Improved Search for Single Top Quark Production at DØ in Run II

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On behalf of the Single Top Working Group:

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All-DØ Meeting, 2/25/2005

Outline

- Single Top Physics
- Top Quark Electroweak Interactions
- Event Selection
- Final Analysis Methods
  - Cut-based analysis
  - Neural Network Analysis
- Result
- Conclusions/Outlook

Analysis currently in collaboration review. See http://www-d0.fnal.gov/Run2Physics/top/d0_private/wg/singletop/singletop.html for conference note (#4722) and analysis note (#4760)

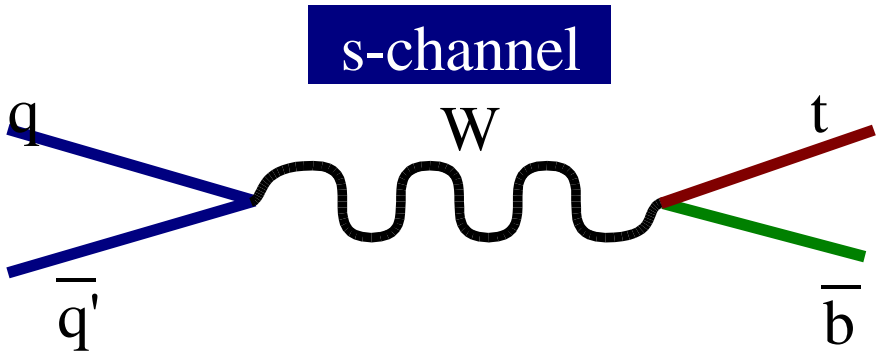
Jianming's Challenge

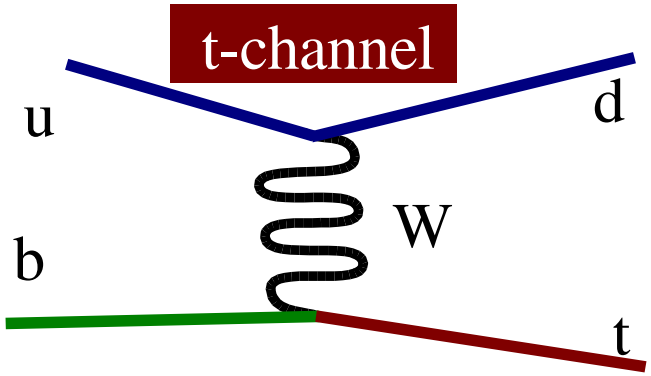
from September 17, 2004 Conveners meeting

"A significantly improved single top cross section limit with full statistics by March"

Single Top Physics at the Tevatron

- Electroweak Production of Single Top Quarks

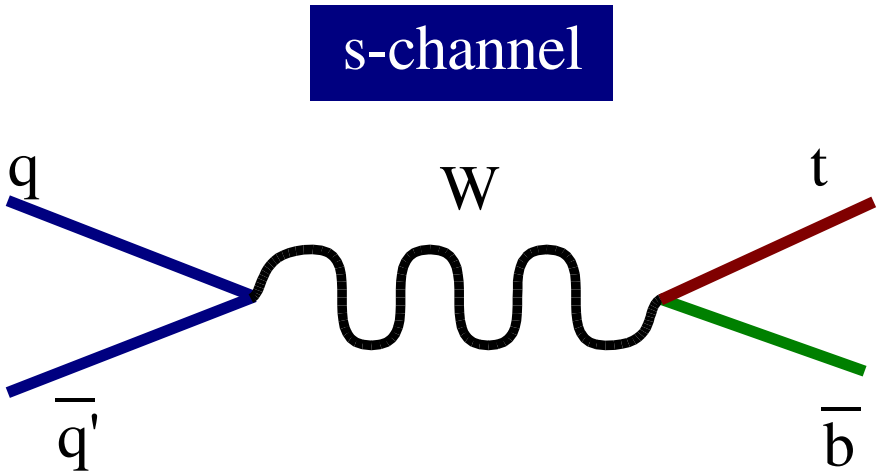


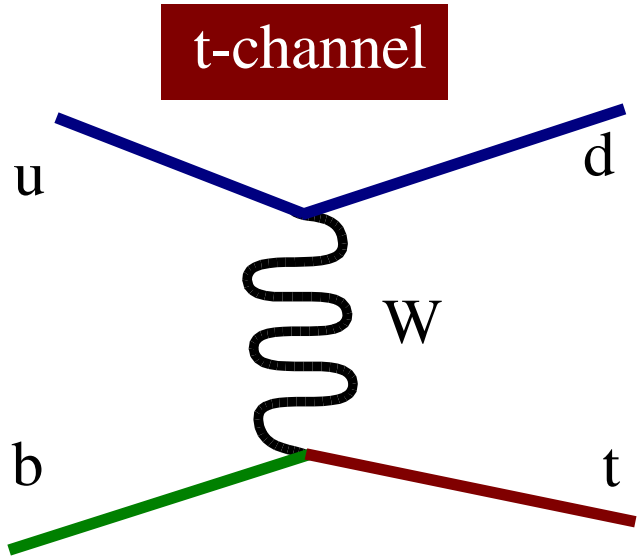


Goals for Single Top in Run II:

- Observe Single Top Production
- Measure Production cross section
  - Confirm Standard Model Prediction
    - CKM matrix element V_{tb}
- Look for Physics beyond the Standard Model
- Measure top quark spin

Electroweak Production of Top at the Tevatron





- Production cross section:

	s-channel	*t-channel*	*s+t channel*
– NLO cross-sections:	0.88pb ± 8%	1.98pb ± 11%	
– Run I 95% CL limits, DØ:	<17pb	<22pb	
CDF:	<18pb	<13pb	<14pb
– Run II: DØ(prelim, 160pb^{-1}):	<19pb	<25pb	<23pb
CDF(paper, 160pb^{-1}):	<13.6pb	<10.1pb	<17.8pb

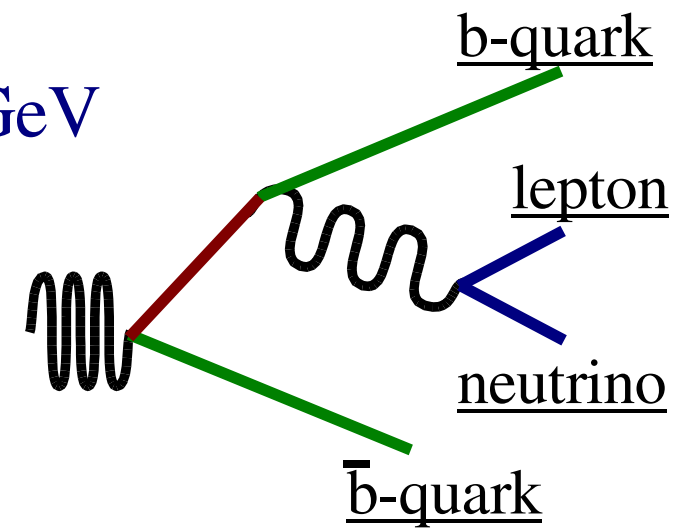
Analysis Outline

1. Event Selection
   - Select clean sample of real-lepton events
   - Maximize acceptance
   - Check background modeling in detail
2. Final Analysis: separate signal from background
   - Find sensitive variables for s-channel and t-channel
     - Check background modeling and correlations in detail
   - Cut-based and neural network analyses
     - Separate signal from backgrounds separately for s-channel and t-channel
3. Determine cross section limit
   - Expected limit and observed limit for s-channel and t-channel
     - Using event counting (cut-based) and binned likelihood fit

Single Top Event Selection

- Dataset: Pass 1 data between 8/2002 and 3/2004, 230pb^{-1}
- Lepton: 1 electron or muon, p_T > 15GeV
- Neutrino: missing transverse energy > 15GeV
- Jets:
  - p_T > 15GeV, $|\eta^{det}|<3.4$, p_T (jet 1)> 25GeV
  - $2 \leq n_{jets} \leq 4$
  - At least one SVT tag

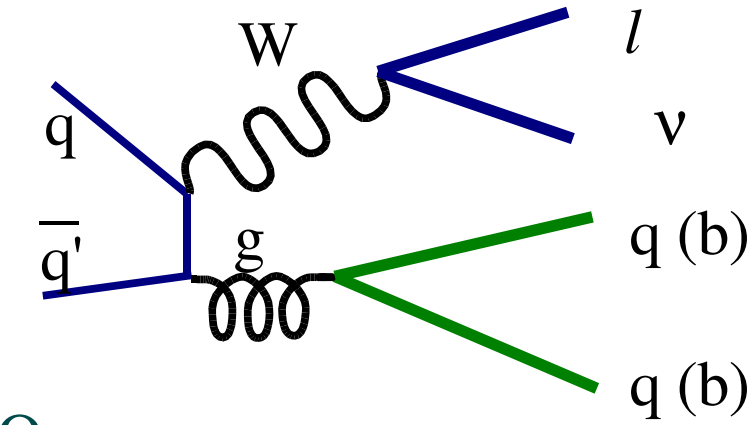
$|\eta^{det}(\text{jet } 1)|<2.5$

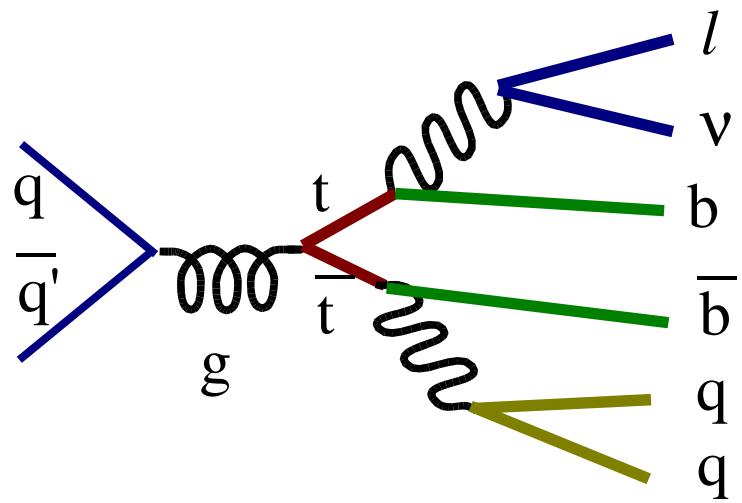


- Trigger:
  - L1: Lepton: ≥1 EM object, pT>10GeV or ≥1 muon hit Jets: ≥1 jet
  - L2: Lepton: ≥1 EM object, pT>12GeV or ≥1 muon Jets: ≥ 1 jet
  - L3: Lepton: ≥1 EM object, pT>15GeV Jets: ≥ 1 jet
- Reject mis-reconstructed events

