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Measurement of Top Quark Spin Correlation

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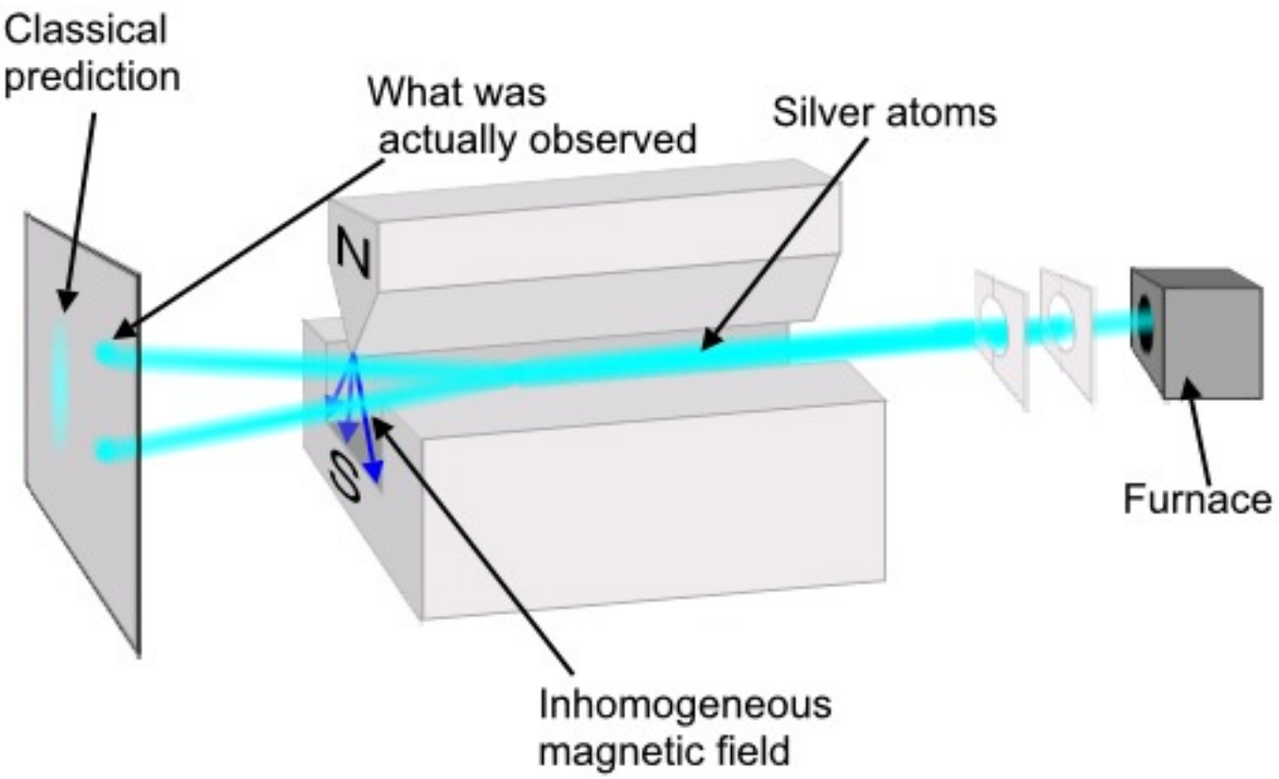
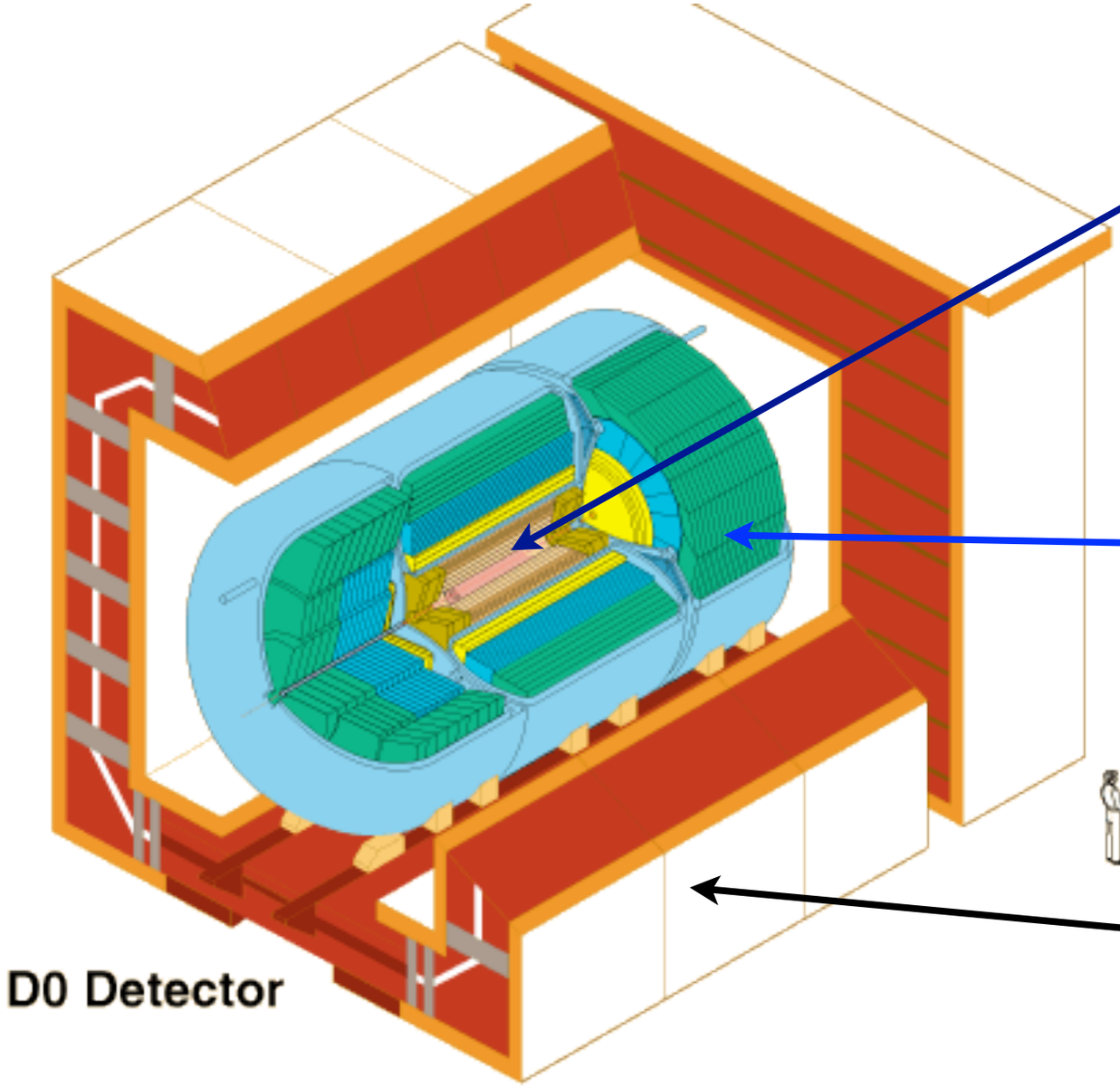
New Perspectives

