Single Top Production

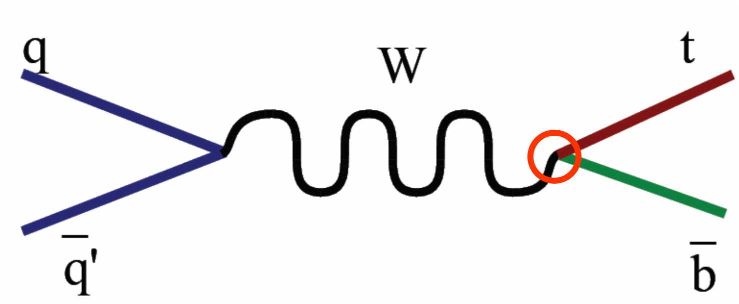
at the Tevatron
Searches

Approved Analysis

Top Quark Symposium
University of Michigan
April 7, 2005
Gordon Watts
for DØ and CDF

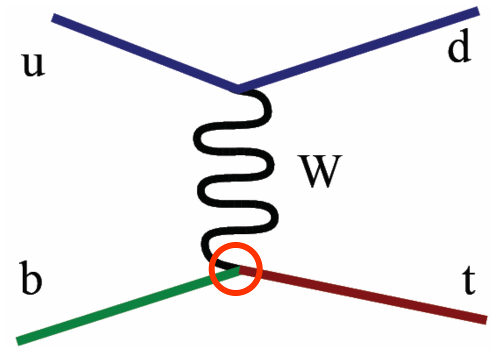
A Lonely Production

s-channel



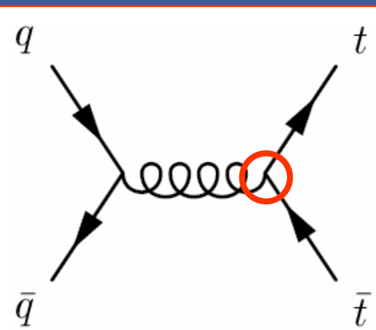
σ_{NLO} = 0.88pb ± 8%

t-channel



σ_{NLO} = 1.98pb ± 11%

hep-hp/207055 (Harris, Laenen, Phaf, Sullivan, Weinzierl)

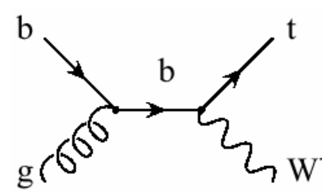


Pair Production

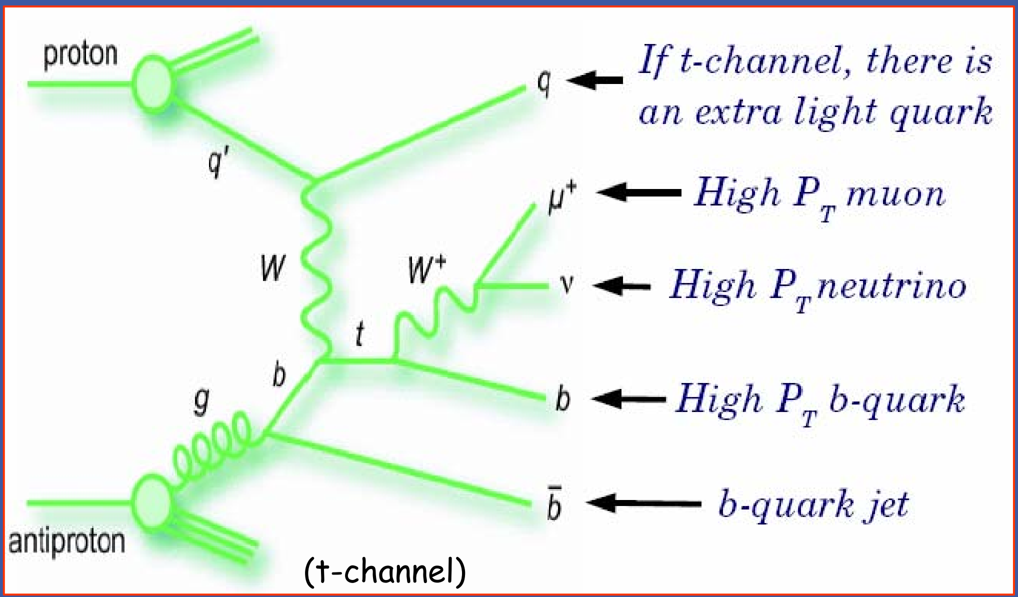
Weak Decay Vertex
- V_{tb}, unitarity
- Exotic Models (FCNC, Top Flavor, 4^{th} Gen)
- SM Higgs Background
- W+Jets Proving Ground

Discovery First!

Too small for the Tevatron (LHC?) Tait – hep-ph/990352



Signature & Backgrounds



Signal for *s* and *t* channel mostly similar

- Lepton + Missing E_T + Jets
- t-channel extra b tends to be forward
- Similar to top pair production, but with less jets

⇨ Harder Signal To Find

Backgrounds

- W/Z + jets Production
- Fake Leptons
- Top Pair Production
- WW, WZ, Z$\tau\tau$, etc.

Much worse than for pair production because of lower jet multiplicity

Anything with a lepton + jets + $\not{E}_T$ signature

The MC Situation

(single top)

ZTOP single top generator is most often used as bench mark…

http://home.fnal.gov/~zack/ZTOP/ZTOP.html

Not an event generator, so…

The trick is in getting the t-channel correct…

Re-weights MADEVENT to fit the ZTOP distributions

- Generate bq,gq $\rightarrow$ t+b+q′ separately…

Modified version of CompHEP

- Match 2 $\rightarrow$ 2 and 2 $\rightarrow$ 3 process using b p_T for cross over
- Comparison with ZTOP shows no difference

The MC Situation

(background)

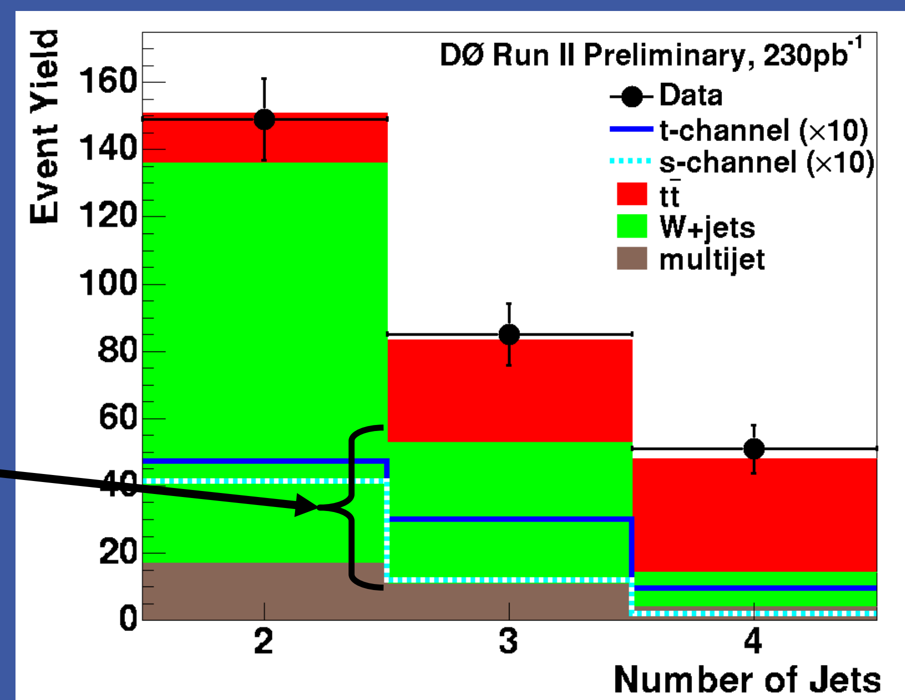
W+Jets with Heavy Flavor is most important

- Jet Double Counting issues
- HF factions – both b and c

(charm tagging not measured!)

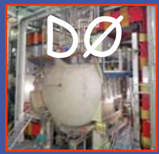
CDF and DØ use ALPGEN
Full Event Simulation
HF fraction (b, c) from ALPGEN
    Wbb from NLO calculation

Bowen, Ellis, Strassler: understand W(b,c) as it affects shape variables!



Steve: "There is more than one R"

Search Strategy



Common Analysis Strategy

Basic Selection Cuts → Clean up the data, remove detector backgrounds. Does not maximize S:B.

↓

Final Cuts → Apply btagging, understand shape variables (s, t channel), multivariate analysis, etc.

