Top Quark Properties Measurement with the DØ Detector

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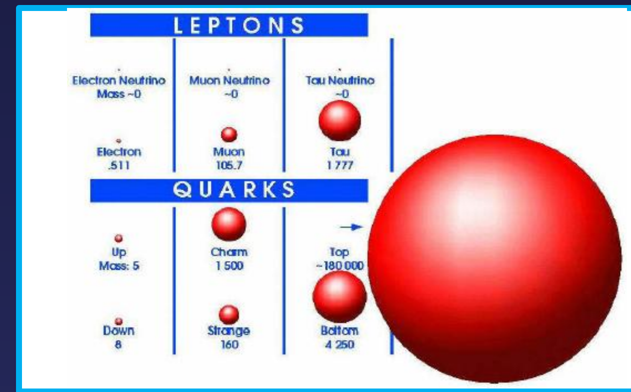
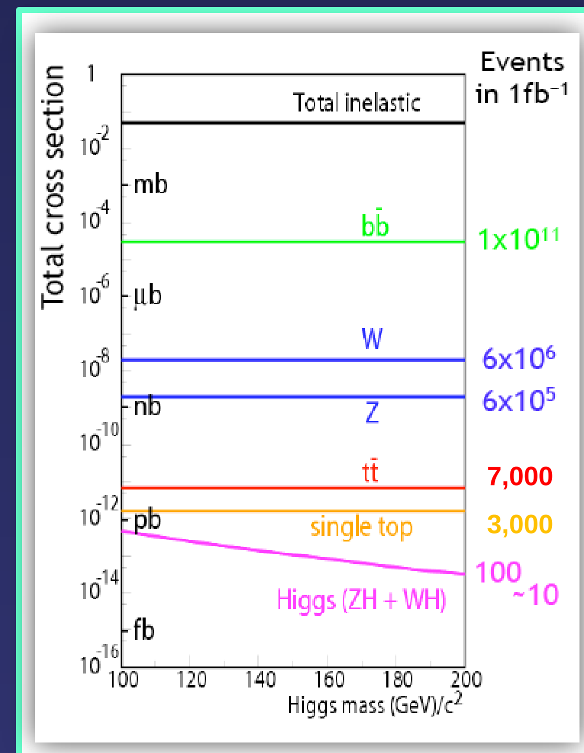
Why Look at The Top Quark?

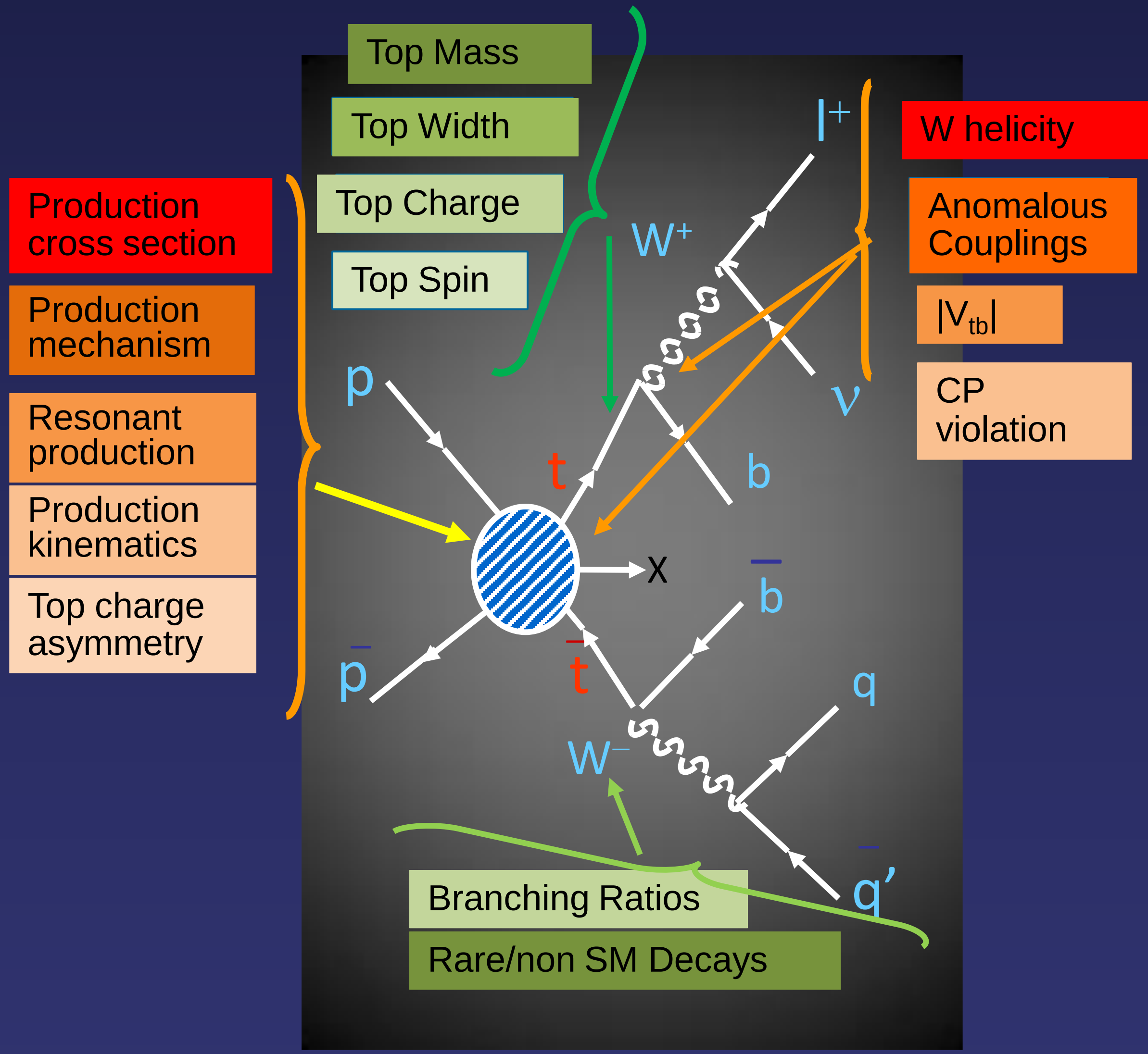
- Was discovered at Fermilab in1995
- The heaviest known fundamental particle
  - m_t = 173.1 1.3 GeV (~0.75% precision)
  - τ = 5 10^{-25} s $<< \Lambda_{QCD}^{-1}$ Decays before hadronization
- Mass close to scale of electroweak symmetry breaking
  - Only quark for which coupling to Higgs is significant
  - May shed light on EWSB mechanism
- Top quark plays special role in many of the new physics models
- Even more than a decade after its discovery, our sample consists of ~ 1000 top quark events
  - Many of the measurements of top quark properties are still statistics limited





What Should we Know about the Top?

