Recent CDF Results on the Measurement of W Polarization in Top Decay

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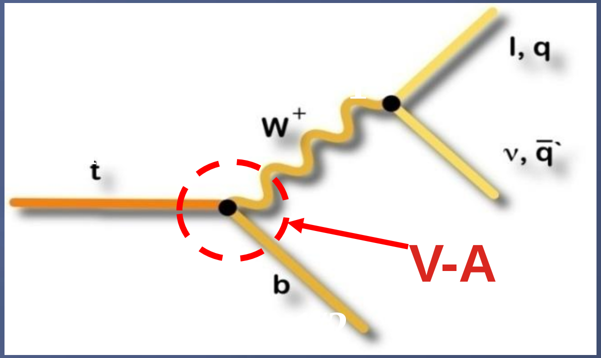
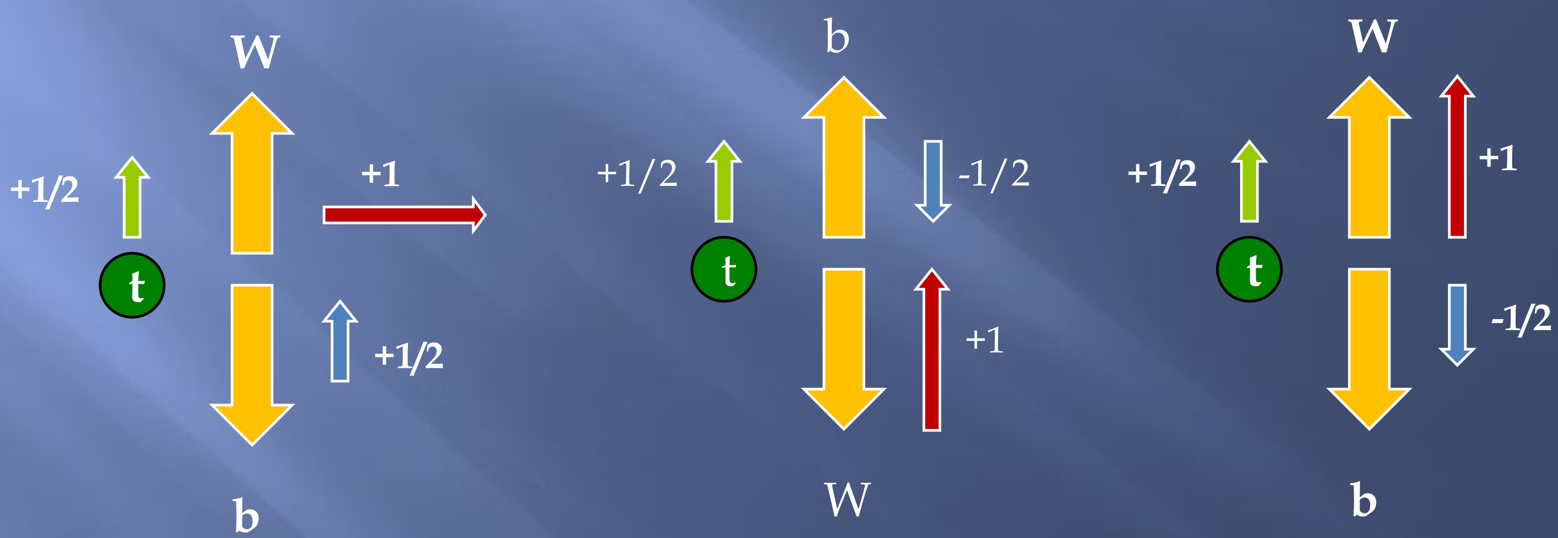
Outline

- W-boson polarization from top-quark decay
  - Motivation and sensitive variables
  - Existing results
- New CDF measurement of W polarization from top decay
  - Event selection
  - Measurement technique
  - Calibration and sensitivity
  - Result
- Summary

Polarization of W from Top Decay

- V-A coupling in the SM
  - longitudinal fraction f_0 ~70%
  - left-handed fraction f_- ~30%
  - right-handed fraction f_+ ~0%



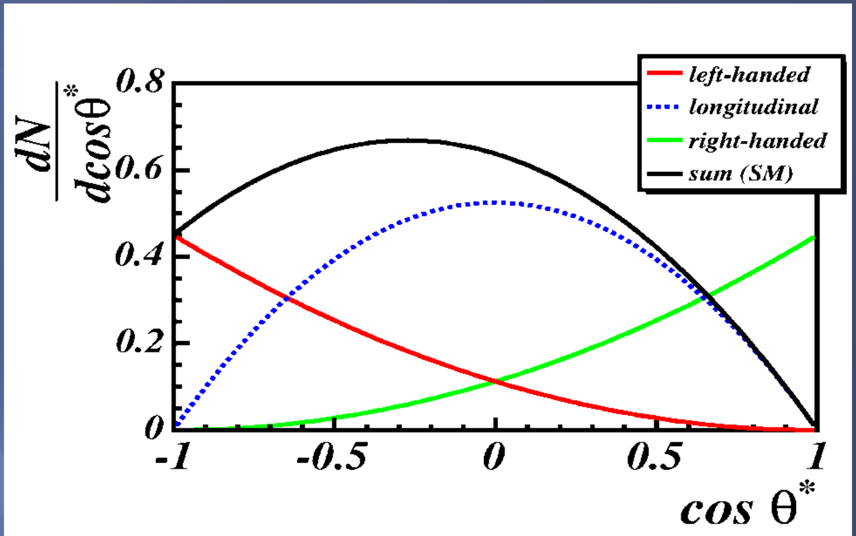


Longitudinal : J.P=0 Left-handed : J.P=-1 Right-handed : J.P=+1

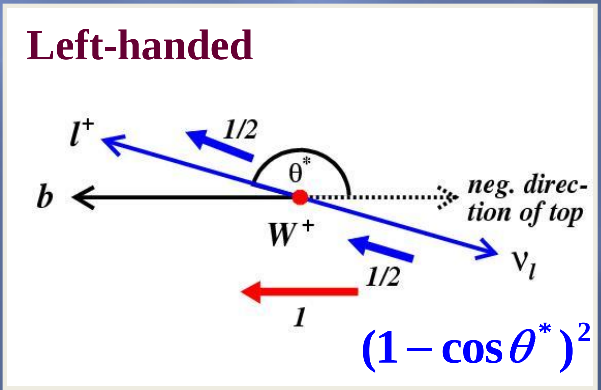
- The SM prediction modified in various new physics models
- W-helicity fractions are sensitive to non-SM tWb couplings

