Evidence for single top quark production at D0 using boosted decision trees

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On behalf of the D0 collaboration

Single Top Production

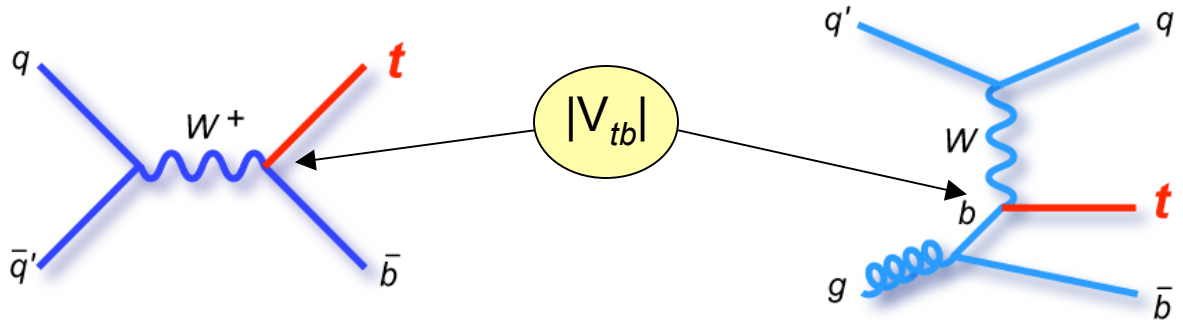
Weak interaction vertex
produces *one* top quark

→ Direct measurement of $|V_{tb}|$

→ Sensitive to a fourth quark family

Also important:

Single top is background
to WH search!



s-channel (*tb*):

- SM cross-section 0.88 ± 0.11 pb
- Sensitive to new resonances

t-channel (*tqb*):

- SM cross section 1.98 ± 0.25 pb
- Sensitive to FCNC

What the Detector Sees

Experimental Signature:

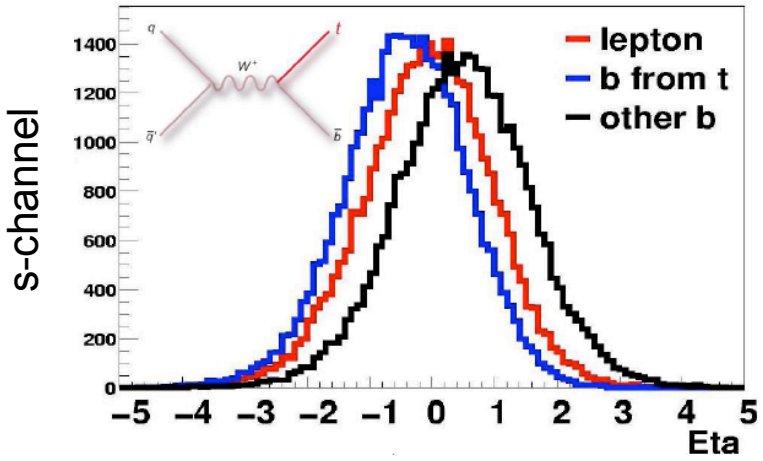
- One high-p_T central lepton
- Significant missing E_T
- 2-4 jets, with at least one *b* jet
- For specifics on event selection, see talk by Monica Pangilinan

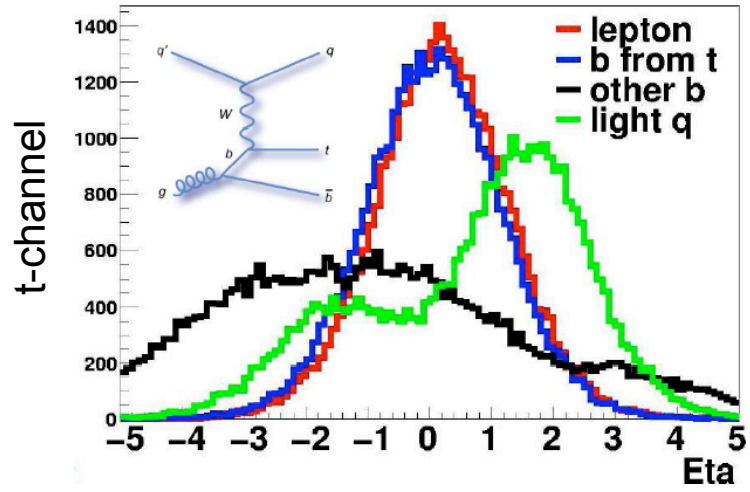
Backgrounds:

- *W* + jets
- top quark pair production
- fake-lepton multijet events

Multivariate Analyses:

- Bayesian NN (Monica Pangilinan)
- Matrix Element (Chris Potter)
- **Boosted Decision Trees**

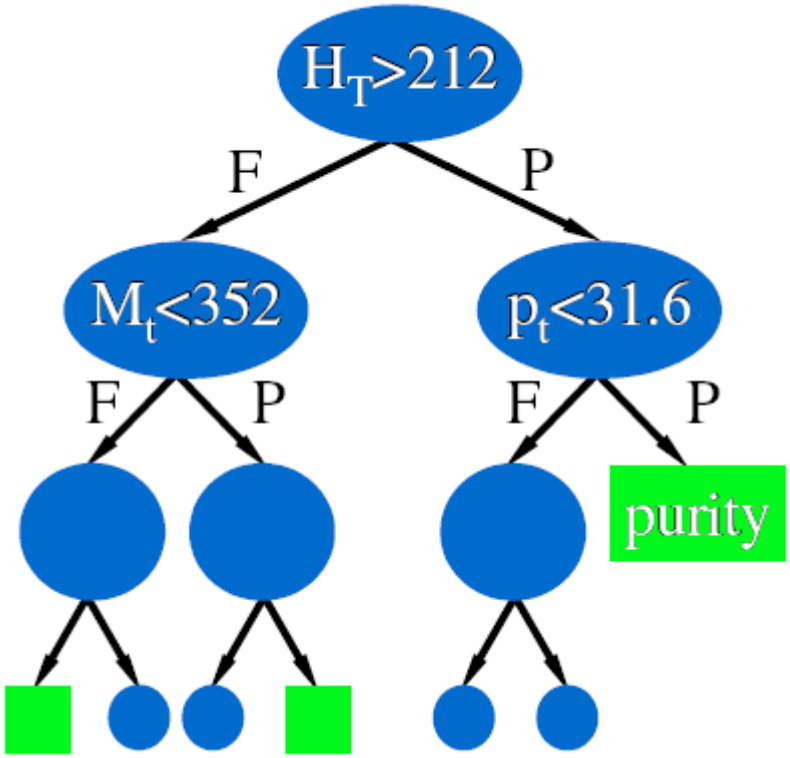




Decision Trees in Particle Experiment

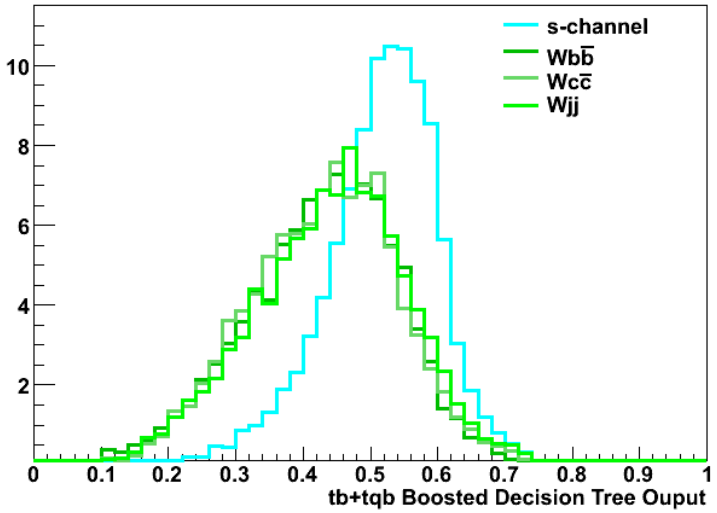
mathematically, they're *rooted binary trees*…

