



Studies of $W(\rightarrow l\nu) + jj$ events

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with inputs from WW \rightarrow lvjj team members

Disclaimer: CMS results/plots presented in these slides are very very preliminary and are **NOT** approved for presentation outside the CMS.

LPC Physics Forum
(April 14, 2011)



Why look at $W(\rightarrow lv)+jj$?

- ◆ $W(\rightarrow lv)+jj$ is important for variety of reasons
 - ✓ Establish electroweak WW diboson production at CMS using $W\rightarrow jj$
 - ✓ BR is 6 times larger than $WW\rightarrow l\nu l\nu$ yielding more events
 - ✓ Main search mode for SM Higgs with mass above 250 GeV
 - Can still contribute significantly if $m_H > 160$ GeV
 - ✓ Search for resonances/bumps from new physics in dijet mass in the \sim few hundred GeV range produced in association with W
- ◆ WW (and WZ) $\rightarrow l\nu jj$ is fully reconstructible: can look for WW “bumps”
 - W pair with muon/electron + MET + exactly 2 jets. Solve for kinematics. Most events have solutions with 2 real roots for p_z of ν .
 - Main backgrounds are $W+jj$ and top.
 - Top background can be reduced by asking for no b tags and for exactly 2 jets (“top veto”).
 - $W+jj$ background can be reduced by requiring a W mass for the jet pair and other kinematic cuts

CDF result on W+jj



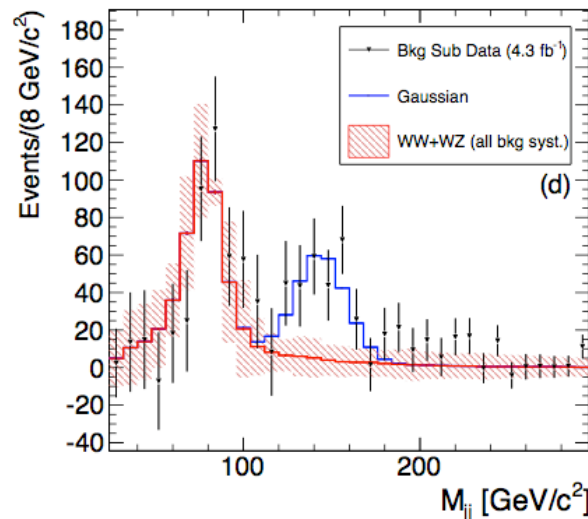
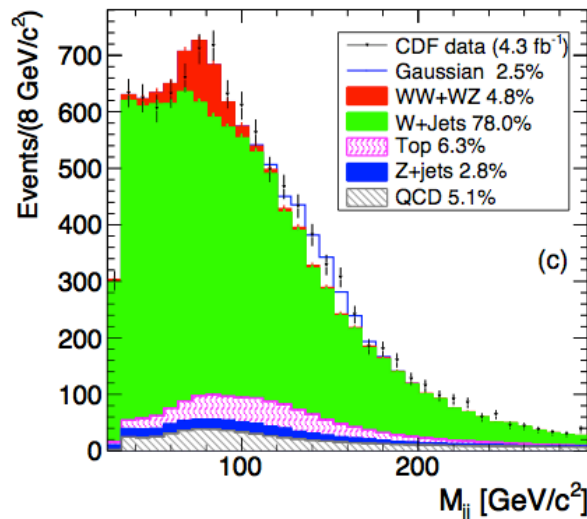
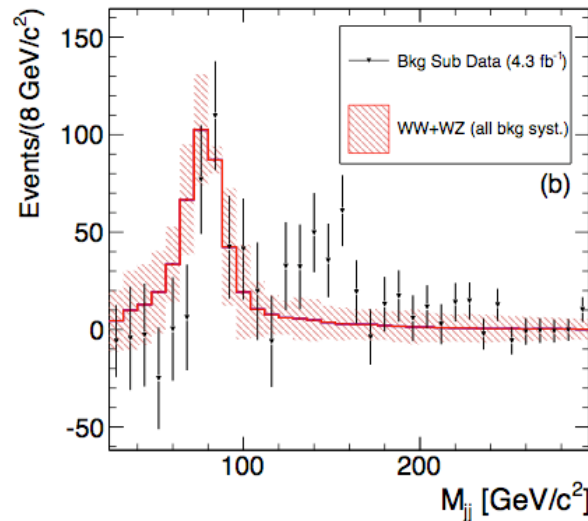
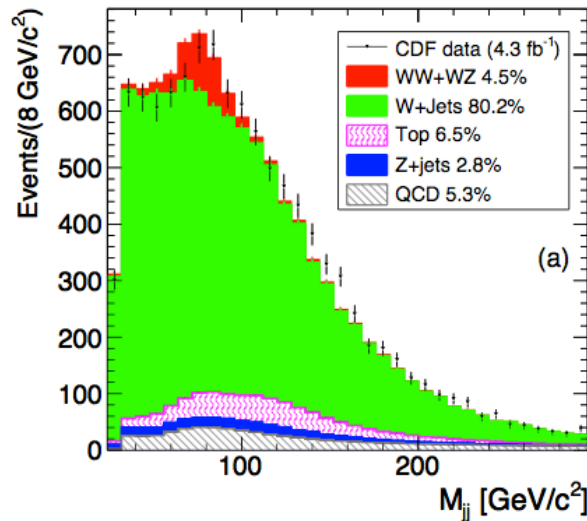
arXiv: 1101.6079 (Apr 4)

◆ CDF has a dijet W signal on a large Wjj bkg.

◆ However, the Wjj MC doesn't reproduce the featureless falloff of dijet mass spectrum.

◆ CDF finds an excess of 253 events in the dijet mass window 120–160 GeV. Significance is 3.2σ .

◆ The bump is compatible with a particle of mass 150 GeV and width 14 GeV. Not compatible with SM Higgs boson.



CDF W+jj: some details



Event selection

◆ W → lv reconstruction

$E_T^l > 20$ GeV, MET > 25 GeV

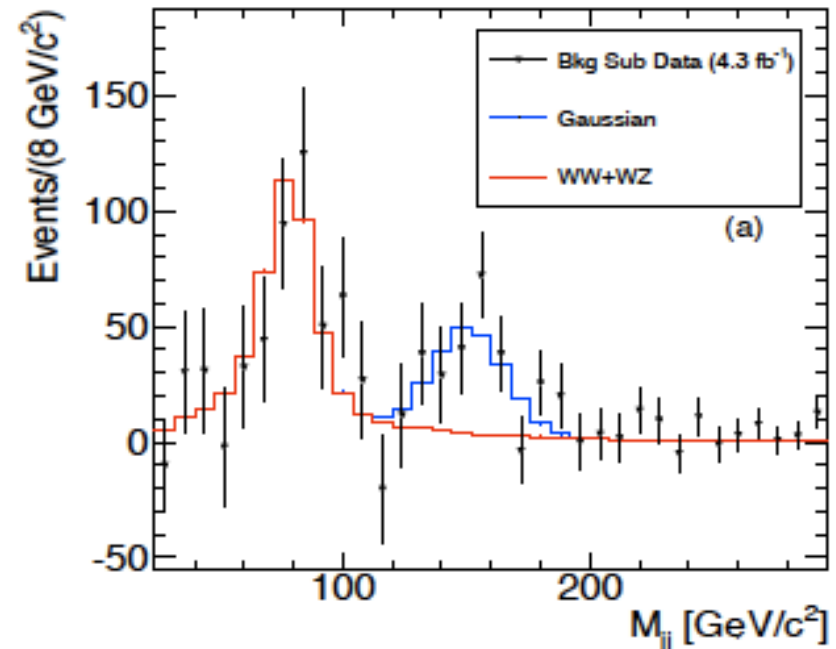
$m_T > 30$ GeV, Z veto

◆ 2 jets with $p_T > 30$ GeV and $|\eta| < 2.4$

$|\Delta\phi(\text{jet1}, \text{MET})| > 0.4$

$|\Delta\eta(\text{jet1}, \text{jet2})| < 2.5$

$p_{T}^{\text{dijet}} > 40$ GeV



Signal extraction

5 templates:

- 1 $W + \text{jets}$ (unconstrained, normalization determined from the fit) Shape from MC: verified on Z+jets
 - 2 QCD (normalization constrained to its fraction with 25 % error) Shape from MC: verify on QCD data
 - 3 $Z + \text{jets}$ (normalization constrained to the measured cross section)
 - 4 top & single top (normalization constrained to the theoretical cross section)
 - 5 WW/WZ (normalization constrained to the theoretical cross section)
- shape from MC

More details: Wine & Cheese talk on April 6 <http://theory.fnal.gov/jetp/talks/Viviana.pdf>

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

Student thesis: <http://lss.fnal.gov/archive/thesis/fermilab-thesis-2010-51.pdf>

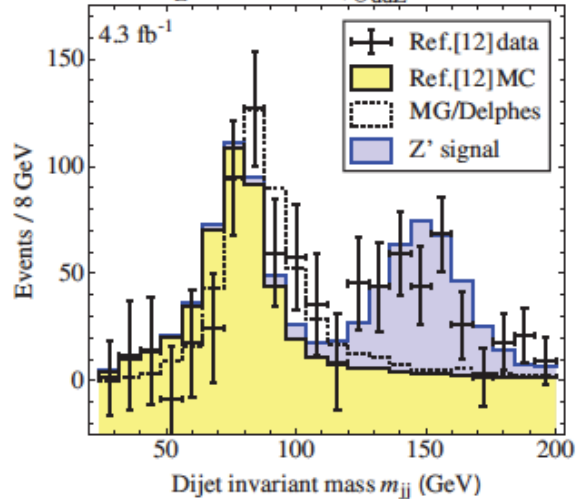
Theoretical interpretations of CDF bump



Light Z' boson

arXiv: 1103.6035, Buckley et al

$m_{Z'} = 150 \text{ GeV}, g_{ddZ'} = 0.25$



This Z' has suppressed coupling to leptons, but substantial couplings to quark. Can also explain top F-B asymmetry.

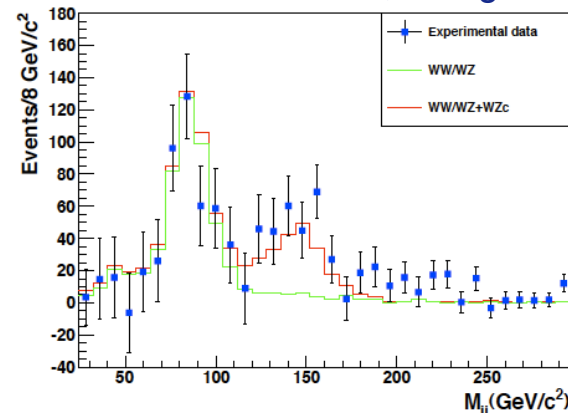
Technicolor

techni- $\rho \rightarrow WZ$
can enhance W_{jj} with low m_{jj}

Propose a subgroup of $SU(3)$. Predict comparable F-B asymmetry in tt and cc but suppressed in bb system. Excess in W_{jj} but suppressed in Z_{jj} .

Color octet axial-vector boson

arXiv: 1101.6079, Wang et al



Also explains top F-B asymmetry.

SUSY particle

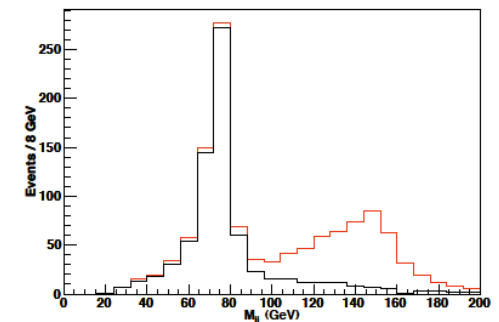
arXiv: 1104.2014, Sato et al

An MSSM particle with $\tan\beta \approx 10$

First observation of a SUSY particle !

