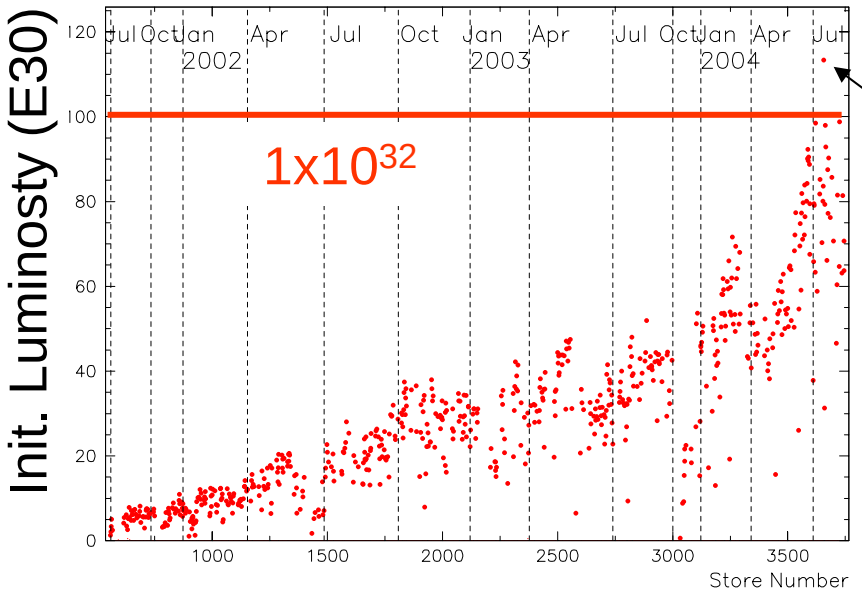
Search for a Heavy Fourth Generation t' Quark in the Top Quark Sample at CDF

- Can a t' Exist?
- Event Selection
- Analysis Strategy
- Extracting Limits
  - A priori limits
  - Systematic Errors
- Results
- Future



Over 10^{32}

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Can a t' Exist?

- **Z width measurement rules out a fourth generation with a light neutrino m(ν_4)<m(Z)/2**
- **Even if m(ν_4)>m(Z)/2, precision electroweak data restrict masses and couplings of new quarks and leptons (PDG)**
- **He/Polonsky/Su (hep-ph/0102144): a generic 4th chiral generation is consistent with EWK data; can accommodate a heavy Higgs (500 GeV) without any other new physics.**
- **N=2 SUSY requires three more "mirror" generations – the SUSY breaking mechanism can induce couplings of the mirror quarks with the known ones**
- **Other models (eg: "Beautiful Mirrors" hep-ph/ 0109097) include possibilities of a new heavy up-type quark decaying to Wb**

Decay of t'

The most natural decay would be t' → W b'.
This is suppressed if M(t') < M(b') + M(W)

- **There is reason to believe (from precision ewk data) that the mass splitting between a t' and a b' quark should be relatively small (PDG). So:**

If M(t') < M(b') + M(W), then….

- **t' → W b (Cabibbo suppressed)**
- **t' → Ws, Wd (doubly/triply Cabibbo suppressed)**
- **t' → l ν b' (virtual W)**

not required to be a *b* quark

We will search for: $p\bar{p} \to t'\bar{t}' \to WqW\bar{q} \to \ell\nu q(q\bar{q})\bar{q}$

Analysis Strategy

- We have developed techniques for extracting standard $t\bar{t}$ from the data using kinematic selection.
  - No b-tag requirement
  - Use a kinematic quantities to separate signal from background
    - Used H_T = Sum E_T of lepton + Missing E_T + E_T of Jets (Scalar Sum)
    - Also used a Neural Network with a set of kinematic variables.
  - Fit quantity in data for backgrounds + signal ($t\bar{t}$)
    - Extract a cross section

