# Search for Single-Top Quark Production at CDF

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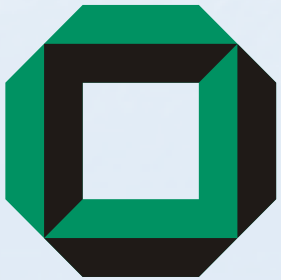
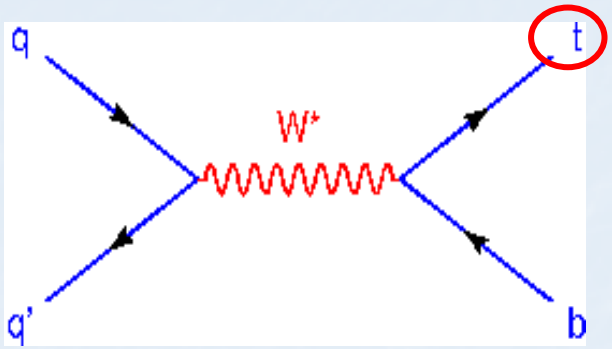
on behalf of the CDF collaboration

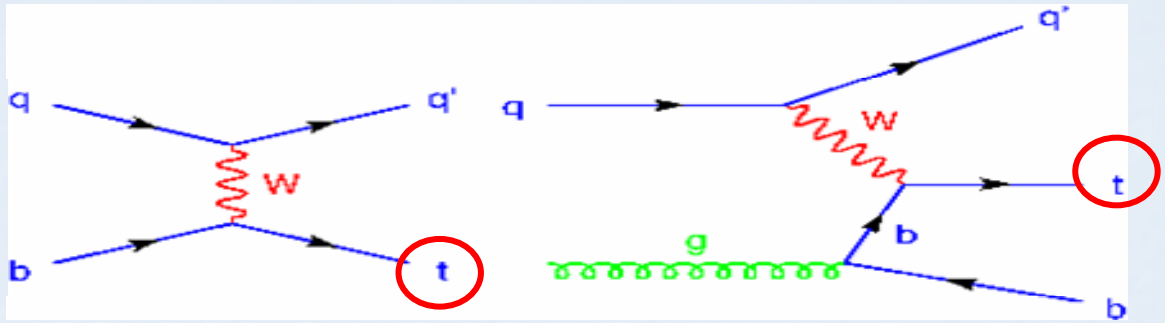


HEP2005 Lisboa, 7/23/2005

# Single Top Production at Tevatron




*s-channel production (W*)*



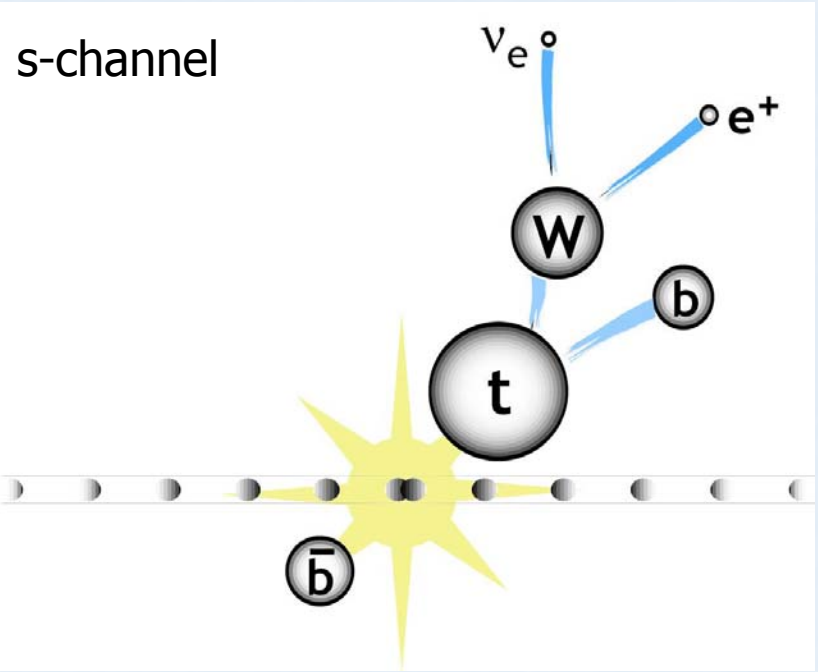

*t-channel production (Wg fusion)*

- $V_{tb}$ CKM matrix element
- top polarisation and V-A structure of EWK top interaction
- Probe b-quark PDF (t-channel)
- Look for physics beyond SM
  - 4th generation
  - anomalous $W_{tb}$ couplings
  - FCNC ($t \rightarrow Z/\gamma\ c$)
- Irreducible background to associated Higgs production

