Search for Single Top Quark Production at the Tevatron

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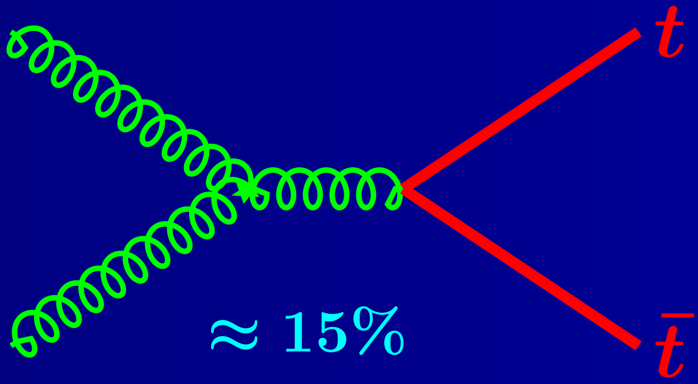
on behalf of the DØ and CDF collaborations

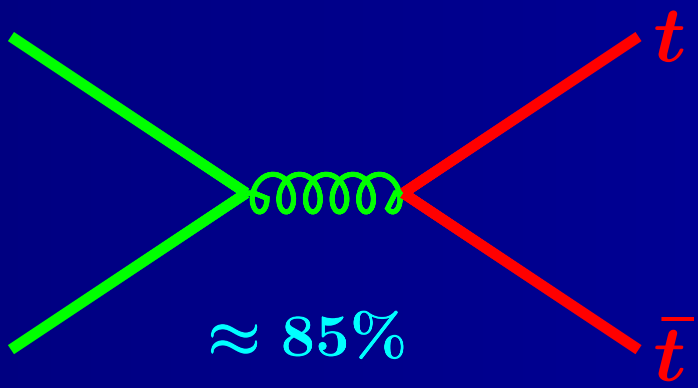
Top Pair Production

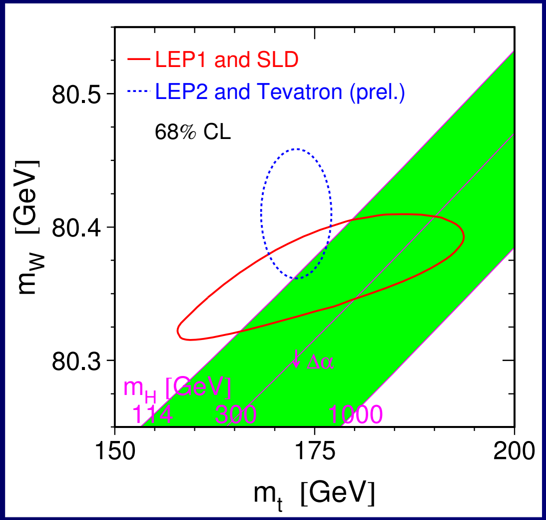
Top quarks exist at the interface between QCD and Electroweak

- heaviest known elementary particle
- decays before it hadronizes
- provides unique test of QCD
- constrains mass of the SM Higgs



$\sigma_{\text{NLO}} = 6.77 \pm 0.42$ pb
at $m_t = 175$ GeV





Weak Decay Vertex

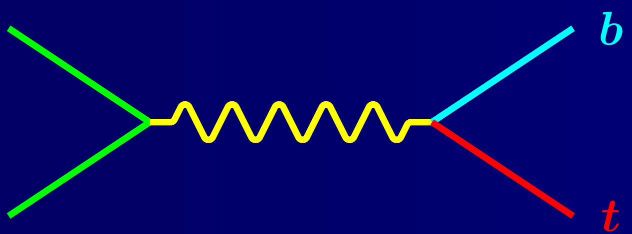
top quark decay

- decay properties
- $|V_{tb}|$

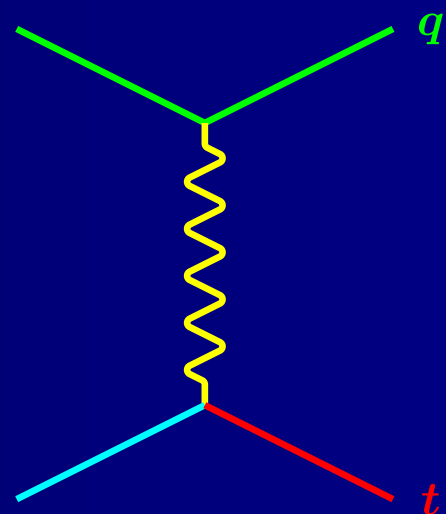
single top production

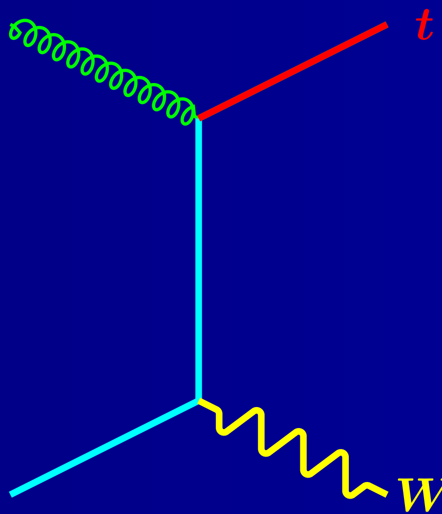
- cross section
- $|V_{tb}|$

Single Top Production



s channel





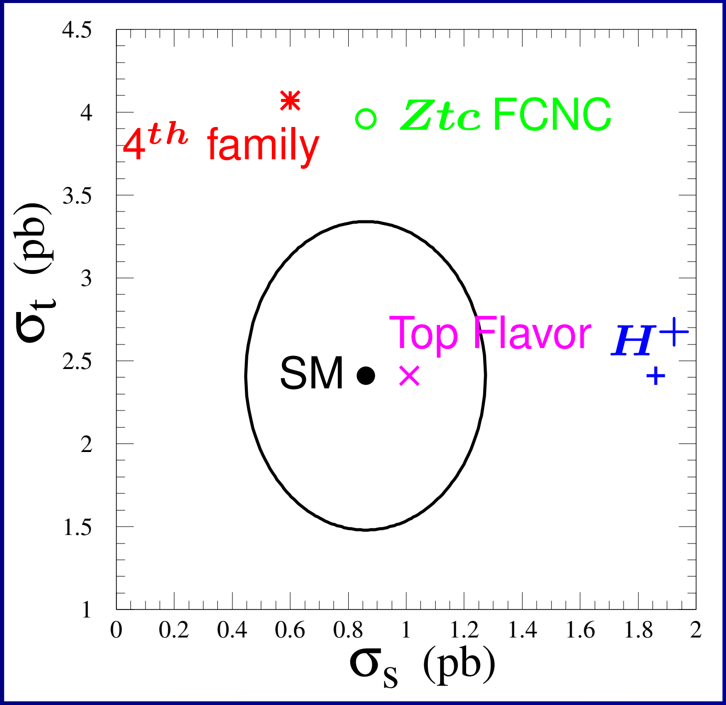
t channel

$W\,t$ production

		s-channel	t-channel	tW production	combined s&t
σ_{NLO}	Tevatron	$0.88^{+0.07}_{-0.06}$ pb	$1.98^{+0.23}_{-0.18}$ pb	0.093 ± 0.024 pb	
	LHC	10.6 ± 1.1 pb	247 ± 25 pb	$62^{+17}_{-\ 4}$ pb	
Run I 95%	CDF	< 18 pb	< 13 pb		< 14 pb
CL Limit	DØ	< 17 pb	< 22 pb		

