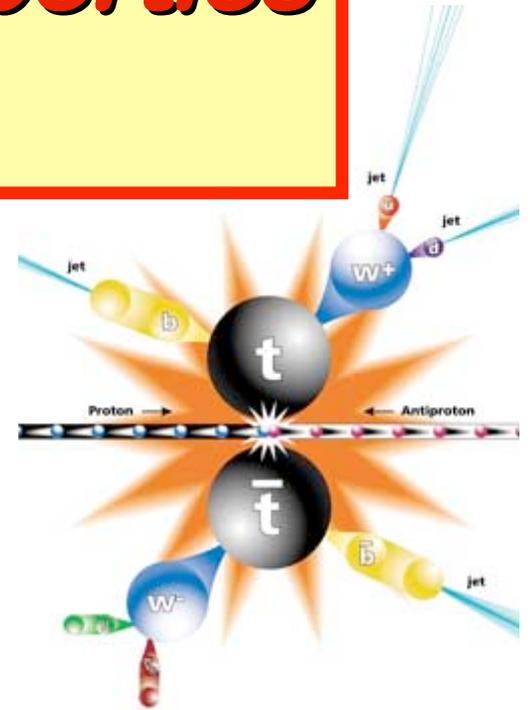


Top Production and Properties at the Tevatron

Un-ki Yang

University of Manchester

University of Chicago



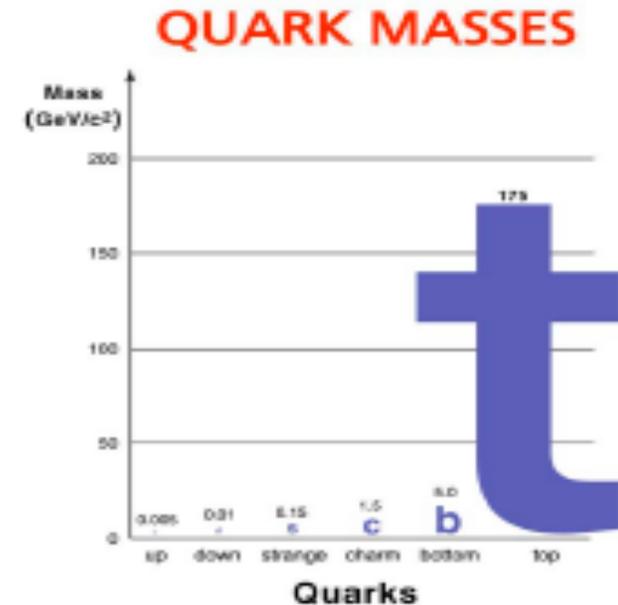
On behalf of the DØ and CDF Collaborations



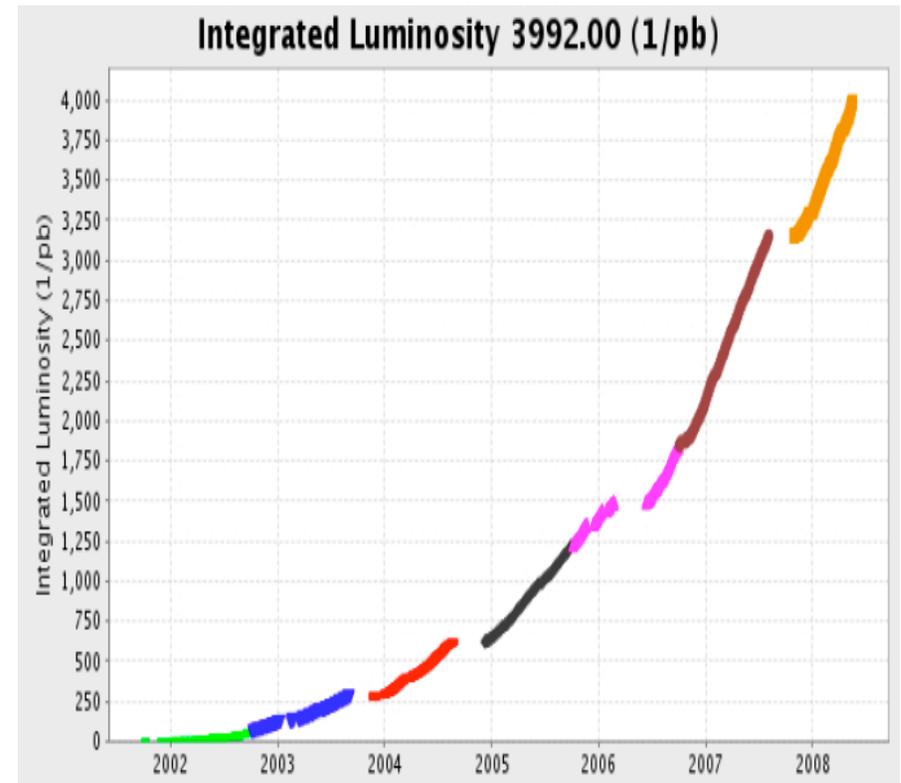
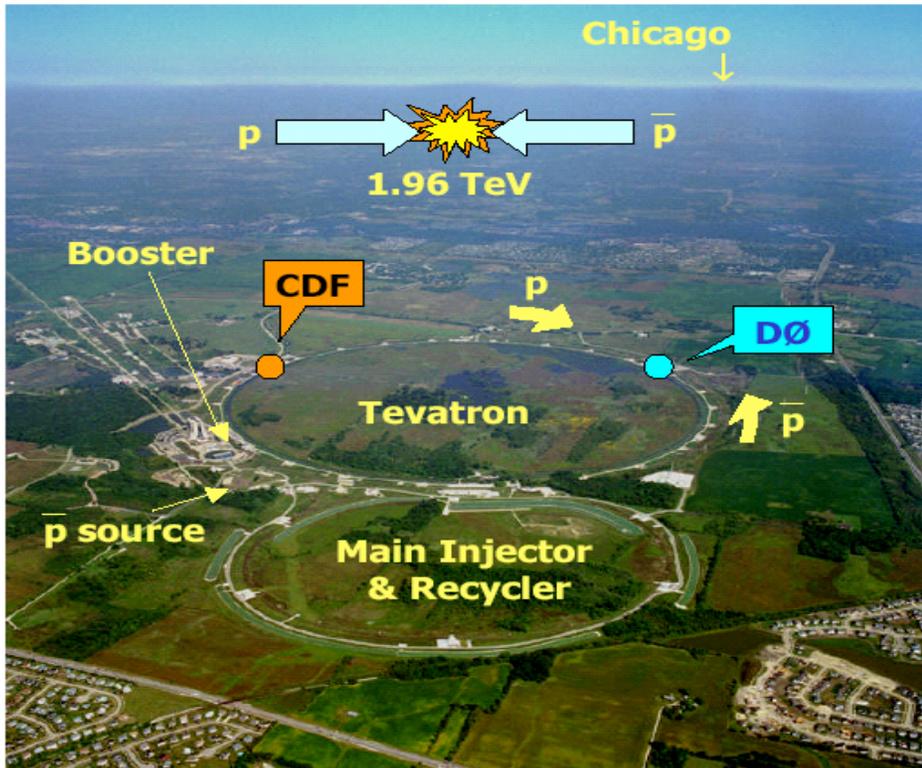
Heavy Quarks and Leptons, Melbourne, June 5-9, 2008

Why Study Top Quark?

- Since top quark discovery in 1995,
 - It completes the 3 generations
 - Top mass is now 172 GeV to <1%
 - Many properties being explored
- Many open questions
 - Why so heavy?
 - Any close relation between top and mass generation?
 - What BSM? non-zero $m(\nu)$, and missing dark matter
- New physics at Tera scale
 - Coupled with heavy top?
 - Study at the energy frontier, Tevatron (current) and LHC



