Measurements of the W Helicity in Top Decays at CDF

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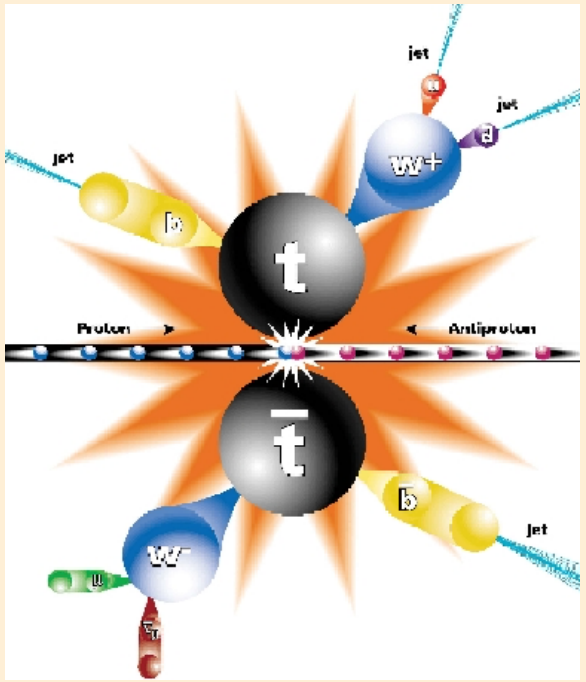
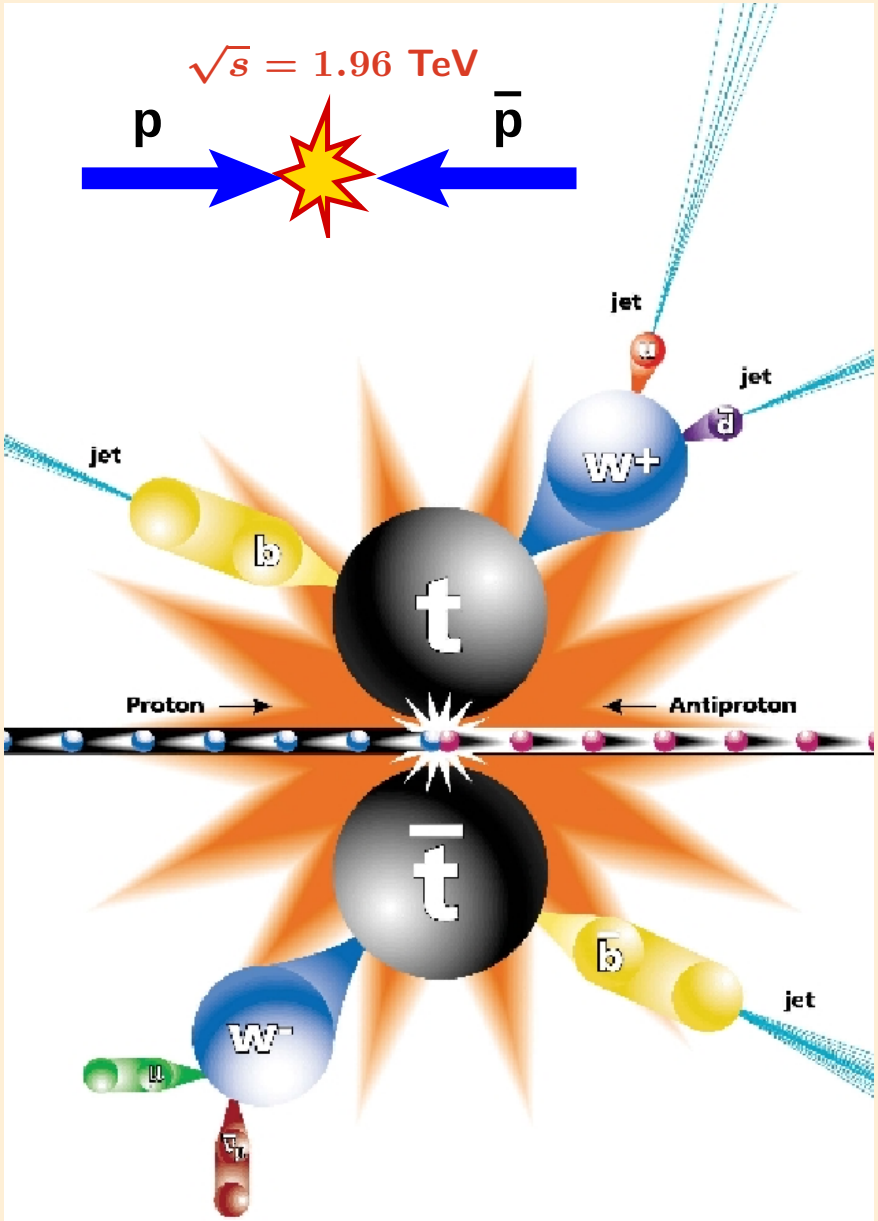
On behalf of the CDF collaboration

- Motivation
- W Helicity in top decays
- Analysis methods
- Results



Motivation



- **1995:** Top quark discovery
- **2006:** Top mass known with a precision of about 1.3% (2.4% Run I)

Open question:

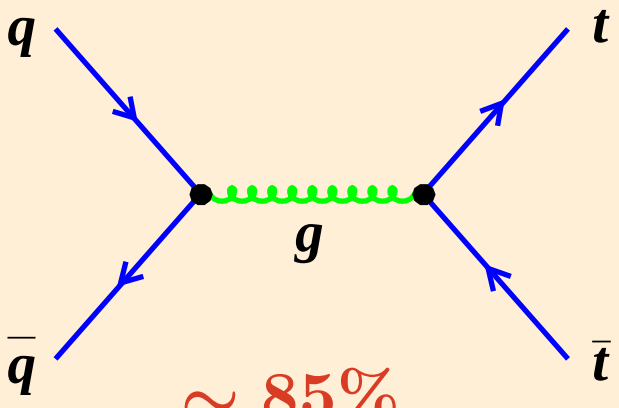
Does the discovered top quark have all properties of the SM top ?