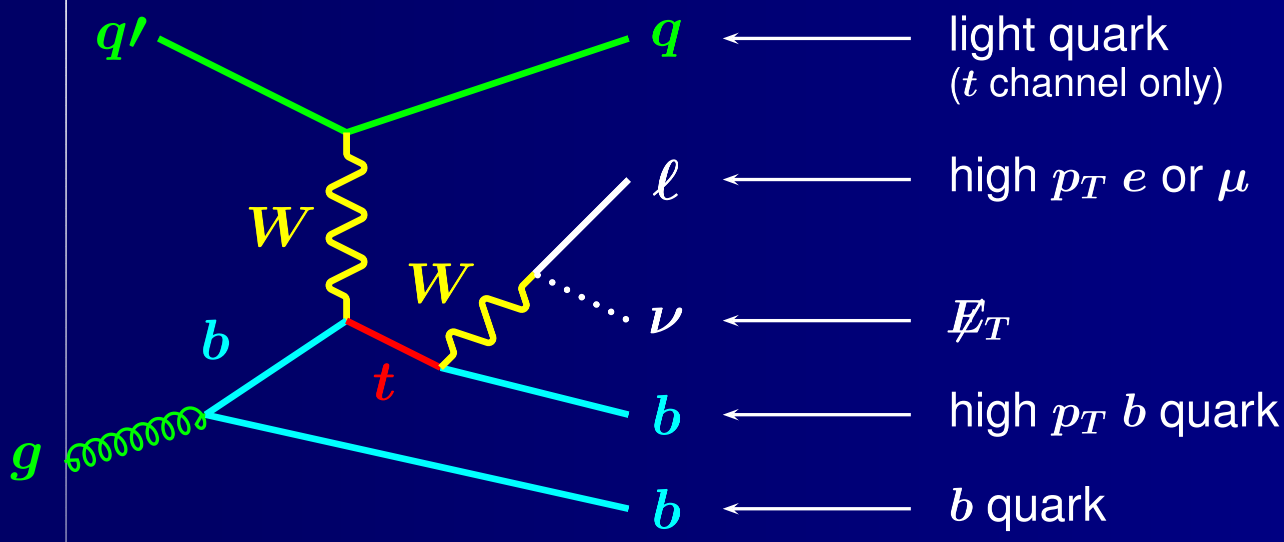
Goals

- Observe single top quark production
- Measure the production cross section
  - extract $|V_{tb}|$
  - study top quark polarization
  - background to SM Higgs production
- Look for physics beyond the Standard Model $\Rightarrow$ different sensitivity for s- and t-channels
  - FCNC
  - anomalous couplings
  - 4^{th} generation
  - top flavor
  - etc. . .



Tait & Yuan, PRD 63, 014018 (2000)

Event Signatures



signal for s- and t-channels similar

like $t\bar{t}$ production, but with fewer jets

- lepton + $\not\!\!E_T$ + jets
- t channel b jet tends to be forward

Backgrounds

anything with lepton + $\not\!\!E_T$ + jets

- W/Z + jets production
- top pair production
- multi-jet events (misidentified lepton)
- $WW, WZ, Z \rightarrow \tau\tau$

significantly worse than for $t\bar{t}$ production because of the lower jet multiplicity

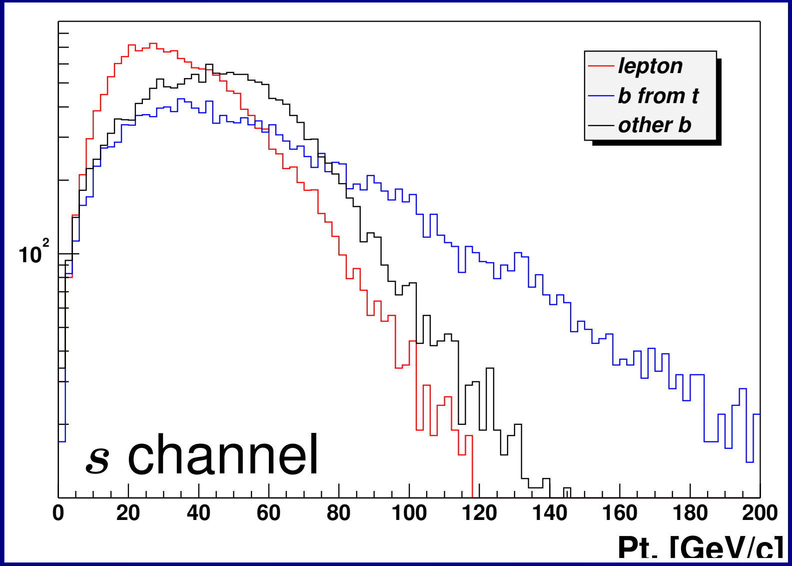
hard signal to find

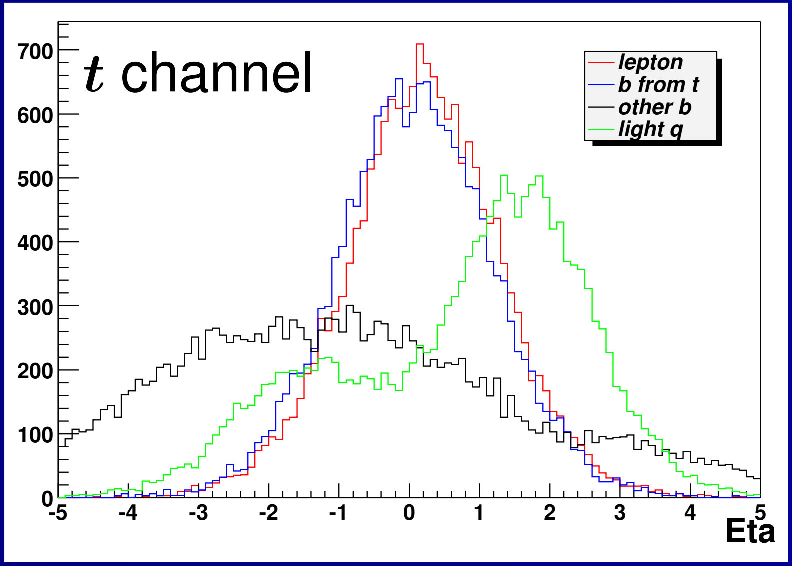
Signal Modeling

Understanding the characteristics of single top signal crucial for discovery

- s-channel MC generators agree well with NLO calculations
- t-channel generators are still an issue $\Rightarrow$ Match $\mathbf{2} \rightarrow \mathbf{3}$ and $\mathbf{2} \rightarrow \mathbf{2}$ processes using the b p_T spectrum
- CDF: re-weight MadEvent to fit ZTop NLO distributions
- DØ: modified version of CompHEP

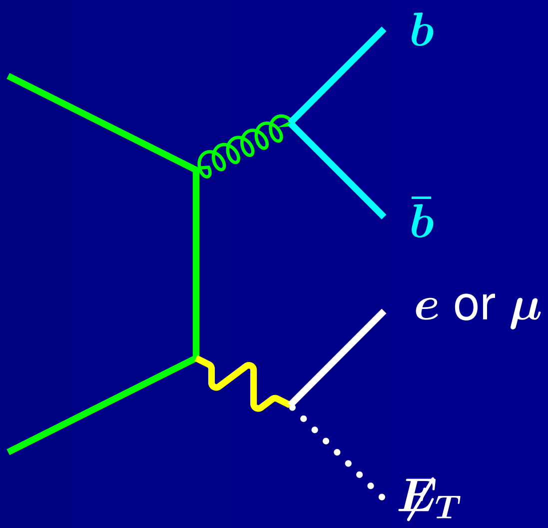
(CompHEP and ZTop agree well)



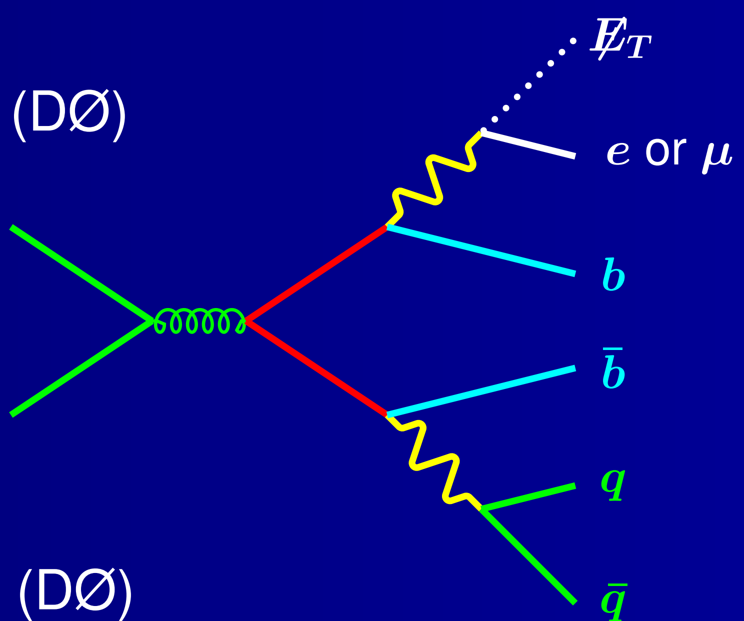


Background Modeling

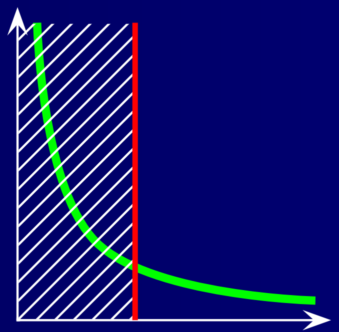
- Based on data as much as possible . . .
- W/Z + jets production
  - estimated from data & MC
  - heavy flavor fractions (b,c) from ALPGEN (CDF) and MCFM (DØ)
  - normalization from pre-tagged sample



