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Towards jet reconstruction in a realistic dual readout total absorption calorimeter

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Abstract. Calorimeters implemented in future lepton colliders will inevitably suffer from leakage on account of space restrictions and will need to operate in strong magnetic fields. Both these circumstances will affect the reconstruction of jets and will give rise to the need for corrections. In dual readout calorimeters, these corrections are complicated by the need to deal with more than one signal. In this article we describe simulation studies of these corrections in a total absorption dual readout calorimeter.

1. Introduction

The chief purpose of high resolution calorimeters at future lepton colliders is likely to be di-jet and multi-jet spectroscopy. The primary figure of merit will be mass resolution and the main limitation will be hadron energy resolution.

Compensation by means of Dual Readout (DR) in totally active calorimeters [1] addresses this limitation but the design of collider experiments requires a careful optimization of various aspects: scientific, technical and financial. In particular, the requirements of a calorimeter inside the superconducting coil inevitably limits the thickness of a calorimeter and leads to leakage fluctuations while the magnetic field leads to magnetic corrections. Both these effects can limit the achievable resolution.

A longitudinally segmented total absorption calorimeter offers several possible ways of addressing these limitations and these have been the subject of simulation studies. The progress of this work is reviewed in the following sections. For particulars relating to the simulation package please refer to a paper presented by Hans Wenzel [2] in these proceedings Other related papers in these proceedings are refs. [3] and [4].

1.1. The calorimeter

A cylindrical calorimeter is filled with sensitive BGO-like material of uniform composition. Only the finer segmentation distinguishes the initial “EM” section from the remaining “HAD” volume. Different compositions and segmentations were investigated:

- EM calorimeter: 6-8 layers 5-3 cm thick with the same transverse segmentation.
- HAD calorimeter: 9-17 layers 10-6 cm thick, with the same transverse segmentation.
- The muon system/tail-catcher is implemented as a 48 layer sampling calorimeter.

Total calorimeter thickness: 120-126 cm, which corresponds to about 5.5 interaction lengths and is therefore subject to significant leakage. Magnetic fields up to 5T are catered for.

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2. Leakage and the Dual Readout compensation

Dual Readout compensation was first studied in detail for single hadron showers in the absence of magnetic field. The effects of leakage on the DR compensation (often referred to as the DR "correction") in these conditions were studied and different leakage correction methods devised and compared.

2.1. The DR correction

Data is simulated for incident pions and electrons. The ionization energy deposited is identified with the scintillation signal (S) and both ionization (S_i) and Čerenkov (C_i) energy depositions are recorded for each calorimeter element *i* and summed to form the total raw signals S_r and C_r, respectively. Assuming no energy loss for electrons, the corresponding raw signals are normalized to the incident electron energies and the corresponding normalization is applied to the pion signals: the normalized electron-energy distributions then peak around the average energy by construction whereas the average normalized pion energies manifest the expected losses due principally to nuclear breakup. Their S-distributions also manifest pronounced low-energy "tails" corresponding to leakage. Pions which pass through the calorimeter without hard interaction give rise to the usual minimum ionizing peak referred to as "punch-through". Whereas "punch-through" events are generally ignored in the calorimeter and delegated to the tracking elements, leakage must always be corrected for event-by-event in order to minimize the effects of its fluctuations on the calorimeter's energy resolution.

In the case of DR calorimeters leakage can also distort the correlation between the C and S which is used for the DR (compensation) correction as illustrated in figure 1. The correlation between S/E_π and C/S shown in Figure 1a clearly illustrates the effect of leakage on this correlation while Figure 1b illustrates how leakge is corrected for in one of a series of vertical slices of the correlation.