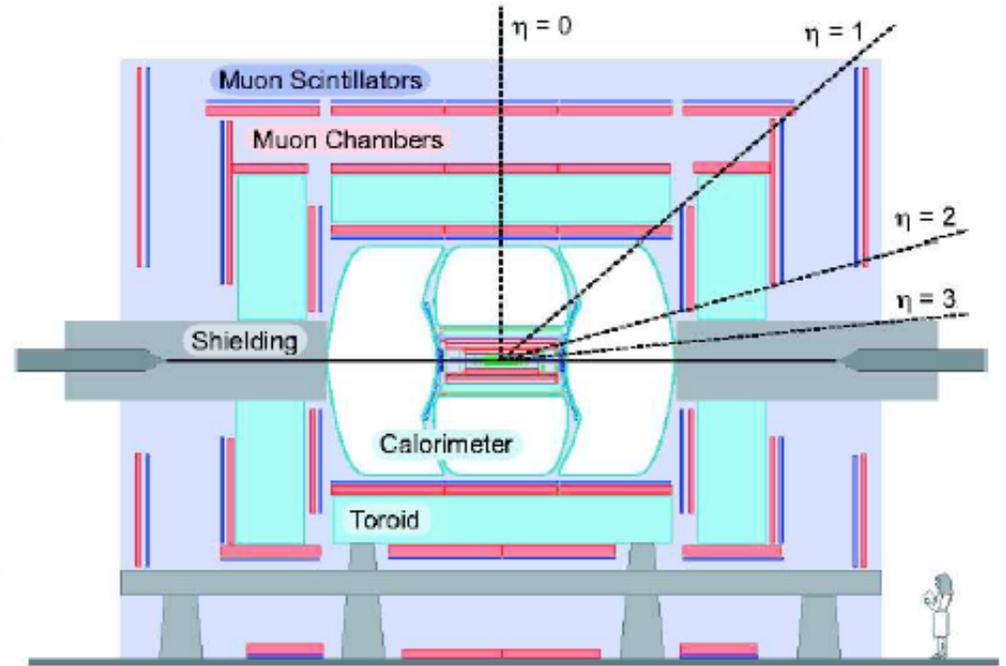
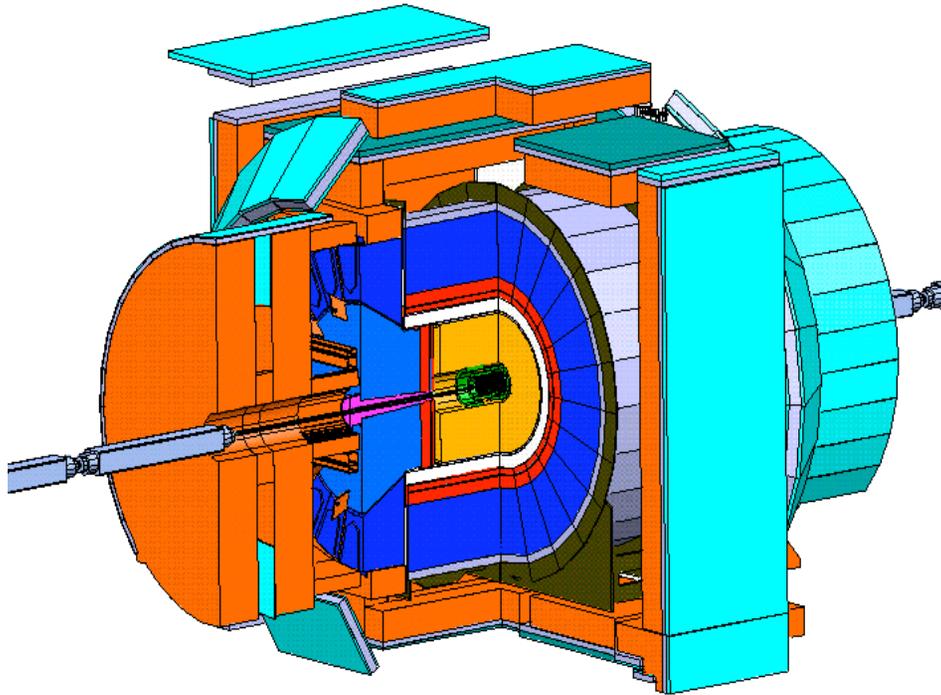
Tevatron : Great Performance



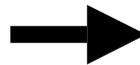
- Record inst. luminosity: $3.15 \times 10^{32} / \text{cm}^2 \text{s}$
- Both experiments: 3.5 fb^{-1} on tape :
~23k top pairs produced, 30 x Run I

Un-ki Yang, HQL 2008

The CDF and DØ Detectors



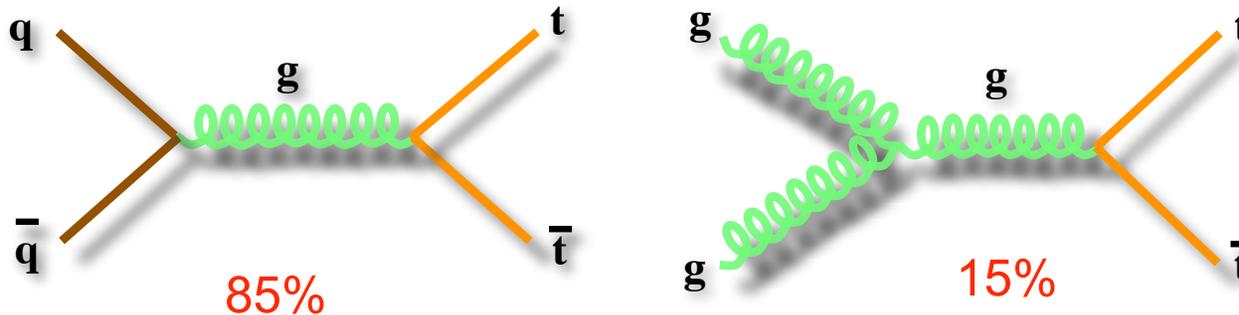
Precision tracking with silicon
Calorimeters ($\sigma/E \sim 80\% \sqrt{E}$)
Muon chambers
DØ : large muon coverage
CDF: large tracking volume



Multi-purpose detector;
precision measurements
search for new physics

Top Pair Production

- At Tevatron, mainly produced in pair via strong interaction

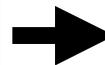


Single top:
Kirsch's talk

$$\sigma(\bar{p}p \rightarrow t\bar{t} @ M_{\text{top}} = 175 \text{ GeV}/c^2) \approx 6.7 \text{ pb}$$

- **Measurements: test of the SM and probe new physics**

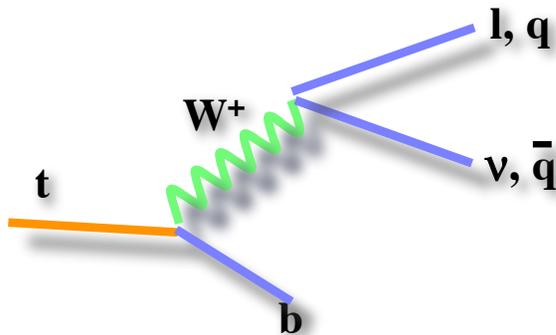
SM QCD production
SM top?
Anomalous productions?
 $p\bar{p} \rightarrow X(Z', \text{top-color}) \rightarrow t\bar{t}$
 $p\bar{p} \rightarrow \tilde{t}\tilde{t} \rightarrow t\bar{t} \tilde{X}\tilde{X}$



Inclusive cross section
Diff. cross sections:
Resonance search
Forward-back asymm.

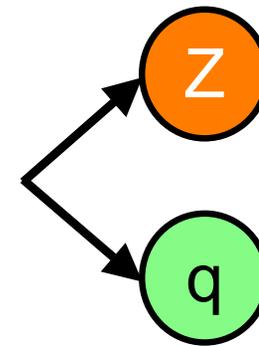
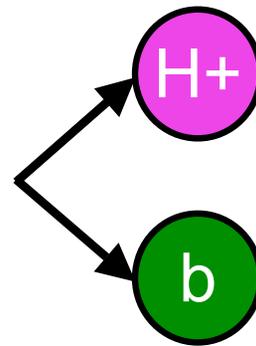
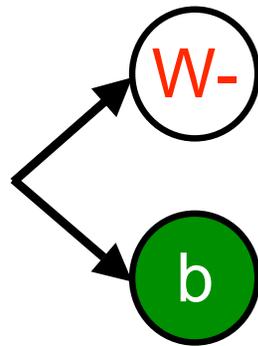
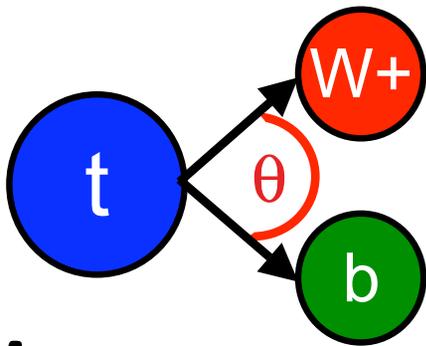
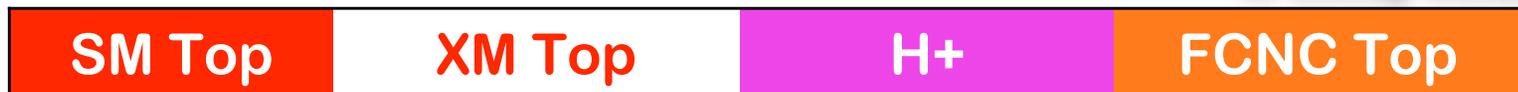
Top Decays

- In SM, $top \rightarrow Wb$ (100%) as free quark with $\tau_{top} \sim 10^{-25}$ s



W decay mode	lepton plus jets	tau plus jets	all hadronic
	lepton plus jets	tau plus jets	
$e\nu/\mu\nu$	dilepton	tau plus jets	lepton plus jets
$e\nu/\mu\nu$	dilepton	tau plus jets	lepton plus jets

