# Search for the Higgs Boson in the WH→WWW→lv.jj.jj Channel

Zachary Hynes

2009 Fermilab SIST Student

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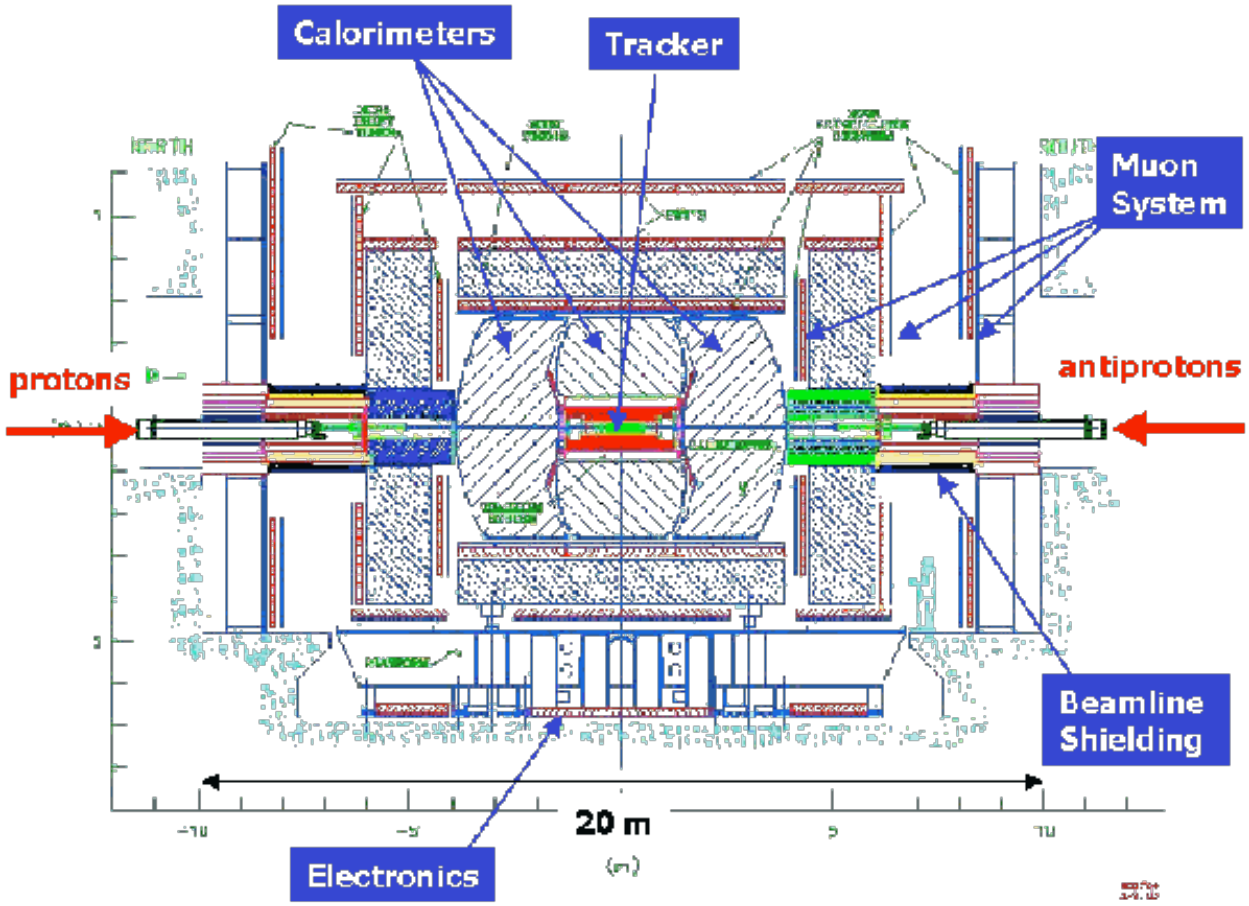
# D0 Detector and Collaboration

