

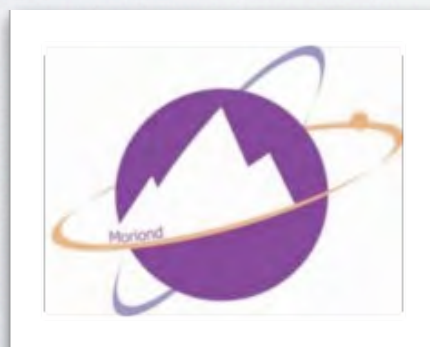
Single Top Quark Production at DØ

Jyoti Joshi

(University of California, Riverside)
for the DØ Collaboration

Rencontres de Moriond,

3-10 March, 2012



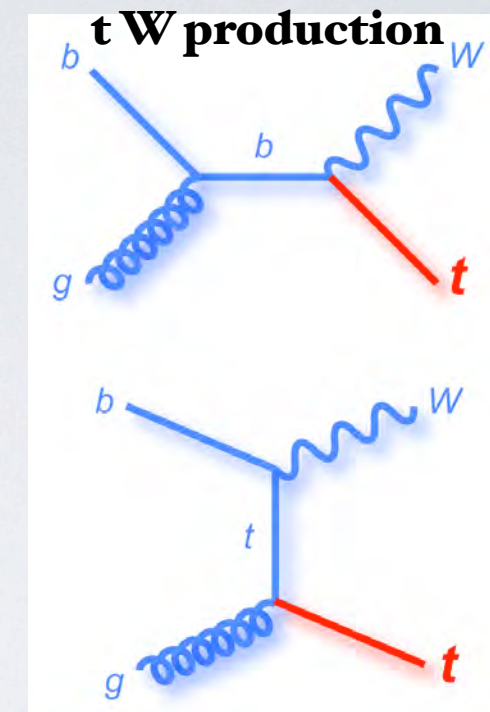
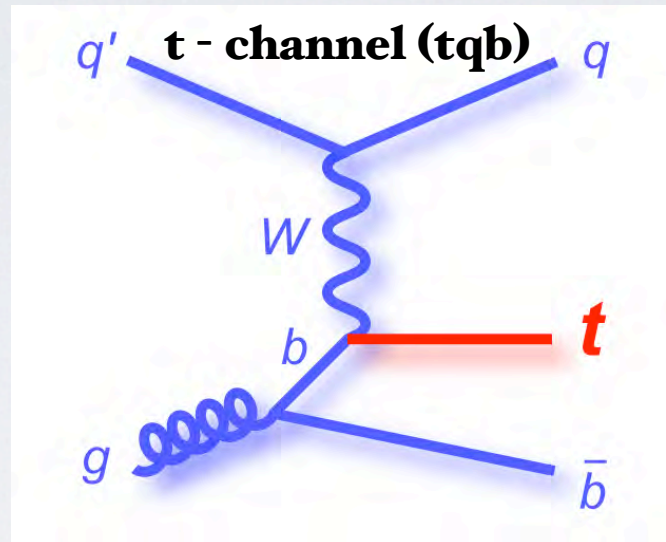
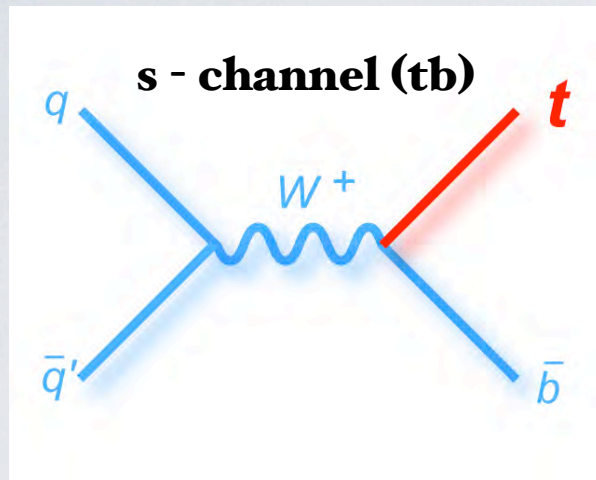
Outlines :

- * Single Top Production
- * Background and Event Yields
- * MVA Techniques
- * Cross-section Measurement
- * Anomalous ***Wtb*** Couplings

Single Top Quark Production

Three modes via which Single Top can be produced in Hadron Colliders.

Two have high enough rates to be studied at Tevatron.



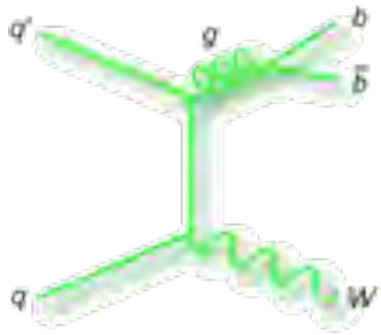
	tb [pb]	tqb [pb]	tW [pb]
Tevatron ^{&} (1.96 TeV)	1.04 ↓ x4.4	2.26 ↓ x28	0.30 ↓ x26
LHC ^{\$} (7 TeV)	4.59	64.2	7.8

&: PRD 74, 114012 (2006)
 \$: PRD 81, 054028 (2010)
 PRD 83, 091503 (2011)

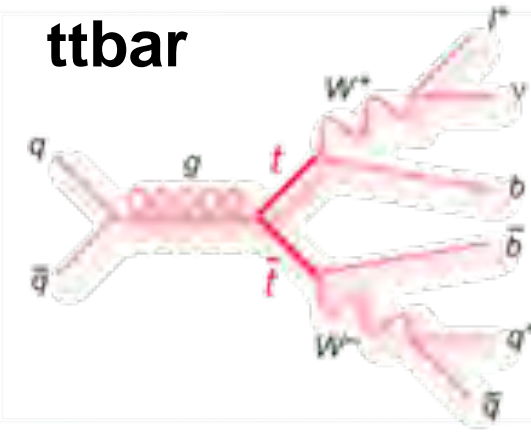
Background and Event Yields

S:B~1:20

W+jets



ttbar

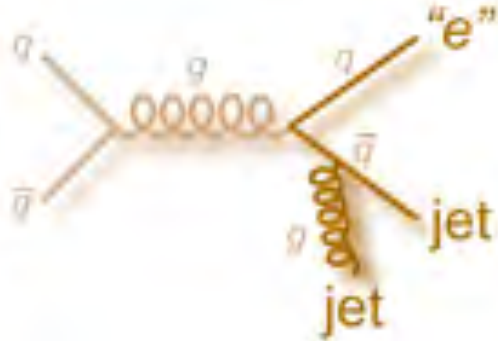


Event yields in 5.4/fb DØ data

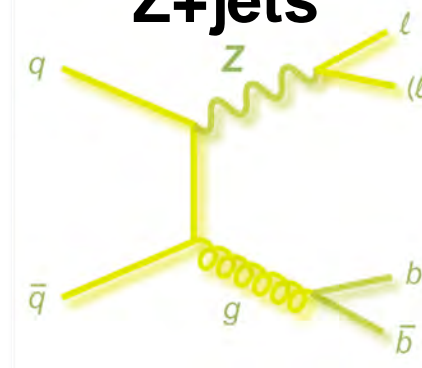
e,μ, 2,3,4-jets 1,2-tags combined

t-channel	239 ± 28
s-channel	160 ± 27
W+jets	4943 ± 598
Z+jet, dibosons	576 ± 113
tt	2124 ± 383
Multijets	451 ± 56
Total prediction	8492 ± 987
Data	8471 ± 92

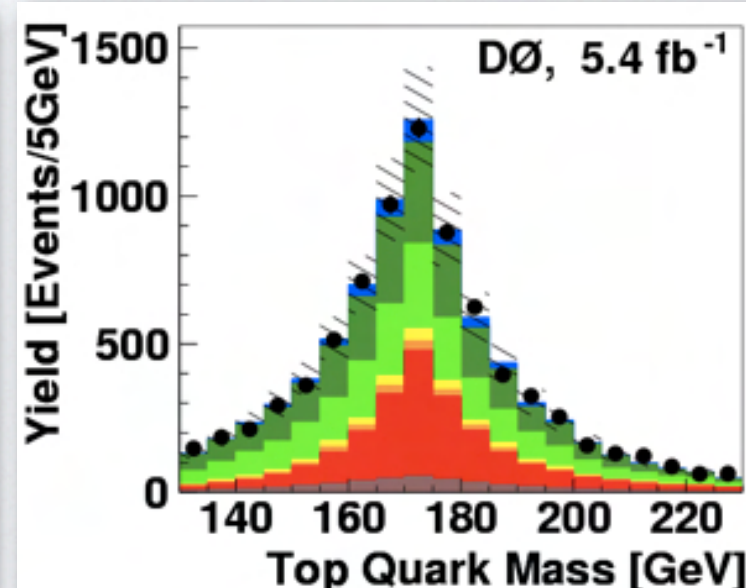
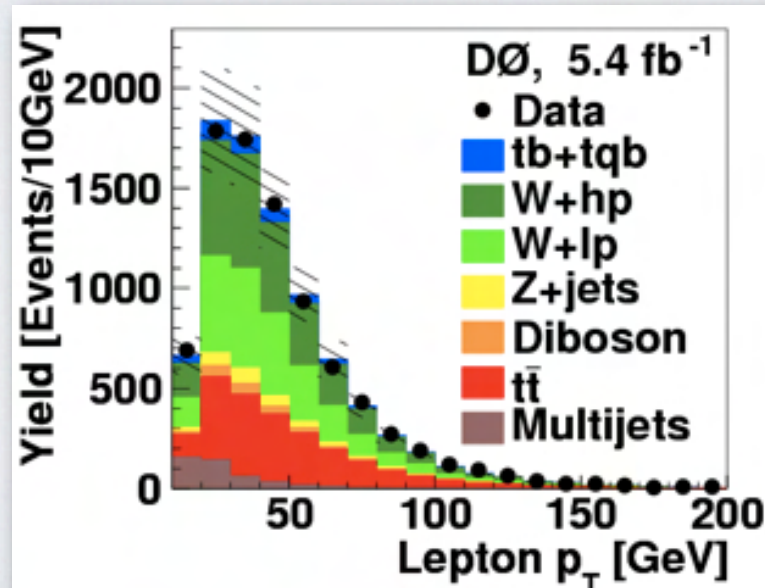
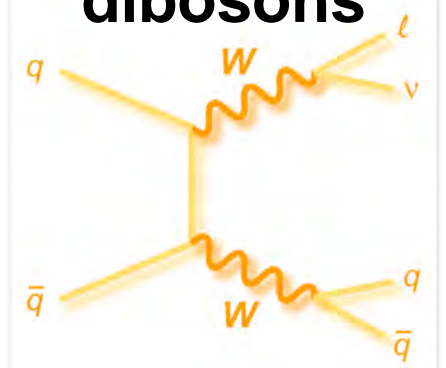
Multijets



Z+jets



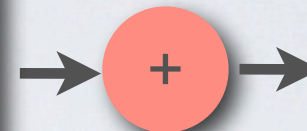
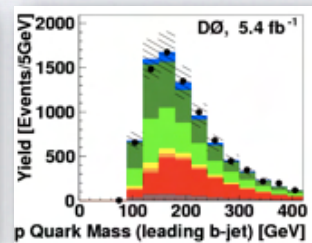
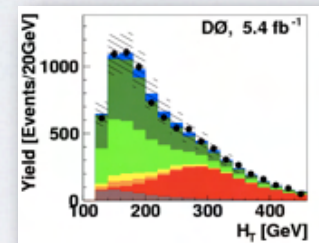
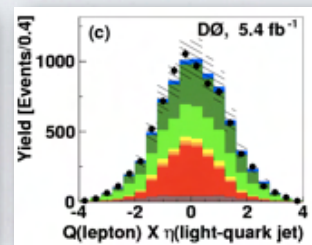
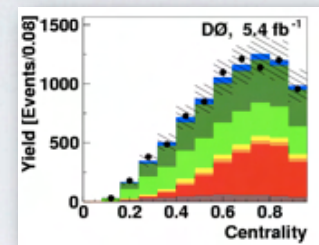
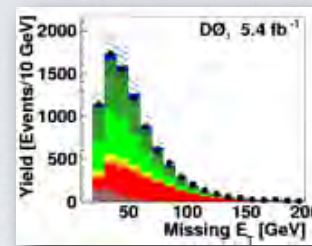
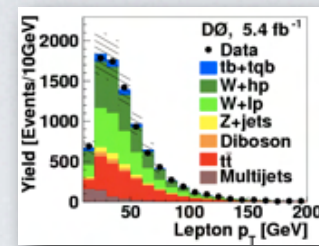
dibosons



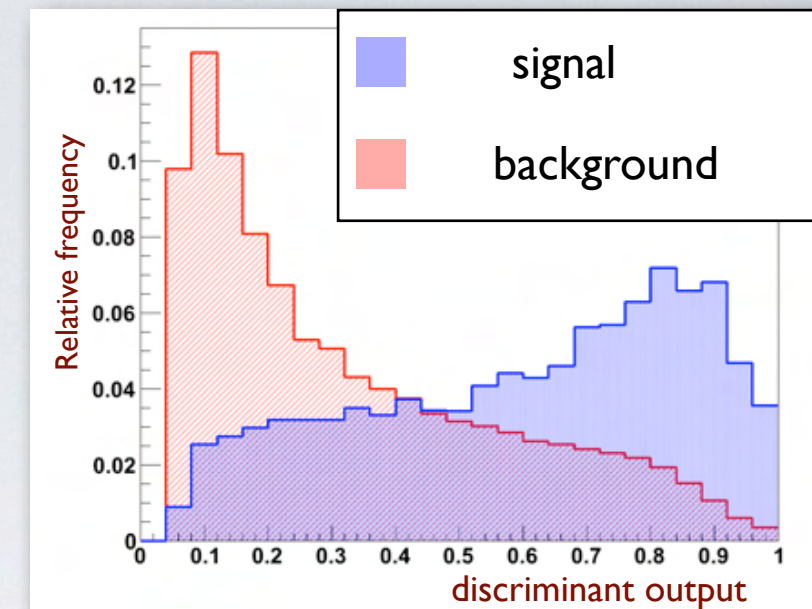
**Good data/MC
agreement**

Multivariate Analysis

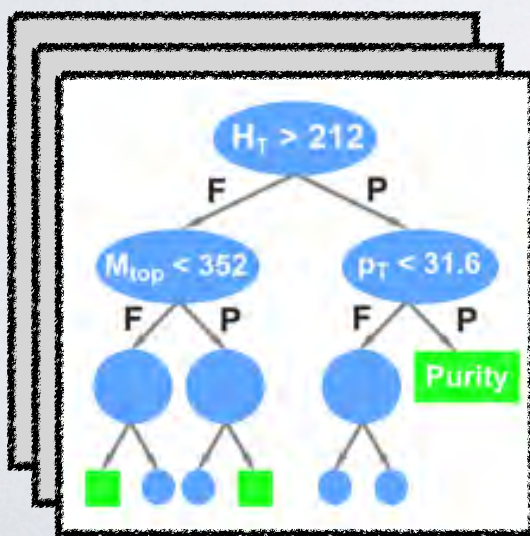
Combine different kinematic variables with some discrimination power into one variable with larger discrimination.



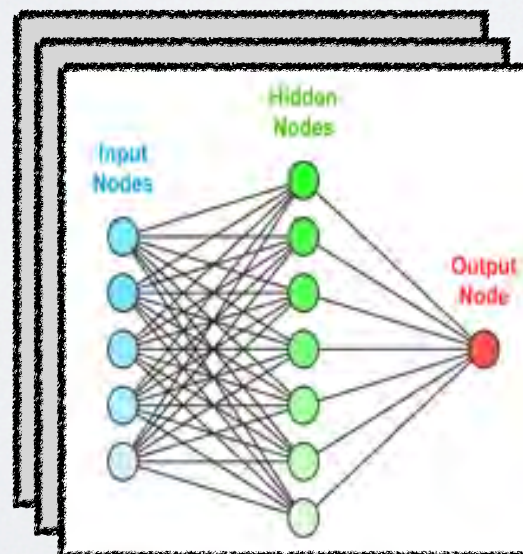
After training



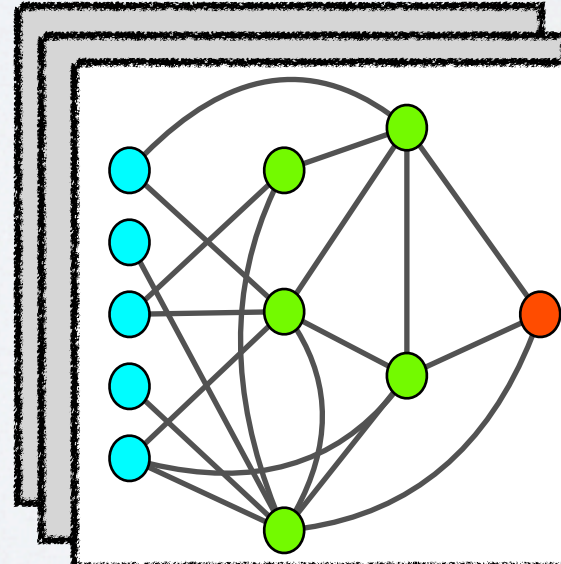
Boosted Decision Tree (BDT)



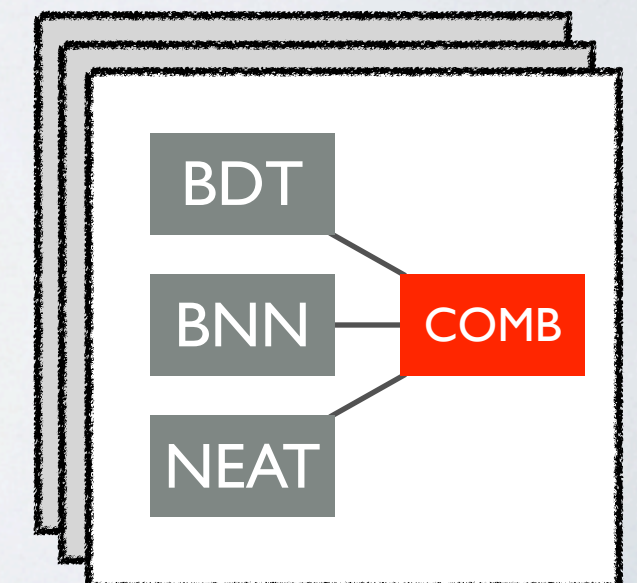
Bayesian Neural Networks (BNN)



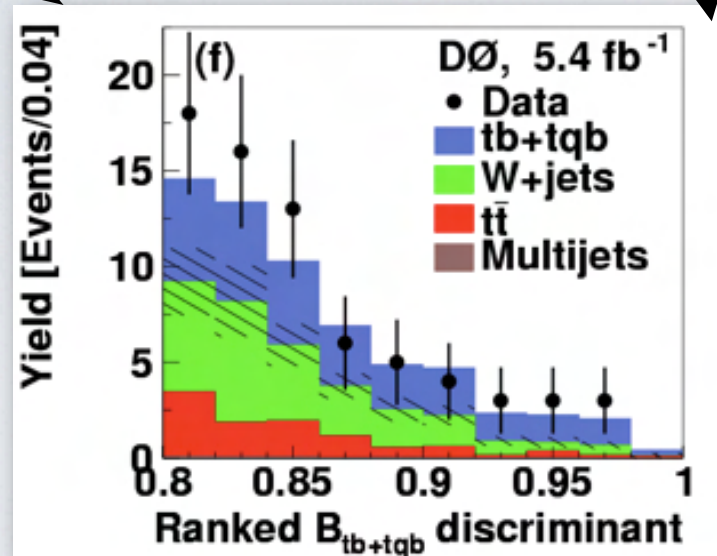
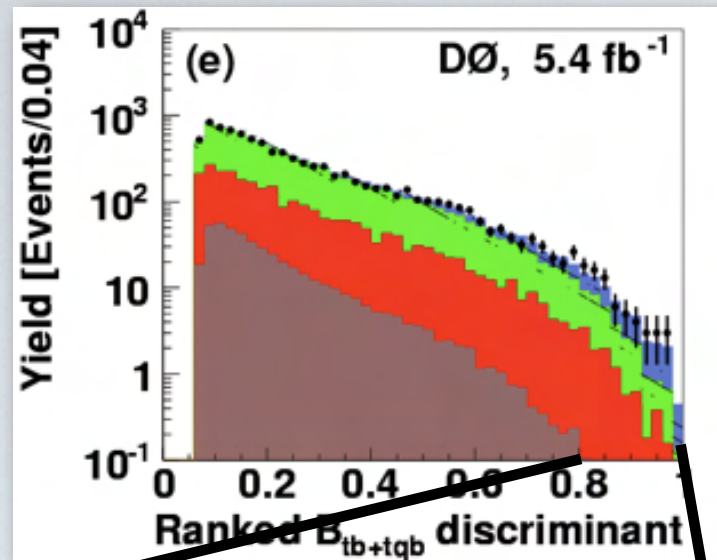
Neuroevolution of Augmenting Topologies (NEAT)



