For the LHC part, valuable help received from:

Catalin Ciobanu, University of Illinois, CDF

Beyond
Single Top Quark Physics at the Tevatron and
Single Top Production

Why look for single top:
- Cross section $|V_{tb}|^2$: the only way to directly measure CKM matrix el. $V_{tb}$
- Single top is background to other signals: e.g., Higgs searches.
- Test non-SM phenomena:
  - Heavy W, boson
  - Anomalous Wtb couplings
  - FCNC couplings

At the Tevatron relevant channels are:
- t-channel W-gluon fusion:
  - Hard b-jet, W decay products, soft b
  - 1.98 pb at $s=1.96$ TeV
- s-channel W*:
  - Usually lost, light quark jet
  - Hard b-jet, W decay products, soft b
  - 0.88 pb at $s=1.96$ TeV

From Run I to Run II

Results at \( s = 1.8 \) TeV from CDF and D\( \phi \):

- Single top has not been observed; 95\% CL limits were set:
  - \( t \)-channel: D\( \phi \) limit: 22 pb, CDF limit: 13 pb (theoretical x-section: 1.40 pb)
  - \( s \)-channel: D\( \phi \) limit: 22 pb, CDF limit: 17 pb (theoretical x-section: 0.76 pb)

- Preliminary CDF analysis done for 107 pb\(^{-1}\) of data:
  - Search for \( s \) and \( t \)-channels combined production
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For Run II:

- Higher rate: 32\% increase in the combined \( s \) and \( t \)-channel x-section
- More luminosity – right now CDF has 180 pb\(^{-1}\) – that is 70\% more data!
- Still small: 2.9 pb versus 6.7 pb for top pair production
- Better detector acceptance

Most recent Run 1 CDF study finds a 2.2\% excess and limit of 24 pb (7-imp NN)

Combined \( s \) and \( t \)-channels search: CDF limits: 14 pb (7\( \to \) HT, \( M_{\text{inb}} \))

Look in the W+2 tight jets channel:

- "tight" jet: $E_T > 15$ GeV, $|\eta| < 2.8$
- at least one SVX B-tag
- exactly one lepton with $E_T > 20$ GeV, $|\eta| < 2.0$
- missing energy: $E_T > 20$ GeV
- veto Z's, dilepton events
- apply a top mass window cut: $140 < M_{lb} < 210$ GeV/c$^2$

Monte Carlo samples:
- single top signal: Pythia (1M events)
- HERWIG tt background
- Madevent+Pythia (~200k)
- ALPGEN+HERWIG Wbb used to model the shapes of the non-top backgrounds: Wbb, Wc, Wc, mistags, non-W events
Expected Yield

For \( L = 107.1 \text{ pb}^{-1} \):

- **Total non-top**
  - 13.8 ± 2.8

- **Z+bb**
  - 0.07 ± 0.03

- **Di boson**
  - 0.7 ± 0.2

- **Non-W**
  - 2.2 ± 0.7

- **Mistag**
  - 2.9 ± 0.9

- **Wc**
  - 3.1 ± 1.0

- **Wcc**
  - 1.4 ± 0.8

- **Wbb**
  - 3.5 ± 1.5

- **tt**
  - 2.3 ± 0.7

- **0.80 ± 0.18**

- **1.64 ± 0.51**

- **N in 107.1 pb\(^{-1}\)**

The variable with the most discrimination power is \( H_T \), the total transverse energy in the event.

The event: Will fit the \( H_T \) shape in data as the sum of weighted MC shapes.

Use maximum likelihood method with Gaussian background constraints. Use weighted MC shapes.

For \( L = 107.1 \text{ pb}^{-1} \):

- Expect \( 19 \) signal events
- Expect \( 16.1 \) background events
- Observe 19 (expect 18.5)
Fitting $H^1$ distributions

Fit yields 2.9±4.5 signal events (exp. 2.4 events).

Signal shapes similar for s- and t-channels:

$H^1$ distributions for signal and backgrounds:

- Data
- SM
- non-top
- $t\bar{t}$
- single top
Limit at 95% C.L. is 17.5 pb

This accounts for the systematics:

- Jet Et scale: 20.9%
- ISR/FSR: 4.0%
- Top Mass: 6.2%
- PDF, signal generator, background model: 1-2%

Same luminosity: 107 vs 106 (pb-1)

Now: 17.5 pb limit for 2.86 pb x-section

14 pb limit for 2.16 pb x-section

Compare to Run I:

- Same luminosity
- 107 vs 106 pb-1
- Now: 17.5 pb limit for 2.86 pb x-section

95% C.L. limit

discussed later.

Several ways to improve this will be marginally better limit!

Several ways to improve this will be discussed later.

