Top quark Properties at the Tevatron

Veronica Sorin
IFAE-Barcelona

On behalf of the CDF and D0 Collaborations

2010 Moriond QCD

Top turns 15 !

Discovered in 1995 at the Tevatron

by the CDF and D0 collaborations

- On the year of its 15th birthday:
  - is it just an "ordinary" quark?
  - does it have an special role in the EWSB ?
- With 50 times more data than available at the discovery time, we can now study its properties accurately
- Extensive program at the Tevatron

Is it the SM top?

Strong top pair production

7.50 ± 0.48 pb CDFNote 9913

σ_{NLO} = 7.46 ± 0.8 pb (Mt=172.5GeV)

Cacciari et al,arXiv:0804.2800. Compatible Predictions:
N. Kidonakis and R.Vogt arXiv:0805.3844
S. Moch and P. Uwer, arXiv:0906.5273

EWK single-top production

Observation!
(see Garcia-Bellido's talk)

Top Mass

Tevatron combination

173.1 ± 1.3 (stat+syst)

★ 0.75% precision !

(hep-ex 0903.2503)

new single measurement

172.8 ± 1.3 (stat+syst)

CDFNote 10077

What else can we do experimentally?

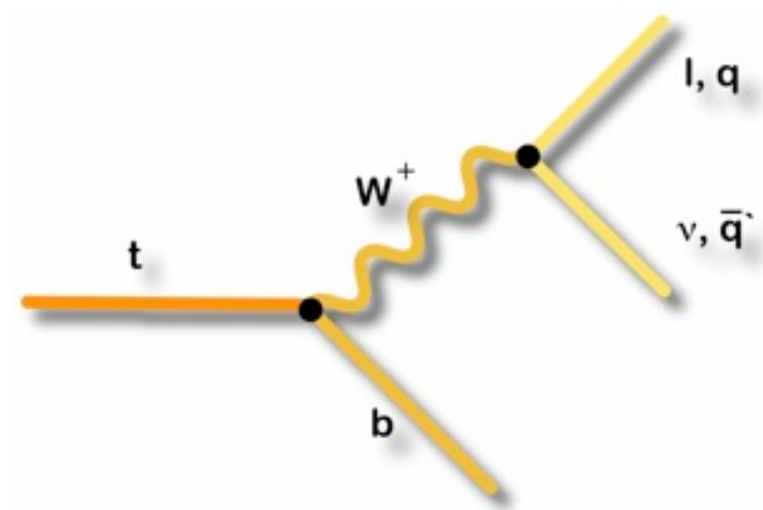
Top in the SM

$t \rightarrow Wb \sim 100\%$

tWb vertex structure

determined by the

charged current V-A interaction

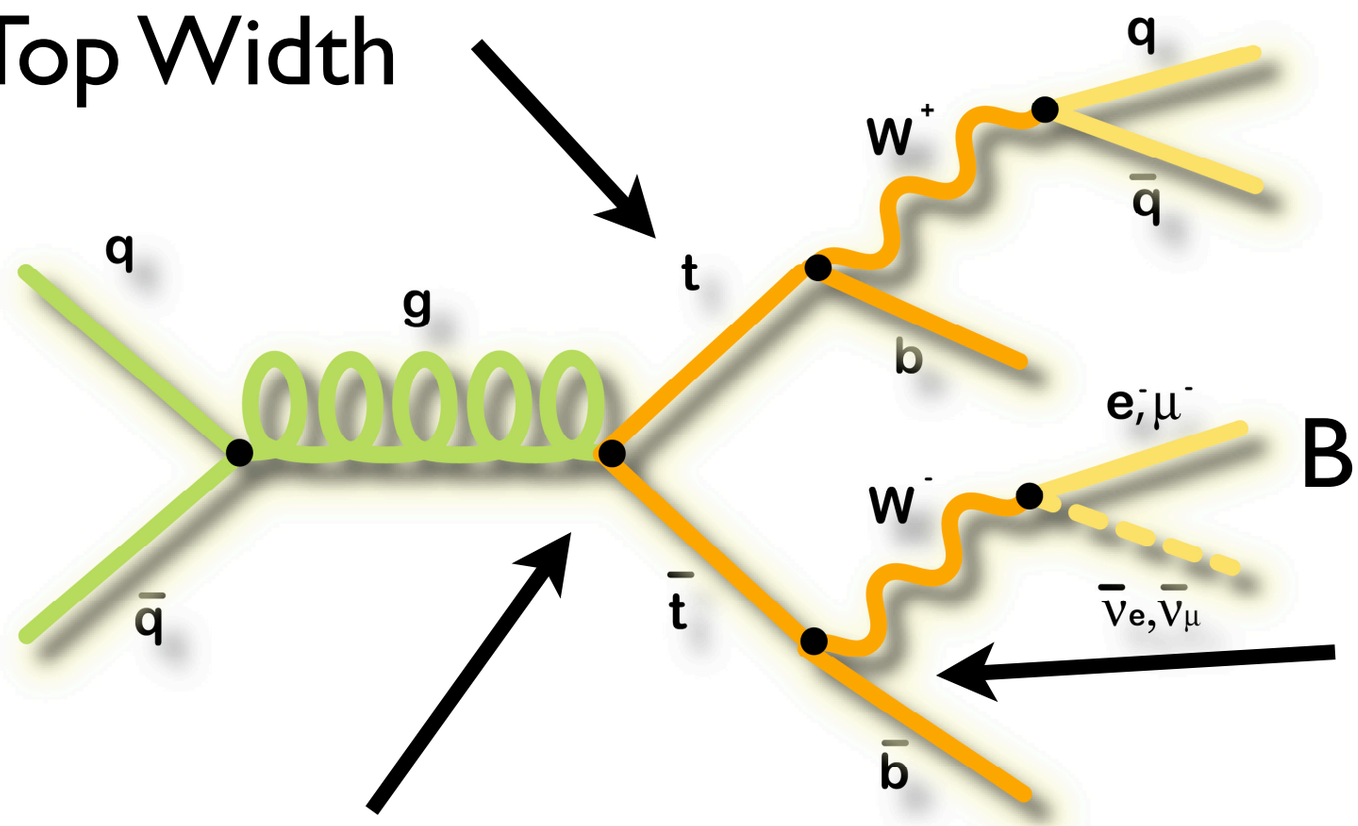


with a short lifetime $\tau \approx 10^{-25}$s
an order of magnitude smaller
than the hadronization time

Top quark properties can be studied
using its decay products

Top Properties

Top Charge
Top Width



Branching ratio
W Helicity
Anomalous
Couplings

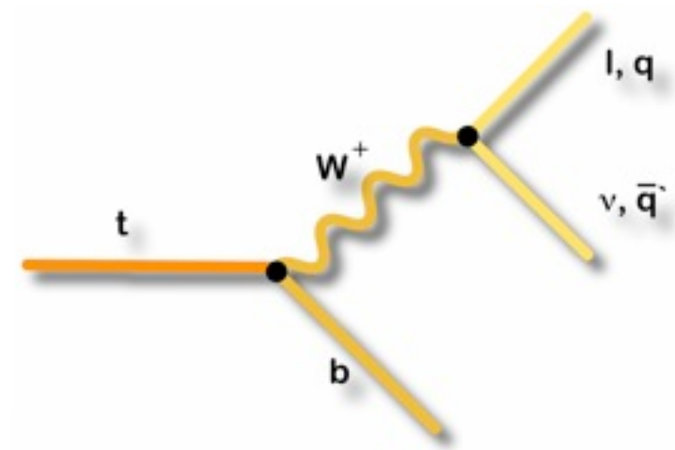
Spin Correlations
Forward-Backward Asymmetry

