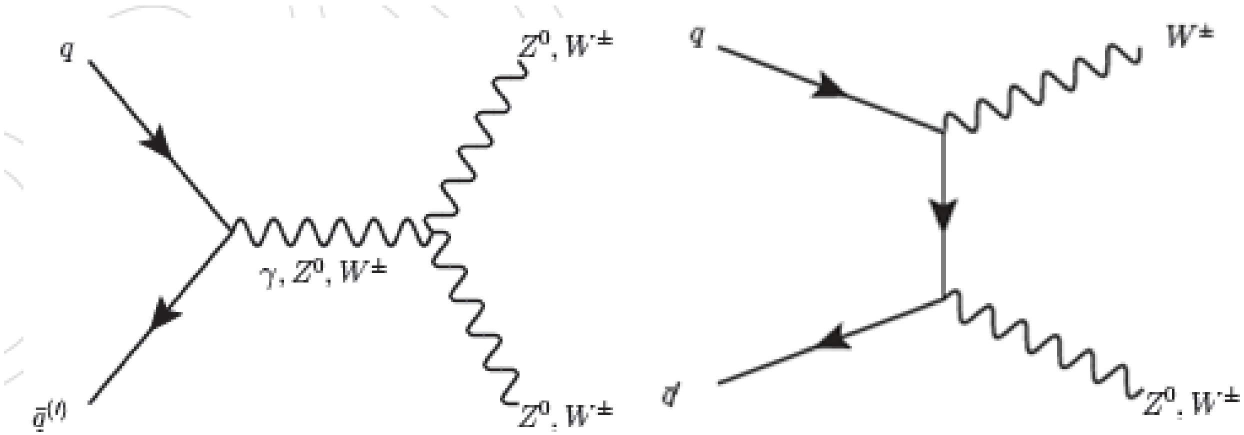
Semi-leptonic VW production at CMS

Jake Anderson, on behalf of CMS

Fermilab

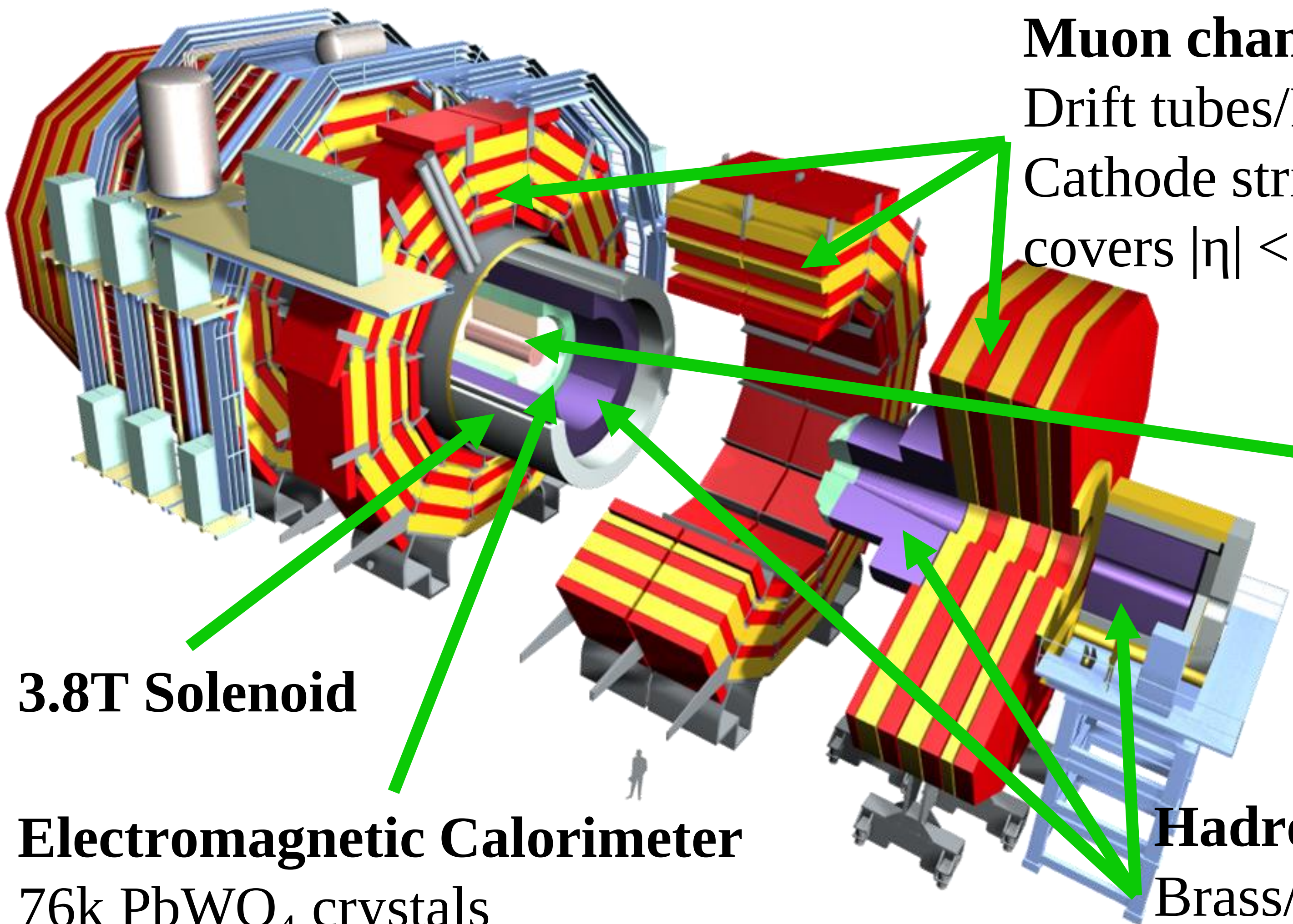
LHC WV production

- WV production (leading order α_s)



- *s*- and *t*-channel diagrams diverge, but the sum is finite.
- NLO contributions are large, >~ 50% of LO.
  - includes vector boson fusion, gluon fusion, etc.
- Searching in semi-leptonic final state maintains a large branching fraction at the cost of large background.

The CMS detector



Muon chambers
Drift tubes/RPC in barrel
Cathode strip/RPC in endcaps
covers $|\eta| < 2.4$

