

New physics observed at the Tevatron?

– theoretical aspects

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As we've seen in Claus' talk, it's not at all clear how significant the W_{jj} signal is

However, theorists must have their fun.

I will concentrate on W_{jj}

arXiv:1104.0699

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1. Invariant Mass Distribution of Jet Pairs Produced in Association with a W boson in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV.

CDF Collaboration (T. Aaltonen (Helsinki Inst. of Phys.) *et al.*). FERMILAB-PUB-11-164-E. Apr 2011. 8 pp.

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1. Z' from SU(6) × SU(2)_h GUT, W_{jj} anomaly and Higgs boson mass bound.

[Jihn E. Kim](#), [Seodong Shin](#). Apr 2011.

e-Print: [arXiv:1104.5500](#) [hep-ph]

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2. Impact of extra particles on indirect Z' limits.

[F. del Aguila](#), [J. de Blas](#), [P. Langacker](#), [M. Perez-Victoria](#). UG-FT-285-11, CAFPE-155-11. Apr 2011. 22 pp.

e-Print: [arXiv:1104.5512](#) [hep-ph]

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3. Spontaneous Parity Violation in SUSY Strong Gauge Theory.

[Naoyuki Haba](#), [Hiroshi Ohki](#). Apr 2011. 14 pp.

e-Print: [arXiv:1104.5405](#) [hep-ph]

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Types of proposed explanations

- **Standard Model:**

Some background or subtraction is not well-understood
(*Sullivan & Menon, Plehn & Takeuchi*)

- **Beyond the Standard Model:**

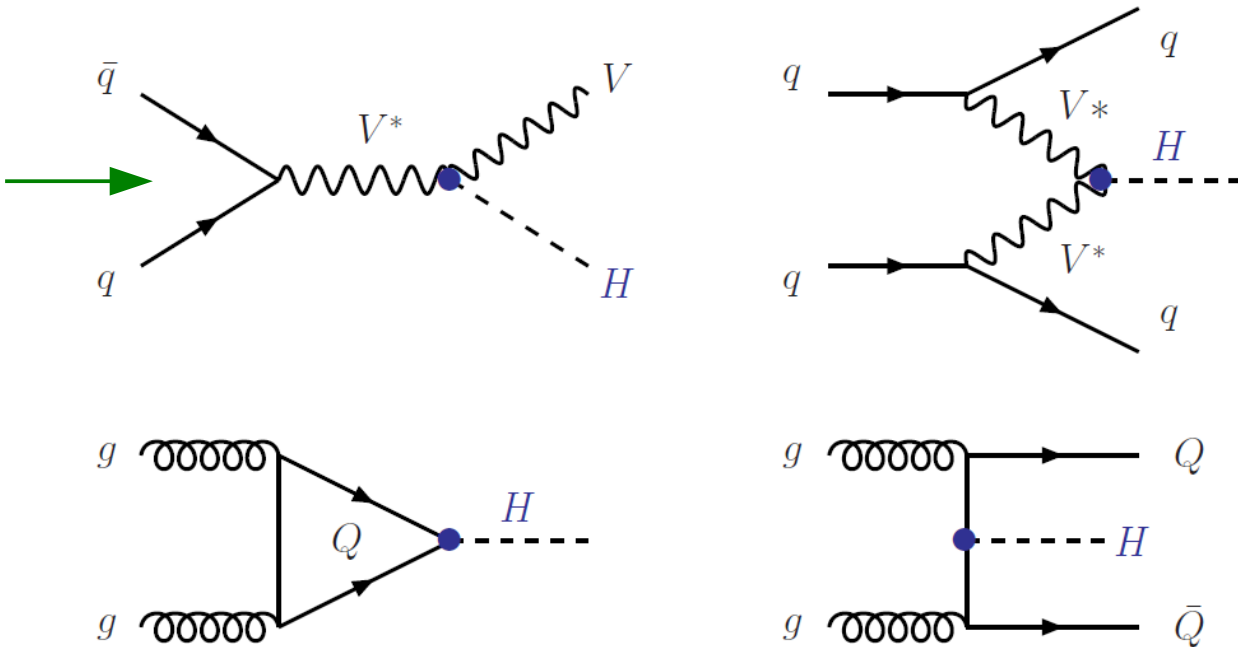
Some new particle resonance is being produced

- Higgs bosons
- Z' bosons
- R-parity violating SUSY
- Light colored scalars from SUSY or GUTs
- Technicolor
- String theory (also Z' bosons)

