Study of the di-jet mass spectrum in events with a W boson

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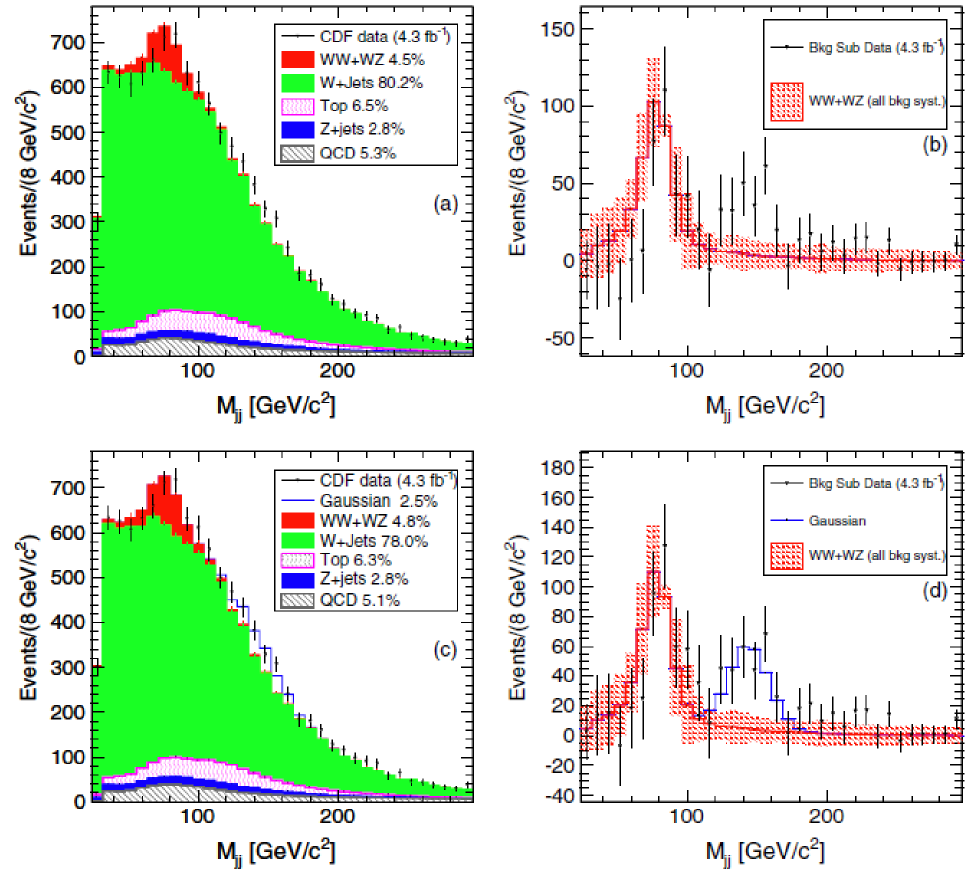
On behalf of the CMS collaboration

Motivation

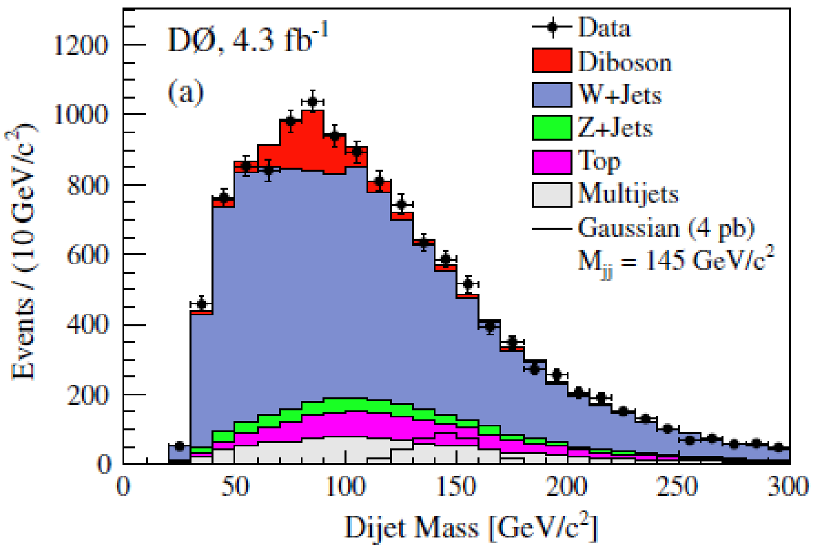
- The CDF collaboration published evidence of a narrow structure in the di-jet mass spectrum produced in association with a W boson.
  - m ≈ 145 GeV
  - The enhancement is consistent with the detector resolution (~10%).
  - They estimate the cross-section to be 4 pb and the significance of the bump to be 3.2σ.
  - Since adding additional data the significance has improved to ~4σ.

