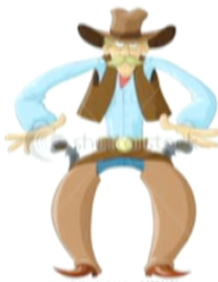
Title: Safe SupeRsymmetry

Date: Mar 07, 2012 11:00 AM

URL: http://pirsa.org/12030104

Abstract: Supersymmetry is a popular candidate for the 'model beyond the Standard Model', however minimal versions of it are quite constrained by the first year of data from the LHC. In this talk I will focus on supersymmetry scenarios where the gaugino masses are Dirac rather than Majorana. This seemingly innocuous change has a profound impact on collider bounds -- reducing the bound on (1st and 2nd generation) squark masses by nearly a factor of two. In addition, Dirac gaugino scenarios have amazing flavor properties, smoking gun LHC signals, and cosmological implications.

W+jj: collider physics on the wild frontier



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Fermilab

Perimeter Institute
March 7th, 2012

Motivation

the LHC era is here!

there are some signals we certainly 'expect' to see at the LHC, but hopefully there will be total surprises as well

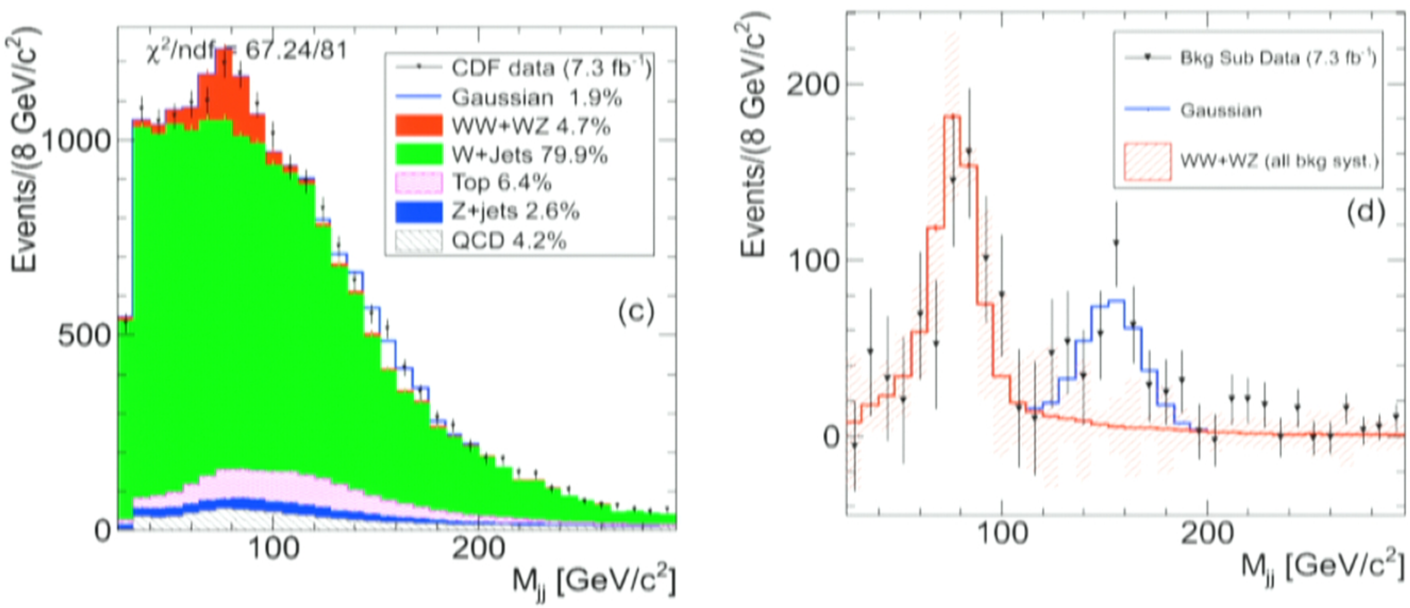
interpreting and understanding these surprises requires a blend of experimental particle physics, **model building**, and **phenomenology (QCD & Monte Carlo)**

we got some practice at this interplay last summer with some Tevatron surprises...

the CDF 'bump' (1104.0699+update)

7.3 fb^{-1} data: central l(e/μ), MET > 25 GeV, 2 jets p_T > 30.0 GeV, $p_{T,jj}$ > 40.0 GeV

look in dijet mass spectrum



4.1 (syst) sigma excess

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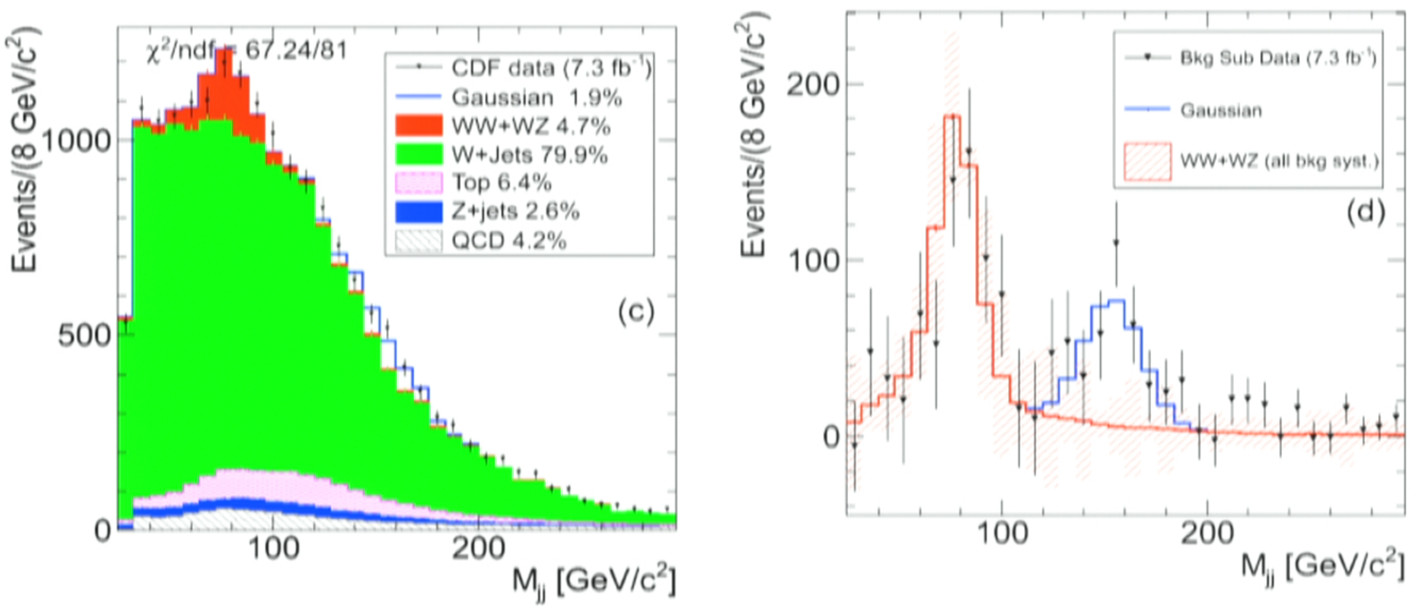


4.1 (syst) sigma excess

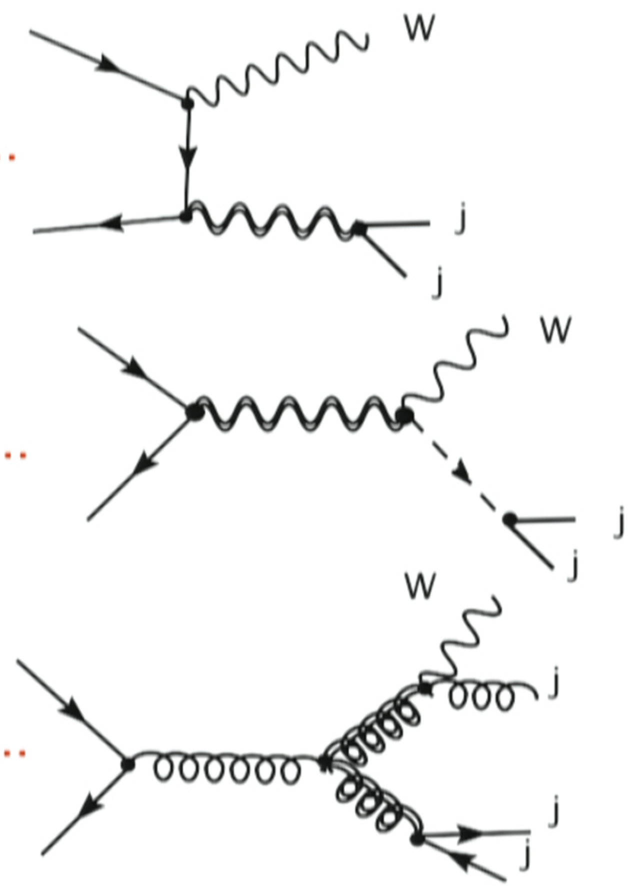
what (new physics) it could be...

tough to get a large enough cross section.. recall $\sigma(p\bar{p} \to WW/WZ) \sim 18$ pb

one resonance...

two resonances...

pair production...



more?

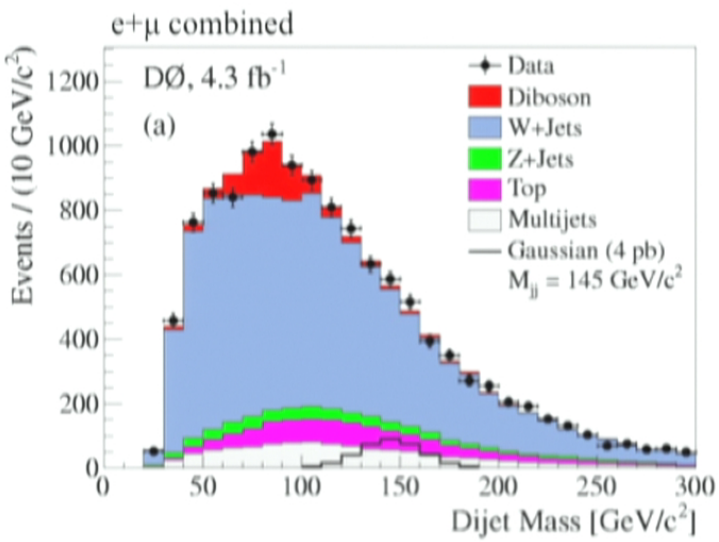
wait a minute...