R. Marginean talk, Sat. Top Session

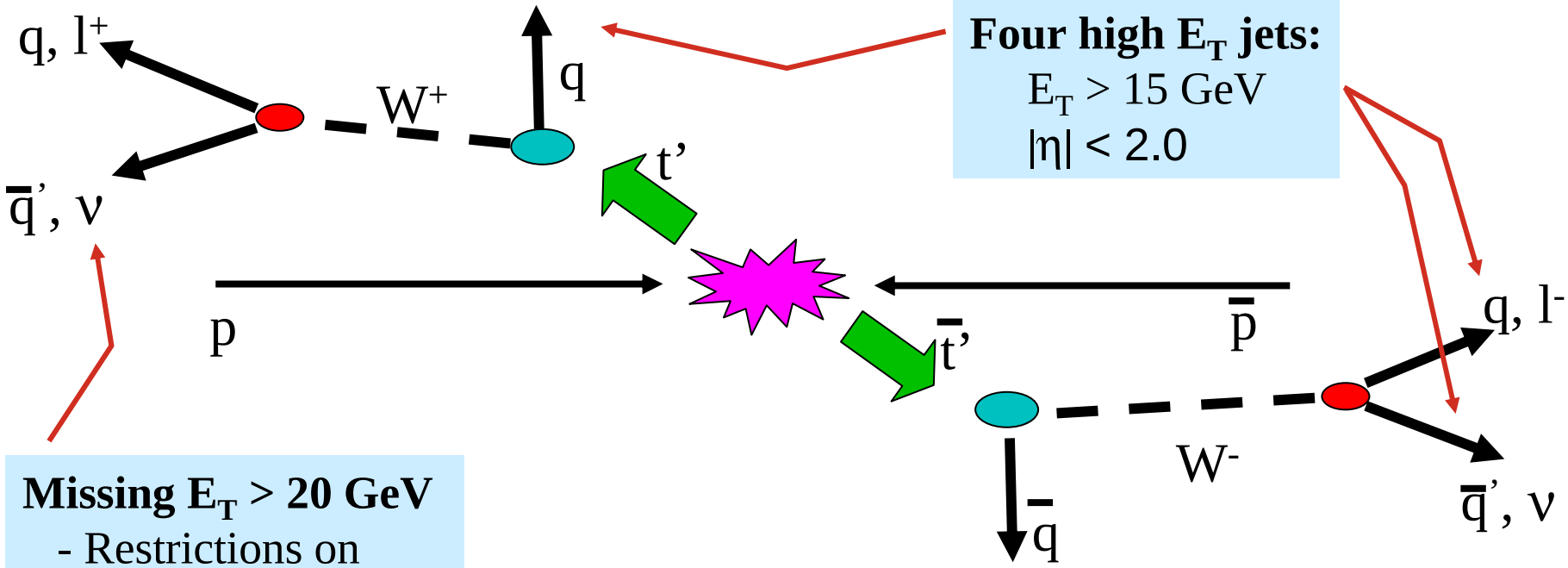
- Use same approach can be used to search for $t'\bar{t}'$ production.
  - No b-tag requirement (sensitive to t' → Wq)
  - Use a kinematic quantity to separate signal from background
    - Use H_T
  - Fit data for backgrounds (including $t\bar{t}$) + signal ($t'\bar{t}'$)
    - Extract a 95%CL limit on $\sigma(t') \times B(t' \to Wq)^2$