Everything!



<u>Questions we can answer</u>

- Higgs boson mass?
- Charged Higgs bosons?
- New massive particles?
- Measurements that can only be made here (e.g charge assymetry)
- Do all quarks have the expected couplings?

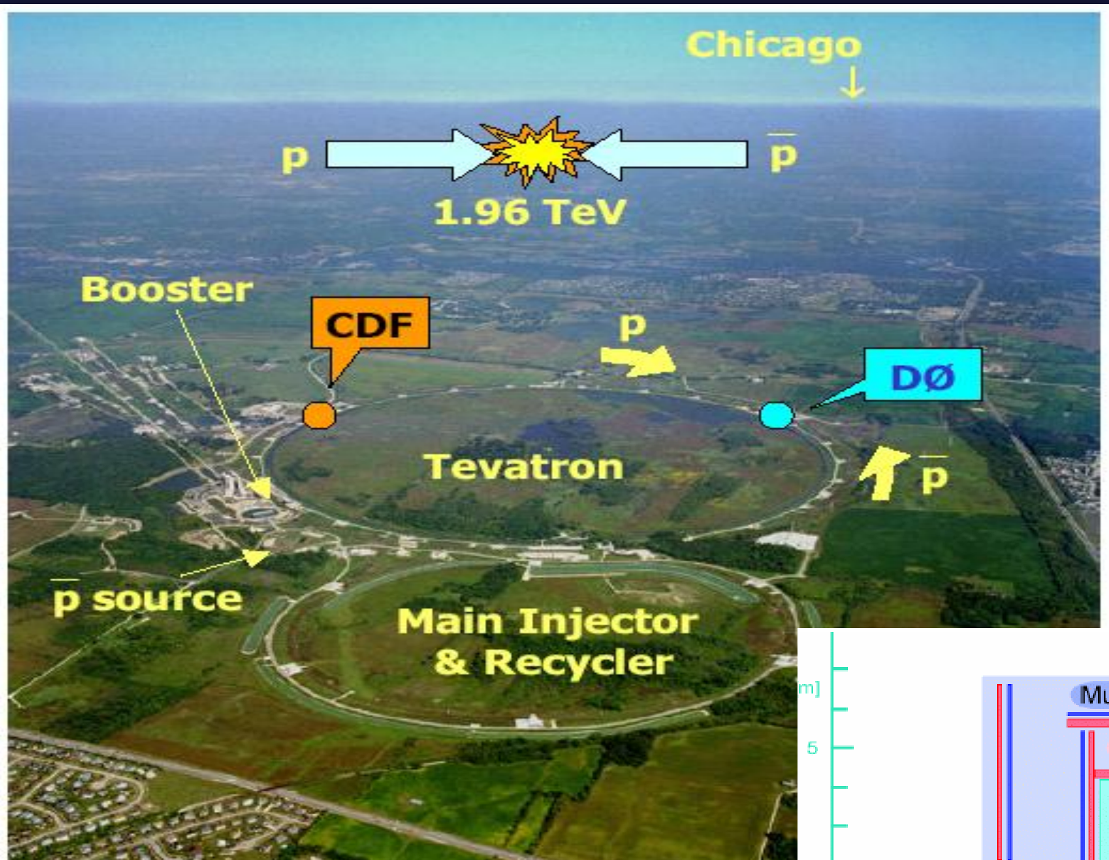
….. and many more, including

- Unknown unknowns??

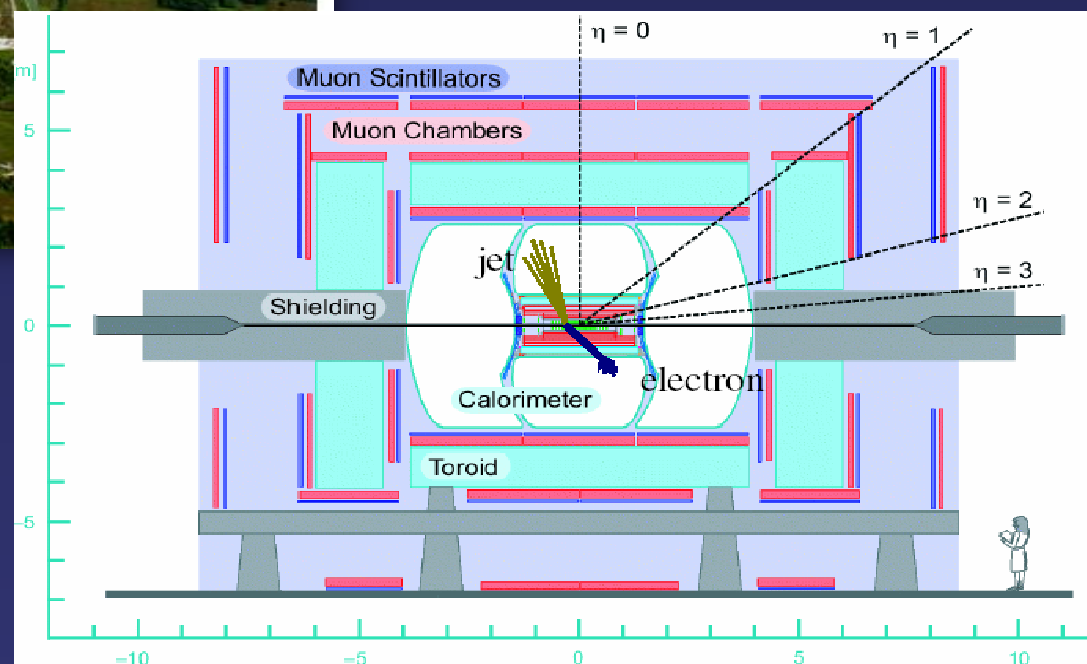
Outline

- Introduction
  - why look at top?
- Anomalous Wtb couplings
  - Top quark pair production
  - Single top quark production
- Spin correlations

