A standard model explanation of the CDF dijet excess in Wjj

Based on Z.S., Arjun Menon, Phys. Rev. D, 83, 091504(R) 2011

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Illinois Institute of Technology
CTEQ Collaboration

C T E Q

August 9, 2011

Outline

An article appears. . .

The New York Times

Science

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ENVIRONMENT | SPACE & COSMOS

At Particle Lab, a Tantalizing Glimpse Has Physicists Holding Their Breaths

By DENNIS OVERBYE
Published: April 5, 2011

Physicists at the Fermi National Accelerator Laboratory are planning to announce Wednesday that they have found a suspicious bump in their data that could be evidence of a new elementary particle or even, some say, a new force of nature.

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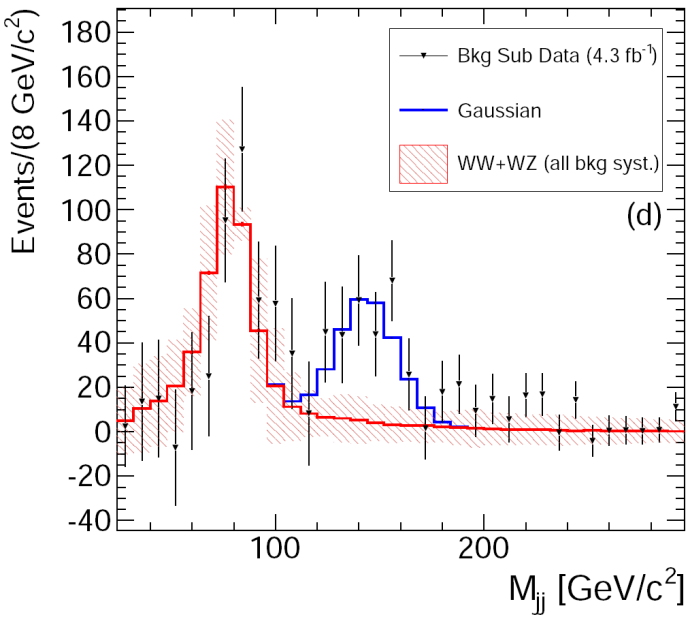
The results, if they hold up, could be a spectacular last hurrah for Fermilab's Tevatron, once the world's most powerful particle accelerator and now slated to go dark forever in September or earlier,

Web Ad

A suggestive plot...



CDF, PRL 106, 171801 (2011)

- Drawing a Gaussian peak guides the eye...
- Is this the discovery everyone's been waiting for?

Speculative new physics explanations proliferate

- Higgs, Z', color octets, SUSY, etc.

  Buckley, Hooper, Kopp, Neil [1103.6035]; Yu [1104.0243]; Eichten, Lane, Martin [1104.0976]; Kilic, Thomas [1104.1002]; Wang, Wang, Xiao, Xu, Zhu [1104.1161]; Cheung, Song [1104.1375]; He, Ma [1104.1894]; Wang, Wang, Xiao, Xu, Zhu [1104.1917]; Sato, Shirai, Yonekura [1104.2014]; Nelson, Okui, Roy [1104.2030]; Anchordoqui, Goldberg, Huang, Lust, Taylor [1104.2302]; Dobrescu, Krnjaic [1104.2893]; Popovic [1104.3111]; Fodor, Holland, Kuti, Nogradi, Schroeder [1104.3124]; Jung, Pierce, Wells [1104.3139]; Buckley, Fileviez-Perez, Hooper, Neil [1104.3145]; Zhu [1104.3227]

- How about just the Standard Model?

  Z.S., Arjun Menon, Phys. Rev. D 83, 091504(R) (2011) [1104.3790]

  Plehn, Takeuchi, J. Phys. G38, 095006 (2011) [1104.4087]

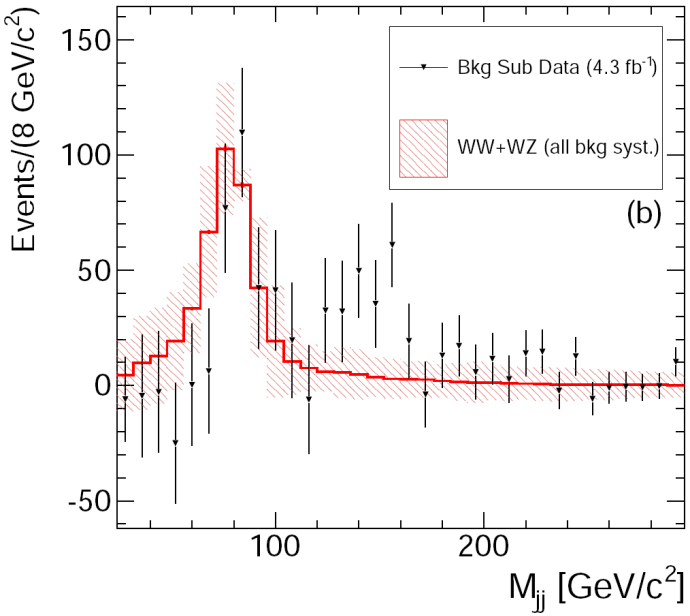
- More Higgs, Z', color octets, SUSY, etc.

