Search for a heavy top t'→Wq in top events
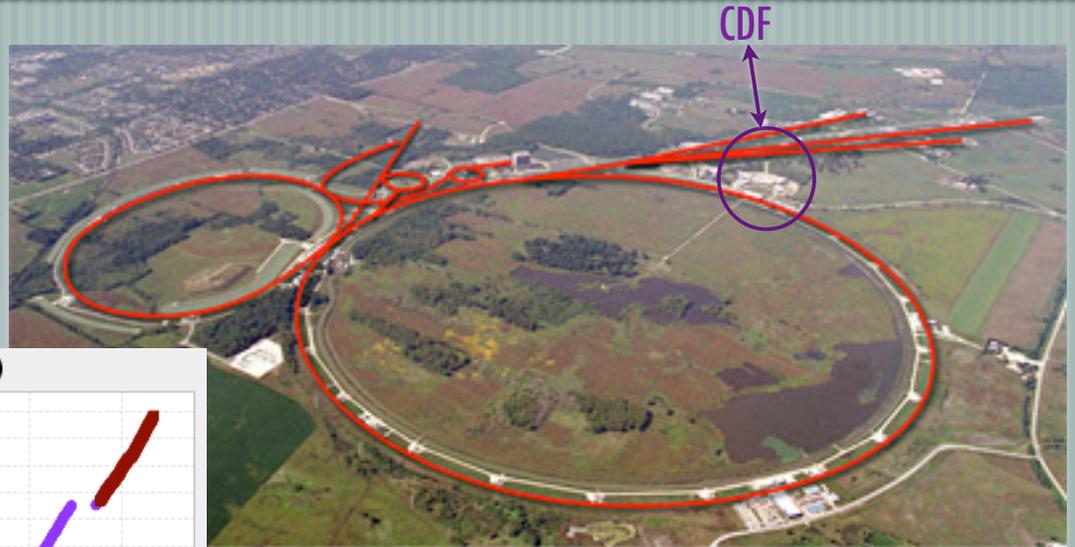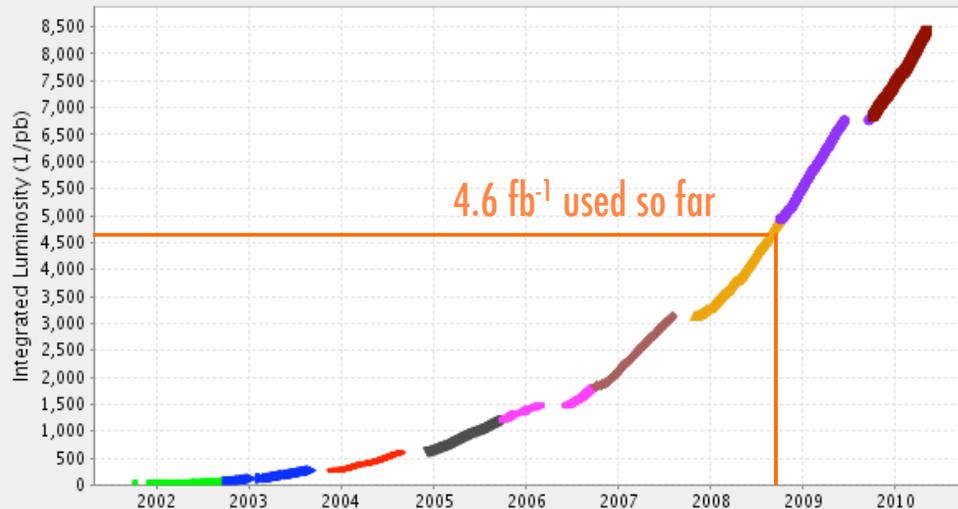
David Cox

University of California, Davis

on behalf of the CDF Collaboration

PHENO 2010

CDF & the Tevatron
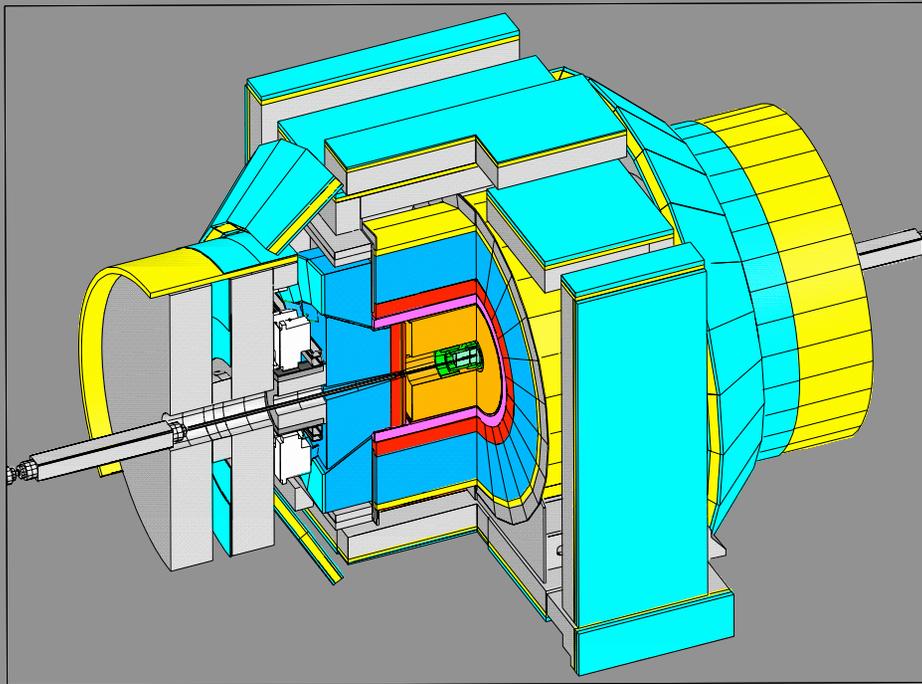
$p\bar{p}$ collisions at 1.96 TeV