- Production mechanism
- Charge, lifetime, spin
- Decay: branching ratios, couplings, W helicity

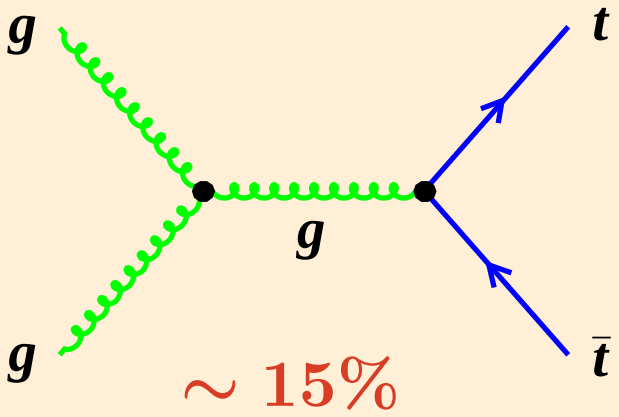
This talk: New CDF W helicity measurements in top decays

Top Production at the Tevatron

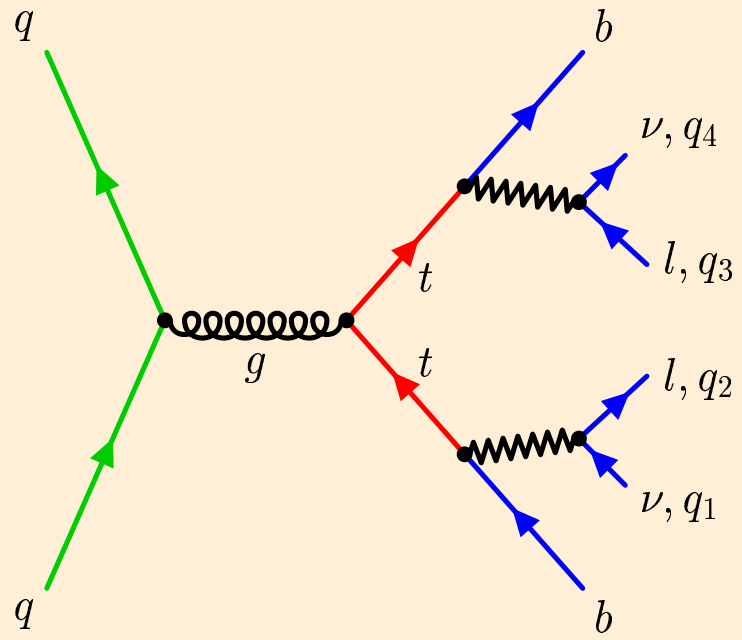
Dominant process:
Top pair production



$\sim 85\%$



$\sim 15\%$

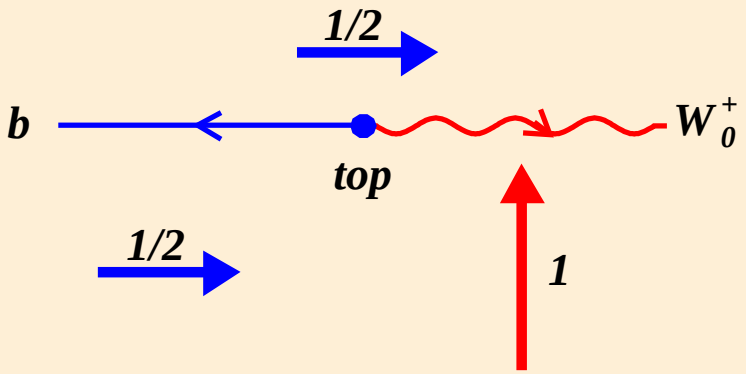


$\ell : e, \mu$

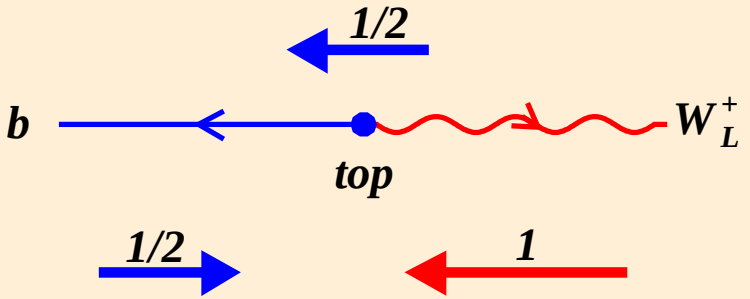
- **Dilepton channel:** $\ell_1\nu_1 + \ell_2\nu_2 + b\bar{b}$
  $BR \sim 5\%$, moderate background
- **Lepton+Jets channel:** $\ell\nu + q_1\bar{q}_2 + b\bar{b}$
  $BR \sim 30\%$, moderate background
- **All hadronic:** $q_1\bar{q}_2 + q_3\bar{q}_4 + b\bar{b}$
  $BR \sim 46\%$, huge background

W Helicity in Top Decays

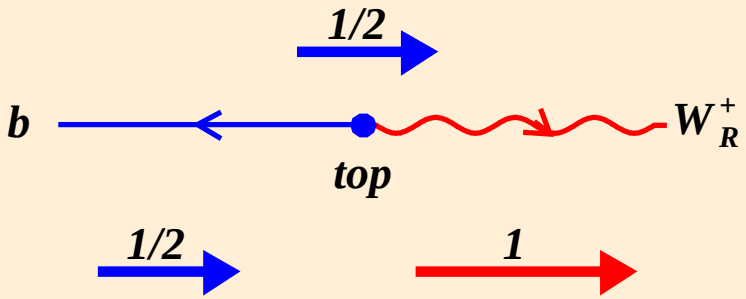
Longitudinal: $F_0 = 0.7$ (SM)



Left-handed: $F_- = 0.3$ (SM)



Right-handed: $F_+ = 0$ (SM)



forbidden !

