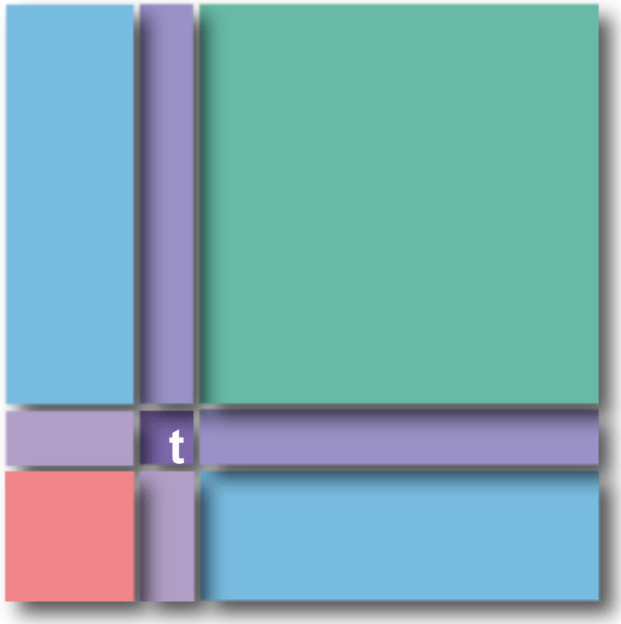
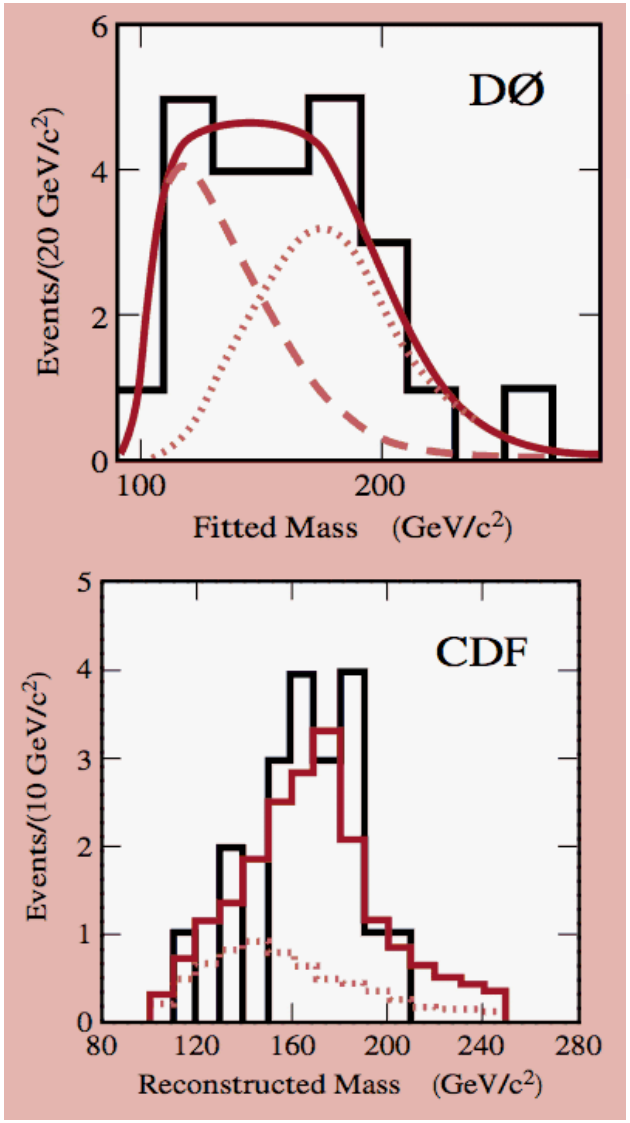
Searches for New Physics in the Top Quark Sector



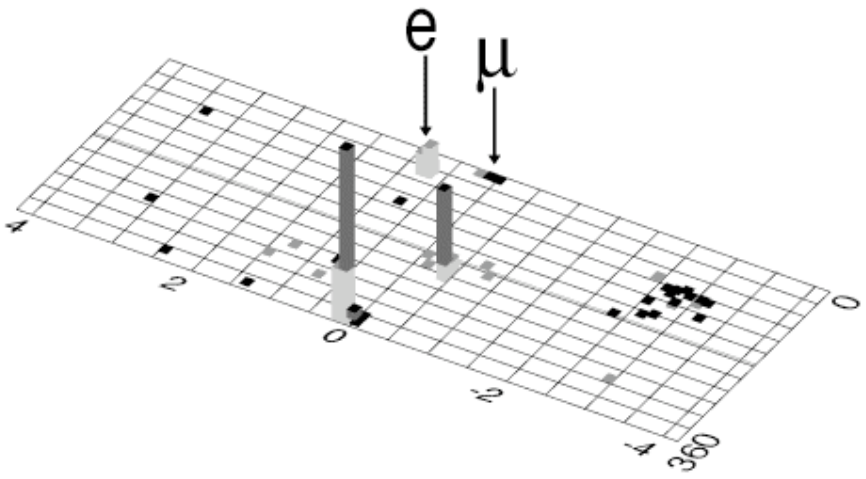
Prof. Robin Erbacher

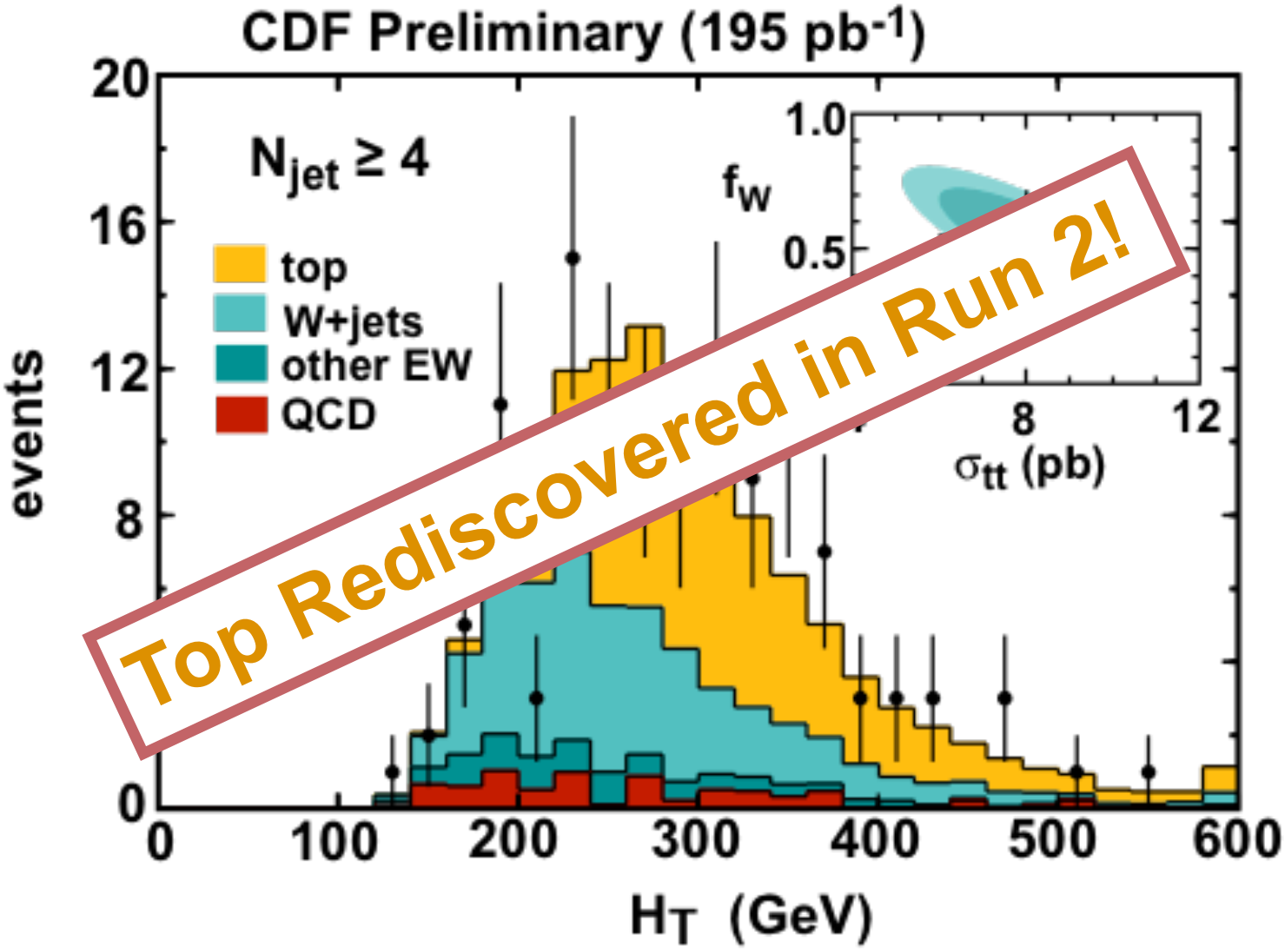
University of California, Davis

European Physical Society Meeting
Krakow, Poland – July 2009

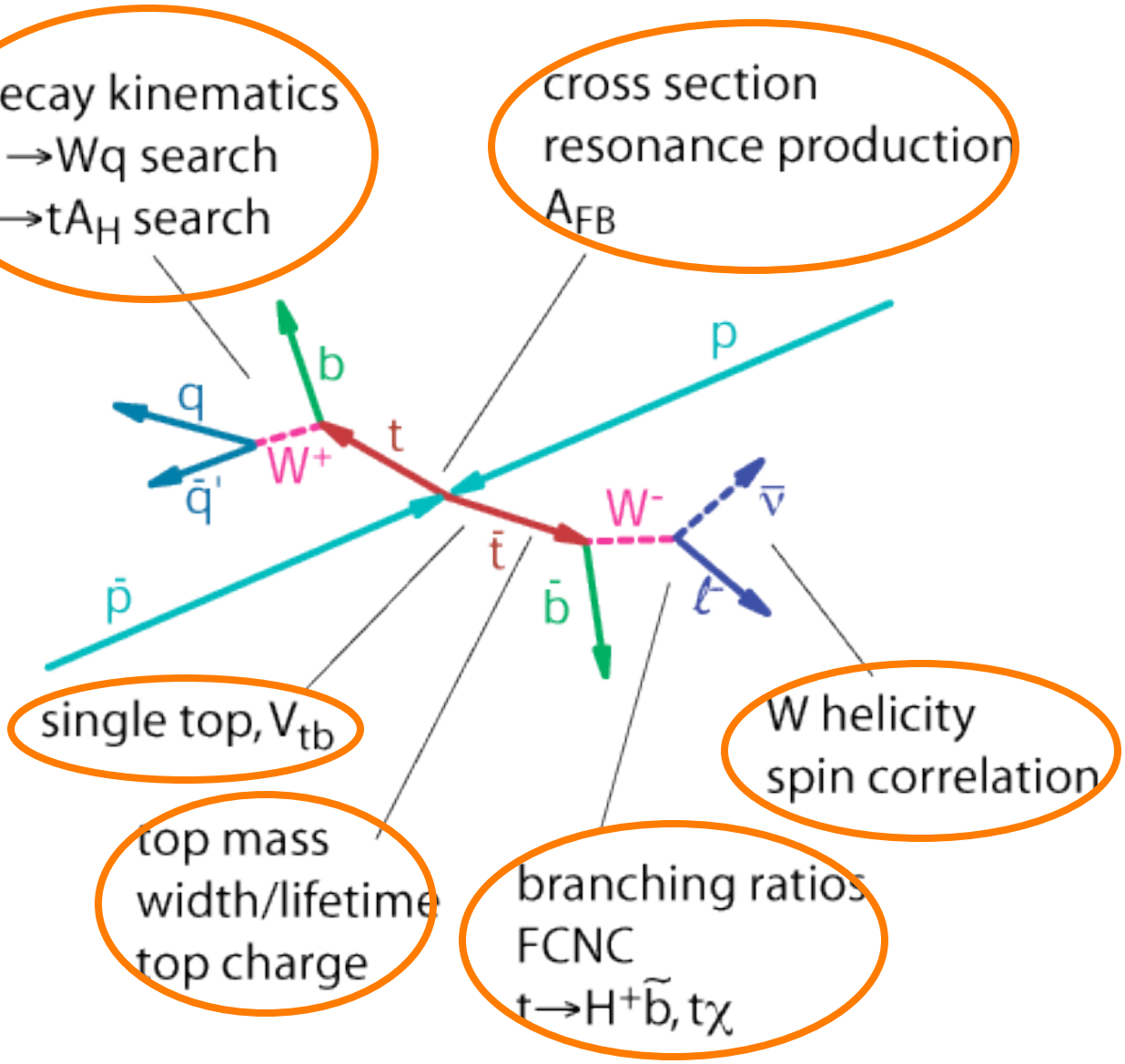


Top Discovery! Tevatron Run 1 1994-5




CDF Preliminary (195 pb-1)
Njet ≥ 4
top
W+jets
other EW
QCD
events
HT (GeV)
fW
σtt (pb)
Top Rediscovered in Run 2!

Many top properties measurements are beginning to have sensitivity: lots about top still to understand!



New Physics?!?

