Study of diboson WW,WZ production in W(→lν)+jj events

Analysis Note: AN-11-151

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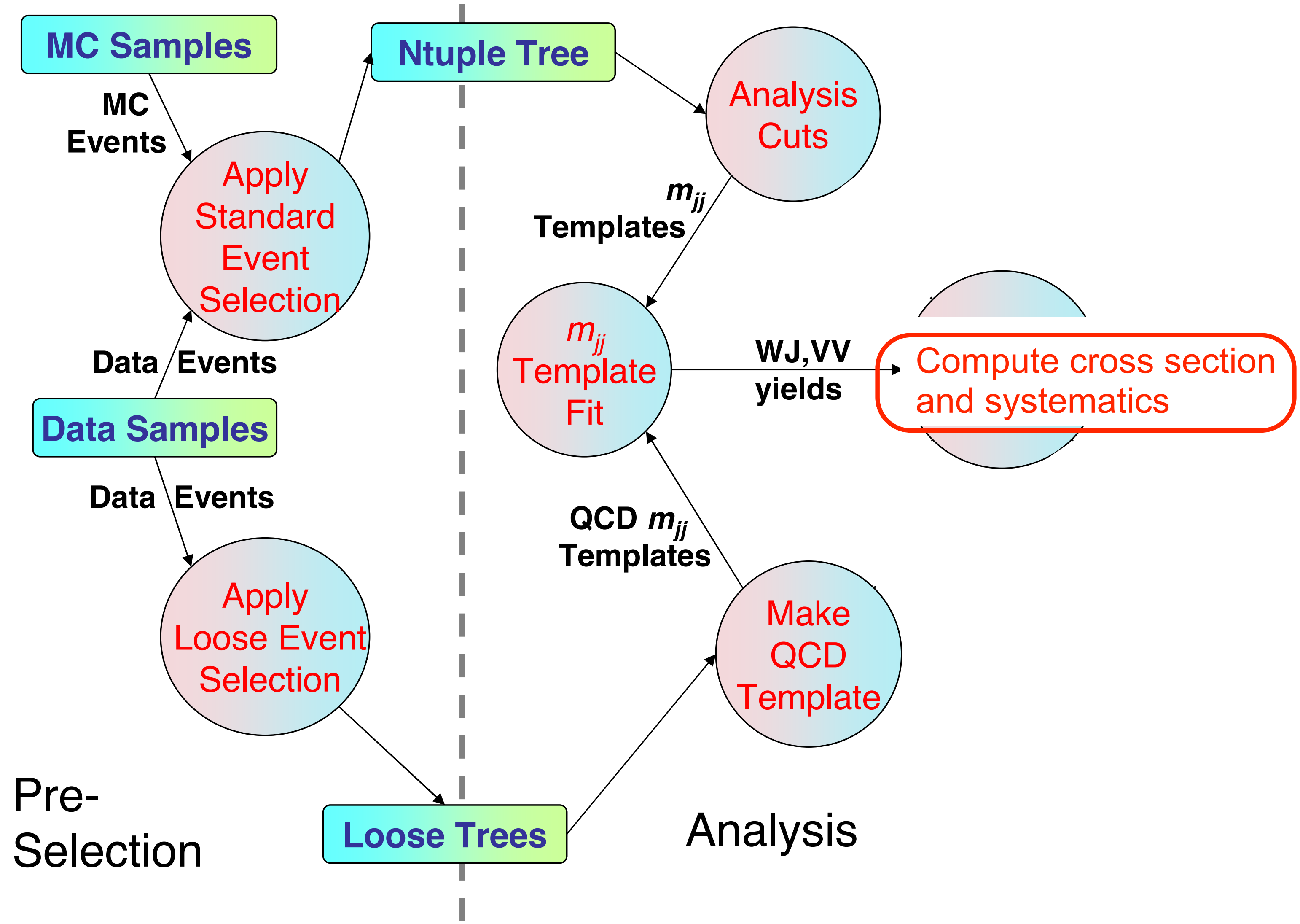
Diboson meeting, October 26, 2011

Analysis overview



Data sample

$\int L\, dt = 2.1\ fb^{-1}$

Data Set Used for This Analysis (2.1 fb^{-1})

Data Set Name	Run Range	Lumi (pb^{-1})
2010 Muon Data		
/Mu/Run2010A-Apr21ReReco-v1/AOD	136033-149442	3.180
/Mu/Run2010B-Apr21ReReco-v1/AOD	136033-149442	31.094
2011 Muon Data		
/SingleMu/Run2011A-May10ReReco-v1/AOD	160404-163869	200.205
/SingleMu/Run2011A-PromptReco-v4/AOD	165071-168437	885.807
/SingleMu/Run2011A-05Aug2011-v1/AOD	170249-172619	361.738
/SingleMu/Run2011A-PromptReco-v6/AOD	172620-175770	641.911
Total		2123.937
2010 Electron Data		
/EG/Run2010A-Apr21ReReco-v1/AOD	136033-149442	3.153
/Electron/Run2010B-Apr21ReReco-v1/AOD	136033-149442	32.315
2011 Electron Data		
/SingleElectron/Run2011A-May10ReReco-v1/AOD	160404-163869	204.652
/SingleElectron/Run2011A-PromptReco-v4/AOD	165071-168437	886.790
/SingleElectron/Run2011A-05Aug2011-v1/AOD	170249-172619	361.719
/SingleElectron/Run2011A-PromptReco-v6/AOD	172620-175770	641.911
Total		2130.541

- Certified Golden JSON Files are used.

Monte Carlo samples

/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

signal:

/WW_TuneZ2_7TeV_pythia6_tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/WZ_TuneZ2_7TeV_pythia6_tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/TTJets_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v2/AODSIM

/TTTo2L2Nu2B_7TeV-powheg-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM

/QCD_Pt-20_MuEnrichedPt-15_TuneZ2_7TeV-pythia6/Summer11-PU_S4_START42_V11-v2/AODSIM

/WJetsToLNu_TuneD6T_7TeV-madgraph-tauola/Fall10-START38_V12-v1/AODSIM

/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/DYToTauTau_M-20_CT10_TuneZ2_7TeV-powheg-pythia-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/Tbar_TuneZ2_s-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/Tbar_TuneZ2_t-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/Tbar_TuneZ2_tW-channel-DS_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/T_TuneZ2_s-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/T_TuneZ2_t-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/T_TuneZ2_tW-channel-DS_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/QCD_Pt-30to80_EMEnriched_TuneZ2_7TeV-pythia/Summer11-PU_S4_START42_V11-v1/AODSIM

/QCD_Pt-80to170_EMEnriched_TuneZ2_7TeV-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM

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/WJetsToLNu_TuneZ2_matchingdown_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/WJetsToLNu_TuneZ2_matchingup_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/WJetsToLNu_TuneZ2_scaledown_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/WJetsToLNu_TuneZ2_scaleup_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM

/WToLNu_1jEnh2_2jEnh35_3jEnh40_4jEnh50_7TeV-sherpa/Summer11-PU_S4_START42_V11-v1/AODSIM

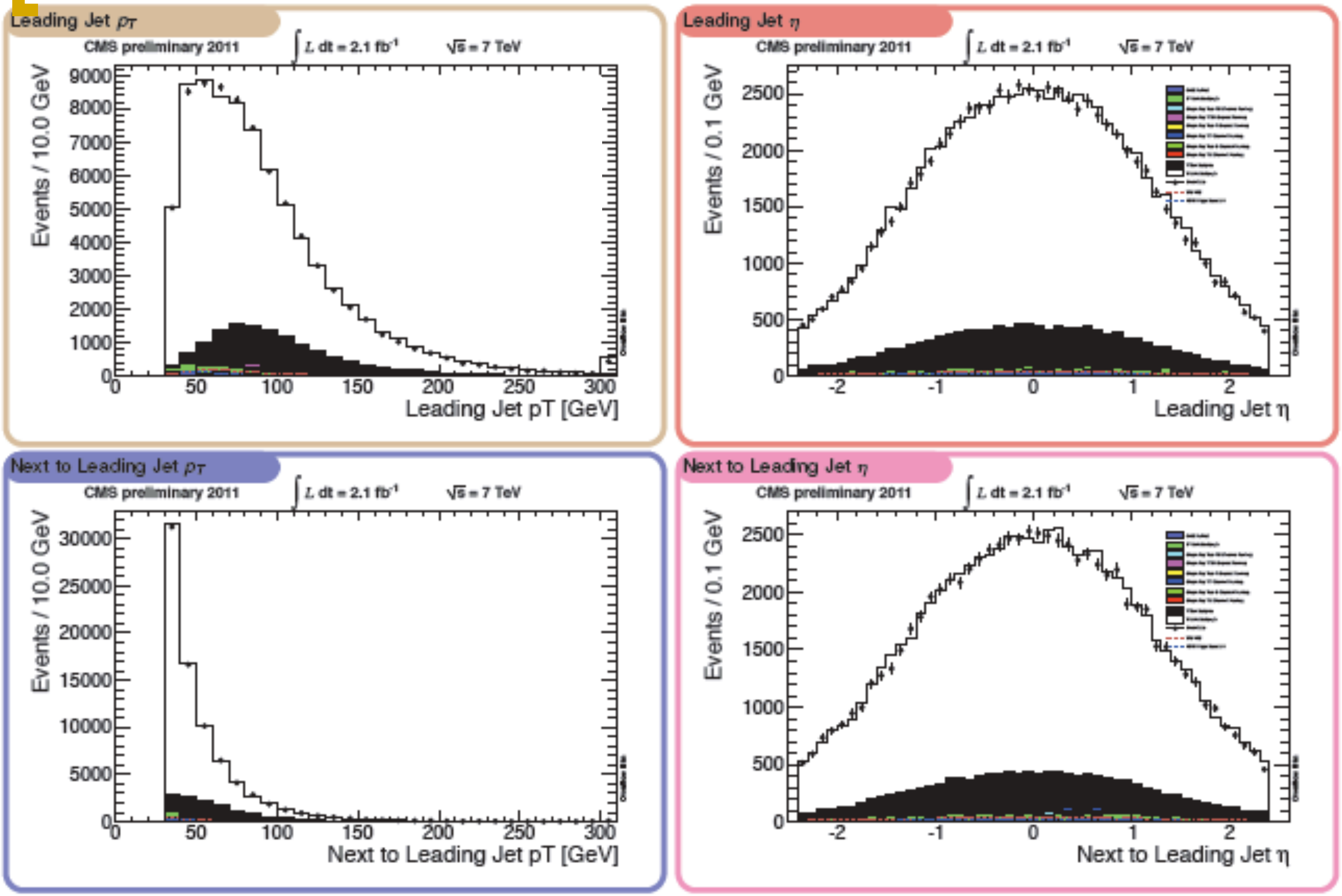
Event selection

- Muon event selection:
  - Standard ~~VBF~~ VBTF muon selection
  - muon $p_T > 25$ GeV/c, for acceptance : muon $|\eta| < 2.1$
  - Combined relative isolation less than 0.10 (Pileup Corrected)
  - Second lepton veto
- Electron event selection :
  - Standard WP70 Requirements except isolation
  - Combined relative Isolation < 0.05 (Pileup Corrected)
  - $E_T > 30$ GeV, $\eta < 2.5$ (excluding $1.4442 < |\eta| < 1.566$)
  - Second lepton veto
- Jet/MET requirements :
  - Require pf-MET > 30 GeV for this analysis.
  - Corrected jet $p_T > 30$ GeV, $\eta < 2.4$ and $\Delta R(\ell, j) > 0.3$
  - Default (JetMET POG recommended) charge hadron subtraction (PF2PAT/PfNoPU), FastJet PU subtraction, L2L3 Corrections and Loose jet id criteria
- Kinematic Requirements:
  - W Transverse Mass > 40 GeV
  - Di-jet system $p_T > 40$ GeV

combination of single mu triggers: most contribution from Mu17 and IsoMu24

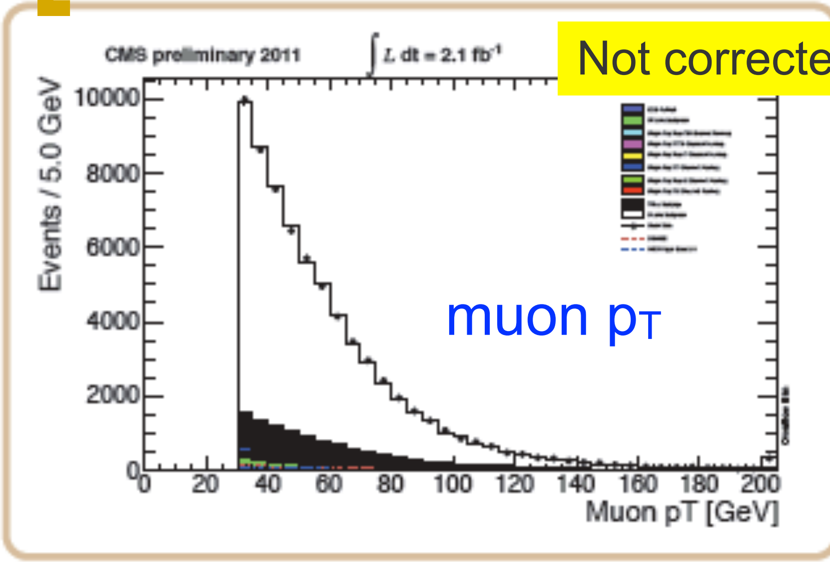
combination of single electron triggers: most contribution from Ele 25,27,32

