

SEARCH FOR FOURTH GENERATION T' QUARK AT THE TEVATRON

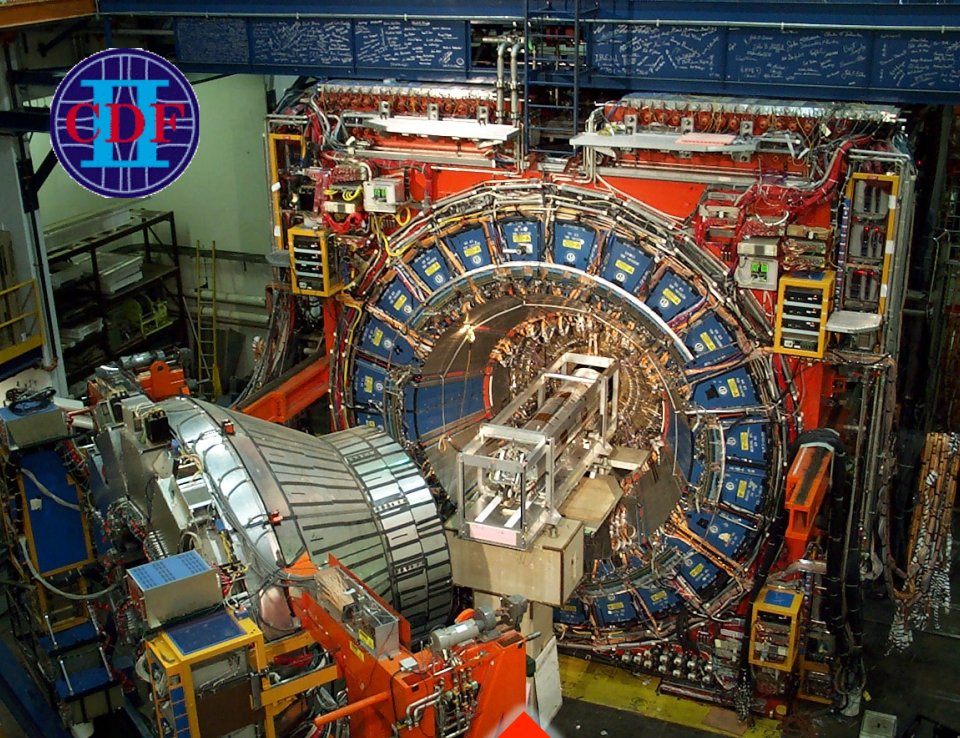


Alison Lister

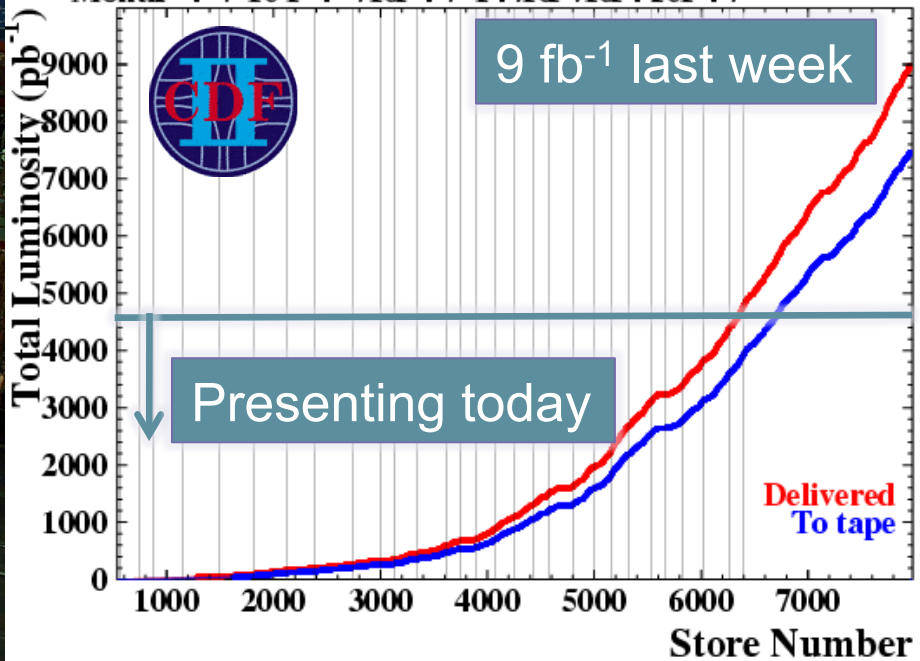
Université de Genève

On behalf of the CDF and D0 Collaborations

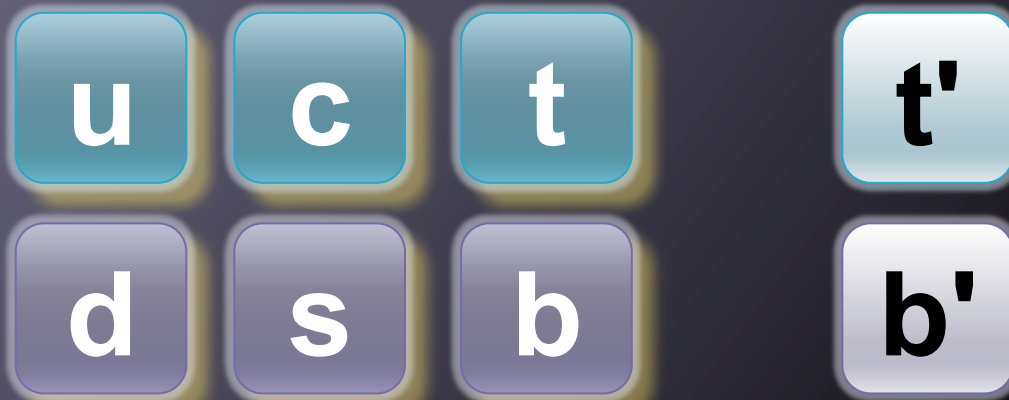




Year 2002 2003 2004 2005 2006 2007 2008 2009
 Month 4 7 10 1 4 7 10 1 4 7 10 1 4 7 10 1 4 7



Another Quark Generation?

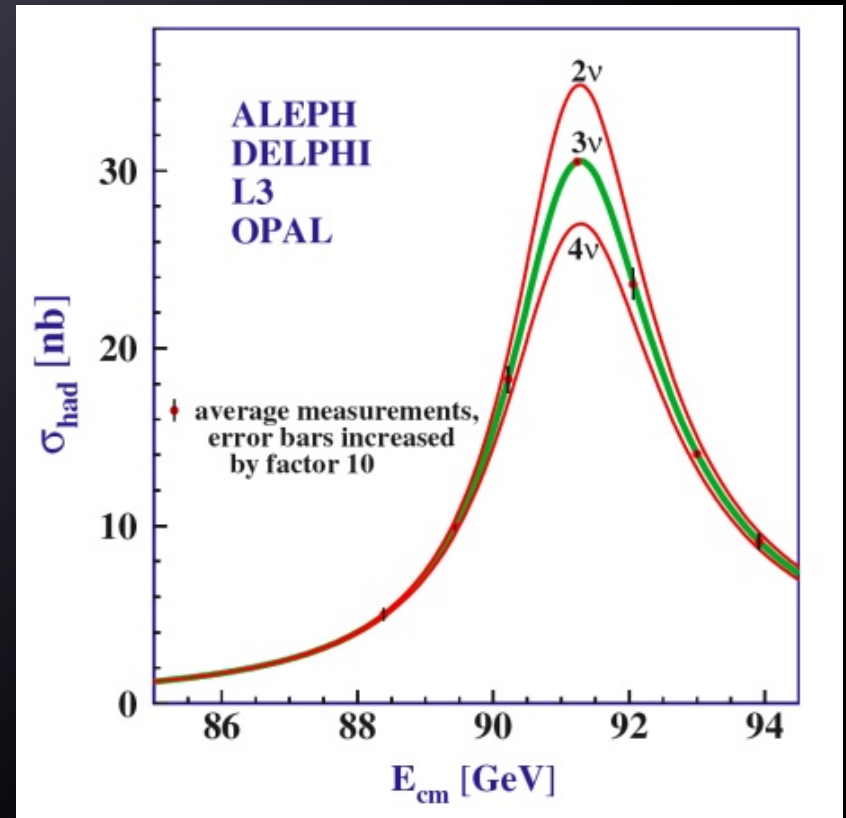


For b' search see
L. Scodellaro
Sat. 15:20 track 10

- ⊙ Not forbidden by EWK precision data
 - Mass order few hundred GeV
 - Small mass splitting preferred: $M(t') - M(b') < M(W)$
- ⊙ Would have big effect on Higgs sector
 - Oblique corrections could drive mass up to ~ 500 GeV
- ⊙ Could be lepton too if $m(\nu_4) > \sim 50$ GeV

Why not 4 generations?

