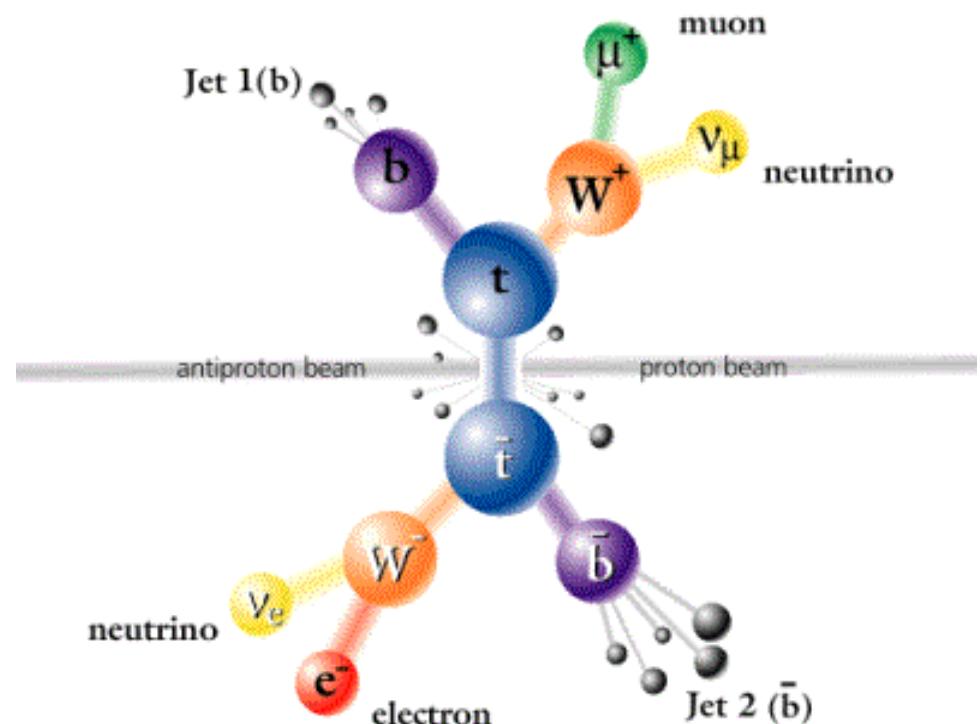


Top Quark Properties at the Tevatron



Markus Klute

Massachusetts Institute of Technology

For the CDF and D0 Collaborations

Rencontres de Moriond EWK 2006

Top Quark Physics

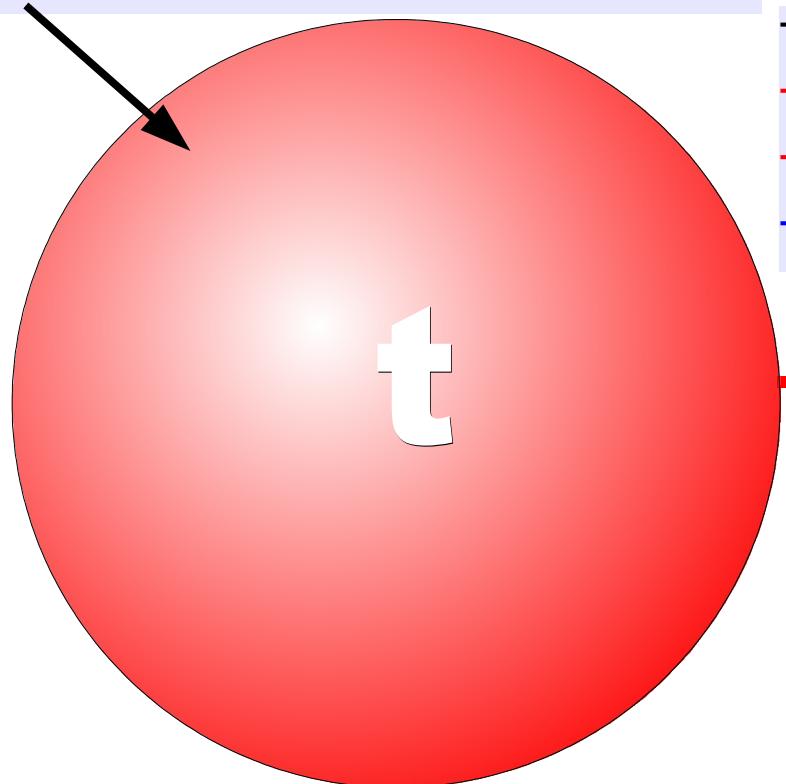
Production Cross-Section

Production Kinematics

Spin Polarization

Production via interm. Resonances

t' Production



Top Mass
Top Charge
Top Lifetime
Top Spin

W Helicity

Tevatron Run I: top quark discovery

Tevatron Run II: high precision tests ...

Why is top so heavy ?

Is top/third generation special ?

Is top involved in EWSB ?

Is top connected to new physics ?



Anomalous Couplings

CP Violation

Rare / non-SM Decays

Branching Fractions

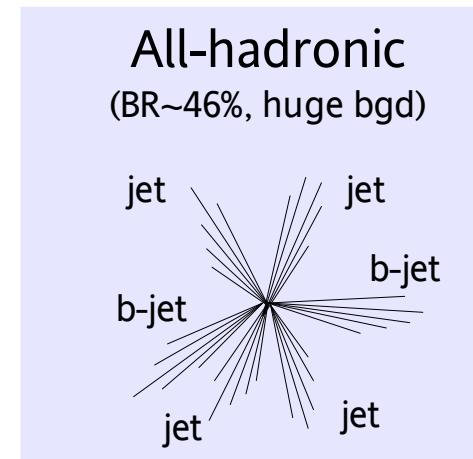
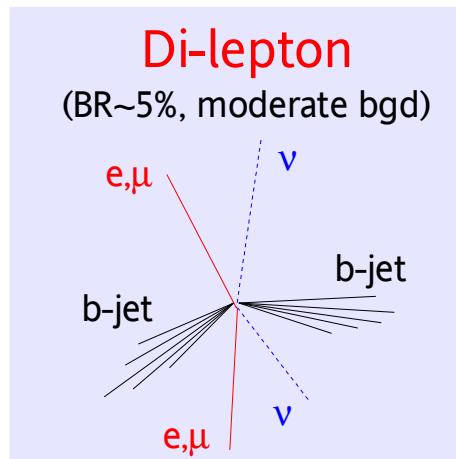
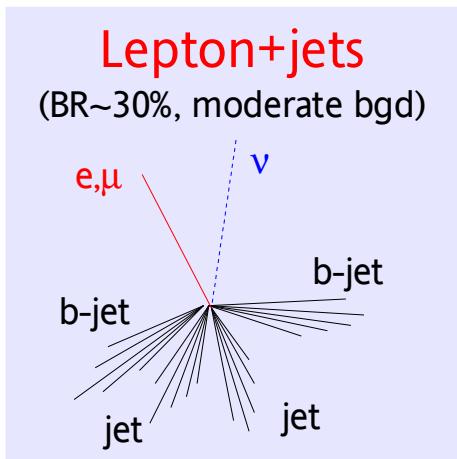
CKM matrix element $|V_{tb}|$



Very rich Top Physics program at the Tevatron.

Top Quark Sample

- all top measurements (so far) are based on **pair-produced** top quarks.
- all top property measurements are **limited by statistics**.
- all top property measurements are based on final states with at **least one lepton**.
- typical final state signatures in top pair production:



- analysed sample sizes vary from **150-700pb⁻¹**.
- number of candidate events used for top property measurements presented here vary from 17 (lepton+jets with 2 b-tags) to several hundred candidate events (lepton+jets with 0 b-tag).