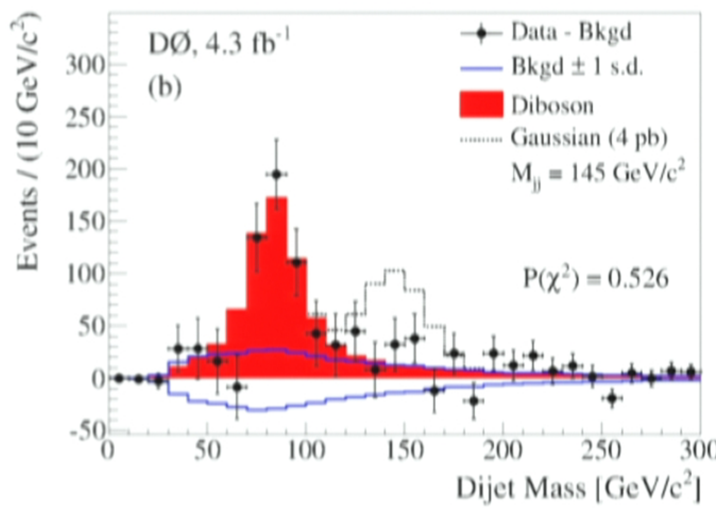
"I thought this went away...?"
or "I heard this went away..."

NOPE

the DØ response (1106.1921)

4.3 fb^{-1} data, ~~same~~ similar analysis as CDF (no reweight!)





some excess, **BUT consistent with the SM**

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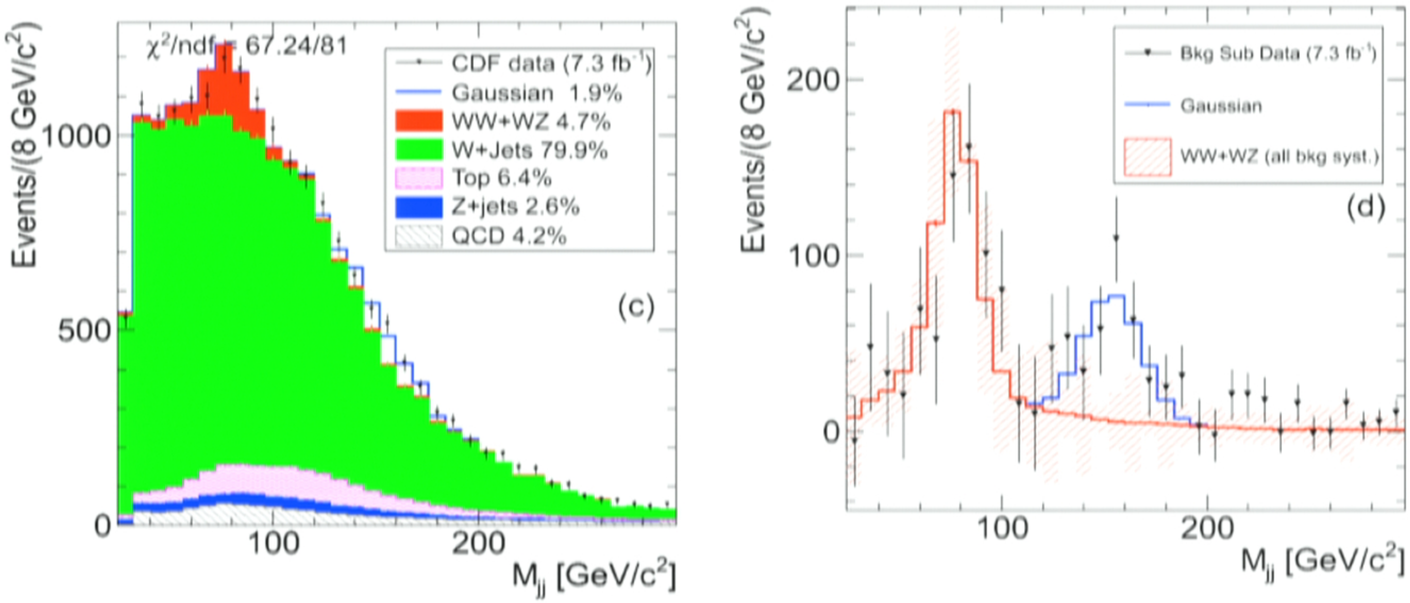

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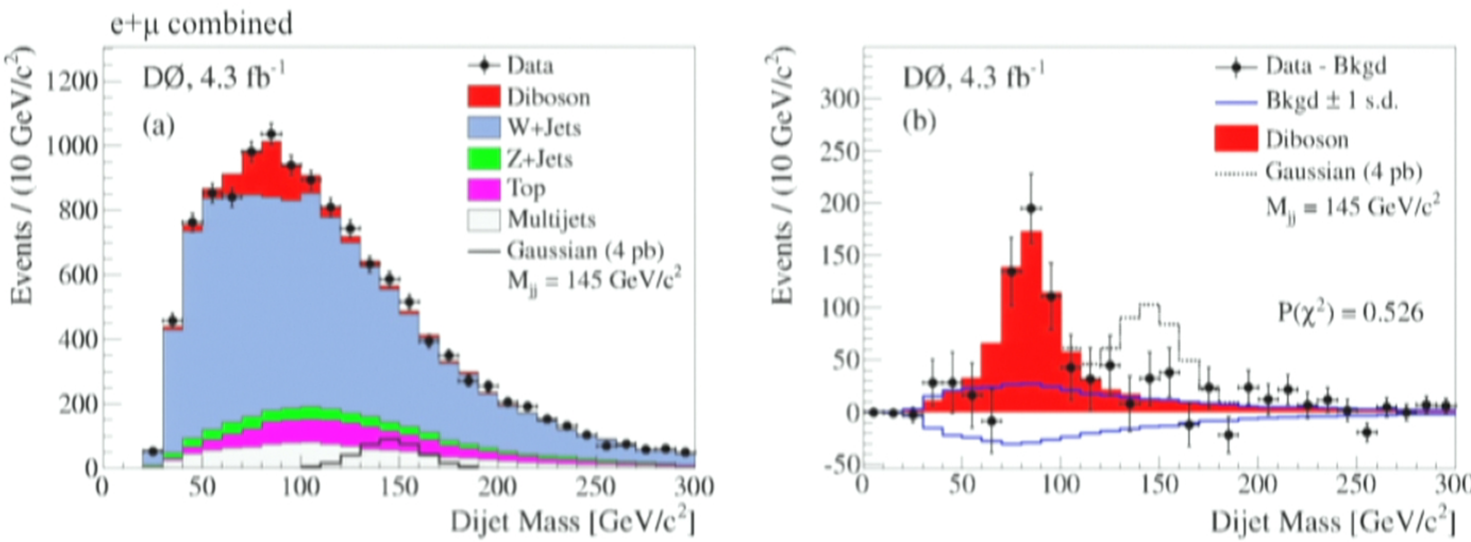

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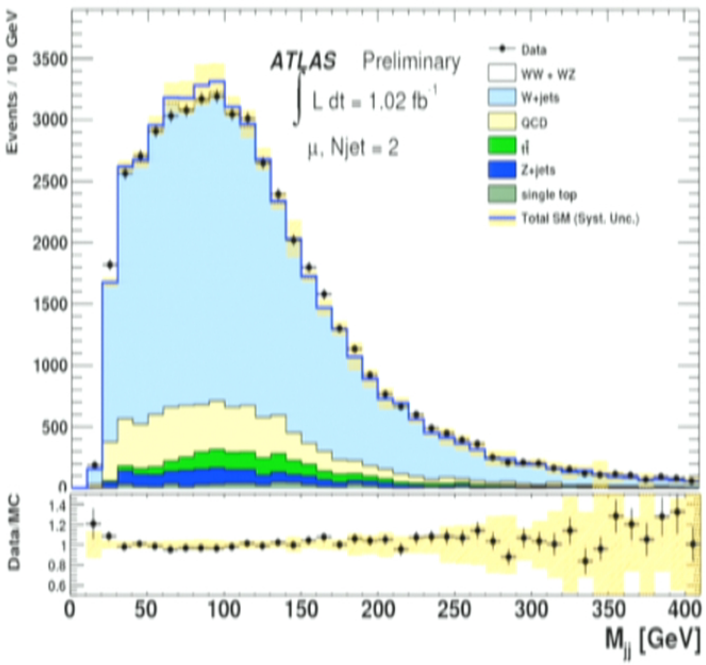

ATLAS analysis (1 fb^{-1}) sees no deviation from SM

BUT not yet sensitive to WW/WZ

- W+jets increases by x10,
- qqbar induced processes only increase by ~ x4

difficult to study at the LHC

may rule out glue-induced or large coupling new physics

estimate that MUCH more data needed if qqbar induced NP. syst?

(Eichten, AM, Lane 1107.4075, Buckley, AM et al 1107.5799)

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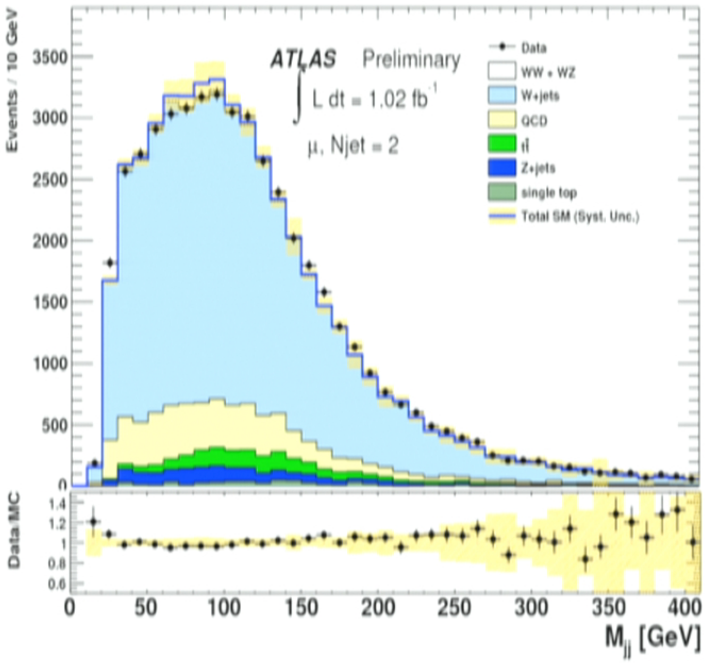