- Z-width measurements from LEP
- Constraint
 - $M(\nu_4) > \frac{1}{2} M(Z)$



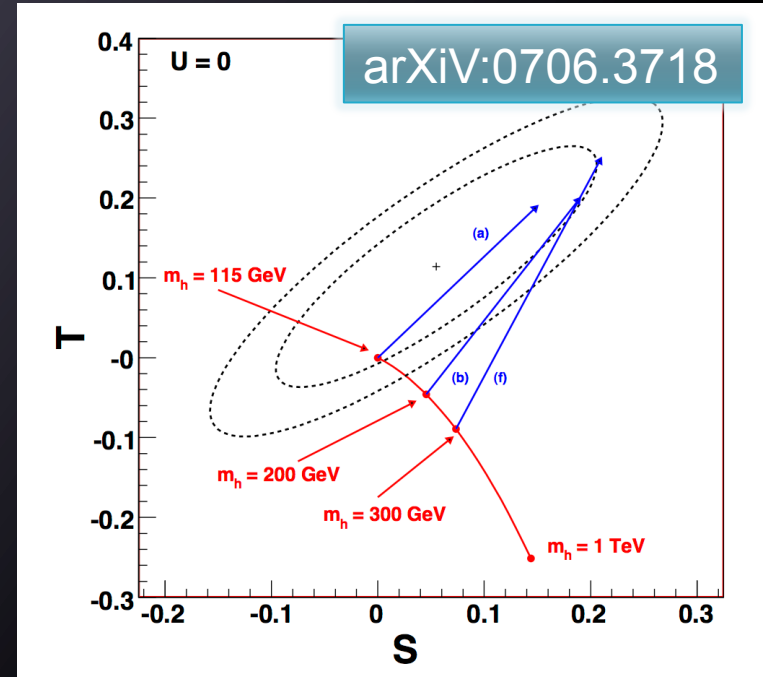
Why not 4 generations?

- Generation Mixing
 - CKM Matrix
- Constraint
 - Flavour physics measurements and unitarity triangle sets limits on 4th generation models
- BUT
 - Mixing between 3rd and 4th generation only weakly constrained

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

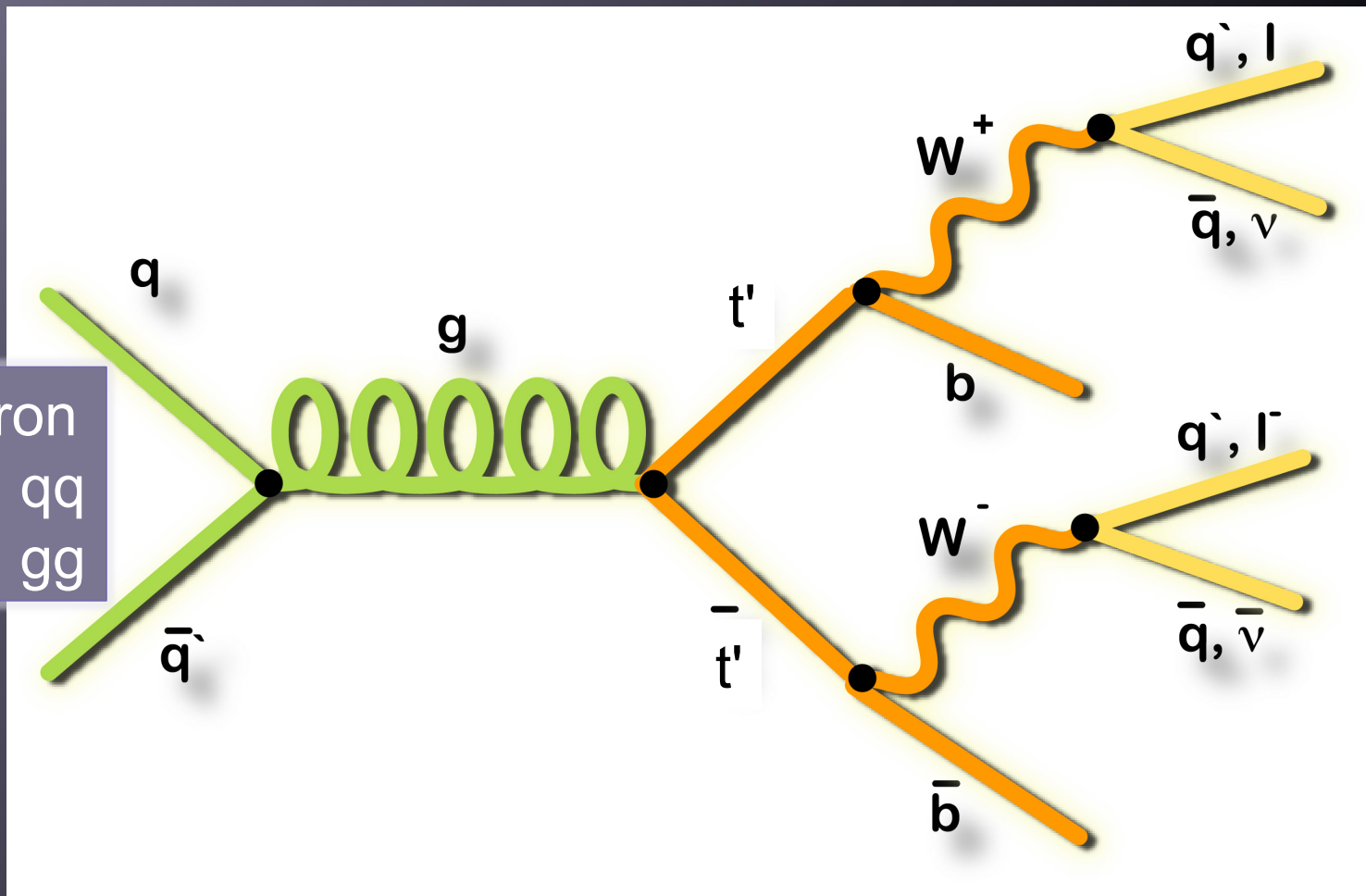
Why not 4 generations?

- ⦿ Electroweak Effects
- ⦿ Constraints
 - S,T fits to SM constrain available phase-space for 4th generation
- ⦿ But
 - Possible with electroweak radiative corrections
 - Could even argue would agree better 😊



parameter set	m_{u_4}	m_{d_4}	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