Outline

- The Tevatron
- CDF and D0 Detectors
- Top Mass Measurements
- Top Production at the Tevatron
- Single Top Searches



Covered in previous talks:

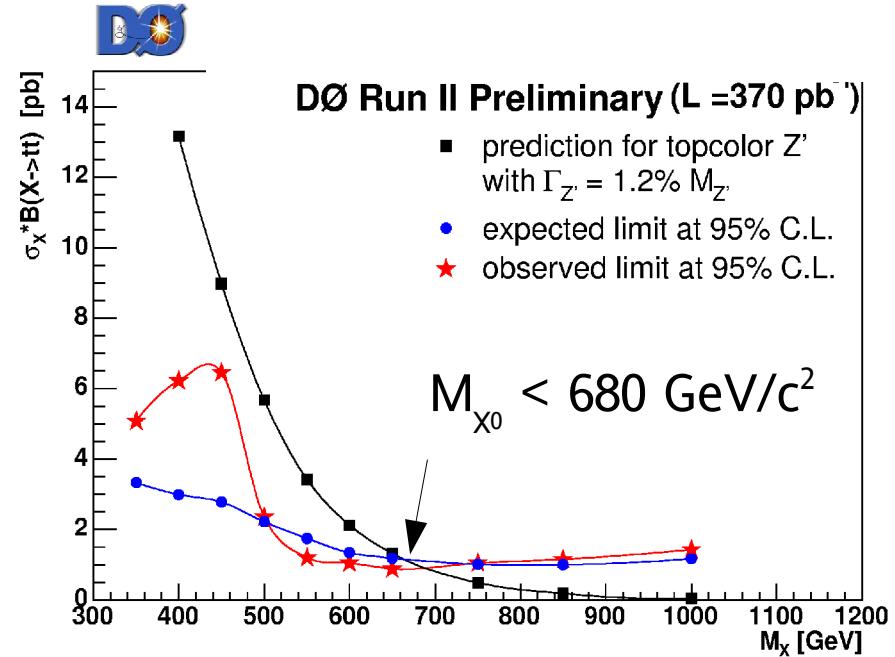
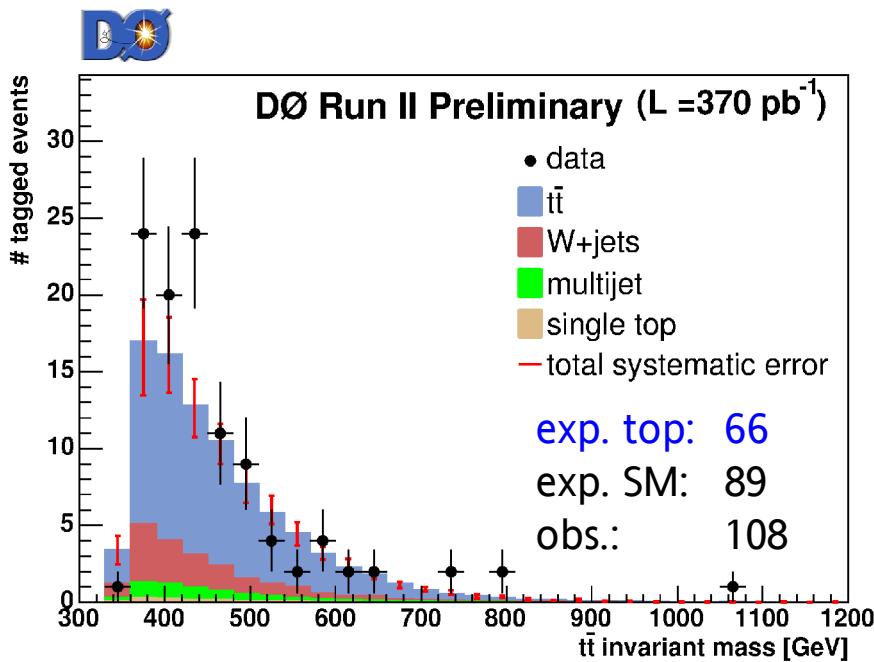
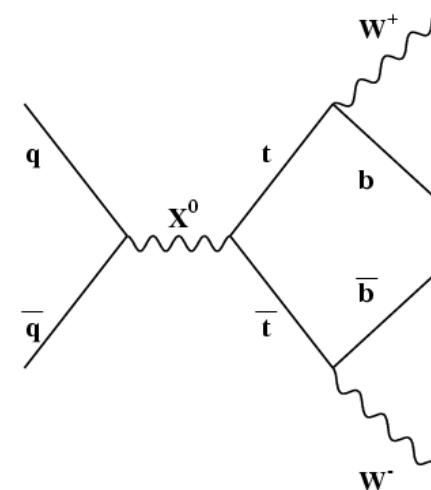
Top Mass from CDF: [E. Brubaker](#)
Top Mass from D0 and CDF and D0
Xsec and Single Top: [M. Kopal](#)

- Anomalous Top Pair Production
 - * via intermediate Resonances
 - * by a long-lived Particle
 - * 4th Generation Quarks
- Top Charge
- W-helicity in Top Quark Decays
- Other Top Properties Measurements
- Summary

Search for Top Production via intermediate Resonances (I)

Does something new produce top pairs (at D0) ?

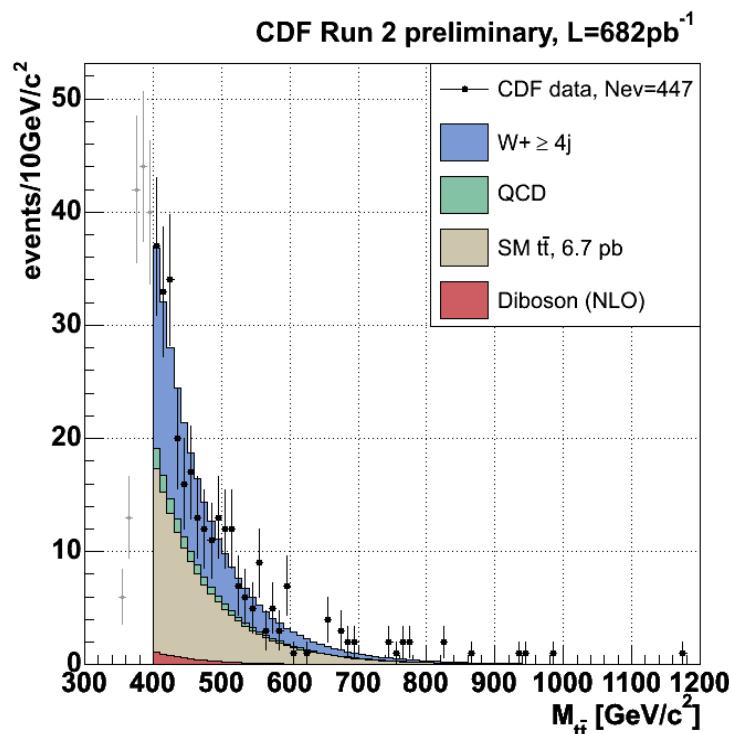
- lepton+ ≥ 4 jets with ≥ 1 b-tag in 370pb^{-1} .
- kinematic fit to ttbar hypothesis.
- fix SM ttbar production to expected rate (6.7pb).
- no significant excess observed.
- derive limit on $\sigma_x \times \text{BR}(X \rightarrow t\bar{t})$.
- interpret in terms of mass limit in possible model,
e.g. topcolor assisted technicolor Z' (hep-ph/9911288)