The Tevatron Accelerator



The D∅ Detector

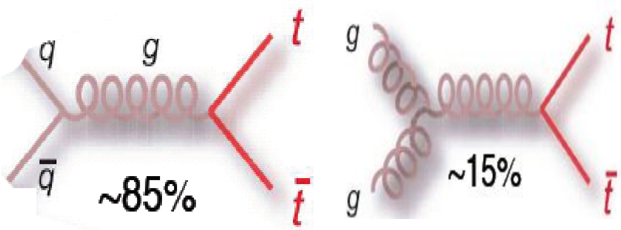


- ~ 20 countries
- ~ 80 institutions
- ~ 700 enthusiastic physicists per experiment

Production

Top quark pair production

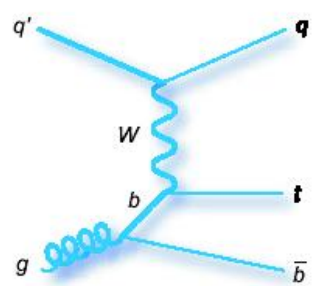
σ ~7 pb



Single top quark production

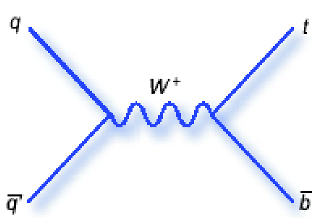
***t*-channel**

σ ~2 pb



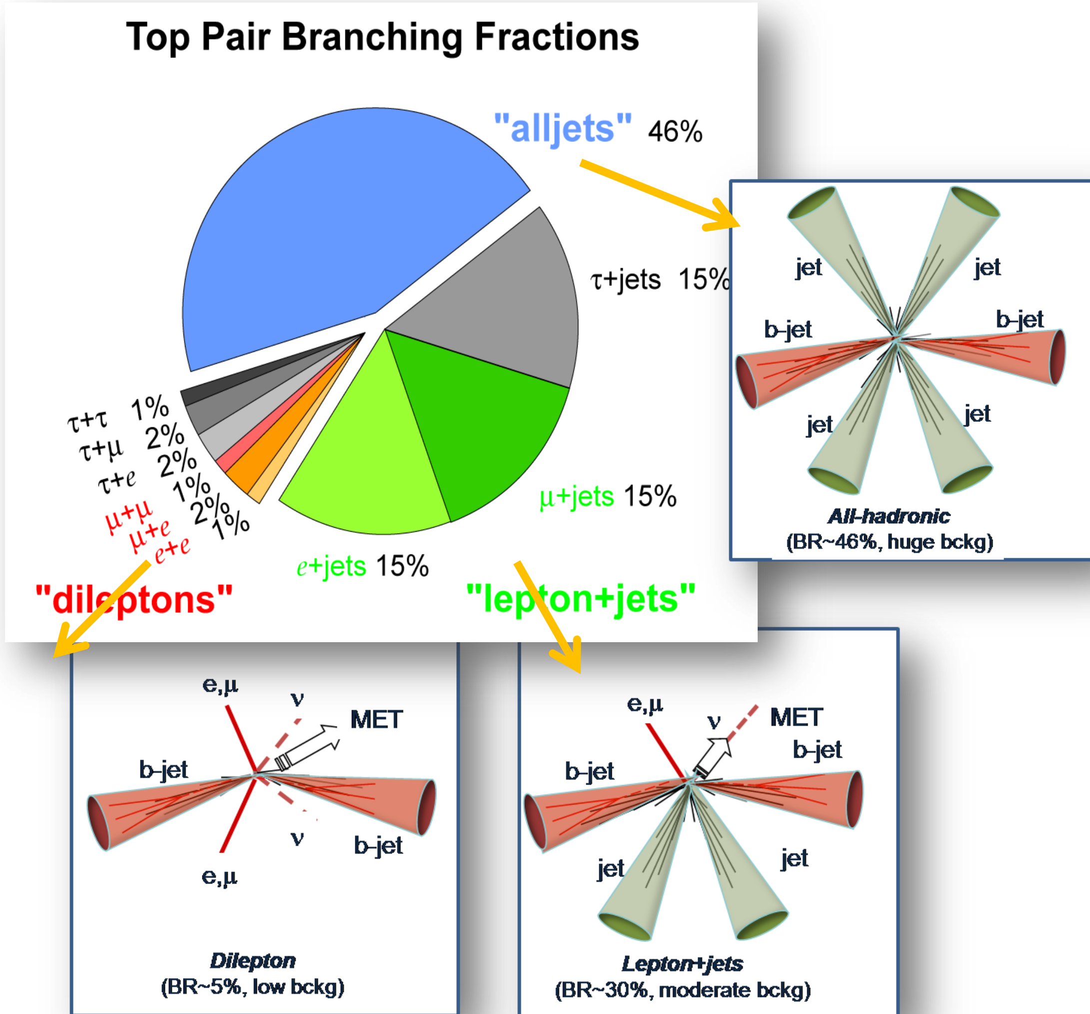
***s*-channel**

σ ~1 pb



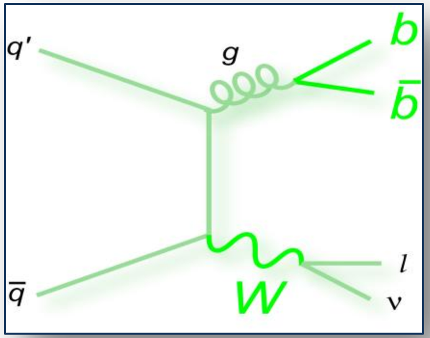
Decay

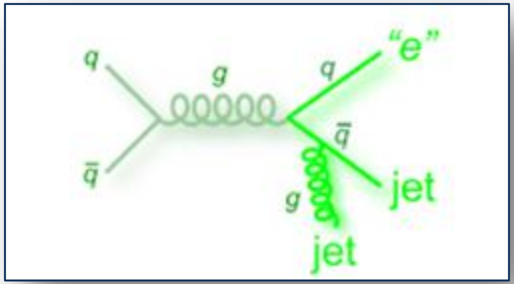
Within Standard Model t→Wb ~ 100%

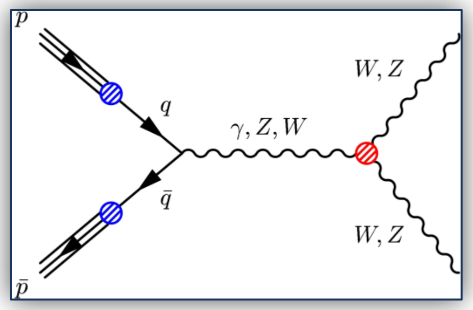


- Dominant Backgrounds
  - Dominant backgrounds :
    - W+jets and multijet production (ℓ+jets channel) and
    - Z+jets WW+jets (dilepton channel)