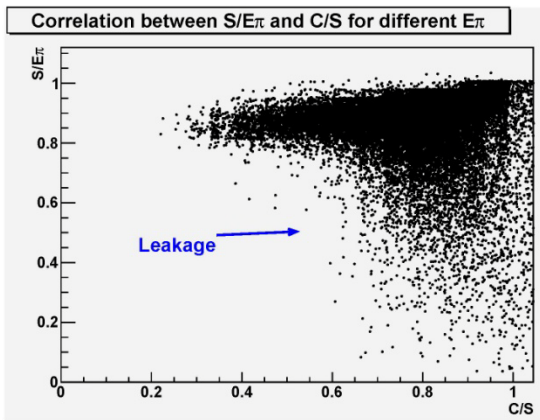

Figure 1a. S/E_π versus C/S illustrating effect of leakage on correlation

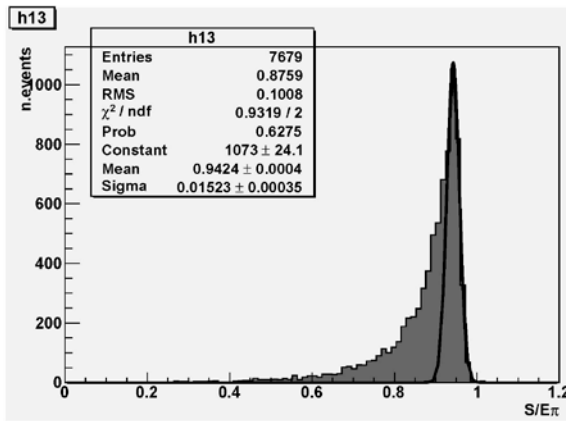

Figure 1b. A vertical slice of Figure 1a illustrating fit to correct effect of leakage

The resulting correlation is fitted with: $S/E_\pi = a(C/S)^2 + b(C/S) + c$, which is used to "correct" (DR correction) S:

$$S_{corr} = \frac{S}{a(C/S)^2 + b(C/S) + c}$$

Correction functions are are evaluated independently at each energy but are seen to manifest only a weak energy dependence (figure 2b). Distributions of S_{corr} peak at the correct energy as illustrated in Fig. 2a but retain the low energy tail corresponding to the leakage. The leakage energy fluctuates and the fractional fluctuation increases with energy until it exceeds the stochastic term and sets the limit on the achievable energy resolution. Leakage therefore needs to be corrected for event-by-event.

2.2. Leakage corrections

Two kinds of leakage correction are considered.

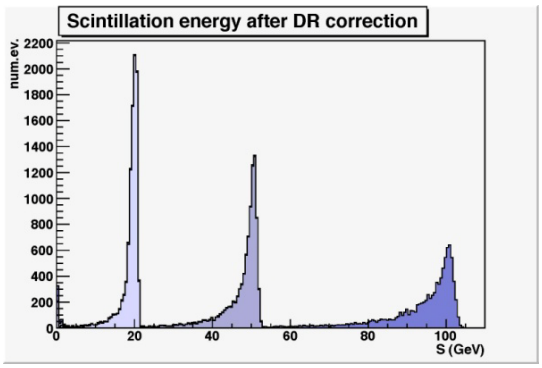

Figure 2a. Distributions of S_{corr}

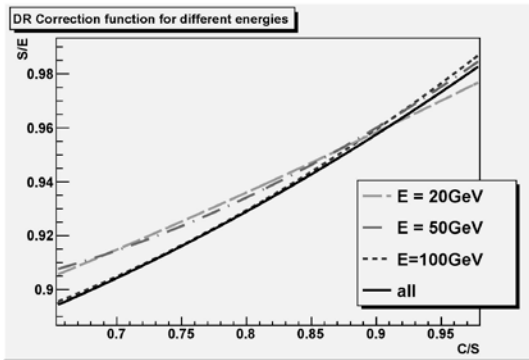

Figure 2b. .DR correlations at different energies

2.2.1. *Leakage corrections using the muon counters as "tail-catcher"*

For this correction, we use the correlation between the energy deposited in the calorimeter and the energy detected in the tail-catcher (figure 3a). The correction is applied before the DR correction and also partially corrects for punch-through.