↓

Limit Fitting → Use binned maximum likelihood (fit distributions to maximize limit)

The Approach

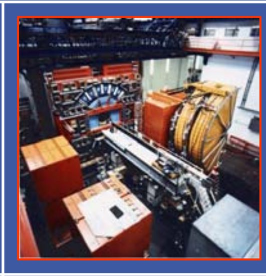
Improve S/B to maximize separation in one distribution (Q×η)

- Basic Selection Cuts More Restrictive

Use Multiple distributions, combined with a Neural Network, to maximize separation

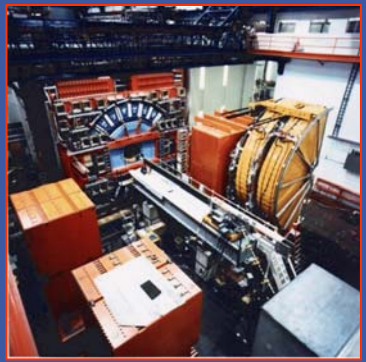
- Basic Selection are efficient, but let in a great deal more background.

Basic Selection Cuts

	 CDF	 DØ
Lepton (e, μ)	$P_T > 20$ GeV	$P_T > 15$ GeV
Jet	$E_T > 15$ GeV, $\|\eta\|<2.8$, $N_J=2$	$E_T > 15$ GeV (Jet 1: $E_T>25$ GeV), $\|\eta\|<3.4$, $2\leq N_J\leq 4$
Missing E_T	$E_T > 20$ GeV	$E_T > 15$ GeV

Along with other clean-up cuts

Basic Selection Cuts



1 Lepton p_T>20 GeV
MET>20 GeV
Exactly 2 jets E_T>15 GeV $|\eta|$<2.8
≥ 1 b-tag
$M_{l\nu b}$ [140,210] GeV

- One good quality isolated e(μ), E_T > 15 GeV, $|\eta|$ < (2.0)
- MET > 15 GeV
- 2 ≤ Njets ≤ 4
  p_T > 15GeV
  $|\eta|$ < 3.4
  p_T (jet 1) > 25GeV
  Require at least one b-tagged jet
- Reject misreconstructed events
  and regions not well described by backgrounds

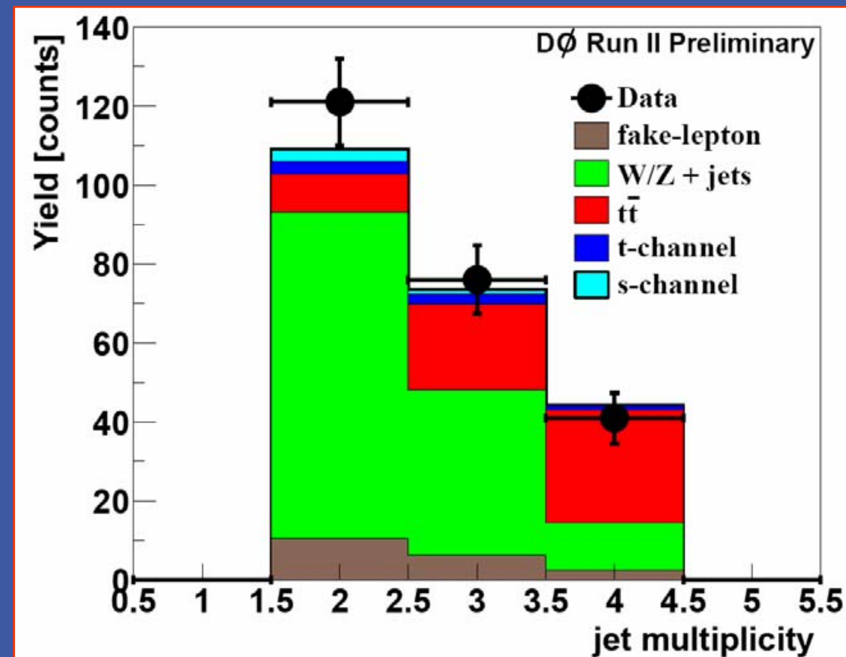
Quick Comment On Preselection Cuts

Both CDF and DØ cut on the number of jets.

Exactly 2 jets ET>15 GeV |η|<2.8

$2 \leq N_j \geq 4$

The motivation is pretty clear ⇨



A "jet"-theorist: "Dude. What's a jet?"

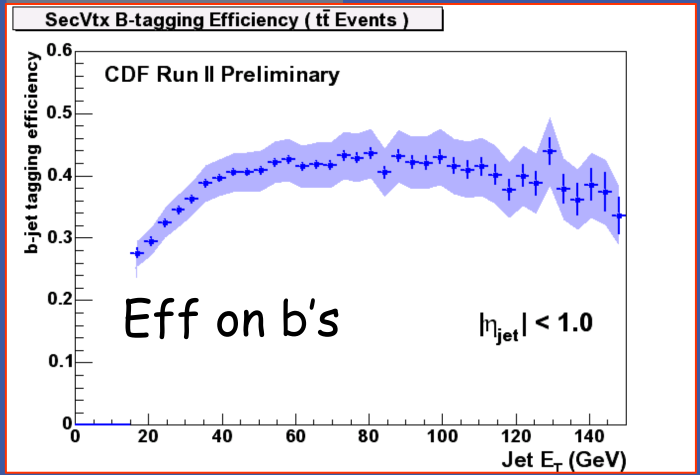
Would prefer energy based variables like H_T

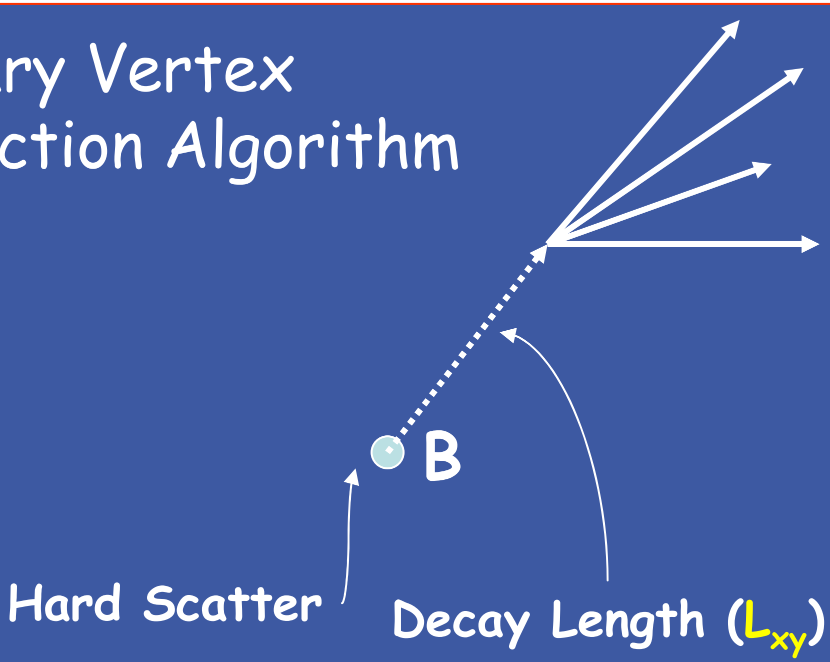
Even with those, however, N_J is powerful.

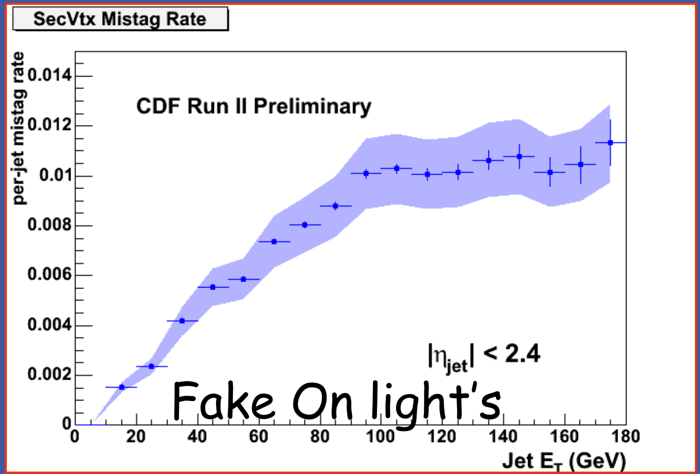
Final Cuts I

B-Tagging

Both apply a secondary Vertex Reconstruction Algorithm (L_{xy})





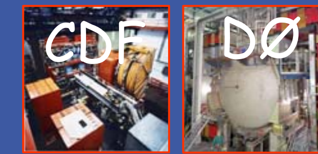


→ Charm Tagging Rates ~ 30% of b

Both experiments classify events by single or more than one tag

CDF Recently released improved version of tagging (15%), but it isn't used in blessed single top results. DØ's is a comparable to what is *shown* here.