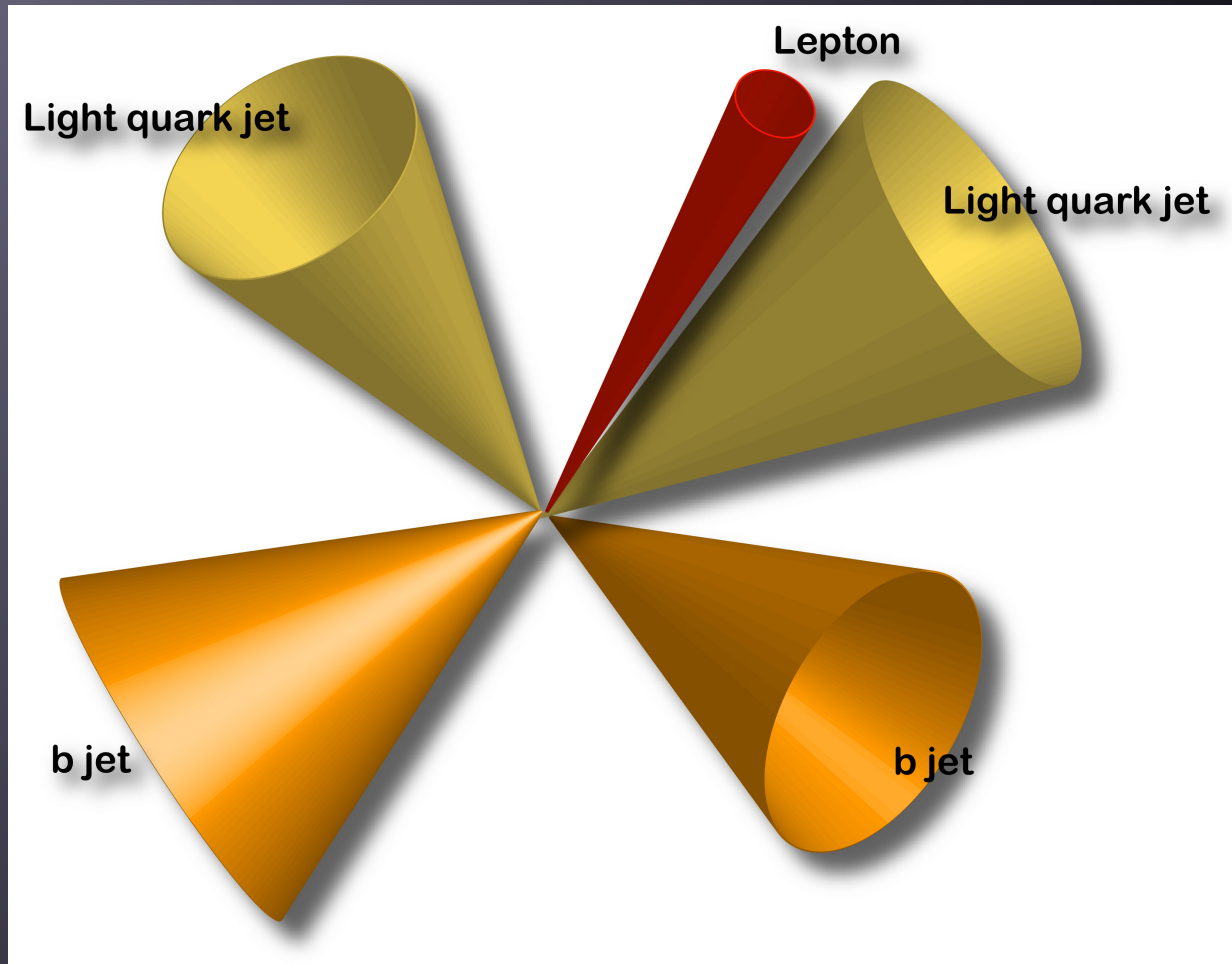
Looks like a Top... but not quite...



Tevatron
~85% $q\bar{q}$
~15% $g\bar{g}$

Also: Generic search for events in this final state in the tails of some distributions....

Our Search: Lepton + Jets + MET



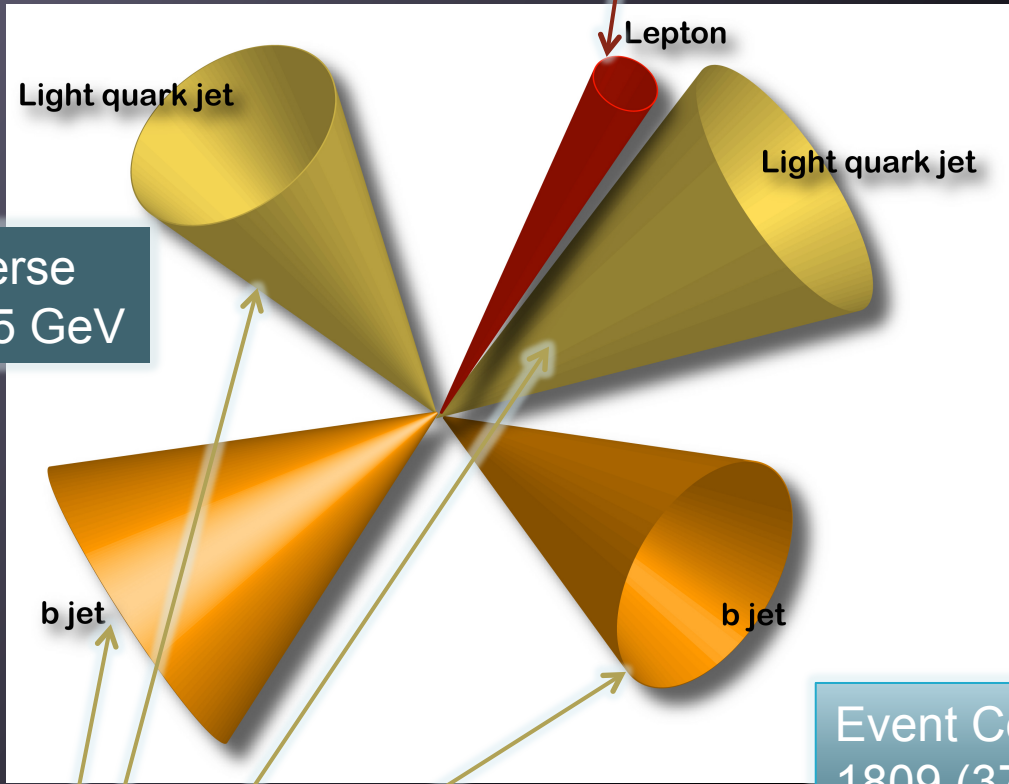
Good compromise between BR and background rates

Event Selection

Trigger on electron or muon
CDF: new: muons from jets+MET trigger
D0: some triggers with ≥ 1 jets too

Number are: D0 (CDF)

1 isolated electron or muon $p_T > 20$ (25) GeV



Missing Transverse Energy $> 20 / 25$ GeV

Mis-measured muon removal

QCD Removal cuts

Event Counts:
1809 (3724) events
1002 (1677) electrons
807 (2047) muons

4 jets (no b-tagging) corrected $E_T > 20$ GeV
D0: leading jet > 40 GeV

Sample Composition

- Signal modelled as $g \rightarrow t't'\bar{b}$
 - 100% BR to Wb
 - Width < detector resolution
- Dominant backgrounds
 - $t\bar{t}$
 - 100% BR to Wb
 - Constrained to NLO cross section
 - W +jets
 - Merged from $W+0\dots 3p$ exclusive + $W+4p$ inclusive
 - QCD (1 jet fakes a lepton)
 - Shapes from jet-triggered data
 - Require limit on fraction of energy in EM calorimeter
 - Normalisation from fit with Missing E_T cut relaxed
 - Other: single top, diboson, Drell-Yan, Z +jets
 - From MC

t' -mass	theory cross section (pb)	t' events
200 GeV	3.189	441.
225 GeV	1.400	218.
250 GeV	0.800	133.
275 GeV	0.430	75.
300 GeV	0.227	44.
325 GeV	0.121	23.5
350 GeV	0.064	12.6
375 GeV	0.034	7.0
400 GeV	0.018	3.7
425 GeV	0.010	2.0
450 GeV	0.005	1.0
475 GeV	0.003	0.5
500 GeV	0.001	0.3



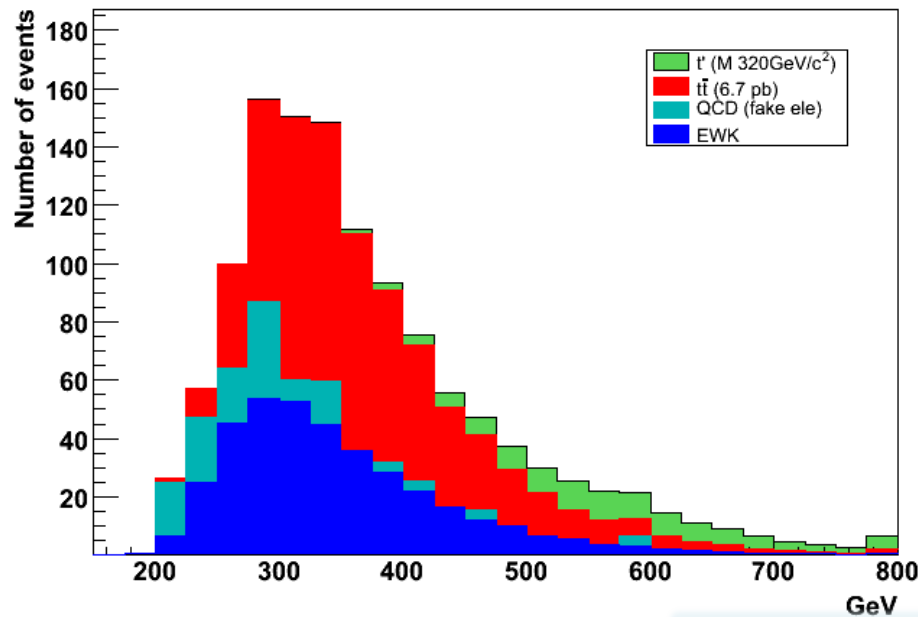
All MC samples are run through CDF detector simulation