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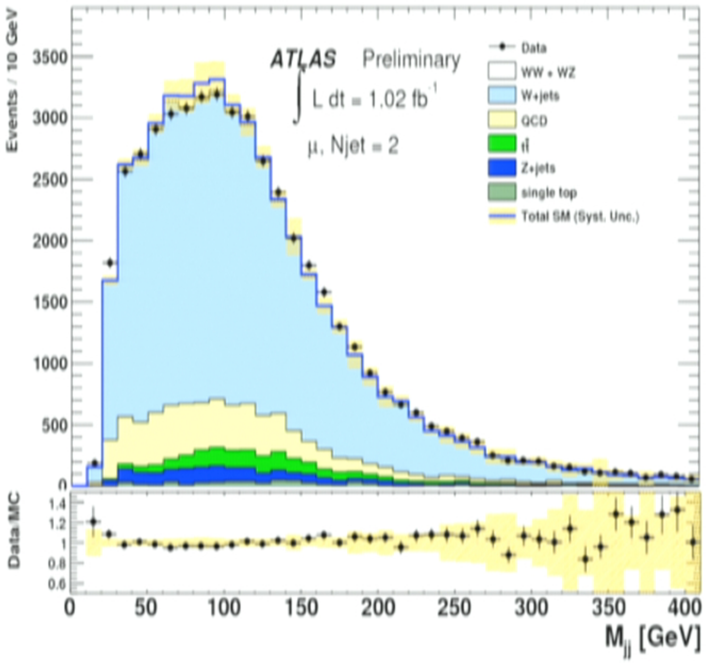

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what about this task force?

came.. saw... **agreed to disagree**

did get better estimates of how consistent/discrepant results are:

CDF: 3.0±0.7 pb

D0: $0.82^{+0.83}_{-0.82}$ pb

($0.42^{+0.76}_{-0.42}$ pb)

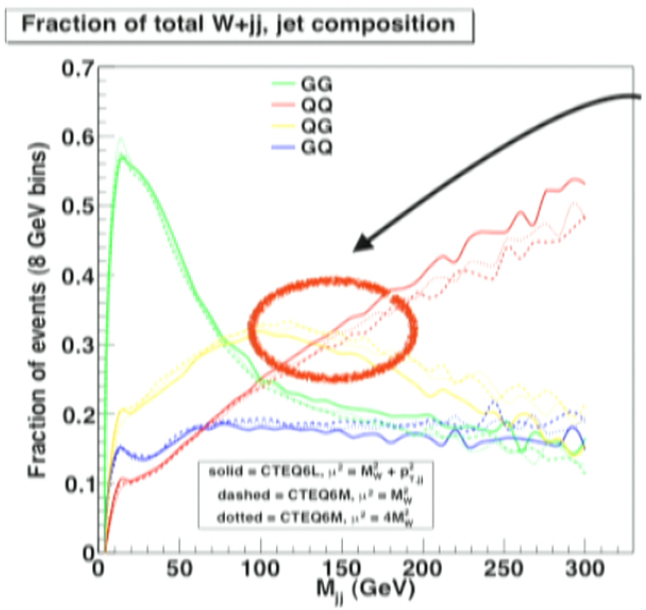
using H(bb)W, m_H = 150 GeV
acceptance*efficiency

& studied how MC choices/tunings effect results

first : quarks vs. gluons

lots of noise about mis-modeled gluon Jet Energy Scale (JES) as an explanation

- JES(p_T, η) known to % level for light quarks (from ttbar), but what about gluon-jets?



could be important ...

BUT if gluon JES is different, other processes will also be effected (dijets, gamma/Z + jets, etc.), as will other distributions

what makes a gluon jet?

SEE: www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html

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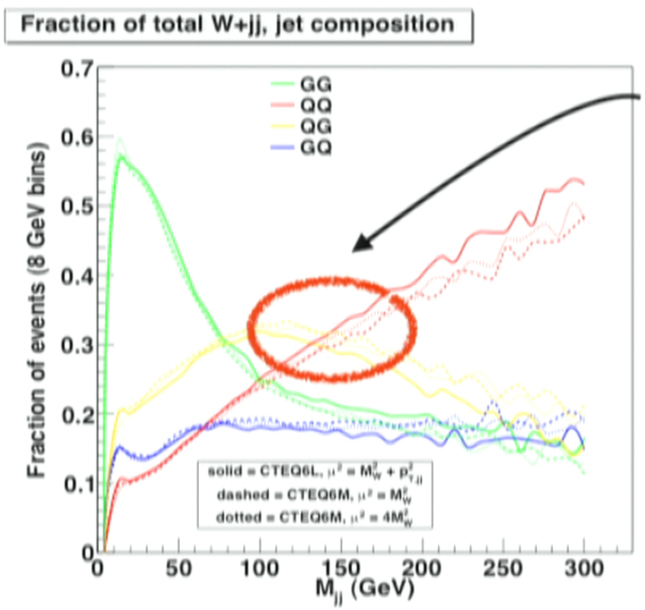

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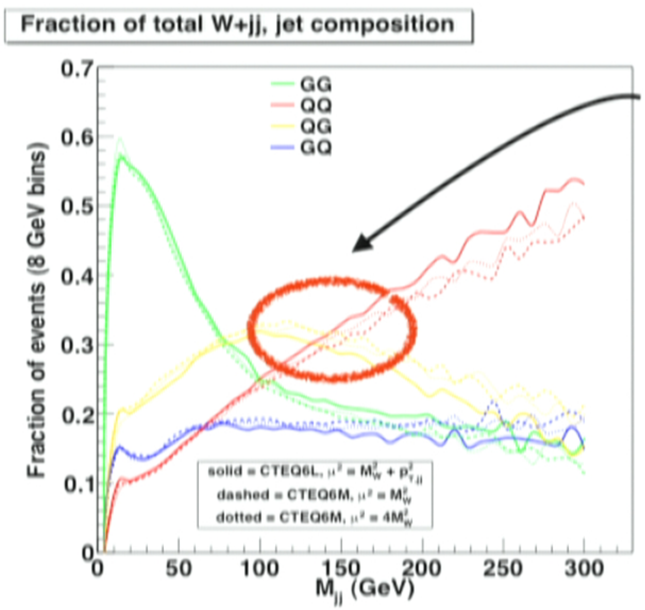

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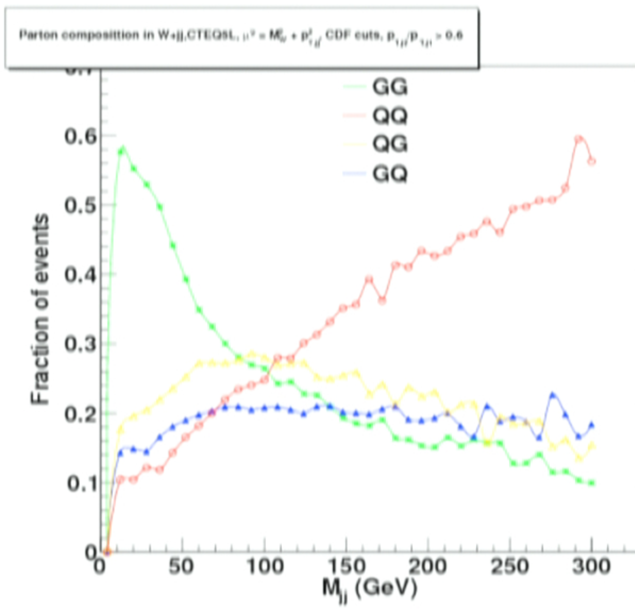

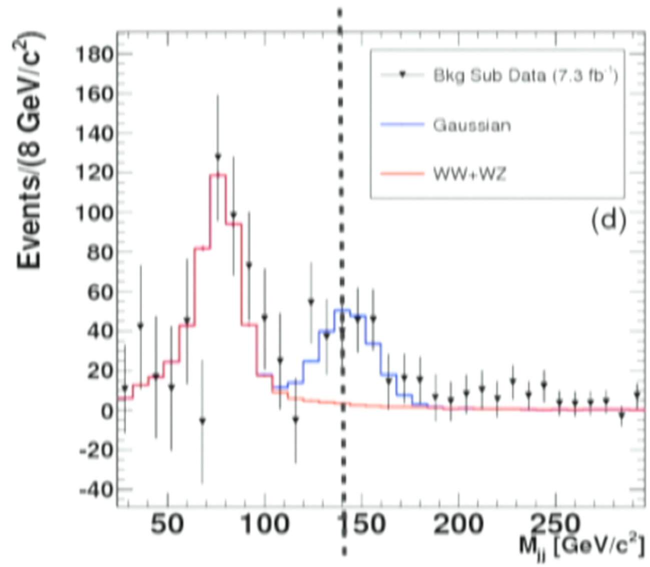

increasing $p_{T,2}/p_{T,1}$

many other checks pursued by CDF (see CDF note 10601 (July '11))

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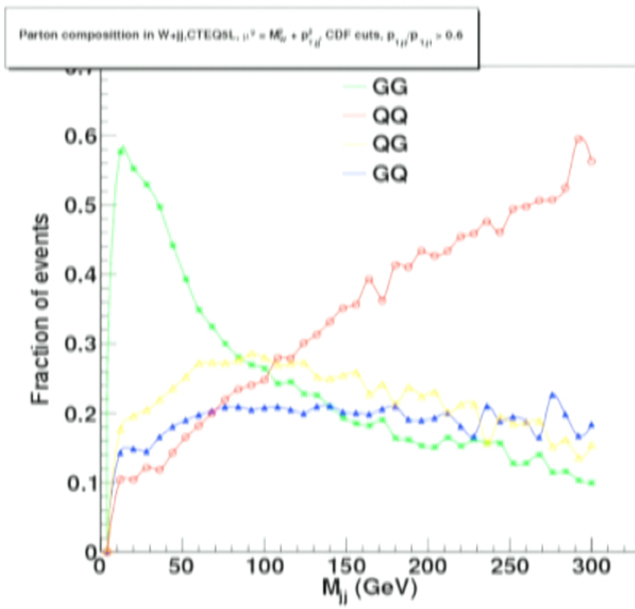

