Measurement of WW+WZ cross section using semileptonic final state (lνjj)

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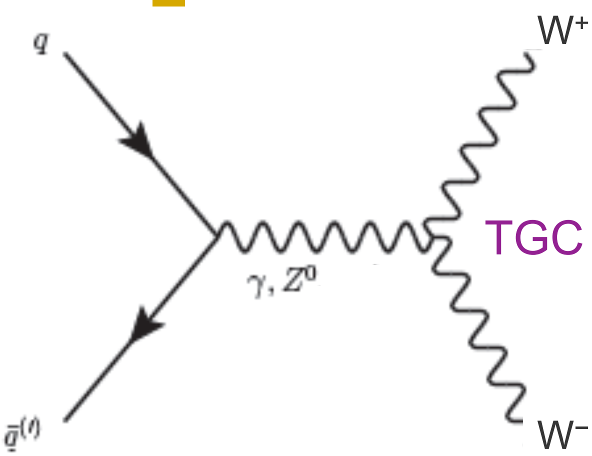
- AN-2011-151
- Part of EWK-11-011 (Perhaps need a new CADI entry)

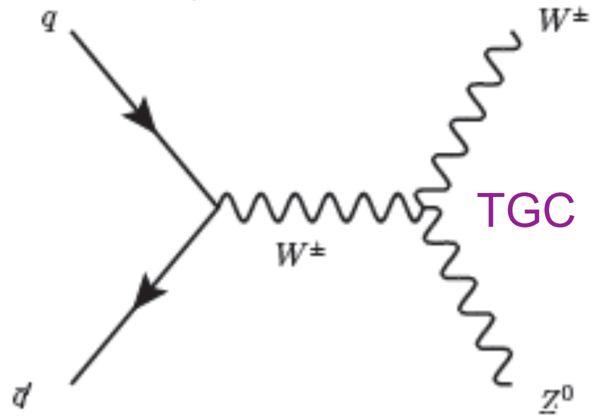
SMP-VV Meeting, April 20, 2012

Recap of the physics motivation

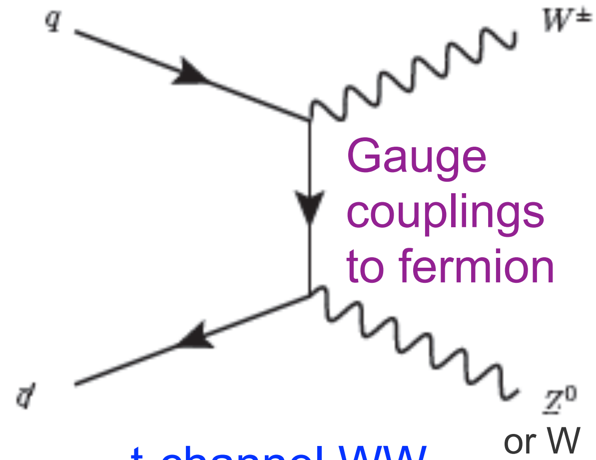
at Leading Order in α_S



s-channel WW production



s-channel WZ production



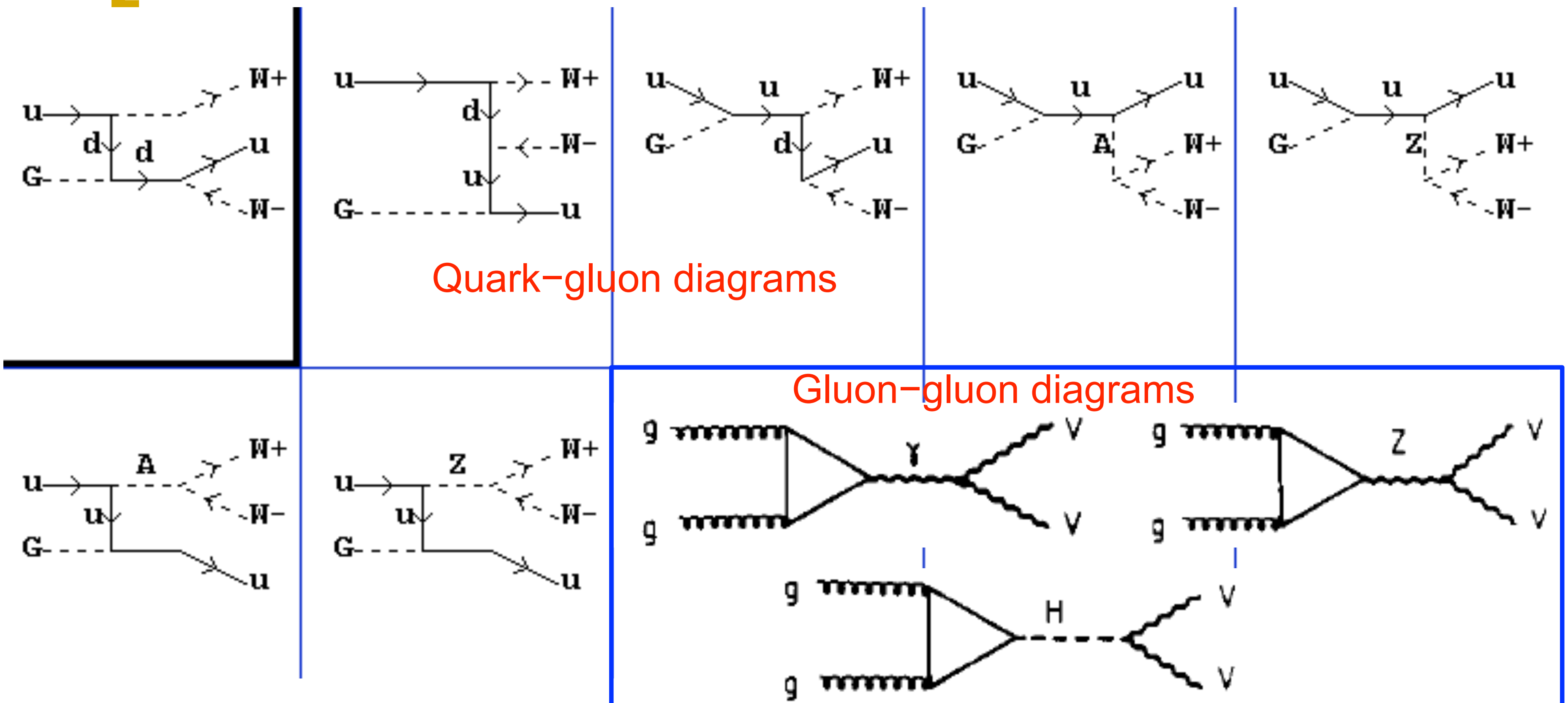
t-channel WW, WZ production

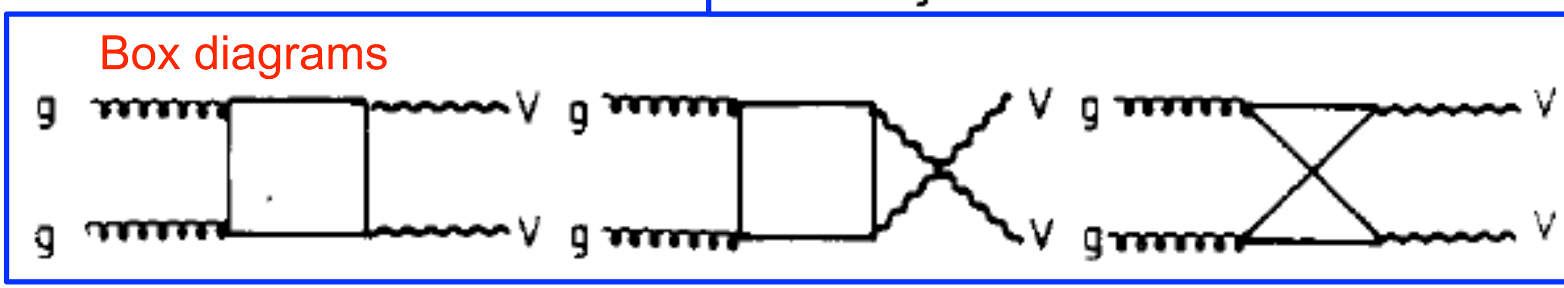
Some quick Observations:

1. An important milestone to observe diboson in semi-leptonic final state first, on way to discovering Higgs (either $WH\rightarrow l\nu bb$ or $H\rightarrow WW\rightarrow l\nu jj$) or new physics signal containing an s-channel dijet resonance. Sensitive to gauge coupling.

2. Although W and Z boson masses differ by 10 GeV the dijet mass resolution near 80-100 GeV is ~ 10 GeV ➜ cannot distinguish well between WW and WZ.

