

Scriptum V 0.5 Felix Sefkow, Angela Lucaci, Erik van der Kraaij

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Introduction

This scriptum is a guide through an exercise with simulated and real data. Together with the short introductory lecture, it should convey an impression on the following topics:

- technologies for highly segmented imaging calorimeters
- topology of electromagnetic and hadronic showers, fluctuations
- particle flow algorithms at work
- multi-particle event reconstruction

The exercise uses graphical event displays and interactive reconstruction algorithms, it involves some simple statistical analysis, but does not require specific computing skills. The analysis can be done using spread sheets, or prepared ROOT tools which are straightforward to use.

A) Shower topologies and fluctuations

The goal of part A is to observe the energy dependence and fluctuations of electromagnetic and hadronic showers, to understand their differences and to compare the shower evolution in different media.

A) 1. Electromagnetic showers

Tools: CED event display [1], event-by-event longitudinal shower profile

Data: electron test beam events in the CALICE calorimeter at 10 GeV and 50 GeV beam energy **Task**:

- 1. Scan about 50 events. For each event, record the layer number with max energy and the energy sum
- 2. Analysis: determine mean and r.m.s. of each for both energies

Instructions:

The software used by the CALICE collaboration is based on the ILC software [2] (Marlin, LCIO, LCCD, etc). To be able to use it, you have to set some environment variables. This can be easily done by issuing the following on the command line:

source /afs/cern.ch/eng/clic/work2/alucacit/EDIT2011/CALICE/
envCalice.sh

The next step is to open the window which will contain the event display: glced&



Now you can start Marlin: Marlin \ /afs/cern.ch/eng/clic/work2/alucacit/EDIT2011/CALICE/steer/ eventDisplay_ePlus_10GeV.xml

An example of the event display for a shower produced by a 10 GeV positron in the CALICE HCAL and Tail Catcher is shown in Fig. 1. a).



Fig. 1. a): An example of the event display for a shower produced by a 10 GeV positron in the CALICE HCAL and Tail Catcher.



Fig. 1. b): Longitudinal profile in the HCAL produced by 10 GeV positrons.

Please note that at any point in time, you can enable the 'help' for the event display by either rightclicking on the event display window, or by typing 'h'. Be aware of the fact that the 'layers' that appear in the help window do not refer to the HCAL physical layers, but to internal level associated to CED commands. For a description of the color coding of the displayed HCAL cells, please see [3].

You can rotate and zoom into the detector using the mouse, and you can move it along the z-axis using the 'up' and 'down' keys.

Apart from the event display window, a canvas will appear, displaying the energy sum deposited in the HCAL versus the HCAL layer number, on an event by event basis. From this histogram you can read the number of the layer which contains the maximum energy deposition, and the corresponding energy sum.

To proceed to the next event, just press ENTER.

To plot the layer number with the maximum energy deposition and the corresponding energy sum, you can simply use a pencil and a piece of paper, or, if you prefer, you can use a ROOT [4]. For example, you can use your favourite editor (e.g. emacs) to enter the values in an ASCII file called for example 'results.dat'. Then you can use ROOT to plot your values. Assuming your file contains 2 columns: the layer with the maximum energy and the energy sum per layer, you can do the following:

- Start ROOT: root -1
- Create and ntuple which will read your ASCII file: TNTuple ntuple("ntuple", "some name", "layer:energy"); ntuple.ReadFile("results.dat");
- Now you can plot your variable: ntuple.Draw("energy");



- the layer number with max energy
- the energy sum

2. Analysis:

- measure the hadronic interaction length for iron and tungsten
- test its energy dependence
- determine mean and r.m.s. of the energy sums
- determine mean and width of the shower max, measured from the shower start
- measure mean energy for the 10 events with the latest start

Instructions:

For the analysis, the same software is used as for the electromagnetic showers (see instructions in A.1.). First, don't forget to open the window which will contain the event display: **glced&** The necessary steering files can be found here:

[optional]

[optional]

Marlin \

/afs/cern.ch/eng/clic/work2/alucacit/EDIT2011/CALICE/steer/ eventDisplay_piMinus_10GeV.xml

Please note that in case of hadronic showers, the CALICE prototype contained an ECAL, an HCAL and a Tail Catcher. Events which start to shower in the HCAL are preselected. The procedure to find the shower start is already included in your steering file. The layer in which is the shower starting point is found will be printed on the screen, but it is also possible to visualize the corresponding layer on the event display, by typing the '@ 'key.

For an example event display, please see Fig. 2. a).