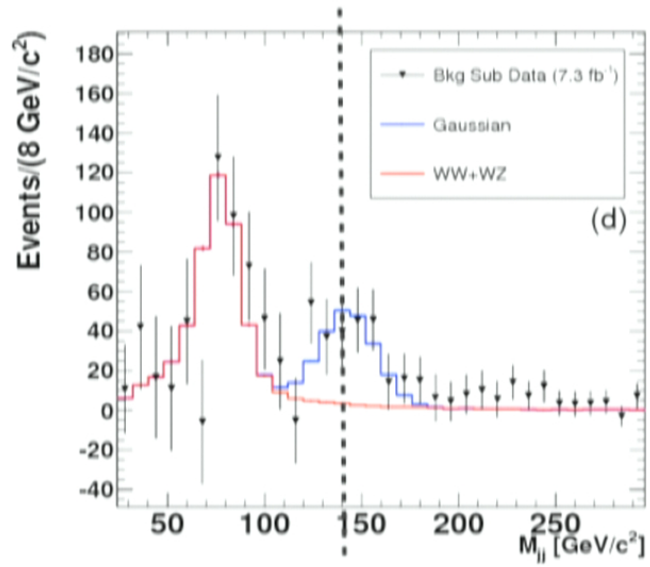

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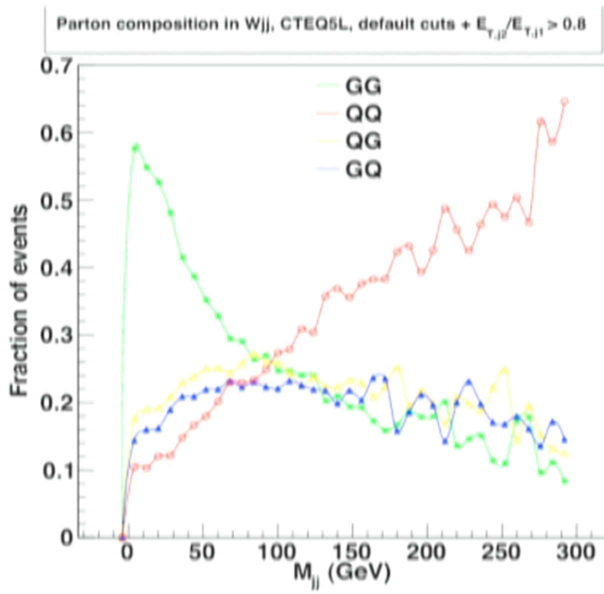

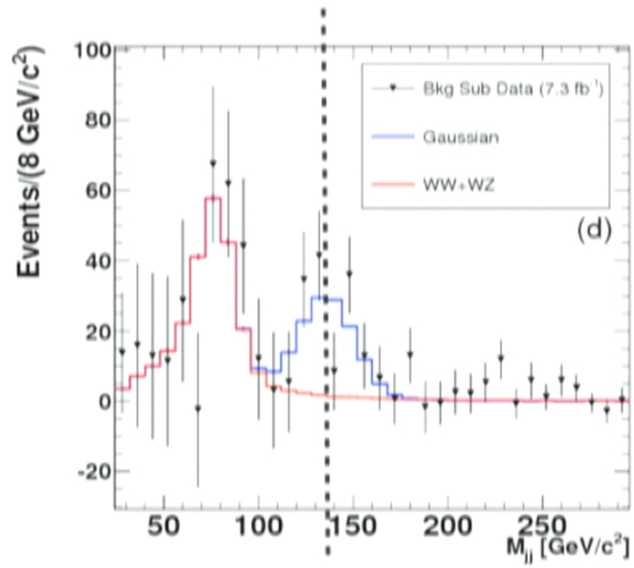

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SM: what it's not

- an artifact of LO background modeling:

dominant W+ jets background modeled with ALPGEN + PYTHIA, subject to large scale uncertainties

BUT:

can be improved by using NLO calculations (via MCFM)

- K factors (w/ CDF cuts) are O(1)
- ratios of subdominant backgrounds to W+jet agree w/ CDF
- shape of W + jets agrees with NLO calculation in the region of interest
- theory error estimates << S/B

(J. Campbell, AM, C. Williams 1105.4594)
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in exclusive n_{jet} = 2 sample, requires losing/vetoing 2 jets from ttbar (semi-leptonic), not well described by fixed order calculation

has a feature at ~150 GeV at parton level, looks dangerous

(Plehn, 1104.4087)

BUT:

- addition of parton shower brings top closer to CDF value
- parton shower also softens the feature, moving it to lower m_{jj}. detector effects will also go in this direction

still worried?

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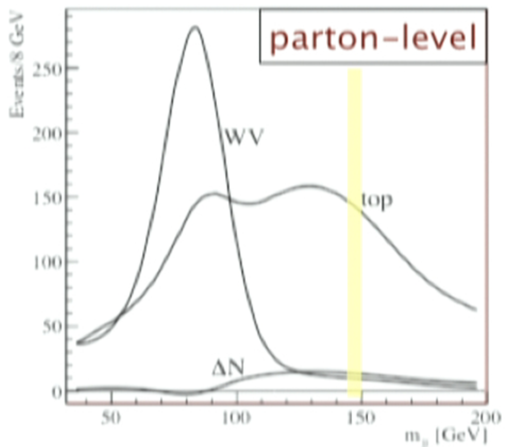

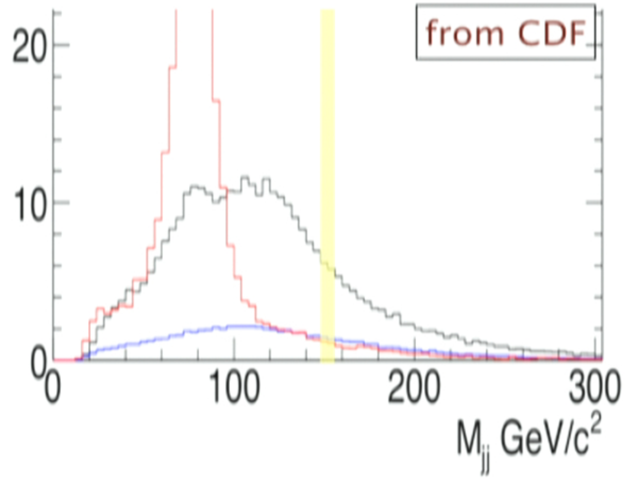

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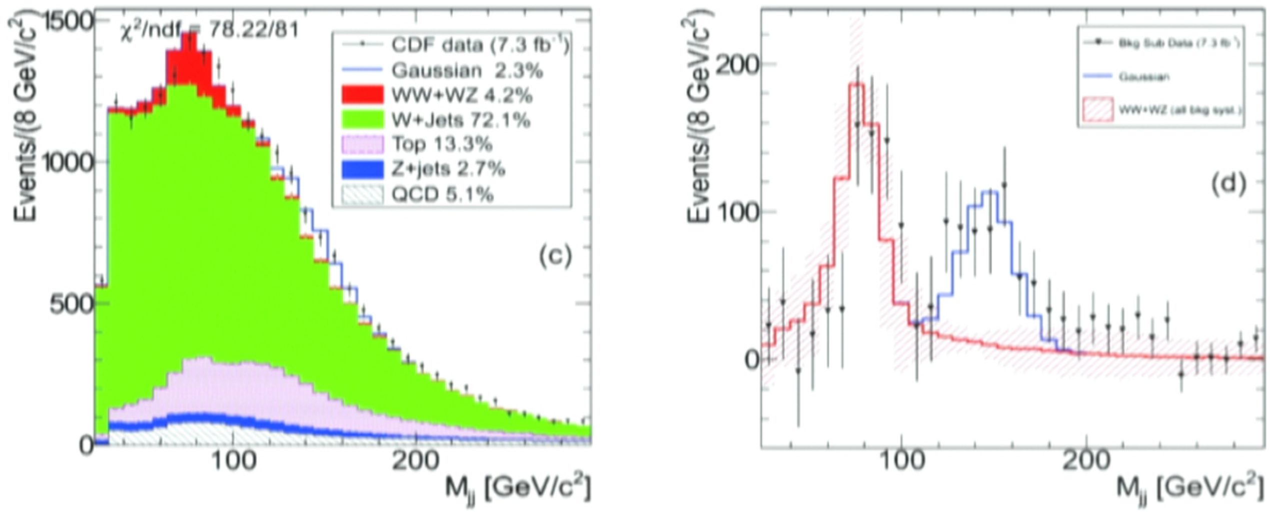
- from ttbar mismodeling (theory):

ALSO: excess still present in inclusive (2^+ jets) studies (same significance), where there is no such veto issue

www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html



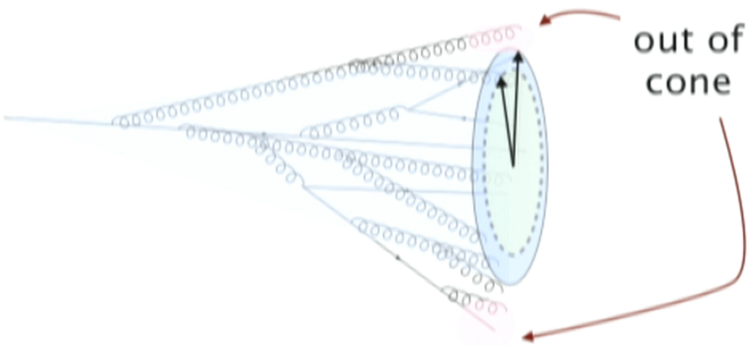
inclusive: NLO rates are now consistent with CDF, ttbar K factor w/ CDF cuts is < 1

(J. Campbell, AM, C. Williams 1105.4594)

what could it be?

biggest difference is systematics: number, treatment

ex.) D∅ adds in `out-of cone' radiation, CDF does not
(not clear they have the same definition of 'out-of-cone')



leads to slightly different definition of jets

CDF excess is quite sensitive to p_T

jet p_T > 30.0 GeV : 3.2 σ at 4.3 fb^{-1}
jet p_T > 20.0 GeV : 1.1 σ

analysis with harder p_T cuts would **really** clear this up.

no matter what: if different treatment of systematics can cause such effects --> we're in **deep** trouble

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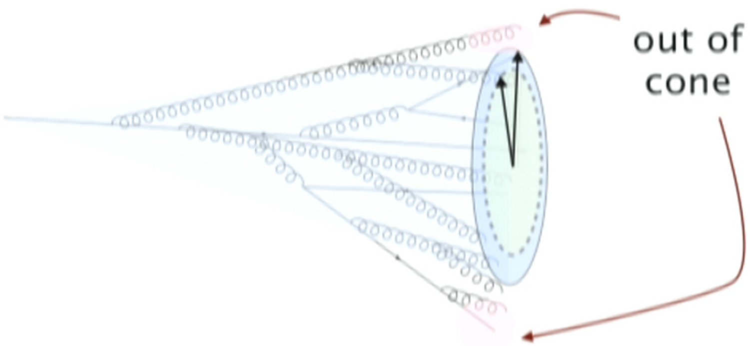

