Measurements of top quark properties

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(on behalf of the CDF and DØ Collaborations)

Rencontres de Moriond
QCD and High Energy Interactions
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Introduction to top quark properties

Top Quark:

Particle type: weak isospin partner of the bottom quark

Spin: +1/2

Mass: 172.4±1.2 GeV/c^2

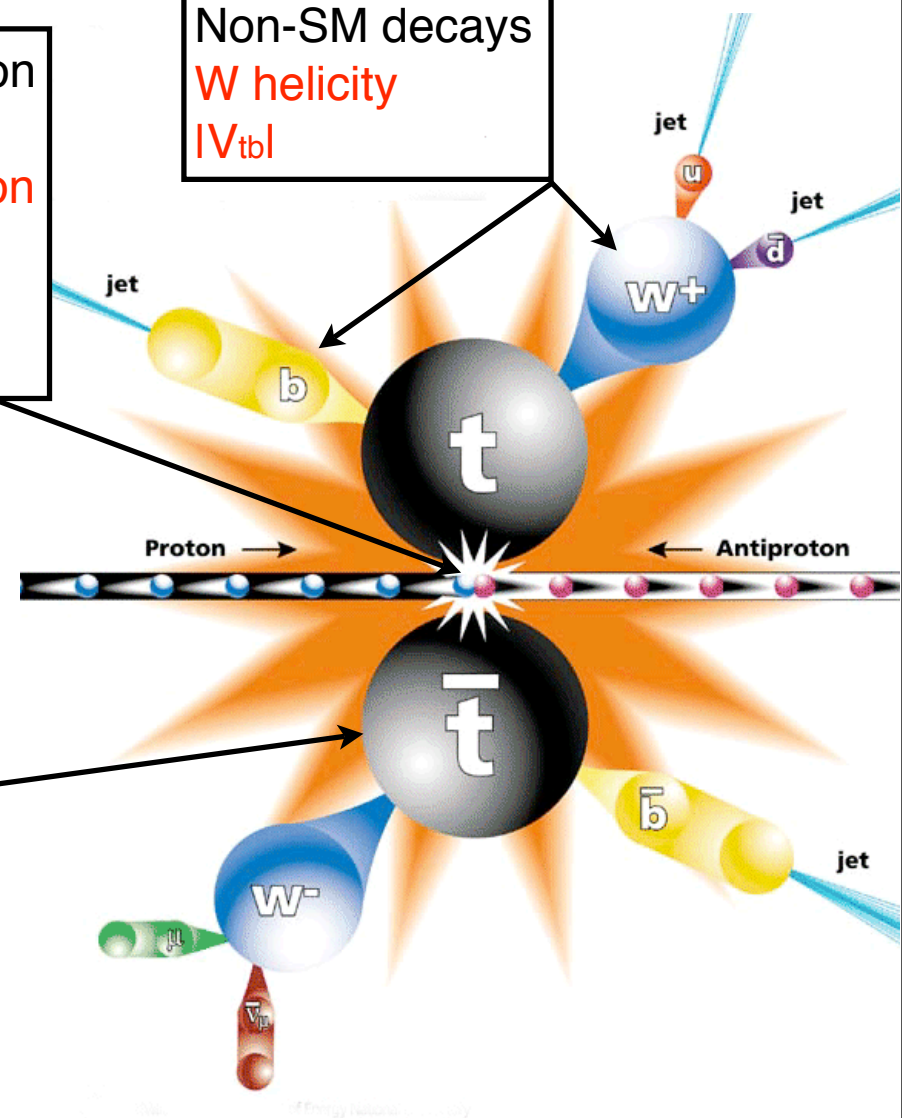
Width: ~1.5 GeV/c^2 or ~10^{-24} s

Couplings: Strong (color triplet),
EM (Q=+2e/3),
Weak ($I_{3,L}$=+1/2)

Decay: almost exclusively to W+b

Production cross section
FB Asymmetry
Differential cross section
Production mechanism
Resonance production
Stop, t' production

Branching ratios
Rare decays
Non-SM decays
W helicity
$|V_{tb}|$



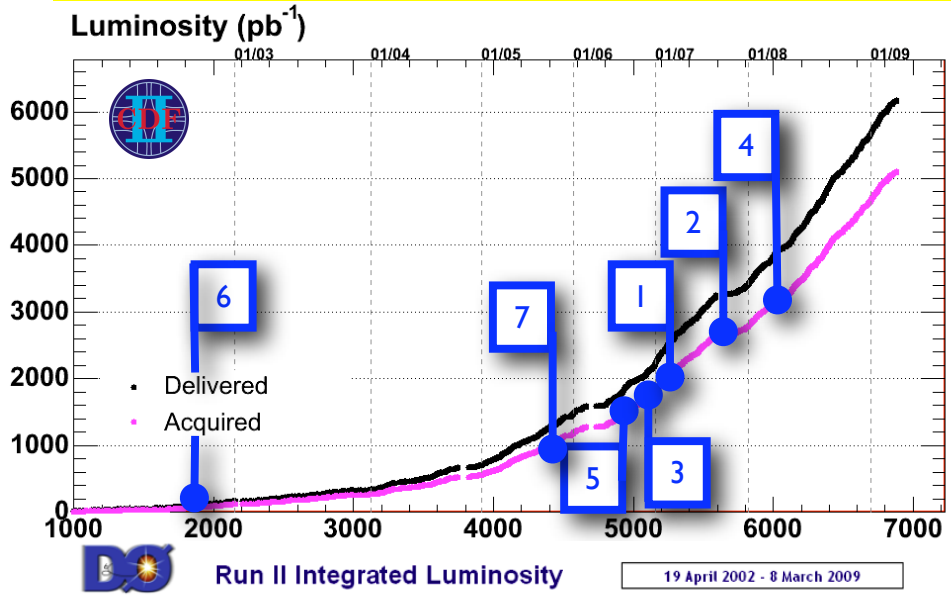
Top charge
Top spin
Top mass
Top width

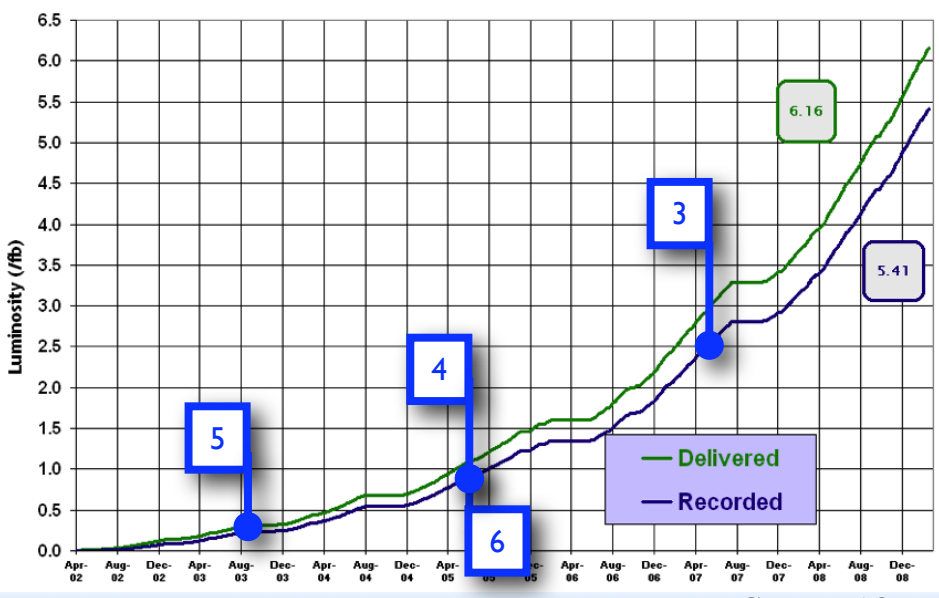
Also....
Single top cross section ($|V_{tb}|$)
Anomalous coupling

Precision in top quarks

The Tevatron top physics program seen from the perspective of *precision*:

Collision data delivered and recorded vs. time





Luminosity dominated

Pair production cross section ..... ±9% (combined) and ±10−25%

Systematics dominated

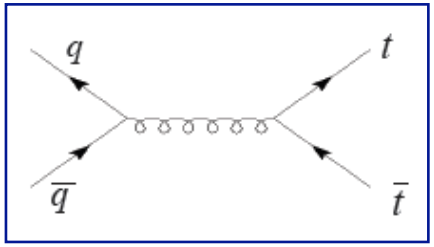
Top mass..... ±0.7%

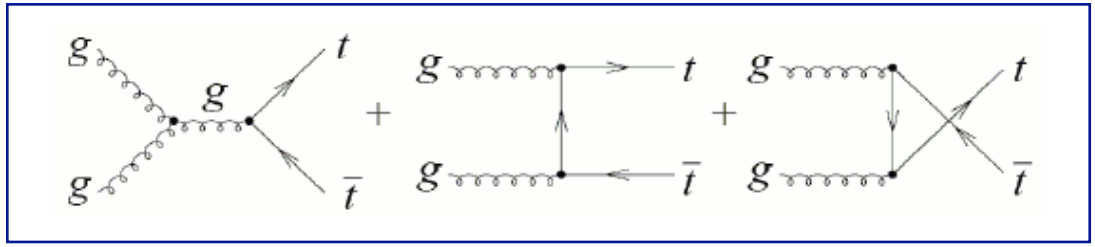
Statistics dominated

(Single top production)

1. Production mechanism.....
2. Differential cross section...
3. W helicity.....
4. FB Asymmetry.....
5. Top charge.....
6. $|V_{tb}|$ .....
7. Top width .....

Top *gg* and *qq* production



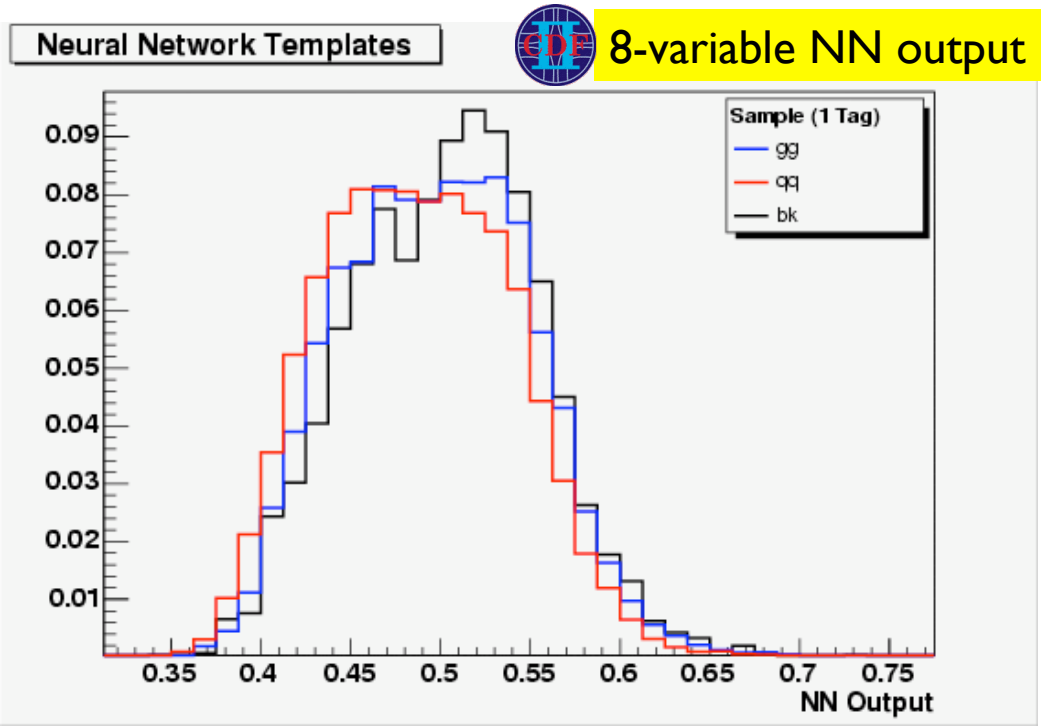


Production through virtual Z and γ are much smaller

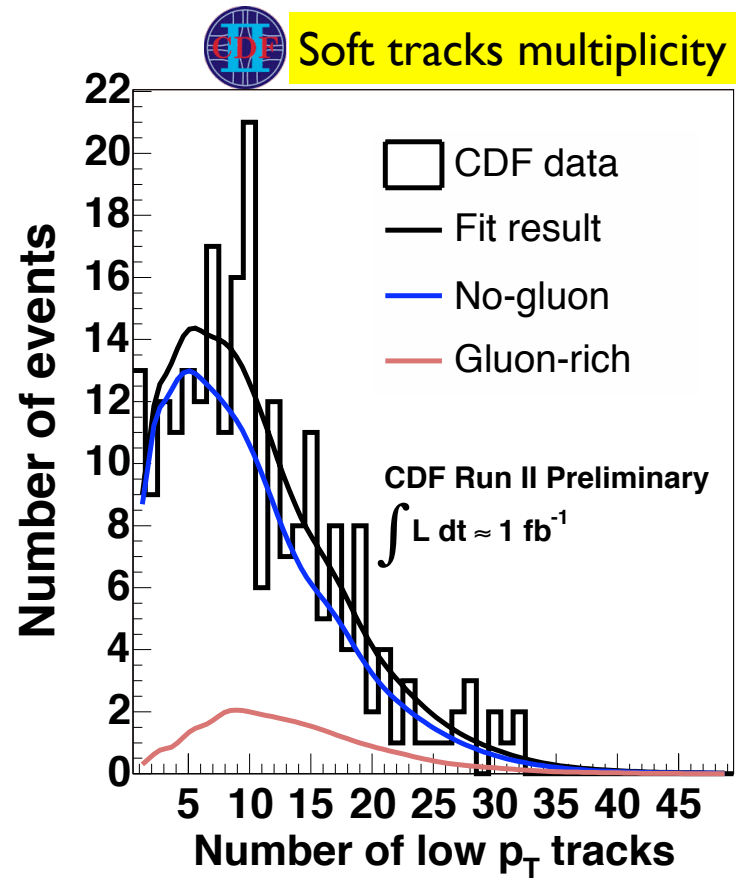
@ Tevatron: ~85%
More central, with like spins

