Experimental Searches for Technicolor

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Fermilab

- Collider searches for low scale technicolor in leptonic and semi-leptonic final states
- Search for high mass technicolor particles in dijet events
- Outlook for the near future

Lattice Meets Experiment, Fermilab, October 15, 2011

Goal of this talk

✦To give you a sense of how TC searches are carried out at colliders
- with what assumptions ?
- which modes ? which part of phase space ?

✦Give you a sense of
- where we are after analyzing first 1 fb^{-1} of LHC data ?
- what we can do with 20 fb^{-1} data ?
- some rules-of-thumb to help you think about them
- issues on the experimental side

What this talk is not

A comprehensive summary of phenomenology & experimental searches

Because:
- You have probably seen it before
- Many experimental results are quite old and superseded
- I am not an expert on most of these searches

Low scale technicolor (LSTC) model

Lane and Eichten, Phys. Lett. **B222,** 274 (1989)

- Dynamical electroweak symmetry breaking
- No Higgs particle required
- Instead requires new particles, technihadrons and technifermions, based on new type of Strong interaction - Technicolor

✦**Narrow resonances.** Main search modes:

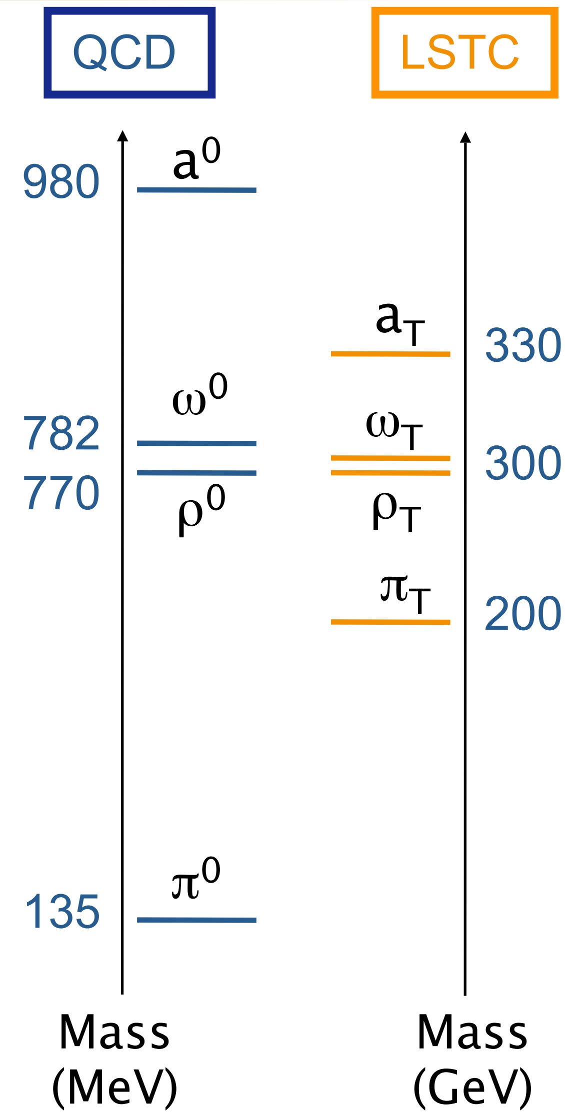
$\rightarrow \pi_T \rightarrow jj$

$\rightarrow \rho_T^0, \omega_T^0, a_T^0 \rightarrow l^+l^-, Z\gamma$

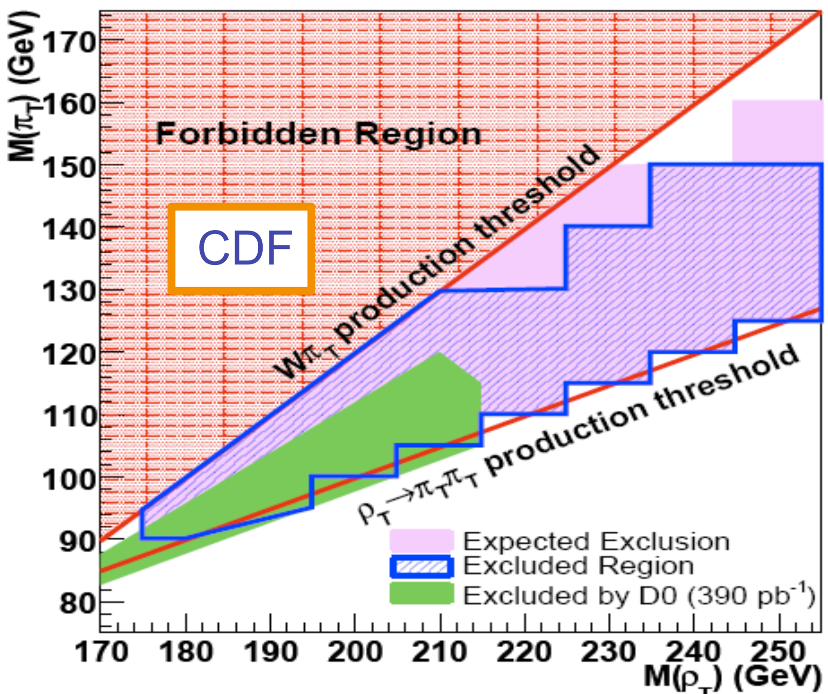
$\rightarrow \rho_T^{\pm}, \omega_T^{\pm}, a_T^{\pm} \rightarrow W^{\pm}Z, W^{\pm}\gamma$

