Tagging b jets Associated with Heavy Neutral MSSM Higgs Bosons

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ACAT 2005
May 22 - 27, 2005
DESY, Zeuthen, Germany
Outline

- The problem of tagging b jets in the Compact Muon Solenoid experiment (CMS) at Large Hadron Collider (LHC)
  - Standard method of track counting
- Tools for the NN approach
  - ROOT tools
    - MLP and NeuNet
    - Kohonen's SOM and LVQ algorithms
      - SOM_PAK and LVQ_PAK
- Results from neural classification
Compact Muon Solenoid detector for the Large Hadron Collider.
Geant4 based simulation of a SUSY event in the CMS detector containing missing transverse energy, jets and several leptons in the barrel detector. *Picture: IguanaCMS.*
b-tagging

• At LHC the Higgs production in association with b-quarks

\[ pp \rightarrow b\bar{b}H_{\text{SUSY}}, \quad H_{\text{SUSY}} \rightarrow \tau\tau \]

is the most important production mechanism for MSSM Higgs bosons at large tan\(\beta\)

• The associated b-quarks hadronize forming soft jets, which can be used for identifying the signal events from the background

• b-tagging is a powerful tool to suppress the Drell-Yan background

\[ pp \rightarrow Z,\gamma^* \rightarrow \tau\tau \]

for which the associated jets are mostly light quark and gluon jets, or which has no associated jets at all
Track counting b-tagging (1/2)

- The identification of b jets is based on the relatively long lifetime of B hadrons, $c\tau \sim O(5 \text{ mm})$
  - Reconstruction of secondary vertex or
  - Measuring the track impact parameters (IPs)
    - Defined as the minimum distance between the track trajectory and the primary interaction point
Track counting b-tagging (2/2)

- The most simple algorithm to identify b jets is to count tracks in the jet cone with significant enough IP (IP/error)
  - This algorithm has been shown to give 35% tagging efficiency for b jets with 1% mistagging probability

- S. Lehti, Tagging b-jets in $\text{#rm } b \bar{b} H_{\{SUSY\}} \rightarrow \tau \tau$, CMS NOTE-2001/019; G. Segneri and F. Palla, Lifetime Based b-tagging with CMS, CMS NOTE-2002/046.
Neural network approach (1/2)

- Since a neural network (NN) approach has been shown to be applicable to the problem of Higgs boson detection at LHC, we study the use of NNs to the problem of tagging b jets


Neural network approach (2/2)

- In the NN approach to the b-tagging problem we feed networks with the same events and the same seven variables as used in the traditional track counting algorithm:
  - Number of tracks in the jet cone of 0.5
  - IPs and related IP significances for three leading tracks

- CMS ORCA simulation package (version 8_8_0) was used to create:
  - 40k signal events
  - 40k Drell-Yan background events
  - Fully simulated with track and jet reconstruction
Example of variables used in the NN teaching. a) A leading track IP distribution for a signal and background events. b) A significance of a leading track IP.
Neural networks in data analysis framework
ROOT (1/2)

• ROOT provides flexible object oriented implementation of MLPs
  – Various learning methods are provided
    • Steepest descent algorithm
    • Broyden-Fletcher-Goldfarb-Shanno algorithm
    • Variants of conjugate gradients
  – Visualization of the network architecture and learning process
  – Network can be exported as a standalone C++ code

ROOT provides also another feed forward NN tool NeuNet, which uses a common back-propagation learning method.

- **J.P. Ernenwein, NeuNet,**
  [http://e.home.cern.ch/e/ernen/www/NN](http://e.home.cern.ch/e/ernen/www/NN).
Self-organizing maps

- We use public-domain program package SOM_PAK
  - C library from Helsinki University of Technology SOM programming team directed by Teuvo Kohonen
  - This unsupervised learning package provides compact implementation of SOM algorithm


Learning vector quantization

- We use program package LVQ_PAK
  - C library from Helsinki University of Technology LVQ programming team
  - Implementation of the supervised Kohonen's LVQ algorithm is compact and fast

Example graphics from ROOT MLP tool. Impact parameter significances are found to have the best classification power.
Choosing learning algorithm

- From different ROOT MLP learning algorithms we found Broyden-Fletcher-Goldfarb-Shanno algorithm (BFGS) best
  - Following results use this learning algorithm

- Also Stochastic minimization performed relatively well
  - This is the simplest learning method available in ROOT
  - Robbins-Monro stochastic approximation applied to MLPs
  - Further tuning of the parameters for this method might improve performance

- C. Delaere, *TMultiLayerPerceptron: Designing and using Multi-Layer Perceptrons with ROOT*,
ROOT NeuNet and MLP Results
Example output from ROOT MLP tool. Neuron weights after learning in 7-15-7-1 configuration are shown.
SOM and LVQ Results (1/2)

Example graphics from SOM_PAK. Semantic map after unsupervised learning phase is divided into two regions representing signal (s) and background (b).
SOM and LVQ Results (2/2)

- Using same seven variables, SOM was able to classify unseen events with b-tagging efficiency of 72% with 12% mistagging rate
- SOM was able to filter away 44% of background events with 0.2% misclassification probability to signal
  - Further improvements are expected with SOM configuration optimization
  - Also, preliminary results on subsequent LVQ_PAK tuning indicate 2% tagging efficiency improvement
Conclusion

- We have shown that neural classification can be performed successfully in b-tagging problems
  - ROOT tools MLP and NeuNet were found useful
- The classification power is competitive to traditional track counting method
- We have also shown how SOM can be taught to separate Higgs signal from LHC background
- Simultaneous use of traditional tagging methods and neural computing, including unsupervised teaching, is promising technique for Higgs particle searches