94-522

сообщения
объединенного
института
ядерных
исследований
дубна

E13-94-522

A.R.Astvatsaturov, M.Bosman[1],
J.A.Budagov, V.V.Glagolev

ATLAS CALORIMETERS ENERGY CALIBRATION FOR JETS

[1]Institut de Fisica d'Altes Energies, Barcelona, Spain

1994

1 Introduction

ATLAS calorimeter [1] energy calibration was done in the full ATLAS simulated geometry for central region $\eta = 0.4 - 0.6$ (see Fig.1). The samples of single jet events were generated with energy 20, 50, 100, 500 GeV and 1 TeV. The analysis of the simulated data shows that standard calibration using just sampling coefficients for calorimeter parts with different sampling ratio gives the nonlinear calorimeter response. This effect appeares due to noncompensated calorimeter structure. Weighting technique [2, 3, 4, 5] was applied for calorimeter resolution improvement and linearity restoration.

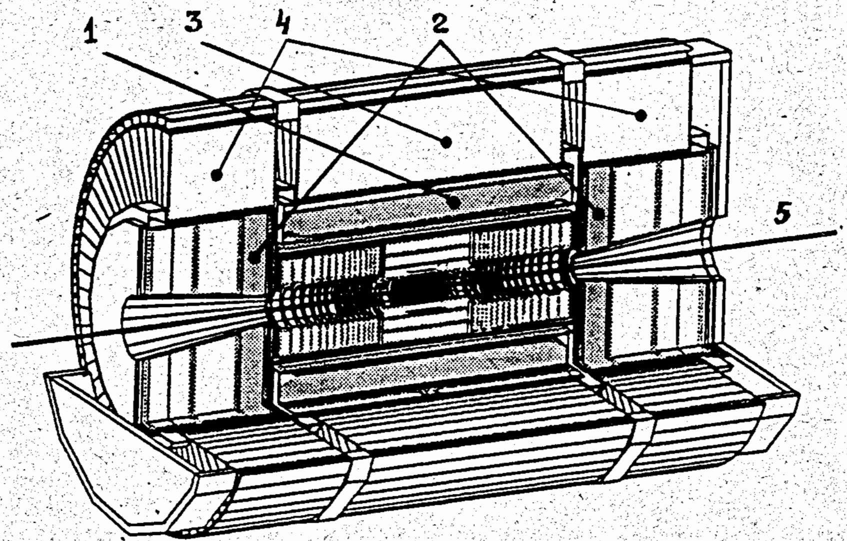

Figure 1: *Conceptual layout of the ATLAS calorimetry*
(1 – EM barrel, 2 – EM endcap, 3 – HA barrel, 4 – HA endcap, 5 – beam line)

2 Barrel calorimeters geometry

The common view of the ATLAS calorimeter system is represented on Fig. 1. The rapidity region up to $\eta = 1.5$ is covered by barrel calorimeters. These calorimeters are subdivided into three detector types [1] :

- Preshower detector (ps) is located in front of electromagnetic calorimeter and serves for particle identification, direction measurements and correction of energy losses in the dead material before calorimeters. Using tapered material the total thickness of the preshower detector, irrespective of η is 3 X_0. The readout is organized in two 'shells' of ministrips, perpendicular to each other and located after 2 and 3 X_0 for the ϕ and η shell respectively.

- Electromagnetic calorimeter (em) is implemented as the liquid argon (LAr) sampling calorimeter with Accordion technique. The transverse readout segmentation is 0.025×0.025 in the terms of pseudorapidity (η) and azimutal angle (ϕ) variables. The longitudinal calorimeter subdivision includes three sections with 8 X_0 each.

- Hadron tile calorimeter (ha) contains the steel absorber plates which are interlaced with 2 mm thick scintillator tiles. The $\eta \times \phi$ readout granularity is 0.1×0.1. The longitudinal readout segmentation contains three sections. The total calorimeters (ps + em + ha) depth at $\eta = 0$ is about 10 λ.