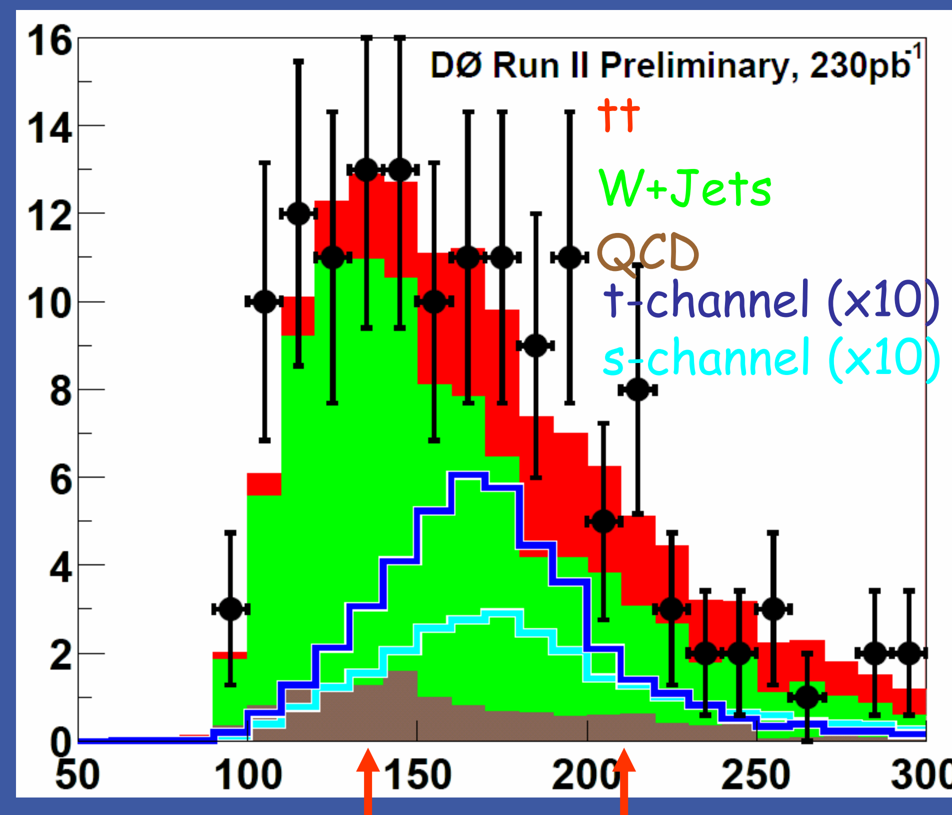
Final Cuts II



Top Mass Cut M_{lbn} – Lepton, b-tagged jet, neutrino (Missing E

CDF: 140 GeV ≤ M_{lbn} ≤ 210 GeV

DØ: Input to Multivariate Analysis



Final Sample Statistics

Luminosity

DØ: 230 pb-1
CDF: 162 pb-1

Acceptance(%)

	DØ	CDF
		08
		07

These Are Small Numbers!

CDF: Expects ~2 events on ~34
DØ: Expects ~5 events on ~280

$S/\sqrt{B}$

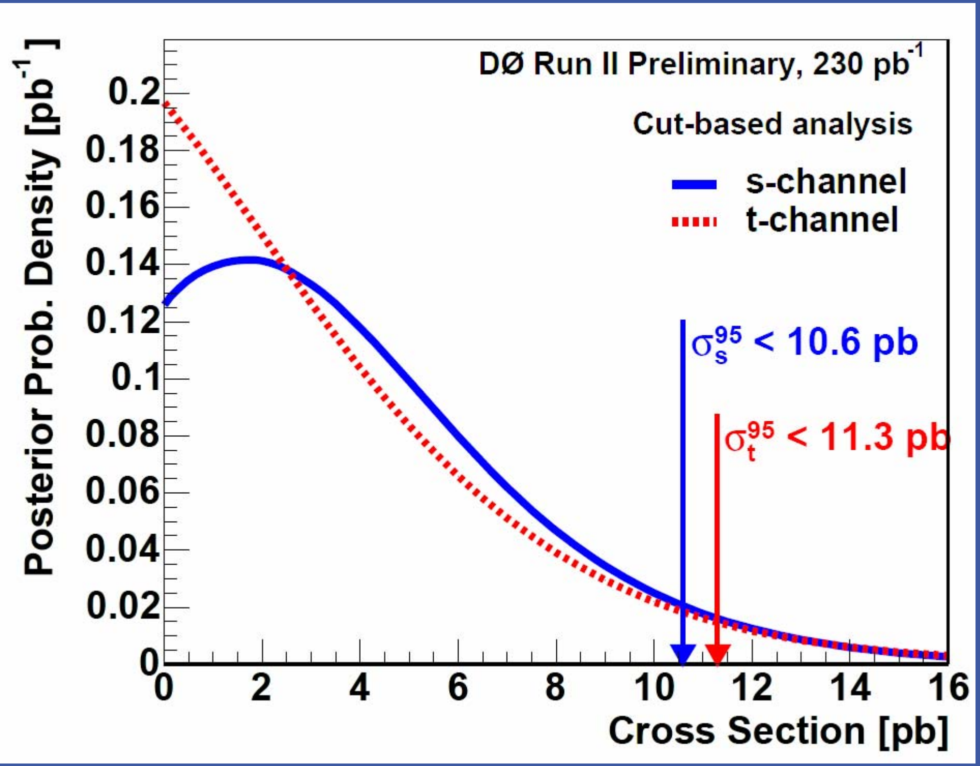
	DØ	CDF
s-channel	0.32	0.25
t-channel	0.28	0.48

Straight Cut Analysis

How Well Can We Do With a Straight Cut Analysis?

Selected Variables:

- Object E_T/p_T – Jet #1
- H_T – like (various sums of the object's E_T's)
- Invariant Mass of combinations of masses (like $M_{lb\nu}$)

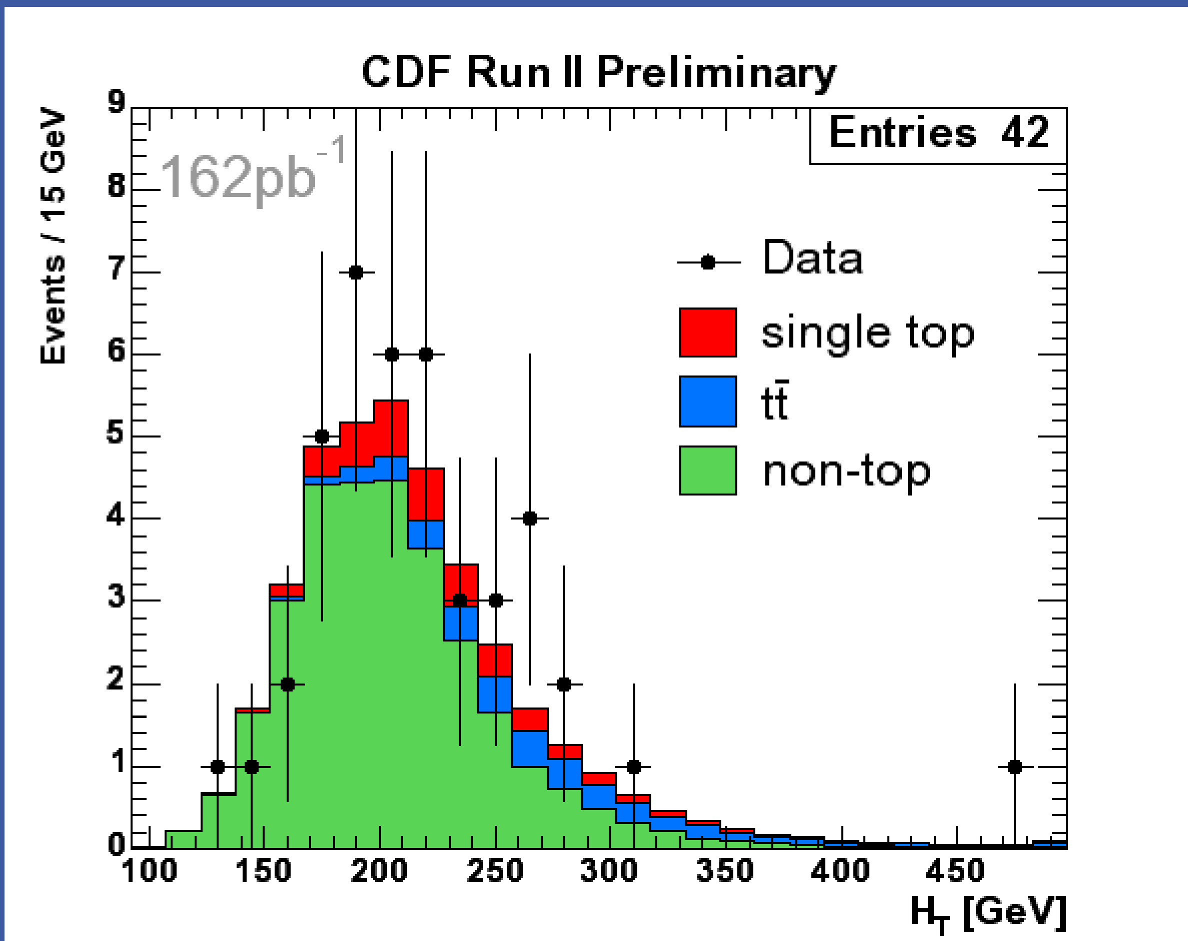


Details of Cuts Based

	s-channel	t-channel
tb	4.5 ± 1.0	3.2 ± 0.8
tqb	5.5 ± 1.2	7.0 ± 1.6
$t\bar{t}$	27.6 ± 7.6	55.9 ± 12.3
W+jets	102.9 ± 13.7	72.6 ± 9.7
Mis-ID'd lepton	17.2 ± 2.0	17.0 ± 2.0
Background sum	153.1 ± 24.5	148.7 ± 24.8
Observed events	152	148