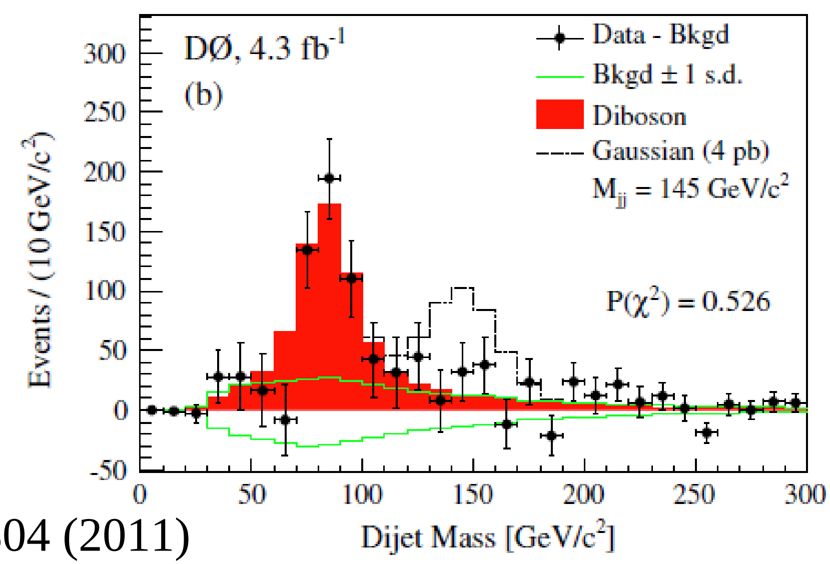


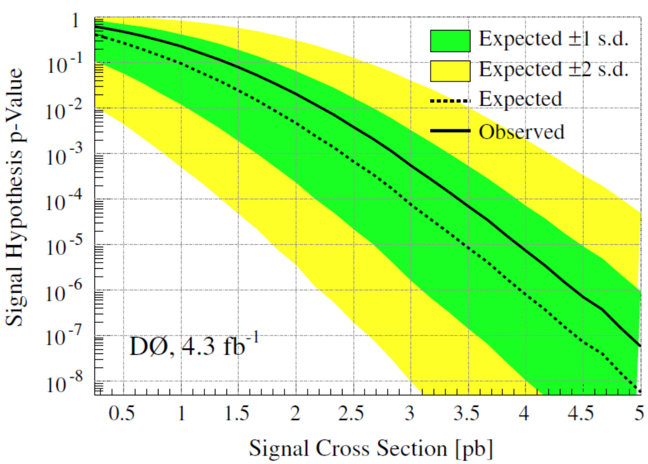
PRL **106**, 171801 (2011)

What does D0 see?

- D0 does not find any evidence of a similar enhancement.
  - Set an 95% CL upper limit on production reported by CDF at 1.9 pb.
  - Report and exclusion of 4 pb cross-section at 4.3σ.







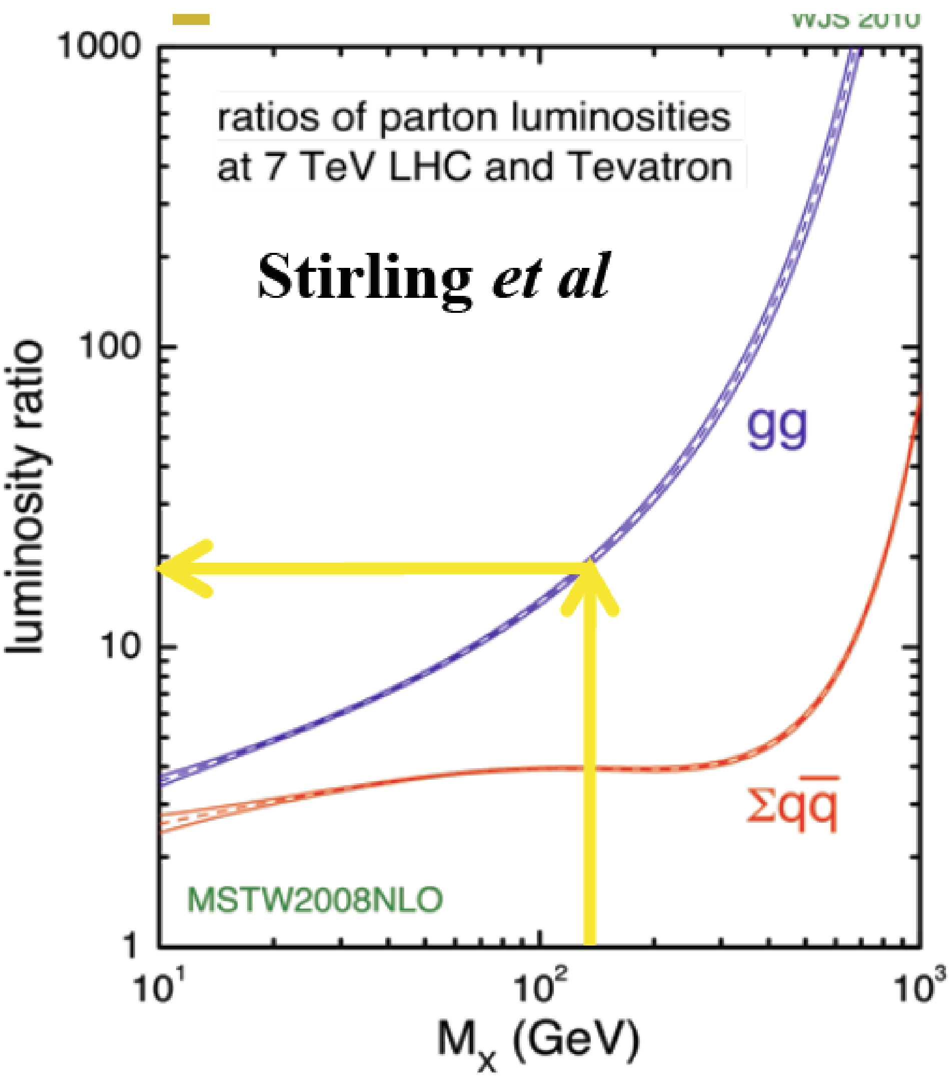
PRL **107**, 011804 (2011)

