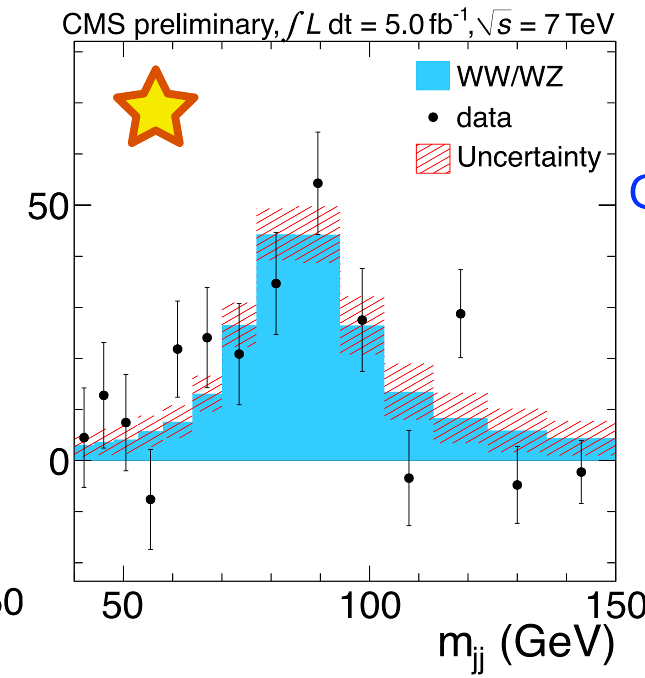
- NLL output from the fit for α and β in muon non-b-tagged sample is well-behaved





