Top Physics at CDF

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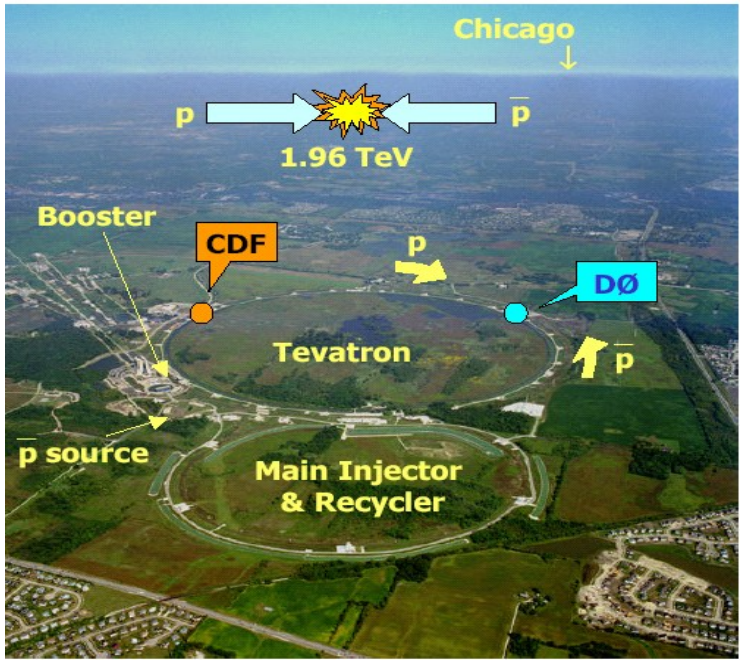
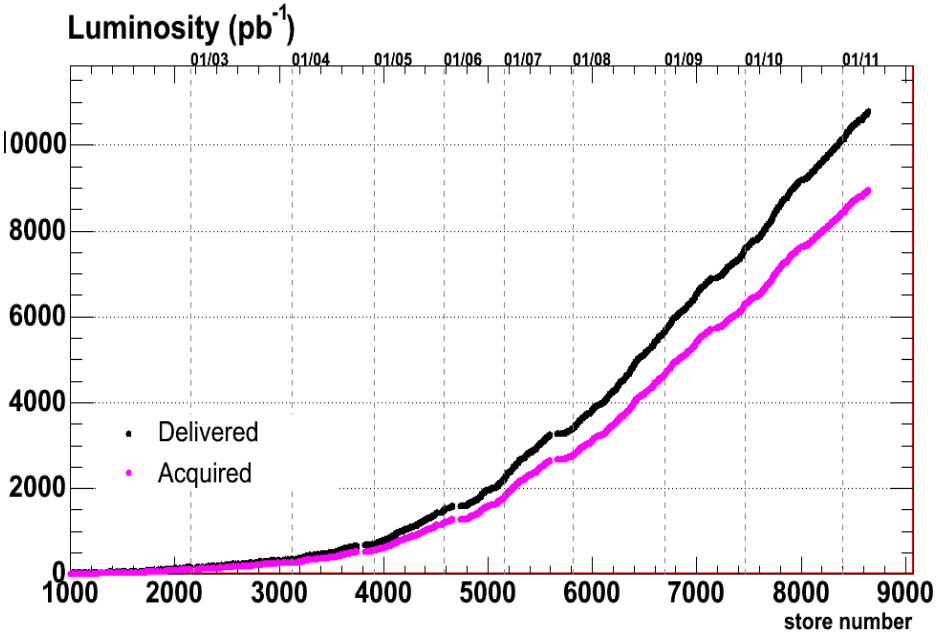
(Seoul National University)

on behalf of
the CDF Collaboration

DIS 2011
(April 11-15)

CDF Experiment and Data

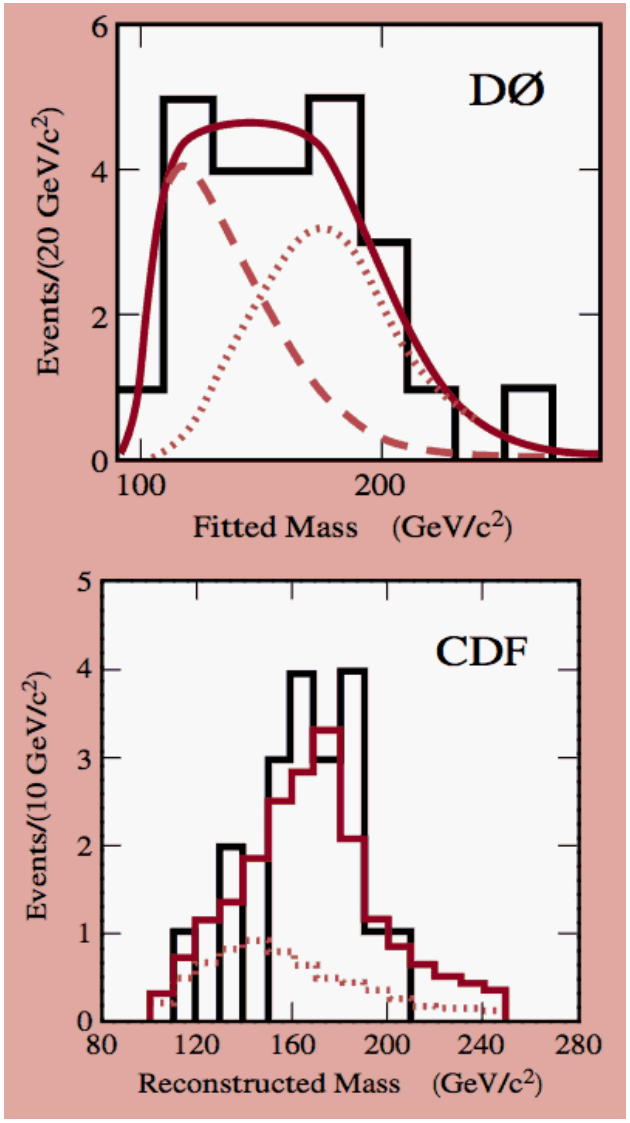




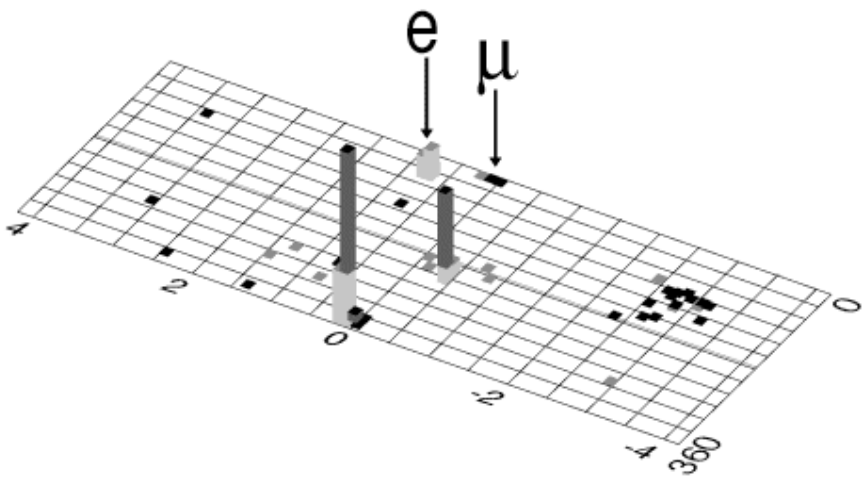
- *Run I (1992~1996): ~110 pb^{-1}, 1.8 TeV*
- *Run II(2001~2010): ~7.0 fb^{-1}, 1.96 TeV*
  - *1 km Radius Ring*
  - *36 x 36 bunches, 396 ns spacing*
  - *280 Billion protons/bunch*
  - *80 Billion anti-p/bunch*
  - *2 million collisions/sec*

	Run II
Delivered	*10.6 fb^{-1}*
Recorded	*9.5 fb^{-1}*
Produced	*8.2 fb^{-1}*
Analyzed	*4~6 fb^{-1}*

