Measurement of the t-channel single top quark production cross-section at D0

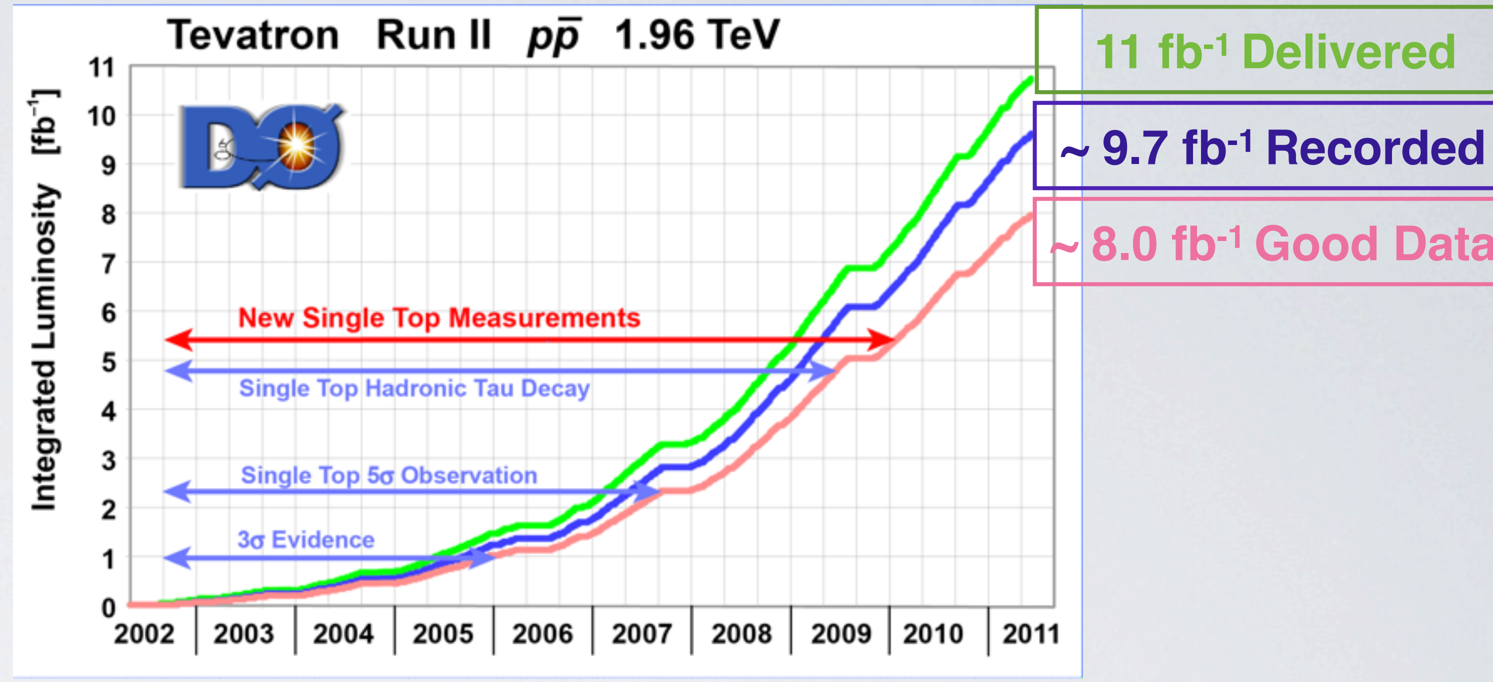
Jyoti Joshi
(Panjab University)
On Behalf of D0 Collaboration

New Perspectives,
31 May, 2011

Outlines :

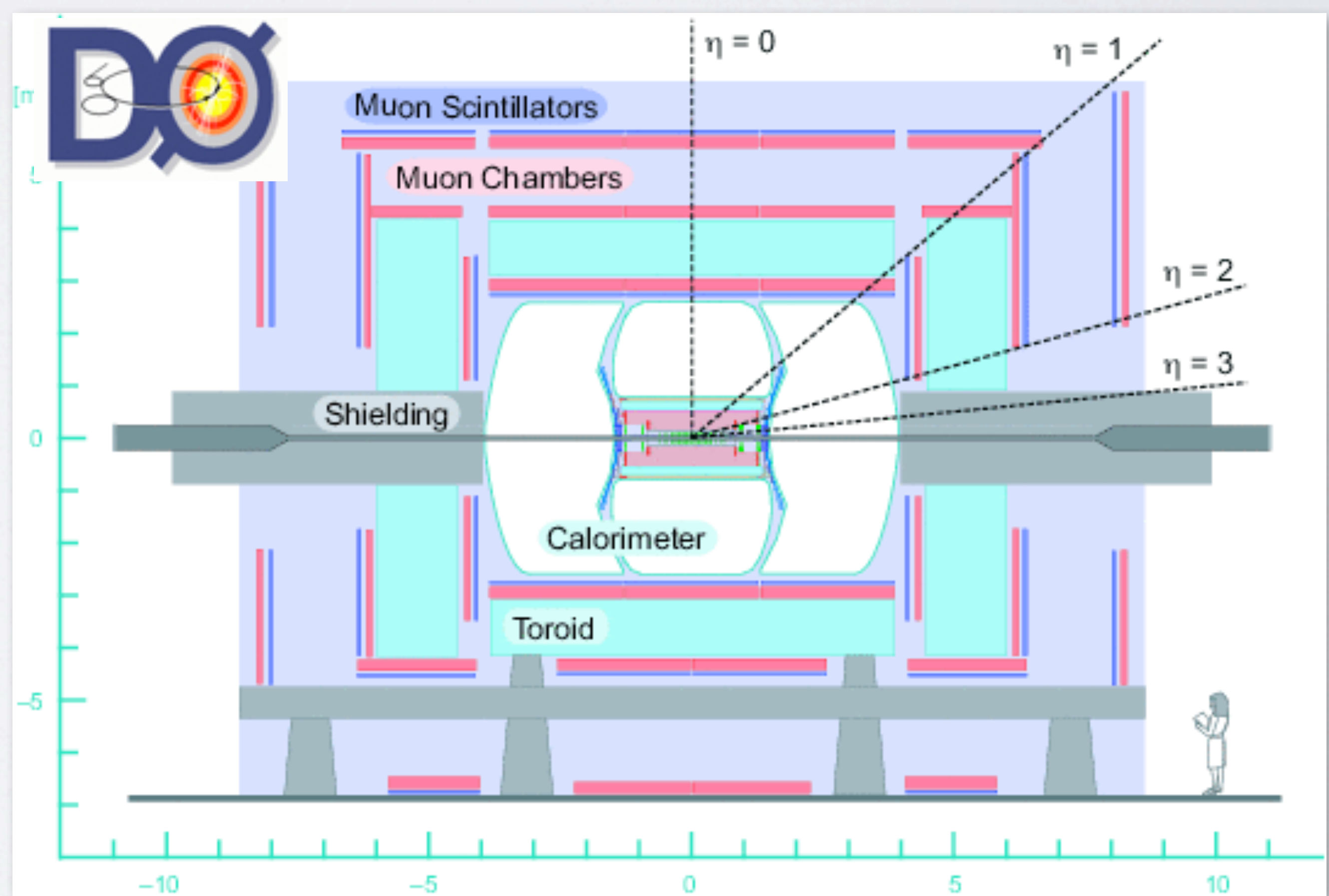
* Tevatron and D0 Detector
* Single Top Production
* Motivations and Challenges involved
* Event Selection
* Signal and background Modeling
* MVA Techniques
* Cross-section Measurement
* Systematic Uncertainties
* Combined Result

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 ~$3 \times 10^{32} cm^{-2} s^{-1}$.
- Target of recording 10 fb^{-1} till the end of this fiscal year.

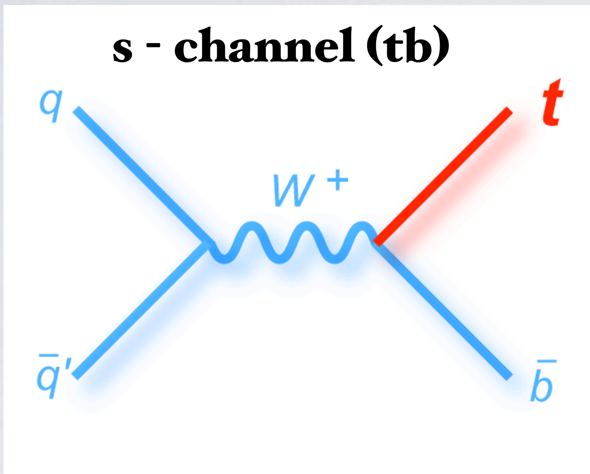


The DØ detector is a multi-purpose particle detector to study interactions originating from proton-antiproton collisions at the Tevatron Collider at Fermilab.

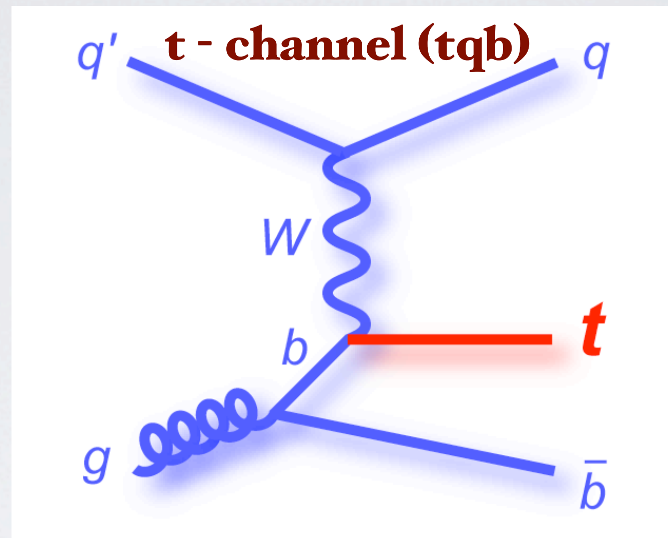
Jyoti Joshi, New Perspectives 2011.

Single Top Quark Production

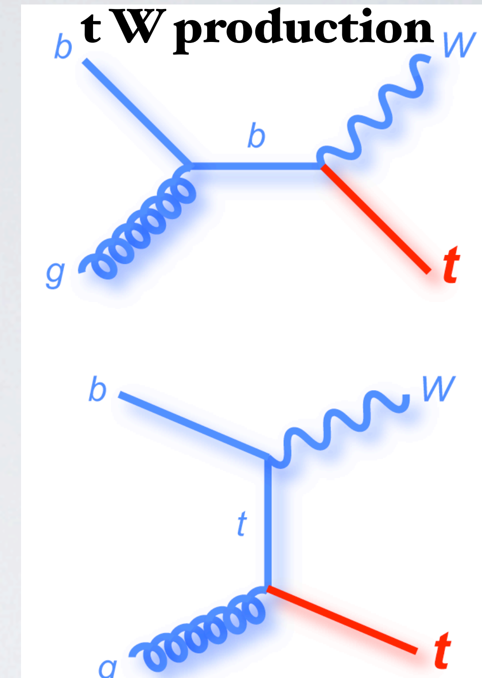
Three modes via which Single Top can be produced in Hadron Colliders.



