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Search for Single Top Quark Production and Measurements of Top Quark Decay Properties at the Tevatron

Aurelio Juste
Fermi National Accelerator Laboratory
On behalf of the CDF and DØ Collaborations

OUTLINE

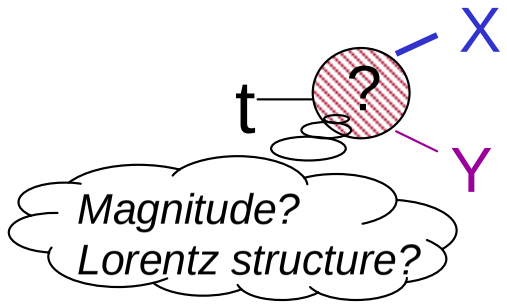
- Introduction
- Search for Single Top Quark Production
- Direct Measurement of B(t→Wb)
- Measurement of W Helicity
- Outlook

Charged Current Top Quark Interactions

- **Large m_t $\Leftrightarrow$ New Physics (EWSB-related)??**

  $\Rightarrow$ interactions between the top quark and weak gauge bosons extremely interesting!!

  $\Rightarrow$ in a hadron collider only the W-t-b vertex can sensitively be probed



In the SM:

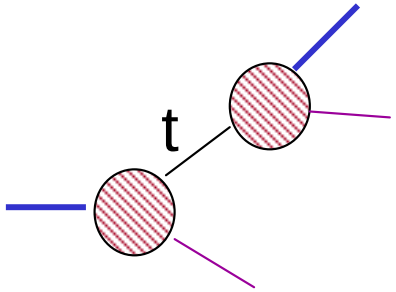
X=W 100% of the time

Y=b ~100% of the time ($|V_{tb}|$~1)

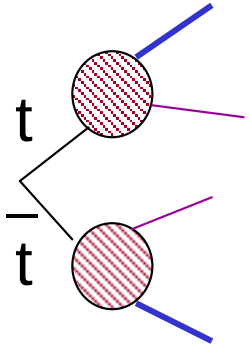
$g_{Wtb} \propto |V_{tb}|$ (V-A)

- Charged current interactions define most of the top quark phenomenology:

Single Top
(Production and Decay)



Top Pair
(Decay)

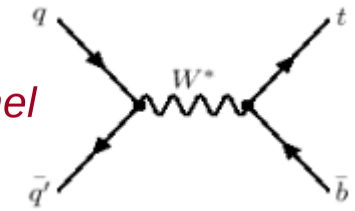


Single top production rate
B(t$\rightarrow$Wb)
$|V_{tb}|$
W helicity
Top polarization
Anomalous couplings
Spin correlations
Rare decays
Top width
…

Overview of Search for Single Top Quark Production

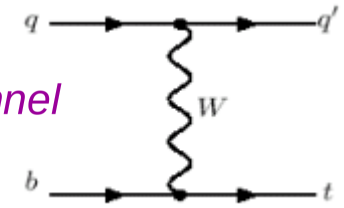
- Main production mechanisms for (SM-like) single top production:

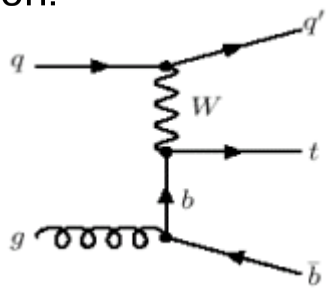
s-channel



σ_s =0.88±0.07 pb

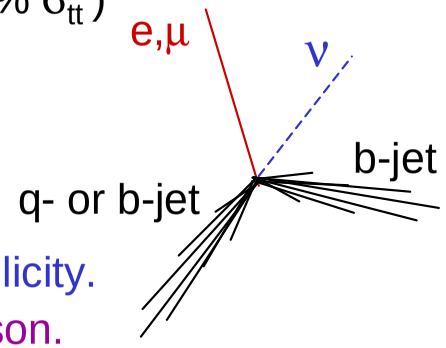
t-channel





σ_t =1.98±0.21 pb

- Not observed yet, despite the expected "large rate" (σ_{s+t} ~ 40% σ_{tt})
  Existing Run I upper limits (@ 95% CL):
  CDF: σ_s < 18 pb, σ_t < 13 pb, σ_{s+t} < 14 pb
  DØ: σ_s < 17 pb, σ_t < 22 pb