- D0 Data
- Analysis tools developed by the D0 collaboration

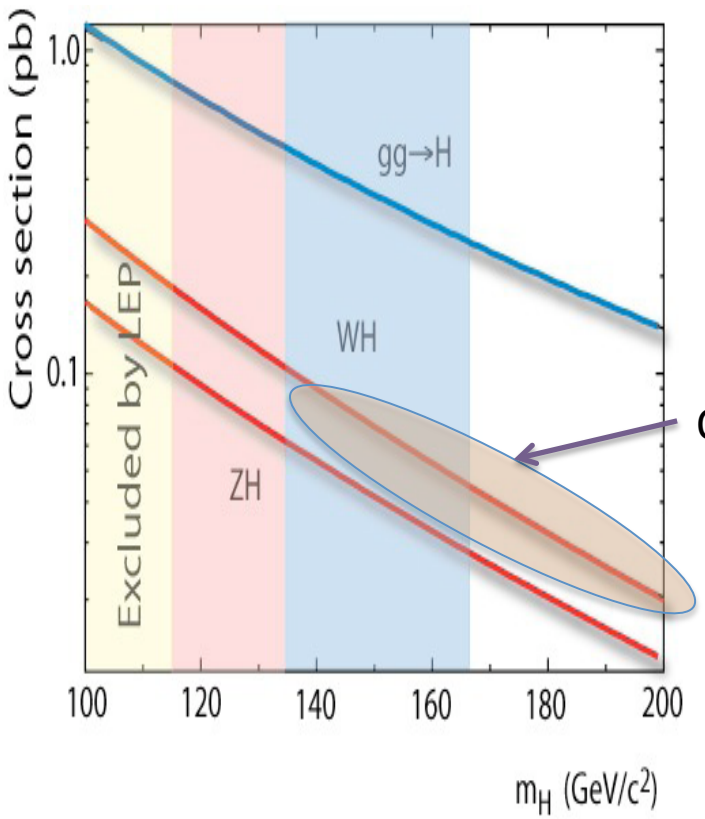



*Drawing of the D0 Detector*

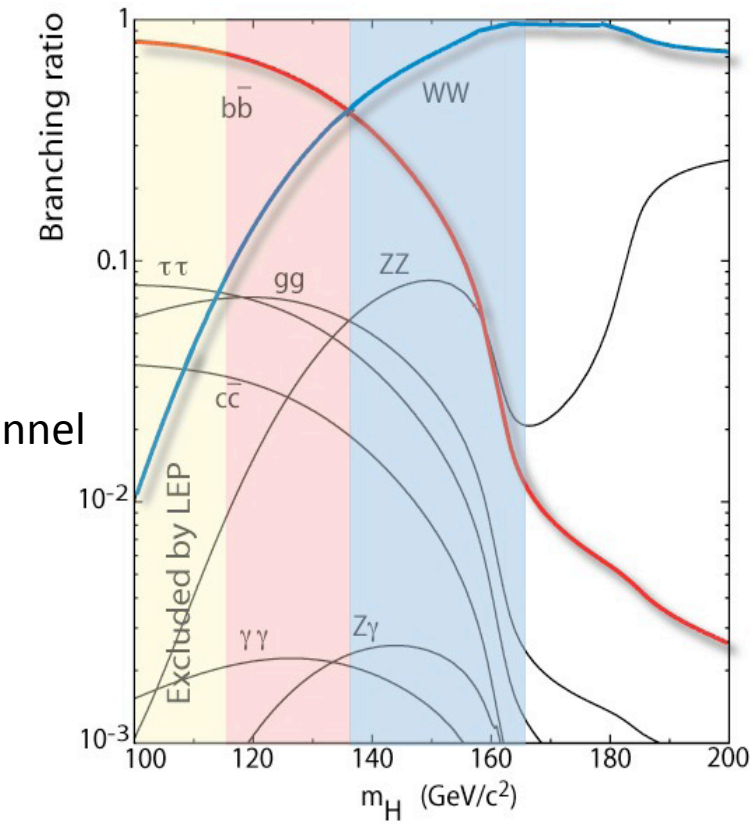
# Overview of the Search for the Higgs Boson

- Explains why particles have mass
- Should have mass in range of 114.4 GeV to 200 GeV
- Can't be observed directly, only indirectly through its decay into particles that can be observed by detectors like D0
- CDF and D0 exclude the possibility of a Higgs boson with 160 GeV<$m_H$<170 GeV at 95% C.L.