| $s^{1/2}$ *=1.96TeV* | NLO Cross-sections |
|---|---|
| t-channel | 1.98±0.25 pb |
| s-channel | 0.88±0.11 pb |
| t-tbar | 6.77±0.42 pb |

- ***B.W. Harris et al.: Phys. Rev. D 66, 054024***
- ***Z. Sullivan: Phys. Rev. D 70 114012***
- ***Kidonakis 2003: Phys. Rev. D 68 114014***

# Event Signature

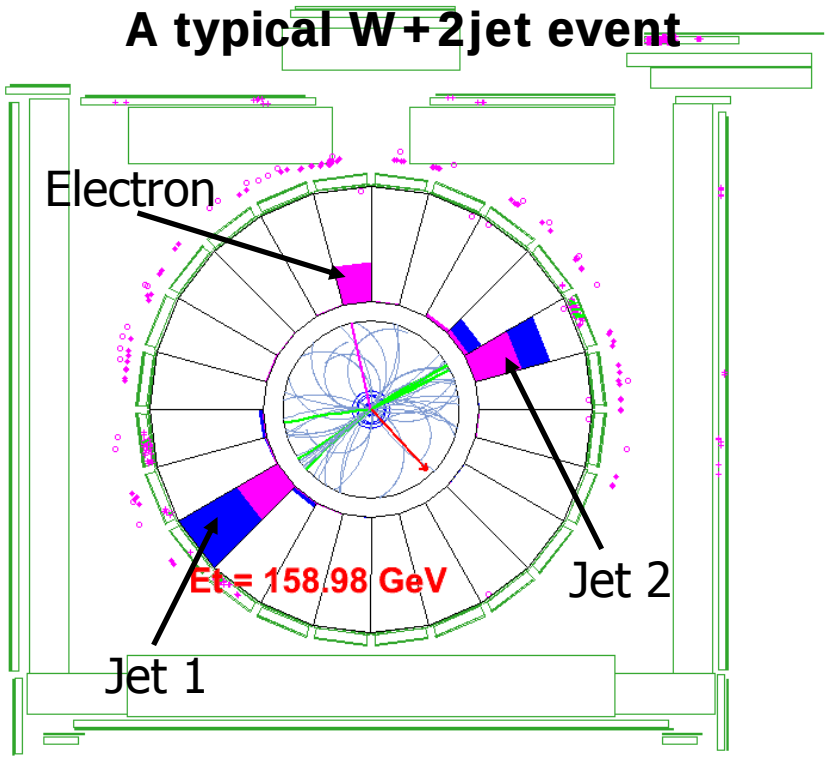



- High-$P_T$ electron or muon
- Missing transverse energy
- 2 jets
  - s-channel: 2 b-jets
  - t-channel:
    1 b-jet + 1 light-quark-jet + 1 soft b-jet (from gluon splitting) which is rarely seen

# CDF Run II Analysis: Event Selection

- Phys.Rev.D71:012005,2005

- Look in the **W+2 jets** channel:
  - 1 lepton with $E_T$>20 GeV, $|\eta|$<1.0
  - missing transverse energy: $ME_T$>20 GeV
  - 2 jets : $E_T$> 15 GeV, $|\eta|$ < 2.8
  - at least one b-tag (displaced sec. vertex)
  - Veto dilepton from Z and ttbar, conversion events
- Topological cuts:
  - 140 < $M_{l\nu b}$ <210 GeV/$c^2$
  - (combined and separate searches)
  - leading jet $E_T$ > 30 GeV
  - (separate search for t-channel only)
- Backgrounds: non-top and tt