	s-channel		t-channel	
Channel	Variables	Cuts	Variables	Cuts
Electron				
=1 Tag	$p_T(\text{jet1}_{\text{tagged}})$	> 27 GeV	$H_T(\text{alljets})$	> 71 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 70 GeV	$M(\text{alljets})$	> 57 GeV
	$\sqrt{\hat{s}}$	> 196 GeV	$\sqrt{\hat{s}}$	> 203 GeV
			$\lvert 175 - M(\text{top}_{\text{tagged}})\rvert$	< 57 GeV
			$p_T(\text{jet1}_{\text{tagged}})$	> 21 GeV
≥2 Tags	$p_T(\text{jet1}_{\text{tagged}})$	> 42 GeV	$p_T(\text{jet1}_{\text{tagged}})$	> 34 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 98 GeV	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 75 GeV
	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 304 GeV	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 504 GeV
	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 304 GeV	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 504 GeV
Muon				
=1 Tag	$p_T(\text{jet1}_{\text{tagged}})$	> 33 GeV	$\lvert 175 - M(\text{top}_{\text{tagged}})\rvert$	< 60 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 74 GeV	$\sqrt{\hat{s}}$	> 210 GeV
	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 504 GeV	$M(\text{alljets})$	> 70 GeV
	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 504 GeV	$H_T(\text{alljets})$	> 58 GeV
≥2 Tags	$p_T(\text{jet1}_{\text{tagged}})$	> 33 GeV	$\lvert 175 - M(\text{top}_{\text{tagged}})\rvert$	< 213 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 74 GeV		
	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 504 GeV		
	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 504 GeV		

Relative Sizes Of Backgrounds



(Sum Of Jets In Event)

W+Jets Is Largest Background!

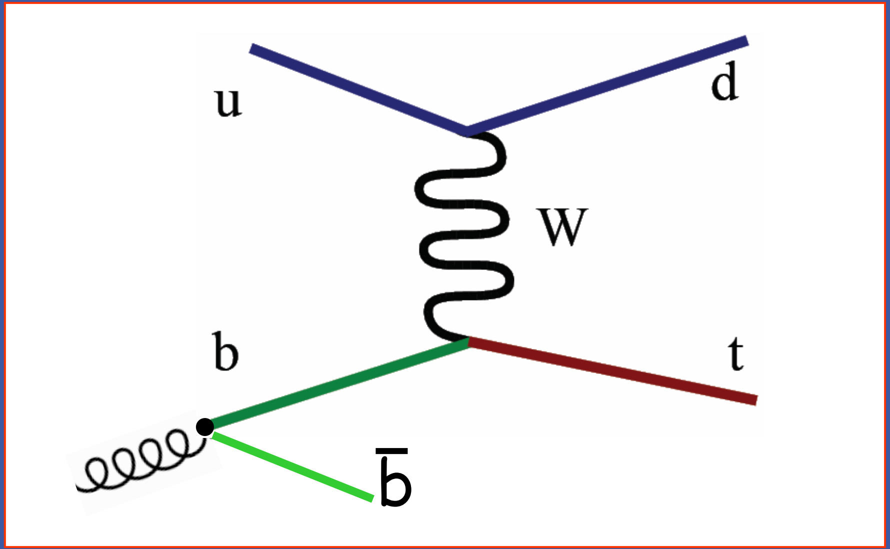
One of hardest to get right!

Single b-tag required for this plot.

Need to take advantage of other topologies to improve limit!

Getting Clever

t-channel



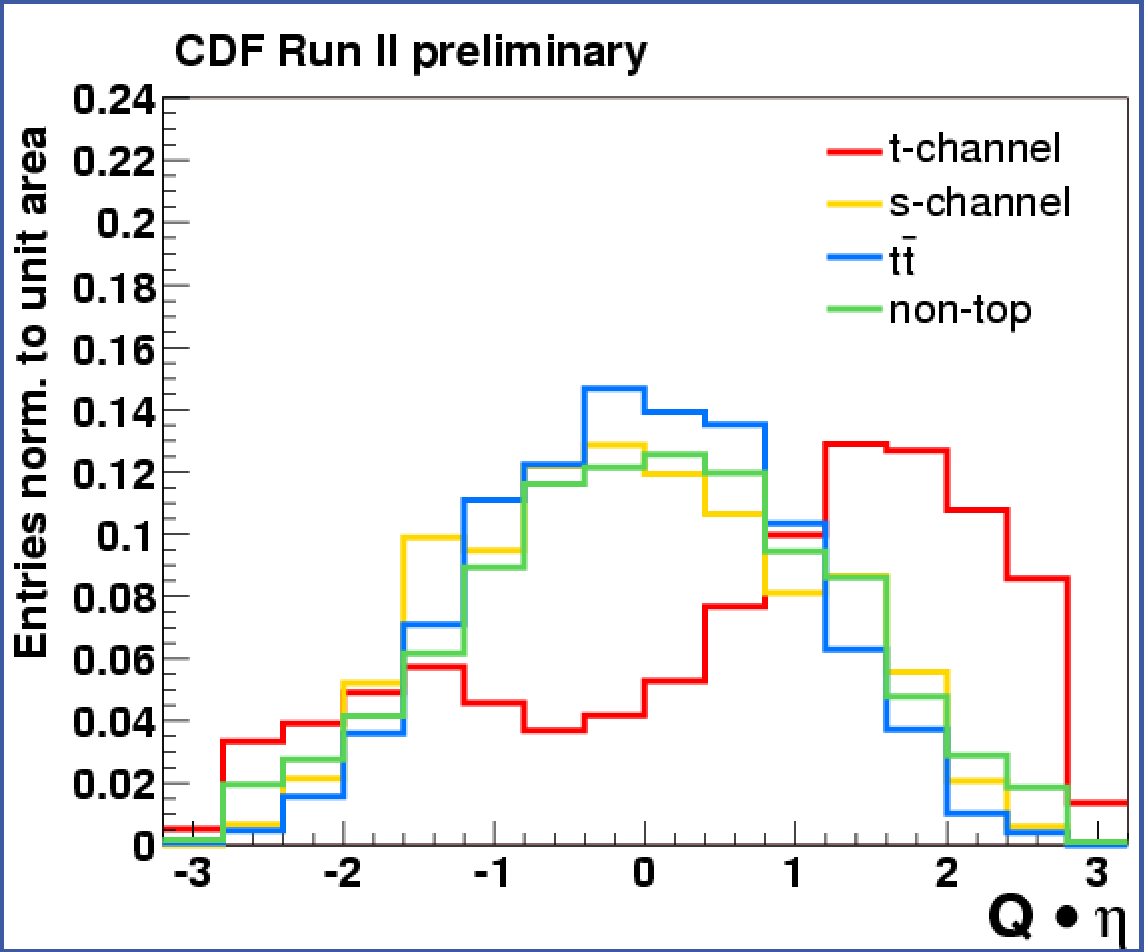
Charge of up quark determines charge of W lepton (p vs $\bar{p}$)
Recoil against gluon/quark makes for asymmetry

⇨ Look at d-quark Jet Rapidity normalized by Charge!

Q X η

Monte Carlo Templates

CDF Uses these distributions as input to the final limit calculation for separate s,t - channel limits

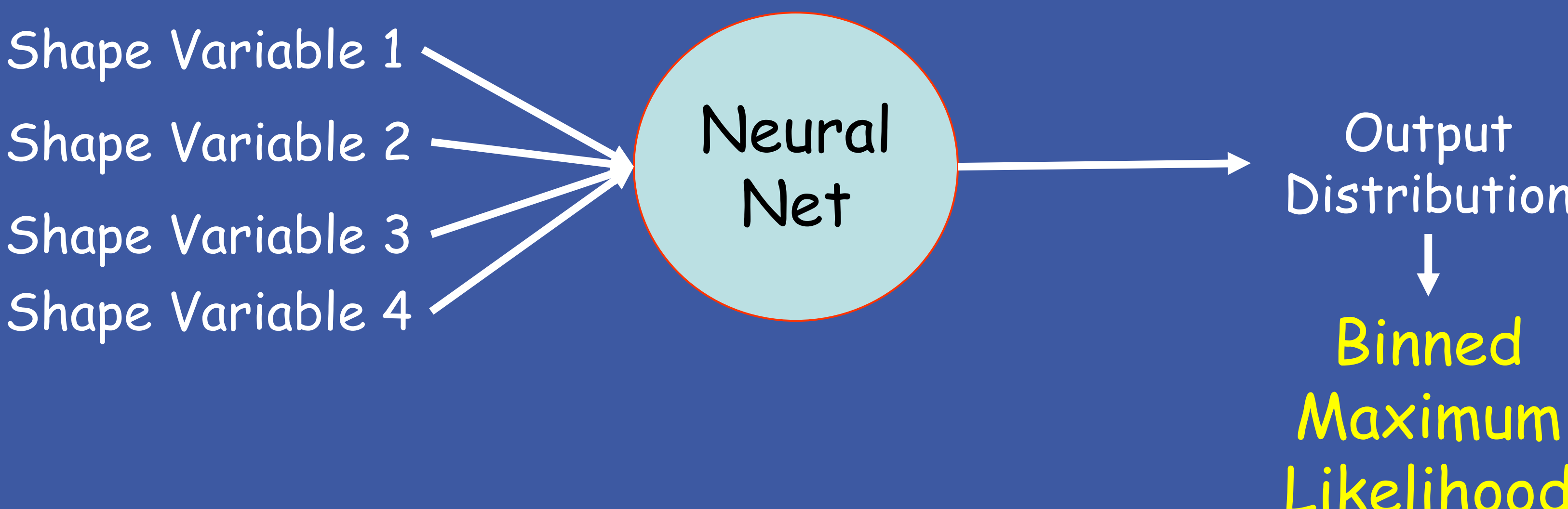


Use H_T for a combined s+t channel limit

Other Variables

DØ S/B is worse by design than CDF's

- Basic Selection Cuts: Let in as much signal as possible
  - ⇨ Use a Multivariate analysis to separate the signal from background
- A multi-dimensional maximum likelihood possible…
  - Statistics are prohibitive!