# Higgs Production and Decay Modes




Our channel




Cross-sections for associated production of Higgs and production via gluon fusion as a function of Higgs mass

Branching ratio for Higgs as a function of Higgs mass

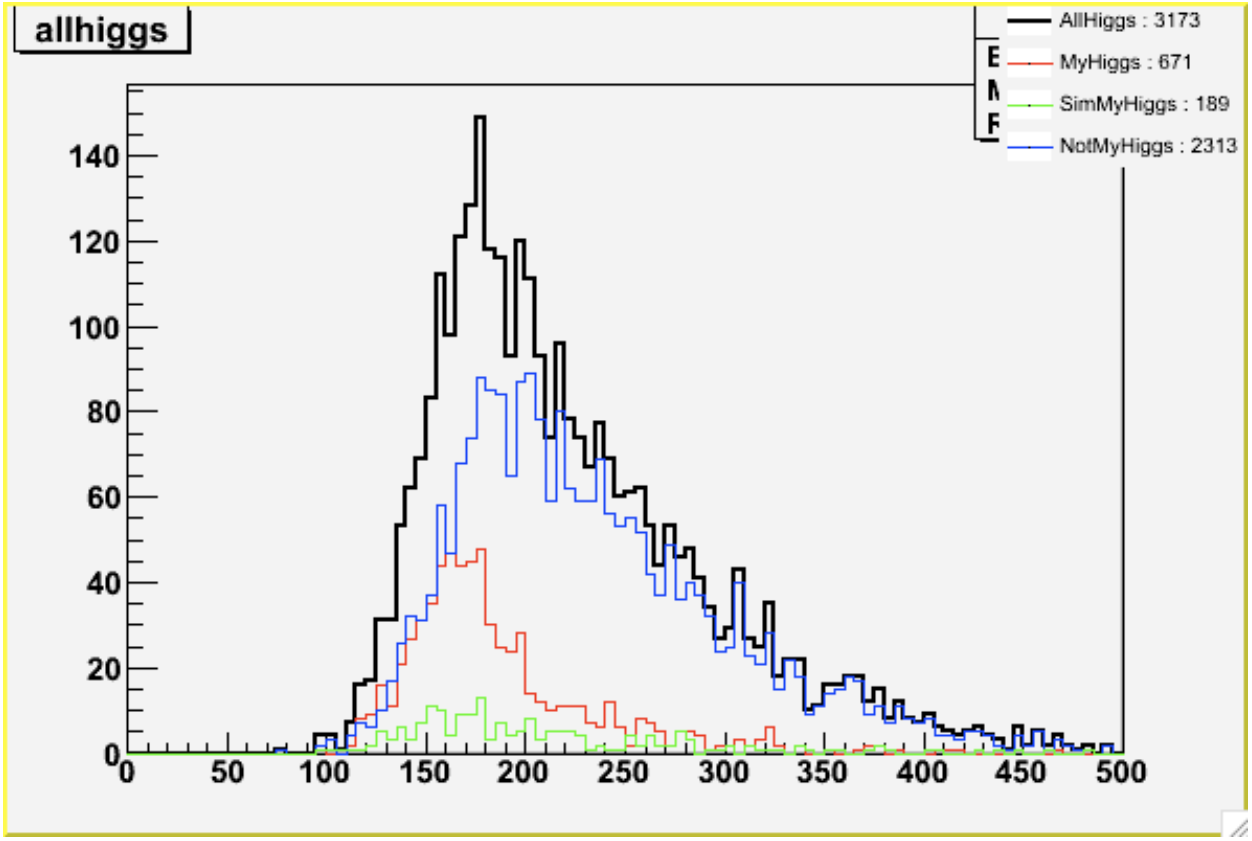
# WH→WWW→lv.jj.jj

- This is the first examination of this high-mass Higgs channel with the four jet, lepton, neutrino decay mode
- Other analyses: di(tri)-lepton decay mode
- Lepton: Electron and Muon Channel
- Key physics backgrounds:
  - w+jets
  - t-tbar
  - and others…
- Multijet background (QCD)

# WH→WWW→lν.jj.jj

- Why this channel?
  - W→jj (60%), W→lν (10%)
  - Six entities in final state: reduces backgrounds
  - Not limited by b-tagging efficiencies (jets from light and c-quarks)
  - If there are signs of the Higgs boson, we can make an estimate of its mass from the four-jet mass (H→WW→jj.jj)

