Top Decay Properties and Search for Single Top Production at the Tevatron

on behalf of the CDF and DØ Collaborations

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Top Quark Properties

- **top decay properties:**
  - W helicity measurements:
    - SM excludes right handed W polarization
  - search for $t \rightarrow H^+ b$
  - prediction of light, charged Higgs in SSM
  - $BR(t \rightarrow Wb)/BR(t \rightarrow Wq)$
  - contribution from FCNC or 4th generation quark

- **single top production:**
  - measurement of $|V_{tb}|$
W Helicity in Top Decays

top decay in the SM: (V-A) charged current interaction

helicity states of the W:

\[ W^+ \]

fraction of longitudinally polarized W

\[ f_0 = \frac{m_t^2}{2M_W^2 + m_t^2 + m_b^2} \]

\[ = (70.1 \pm 1.6)\% \]

\[ t \]

\[ b \]

\[ \frac{-ig}{2\sqrt{2}} \gamma^\mu (1 - \gamma^5) V_{tb} b W^\mu \]

left handed fraction

\[ f_- \approx 30\% \]

right handed fraction

\[ f_+ \approx 0\% \]
W polarizations can be disentangled:
- $\cos \theta^*$ distribution (in W rest frame)
- lepton $p_T$ distribution

**longitudinal W-polarization:**
- leptons are emitted perpendicular to W boson direction
- harder $p_T$ distribution

**left-handed W:**
- leptons are emitted opposite to W boson direction
- softer $p_T$ distribution

SM $\approx 70\% W_0 + 30\% W_L$
Limits on $f_0$

**likelihood analysis of $p_T$ spectrum**
combined lepton+jet and dileptons samples: 70 events

**likelihood analysis of $\cos\theta^*$**
combined lepton+jet sample: 31 events

CDF Run II Preliminary (162 pb$^{-1}$)

$$\cos\theta^* \approx \frac{2m_{lb}^2}{m_t^2 - m_W^2} - 1$$

C$D$F $D0$-Collaborations - Ursula Bassler, LPNHE-Paris

$\int Ldt = 200$ pb$^{-1}$

**likelihood analysis of $p_T$ spectrum**
combined lepton+jet and dileptons samples: 70 events

- $f_0 = 0.27^{+0.35}_{-0.21} (stat + syst)$
- $f_0 < 0.88@95\% CL$

$\cos\theta^* = 9.9^{+1.7}_{-1.7}$ evts

$\cos\theta^* = 24.6 \pm 3.0$ evts

**SM-assumption**: $f_+ = 0$ – no right handed W

**main systematic uncertainties**: background normalization, $m_t$

$\pm 0.34 (syst)$

$\pm 0.17 (syst)$

$\pm 0.30 (stat)$

$\pm 0.34 (stat)$

$\pm 0.25 @95\% CL$
Limits on $f_+$

- lepton+jets sample (169 pb$^{-1}$)
- simulate templates of $\cos \theta^*$ for $0 \leq f_+ \leq 0.3$
- likelihood analysis with $f_0 = 70\%$

**topological selection: 80 evts**

- b-tagged selection: 31 evts

$f_+ = -0.11 \pm 0.19 (\text{stat})$

$f_+ < 0.24 @ 90\% CL (\text{stat} + \text{syst})$

$\Rightarrow W$ helicity determinations are compatible with Standard Model expectations
MSSM Search for $t \rightarrow H^+ b$

- for charged Higgs-bosons with $m_H < m_t$, the decay $t \rightarrow H^+ b$ modifies $tt$ signatures according to $H^\pm$ decay modes
  
  **large $\tan\beta$:** $H^\pm \rightarrow \tau\nu$  
  excess of $\tau$ decays
  
  **small $\tan\beta$:** $H^\pm \rightarrow cs$  
  excess in all-hadronic decays
  
  $H^\pm \rightarrow W_bb$  
  2 extra $b$ jets

inputs for $H^\pm$ limits:

- $\sigma(tt \rightarrow \text{dilepton})$
- $\sigma(tt \rightarrow \text{lepton+jets})$
- limit on $\sigma(tt \rightarrow \text{lepton+}\tau)$

model independent analysis: $BR(t \rightarrow Hb) < 0.70 \ @95\%CL$
Limit on $|V_{tb}|$

Unitarity constraint on the CKM-matrix with 3 families

$\Rightarrow$ BR($t \rightarrow Wb$) at nearly 100% in the SM

\[
R = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} > 0.998 \text{ at } 90\% \text{ CL} (PDG)
\]

- limit on R from BR($t \rightarrow Wb$)/B($t \rightarrow Wq$) using tag-rate $R \varepsilon_b$:
  - the probabilities for 0-, 1- and 2- tagged top events are
    \[
    \varepsilon_0 = (1 - R \varepsilon_b)^2 \quad \varepsilon_1 = 2R \varepsilon_b (1 - R \varepsilon_b) \quad \varepsilon_2 = (R \varepsilon_b)^2
    \]
  - estimate background level in tt-sample
  - compare tag rates with expectation
  - compute most likely value of $R \varepsilon_b$ and set lower limit on R