Event Selection

high P_T e or μ:
P_T > 20 GeV/c

Use Lepton + Jets Decay Mode

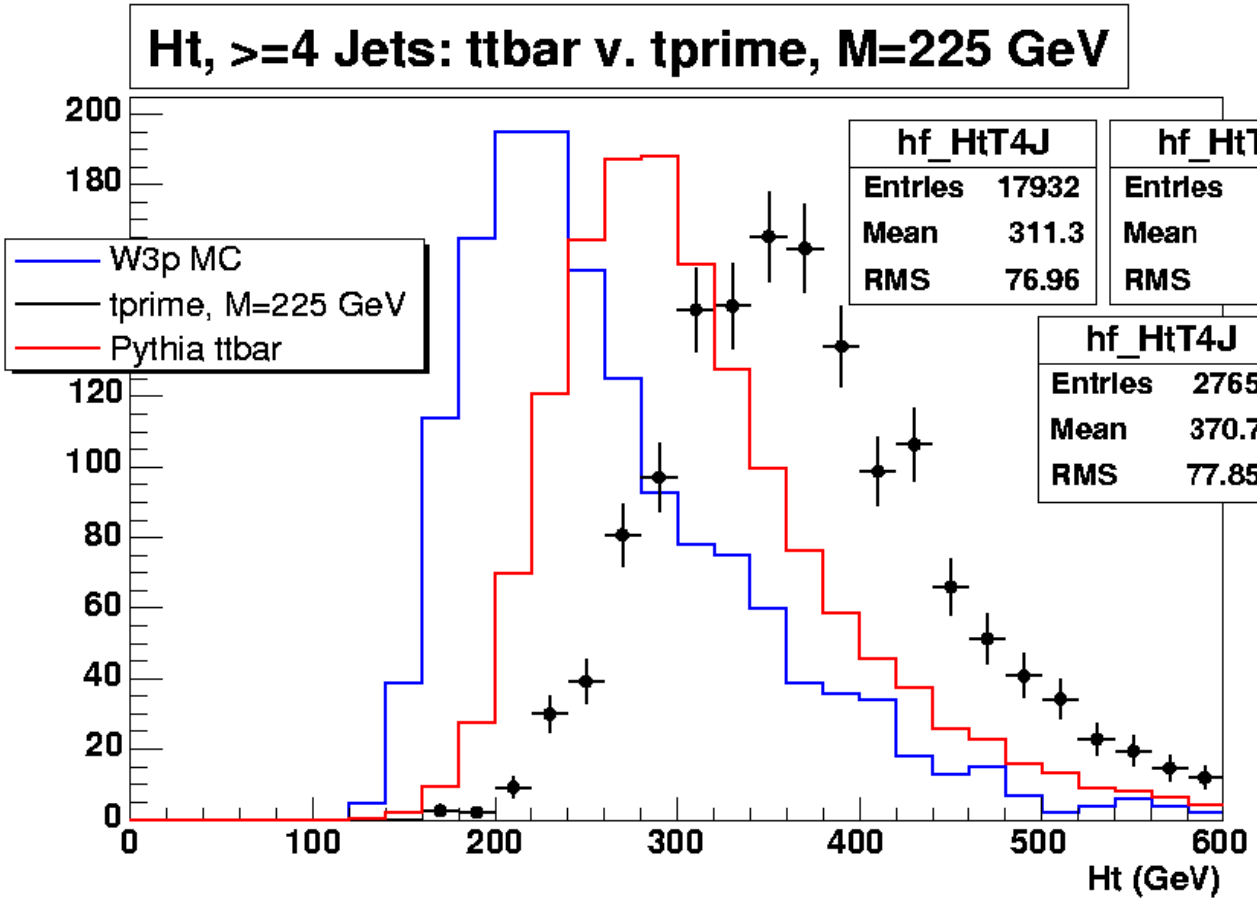
Four high E_T jets:
E_T > 15 GeV
|η| < 2.0



Missing E_T > 20 GeV
- Restrictions on direction.

Select runs where detector was operating well. ➔ 195 pb^{-1} of integrated luminosity

Separation of Signal & Background



Perform a maximum Likelihood Fit with several components

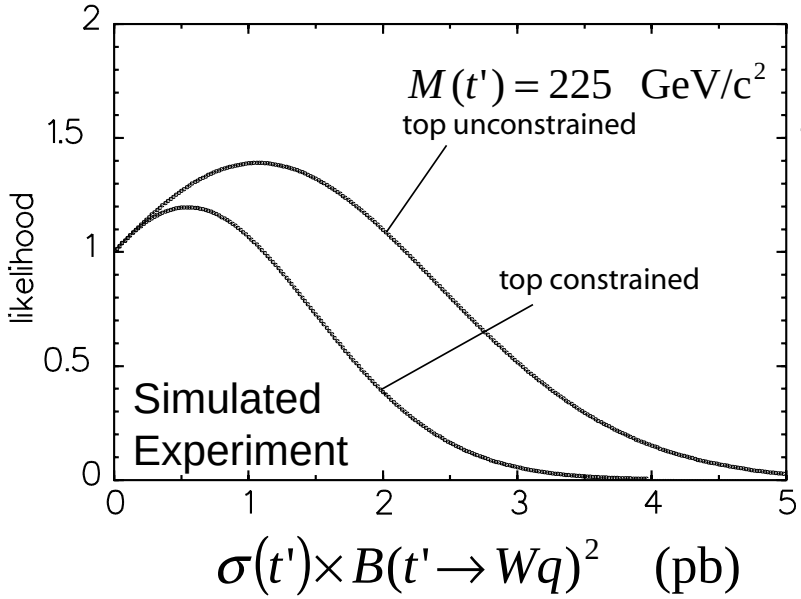
$$L(\sigma_{t'}) = \prod_i P(n_i \mid \mu_i)$$

