Top Quark Production and Properties at the Tevatron (Excluding Top Mass)

Frank Fiedler, LMU München

on behalf of the CDF and DØ Collaborations

Les Rencontres de Physique de la Vallée d'Aoste,
27. 2. - 5. 3. 2005

Overview:

- Introduction: top quarks at the Tevatron
- The total $t\bar{t}$ production cross-section
- Further $t\bar{t}$ measurements
- Single top quark production
- Conclusions

many Tevatron Run II results are preliminary!
updates imminent for most of the measurements!

Why Study the Top Quark?

Its mass makes the top quark special among the fermions

- see George Velev's talk on top mass measurements

Questions to ask the top quark:

"Do you really behave (only) like the Standard Model top quark?"

"If so, what can you tell us about the Standard Model?"

Obtaining answers:

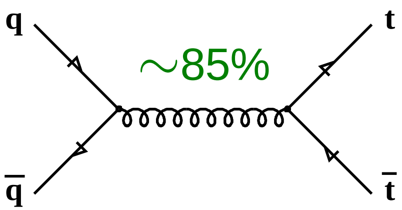
Tevatron experiments CDF & DØ: currently the only experiments where the top quark can be studied

- total $\mathrm{t\bar{t}}$ production cross-section ($\rightarrow$ test perturbative QCD $\rightarrow$ new physics?)
- differential cross-sections, top quark properties, decay branching ratios, ...
  ($\rightarrow$ new physics in $\mathrm{t\bar{t}}$ production / top decay?)
- single top production ($\rightarrow$ V_{tb} / new physics)

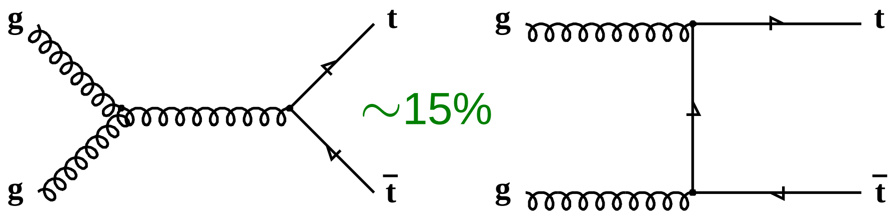
Standard Model Top Production at the Tevatron

top pair production (strong interaction)

Feynman diagrams (LO):



$\sim$85%

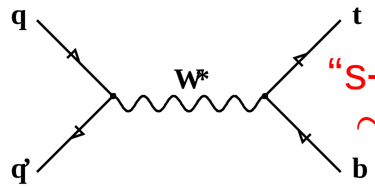


$\sim$15%

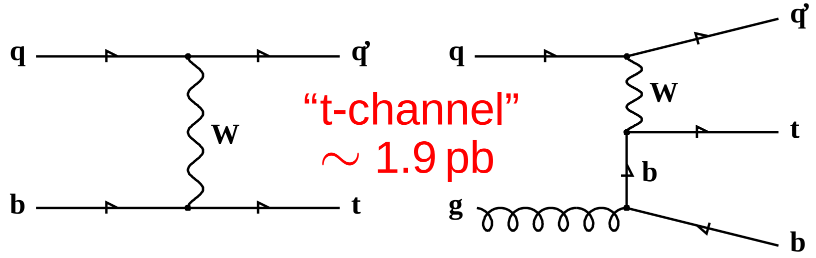
$$\sigma \sim 6\,\mathrm{pb}$$

single top quark production (electroweak interaction)

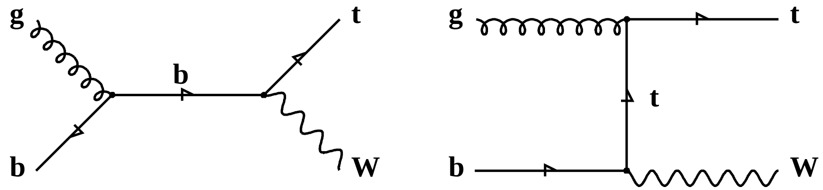
Feynman diagrams (LO):



"s-channel"
$\sim$ 0.9 pb



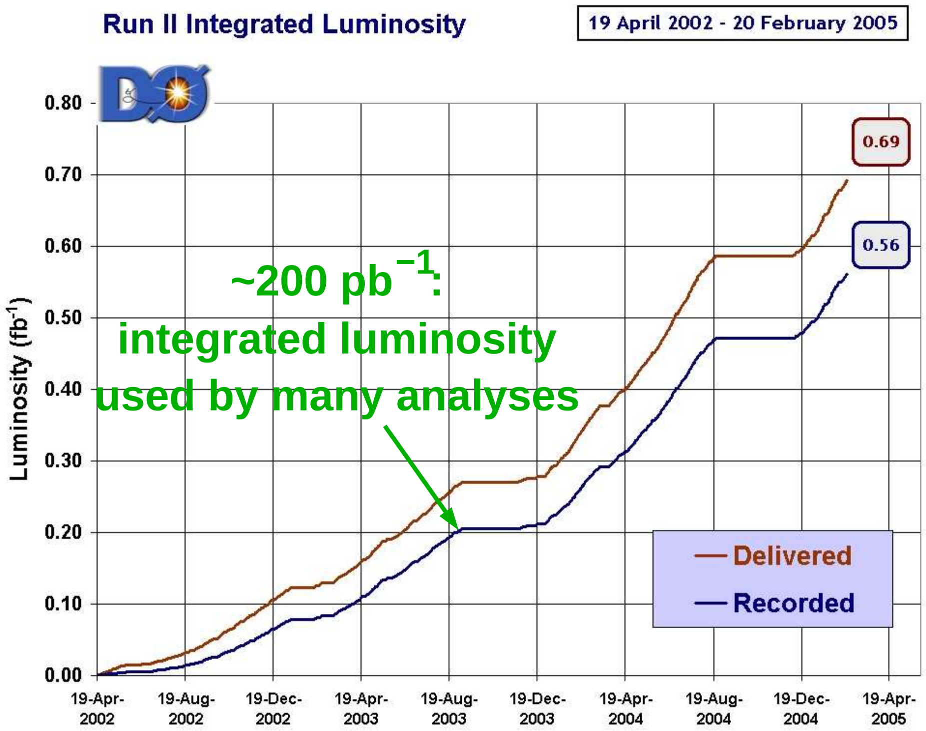
"t-channel"
$\sim$ 1.9 pb



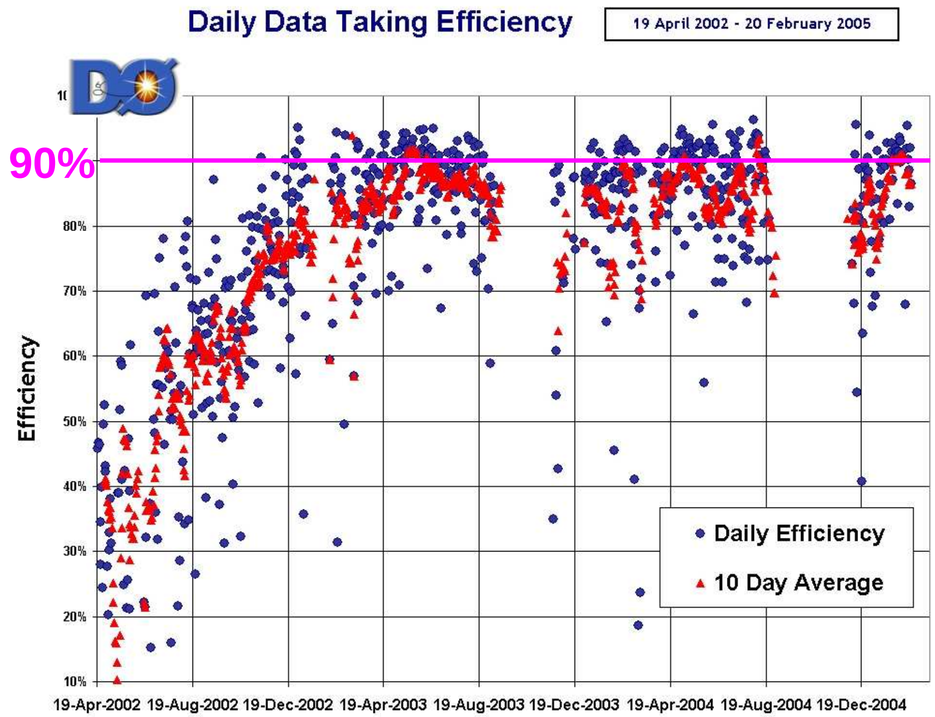
t+W associated production
$\sim$ 0.12 pb

Tevatron Data Taking Performance

Tevatron performance



DØ data taking efficiency

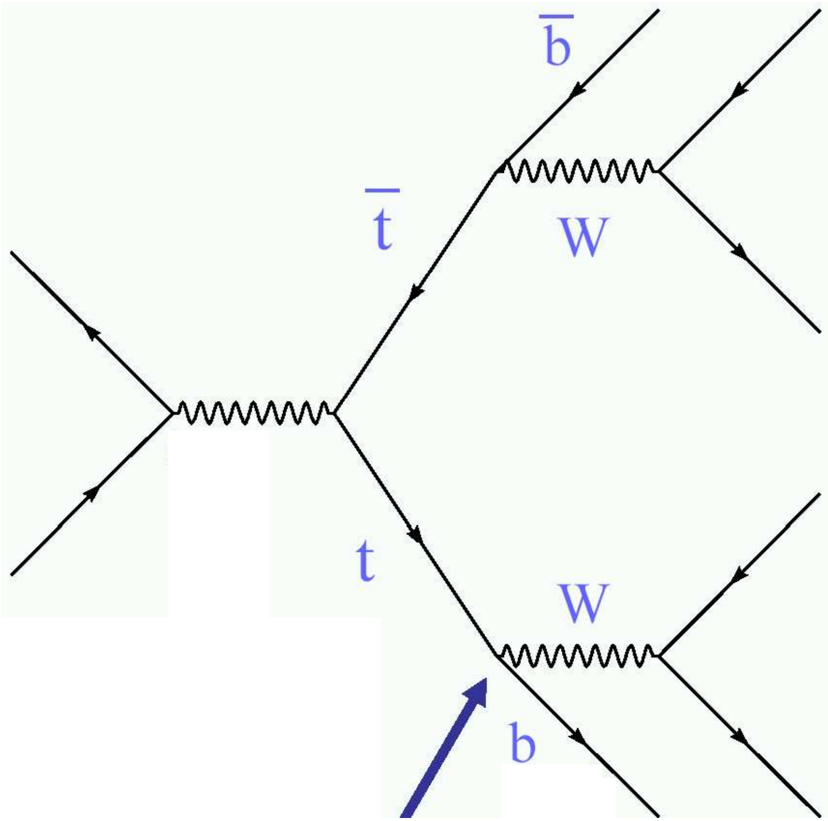


$\Rightarrow$ similar numbers for CDF

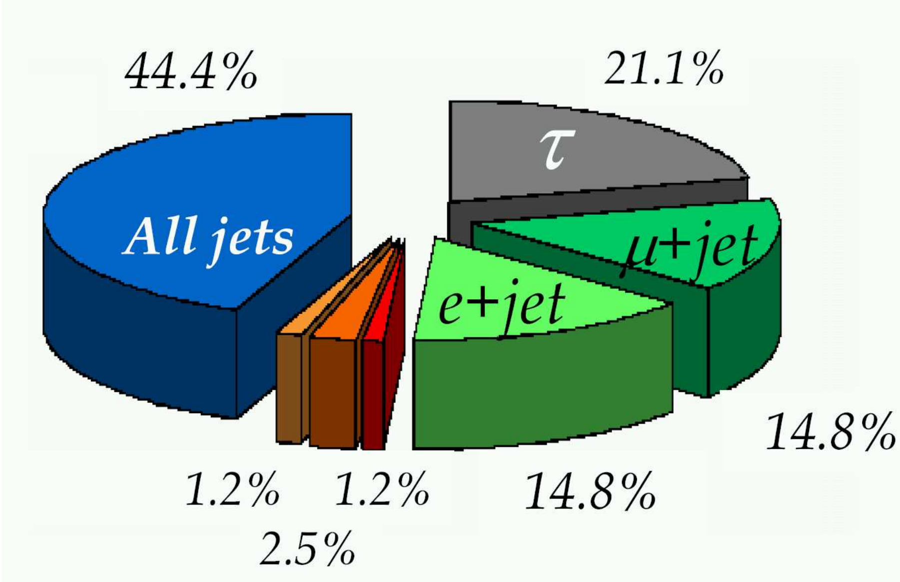
$\Rightarrow$ already surpass Run I integrated luminosity by a factor >5

