W Helicity and Branching Ratios in Top Quark Decays at Tevatron

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Results from 160 - 200 pb^{-1} of Run II data

- **W helicity in top quark decays**
- **BR**$(t \to Wb)$**/BR**$(t \to Wq)$
- **BR**$(t \to \tau\nu b)$

W Helicity in Top Quark Decays

SM: only left-handed and longitudinal Ws in top decays

- angular momentum, W couples only to LH fermions

SM (V-A) predictions for W helicity state

$$F_0 \approx \frac{1}{1+2(\frac{M_W}{M_{top}})^2} \approx 0.70 \quad \text{(longitudinal)}$$

$$F_- \approx \frac{1}{1+2(\frac{M_{top}}{M_W})^2} \approx 0.30 \quad \text{(left-handed)}$$

$$F_+ \approx 0.0 \quad \text{(right-handed)}$$

nonzero $F_+ \rightarrow$ nonzero V+A component
$\rightarrow$ non-SM physics

Run 1 Results

$$F_0 = 0.56 \pm 0.31 \pm 0.07 \quad \text{(D0)}$$

$$F_0 = 0.91 \pm 0.37 \pm 0.13 \quad \text{(CDF)}$$

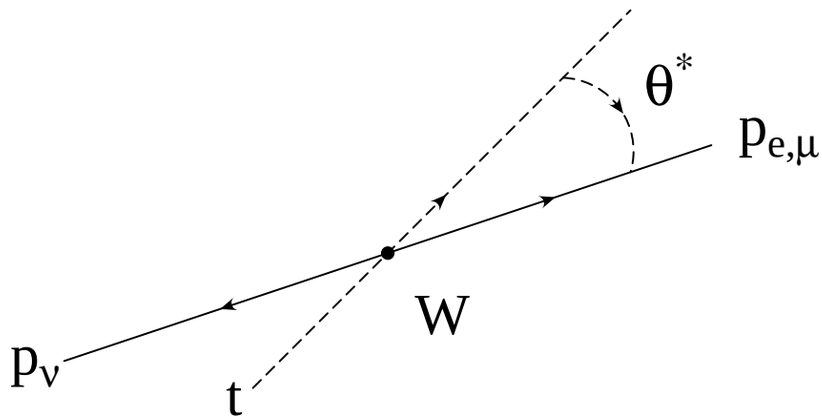
$$F_+ = 0.11 \pm 0.15 \quad \text{(CDF)}$$

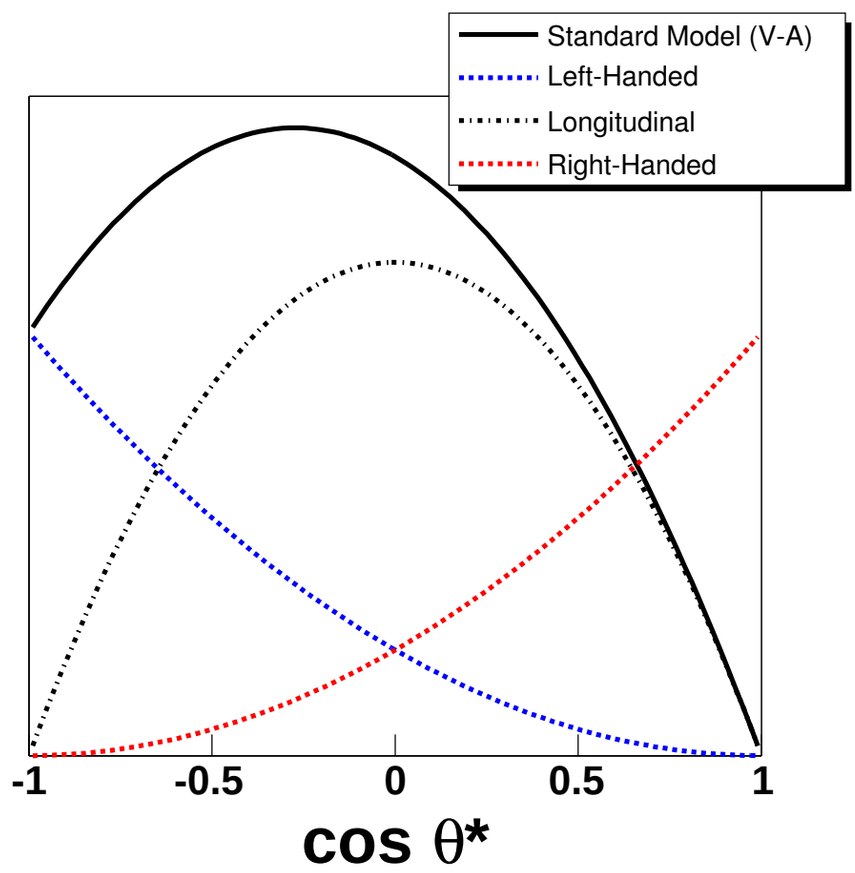
Pure V+A theory ($F_- = 0$, $F_+ = 0.30$)
excluded at 99.6% CL (CDF)

