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Calorimeter Optimization for Jet Identification

Gary R. Bower

Stanford Linear Accelerator Center

Abstract. During LCWS 1999 at Sitges, Spain, we presented a set of discriminators for reconstructing jets in high energy lepton colliders. We have extended that study by adding new event types, by adding new discriminators, and by using a neural net rather than cuts to identify jets. We apply these techniques to detector simulations to begin a study of calorimeter optimization.

EXTENSION OF THE SITGES STUDY

It will be helpful if the reader has available our previous paper in the forthcoming proceedings of LCWS 1999. The current paper is limited to 40% of the size of the Sitges paper. It is impossible to reprise the information presented there. In this paper, we will refer to the earlier phase of the study presented at Sitges as the “Sitges study.”

The new event types

The Sitges study of jet reconstruction was based on comparison of events with a 500 GeV center-of-mass energy. We compared $Z/\gamma \rightarrow$ qqbar, ZZ, and ttbar. In the current study we add $Z/\gamma \rightarrow$ WW and ZH with a Higgs mass of 114 GeV. The ZZ, WW and ZH events provide an additional challenge because their jet structure is quite similar. The reason for the choice of Higgs mass was twofold. Since the Higgs mass is uncertain, we have selected a value at the low end of the allowed range set by the recent LEPII results in order to work with the most difficult case to disentangle from ZZ and WW events. Also, the recent hint of a possible signal at 114 GeV reported at LEPII suggests using that value.

The new discriminators

In the Sitges study one of the discriminators was the event thrust axis hemisphere mass. Each event had two such mass values and they were treated symmetrically as two discriminators. The addition of the ZH events to the study suggests distinguishing the masses of the two hemispheres. We have replaced the two hemisphere mass discriminators with four discriminators for each event: the higher hemisphere mass, the lower hemisphere mass, the sum of the hemisphere masses and their difference. Of course, mathematically two of these are redundant but it is expedient when using these values in cuts or in a neural net to do the math ahead of time and simply use the four correlated values.

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Stanford Linear Accelerator Center, Stanford University, Stanford, California, 94309

The use of a neural net

Discriminators were used with a set of cuts in the Sitges study to identify event types. However, the problem is multi-dimensional and a neural net will give better results, especially when the two new event types are added. Accordingly, we switched to a neural net for our work and used the Stuttgart SNNS package[1].

We used the most elementary configuration by choosing a fully connected feed-forward net with a back-propagation learning function. We have used our complete set of discriminator values as input nodes and we have chosen one layer of hidden nodes with the number of hidden nodes equal to one more than the number of input nodes. We chose five output nodes, one for each event type. We trained the net on a different data set than the one used to produce the results presented here.

Methodology review

Regarding calorimeter design, the goal of this study is to develop a tool for comparing different design choices. This tool can measure a calorimeter's ability to perform jet reconstruction of various event types. We define the best possible performance by measuring how well we can do jet reconstruction based on the events at the physics generator level, the equivalent of a perfect detector. We define the worst performance by simulating the detector response to the physics generator level events and then defining calorimeter clusters by simply combining contiguous hits into a single cluster. We treat each cluster as a particle. This uses the simplest possible cluster formation method and makes no use of tracking information. With this high and low benchmark we will be able to evaluate more sophisticated "energy flow" schemes and we will be able to compare different calorimeter designs.

THE NEW RESULTS

This is a continuing study and the limited results presented here are intended to give a concrete numerical indication of what can be done with this approach. We show results based on the North American Study Group's so-called Large detector design which contains a pixel vertex detector and a TPC for tracking. Outside the TPC is a highly segmented electromagnetic sampling calorimeter and, outside that is a hadronic sampling calorimeter with coarser segmentation. Outside the hadronic calorimeter is a 3 Tesla warm solenoid.

Simple calorimeter clusters as described above were defined separately in the EM and Hadronic sections. The EM clusters were assumed to be photons and assigned a particle rest mass of zero and the Hadronic clusters were assigned a pion mass. The cluster energy combined with this mass assignment was used to define the particle four-momentum. The direction of the momentum vector is from the interaction point to the cluster. There is a minimum cluster energy required for a cluster to count as a particle. This minimum was defined so the number of "cluster" particles is approximately equal to the true number of final state particles reaching the calorimeter. The cutoff was 0.25 GeV.