CDF

Integrated Luminosity 8434.67 (1/pb)

4.6 fb^{-1} used so far

- Fiscal Year 10
- Fiscal Year 09
- Fiscal Year 08
- Fiscal Year 07
- Fiscal Year 06
- Fiscal Year 05
- Fiscal Year 04
- Fiscal Year 03
- Fiscal Year 02

Continual improvements in instantaneous luminosity means more data per year for CDF every year

CDF Detector

The CDF detector is a general purpose solenoidal detector which combines precision charged particle tracking with projective calorimetry and fine grained muon detection

What is a t' quark

A t' is a fourth generation top-like quark or similar object

Predicted by a variety of theoretical models: Flavor democracy, GUT SO(1,13), Two Higgs doublet scenarios, Beautiful Mirrors, Little Higgs
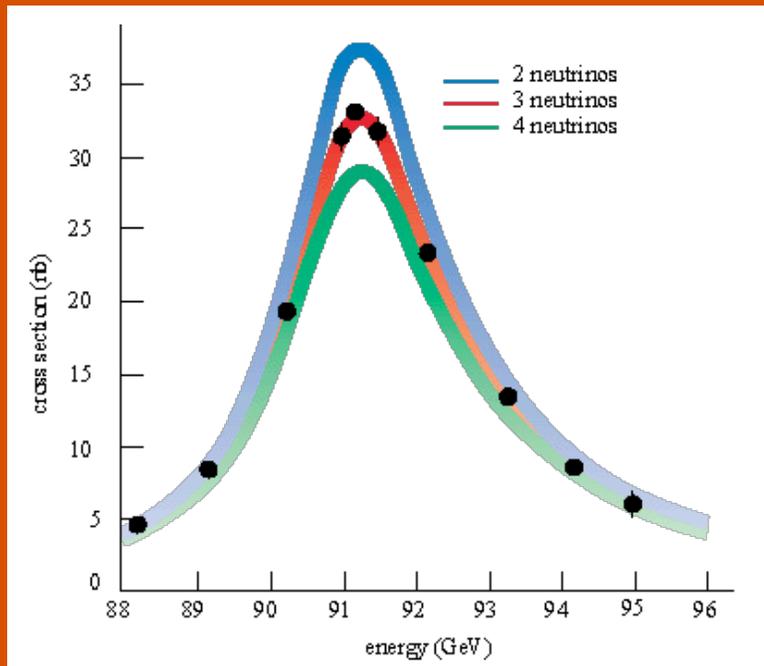
L+J Signature:

High Transverse Momentum (p_T) Lepton

Large Missing Energy (E_T)

Jets with Large Transverse Energy (E_T)
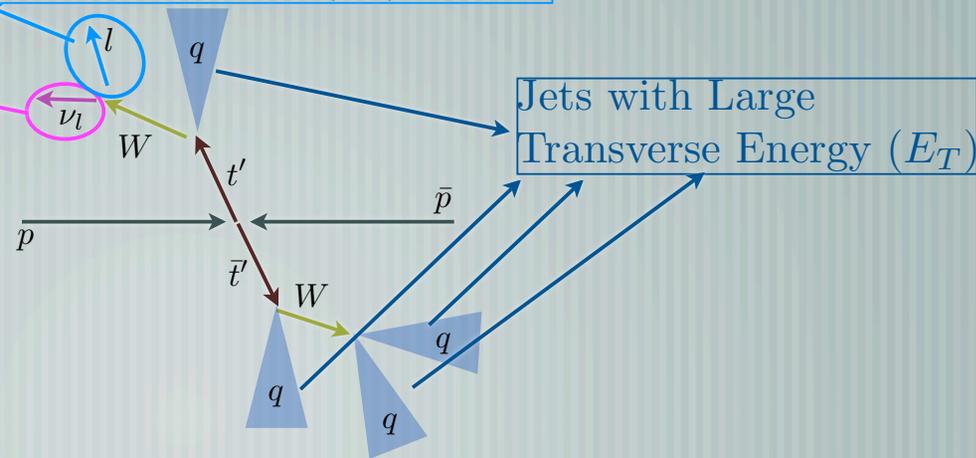
Existing Limits

LEP measurements of the Z boson exclude a light fourth neutrino

Constraints from radiative corrections to electroweak parameters also exist (parameterized with S,T,U)

parameter set	$m_{t'}$	$m_{b'}$	m_H	ΔS_{tot}	ΔT_{tot}
(a)	310	260	115	0.15	0.19
(b)	320	260	200	0.19	0.20
(c)	330	260	300	0.21	0.22
(d)	400	350	115	0.15	0.19
(e)	400	340	200	0.19	0.20
(f)	400	325	300	0.21	0.25

$$m_{v_4} = 100 \text{ GeV/c} \quad m_{l_4} = 155 \text{ GeV/c}$$

There are reasonable constructions of a fourth generation which are not excluded

Source: Phys. Rev. D76:075016, 2007   arXiv:0706.3718v1

Why look for it?

Several theoretical models predict it

Presence of a fourth generation relaxes Higgs bounds

Some models improve the fit to the electroweak observables with a fourth generation

Why not?