**Run: 153389 · Event: 361345**

- CEM Electron $E_T$=50.9 GeV, $\eta$ =0.24
- MET=25.7 GeV, Phi=5.6
- Jet1 $E_T$=173.8 GeV, $\eta$ =0.45
- Jet2 $E_T$=149.8 GeV, $\eta$ =-0.13
- HT = 475 GeV, M$l\nu$b=173 GeV/$c$2

# Backgrounds

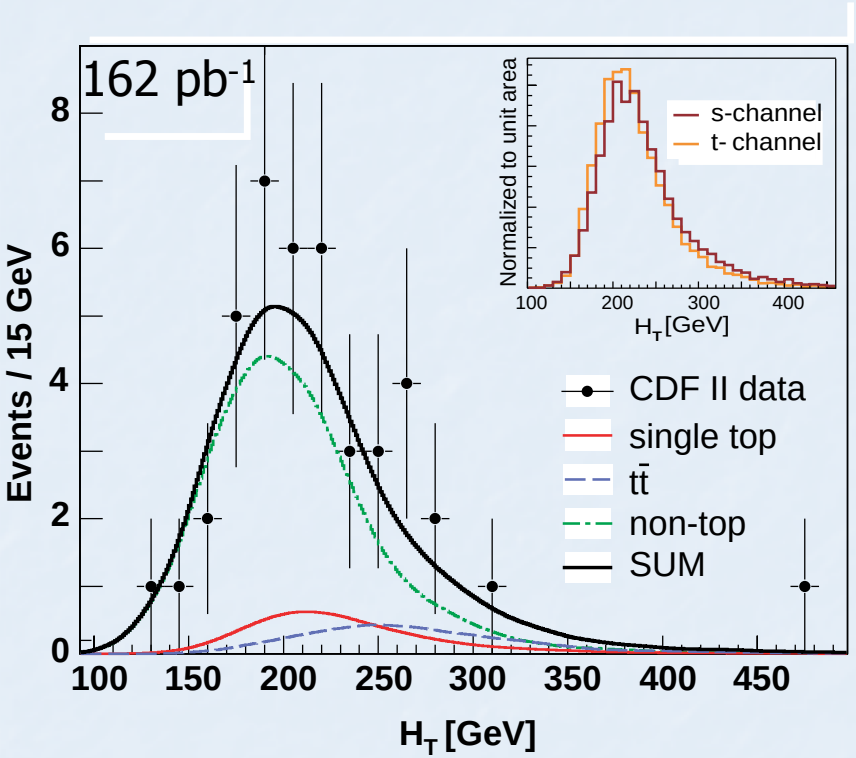
- W+jets (Wbb, mistagged Wcc, Wc…)
  - Challenging background both in term of quantification & shape variables
  - Estimated from data & MC
  - Heavy Flavor fractions (b,c) from ALPGEN + Herwig
  - Normalization from data before b-tagging
- Multijet events
  - Jet misidentified as lepton & semi-leptonic decay of HF jets (bb)
  - Estimated from data
- WW, WZ, $Z \rightarrow \tau\tau$, Top pair production
  - Estimated from Pythia and theoretical cross section

# Event yield with 162 $pb^{-1}$

| Process | Combined | 1-tag | 2-tag |
|---|---|---|---|
| tt | 3.8 ± 0.9 | 3.2 ± 0.7 | 0.60 ± 0.14 |
| Non-top | 30.0 ± 5.8 | 23.3 ± 4.6 | 2.59 ± 0.71 |
| Sum Background | 33.8 ± 5.9 | 26.5 ± 4.7 | 3.19 ± 0.72 |
| t-channel | 2.8 ± 0.5 | 2.7 ± 0.4 | 0.02 ± 0.01 |
| s-channel | 1.5 ± 0.2 | 1.1 ± 0.2 | 0.32 ± 0.05 |
| Sum Single-Top | 4.3 ± 0.5 | 3.8 ± 0.4 | 0.34 ± 0.05 |
| **Sum Expected** | **38.1 ± 5.9** | **30.3 ± 4.7** | **3.53 ± 0.72** |
| **Observed** | **42** | **33** | **6** |