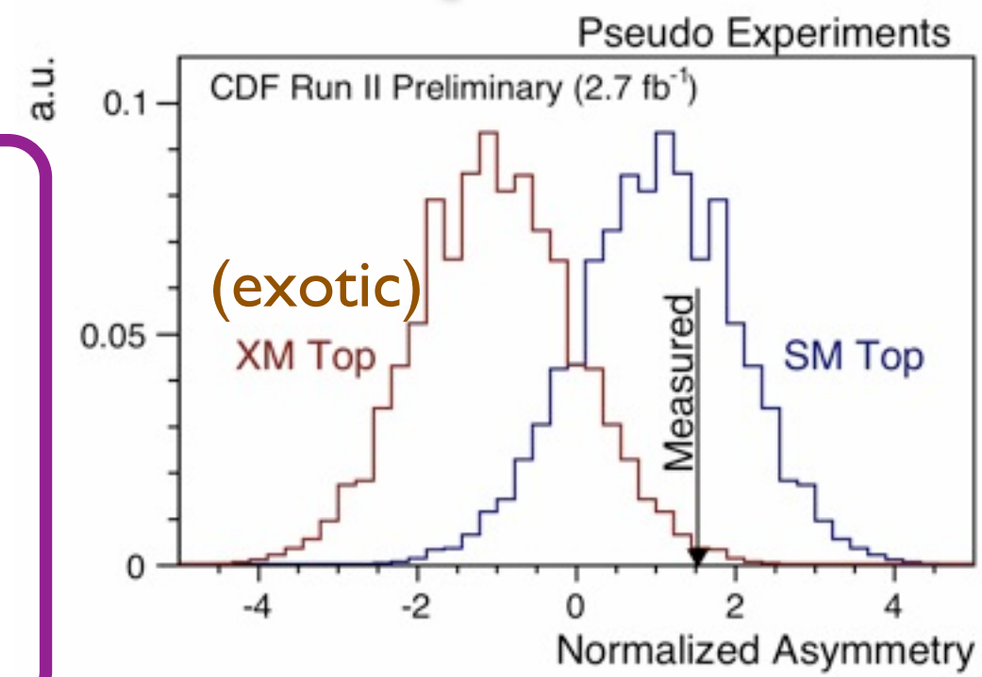
Top Charge

2.7 fb^{-1}

If SM, expect 2/3

- but what if instead of W^+b , we find W^-b ?
- is this actually an exotic quark of charge -4/3 ?





Lepton+Jets and ≥1 b-tagged jet

- reconstruct event with kinematic fitter
- charge of lepton provides charge of W
- Soft Lepton Tag provides the b-jet flavor

Similar analyses, using a Jet Charge algorithm for b-jet flavor found both at D0 and CDF strong evidence in favor of SM

PRL 98, 041801 (2007) , D0

p-value XM = 0.0094
exclude 4/3 hypothesis with 95%CL
(p-value compared with a-priori 5% Type I error)

Top Width

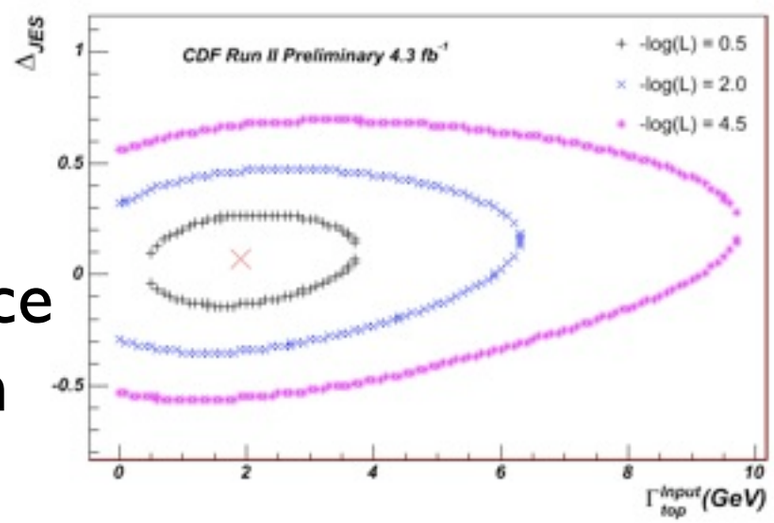
4.3 fb^{-1}

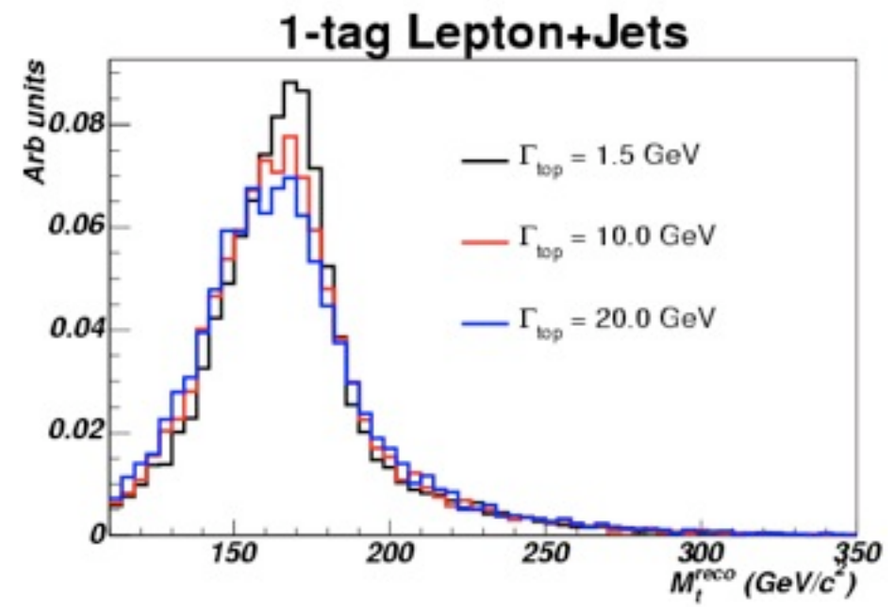
SM predicts ~1.5 GeV (M_t = 175 GeV/c^2)