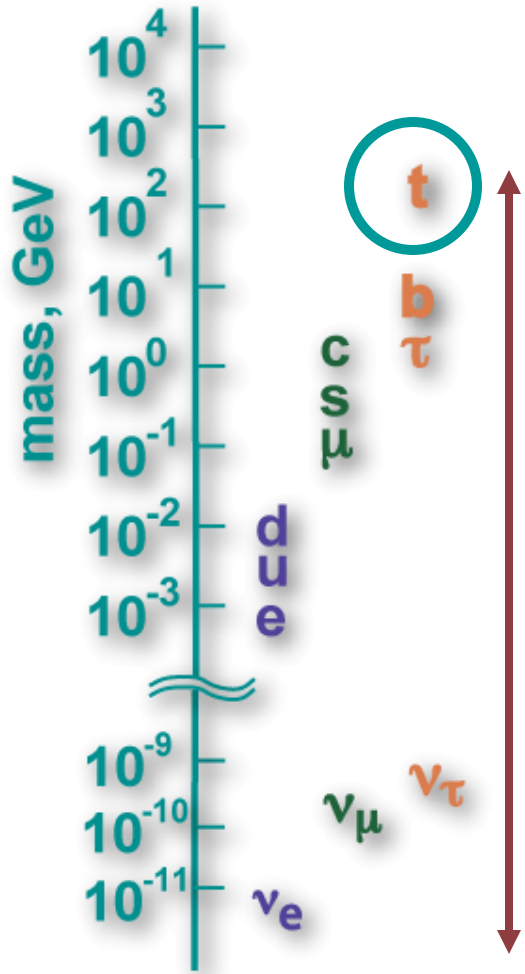
Something about top history



Top Discovery!
Tevatron Run 1
1994-5

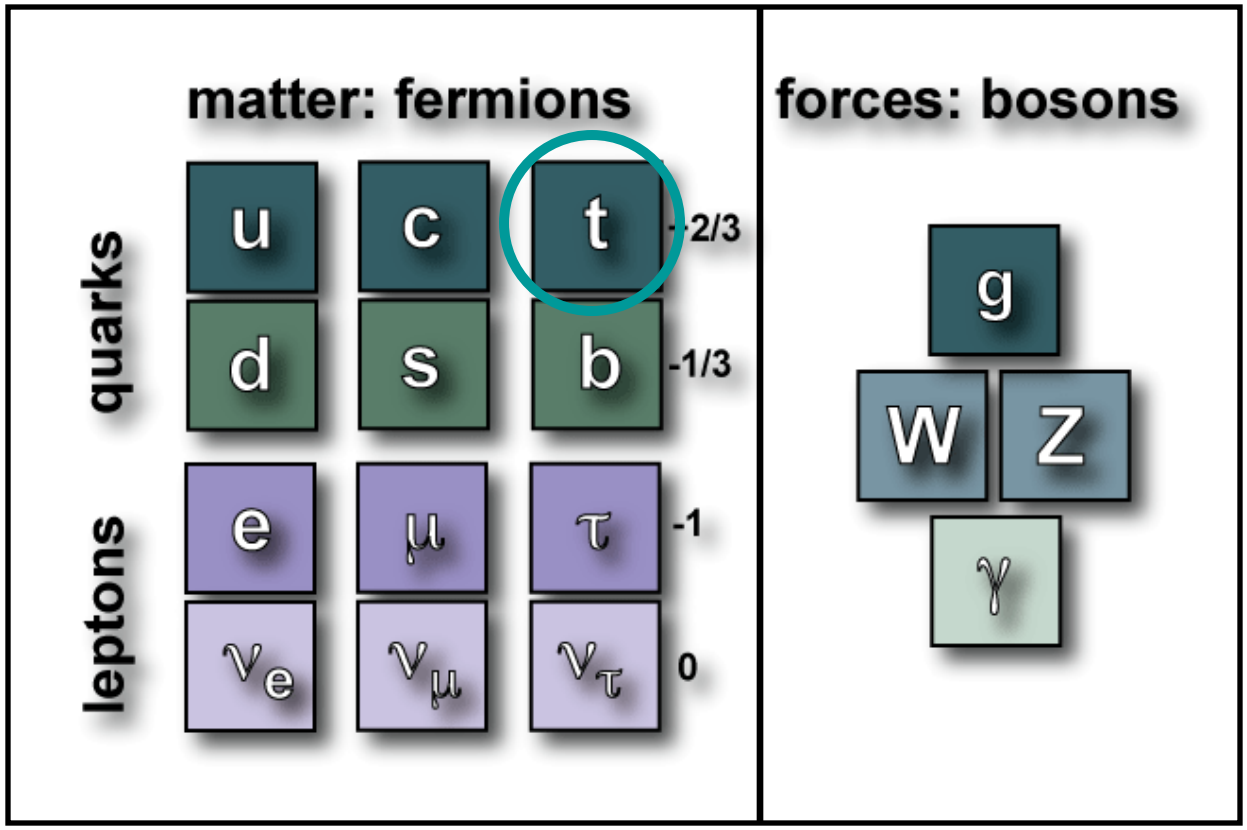


Top quark in the SM



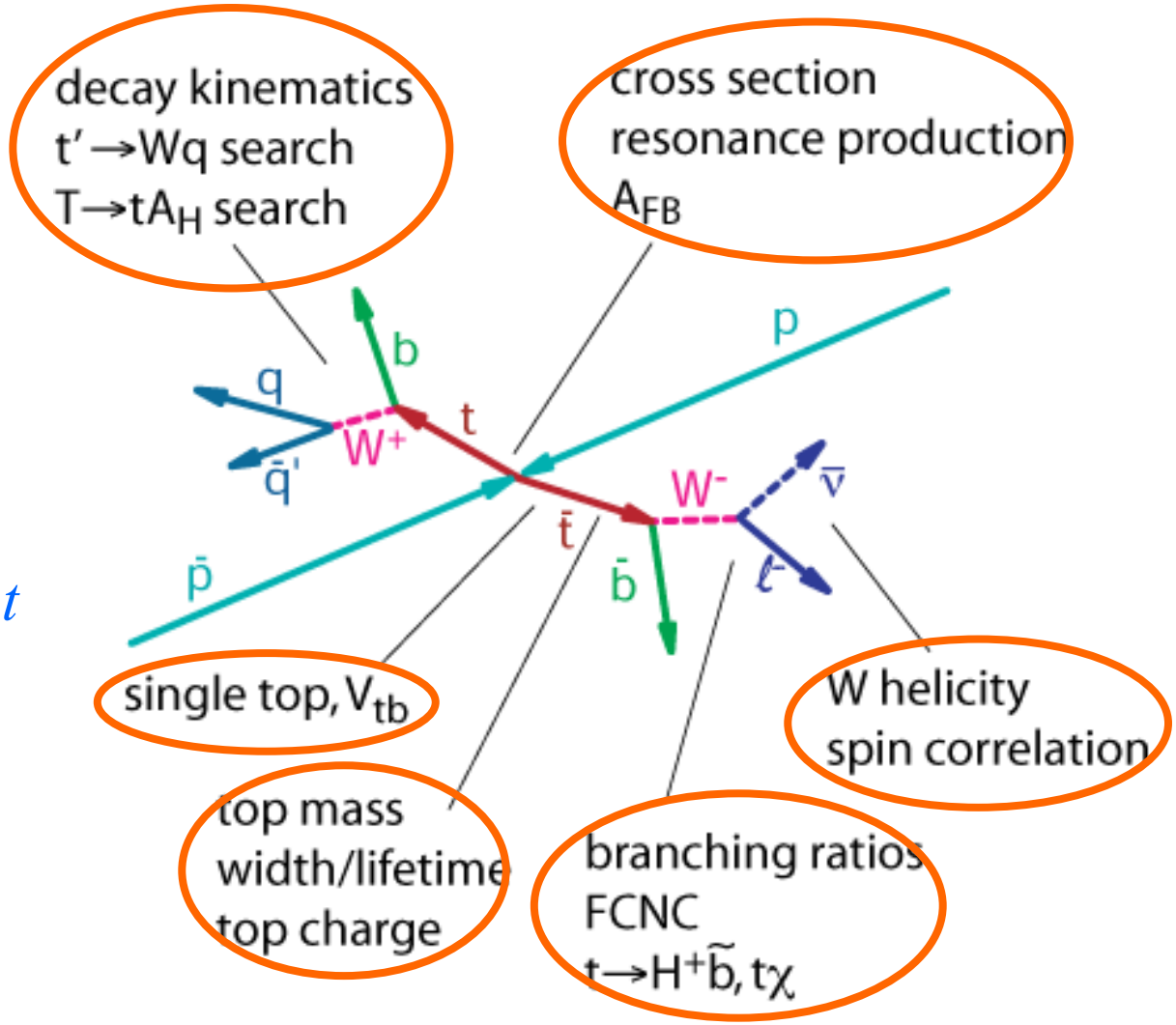
5 orders of magnitude!

Periodic Table of the Particles



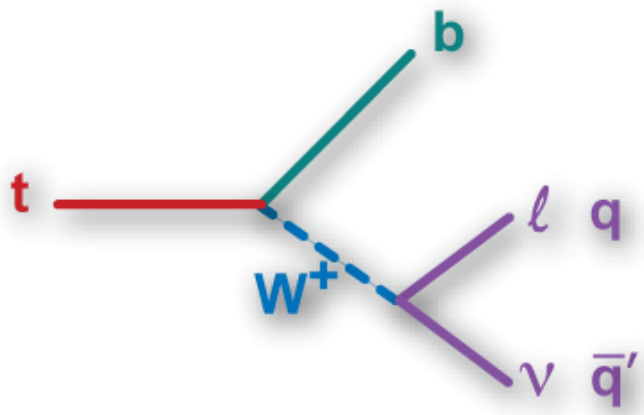
Why Study Top Properties?

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



New Physics?!?

Top quark Decay



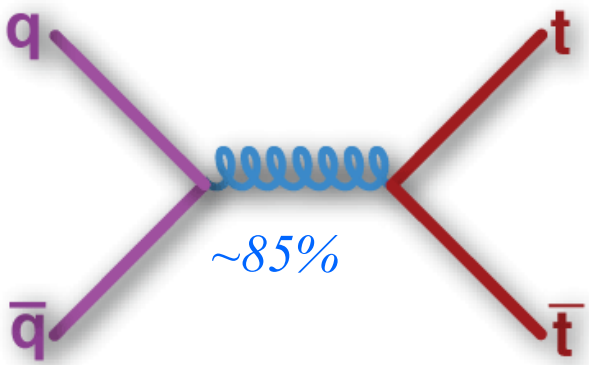
- *In the SM: Br(t →Wb) ~ 100%*
- *Decay channels classified by W decays*
- *Top pair decay channels (l=e,μ)*
  - *Dilepton: lνlνbb (5%)*
  - *Lepton+jets: lνqqbb (30%)*
  - *All-hadronic: qqqqbb (45%)*

Top Pair Decay Channels

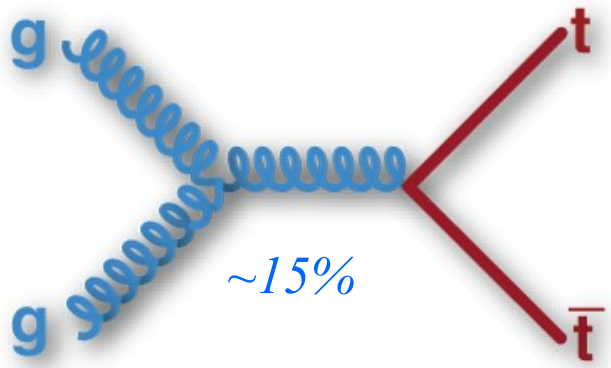
W decay	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$
$\bar{c}s$	electron+jets	muon+jets	tau+jets	all-hadronic	
$\bar{u}d$					
τ^-	eτ	μτ	ττ	tau+jets	
μ^-	eμ	μμ	μτ	muon+jets	
e^-	ee	eμ	eτ	electron+jets	

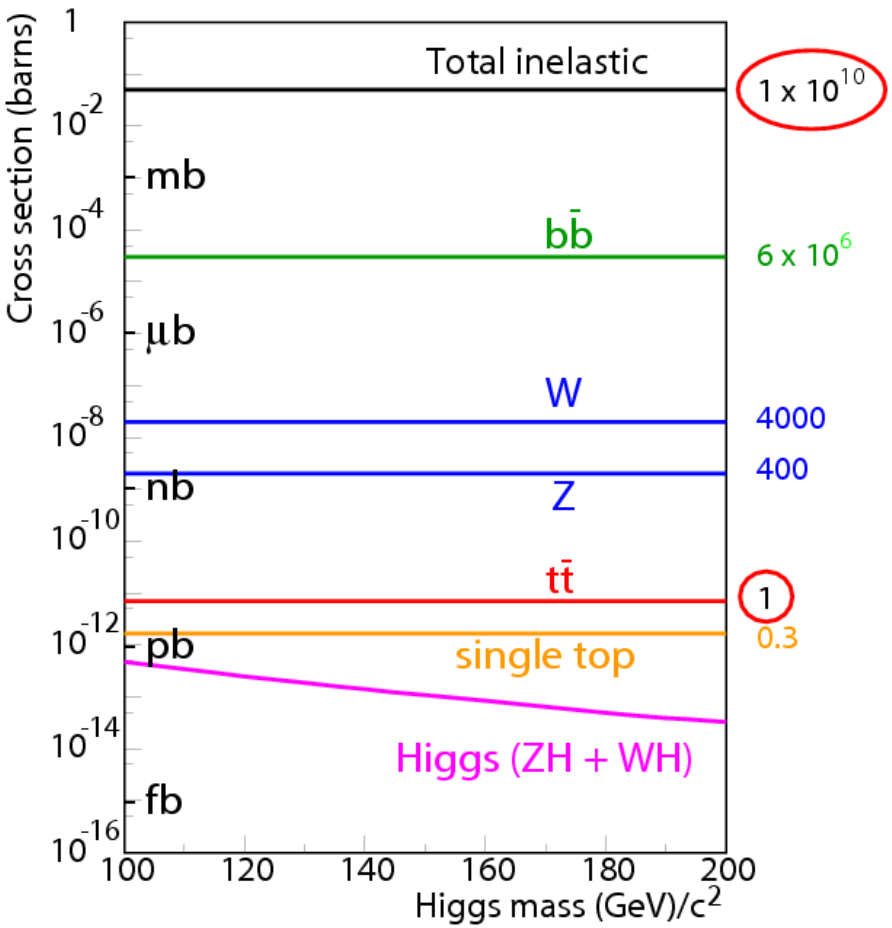
dileptons

How is top produced?