~15%
More forward, with unlike spins

Technique 1: Kinematic Information (angles)

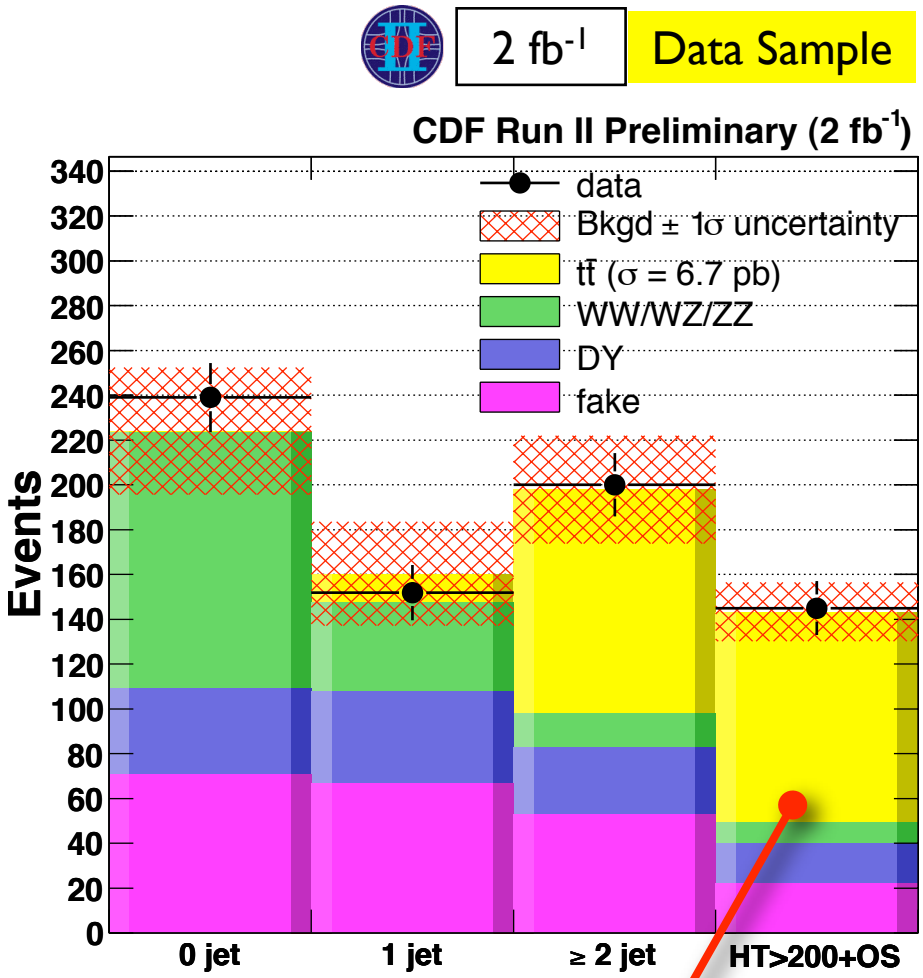


Technique 2: Gluon radiation

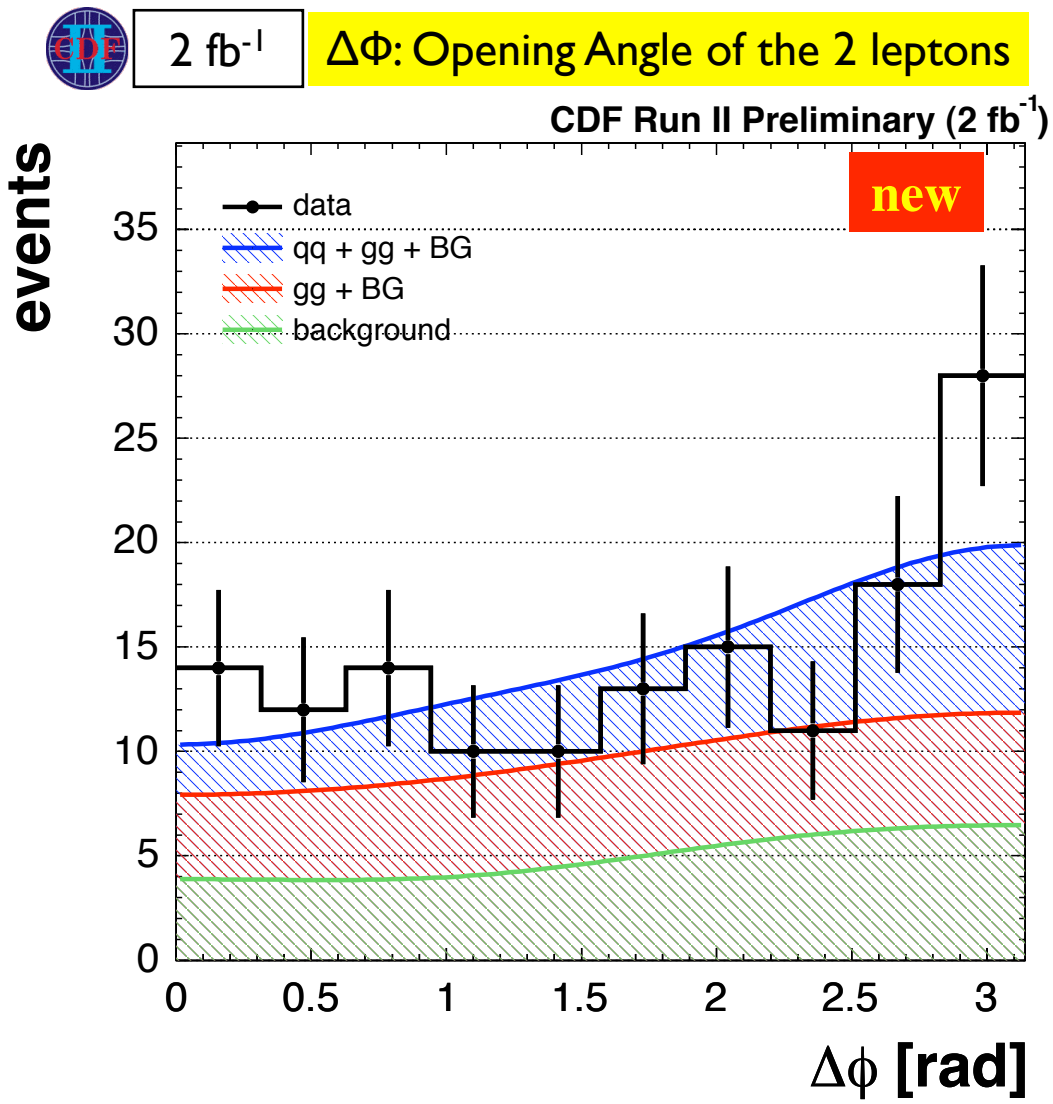


Top *gg* and *qq*: Dilepton channel

Dilepton channel, no *b*-tag

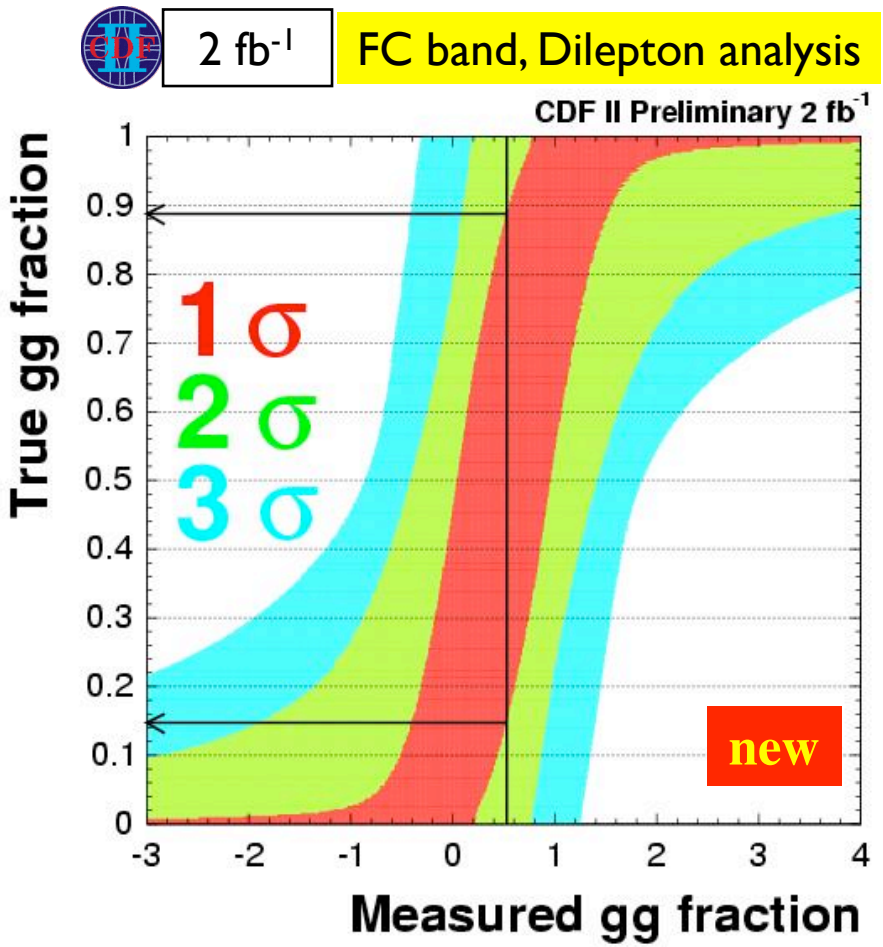


≥ 2 jets, HT and OS



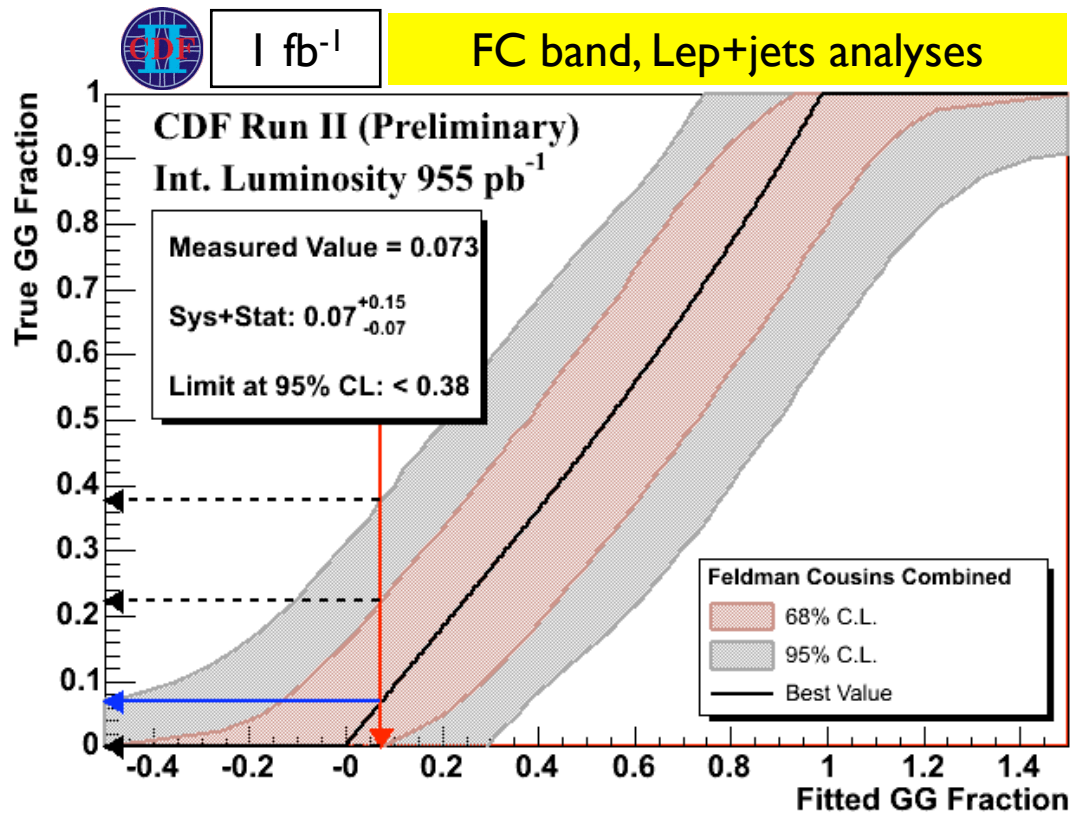
$$Fgg = 0.53 \,^{+0.36}_{-0.38} \left(\,^{+0.35}_{-0.37} (\text{stat}) \,^{+0.07}_{-0.08} (\text{syst}) \right)$$

Top *gg* and *qq* production: status



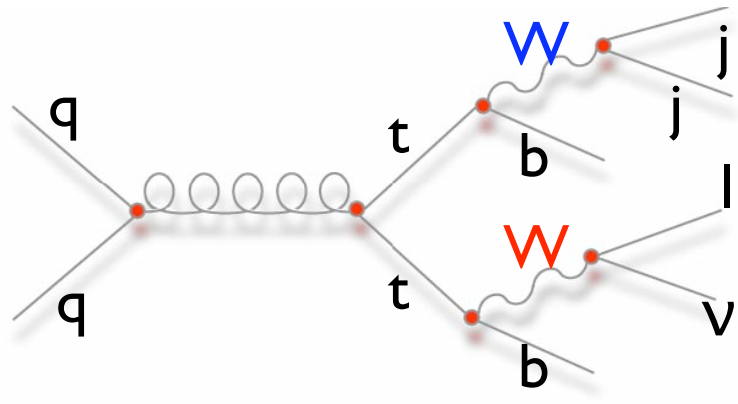
Current best: combination of NN and Soft Tracks methods using Lepton+jets channel

$$f(gg) = 0.07^{+0.15}_{-0.07}$$ (~±70%)



