Search for Electroweak Top Quark Production at DØ

- Electroweak Top Quark Production
- Analysis and Observed 95% CL Limits with 370 pb^{-1}
- Future Analysis Improvements with 1 fb^{-1}

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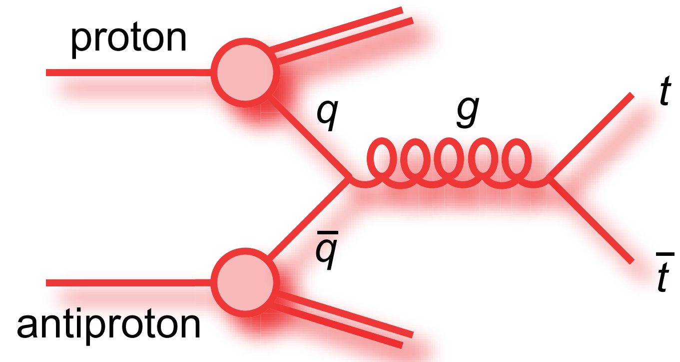
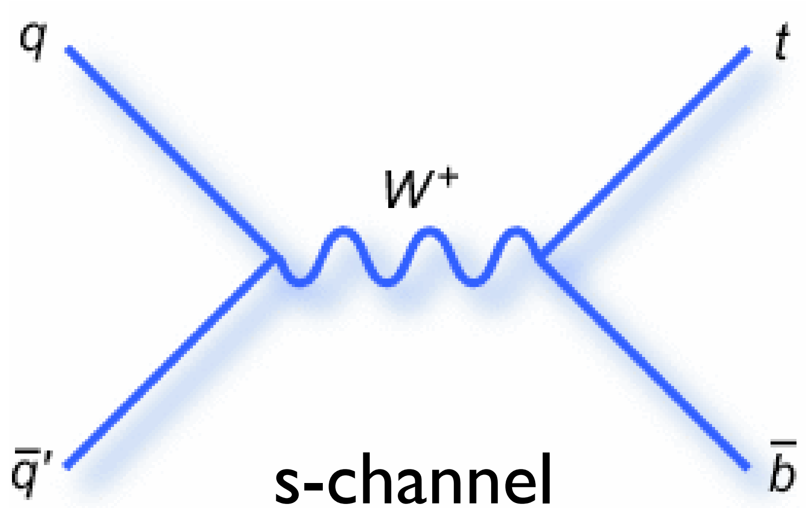
Electroweak Top Quark Production

- At the Tevatron, most top quarks are produced via QCD pair production.
  - $\sigma \sim 7$ pb @ $\sqrt{s} = 1.96$ TeV. This production mode has been extensively studied at the Tevatron and the observed cross section agrees with theory

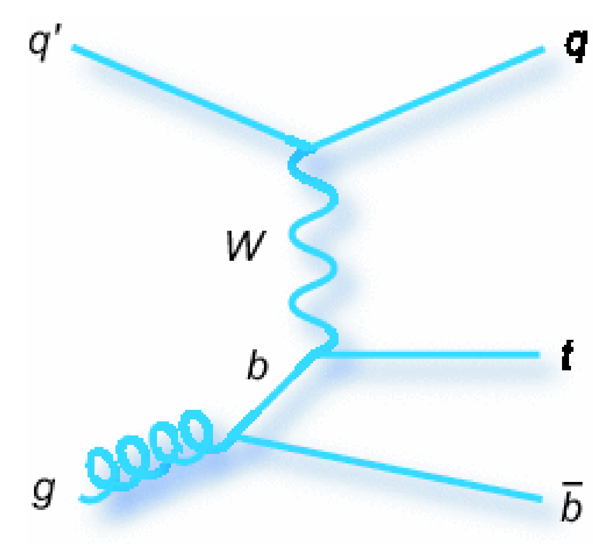


- The Standard Model also allows for top quark production via the electroweak interaction.