Top as a Window to New Physics…

Top can reveal physics beyond the Standard Model in various ways:

- Top results point to new physics:

Properties lead to expectations of partners or other new particles.

- Top is Not what we expect:

Measured top properties are anomalous, contrary to SM.

- Top is Not all that we find:

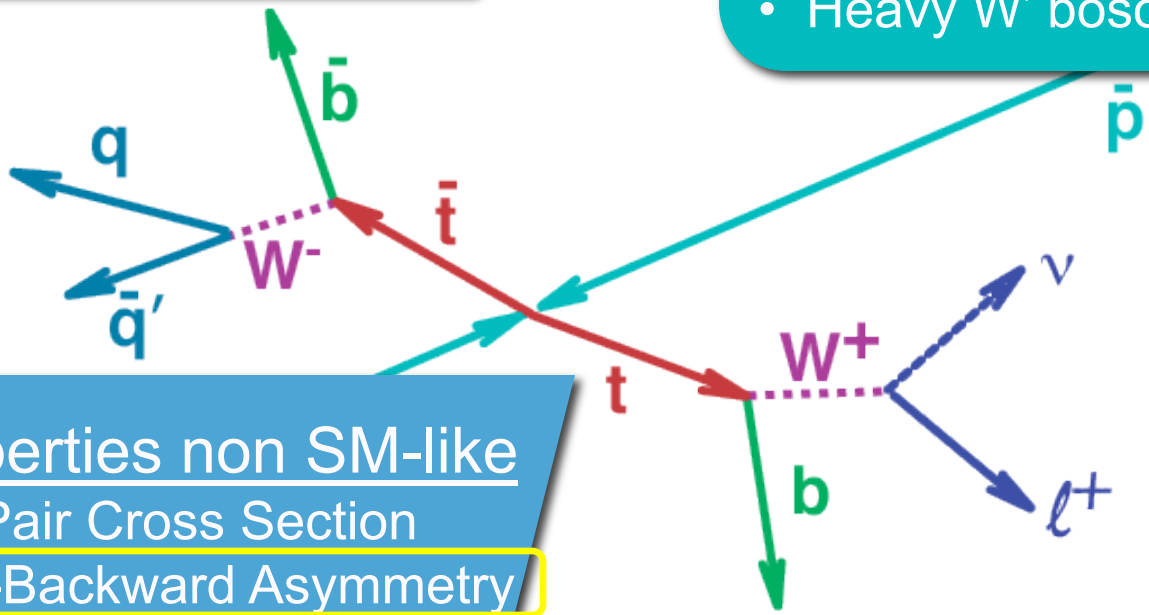
New physics mimics top signatures.

Top points to new particles

- Top Mass
- EWK Production: single top
- M_{tt} : New resonant production
- BR: Top → charged higgs

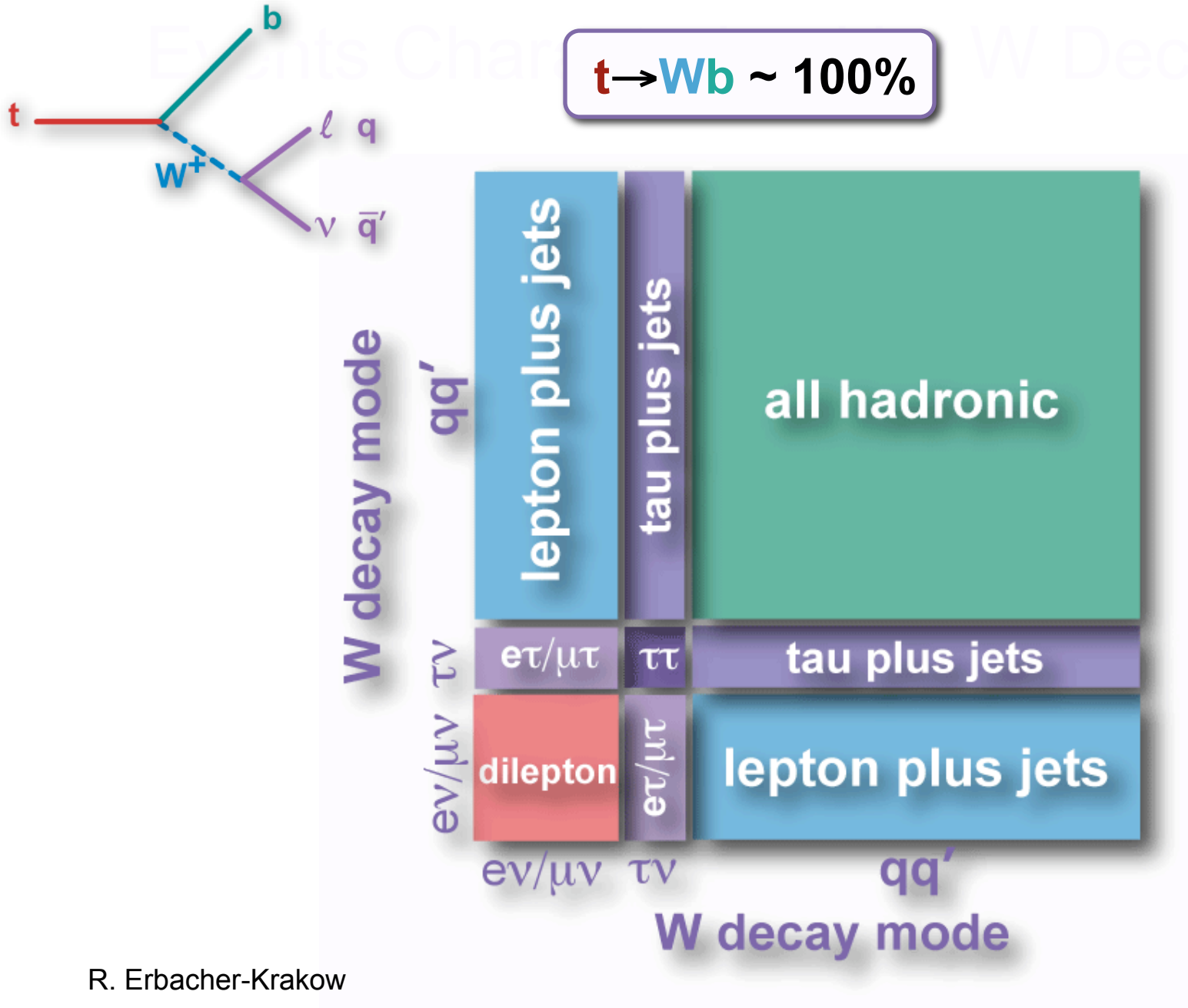
New Physics Mimics Top

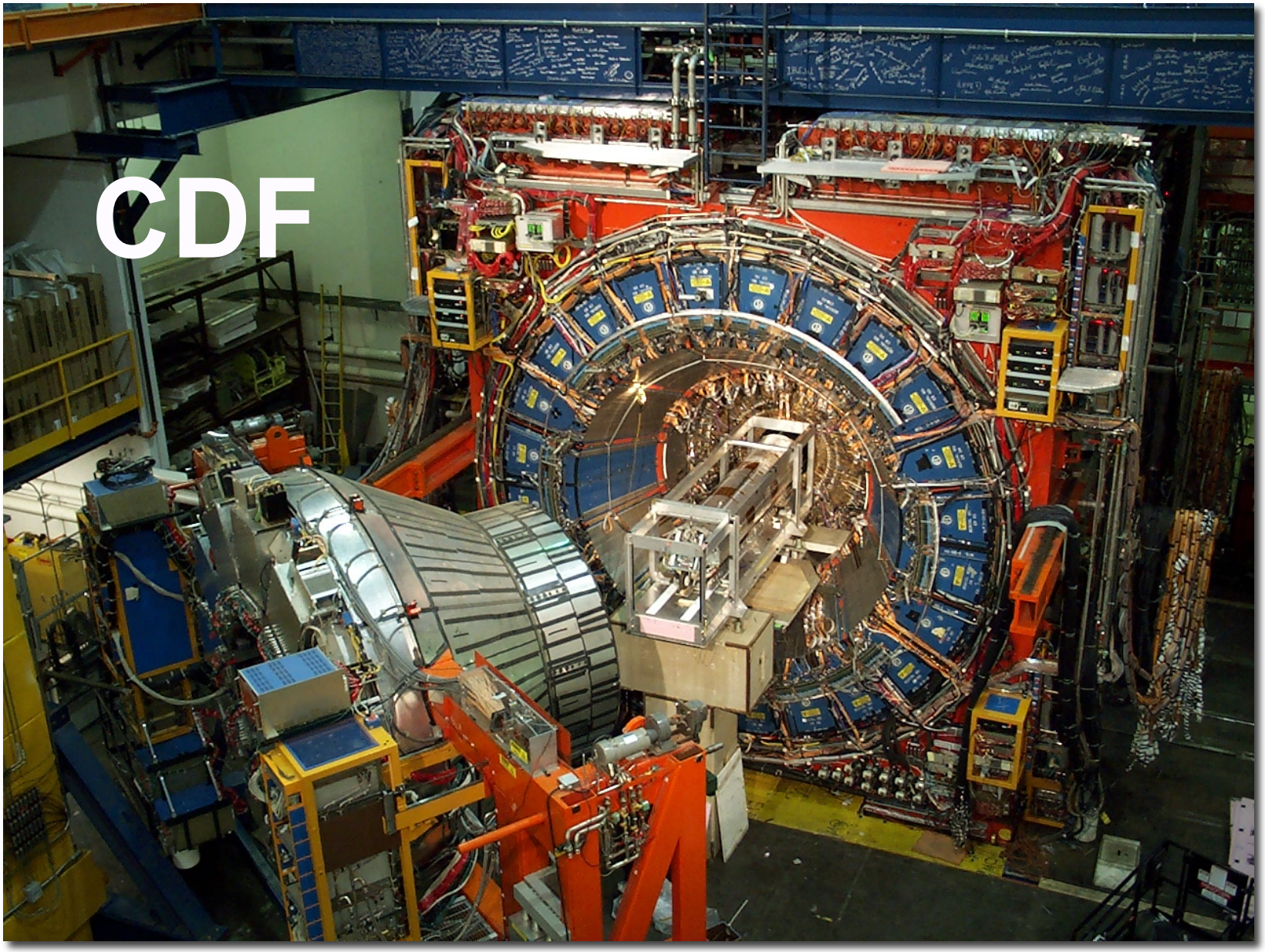
- SUSY stop production
- t' -- Massive top, T A_bt
- Massive b' → tW
- Heavy W' boson to tb



Top Properties non SM-like

- Top Pair Cross Section
- Forward-Backward Asymmetry
- W helicity (V-A)
- FCNC


t→Wb ~ 100%
b
t
ℓ q
W+
ν q̄′
W decay mode
qq′
lepton plus jets
tau plus jets
all hadronic
τν
eτ/μτ
ττ
tau plus jets
eν/μν
dilepton
eτ/μτ
lepton plus jets
eν/μν τν qq′
W decay mode


CDF

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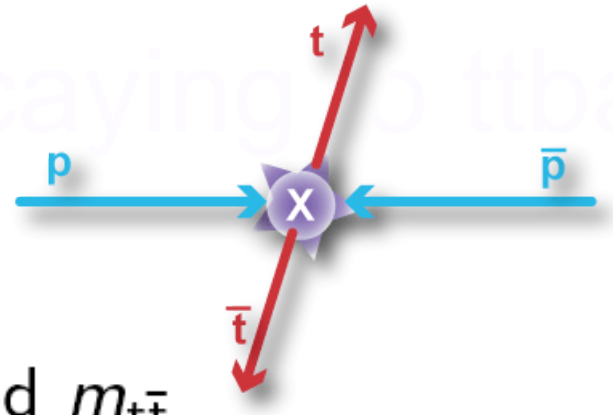
Top as Indicator of Where New Physics Lies

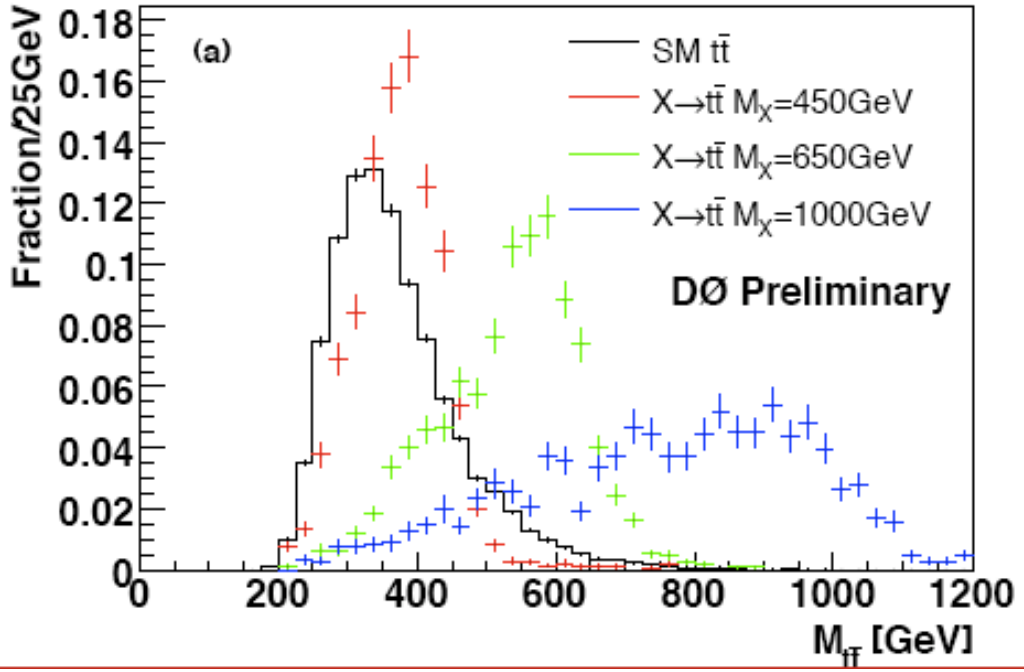
Top Measurements Point to New Particles

- Top Mass
- EWK production: single top
- New resonance production
- Top decaying to charged higgs

New Resonance Production?