- Lepton+Jets channel (≥4 jets), ≥1b-tag

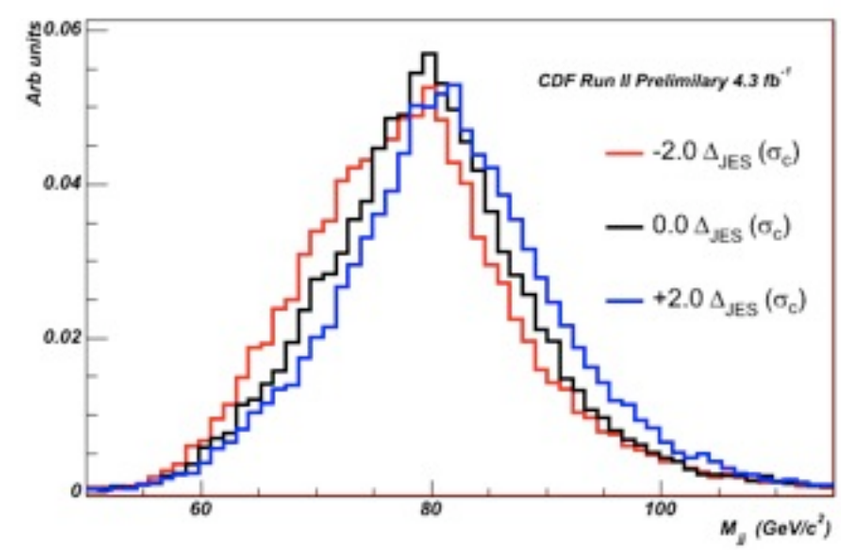
2D Template analysis

fit to the data





Mjj used to reduce systematic from JES



0.4 GeV < Γ_{top}< 4.4 GeV @ 68% CL

Γ_{top}< 7.5 GeV @ 95% CL

Previous experimental limit

Γ_{top}< 13.1 GeV @ 95% CL

(PRL 102, 042001 (2009) , CDF)

Consistent with SM

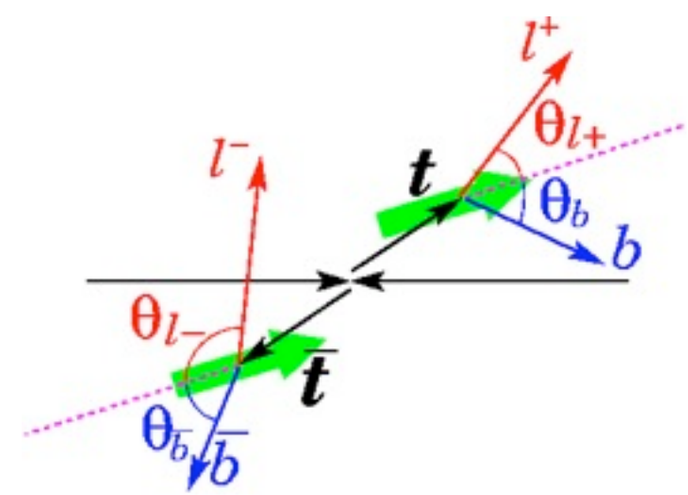
Spin Correlations

The spin-spin correlation at top pair production not diluted due to hadronization

⇓

results in characteristic angular distributions and correlation of top decay products

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_1\, d\cos\theta_2} = \frac{1}{4}(1 - C\cos\theta_1\cos\theta_2)$$



denotes angle of a decay product flight direction in top (anti-top) rest frame with respect to a chosen quantization axis for top (anti-top), with C : strength of spin-spin correlation [-1,1]