- Signal and Background Modeling
  - The SM top pair samples are generated using ALPGEN +PYTHIA
  - Single top quarks production is modeled using COMPHEP
  - Other backgrounds are modeled using ALPGEN or PYTHIA except multijet background which is determined from data

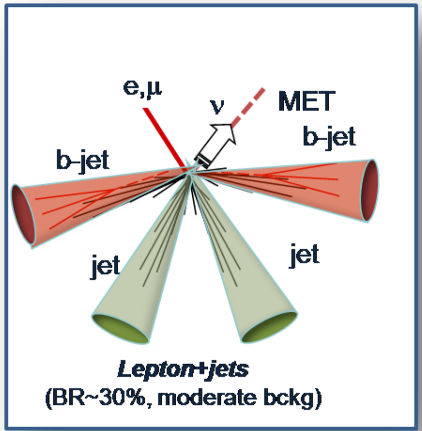






General Selection

- For lepton + jets channel require one isolated electron or muon, 3 or more jets and missing energy
- Since top quark decay final states include jets originating from b quarks and most of the background doesn't , we make use of b-tagging algorithm to further reduce our background contributions
- Events are divided into sub-samples depending on lepton, jets and b-tags.
- These channels are kept separate and are combined at the end to get the final result
  - All channels are constructed to be orthogonal



Selection in l+jets channel

$e: \quad p_T > 20\ GeV, |\eta| < 1.1$

$\mu: \quad p_T > 20\ GeV, |\eta| < 2.0$

Missing E_T :

$e: \ > 20\ GeV; \quad \mu: > 25\ GeV$

Jets :

$\geq 3\ jets$

$p_T > 20 GeV, |\eta| < 2.5$

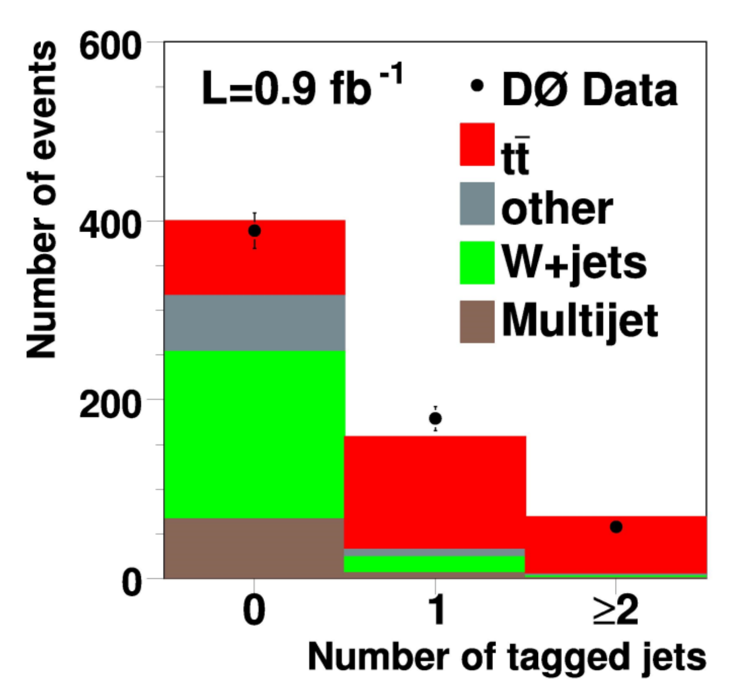
$p_{T,1} > 40\ GeV$

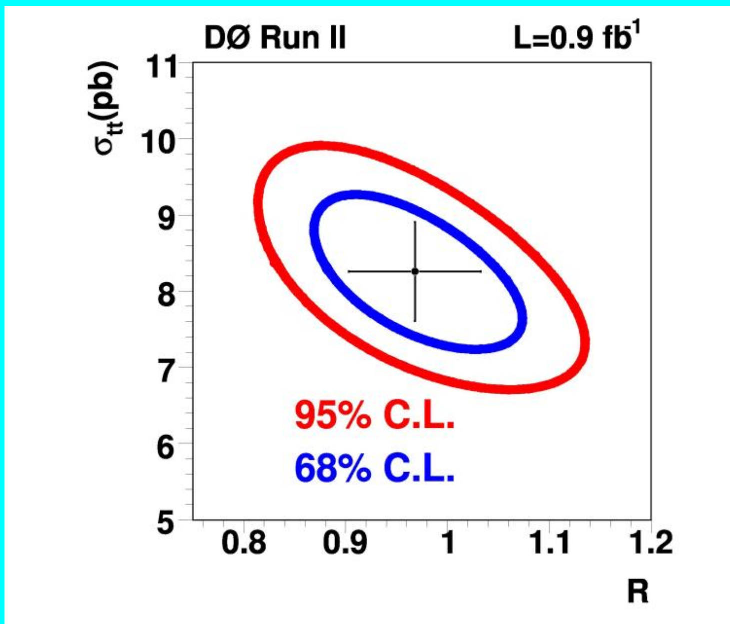
Measurement of $|V_{tb}|$

- Under the assumption of unitarity and three generations of quarks: |Vtb|=0.9991(00)

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

- Can measure the branching ratio by counting the rate of *b-tags in ttbar events*



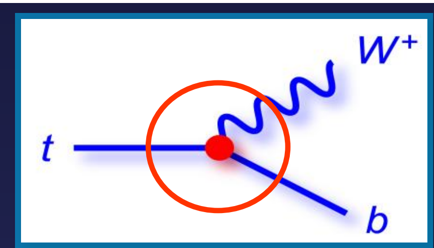


$$\frac{|V_{tb}|^2}{|V_{ts}|^2 + |V_{td}|^2} > 3.8$$

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

PRL 100, 192003 (2008)

Anomalous Wtb Coupling



- If top quark plays a special role in EWSB its couplings to W bosons may differ from predictions
- Modifications to top quark interactions, in particular with weak gauge bosons, could yield the first signs of new physics