  Ko, Omura, Yu [1104.4066]; Fox, Liu, Tucker-Smith, Weiner [1104.4127]; Jung, Ko, Lee [1104.4443]; Chang, Lee, Song [1104.4560]; Nielsen [1104.4642]; Bhattacherjee, Raychaudhuri [1104.4749]; Cao, Carena, Gori, Menon, Schwaller, Wagner, Wang [1104.4776]; Babu, Frank, Rai [1104.4782]; Dutta, Khalil, Mimura, Shafi [1104.5209]; Haba, Ohki [1104.5405]; Kim, Shin [1104.5500]; del Aguila, de Blas, Langacker, Perez-Victoria [1104.5512]; Carpenter, Mantry [1104.5528]; Huang [1104.5389]; Sidharth [1105.0277]; Usubov [1105.0969]; Segre, Kayser [1105.1808]; Enkhbat, He, Mimura, Yokoya [1105.2699]; Chen, Chiang, Nomura, Fusheng [1105.2870]; Bettoni, Dalpiaz, Dalpiaz, Fiorini, Masina, Stancari [1105.3661]; Liu, Nath, Peim [1105.4371]; Campbell, Martin, Williams [1105.4594]; Alves, Barreto, Dias [1105.4849]; Hektor, Hutsi, Kadastik, Kannike, Raidal, Straub [1105.5644]; Branco, Ferreira, Lavoura, Rebelo, Sher, Silva [1106.0034]; Hewett, Rizzo [1106.0294]; Fan, Krohn, Langacker, Yavin [1106.1682]; Evans, Feldstein, Klemm, Murayama, Yanagida [1106.1734]; Harnik, Kribs, Martin [1106.2569]; Fok, Kribs [1106.3101]; Gunion [1106.3308]; Faraggi, Mehta [1106.5422]; White [1106.5662]; Eshel, Lee, Perez, Soreq [1106.6218]; Ghosh, Maity, Roy [1107.0649]; Graesser, Shoemaker, Vecchi [1107.2666]; Vecchi [1107.2933]; Eichten, Lane, Martin [1107.4075]; Anchordoqui, Antoniadis, Goldberg, Huang, Lust, Taylor [1107.4309]; + a few I've probably missed. . .

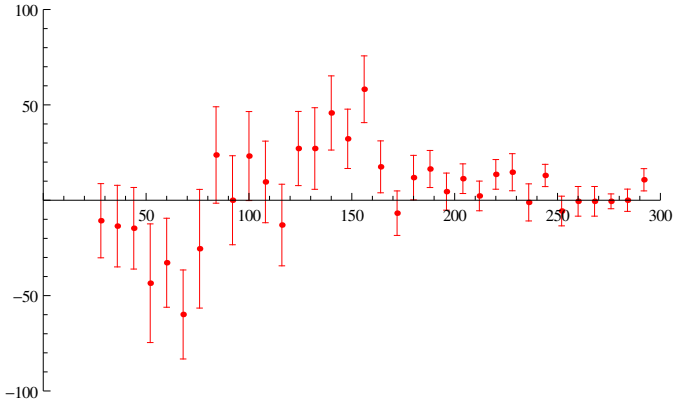
Outline

A less biased view of the *Wjj* data

- CDF "bkg sub" data (without the Gaussian)



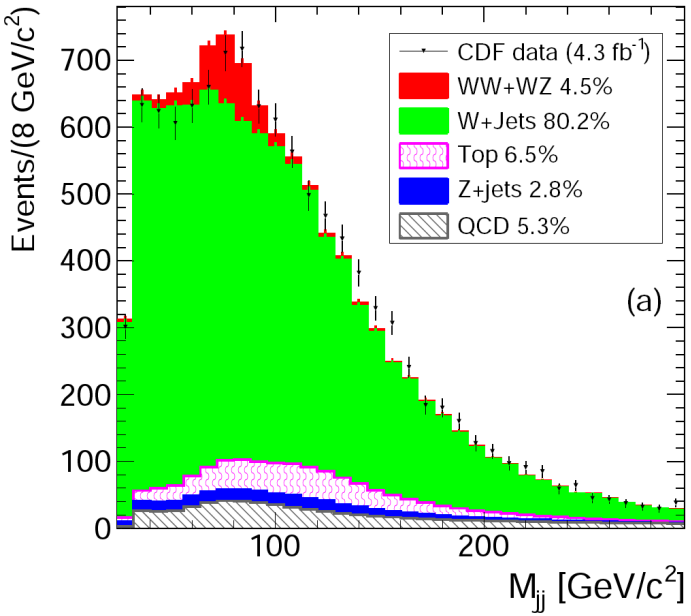
- Fully background subtracted (a clearer picture)



- There is a clear systematic shape problem across 28–300 GeV, not just 120–160 GeV
  - The systematic deficit below *WW* threshold is most worrisome
  - The systematic excess is everywhere above *WW* threshold
- It appears a broad kinematic background is missing...