σ_{SM} = 1.04 ± 0.04 pb



σ_{SM} = 2.26 ± 0.12 pb

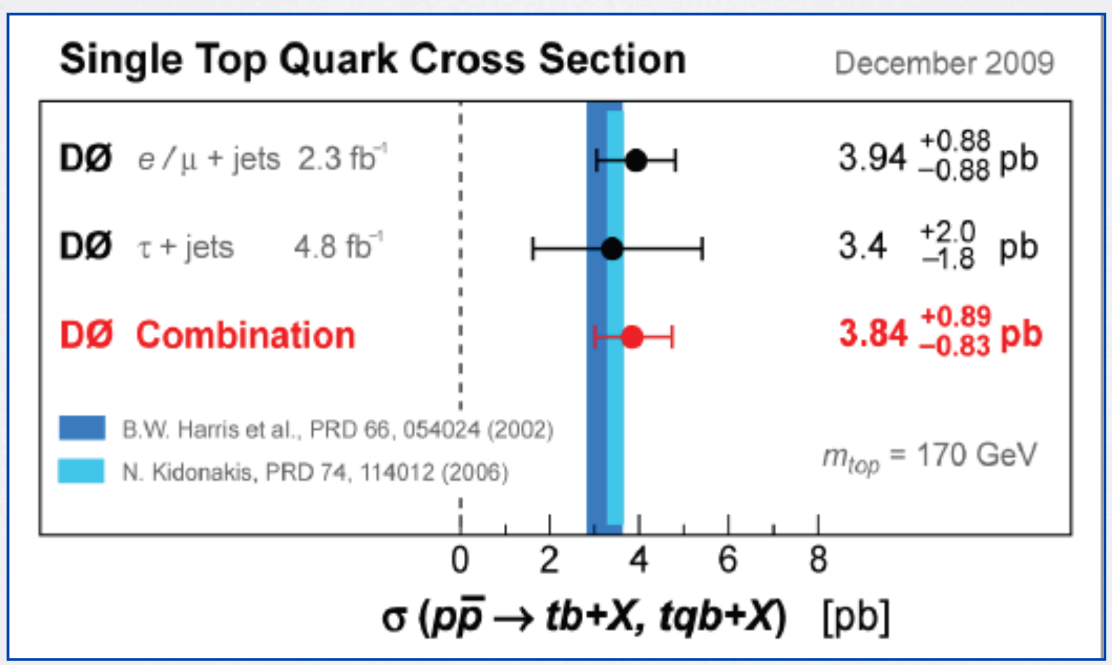


σ_{SM} = 0.29 ± 0.06 pb

To small to see at the Tevatron

Top Mass = 172.5 Gev; σ = (N)NLO pb
N. Kidonakis, PRD 74, 114012 (2006)

Result till 2009 ⇒



5σ Observation with uncertainty of 22% (with 18% statistical and 13% systematics)

Jyoti Joshi, New Perspectives 2011.

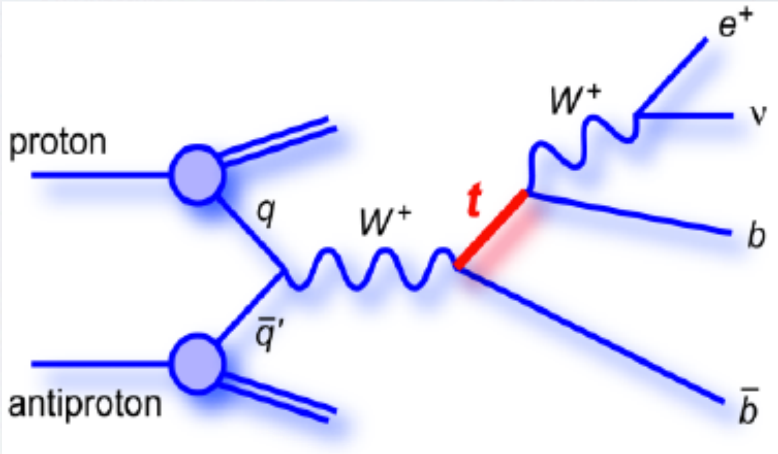
Motivations of the analysis

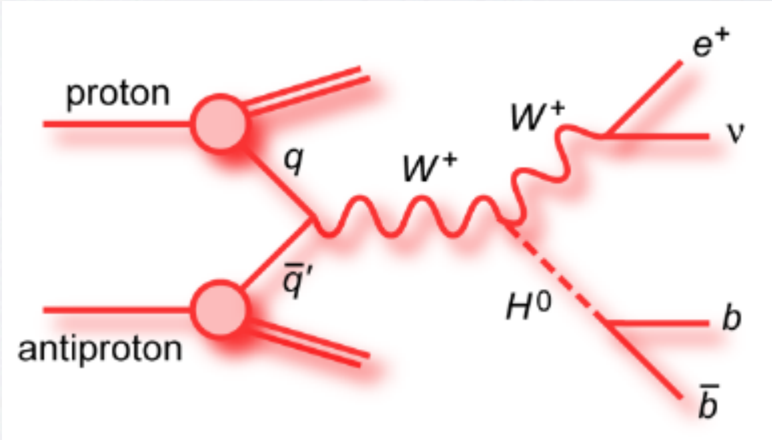
- Sensitive to many beyond SM processes.
  * t-channel process is sensitive to flavor-changing neutral currents (FCNC) and fourth generation quark.
  * Study of anomalous Wtb couplings.

- 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.

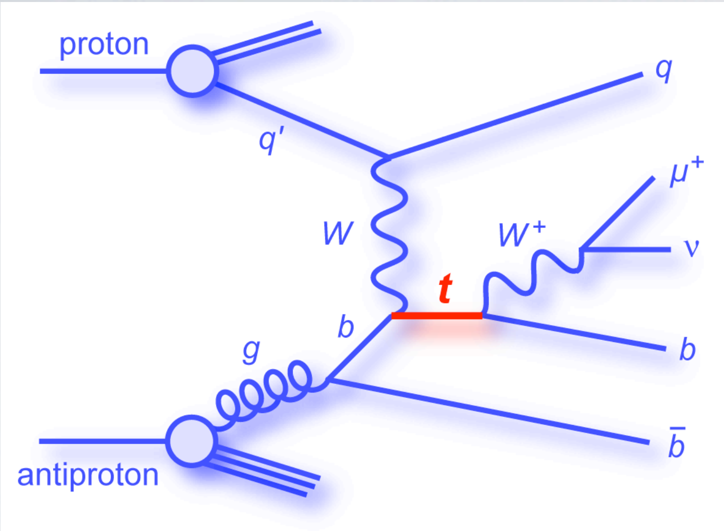
- Same final states as WH
  * Same backgrounds.
  * Test techniques to extract small signal.



