Search for Physics Beyond the Standard Model in \( \bar{t}t \) Production

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Run1 results
- Kinematics of \( \bar{t}t \) events
- Jet multiplicity
- Search for V+A, H+,
- Resonances, rare decays...

Run2 prospects
The New CDF Detector

- 7-8 silicon layers
- 722k channels
- \( r_{\phi}, r_z \) views
- \( z_0^{\text{max}} = 45, \eta^{\text{max}} = 2 \)
- \( 1.3 < R < 30 \text{cm} \)

- \( \mu \) coverage extended to \( \eta = 1.5 \)

- Tile/fiber endcap calorimeter (faster, no gap)

- TOF (100ps@150cm)

- 96 layer drift chamber
- 30k channels
- \( \sigma(1/p_T) \sim 0.1\%/\text{GeV} \)
- \( \sigma(\text{hit}) \sim 150\mu m \)

- Fully digital DAQ (132ns)
- Pipelined trigger (drift chamber tracks @ L1, silicon tracks @ L2)
Top Physics

W helicity

Production cross section
Production kinematics
Resonant production
Spin correlations

Top mass
Top Pt

BSM?
(SUSY, technicolor, ...)

W helicity

l^+,q

ν, q'

p

W^-

b

t

ν, q'

l^-,q

l^-,q

l^+,q

ν, q'

b

Top mass
Top Pt

Decay modes
Branching ratios

|V_{tb}|

Rare/non-SM decays

Exciting possibilities
Third generation, high mass...
Special role in EW symmetry breaking?

7/18/2003
Searches with Top - P. Merkel, Fermilab - CDF
Kinematics of Top Events

• It is important to compare various distributions of the reconstructed top quark and especially of the $t\bar{t}$ system, with SM predictions. Discrepancies could indicate new physics.

• A list of some of the distinctive features that were seen in the RunI dataset (no significant effects observed yet):

  - increase of measured $M_t$ w/ jet multiplicity?
  - slight excess of $W+2\text{jet}$ events where 1 jet is tagged by 2nd-vertex AND soft-lepton-tag (Phys.Rev.D65 (2002) 052007)
  - 2/9 di-lepton evts have unexpectedly large $E_t+E_t(l_1)+E_t(l_2)$ (compare Hall and Barnett, hep-ph/9609313)
  - measured $M(t\bar{t})$ seems to deviate a little from expected distribution
  - measured $P_t(t\bar{t})$ seems a bit harder than expected (but difficult measurement)
  - measured rapidity of $t\bar{t}$ system has different shape than expected
Measure $p_T$ of hadronically decaying top in $1+\text{jets\,\,tt}$ channel

Constrain $M_{\text{top}}=175\text{ GeV}$, perform kinematic fit

In 106 pb$^{-1}$: 61 evts found

BG estimate: 31.9±4.6 evts

Use unsmearing procedure and unbinned likelihood fit to extract true $p_T$($\text{top}$)

- **Upper limit:**
  \[ R_4(225<p_T<425\text{ GeV/c}) < 0.16 @ 95\% \text{ C.L.} \]
Search for Higgs in W+2jets Events

Search for \( pp \rightarrow W+X \rightarrow l+bb \) in 109pb\(^{-1}\)

- Most of the signal expected in W+2jets bin; use other bins to check BG calculation
- 1 or 2 b-tags required: 2\(^{\text{nd}}\)-vertex and soft-lepton-tags
- W+3jets bin in reasonably good agreement; small excess in W+2jets bin
- increase sensitivity of search, look for resonant mass peak in \( M_{jj} \)
- No resonance seen in CDFI data
- Use binned max-likelihood fit, constraining QCD and \( t\bar{t} \) contributions, to extract \( N_{WX} \)
- Use SM Higgs production \((pp \rightarrow WH^0)\) as a model to extract upper limit

\[ \sigma(p p \rightarrow WX) \times B(X \rightarrow b \bar{b}) = [14,19] \text{ pb} \]
for \( M_X = [70,120] \text{GeV} \)

- statistically compatible w/ no signal (SM Higgs)
- ~2 orders of magnitude away from sensitivity to SM Higgs

Searches with Top - P.Merkel, Fermilab - CDF
tt signal region: 3,4 jet bins
We also looked for additional heavy flavor
"Superjets": 2nd-vertex-tag AND soft-lepton-tag
statistics limited: 14 evts observed, 4.4±0.6 expected in W+2,3 jets bin (while good agreement when integrating over all Njet bins)
many checks performed in order to understand this slight excess
either statistical fluctuation OR misunderstanding of detector OR new physics…
Need more data from RunII to re-evaluate this analysis

- 0.4% probability of consistency w/ SM in the 4 jet bins
- “a posteriori” probability of consistency in 2jet bin is $P=10^{-3}$
Search for $\bar{t}t$ Resonances