$$\mu_i = \sum_j L_j \sigma_j \varepsilon_{ij}$$

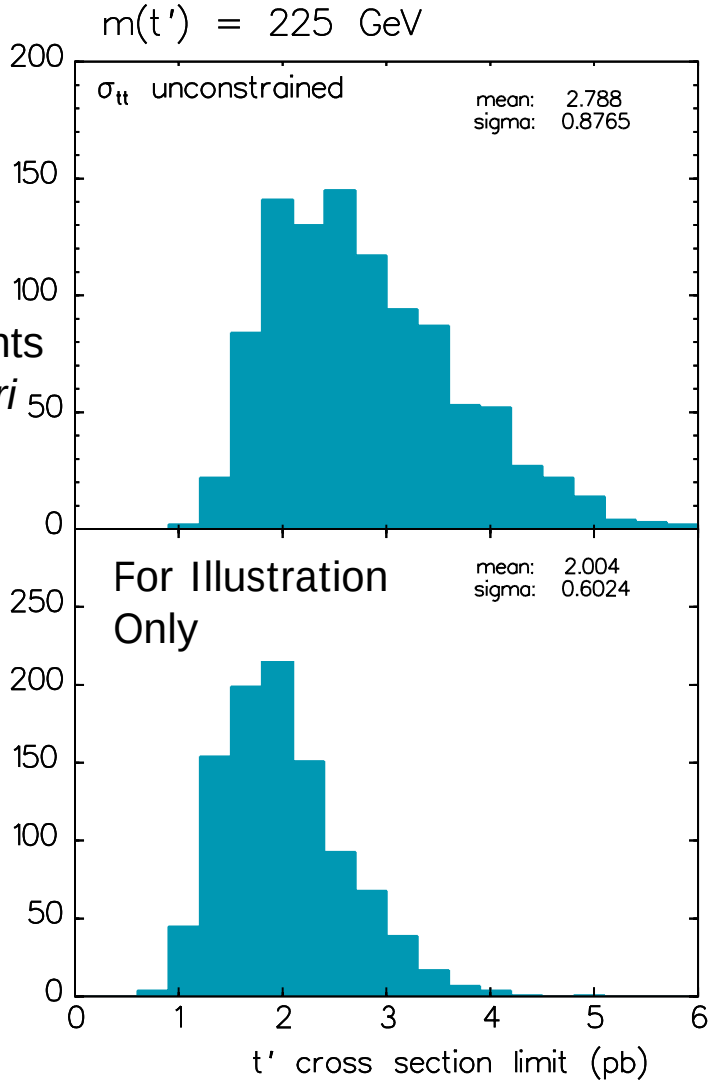
H_T distribution for W+4p, ttbar, and t' where M(t')=225 GeV

Extracting a Limit

- Map out L as a function of $\sigma(t')\times B(t'\to Wq)^2$
  - Integrate to find 95% CL Limit
  - $t\bar{t}$ could float or be constrained.



Run many pseudoexperiments to map out *a priori* limits



Will constrain $t\bar{t}$ cross section to theory ± δ(theory): 6.7± 0.9 pb

Systematic Uncertainties

Effect	Error
Jet Energy Scale	$\delta\sigma_{t'}$=1.30 + 0.16$\sigma_{t'}$ for $M_{t'}$=225GeV
W+Jets Q^2 Scale	$\delta\sigma_{t'}$=0.45 pb for $M_{t'}$=225 GeV
Top Mass	**Quote at 170,180**
Lepton Isolation	**5%**
Lepton ID	**6%**
ISR/FSR	**1.5%/0.5%**
Luminosity	**5.9%**
QCD Background	**Negligible Effect**
PDF (accept.)	**3.5%**