Strong Pair Production at the Tevatron





One top pair each 10^{10} inelastic collisions at $\sqrt{s} = 1.96$ TeV

Top pair production cross section

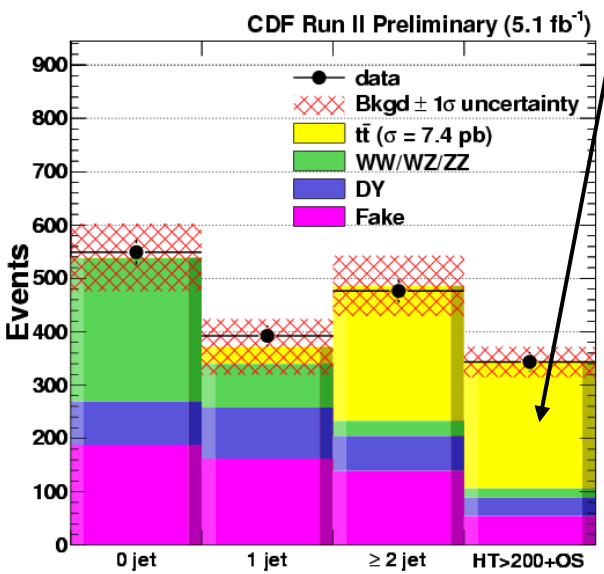
Top Pair Production Cross Section

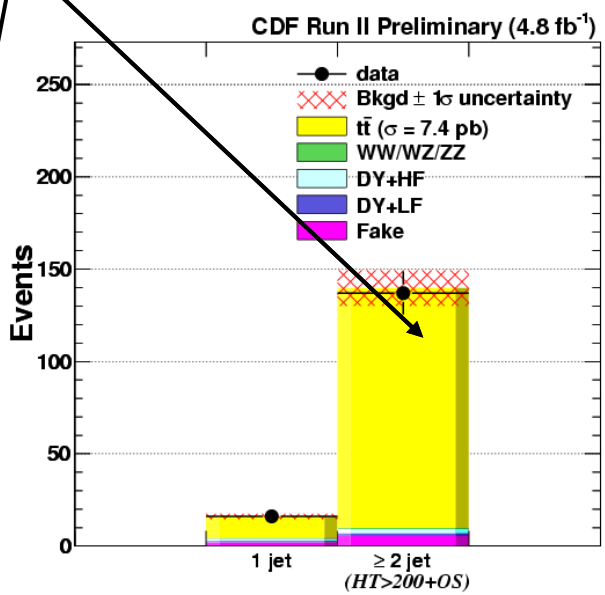
$$\sigma(tt) = \frac{N_{events} - N_{background}}{\mathcal{L}uminosity * \varepsilon}$$

$$\sigma(\bar{p}p \rightarrow t\bar{t} @ M_{top} = 172.5 GeV) \approx 7.4 \text{ pb}$$

t-tbar!

- *Top Pair Production*
- *Cross Section:*
  - *As QCD predicts?*
  - *Only SM top?*
  - *By heavy particles?*

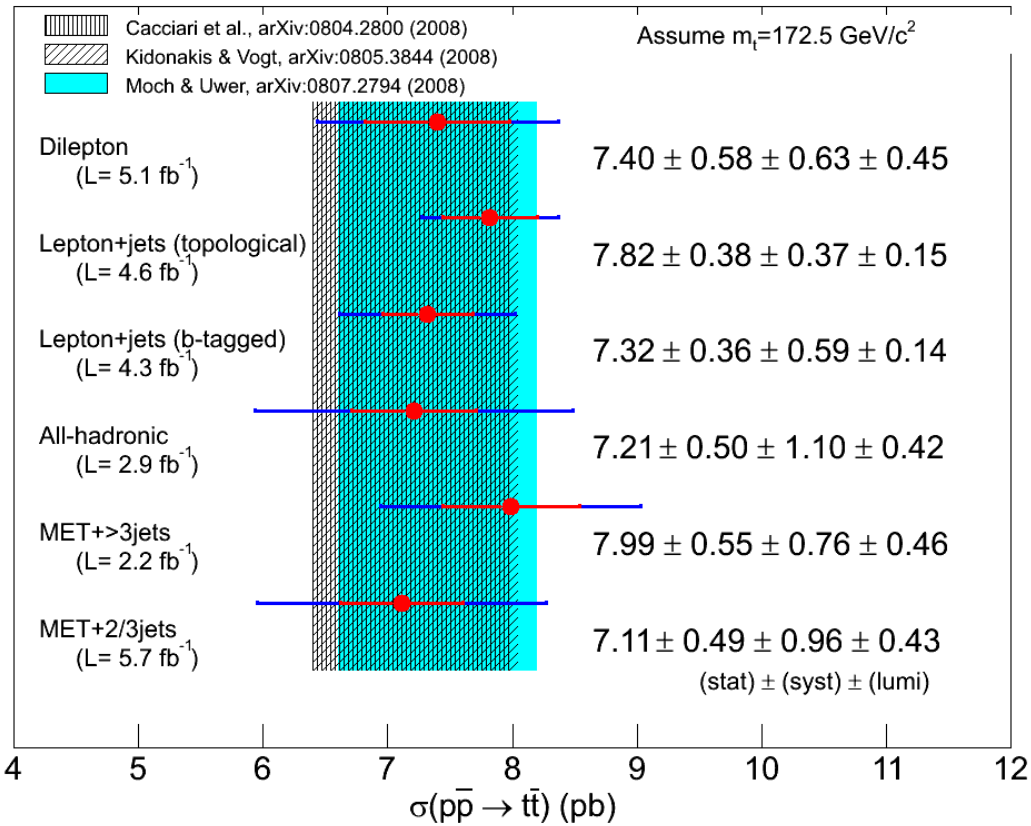


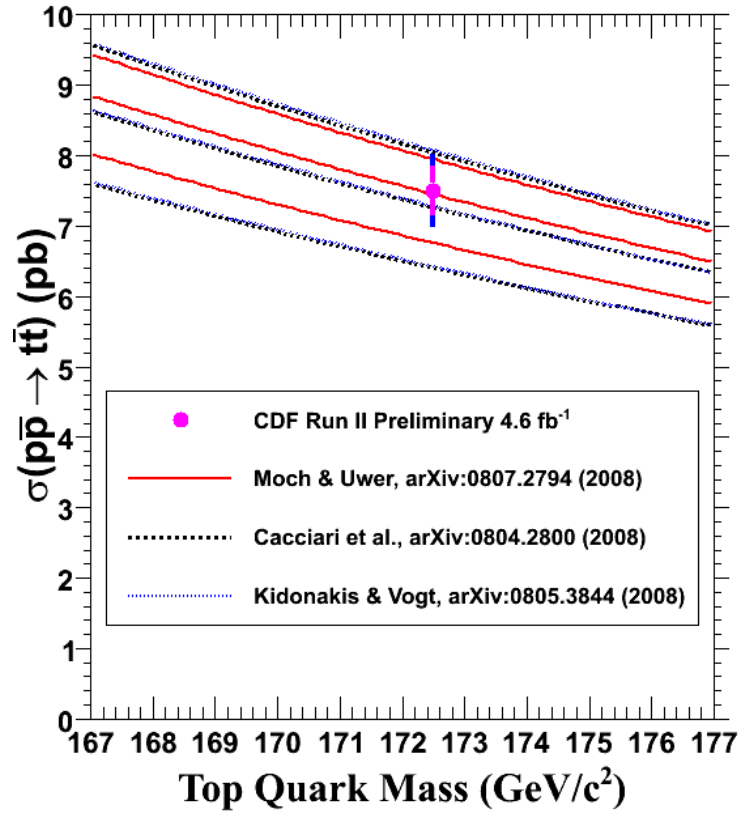


$$\sigma_{t\bar{t}} = 7.40 \pm 0.58(stat) \pm 0.63(syst) \pm 0.45(lumi) pb$$ *(For pre-tag)*

$$\sigma_{t\bar{t}} = 7.25 \pm 0.66(stat) \pm 0.47(syst) \pm 0.44(lumi) pb$$ *(For b-tag)*

Top Pair Production Cross Section

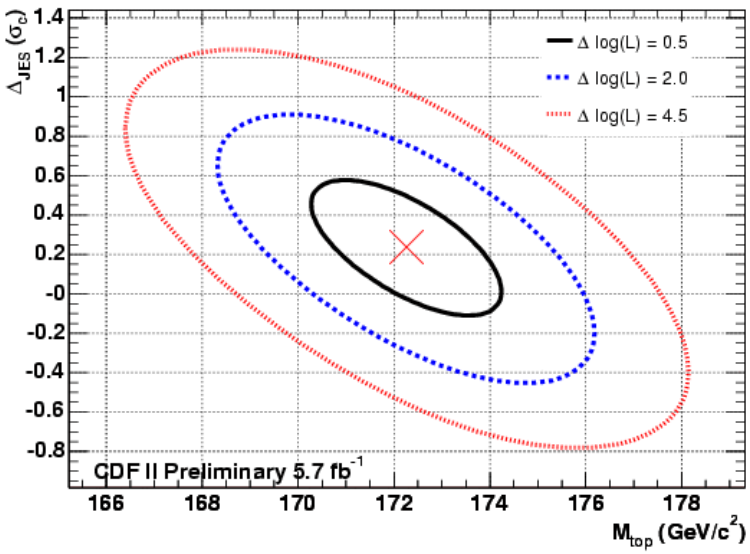


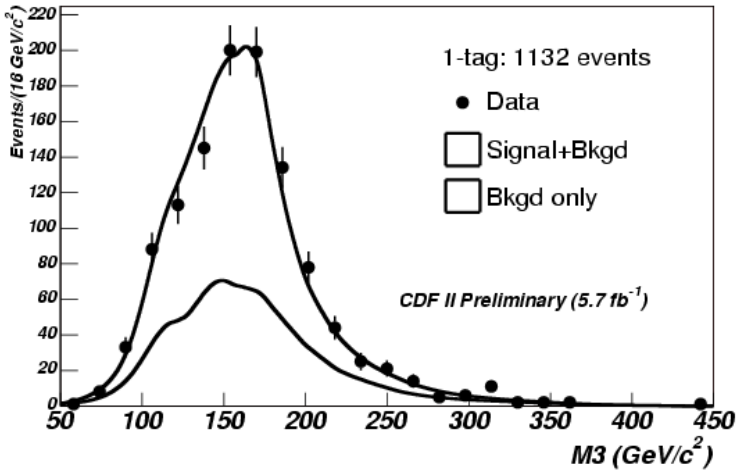


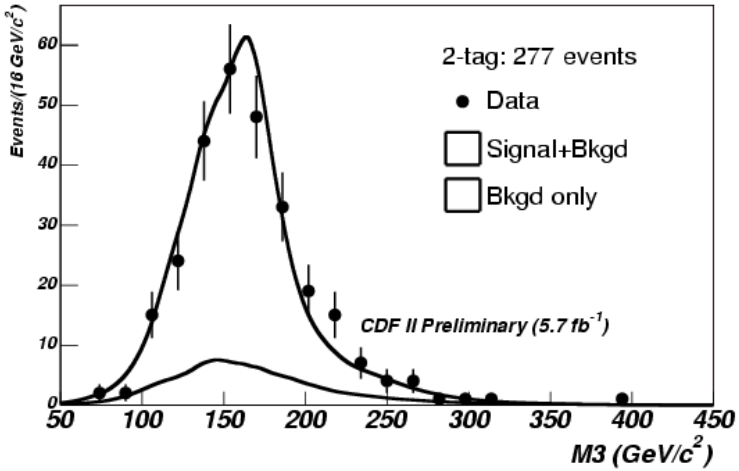
Top quark mass

Top mass in jets + missing E_T

- *Signal is $W \rightarrow \tau\nu$ (hadronic decay) or missing lepton + jets*
  - *Reject events with found leptons*
- *NN selection and template fit to 3 jets of hadronic top decay*