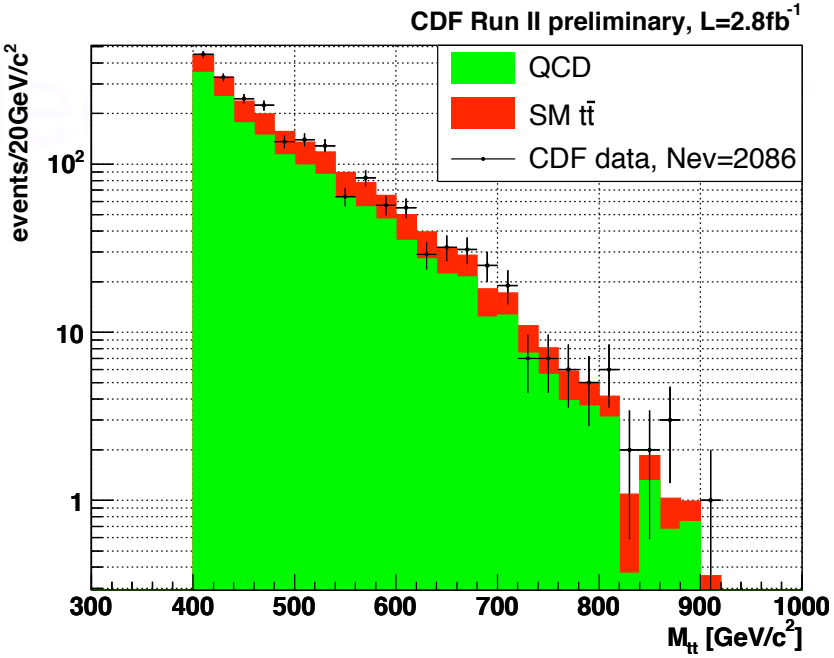
reconstructed $m_{t\bar{t}}$

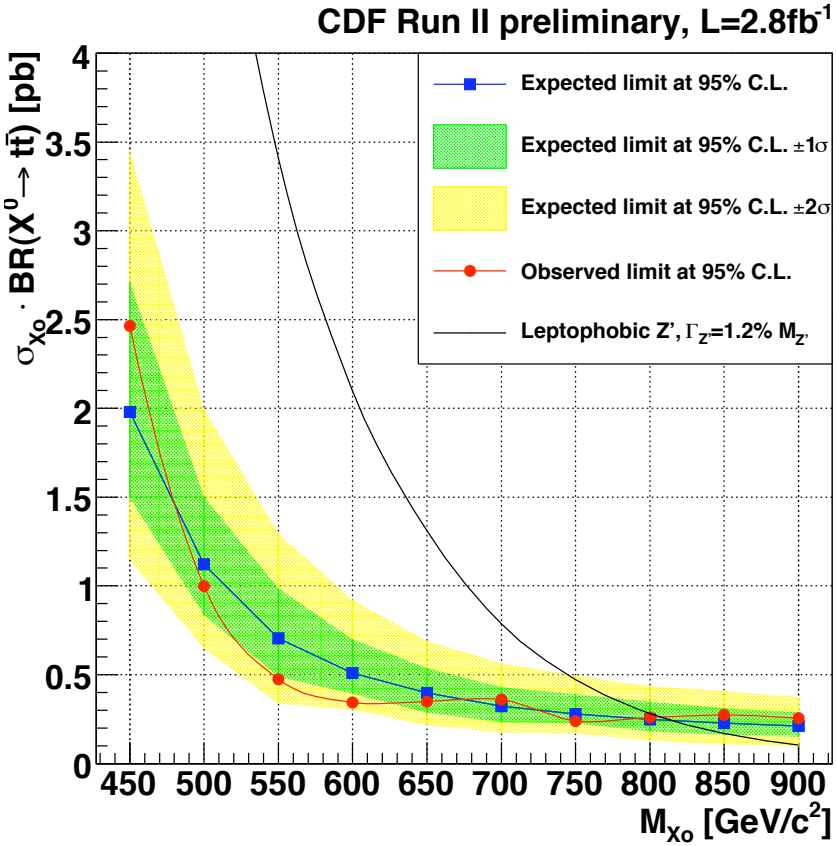


Bump-hunting for X→ttbar!

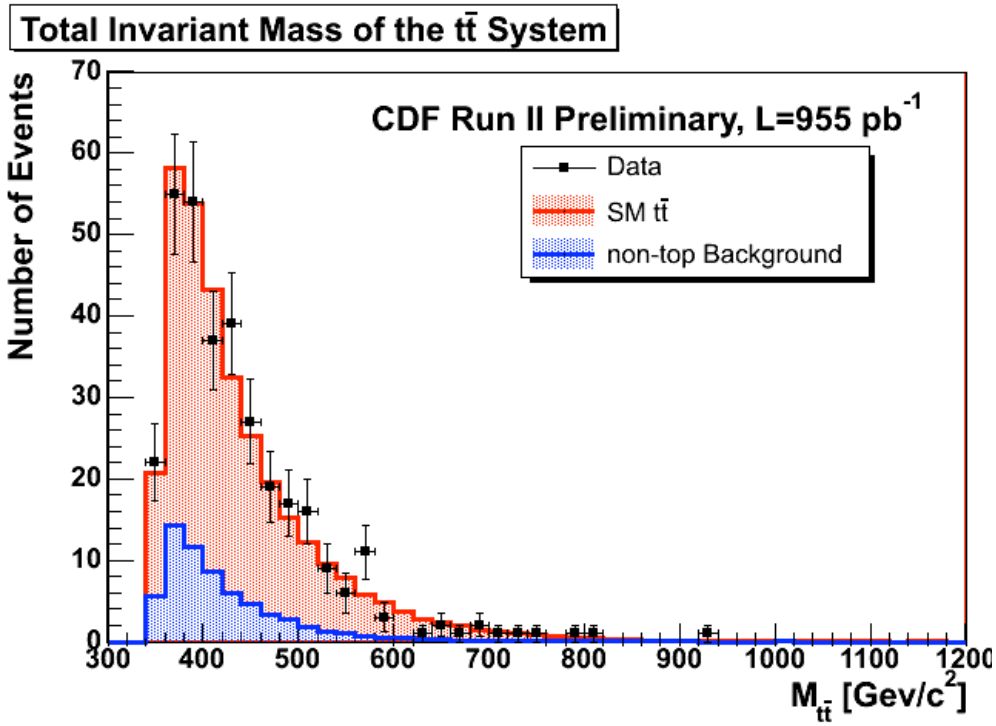
(Narrow resonance $\Gamma_X = 0.012M_X$)

New Resonance Production?





- First measurement in the all-hadronic channel
- Good agreement with SM
- Set Z' limit at 805 GeV

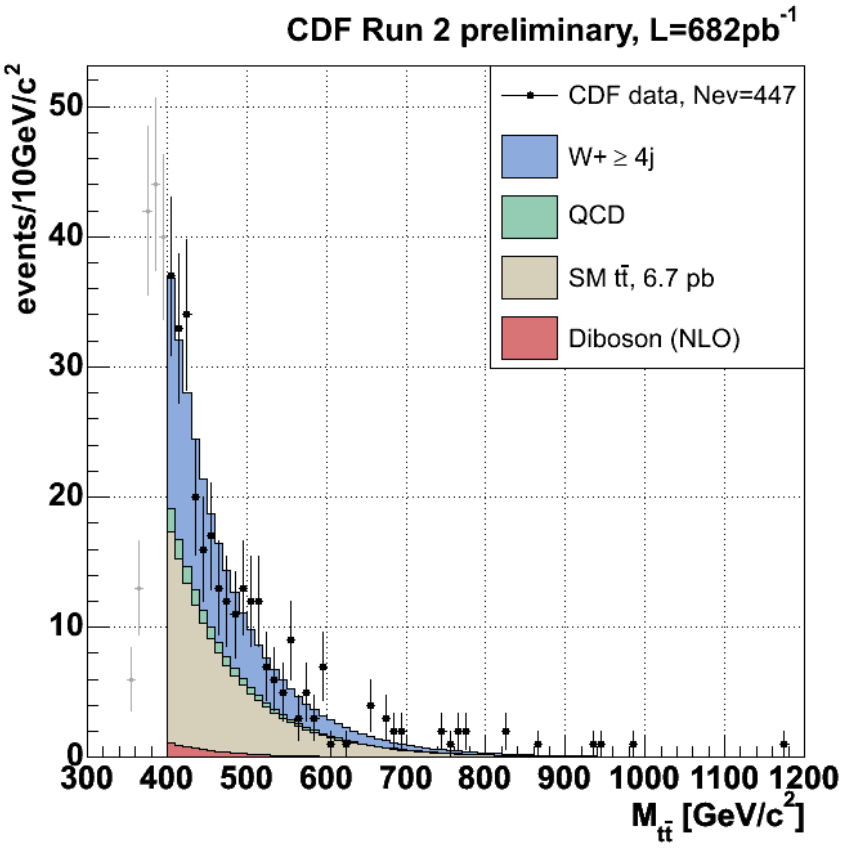


Earlier CDF Searches

Observed Limits for 700pb^{-1} and 1 fb^{-1} both:

$M_{Z'} > 725$ GeV

M_{tt} and Z′



R. Erbacher-Krakow

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Anomalies in Top Properties

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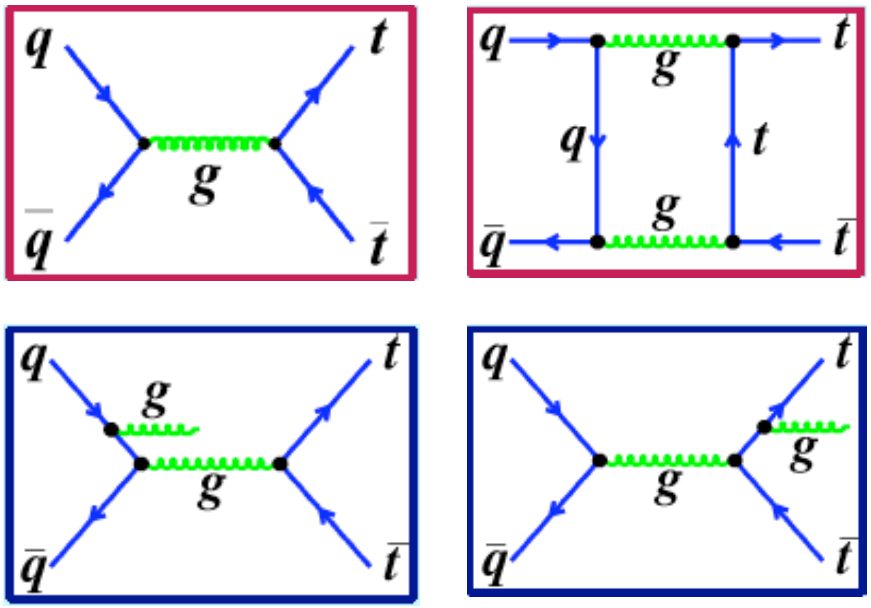
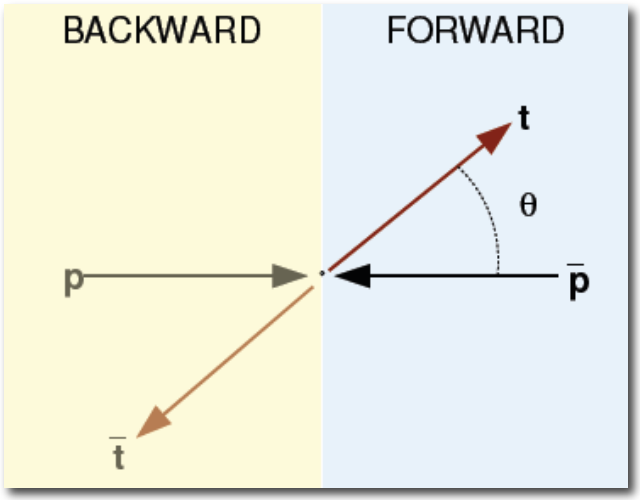
- FCNC