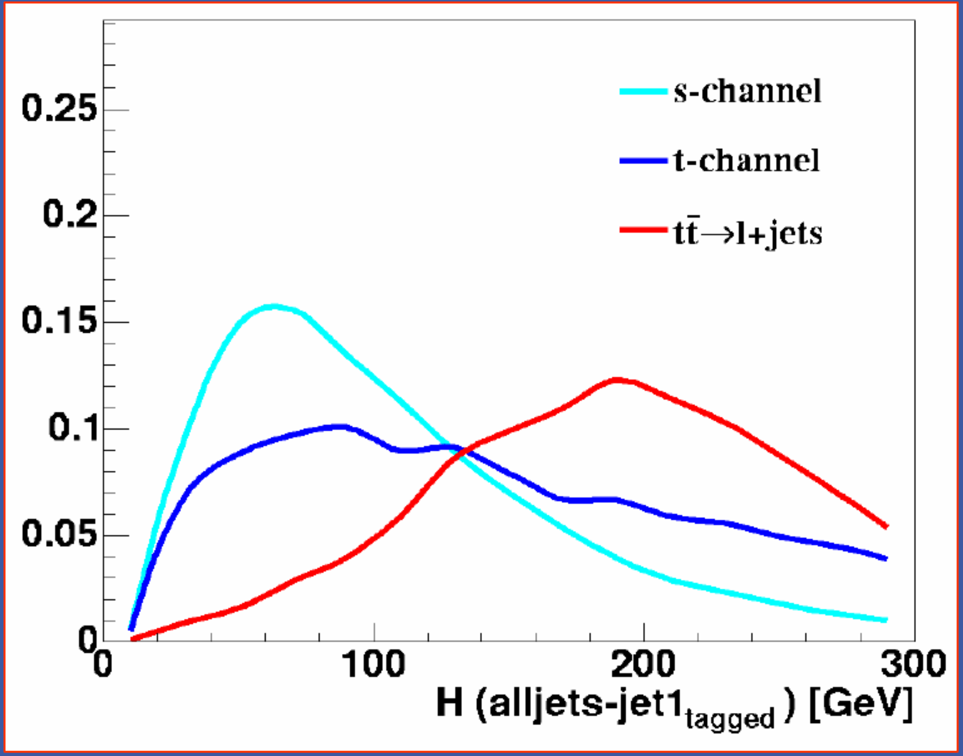
Input Variables I

DØ

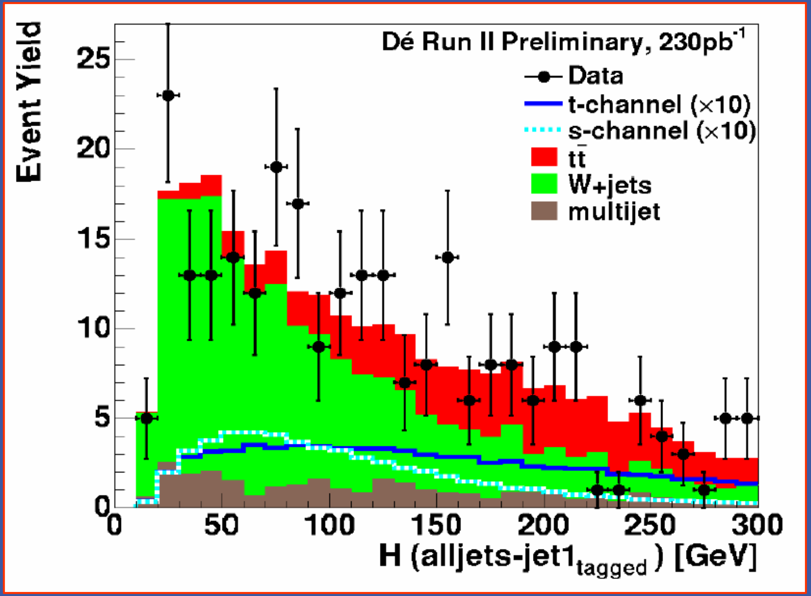
Event Energy, Object Properties

p_{Tjet1}, H, H_T…

MC Shapes



Cross Check Background Model

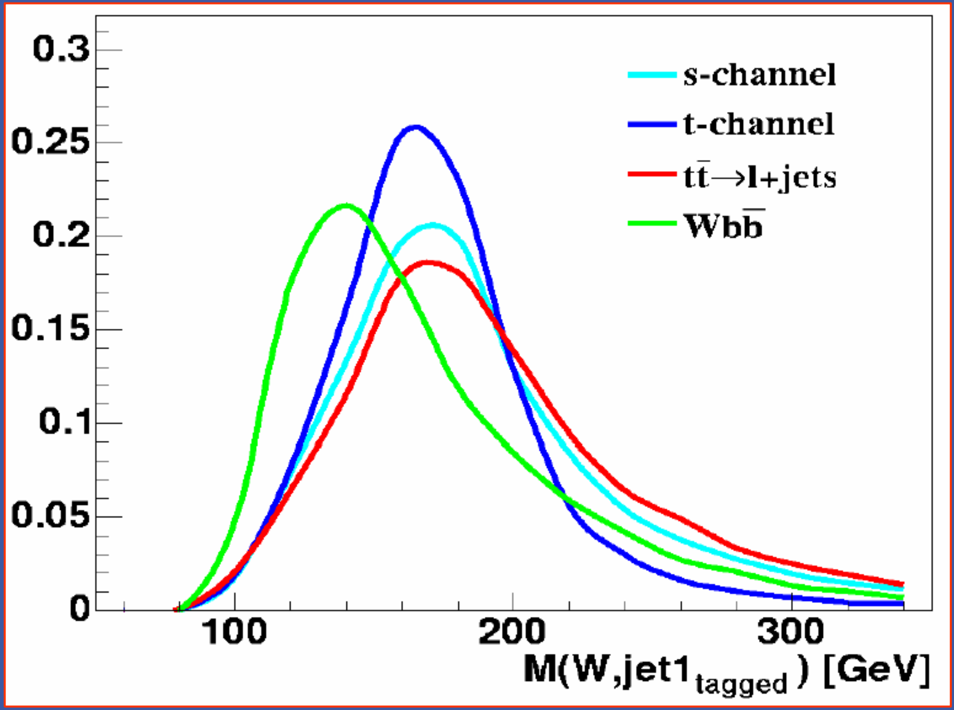


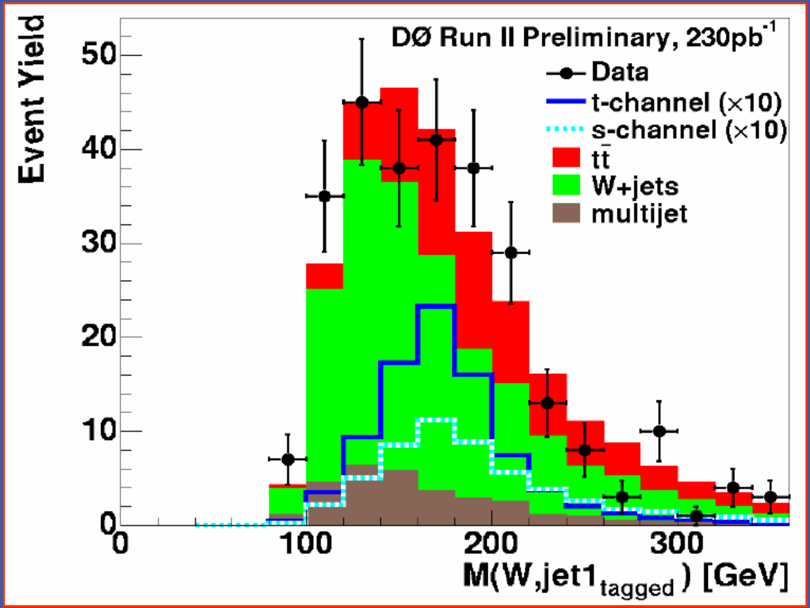
Input Variables II

Object Combinations

M_{top}, $M_{all\ jets}$

MC Shapes





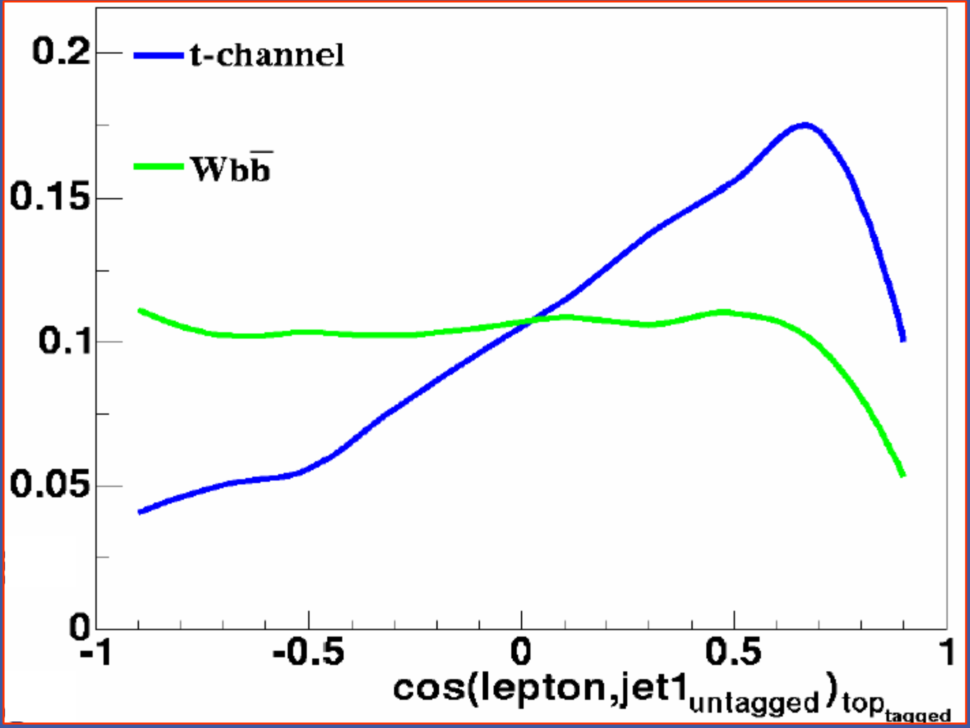
Cross Check Background Model

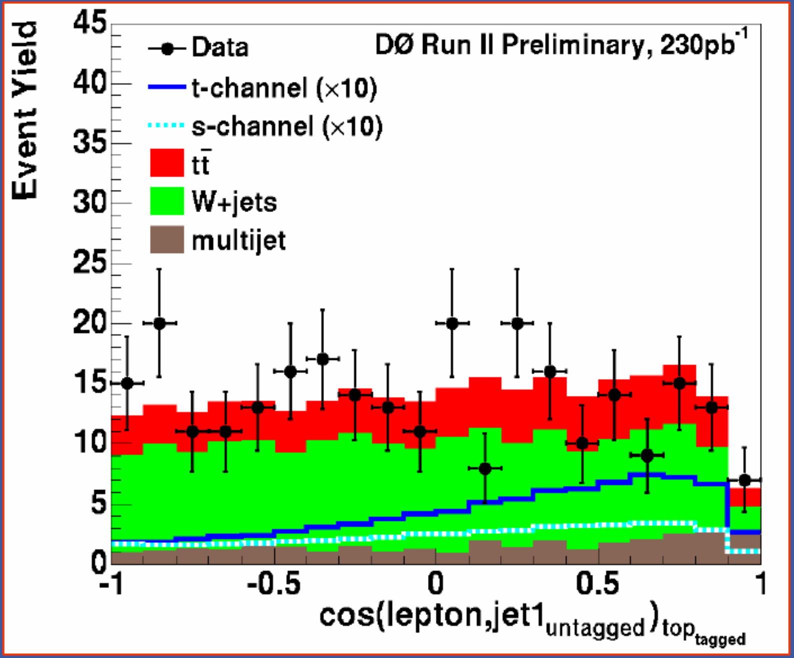
Input Variables III

Angular Variables

cos(lepton,jet1 untagged)$_{top}$

MC Shapes





Cross Check Background Model

Input Variables

Event Energy

p_{Ttag}, p_{Tuntag}, $p_{Ttopjet}$, $p_{Tjet1,jet2}$, H (all jets but tagged), H_T (jets), H_T (jets-tagged), H(jets-top quark jet), H_T (jets-top quark jet)

Object Combinations

M (jets), p_T (all jets – tagged), M_{top} (tagged jet), s, M(jets-tagged), M_T(jets 1&2), p_T(jets 1&2), M(jets-top quark jet) M_{top} (best jet)

