New Results from Single-Top Searches with the CDF II Detector

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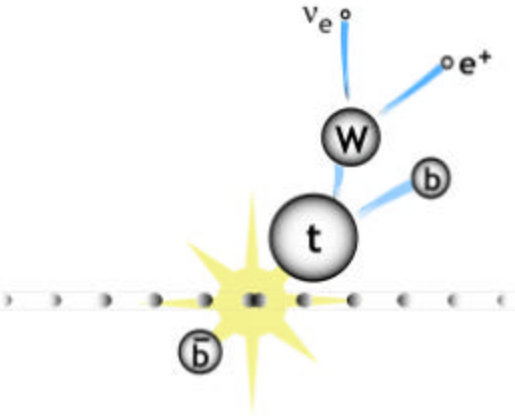
for the CDF Collaboration



DPF 2004, Riverside, August 30, 2004

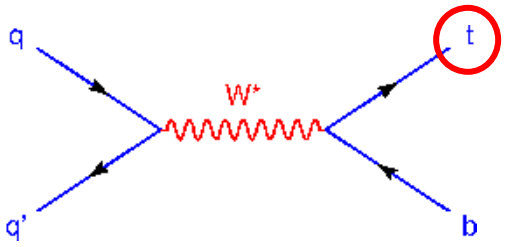
Single Top Production

Run I at the Tevatron:

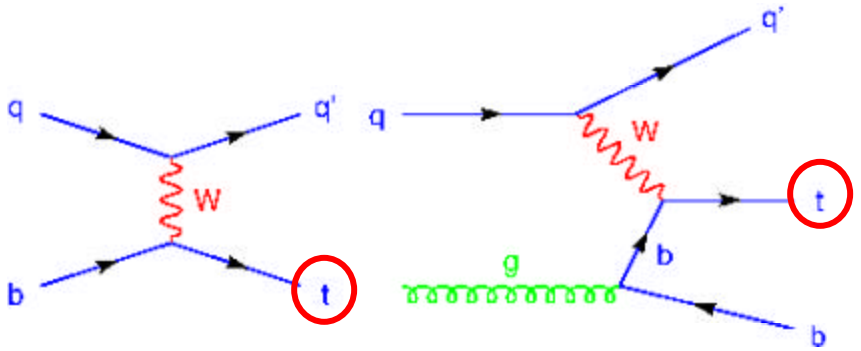
DØ Run I Limits at 95% C.L.:
t-channel: 22 pb ($ß_{95}$=15.2)
s-channel: 17 pb ($ß_{95}$=22.7)

CDF Run I Limits at 95% C.L.:
t-channel: 13 pb ($ß_{95}$=9.0)
s-channel: 18 pb ($ß_{95}$=23.7)
Combined: 14 pb ($ß_{95}$=6.5/6.2)
NN: 24 pb ($ß_{95}$=11.1/4.8)

$ß \propto s/s_{SM}$



s-channel production (W)*



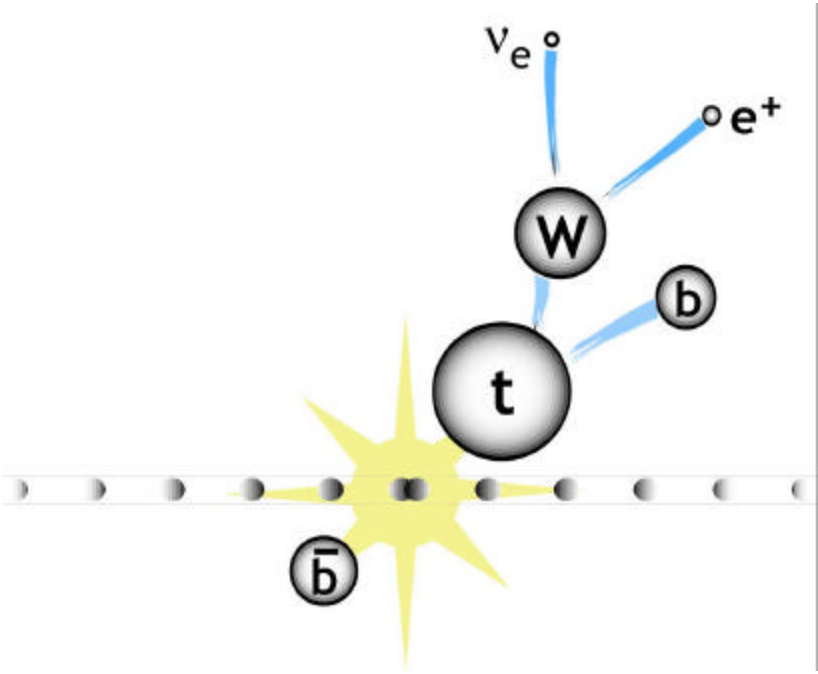
t-channel production (Wg fusion)

$s^{1/2}$ =1.96TeV	NLO Cross-sections
t-channel	1.98±0.25 pb
s-channel	0.88±0.11 pb

B.W. Harris et al.: Phys. Rev. D 66, 054024
Z. Sullivan hep-ph/0408049

Analysis Overview

- Look in the **W+2 jets** channel:
  - 1 lepton with E_T>20 GeV, |η|<1.0
  - missing transverse energy: MET>20 GeV
  - 2 jets : E_T> 15 GeV, |η| < 2.8
  - at least one b-tag (displaced sec. vertex)
  - Veto Z, dilepton, conversion events



- Topological cuts:
  - 140 < M_{lvb} <210 GeV/c^2
    (combined and separate searches)
  - leading jet E_T > 30 GeV
    (separate search for t-channel only)

- Backgrounds: non-top and $t\bar{t}$

Single-Top Analyses

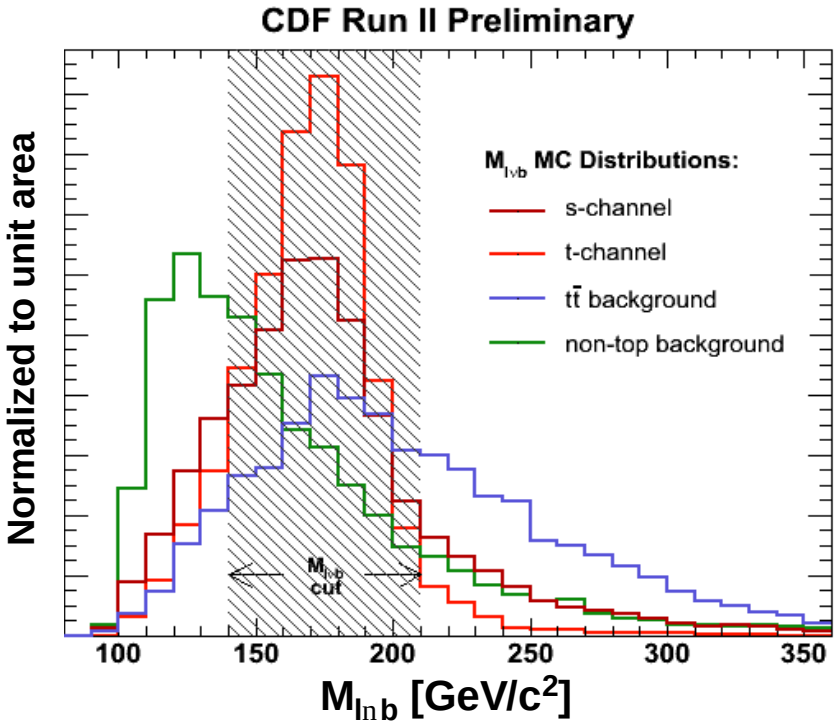
- We present two analyses: combined and separate searches
- Combined Search:
  - Signal: s-channel and t-channel single-top events
  - Both cross-sections proportional to $|V_{tb}|^2$
  - Exploits distributions similar for s- and t-channels:
    - H_T = the total transverse energy in the event (E_T^{lep} + MET + ΣE_T^{jet})
- Separate Search:
  - 1. Signal = t-channel (s-channel is a background)
    - FCNC couplings, anomalous V+A contributions to the W-t-b vertex, etc.
    - Q•η variable (Q = lepton charge, η = pseudorapidity of non b-tagged jet)
    - Q•η asymmetric in t-channel events: N(Q•η>0) = 2* N(Q•η<0)
  - 2. Signal = s-channel (t-channel is a background)
    - Heavy charged vector bosons W', CP-violation effects within MSSM, Kaluza-Klein excited W-boson within MSSM
    - Double b-tags – simple counting

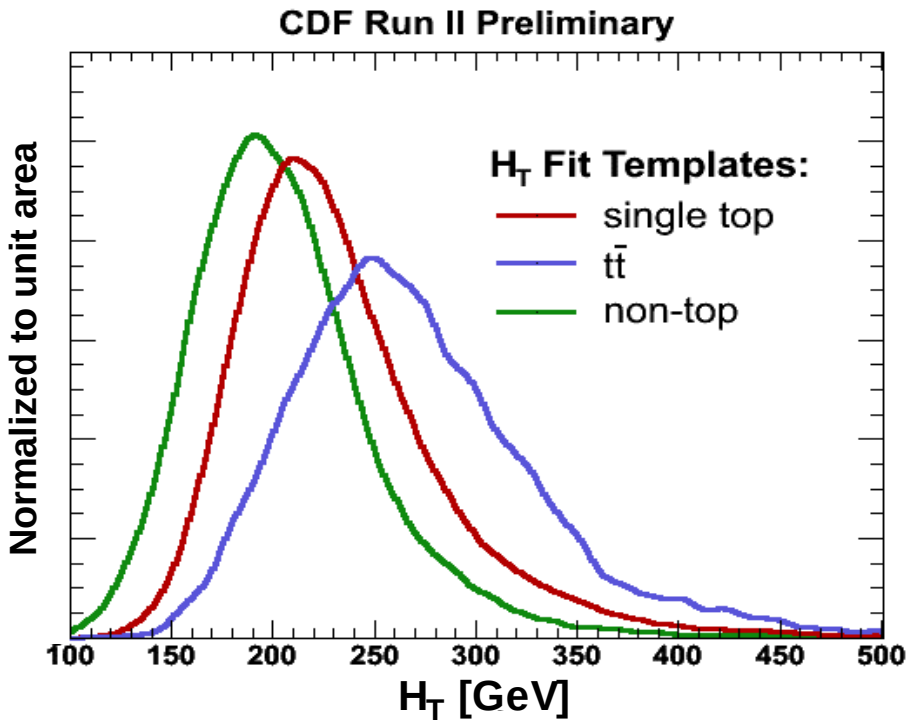
Recent Improvements

- Better background modeling:
  - We now include the individual contributions to the non-top backgrd.
- Better signal modeling:
  - Previous analyses used Pythia:
    - Spin correlations are not incorporated in Pythia
    - For t-channel, 2nd b-quark P_T spectrum is softer in Pythia than the NLO result
  - MadEvent (TopReX used for extracting systematic uncertainty on MC signal model):
    - Parton showering still done by Pythia
    - Both generators reproduce the expected top polarization distributions
    - We mix two t-channel samples: 2->2 (b-pdf) and 2->3 (g-pdf)
      (E.E. Boos, L.V.Dudko, V.I.Savrin, CMS Note 2000/065)
- Improved systematic uncertainties calculation:
  - ISR/FSR uncertainties evaluated by tuning radiation in Pythia.
  - Now use a likelihood function with built in factors for the systematic uncertainties (correlations among them naturally accounted for).