Theory Overview

Flavor Democracy: Four generations of leptons with equal Yukawa couplings - t',b' required for anomaly cancellation [JHEP 0212 (2002) 036]

GUT SO(1,13): Four generations from symmetry breaking [Bled workshops in physics, Vol.7, No.2, DMFA-Zaloznistvo, Ljubljana, Dec. 2006]

Two Higgs Doublet: N=2 Supersymmetry requires 3 additional fermion generations [Phys. Rev. D64 (2001) 053004]

Little Higgs: Cancels quadratic divergences using additional particles (Not supersymmetric) [Phys. Rev. D 68, 097301 (2003)]
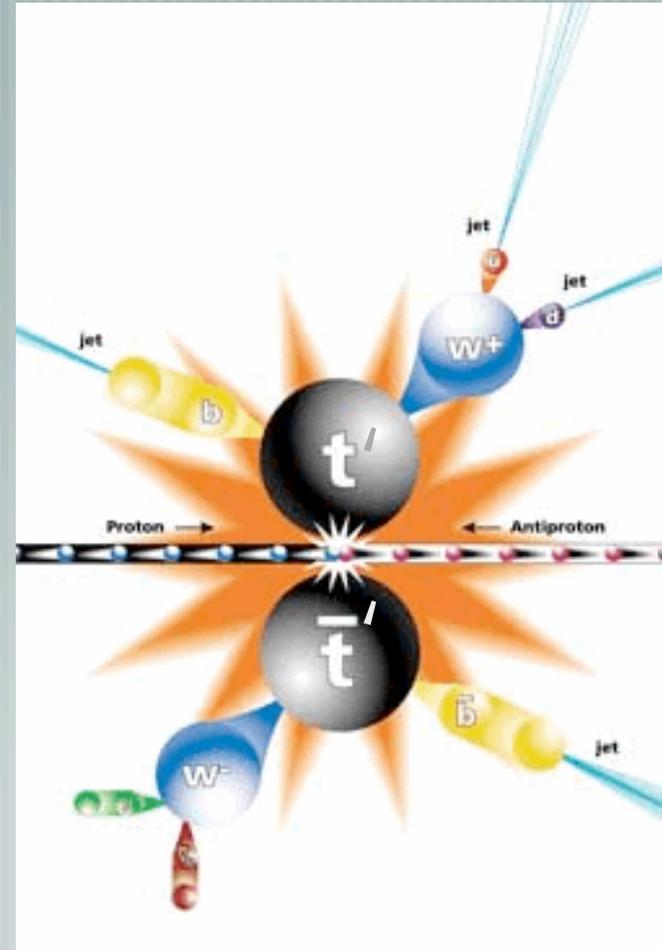
Beautiful Mirrors: Extra quarks improve agreement between measured asymmetry and predicted (Possible vector-like coupling) [Phys. Rev. D65:053002, 2002]

The t' search at CDF

Assumptions

- t' → Wq (BR ≈ 100%) *

- t' is pair produced strongly

- t' mass > top quark mass

*: Usually $M_{t'} - M_{b'} < M_W$

Event Selection

- Exactly one high-p_T ($p_T \geq 25 \text{ GeV} / \text{c}$) isolated electron or muon

- Large missing transverse energy ($\not{E}_T \geq 20 \text{ GeV}$)

- At least four energetic jets ($E_T \geq 20 \text{ GeV}$)

- Additional cuts to reduce QCD backgrounds and lepton mismodeling are also applied

QCD & Mismodeling Cuts

To reduce the QCD background we apply cuts similar to those used in the CDF single top searches

$$M_{T,W} > 20 \text{ GeV}$$

$$\not{E}_{T,sig} > -0.05 \times M_{T,W} + 3.5$$

Where $M_{T,W}$ is the W boson transverse mass and $\not{E}_{T,sig}$ is the significance of the $\not{E}_T$

We apply additional cuts to events with high lepton p_T or high lead jet E_T. These cuts are derived from the 2 and 3 jet region and apply to the lepton-$\not{E}_T$ and lead jet E_T-$\not{E}_T$ delta phi variables.

Search Technique

To distinguish between backgrounds and signal we fit to the observed 3D distribution of reconstructed mass, total transverse energy $(H_T = \sum_{jets} E_T + E_{T,l} + \not{E}_T)$ and jet category (number of jets and χ^2)

The fit used is a binned likelihood fit

Systematic errors are treated as parameters in the fit and are allowed to float within their expected (Gaussian)