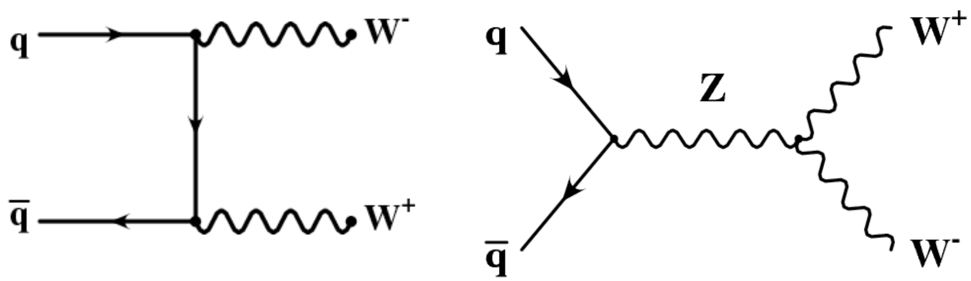
Significant contribution from (N)NLO diagrams

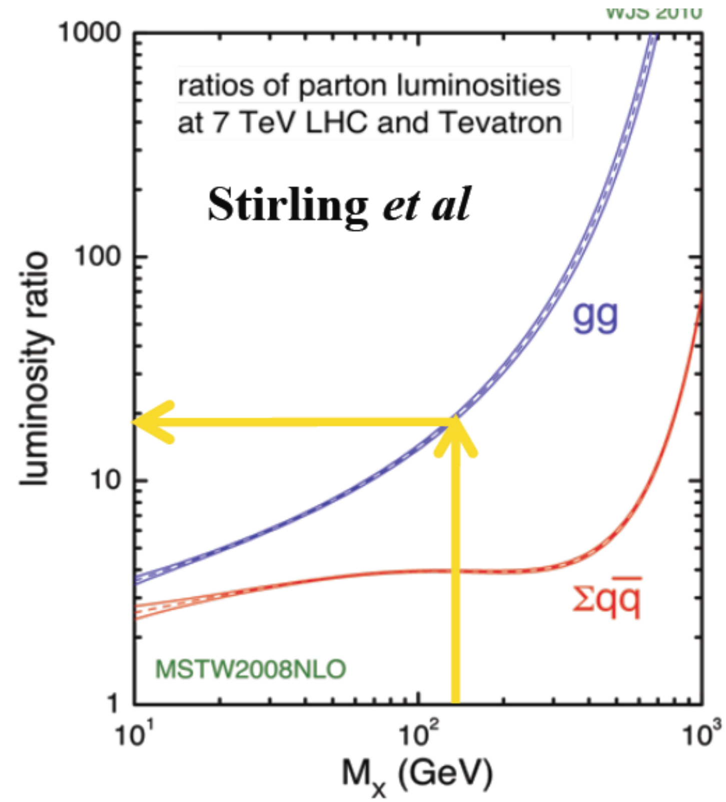




Plus more diagrams from NLO in α_{EWK}

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.

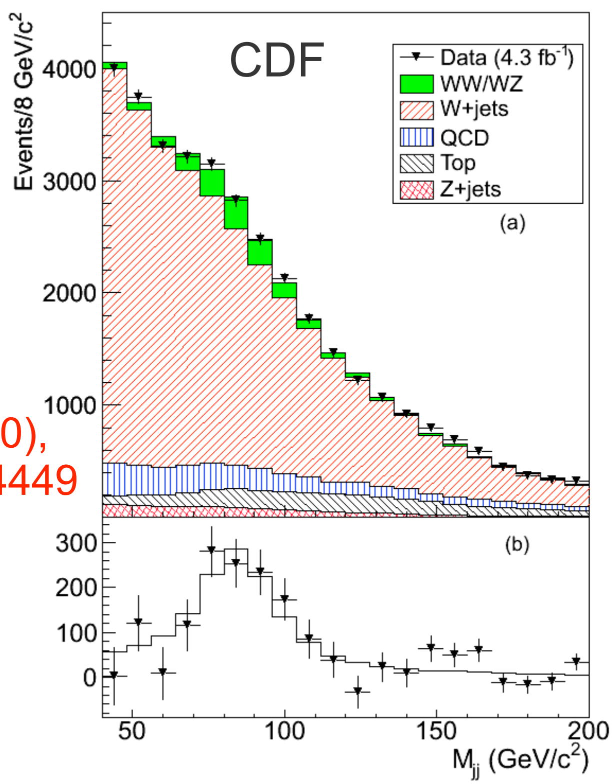
Previous measurements at hadron colliders

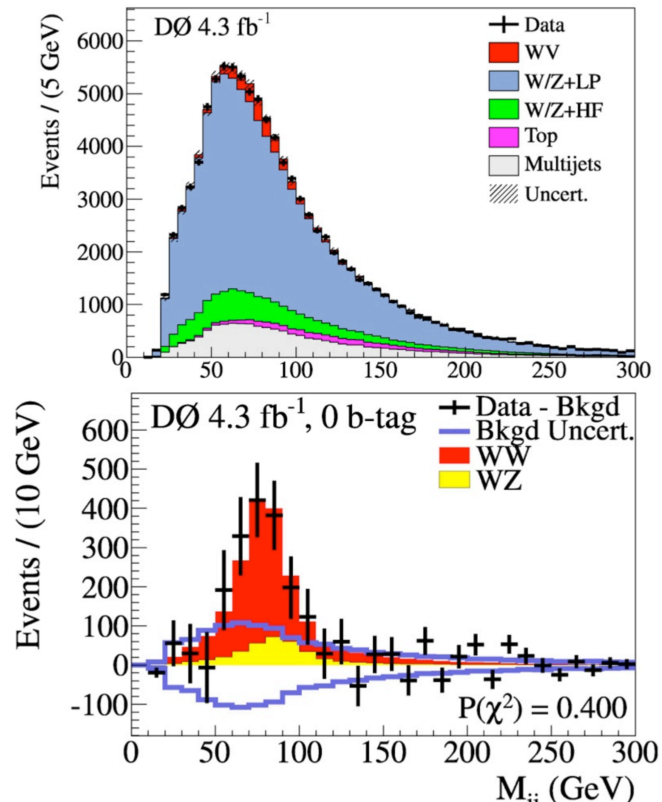
- CDF and D0 have publications with 5σ significance in the last 1–2 years:

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

  http://www-d0.fnal.gov/Run2Physics/WWW/results/final/EW/E11E/
- Both are published (or submitted) as observation papers.