Unified flavor symmetry

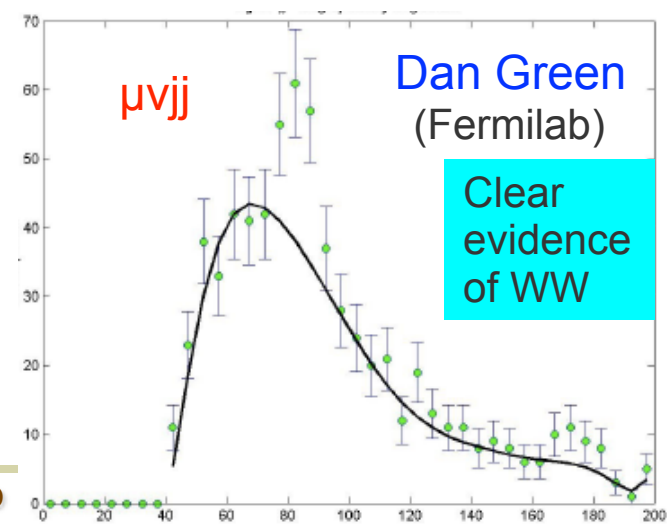
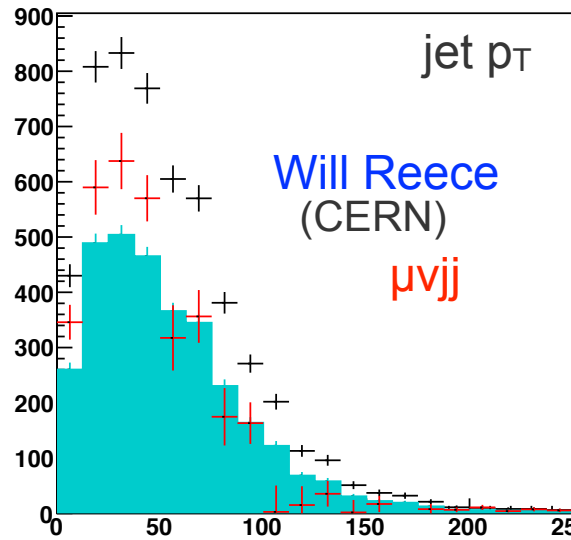
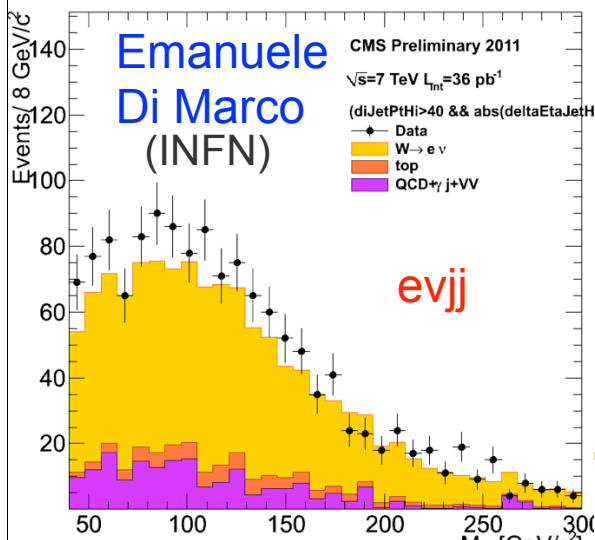
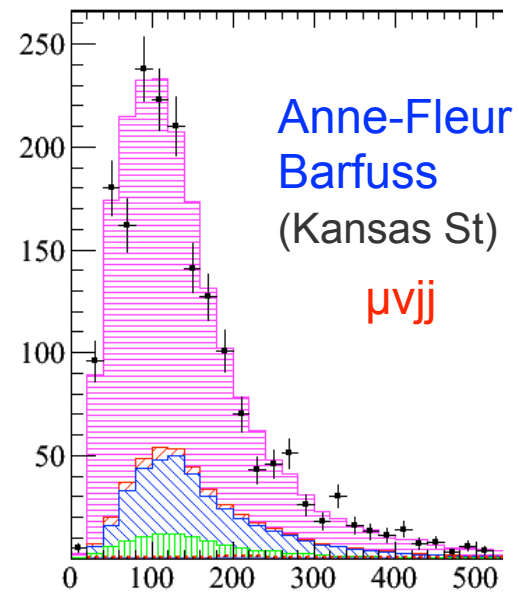
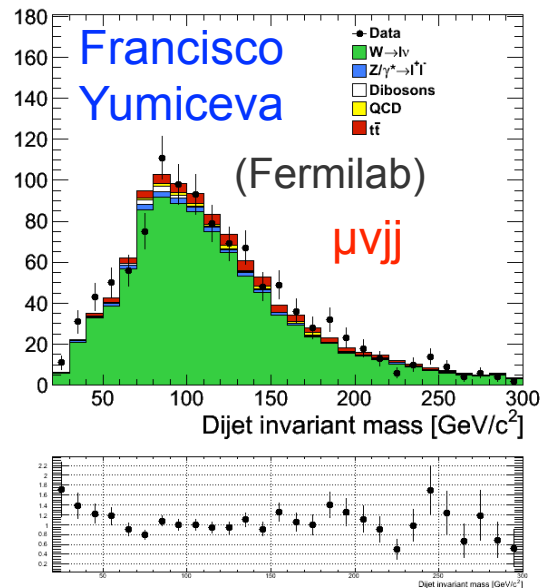
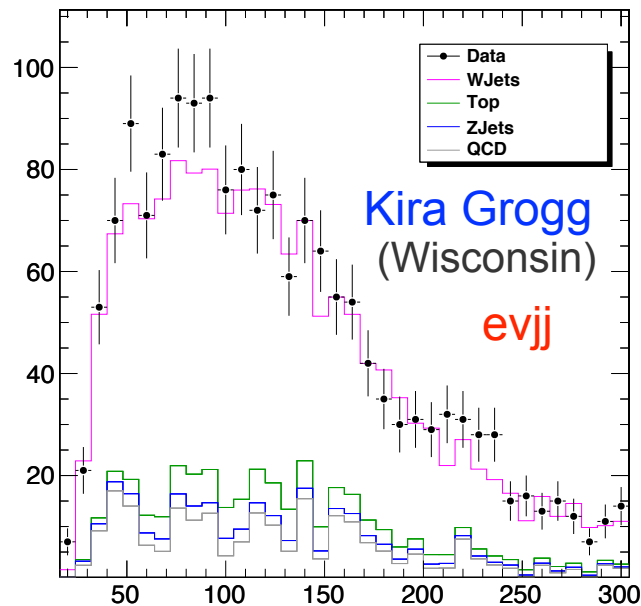
arXiv: 1104.2030, Nelson et al



Huge excitement in CMS over CDF bump

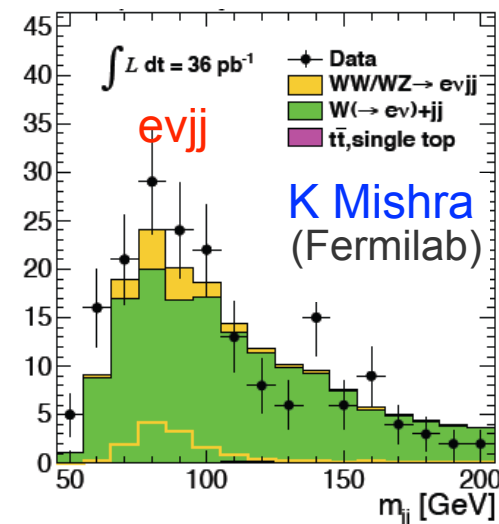
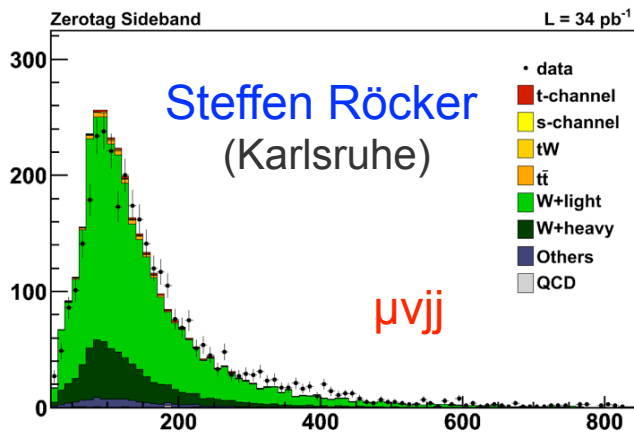
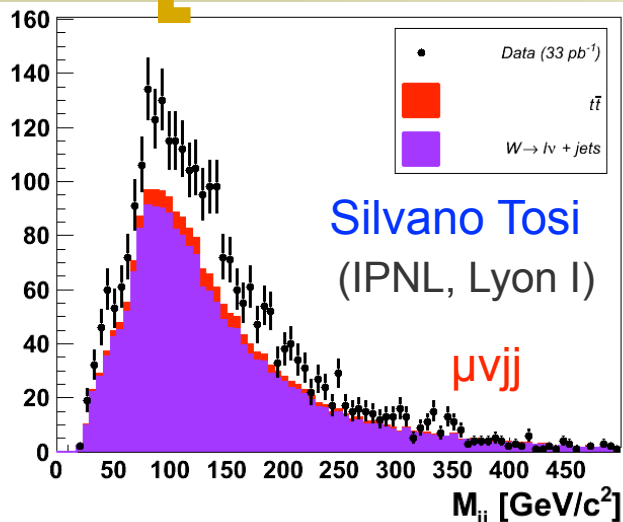


Lot of activity within CMS to reproduce CDF analysis within 24 hours !





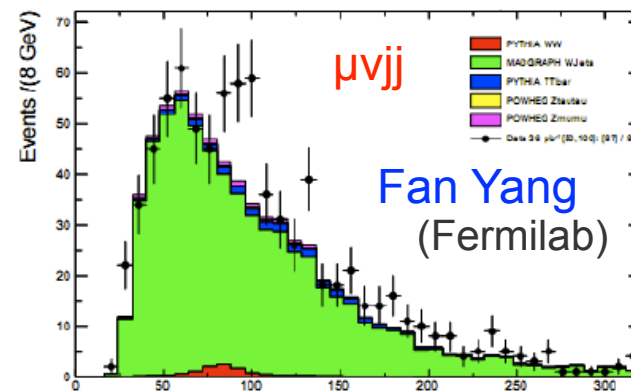
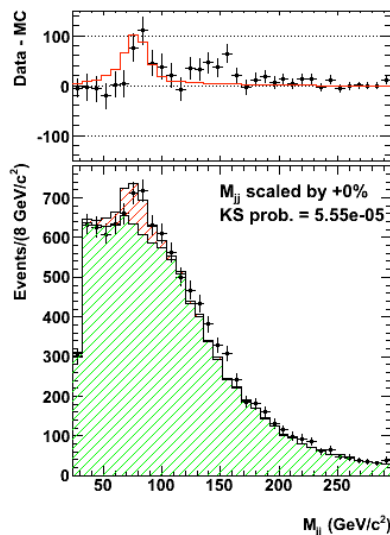
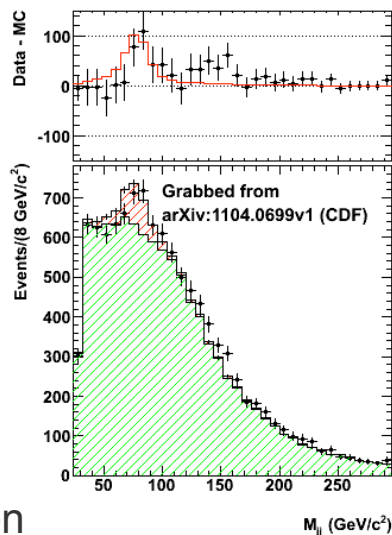
Huge excitement in CMS over CDF bump !