M~reco~ - Kinematic Fitter

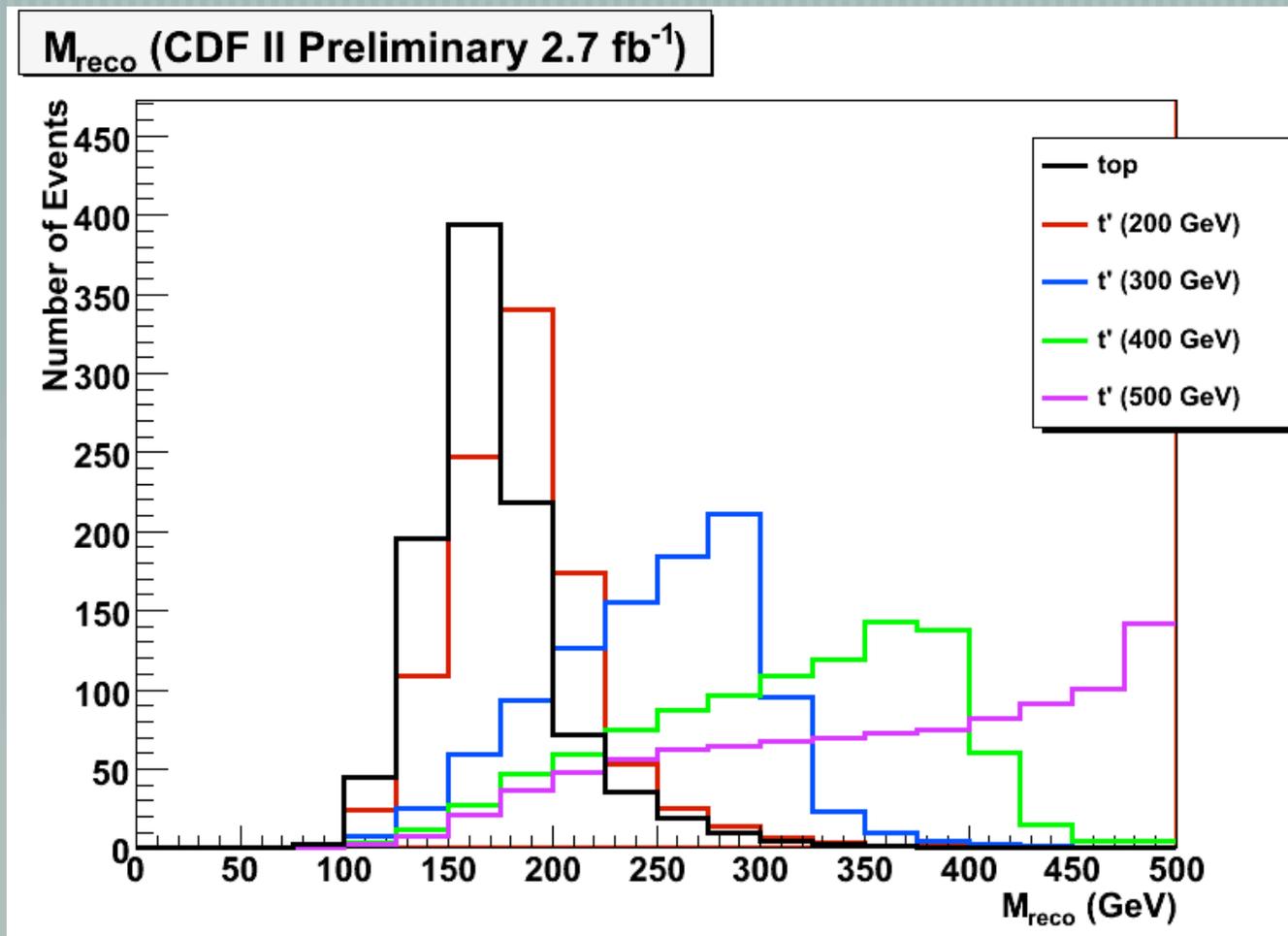Calculate a χ^2 based on the kinematic quantities
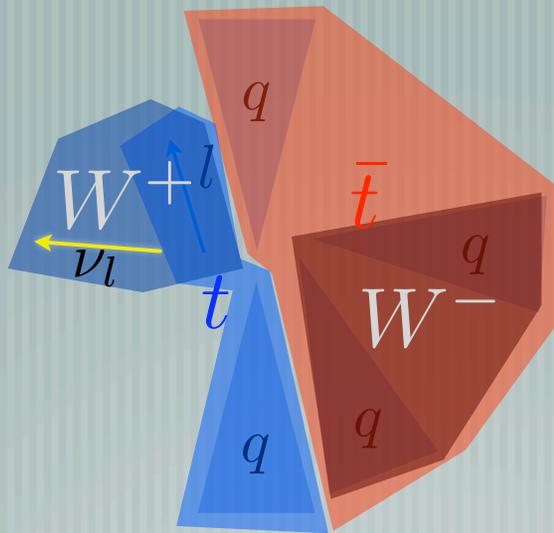
Constrain W decay products to W mass and the top / anti-top mass to be equal

$$\chi^2 = \sum_{i=\ell,4jets} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,fit} - p_j^{UE,meas})^2}{\sigma_j^2} + \frac{(m_{jj} - m_W)^2}{\Gamma_W^2} +$$

$$\frac{(m_{\ell\nu} - m_W)^2}{\Gamma_W^2} + \frac{(m_{bjj} - m_t)^2}{\Gamma_t^2} + \frac{(m_{b\ell\nu} - m_t)^2}{\Gamma_t^2}$$

UE = unclustered energy

Kinematic Fitter Output

# Backgrounds

We model our backgrounds in three separate ways

- The backgrounds from ttbar production and electroweak processes are modeled via MC samples whose normalization is constrained to expected values

- The backgrounds from W+jets is modeled with MC and it's normalization is allowed to float in the fit