✦In experimental searches

- assume **degenerate** ρ_T, ω_T
- **ignore** a_T, higher resonances

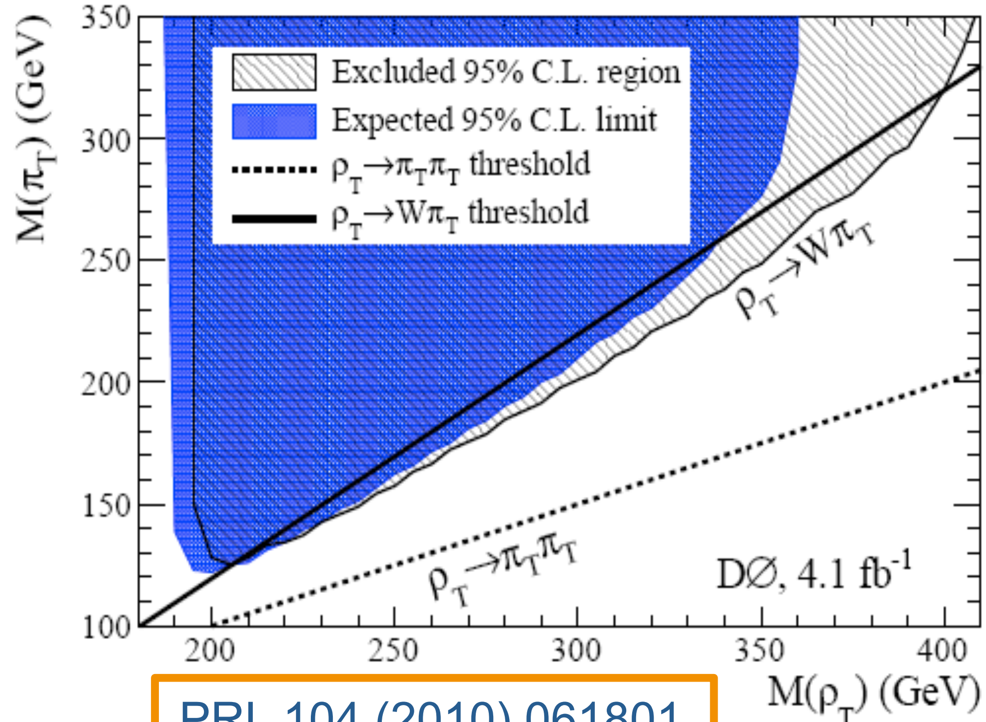


Quick overview of LSTC limits from Tevatron



PRL 104 (2010) 111802

search for $\rho_T \to W(\to l\nu)\ \pi_T(\to jj)$



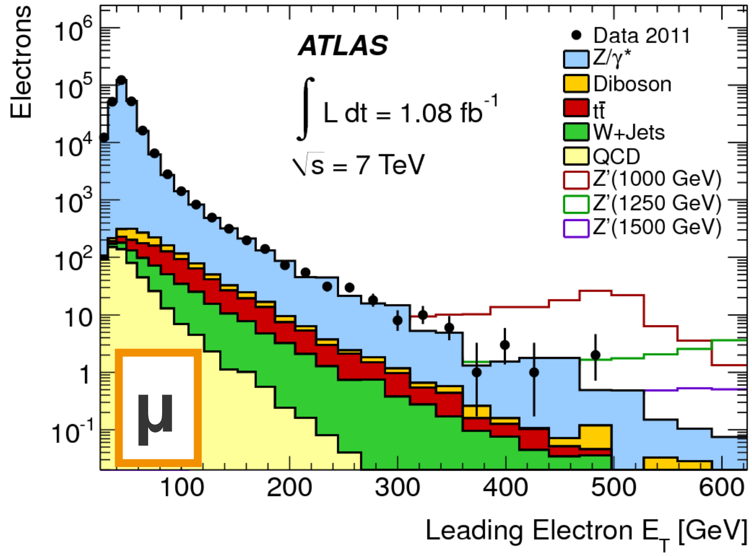
PRL 104 (2010) 061801,

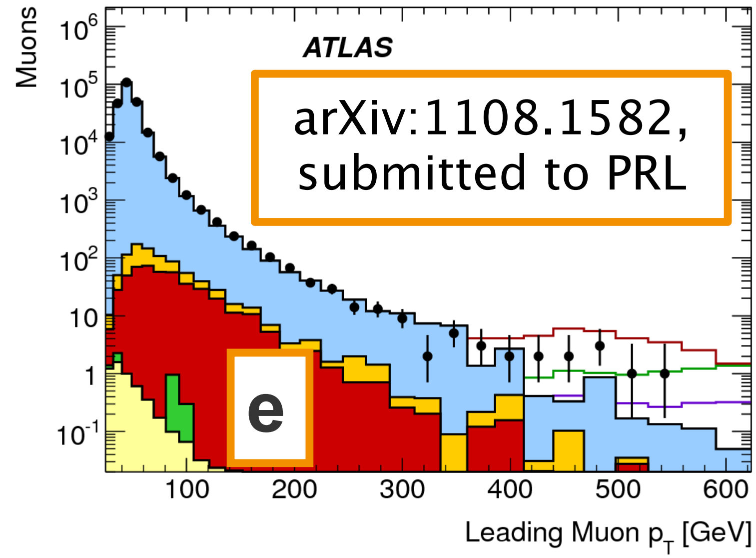
Search for $\rho_T \to WZ \to 3l + \nu$

→ For lower $M(\pi_T)$, look for $\rho_T \to W\pi_T$. Best limit from CDF : $M(\rho_T)$ > **250 GeV**
→ For higher $M(\pi_T)$, use $\rho_T \to$ **WZ**. Best limit from D∅ : $M(\rho_T)$ > **400 GeV.**

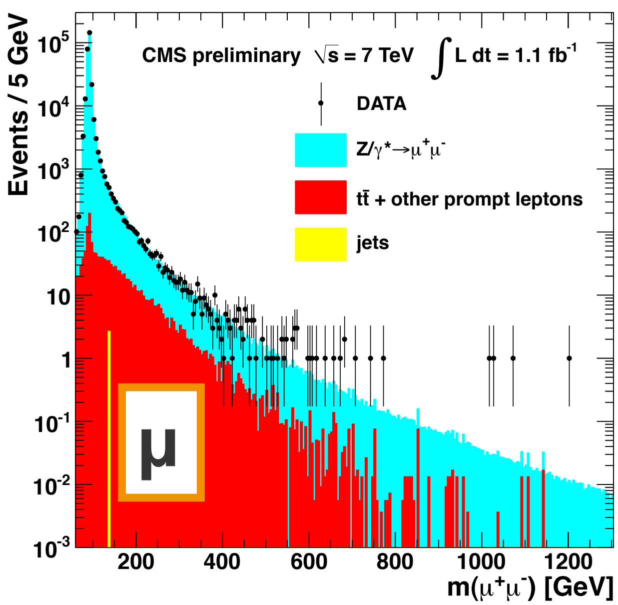
LSTC in purely-leptonic final states

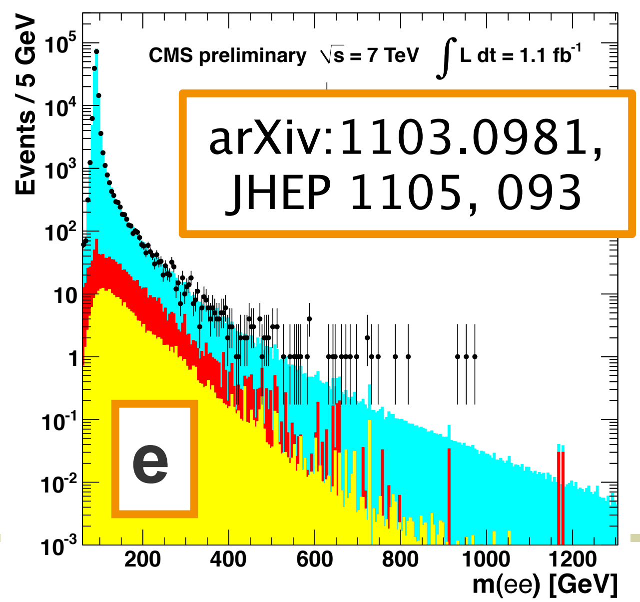
LHC results from dilepton channel (1.1 fb^{-1})





Exclude SM Z' up to 1.8 TeV, Randall-Sundrum KK graviton up to 1.6 TeV. In a separate analysis, set limit on TC, see next slide.

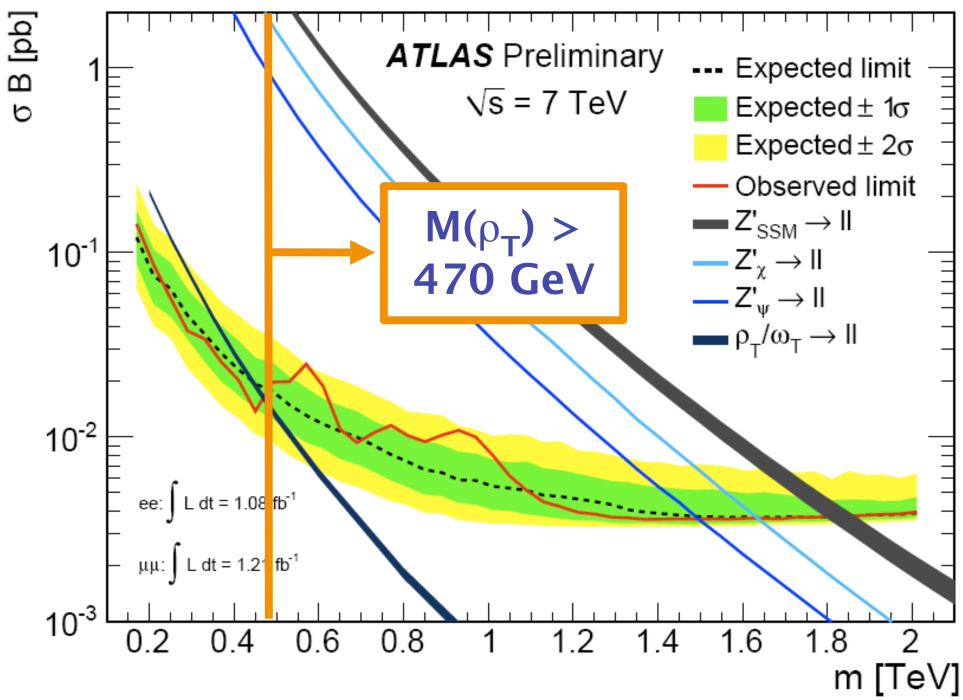


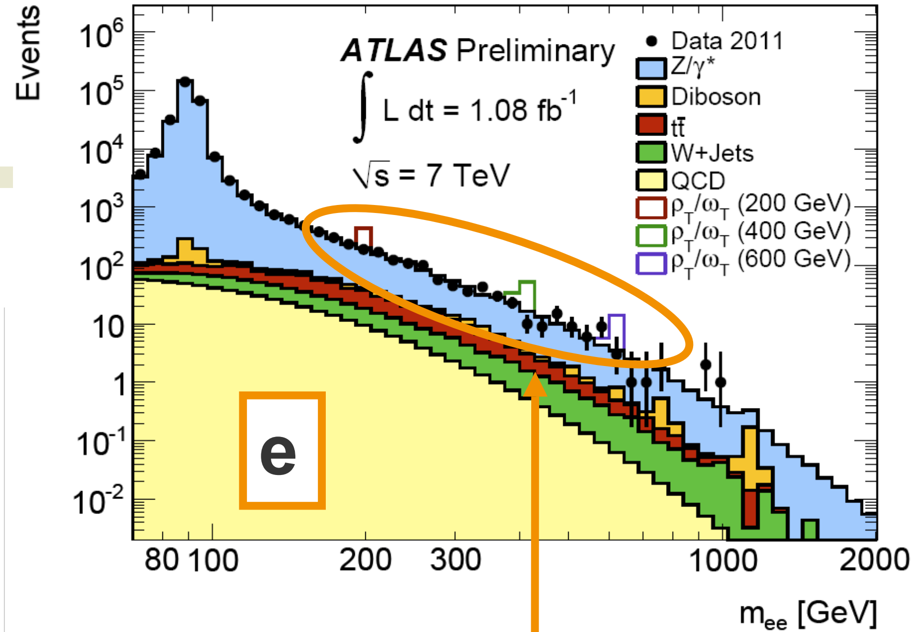


Exclude SM Z' up to 2 TeV, super-string inspired Z' up to 1.6 TeV, Randall-Sundrum KK graviton up to 1.8 TeV. CMS hasn't set limit on TC, but should be straightforward to do so.