s-channel

$\sigma = 0.88 +/- 0.07$ pb @ NLO

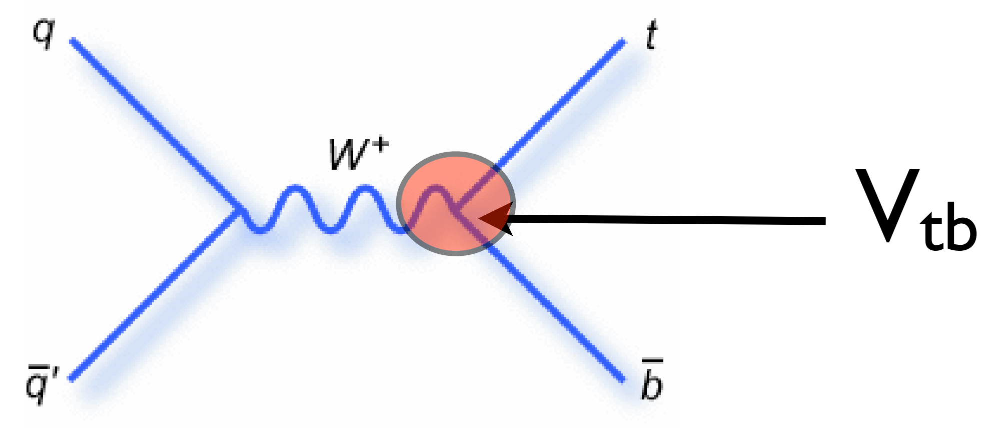


t-channel

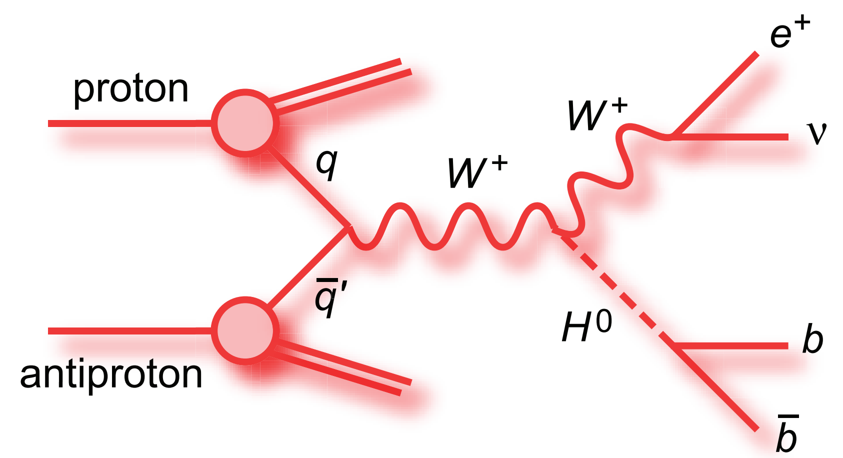
$\sigma = 1.98 +/- 0.21$ pb @ NLO

Why Is Single Top Interesting?

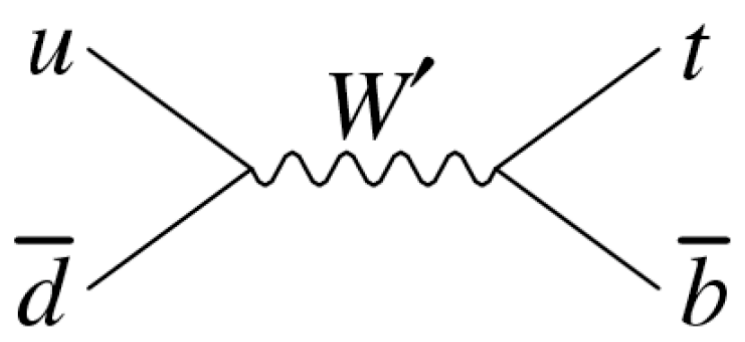
- Only direct measurement of $|V_{tb}|^2$

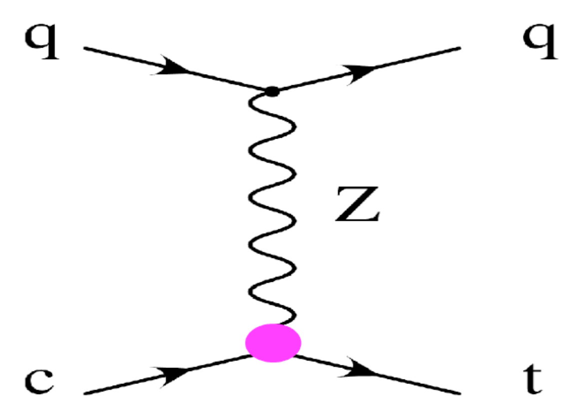


- Major background to Standard Model Higgs search.



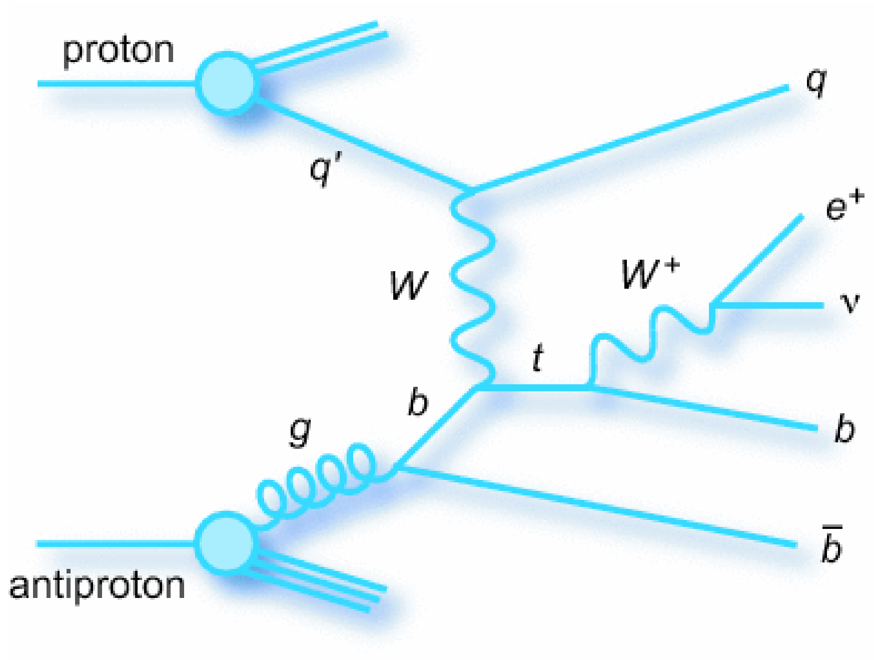
- Sensitive to Beyond-the-Standard Model physics





Event Topology & Selection

- We want to select events with a similar final state as single top. We make the following selection cuts



  - 1 isolated lepton with p_T > 15 GeV
  - Missing E_T > 15 GeV
  - At least 2 jets with p_T > 15 GeV
  - At least one b-tagged jet