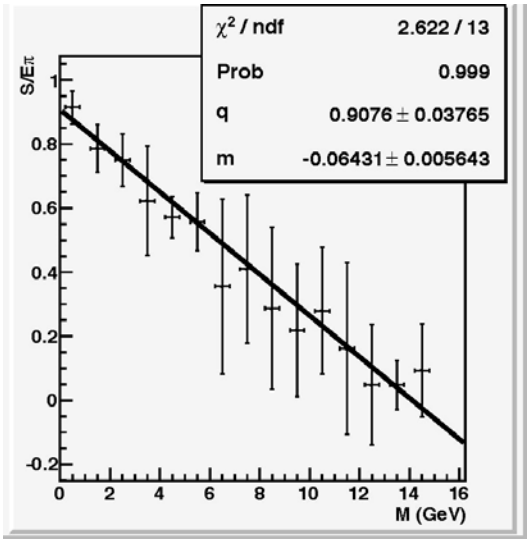

Figure 3a. Correlation between S/Eπ and the energy deposited in the tail-catcher

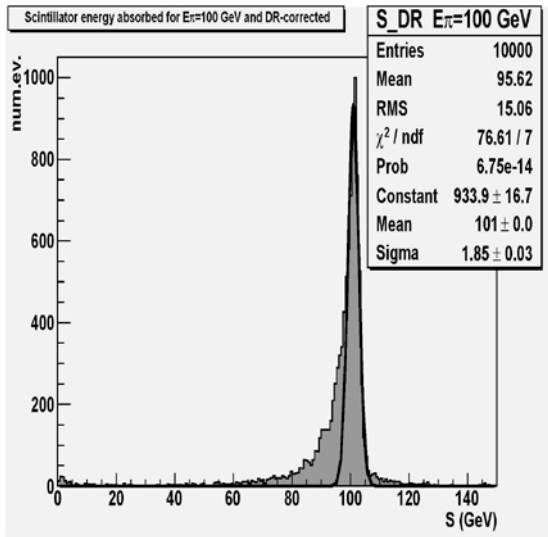

Figure 3b. .The distribution of S_{corr} after correction for leakage, using the correlation function in figure 3a, and the DR correction

Given that the tail-catcher is located outside the solenoid, the correction is expected to be under-estimated as would appear to be the case from figure 3b. Nevertheless, the resolution is ~0.2 GeV and the energy close to the correct one.

2.2.2. *Leakage corrections using longitudinal segmentation.*

Since leakage depends on shower evolution it longitudinal segmentation is expected to be useful for leakage correction. At first approximation, we use only the outermost layers: (S/E_p) was plotted against the fractional energy deposited in the two outermost layers. The resulting correlation function (fig. 4a) was then used to correct for the leakage event-by-event. Although we expect the correction to be over-estimated, the resulting distribution of S at 100GeV (figure 4b) is seen to be symmetric and centered close to the correct energy. The resolution is seen to be ~ 0.2 GeV.

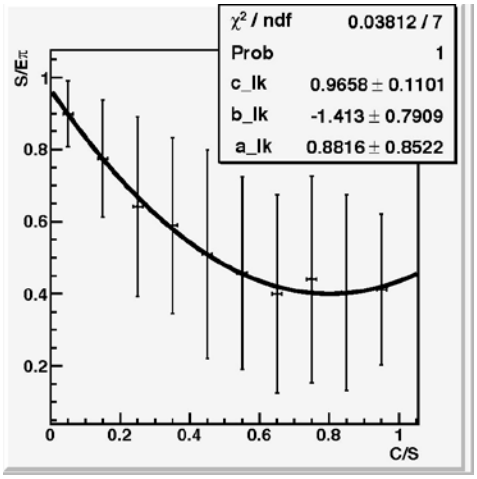

Figure 4a. Correlation between S/Eπ and the energy deposited in the last two layers of the calorimeter

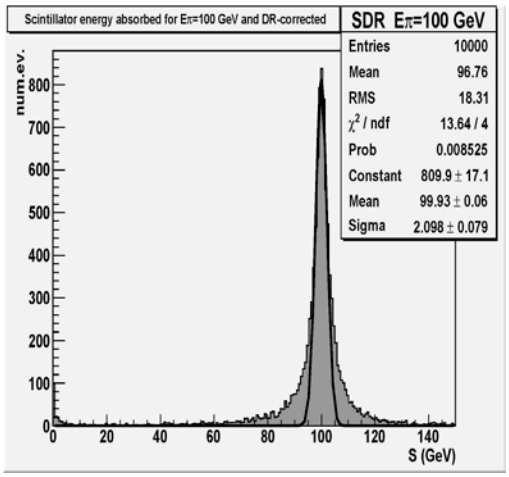

Figure 4b. The distribution of S_{corr} after correction for leakage using the correlation function in figure 3a

However, the above algorithm does not exploit all the information available: leakage fluctuations depend on the starting point of the hadron shower ("Interaction Depth or ID") and the extension of the shower, so it is expected that full use of the depth segmentation will improve the leakage corrections. S a first step in this direction, the data was therefore subdivided according to its ID and correlations for the DR and for the MLK corrections were evaluated separately for each ID.