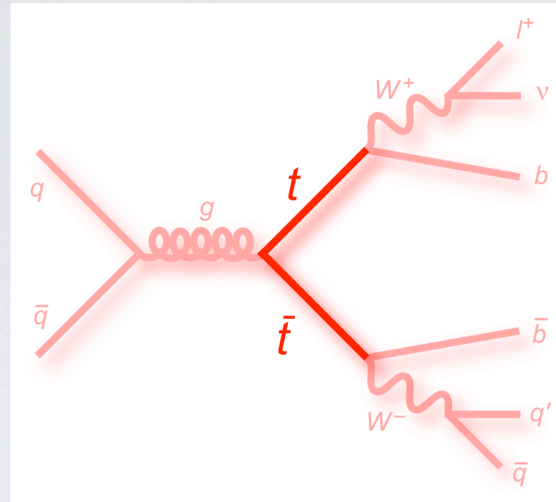


A Challenging Analysis

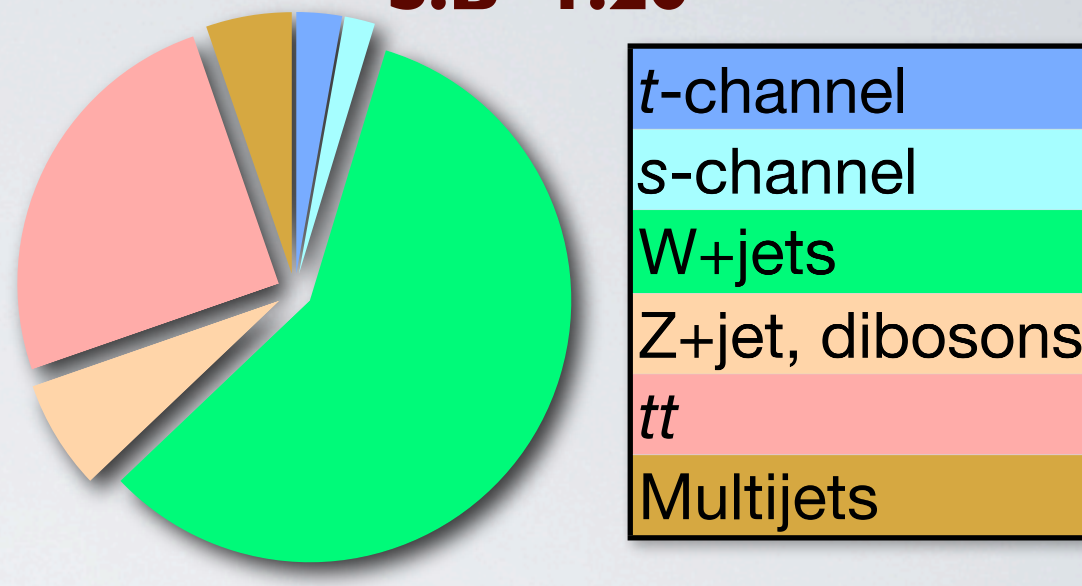
t-channel



Top Pairs

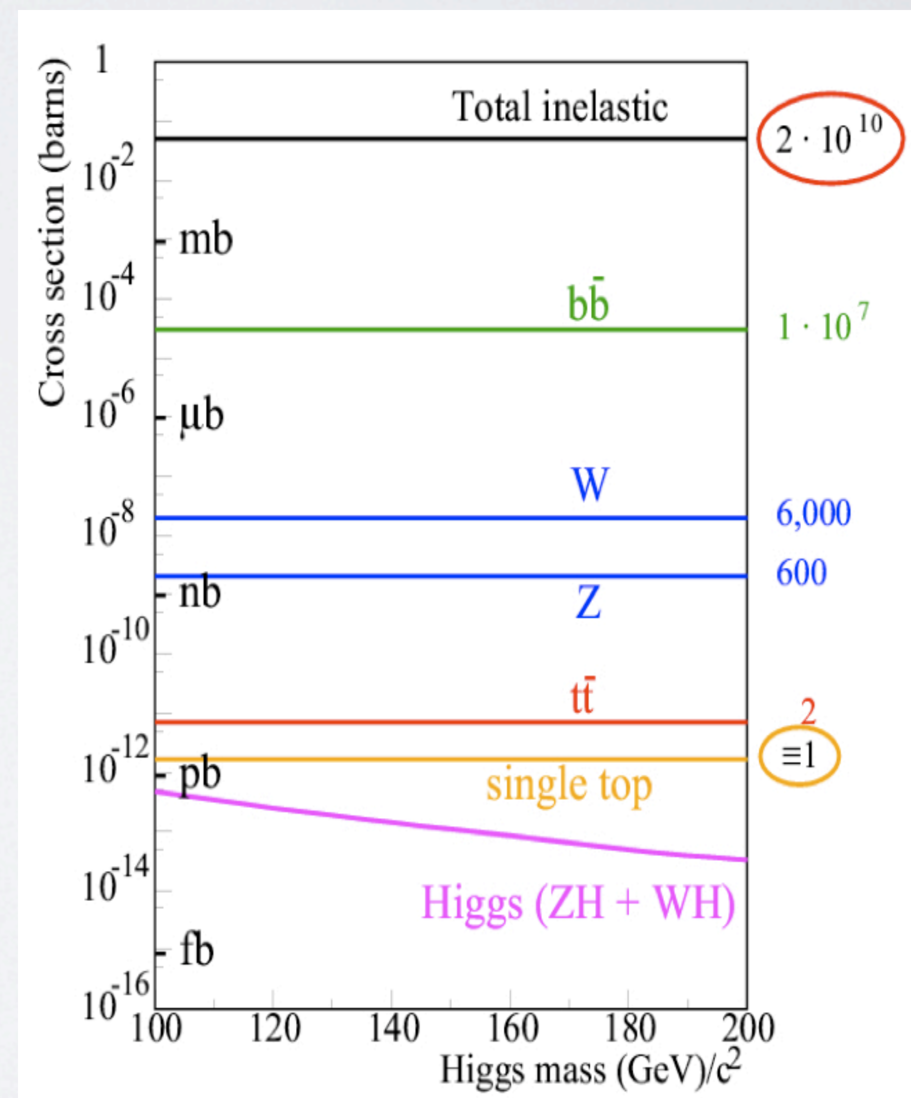


S:B~1:20



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. (~ 1/2 of ttbar)
- Mostly found in events with two and three jets.
- Background dominated after b-jet identification S:B ~ 1:20
- ttbar, multijets, W+jets backgrounds mimics signal signature very closely.



Jyoti Joshi, New Perspectives 2011.

Event Signatures and Selection

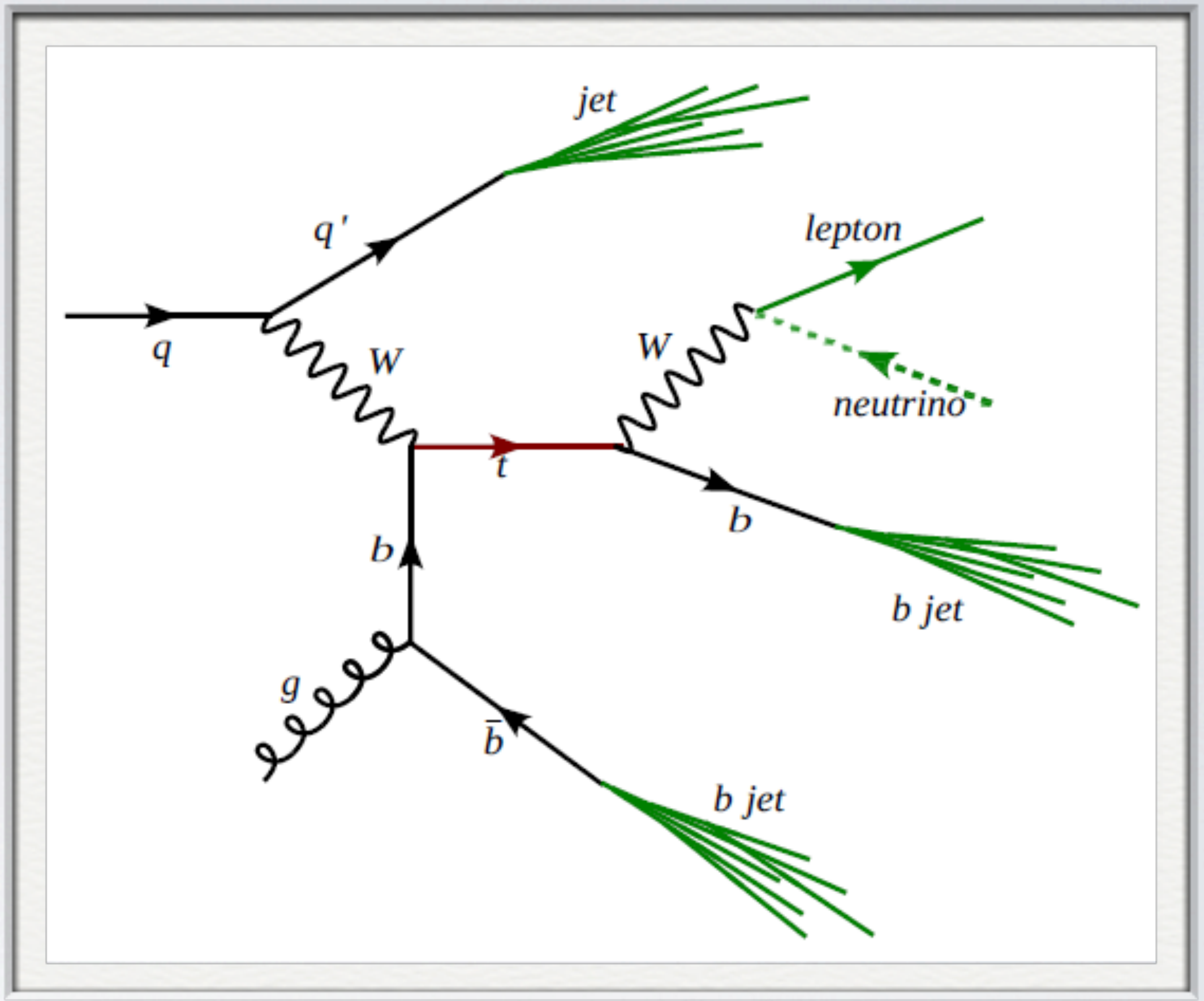
- **One High p_T isolated Lepton**
  - **Electron Selection** - $p_T > 15$ GeV, $|\eta| < 1.1$
  - **Muon Selection** - $p_T > 15$ GeV, $|\eta| < 2.0$

- **Large Missing transverse energy**
  - 15 GeV < MET < 200 GeV

- **Two, three and four jets**
  - $p_T > 25$ GeV (jet1), $p_T > 15$ GeV (other jets)
  - $|\eta| < 3.4$

- **Total Transverse Energy**
  - H_T > 120 - 160 GeV

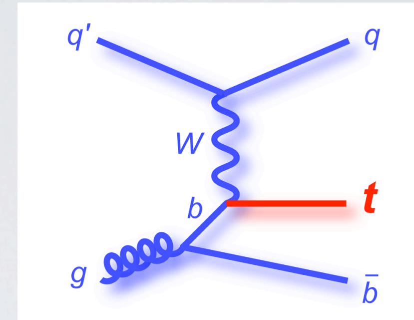
- **B-Tagging Selection**
  - One "tight" jets or Two "loose" jets originating from fragmentation of b quarks.



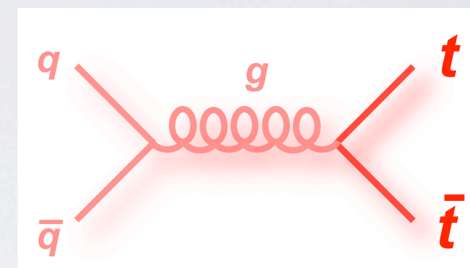
$\sigma_{SM} = 2.26 \pm 0.12$ pb

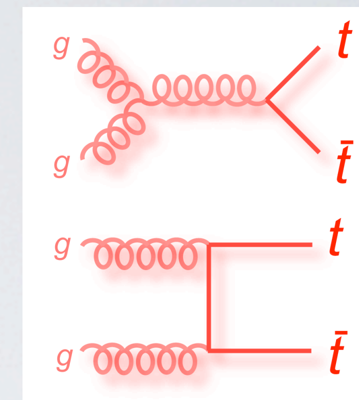
Signal and Background Modeling

- Single Top Signal events are modeled using SINGLETOP
  - Based on COMPHEP
  - PYTHIA for parton hadronization

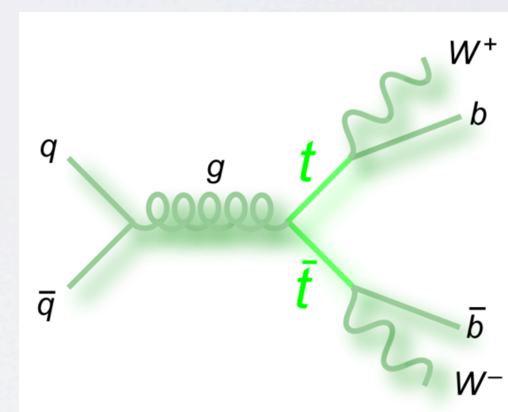


- Top pair background is modeled using APLGEN event generator and PYTHIA for parton hadronization.





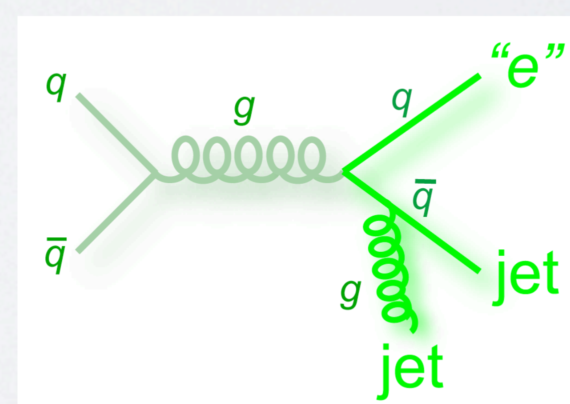
- W+jets modeled using ALPGEN+PYTHIA. Dominant background for single top.



- Multijet background is modeled directly from data.

- Z+jets is modeled using ALPGEN+PYTHIA.

- Dibosons are modeled with PYTHIA.