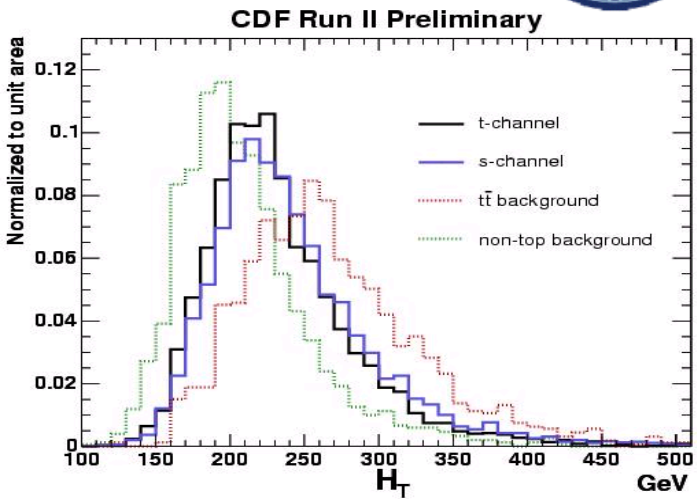


- Experimental signature: similar to tt→l+jets but lower jet multiplicity.
- Backgrounds: W+jets, tt, multijets (misidentified leptons), diboson.
- Experimental strategy:
  - Optimize event preselection to maximize signal acceptance while reducing backgrounds/misreconstructed events as much as possible.
  - B-tagging extremely important.
  - Make use of topological information to further discriminate signal from background.

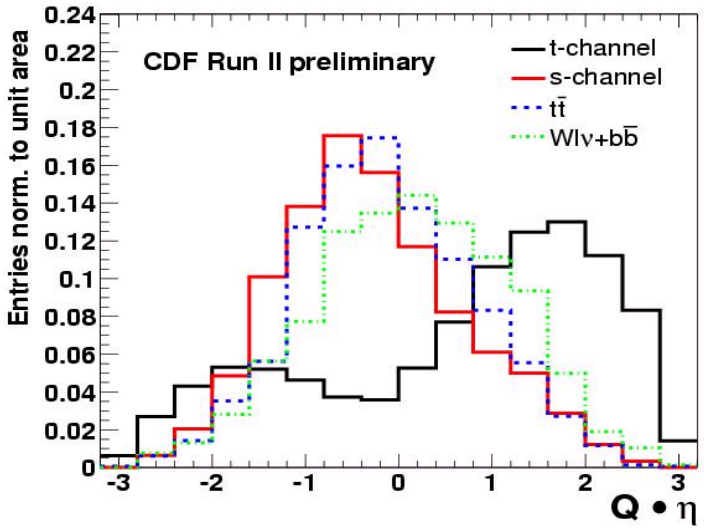
Search for Single Top Quark Production

- Pre-selection:
  - 1 e or μ, p_T>20 GeV, $|\eta_{det}|$<1.1
  - Missing transverse energy (MET)>20 GeV
  - =2 jets, p_T>15 GeV, $|\eta_{det}|$<2.8
  - ≥1 secondary vertex (SVX-)tagged jet

  Topological selection:
  - 140 GeV ≤ M_{lvb} ≤ 210 GeV
  - Leading jet: p_T ≥30 GeV (only t-channel search)
- Good agreement between observation and expectation. L=162 pb^{-1}



	Combined search	*t-channel search*
s-channel	1.19± 0.25	1.16± 0.24
t-channel	2.39± 0.56	2.34± 0.54
tt	3.47± 1.04	3.39± 1.02
non-top	20.7± 4.1	17.4± 3.3
Total expected	27.8± 4.3	24.3± 3.5
Observed	**28**	**25**



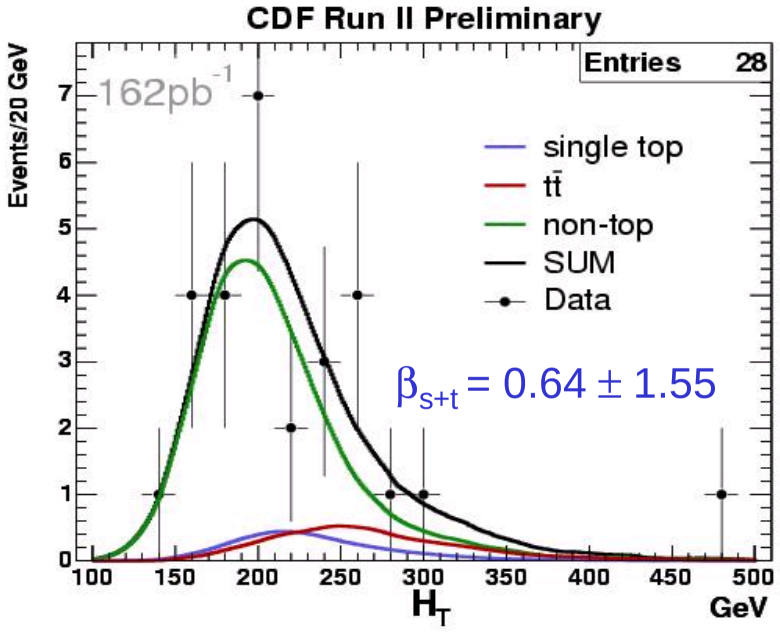
- Consider discriminant variables:
  - Combined (s+t channels) search: H_T = p_T (lepton)+MET+∑ p_T(jet)
  - t-channel search: Q(lepton)•η (untagged jet)