BNN Combination



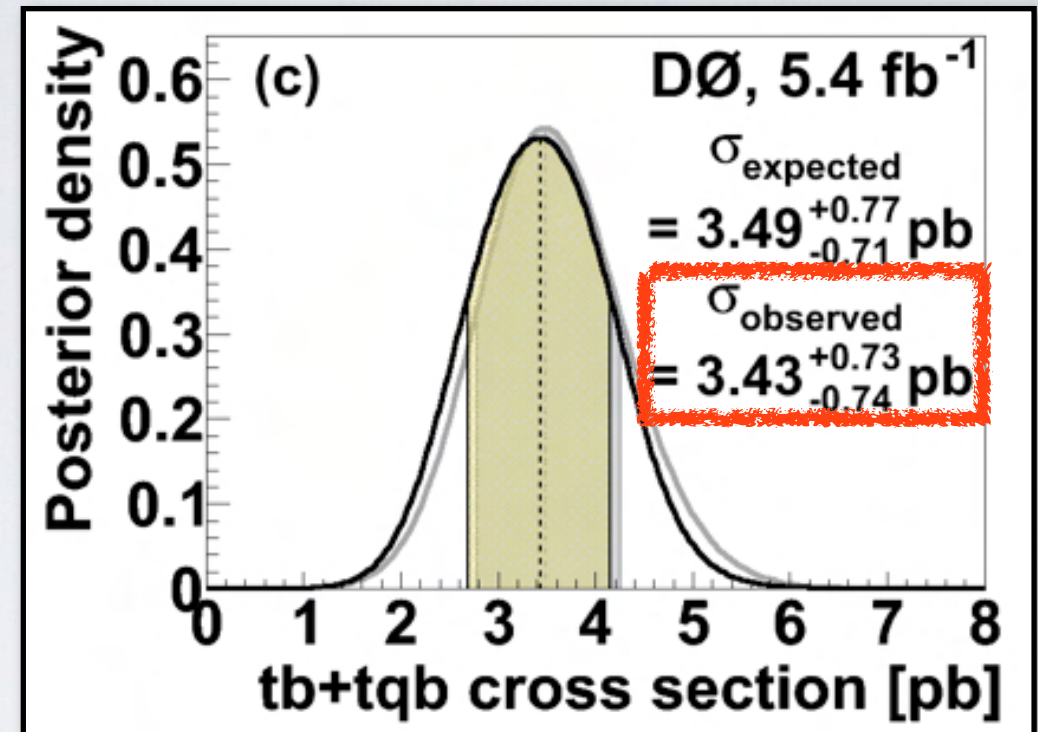
s+t-channel Cross Section and V_{tb}



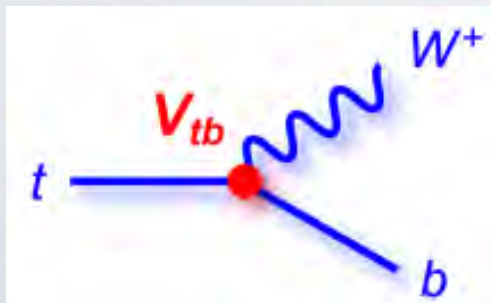
Bayesian
Statistical

Analysis

PRD 84, 112001
(2011)



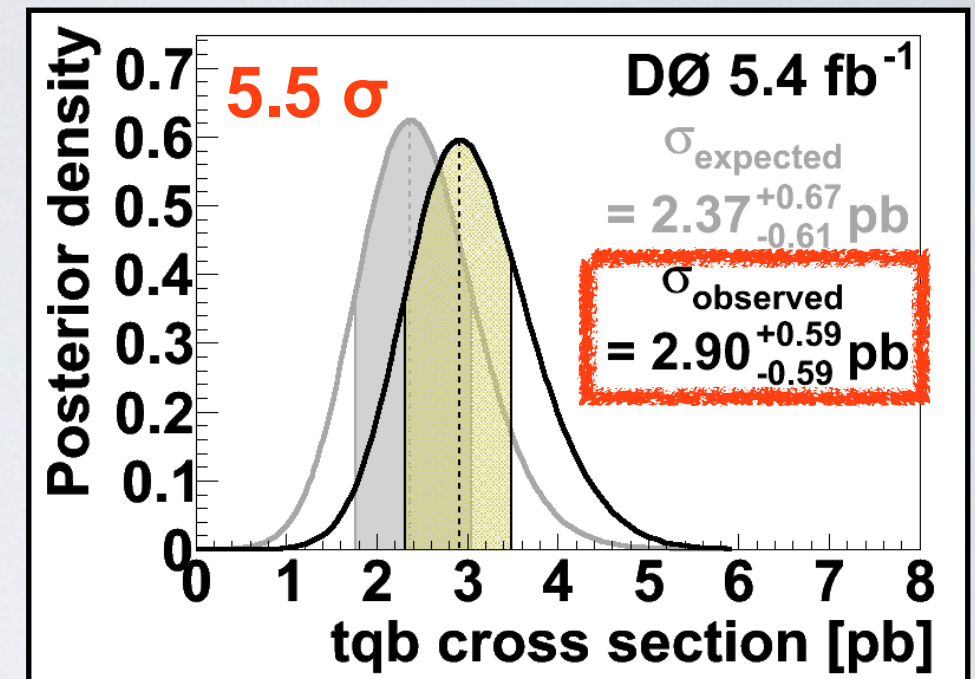
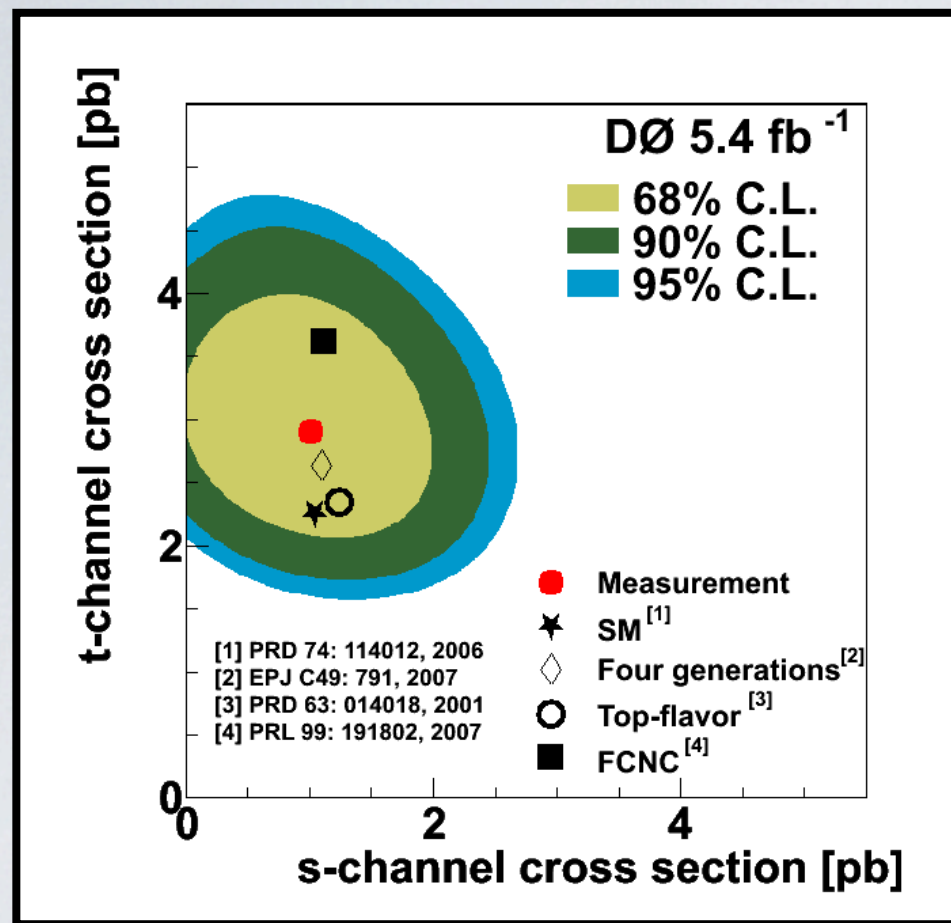
- Bayesian posterior probability density is constructed forming a binned likelihood, with the
position of maximum = cross section and
width of the curve (68% asymmetrical interval) = Uncertainty



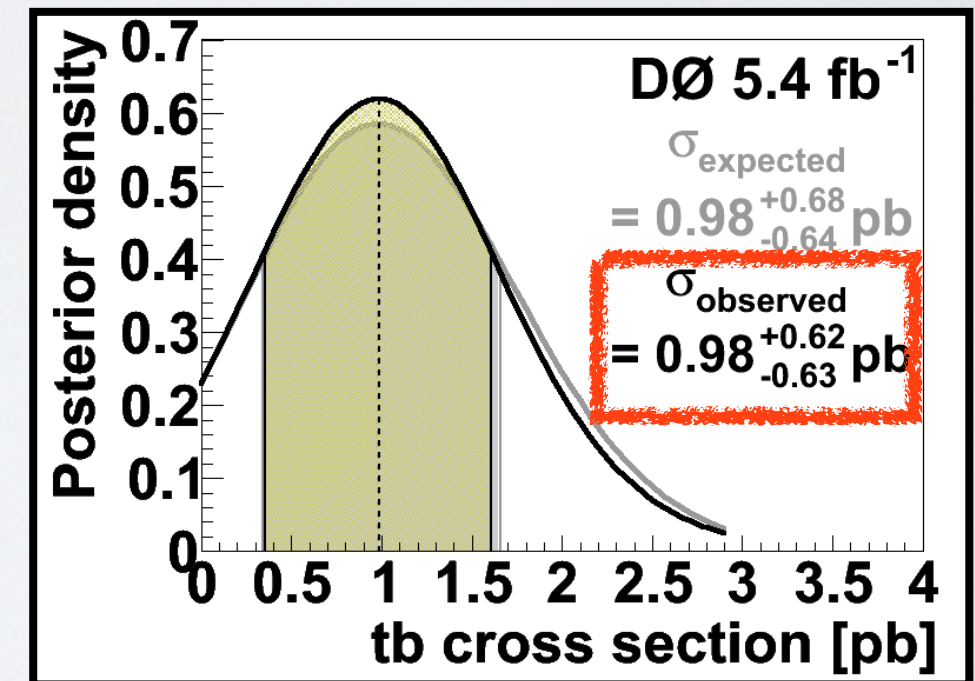
$$|V_{tb} f_L^1|^2 \propto \sigma(s + t\text{-channel})$$

$$|V_{tb}| > 0.79 @ 95\% \text{ C.L.}$$

s and t-channel Cross-Section Measurement



PLB 705, 313 (2011)

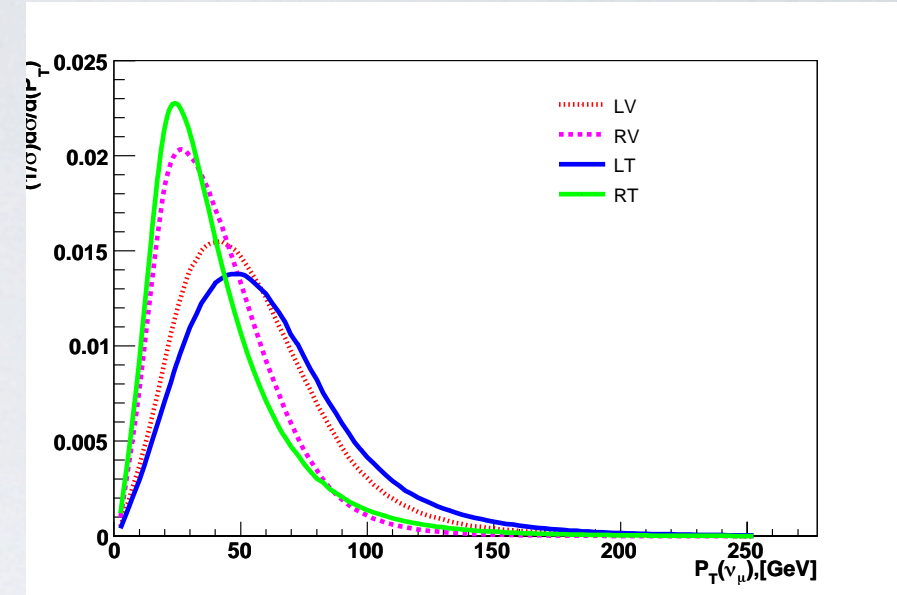


A 2D Bayesian posterior probability density is computed. A 1D Bayesian posterior probability density for t-channel (s-channel) is obtained by integrating s-channel (t-channel) signal assuming a flat prior.

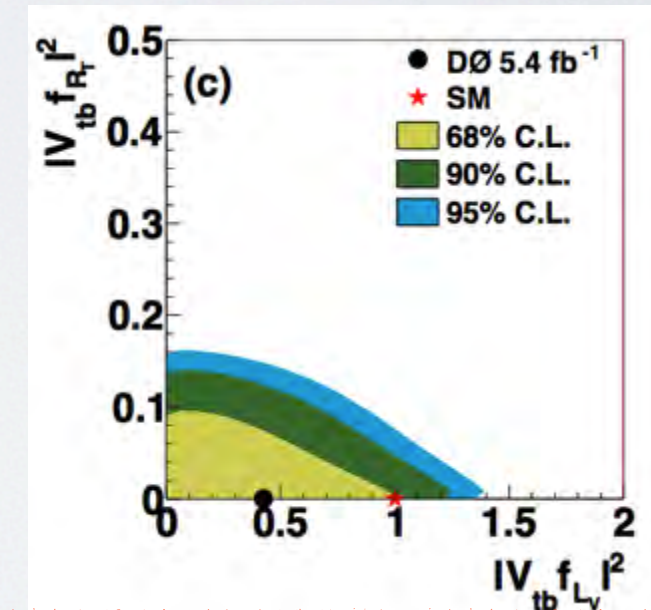
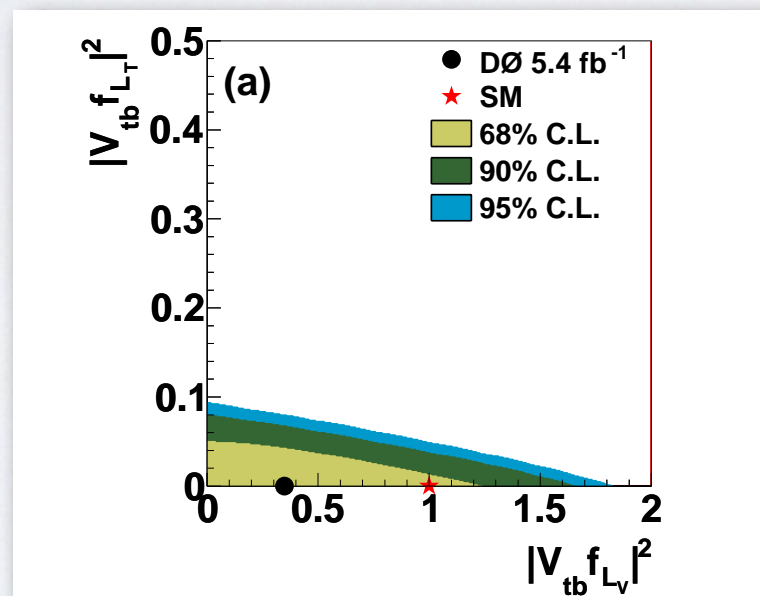
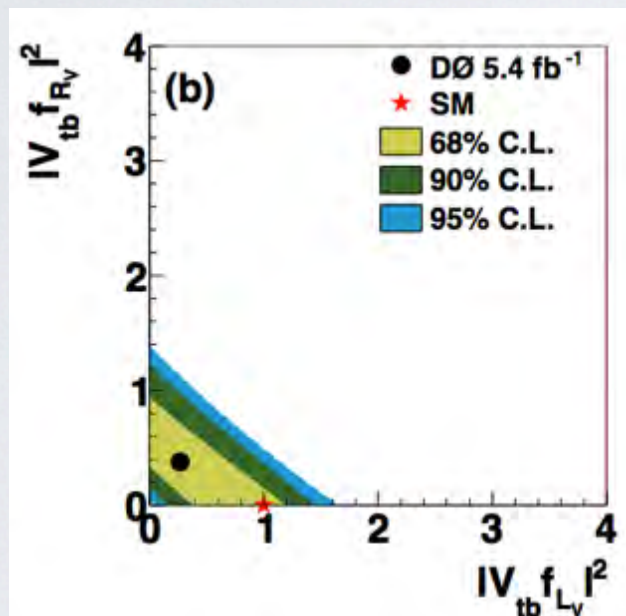
We get a significance of **5.5 sigma** for t-channel and s-channel still has low significance.

Anomalous Wtb Couplings in single top production

- New Physics can manifest itself either in terms of
 - * new particles or
 - * Modified couplings changing the cross-sections of existing processes and angular distributions of SM processes
- We use the same 5.4 fb^{-1} dataset and event selection to look for anomalous Wtb couplings



$$\mathcal{L} = -\frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (L_V P_L + R_V P_R) t W_\mu^- - \frac{g}{\sqrt{2}} \bar{b} \frac{i \sigma^{\mu\nu} q_\nu}{M_W} (L_T P_L + R_T P_R) t W_\mu^- + h.c.$$



$$|R_V|^2 < 0.93 @ 95\% \text{ C.L.} \quad |L_T|^2 < 0.06 @ 95\% \text{ C.L.} \quad |R_T|^2 < 0.13 @ 95\% \text{ C.L.}$$

PLB 708, 21 (2012)

Conclusions

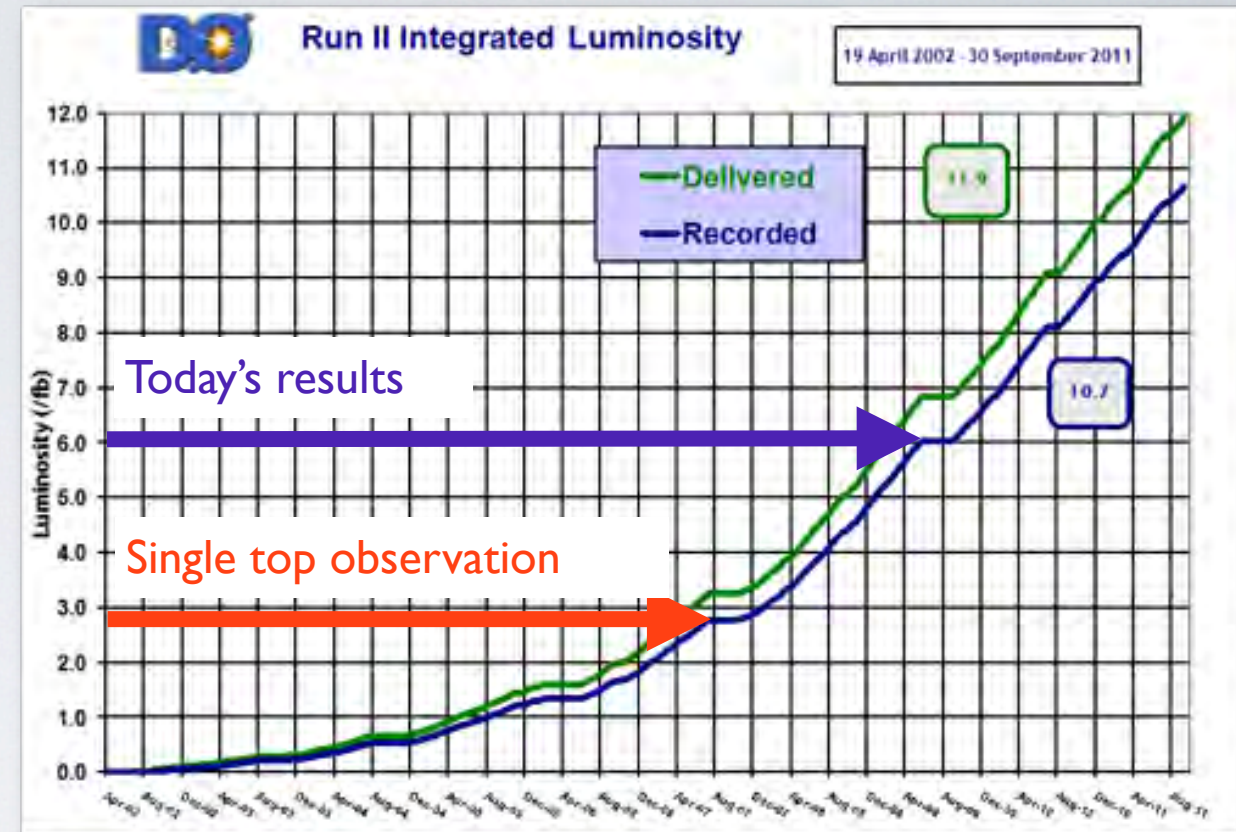
- Single top quark production provides us with a window of the top quark electroweak interaction.
- Searching for and measuring the different production channels are important to test the SM predictions.
- We can also probe for extensions of the electroweak interaction by searching for anomalous single top quark production.
- Work is in progress in searching for s-channel single top quark production using the 9.7 fb^{-1} dataset.