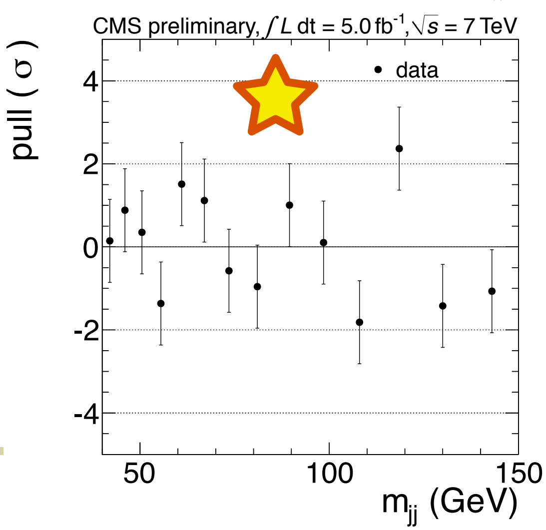
Fit results: μ+jj





χ^2/dof = 9.73/12

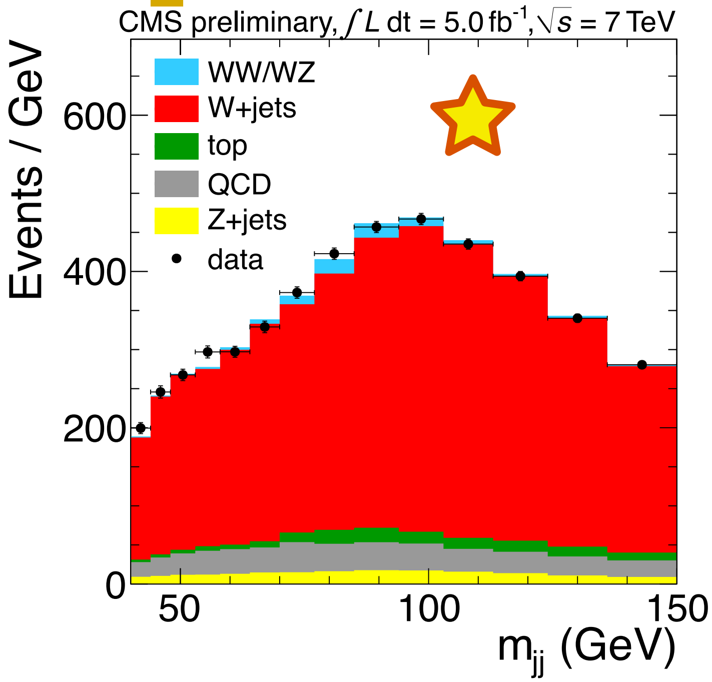
Good description of data

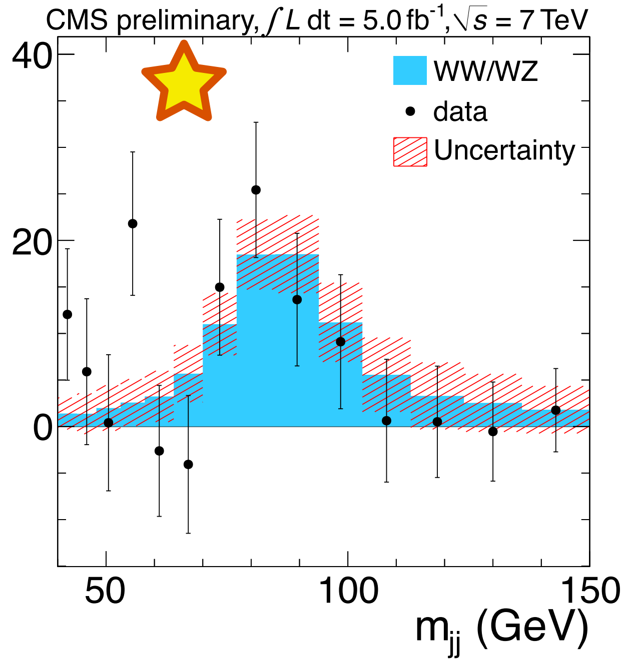


 # diboson = 1899 ± 389

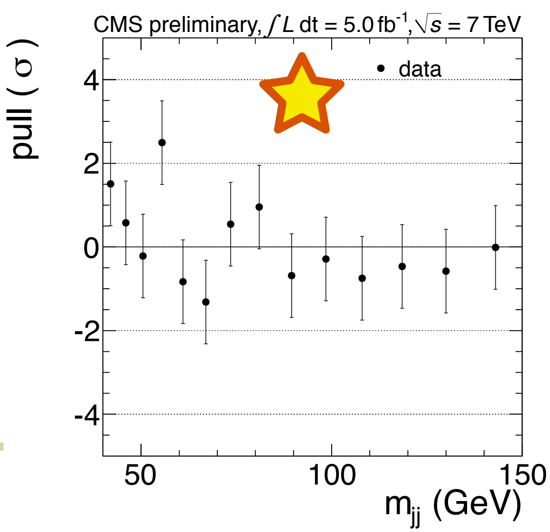
MC prediction = 1697

Fit results: e+jj





$\chi^2/\text{dof} = 5.30/12$



 # diboson = 783 ± 302

MC prediction = 867

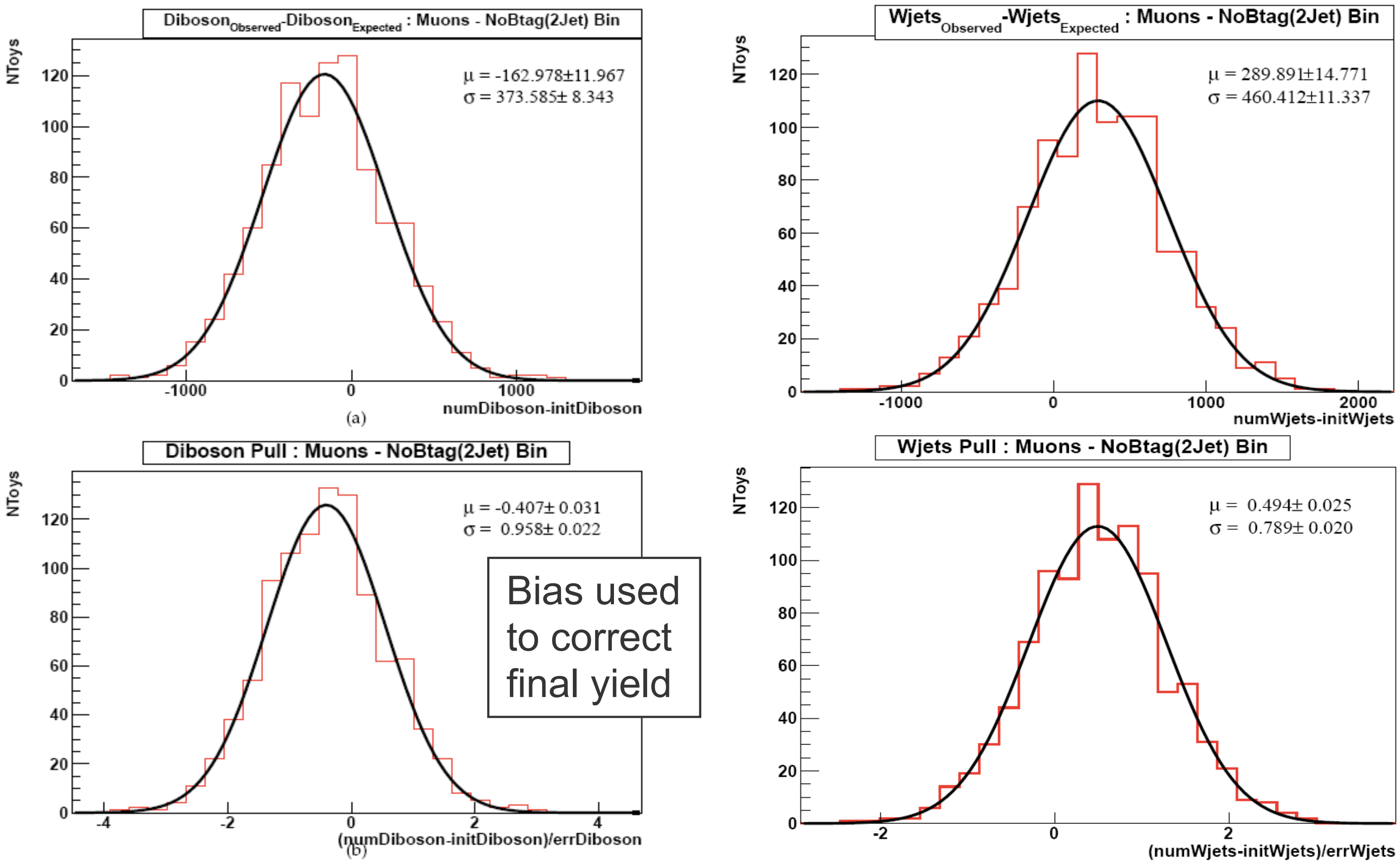
Fit results table

Process		Muon channel		Electron channel
Diboson (WW+WZ)	NLO prediction = 1697	1899 ± 389	NLO = 867	783 ± 302
W plus jets		67384 ± 586		31644 ± 850
$t\bar{t}$		1662 ± 117		946 ± 67
Single top		650 ± 33		308 ± 17
Drell-Yan plus jets (Z+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 $\times$ efficiency ($\mathcal{A}\varepsilon$)		5.153×10^{-3}		2.633×10^{-3}

Fit Validation Procedure

- Perform the fit to obtain the expected yields.
- Generate Toy Monte Carlo for each process from the corresponding MC.
- Construct 1000 Sample Datasets.
  - Take correlations (between expected yields) into account.
  - Implement smearing by Fit and Poisson errors
- Perform the fit for each sample dataset.
- Examine the resultant Yields and Pulls.

Fit Validation Results



Bias used to correct final yield

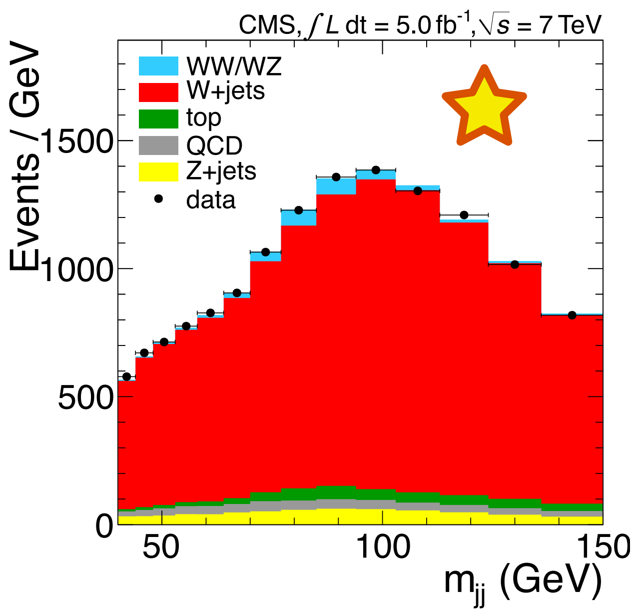
Figure 33: Fit validation in the untagged (2-jet) bin of the muon channel, using 1000 Toy MC datasets. Diboson (a) Fitted-Given Yield, (b) Pull=(Fitted-Given)/Error.

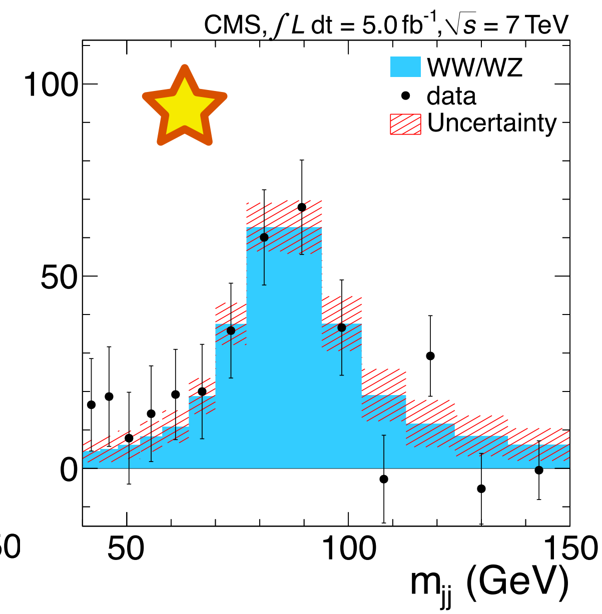
Other syst uncertainties for cross section

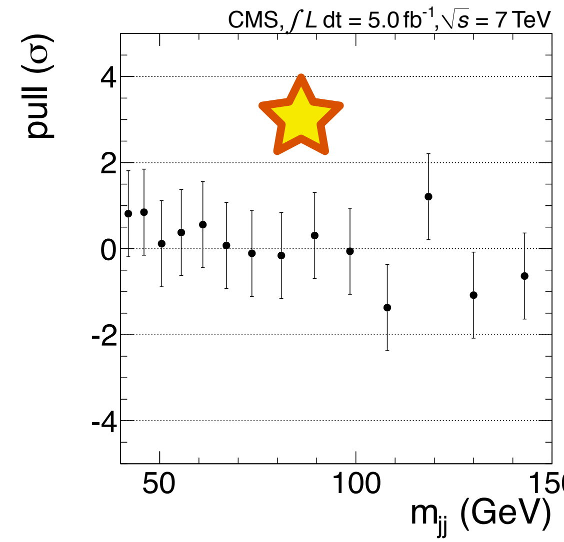
- In addition to the uncertainty in the event yield, there are additional uncertainties in
-efficiency, acceptance, luminosity, linewidth/resolution etc.
- These are small compared to the uncertainty in signal yield.