- Explore properties and search for new physics

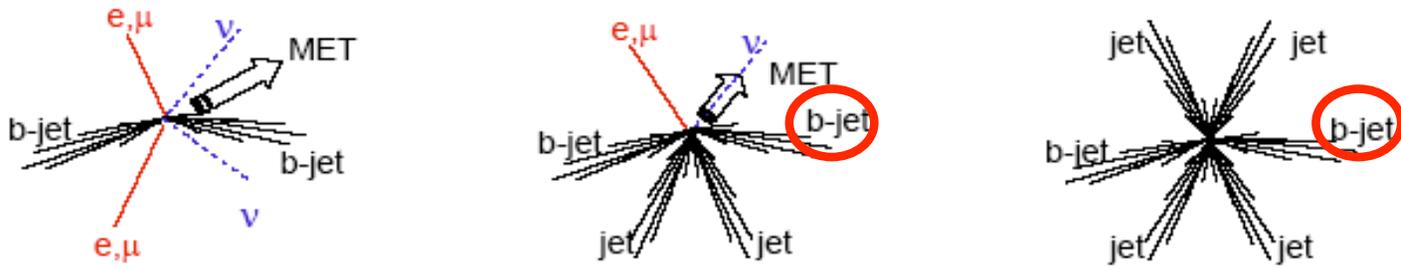


Mass:
Wang's talk

Un-ki Yang, HQL 2008

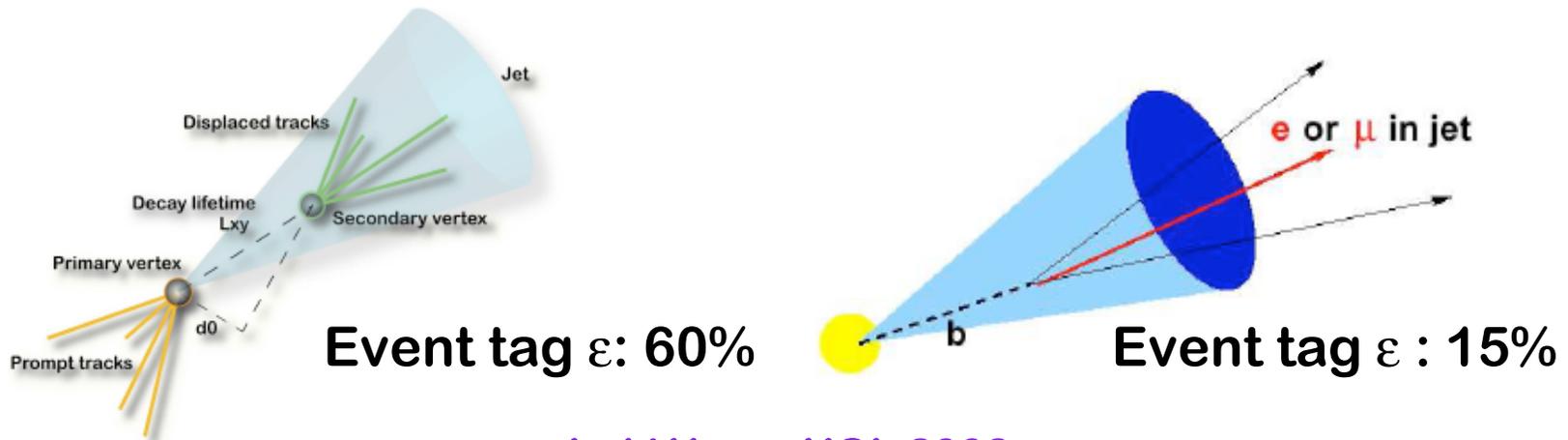
Top Identification

- Top events: high-pt lepton, b jet, light-quark jet, MET(ν)



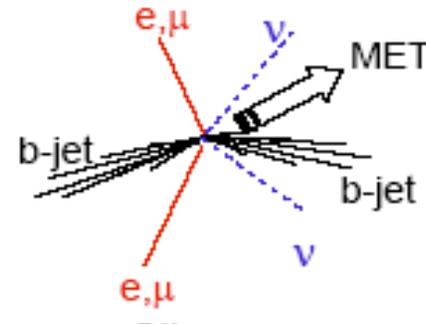
Evs: 2fb^{-1} 13k	Dilepton	Lep + Jets	All Had	τ not
	0.7k \rightarrow 100	4k \rightarrow 400	6k \rightarrow 600	

- B-jet identification: decay length ($L_{xy} \sim 3\text{mm}$), semi-lep. b decay



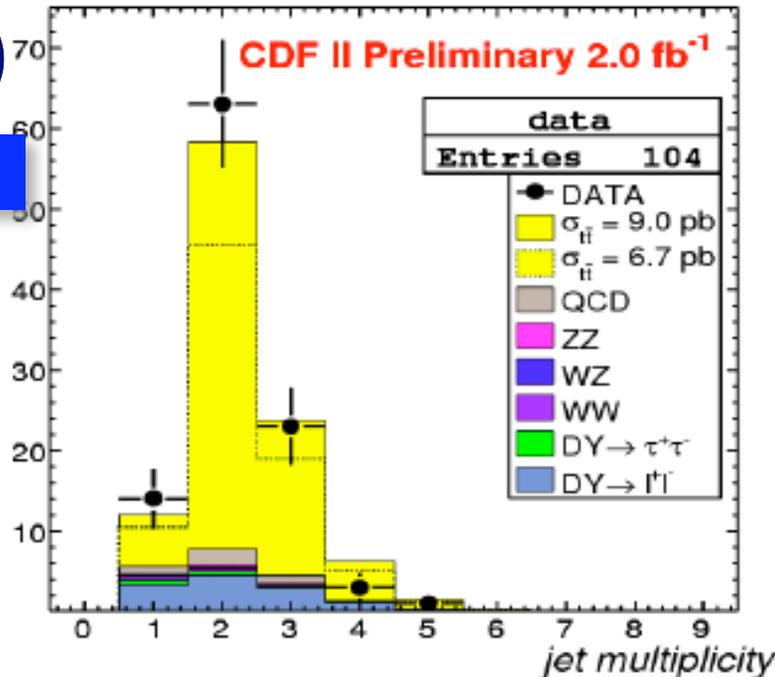
Cross Section in Dilepton

- Two high-pt leptons, 2 jets, and MET
 - Main bkgds: DY, WW, W+jets
 - Signal to bkgds: 6:1 (1 b-tag)



2.0 fb⁻¹

Tagged Top Candidates With N_{jet} ≥ 1



$$\sigma = 9.0 \pm 1.1(\text{stat}) \pm 0.7(\text{sys}) \pm 0.50(\text{lum}) \text{ pb}$$

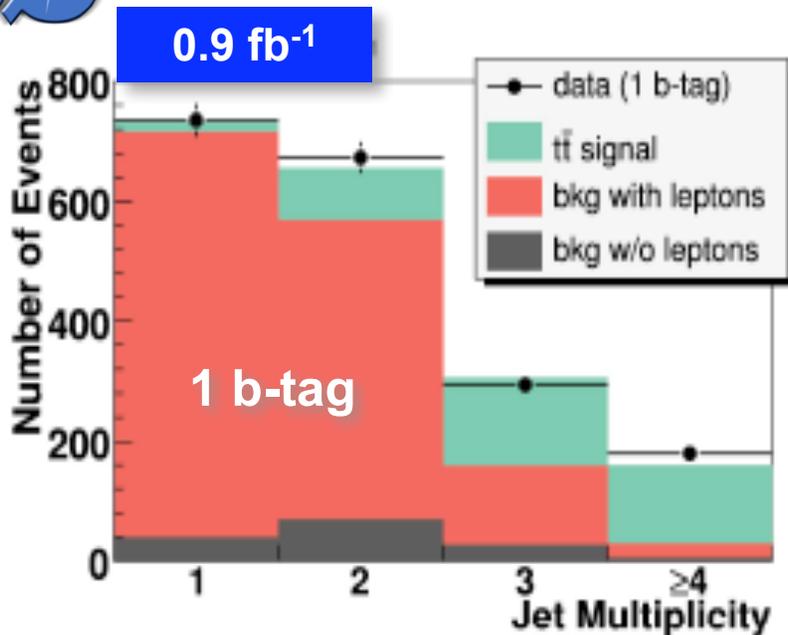
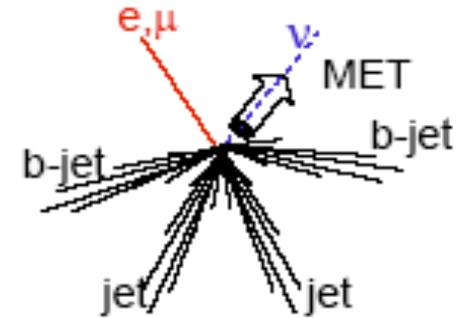
- Both measured σ with/out b-tag
- Lepton+trk: large accept.
- D0 lepton+tau: sensitive to $t \rightarrow H(\rightarrow \tau\nu)b$



All Consistent

Cross Section in Lepton+Jets

- High-pt lepton, 3 jets, and MET
 - Main bkgds: $Wb\bar{b}/c\bar{c}$, W +jets, Multi-jets
 - Signal to bkgds: 3:1 (1 b-tag)



$$\sigma = 8.1 \pm 0.5(\text{stat}) \pm 0.7(\text{sys}) \pm 0.50(\text{lum}) \text{ pb}$$