- Model independent search for narrow vector particle $X \rightarrow \bar{t}t$ in $l+\text{jets}$ sample
- CDFI found no evidence for a $\bar{t}t$ resonance
- Establish upper limits on $\sigma*B$ for narrow resonances
- Use limits to constrain a model of topcolor assisted technicolor ($Z' \rightarrow \bar{t}t$)

Exclude a narrow, leptophobic $X$ boson with $m_X < 560$ GeV/$c^2$
SM V-A predicts W helicity:

\[ F_0 = 70\% \text{ longitudinal} \]
\[ F_- = 30\% \text{ left-handed} \]

\[ [V+A: 70\% \text{ long., } 30\% \text{ r.-h.}] \]

Use invariant mass of lepton and b quark (frame independent):

\[ M_{lb}^2 = \frac{1}{2} (M_t^2 - M_W^2)(1 + \cos \Psi^*_l) \]

Fit for fraction of right-handed (V+A) component: \( f_{V+A} \)

Use Pt of lepton:

Fit for \( F_0 \), then fit for \( F_+ \) while fixing \( F_0 \)

Run II measurement already more sensitive than in Run I!
V+A Results

CDF I preliminary

CDF I Result (109pb⁻¹):
(Using tt dilepton, and lepton+jets events with 1 and 2 SVX b-tagged jets)

\[ f_{V+A} = -0.21^{+0.42}_{-0.25} \pm 0.21 \]

CDF I Result (106pb⁻¹):
\[ F_0 = 0.91 \pm 0.37 \pm 0.13 \]
\[ F_+ < 0.28 \text{ @ 95% C.L.} \]

Previously:
CDF I preliminary

CDF I Result (109pb⁻¹):
(Using tt dilepton, and lepton+jets events with 1 and 2 SVX b-tagged jets)

Using \( M^2_{l+b} \)

Using \( P_t(l) \)

7/18/2003
Searches with Top - P.Merker, Fermilab - CDF
Search for $H^+$:


- 2-Higgs-doublet model, MSSM:
  - $t \rightarrow H^+ b$ competes with SM $t \rightarrow W^+ b$, if $m_H < (m_{t_{top}} - m_b)$
  - $t \bar{t}$ production/decay provides source of Higgs (strong interaction):
    - $W^\pm H^\mp b \bar{b}$, $H^+ H^- b \bar{b}$
  - Direct Higgs pair production (weak interaction): $H^+ H^-$
    - In MSSM (for large $\tan \beta$), dominant decay mode $H^+ \rightarrow \tau \nu$
  - Predict excess of top events with tau leptons!
  - Direct search for signature of $\tau$ lepton in $t$ decays $\rightarrow$ upper limit on $B(t \rightarrow H^+ b)$
  - Signature: $l^+ \tau + E_T + 2\text{jets} + X$
  - In 106pb$^{-1}$ 4 candidates found
  - Expect: 4.0$\pm$0.6 from SM (BG+top)

CDF Run I

Searches with Top - P. Merkel,
Fermilab - CDF

Very interesting channel for Run II

Expected sensitivity for Run II:
$\delta(B(t \rightarrow Wb) / B(t \rightarrow Xb)) = 9\%$

7/18/2003
Unusual decays of the top quark might provide insight into the mechanism of EW symmetry breaking

**Rare decays:** \( t \rightarrow q\gamma, t \rightarrow qZ \)

- Look for \( tt \) events w/ \( t \rightarrow q\gamma \) and the other \( t \rightarrow Wb(\rightarrow l\nu b \text{ or } qqb) \)
  - \(<1 \text{ evt expected from SM BG sources}\)
  - 1 evt found in 110pb\(^{-1}\): \( P_t(\mu)=72\text{GeV}, E_t(\gamma)=88\text{GeV}, E_t=24\text{GeV}, 3 \text{ jets}\)
  - Also kinematically consistent w/ \( t \rightarrow W^+b \) & \( t \rightarrow W^-\gamma \), but \( E_t(\gamma) \) exceptionally large!
    - \( B(t \rightarrow c+\gamma) + B(t \rightarrow u+\gamma) < 3.2\% \text{ @ 95\% C.L.}\)

- Look for \( tt \) events w/ \( t \rightarrow qZ(\rightarrow q\text{ee or } q\mu\mu) \) and the other \( t \rightarrow Wb(\rightarrow qqb) \)
  - Less sensitive because \( B(Z \rightarrow \text{leptons}) \) small
  - 1.2 evts expected from SM BG sources
  - 1 evt found in 110pb\(^{-1}\): \( Z \rightarrow \mu\mu + 4 \text{ jets}\)
  - Kinematics fit better the \( Z+\text{multijet} \) hypothesis than FCNC decay
    - \( B(t \rightarrow c+Z) + B(t \rightarrow u+Z) < 33\% \text{ @ 95\% C.L.}\)
pp collisions at $\sqrt{s}=1.96$ TeV