Discriminating Variables

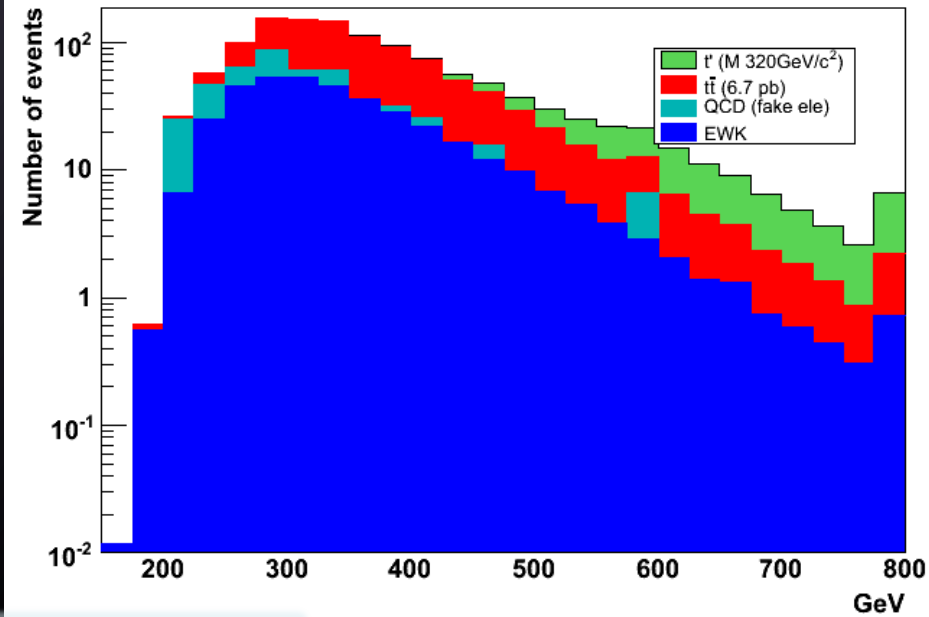
- Total transverse reconstructed energy (H_T)

$$H_T = \sum_{jets} E_{T,jets} + E_{T,lepton} + \cancel{E}_T$$

H_T ($L = 2.3 \text{ fb}^{-1}$)



H_T ($L = 2.3 \text{ fb}^{-1}$)

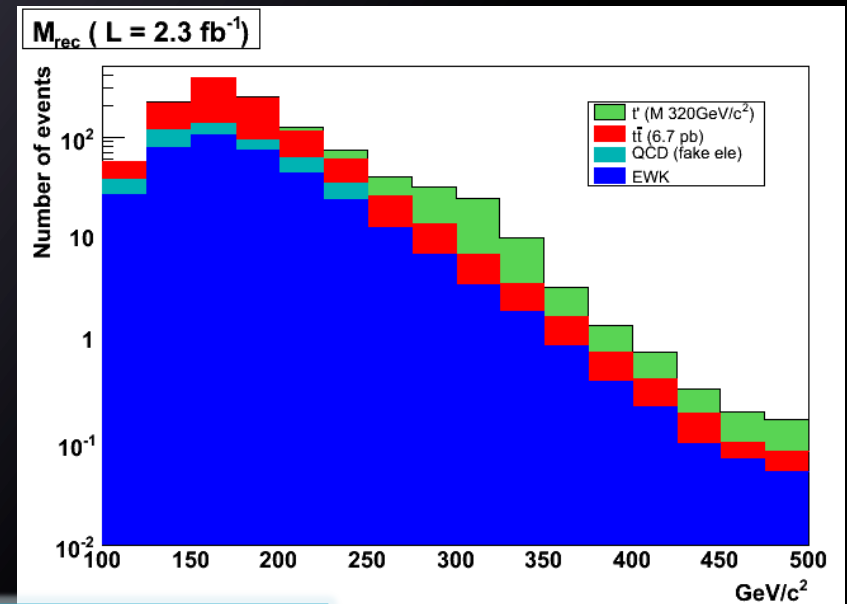
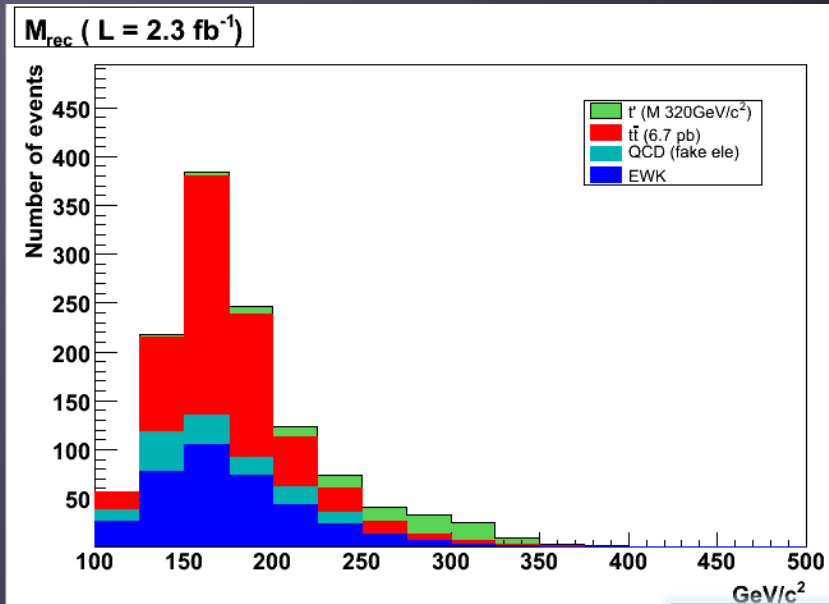