Event Yields after b-tagging

Background dominated after b-jet identification

S:B~1:35 (t-channel)

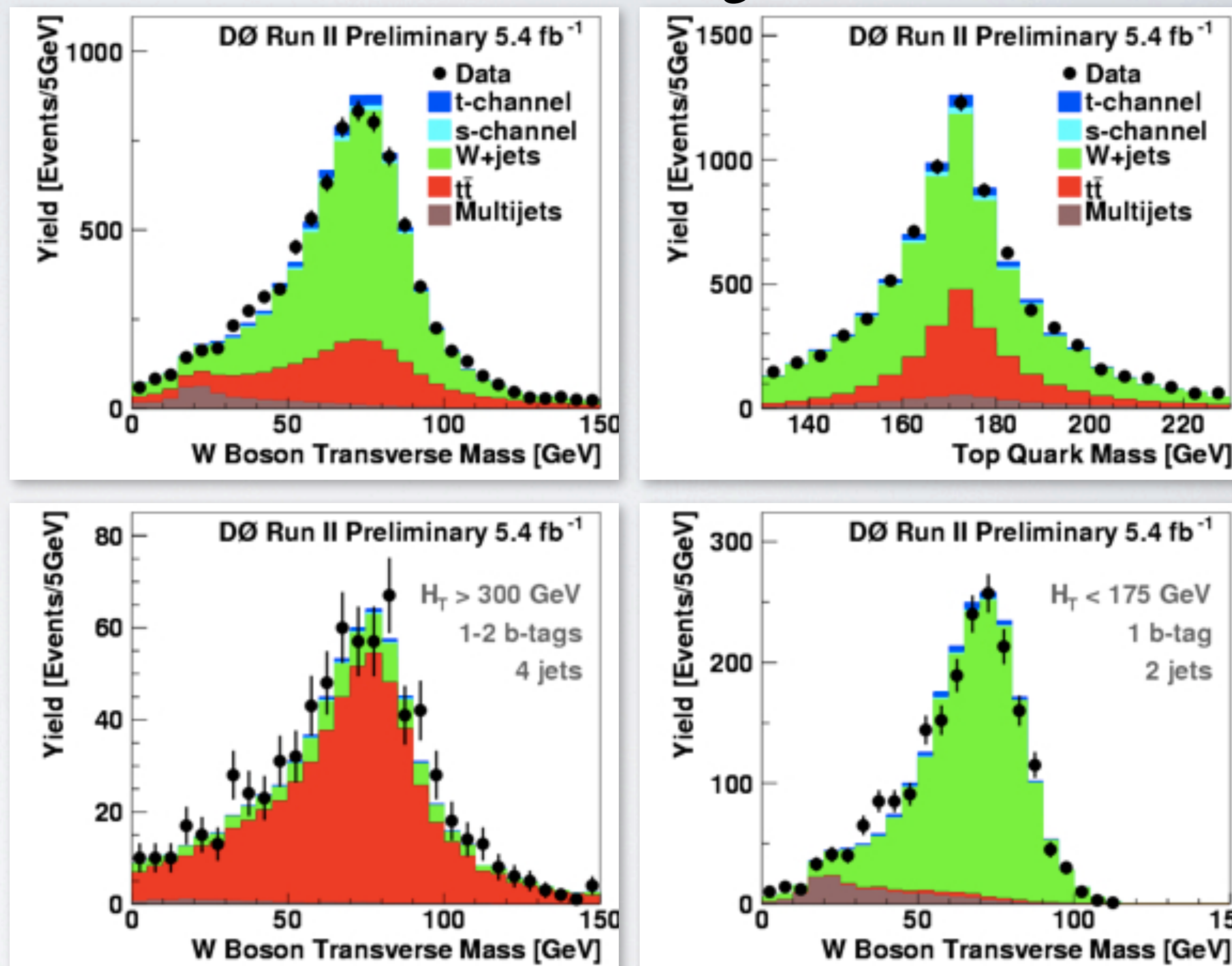
preliminary

Event Yields in 5.4 fb^{-1} of DØ Data

e,μ, 2,3,4-jets, 1,2-tags combined

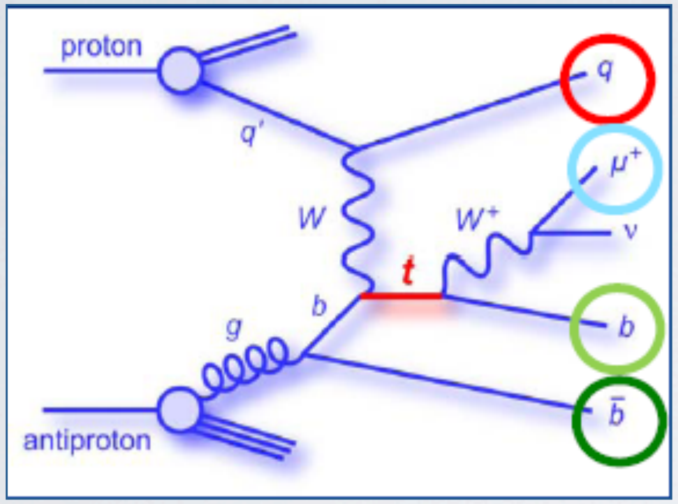
tqb	239 ± 28
tb	160 ± 27
W+jets	4,943 ± 598
Z+jets, dibosons	576 ± x113
$t\bar{t}$ pairs	2,124 ± 383
Multijets	451 ± 56
Total prediction	**8,492 ± 987**
Data	**8,471**

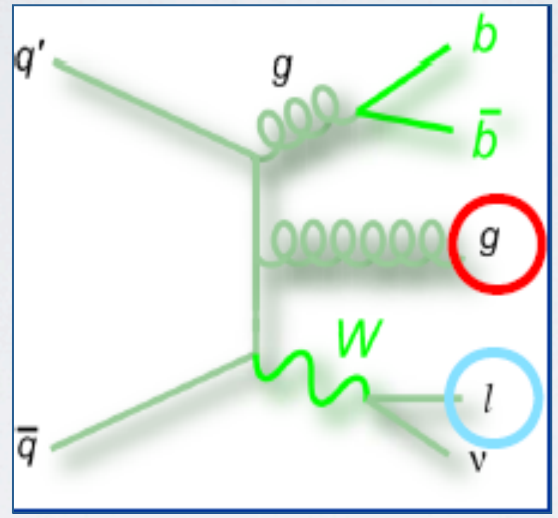
Good data/MC agreement



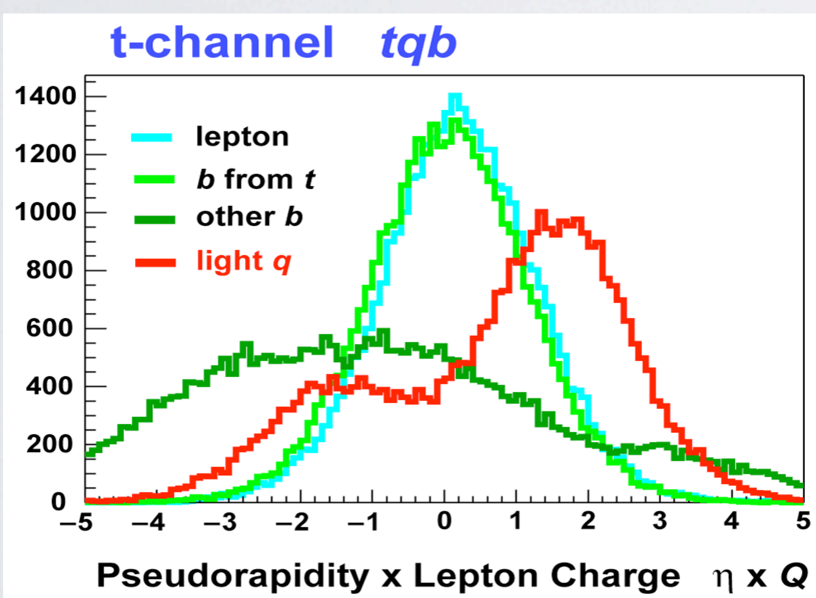
Multivariate Analysis

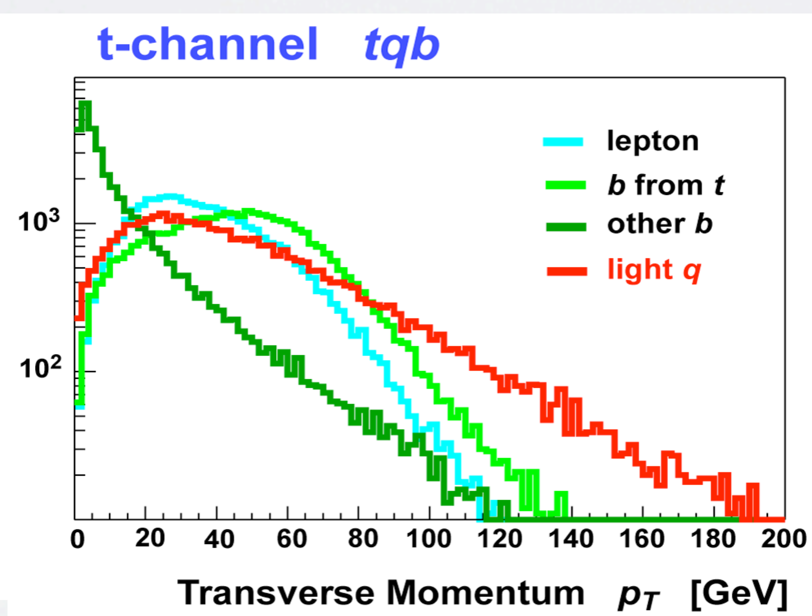
➢ **Exploit kinematic differences between signal and background. Three Multivariate Analysis Techniques are used to separate signal from background. Combined different distribution with some discrimination power in one variable with larger discrimination.**

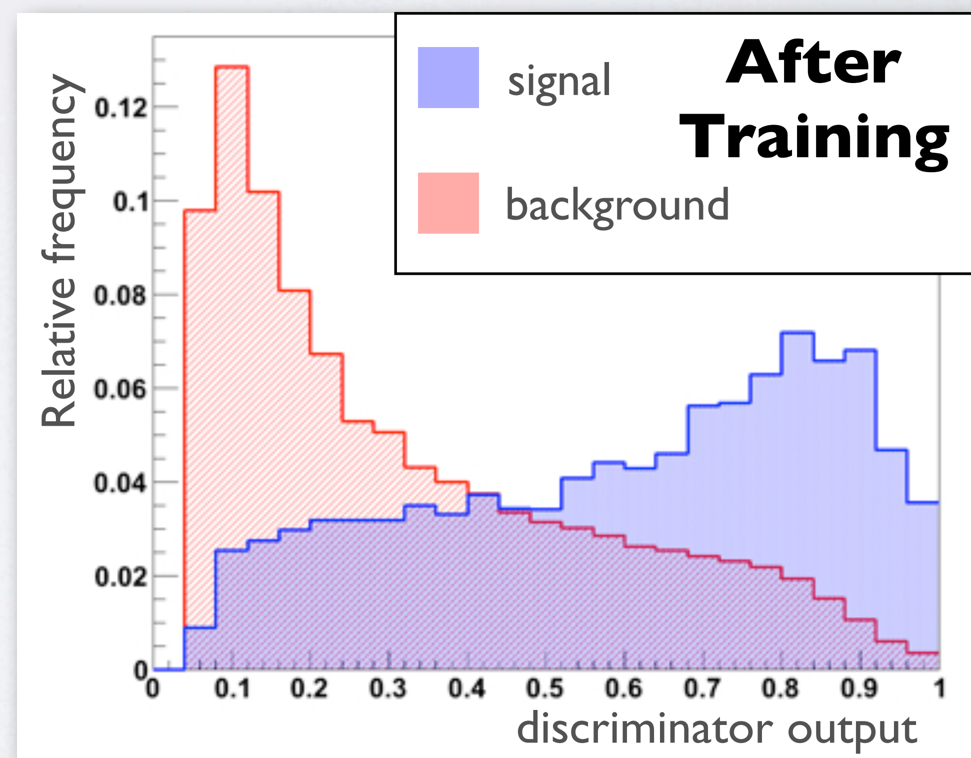




Even though final states of signal and background are consistent of the same particle types, MVA can extract the signal due to characteristics shape of variables with high discriminating power.