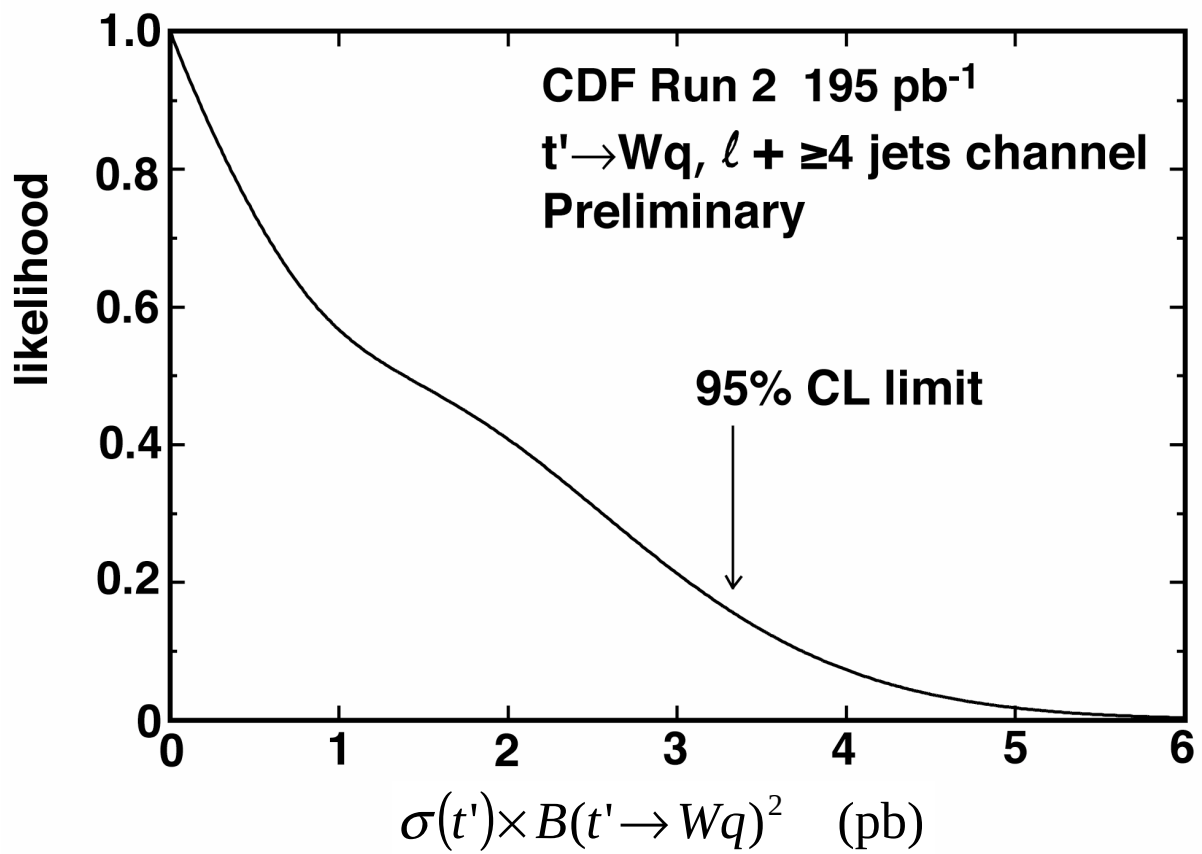
- Systematic Uncertainties impact the limit:
  - Can be dependent on the mass of the t'.
- Incorporate into likelihood
  - Degrades limit
  - Most systematics use a gaussian term.
  - Jet Energy Scale uses a more complicated function.