31st May 2011

What I think of when spins are measured:



The DØ Experiment



Central tracker

Consists of a silicon tracker and a scintillating fibre tracker. Both inside a 2T solenoidal field.

Calorimeter

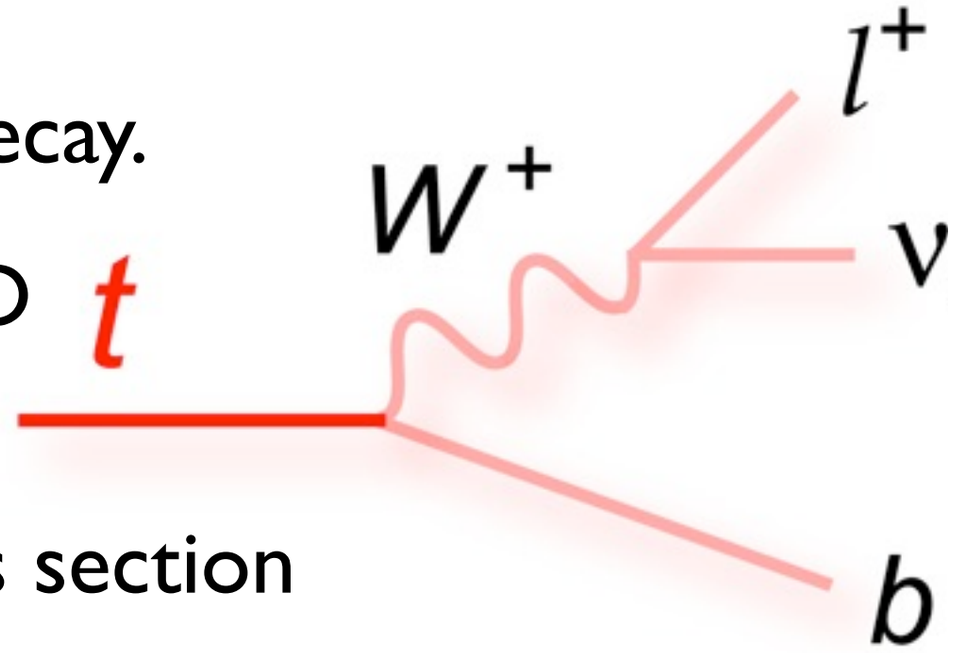
Made of liquid Argon and uranium. Large angular coverage and excellent energy resolution.

Muon system

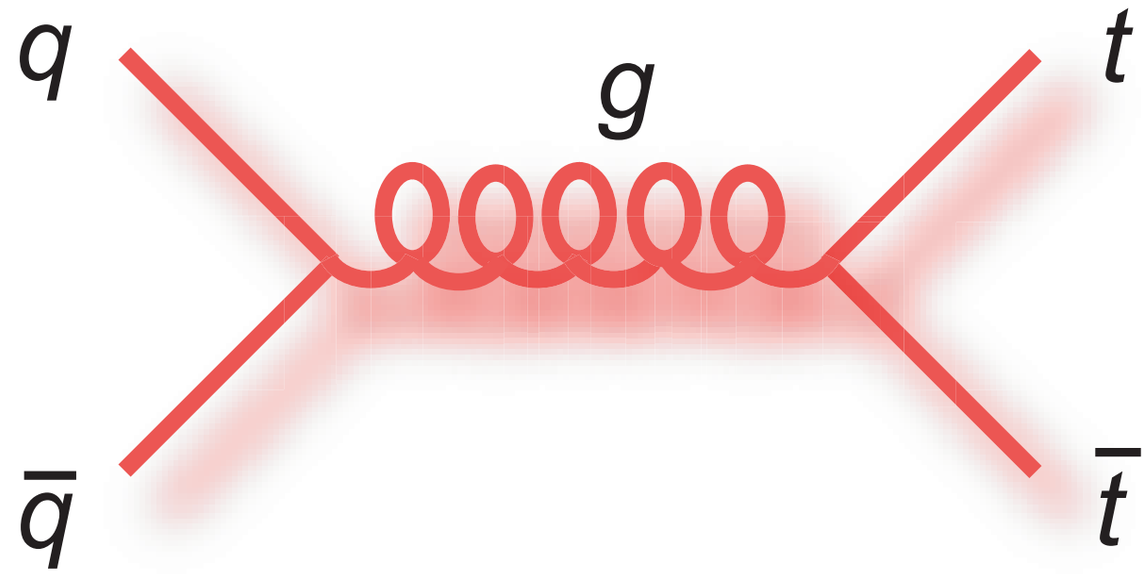
Consists of wire chambers and scintillator planes. 1.8T toroidal field for momentum measurement.

Why Is Spin Correlation Interesting?

- Tests whole chain from production to decay.
- Only in top production can we see QCD correlating the spins during production.
- Find effects which modify the total cross section by only a small amount.
- Observing Spin Correlations would place an upper limit on top quark lifetime.