- Both measured σ in 1 b-tag and 2 b-tag
- Event topology
- CDF soft lepton tag



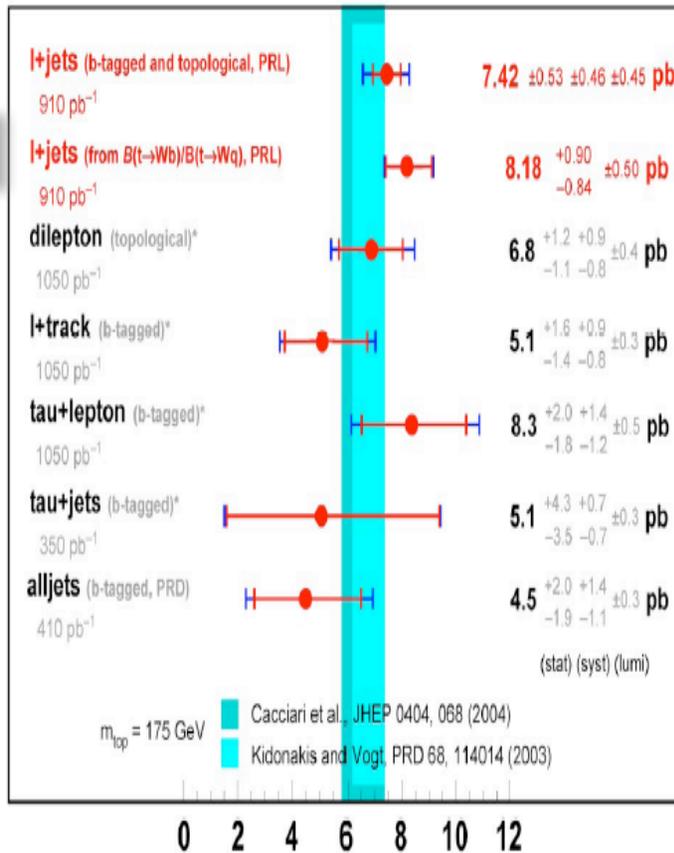
All Consistent

Cross Section Summary

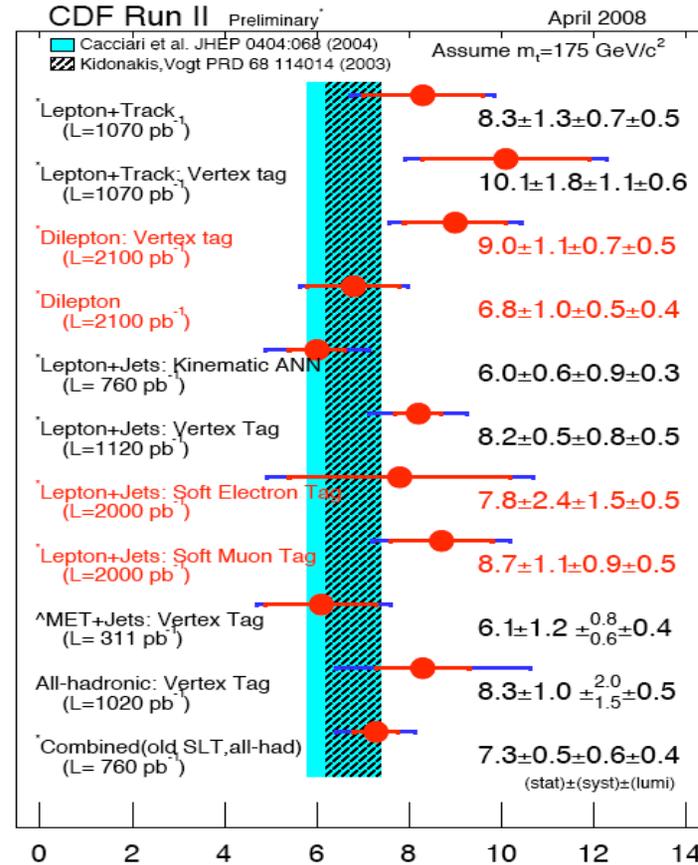


DØ Run II preliminary* March 2008

~ 1 fb⁻¹



1~2 fb⁻¹



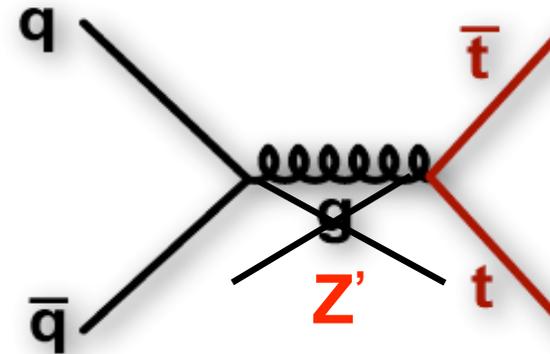
- All consistent: combined $\delta\sigma$: ~10%, $\delta\sigma(\text{theory}) < 15\%$
- Lepton+jets: the most precise, dominated by JES and b-tag
- What about differential cross section?

Un-ki Yang, HQL 2008

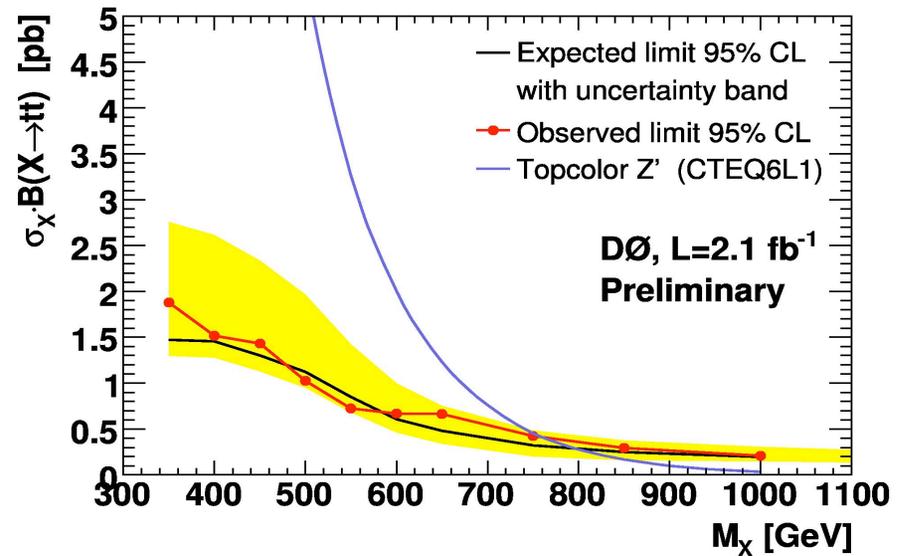
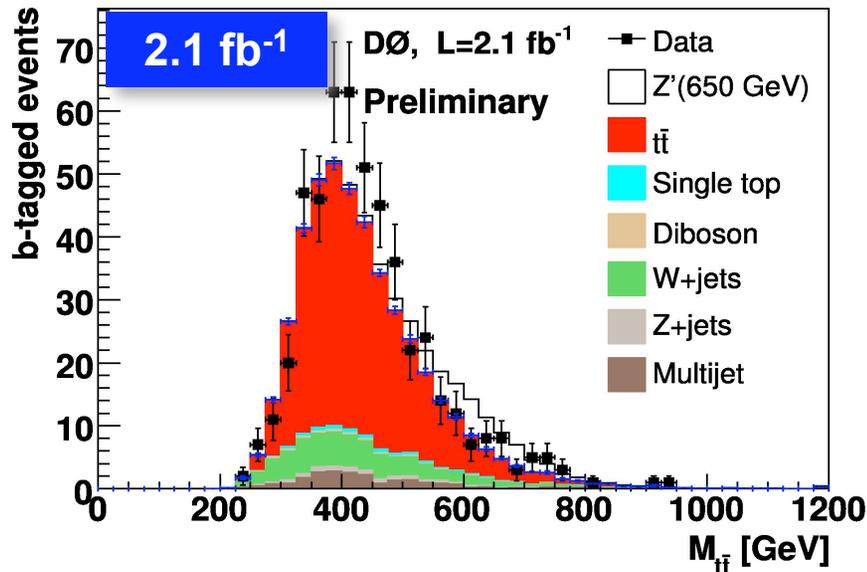


Resonances Search

- Direct search for heavy resonance
 - New heavy particle coupled with 3rd gen. family
 - A narrow-width Z' , top-color
- Reconstruct $M_{t\bar{t}}$ dist. in lepton+ 4 jets (1 b-tag)



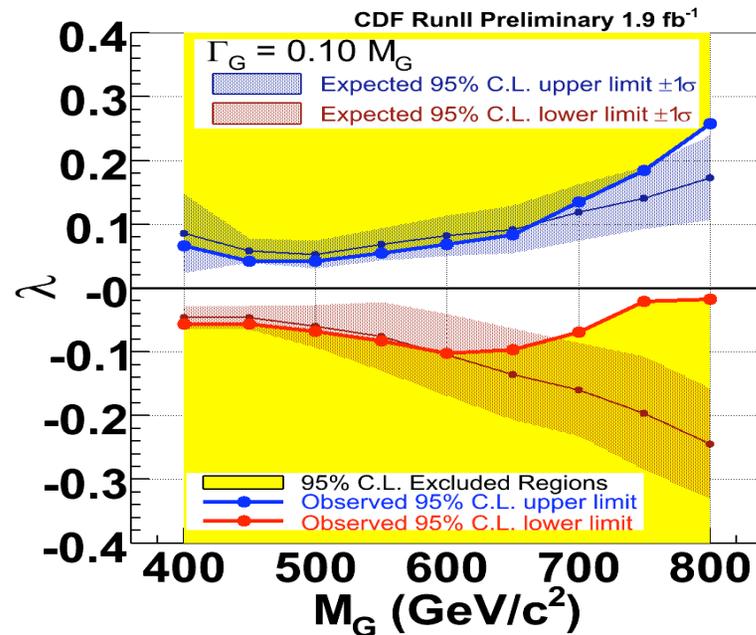
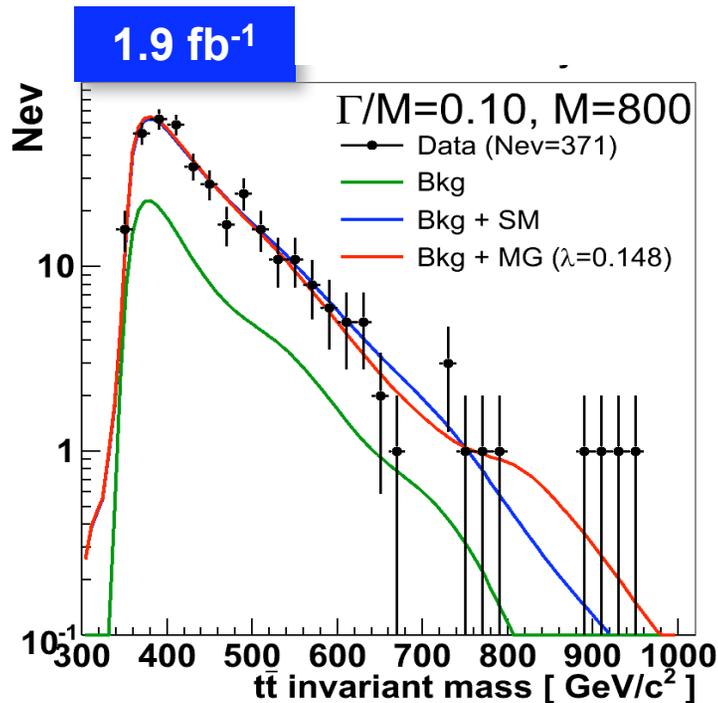
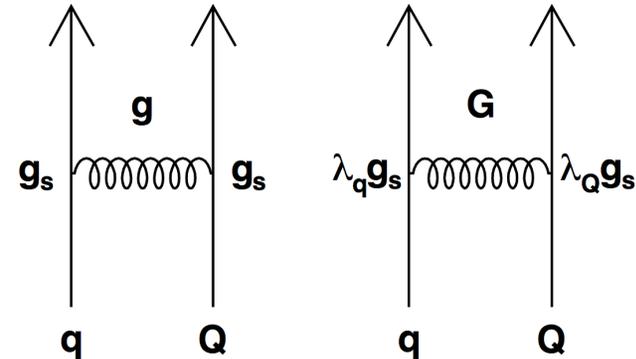
$M_{Z'} > 760 \text{ GeV}$ for $\Gamma_{Z'}/M_{Z'} = 1.2\%$