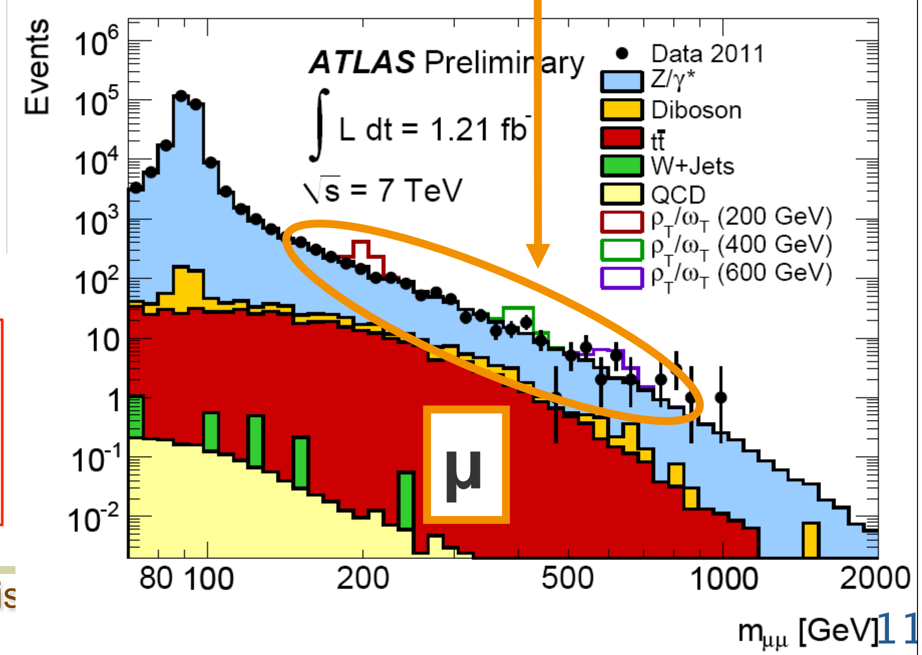
Limit on $\rho_T \to l^+l^-$

ATLAS-CONF-2011-125





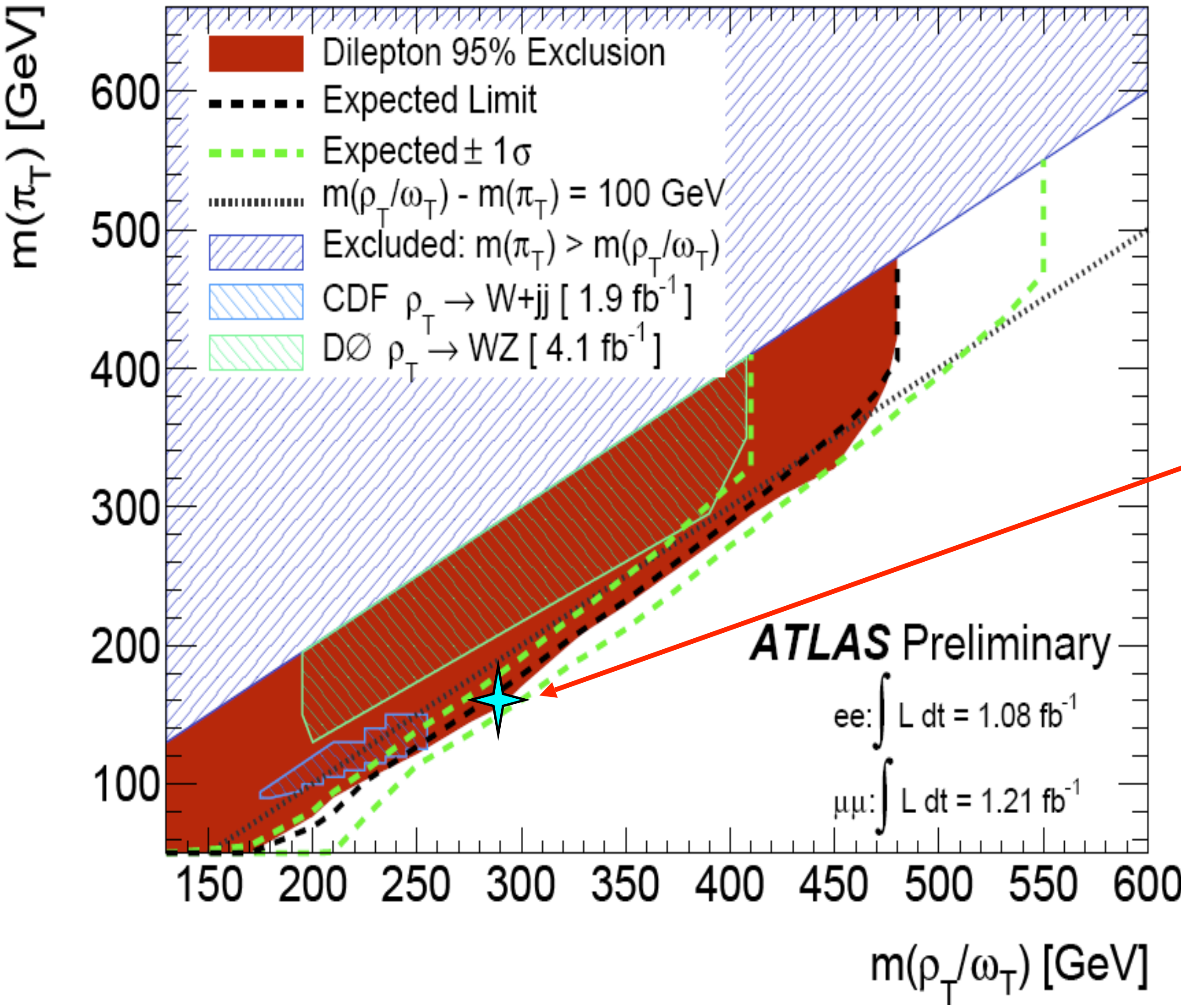
Examples of expected signal peaks



- Assume $M(\pi_T) = M(\rho_T) - 100$, GeV
- With 95% CL exclude ρ_T up to mass 470 GeV

Limit in $M(\rho_T)$, $M(\pi_T)$ plane

ATLAS-CONF-2011-125



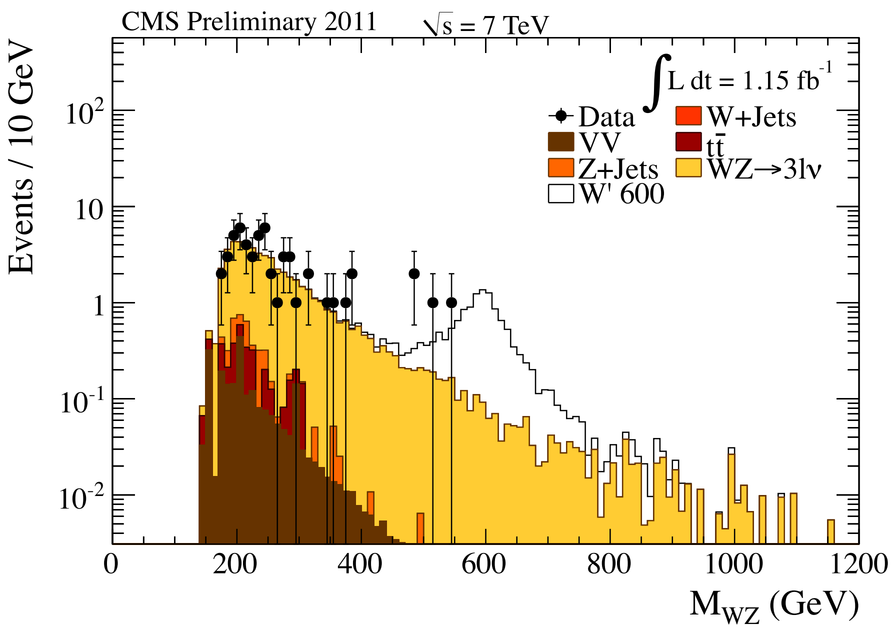
Perform a 2d scan of both $M(\rho_T)$ and $M(\pi_T)$

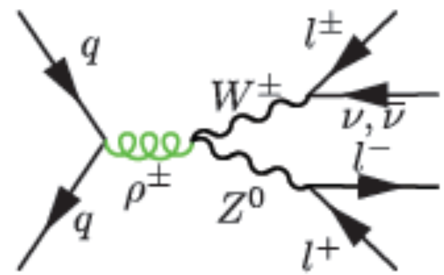
LSTC interpretation of CDF Wjj excess:

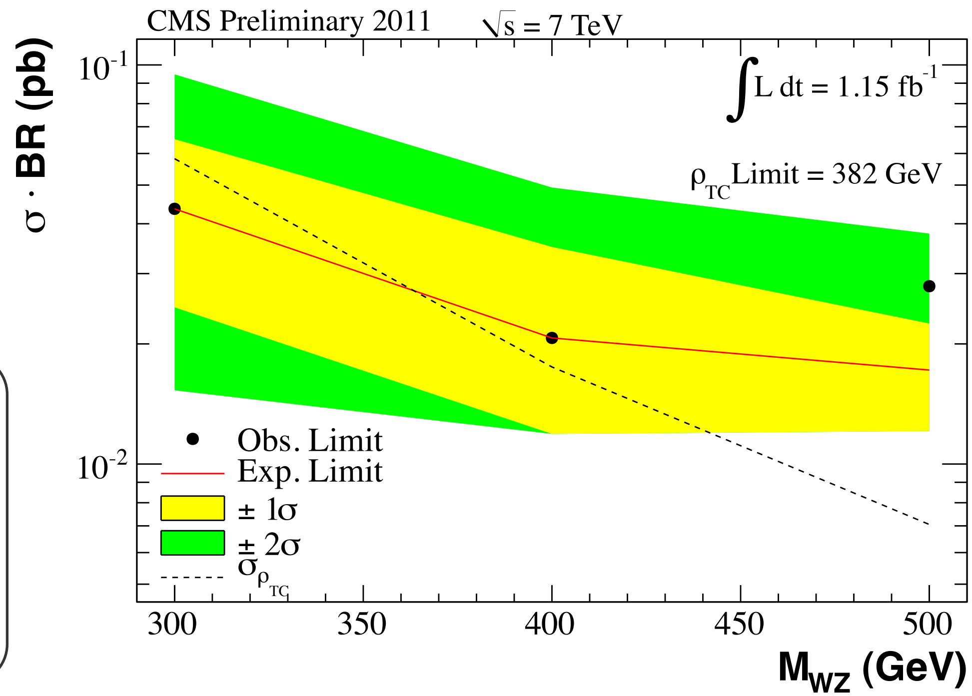
Central value corresponding to Wjj excess is just inside the excluded region

Search for $\rho_T \rightarrow WZ \rightarrow 3$ leptons + ν

CMS EXO-11-041







In the parameter space:

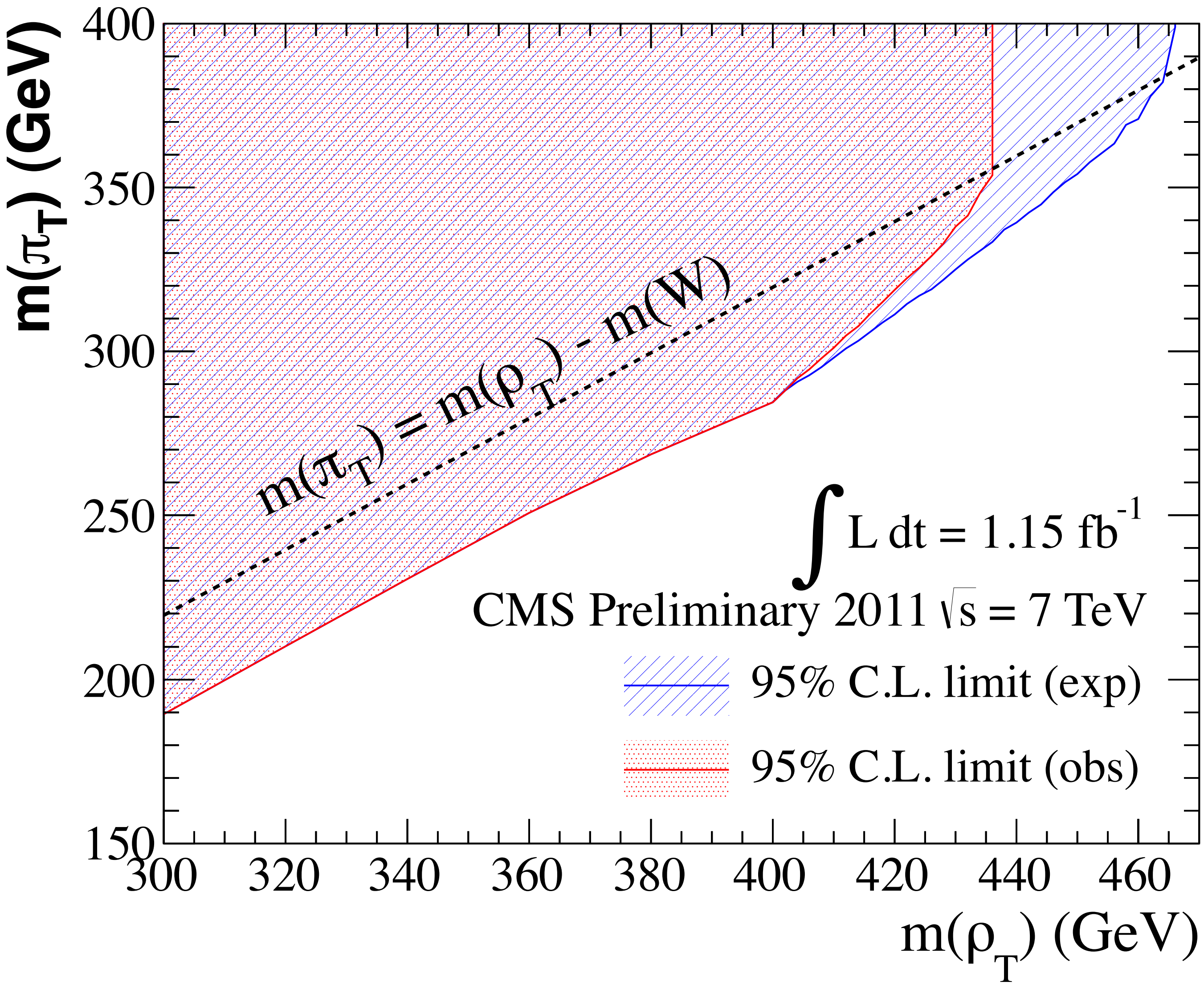
$$M(\pi_{TC}) = \tfrac{3}{4}M(\rho_{TC}) - 25\ \mathrm{GeV}$$

exclude ρ_T up to mass **382** GeV with 95% CL

Event selection and WZ cross section details are in a backup slide.

Limit in $M(\rho_T)$, $M(\pi_T)$ plane

CMS EXO-11-041



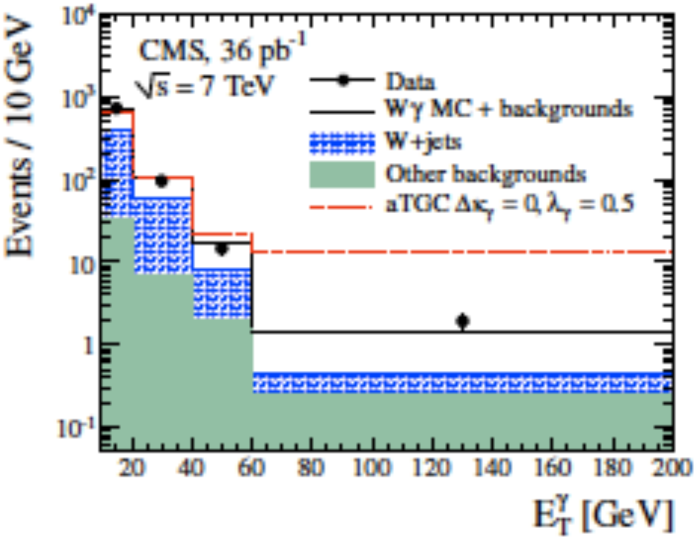
Perform a 2d scan of both $M(\rho_T)$ and $M(\pi_T)$

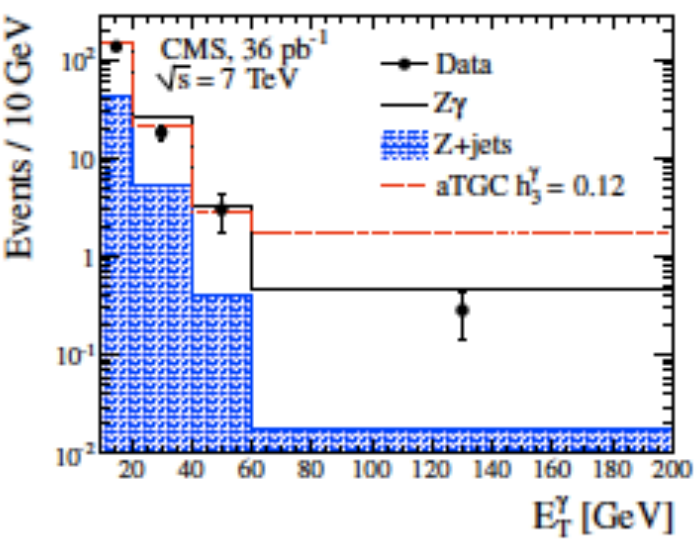
Exclude $M(\rho_T) < 436$ GeV

How about $\rho_T \to W(\to l\nu)\gamma$ and $Z(\to ll)\gamma$?

arXiv:1105.2758

Phys. Lett. B 701, 535 (2011)





- W: isolated lepton p_T>20 GeV, MET>25 GeV
- Z: dilepton invariant mass >50 GeV
- γ: E_T>10 GeV, ΔR(l,γ) > 0.7

Main background from W/Z+jets.

process	$N^{e\nu}_{bkg}$	$N^{\mu\nu}_{bkg}$
W+jet	$220 \pm 16 \pm 14$	$261 \pm 19 \pm 16$
other backgrounds	7.7 ± 0.5	16.4 ± 1.0
all data	452	520

Wγ

Z+jet	$20.5 \pm 1.7 \pm 1.9$	$27.3 \pm 2.2 \pm 2.3$
other backgrounds	neglected	
all data	81	90