Inner tracker
Silicon pixels
Silicon strips

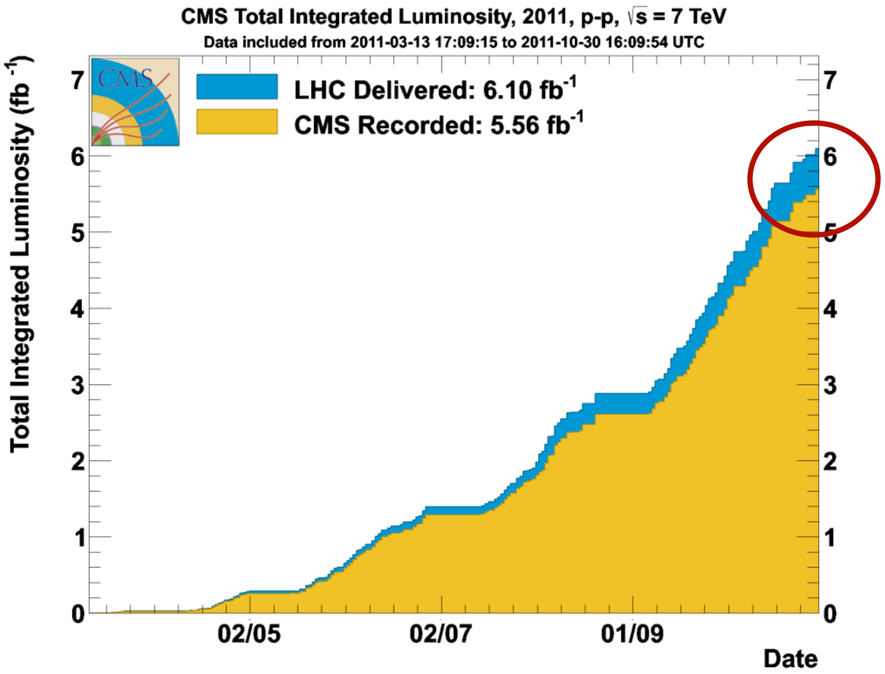
3.8T Solenoid

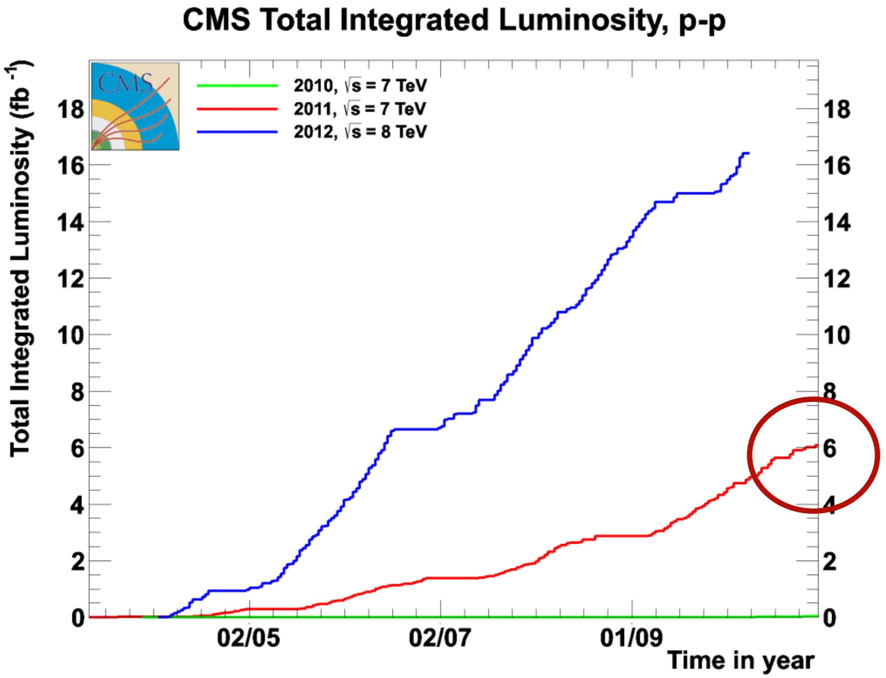
Electromagnetic Calorimeter
76k $PbWO_4$ crystals

Hadronic Calorimeter
Brass/scintillator
Iron/quartz fiber

LHC dataset

- CMS has been efficiently collecting data for ~3 years.
- The current WV results are based on the full dataset collected at $\sqrt{s}$ = 7 TeV of 5 fb^{-1}.
- Already CMS has recorded more than 15 fb^{-1} at 8 TeV.