Re-examining the CDF fit

- The original analysis was designed to measure WW/WZ
- CDF fit



- Normalizations were floated for
  - dibosons (WW/WZ)
  - "Wjj" ($Wjj + Zjj$+top+QCD)
- More specifically, the ratio of $t\bar{t}$ to Wjj was fit to data
- The proportion of single-top was fixed via Monte Carlo

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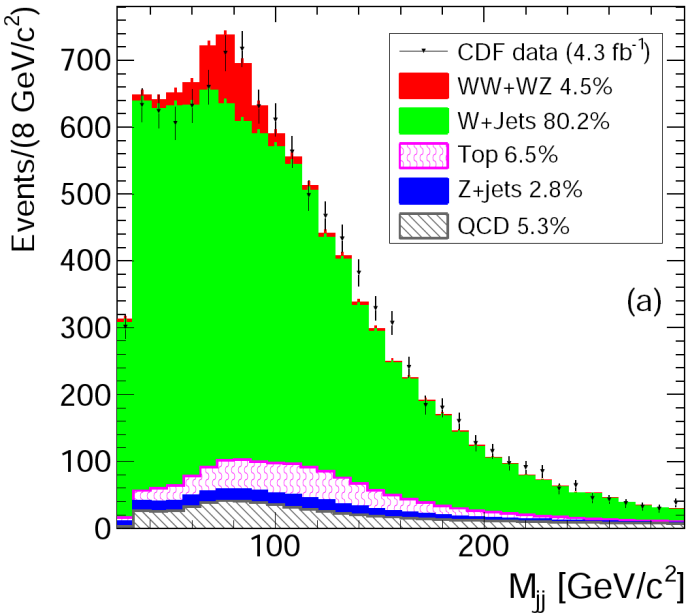
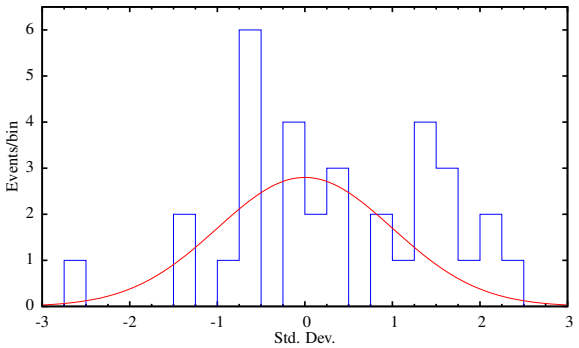


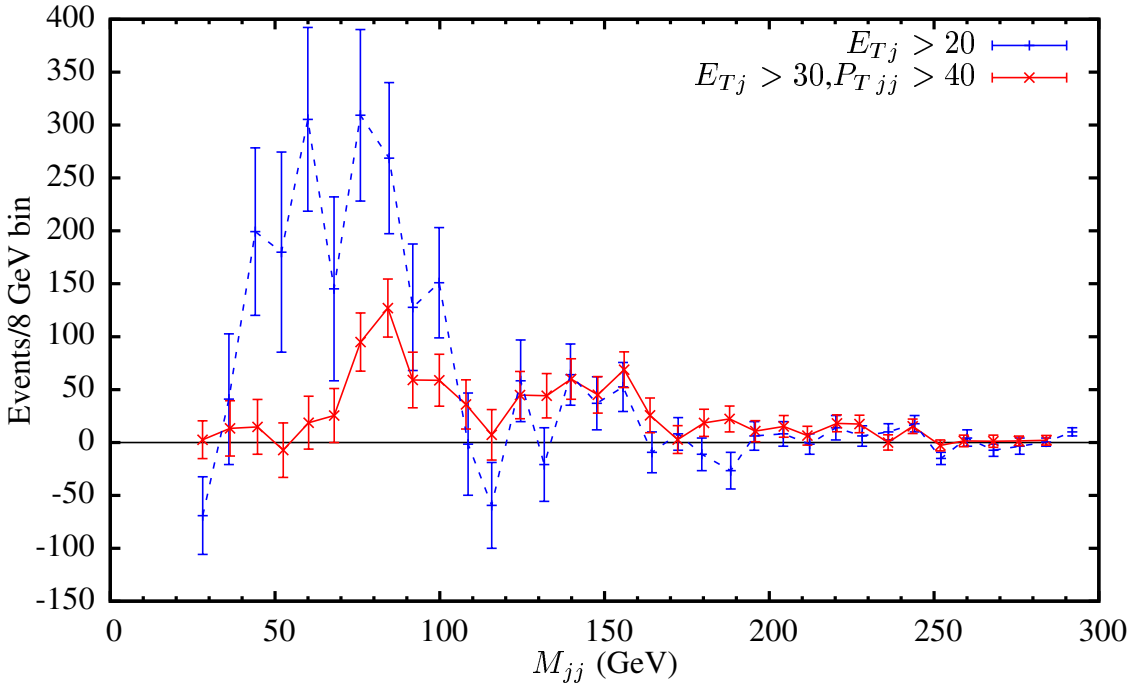
- Normalizations were floated for
  - dibosons (WW/WZ)
  - "Wjj" ($Wjj + Zjj$+top+QCD)
- Extracting the data and CDF fit we found $\chi^2/\mathrm{d.o.f.} = 44.5/19$ — not surprising
- Distribution of errors