Modified Likelihood:

$$L(\sigma_{t'}) = \prod_i P(n_i \mid \mu_i) \times G(f_1) \times G(f_2) \times \cdots$$

$$\mu_i = \sum_j f_j L_j \sigma_j \varepsilon_{ij}$$

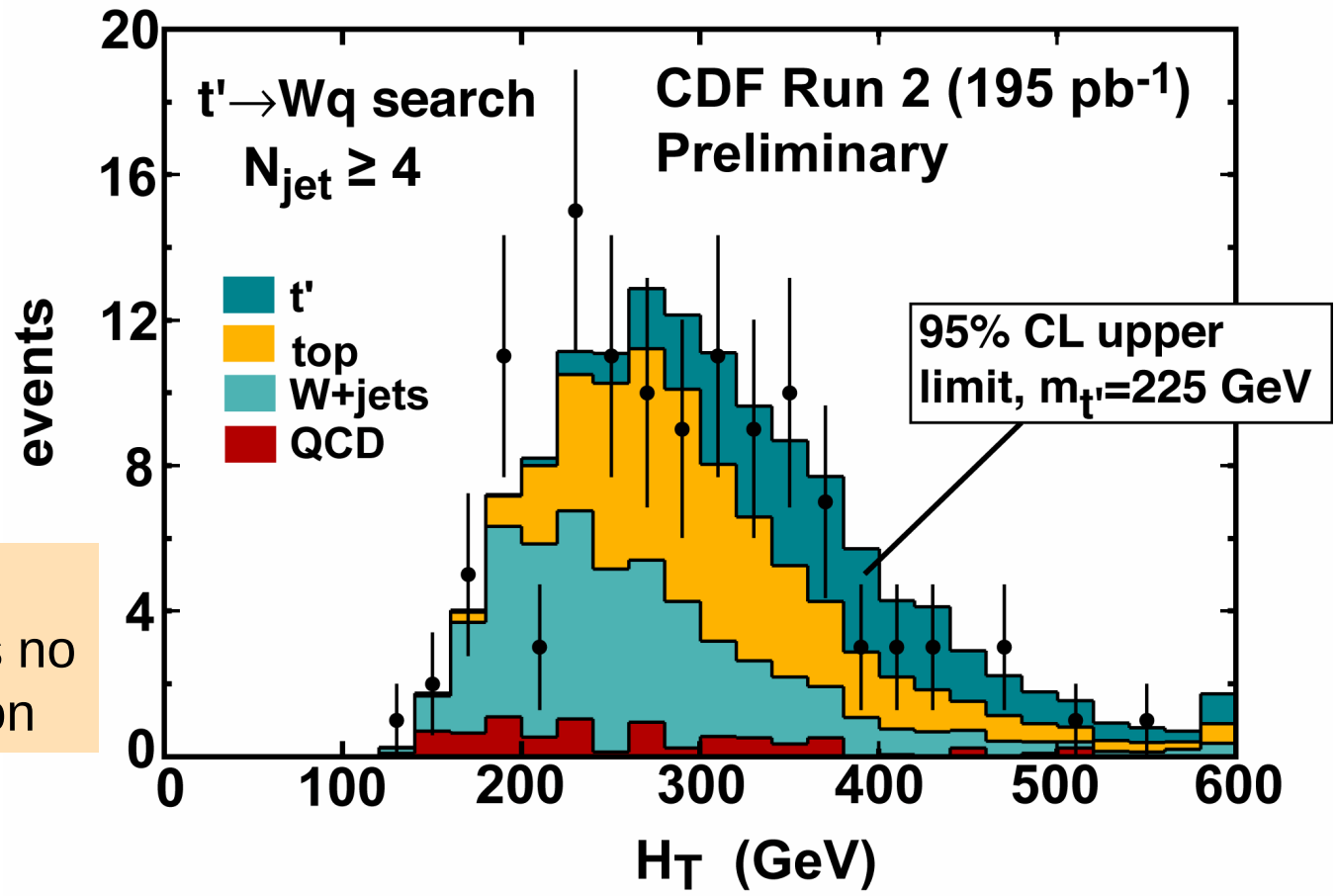
Looking at the data…



Shown for $M_{t'} = 225$ GeV/c^2

Must repeat at different $M_{t'}$ to find limit as a function of mass.