This talk: Run II results on F_+ (D0) and F_0 (CDF)

W Helicity: Two Variables

Angle θ^* between charged lepton in W rest frame and original W momentum: larger for LH Ws than RH Ws



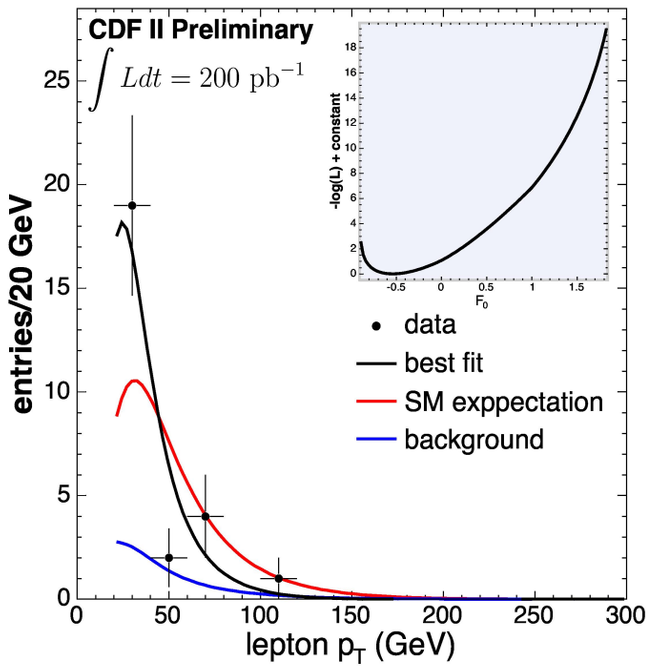


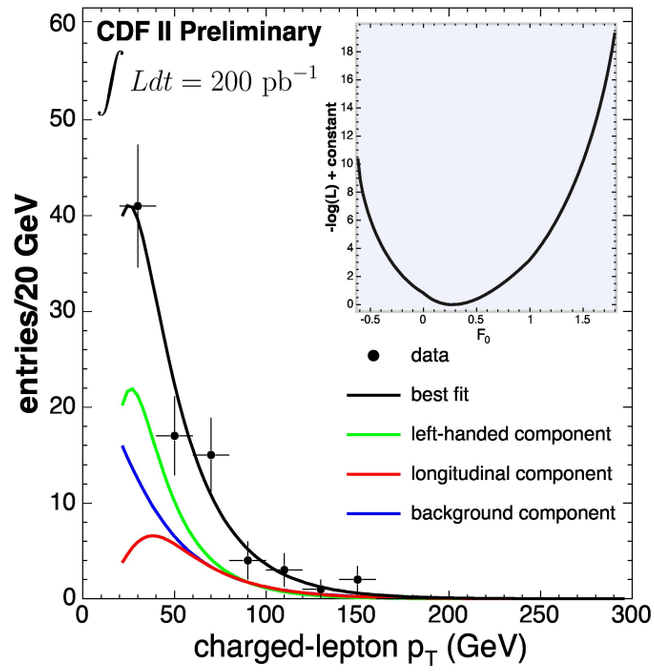
Charged lepton P_T in lab frame: LH softer than RH