Possible explanations

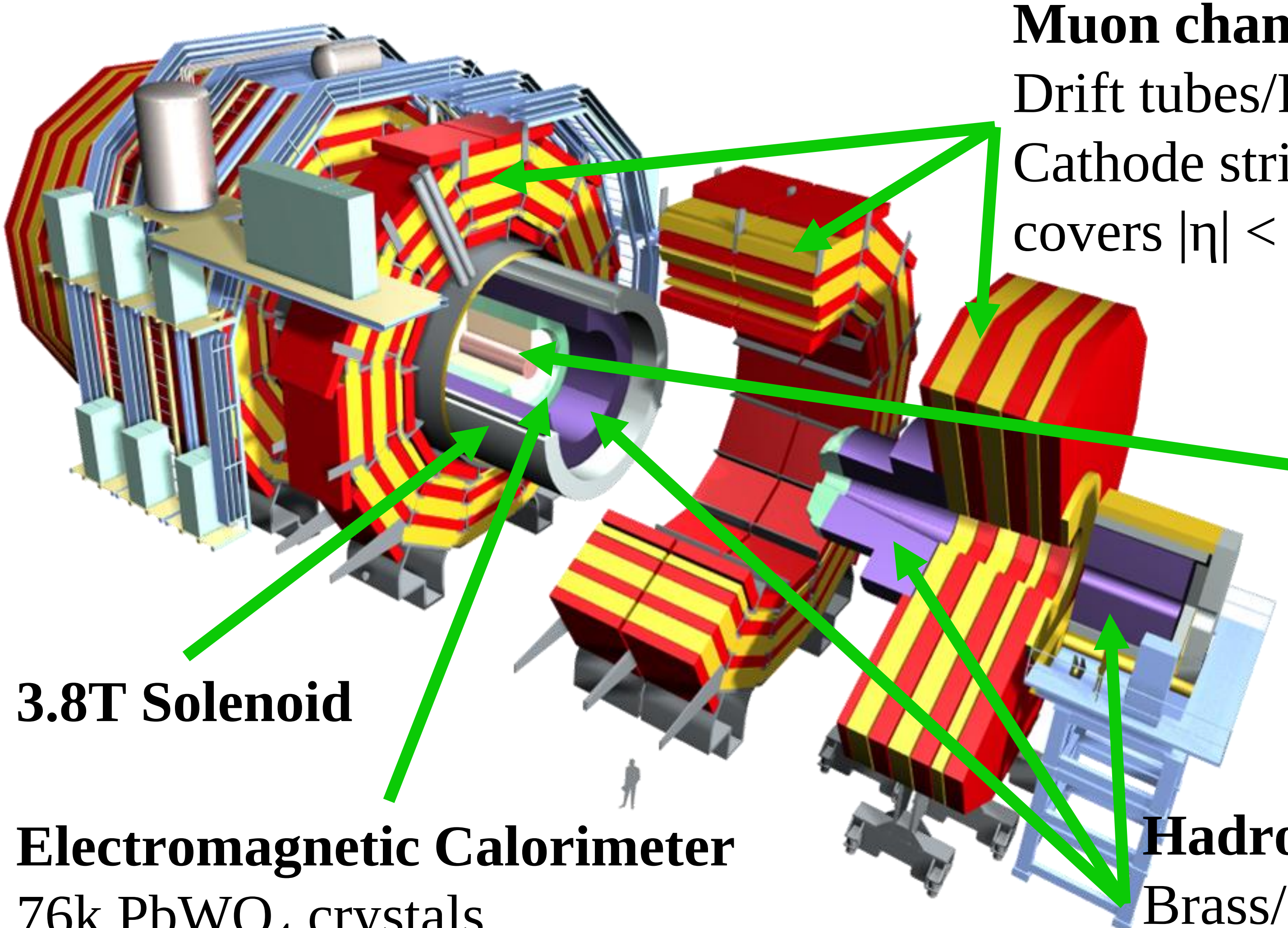
- After CDF's initial claims a flurry of papers to explain the excess were put forward.
- We have selected two new physics models as they presented testable cross-sections of pseudo-scalar and vector resonances.
  - Technicolor: $\rho_T \rightarrow W \pi_T$
  - Leptophobic Z′: *t*-channel W Z′ production
- We also included Standard Model WH production x100 as an example of a scalar resonance.
- We also set a limit on a generic Gaussian signal consistent with detector resolution.