Templates for Combined Search

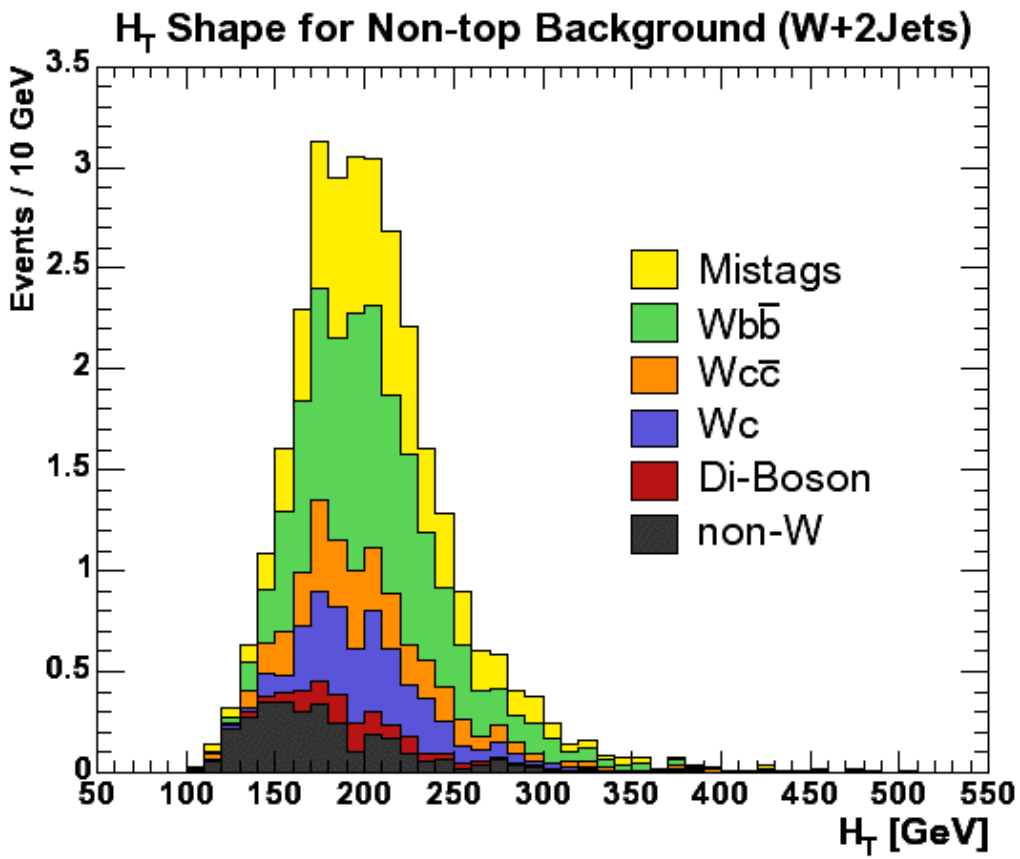
- Two-variable analysis: cut on reconstructed top mass $M_{l\nu b}$ then fit the total transverse energy H_T





Non-top Background for Combined Search

- Non-top background for L=162 pb^{-1} after M_{lvb} cut:



CDF Run II Preliminary

Process	N in 162 pb^{-1}
$Wb\bar{b}$	11.0 ± 3.4
$Wc\bar{c}$	3.6 ± 1.1
Wc	3.8 ± 1.1
Mistags	7.5 ± 1.6
Non-W	3.0 ± 0.7
Diboson	1.0 ± 0.2
Total non-top	**30.0 ± 5.8**

Event Count Combined Search

CDF Run II Preliminary

Process	Number of events/162 pb^{-1}
$t\bar{t}$	3.8 ± 0.9
Non-top	30.0 ± 5.8
Sum Background	33.8 ± 5.9
t-channel	2.8 ± 0.5
s-channel	1.5 ± 0.2
Sum Single-Top	4.3 ± 0.5
Sum Expected	**38.1 ± 5.9**
Observed	**42**

S/B = 12 %

Likelihood Function

- Improved Likelihood Function:

$$L(s_s, s_{b_1}, s_{b_2} \mid d_1,\ldots,d_7) = \prod_{k=1}^{N_{bins}} \frac{e^{-\mu_k} \cdot \mu_k^{n_k}}{n_k!} \cdot \prod_{j=1,2} G(s_{b_j} \mid s_j^{exp}, \Delta_j^{exp}) \cdot \prod_{i=1}^{7} G(d_i \mid 0,1)$$

Poisson, bin k b_1, b_2, Gauss constraints syst. uncert.

Expected mean in bin k:

$$\mu_k = \sum_{j=1}^{3} s_j \cdot \left\{ \prod_{i=1}^{7} \left[1 + \mid d_i \mid \cdot \left(e_{ji+} H(d_i) + e_{ji-} H(-d_i) \right) \right] \right\}$$

$$\cdot a_{jk} \cdot \left\{ \prod_{m=1}^{7} \left[1 + \mid d_m \mid \cdot \left(k_{jmk+} H(d_m) + k_{jmk-} H(-d_m) \right) \right] \right\}$$

k = bin index

j = process index

i,m = syst. effect index

$e_{ji+/-}$ = acc. shifts

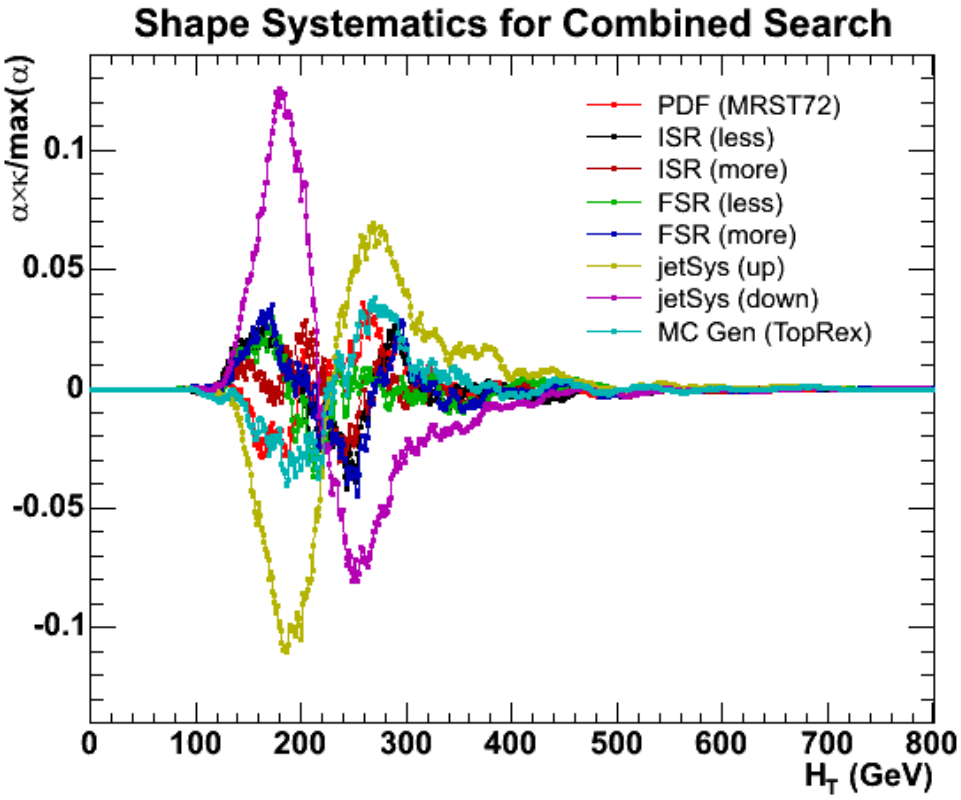
$k_{jmk+/-}$ = shift, bin k

Acceptance Uncertainties ε's

CDF Run II Preliminary

		Separate Search		Combined Search
No.	Source	t-channel	s-channel	
1	Jet en. scale (+1σ/-1σ)	+2.4 / -6.7%	+0.4 / -3.1%	+0.1 / -4.3%
2	ISR	±1.0%	±0.6%	±1.0%
3	FSR	±2.2%	±5.3%	±2.6%
4	PDF	±4.4%	±2.5%	±3.8%
5	MC Generator	±5.0%	±2.0%	±3.0%
6	Top mass (-5 /+5 GeV)	-6.9 / +0.7%	-2.3%	-4.4 / -0.7 %
7	ε_{trig}, ε_{ID}, luminosity	±9.8%	±9.8%	±9.8%

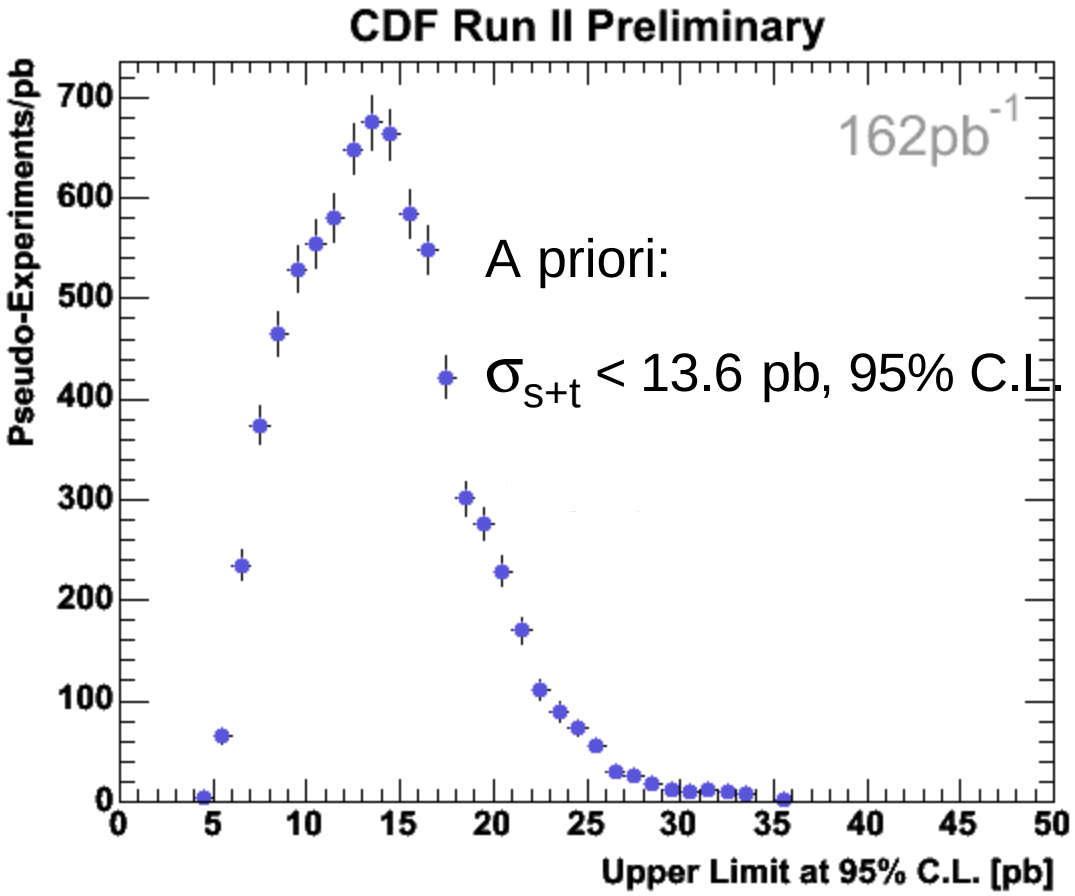
Shape Uncertainties κ's



- For a given systematic effect *m*, κ_{jmk}'s are obtained from the difference between the shifted H_T template and the default H_T template, divided by the default bin contents α_{jk}

$$\left\{\prod_{i=1}^{7}(1+e_{ji}\cdot d_i)\right\}\cdot a_{jk}\cdot\left\{\prod_{m=1}^{7}(1+k_{jmk}\cdot d_m)\right\}$$

A-priori limits
Combined Search



Run *N*=7000 simulated (MC) experiments. The 95% C.L. limit b_{95} is defined as the median of the *N* individual upper limits:

A-priori, no syst: 12.4 pb

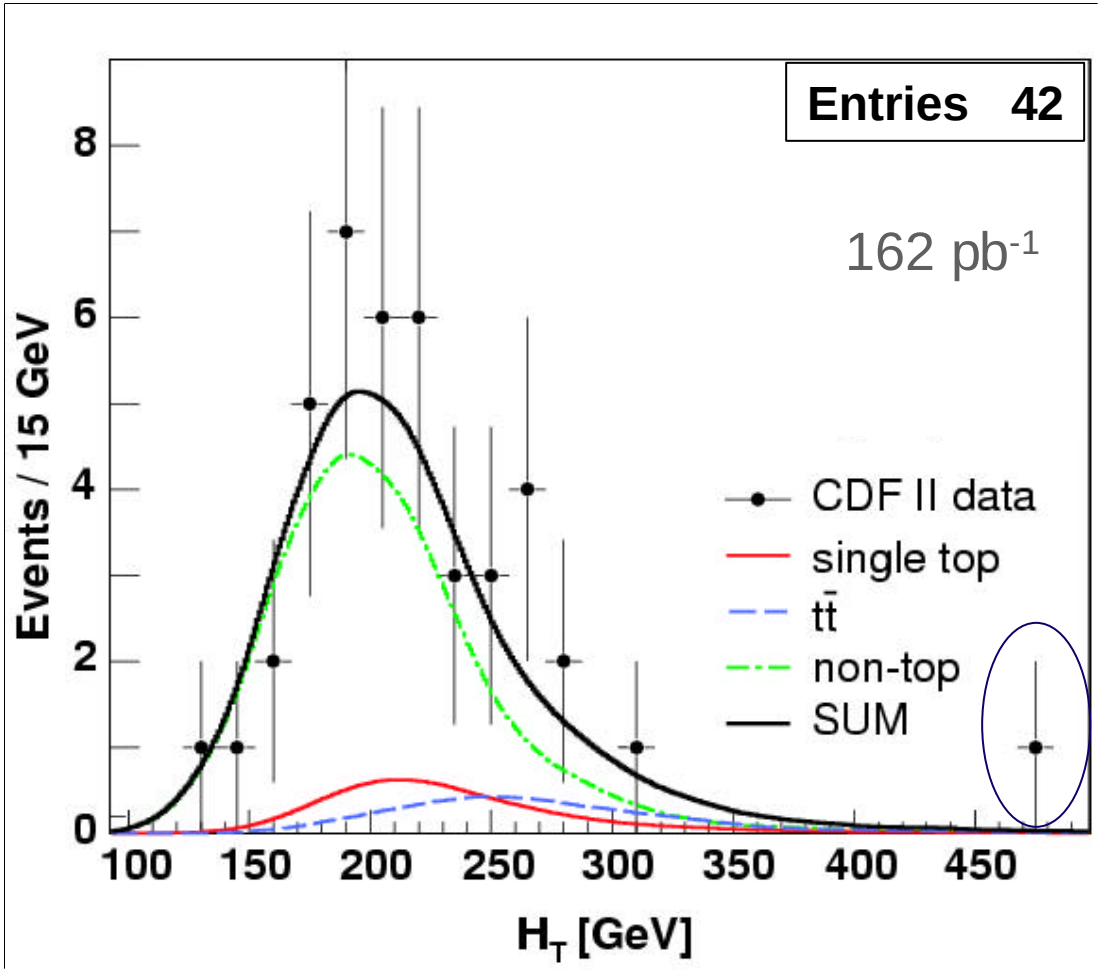
b_{95} **= 4.3**

A-priori, w/ syst: 13.6 pb

b_{95} **= 4.8**

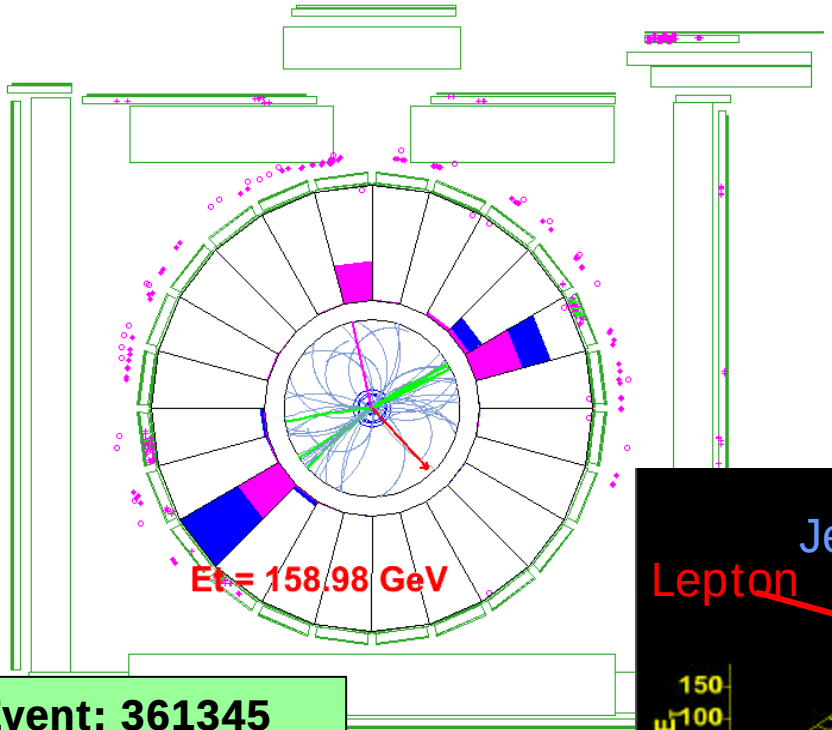
CDF II Data

CDF Run II Preliminary

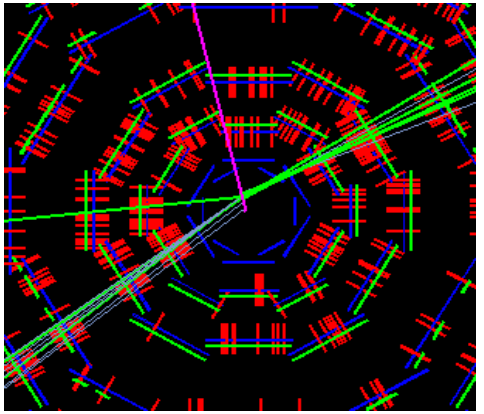


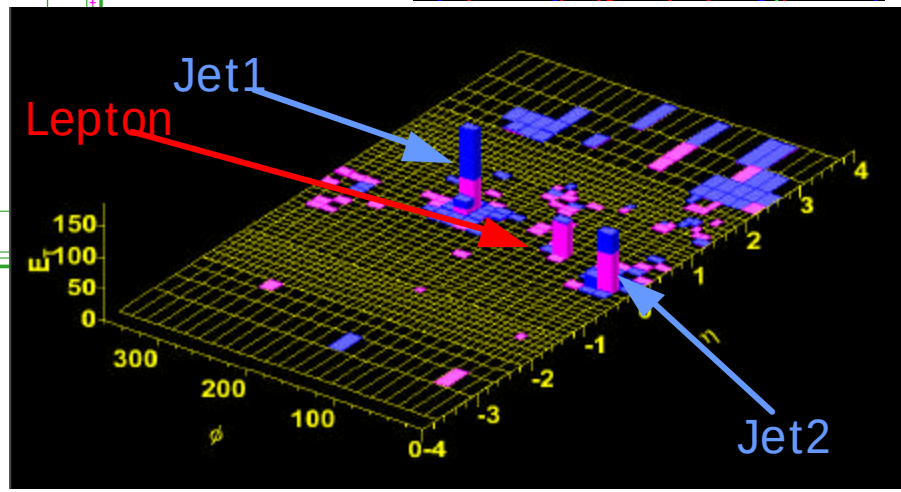
Event Display

The least “non-top-like” event (H_T = 475 GeV, M_{lvb}=173 GeV/c^2):



SVX L1/2/3 and L00

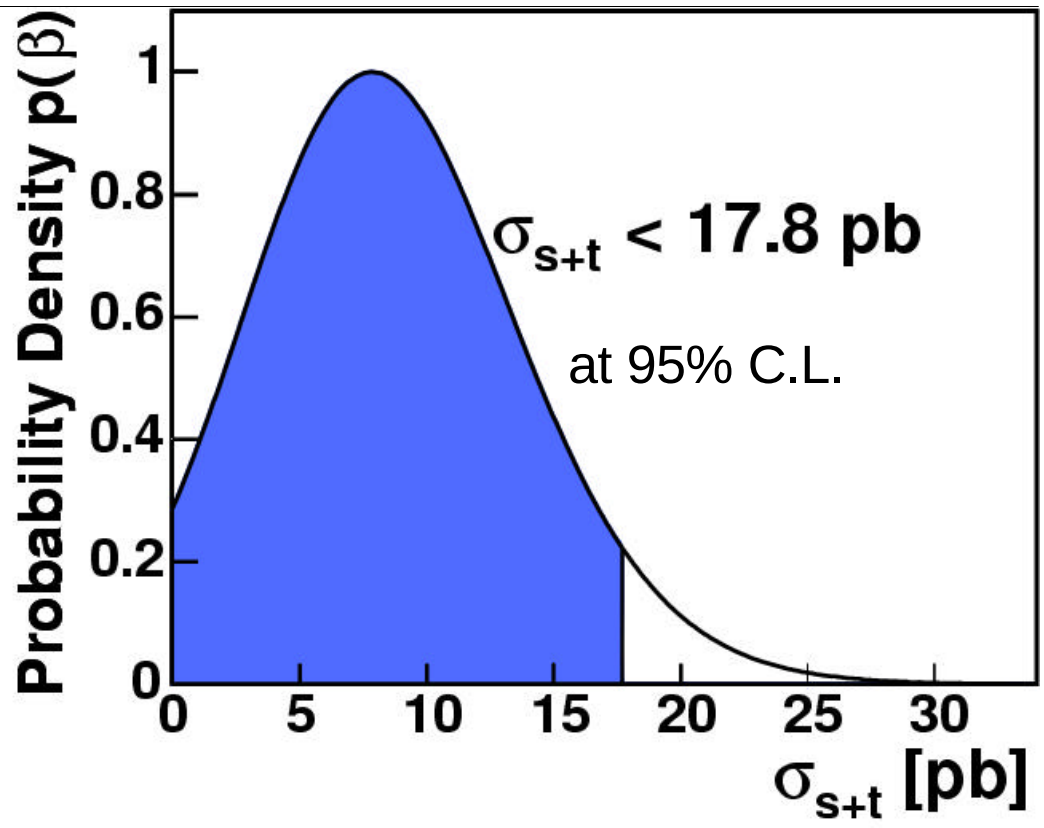




Run: 153389 · Event: 361345

- CEM Electron E_T=50.9 GeV, η =0.24
- MET=25.7 GeV, Phi=5.6
- Jet1 E_T=173.8 GeV, η =0.45
- Jet2 E_T=149.8 GeV, η =-0.13

95% CL Limit from Data Combined Search



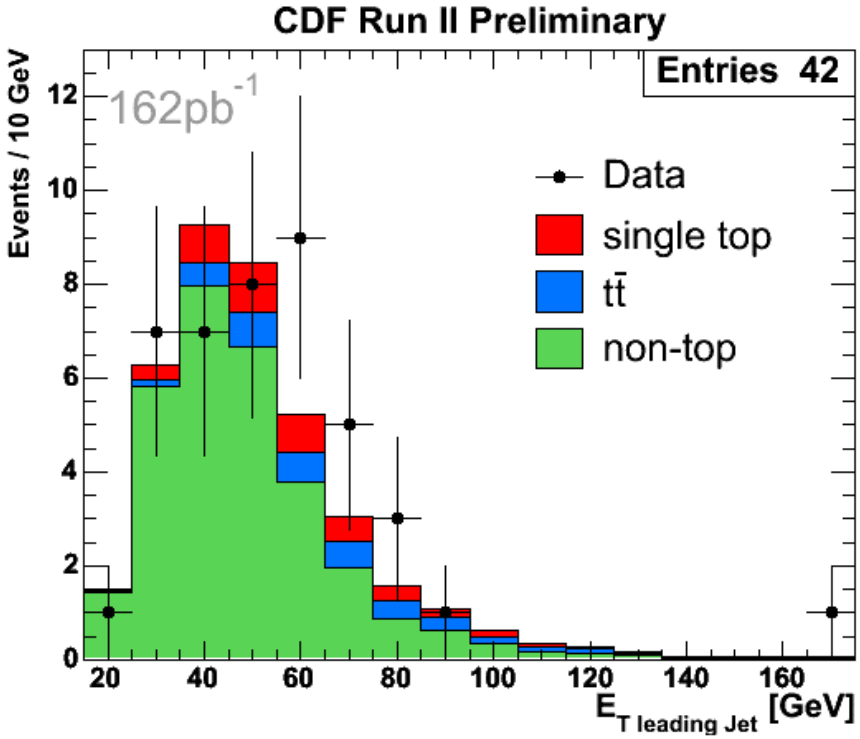
95% CL upper limit higher than expected (a-priori). A-posteriori, including systematic uncertainties:

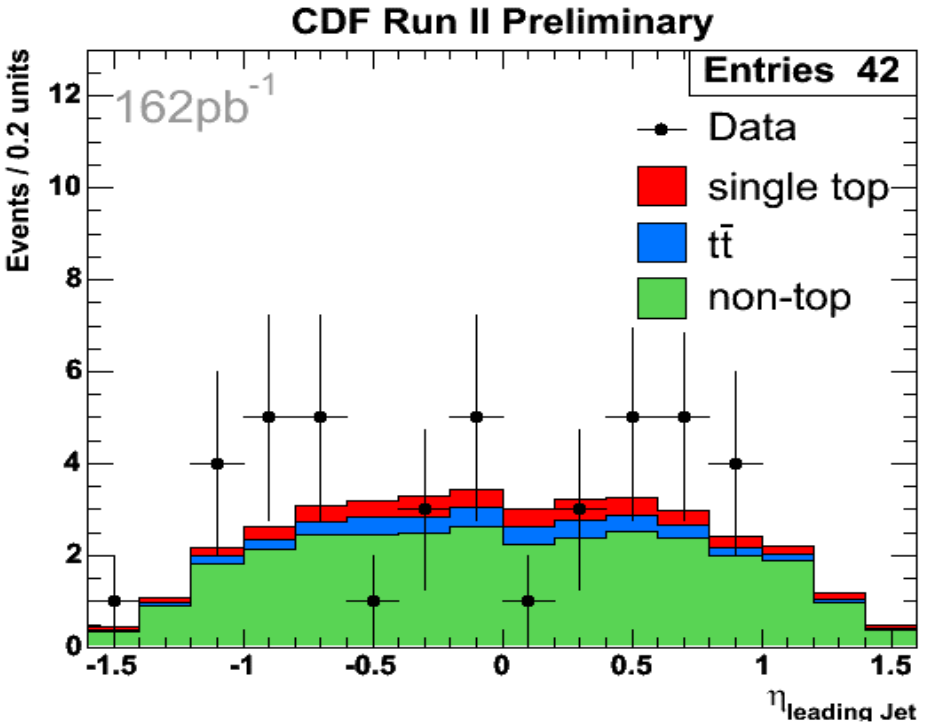
s_{95} = **17.8 pb**

b_{95} = **6.2**

Kinematic Plots for Combined Search

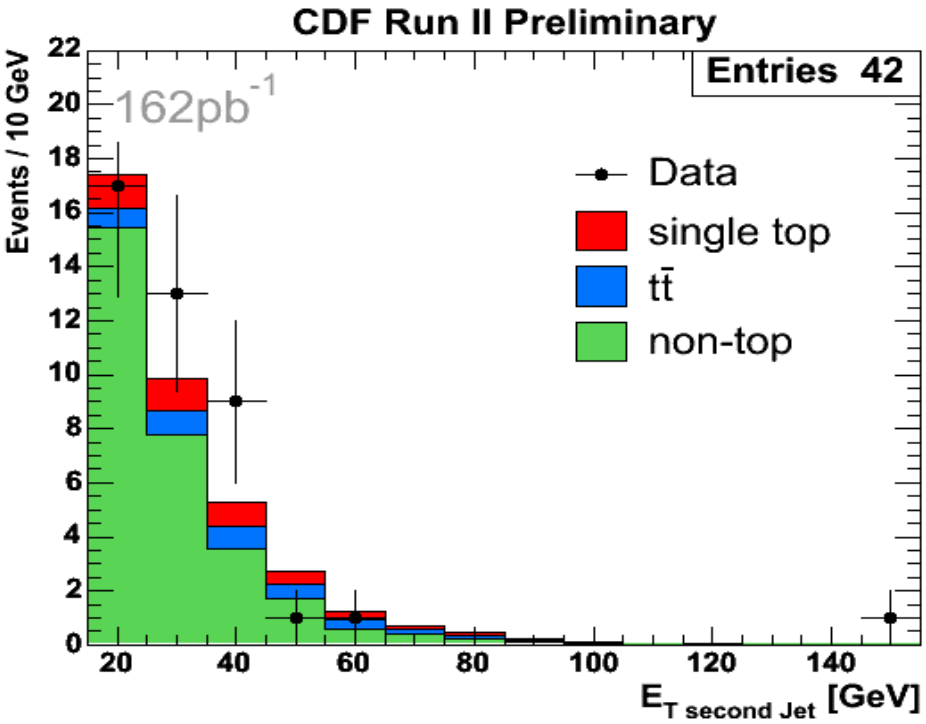
Highest E_T (leading) jet: E_T and η distributions

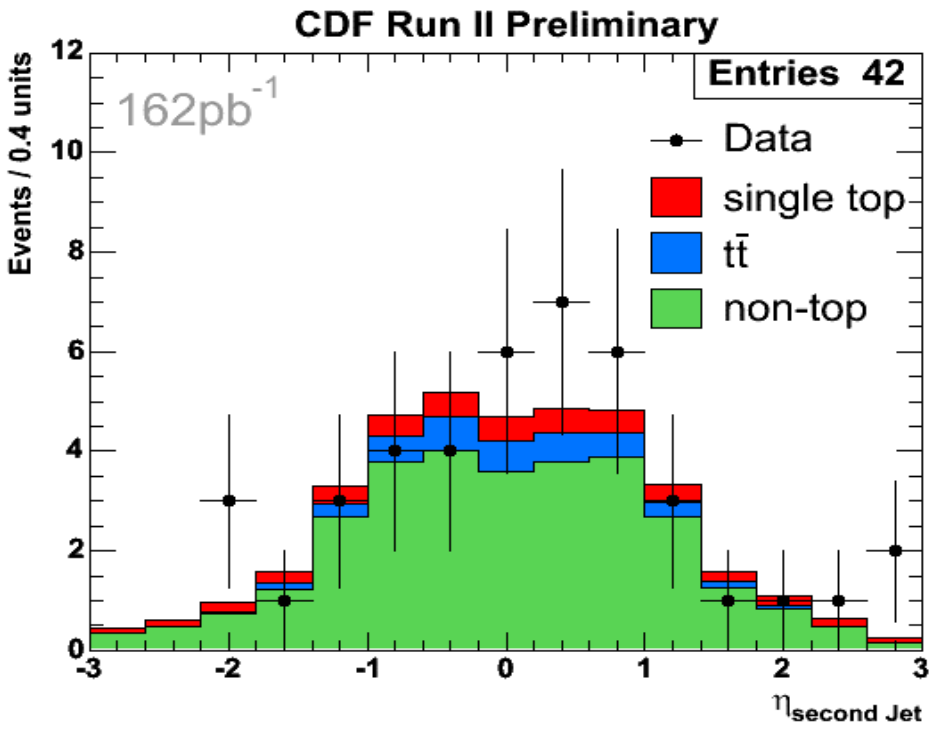




Kinematic Plots for Combined Search

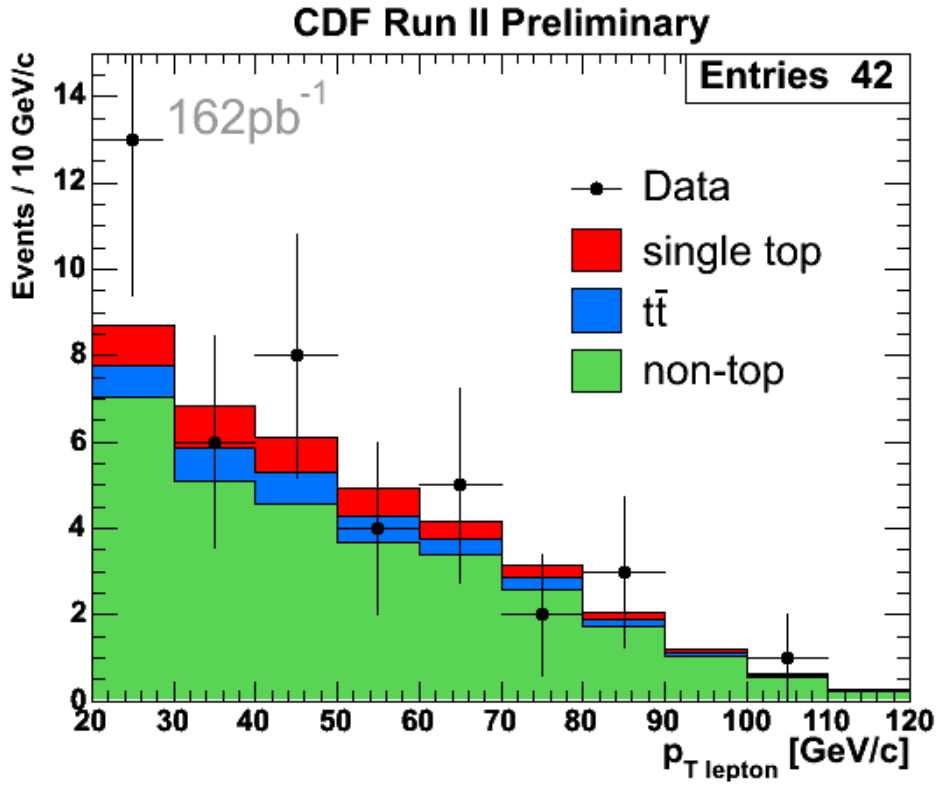
Second-highest E_T jet: E_T and η distributions