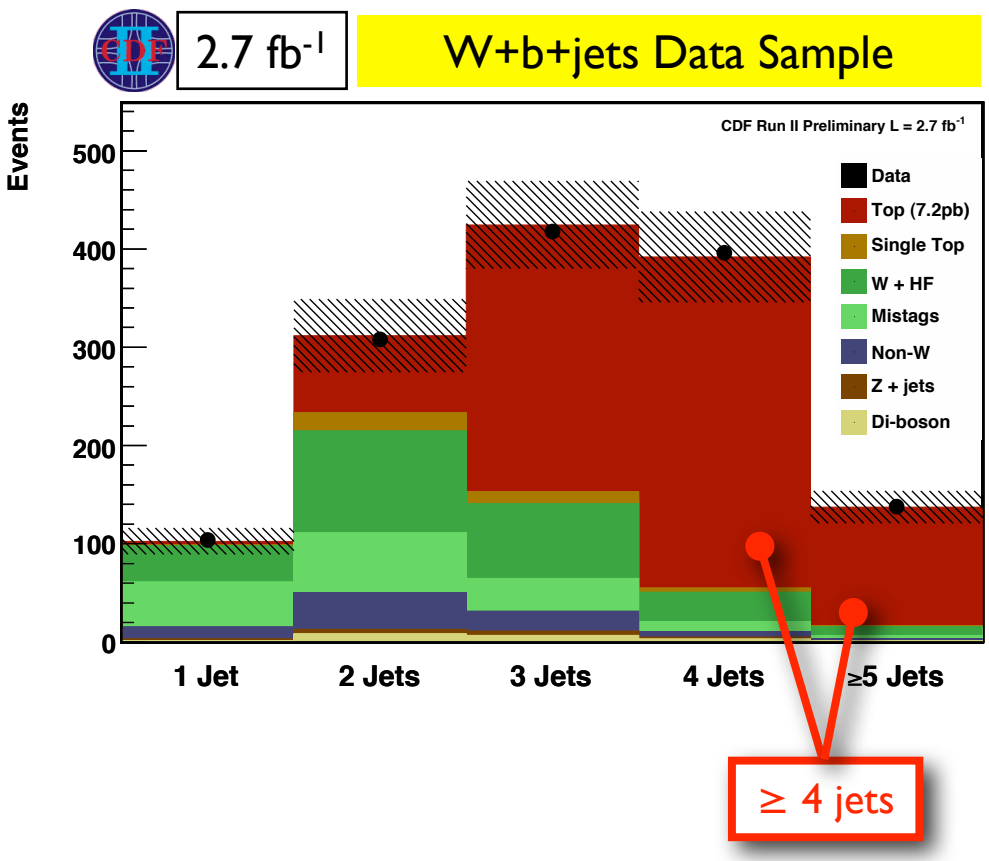
[PRD79:031101,2009 (2009)]

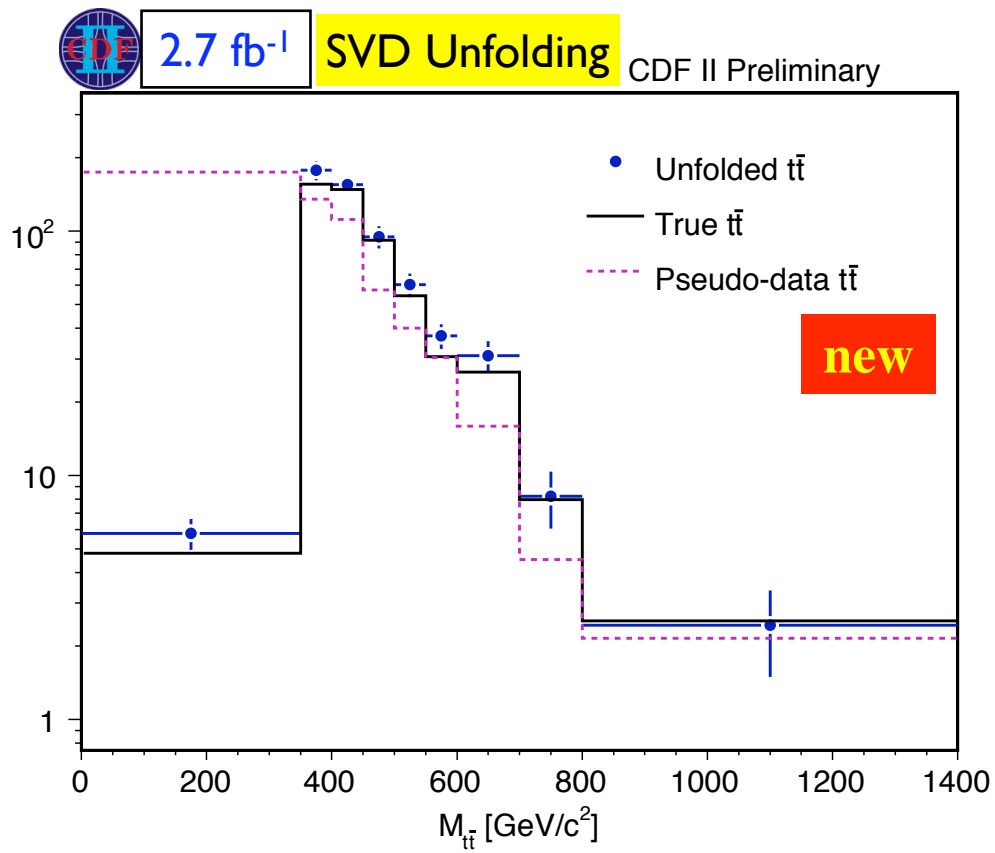
M_{tt} differential cross section



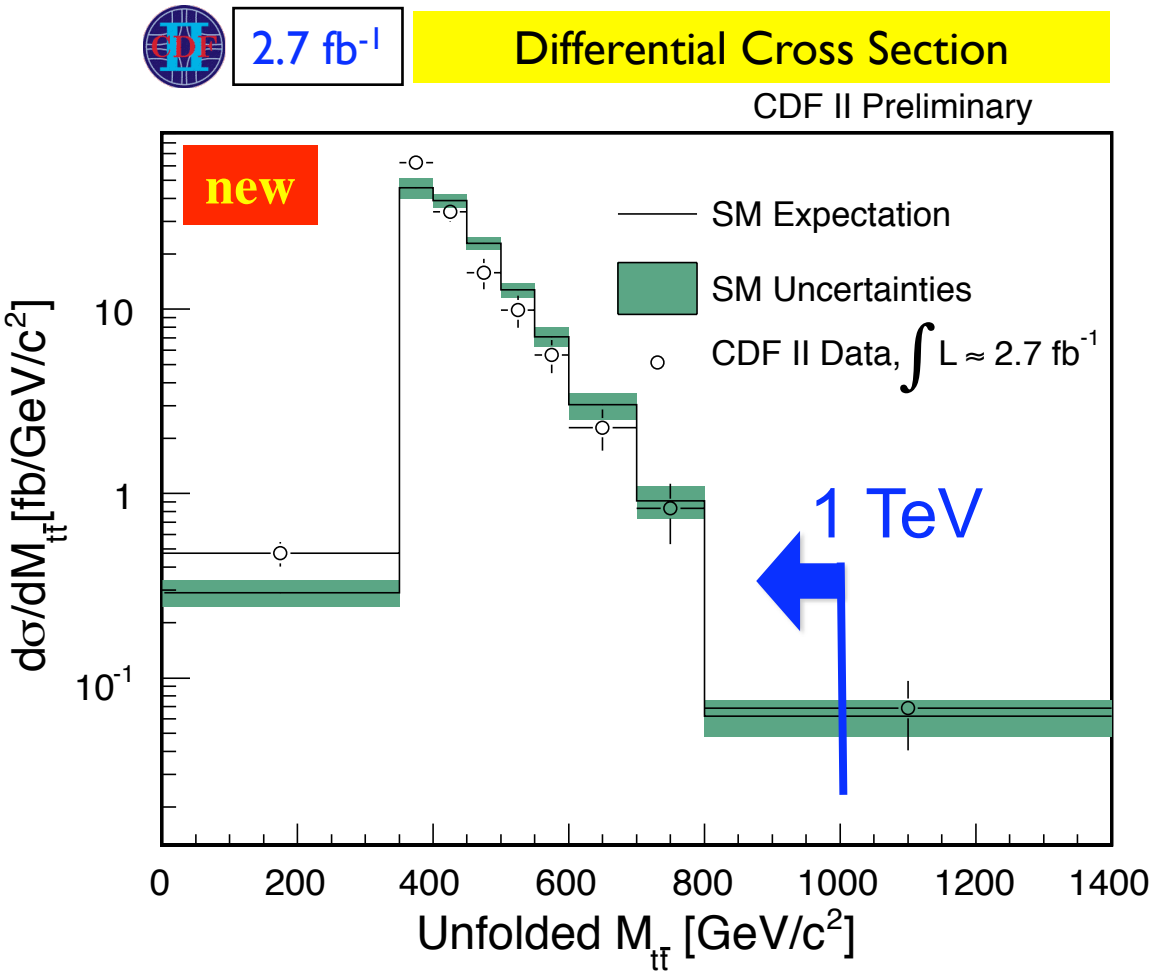
$$\frac{d\sigma^i}{dM_{t\bar{t}}} = \frac{N_i - N_i^{bkg}}{\mathscr{A}_i \int \mathscr{L} \Delta^i_{M_{t\bar{t}}}}$$

updated from 1.7 fb^{-1} version with reduced systematics from JES



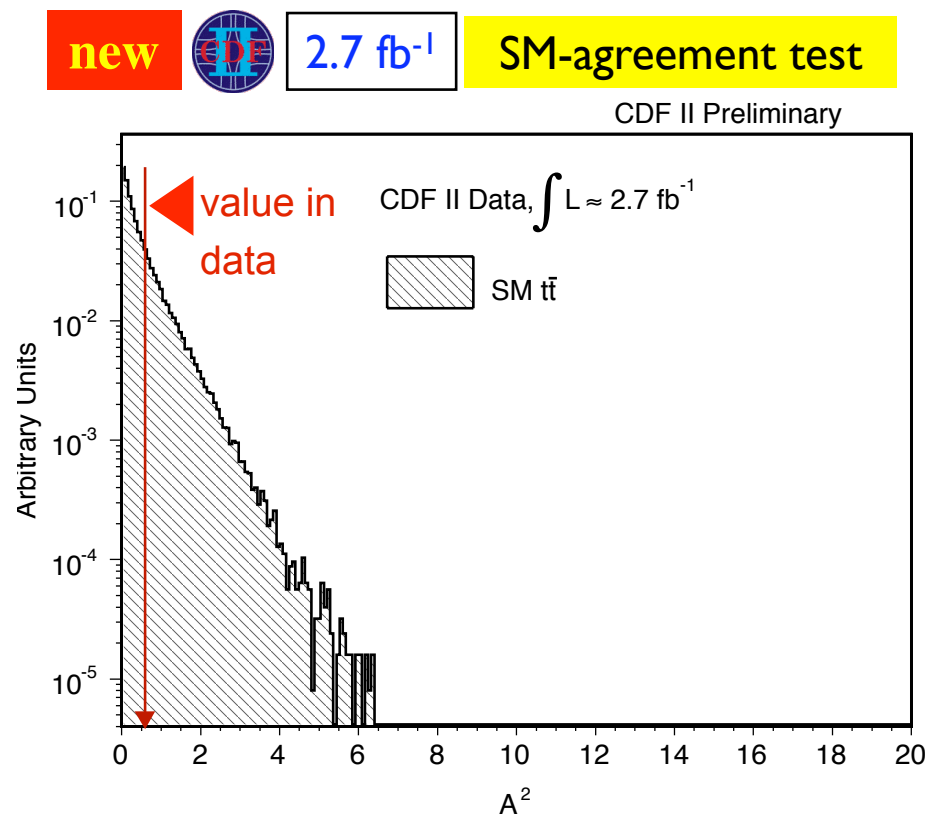


M_{tt} differential cross section (cont.)



-Agreement with SM: 28% of PE have larger deviation than observed.