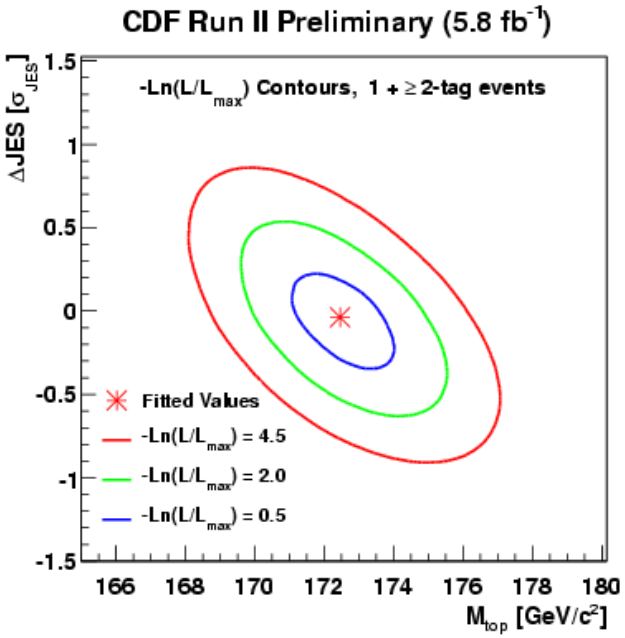


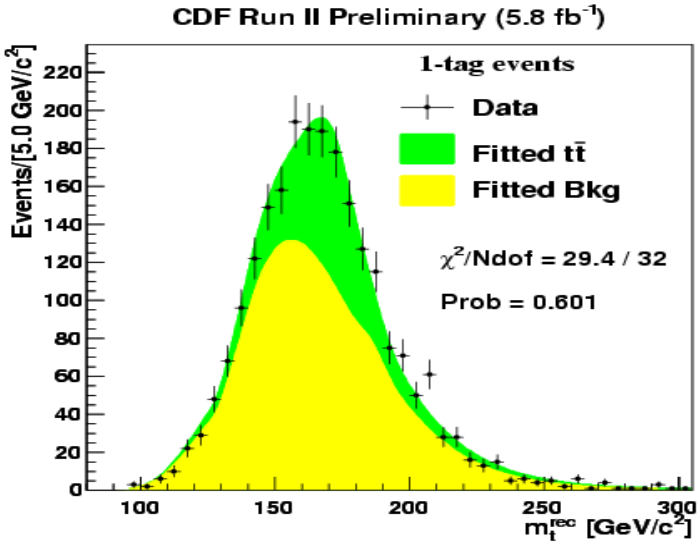
M_{top} = 172.3 ±2.4 (stat.+JES) ±1.0 (syst) GeV/c^2

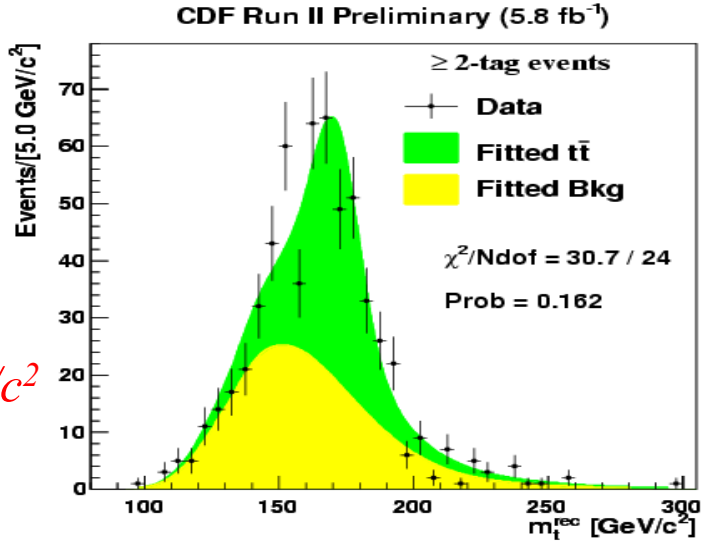
= 172.3 ± 2.6 GeV/c^2

Top mass in all hadronic channel

- *NN selection and Template fit method*
  - *Kinematic fit and b tags pick out best f 24 combinations*



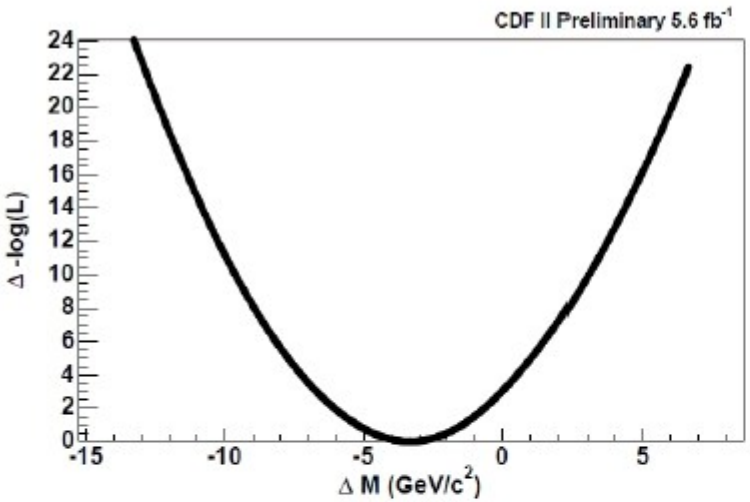


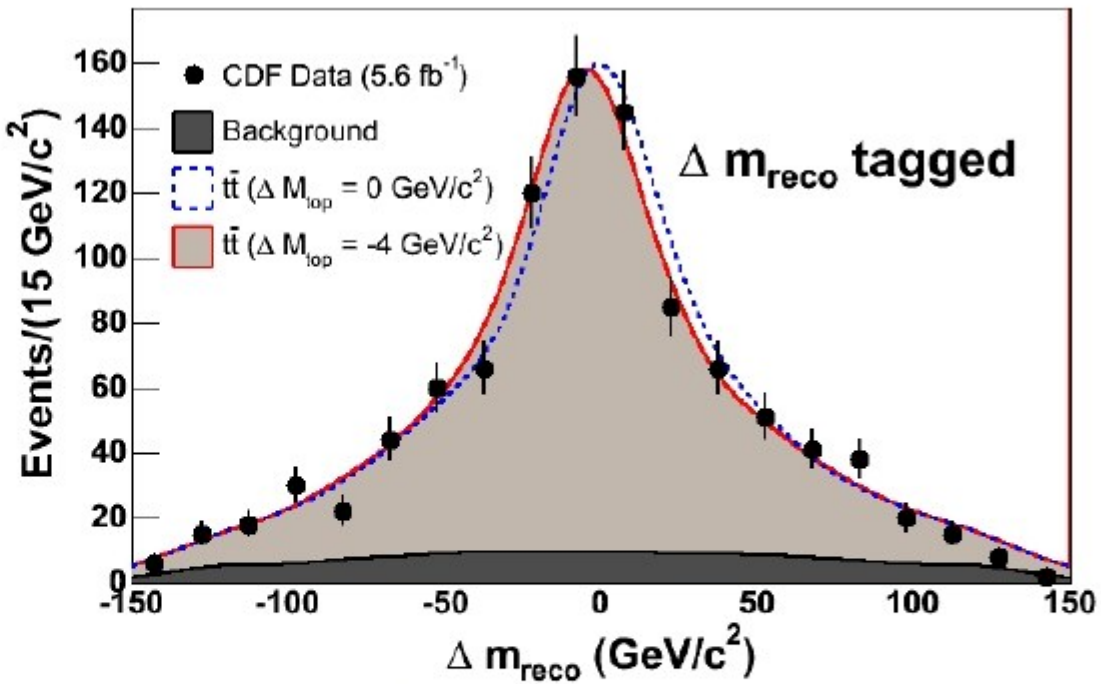


$$M_{top} = 172.5 \pm 1.4\ (stat) \pm 1.0\ (JES) \pm 1.2\ (syst)\ GeV/c^2$$

$$= 172.5 \pm 2.0\ GeV/c^2$$

Mass difference between t and tbar

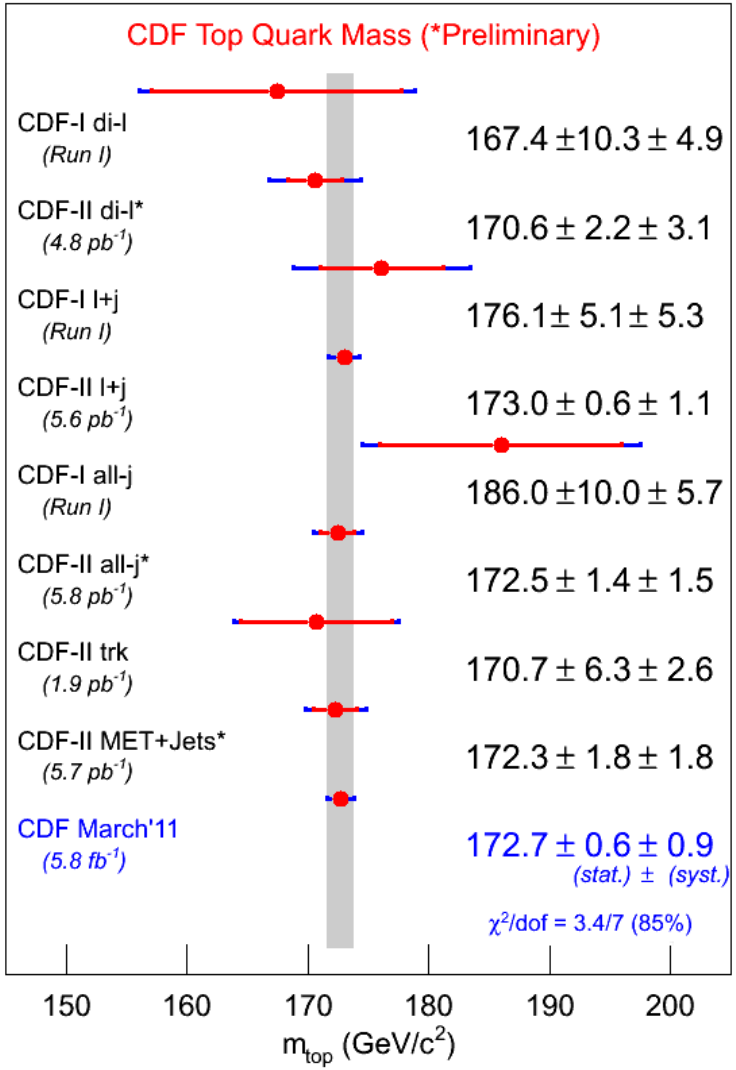


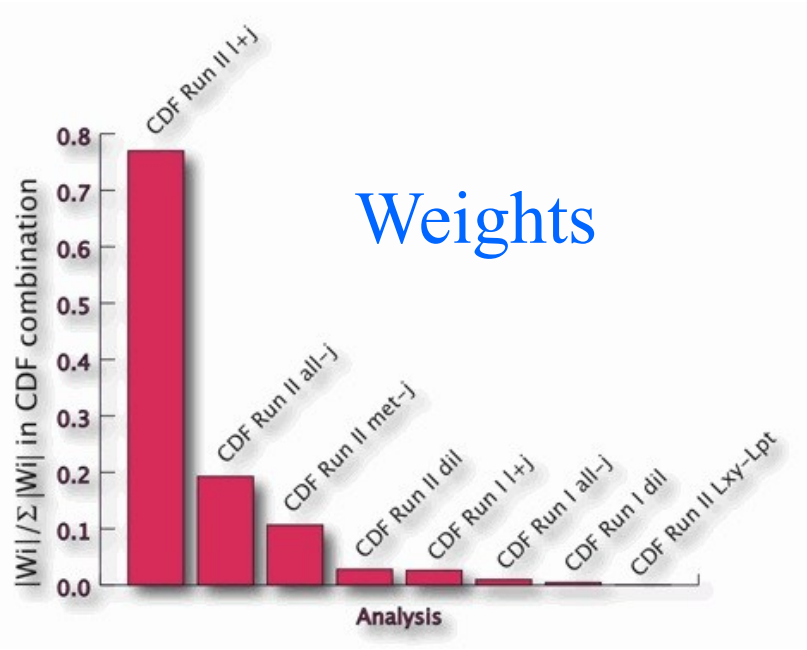


~ 2sigma deviation from standard model

$$-3.3 \pm 1.4\ (\text{stat}) \pm 1.0\ (\text{syst})\ \text{GeV}/c^2$$
$$= -3.3 \pm 1.7\ \text{GeV}/c^2$$

