Beyond the SM searches with Top Quarks at DØ

Yvonne Peters
Newton International Fellow @
University of Manchester

On Behalf of the DØ Collaboration
The Top Quark

- Heaviest known elementary particle
  - 173.1±1.3GeV

- Standard Model:
  - Large coupling to Higgs
  - Electric charge +2/3 e
  - Short lifetime 0.5x10^{-24}s
  - 100% decay into W^+b
  - Production in pairs or singly

- But:
  Is the top quark the particle we think it is?

- Especially interesting to look for new physics!
Where do we look?

- Forward-Backward Asymmetry
- \( t\bar{t} \) resonances (\( Z' \) production)
- Associated production with Higgs (\( t\bar{t}H \))

Red: production
Green: Decay

Charge Higgs
\( W' \) production

Ratio of branchings fractions

Only some selected results (mass difference, spin correlation, \( W \) helicity...not shown here)
Outline

Single top production

t\bar{t} production

t\bar{t}H search

t\bar{t}\bar{t} resonances

W' search

charged Higgs

ratio of branching fractions

top decay

forward backward charge

Asymmetry
Production mechanism

Pair production (t\bar{t}) via strong interaction

85% q\bar{q} annihilation and 15% gg fusion

For details see Sebastien's talk

Single top production via electro-weak interaction

Observed in 2009

For details see Reinhard's talk
**t\(\bar{t}\) resonances**

- Is the t\(\bar{t}\) produced in the way we think it is?
- SM: No t\(\bar{t}\) resonance
- Many models predict a t\(\bar{t}\) resonance:
  - Axigluons
  - Colorons
  - Kaluza-Klein gluon
  - G'
  - Topcolor assisted technicolor: Z'
  - ....
**tt̅ resonances**

- Model independent search: Expect a bump in $M_{tt̅}$ distribution
- Assume narrow resonance
- Set limits on $\sigma(p\bar{p}\to X) \times B(X\to tt̅)$
- Benchmark model: Topcolor assisted technicolor $Z'$

\[ M_{Z'} > 820 \text{GeV} \]
Asymmetry

- Is the $t\bar{t}$ production what we think it is?
- NLO QCD calculations: Forward-backward charge asymmetry of $\sim5\%$
  - From interferences between diagrams
- Measure

\[
A_{fb} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}
\]
Asymmetry

- $A_{fb} = 12 \pm 8 \text{ (stat)} \pm 1 \text{(syst)} \%$
  - In agreement with SM $A_{fb} = 5 \pm 1.5 \%$
  - Search for $Z'$: Left-handed decay would give large positive asymmetry
    - Limit on $f = N(p\bar{p} \rightarrow Z' \rightarrow t\bar{t})/N(p\bar{p} \rightarrow t\bar{t})$

**ttH search**

- Associated production of Higgs and $t\bar{t}$ pair
  - Expect more jets, more b-jets than in $t\bar{t}$
    - Use additional topological information

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**Graphical Content**

**D0 Run II 2.1 fb$^{-1}$ Preliminary**

- Histogram showing number of events for $\geq 5$ jets, $\geq 3$ tag

**DØ Preliminary**

- ttH $\rightarrow t\bar{t}bb$

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Yvonne Peters
**t\bar{t}H search**

- t' produced via a heavy color-octet vector particle (G'):
  - Enhanced cross section wrt. SM t\bar{t}H
  - Use t\bar{t}H search to exclude region on (m_{t'}, M_H) parameter space
- s_L: mixing angle between t and t'
- r: coupling strength

![Diagram](image-url)

**Graphical Data**

- $m_{t'} = M_{G'}/2$
- $r = 0.4$, $s_L = 0.2$

**DØ Run II Preliminary (1fb⁻¹)**

- **Expected limit @ 95% CL**
- **Excluded region @ 95% CL**

**Graph Details**

- $M_H$ vs. $m_{t'}$ (GeV)
- $m_{t'}$ ranges from 360 to 440 GeV
- $M_H$ ranges from 110 to 170 GeV
And does the top quark decay as expected?
Ratio of branching fractions

- Measure $\sigma_{tt}$ and the ratio of branching fractions
  
  \[ R = \frac{BR(t \rightarrow Wb)}{BR(t \rightarrow Wq)} = \frac{|V_{tb}^2|}{|V_{td}^2| + |V_{ts}^2| + |V_{tb}^2|} \]

- Measure distribution of events with 0, 1, $\geq 2$ b-jets

\[ \sigma_{t\bar{t}} = 8.18^{+0.90}_{-0.84} (stat + syst) \pm \cdot \cdot (lumi) \text{ pb} \]

\[ R = 0.97^{+0.09}_{-0.08} (stat + syst) \]

$R > 0.79$ @ 95% C.L.

Under assumption of unitary 3x3 CKM Matrix:

$|V_{tb}| > 0.89$ @ 95% C.L.