Search for Single Top Quark Production

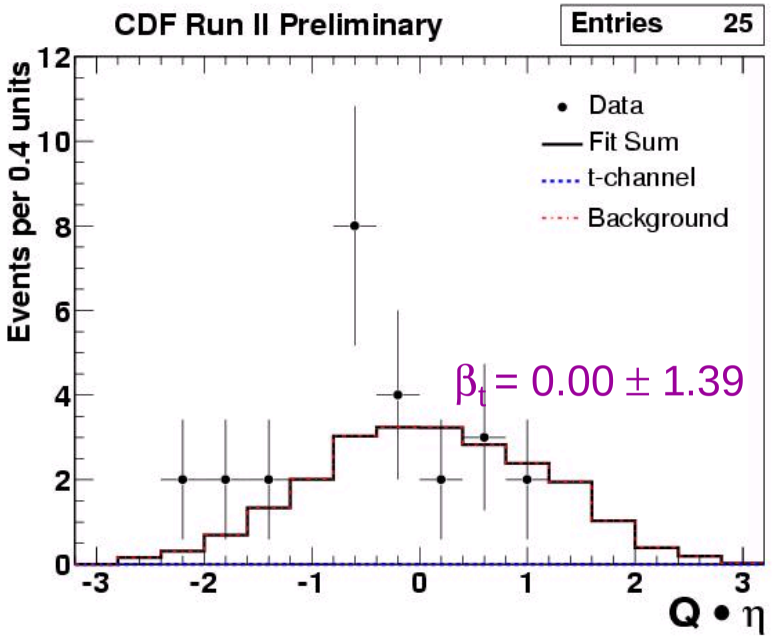
- Maximum likelihood fit to data H_T or $Q \bullet \eta$ distributions using a sum of templates determined from MC: single top (PYTHIA), tt (HERWIG), non-top: Wbb (ALPGEN)
- Background allowed to float but constrained to expectation.
- Fit parameters:

$$\beta_i = \frac{\mu_i}{\mu_i^{SM}} = \frac{\sigma_i}{\sigma_i^{SM}};\ \mathrm{i} = \text{single top}, t\bar{t}, \text{non-top}$$

Combined search



t-channel search



$\Rightarrow$ Fitted signal content compatible with zero.

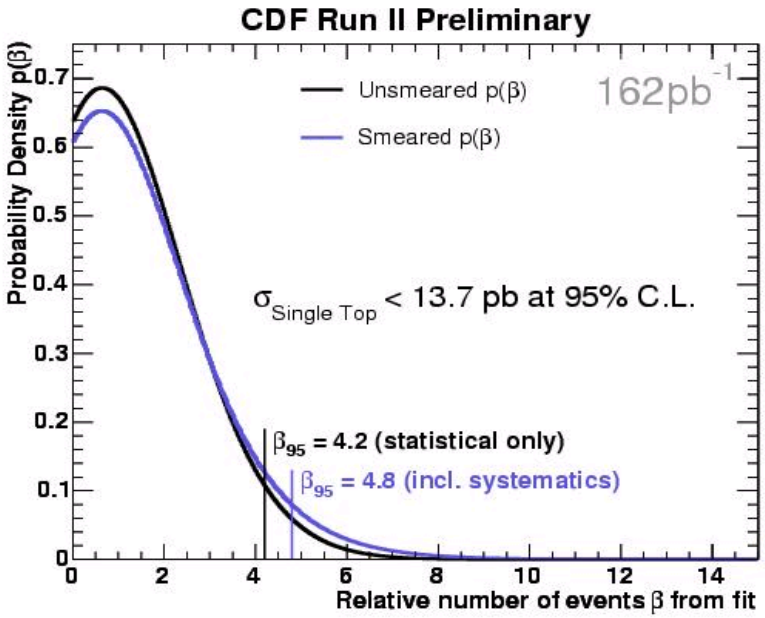
Search for Single Top Quark Production

- Upper limit on cross-section determined from a Bayesian approach.
- Systematic uncertainties included by convolution procedure:

$$\mathbf{L_{sm}}(\beta) = \int_{-\infty}^{+\infty} \mathbf{L}(\beta') \cdot \frac{1}{\sigma(\beta)\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{\beta-\beta'}{\sigma(\beta)}\right)^2\right) \mathbf{d}\beta'$$