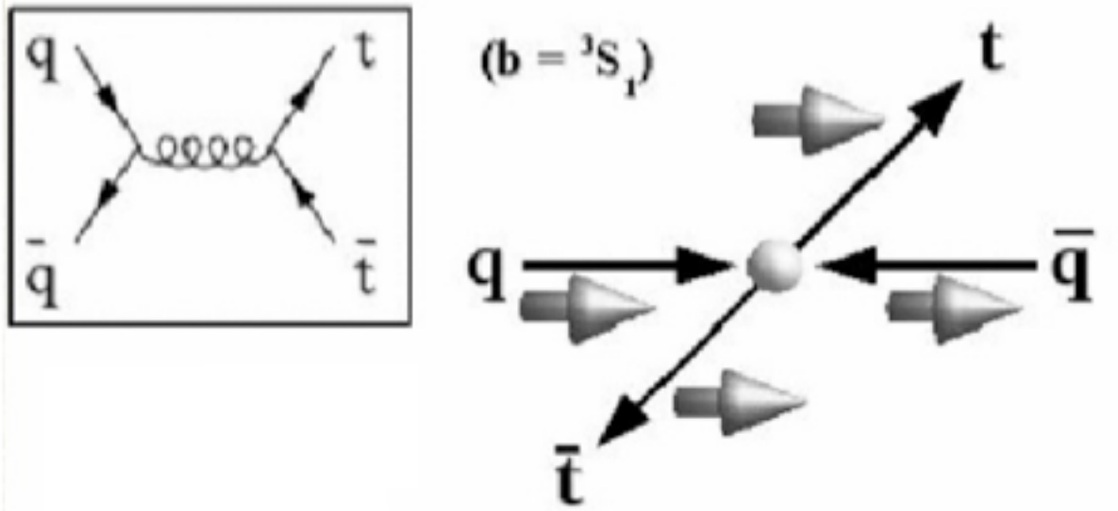


Top Production at Tevatron



- SM cross section ≈ 7.5pb, dominated by quark antiquark fusion.
  - 85% quark-antiquark and 15% gluon gluon.
- Can be modified by Stop pairs, Z', KK gluons, Higgs decaying to tops.

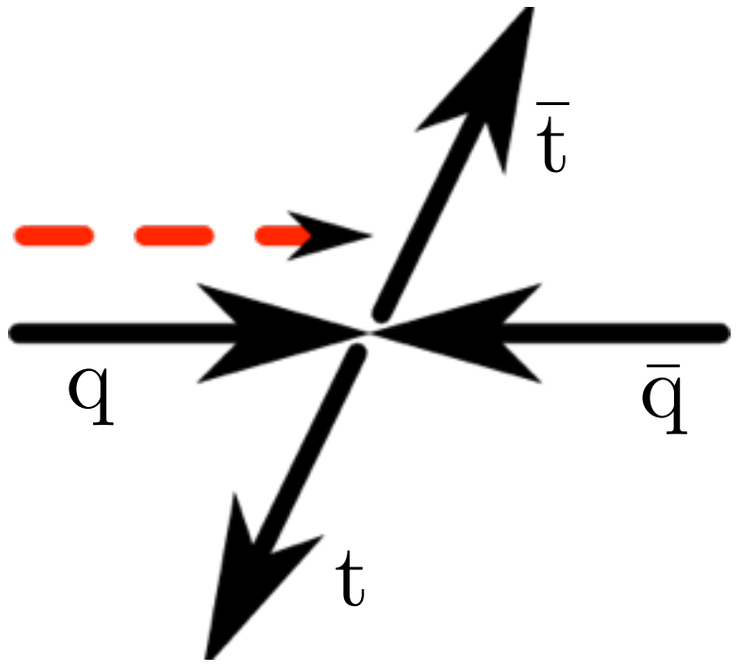
Spin Correlations in Production



$$A = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\downarrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\downarrow\uparrow} + N_{\uparrow\downarrow}}$$

- Strength of correlation, ***A***, depends on spin quantisation axis.

Quantisation Axis



- Use direction of one of the incoming protons.
- Simple to construct, optimal for top pairs produced at threshold.
- Highest correlation, A=0.777 @ NLO.

Bernreuther, Brandenburg, Si and Uwer, Nucl. Phys. B 690, 81 (2004)

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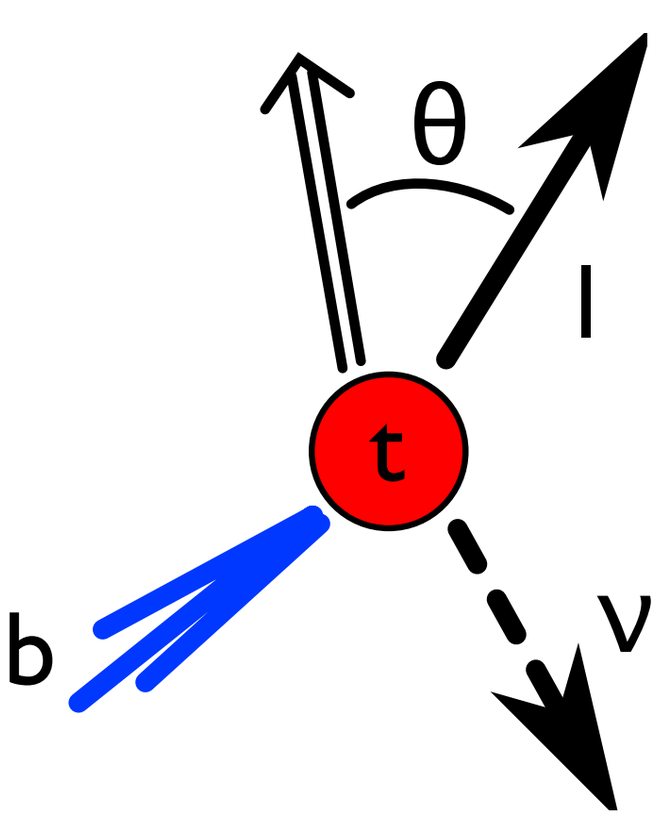
Analysing the Top Spin

- Information about direction of top spin is passed on to its decay products.



