Evidence for Single Top Quark Production at DZero Using the **Matrix Element Analysis Technique** on 1 fb^{-1} of Data

Chris Potter

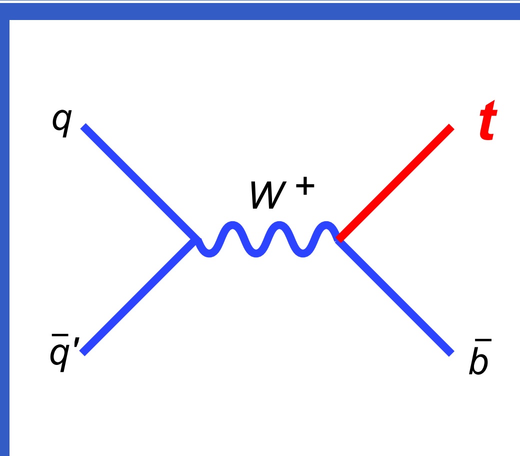
(On Behalf of the DZero Collaboration)

McGill University

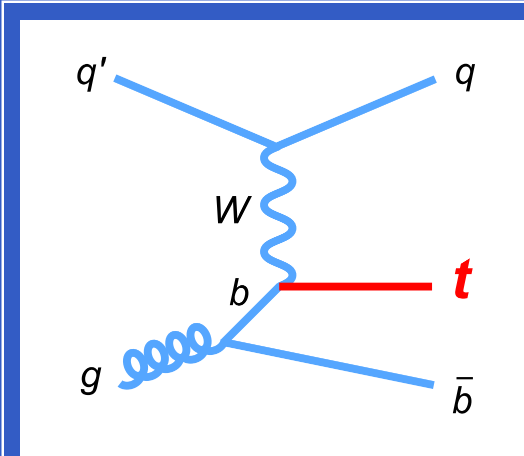
Outline

- Single Top Preselection
- Matrix Element (ME) Technique
  - Matrix Element Discriminant
  - Differential Cross Section
  - Matrix Element Processes
- ME Discriminant Performance
  - ME Discriminants in Monte Carlo Simulation
  - ME Discriminants in Data Control Sample
  - Ensemble Tests
- Results
  - ME Discriminant Plots in Data
  - Expected and Measured Cross Section
- Summary and Conclusion

Single Top Preselection



s-channel (“tb”)



t-channel (“tqb”)

The Matrix Element analysis technique is one of several multivariate techniques applied after a common DZero single top preselection. See talks by M. Pangilinan, J. BackusMayes and J. Benitez. The preselection requires:

- Missing $E_T > 15$ GeV
- One isolated lepton:
  - one isolated e with $p_t > 15$ GeV and $|\eta^{det}| < 1.1$
  - *or* one isolated μ with $p_t > 18$ GeV and $|\eta^{det}| < 2.0$
- Two or three jets, one or two of which are b-tagged:
  - leading jet $p_t > 25$ GeV and $|\eta^{det}| < 3.4$
  - second leading jet $p_t > 20$ GeV and $|\eta^{det}| < 2.5$

Matrix Element Discriminant

The Matrix Element technique can be thought of as a “reverse Monte Carlo generator”. It uses only the measured p^μ of the reconstructed objects and maps back to a probability density function (via the “transfer function”) which is determined by the matrix element.

- The Matrix Element Discriminant is defined to be:

$$D_S(\vec{x}) = P(S|\vec{x}) = \frac{P_S(\vec{x})}{P_S(\vec{x})+P_B(\vec{x})}$$

- The probability density function is:

$$P(\vec{x}) = \frac{1}{\sigma} \times \frac{d\sigma}{d\vec{x}}.$$

- The differential cross section is calculated from:

$$d\sigma(\vec{x}) = \sum_{i,j} \int d\vec{y} \left[f_i(q_1, Q^2) dq_1 \times f_j(q_2, Q^2) dq_2 \times \frac{d\sigma_{hs,ij}(\vec{y})}{d\vec{y}} \times W(\vec{x}, \vec{y}) \times \Theta_{\mathrm{Parton}}(\vec{y}) \right]$$