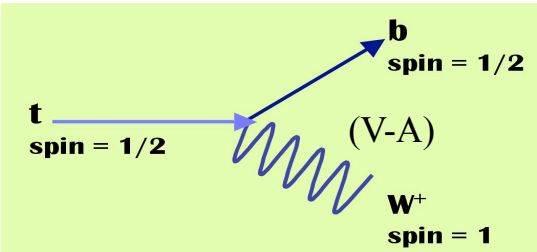
-Dominant systematics from JES, PDF and backgrounds



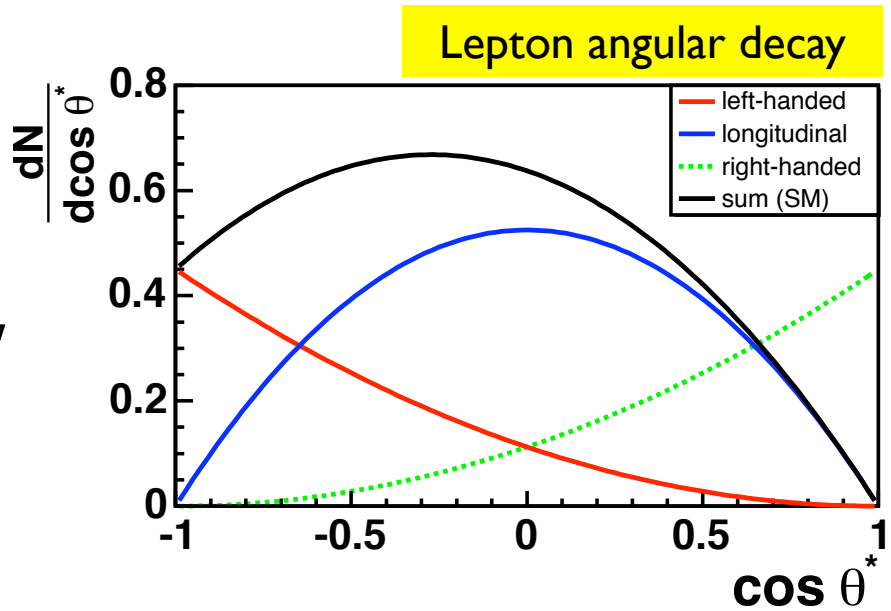
For resonant production searches see the talk on New Physics using top quarks

Helicity of W bosons in top decays

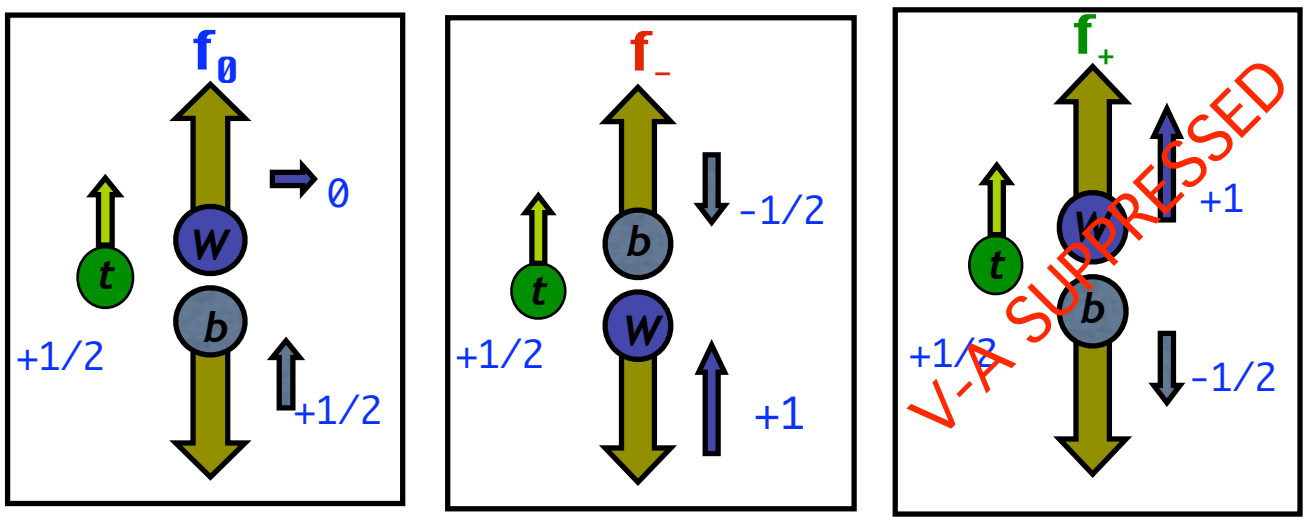
- Positive W helicity f_+ suppressed by chiral factors ~ M_b^2 / M_W^2
- Relative fraction of f_0 to f_- is:



$$f_0 = \frac{M_t^2 / 2M_W^2}{1 + M_t^2 / 2M_W^2} \cong 0.7$$

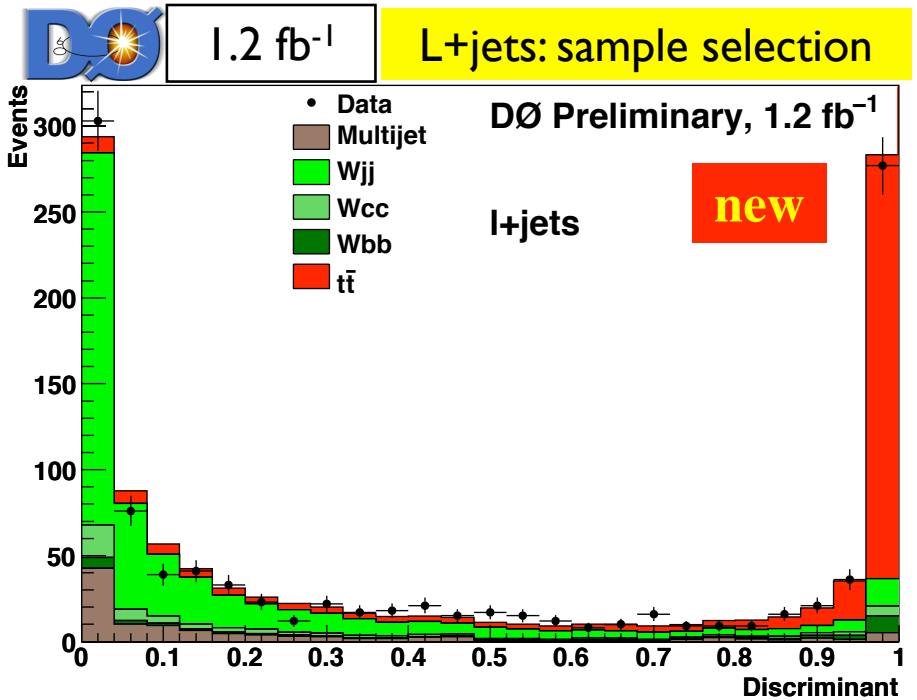


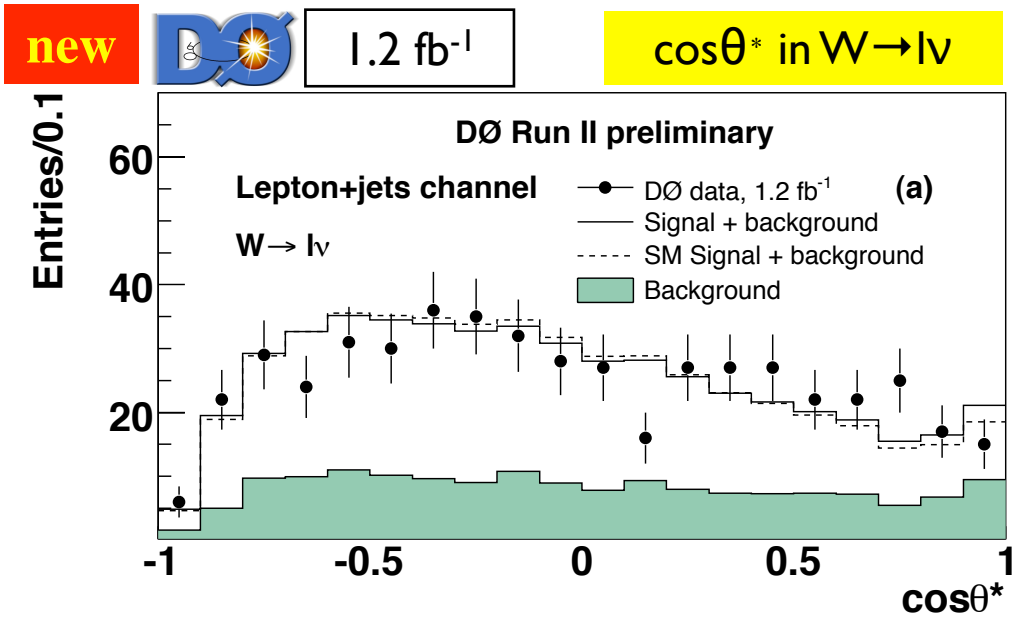
Longitudinal fraction Left-Handed fraction Right-Handed fraction

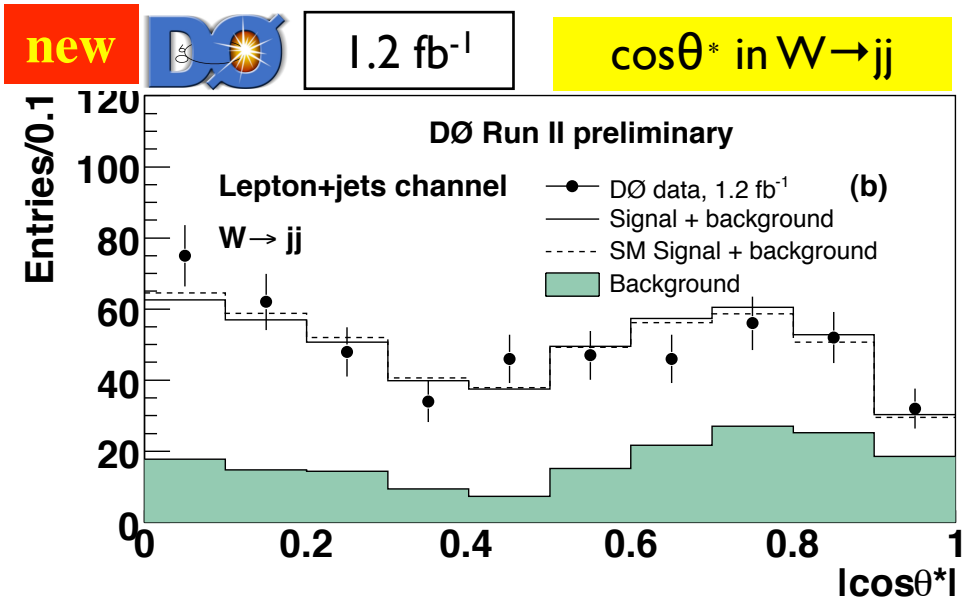


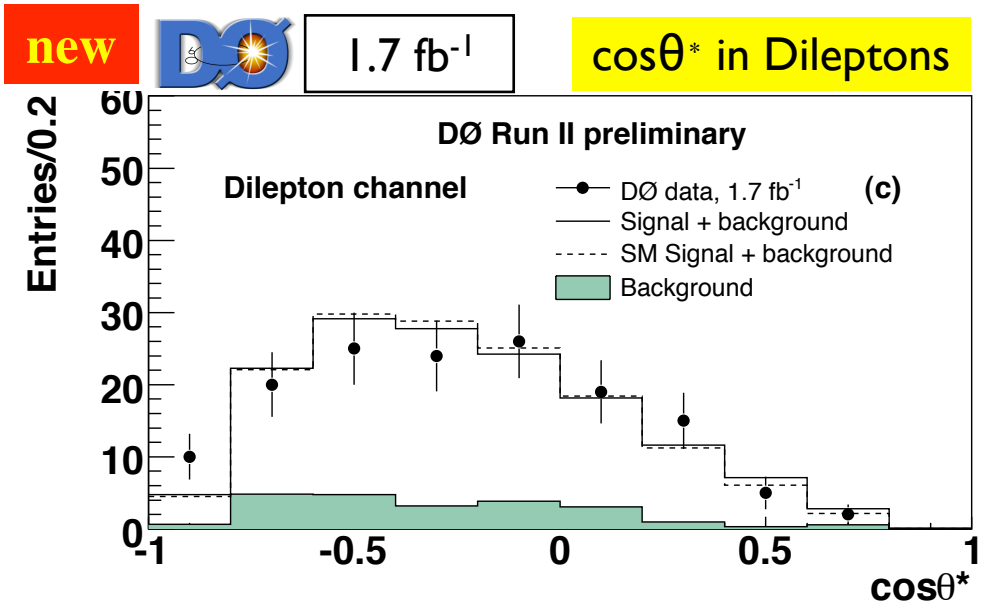
cos θ* is the angle between the d-type fermion in the W rest frame and the W flight-direction in the top rest frame