# 4 Jet Mass: Muon Channel, Higgs Mass= 170 GeV



# Data and MC Processing with CAF

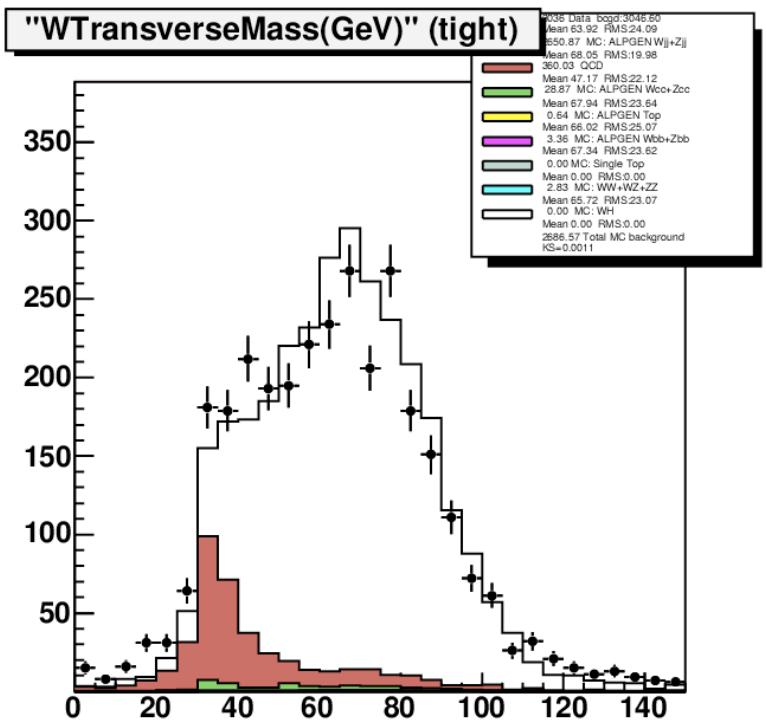
- Common Analysis Format (CAF)
- Packages:
  - Base package: vjets_cafe v03-04-00
  - Analysis package: wh_cafe whtree_v01-01-00
- C++ Processors:
  - Apply Cuts
  - Flavor-tag Jets
  - Write TTrees
  - Execute user-specified functions
- SAM Dataset Definitions (Muon Channel):
  - Data: VJets_MUInclusive_Summer09_RunIIb_v2
  - MC: Common Samples Group

# Post-processing of Data and MC Backgrounds

- CAF processors applied basic cuts to data and MC in previous step
- If Higgs boson exists, we expect to find 5-10 Higgs events for high mass Higgs in this channel with 4 $fb^{-1}$
- MC backgrounds should model data well
- We use analysis scripts associated with the CAF analysis packages to check for agreement between MC background and data
  - wh_cafe/datavsmc/rundatavsmc.csh
  - wh_cafe/datavsmc/tree_datavsmc.cc
  - wh_cafe/datavsmc/WHTreeAnalyze.h

# Fitting Data to MC Backgrounds

- W+jets peak for W Transverse Mass close to 80 GeV (Approximates mass of W boson)
- wh_cafe package version issues
- Analysis script does not carry out necessary reweightings
- W+Jets Scale Factor: 7.1; other Higgs searches suggest this value is too high

