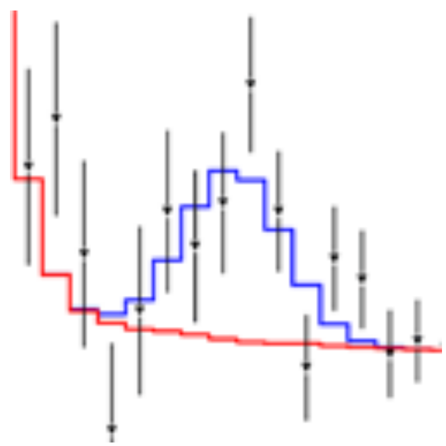
Discovery or Illusion: The Tale of a Tantalizing Bump

Kalanand Mishra

Fermilab, CMS Collaboration



Florida Tech, October 5, 2012

Just to make sure we start at the same page ....

We have all seen a bump !
Typically a road sign alerts us

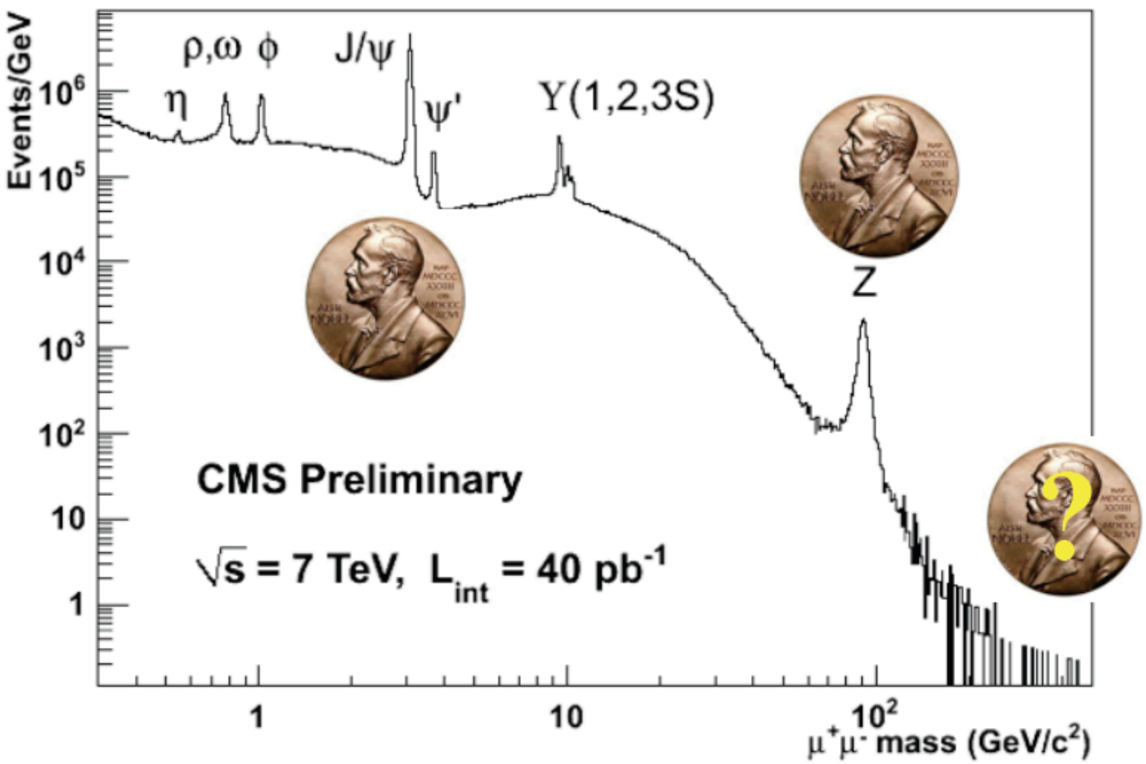
We slow down & go over the bump

But once in a while there are unexpected bumps in the road ....

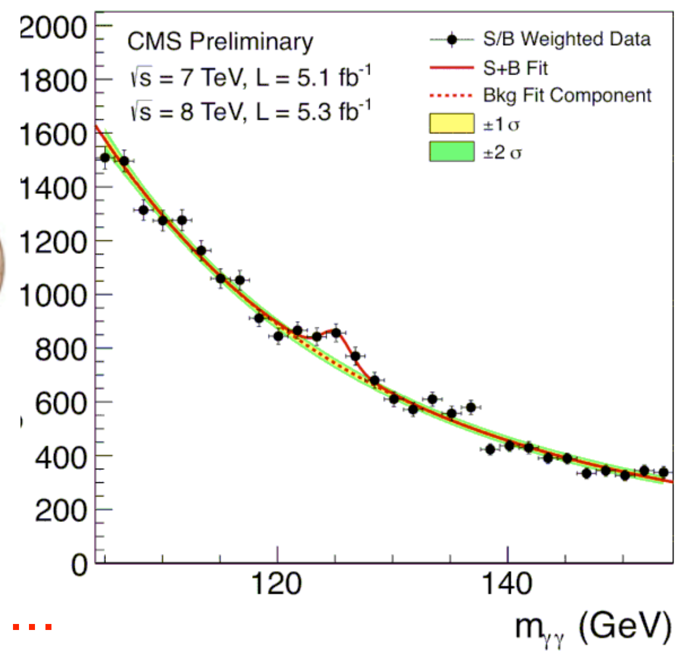
Particle physics is no different

It is a story of bumps, regular or otherwise

We have known regular/expected bumps

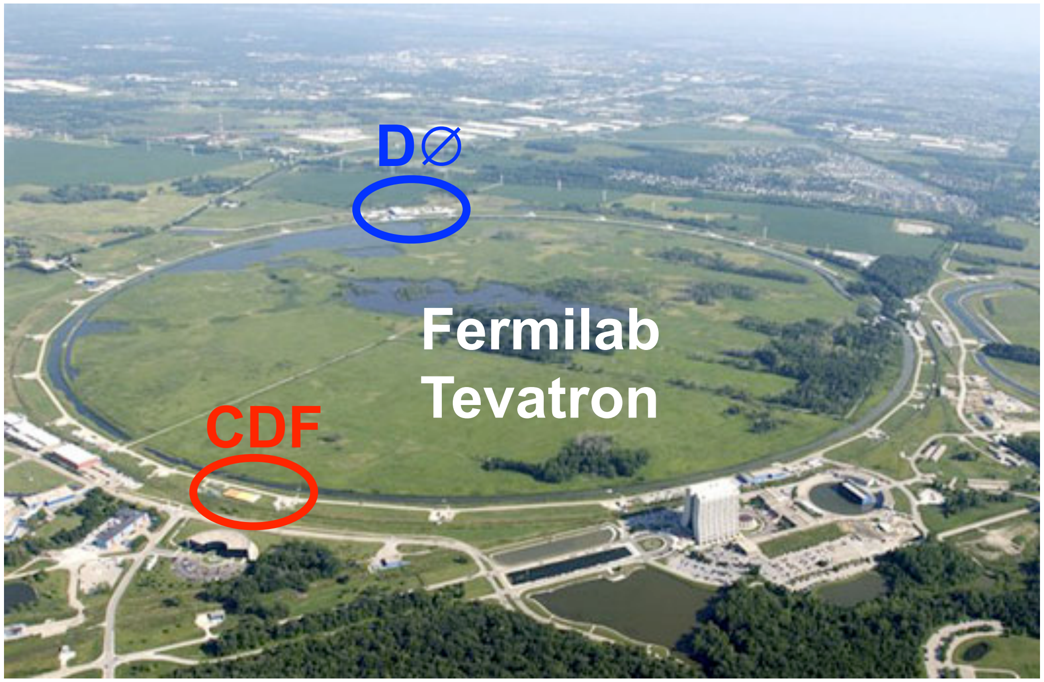


Recently we discovered the long sought-after but expected bump

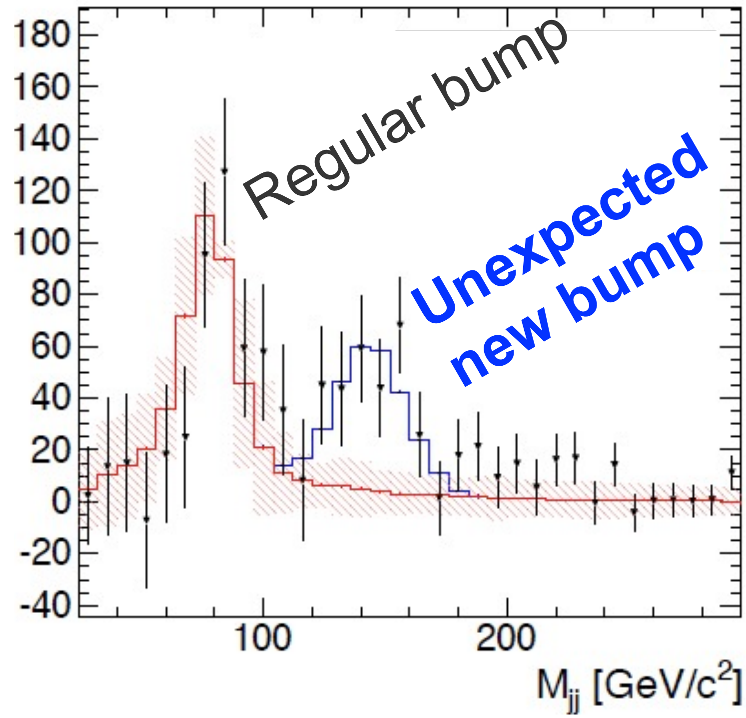


But this talk is about an unexpected bump ...

Once in a long while we find the unexpected



In April last year the CDF experiment generated huge excitement by reporting an unexpected bump right next to a regular bump.



If confirmed this could herald the observation of a new force of nature.

It was like a feeding frenzy there for a while!!!

The New York Times

At Particle Lab, a Tant
Holding Their Breaths

By DENNIS OVERBYE
Published: April 5, 2011

Suspicious Bump

Posted on April 6, 2011 by woit

Last night a new preprint from CDF appeared at th
their data, at about 3 sigma significance, that could

FLIP TANEDO I USLHC I USA

A hint of something new in "W+dijets" at CDF

DISCOVER
MAGAZINE

Health & Medicine | Mind & Brain | Technology | Space | Human Origins | Living Worl

Cosmic Variance

« Sir Martin Rees Wins the Templeton Prize
NASA Gives Up on LISA »

Anomalies at Fermilab

by Sean Carroll

The Tevatron accelerator at Fermilab is shutting down soon, for some unavoidable reasons
taking over) and some frustrating ones (we're out of money). But there may be life in the ol

Fermilab's data peak that causes excitement

CNN U.S.

symmetry dimensions of particle physics

Is it a new particle, or just a fluke?

April 08, 2011 | By Elizabeth Landau, CNN
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Fermilab: CDF "new force" seminar tonight

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The Tevatron goes bump

The last and greatest breakthrough from a fanta
a false alarm on the frontiers of physics?

7 April 2011 Last updated at 13:48 ET

BBC

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Tevatron accelerator yields hints of new particle

By Jason Palmer
Science and technology reporter, BBC News

Fermilab *Today* Thursday, April 7, 2011

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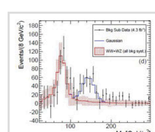
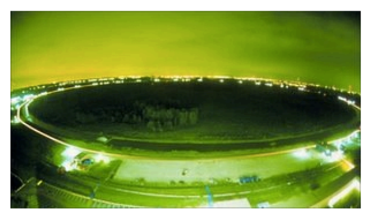
Result of the Week

The data peak that causes excitement

Wednesday afternoon, the CDF collaboration announced that it has evidence of a peak in a specific sample of its data. The peak is an excess of particle collision events that produce a W boson accompanied by two hadronic jets. This peak showed up in a mass region where we did not expect one. The peak was observed in the 140 GeV/c^2 mass range, as shown in the plot above. It is the kind of peak in a plot that, if confirmed, scientists associate with the existence of a particle. The significance of this excess was determined to be 3.2 sigma, after accounting for the effect of systematic uncertainties. This means that there is less than a 1 in 1375 chance that the effect is mimicked by a statistical fluctuation. Particle physicists consider a result at 5.0 sigma to be a discovery.

The excess might be explained by the production of a new, unknown particle that is not predicted by the Standard Model, the current standard theory of





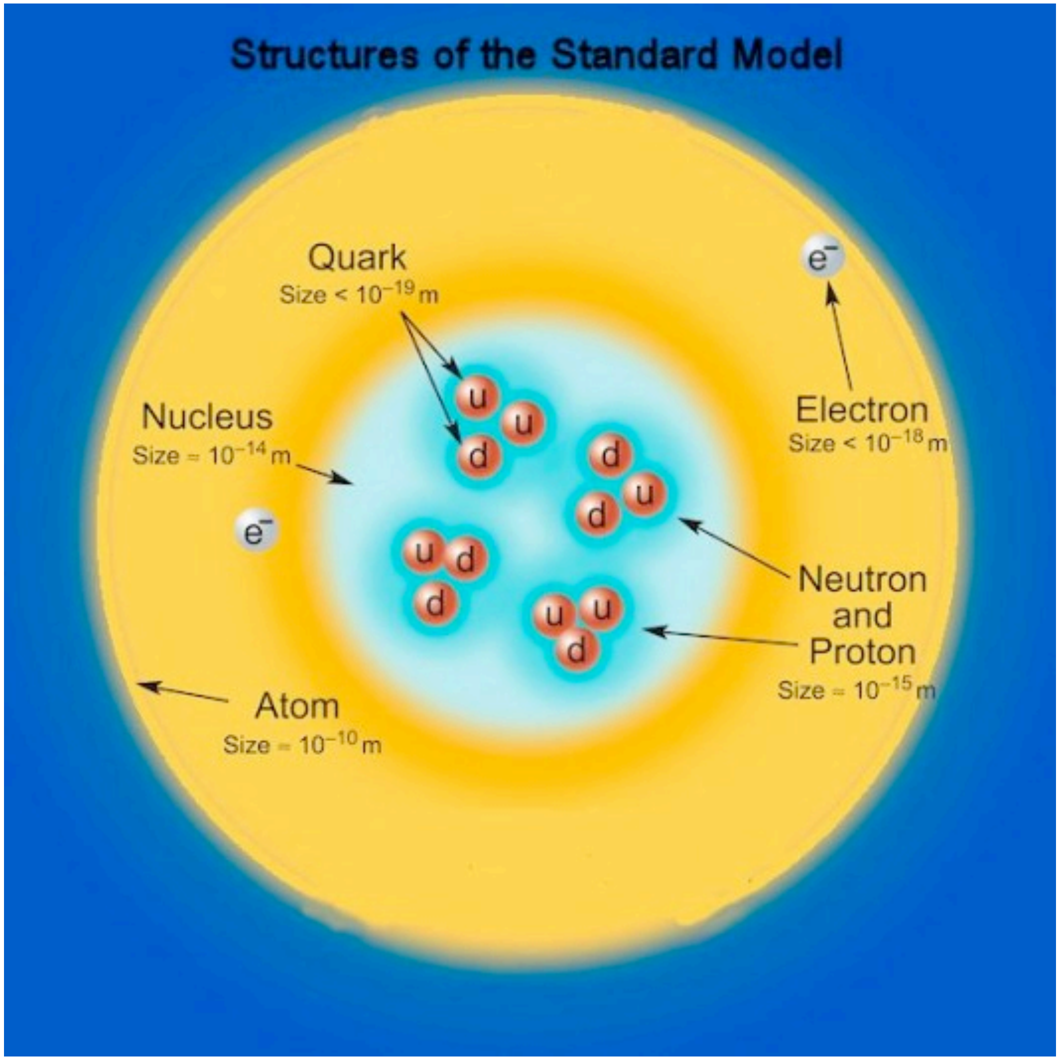
The Tevatron was, until the advent of the LHC, the highest-energy accelerator in the world

Outline

- Introduction
  - -Standard Model, Tevatron results, interpretations
- Over to LHC
  - -motivation, difficulty, signal expectation
- LHC and CMS detector
  - -data sample, trigger, calibration
- CMS observation of the expected bump
- CMS analysis to search for the unexpected bump
  - -background estimation
  - -results, interpretation
- Summary

Introduction

Standard Model of particle physics



Standard Model is a fundamental theory of matter and forces

LHC: the biggest, baddest atom smasher

Accelerates protons to 99% of the speed of light. Smashes them 20 million times a second.