- top pair production
  - contribution from the ℓ + jets channel
  - estimated from PYTHIA (CDF) and ALPGEN (DØ)
- multi-jet events
  - jet misidentified as lepton
  - semi-leptonic decay of HF jets (bb)
  - estimated from data
- $WW, WZ, Z \rightarrow \tau\tau$
  - Estimated from PYTHIA (CDF) and ALPGEN (DØ)

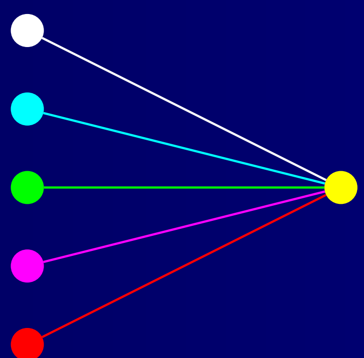


Search Strategy



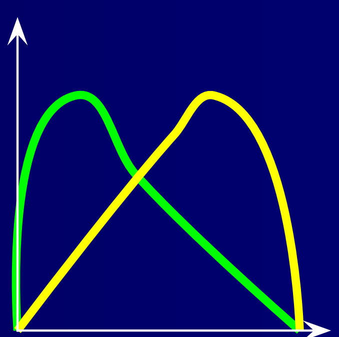
Event Selection

- select W-like events
- remove background-like events
- optimize sensitivity



Separate Signal from Background

- find discriminating variables
- compare data with Monte Carlo

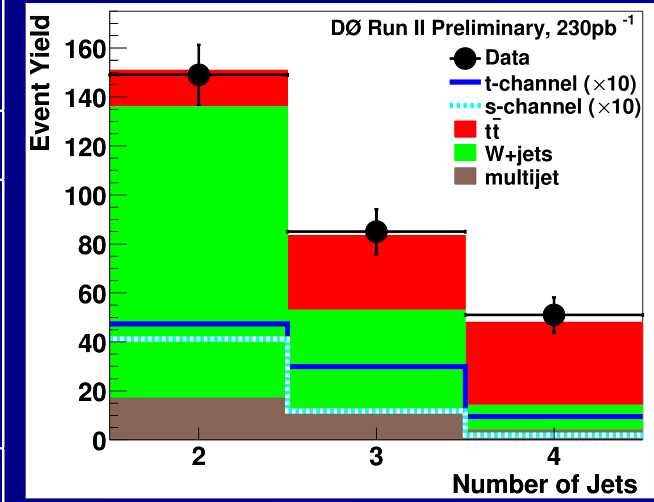


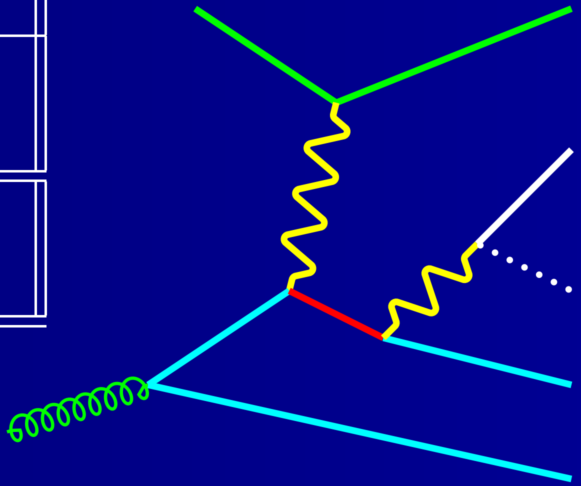
Determine Cross Section

- event counting
- likelihood

Event Selection

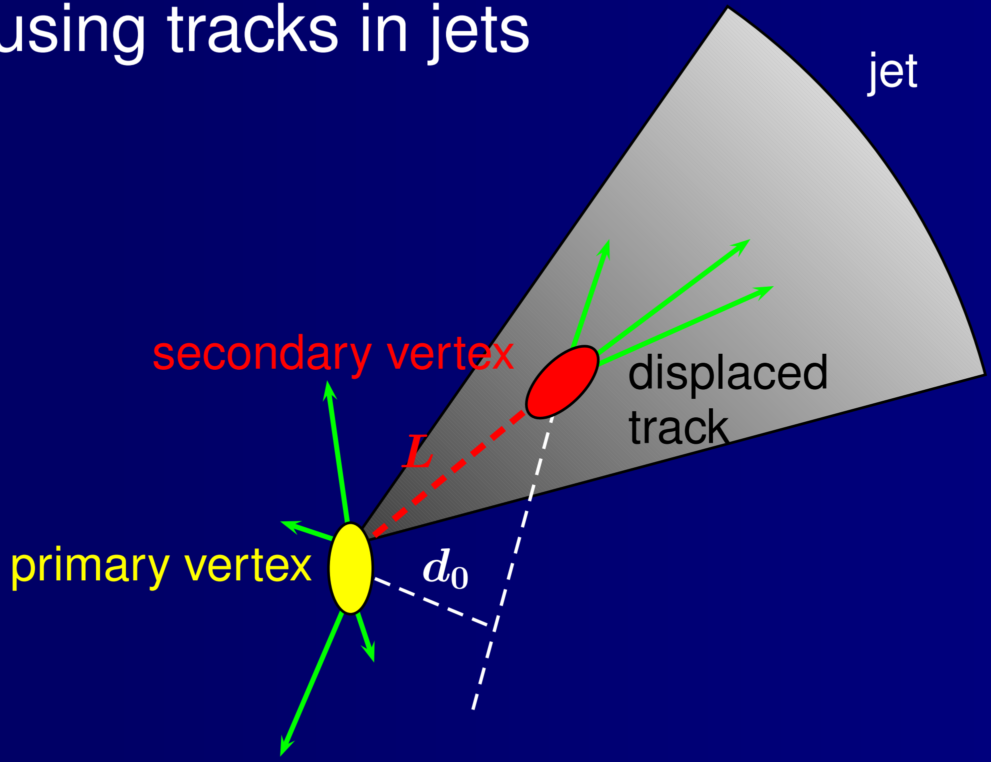
Object	CDF	DØ
Lepton	$e\ p_T > 20$ GeV $\lvert\eta\rvert < 1$ $\mu\ p_T > 20$ GeV $\lvert\eta\rvert < 1$	$e\ p_T > 15$ GeV $\lvert\eta\rvert < 1.1$ $\mu\ p_T > 15$ GeV $\lvert\eta\rvert < 2.0$
Neutrino	$\not{E}_T > 20$ GeV	$\not{E}_T > 15$ GeV
Jets	exactly 2 $p_T > 15$ GeV $\eta\rvert < 2.8$	$2 \leq N_{\mathrm{jets}} \leq 4$ $p_T > 15$ GeV $\lvert\eta\rvert < 3.4$ leading jet $p_T > 25$ GeV and $\lvert\eta\rvert < 2.5$
b tag	≥ 1 (leading jet $p_T > 30$ GeV in 1 b-tag channel)	≥ 1 (require at least one untagged jet for t channel)
Mass Cut	$140 < M_{\ell\nu b} < 210$ GeV $76 < M_{\ell\ell} < 106$ GeV	
acceptance s t	$1.06 \pm 0.08\%$ $0.89 \pm 0.07\%$	$2.7 \pm 0.2\%$ $1.9 \pm 0.2\%$