Thanks



BACKUP

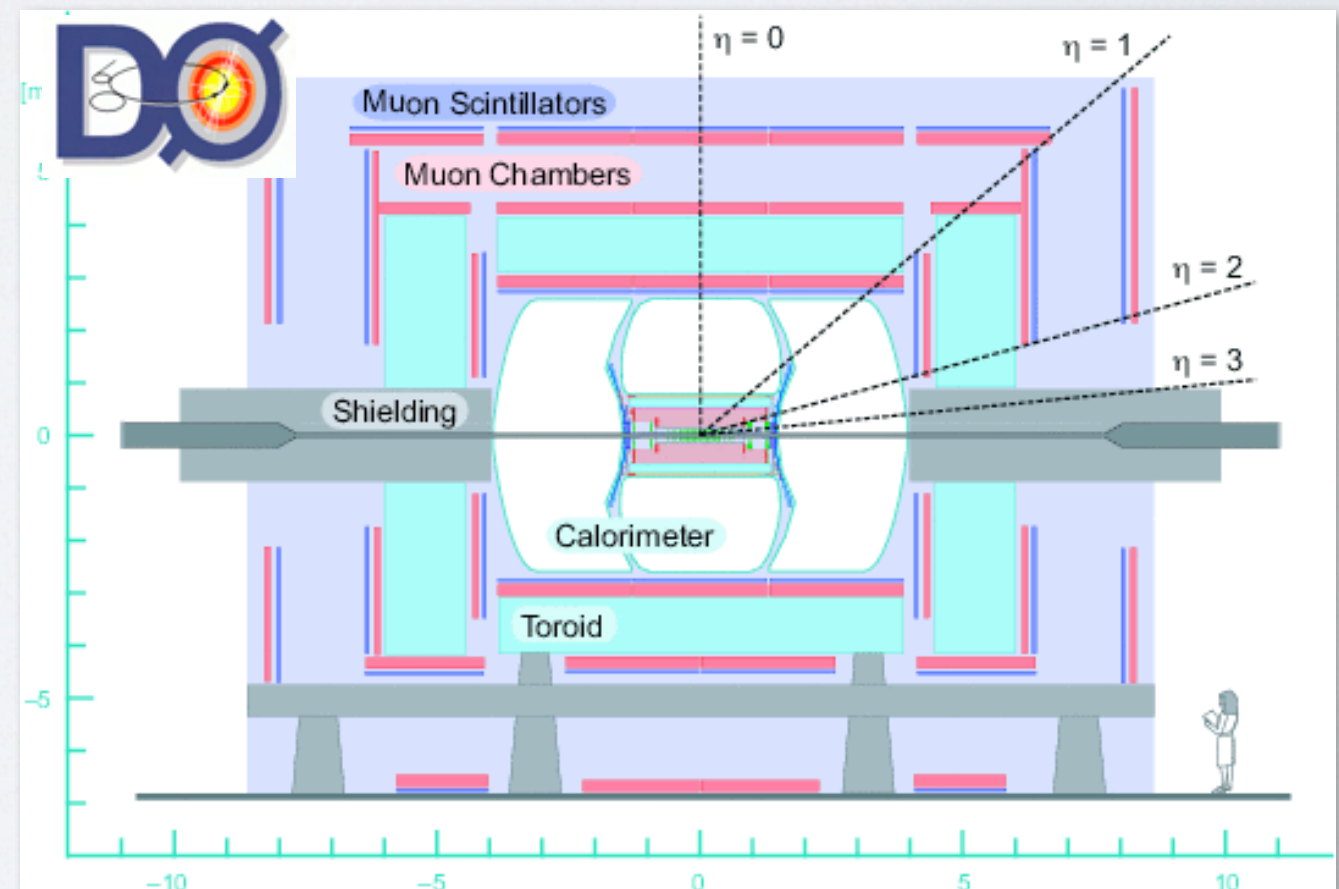
Tevatron Collider and DZero Detector



The Tevatron Collider

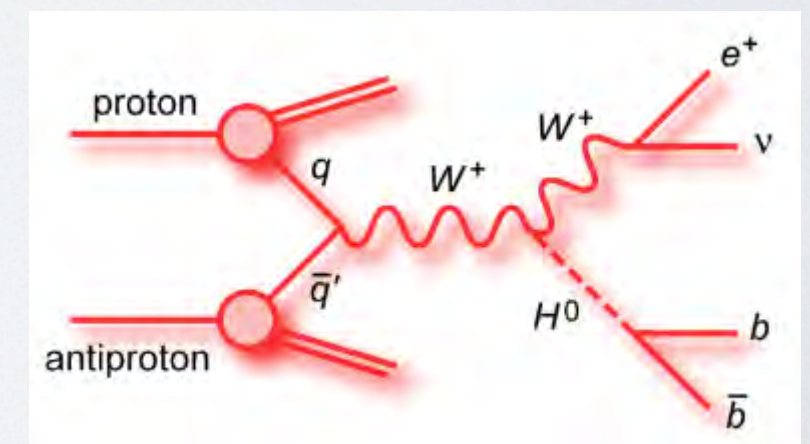
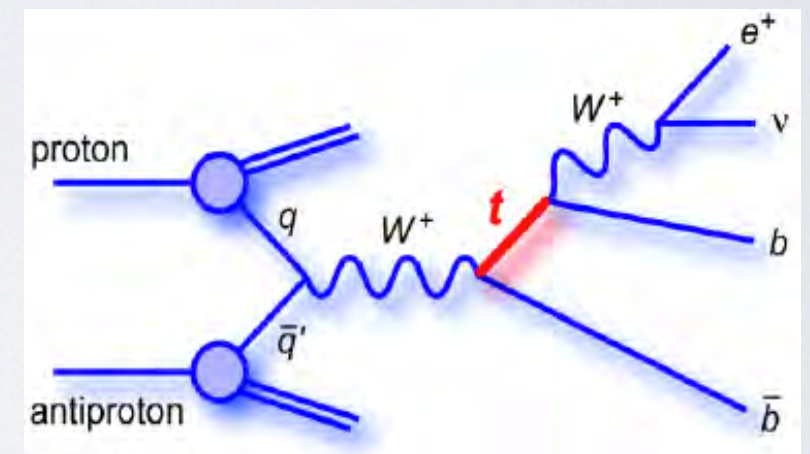
- Proton-antiproton collider with center of mass energy, $\sqrt{s} = 1.96$ TeV.
- 36x36 bunches with 396 ns between crossing.
- Inst. luminosity $\sim 3 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$.
- Target of recording 10 fb^{-1} till the end of this fiscal year.

The DØ detector is a multi-purpose particle detector to study interactions originating from proton-antiproton collisions at the Tevatron Collider at Fermilab.



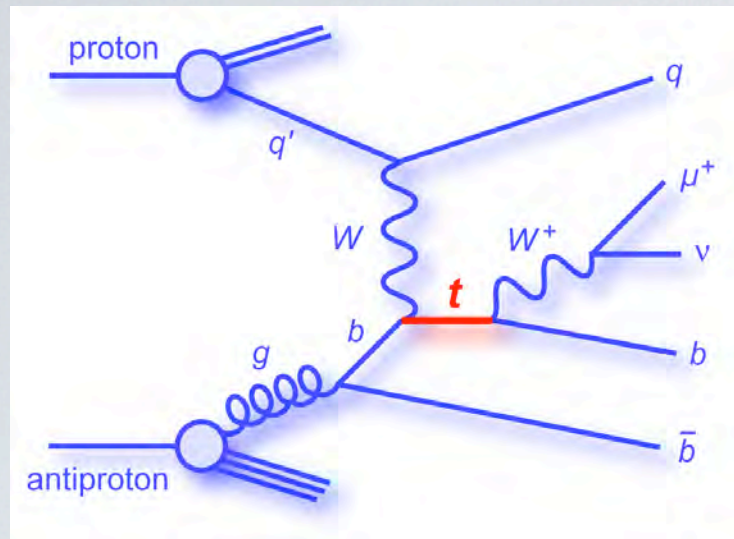
Motivations of the analysis

- ★ Sensitive to many beyond SM processes.
 - * t-channel process is sensitive to flavor-changing neutral currents (FCNC) and fourth generation quark.
 - * Study of anomalous Wtb couplings.
- ★ Direct Probe of the Wtb interaction with no assumption on the number of quark families or unitarity of the CKM matrix.
- ★ To study different top properties :
 - * Top decay width and lifetime.
 - * CP Violation.
- ★ Same final states as WH
 - * Same backgrounds.
 - * Test techniques to extract small signal.

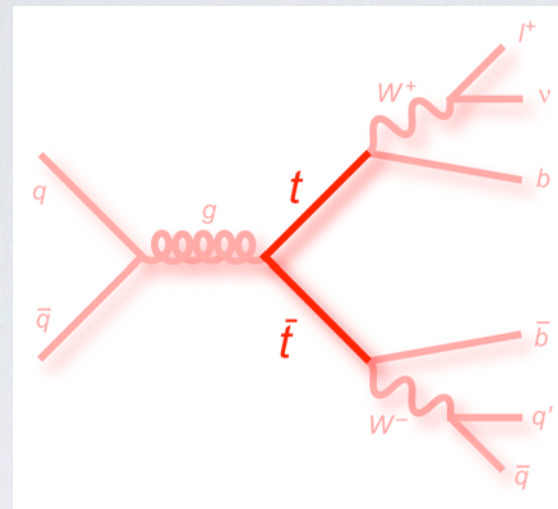


A Challenging Analysis

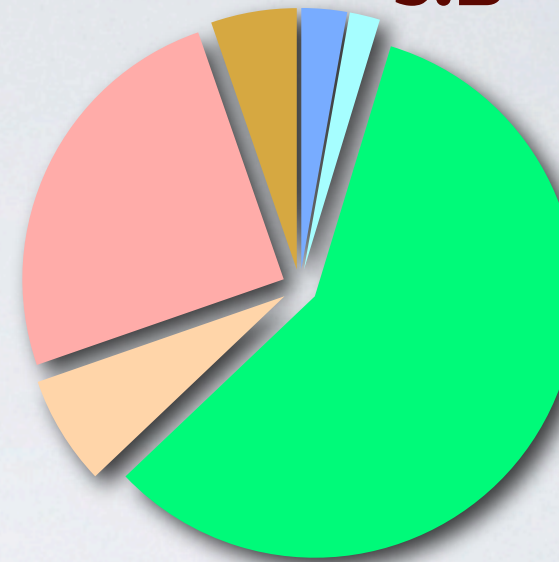
t-channel



Top Pairs



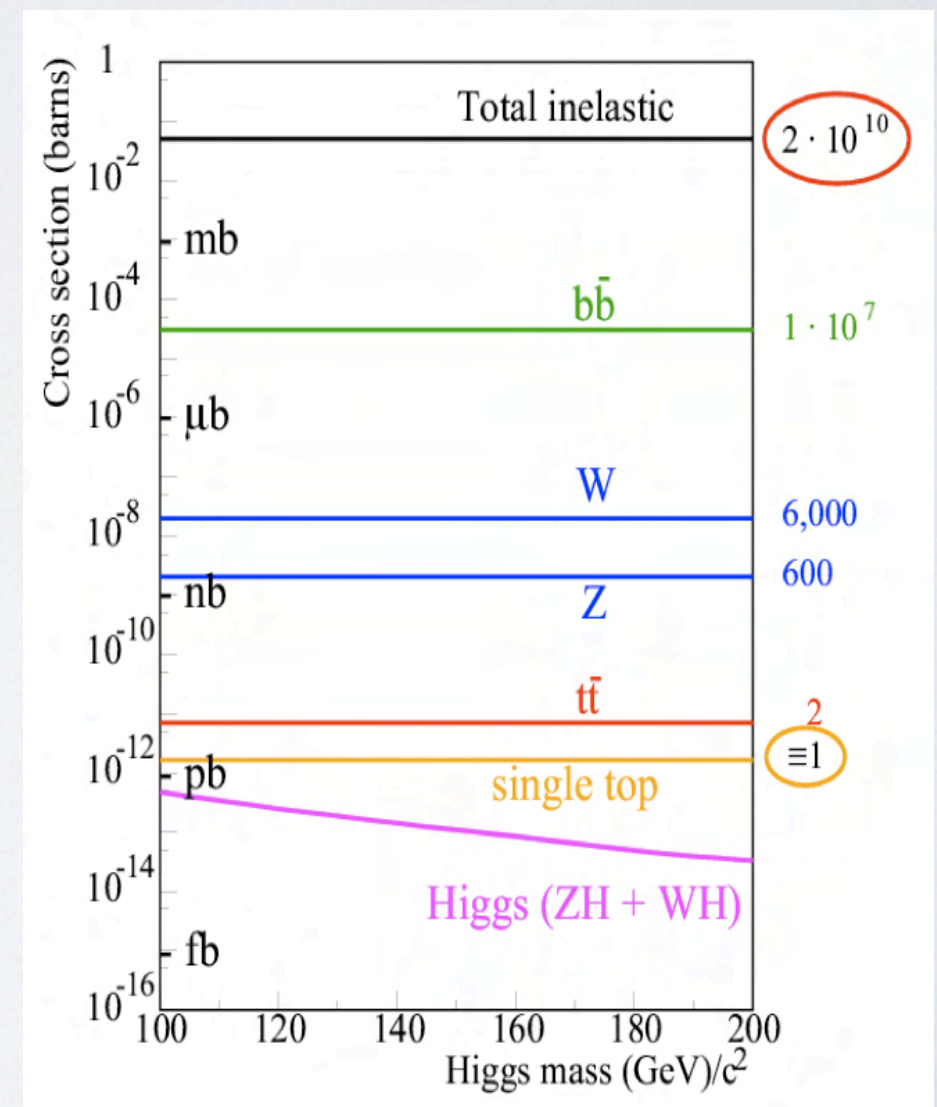
S:B~1:20



t-channel
s-channel
W+jets
Z+jet, dibosons
tt
Multijets

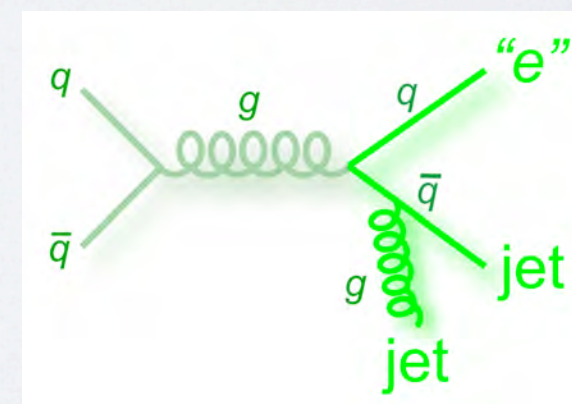
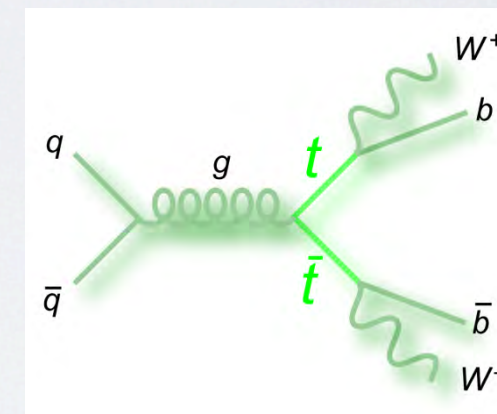
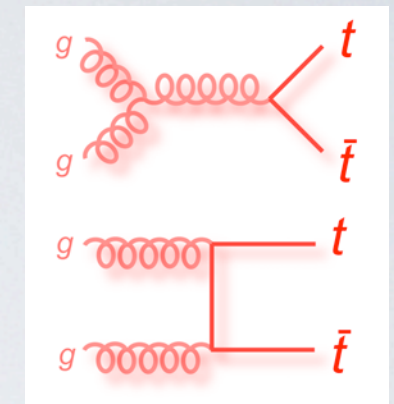
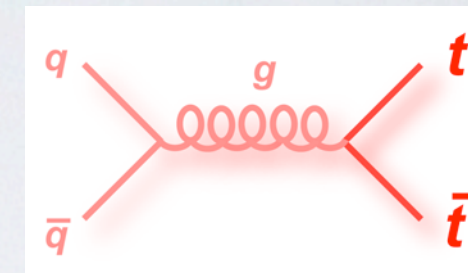
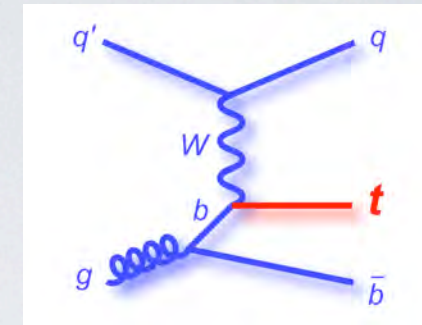
Experimentally Very Challenging :

- Observed at Tevatron 14 years after the observation of top quark produced by strong interaction.
- Smaller cross section as compared to top pair production. ($\sim 1/2$ of $t\bar{t}$)
- Mostly found in events with two and three jets.
- Background dominated after b-jet identification
S:B $\sim 1:20$
- $t\bar{t}$, multijets, W+jets backgrounds mimics signal signature very closely.



Signal and Background Modeling

- Single Top Signal events are modeled using SINGLETOP
 - Based on COMPHEP
 - PYTHIA for parton hadronization
- Top pair background is modeled using APLGEN event generator and PYTHIA for parton hadronization.
- W+jets modeled using ALPGEN+PYTHIA. Dominant background for single top.
- Multijet background is modeled directly from data.
- Z+jets is modeled using ALPGEN+PYTHIA.
- Dibosons are modeled with PYTHIA.



Event Signatures and Selection

One High p_T isolated Lepton

- ◆ **Electron Selection** - $p_T > 15 \text{ GeV}$, $|\eta| < 1.1$
- ◆ **Muon Selection** - $p_T > 15 \text{ GeV}$, $|\eta| < 2.0$

Large Missing transverse energy

- ◆ $15 \text{ GeV} < \text{MET} < 200 \text{ GeV}$

Two, three and four jets

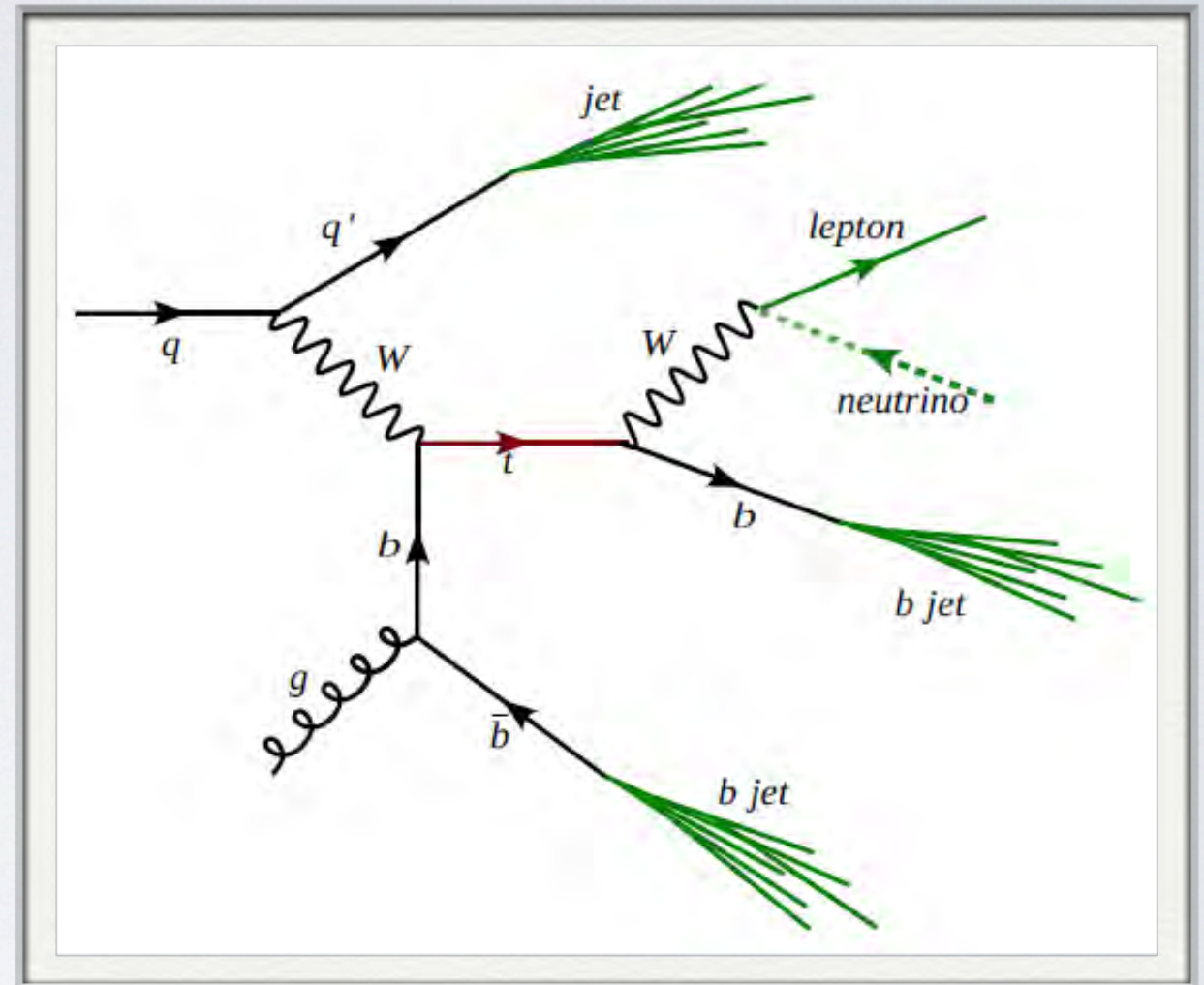
- ◆ $p_T > 25 \text{ GeV}$ (jet1), $p_T > 15 \text{ GeV}$ (other jets)
- ◆ $|\eta| < 3.4$

Total Transverse Energy

- ◆ $H_T > 120 - 160 \text{ GeV}$

B-Tagging Selection

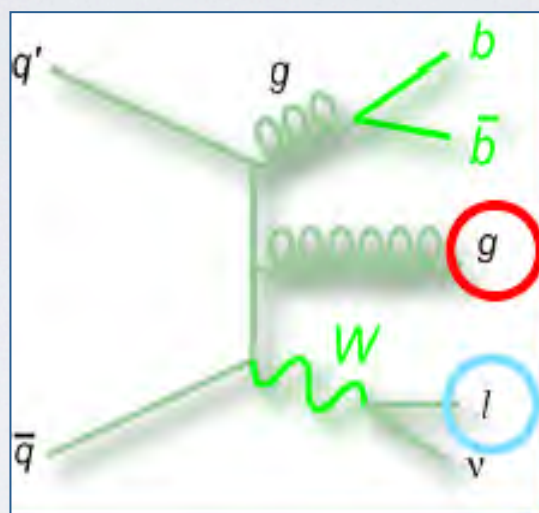
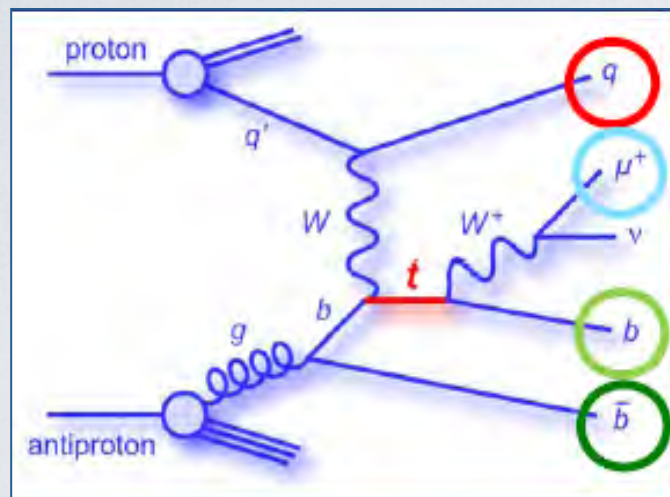
- ◆ One “tight” jets or Two “loose” jets originating from fragmentation of b quarks.