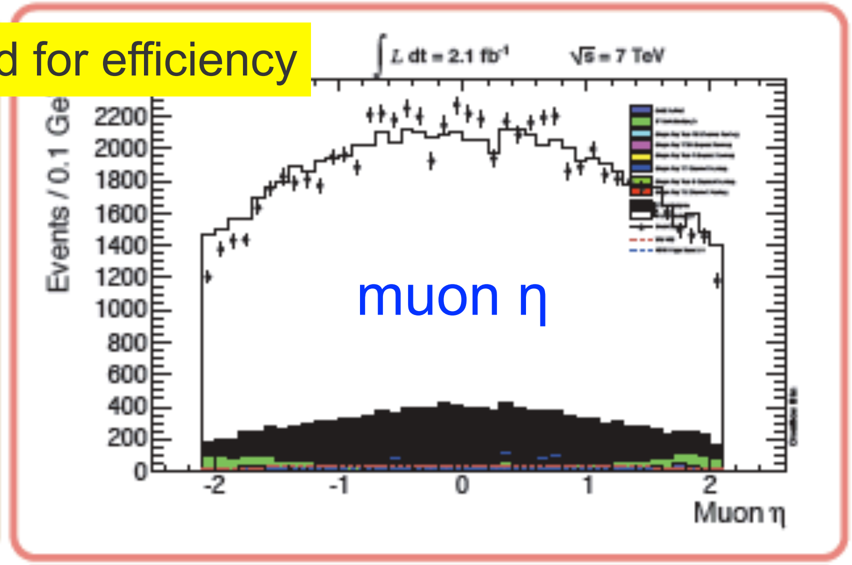
Control plots: leading & second jet p_T and η

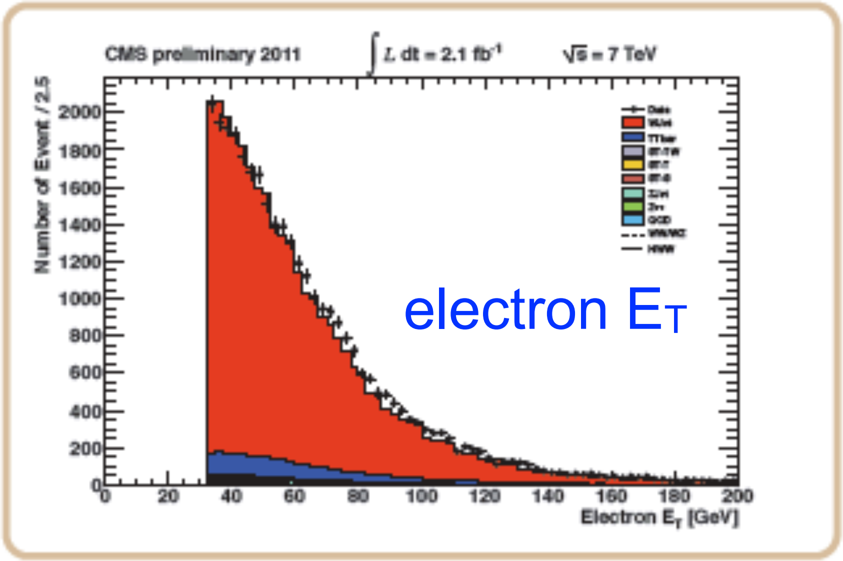


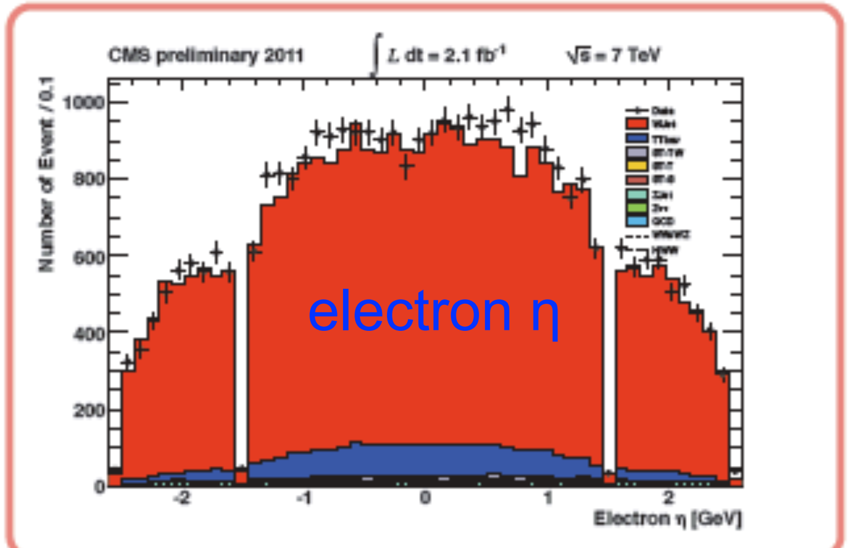
Control plots: lepton p_T and η

Not corrected for efficiency



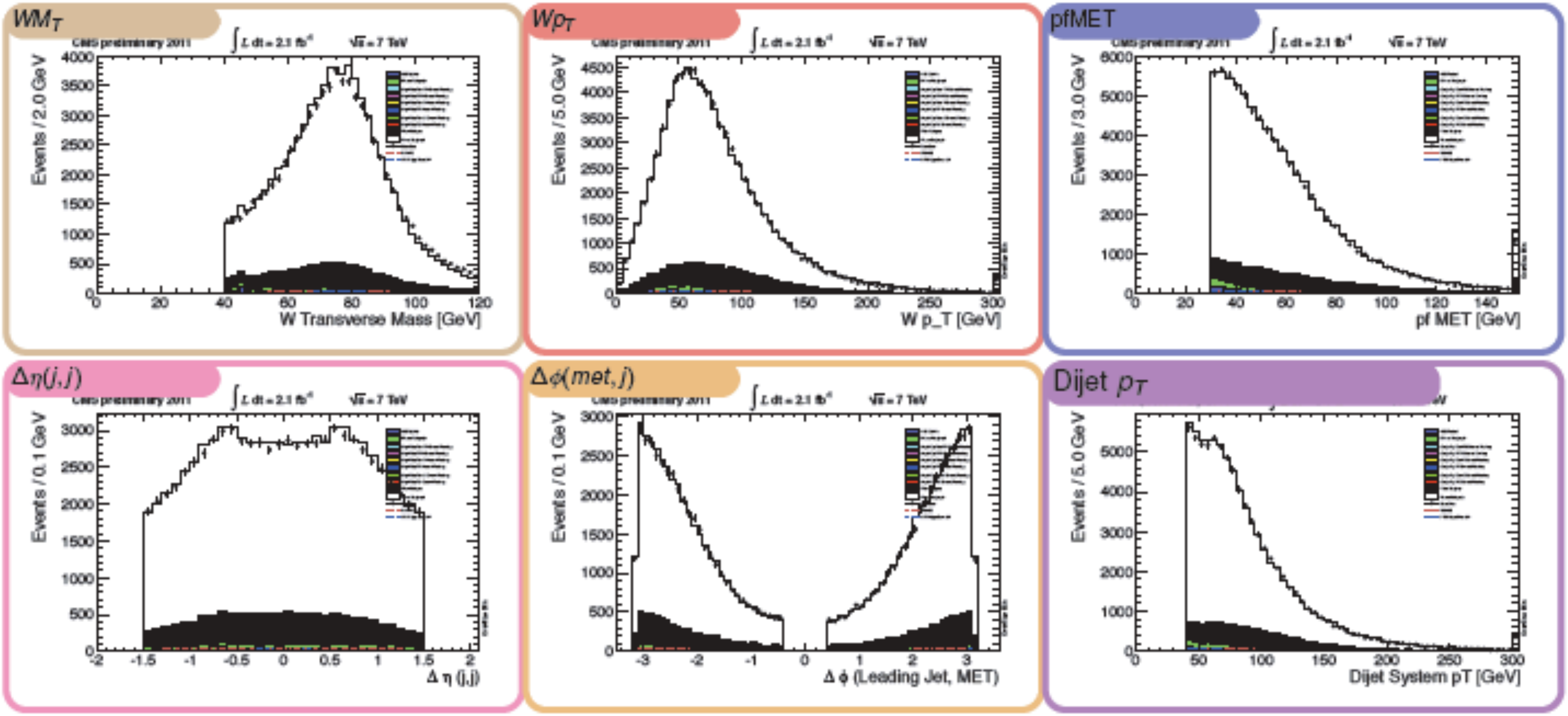






More control plots

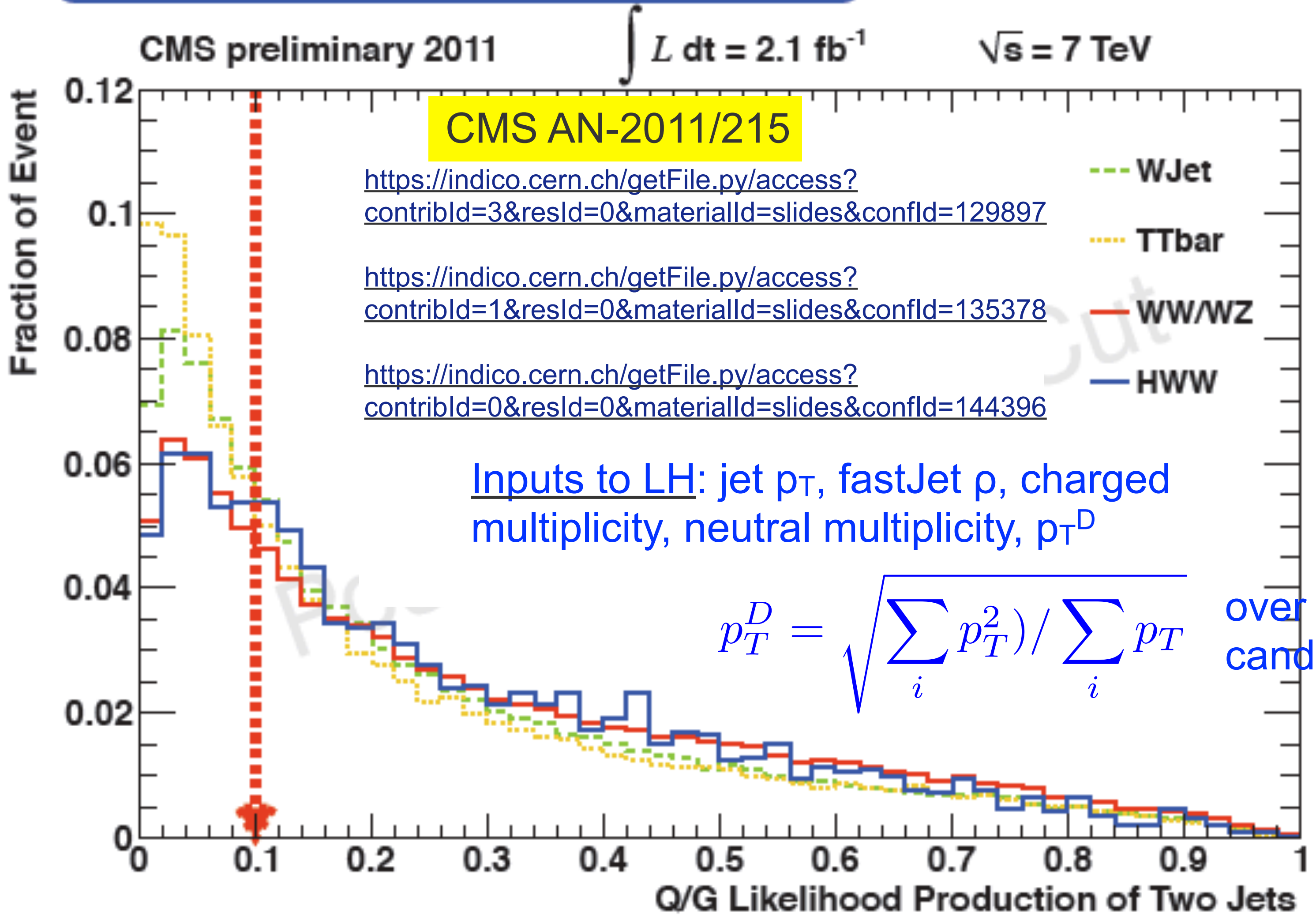
More distributions after the analysis cuts



