Single Top Quark Measurements at the Tevatron

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for the DØ and CDF collaborations

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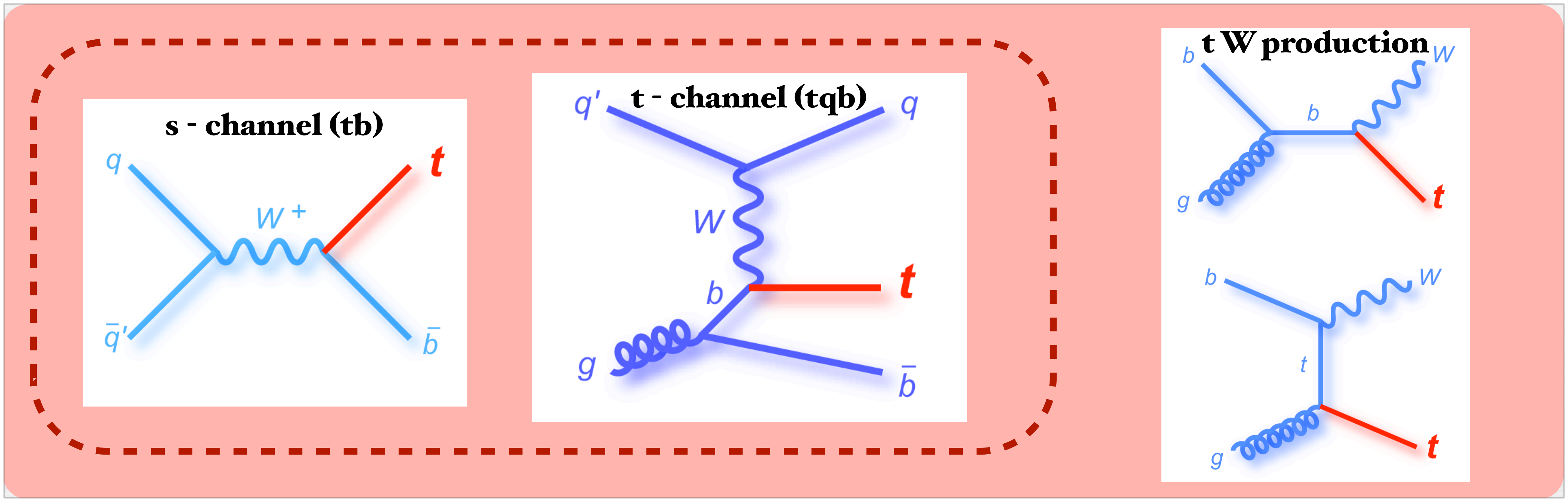
Outline

- Single Top Quark Production
- Motivations to Study Single Top Quark Production
- Experimental Setup: Tevatron and Detectors
- Event Selection, Signal and Background Modeling
- Multivariate Methods
- Cross - Section Measurement
- Summary

Electroweak 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	0.3 ↓x26
LHC (7 TeV)	4.59	64.2	7.8

PRD 74, 114012 (2006)
PRD 81, 054028 (2010)
PRD 83, 091503 (2011)

Motivations

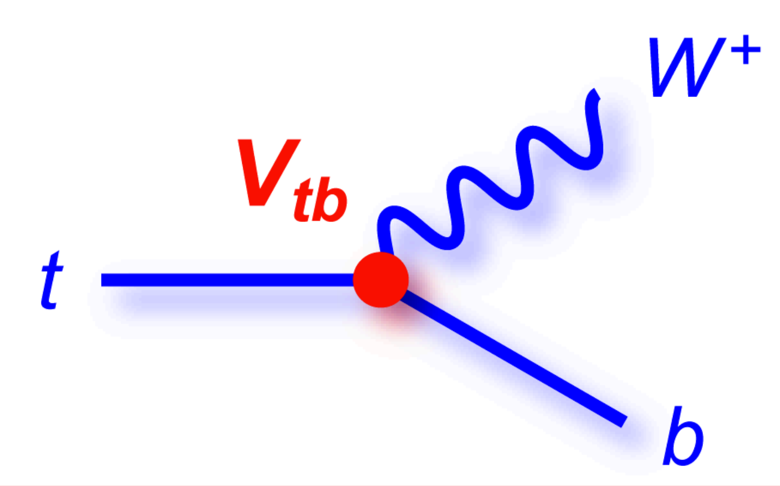
- Measurement of top properties :
  spin polarization, top decay width and lifetime, CP violation

- Probe new physics : 4^{th} quark generation ?
  tb: W' , $H^{\pm}$? tqb: FCNC ?

- Background for WH ⟶ Wbb:
  similar analysis

Wtb coupling

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



- Direct $|V_{tb}|$ measurement
- Test CKM unitarity
- Anomalous Wtb couplings

Brief History of search of single top quark

DØ

- Search: PRD 63, 031101 **(2000)**
- Search: PLB 517, 282 **(2001)**
- Search: PLB 622, 265 **(2005)**
- W': PLB 641, 423 **(2006)**
- Search: PRD 75, 092007 **(2007)**
- **Evidence:** PRL 98, 181802 **(2007)**
- FCNC: PRL 99, 191802 **(2007)**
- W': PRL 100, 211802 **(2007)**
- Evidence: PRD 78, 012005 **(2008)**
- Wtb: PRL 101, 221801 **(2008)**
- Wtb: PRL 102, 092002 **(2009)**
- H^+: (PRL) arXiv:0807.0859
- **Observation: (PRL) arXiv:0903.0850**

CDF

- Search: PRD 65, 091102 **(2002)**
- W' PRL 90, 081802 **(2003)**
- Search: PRD 69, 052003 **(2004)**
- Search: PRD 71, 012005 **(2005)**
- **Evidence:** PRL 101, 252001 **(2008)**
- FCNC: (PRL) arXiv:0812.3400
- W': (PRL) arXiv:0902.3276
- **Observation: (PRL) arXiv:0903.0885**

PRL 98, 181802 (2007) PHYSICAL REVIEW LETTERS

Evidence for Production of Single Top Quarks and First Direct Measurement of $|V_{tb}|$

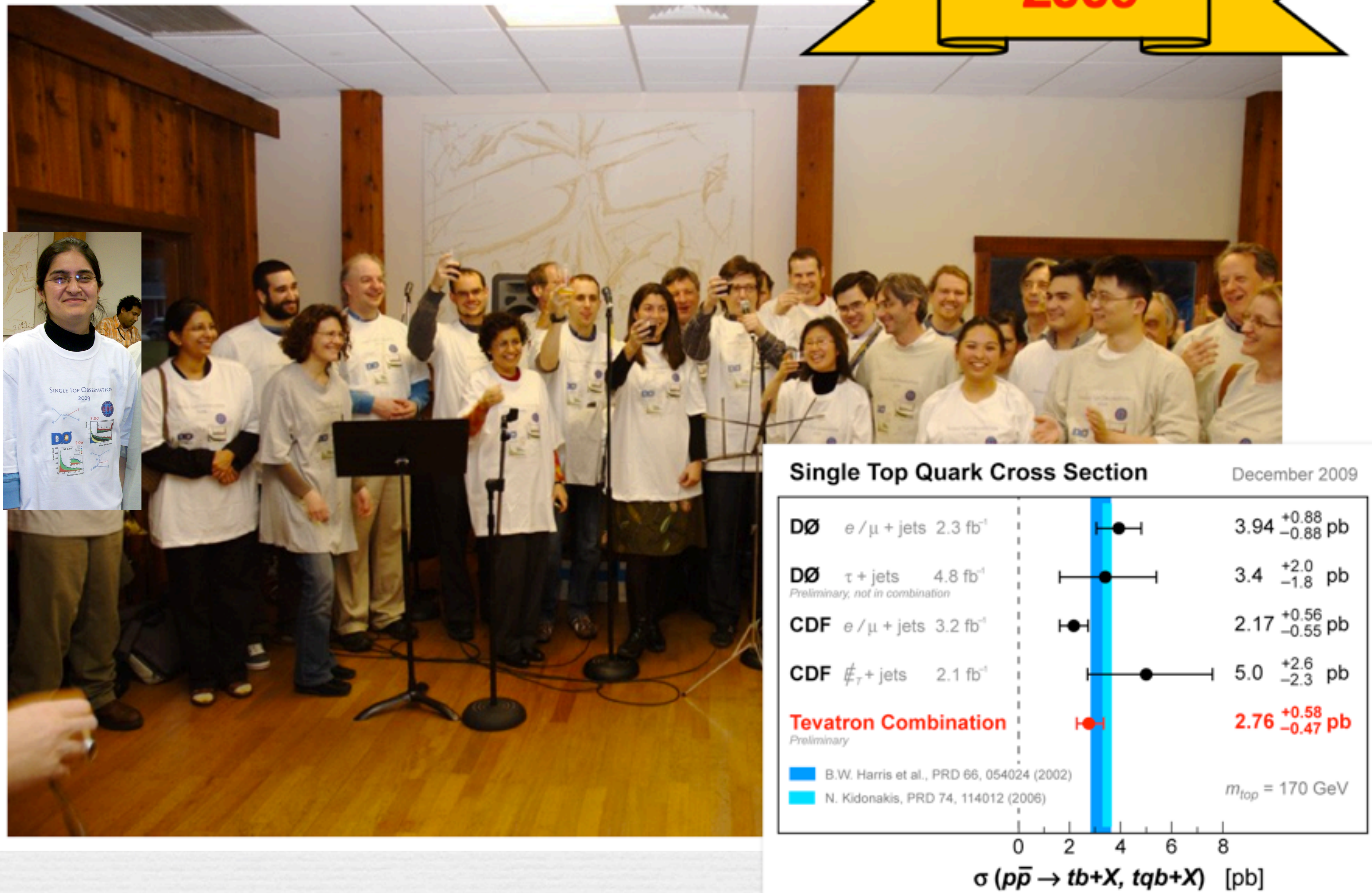
PRL 101, 252001 (2008) PHYSICAL REVIEW LETTERS

Measurement of the Single-Top-Quark Production Cross Section at CDF

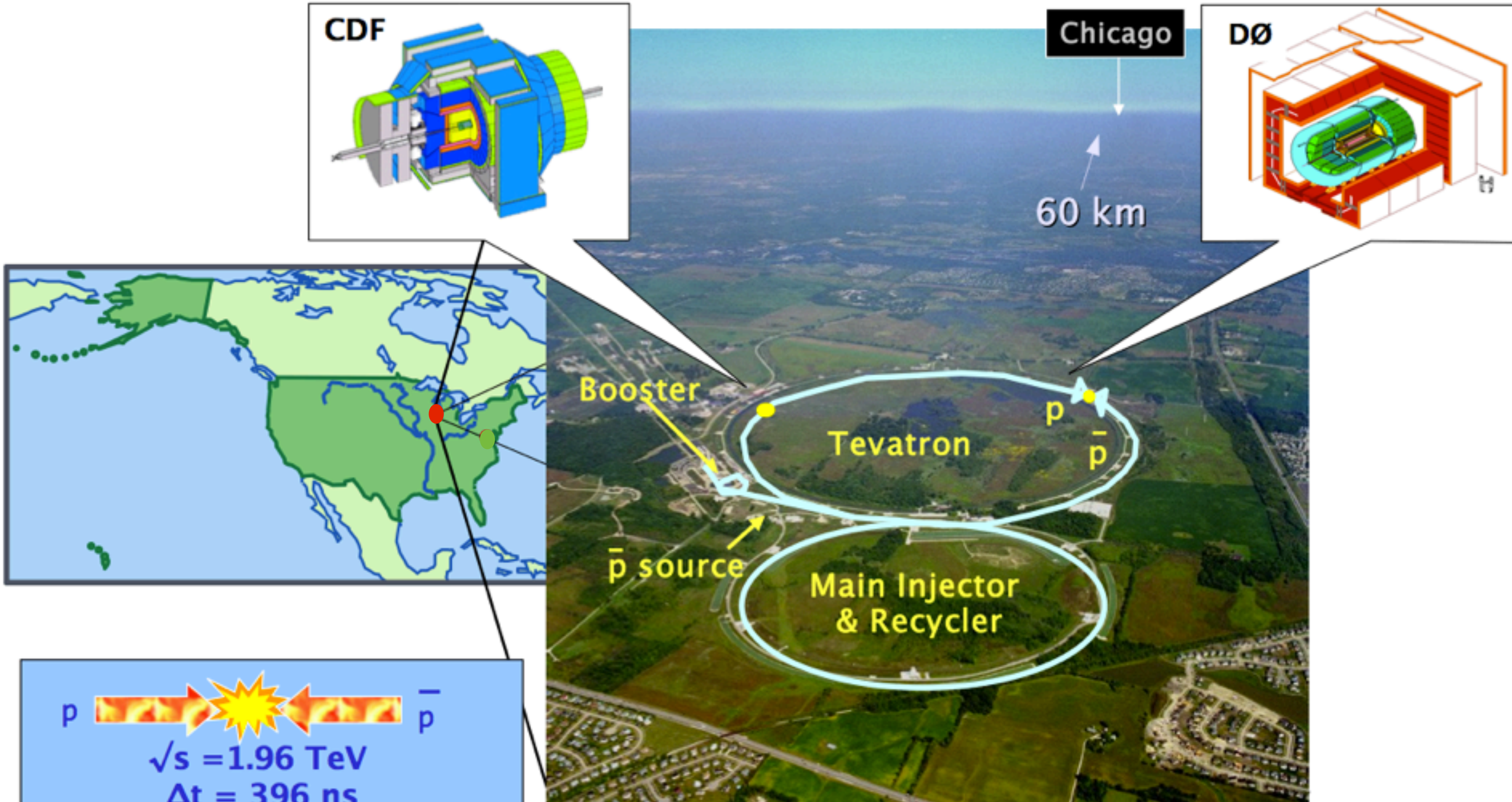
DØ and CDF Observation
PRL "Editor" Suggestion"
~ 200 citations.

Single Top Quark Observation

2009



The Tevatron ppbar Collider at Fermilab



p → ← $\bar{p}$

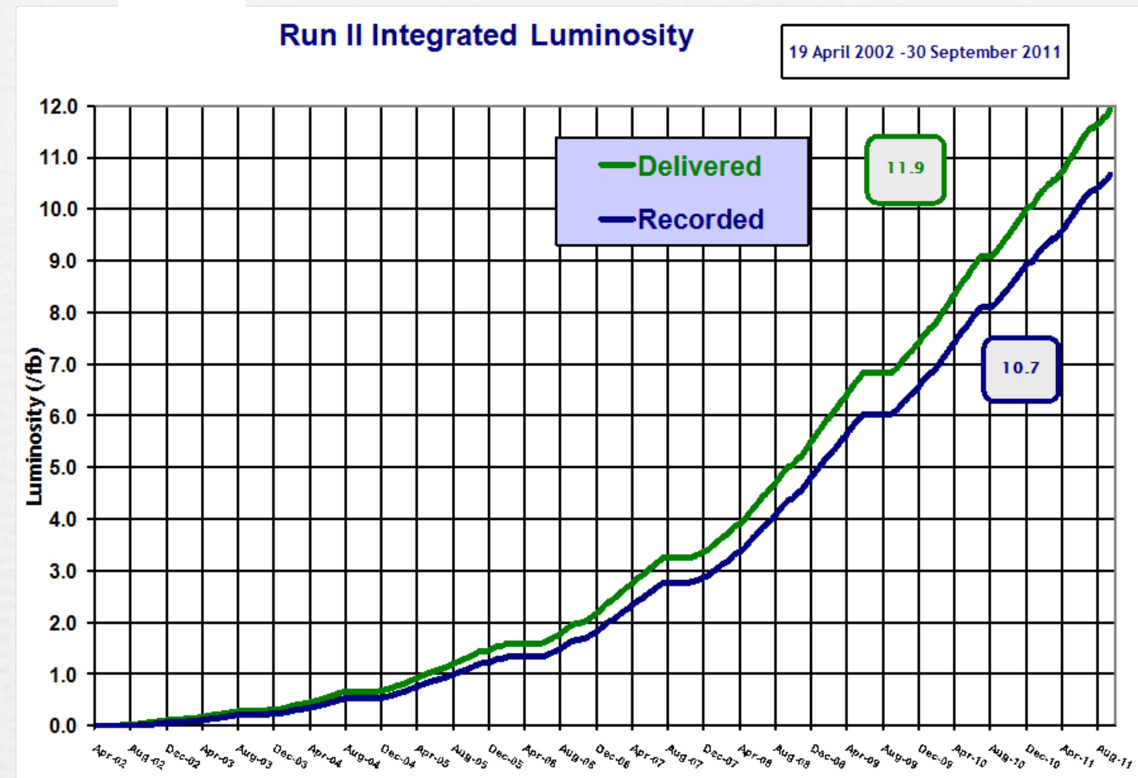
$\sqrt{s}$ =1.96 TeV

Δt = 396 ns

Run I 1987 (92)–95
Run II 2001–11: 100x larger dataset at increased energy

10^{-12}s after big bang!

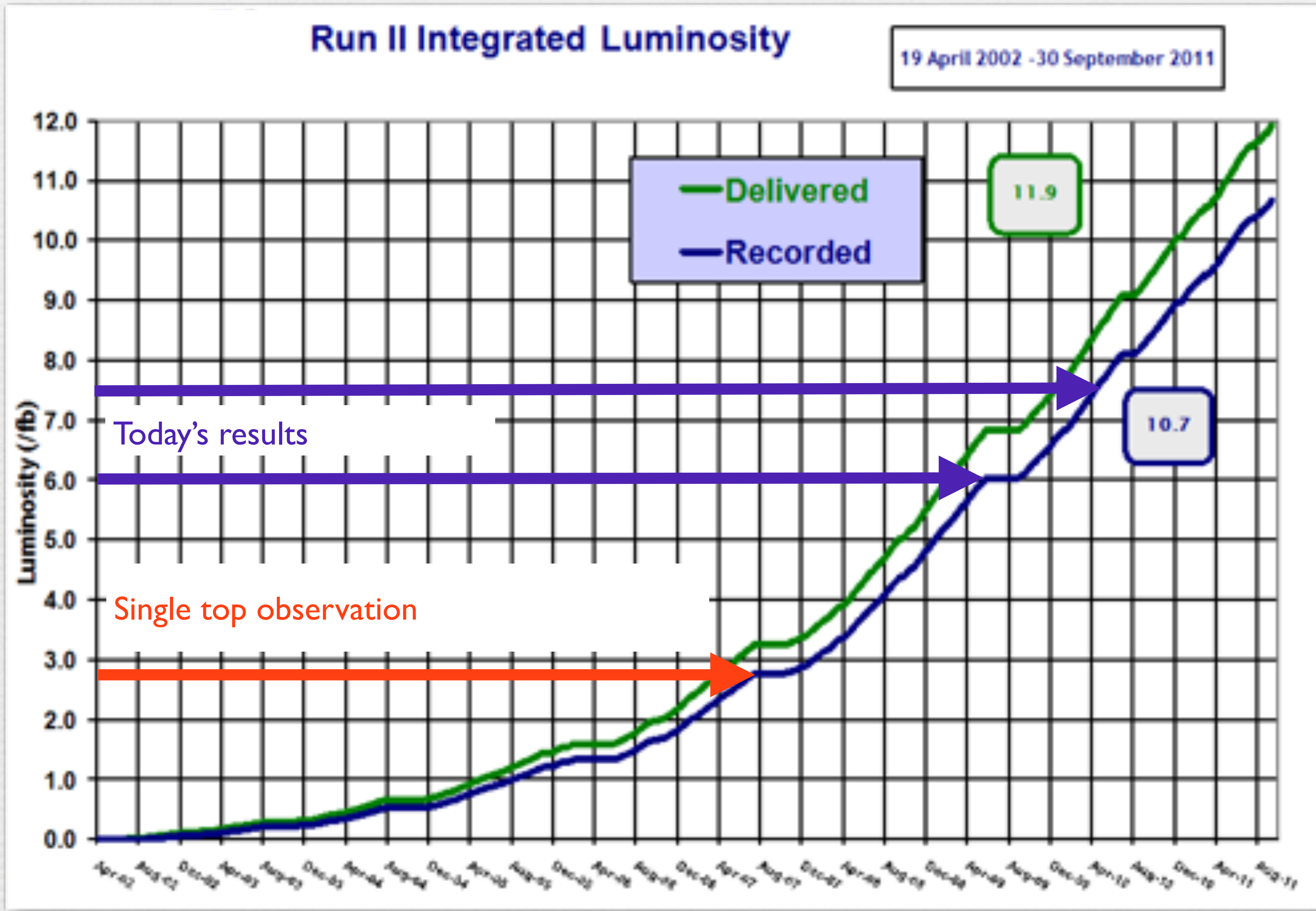
Tevatron Shutdown - 30 September 2011



Tevatron complex shut down after 26 years of successful operation.

