Single Top Quark Combination Using Bayesian Neural Networks

Fermilab
SULI Presentation
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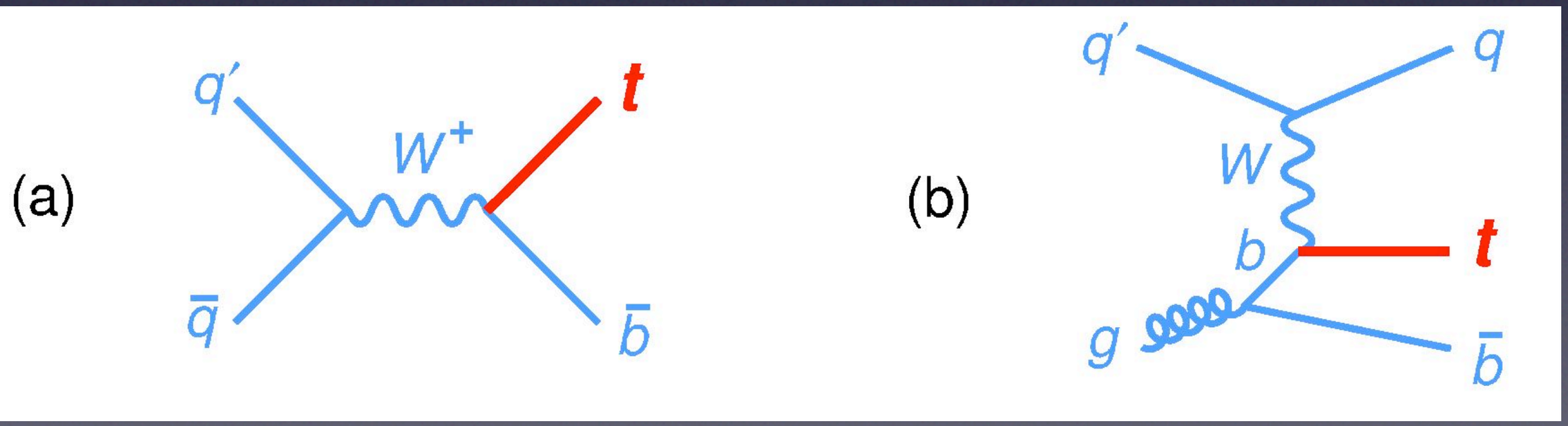
Outline

- Standard Model & Single Top Quark Production
- Motivations & Previous Studies
- Analysis Strategy
- Data: Analysis Channels
- Neural Networks
- Results: Cross Section Measurement
- Conclusions & Future Work

Standard Model (SM) & Single Top Quark Production

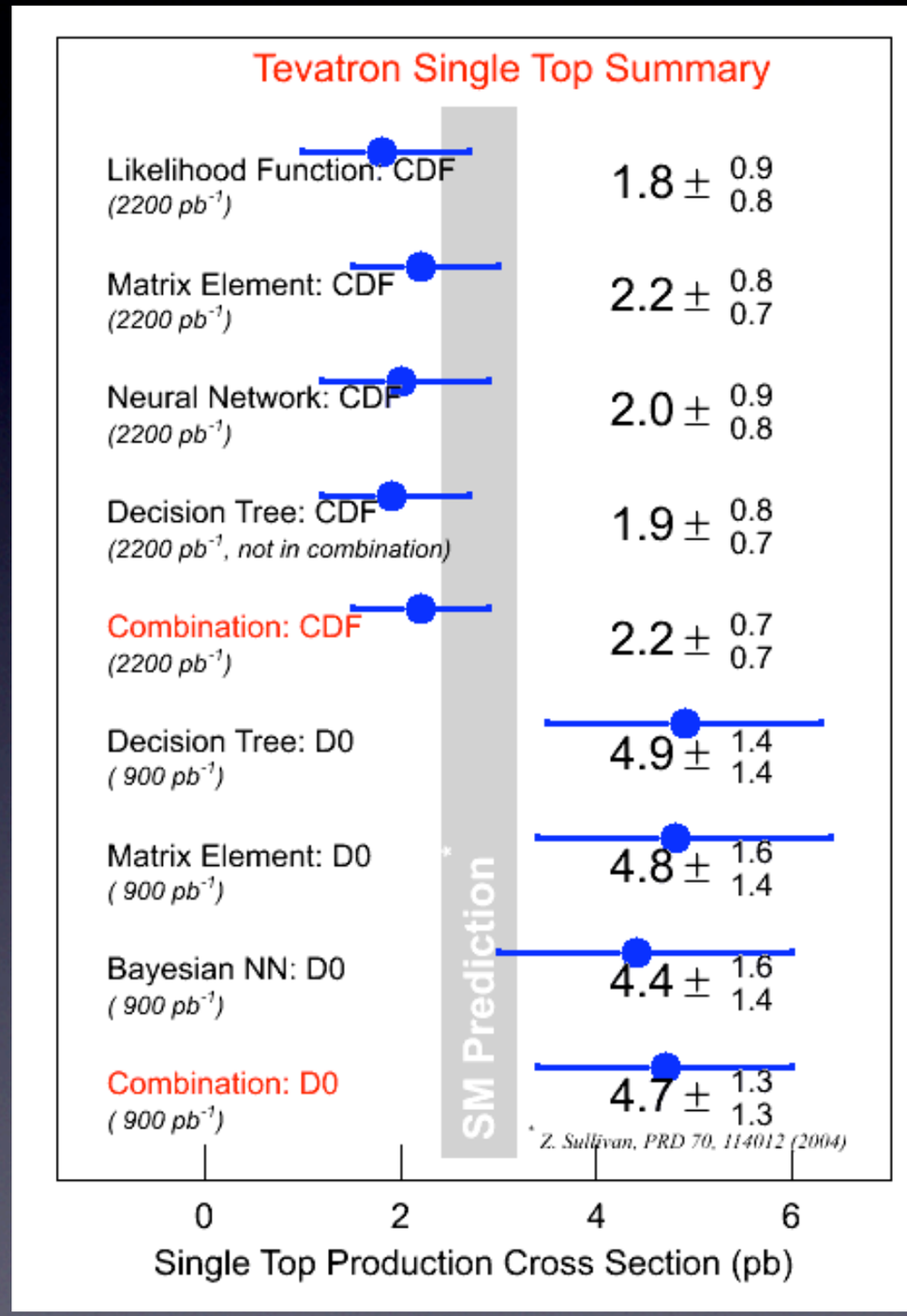
- Describes all particle interactions
- Predicts 2 dominant modes for single top production at Tevatron
- (a) "S-channel": SM cross section = 0.88 +/- 0.14 pb
  (b) "T-channel": SM cross section = 1.98 +/- 0.30 pb

[with M_{top} = 175 GeV]