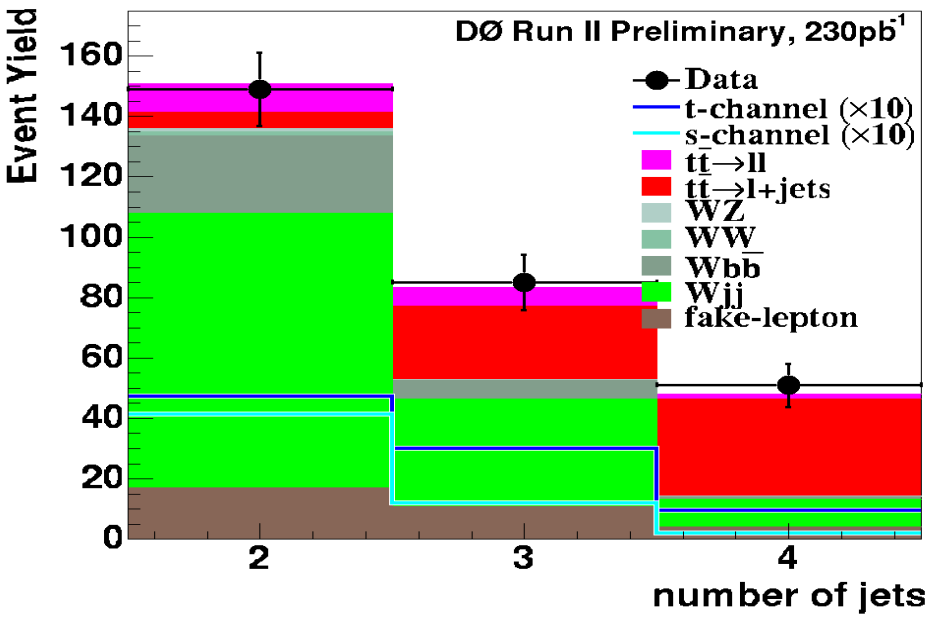
Backgrounds

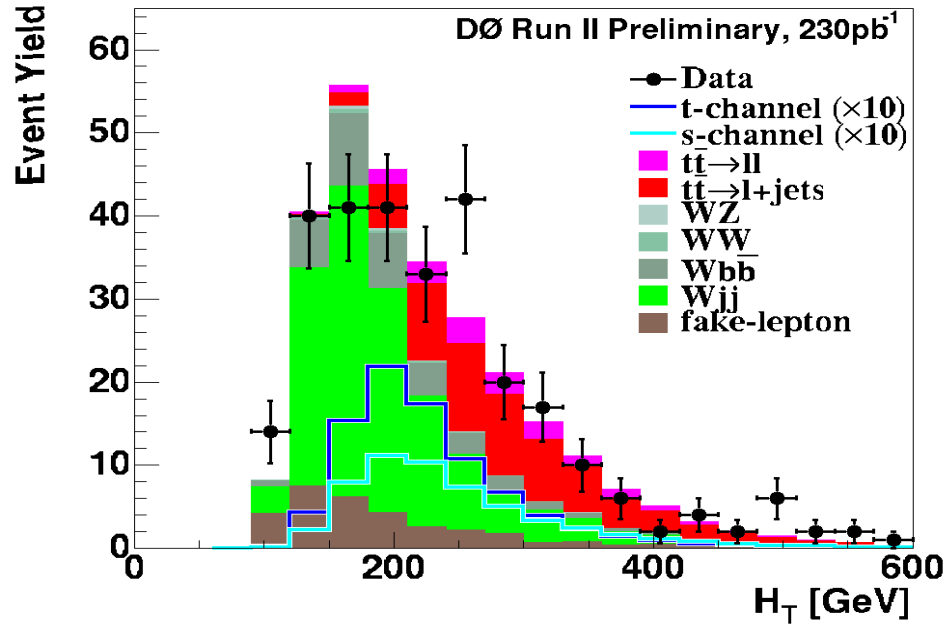
- W+jets production (real-*l*)
  - Estimated from data/MC
    - Distributions from W+jets MC
    - Normalization from pre-tagged data
    - Heavy flavor fraction normalized to NLO
- Mis-reconstructed multi-jet events (fake-*l*)
  - Estimated from data
- Top-pair production
  - Both lepton+jets and di-lepton
  - Estimated from MC
- WW/WZ
  - Estimated from MC

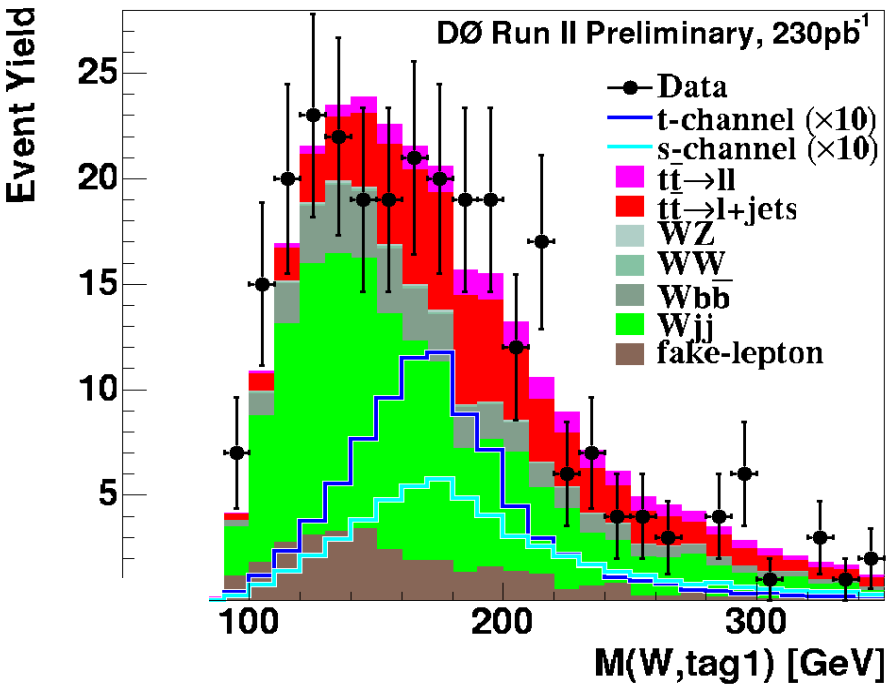




Yields after Event Selection







	Event Yields	
	s-channel	t-channel
s-channel signal	5.5	4.7
t-channel signal	8.6	8.5
W+jets	169	164
top pairs	78	76
fake-lepton	31	31
Sum of Backgrounds	287±44	276±41
Observed event yield	283	271