PRL 104, 101801 (2010), arXiv: 0911.4449



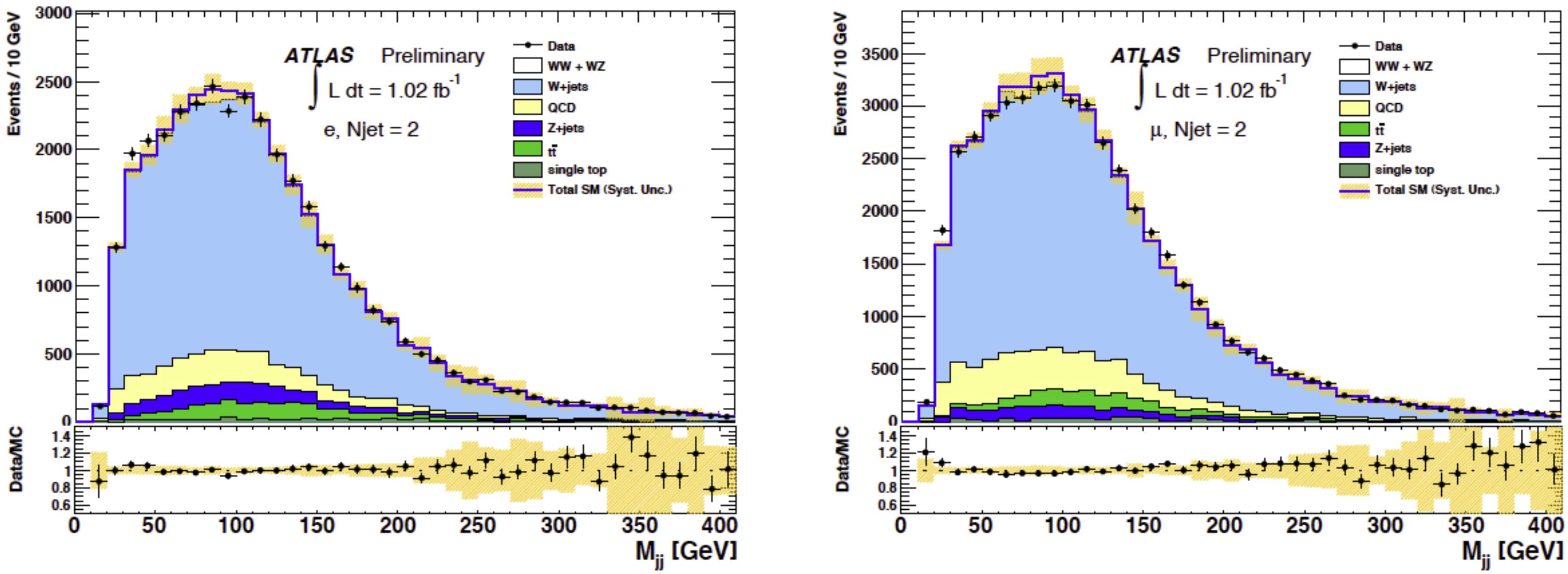


Submitted to PRL (Dec 2011), arXiv: 1112.0536

ATLAS

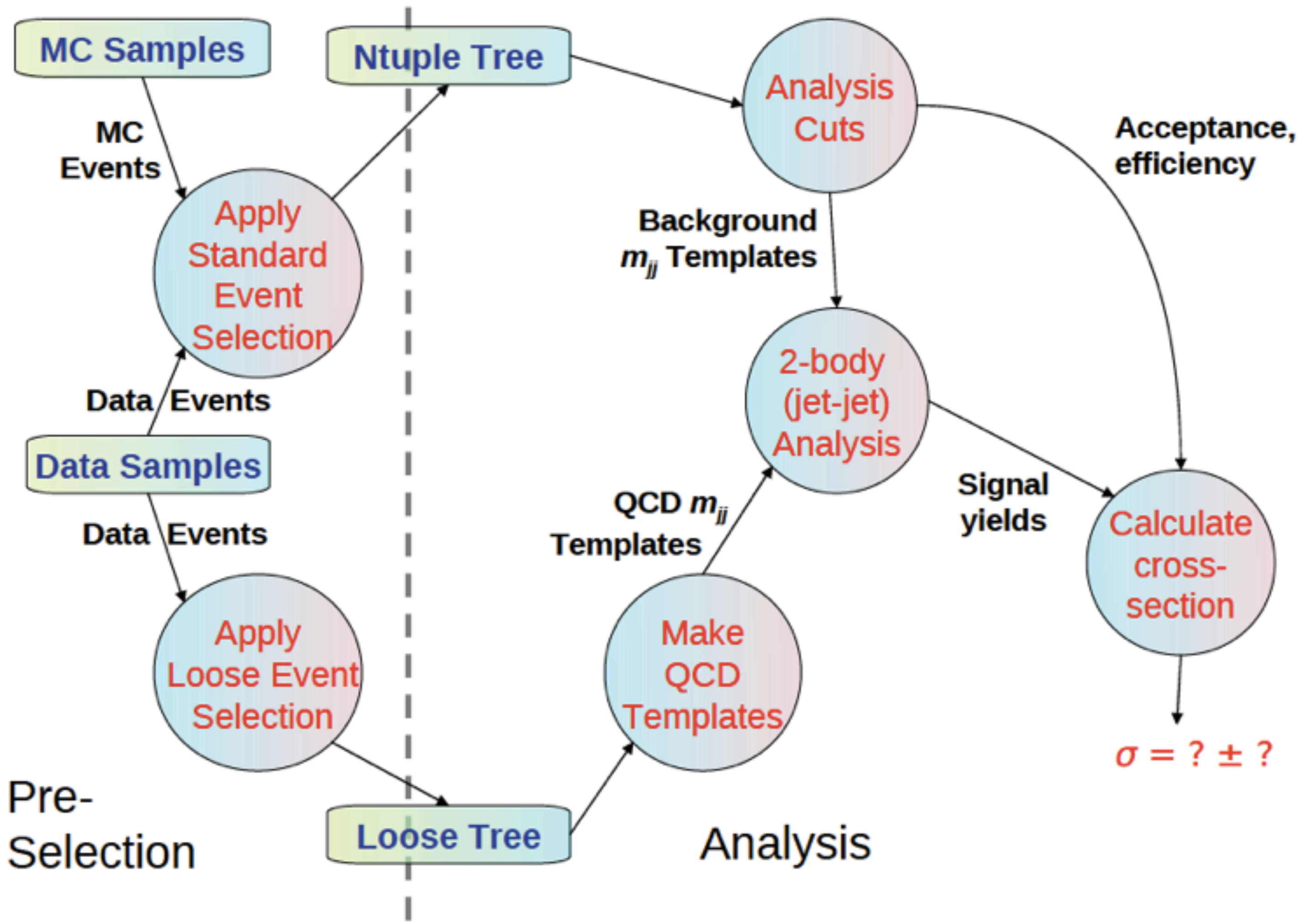
ATLAS doesn't yet have a paper/public result on this topic. The closest ones are:

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
typo ~~/ElectronHad/~~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}>40GeV (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, |η| <2.5 (excluding 1.44 < |η| <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	0.05	
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

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

Object selection: jets/MET

- **Two or three anti-KT 0.5 PFJets after PfNoPU in each event**

- **Corrected p_T >35 GeV and $|\eta|$ <2.4**
- **$|\Delta R(\text{lepton},j)|$ > 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	$p_T^{\text{jet}} > 35$ 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	
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]	$A \times \varepsilon\ (ejj)$	$A \times \varepsilon\ (ejj\text{,b-tag})$	$A \times \varepsilon\ (\mu jj)$	$A \times \varepsilon\ (\mu jj\text{,b-tag})$
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}

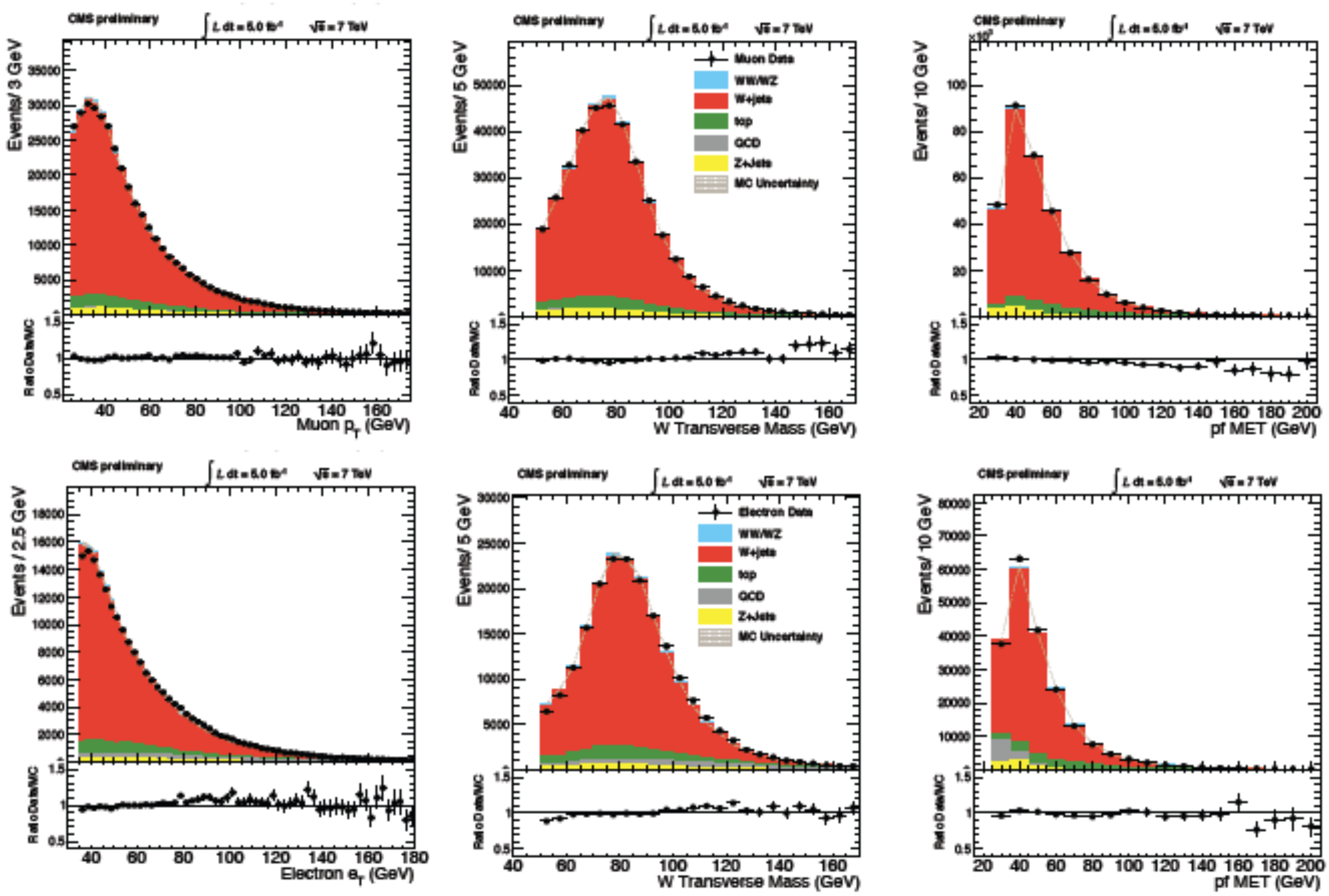
total = 0.88% including the BR (~11% for each lepton, 67% jj)