Reasonable agreement between data and MC

Quark-gluon likelihood

The Likelihood product of jet1 ×jet2 > 0.1



CMS AN-2011/215

https://indico.cern.ch/getFile.py/access?contribId=3&resId=0&materialId=slides&confId=129897

https://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=135378

https://indico.cern.ch/getFile.py/access?contribId=0&resId=0&materialId=slides&confId=144396

Inputs to LH: jet p_T, fastJet ρ, charged multiplicity, neutral multiplicity, p_T^D

$$p_T^D = \sqrt{\sum_i p_T^2)/\sum_i p_T}$$

over all PF cands in jet

Topological cuts

Apply some simple topological cuts to suppress backgrounds and enhance S/B for the diboson signal.

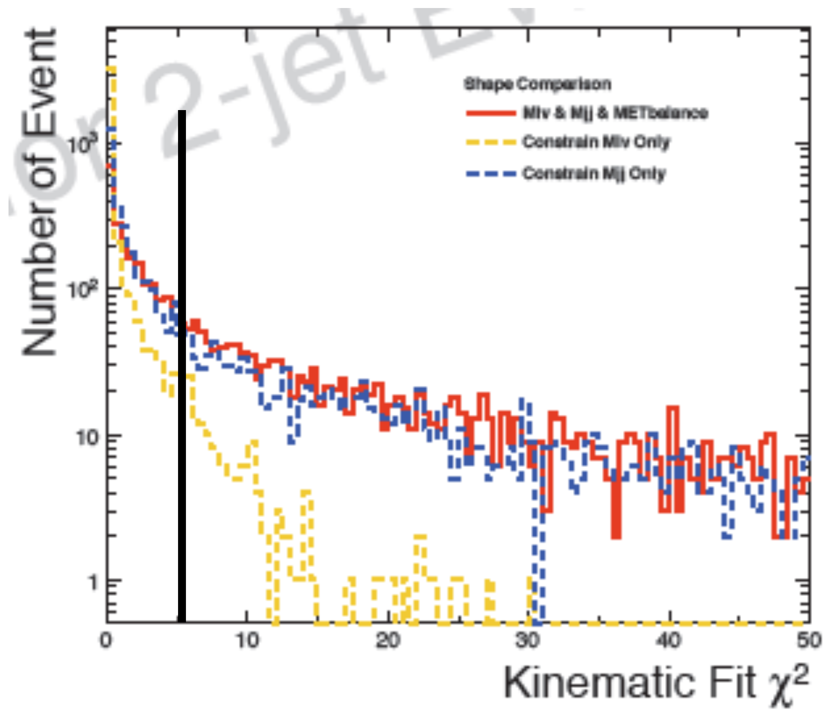
After these cuts mostly pure W events are left : diboson, W+jets, and top.

Leptonic W

- pf MET > 30 GeV
- W transverse mass > 50 GeV

Dijet system

- Dijet p_T > 40 GeV
- $\Delta\eta$ (j1, j2) < 1.5
- Quark-gluon likelihood > 0.1
- χ^2 of the kinematic fit < 5



Signal extraction procedure

Perform an unbinned maximum likelihood fit of the m_{jj} distribution

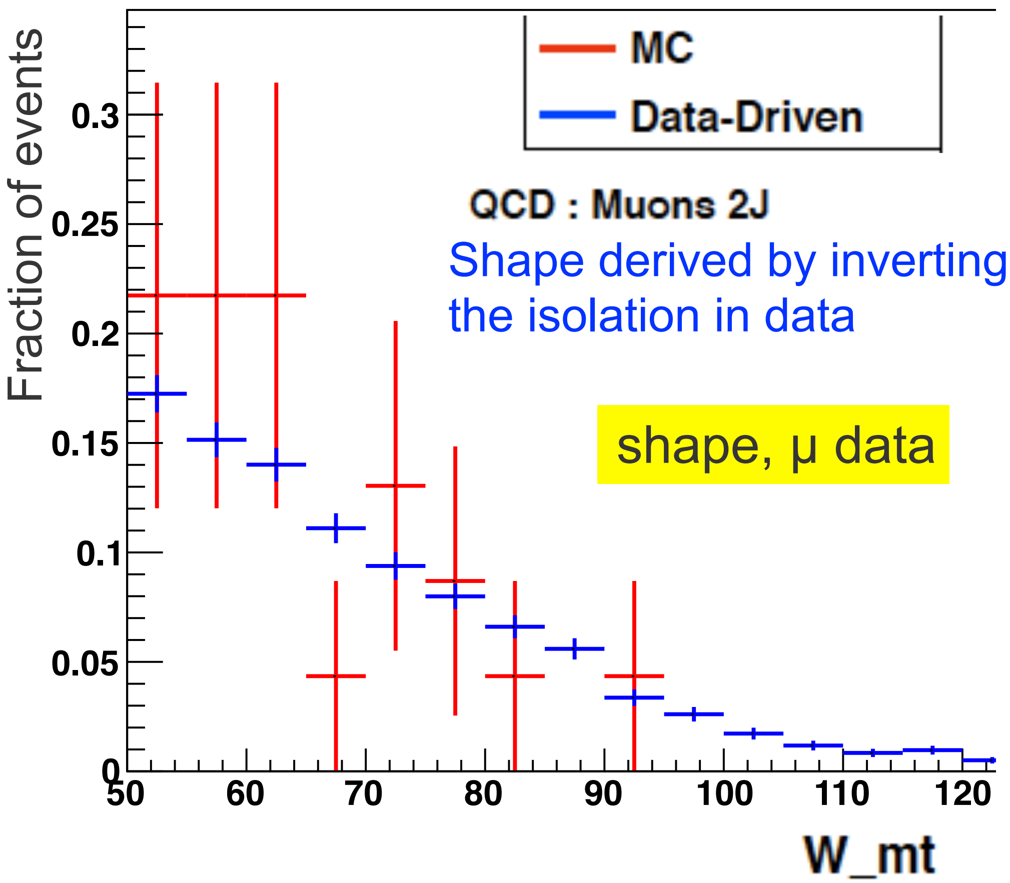
- Take QCD shape from data; W+jets shape from MC but with inputs from data.
  - All other shapes from MC: diboson, top, single top, Z+jets.
- Fit for the normalization of each component
  - Leave diboson and W+jets fully unconstrained.
  - Constrain ttbar, single top, and Z+jets to their known cross section within uncertainty (i.e., Gaussian constraint).
  - Constrain QCD normalization from a fit to the W transverse mass in data.
- Constrain jet energy scale from fit to m_{jj} in top quark semi-leptonic events.

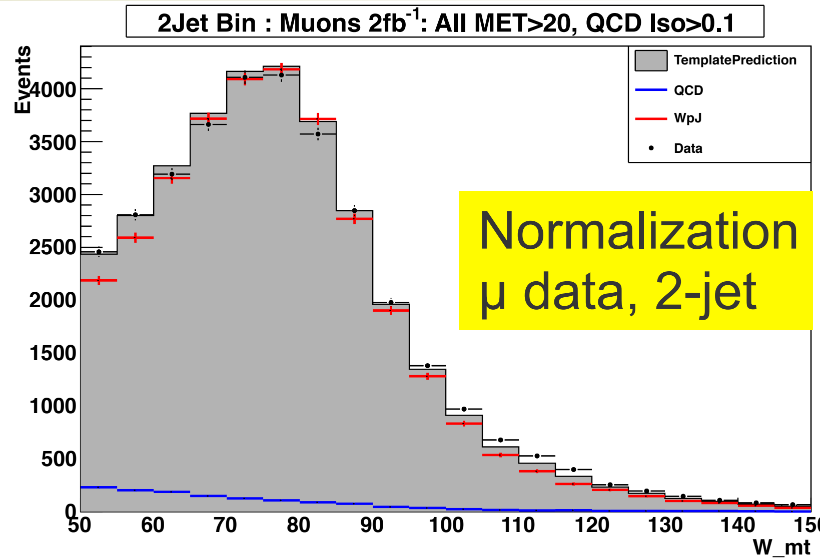
Table 31: Determination of the m_{jj} shape and normalization.

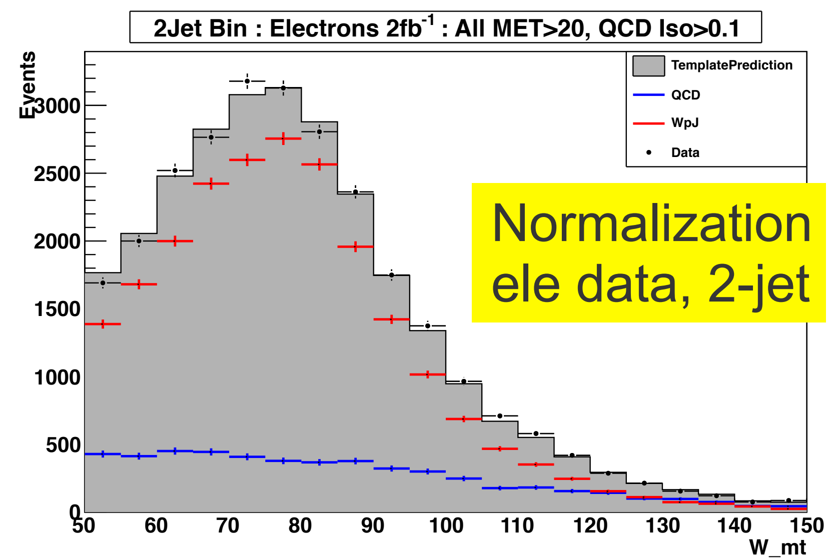
Process	Shape	Shape syst.	Normalization	Norm. syst.
W+jets	MC/ data	q^2, matching, JES	Unconstrained	Unconstrained
diboson	MC	JES	Constrain: CMS WW,WZ	Gaus $\sigma = 15\%$
$t\bar{t}$, single top	MC	JES	Constrain: NLO	Gaus $\sigma = 10\%$
Z+jets	MC	JES	Constrain: NLO	Gaus $\sigma = 15\%$
QCD	data	JES	Constrain: m_T fit in data	Gaus $\sigma = 50\%$

QCD shape & normalization: derive from data

Perform fit to W m_T to constrain QCD.