Top quark mass combination





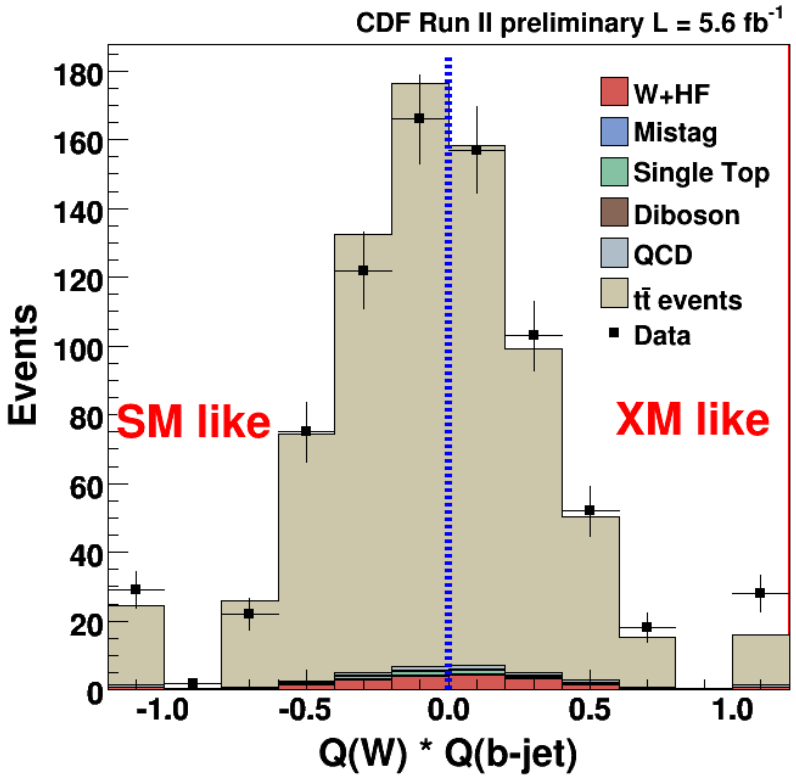
$$M_{top} = 172.70 \pm 1.09\ GeV/c^2$$

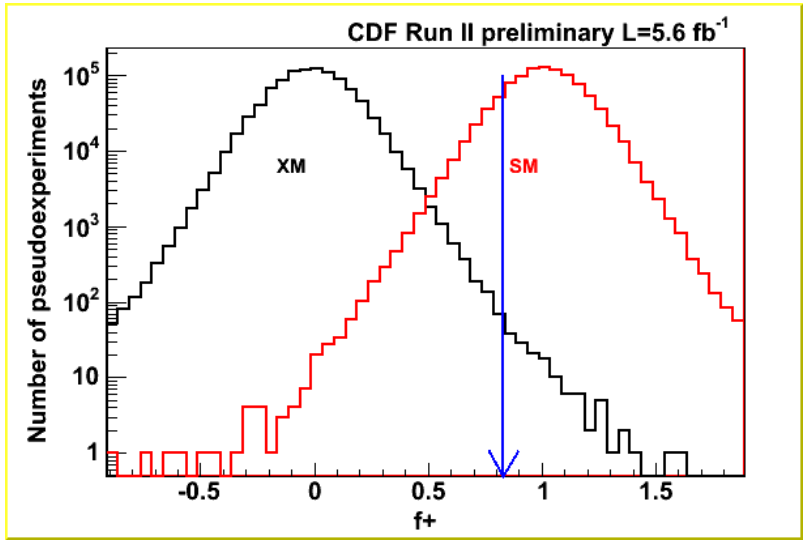
- *Equivalent to a 0.63% precision*
- *Separate channels consistent with each other at >20% level*

Top quark properties

Top quark charge

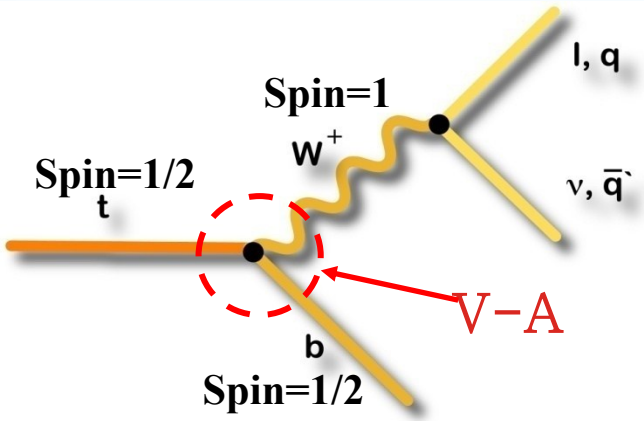
- *Lepton + jets events with two b tags*
- *Use kinematic fit in to choose best combination of W^+b and W^-b*
- *Flavor tag b jets using soft leptons or jet charge*
- *Compare probabilities for Q=+2/3 vs. -4/3 solutions*

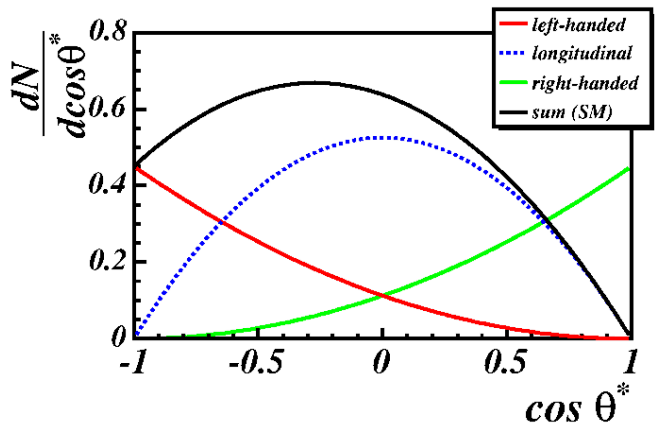




- *Compare to MC trials*
- *Consistent with SM at 13% CL*
- *Exclude Q=-4/3 @95% CL*

W boson polarization in top decay



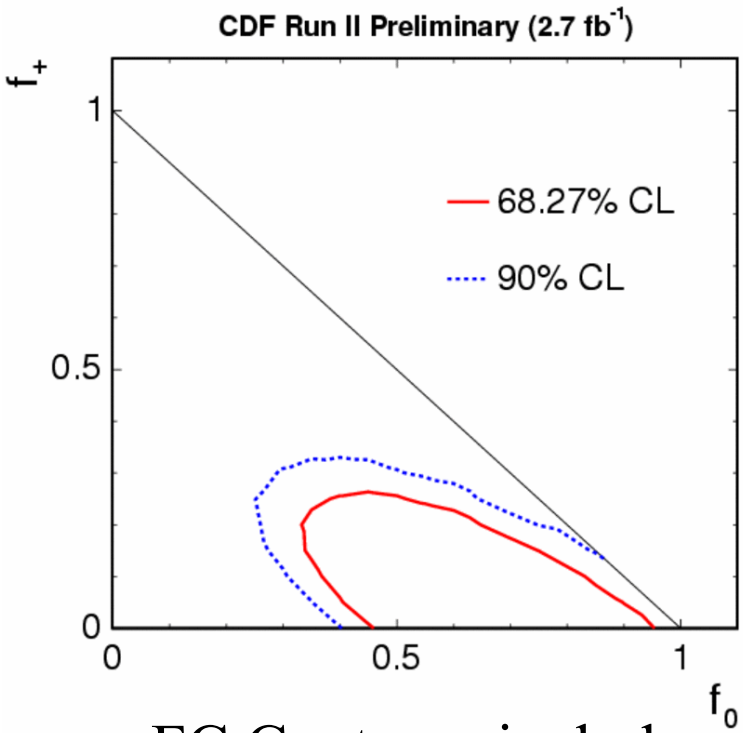


- *The SM top decays via EW interaction: Br(t → bW) ~ 100%*
  - *Top decays as a bare quark ⇒ spin info transferred to final states*
- *V-A coupling in the SM ⇒* $F_0 \equiv BR(t \to W_0 b) \approx \frac{m_t^2}{m_t^2 + 2M_W^2} \approx 70\%, \quad F_- \approx 30\%, \quad F_+ \approx 0\%$
  - *longitudinal fraction f0 ~ 70%*
  - *left-handed fraction f- ~ 30%*
  - *right-handed fraction f+ ~ 0%*
- *The SM prediction modified in various new physics models*
- *W polarization fractions are sensitive to non-SM tWb couplings*
- *Use cos θ* : Angle between lepton (down-type quark) in W rest frame and the momentum of the W in the top-quark rest frame*

Result from lepton+jets events

- *Simultaneous measurement:*
  - $f_0 = 0.88 \pm 0.11$ *(stat)* ± 0.06 *(sys)*
  - $f_+ = -0.15 \pm 0.07$ *(stat)* ± 0.06 *(syst)*
  - *Correlation coefficient of -0.59*
  - *As measured central values are unphysical use Feldman Cousins (FC) method to obtain confidence level intervals*

- *Model dependent measurements:*
  - $f_0 = 0.70 \pm 0.07$ *(stat)* ± 0.04 *(syst) constraining* $f_+ = 0.0$
  - $f_+ = -0.01 \pm 0.02$ *(stat)* ± 0.05 *(syst) constraining* $f_0 = 0.7$
    - *Upper limit at 95% CL :* $f_+ < 0.12$



FC Contours include stat+syst uncertainties

Published for PRL publication FERMILAB-PUB-10-041-E,
Phys. Rev. Lett. **105**, 042002 (2010)

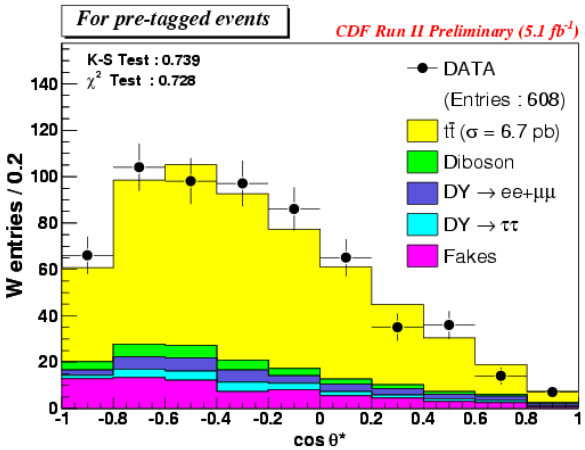
Result from dilepton events

- *Used 343 pre-tagged di-lepton candidates (304 passed reconstruction) with 5.1 fb^{-1} and 137 b-tagged events (118 passed reconstruction) with 4.8 fb^{-1}*