Some interesting observations from

Tommaso Tabarelli

(Milano-Bicocca)



Follow discussion in V+jets HN:

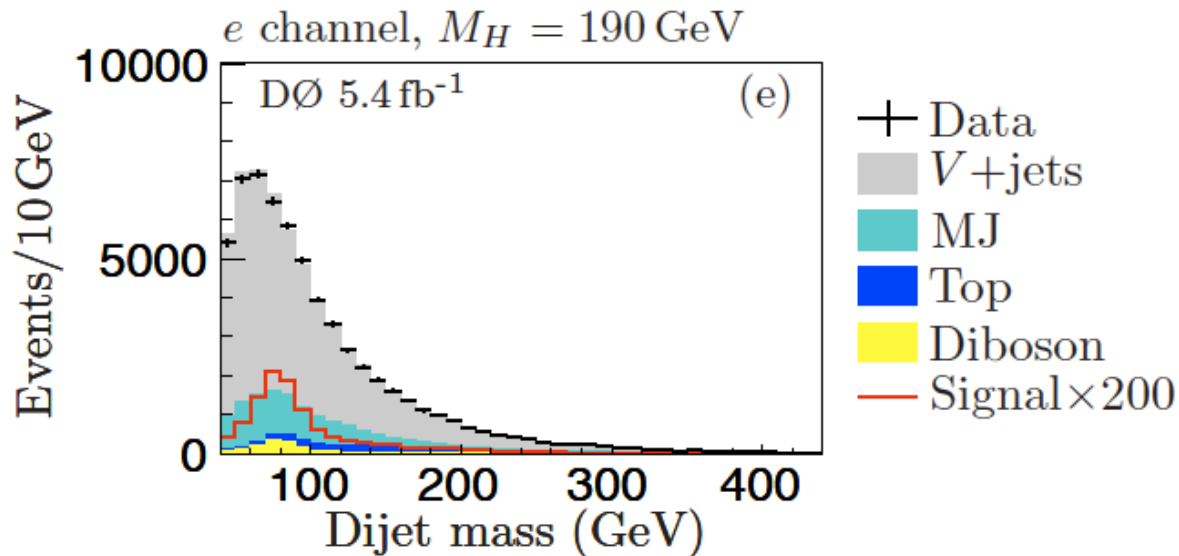
<https://hypernews.cern.ch/HyperNews/CMS/get/ewk-vplusjets.html>

DØ public result on the topic



Higgs search in $lvjj$

arXiv: 1101.6079 (Feb 2, '11)



This is a multi-variate analysis. They have public plots of some variables for e^- and other variables for μ^- channel. I couldn't find the correspond plot for μ channel.

Event selection

- ◆ $W \rightarrow lv$ reconstruction
 $E_T^l > 15$ GeV, MET > 15 GeV
 $m_T > (40 - 0.5 * MET)$ GeV
- ◆ ≥ 2 jets with $p_T > 20$ GeV and $|\eta| < 2.5$

No obvious bump visible in the DØ data in in the same mass range as CDF. But then it is hard to tell in this plot.

Does LHC have sensitivity with $L=50 \text{ pb}^{-1}$?



Process	Cross section: Tevatron (pb)	Cross section: LHC (pb)
WW	12	43
WZ	3.5	18

Ratio of WW+WZ cross section: Tevatron/LHC = 1/4

Ratio of integrated luminosity: Tevatron/LHC = 4300 / 50 = 86

- ◆ We need about 20–25 times more data to have the same sensitivity.
- ◆ With 4.3 fb^{-1} CDF has ~ 1500 WW+WZ($\rightarrow l\nu jj$) events from both e, μ channels
 - We should have about 60 events from 2010 data (WW: $43 \text{ pb} * 0.33$ acceptance * 0.5 efficiency * 2/9 * 2/3 BR * 36 pb^{-1} lumi = 45, similarly for WZ).
- ◆ CDF finds an excess of 253 events over a background of ~ 2000 in the mass window 120–160 GeV
 - Scaling to 2010 luminosity we expect an excess of 8–9 events with similar S/B
 - Clearly, not significant enough to generate excitement
 - Need $\sim 1 \text{ fb}^{-1}$ to be competitive with Tevatron. So by summer

However, maybe the enhanced partonic luminosity (gg and qg) at LHC can produce this excess at higher rate or via other mechanism. Need to watch out.

Quick analysis of CMS $W(\rightarrow lv)+jj$ data



◆ $W \rightarrow ev$ reconstruction

- $E_T > 25$ GeV, $|\eta| < 2.5$ (2.1) for electron (muon)
- Passing Top PAG recommended isolation/Id criteria
- W transverse mass: $m_T > 50$ GeV, PF MET > 25 GeV
- Z veto

◆ Require two PF jets in the event

- each jet with corrected $p_T > 20$ GeV and $|\eta| < 2.4$
- $|\cos\theta^*| < 0.4$, $|\Delta\phi(\text{jet1}, \text{jet2})| > 1.5$
- $|\Delta\phi(\text{jet1}, \text{MET})| > 0.6$
- $|\Delta\phi(W, W) - \pi| < 0.2$
- No b-tagged jets

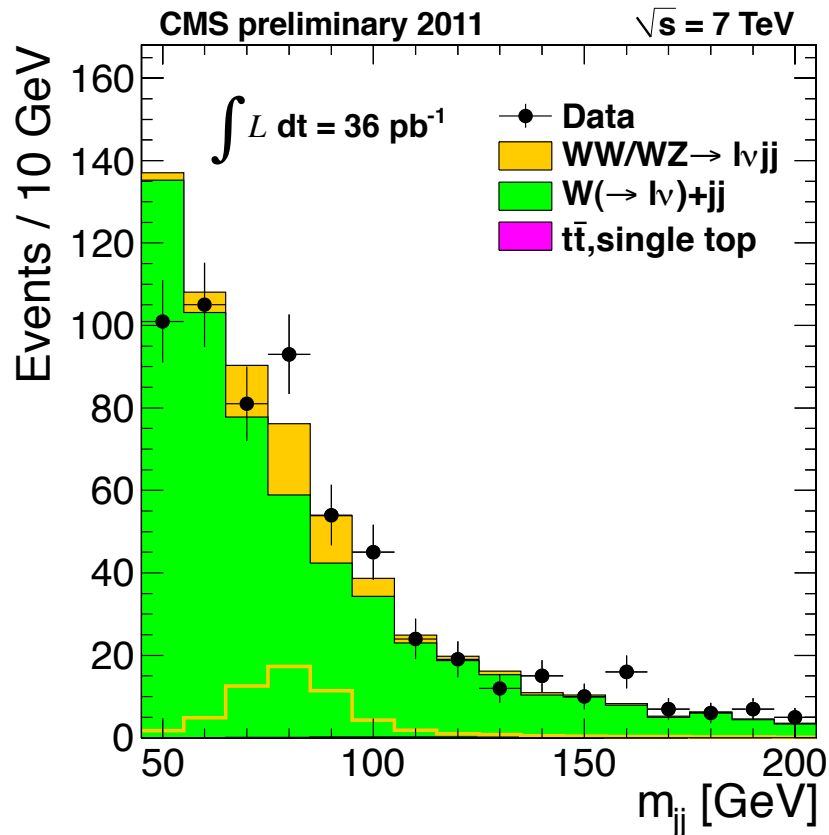
Apply standard
“L2 L3” correction
and “residual
correction” in data

Using 36 pb^{-1} data from 2010 run

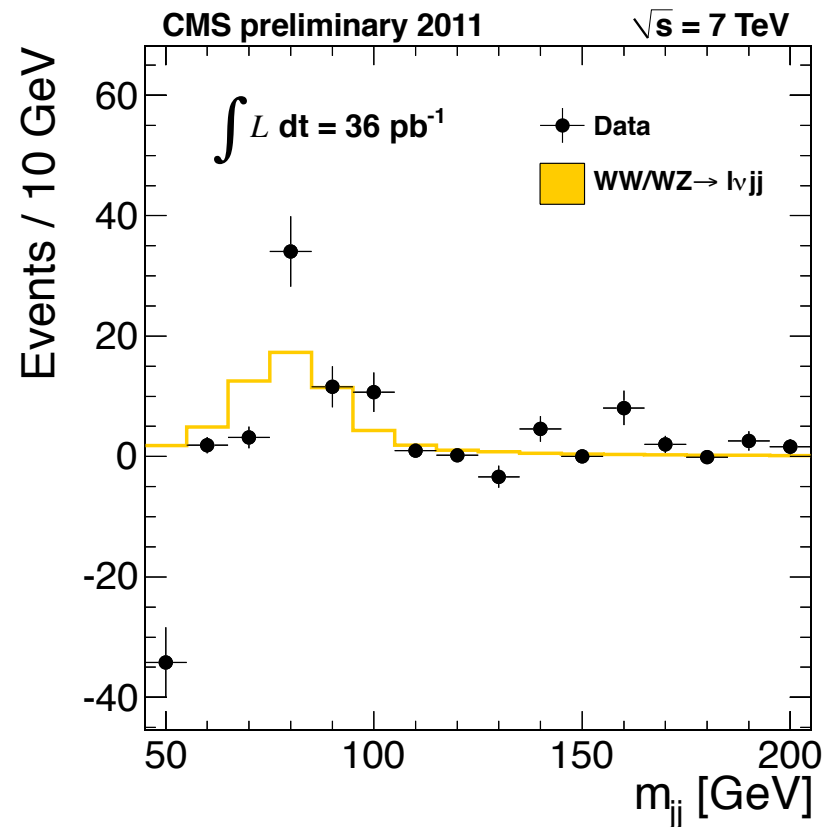
MC:

W+jets: Madgraph, Top: Powheg, WW+WZ: Pythia
(all with pileup conditions observed in 2010 data)

m_{jj} distribution in CMS data (e, μ combined)

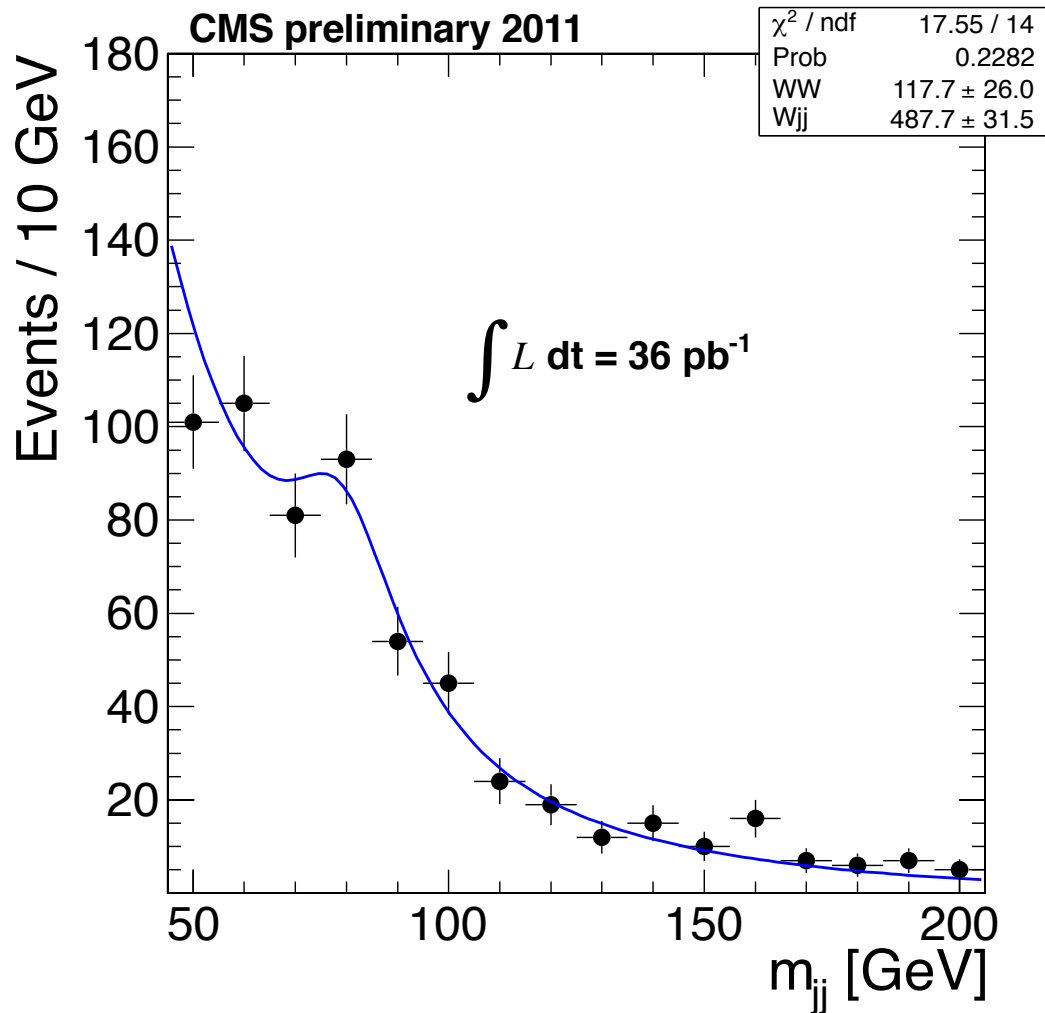


observed events in data = 600
 MC predicts:
 W+jj = 554
 Ttbar, single top = 2
 WW + WZ = 58