$\Rightarrow$ physics analyses typically use $\leq 200\,\mathrm{pb}^{-1}$ so far

$t\bar{t}$ Event Topologies (I)



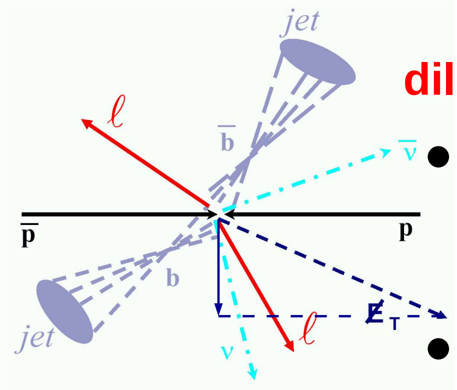
$|V_{tb}| >> |V_{ts}|, |V_{td}|$
$\Rightarrow \mathrm{Br}(t \rightarrow Wb) \sim 100\%$



topology determined by W decays:

- 5% dilepton events
- 30% lepton+jets events
- 44% hadronic events
- 21% events with τ leptons

$t\bar{t}$ Event Topologies (II)

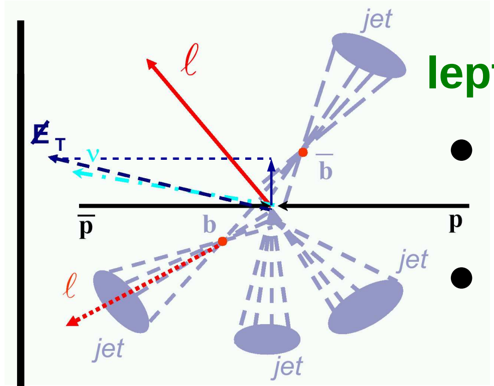


dilepton events: 5%

- 2 energetic, isolated leptons of opposite charge
- 2 energetic b jets
- missing transverse energy

- lepton(+jets) trigger

⟶ small but pure sample



lepton+jets events: 30%

- 1 energetic, isolated lepton
- 4 energetic jets (of which 2 b jets)
- missing transverse energy

- lepton(+jets) trigger

⟶ large event sample, still good purity

hadronic events: 44%

- 6 energetic jets (of which 2 b jets)
- event balanced in transverse plane
- only jet based triggers

⟶ large background (⇒b identification!)

events with τ leptons: 21%

- additional neutrino(s) from τ decay
- challenging to reconstruct

⟶ interesting for new physics searches (e. g. $t \to H^+ b$)

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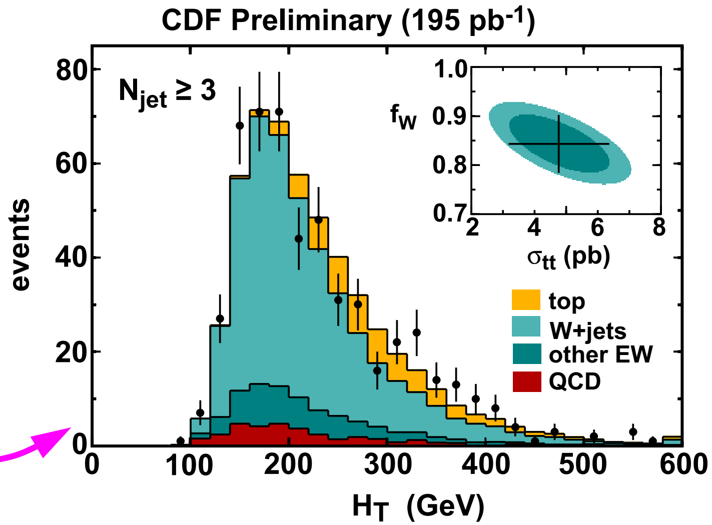
updates imminent for most of the measurements!

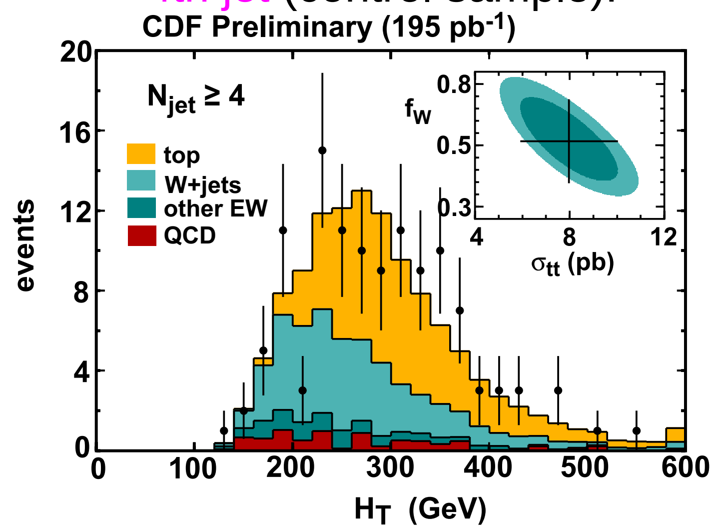
Lepton+Jets, CDF Topological Analyses (I)

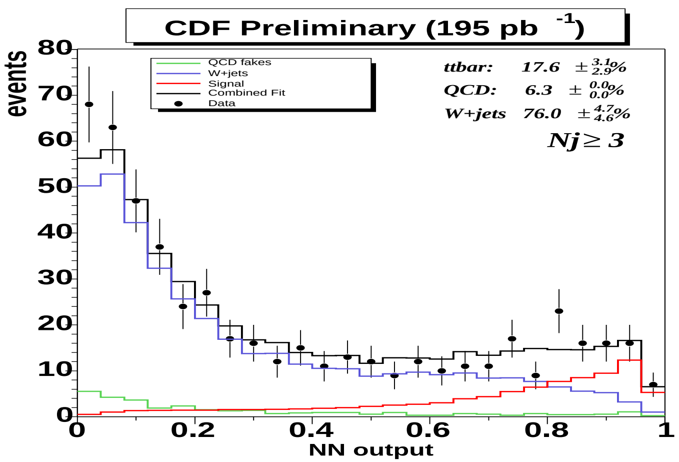
Event selection:

- 1 lepton ($p_T > 20\,\mathrm{GeV}$),
- $\not{E}_T > 20\,\mathrm{GeV}$,
- $\geq$3 jets ($E_T > 15\,\mathrm{GeV}$, $|\eta| < 2.0$)



+ 4th jet (control sample):





H_T distribution, $\geq$3 jets:

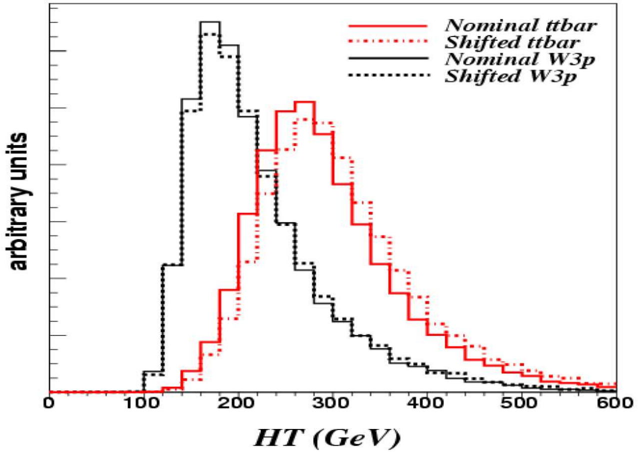
$$\sigma(t\bar{t}) = (4.7 \pm 1.6 \pm 1.8)\,\mathrm{pb}$$

NN output distribution, $\geq$3 jets:

$$\sigma(t\bar{t}) = (6.7 \pm 1.1 \pm 1.6)\,\mathrm{pb}$$

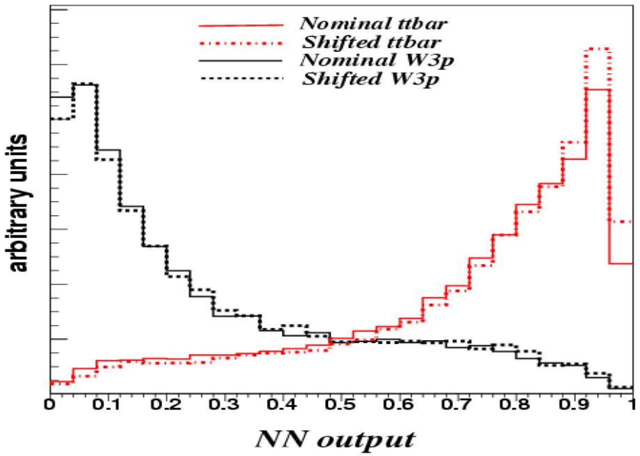
Lepton+Jets, CDF Topological Analyses (II)

- neural network inputs chosen to optimise total error
- both analyses: main systematic error from **jet energy scale**



analysis using H_T distribution only:

jet energy scale:	$\pm 30\%$
total systematic error:	$\pm 39\%$
statistical error:	$\pm 34\%$



optimised analysis using neural network:

jet energy scale:	$\pm 16\%$
total systematic error:	$\pm 22\%$
statistical error:	$\pm 16\%$

Lepton+Jets, DØ Topological Analysis (I)

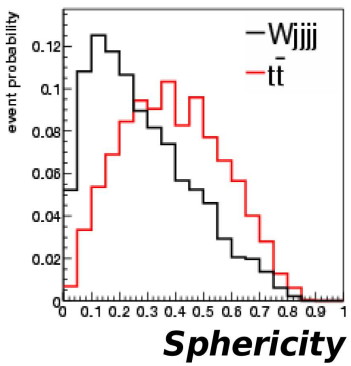
Event selection:

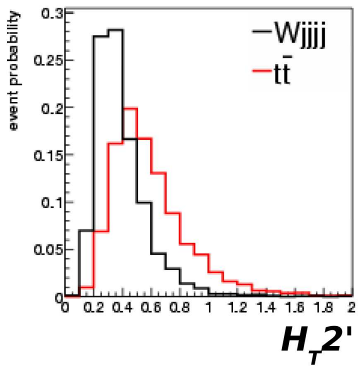
- 1 isolated energetic lepton ($p_T > 20$ GeV)
- missing transverse energy ($\not{E}_T(e\text{+jets}) > 20$ GeV,
  $\not{E}_T(\mu\text{+jets}) > 17$ GeV)
- at least 4 jets ($E_T > 15$ GeV, $|\eta| < 2.5$)

Determination of the $t\bar{t}$ content:

- avoid dependence on absolute energy scale for first analysis

$\longrightarrow$ construct a likelihood discriminant using angular variables and ratios of energy dependent variables, like:



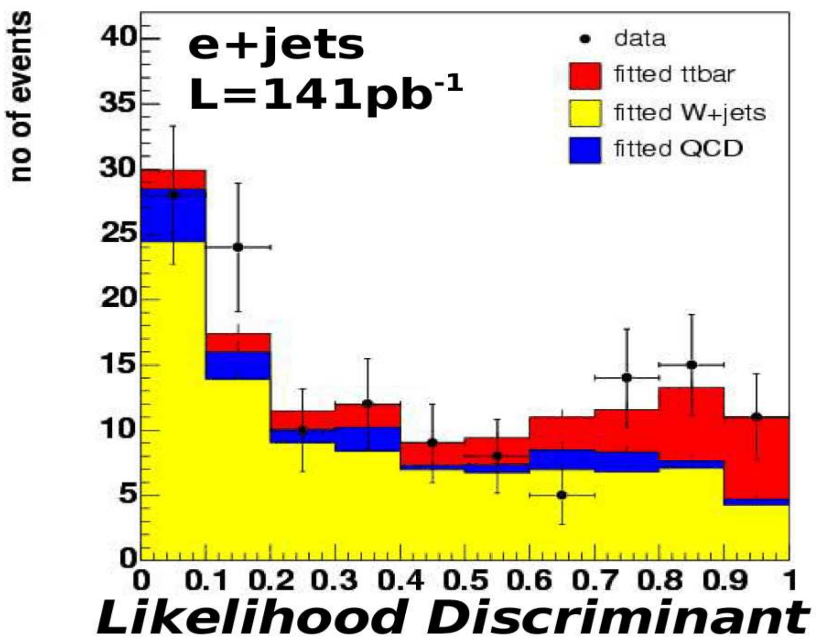


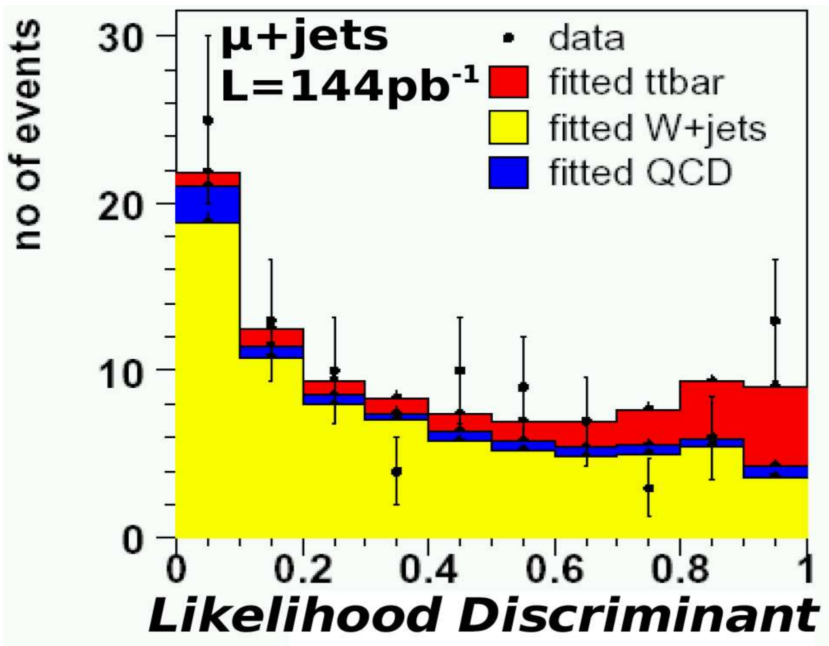
sphericity: $\mathcal{S} = 3/2(\lambda_2 + \lambda_3)$
λ_i: eigenvalues of normalised momentum tensor
dijet event $\rightarrow S \sim 0$, isotropic event $\rightarrow S \sim 1$

$\boldsymbol{H'_{T2} = H_{T2}/H_z}$: measures event centrality
H_{T2}: scalar jet p_T sum, excluding leading jet
H_z: scalar $|p_z|$ sum of jets, lepton, and neutrino

Lepton+Jets, DØ Topological Analysis (II)

Likelihood distributions (separately for e+jets and μ+jets events):





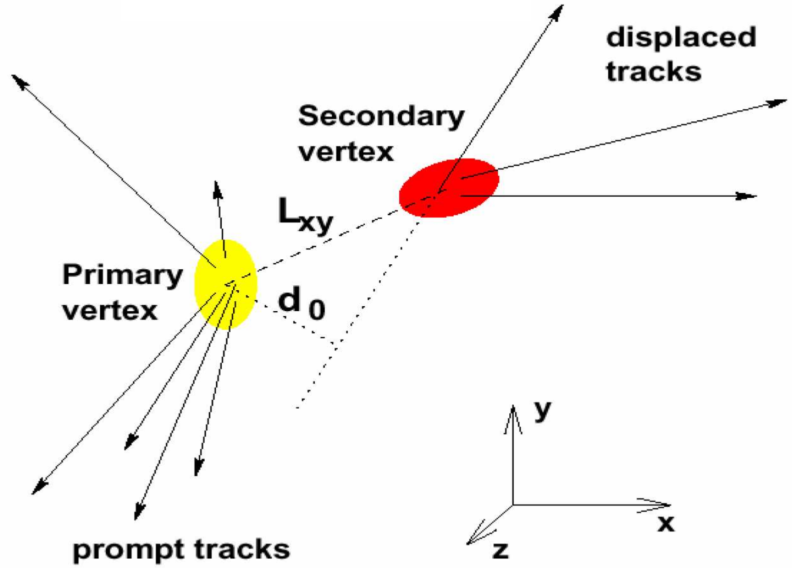
Result (combined):

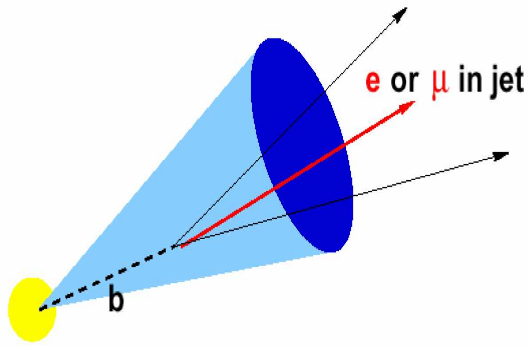
$$\sigma(t\bar{t}) = (7.2^{+2.6}_{-2.4}(\mathrm{stat})\ ^{+1.6}_{-1.7}(\mathrm{syst}) \pm 0.5(\mathrm{lumi}))\ \mathrm{pb}$$

B Tagging

- every $t\bar{t}$ event contains 2 b-jets ($Br(t \to Wb) \approx 100\%$ in the SM)

$\longrightarrow$ improve signal/background ratio by b-tagging:





- tracks with large impact parameter
- secondary vertices

example: DØ event tagging probabilities:
$\varepsilon(t\bar{t}) \sim 60\,\%$, $\varepsilon(W\text{+jets}) \sim 4\,\%$
(events with $\geq$4 jets, $\geq$1 tag)

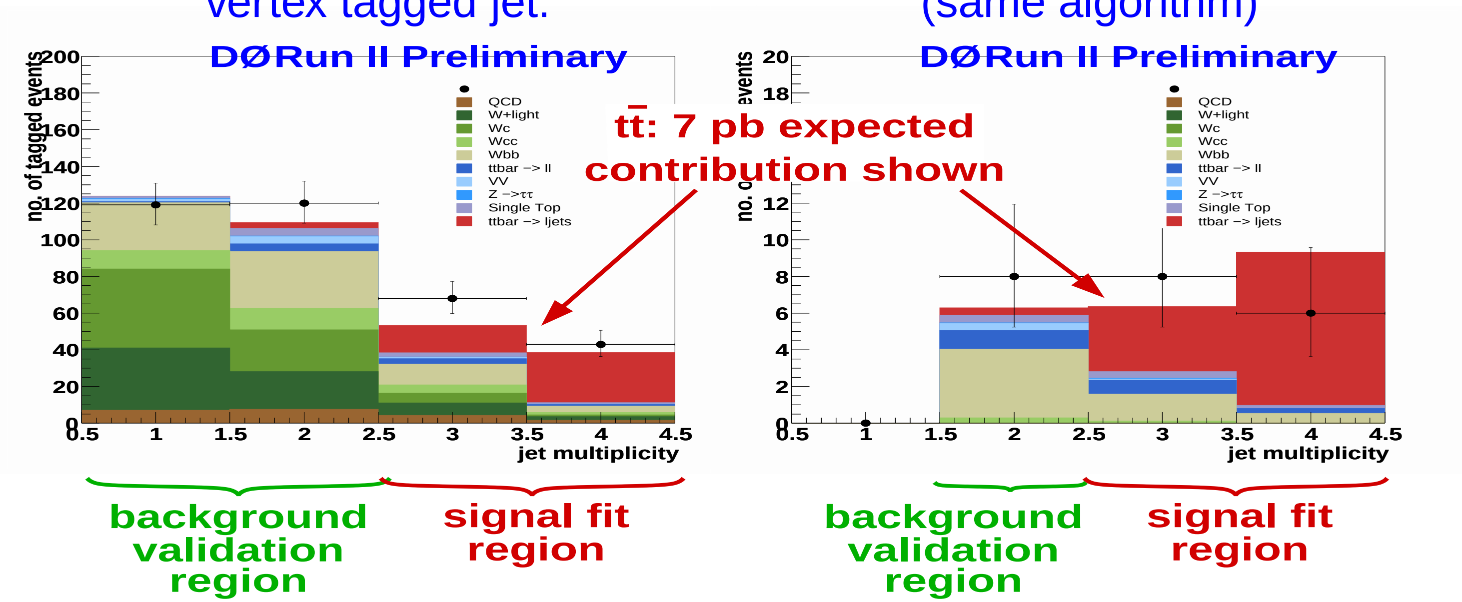
- soft leptons (muons) from semileptonic decays

example: CDF event tagging probabilities:
$\varepsilon(t\bar{t}) \sim 16\,\%$, $\varepsilon(W\text{+jets}) \sim 3\,\%$
(events with $\geq$3 jets, $\geq$1 tag)

Lepton+Jets, DØ B-Tagging Analyses

- Select events with 1 lepton ($p_T > 20\,\mathrm{GeV}$), missing E_T ($\not{E}_T(e\text{+jets}) > 20\,\mathrm{GeV}$, $\not{E}_T(\mu\text{+jets}) > 17\,\mathrm{GeV}$), n jets ($E_T > 15\,\mathrm{GeV}$), and ...

exactly one secondary vertex tagged jet: | $\geq$2 tagged jets (same algorithm)



secondary vertex b tagging (158–$169\,\mathrm{pb}^{-1}$):

$$\boldsymbol{\sigma(t\bar{t}) = (8.2 \pm 1.3^{+1.9}_{-1.6} \pm 0.5)\,\mathrm{pb}}$$

impact parameter b tagging, similar analysis (158–$169\,\mathrm{pb}^{-1}$):

$$\boldsymbol{\sigma(t\bar{t}) = (7.2^{+1.3}_{-1.2}\,{}^{+1.9}_{-1.4} \pm 0.5)\,\mathrm{pb}}$$

Lepton+Jets, CDF Vertex B-Tag Analyses

- Select events with 1 lepton ($p_T > 20\,\mathrm{GeV}$), $\not\!\!E_T > 20\,\mathrm{GeV}$, and $\geq$ 3 jets ($E_T > 15\,\mathrm{GeV}$, $|\eta| < 2.0$)

- require at least one secondary vertex tagged jet
- n_{jet} distribution:

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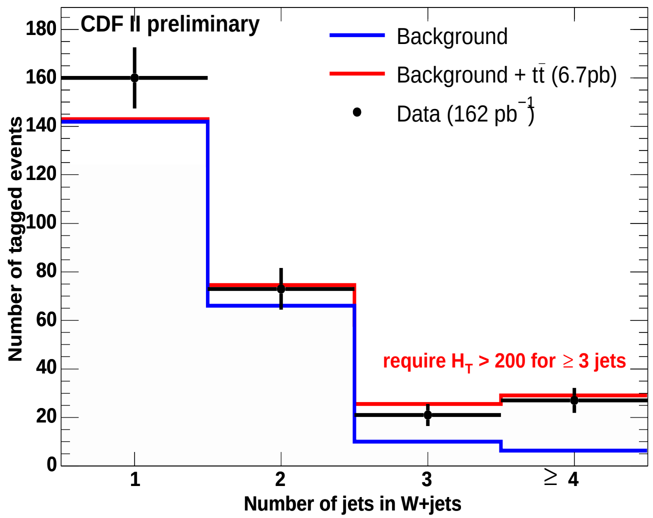
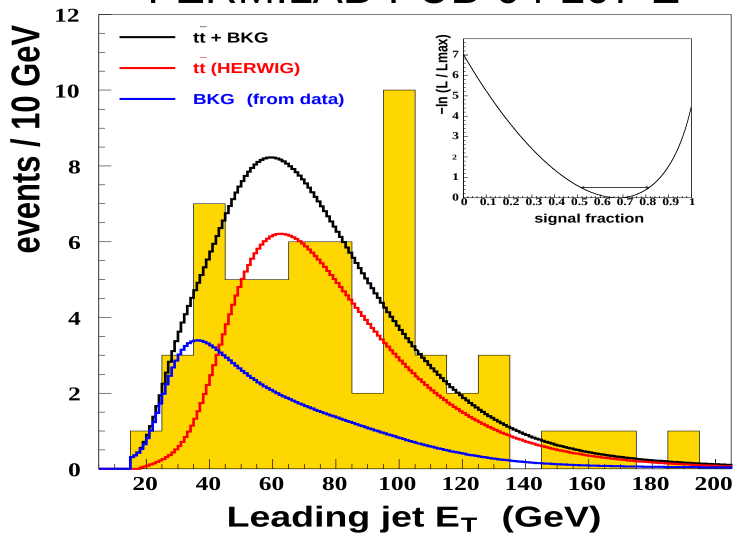