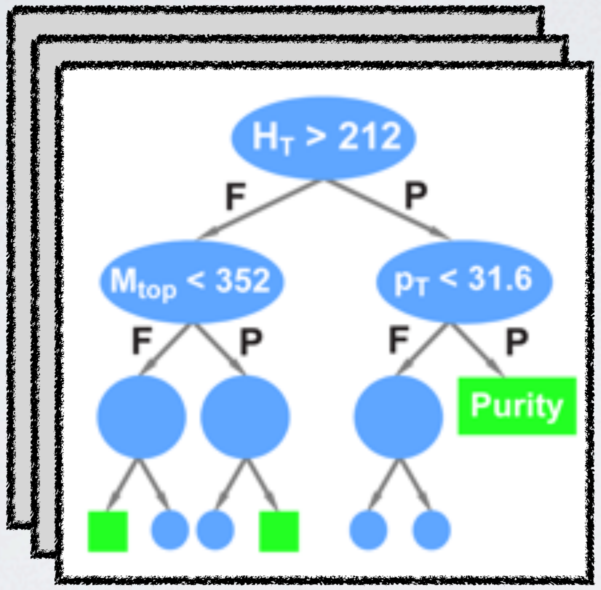


Jyoti Joshi, New Perspectives 2011.

Multivariate Techniques Used

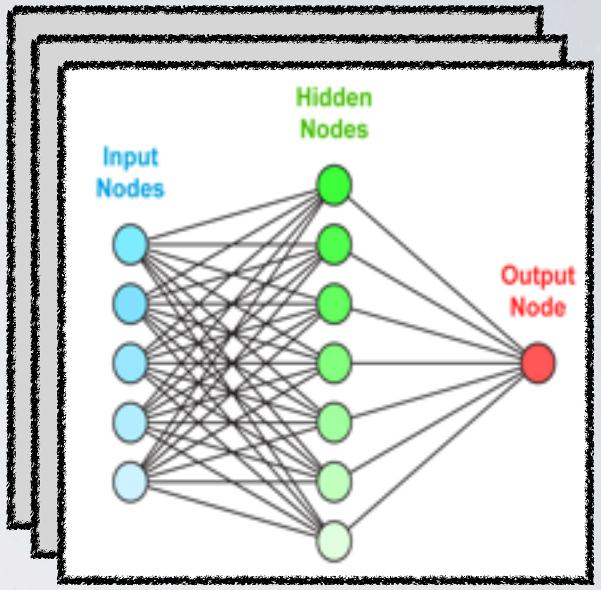
Boosted Decision Tree (BDT)

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



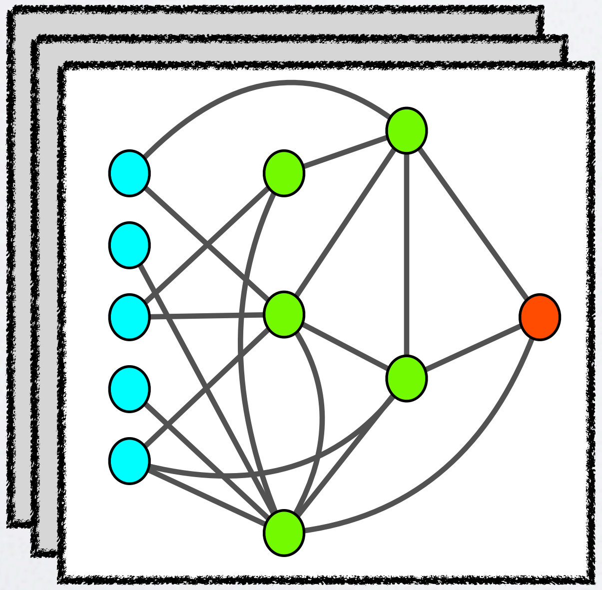
Neural Networks (NN)

- 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)

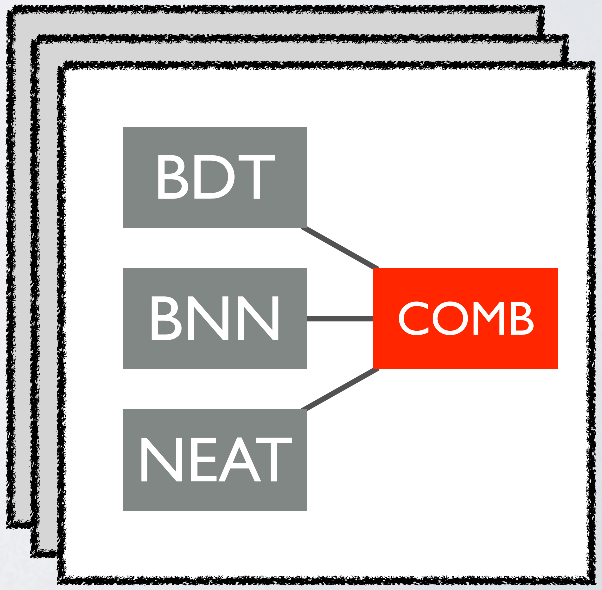
- Genetic algorithms evolve a population of NN.
- Topology of the NN is also part of the training.



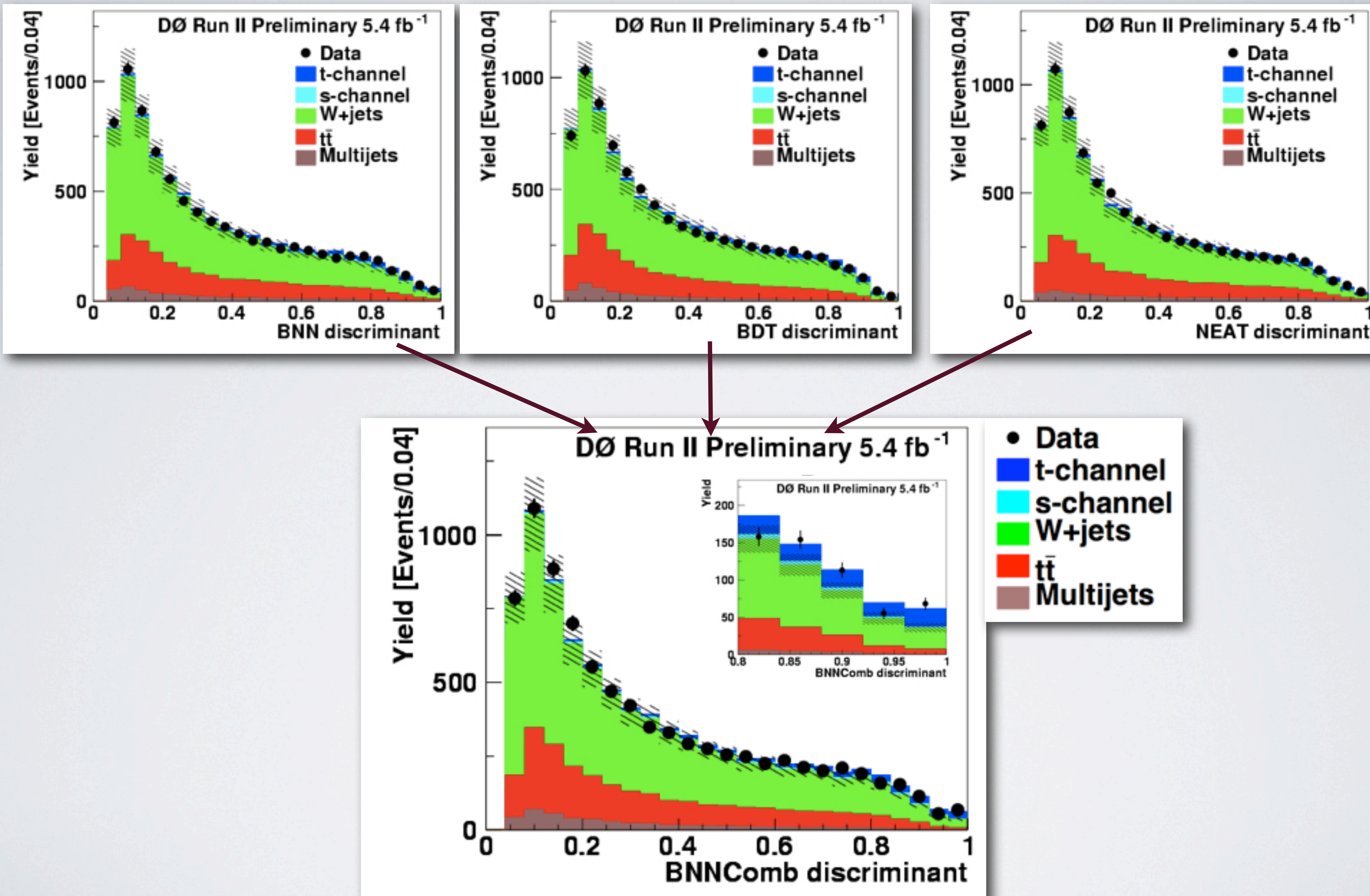
BNN Combination

Correlation between methods ~58-85%

- Different discriminant are combined in one.