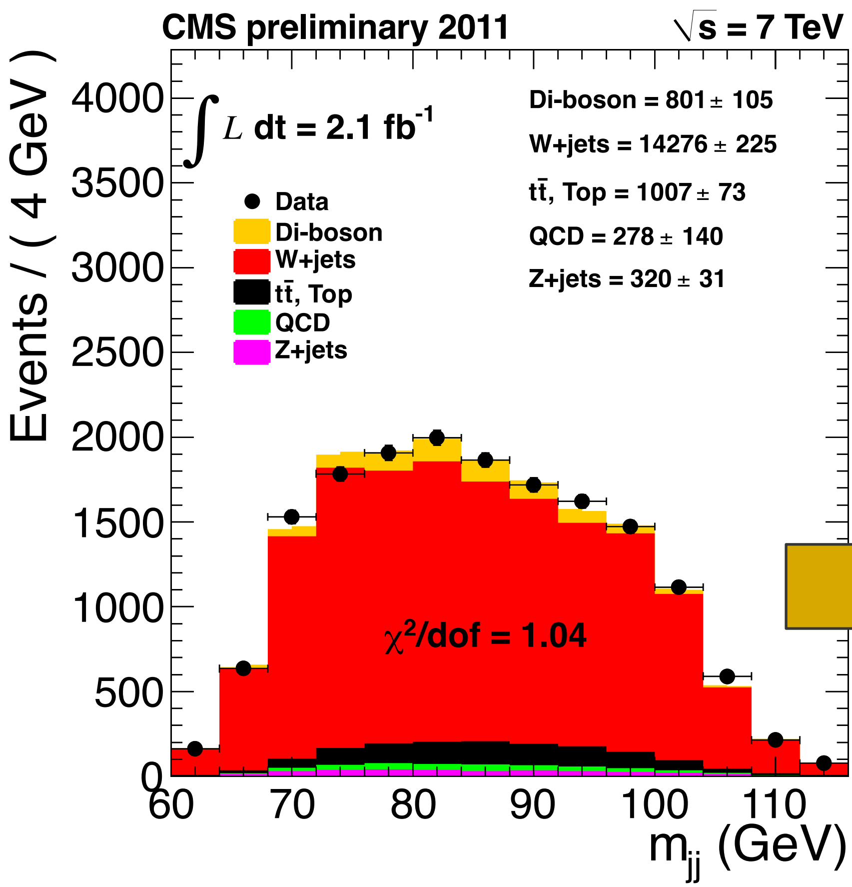


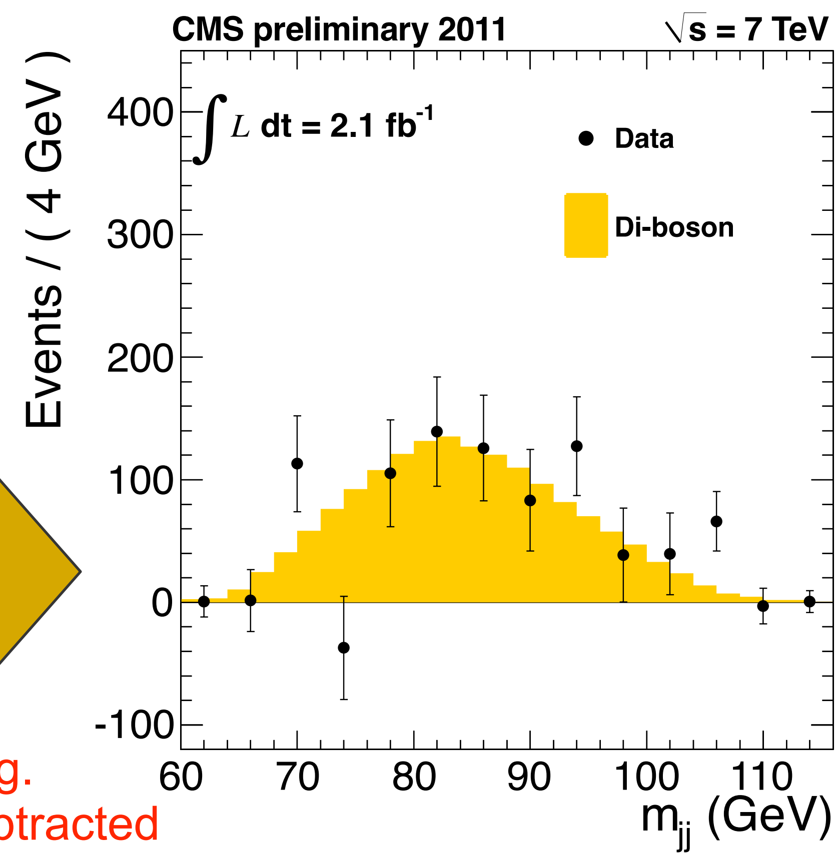


With our final selection, ~0.8% events in the μ data and ~3% in ele data are from QCD.

2-jet sample: fit results

Since the 2-jet and 3-jet samples have different S/B and different background composition (e.g., much larger top in 3-jet case), we gain precision by splitting.

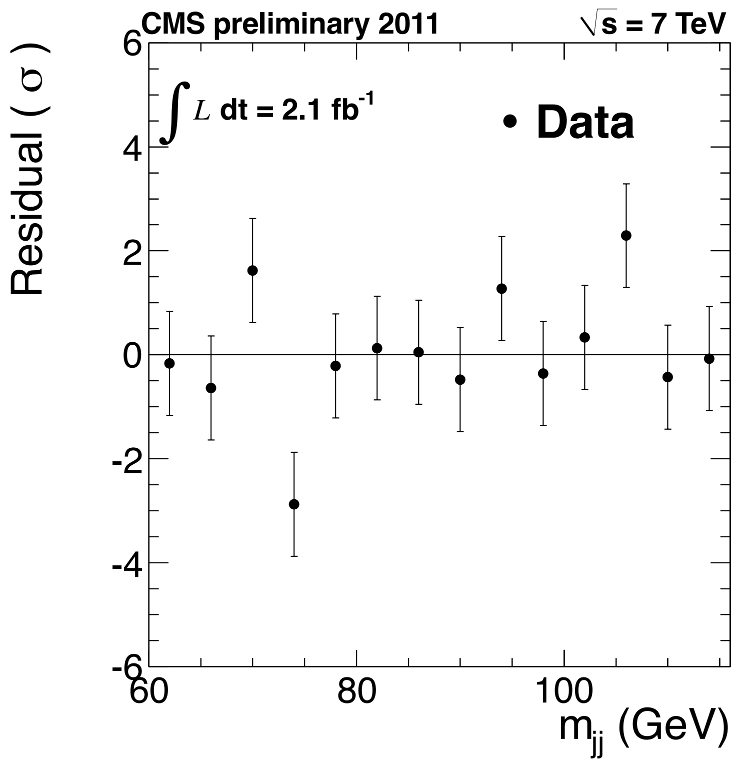




Bkg. subtracted

Normalized residual on the next slide

2-jet: normalized residual, executive summary



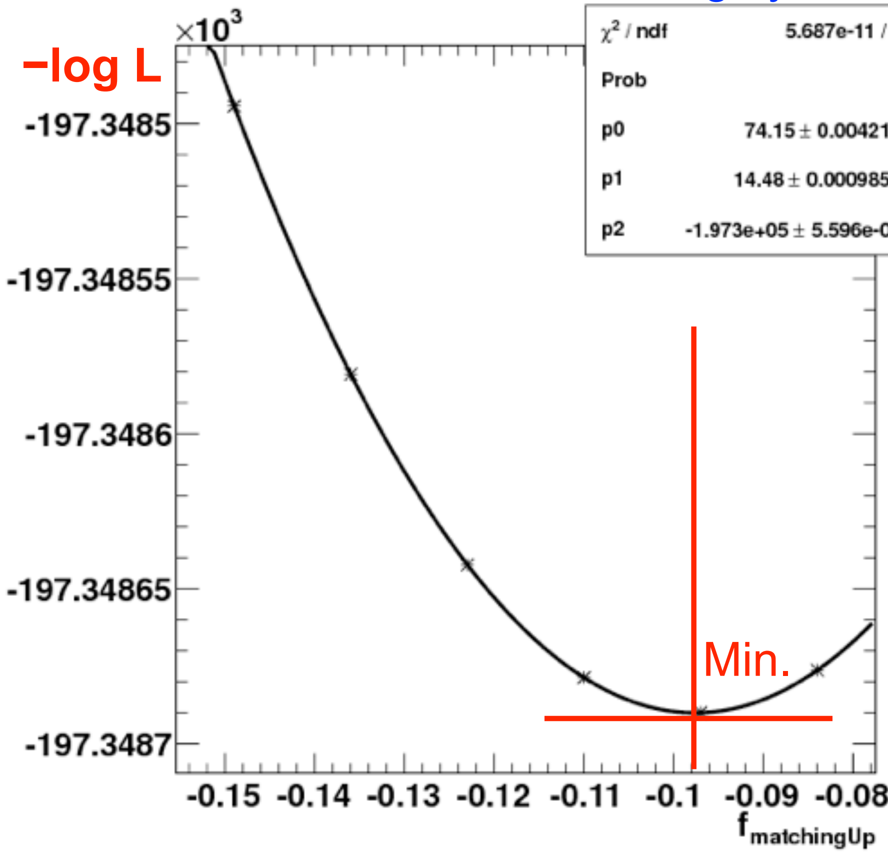
✦A clear diboson peak is established
✦The break down between ttbar and single top backgrounds is about 2:1

- -Requiring the two jets to be anti b-tagged helps in reducing top events
- -However, one has to correct for b-tagging data/MC scale factors (which depend on nJets, nTags, and jet p_T) and incur additional systematics
- -On the other hand, the top background is well modeled and well understood, so syst. in under control

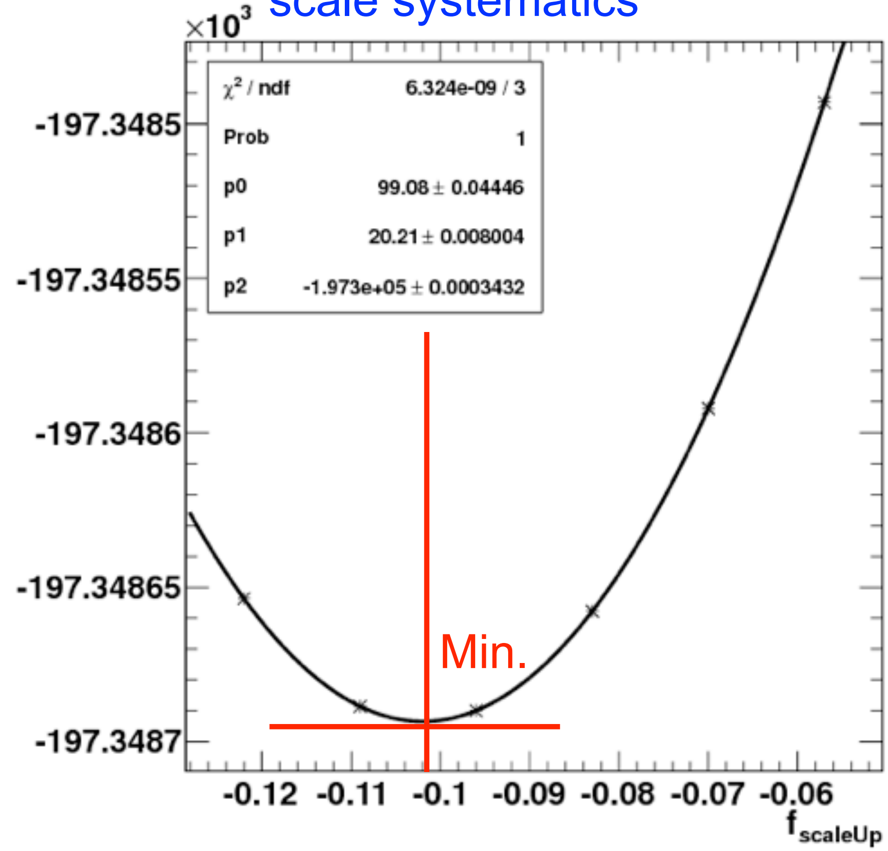
✦S/B in the W mass window 65−95 GeV ≈ 6%