Simultaneous f_0 and f_+ fractions

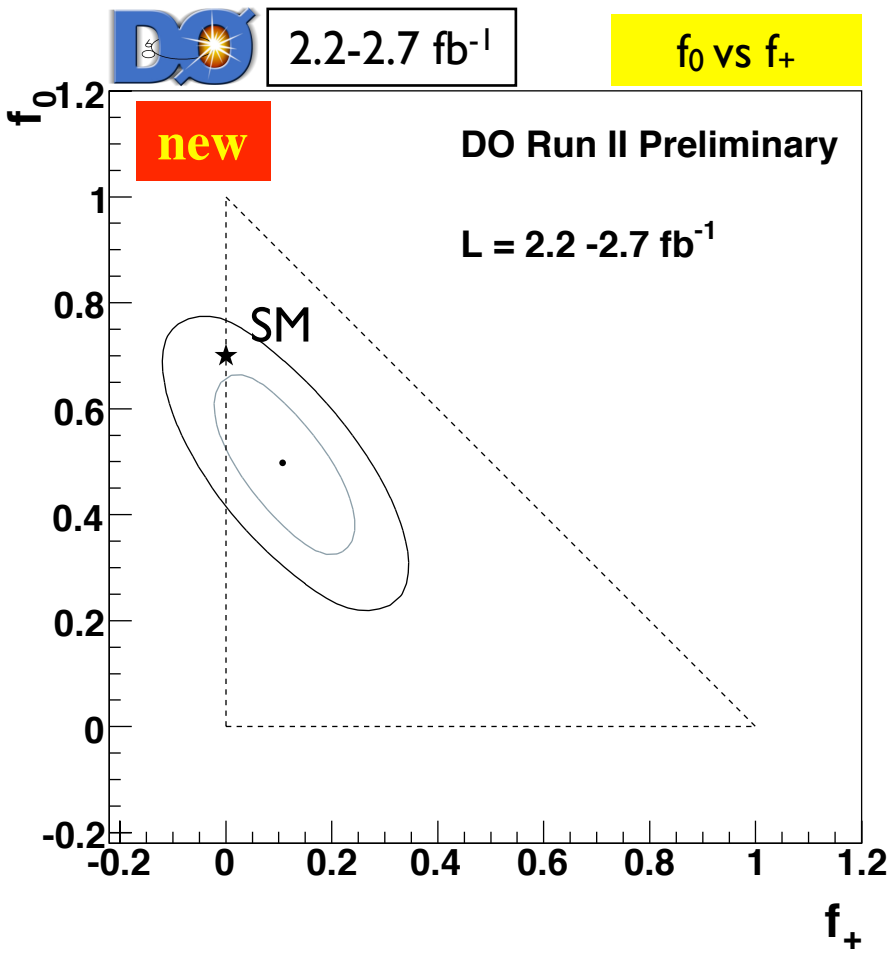




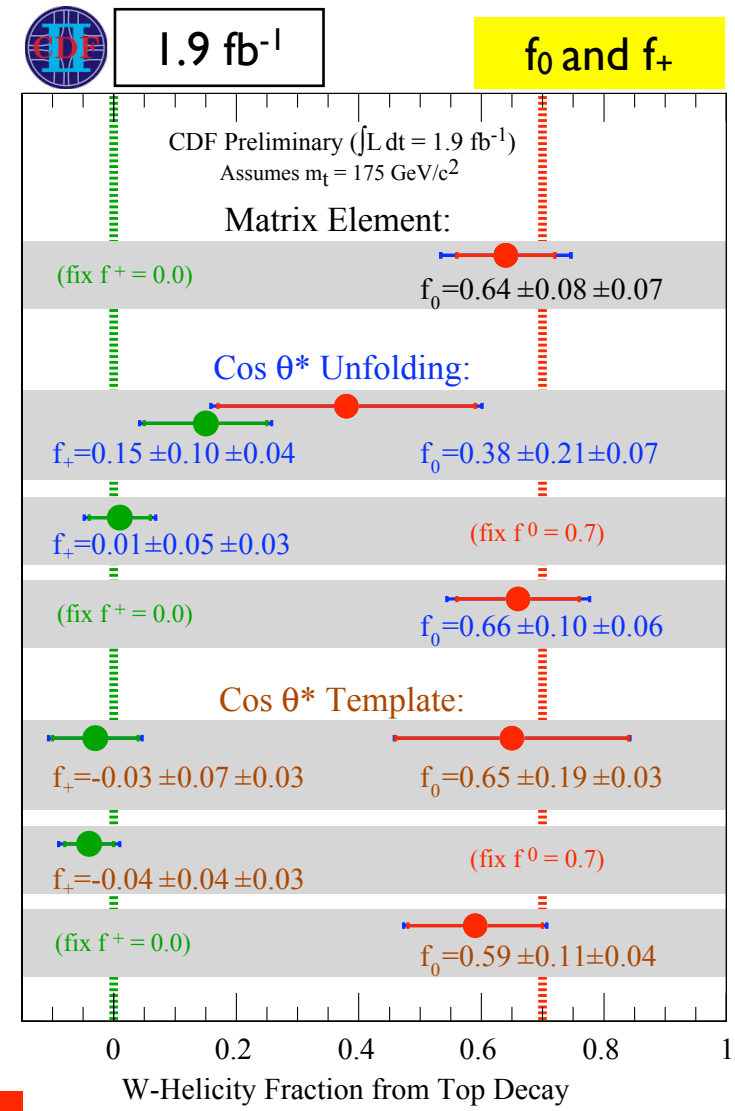




f_0 and f_+ fractions: status



$$f_0 = 0.490 \pm 0.106\ (\text{stat.}) \pm 0.085\ (\text{syst.})$$
$$f_+ = 0.110 \pm 0.059\ (\text{stat.}) \pm 0.052\ (\text{syst.}).$$



new CDF combination of cosθ* methods

~±15% **$f_0 = 0.62 \pm 0.11$** assuming $f_+ = 0.0$

$f_+ = -0.04 \pm 0.05$ assuming $f_0 = 0.7$

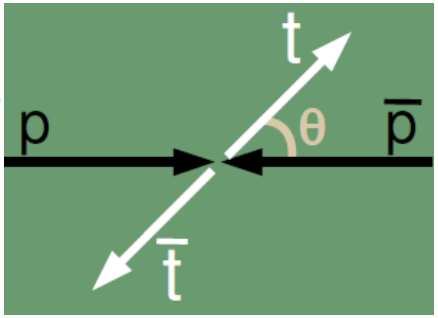
$f_0 = 0.66 \pm 0.16$ and $f_+ = -0.03 \pm 0.07$

Top Forward-Backward Asymmetry

Arises at higher than tree-level order [PRD 77, 014003]: A_{fb} (SM, NLO)= 0.050 +/- 0.015

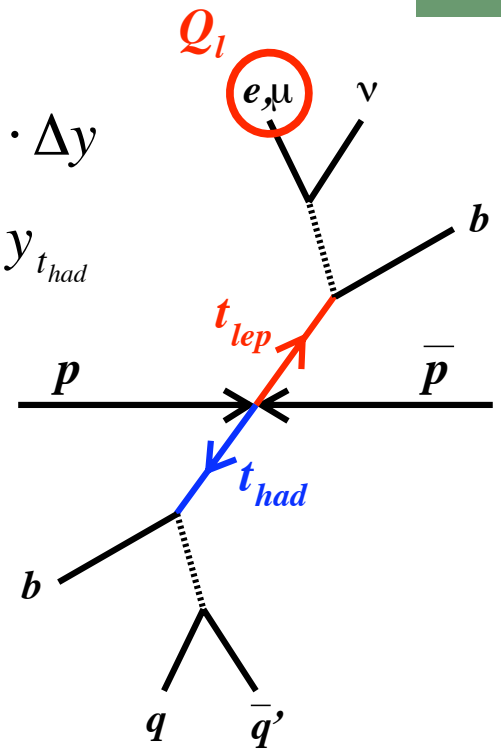
$$A_{\rm FB}^{p\bar{p}} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}.$$

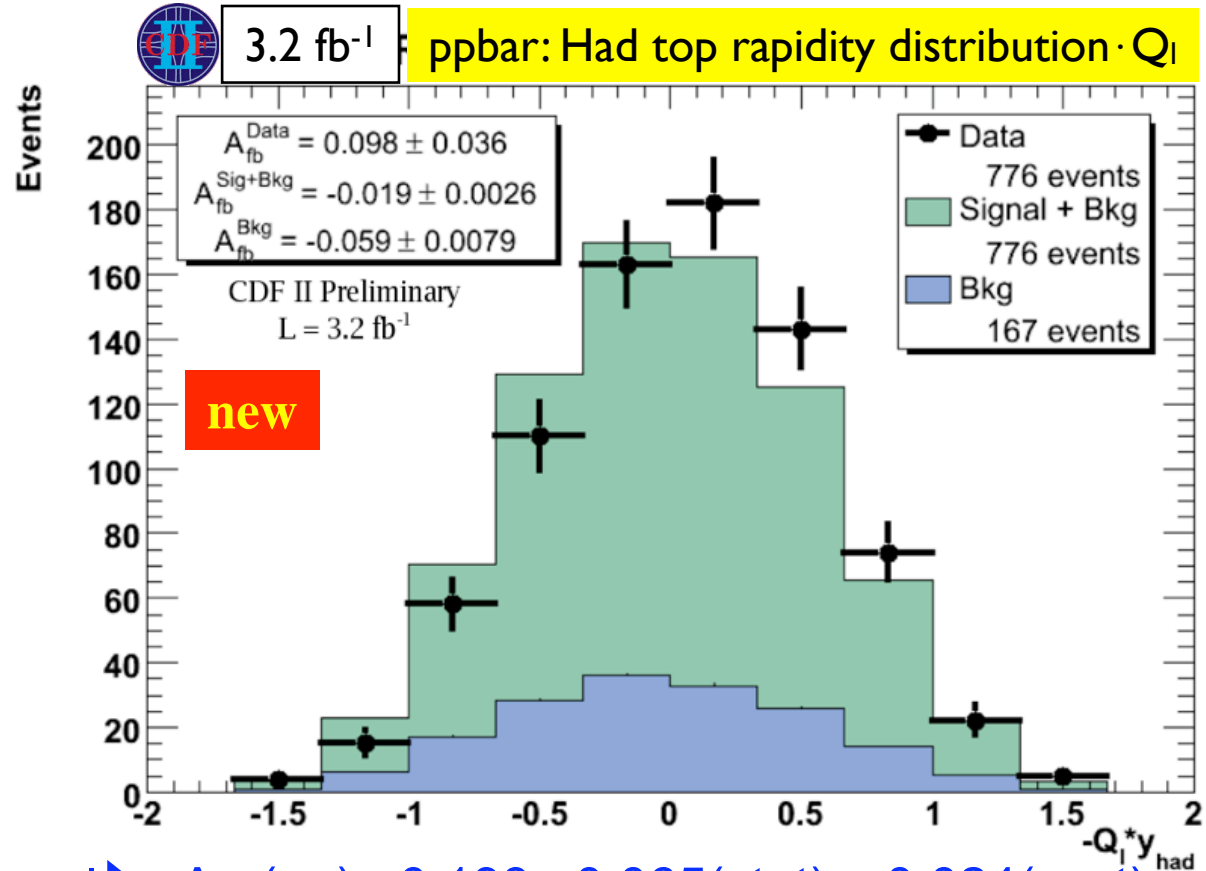
$$A_{\rm FB}^{t\bar{t}} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}.$$



$$y_t - y_{\bar{t}} = Q_l \cdot \Delta y$$

$$\Delta y = y_{t_{lep}} - y_{t_{had}}$$

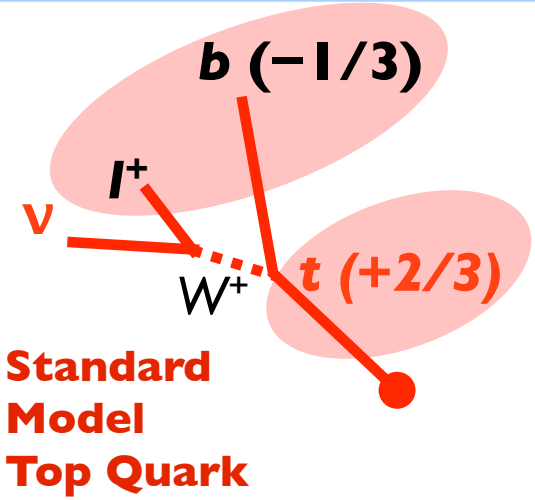


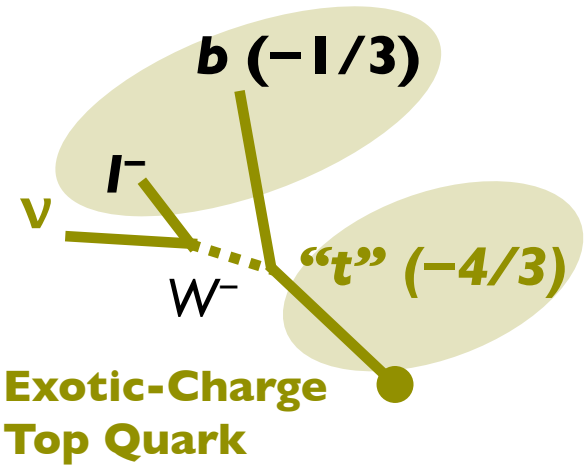


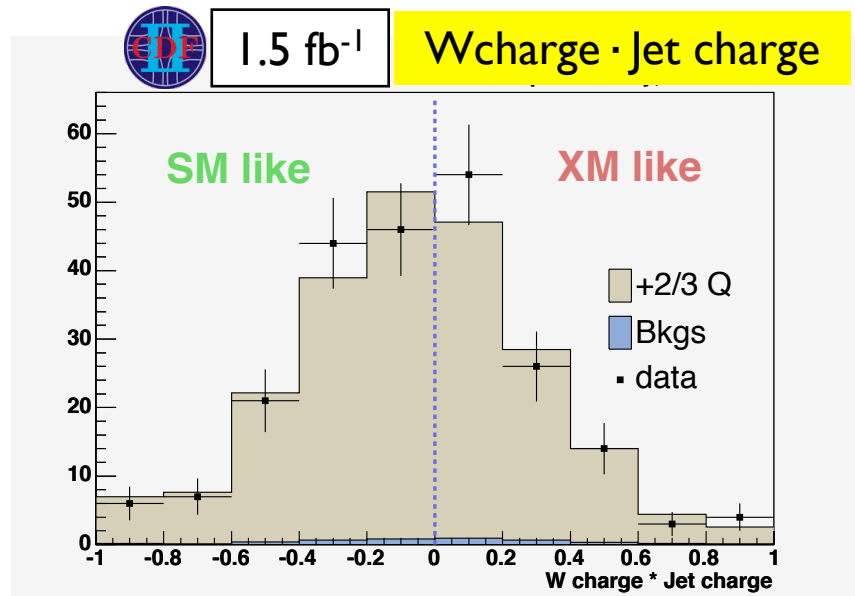
[PRL 100:142002,2008]

Parton-level ▶ A_{fb} (pp)= 0.193 ±0.065(stat) ± 0.024(syst)

Top quark charge







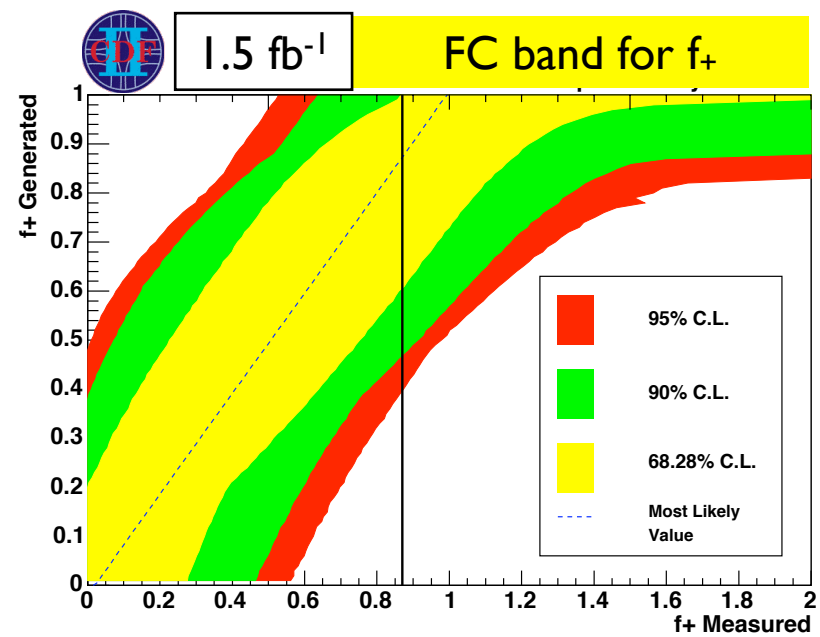
See [D. Chang et al., PRD59 (1999) 091503] for details

Requires *b*-quark charge from jet charge

- (Weighted) sum of charge of tracks in *b*-jet
- Calibrated using *bb* dijets, with 1 soft μ

f_+ = fraction of pairs with top charge +2/3

CDF $f_+ = 0.87$ →



D0 $f_- = -0.13 \pm 0.66(\text{stat}) \pm 0.11(\text{syst})$

$f_- < 0.8$ @ 90% C.L. [PRL 98:041801,2007]

|q|=4*e*/3 excluded at ~90% C.L.