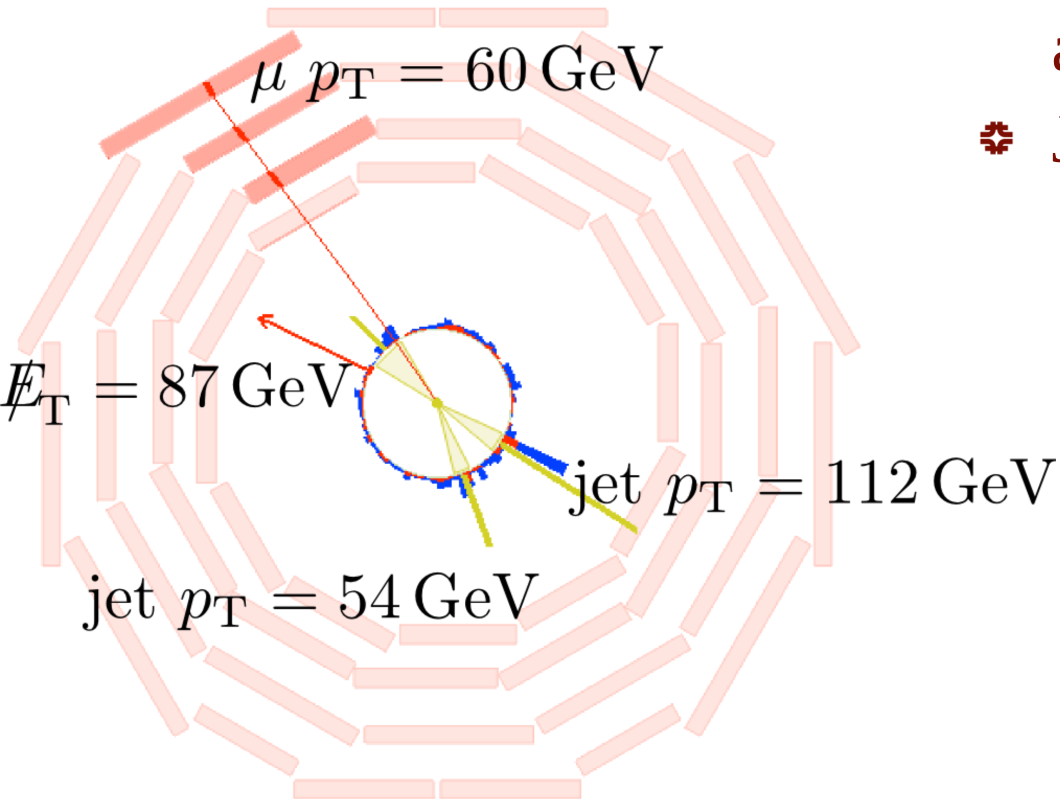




Selecting events (leptons)

- Our data was collected primarily using single lepton (*e* or μ) triggers.
  - p_T > 24 GeV (muons) or p_T > 25-32 GeV (electrons)
- Lepton must originate at primary vertex
- Veto events with a second, looser lepton
- Muon selection
  - p_T > 25 GeV
  - $|\eta| < 2.1$
  - relative isolation in a cone ($\Delta R<0.3$) < 10%
  - ME_T > 25 GeV
  - W m_T > 30 GeV
- Electron selection
  - p_T > 35 GeV
  - $|\eta| < 2.5$ (excluding barrel endcap transition)
  - relative isolation < 5%
  - ME_T > 30 GeV
  - W m_T > 50 GeV

Selecting events (jets)



- Particle flow based jets clustered using anti-k_T algorithm with R = 0.5.
- Jet criteria
  - p_T > 35 GeV
  - |η| < 2.6
  - |Δφ(jet 1, ME_T)| > 0.4
  - p_T (jet 3) < 30 GeV
  - Veto jets within ΔR < 0.3 of lepton.
  - |Δη (jet1, jet2)| < 1.5
  - p_T (dijet system) > 20 GeV
  - veto b-tagged jets using secondary vertex tagging.

Determining yields

- We determine the signal and background yields in a maximum likelihood fit to m_{jj} spectrum from 40-150 GeV.
- We constrain the normalization of the backgrounds during the fit using a Gaussian constraint.

component	template source	normalization constraint
diboson (WV)	MC	unconstrained
W+jets	MC	31.3 nb ± 5% (NLO) [FEWZ]
top pairs	MC	165 pb ± 7% (NNLL) [Kidonakis]
single top	MC	85 pb ± 5% (NNLL) [Kidonakis]
Drell-Yan + jets	MC	3.05 nb ± 4.3% (NNLO) [FEWZ]
multijet (QCD)	data	from data via ME_T fit

Signal MC samples

- We use PYTHIA6, Z2 underlying event tune, to generate inclusive WW and WZ samples.
  - Using these samples we evaluate the acceptance and efficiency used to go from an event yield to a cross section.
  - In this we also assume that the ratio of WW/WZ cross sections is as predicted by MCFM at NLO in the standard model.
  - The acceptance is also corrected for the boson branching fractions.
- This sample is also used to create the signal templates used in the yield extraction fit.

QCD multijet determination

- We determine the contribution of the multijet QCD background from events which fail lepton isolation with a looser ME_T cut, giving us a rich QCD sample.
- From this sample, we derive the templates for the QCD multijet contribution to the m_{jj} spectrum
- We fit the ME_T spectrum to separate QCD from events with real neutrinos and to determine the normalization and constraint for the multijet component of the spectrum.

W+jets background

- Using a MADGRAPH for W+jets, there is an inherent uncertainty in the factorization-renormalization scale q_0 and the ME/PS matching scale μ_0.