W Helicity: Lepton P_T (CDF)

Use well measured lepton Pt (smeared by top P_T)

Expect lepton P_T from long. W harder than from LH W and even harder from RH W





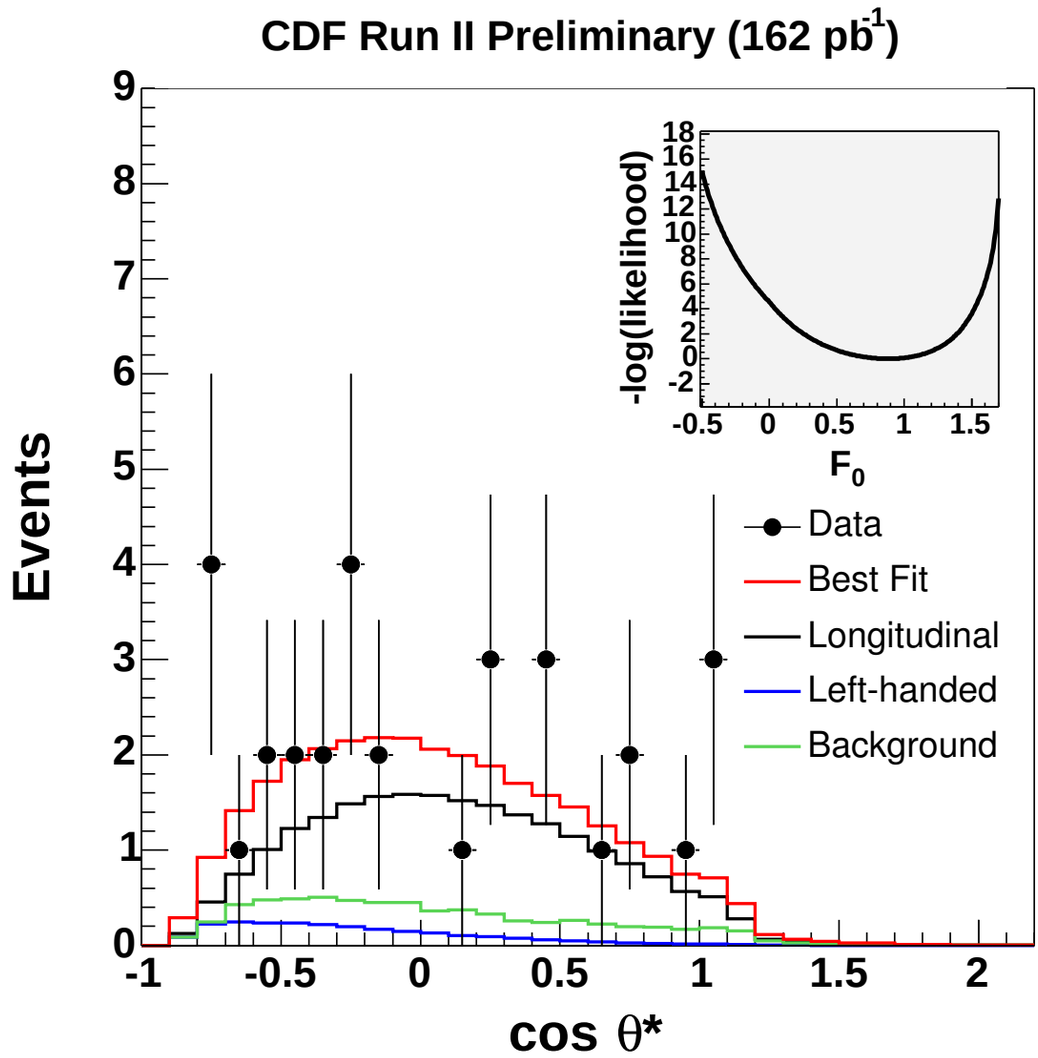
dilepton combined

dilepton	$F_0 < 0.52$ @ 95% CL
lep + jets	$F_0 = 0.88^{+0.12}_{-0.47}$ (stat + syst)
	$F_0 > 0.24$ @ 95% CL
combined	$F_0 = 0.27^{+0.35}_{-0.21}$ (stat + syst)
	$F_0 < 0.88$ @ 95% CL

Look forward to more data in dilepton channel.