Source of uncertainty	Magnitude
Luminosity	2.2%
Jet energy scale, resolution, and $\not{E}_T$	$< 1\%$
Theory acceptances (PDF)	4% (includes jet veto syst)
Lepton trigger eff.	1%
Lepton selection eff.	2%
Pile-up	$< 1\%$
b-tag veto	$< 1\%$

Combined result







Event category	Measured cross section
μjj	73.41 ± 15.07 pb
ejj	60.14 ± 21.50 pb
Theory prediction [4]	65.6 ± 2.2 pb

NLO, MCFM

$$\sigma = \frac{N^{\mathrm{Sig}}}{A\,\epsilon\,\mathcal{L}}$$

Combining the two channels

$\sigma = 66.70 \pm 11.74$ pb

$66.70 \pm 8.08\,(\mathrm{stat}) \pm 8.52\,(\mathrm{syst})$ pb

#diboson = 2682 ± 339(stat) ± 357(syst), MC prediction = 2564

Limits on Anomalous Triple-Gauge Couplings (ATGC)

Anomalous gauge couplings

5 independent couplings remain after assuming basic symmetry

$$\mathcal{L}_{anom} = ig_{WWZ}\left[\Delta g_1^Z\left(W^*_{\mu\nu}W^\mu Z^\nu - W_{\mu\nu}W^{*\mu}Z^\nu\right) + \Delta\kappa^Z W^*_\mu W_\nu Z^{\mu\nu} + \frac{\lambda^Z}{M_W^2}W^*_{\rho\mu}W^\mu_\nu Z^{\nu\rho}\right] + ig_{WW\gamma}\left[\Delta\kappa^\gamma W^*_\mu W_\nu \gamma^{\mu\nu} + \frac{\lambda^\gamma}{M_W^2}W^*_{\rho\mu}W^\mu_\nu \gamma^{\nu\rho}\right],$$

- LEP parameterization (Δ is defined as a difference from the SM prediction)
  - light Higgs boson scenario

$$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \cdot tan^2\theta_w \quad \text{and} \quad \lambda_Z = \lambda_\gamma = \lambda$$

  - Effectively reduces number of unknown variables to three

Used at Tevatron, and being pursued in CMS WW leptonic analysis. **Implemented in MCFM.**

Further assume that $\Delta g_1^Z = 0$ (SM), leaves two parameters: λ_Z , $\Delta\kappa_\gamma$

Current Limits

Table 21: Current limits on anomalous couplings. The world best limits are based on a fit of LEP measurements. The LHC and Tevatron results are shown for comparison.

LEP

Coupling	Particle Data Group Fit
Λ_γ	$0.028^{+0.020}_{-0.021}$
Λ_Z	$0.088^{+0.060}_{-0.057}$
Δg_1^Z	$0.016^{+0.022}_{-0.019}$
$\Delta\kappa_\gamma$	$0.027^{+0.044}_{-0.045}$
$\Delta\kappa_Z$	$0.026^{+0.059}_{-0.056}$

[-0.026, 0.208] @ 95% CL

[-0.063, 0.115] @ 95% CL

Coupling	Tevatron (WW +WZ $\to \ell\nu$2jet)	Tevatron (WW $\to \ell^+\nu\ell^-\overline{\nu}$)
$\Lambda = \Lambda_\gamma = \Lambda_Z$	[-0.10,0.11] at 95% C.L.	[-0.14,0.18] at 95% C.L.
$\Delta\kappa_\gamma$	[-0.44,0.55] at 95% C.L.	[-0.54,0.83] at 95% C.L.
Δg_1^Z	[-0.12,0.20] at 95% C.L.	[-0.14,0.30] at 95% C.L.

Coupling	CMS 35 pb^{-1} (WW $\to \ell^+\nu\ell^-\overline{\nu}$)	ATLAS 1 fb^{-1} (WW $\to \ell^+\nu\ell^-\overline{\nu}$)
Λ_Z	[-0.19,0.19] at 95% C.L.	[-0.079,0.77] at 95% C.L.
$\Delta\kappa_\gamma$	[-0.61,0.65] at 95% C.L.	[-0.071,0.071] at 95% C.L.
Δg_1^Z	[-0.29,0.31] at 95% C.L.	[-0.052,0.082] at 95% C.L.