t' normalisation arbitrary

Discriminating Variables

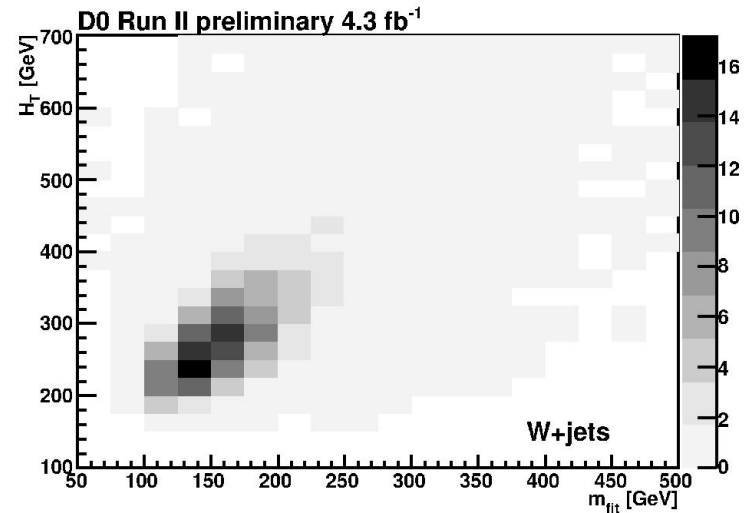
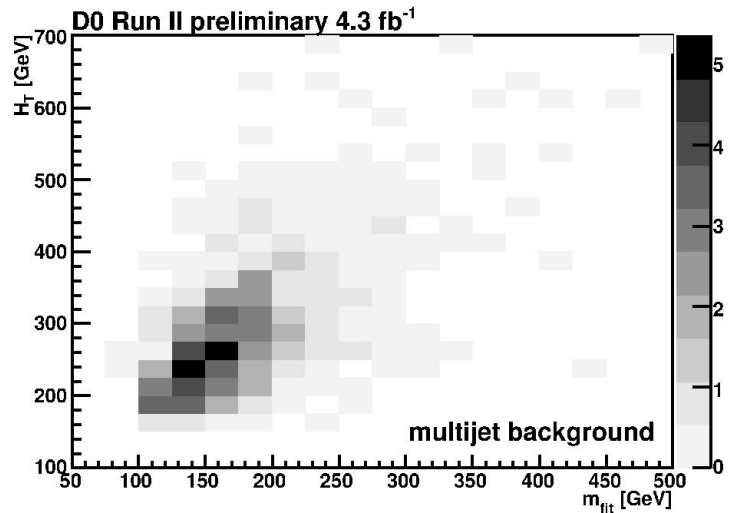
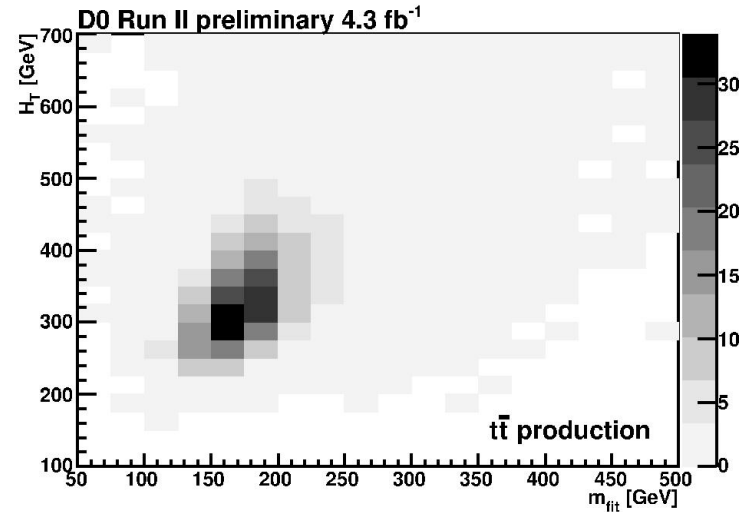
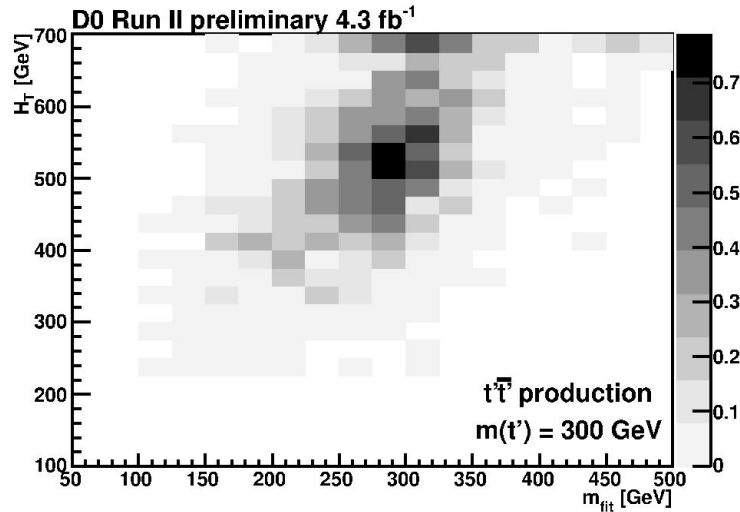
- Reconstructed top mass (M_{reco} CDF, M_{fit} D0)
 - From the combination with the lowest χ^2
 - e.g CDF

$$\chi^2 = \sum_{i=l,4jets} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i} + \sum_{j=x,y} \frac{(p_j^{UE,fit} - p_j^{UE,meas})^2}{\sigma_j} + \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{l\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - Mt)^2}{\Gamma_t^2} + \frac{(M_{bl\nu} - Mt)^2}{\Gamma_t^2}$$



t' normalisation arbitrary

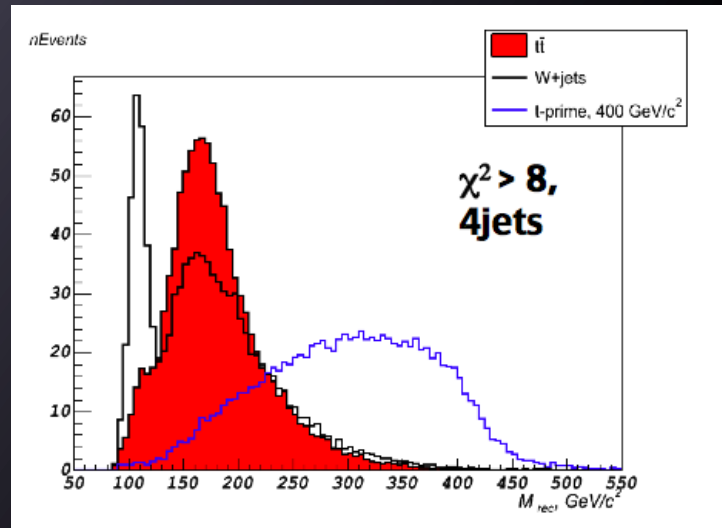
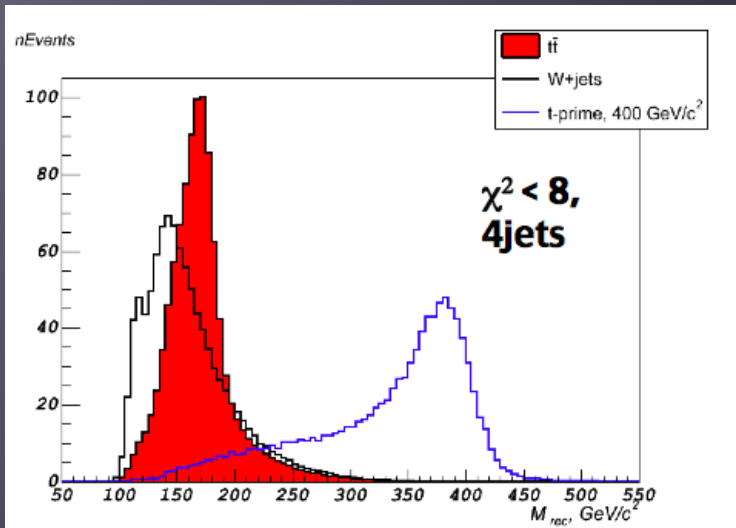
Discriminating Variables





The Fit

- ‘3D’ fit: H_T vs M_{reco} vs N_{jet} / good-bad χ^2
 - New: separate into 4 and ≥ 5 jets and into $\chi^2 < 8$ and $\chi^2 > 8$



- Binned Poisson Likelihood approach
 - Systematics represented as nuisance parameters
 - Remove by profiling
 - Obtain posterior in signal cross section
 - Using Bayes Theorem and uniform prior



The Fit

- ⊙ 2D fit: H_T vs M_{fit}
- ⊙ Fit for background only
 - 3 parameter fit: $t\bar{t}$, QCD and W-like (mostly W +jets)
- ⊙ Fit for background + signal
 - 4 parameter fit: also $t't'\bar{t}$ (free)
- ⊙ Likelihood ratio as test statistic
- ⊙ Set limits using CL_S method
 - $1 - CL_{S+B} / CL_B = 0.95 \rightarrow 95\% \text{ CL exclusion}$

$$L = -2 \log\left(\frac{P_{S+B}}{P_B}\right)$$

Systematics

◎ CDF

- Three types
 - All Gaussian-constrained
- Normalization uncertainties
 - Integrated luminosity, ID scale factors, background cross sections
- Shape (+normalization) uncertainties
 - jet energy scale, Q^2 scale, ISR/FSR
- MC statistics
 - Handled using “Barlow-Beeston lite” method
 - Bins combined automatically to ensure accuracy