- The errors do not follow a Gaussian distribution: skew confirms shape problem
- More specifically, the ratio of $t\bar{t}$ to Wjj was fit to data
- The proportion of single-top was fixed via Monte Carlo

Loosening the cuts (a subtle hint)

- CDF has examined several alternate cuts
- Overlaying two of the data sets appears to point to a clear problem: there are more events above 104 GeV with tight cuts than loose cuts!



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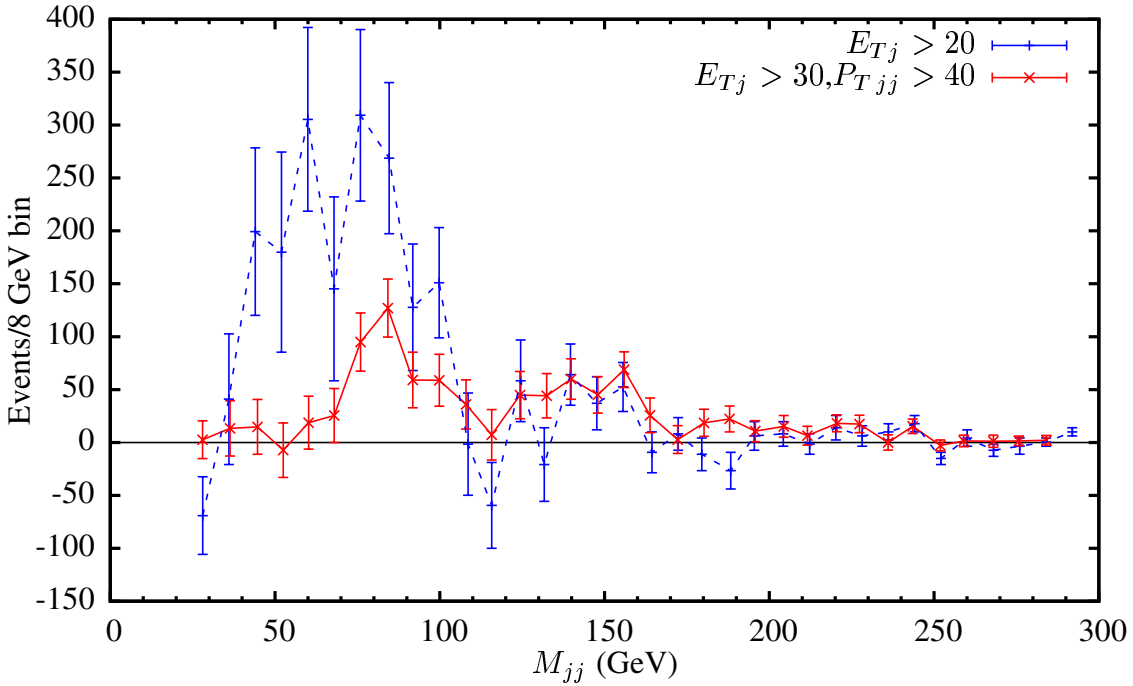
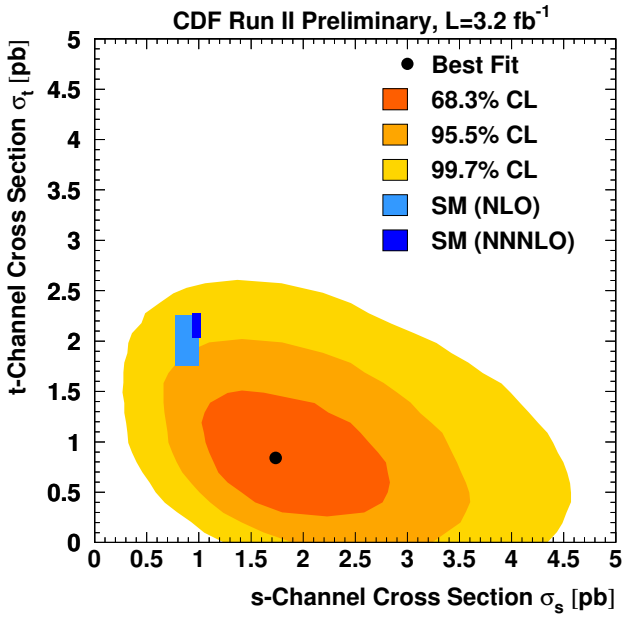