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

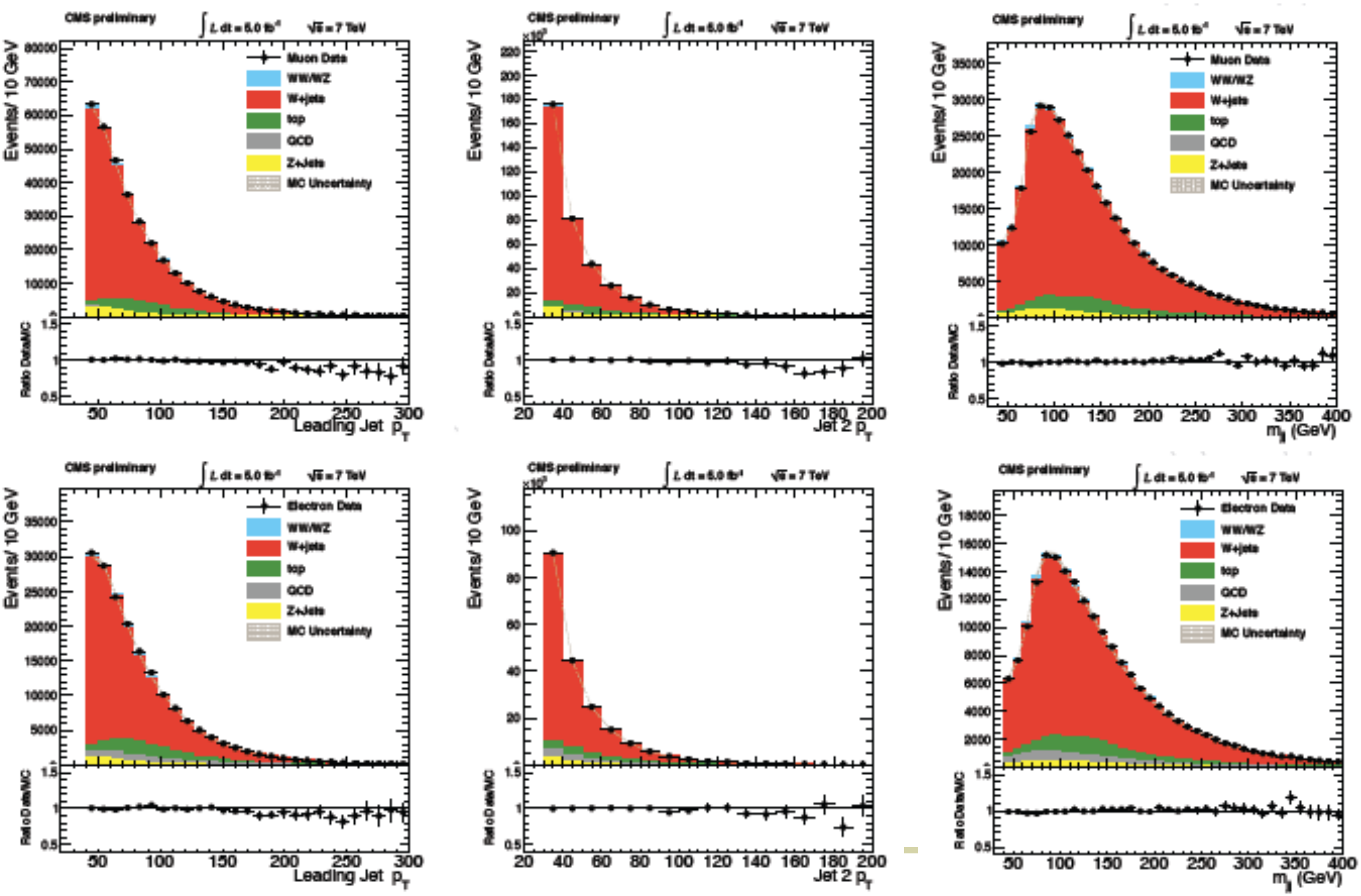
Background rate

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

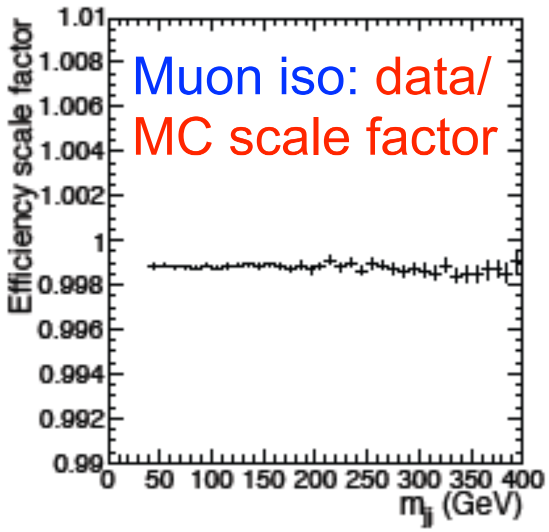


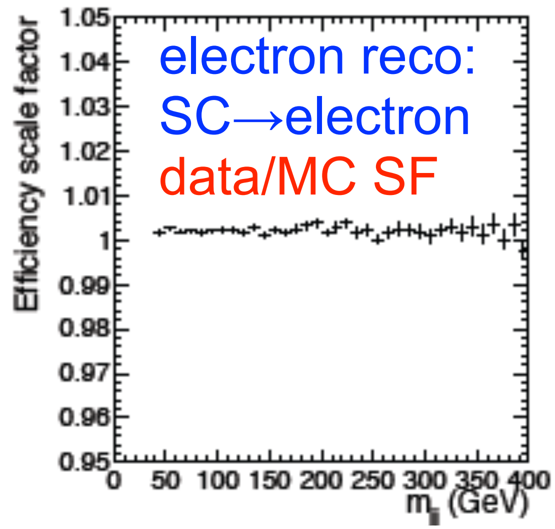
Control plots: dijet system

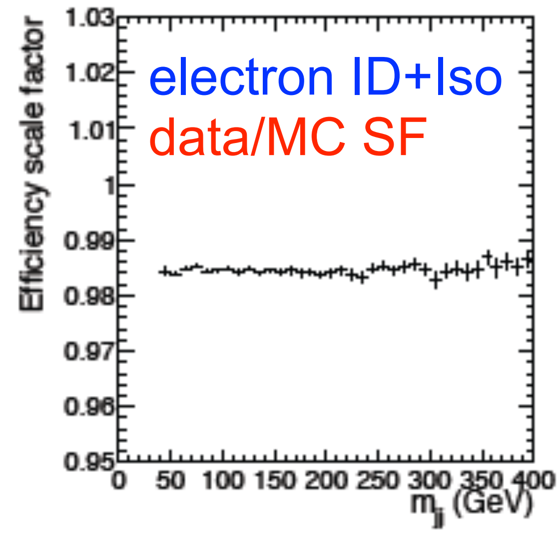


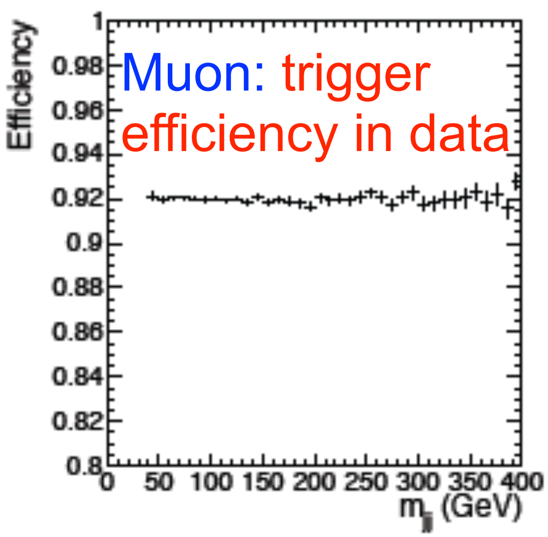
Lepton efficiency from tag & probe

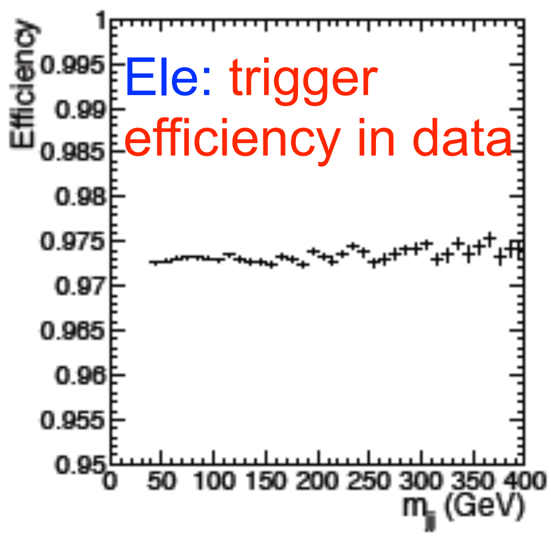
lumi-weighted average

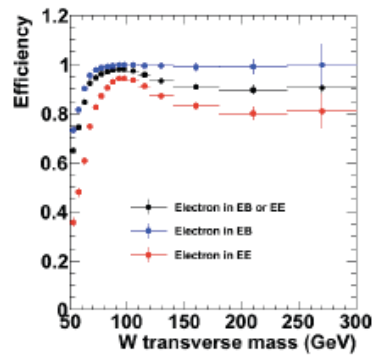


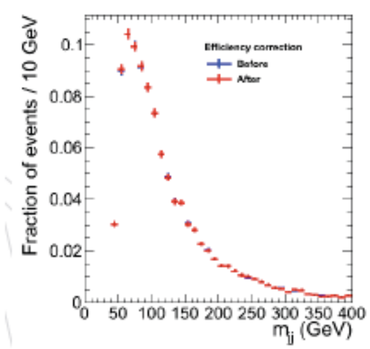












W m_T trigger turnon for electron

Maximum likelihood fit

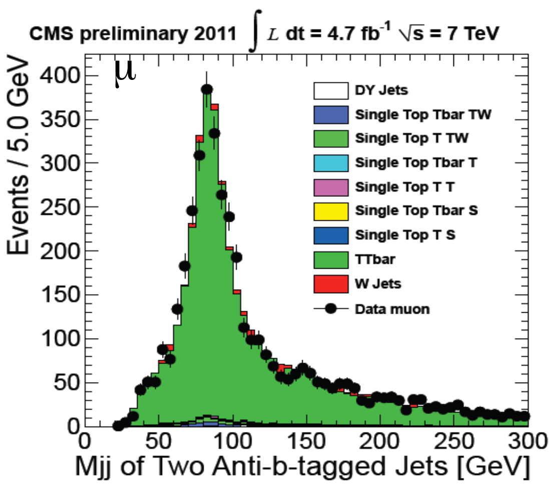
- ✦Unbinned maximum likelihood fit within 40 < Mjj < 150 GeV
- ✦Four Separate Fits: μ+jj non b-tag, μ+jj b-tag, el+jj non b-tag, el+jj b-tag
  - -Combine the results when setting exclusion limits

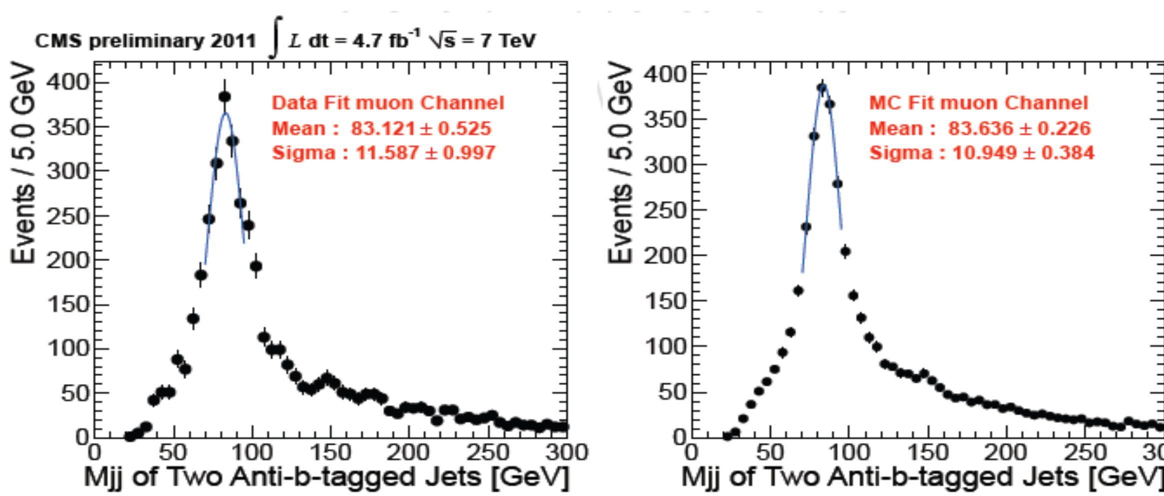
- ✦Diboson normalization is completely floated/unconstrained
  - -Other components are constrained within NLO uncertainty