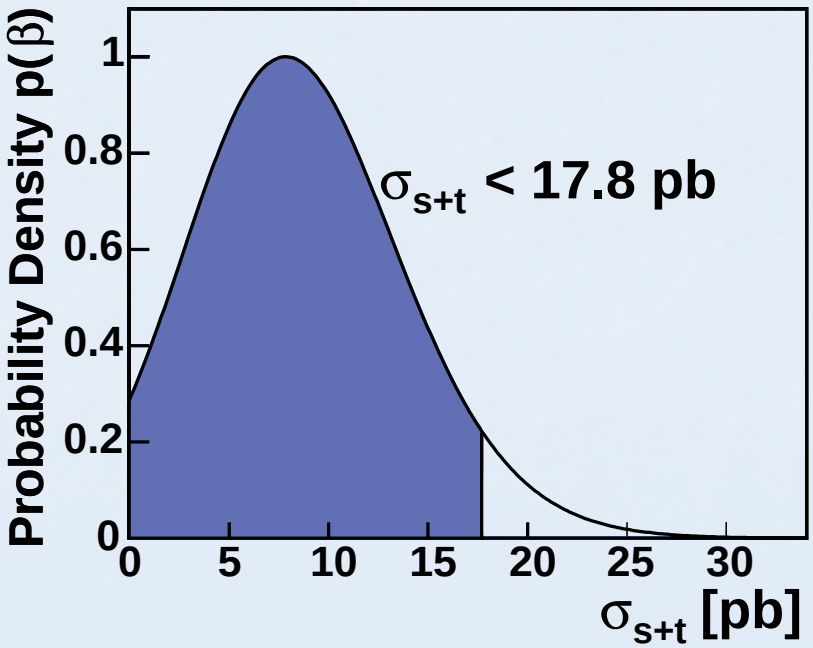
Background dominated

# Results of combined search




**Expected limit: 13.6 pb**

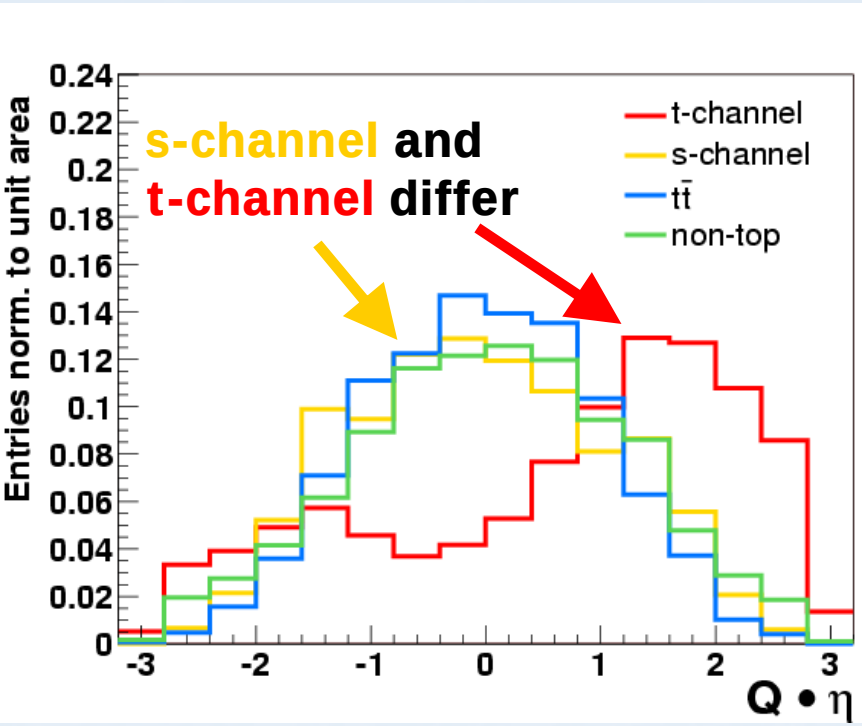
**Observed limit: 17.8 pb**

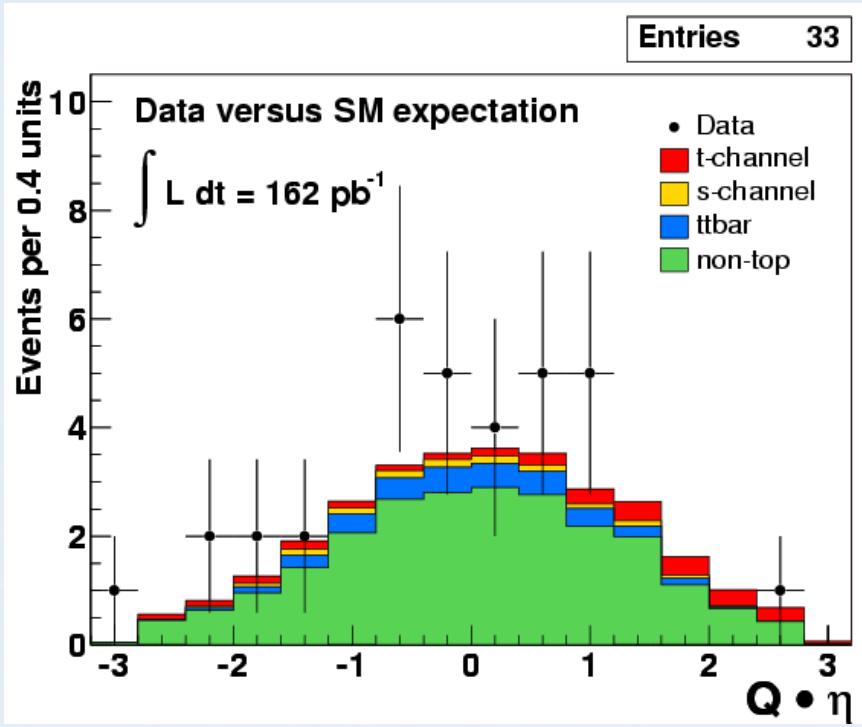



Most probable value:

| β units | pb |
|---|---|
| $2.7^{+1.8}_{-1.7}$ | $7.7^{+5.1}_{-4.9}$ |