subtracting W+jj +top bkg from MC

CMS data: WW+WZ signal estimation



(e, μ data combined)

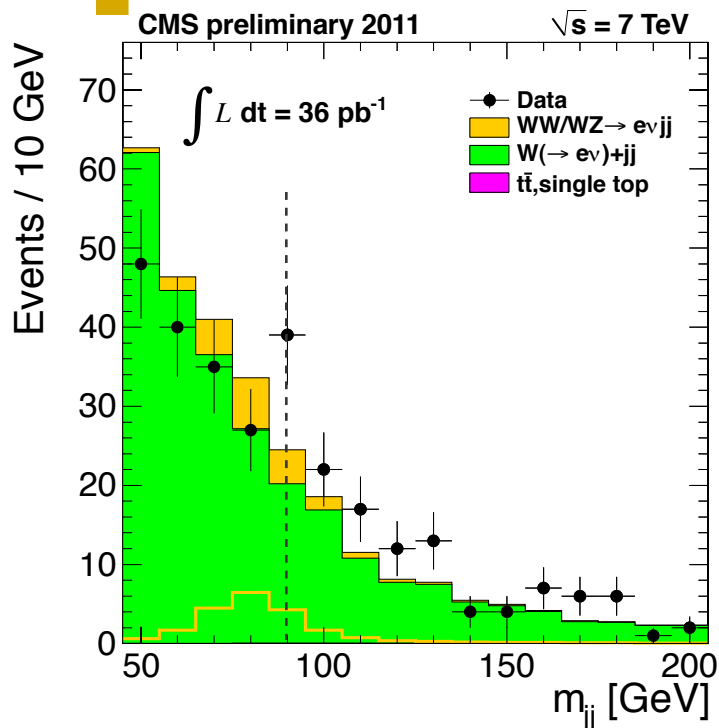
Shape derived from MC.
Fit for the normalization.

WW + WZ yield = 118 ± 26
W+jets yield = 488 ± 32

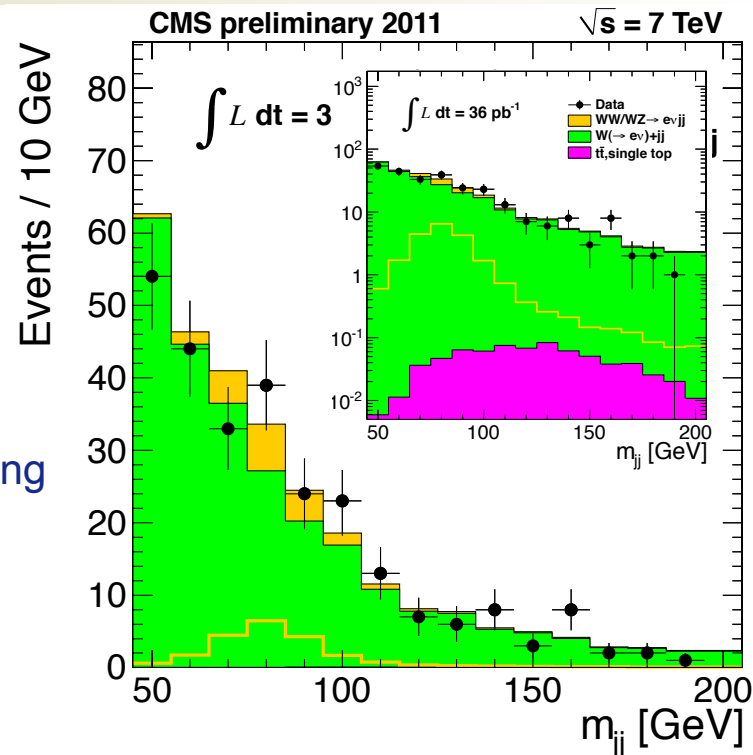
**Clear evidence of diboson
production in $lvjj$ final state
in CMS**



m_{jj} distribution for $W(\rightarrow ev)+jj$ events



After adjusting JES



- See clear W bump
- The bump is shifted right
- Need to adjust JES to have W peak at 80 GeV

observed events in data = 267

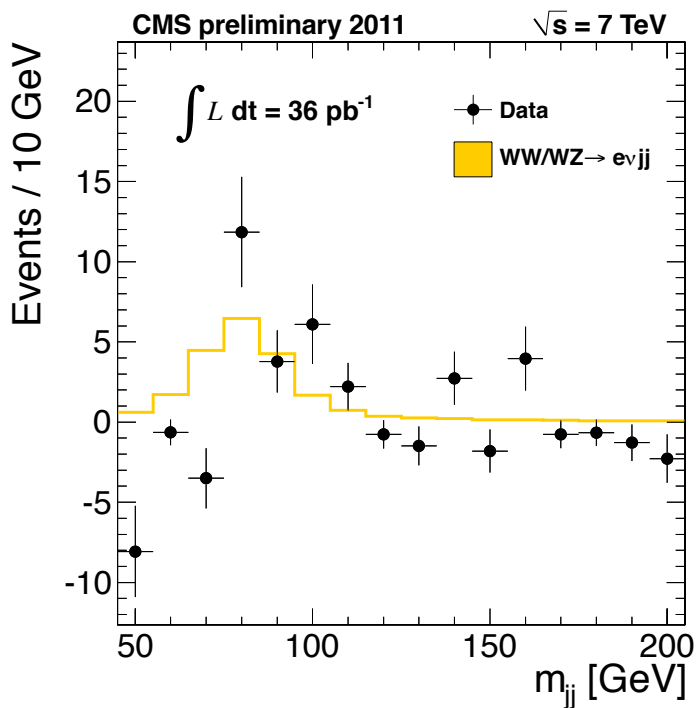
MC predicts:

- W+ jj = 257
- Ttbar, single top = 0.7
- WW + WZ = 21

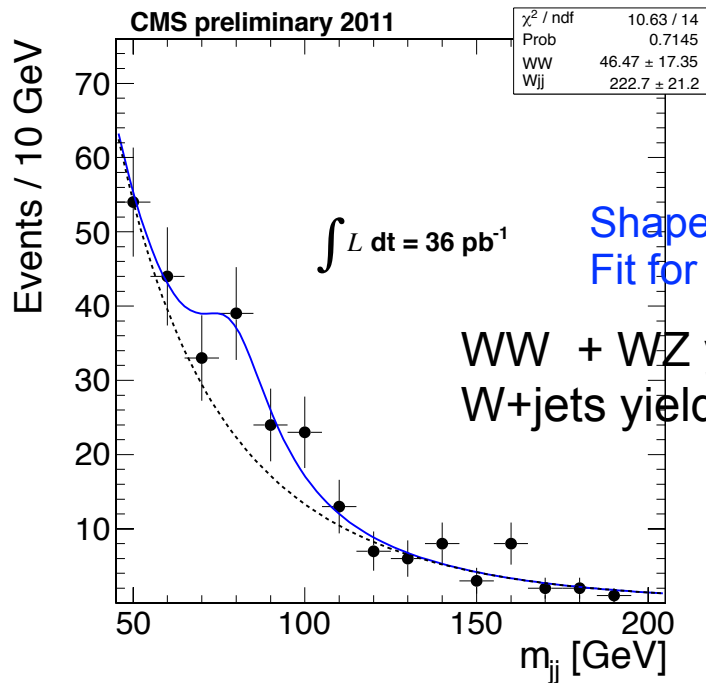
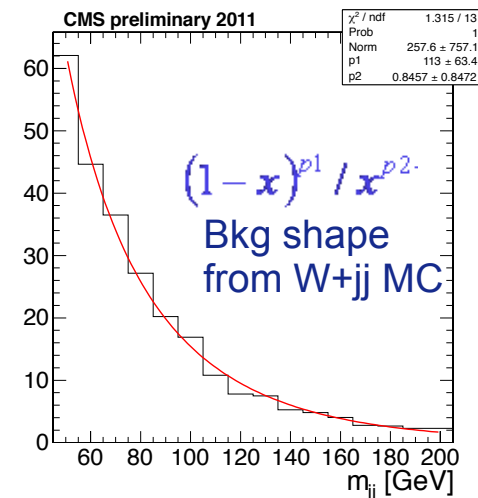
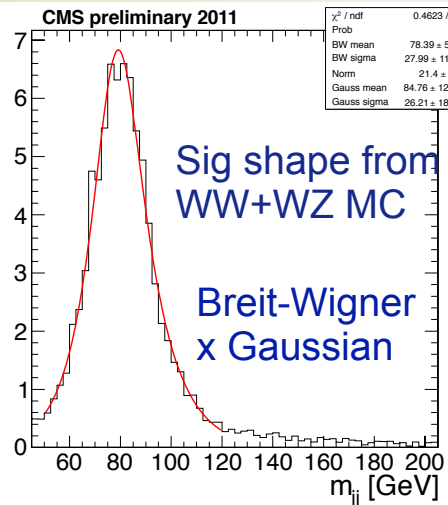
m_{jj} distribution after background subtraction