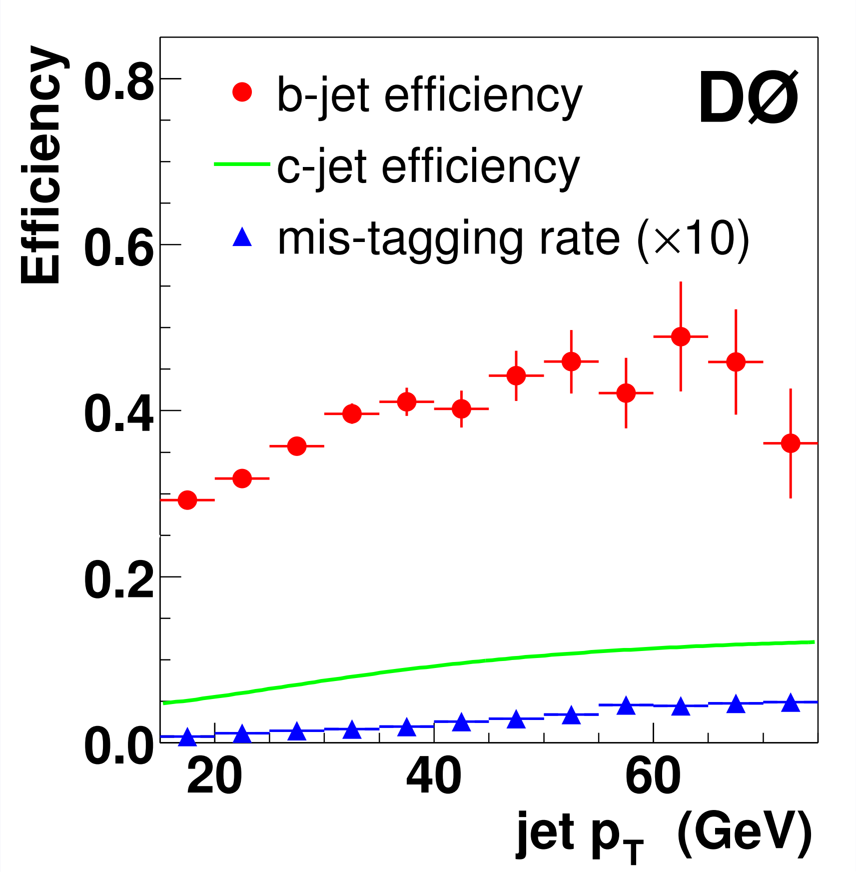




Secondary Vertex Tagger

Explicitly reconstruct 3D vertices using tracks in jets





similar efficiency and mis-tags for CDF (CDF & DØ will utilize taggers with improved efficiency in future analyses)

Events classified by presence of single or multiple tagged jets

Systematic Uncertainties

CDF (fractional changes in ϵ_{evt})

Source	t channel	s channel	combined
JES	$^{+2.4}_{-6.7}$	$^{+0.4}_{-3.1}$	$^{+0.1}_{-4.3}$
ISR	± 1.0	± 0.6	± 1.0
FSR	± 2.2	± 5.3	± 2.6
PDF	± 4.4	± 2.5	± 3.8
Generator	± 5	± 2	± 3
M_t	$^{+0.7}_{-6.9}$	-2.3	-4.4
trigger, ID, $\mathcal{L}$	± 9.8	± 9.8	± 9.8

dominant sources

- b tag: 7%
- luminosity: 6%
- M_t: 4%
- JES: 4%

DØ

normalization	
$\sigma_{t\bar{t}}$ theory & mass	18%
$\sigma_{s(t)}$ theory	$15(16)\%$
jet fragmentation	5%
ℓ ID	5%
shape and normalization	
b tag (single/double)	$10/20\%$
JES	10%
trigger	6%
jet ID	5%

Some uncertainties will improve with increased luminosity

Cut-Based Analysis

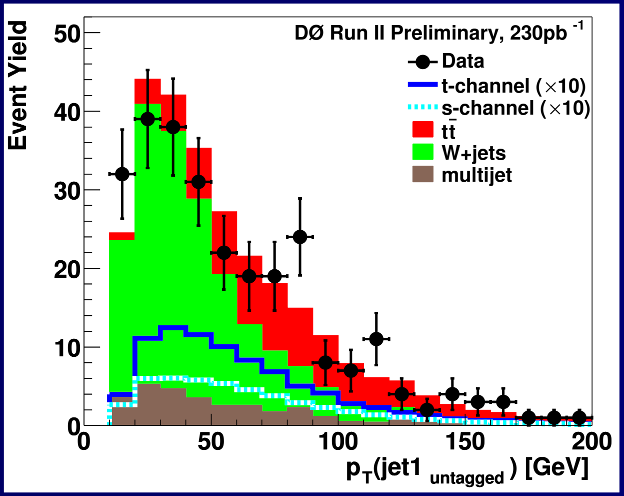
Cut on sensitive variables to isolate single top

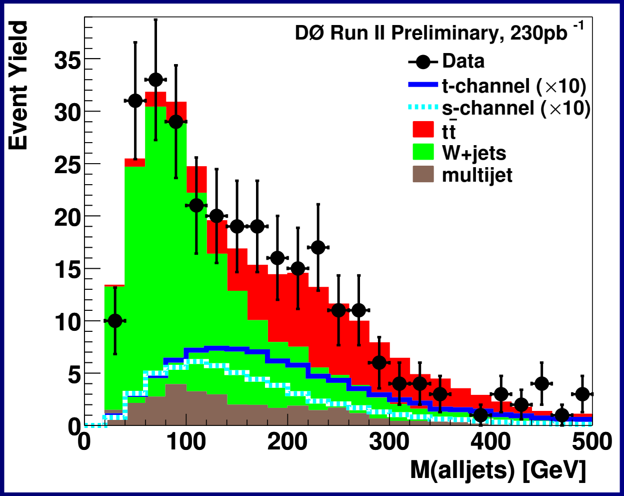
$\mathcal{L} = 230\,\mathrm{pb}^{-1}$

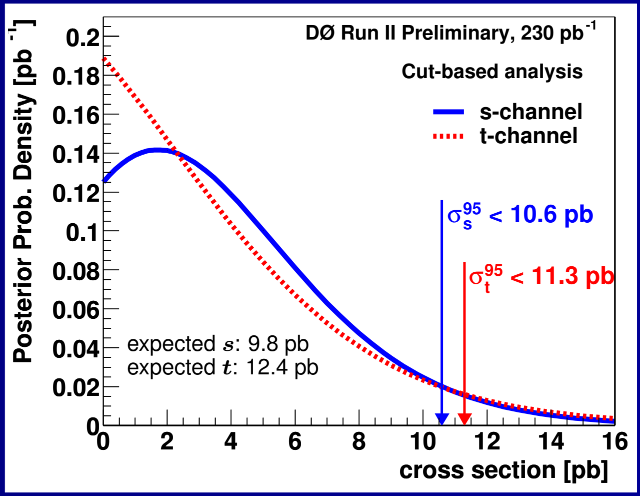
- optimize s- and t-channel searches separately
- loose cuts on energy-related variables
  - p_T of leading jet
  - H_T-like (various combinations)
  - invariant mass

    (various combinations)

	Event Yield	
	s channel	t channel
s channel signal	**4.5**	3.2
t channel signal	5.5	**7**
Background	153 ± 25	149 ± 25
Observed	152	148
Signal/Background	1 : 34	1 : 21



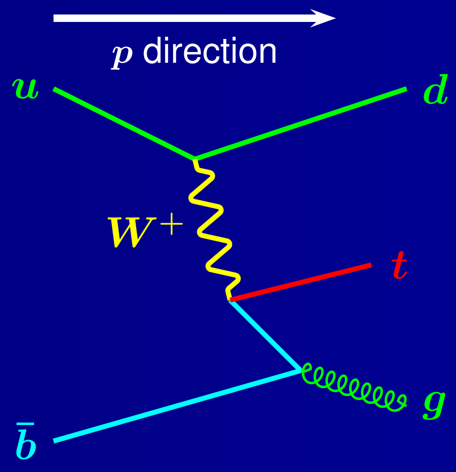




Charge Rapidity Correlation

Charge of the up quark determines charge of the W lepton. In the t channel:

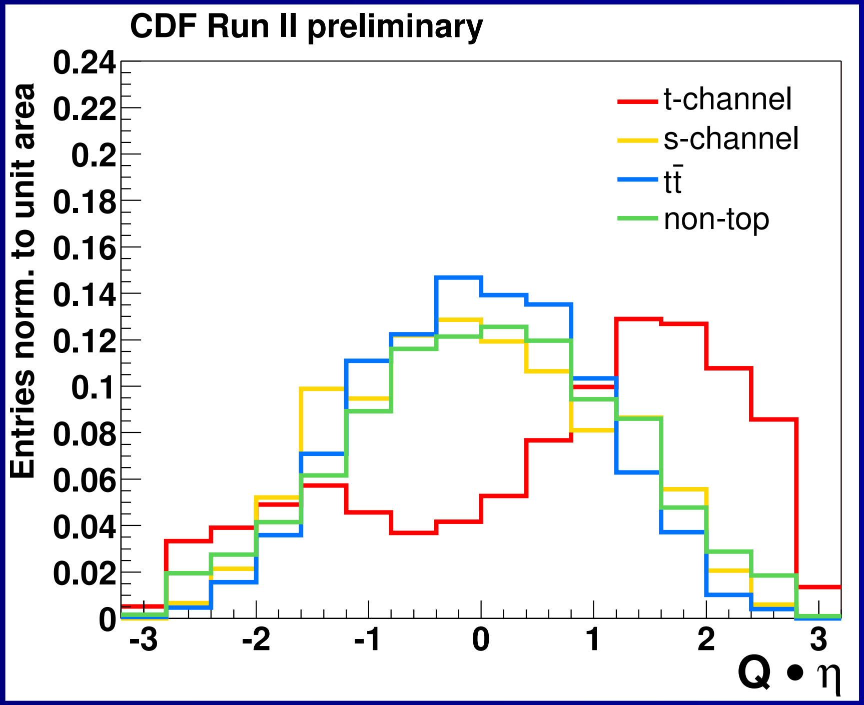
- t: light quark jet in p direction
- $\bar{t}$: light quark jet in $\bar{p}$ direction