Zγ

σ(pp → Wγ → lνγ) = 55.9 ± 5.0 (stat.) ± 5.0 (syst.) ± 6.1 (lumi.) pb
σ(pp → Wγ → lνγ) = 49.4 ± 3.0 pb (NLO)

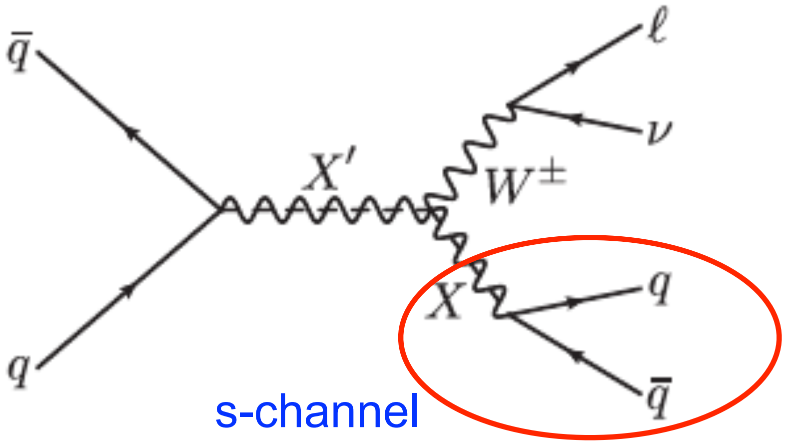
σ(pp → Zγ → llγ) = 9.3 ± 1.0 (stat.) ± 0.6 (syst.) ± 1.0 (lumi.) pb
σ(pp → Zγ → llγ) = 9.6 ± 0.4 pb (NLO)

TC would show up as a Jacobian peak at photon $E_T = \rho_T/2$. Clearly run out of events by 100 GeV in 36 pb^{-1} data. Reload is underway.

LSTC in semi-leptonic final states

What can we look for ? $\rho_T \to W(\to l\nu)\ \pi_T(\to jj)$

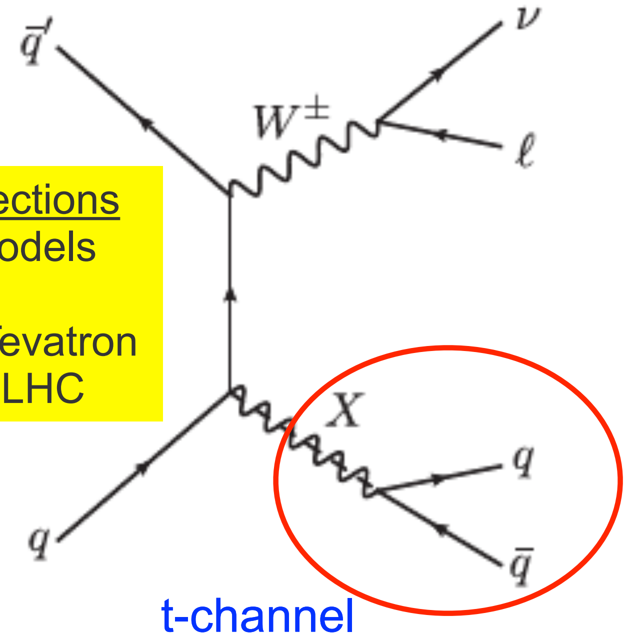
Buckley, Hooper, Kopp, Martin, and Neil; arXiv: 1107.5799



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).

<u>Total cross sections</u>
for various models

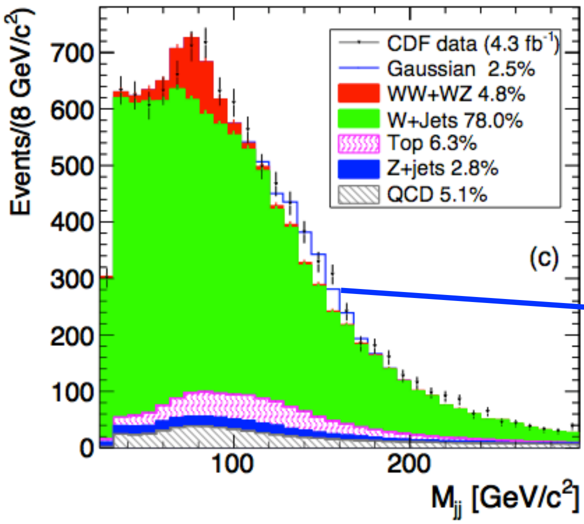
~ 1−3 pb at Tevatron
~ 5−10 pb at LHC

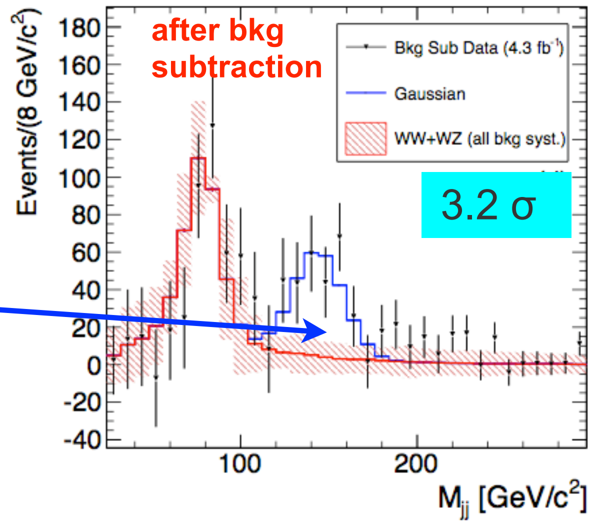


X in this case can be either a scalar or a vector boson.

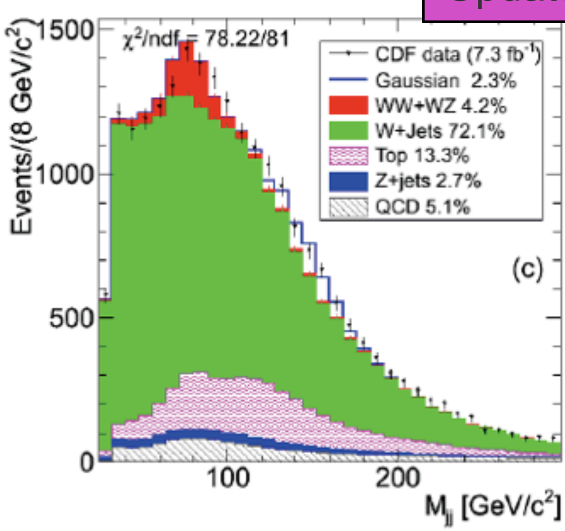
In Pythia "straw-man" implementation, $\pi_T^{\pm}$ and π_T^{0} decay to heavy flavor quarks with BR 80−90%, but cannot decay to gluon. $\pi_T^{0\prime}$ decays to heavy flavor with BR ~50% and decays to gluon pair with BR ~50%. The mixing is such that $\pi_T^{0\prime}$ component is small.

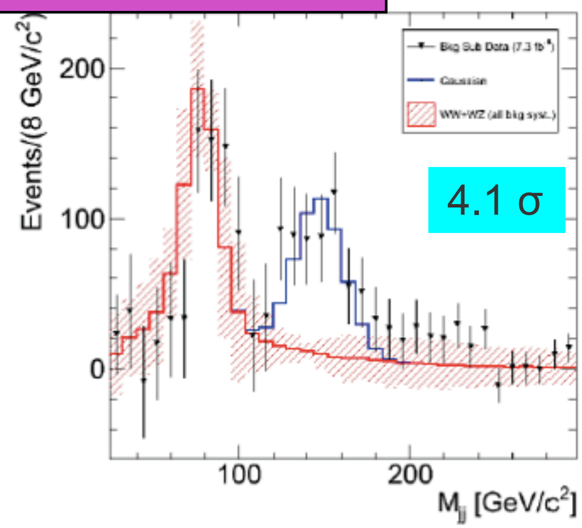
Thing that started it all: CDF saw anomaly in M_{jj}