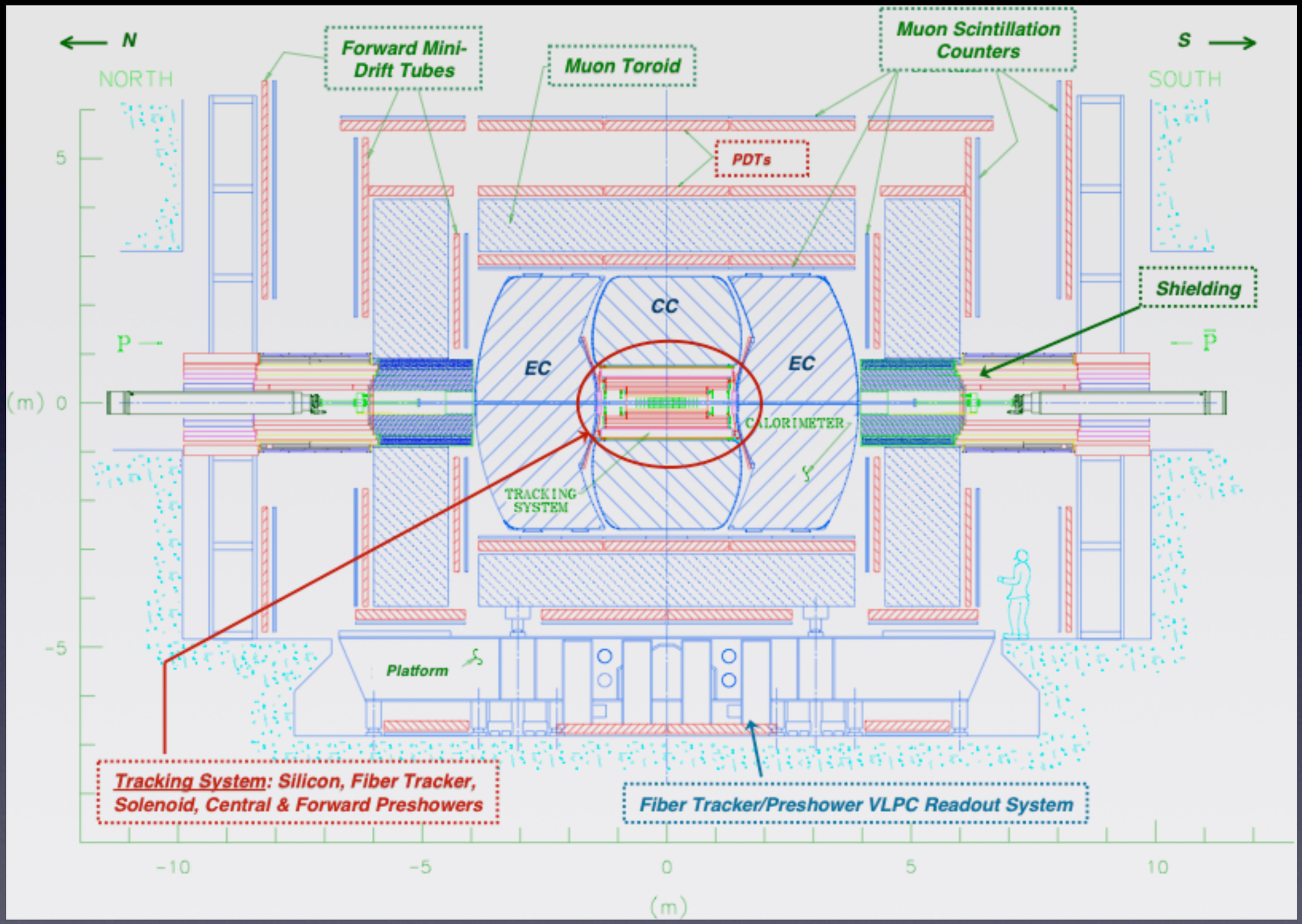


Motivations & Previous Studies

- Precision Test of SM
- Measure $|V_{tb}|$ in CKM Matrix
  ---> 4th quark generation? New physics?
- Top quark polarization ($t_{top} \sim 10^{-23}$ s)
- Claim discovery
- D0 and CDF reported evidence of single top production at ~ 3 std. dev. significance
- D0 (PRL98, 2008; PRD78, 2008)
  - Decision Tree (DT)
  - Matrix Element (ME)
  - Bayesian Neural Network (BNN)
  - Combination of all 3
    > BLUE - Best Linear Unbiased Estimate
- Explored multivariate technique (BNN) for new combination



D0 Detector


N
S
NORTH
SOUTH
Forward Mini-Drift Tubes
Muon Toroid
Muon Scintillation Counters
PDTs
Shielding
CC
EC
EC
CALORIMETER
TRACKING SYSTEM
Platform
P
$\bar{P}$
5
(m) 0
-5
Tracking System: Silicon, Fiber Tracker, Solenoid, Central & Forward Preshowers
Fiber Tracker/Preshower VLPC Readout System
-10
-5
0
5
10
(m)

Analysis Strategy

Analysis Strategy

Run II D0 Data (0.9 fb^{-1})

Signal/Background Models

Backgrounds:
ttbar, W+jets,
fake-leptons

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Event Selections

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Multivariate Techniques:

- Decision Trees
- Bayesian Neural Network
- Matrix Element

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2nd BNN iteration

Perform BNN Combination

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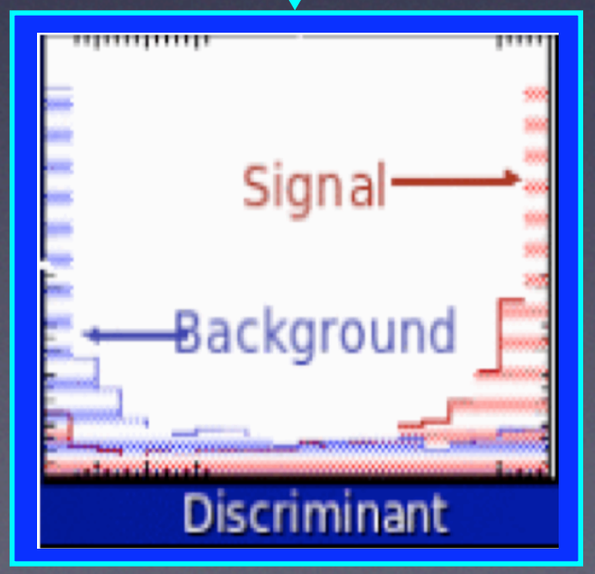

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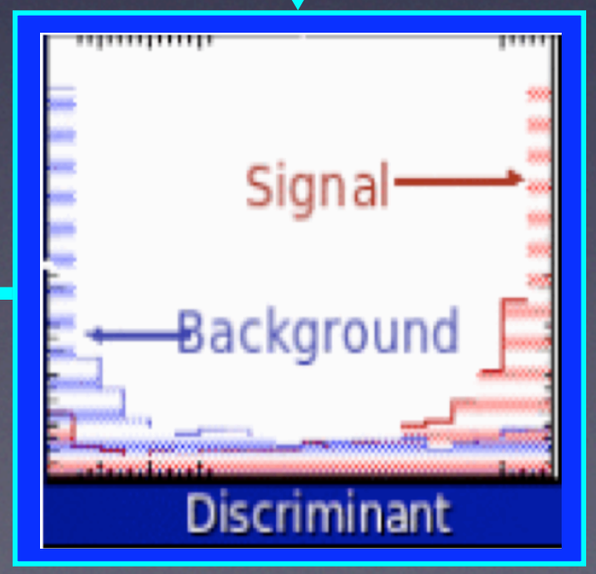

Bayesian Statistical Analysis

Analysis Strategy

Run II D0 Data (0.9 fb^{-1})

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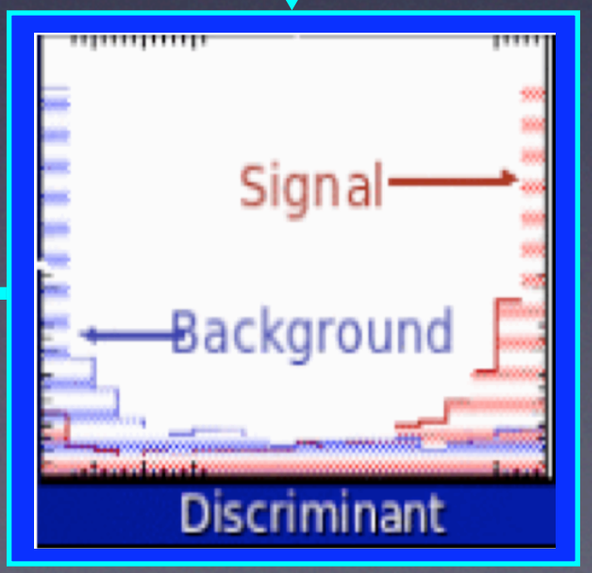
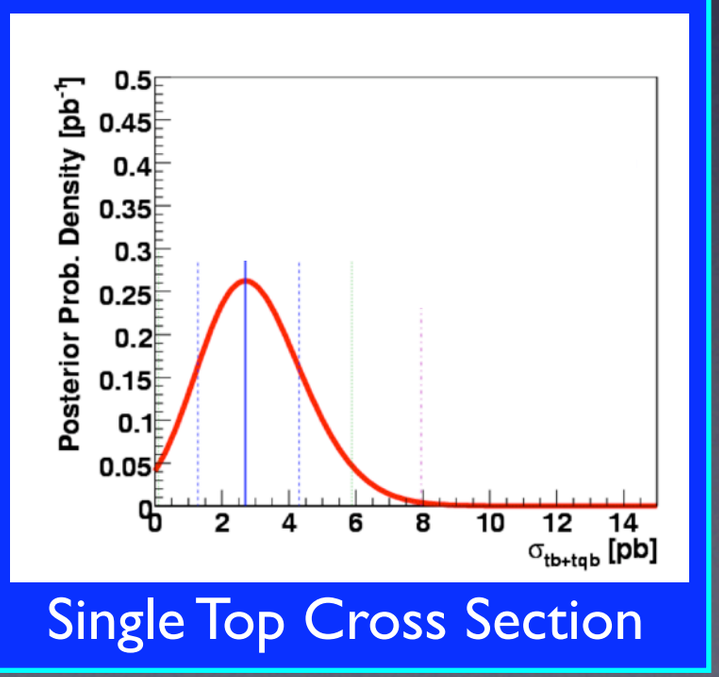