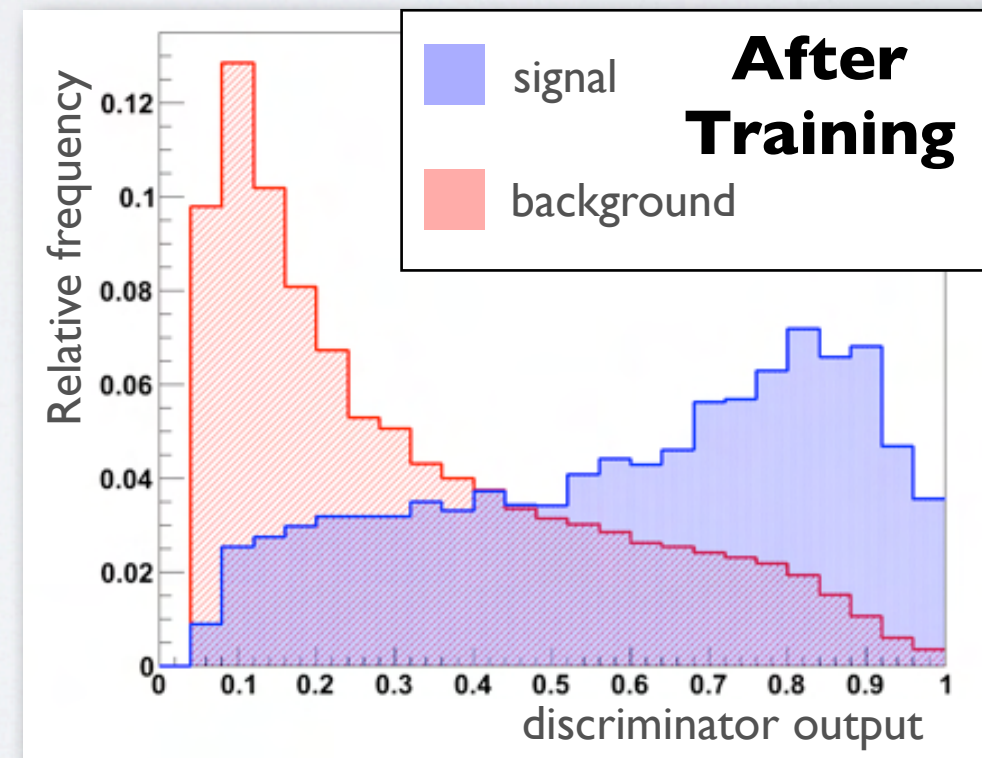
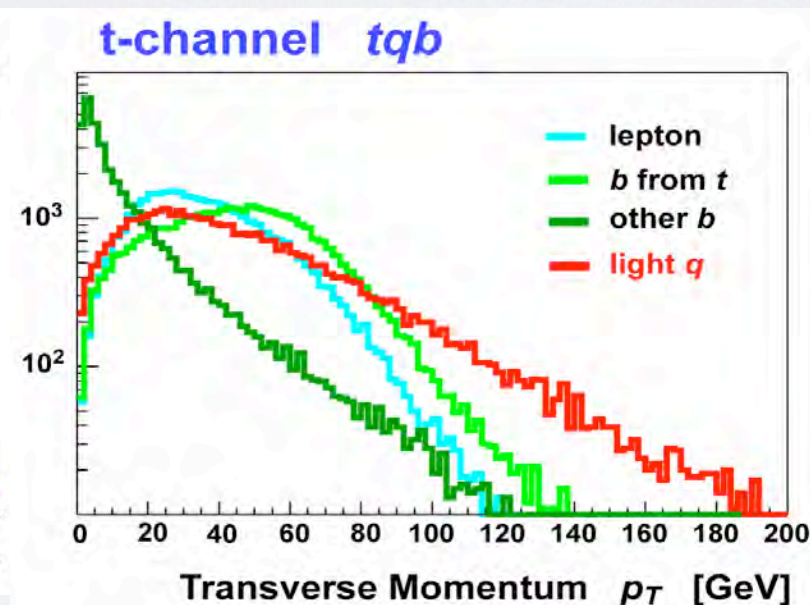
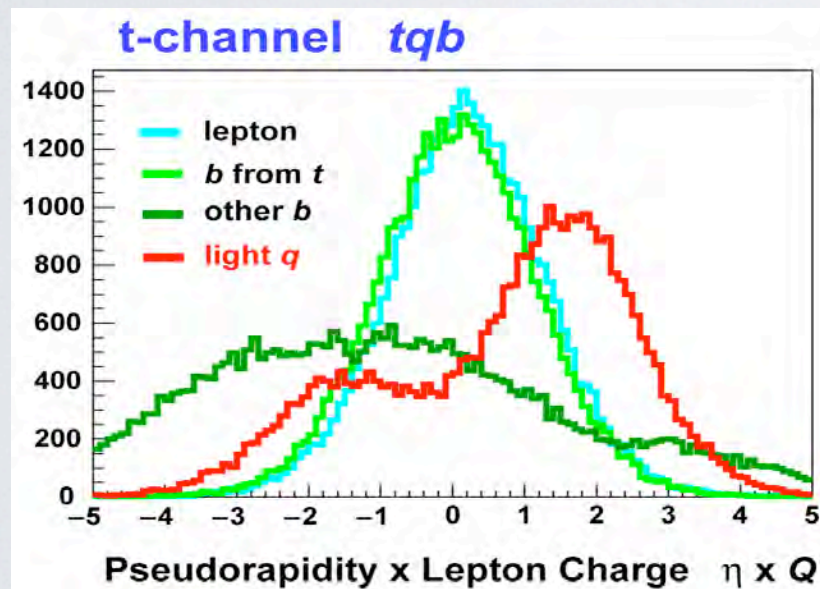
$$\sigma_{\text{SM}} = 2.26 \pm 0.12 \text{ pb}$$

Multivariate Analysis

- **Exploit kinematic differences between signal and background. Three Multivariate Analysis Techniques are used to separate signal from background. Combined different distribution with some discrimination power in one variable with larger discrimination.**



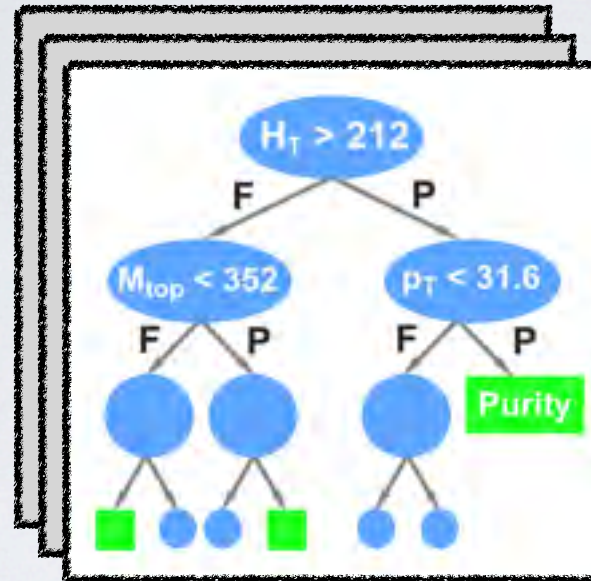
Even though final states of signal and background are consistent of the same particle types, MVA can extract the signal due to characteristics shape of variables with high discriminating power.



Multivariate Techniques Used

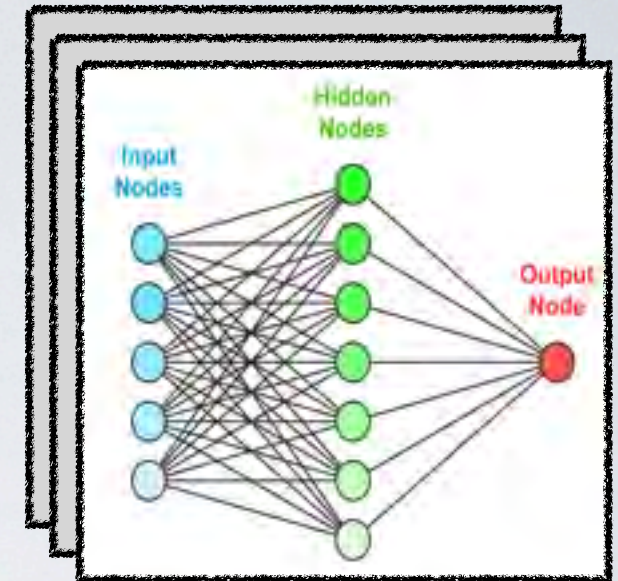
Boosted Decision Tree (BDT)

- Apply sequential cuts keeping failing events.
- Performance is boosted by averaging multiple tree produced by enhancing misclassified events.



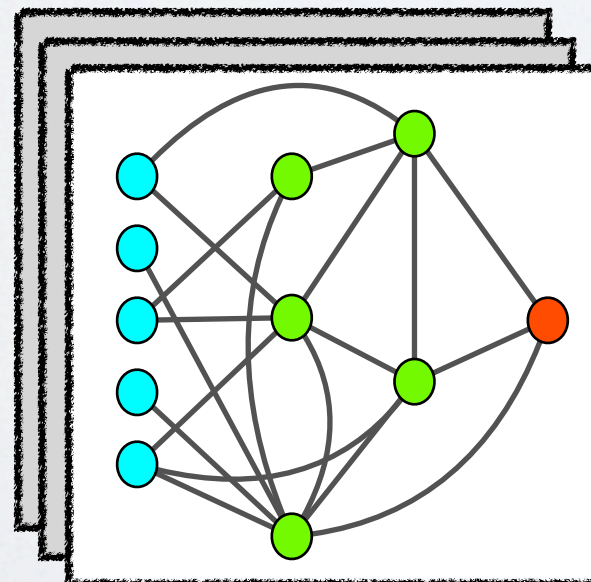
Neural Networks (NN)

- NN train on signal and background, producing one output discriminant.
- Bayesian NN (BNN) average over many networks, improving the performance.



Neuroevolution of Augmenting Topologies (NEAT)

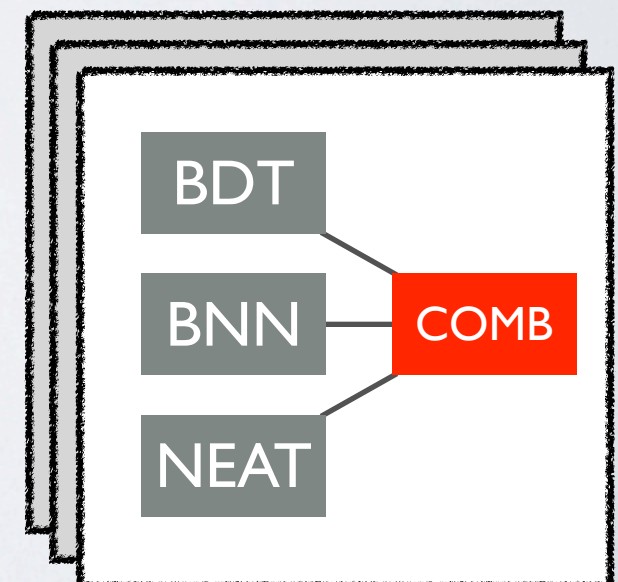
- Genetic algorithms evolve a population of NN.
- Topology of the NN is also part of the training.



BNN Combination

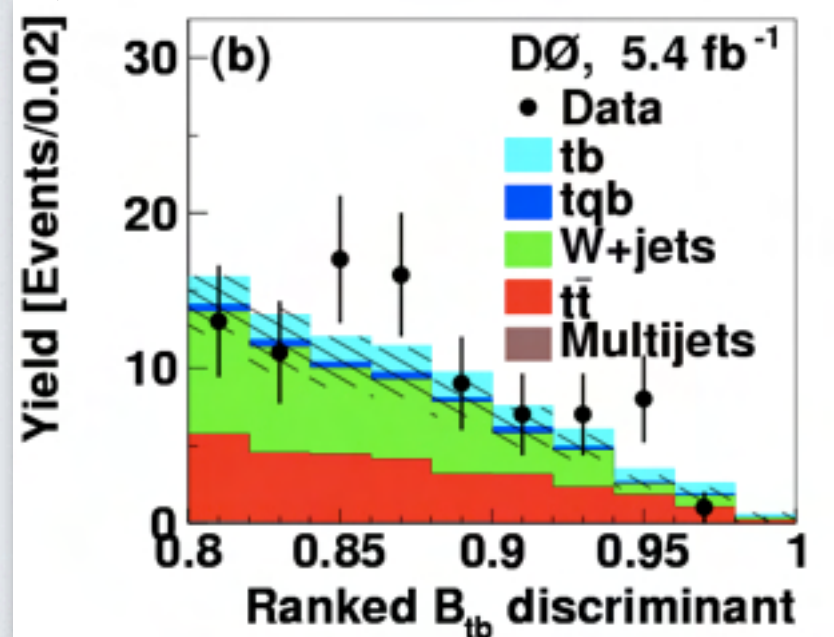
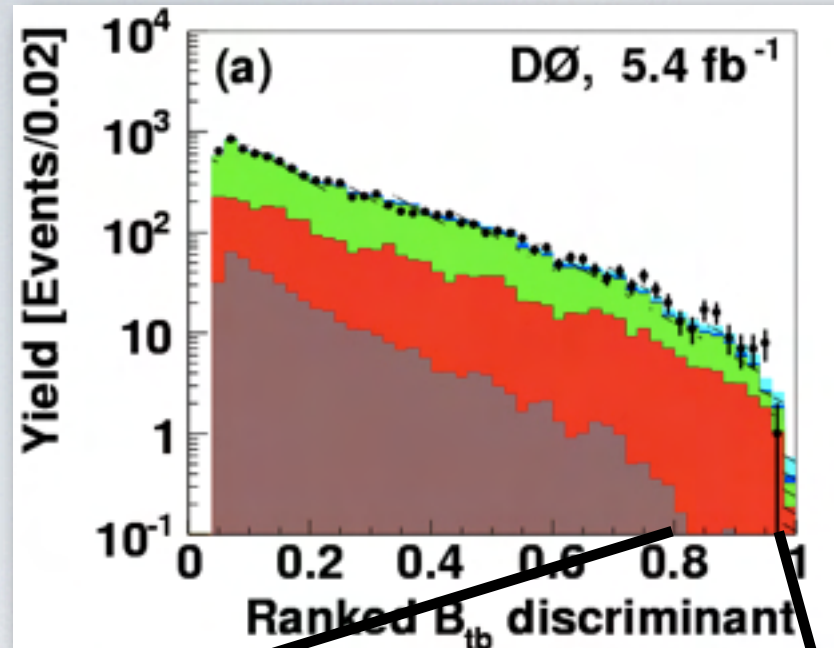
Correlation
between methods
~58-85%

- Different discriminant are combined in one.

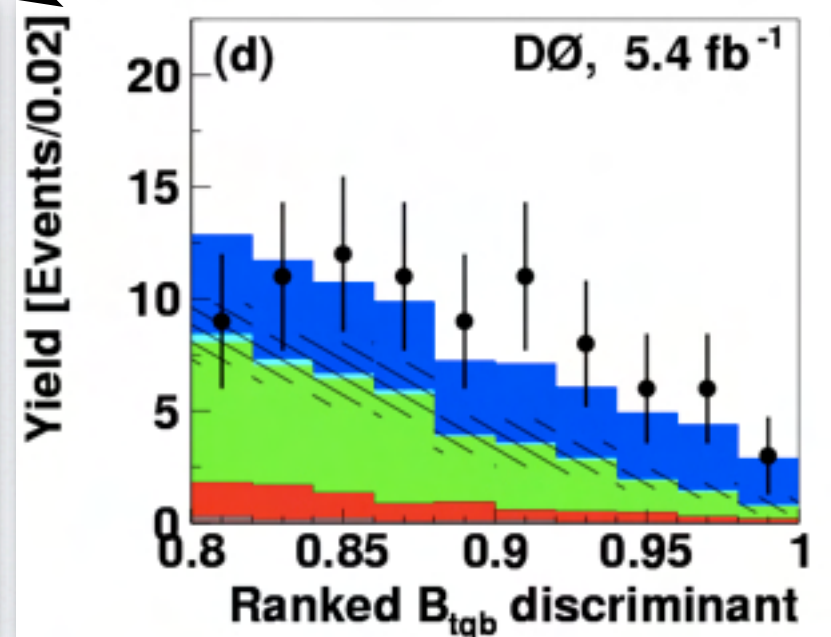
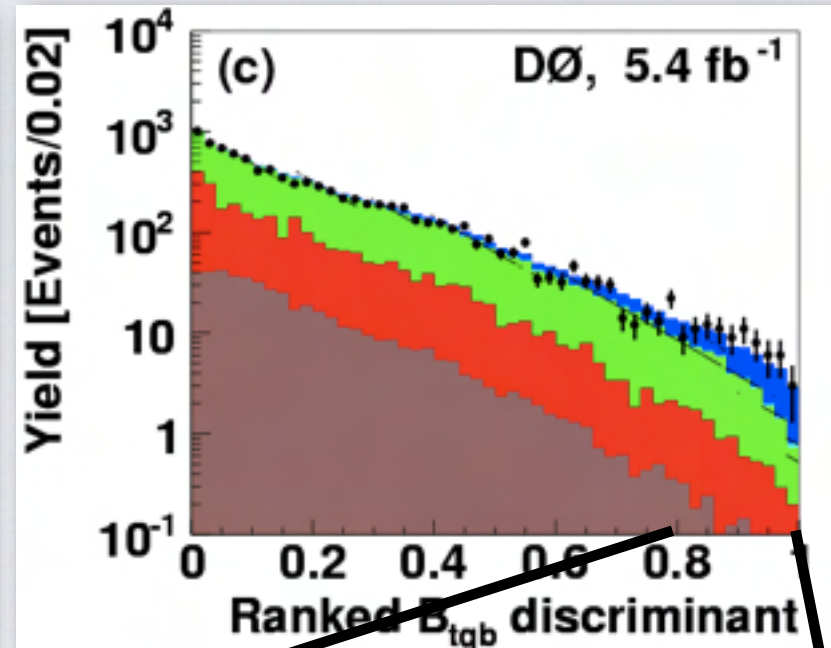