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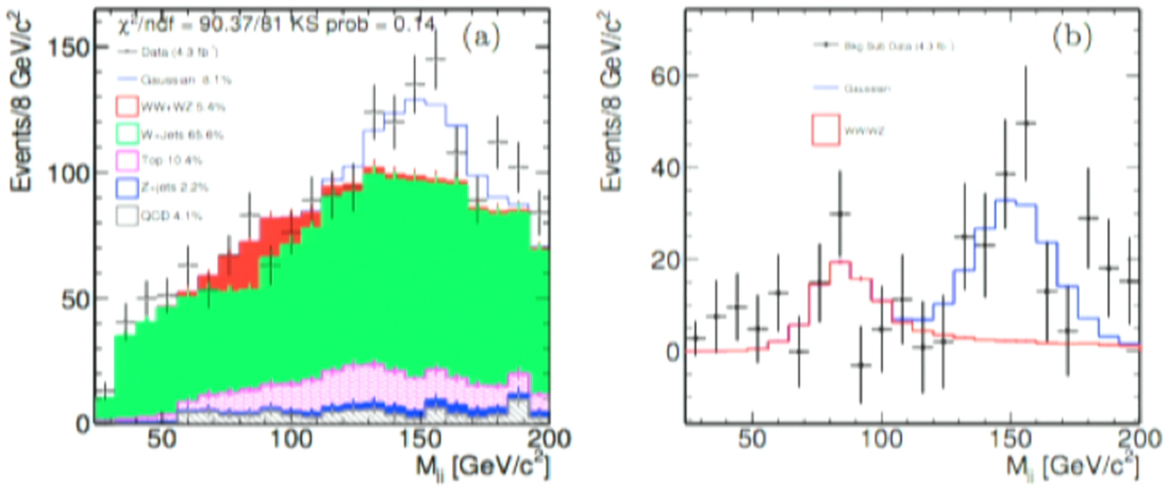
jet p_T > 50 GeV



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where does this leave us?

My opinion: CDF & DØ are likely not that incompatible once compared more equally

& combination will show deviation from backgrounds consistent with ~1–2 pb new physics cross section

even though it's unexpected, it still NEEDS to be understood

- no SM physics explanation so far
- so, what new physics can explain it? & how can we distinguish among models

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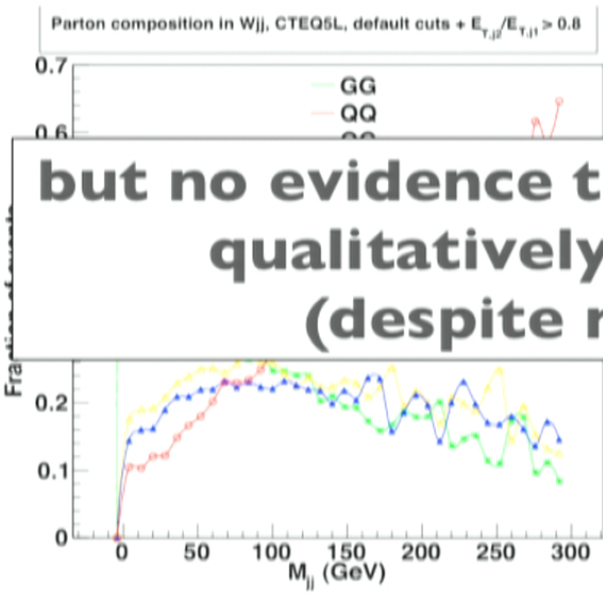
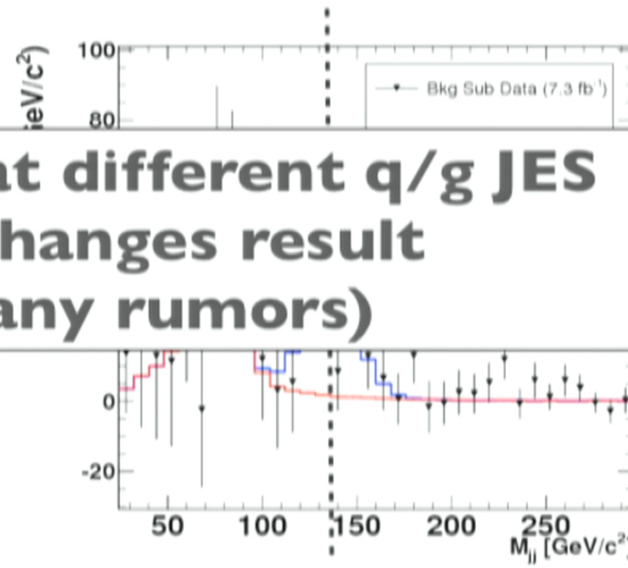


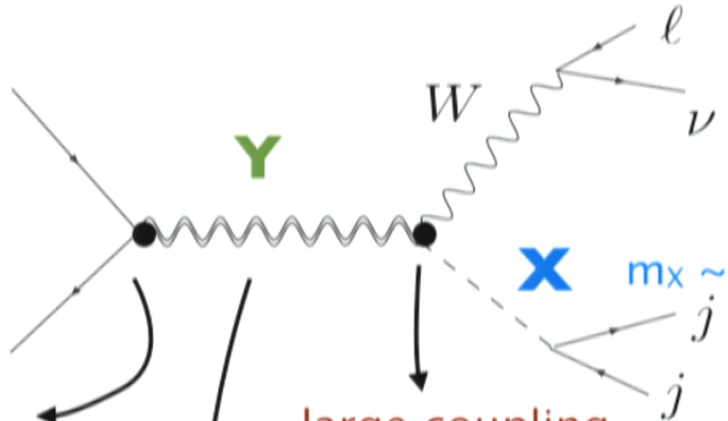


but no evidence that different q/g JES qualitatively changes result (despite many rumors)

increasing $p_{T,2}/p_{T,1}$

many other checks pursued by CDF (see CDF note 10601 (July '11))

W + jj from two resonances



$m_X \sim$ 150–160 GeV

small coupling

large coupling

needed to avoid direct Z'/W' constraints

resonant production of parent resonance

EW charged? spin?

narrow width, large BR to W jj necessary to get enough rate

(Eichten, Lane, AM 1104.0976)

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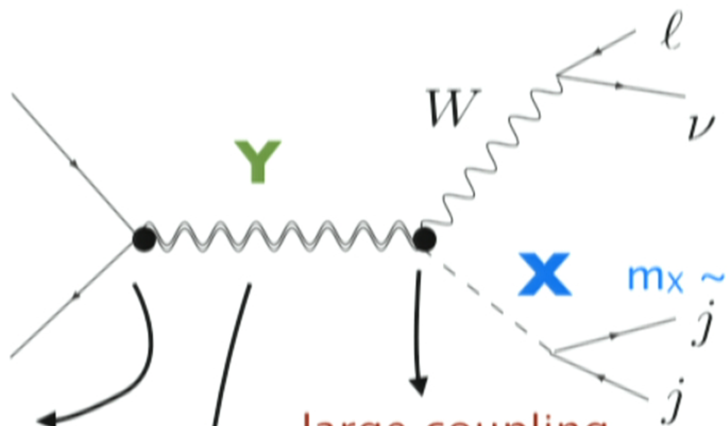

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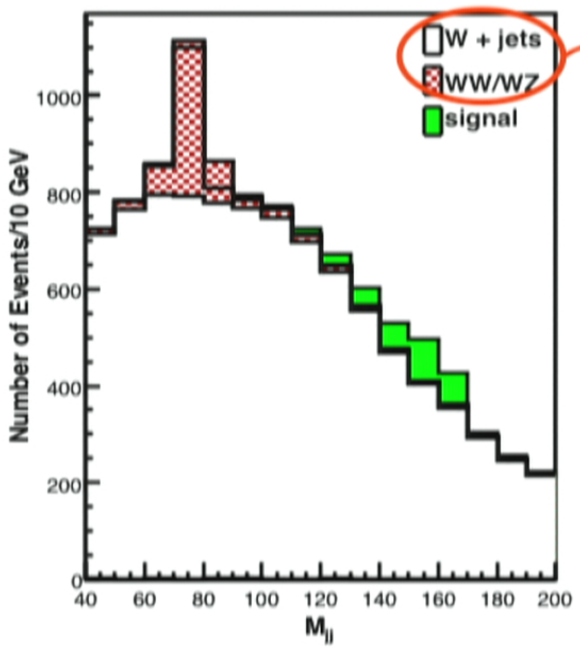
Does it fit: W + jj

signal parameters: $M_Y = 290\,\text{GeV}, M_X = 160\,\text{GeV}, g_{ffY} = 0.1\,g_{SM}$

$\sigma(p\bar{p} \to Y \to W + jj) \sim 2.4\,\text{pb}$

CDF cuts:



ALPGEN, MLM matched

↓

PYTHIA 6.4

↓

granularity

$\delta\eta \times \delta\phi = 0.1 \times 0.1$

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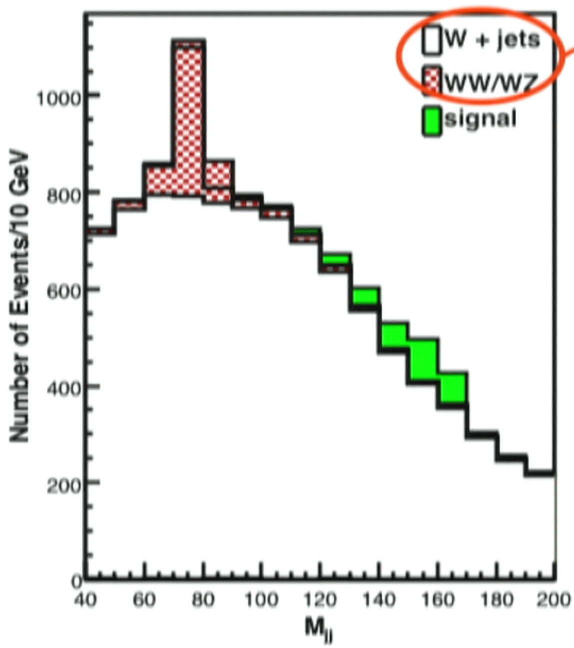