Standard Model Higgs boson

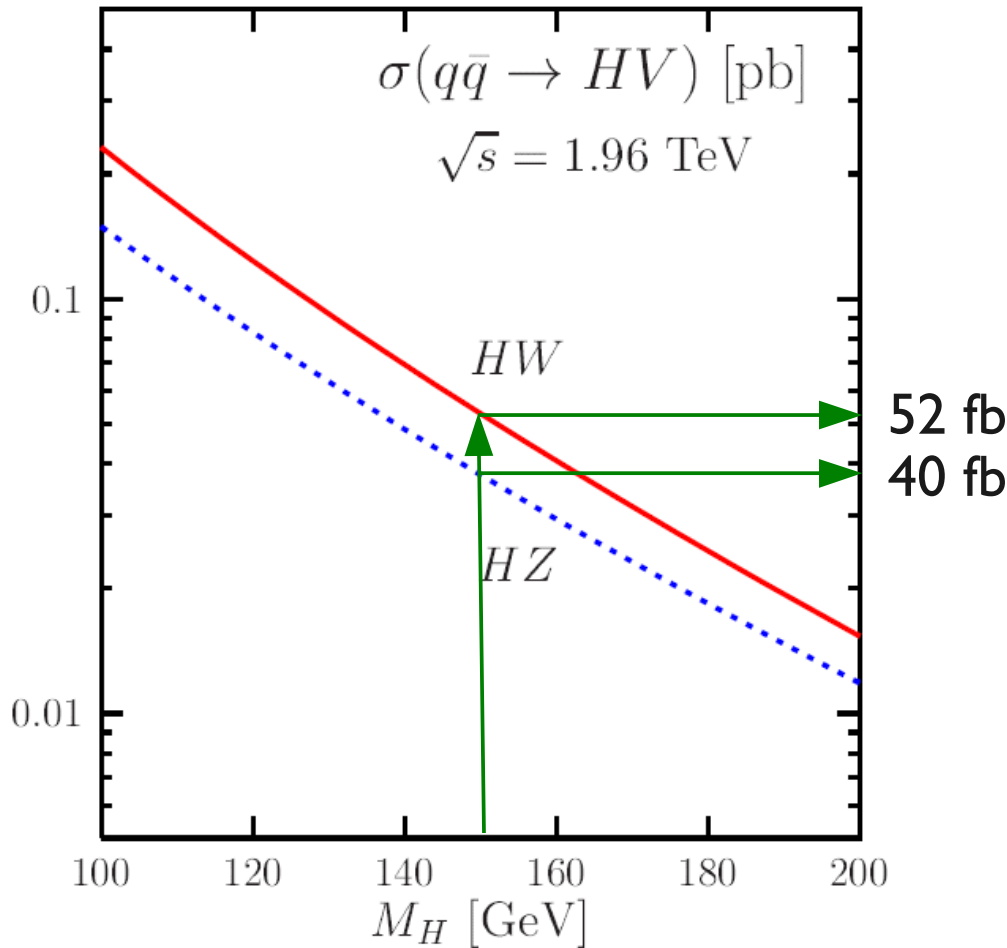
Could the Wjj signal be explained by Higgs production?

Associated
production
 $V=W,Z$



Perhaps if H decays as $H \rightarrow q\bar{q}$, gg ,
the Wjj signal could be explained?

Cross section



$M_H = 150$ GeV:

$BR(H \rightarrow bb + gg) = 0.21$

$\sigma(HW) \times BR \approx 11$ fb

Thus, there are some problems:

- Observed $\sigma(Wjj) \approx 4$ pb
- No b jet excess seen
- Should also see Zjj excess
- Mostly $H \rightarrow WW^*$

\Rightarrow It can't be a SM Higgs

Fig. From A. Djouadi, hep-ph/0503172

Beyond the SM Higgs bosons

What about extended Higgs sectors?