Correlation between

- rapidity of untagged jet
- lepton charge

$Q \cdot \eta$ distribution asymmetric for the t channel $\Rightarrow$ look at d-quark jet rapidity normalized by charge

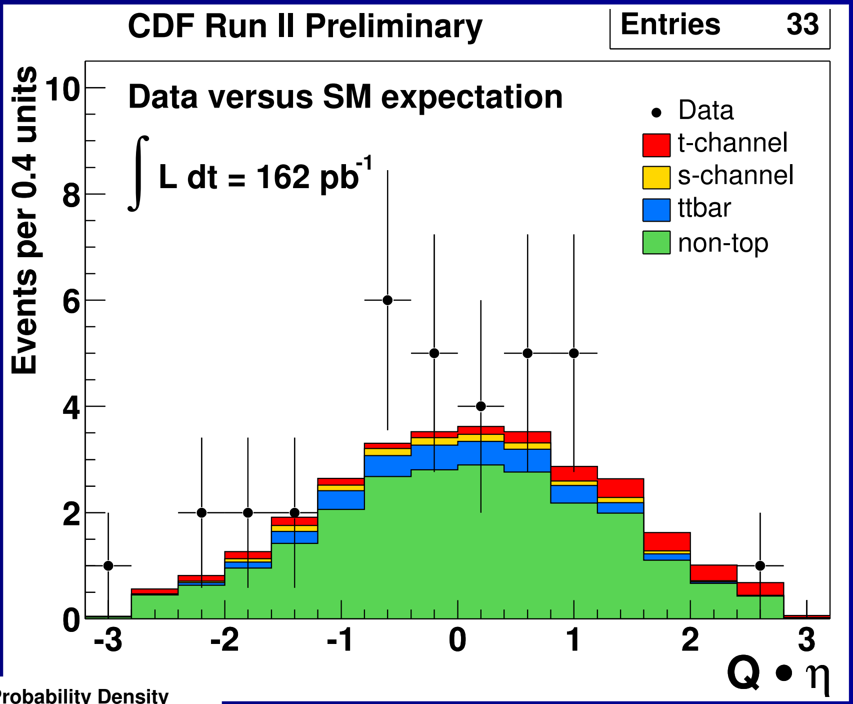


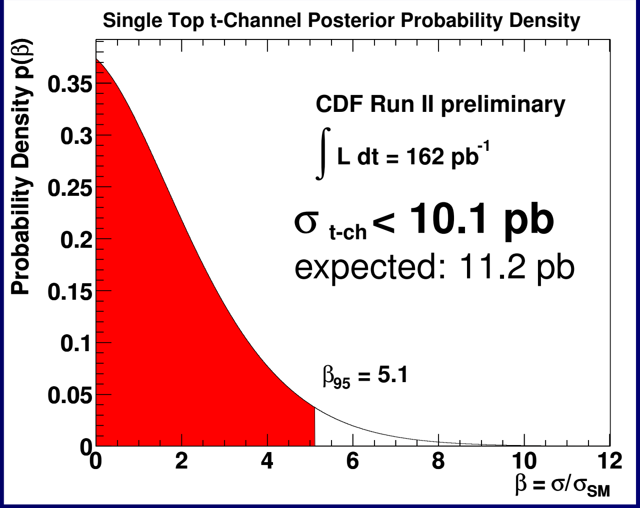
Charge Rapidity Correlation

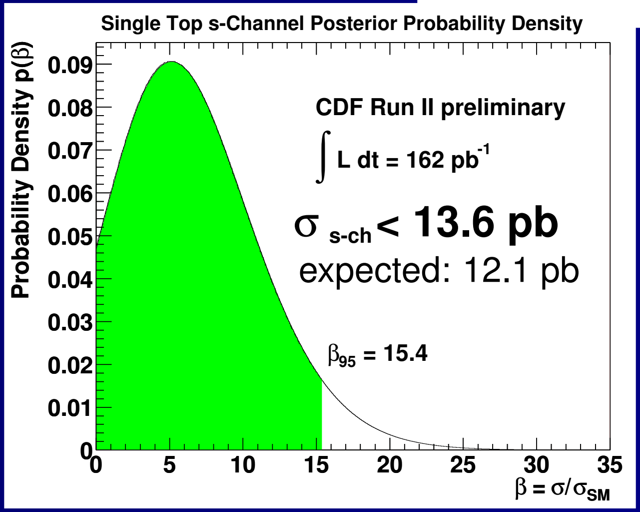
Maximum likelihood fit to the data

- background allowed to float but constrained to expectation
- shape of systematic uncertainties included in likelihood

Phys. Rev D71, 012005 (2005)