Datasets Used

Total Integrated luminosity Used = 5.4 fb^{-1} (DØ), 7.5 fb^{-1} (CDF)



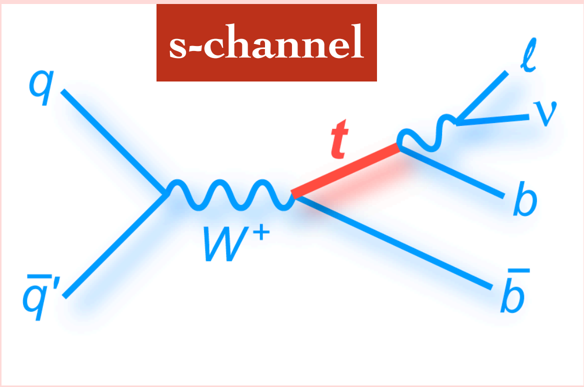
Event Signature and Selection

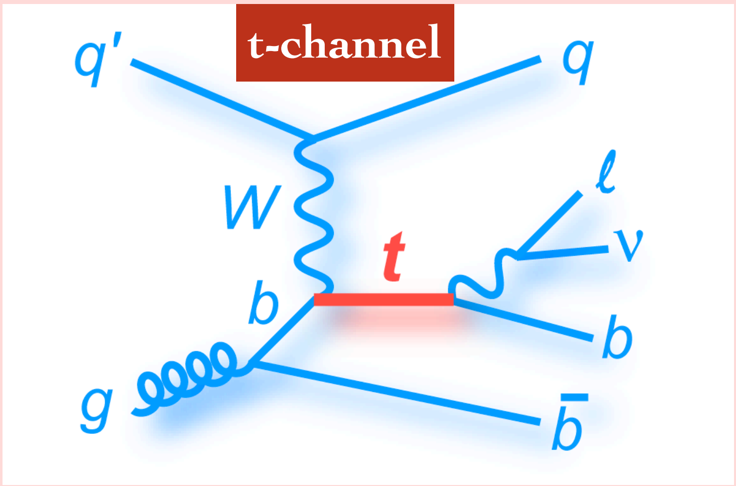
- One high p_T isolated lepton
- Large missing transverse energy
- Two, three and four jets
- B-tagging selection
  - One "tight" jets or Two "loose" jets originating from fragmentation of b quarks.

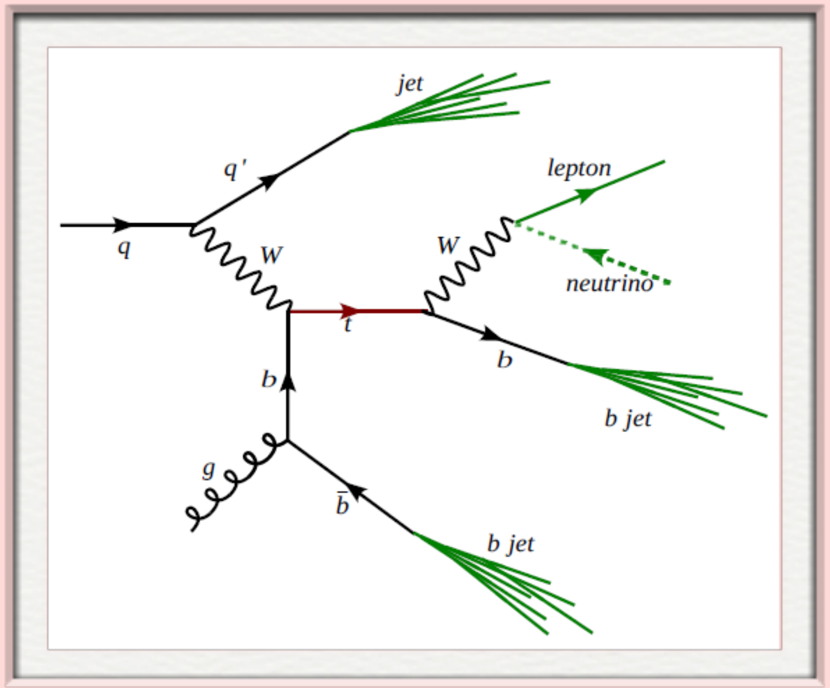
Background Rejection :

- DØ : Cut on scalar sum (H_T and H_T(alljets)) to suppress QCD and soft-scattering processes.
- CDF : Veto QCD, dilepton, Z and cosmic

Still large backgrounds share similar final states after the background rejection.







Signal and Background Modeling

Single Top signal, MC

- COMPHEP-SINGLETOP generator

W+jets, MC

- Largest Background
- ALPGEN-PYTHIA generator
- Normalization and heavy flavor fraction from data

ttbar, MC

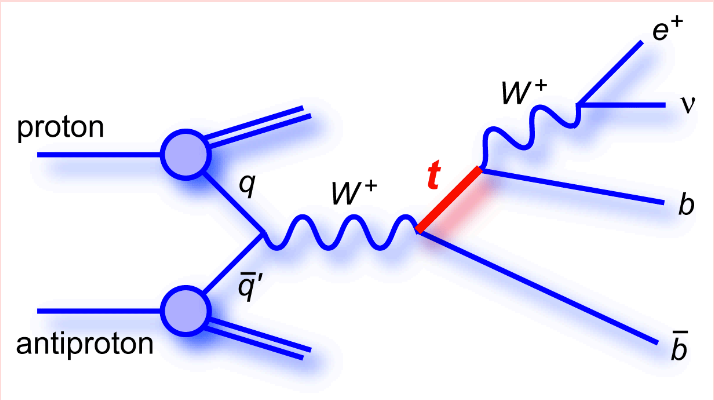
- ALPGEN-PYTHIA generator
- Normalized to σ_{NNLO} = 7.27 pb (PRD 78, 074005 (2008))

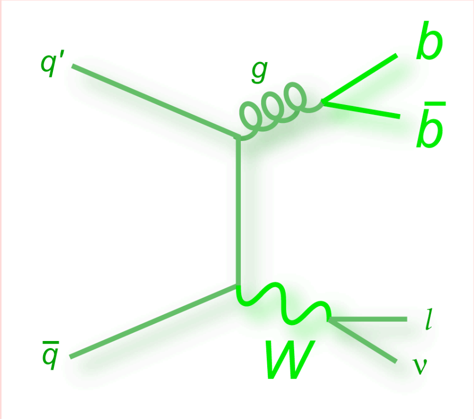
Multijets, MC

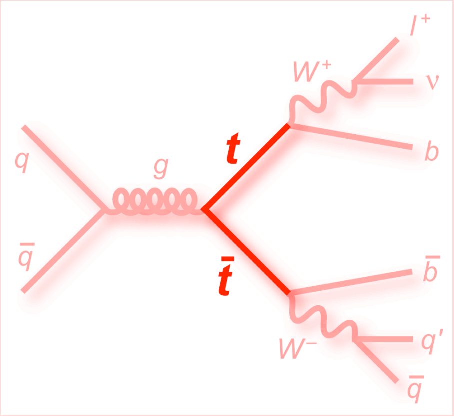
- Orthogonal sample for data
- mis-identified lepton

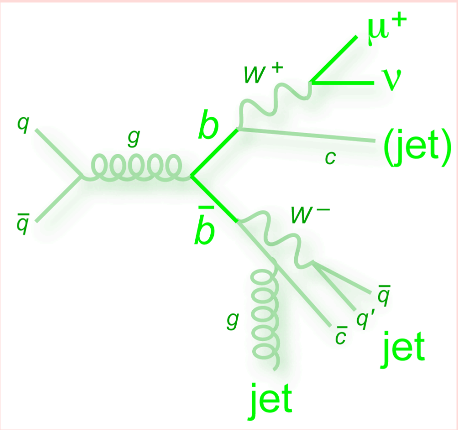
Z+jets and diboson, MC

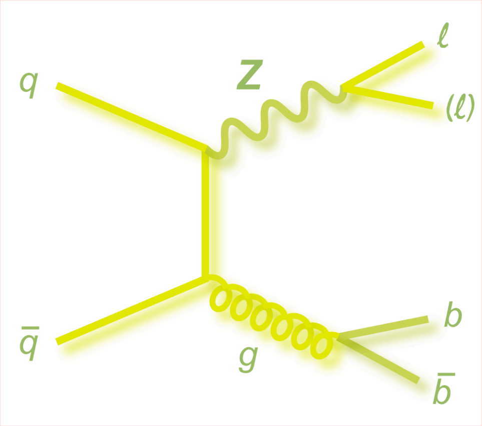
- ALPGEN-PYTHIA generator

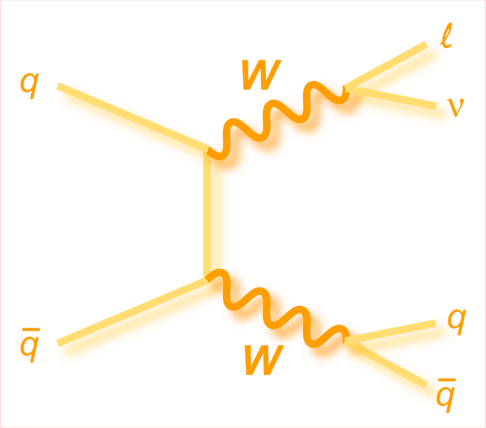












Signal and Background Modeling

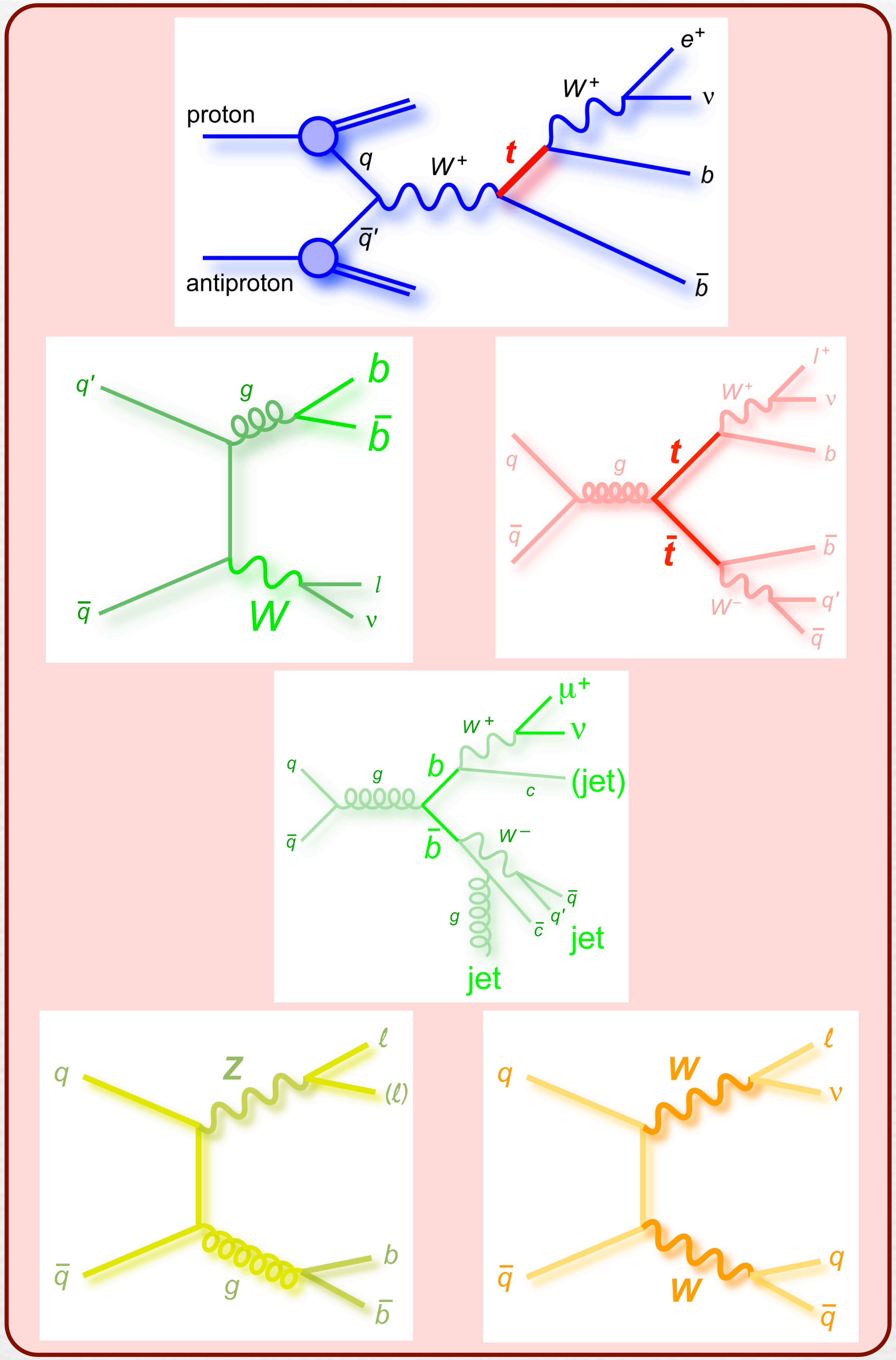
Single Top signal, MC
- POWHEG-PYTHIA generator

W+jets, MC
- Largest Background
- ALPGEN-PYTHIA generator
- Normalization and heavy flavor fraction from data

ttbar, MC
- PYTHIA generator
- Normalized to σ_{NNLO} = 7.3 pb

Multijets, MC
- Orthogonal sample for data
- mis-identified anti-lepton

Z+jets and diboson, MC
- ALPGEN-PYTHIA generator



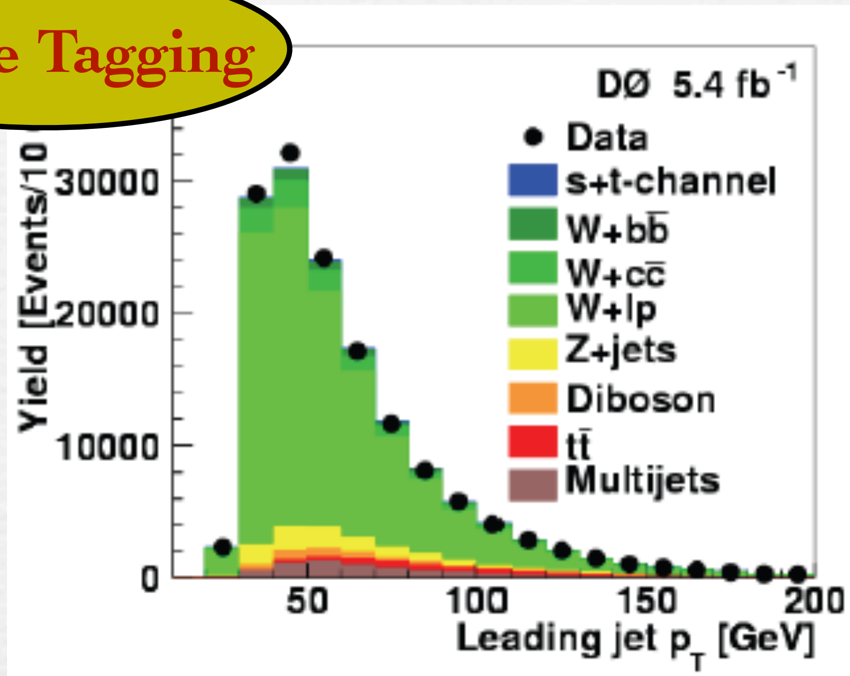
Data-Background Comparison

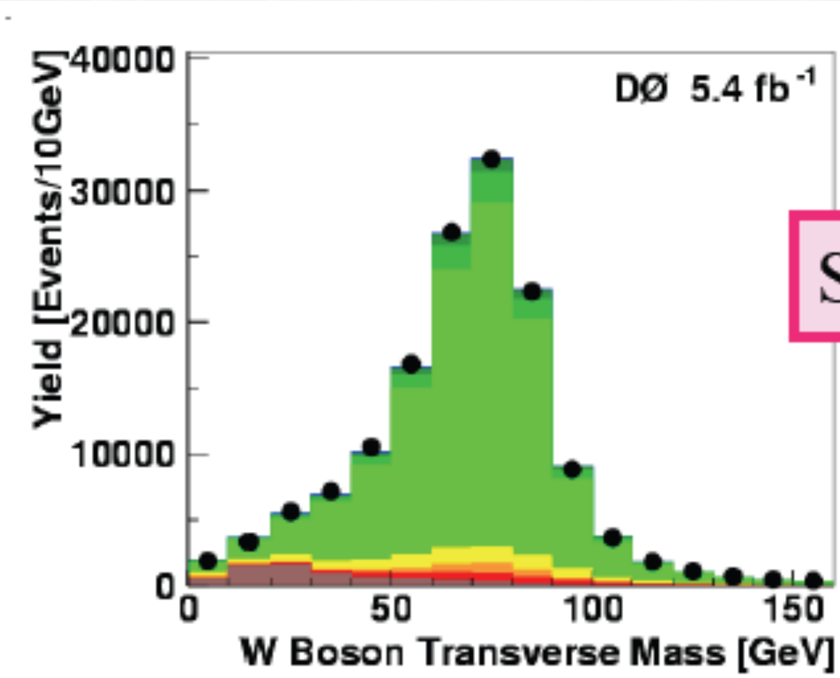
Event yields in 5.4/fb DØ data	
e,μ, 2,3,4-jets 1,2-tags combined	
t-channel	239 ± 28
s-channel	160 ± 27
W+jets	4943 ± 598
Z+jet, dibosons	576 ± 113
tt	2124 ± 383
Multijets	451 ± 56
Total prediction	8492 ± 987
Data	8471 ± 92

Event yields in 7.5/fb CDF data	
e,μ, 2,3-jets 1,2-tags combined	
t-channel	298 ± 39
s-channel	215 ± 20
tW-channel	45 ± 13
W+jets	5797 ± 644
Z+jet, dibosons	452 ± 65
tt	1923 ± 214
Multijets	467 ± 190
Total prediction	9196 ± 1289
Data	8655