In two-Higgs doublet models, the Yukawa couplings of the Higgs bosons are modified with factors of $\tan \beta$ and $\cot \beta$

- Thus: at large or small $\tan \beta$ the couplings and cross sections can be appreciably larger

→ But we still have the other problems

[But see B. Dutta, S. Khalil, Y. Mimura, Q. Shafi, arXiv:1104.5209]

Z' bosons

- Z' bosons: extra gauge bosons from enlarged gauge sectors
- Usually from a $U(1)'$ subgroup:
 - Occurs e.g. in $SO(10)$ or E_6 GUTs
 - Can also be $U(1)_{B-L}$ which is anomaly free
 - *Then B–L conservation is no longer an accidental symmetry, but conservation of gauge charge!*
- Z' can't be massless $\rightarrow U(1)'$ must be spontaneously broken

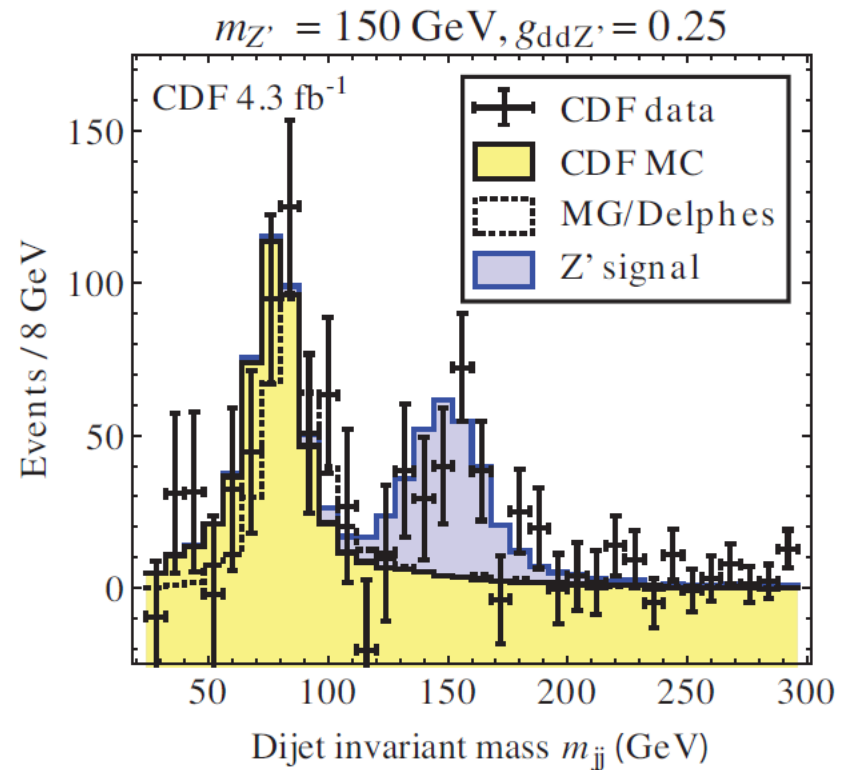
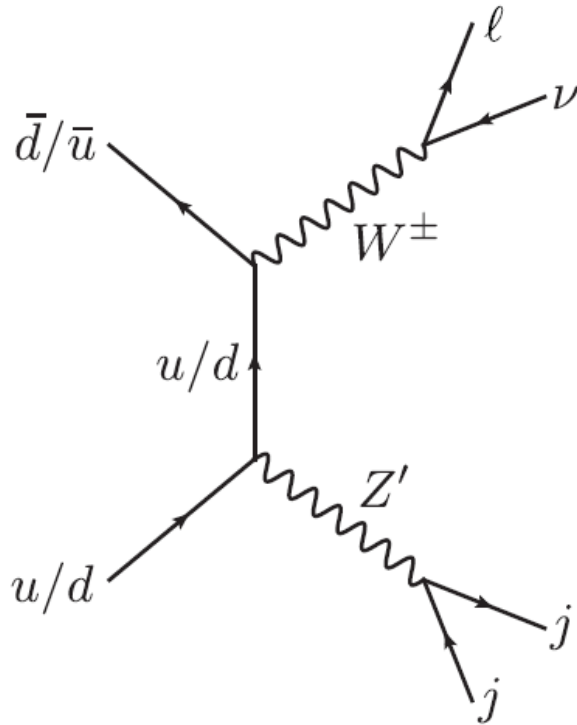
Z' bosons

- Often considered to be the easiest possible new physics at LHC, using $Z' \rightarrow e^+e^-$ or $Z' \rightarrow \mu^+\mu^-$
- Mass bound: $m_{Z'} > 1 \text{ TeV}$ (if coupling like Z)
- Normally assumed that Z' couples to leptons and quarks with similar strengths
 - Either: assume same couplings as SM Z-boson
 - Or assume a specific model, SO(10), E6, etc.
- Can't explain W_{jj} , would have seen $W+\text{leptons}$

Leptophobic Z'