- The total cross section, for normalizing the probability density function, is:

$$\sigma = \sum_{i,j} \int d\vec{x} d\vec{y} \left[\frac{d\sigma_{i,j}(\vec{y})}{d\vec{y}} \times W(\vec{x}, \vec{y}) \times \Theta_{\mathrm{cuts}}(\vec{x}) \right]$$

The Differential Cross Section

$$d\sigma(\vec{x}) = \sum_{i,j} \int d\vec{y}\, dq_1 dq_2\; f_i(q_1, Q^2) \times f_j(q_2, Q^2) \times \frac{d\sigma_{hs,ij}(\vec{y})}{d\vec{y}} \times W(\vec{x}, \vec{y}) \times \Theta_{\mathrm{Parton}}(\vec{y})$$

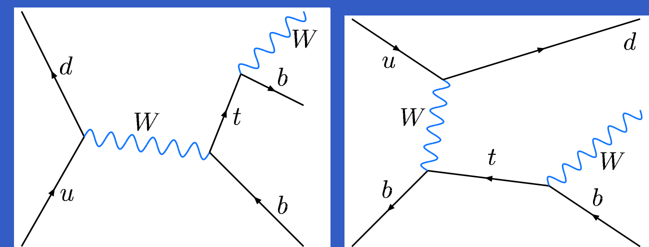
- $\sum_{i,j}$ is a sum of initial parton flavors in the hard scatter collision.
- $\int d\vec{y}\, dq_1 dq_2$ is an integration over the matrix element phase space.
- $f_i(q, Q^2)$ is the parton distribution function for parton i carrying momentum q,evaluated at the factorization scale Q^2.
- $\partial\sigma_{hs,ij}(\vec{y})/\partial\vec{y}$ is the differential cross section for the hard scatter collision. This quantity is proportional to the square of the leading order matrix element as given by:

$$d\sigma_{hs} = \frac{(2\pi)^4}{4\sqrt{(q_1 q_2)^2 - m_1^2 m_2^2}} |\mathcal{M}|^2 d\Phi_n(\vec{y})$$

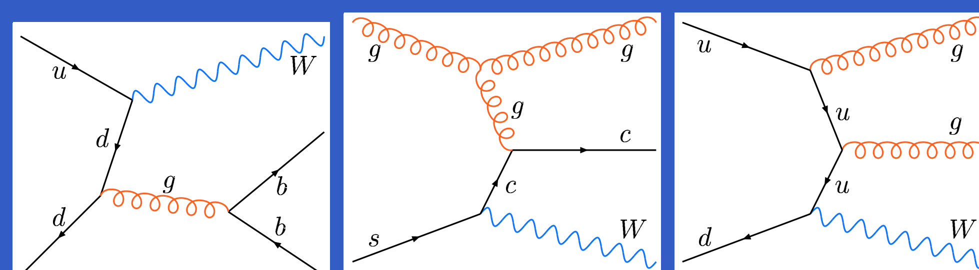
- $W(\vec{x}, \vec{y})$ is called the transfer function, which represents the conditional probability of the observed state in the detector ($\vec{x}$) given the original partons ($\vec{y}$) (Monte Carlo).
- $\Theta_{\mathrm{Parton}}(\vec{y})$ represents the parton level cuts applied in order to avoid singularities in the matrix element evaluation.
- The b-tag information is also used.