Bayesian Statistical Analysis

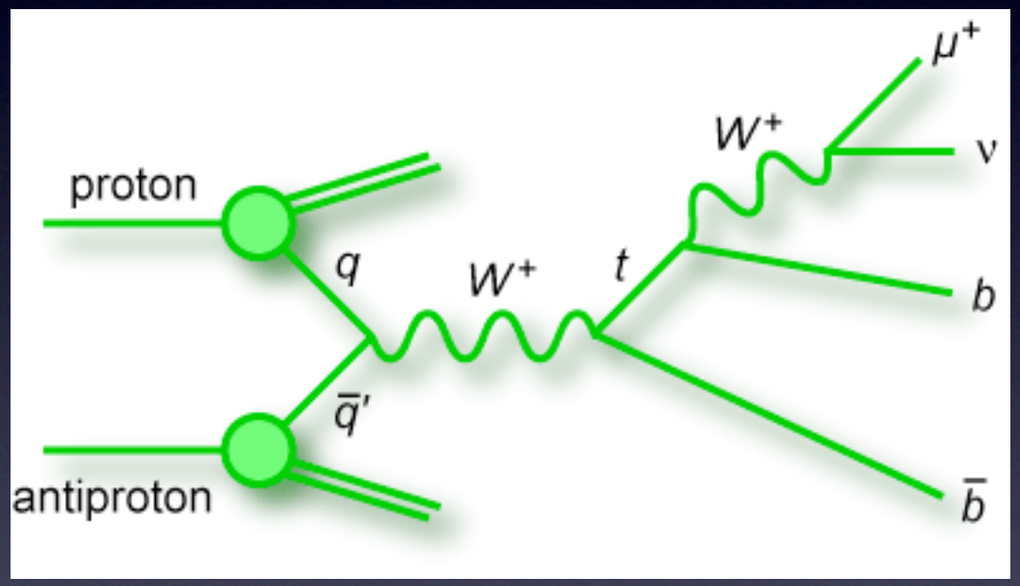


Single Top Cross Section

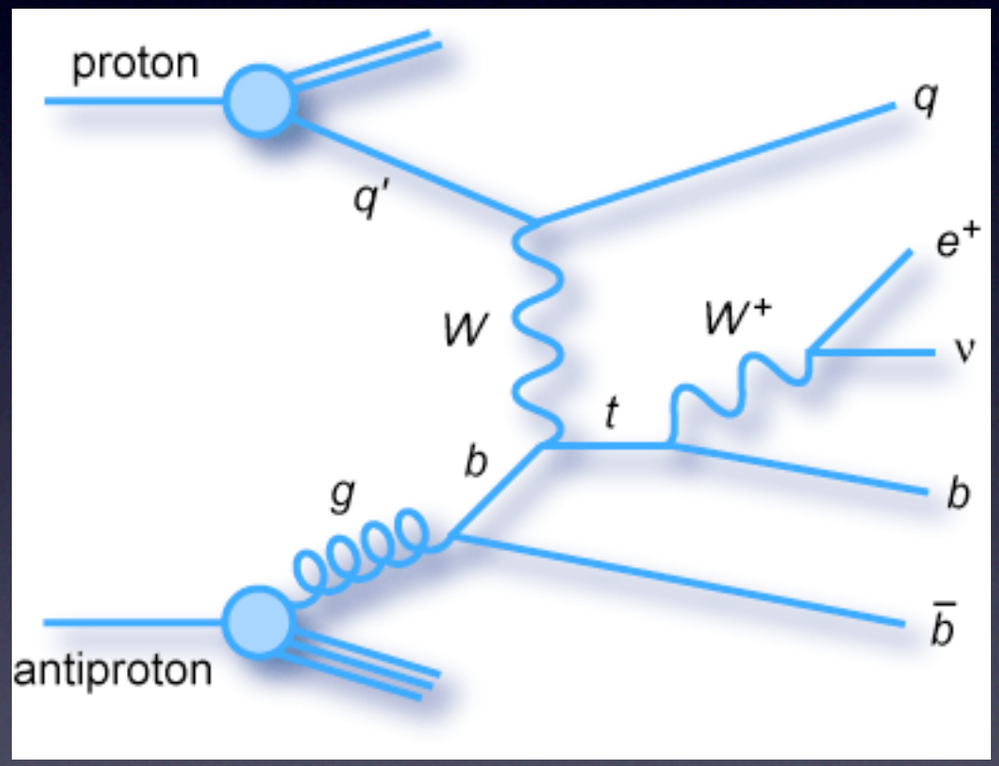
Analysis Channels

- 12 analysis "channels": lepton (e,mu), no. of b-tags (1,2), jet multiplicity (2,3,4)

S-channel



T-channel

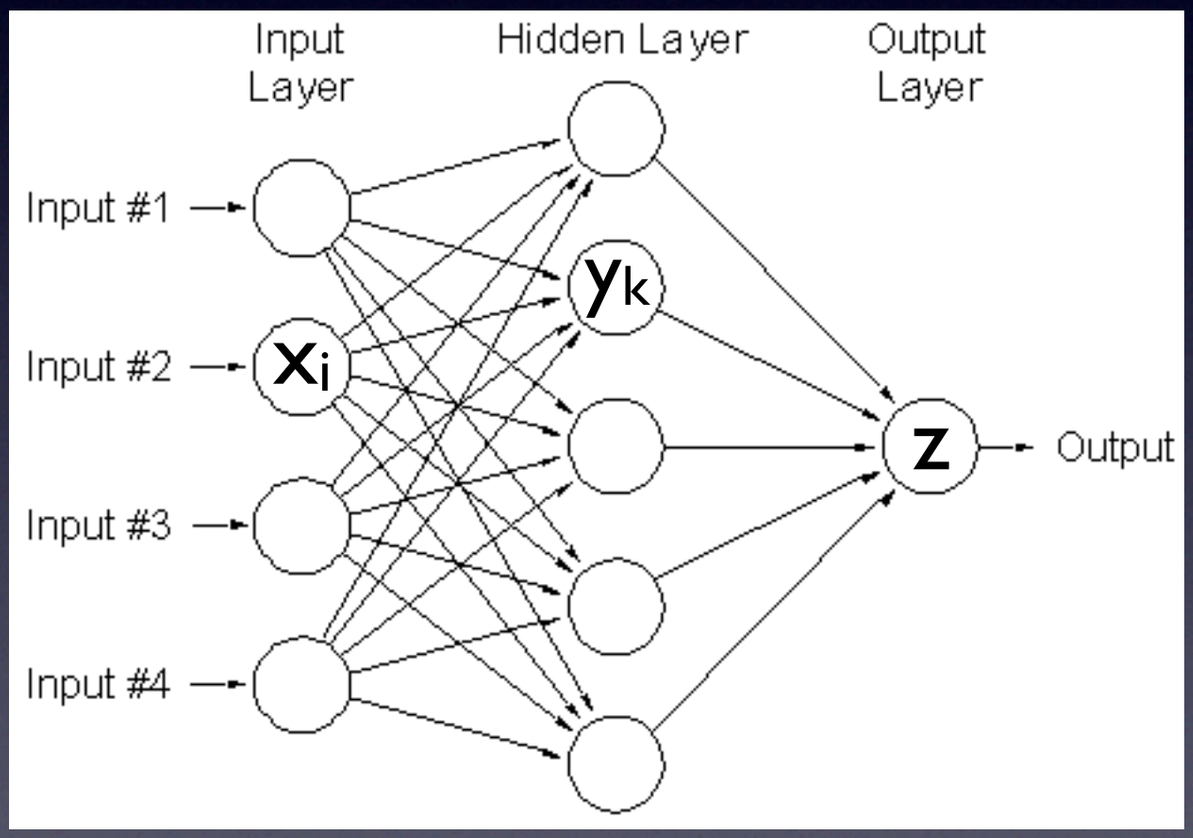


- Single top signature:
  (1) One high isolated transverse momentum, central rapidity and charged lepton
  (2) Missing transverse energy (W decay ---> lep + neutrinos)
  (3) b-jet from top quark