Large Hadron Collider at a glance

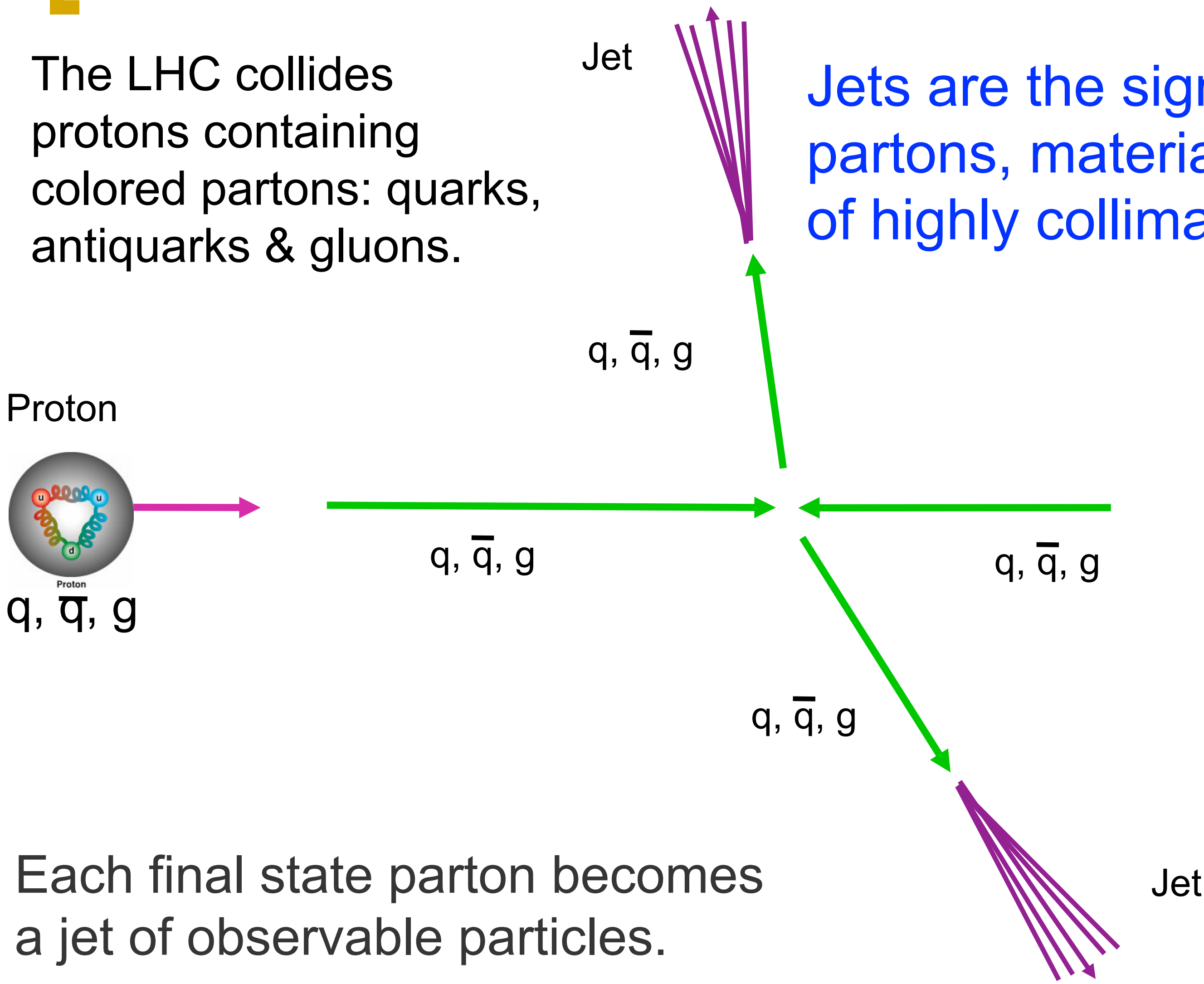
- 4.5 km radius, 27 km circumference
  (Tevatron at Fermilab: 1 km, 6.3 km)
- operational: 2009-25?? (Tevatron: 1985-2011)
- at CERN (Geneva, Switzerland)
- detectors: Alice, Atlas, CMS, LHCb
- E_{beam}: 4+4 TeV proton−proton (goal 7+7 TeV)
- physics goals: Higgs & New Physics Discovery

Fun fact

Beams store 400 MJ → beam dump (60 μm) creates 10 TW of power, i.e, 1/3rd of the entire world's instantaneous power.

Particle jets

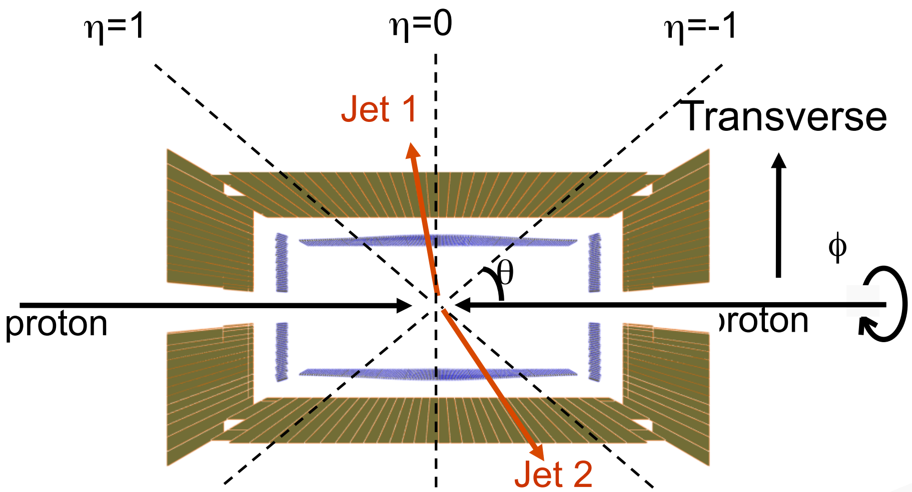
The LHC collides protons containing colored partons: quarks, antiquarks & gluons.

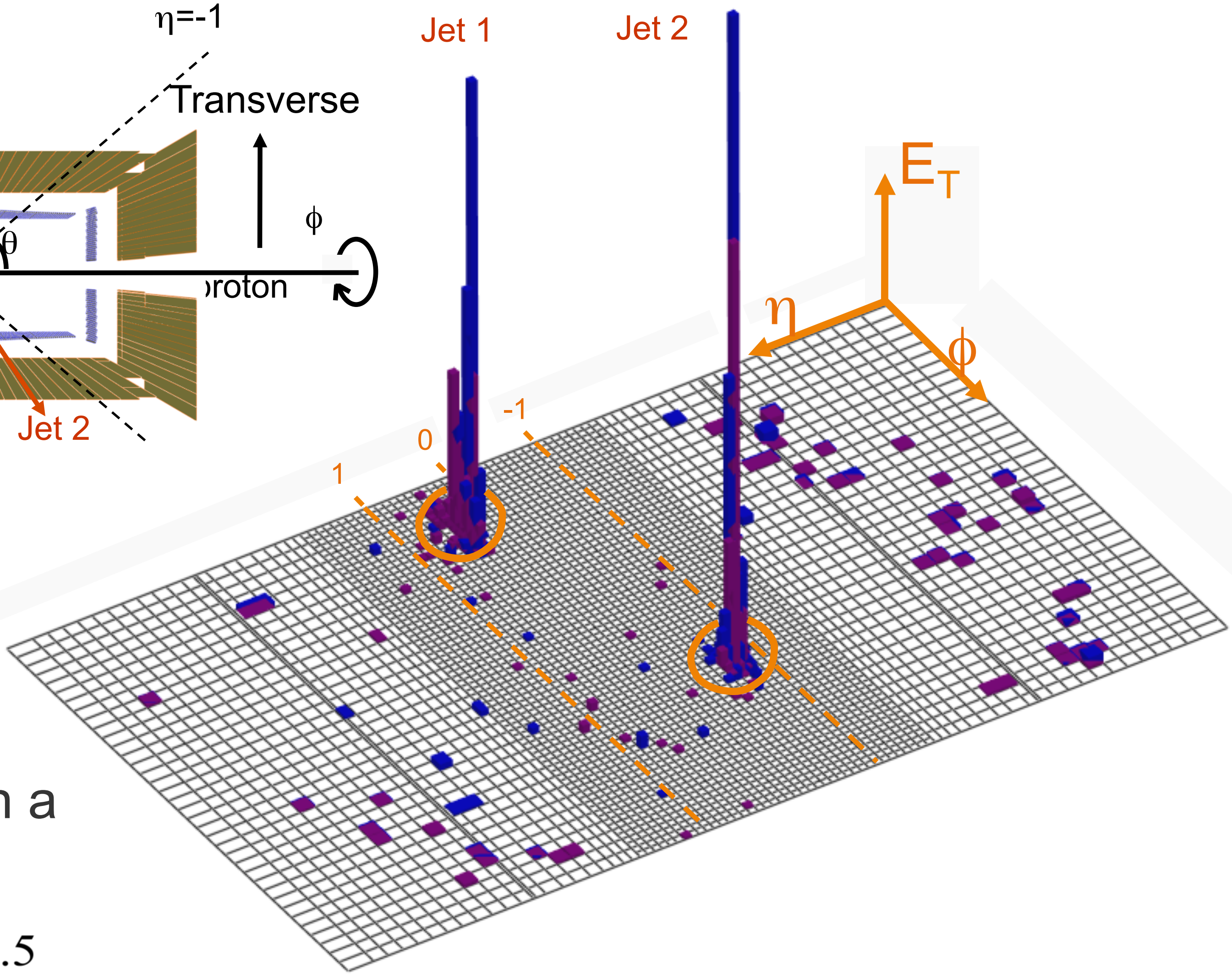


Jets are the signature of partons, materialized as sprays of highly collimated particles.

Each final state parton becomes a jet of observable particles.

Experimental observation of jets

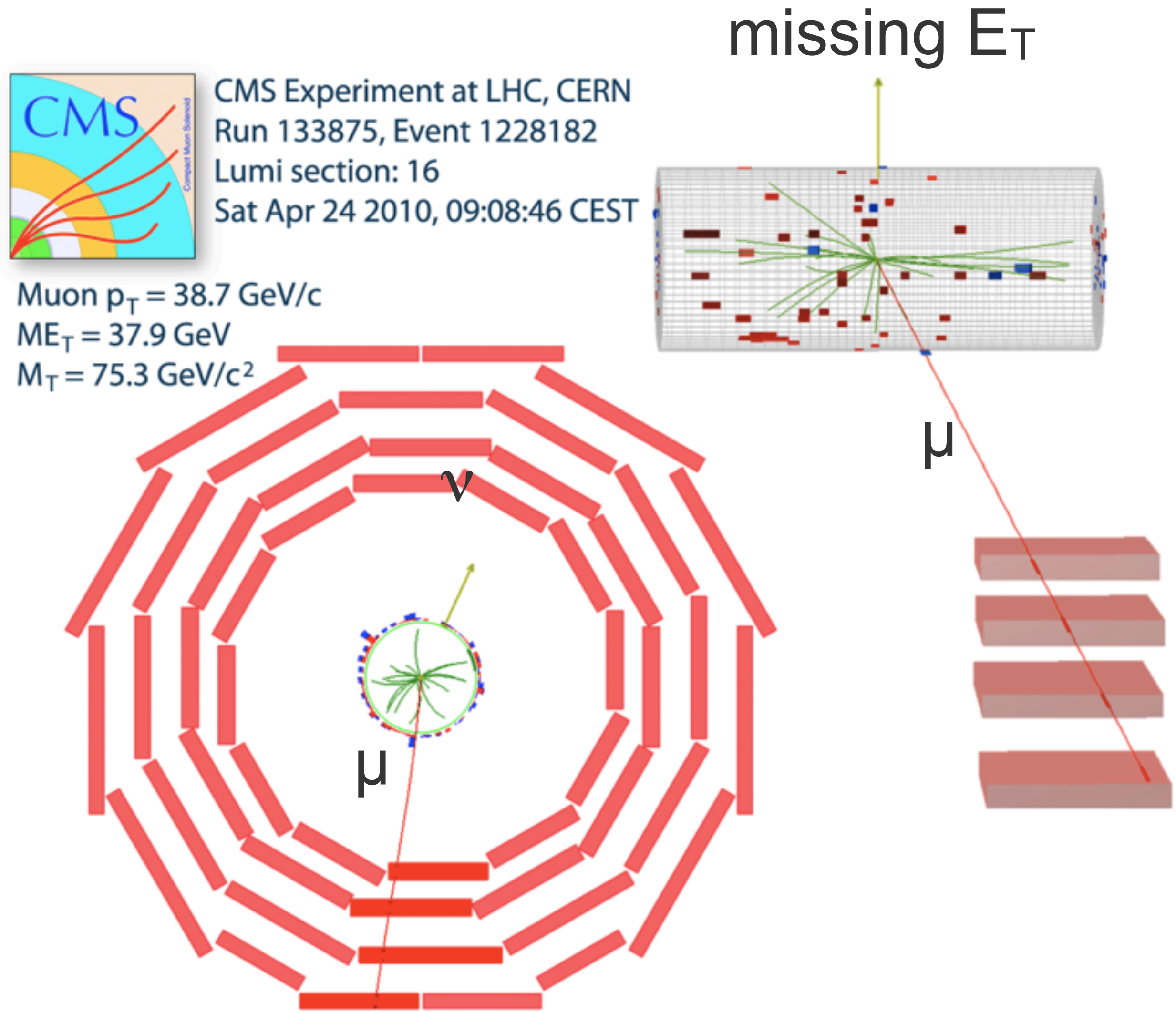




Simply speaking, a jet is the sum of particle 4-vectors in a cone of radius

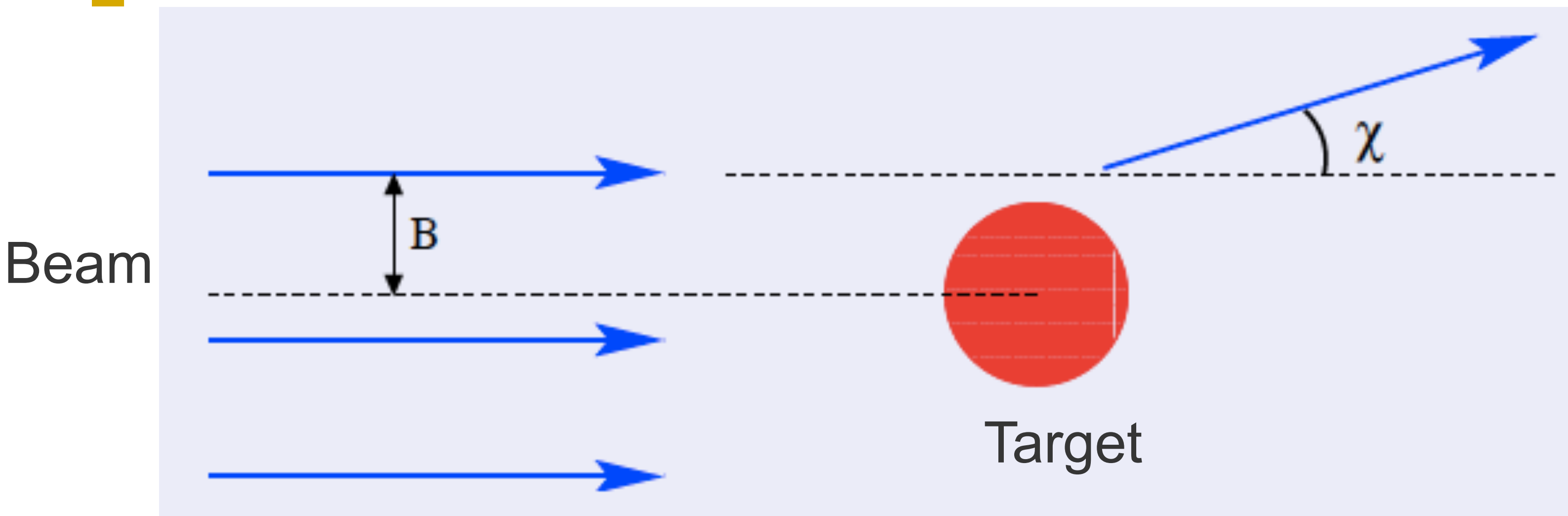
$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.5$$

Missing energy due to neutrino



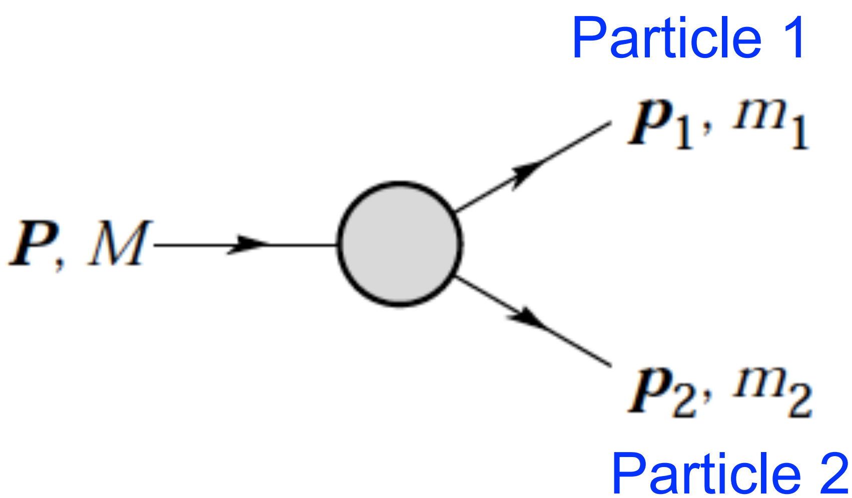
When the W boson decays to an electron or muon and a neutrino, the neutrino escapes the detector without being detected. This causes an energy imbalance and we "measure" missing transverse energy (MET).