How the inputs were simulated

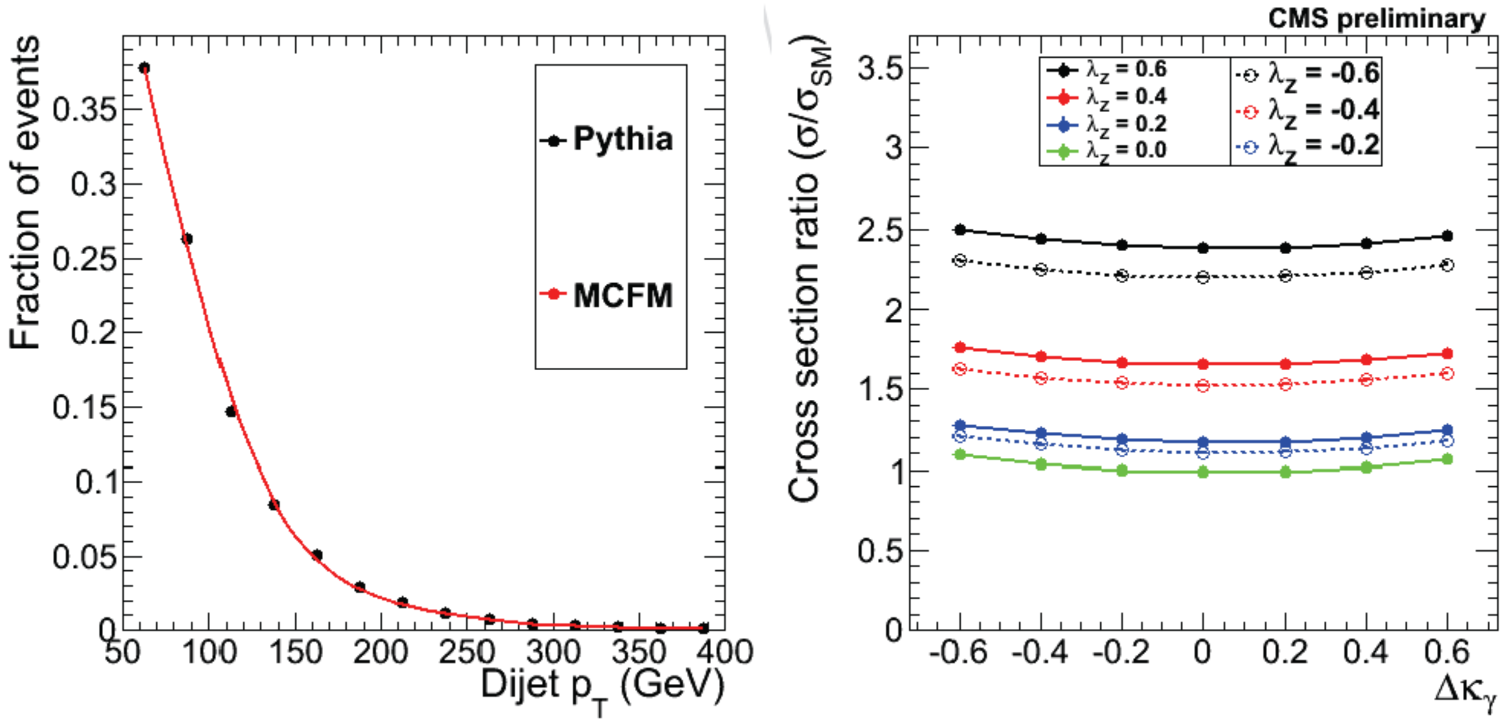
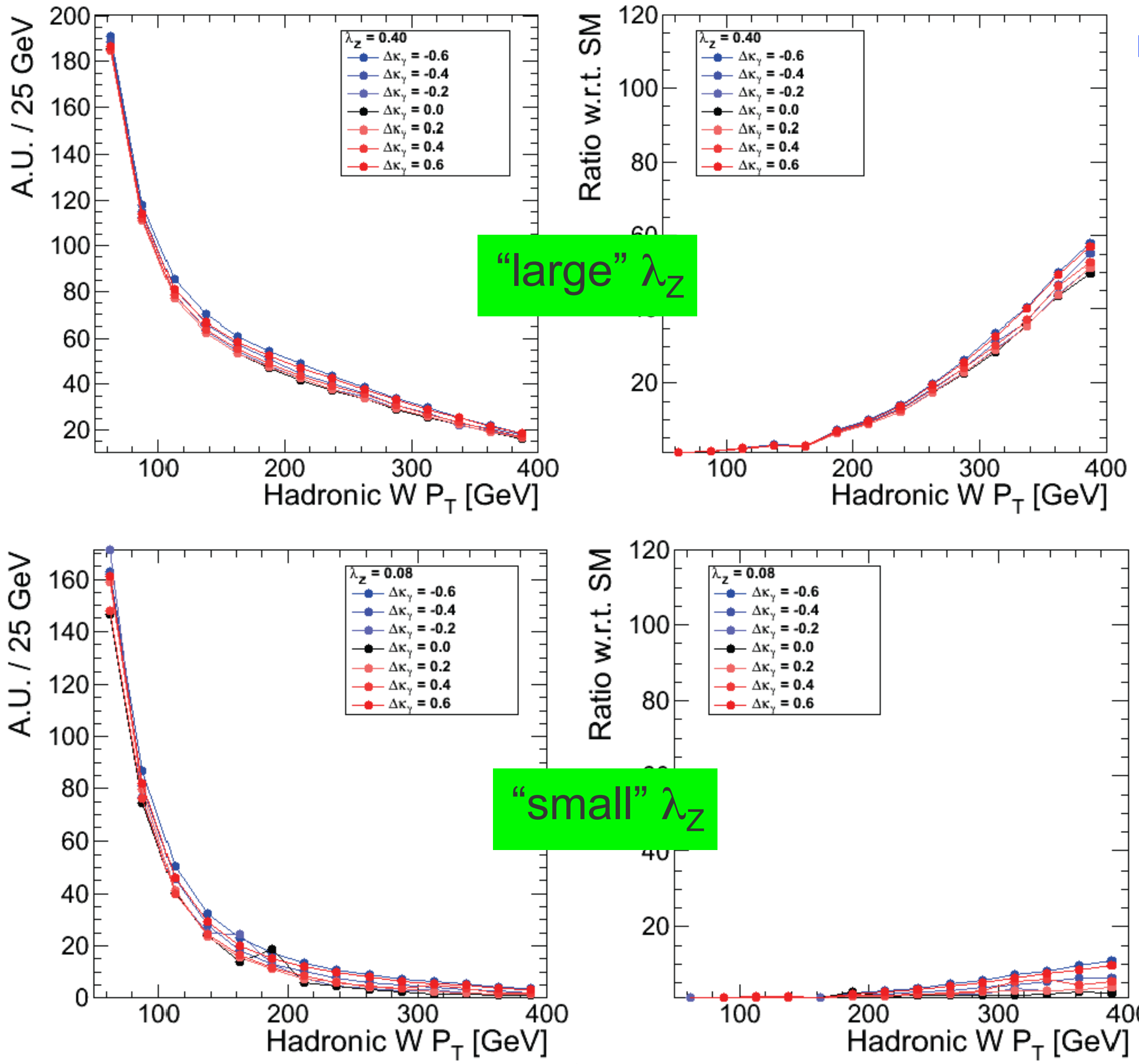


Figure 45: (left) Comparison of dijet p_T distribution for WW events in Pythia (after Gen–RECO matching) and LO MCFM. The agreement between the two is good. (right) Change in cross section compared to the standard model couplings as a function of Λ_Z and $\Delta\kappa_\gamma$.

- Generate 1M evt per datapoint with MCFM NLO
- Reweight SM Pythia MC with these predictions