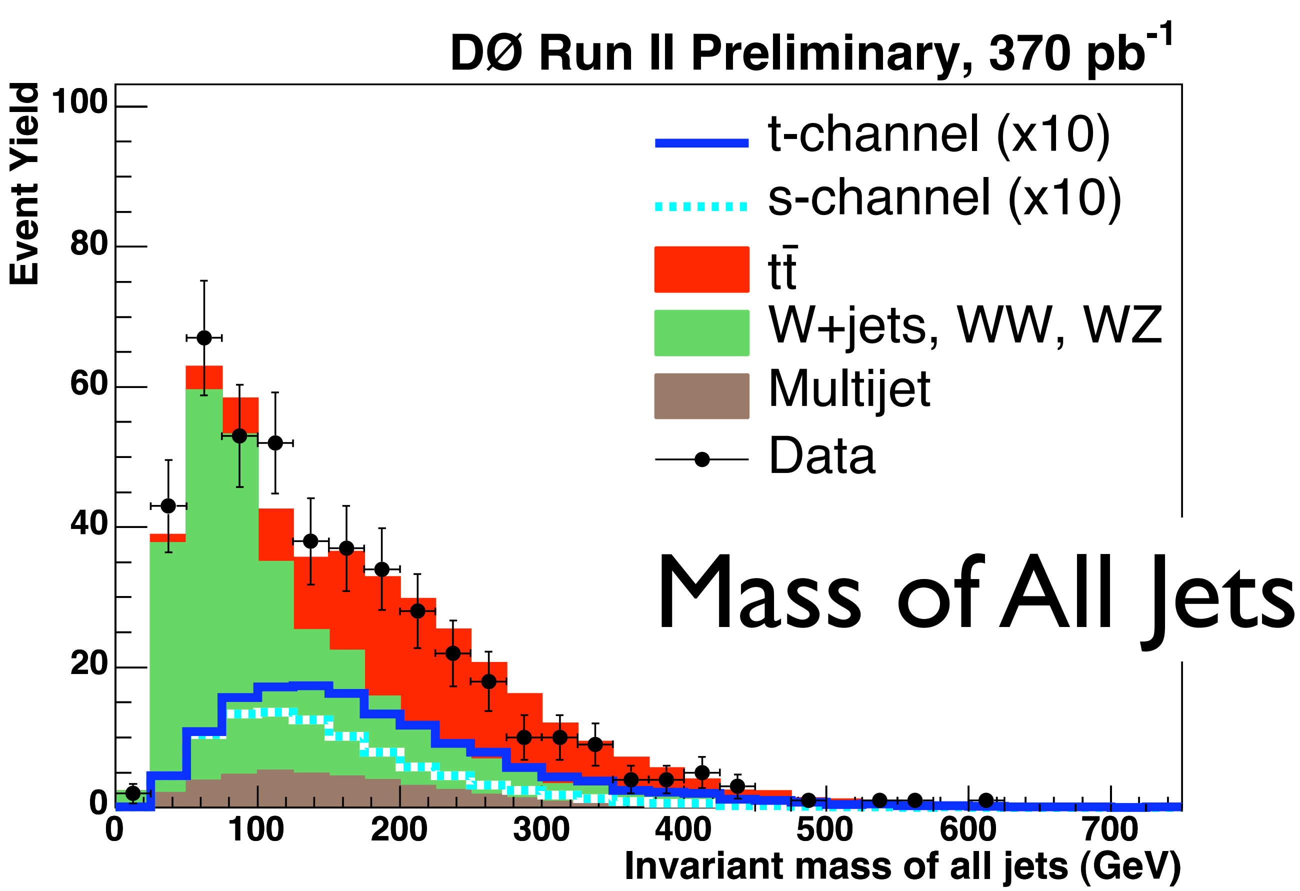
- After these selection cuts, the background composition is mainly W+jets, ttbar, and QCD multijet production.
  - W+jets and ttbar are modeled used Alpgen MC + full detector simulation
  - QCD background modeled using data
  - ttbar is normalized to the theory cross section while W+jets and QCD backgrounds are normalized to data before b-tagging

Event Yields After Selection Cuts

- We apply a very loose set of selection cuts to maximize signal acceptance.

	s-channel	t-channel
Expected Signal	9.5	15.0
Expected Background	452	
S/B	1/50	1/30

- After selection cuts, we see good agreement between data and our background model.

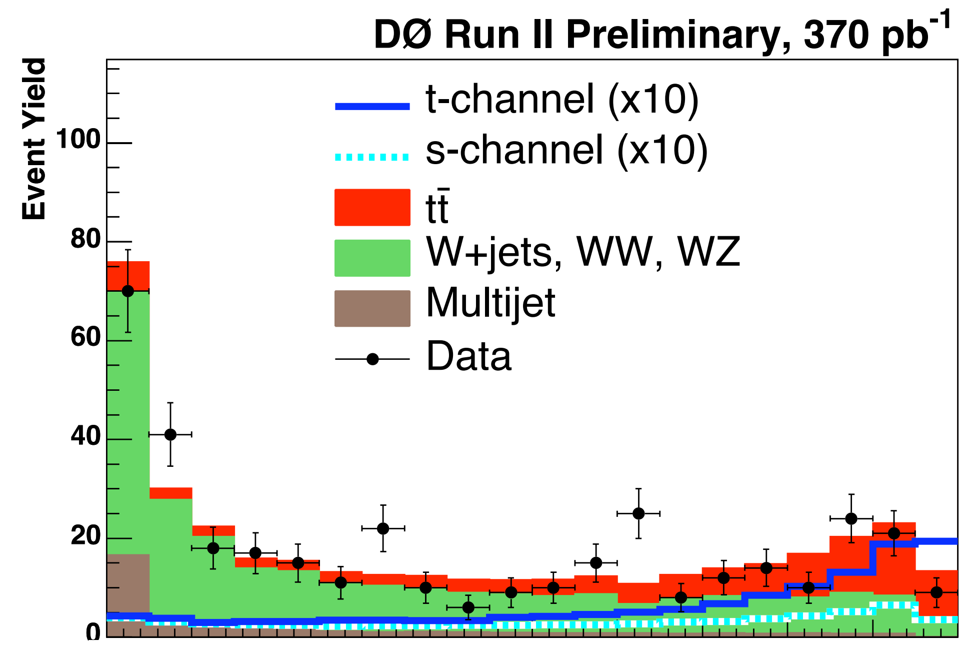


- We need to employ multivariate techniques to help separate signal and background
  - Neural Networks, **Likelihood**, Boosted Decision Trees