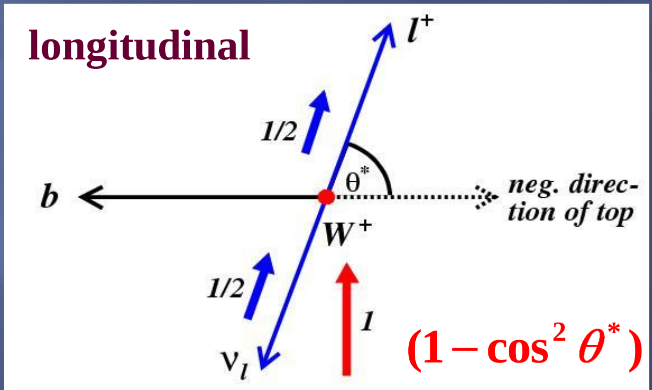
Measuring W Polarization

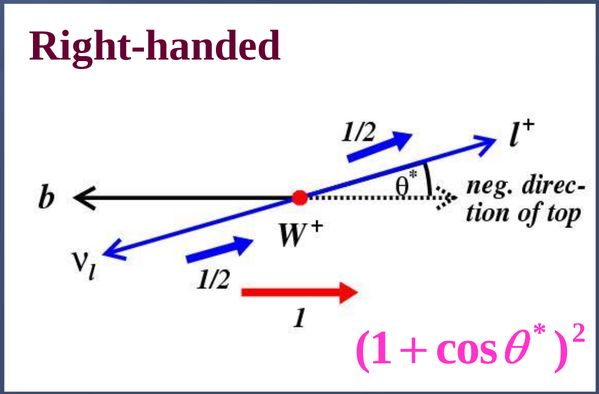
- Polarization states reflected in the angular distribution:
  - θ^*: Angle between lepton (down-type quark) in W rest frame and the momentum of the W in the top-quark rest frame



$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = f_- \cdot \frac{3}{8}(1-\cos\theta^*)^2 + f_0 \cdot \frac{3}{4}(1-\cos^2\theta^*) + f_+ \cdot \frac{3}{8}(1+\cos\theta^*)^2$$

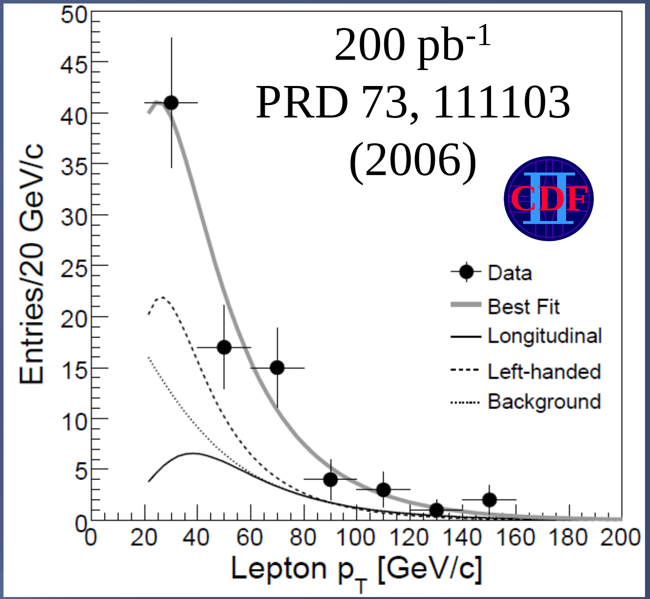


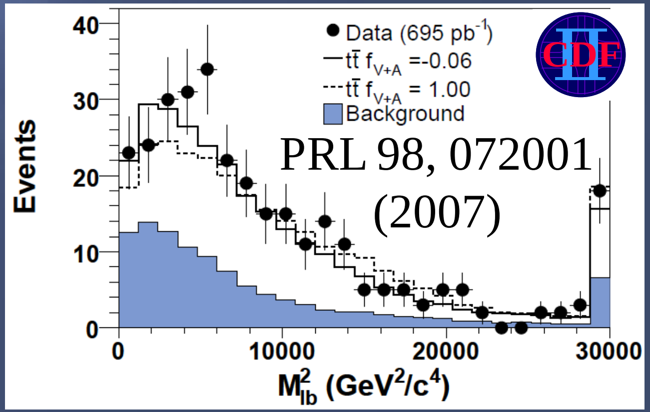




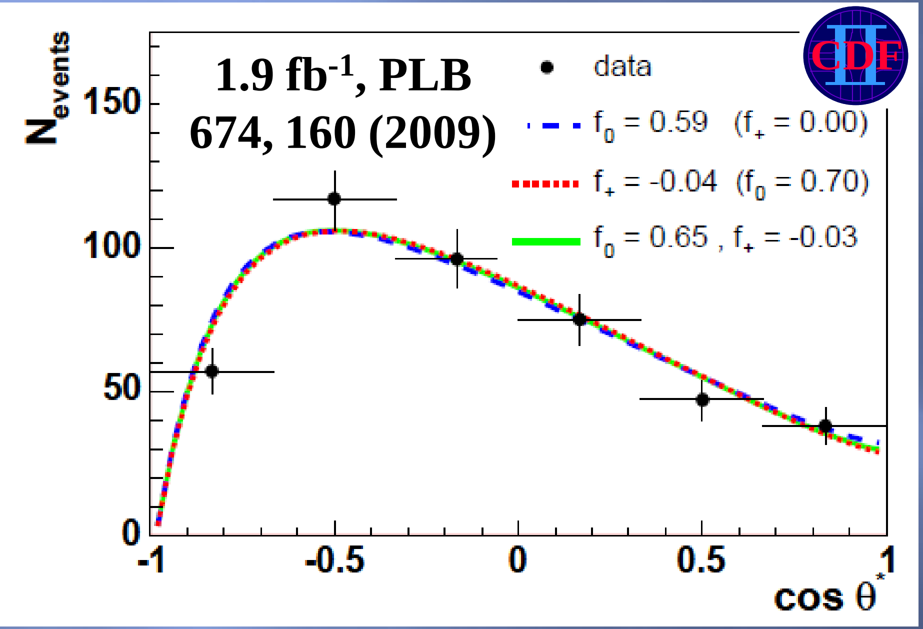
Sensitive Variables

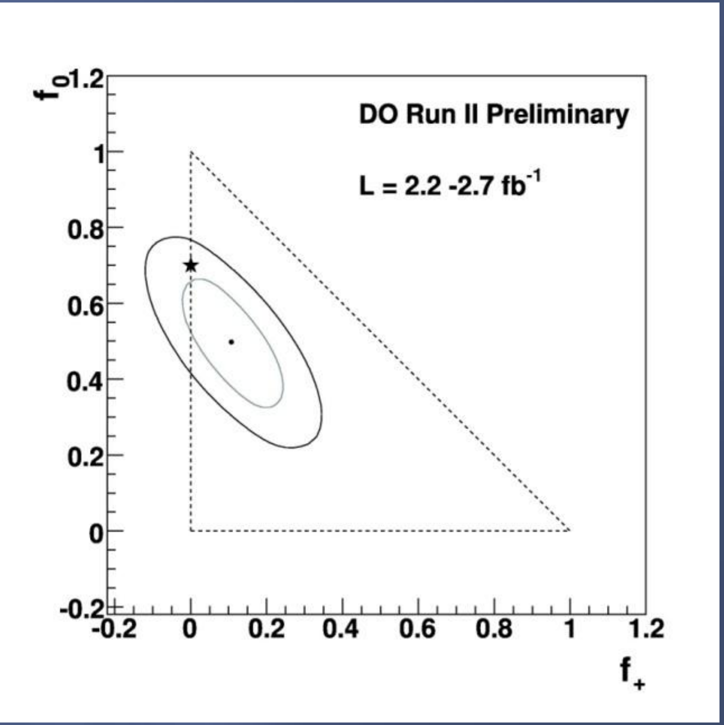
- Lepton P_T
- $M_{lb}^{\,2}$: invariant mass squared of lepton and b-quark
  - Note: $M^2_{lb} \approx 1/2\,(M^2_t - M^2_W)(1 + \cos\theta^*)$
- Cos θ^*
  - Leptonic W decay ($W \rightarrow l\nu$)
  - Hadronic W decay ($W \rightarrow qq'$)
    - Contains sign ambiguity as the down-type quark can't be properly identified
    - Improves the statistical sensitivity on f_0
  - Previous CDF measurements used information from leptonic W
  - Several D0 measurements use information from both leptonic and hadronic W