Cross section = production rate



- Cross section = Number of particles passing through a unit area perpendicular to the beam
- Physical unit: barn = 10^{-28} m^2 = 10^{-24} cm^2
- Originally used in nuclear physics for expressing the cross sectional area of nuclei and nuclear reactions

Invariant mass of two particles



$E_1^2 = p_1^2 + m_1^2$

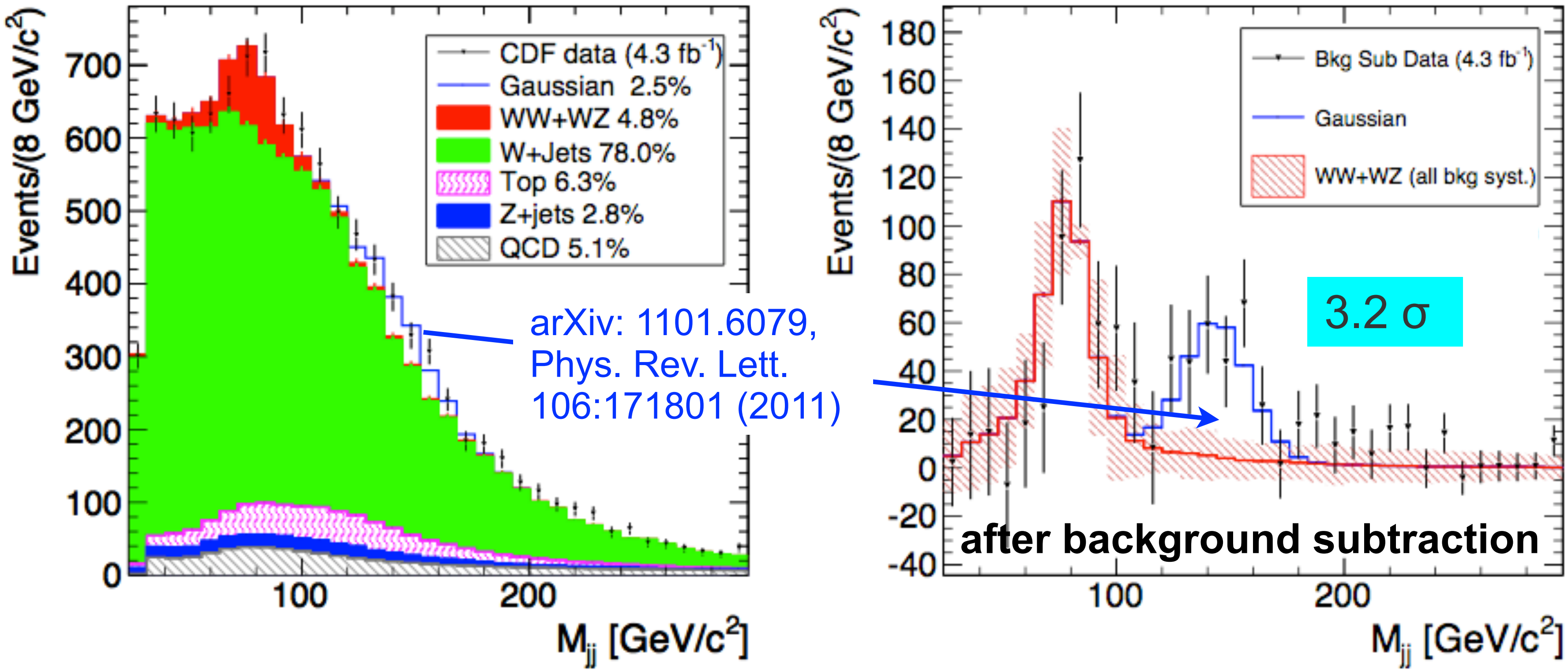
$E_2^2 = p_2^2 + m_2^2$

Invariant mass can be obtained from the 4-vector sum of the two particles

$$\begin{aligned} M^2 &= (E_1 + E_2)^2 - \|\mathbf{p}_1 + \mathbf{p}_2\|^2 \\ &= m_1^2 + m_2^2 + 2\,(E_1 E_2 - \mathbf{p}_1 \cdot \mathbf{p}_2)\,. \end{aligned}$$

Back to the story of bump

Bump in the invariant mass distribution of jet pairs in W+jj events

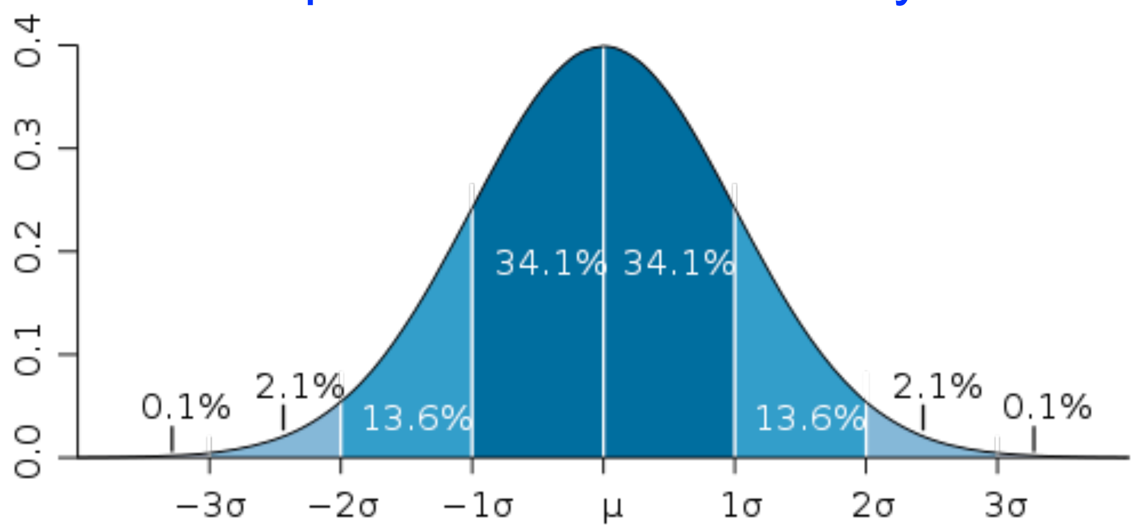


arXiv: 1101.6079,
Phys. Rev. Lett.
106:171801 (2011)

- Peaked near 150 GeV, width = 15 GeV
- Production cross section at Tevatron 4 pb, cannot be Higgs

Why the fuss: How big is 3-sigma anyway?

If the measurement is Gaussian then its width (sigma) represents the uncertainty in the measurement



There is 1-in-1,000 chance of the background to fluctuate as high as the observed bump! So, very significant !!!

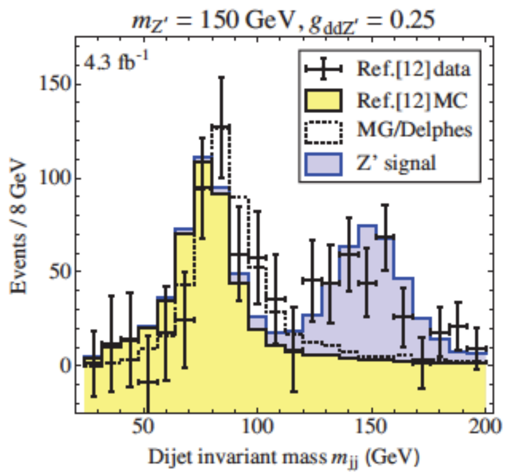
But here goes the caveat ...

What is the "error on your error" i.e., how well do you know the sigma? Often, the answer determines the limitation on knowing the significance. This is why the standard for discovery is higher. At 5-sigma, there's one chance out of 3 million that you're leaping to the wrong conclusion.

Aftermath I: What could the "bump" be?

Light Z' boson

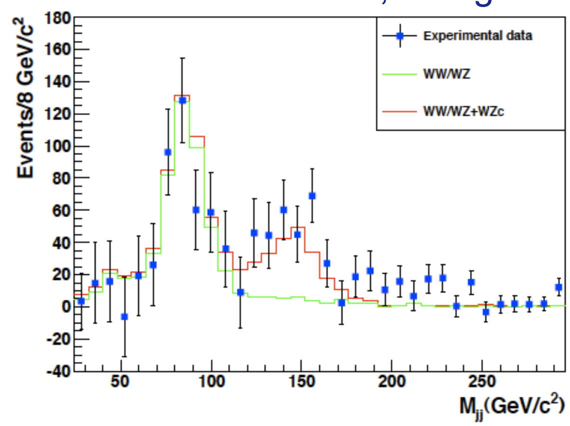
arXiv: 1103.6035, Buckley et al
arXiv: 1104.3139, Jung et al



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

Color octet particle

arXiv: 1101.6079, Wang et al



Also explains top F-B asymmetry.

Intrinsic s in nucleon

arXiv: 1104.1894, He & Ma

Nucleon intrinsic s quarks contribute to W boson production in association with single top. This causes excess in dijet mass in W+jj but not in Z+jj.

SUSY particle

arXiv: 1104.2014, Sato et al

An MSSM particle with tanβ≈10

First observation of a SUSY particle !

Technicolor

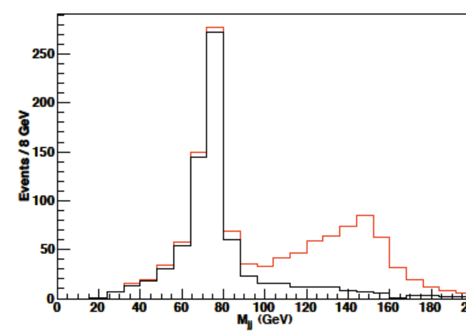
arXiv: 1104.1255, Andersen et al
arXiv: 1104.0976, Eichten et al

Techni-π/ρ→WZ can enhance Wjj with low m_{jj}

Unified flavor symmetry

arXiv: 1104.2030, Nelson et al

Propose a subgroup of SU(3). Predict comparable F-B asymmetry in tt and cc but suppressed in bb system. Excess in Wjj but suppressed in Zjj.



Technicolor model

- A model beyond the standard model in which the elementary particles acquire mass via a different mechanism.
  - -no Higgs bosons
  - -generates masses for the W and Z bosons through the dynamics of a new force.

- Modeled on quantum chromodynamics (QCD), the "color" theory of the strong nuclear force, which inspired its name.

- Such a force must become strong and confining (hence unobservable) at low energies that have been experimentally probed.

- Can explain CDF bump

Z′ model

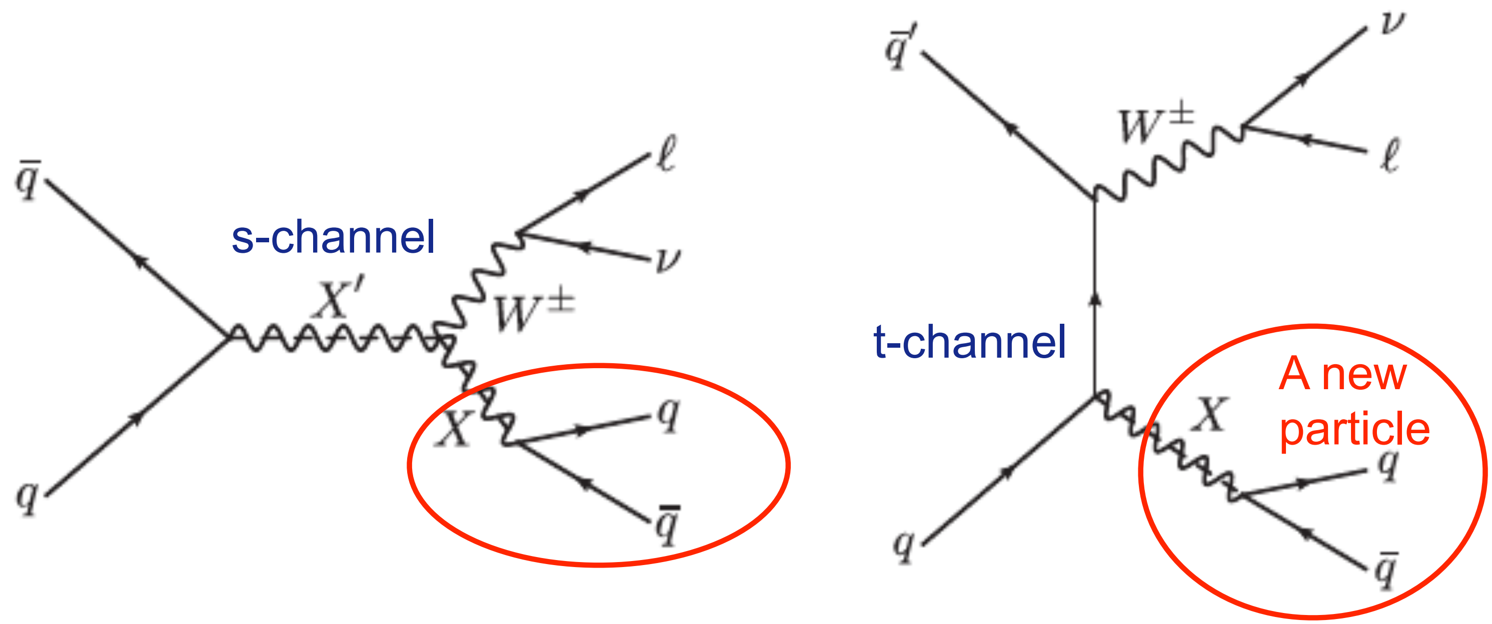
- A new boson particle similar in behavior to Z.
  - -suppressed couplings to leptons
  - -large couplings to Standard Model quarks.

- Can explain three recent anomalies reported by the Tevatron
  - -top-quark forward-backward asymmetry
  - -excesses in events containing three b-quarks
  - -CDF bump

- Could also mediate the interactions of dark matter,
  - -leading to potentially interesting implications for direct detection of dark matter

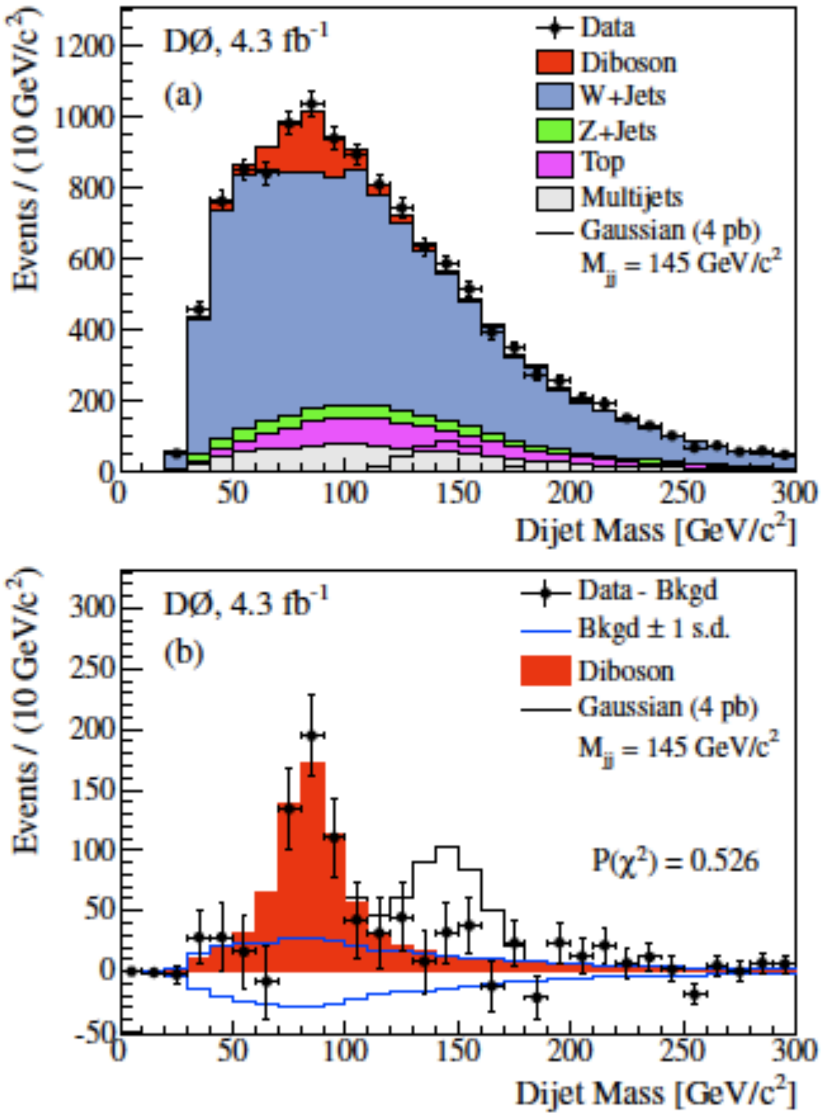
Common theme among all these models

A new particle of mass ~150 GeV produced in $q\bar{q}$ annihilation



Buckley, Hooper, Kopp, Martin, Neil; arXiv: 1107.5799

Aftermath II: D∅ doesn't confirm the anomaly



arXiv: 1106.1921, Phys. Rev. Lett. 107:011804 (2011)

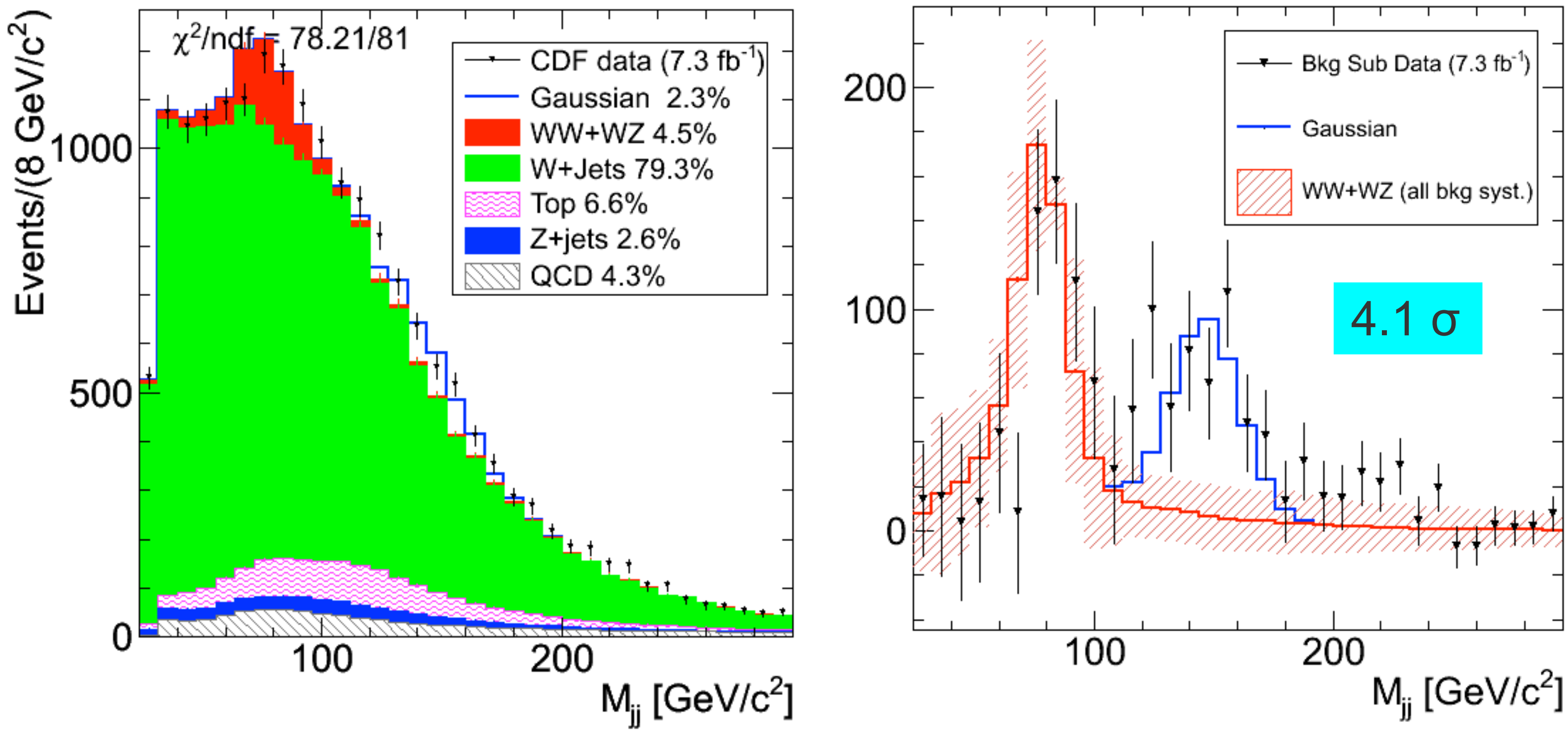
✦W+jj data show the expected behavior

✦No bump near 150 GeV

✦Exclude 4 pb cross section at 99.9999% confidence level

Aftermath III: the signal getting bigger at CDF!

http://www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html (Using 7.3 fb^{-1} data)



At this point the statistical significance is not in doubt, but understanding of background modeling is.