What should the LHC expect?

- At the LHC the gg and qg processes go up considerably more than $q\bar{q}$.
  - $q\bar{q}$ x3
  - qg x20
- This means that W+jet production is enhanced at the LHC relative to the Tevatron when compared to a $q\bar{q}$ processes, making the background environment more challenging.



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

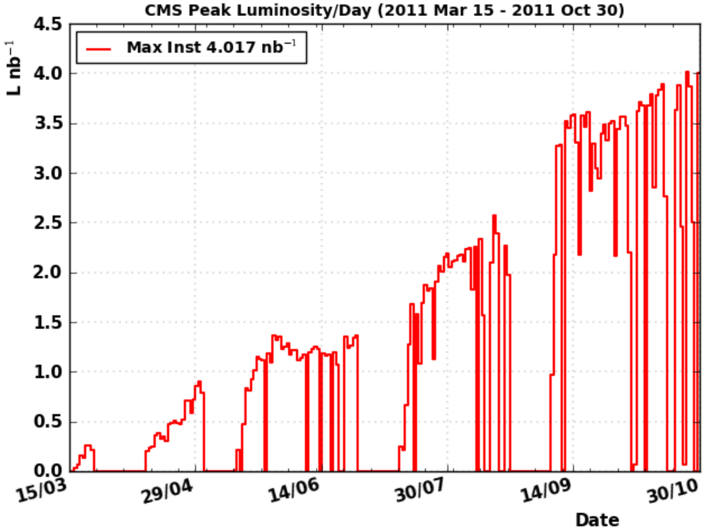
3.8T Solenoid

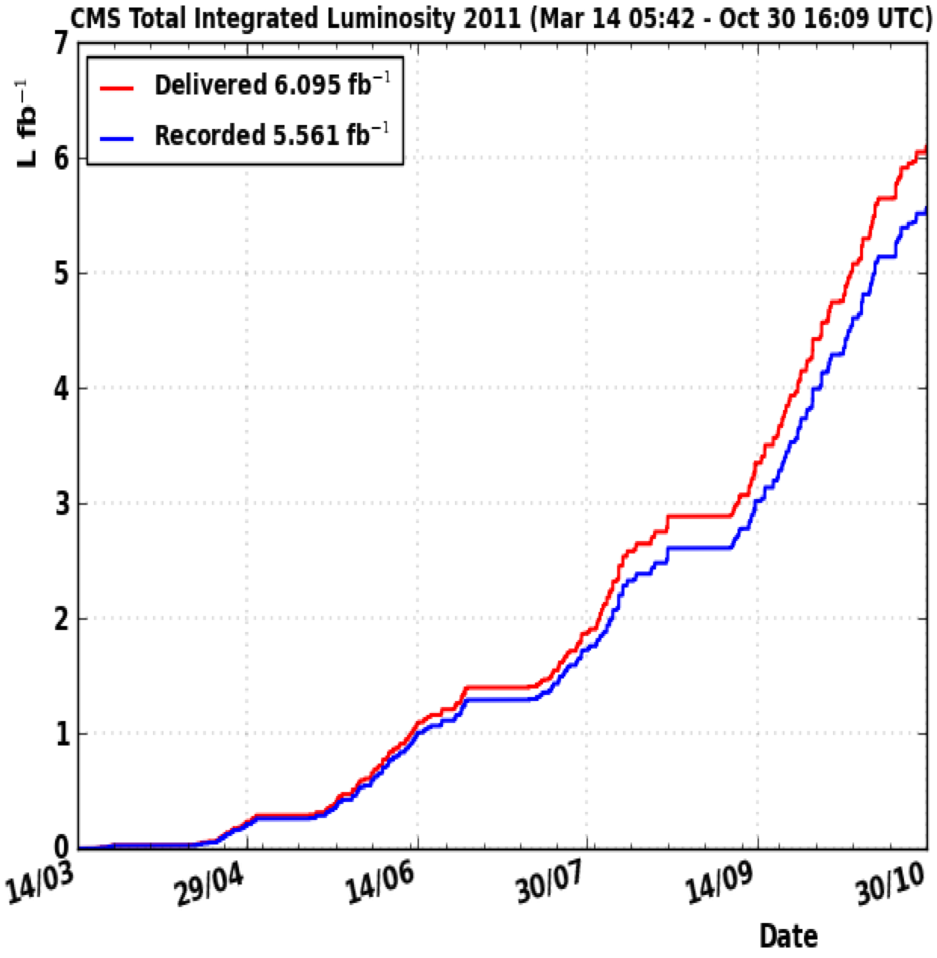
Electromagnetic Calorimeter
76k $PbWO_4$ crystals