Single top discriminants

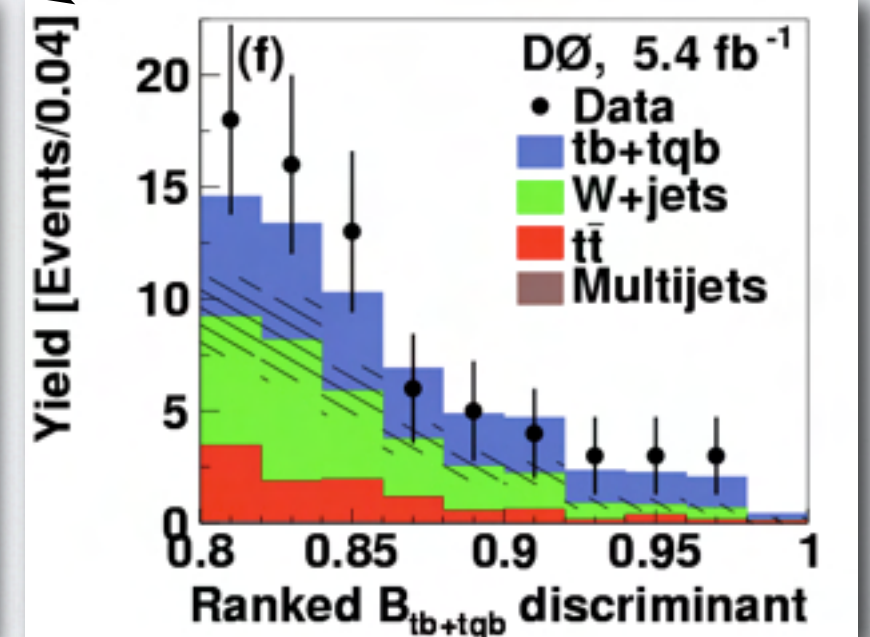
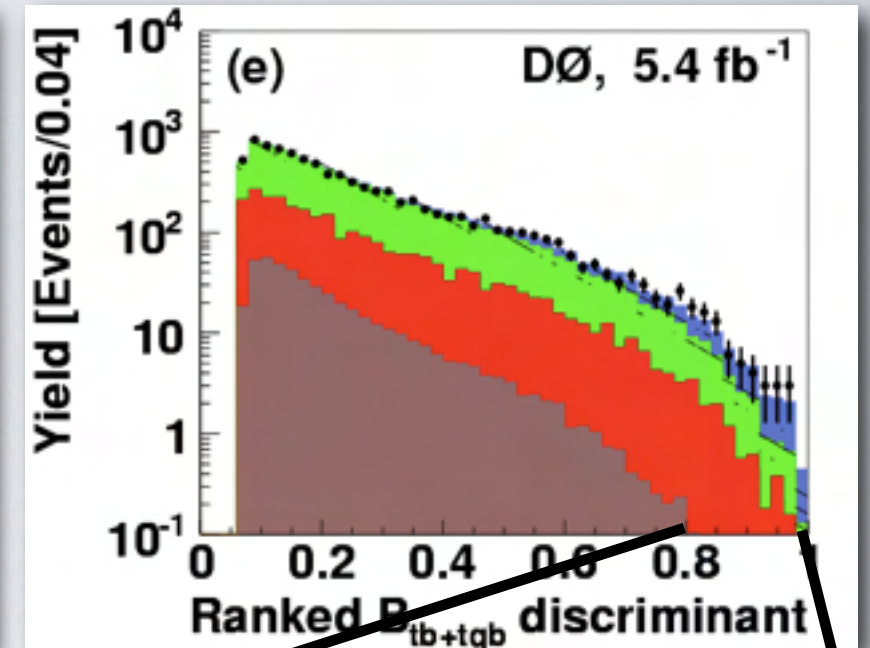
**s-channel
discriminant**



**t-channel
discriminant**



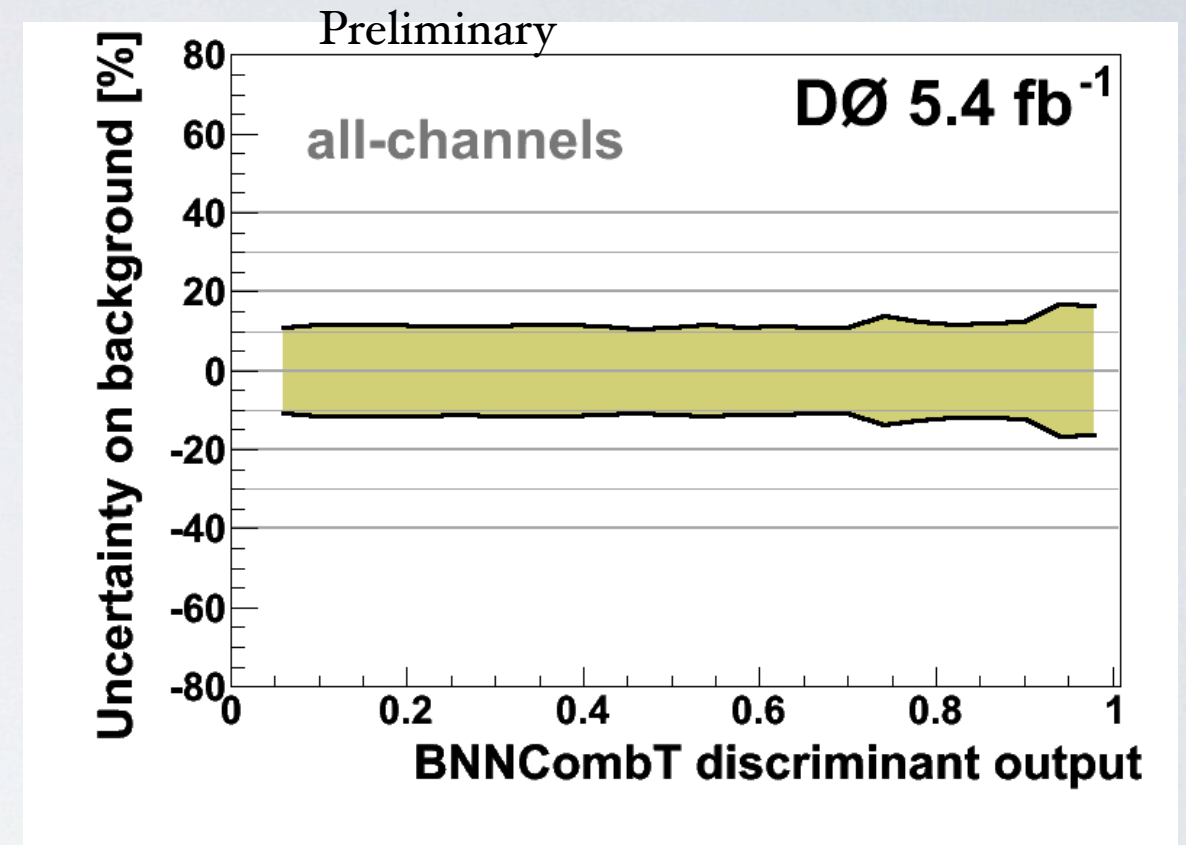
**s+t-channel
discriminant**



Systematic Uncertainties

Main Sources of systematic uncertainties :

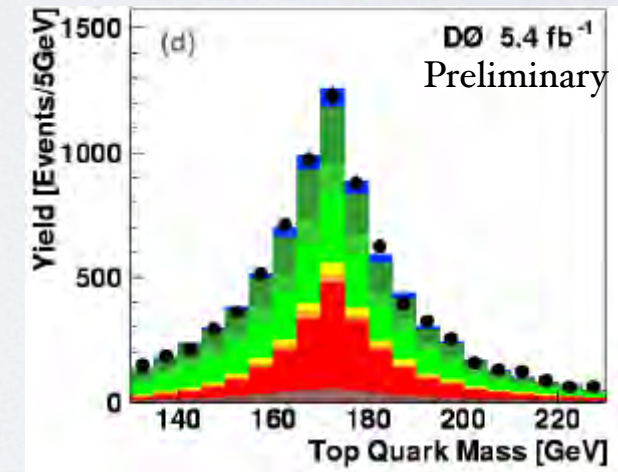
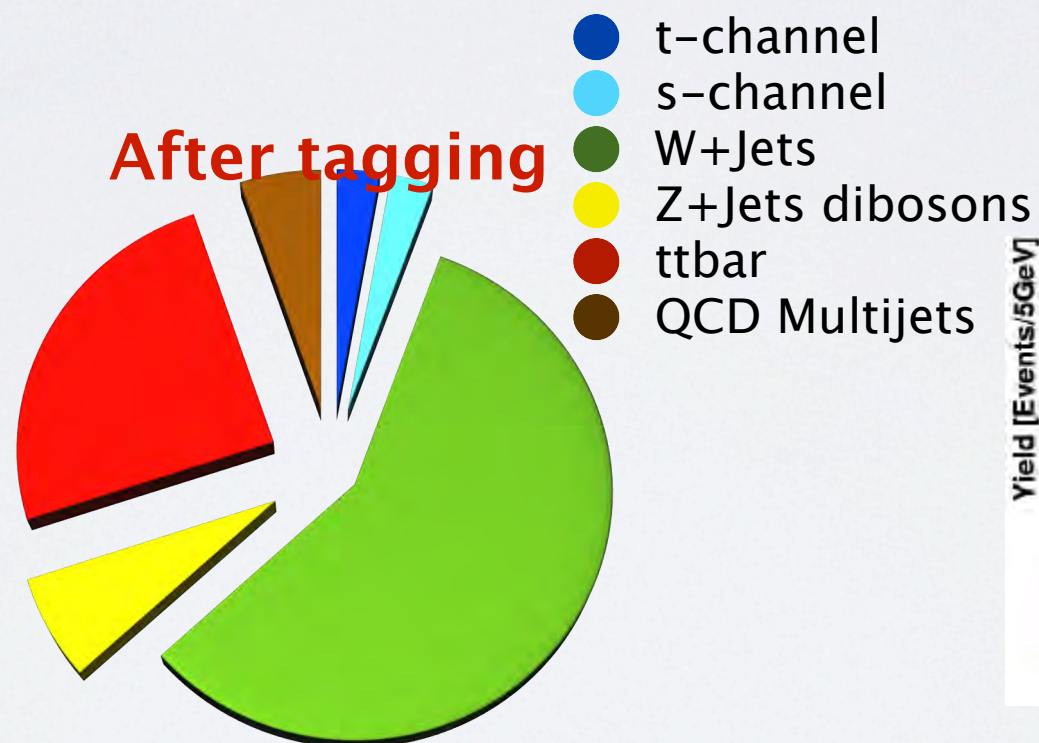
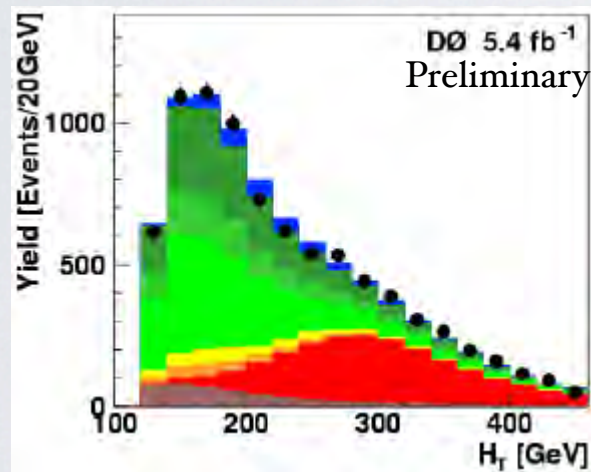
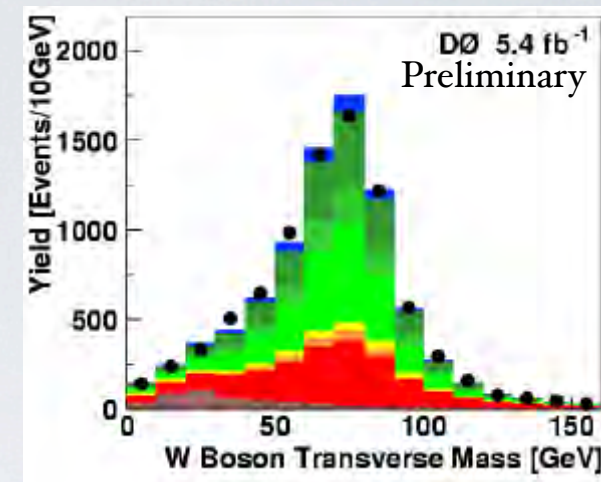
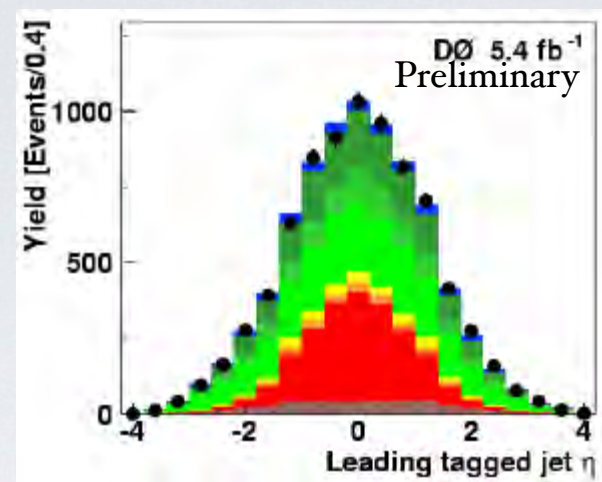
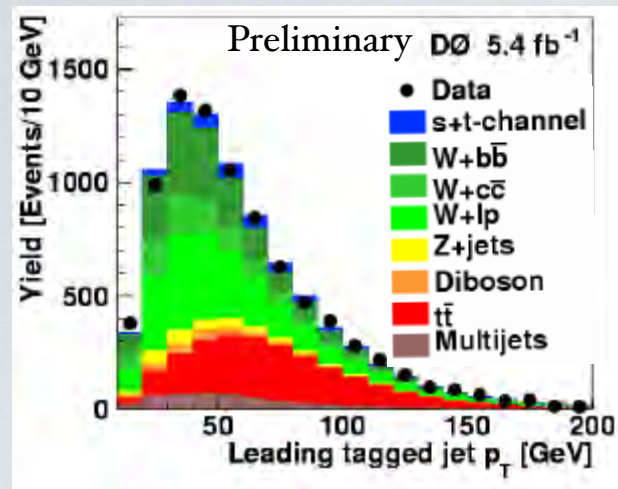
- * Jet Energy Scale ($< 15\%$)
- * Jet Energy Resolution ($< 12\%$)
- * W +jets heavy flavor scale factor (12%)
- * Taggability and B-tagging
- * Integrated Luminosity (6%)



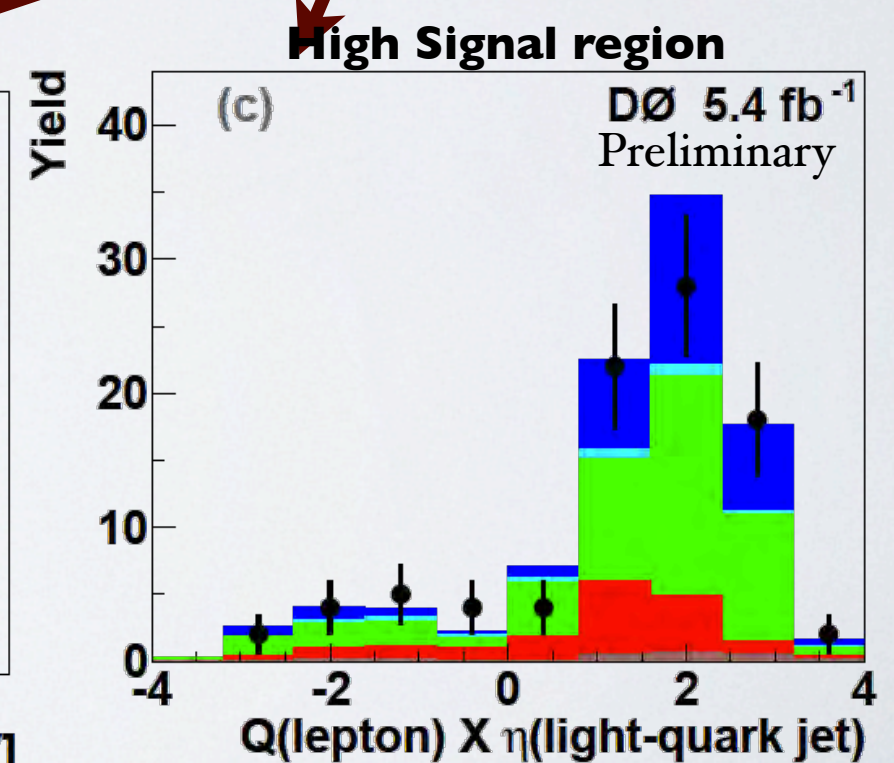
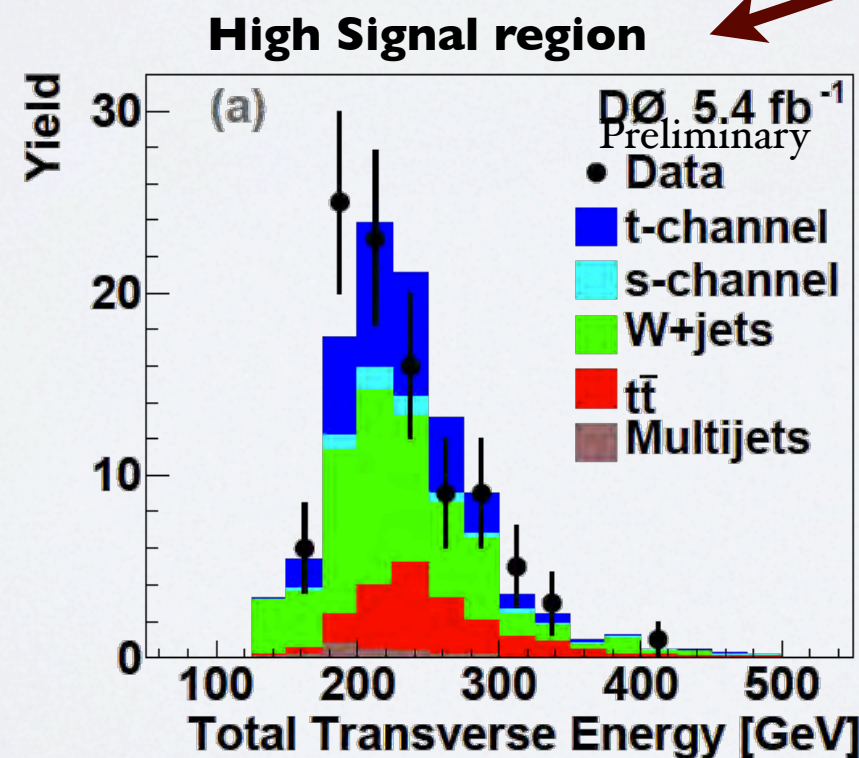
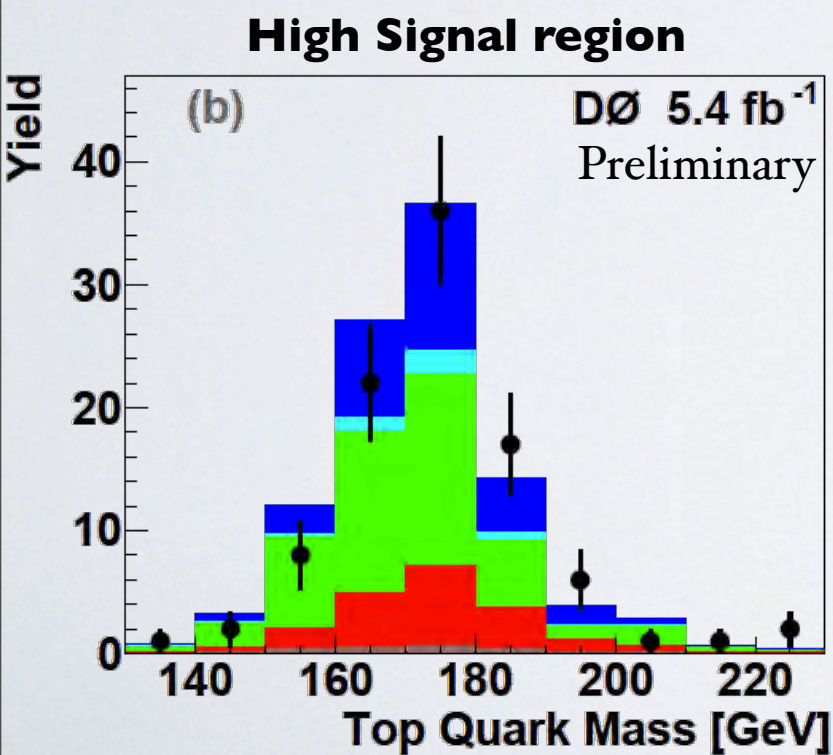
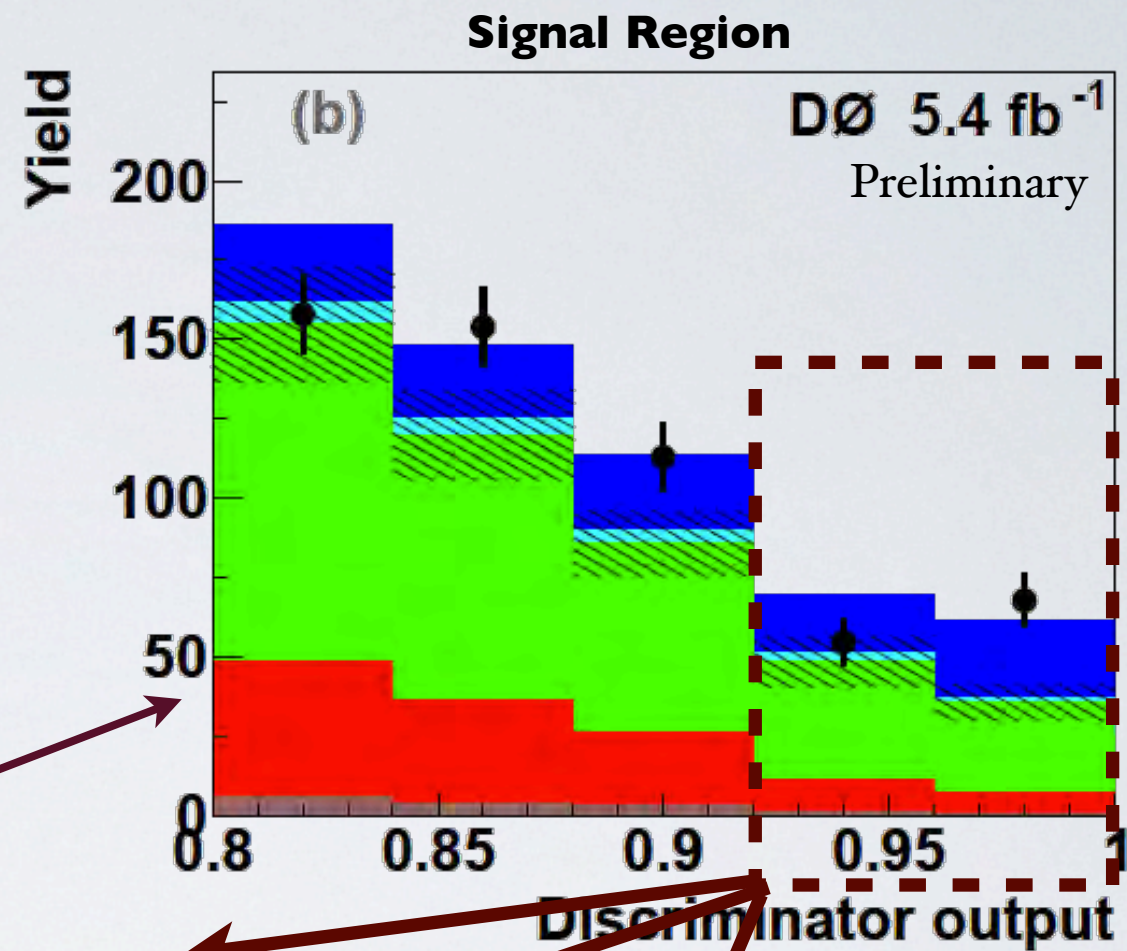
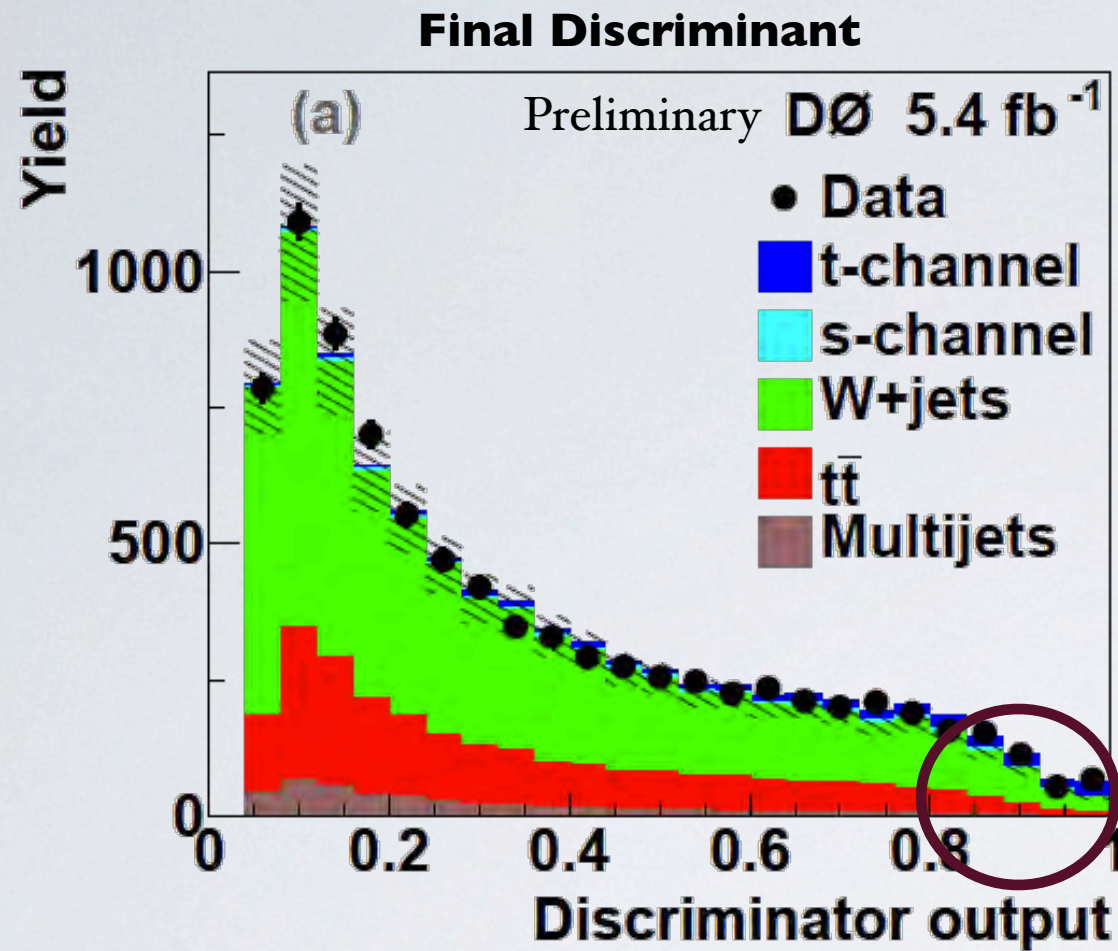
Other Source of uncertainties :