Over to LHC

Critical to repeat the analysis at LHC

The opposite results from CDF and DØ are highly unlikely to arise from statistical fluctuations, leaving only underlying systematic issues or actual new physics as possible resolutions.

Case 1: It is New Physics (classic mis-modeling/fluctuations in two Tevatron experiments)

- Need LHC to break the tie: Perform similar analysis at LHC:

Case 2: The excess is caused by subtle mis-modeling of the Standard Model backgrounds, or instrumental mis-calibration

- It is possible that the same error could propagate to the LHC experiments. Or in other analyses with similar final states.

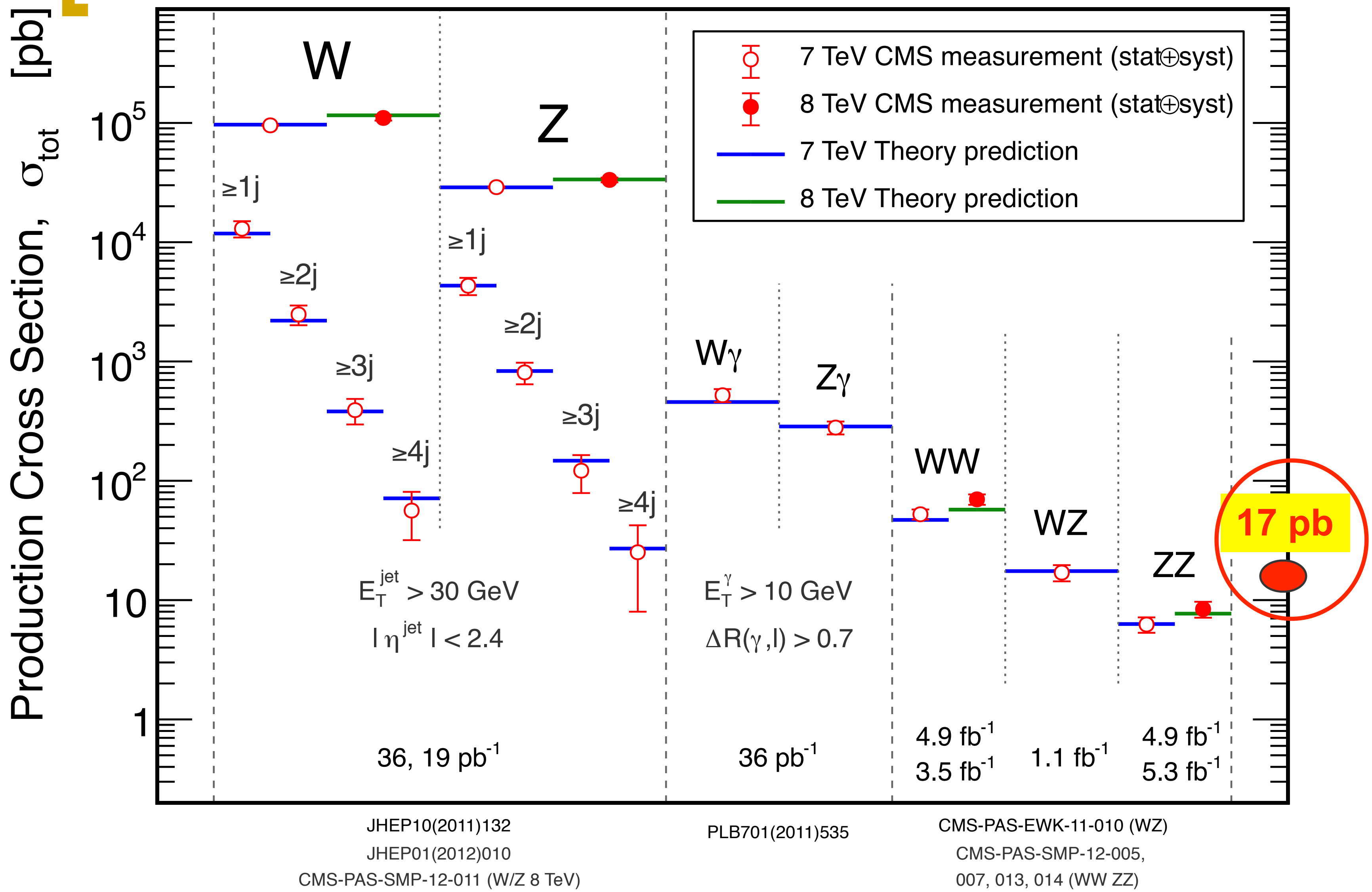
What we expect at LHC

- Need a reference process to scale from Tevatron to LHC
- Assume that the signal is produced in $q\bar{q}$ annihilation
  - A conservative assumption because qg and gg processes have much higher relative partonic luminosity at LHC

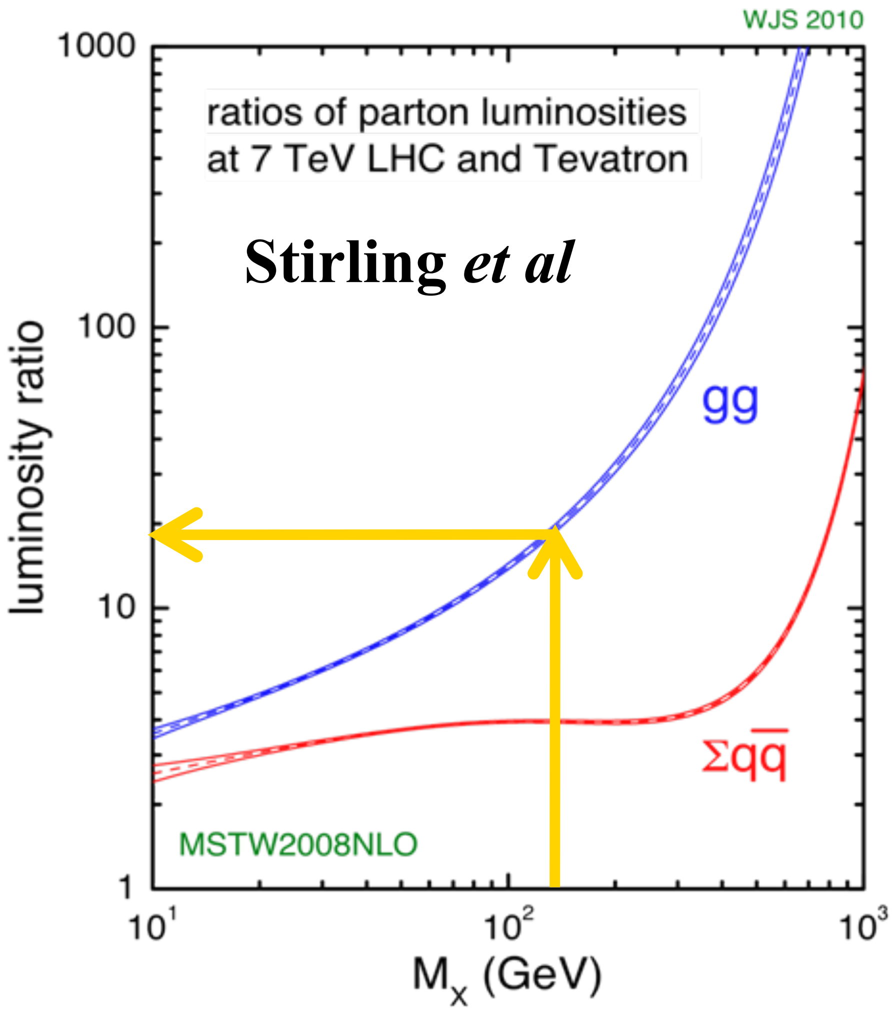
Process	Cross section: Tevatron (pb)	Cross section: LHC (pb)	Ratio
WW	12	43	3.6
WZ	3.5	18	5.1
☑ WH(150)	0.072	0.300	4.2

- WH(150) is a natural choice
- **4 pb at Tevatron becomes 16.7 pb at LHC!**

Putting this in perspective ....



Difficulty to reconstruct $q\bar{q}$ signal at LHC



$q\bar{q} \rightarrow$ WW, WZ cross section at 7 TeV is **~ 4 times** that at 2 TeV

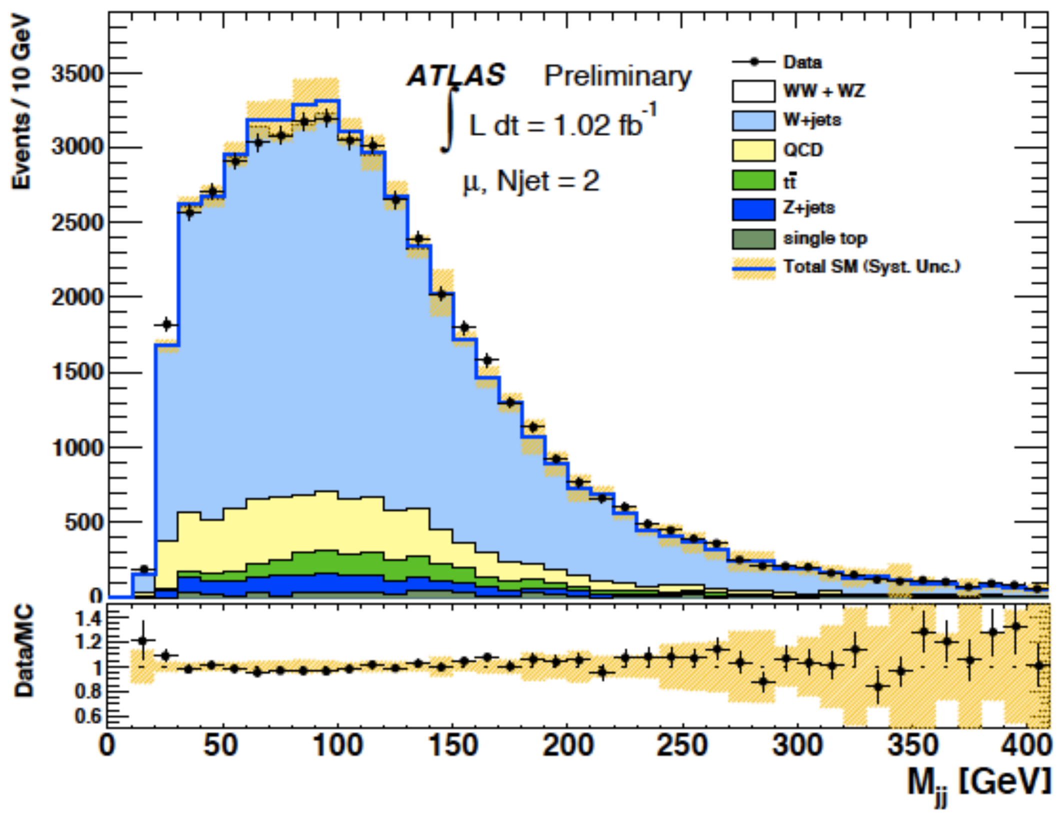
Major backgrounds are W/Z+jets, single top & $t\bar{t}$, QCD multi-jet etc. which rise **by factor 10** due to rise in qg and gg cross sections

$\Rightarrow$ Small signal, worse S/N

Need stronger cuts

Life is hard if looking for $q\bar{q}$ signal at LHC

ATLAS result shown at EPS



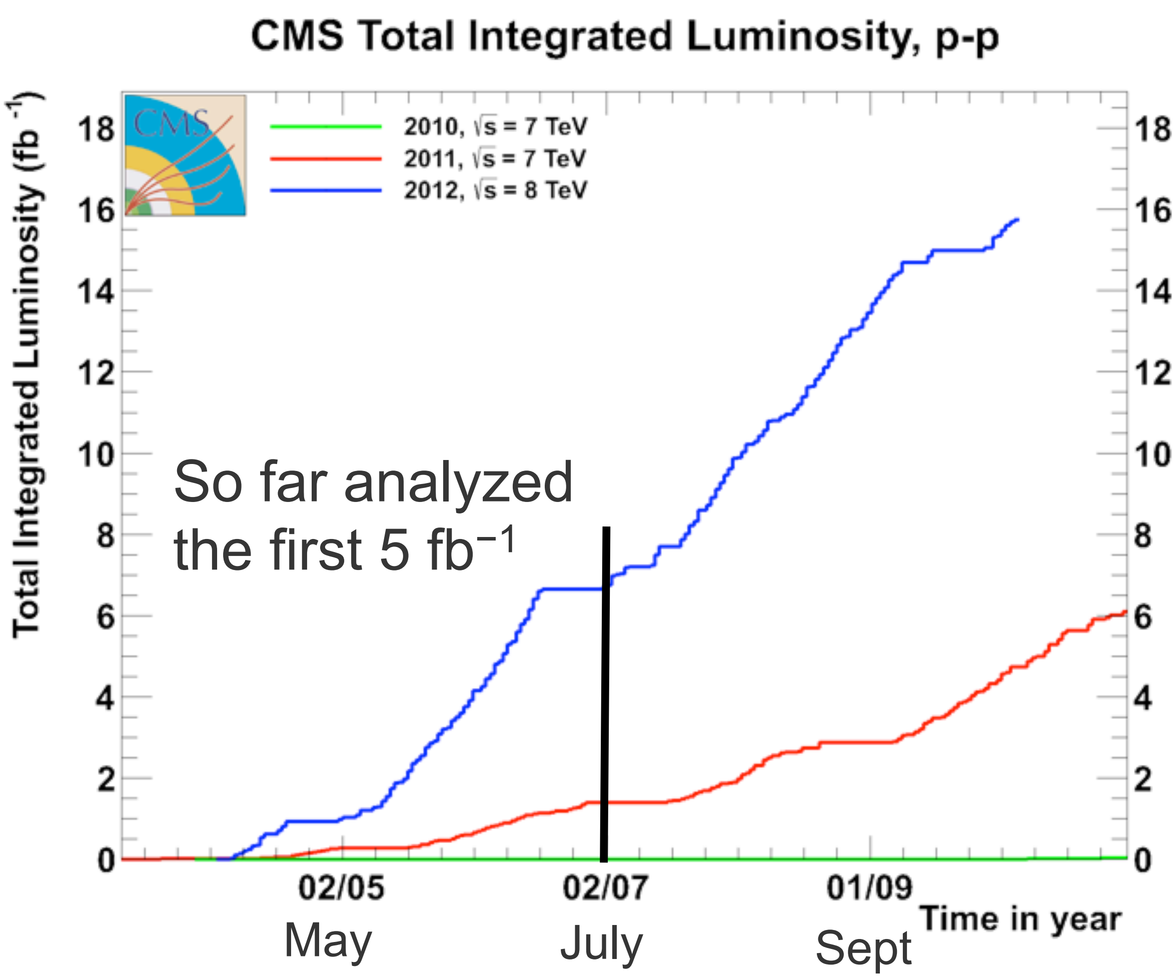
- Get swamped by W+jets
- **See no diboson peak**, nothing other than W+jets: S/B →0
- Large syst uncertainty

Worse than Tevatron: With non-optimized selection no sensitivity to CDF bump.

At the minimum should be able to see diboson peak.

LHC and CMS detector

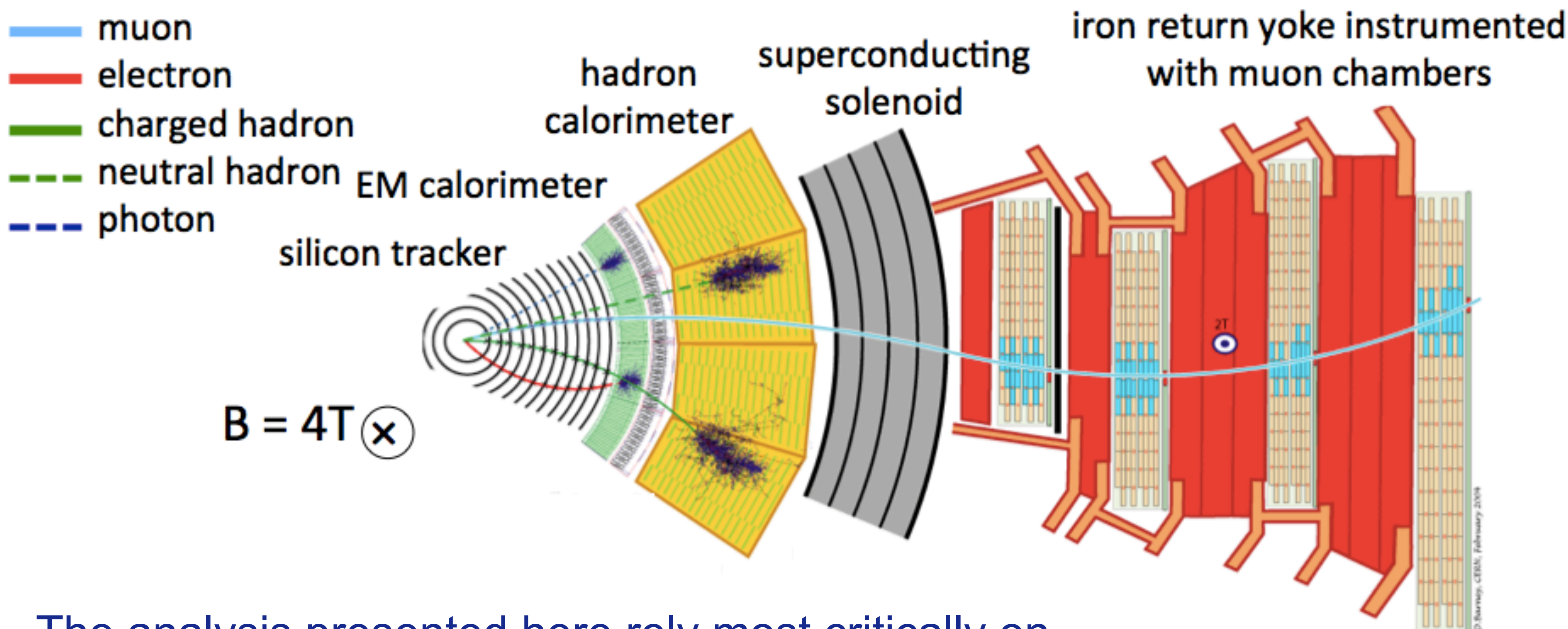
LHC data



This is a significant amount of data: ~50 times larger than the Tevatron combined for $q\bar{q}$ process.