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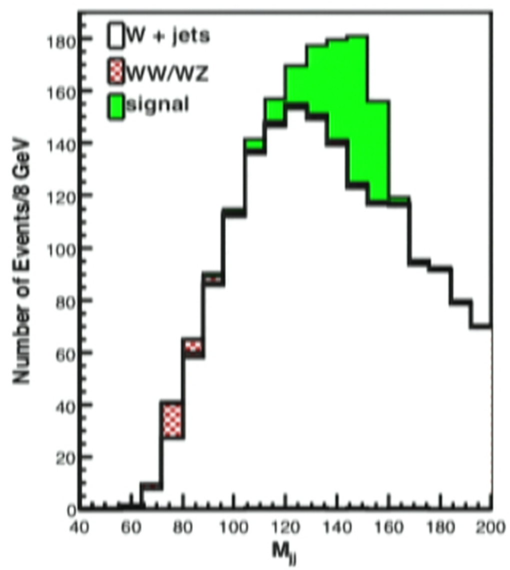
granularity

$\delta\eta \times \delta\phi = 0.1 \times 0.1$

extra cuts: $\Delta\phi_{jj} > 1.75,$ $p_{T,W} > 60\,\text{GeV}$

enhance signal

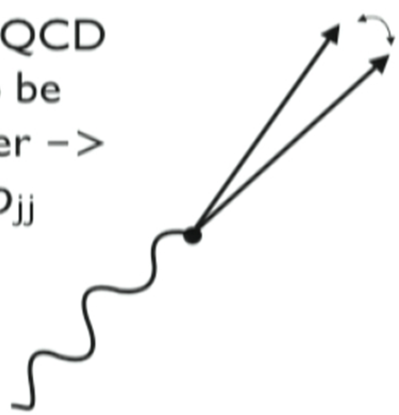


(ELM '11)

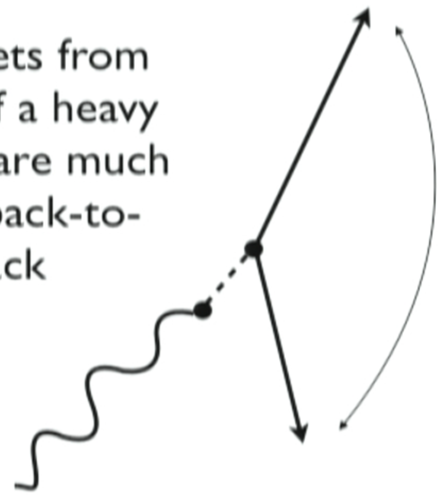
Does it fit: W + jj

the $\Delta\varphi_{jj}$ cut enhances the signal, strengthens claim that jets come from a heavy particle, but doesn't favor any particular topology

background: QCD jets like to be close together -> small $\Delta\varphi_{jj}$



signal: jets from decay of a heavy particle are much more back-to-back

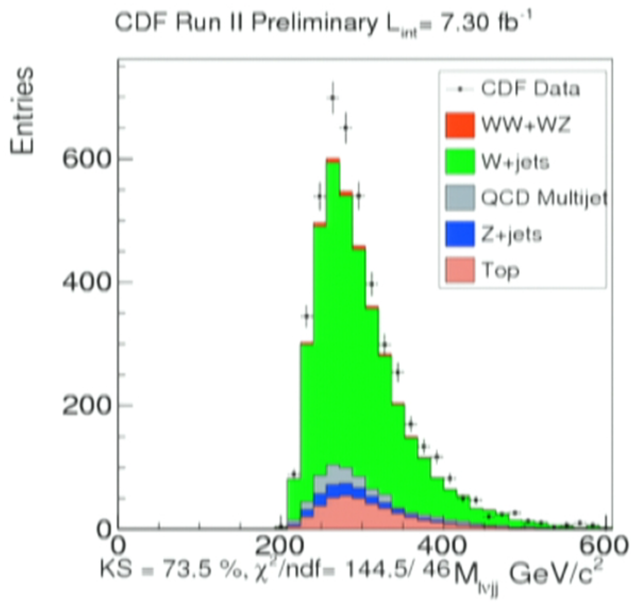


What else?

For the two resonance story to make sense there **must** be a peak in the total Wjj invariant mass near ~300 GeV

Does it fit: W + jj

but:



$L = 7.3\ fb^{-1}$ +
dijet mass window cut
115 GeV < M_{jj} < 175 GeV

SEE: www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html

with CDF cuts alone, ρ_T peak sits on top of sculpted background.. additional cuts can help

Does it fit: W + jj

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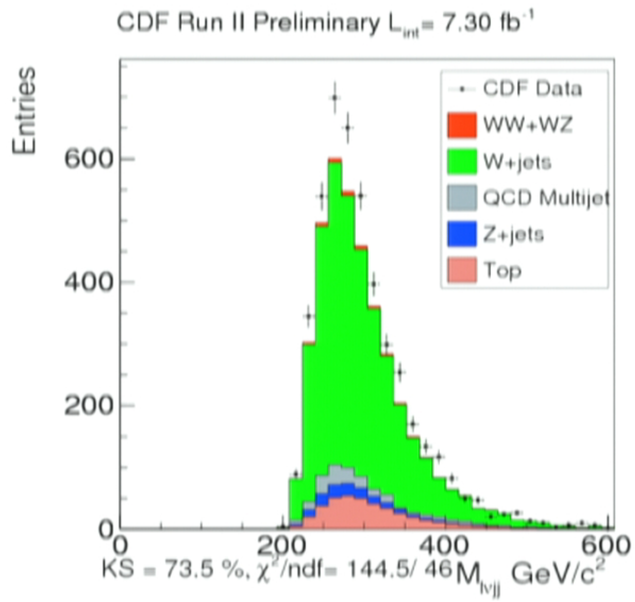


$L = 7.3\ fb^{-1}$ +
dijet mass window cut
$115\ GeV < M_{jj} < 175\ GeV$

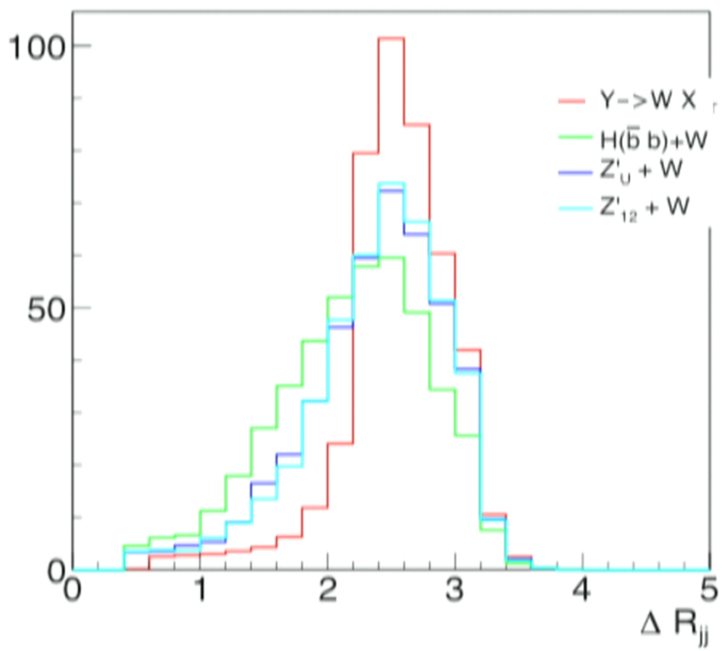
SEE: www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html

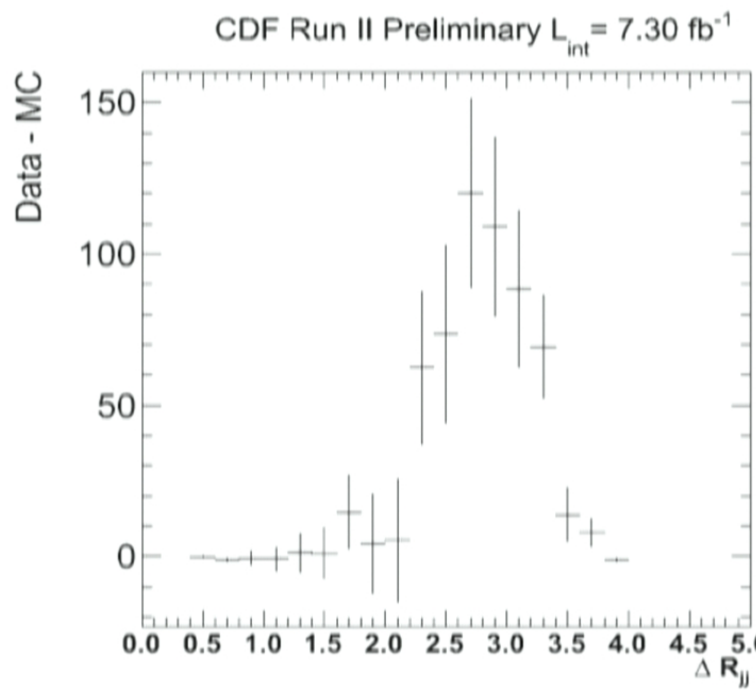
with CDF cuts alone, ρ_T peak sits on top of sculpted background.. additional cuts can help

what can kinematic distributions tell us?