- * Color reconnection (1%)
- * Relative b/light-jet calorimeter response ($< 1\%$)
- * Higher order jet fragmentation effects (few % for $t\bar{t}$)

Background Modeling after tagging



More Results

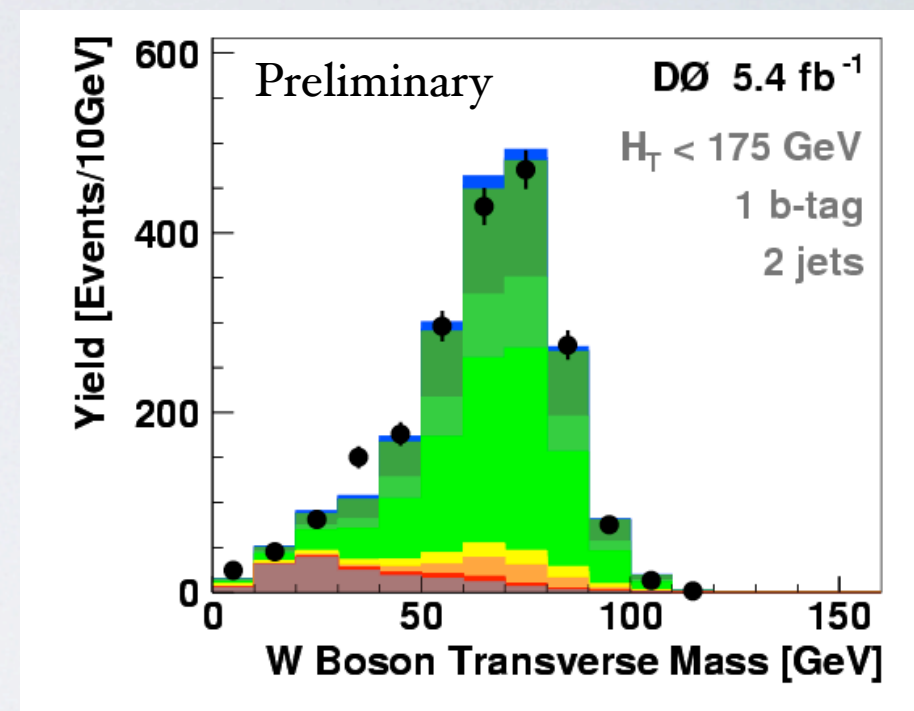


Cross-Checks

Crosscheck to see if background model reproduces the data in regions dominated by one type of background for both electron and muon channels.

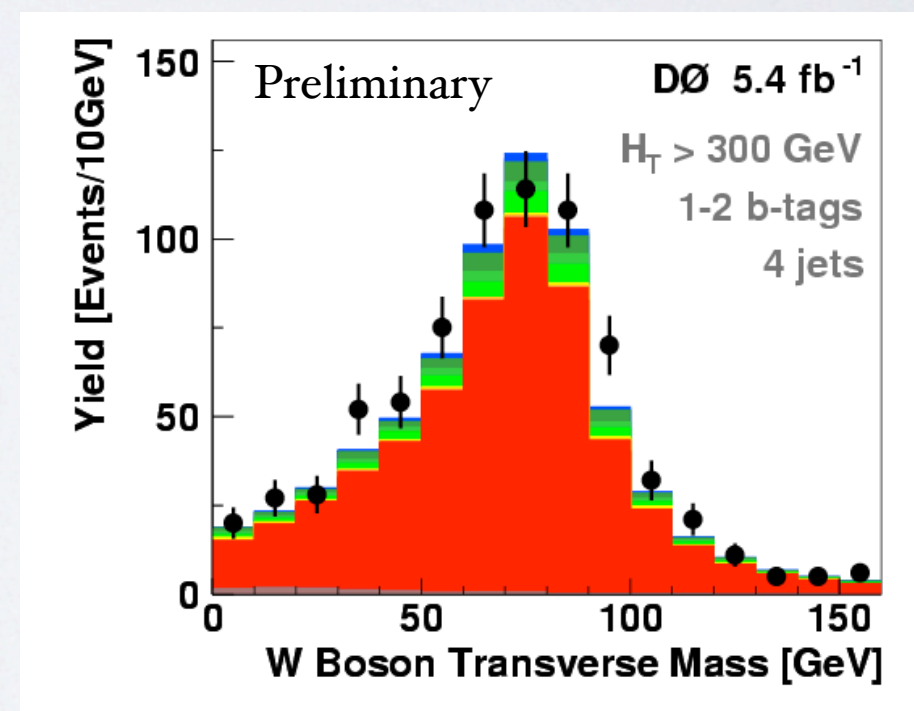
- * “W+jets” sample
 - Exactly 2 jets
 - $H_T < 175$ GeV
 - 1 b-tagged jet

For w+jets sample, w+jets events form **82%** of the sample and ttbar events form less than 2%.



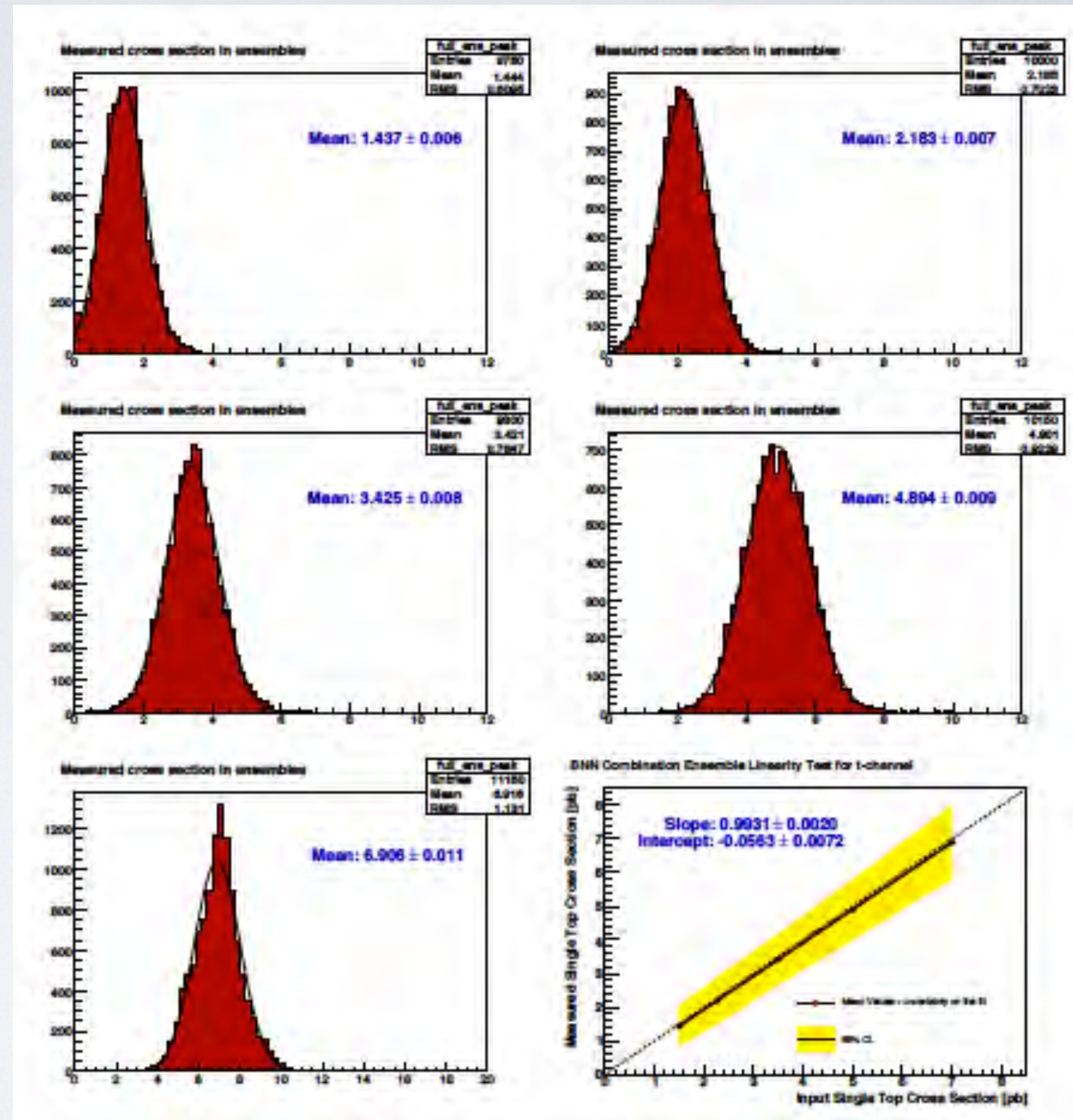
- * “TTbar” sample
 - Exactly 4 jets
 - $H_T > 300$ GeV
 - 1 or 2 b-tagged jets

For ttbar sample, ttbar events form **84%** of the sample and w+jets events form only 12%.



Linearity Test for Comb. t-channel

To check for potential biases that can be introduced in the measured cross-section, we generate a set of ensembles of pseudo-datasets from pool of background events for different signal cross section values. Gaussian has been fitted over the peak of all distribution and a linear fit is done to measured cross-section (which is taken as a mean and error of the fitted gaussian) vs. input signal cross-section.



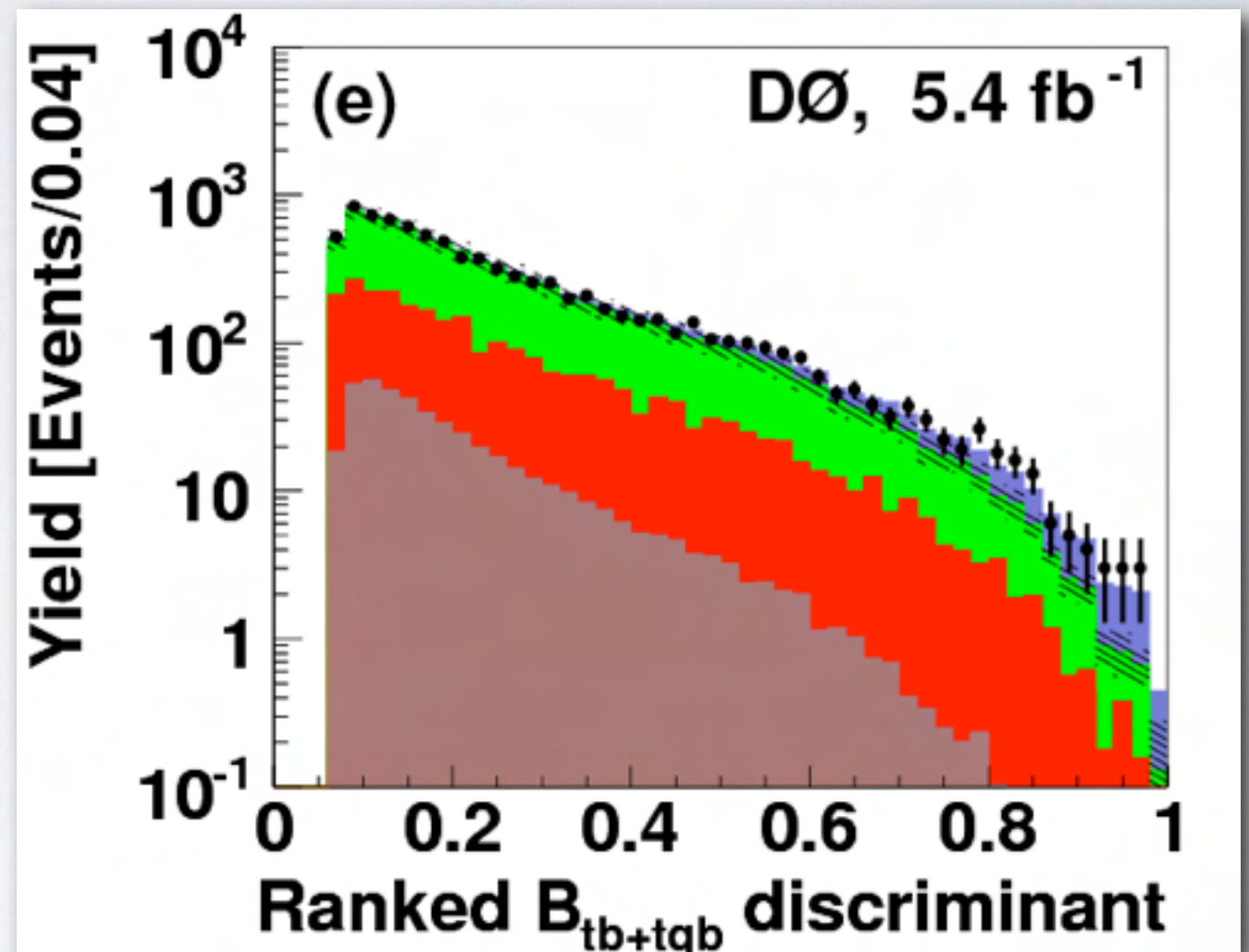
Cross Section Measurement

Binned likelihood

$$L(\mathbf{D}|\mathbf{d}) = \prod_i \frac{e^{-d_i} d_i^{D_i}}{\Gamma(D_i + 1)}$$

Mean event count

$$d = \underbrace{\sigma}_{\text{signal production rate}} \underbrace{a}_{\text{signal acceptances}} + \underbrace{b}_{\text{background event yields}}$$

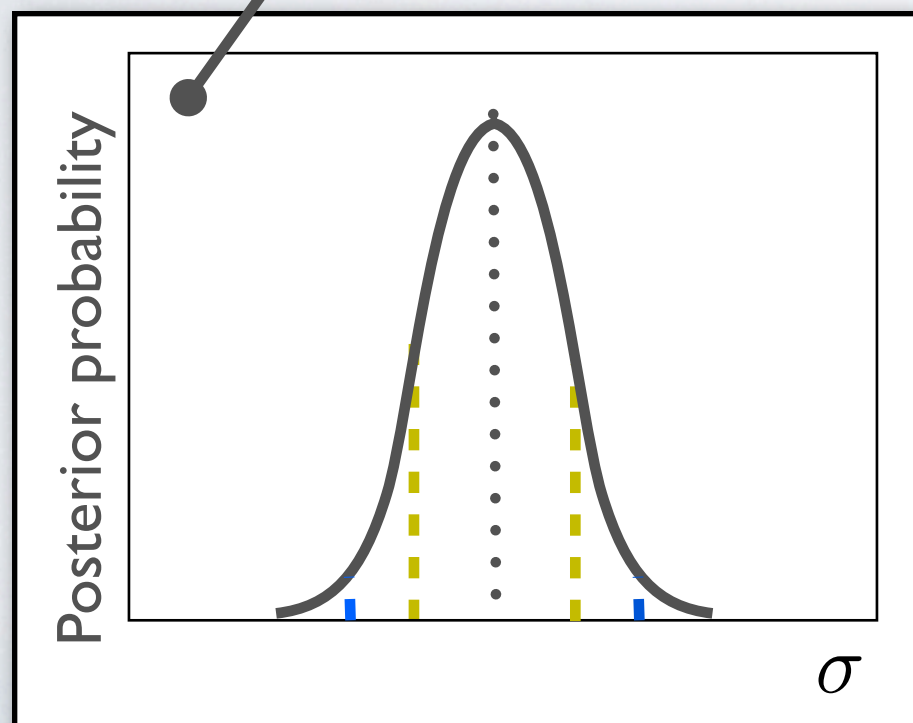


Bayesian Statistical Analysis

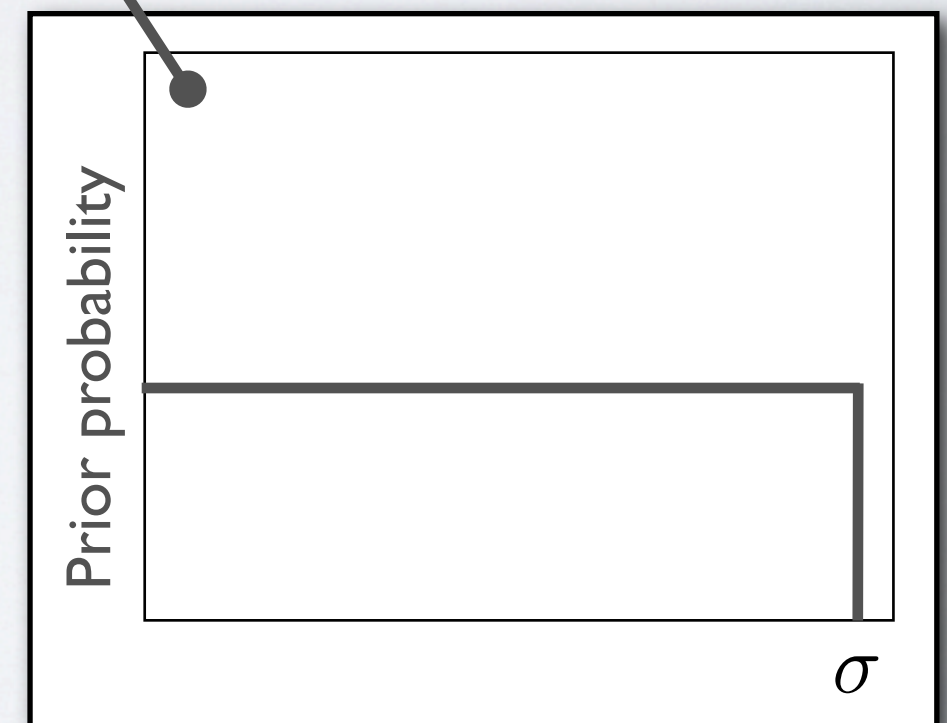
The prior distribution is updated by the likelihood that depends on the data.