Measurements of $|V_{tb}|$ and top width

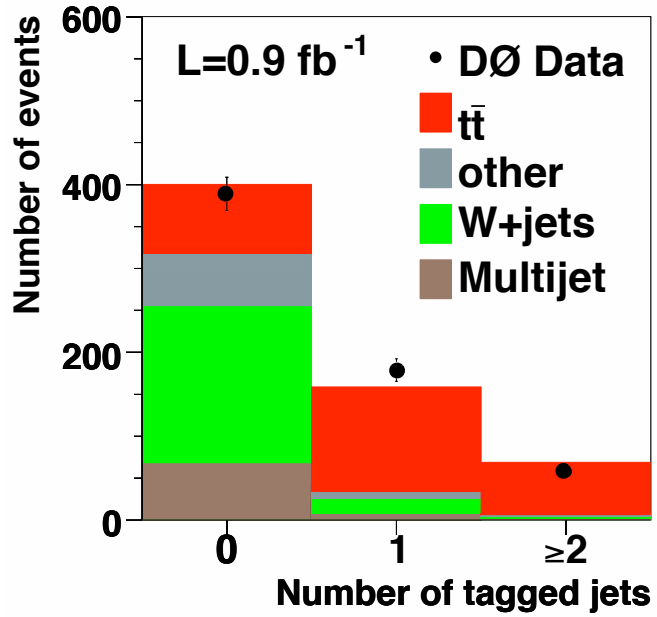
Under the assumption of unitarity and three generations of quarks:

$|V_{tb}| = 0.999100^{+0.000034}_{-0.000004}$ [J.of Phys. G 33, 1 (2006)]

$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

Measure the branching ratio by counting the rate of *b*-tags in t-tbar events

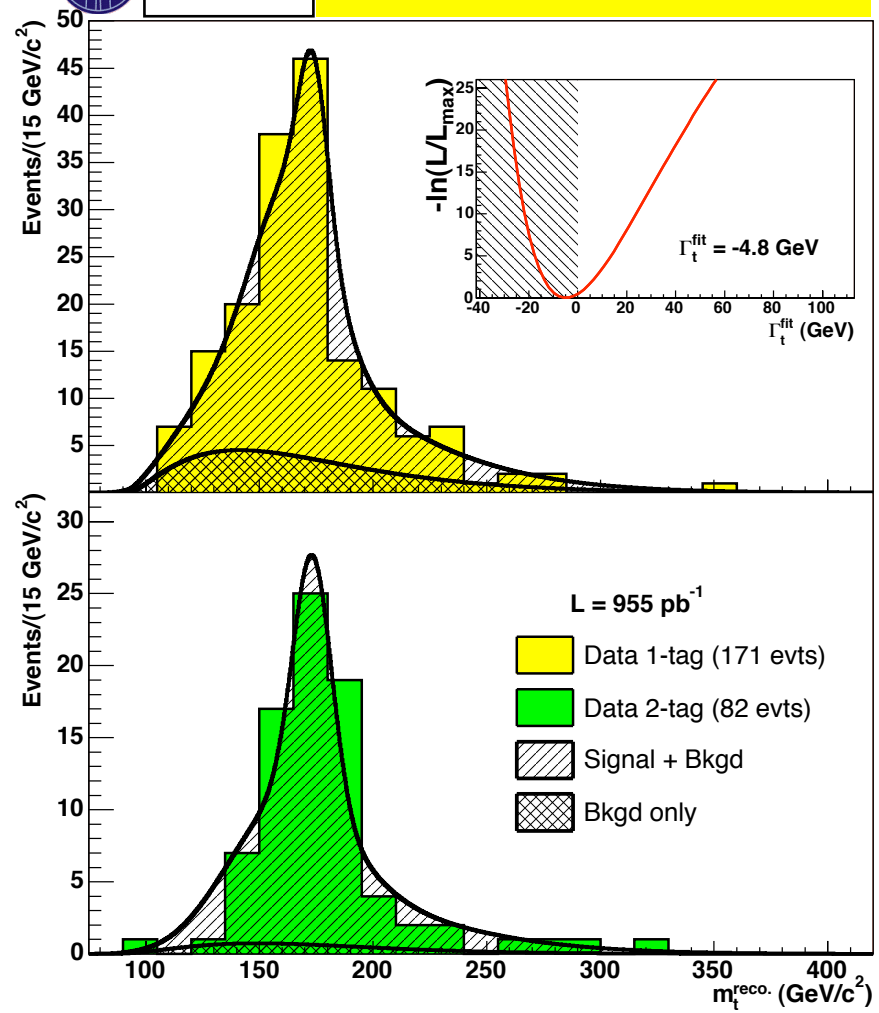
0.9 fb^{-1} Tag multiplicity



$R = 0.97^{+0.09}_{-0.08}(stat + syst)$ (~±10%)

$|V_{tb}| > 0.89$ @ 95% C.L. [PRL100:192003,2008)]

1 fb^{-1} Fits on Reconstructed Mass



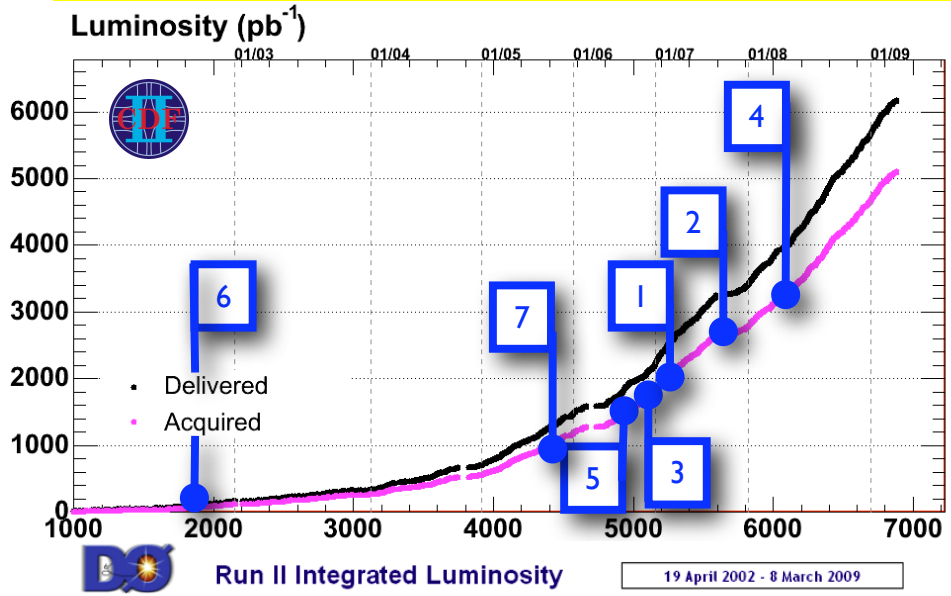
$\Gamma_{top} < 13.1$ GeV at 95% C.L.

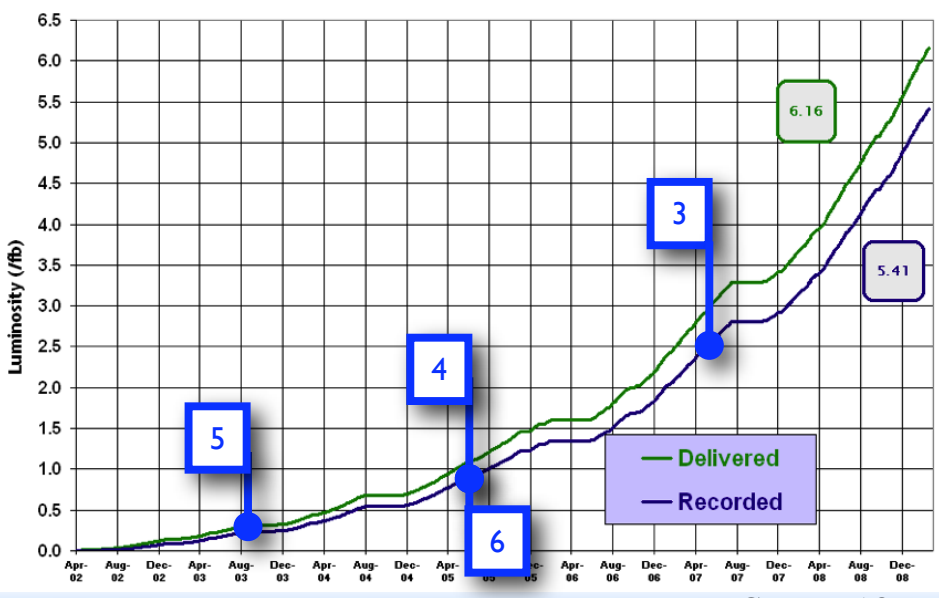
[PRL 102, 042001 (2009)]

Summary

The Tevatron top physics program seen from the perspective of *precision*:

Collision data delivered and recorded vs. time





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(Single top production)

1. Production mechanism..... ~±70%
2. Differential cross section... up to ~1 TeV
3. W helicity..... ~±15%
4. FB Asymmetry..... ~±140%
5. Top charge..... not 4e/3, @~90% CL
6. $|V_{tb}|$ ..... ~±10%
7. Top width ..... <13.1 GeV @ 95%CL

Summary

The Tevatron top physics program seen from the perspective of *precision*:

Luminosity dominated

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FB Asymmetry..... ~±140%

Top charge..... not 4e/3, @~90% CL

$|V_{tb}|$ ..... ~±10%

Top width ..... <13.1 GeV @ 95%CL

For more information visit:

http://www-cdf.fnal.gov/physics/new/top/top.html

http://www-d0.fnal.gov/Run2Physics/WWW/results/top.htm

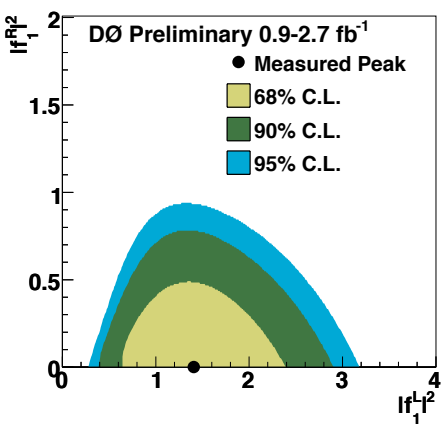
Backup

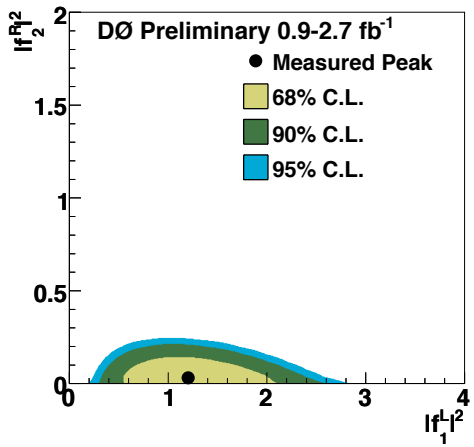
Anomalous couplings

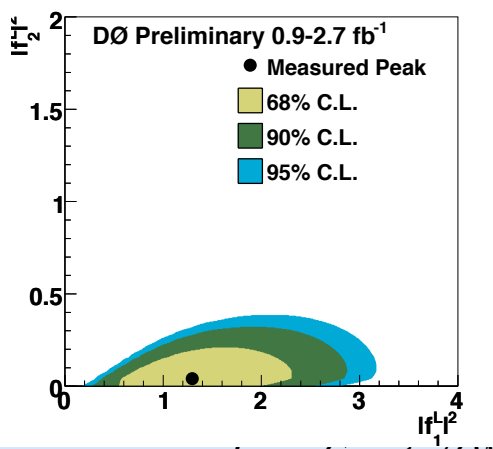
$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}(f_1^L P_L + f_1^R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}V_{tb}}{M_W}(f_2^L P_L + f_2^R P_R)tW_{\mu}^{-} + h.c.$$

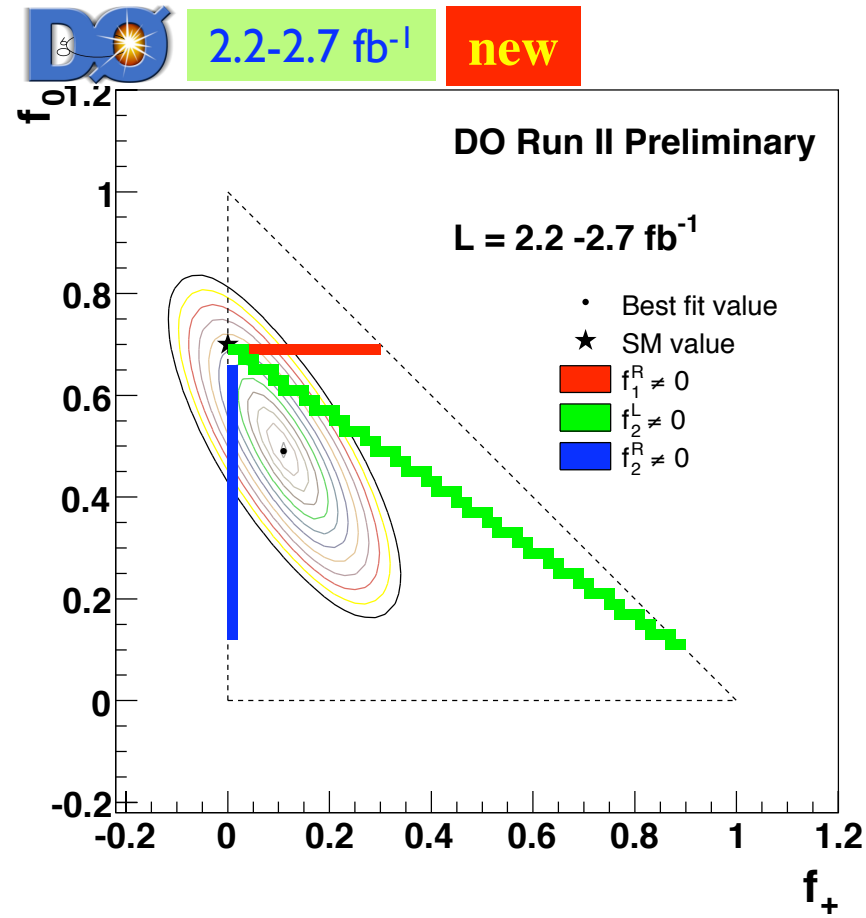
Observables:
-rate and kinematics of single top
-W helicity states