Existing Measurements





- CDF analysis uses Cosθ* of the leptonic W for lepton+jets

f_0	f_+
$0.66 \pm 0.16 \pm 0.05$	$-0.03 \pm 0.06 \pm 0.03$
$0.62 \pm 0.10 \pm 0.05$	Fixed f_+=0.0
Fixed f_0=0.7	$-0.04 \pm 0.04 \pm 0.03$

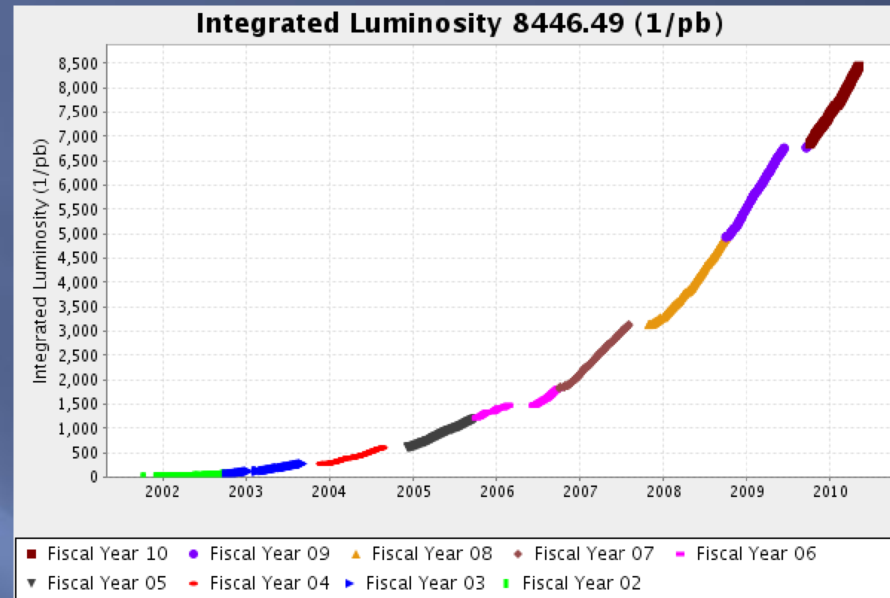
- D0 analysis uses both lepton+jets and dilepton candidate events
  - Templates based on Cosθ*
- Perform simultaneous measurement
  $f_0 = 0.49 \pm 0.11$ (stat) ± 0.09 (syst)
  $f_+ = 0.11 \pm 0.06$ (stat) ± 0.05 (syst)

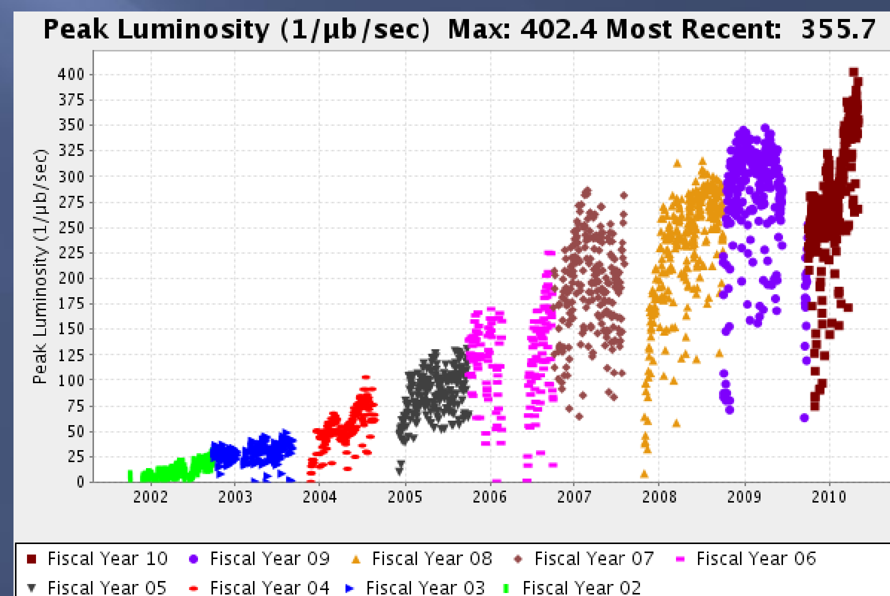
NEW CDF RESULTS

Accepted for PRL publication

FERMILAB-PUB-10-041-E, arXiv:1003.0224v1 [hep-ex]