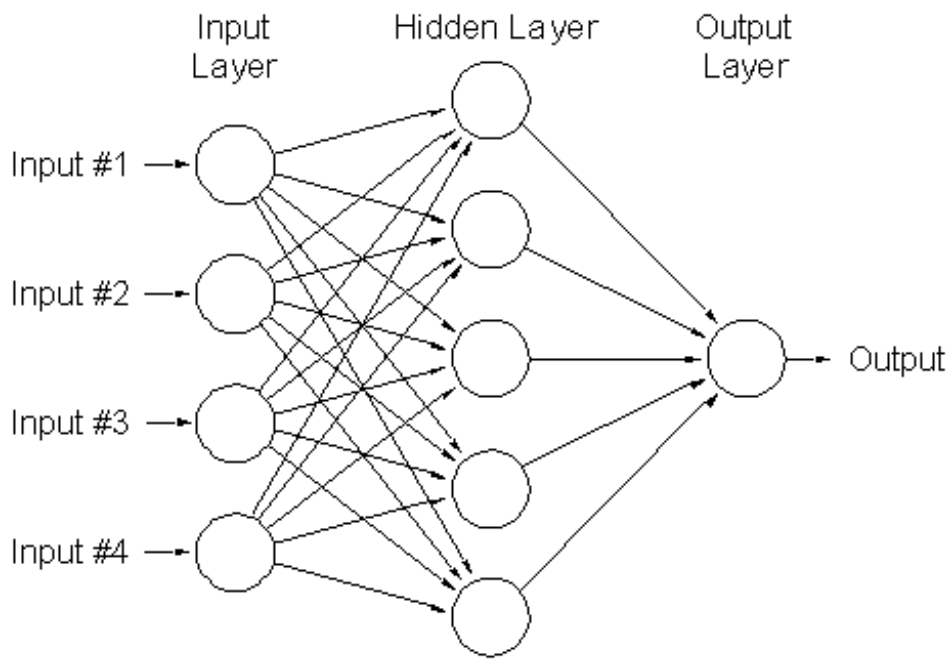


# Development of Multivariate Classifiers

- Signal and Background events cannot be distinguished on one criterion
- HEP analyses use multivariate techniques:
  - Neural Networks
  - Random Forests

# Neural Networks

- Input nodes: event variables
- Hidden layers of nodes strengthen classification capacity
- Output node: classification result
- The network is trained and tested on signal and background MC samples before being applied to data



# Toolkit for Multivariate Data Analysis (TMVA)

- Neural Network Development with TMVA
  - TMVA: Used in conjunction with ROOT
  - Select input variables for which signal and background distributions show some differences
  - Apply final cuts
  - Design an architecture
    - Hidden Nodes
    - Activation Functions
    - Training cycles