$$C = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

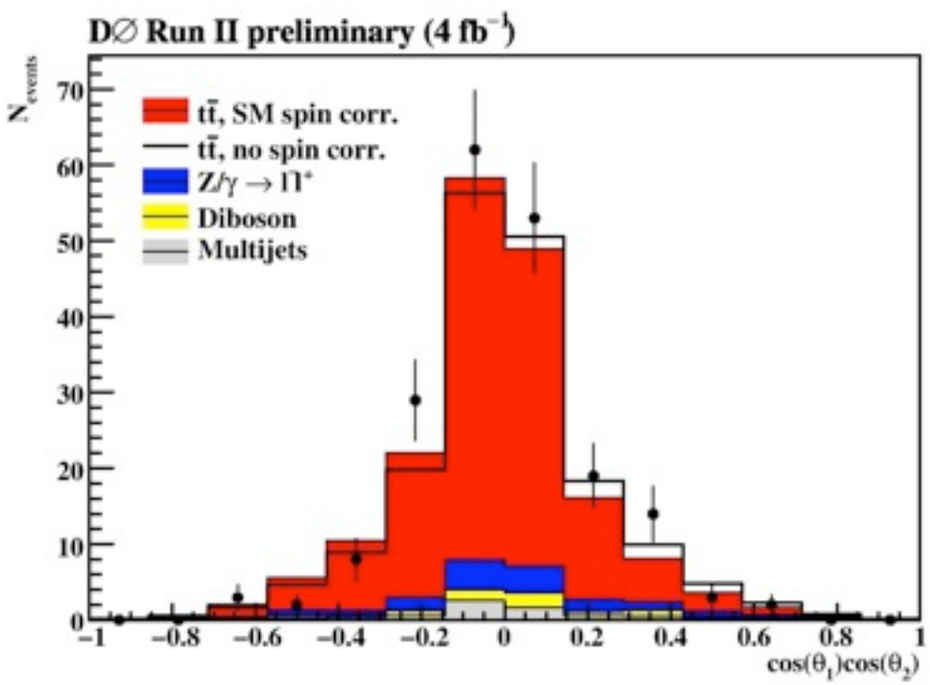
Spin Correlations : Dilepton Channel

4 fb^{-1}

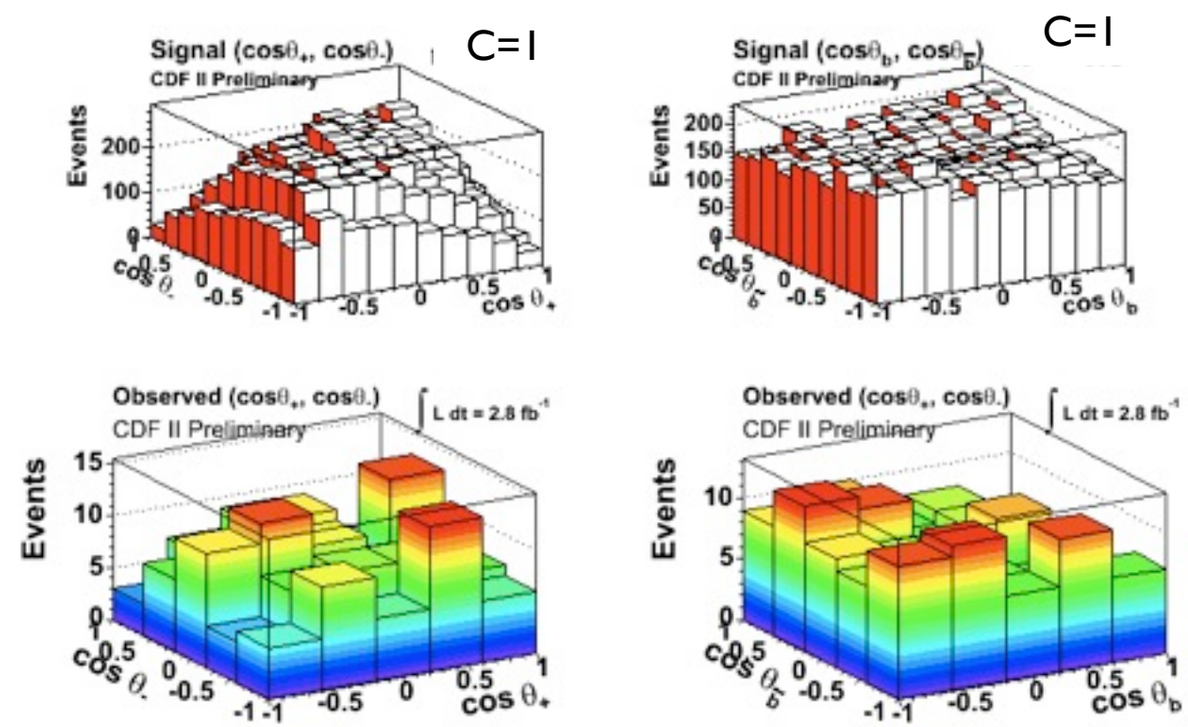
Template analyses

2.8 fb^{-1}

Using the beam axis,
SM NLO : C=0.78



In the off-diagonal basis,
SM NLO : C=0.78
using also b/bbar information



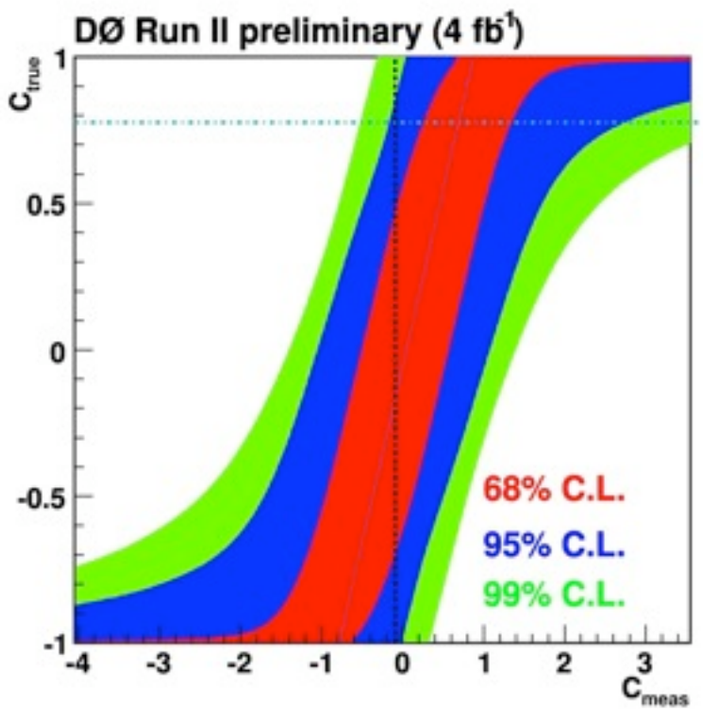
Spin Correlations : Dilepton Channel

4 fb^{-1}

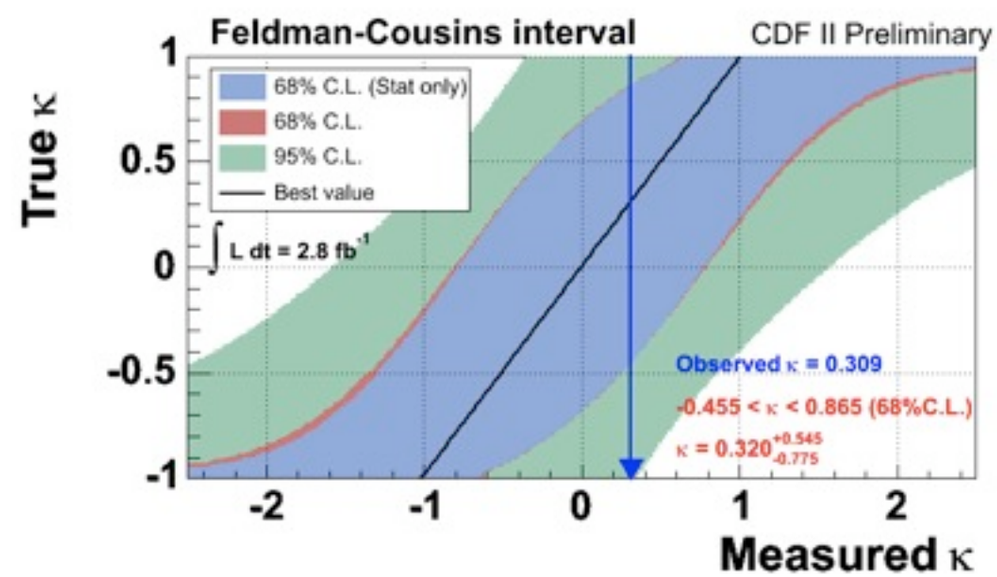
Template analyses

2.8 fb^{-1}

Using the beam axis,
SM NLO : C=0.78



In the off-diagonal basis,
SM NLO : C=0.78
using also b/bbar information



$C = -0.17\ ^{+0.64}_{-0.53}$ (stat+syst)

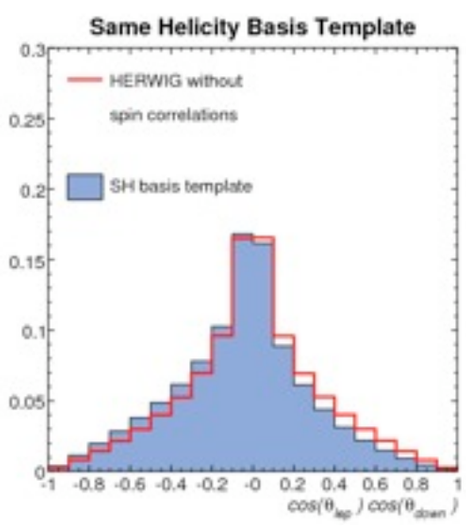
$K = 0.32\ ^{+0.55}_{-0.76}$ (stat+syst)

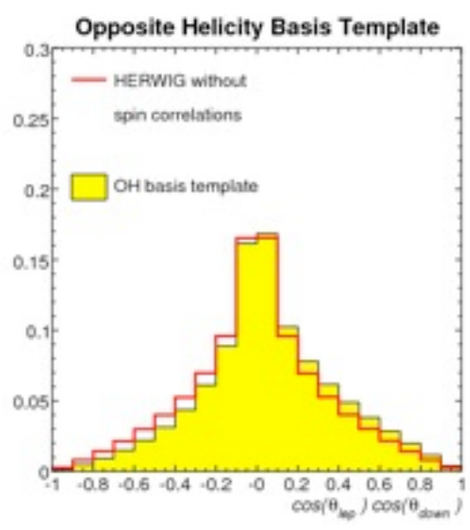
Spin Correlations : L+J Channel

In the helicity basis:

SM NLO : C = 0.4

2D fit to angular distributions of lepton and the down-type or bottom quark from the hadronically decaying top.