Matrix Element Processes

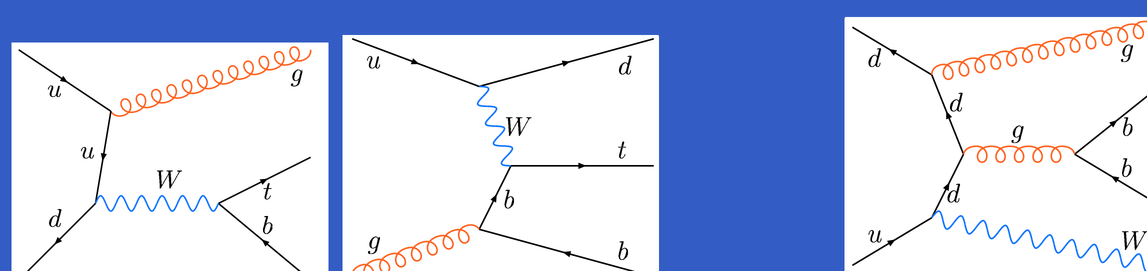
- Two Jets Signal: $\boxed{P_{tb}(\vec{x})}$



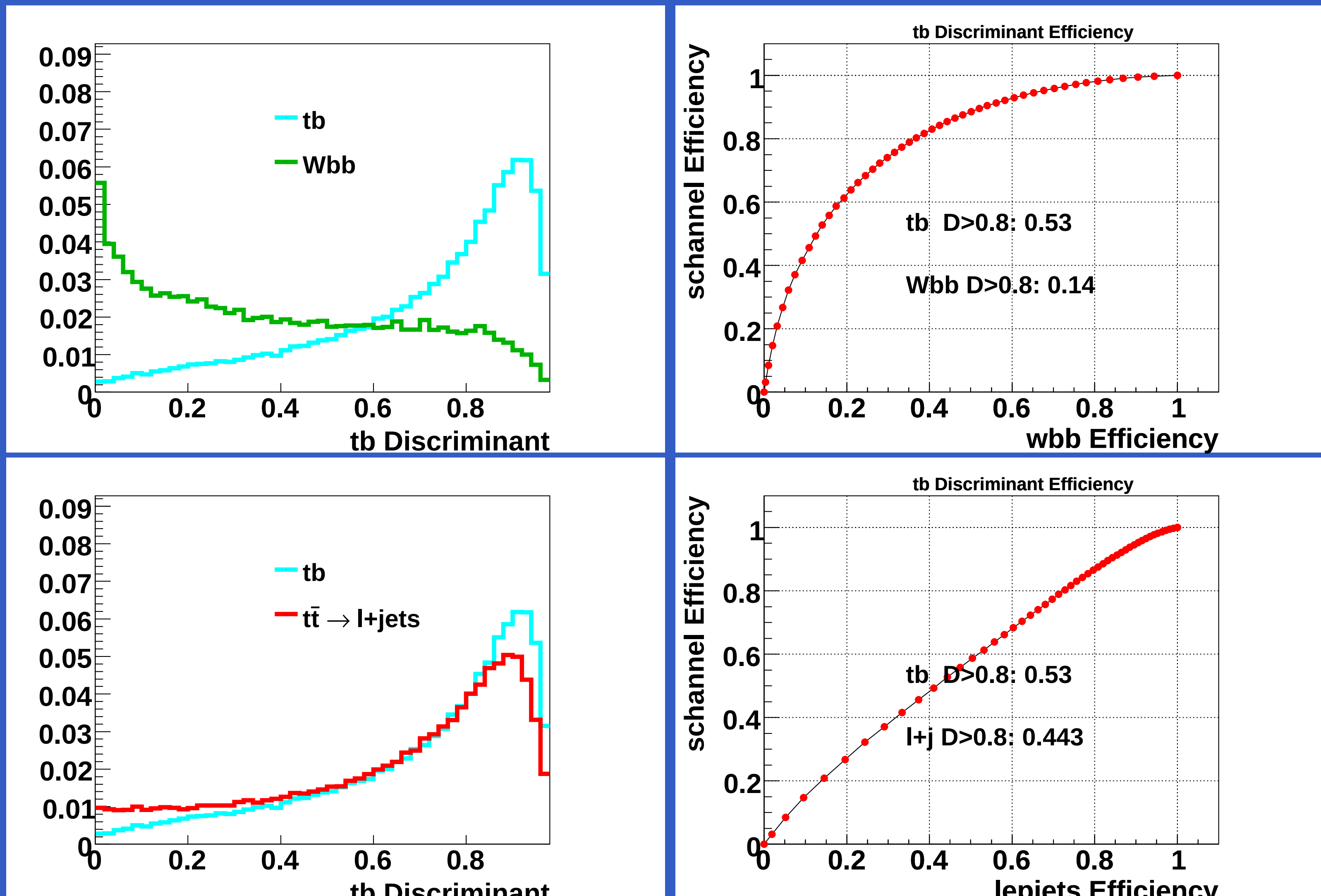
- Two Jets Background: $\boxed{P_B(\vec{x}) = C_{Wbb}P_{Wbb}(\vec{x}) + C_{Wcg}P_{Wcg}(\vec{x}) + C_{Wgg}P_{Wgg}(\vec{x})}$