- Perhaps $g_{Zll} \ll g_{Zqq}$ or even $g_{Zll} = 0$
 - Perhaps that could explain Wjj
 - but then anomaly cancellation doesn't work
 - need extra fermions
- This would also allow the Z' to be much lighter
 - Not produced in e^+e^- colliders
 - Does not decay to leptons

Wjj from a light leptophobic Z'

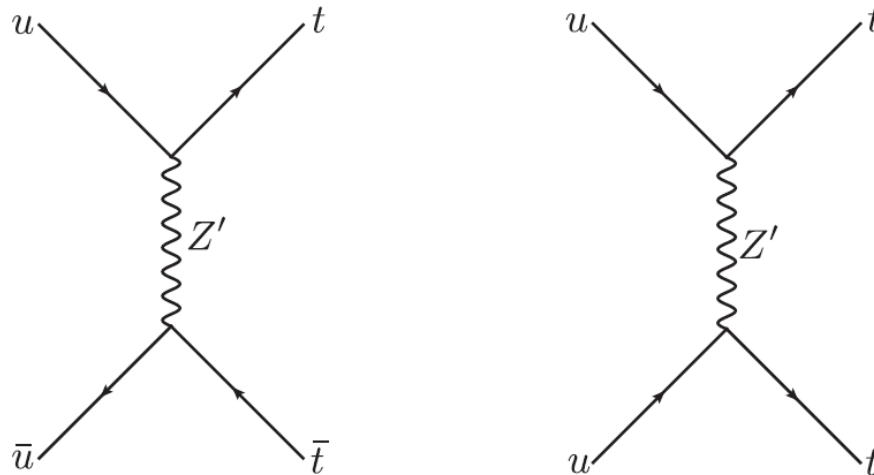


From M. Buckley, D. Hooper, J. Kopp, E. Neil, arXiv:1103.6035v3

$t\bar{t}$ asymmetry and Z'

A $t\bar{t}$ asymmetry can be generated by such a Z' exchange:

[S. Jung, H. Murayama, A. Pierce, J. Wells, arXiv:0907.4112]



[From M. Buckley, D. Hooper, J. Kopp, E. Neil, arXiv:1103.6035]

Hard to avoid too large $\sigma(t\bar{t})$ while explaining the asymmetry
– but Z' in the t-channel interferes with QCD \rightarrow smaller σ

Supersymmetry

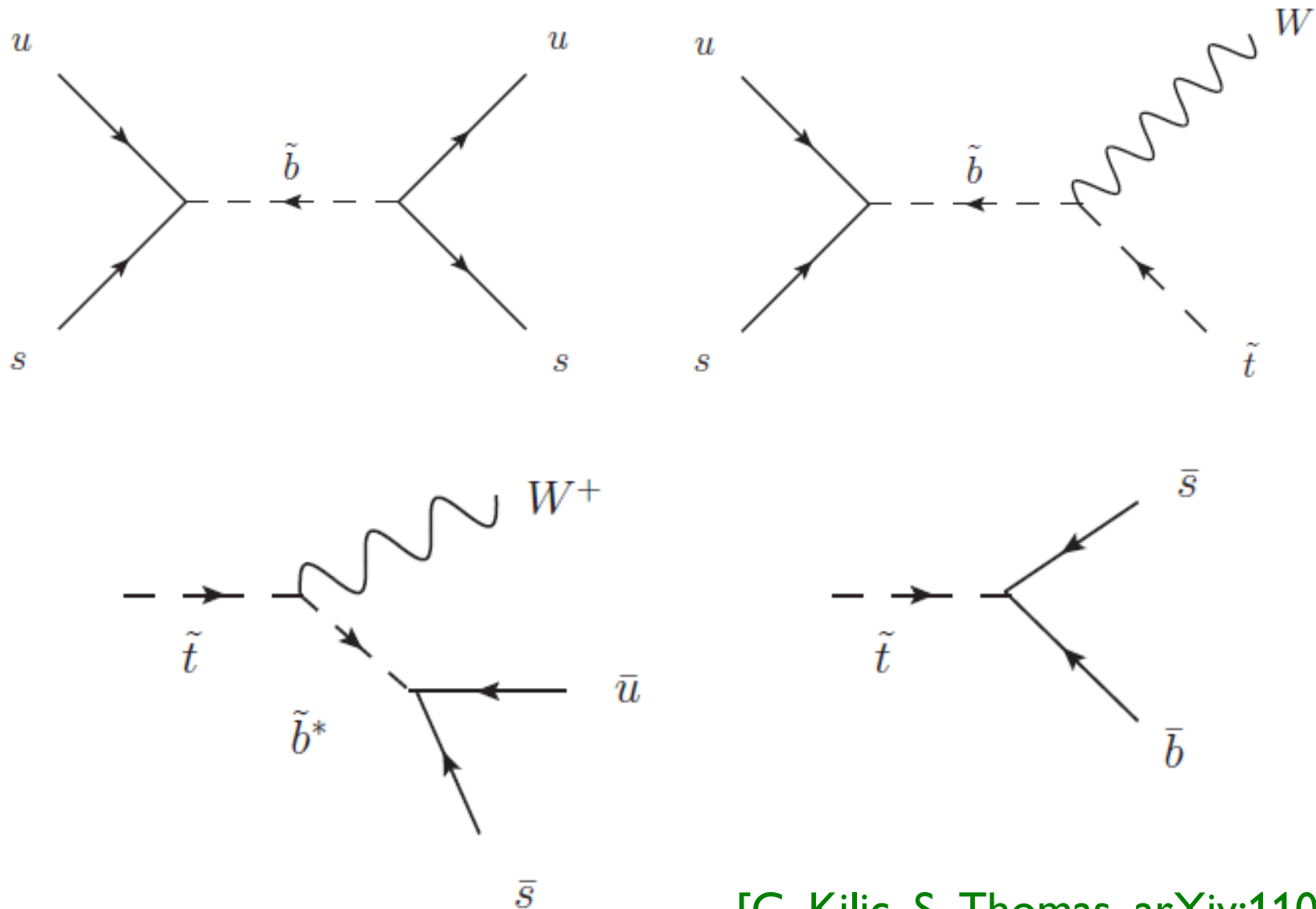
- In supersymmetric models (e.g. MSSM), ***R-parity*** is often introduced (somewhat *ad hoc*) to prevent proton decay
 - SUSY particles are always produced in pairs
 - LSP (lightest supersymmetric particle) is stable
(dark matter candidate)
- Hard to think of SUSY explanations for both Wjj and $t\bar{t}$
- But there are R-parity violating SUSY models: SUSY particles can be singly produced
 - can have an s-channel resonance