- It is only a partial overlap — these are samples of exclusive jets the weaker jet veto with $E_{Tj} > 30$ is allowing 3-jet events to sneak into the 2-jet sample
- Conclusion: Some of the excess is due to *Wjjj* contamination

Outline

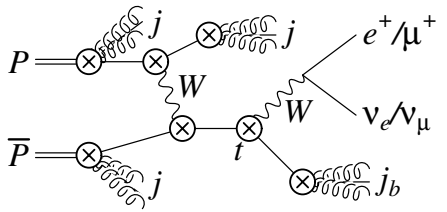
Single-top at CDF: a stranger anomaly

- Single-top-quark production is also a Wjj measurement
- CDF measurement

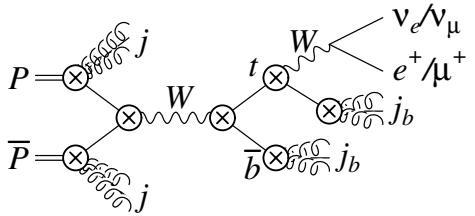


CDF, PRD 82, 112005 (2010)

- t-channel: mostly 1 b-tag



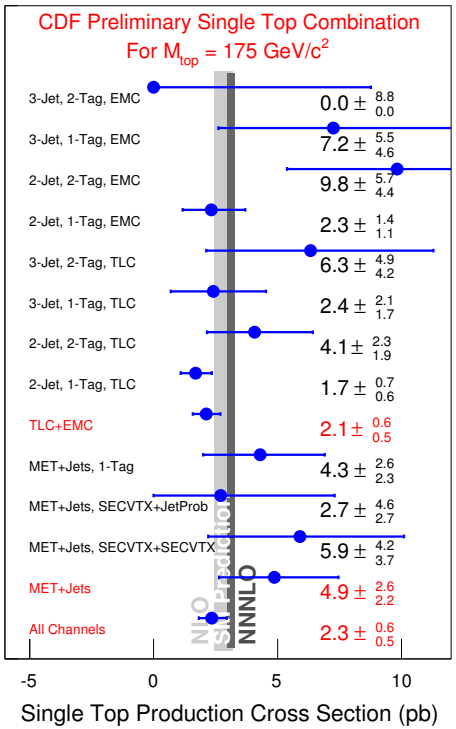
- s-channel: mostly 2 b-tags



- Some mixing occurs, confusing the channels

- CDF observes far too few 1 b-tag events, far too many 2 b-tag events
- This translates to $\sim 1/2$ expected t-channel, $\sim 3\times$expected s-channel
- The sum of t-channel and s-channel is about right...

Extracting contribution to $Wjj/Wjjj$ from the CDF single-top measurement



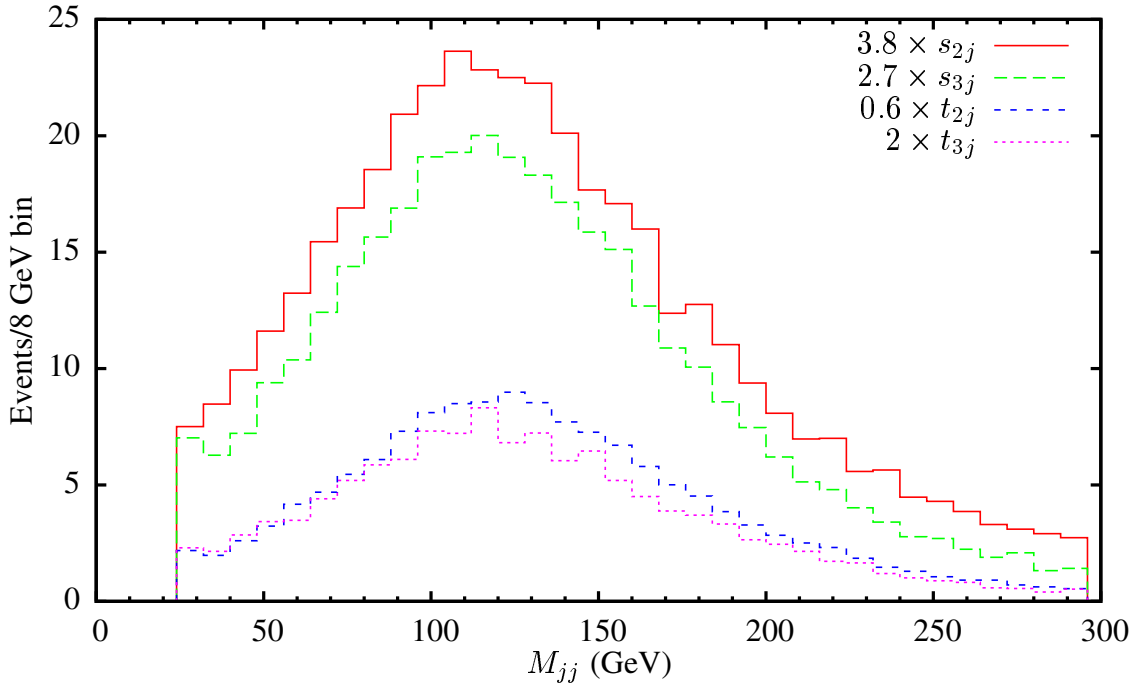
- We extract t-/s-channel for $Wjj/Wjjj$ using:
  - The same trigger as Wjj analysis (TLC)
  - Exclusive 2-/3-jet predictions from Z.S., PRD 70, 114012 (2004)
  - $\sim 50\%$ b-tagging rate
- K-factors by final state (large experimental errors):