Discriminant Outputs for t-channel



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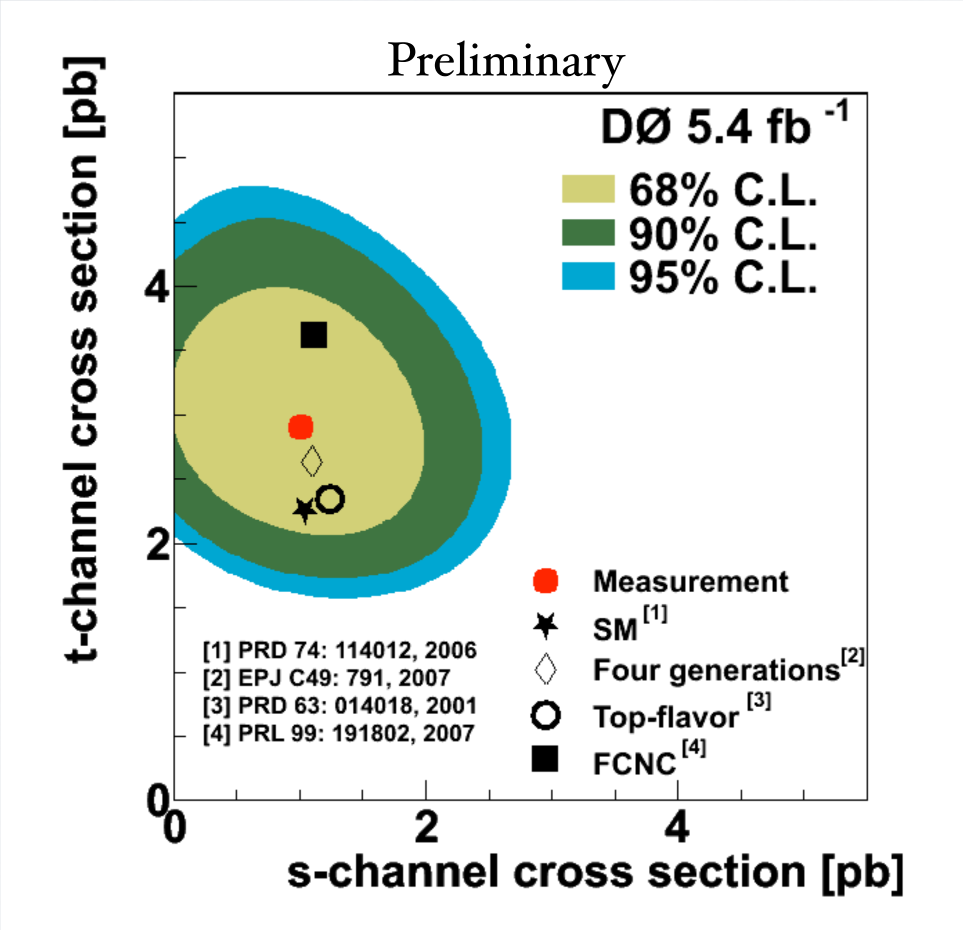
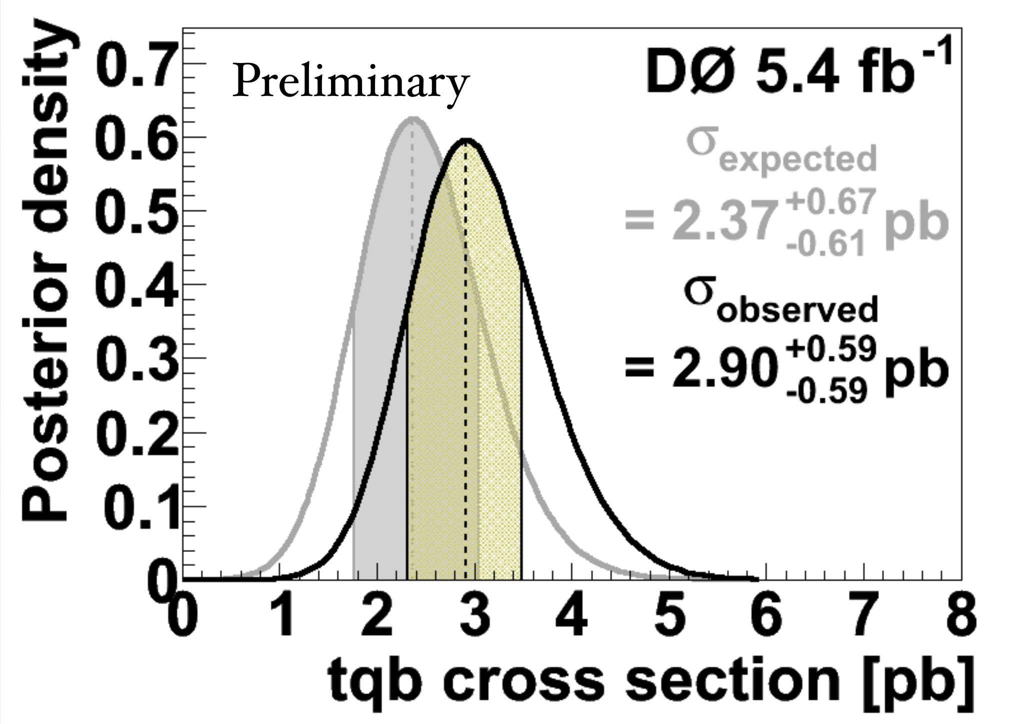
Cross-Section Measurement





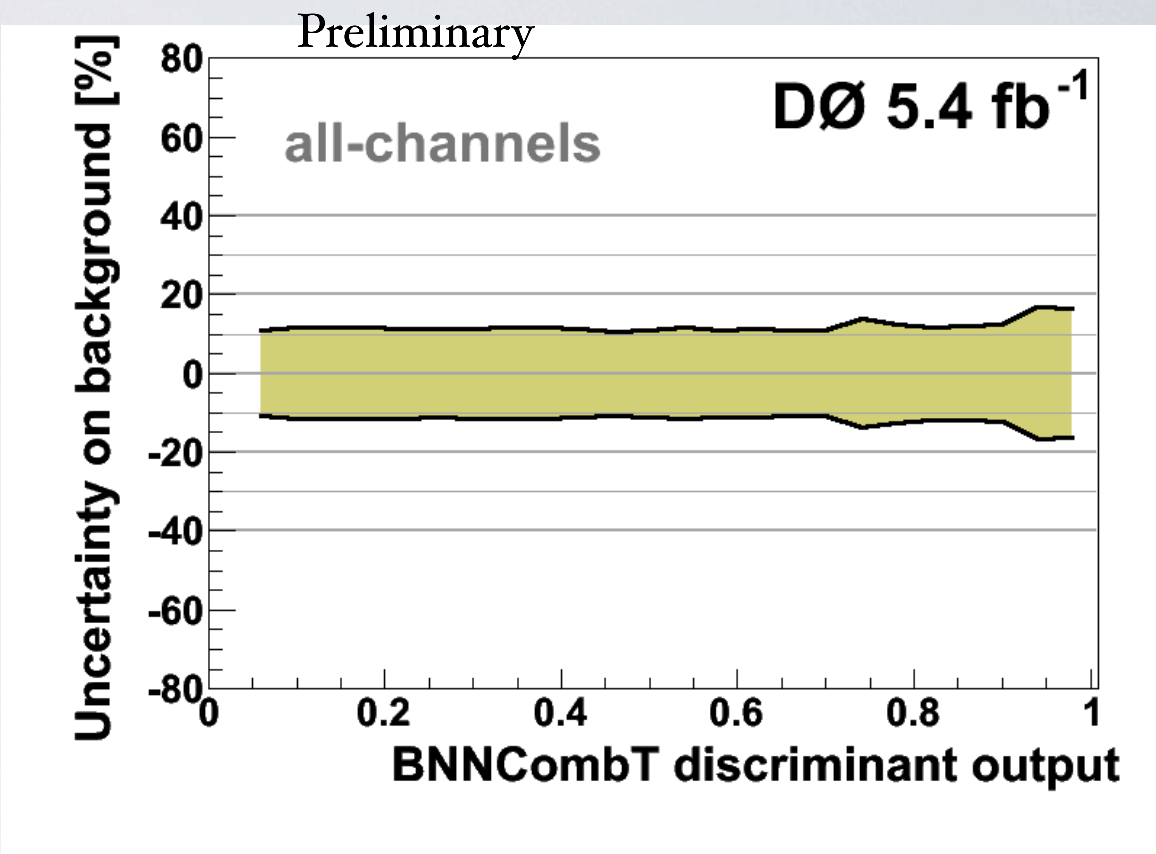
Measured Value = Peak of the curve
Uncertainty = width of the curve (68% asymmetrical interval)

- **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.**

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 ttbar)

Conclusions

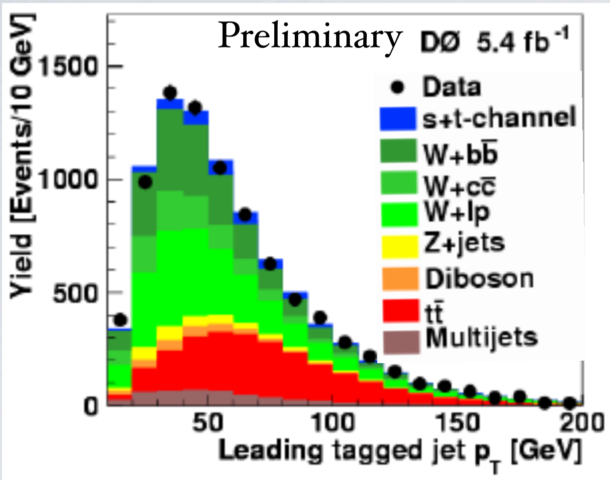
Preliminary

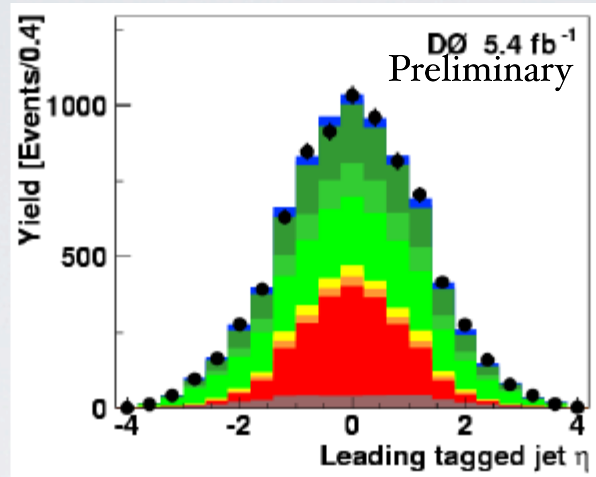
Top mass [GeV]	cross sections [pb]			
	t-channel		s-channel	
170	2.80	+0.57 -0.61	1.31	+0.77 -0.74
172.5	**2.90**	**+0.59 -0.59**	**0.98**	**+0.62 -0.63**
175	2.53	+0.58 -0.57	0.65	+0.51 -0.50

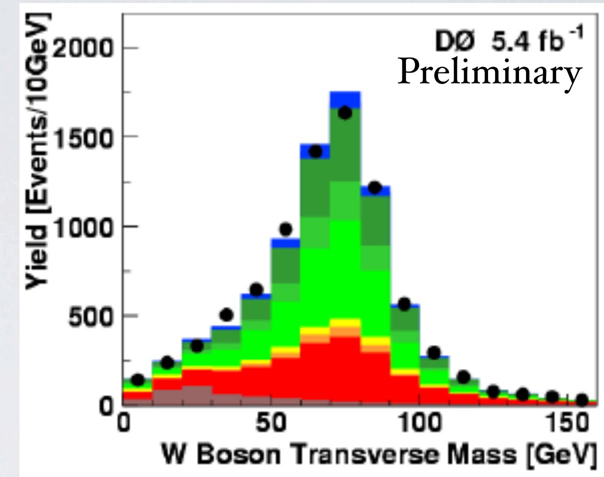
- An ambitious single top program is being pursued at D0.
- New model-independent measurement of t-channel cross section was presented by DØ using twice as much data as the observation result.
- Significance of the results is estimated to be larger than five standard deviations (5σ) and also the measurement has a relative low uncertainty. Submitted to PLB.
- More cross sections measurements and search for new physics are expected to be ready soon based on this new dataset.
- The next big challenge is to measure s-channel cross section. This is one of the Tevatron legacy measurements because s-channel cross section is expected to be very low at LHC.

