Measurements of the Fraction of Longitudinally-Polarized W Bosons Produced in Top-Quark Decays

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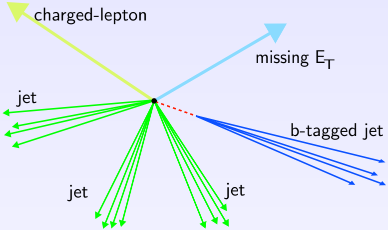
Introduction/Physics Motivation

- SM: Only left-handed and longitudinal Ws may be produced in $t \to Wb$.
- SM: Top decays to longitudinal Ws are *enhanced*.

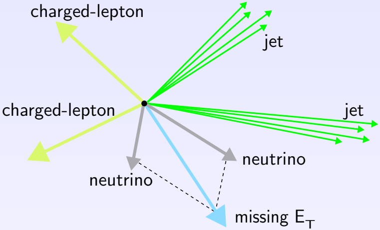
$$F_0 = \frac{\Gamma(t \to W_0 b)}{\Gamma(t \to W_0 b) + \Gamma(t \to W_\pm b)} = (1+2(m_W/m_t)^2)^{-1} \simeq 0.7|_{m_t=175\ \mathrm{GeV}}$$

- Exploring the the tWb coupling should lend insight to the nature of EWSB.
- It's a reasonable place to look for new physics.
- Here is an opportunity to test a prediction of the SM.

Lepton+Jet and Dilepton $t\bar{t}$ Samples



lepton+jets signature

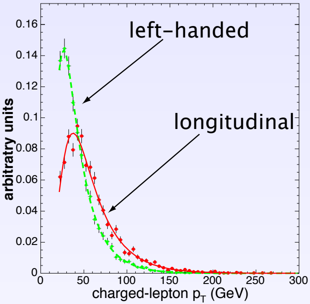


dilepton signature

- Drawn from data recorded at CDF II through September 2003
- $\int L dt = 162 - 192\ \mathrm{pb}^{-1}$

sample	charged leptons
lepton+jets	57
dilepton	26
total	83

Two Approaches to Measuring W Helicity

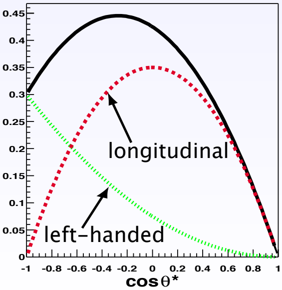


Lepton p_T Method

- Analyze the charged-lepton p_T spectra of $t\bar{t}$ samples
- Used in Run I measurement: $F_0 = 0.91 \pm 0.37(stat) \pm 0.13(syst)$
- Advantage: larger statistics (can use lepton+jets *and* dilepton samples)

$\cos(\theta^*)$ Method

- Analyze the pseudo-$\cos(\theta^*)$ distribution of b-tagged lepton+jets samples
- Used in the Run I measurement $F_+ < 0.18$ @ 95% CL
- Advantage: more information per event, better seperation



Lepton p_T Method: Likelihood Function (simplified)

$$\mathscr{L}(F_0, \beta) = G(\beta; \beta_0, \sigma) \prod_{i=1}^{N} P(x_i; F_0, \beta)$$

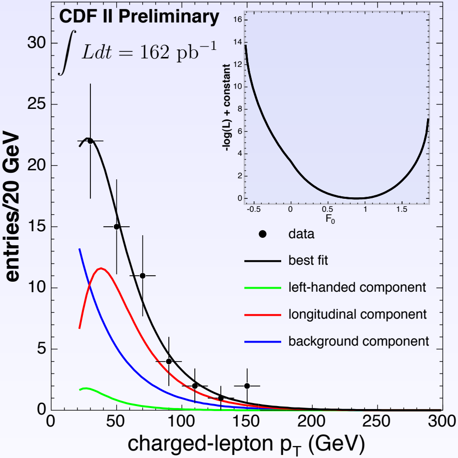
$$P(x_i; F_0, \beta) = \beta P(x_i; \mathrm{bg}) + (1-\beta)\{F_0 P(x_i; 0) + (1-F_0) P(x_i; -1)\}$$

- F_0: the fraction of longitudinally-polarized Ws
- β: the background fraction
- $\beta_0 \pm \sigma$: prior estimate of the background fraction
- $G(\beta; \beta_0, \sigma)$: Gaussian constraint on the background fraction
- $P(x_i; \mathrm{bg})$: PDF of charged-leptons with $p_T = x_i$, given they are due to a background process
- $P(x_i; h)$: PDF of charged-leptons with $p_T = x_i$, given they are due to a W (from top decay) with helicity h