- result ($162\,\mathrm{pb}^{-1}$):

$$\sigma(t\bar{t}) = (5.6^{+1.2}_{-1.1}\,{}^{+0.9}_{-0.6})\,\mathrm{pb}$$

- require exactly one secondary vertex tagged jet
- $t\bar{t}$ fraction from leading jet E_T spectrum
- background shape from data (events w/o b-tag)

FERMILAB-PUB-04-207-E

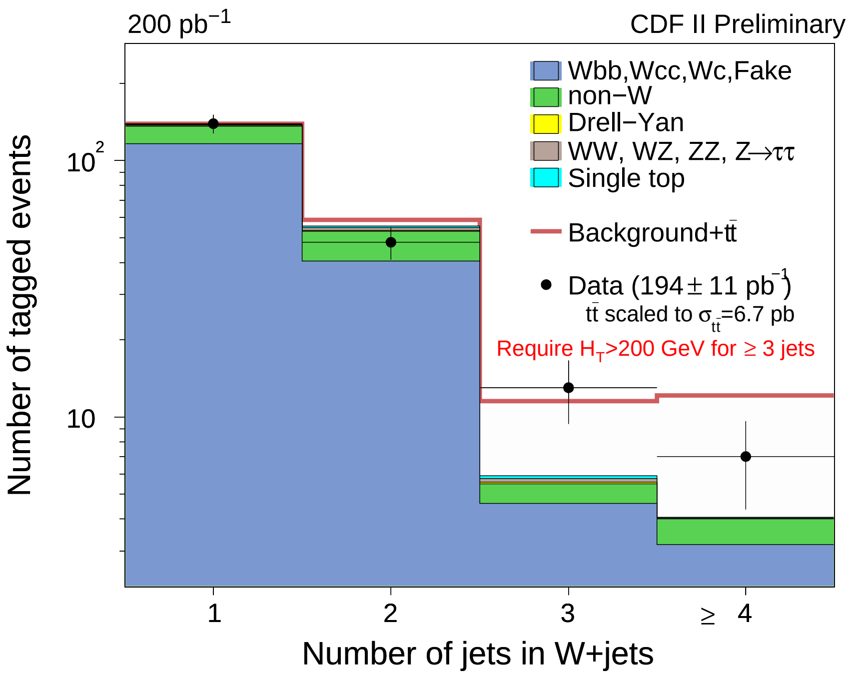


- result ($162\,\mathrm{pb}^{-1}$):

$$\sigma(t\bar{t}) = (6.0 \pm 1.6 \pm 1.2)\,\mathrm{pb}$$

Lepton+Jets, CDF Analysis, Soft Muon Tagging

- Select events with 1 lepton ($p_T > 20\,\mathrm{GeV}$), $\not\!\!E_T > 20\,\mathrm{GeV}$, and n jets ($E_T > 15\,\mathrm{GeV}$, $|\eta| < 2.0$)
- require one jet to be b-tagged by the presence of a soft muon inside a jet from a semimuonic b or c decay



- Result ($200\,\mathrm{pb}^{-1}$):

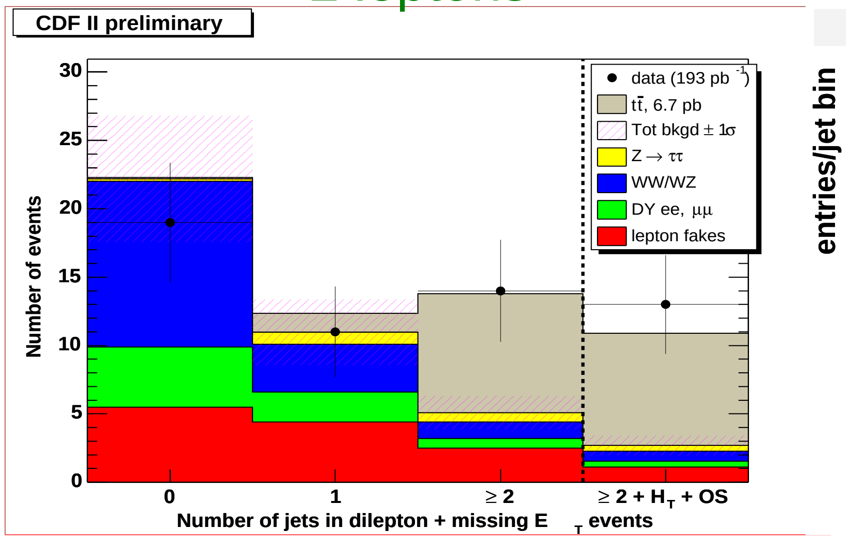
$$\boldsymbol{\sigma(t\bar{t}) = (5.2^{+2.9}_{-1.9}\,{}^{+1.3}_{-1.0})\,\mathrm{pb}}$$

Dilepton Analyses (I)

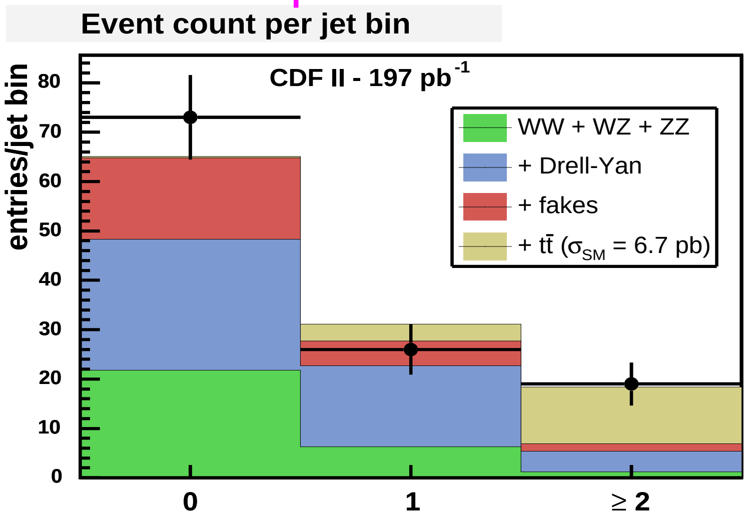
CDF measurements ($\sim 200\text{pb}^{-1}$):

- events with 2 isolated tracks ($p_T > 20\,\text{GeV}$), $\not\!\!E_T > 25\,\text{GeV}$, and n jets

2 leptons



1 lepton + 1 track



- combined result ($200\,\text{pb}^{-1}$):

$$\boldsymbol{\sigma(t\bar{t}) = (7.0^{+2.4}_{-2.1}\,^{+1.6}_{-1.1} \pm 0.4)\,\text{pb}}$$

PRL 93, 142001 (2004)

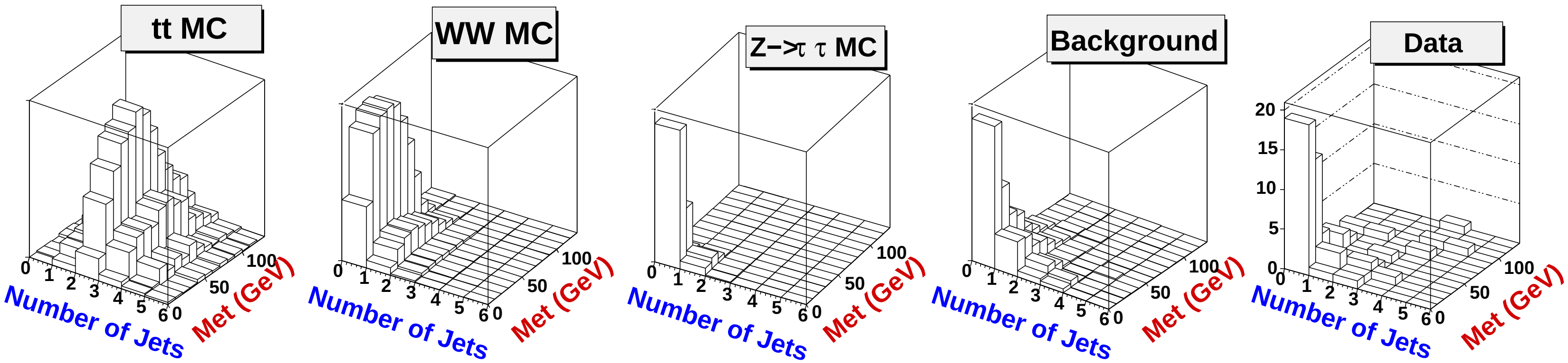
similar DØ "2 lepton" type measurement (140–$156\,\text{pb}^{-1}$):

$$\boldsymbol{\sigma(t\bar{t}) = (14.3^{+5.1}_{-4.3}\,^{+2.6}_{-1.9} \pm 0.9)\,\text{pb}}$$

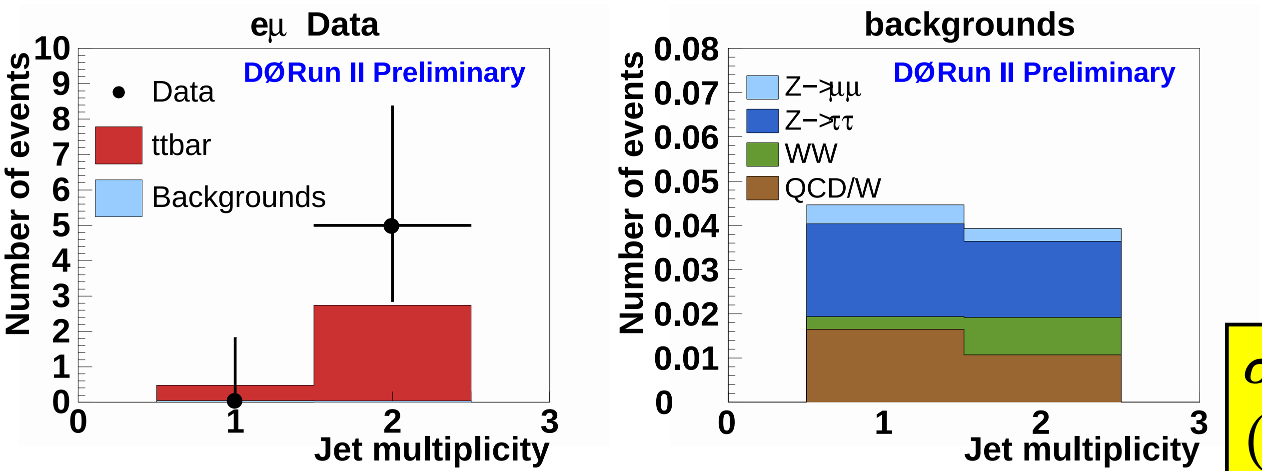
Dilepton Analyses (II)

Variations of the $t\bar{t}$ dilepton analysis:

- measure $t\bar{t}$, WW, and $Z \to \tau\tau$ production (CDF, $200\,\mathrm{pb}^{-1}$):



- apply b-tagging (DØ, $158\,\mathrm{pb}^{-1}$):



$$\boldsymbol{\sigma(t\bar{t}) = (8.6^{+2.5}_{-2.4} \pm 1.1)\,\mathrm{pb}}$$

$$\sigma(WW) = (12.6^{+3.2}_{-3.0} \pm 1.2)\,\mathrm{pb}$$

$$\boldsymbol{\sigma(t\bar{t}) = (11.1^{+5.8}_{-4.3} \pm 1.4 \pm 0.7)\,\mathrm{pb}}$$