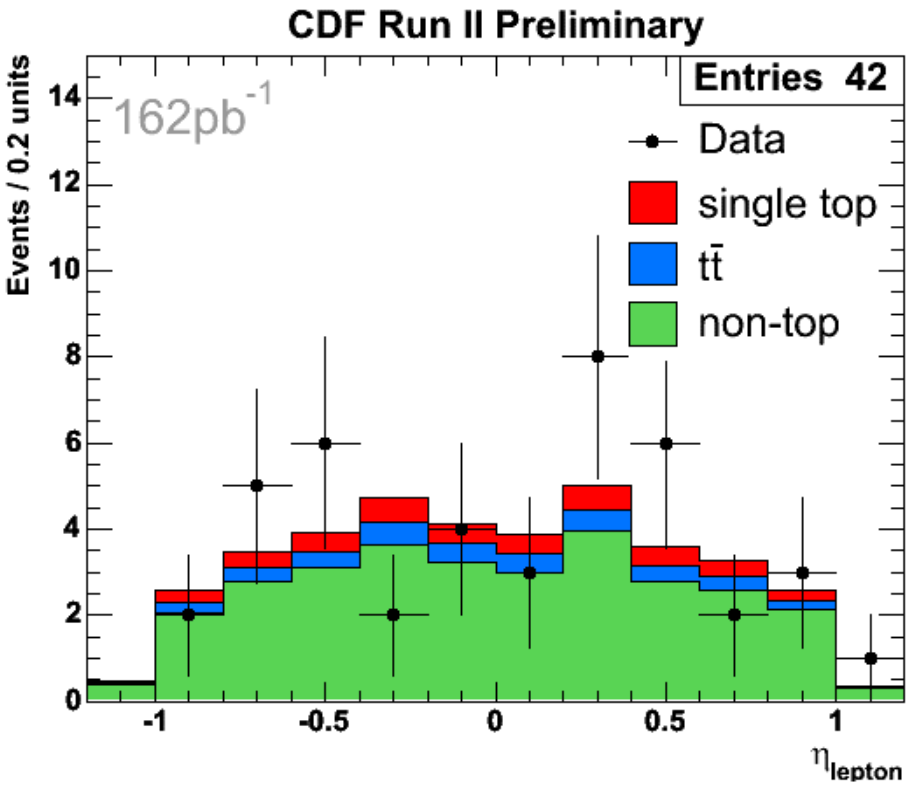




Kinematic Plots for Combined Search

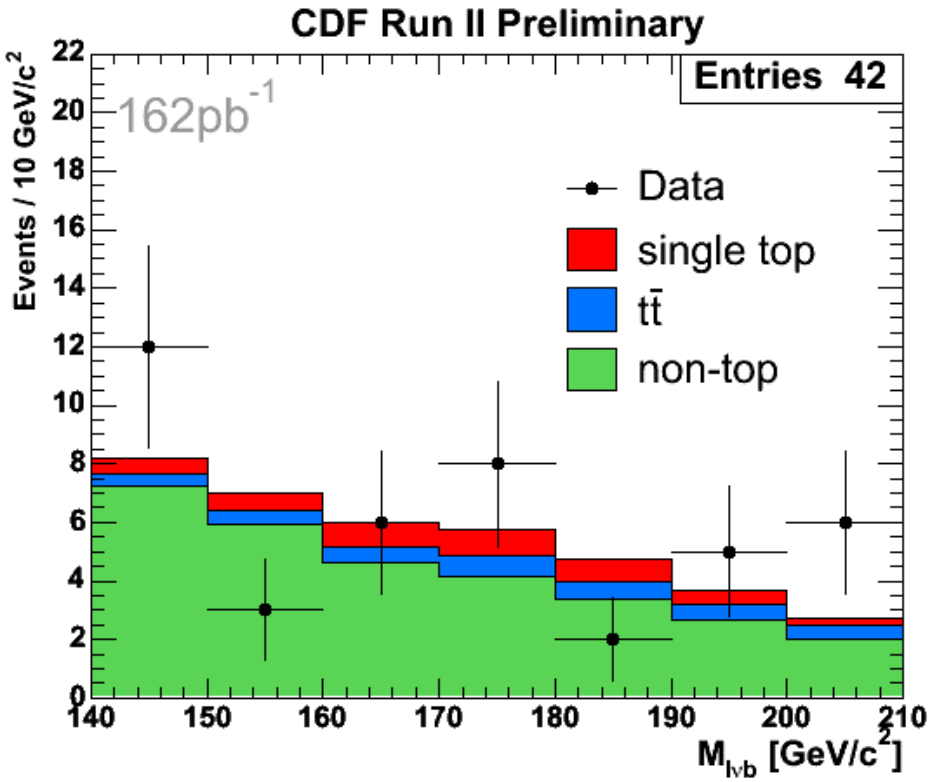
Lepton P_T and η distributions

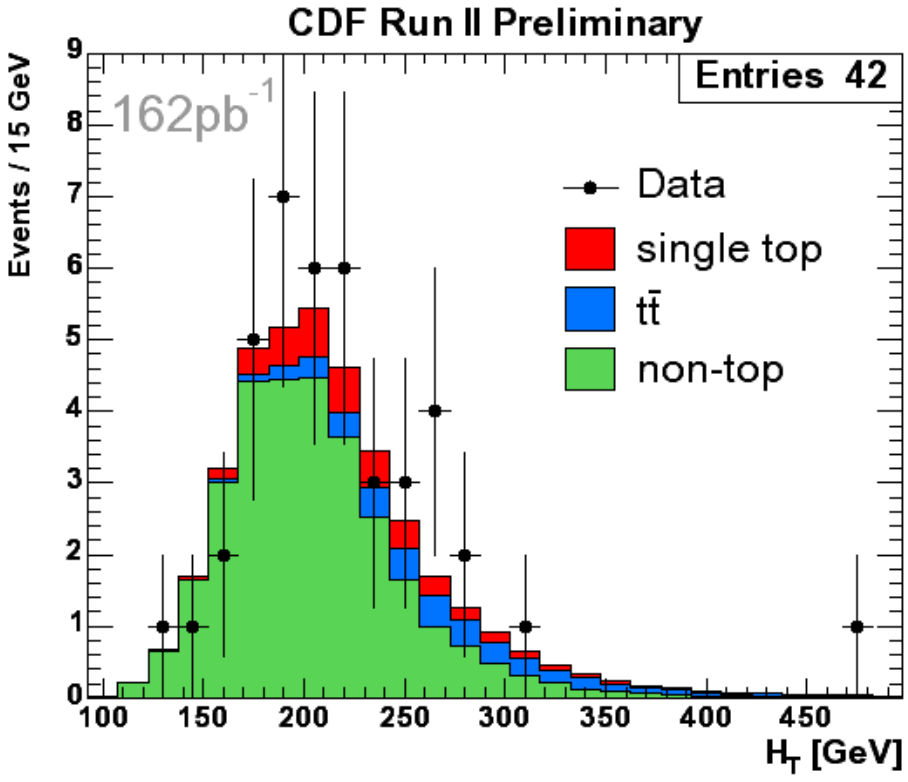




Kinematic Plots for Combined Search

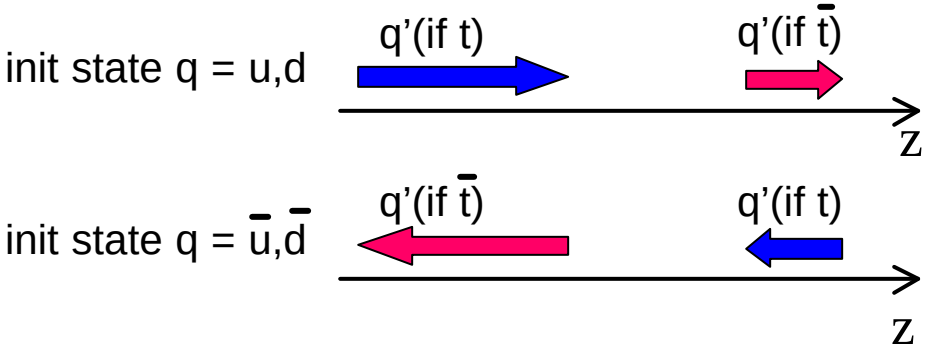
M_{lvb} and H_T distributions

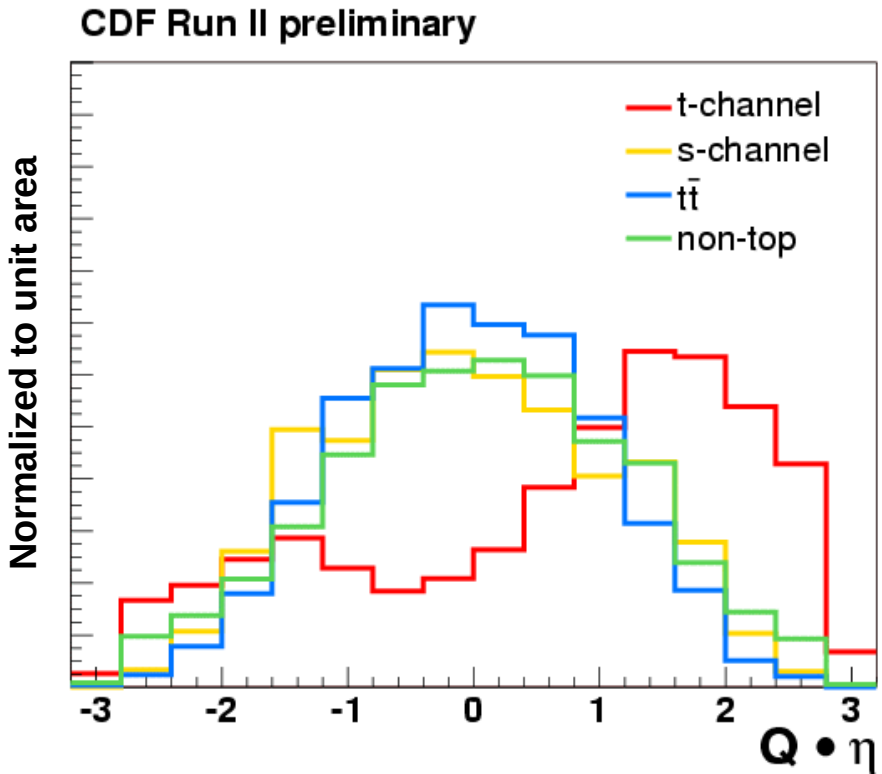




Separate Search

- s- and t- channels have different sensitivities to new physics
- For the t-channel:
  - Same event preselection (w/ $M_{l\nu b}$ cut)
  - E_T(leading jet) > 30 GeV
  - 1-tag events only
  - Use Q•η distribution:

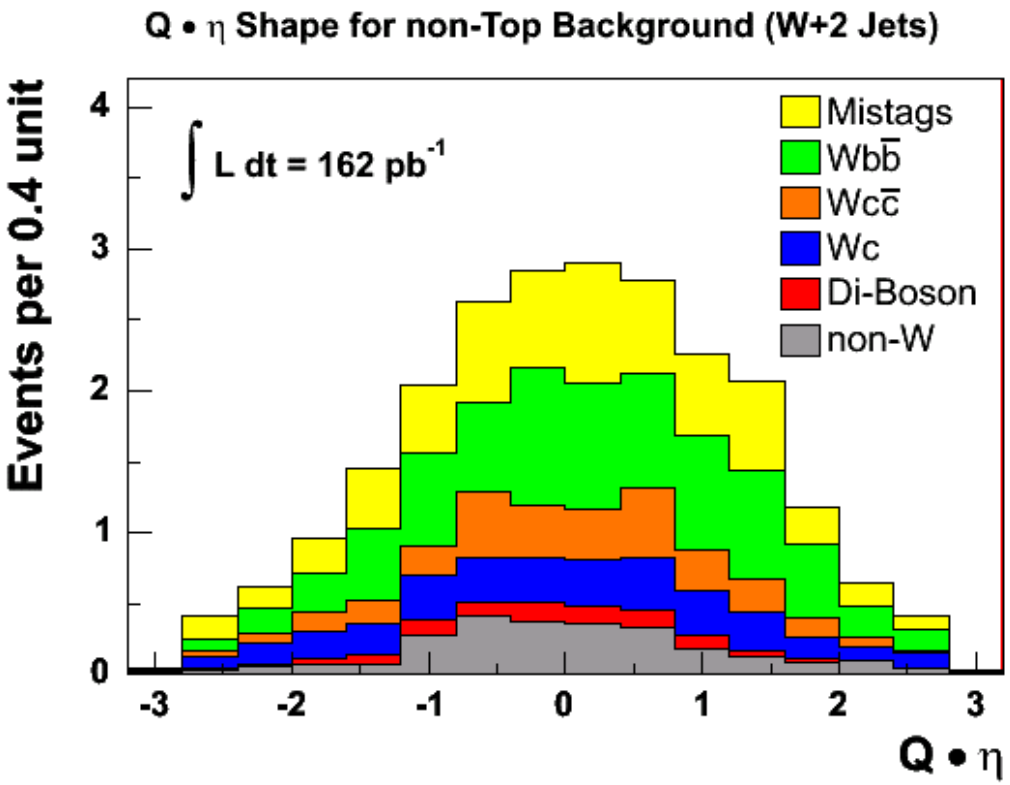




- Event counting for s-channel:
  - 2-tag events only

Non-top Background for Separate Search

- Non-top background for L=162 pb^{-1}:



CDF Run II Preliminary

Process	N in 162 pb^{-1}
$Wb\bar{b}$	7.5 ± 2.4
$Wc\bar{c}$	3.0 ± 0.9
Wc	3.3 ± 1.0
Mistags	6.1 ± 1.4
Non-W	2.5 ± 0.6
Diboson	0.9 ± 0.1
Total non-top	**23.3 ± 4.6**