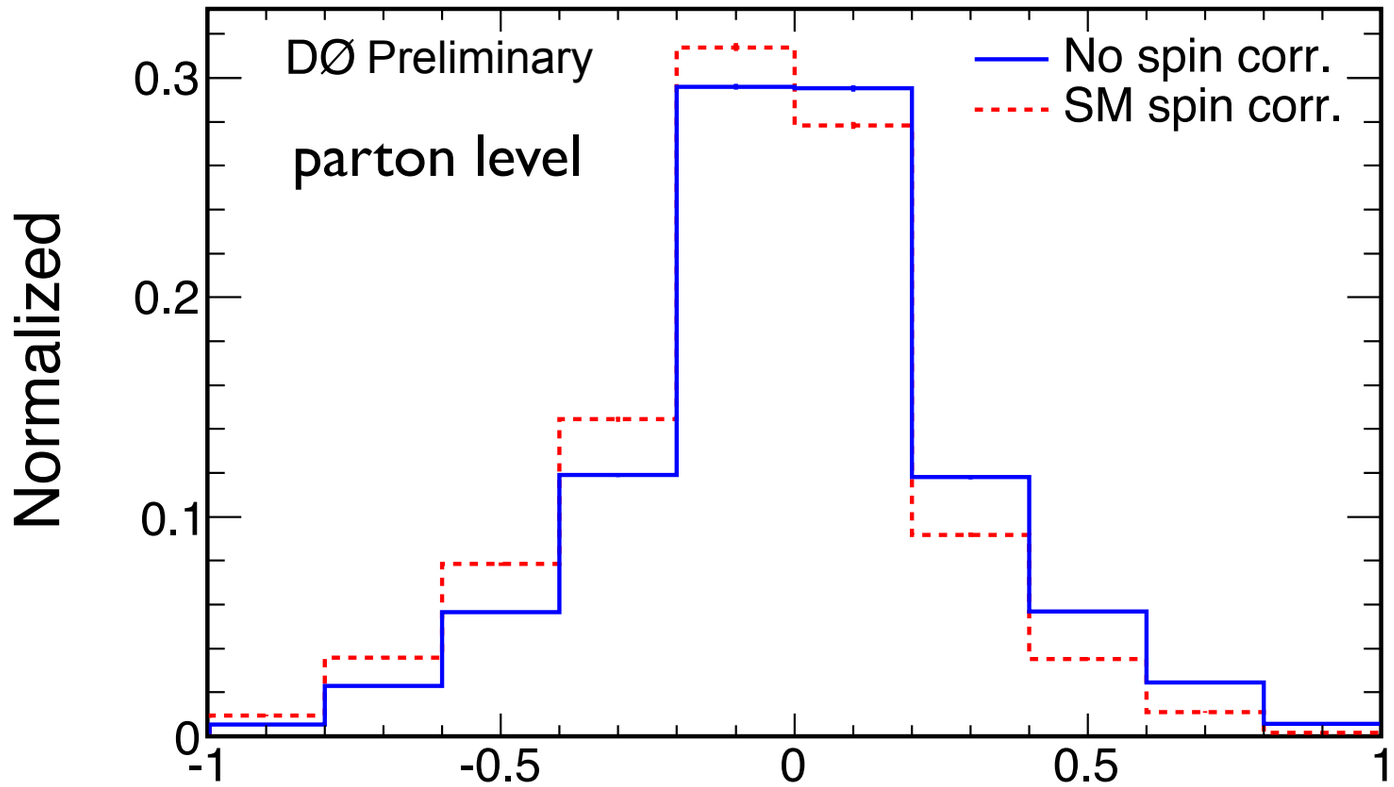
spin analysing power

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta_i} = \frac{1}{2}\left(1 + \alpha_i \cdot \cos\theta_i\right)$$

Spin analysing power for lepton and down type quark $\alpha=1$.

Use the lepton!

Putting It All Together



$$\frac{1}{\sigma}\frac{\mathrm{d}^2\sigma}{\mathrm{d}\cos\theta_1 \mathrm{d}\cos\theta_2} = \frac{1}{4}\left(1 - C\cdot\cos\theta_1\cos\theta_2\right)$$

- Want to measure $C = \alpha_1\alpha_2 A$.
- Sizeable effect at parton level.

$\cos\theta_1$ decay angle of lepton
$\cos\theta_2$ decay angle of antilepton

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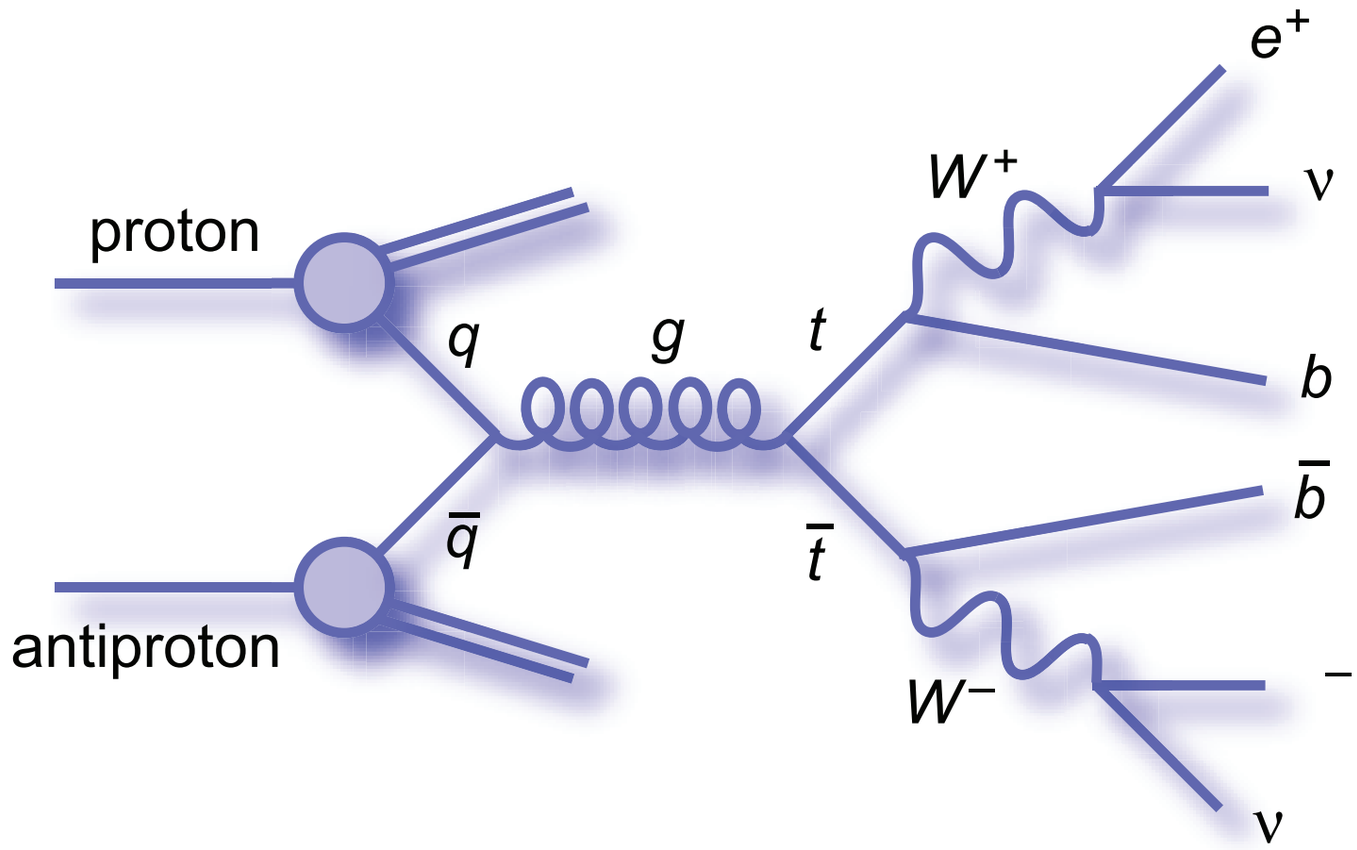
Event Selection