Process	Wbj	Wbb	$Wbjj$	$Wbbj$
t-chan.	$0.6^{+0.3}_{-0.2}$	$0.4^{+0.2}_{-0.2}$	$0.9^{+0.8}_{-0.7}$	$2.0^{+1.5}_{-1.3}$
s-chan.	$0.5^{+0.2}_{-0.1}$	$3.8^{+2.1}_{-1.7}$	$0.6^{+0.5}_{-0.4}$	$2.7^{+2.1}_{-1.8}$

- There is a large downward fluctuation of t-channel in the 2-jet sample (almost cancelled by the upward fluctuation in the 3-jet sample)
- s-channel has a large upward fluctuation in CDF data
- Jets defined as $E_{Tj} > 20$ GeV in this data — both 2/3-jet samples here will contribute to Wjj when jet veto is tightened

Why would we expect single-top to help?

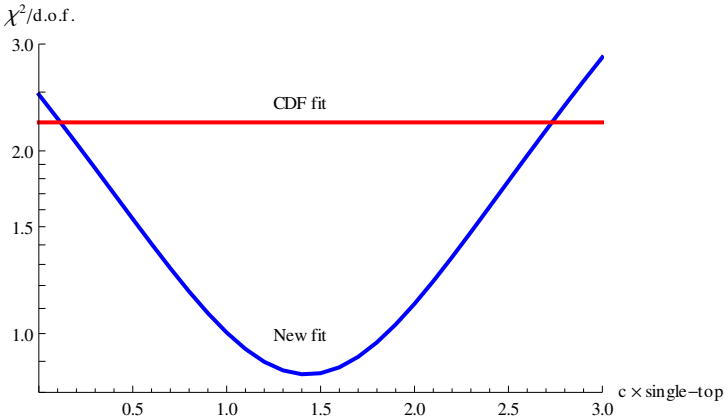
- Events with top quarks naturally have kinematic peaks between 100–140 GeV.
  - $E_b \sim 70$ GeV in top frame, $E_{Tj} > 30$ GeV cut is applied
  - Generically induces a peak in $M_{jj} \gtrsim 100$ GeV



- The M_{jj} shapes of s-/t-channel modes, and 2/3-jets are the same!
- Let's see what data-derived top does to the M_{jj} fit in Wjj ...

Using CDF data-derived single-top in Wjj fit

- Minimal χ^2 fit

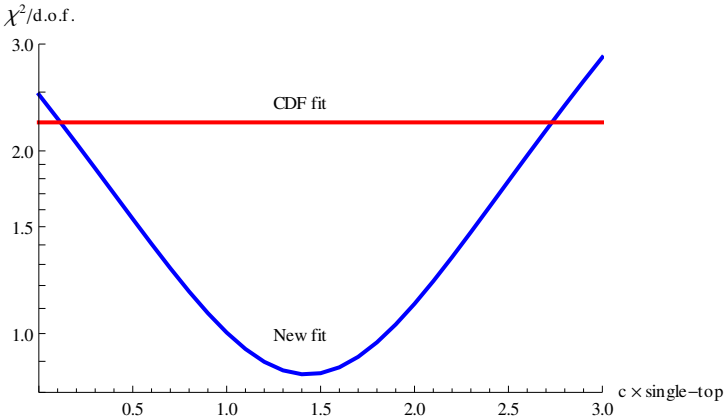


- Best fit at 0.5σ excess
  1.4×data-derived single-top

- We find $\chi^2/\mathrm{d.o.f.} = 26.0/26$ using $c = 1.0\times$data-derived single-top
  - $a \times Wjj_r$ — all backgrounds except dibosons and single-top ($a_{\mathrm{best}} = 0.91$)
  - $b \times VV$ — WW/WZ dibosons ($b_{\mathrm{best}} = 0.91$)
  - $c\times$single-top — where we add $0.6 \times t_2 + 2 \times t_3 + 3.8 \times s_2 + 2.7 \times s_3$