3 Simulation data banks

For simulation and analysis of the ATLAS calorimeters response on the hadron jets we have used SLUG, DICE and ATRECON codes [6] . The two samples of jets with energy 20, 50, 100, 500 GeV and 1 TeV were generated at $\eta = 0.4$ and $\eta = 0.6$ directions in the full ATLAS geometry starting from the beams intersection point (see Fig. 1). When simulating the magnetic field was turned on and absence of electronic noise was assumed. It was done by means of the DICE program based on the GEANT framework. At this simulation stage there are output DICE banks which contain the response of all ATLAS detector systems (tracker, calorimeters and muon detectors). At the second step we use ATRECON code for extracting calorimeter signals from the primary data banks and preparing files which will be read by our calibration program. Such secondary banks generated by ATRECON contain sequatial unformatted records with following necessary information per each jet:

- number of flashed calorimeter cells,

- index of calorimeter tower longitudinal layer, η, φ and amplitude signal for each flashed cell.

Jet cone size $\delta R = \sqrt{\delta\eta^2 + \delta\varphi^2} = 0.6$ was applied for hadron energy collection.

4 Calorimeter calibration

4.1 Standard calibration

At the first time we did traditional calorimeters calibration. Such type of calibration in our case could be expressed in the form:

$$E_{rec} = c_1 \sum_i A_{i1} + c_2 \sum_i A_{i2} + \\ + c_3 \cdot \sum_{j=3}^{5} \sum_i A_{ij} + c_4 \cdot \sum_{j=6}^{8} \sum_i A_{ij} \ , \quad (1)$$

where
j – index of the calorimeter longitudinal segmentation;
(j=1,2 for PS, j=3, 4, 5 for EM and j=6, 7, 8 for HA);
i – index of the calorimeter tower transversal segmentation;
A_{ij} - amplitude of the signal from the tower with indexes i, j;
$c(k)$, k=1, ..., 4 - callibration coefficients.

This standard calibration used just sampling coefficients for calorimeter parts with different sampling ratio. ATLAS calorimeters were calibrated with equation (1) at 50 GeV and $\eta = 0.4$. Coefficients $c(k)$ were obtained by minimizing the energy resolution and tuning the mean value of reconstructed energy to 50 GeV. Then we applied this standard calibration coefficients on the other simulated jet banks with different energy and η values. The results are shown on Fig. 4 (open points). The obtained energy resolution is:

$$\frac{\sigma(E)}{E} = \frac{41.7\%}{\sqrt{E}} \oplus 2.2\%$$

for $\eta = 0.4$ and

$$\frac{\sigma(E)}{E} = \frac{40.1\%}{\sqrt{E}} \oplus 2.3\%$$

for $\eta = 0.6$
and a bad linearity of the calorimeter response (deviation is about 10% at the TeV energy region). This nonlinear calorimeter behaviour araises due to the steel used as absorber. Such types of calorimeters are noncompensated ones.

4.2 Weighting technique

The noncompensation problem of the calorimeters consists in different amplitude responce for electrons and for hadrons in hadron shower and could be solved by application of the weighting technique method [2, 3, 4, 5] for obtaining calorimeter good linearity and energy resolution in the broad energy

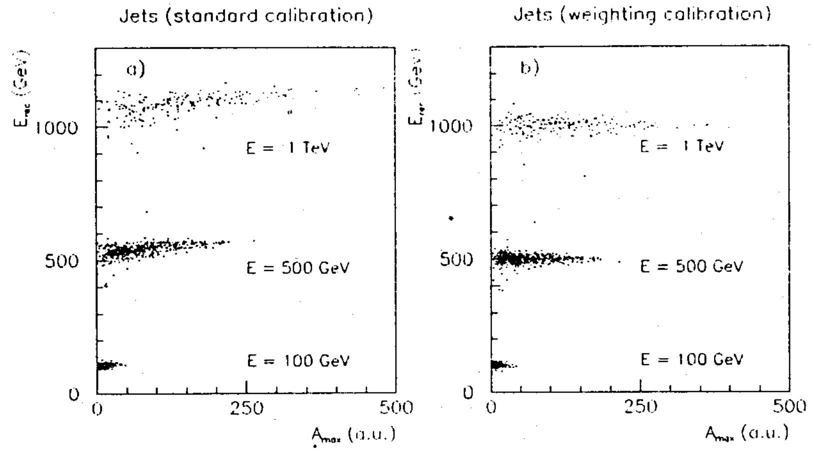

Figure 2: *Total reconstructed energy versus the maximum local single channel amplitude per event*

range. Weighting technique is the selection of some parameters which provide correct energy reconstruction by means of suppressing a large local e.m. energy deposition component of hadron shower.