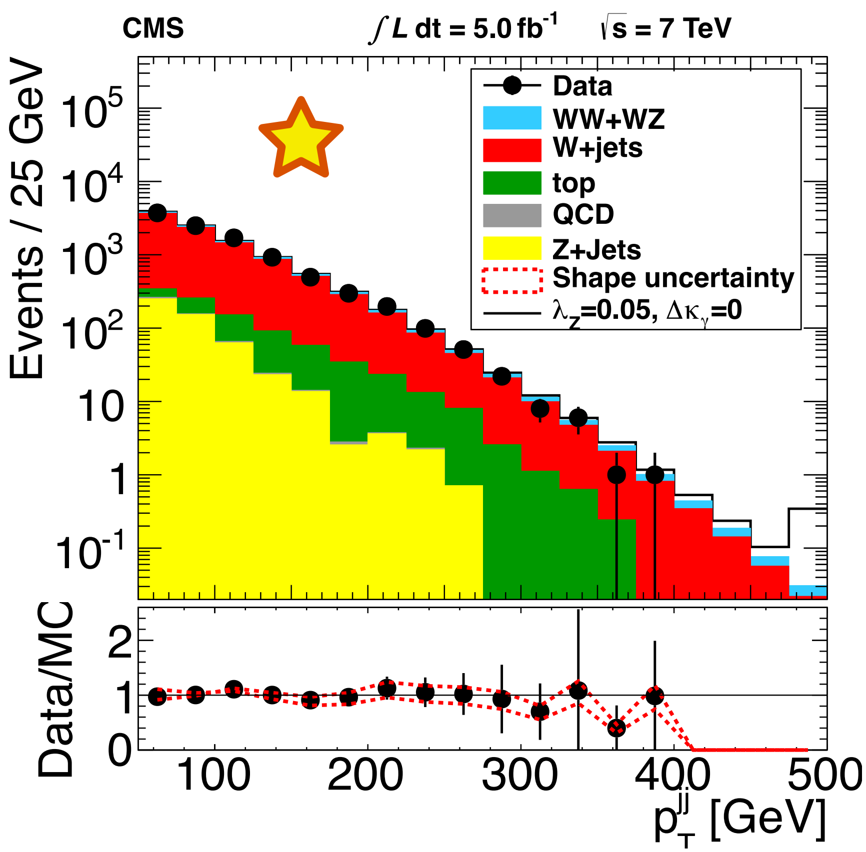
Dijet (Hadronic W) Pt is the observable



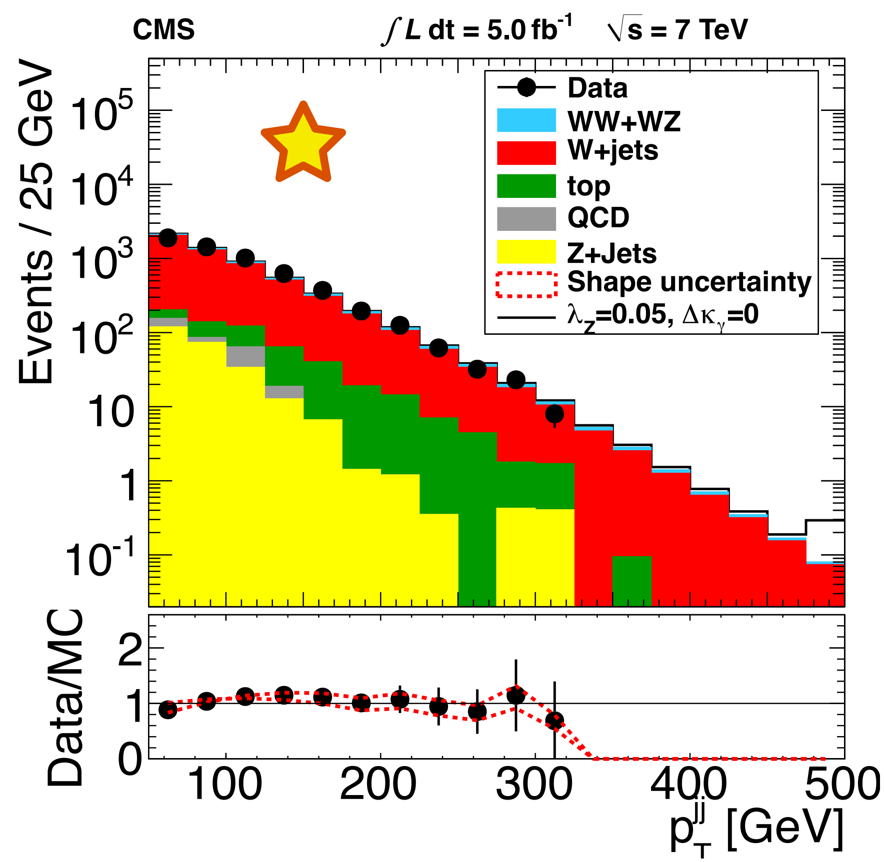
- Ratio plots (right column) a couple effects:
  - We are more sensitive to λZ than to $\Delta\kappa\gamma$
  - The effect of deviations in these variables is seen most prominently in the (low statistics) high pT tails

Dijet (Hadronic W) Pt is the observable

Muon



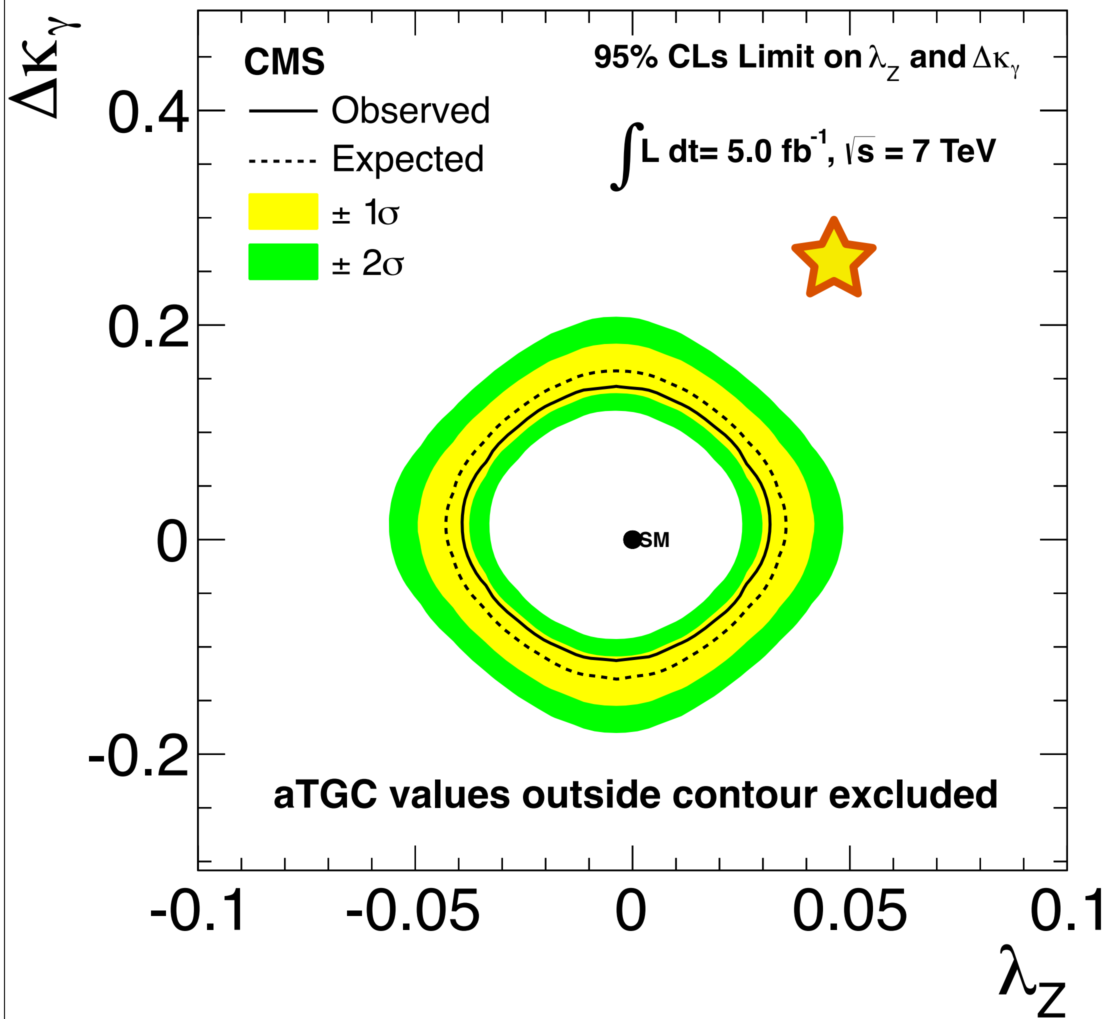
Electron



Limiting setting procedure

- ✦Signal, data, total background shapes are fed to the limit setter
- ✦Systematics include:
  - SM process normalization from the fit
  - Luminosity (signal yield, 2.2%)
  - Lepton selection / trigger efficiency (1-2%)
  - Background shape uncertainty
    - -Factorization/renormalization scales for W+jets
    - -Scales for diboson
    - -Jet veto systematics

Final Limits



$-0.038 < \Lambda_Z < 0.030$,
(assuming $\Delta\kappa_\gamma = 0$)

$-0.111 < \Delta\kappa_\gamma < 0.142$
(assuming $\Lambda_Z = 0$)

These limits are competitive to the current world average (dominated by LEP combination).