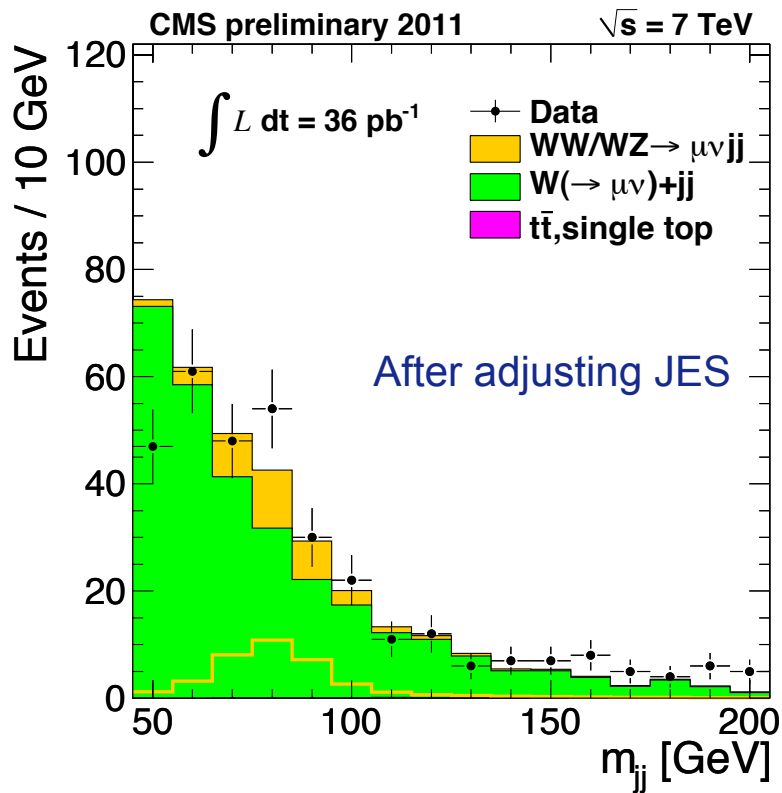
subtracting W+jj +top bkg from MC



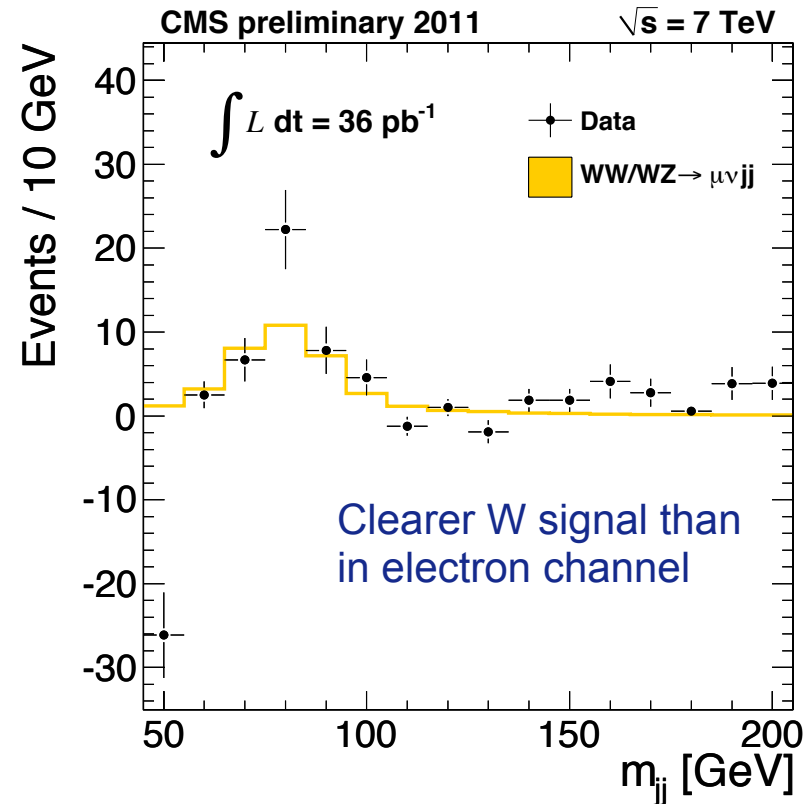
Any excess between 120–160 GeV is not significant, but is consistent with CDF result.



m_{jj} distribution for $W(\rightarrow \mu\nu)+jj$ events



observed events in data = 333
 MC predicts:
 W+ jj = 297
 T \bar{t} , single top = 1.3
 WW + WZ = 37



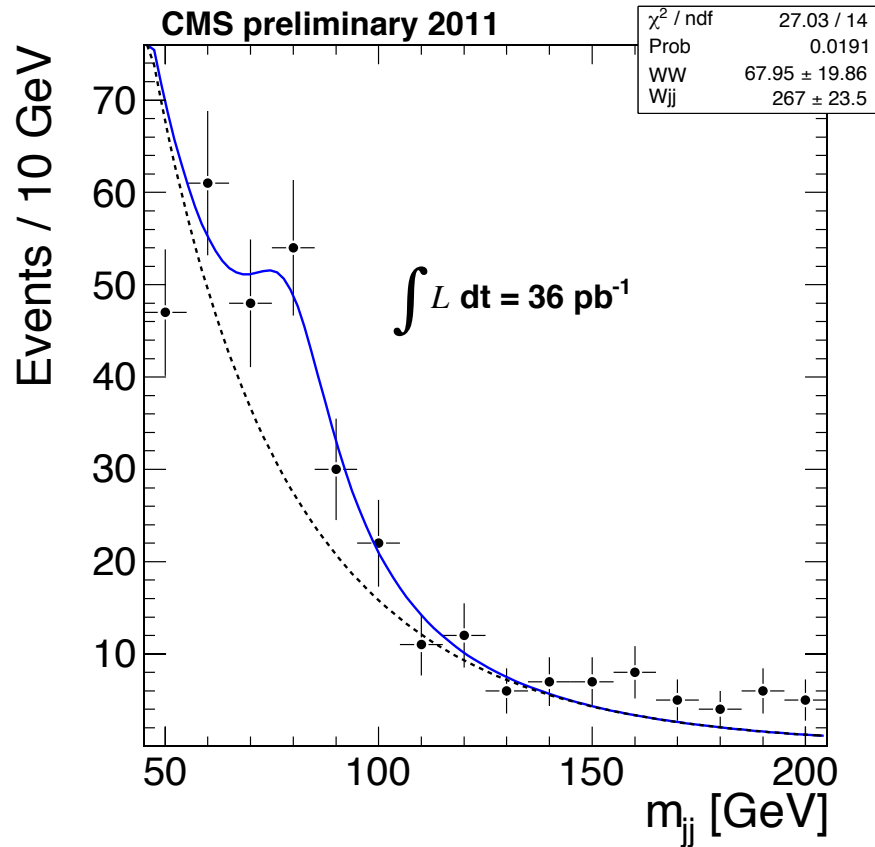
subtracting W+ jj +top bkg from MC

From Fan Yang

m_{jj} distribution: WW+WZ signal estimation



From Fan Yang

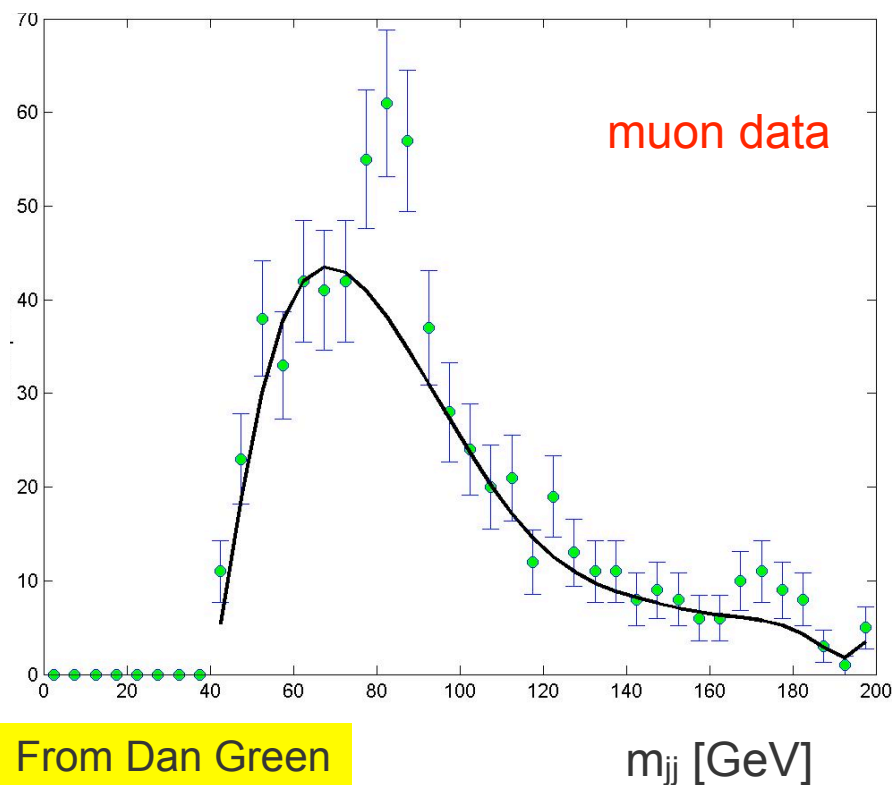
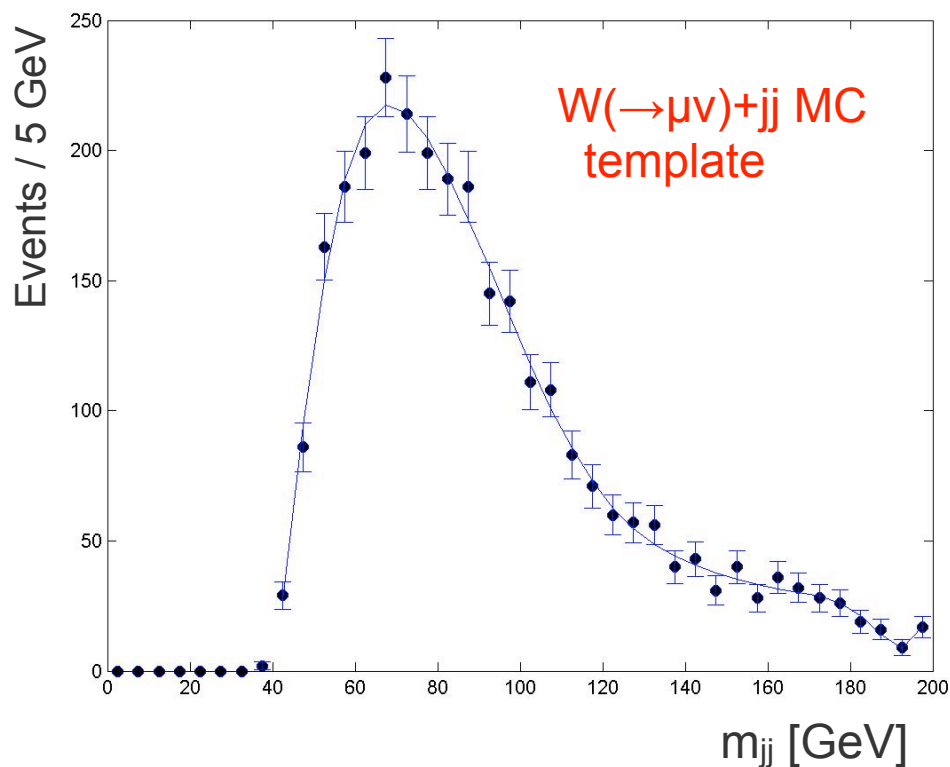


WW + WZ yield = 68 ± 20
W+jets yield = 267 ± 24

WW signal is robust w.r.t. selection cuts (I)



Dan Green performed analysis using top PAG skim of muon data, and somewhat different selection cuts. He gets the same number of signal events.

