

# Application of Neural Networks to $b$ -quark jet detection in $Z \rightarrow b\bar{b}$ .

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*REU 2005*

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August 4, 2005

# Outline

- 1 Introduction
- 2 Neural Networks
  - Training
  - MC Reconstruction Options
  - Improvement Over Cut Method
- 3  $Z \rightarrow b\bar{b}$  Analysis
  - Background Subtraction
- 4 Summary

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# The Standard Model

- Standard Model (SM) very successful.
- However, no known mechanism for electro-weak symmetry breaking.
- Theories predict at least one Higgs field.
- Higgs field gives mass to  $W^\pm$  and  $Z$  weak bosons.

# Higgs Fields

- Theories predict one or more Higgs bosons.
- Promising channels for Higgs detection at the Tevatron:

$$p\bar{p} \rightarrow WH \rightarrow l\nu b\bar{b},$$

$$p\bar{p} \rightarrow ZH \rightarrow l^+l^- b\bar{b},$$

$$p\bar{p} \rightarrow ZH \rightarrow \nu\bar{\nu} b\bar{b}.$$

# Why $b$ -jets

- Calibration for  $b$  calorimeters.
- Measure mass of  $Z$  from  $Z \rightarrow b\bar{b}$ .
- Compare with known mass of  $Z$ .

## Purity & Efficiency

- Only use taggable MC jets.
- Each jet matched with 2 tracks within  $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 1.0$ .
- Only use MC jets with at least 1 secondary vertex.
- Assume 0 vertex jets are non- $b$ -jets.

$$\text{efficiency} = \frac{\text{correctly tagged } b\text{-jets}_{\text{nv}>0}}{b\text{-jets}_{\text{nv}>0} + b\text{-jets}_{\text{nv}=0}},$$

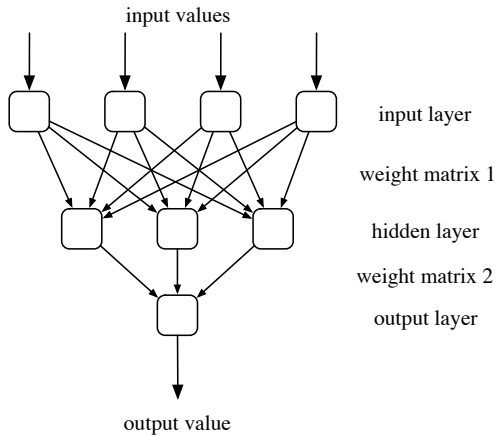
$$\text{purity} = \frac{\text{incorrectly tagged non-}b\text{-jets}_{\text{nv}>0}}{\text{non-}b\text{-jets}_{\text{nv}>0} + \text{non-}b\text{-jets}_{\text{nv}=0}}.$$

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# Multilayer Perceptron

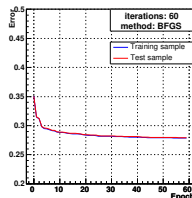
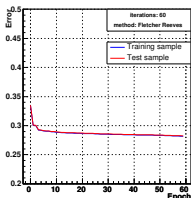
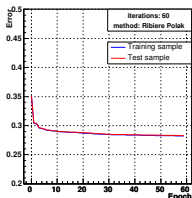
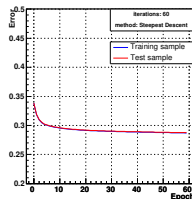
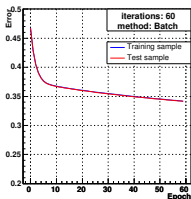
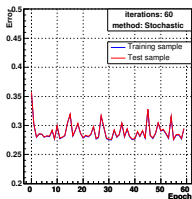
- Multilayer perceptron (feed-forward network)
- TMultiLayerPerceptron class in ROOT 4.04/02



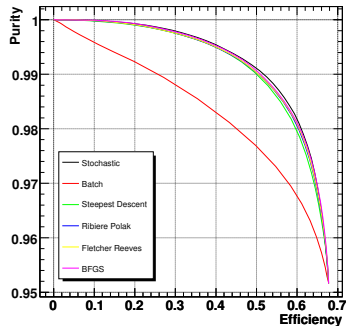
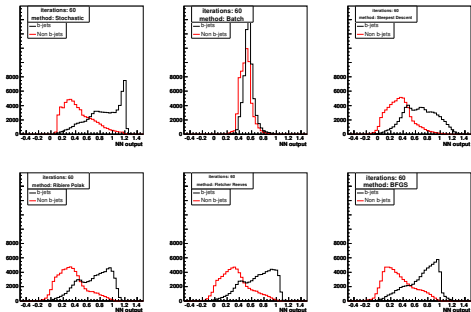
# Training