various signals,
$\sigma(Wjj) = 2$ pb

CDF data in excess region
115 GeV < M_{jj} < 175 GeV

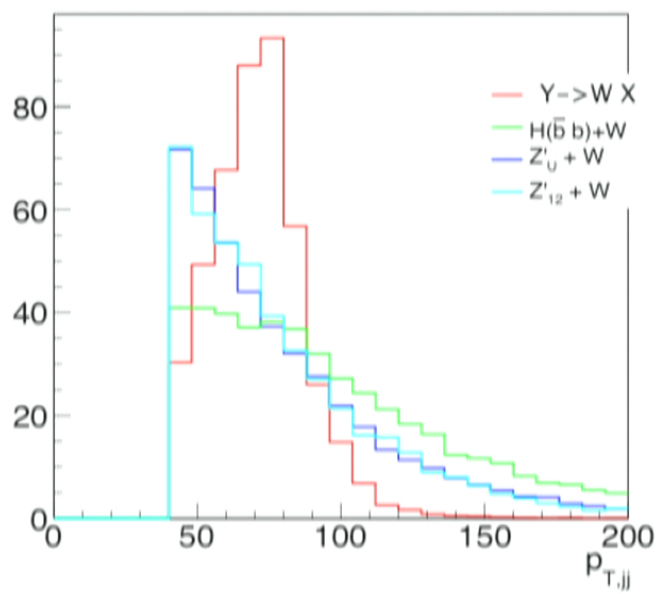


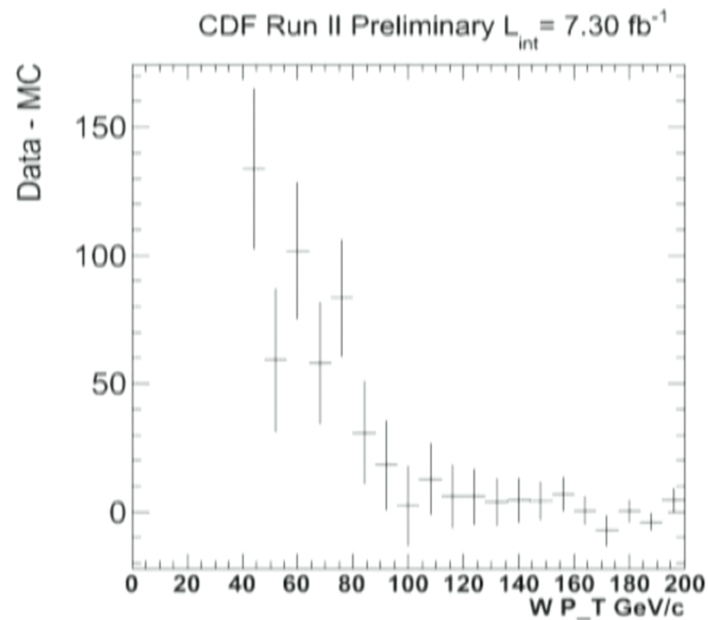


H(b bbar)W -- model used by CDF/D0 to estimate acceptance
Z' with flavor preserving/violating couplings

what can kinematic distributions tell us?

dijet p_T : hard cutoff in two-resonance models set by mother mass





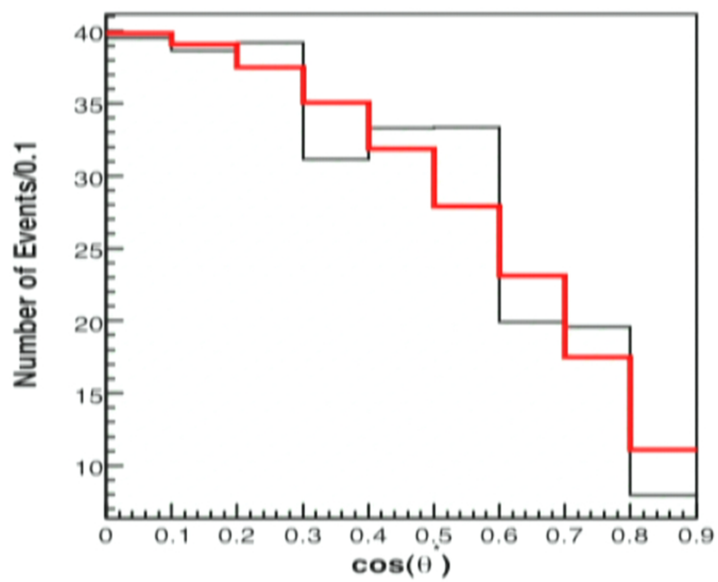
different signals also have different correlated Tevatron/LHC signals

Which two-resonance explanation?

there is more than one two-resonance explanation...

angular distributions can help distinguish spins

Specifically: c/m scattering angle ~$\sin^2\theta^*$ for spin-1 mother resonance, flat for spin-0



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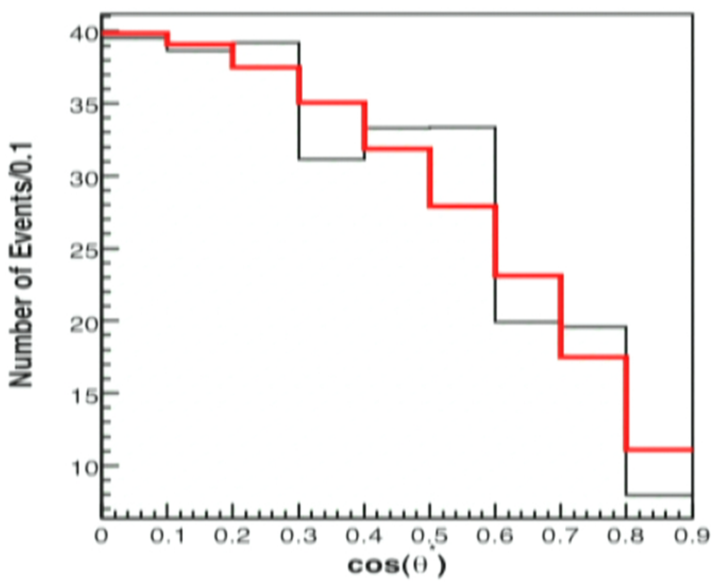

whats the bigger picture?

on one hand, just a 'simplified model' involving two resonances, few inputs:

($M_{\rho T}$, sin χ) --> Wjj, correlated signals,

forget UV for now

however...

ingredients naturally present in Technicolor

technicolor = EWSB by strong dynamics

add in some new fermions: "techni-fermions"

$$T_{iL} = (N_{TC}, 2)_0$$
$$T_{iR} = (N_{TC}, 1)_{\pm 1/2}$$

chiral EW charges

new strong gauge interaction "technicolor"

techni-chiral symmetry spontaneously broken, contains EWS

for N_D doublets, we have $(2\,N_D)^2 - 1$ goldstones

-3 eaten by W/Z

$(2\,N_D)^2 - 4$ uneaten, "techni-pions"

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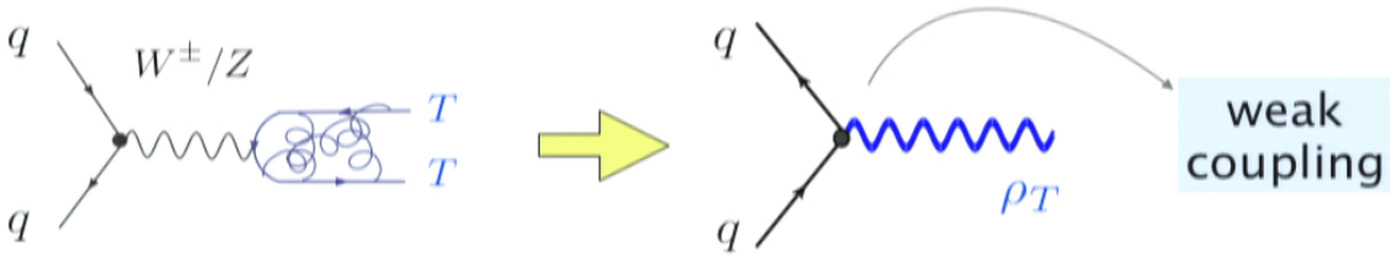
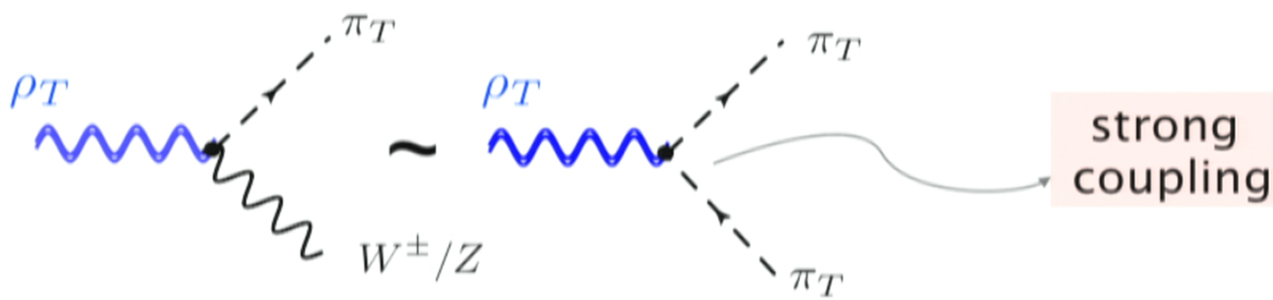
what else is around?.. expect spin-1 resonances in analogy to QCD

$\rho_T, a_T, \omega_T, \ldots$



while



but mass ($\sim\Lambda_{TC}$?) , coupling, hierarchy not calculable, must be modeled

some intuition from QCD... but no reason TC should have QCD-like dynamics (different N_C, N_F, etc.)

wait a minute... technicolor?!!?!

parameters that fit are motivated by modern TC lore

ex.) $M_{\rho T} < 2\, M_{\pi T} < M_{\pi T} + M_W$ if TC is **near-conformal**, $\langle \bar{T}T \rangle$ can have a large anomalous dimension, which effects $M_{\pi T}$, not $M_{\rho T}$

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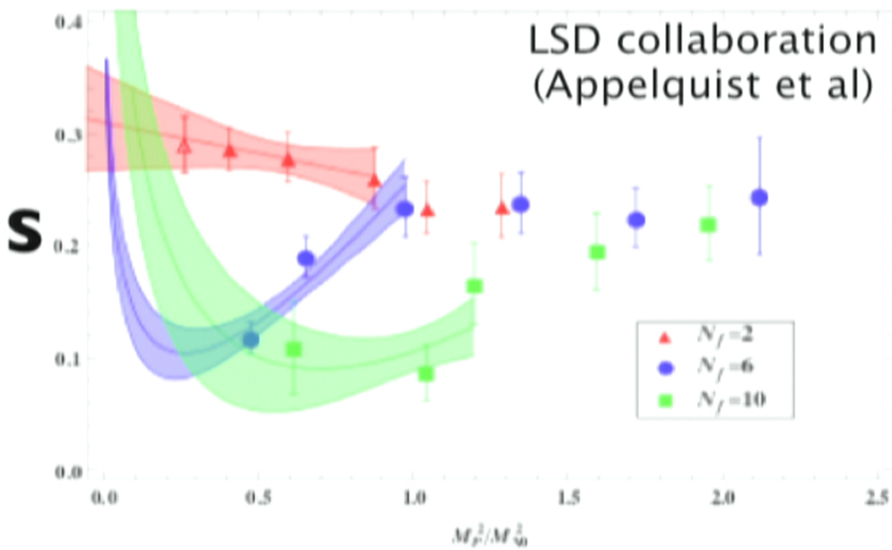