BACKUP

Background Modeling after tagging

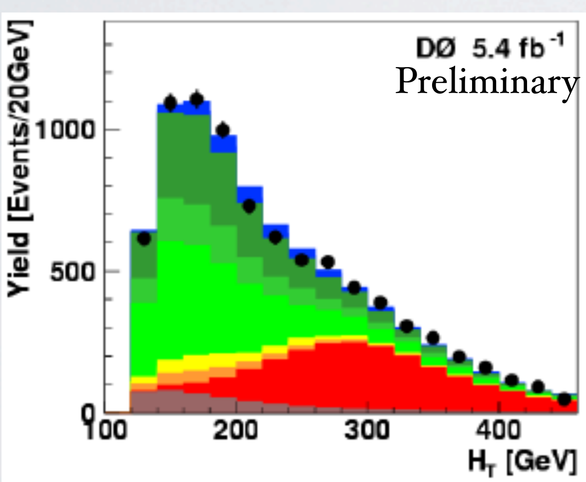


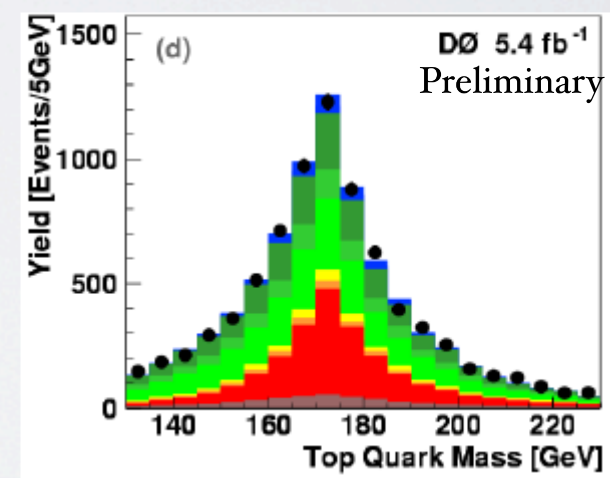




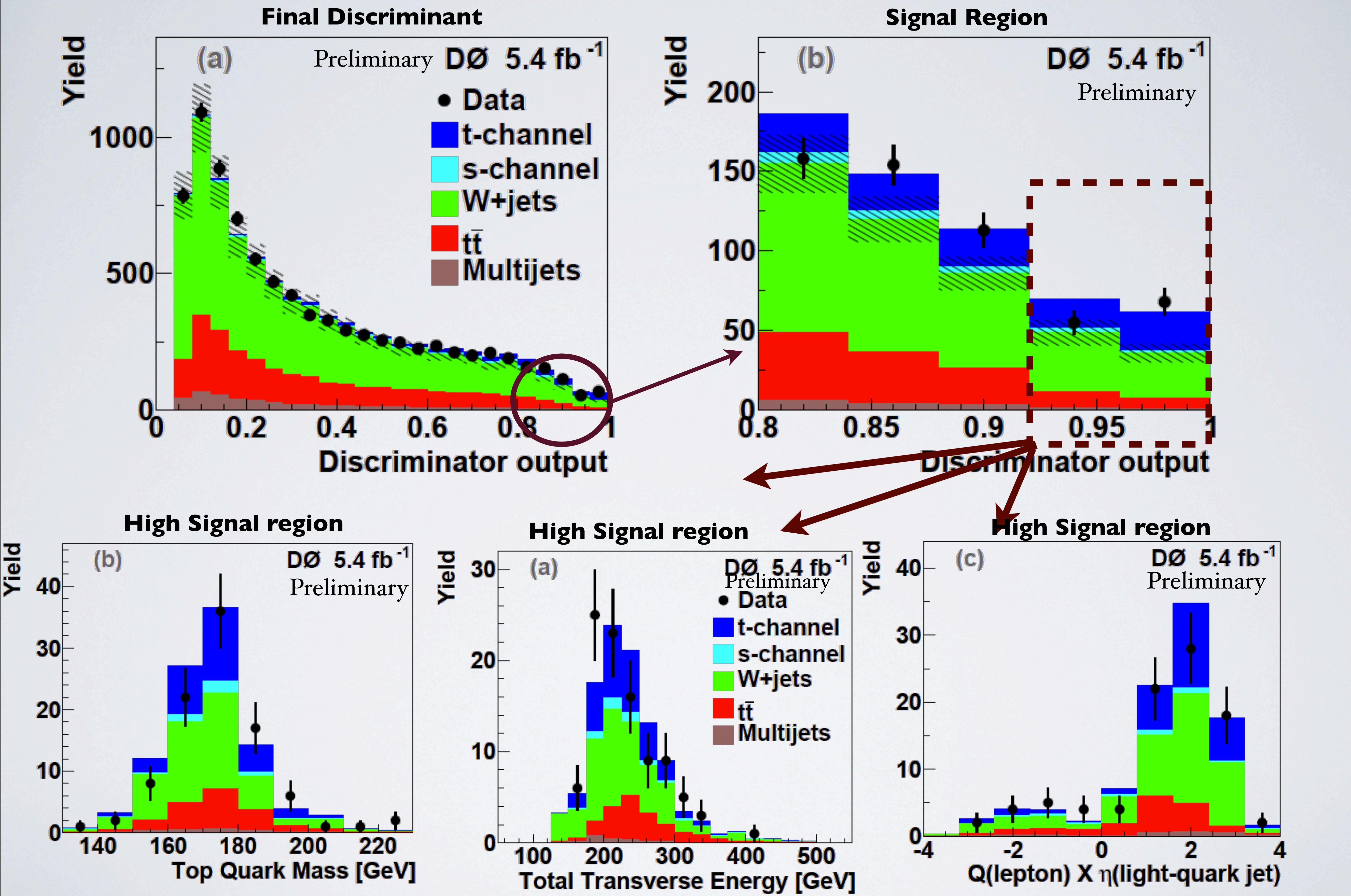
After tagging

- t-channel
- s-channel
- W+Jets
- Z+Jets dibosons
- ttbar
- QCD Multijets





More Results

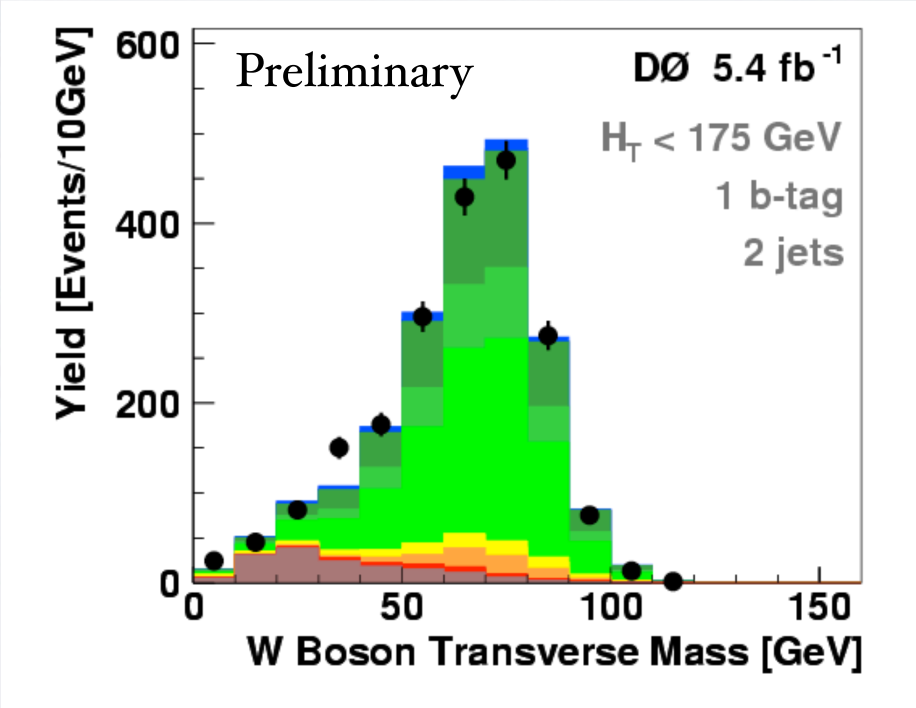


Cross-Checks

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

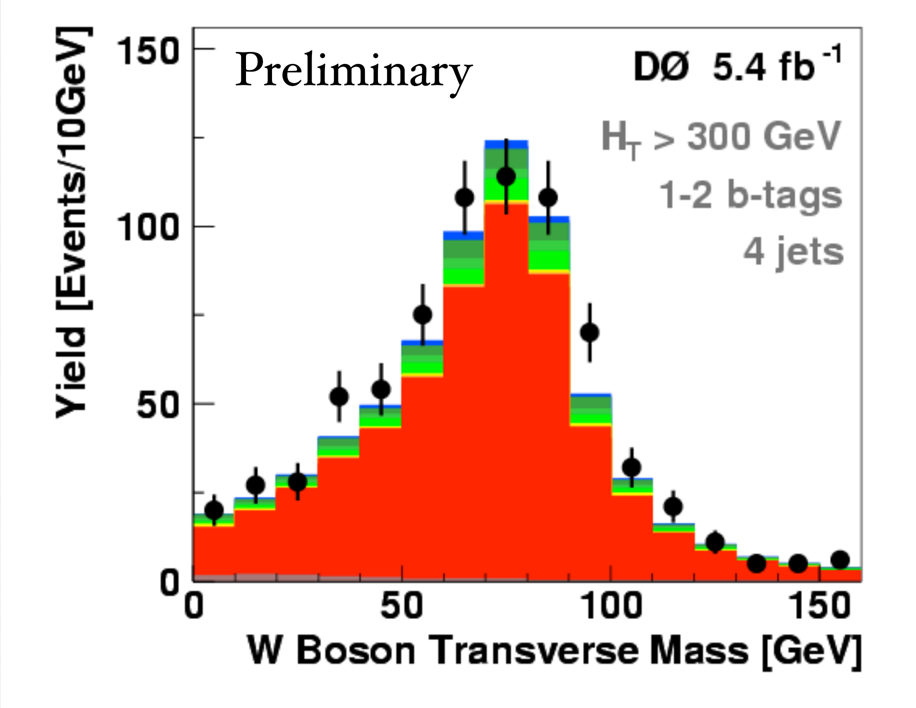
- "W+jets" sample
  - Exactly 2 jets
  - $H_T < 175$ GeV
  - 1 b-tagged jet