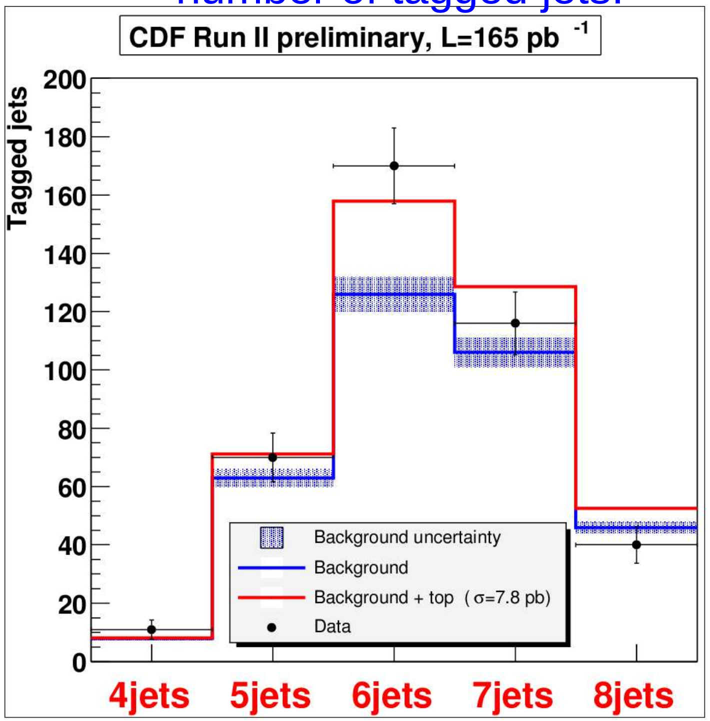
Alljets Analyses

- Need b-tagging + tight kinematic criteria to see a signal:

CDF:

- 6 to 8 jets (signal region)
- no isolated leptons
- kinematic cuts

$\longrightarrow$ number of tagged jets:



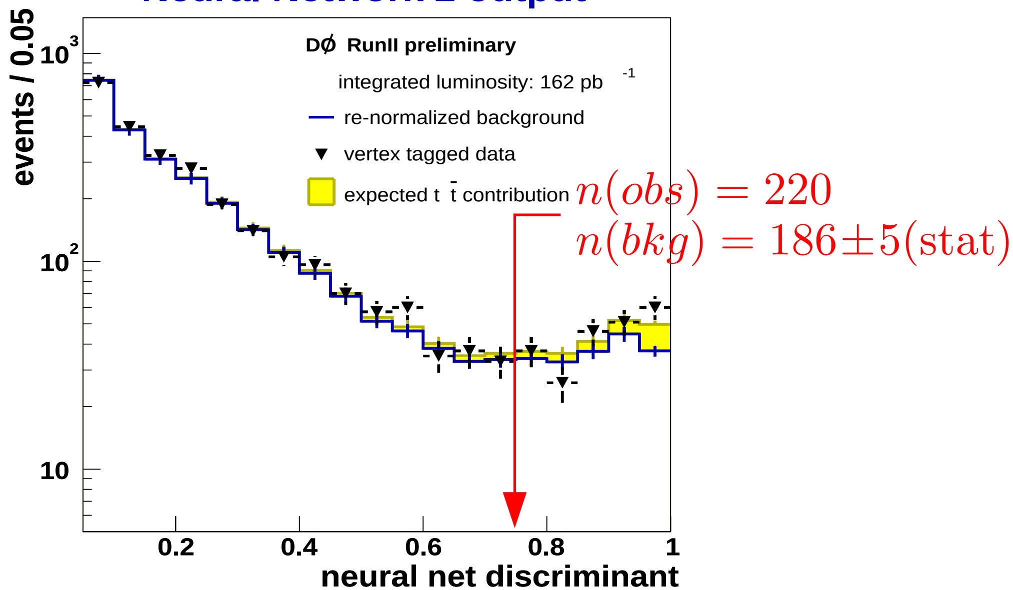
$$\sigma(t\bar{t}) = (7.8 \pm 2.5^{+4.7}_{-2.3})\ \text{pb}$$

DØ:

- $\geq$6 jets
- exactly 1 b-tagged jet
- kinematic neural network

$\longrightarrow$ second neural network including reconstructed masses:

Neural Network 2 output

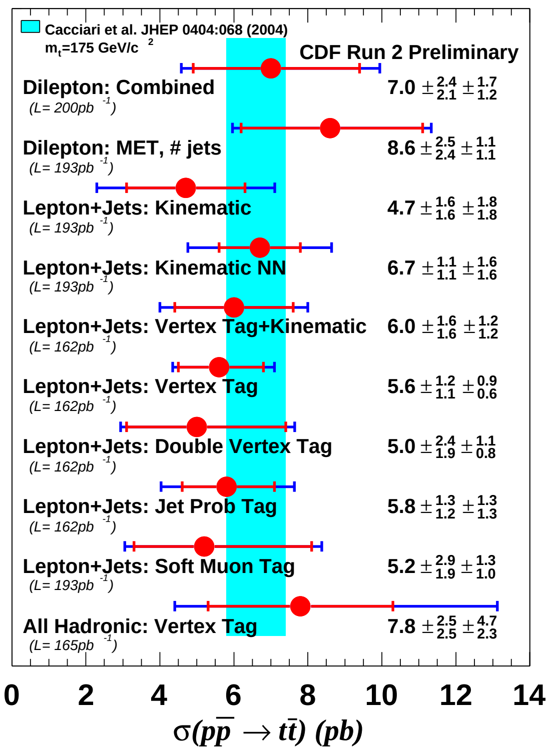


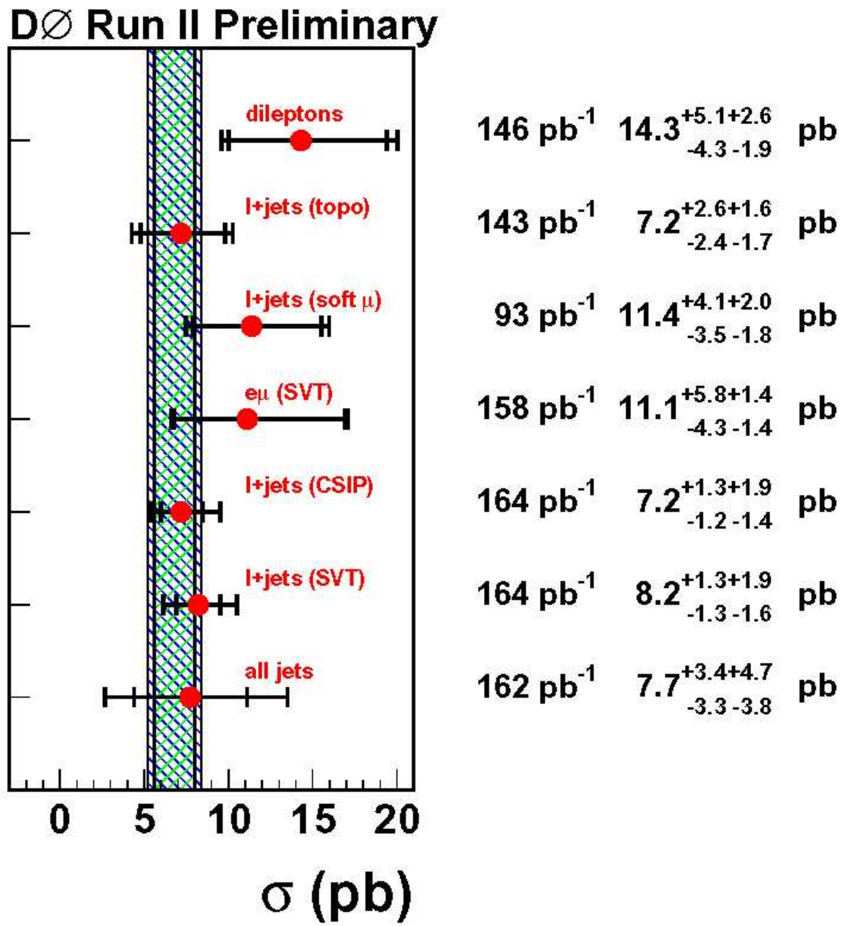
$$\sigma(t\bar{t}) = (7.7^{+3.4}_{-3.3}\,{}^{+4.7}_{-3.8} \pm 0.5)\ \text{pb}$$

The $t\bar{t}$ Production Cross-Section

- Production cross-section $\sigma(p\bar{p}) \to t\bar{t} + X$

CDF Run II Preliminary





⇒ all results consistent so far (detectors and SM work ok)

⇒ consistent combination in progress

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updates imminent for most of the measurements!

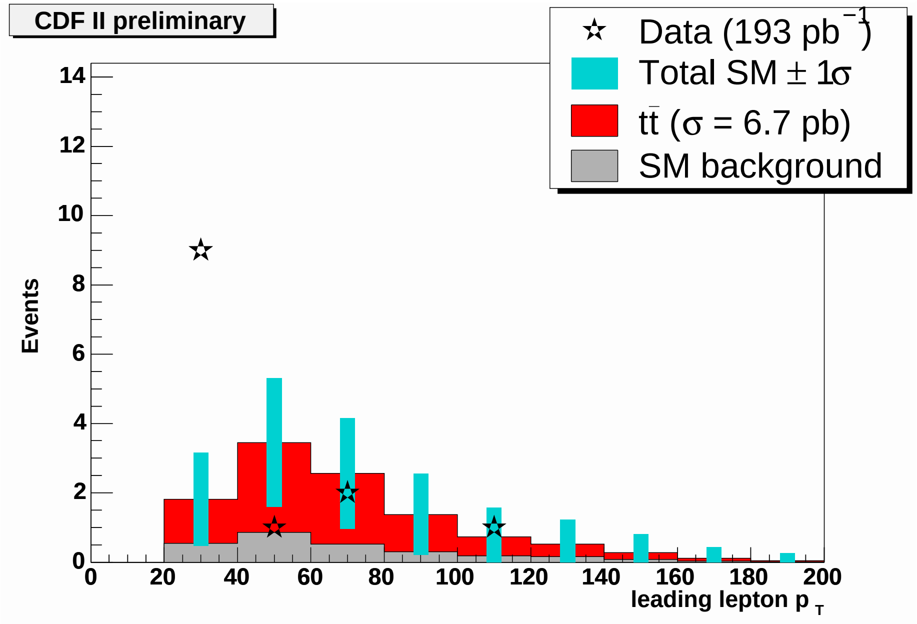
Anomalies in $t\bar{t}$ Production? (I)

Measured $t\bar{t}$ production in a large variety of channels

$\longrightarrow$ Any room for physics beyond the Standard Model?