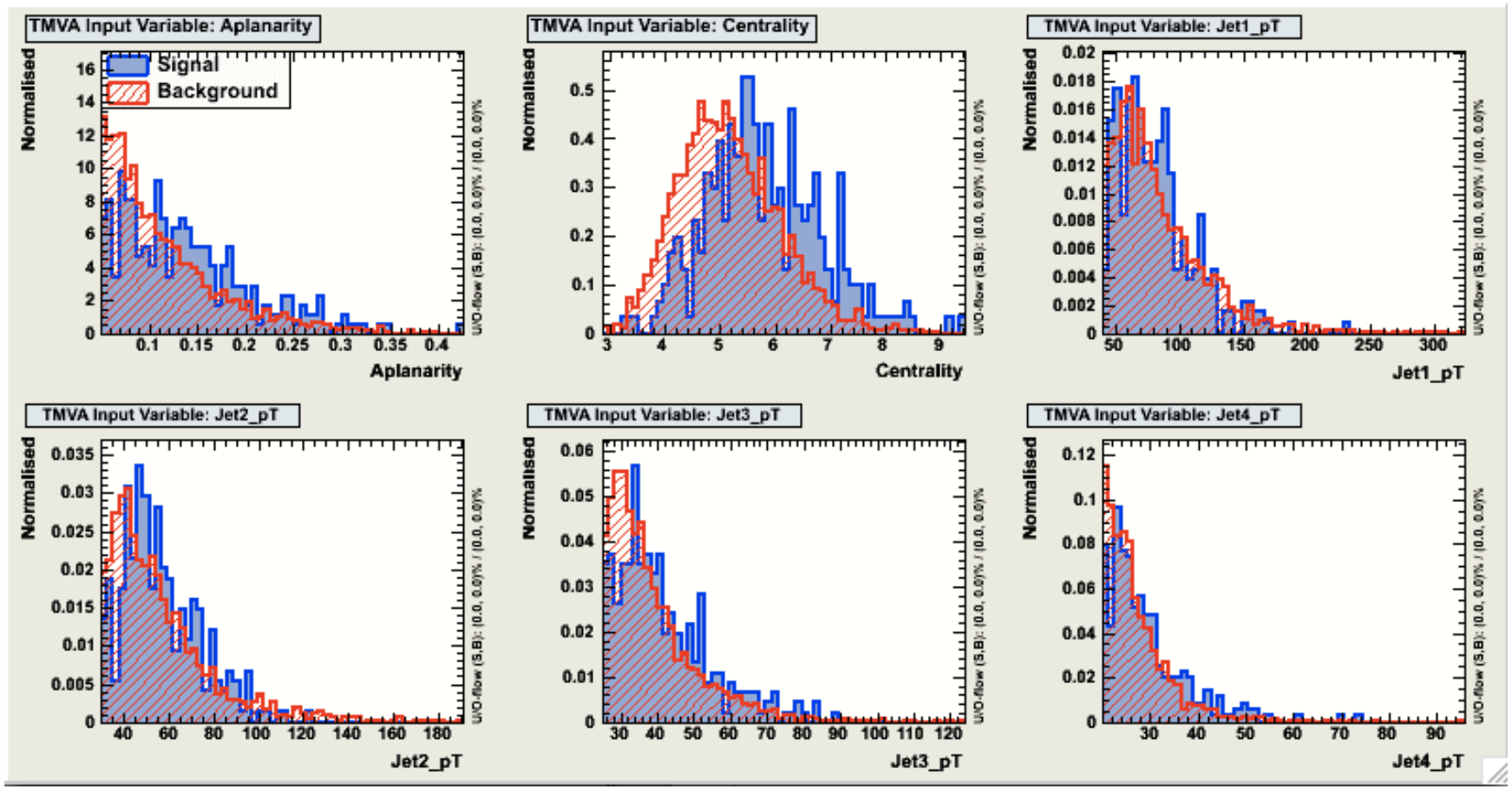
# Neural Network Development with TMVA

- Signal MC: Higgs Mass of 180 GeV
- Background MC: w+5lp→lv+5lp (inclusive)
  - Why this background?
- Architecture
  - Two layers of 8 hidden nodes
  - 12 parameters in use (Jet $p_T$'s, event shape variables, W Transverse Mass, and others)

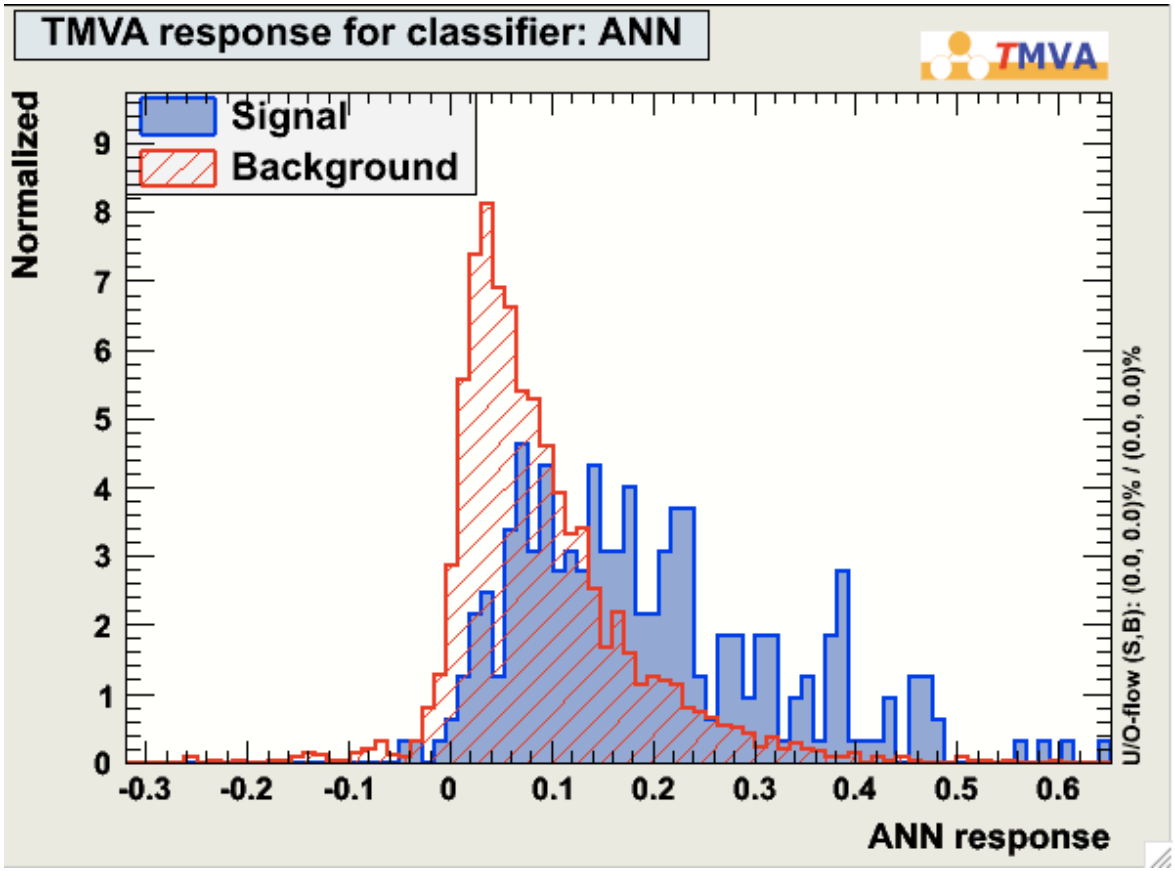
```
TCut c_Jet1_pT="Jet1_pT>40";
TCut c_Jet2_pT="Jet2_pT>30";
TCut c_Jet3_pT="Jet3_pT>25";
TCut c_Jet4_pT="Jet4_pT>20";
TCut c_Jets_pT=c_Jet1_pT&&c_Jet2_pT&&c_Jet3_pT&&c_Jet4_pT;
//Other topological variable cuts
TCut c_Aplanarity="Aplanarity>0.05";
TCut c_Lepton_pT="Lepton_pT>20";
TCut c_MET="MET>20";

TCut
c_preselection=c_Jets_pT&&c_Aplanarity&&c_Lepton_pT&&c_MET;
```