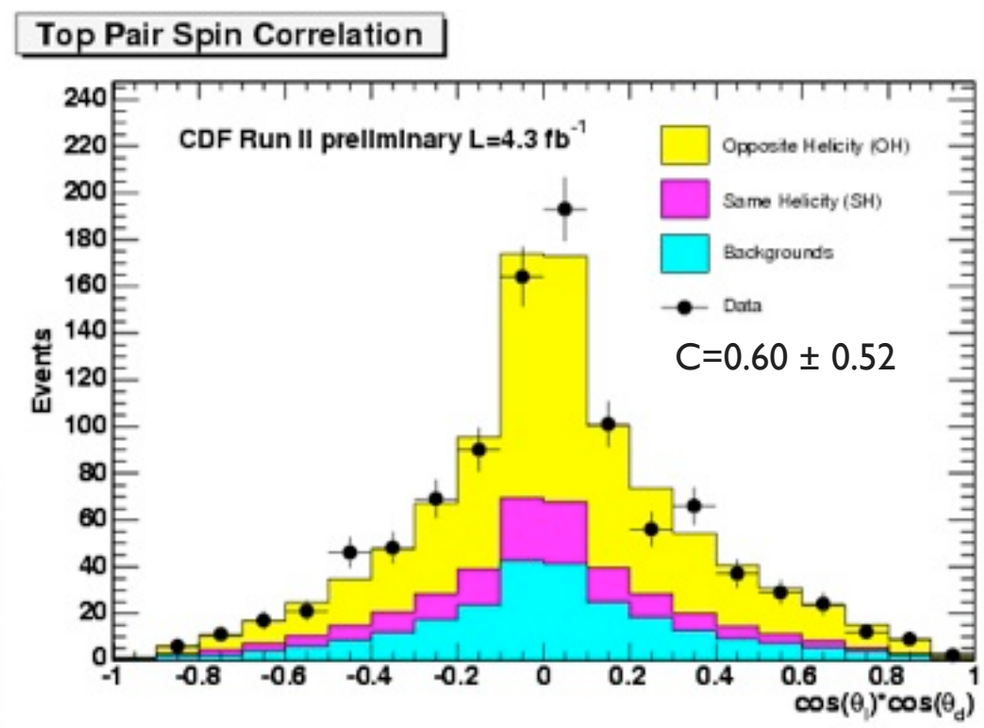
down-type quark chosen as jet closest to the b in W rest frame

Mahlon and Parke, PRD 53, 4886 (1996)

Template analyses

4.3 fb^{-1}

b-tagged sample



C= 0.60 ± 0.50 (stat) ± 0.16 (syst) , consistent with SM

Branching fractions Ratio

1. fb^{-1}

$t \rightarrow Wb \sim 100\%$??

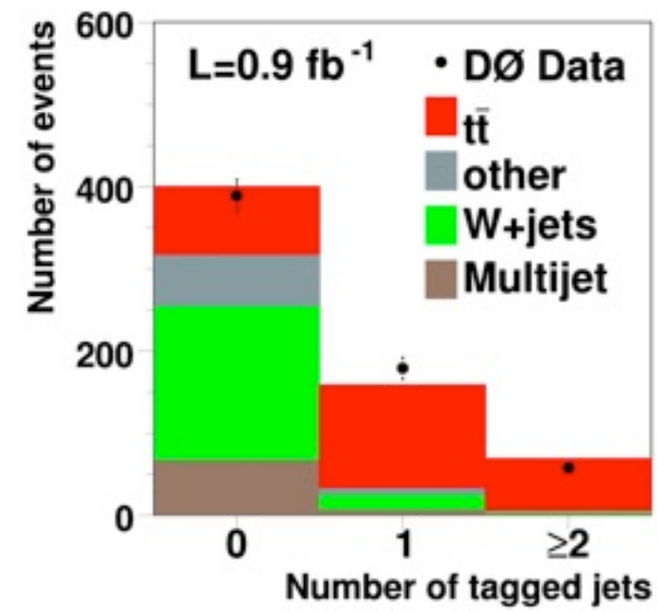
$R = B(t \rightarrow Wb)/B(t \rightarrow Wq)$

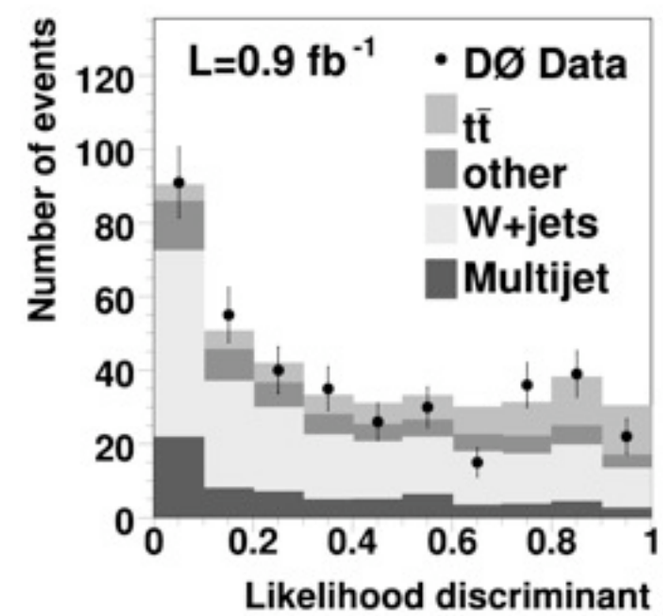
Lepton+Jets events:

- divide sample in 0 , 1 and ≥2 btagged jets.
- Probability to have n-tagged jets depends on decay mode (bb, bq ,qq : q down-type) and overall will depend on R.
- Build a discriminant exploiting kinematic differences between top and background events
- Fit number of events on the 1 and 2 btagged samples, and the discriminant for the 0 tagged one.
- Simultaneous fit of R and cross section:

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

$\sigma_{tt} = 8.18\ ^{+0.90}_{-0.84}$ (stat+syst)





D0 PRL 100 192003 (2008)