For some events, particularly Z/γ → qqbar, there can be considerable boost due to initial state radiation and a cut is made to exclude events with a boost greater than 0.2c. Since the calorimeter is nearly hermetic, no cut was made on thrust axis orientation. Also, since the goal of this study is to investigate hadronic jets, a cut is made to exclude any event with less than 5 particles in either thrust hemisphere resulting in a sample with no semi-leptonic decays.

For each event, the neural net yields five numbers that can be approximately interpreted as the probability that the event was one of the five types, ie, qqbar, WW, etc. One could consider various criteria for using these probabilities to assign an event type. To get as many identifications as possible (high efficiency) at the cost of purity, one would choose for each event the type that had the highest probability and assign the event that type regardless of how close that probability was to the next highest probability. We have used this method. This results in every event being assigned a type. If one wanted to identify a particular event type with a higher degree of accuracy (a purer sample) one would require that the probability to be the type of interest be greater by δ than the probability that the event is of one of the other four types. The larger δ, the greater the accuracy.

Below we present two tables, one for efficiency and one for accuracy. In each table, we present results for the two cases described above: generator level events and detector simulated events where particles are defined entirely by the simple contiguity based clustering algorithm. For each event type, the efficiency is the percentage of events of the specific type that were correctly identified by the net as being that type. For each event type, the accuracy is the percentage of events identified by the net to be the specific type that are, in fact, that type. The accuracy combined with cross-section information could be used to determine the more conventional measure known as the "purity" of the identification.

TABLE 1. Efficiency.

Data Type	qqbar	WW	ZZ	ZH	ttbar
Generator Level	91%	90%	97%	96%	100%
Simple Clusters	76%	66%	53%	74%	86%

TABLE 2. Accuracy.

Data Type	qqbar	WW	ZZ	ZH	ttbar
Generator Level	95%	98%	87%	97%	98%
Simple Clusters	74%	60%	74%	64%	86%

Interpretation

The combination of an extensive set of discriminators and the use of a neural net has achieved remarkably good results. The generator level results represent the best a perfect detector would reach with this set of discriminators. We see efficiencies in the range 90% to 100% for the five types while simultaneously maintaining an accuracy range of 87% to 98%. On the other hand, the worst we will do with a real detector is efficiencies in the range 53% to 86% with a simultaneous accuracy range of 60% to 86%. It is also remarkable that these discriminators can achieve such good results distinguishing the three nearly identical color singlet event types, WW, ZZ, and ZH.

A realistic assessment of the efficiencies and accuracies that are possible with a detector will require more sophisticated cluster formation and track-cluster association algorithms. The simple clustering scheme used here assumes that the momentum of the particle reconstructed from a cluster pointed from the event interaction point towards the cluster. This is correct for neutral particles, but the charged particles' trajectories are curved by the solenoidal magnetic field and this certainly will introduce an unrealistic apparent broadening of jets.

As we look in detail at the different event types we see that the ttbar events have the highest efficiency and accuracy in both the ideal generator case and the worst simulation case. If we are able to approach the ideal limit we see the possibility of nearly perfect identification of the ttbar events. The present set of discriminators is based entirely the momentum of the final state particles and involves no particle identification features such as finding B meson vertices which would be expected to further improve the discrimination of ttbar and ZH events with their high incidence of B mesons.

NEXT STEPS

We need a more sophisticated "energy flow" algorithm to get a realistic assessment of the efficiencies and accuracies attainable. Once this is available it will finally be possible to make useful comparisons of different detector designs and to vary such parameters as the granularity of the calorimeter. The focus of this paper is calorimeter design and the current set of discriminators will be more than adequate for such design studies. However, the study of the discriminators as a physics analysis tool can be carried further. In particular, one can investigate the events that fail to be identified correctly and search for further discriminators.

The present focus of most linear collider detector studies is in the 500 GeV energy range. However, in the long run, the detector will certainly be expected to perform with accelerator energy upgrades to 1 TeV and beyond and the present study will eventually include such higher energy events. The five event types contained in the current study cover the most common event types expected at 500 GeV. However, there are lower rate event types that embody interesting physics, especially at higher energies. We anticipate extending the study to some of those lower rate cases as well as to some challenging SUSY scenarios.

REFERENCES

1. http://www.informatik.uni-stuttgart.de/ipvr/bv/projekte/snns/snns.html