Summary

- Observe diboson events in semi-leptonic final state
  2682 ± 339(stat) ± 357(syst) events, when 2564 expected
  Consistent with the NLO predictions
  This is the first observation in this channel at a pp collider

- Compute cross section
  66.70 ± 8.08 (stat) ± 8.52 (syst) pb, SM prediction 65.6 ± 2.2 pb

- Set exclusion limits on anomalous TGC:

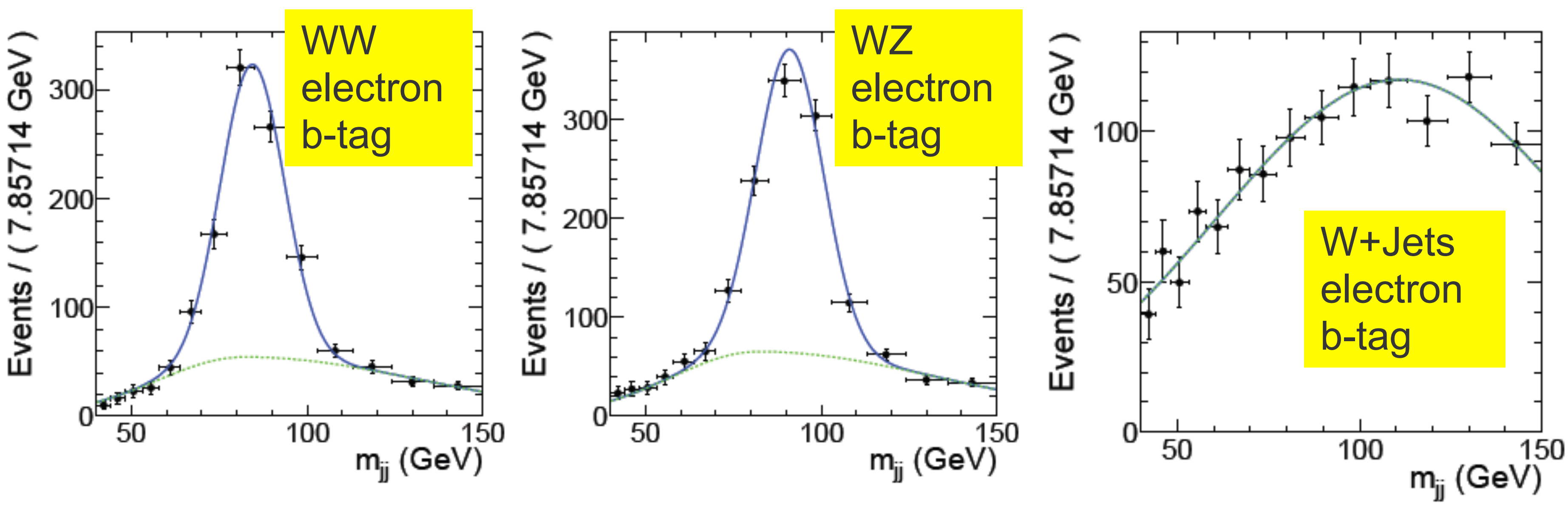
$$-0.038 < \Lambda_Z < 0.030,$$
$$-0.111 < \Delta\kappa_\gamma < 0.142$$

- SMP-12-015 seeking approval for publication

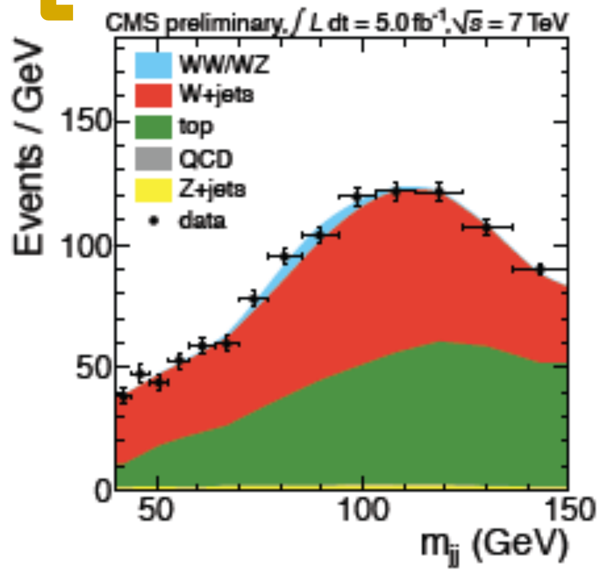
backup slides

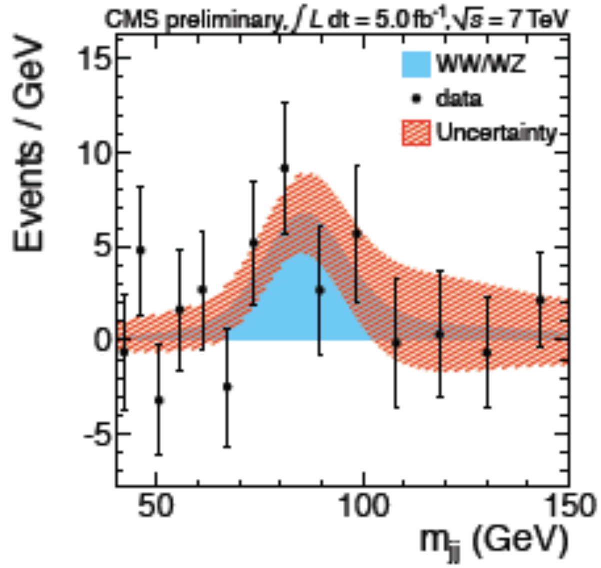
MC Parametrization for b-tag channels

- Due to low MC statistics, need to smooth shapes for b-tag channels
  - For diboson signal, fit with 2 components, resonant and non-resonant
  - For W+Jets, we use a wide Gaussian
- All other processes remain as in the non-b-tagged channels