The noncompensation problem of the ATLAS calorimeter can be abolished by means of one of the following mathematical equations for amplitude value conversion [2, 3, 4, 5]:

$$A^w_{ij} = A_{ij} \cdot (1 - \frac{P_j}{A_j} A_{ij}) \ , \quad (2)$$

$$A^w_{ij} = A_{ij} \cdot [1 + \alpha \frac{A_{ij}}{V_{ij}} + \beta (\frac{A_{ij}}{V_{ij}})^2] \ , \quad (3)$$

$$A^w_{ij} = A_{ij} \cdot (1 + \delta e^{-\rho \frac{A_{ij}}{V_{ij}}}) \ , \quad (4)$$

where
A^w_{ij} - weighted amplitude signal from the tower with indexes i, j;
$A_j = \sum_i A_{ij}$;
P_j – weighting coefficients ;
$V^{em(ha)}_{ij} = v^{em(ha)}_{ij} / v^{em(ha)}_0$ – em (h)-calorimeter normalized volumes; are taken as em (h) - calorimeter's (i,j) cell volumes devided by corresponding (em or h) cell volume at $\eta = 0$
The other symbols have the same meaning as in formula (1).

In equations (2) - (4), expression in braces serves to decrease ratio $e/h > 1$ by suppressing a large local (on the level of readout cell) e.m. energy deposition component of hadron shower.

Application of all above-mentioned functions was done. These functions (2) - (4) gave practically the same results. For energy E_{rec} reconstruction we choose formula (2) which was applied for ATLAS test beam analysis [5]. It means that the formula for energy E_{rec} reconstruction could be written as:

$$E_{rec} = c_1 \sum_i A_{i1} + c_2 \sum_i A_{i2} +$$
$$+c_3 \cdot \sum_{j=3}^{5} \sum_i A_{ij} \cdot (1 - \frac{P_j}{A_j} A_{ij}) +$$
$$+c_4 \cdot \sum_{j=6}^{8} \sum_i A_{ij} \cdot (1 - \frac{P_j}{A_j} A_{ij}) , \qquad (5)$$

where
P_j, $j = 3, ..., 8$ - weighting coefficients.
The other symbols have the same meaning as in formula (4).

For EM calorimeter were used the identical P_j parameters due to the identical radial lengths of the longitudinal segments.

Calibration coefficients were obtained by minimizing the functional:

$$F = \frac{\sum_{k=1}^{N} (E_k - E_{inc})^2}{N} + (\bar{E}_{rec} - E_{inc})^2 , \qquad (6)$$

where
E_{inc} - original jet energy;
E_k - one event energy deposition;
$\bar{E}_{rec} = (\sum_{k=1}^{N} E_k)/N$; (N - number of events).

Minimization has been made by MINUIT program with MIGRAD method used. Parameters were obtained on the $\eta = 0.4$ jet samples by minimizing the energy resolution and equating the mean reconstructed energy to the incident one at each energy point. Obtained parameter values are:

$$c_1^{(ps)} = 18.8, c_2^{(ps)} = 11.3 ,$$
$$c_3^{(em)} = 6.97 + 2.68 \cdot e^{-0.022 \cdot E} , \qquad (7)$$
$$c_4^{(ha)} = 45.5 .$$
$$P_3 = P_4 = P_5 = 0.1 , P_6 = 0.15 , P_7 = 0.27 , P_8 = 0 .$$

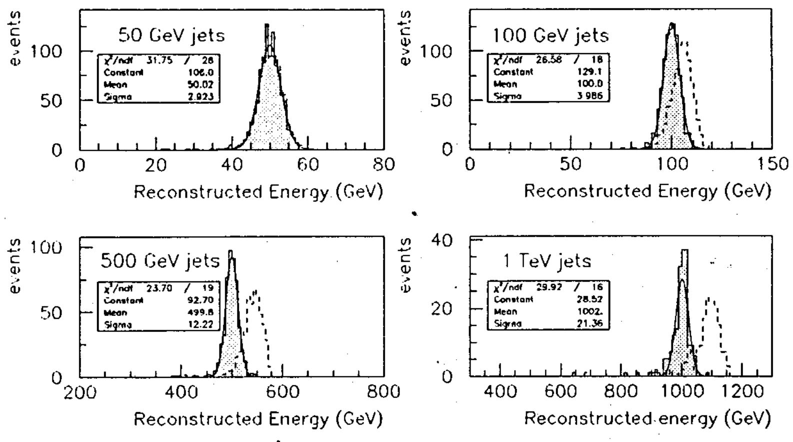

Figure 3: *Comparision of reconstucted energy distributions obtained by standard calibration (dashed line) and by weighting technique (solid line)*