W Helicity: cos(θ^*) (CDF)

- Use approximation $\cos\theta^* \approx \frac{2m_{lb}^2}{m_t^2 - M_W^2} - 1$
- Use top mass fitter to choose correct lepton,b jet pair
- Perform binned likelihood fit to 31 events in data

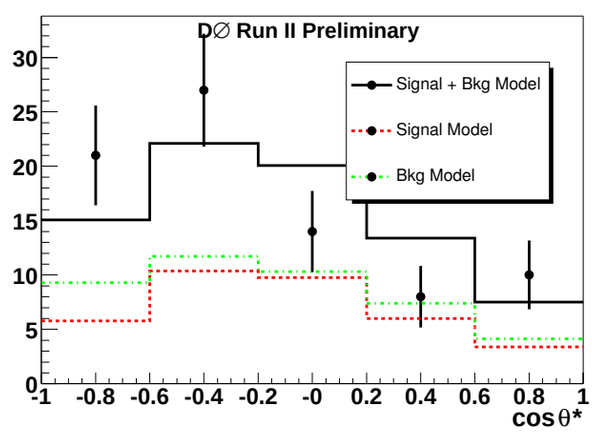


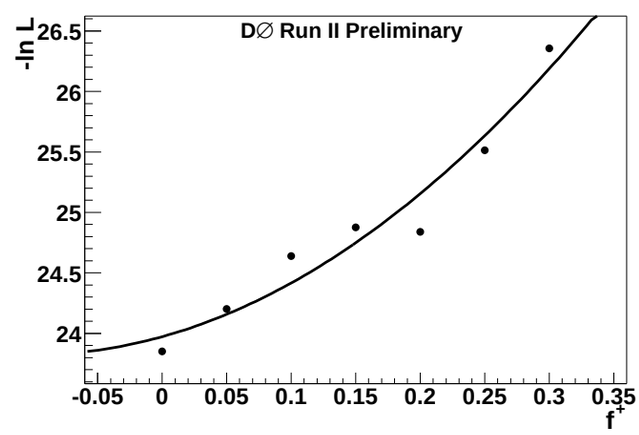
$$F_0 = 0.89^{+0.30}_{-0.34}\ (\text{stat}) \pm 0.17\ (\text{syst})$$

$$F_0 > 0.25\ @\ 95\%\ \text{CL}$$

W Helicity: cos(θ^*) Topological (D0)

- cut on 6-variable topological likelihood
- optimized for F_+ measurement
- perform constrained fit to reconstruct top quark
  $\longrightarrow$ select b-jet associated with leptonic W
  $\longrightarrow$ use returned object momenta to calculate cosθ^*
- binned likelihood fit to extract F_+ from data