Likelihood Analysis w/ 370 pb^{-1}

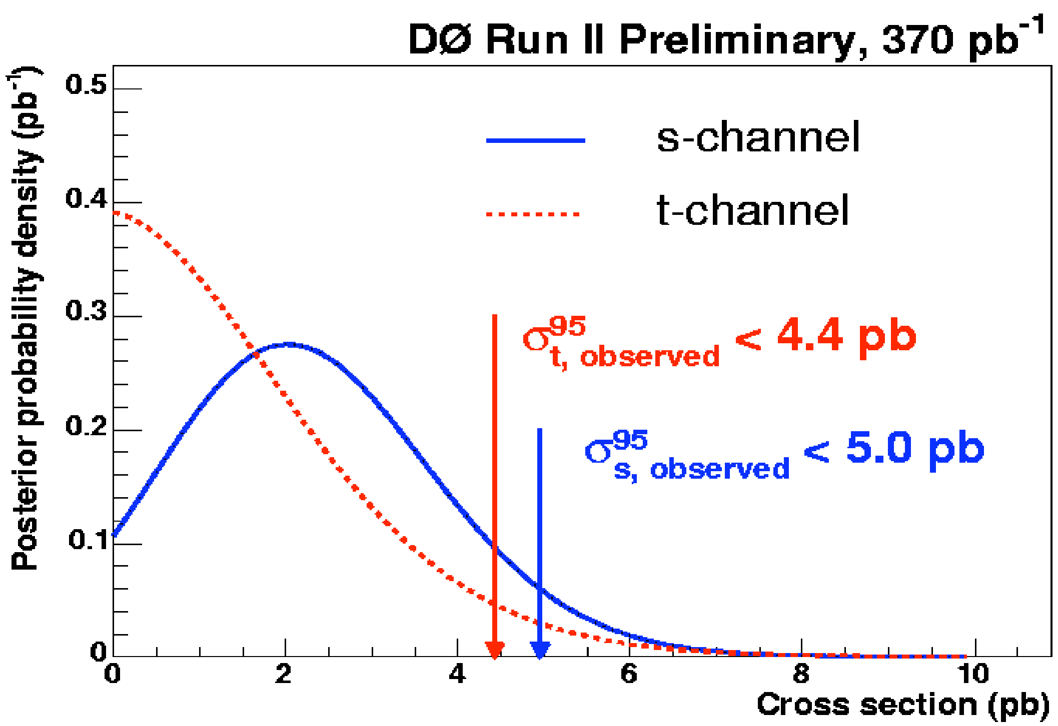
- Analysis made public for ICHEP last year
- Likelihoods trained with two signals and against two backgrounds: ttbar and Wbb

$$\mathcal{L}_{s|t;Wbb|t\bar{t}}(\vec{x}) = \frac{\mathcal{P}_{\mathrm{s|t}}(\vec{x})}{\mathcal{P}_{\mathrm{s|t}}(\vec{x}) + \mathcal{P}_{\mathrm{Wbb|t\bar{t}}}(\vec{x})}$$