Examining the Wtb vertex

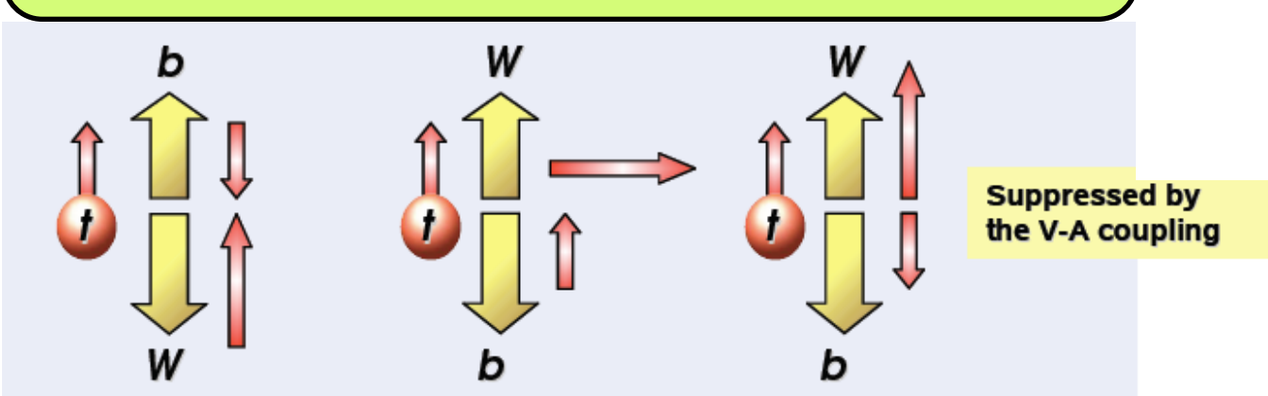
W boson helicity

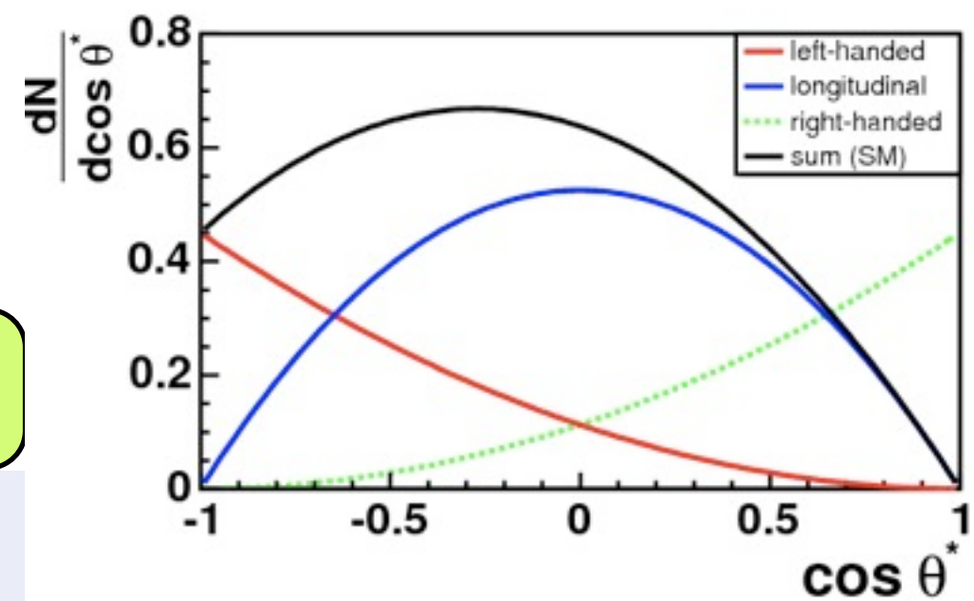
In SM

$t \rightarrow Wb \sim 100\%$

due to the V-A nature of the vertex, expect:

Left-Handed	Longitudinal	Right-Handed
$f_- \cong 0.3$	$f_0 \cong 0.7$	f_+ : Suppressed





decay angle of down-type fermion in the W rest frame with respect to the top quark direction

W Helicity

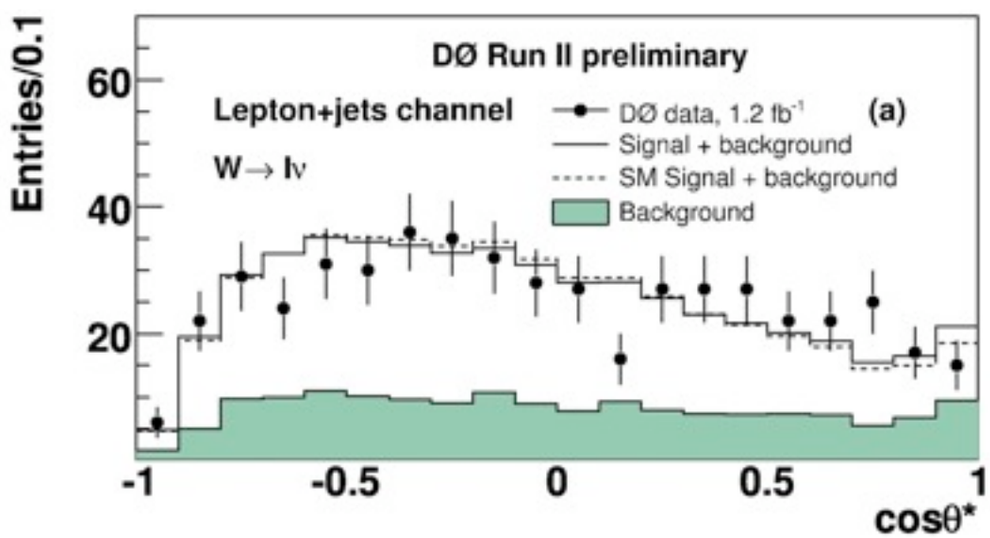
2.7 fb^{-1}

2D model independent fit

2.7 fb^{-1}

Template analysis

Lepton+Jets and Dilepton



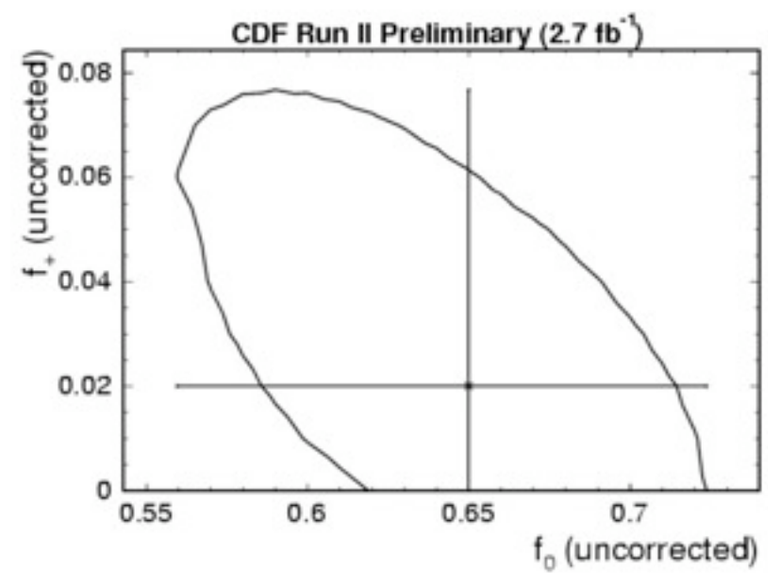
f_0 = 0.490 ± 0.106 (stat) ± 0.085 (syst)

f_+ = 0.110 ± 0.059 (stat) ± 0.052 (syst)

1fb^{-1} Reference: D0 PRL 100 062004 (2008)

Matrix Element analysis

Lepton+Jets Channel



f_0 = 0.88 ± 0.11 (stat) ± 0.06 (syst)

f_+ = -0.15 ± 0.07 (stat) ± 0.06 (syst)