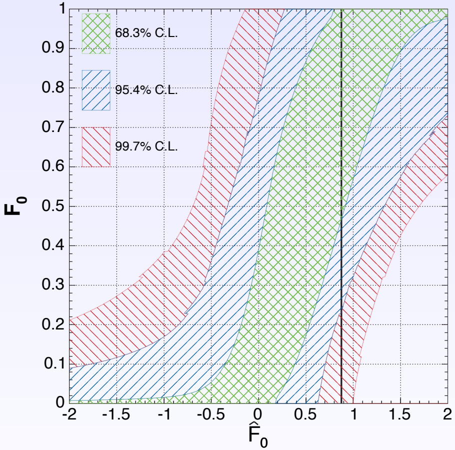
Lepton p_T Method: Systematic Uncertainties

Source	$\Delta\hat{F}_0$ (l+jets)	$\Delta\hat{F}_0$ (dileptons)	$\Delta\hat{F}_0$ (combined)
bg normalization	0.11	0.04	0.10
top mass uncertainty	0.09	0.12	0.11
ISR/FSR	0.04	0.06	0.05
PDF uncertainty	0.03	0.04	0.03
shape uncertainty	0.03	0.02	0.02
MC statistics	0.01	0.01	0.01
acceptance correction	0.01	0.03	0.02
trigger correction	0.01	0.02	0.02
total	0.17	0.16	0.17

Lepton p_T Method: Lepton+Jets Only Result



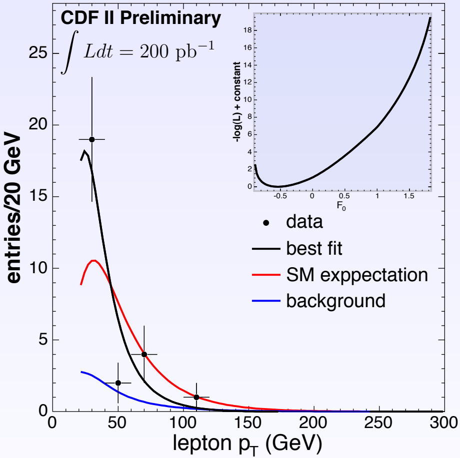
$\hat{F}_0 = 0.88$



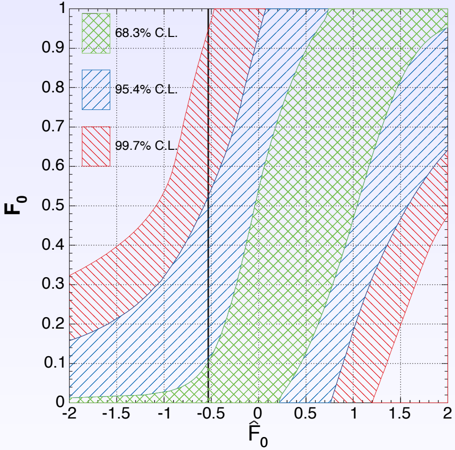
$F_0 = 0.88^{+0.12}_{-0.47}$ (stat. + syst.)

$F_0 > 0.24$ @ 95% CL

Lepton p_T Method: Dilepton Only Result

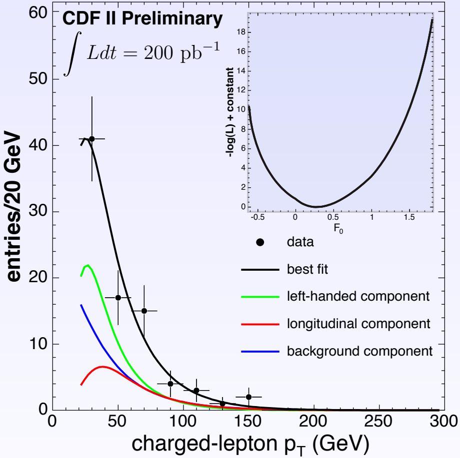


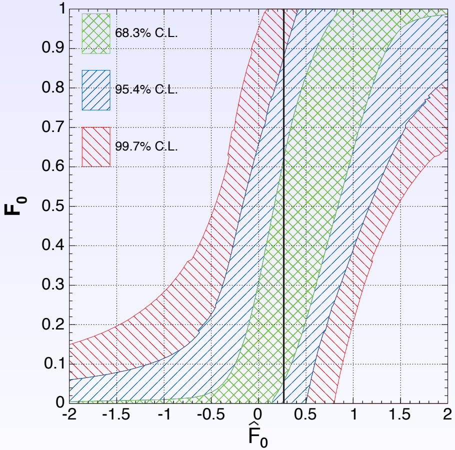
$$\hat{F}_0 = -0.54$$



$$F_0 < 0.52 \text{ @ } 95\% \text{ CL}$$

Lepton p_T Method: Combined Result



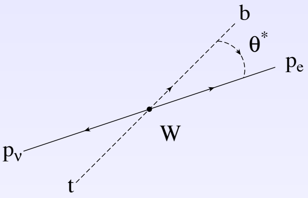


$\hat{F}_0 = 0.27$

$F_0 = 0.27^{+0.35}_{-0.21}$ (stat. + syst.)