2-jet: optimization for q^2 & matching scales

Matrix element−PS matching systematics

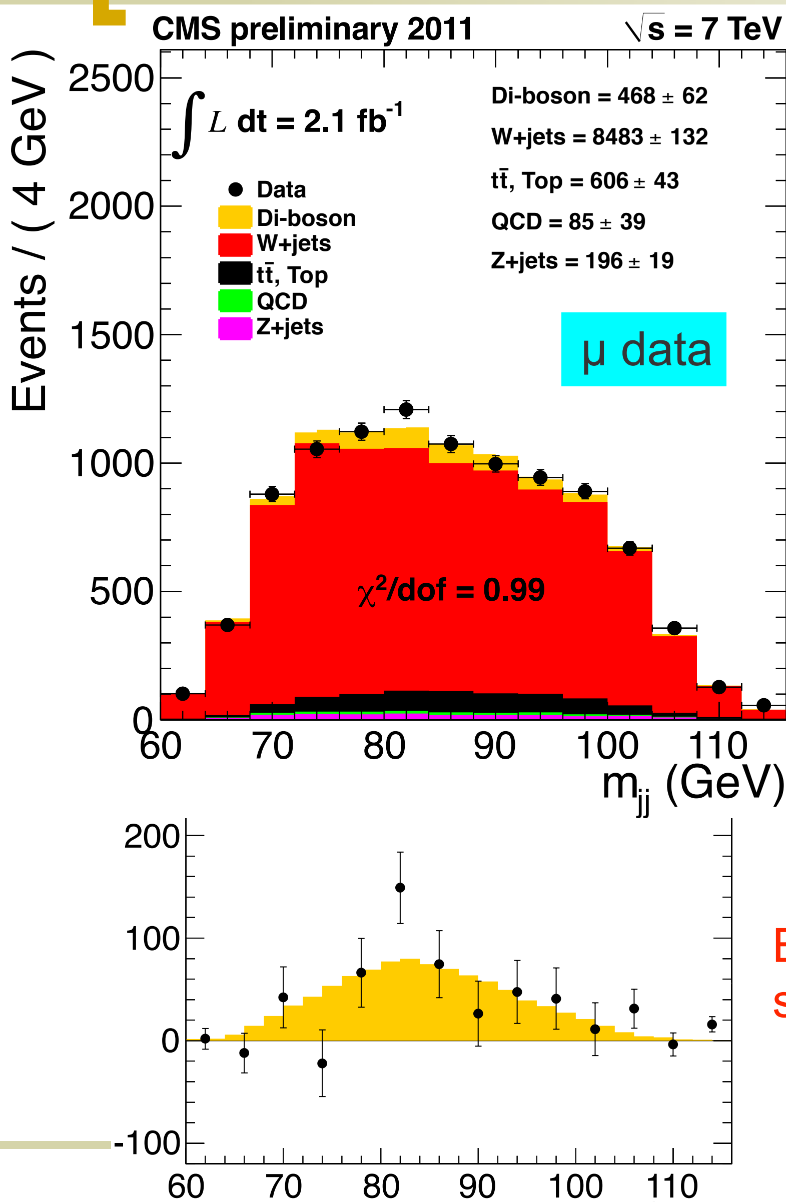


Renormalization/factorization scale systematics

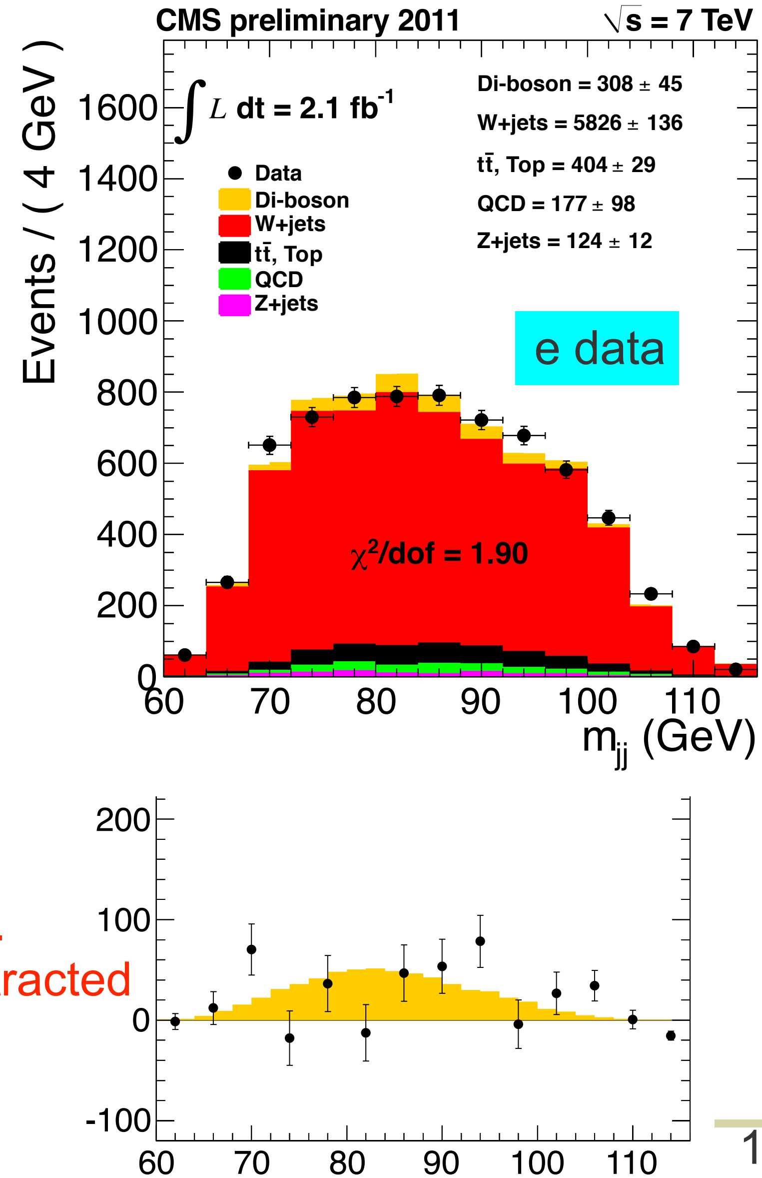


We will generate several hundred toy MC experiments to estimate both systematics.

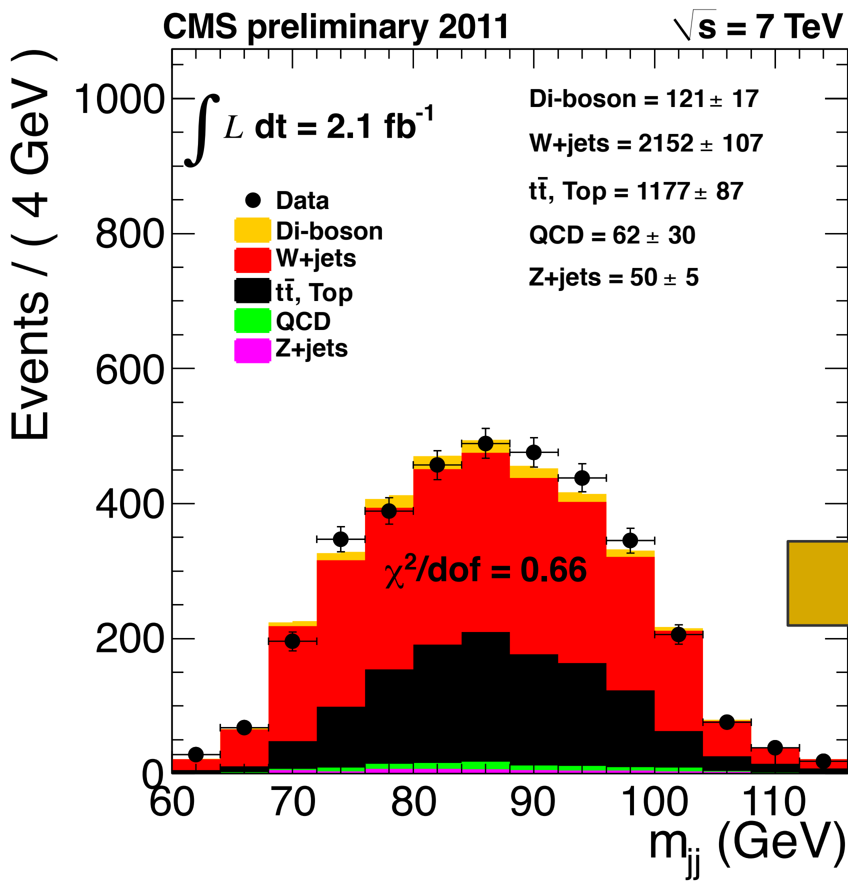
2 jet cross checks: μ, e channels separately

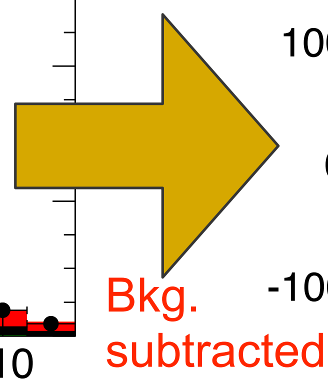


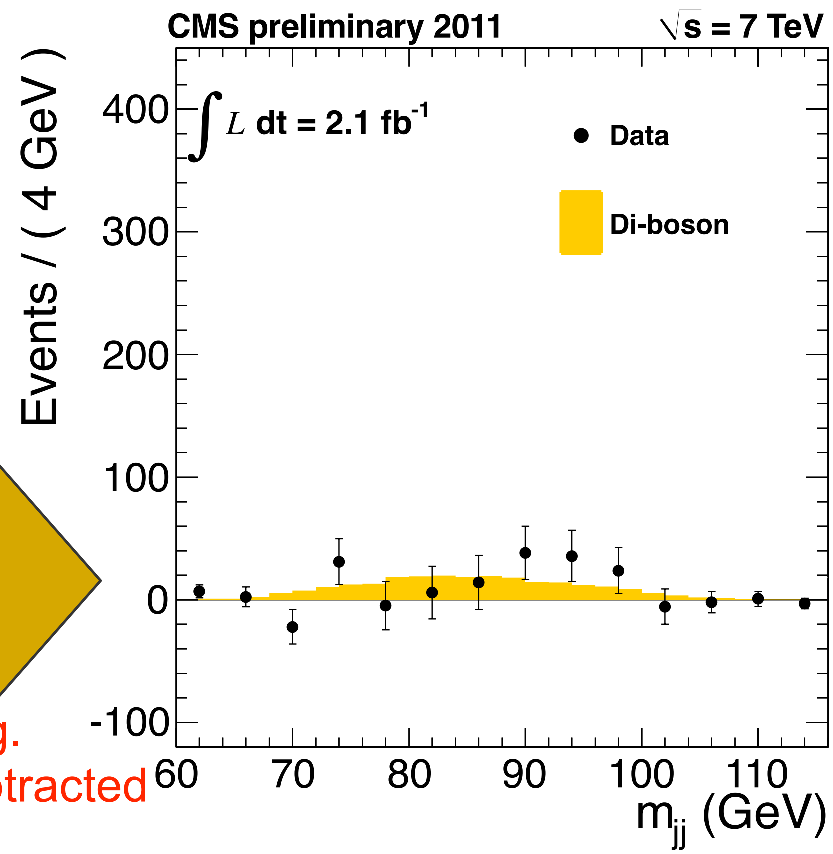
Bkg. subtracted



3-jet sample: fit results

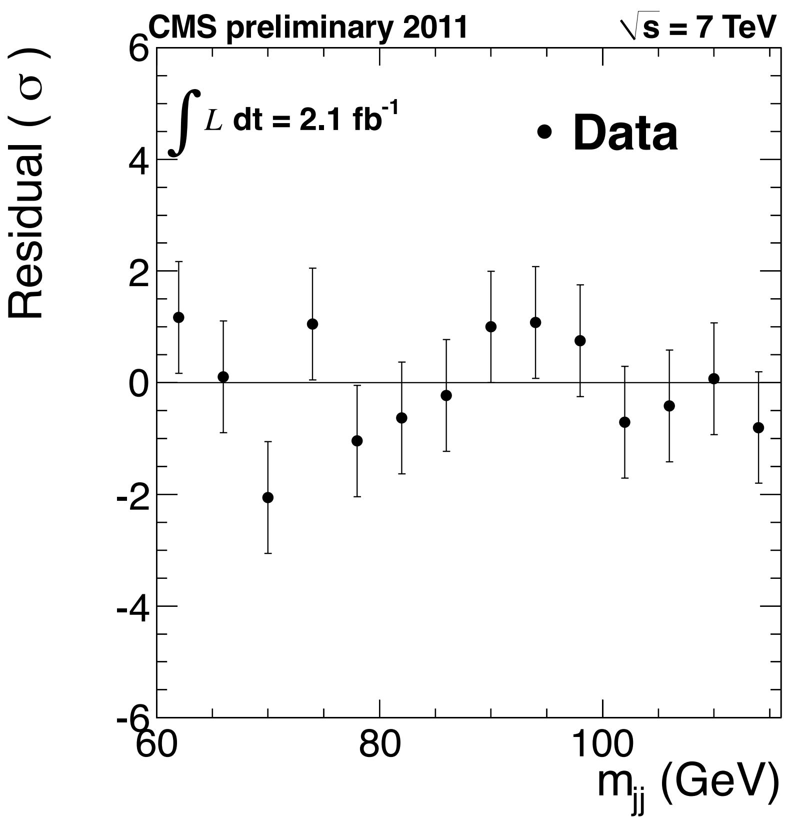






Normalized residual on the next slide

Fit results: 3-jet sample (II)



✦About 50% of the diboson events have an additional (gluon) jet from ISR/FSR

- The ISR events have the invariant mass peaked at right place, but FSR events have large low mass tail.