Most general CP-conserving Wtb vertex up to mass dimensions 5

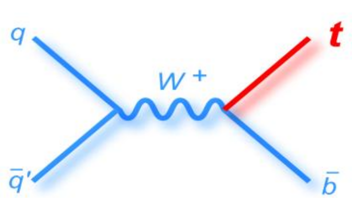
$$L_{tWb} = \frac{g}{\sqrt{2}} W_\mu^- \bar{b} \gamma^\mu \left(f_1^L P_L + f_1^R P_R \right) t - \frac{g}{\sqrt{2} M_W} \partial_\nu W_\mu^- \bar{b} \sigma^{\mu\nu} \left(f_2^L P_L + f_2^R P_R \right) t + h.c.$$

where, in the SM $f_1^L \approx 1,\ f_2^L = f_1^R = f_2^R = 0$

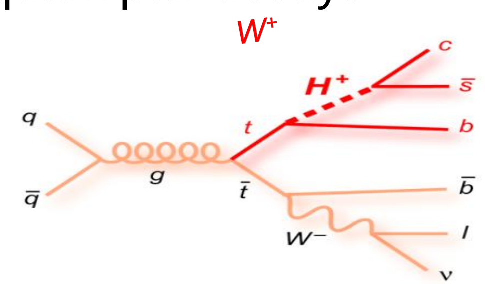
- Left and Right handed Tensor(2) coupling
- Left and Right handed Tensor(2) coupling

- Probing tWb vertex:

single top quark production and decay



Top quark pair decays



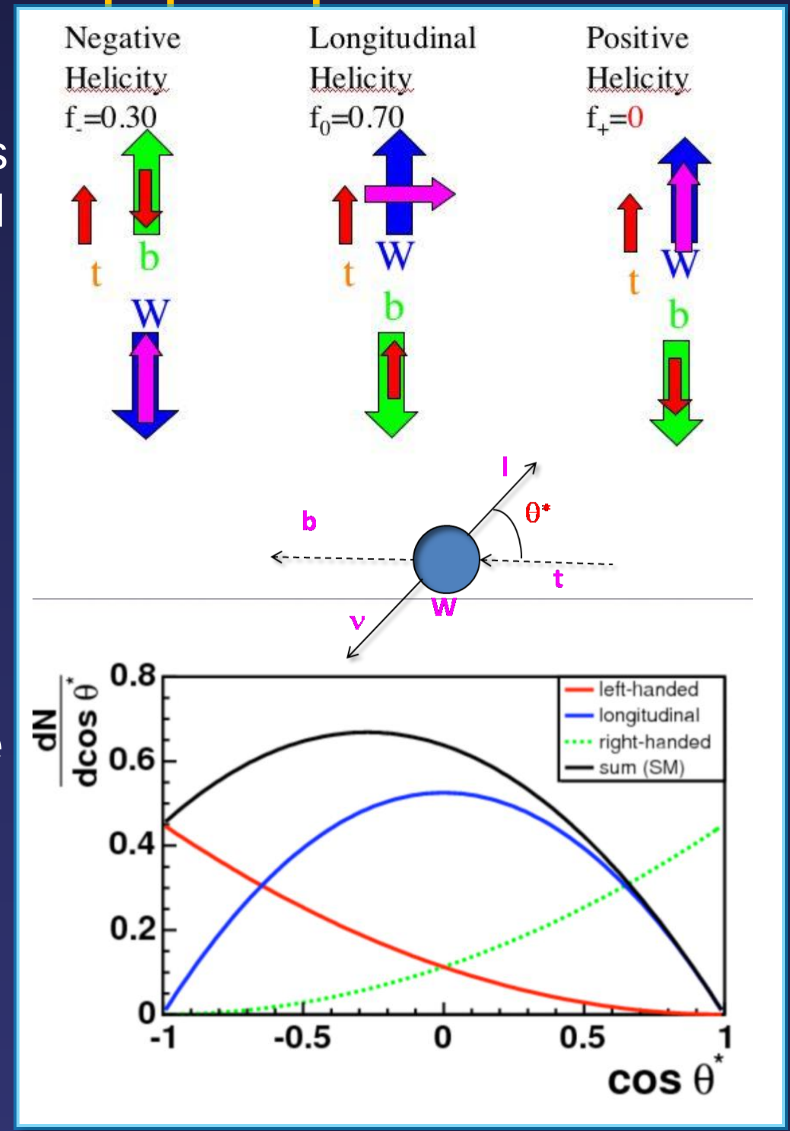
Both measurements can be combined to fully specify the tbW vertex (Phys. Lett. B 631, 126 (2005))

Model-independent measurement of the W boson helicity from t→Wb decays in top pair production

- A different Lorentz structure of the t → Wb interaction would alter the fractions of W bosons produced in each polarization state from the SM
- Model-independent measurement based on reconstruction of cosθ* distribution

  Distribution of cos θ* depends on the W boson helicity fractions
- Generate samples corresponding to each of the three W boson helicity states by reweighting the generated cosθ* distributions
- Simultaneous measurement of f_0 and f_+

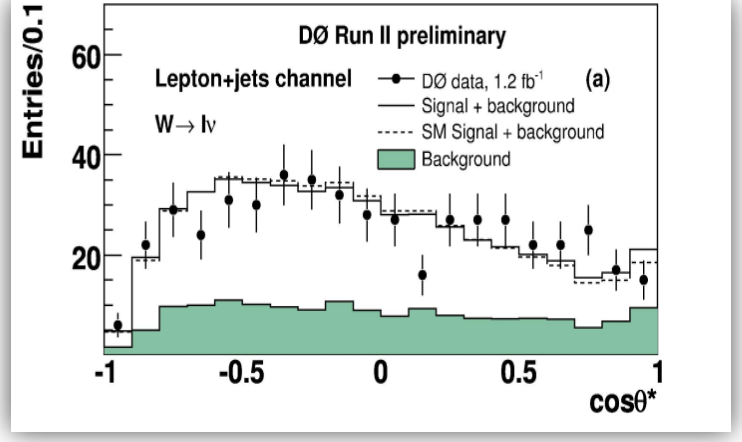
  (the negative helicity fraction f_- is then fixed by the requirement that $f_- + f_0 + f_+ = 1$)