- $\tau_t < \tau_{QCD}$: spin information of t quark preserved
- Study of V-A structure of weak interaction:

  V-A: $F_0 = 0.7,\ F_- = 0.3$

  V+A: $F_0 = 0.7,\ F_+ = 0.3$

  SM: $f_{V-A} = 1,\ f_{V+A} = 0$

  $F_+ = 0.3 \cdot f_{V+A}$ $(F_0 = 0.7)$

Deviations from SM values would indicate new physics

W Helicity angle θ^*

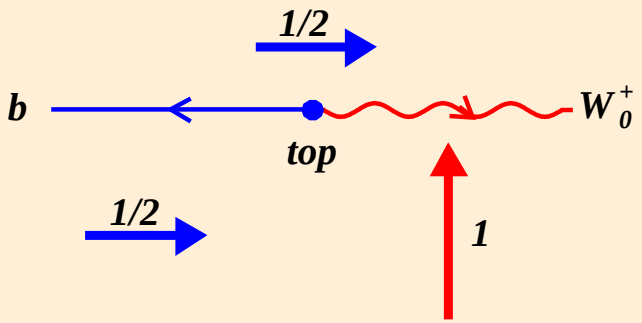
Look at decay $t \longrightarrow bW^+ \longrightarrow b\,\ell^+\nu$

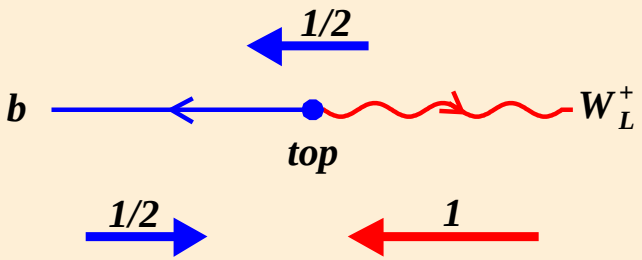
ν: always left-handed ($m_\nu = 0$)

$\Rightarrow \ell^+$: always right-handed

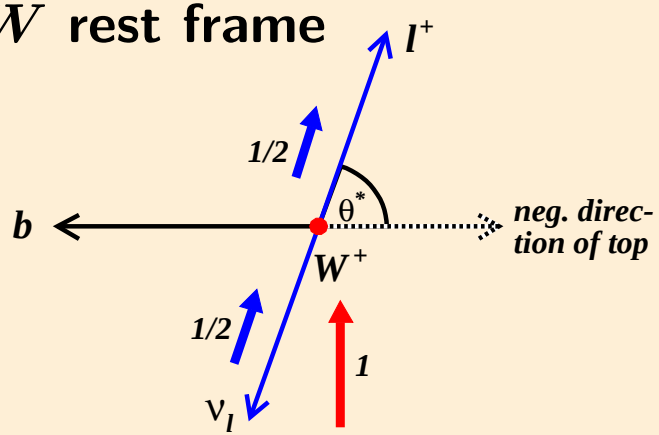
θ^*: $\angle\ \ell\ (e, \mu)$ in W rest frame with respect to neg. direction of t in W rest frame

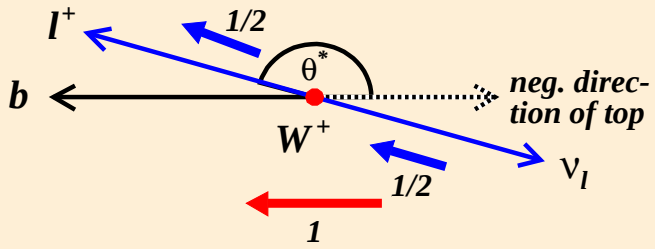
Top rest frame





W rest frame





Longitudinal:

maximum at

$\theta^* = 90°$

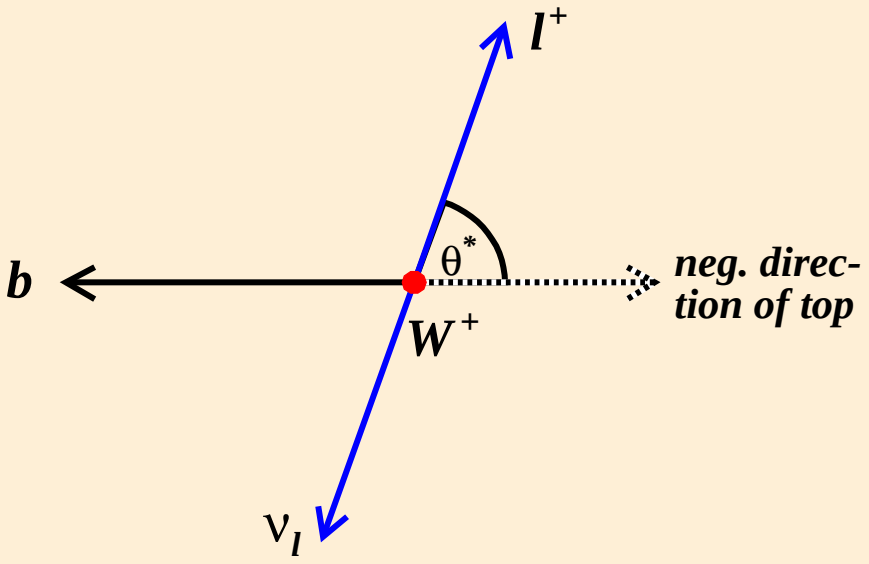
Left-handed:

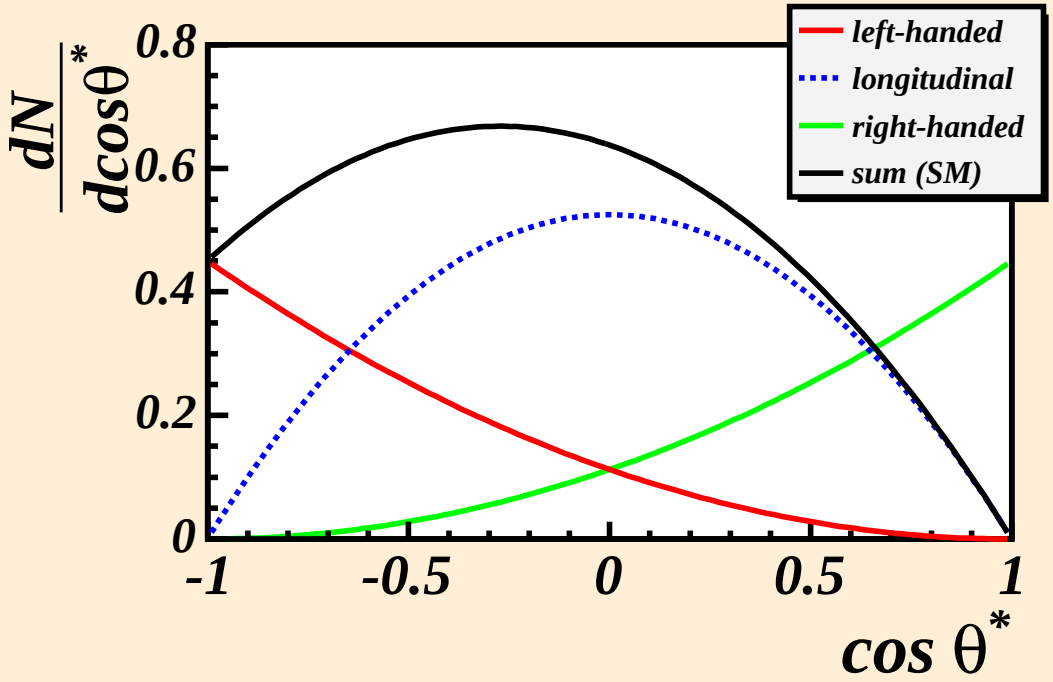
maximum at

$\theta^* = 180°$

$\cos\theta^*$ Distr. for Different W Helicities

W rest frame





Left-handed: $\sim \frac{3}{8}\left(1-\cos\theta^*\right)^2$

Longitudinal: $\sim \frac{3}{4}\left(1-\cos^2\theta^*\right)$

Right-handed: $\sim \frac{3}{8}\left(1+\cos\theta^*\right)^2$

Standard model:

$$F_0 \cdot \frac{3}{4}\left(1-\cos^2\theta^*\right) + F_- \cdot \frac{3}{8}\left(1-\cos\theta^*\right)^2$$

with $F_0 = 0.7$, $F_- = 0.3$ and $F_+ = 0$ ($m_t = 175$ GeV/c^2)

Sensitive Variables

Transverse momentum: p_T^ℓ

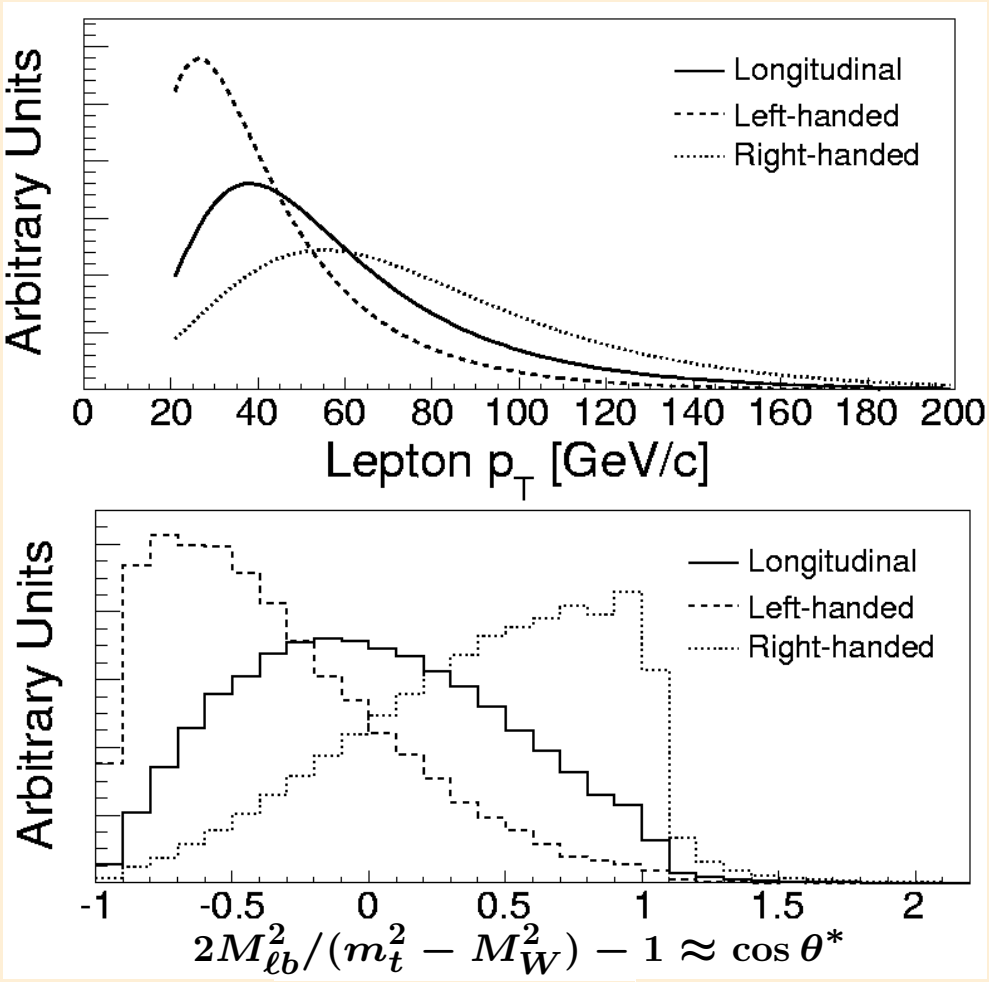
- Applicable for Dilepton and Lepton+Jets channel
- No ambiguities

Invariant mass: $M_{\ell b}^2$

- Applicable for Dilepton and Lepton+Jets channel
- Use ℓ and b-jet four-vectors
- Good separation power