◎ D0

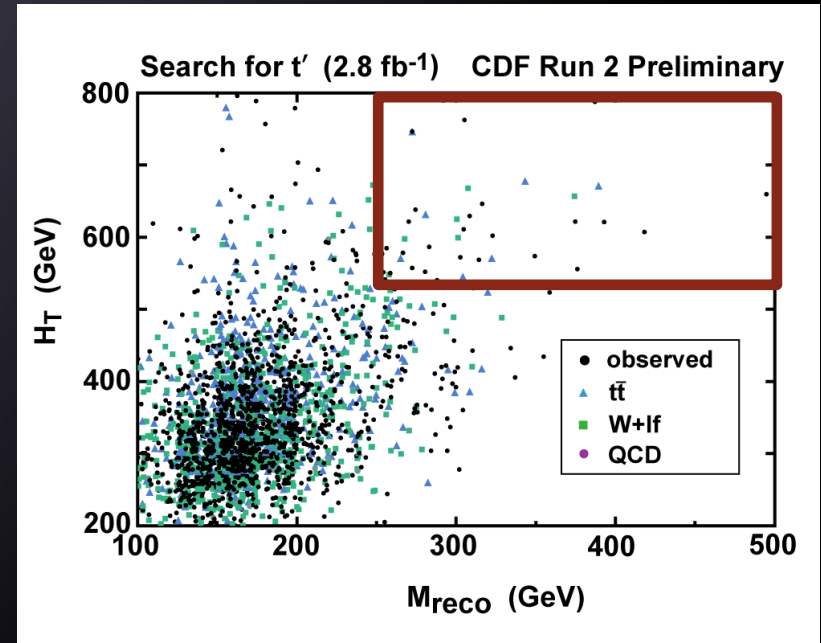
- Profiling all systematics
 - Same code as used for Higgs exclusion



Model Independent Limits (2.8 fb^{-1})

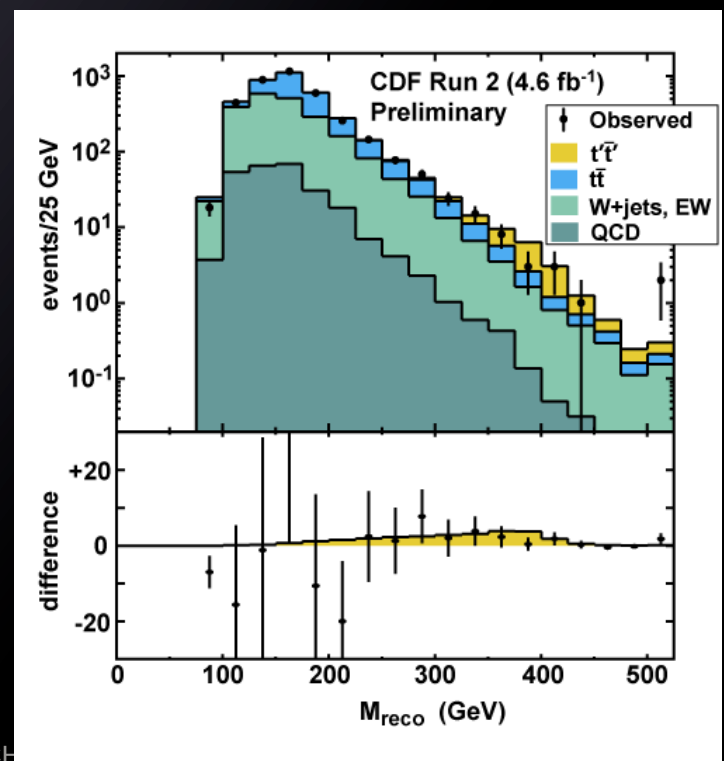
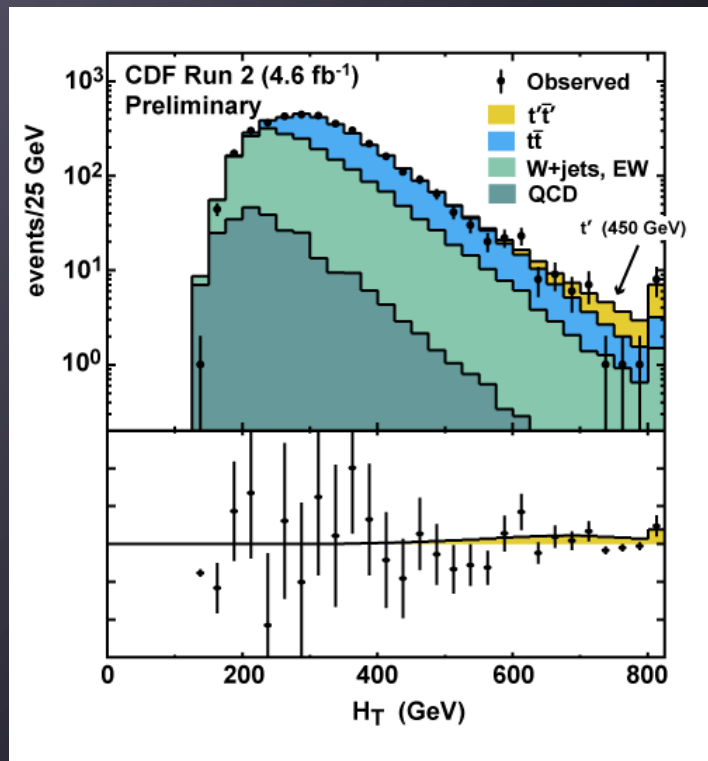
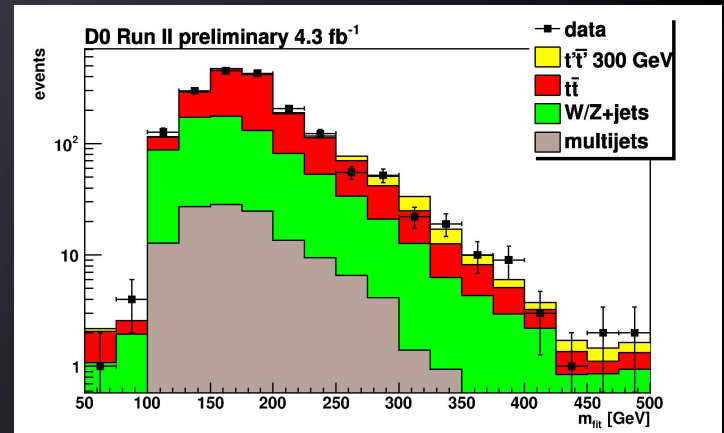
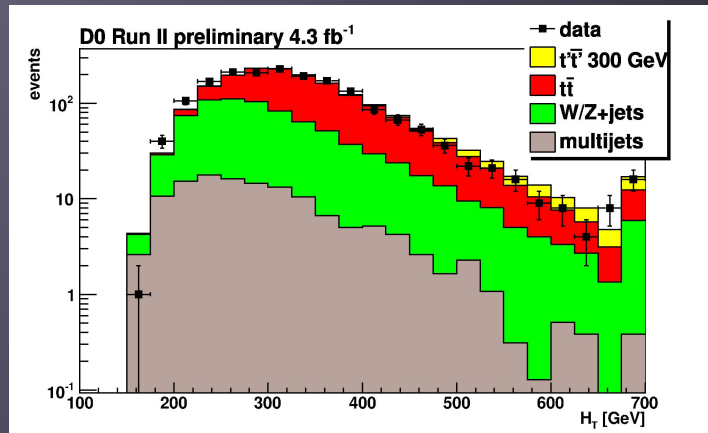
No signal model other than
“something that is in the high M_{reco} , high H_T region”

- Starting from highest H_T and M_{reco} bin
 - Get p-value of that bin
 - Extend by 1 bin in each dimension and repeat fit
- Largest excess
 - $M_{\text{reco}} > 250 \text{ MeV}/c^2$, $H_T > 550 \text{ MeV}$
 - 29 events, 18.03 expected
 - p-value 0.01
- Global p-value takes into account trials factor
 - Excess ~ 2 sigma