$F_0 < 0.88$ @ 95% CL

$\cos(\theta^*)$ Method: Preliminaries

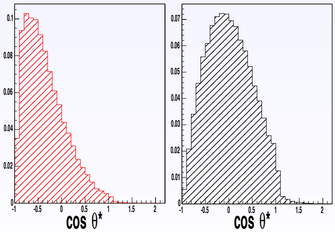


- Discriminate left-handed from longitudinal Ws with $\cos(\theta^*)$
- Use the approximation:

$$\cos(\theta^*) \simeq \frac{2m_{lb}^2}{m_t^2 - m_W^2} - 1$$

- The top-mass fitter does the best job of choosing the correct lepton/b-jet pair

- Mass fitter gives correct match $60\% - 70\%$ of the time
- Only lepton + 4 jet events are considered
- Right: signal templates used in this analysis, generated by `MadEvent`



$\cos(\theta^*)$ Method: Binned Likelihood Function (simplified)

$$\mathscr{L}(F_0, \beta) = G(\beta; \beta_0, \sigma) \prod_{i=1}^{N_{bins}} \frac{\mu_i^{x_i} e^{-\mu_i}}{x_i!}$$

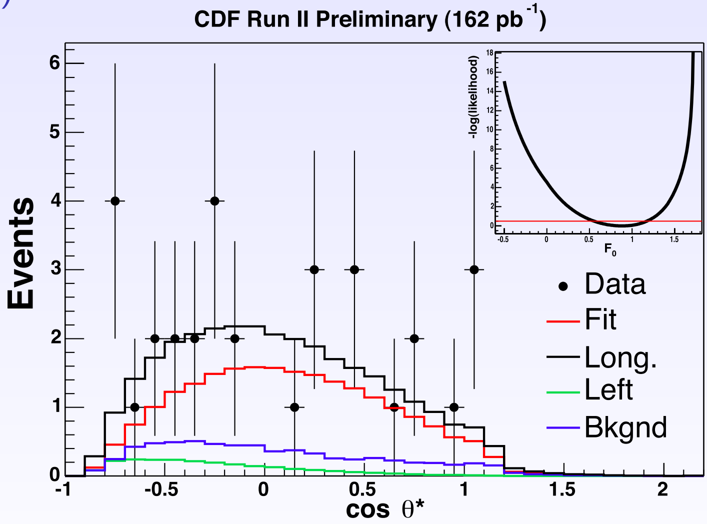
$$\mu_i \propto \beta T_{\mathrm{bg},i} + (1-\beta)(F_0 T_{0,i} + (1-F_0) T_{-1,i})$$

- F_0: the fraction of longitudinally-polarized Ws
- β: the background fraction
- $\beta_0 \pm \sigma$: prior estimate of the background fraction
- $G(\beta; \beta_0, \sigma)$: Gaussian constraint on the background fraction
- x_i: content of the ith bin
- $T_{\mathrm{bg},i}$: Template for events reconstructed with $\cos(\theta^*)$ in the ith bin, given they are due to a background process
- $T_{h,i}$: Template for events with $\cos(\theta^*)$ in the ith bin, given they are due to a W (from top decay) with helicity h

$\cos(\theta^*)$ Method: Systematic Uncertainties

Source	$\Delta\hat{F}_0$
Background Shape	0.12
Top Mass Uncertainty	0.09
Jet Energy Scale	0.06
PDFs	0.04
MC Modeling	0.03
ISR/FSR	0.02
SecVtx b-tagging	0.01
MC Statistics	0.01
Acceptance Correction	< 0.005
Total	0.17

$\cos(\theta^*)$ Method: Result



- $F_0 = 0.89^{+0.30}_{-0.34}$ (stat) ± 0.17 (syst)
- $F_0 > 0.25$ @ 95% CL

Conclusions

- We've measured F_0 in 200 pb^{-1} of top-quark decays at CDF II
- For $m_t = 175$ GeV the SM prediction is $F_0 = 0.703$
- The two analyses show good agreement in the lepton+jets channel:
  - $cos(\theta^*)$ method result:
    $F_0 = 0.89^{+0.30}_{-0.34}$ (stat.) $\pm\, 0.17$ (syst.), $F_0 > 0.25$ @ 95% CL
  - lepton p_T method, lepton+jets result:
    $F_0 = 0.88^{+0.12}_{-0.47}$ (stat. + syst.), $F_0 > 0.24$ @95%CL
- The result in the dilepton sample is anomalous the 2σ-level
  - lepton p_T method, dilepton result:
    $F_0 < 0.52$ @ 95% CL
- lepton p_T combined result *is consistent* with the SM:
  $F_0 = 0.27^{+0.35}_{-0.21}$ (stat. + syst.)
- More data is coming; will the dilepton anomaly persist??