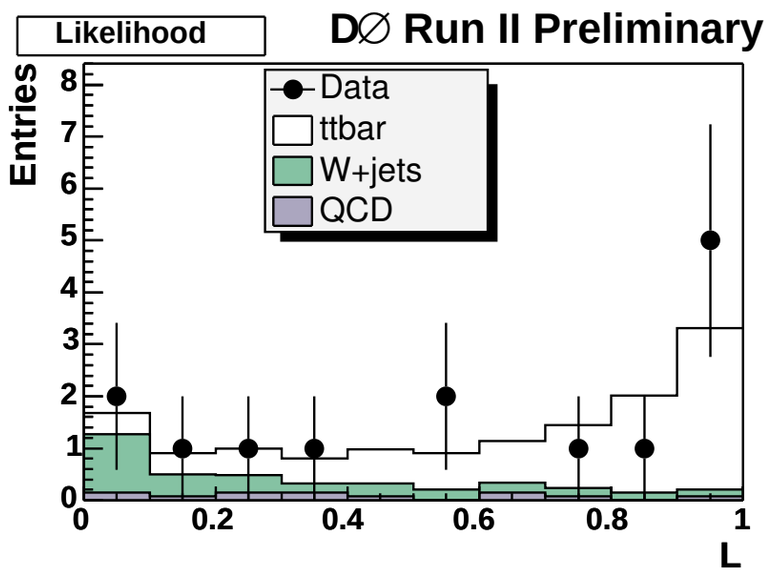


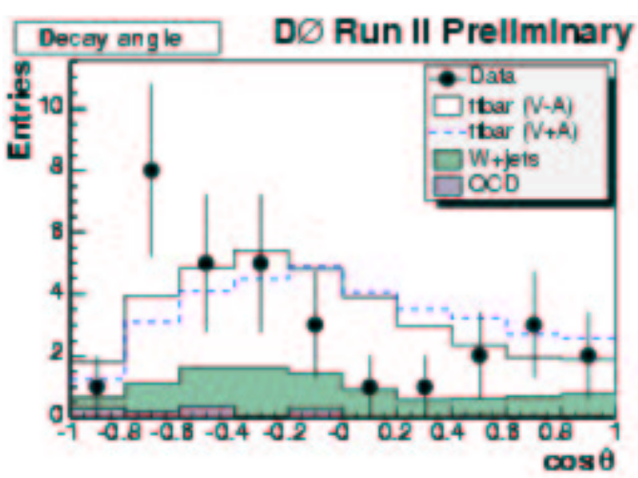


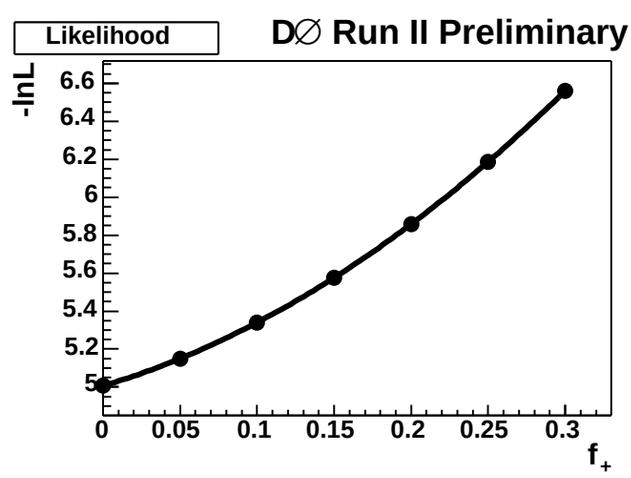
$$F_+ = -0.13 \pm 0.23 \text{ (stat)}$$
$$F_+ < 0.24 \text{ @ } 90\% \text{ CL}$$

W Helicity: $\cos(\theta^*)$ b-tag (D0)

- ≥ 1 b-tagged jet
- use 6-variable topological likelihood to find signal,background fractions







$$F_+ = -0.11 \pm 0.19 \text{ (stat)}$$
$$F_+ < 0.24 \text{ @ } 90\% \text{ CL}$$

Branching Ratios (CDF)