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/resolution from top evens

- **Compare to the (almost) pure ttbar control sample:**
  - **Exactly four jets - two b-tagged and two anti-btagged**
  - **Use the anti-btagged 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 is propagated to our templates and makes a negligible impact**

QCD template and normalization

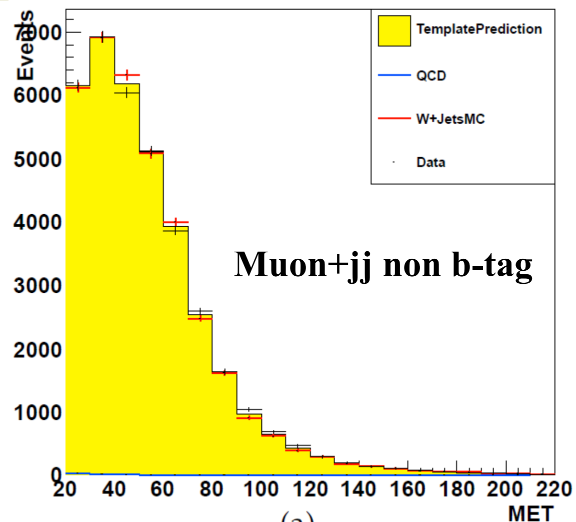
❖Invert the lepton Isolation
❖Fit MET distribution

➢Relative Fractions (accounting for acceptances):

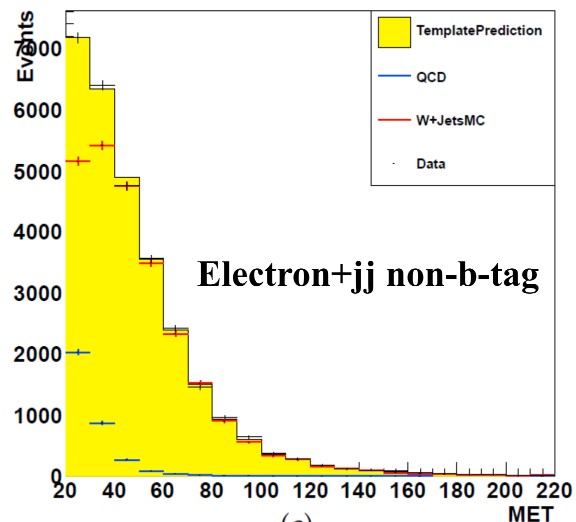
➢μ 2J : 0.0016 ± 0.0042
➢el 2J : 0.0617 ± 0.0038
➢μ btag : 0.0
➢el btag : 0.028 ± 50%

➢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:

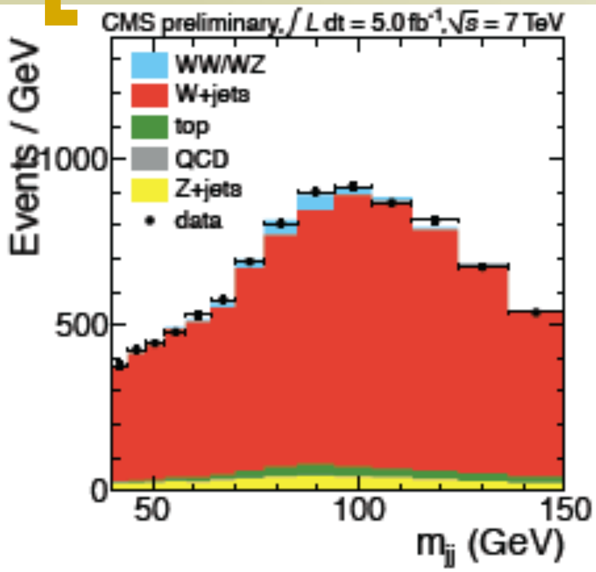
- **Fit with the default NLO MC: Matrix Element – Parton Shower matching threshold = 20GeV, Factorization Scale = 20 GeV**
- **Repeat the fit with alternate ME-PS matching (Factorization) samples where threshold and scale vary by a factor 2, and compute the systematics**
- **Overcovers the errors and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

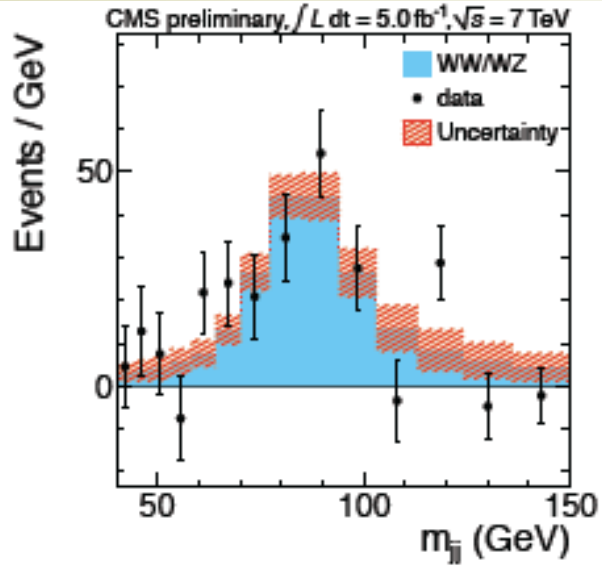
We let these scales float within MC uncertainty:

- **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**

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

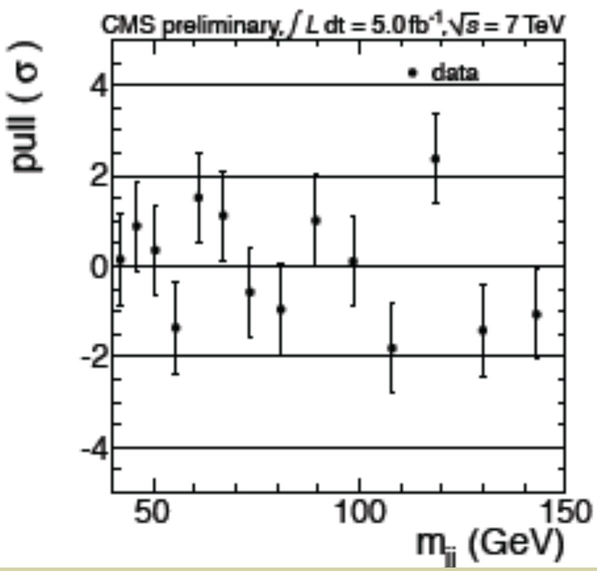
Fit results: μ+jj non b-tag





$\chi^2/\mathrm{dof} = 9.73/12$

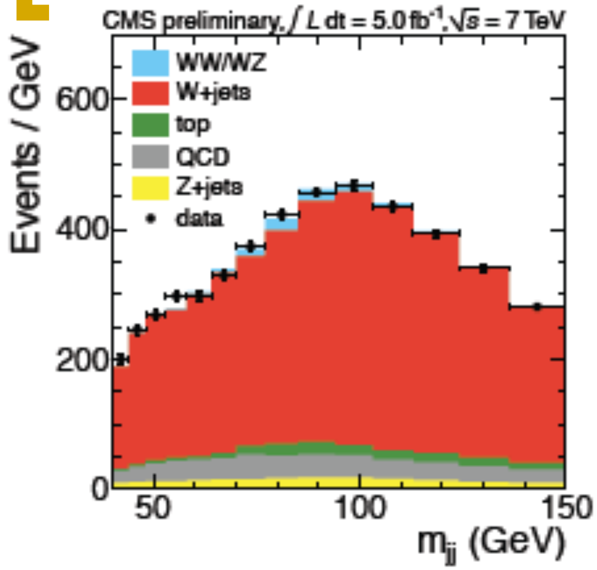
Good description of data

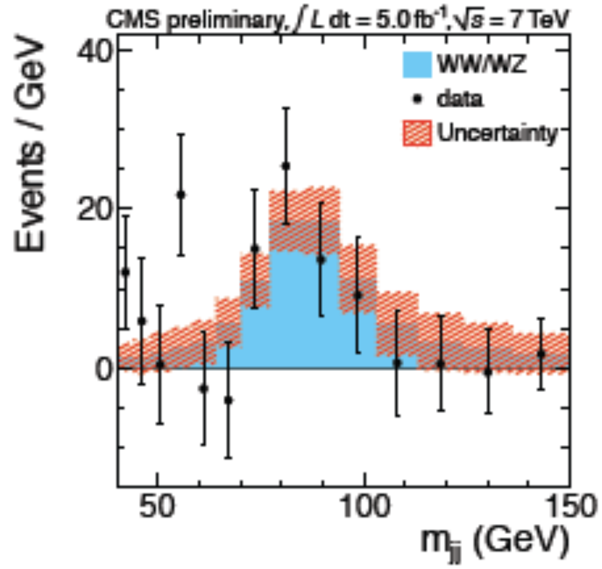


 # diboson = 1736 ± 389

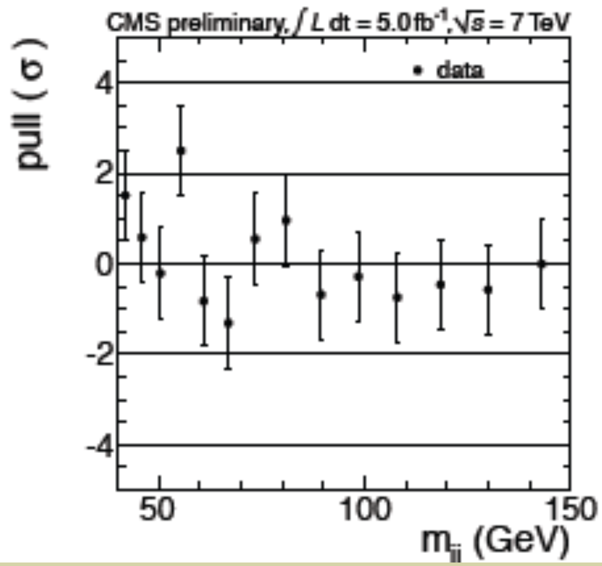
MC prediction = 1697

Fit results: e+jj non b-tag





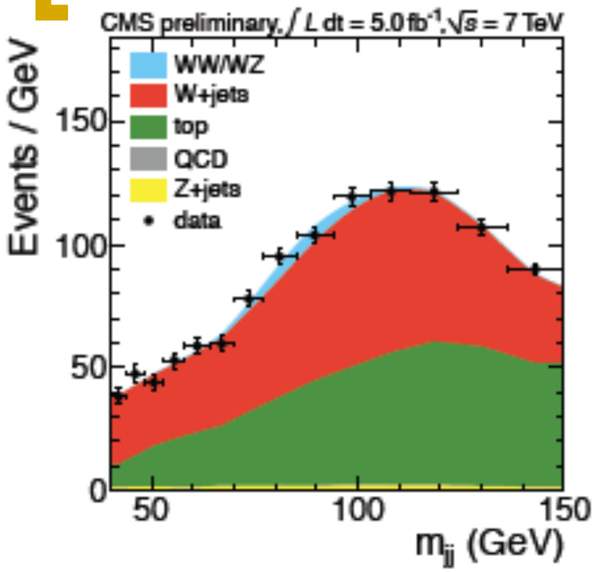
χ^2/dof = 5.30/12

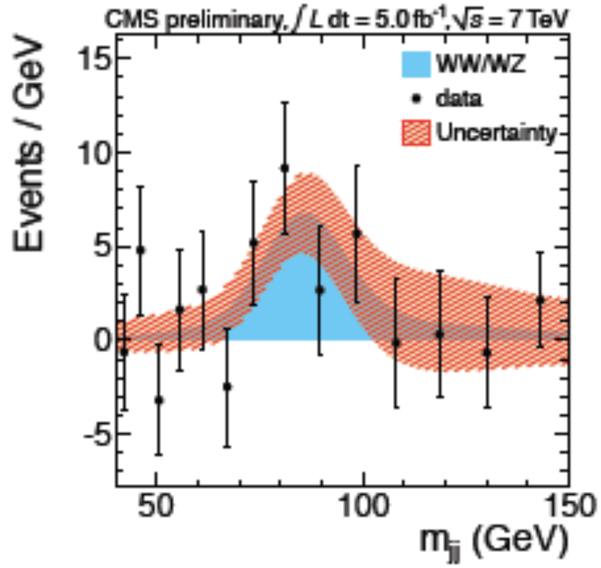


 # diboson = 727 ± 302

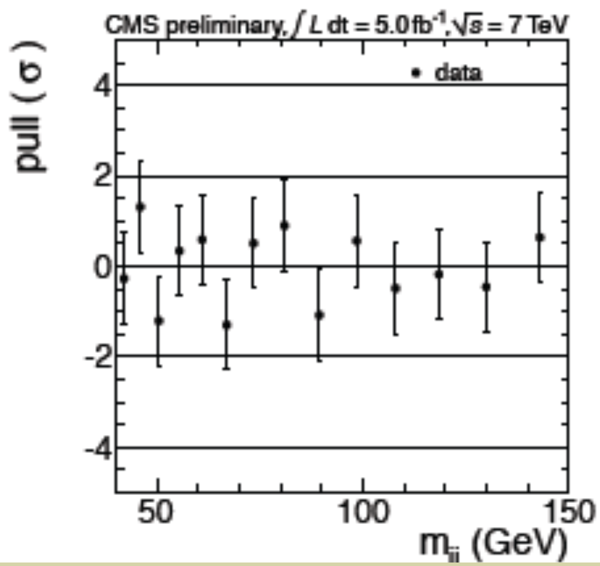
MC prediction = 867

Fit results: μ+jj b-tag





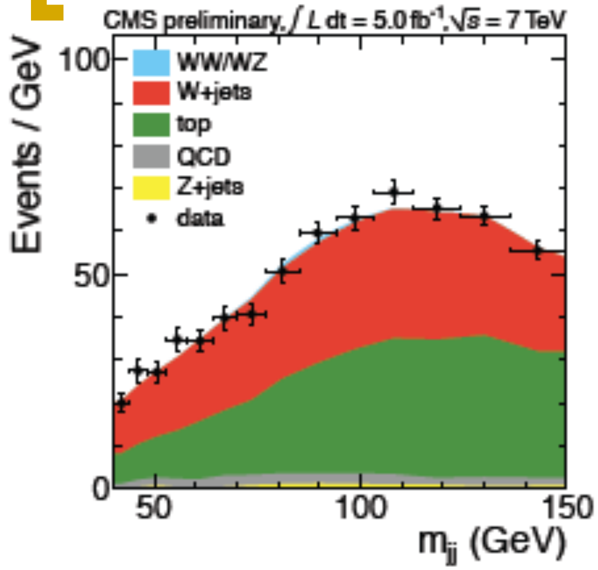
$\chi^2/\mathrm{dof} = 7.78/12$

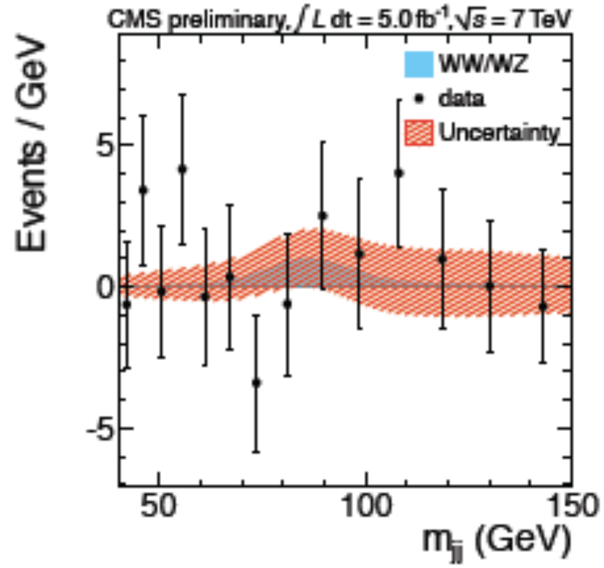


 # diboson = 226 ± 203

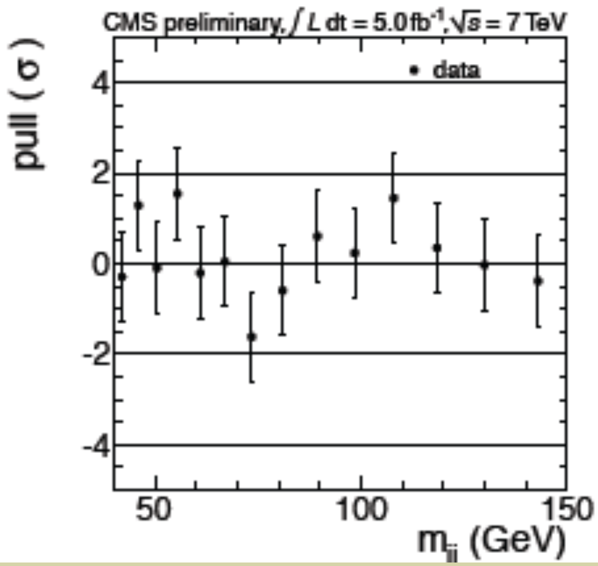
MC prediction = 211

Fit results: e+jj non b-tag





χ^2/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

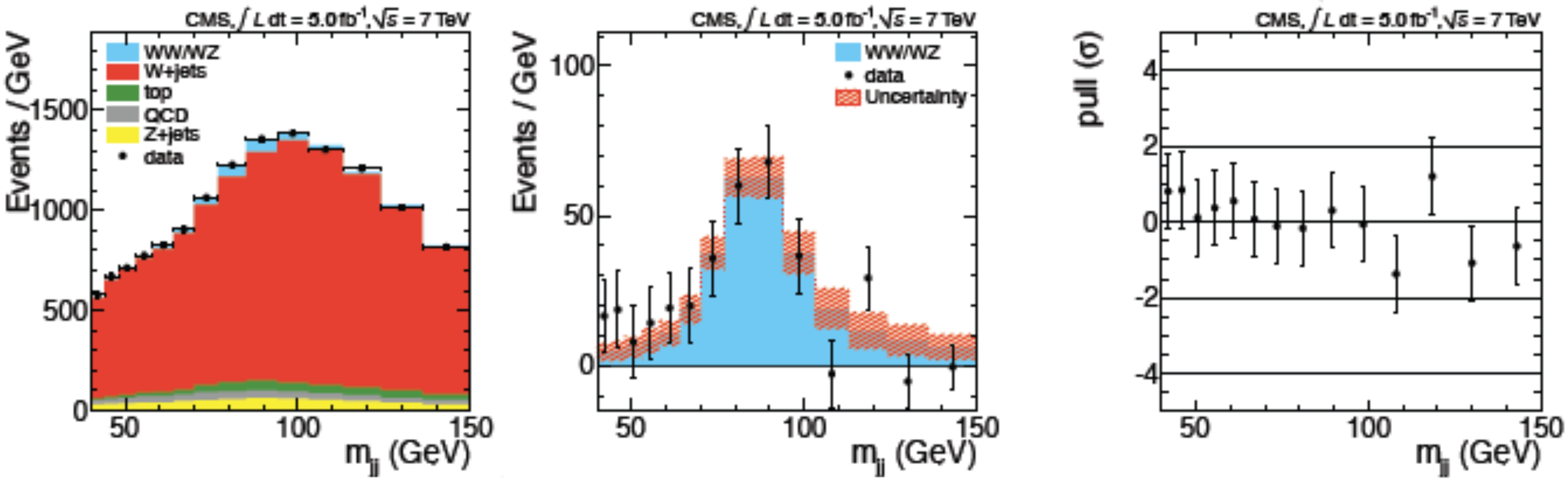
Bin	Muons, b-tagged		Electrons, b-tagged	
	Predicted	Extracted	Predicted	Extracted
Dibosons	211	226 ± 203	110	35 ± 86
Multijet	16	16 ± 42	171	231 ± 78
Single Top	1220	1219 ± 60	618	626 ± 31
$t\bar{t}$	3206	3192 ± 191	1846	1976 ± 104
W+Jets	5082	5082 ± 206	2551	2693 ± 107
Drell-Yan+Jets	206	206 ± 9	857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