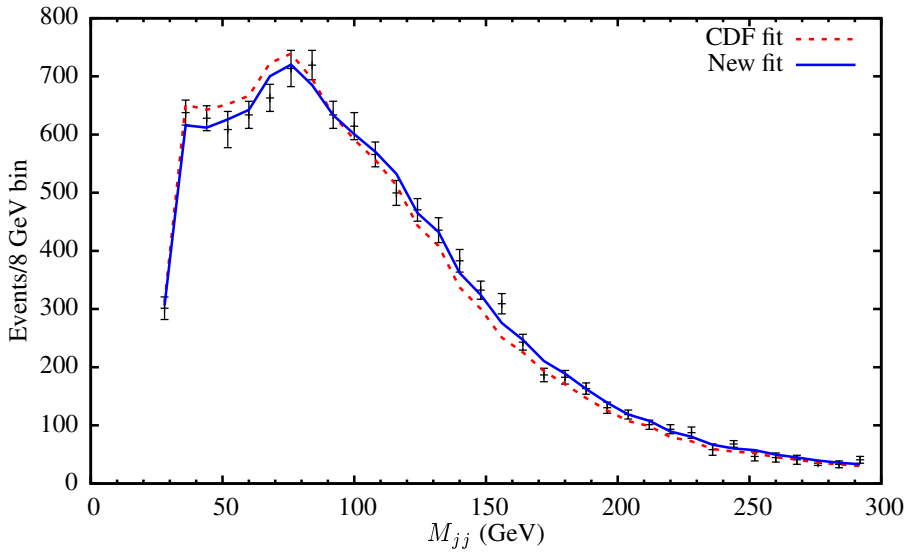
Using CDF data-derived single-top in *Wjj* fit

- Minimal χ^2 fit



- Best fit at 0.5σ excess
  1.4×data-derived single-top

- Comparison of fits using:
  - single top from Monte Carlo (CDF fit)
  - single top from data (our New fit)



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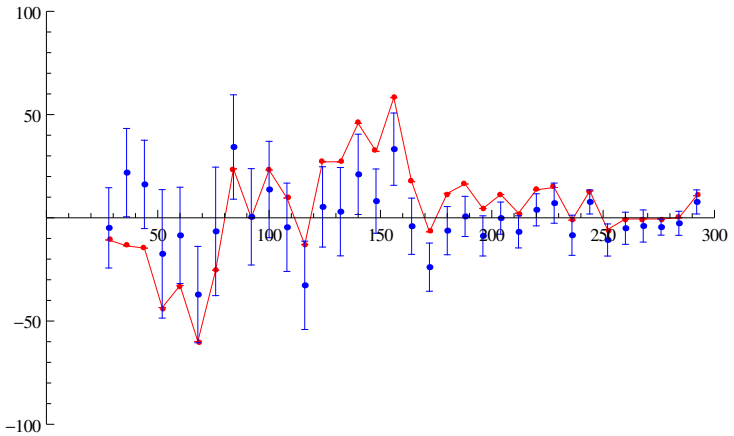
  - $b \times VV$ — WW/WZ dibosons ($b_{\mathrm{best}} = 0.91$)
  - $c\times$single-top — where we add $0.6 \times t_2 + 2 \times t_3 + 3.8 \times s_2 + 2.7 \times s_3$
- Conclusion: Single-top excess completely explains *Wjj* excess