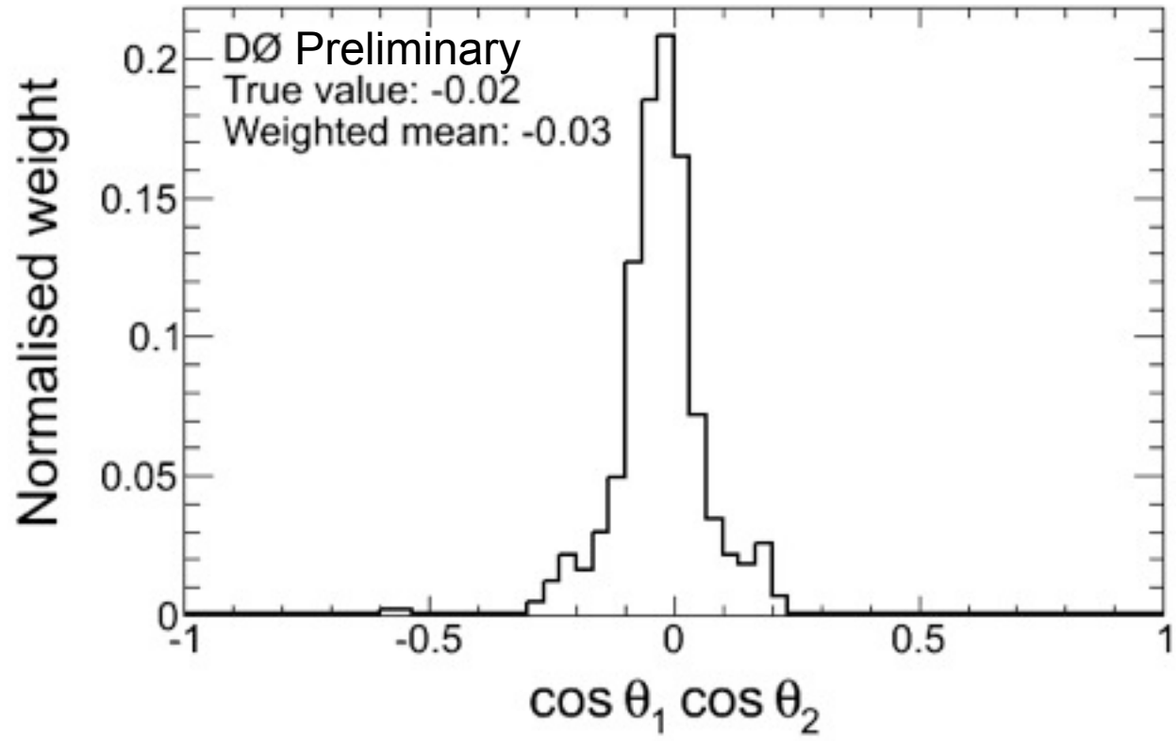


- Require two oppositely charged leptons (p_T>15 GeV) and two jets (p_T>20 GeV).
- In 5.4 fb^{-1} of data select about 300 events in dilepton final state.
- Main background from $Z \rightarrow l^+l^-$.