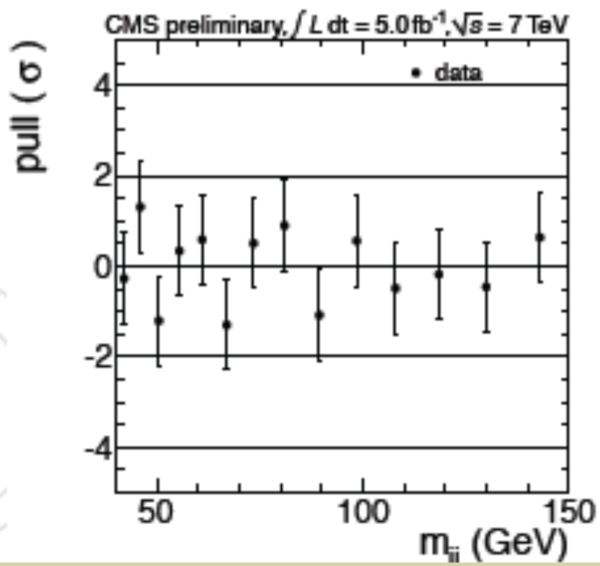


Fit results: μ+jj b-tag





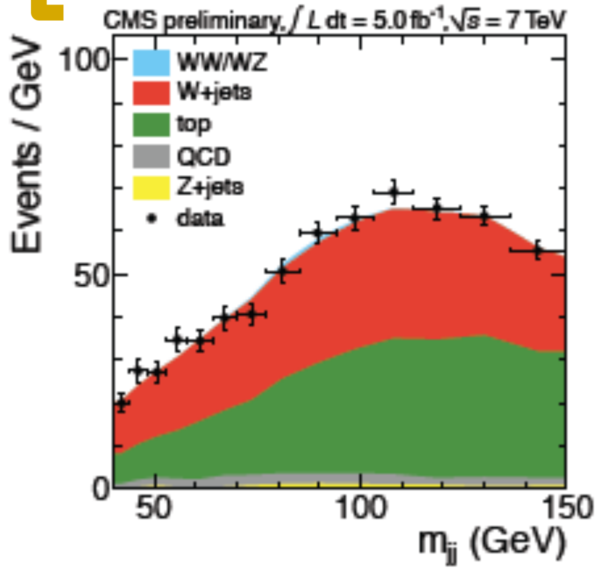
$\chi^2/\mathrm{dof} = 7.78/12$

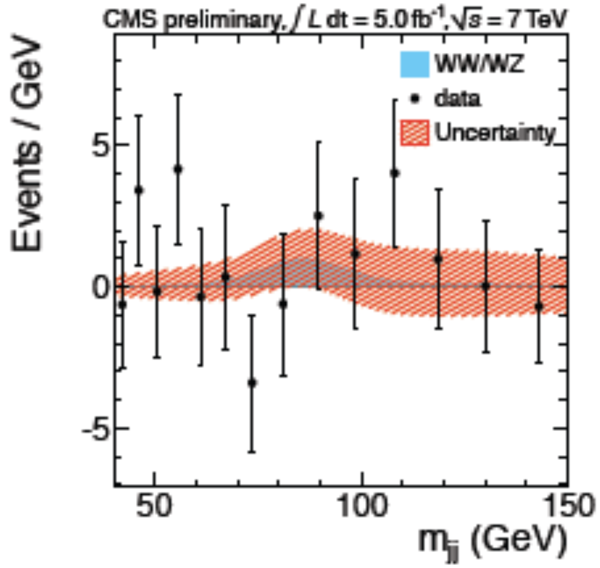


 # diboson = 226 ± 203

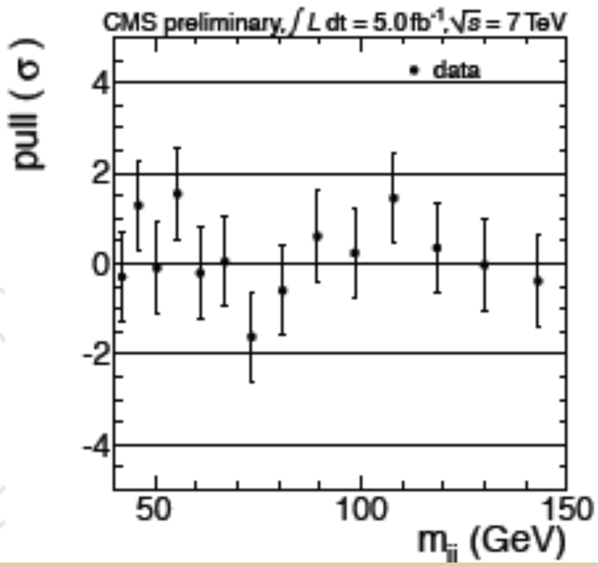
MC prediction = 211

Fit results: e+jj non b-tag





$\chi^2/\mathrm{dof} = 9.85/12$



 # diboson = 35 ± 86

MC prediction = 110

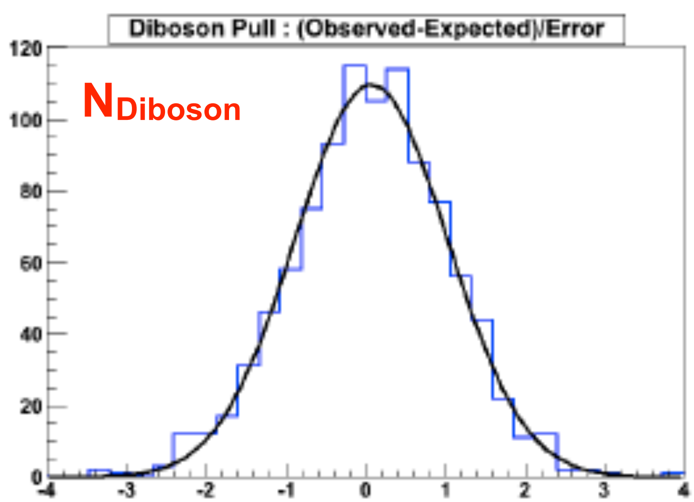
Fit results table

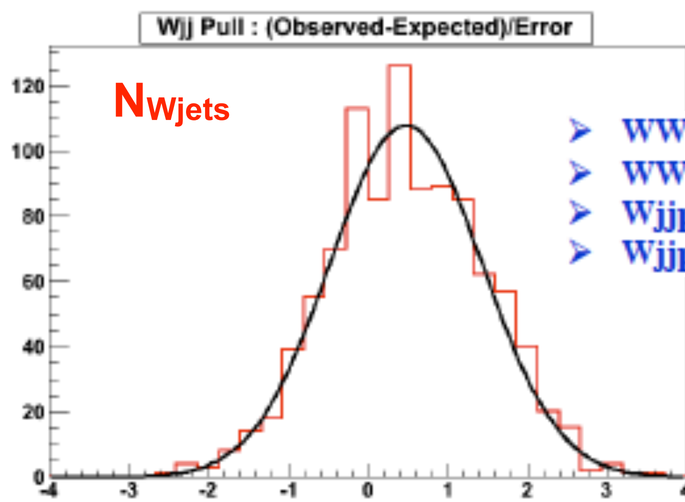
Bin	Muons, non-b-tagged		Electrons, non-b-tagged	
	Predicted	Extracted	Predicted	Extracted
Dibosons	1697	1736 ± 389	867	727 ± 302
Multijet	123	119 ± 317	2610	3204 ± 867
Single Top	653	652 ± 33	332	332 ± 17
$t\bar{t}$	1679	1666 ± 117	963	953 ± 67
W+Jets	76129	67674 ± 586	37137	32706 ± 850
Drell-Yan+Jets	3610	3613 ± 155	1487	1485 ± 64
Total Yields	83891	75460	43396	39407
Data	—	75419	—	39365

Bin	Muons, b-tagged		Electrons, b-tagged	
	Predicted	Extracted	Predicted	Extracted
Dibosons	211	226 ± 203	110	35 ± 86
Multijet	16	16 ± 42	171	231 ± 78
Single Top	1220	1219 ± 60	618	626 ± 31
$t\bar{t}$	3206	3192 ± 191	1846	1976 ± 104
W+Jets	5082	5082 ± 206	2551	2693 ± 107
Drell-Yan+Jets	206	206 ± 9	857	858 ± 37
Total Yields	9941	9941	6153	5648
Data	—	9940	—	5695

Validation of fit results

To make sure that the template fit is unbiased and to check the coverage of statistical uncertainty reported by the fit, we generate 1000 pseudo experiments (PE) using the shape that best describes the data. Then we fit each of these PE samples using our nominal shape and plot pull distribution for each parameter.