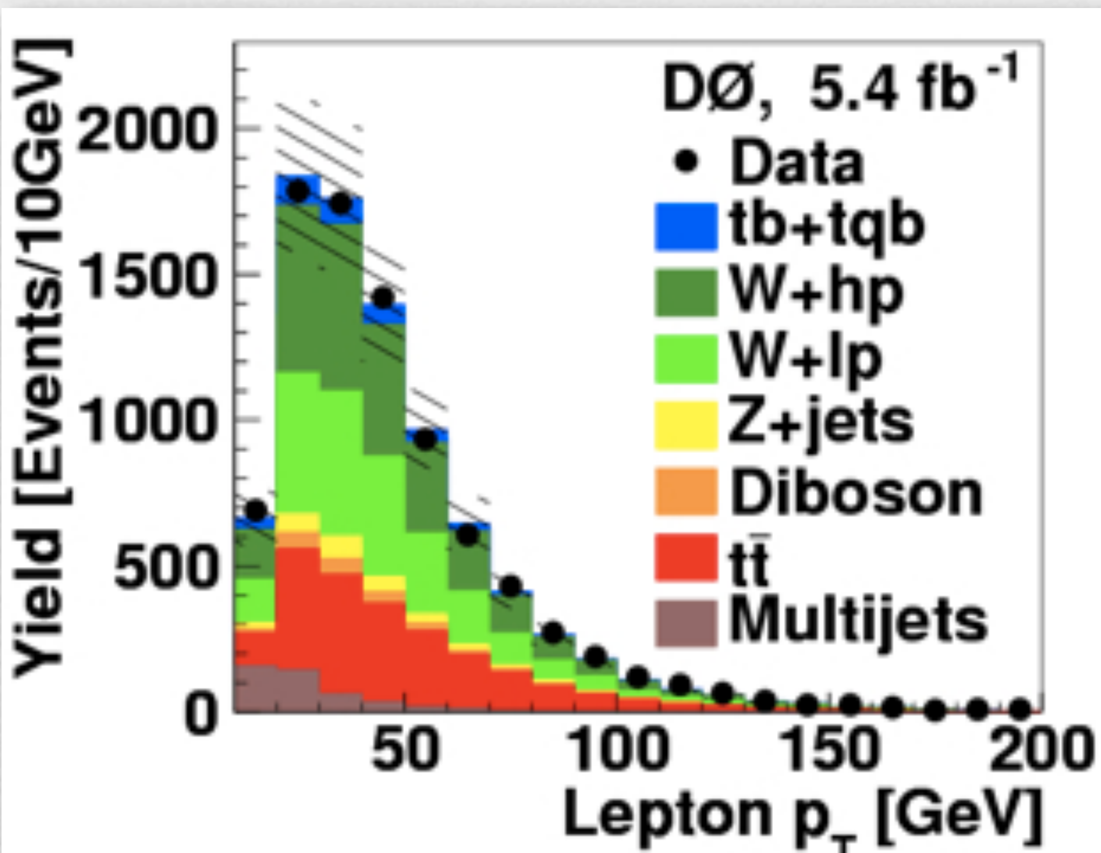
Data-Background Comparison

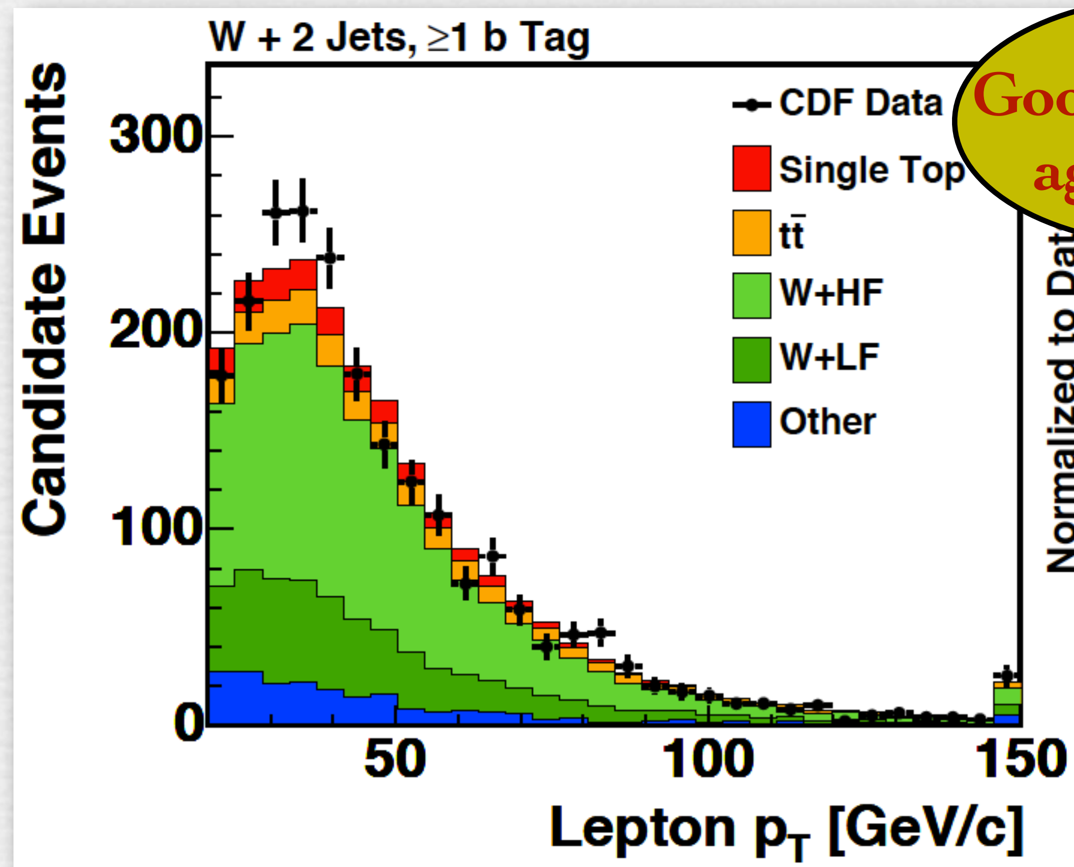
Before Tagging





S:B = 1:224

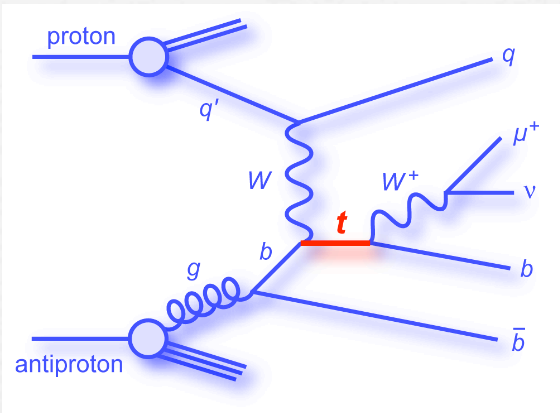




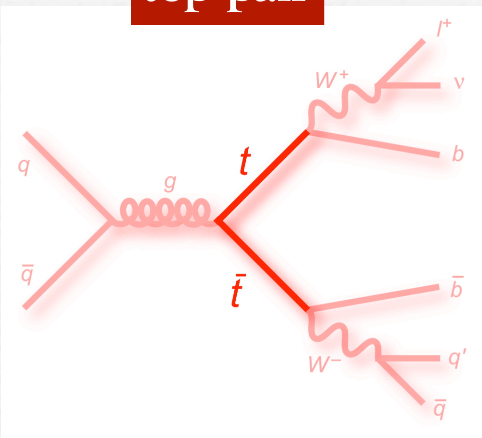
Good data/MC agreement

A Challenging Analysis

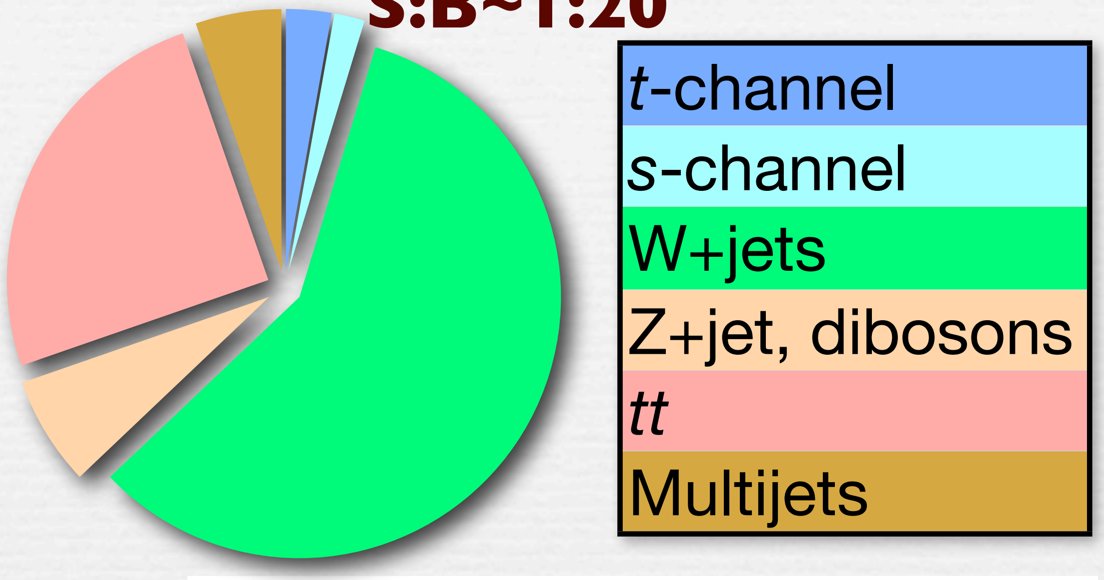
t-channel



top-pair

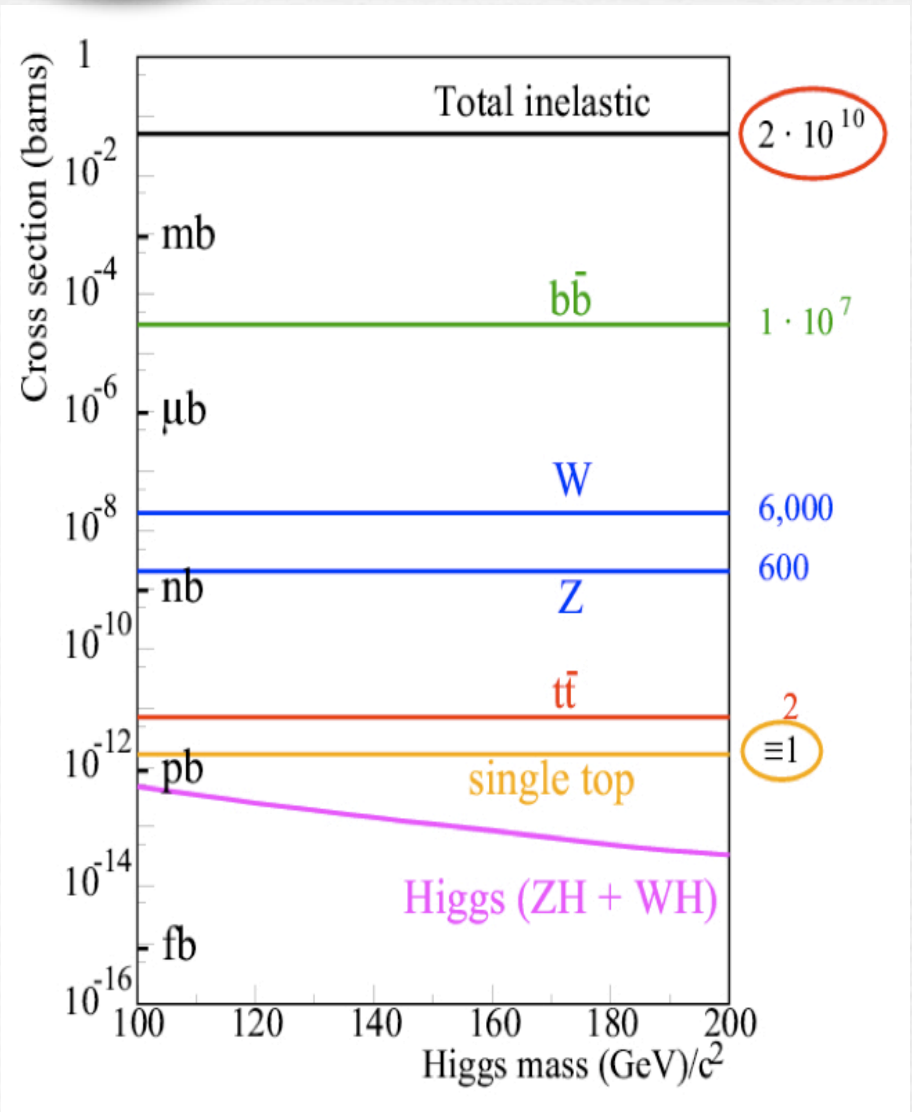


S:B~1:20



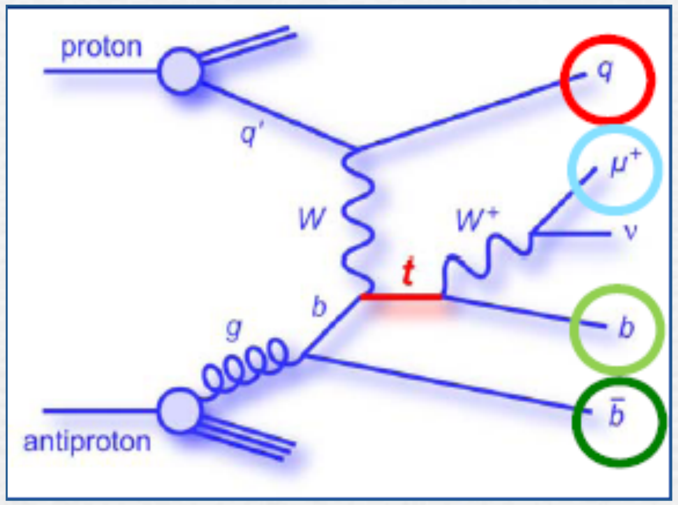
Experimentally Very Challenging :

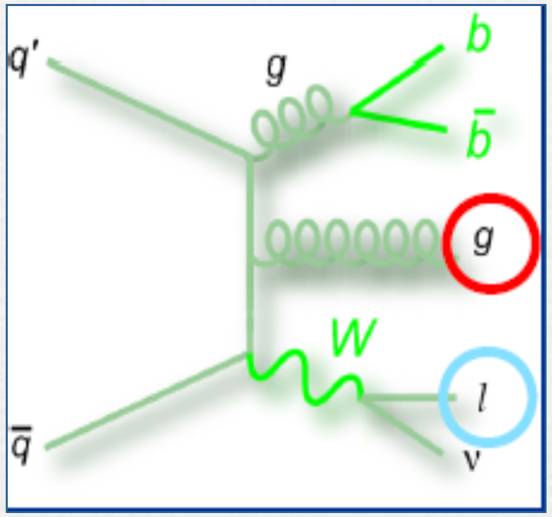
- Observed at Tevatron 14 years after the observation of top quark produced by strong interaction.
- Smaller cross section as compared to top pair production. (~ 1/2 of ttbar)
- Background dominated after b-jet identification S:B ~ 1:20. And **expected single top is still smaller than the uncertainty on the background**.
- ttbar, multijets, W+jets backgrounds mimics signal signature very closely.
- Counting experiment not possible !



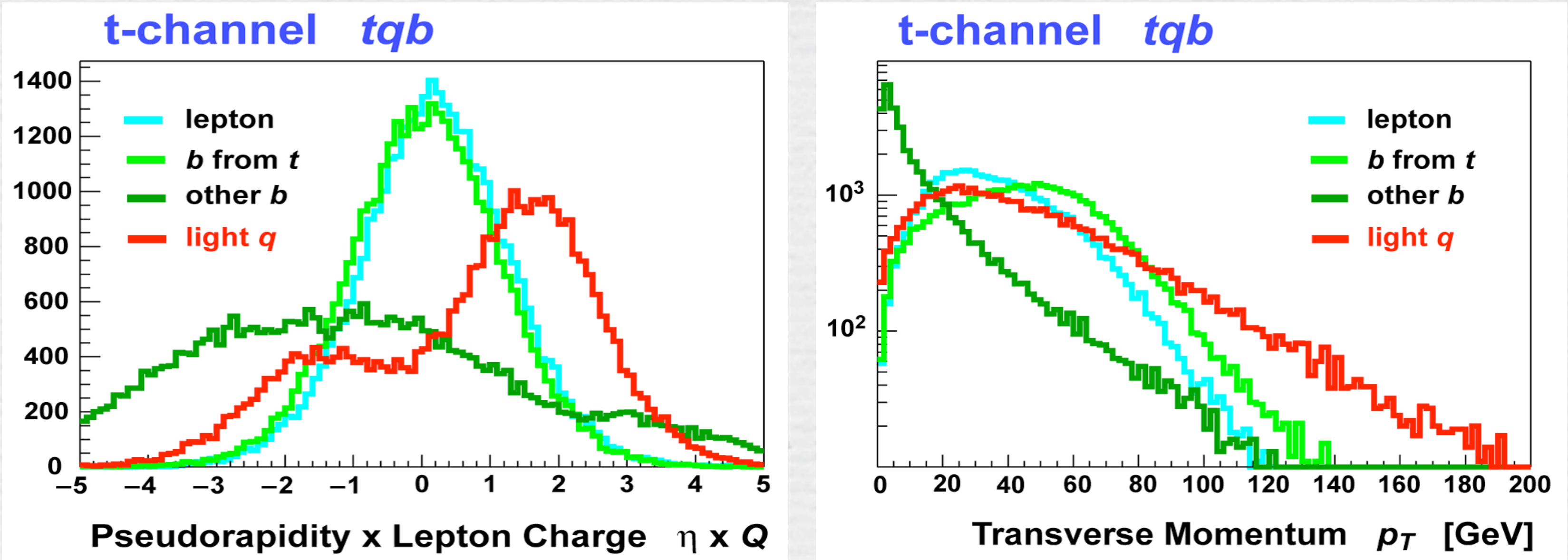
Multivariate Analysis

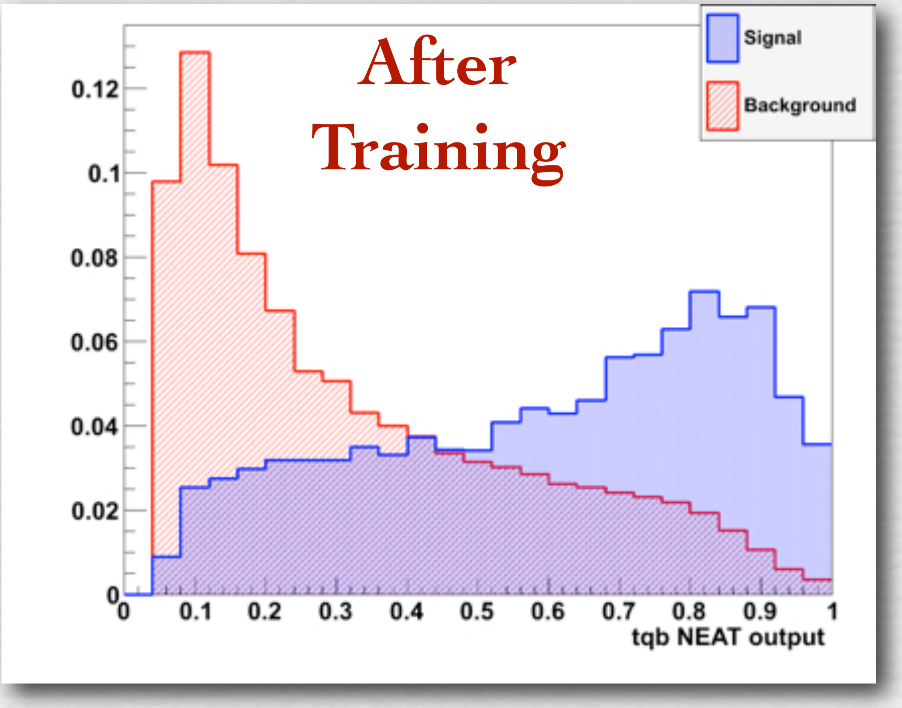
➢ **Exploit kinematic differences between signal and background. Combined different distribution with some discrimination power in one variable with larger discrimination.**





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.

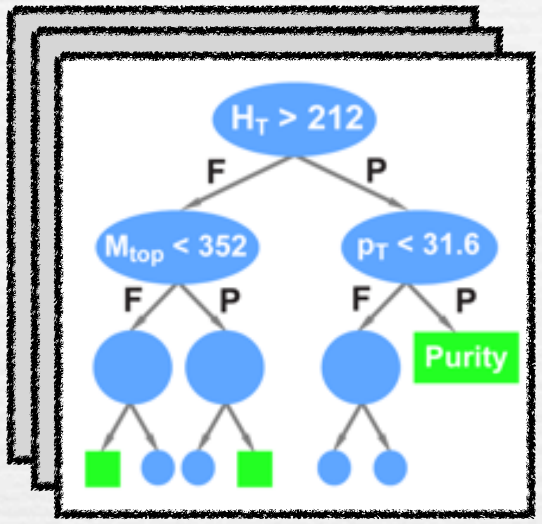




Multivariate Analysis Techniques

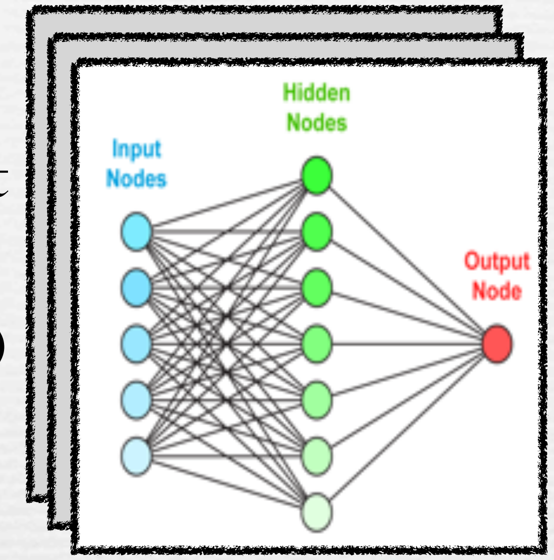
Boosted Decision Tree (BDT)

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



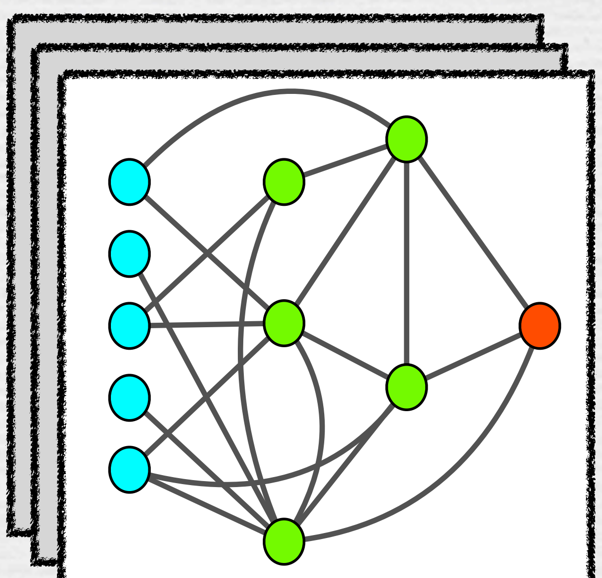
Neural Networks (NN)

- 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)

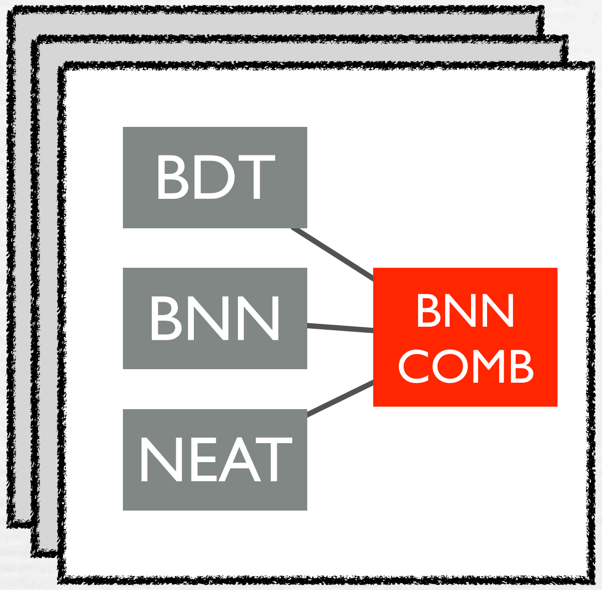
- Genetic algorithms evolve a population of NN.
- Topology of the NN is also part of the training.