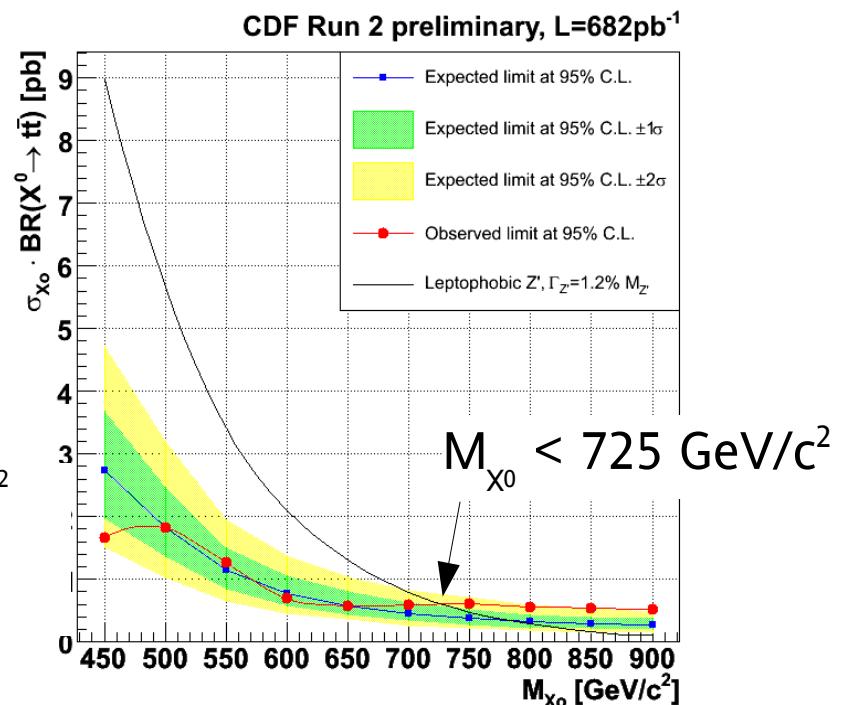
Search for Top Production via intermediate Resonances (II)

Does something new produce top pairs (at CDF) ?

- lepton+ ≥ 4 jets (no b-tagging) in 680pb^{-1} .
- use matrix element technique to increase sensitivity.
- fix SM ttbar, diboson, QCD to expected rates.
- assume everything else is W+jets.
- no significant excess observed.



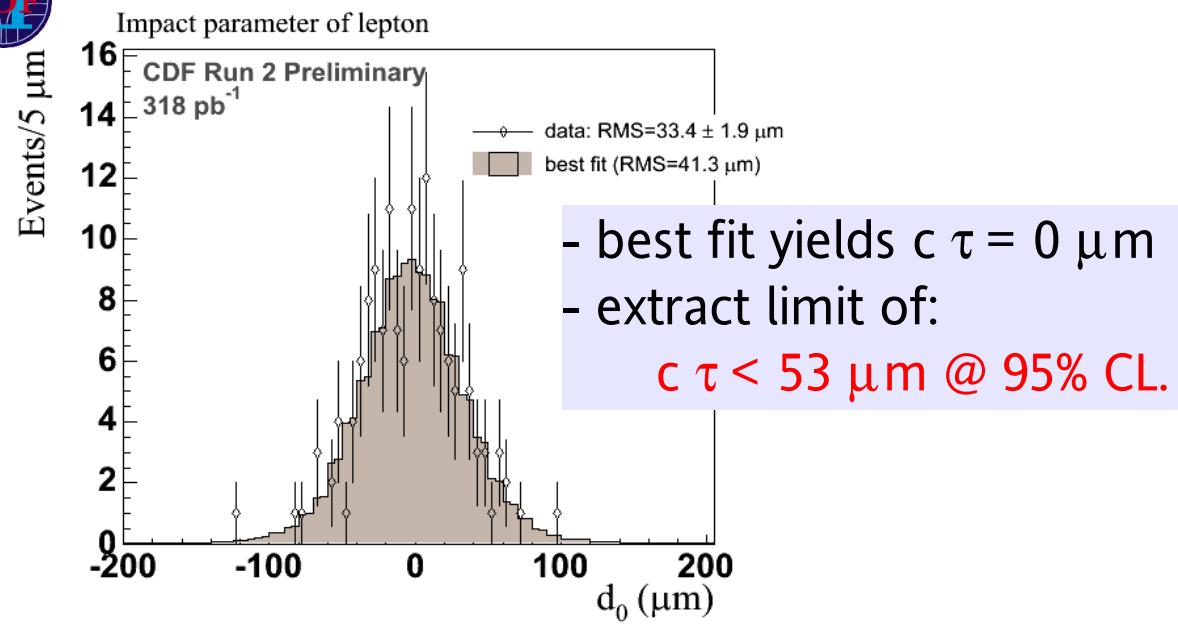
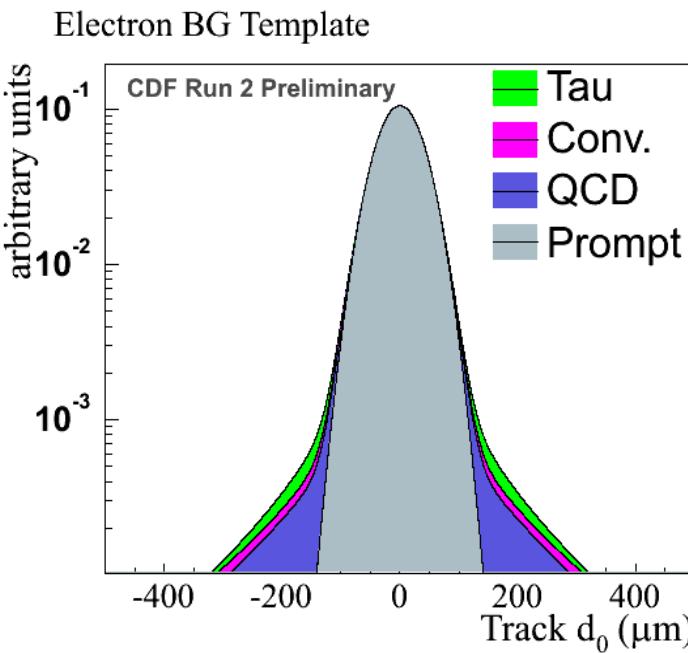
$M_{X_0} > 400 \text{ GeV}/c^2$
exp. top: 141
obs.: 302



Top Quark Lifetime

Does something new decay into top quarks ? A long-lived particle ?