(I) Model independent analyses:

- Compare cross-sections in different channels (CDF, $125\,\mathrm{pb}^{-1}$):
  $\sigma(\mathrm{dilepton})/\sigma(\ell + \mathrm{jets}) = 1.45\,^{+0.83}_{-0.55}$
- CDF $t\bar{t}$ dilepton events:
  - look at four kinematic distributions (chosen a priori)
  - three of four distributions look $\sim$ as expected
  - most significant deviation from expectation: leading lepton p_T spectrum $\longrightarrow$



FERMILAB-PUB-04-396-E:

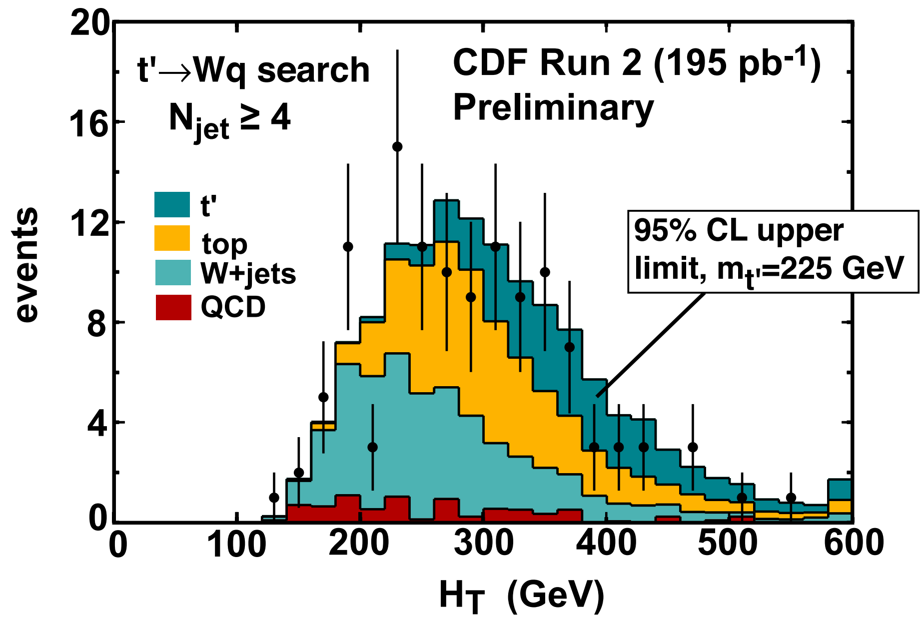
  - overall 1.0–4.5% compatibility with the SM prediction ($193\,\mathrm{pb}^{-1}$)

Anomalies in $t\bar{t}$ Production? (II)

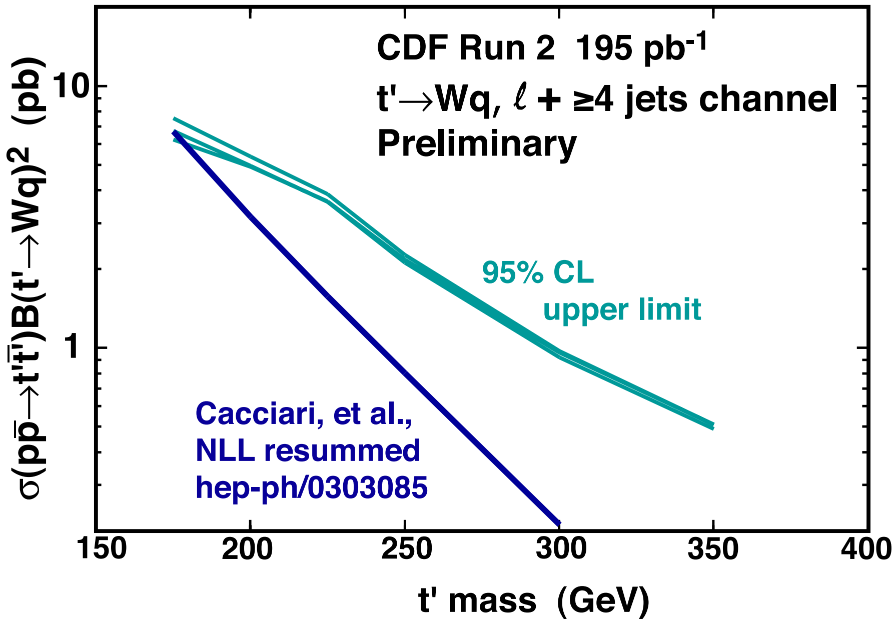
(II) Model dependent analysis:

- search for $t' \longrightarrow Wq$ decays

excess of events at large H_T?



limit as a function of assumed t' mass:



Anomalies in Top Decays? – Overview

Expect to see only $t \to Wb$ decays at the Tevatron

$\longrightarrow$ anything else would indicate new physics

(I) Is the “W” we measure the W we expect?

- W helicity measurements
- measurement of $t \to \tau\nu b$
- search for charged Higgs bosons in top decay

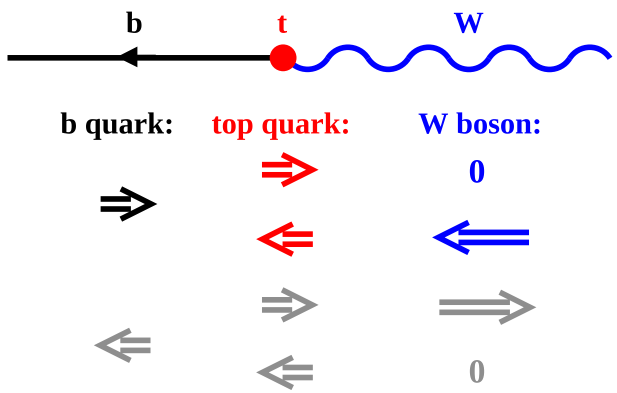
(II) Is the “b” we measure the b we expect?

- measurement of $Br(t \to Wb)/Br(t \to Wq)$

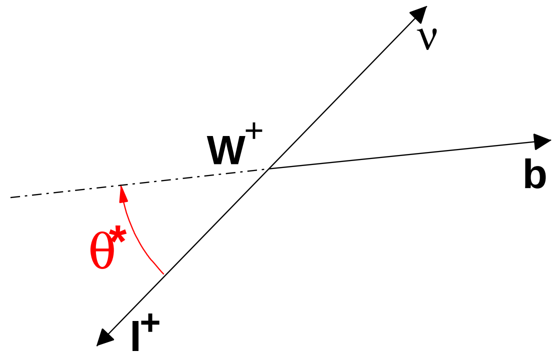
W Helicity in Top Decays (I)

- (V–A) structure of the weak interaction

$\Rightarrow$ spins of top decay products:



(spin component along b/W momentum axis)



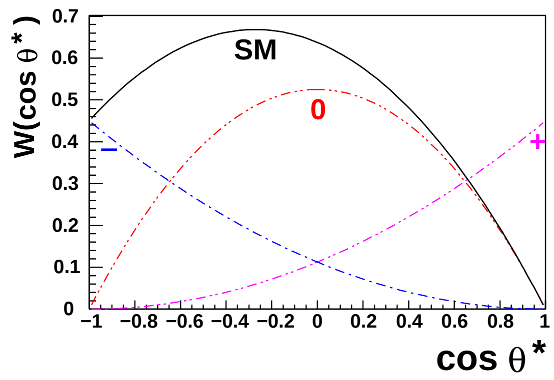
$\Rightarrow$ SM predictions: fraction of top decays with a...

longitudinal W boson $F_0 = \frac{1}{1+2m_W^2/m_t^2} \approx 0.70$

left-handed W boson $F_- = 1 - F_0 \approx 0.30$

right-handed W boson $F_+ = 0$

$\Rightarrow$ distributions of decay angle θ^* in W rest frame for different W helicities:



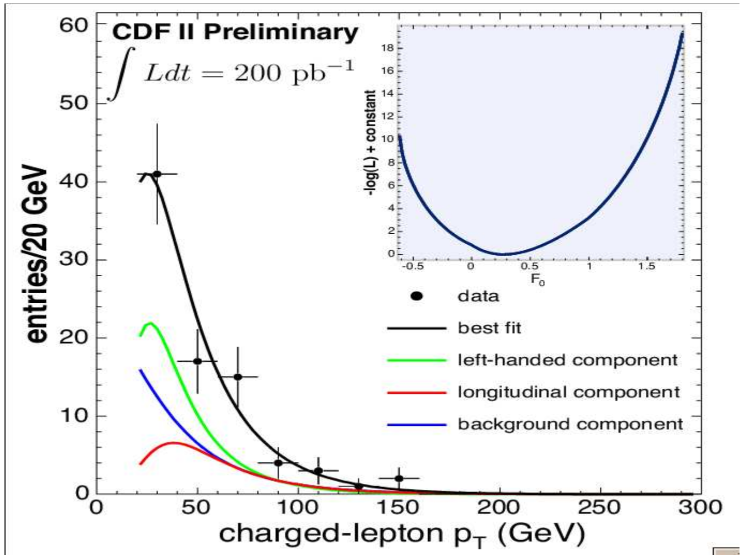
W Helicity in Top Decays (II)

Measurement strategies at Tevatron Run II:

- lepton p_t from leptonically decaying W (CDF)
- explicit reconstruction of decay angle $\cos\theta^*$ (CDF & DØ)

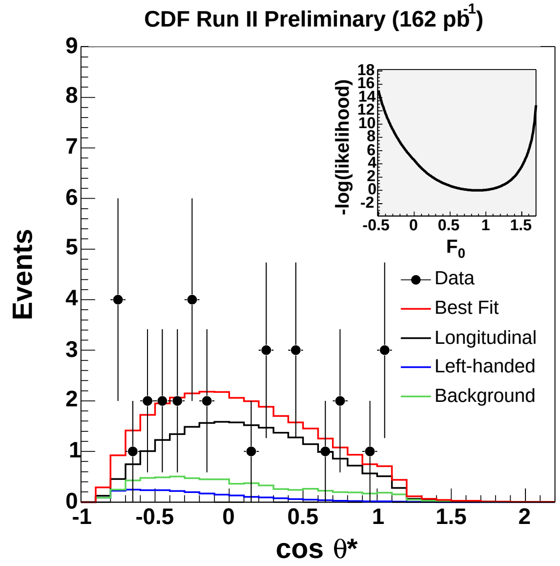
CDF Run II measurements:

lepton p_t spectrum:



$$F_0 = 0.27\,^{+0.35}_{-0.24}$$

decay angle:



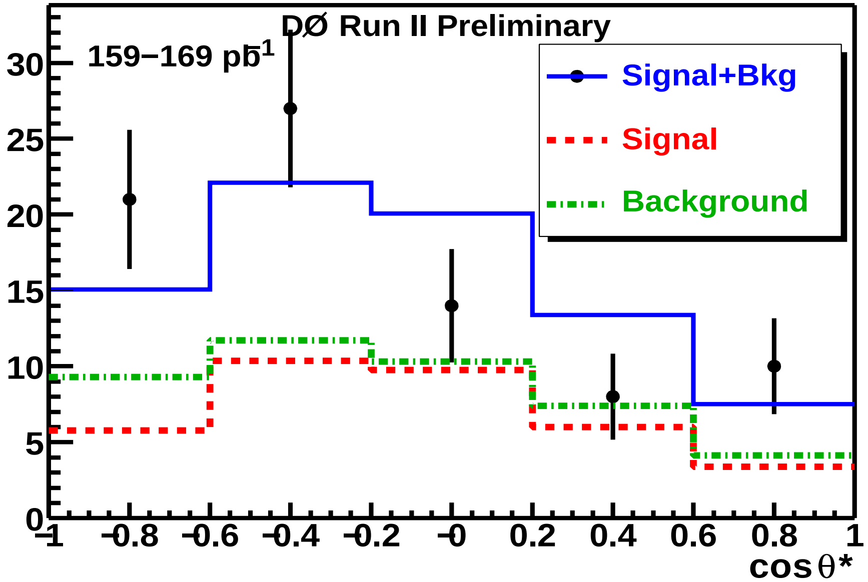
$$F_0 = 0.89\,^{+0.30}_{-0.34}(\mathrm{stat}) \pm 0.17(\mathrm{syst})$$

DØ Run I: extended matrix element (cf. m_t measurement) $\rightarrow F_0 = 0.56 \pm 0.31$

W Helicity in Top Decays (III)

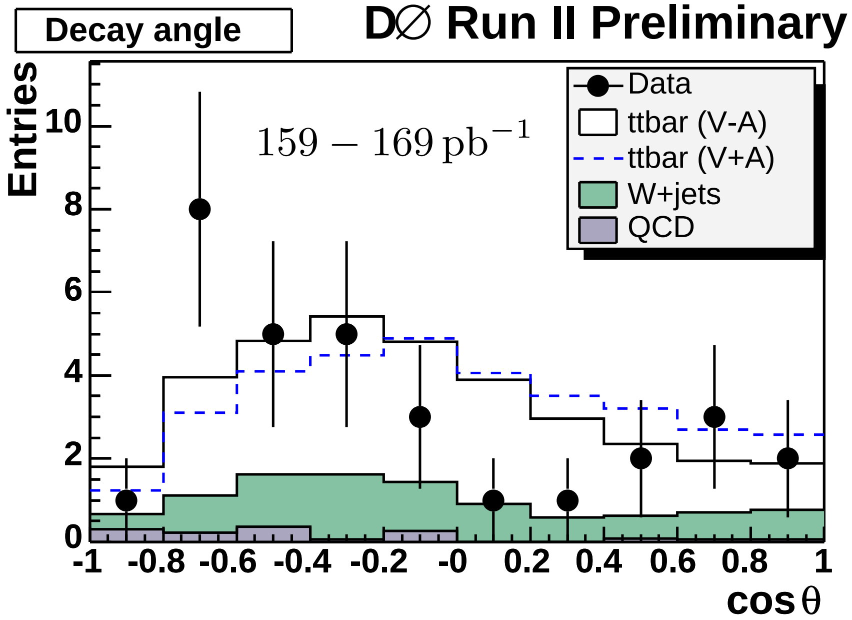
DØ Run II measurements:

decay angle, topological selection:



$F_+ < 0.24$ at 90% C.L.

decay angle, b-tagged events:



$F_+ < 0.24$ at 90% C.L.