W/O assumption of unitarity or 3 generations:

\[ (1-R)/R = (|V_{ts}|^2 + |V_{td}|^2)/|V_{tb}|^2 < 0.27 \text{ @ 95% C.L.} \]
Light charged Higgs

- $m_t > M_{H^+}$: Decays $t \rightarrow W^+b$ and $t \rightarrow H^+b$ can compete.

Consider $H^+ \rightarrow \tau^+\nu$ and $H^+ \rightarrow c\bar{s}$ decay.

Different behavior in the same final state for increasing $\text{Br}(t \rightarrow H^+b)$.

Different behavior in different final states for increasing $\text{Br}(t \rightarrow H^+b)$. 

Br = 0

Br = 0.5
We explore different methods:
Extract limits on $\text{Br}(t \rightarrow H^+ b)$ from

- Cross section ratios:
  $\frac{\sigma_{t\bar{t}}(\tau \ell)}{\sigma_{t\bar{t}}(l\text{jets}+\ell\ell)}$ & $\frac{\sigma_{t\bar{t}}(\ell\ell)}{\sigma_{t\bar{t}}(l\text{jets})}$

- Topological information

- A global fit to all final states
  - Simultaneous fit of $\sigma_{t\bar{t}}$ and $\text{Br}(t \rightarrow H^+ b)$ for tauonic model
Light charged Higgs

- Use the limits on the top to charged Higgs branching ratio to exclude MSSM parameter space

- Benchmark: $M_{h_{\text{Max}}}$ scenario
  - Strength of supersymmetric Higgs mixing: $\mu = 200$ GeV
  - Sfermion mass scale $M_{\text{SUSY}} = 1000$ GeV
  - Gaugino mass $M_2 = 200$ GeV
  - Gluino mass $M_3 = 800$ GeV
  - Trilinear Higgs-squark coupling $A$
  - Stop mixing parameter large
    - $X_t = A - \mu \cot(\beta) = 2M_{\text{SUSY}}$
    - Provides largest parameter space in direction of $M_{h_{\text{Max}}}$
Light charged Higgs

- Benchmark: CPX scenario
  - Increased $\tau\nu$ and $c\bar{s}$ decay, $t^*b$ decay suppressed
  - Hierarchy between first two and third generation introduced

- Parameters:
  - $\mu = 2000$ GeV, $M_{\text{SUSY}} = 500$ GeV,
    $A_t = 1000*\exp(i\,\pi/2)$,
    $M_2 = 200$ GeV,
    $M_3 = 1000*\exp(i\,\pi)$

- First limits from Tevatron on CPX model!
For $m_t < M_{H^+}$: Single top production via $H^+$ possible

Search for bump in $t\bar{b}$ invariant mass distribution

Limits on $\sigma(p\bar{p}\rightarrow H^+)\times B(H^+\rightarrow t\bar{b})$

Phys. Rev. Lett. 102, 191802 (2009)
W' search

- Search for heavy gauge boson W' in single top production
  - Look for bump in invariant t\bar{b} mass
    \[ \mathcal{L} = \frac{V_{ij}}{2\sqrt{2}} g_w \bar{f}_i \gamma \mu \left[ a_R^{ij} (1 + \gamma^5) + a_L^{ij} (1 - \gamma^5) \right] W'_\mu f_j + \text{H.c.} \]
  - SM-like W': \( a^L=1, a^R=0 \)
    - Interference with SM W
    - \( M_{W'} > 731 \text{GeV} \)
  - Alternative model:
    Right handed W' (\( a^L=0, a^R=1 \))

Conclusion and outlook

- The top quark is an ideal place to search for new physics!
- Extended search program at D0
  - $W'$, $Z'$, $G'$, $t'$, $H^+$, $H$, ...
- More data to analyze, more new physics to explore!
  - More than 6fb$^{-1}$ of data on disk now!
- For the latest results of the full top program go to:

  http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html
Stay tuned!
BACKUP
Two Higgs Doublet Model (2HDM)

- Extension of the Standard Model with a second complex Doublet
  - Two vacuum expectation values $v_1$ and $v_2$
  - In total five physical Higgs Bosons: $A^0$, $h^0$, $H^0$, $H^\pm$

- Higgs-Fermion couplings not fixed by the model – but requirement: Avoid FCNC
  - **TYPE I**: only one Higgs doublet couples to Fermions
  - **TYPE II**: one Higgs doublet couples to up-type Fermions, the other to down-type Fermions
  - **Type III**: both Higgs doublets couple to fermions

- **MSSM**: Type II 2HDM needs to be realized
  - Leading order: independent parameters: $m_A$ and $\tan(\beta) = v_1/v_2$
tt resonances

- Some more info: measured cross section and expected limits

![Graph showing measured cross section and expected limits for tt resonances](image)