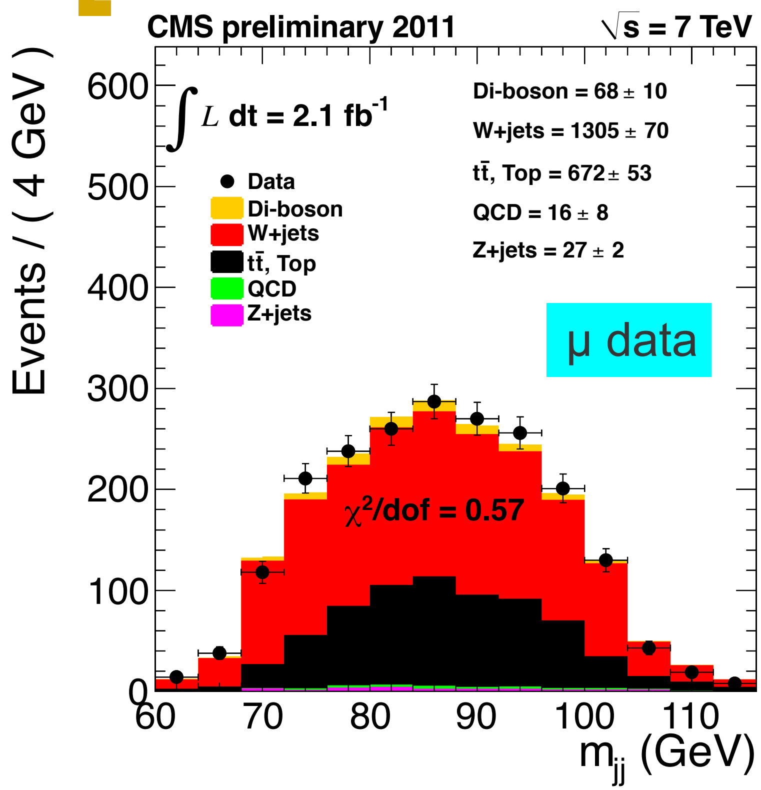
✦Since we take the two highest p_T jets in the current analysis, we choose the right combination about 1/3rd of the time

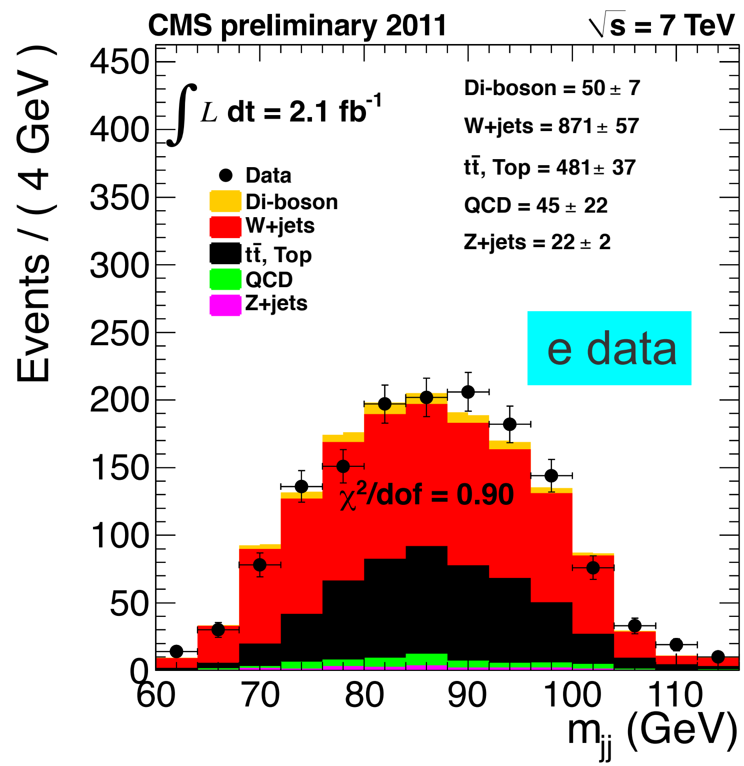
- Potentially, one can improve by choosing the two jets with invariant mass closest to the W mass, but this needs further studies and validation.

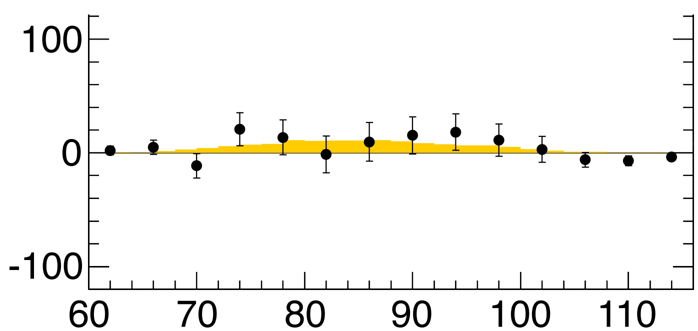
✦The break down between ttbar and single top backgrounds is about 5:1

✦S/B in the W mass window ≈ 4%

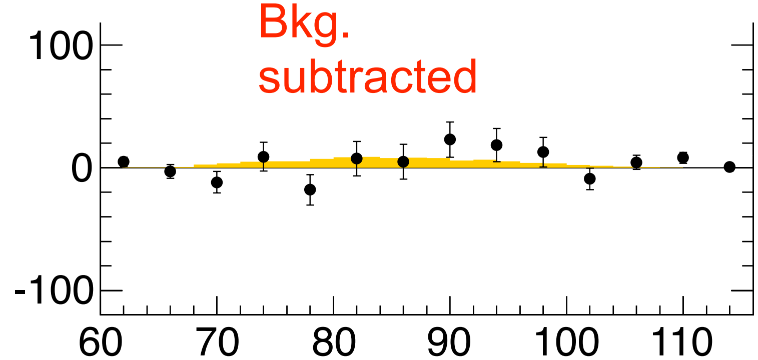
Cross checks: μ and e channels separately







Bkg. subtracted



WW+WZ Cross section results (preliminary)

2-jet sample:
signal events = 801 ± 105
accep*eff = 0.0675
luminosity = 2.1 fb^{-1}
branching ratio = 0.108 * 0.68
***cross section = 76.9 ± 10.1 pb**

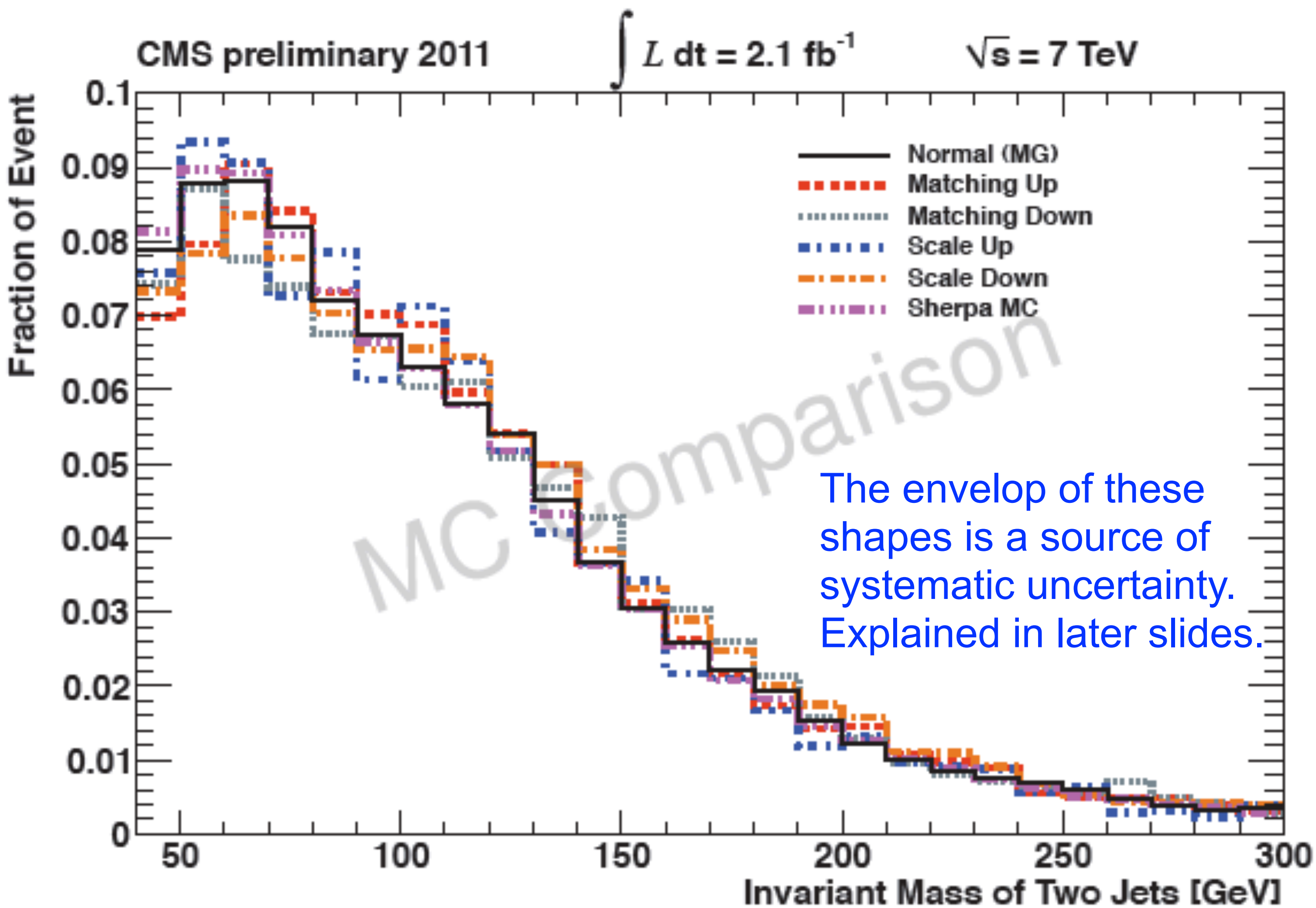
3-jet sample:
signal events = 121 ± 17
accep*eff = 0.0108
luminosity = 2.1 fb^{-1}
branching ratio = 0.108 * 0.68
***cross section = 72.6 ± 10.2 pb**

Standard Model electroweak production cross section at NLO:
σ(WW) = 43 pb, σ(WZ) = 18 pb **± 10 %** [gg and NLO EWK not included]

CMS lepton channel measurements: σ(WW) = 55.3 ± 8.3 pb, σ(WZ) = 17.0 ± 2.8 pb [PAS-EWK-11-010]

***Caveat**: Haven't included acceptance systematics (≈3%), luminosity systematics (≈4%), MC scale uncertainty (~few %), and trigger correction yet. Will update acceptance after we determine it more precisely from MCFM (NLO).