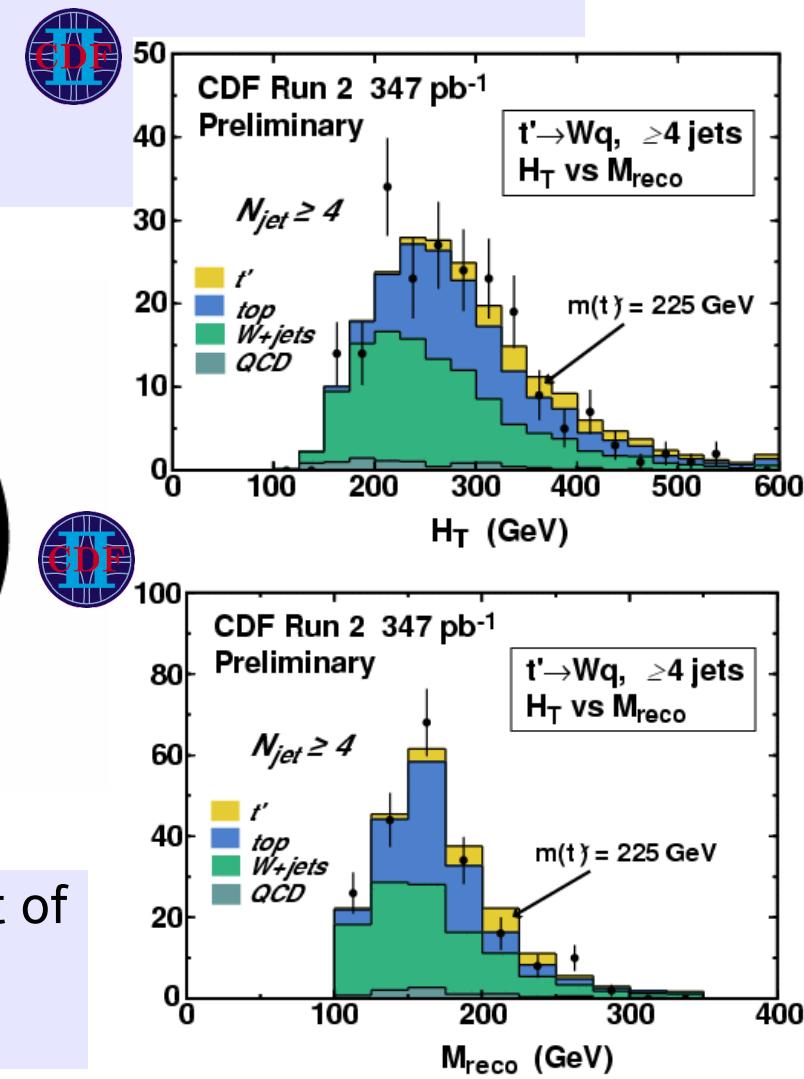
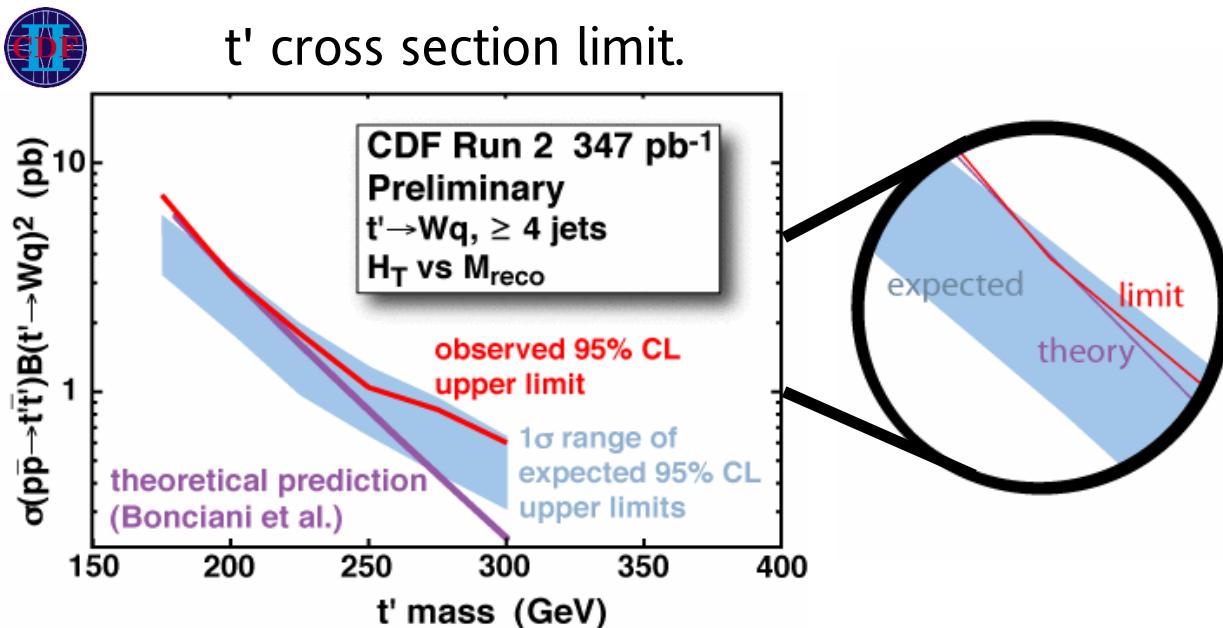
- first direct limit on the lifetime of the top quark.
- top quark lifetime in Standard Model $\sim 10^{-24}$ s ($c\tau = 3 \times 10^{-10} \mu\text{m}$)
- search for anomalous top production by a new, long-lived particle.
- lepton+ ≥ 3 jets with ≥ 1 b-tag in 318 pb^{-1}
 - 97 e candidates
 - 60 μ candidates
- measure the impact parameter d_0 for lepton tracks.
- use max. likelihood method with templates of arbitrary lifetime.



Top' Quark Search

Can we find something new with large mass and top properties?

- heavy 4th generation quark (He et al, hep-ph/0102144)
- search for $t' \rightarrow Wq$ in lepton + jets + missing E_T events (CDF, 347 pb⁻¹)
- try to remain model independent
- reconstruct t' candidate mass
- fit templates in (H_T , $M_{t'}$)



translate cross section limit into a t' prime mass limit of
196 – 207 GeV/c² @ 95 CL

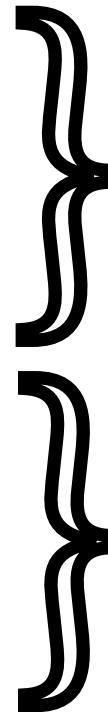
expect $m(t') > 300$ GeV/c² with 2fb⁻¹ unless ...

Outline

- The Tevatron
- CDF and D0 Detectors
- Top Mass Measurements
- Top Production at the Tevatron
- Single Top Searches

- Anomalous Top Pair Production
 - * via intermediate Resonances
 - * by a long-lived Particle
 - * 4th Generation Quarks

- Top Charge
- W-helicity in Top Quark Decays
- Other Top Properties Measurements
- Summary



Covered in previous talks:

Top Mass from CDF: [E. Brubaker](#)

Top Mass from D0 and CDF and D0

Xsec and Single Top: [M. Kopal](#)

Covered in this talk ...

no evidence for new physics.

Top Quark Charge (I)

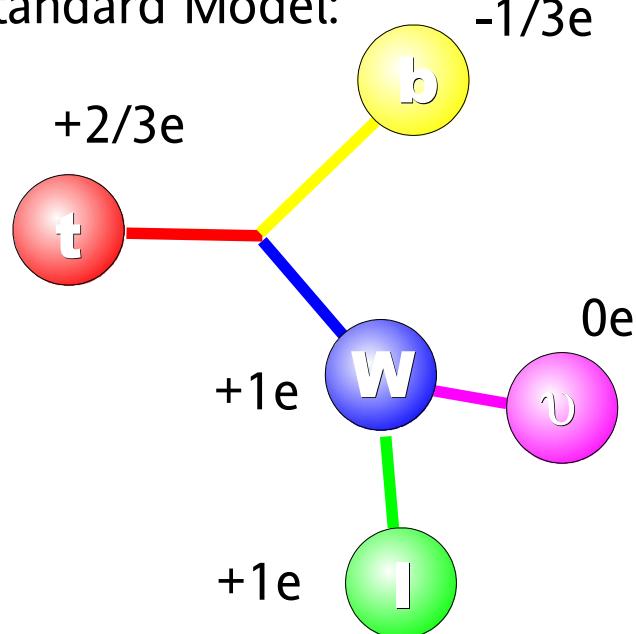
SM: Top Charge $+2/3e$

Other Models predict $-4/3e$

Strategy:

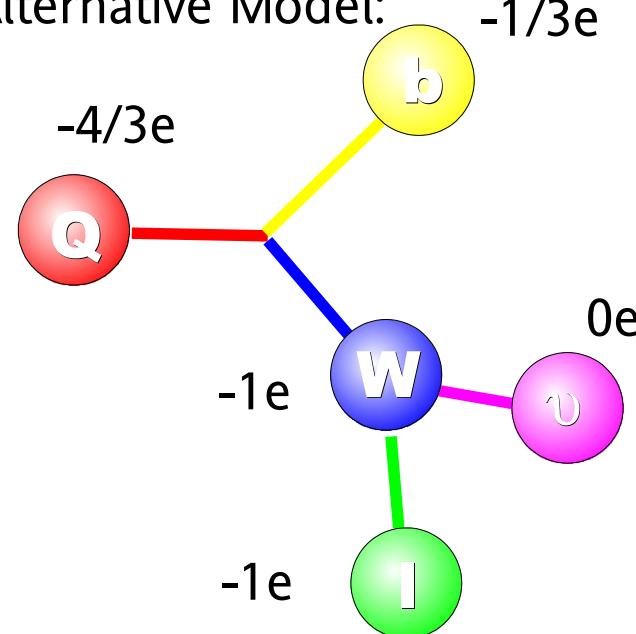
- measure $\sigma(t + \gamma)$ (@ LHC)
- b-jet charge (here)

Standard Model:



?

Alternative Model:



Analysis Strategy at D0:

- associate lepton and b quark to top quark
use a kinematic fit for ttbar hypothesis
- determine charge of the b-jet
 p_T weighted sum of charged tracks
associated to a b-jet.

e.g.: exotic 4th generation + Higgs triplet.

D. Chang et al. Phys Rev D59, 09153 (1999)

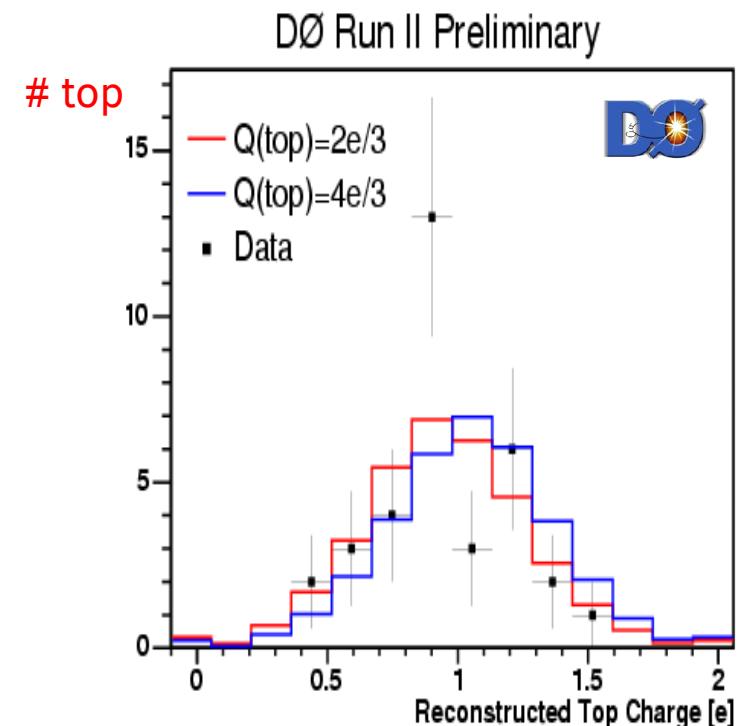
Current cross section measurements
would not contradict two possible
top quark charges.

Top Quark Charge (II)

Very first measurement of one of the most fundamental top properties:

D0 RunII (365pb^{-1})

- 17 candidate events with two tagged b-jets, lepton, missing E_T , ≥ 4 jets.
- two entries per event for top and anti-top.
- discriminate b and bbar with jet charge algorithm,
$$q_{jet} = \frac{\sum_i q_i p_{Ti}^{0.6}}{\sum_i p_{Ti}^{0.6}}, \text{ pT} > 0.5 \text{ GeV} \& \Delta R < 0.5.$$
- calibrate Monte Carlo with data using two jet heavy flavor sample with opposite jet tagged with μ charge.
- excluded the hypothesis of an exotic quark with charge = $-4/3$ e at 94% confidence level.
- CDF result with 1fb^{-1} coming ...



Helicity of the W (I)

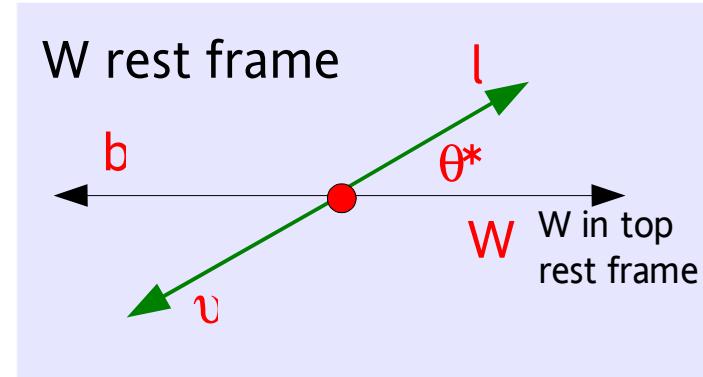
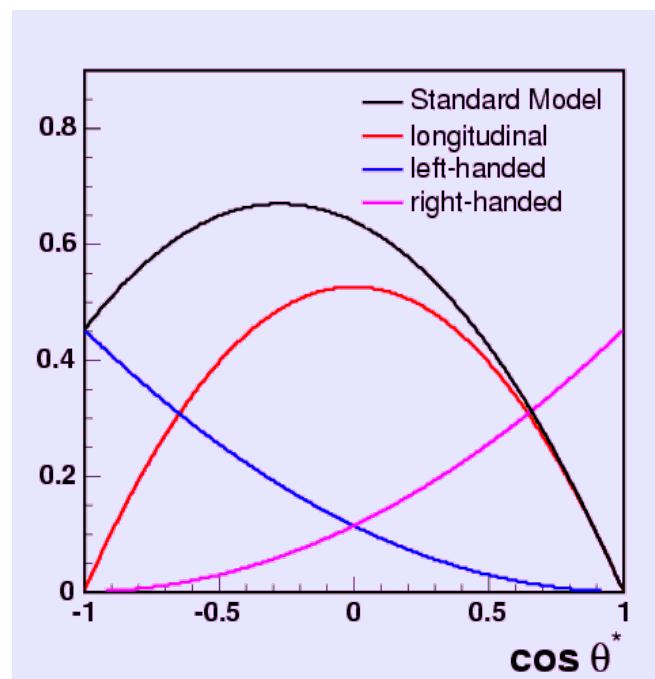
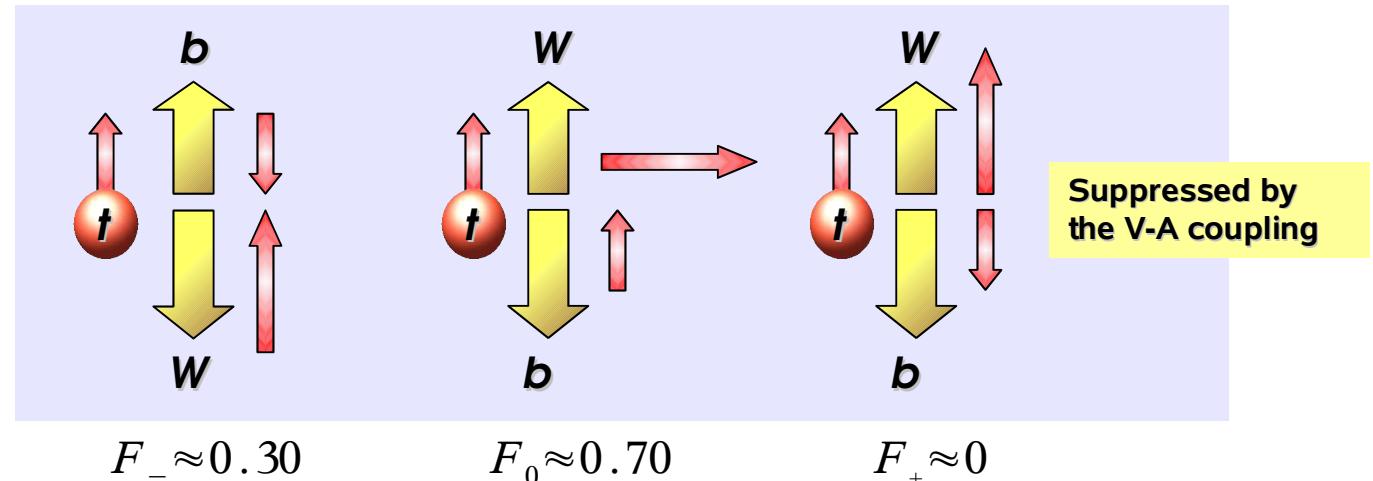
Top decays via weak interaction \rightarrow V-A coupling like all other quarks: $\frac{-ig}{2\sqrt{2}} \bar{t} \gamma^\mu (1-\gamma^5) V_{tb} b W_\mu$