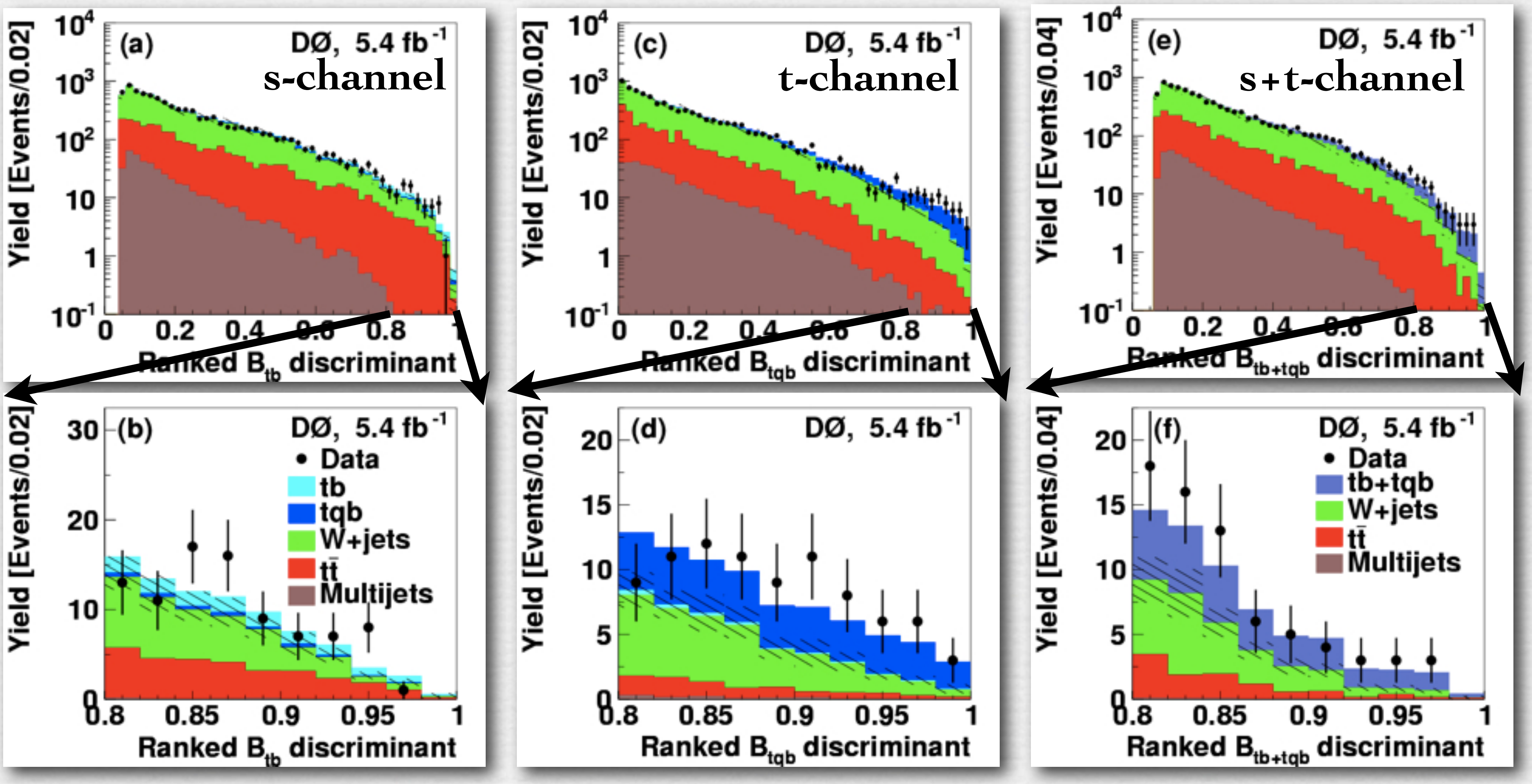


- Use three multivariate method to extract signal.
- Six analysis channels : 2, 3 or 4-jets & 1 or 2 b-tags
- Each MVA method trained separately for s- and t-channel.

MVAs Combination

- All 3 MVAs are ~ 70% correlated
- Combined 3 MVAs with a final combination BNN
- Combined s- and t-channel discriminant with SM predicted relative ratio.





Cross Section Measurement

- **Bayesian approach is used**

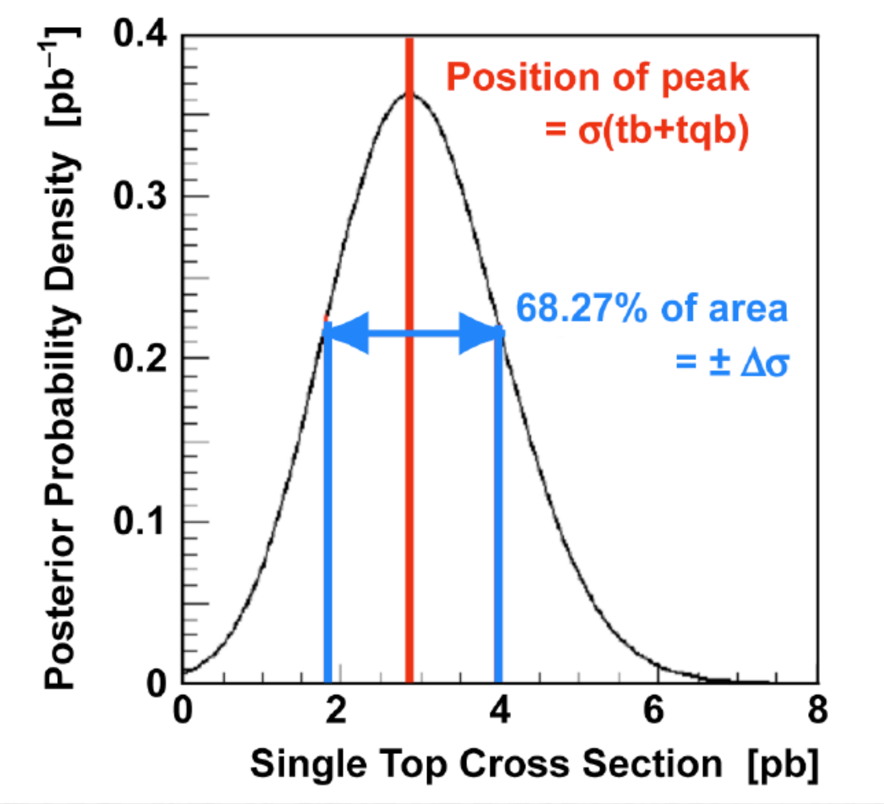
$$d = S + B = \sigma \mathcal{A}\mathcal{L} + B = \sigma a + \sum_{i=1}^{\text{Nbkgds}} b_i$$

d = Predicted number of data events
S = Predicted number of signal events
B = Predicted number of background events
σ = Cross section
$\mathcal{A}$ = Signal acceptance
$\mathcal{L}$ = Integrated luminosity
a = Effective luminosity
b_i = No. of events in each background component

$$\text{Prob}(D|d) \equiv \text{Prob}(D|\sigma, a, \mathbf{b}) = \prod_{i=1}^{\text{Nbins}} \text{Prob}(D_i|d_i)$$

D = Observed number of data events
$\mathbf{b}$ = Vector of background components

$$\text{Posterior Probability Density}(\sigma|D) \propto \int_a \int_{\mathbf{b}} \text{Prob}(D|\sigma, a, \mathbf{b})\ \text{Prior}(a, \mathbf{b})\ \text{Prior}(\sigma)\ da\ d\mathbf{b}$$



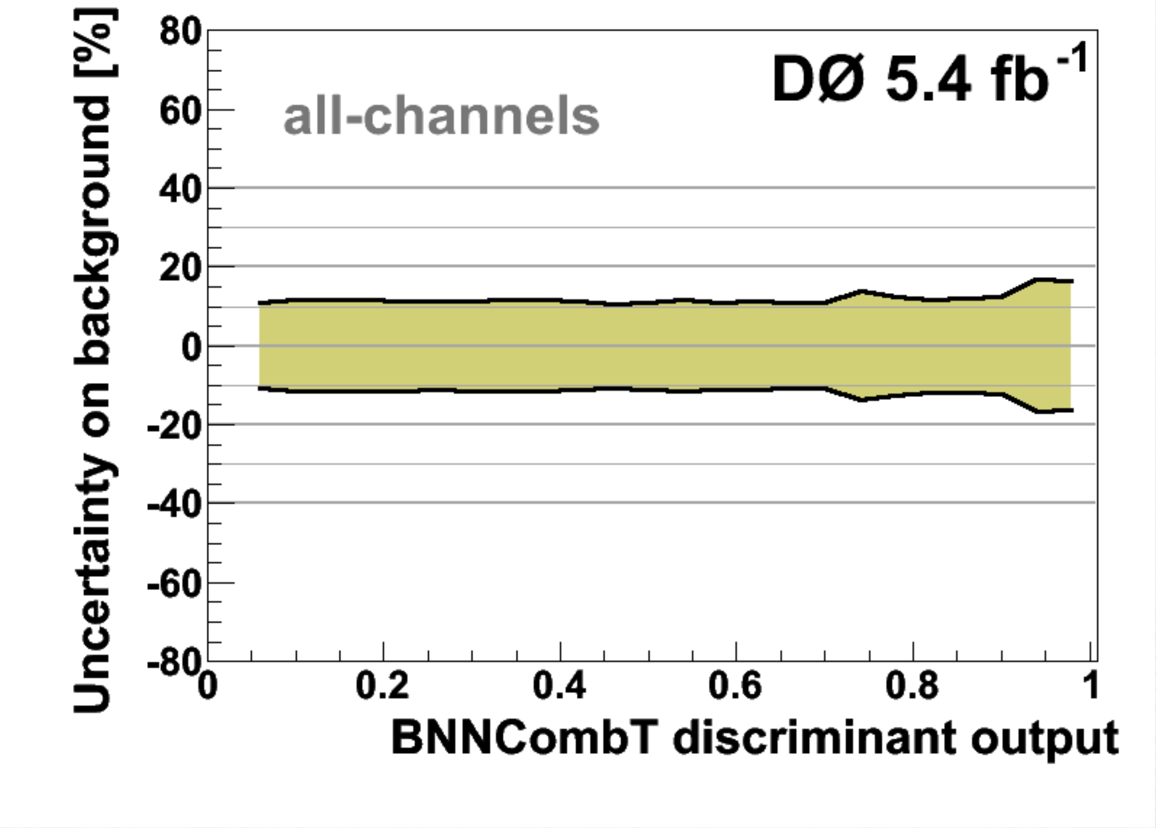
- A flat prior for σ (Prior(σ)) is used.
- Prior(a,**b**) include the shape and normalization systematic uncertainties.

Cross-Section is obtained from the peak position of the posterior prob. density.

Systematics Uncertainties

Main Sources of systematic uncertainties :

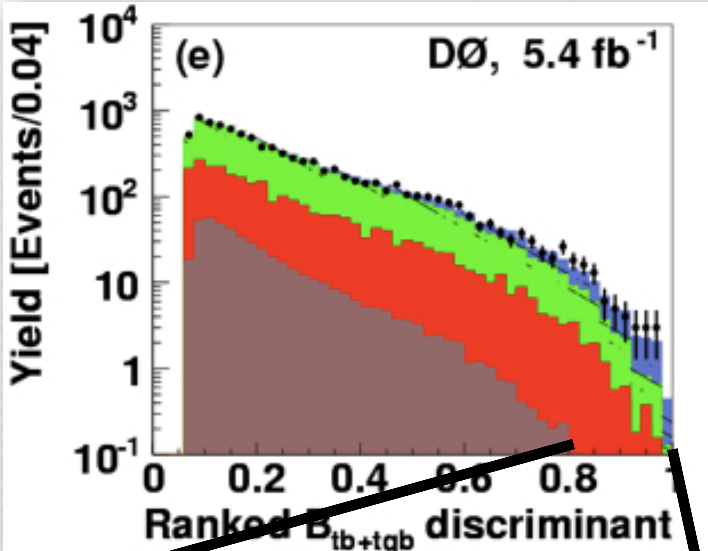
- Jet Energy Scale (0-15%)
- Jet Energy Resolution (0-12%)
- W+jets heavy flavor scale factor (12%)
- Taggability and B-tagging (6-21%)
- Integrated Luminosity (6%)

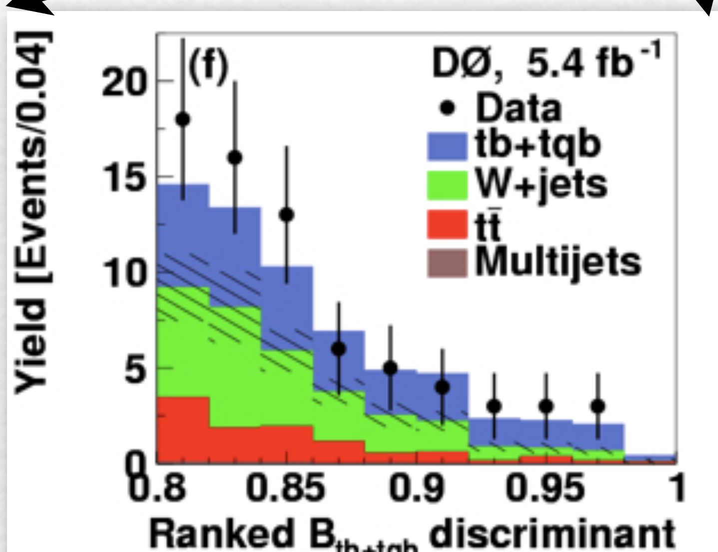


Other Source of uncertainties :

- Color reconnection (1%)
- Relative b/light-jet calorimeter response (<1%)
- Higher order jet fragmentation effects (few % for ttbar)

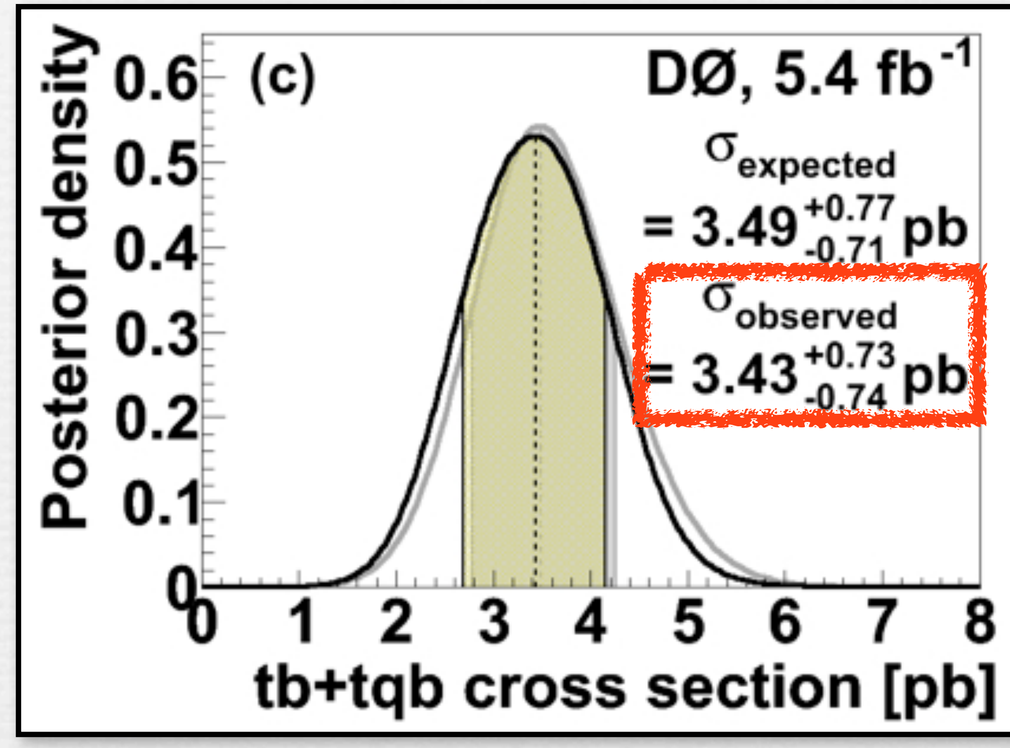
s+t-channel cross section and $|V_{tb}|$



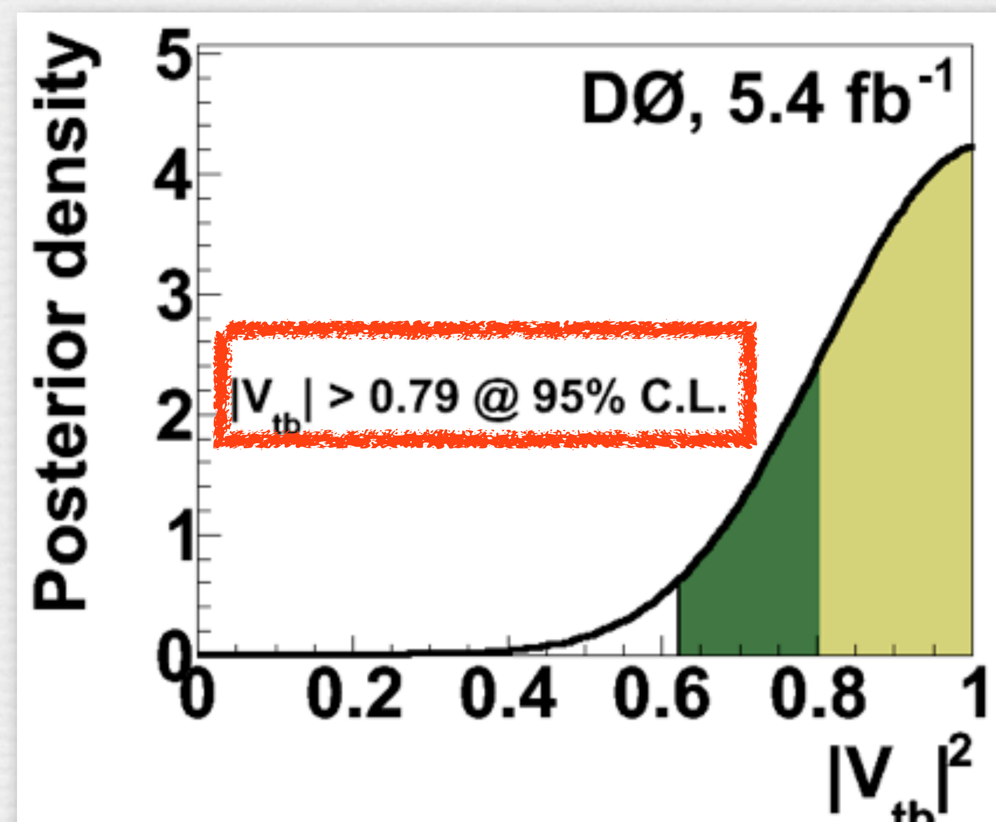


Bayesian Statistical Analysis

PRD 84, 112001 (2011)



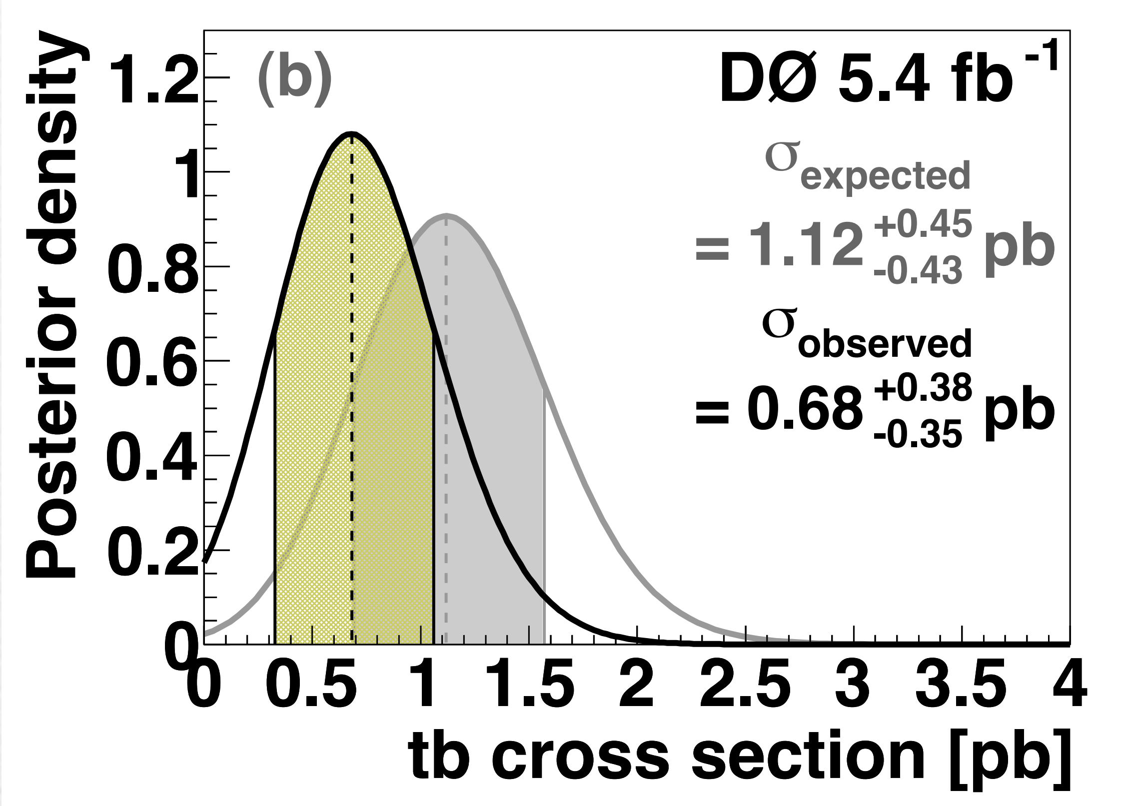
$$|V_{tb} f_L^1|^2 \propto \sigma(s + t\text{-channel})$$



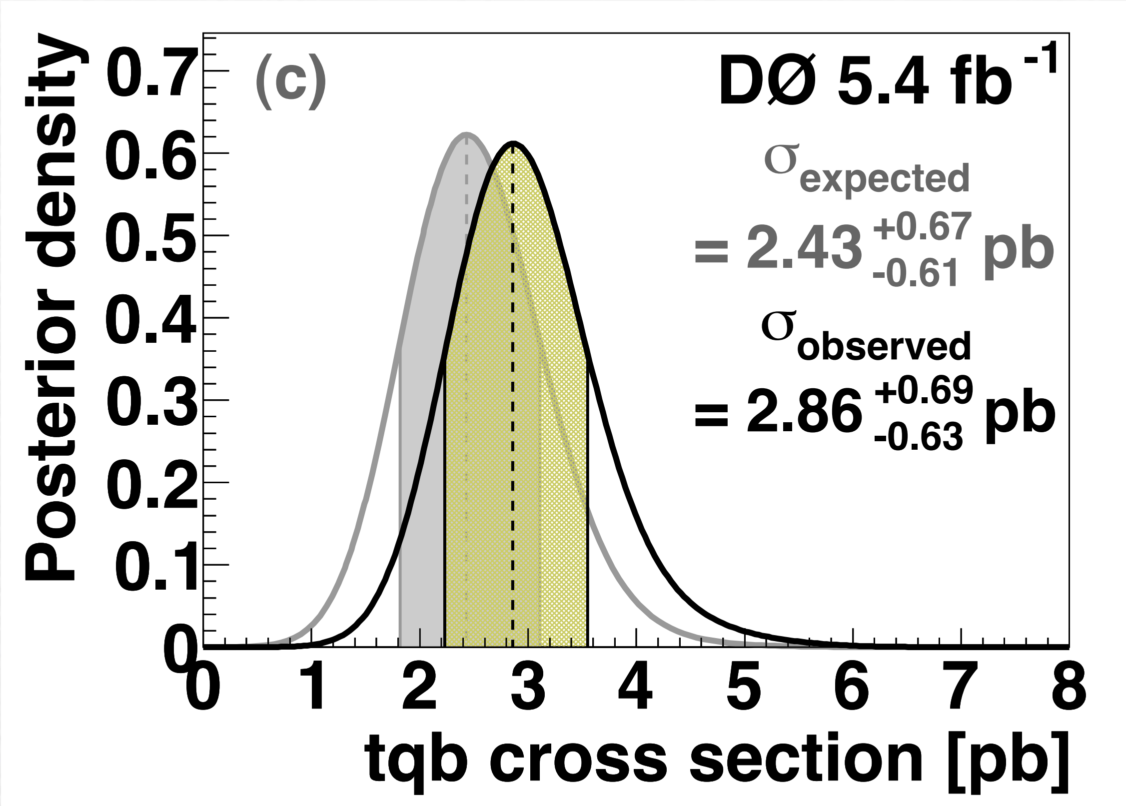
- Pure V–A and CP-conserving interaction.
- $|V_{td}|^2 + |V_{ts}|^2 << |V_{tb}|^2$
- Doesn't assume 3 generations or unitarity of the CKM matrix.