Forward-Backward Production Asymmetry A_{fb}

Diagram interferences for qq

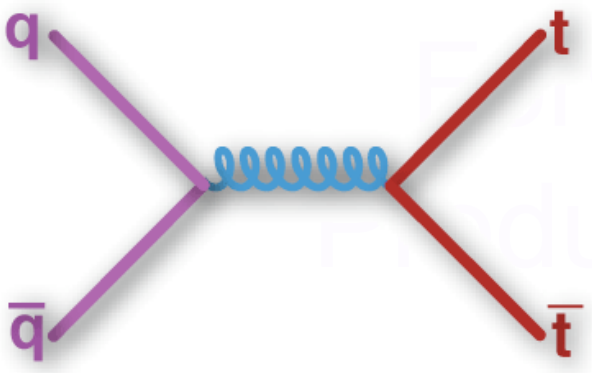
Kuhn, Rodrigo et al., PRL 2008





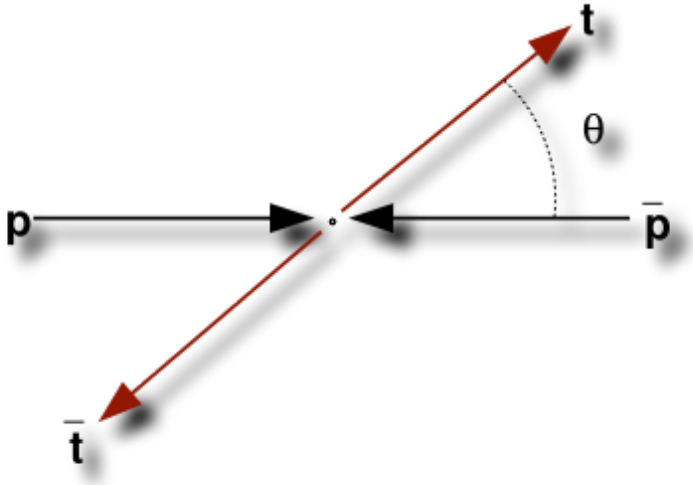
$$A_{fb} = \frac{F - B}{F + B}$$

- No asymmetry expected at LO, but 4-6% expected at NLO in parton frame
- Reduced Asymmetry in tt+jet -- *Uwer, et al.*



Forward-Backward Production Asymmetry A_{fb}

- Great test of the Standard Model
- Test of discrete symmetries of the strong interaction at high energies
- Challenging at LHC since gg fusion dominates
- Look for signs of new production mechanisms: massive gluons, Z'…



A_{fb}: Reconstructing the Production Angle

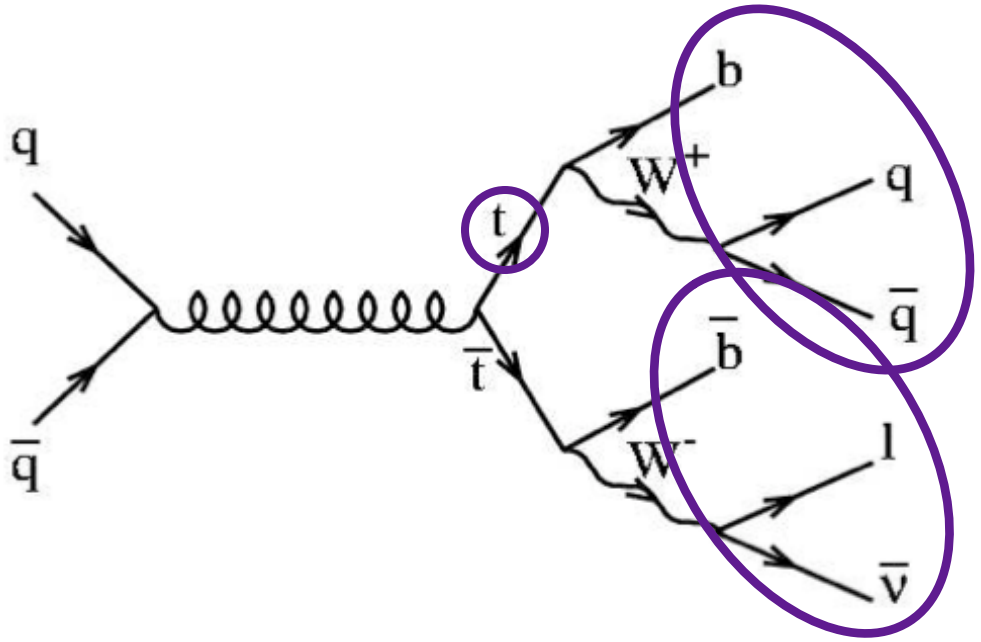
Several possible reconstruction methods:

- Measure the production angle of the + charged top, regardless of decay.

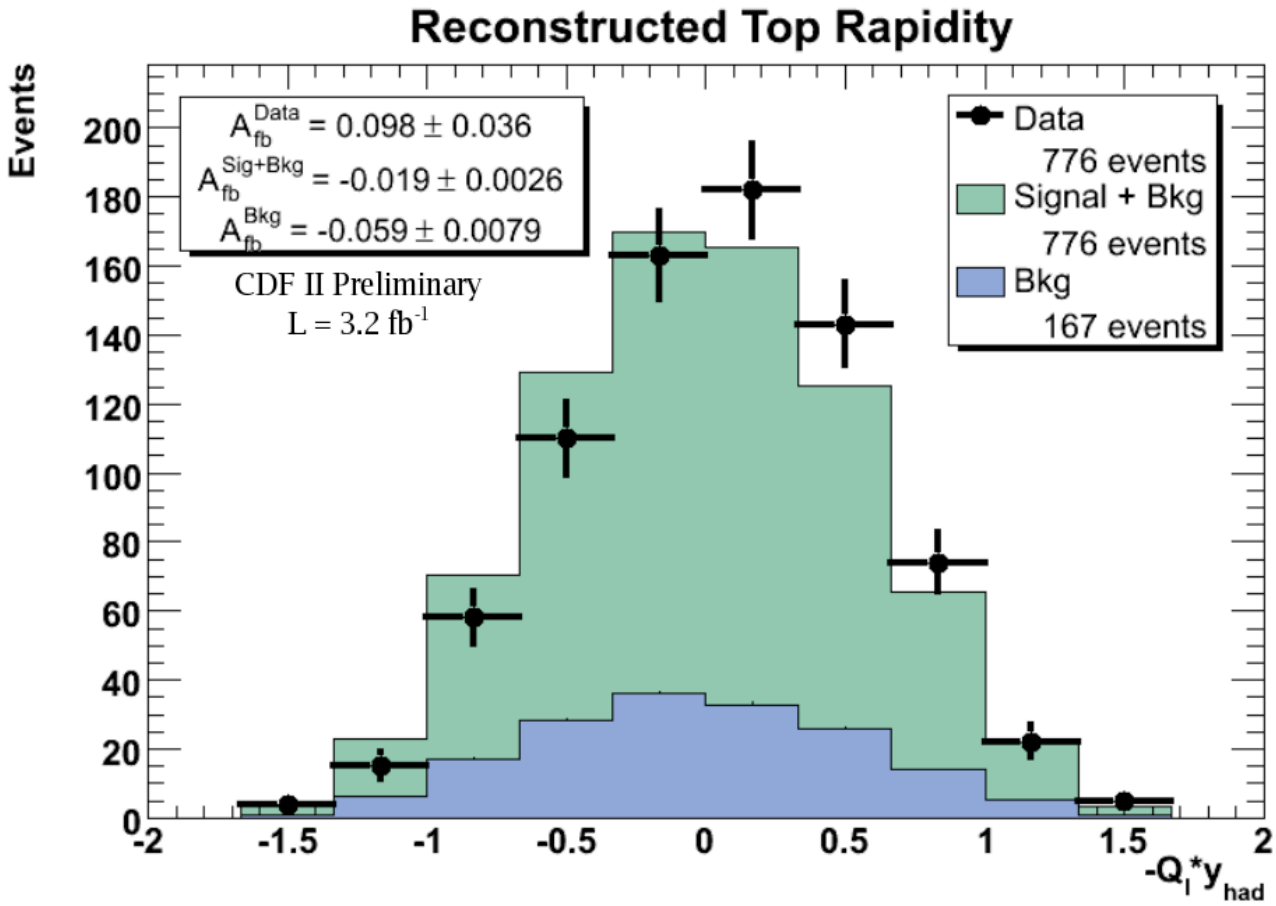
- Assume CP in strong interactions, and measure the angles for either:

– leptonic side: $Q_{lepton} \cdot y_{lep}$

–hadronic side: $-Q_{lepton} \cdot y_{had}$ → *1.5 x better resolution*

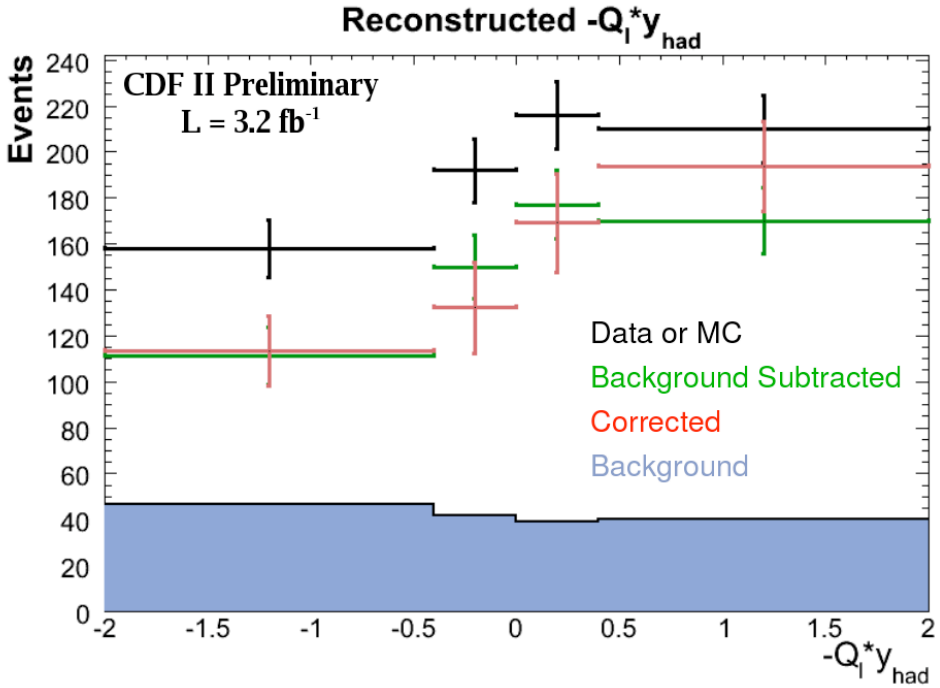


Latest A_{fb} Result from CDF



Uncorrected Distribution

Latest A_{fb} Result from CDF



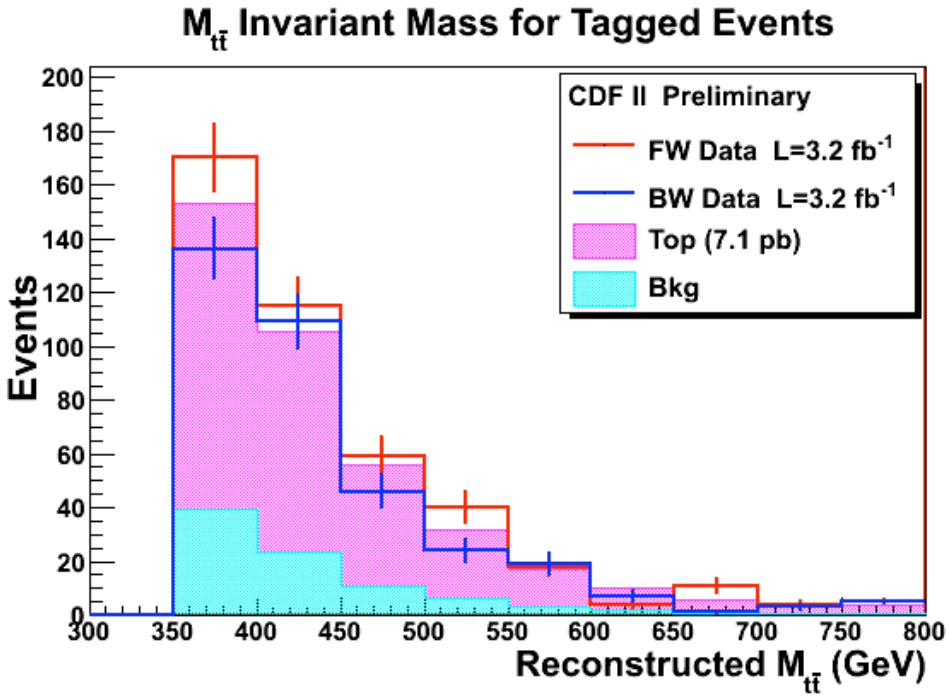
- Rebin: 4 bins optimized to minimize bias in underlying shape
- Subtract backgrounds, correct for reconstruction and acceptance
- Extract A_{fb}

$A_{fb} = (19 \pm 7(\text{stat}) \pm 2(\text{syst}))\ \%$

(Fully corrected)