W helicity manifests itself in decay product kinematics.

F_- : left-handed fraction

F_0 : longitudinal fraction

F_+ : right-handed fraction



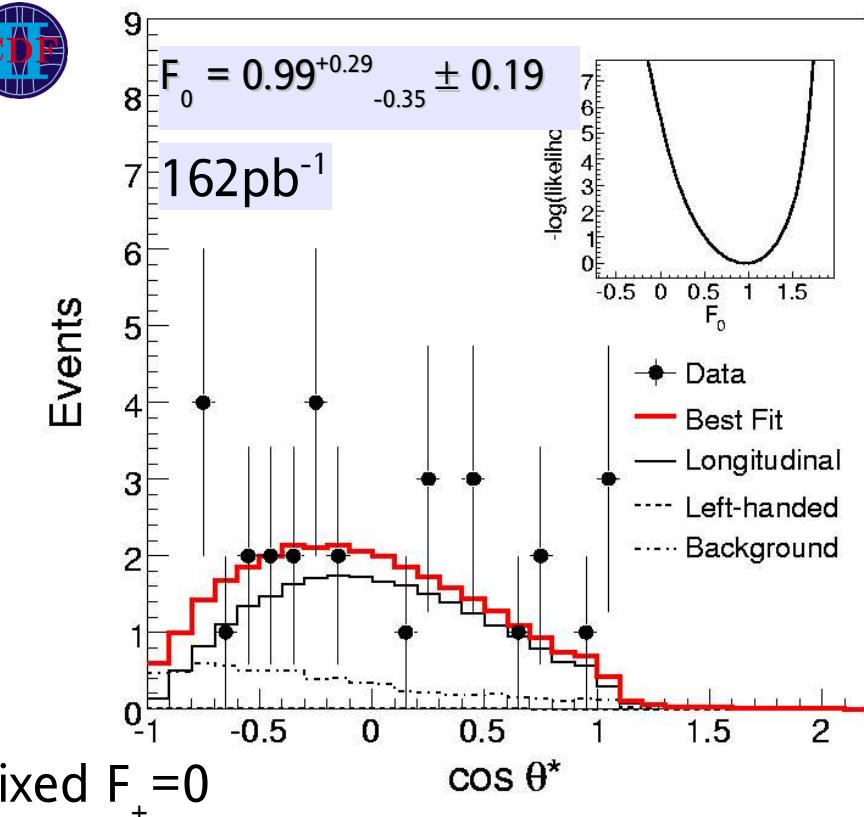
$$w(\cos \theta) = F_- \cdot \frac{3}{8}(1-\cos \theta)^2 + F_0 \cdot \frac{3}{4}(1-\cos^2 \theta) + F_+ \cdot \frac{3}{8}(1+\cos \theta)^2$$

Helicity of the W (II)

$\cos\theta^*$ (m_{lb}) method:

- lepton+jets with 1b-tag sample
- full event reconstruction
- approximation for $\cos\theta^*$

$$\cos\theta^* = \frac{2 m_{lb}^2}{m_t^2 - m_W^2} - 1$$



charged lepton p_T method:

- left-handed W lepton p_T soft
- longitudinal W lepton p_T harder
- lepton+jets with 1, 2btags and dilepton sample.
- $F_0^{\text{comb}} = 0.31^{+0.37}_{-0.23} \pm 0.17$



Our knowledge on F_0 :

D0 RunI	125 pb ⁻¹	$F_0 = 0.56 \pm 0.32$
CDF RunII	200 pb ⁻¹	$F_0 = 0.74^{+0.22}_{-0.34}$

... no deviation from the SM prediction.

So far, fixed $F_+ = 0$ and fitted F_0 .
 Eventually, do simultaneous fit for F_0 and F_+ .

hep-ex/0511023

Helicity of the W (III)

Observation of positive helicity ($F_+ > 0$) would indicate V+A coupling.

D0 measurements:

- a) lepton+jets with topological + b-tag selection used $\cos\theta^*$ method.
 - b) dilepton selection used charged lepton p_T method.
- $F_+^{\text{comb}} = 0.04 \pm 0.11(\text{stat.}) \pm 0.06 (\text{syst.})$

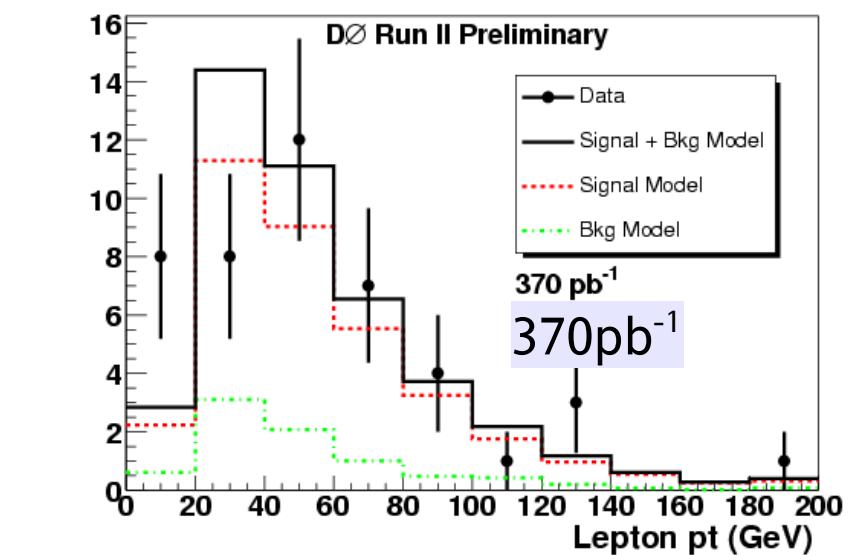
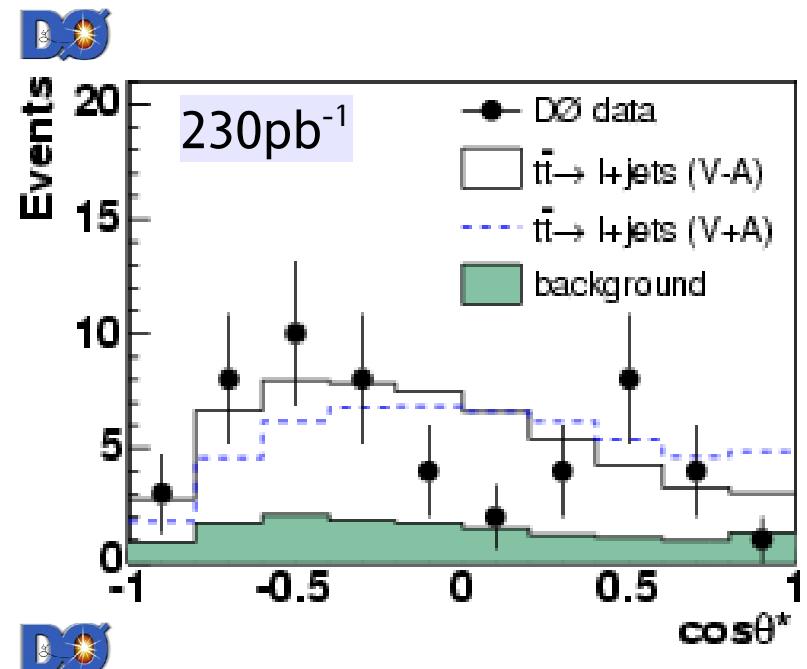
Our knowledge on F_+ :