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)	3%
Lepton trigger eff.	1%
Lepton selection eff.	2%
Pile-up	$< 1\%$
b-tag veto	$< 1\%$

Combined result



Event category	Measured cross section
μjj	67.11 ± 15.04 pb
ejj	55.00 ± 22.85 pb
μjj,b-tag	70.32 ± 63.16 pb
ejj,b-tag	20.92 ± 51.41 pb
Theory Prediction [4]	65.6 ± 2.2 pb

NLO, MCFM

#diboson = 2724 ± 540, MC prediction = 2885

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

Combining all four channels we obtain:

$$\sigma = 61.39 \pm 11.98 \text{ pb}$$

Summary of results and plan for publication

- Observe diboson events in semi-leptonic final state
  - 2724 ± 540 events, when 2885 expected
  - Consistent with the NLO predictions
  - This is the first observation in this channel at a pp collider

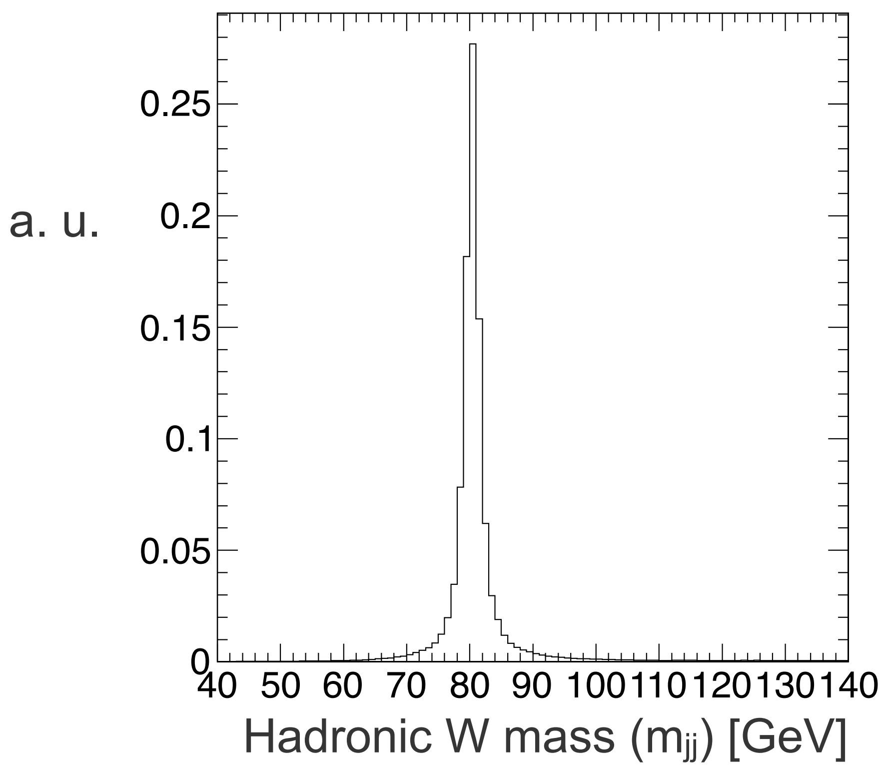
- Compute cross section
  - 61.4 ± 12.0 pb, SM prediction 65.6 pb

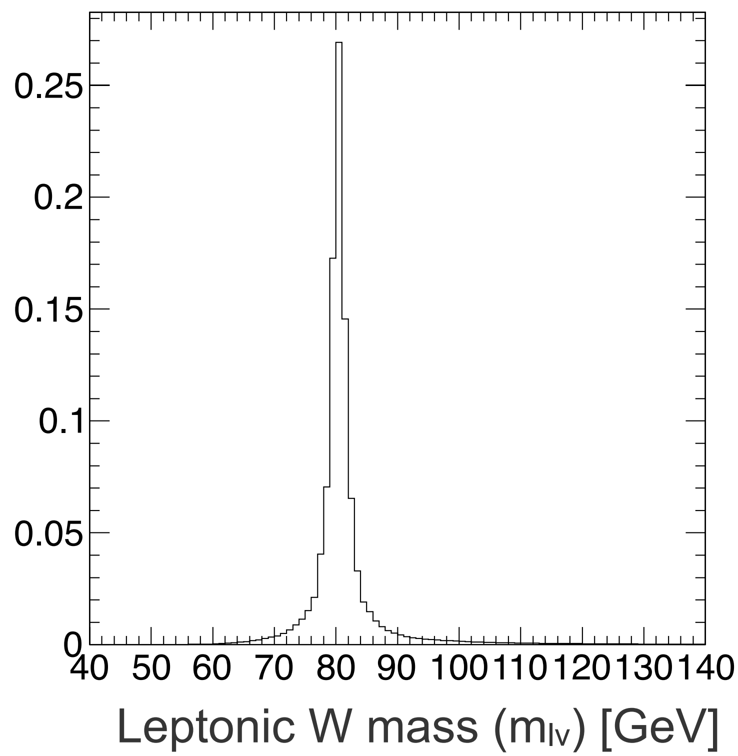
- Analysis note AN-2011-151 v3 ready for scrutiny by this group
  - working to understand the sensitivity to anomalous TGC
  - will decide in the next 1-2 weeks the feasibility of deriving aTGC limits in this round of analysis or to combine later with other diboson channels
  - aim for approval in May for the publication of this analysis

backup slides

Diboson lineshape

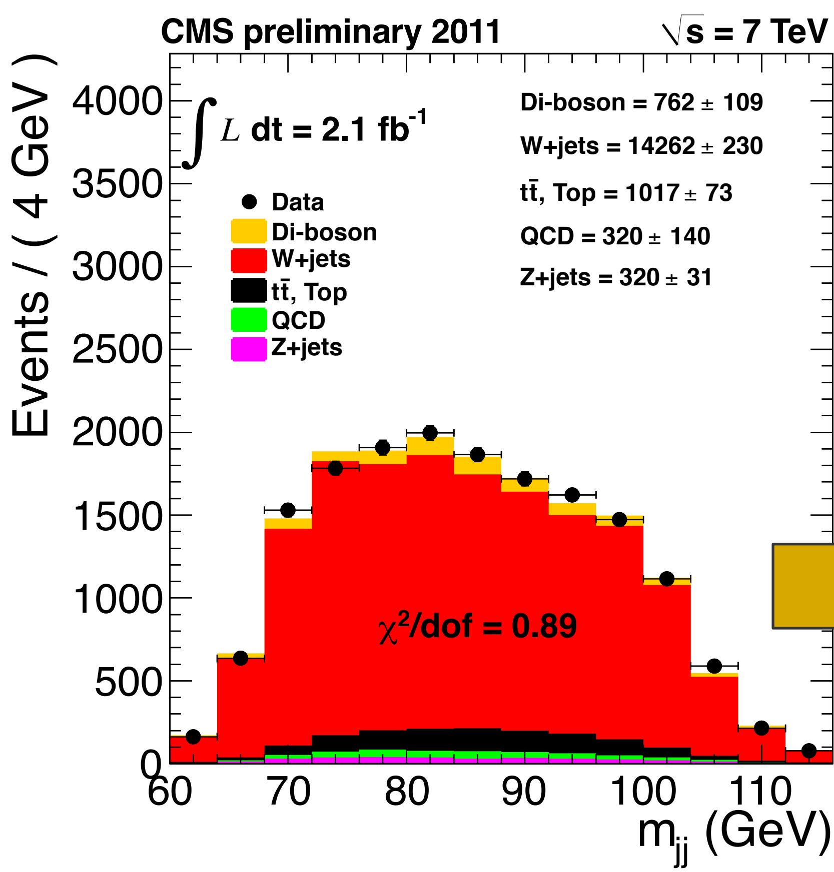
In order to get NLO shapes, we generated diboson samples using MCFM. But diboson m_{jj} shape is almost a delta function. Smearing this by detector resolution will get us a Gaussian shape which is not good. Need to explore some data driven shape.