Tevatron Run II





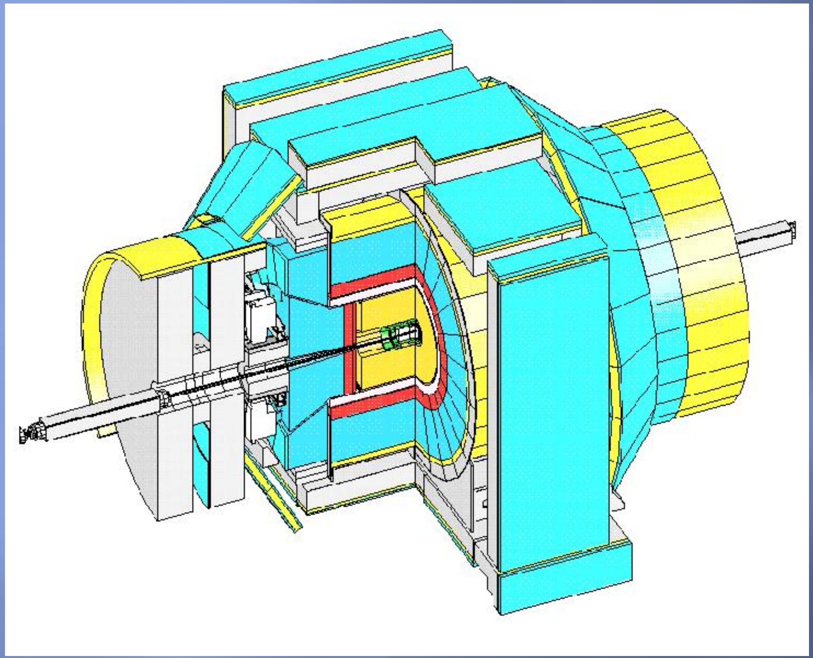
Tevatron Run II

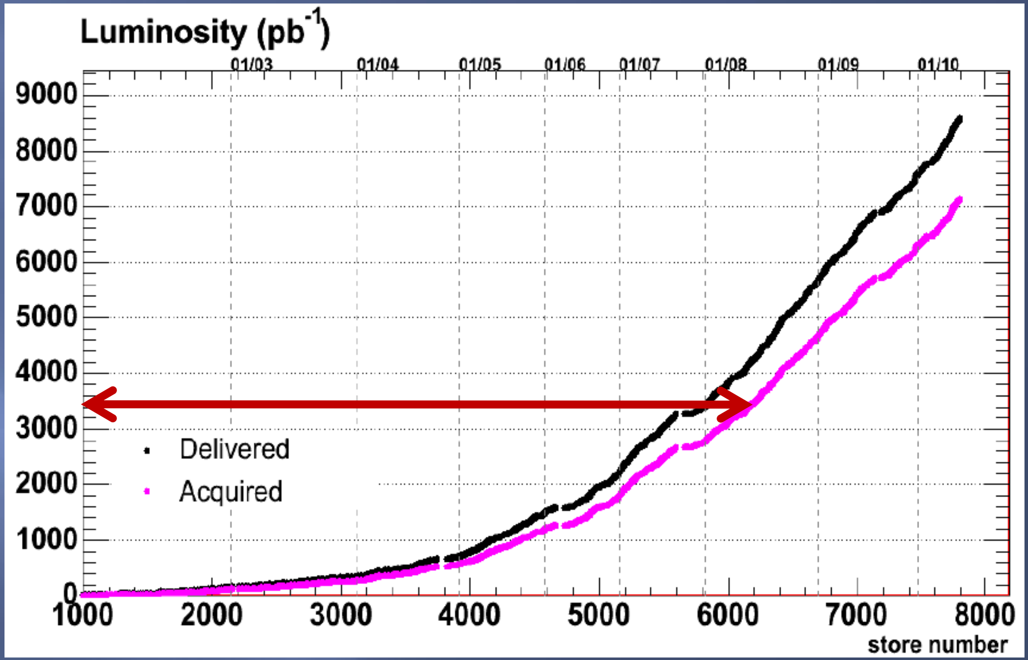
Proton-antiproton collider (2001-2011)

$\sqrt{s}$ = 1.96 TeV

- Peak Luminosity record :
  $4.02 \cdot 10^{32}$ cm^{-2}sec
- Total integrated luminosity delivered :
  over ~8 fb^{-1}
  - ~7 fb^{-1} recorded per experiment
  - Doubled data set each year for four years

Detector and Dataset





- The CDF detector:
  - Silicon tracking , Large radius drift chamber, 1.4 T solenoid, Projective calorimetry ($|\eta| < 3.5$), Muon chambers ($|\eta| < 1.0$), Particle identification
  - ***All crucial for top physics***
- Analysis based on data collected by CDF II detector between February 2002 to April 2008
  - Integrated luminosity 2.7 fb^{-1}

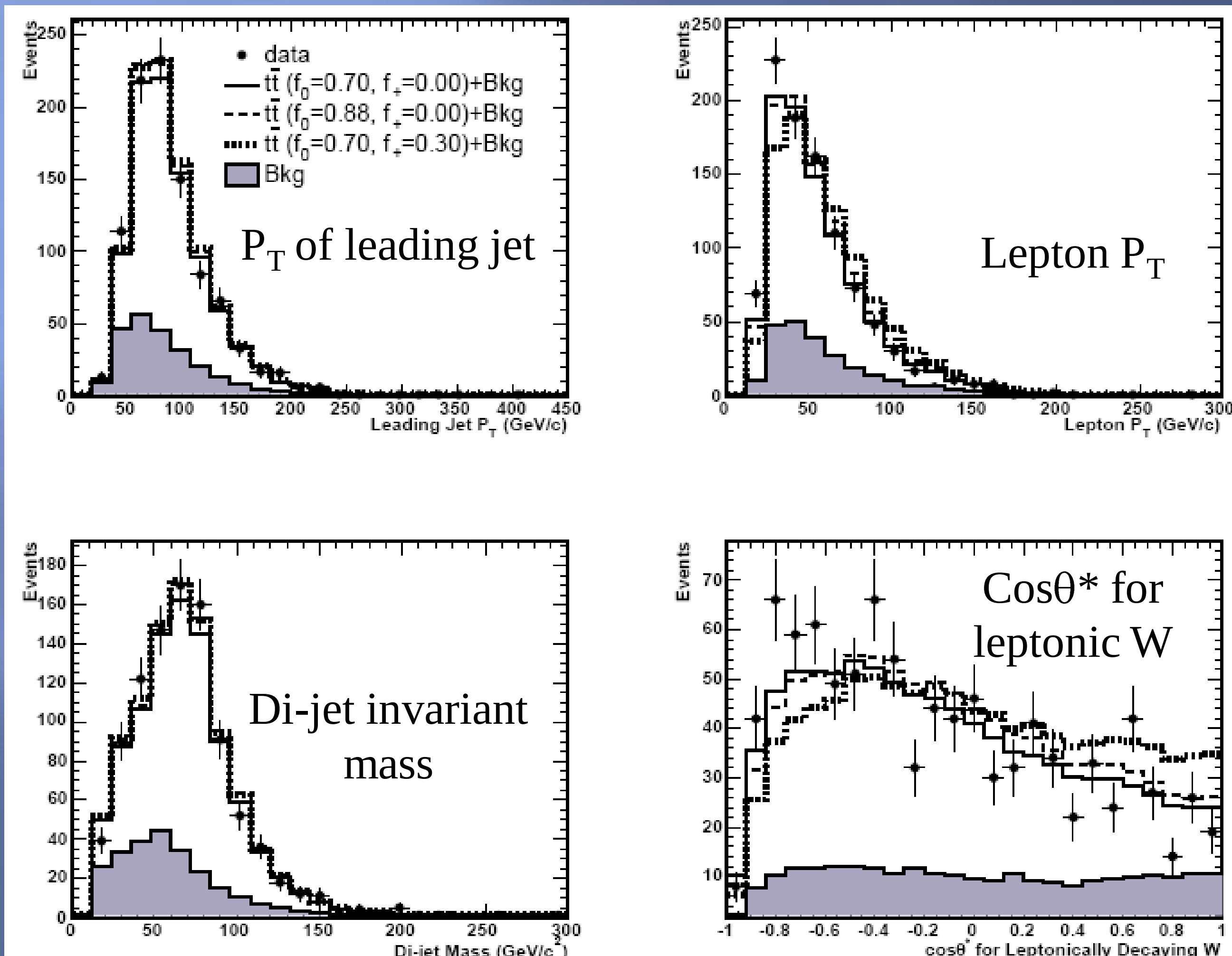
Event Selection

- Triggers:
  - High P_T leptons triggers
  - Trigger requiring large missing E_T associated with jets
    - Increase acceptance by 30%. Not used in the best previous CDF measurement.
- ≥4 jets with E_T>20 GeV, ≥1 b-tag
- One isolated lepton with E_T>20 GeV
- Missing E_T > 20 GeV

Sample composition: based on the ttbar cross section measurement in the lepton+jets channel

Process	Central e, μ	Forward e	$\not{E}_T$+jets μ
$t\bar{t}$ (σ = 6.7 pb)	478 ± 66	58 ± 8	134 ± 19
W+hf	71 ± 22	13 ± 9	19 ± 6
W+lf	23 ± 6	5 ± 7	6 ± 2
EWK	17 ± 10	3 ± 1	5 ± 3
QCD	28 ± 22	46 ± 37	1 ± 1
Total expected	616 ± 74	125 ± 40	165 ± 20
Observed	650	136	178

Validation of Signal and Background Modeling



Extensively check signal and background modeling by comparing the data and MC distributions of many different variables in signal sample and high statistics control sample

Event-by-Event Likelihood

- Use probability densities based on matrix elements of signal (ttbar) and dominant background (W+jets)
- Construct probability density for each event

$$P_{evt,i}(C_s, f_0, f_+) = C_s \frac{P_{signal,i}(x; f_0, f_+)}{\langle Acc_{sig}(x; f_0, f_+) \rangle} + (1 - C_s) \frac{P_{bkg,i}}{\langle Acc_{bkg}(x) \rangle}$$

- Multiply all the event probabilities to obtain likelihood

$$L(C_s, f_0, f_+) = \prod_{i=1}^{Nevents} P_{evt,i}(C_s, f_0, f_+)$$

- For each (f_0, f_+) optimize likelihood to get C_s
  - From $-\ln L(f_0, f_+)$ distribution obtain the measured f_0 and f_+, and statistical uncertainties

Matrix Element Method

$$P_{signal}(x; f_0, f_+) = \sum_{perm.} \int \frac{d\sigma(y; f_0, f_+)}{dy} W(x,y)\, dq_1 dq_2 f(q_1) f(q_2)$$

- **dσ** is the differential ttbar cross section

$d\sigma = |M|^2 d\Phi$: LO qqbar matrix element from Mahlon & Parke *(PLB 411, 173 (1997); PRD 53, 4886 (1996))*.