Hadronic Calorimeter
Brass/scintillator
Iron/quartz fiber

The dataset

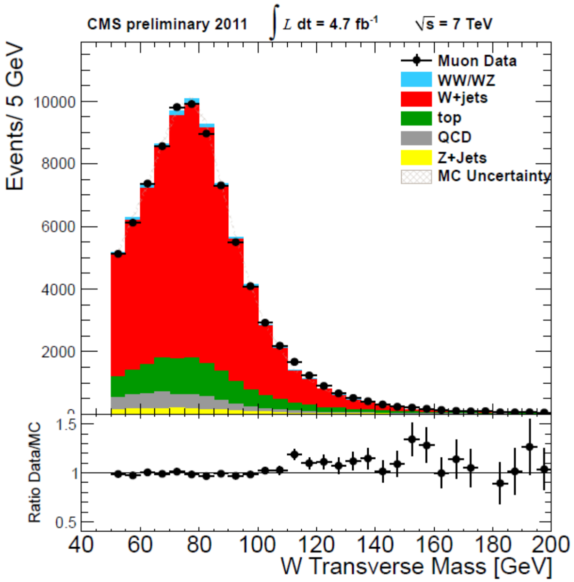
- We analyze the full dataset collected in 2010-2011.
  - LHC delivered: 6.1 fb^{-1}
  - CMS recorded: 5.6 fb-1
- Peak instantaneous luminosity: 4.02 nb^{-1}/s





Data selection

$W \rightarrow \ell\nu$ selection	Jet selection
Single lepton trigger	$p_T^{\text{lead jet}} > 40$ GeV
High-quality lepton ID and isolation	$p_T^{\text{2nd jet}} > 30$ GeV
Muon (electron) $p_T > 25(35)$ GeV	dijet $p_T > 45$ GeV
$\not{E}_T > 25(30)$ GeV for muon (electron) samples	$\Delta\eta_{jj} \leq 1.2$
W transverse mass > 50 GeV	$\Delta\phi(\not{E}_T, \text{lead jet}) > 0.4$
Second lepton veto	$0.3 < p_T^{\text{2nd jet}} / m_{jj} < 0.7$



- With these selections our data sample is dominated by the irreducible W+jets background.
- We do retain a clearly visible WW/WZ component in the data.
- Cuts are similar to those used by the Tevatron, but tailored to LHC scenario.

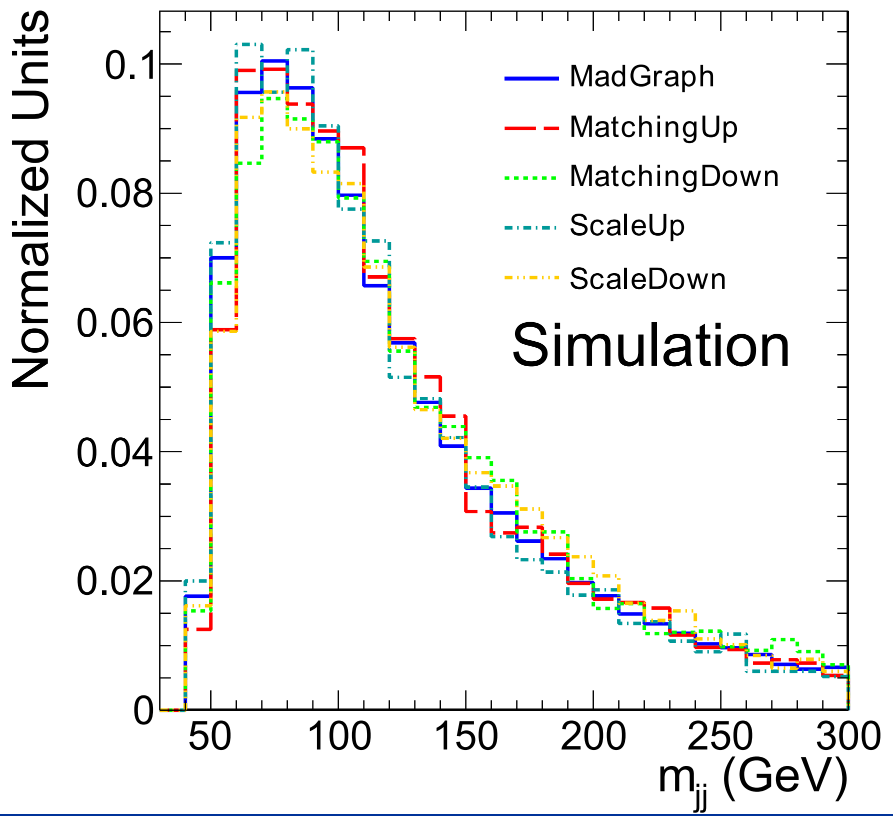
Background modeling

Process	Shape	External constraint on normalization
W plus jets	MC/data	Unconstrained
Diboson	MC	Constrained: (NLO) 61.2 pb $\pm$ 10% [23]
$t\bar{t}$	MC	Constrained: (NLO) 163 pb $\pm$ 7% [24]
Single top	MC	Constrained: (NNLO) [25–27] $\pm$ 5%
Drell-Yan plus jets	MC	Constrained: (NLO, $m_{ll} > 50$ GeV) 3048 pb $\pm$ 4.3% [23]
Multijet	data	Constrained: $\not{E}_T$ fit in data $\pm$ 50% (100%) for electron (muon)