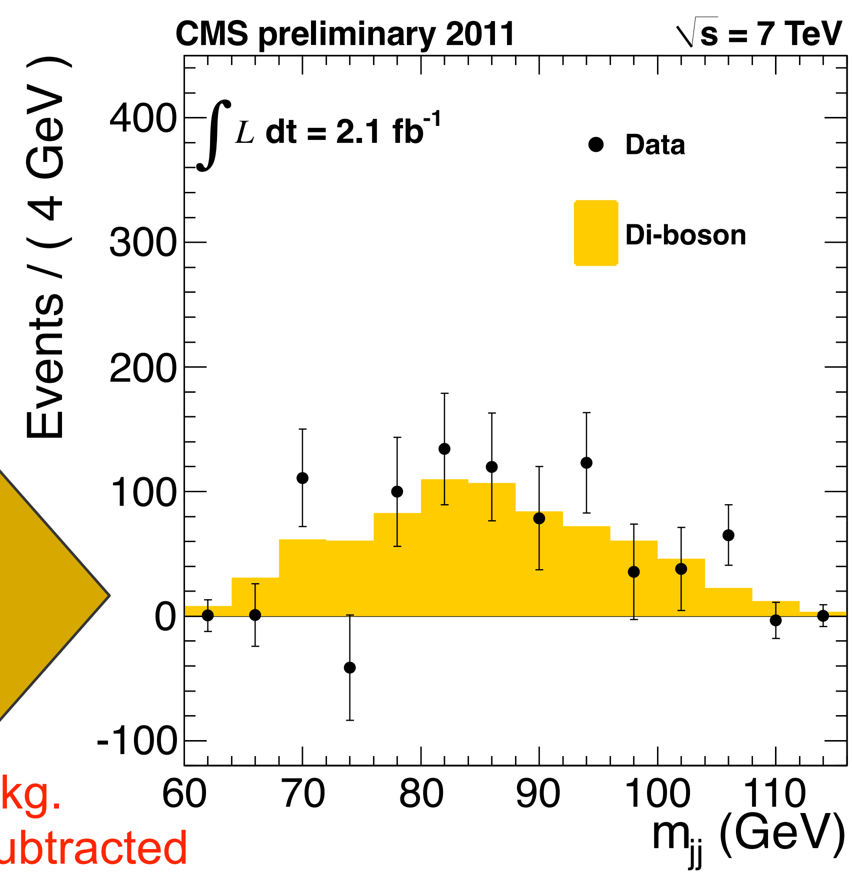


2-jet sample: fit using diboson shape from data

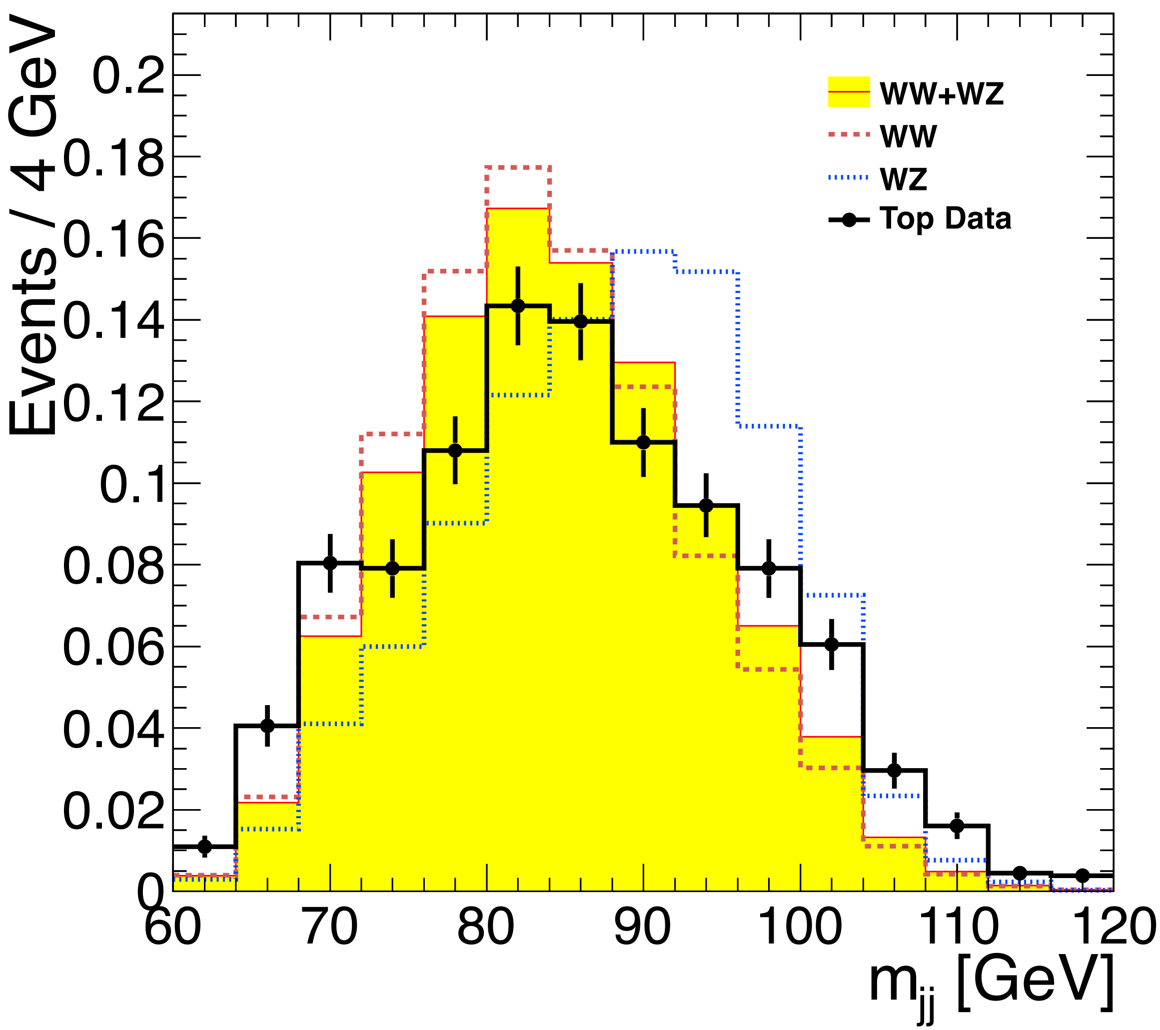
The shape works fine. The result is essentially identical to the one obtained using MC template (slides 3−4). The data statistics hurt.



Bkg. subtracted



Comparison of data and MC templates (2-jet)



There are caveats in using hadronic W shape from top:

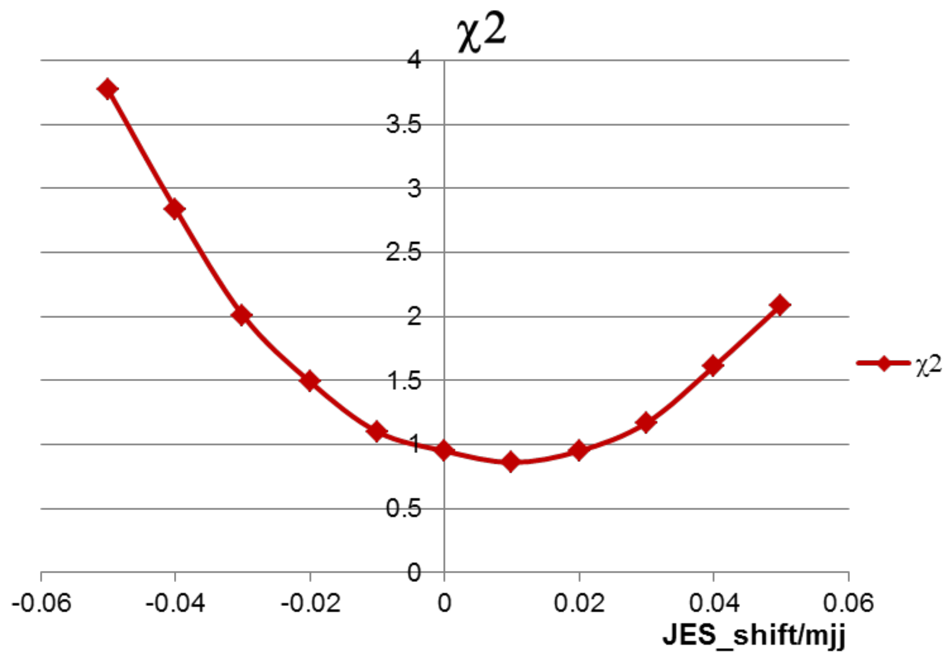
- Only hadronic W, no hadronic Z. The two shapes have minor differences although we cannot resolve between them given JER.
- Top events have extra b jets that change the event topology somewhat. For example, the hadronic W p_T would be different.

I conclude that the result doesn't depend on choice of diboson shape (within reason) and we should stick with the MC shape.

Scan of jet energy scale

- The default fit allows the JES to float and returns a value of 0.003 m_{JJ}
- We perform a manual scan by fixing JES and repeating the fit

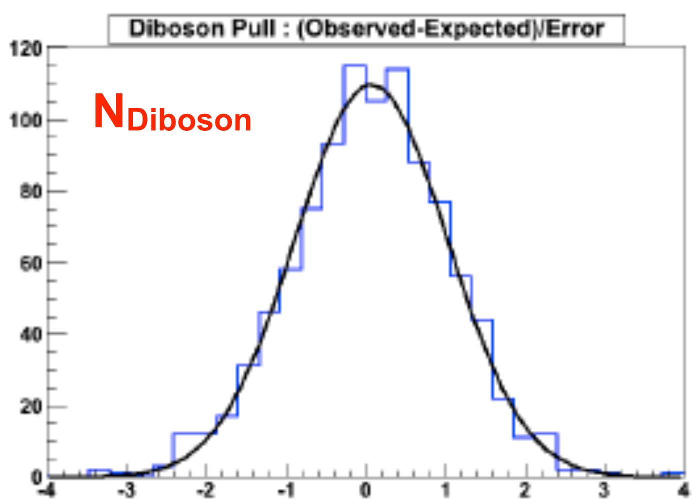
JES_shift/mjj	WW	χ^2
-0.05	1012	3.77
-0.04	960	2.84
-0.03	901	2.01
-0.02	874	1.49
-0.01	877	1.1
0	793	0.95
0.01	676	0.86
0.02	594	0.95
0.03	496	1.17
0.04	354	1.61
0.05	261	2.09

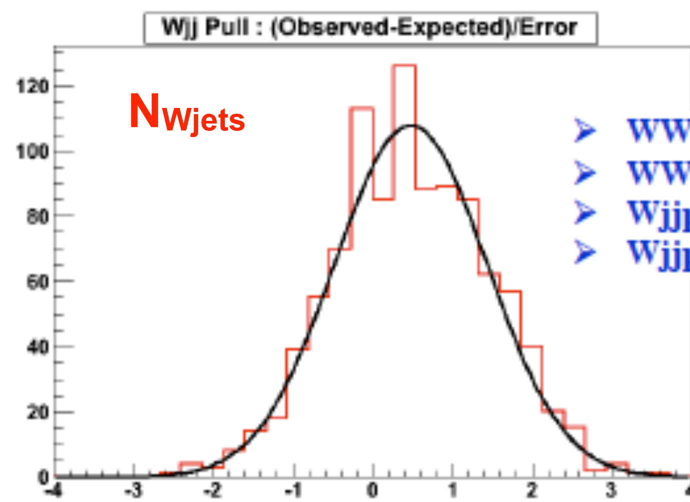


The fit is stable and has a χ^2 minimum near 0.

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