- *Simultaneous measurement:*
  - *Before b-tagging :* $f_0^{2D} = 0.73 \,^{+\,0.18}_{-\,0.17}(\mathrm{stat}) \pm 0.06(\mathrm{syst})$

    $f_+^{2D} = -0.08 \pm 0.09(\mathrm{stat}) \pm 0.03(\mathrm{syst})$
  - *After b-tagging :* $f_0^{2D} = 0.78 \,^{+\,0.19}_{-\,0.20}(\mathrm{stat}) \pm 0.06(\mathrm{syst})$

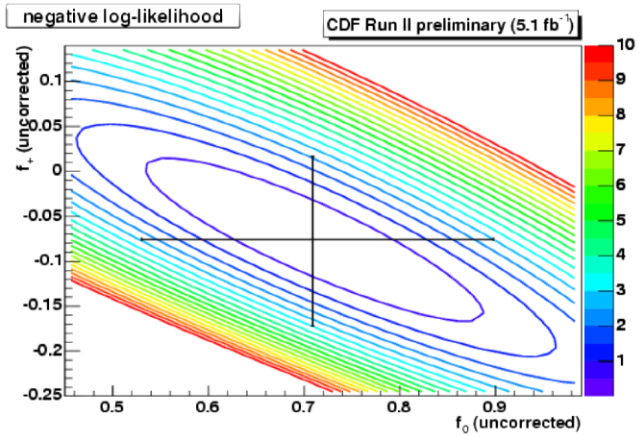
    $f_+^{2D} = -0.12 \,^{+\,0.11}_{-\,0.10}(\mathrm{stat}) \pm 0.04(\mathrm{syst})$



- *Model dependent measurements:*
  - *Before b-tagging :* $f_0^{1D} = 0.60 \pm 0.09(\mathrm{stat}) \pm 0.06(\mathrm{syst})$

    $f_+^{1D} = -0.06 \pm 0.04(\mathrm{stat}) \pm 0.03(\mathrm{syst})$
  - *After b-tagging A* $f_0^{1D} = 0.62 \pm 0.11(\mathrm{stat}) \pm 0.06(\mathrm{syst})$

    $f_+^{1D} = -0.07 \,^{+\,0.06}_{-\,0.05}(\mathrm{stat}) \pm 0.03(\mathrm{syst})$
  - *Determined upper limit on f+<0.07 at 95% CL*

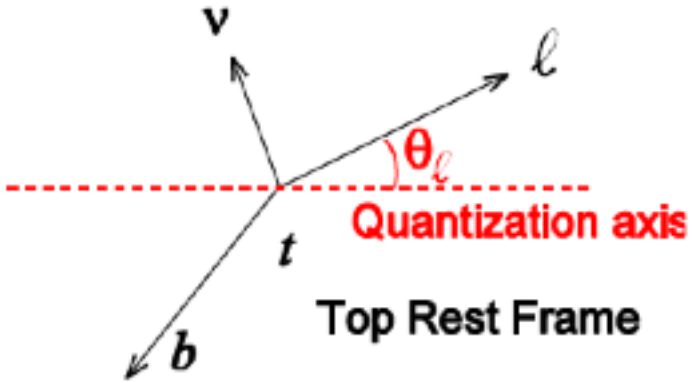


Spin Correlations in L+Jets Channel

- *Decay product momenta distributed according to*

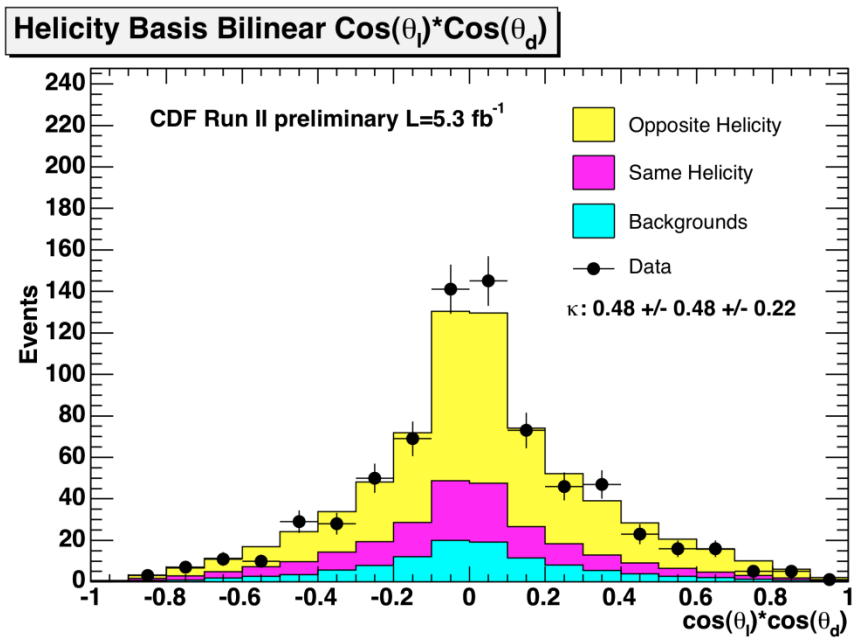
$$f_{\uparrow,\downarrow}(\cos\theta_i) = \frac{1}{2}(1 \pm A_i \cos\theta_i)$$

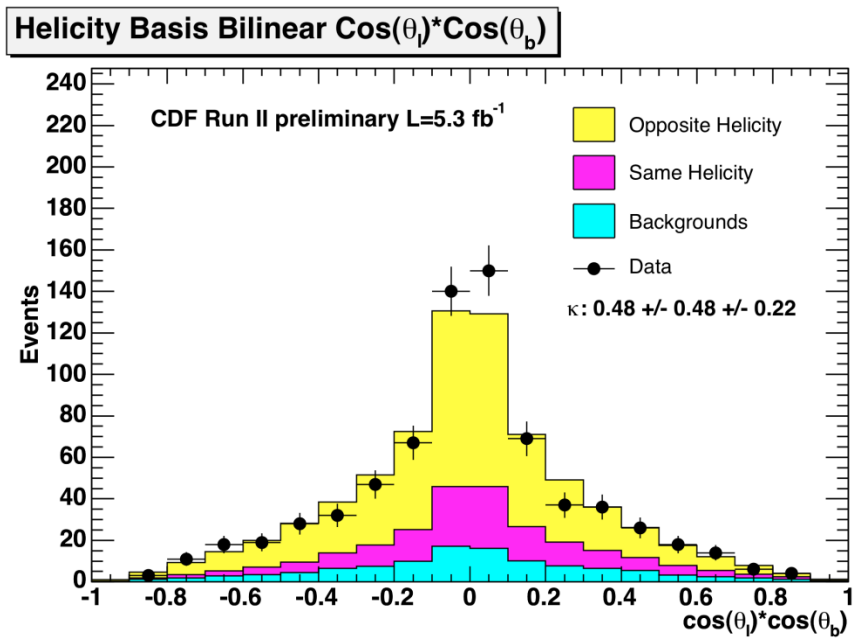
  - *θ_i is angle between decay product momentum and chosen spin quantization axis*
  - *Analyzing power A_i is the strength of the correlation between the decay product momentum and the top spin*
    - *G. Mahlon and S. Parke, Phys. Rev.**D 53**, 4886 (1996)*



Decay Product	Analyzing Power A_i
Lepton	+1.0
Down	+1.0
Bottom	-0.41
Up	-0.31
Neutrino	-0.31

Results In Helicity Basis





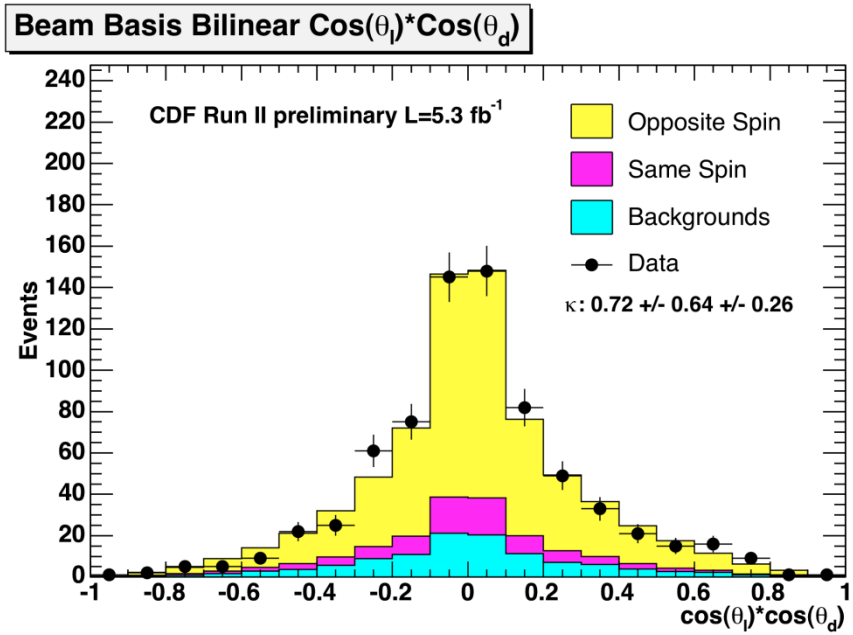
$$F_{OH} = 0.74 \pm 0.24_{stat} \pm 0.11_{syst}$$

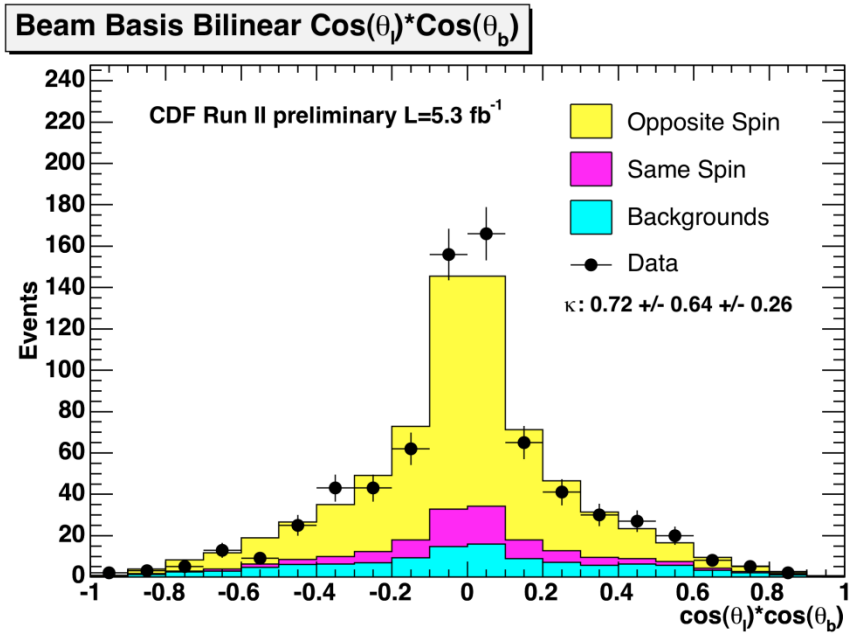
$$F_{OH}^{Theory} = 0.675$$

$$\kappa_{helicity} = 0.48 \pm 0.48_{stat} \pm 0.22_{syst}$$

$$\kappa_{helicity}^{Theory} = 0.35$$

Results In Beamline Basis





$$F_{OS} = 0.86 \pm 0.32_{stat} \pm 0.13_{syst}$$

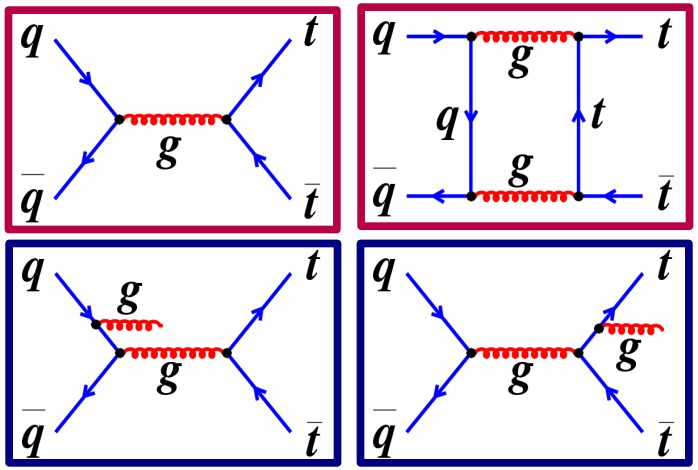
$$F_{OS}^{Theory} = 0.885$$

$$\kappa_{beam} = 0.72 \pm 0.64_{stat} \pm 0.26_{syst}$$

$$\kappa_{beam}^{Theory} = 0.77$$

Forward Backward Asymmetry (A_{FB})

