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HADRONIC ENERGY RESOLUTION IMPROVEMENT IN CALORIMETERS WITH FINE TRANSVERSE SEGMENTATION

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ABSTRACT

The fine transverse segmentation of the ATLAS Forward Calorimeter allows a significant improvement in the hadronic energy resolution by a weighting technique. The scheme was implemented in the analysis of the 1998 'Module 0' beam test data. It performs a 'software compensation', bringing the e/π ratio close to 1. Optimization of the cluster radius for the signal/noise ratio and coherent noise suppression are intrinsic features of this approach. The present report considers single hadron optimization, but this technique is also applicable to the analysis of jets. In addition it has strong potential for pile-up background reduction on an event-by-event basis. I expect this scheme can be applied to other calorimeters with fine transverse segmentation.

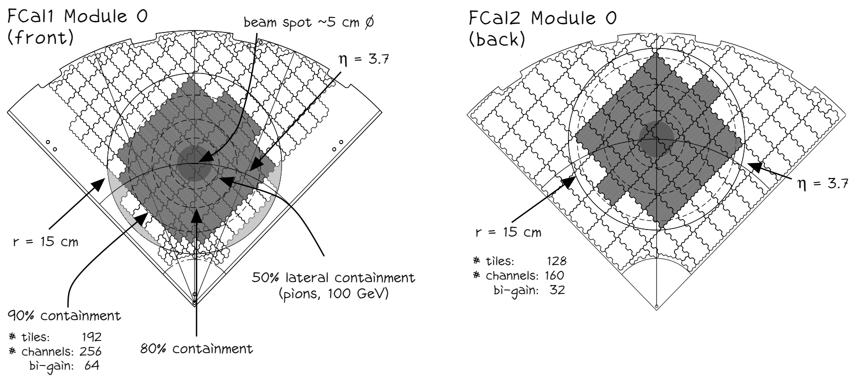

Figure 1: *Beam's eye view of 'Module 0' Electromagentic (EM) and Hadronic sections. In use, the Hadronic FCal-2 is positioned directly behind the EM FCal-1 (fig.2).*

1 Introduction

Different response of calorimeters to e/γ and hadrons (non-compensation) is a traditional concern in high energy physics experiments. It results in degradation of the hadronic energy resolution by fluctuations of π_0 (γ) energy in the shower. The fraction of the energy carried by π_0 depends on the incoming hadron energy, leading to the response non-proportionality.

In case of jet measurements, the fraction of EM energy also fluctuates from jet to jet, degrading the energy resolution in the same way as fluctuations of π_0 energy in the individual hadronic shower. There are indications [1] that at high energies effects (above 200GeV) of the non-compensation fade out, but the wide jet/hadron energy range still remains a concern.

Various strategies are employed to estimate the fraction of EM energy in the hadron/jet shower. Calorimeters with fine segmentation [2] allow use of local response density as a correction parameter. Integral parameters like shower spread [3] or fraction of signal in the central cell may be used for coarser structures. This study is based on a calorimeter of intermediate type, combining fine transverse and very coarse longitudinal granularity.

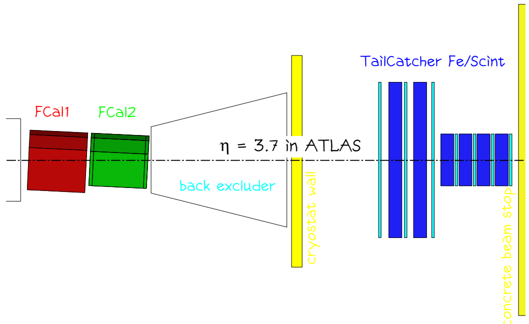

Figure 2: *ATLAS FCAL 'Module 0' experimental setup (beam line and downstream μ-counters are not shown)*

2 Experimental setup

The ATLAS Forward Calorimeter 'Module 0' prototype [4] has fine transverse segmentation: 50% of the hadronic shower is shared among 7 channels in FCal-1 and 4 channels in FCal-2 (fig.1). Longitudinal segmentation of the 'Module 0' included only two sections. Since the total depth of FCal-1 and FCal-2 was only 6.4λ, they were backed by a coarse iron/scintillator Tail Catcher. The size of the cryostat resulted in some 2.5m of liquid argon excluder and air between FCal-2 and the Tail Catcher (fig.2).