Separate s- and t-channel 1D measurements

s-channel



t-channel



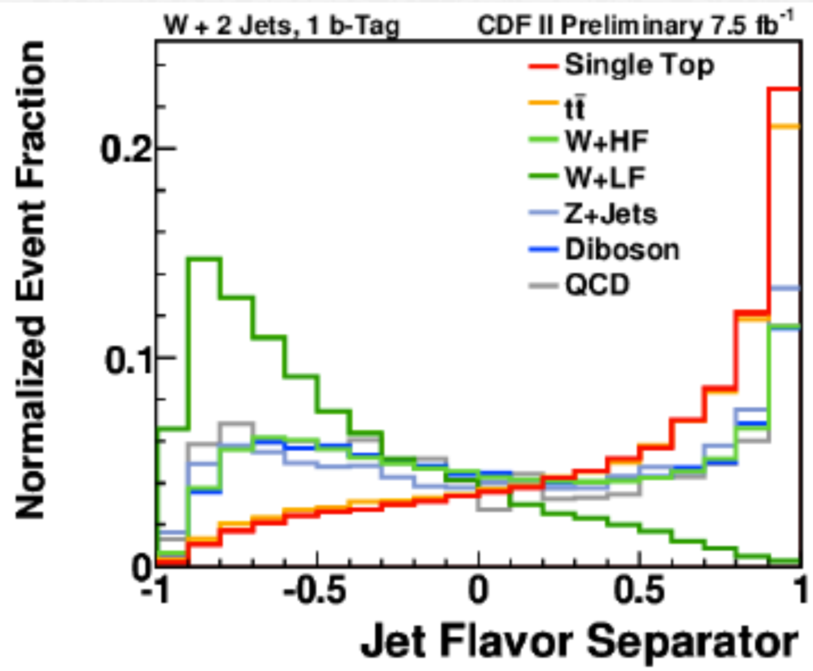
- $\sigma_s = 0.68^{+0.38}_{-0.35}$ pb
- We found no evidence for s-channel yet.

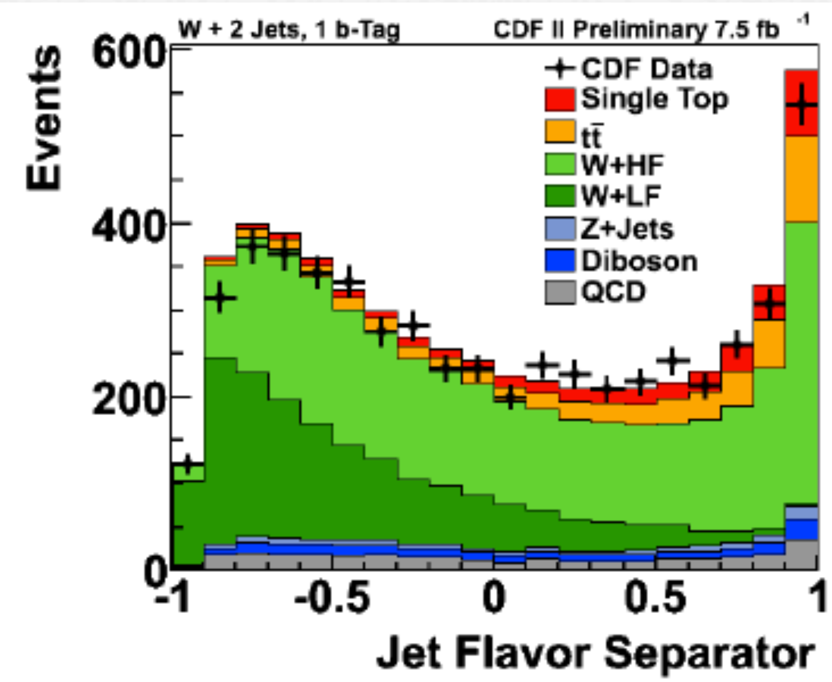
- $\sigma_t = 2.86^{+0.69}_{-0.63}$ pb
- **5.5σ !** First Observation of single top t-channel

PRD 84, 112001 (2011)

Neural Networks

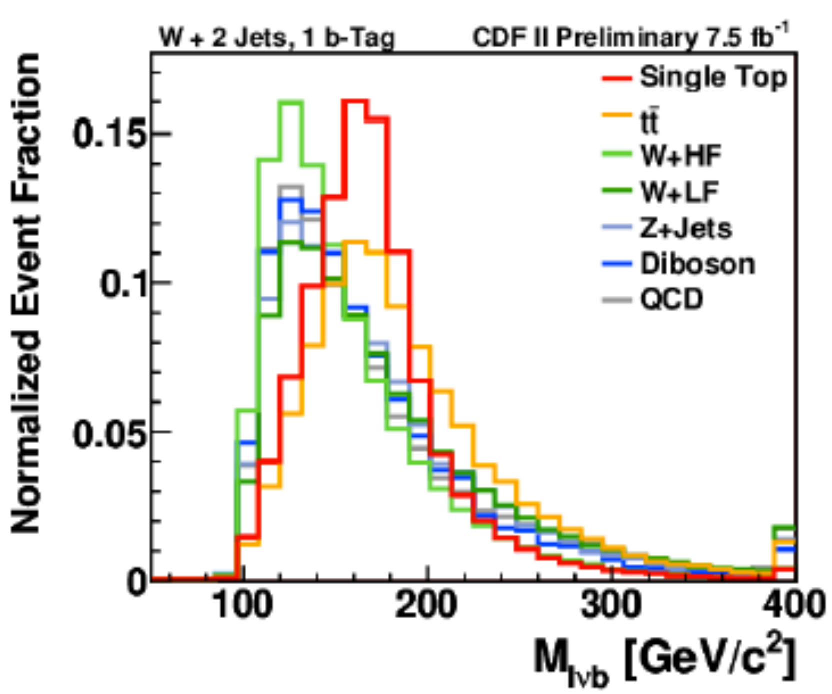
- Train the NN with ~11-14 variables in four channels (2, 3-jets with 1, 2 b-tags)

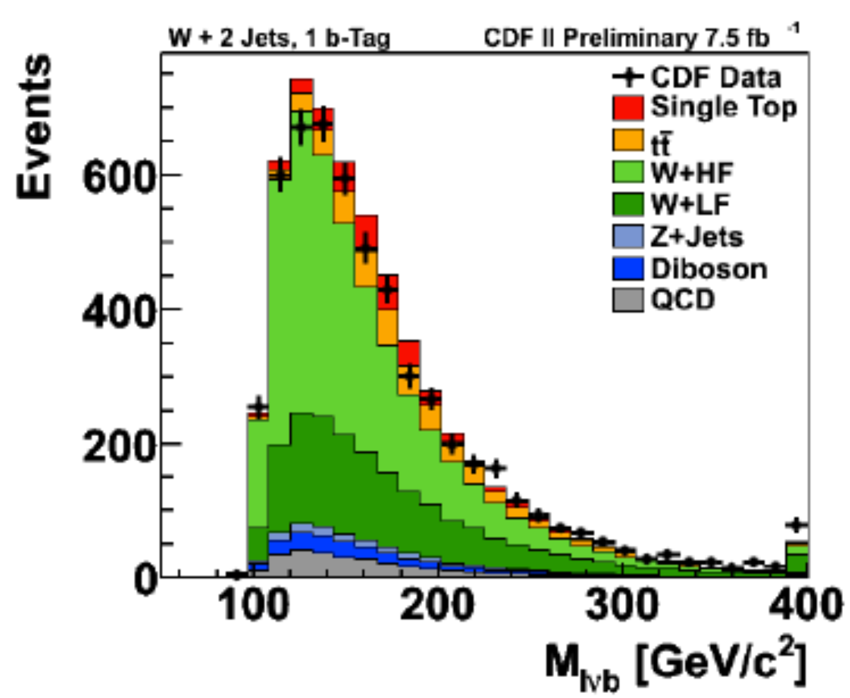


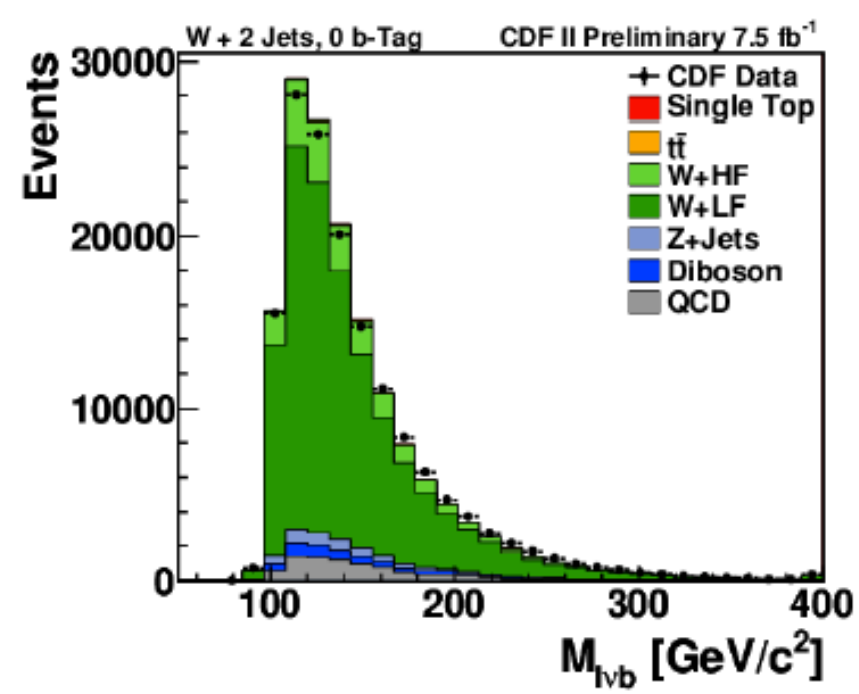


NN jet flavor separator

Reconstructed top mass

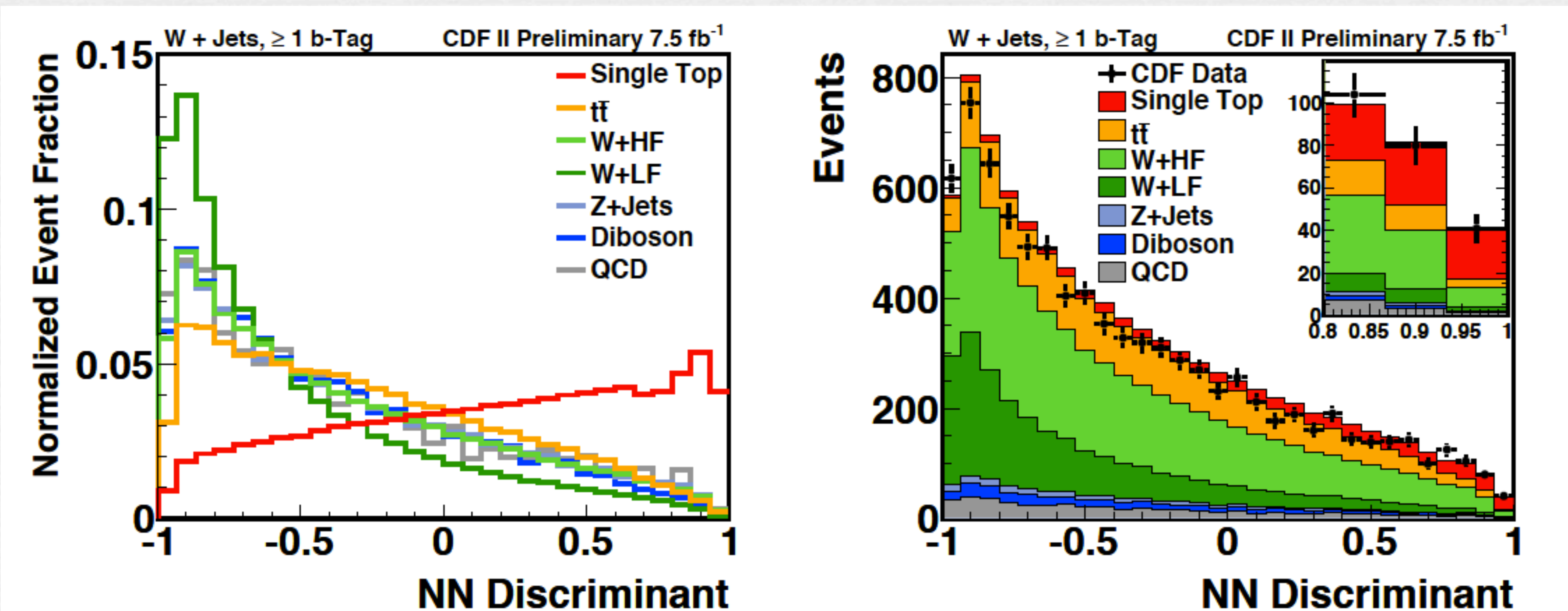






NN Training and Discriminant

- Train for s-channel in 2 jet 2 b-tags and train for t-channel in rest of the channels.
- To further improve the measurement, Train the NN with systematic mixed samples for better uncertainty constraint (~ 3% improvement expected on the uncertainty of cross section measurement).



Systematics Uncertainties

Main Sources of systematic uncertainties :

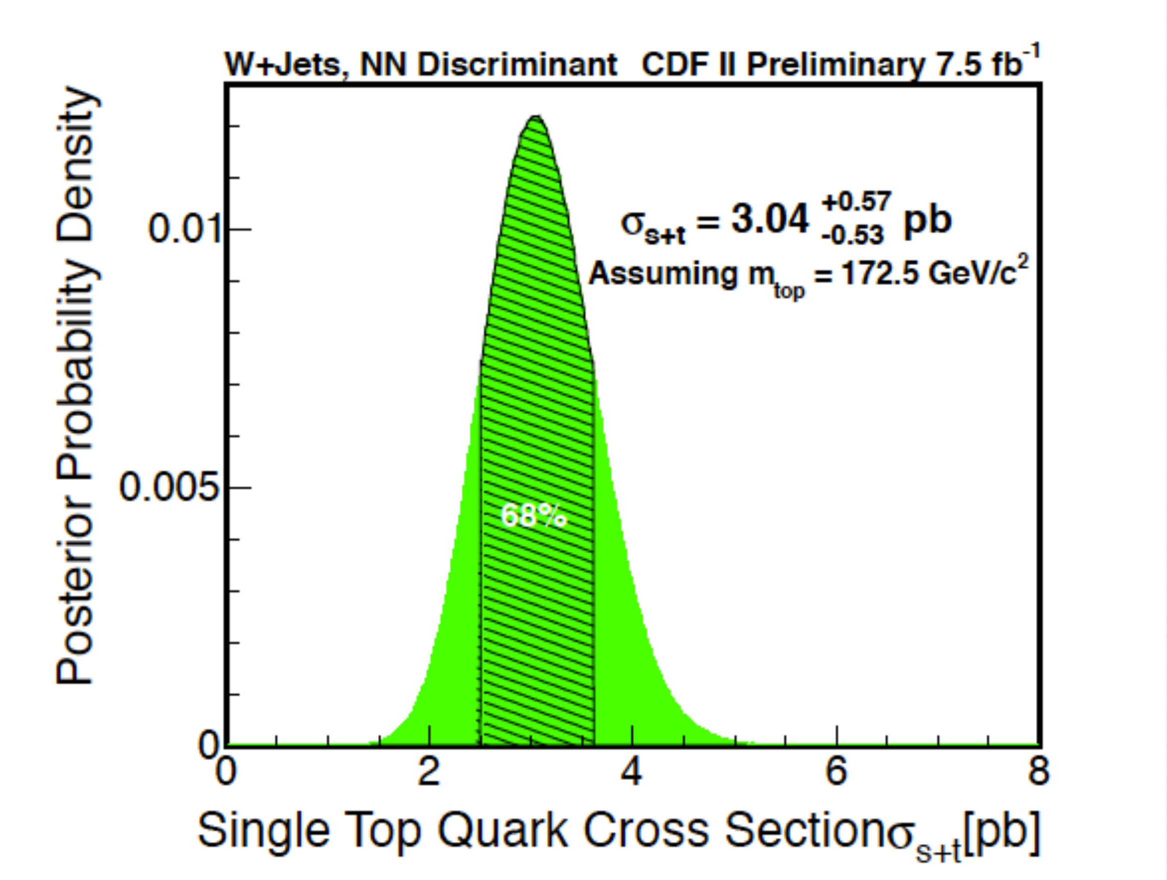
- Jet Energy Scale (0 - 8%)
- Initial and Final state radiation (0 - 6%)
- W normalization (30%)
- Taggability and B-tagging
- Integrated Luminosity (6%)

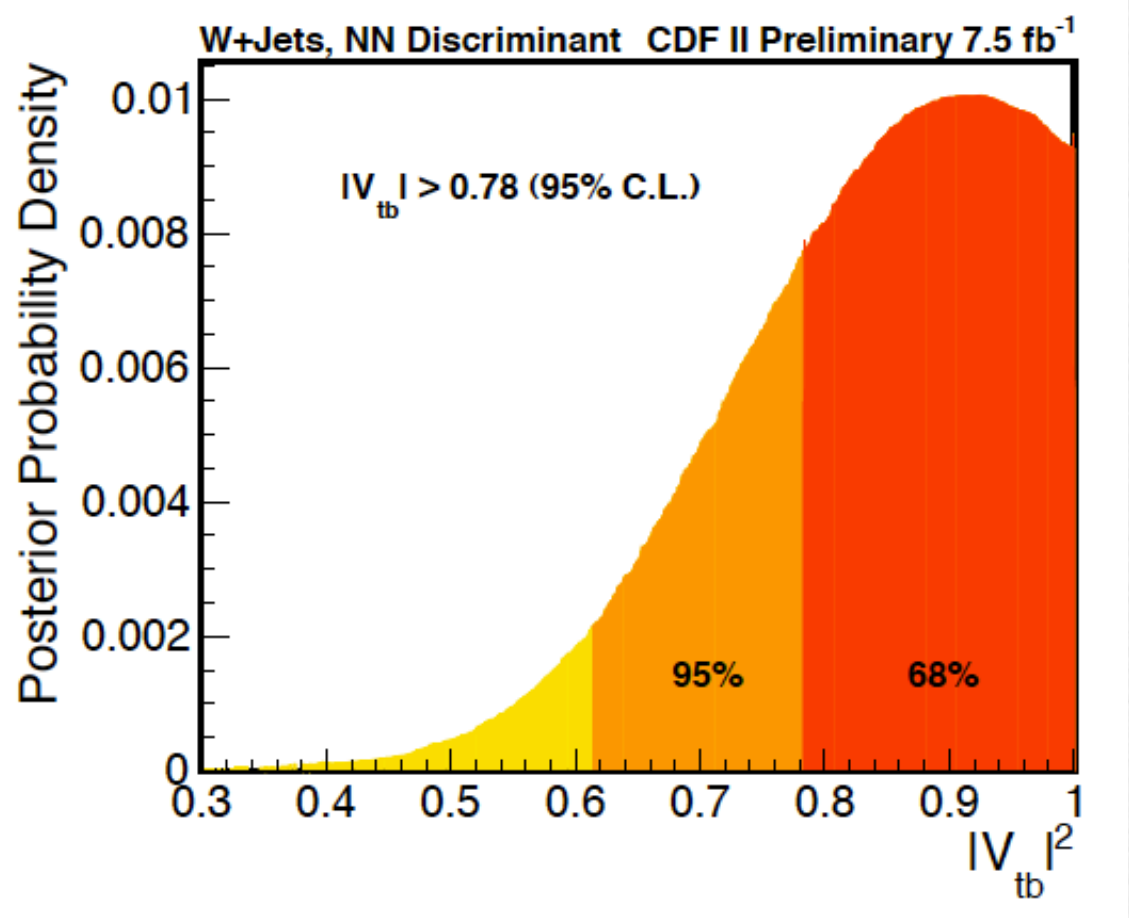
Other Source of uncertainties :