CDF Run I measurement:

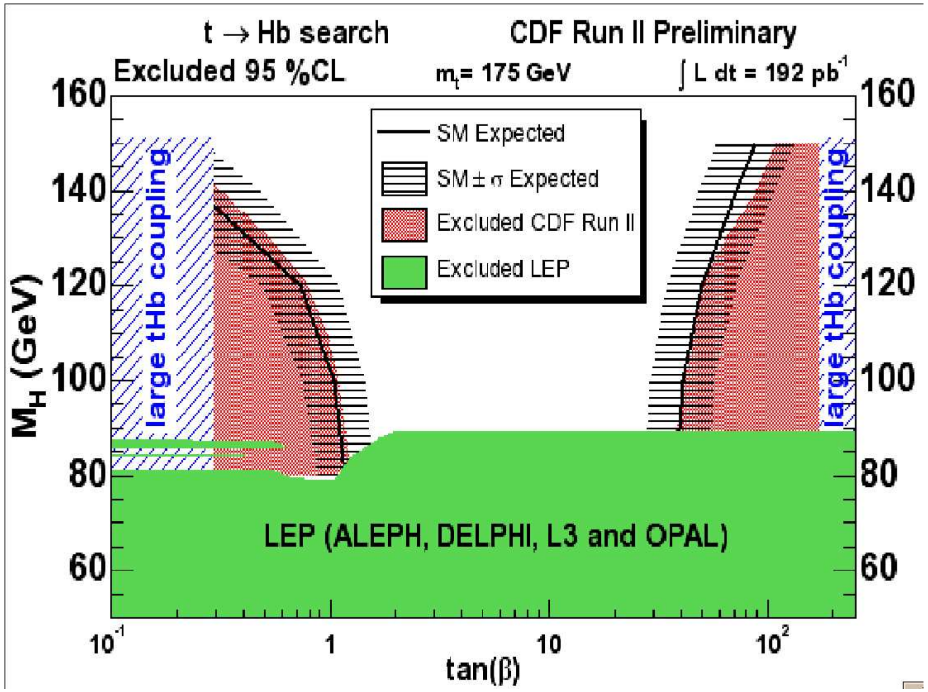
$m_{\ell b}$ (similar to $\cos\theta^*$) & lepton p_t: $F_+ < 0.18$ at 95% C.L.

Charged Higgs Search

charged Higgs with $m_{\mathrm{H}^{\pm}} < m_{\mathrm{t}}$?

$\longrightarrow$ subtle changes in event topology according to $H^{\pm}$ decay:

large $\tan\beta$:	$\mathrm{H}^{+} \to \tau\nu$	excess of τ decays in $\mathrm{t\bar{t}}$ events
small $\tan\beta$:	$\mathrm{H}^{+} \to \mathrm{c\bar{s}}$	excess of fully hadronic $\mathrm{t\bar{t}}$ events
	$\mathrm{H}^{+} \to \mathrm{Wb\bar{b}}$	2 extra b jets in $\mathrm{t\bar{t}}$ events



inputs to CDF analysis:

- $\sigma(\mathrm{t\bar{t}} \to \mathrm{dilepton})$
- $\sigma(\mathrm{t\bar{t}} \to \ell + \mathrm{jets})$
- $\dfrac{\sigma(\mathrm{t\bar{t}} \to \ell + \tau)}{\mathrm{SM\ expectation}} < 5.0$ at 95% C.L.

Top Decays

Does the top quark decay to other quarks than b quarks?

- compare $t\bar{t}$ event rates with 0 (CDF only), 1, and 2 b-tagged jets

$$\frac{Br(t \to Wb)}{Br(t \to Wq)} = \begin{cases} 1.11 \; ^{+0.21}_{-0.19}(\mathrm{stat}+\mathrm{syst}) & \mathrm{CDF},\ 162\,\mathrm{pb}^{-1} \\ 0.65 \; ^{+0.34}_{-0.30}(\mathrm{stat}) \; ^{+0.17}_{-0.12}(\mathrm{syst}) & \mathrm{D\O},\ \mathrm{imp.\ par.},\ 158-169\,\mathrm{pb}^{-1} \\ 0.70 \; ^{+0.27}_{-0.24}(\mathrm{stat}) \; ^{+0.11}_{-0.10}(\mathrm{syst}) & \mathrm{D\O},\ \mathrm{sec.\ vtx.},\ 158-169\,\mathrm{pb}^{-1} \end{cases}$$

Note: Cannot measure $|V_{\mathrm{tb}}|$ in top decays:

$$\frac{Br(t \to Wb)}{Br(t \to Wq)} = \frac{|V_{\mathrm{tb}}|^2}{|V_{\mathrm{td}}|^2 + |V_{\mathrm{ts}}|^2 + |V_{\mathrm{tb}}|^2} = \frac{|V_{\mathrm{tb}}|^2}{1} \text{ in the SM}$$

$$= \frac{|V_{\mathrm{tb}}|^2}{?} \text{ for} > 3 \text{ generations}$$

$\Rightarrow$ single top production: SM cross-section $\sim |V_{\mathrm{tb}}|^2$!

+ sensitivity to new physics...

Top Quark Production and Properties at the Tevatron (Excluding Top Mass)

Frank Fiedler, LMU München
on behalf of the CDF and DØ Collaborations

Les Rencontres de Physique de la Vallée d'Aoste,
27. 2. - 5. 3. 2005

Overview:

- Introduction: top quarks at the Tevatron
- The total $t\bar{t}$ production cross-section
- Further $t\bar{t}$ measurements
- Single top quark production
- Conclusions

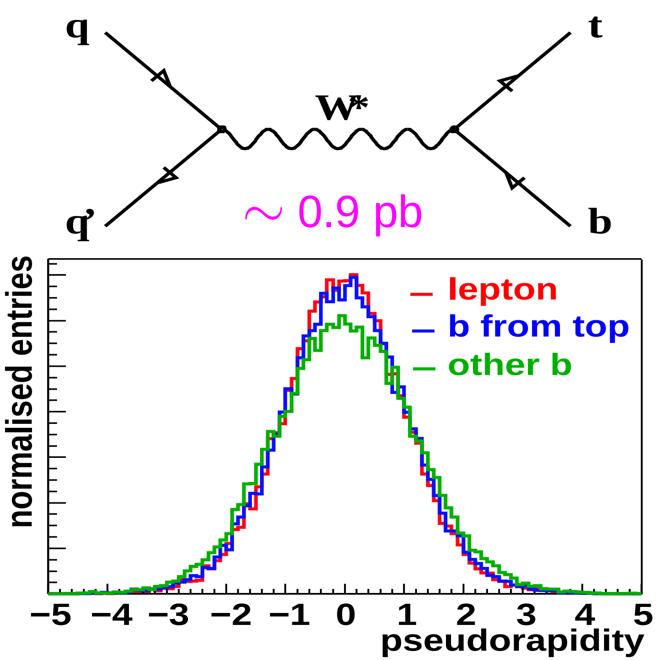
many Tevatron Run II results are preliminary!
updates imminent for most of the measurements!

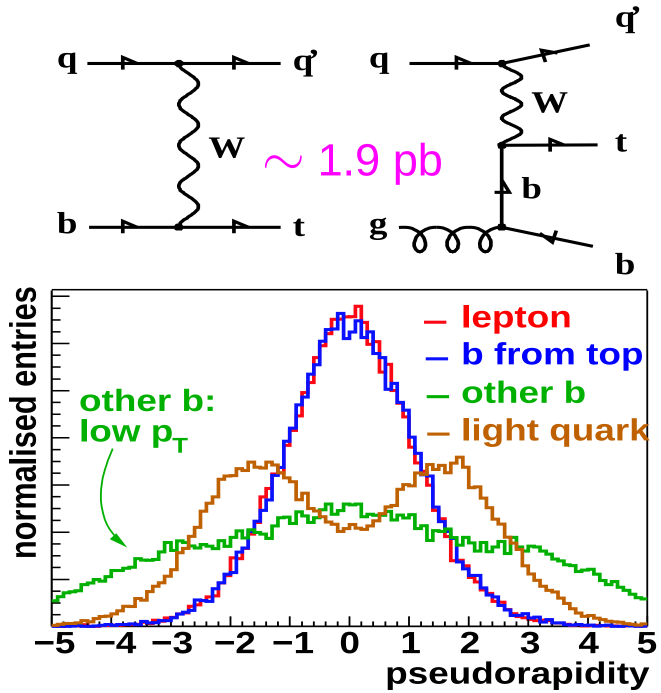
Reconstruction of Single Top Events (I)

Concentrate on s and t channel production (t+W not feasible at the Tevatron)

Expected event topology: (only consider leptonic W decays)

- top decay products: lepton, $\not\!\!E_T$, one energetic b jet
- **s-channel:** another energetic b jet
- **t-channel:** other b jet at large $|\eta|$, low p_T
  additional light quark jet



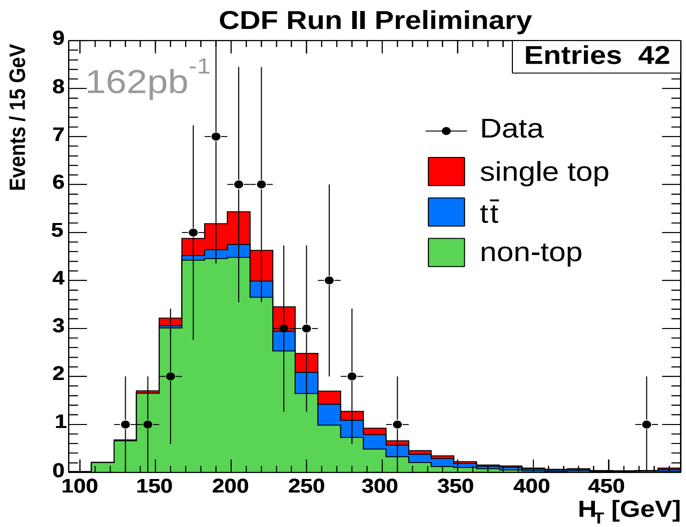


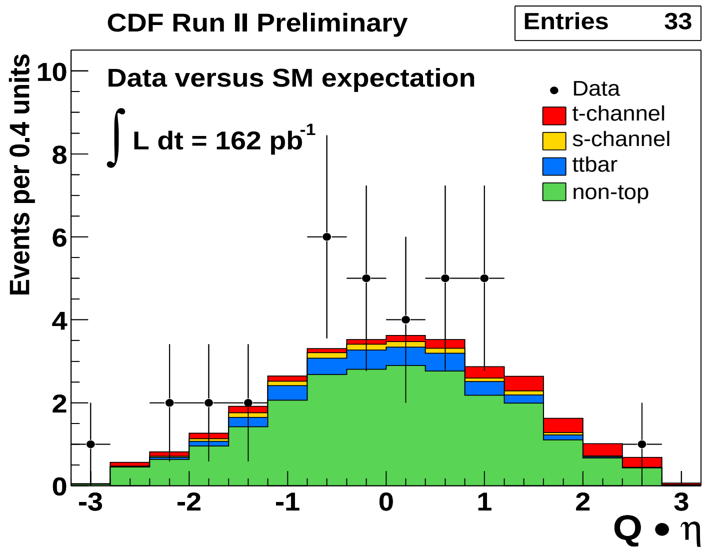
Challenge: large W+jets background

Reconstruction of Single Top Events (II)

Selection of single top events at DØ/CDF:

- energetic isolated charged lepton, $Z \to \ell\ell$ veto
- missing transverse energy
- 2–4 / 2 jets, at least one b-tagged jet
- H_T cut / reconstructed top mass: $140 < m_{b\ell\nu} < 210\,\mathrm{GeV}$
- $Q_{\mathrm{lepton}} \cdot \eta_{\mathrm{b\,jet}}$ distribution to disentangle s and t channels





Phys. Rev. D, 71 012005 (2005)

Single Top Results

- $\sigma(\text{single top}) <$ ...

	s channel	t channel	s+t channel
CDF	13.6 pb	10.1 pb	17.8 pb
DØ	19 pb	25 pb	23 pb

$\Rightarrow$ limits from Run II better than from Run I

- compare with expected t-channel cross-section of $\sim$1.9 pb:

$\Rightarrow$ need more integrated luminosity to measure $|V_{\mathrm{tb}}|$

- new, refined analyses with more data on their way...
- expect to see (SM) single top production with a few fb^{-1}

(...hope to find new physics...)