3 Transverse Weighting Technique

The technique described here is based on individual weighting of channels, depending on the distance between the channel and the shower. To take into account the ATLAS FCal segmentation geometry, distance to channel was defined as a distance to channel 'edge' instead of the channel center. The distance to the channel edge is defined as an average of distances to the three closest tubes within the channel, as shown at fig.3 (left).

The Transverse Weighs have to be optimised for best performance of the calorimetric system. It is natural to start with minimization of the energy resolution for pions of highest available energy (eq.1).

$$\left\{ \begin{array}{l} E^2_{RMS} = \sum_{i=1}^{N_{EVT}} (S_i - < S >)^2 = min \\ < S >= \frac{1}{N_{EVT}} \sum_{i=1}^{N_{EVT}} S_i = E^{max}_{BEAM} \end{array} \right. \quad (1)$$

Each event response S_i in eq.1 is calculated according to eq.2, where W

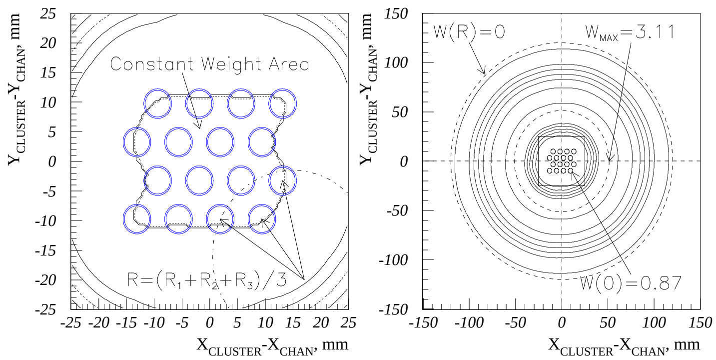

Figure 3: *Distance to the channel edge definition and 2-dim Weight plot.*

is the Transverse Weighting Function to be found.

$$S_i = \sum_{k=1}^{N_c} A_k^i \times W(x^k - x^i_{cluster}, y^k - y^i_{cluster}) \quad \text{i = event number, } N_c = \text{Number of channels} \qquad (2)$$

There are a number of ways to define W(Δx,Δy). A single-argument W(Δx,Δy)=W(R) was used in this study, where R is the distance from channel to cluster, as shown on fig.3. W(R) is derived by simple linear interpolation (eq.3) between a set of values W_k at discrete points R_k (k=1...N). W_k are used as free parameters in the optimization, together with weights for the Tail Catcher segments. In this study, N=17 was chosen for each module. Together with 6 segments of the Tail Catcher, it provided 40 free parameters.

$$\begin{cases} W(R) = W_1 & \text{if } R < R_1 \\ W(R) = W_N & \text{if } R > R_N \\ W(R) = W_k \times \frac{R_{k+1}-R}{R_{k+1}-R_k} + W_{k+1} \times \frac{R-R_k}{R_{k+1}-R_k} & \text{otherwise} \end{cases} \qquad (3)$$

Analytical solution of eq.1 is presented in fig.4. The behaviour of these curves has a very intuitive explaination. The predominantly hadronic peripheral part of a shower has to be boosted to bring the total hadronic signal to the level of the electromagnetic one, so the weight increases from R=0 to R=50mm. This action boosts the halo of the electromagentic shower. To keep the calibration in check, the very central region is slightly suppressed - the weight at R=0 is actually less than 1.

As the channel gets far from the cluster, more noise than signal is added. Optimization takes care of this, dropping the weight down to zero at R=130mm.

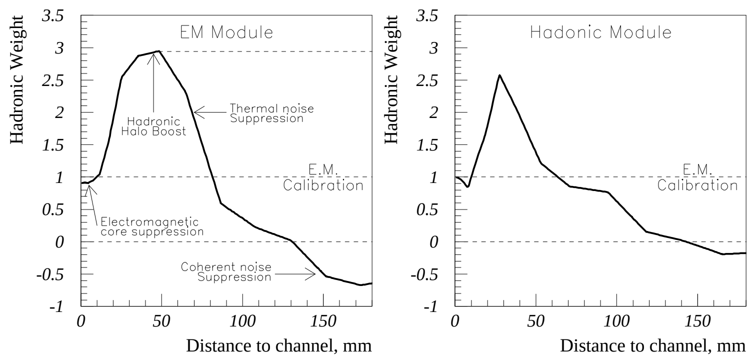

Figure 4: *Transverse Weighting W(R), optimizing* 200GeV *hadrons energy resolution*

Moreover, at even larger radii the weight swings to the negative side. This behaviour is nothing but suppression of the coherent noise, which is known to be substantially larger in the EM module than in the Hadronic.