- On target for 30 fb^{-1} by the end of 8 TeV run this year
- Routinely record 6−7 Hz/nb (i.e., 6−7 x 10^{33} $cm^{-2}s^{-1}$)

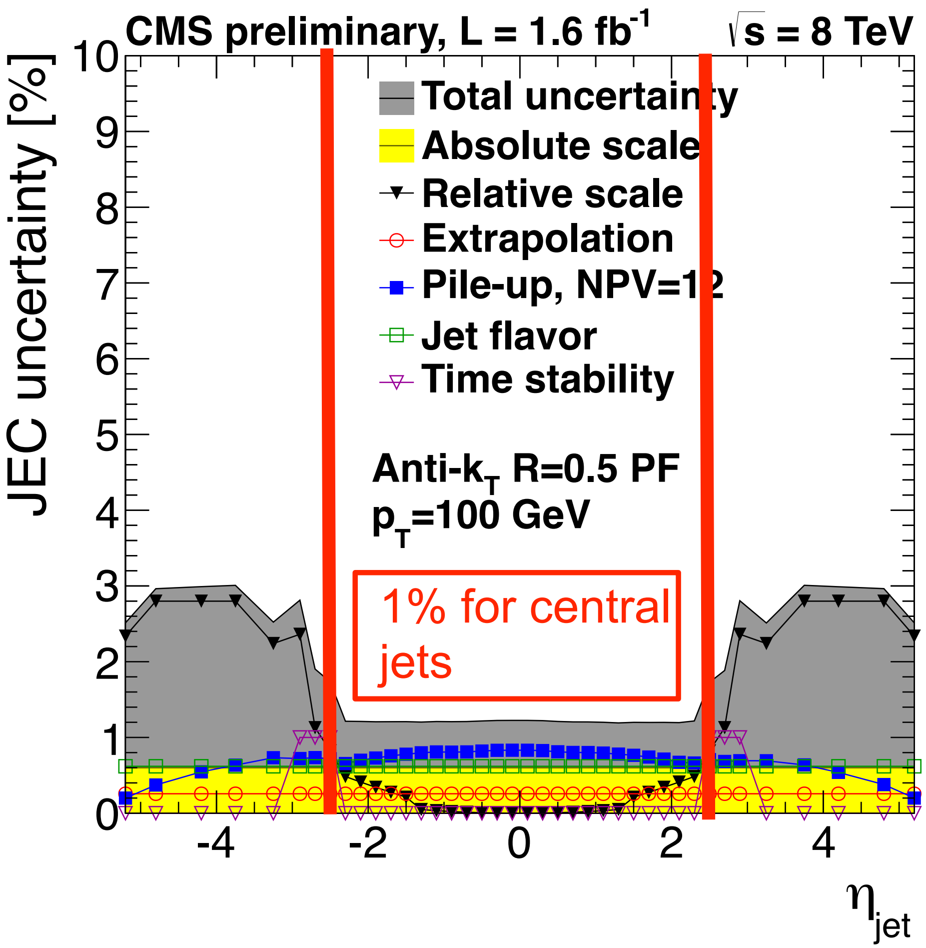
CMS detector



The analysis presented here rely most critically on

- **electrons**: tracks matched to clusters in EM calorimeter
- **muons**: minimum ionizing tracks, penetrate deep into muon system
- **jets / H_T**: constructed with combined tracking + calo info
- **MET**: constructed with combined tracking + calo info, hermetic detector

Good understanding of detector performance



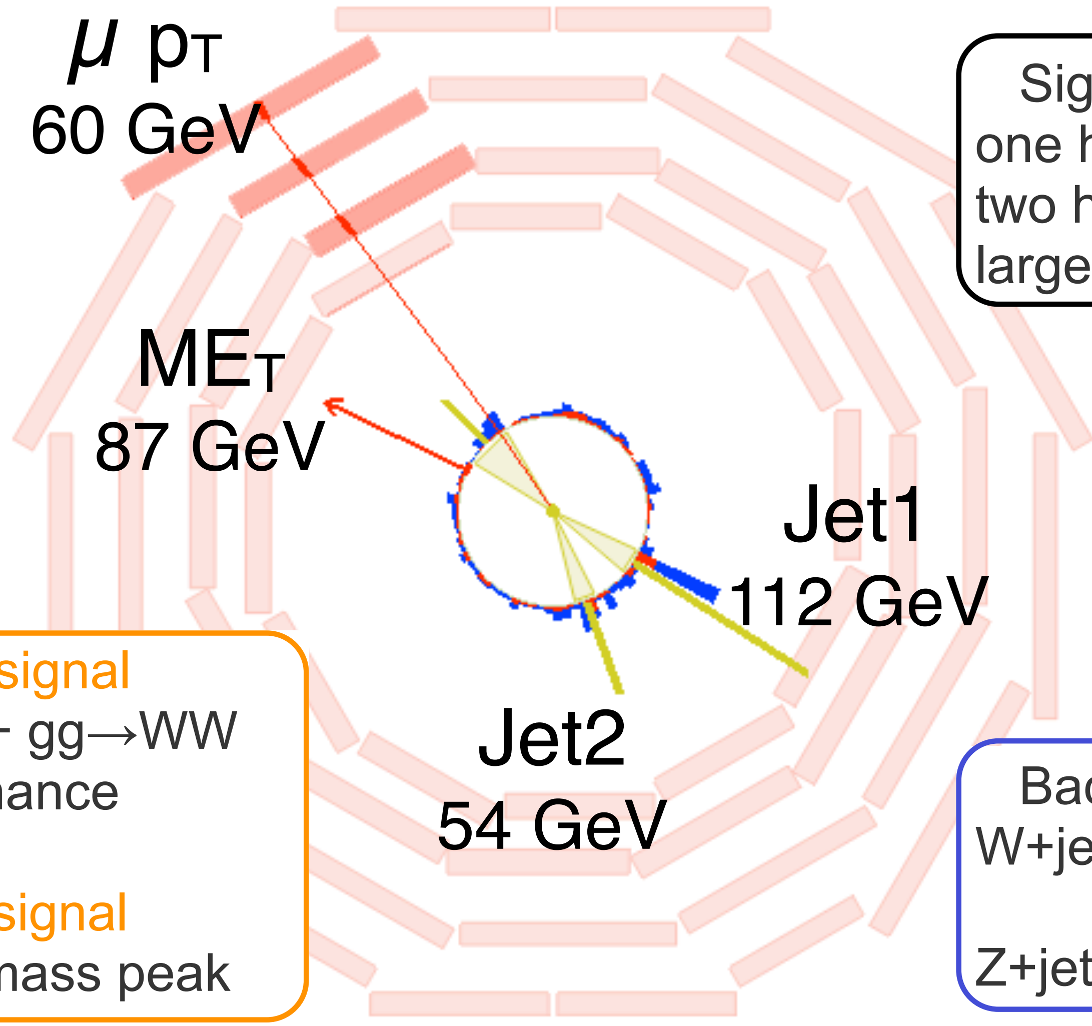
✦An example: jet energy scale

- arguably the most difficult calibration task at hadron collider
- achieving 1% is a milestone!
- very well calibrated jets

CMS measurement: observation of diboson bump

A typical event looks like this

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP12015



Signature:
one high p_T lepton
two high pT jets
large missing E_T

Lepton p_T > 25 GeV
(35 GeV for ele)
ME_T > 25 (30) GeV
Jet p_T > 35 GeV
$\Delta\eta$(Jet1, Jet2) < 1.5

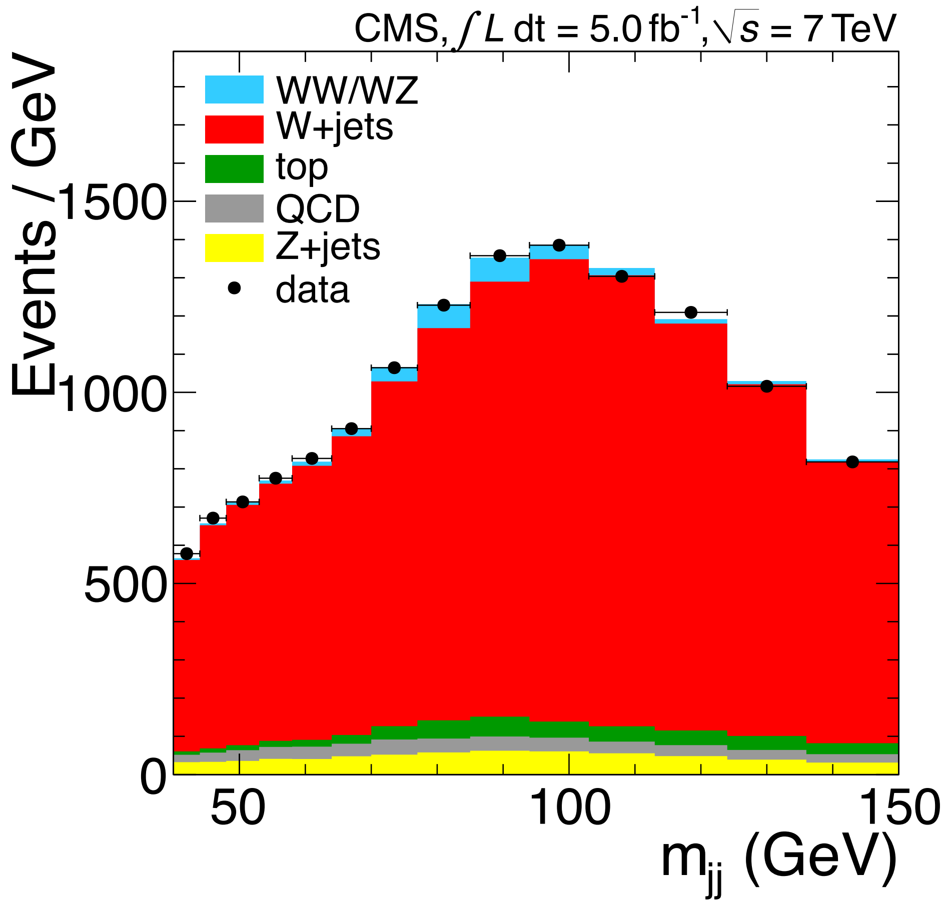
SM WW signal
qq→WW + gg→WW
no resonance

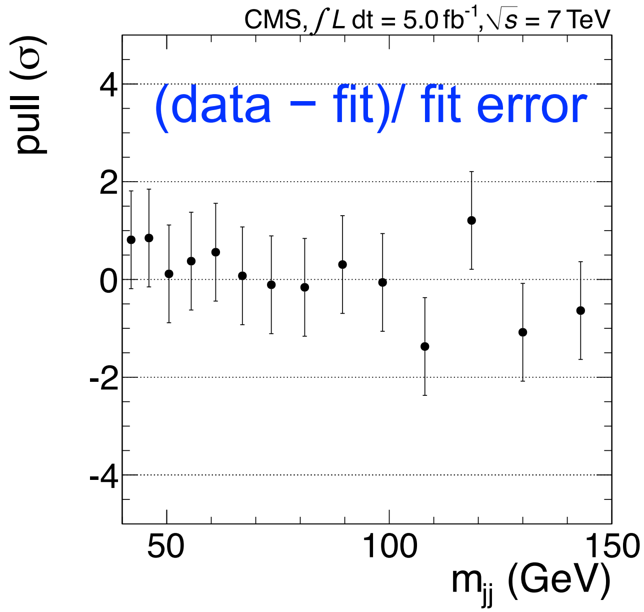
H→WW signal
resonant mass peak

Background:
W+jets (dominant)
top
Z+jets, multijet

First need to see the expected bump !

Jet resolution doesn't allow to cleanly separate W from Z. Get both.





Large background. Main thrust of the analysis is to model it well.

W+jets shape uncertainty

Two relatively unknown parameters in W+jets shape

- Factorization/renormalization scale (μ)
- Matrix Element − Parton Shower matching threshold (q)

Need to vary them in the fit to get a good modeling of data:

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

where $0 < \alpha < 1$, $0 < \beta < 1$

- α and β are consistent between muon and electron data
- Data prefer smaller value for ME-PS threshold than 20 GeV

Fit to extract diboson signal

- Diboson contribution floated completely
- QCD constrained using data
- Other backgrounds constrained using the most state of the art theory predictions (NLO or NNLO)

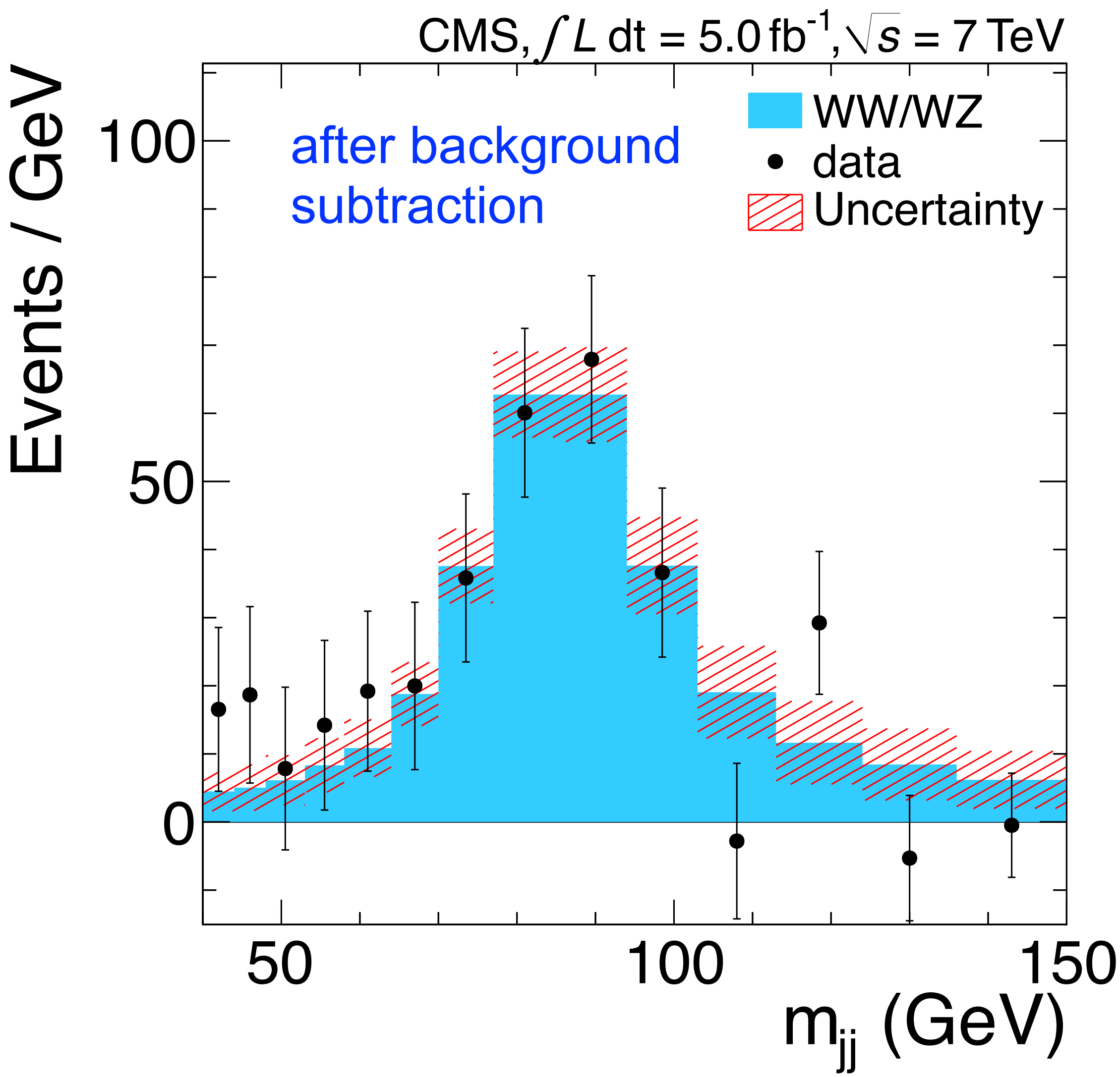
Fit results

Process	Muon channel	Electron channel
Diboson (WW+WZ)	1899 ± 389	783 ± 302
W plus jets	67384 ± 586	31644 ± 850
$t\bar{t}$	1662 ± 117	946 ± 67
Single top	650 ± 33	308 ± 17
Drell-Yan plus jets (Z+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}

Channel	Observed	Expected (NLO)
Muon	1900 ± 400	1700
Electron	800 ± 300	870

Theory has about 5% uncertainty

Diboson signal



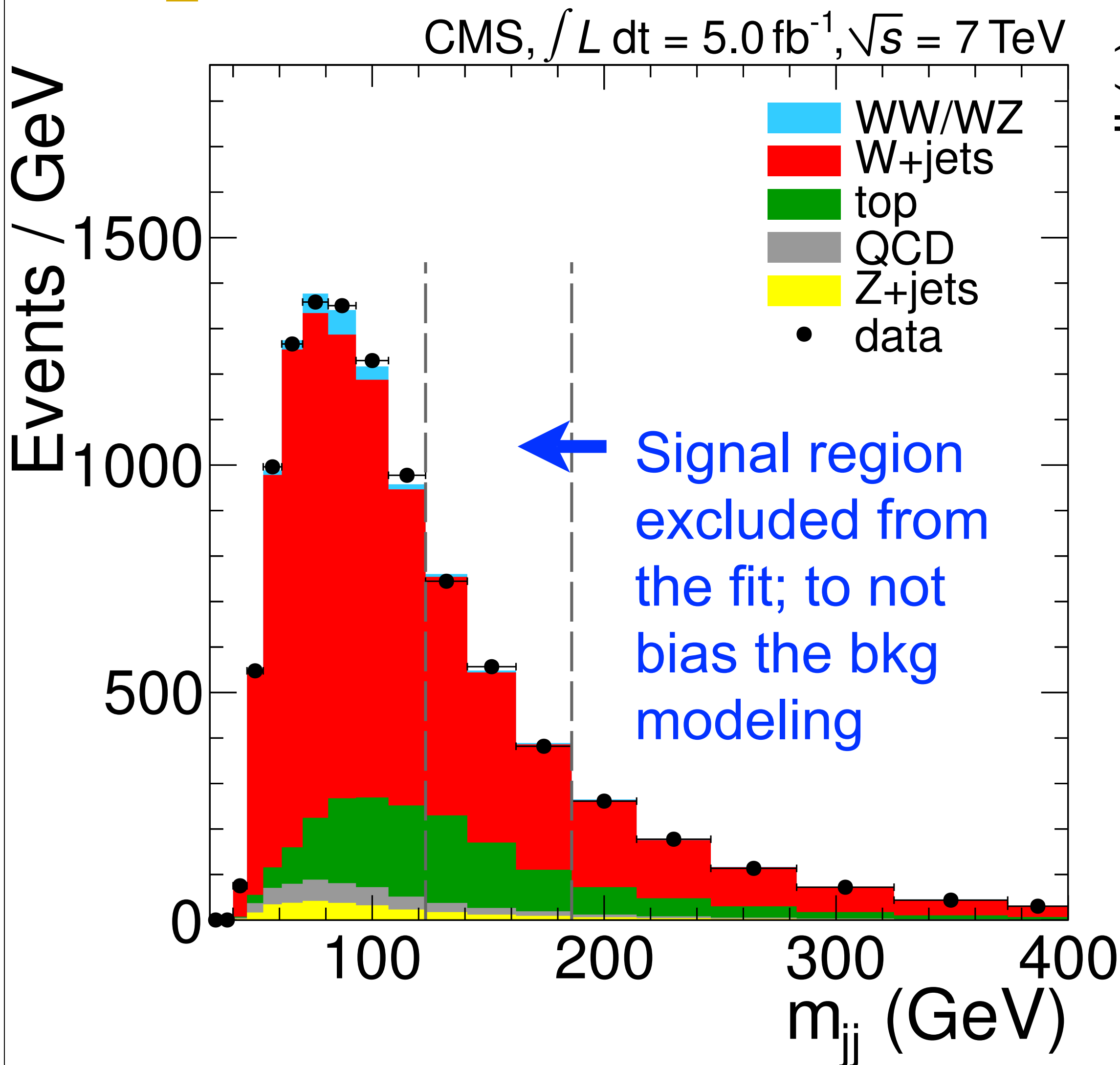
#diboson = **2700** ± 340(stat) ± 360(syst)