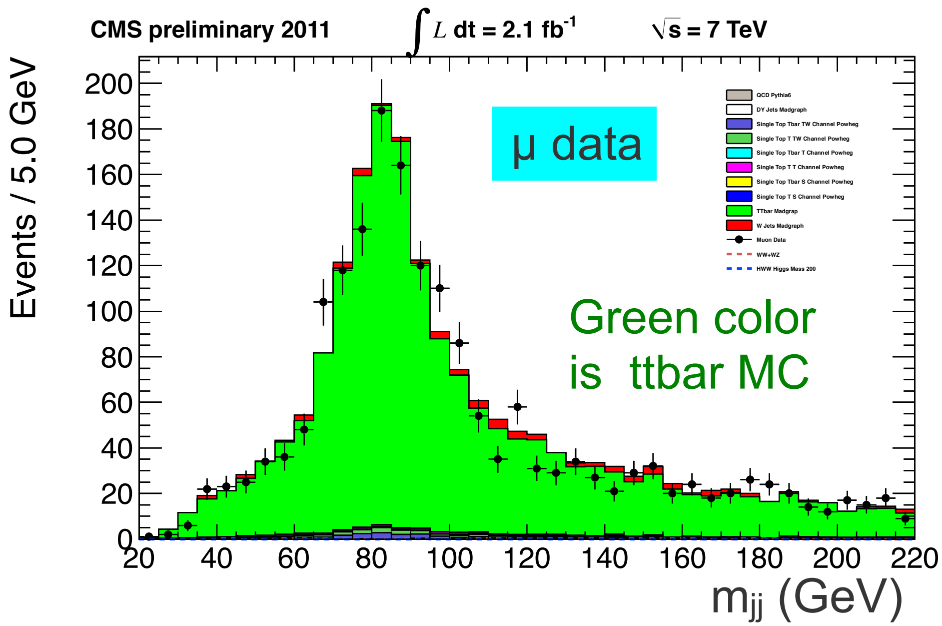
Systematic uncertainties: W+jets shape

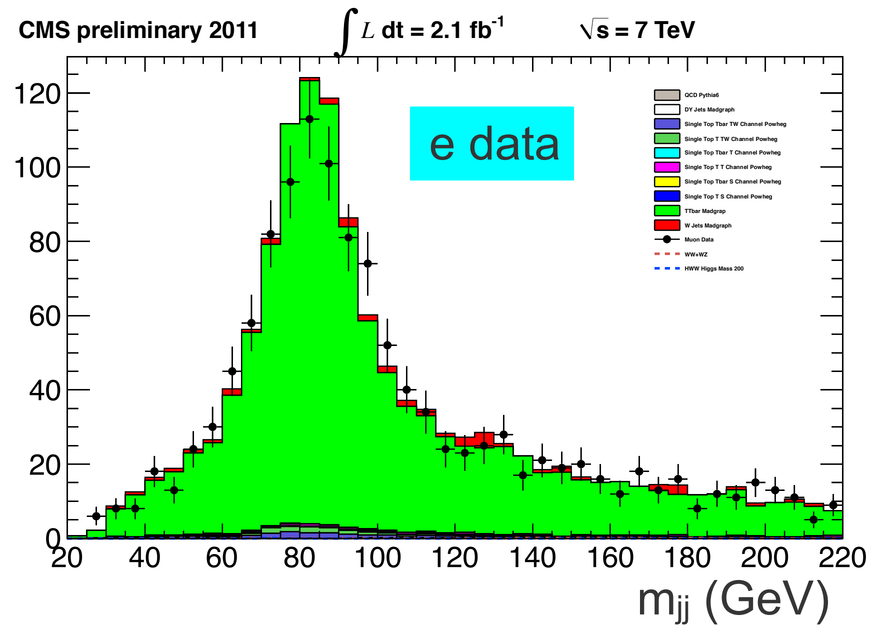


The envelop of these shapes is a source of systematic uncertainty. Explained in later slides.

Jet energy scale/ resolution from top events

In events with top quark pair, reconstruct pure hadronic W “out-of-box”.

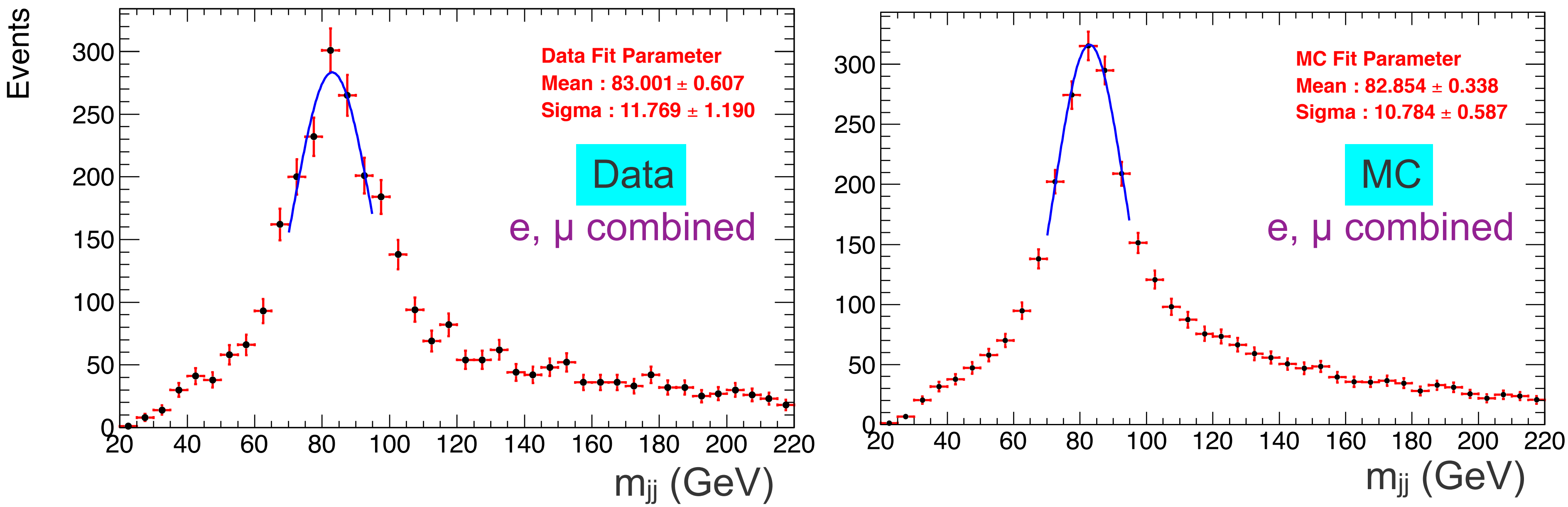




- Require exactly 4 jets, 2 b-tags (SSV-HE-M), and a leptonic W.
- Then plot m_{jj} of the two non b-tagged jets.
- The jet energy scale and resolution in data and MC match very well for these pure hadronic W events.

Jet energy scale/ resolution from top events

Fit the core of the distribution from previous slide with a Gaussian.



✦In both data & MC the peak position is consistent with nominal W mass.

✦Mean value of the peak (and hence JEC) in data & MC agree to within 0.2% ! The uncertainty in JEC in data is 0.73%.

✦We vary the JEC up and down by this error to compute JEC systematics.

Combining systematic uncertainties in yield

- We have considered three categories
  - Matching : Repeat the fit using Up and Down Samples and take the larger of the two variations to obtain the error.
  - Factorization Scale: Likewise, repeat the fit using Up and Down Samples as the Wjj template and take the larger of the two variations to obtain the error.
  - Yield Dependent: Remaining uncertainties proportional to the WJet yield, added in quadrature.
  - JEC : Shift jet energy scale to study this systematic.
- Assume there is no correlation among above categories.

$$\sigma^2_{\mathrm{Tot}} = \sigma^2_{\mathrm{Matching}} + \sigma^2_{\mathrm{Scale}} + \sigma^2_{\mathrm{JEC}} + \sigma^2_{\mathrm{Remaining}}$$

Additionally, we have systematic uncertainties in [acceptance*efficiency].

Things to do

✦Complete the computation of remaining systematics due to acceptance* efficiency, and factorization scales.

✦Update the analysis note with results for 2.1 fb^{-1} analysis

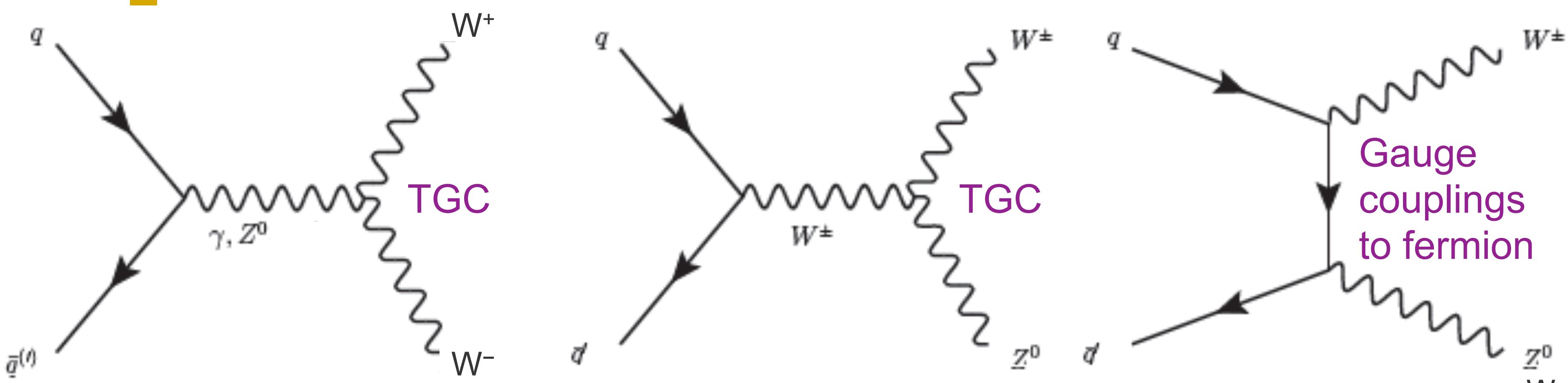
- AN-11-151

✦The analysis is for the most part systematics dominated

- Aim for publication with this data sample
- Aim to have an updated version of the AN with finalized systematics uncertainty by the second week of November.