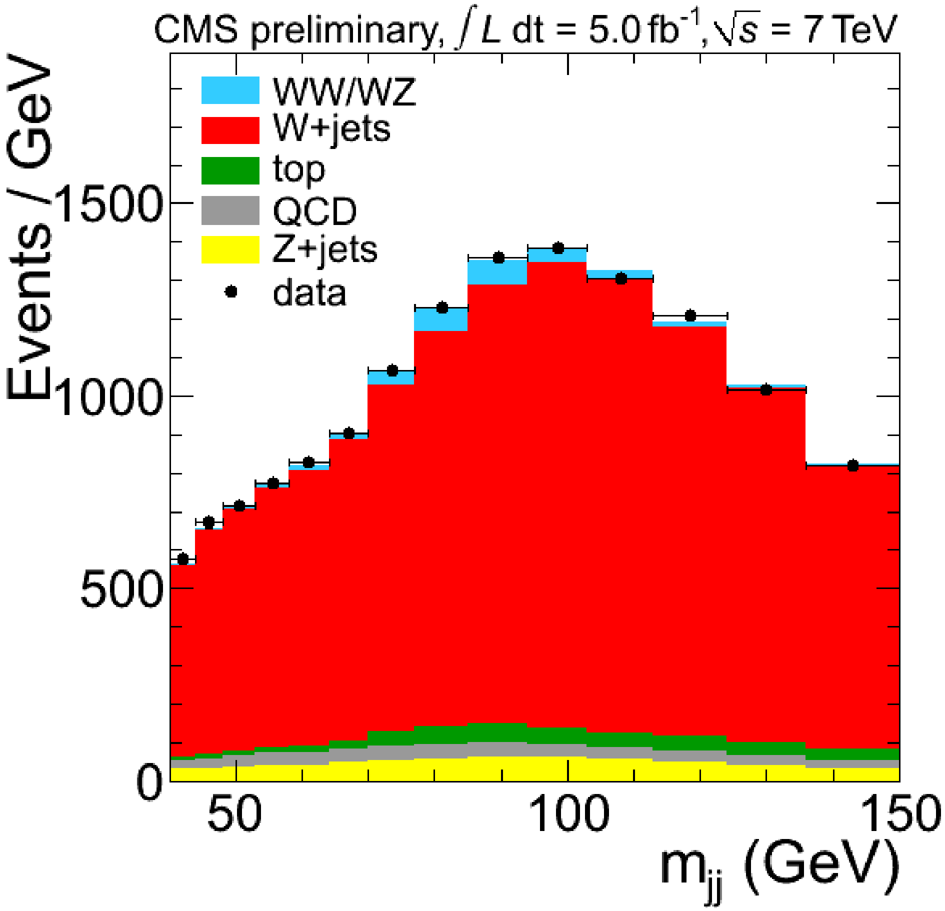
$$q_0^2 = m_W^2 + p_{\mathrm{T},W}^2 \text{ and } \mu_0 = 20\,\mathrm{GeV}$$

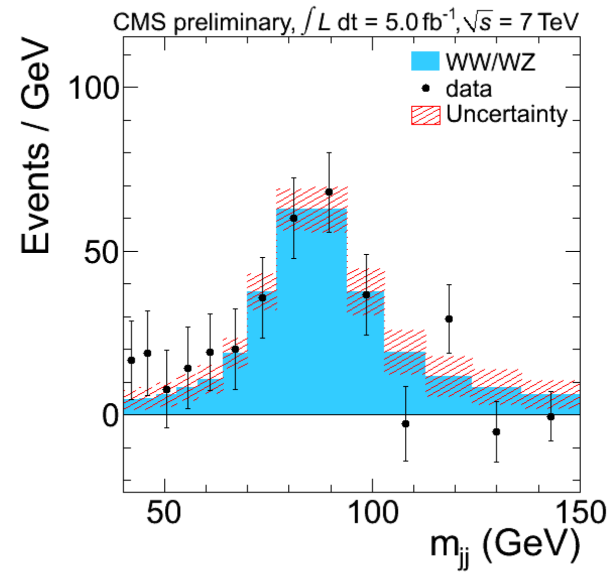
- We have samples with $2q_0$, $q_0/2$, $2\mu_0$ and $\mu_0/2$ and create a combination