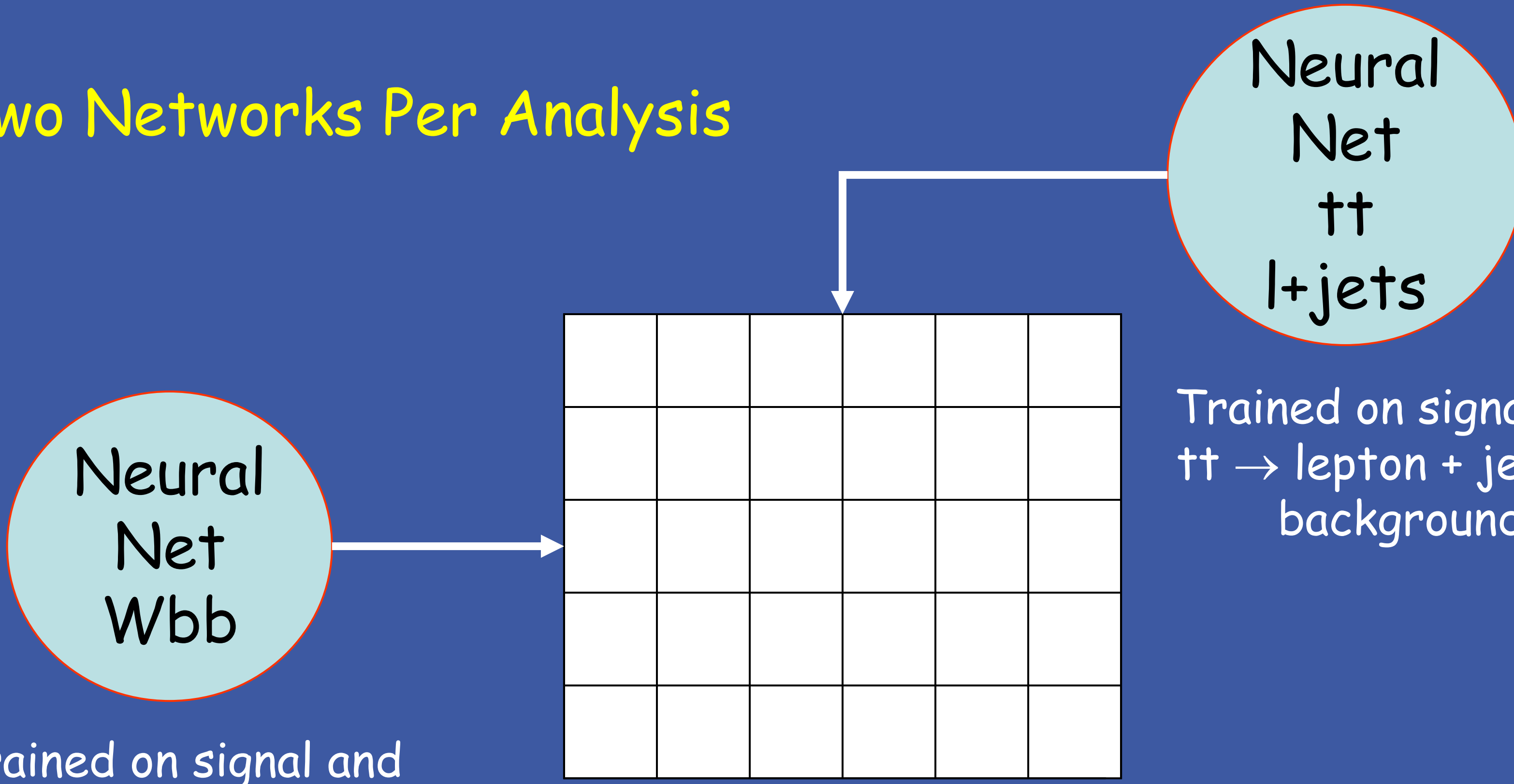
Angular Variables

ΔR(jets 1&2), η(untagged)XQ(lep), cos(lepton, untagged)$_{\text{top rest}}$, cos(jets, jet1 tagged)$_{\text{all jets rest}}$, cos(lepton, Q(lepton)xz)$_{\text{best top rest}}$, cos(jets, jet1 not best)$_{\text{all jets rest}}$

Both s&t, t-only, s-only

Neural Net Design

Two Networks Per Analysis



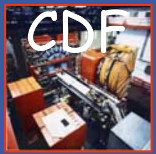
Trained on signal and $t\bar{t} \rightarrow$ lepton + jets as background

Trained on signal and Wbb as background

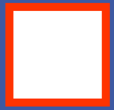
2d Histogram used in binned likelihood fit

We also use Decision Trees in place of NN

Systematic Uncertainties



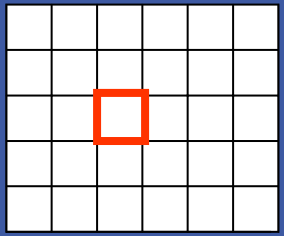
Fitting Shape Variables Requires Special Handling of Systematic Errors



1 bin

Calculate the Systematic Errors For That 1 Bin

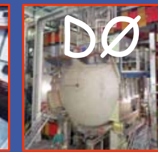
Jet Energy Scale, Trigger, BTagging, etc.