- Adjust weights according to output error.
- One weight update is an epoch/cycle/iteration.
  - Too many iterations  $\implies$  over-trained.
  - Too few iterations  $\implies$  under-trained.
- Various training algorithms.
  - 1 Stochastic minimization
  - 2 Steepest descent with fixed step size (batch learning)
  - 3 Steepest descent algorithm
  - 4 Conjugate gradients with the Polak-Ribiere updating formula
  - 5 Conjugate gradients with the Fletcher-Reeves updating formula
  - 6 Broyden, Fletcher, Goldfarb, Shanno (BFGS) method

# Methods Training Error.



# Methods Signal/Background & Purity V.S. Efficiency



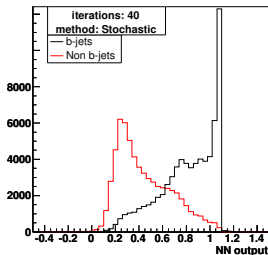
# Variable Sets

Investigated mainly two variable sets:

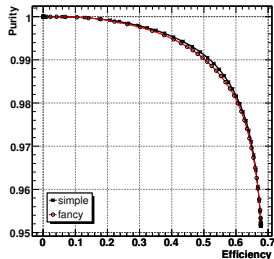
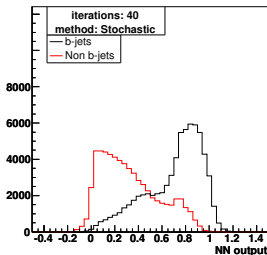
- “simple”
  - 1 3D decay length significance
  - 2  $\Delta R$
  - 3 mass
  - 4 2D decay length
  - 5  $\chi^2$
  - 6 multiplicity
- “fancy” = “simple” +
  - 7 number of vertices
  - tertiary vertex:
    - 8 3D decay length significance
    - 9  $\Delta R$
    - 10 mass
    - 11  $\chi^2$
    - 12 multiplicity

# Variables Signal/Background & Purity V.S. Efficiency

simple



fancy

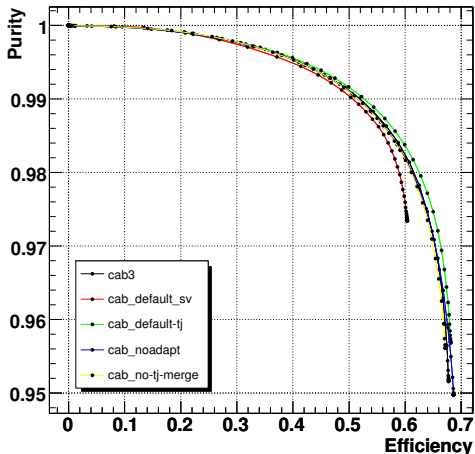


# Hidden Neurons

- Compared performance of NNs with different number of hidden neurons.
- 6 hidden for “simple”.
- 12 hidden for “fancy”.
- Two hidden layers did not help.

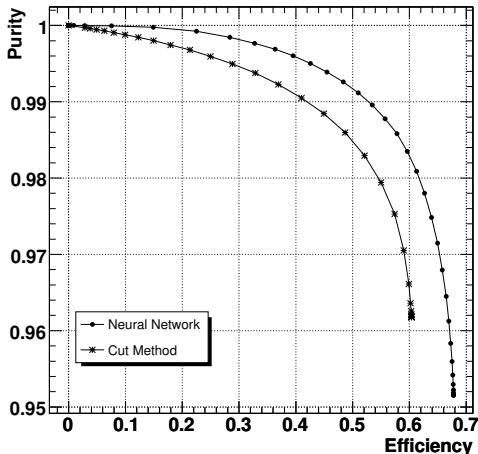
# MC Reconstruction Options

- MC data from 5 different reconstruction options were compared.
- Default secondary vertexing options were worse than other reconstruction options.



# MC Reconstruction Options

Improvement over previous cut on only 3D decay length significance.