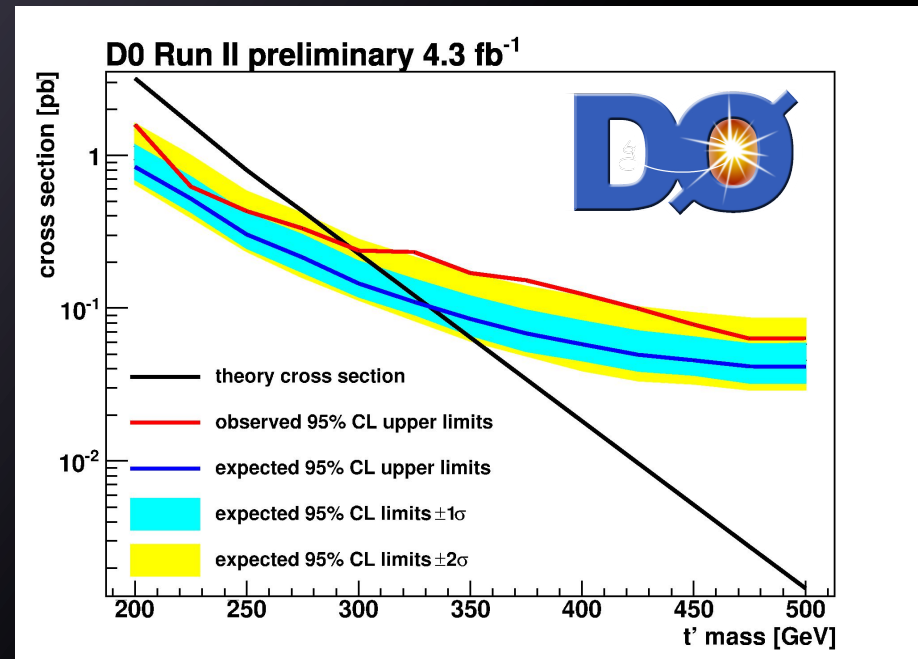
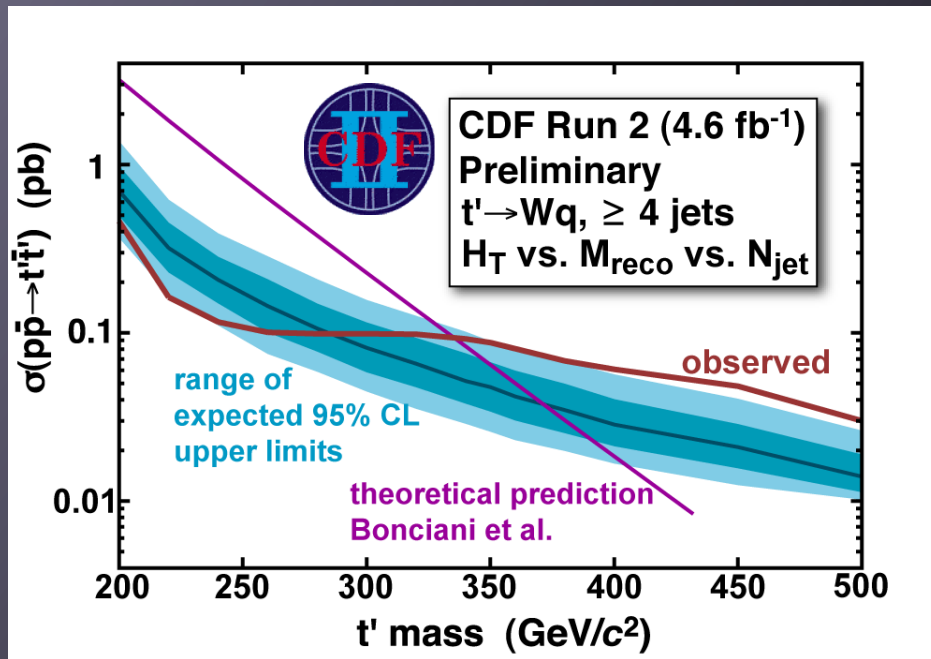
P-value:
Probability that the number of observed events in that range is compatible with the background only hypothesis

The Variables in Data



Limits

- Assume $BR(t' \rightarrow Wb) \approx 100\%$
- Assume strong SM production ($g \rightarrow t't'\text{bar}$)



Exclude $M(t') < 335$ (296) GeV @ 95% CL at CDF (D0)

Conclusions

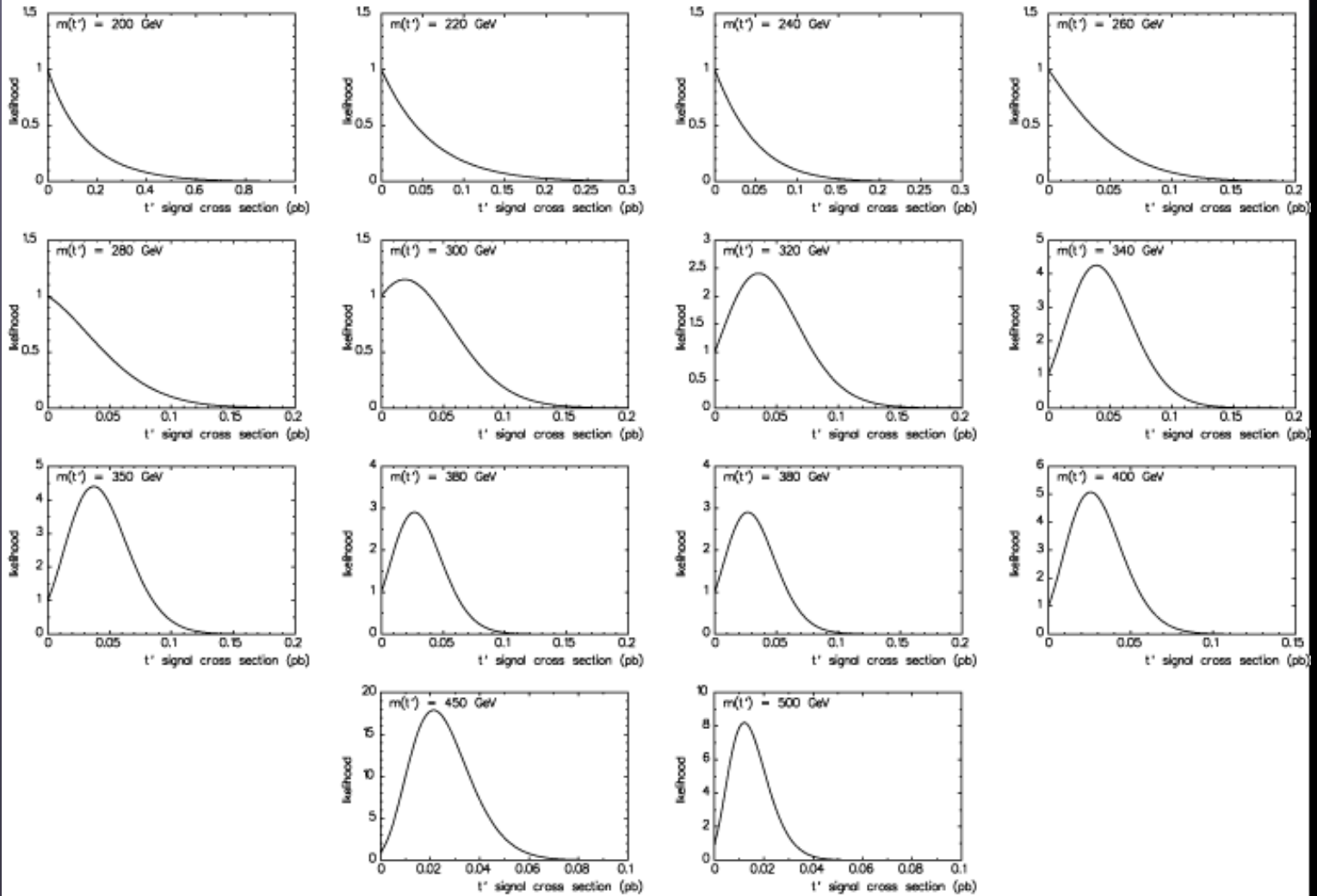
- Search for 4th generation top-like quark
- No significant excess seen in high H_T , high M_{reco}
 - Largest excess order 2 sigma
 - Seen by both experiments
 - Not going away and not getting larger... most frustrating ☺
- Exclude 4th generation t' with 100% BR to Wq up to $M(t') < 335$ (296) GeV @ 95% CL at CDF (D0)