Decay angle: $\cos\theta^*$

- Applicable for Lepton+Jets
- Use t, W and ℓ four-vectors
- Full rec. of $t\bar{t}$ kinematics
- Good separation power



Run I: p_T^ℓ, M_{lb}^2

Early Run II: p_T^ℓ, $M_{\ell b}^2$

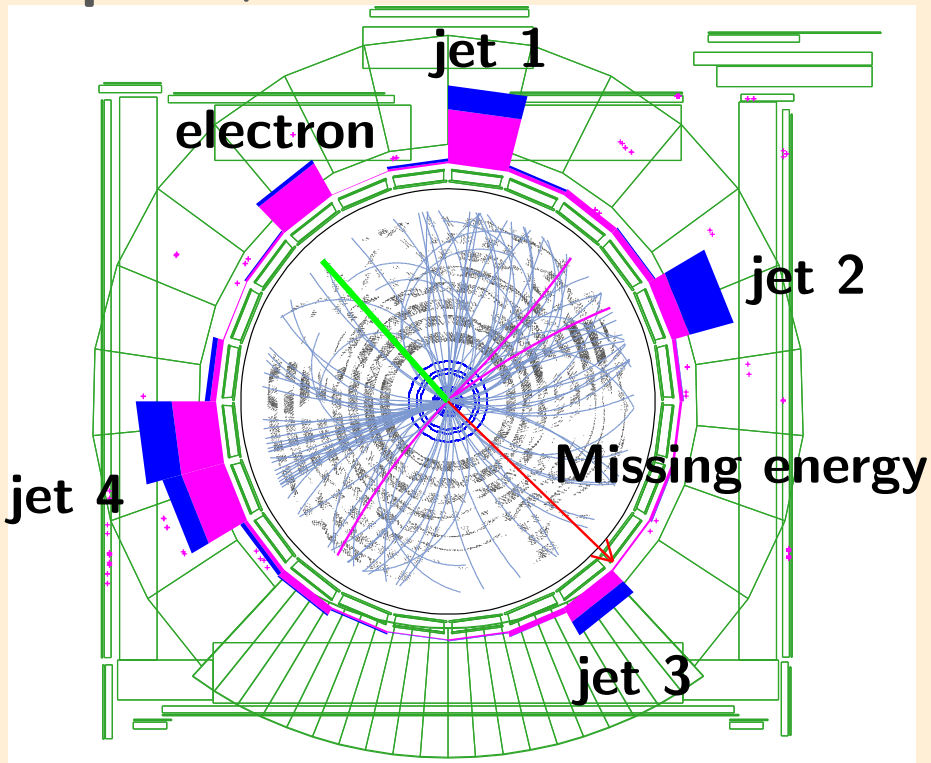
New Run II results: $\cos\theta^*$, $M_{\ell b}^2$

Overview of W Helicity Analyses at CDF

Period	Sensitive variable	Meas. quantity	Decay channel	N_{jets}	$\mathcal{L}\ [pb^{-1}]$
Run I	p_T^ℓ	F_0, F_+	Lepton+Jets	≥ 3	**106**
			Dilepton	≥ 2	**106**
	$M_{\ell b}^2$	f_{V+A}	Lepton+Jets	≥ 3	**109**
			Dilepton	≥ 2	**109**
		Comb.: $F_+ = -0.02 \pm 0.11$; p_T^ℓ: $F_0 = 0.91 \pm 0.39$			
Early Run II	p_T^ℓ	F_0, F_+	Lepton+Jets	≥ 3	**162**
			Dilepton	≥ 2	**193**
	$\frac{2M_{\ell b}^2}{m_t^2 - M_W^2} - 1 \approx \cos\theta^*$	F_0, F_+	Lepton+Jets	≥ 3	**162**
		Comb.: $F_0 = 0.74^{+0.22}_{-0.34}$, $F_+ = 0.00^{+0.20}_{-0.19}$			
Run II (new)	$\cos\theta^*$	F_0, F_+	Lepton+Jets	≥ 4	**320**
	$M_{\ell b}^2$	f_{V+A}	Lepton+Jets	≥ 3	**695**
			Dilepton	≥ 2	**750**