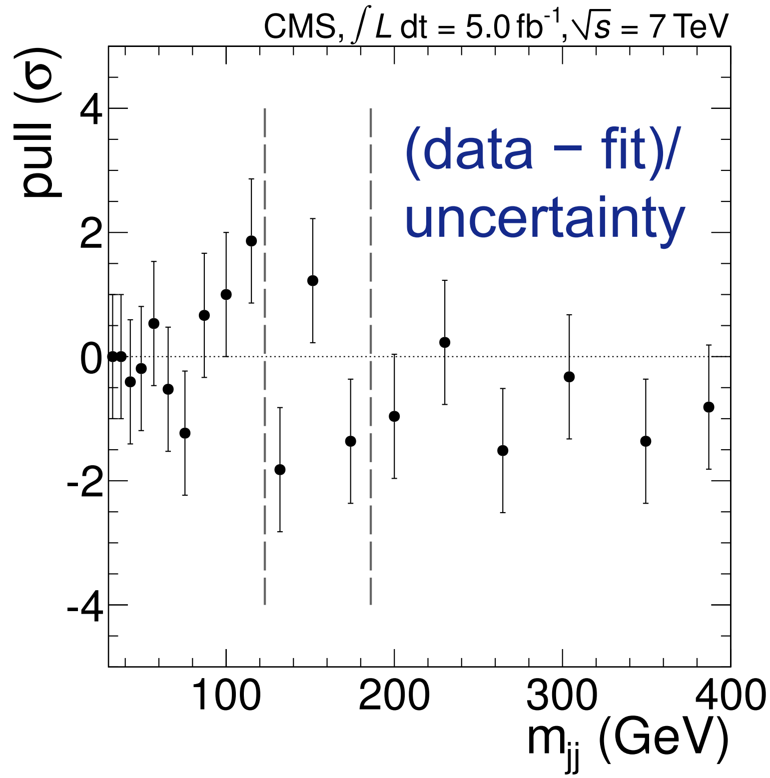
- The <u>first observation</u> of diboson in semi-leptonic channel at LHC.

Thus we have established the expected bump !

CMS search for the unexpected bump

Dijet mass spectrum





Good modeling of data.

Fit using Standard Model contribution only

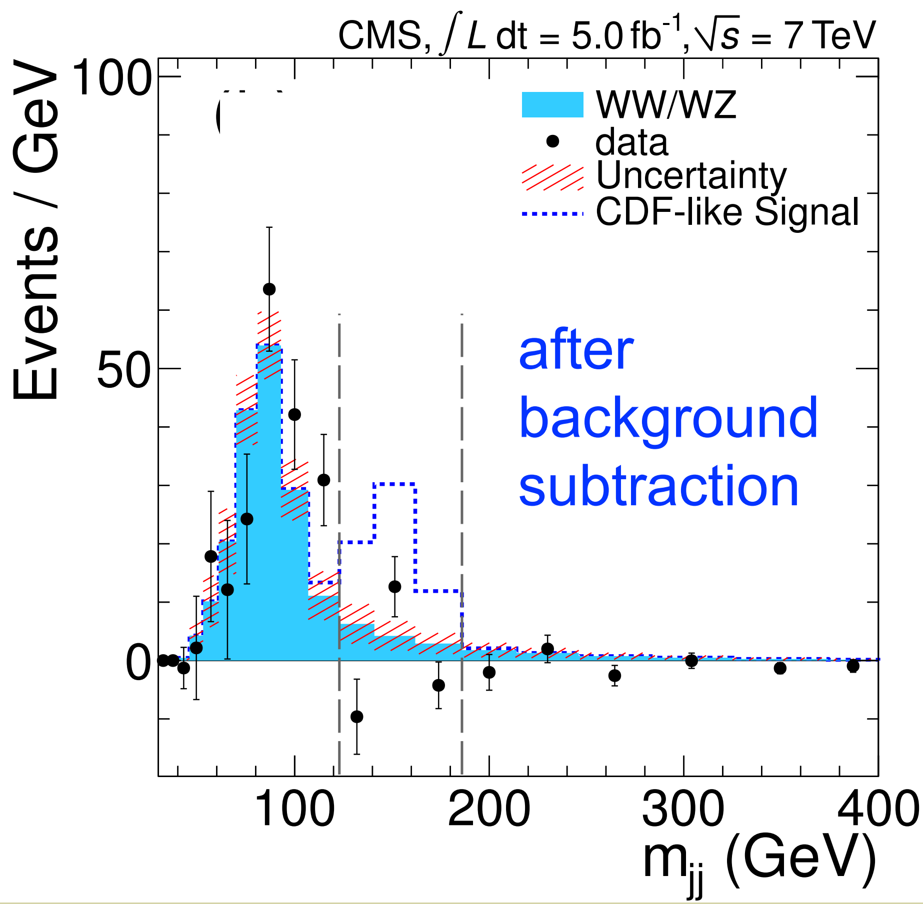
	muons		electrons	
Process	2-jet	3-jet	2-jet	3-jet
W plus jets	58919 ± 530	13069 ± 366	29787 ± 1153	8397 ± 292
Dibosons	1236 ± 114	333 ± 32	685 ± 65	184 ± 18
$t\bar{t}$	4570 ± 307	9049 ± 382	2556 ± 174	4265 ± 253
Single-top	1765 ± 87	1001 ± 50	916 ± 46	521 ± 26
Drell–Yan plus jets	1837 ± 79	561 ± 24	1061 ± 46	364 ± 16
Multijet (QCD)	29 ± 284	0 ± 90	3944 ± 1133	324 ± 160
Fit χ^2 probability	0.454	0.729	0.969	0.991
Total from fit	68294 ± 307	24013 ± 193	38949 ± 228	14055 ± 143
Data	67900	24046	38973	14145

No significant excess in data in any of the four channels

- Good modeling of data by the Standard Model processes

What about the signal region?

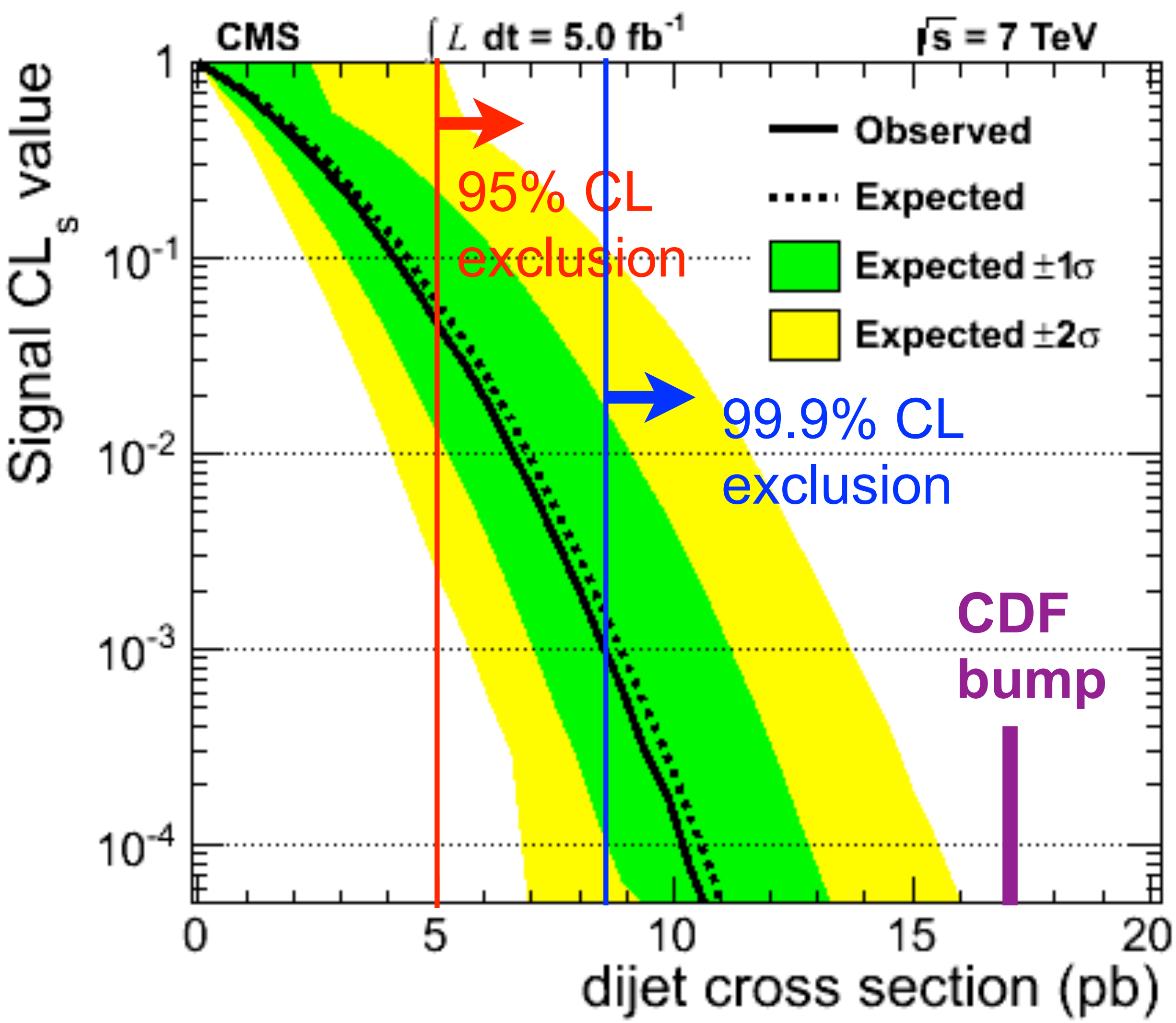
In the signal region $123 < m_{jj} < 186$ GeV (excluded from the fit)				
Total predicted	14511 ± 125	7739 ± 95	7944 ± 92	4347 ± 70
Data	14050	7751	8023	4438



No excess in the signal region

- Set upper limit on the magnitude of the bump
  - -Assume a Gaussian peak at 150 GeV, width 15 GeV

Upper limit on generic New Physics signals

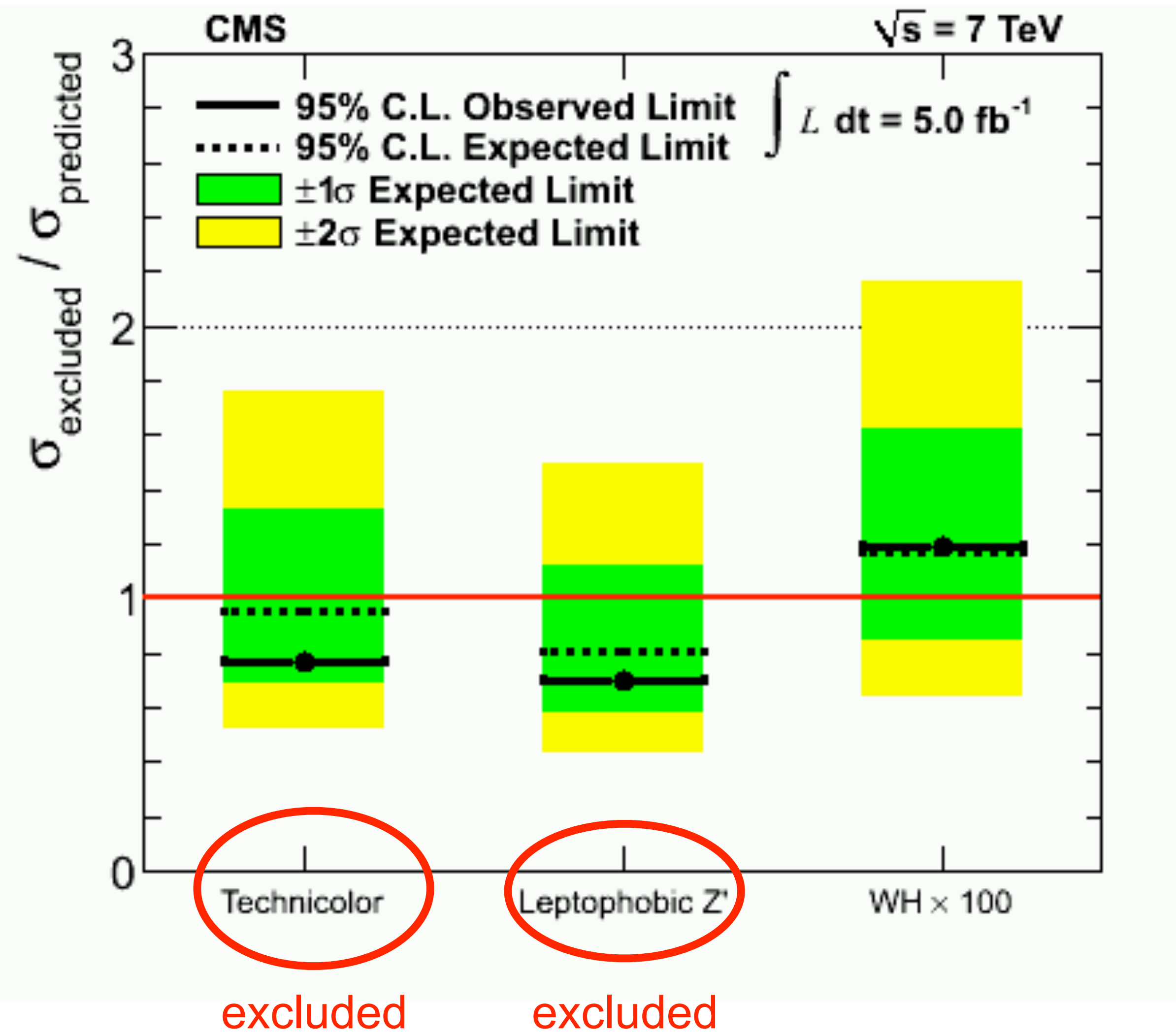


What does this plot mean?

- A p-value below X % means that we exclude the signal with [100-X]% confidence

- Exclude CDF bump with very high confidence level

Also exclude two plausible interpretations



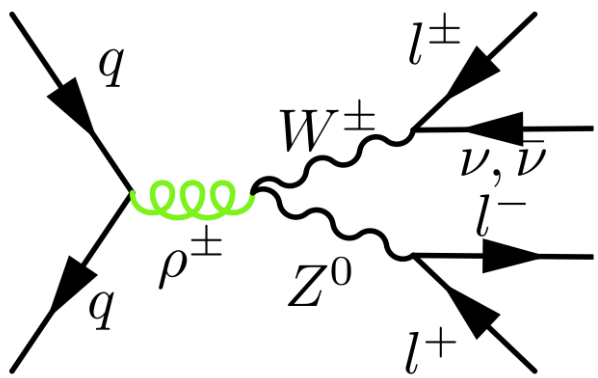
What does this plot mean?