Normalization: σ(β)~20%
Shape: σ(β)~22% (combined)
~54% (t-channel)

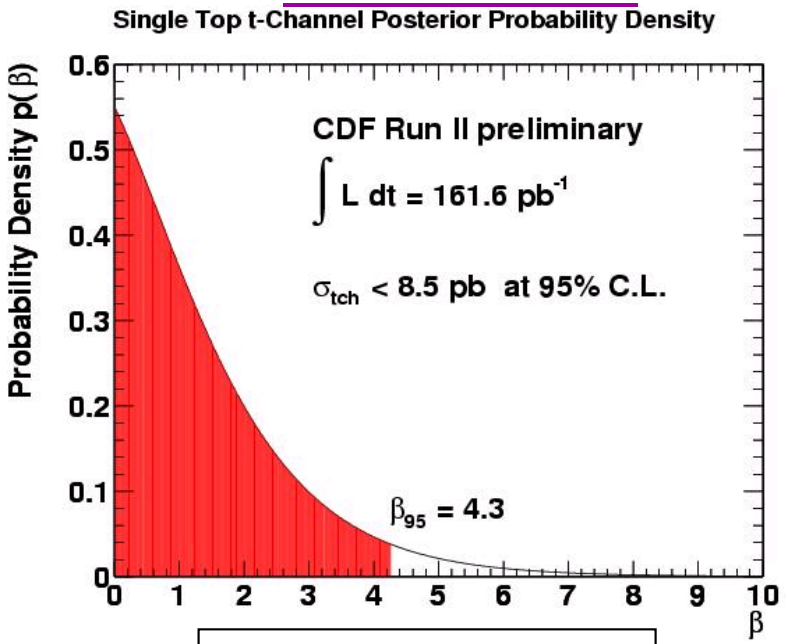
Combined search



$\sigma_{s+t} < 13.7$ pb @ 95% CL

Expected: $\sigma_{s+t} < 14.1$ pb @ 95% CL

t-channel search



$\sigma_t < 8.5$ pb @ 95% CL

$\sigma_t < 11.3$ pb @ 95% CL

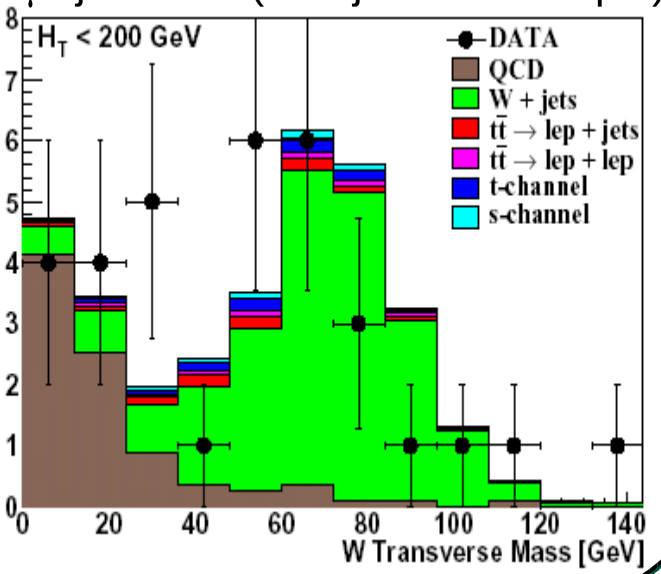
Search for Single Top Quark Production

- Pre-selection:
  - 1 e, p_T>15 GeV, $|\eta_{det}|$<1.1 or 1μ, p_T>15 GeV, $|\eta|$<2.0
  - Missing transverse energy (MET)>15 GeV
  - 2≤# jets≤4 , Leading jet: p_T>25 GeV, $|\eta_{det}|$<2.5
    Additional jets: p_T >15 GeV, $|\eta_{det}|$<3.4
  - ≥1 b-tagged jet. Consider 2 classes of tagging algorithms:
    → lifetime-based: secondary vertex (SVT) and jet lifetime probability (JLIP) tag } ⇒ Stringent cross-check!!
    → semileptonic decay-based: soft-μ (SLT) tag

  No topological selection applied yet ⇒ large room for improvement!!!
- Four orthogonal analysis channels:

  e+jets: SVT,JLIP SLT
  μ+jets: SVT SLT
- Single top signal: modeled using *SingleTop* MC (based on CompHEP)
  ⇒ reproduces NLO distributions.
- Background estimates:
  - Multijets: from data
  - W+jets: from data using measured inclusive tag rate functions on a multijets sample.
  - tt: from ALPGEN MC