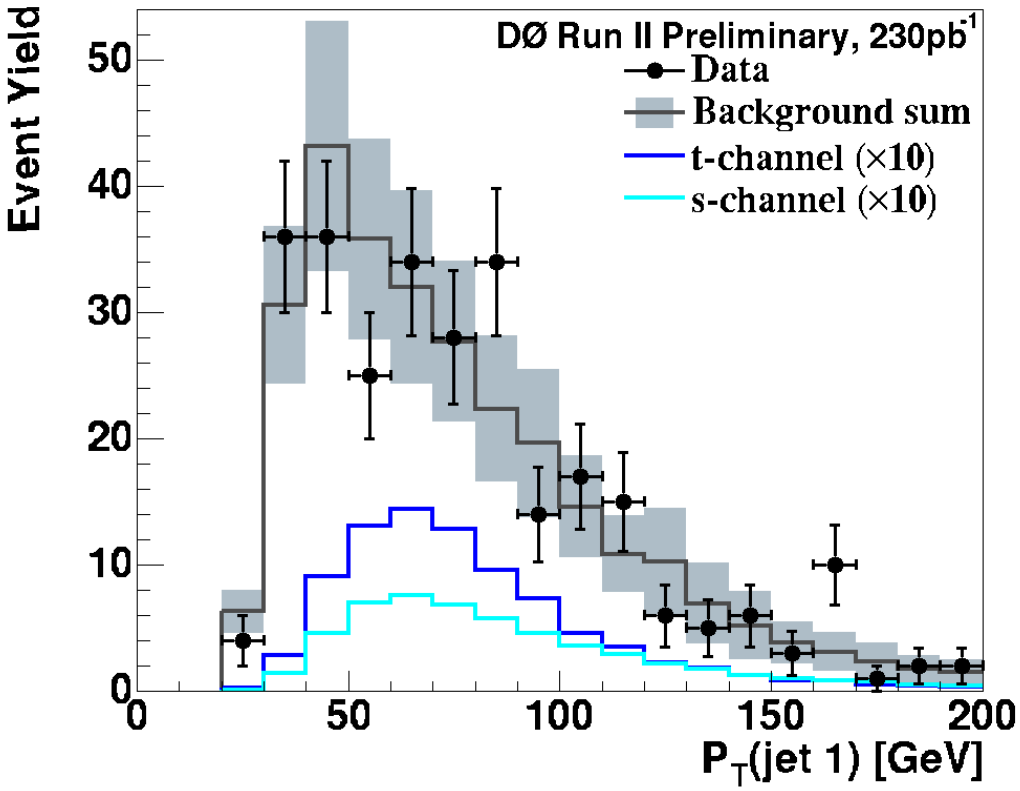
Systematic Uncertainties

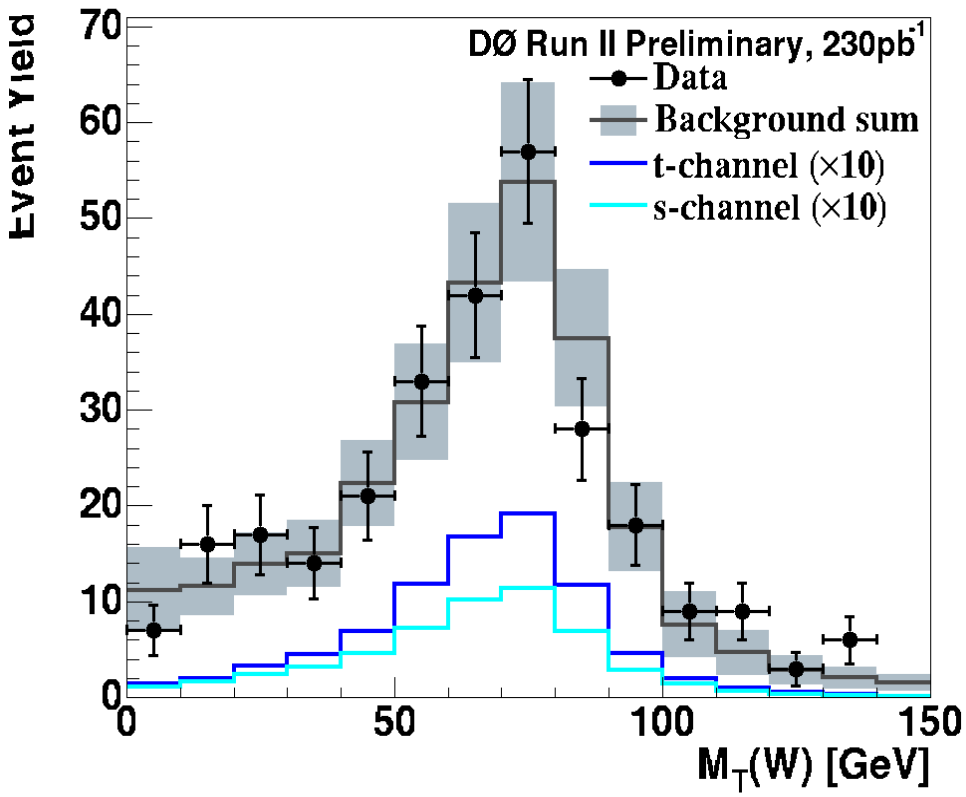
- For signal acceptance and Monte Carlo Backgrounds
  - Jet Energy Scale ~8%
  - Tagger Modeling ~8%
  - Trigger Modeling ~5%
  - Object ID ~ 5%
  - Background normalization ~15%

Luminosity 6.5%

Total Uncertainty:

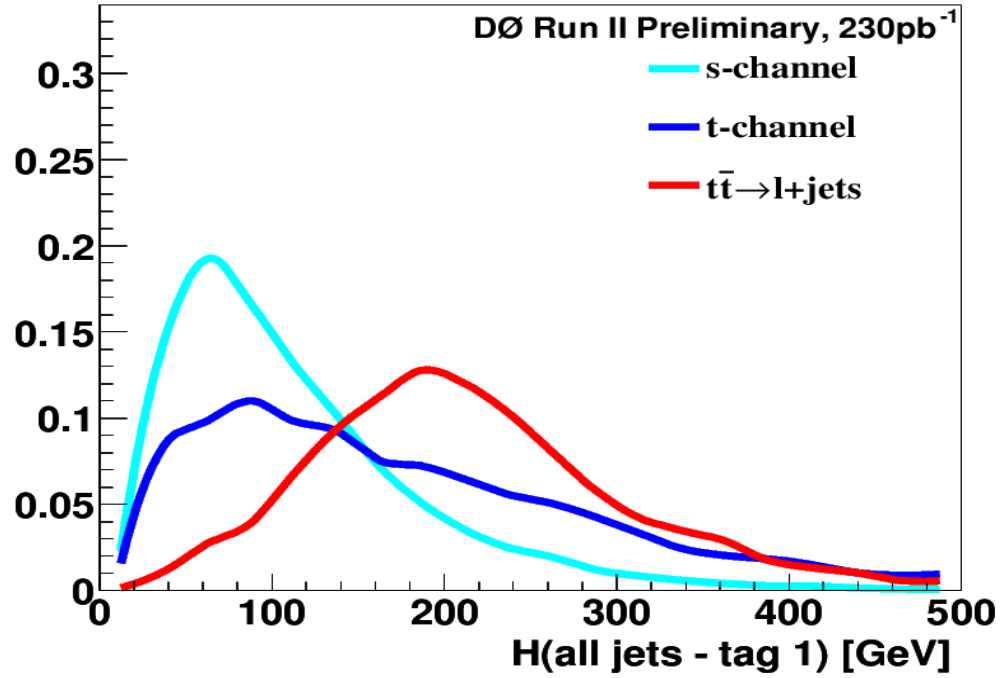
	=1 tag	≥2 tags
Signal acceptance	15%	25%
Background sum	10%	25%

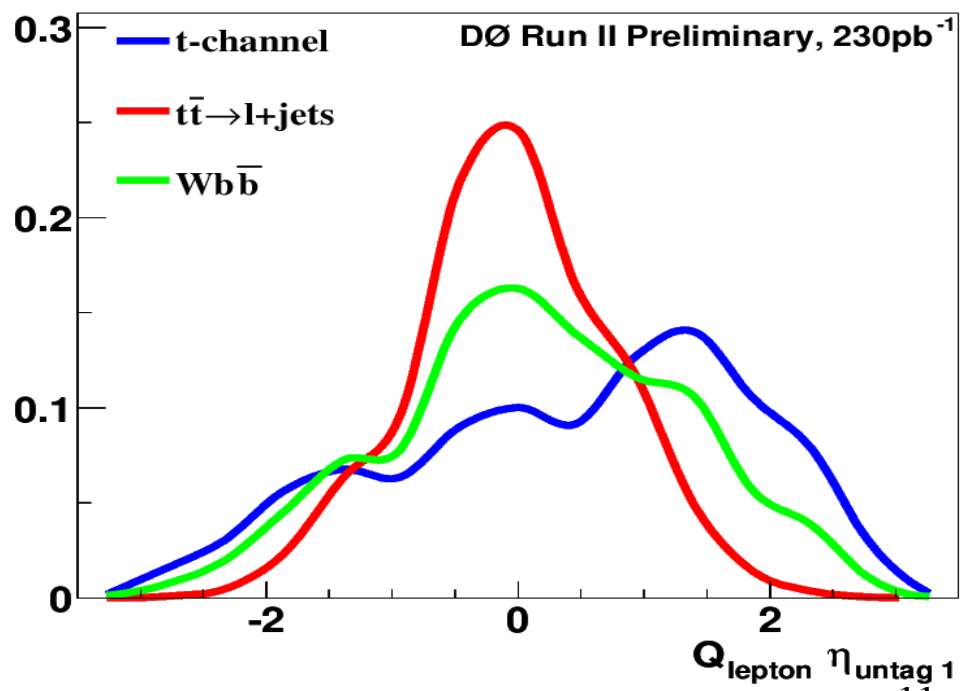




Sensitive Variables

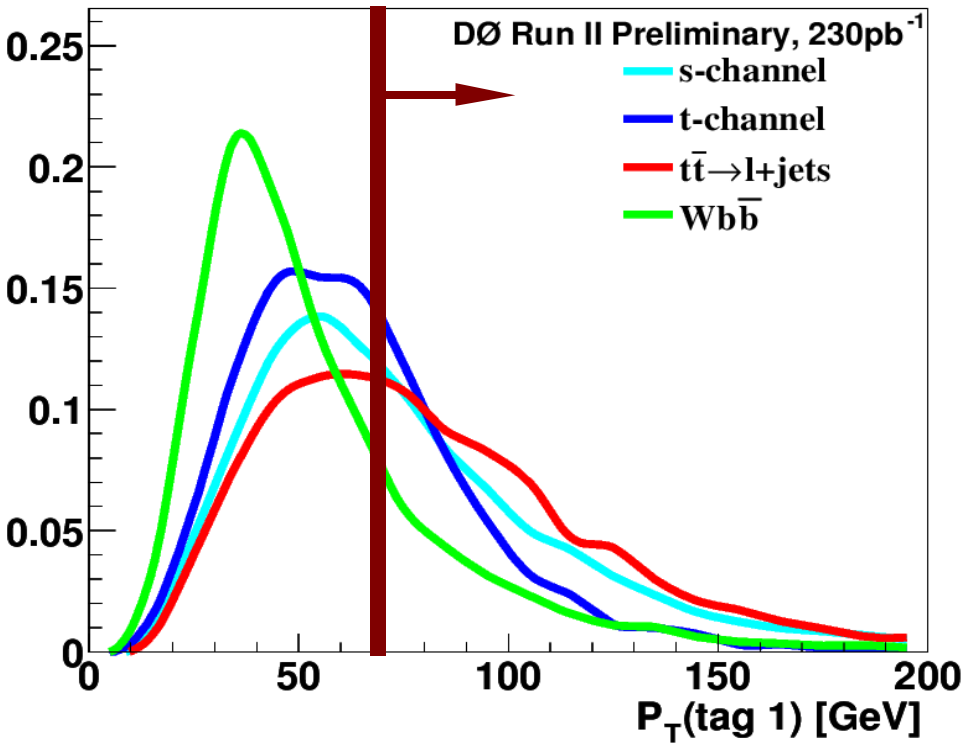
- Object kinematics
  - Jet p_T for different jets
- Event kinematics
  - H (total energy)
  - H_T (transverse energy)
  - M (invariant mass)
  - M_T (transverse mass)
  - Summing over various objects in the event
- Angular variables
  - Jet-jet separation
  - Jet pseudorapidity (t-channel)
  - Top quark spin
- 25 variables total