BACKUP

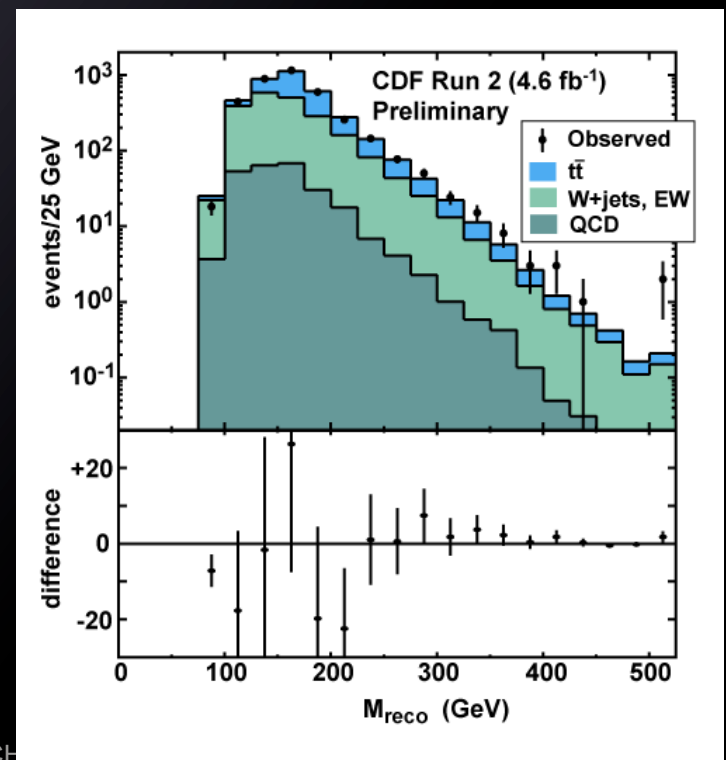
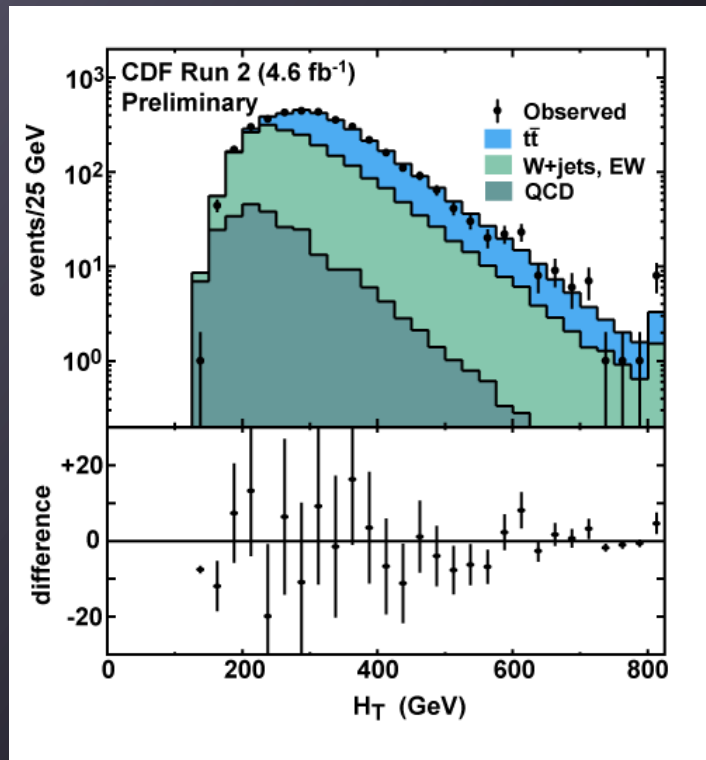
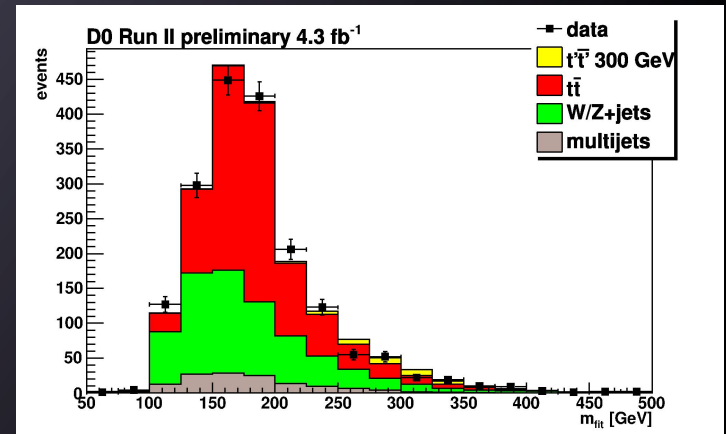
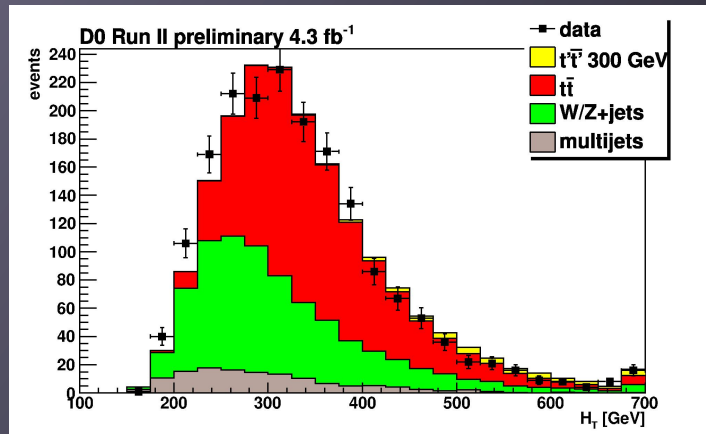


Likelihood Functions

CDF Run 2 (4.6 fb⁻¹) - t' Search Likelihoods - Preliminary

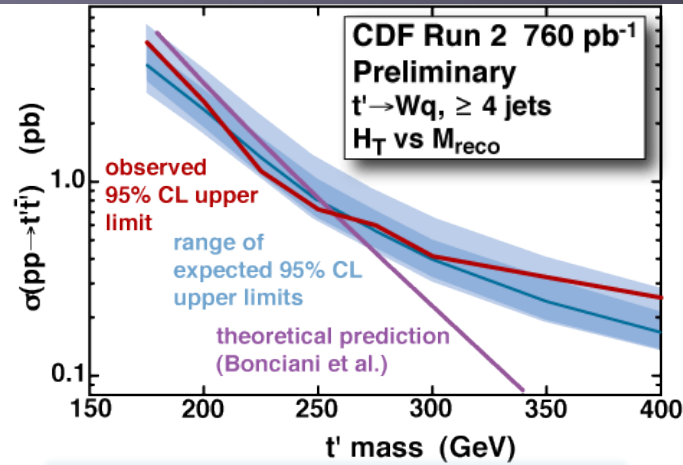


The Variables in Data

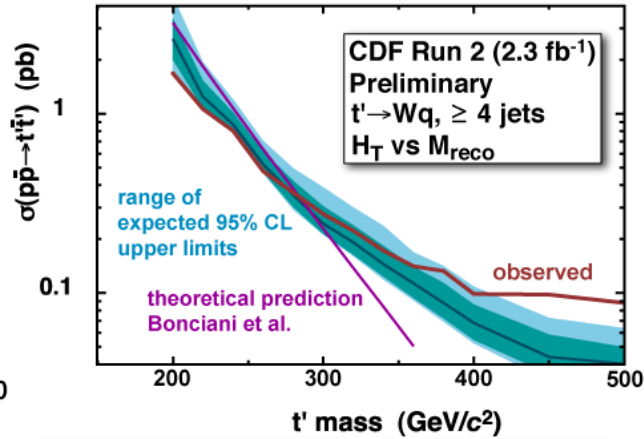




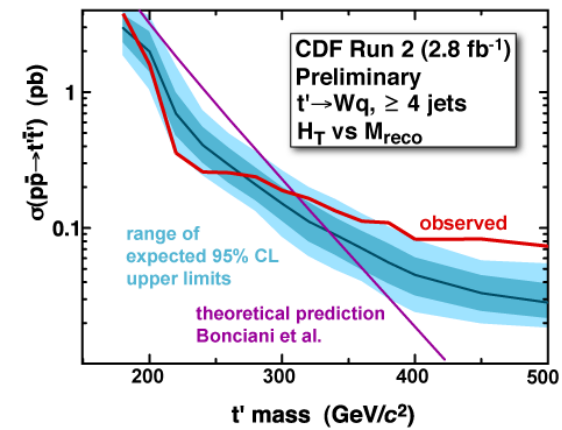
Previous Results



Limit: $M(t') > 256 \text{ GeV}/c^2$



Limit: $M(t') > 284 \text{ GeV}/c^2$



Limit: $M(t') > 311 \text{ GeV}/c^2$

1118 events
Better QCD model
Better QCD removal cuts
New W+jets modelling