- If the ratio of the excluded over predicted is < 1 then we exclude the model

- Exclude technicolor and Z' models

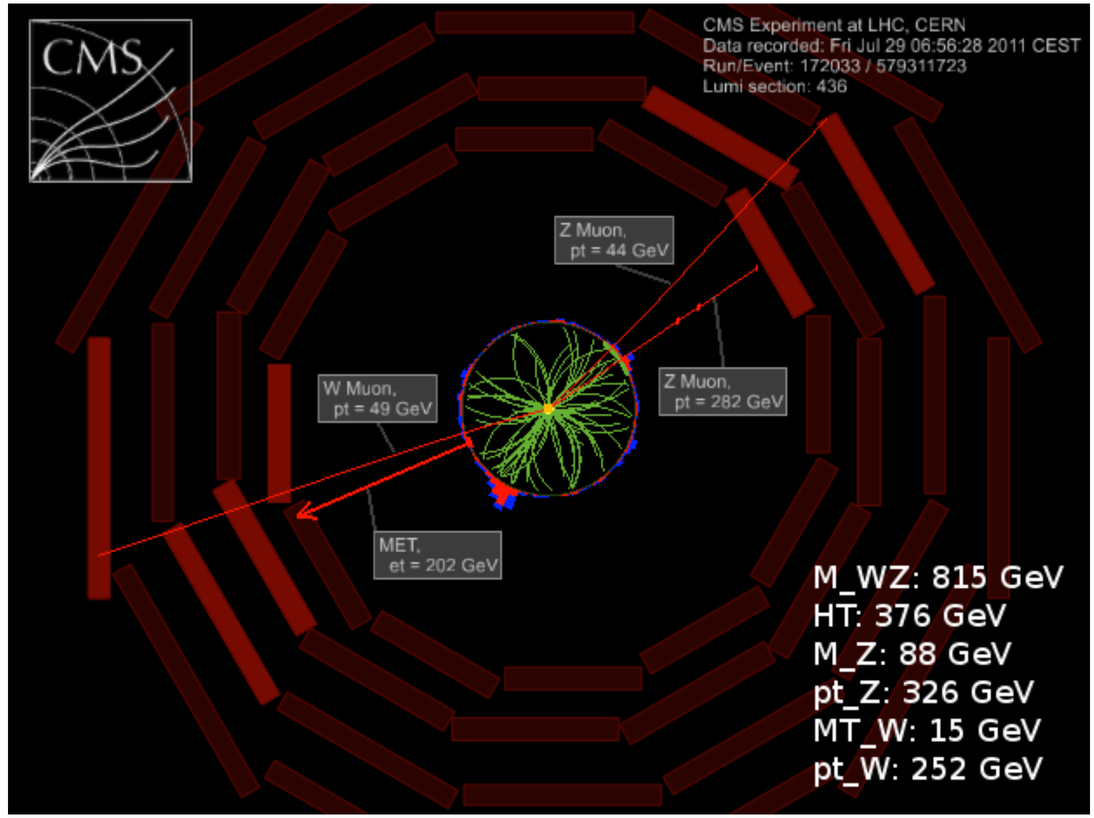
Other interpretations can be tested using our p-value plot

A second way to test the bump



Lane and Eichten, "Low scale technicolor", Phys. Lett. B222, 274 (1989)

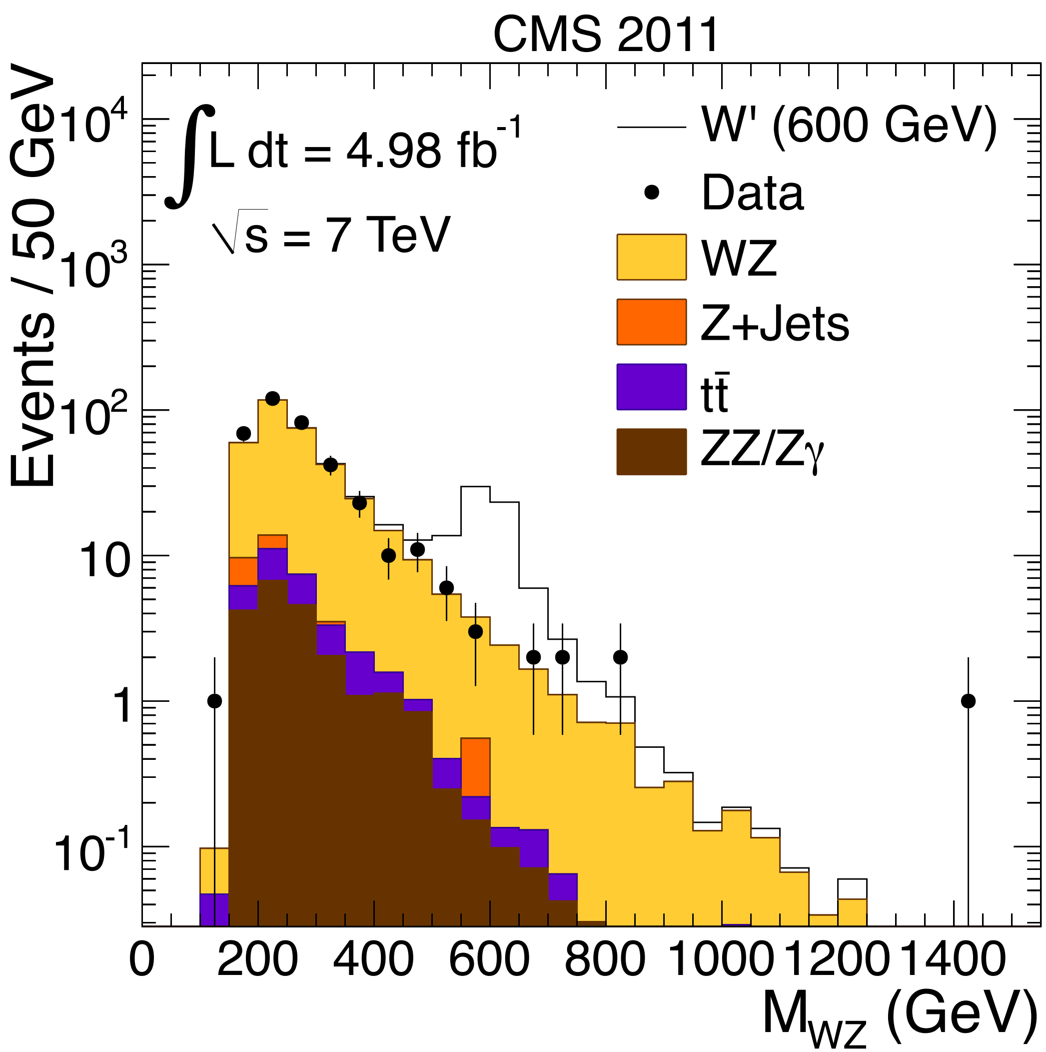
If technicolor interpretation is correct



- Techni-rho produced in qq annihilation, as before
- Can decay into WZ: $\rho_{TC} \rightarrow WZ$

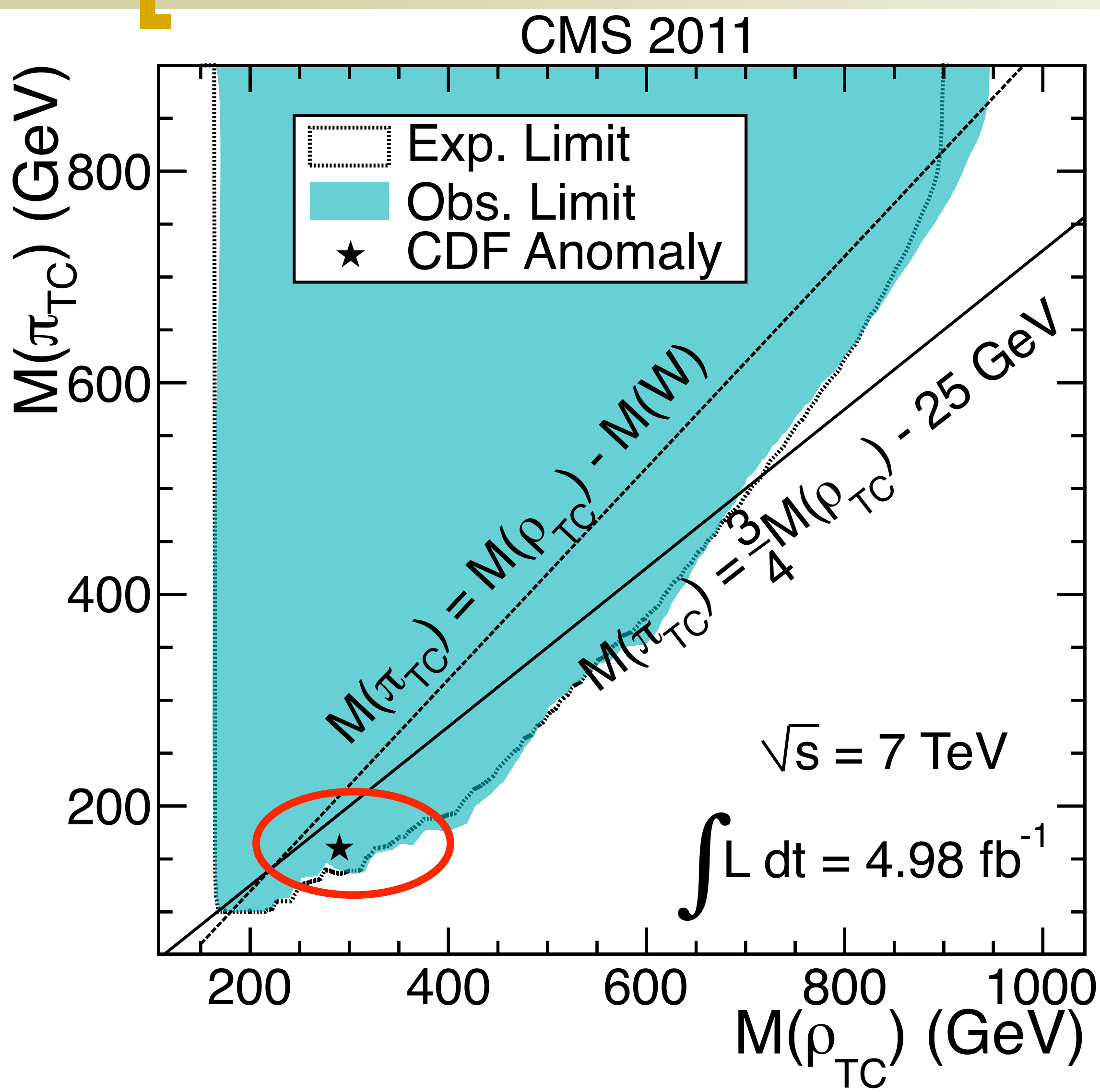
WZ ($\to \ell\ell\ell'\nu$) invariant mass spectrum

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11041



- Smoothly falling spectrum, no bump
- Set upper limit on the magnitude of the bump

Again no evidence of unexpected bump



CDF anomaly:
(ρ_{TC}=290, π_{TC}=160)

Exclude low scale techni-color interpretation of CDF anomaly

Summary I

- CMS has analyzed the W+jj data
  - Data well-described by the Standard Model processes
  - Measure expected bump from W/Z near 80−90 GeV
- No evidence for any resonant bump near 150 GeV
  - Exclude CDF bump with high confidence level
  - Also exclude technicolor & Z' interpretations of CDF bump

Summary II

- At 95% confidence level we set an upper limit of 5 pb
  - So if a resonant signal exists near 150 GeV it has to be smaller than 5 pb, i.e., 1/4th of the CDF bump or smaller
- No new force of nature with a particle of mass near 150 GeV
  - At least for now the Higgs mechanism is triumphant and explains electroweak symmetry breaking

BACKUP SLIDES

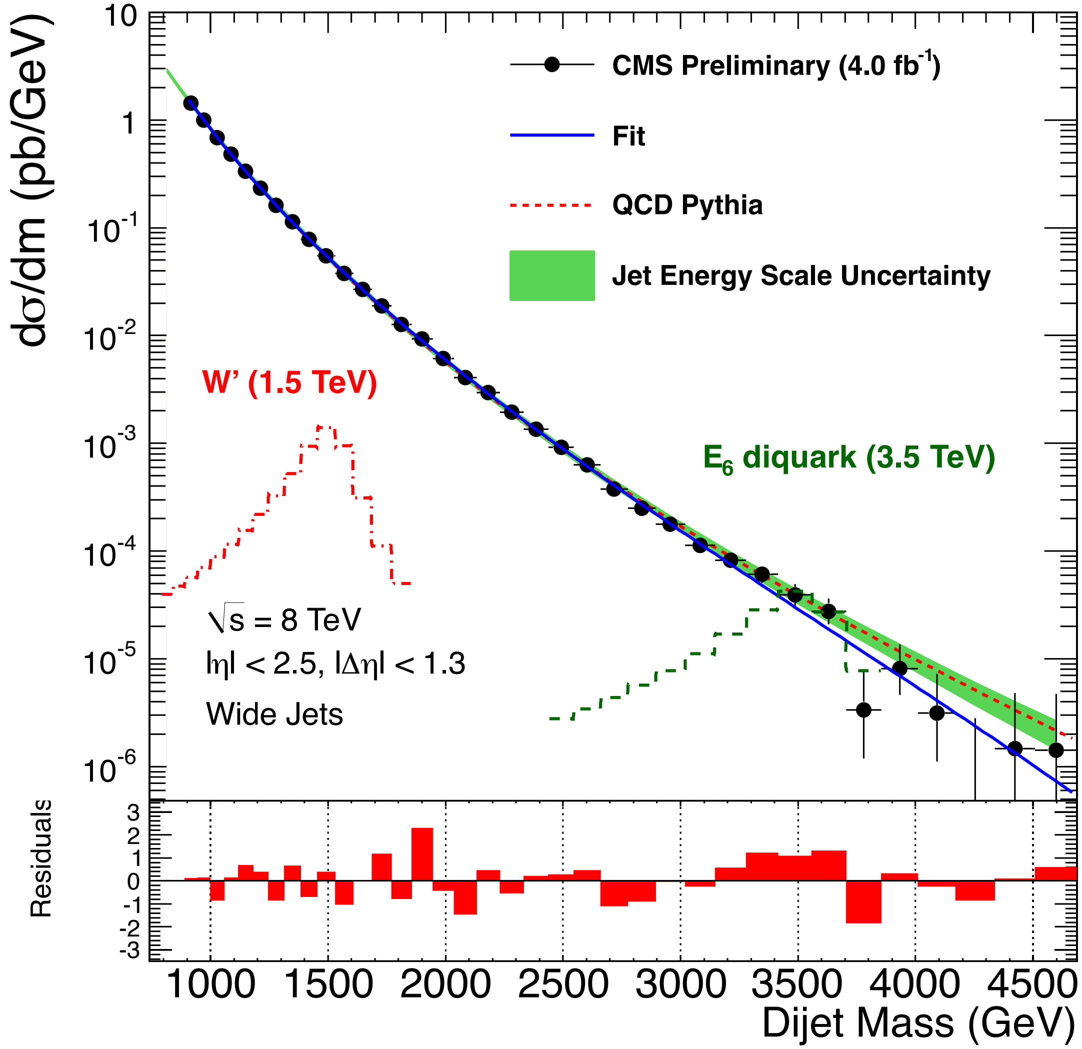
Triggers for this analysis

At hadron colliders trigger is very important ("if you don't trigger on 'em they don't exist"). Have to sift through billions of proton-on-proton collision to find an event of interest !!!

- Use a simple trigger scheme that requires
  - one isolated lepton
  - threshold: 24 GeV for muon, 27 GeV for electron
  - MET > 20 GeV in case of electron

- Offline analysis-level thresholds are higher than in trigger

Why 150 GeV seemed like an April surprise?



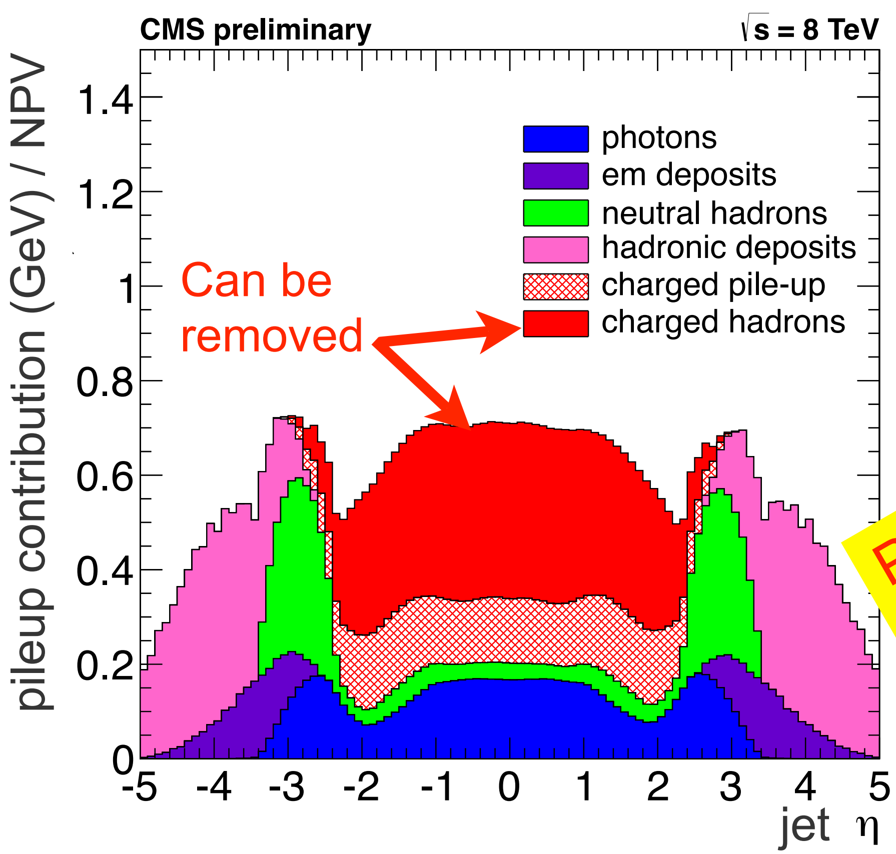
The plot shows the dijet mass spectrum in dijet data at $\sqrt{s}$ = 8 TeV

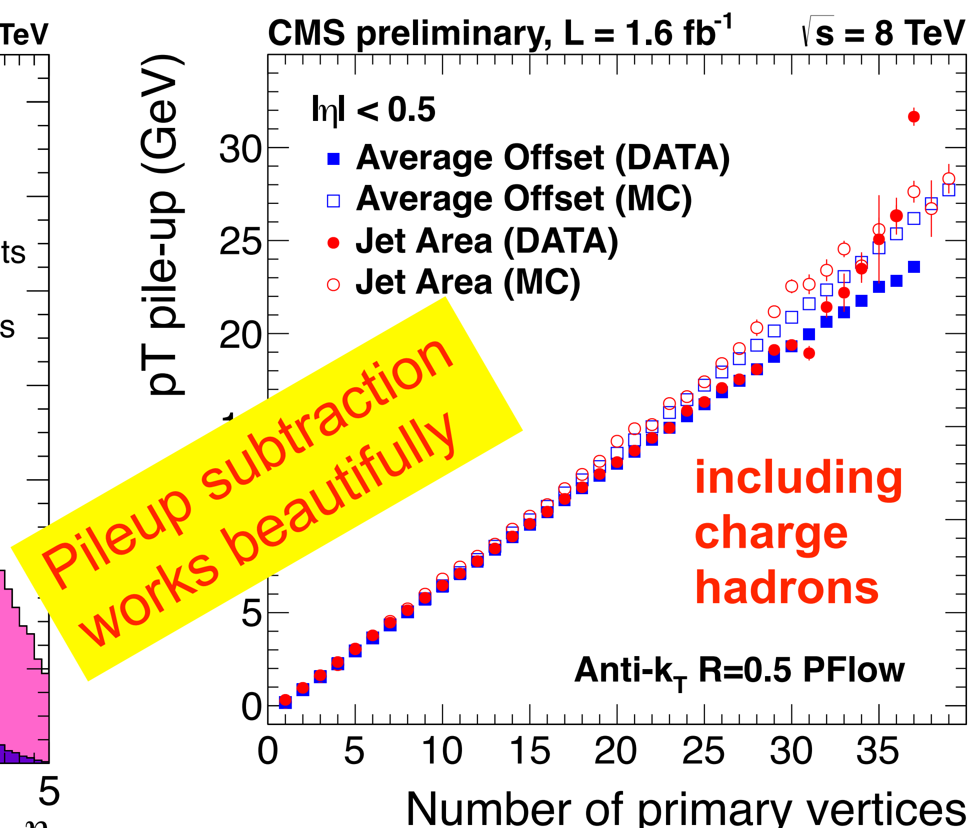
- Dijet mass spectrum in W +jj events should have similar behavior as the inclusive dijet events
- Expect featureless falloff without any bump beyond 80−90 GeV (from W and Z)

A bump near 150 GeV would be a clear hint of New Physics at low mass.