- Three Jets Signal and Background: $\boxed{P_{tqb}(\vec{x}) \text{ and } P_B(\vec{x}) = P_{Wbbg}(\vec{x})}$

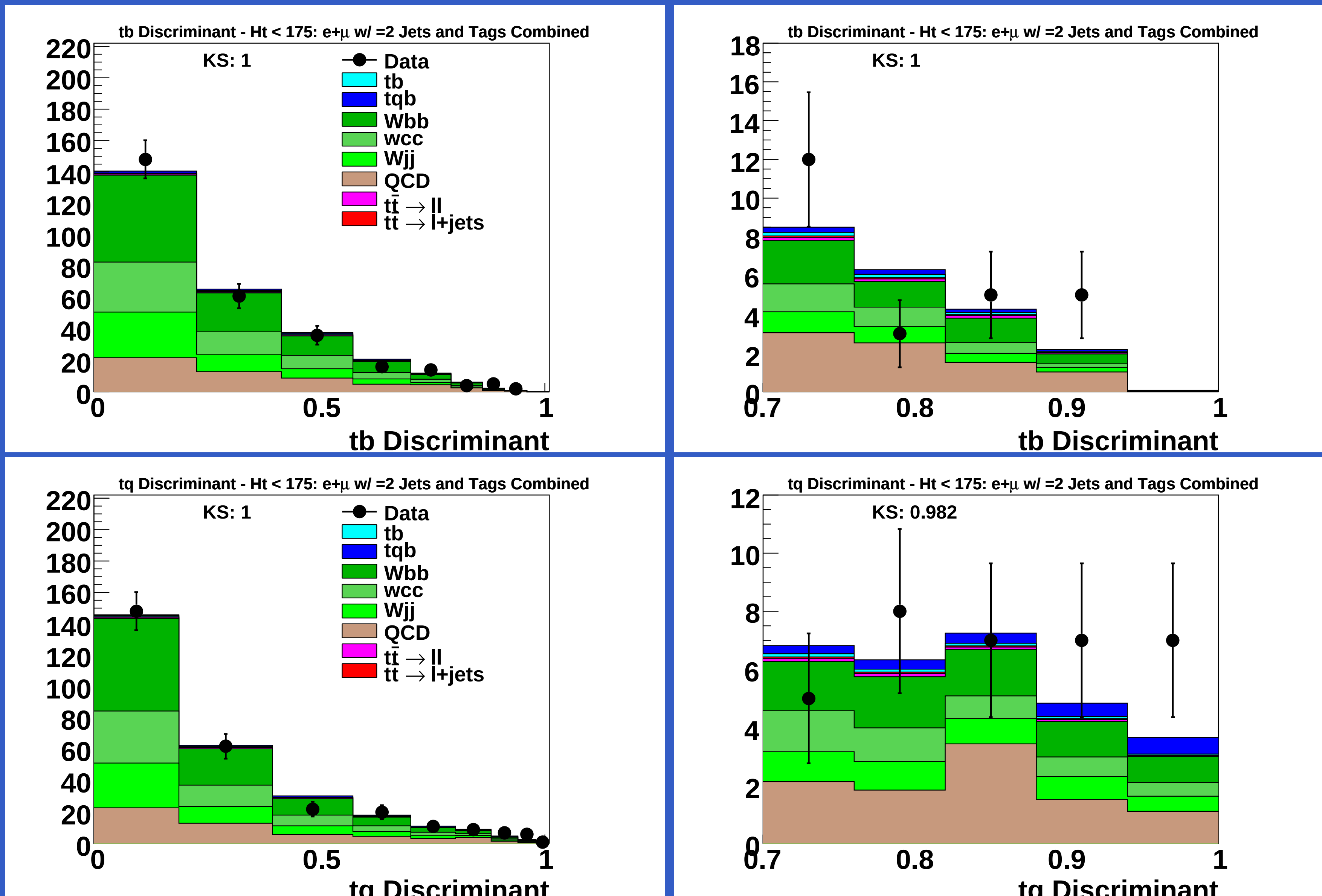


ME Discriminant (tb) in Simulation



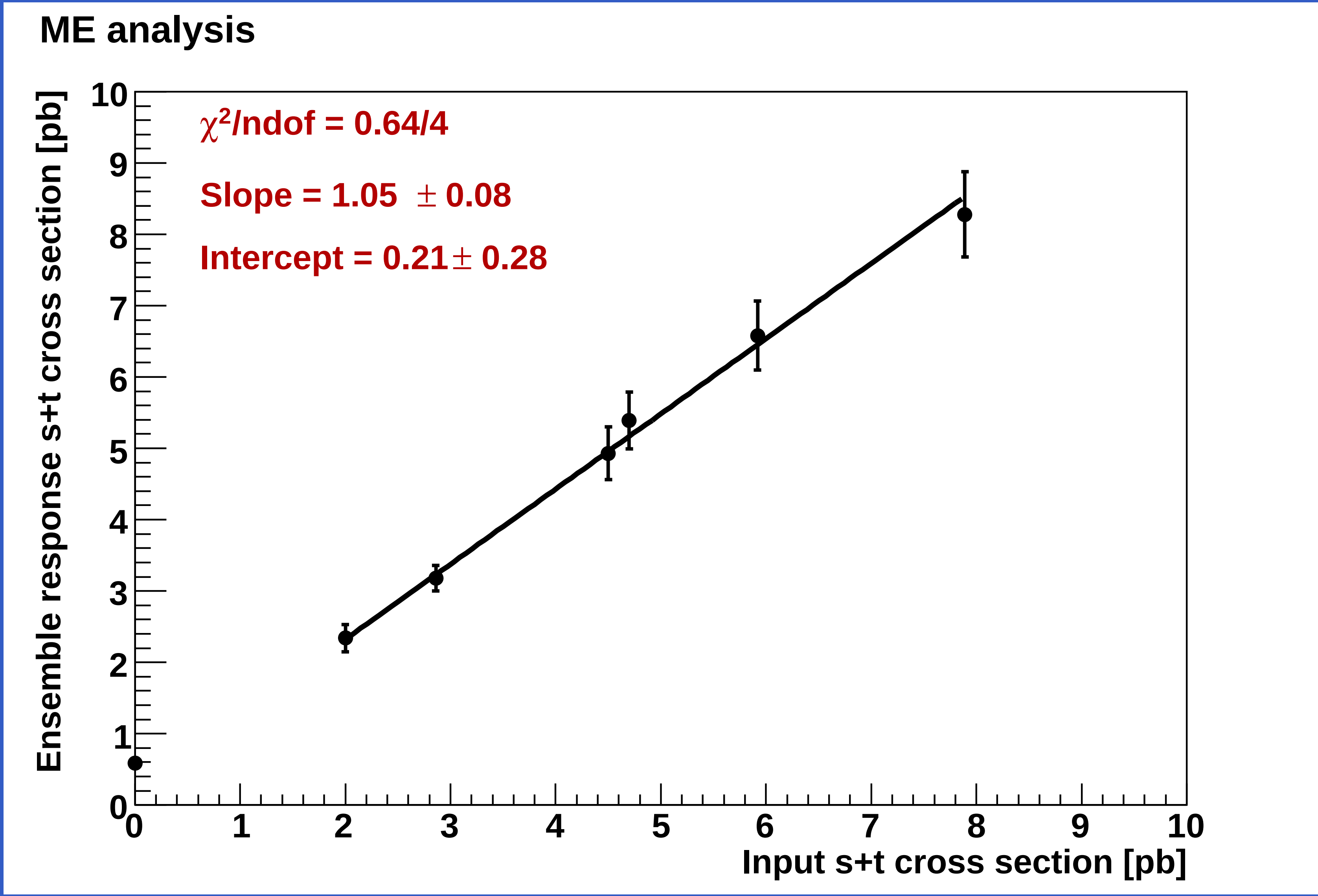
The one-dimensional tb discriminant for tb and Wbb Monte Carlo simulation (top left), the tb efficiency versus the Wbb efficiency as the discriminant cut is varied (top right), and similar for $t\bar{t} \longrightarrow \ell$+jets Monte Carlo simulation (bottom left and right).