BACKUP SLIDES

Diboson production at LHC at Leading Order in α_S



s-channel WW production

s-channel WZ production

t-channel WW, WZ production

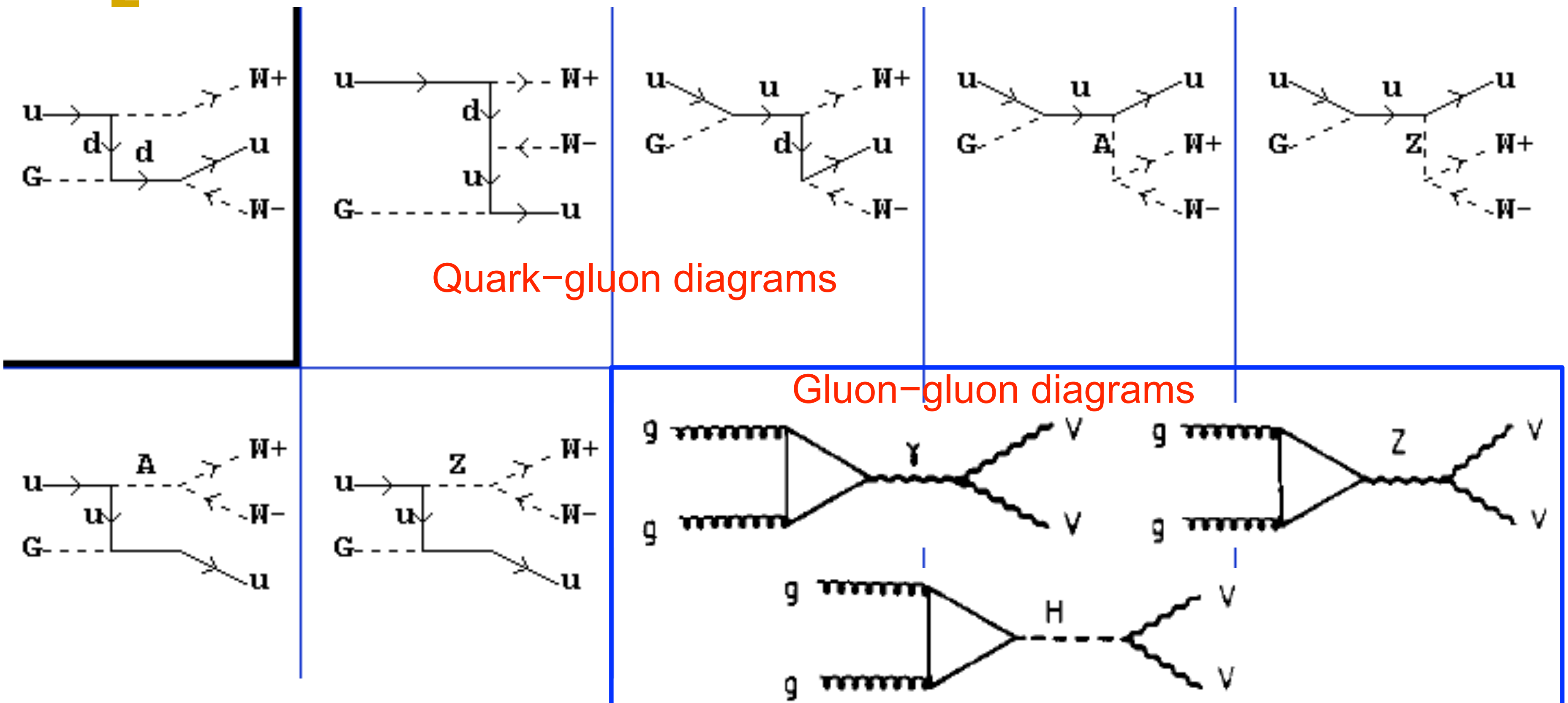
Some quick Observations

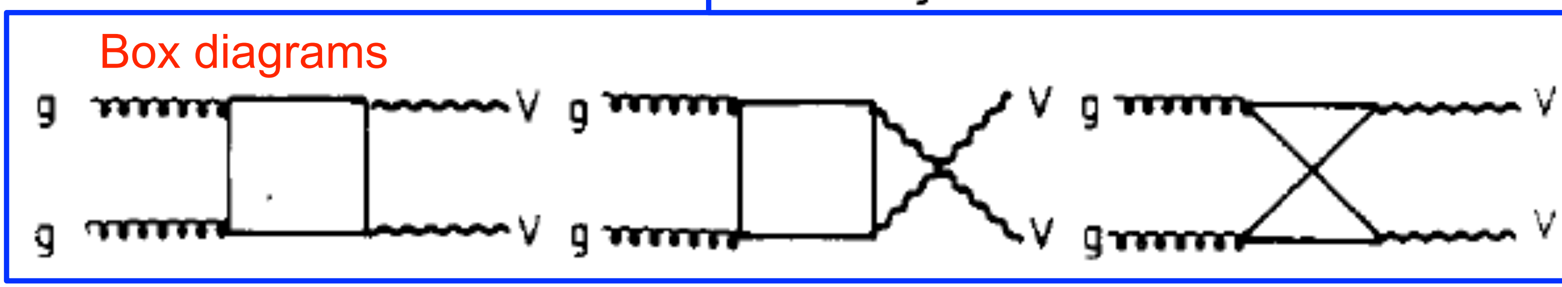
1. In standard model, the s- and t-channel diagrams are both divergent but when combined together divergencies cancel out miraculously. Sensitive to gauge coupling.

2. Because of qqbar initial state the production rate at LHC is only ~ 3x Tevatron.

3. One W or Z decays hadronically. Although W and Z boson masses differ by 10 GeV the dijet mass resolution is ~ 10 GeV ➜ cannot distinguish between WW and WZ.

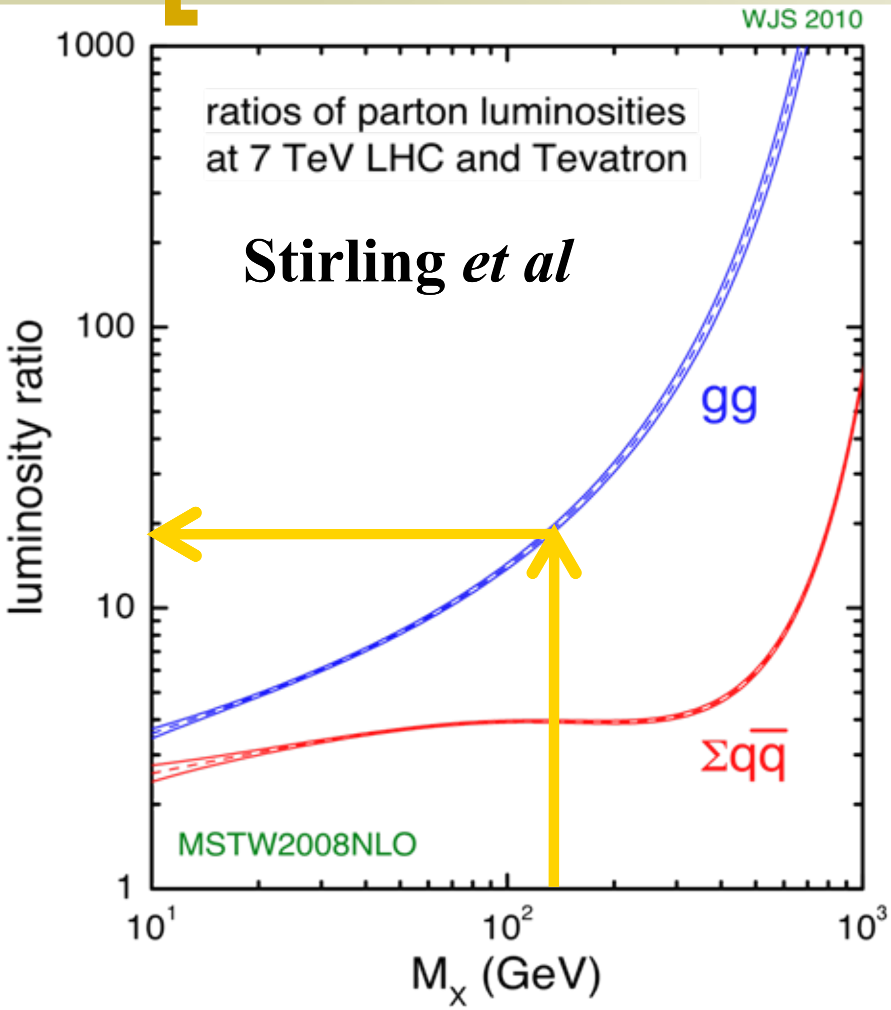
Diboson production mechanism at NLO



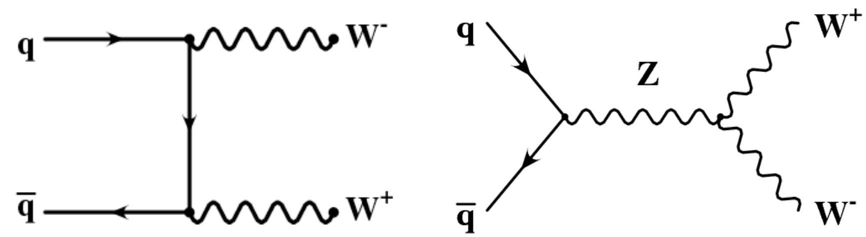


Plus more diagrams from NLO in α_{EWK}

LHC vs Tevatron: partonic luminosity hurts



$q\bar{q}$ → WW, WZ cross section at 7 TeV is ~ 3 times that at 2 TeV



Major backgrounds are W+jets, single top & $t\bar{t}$, QCD multi-jet etc. which rise sharply due to rise in qg and gg cross sections

⇒ Small signal, worse S/N

With 3x more signal and 20x more background would have 6 times worse S/B with identical detector. We are doing much better than that.

Muon selection

- Muon Trigger : 2010 triggers, Mu 17, IsoMu 17, IsoMu 24
- Global & Tracker Muon Preselection : Muon quality cuts
  - muon $\chi^2 < 10$, muon validHits ≥ 11, muon hits > 0
  - muon $|\eta| < 2.4$, muon $p_T > 20$ GeV/c
  - muon MuonChamberMatches > 1
  - muon NumberOfValidPixelHits > 0
  - Combined relative isolation less than 0.30 (Pileup Corrected)
- Global Muon at Analysis Level: Signal muon selection
  - muon $p_T > 25$ GeV/c, for acceptance : muon $|\eta| < 2.1$
  - Combined relative isolation less than 0.10 (Pileup Corrected)
  - Transverse impact parameter with respect to beamspot $<$0.02cm
  - If the event has two or more muons, reject the event
  - Loose electron veto.
- Kinematic Requirements: Background Suppression
  - pf-MET > 30 GeV
  - W Transverse Mass > 40 GeV
  - Di-jet system $p_T > 40$ GeV

Electron selection

- Electron Trigger : 2010 triggers, Ele 22, 27, 32, inclusive W.
- ECAL seeded gsf electrons
- WP80 Requirements: https://twiki.cern.ch/twiki/bin/view/CMS/SimpleCutBasedEleID
  - Conversion Rejection: missing hits$\leq$ 0, Dist(0.02), $\Delta \cot\theta$ (0.02).
  - Combined and relative iso for barrel and endcap respectively.
  - $\sigma_{i\eta i\eta} < 0.01$ (Barrel) or 0.03 (Endcap)
  - $|\Delta\phi| < 0.03$ (Barrel) or 0.02 (Endcap)
  - $|\Delta\eta| < 0.004$ (Barrel) or 0.005 (Endcap)
  - Combined relative Isolation < 0.05 (Pileup Corrected).
  - If the event has two or more electrons, reject the event
  - Loose muon veto.
- $E_T > 30$ GeV, $\eta < 2.5$ (excluding $1.4442 < |\eta| < 1.566$)
- Kinematic Requirements: Background Suppression
  - pf-MET > 30 GeV
  - W Transverse Mass > 40 GeV
  - Di-jet system $p_T > 40$ GeV

Jet/MET selection

- PF-MET is used and require pf-MET > 30 GeV for this analysis.
- At least two Particle Flow Jets in each event
- Corrected jet $p_T > 30$ GeV, $\eta < 2.4$ and $\Delta R(\ell, j) > 0.3$
- Default (JetMET POG recommended) charge hadron subtraction (PF2PAT/PfNoPU), FastJet PU subtraction, L2L3 Corrections and 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 deposites < 0.99
- Kinematic Requirements: Background Suppression
  - Di-jet system $p_T(jj) > 40$ GeV
  - $\Delta\eta(j,j) < 1.5$
  - $\Delta\phi(\mathrm{MET}, \mathrm{Leading\ Jet}) > 0.4$

Cross section measurement

$$\sigma \cdot Br = \frac{N_{candidates} - N_{background}}{Acceptance \cdot Efficiency \cdot L}$$

From MC

MC uncertainty

Currently take from MC

= lepton selection efficiency x trigger efficiency x event selection cut efficiency

External input
6% uncertainty

Lepton efficiency will come from Tag&Probe measurements in data and MC

$$\epsilon_{X} = \epsilon_{MC\text{-}X} \times \rho_{eff\text{-}X},$$

$$\rho_{eff\text{-}X} = \frac{\epsilon_{TNP\text{-}X}(data)}{\epsilon_{TNP\text{-}X}(MC)}$$

Since we cannot distinguish between WW and WZ we take the weighted acceptance = $(43 \,.\, A_{WW} + 18 \,.\, A_{WZ}) / (43+18)$