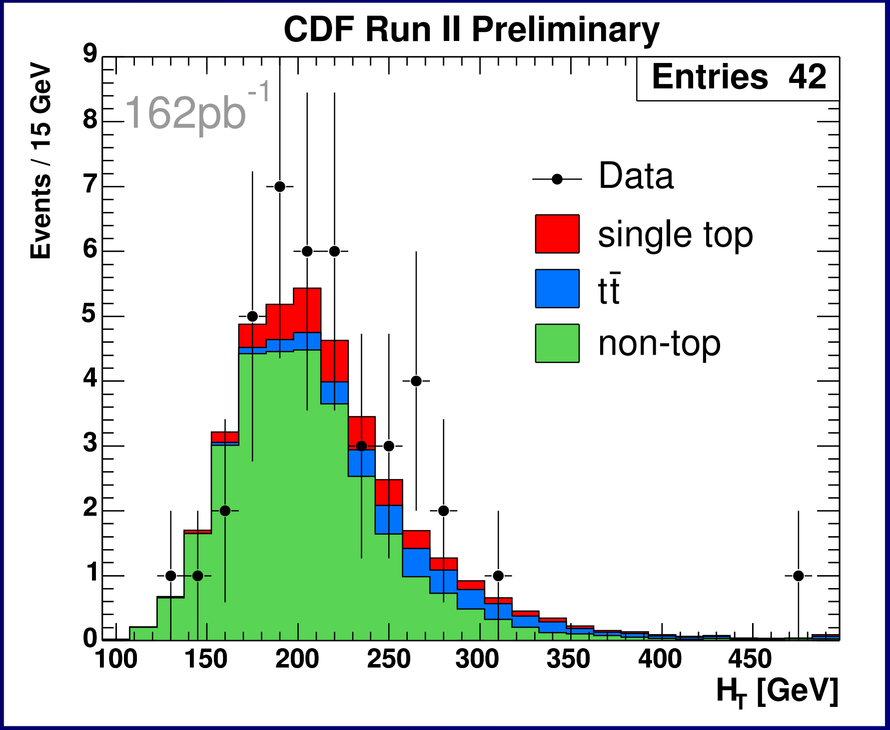


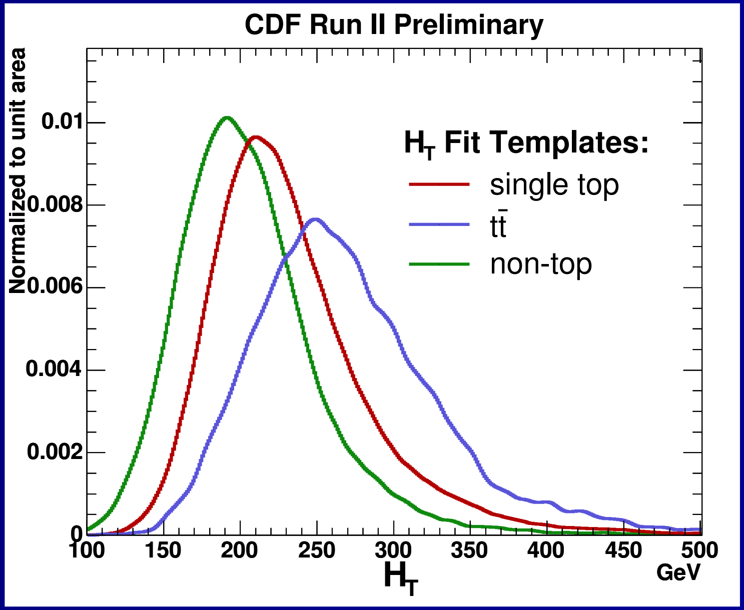
$$\mathcal{L} = 162\,\mathrm{pb}^{-1}$$

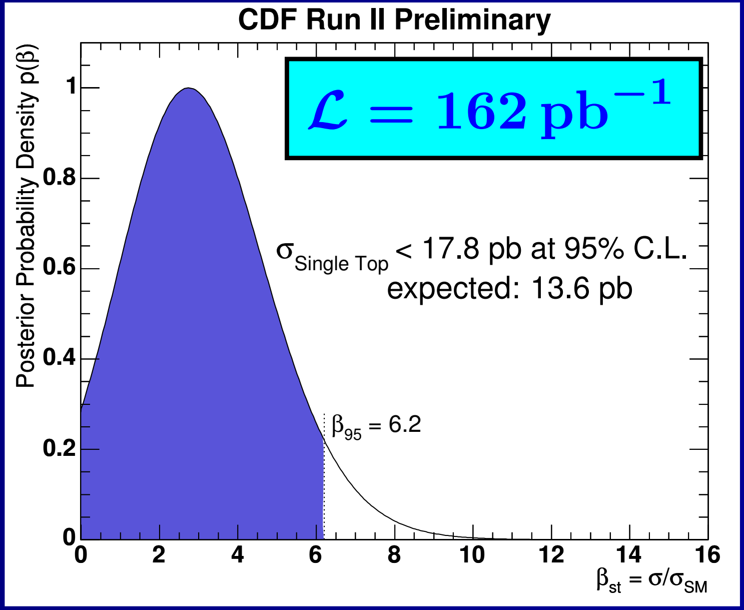
Combined Search

H_T distribution similar for s- and t-channel single top production, but different for background processes.

Phys. Rev D71, 012005 (2005)



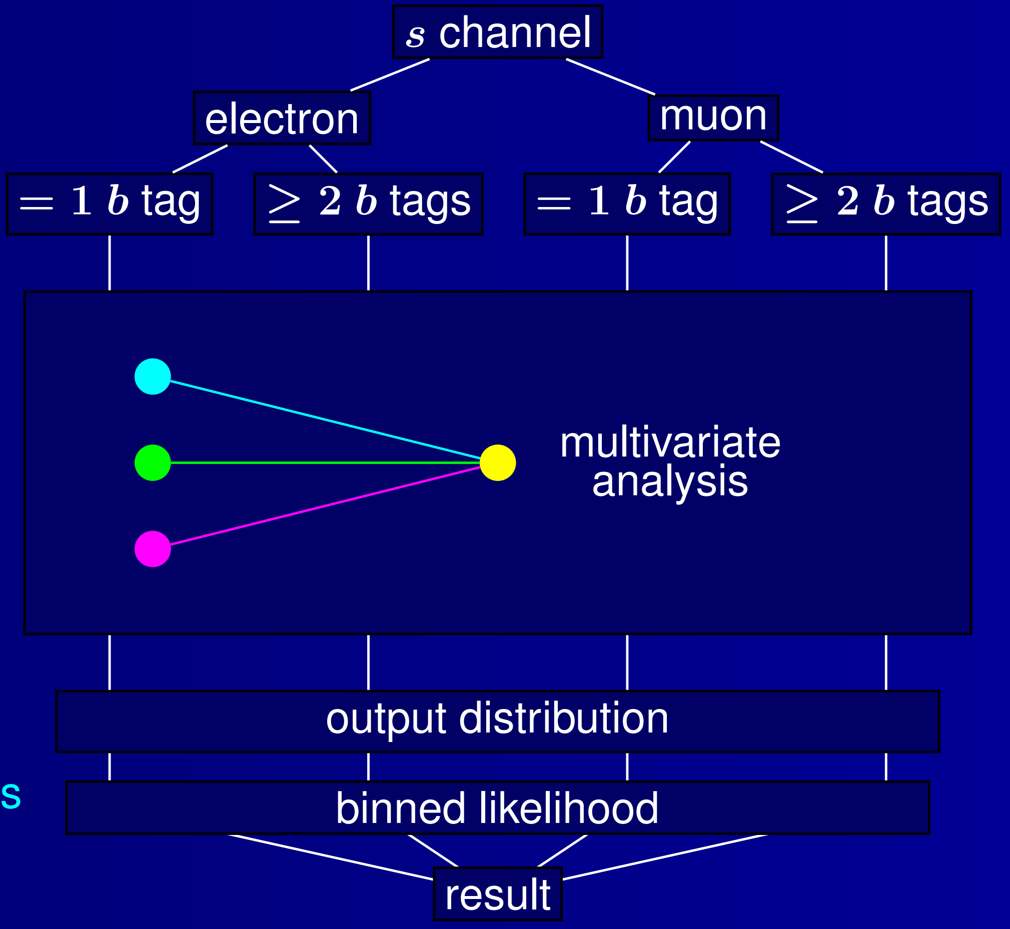




Multivariate Analyses

Use multivariate analysis techniques to separate signal from background

- neural networks
- decision trees
- likelihood discriminant



$\Rightarrow$ loosen selection cuts to maximize signal. In each analysis, optimize separately on

- s- and t-channel
- e and μ channel
- number of b tags

8 separate samples

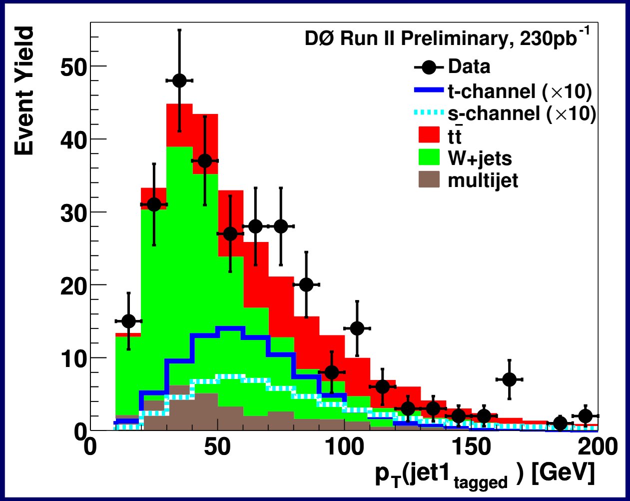
and focus on dominant backgrounds: W+jets and $t\bar{t}$

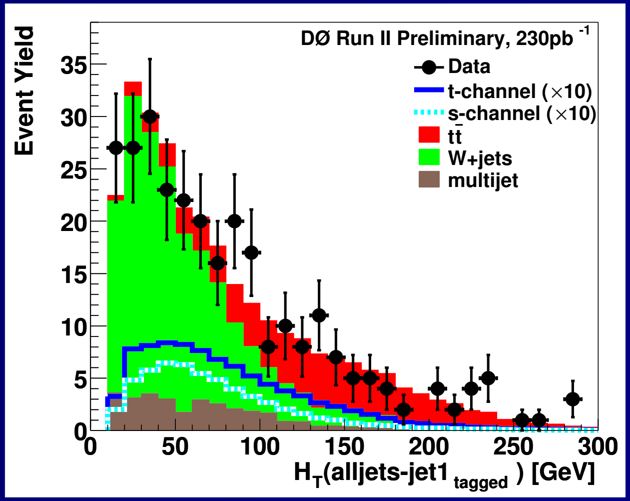
see Y. Coadou's talk on Friday for additional details