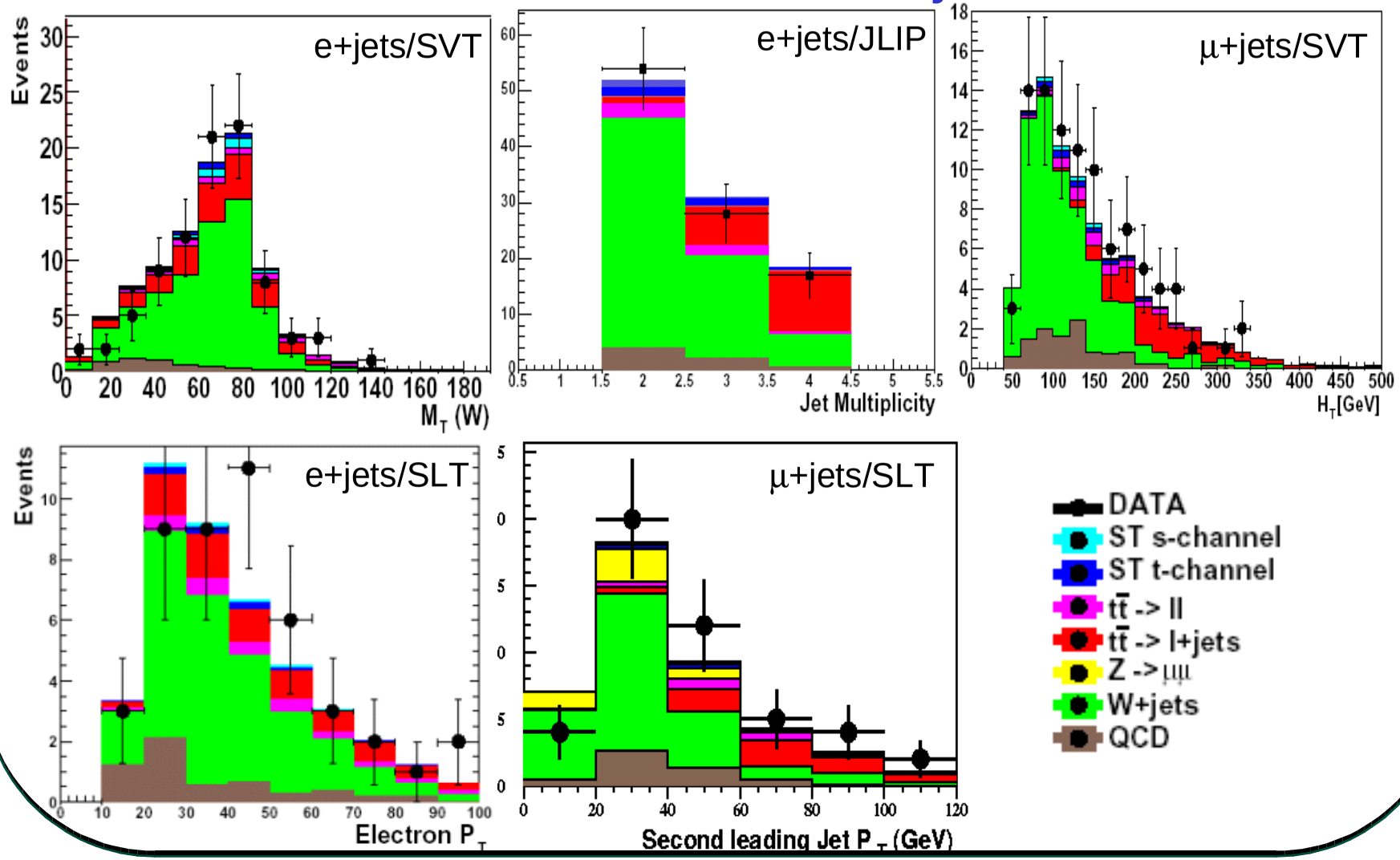
μ+jets/SVT (W+2j control sample)



Search for Single Top Quark Production

- Good agreement between expectation and observation:

DØ Run II Preliminary



Search for Single Top Quark Production

L=164 pb^{-1}

	e+jets			μ+jets	
	SLT	*SVT*	*JLIP*	*SLT*	*SVT*
s-channel	0.67± 0.14	1.87± 0.46	1.88± 0.46	0.63± 0.13	1.38± 0.35
t-channel	0.95± 0.20	3.14± 0.76	3.20± 0.82	0.88± 0.19	2.19± 0.56
tt	9.60± 1.65	23.31± 4.90	24.50± 5.48	8.43± 1.44	18.57± 3.75
non-top	31.1± 5.2	63.5± 12.3	71.7± 13.7	34.3± 5.1	67.0± 11.8
Total expected	42.4± 5.4	91.9± 13.3	96.3± 14.8	44.2± 5.3	89.2± 12.4
Observed	**49**	**88**	**99**	**48**	**94**

- Upper limit on cross-section determined from Modified Frequentist (CL_s) method.
- Expected cross-section limits @ 95% CL from combination of e+jets and μ+jets for SVT and SLT analysis channels:

	Without Systematics	***With Systematics***
σ_s *(pb)*	<6.4	**<13.8**
σ_t *(pb)*	<9.0	**<19.8**
σ_{s+t} *(pb)*	<7.9	**<15.8**

Sensitivity already better than Run I but…
this is just half of the analysis!!