4 Transverse Weighting effect on hadronic measurements

Results of hadron measurements using Transverse Weighting were compared to traditional flat (position-independent) weighting of the longitudinal segments. In case of flat weighting, cluster radius and weight were optimized for both EM and Hadronic modules, together with weights for the Tail Catcher segments.

Fig.5 shows that flat weighting results in a non-Gaussian hadronic response spectrum, typical of non-compensated calorimeters. Applying the Transverse Weighting results in elimination of the 'electromagnetic tail' and a narrowing of the response peak. Improvement of the energy resolution is demonstrated on fig.6. The standard parametrization $\frac{\sigma_E}{E} = a \oplus \frac{b}{\sqrt{E}} \oplus \frac{c}{E}$ is used, with the noise term $\frac{c}{E}$ determined independently for every energy using random trigger events.

While the noise (electronics in our case) and stochastic term $\frac{b}{\sqrt{E}}$ improvement is close to 10%, the constant term is decreased substantially. As expected, 'Module 0' with transverse weighting performs much closer to a compensated device than with flat weighting (fig.7). The proportionality of the hadronic response improves substantially as well, since the energy-dependent π_0 component has a response closer to the rest of the hadronic shower.

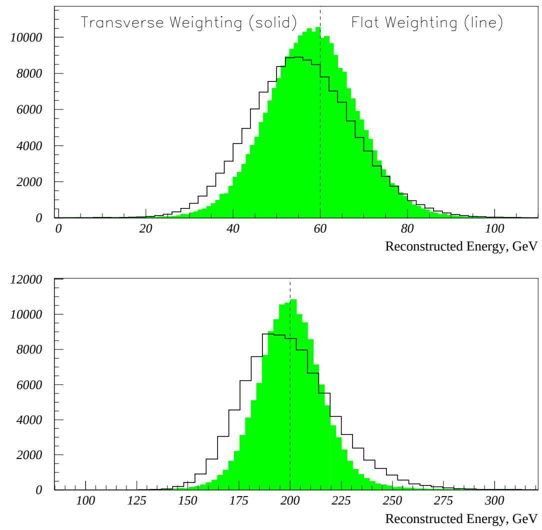

Figure 5: *Response to* 60GeV *(top) and* 200GeV *(bottom) hadrons, Transverse Weighting (solid) vs. Flat (line)*

The Transverse weighting technique should improve jet energy resolution, specially in the EndCap/Forward region, where jets are narrow and fluctuations are determined by a few core particles hitting a very compact area. This procedure allows modification by adding more binding conditions to eq.1 to improve response proportionality. Non-discrete schemes with smaller number of free parameters will also be considered.

5 Acknowledgements

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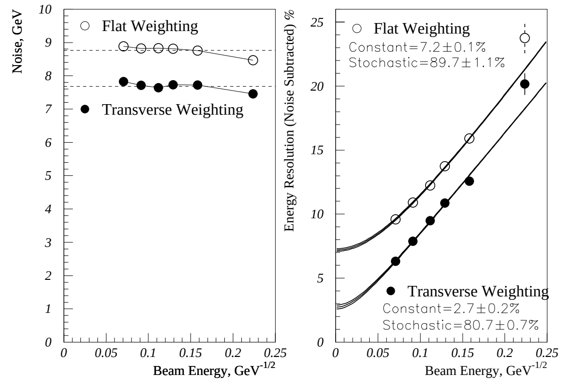

Figure 6: *Energy resolution of the 'Module 0' (Transverse and flat weighting procedures)*

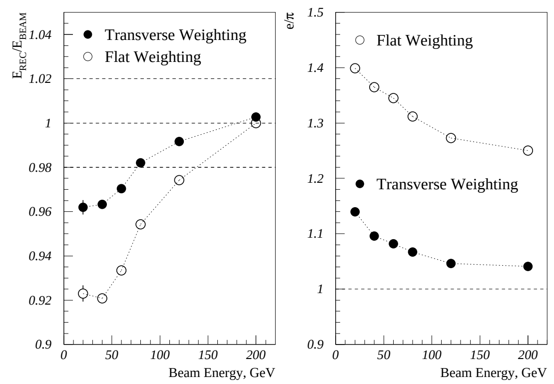

Figure 7: *Proportionality of the 'Module 0' (Transverse and flat weighting procedures)*

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