H_T Distribution



Remember, data prefers no t' contribution

Plot for fit result with t' signal included at 95% CL limit

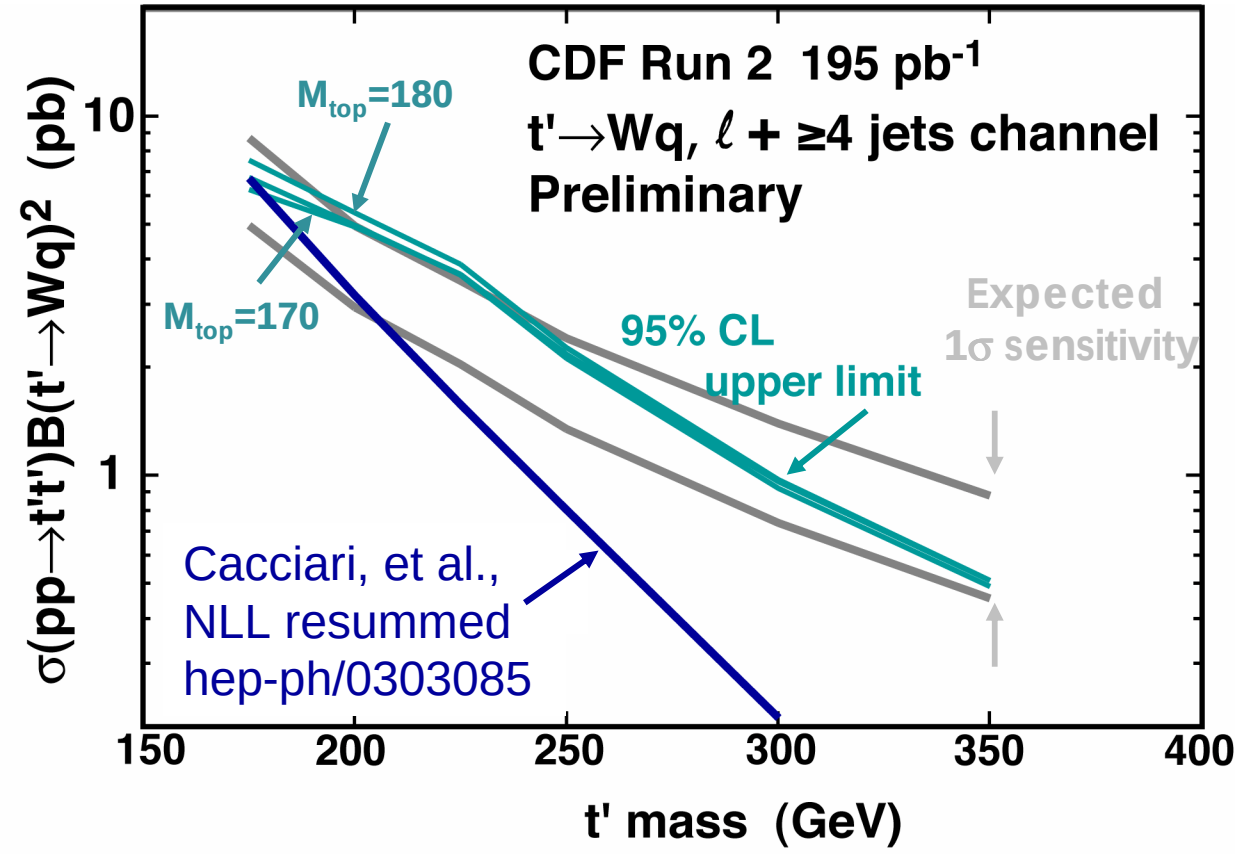
[σ(ttbar) →6.12 pb in this fit]

95% CL Limits

Constraints vary with assumed top mass, but not by much.