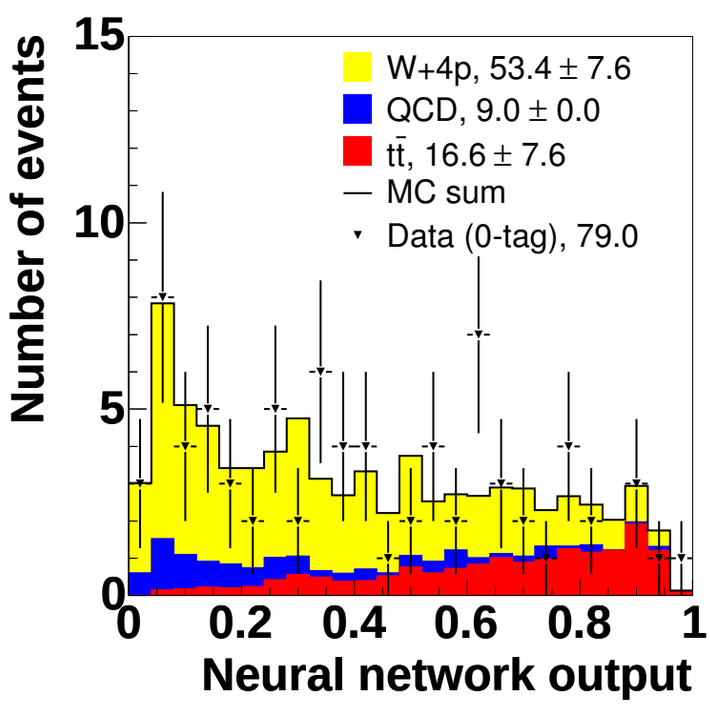
Standard Model: BR($t \to Wb$) $\cong$ 100%

$$\mathrm{R} \equiv \frac{BR(t \to Wb)}{BR(t \to Wq)} \cong 1$$

Measure R in $t\bar{t}$ events by measuring b-tag ratio N_0/N_2 or N_0/N_1 or N_1/N_2

Count number of events with 0, 1, and 2 b-tags in $t\bar{t}$-enriched samples: dilepton, W+3 jets, W+$\geq$ 4 jets

Estimate background as function of number of b-tagged jets (e.g. Neural Network using event kinematics)

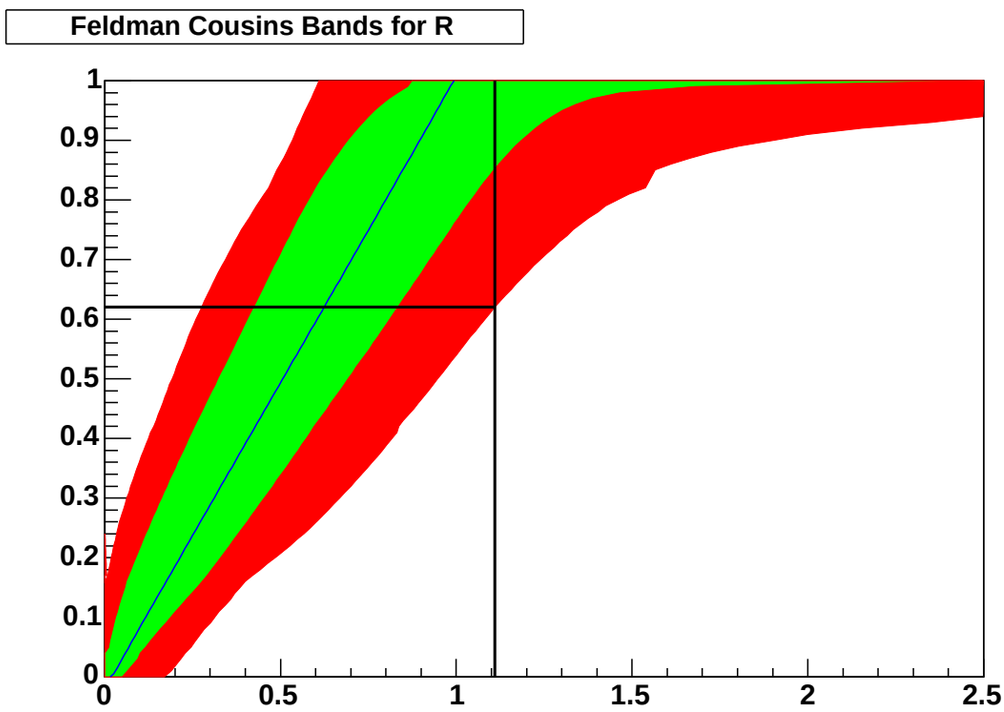


Branching Ratios (CDF)