Pioneering Work

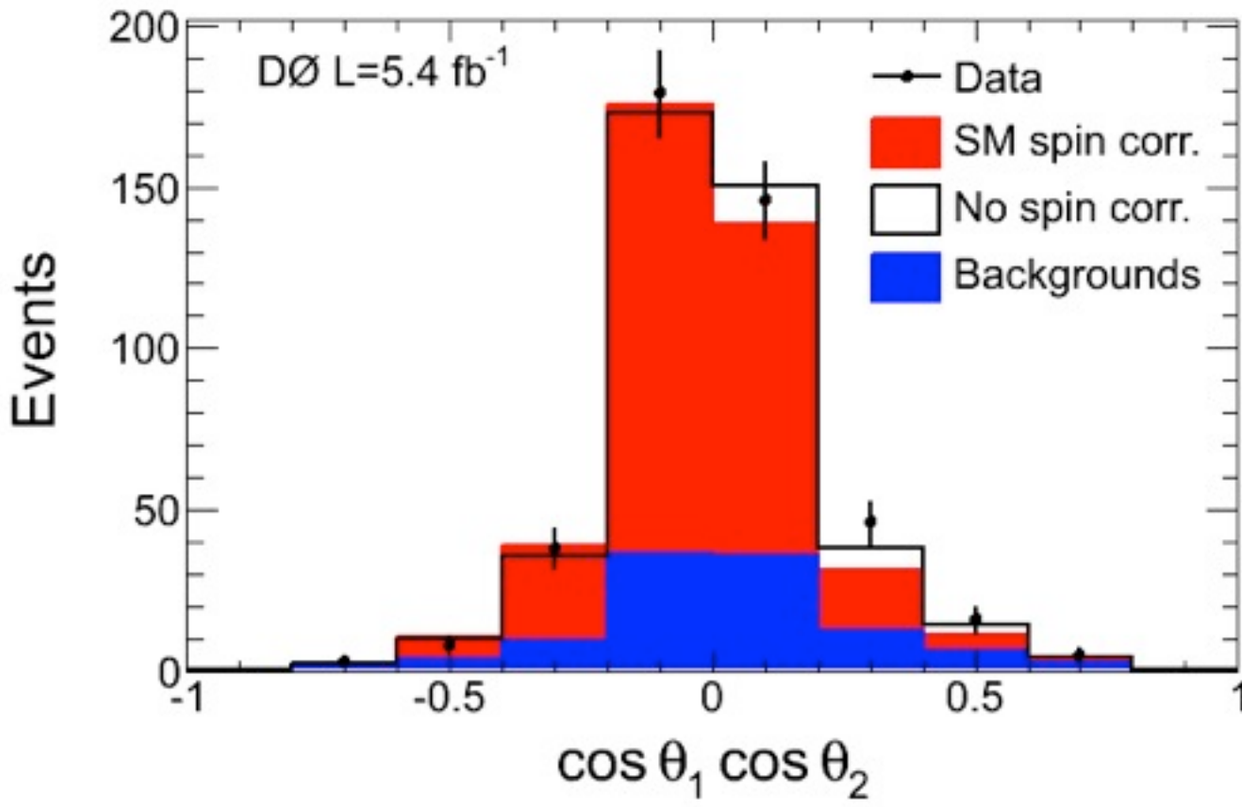
One Last Obstacle

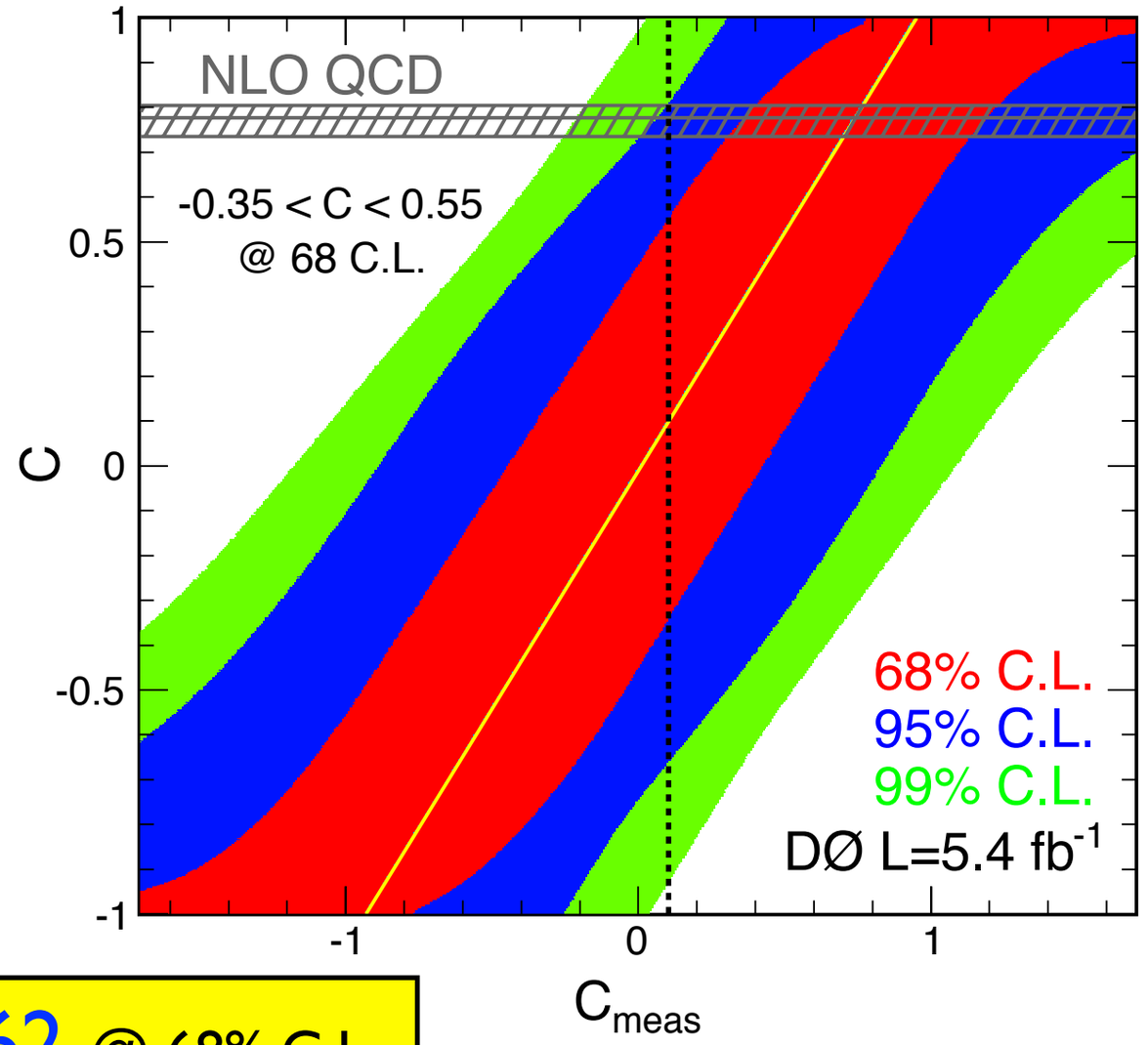
- Need to reconstruct top quark four vectors.
- Using M_{top} and M_W as constraints leaves us two short.
- Sample over neutrino η!
- Taking the weighted mean of all solutions as our estimator.



$$w = \exp\left(-\frac{(\not{E}_T^x - \nu_x - \bar{\nu}_x)^2}{\sigma^2}\right) \times \exp\left(-\frac{(\not{E}_T^y - \nu_y - \bar{\nu}_y)^2}{\sigma^2}\right)$$

Result





NLO QCD C=0.777,
σ_{tt}=7.46pb

$-0.23 < C < 0.62$ @ 68% C.L.