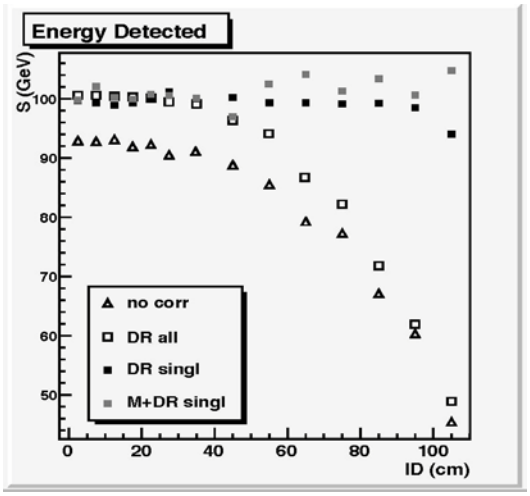

Figure 5a. The effect of these corrections are shown as a function ID. Significance increases with ID as expected

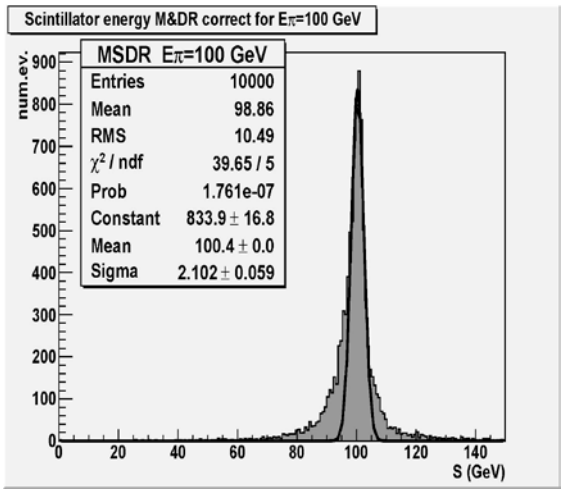

Figure 5b. Effect of corrections on the overall energy distribution

This led to a noteworthy reduction in the non-Gaussian tails observed in figure 3b, particularly at higher energies. Overcorrection is also evident for higher IDs. Punch-through is eliminated.

3. Applying corrections to jets

The processes are complicated by the mixed content and by jet reconstruction. The weak dependence.

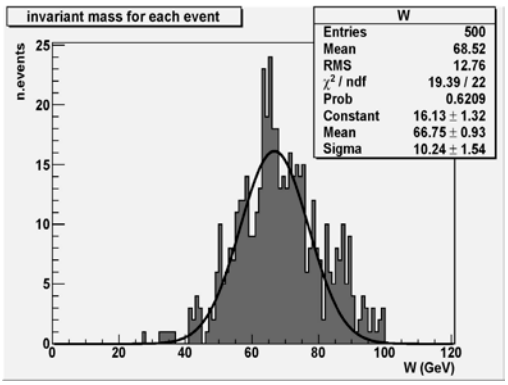

Figure 6a. W invariant mass distribution before corrections

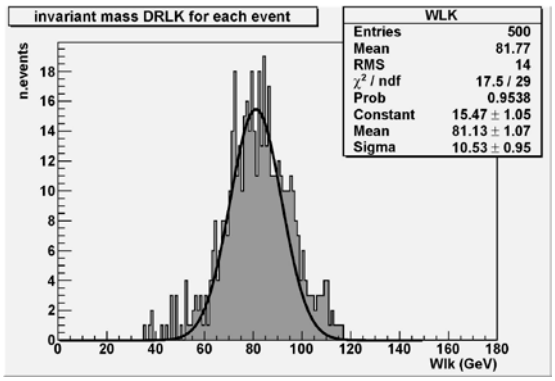

Figure 6b. W invariant mass distribution after corrections

of the DR correction should help and by restricting the study to jets from single W or W/Z to begin with, one can both try to implement corrections on reconstructed jets (as one must finally do in a realistic environment) and implement corrections independently of jet reconstruction by summing over the whole event, safe in the knowledge that the event contains only jets

In this spirit, hadron DR and leakage correction functions (from single pion data) are first applied to reconstructed jets (figure 6). New DR corrections are then evaluated for comparison by summing for S and C over all elements of the calorimeter (before jet reconstruction): they are smaller for all jet energies and this could be a reflection of the smaller average energy but also of a larger em content. However, no significant improvement is observed in the reconstructed W mass.