Repeat for All Bins

Shape Fluctuations Will Be Properly Accounted For

Systematics



DØ

Monte Carlo Systematic Uncertainties	
Components affecting normalization	
$\sigma_{t\bar{t}}$ theory and mass	18 %
$\sigma_{s(t)}$ theory	15 %(16 %)
Jet Fragmentation	6.0 %
ℓ ID	4.1 %
Branching Fraction	2.0 %
Components affecting shape and normalization	
SVT modeling, single (double) tag	10 %(20 %)
Jet Energy Scale	10 %
Trigger Modeling	6 %
Jet ID	5 %
Jet Energy Resolution	4 %

Some will improve with increased Luminosity

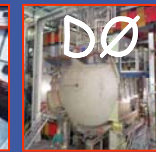
CDF

B-ID: 7%
Luminosity: 6%
Top Quark Mass: 4%
JES: 4%

TABLE III. Fractional changes in ϵ_{evt} of single-top processes in %. ϵ_{trig} is the trigger efficiency, ϵ_{ID} the lepton identification efficiency.

i	Source	t-channel	s-channel	Combined
1	JES	$^{+2.4}_{-6.7}$	$^{+0.4}_{-3.1}$	$^{+0.1}_{-4.3}$
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	Generator	±5	±2	±3
6	Top quark mass	$^{+0.7}_{-6.9}$	-2.3	-4.4
7	ϵ_{trig}, ϵ_{ID}, luminosity	±9.8	±9.8	±9.8

Final Results



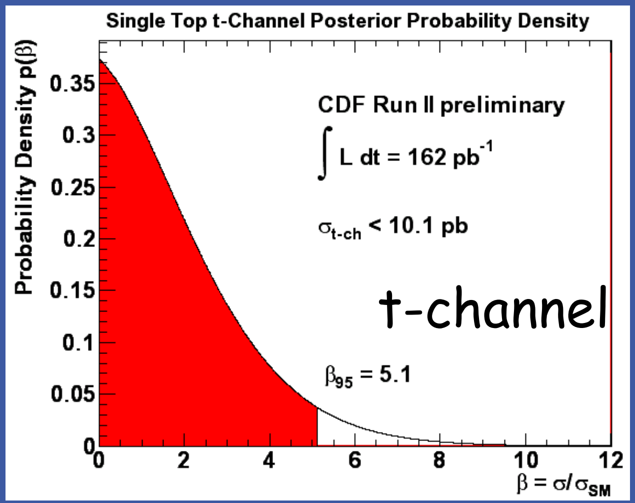
95% C.L. limits Observed (Expected)

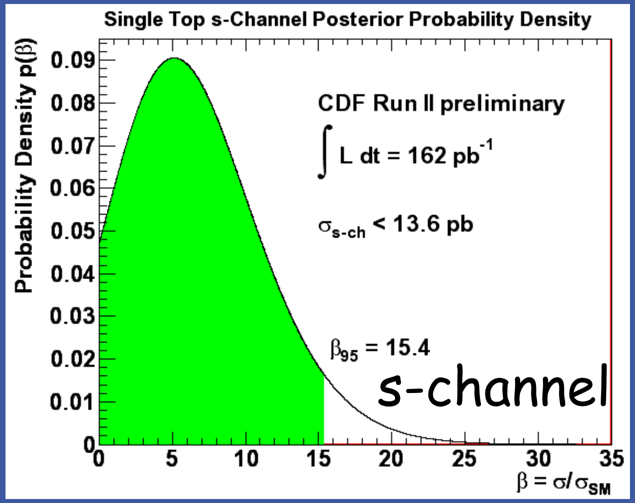
Channel	CDF (pb)	DØ (pb)	SM
s+t	<17.8 (13.6)		2.86pb
t	<10.1 (11.2)	<5.8 (5.0)	1.98pb
s	<13.6 (12.1)	<6.4 (4.5)	0.88pb

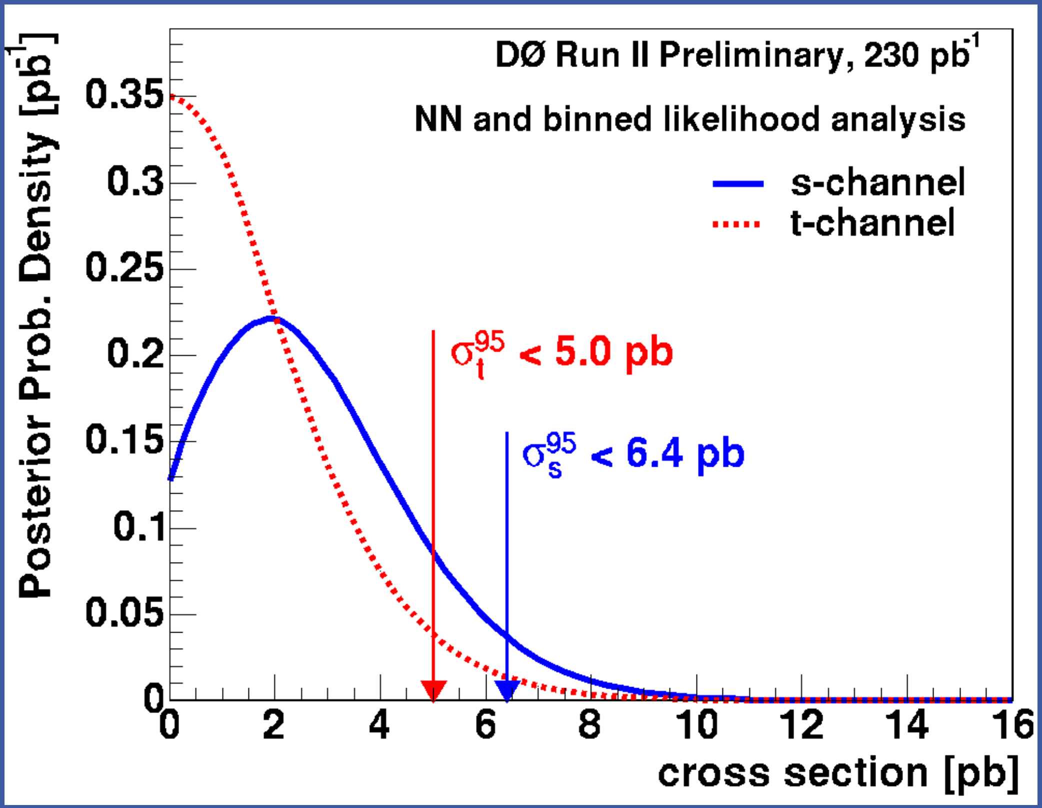
Luminosity 162 pb^{-1} 230 pb^{-1}

(recall Straight Cut Limit was s:10.6, t: 11.3)