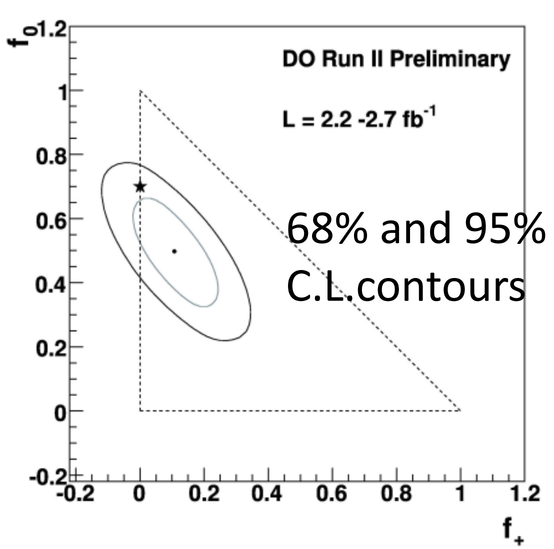


Measuring W Boson Helicity

Main source uncertainties

Source	f_+	f_0
ttbar Modeling	0.028	0.055
Back. Modeling	0.026	0.039
Jet Energy Scale	0.019	0.029





68% and 95% C.L.contours

- A model-independent measurement of the helicity of W bosons in top pair production

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

- if f_0 constrained to the standard model value

$$f_+ = 0.019 \pm 0.031\ (\text{stat.}) \pm 0.047\ (\text{syst.})$$

This is the most precise such measurement

Anomalous couplings in Single top Production

- Most general CP-conserving Wtb vertex up to mass dimension 5 involves four couplings

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

where, in the SM $f_1^L \approx 1,\ f_2^L = f_1^R = f_2^R = 0$

- Left and Right handed Tensor(2) coupling
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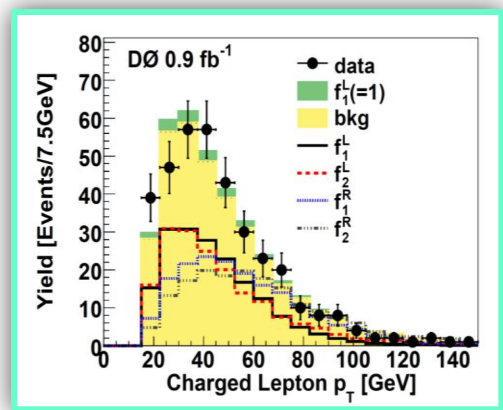
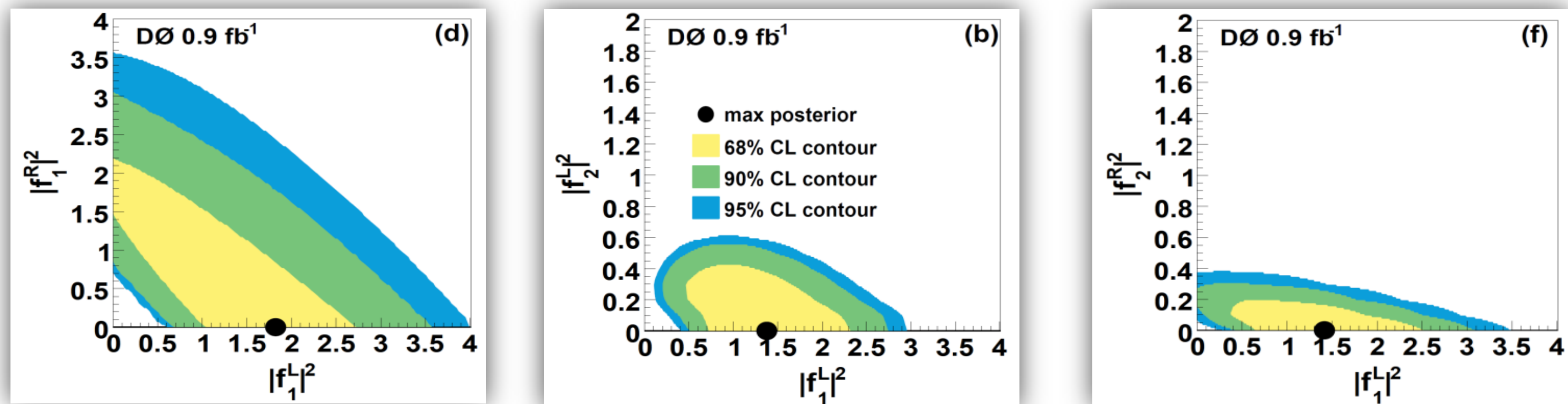


Results



First experimental limits on tensor couplings!(PRL 101, 221801 (2008))

Combining W Helicity and Anom. Wtb Couplings

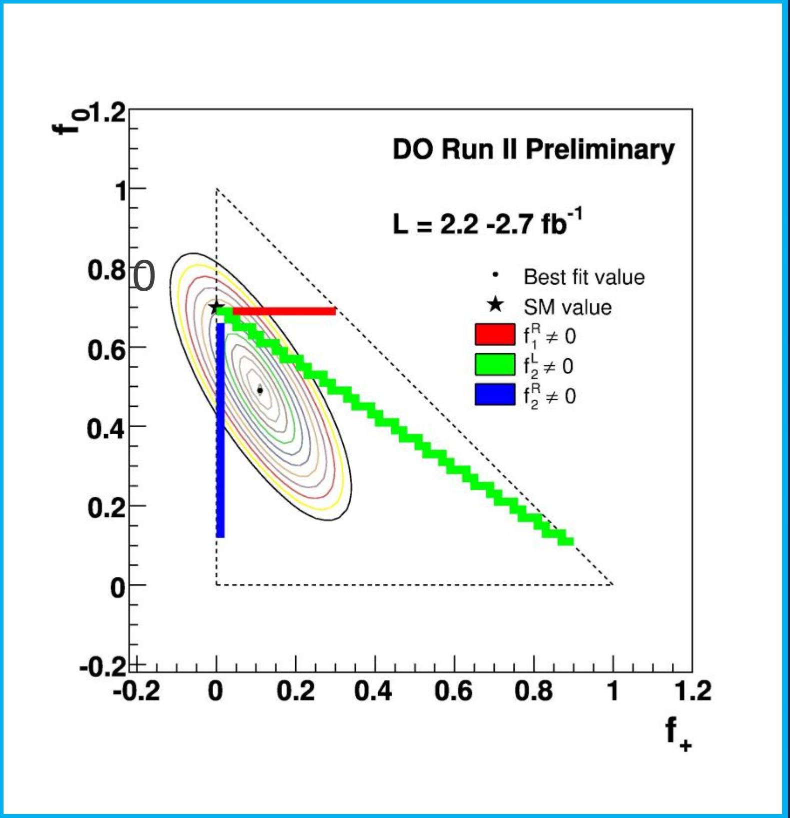
- General Analysis of Single Top Production and W Helicity in Top Decay
  (PLB 631, 126 (2005))