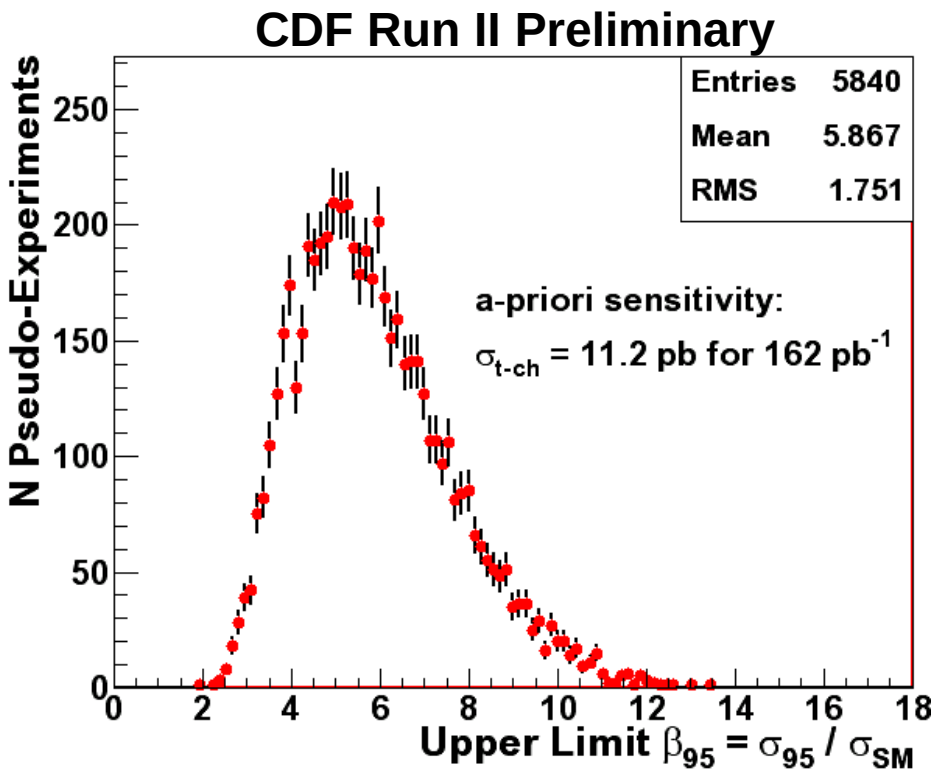
Event Count Separate Search

CDF Run II Preliminary

Process	Number of events	
	1-b-tag-bin	2-b-tag-bin
$t\bar{t}$	3.2 ± 0.7	0.60 ± 0.14
Non-top	23.3 ± 4.6	2.59 ± 0.71
Sum Background	26.5 ± 4.7	3.19 ± 0.72
t-channel	2.7 ± 0.4	0.02 ± 0.01
s-channel	1.1 ± 0.2	0.32 ± 0.05
Sum Single-Top	3.8 ± 0.5	0.34 ± 0.05
Sum Expected	30.3 ± 4.7	3.53 ± 0.72
Observed	33	6

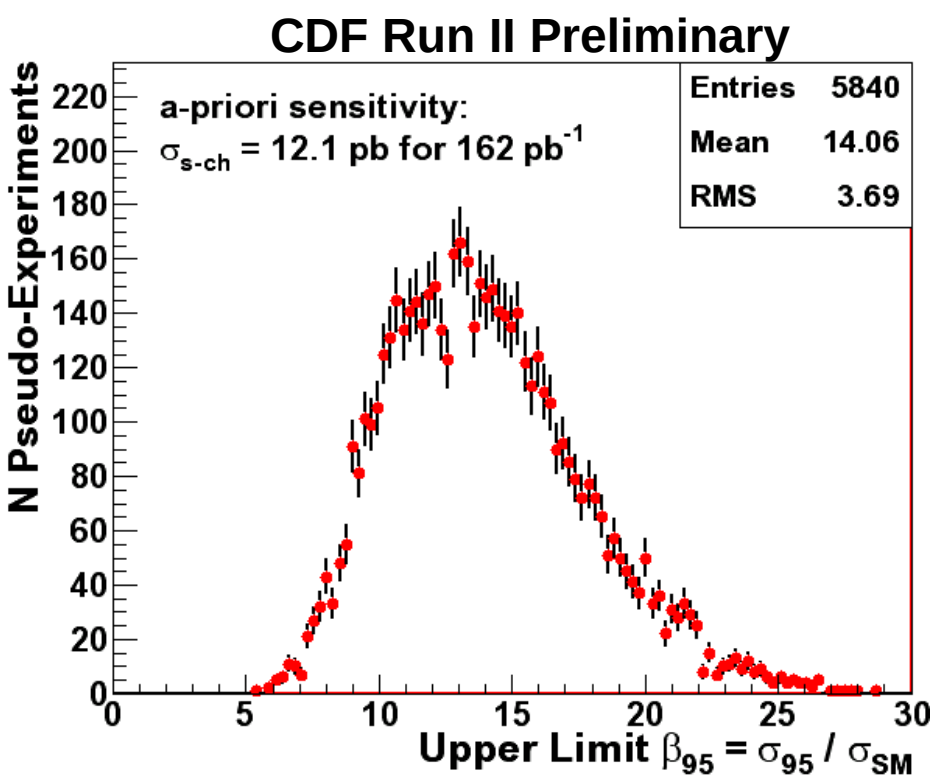
A-priori Limit for Separate Search

t-channel:



b_{95} = 5.6

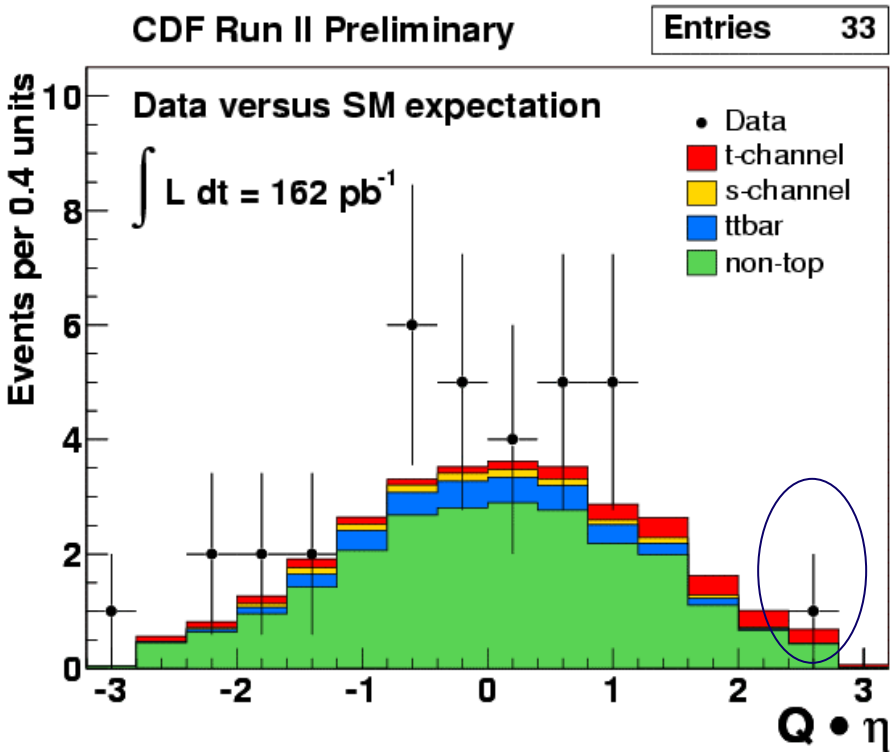
s-channel:



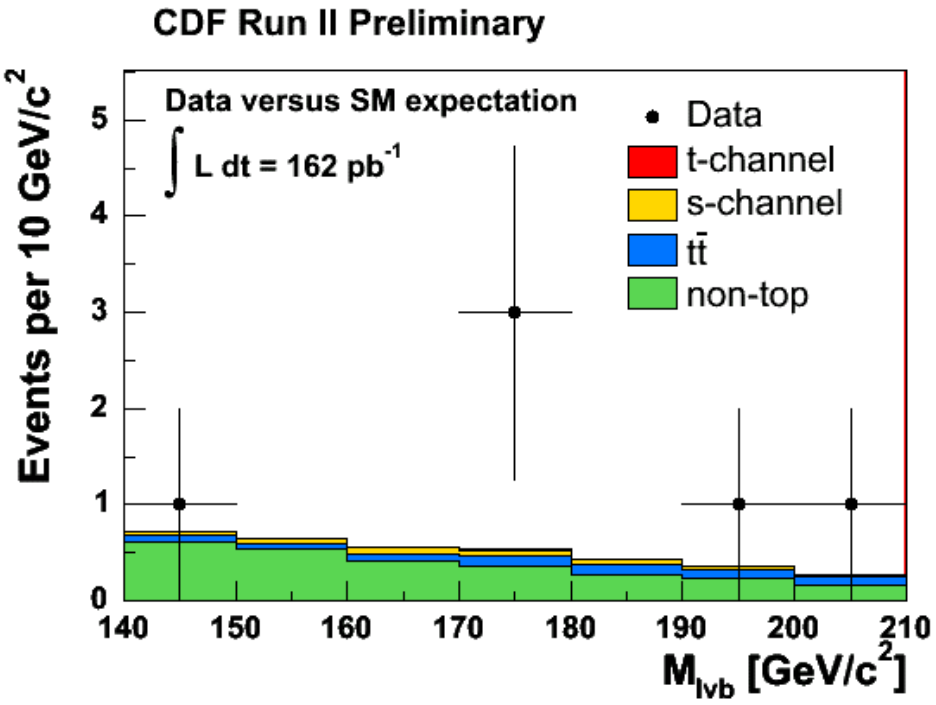
b_{95} = 13.7

CDF II Data

1-tag bin: 33 events (30.3 exp)

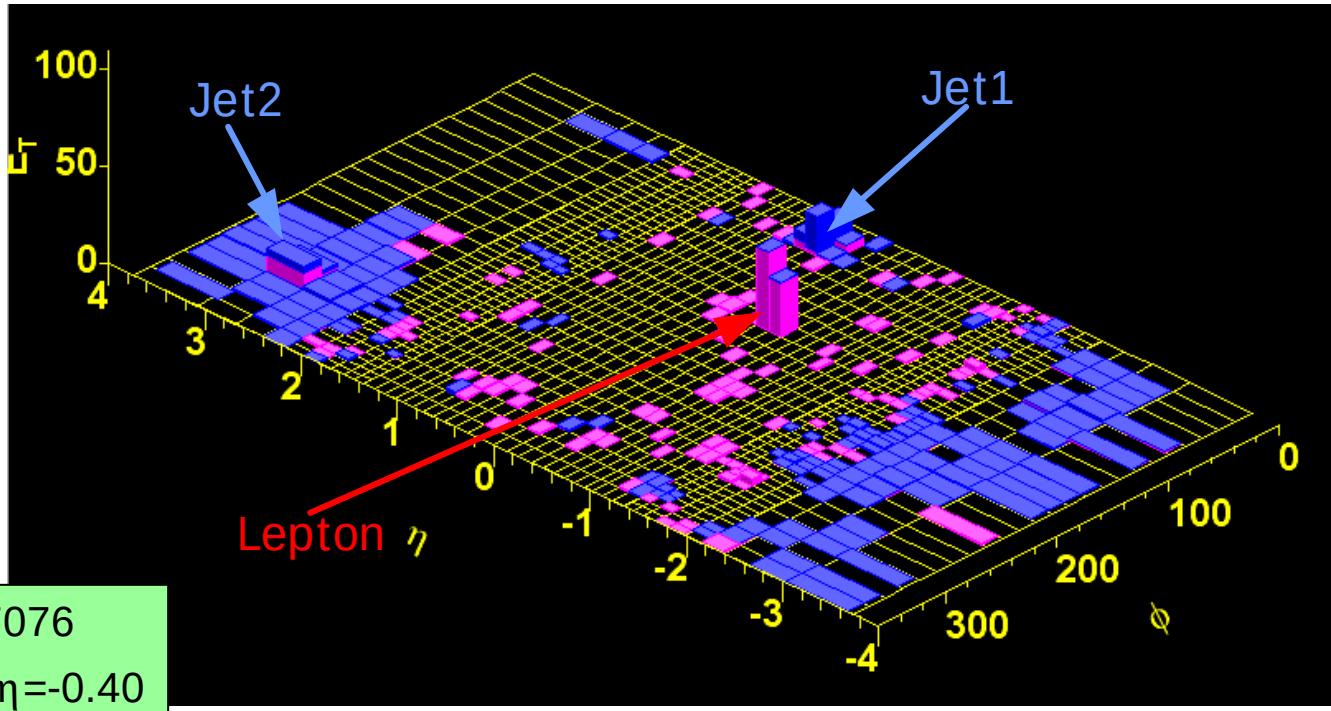


2-tag bin: 6 events (3.5 exp)