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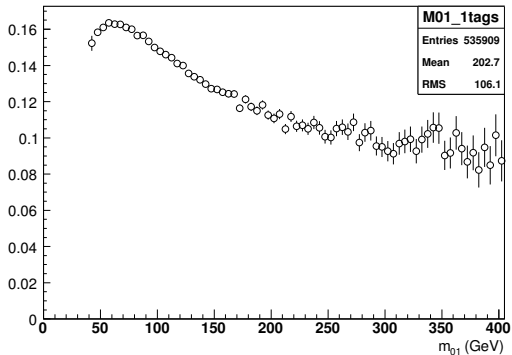
# NN Cut

- $\approx 100 \text{ pb}^{-1}$  of DØ Run II data with Andy Haas' reconstruction options.
- Look for  $Z \rightarrow b\bar{b}$  events using the NN.
- Cut on NN output to yield 50% efficiency and 99% purity for  $b$ -tagging.

# Background Subtraction

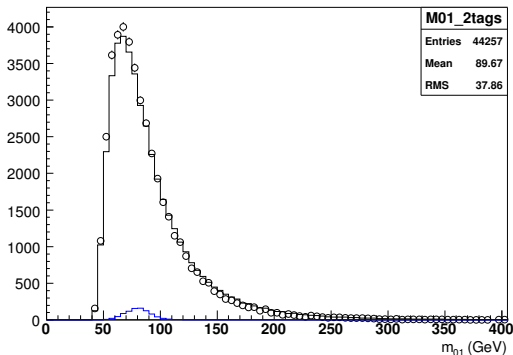
- Background is essentially heavy-flavor dijet and mistagged gluon/light-quark jet production.
  - Cannot be accurately simulated with current techniques.
- Want to estimate background of double  $b$ -tagged data to subtract it.
- Use a tag-rate function (TRF) to estimate the background.

# Tag-rate function



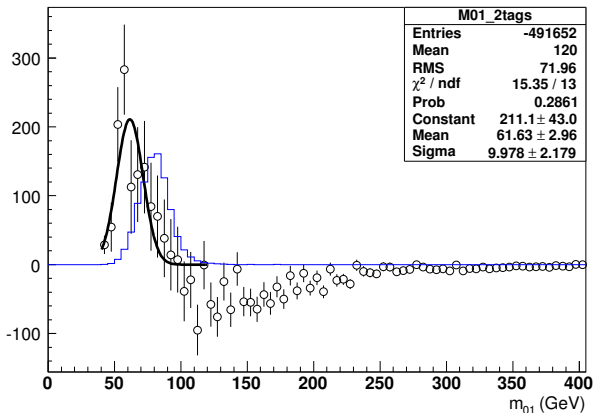
TRF derived from the single  $b$ -tagged data used to estimate the double-tagged background.

# Background Comparison



Comparison between double  $b$ -tagged data (points) and the expected background before any background corrections.

# Background Subtraction

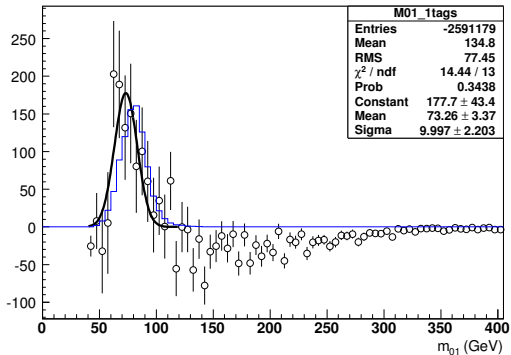


The  $Z \rightarrow b\bar{b}$  peak derived from the data after no corrections.

## $0 \rightarrow 1$ Correction

- What is it?
  - Double-tagged data has more heavy-flavor jets than the single-tagged data which the TRF is applied to.
  - The difference in heavy-flavor jets is the  $0 \rightarrow 1$  shift.
- How to fix it?
  - Compare untagged data with single tagged data.
  - Subtract the  $0 \rightarrow 1$  correction.

# 0 $\rightarrow$ 1 Correction



The  $Z \rightarrow b\bar{b}$  peak derived from the data after the 0  $\rightarrow$  1 correction.

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# Summary

- NNs yield better  $b$ -jet detection performance than a decay length significance cut alone.
- Tertiary vertex NN variables don't yield an improvement.
- MC reconstruction options can make a difference.
- Further corrections to the background subtraction are needed.