Search for Massive Gluon

- Direct search for Massive Gluon
 - Reconstruct $M_{t\bar{t}}$ using Matrix Element Method in lep+4 jets
 - Set upper/lower limits on $\lambda = \lambda_q \lambda_Q$, for $M_G = 400 - 800$ GeV

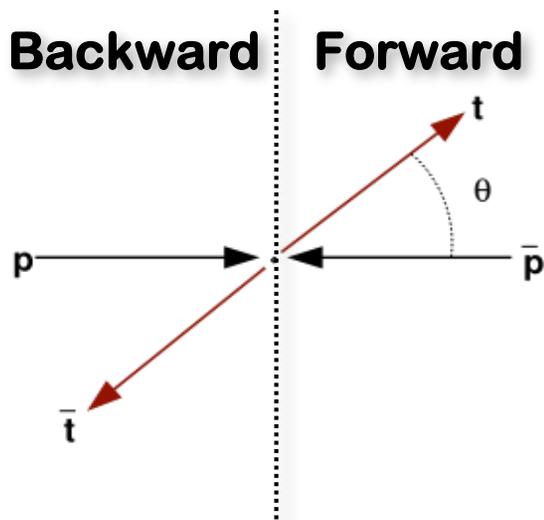


For $M_G = 800$ GeV @ 95% C.L.
Lower / upper limit = -0.02 / 0.26



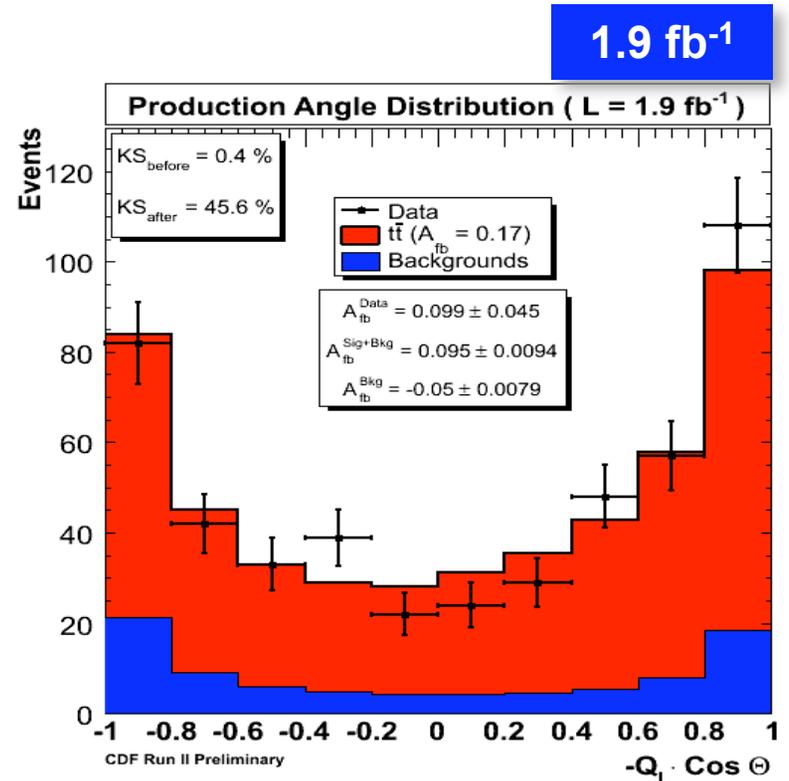
Forward-Backward Asymmetry

- Asymmetry from interference between LO and NLO terms



$$A_{fb} = \frac{N_{(-Q_\ell) \cdot \text{Cos}\Theta > 0} - N_{(-Q_\ell) \cdot \text{Cos}\Theta < 0}}{N_{(-Q_\ell) \cdot \text{Cos}\Theta > 0} + N_{(-Q_\ell) \cdot \text{Cos}\Theta < 0}}$$

measured in both $p\bar{p}$
and $t\bar{t}$ (30%↑) rest frames



$$A_{FB}^{p\bar{p}} = 0.17 \pm (0.07)_{stat} \pm (0.04)_{syst}$$

$$A_{fb}^{Theory \text{ NLO}} = 0.03 - 0.05$$



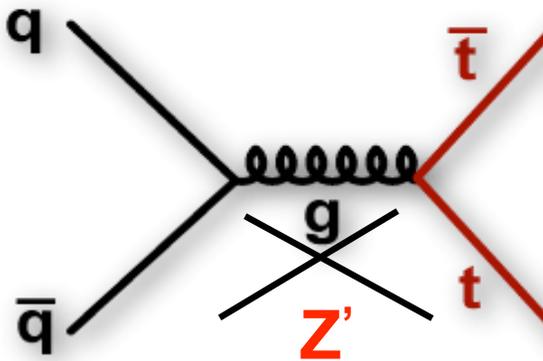
Forward-Backward Asymmetry

- A_{FB} measured in $t\bar{t}$ rest frame

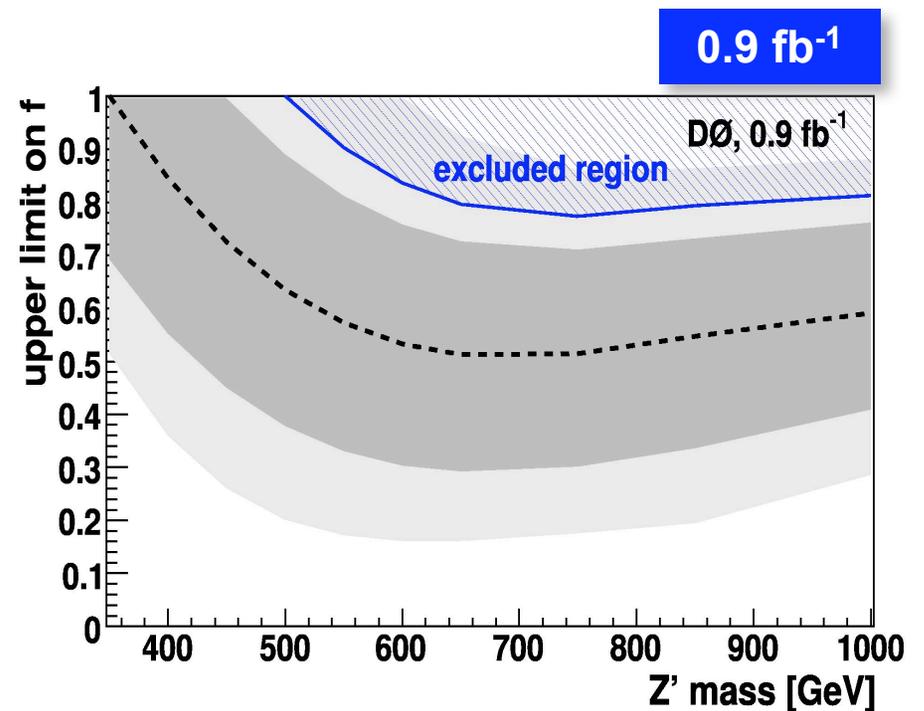
$$A_{fb} = 0.12 \pm (0.08)_{stat} \pm (0.01)_{syst}$$

consistent with SM & CDF

- Probe New physics:
leptophobic Z



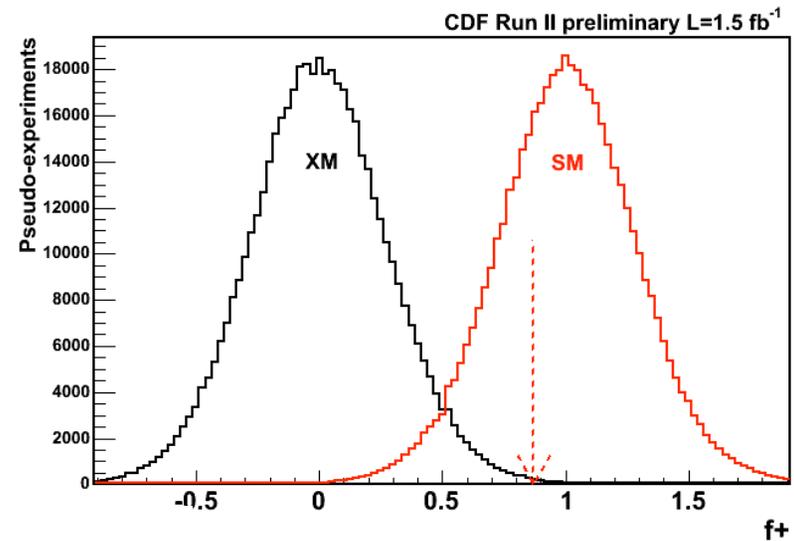
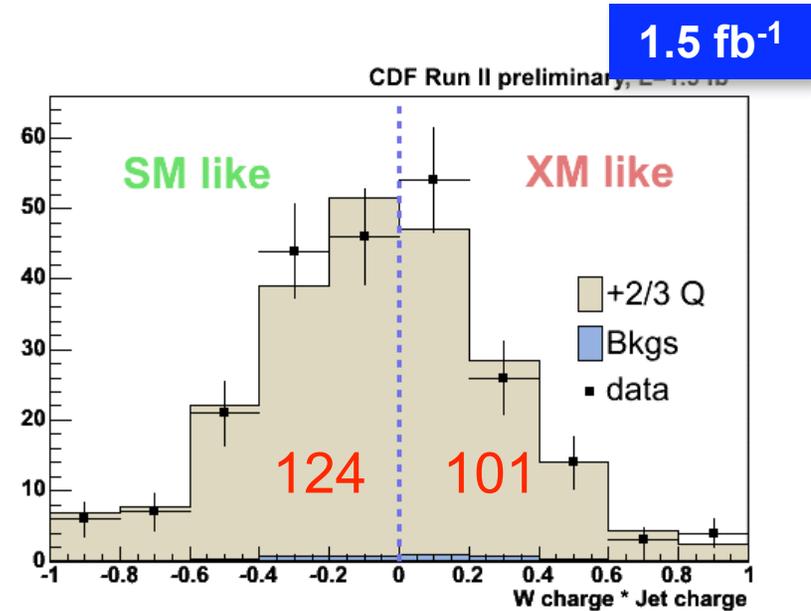
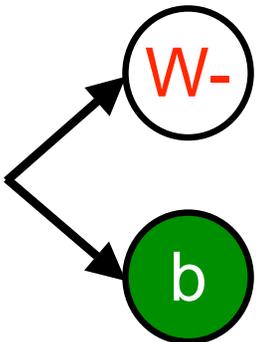
$$f = \frac{\sigma(p\bar{p} \rightarrow Z' \rightarrow t\bar{t})}{\sigma(p\bar{p} \rightarrow t\bar{t})}$$