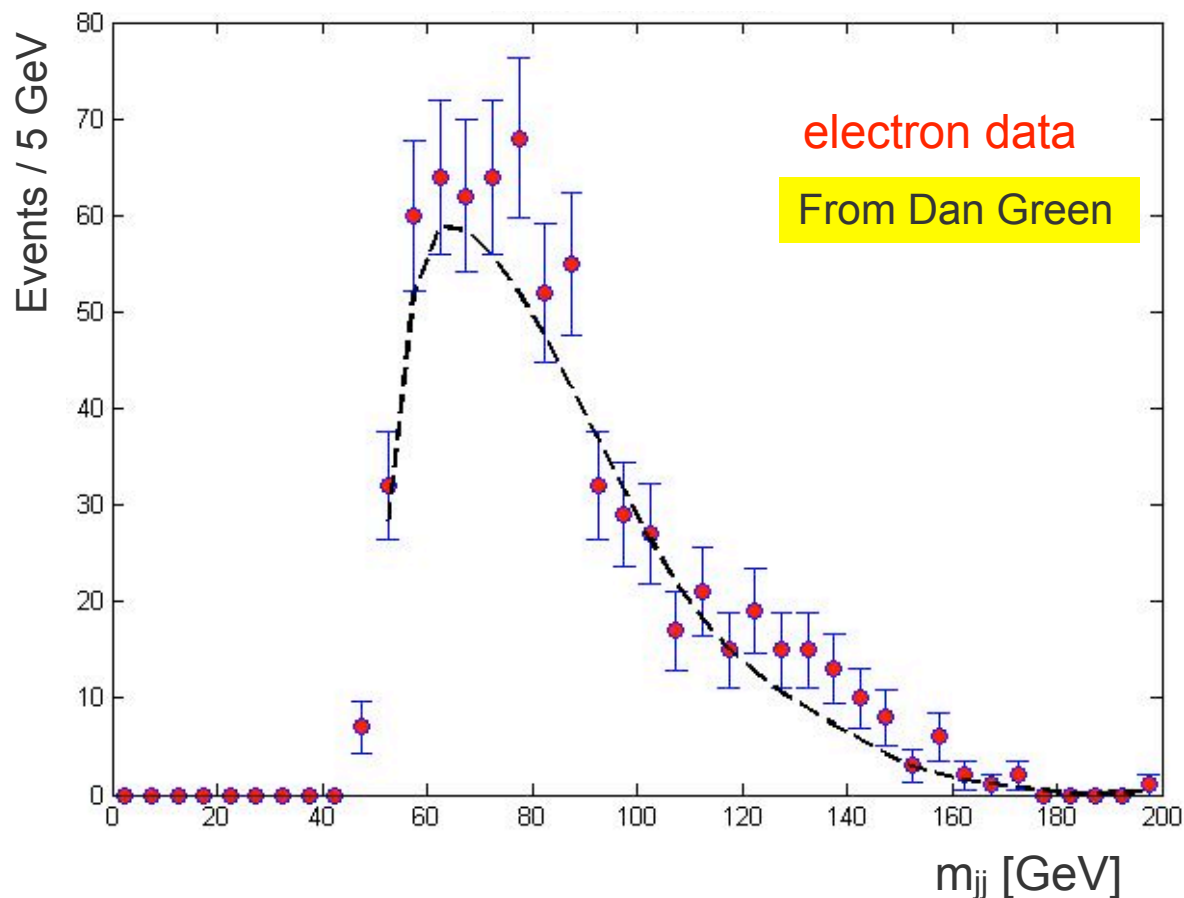


The fit after all cuts is to the W_{jj} MC shape. The evidence remains for a W signal in the μ data with $\sim 60 \pm 20$ events above a smooth background.

WW signal is robust w.r.t. selection cuts (II)

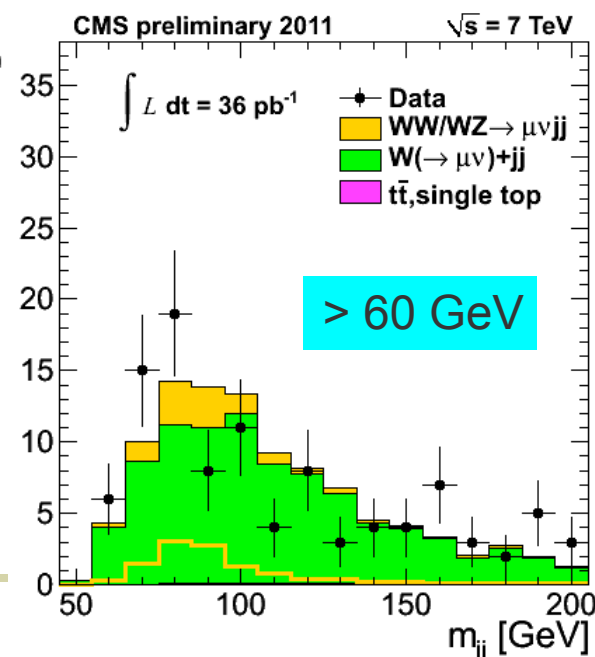
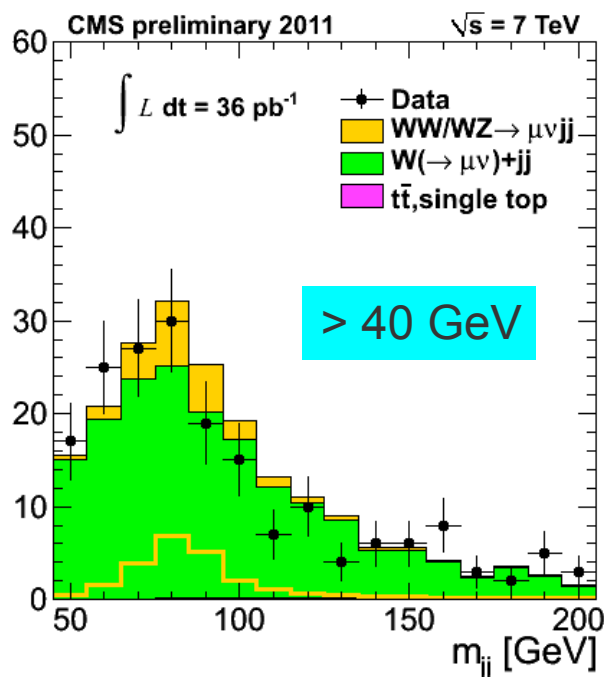
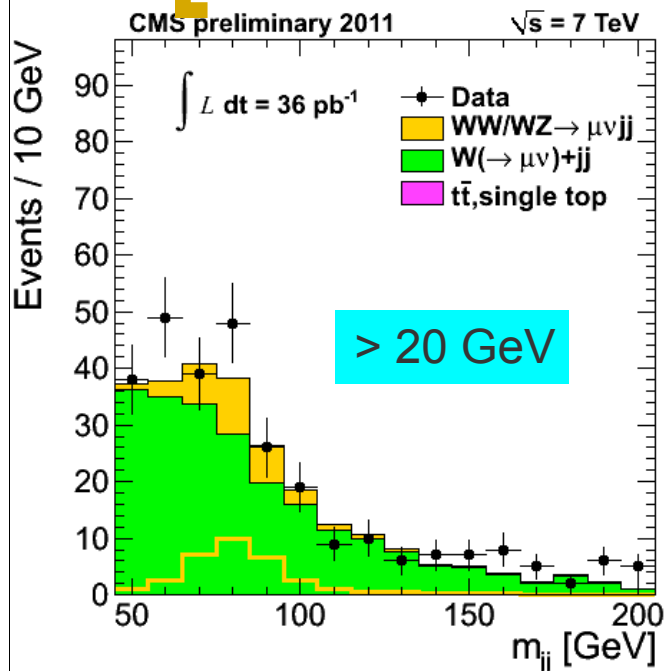


Dan's analysis of electron data using top PAG skim and somewhat different selection cuts. He gets the similar number of signal events.





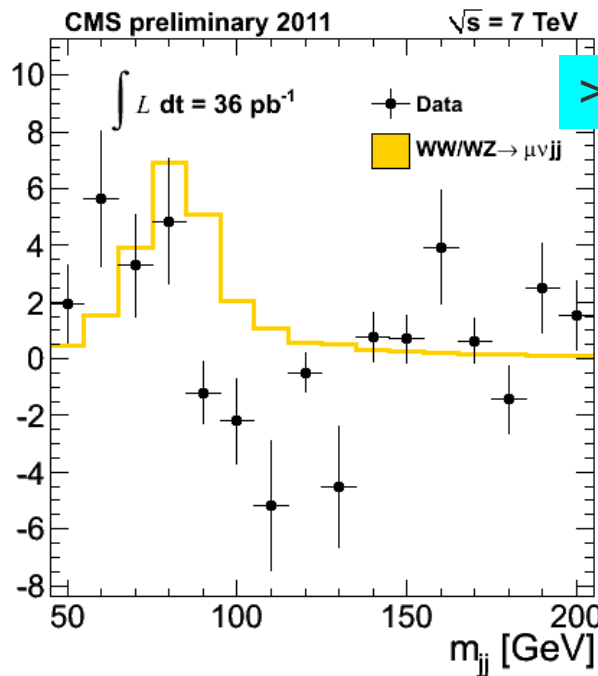
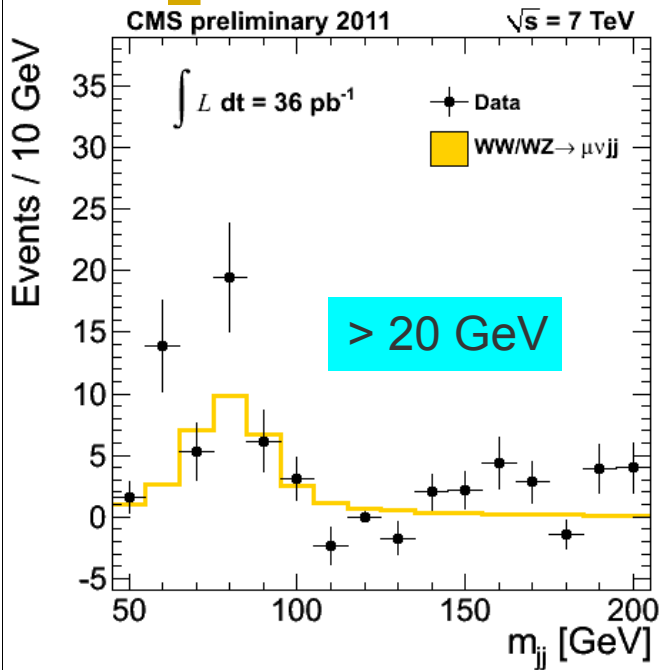
Effect of p_T^{dijet} cut



The dijet p_T cut does not seem to be enhancing any resonance in 120–160 GeV. Neither it should (this object should be produced mostly at rest). I do not see physics motivation for this cut.

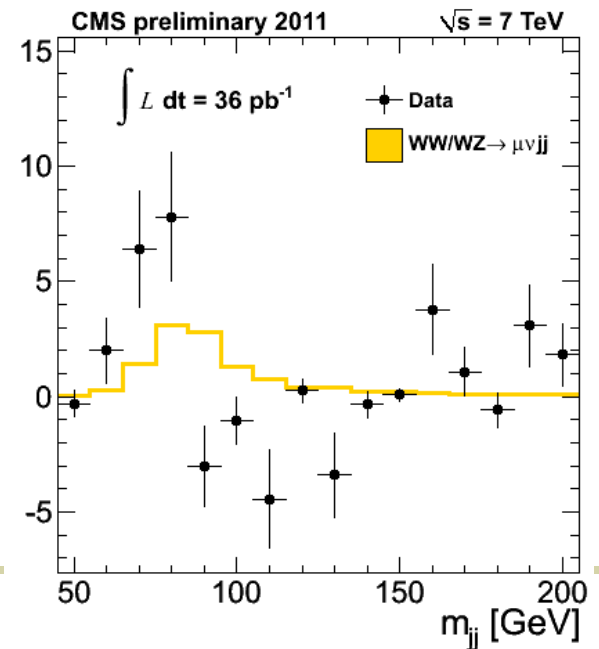


Effect of p_T^{dijet} cut (after bkg subtraction)



Same conclusion as on the last slide.