Neural Networks

- Used for pattern recognition --> ideal for separating signal from background

Example Neural Network



Mathematics of Neural Networks

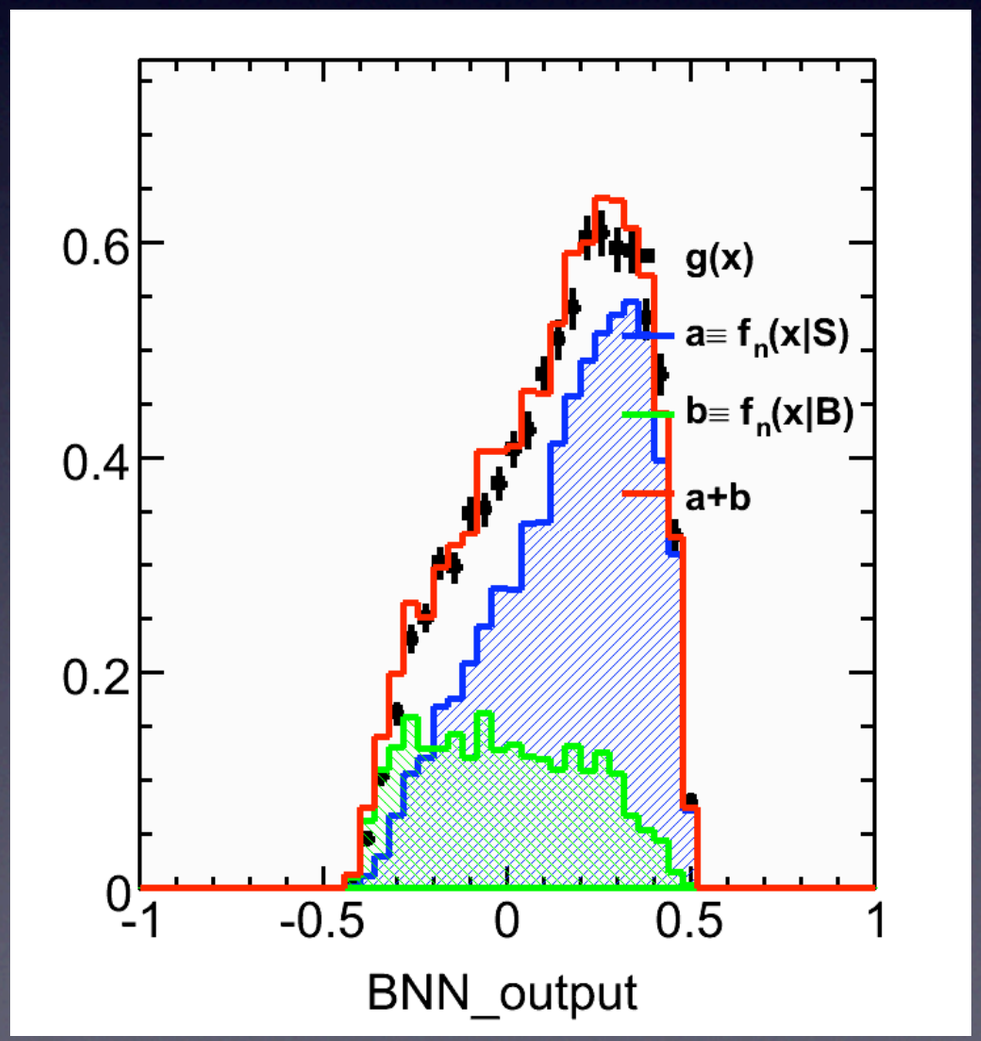
$$y_k = x_o' + \sum_i^n w_i \cdot x_i$$

$$z = x_o'' + \sum_k^m w_k \cdot y_k$$

✻ BNN: weighted average of several single NN that enhances performance
More information: http://www.cs.toronto.edu/~radford/fbm.software.html

Bayesian Neural Networks

- Trained BNN using 1/3 of data, remaining 2/3 for analysis and systematics.
- Check for convergence of network (figure below)
  Example: electron, 1 tag, 2 jet



$n(x) = g(x|S) / [g(x|S) + g(x|B)]$

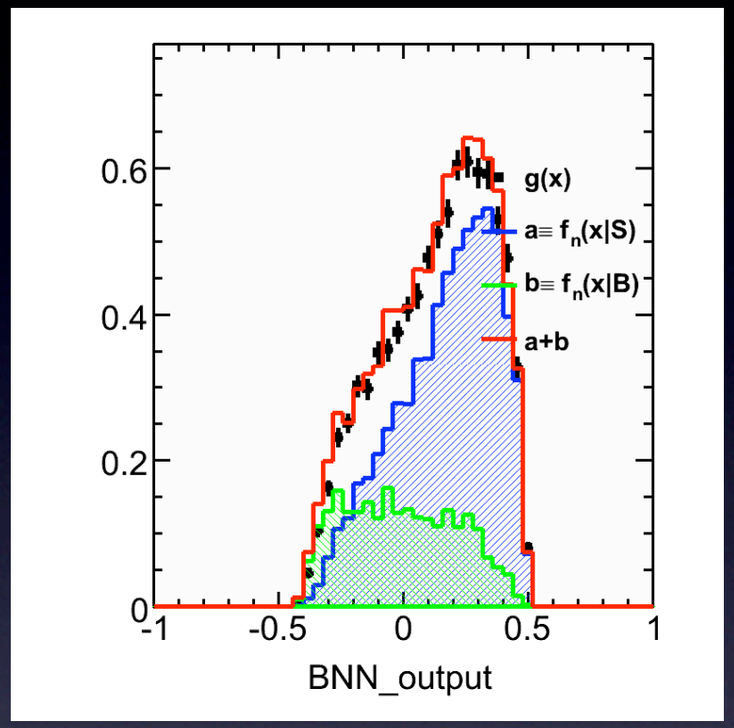
then with

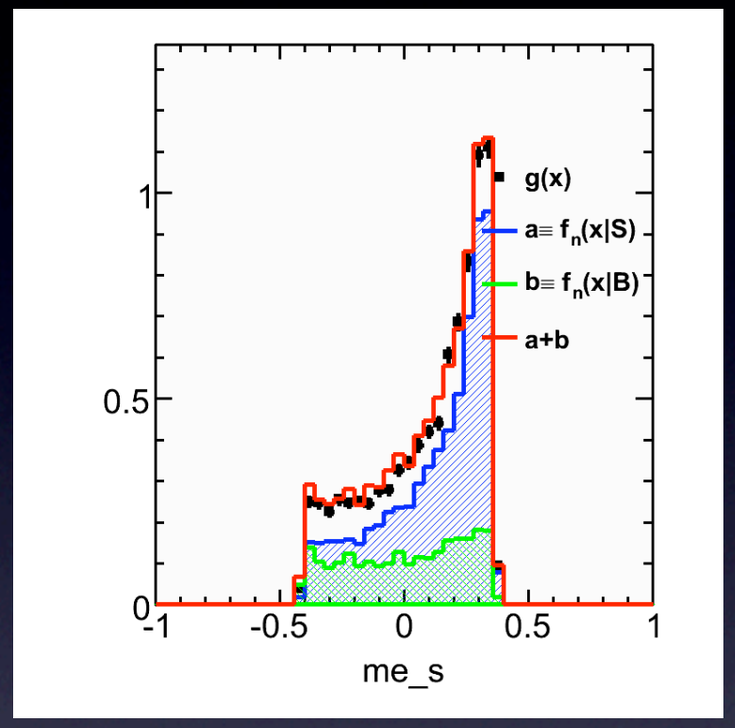
$f_n(x|S) = n(x) * g(x|S)$
$f_n(x|B) = n(x) * g(x|B)$