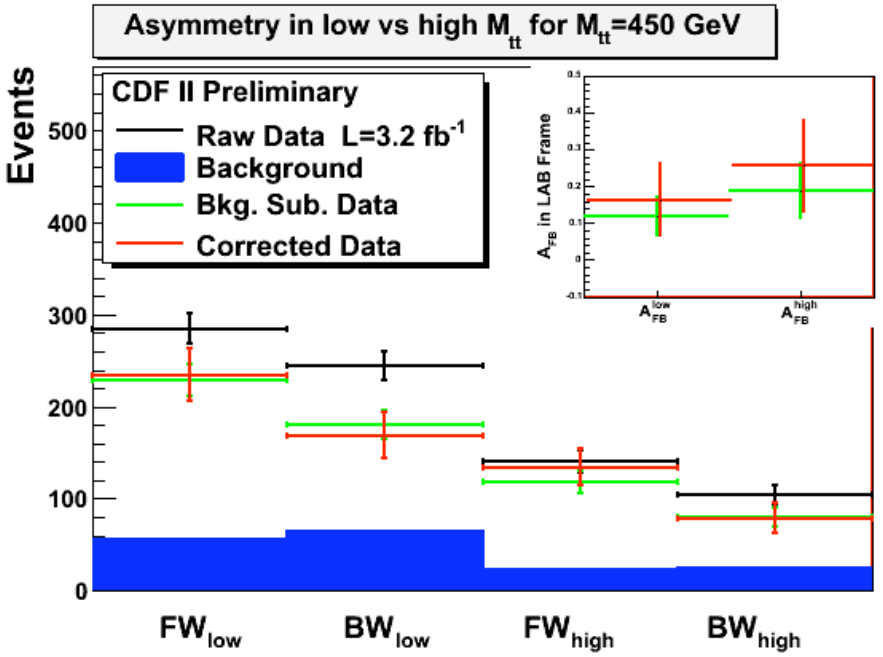
Compare NLO theory:
*(5 ±1%) for Q*y*
Kuhn, Rodrigo PRL '98
Frixione, Webber MC@NLO

New Study: Explore A_{fb} versus M_{tt}



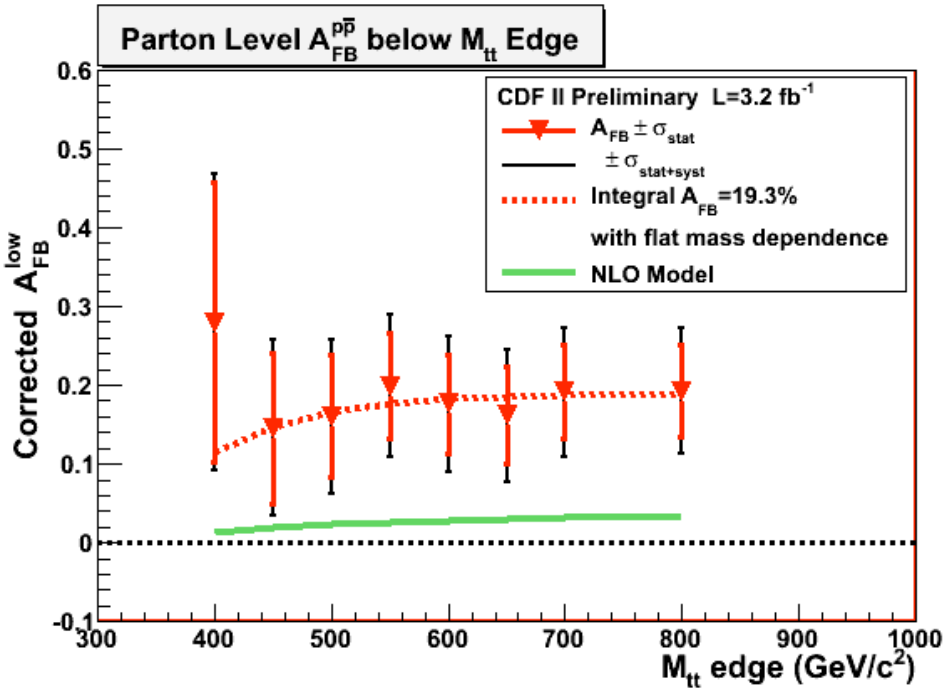
Investigate Mass Dependence:

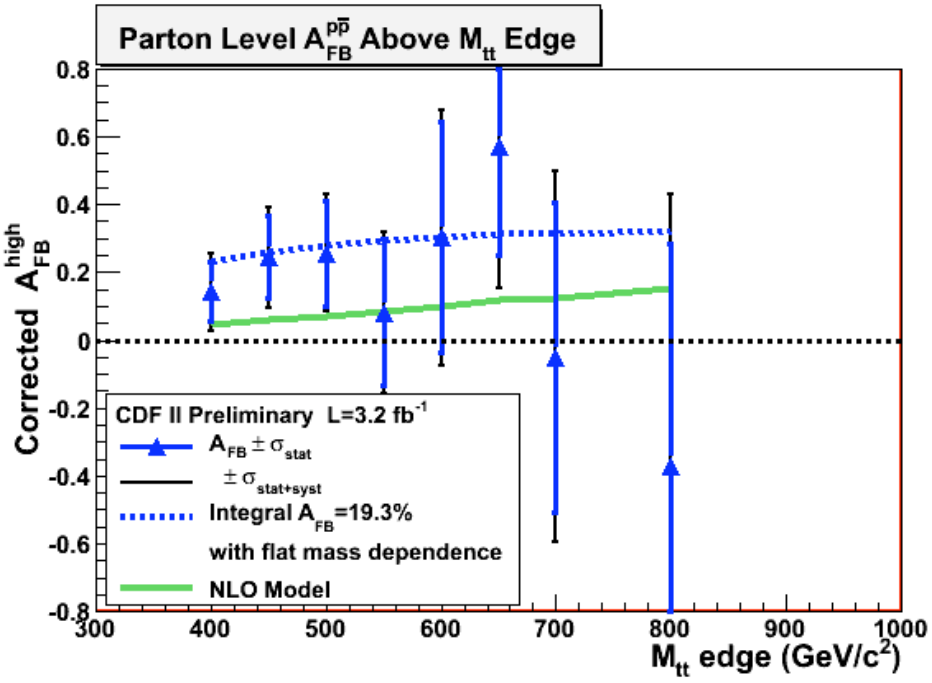
NLO ~linear prediction by Alameida, Sterman, Vogelsang (*arXiv:0805.1885v1)*



New Study: Explore A_{fb} versus M_{tt}

No significant mass dependence found so far.





Integral A_{fb} below M_{tt} cut

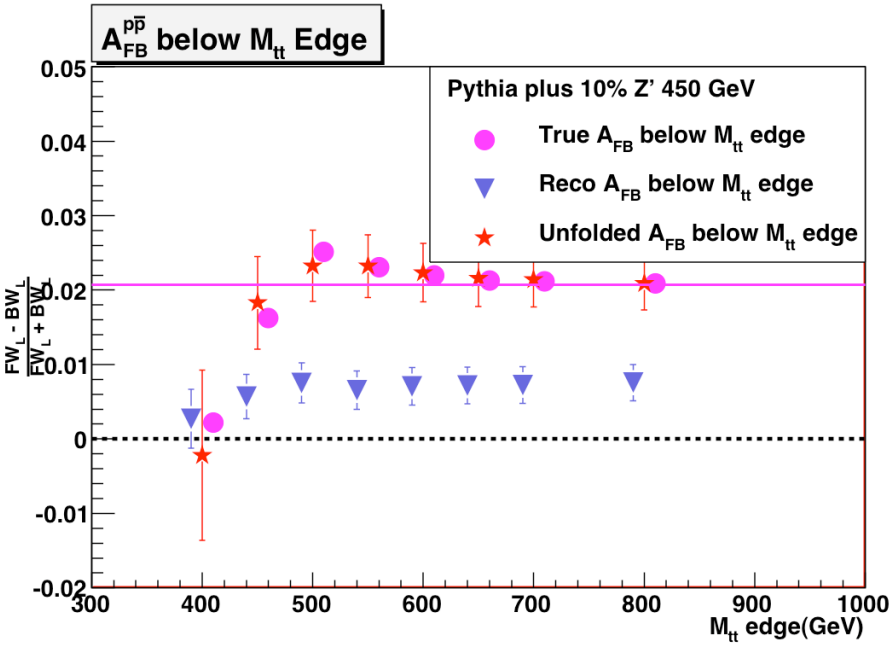
Integral A_{fb} above M_{tt} cut

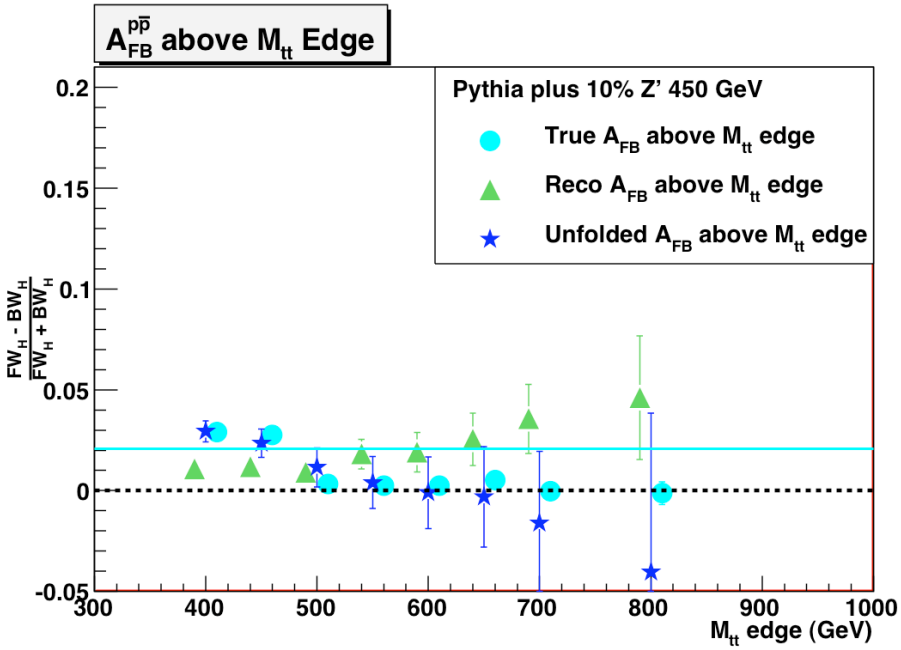
Full study results

http://www-cdf.fnal.gov/physics/new/top/2009/tprop/AfbMtt/

New Study: Explore A_{fb} versus M_{tt}

Pythia with 10% Z' at 450 GeV





Integral A_{fb} below M_{tt} cut

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Full study results

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New Physics Mimics Top

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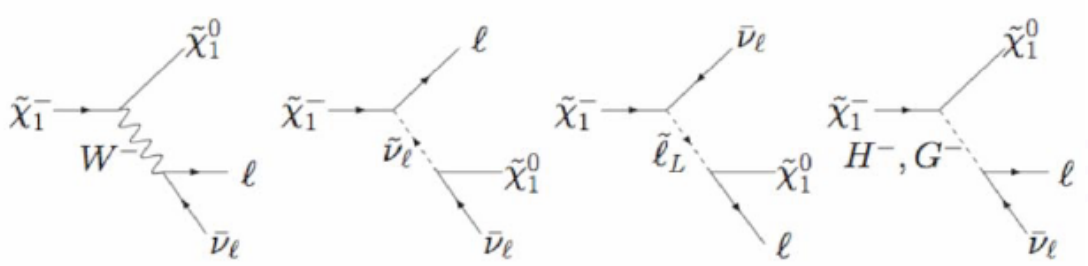
- t' -- Massive top, T A_ht
- b' decaying to tW
- Heavy W' boson to tb



Can light SUSY *stop* hide alongside Top dileptons?

If we assume:

1. $\tilde{\chi}_1^0$ is the LSP
2. $m_{\tilde{t}_1} \lesssim m_t$
3. $m_{\tilde{\chi}_1^+} < m_{\tilde{t}_1} - m_b$

Then stop pairs can look like top pairs!

$$\tilde{t}_1 \to b\tilde{\chi}_1^\pm \to b\tilde{\chi}_1^0 l\nu$$

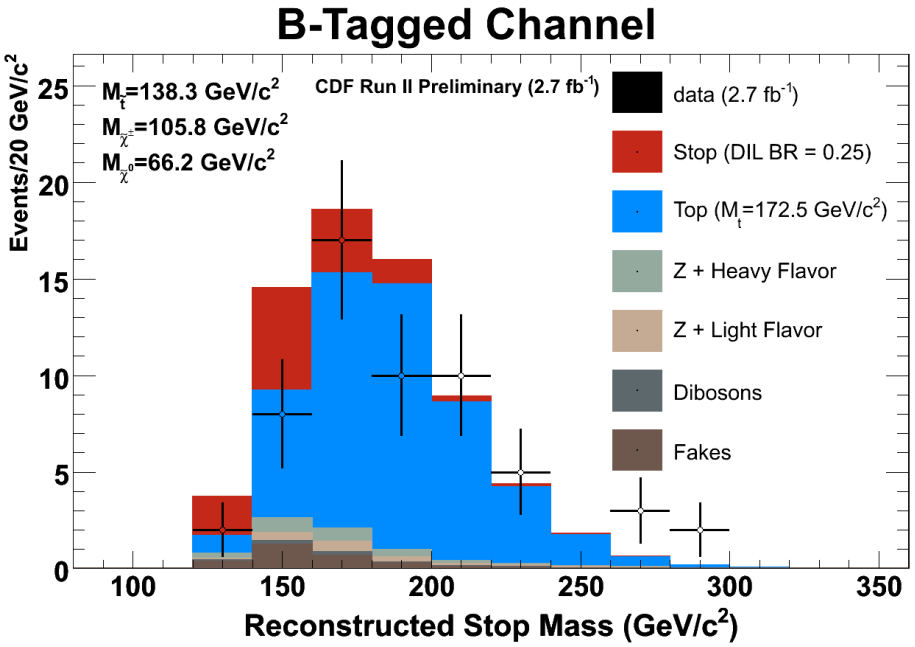
- M(stop)<M(top) in SUSY electroweak baryogenesis models.