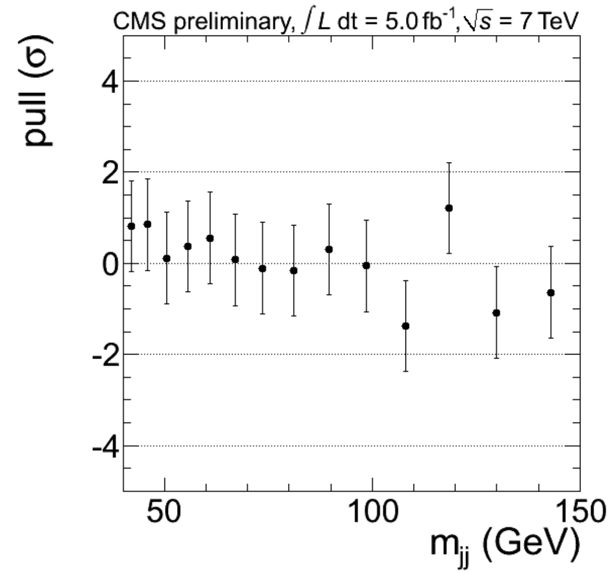
$$\mathcal{F}_{W+\mathrm{jets}} = \alpha\mathcal{F}_{W+\mathrm{jets}}(\mu_0, q') + \beta\mathcal{F}_{W+\mathrm{jets}}(\mu', q_0) + (1-\alpha-\beta)\mathcal{F}_{W+\mathrm{jets}}(\mu_0, q_0)$$

- The fit to the data determines the α and β parameters and whether $2q_0$ ($2\mu_0$) or $q_0/2$ ($\mu_0/2$) is used.
- The uncertainty in these determinations is folded into the uncertainty on the diboson yield.

Fit results (I)







Fit results (II)

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 $\times$ efficiency ($\mathcal{A}\varepsilon$)	5.153×10^{-3}	2.633×10^{-3}
Expected WW+WZ yield from simulation	1697 ± 57	867 ± 29

- This translates into a WV cross section
  - $\sigma = 68.89 \pm 8.71(\text{stat}) \pm 9.70(\text{syst}) \pm 1.52(\text{lumi})$ pb
  - profiled likelihood ratio significance 4.3σ.
- Compared to MCFM cross section of
  - $\sigma_{NLO} = 65.6 \pm 2.2$ pb

Systematic uncertainties

- We evaluate the uncertainty of the trigger and lepton selection efficiencies using data. (1-2%)
  - MC was corrected to achieve efficiency agreement.
- We use MCFM with various PDF sets to evaluate the uncertainty on the acceptance (3%).
- Jet veto uncertainty for 3rd jet (2%).
- ME_T modeling differences between data and simulation (0.5%).
- We evaluate systematic efficiency uncertainties due to the b-tag veto to be negligible.
- Using a pure top pair sample, we look at jet energy uncertainties and find them to be negligible also.
- The luminosity uncertainty is 2.2%.

Conclusion

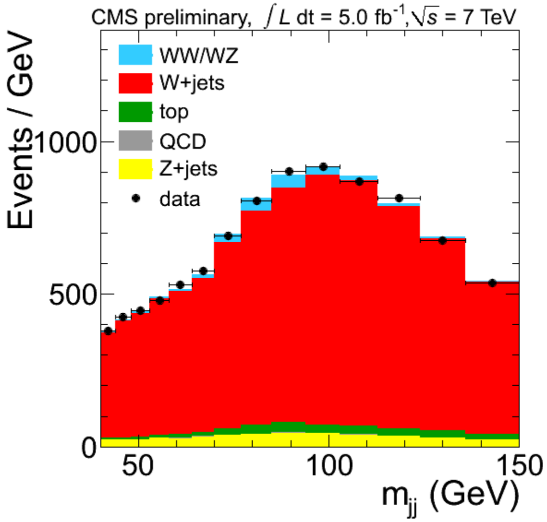
- CMS has measured the WW+WZ cross-section in semi-leptonic decays.
- We have been able to model and control the backgrounds and achieve a signal significance of 4.3σ in the combination of both lepton flavors.
- The result is consistent with the predictions of MCFM for the combined cross-section.
- This is the first step by CMS to look at this diboson final state and can be used to search for anomalous gauge couplings.