- The QCD background is modeled from a sample of data collected using jet triggers in which some of the lepton id requirements were loosened
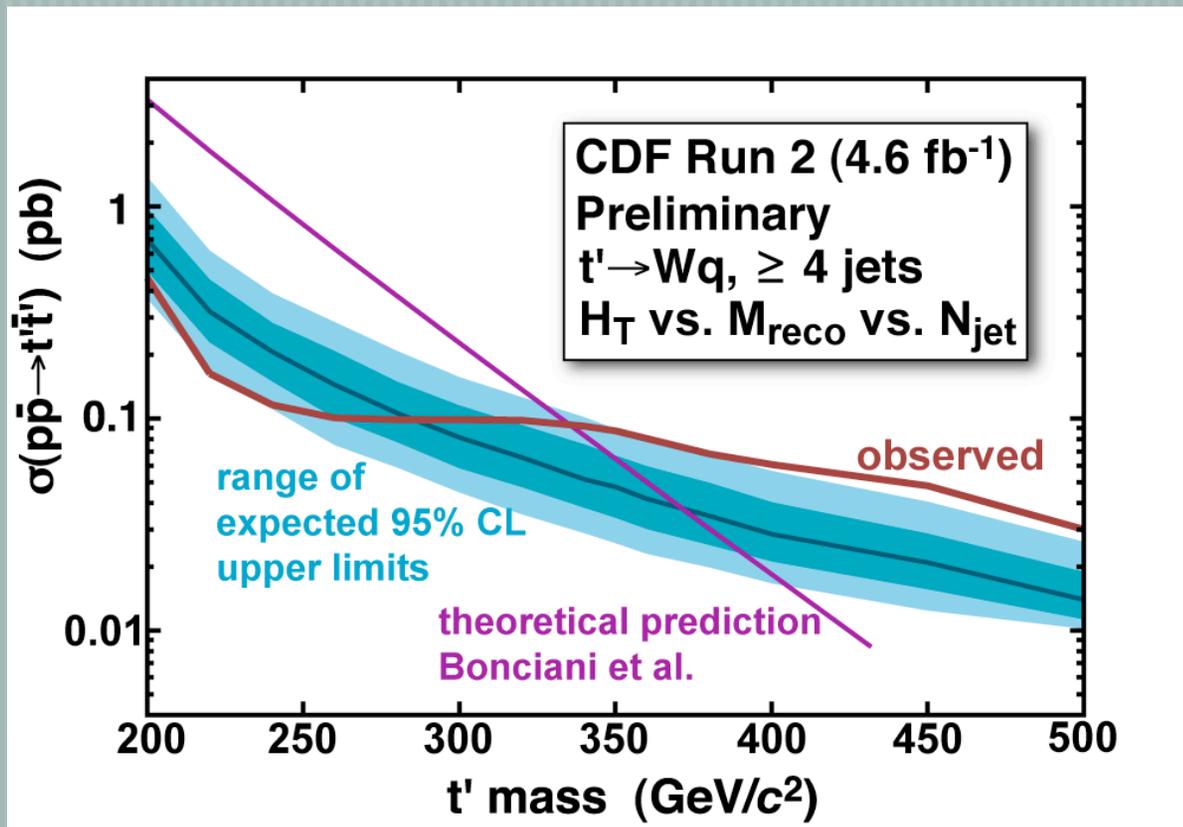
Search Results
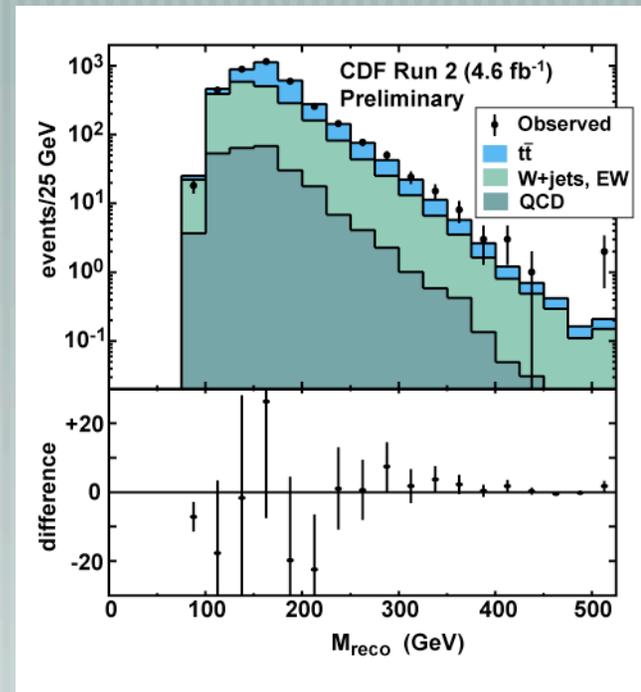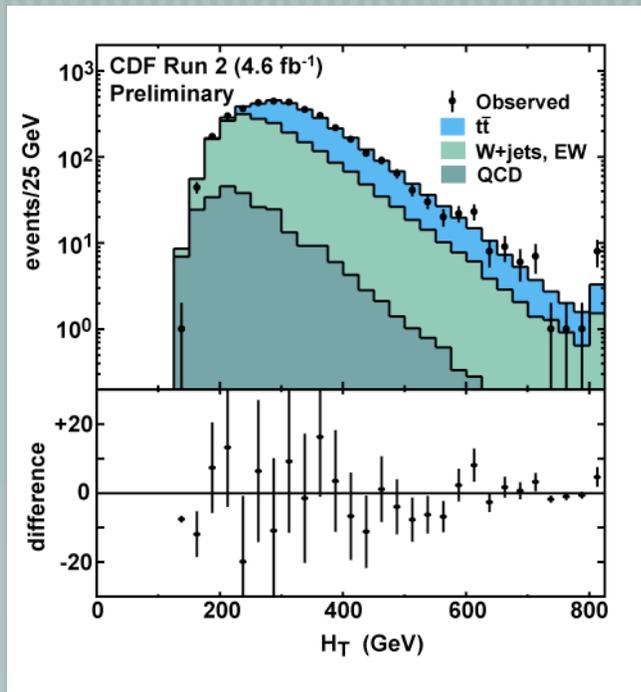
The W+jets & t' cross sections float in the fit. The top cross section is constrained to a normal distribution with mean at 7.23 pb

Search Results
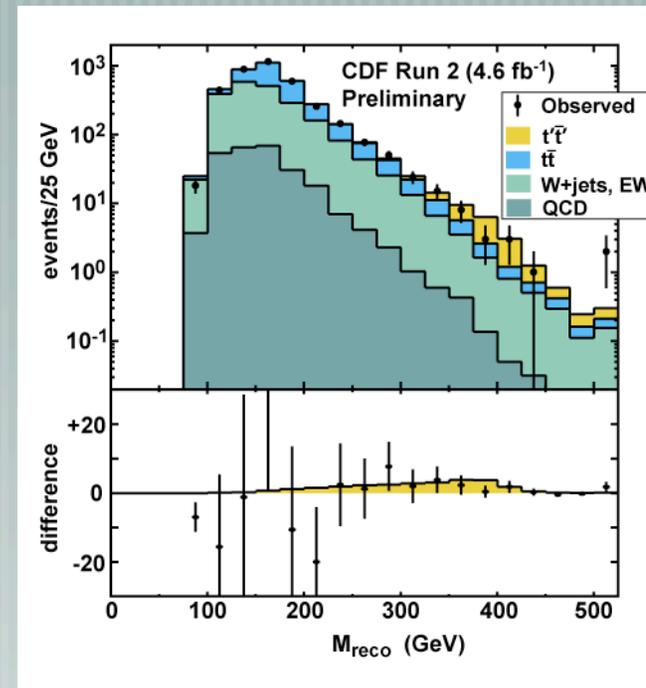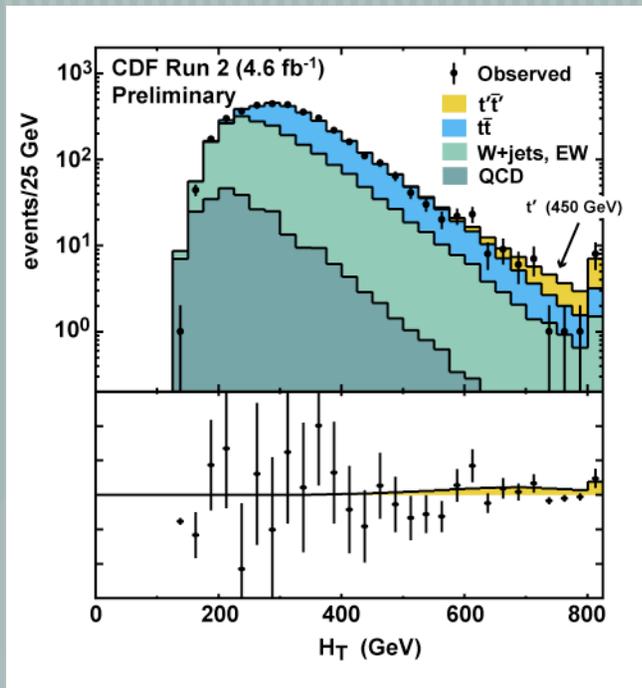
Distributions shown for the maximum likelihood with the t' cross section set to 0.066 pb