Several ways to improve this will be discussed later.
Looking for the two signal channels individually is desired:

- Different sensitivities to new physics:
  - Heavy charged vector bosons $W'$, CP-violation effects within MSSM
  - FCNC couplings, anomalous $V+A$ contributions to the $W$-t-b vertex, etc.

To go back to extracting $V_{tb}$ we will have to know the individual rates

We use the same selection as in the combined search.

Now treat $W^*$ as a background, therefore perform a 4-component fit

$q$ is the lepton charge and $\eta$ the pseudorapidity of the non-$b$ jet.

A variable with good $W^* - W$-gluon separation potential is $Q \times \eta$, where

However, using $H_T$ is no longer appropriate.

$Q x \eta$, where $Q$ is the lepton charge and $\eta$ the pseudorapidity of the non-$b$ jet.

Now treat $W^*$ as a background, therefore perform a 4-component fit.
Fitting $Q_{l}$

$t$-channel exhibits an asymmetry toward $Q_{x}$ positive values (twice as many events than in the negative $Q_{x}$ range).

Fit to data yields: $1.4 \pm 3.7$ $t$-channel signal events (exp. 1.6 events).
95% C.L. limit

Limit at 95% C.L. is 15.4 pb

This accounts for the systematics:

- Jet ET scale: 21.5%
- ISR/FSR: 6.9%
- Top Mass: 6.7%
- Signal generator: 21.1%
- Background model: 43.0%
- PDF: 4.3%

Now: 15.4 pb limit for 1.98 pb x-section

Compare to Run I:

13 pb limit for 1.40 pb x-section

Again a better limit!
Future Prospects

Neural Network with 5 input variables: HT, ET(j1), ET(j2), ET, PT(j1-j2), Looking in the W+2j channel, no M_{lnb} cut
Assuming the background uncertainties will scale as L^{-1/2}

Right now: 3 sigma with 2.5 fb^{-1}
Improvements to come. We try:

- Soft lepton tagger, Jet Prob. tagger
- Use of forward electrons
- Better discriminant variables:
  - Matrix elements (or ratios of these)
  - Better discriminant variables: Matrix elements (or ratios of these)
- Use of forward electrons

Will lead to better M_{lnb} resolution
- Use the top mass hypothesis to constrain the event
- Better discriminant variables:
  - Matrix elements (or ratios of these)
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Better understanding of the systematic uncertainties is crucial.

Neural Network with 5 input variables: HT, ET(j1), ET(j2), ET, PT(j1-j2), Looking in the W+2j channel, no M_{lnb} cut
Assuming the background uncertainties will scale as L^{-1/2}

Looking in the W+2j channel, no M_{lnb} cut
Neural Network with 5 input variables: HT, ET(j1), ET(j2), ET(j1), PT(j1-j2)
LHC will be a top quark factory. Will discuss each of the three modes in what follows.

**Single Top at the LHC**

Negligible at the Tevatron

Associated Vt production: 50-60 pb

s-channel single top: 6.6 (top) and 4.8 (antitop) = 11 pb
e.g. per day ~6000 events, at 10^{33} cm^{-2}s^{-1}

t-channel single top: 153 (top) and 90 (antitop) = 243 pb
top pair production: ~800 pb (mostly via gluon-gluon fusion)

Some cross section values for \( s = 14 \) TeV:

- 8 million top pairs per experiment per year (~10 fb^{-1} / year)

Top pair production is ~800 pb (mostly via gluon-gluon fusion)
The quest continues – newer det. simulation

With 10 fb⁻¹, \( (S+B)/S = 1.4\%

Signal peak visible in reconstructed \( M_{\text{top}} \) distribution

Reject WZ candidates with: 80 < \( M_{jj} \) < 100 GeV \^c²

Exactly one b-tagged jet – the central one

Leading jet \( E_T \) < 100 GeV (to reduce tt)

One jet: \( E_T > 20 \) GeV, \(|p_T| > 2.5\), the other \( E_T > 50 \) GeV, \(|p_T| > 4.0\)

Two jets with \( E_T > 20 \) GeV, \(|p_T| > 4.0\)

Missing \( E_T > 20 \) GeV, \( 50 > M_{jj} > 100 \) GeV \^c²

One isolated lepton with \( p_T > 20 \) GeV \^c \(|\not{p_T}| > 2.5\)

Pythia 5.72 signal, it, WZ, V\ell\ell, V+jets, +\ell+Jets, Selection:

Full calorimeter simulation + b-tag efficiency parametrization

CMS study (hep-ph/0003033):

t-channel single top (CMS)
ATLAS study of W-gluon single top (Dugan O'Neil’s Ph.D. thesis):

- From factorization and renormalization scale dependence (3% from NLO calculation)
- Theoretical uncertainty:
- Luminosity uncertainty: Traditionally 4-5%.
- Systematic >20%. Here things can easily be off by a lot, especially in the first year.
- Statistical: 5% is a perhaps reasonable/optimistic guess for L=10 fb⁻¹.