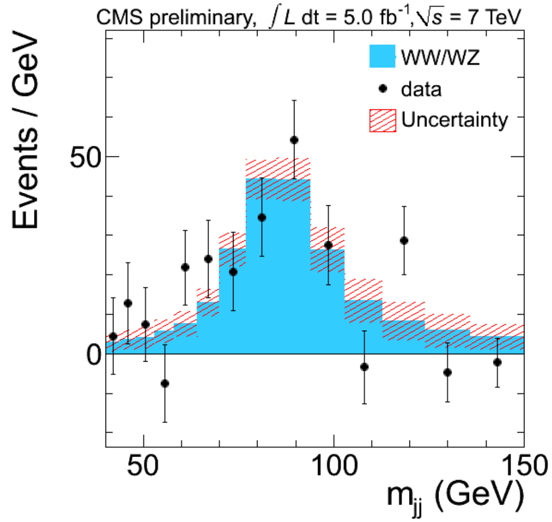
backup

By lepton flavor

muons:

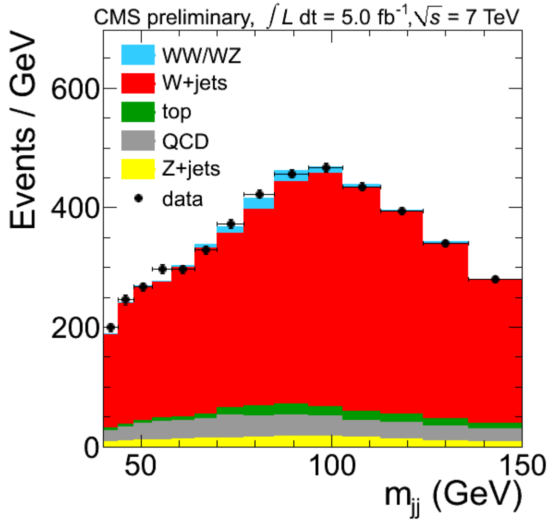
σ = 73.4 ± 15.1 pb

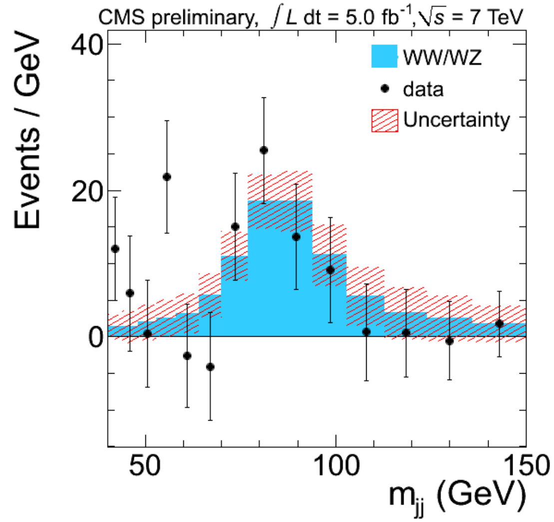




electrons:

σ = 60.1 ± 21.5 pb





Acceptance systematic

Source of uncertainty	Relative variation in acceptance value
PDF: CT10	1.4%
PDF: CTEQ61M	−0.7%
PDF: MSTW8NL	0.4%
PDF: MSTW8NN	0.1%
PDF: MSTW8LO	−1.3%
Scale: $2\ \mu_0$	−0.01%
Scale: $0.5\ \mu_0$	0.8%
Scale: $\sqrt{M_W^2 + p_{T,jet1}^2}$	−0.3%
Scale: H_T	0.1%

Jet veto systematic

- We use uncertainty based on comparing generator level veto efficiency for various samples and generators.

sample	efficiency
PYTHIA WW	88.72%
PYTHIA WZ	87.48%
MADGRAPH	89.57%