ME Discriminants in a Data Control Sample



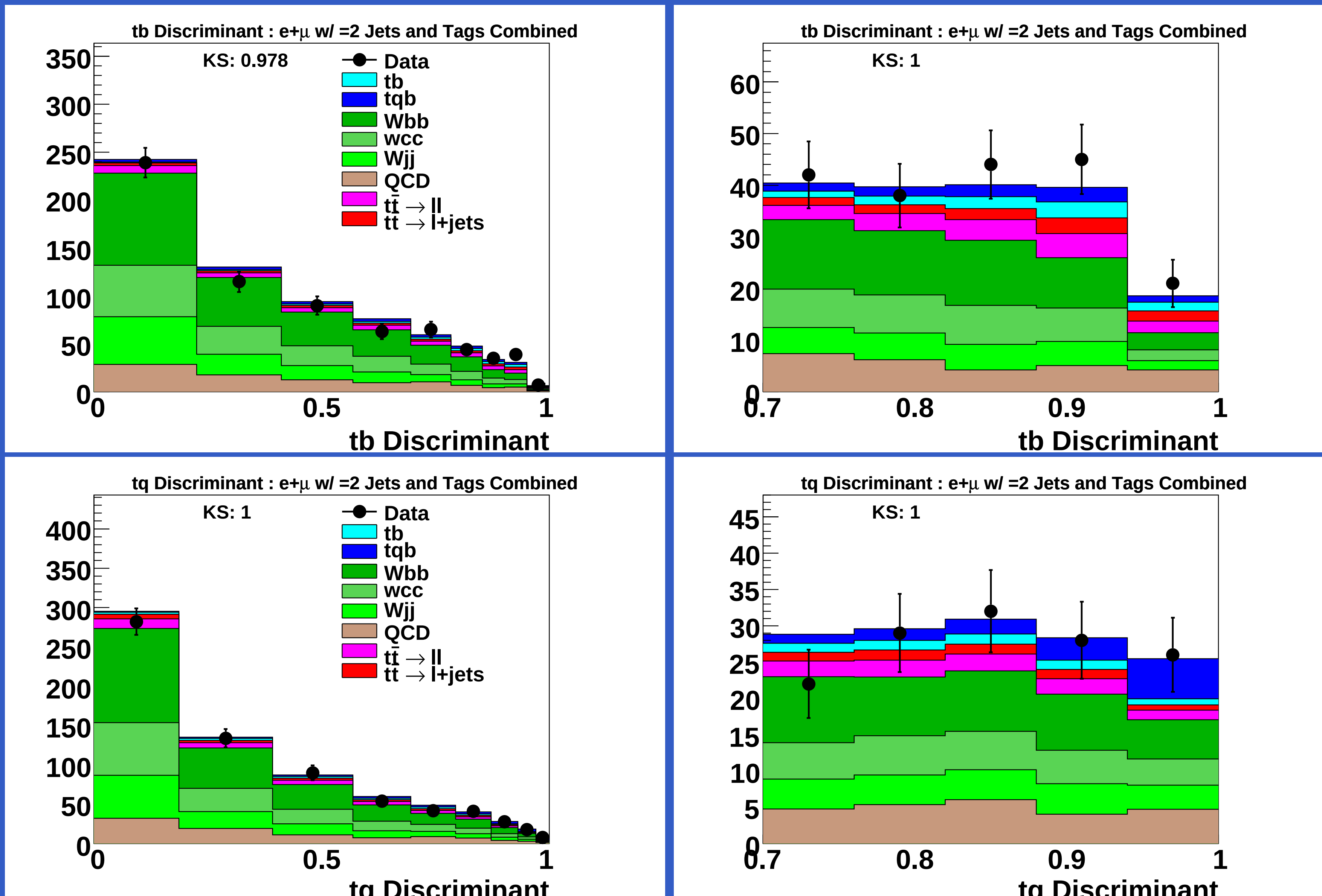
The tb and tqb ME discriminants in a “soft W+jets” control sample defined by the standard single top preselection plus $H_T = \sum_{\ell+E_T^{miss}+jets} |E_T| < 175$ GeV.