Dealing with pileup: subtract its contribution

✦ Pileup affects jet energy, MET, and lepton isolation
- Example: pileup contribution to jet p_T per primary vertex.
- Measure in data using several methods. Get consistent results.





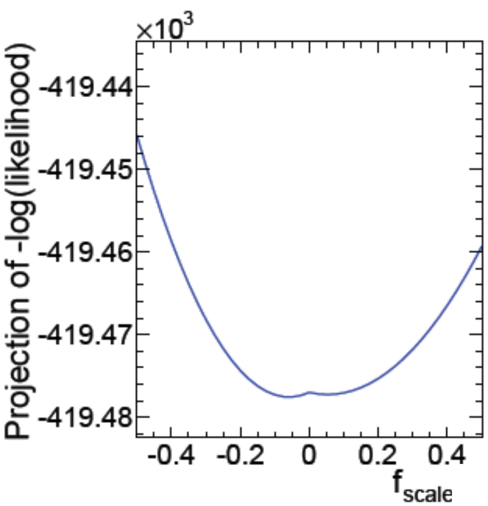
WW+WZ→$\ell\nu$qq: understanding W+jets bkg

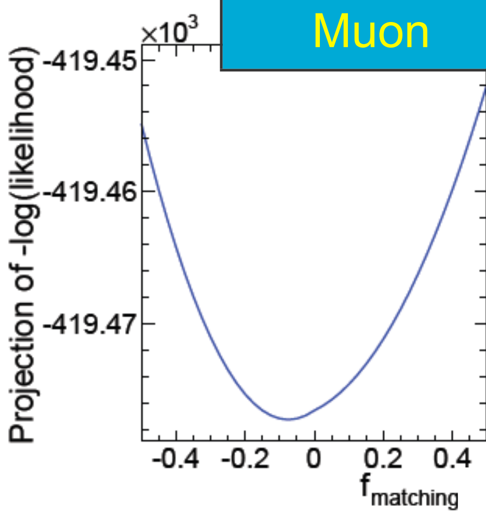
Process	Muon channel	Electron channel
Diboson (WW+WZ) — NLO prediction = 1697 / NLO = 867	1899 ± 389	783 ± 302
W plus jets	67384 ± 586	31644 ± 850
$t\bar{t}$	1662 ± 117	946 ± 67
Single top	650 ± 33	308 ± 17
Drell-Yan plus jets (Z+jets)	3609 ± 155	1408 ± 64
Multijet (QCD)	296 ± 317	4195 ± 867
Fit χ^2/dof (probability)	9.73/12 (0.64)	5.30/12 (0.95)
Total from fit	75420	39371
Data	75419	39365
Acceptance × efficiency ($\mathcal{A}\varepsilon$)	5.153×10^{-3}	2.633×10^{-3}

W+jets shape uncertainty

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

	α (fSU)	β (fMU)
Electron	-0.003 ± 0.074	-0.136 ± 0.081
Muon	0.053 ± 0.078	-0.075 ± 0.065



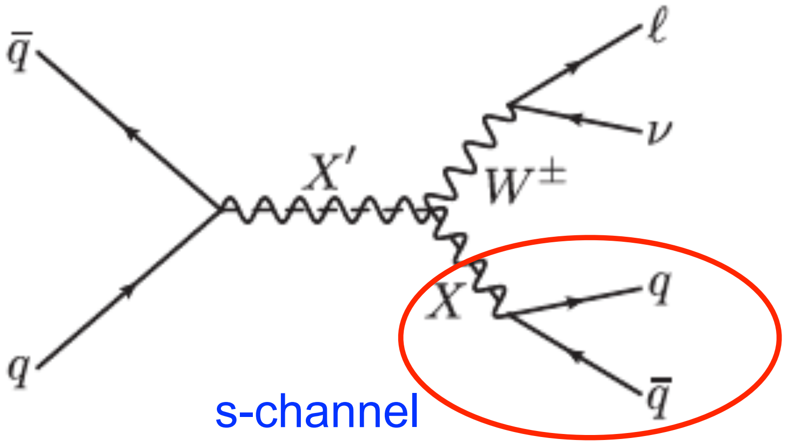


Factorization/renormalization scale and ME-PS matching scale vary in the fit.

- α (scale ↑ or ↓ fraction) and β (matching ↑ or ↓ fraction) are consistent b/w electron and muon data
- NLL versus α and β is well-behaved

Search for NP in W+2jet e.g. $\rho_T \to W(\to l\nu)\ \pi_T(\to jj)$

Buckley, Hooper, Kopp, Martin, and Neil; arXiv: 1107.5799

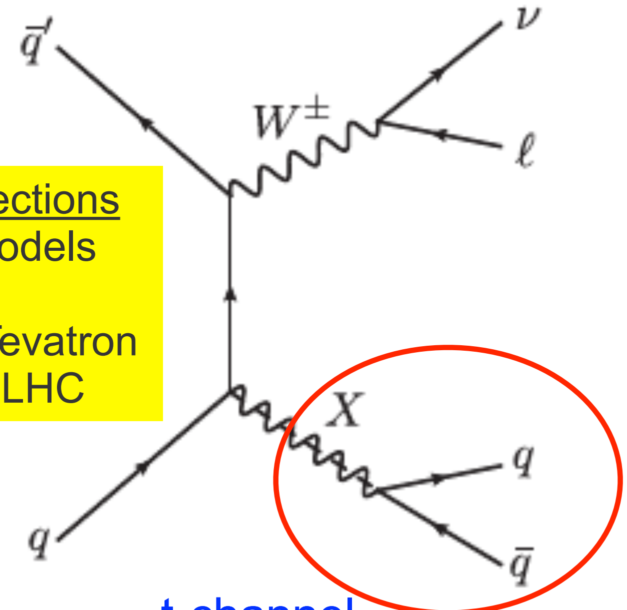


s-channel

In low-scale technicolor (LSTC) models, could originate from events in which a ∼300 GeV neutral (charged) technirho, ρ_T, is produced and then decays to a $W^\pm$ and a ∼150 GeV charged (neutral) technipion, π_T, which decays to jets (some fraction of which can be b-jets, depending on the CKM-like angles in the technicolor sector).

Total cross sections for various models

~ 1−3 pb at Tevatron
~ 5−10 pb at LHC

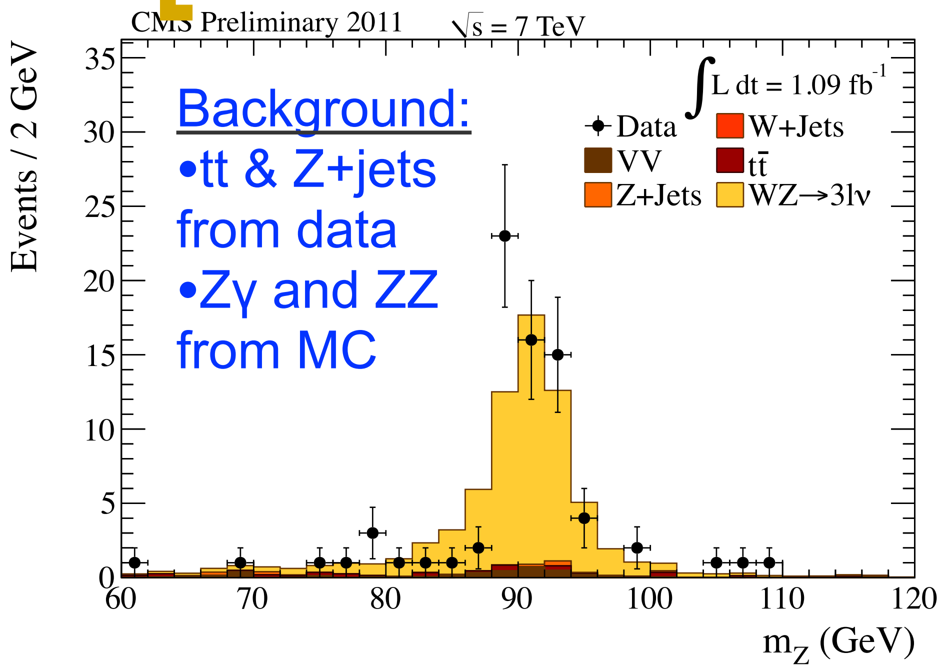


t-channel

X in this case can be either a scalar or a vector boson.

In Pythia "straw-man" implementation, $\pi_T^\pm$ and π_T^0 decay to heavy flavor quarks with BR 80−90%, but cannot decay to gluon. $\pi_T^{0\prime}$ decays to heavy flavor with BR ~50% and decays to gluon pair with BR ~50%. The mixing is such that $\pi_T^{0\prime}$ component is small.

WZ→ℓℓℓ'ν cross section at 7 TeV (1.1 fb^{-1})



http://cdsweb.cern.ch/record/1370067
(CMS PAS EWK-11-010)

- Two iso ℓ: p_T > 20/15 GeV (e/μ)
- 3rd lepton p_T > 20, ME_T>30 GeV
- 60 < $m_{\ell\ell}$ < 120 GeV; veto 2nd Z
- Accept. x efficiency = 19−25%

Main systematics: bkg estimation, efficiency, acceptance/theory.

Channel	$A \cdot \epsilon$	$N_{observed}$
eee	0.193 ± 0.003	22
$ee\mu$	0.234 ± 0.003	20
$\mu\mu e$	0.190 ± 0.003	13
$\mu\mu\mu$	0.249 ± 0.003	20

σ = 17.0 ± 2.4 (stat) ± 1.1 (sys) ± 1.0 (lum) pb

NLO: 17.5 ± 0.6 pb (MCFM, real-width bosons, CTEQ6L, error is PDF uncertainty)

CMS analysis

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEWK11017

(submitted to PRL)

$W \to \ell\nu$ selection	Jet selection
Single-lepton trigger	$p_T^{j1} > 40\,\mathrm{GeV}$
Lepton identification and isolation	$p_T^{j2}, p_T^{j3} > 30\,\mathrm{GeV}$
$p_T^{\mu(e)} > 25\ (35)\ \mathrm{GeV}$	$\lVert\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2}\rVert > 45\,\mathrm{GeV}$
$\not\!\!E_T^{\mu(e)} > 25\ (30)\ \mathrm{GeV}$	$\lvert\Delta\eta(j1, j2)\rvert < 1.2$
$M_T > 50\,\mathrm{GeV}$	$\Delta\phi(\not\!\!E_T, j1) > 0.4$
Exclude events with > 1 lepton	$0.3 < p_T^{j2}/m_{jj} < 0.7$

Efficiency x Acceptance for a few typical models

		$\varepsilon\mathcal{A}$			
		muons		electrons	
Signal model	$\sigma \times \mathcal{B}$ (pb)	2-jet	3-jet	2-jet	3-jet
Technicolor	7.4	0.065	0.020	0.039	0.011
Z'	8.1	0.070	0.023	0.042	0.014
WH	0.059	0.060	0.019	0.038	0.013

CMS analysis: what are the differences

arXiv:1208.3477 (submitted to PRL)

$W \to \ell\nu$ selection	Jet selection	
	$p_T^{j1} > 40\,\text{GeV}$	vs 30 GeV at CDF
$p_T^{\mu(e)} > 25\ (35)\ \text{GeV}$	$\|\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2}\| > 45\,\text{GeV}$	vs 40 GeV
$\not{E}_T^{\mu(e)} > 25\ (30)\ \text{GeV}$	$\|\Delta\eta(j1, j2)\| < 1.2$	vs no cut
$M_T > 50\,\text{GeV}$	$0.3 < p_T^{j2}/m_{jj} < 0.7$	vs no cut

These are not real differences. Due to trigger constraints have higher lepton and MET threshold.

Also analyze 3-jet events

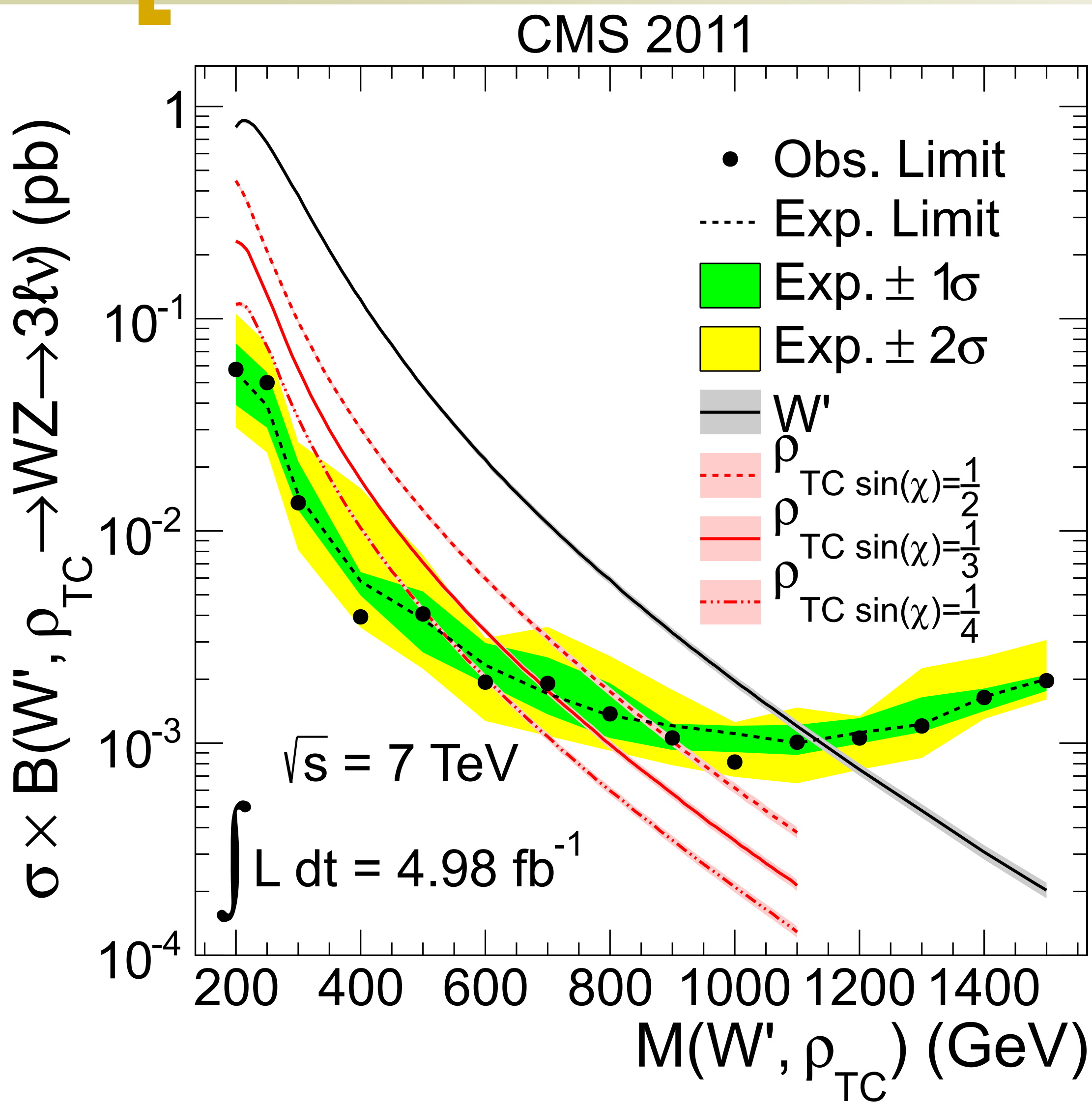
- Higher leading jet p_T helps in beating down the background
- Higher boost, smaller Δη, and Jacobian cut for dijet system
- Improve S/B for all resonant signal (diboson, TC, Z', WH)

Modeling of the Standard Model background

- Analogous to the diboson analysis described previously
- W+jets contribution floated completely
- QCD constrained using data
- Other backgrounds constrained using the most state of the art theory predictions

Process	Shape	Constraint on normalization
W plus jets	MC/data	Unconstrained
Diboson (WW+WZ)	MC	61.2 pb ±10% (NLO)
$t\bar{t}$	MC	163 pb ±7% (NLO)
Single-top	MC	84.9 pb ±5% (NNLL)
Drell–Yan plus jets	MC	3.05 nb ±4.3% (NNLO)
Multijet (QCD)	data	$\not{E}_T$ fit in data

Upper limits on technicolor particle ρ_{TC}



Exclude ρ_{TC} at 95% confidence level up to masses in the range 600−900 GeV (depending on the technicolor coupling value)

Summary I

- CMS has analyzed the W+jj data
  - Data well-described by the Standard Model processes
  - Measure the peak from hadronic W/Z near 80−90 GeV
  - Make the first observation of diboson production in semi-leptonic final state

- No evidence for any resonant bump near 150 GeV
  - Exclude CDF bump with high confidence level
  - Also exclude technicolor & Z' interpretations of CDF bump
  - The conclusion is also supported by WZ data
  - Exclude large parameter space for low scale technicolor

Summary II

- At 95% confidence level we set an upper limit of 5 pb
  - So if a resonant signal exists near 150 GeV it has to be smaller than 5 pb, i.e., 1/4th of the CDF bump or smaller
- We have excluded the technicolor and Z' models with "nominal" parameters values
  - Variations in these parameters & couplings can possibly reduce the signal strength to the level allowed by CMS data
  - However, such variations run into conflict with other experimental constraints
- No new force of nature with a particle of mass near 150 GeV
  - At least for now the Higgs mechanism is triumphant and explains electroweak symmetry breaking