# Results of separate search




**t-channel:**

Expected limit: 11.2 pb

Observed limit: 10.1 pb

**s-channel:**

Expected limit: 12.1 pb

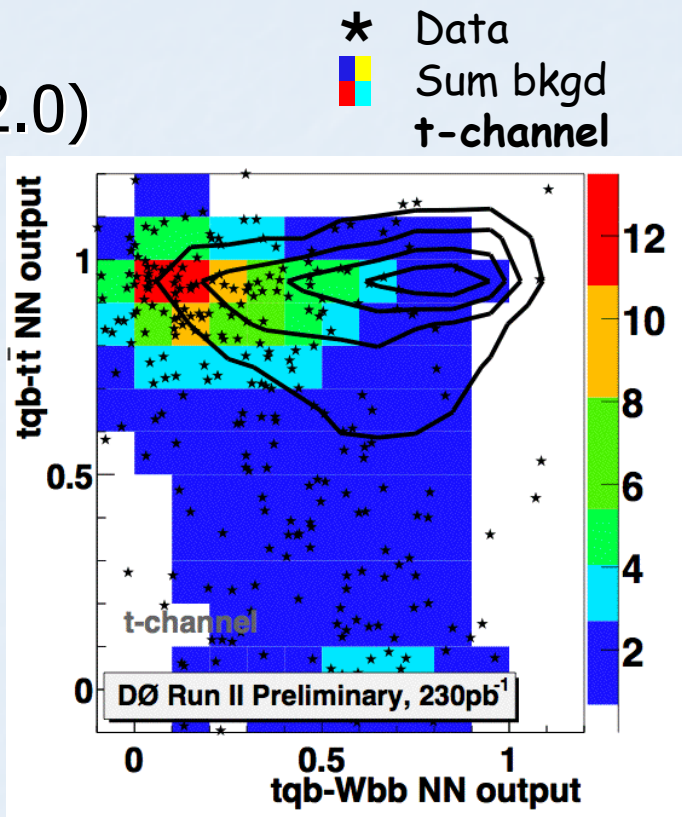
Observed limit : 13.6 pb

Most probable value:

| Channel | β units | pb |
|---|---|---|
| t-channel | $0.0^{+2.4}_{-0.0}$ | $0.0^{+4.7}_{-0.0}$ |
| s-channel | $5.2^{+4.3}_{-4.3}$ | $4.6^{+3.8}_{-3.8}$ |