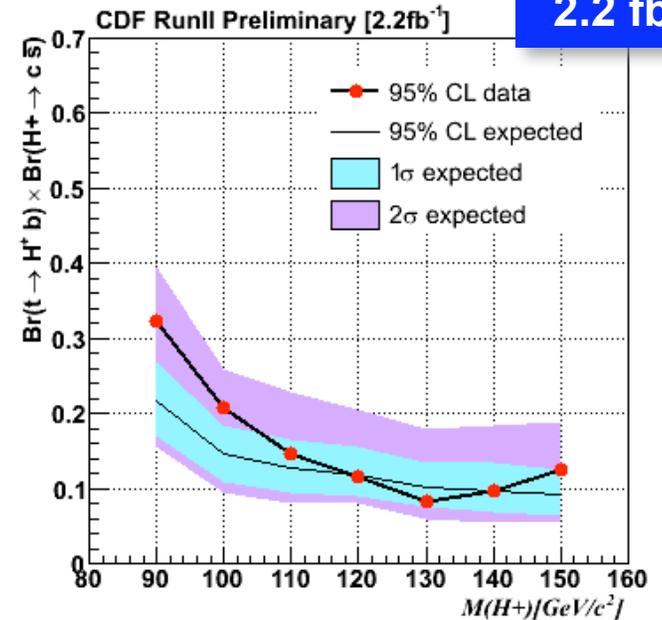
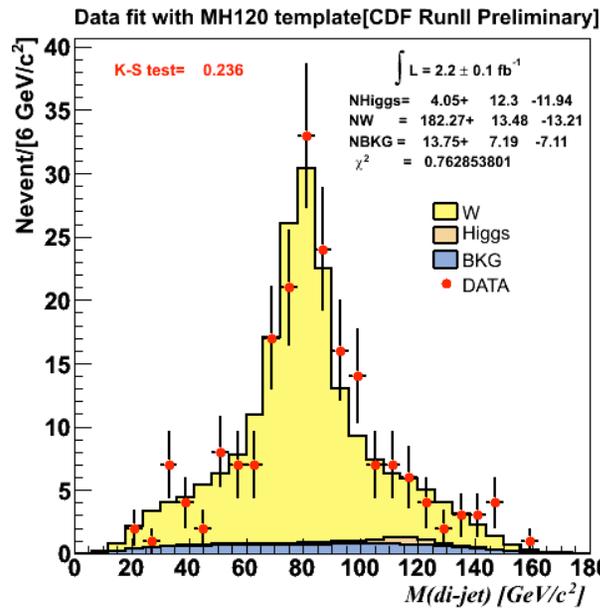
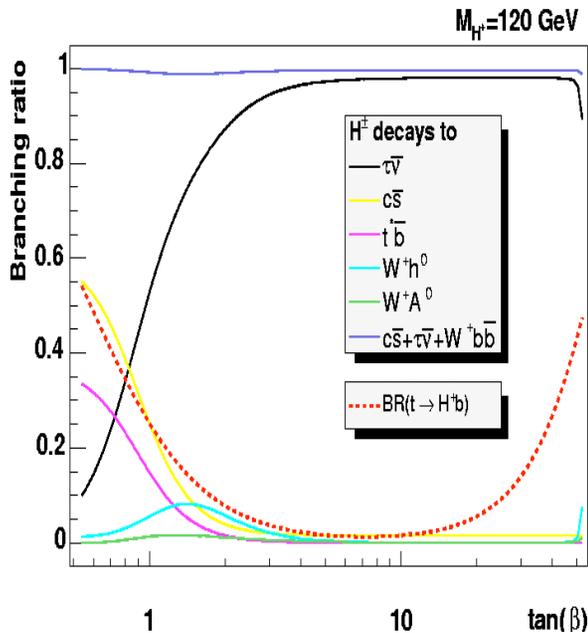
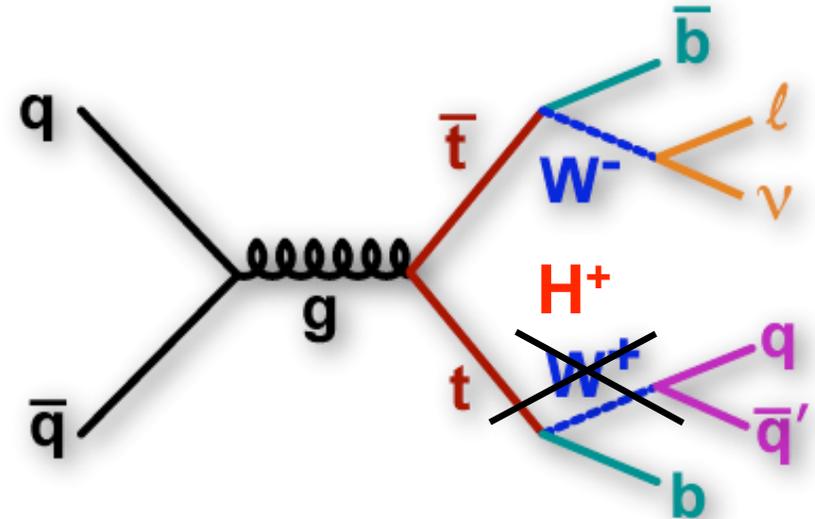
Top Charge?

- Standard Model: $Q_{\text{top}} = 2/3e$
- Exotic model: $-4/3e$ ($t \rightarrow W\text{-}b$)
- Method: W charge * b -jet charge
 - B jet and its charge?
 - Correct pair of b , W ?
- CDF result
 - Dilepton: use smaller m_{lb}^2
 - Lep+jet: use χ^2 mass fitter
 - XM top charge of $-4e/3$ excluded with 87% C.L.



Charged Higgs Search

- In MSSM, charged Higgs exists:
 H^+ decays into $c\bar{s}$, $\tau\nu$
- Search for a second bump
 in W di-jet mass from top decays
 in $lep+4jets$: use mass fitter



2.2 fb⁻¹



Charged Higgs

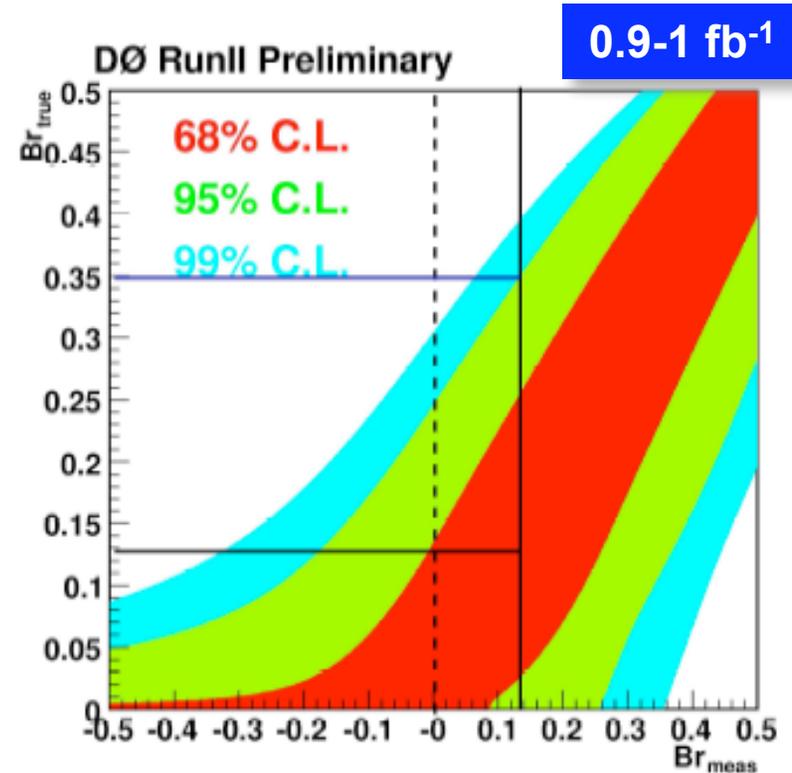
- Another approach

$$R_\sigma = \frac{\sigma(p\bar{p} \rightarrow t\bar{t})_{\text{lep+jets}}}{\sigma(p\bar{p} \rightarrow t\bar{t})_{\text{dilepton}}} = 1?$$