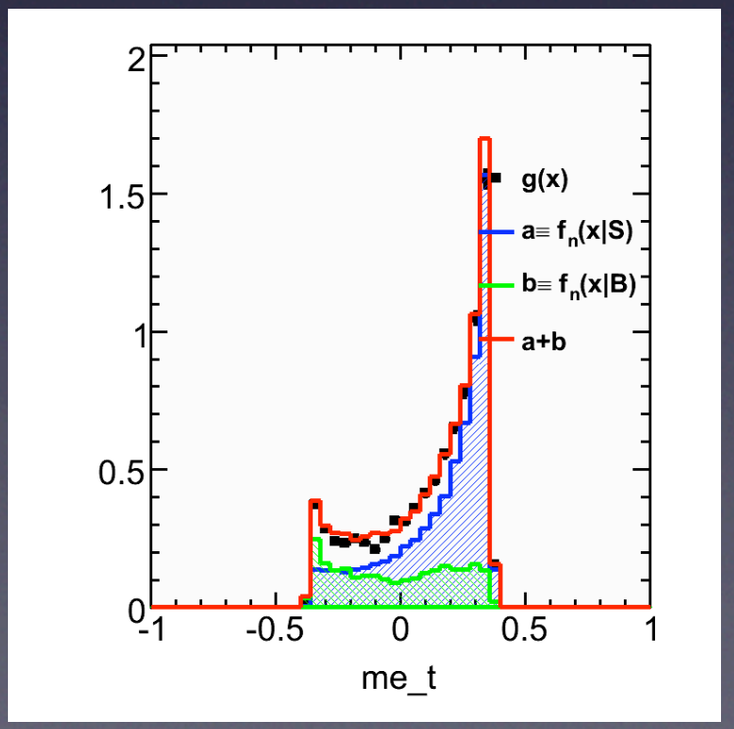
we get
$f_n(x|S) + f_n(x|B) \dashrightarrow g(x|S)$