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



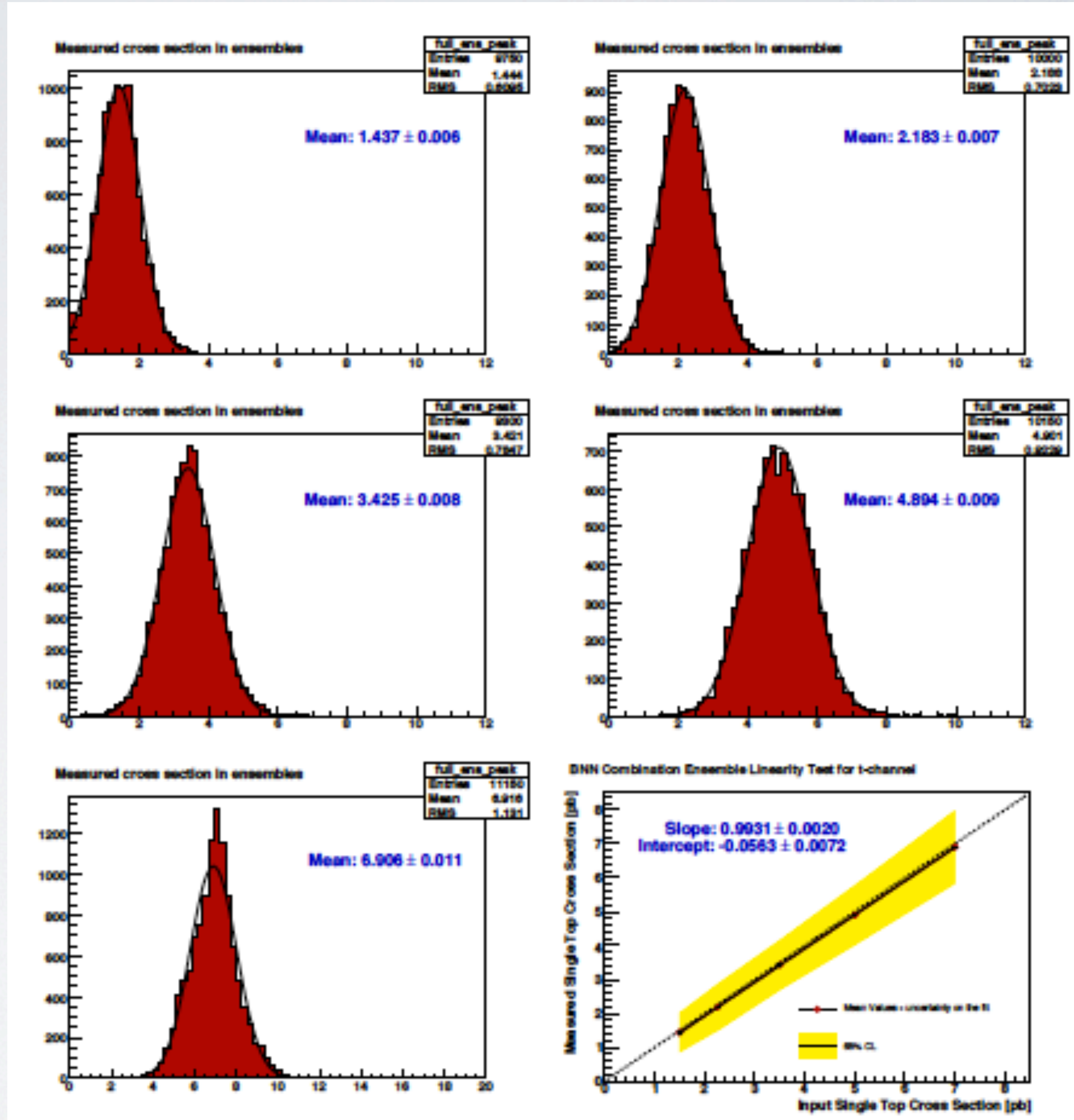
- "TTbar" sample
  - Exactly 4 jets
  - $H_T > 300$ GeV
  - 1 or 2 b-tagged jets

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



Linearity Test for Comb. t-channel

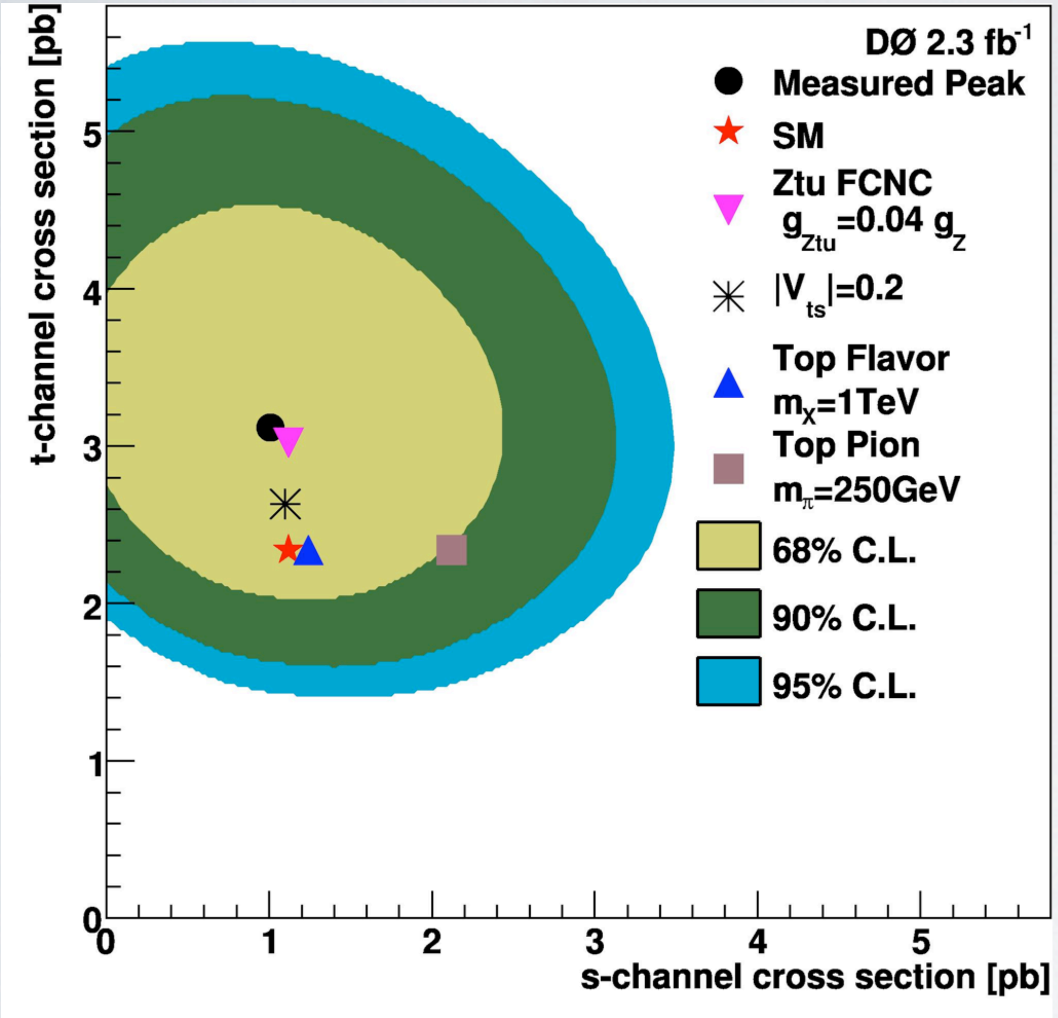
To check for potential biases that can be introduced in the measured cross-section, we generate a set of ensembles of pseudo-datasets from pool of background events for different signal cross section values. Gaussian has been fitted over the peak of all distribution and a linear fit is done to measured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



Jyoti Joshi, New Perspectives 2011.

Evidence of t-channel - 2.3 fb^{-1} Analysis

arXiv:0907.4259v2 [hep-ex]

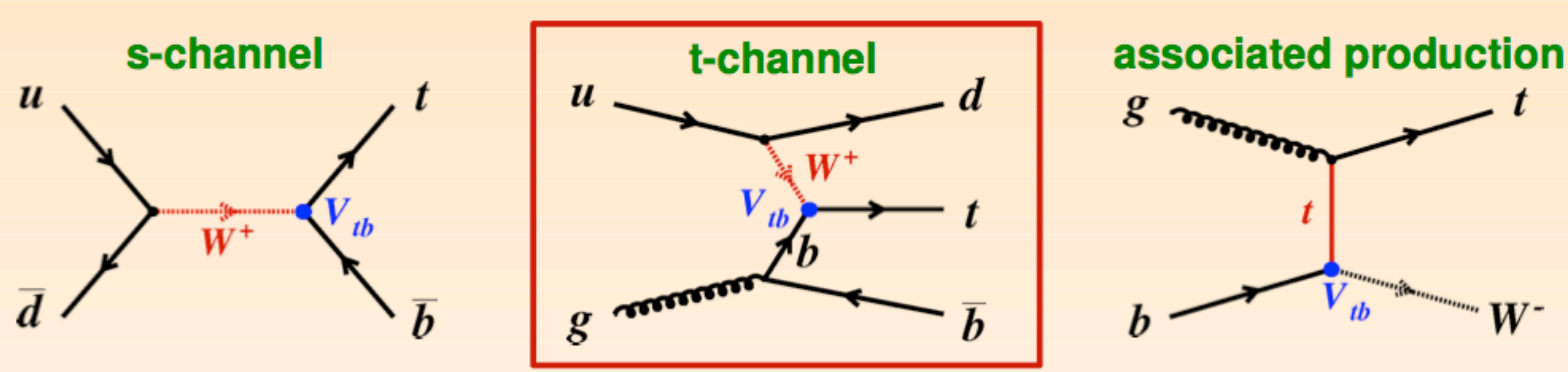


Observed Cross-section = $3.14^{+0.94}_{-0.81}$ pb

Single top s-channel as legacy measurement

- Evidence and observation of s-channel.
- It will be difficult for the LHC to improve any measurement from Tevatron.

Jeannine Wagner-Kuhr, Physics at the Terascale Workshop DESY,12.11.2009



1) PRD 74, 114012 (2006) 2) values scaled to 10TeV based on PRD 70, 114012 (2004); Nucl. Phys. B726, 109 (2005) 3) JHEP 0910, 042 (2009)	Tevatron [pb] $\sqrt{s}$=1.96 TeV	LHC [pb] $\sqrt{s}$=7 TeV	LHC [pb] $\sqrt{s}$=10 TeV
s-channel	1.0 1)	3	**5** 2)
t-channel	2.2 1)	65	**124** 3)
associated production	0.26 1)	11	**29** 2)

s-channel 1D Posterior