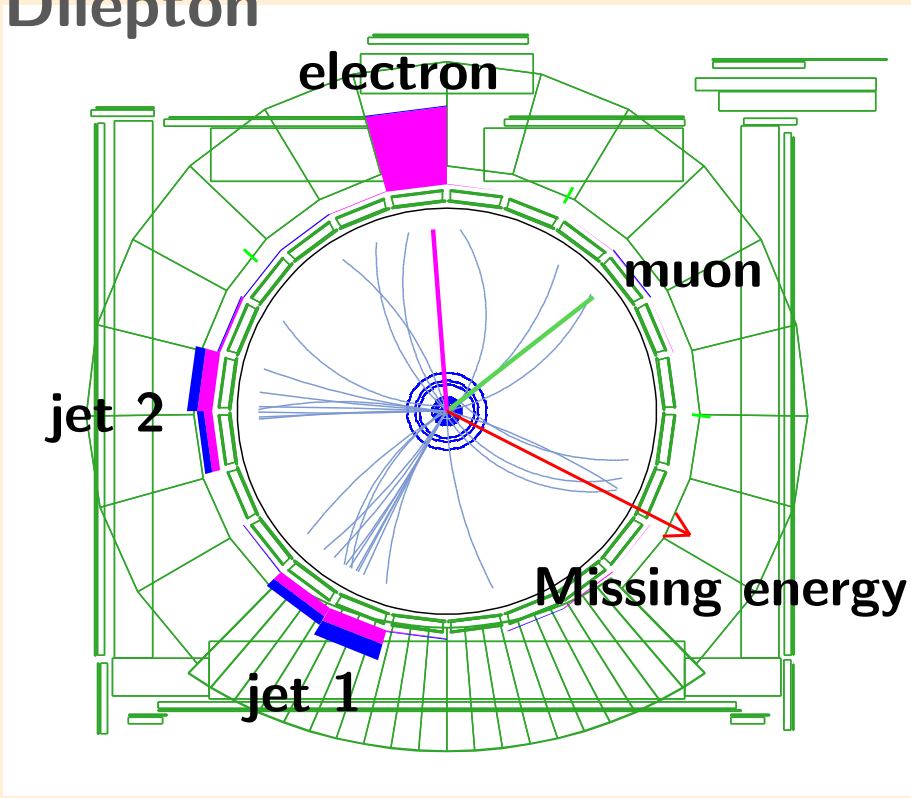
Event Selection

Lepton+Jets



- $p_T^\ell > 20$ GeV/c, $\not\!\!E_T > 20$ GeV
- $N_{\text{jets}} \geq 3$ or 4 with $E_T > 15$ GeV and $|\eta| < 2.0$
- ≥ 1 jets tagged as b-jet

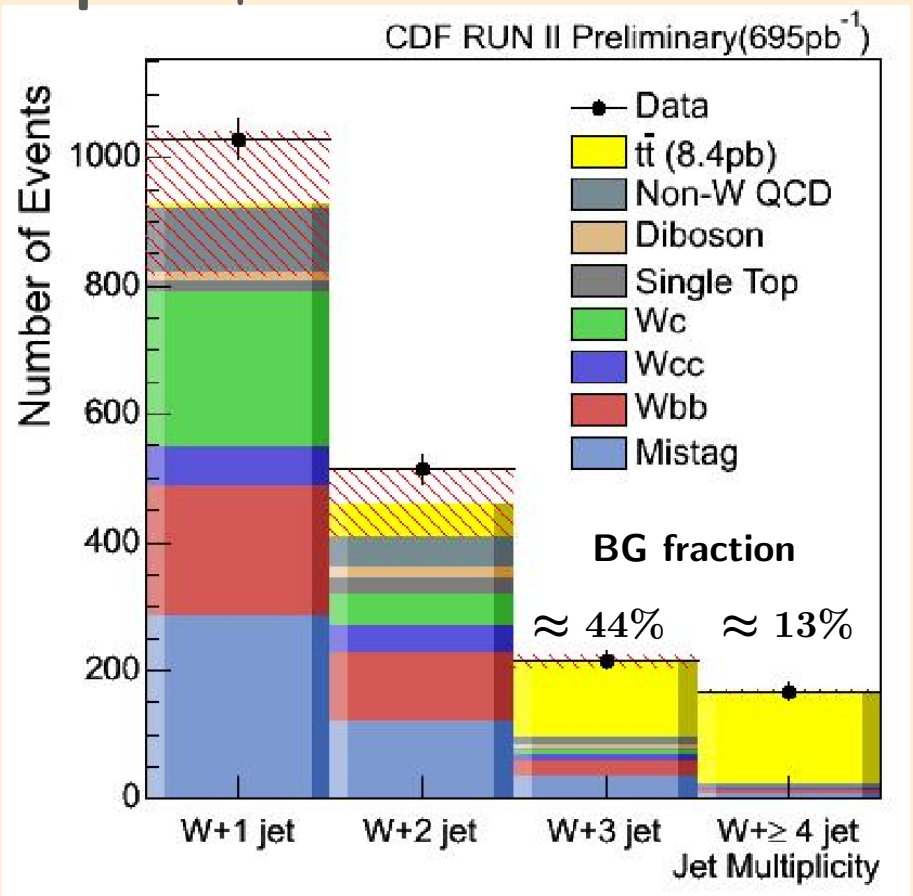
Dilepton



- $p_T^{\ell_{1,2}} > 20$ GeV/c, $\not\!\!E_T > 25$ GeV
- Opposite charged leptons
- $N_{\text{jets}} \geq 2$ ($E_T > 15$ GeV, $|\eta| < 2.5$)
- $H_T > 200$ GeV (tot. trans. energy)

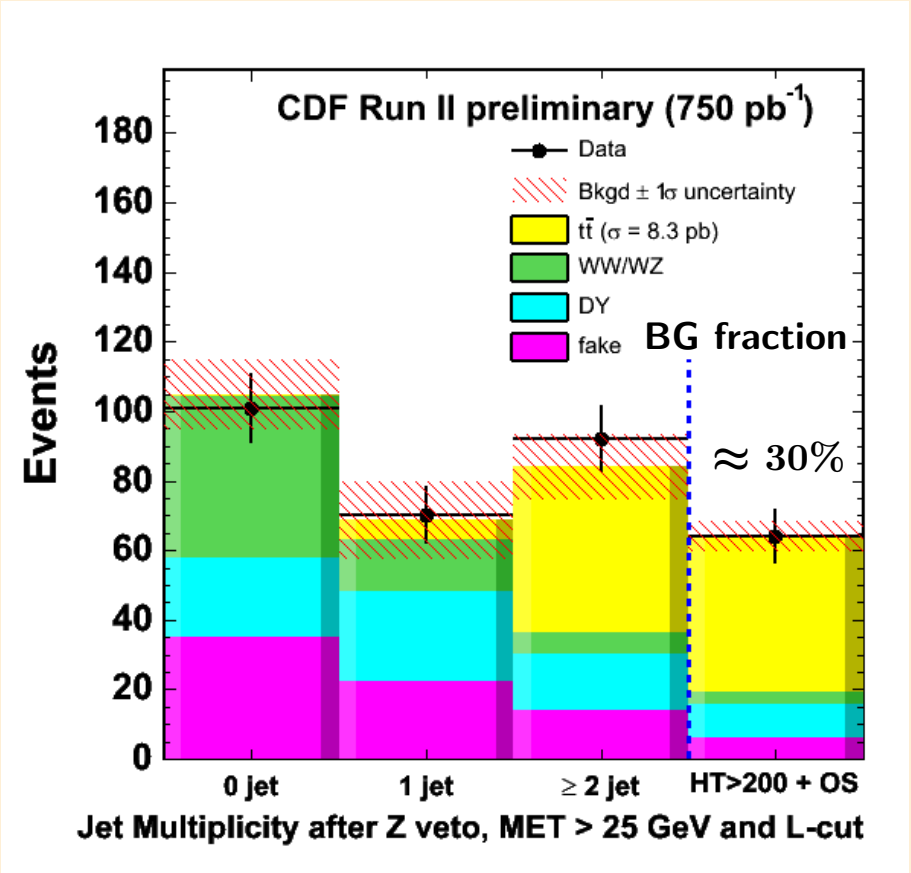
Background Estimates

Lepton+Jets



- Di-boson, single top are extracted from Monte Carlo's
- Mistags, QCD-BG estimated from data, W + jets from data & MC