Event Display

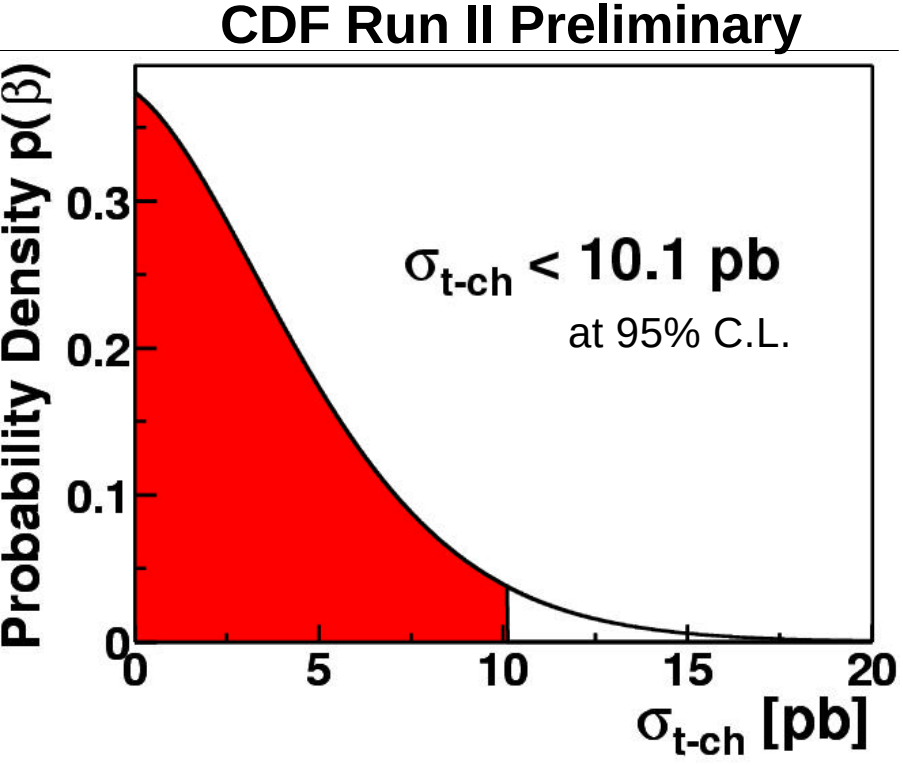
The most t-channel single-top-like event ($Q \bullet \eta = 2.6$, M_{lvb}=200 GeV/c^2):

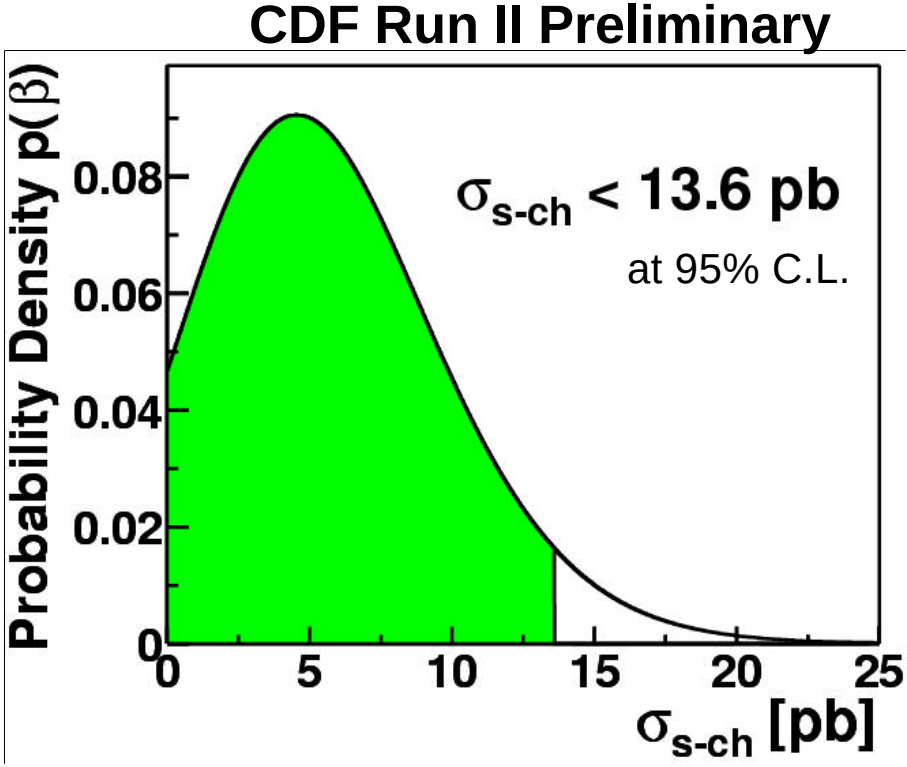


Run: 167565 · **Event:** 437076

- CEM Electron E_T=67.0 GeV, η=-0.40
- MET=47.9 GeV, Phi=3.9
- Jet1: E_T=65.5 GeV, η=0.23
- Jet2: E_T=32.3 GeV, η=2.6

95% C.L. from Data Separate Search





t-channel: s_{95} = **10.1 pb**

b_{95} = **5.1**

s-channel: s_{95} = **13.6 pb**

b_{95} = **15.4**

MPV and Credibility Intervals

- Maximum of p(β) defines the Most Probable Value (MPV)
- 68.3% credibility intervals with Highest Posterior Probability Density (HPD)

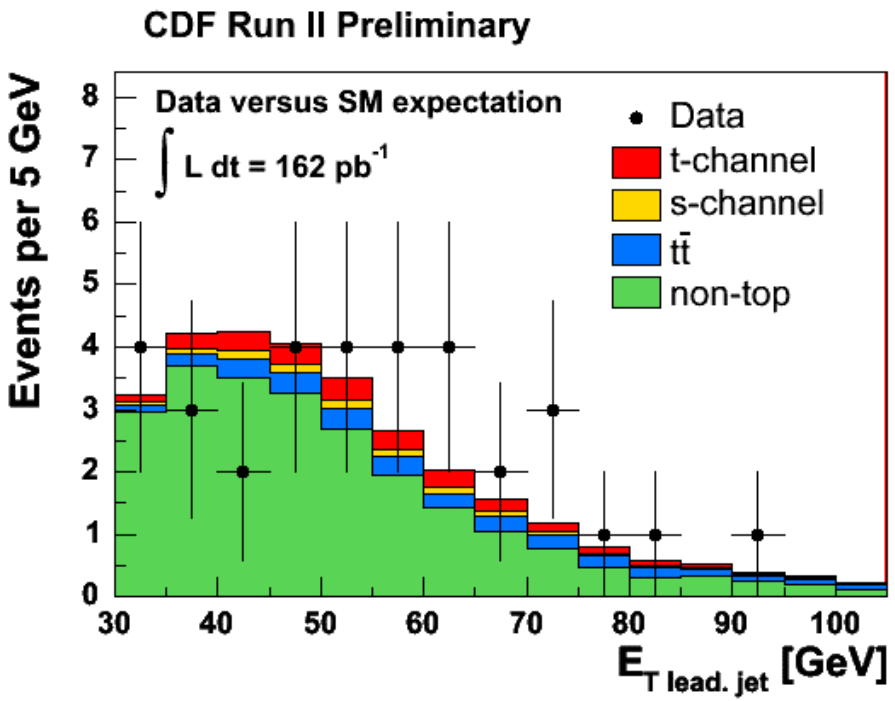
CDF Run II Preliminary

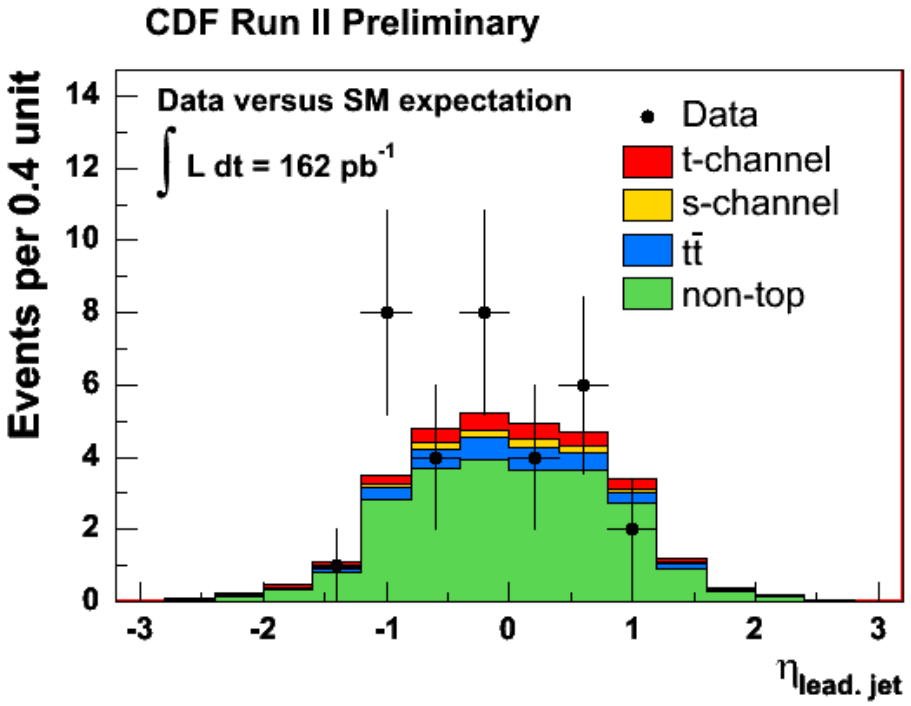
Channel	MPV(β units)	MPV(pb)
Combined	$2.7^{+1.8}_{-1.7}$	$7.7^{+5.1}_{-4.9}$
t-channel	$0.0^{+2.4}_{-0.0}$	$0.0^{+4.7}_{-0.0}$
s-channel	$5.2^{+4.3}_{-4.3}$	$4.6^{+3.8}_{-3.8}$

Credibility intervals ($ß_{low}$, $ß_{high}$) such that $p(ß_{low}) = p(ß_{high})$.