Check 2 at a time









Scenario	Coupling	Coupling limit if $f_1^L = 1$
(f_1^L, f_1^R)	$\lvert f_1^L\rvert^2 = 1.36^{+0.56}_{-0.46}$	
	$\lvert f_1^R\rvert^2 < 0.72$	$\lvert f_1^R\rvert^2 < 0.72$
(f_1^L, f_2^L)	$\lvert f_1^L\rvert^2 = 1.44^{+0.65}_{-0.51}$	
	$\lvert f_2^L\rvert^2 < 0.30$	$\lvert f_2^L\rvert^2 < 0.19$
(f_1^L, f_2^R)	$\lvert f_1^L\rvert^2 = 1.16^{+0.51}_{-0.44}$	
	$\lvert f_2^R\rvert^2 < 0.19$	$\lvert f_2^R\rvert^2 < 0.20$

Measurement of $|V_{tb}|$

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$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

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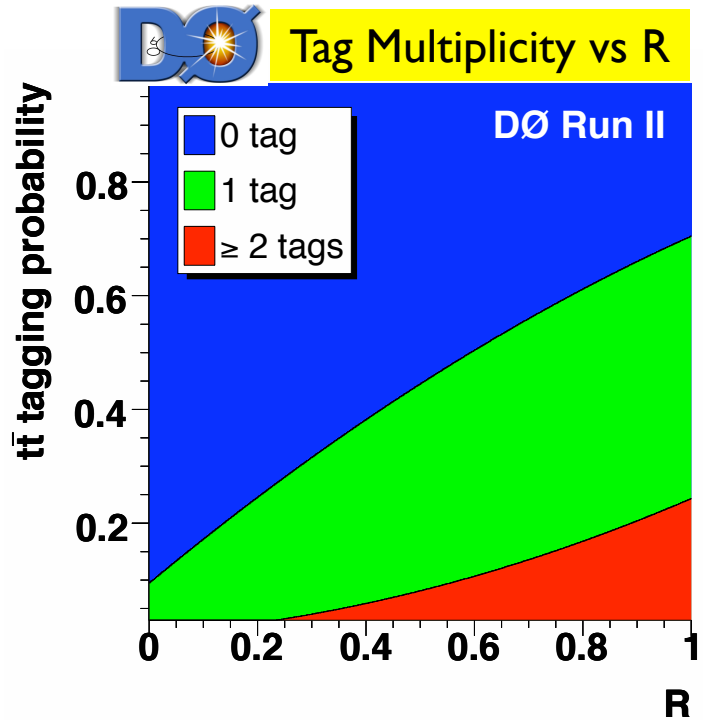
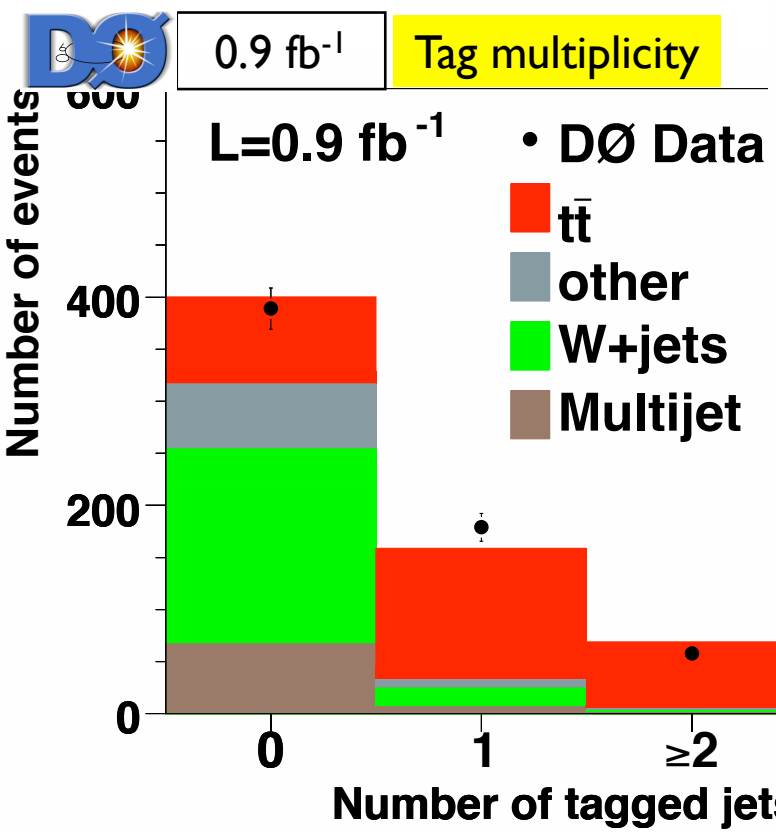
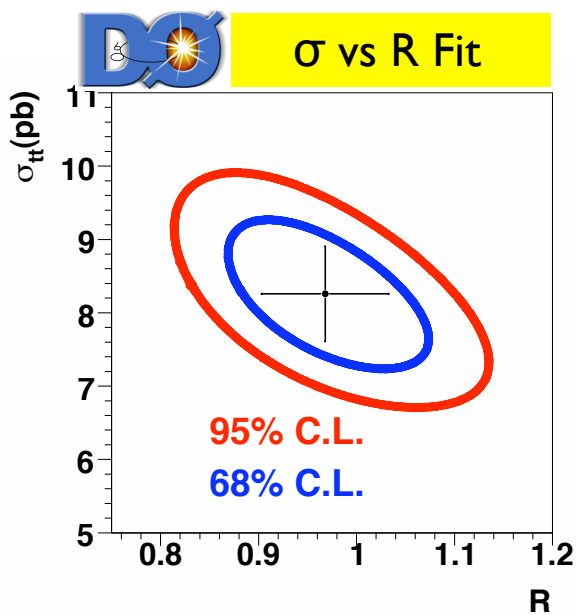






$$R = 0.97^{+0.09}_{-0.08}(stat + syst)$$

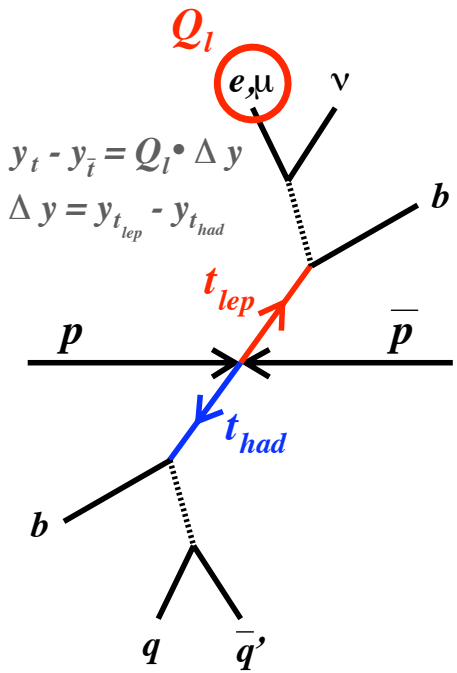
$|V_{tb}| > 0.89$ @ 95% C.L.

[PRL100:192003,2008)]

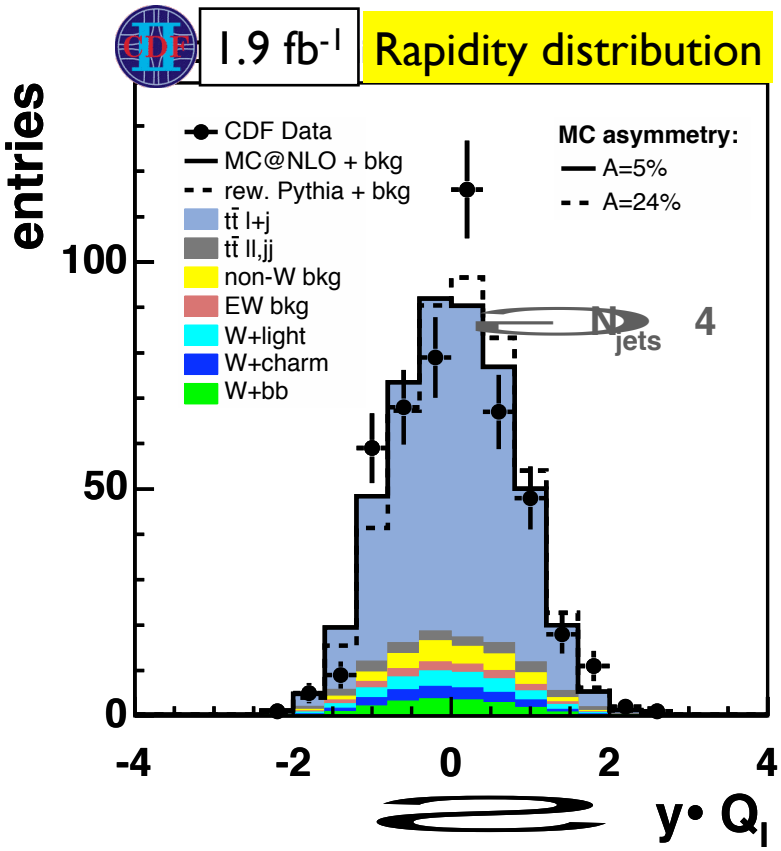
Top Forward-Backward Asymmetry

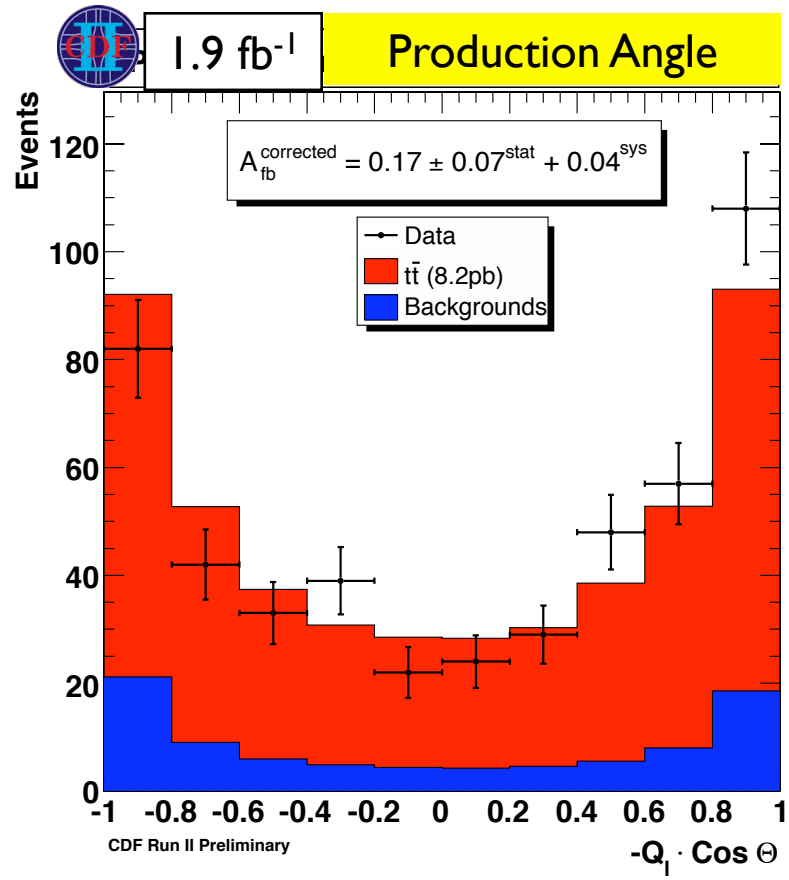
Arises at higher than tree-level order (PRD 77, 014003): A_{fb} (SM, NLO)= 0.050 +/- 0.015

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}.$$



$$A_{FB}^{p\bar{p}} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}.$$





A_{fb} (tt)= 0.24 ± $(0.13)^{stat}$ ± $(0.04)^{syst}$

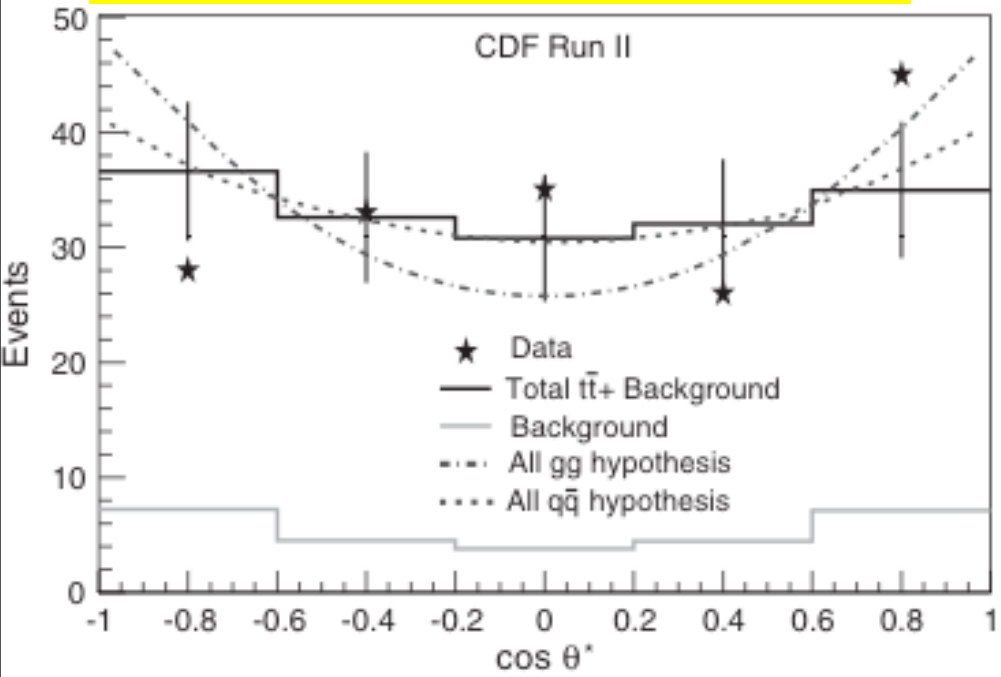
A_{fb} (pp)= 0.17 +/- $(0.07)^{stat}$ +/- $(0.04)^{syst}$