Stable data-taking since June ‘02 shutdown ~ 200 pb$^{-1}$ on tape

~ 5-8 pb$^{-1}$/wk @ > 90% efficiency

Record instantaneous luminosity after January shutdown ~4.7x10$^{31}$cm$^{-2}$s$^{-1}$

Most of the RunII results so far used 72 pb$^{-1}$ (March ‘02 – January ‘03)
New results from ~120 pb$^{-1}$ expected soon!
First cross section and $M_{\text{top}}$ measurements using 72 pb$^{-1}$

New results from $\sim$125 pb$^{-1}$ expected soon

Some searches are already on the way, like single top and V+A

7/18/2003

Searches with Top - P. Merkel,
Fermilab - CDF
Summary & Outlook

- Many interesting and promising tests for new physics in the top sector
- Cross-section of CDF RunI results presented
- Standard top measurements established in RunII
- Some searches in tt events already started

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Estim.uncertainty</th>
<th>Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_t$</td>
<td>2-3 GeV/ $c^2$</td>
<td>Indirect $M_H$</td>
</tr>
<tr>
<td>$\sigma_{tt}$</td>
<td>7%</td>
<td>QCD couplings</td>
</tr>
<tr>
<td>$\sigma_{ll}/\sigma_{l+j}$</td>
<td>12%</td>
<td>Non-SM decays</td>
</tr>
<tr>
<td>$B(t\to Wb)/B(t\to Wx)$</td>
<td>2.8%</td>
<td>“</td>
</tr>
<tr>
<td>$B(t\to Wb)/B(t\to Xb)$</td>
<td>9%</td>
<td>“</td>
</tr>
<tr>
<td>$B(t\to W_{long})$</td>
<td>5.5%</td>
<td>Non-SM couplings</td>
</tr>
<tr>
<td>$B(t\to W_{V+A})$</td>
<td>2.7%</td>
<td>“</td>
</tr>
<tr>
<td>$\sigma*B(Z\to tt)$</td>
<td>$\sim 90$ fb</td>
<td>exotics</td>
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BACKUP SLIDES:
$M_{\text{top}}$ versus # of jets

**Tevatron Top Quark Mass Measurements**

- $168.4 \pm 12.8$ GeV/c²  
  Dilepton
- $173.3 \pm 7.8$ GeV/c²  
  Lepton+jets
- $172.1 \pm 7.1$ GeV/c²  
  Combined
- $167.4 \pm 11.4$ GeV/c²  
  Dilepton
- $176.1 \pm 7.4$ GeV/c²  
  Lepton+jets
- $186.0 \pm 11.5$ GeV/c²  
  All-Hadronic
- $176.1 \pm 6.6$ GeV/c²  
  Combined
- $174.3 \pm 5.1$ GeV/c²

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7/18/2003  
Searches with Top - F. Merkel,  
Fermilab - CDF
Pt(t\bar{t})

- transverse momentum of tt system; the spectrum based on 32 CDF tagged events, which are the basis of the CDF top mass measurement, seems to be a little harder than that expected from MC calculations; it is a difficult variable to measure because of possible filter biases.
Precision measurements of top and W masses constrain the mass of the Standard Model Higgs

- $M_W : CDF \oplus D\phi$
  - $\sigma_M \sim 30 \text{ MeV} (2 \text{ fb}^{-1})$
  - $\sigma_M \sim 20 \text{ MeV} (10 \text{ fb}^{-1})$

- $M_t : CDF \, \text{or} \, D\phi$
  - $\sigma_M < 4 \text{ GeV} (2 \text{ fb}^{-1})$
  - $\sigma_M < 2 \text{ GeV} (10 \text{ fb}^{-1})$

With only 2 fb$^{-1}$ we may find a contradiction with the Standard Model Higgs direct search limit
Anomalies in the Top Quark Sample?

- found in dilepton sample
- electron in crack called jet
- 180 GeV $E_T$ electron!
- 110 GeV missing $E_T$!
Search for Single top
Probes the electroweak Wtb vertex

- Search for anomalous couplings - large production rates or anomalous angular distributions
- Background to Higgs

CDF I has performed searches for s and t channels separately in RunI:
- 1.98 ± 0.13 pb
- 0.88 ± 0.05 pb

CDF I has also searched for combined process:
- $\sigma(t) < 14 \text{ pb at 95\% C.L.}$

- If SM is correct, observation in RunIIa
- Expect about 100-150 events in 2 fb$^{-1}$
- Measure $|V_{tb}|$ with 10-15\% precision

Two (out of 9) CDFI di-lepton events have unexpectedly large MET + ΣEt (both give very poor "fits" to tt hypothesis); one such event exists in D0 sample. (Flagged by Hall and Barnett as candidates for SUSY events in their DPF 96' paper).

- tt or decay of SUSY quarks with masses around 300 GeV?