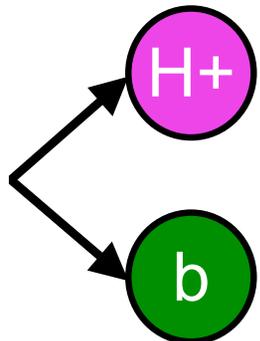
if $H^+ \rightarrow c\bar{s}$, $R > 1$

- Result: agree with SM

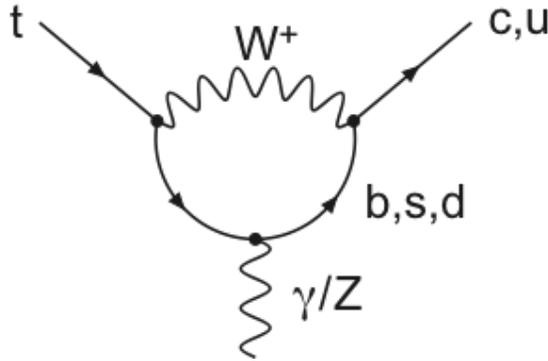
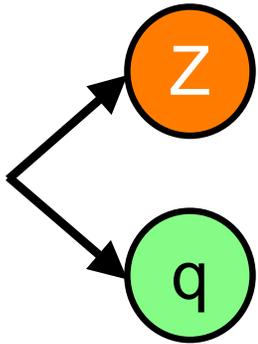
$$R_\sigma = 1.21^{+0.27}_{-0.26} \text{ (stat+sys)}$$



- Upper limit on $BR(t \rightarrow H^+ b) < 0.35$ at 95% CL, assuming $m(H) = 80$ GeV, $Br(H^+ \rightarrow c\bar{s}) = 1$



FCNC Search

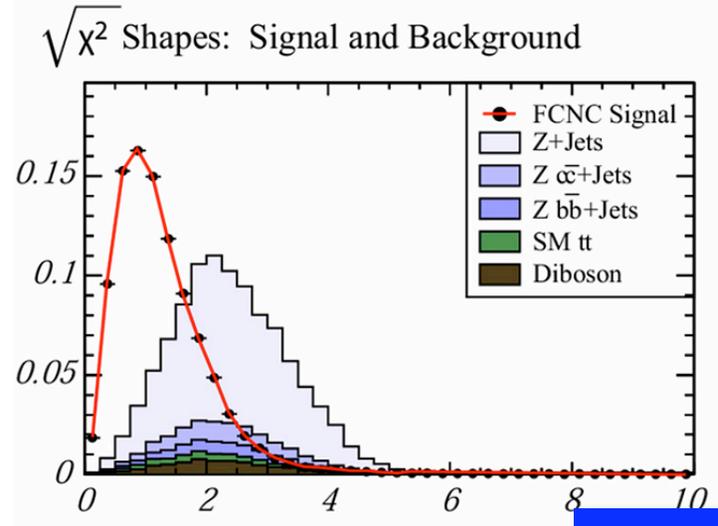


➤ Flavor Changing Neutral Current

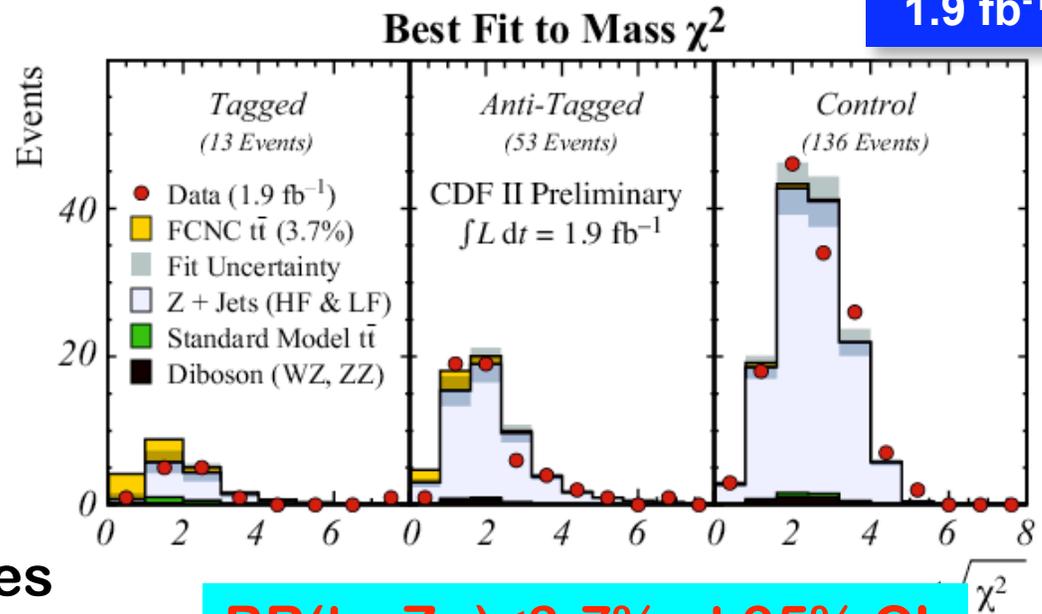
- Highly Suppressed
- $\text{Br}(t \rightarrow Zq) = \mathcal{O}(10^{-14})$
- Any signal: new physics

➤ Method:

- **Z + 4 Jets** ($t \rightarrow Wb$, $t \rightarrow Zq$)
- Use χ^2 mass fitter
- B-tag and anti-tag samples



1.9 fb⁻¹

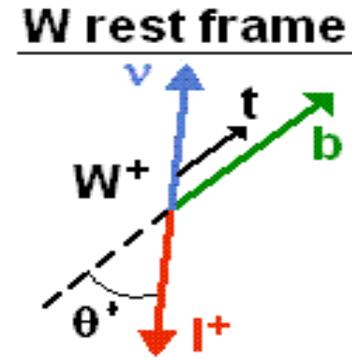


**BR($t \rightarrow Zq$) < 3.7% at 95% CL
improved by factor of 3.5**

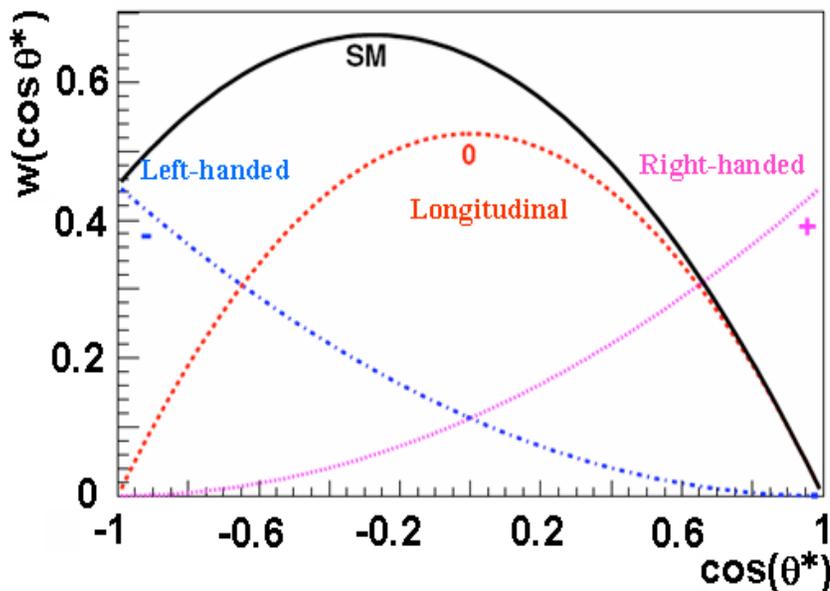


W Helicity

- The V-A nature of the decays:
only 2 helicities allowed
SM : $F_- = 0.3$, $F_0 = 0.7$, $F_+ \approx 0$
- D0 use both $\cos\theta^*$ in lep+jets,
lepton P_t in dilepton