CDF RunI 110pb^{-1} $F_+ < 0.18$ @ 95%CL

CDF RunII 200pb^{-1} $F_+ < 0.27$ @ 95%CL

D0 RunII $230\text{-}370\text{pb}^{-1}$ $F_+ < 0.25$ @ 95%CL

... no deviation from the SM prediction.



hep-ex/0505031

Summary

Measurement	Best Results	Dataset
Mass	$172.0 +/- 2.7 \text{ GeV}/c^2$	750pb^{-1}
Cross Section	$7.3 +/- 1.1 \text{ pb}$	750pb^{-1}
W Helicity	$F_0 = 0.74+0.22-0.34$	162pb^{-1}
W Helicity	$F_+ < 0.18 @ 95\%CL$	109pb^{-1}
Top Charge	rule out +4/3 model @ 94%CL	365pb^{-1}
Resonance Searches	$M_{x0} < 725 \text{ GeV}/c^2$	680pb^{-1}
Top Lifetime	$c\tau < 53 \mu\text{m} @ 95\%CL$	318pb^{-1}
4th Generation t' Quark	$196 < M(t') < 207 \text{ GeV}/c^2 @ 95\%CL$	347pb^{-1}
Charged Higgs Searches	Limits on $\text{BR}(t \rightarrow H+b)$	194pb^{-1}
Anomalous Kinematics	no high p_T excess	194pb^{-1}
$\text{BR}(t \rightarrow Wb) / \text{BR}(t \rightarrow Wq)$	$> 0.61 @ 95\%CL$	230pb^{-1}
Single Top	s-channel: $\sigma(tb) < 5.0 \text{ pb}$	370pb^{-1}
Single Top	t-channel: $\sigma(tqb) < 4.4 \text{ pb}$	370pb^{-1}
Spin Correlation	$\kappa > -0.25$	125pb^{-1}
...

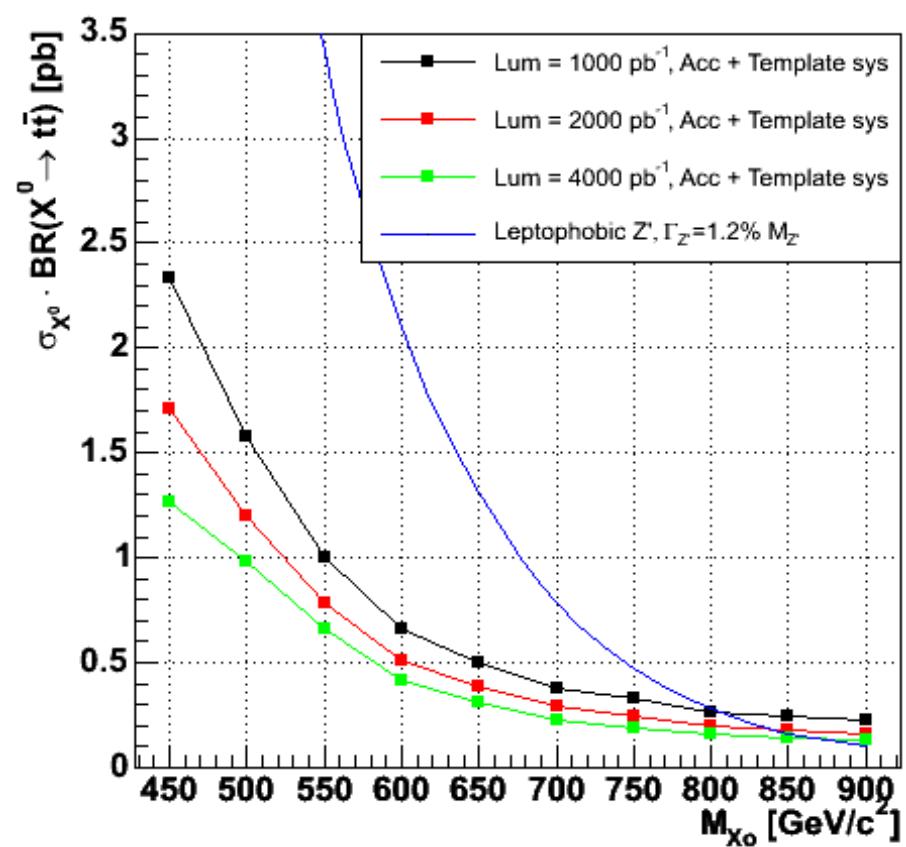
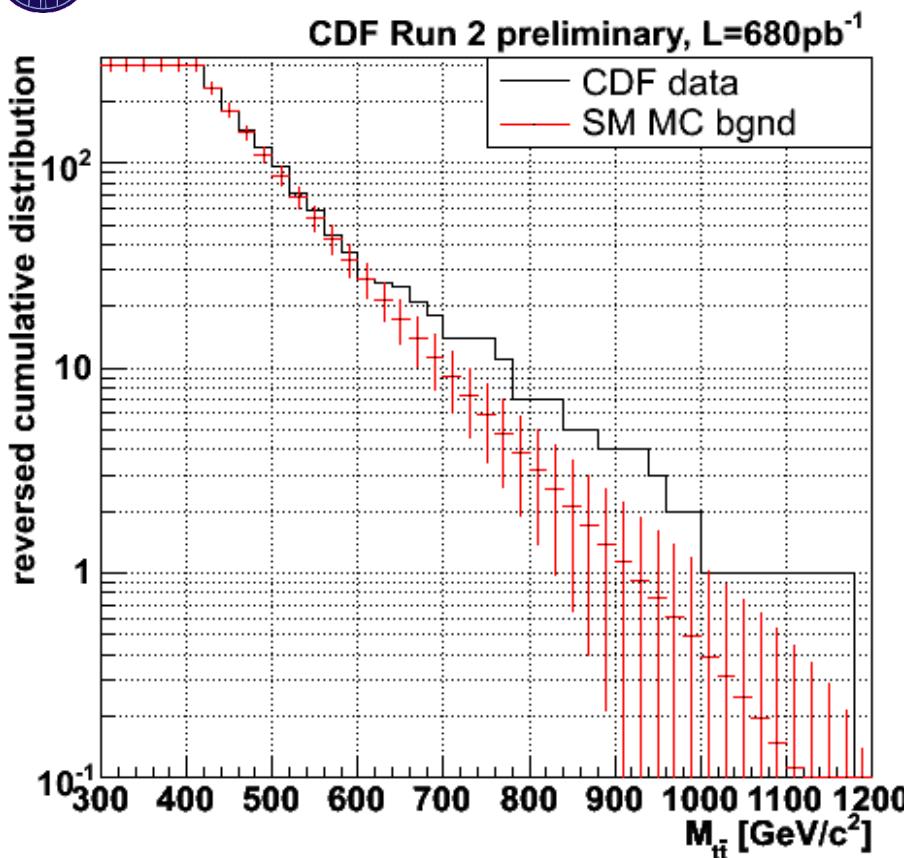
- The observed Top Quark is consistent with Standard Model.
- Top Property measurements are limited by statistics.
- Expect results with 1fb^{-1} datasets from CDF and D0 in Summer 2006.