- *Asymmetry caused by interference of ME amplitudes for same final state*

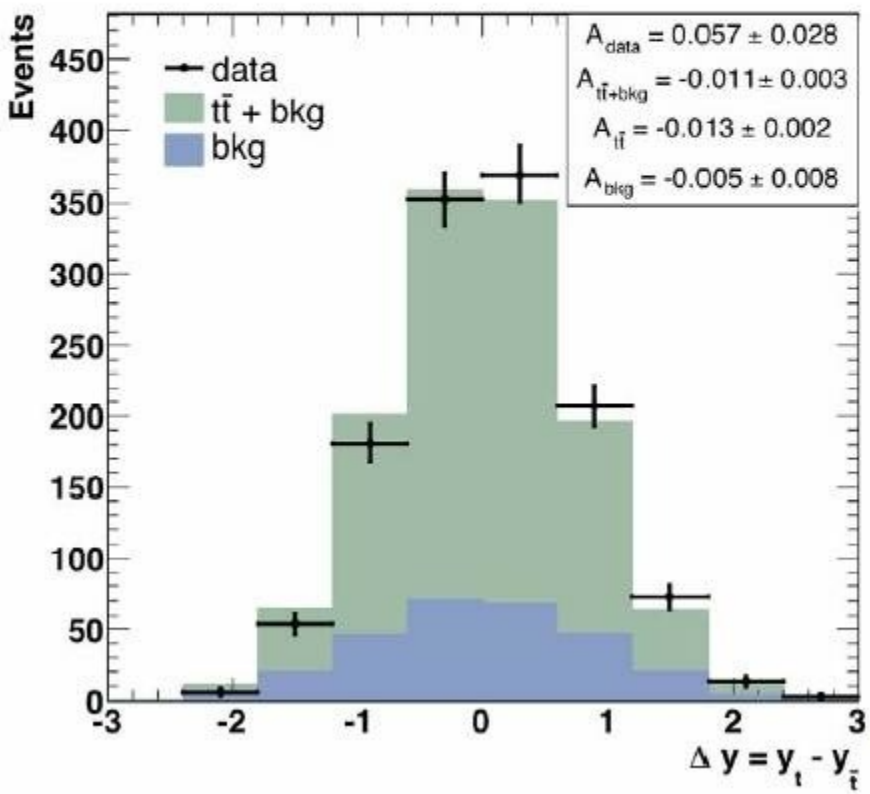


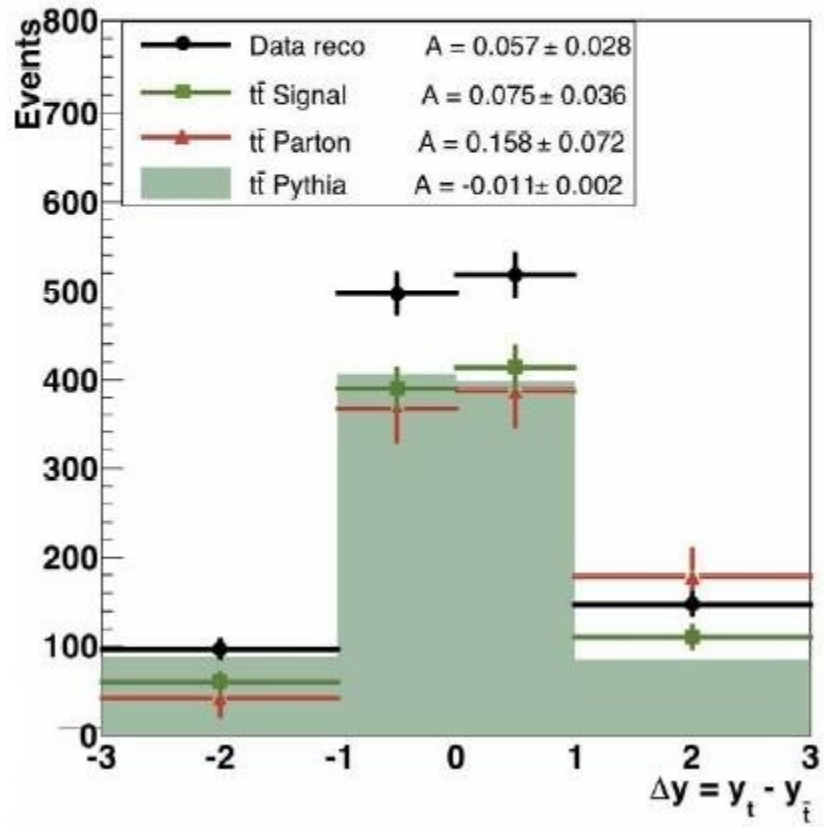
- *The SM prediction:*
  - *In ttbar frame: Afbttbar = 0.05 ± 0.015 (QCD at NLO)*

- *Can be significantly enhanced in different BSM models:*
  - *Z'-like states with parity violating coupling (PLB 387, 113 (1996)), theories with chiral color (PLB 190, 157 (1987), PLB 200, 211(1988))*

L+jets result ($5.3fb^{-1}$)

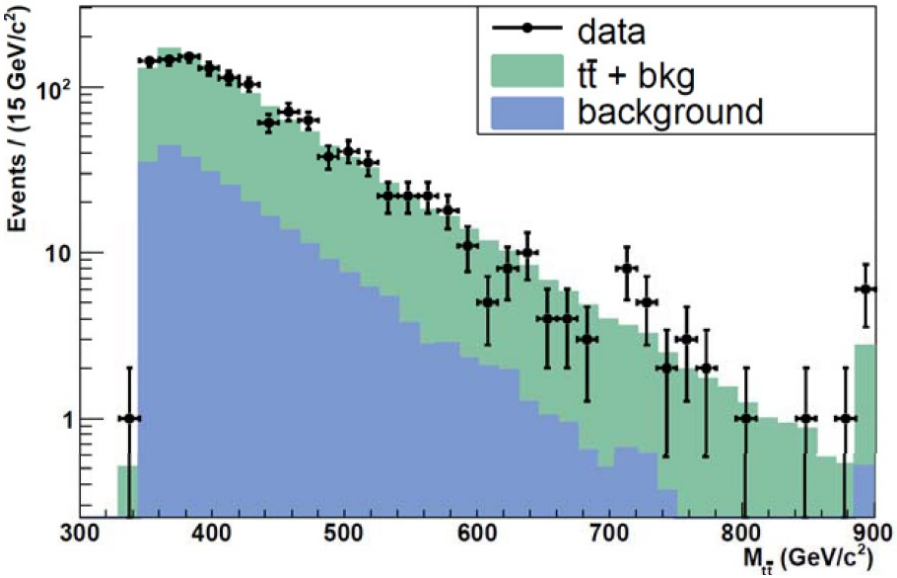
- $\Delta Y(= y_t - y_{tbar})$
- *Background subtracted, then unfolded back to parton level*
- $A^{ttbar} = 0.158 \pm 0.074$

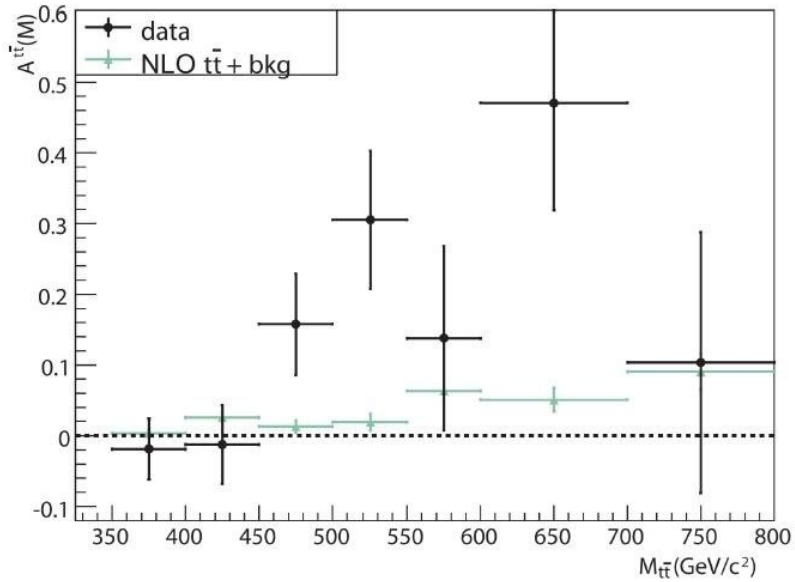




L+jets result ($5.3fb^{-1}$)

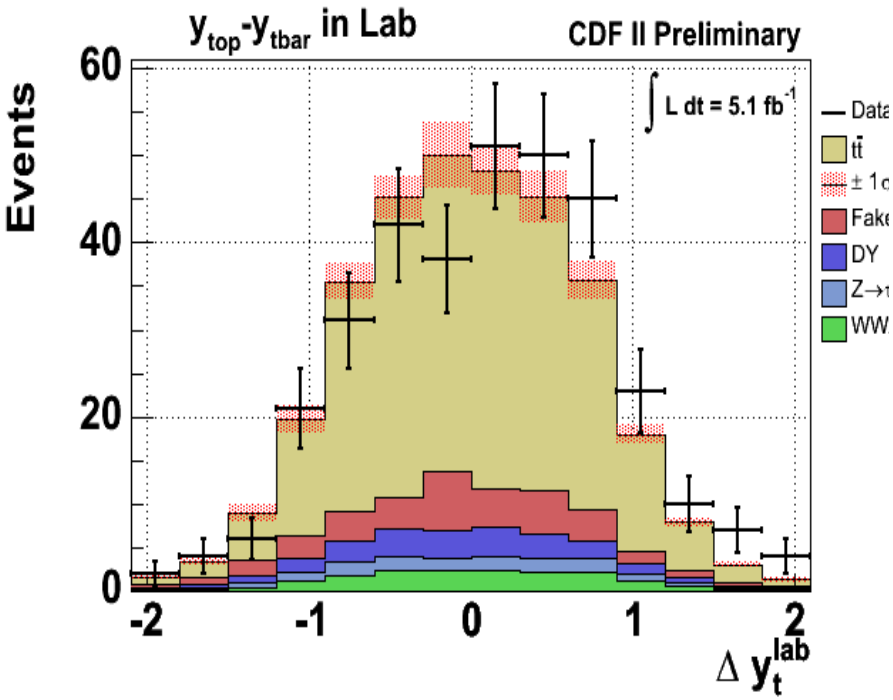
- *Found A_{FB} has a strong dependence on M_{tt}*
- *Many possible theoretical scenarios where A_{FB} depends on M_{tt}*