Residual shape and size dependencies disappear

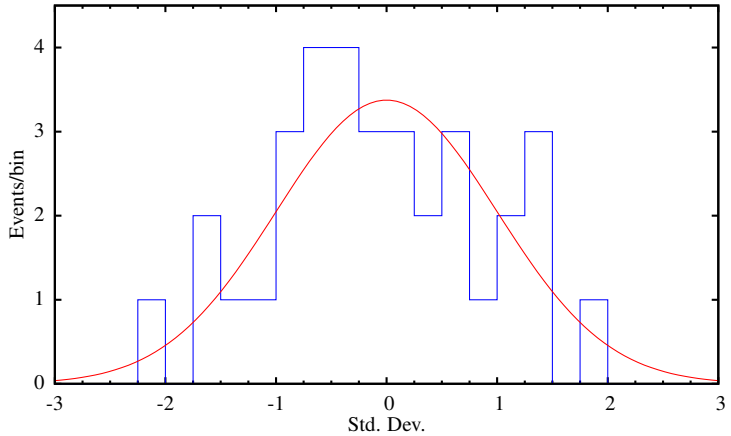
- Fully background subtracted



Line: Old CDF residuals

Error bars: New fit residuals

- Distribution of errors

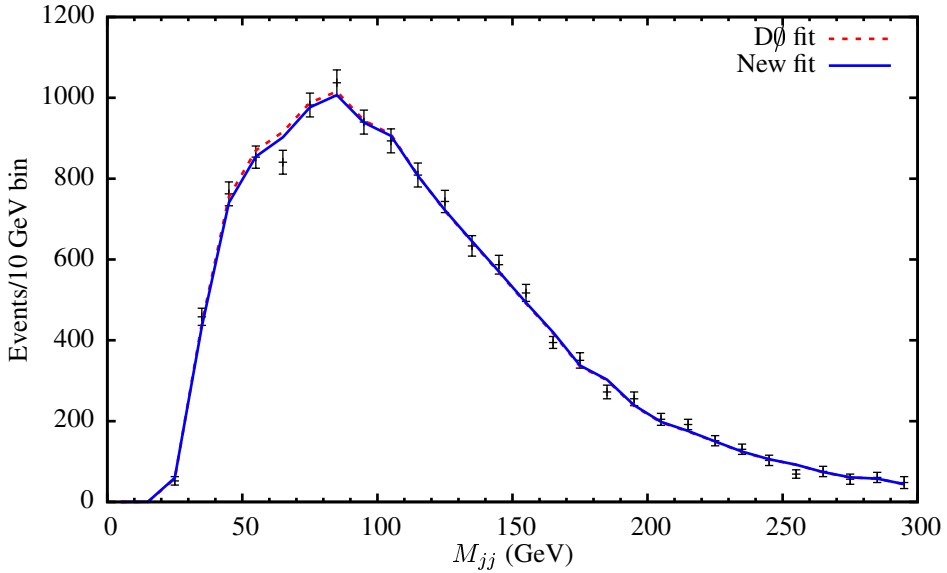


- Textbook sampling of Gaussian

- Conclusion: There is no remaining statistical deviation from a perfect fit to background.

Comparison to DØ data

- In PRD 83, 091504 (2011) we predicted DØ would see at most a small excess in *Wjj*
  - This was based on earlier DØ data (PRD 82, 112005), which found 1.28 $\times$ *t*-channel, 0.94 $\times$ *s*-channel
- DØ has since measured *Wjj* in PRL 107, 011804 (2011):

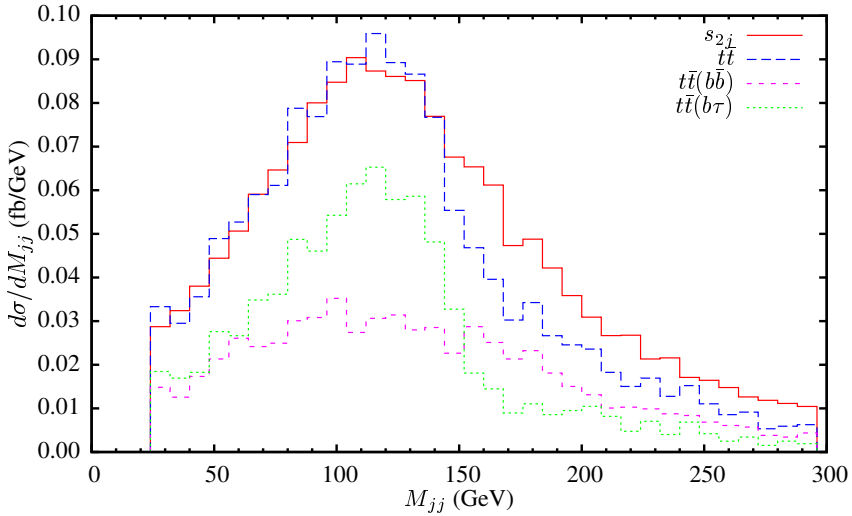


- The $\chi^2/\mathrm{d.o.f.}$ does improve slightly with data-derived single-top
- There is no statistically significant excess in the DØ *Wjj* data
- Conclusion: *Wjj*/single-top discrepancies are an artifact of CDF data

Outline

Is the *Wjj* excess single top?

- We have demonstrated the shape and normalization of the CDF anomaly in *Wjj* are completely consistent with the CDF measurement of single-top quark production.
- We focused on single-top because CDF claimed to fit $t\bar{t}$ to data.
- Mismodeling of $t\bar{t}$ could be playing a role as well



  - $b\bar{b}$ from $t\bar{t}$ has a similar shape to *s*-channel
  - bj from $t\bar{t}$ (with j (or τ) from W decay) is more peaked
- There is not enough information to determine the contribution of $t\bar{t}$
- Conclusion: The solution probably involves all top production modes.

Conclusions

- There are actually 2 anomalies in CDF data:
  - There is a systematic shape problem in Wjj
  - There are factor 2–3 discrepancies in early single-top data

    There is a large excess of $W + 0\,b$-tag, $W + 2\,b$-tag events
    There is a large deficit of $W + 1\,b$-tag events
- The Wjj anomaly is completely explainable in normalization and shape as the same upward fluctuation as is observed in single-top
  - CDF will have to address both problems at once
- As there is no excess in DØ, this is limited to CDF
- Wjj was seen as an anomaly because Monte Carlo was used to predict backgrounds instead of data
  - Remember, single-top is a dangerous background to $WH \to Wb\bar{b}$ and some SUSY channels

THANK YOU