International Journal of Modern Physics A

STUDY OF AN ALGORITHM FOR ENERGY FLOW IN THE SiD DETECTOR

Wolfgang F. Mader

Dept. of Physics and Astronomy, The University of Iowa, 203 Van Allen Hall
Iowa City, Iowa 52242/1479 U.S.A.

Received (Day Month Year)
Revised (Day Month Year)

The development of a tracking algorithm for minimum ionizing particles based on the SiD detector design for a future e^+e^-linear collider is described. Their identification and reconstruction, using the electromagnetic calorimeter alone, is an important step towards an Energy Flow algorithm which can play a key role in the measurement of the jet energy and the identification of long-lived particles. Implementation and possible future improvements of this algorithm are discussed.

Keywords: Linear Collider; Energy Flow; MIP-tracking.

1. Introduction

An e^+e^- linear collider is a precision instrument which would provide us with the possibility to test the Standard Model with unprecedented accuracy at the electroweak scale. In addition, it will have the potential to discover new physics processes in an energy regime up to 1 TeV or beyond[1]. In order to achieve the maximum sensitivity to the physics anticipated from this machine, the detector design has to be optimized using experimental as well as reconstruction techniques never before implemented.

The studies described in this document are based on the Silicon Detector[2] (SiD). Of particular importance in this design are the electromagnetic and the hadron calorimeters. They play a key role in the reconstruction of jets, e.g. from decays of vector bosons, decays of top quarks or possible Higgs bosons. It will be essential to be able to distinguish the presence of a Z^0 or $W^\pm$ boson by its hadronic decay modes into two jets. This implies a precision of the di-jet mass measurement which is comparable to the natural width of these bosons, requiring a jet energy resolution of $\sigma_E/E \approx 30\%/\sqrt{E}$. Methods used during the LEP era involving kinematic fits achieved a resolution of[3] $\sigma_E/E \approx 60\% \cdot (1 + \cos\Theta)/\sqrt{E}$. This has to be improved in order to be able to fully exploit the capabilities of a future e^+e^-linear collider.

2. Energy Flow Jet Reconstruction

The method currently studied to achieve this goal is the Energy Flow jet reconstruction technique. This implies the use of tracking to reconstruct charged particles, electromagnetic calorimetry to reconstruct photons and electromagnetic and hadron calorimetry to identify and measure the energy deposit of neutral hadrons. In an average event at typical linear collider center-of-mass energies between 500 GeV and 1 TeV, $\approx 60\%$ of the energy deposited in the calorimeters is expected to come from charged particles, photons contribute $\approx 25\%$ and neutral hadrons $\approx 15\%$[4].

3. The SiD Detector

The Energy Flow jet reconstruction algorithm requires that showers from photons and those from charged or neutral hadrons are separable. This implies a high granularity of the calorimeters, both transversely and longitudinally.

The SiD detector design currently used in the simulation consists of five layers of Silicon based pixel (CCD) vertex detectors ($1\,\mathrm{cm} < r < 7\,\mathrm{cm}$) and a five-layer Silicon microstrip tracking system ($20\,\mathrm{cm} < r < 125\,\mathrm{cm}$). The electromagnetic calorimeter (EMCal) consists of 30 layers of $(0.5\times0.5)\,\mathrm{mm}^2$ Silicon cells alternating with 0.25 cm ($0.5X_0$) Tungsten layers ($127\,\mathrm{cm} < r < 142\,\mathrm{cm}$), representing a total of 20 radiation lengths (X_0) or 0.8 hadronic interaction lengths (λ_I). The hadron calorimeter consist of 34 layers of $(1\times1)\,\mathrm{cm}^2$ Silicon cells with 1 cm scintillating material and 20 cm of stainless steel per layer, representing $40X_0$ and $4\lambda_I$. The inner part of the detector is surrounded by a solenoidal coil ($250\,\mathrm{cm} < r < 330\,\mathrm{cm}$), creating a five Tesla magnetic field. The muon tracking system ($340\,\mathrm{cm} < r < 545\,\mathrm{cm}$) is designed to also serve as a tail catcher for a possible punch-through of hadron showers.

4. An Algorithm for Energy Flow in the EMCal

4.1. *Objectives/Benefits*

The goal of this analysis is the development an algorithm to detect and trace minimum ionizing particles (MIPs) in the EMCal, and to reconstruct associated hadron showers without assistance from the central tracking system. There are several benefits from this approach, three of them are discussed below.

(1) Electromagnetic and hadron showers can be separated by analyzing their shower shapes. However, having a longitudinally segmented calorimeter, the actual starting point of the shower and the possible MIP-track associated with it can be used as an additional distinctive feature.
(2) In particular in the forward direction, the track reconstruction efficiency is reduced by the decreasing number of possible tracker-hits due to geometry. The extrapolation of identified MIP-tracks into the central tracking system can be used to assign unassociated hits and to improve the tracking efficiency.
(3) Charged tracks produced in the decays of long-lived particles like K^0_S, Λ or possible SUSY particles only leave a limited number of hits in the central tracking

system. The identification of MIPs can help to improve the detection efficiency in the same way as described above.