- *W(x,y)* models detector resolution effects
  - Relates a set of observable x to corresponding parton level quantities y

$$W(x,y) = \delta^3(p^y_{lepton} - p^x_{lepton}) \prod_{j=1}^{4} W_{jet}(E^x_j, E^y_j) \prod_{i=1}^{4} \delta^2(\Omega^y_i - \Omega^x_i)$$

- **f(q)** is from the parton distribution function
  - Take into account the flavors of colliding quark and anti-quark
- Partons are identified with the four highest E_T jets and all the corresponding jet-parton permutations are considered

Matrix Element Method (cont')

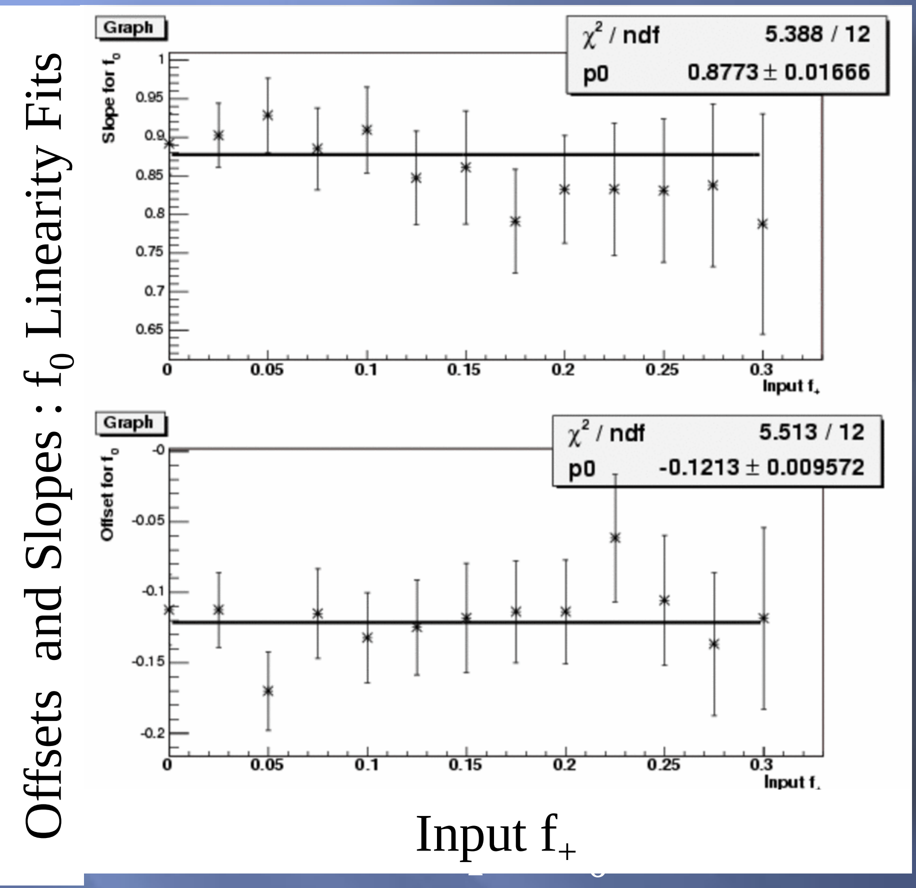
- W polarization fraction in the matrix Element:

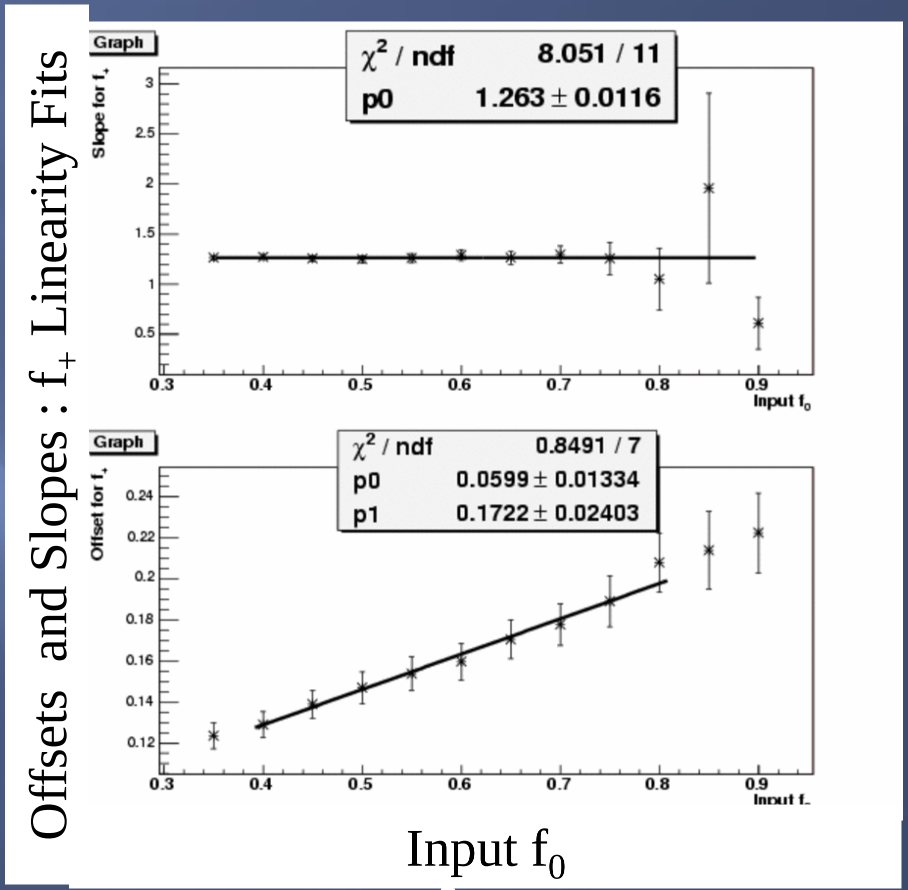
$$|M|^2 \propto w_{lep}(\cos\theta^*) \times w_{had}(\cos\theta^*)$$

$$w(\cos\theta^*) = f_+ \frac{3}{8}(1-\cos\theta^*)^2 + f_0 \frac{3}{4}(1-\cos^2\theta^*) + (1-f_0-f_+)\frac{3}{8}(1+\cos\theta^*)^2$$

- $P_{bkg,i}$ is similar, no dependence on f_0 and f_+
- Construction of signal and background probabilities are based the techniques used for the top mass measurement (PRL 99, 182002 (2007))