# D0 analysis (230 pb$^{-1}$)

- hep-ex/0505063, submitted to PLB
- Lepton (e/$\mu$): $P_T$>15 GeV, $|\eta_{e(\mu)}|$<1.1 (2.0)
- Jets: $2 \le N_{jets} \le 4$, $E_T$>15 GeV, $|\eta|$<3.4, Missing $E_T$: $E_T$>15 GeV
- Combined several discriminating kinematic variables in neural networks (Wbb & tt$\to$l+jets)
- Use 2D output in a likelihood




| Source | $s$-channel search | $t$-channel search |
|---|---|---|
| $tb$ | $5.5 \pm 1.2$ | $4.7 \pm 1.0$ |
| $tqb$ | $8.6 \pm 1.9$ | $8.5 \pm 1.9$ |
| $W$+jets | $169.1 \pm 19.2$ | $163.9 \pm 17.8$ |
| $t\bar{t}$ | $78.3 \pm 17.6$ | $75.9 \pm 17.0$ |
| Multijet | $31.4 \pm 3.3$ | $31.3 \pm 3.2$ |
| Total background | $287.4 \pm 31.4$ | $275.8 \pm 31.5$ |
| Observed events | 283 | 271 |

Expected/Observed limit

$\sigma_s$ < 4.5 / 6.4 pb

$\sigma_t$ < 5.8 / 5.0 pb

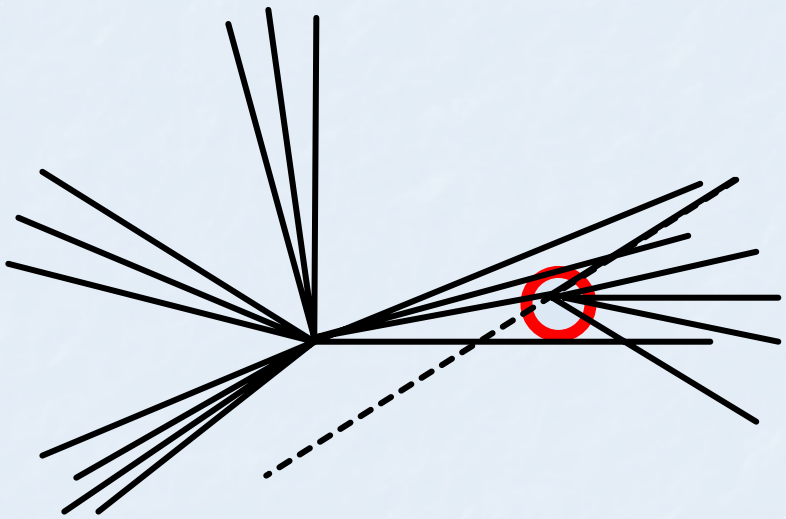
# CDF: Improvements planned for the 2005/2006 analysis:

# Electrons in forward region

- Up to now: Only electrons in central region of the CDF detector ($|\eta|<1.1$)
- ~30% of signal events have electrons in forward region
- To better discriminate against QCD multijet-BG: use Neural Network techniques
  - First studies: 20% less BG using NN techniques

# Extended b-tagging

Secondary vertex mainly exploits long lifetime



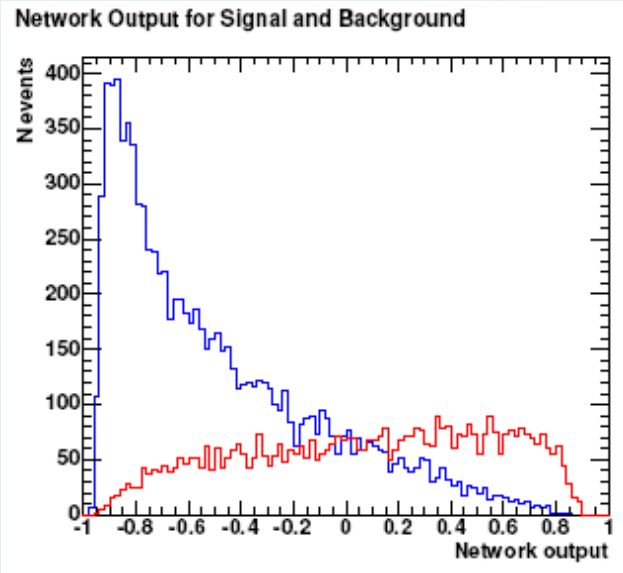
- Improve purity by including
  - Long lifetime
    - Decay length of secondary vertex
    - $D_0$ of tracks
  - Large mass
    - Mass at secondary vertex
    - $p_T$ of tracks w.r.t jet axis
  - Decay multiplicity
    - # of tracks
  - Decay probability into leptons
    - #of leptons