- The background shapes are taken from simulation for most of the minor backgrounds. (not W+jets, QCD)
  - The QCD shape and normalization are derived from data control regions
- The background normalizations are constrained to best NLO(+) predictions including their errors.
- The W+jets shape is a MC based shape with two free parameters and its normalization is unconstrained. (more on the next slide)

W+jets background (I)

- Our data sample is dominated by W+jets events.
- We use MADGRAPH generated MC to model this background.
  - factorization/renormalization scales: $q^2 = m_W^2 + p_{T,W}^2$
  - ME/PS matching scale: $\mu^2 = 20$ GeV
- Additional samples with double and half nominal are also generated.
- These variation can affect the dijet mass spectrum and are not uniquely defined for W+jets



W+jets background (II)

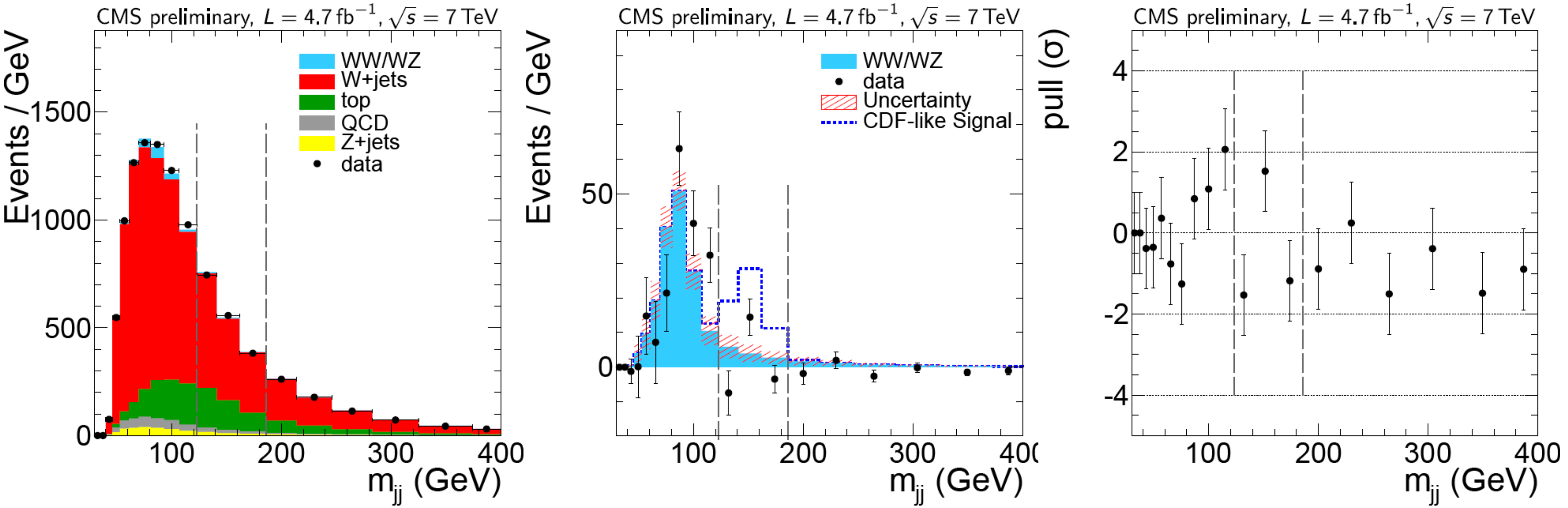
- We combine the nominal (μ_0, q_0) W+jets MC linearly with the alternate samples to find an empirical "best" combination.

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

  - α and β range from -1 to 1 and are unconstrained in the fit.
    - $\alpha < 0 \Rightarrow q' = q_0/2$; $a > 0 \Rightarrow q' = 2q_0$
    - same relation for β and μ′.
  - Because α and β are floating in the fit that determines all of the background normalizations the uncertainty on the background shape is naturally folded into the uncertainty on the background normalization.

Fit to the dijet mass spectrum

- We fit the mass spectrum from 40 to 400 GeV excluding the region from 123 to 186 GeV using an unbinned maximum likelihood fit.
  - We observe no significant excess in the data or evidence for a peaked structure beyond WW/WZ.