Probability Density

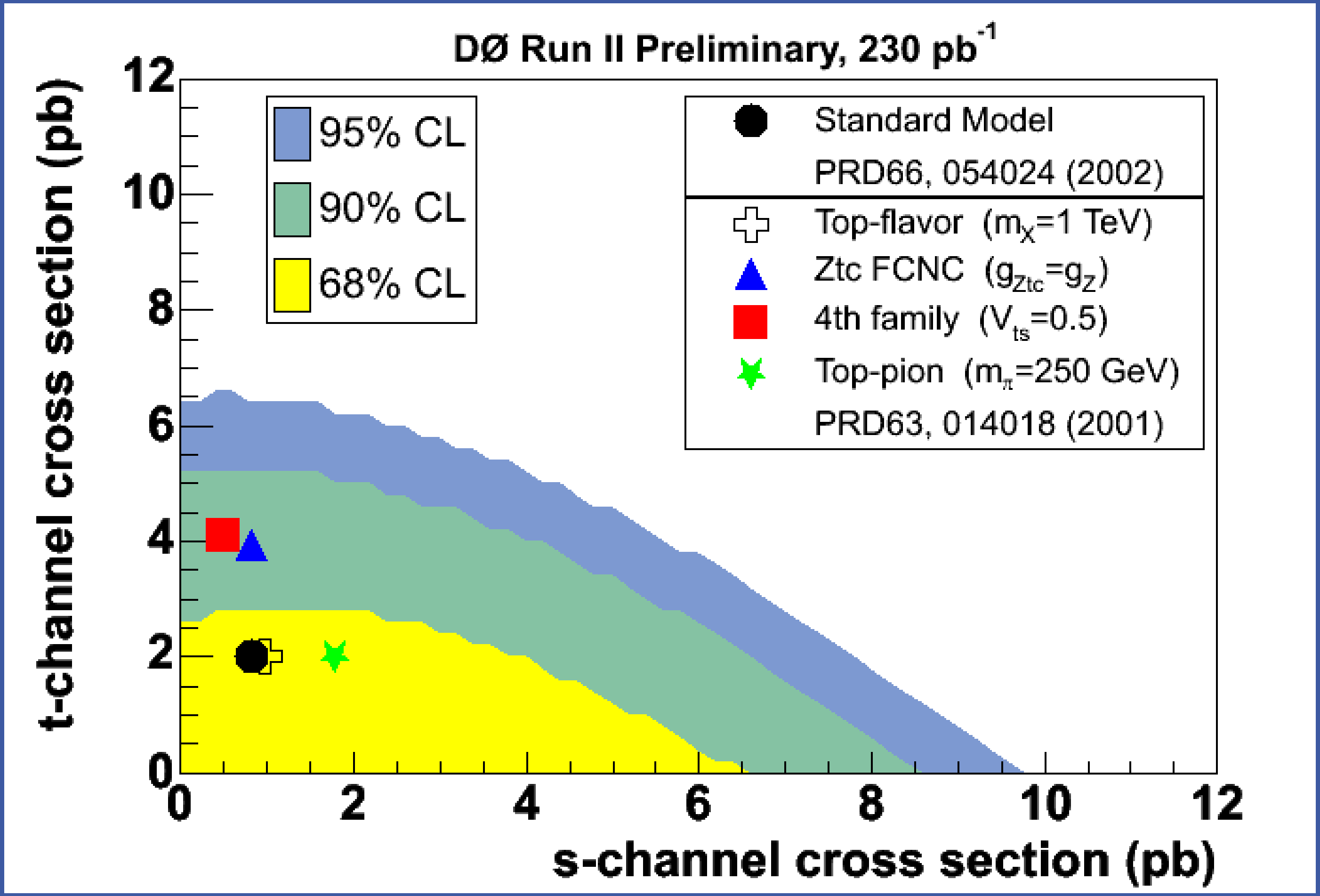




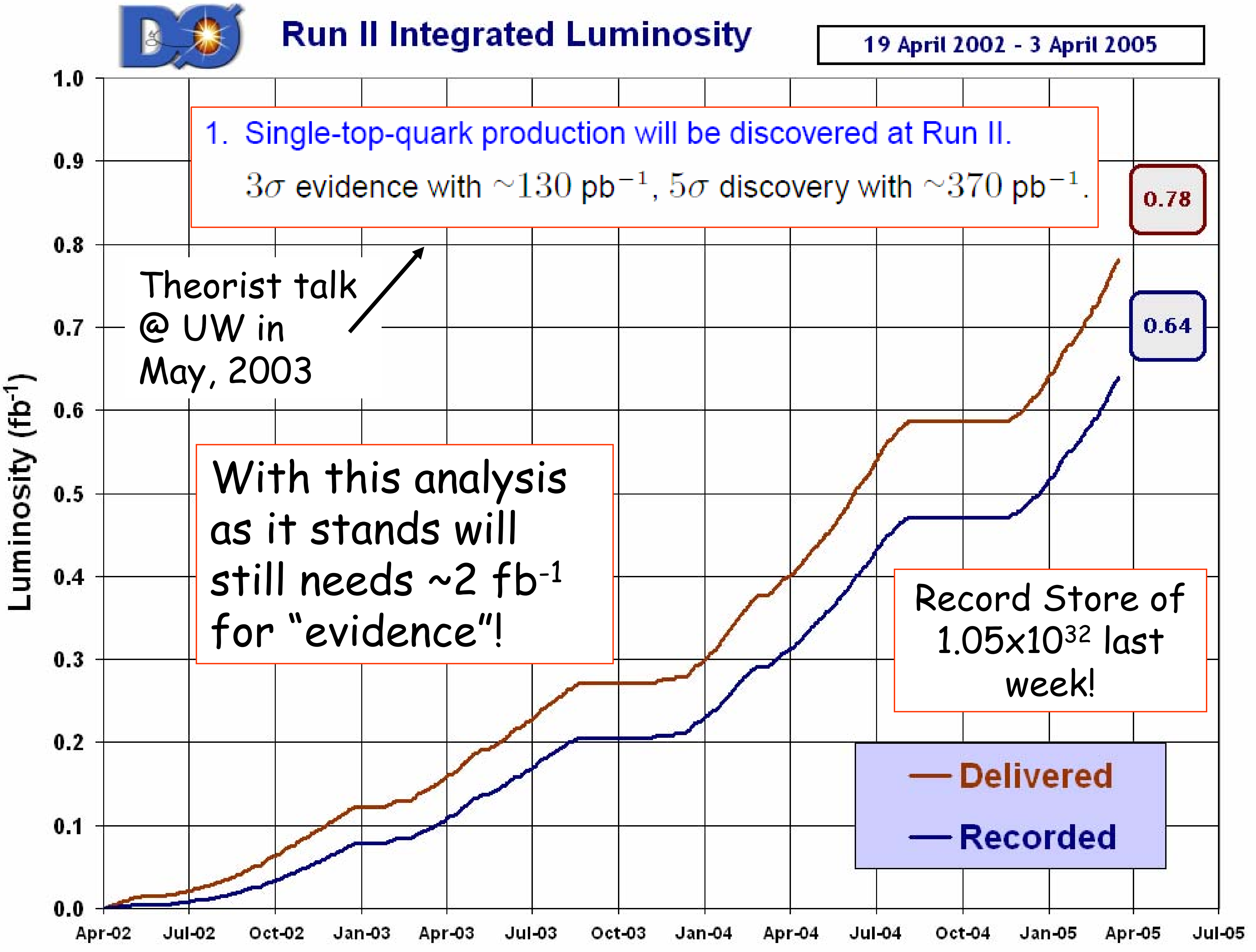



Beyond The Standard Model

μ data only



e data only


DØ
Run II Integrated Luminosity
19 April 2002 - 3 April 2005
1. Single-top-quark production will be discovered at Run II.
3σ evidence with ~ 130 pb^{-1}, 5σ discovery with ~ 370 pb^{-1}.
Theorist talk @ UW in May, 2003
0.78
0.64
With this analysis as it stands will still needs ~2 fb^{-1} for "evidence"!
Record Store of 1.05×10^{32} last week!
Delivered
Recorded
Luminosity (fb^{-1})
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05

Near Future

Upgrade to modern b-quark tagging
Explore multivariate methods
Increased Dataset!

Aggressive Program to Increase Acceptance
B-tagging improvements
Neural Network & Other Technique (DTs) Improvements

CDF: PRD is published
DØ: Paper in preparation

☺ Last paper published before evidence! ☺

(I suspect)

Monte Carlo Understanding

No Particular W+Jets Background Type is dominate!

Production Mechanisms affect shapes

How well do we know
Charm Tag Rate
Production Fractions?

Wjj Channel	b-jet	c-jet	non-b/c-jet	Total
Wqq	2%	1%	6%	9%
Wqg	11%	8%	14%	33%
Wgg	7%	5%	5%	17%
Wcq	0%	14%	1%	15%
Wcg	1%	10%	0%	11%
$Wc\bar{c}$	0%	5%	0%	5%
$Wb\bar{b}$	10%	0%	0%	10%
Total	31%	43%	26%	100%

From hep-ph/041223
(Bowen, Ellis, Strassler)

SingleTop at TeV4LHC

See TeV4LHC & Web...

Start of Workshop

Single Top Theory – Qing-Hong Cao
Single Top Experiment – R. Schwienhorst

Working Group Meeting

Single top: Simulations & Strategies; Zack Sullivan
Single top in MCFM; Keith Ellis
Effective NLO generator SingleTop from CompHEP;
Edward Boos
Electroweak & Single Top Plans (Discussion)

BNL

Single Top Production: Ellis

Conclusions

- Both Experiments Have Recent Limits
  - CDF's Published
  - DØ's Soon to be submitted
- Straight Event Counting does not suffice
  - Depend more heavily on modeling than ever before
- Both Experiments still have plenty of room for improvements

95% C.L. limits Observed (Expected)

Channel	CDF (pb)	DØ (pb)
s+t	<17.8 (13.6)	
t	<10.1 (11.2)	<5.8 (5.0)
s	<13.6 (12.1)	<6.4 (4.5)
	162 pb^{-1}	230 pb^{-1}

- Theory Input Will Help
  - W+Jets Background Sys
- Thanks to all who helped with this talk!