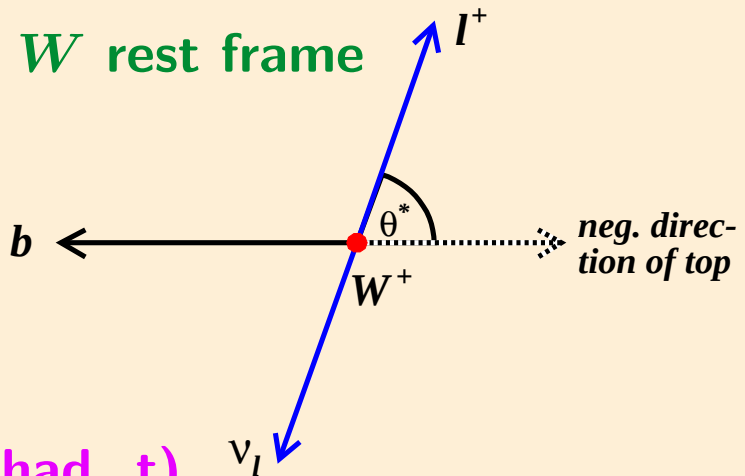
Dilepton



- MC: WW, WZ, $Z \to \tau\tau$ (DY)
- $Z \to ee$, $\mu\mu$ (DY), fake leptons (W + jets) estimated from data

New Method: $\cos\theta^*$

$\cos\theta^*$: 4-vector of ℓ, W and t needed



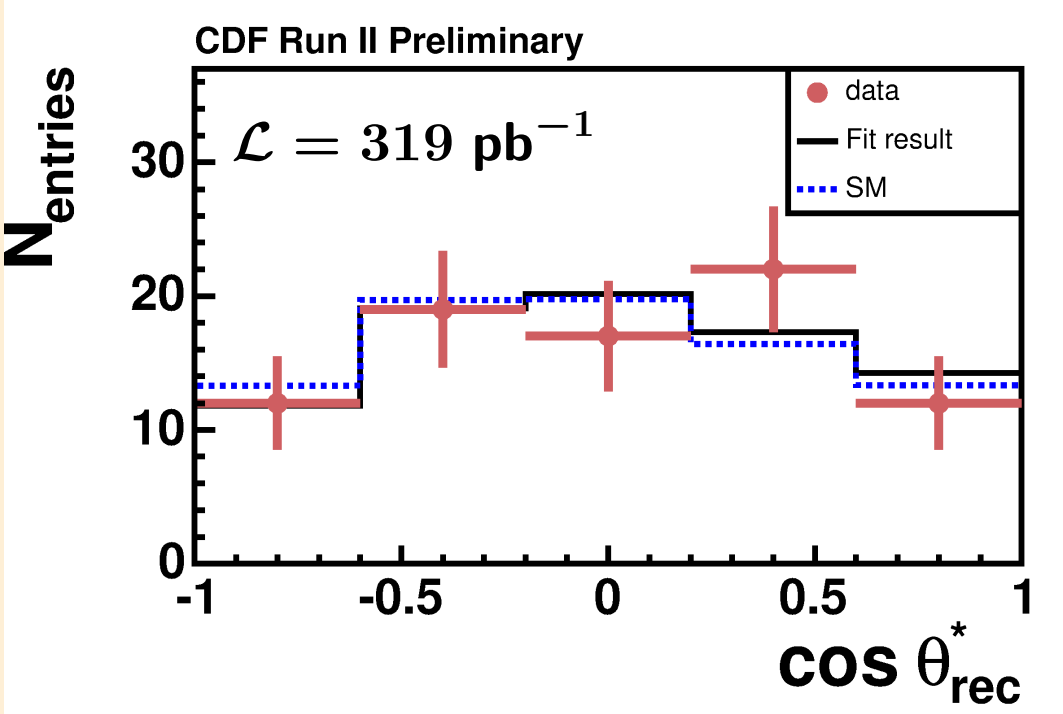
- **ν**: Only p_T ($\not\!\!E_T$) known
  $\rightarrow$ 2 $p_{z,\nu}$ solutions
- Assignment of jets to b and light quarks from $t\bar{t}$ leads to

  b (semilep. t) **$W \rightarrow q_1\bar{q}_2$** **$b$ (had. t)**

  $$N_{jets} \cdot \frac{(N_{jets}-1)\cdot(N_{jets}-2)}{2} \cdot (N_{jets}-3) \quad \text{combinations}$$

- Selection criteria of best possible combination:
  - Choose always smaller $|p_{z,\nu}|$ solution
  - Constraints on $m_{W\rightarrow jj}$ and $m_{t\rightarrow b\ell\nu} - m_{t\rightarrow bjj}$
  - b likeness of b-jet candidates
  - Constraint on the sum of the rec. E_T of top quarks (should be equal to E_T of event in LO)

$\cos\theta^*$ Method - Result



Signal template:

Calculated from theoretical distr. and corrected for detector effects using MC

Fit:

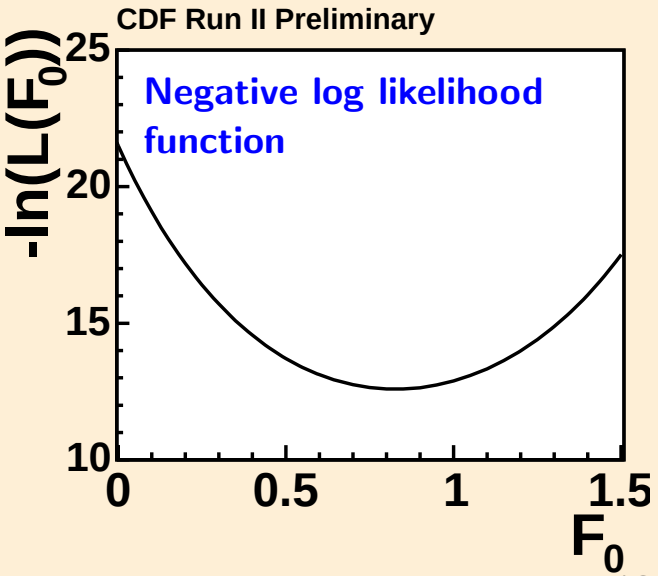
1 free parameter: F_0 or F_+, other parameter fixed to SM value

Result:

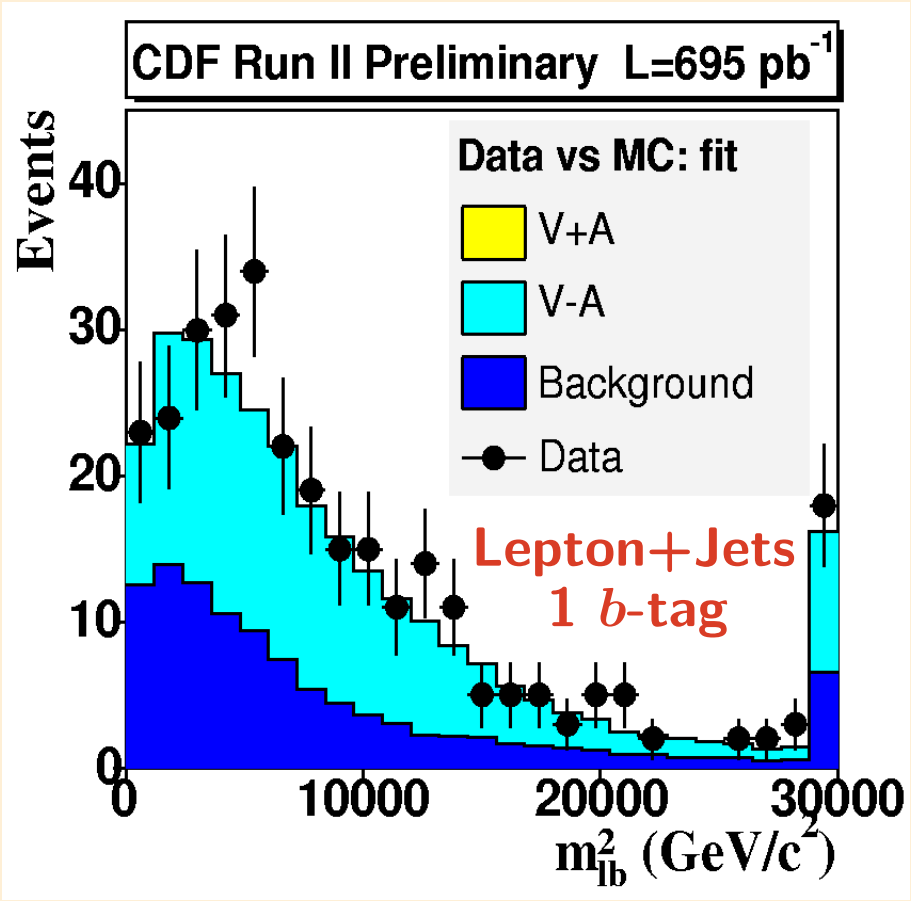
$F_0 = 0.85^{+0.15}_{-0.22} \pm 0.06$ $F_+ = 0$ fixed

$F_+ = 0.05^{+0.11}_{-0.05} \pm 0.03$ $F_0 = 0.7$ fixed

Well consistent with SM prediction



New M_{lb}^2 Analysis with $700\,\text{pb}^{-1}$



$V-A$: $F_0 = 0.7$, $F_- = 0.3$
$V+A$: $F_0 = 0.7$, $F_+ = 0.3$
SM: $f_{V-A} = 1$, $f_{V+A} = 0$
$F_+ = 0.3 \cdot f_{V+A}$ $(F_0 = 0.7)$

Signal templates:

Extracted from Monte Carlo
(ALPGEN, f_{V-A} / f_{V+A} switch)

Data samples:

Lepton+Jets:

1 b-tag: 1 hyp. $\rightarrow$ 1D histogram

2 b-tags: 2 hyp. $\rightarrow$ 2D histogram

Dileptons: 4 hyp. $\rightarrow$ 2 solutions in 2D histogram

Combined result:

$f_{V+A} = -0.06 \pm 0.24$

$f_{V+A} < 0.29$ @ 95 C.L.

$F_+ = -0.02 \pm 0.08$ with $F_0 = 0.7$

Well consistent with SM

Summary and Outlook

Measurements of the W helicity in top decays at CDF:

- ◇ **New method: full reconstr. of $\cos\theta^*$ ($\mathcal{L} = 320$ pb^{-1})**
- ◇ **M^2_{lb} analysis with $\mathcal{L} = 700$ pb^{-1}**

$\Rightarrow$ **Measured W helicities are well consistent with SM:**

$$F_+ = -0.02 \pm 0.11 \text{ (Run I)} \;\rightarrow\; F_+ = -0.02 \pm 0.08 \text{ (today)}$$

$$F_0 = 0.91 \pm 0.31 \text{ (Run I)} \;\rightarrow\; F_0 = 0.85^{+0.16}_{-0.23} \; (\mathcal{L} = 320 \text{ pb}^{-1})$$

Entering interesting regime:

- ◇ **Will the agreement stay with increasing luminosity?**
- ◇ **What is the result for a simultaneous fit of F_0 and F_+ ?**