Cuts Applied to Input MC Samples

# Event Variable Distributions for TMVA Analysis



# MVA Output Distribution




Signal MC: Higgs Mass at 180 GeV

Background MC: w+5lp→lv+5lp

# Lessons from Analysis Process

- Learning the "system"
  - What are the pieces of an analysis?
  - What are the individual tools of an analysis?
  - How does everything fit together?
- Support from other analysis groups
  - Make contact with others in D0 doing similar analyses
  - Use their tools and experiences to guide our analysis
- Organization
  - Attention to detail at every step

# Future Plans for Analysis

- Exciting times in HEP; I will continue with this analysis for the next month
- Next steps:
  - Use new packages to reprocess data and MC
  - Attain agreement between data and MC for basic cuts
  - Identify final cuts to be made
  - Code sophisticated event variables to strengthen MVA
  - Try out new classifiers; Bagged and Boosted Decision Trees are growing in popularity throughout HEP

# Backup Slides

# Internship Experience

- I learned a number of tools applicable in many fields outside of HEP:
  - Linux OS
  - C++
  - ROOT
  - Multivariate Analysis

ROOT

An Object-Oriented
Data Analysis Framework

Scientific
Linux
Fermi
4x

TMVA

# Resources


- Tevatron New Phenomena, Higgs Working Group, D0 Collaboration, and CDF Collaboration. "Combined CDF and DZero Upper Limits on Standard Model Higgs-Boson Production with up to 4.2 fb-1 of Data." *ArXiv*. 24 Mar. 2009. Web. 2 Aug. 2009. <http://arxiv.org/pdf/0903.4001v1>.
- Hoecker, A., et. al. "TMVA - Toolkit for Multivariate Data Analysis." *ArXiv. 11 June 2007. Web. 4 Aug. 2009. <http://arxiv.org/pdf/physics/0703039v4>.*

- Packages used in our analysis: wh_cafe whtree_v01-01-00 and hww_cafe v00-02-br

# Image Credits

- MIT Dome:
  http://web.mit.edu/rhic/star/analysismeeting2009/images/mit.jpg
- Drawing of D0 detector:
  http://www.fnal.gov/pub/now/live_events/images/D0sideview.gif
- D0 logo:
  http://www-d0.fnal.gov/computing/mcprod/d0logo_white.JPG
- Neural Network Diagram:
  http://www.odec.ca/projects/2007/stag7m2/images/fig2.gif
- Higgs Branching Ratios and Production Cross-Sections:
  Yamada, Ryuji. "WH→W(WW) →lν.(jj.jj), or → jj.(jj.jj)". *WH_WWW1.ppt*. 18 Sep. 2008. PowerPoint obtained from R. Yamada. 4 Aug. 2009.
- 4-Jet Mass Histogram:
  Yamada, Ryuji, et al. "WH→W(WW) →lν+4jets: Higgs Mass =160 and 170 GeV- MC Results". *WH_WWW_lν4jets_MCresults.pdf*. PowerPoint obtained from R. Yamada. 4 Aug. 2009.