Search Results

Latest 95% CL exclusion limit

t′ mass > 335 GeV/c²

Conclusions

Current t' 95% CL exclusion: 335 GeV/c^2

We're adding more data and parralle b-tagging and dilepton searches

New and improved results expected soon

More information at
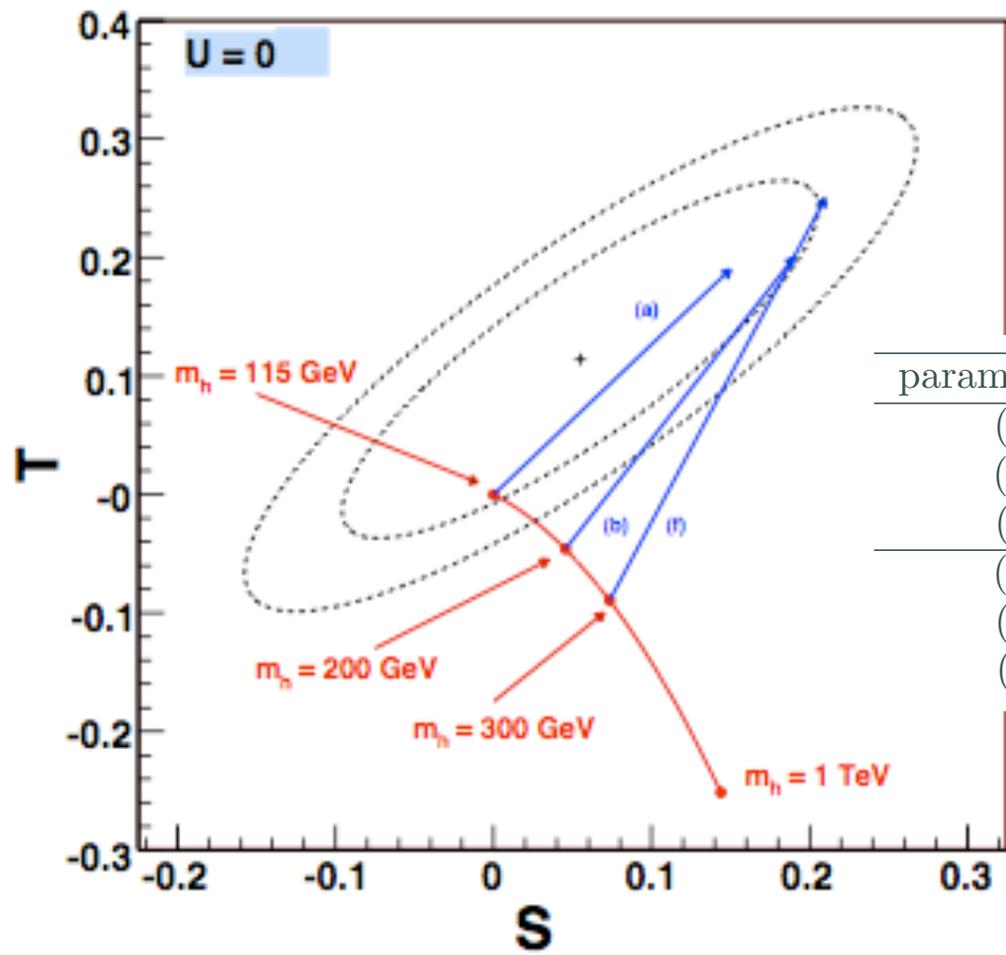http://www-cdf.fnal.gov/physics/new/top/2010/tprop/Tprime_v46_public/public_4.6.html