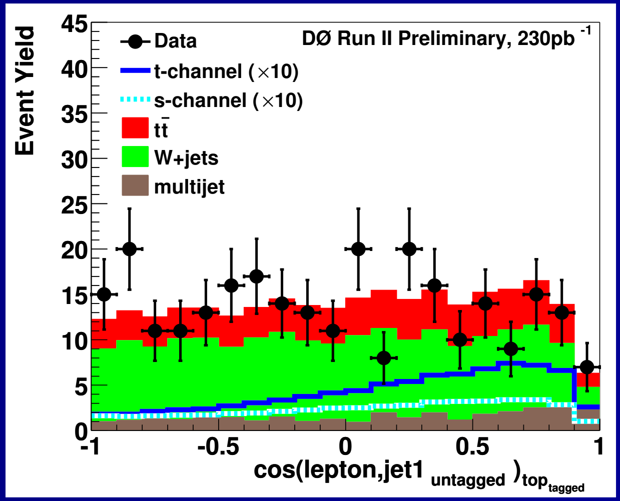
Neural Network

3 broad categories of variables; 25 distributions

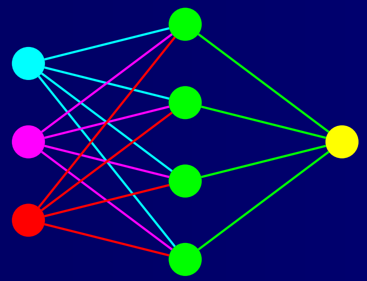
object kinematics global event kinematics angular correlations



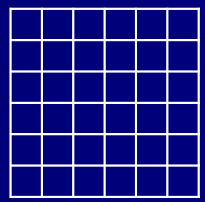




Two networks per analysis



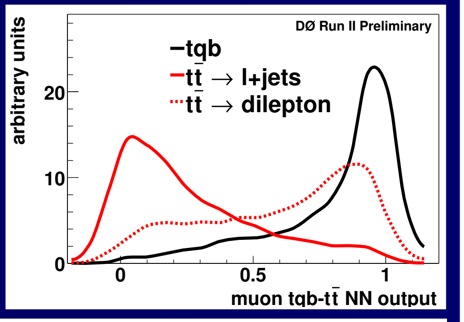
trained on
signal & $t\bar{t}$

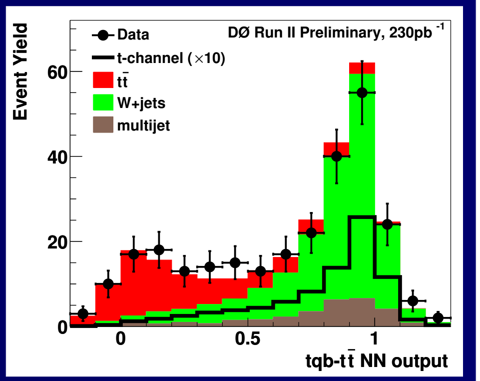


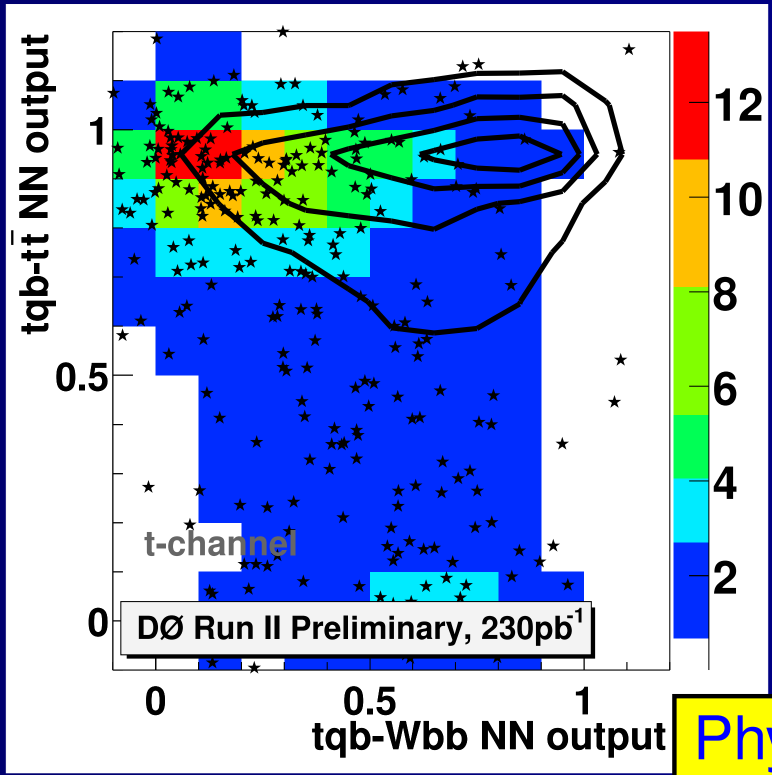
trained on
signal & $Wb\bar{b}$

Systematic uncertainties were calculated for each bin, then repeated for all bins to properly account for shape fluctuations.

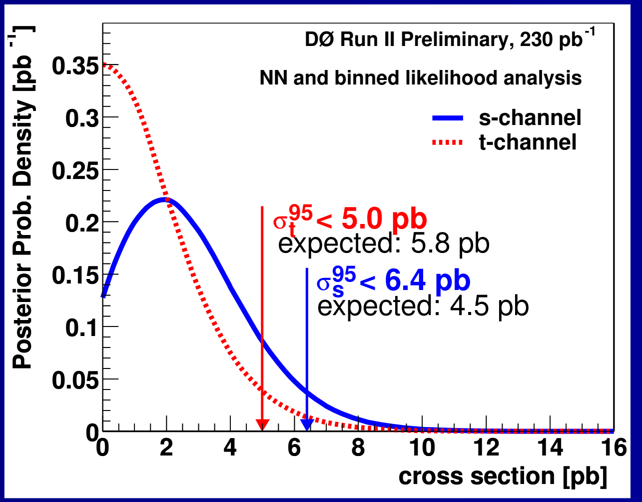
Neural Network



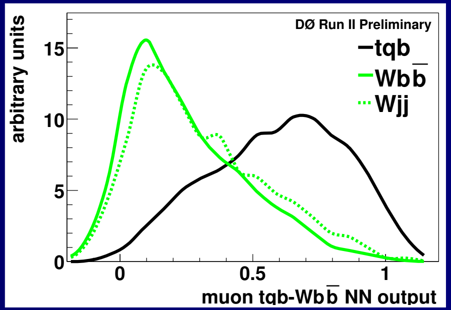


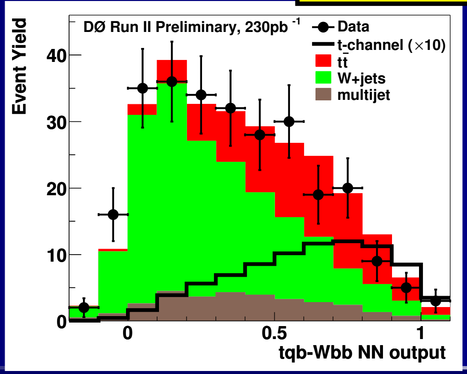


Limit extracted from 2D binned likelihood



Phys. Lett. B622, 265 (2005)