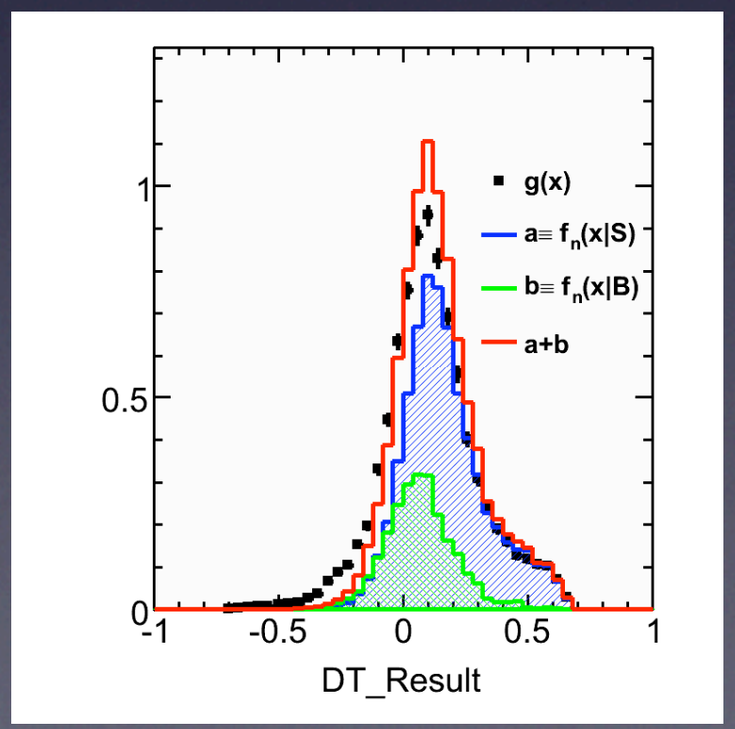
BNN Performance

- Channel: electron, 1 tag, 2 jet



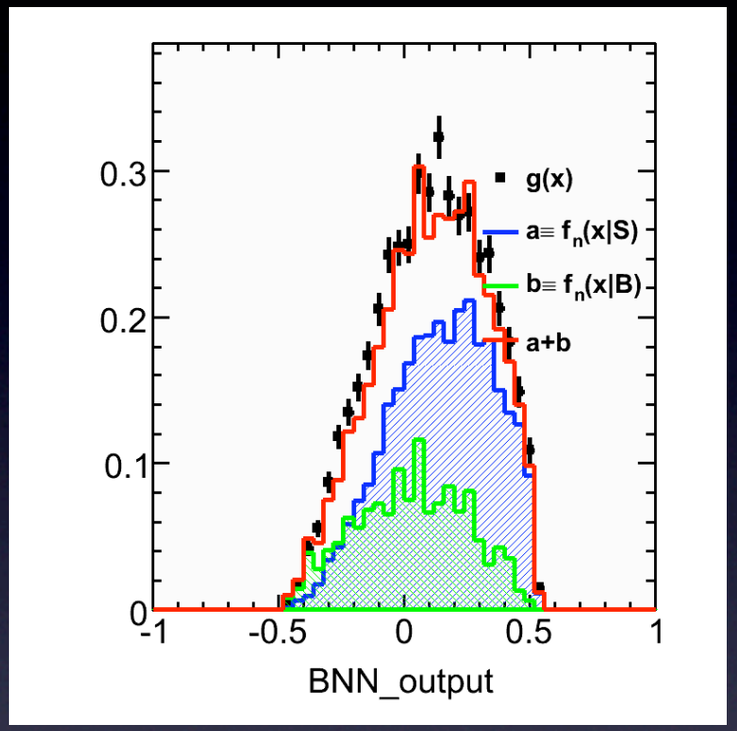


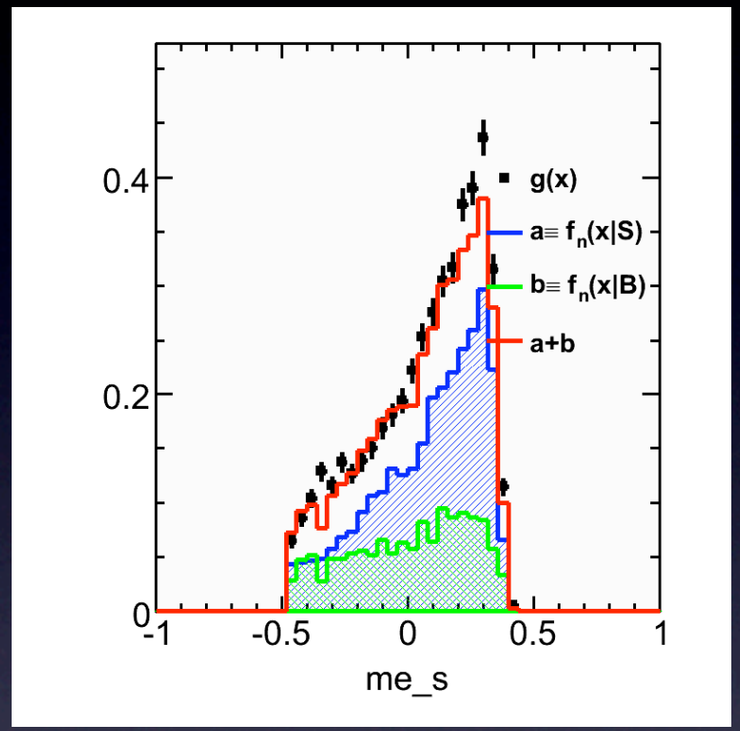


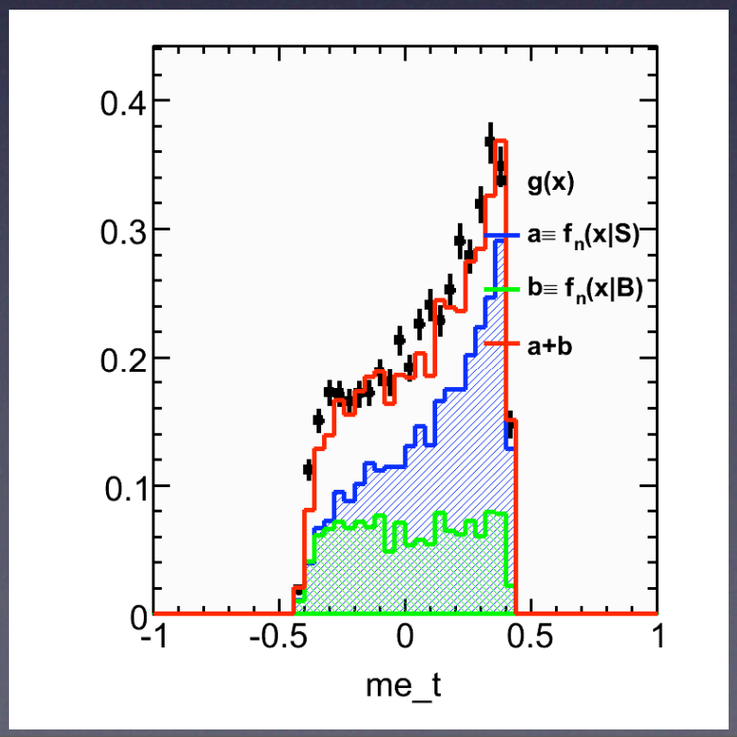


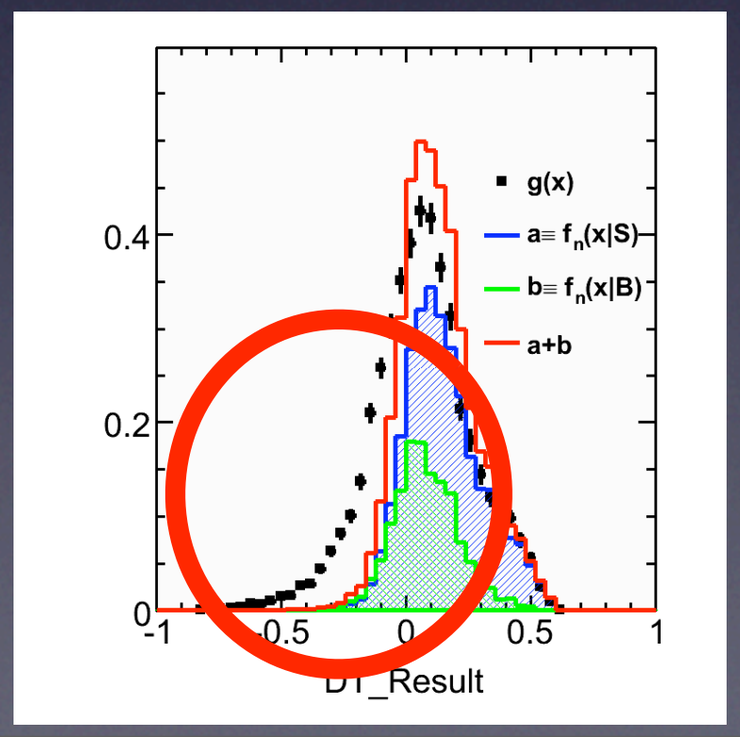
BNN Performance

- Channel: electron, 1 tag, 3 jet



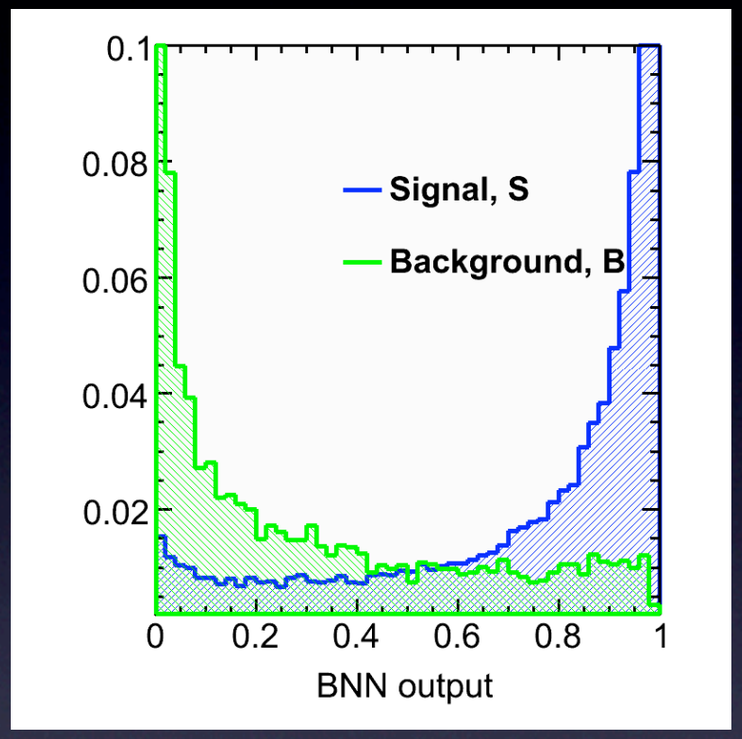


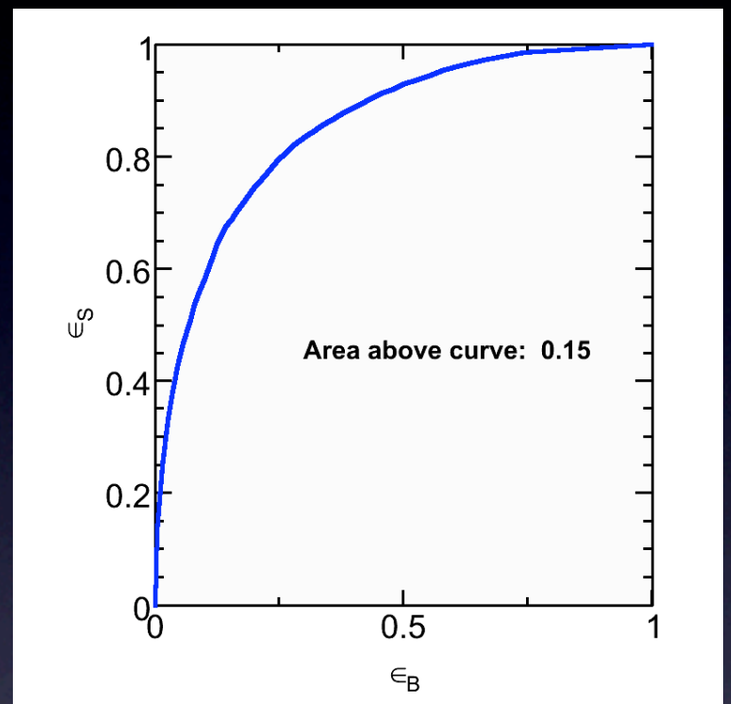


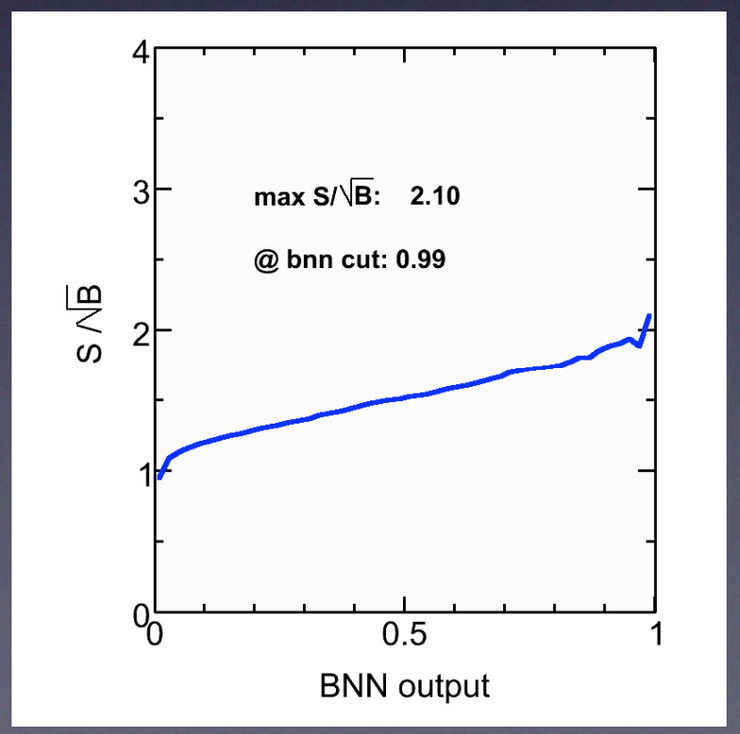


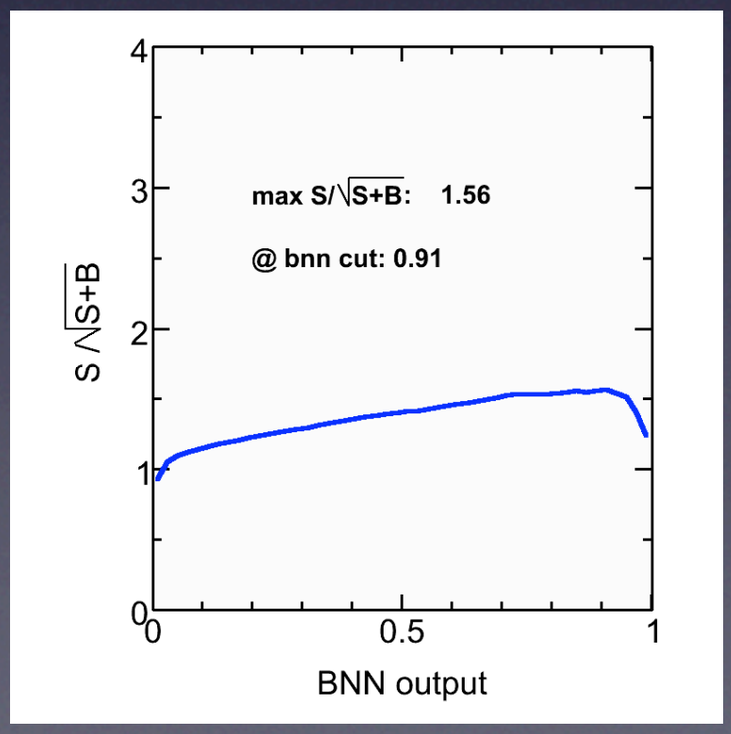
BNN Verification Plots

- Channel: electron, 1 tag, 2 jet



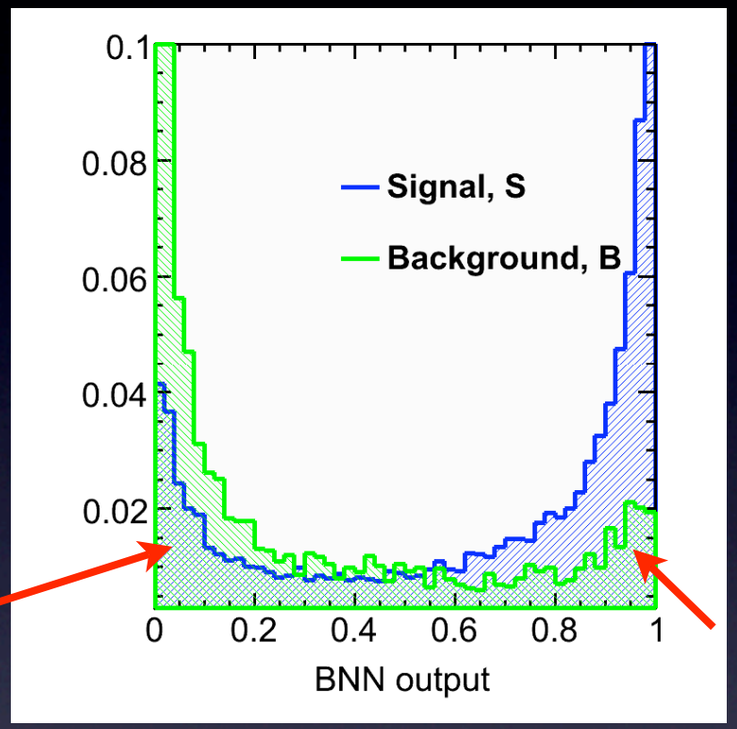


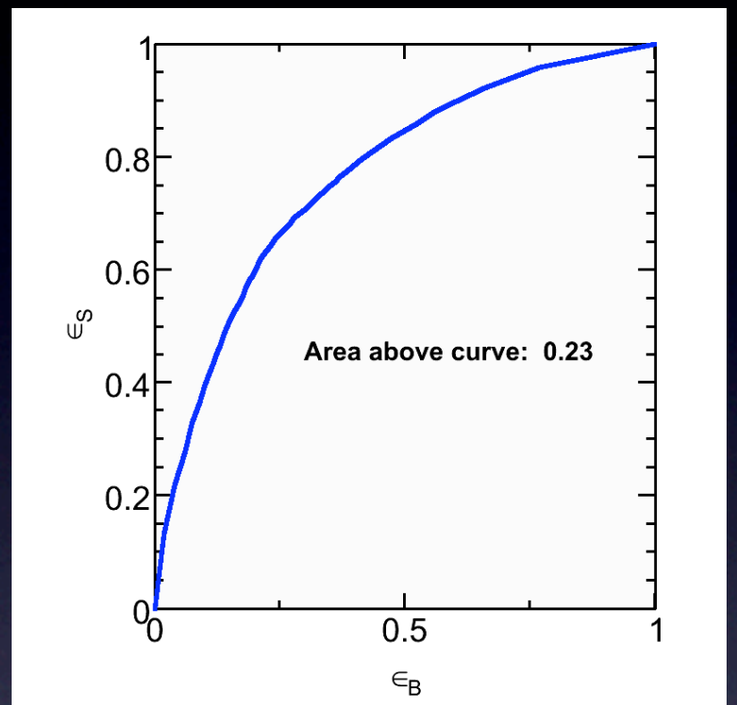