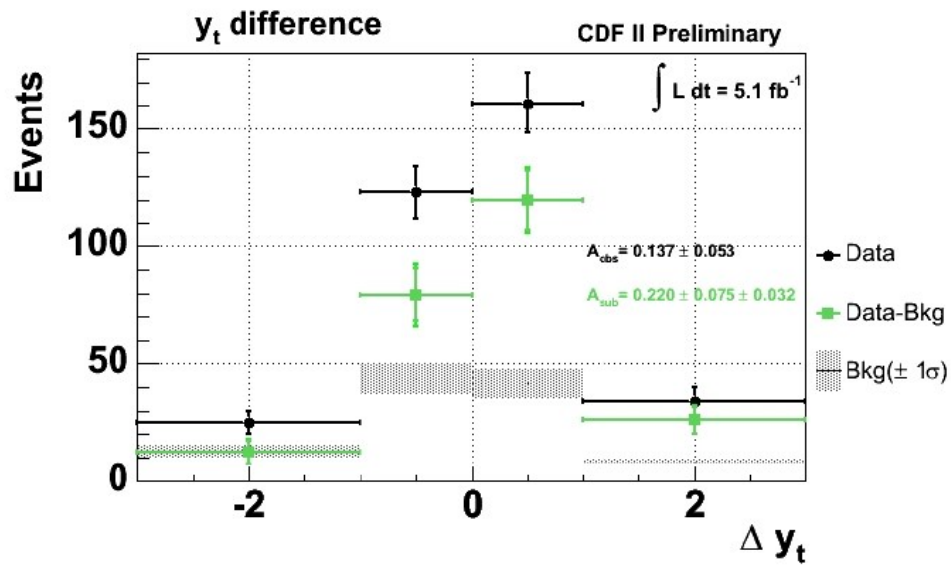




selection	all M	$M < 450$ GeV/c^2	$M \geq 450$ GeV/c^2
reco data	0.057±0.028	-0.016±0.034	0.212±0.049
MC@NLO	0.017±0.004	0.012±0.006	0.030±0.007

Dilepton results ($5.1 fb^{-1}$)





- $A_{\text{obs}} = 0.137 \pm 0.053(\text{stat.})$
- $A_{\text{sub}} = 0.220 \pm 0.075(\text{stat.}) \pm 0.032(\text{bkg shape})$

$$\Downarrow$$

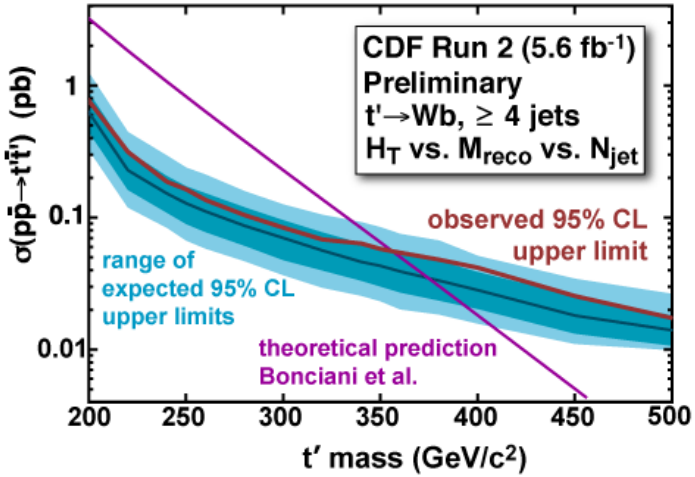
$$A_{\text{true}} = 0.445 \pm 0.152(\text{stat.}) \pm 0.065(\text{bkg shape})$$

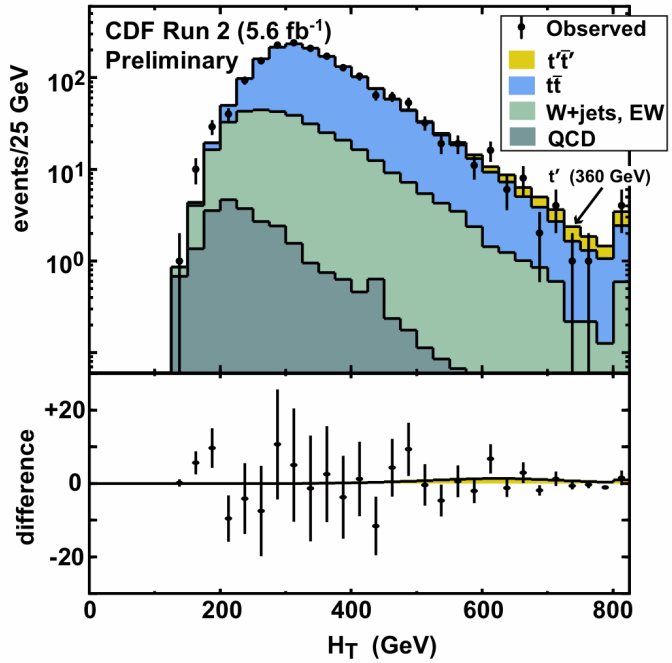
Confirms observation in L+jets !!

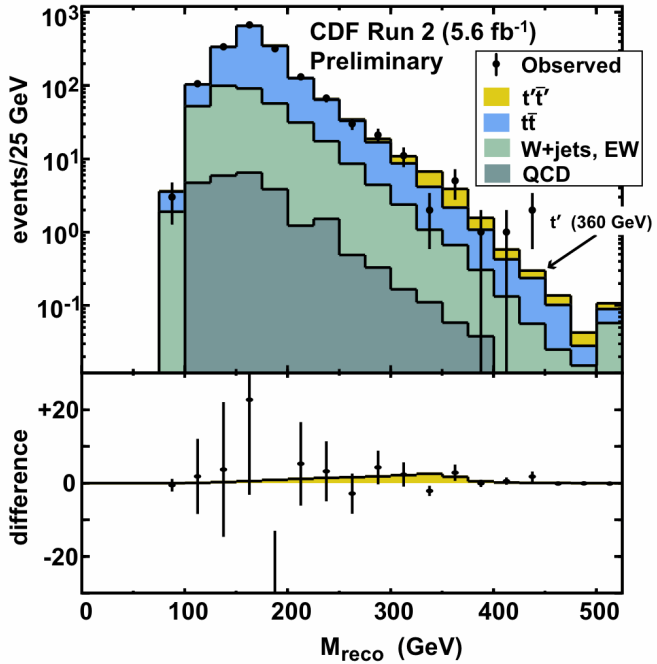
Searches in the Top Sector

Search for $t' \rightarrow Wb$

- *4th Generation not excluded*
- *Can explain A_{FB}*
- *Reconstruct like SM top in W+jets*
- *Exclude standard model 4th-generation t' with M<358 GeV at 95% CL.*

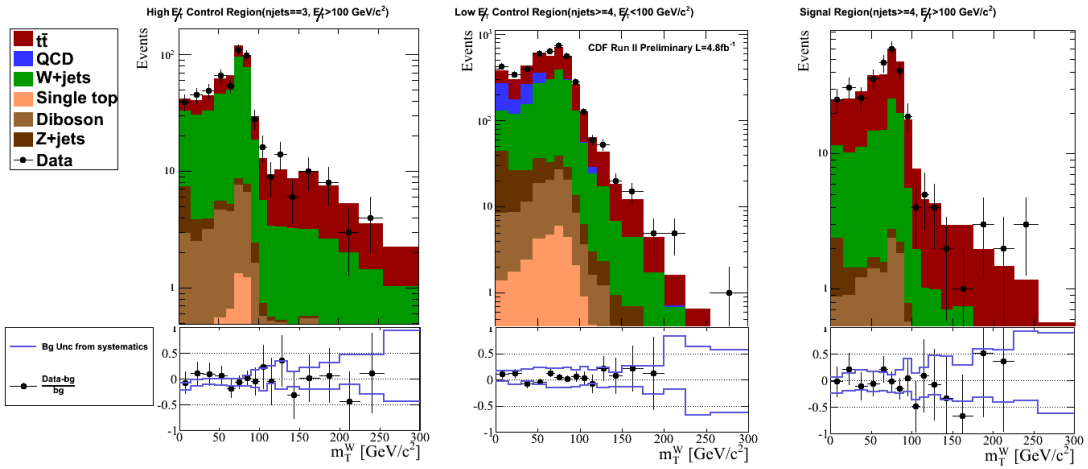


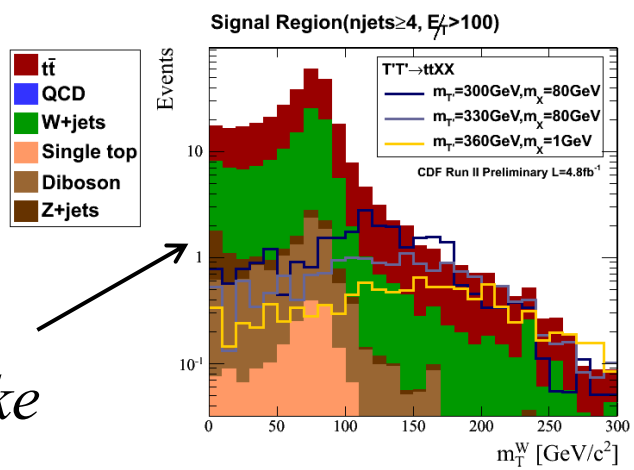




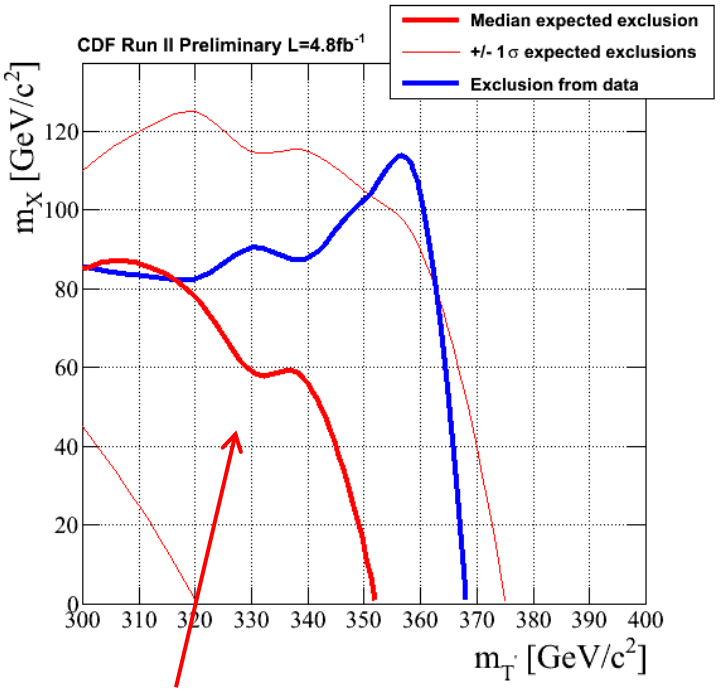
Dark matter search in $T' \rightarrow tX$

- *Search for excess ET / in tt events with decay to W+jets*





What excess could look like



Excluded Region

Summary

- *Recent top properties results from CDF are shown*
  - *All the measurements are consistent with the SM prediction so far*
- *All the top properties measurement are currently statistics limited*
  - *More than 1000 reconstructed ttbar events in ~6 fb^{-1} of dataset*
  - *Results will be updated with 7~8 fb^{-1} data soon*
- *Tevatron's top physics program and understanding of systematic effects will continue to play a significant role for years to come*