Calibration



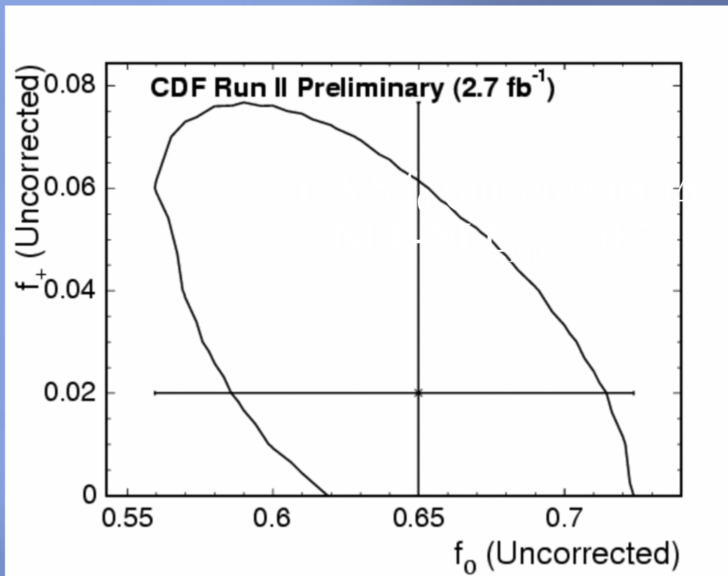


- For the model independent fit we have a family of $f_{0(+)}$ response curves in slices of input $f_{+(0)}$
  - Linear fits to these curves are used to derive calibration functions

Validation and Sensitivity Studies

- Performed data-size pseudo experiments with wide range of (f_0, f_+) input values
  - The fit is unbiased in all cases
  - Find that near physical boundaries the statistical uncertainties are underestimated
    - Apply appropriate corrections to the measured statistical uncertainties
- Assuming SM value of polarization fractions, the expected statistical uncertainties for the simultaneous measurement
  - $\delta f_0 = 0.12$
  - $\delta f_+ = 0.07$

Data Fit: Simultaneous Measurement

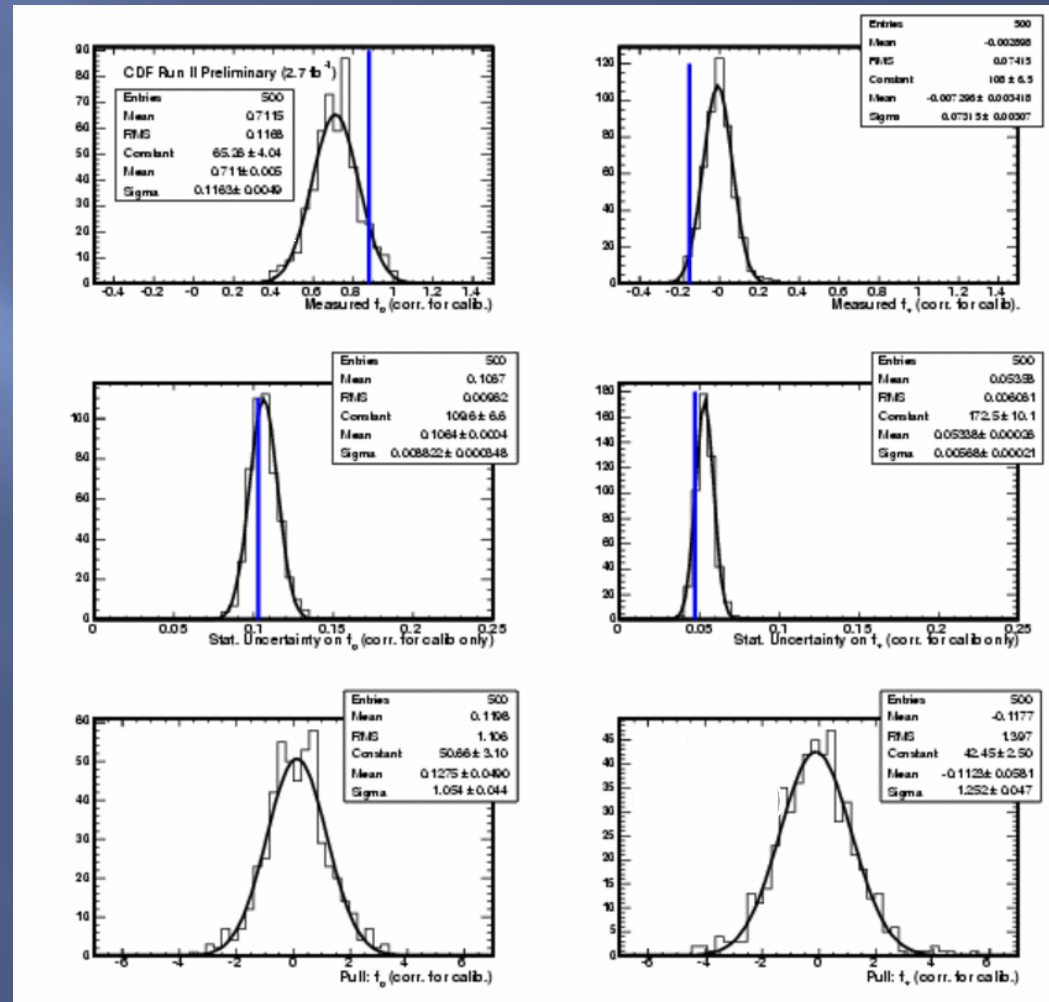


- With 828 selected events after all corrections

  f_0=0.88 ± 0.11 (stat.)

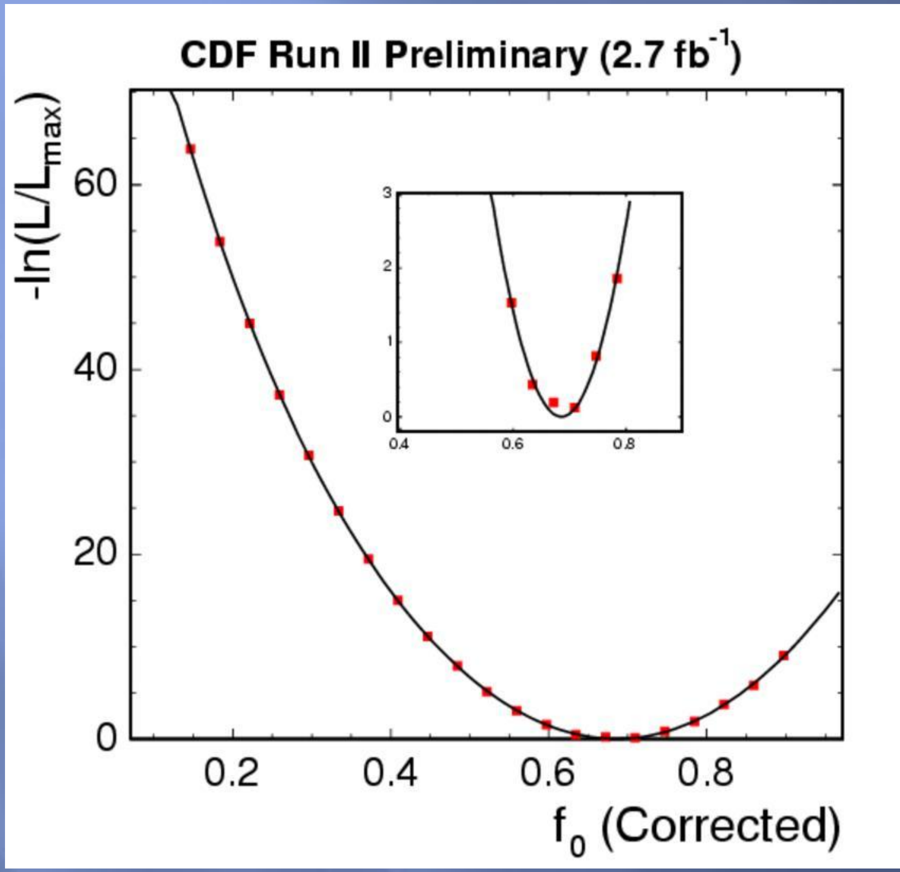
  f_+= -0.15± 0.07 (stat.)