Ensemble Tests



The linear response of the ME analysis method for seven ensemble test sets: three sets with Standard Model single top content and four sets with non-Standard Model content.

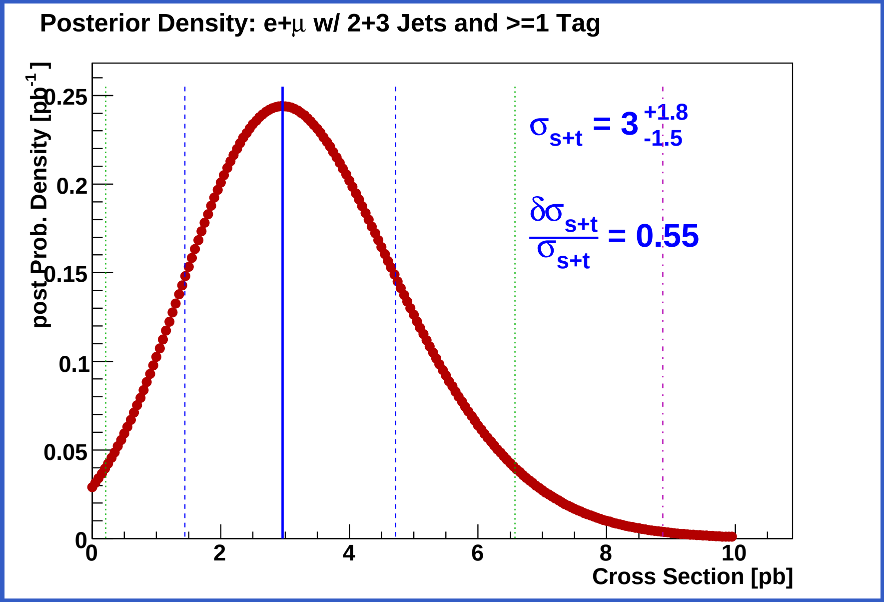
ME Discriminant Plots in Data

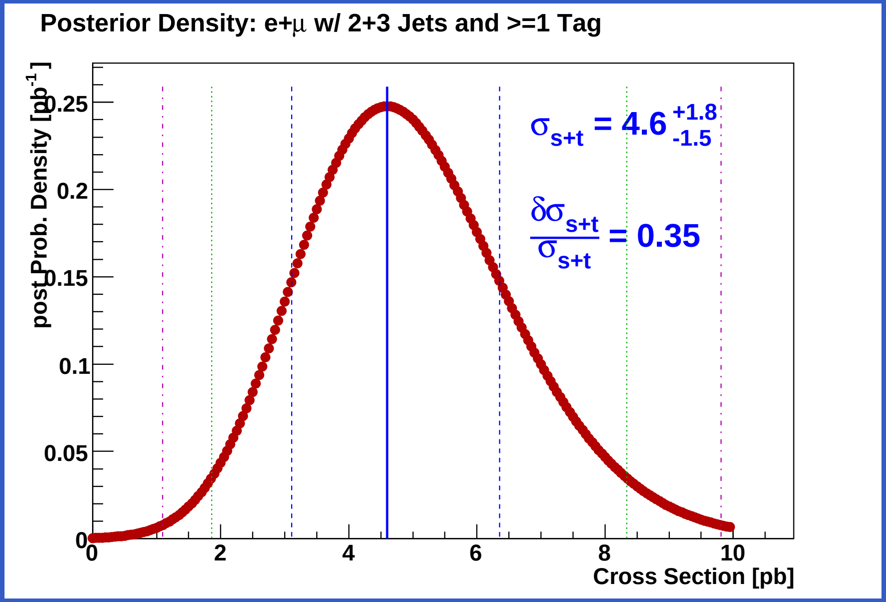


The tb and tqb ME discriminants in the full ≈ 1 fb^{-1} data sample for both e and μ channels with two jets and > 0 b-tags.

Expected and Measured Cross Sections

- The uncertainty on the measured cross section is 32 % without including systematic uncertainties, and 35 % including systematic uncertainties. The result is statistics-driven.
- *Expected* posterior probability density plot (left) and *measured* posterior probability density plot (right) for the combination of all channels and including systematic uncertainties:



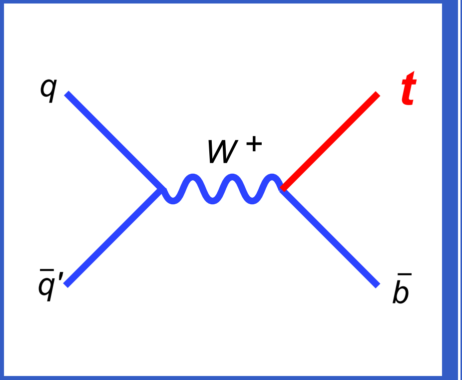


- The expected and measured cross sections (with systematics):

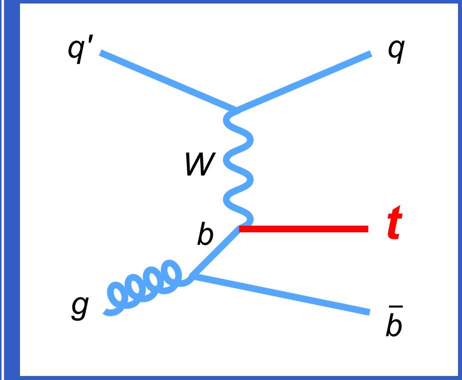
Expected: $3.0^{+1.8}_{-1.5}$ pb	Measured: $4.6^{+1.8}_{-1.5}$ pb

The significance of this result is 2.9σ.

Conclusion



s-channel (“tb”)



t-channel (“tqb”)

- DZero has found evidence for single top quark production at the Tevatron.
- The Matrix Element method is one of several multivariate techniques useful for discriminating signal from background in the single top analysis.

Method	Cross Section [pb]	Significance
Matrix Element	$4.6^{+1.8}_{-1.5}$	2.9σ
Bayesian NN	5.0 ± 1.9	2.4σ
Decision Tree	4.0 ± 1.4	3.4σ

- Including more background probability density functions ($t\bar{t} \to \ell$+jets, $t\bar{t} \to \ell\ell$) would improve the discrimination between background and signal.