Reference: CDF arXiv:1003.0224v1

Anomalous Couplings

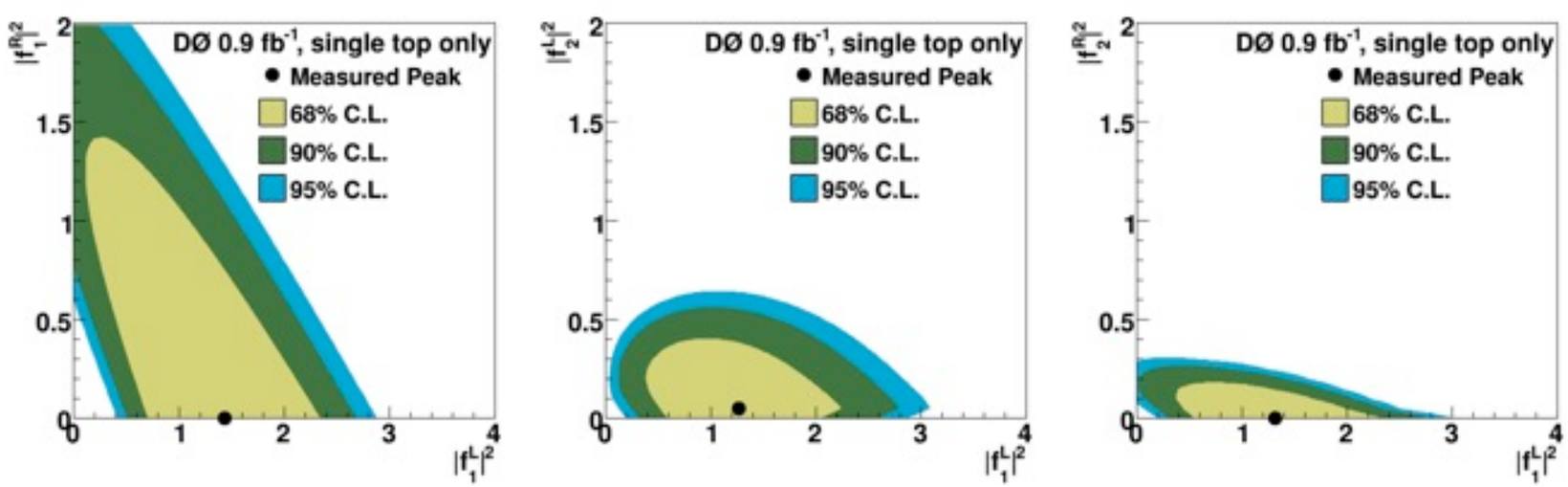
$$L_{tWb} = \frac{g}{\sqrt{2}} W_\mu^- \bar{b} \gamma^\mu \left(f_1^L P_L + f_1^R P_R \right) t - \frac{g}{\sqrt{2}M} \partial_\nu W_\mu^- \bar{b} \sigma^{\mu\nu} \left(f_2^L P_L + f_2^R P_R \right) t$$

2.7 fb^{-1}

+ *h.c.*

SM values : $f_1^L = 1$, $f_1^R = f_2^L = f_2^R = 0$

- observables like the W helicity fractions or the single top cross section/ kinematics will depend on the tWb couplings (C.R. Chen, F. Larios and C.P Yuan, Phys.Lett.B631:126)
- Measurements can therefore be used to do a general analysis of the vertex
- By investigating one pair of coupling form factors at a time (others at SM value):



Anomalous Couplings

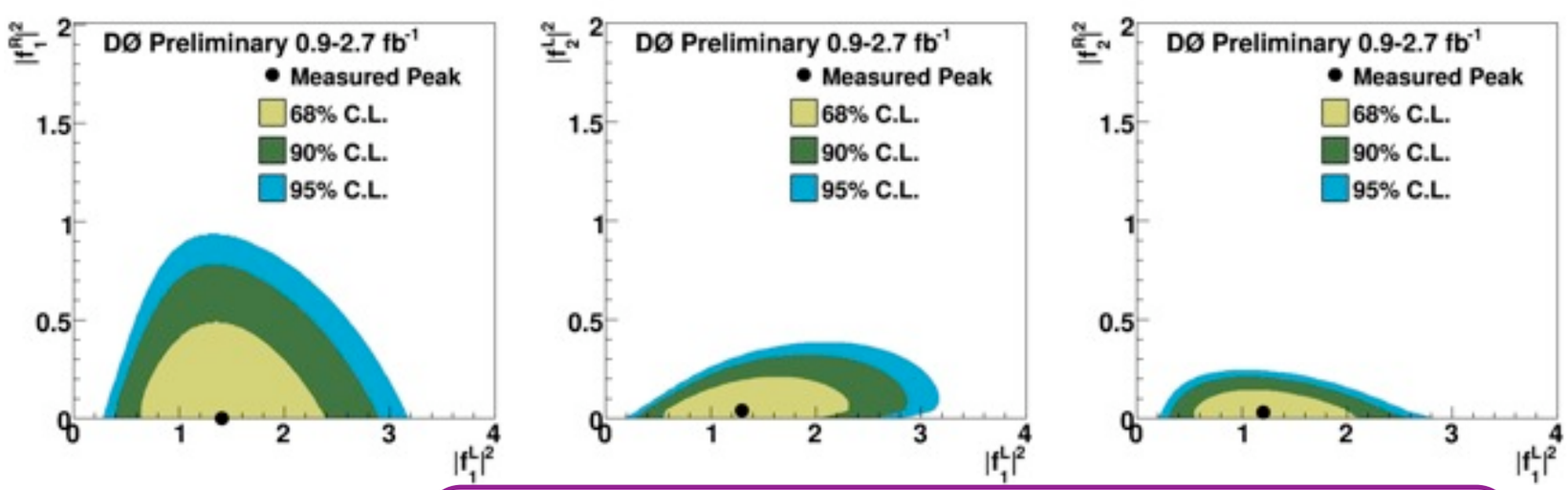
$$L_{tWb} = \frac{g}{\sqrt{2}} W_\mu^- \bar{b} \gamma^\mu \left(f_1^L P_L + f_1^R P_R \right) t - \frac{g}{\sqrt{2}M} \partial_\nu W_\mu^- \bar{b} \sigma^{\mu\nu} \left(f_2^L P_L + f_2^R P_R \right) t$$

2.7 fb^{-1}

+ *h.c.*

SM values : $f_1^L = 1$, $f_1^R = f_2^L = f_2^R = 0$

- observables like the W helicity fractions or the single top cross section/ kinematics will depend on the tWb couplings (C.R. Chen, F. Larios and C.P Yuan, Phys.Lett.B631:126)
- Measurements can therefore be used to do a general analysis of the vertex
- By investigating one pair of coupling form factors at a time (others at SM value):



find 95%CL if $f_1^L = 1$

$|f_1^R|^2 < 0.72$

$|f_2^L|^2 < 0.19$

$|f_2^R|^2 < 0.20$

Consistent with SM

1fb^{-1} Reference:
D0 PRL 102 092002 (2009)

Forward-backward asymmetry

- NLO QCD calculations predict a charge asymmetry:

  Ac = 5 ± 1.5 % ($p\bar{p}$ frame)