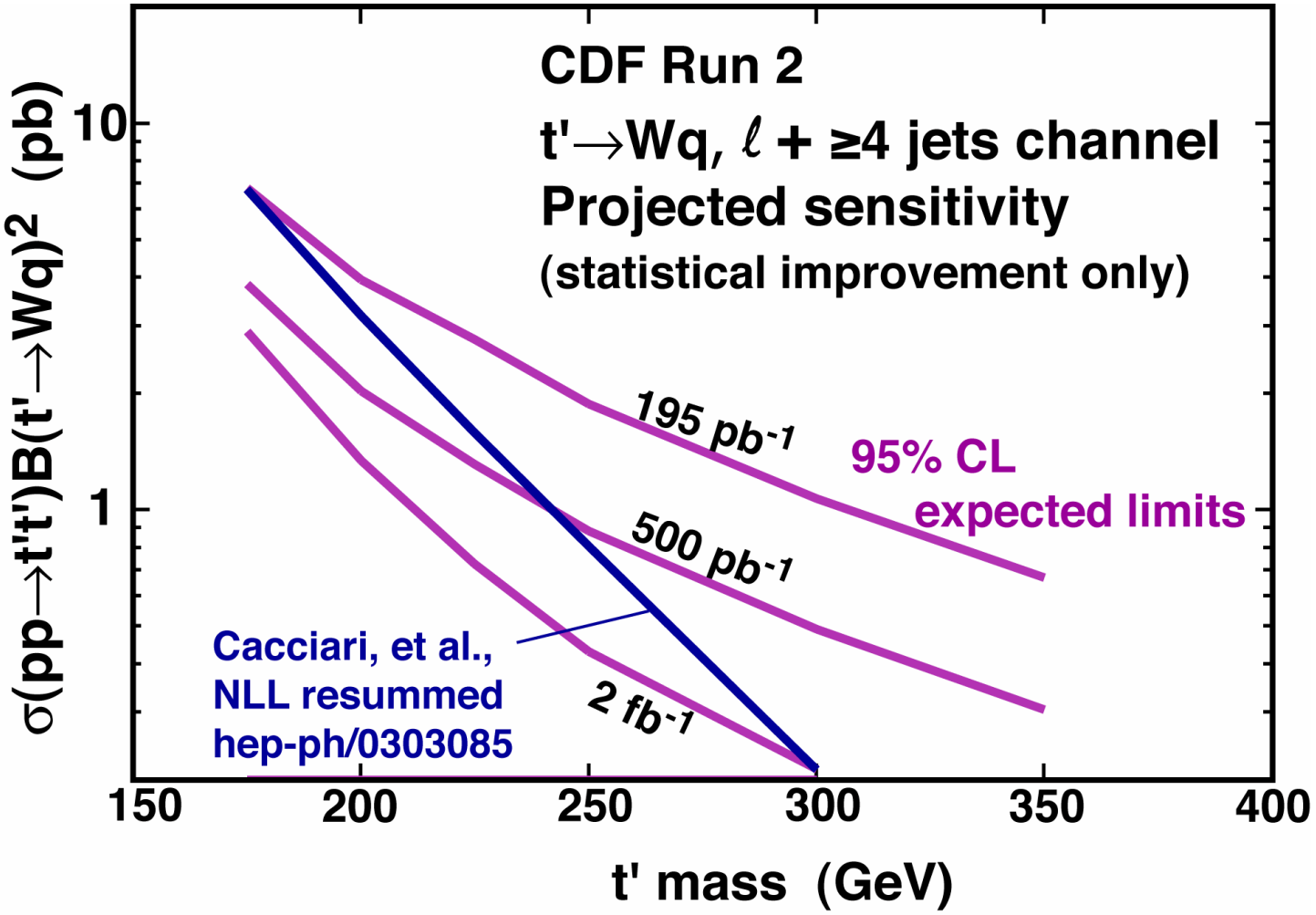
M_{top}	$\sigma_{constraint}$ *
170	7.8 ± 1.0 pb
175	6.7 ± 0.9 pb
180	5.75 ± 0.7 pb

*** Taken from hep-ph/0303085**



Limits on $\sigma * BR(t' \rightarrow Wq)^2$

Future Projections



This assumes no improvement in systematic errors

Final Comments

- Analysis is based on ~200 pb^{-1} of integrated Luminosity.
  - Fermilab recently shutdown for ~13 weeks.
  - CDF has an additional ~ 200 pb^{-1} of data that will be analyzed in coming months.
  - Run II expected to collect 4 – 8 fb^{-1}
- Expect to improve simulation of detector
  - Provides a reduction of the energy scale systematic.
  - Also expect to reduce other systematic errors.
    - Some Systematic (incl. Jet Energy Scale) improve with luminosity.
- With the kinematic analysis of $\sigma(t\bar{t})$ we obtained a substantial improvement by using a series of kinematic variables as input to a neural network.
  - Over the next several months we expect to move in this direction for the t' search as well.