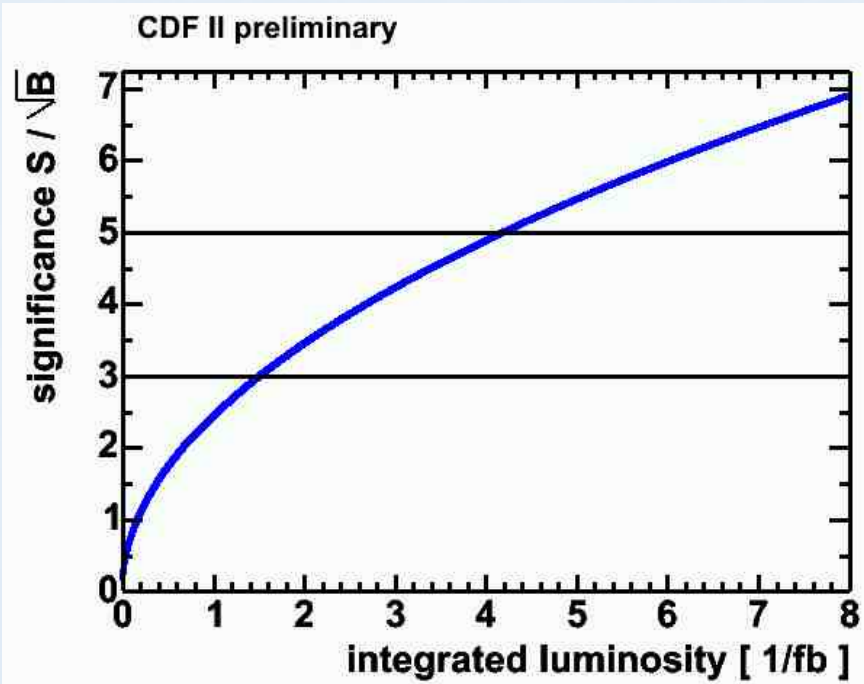
- First studies using Neural Network Techniques:
  - Efficiency on single top signal: **~90%**
  - Remove **~60%** of vertex tagged W+non-b jets events

# Advanced analysis methods

**Neural Network:**
Output for
Signal (35%)
Background (65%)
17 variables used

- First studies ($162pb^{-1}$)
  - Maximum $S/\sqrt{B}$ : 0.98
  - Improvement by +32%
- Projections (combined search):
  - With $1fb^{-1}$ expect $S/\sqrt{B} = 2.4$
  - Reach $S/\sqrt{B} = 3.0$ for $1.5\ fb^{-1}$ with $N_{sig} = 27.3$ events



# Summary & Outlook

| Channel | CDF [pb] (162 $pb^{-1}$) | D0 [pb] (230 $pb^{-1}$) |
|---|---|---|
| s+t | <17.8 (13.6) | |
| s | <13.6 (12.1) | <6.4 (4.5) |
| t | <10.1 (11.2) | <5.8 (5.0) |

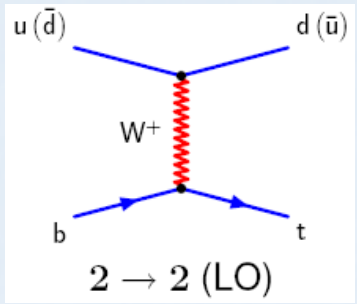
- First pass completed for CDF and D0
- CDF planning several improvements
  - Forward electrons
  - B-tagging
  - Use of advanced analysis methods
  - More data…
- Challenging analysis, observation feasible in Run II