- Combine W helicity measurement in top pair decays

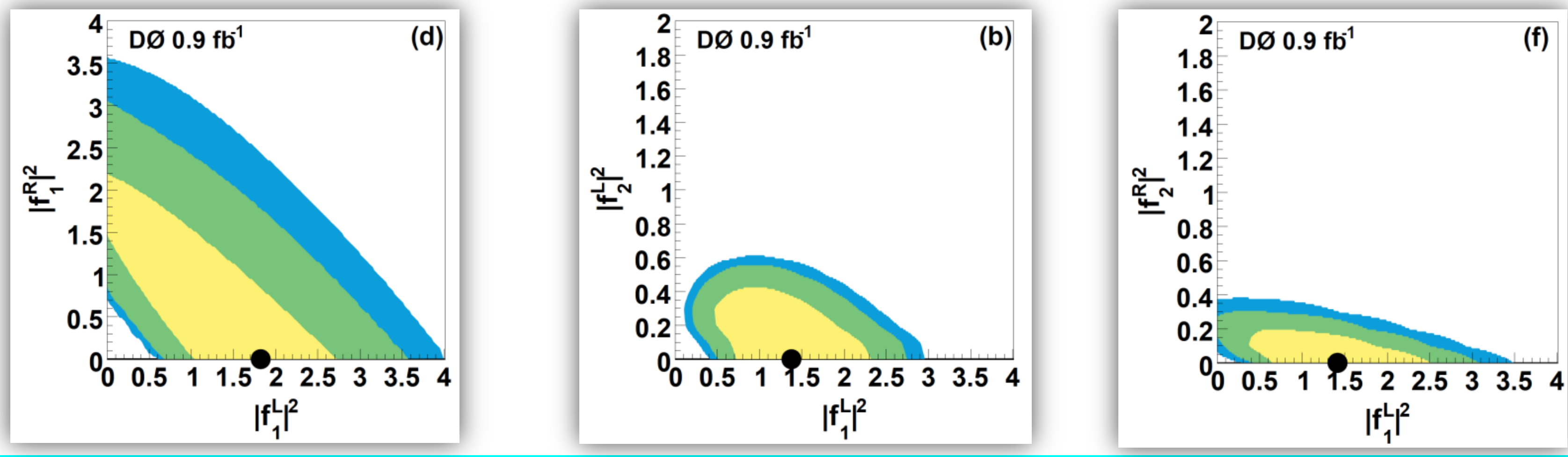
  with

- Anomalous couplings measurement in single top (PRL 101, 221801 (2008))

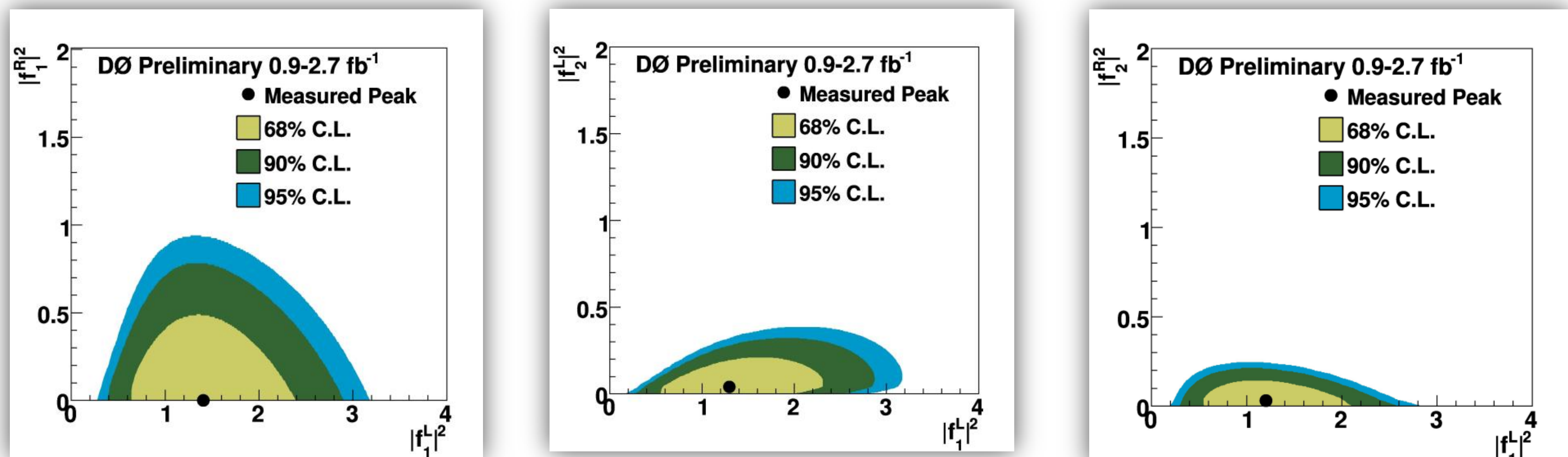
$$f_{0,\mathrm{meas}} - f_0\left(f_1^L, f_2^L, f_1^R, f_2^R\right)$$
$$f_{+,\mathrm{meas}} - f_+\left(f_1^L, f_2^L, f_1^R, f_2^R\right)$$
$$\Delta\sigma_{\mathrm{s,\ meas}} - \Delta\sigma_{\mathrm{s}}\left(f_1^L, f_2^L, f_1^R, f_2^R\right)$$
$$\Delta\sigma_{\mathrm{t,\ meas}} - \Delta\sigma_{\mathrm{t}}\left(f_1^L, f_2^L, f_1^R, f_2^R\right)$$