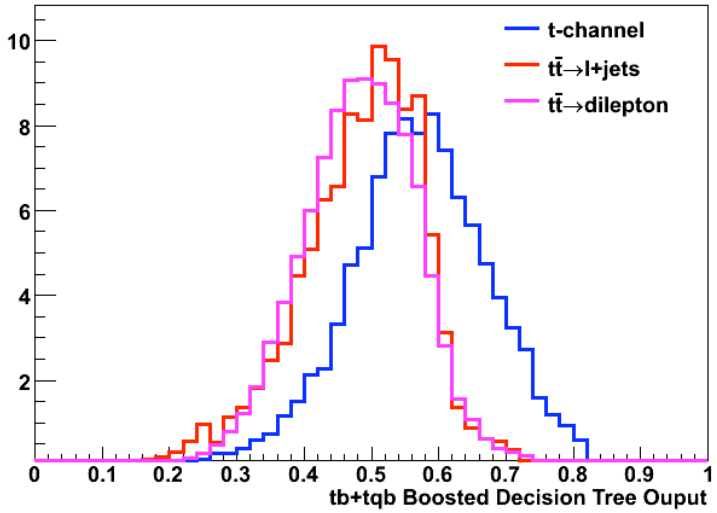
- Each *node* (blue) simultaneously represents a set of events *and* a cut
- Two child nodes split each node into events that pass cut and events that fail
- Cuts chosen to achieve maximal separation between signal and background (see slide 6)
- Splitting terminates eventually, forming *leaves* (green)
- Associated with each leaf is its *purity*, the weighted fraction of events in that leaf that are signal



Analysis via Decision Trees

- The decision tree sorts data into many disjoint sets, corresponding to its leaves
- Output for each event is the purity of the corresponding leaf
- Decision tree output serves as *discriminant*—by design, output distributions vary greatly between signal and background
- We use discriminant distributions to perform a *shape-based* analysis on the data





Decision Tree Training

Need a measure of *impurity* for nodes—such a function must be:

- Maximal for equal mix of signal and background
- Minimal for nodes with only signal or background
- Symmetric about purity $p = ½$

→ Use *Gini* measure:

$$Gini \propto p(1-p)$$

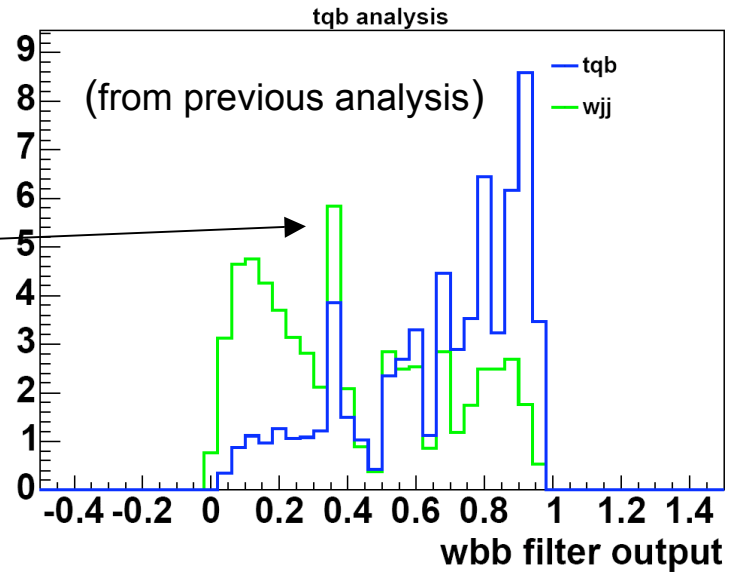
Training Procedure:

- Training sample: 1/3 of signal and background models
- List of 49 discriminating variables
- For each variable, choose cut to **maximize decrease in impurity**
- Choose best cut from list
- Split sample based on cut, then repeat process on resulting subsets
- Stop when split would produce subset with <100 events
- Test performance with other 2/3 of signal and background model

Boosting

Limitations of *one* tree:

- Small changes in training sample → big changes in decision tree
- Decision tree output often has weird spikes
- Many events *misclassified*—e.g. signal event in leaf that's primarily background



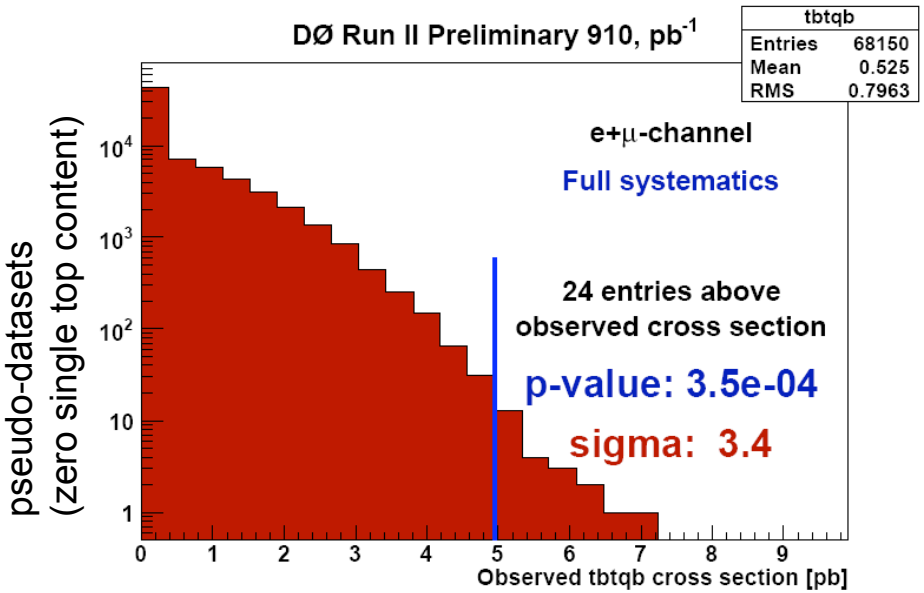
Improvement through *Boosting*:

- Train sequence of decision trees—we use 20
- Reweight training sample for each tree to focus on misclassified events
- For discriminant, use weighted average of decision tree outputs
- Weight trees according to fraction of events that were misclassified

Results

Expected: $\sigma_{tb+tqb} = 2.7^{+1.6}_{-1.4}$ pb

Observed: $\sigma_{tb+tqb} = 4.9^{+1.4}_{-1.4}$ pb



- p-value significance: 24/68150 = 0.00035
- Gaussian equivalent: **3.4 sigma evidence!**
- SM Compatibility: 11%

(for more details on determining significance, see talk by Monica Pangilinan)

$|V_{tb}|$ Measurement

$\sigma_{tb+tqb} \propto |V_{tb}|^2 \rightarrow$ Can determine $|V_{tb}|$ with same procedure as used for cross-section

We assume:

- SM top quark decay ($V_{td}^2 + V_{ts}^2 << V_{tb}^2$)
- CP-conserving V-A coupling (all form factors zero except f_1^L)

Results:

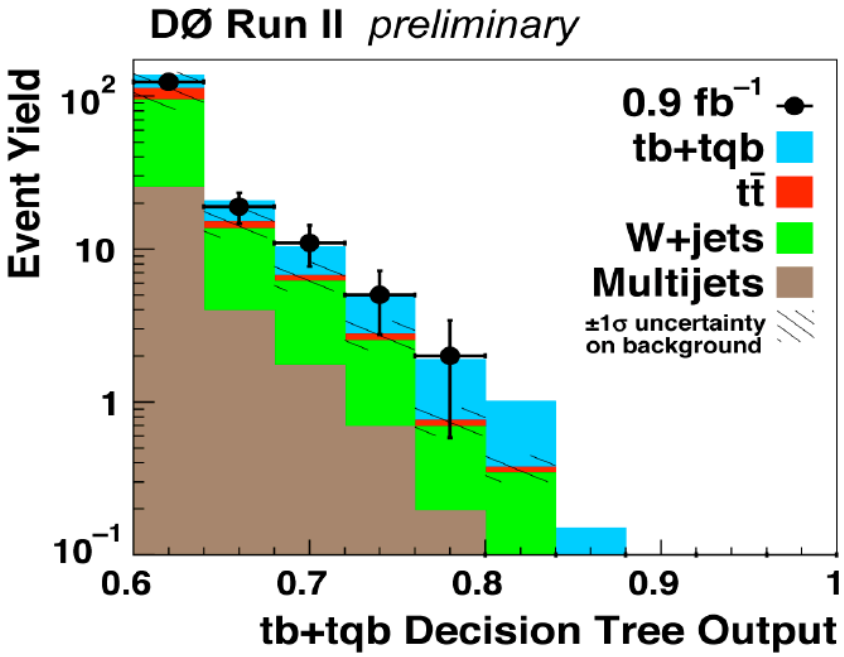
- $|V_{tb}f_1^L| = 1.3 \pm 0.2$
- **$|V_{tb}| > 0.68$ at 95% C.L.** assuming $f_1^L = 1$ (SM)

Not assumed:

- 3 quark families
- CKM unitarity

Summary

Using boosted decision trees, we see **3.4 sigma evidence** for single top!



$\sigma_{tb+tqb} = 4.9 \pm 1.4$ pb

First direct measurement of $|V_{tb}|$:

$0.68 < |V_{tb}| \leq 1$ at 95% C.L.

(assuming SM form factors)