Backup

Search Results

Cut and Count

n	Min M_{rec} [GeV/c^2]	Min H_T [GeV]	observed	expected	p-value
1	475	775	0	0.021	1.000
2	450	750	0	0.116	1.000
3	425	725	1	0.228	0.2040
4	400	700	2	0.371	0.0540
5	375	675	3	0.718	0.0364
6	350	650	4	1.503	0.0660
7	325	625	4	2.876	0.3251
8	300	600	12	5.498	0.0110
9	275	575	14	9.885	0.1273
10	250	550	29	18.03	0.0105
11	225	525	41	31.34	0.0555
12	200	500	58	52.05	0.2219
13	175	475	92	91.14	0.4779
14	150	450	152	158.7	0.7141
15	125	425	222	231.0	0.7318
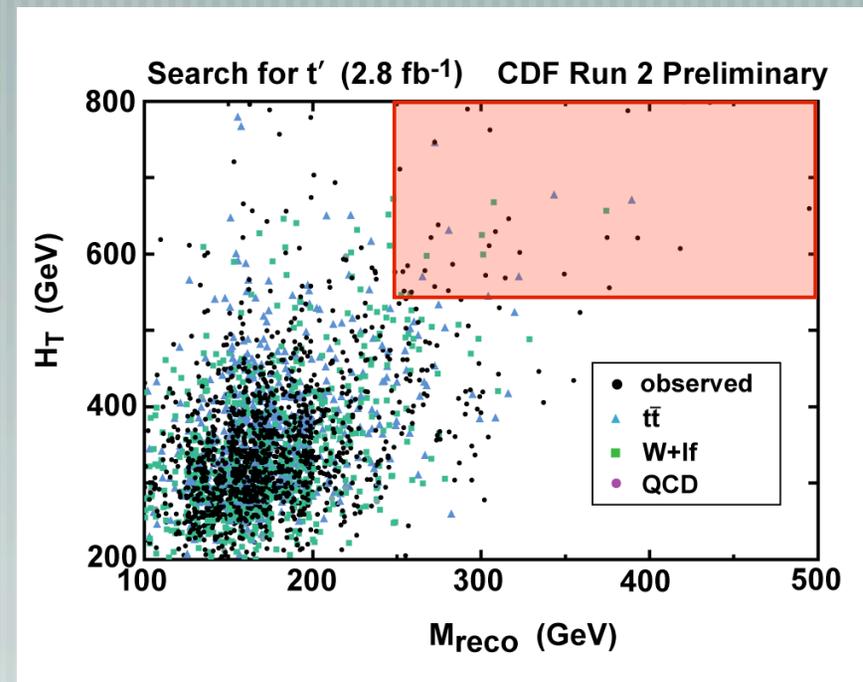
Note: global p-value less significant than value for a single cut and count

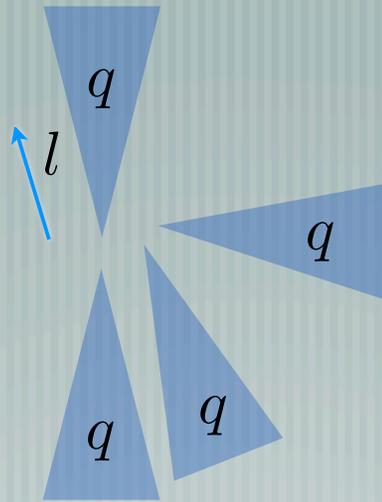| parameter set	$m_{t'}$	$m_{b'}$	m_H	ΔS_{tot}	ΔT_{tot}
(a)	310	260	115	0.15	0.19
(b)	320	260	200	0.19	0.20
(c)	330	260	300	0.21	0.22
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(e)	400	340	200	0.19	0.20
(f)	400	325	300	0.21	0.25

M_{reco} - Kinematic Fitter

An Event
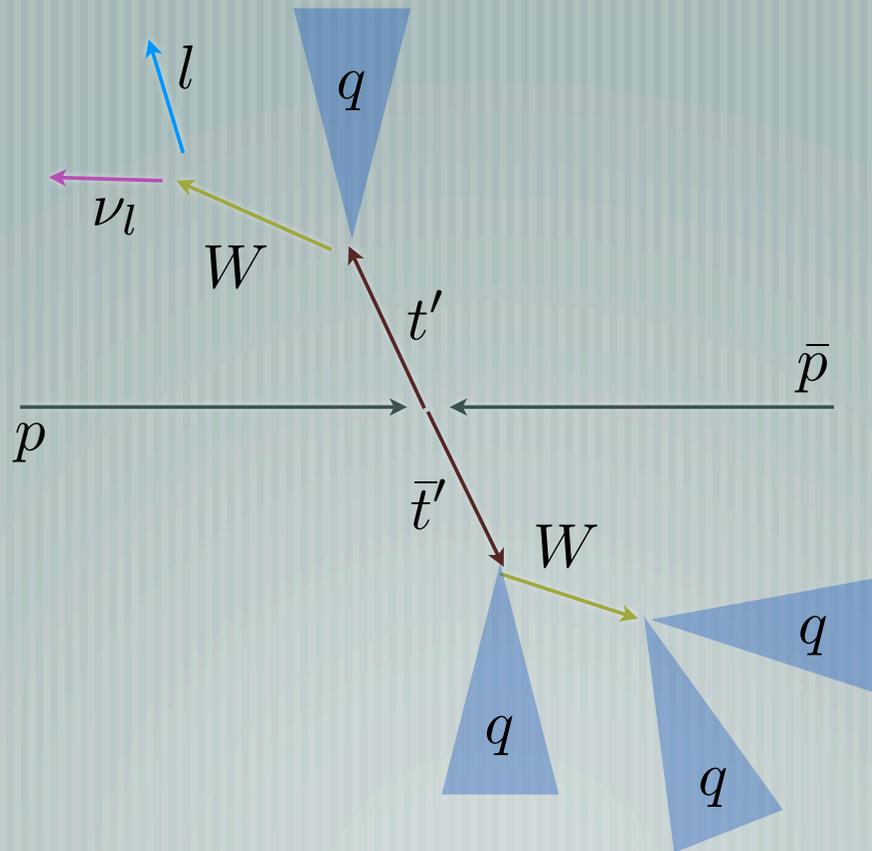
M$_{reco}$ - Kinematic Fitter

As seen in the detector

M_reco - Kinematic Fitter

As seen in the detector

q

W^+ l

$\bar{t}$

ν_l

t

W^-

q

q

q

Need to reconstruct
the ν_l first then
the W's then the
base quarks
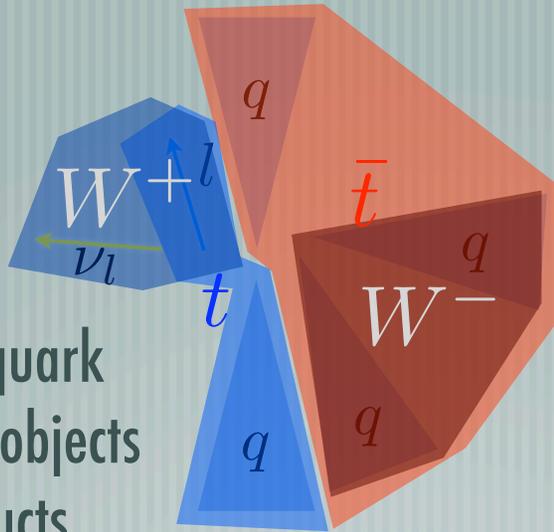
To reconstruct a base quark
need to assign detected objects
to quark decay products