- Look for a light stop that mimics top dilepton signatures:

$\tilde{\chi}_1^\pm$ decays to $\tilde{\chi}_1^0 + \ell + \nu$ via

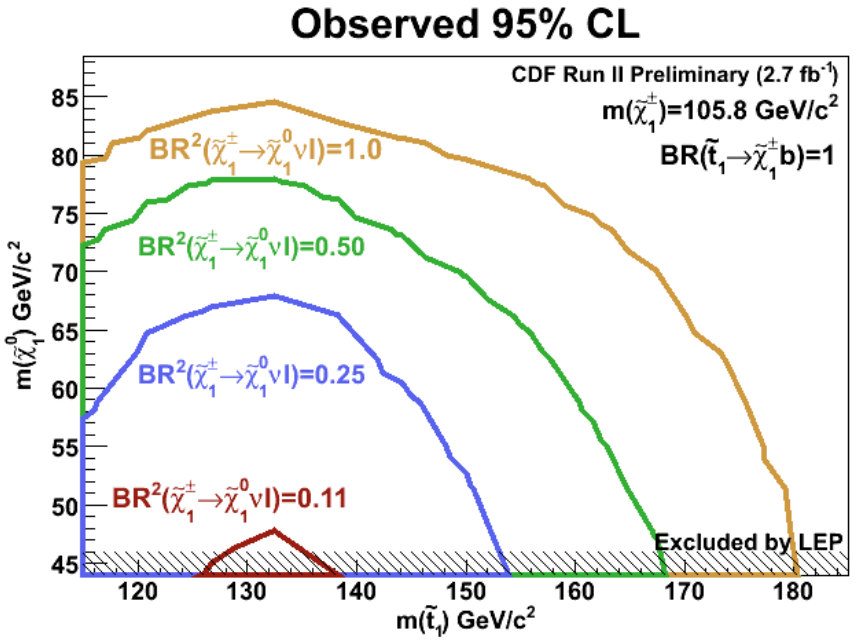
$$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + W^{\pm(*)} \to \tilde{\chi}_1^0 + \ell + \nu,$$
$$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + H^\pm \to \tilde{\chi}_1^0 + \ell + \nu,$$
$$\tilde{\chi}_1^\pm \to \ell + \tilde{\nu}_\ell \to \tilde{\chi}_1^0 + \ell + \nu,$$
$$\tilde{\chi}_1^\pm \to \nu + \tilde{\ell}_L \to \tilde{\chi}_1^0 + \ell + \nu,$$
$$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + G^{\pm(*)} \to \tilde{\chi}_1^0 + \ell + \nu.$$

Reconstruction difficult due to many invisible particles.



Example for a particular choice of stop, chargino, and neutralino masses

First limits on a light SUSY *stop* hidden in these ranges

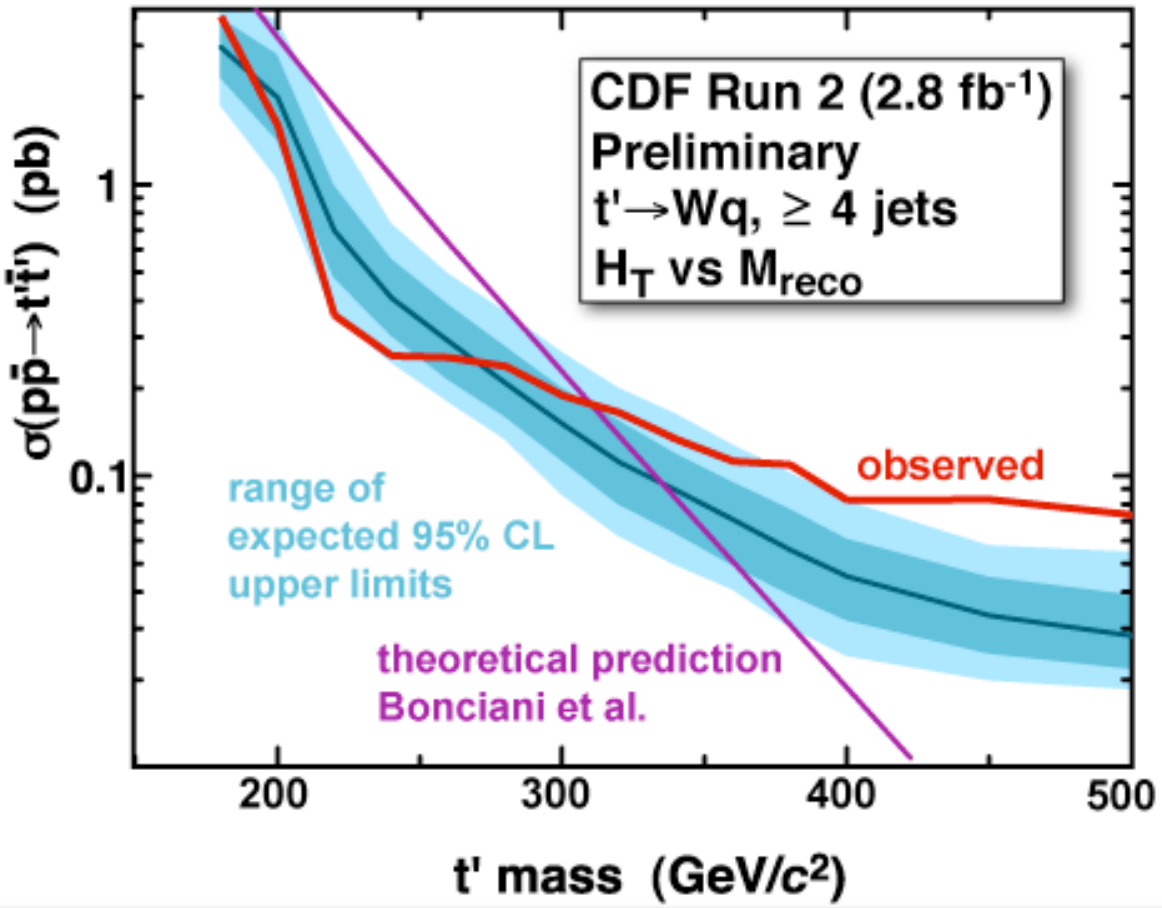


CDF: No evidence for stop
(Limits in M(χ^o) - M(stop) plane)

Massive or 4th Generation Top: t′

- While on the energy frontier, we look for interesting events on the tails of the top quark distributions
- Can a t′ exist? Can it mimic top?
- Generic 4th chiral generation is consistent with EWK data; can accommodate a heavy Higgs (500 GeV) without any other new physics
- Several SUSY models provide for a 4th generation t′ or mimic top-like signatures *(Beautiful Mirrors: Choudhury, Tait, Wagner)*
- Little Higgs models predict a heavy t′ -like particle

Massive or 4th Generation Top: t′

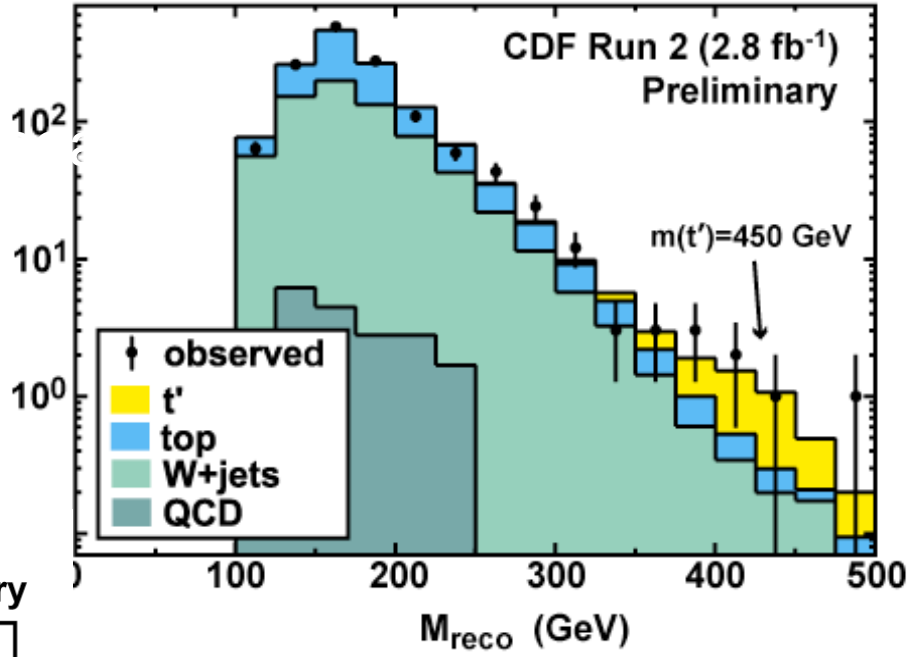


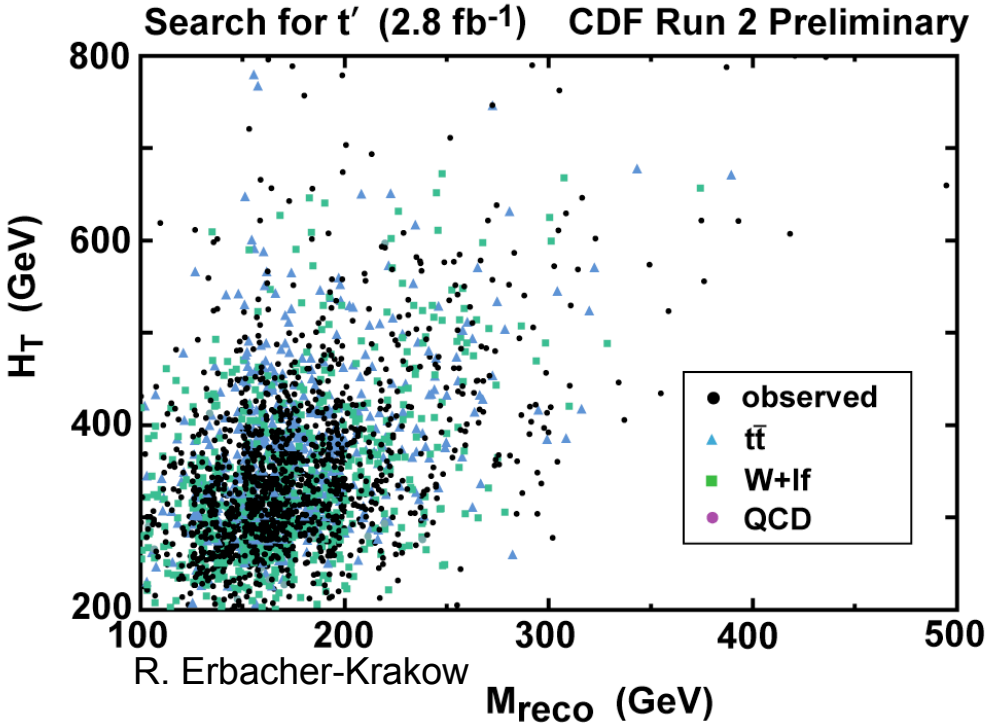
Exclude with 95%CL region of t′ masses below 311 GeV