$\sigma_{tt} = 8.07^{+1.1}_{-0.9}$ pb

Consistent with the NLO QCD prediction at 2SD and also with the no correlation hypothesis.

The Quest for Precision

Matrix Elements

Parton density function

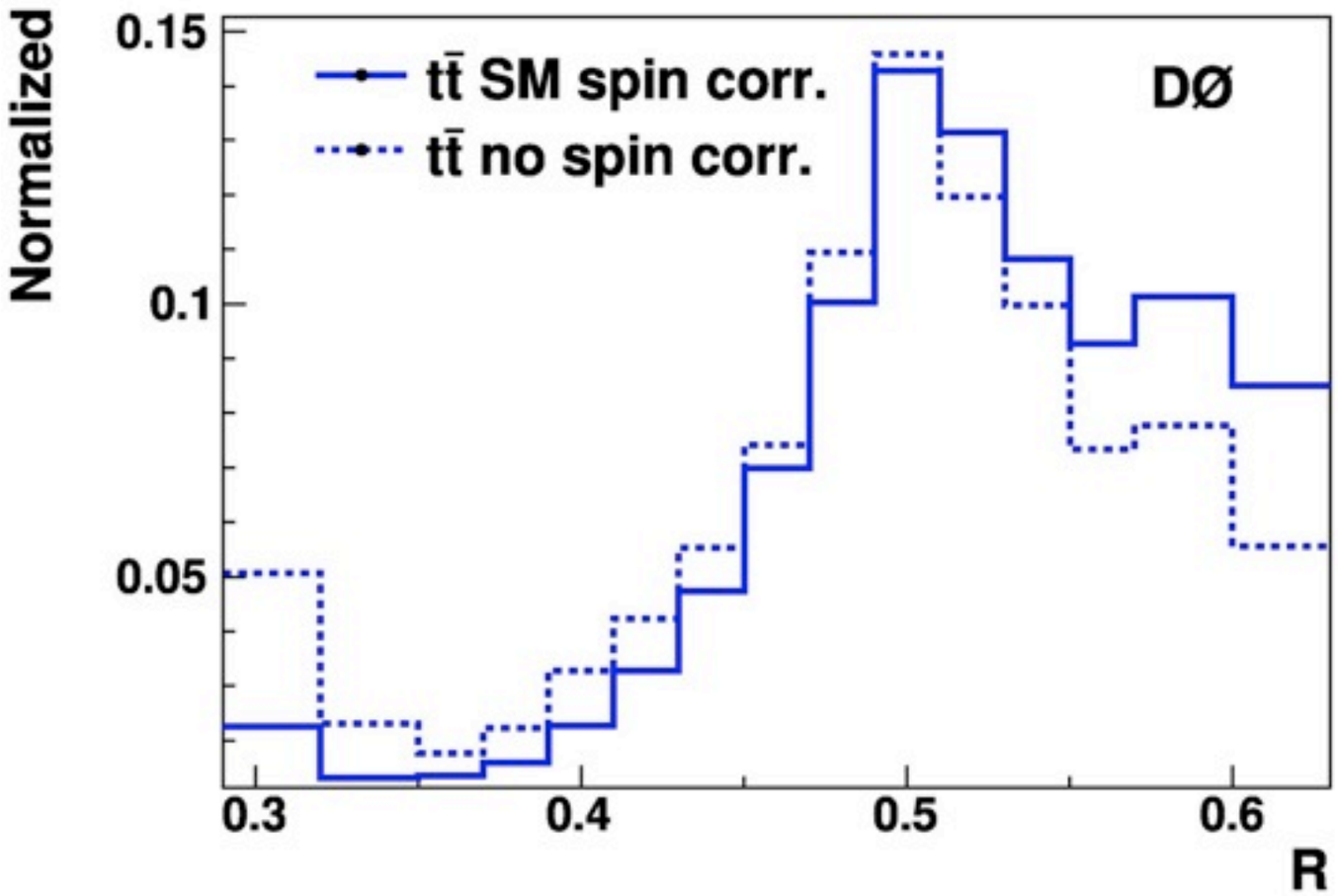
$$P_{\mathrm{sgn}}(x;H) = \frac{1}{\sigma_{\mathrm{obs}}} \int f_{\mathrm{PDF}}(q_1)\, f_{\mathrm{PDF}}(q_2)\, \mathrm{d}q_1\, \mathrm{d}q_2 \cdot \frac{(2\pi)^4 |\mathcal{M}(y,H)|^2}{q_1 q_2 s} W(x,y)\, \mathrm{d}\Phi_6.$$

Matrix element

Transfer function

- For each event calculate P(H=c), assuming correlation, and P(H=u) assuming no correlation.
- Using the well understood ME framework of top mass measurements.