12 different possible ways of assigning jets to partons plus
an unknown ν p_z
Gives 24 possibilities per event

Coming Improvements

- Complementary search for b'

- Including dilepton channel

- New optimizations by dividing signal region based on quality of reconstruction

- Include additional triggers adding ($\approx$33% more data)

- B-tagging (Assume t' $\rightarrow$ Wb instead of t' $\rightarrow$ Wq)

- Examine other production models / limit more theories

Theory Overview

Flavor Democracy: Four generations of leptons with equal Yukawa couplings - t',b' required for anomaly cancellation [JHEP 0212 (2002) 036 - arXiv:hep-ph/0204217v2]

GUT SO(1,13): Four generations from symmetry breaking [Bled workshops in physics, Vol.7, No.2, DMFA-Zaloznistvo, Ljubljana, Dec. 2006 - arXiv:hep-ph/0612250v1]

Two Higgs Doublet: N=2 Supersymmetry requires 3 additional fermion generations [Phys. Rev. D64 (2001) 053004 - arXiv:hep-ph/0102144v2]

Little Higgs: Cancels quadratic divergences using additional particles (Not supersymmetric) [Phys. Rev. D 68, 097301 (2003)]

Beautiful Mirrors: Extra quarks improve agreement between measured asymmetry and predicted (Possible vector-like coupling) [Phys. Rev. D65:053002, 2002 -arXiv:hep-ph/

Background

We model our main backgrounds with three different samples of events

- ttbar MC events produced using PYTHIA with a top mass of 175 GeV/c

- Fake lepton (QCD) events constructed using a data sample which fails some electron id cuts

- An ALPGEN+PYTHIA generated MC sample of W+light flavor events

Other Backgrounds

Model small backgrounds:
Diboson, single top,
W+heavy flavor, Z+jets
with W+light flavor

Black: Others
Red: W+lf
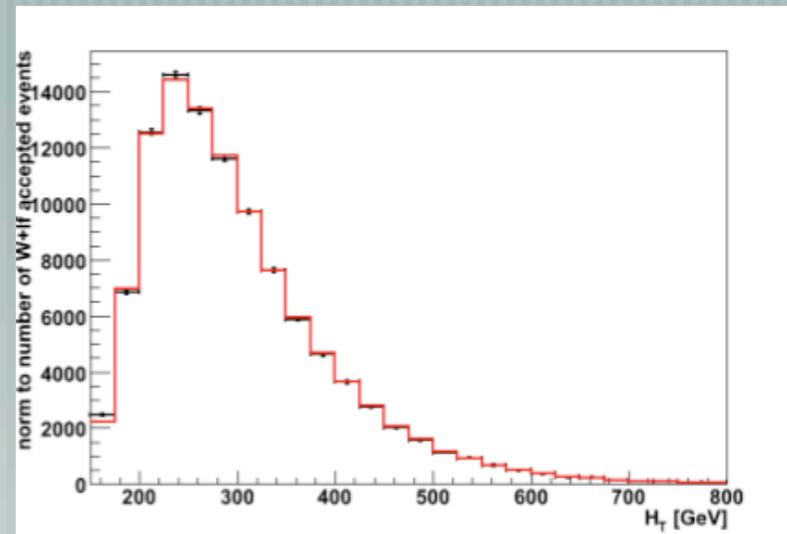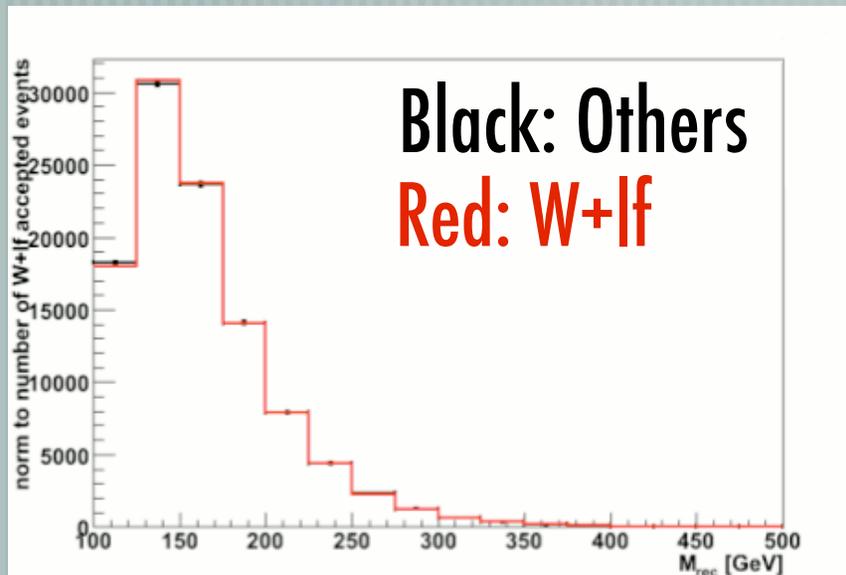
For our sample W+lf has a
similar shape to other
backgrounds

Mismodeling Cuts

We apply additional cuts to events with high lepton p_T or high lead jet E_T. These cuts are derived from the 2 and 3 jet region and apply to the lepton-$\not{\!\!E}_T$ and lead jet E_T-$\not{\!\!E}_T$ delta phi variables.