Stay tuned!

⇒ Significantly increased statistical sensitivity expected from use of topological information.

⇒ The (conservative) systematic uncertainties assumed have a large impact mainly due to the (temporary) low sample purity.

Direct Measurement of B(t→Wb)

- Allows to directly test the SM prediction of B(t→Wb)~1.
- Split preselected lepton+jet sample in 4 separate subsamples:

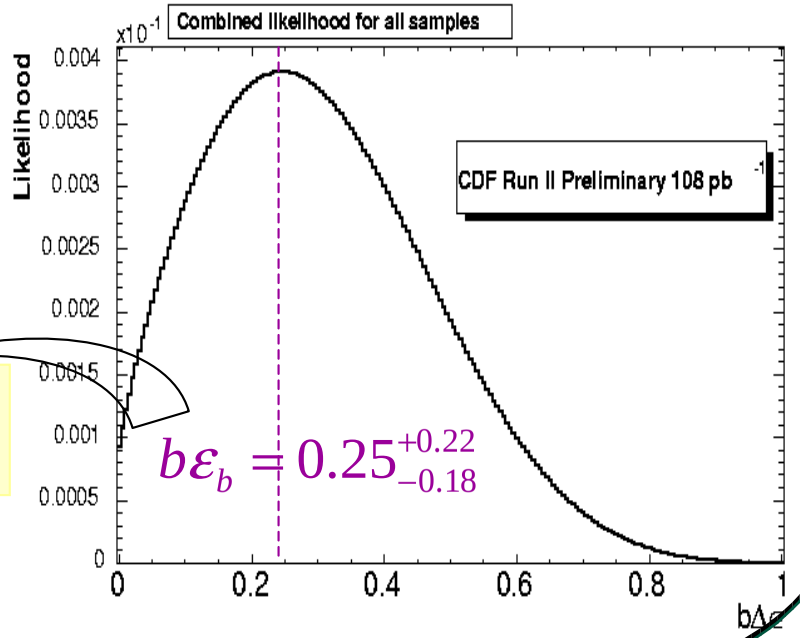
- Compute event tagging probability for each of the subsamples as a function of $b\varepsilon_b$, with b=B(t→Wb) and ε_b = efficiency to tag a b-jet from ttbar.
- Perform likelihood fit to the 4 subsamples simultaneously to determine the value of $b\varepsilon_b$ most consistent with the observation.
  (Total number of tt also fitted)
- Dataset: ~108 pb^{-1}

	3-jet	*≥4-jet*
1-tag	12	19
2-tag	2	2

- Result:

Assuming ε_b=(45.5±4.5)% as measured in calibration samples

$$B(t \to Wb) = 0.54^{+0.49}_{-0.39}$$



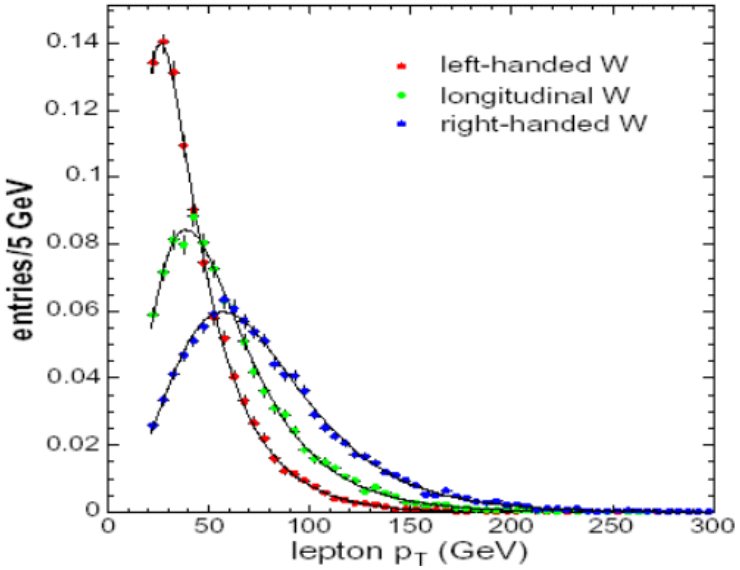
Overview of Measurement of W Helicity

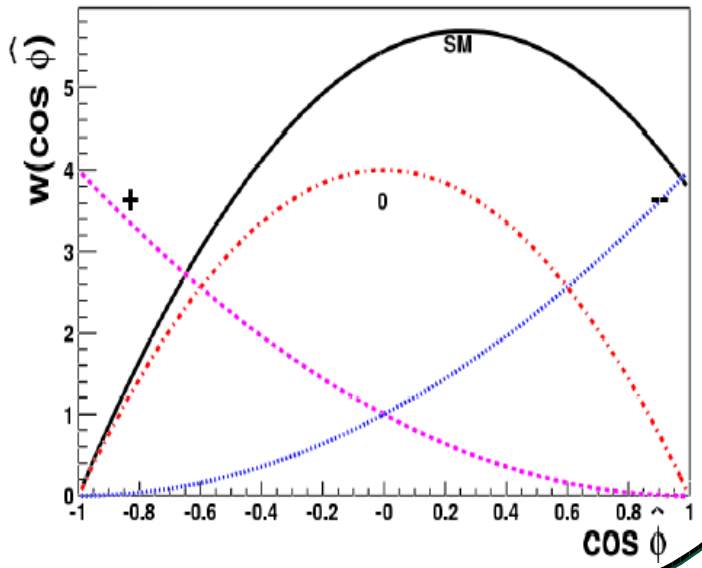
- Within the SM, only two W helicity configurations allowed:
  - Longitudinal: $F_0 \sim 70\%$
  - Left-handed: $F_- \sim 30\%$

- Lepton kinematical distributions rather sensitive to W helicity:
  - p_T distribution in LAB frame
    $\Rightarrow$ final states: lepton+jets, dileptons.
  - ϕ(lepton,b) distribution in W rest frame
    $\Rightarrow$ explicit top reconstruction needed;
    $\Rightarrow$ final states: lepton+jets only

- B-tagging useful in lepton+jets channel to increase signal purity and reduce combinatorial background.

- Previous Run I results (CDF):
  $F_0 = 0.91 \pm 0.37(\text{stat}) \pm 0.13\ (\text{syst})$
  $F_+ = 0.11 \pm 0.15(\text{stat})$





Measurement of W Helicity

- Sophisticated approach developed for measurement of top quark properties with maximal use of statistical information.

  First application ⇒ world's most precise single measurement of the top quark mass!!
- Likelihood fit based on event-by-event 12-fold probability density including:
  - signal (tt) and background (W+4j) contributions based on LO matrix elements,
  - resolution effects,
  - optimal treatment of combinatorial background.

- Dataset: 125 pb^{-1} (collected in Run I)

  Lepton+jets final state (untagged analysis)

Cuts	#Events	S/B
Preselection (*)	91	~1/2
+ =4 jets	71	
+ $P_{bckg}<10^{-11}$	22	~1/1

  (*) PRD 58 (1998), 052001

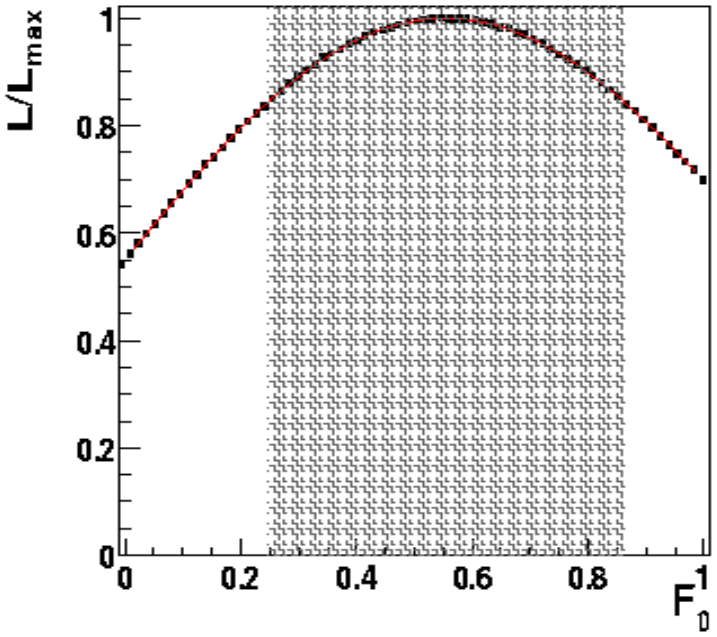
- Result (to be submitted to Phys. Rev. Lett.):

$F_0 = 0.56 \pm 0.31(stat+m_t) \pm 0.07\ (syst)$

Statistics limited (only 22 events!).