Update in progress this summer…

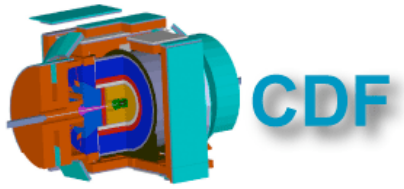
Massive Top

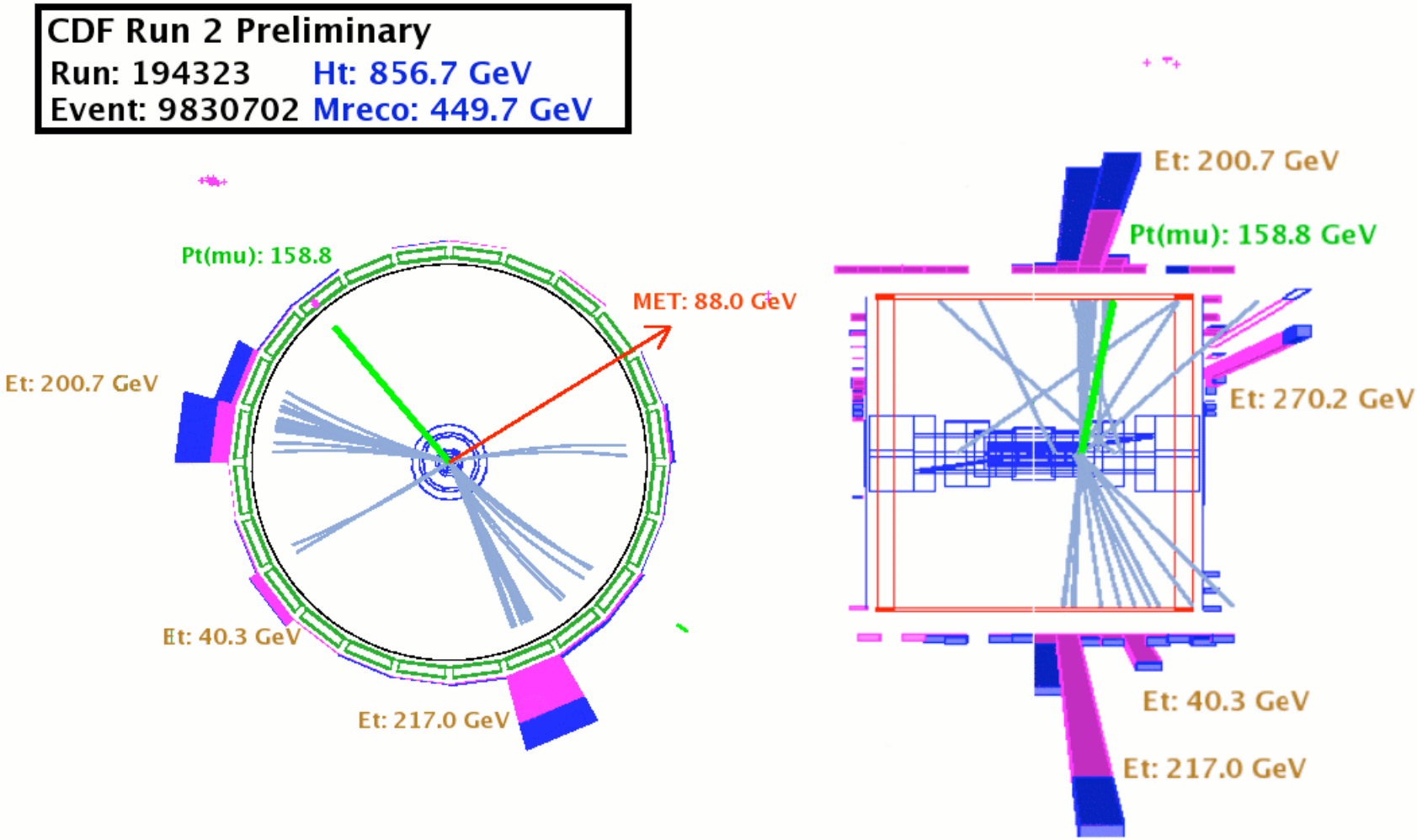
2-d Scatter: Expected (MC) for M(t) = 175 GeV v. data (black), number points for ~2.8 fb^{-1}



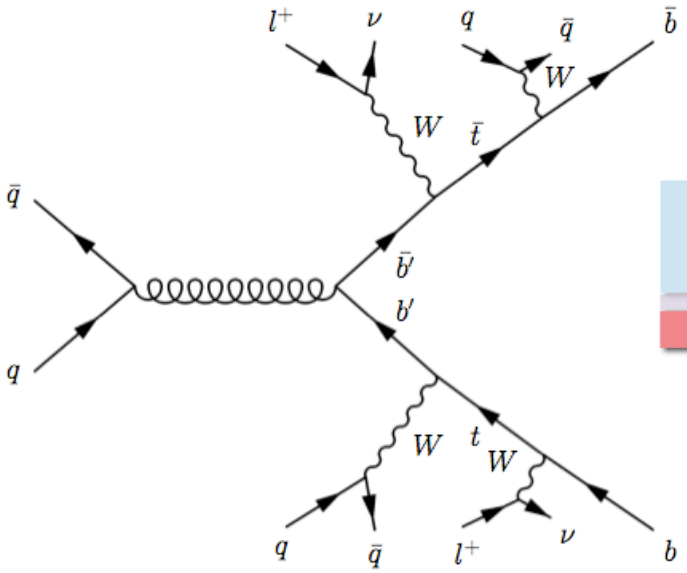


1-d Projection: Fit results for M(t′) = 450 GeV

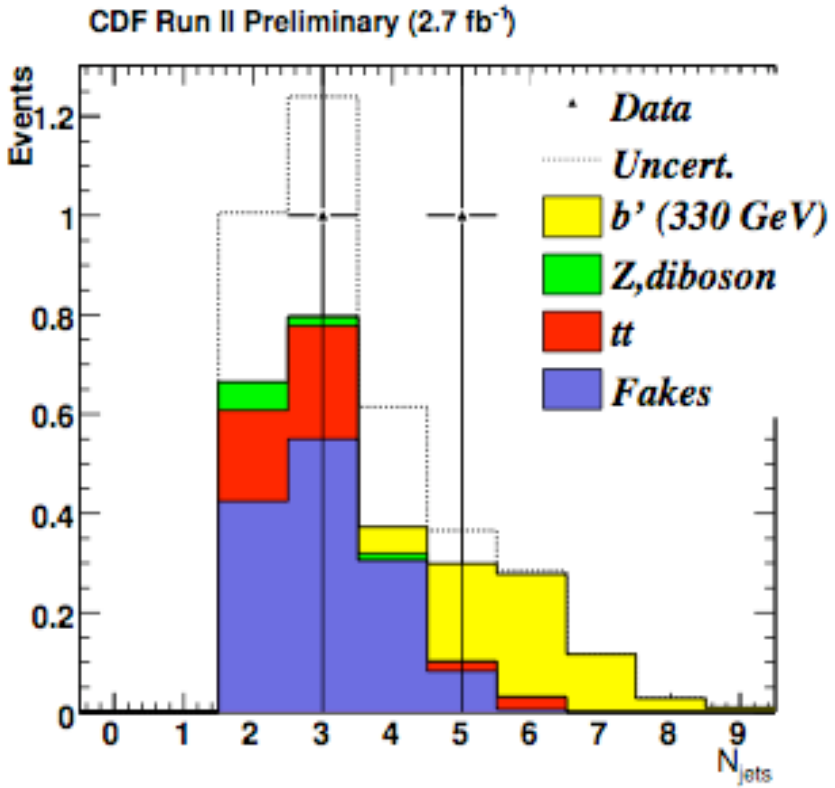




Couple of Strange Ones…



Search for b′ → tW



- Search: 4th generation down-type quark, as well as heavy B,$T_{5/3}$
- Signature: Distinctive same-sign leptons, MET, b-tags, many jets
- Results: Expect 1.9 events, Observe 2 events

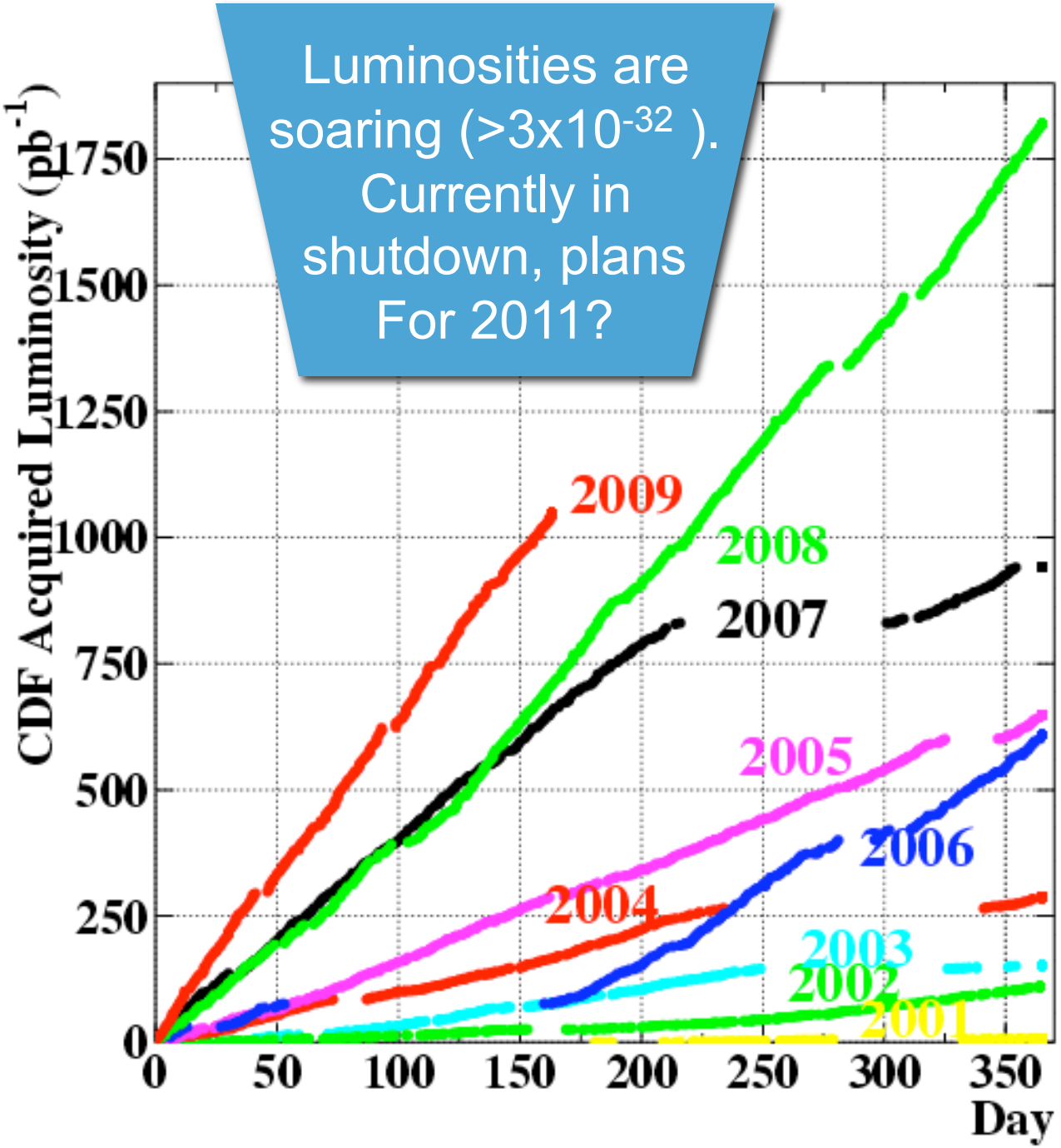
M(b′) > 325 GeV
M(B,$T_{5/3}$) > 351 GeV

Summary

- The top quark is the least known quark, and the most interesting for new physics.

- The top physics program is very active at the Tevatron, with both precision measurements and first properties and search results appearing all the time.

- Beginning to have sensitivity to the unexpected in particle properties and in the data samples!

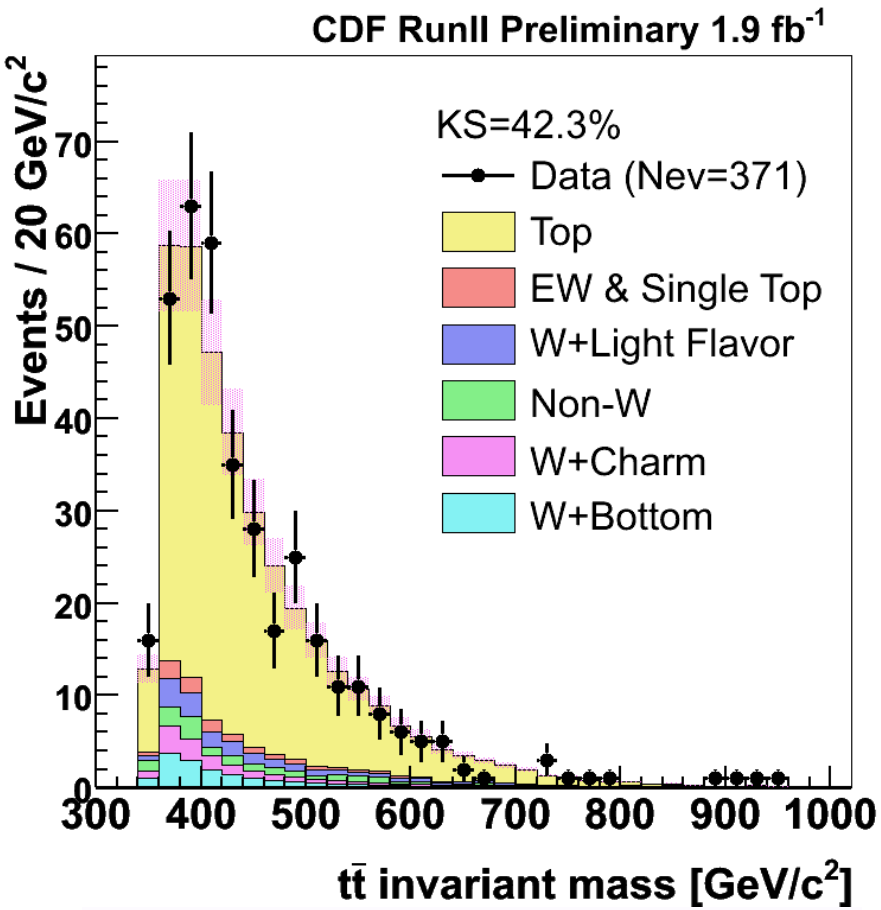


Tevatron luminosity profile

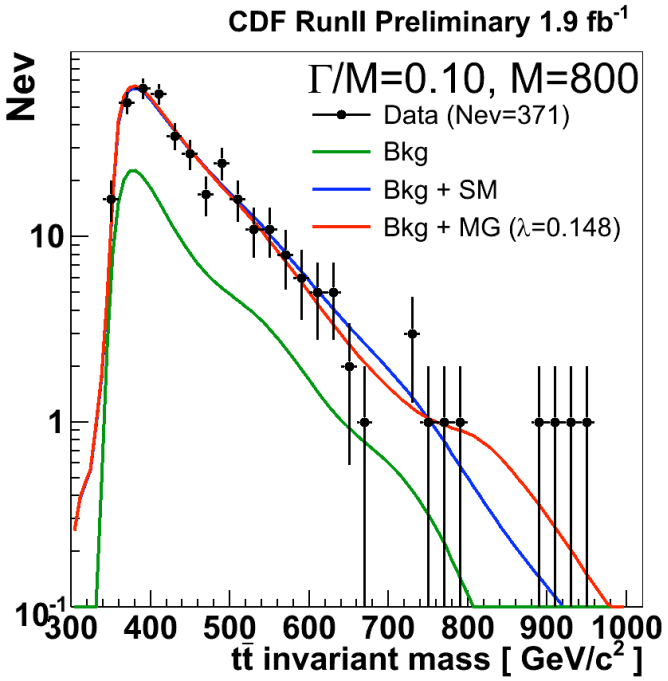
Conclusions

Some Previous CDF Results…

M_{tt} and Massive Gluon



Dynamic Likelihood (ME-style) Reconstruction



New Color Octet Particle G:

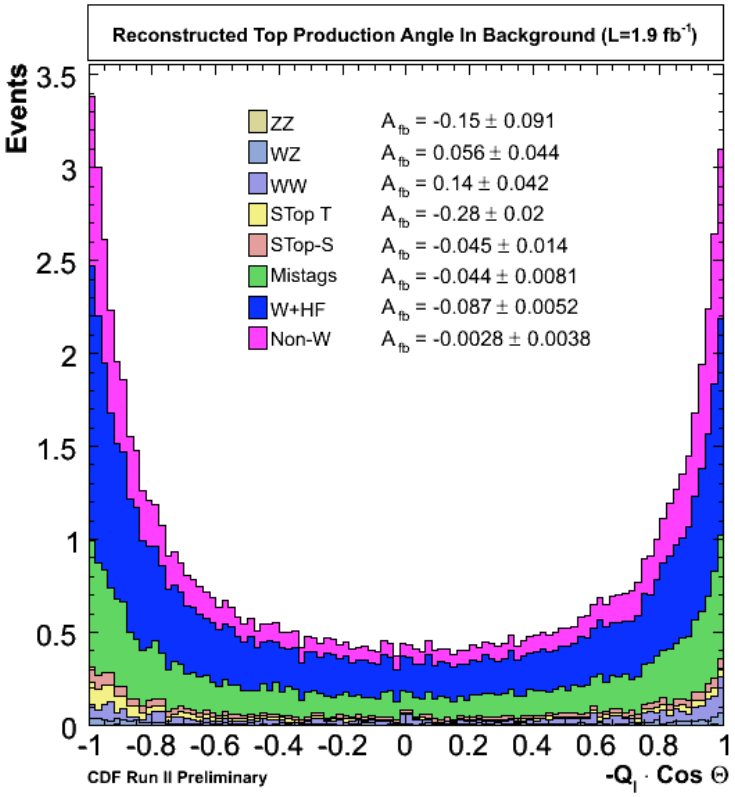
Limits on coupling $\lambda=\lambda_q\lambda_G$:

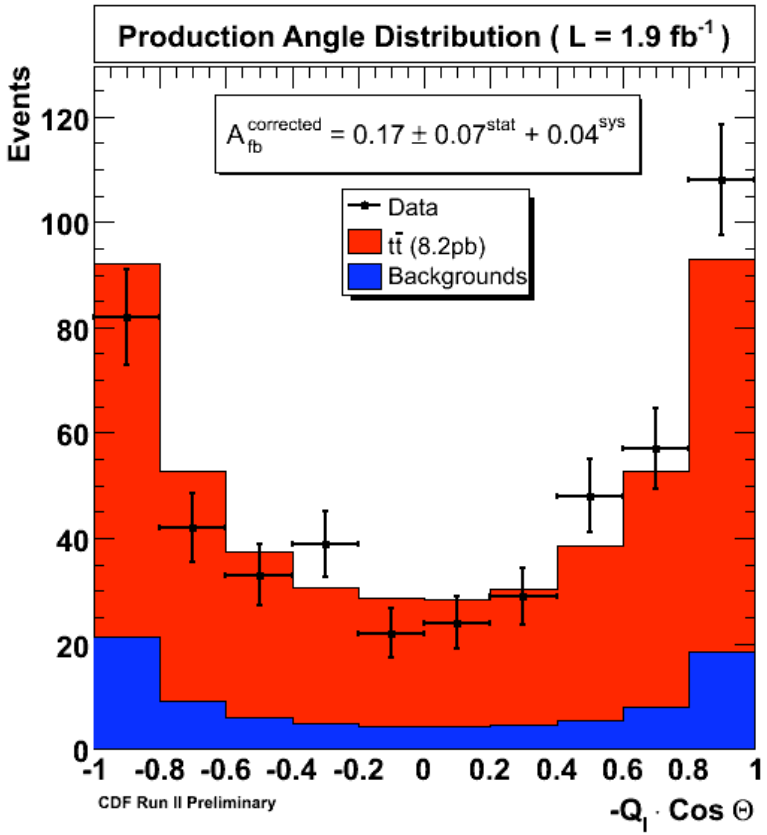
Fitted coupling strength consistent with SM within 1.7σ in the (width/mass) range from 0.05 to 0.5

A_{fb} Result from CDF

*NLO: (4 ±1%) in cosθ**
(lab frame)

Background distributions





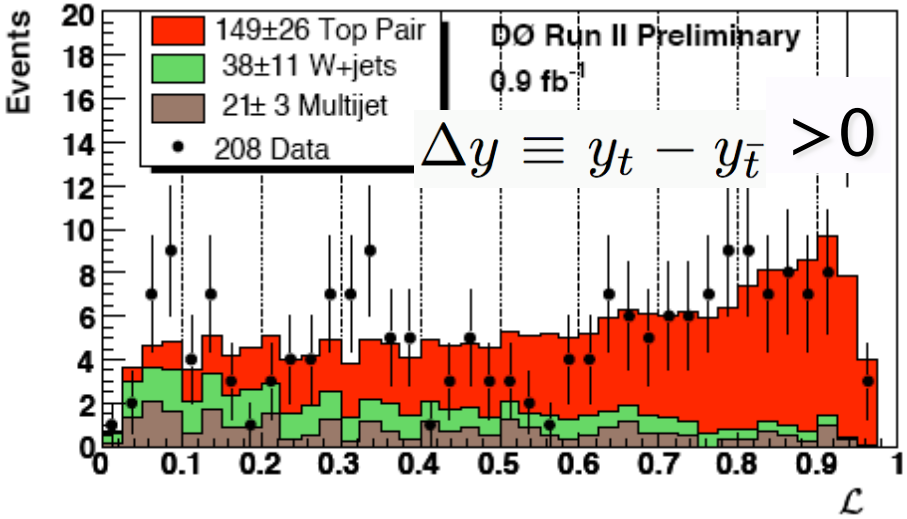
A_{fb}=(17 ± 7(stat) ± 4(syst)) %

(Fully corrected)

R. Erbacher-Krakow

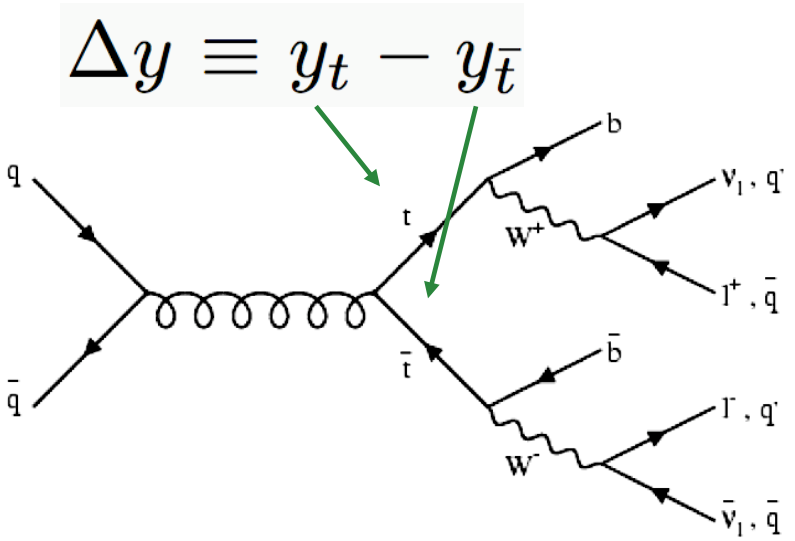
A_{fb} Result from D0

$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$



A_{fb} = 12 ± 8(stat) ± 1(syst) %

(Unfolded for reconstruction)



How would new physics look?

F: fraction of top pair events produced via Z' resonance

For $M_{Z'}$ = 750 GeV:

F < 0.44 (expected)

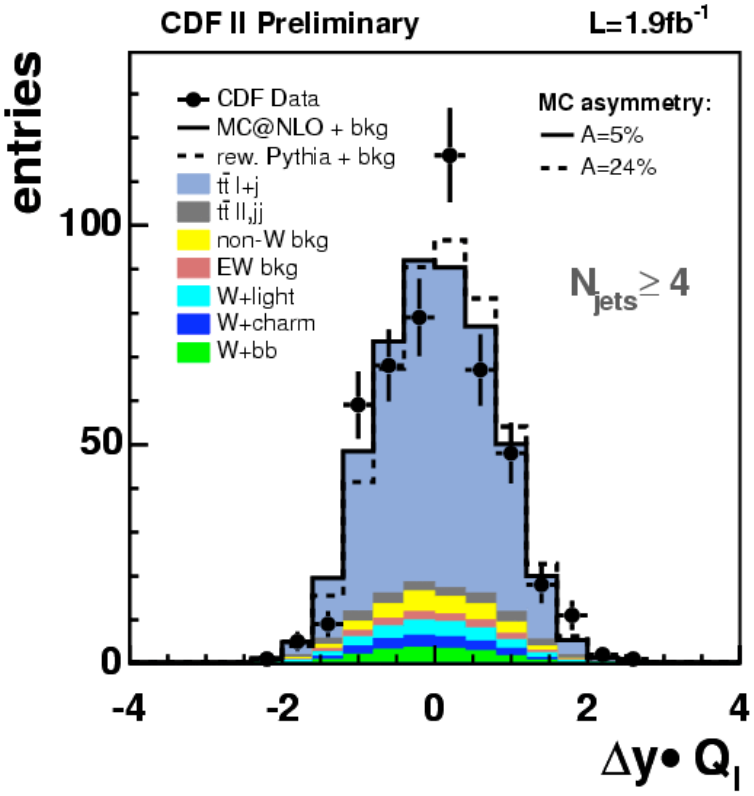
F < 0.81 (observed)

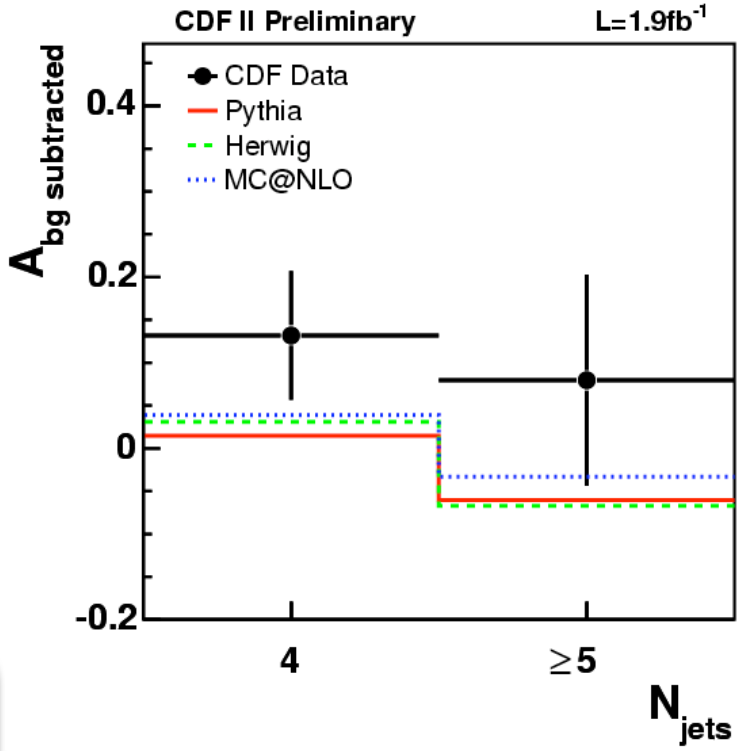
2nd A_{fb} Results from CDF

A(parton rest frame) = 1.3A(lab frame)

Compare with D0 result:

A_{fb}(bkg sub)=(14.4 ± 6.7(stat)) %





A_{fb}=(24 ± 13(stat) ± 4(syst)) %

(Fully corrected)

NLO: (4-7%) in $\Delta y^{*}Q_{l}$