Update using 7.3 fb^{-1} data





✦W+jj data doesn't have the featureless falloff of dijet mass spectrum

✦CDF finds an excess of 253 events, peaked at 145 GeV, width = 15 GeV

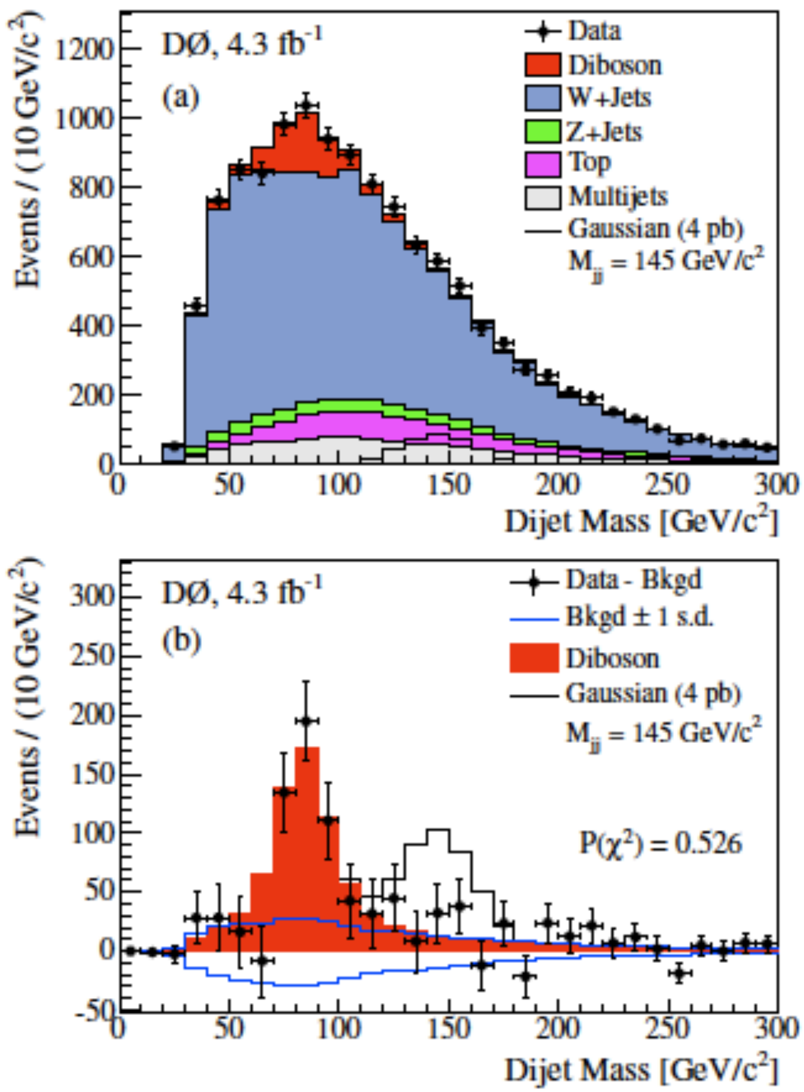
✦Significance 3.2σ, prod cross section 4 pb

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

http://www-cdf.fnal.gov/physics/ewk/2011/wjj/

Significance has been growing with more data ! Statistical significance is not in doubt, but understanding of background modeling and jet calibration is.

D∅ doesn't confirm this anomaly



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

✦W+jj data from D∅ DOES show the featureless falloff of dijet mass spectrum in the range 110−170 GeV

✦ D∅ doesn't find any excess peaked at 145 GeV

✦Excludes production cross section 4 pb at 99.9999% CL and 1.9 pb at 95% CL

✦D∅ data is fully consistent with the Standard Model W+jets and diboson production in this region

See details at:

http://www-d0.fnal.gov/Run2Physics/WWW/results/final/HIGGS/H11B/

Critical to understand what is going on here

The differences between the results of 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 upward /downward fluctuations in two expts)

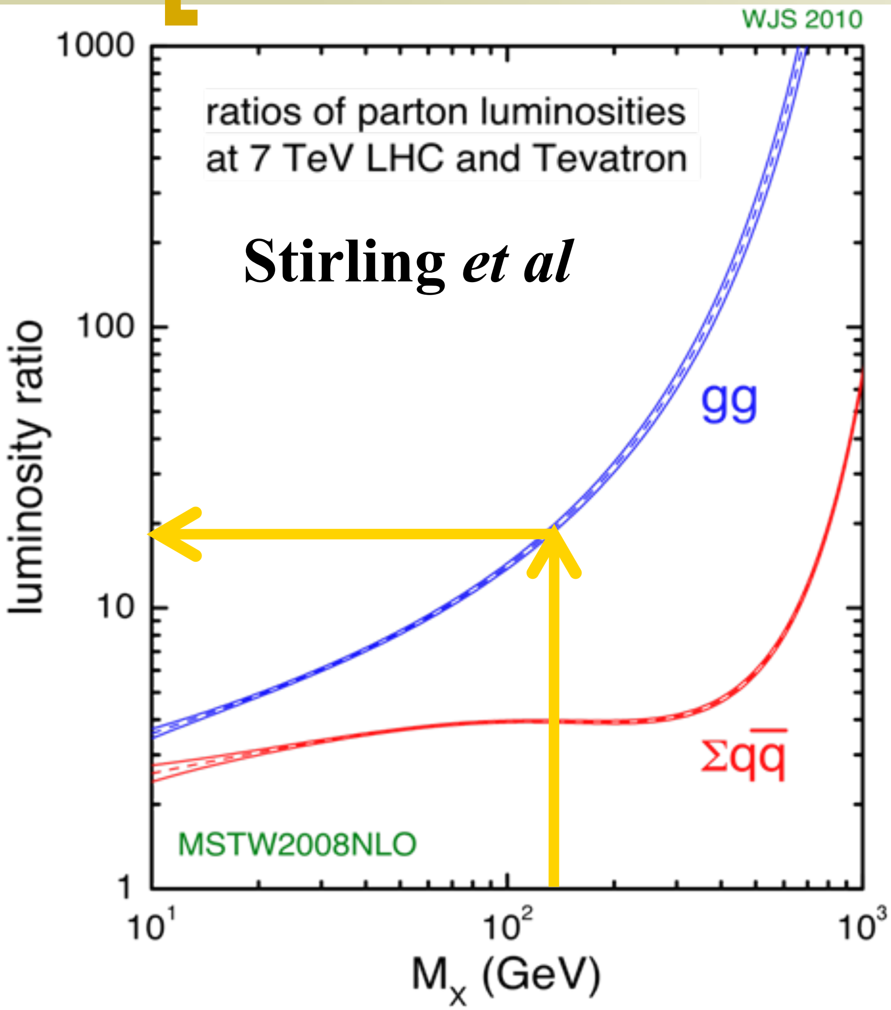
- Will show up in other places. Need to analyze:
  - -other channels (Z+jj, γ+jj),
  - -disjoint sub-samples (2-jet events vs 3-jet events) which have different S/B
  - -signal-enhanced data (e.g., require the two jets to be close in rapidity, etc.)

- Perform similar analysis at LHC:
  - -Need to optimize carefully because of much smaller S/B (see next slide).
  - -Cannot work with “loose” selection, but do not want to throw away signal.

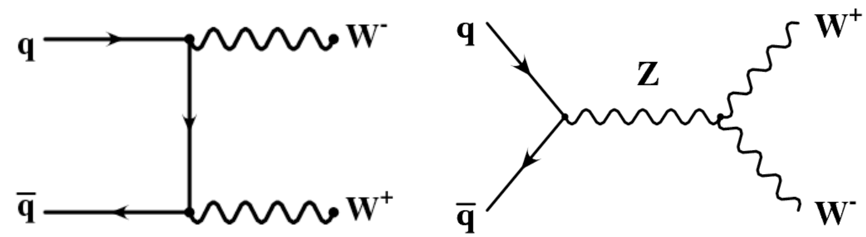
Case 2: CDF excess is caused by some subtle mis-modeling of the Standard Model backgrounds, or instrumental (mis-)calibration effect

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

LHC vs Tevatron: can LHC probe it ?



$q\bar{q}$ → WW, WZ cross section at 7 TeV is **~ 3.5 times** that at 2 TeV



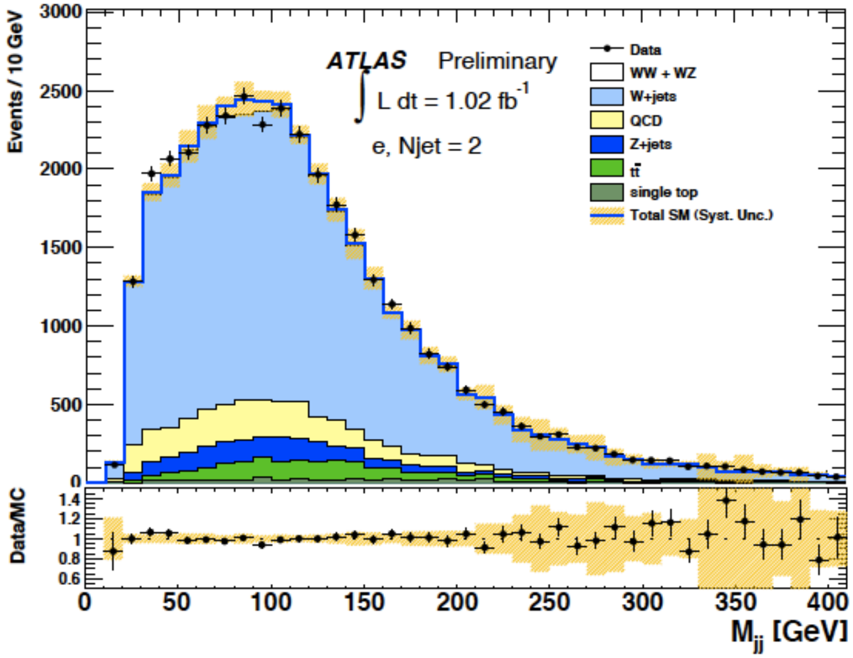
Major backgrounds are W/Z+jets, single top & $t\bar{t}$, QCD multi-jet etc. which rise **by factor 20** due to rise in qg and gg cross sections