Compare predicted vs. measured tag rates
as function of R

Form likelihood: find R value most consistent with data

$$R = 1.11^{+0.21}_{-0.19} \text{ (stat+syst)}$$



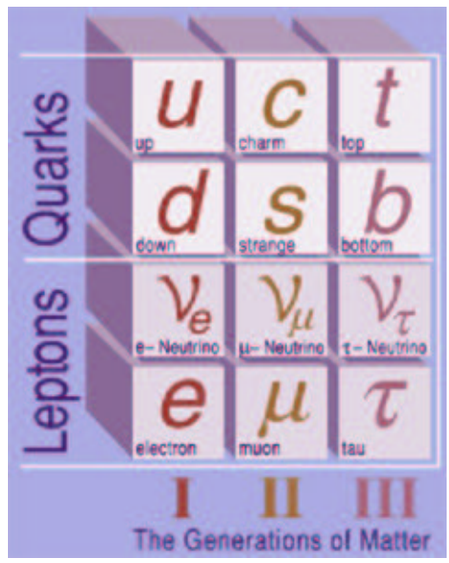
$$R > 0.62 \quad @ \quad 95\% \text{ CL}$$

Strongest constraint on R to date.

BR($t \to \tau\nu b$) (CDF)

Look for anomalous τ lepton rate in top decay.
Run I: hint of excess above SM prediction ($H^{\pm}$?)

$$t\bar{t} \to Wb \;\; Wb \to \tau_{had}\nu_{\tau}b \;\; (e,\mu)\nu_e b$$



Examples of hadronic decay modes of τ

- $\tau^- \to \pi^-\nu_\tau 2\pi^o$
- $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$

Hard to distinguish from light quark jets.

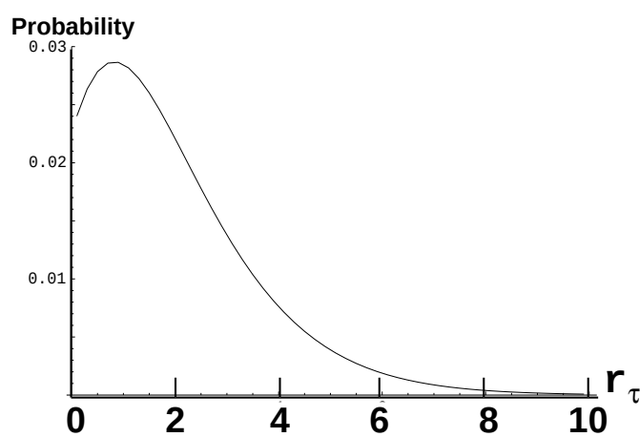
Backgrounds
Taus faked by **jets**, electrons, muons
$\to$ measure rate from independent data samples
Real τs: Z$\to \tau\tau$ + jets
$\to$ Z mass reconstruction cut

$\mathbf{BR}(t \to \tau\nu b)$ **(CDF)**

Sample	electron $+\tau$	muon $+\tau$
Background	$0.77 \pm 0.12 \pm 0.13$	$0.53 \pm 0.0.08 \pm 0.08$
$t\bar{t}$	$0.59 \pm 0.05 \pm 0.10$	$0.44 \pm 0.04 \pm 0.07$
Data	2	0

$$r_\tau \equiv \frac{\mathrm{BR}(t \to b\tau\nu)}{\mathrm{BR}_{\mathrm{SM}}(t \to b\tau\nu)}$$

Expect $r_\tau = 1$ if Standard Model is correct.
Calculate probability distribution $P(N_{\mathrm{obs}} = 2 \,|\, r_\tau)$



$\mathbf{r}_\tau < \mathbf{5.0}$ at 95% CL

$\longrightarrow$ consistent with Standard Model

Summary

Top quark is discovered, its SM properties $\sim$ verified

Time to look at more details,
look for hints of non-SM physics

Run II results

- several different, complementary methods for studying W helicity in top quark decays
- what top decays into

Lots of work done, lots more to-do.

Analyses are statistically limited

$\rightarrow$ **looking forward to more than order of magnitude more data from Tevatron**