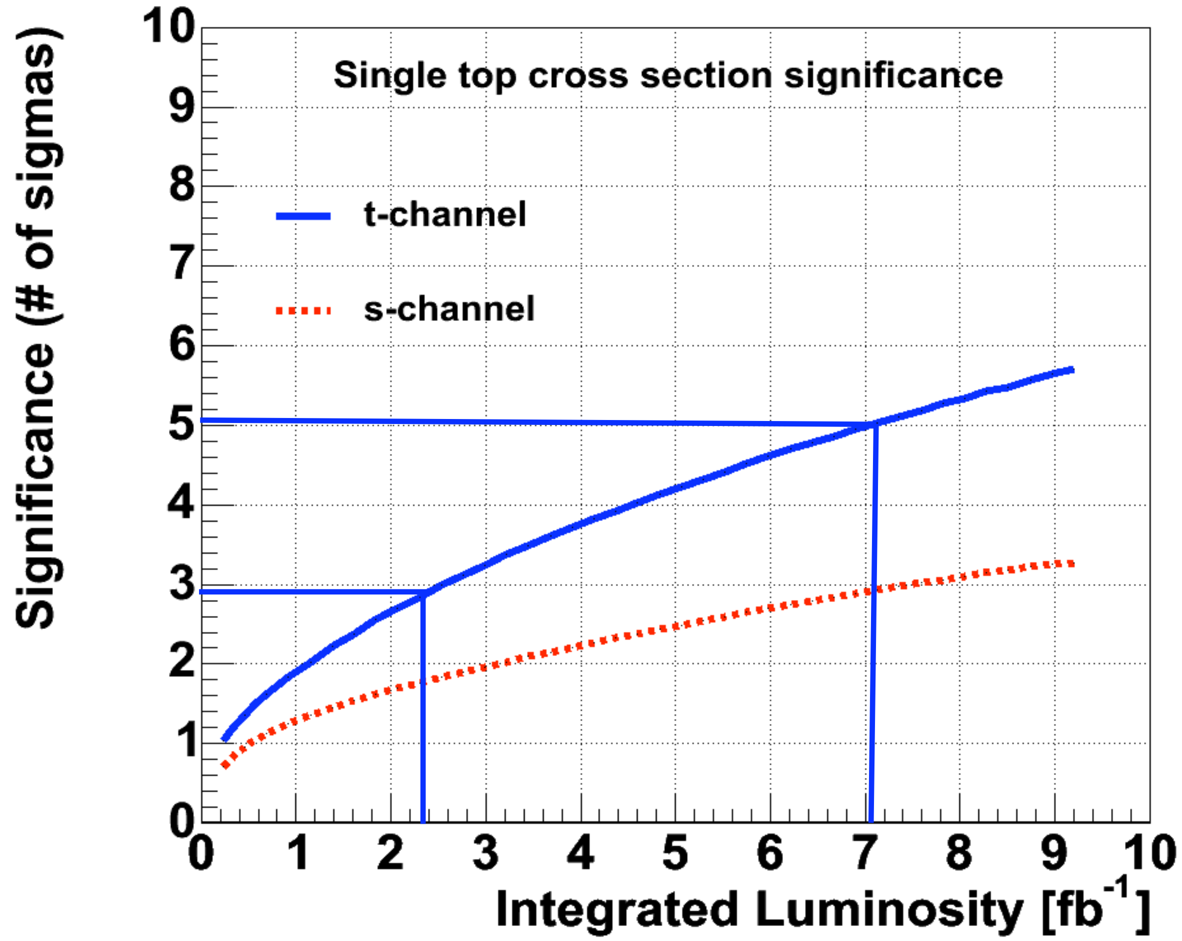
$L_{\text{t-channel|Wbb}}$

- No excess of signal events was observed in the data, therefore we set an upper limit on the production
  - $\sigma_{\text{t-channel}} < 4.4$ pb
  - $\sigma_{\text{s-channel}} < 5.0$ pb
- Leading systematic errors are:
  - b-tagging (6-17%) and JES(5%)



The Road To Discovery

- Using the 370 pb^{-1} analysis, we can extrapolate to the integrated luminosity needed for 3σ evidence and 5σ discovery.
  - It is clear that we need to improve the analysis if we want to discover and study single top during RunII.



- For the 1 fb^{-1} analysis, we will have improved:
  - b-tagging
  - Jet energy scale
  - Calorimeter calibration
- In parallel, we can work to improve our signal-background separation techniques. The next few slides will show one improved analysis technique.

Single Top Matrix Element Analysis

- Compute signal and background probabilities by weighting events based on the LO matrix element value for the signal and background processes.
- To evaluate the matrix element, we need to know the state **y** which caused state **x** in the detector. This requires integrating over the entire matrix element phase space

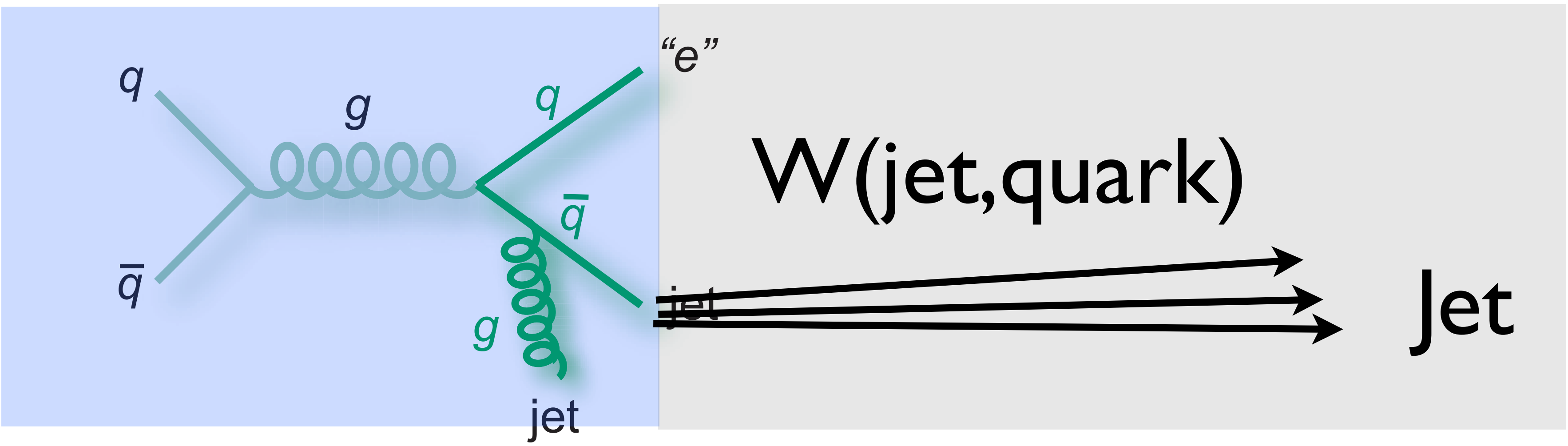
$$P_S(\vec{x}) = \frac{1}{\sigma_S} \int \frac{d\sigma_S(\vec{y})}{dy} \times W(\vec{x}, \vec{y}) dy \qquad \frac{d\sigma_S}{dy} \propto |\mathcal{M}_S|^2$$

  - **y** is the final state particles' 3-momenta
  - **x** is the detector objects' 3-momenta
  - dσ/dy is the differential cross section for a given process
  - W(**x**,**y**) is the probability density of observing state **x** in the detector given that is originated from state **y**.