- WWpull_mean=0.07+/-0.03
- WWpull_sigma=0.96+/-0.02
- Wjjpull_mean=0.48+/-0.03
- Wjjpull_sigma=0.96+/-0.02

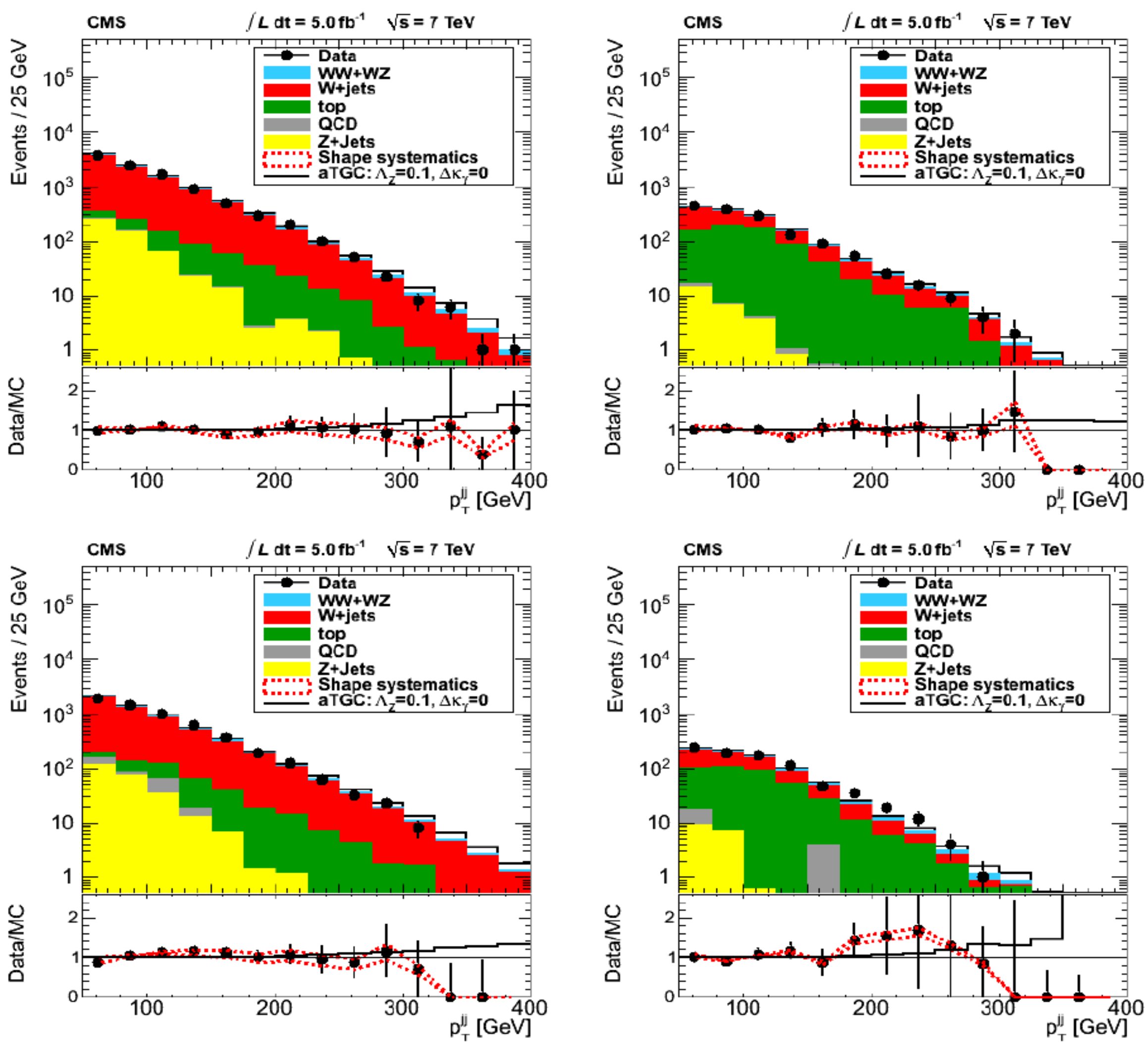
- Fitter returns consistent results: negligible bias
- Statistical uncertainties reported by the fit are correct

Limit inputs

No b-tag | b-tag

Muon

Electron



PAG review Q&A

- June 2 email from Matt Herndon
  - Thanks for your responses. This satisfies my concerns on the procedure for now. I may have
- June 1 email from Matt Herndon
  - (1) So there do seem to be some large fluctuations in the templates while
- May 29 email from Matt Herndon
  - (1) I think that this analysis is ready to go to preapproval once the paper draft is on hand.
- May 19 email from Matt Herndon
  - (1) Could you reinterpret the results of the electron and muon fits…
  - (2) Perform 1 combined fit where the scale choice is common for electron and muons?
  - (3) Can you report the cross section using a more standard methodology…
  - (4) Given the fit values of the scales…
  - (5) Could you show the shape of the likelihood as a function of scale.
- May 15 email from Matt Herndon
  - Table 1: The table description and layout do not make sense to me.
  - Table 4: This table say that the equivalent luminosity of each sample is available.
  - 259 You're not currently using b-tagging to measure a WZ lnubb cross section.
  - Figure 4: Though the agreement looks decent…
  - Table 7: The results seem to indicate…
  - 430 What about lepton identification efficiencies and MET/mT calculation?
  - 440 Since you use a sample of events based on 200pb-1…
  - Figures 22-26. This could be studied further…
  - 502 Section 12.1 It is difficult to believe…
  - 517 Do you intend to keep the b-tagged part of the analysis.
  - 815 15.1 JES Why use a non standard method of constraining the JES.
  - Figure 33,34,35 The scale of the disagreement between the prediction and the data is large.

- Extensive review by the PAG
  - Thanks to Matt H. for the useful comments
- The thrust of many questions are already dealt with in the body of this presentation; here we recap a couple highlights.
- Documented here: https://twiki.cern.ch/twiki/bin/viewauth/CMS/SMP-12-015-ARC

PAG review Q&A: W+Jets scale choice

- "Check fits of electrons/muons separately to see if the two subsets pick out the same scale within errors" (Done - slide 23)
- Also several alternative fits done with fixed choices in alpha & beta, all documented with fit plots in AN Appendix E, cross-checks

α (fSU)	β (fMU)	Δ diboson yield	notes
0	0	+26	Within errors
1 (2x nom.)	0	-1053	
-1 (1/2x nom.)	0	+2139	
0	1	-926	
0	-1	+865	
$+1\sigma$	0	-105	
-1σ	0	+119	
0	$+1\sigma$	-38	
0	-1σ	+40	

PAG review Q&A: B-tagging

- What about WZ → lνbb ?
  - (*A* x ε x *BR*) numbers include W(lν)Z(bb) hadronic BR
  - B-tagging is inefficient, so some Zbb events fall into non-tagged category
  - Part of inefficiency is due to loose lepton veto requirement; this analysis is not yet optimized for this subchannel, not a lot of statistics available yet.

- Do you intend to keep the b-tag part of the analysis?
  - Yes; b-tag channels are given the same rigor as non-b-tag channels; the only additional attention we pay now to b-tagged channels is to smooth the backgrounds because of limited statistics
  - Currently studying W+n parton samples to increase statistics for heavy flavor