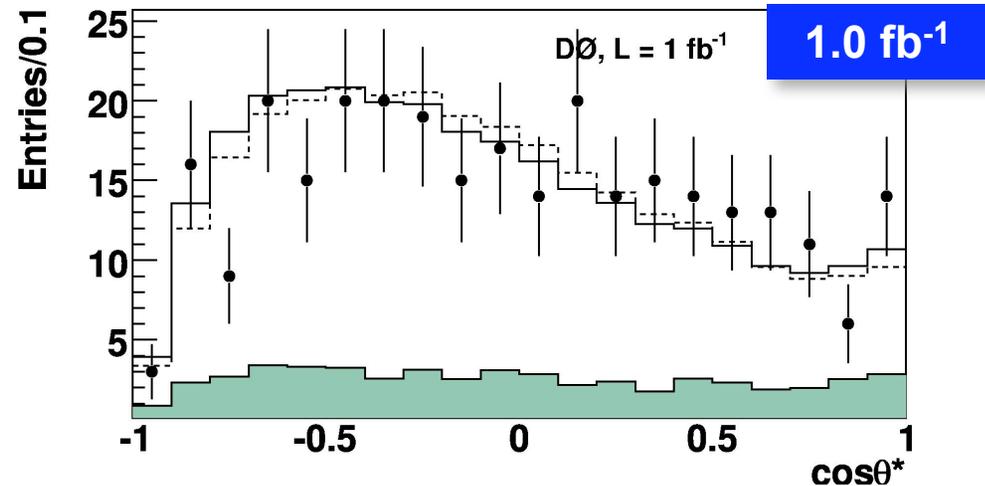


- Simultaneous Fit to F_0 , F_+



$$F_0 = 0.42 \pm 0.17(\text{stat}) \pm 0.10(\text{sys})$$

$$F_+ = 0.12 \pm 0.09(\text{stat}) \pm 0.05(\text{sys})$$

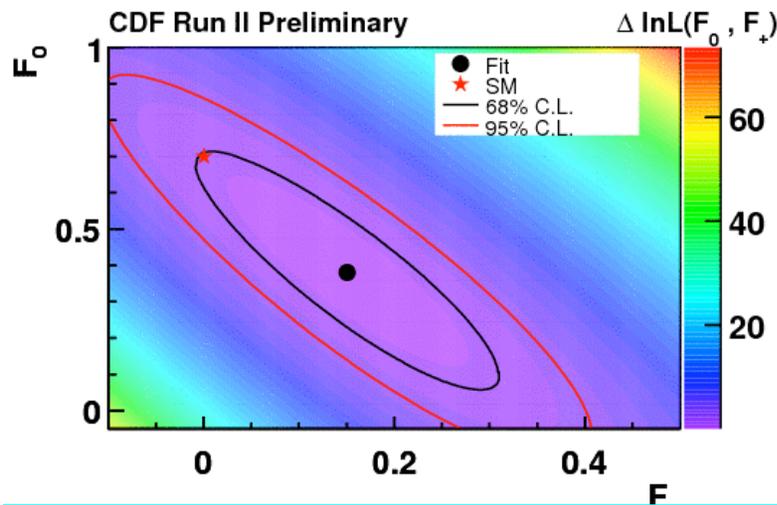




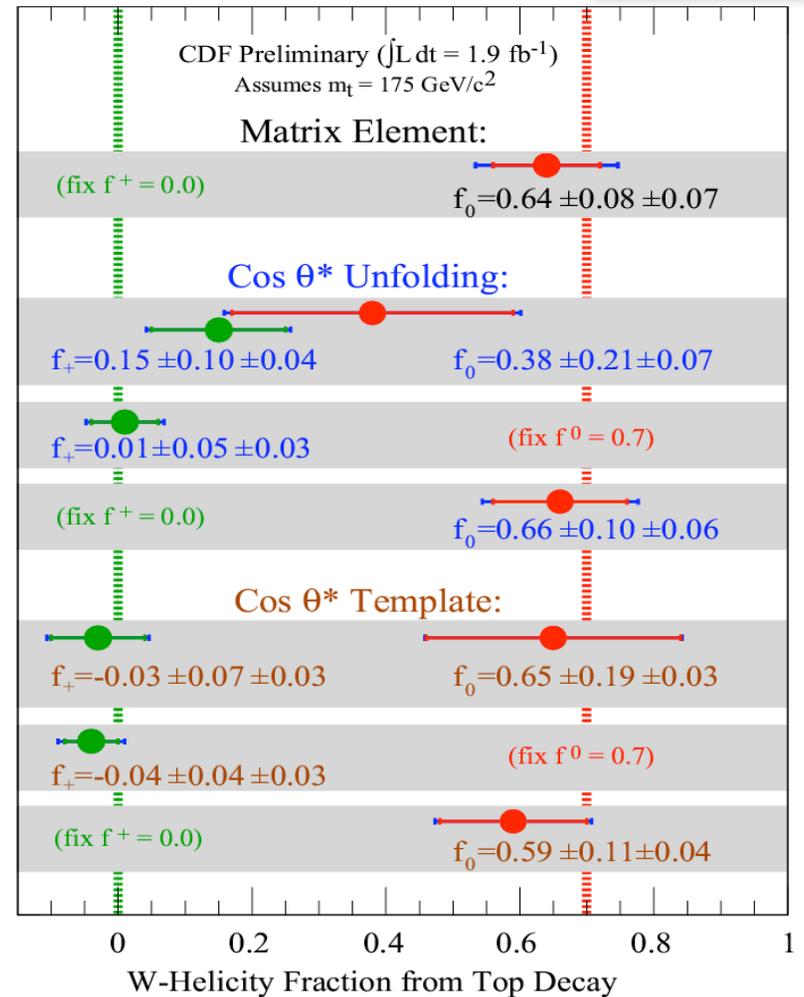
W Helicity

1.9 fb⁻¹

- CDF use two diff. techniques
 - Matrix Element method
 - Fully rec. decays using χ^2 mass fitter
 - $\cos\theta^*$ unfolding
 - $\cos\theta^*$ template
- Simultaneous Fit to F_0, F_+



$F_0 = 0.38 \pm 0.21(\text{stat}) \pm 0.07(\text{sys})$
 $F_+ = 0.15 \pm 0.10(\text{stat}) \pm 0.04(\text{sys})$



Conclusions and Prospects

- Present several Tevatron top physics results
 - Production cross sections:
consistent with SM, toward $<10\%$ precision
 - Many top properties measured:
all consistent with SM
 - But starting to have sensitivity to the unexpected
and new phenomena in the top quark sector
- Tevatron and both CDF and D0 doing very well
at the energy frontier ($\sim 6-9 \text{ fb}^{-1}$ by the end of Run II):
 - A big surprise in top sector before surprise
from LHC? -

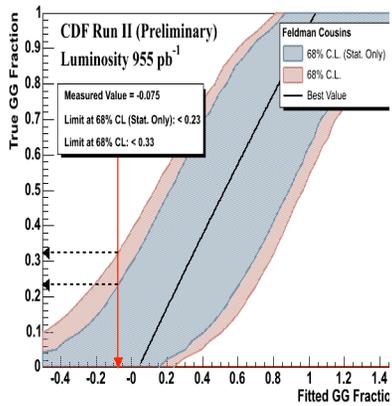
Many More Rich Results

➤ Visit CDF and D0 public areas

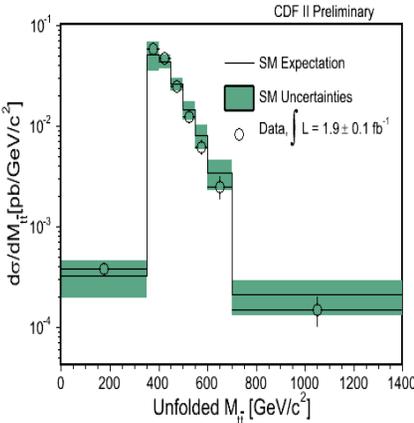
- http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html
- <http://www-cdf.fnal.gov/physics/new/top/top.html>



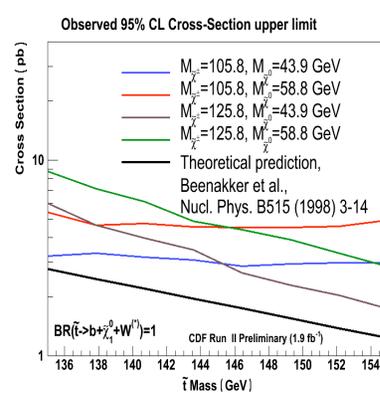
$\sigma(gg \rightarrow tt)/\sigma(qq \rightarrow tt)$



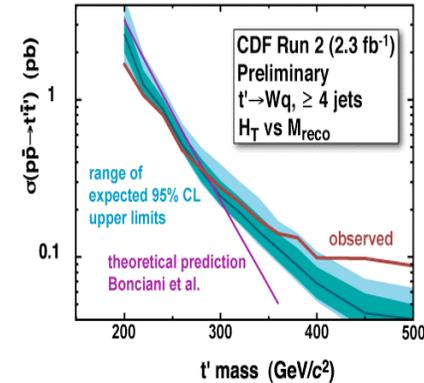
$d\sigma/dM(tt)$



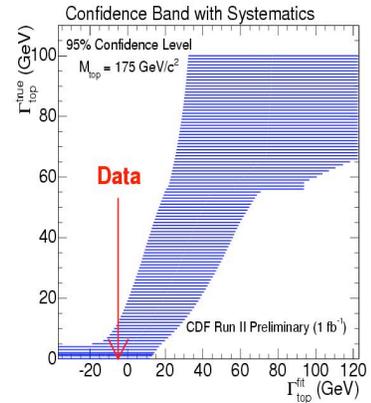
Scalar top



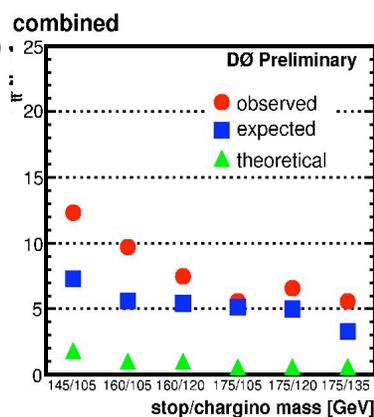
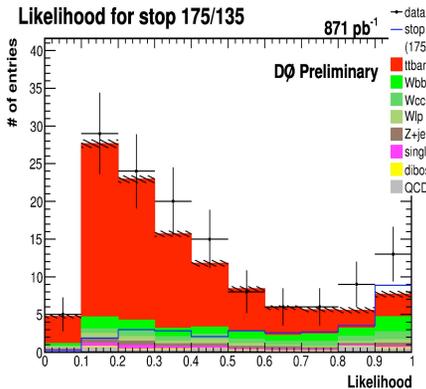
t' search



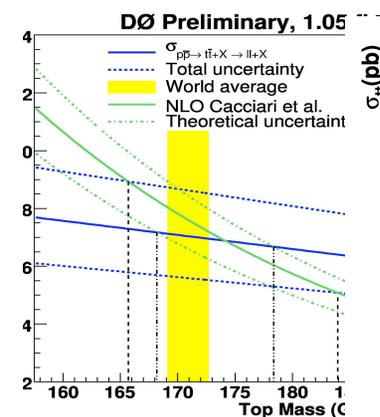
top width



Scalar top



Mt from σ(tt)



R and Vtb