Discrimination Power

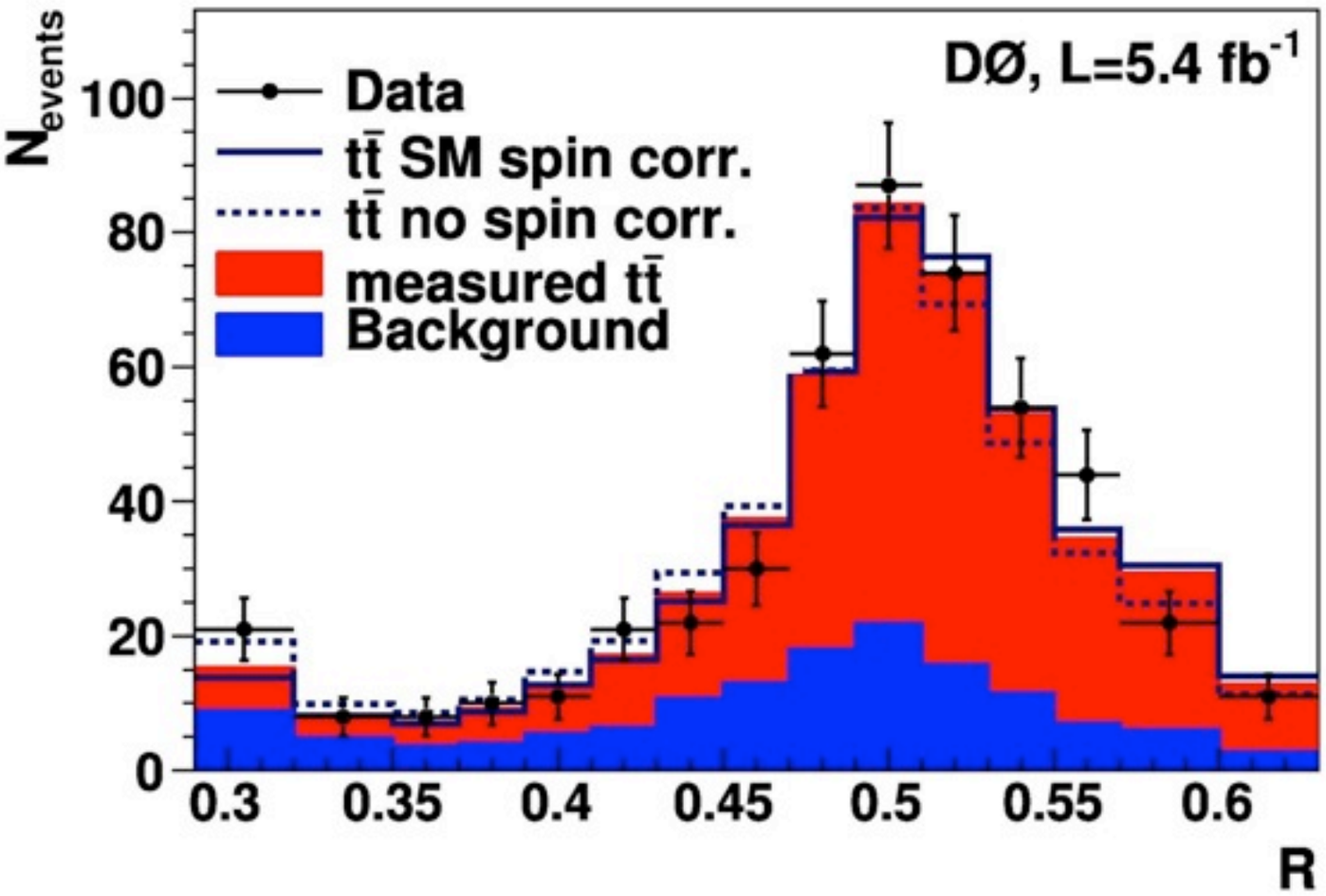


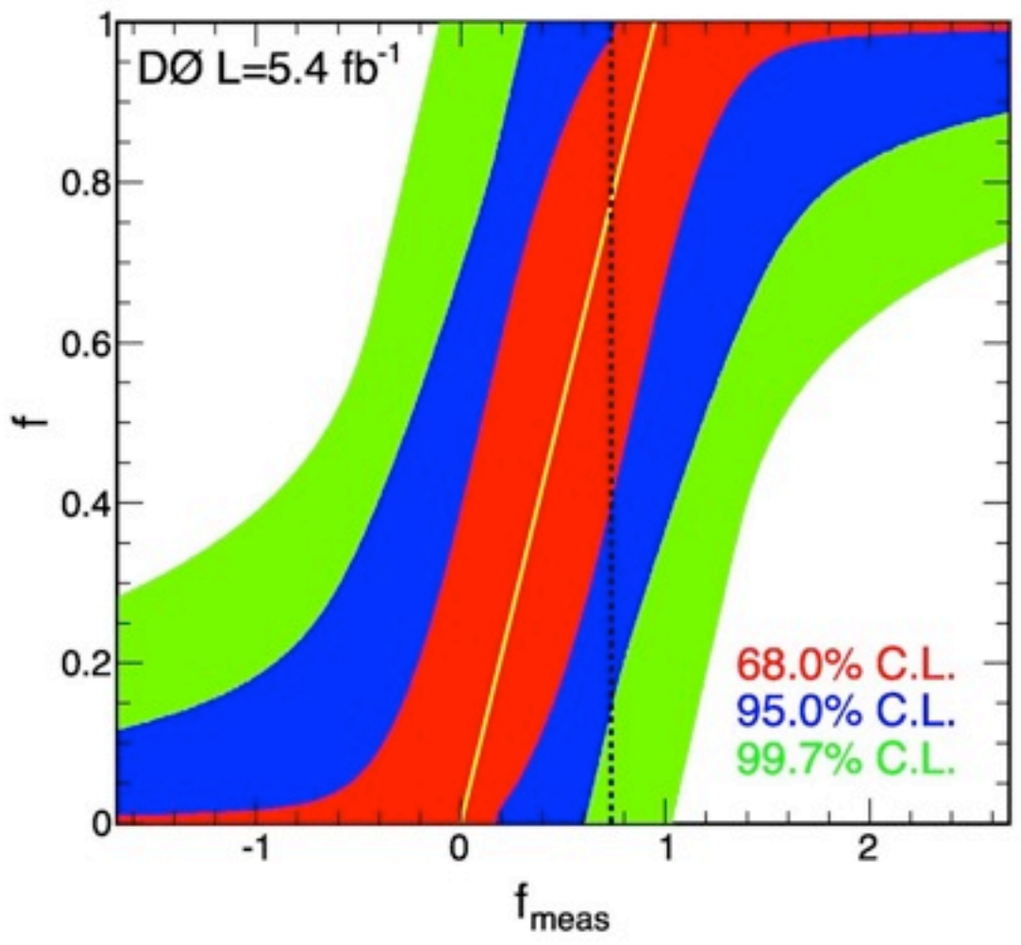
- Use the ratio as discriminating variable:

$$R = \frac{P_{\mathrm{sgn}}(H = c)}{P_{\mathrm{sgn}}(H = u) + P_{\mathrm{sgn}}(H = c)}$$

- MC@NLO with and without correlation to model the two cases.

Fit to Data





-0.26 < C < 0.88 @ 68% C.L.

Most precise measurement of C to date!

Conclusion

- Two measurements of this fundamental property of the top quark in dilepton events.
- Consistent with the SM prediction.
- Most precise measurement to date:

$-0.26 < C < 0.88$ @ 68% C.L.

- Complementary to LHC.