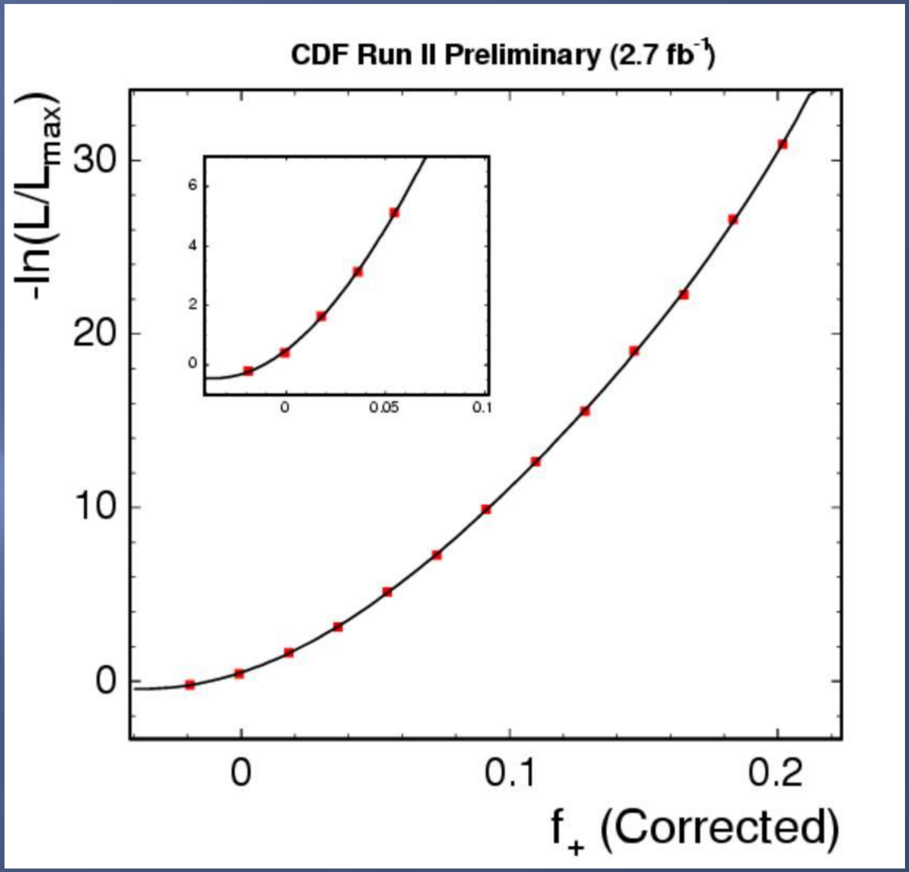
  Correlation between measured f_0 and f_+ -0.59



Comparing data result with PSEs generated with f_0=0.7, f_+=0.0

Data Fit





- With 964 events after all corrections
  - $f_0 = 0.70 \pm 0.07$ (stat), constraining $f_+ = 0.0$
  - $f_+ = -0.01 \pm 0.02$ (stat), constraining $f_0 = 0.7$

Systematic Uncertainty

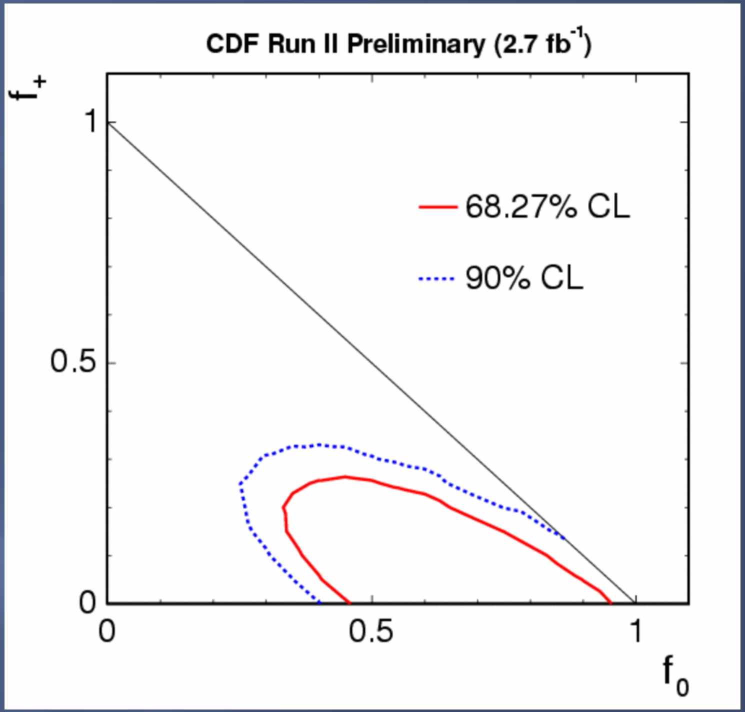
TABLE II: Summary of systematic uncertainties.

Source	Δf_0	Δf_+	Δf_0 simultaneous	Δf_+ simultaneous
ISR/FSR	0.020	0.018	0.020	0.021
PDF	0.024	0.013	0.009	0.016
JES	0.018	0.017	0.004	0.012
Parton shower	0.012	0.008	0.031	0.017
Background	0.009	0.038	0.042	0.039
Method-related	0.010	0.005	0.024	0.024
b-tag SF	0.004	0.002	0.002	0.002
Total	0.041	0.048	0.062	0.057

- Systematic uncertainties are obtained at the SM values of polarization fractions

Results

- Simultaneous measurement:
  - $f_0 = 0.88 \pm 0.11$ (stat) $\pm$ 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(stat) 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

A factor of ~1.3 improvement on the combined statistical systematic precision on f_0 for a 1.4 times increase in luminosity