Calculating The Differential Cross Section

- At the matrix element level, there are 14 independent quantities.
  - lepton (3), leading parton (3), second parton (3), neutrino (3), x_1 (1), and x_2 (1)
- From the event, we know the angles of the final state particles and we can enforce momentum conservation which takes the integral from 14D to 4D.
- Because we don't know the true parton energy, we create "transfer functions", W(x,y), to relate the measured energy in the detector to the actual parton energy.

$$P_S(\vec{x}) = \frac{1}{\sigma_S} \sum_{\mathrm{Jet-Parton}} \int \frac{d\sigma_S(\vec{y})}{dy} \times W_{\mathrm{Jet1}}(\vec{x},\vec{y}) \times W_{\mathrm{Jet2}}(\vec{x},\vec{y}) \times W_{\mathrm{Lepton}}(\vec{x},\vec{y}) dy$$



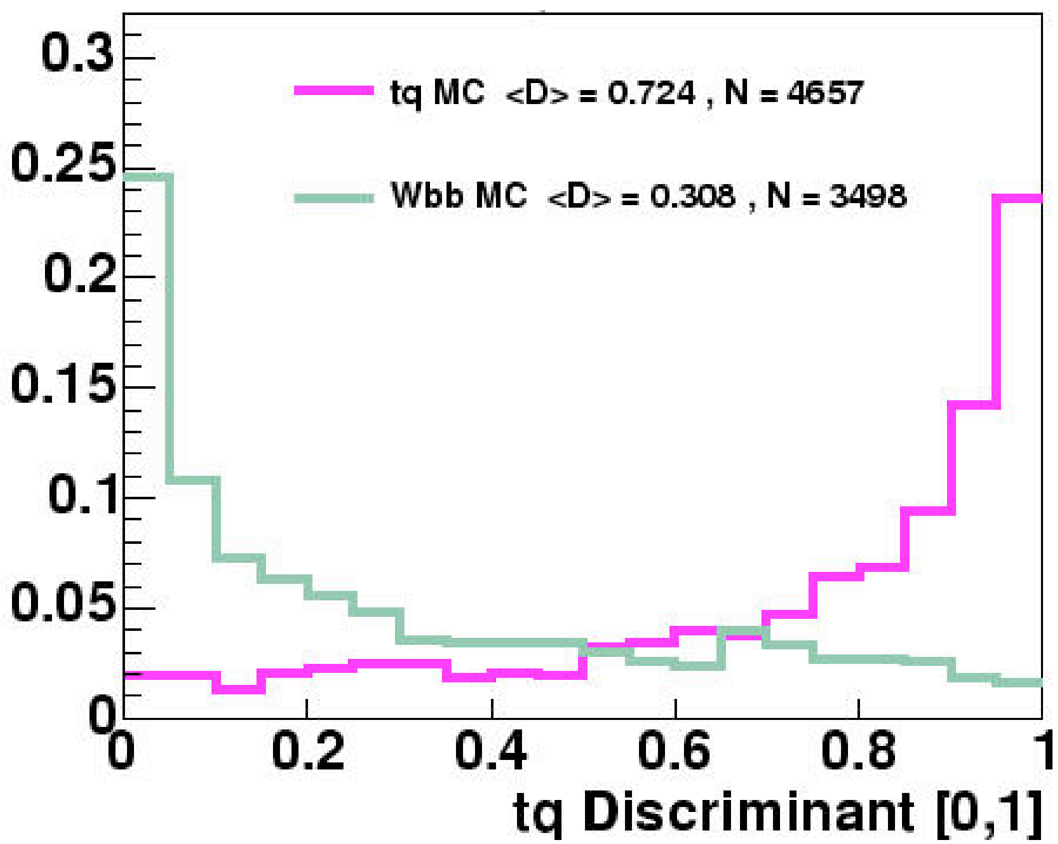
Matrix Element Discrimination Power

- After computing signal and background probabilities, we calculate a discriminant value for each event defined as:

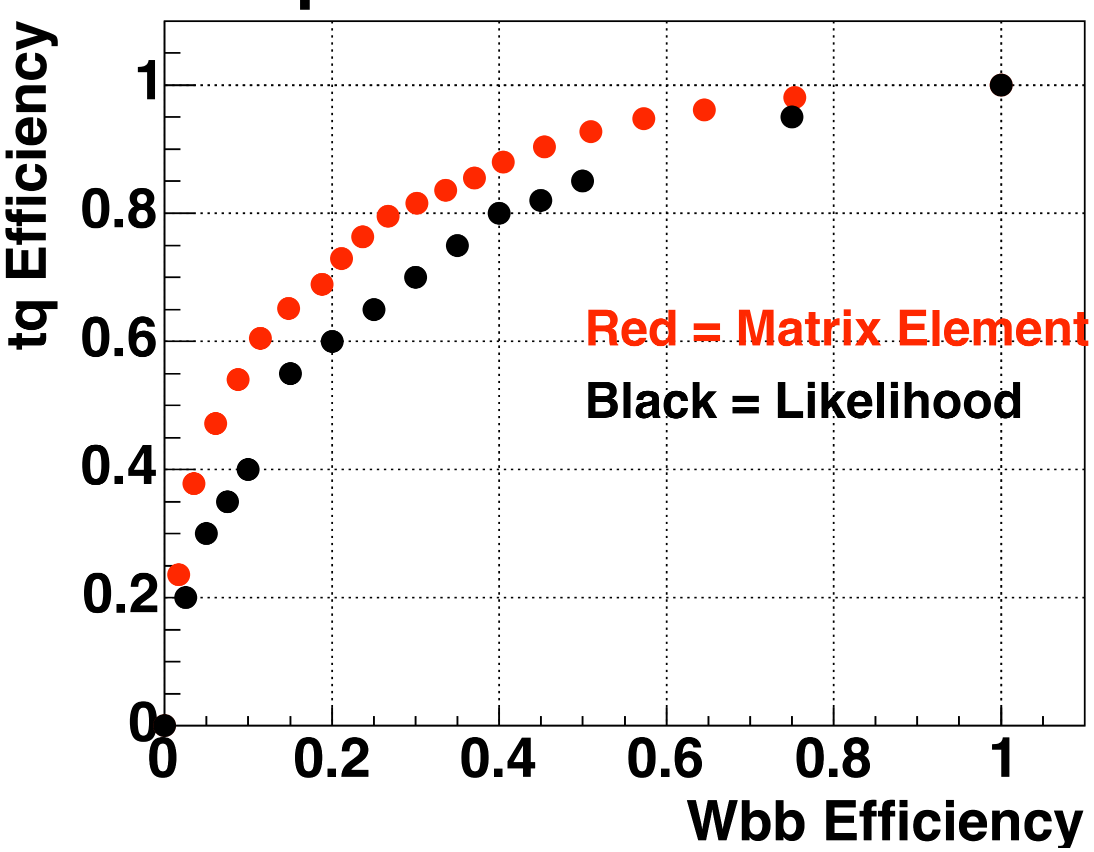
$$D(\vec{x}) = \frac{P_{\text{Signal}}(\vec{x})}{P_{\text{Signal}}(\vec{x}) + P_{\text{Background}}(\vec{x})}$$