- Parton Distribution Functions (1%)
- Mistag normalization (8%)
- MC generator (3 - 7%)

s+t-channel cross section and $|V_{tb}|$

- Cross-section is measured using standard CDF MClimit package
- Systematic uncertainties are handled as Bayesian nuisance parameters.
- $\sigma_{s+t} = 3.04^{+0.57}_{-0.53}$ **pb**, assuming $m_{top} = 172.5\ GeV/c^2$





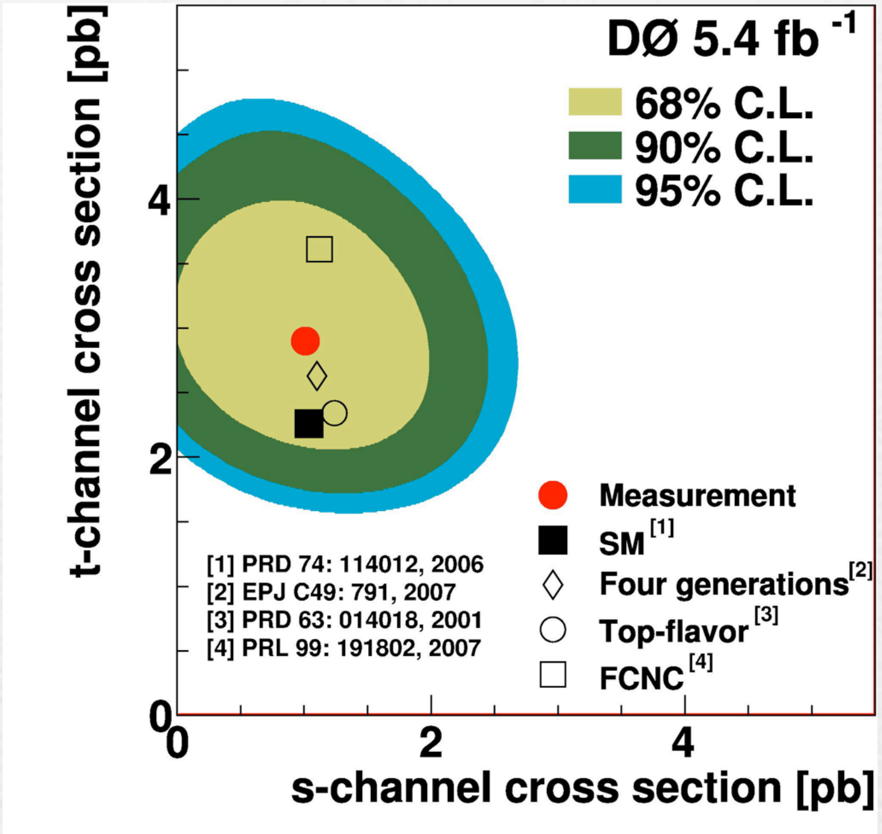
$$|V_{tb,meas}|^2 = \frac{\sigma_{meas}}{\sigma_{SM}} \cdot |V_{tb,SM}|^2$$

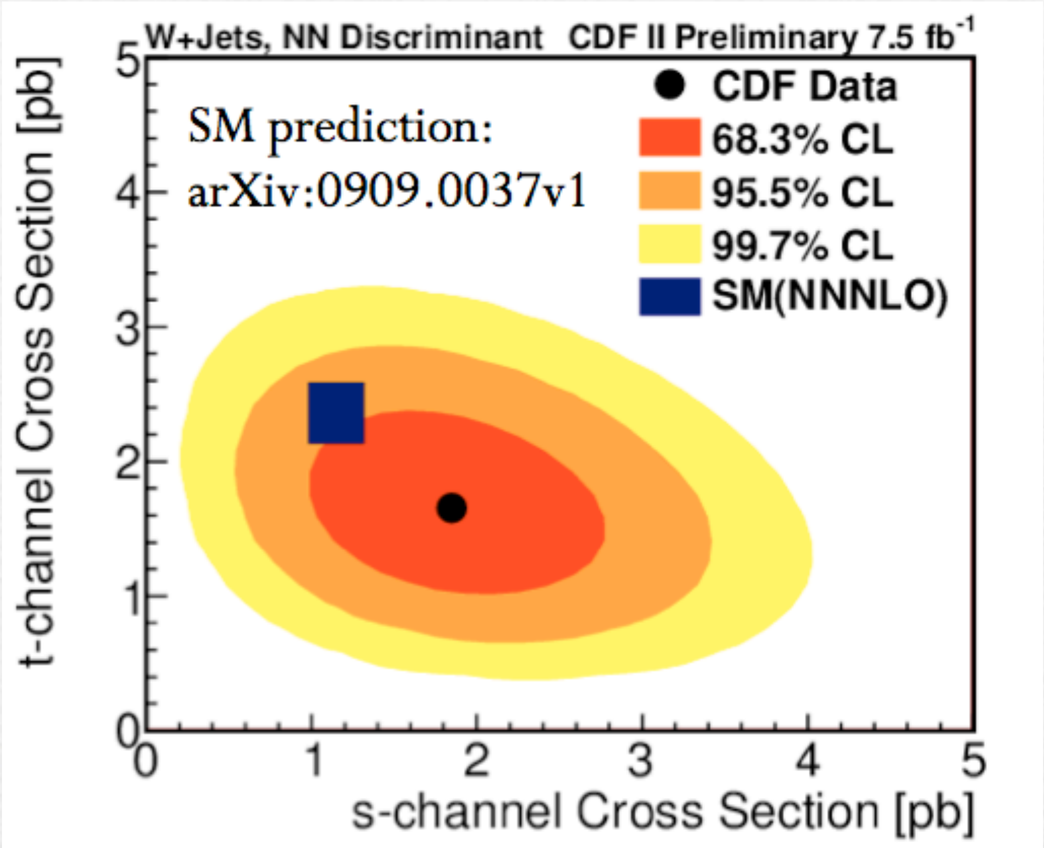
- From the Cross-section posterior

Set limit : $|V_{tb}|$ > **0.78 at 95% C.L.**

Simultaneous 2D measurement

- Remove s/t channel constraint which could be changed by new physics.





Measured cross section

- σ_s = 0.98 ± 0.63 pb
- σ_t = 2.90 ± 0.59 pb

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In Agreement with SM prediction

Measured cross section

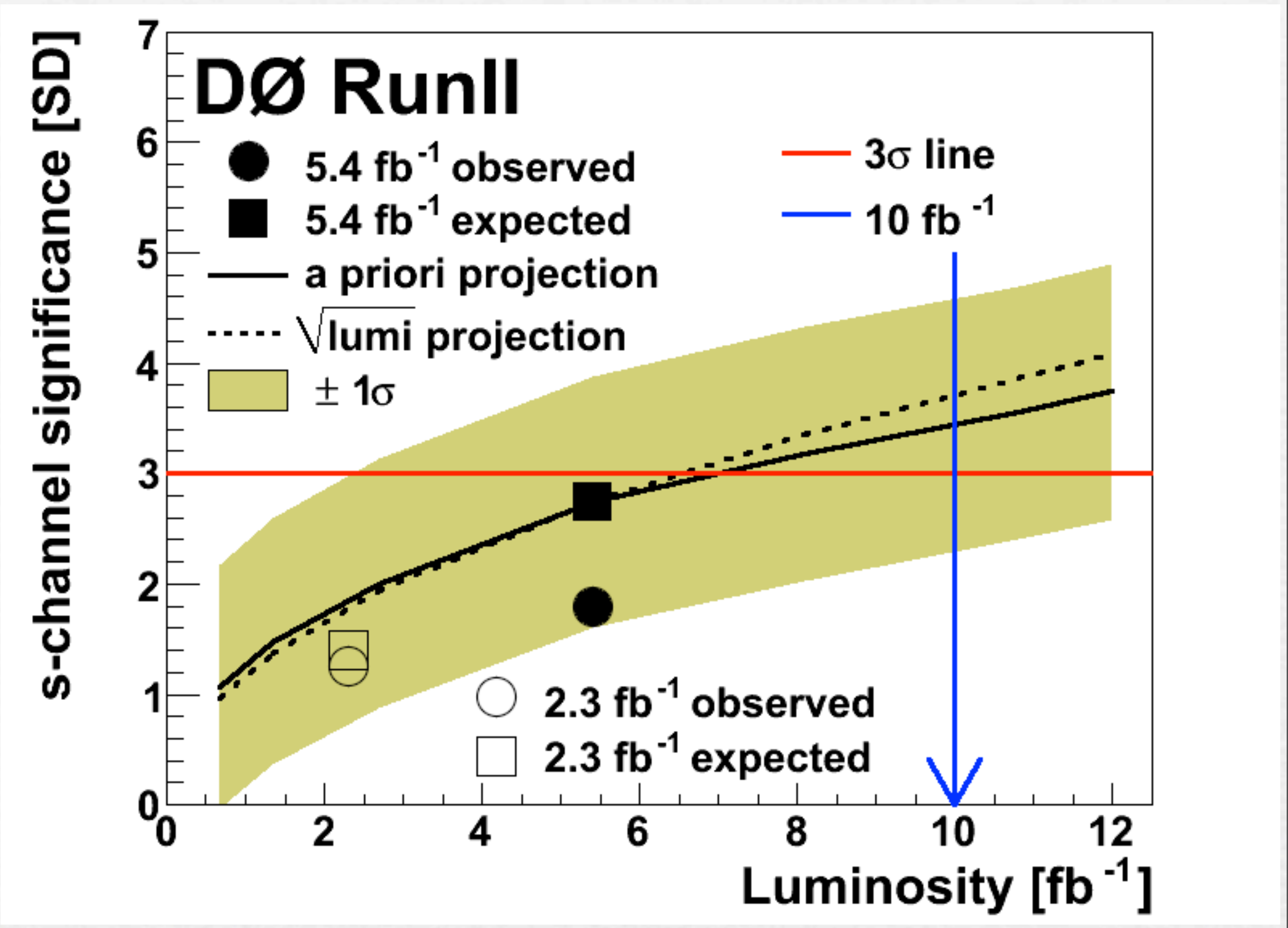
- $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb
- $\sigma_t = 1.49^{+0.47}_{-0.42}$ pb

SM Prediction

- σ_s = 1.04 ± 0.04 pb
- σ_t = 2.26 ± 0.12 pb

Perspectives

- Legacy with full dataset: **s-channel**
  - Only 4X higher production rate at LHC with even more background



- Till Now ::
  - DØ : **3.0σ** of expected sensitivity with 5.4 fb^{-1} of data.
  - CDF : sensitivity not calculated but about **3.0σ** with 7.5 fb^{-1} of data.

- With full dataset ::
  - **Evidence** per experiment possible
  - **Observation** with **DØ + CDF combination** ??

Summary

- Presented the most recent measurement of **single top quark production cross section** using 5.4 fb^{-1} DØ data & 7.5 fb^{-1} CDF data.
- Planning for new combination of DØ and CDF single top results.
- After the observation of t-channel, the search for s-channel will be a Tevatron legacy measurement.
- Searches like CP violation are still interesting at Tevatron and are in the pipeline.
- Stay tuned for single top measurement with full Tevatron dataset.

DØ Single Top Result Page :

http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html#singletop

CDF Single Top Result Page :

http://www-cdf.fnal.gov/physics/new/top/public_singletop.html

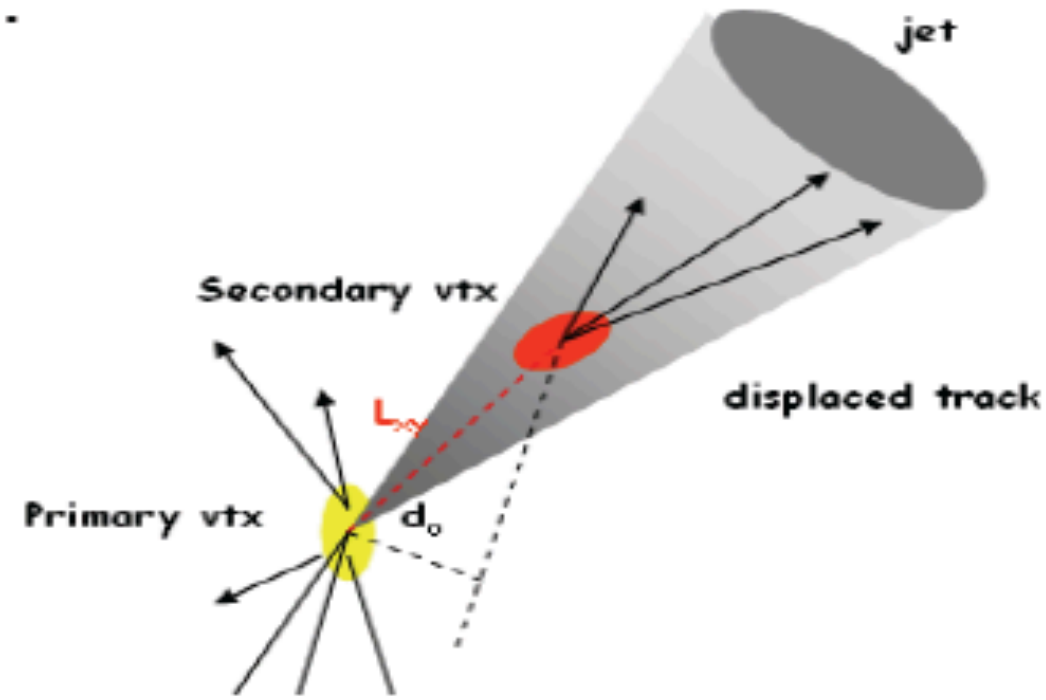

TOP 2012
16 – 21 September 2012
Winchester, UK
5th International Workshop on Top Quark Physics
International Advisory Committee:
Juan Antonio Aguilar Saavedra (University of Granada)
Werner Bernreuther (RWTH, Aachen)
Martine Bosman, chair (IFAE, Barcelona)
Roberto Chierici (CNRS, CERN)
Markus Cristinziani (University of Bonn, CERN)
Jorgen D'Hondt (VUB, Brussels)
Local Organizing Committee:
Veronique Boisvert, chair (Royal Holloway, University of London)
Lucio Cerrito (Queen Mary, University of London)
Akram Khan (Brunel University, London)
Contact: top2012@rhul.ac.uk
More info: http://pprc.qmul.ac.uk/top2012
Photo courtesy of Winchester Cathedral

Thanks

BackUp

b-jet Identification

- Separate b-jets from light-quark and gluon jets to reject most W +jets background
- DØ uses a neural network algorithm with seven input variables based on impact parameter and reconstructed vertex
- Two operating points used in analysis:
  - TIGHT ($\varepsilon_b = 40\%$, $\varepsilon_c = 9\%$, $\varepsilon_l = 0.4\%$)
  - LOOSE ($\varepsilon_b = 50\%$, $\varepsilon_c = 14\%$, $\varepsilon_l = 1.5\%$)
- Leading b-jet $p_T > 20$ GeV
- Define two exclusive samples
  - EqOneTag: 1T, no L
  - EqTwoTag: 2L

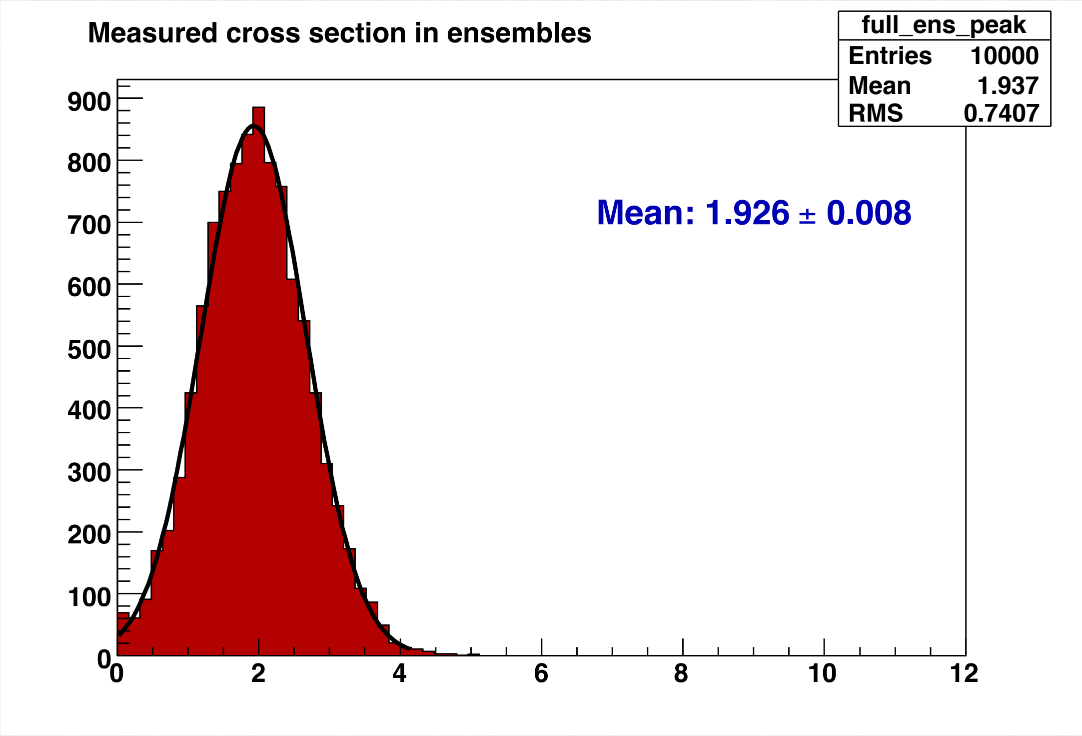


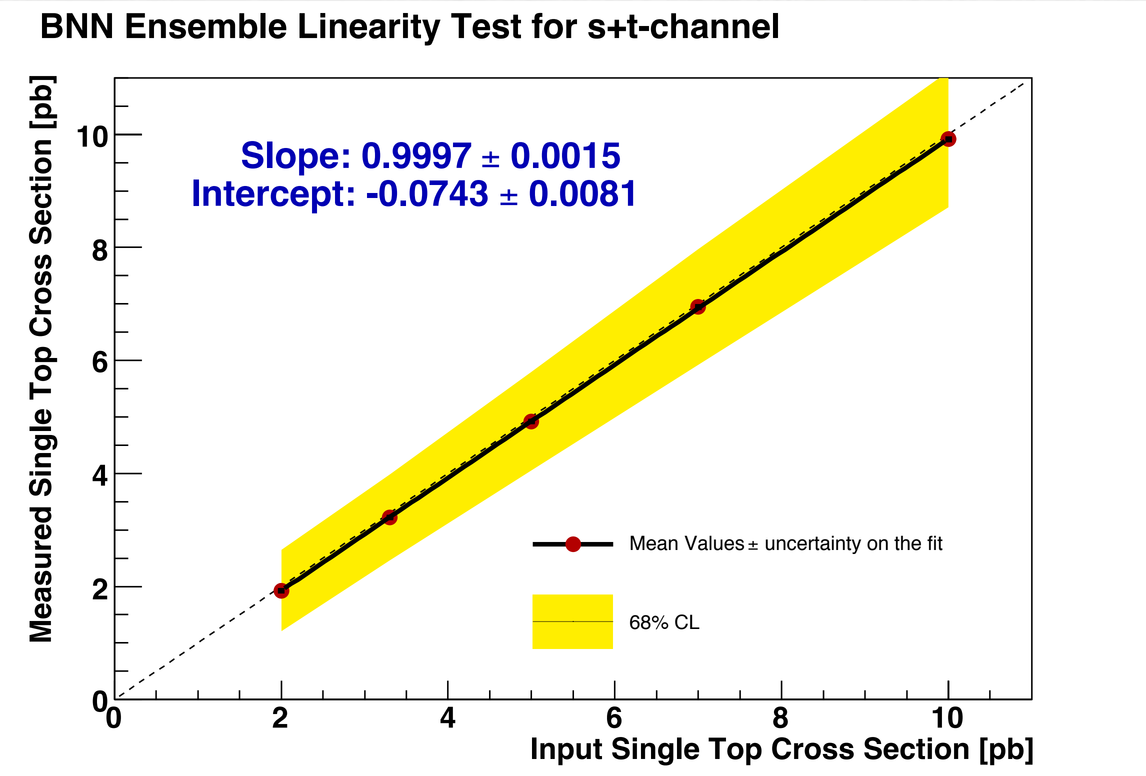
- Uncertainties dominated by variation in data samples used to measure the efficiencies.
- Smaller contribution from MC sample dependence

Ensembles - Linearity test

Test of machinery with many sets of pseudo-data. To ensure no bias in the cross section measurement.

- Subset of our total pool of background events.
- Systematic uncertainties are fully taken into consideration
- Generated several ensembles with different single top content
- The bias is determined from straight-line fit to the mean of distributions vs. input cross-sections.