For measuring the hadronic interaction length for iron and tungsten, you need to know how to calculate the nuclear interaction length for compound materials. This is done similar to the radiation length case. You can find the corresponding formula in the PDG review [5], at page 18. The official PDG values of the interaction lengths of the different absorber materials can be found at [6], by clicking on the corresponding element.

One Fe-HCAL layer contained 16 mm Fe absorber, and another 4 mm steel cassette for holding the scintillator tiles. In the W-HCAL case, one layer contained 10 mm W, plus the 4 mm Fe for the cassette. For simplicity, the interaction length due to the scintillator tiles and to the other components in the detector can be neglected.



Fig. 2. a): An example of the event display of a shower produced by a 10 GeV pion in the CALICE ECAL, HCAL and Tail Catcher, without (left) and with (right) highlighting of the HCAL layer in which the shower starting point is found.



Fig. 2. b): Longitudinal profile in the HCAL from the shower start, for 10 GeV pions.



B) Particle flow algorithm at work

The goal of part B is to understand the principles of particle flow reconstruction. In the interactive program the different steps of the algorithm - track and cluster reconstruction, cluster association and re-clustering - can be executed sequentially. Their results can be monitored in the event display, using color codes and pop-up information boxes.

The exercise uses complex Monte Carlo di-jet events generated at 90 GeV and 500 GeV centerof-mass energy and simulated in a 4π collider detector. It starts with event-by-event analysis of difficult reconstruction situations, and proceeds to a quantitative performance evaluation, comparing with purely calorimetric measurements at the different jet energies.

Tools: Pandora [5] monitoring program, TEve event display

Data: MC di-jet events at a center of mass energy of 90 GeV and 500 GeV, selected with polar angles in the barrel region

Task:

- 1. Explore event display, display options, color coding
- 2. Study display in different reconstruction stages MC truth, different particle types
- tracks, hits, clusters, particle hypotheses
- particle flow objects
- look for different particles, try to find K^{0}_{s} , π^{0} , neutrons

3. Study jet and event energy reconstruction

• look simple and for difficult situations with close-by showers

• study the confusion matrix for a few events, i.e. which kind of true energy deposition is reconstructed as what type of pflow objects

• compare the pflow reconstruction with a purely calorimetric measurement: plot energy sum for pflow objects and for calo clusters

4. Scan 50 events at each cms energy, compare resolutions, and for outliers try to find out what went wrong or was difficult

5. Extract an average confusion matrix for 10 events at each energy



Instructions:

To initialise the necessary software for the jets analysis, please do: source /afs/cern.ch/eng/clic/work2/alucacit/EDIT2011/Jets/envMarlin.sh

The needed steering files can be found in the above directory, under steer.

For the event display, this time you don't need to open a separate window, since this will appear as soon as you start Marlin. The event display was developed by Peter Speckmayer (CERN) as a PandoraMonitoring package, and it is based on ROOT's TEve.

An example of such an event display, for jets produced at the Z threshold is shown in Fig. 3. a) and b). Please note that you can change the angle of observation by either moving the detector with the mouse, or by selecting an option from the 'Camera', as shown in the figure 3. a), left.



Fig. 3. a): Example of an event display of jets produced at the Z threshold: left - (yz) plane, right - (xy) plane.

About the used colour coding:

- Monte Carlo particles: colour according to their PDG, e.g. pions: green, photons: cyan, kaons: gray.
- Clusters:

magenta: clusters linked to a track

blue: clusters without a track

yellow: electromagnetic clusters

• *Current PFOs:* colour coding according to their PDG. For the meaning of the PDG indices, please see the Monte Carlo numbering scheme [8].



Fig. 3. b): Example of an event display of jets produced at the Z threshold, in the (xy) plane. For better visibility, the display of the detector geometry has been disabled. The two clusters for which the information is printed are produced in the HCAL barrel.

References:

- [1] CED event display: http://ilcsoft.desy.de/portal/software_packages/ced/
- [2] ILC software: http://ilcsoft.desy.de/portal/software_packages/
- [3] http://www-flc.desy.de/hcal/calice_soft/pro_test/doc/ADDONPROCS/html/
- classCALICE_1_1EventDisplayProcessor.html
- [4] ROOT: http://root.cern.ch/drupal/
- [5] Pandora PFA algorithm: http://www.hep.phy.cam.ac.uk/twiki/bin/view/Main/PandoraPFA
- [6] http://pdg.lbl.gov/2010/reviews/rpp2010-rev-passage-particles-matter.pdf
- [7] http://pdg.lbl.gov/2010/AtomicNuclearProperties/index.html
- [8] The PDG 35. MONTE CARLO PARTICLE NUMBERING SCHEME