Cut-based Analysis

- Cuts on sensitive variables to isolate single top
  - Using random grid search to optimize set of cuts
  - Optimize separately by lepton and tag multiplicity
    - For s-channel and t-channel searches separately
  - Using energy variables: p_T, M, H, H_T



	Event Yields	
	s-channel	t-channel
s-channel signal	4.5	3.2
t-channel signal	5.5	7
W+jets	103	73
top pairs	28	56
fake-lepton	17	17
Sum of Backgrounds	153±25	149±25
Observed event yield	152	148

Neural Network Analysis

- Multivariate analysis technique

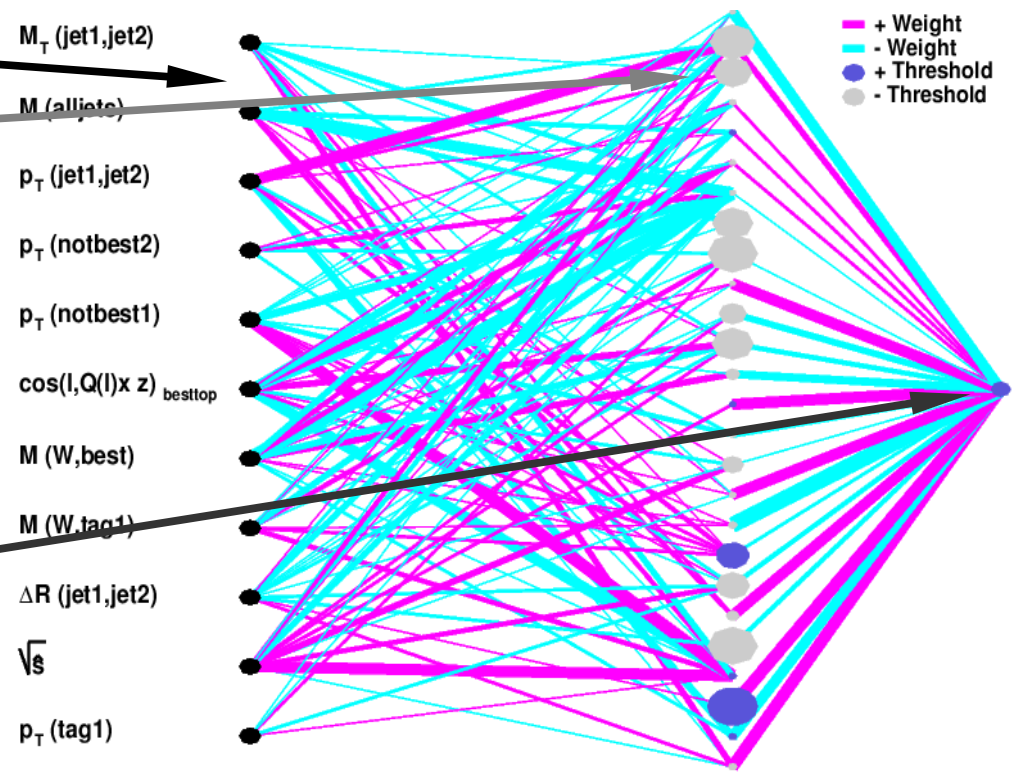
Input Nodes:
a node for each input variable

Hidden Nodes: each node is a linear combination of weighted sigmoids dependent on each variable

$$n_j(\vec{x},\vec{w}) = \frac{1}{1 + e^{-\sum w_i x_i}}$$

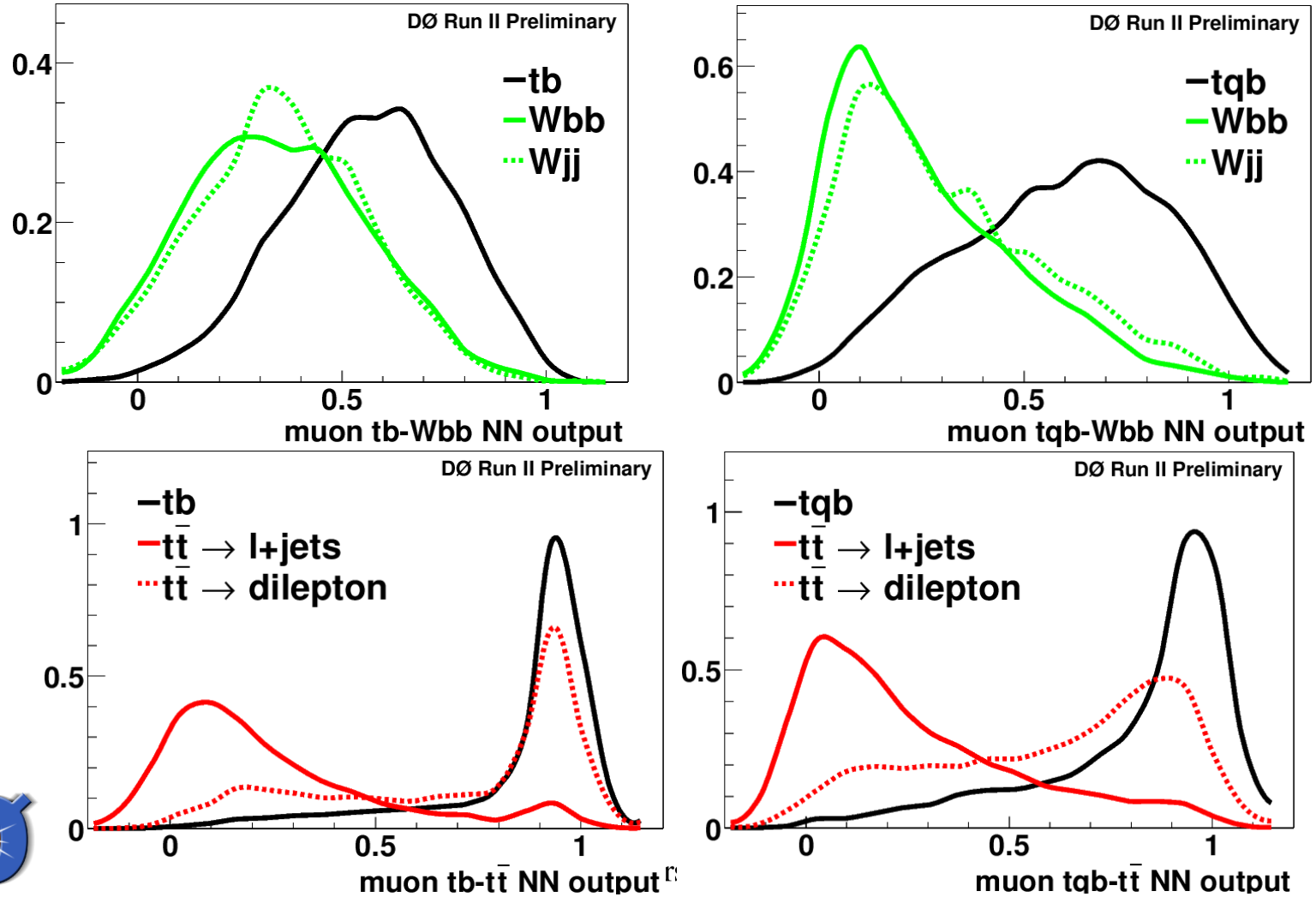
Output Node:
a linear combination of hidden nodes