$> 60 \text{ GeV}$



Next steps for CMS



- ◆ Measure the electroweak $WW+WZ(\rightarrow l\nu jj)$ production rate
 - With both 0 and 1 extra jet
 - This will help constrain the JES and nuisance parameters
 - Thoroughly understand the shape of the W +jets background

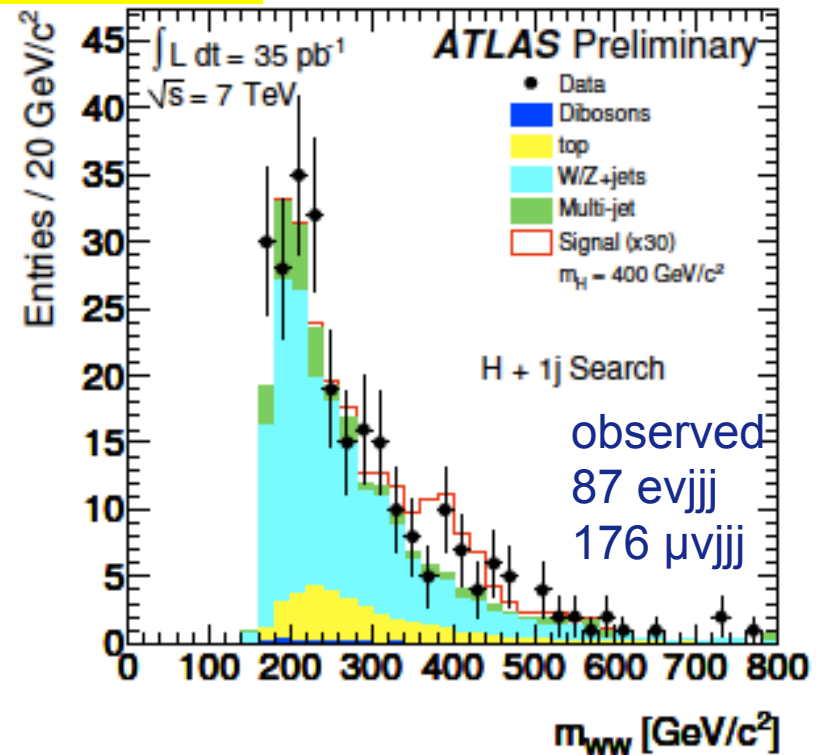
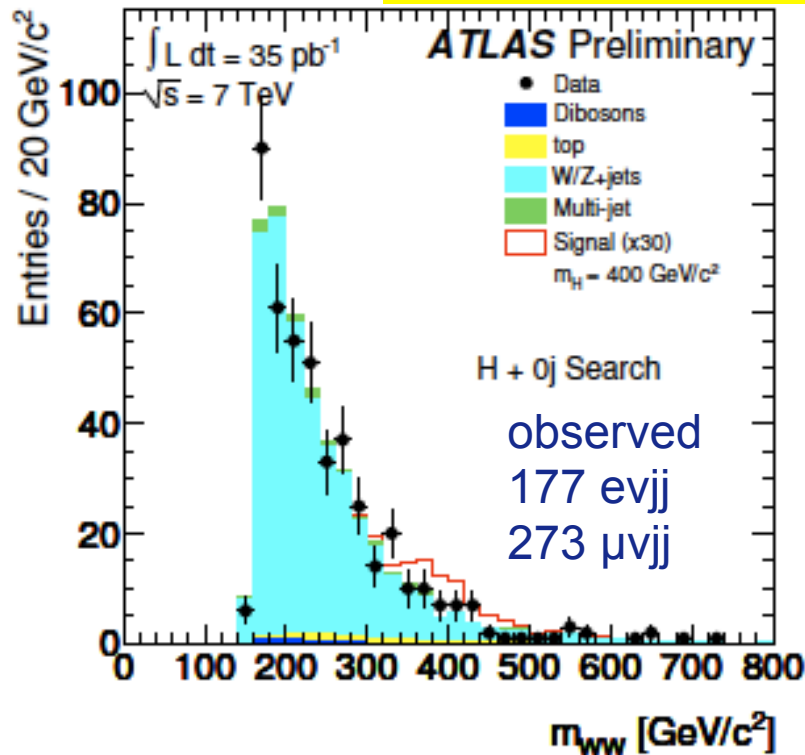
- ◆ Examine the 2011 data as the integrated luminosity increases
 - Trigger is going to be the most critical element in the high lumi high pileup scenario
 - we live by the trigger or die with the trigger
 - Jets and MET with PU are likely to be crucial to optimize.

- ◆ With a firm understanding of the WW production
 - Will be well positioned to search for resonances (a la CDF bump) and Higgs
 - Need $\sim 1 \text{ fb}^{-1}$ to have sensitivity in the interesting kinematic regime
 - Should have it by the end of summer, i.e., soon.

ATLAS Higgs search limit



ATLAS-CONF-2011-052 (Apr 5, '11)

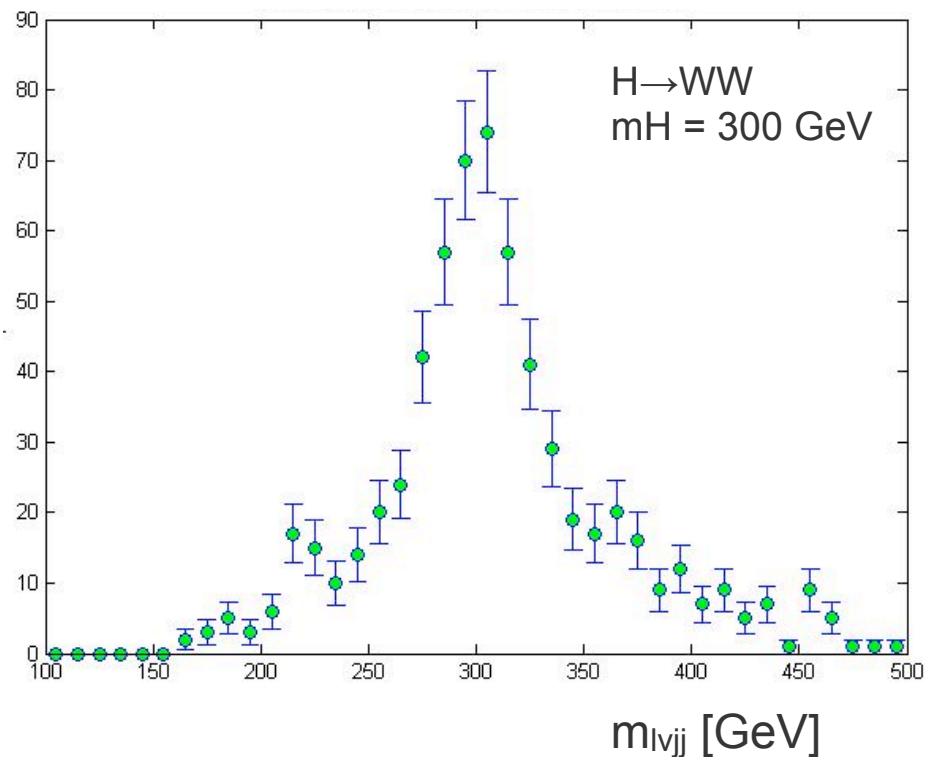


- ◆ $W \rightarrow l\nu$ reconstruction
 $E_T^l > 30 \text{ GeV}$, $\text{MET} > 30 \text{ GeV}$, Veto any second lepton in the event
- ◆ 2 or 3 jets with $p_T > 30 \text{ GeV}$, $|\eta| < 4.5$
 both jets from W decay should have $|\eta| < 2.8$ and $71 < m_{jj} < 91 \text{ GeV}$

CMS m_{WW} mass resolution for $m_H = 300$ GeV



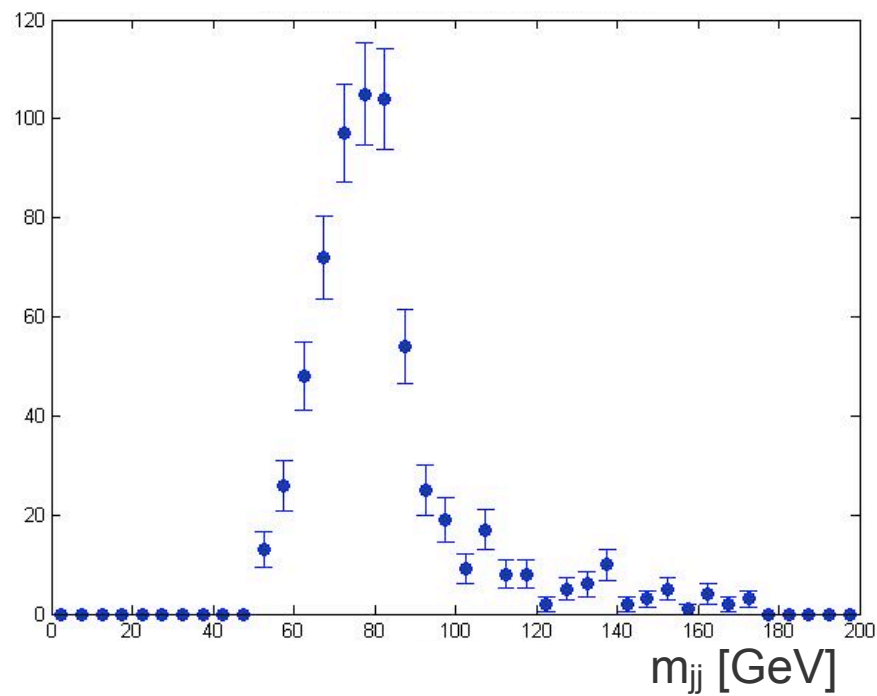
From Dan Green



After the kinematic fit, and asking for no b tags of the 2 jets, the Higgs mass distribution has a ~ 20 GeV resolution, or $dM/M \sim 7\%$.

Once the WW signal is established, look for resonant substructure.

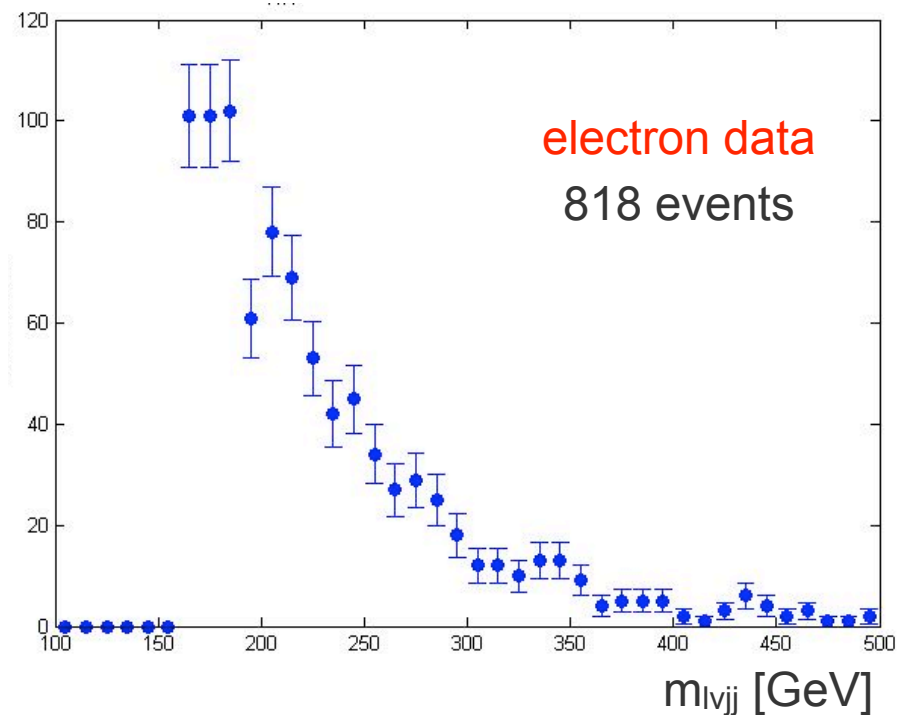
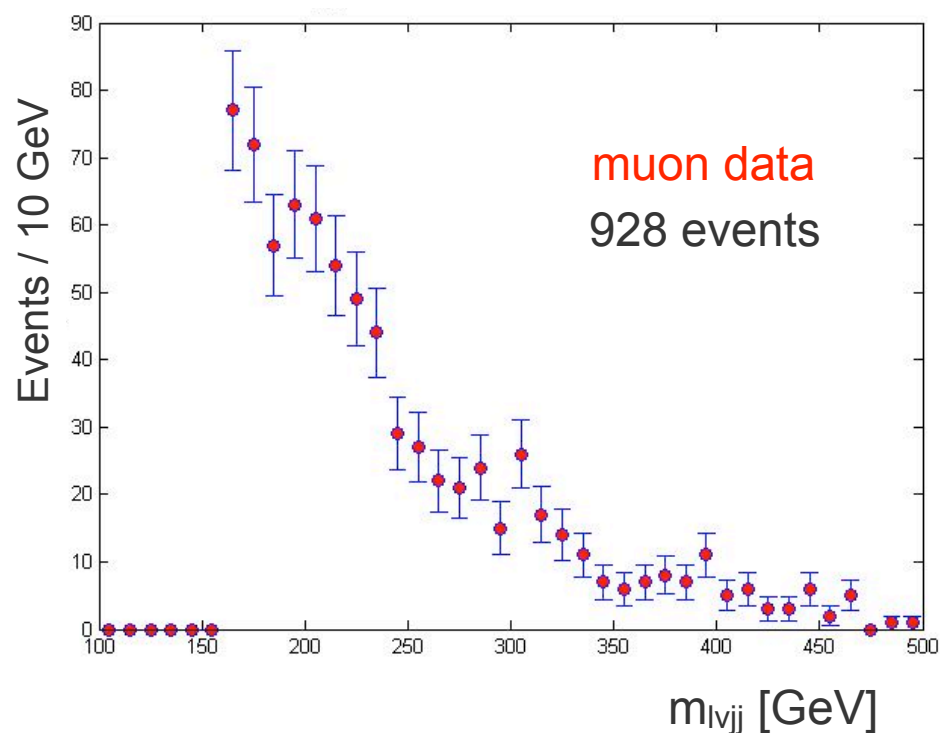
The dM/M resolution in the dijet mass is $\sim 13\%$.