Average the likelihood over the background uncertainties assuming Gaussian priors.

$$p(\sigma) = \frac{1}{\mathcal{N}} \int L(\mathbf{D}|\sigma, \mathbf{a}, \mathbf{b}) \pi(\sigma) \pi(\mathbf{a}, \mathbf{b}) d\mathbf{a} d\mathbf{b}$$



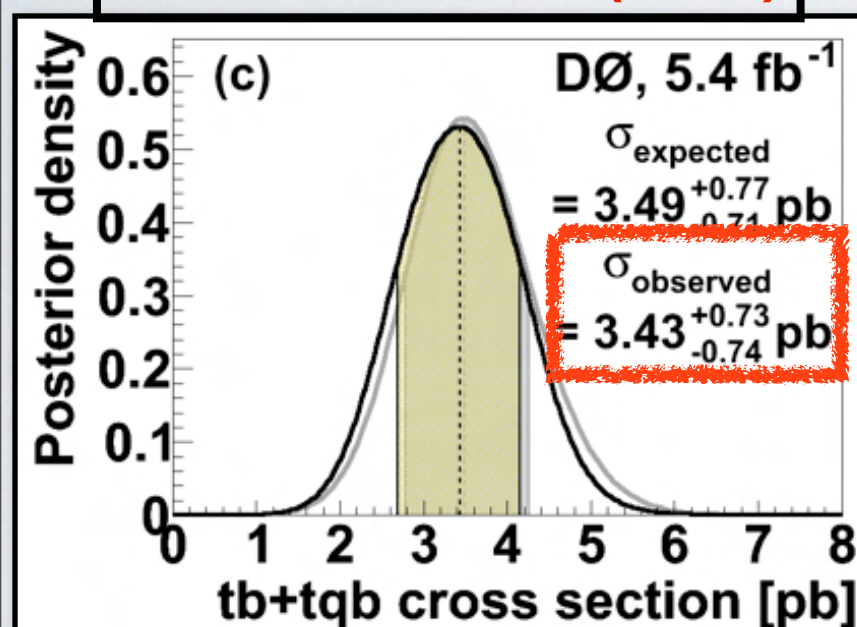
$$L(\mathbf{D}|\sigma, \mathbf{a}, \mathbf{b})$$



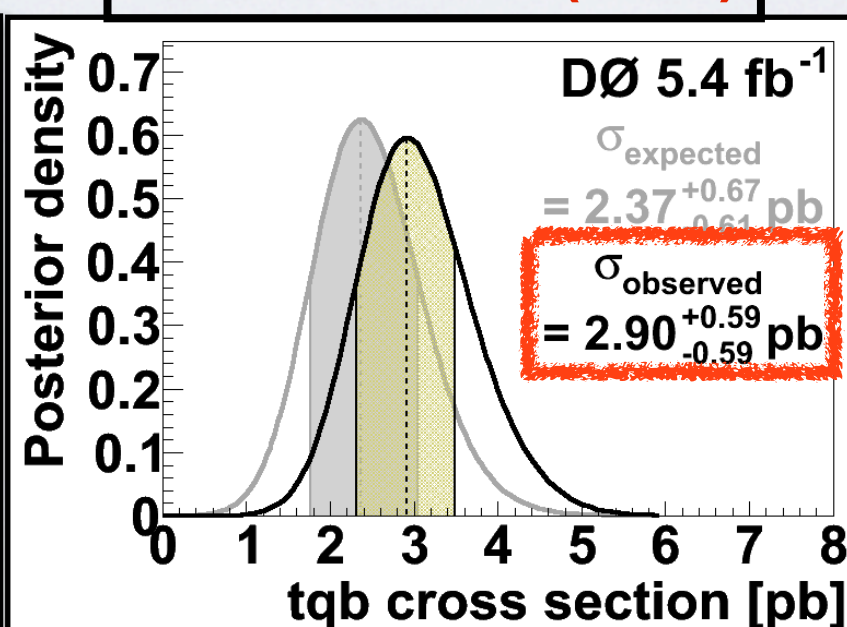
Single top Cross-Section and $|V_{tb}|$ Measurement

- Bayesian posterior probability density is constructed forming a binned likelihood, with the position of maximum = cross section and width of the curve (68% asymmetrical interval) = Uncertainty.
- Same method is applied to search for s-channel single top. The result still has low significance.
- For t-channel cross section measurement, a 2D Bayesian posterior probability density is computed. A 1D Bayesian posterior probability density is obtained by integrating s-channel signal assuming a flat prior. We get a significance of **5.5 sigma** and hence the observation of single top t-channel.

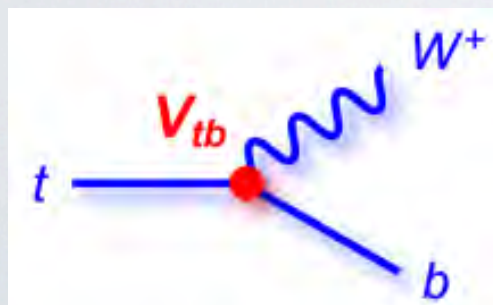
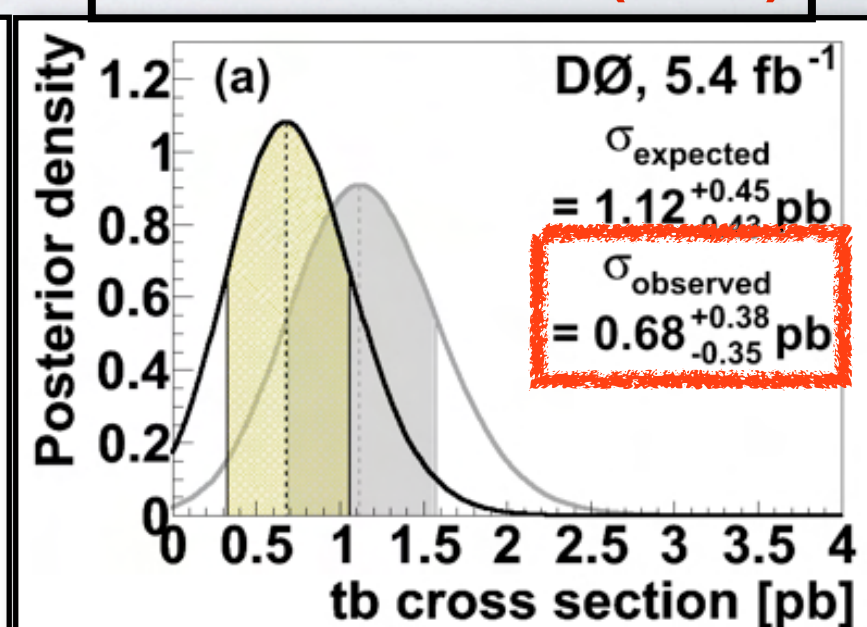
PRD 84, 112001 (2011)



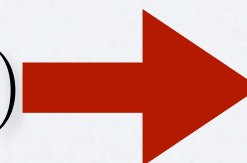
PLB 705, 313 (2011)



PRD 84, 112001 (2011)



$$|V_{tb} f_L^1|^2 \propto \sigma(s + t\text{-channel})$$

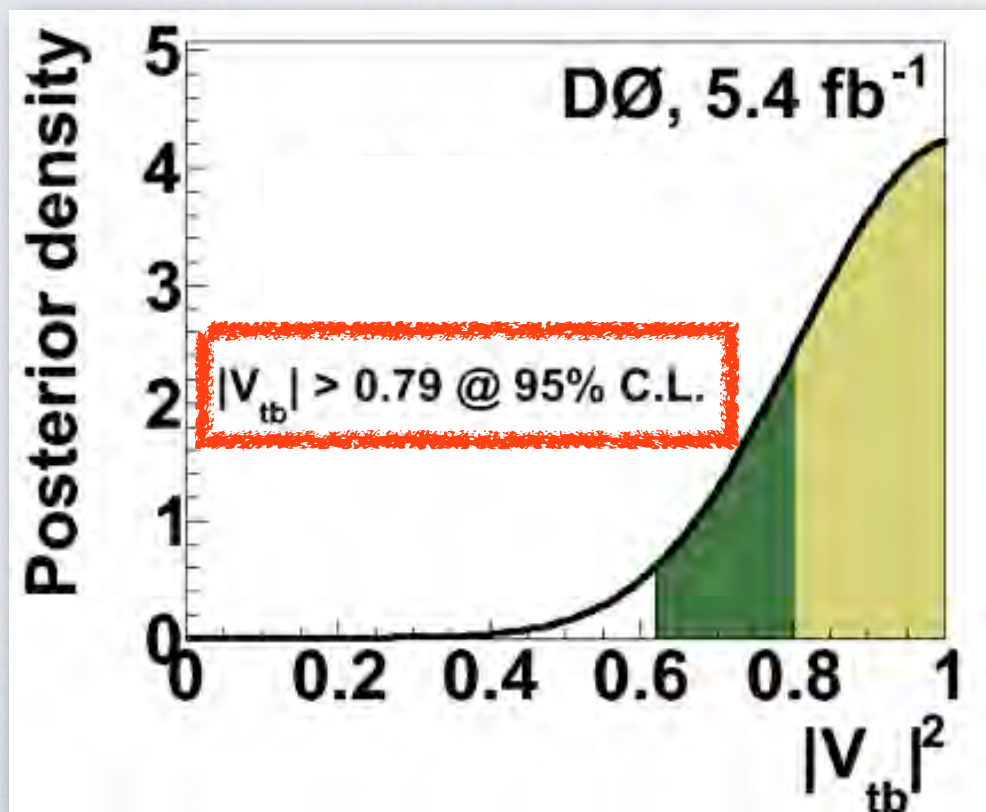
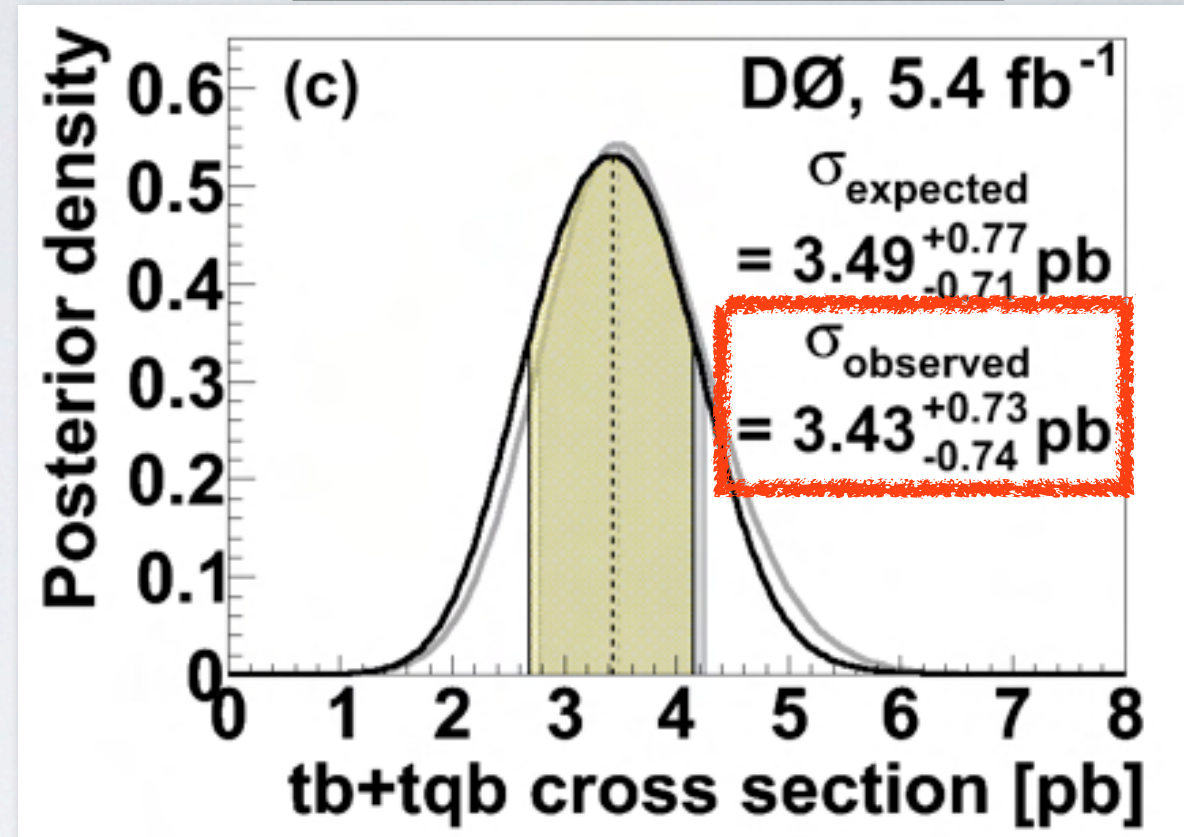


$$|V_{tb}| > 0.79 \text{ @ 95\% C.L.}$$

Single top total Cross-Section and $|V_{tb}|$ Measurement

PRD 84, 112001 (2011)

- Bayesian posterior probability density
 - Binned Likelihood
 - No cut on the discriminant
- Flat, non-negative prior for signal cross section
- Uncertainties and their correlations taken into account
- Measured cross section: Peak
- Uncertainty: Width (68% area)



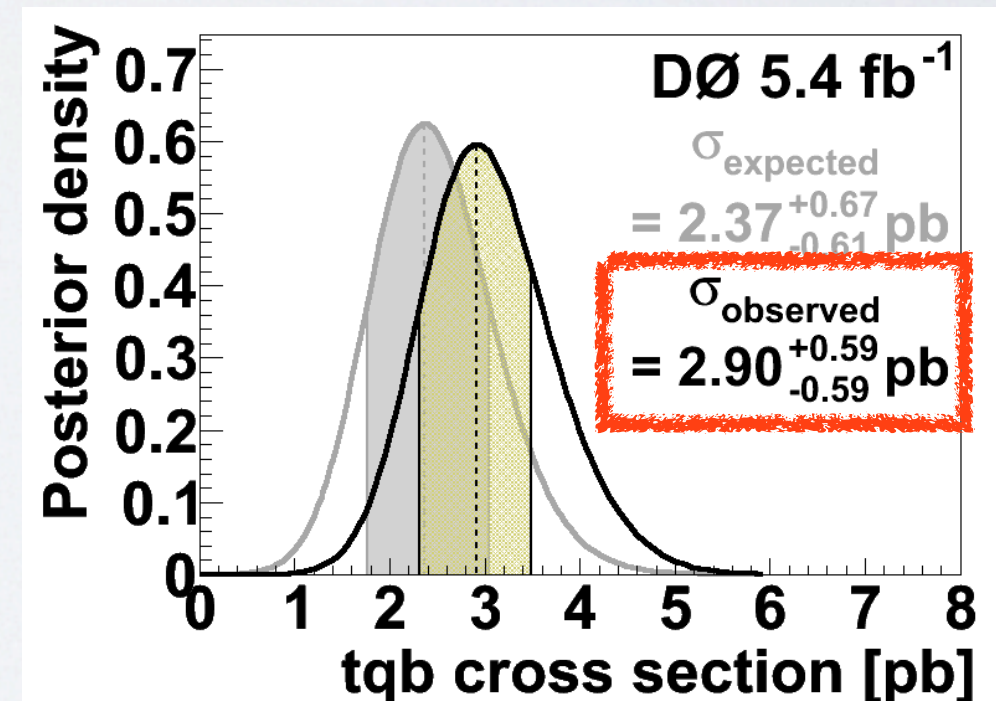
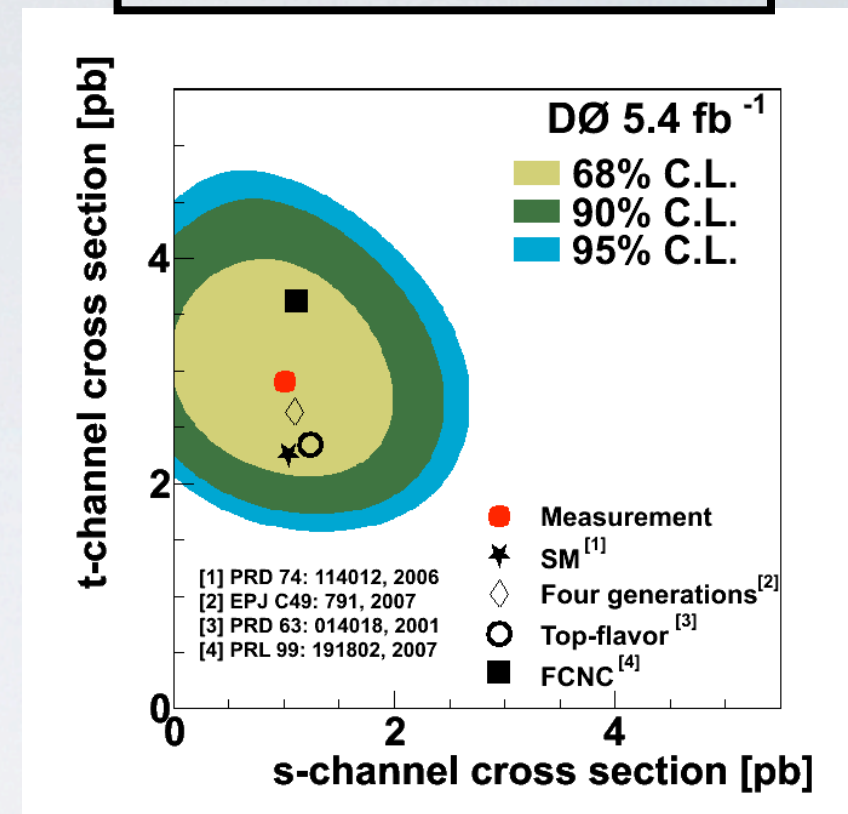
$$|V_{tb} f_L^1|^2 \propto \sigma(s + t\text{-channel})$$

- Measurement assumes SM production mechanisms.
- Pure V-A and CP-conserving interaction.
- $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$.
- Does not assume 3 generations or unitarity of the CKM matrix.

Single top t-channel Cross-Section Measurement

PLB 705, 313 (2011)

- Cross-section measurement is done without assuming SM s-channel. A single discriminant is used to measure the s and t - channels simultaneously.
- A 2D Bayesian posterior probability density is computed.
- A 1D Bayesian posterior probability density is obtained by integrating s-channel signal assuming a flat prior.
- The estimated significance for this result is larger than five standard deviations (5σ).
- The total error of 20% with a systematic uncertainty of 11%.
- The largest uncertainties come from the jet energy scale and resolution, corrections to the b tagging efficiency, and the corrections for the jet flavor composition in W +jets events.