$$f(\vec{x}, \vec{w}) = \sum_j n_j(\vec{x},\vec{w})$$

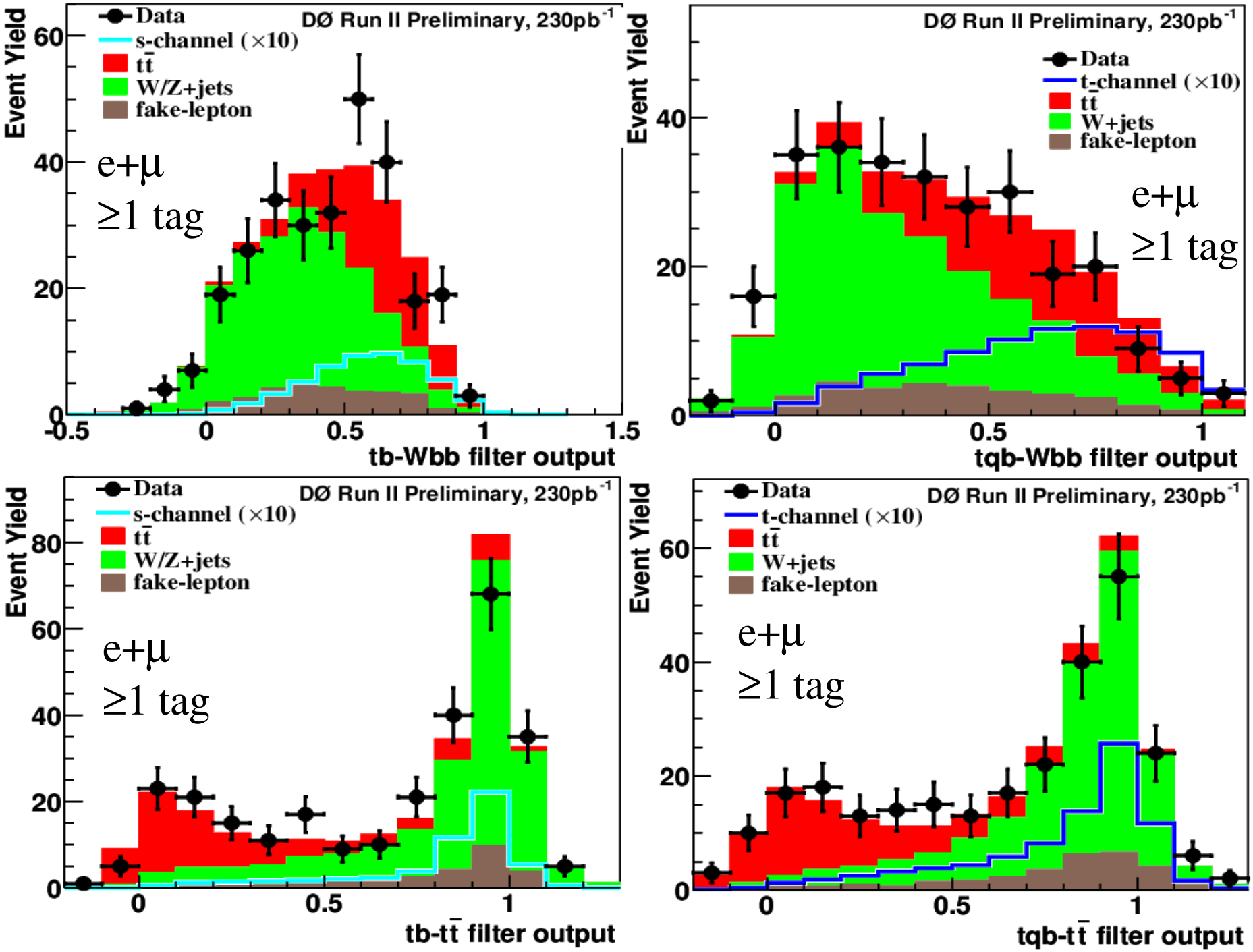


Neural Network Configuration

- Focus on the largest backgrounds: Wbb and tt→*l*+jets
- Same variables for electron and muon channel
- Same filter for =1 tag and ≥2 tags
- 11 variables for each filter

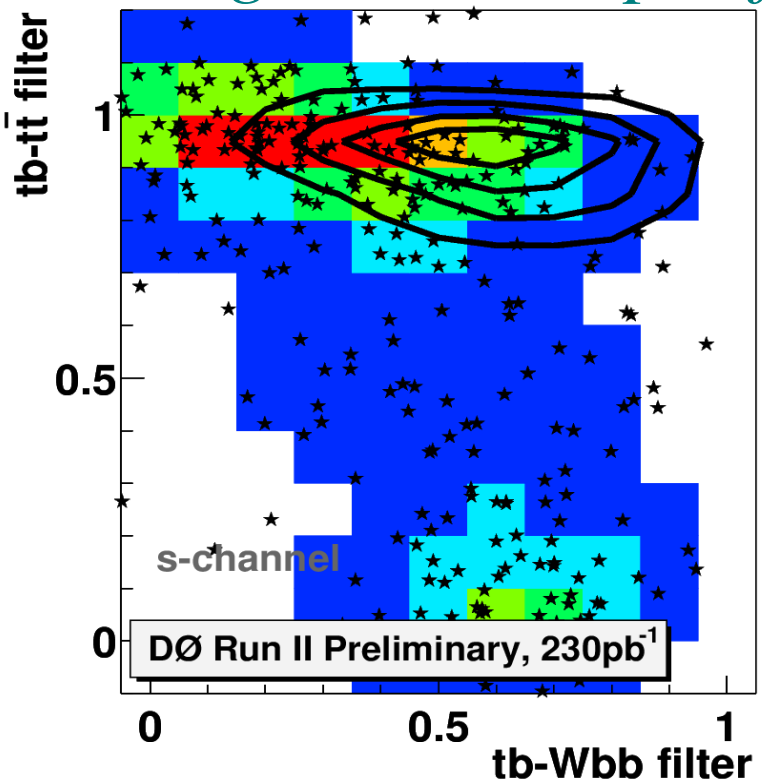


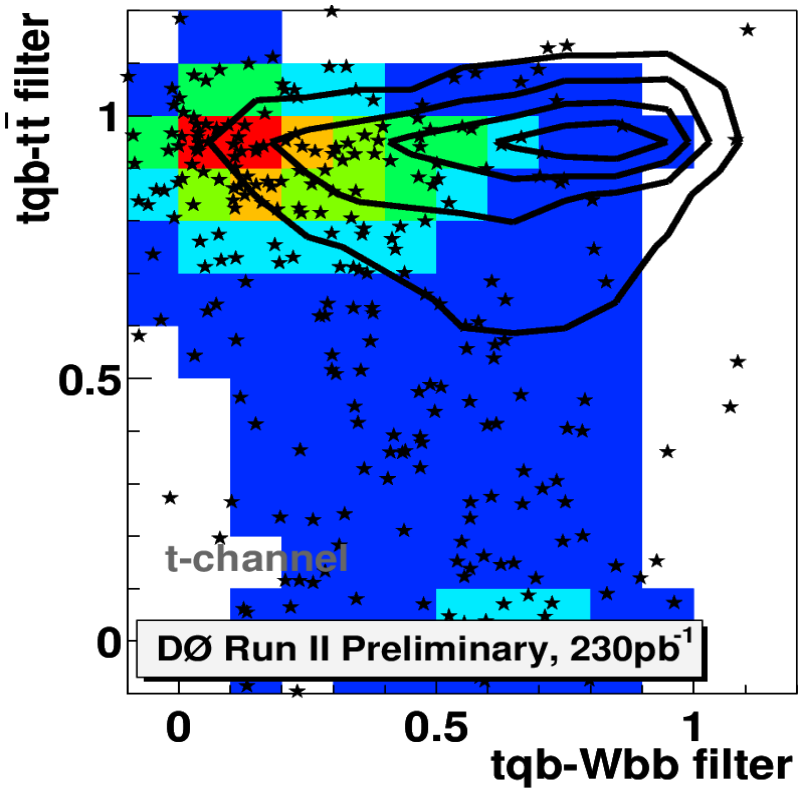
Neural Network Result



Binned Likelihood Fit

2-d histograms as input for binned likelihood fit





Separate histograms for e, μ; =1 tag, ≥2 tags
Derive a likelihood function for each bin
Then combine all bins, leptons, tags

Final Result

- No evidence for single top production
- Set 95% CL limit on production cross section
  - Cut-based: event counting
  - Neural network binned likelihood fit to filter output
- Include systematic uncertainties and correlations
- Bayesian limit setting approach

Cut-based analysis
Expected/Observed limit:

$\sigma_s < 9.8 / 10.6$ pb

$\sigma_t < 12.4 / 11.3$ pb

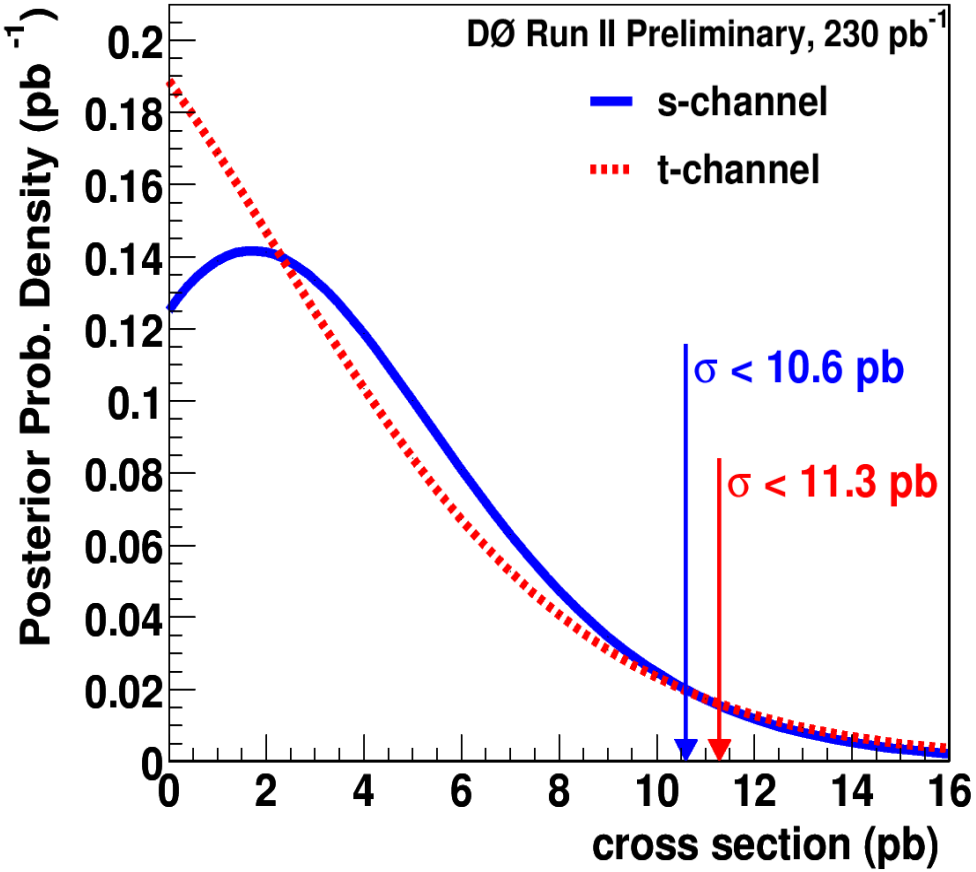
Neural network analysis
Expected/Observed limit:

$\sigma_s < 4.5 / 6.4$ pb

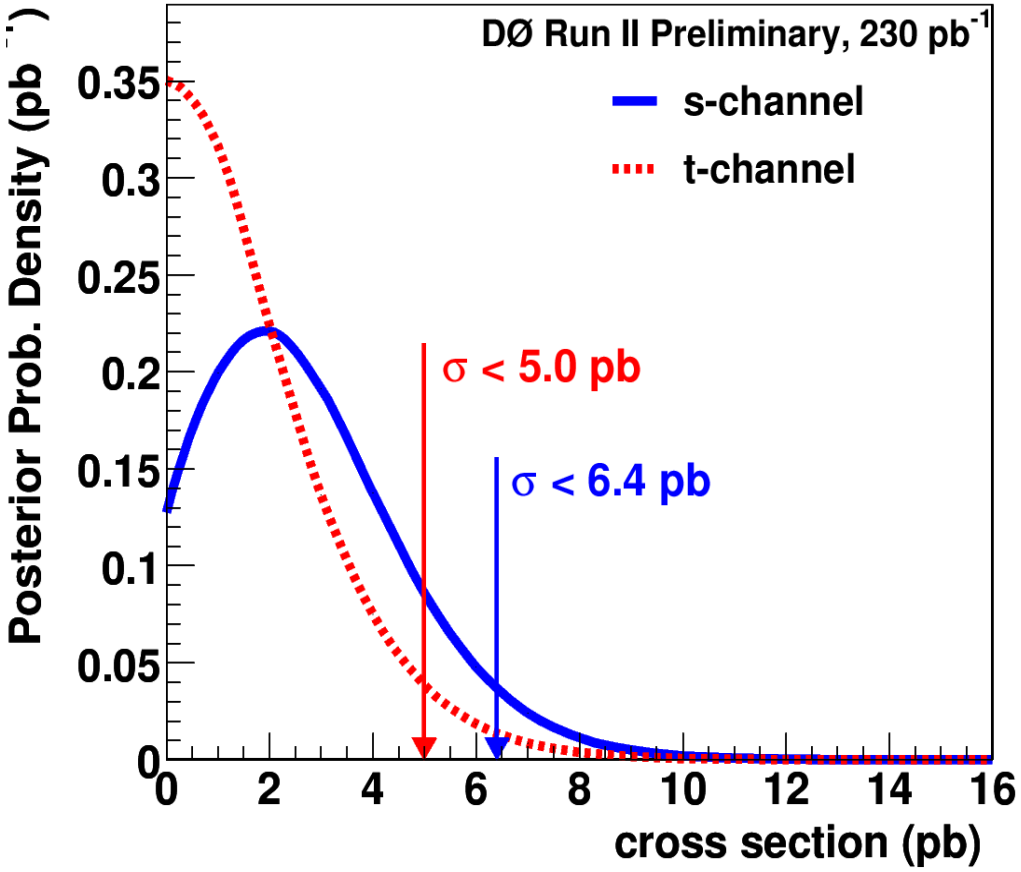
$\sigma_t < 5.8 / 5.0$ pb

Posterior Probability

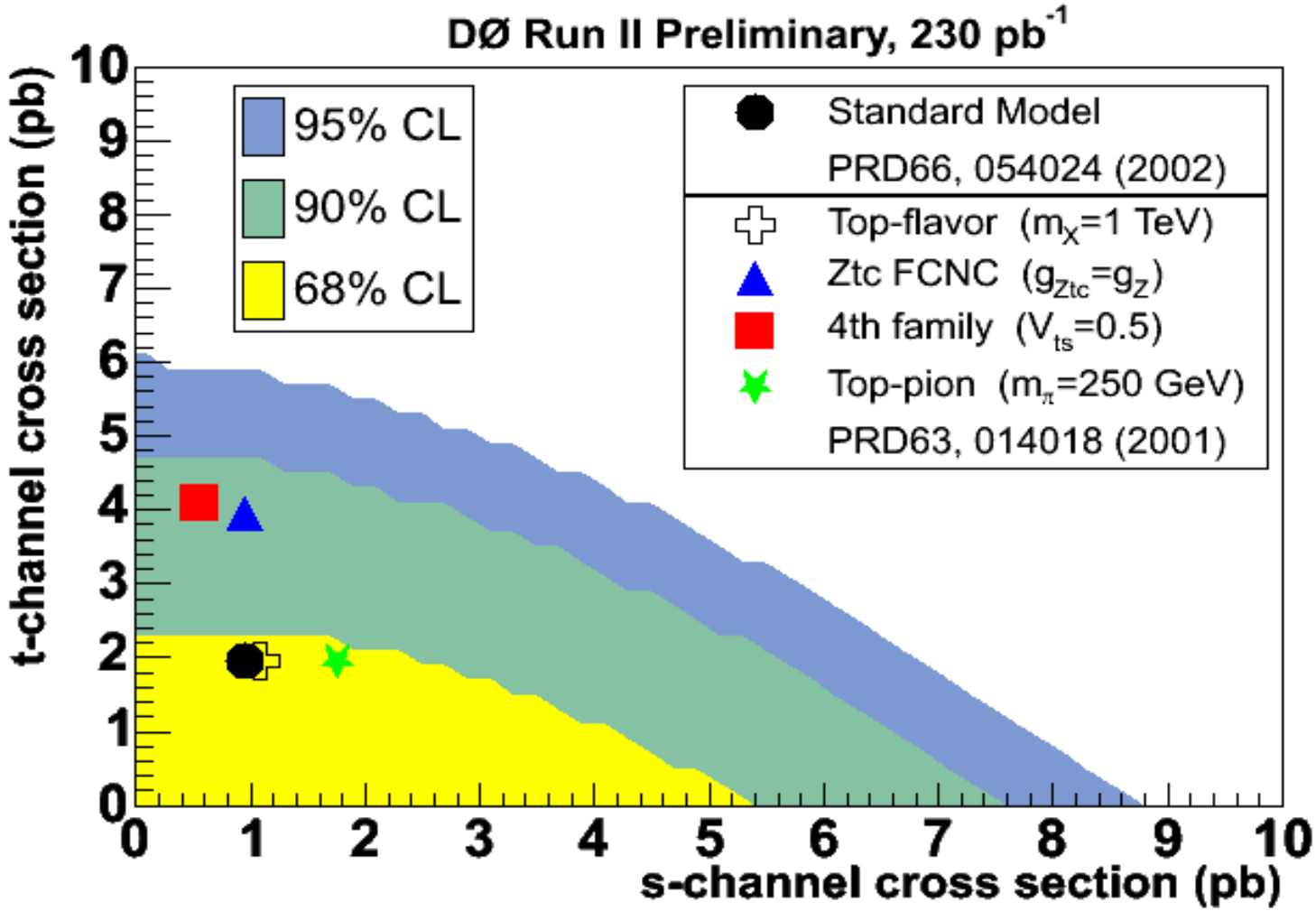
Cut-based analysis



Neural network analysis



Sensitivity to New Physics



Combining neural network s-channel muon-only data and t-channel electron-only data

Jianming's Challenge: how did we do?

"A significantly improved single top cross section limit with full statistics by March"

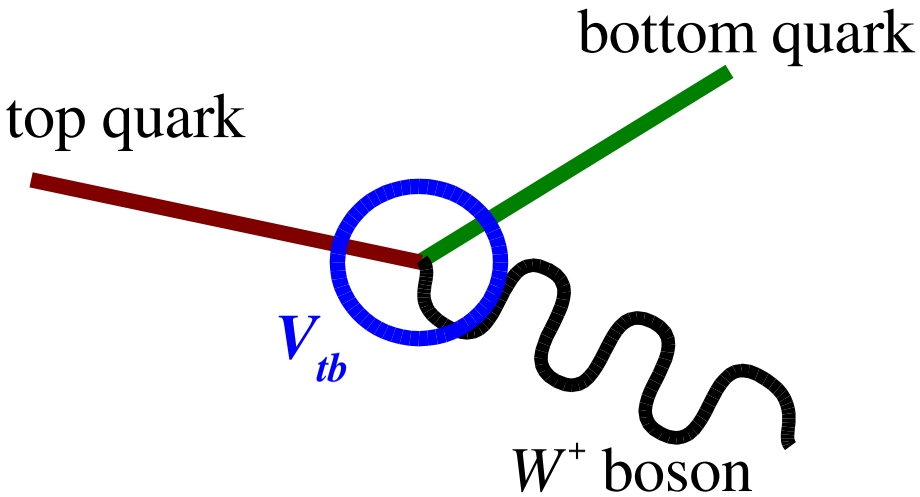
We are not done yet!

- Publish the neural network result
- An observation with the current analysis would require several fb^{-1} of data
- We need to improve all aspects of the analysis
  - More data, τ's, un-tagged events, all-hadronic events
  - Object ID, resolution, trigger, selection cuts, *b*-tagging
  - Sensitive variables, final analysis methods
- Next step:
  - Also get alternative analysis method approved (decision trees)
  - Work on all of the above on $400pb^{-1}$ pass 2 dataset
  - Start looking at p17 data

Plenty of opportunities to contribute!