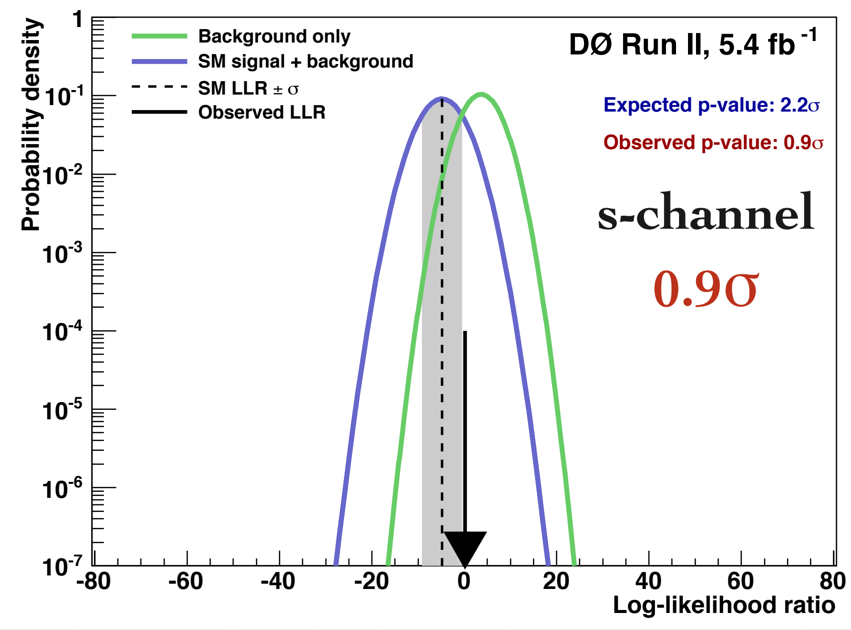
Significance

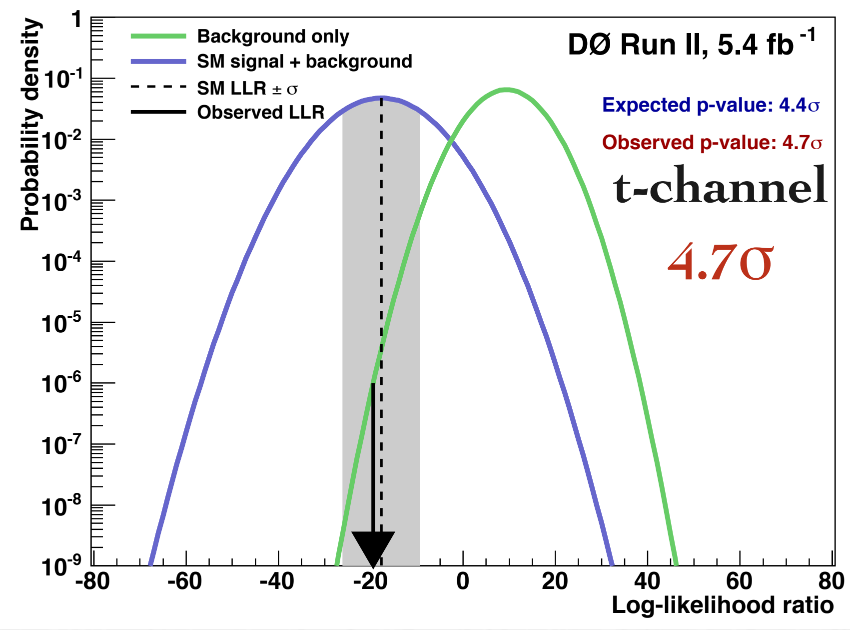
Significance is computed as :

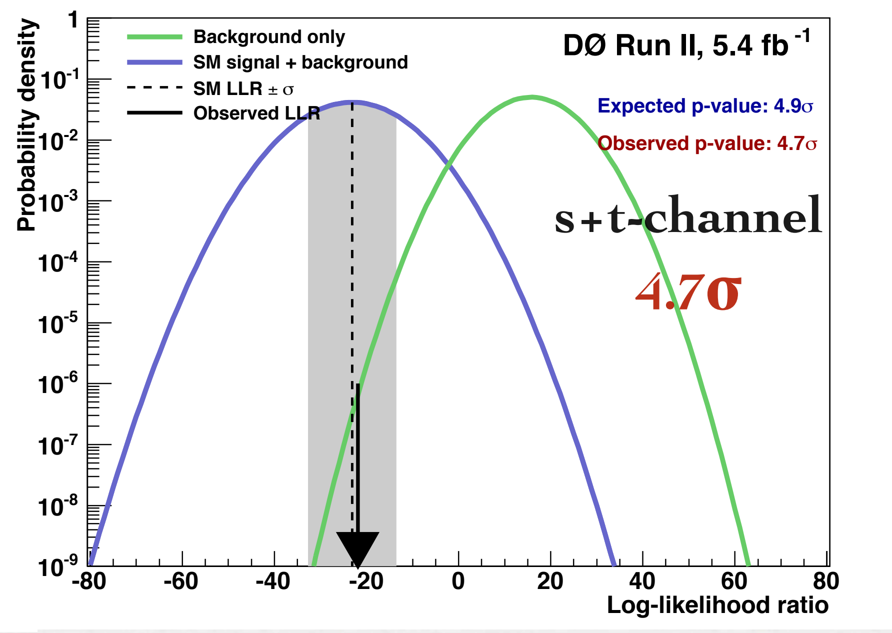
$$Q = -2\ln\frac{L(\mu=1)}{L(\mu=0)}$$

where $L(\mu)$ is the likelihood after integrating over all the systematics for a cross section $\sigma = \mu\sigma_0$, with μ -> strength parameter and σ_0 is the theoretical cross section for signal.
The ratio tests the data compatibility with two null hypothesis: ($\mu = 0$) only background & ($\mu = 1$) background+signal.

The p-value is the probability that the log-likelihood ratio is smaller or equal to the observed result in the case when there is no signal.







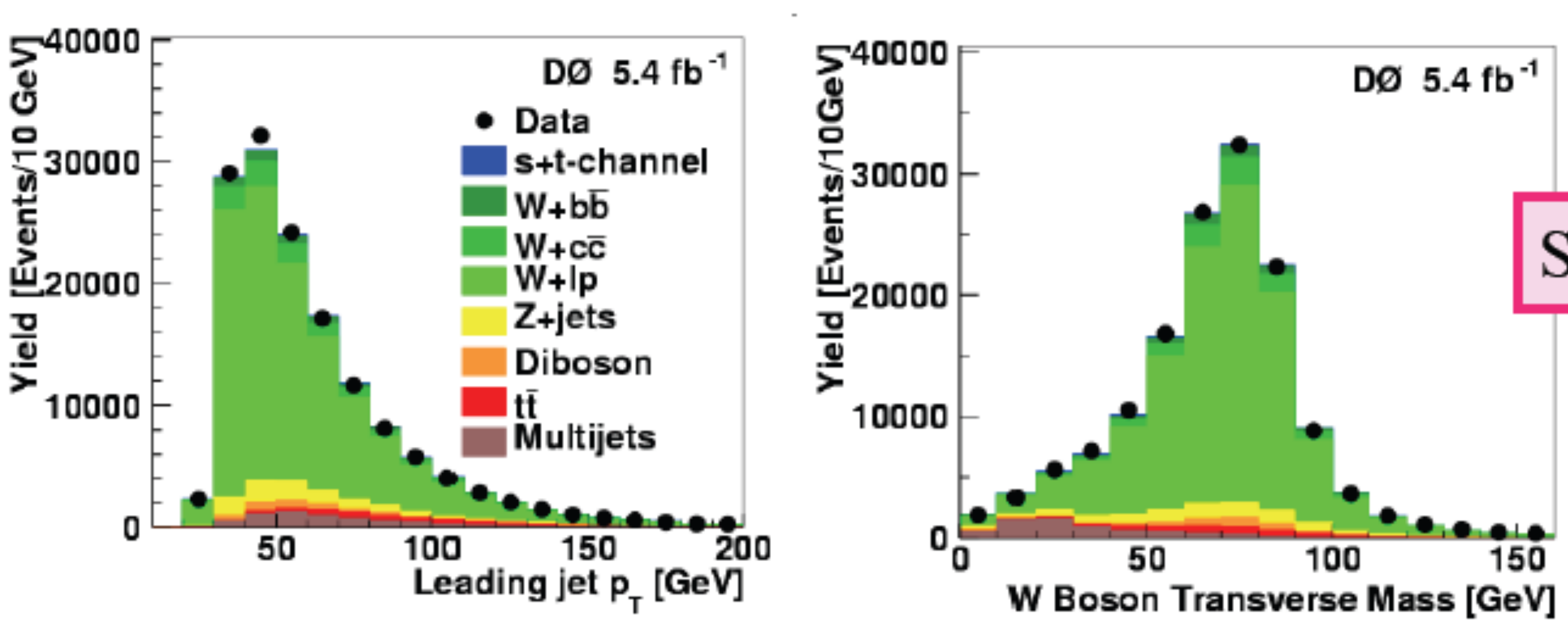
Background Normalization

W+jets and multijet normalized using iterative template fits to data BEFORE TAGGING on three sensitive variables: $P_T(l)$, MET, $M_T(W)$.

$$N^{\text{data}}_{\text{pretag}} - N^{\text{MC}}_{\text{non W+jets}} = \lambda_{\text{W+jets}} N^{\text{MC}}_{\text{W+jets}} + \lambda_{\text{multijet}} N^{\text{data}}_{\text{multijet}}$$

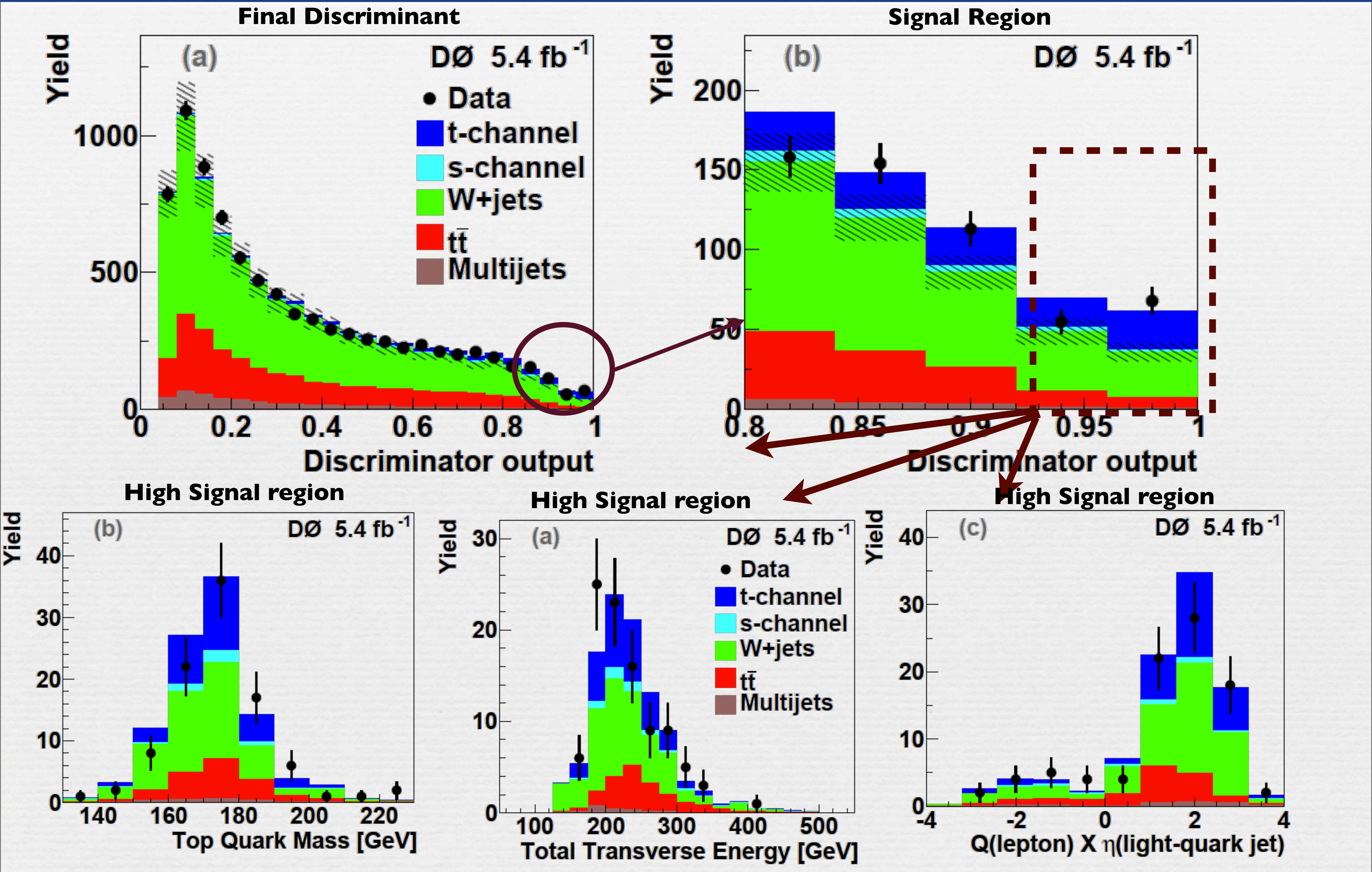
$\lambda_{\text{W+jets}}$ and $\lambda_{\text{multijet}}$ are varied to maximize the product of KS values for the three sensitive variables.

Uncertainties are 30-40% for multijet and 1.8% for W+jets.



S:B = 1:224

High Discriminant Region



Iterative KS Method

QCD and W+jets data-driven normalization is given by Iterative KS (IKS) method.

- Achieve best data/MC comparison for variables which are sensitive to W+jets/QCD distribution.
- Maximize the KS test to the LeptonPt, MET and WTransverseMass distributions to determine the QCD and W+jets fractions.
- The different factions are combined by a weighted average where the weights are given by the best KS achieved for each distribution.

$$S_{W+\text{jets}} = \frac{\sum_{i=\text{var1}}^{\text{varN}} S^{i}_{W+\text{jets}} * \text{KS}^{i}_{\text{max}}}{\sum_{i=\text{var1}}^{\text{varN}} \text{KS}^{i}_{\text{max}}}$$

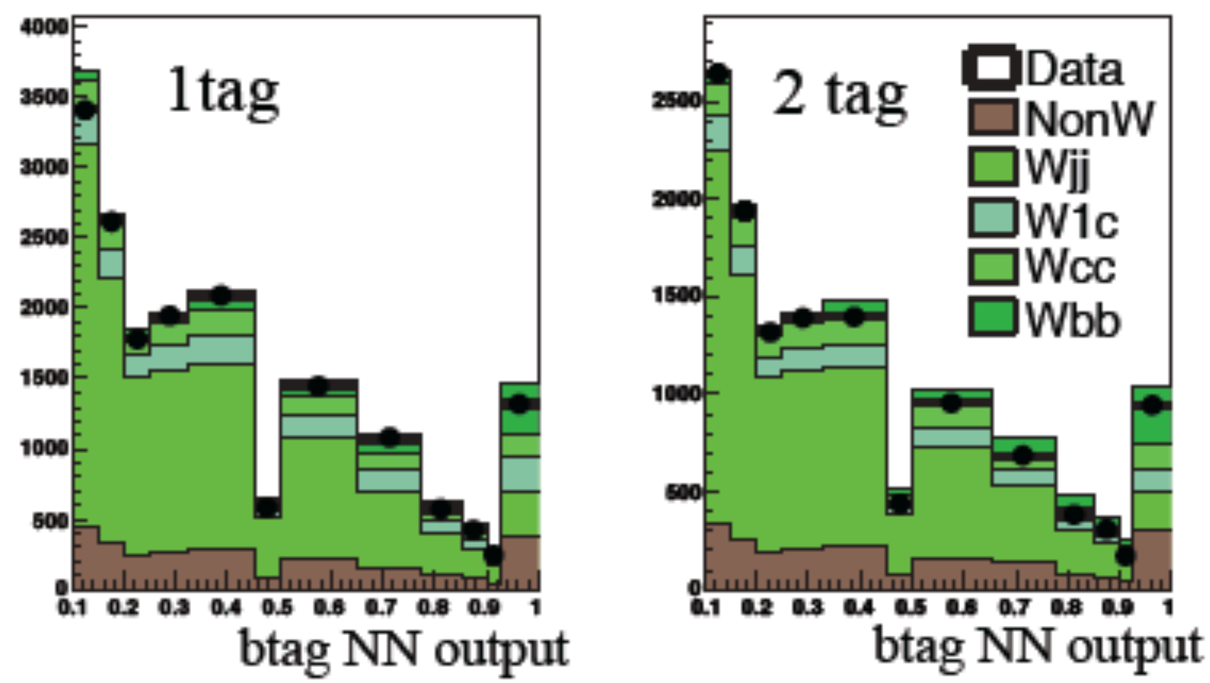
$$S_{\text{multijets}} = \frac{\sum_{i=\text{var1}}^{\text{varN}} S^{i}_{\text{multijets}} * \text{KS}^{i}_{\text{max}}}{\sum_{i=\text{var1}}^{\text{varN}} \text{KS}^{i}_{\text{max}}}$$

W+ Heavy Flavor Normalization

- W/Z + heavy flavor normalized to theory (MCFM-NLO)
  - 1.47 (Wbb,Wcc), 1.32 (Wcj), 1.52 (Zbb), 1.67 (Zcc)
- Normalization checked in 2 jets/0 tag sample

$$N^{(0)} = N^{(0)}_{\mathrm{Wlp}} + \lambda_{\mathrm{HF}} N^{(0)}_{\mathrm{Whp}}$$

  - λ_{HF} found to be consistent with 1
- Uncertainties considered
  - ± 40% single top cross section
    - ± 1% in λ_{HF}
  - ± 10% on the Wcj theory SF
    - ± 7% in λ_{HF}
  - Additional ± 10% Wbb/Wcc
    - ± 8% in λ_{HF}
  - For a total uncertainty of 12%



Systematics Uncertantities

Relative Systematic Uncertainties

Components for Normalization	
Integrated luminosity	6.1%
$t\bar{t}$ cross section	9.0%
Z+jets cross section	3.3%
Diboson cross sections	7.0%
Branching fractions	1.5%
Parton distribution functions (signal acceptances only)	2.0%
Triggers	5.0%
Instantaneous luminosity reweighting	1.0%
Primary vertex selection	1.4%
Color reconnection	1.0%
b/light jet response	(0.3-1.0)%
Electron identification	(2.8-3.8)%
Muon identification	2.1%
Jet fragmentation and higher order effects	(0.7-7.0)%
Initial-and final-state radiation	(0.8-10.9)%
b-jet fragmentation	2.0%
Taggability	(3.1-21.5)%
W+jets heavy-flavor correction	12.0%
Z+jets heavy-flavor correction	12.0%
W+jets normalization to data	1.8%
Multijets normalization to data	(30-40)%
MC and multijets statistics	(0.2-16)%

Components for Normalization and Shape	
Jet reconstruction and identification	(0.04-3.7)%
Jet energy resolution	(0.2-11.6)%
Jet energy scale	(0.3-14.6)%
Vertex confirmation	(0.1-9.6)%
b tagging, single-tagged	(4.3-14.0)%
b tagging, double-tagged	(5.8-11.2)%
Angular correction	0.3%

Components that most affect the cross section measurement are shown in *red*

Other important contributions are shown in *pink*

Measuring Cross Section

Single-bin likelihood

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

$$d = \alpha \mathcal{L} \sigma + \sum_{i=1}^{N} b_i = a\sigma + \sum_{i=1}^{N} b_i$$

Binned likelihood

$$L(\mathbf{D}|\mathbf{d}) \equiv L(\mathbf{D}|\sigma, \mathbf{a}, \mathbf{b}) = \prod_{i=1}^{M} L(D_i|d_i)$$