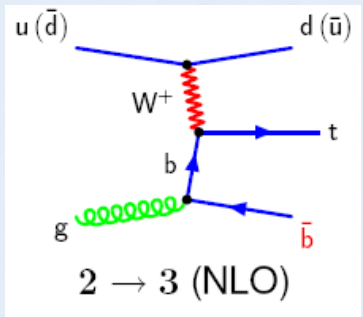
# Backup Slides

# CDF Likelihood Method

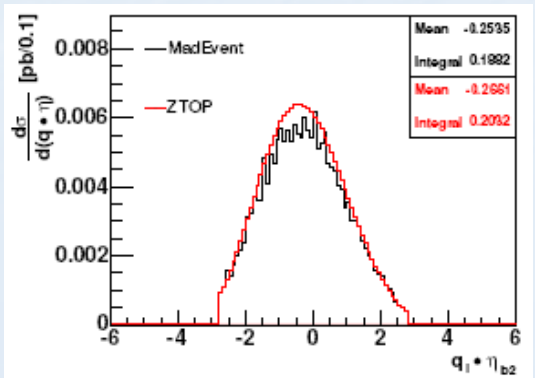
- Inclusion of systematic uncertainties in upper limits
- Consistent Bayesian treatment
- All nuisance parameters representing syst. shifts in acceptance and template shape are included in the likelihood
- All correlations between the parameters are included

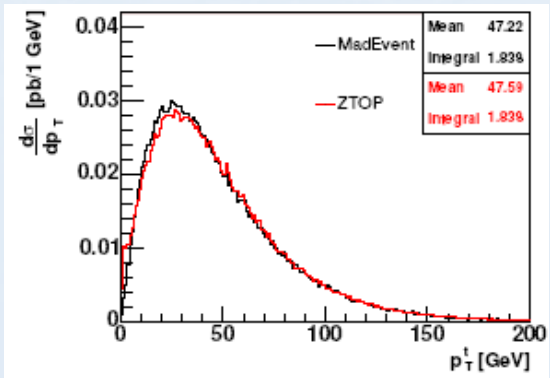
# t-channel matching




- LO process: b-quark structure function
  - $P_T$ too soft, η too forward
- Matching:
  - Generate 2→2 and 2→3 events with MadEvent
  - Match distributions
  - Compare with ZTOP (NLO calculation)
- Good agreement



# CDF Search strategies

- Combined Search:
  - Signal: s-channel and t-channel single-top events
  - Both cross-sections proportional to $|V_{tb}|^2$
  - Exploits distributions similar for s- and t-channels:
    - $H_T$ = the total transverse energy in the event ($E_T$ lep + $ME_T$ + $\Sigma E_T$ jet )
- Separate Search:
  - 1. Signal = t-channel (s-channel is a background)
    - FCNC couplings, anomalous V+A contributions to the W-t-b vertex, etc.
    - $Q \bullet \eta$ variable (Q = lepton charge, $\eta$ = pseudorapidity of non b-tagged jet)
    - $Q \bullet \eta$ asymmetric in t-channel events: $N(Q \bullet \eta > 0) = 2 * N(Q \bullet \eta < 0)$
  - 2. Signal = s-channel (t-channel is a background)
    - Heavy charged vector bosons W', CP-violation effects within MSSM, Kaluza-Klein excited W-boson within MSSM
    - Double b-tags – simple counting

# CDF Acceptance uncertainties

| | | Separate Search | | Combined Search |
|---|---|---|---|---|
| No. | Source | t-channel | s-channel | |
| 1 | Jet en. scale (+1σ/-1σ) | +2.4 / -6.7% | +0.4 / -3.1% | +0.1 / -4.3% |
| 2 | ISR | ±1.0% | ±0.6% | ±1.0% |
| 3 | FSR | ±2.2% | ±5.3% | ±2.6% |
| 4 | PDF | ±4.4% | ±2.5% | ±3.8% |
| 5 | MC Generator | ±5.0% | ±2.0% | ±3.0% |
| 6 | Top mass (-5 /+5 GeV) | -6.9 / +0.7% | -2.3% | -4.4 / -0.7 % |
| 7 | $\varepsilon_{trig}$, $\varepsilon_{ID}$, luminosity | ±9.8% | ±9.8% | ±9.8% |