Results

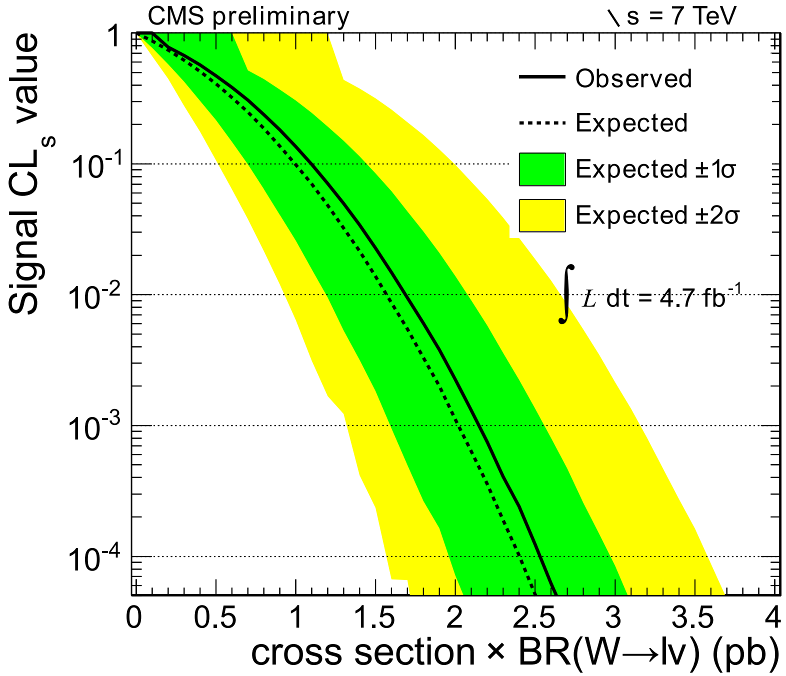
Process	Muon channel		Electron channel	
	2 jets	3 jets	2 jets	3 jets
W plus jets	59430±519	13419±360	29989±1202	8600±287
Dibosons	1167±108	314±31	646±61	174±17
$t\bar{t}$	4258±290	8753±371	2413±164	4085±242
Single top	1663±82	945±47	864±43	492±25
Drell-Yan plus jets	1731±74	528±23	1000±43	343±15
Multijet	28±284	0 ± 90	4024±1181	330±160
Fit χ^2 probability	0.439	0.605	0.966	0.988
Total from fit	68277±307	23960±192	38935±228	14024±142
Data	67900	24046	38973	14145
In the test region $123\,\text{GeV} < m_{jj} < 186\,\text{GeV}$ excluded from the fit				
Total	14494±125	7693±95	7925±92	4319±70
Data	14050	7751	8023	4438

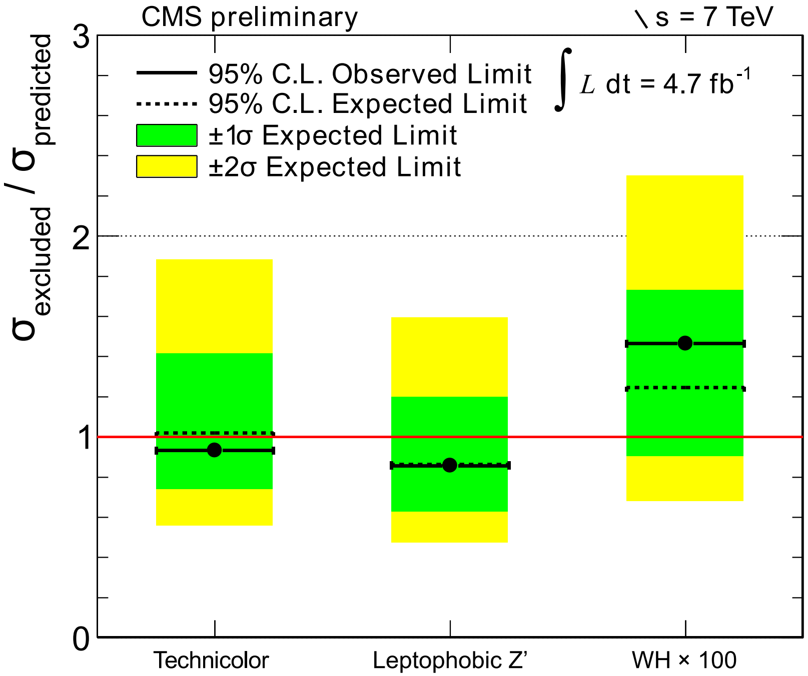
Systematic uncertainties

- We have validated the fitting procedure using pseudo-experiments.
  - We found negligible bias and slightly underestimated errors on the background.
  - We correct the errors by using the pseudo-experiments.
- Other sources of systematic uncertainty include:
  - jet energy scale, resolution, and MET resolution
  - trigger and lepton efficiency uncertainties
  - luminosity uncertainty
- These uncertainties are all included in the limit setting.

Limits

- We place 95% CL limits on a generic Gaussian signal centered at 150 GeV of 1.3 pb.
  - Using WH as a benchmark, 4 pb at the Tevatron corresponds to $\sigma \times BR(W \to \ell\nu) = 3.4$ pb
  - We also exclude the specific Technicolor and letopobic Z′ models at CL 95%.