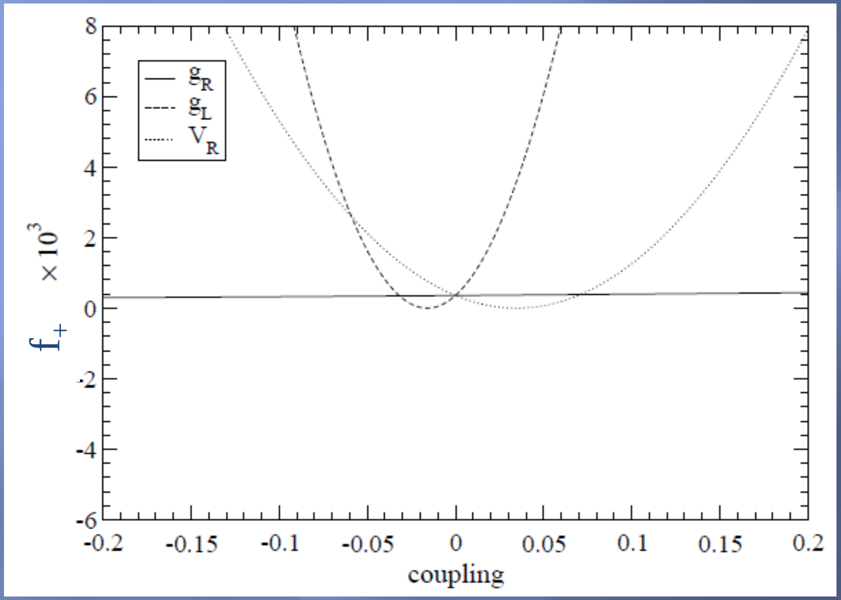
Summary and Future Prospect

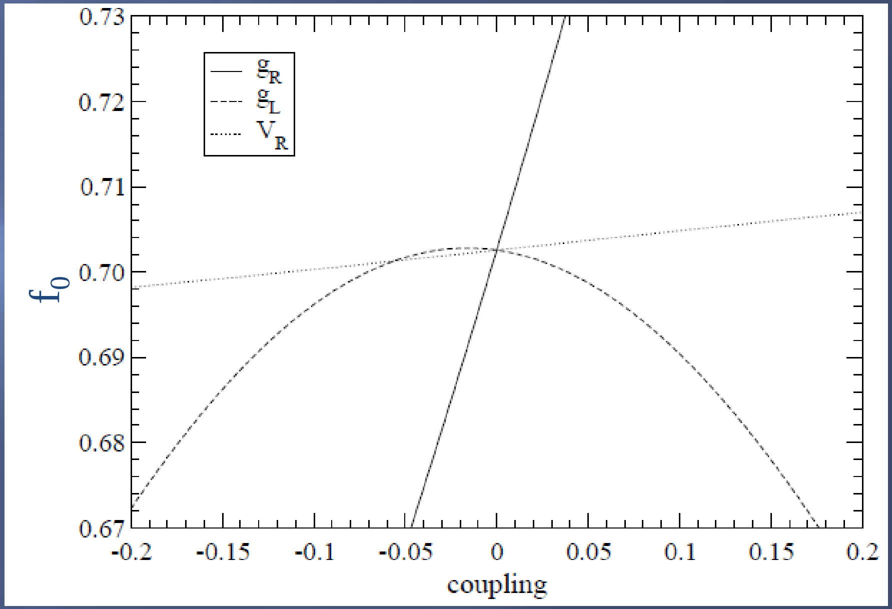
- Measured W-boson polarization in top decay using a matrix element method in 2.7 fb^{-1} data
  - Increased signal acceptance by 30% compared to the previous published analysis
  - Improves accuracy of f_0 measurement relative to CDF's best by ~20% for same luminosity
- Measurements are consistent with the SM
- Most precise measurement of f_0 so far
- Measurements are statistically limited at present
  - Plan to update with 6-8 fb^{-1} data in near future
  - Combine with D0 measurement
  - Combination based on 6-8 fb^{-1} data results will be limited by systematic uncertainty
- Working with theorists to include the measurements in global fit to set constrains on the couplings

BACKUP SLIDES

Sensitivity to New Physics

- W-helicity fractions and ratios are sensitive to non-SM tWb couplings

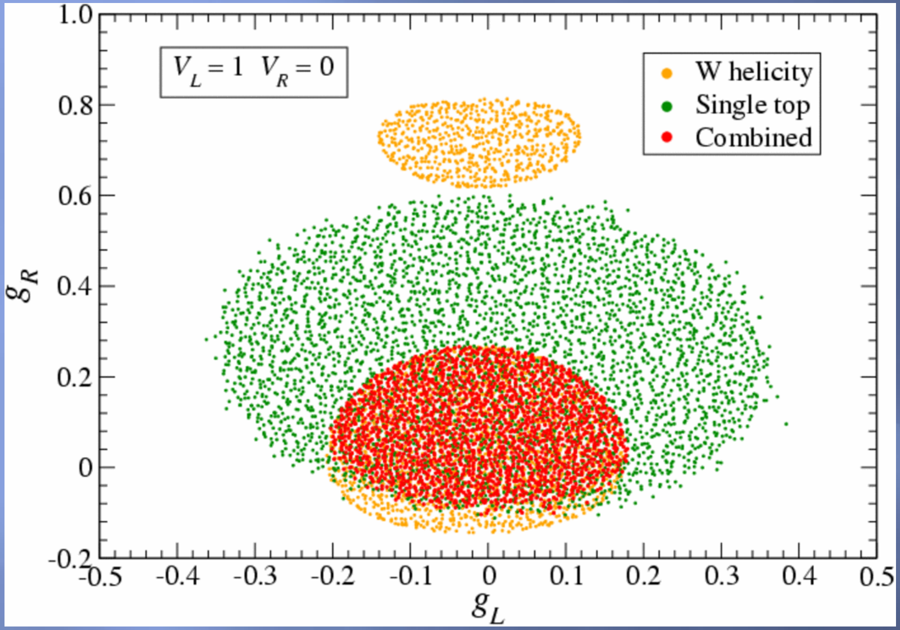


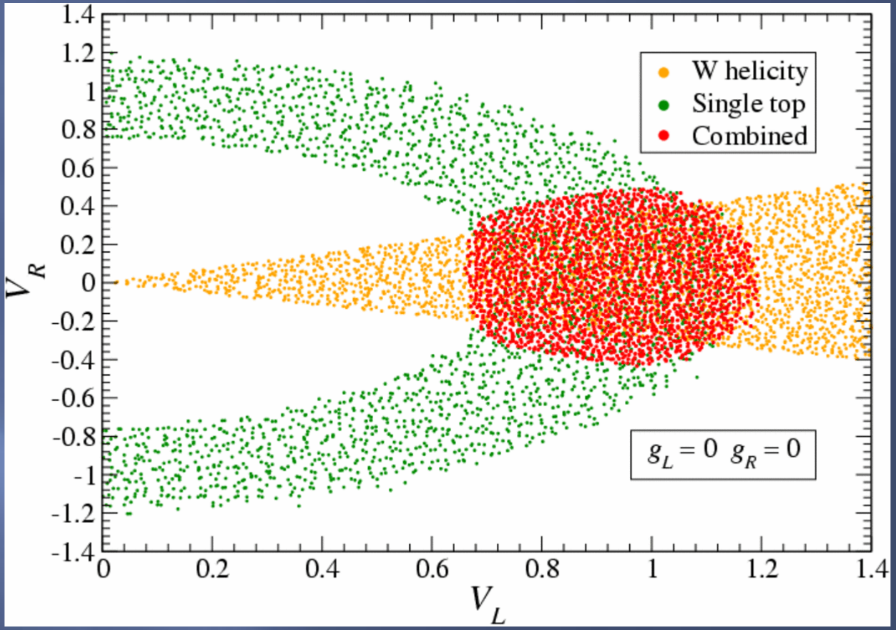


J. A. Aguilar-Saavedra et; al., Eur. Phys. J. C50, 519 (2007)

- Measurements of W-polarization fractions and EW single top production together can set constrains on the anomalous coupling form factors.

tWb Coupling using CDF Results





Courtesy to J. A. Aguilar-Saavedra

Set Contains on couplings using TopFit : a program to fit the Wtb vertex (http://www-ftae.ugr.es/topfit/)

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu} q_{\nu}}{M_W}\left(g_L P_L + g_R P_R\right) t\, W_{\mu}^{-} + \text{h.c.}$$