Efficient and precise MIP-tracking is an important step towards identifying showers from neutral hadrons and reconstructing long-lived particles. The algorithm described here is developed using samples of simulated events based on the GEANT4[5] detector simulation. They comprise single pion tracks (see Fig.1(a)) with energies between $(1-10)\,\mathrm{GeV}$, tracks from single $\mathrm{K^0_S} \to \pi^+\pi^-$ ($E_{\mathrm{K^0_S}} = 10\,\mathrm{GeV}$) decays, and tracks from $\mathrm{t\bar{t}}$ decays.

4.2. *Identification of MIPs*

The first step towards an Energy Flow algorithm is the identification of MIPs from their signature in the EMCal only. A pion with an energy between $(1-10)\,\mathrm{GeV}$ in 50% of all cases leaves a narrow track of minimum ionizing energy deposits. For its reconstruction a MIP-seed is required with at least one isolated hit in the first two layers, i.e. no neighboring cell in the same layer has an energy deposit. The energy deposit has to be consistent with being a MIP and there should be a minimum of 3 hits in the first four layers. This seed is then extended as long as more isolated hits are found in adjacent layers. Exactly one additional neighboring hit is allowed in any two consecutive layers to account for possible energy deposits by δ rays. To account for detector inefficiencies, gaps of the size of one layer are allowed.

4.3. *Performance of the Algorithm*

The performance of the algorithm is tested using the event samples mentioned above. For single pion tracks, the efficiency of the algorithm is $\approx 90\%$ and almost independent of the particle momentum for $p_\pi > 2\,\mathrm{GeV}$. Pions with lower momenta frequently don't reach the EMCal because of the strong magnetic field.

The starting point of the hadron shower is reconstructed with a resolution of $0.6\,\mathrm{cm}$ which corresponds to ± 1 layer (see Fig. 1(b)). Physics processes contributing

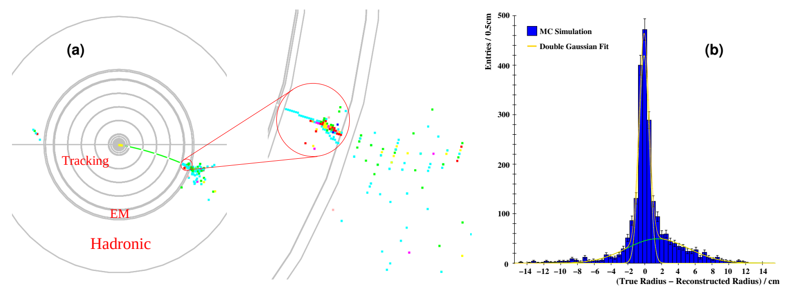

Fig. 1. (a) shows a typical event from the single-pion sample in the $(r-\phi)$ plane. The particle behaves as MIP half way through the EMCal before the shower starts. (b) shows the resolution of the reconstructed shower point in a sample of single pion events.

to the tails on left-hand side and right-hand side of the distribution are $\pi \to \mu\nu_\mu$ decays and scattering processes, respectively.

Applied to single $\mathrm{K^0_S} \to \pi^+\pi^-$ events, the algorithm exhibits an efficiency of $\approx 75\%$, which is close to the product of the efficiencies for two isolated pion tracks. This shows that with the current detector design, the signal loss due to overlapping showers for particles in this energy range is small. Applied to $\mathrm{t\bar{t}}$ events, the number of reconstructed MIPs exceeds the expected number by roughly a factor of two. This is due to overlaps between showers and MIP-tracks, which is not yet properly handled by the algorithm.

4.4. *Possible Improvements – EMCal Standalone Tracking*

An improvement in the MIP resolution can be achieved by modifying the algorithm to include inward-tracking, starting from the outermost layer. Segments from the same MIP which are overlapped by a shower from other particles can then be associated appropriately by a χ^2 criterion defined in track-parameter space. This implies the implementation of a helix fit to EMCal hits only, which is currently under development. Preliminary results show a very high separation power for matching MIP segments compared to random combinations.

To improve the reconstruction of long-lived particles in the SiD, an extrapolation procedure for the EMCal MIP-fit is under development. It will pick up unassociated hits in the last or second-to-last layer of the central tracking system, which have a much higher precision than the ones in the EMCal. With these hits included a reconstruction of long-lived particles and a measurement of their mass seems realistic.

5. Summary

In a future $\mathrm{e^+e^-}$ linear collider experiment, an Energy Flow algorithm is a critical tool to achieve good jet energy resolution and therefore the maximum sensitivity to physics at and beyond the electroweak scale. In particular the tracking of minimum ionizing particles in the electromagnetic calorimeter has a wide range of benefits. An algorithm is developed based on the SiD design, which includes efficient MIP-tracking starting from a seed in the first few layers of the EMCal. The starting point of a possible hadronic shower can be reconstructed with a precision of ± 1 layer. The application of this algorithm to physics events showed the need to implement helix fits to EMCal hits only; preliminary results using this technique look promising.

References

1. T. Csorgo, Phys. Lett. B **409**, 11 (1997) [arXiv:hep-ph/9705422].
2. www-sid.slac.stanford.edu/
3. D. Buskulic *et al.* [ALEPH Collaboration], Nucl. Instrum. Meth. A **360**, 481 (1995).
4. www.linearcollider.ca:8080/lc/vic04/abstracts/detector/calorimetry/steve_magill.ppt
5. S. Agostinelli *et al.* [GEANT4 Collaboration], Nucl. Instrum. Meth. A **506**, 250 (2003).