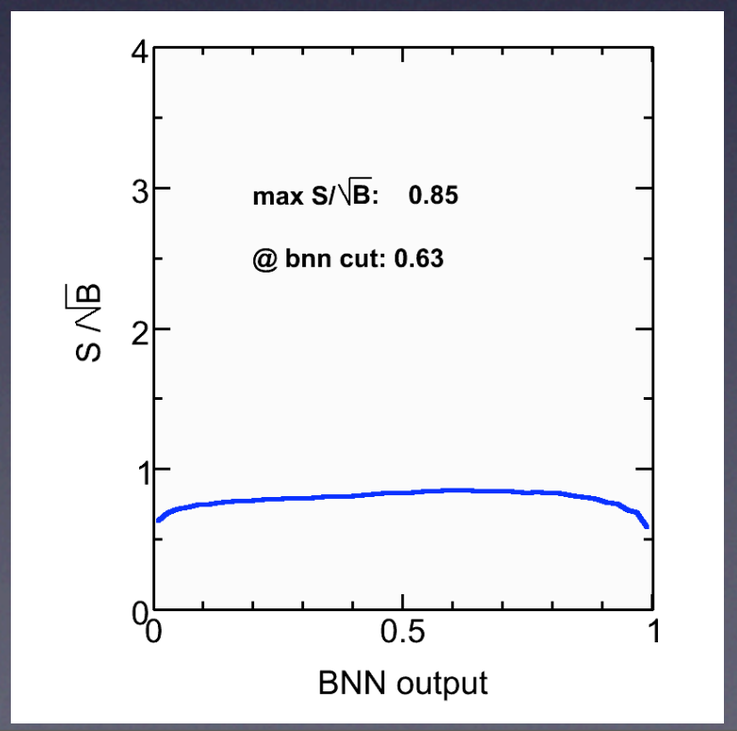


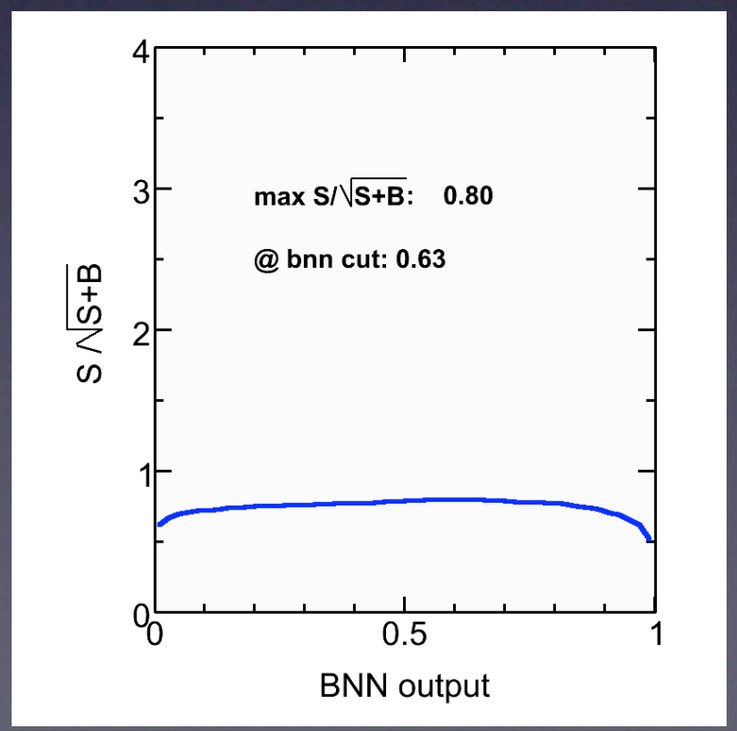
BNN Verification Plots

- Channel: electron, 1 tag, 3 jet

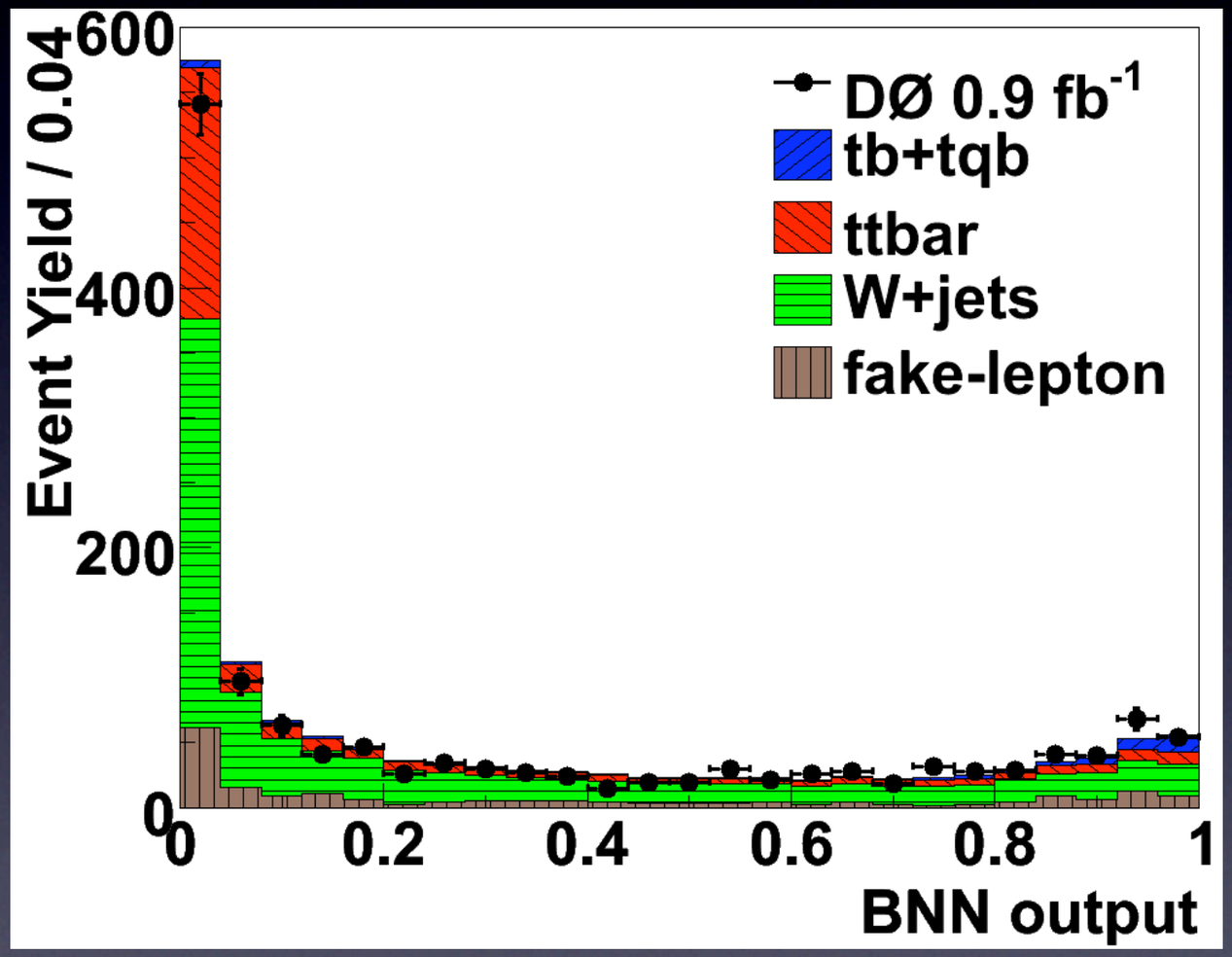


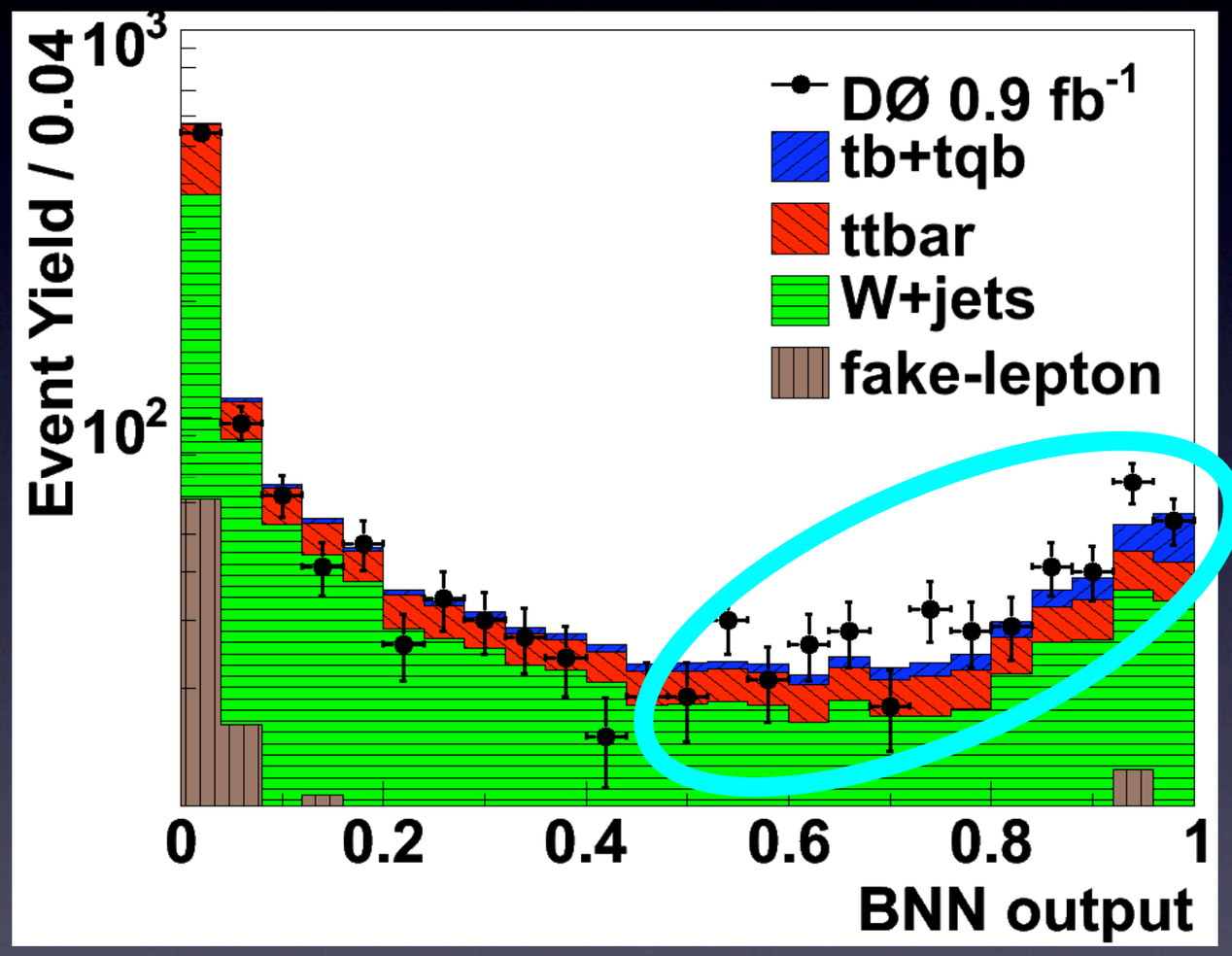






BNN Signal and Background Distributions





Cross Section Measurements [0.9 fb^{-1}]

- Used Bayesian statistical inference to calculate single top cross section (σ)
- Expected measurement:
  $\sigma \pm \Delta\sigma = 2.6 \pm 1.2$ pb (including systematics)
  $\sigma/\Delta\sigma = 2.1$ ---> "significance"
  BLUE significance: 2.3
- Observed measurement:
  $\sigma \pm \Delta\sigma = 6.2 \pm 1.5$ pb (including systematics)
  $\sigma/\Delta\sigma = 4.2$
  BLUE significance: 3.6

Conclusions & Future Work

- Revisited combination of analyses (DT, ME, BNN) in 0.9 fb^{-1} of data
- New BNN method improves results, 15-20% rel. to old BNN
- Unusual features inherent in verification plots ---> separation not optimal yet
- Observed significance improved, yet expected significance deteriorated
- Need to understand discrepancies in DT plots
- Need to optimize BNN training
- Re-calculate single top cross section
- Acknowledgments: Thanks to the U.S. Dept. of Energy SULI program, special thanks to Supriya Jain, Erik Ramberg, and Roger Dixon.