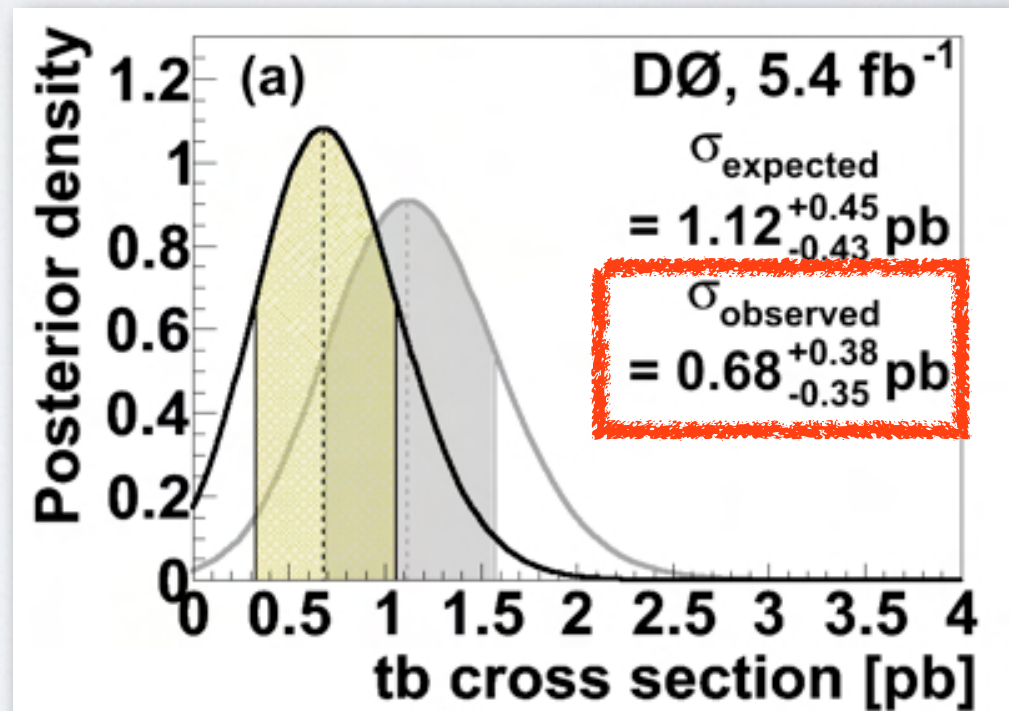
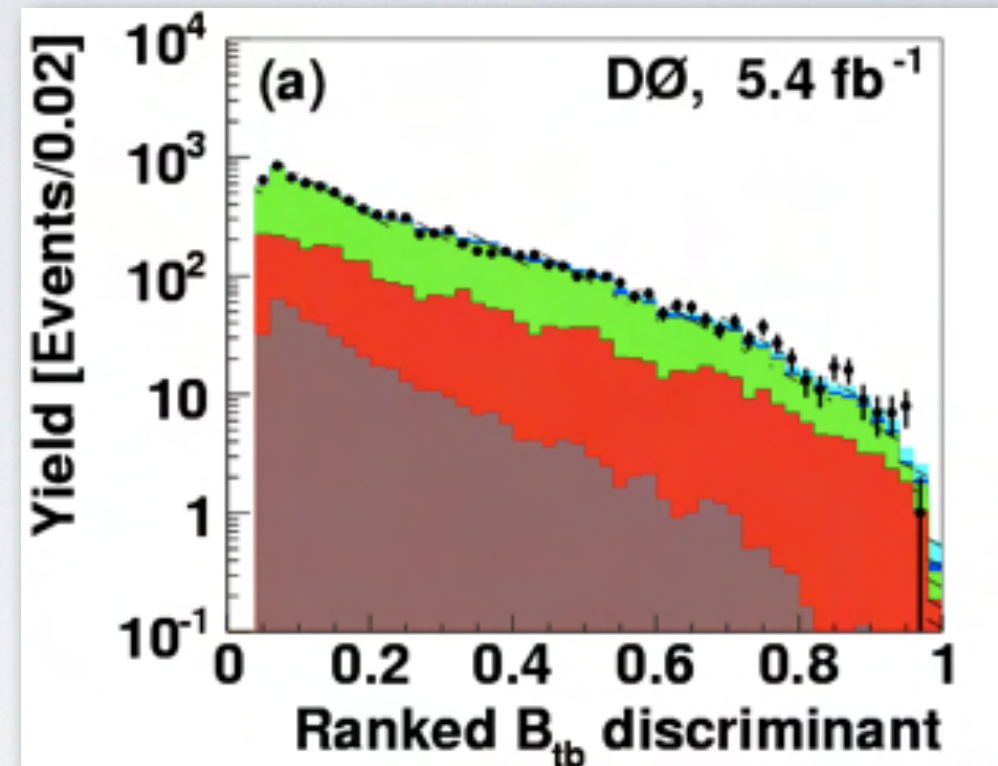


Search for single top s-channel

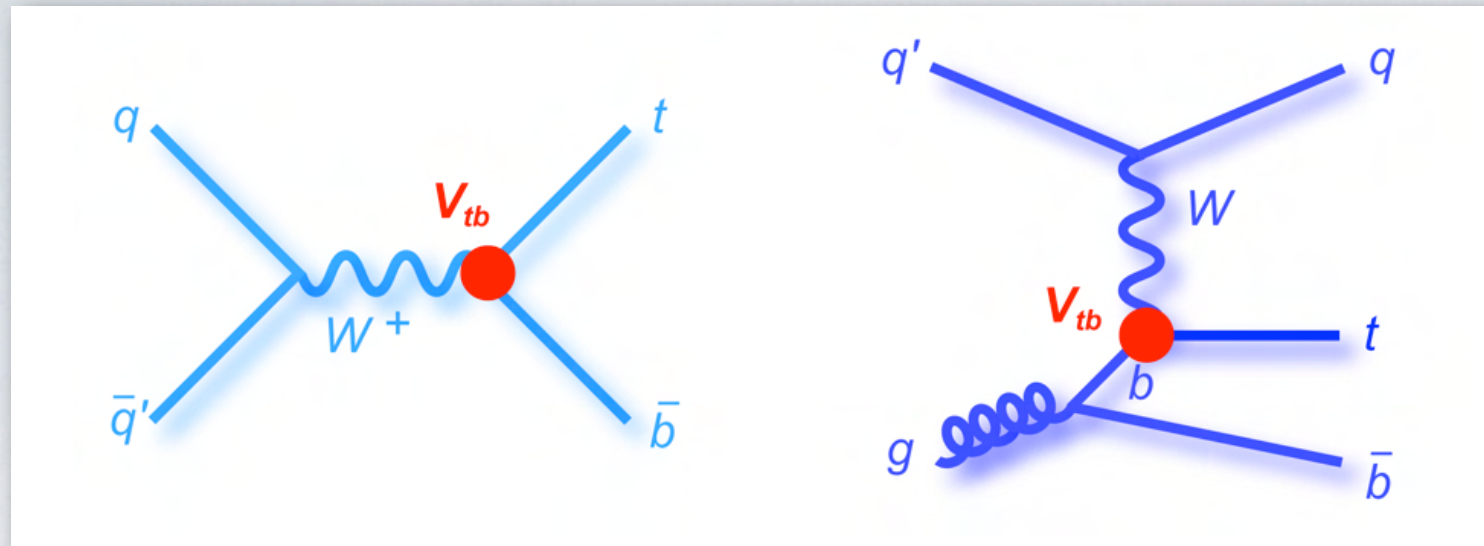
- Same method is applied to search for s-channel single top.
- The result still has low significance.

$$\sigma(s\text{-channel}) = 0.68^{+0.38}_{-0.35} \text{ pb}$$

PRD 84, 112001 (2011)



Anomalous Wtb Couplings in single top production



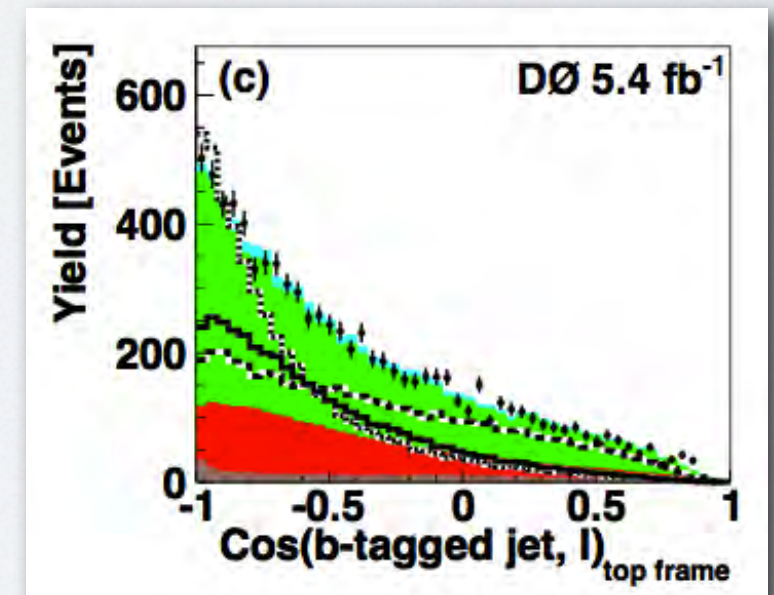
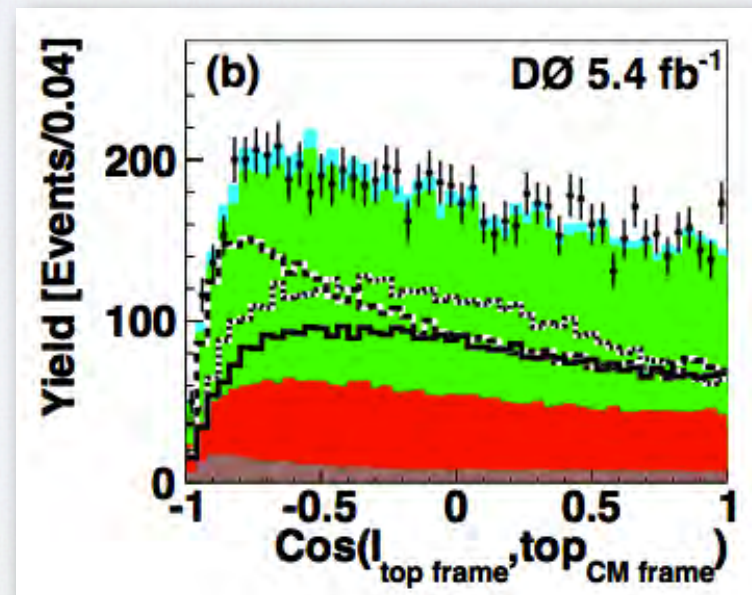
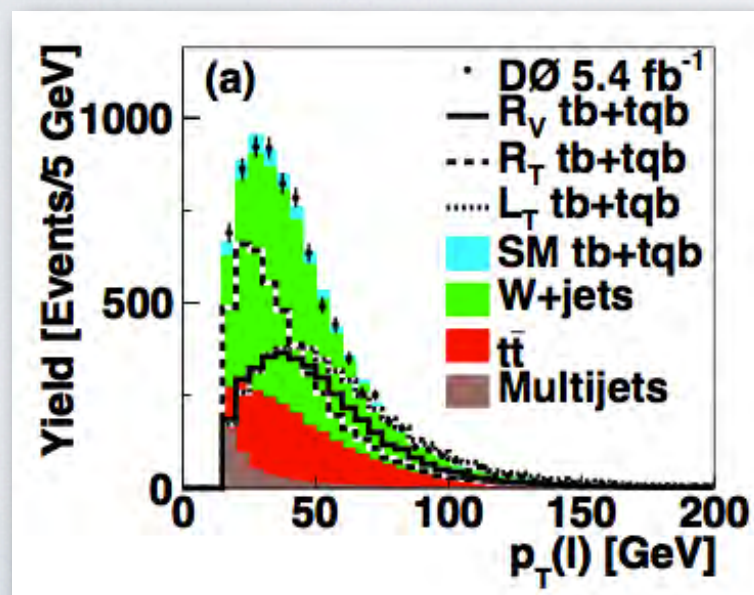
Anomalous right-handed vector (R_V) and left- (L_T) and right-handed (R_T) tensor couplings.

$$\mathcal{L} = -\frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (L_V P_L + R_V P_R) t W_\mu^- - \frac{g}{\sqrt{2}} \bar{b} \frac{i\sigma^{\mu\nu} q_\nu}{M_W} (L_T P_L + R_T P_R) t W_\mu^- + h.c.$$

$$R_V = V_{tb} f_{R_V}$$

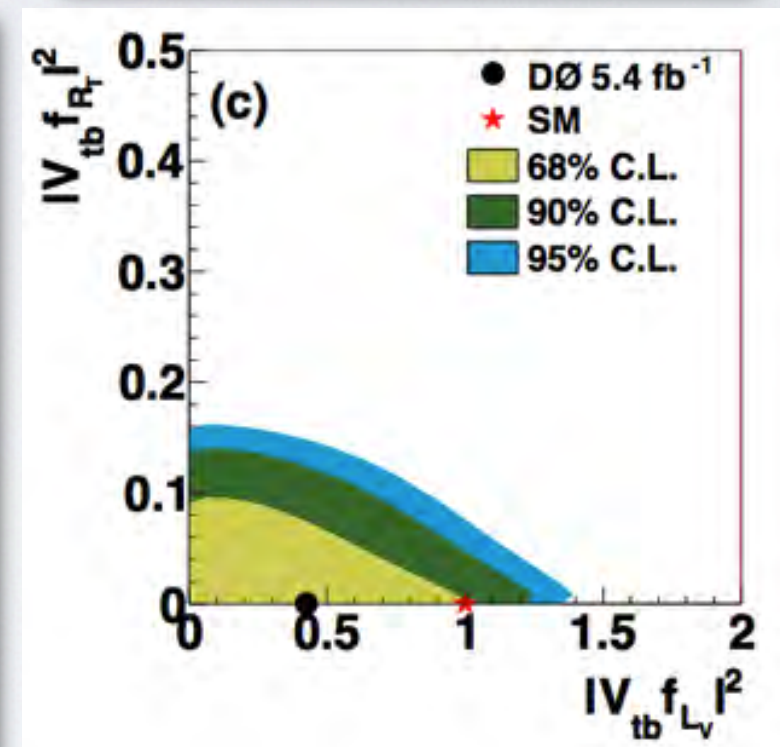
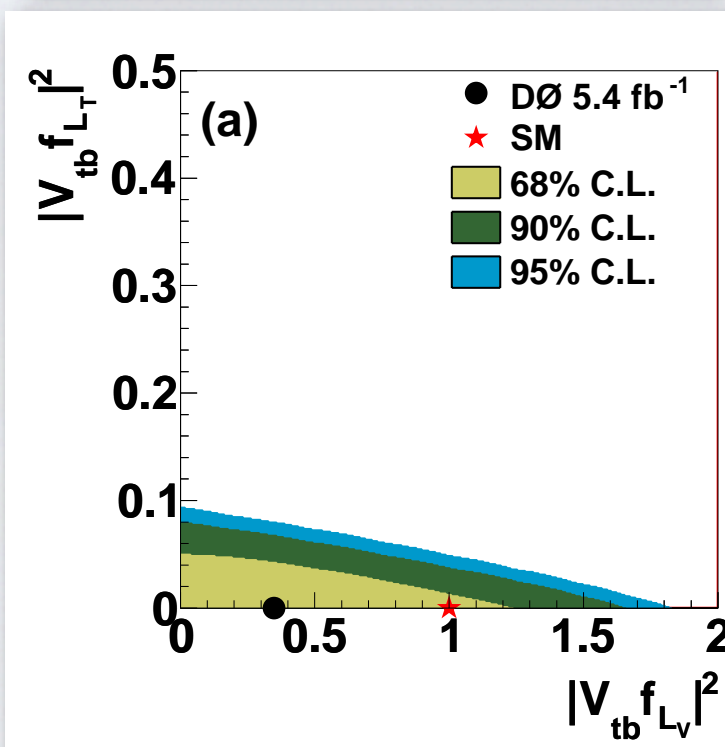
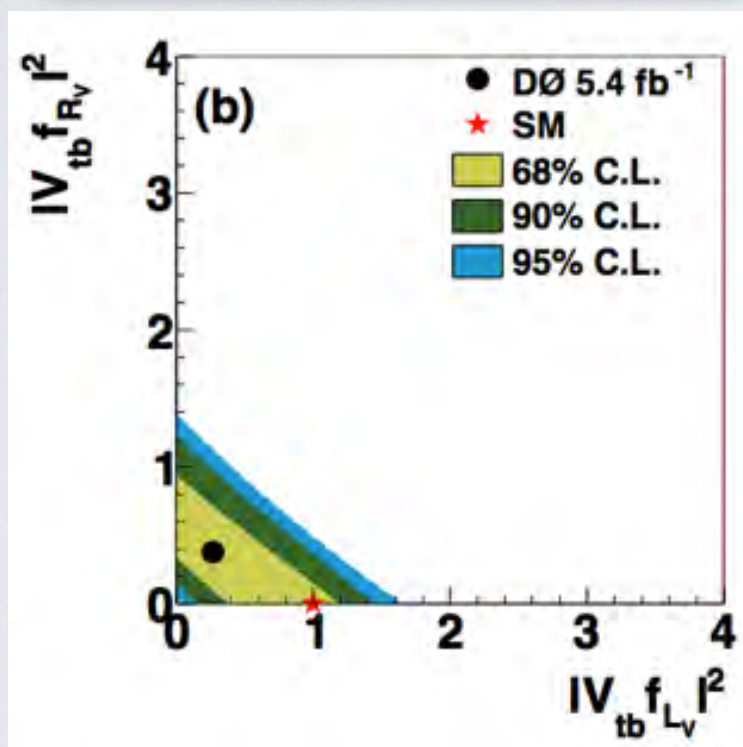
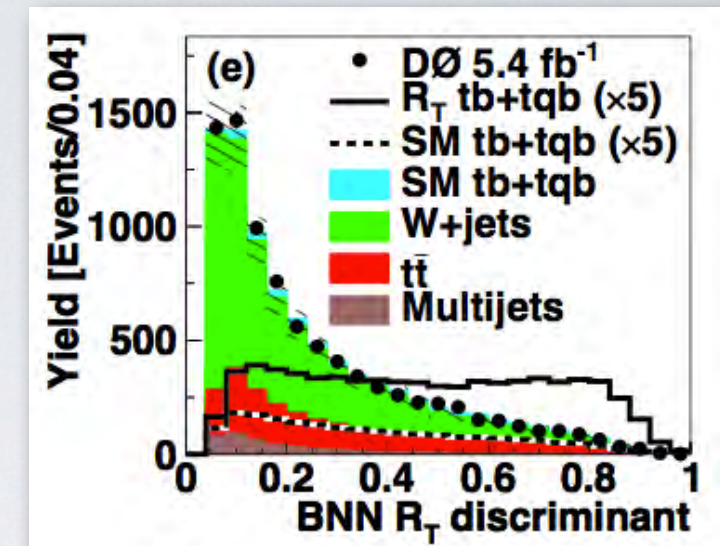
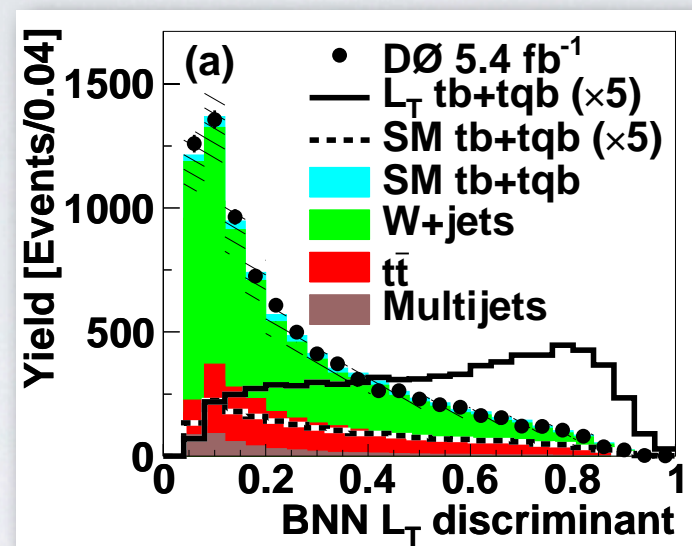
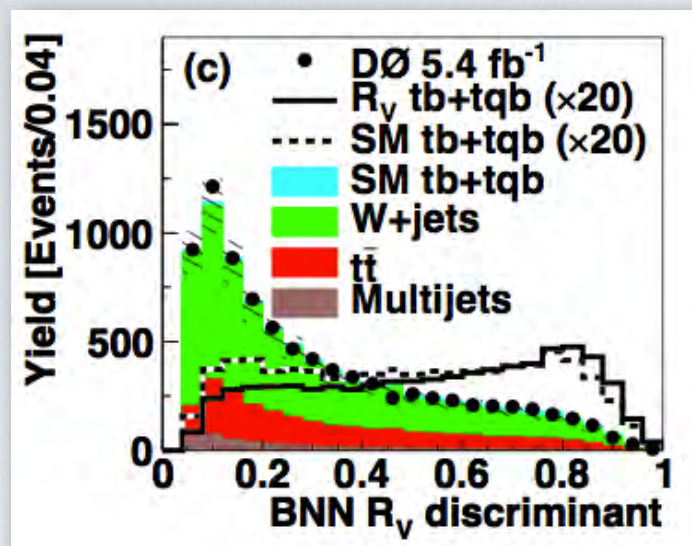
$$L_T = V_{tb} f_{L_T}$$

$$R_T = V_{tb} f_{R_T}$$



Limits on R_V , L_T and R_T

BNN is used to discriminate between anomalous single top quark production from background that includes SM single top.



$$|R_V|^2 < 0.93 @ 95\% \text{ C.L.} \quad |L_T|^2 < 0.06 @ 95\% \text{ C.L.} \quad |R_T|^2 < 0.13 @ 95\% \text{ C.L.}$$

PLB 708, 21 (2012)