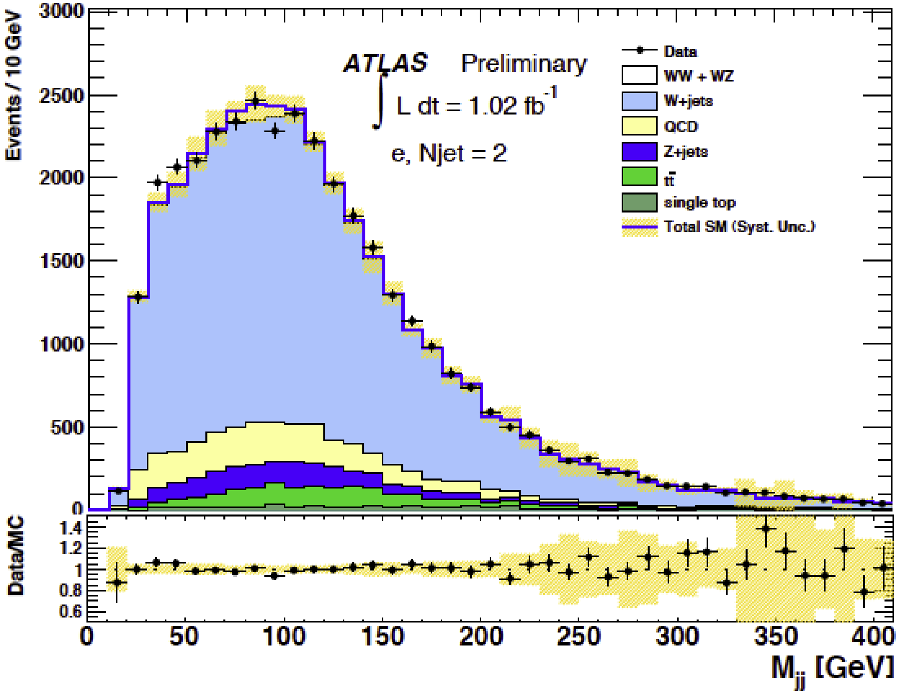
Conclusions

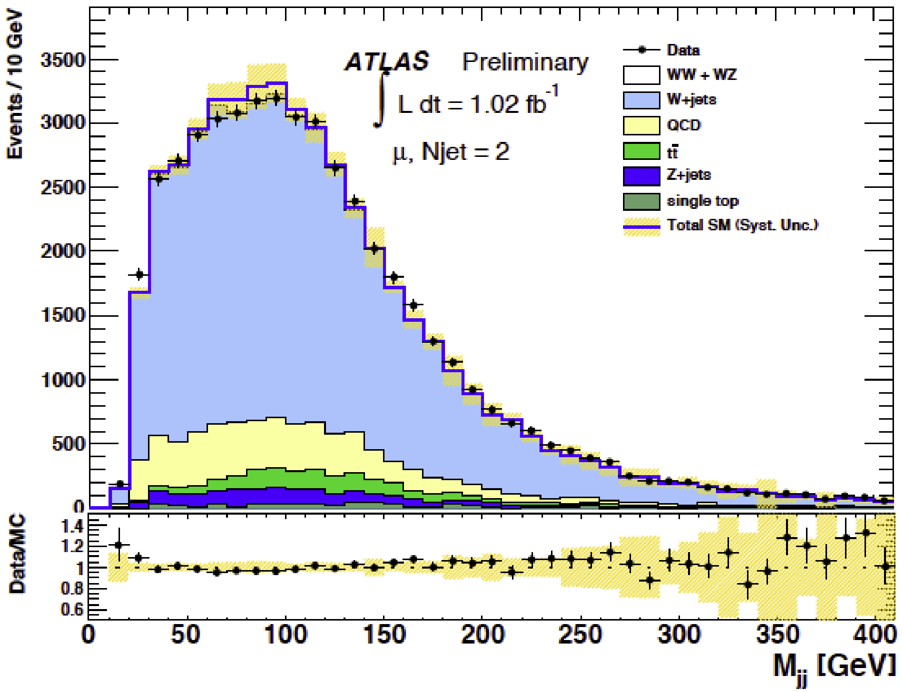
- We have studied the dijet mass spectrum in events with a W boson looking for the enhancement reported by the CDF collaboration.
- We do not observe an significant excess in the data an place 95% CL limits on the cross-section of a CDF-like signal at 1.3 pb.
- We also study two specific models advanced as an explanation of the excess. These too are excluded at 95% CL.

Backup

ATLAS analysis

- ATLAS presented a spectrum at EPS using 1.02 fb^{-1}.
  - Documented in ATLAS-CONF-2011-097
  - They did not report any limits.





Specifics on models

Signal Model	$\sigma \times BR$ (pb)	$\varepsilon \times \mathcal{A}$			
		electron 2 jets	electron 3 jets	muon 2 jets	muon 3 jets
WH	0.0145	0.038	0.013	0.060	0.019
Technicolor [3, 4]	1.58	0.039	0.011	0.065	0.020
Z' [5, 6]	1.72	0.042	0.014	0.070	0.023