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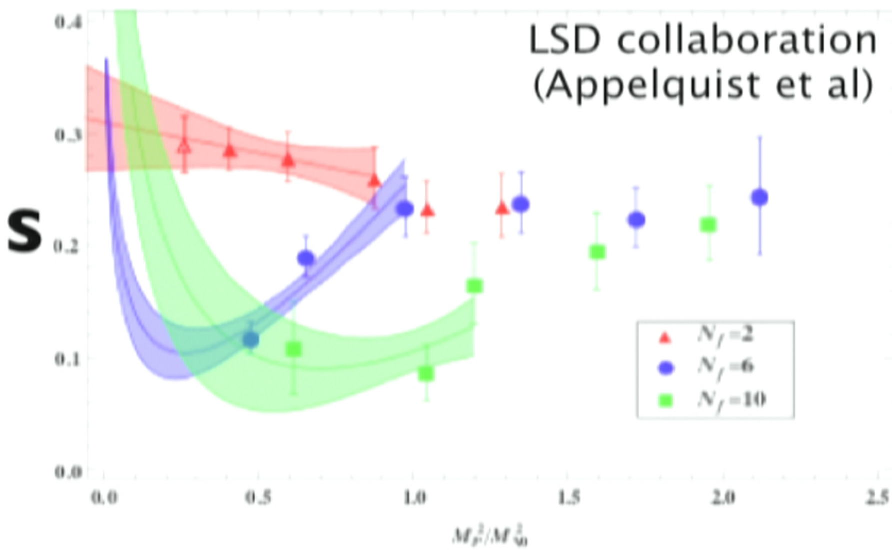


- m_{top}, flavor?? subject of another talk

we still need light resonances...

present in 'multi-scale' technicolor models (Eichten, Lane)

main idea: there are two sources of dynamical EWSB

$$\langle \bar{T}_{1L} T_{1R} \rangle \propto 2\pi v_1^3$$
$$\langle \bar{T}_{2L} T_{2R} \rangle \propto 2\pi v_2^3$$

...for example, T_1, T_2 in different TC reps.

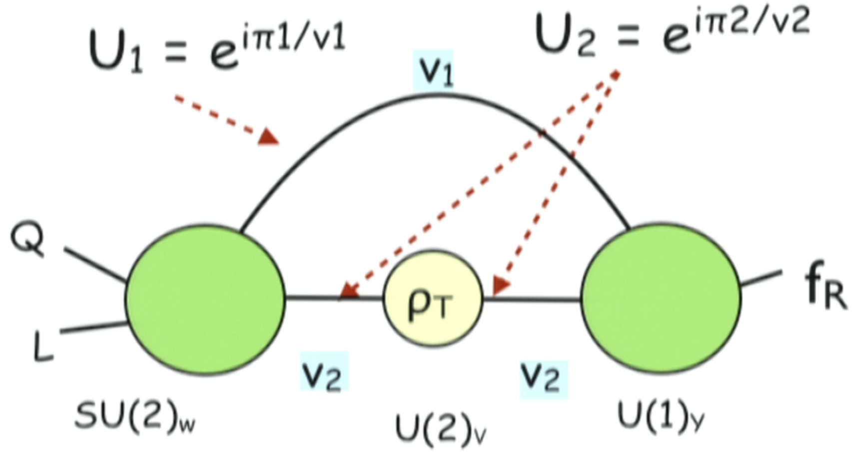
$$\sin\chi = v_2/v_1 \ll 1$$

resonances (ρ_T, a_T, ω_T ..) associated with the v_2 scale are **light**

two vevs -> extra NGBs = **technipions**

model w/ deconstructed language

(Dominici, DeCurtis Chivukula et al)



- ρ_T modeled as massive gauge boson
- one combination of π_i remains uneaten (Lane, AM '09)

fermion – ρ_T coupling suppressed by $\dfrac{M_W}{M_{\rho_T}} \sin\chi \ll 1$

- technipions couple to SM fermions w/ strength ~ m_f

$$\frac{1}{\Lambda^2}\langle \bar{T}_{1L} T_{1R}\rangle \bar{f}_L f_R \quad \longrightarrow \quad m_f\left(+ i\frac{\pi_T}{v} + \cdots \right)\bar{f}_L f_R$$

though model dependent

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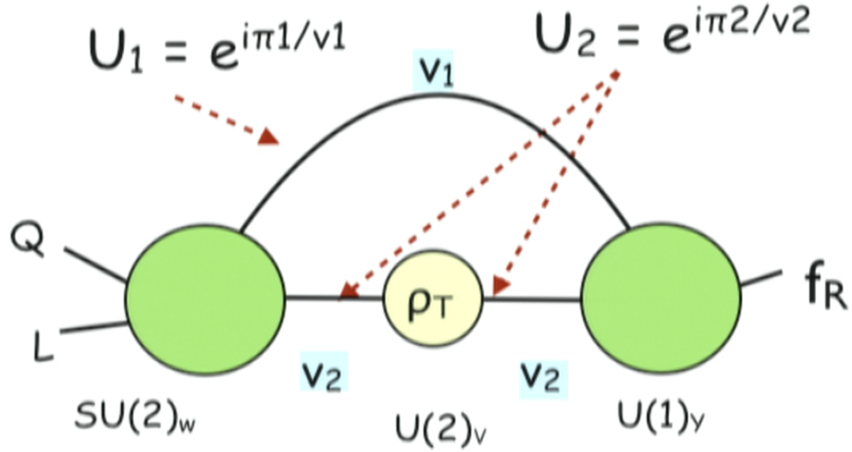

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still hard to see at the LHC...

Better signals in related channels $\rho_T \to Z(l^+l^-)+jj$, $W(l\nu)Z(l^+l^-)$

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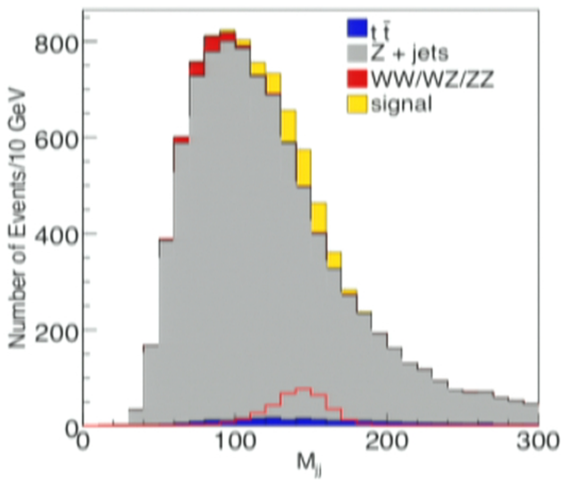

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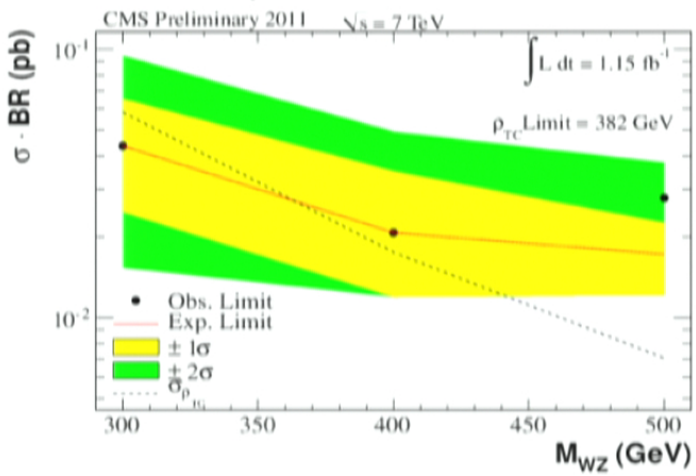

clear signal, plus little/no ttbar, QCD background

$\rho_T \to W(l\,\nu)+\pi(\tau\,\nu_\tau)$ is also a possibility,
may even have hints of signal already...

(Eichten, Lane, AM, 1107.4075, 1201.4396, AM 1108.4025)

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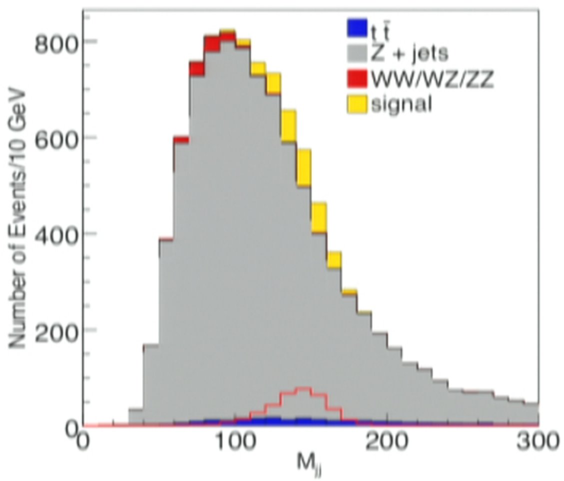

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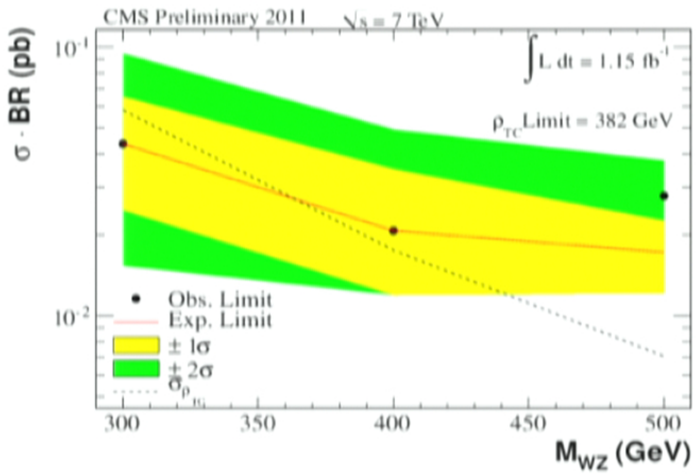

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Conclusions

the CDF bump is absolutely not "wrong", W+jj issue not settled

may be new physics ...

.. but if not, it exposes a mismodeling/misunderstanding in QCD/ detectors that is necessary to understand for future searches (& not just at the Tevatron).

two resonance topology:

- large rate in Wjj with small fermion-resonance coupling
- must see peak in total M_{Wjj}, related signals in $Z(l^+l^-)jj, \bar{f}f$

parameters from Low-Scale Technicolor fit surprisingly well:

- multiple EWSB scales -> light resonances
- coupling to SM suppressed by $v_2/v_1 << 1$

THANK YOU