CDF: 0-, 1- and 2-tagged lepton+jets and di-lepton samples

DØ: 1- and 2-tagged lepton+jets samples with two different b-tagging algorithms
**Determination of R**

**CDF:** tagging probability calibrated on data \( \Delta \epsilon_b = 0.436 \pm 0.032 \)

\[
R = 1.12^{+0.27}_{-0.23} (\text{stat} + \text{syst})
\]

\[
R > 0.61 \@ 95\% CL
\]

\[
|V_{tb}| > 0.79 \@ 95\% CL
\]

**DØ:** impact parameter algorithm for b-tagging:

secondary vertex algorithm for b-tagging:

- independent cross-section determination
- measurements compatible with SM
- main systematic uncertainties: difference of b-tagging probability between the data and the simulation
Single Top Production

- Single top quarks produced by weak interaction are a direct probe of top quark’s weak couplings.
  - Measure $V_{tb}$ without assuming three-generation unitarity.
- Cross section is about half of the top quark pair production cross section (2.9 pb vs. 6.7 pb) but: signal/background is much worse
  - fewer jets, softer kinematics, lower acceptance
  - signature: isolated lepton, missing $E_T$, $\geq 2$ jets
  - $s$-channel: 1 or 2 b-tags  
  - $t$-channel: 1 b-tag + 1 jet
  - major backgrounds: $W$+jets, top-pairs, fake leptons

$\Rightarrow$ Single top production has not been observed yet!
Single Top Search

CDF:
- $W + 2$ jets events
- combined channel: 42 evts observed - $38.1 \pm 5.9$ expected
- $\varepsilon \approx 1\%$ for $S/B \approx 1/10$
- 1 tag evts: $Q_L \cdot \eta_{jet}$ distribution to disentangle s and t channels

- **s-channel:** $\sigma_s < 13.6$ pb (95% CL)
  - expected limit: $\sigma_s < 12.1$ pb
- **t-channel:** $\sigma_t < 10.1$ pb (95% CL)
  - expected limit: $\sigma_s < 11.2$ pb
- combined analysis: $\sigma_{s+t} < 17.5$ pb (95% CL)
  - expected limit: $\sigma_s < 13.6$ pb
- *most likely cross-section:* $2.7^{+1.8}_{-1.7} \cdot \sigma_{SM}$
Single Top Search

**DØ: 230 pb$^{-1}$**

- 2 analysis strategies after pre-selection: cut-based analysis and Neural Network analysis in lepton+jets samples for $W+\geq 2$ jets: $\varepsilon \approx 1.9 - 2.7\%$ for $S/B \approx 1/15$
- detailed study discriminative power of 25 kinematic variables: object kinematics, global event kinematics and angular variables
- cut-based analysis using the 6-7 most efficient cuts
- major systematic uncertainties: b-tagging simulation, JES
Neural Network Analysis

**DØ: 230 pb⁻¹**

- training of 8 different Neural Networks in order to separate the Wbb and the tt-background for s- and t-channels separately for the electron and muon sample

- 11 variables used per NN-analysis

- good separation for tt-background, less for Wbb

- limits extracted from 2D binned likelihood on tt and Wbb NN-output
Single Top Results

cut based analysis:

s-channel: \( \sigma_s < 10.6 \text{ pb} \) (95% CL)
expected limits: \( \sigma_s < 9.8 \text{ pb} \)

\( t \)-channel: \( \sigma_t < 11.3 \text{ pb} \) (95% CL)
expected limits: \( \sigma_t < 12.4 \text{ pb} \)

NN-based analysis:

s-channel: \( \sigma_s < 6.4 \text{ pb} \) (95% CL)
expected limits: \( \sigma_s < 4.5 \text{ pb} \)

\( t \)-channel: \( \sigma_t < 5.0 \text{ pb} \) (95% CL)
expected limits: \( \sigma_t < 5.8 \text{ pb} \)

- single top production expected with the Tevatron Run II data
- improvements on acceptance and systematics ongoing in CDF and DØ

Various exclusion limits are shown, with
- comparison of exclusion limits in the s (tb-muon) and \( t \) (tqb-electron) channels
- close in sensitivity to non SM contributions such as FCNC or 4\textsuperscript{th} quark family
Summary

- Study of top-properties allows to investigate in detail Standard Model prediction
  - increased statistics will allow for precision studies
- No deviations from Standard Model expectations have been observed so far
  - with current precision still room for new physics
- Substantially improved limits for single top search with respect to Run I results
  - further improvements in analysis will allow to reduce the integrated luminosity necessary for single top observation