Kinematic Plots for Separate Search

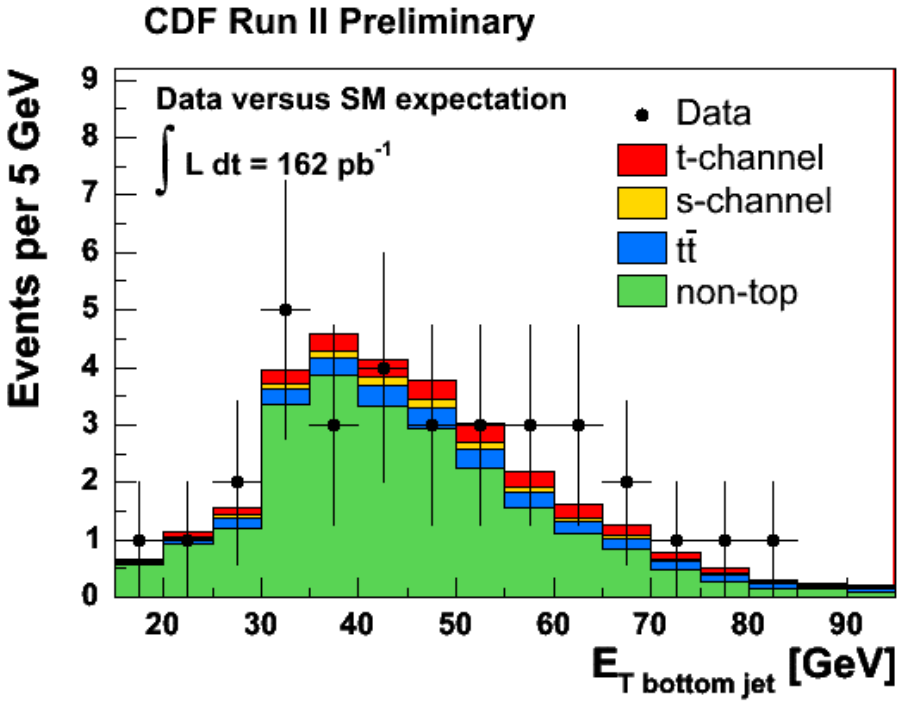
Highest E_T (leading) jet: E_T and η distributions (1-tag sample)

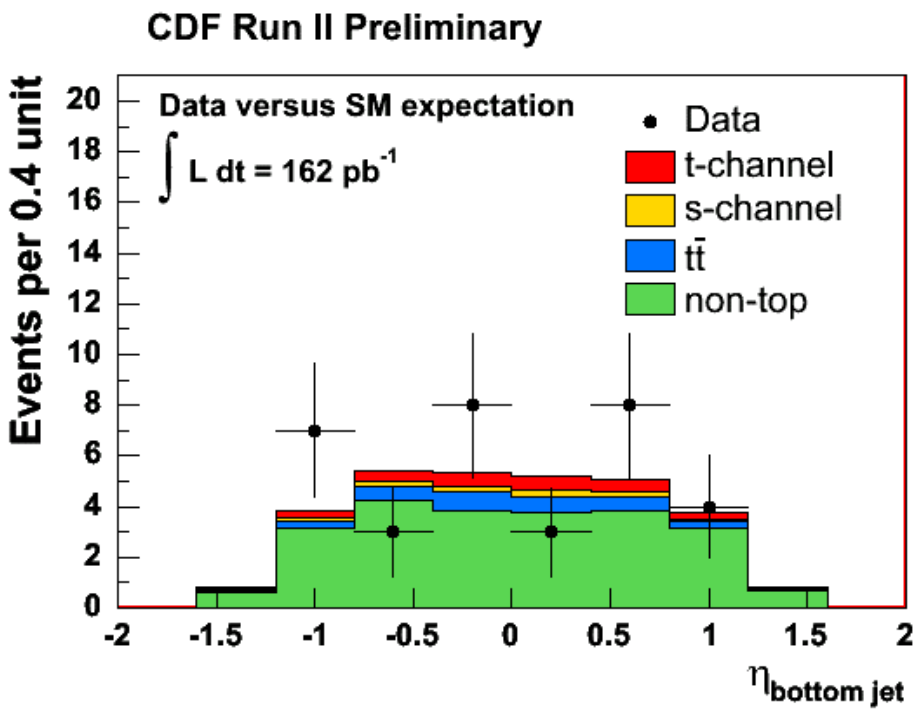




Kinematic Plots for Separate Search

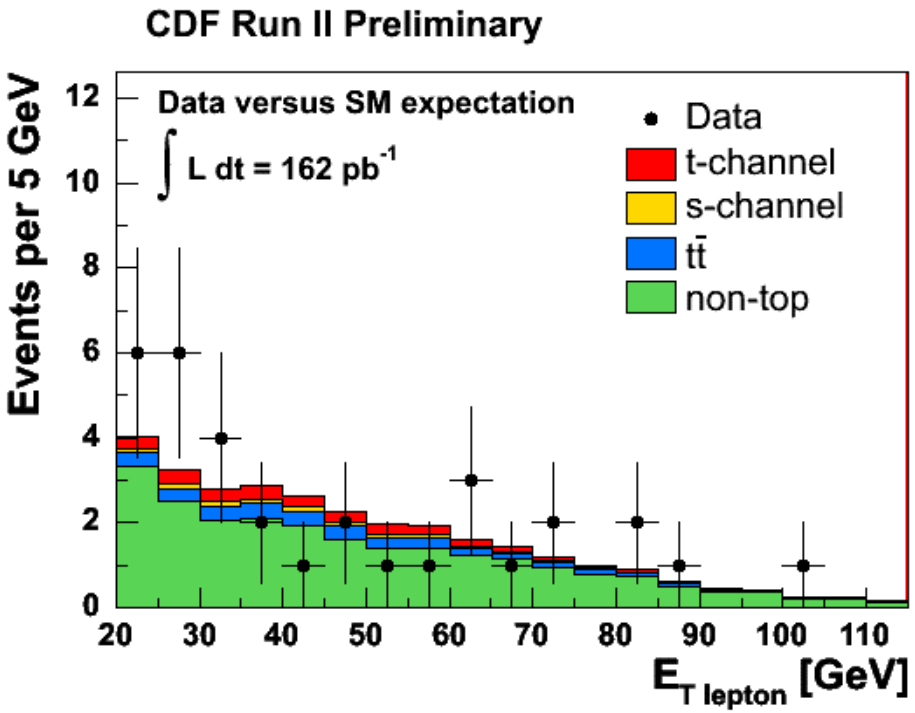
B-tagged jet: E_T and η distributions (1-tag sample)

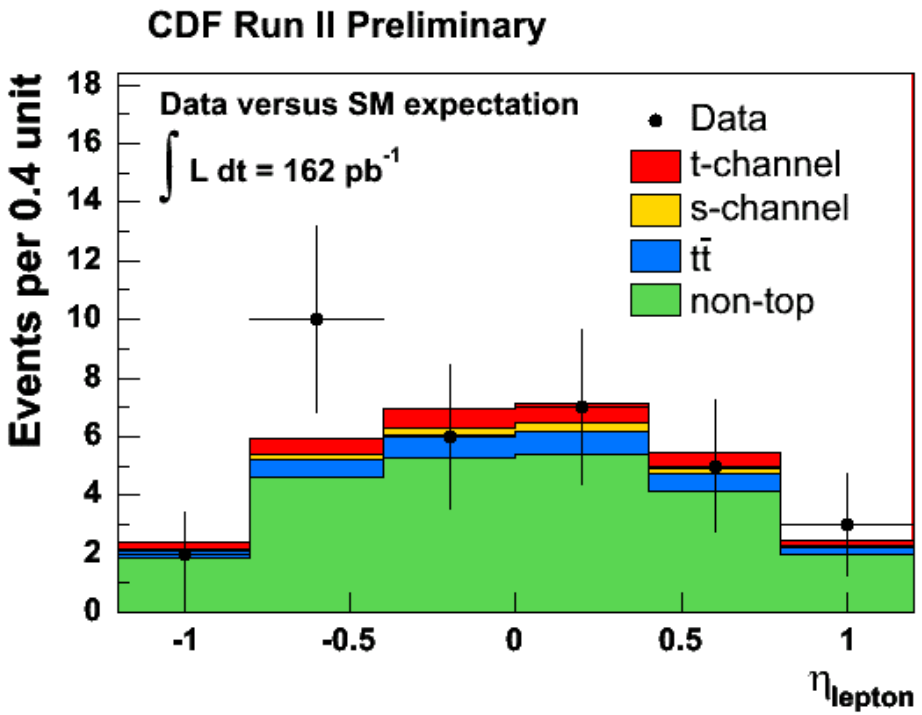




Kinematic Plots for Separate Search

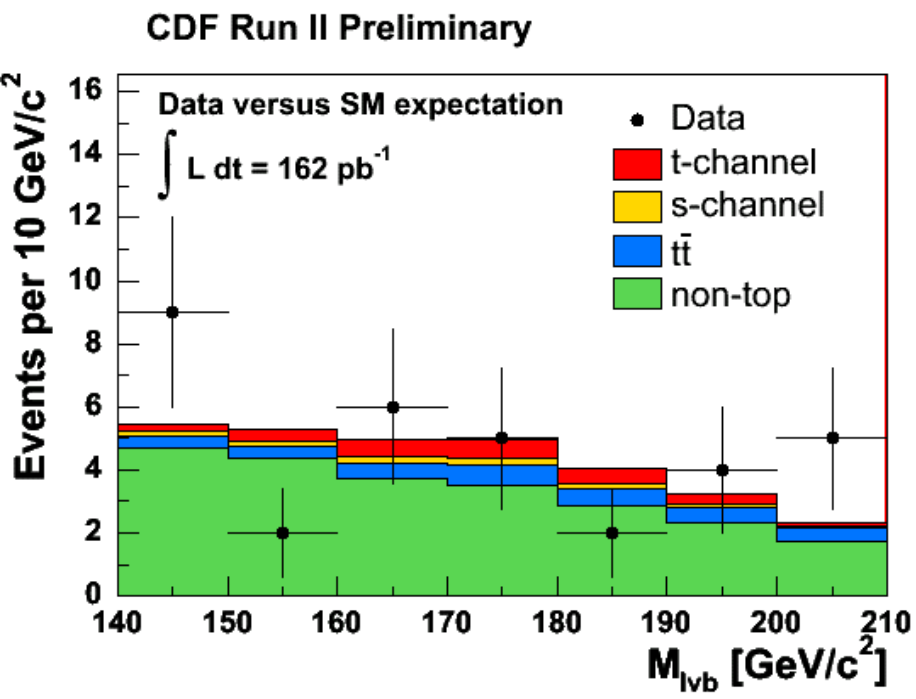
Lepton P_T and η distributions (1-tag sample)



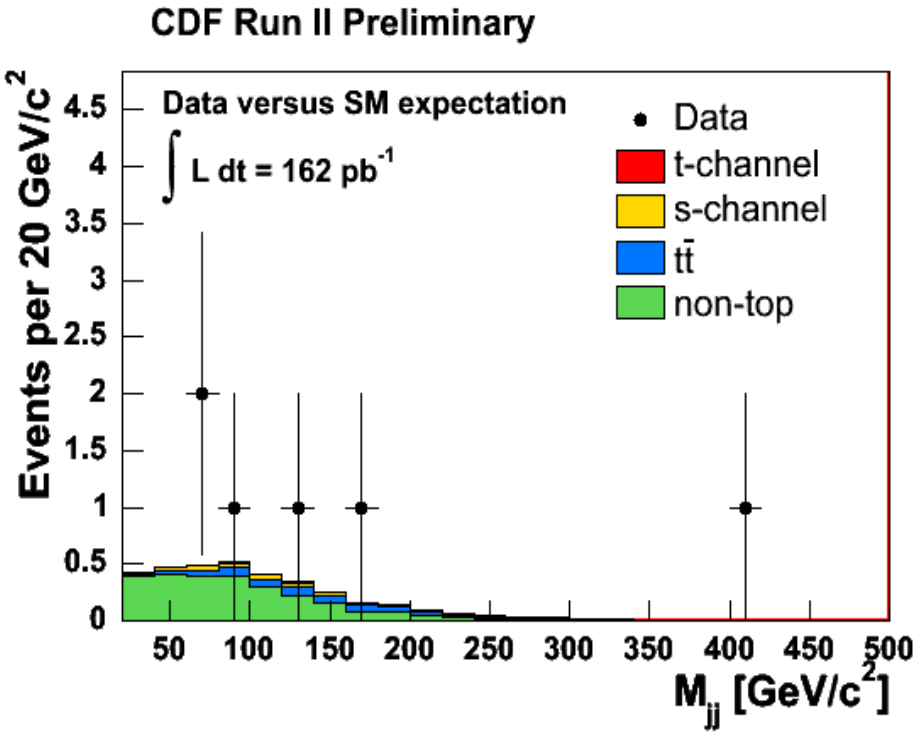


Kinematic Plots for Separate Search

M_{lvb} for the 1-tag sample



M_{jj} for the 2-tag sample



Conclusions

- First Pass of Single Top Search at CDF II completed

- Several Improvements:
  - Background modeling (non-top contributions)
  - Signal generator (MadEvent, TopReX)
  - Fully-Bayesian Likelihood (correlations between effects accounted for)

- Upper Limits: combined search: 17.8 pb (13.6 pb a-priori)
  t-channel: 10.1 pb (11.2 pb a-priori)
  s-channel: 13.6 pb (12.1 pb a-priori)

- Next Iteration: multivariate search and more data…