- If CP, it can be interpreted as

$$A_{FB} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

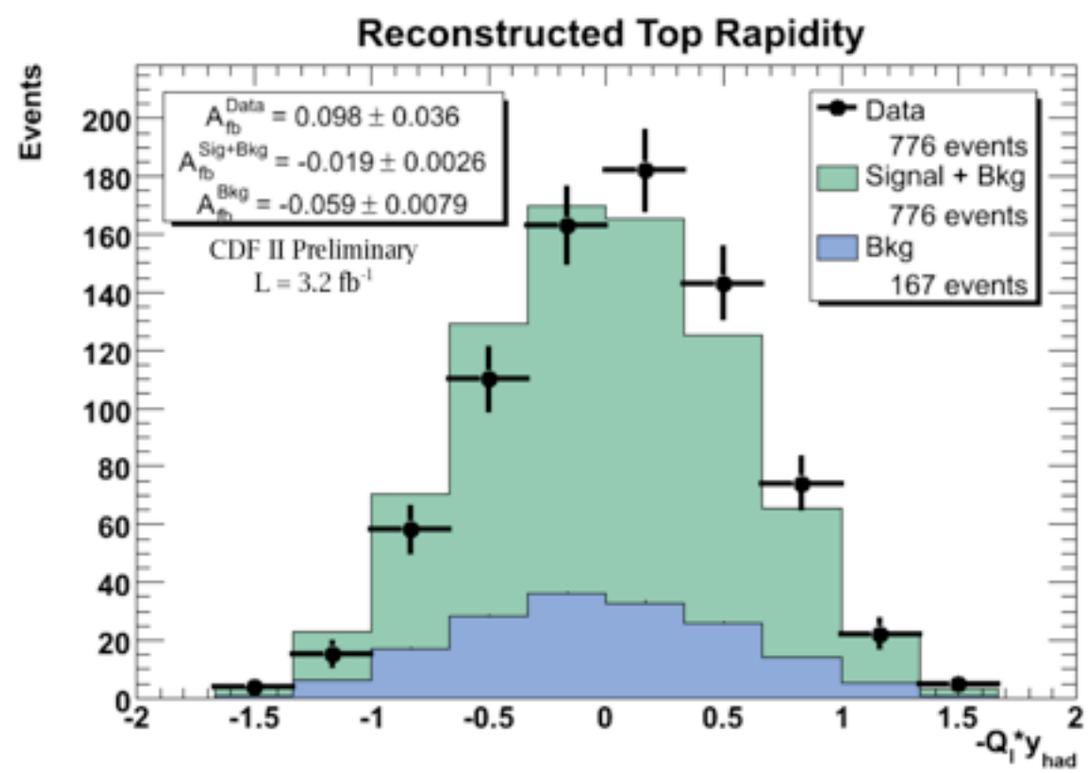
- New physics models could give rise to a A_{FB} asymmetry.

- Lepton+Jets and ≥1b-tag

- Use rapidity of hadronically decaying top

- Correct by detector effects

3.2 fb^{-1}



$p\bar{p}$ frame

Afb= 19.3 ± 6.5 (stat) ± 2.4 (syst) %

References:

CDF PRL 100 202001 (2008) : 1.9fb^{-1} ,Afb =0.17 ± 0.08

D0 PRL 100, 142002 (2008) : 0.9fb^{-1} ,Afb =0.12 ± 0.08 (observed)

Summary

M_t = 172.8 ± 1.3 GeV/c^2

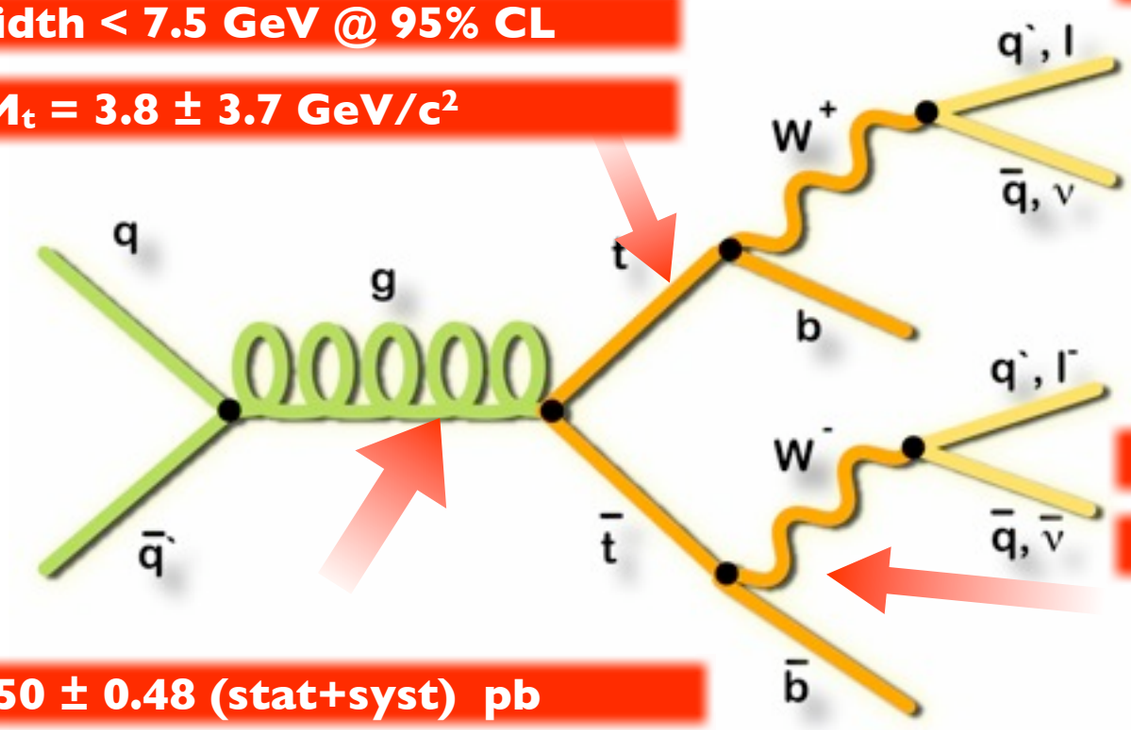
Top charge : not 4/3 @ 95% CL

Top width < 7.5 GeV @ 95% CL

ΔM_t = 3.8 ± 3.7 GeV/c^2

anom coupl : no evidence found

f_+ = 0.110 ± 0.059 (stat) ± 0.052 (syst)



B(t→Wb)/B(t→Wq)=0.97 ± 0.09

BR(t → Zq) < 3.7% at 95% C.L.

σ = 7.50 ± 0.48 (stat+syst) pb

Afb= 19.3 ± 6.5 (stat) ± 2.4 (syst) %

dσ/dMtt no discrepancy with SM

dσ/dpt no discrepancy with SM

fraction via gg fusion : $0.07^{+0.15}_{-0.07}$

Single Top Observation !!

Many Searches

Garcia-Bellido and Goldschmidt's talks

Experiment's web pages:

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

D0: http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html

Conclusions

- We are studying top from many angles
  - performing high precision measurements such as mass and cross sections
  - measuring some properties for the first time
  - ➡ so far experimental measurements agree with SM predictions
- Though some properties still statistically limited, more data is being analyzed
  - ❖ ~7fb^{-1} on tape (expected >10fb^{-1} by end of RunII)
  - ❖ Many properties to be soon combined between D0 and CDF

Stay Tuned !!