R-parity violating SUSY

- With R-parity conservation: LSP is stable and neutral
→ always missing energy in colliders
- This is a part of all search strategies
- If R-parity is not conserved → no missing energy

Things would be very different

R-parity violation allows e.g.



[C. Kilic, S. Thomas, arXiv:1104.1002]

Technicolor

- Technicolor models are models for electroweak symmetry breaking without an elementary Higgs boson
 - Naturalness
 - Higgs mechanism has no dynamical explanation
 - No explanation of flavor
- Electroweak symmetry is broken by strong confining dynamics
 - Original model: copy of QCD with higher scale $\Lambda_{\text{TC}} \sim$ electroweak scale instead of Λ_{QCD}
 - Chiral symmetry breaking \rightarrow breaks electroweak symmetry; Goldstone bosons eaten by W and Z

Technicolor and W_{jj}

- Quarks in QCD correspond to *technifermions* in technicolor:
 - Transform under some representation of the technicolor gauge group
 - Transform as quarks and leptons under $SU(2) \times U(1)$
- Technicolor predicts a number of *technimesons*:
technipions π_T , technirho ρ_T , ...
- Eichten, Lane & Martin propose:

$$p\bar{p} \rightarrow \rho_T \rightarrow W\pi_T \rightarrow W_{jj}$$

[E. Eichten, K. Lane, A. Martin, arXiv:1104.0976]