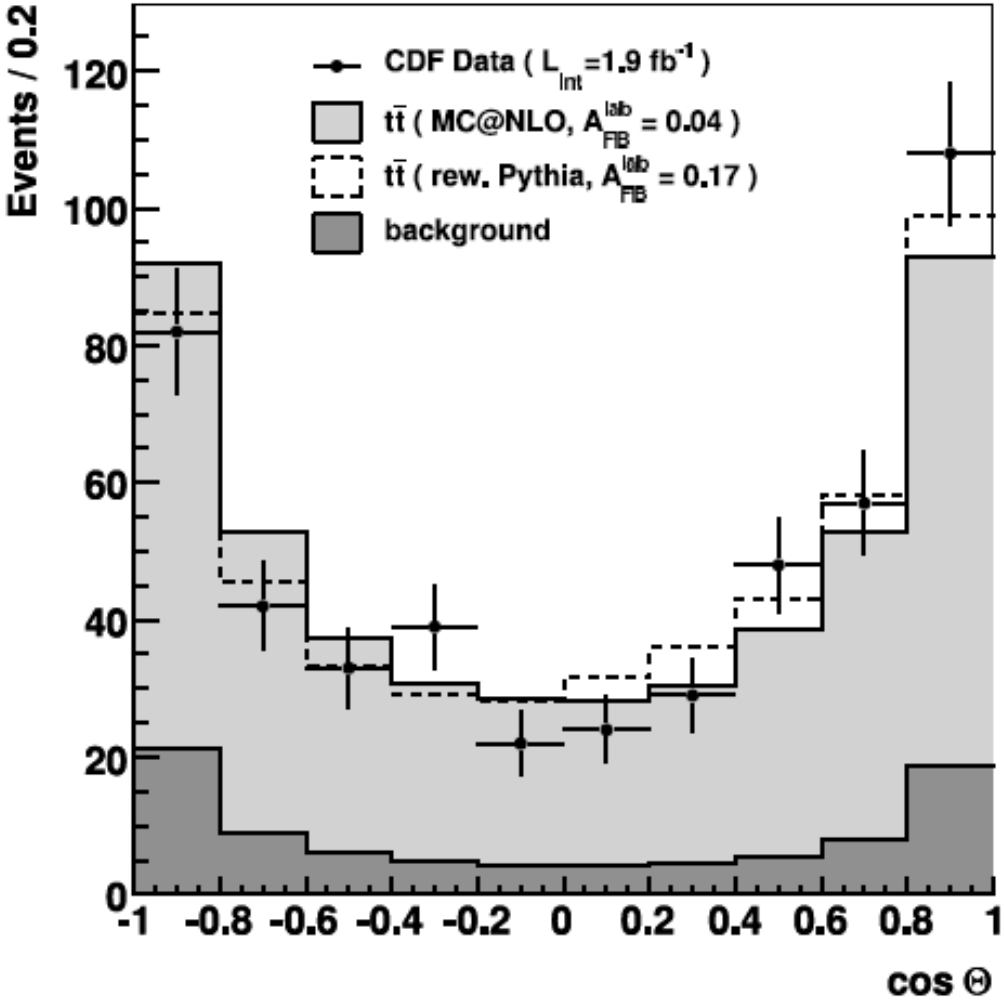
[PRL 101:202001 (2008)]

[PRL 100:142002,2008]

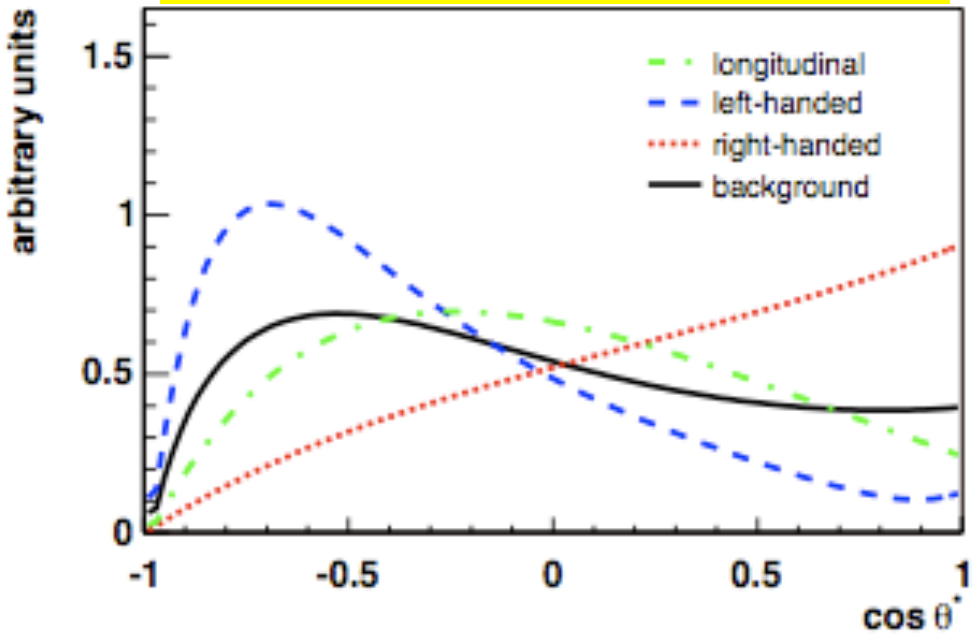
Afb: angle between top and proton direction

qq vs gg: Angle between top momentum and proton direction

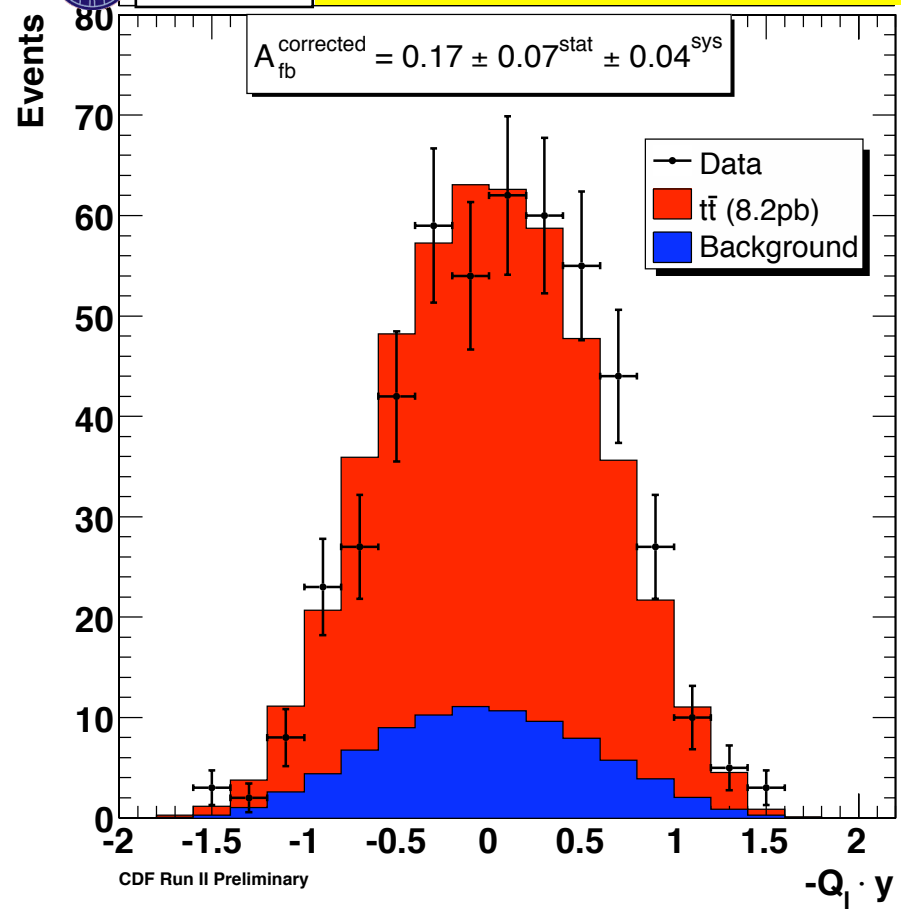




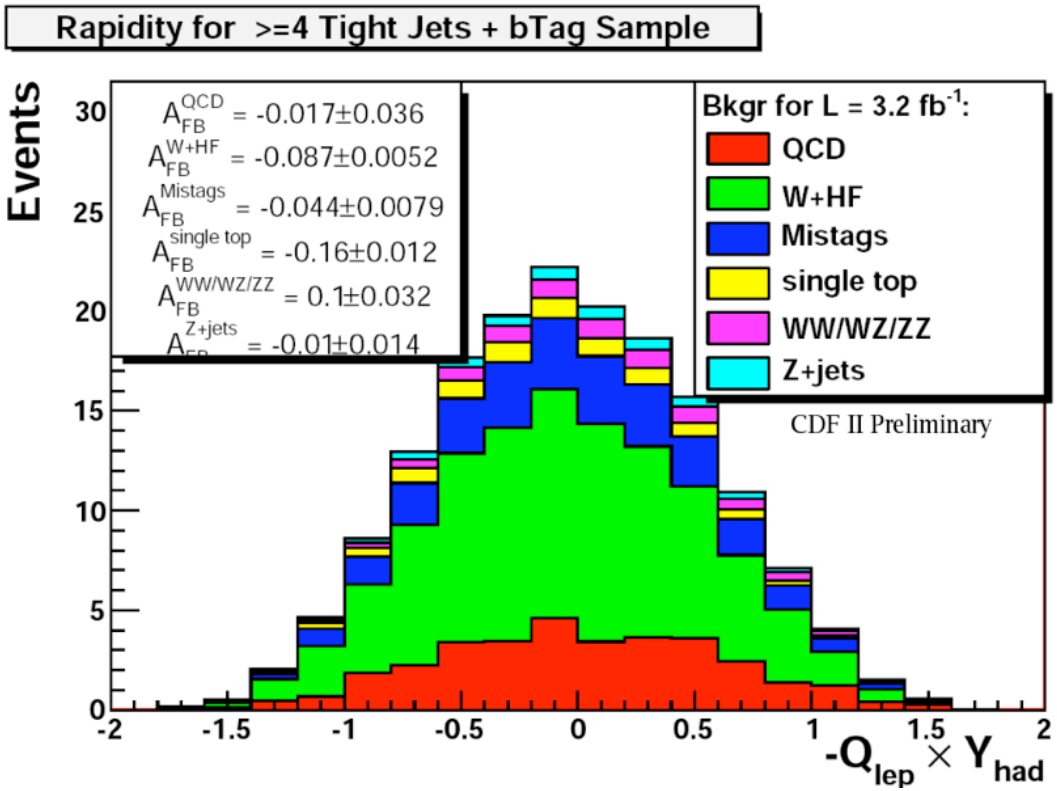
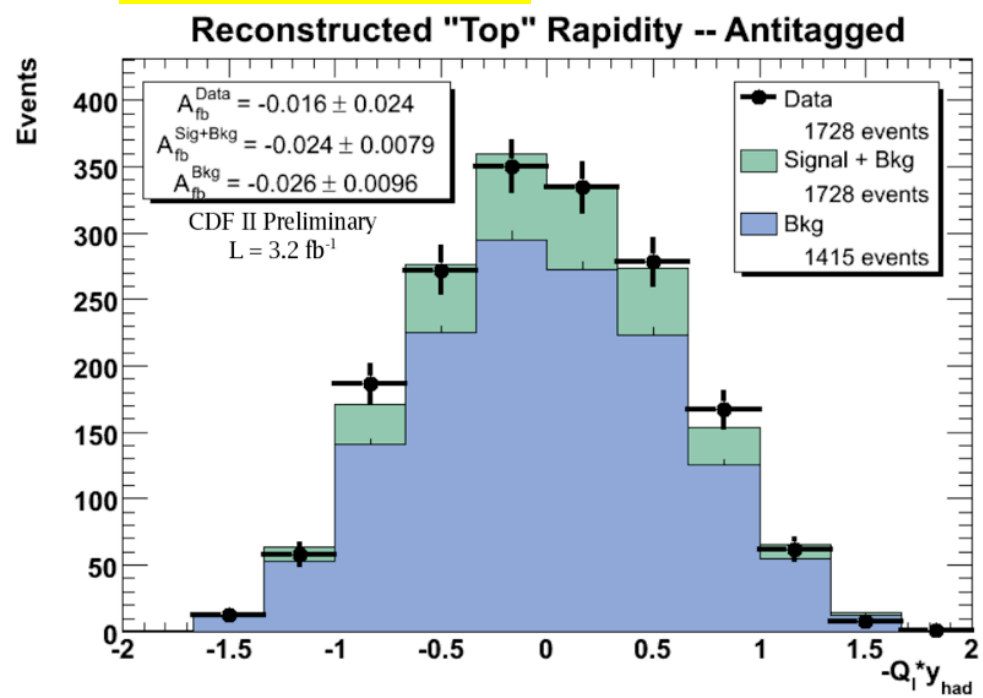
W helicity: Reconstructed lepton angle wrt top direction in W frame



1.9 fb^{-1} Had top rapidity distribution



Afb: Backgrounds



Afb: 0-Tag sample