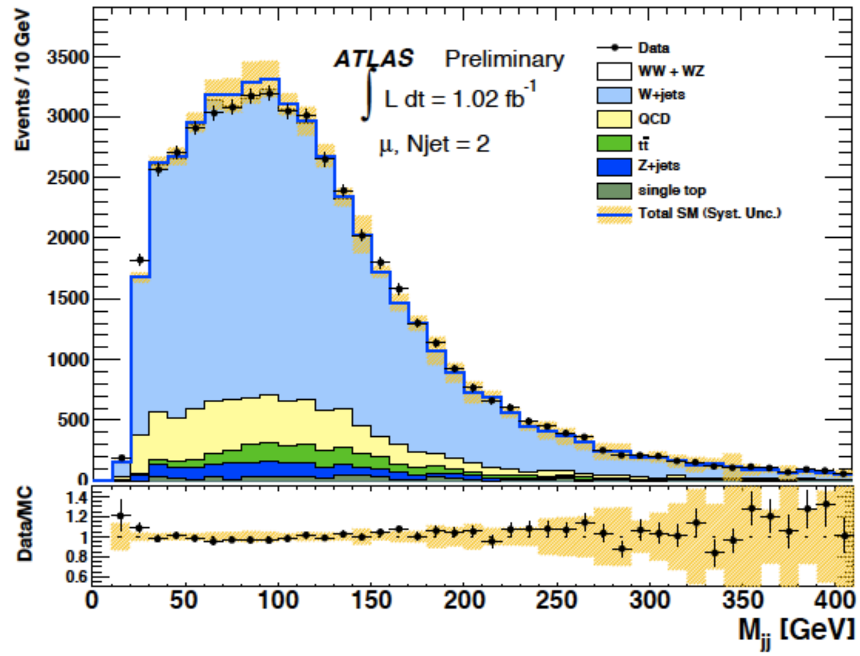
⇒ Small signal, worse S/N

Yes, but the S/B is much worse, and stronger cuts need to be applied in order to extract the signal.

Life is hard if looking for qqbar signal at LHC

ATLAS result shown in EPS





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

Clearly much worse than Tevatron experiments

Need to improve selection criteria to the ones more appropriate for LHC conditions. At the minimum should be able to see diboson peak. CMS is analyzing data carefully. With ~2−5 fb^{-1} we expect to observe or exclude CDF anomaly.

ELM recommendation to improve S/B @LHC

Testing CDF's Dijet Excess and Technicolor at the LHC

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July 20, 2011

- **Cuts to reduce the main background without removing potential new physics signals**

arXiv:1107.4075

Main recommendations

- Lead jet $p_T > 40$ GeV, second jet $p_T > 30$ GeV
- Dijet $p_T > 45$ GeV
- $\Delta\eta$ (j1, j2) < 1.2
- Plus, some model-dependent cuts optimized for TC

These cuts provide significant improvements in S/B for any qq process including the diboson WW/WZ production.

High mass TC: colorons & color octet technirho etc.

What kind of models we can probe ?

Name	Symbol	Spin Parity (J^P)	Color Multiplet	$\Gamma/(2M)$	Channel
Axigluon	A	axial-vector (1^+)	octet	0.05	$q\bar{q}$
Coloron	C	vector(1^-)	octet	0.05	$q\bar{q}$
Excited Quark	q^*	fermion ($1/2^+$	triplet	0.02	qg
Octet Technirho	ρ_{T8}	vector (1^-)	octet	0.01	$q\bar{q}, gg$
E_6 Diquark	D	scalar (0^+)	triplet	0.004	ud
Heavy W	W'	vector (1^-)	singlet	0.01	$q_1\bar{q}_2$
Heavy Z	Z'	vector (1^-)	singlet	0.01	$q\bar{q}$
RS Graviton	G	tensor (2^-)	singlet	0.01	$q\bar{q}, gg$

Color Octet Technirhos

Produced via a vector meson dominance model of mixing between the gluon and color octet technirhos: $q\bar{q}, gg \to g \to \rho_{T8}$

1. Standard Topcolor-Assisted-Technicolor (TC2) couplings
2. Degenerate Technirhos: $M(\rho_{11}) = M(\rho_{12}) = M(\rho_{21}) = M(\rho_{22}) = M(\rho)$ the pole mass.
3. Mixing among the technirhos: $M_8^I = 0$ to reduce the mass shift from the pole mass.
4. Octet Technipion mass: $M(\pi_{22}^8) = 5M(\rho)/6$ to prevent $\rho \to \pi\pi$.
5. Singlet Technipion mass: $M(\pi_{22}^1) = M(\pi_{22}^8)/2$
6. Coloron Mass: $M(V8) = 100$ TeV coloron at "infinity" so it doesn't affect cross section.
7. Parameter $M_8 = 5M(\rho)/6$ which keeps $\rho \to g\pi$ small to avoid a large ρ width.

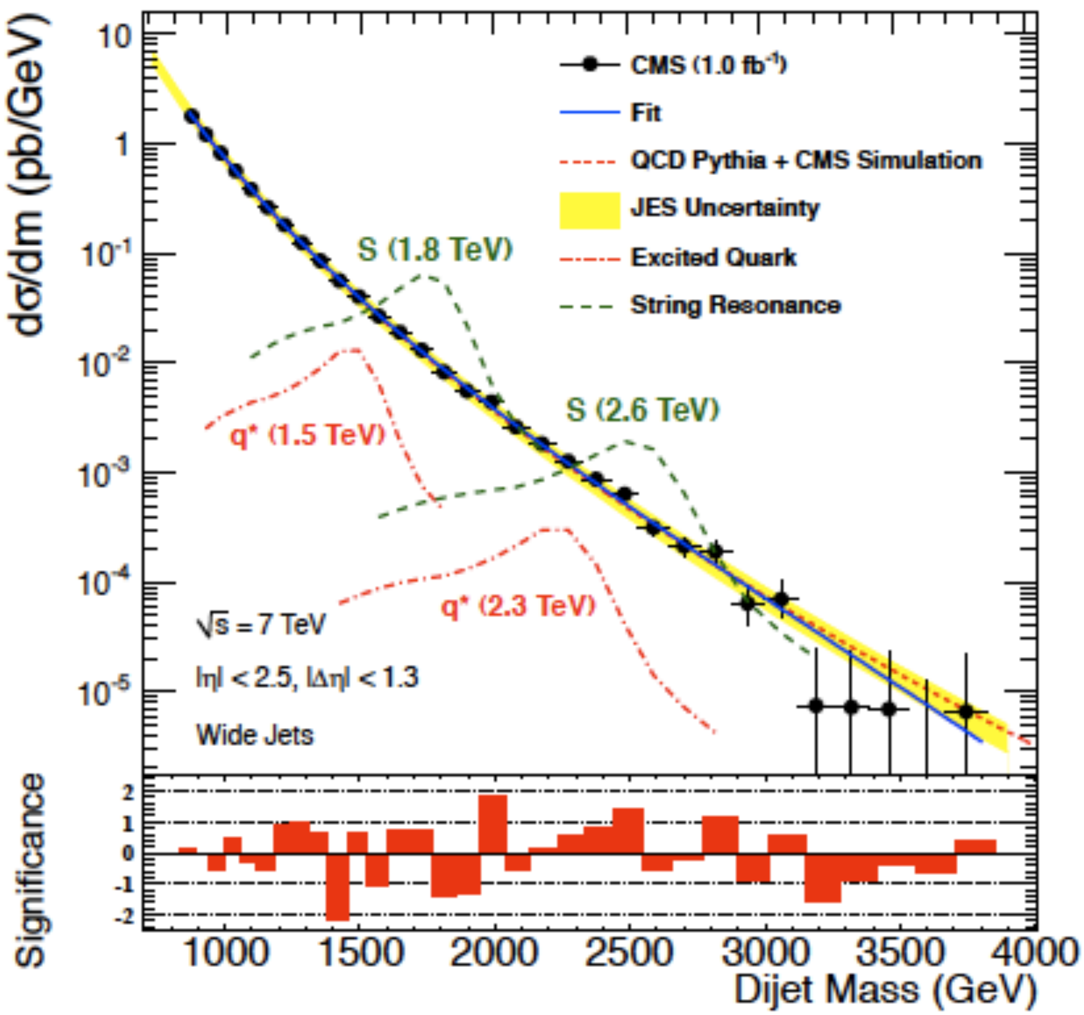
Pythia implementation

Lane & Mrenna

Phys. Rev. D67,115011(2003)
hep-ph/0210299

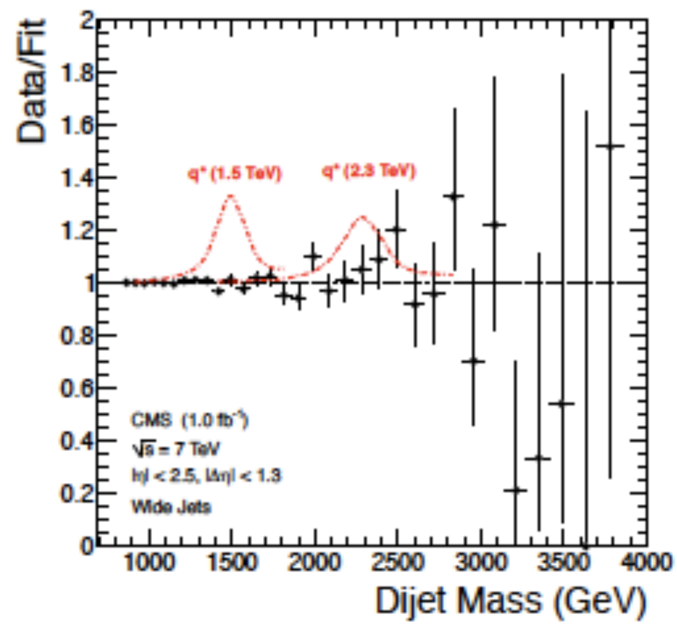
Dijet resonance search

arXiv:1107.4771,   CMS-EXO-11-015



Smooth fall of dijet mass spectrum. Exclude dijet resonances in a large class of models up to very high mass.

Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40



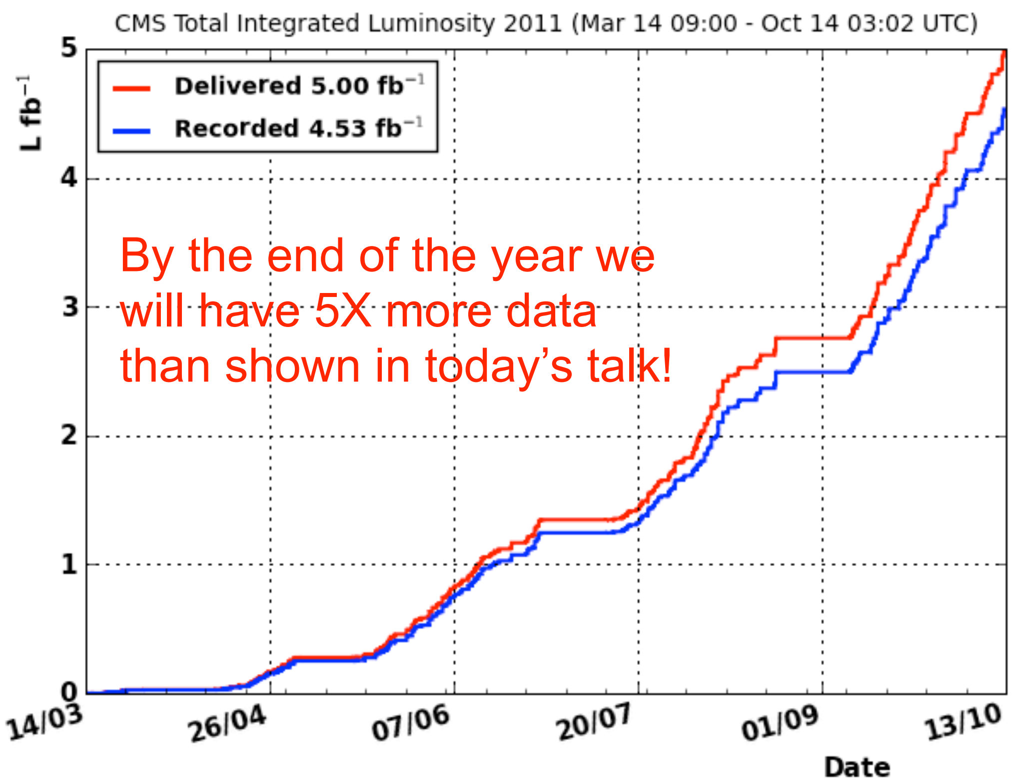
ATLAS has similar limits.

Outlook for 2011 data collection and beyond

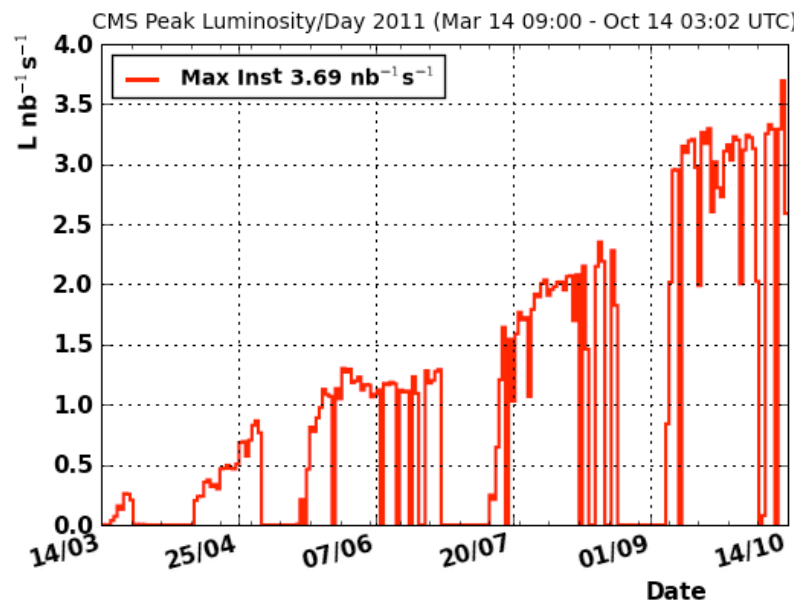
Outlook is bright

Target:
To get 10–30 fb^{-1} at $\sqrt{s}$ = 7 or 8 TeV by 2012. With ~5E33 instantaneous lumi.

- LHC sets new world record luminosity: **3.7** $nb^{-1}s^{-1}$ (i.e., 3.7E33)
- Continuous physics running until 2012
  - short technical stop in December
  - already delivered **5 fb^{-1}** per expt



By the end of the year we will have 5X more data than shown in today's talk!



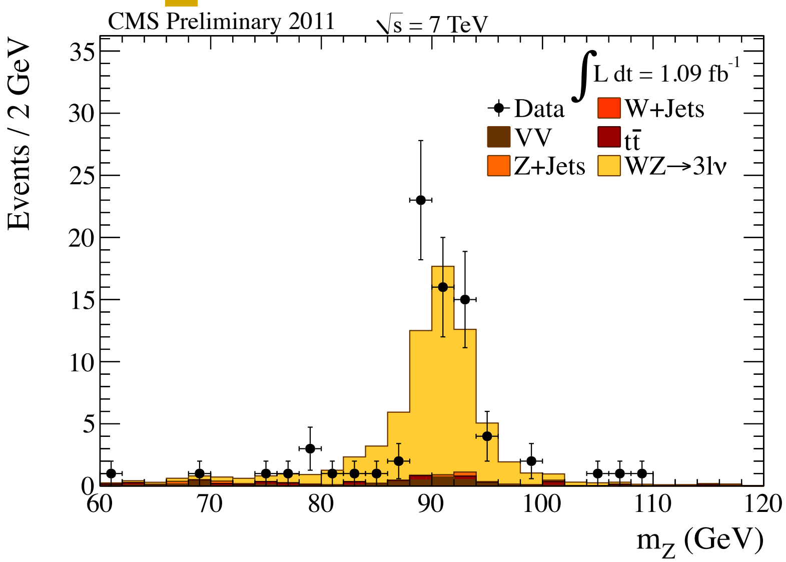
Summary

- Technicolor models are important benchmarks for LHC exotic searches.
- So far data show good agreement with the SM and with most of the state of the art MC predictions.
- LHC sensitivity for technicolor and TC-like models with ~1 fb^{-1} competitive to Tevatron.
  - -Exclusion limits already beyond those of Tevatron experiments.
- More new exciting results to come in the next few months with increased integrated luminosity.

BACKUP SLIDES

WZ→3lν cross section measurement (1.1 fb^{-1})

http://cdsweb.cern.ch/record/1370067?ln=en
CMS-PAS-EWK-11-010



✦Two isolated leptons with p_T 20/10 GeV for electrons or p_T > 15 GeV for muons.
✦3rd isolated lepton p_T > 20 GeV, MET>30 GeV
✦60 < m_{ll} < 120 GeV. Ambiguities resolved by taking the Z candidate closest to M_Z. Veto 2nd Z.

Tiny background. Estimate TTbar and Z+jets from data using matrix method. Take Zγ and ZZ from MC.

Channel	A_{kin}	$A \cdot \epsilon$
eee	0.482 ± 0.003	$0.193 \pm 0.003(stat)$
$ee\mu$	0.488 ± 0.003	$0.234 \pm 0.003(stat)$
$\mu\mu e$	0.432 ± 0.003	$0.190 \pm 0.003(stat)$
$\mu\mu\mu$	0.454 ± 0.003	$0.249 \pm 0.003(stat)$

channel	$N_{observed}$	cross section (pb) x BR
$\sigma_{WZ \to eee\nu}$	22	$0.086 \pm 0.022(stat) \pm 0.007(syst) \pm 0.005(lumi)$
$\sigma_{WZ \to ee\mu\nu}$	20	$0.060 \pm 0.017(stat) \pm 0.005(syst) \pm 0.004(lumi)$
$\sigma_{WZ \to \mu\mu e\nu}$	13	$0.053 \pm 0.018(stat) \pm 0.004(syst) \pm 0.003(lumi)$
$\sigma_{WZ \to \mu\mu\mu\nu}$	20	$0.060 \pm 0.016(stat) \pm 0.004(syst) \pm 0.004(lumi)$

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

$$\sigma(pp \to WZ + X) = 17.0 \pm 2.4\ (\text{stat.}) \pm 1.1\ (\text{syst.}) \pm 1.0\ (\text{lumi.})\ \text{pb}.$$

NLO prediction = 19.8 ± 0.1 pb