Conclusions

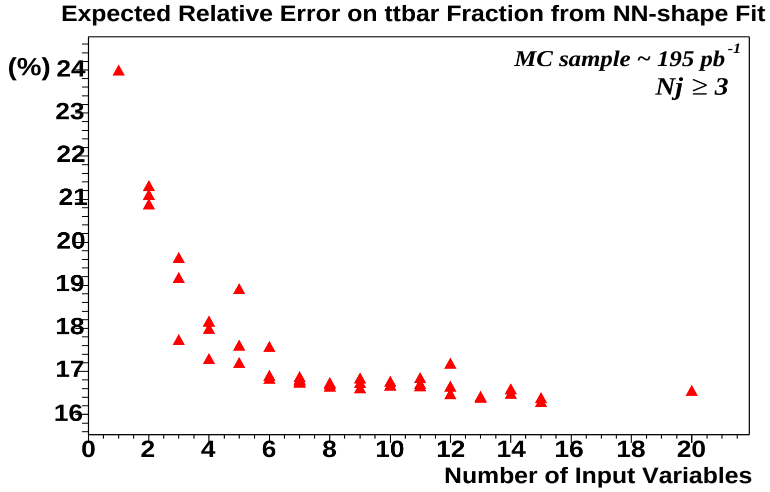
Top physics at Tevatron Run II:

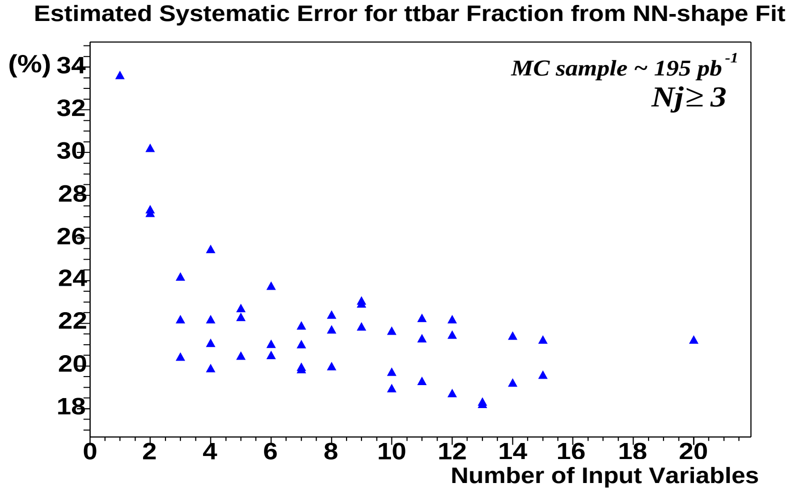
- $t\bar{t}$ **cross-section** measured in many channels: consistent with SM
  $\longrightarrow$ next steps: work on systematic errors (jet energy scale!)
  combination of channels
- **more $t\bar{t}$ measurements**:
  differential cross-sections, W helicity measurements,
  search for rare top decays
  $\longrightarrow$ great potential with increasing data samples
- **Single top production** ($\longrightarrow |V_{\rm tb}|$):
  Run II limits surpass Run I results
  looking forward to more data, and:
  $\longrightarrow$ working towards the discovery of single tops at the Tevatron!
- **Top mass**: see George Velev's presentation

Backup Slides

... on the following pages ...

Lepton+Jets, CDF Topological Selection

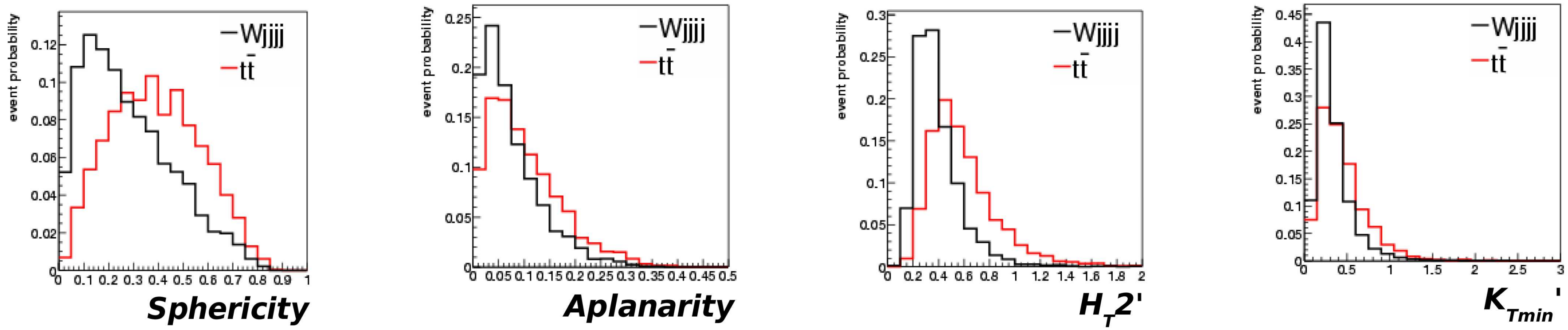




optimum choice:

- scalar sum of transverse energies, H_T
- aplanarity, $\mathcal{A}$
- minimum di-jet mass, $\min(m_{jj})$
- maximum jet rapidity, $\eta_{\max}$
- minimum di-jet separation, $\min(\Delta R_{jj})$
- sum of jet transverse energies excluding the two leading jets, $\sum_{i=3}^{5} E_T^i$
- sum of jet longitudinal momenta divided by sum of jet transverse energies, $(\sum p_z)/(\sum E_T)$

Lepton+Jets, DØ Topological Selection



normalised momentum tensor $M_{ij} = \frac{\sum_k p_k^i p_k^j}{\sum_k |\vec{p}_k|^2}$, eigenvalues: $\lambda_1 \geq \lambda_2 \geq \lambda_3, \sum \lambda_i = 1$

- sphericity: $\mathcal{S} = 3/2(\lambda_2 + \lambda_3)$
- aplanarity: $\mathcal{A} = 3/2 \cdot \lambda_3$
- $H'_{T2} = H_{T2}/H_z$: measures event centrality
  H_{T2}: scalar jet p_T sum, excluding leading jet
  H_z: scalar $|p_z|$ sum of jet, lepton, and neutrino
- $K'_{T\min}$: measure of minimum relative jet p_T
  take the minimum dijet separation, multiply by the smaller of the two jet E_T values
  divide by $E_T(W \to \ell\nu)$ to reduce jet energy scale dependence
  tends to have small values for main background

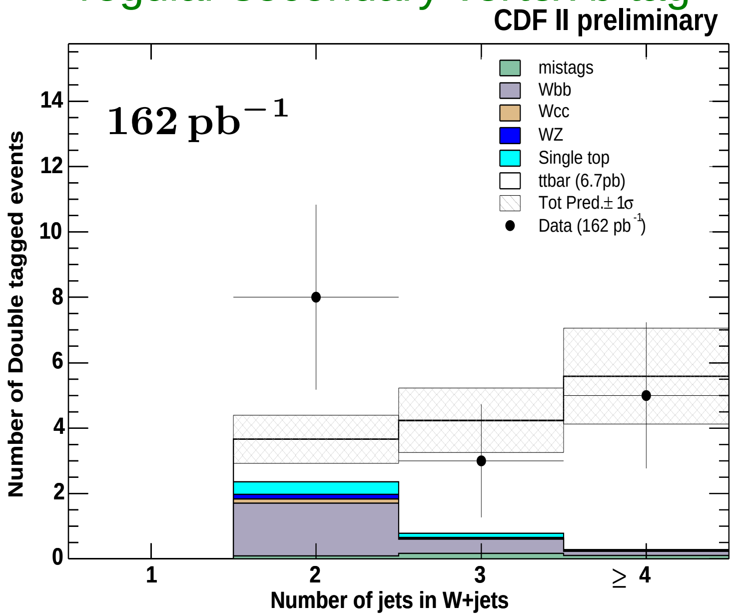
Lepton+Jets, CDF Double Vertex B-Tag Analyses

- select events with 1 lepton, missing $\not\!E_T$, and $\geq$ 3 jets
- require two jets to be secondary vertex b-tagged

$\Rightarrow$ reduced systematic error from background cross-sections

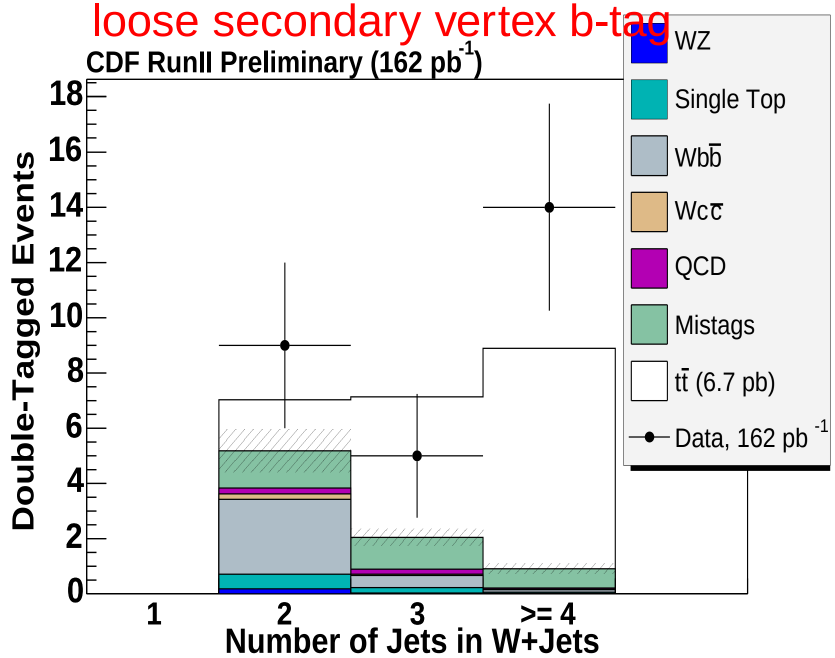
$\Rightarrow$ but b-tagging efficiencies "count twice"

regular secondary vertex b-tag



$$\sigma(t\bar{t}) = (5.4^{+2.4}_{-1.9}(\text{stat})\ ^{+1.1}_{-0.9}(\text{syst}))\ \text{pb}$$

loose secondary vertex b-tag



$$\sigma(t\bar{t}) = (8.2^{+2.4}_{-2.1}(\text{stat})\ ^{+1.8}_{-1.0}(\text{syst}))\ \text{pb}$$

CDF Analysis Looking for Anomalies in Dilepton Events

Look at four kinematic variables in dilepton events

Quantities chosen a priori:

lepton transverse momentum

missing transverse energy

$$T = \int \exp\left\{ -\frac{(\vec{\not{E}}_T^{\text{predicted}} - \vec{\not{E}}_T^{\text{measured}})^2}{2\sigma^2_{\not{E}_T}} \right\} \mathrm{d}\vec{\not{E}}_T^{\text{predicted}}$$

$$\Delta\phi(\ell, \vec{\not{E}}_T)$$