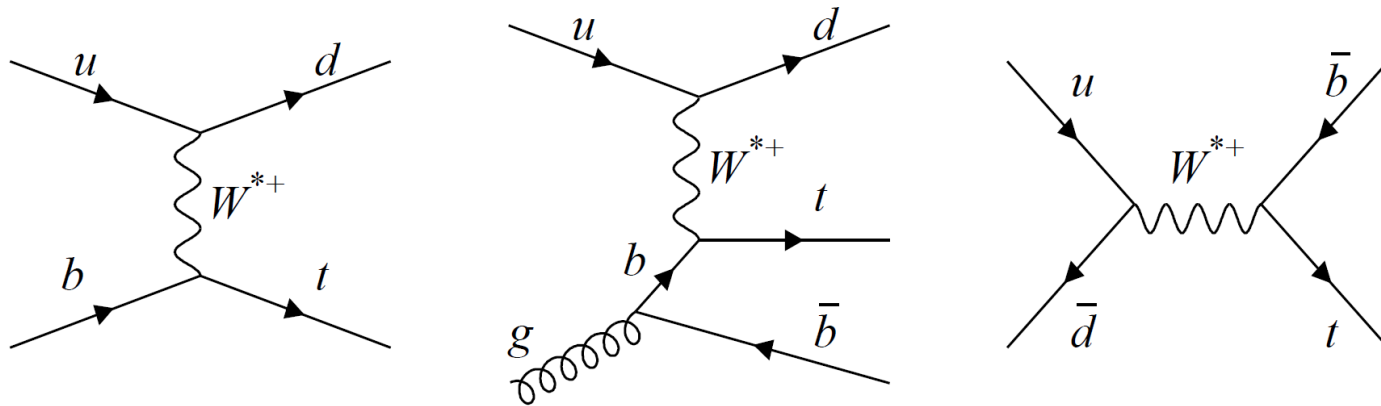
What about string theory?

- I've only seen one paper motivated by string theory
- A specific type of leptophobic Z' bosons predicted by “low-mass string theory” (strings in large extra dimensions)
- There's a $U(3)$ from three D-branes $\rightarrow SU(3) \times U(1)$
 $SU(3)$ is color (gluons); $U(1)$ is baryon number (Z')
- Predicts two additional $U(1)$ bosons, Z' , Z''
- Z' gives W_{jj} as before, Z'' is within reach at LHC
[L. Anchordoqui, H. Goldberg, X. Huang, D. Lüst, T. Taylor, 1104.2302]

Standard Model explanations

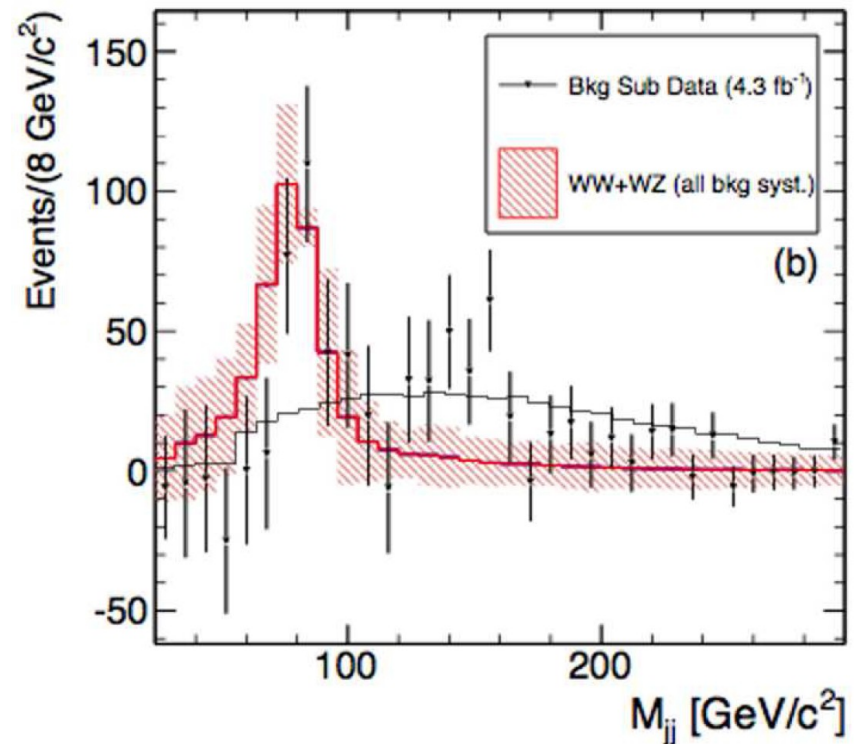
- Sullivan and Menon, and Plehn and Takeuchi have written papers that claim that insufficient subtraction of top backgrounds can be the reason
- Top quarks → second mass peak in dijet mass distribution
 - tt: the b from the top and the up-type quark from the W. Has upper endpoint at
$$\sqrt{(m_t^2 - m_W^2)} = 155 \text{ GeV}$$
 - Single top: b from top plus another jet:
Peak between 100–160 GeV depending on cuts

Single top background



Z. Sullivan and A. Menon,
arXiv:1104.3790:

CDF removed the *tt* background
using data but *single top* background
with Monte Carlo



Summary

- Many theoretical explanations proposed
- Most are beyond-Standard Model
- Now, if the signal persists and is confirmed by D0, what to look for?