Backup Slides

Top Quark Electroweak Interaction



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Weak Interaction Eigenstates are not Mass Eigenstates
  - Top quark must decay to a W plus a d, s, or b quark

$$V_{td}^{\ 2} + V_{ts}^{\ 2} + V_{tb}^{\ 2} = 1$$

    - In SM, from constraints on V_{td} and V_{ts}: $V_{tb} > 0.999$
  - Or: new Physics that couples to the top quark:

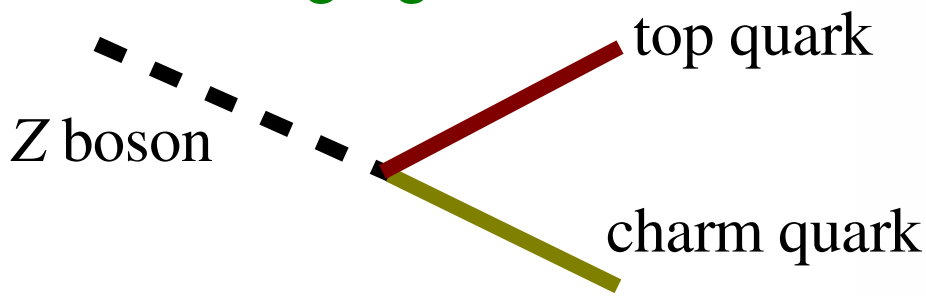
$$V_{td}^{\ 2} + V_{ts}^{\ 2} + V_{tb}^{\ 2} + V_{tx}^{\ 2} = 1$$

    - No constraint on V_{tb}

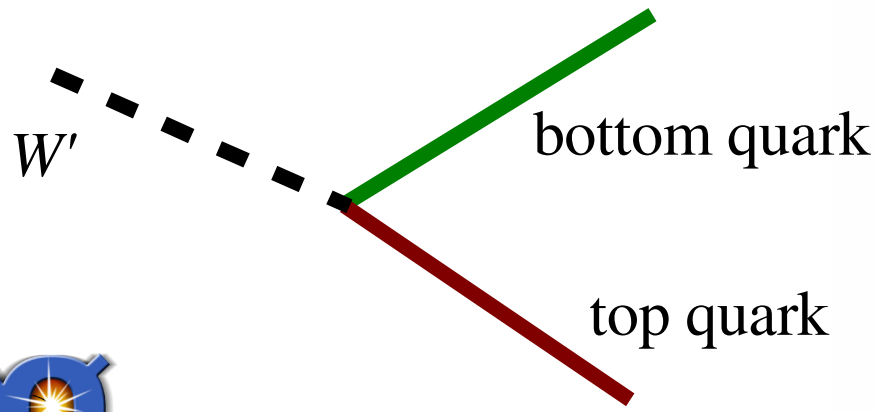
Non-Standard Model Single Top

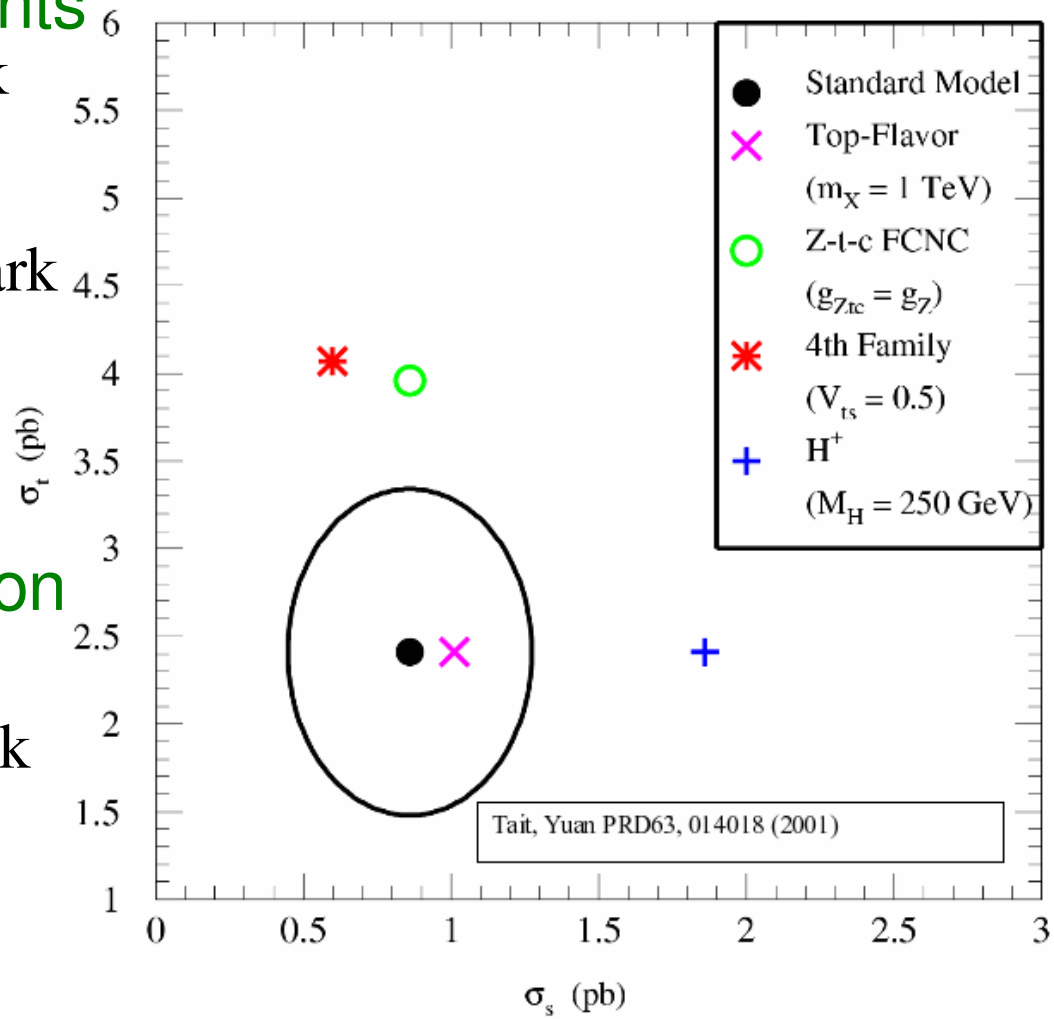
- Single top final state is also produced by many new interactions beyond the Standard Model

Flavor-Changing Neutral Currents



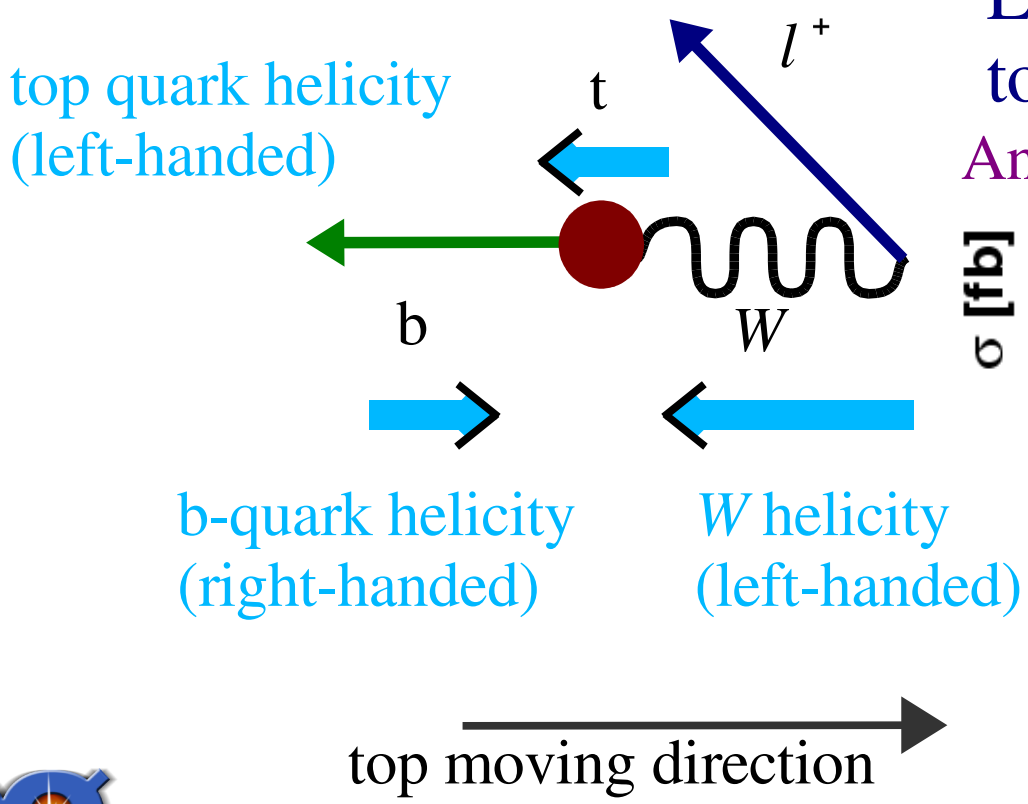
Top-Flavor: another vector boson





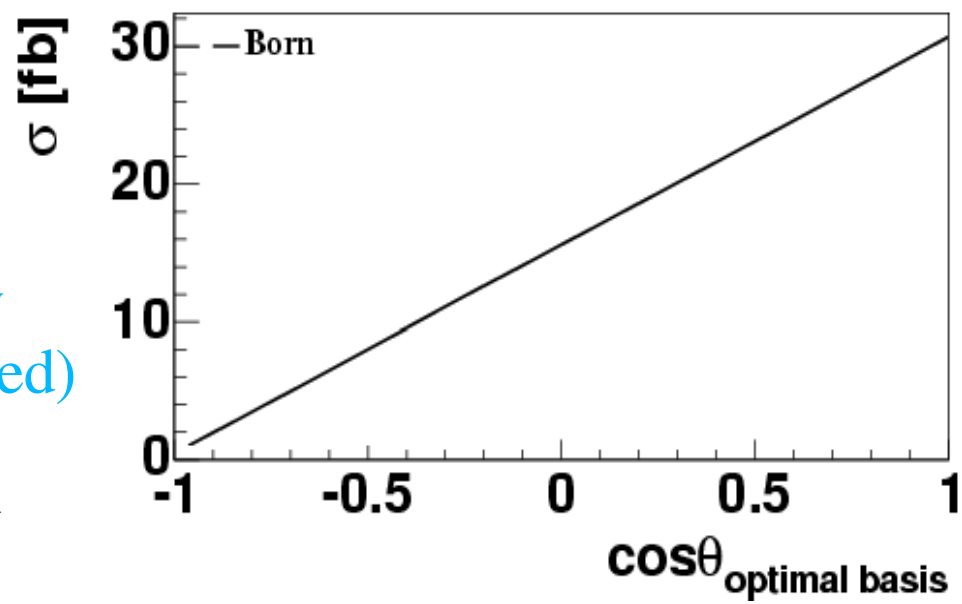
Top Quark Spin

- Top Quark decays before it hadronizes
  - Full spin information is preserved in the decay products
  - Electroweak charged current interaction is left-handed
- Top polarization in the top rest frame:

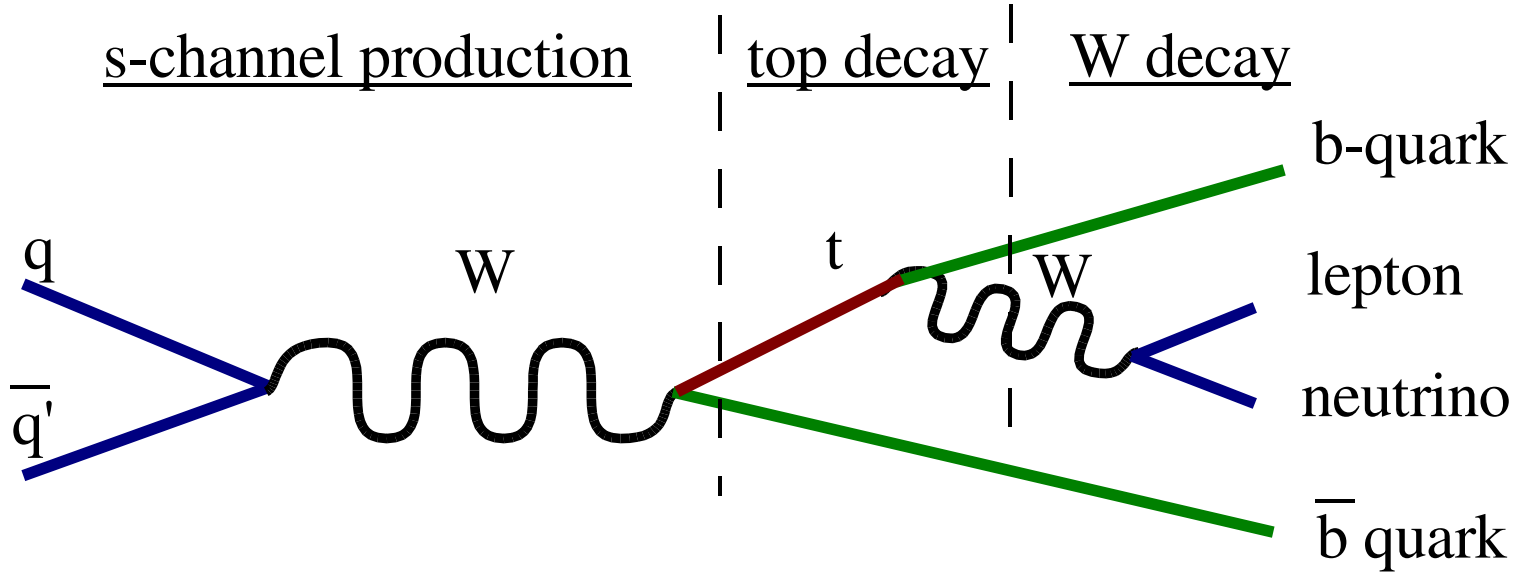


Lepton moves along
top spin direction

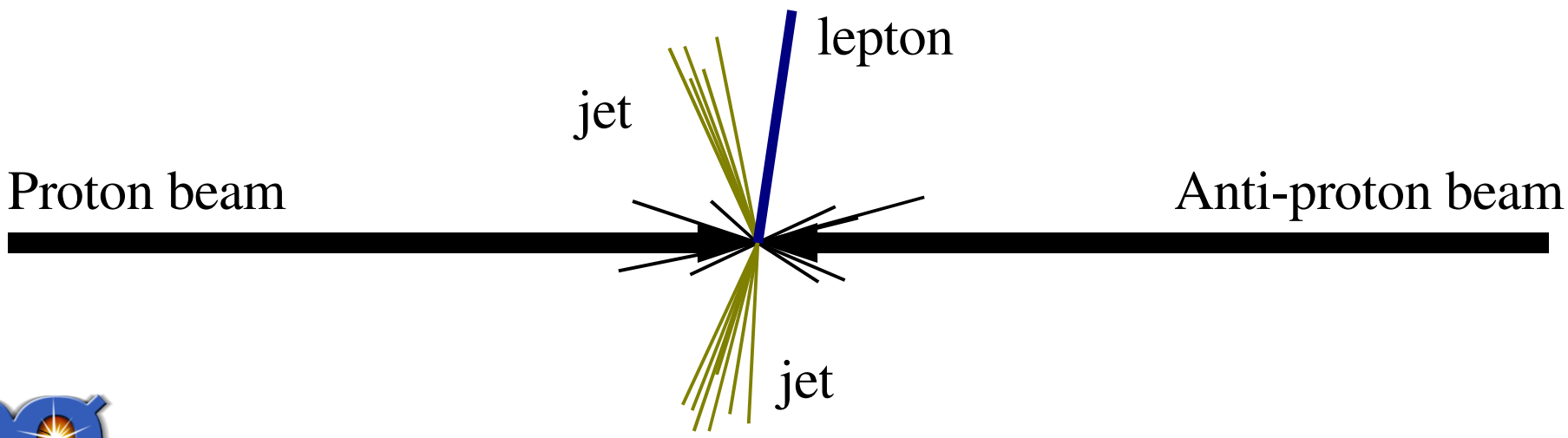
Angle between light quark and lepton:



Single Top Event Signature

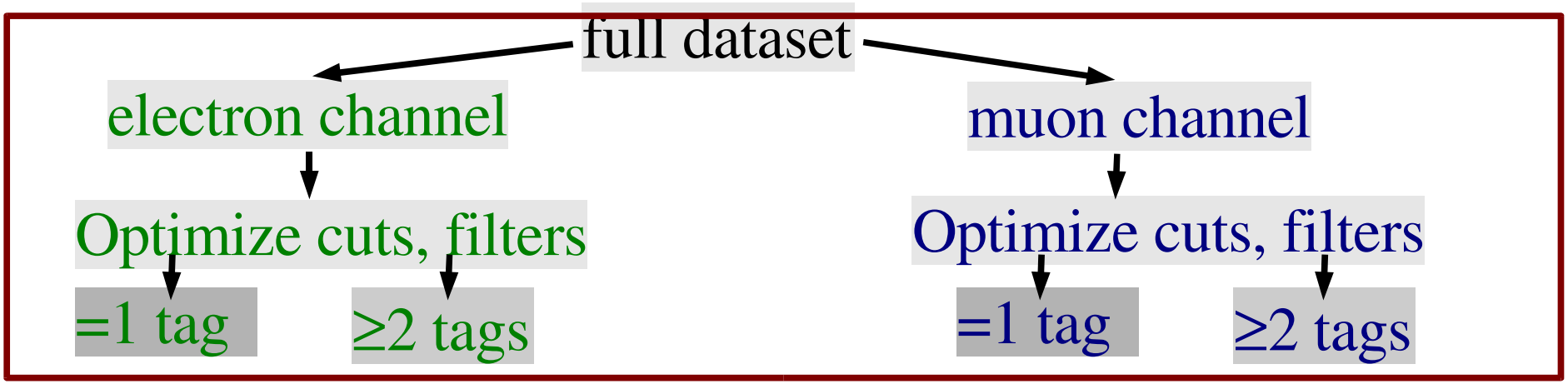


Final State Objects



DØ Single Top Search Strategy

- Split data into orthogonal channels
  - Separate by lepton:
    electron channel ⇔ muon channel
    - Optimize each channel, then combine likelihoods
  - Separate by *b*-tag multiplicity:
    =1 *b*-tag ⇔ ≥2 *b*-tags
    - For t-channel search also require ≥1 non *b*-tagged jet
    - Apply filters individually, combine likelihoods



Cuts used in cut-based analysis

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

Neural Network Variables

- Momentum
  - PT(leading tagged jet)
  - PT(2nd tagged jet)
  - PT(leading untagged jet)
  - PT(jet1,jet2) – PT of four-vector sum of jet 1,2
- Mass
  - M(jets) invariant mass of vector-sum of all jets
  - MT(jet1,jet2) transverse mass of leading two jets vector sum
  - M(W, best jet) (s-channel)
  - M(W, tagged jet) (t-channel)

Neural Network Variables

- Event Energy
  - HT(jets)
- Angular Variables
  - cos(tag jet, all jets)_all jets
  - deltaR(jet1, jet2)
  - Top Spin:
    - s-channel: using best jet
    - t-channel: using tagged jet