CMS m_{WW} distribution in data

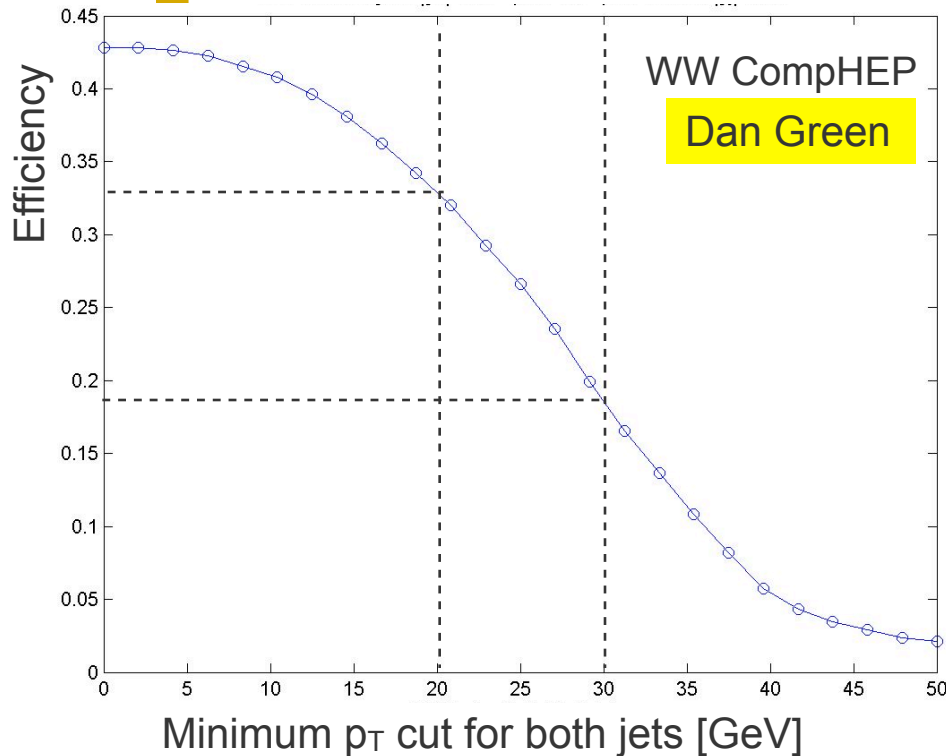


From Dan Green



Not directly comparable with ATLAS because of different threshold cuts.
However, the distributions look similar.

Trigger challenge: effect of jet threshold



- WW reconstruction efficiency is a strong function of the cut on jet p_T .
 - For a cut on both jets of 25 GeV, the overall efficiency is ~25%.
 - 18% for 30 GeV cut
- We lose ~1.5% of efficiency for each 1 GeV increase in jet p_T threshold

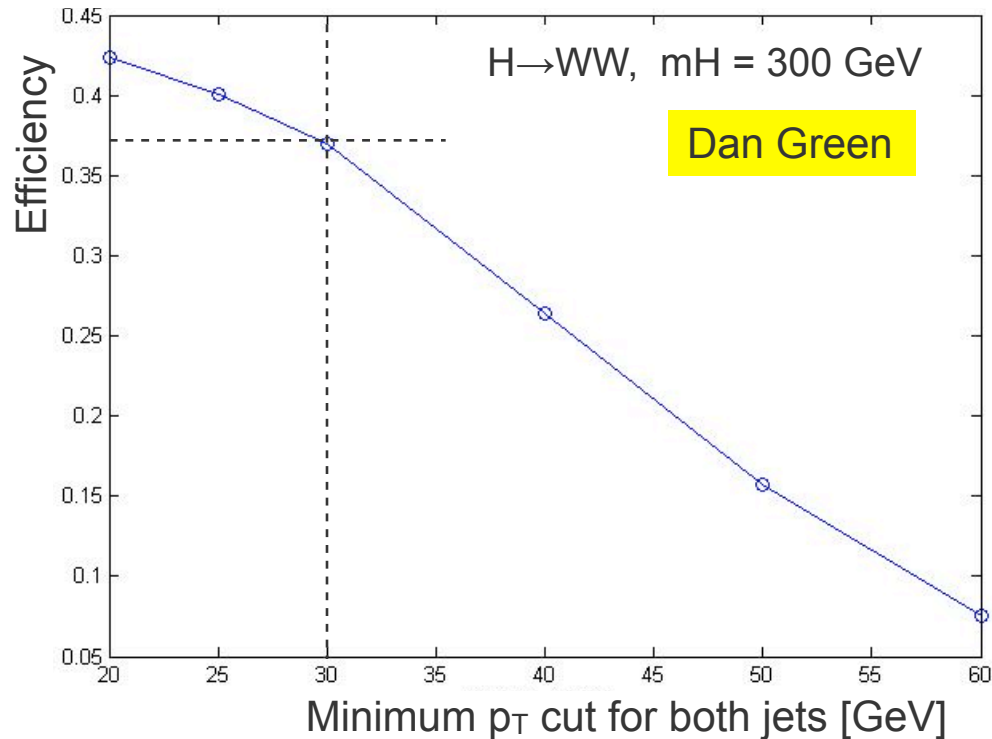
HLT trigger rate (Hz)

Andrea Benaglia & Leonardo di Matteo

$L =$	$5.00E+32$	$1.00E+33$	$2.00E+33$
Ele15_Jet30_Jet30	4.05	8.1	16.2
Ele17_Jet30_Jet30	3.70	7.4	14.8
Ele22_Jet30_Jet30	2.98	5.96	11.92

Adding MET >25 GeV will reduce the rate by a factor 3.5 → viable for 2E33 menu with electron $E_T > 22$ GeV. But MET is uncertain in high PU/OOP. Jet threshold still too high.

Effect of jet threshold on $H \rightarrow WW$ analysis

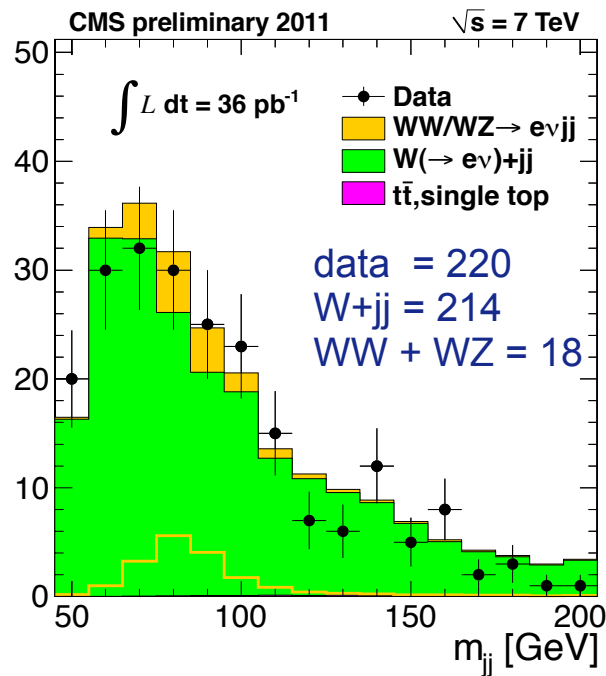


- For a Higgs this heavy a jet threshold of 30 GeV in p_T remains reasonably efficient.
- However, the light Higgs should not be thrown away if it can be retained.
- Even in the mass range 160-200 GeV semileptonic decay mode can add significantly to Higgs sensitivity.

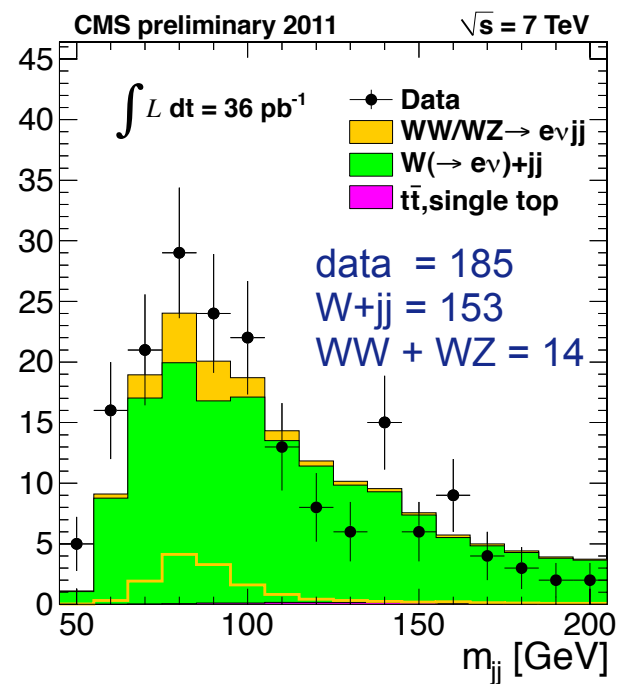
Another consequence of higher jet threshold



jet $p_T > 25$ GeV



jet $p_T > 30$ GeV



W+jj and WW are peaking close to each other. It is harder to discriminate between their shape although the absolute number of W+jj has gone down.

Summary



- ◆ Huge excitement over CDF result in Wjj
 - in both experimental and theoretical community
 - CMS needs an order of magnitude more data for similar sensitivity
 - with 36 pb^{-1} data $\sim 20\text{--}30$ WW candidates in each lepton channel
 - making progress on signal extraction techniques, S/B optimization, ...
 - efforts ongoing to understand $W+jj$ background shape
 - and effect of PU on sig/bkg, MET resolution, jet p_T , lepton iso,...

- ◆ Analysis strategy for summer
 - work hard to have sensible trigger in place to keep most of the interesting Wjj events in high luminosity and pileup conditions
 - measure WW production rate, discover of $H \rightarrow WW$ and dijet resonance in Wjj events

- ◆ Many thanks to **Jeff Berryhill, Andrea Benaglia, and Leonardo di Matteo** for providing results/insights.