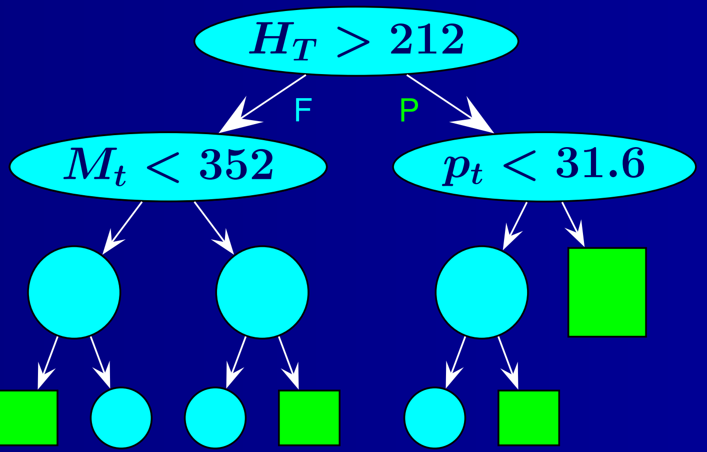




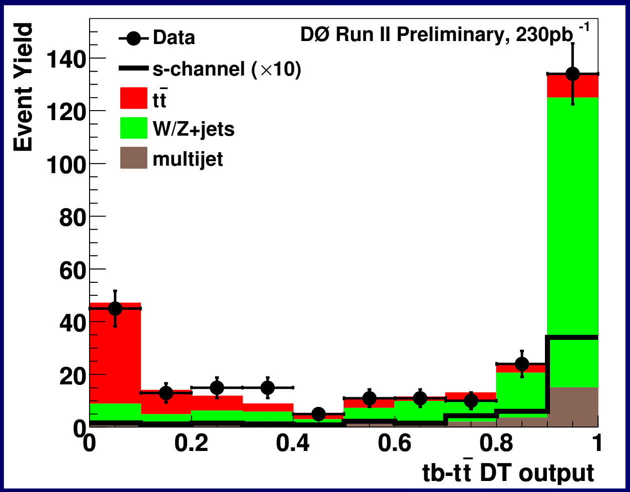
$$\mathcal{L} = 230\,\mathrm{pb}^{-1}$$

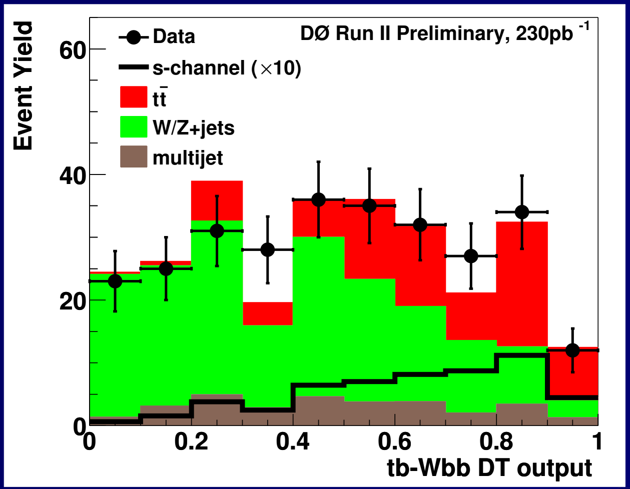
Decision Trees

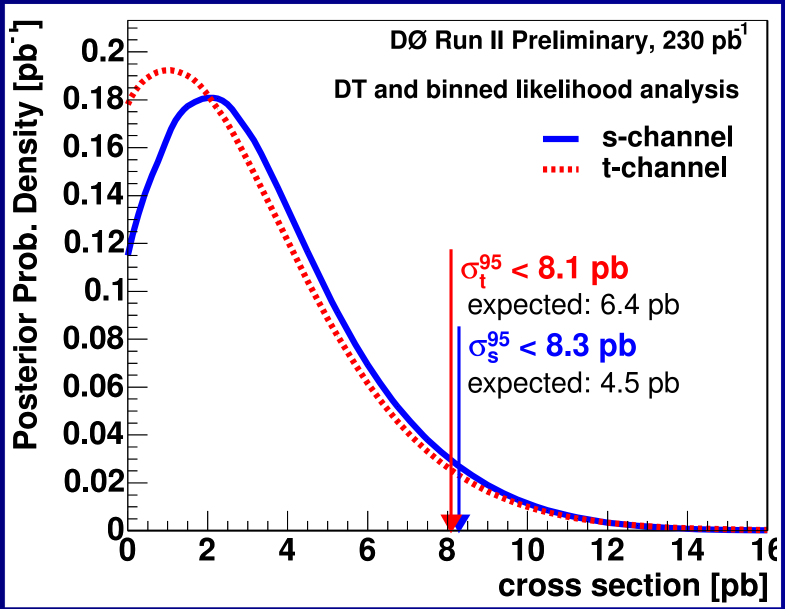
Yields probability for an event to be signal. Follow the NN approach: same configuration, samples, and variables.



$$\mathcal{L} = 230\,\mathrm{pb}^{-1}$$

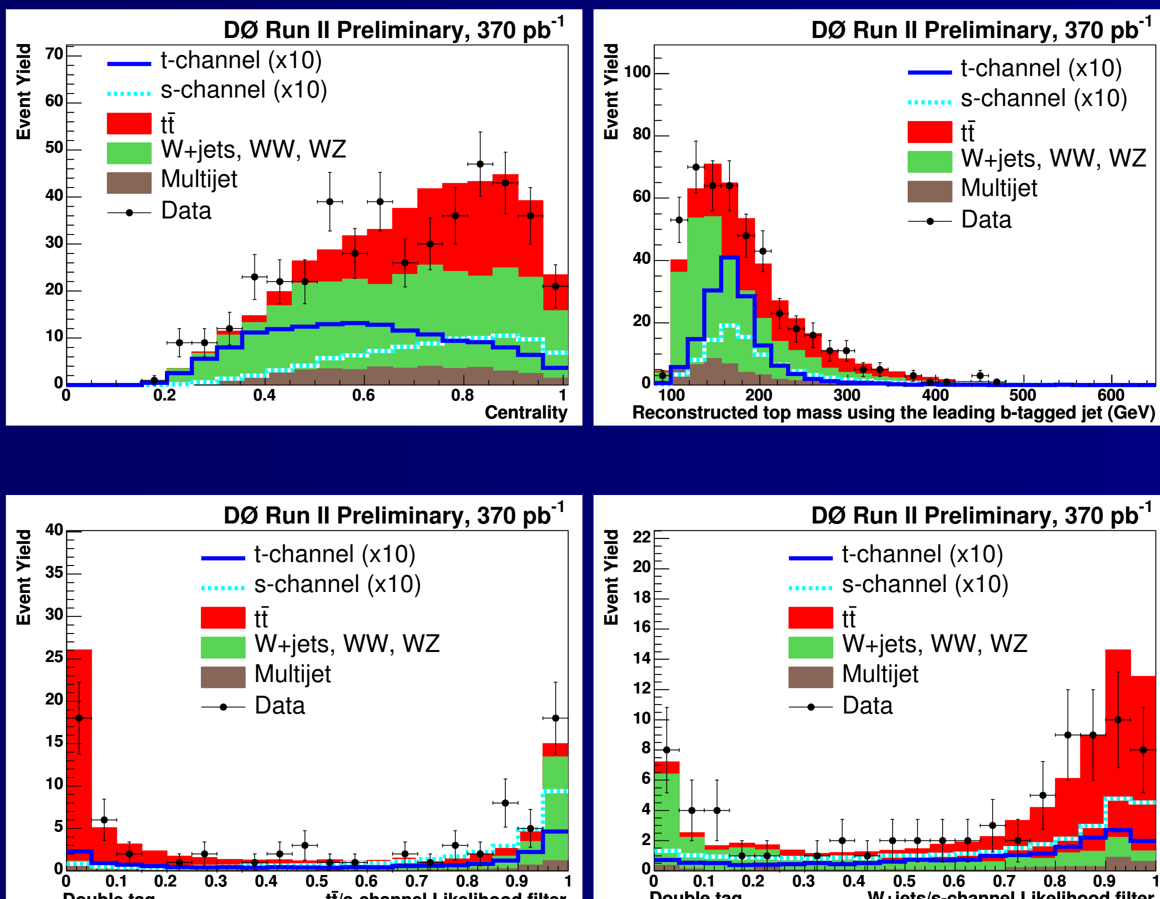






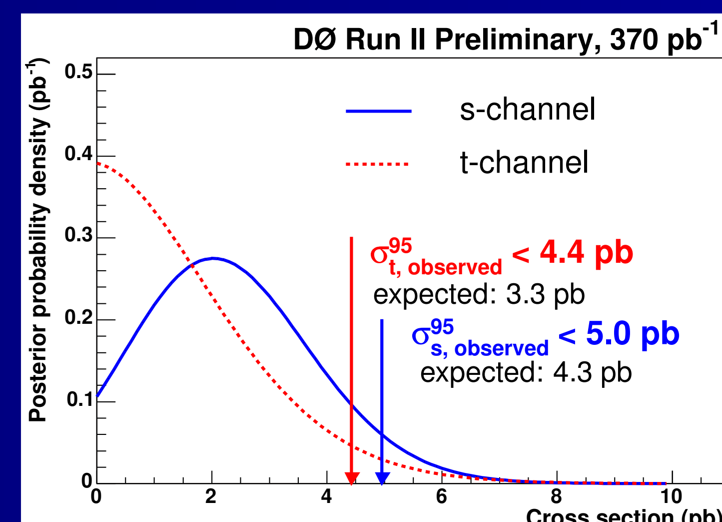
Likelihood Discriminant

Use a likelihood discriminant to separate signal from background. An impact-parameter based b tagger was used instead of SVT. Samples defined similar to the NN/DT analyses.



best limit on single top production

$$\mathcal{L} = 370\,\mathrm{pb}^{-1}$$



Summary

- Single top quark production has not yet been observed (expected/observed):
  s-channel limit: $4.3/5.0$ pb (compared to 0.9 ± 0.1 pb SM expectation)
  t-channel limit: $3.3/4.4$ pb (compared to 2.0 ± 0.2 pb SM expectation)
- Limits can still constrain potential new physics.
- 3σ evidence can be expected with $\approx 1.5\ \mathrm{fb}^{-1}$ (ignoring systematics).
- CDF and DØ are exploring improved multivariate analysis techniques with the $1\ \mathrm{fb}^{-1}$ data sample. Initial results should be available soon.