- Test performance by running over signal MC (should peak at 1) and background MC (should peak at 0)

t-channel vs Wbb

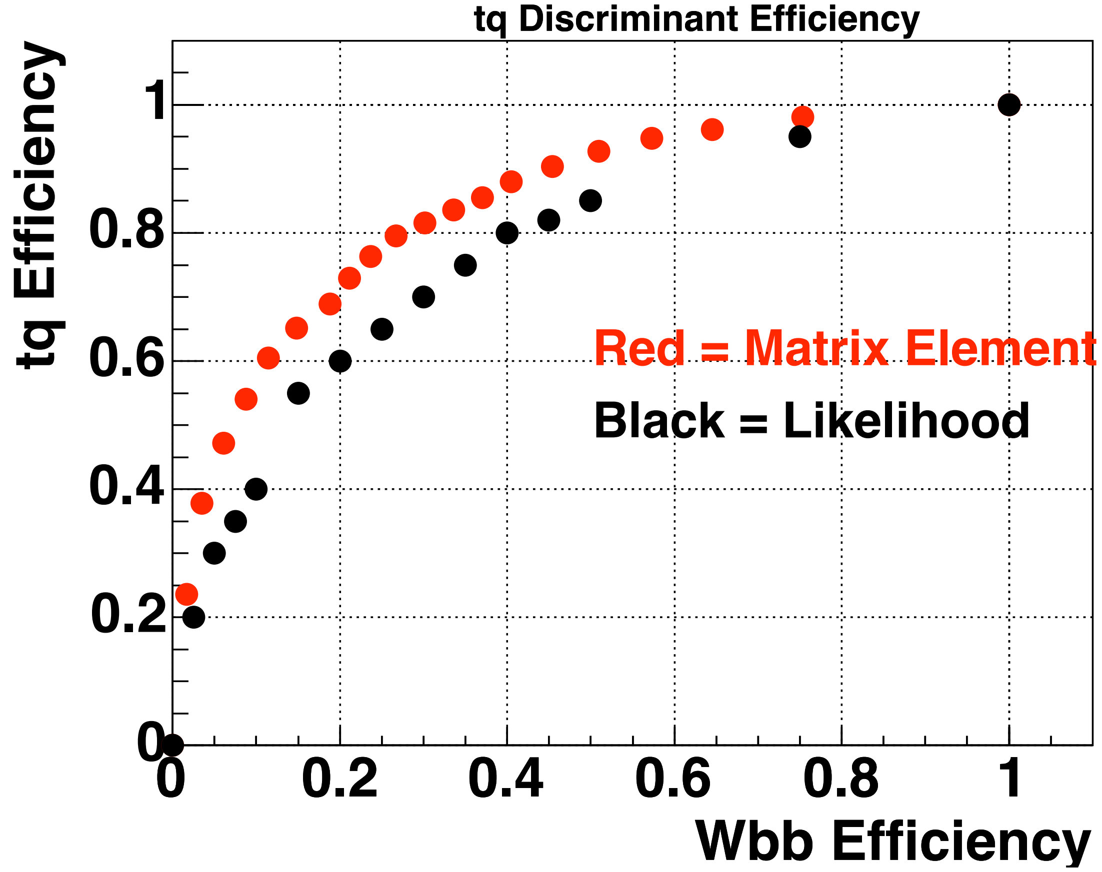


Comparison w/ Likelihood



Summary & Outlook

- Single top interesting as a test of the Standard Model as well as a probe for new physics
- We have analyzed 370 pb^{-1} and set limits on single top quark production



- Using existing analysis techniques, we will need at least 2 fb^{-1} for a 3σ evidence claim.
  - Requires new analysis techniques
- Preliminary results for the new matrix element analysis show an increase in signal acceptance for a given background yield.
- We are currently analyzing the full 1 fb^{-1} dataset and hope to release a preliminary result with the matrix element analysis soon.