Open question:

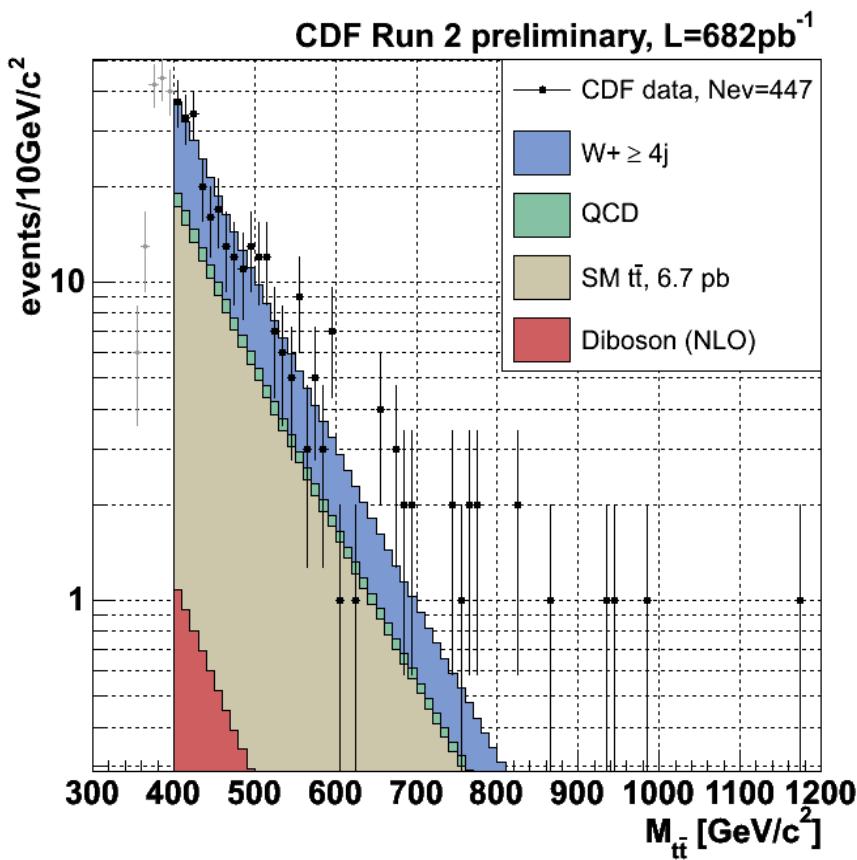
Does physics beyond the Standard Model hide in the large Top Quark samples collected at the Tevatron?

- young physics forum: S. Lager and B. Mohr on Top Physics ...

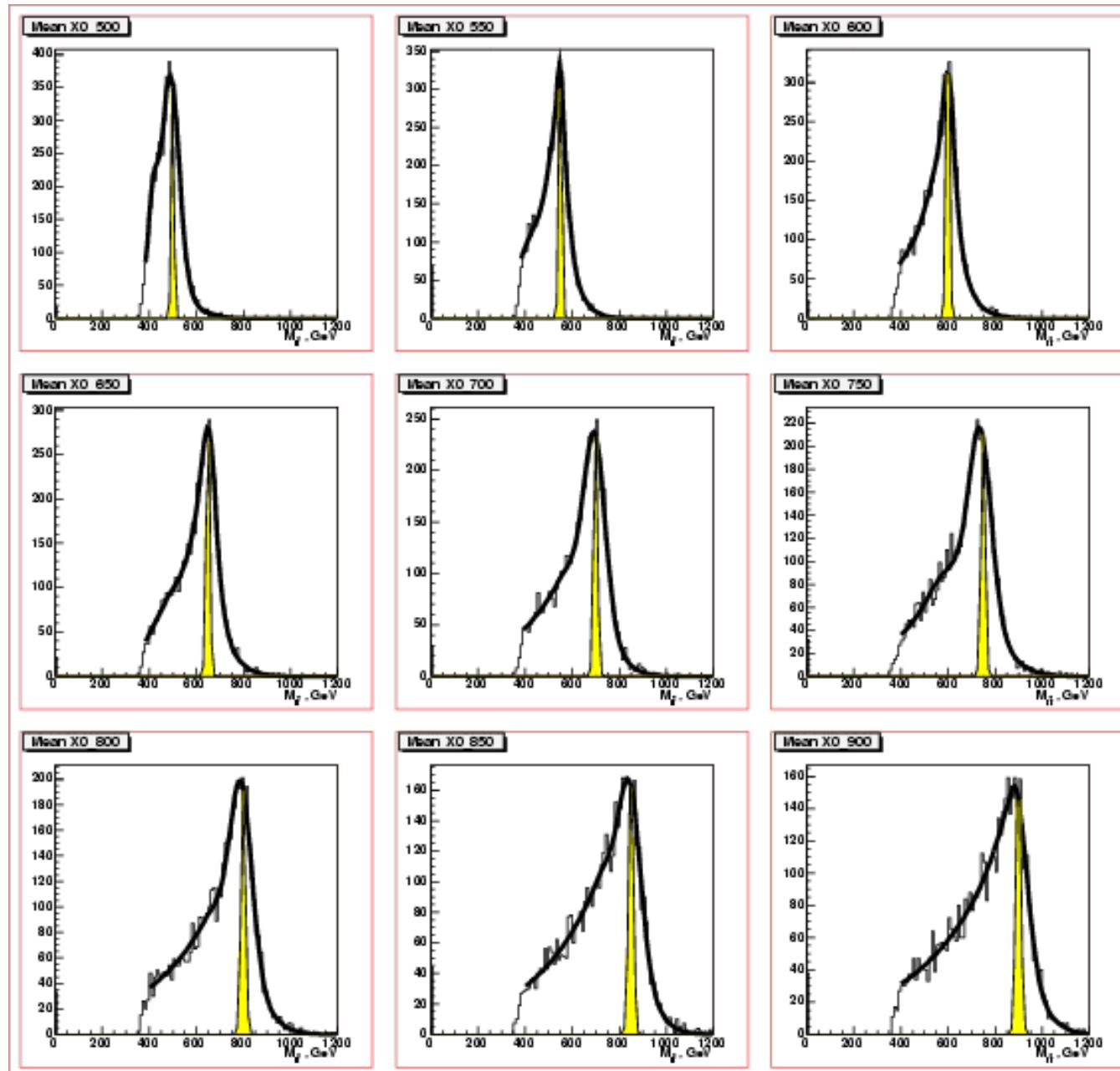
Backup – Resonance Search



Backup – Resonance Search



Backup – Resonance Search



Backup – Top Lifetime