4. Correction for effect of Solenoid magnetic field

A magnetic field correction (ΔM) for every jet is based on the actual collection of charged tracks associated with the jet. The value of the correction reflects the change of the calculated mass of a calorimetric cluster due to the displacement of the energy deposited by charged particles. This change is derived using the momentum vector, as measured by the tracking detectors. The effect of this correction on the W invariant mass is shown in figure 7 for the maximum expected value of the solenoid field, both before and after the DR correction (applied using pion correction functions)
The residuals plotted in figure 7a are defined as follows:

$$R1 = \frac{(M_{corrected} - M_{true})}{M_{true}} \qquad R2 = \frac{M'_{corrected} - M_{true}}{M_{true}}$$

with

$$M'_{corrected} = M_{corrected} + \Delta M$$

where $M_{corrected}$ refers to the invariant mass after the DR correction and ΔM is the magnetic correction.

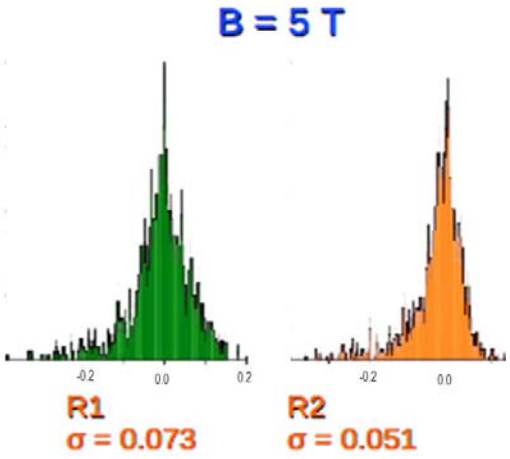

Figure 7a. Residuals (see text for definitions) illustrating effect of corrections on the reconstructed W mass at 5 Tesla

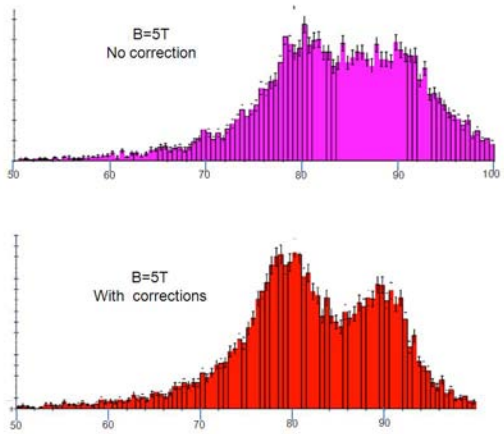

Figure 7b. Invariant mass distribution for a mixture of W and Z bosons before and after corrections

5. Conclusions

Corrections for leakage and magnetic field effects will be essential in future collider calorimeters – DR calorimeters are no exception. From a study involving single hadrons, on concludes that:

- In DR calorimeters, leakage must be accounted for in different stages: first in determining the DR correction and then in correcting for energy loss.
- Longitudinal segmentation is very effective to this end but does not correct for punch-through.
- Muon detector/tailcatcher assemblies can account for punch-through but tend to over-correct for leakage.

Despite the differences in content and energy distributions, one finds no great difference between single hadron DR correction functions and those obtained from simulated jet data. However leakage corrections are decidely smaller.

More work is needed to extend these studies to more realistic multijet environments.

References

[1] Para A 2010 *Total Absorption Dual Readout Hadron Calorimeter for future lepton colliders* (these proceedings)

[2] Wenzel H 2010 *Simulation of total absorption dual readout calorimetry: principles and performance for single hadrons and jets* (these proceedings)

[3] Wenzel H and Magill S 2010 *Enhancing the performance of a total absorption crystal calorimeter with dual readout (DR) by employing Particle Flow techniques* (these proceedings)

[4] Para A 2010 *Detailed Studies of hadron shower modeling in GEANT4* (these proceedings).