- Back up slides

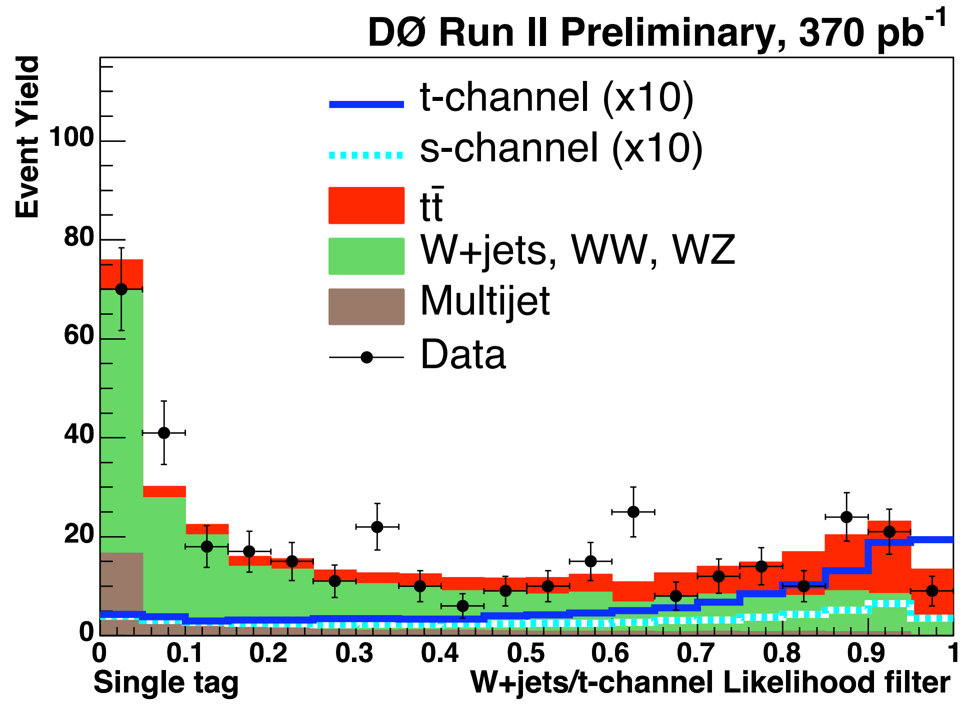
DØ Likelihood Analysis w/ 370 pb^{-1}

- We performed a likelihood analysis using variables that show discrimination between single top signal and background where the likelihood is defined as

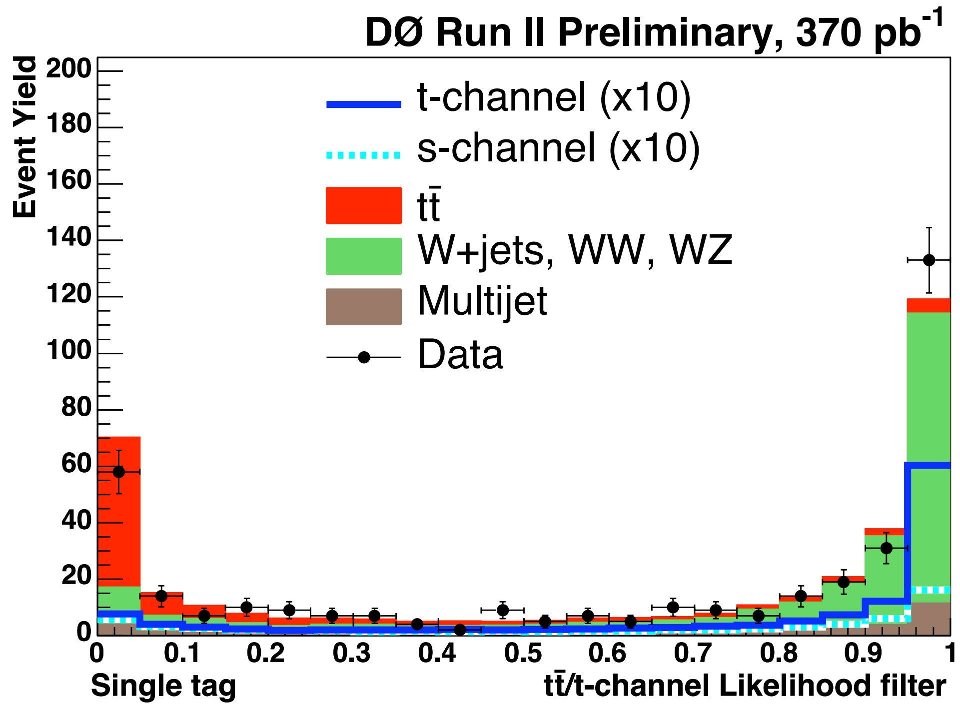
$$\mathcal{L}(\vec{x}) = \frac{\mathcal{P}_{\text{Signal}}(\vec{x})}{\mathcal{P}_{\text{Signal}}(\vec{x}) + \mathcal{P}_{\text{Background}}(\vec{x})} \qquad \mathcal{P}_{\text{S|B}} = \prod_{\text{Vars}} \mathcal{P}_i$$

- We create two likelihoods for each signal: One using Wbb as background and the other using ttbar as background.

- Below is the output when the trained likelihood is applied to background, signal, and data events



Wbb background



ttbar background

95% CL Limits Using 370 pb^{-1}

- We see no excess of signal events above the estimated background so we can set 95% CL limits on each channel's production cross section
- We use a 2D histogram of the s-channel vs t-channel likelihood output as input to a binned likelihood to estimate the cross section limits
  - $\sigma_{t\text{-channel}} < 4.4$ pb
  - $\sigma_{s\text{-channel}} < 5.0$ pb
- Leading systematic errors:
  - b-tagging efficiency (6-17%)
  - Jet Energy Scale (5%)
  - Trigger modeling (5%)
  - Object ID (5%)
  - Theory cross section (18%)

Posterior Density Function