Observed posterior from the data for single top



Observed posterior from the data for single top and W helicity combined



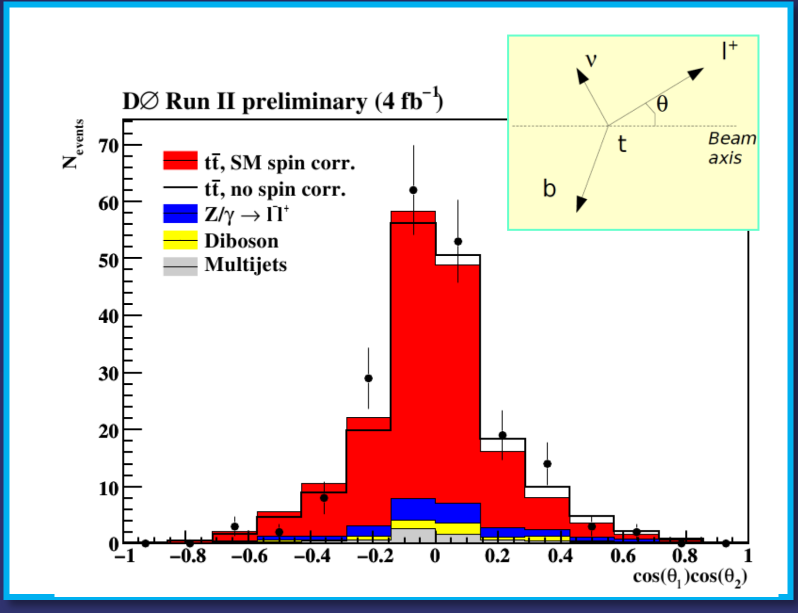
Top-antitop Spin Correlations

- $\tau = 5\ \ 10^{-25}$ s $<< \Lambda_{QCD}^{-1}$

  Top quark decays before hadronization → top spin is transferred to its decay products
- Measurement of correlation between spin of the top quark and spin of the anti-top quark in ppbar collisions.
- New physics can effect the spin correlations and observation may differ from SM expectations
- Measure decay products ($\ell^+\ell^-$) angular corr.elation C in dlepton channels

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

coefficient	LO	NLO
C	0.928	0.777

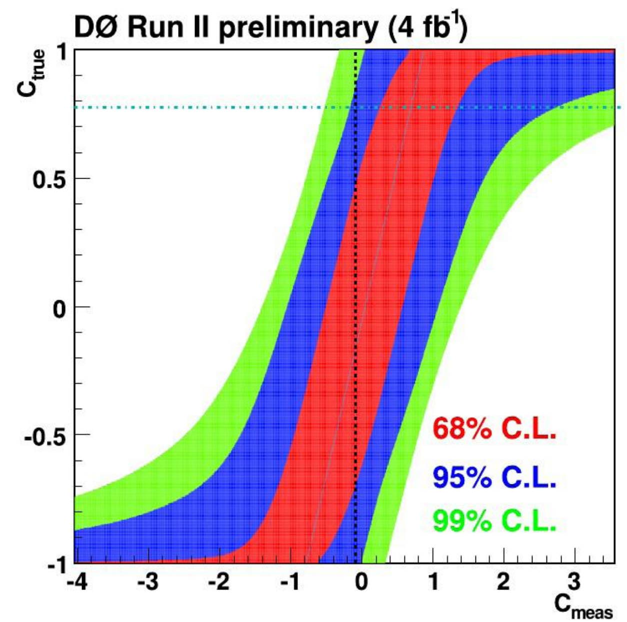


- C is a free parameter and $\theta_{1,2}$ angles between leptons flight directions and beam in *top rest frame*

Top-antitop Spin Correlations

Source	ΔC
Statistical only	+0.503 -0.510
Signal modeling ALPGEN	+0.197 -0.120
Signal modeling MC@NLO	+0.107 -0.085
Top Mass	+0.215 -0.223
Jet energy scale	+0.012 -0.022
Jet energy resolution	+0.000 -0.030
Monte Carlo background x-section	+0.008 -0.008
Monte Carlo signal & bkg branching ratio	+0.002 -0.002
Monte Carlo bkg scale factors	+0.000 -0.000
Monte Carlo statistics	+0.010 -0.010
$t\bar{t}$ cross section error	+0.008 -0.005
Luminosity	+0.002 -0.002
Total systematic	+0.312 -0.270

coefficient	LO	NLO
C	0.928	0.777

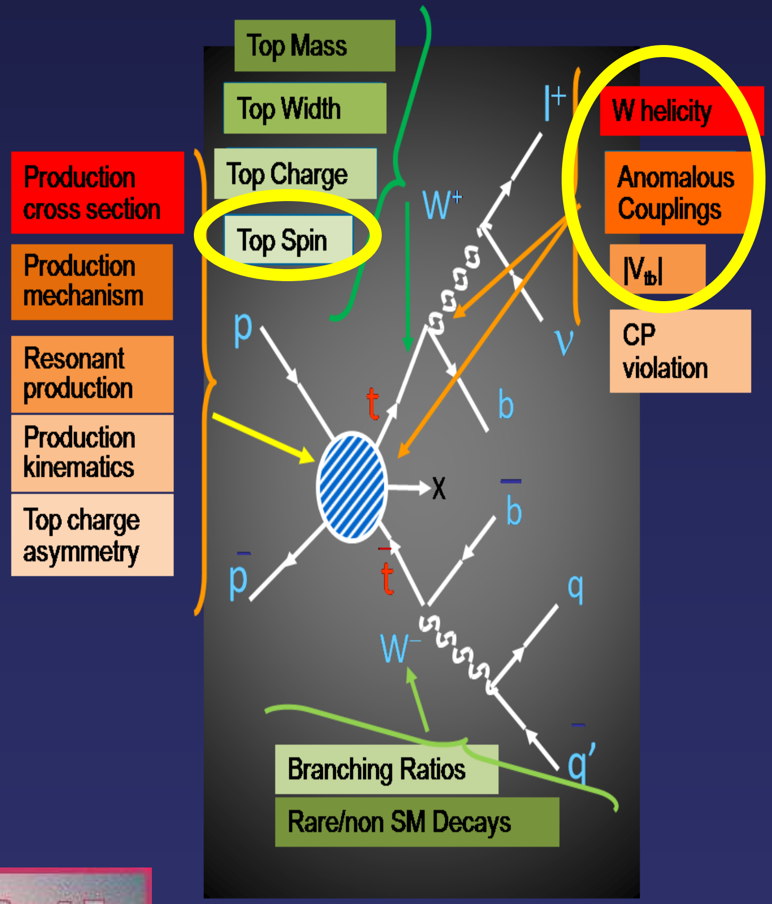


$$C = -0.17^{+0.64}_{-0.53}\,(\text{stat} + \text{syst})$$

Result agrees with the SM prediction for a spin 1/2 top quark of C = 0.777 in NLO QCD within 2 S.D.

Conclusion and Outlook

- I have shown only a small subset of a large and diverse top program to measure top quark properties and search for new physics at D0
- Analyses are becoming increasingly exciting:
  - Ever increasing statistics – more phase space
  - Improved analysis techniques
  - Enhanced understanding by combination channels/processes with complimentary information



So, as far as Tevatron is concerned

Conclusion and Outlook

We may not have to wait for the LHC in order to be surprised