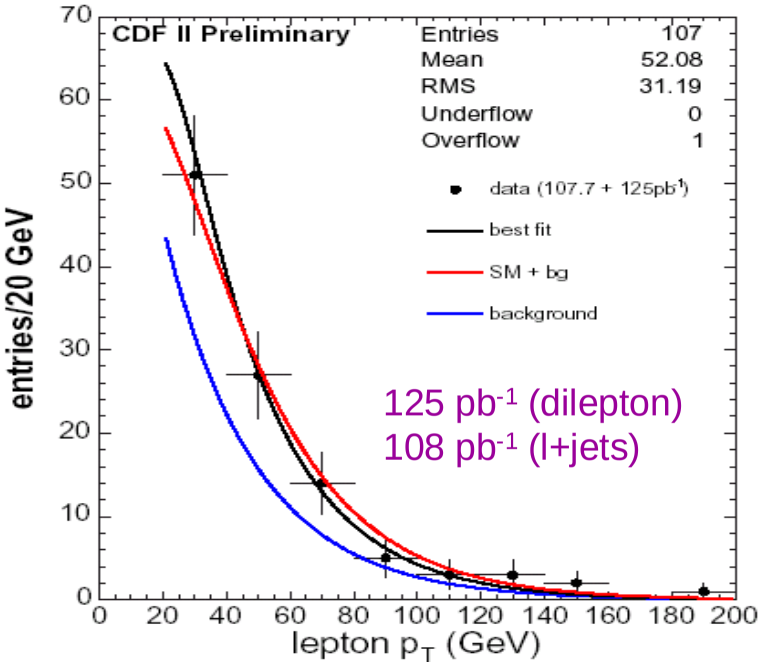
⇒ Large potential with anticipated high statistics Run II datasets.

DØ Preliminary



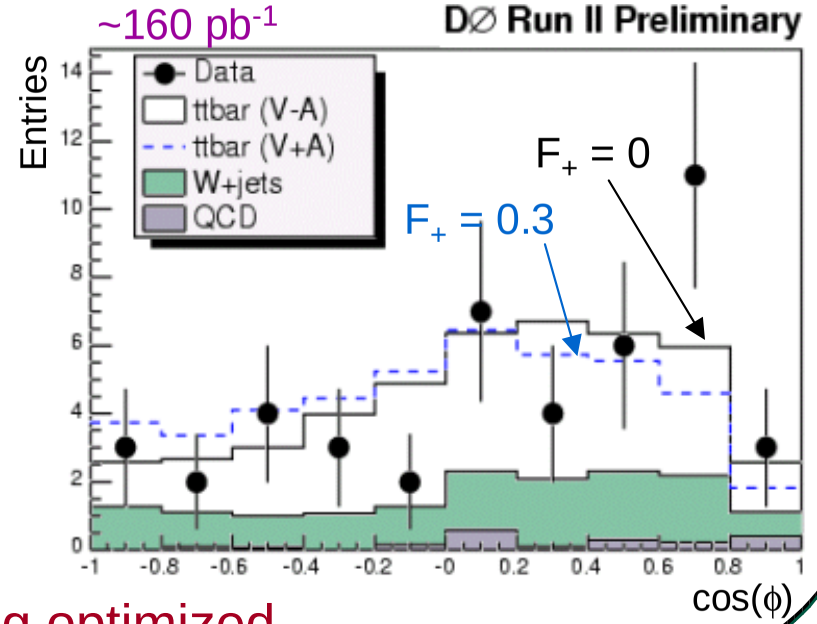
Ongoing Run II W Helicity Analyses

- Consider lepton p_T spectrum.
  Build templates from ttbar HERWIG MC for 3 different W helicity configurations.
- Simultaneous likelihood fit to various channels: lepton+jets (w/ and w/o b-tag) and dilepton.



- Expected sensitivity: $\Delta F_0 \sim 0.47$

- Consider lepton+ ≥4 jets channel with b-tagging (untagged analysis also underway) and event kinematic fitting.
- Data fitted to MC templates in cos(ϕ) distribution corresponding to different values of F_+ (assume F_o SM-like)
- Simultaneous determination of F_+ and signal and background fractions (constrained by a topological likelihood).



Analyses being optimized

Outlook

- Precise measurements of top quark interactions may open a window to New Physics near the EW scale.
- The Tevatron collider experiments, CDF and DØ, are in an unique position to provide incisive tests of the SM in the top quark sector:
  - high performance detectors optimized for this task;
  - large data samples expected in the near future (~0.5 fb^{-1} available for analysis by end of '04).
- The analyses overviewed in this talk are only an example of the extensive menu which will be presented at upcoming conferences:

Stay tuned!!

Single top
B(tà Wb)
$|V_{tb}|$
W helicity
Top polarization
Anomalous couplings
Spin correlations
Rare decays
Top width
…