Selections are rather similar to CMS study, plus:
- ATLAST parametrized detector simulation
- ATLAS study of W-gluon single top (Dugan O’Neil’s Ph.D. thesis)

Result: $\frac{S+B}{S} = 0.9\%$ with 10 fb⁻¹.
- $150 < \text{M}_{1\bar{t}} < 200$ GeV/c²

What about $V_{tb}$? Extracting $|V_{tb}|^2$ from x-section picks up uncertainties:

- $\text{Statistical uncertainty} < 5%$ is a perhaps reasonable/optimistic guess for $L=10$ fb⁻¹.
- $\text{Systematic uncertainty} > 20%$. Here things can easily be off by a lot, especially in the first year.
- $\text{Luminosity uncertainty} < 4-5%$
- $\text{Theoretical uncertainty} < 3%$ from NLO calculation.

$150 < \text{M}_{1\bar{t}} < 200$ GeV/c²

- OneTop+Pythia 5.72 signal, it; M.E.+HERWIG Wbb, Wl
- ATLAST parametrized detector simulation

- $\frac{S+B}{S} = 0.9\%$ with 10 fb⁻¹.
- $150 < \text{M}_{1\bar{t}} < 200$ GeV/c²
- Selections are rather similar to CMS study, plus:
CMS study (S. Sabloskisky, CMS week 9/17/03)

-s-channel single top (CMS)

Selection:
- Use TopRex to generate single top, it, W+jets, Pythia W+jets. Use CMSJET 4.801.
- 2 B-tags with $E_T > 20$ GeV, no other jets with $E_T > 20$ GeV
- One lepton with $E_T > 10$ GeV, $|\eta| < 2.5$
- Vector sum all final state $p_T$: $p_T > 15$ GeV
- Reconstruct top mass: $150 \text{ GeV} < M_{top} < 200 \text{ GeV}$

Results:
- $(S+B)/S = 12\%$, $S/B = 8\%$ for $L = 30 \text{ fb}^{-1}$
- Which implies $|V_{tb}| = 8.3\%$

Disclaimer: Work-in-progress, not yet official results.
s-channel single top (ATLAS)

ATLAS study (hep-ph/0003033)
EW-produced top quarks are highly polarized:

- In the top rest frame, its spin points along the direction of the down (d) quark.

Restrict to t-channel singlet. Measure cos(\theta) distribution, \theta between the direction of the lepton in W rest frame and the direction of the W in the top rest frame.

Chisquare fit, letting the two P contributions float. The error on polarization measurement is 1.6% for 10 fb\(^{-1}\) (Dugan's Ph.D. thesis). Three component fit: f_L, f_R, f_{long}, with f_L+f_R+f_{long}=1.

W boson helicity measurement:

- Again restrict to t-channel signal.
- Used signal samples with P=+1 and P=-1. Consider only W+jet background.
- Measure cos(\gamma) between the direction of the lepton in W rest frame and the direction of the W in the top rest frame.
- Three component fit: f_L, f_R, f_{long}, with f_L+f_R+f_{long}=1

Uncertainties of the order 2-3% for 30 fb\(^{-1}\) of data. The angular distribution is 1.6% for 10 fb\(^{-1}\) (Dugan's Ph.D. thesis). Three component fit: f_L, f_R, f_{long}, with f_L+f_R+f_{long}=1.

Restrict to t-channel singlet. Measure cos(\theta) distribution, \theta between the direction of the lepton in W rest frame and the direction of the W in the top rest frame.

Three component fit: f_L, f_R, f_{long}, with f_L+f_R+f_{long}=1

EW-produced top quarks are highly polarized:

Events Top Polarization in Single Top
CDF and DØ accumulated more events than in entire Run I (factor of 2).

Preliminary CDF study from 107 pb⁻¹ sets promising single top limits.

However, many improvements needed if we are to observe single top in the next 2-3 years.

Precise measurements of |Vtb| as well as top polarization are not within immediate sight.

Higher collider energy = considerable higher cross sections.

Precalimnary CDF study from 107 pb⁻¹ sets promising single top limits.

CDF and DØ accumulated more events than in entire Run I (factor of 2).

LHC will see very exciting results in the first (few) years of running:

- 10–30 fb⁻¹ needed for observation in most searches.
- Higher collider energy = considerable higher cross sections.
- Precise measurements of |Vtb| as well as top polarization are not within immediate sight.

The Monte Carlo efforts are particularly strong: Top Rex, SingleTop.

CDF/DØ can help with insight into systematics. Search strategies are already similar between Tevatron and CERN, but big improvements are needed.

ATLAS and CMS single top studies are very mature.

ATLAS and CMS single top studies are very mature.

Just an idea away!