Bayes' Theorem

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

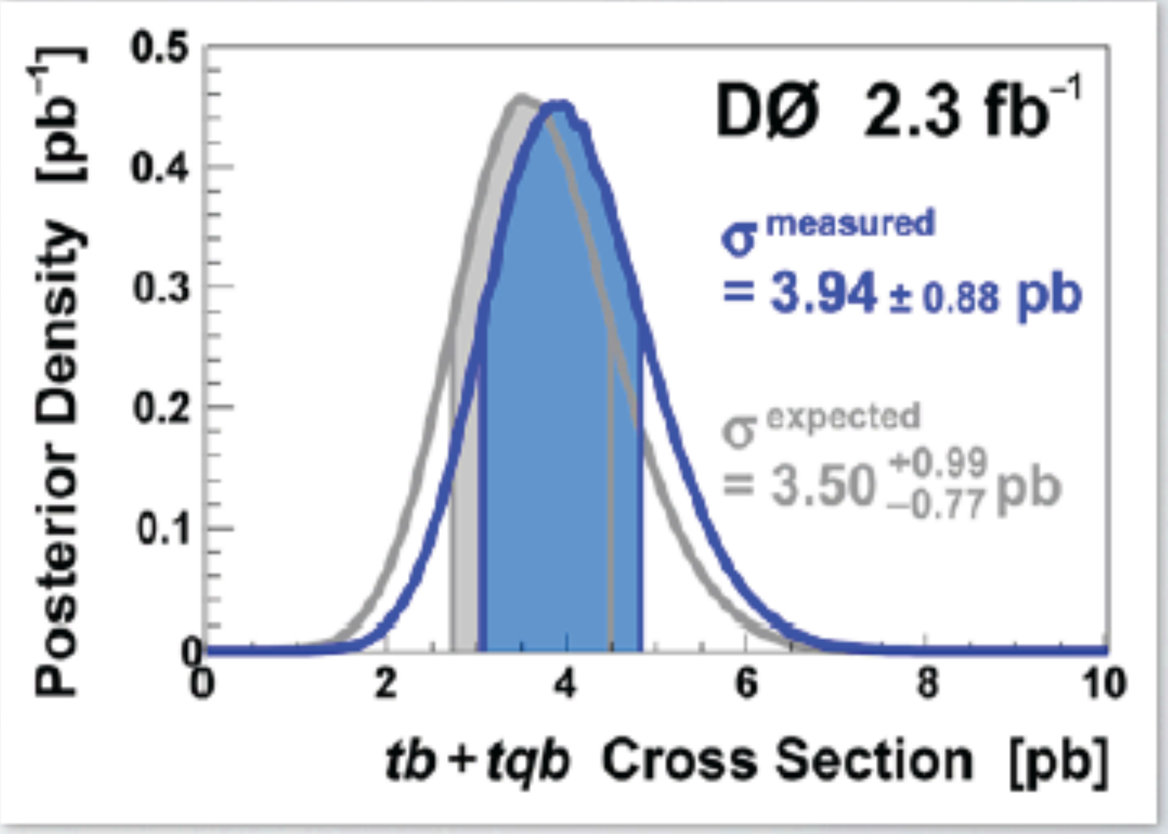
Assuming nonnegative flat prior

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

Numerical integration

$$p(\sigma|\mathbf{D}) \propto \int L(\mathbf{D}|\sigma, \mathbf{a}, \mathbf{b}) \pi(\mathbf{a}, \mathbf{b}) d\mathbf{a} d\mathbf{b}$$

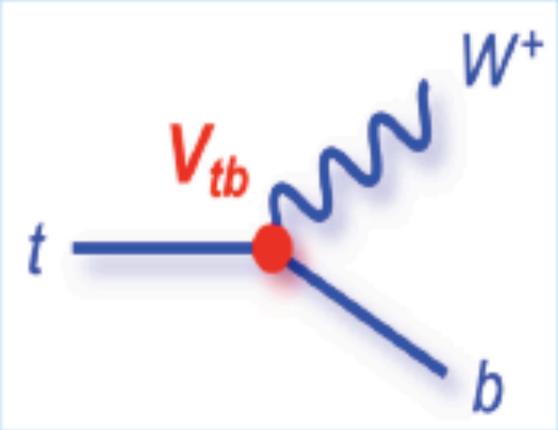
$$\approx \frac{1}{K} \sum_{k=1}^{K} L(\mathbf{D}|\sigma, \mathbf{a}_k, \mathbf{b}_k)$$



CKM Matrix Element $|V_{tb}|$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

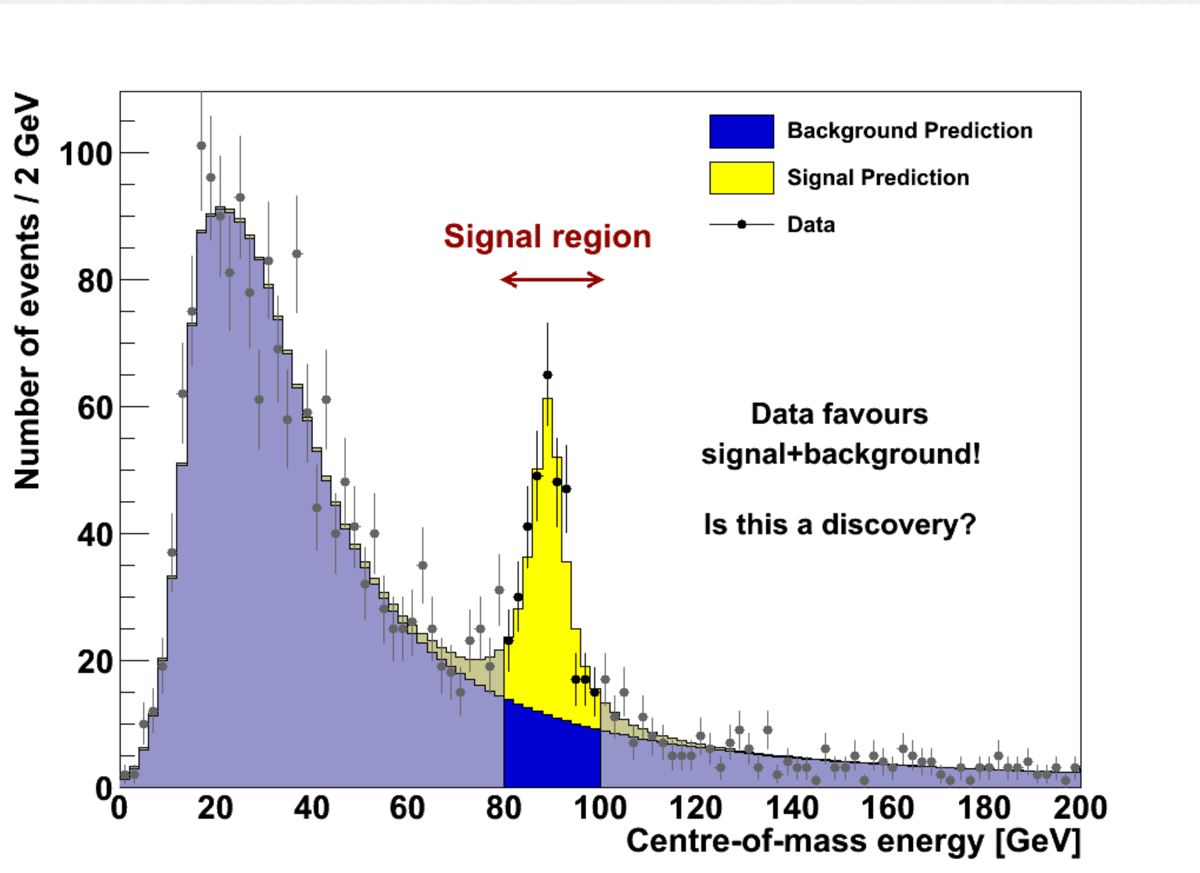


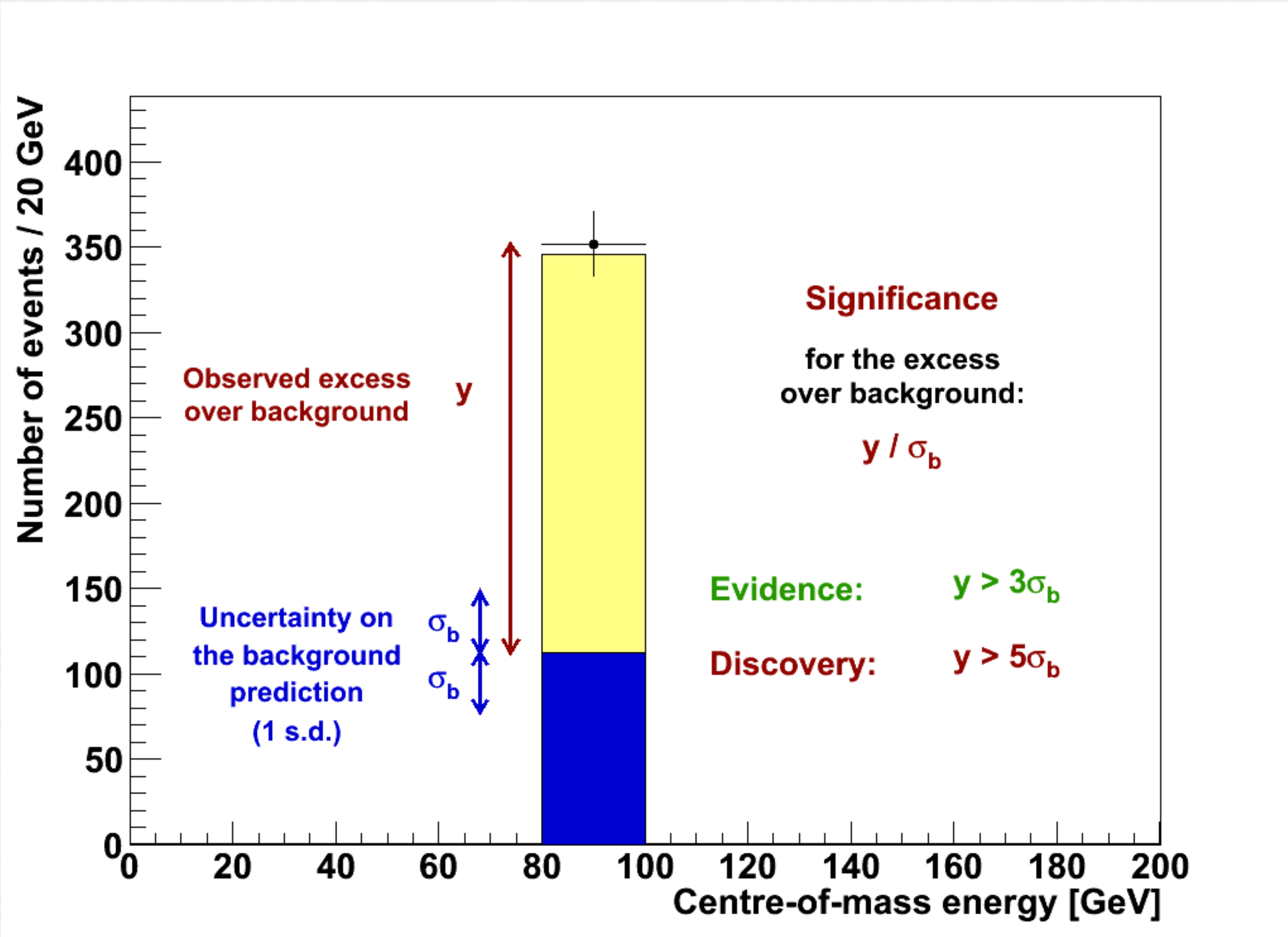
- Weak interaction eigenstates and mass eigenstates are not the same: there is mixing between quarks, described by CKM matrix
- General form of the Wtb vertex

$$\Gamma^{\mu}_{Wtb} = -\frac{g}{\sqrt{2}} V_{tb} \left\{ \gamma^{\mu} \left[f_1^L P_L + f_1^R P_R \right] - \frac{i\sigma^{\mu\nu}}{M_W} (p_t - p_b)_{\nu} \left[f_2^L P_L + f_2^R P_R \right] \right\}$$

- Measurement assumes SM production mechanisms
  - Pure V–A and CP-conserving interaction ($f_1^R = f_2^L = f_2^R = 0$)
    - f_1^L : strength of the left-handed Wtb coupling, is allowed to be anomalous
  - $|V_{td}|^2 + |V_{ts}|^2 << |V_{tb}|^2$
- Does not assume 3 generations or unitarity of the CKM matrix

Significance ?

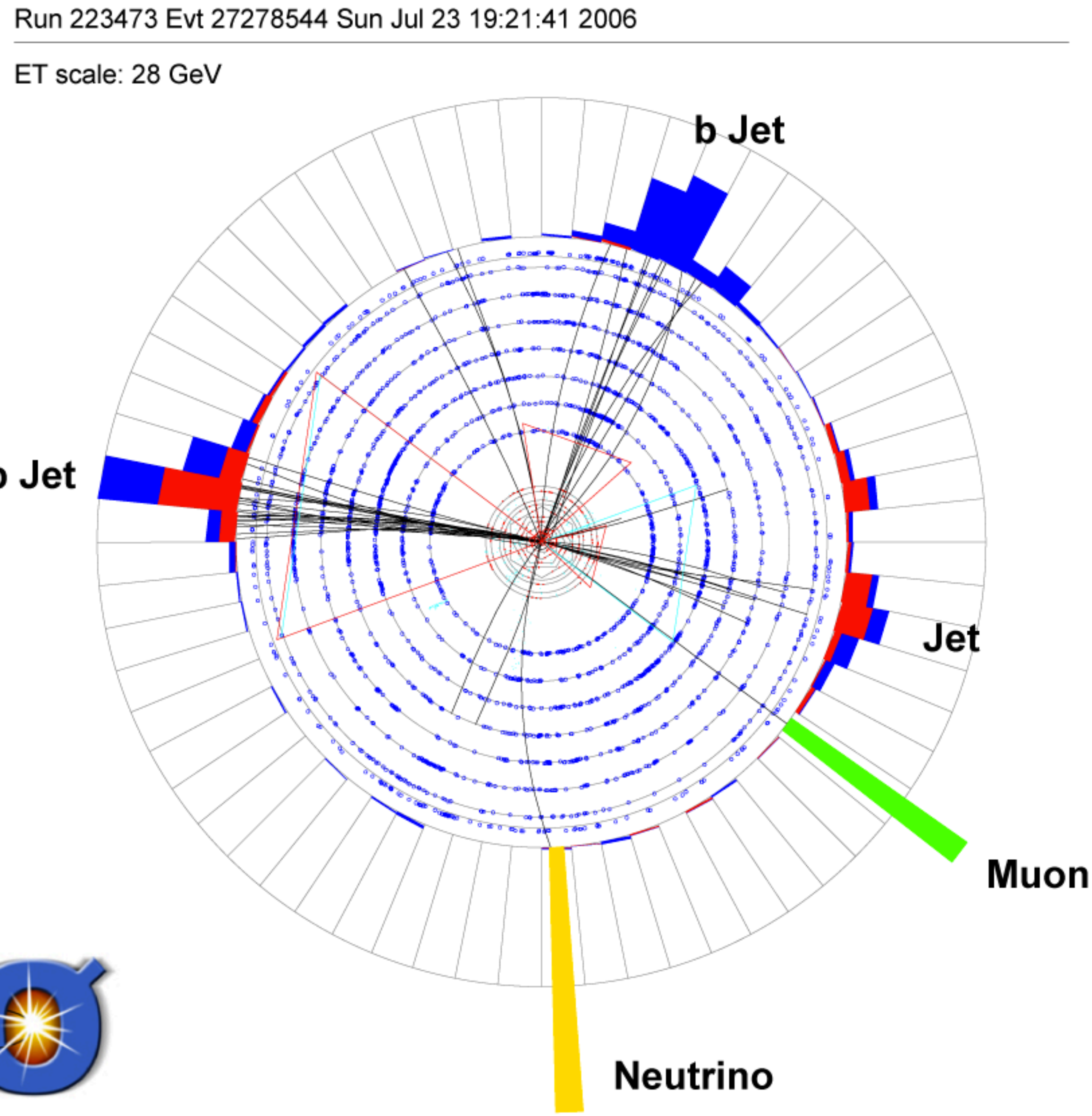




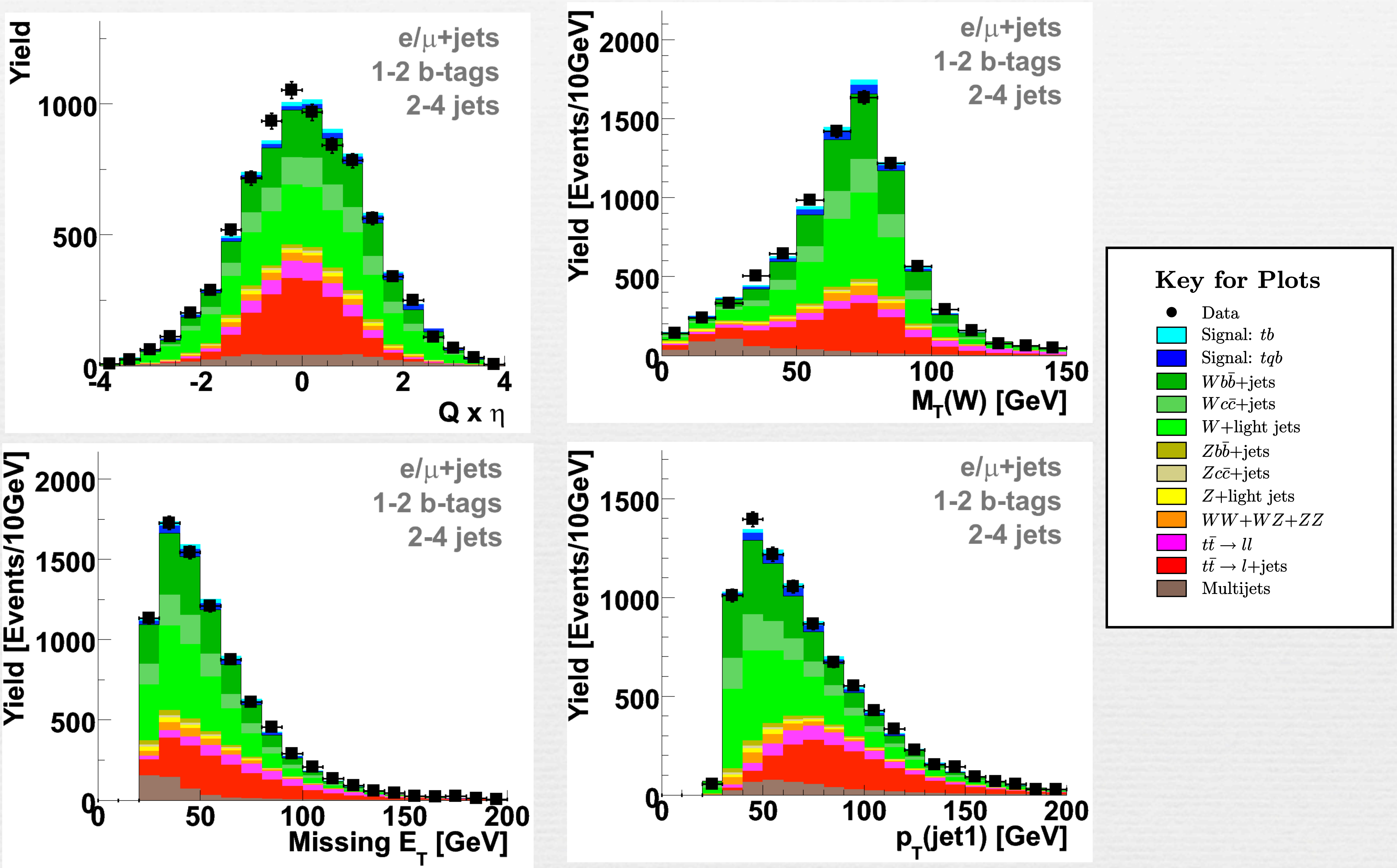
Probability for 3σ upward fluctuation: 0.135%, 5σ: 0.000029%

DØ Experiment Event Display

Single Top Quark Candidate Event, 2.3 fb^{-1} Analysis



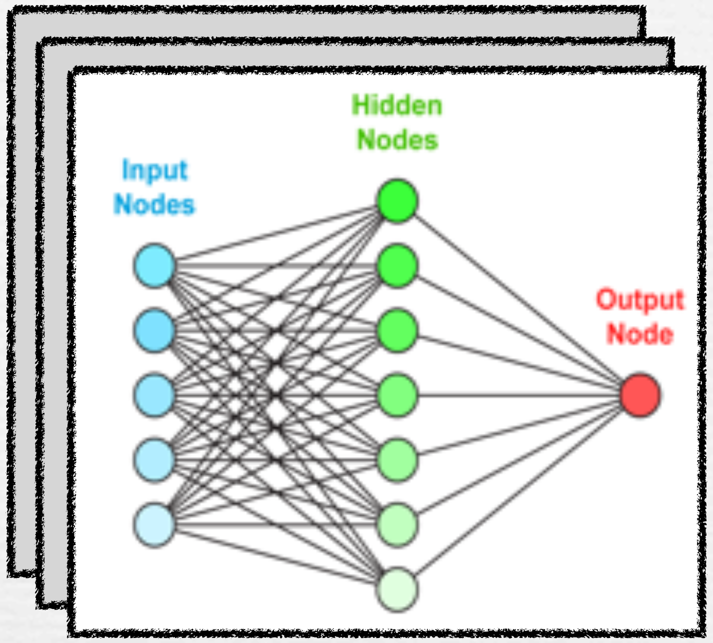
Data-Background Agreement



Good data-background agreement, but no clear excess...

Bayesian Neural Networks

From the structural point of view, **Neural Network (NN)** is an interconnected group of nodes. It can be used to find complex relationships between inputs and outputs, or to find patterns in data.



The NNs we used have:

N_{var} Input nodes

H = 20 Hidden nodes

1 Output node -> **gives the prob. for an event to be signal**

From the mathematical point of view, NN is a **non-linear function** n(x,w) which approximated the discriminant D(x).

- $D(x) = Prob(sig|x) = f(x|sig) / (f(x|sig) + f(x|bkg))$; x = vector of input variables
- $n(x,w) = 1 / (1 + \exp.(-g(x,w)))$ **where** $g(x,w) = b + \sum_{j=1 \text{ to } H} v_j \tanh(a_j + \sum_{i=1 \text{ to } N_{var}} u_{ji}\, x_i)$; $w=(u_{ji}, a_j, v_j, b)$ are NN weights

A **Bayesian Neural Network** is an **average** over the $(1 + H(2+N_{var}))$-dim parameter space w

- **Ideally,** $n(x) = \int_{\{w\}} n(x,w)\, p(w|T)\, dw$; T = set of training data
- **In practice,** $n(x) = 1/100 \sum_{k=201 \text{ to } 300} n(x,w_k(T))$; 300 NNs are iteratively trained, average over the last 100

Model-Independent Measurement of t-channel

- 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.

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