The energy reconstruction algorithm which uses formulae (5), (7) is divergenced after 3 - 4 iteration. Such energy reconstruction was applied to the $\eta = 0.4$ and $\eta = 0.6$ jet banks.

The work of the weighting is clearly demonstrated on Fig.2 showing the total reconstructed energy versus the maximum local single channel amplitude per event in the calorimeter. Plots are presented for jet energies 100, 500 GeV and 1 TeV.

Comparison of the reconstructed energy spectra obtained with and without weighting is on Fig.3 (solid and dashed lines respectively). At the 50 GeV energy point the spectrum from standard calibration is practically the same as one from weighting technique. It is due to the fact that calibration coefficients were found just at this enegry. We can see advantages of weighting with the energy increasing: resolution becomes better in comparison to standard calibration and the mean reconstructed energy value remains correct.

5 Energy resolution and linearity

On Fig. 4 the calorimeter linearity and energy resolution after applying two calibration methods are shown. The energy resolution was fitted by linear (a,b pictures on Fig.4) and squared (c,d pictures on the same Figure) sums

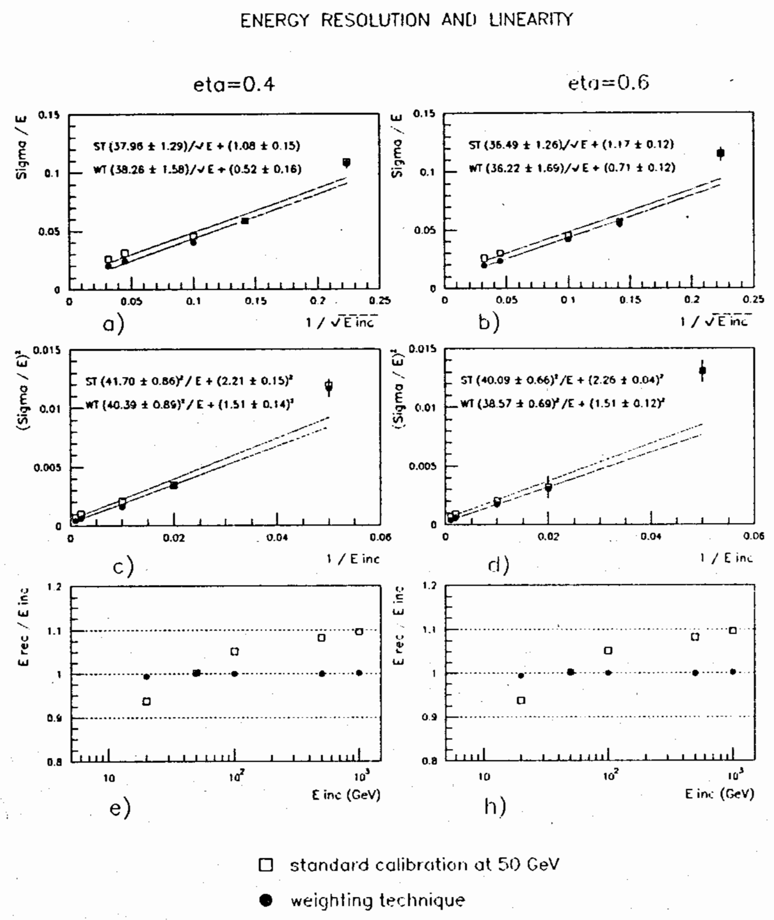

Figure 4: *Calorimeter energy resolution and linearity for hadrons*

respectively by

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} + b\,, \quad \frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b\,.$$

The comparison of standard calibration method to the weighting technique gives a significant advantage in linearity response and better meaning for energy resolution as one can see from Fig.4 .

The achived energy resolution for squared sum formula and linearity are summarized in the table.

Table. Energy resolution and linearity results

Energy Calibr. method	Energy resolution		Max. linearity deviation (%)
	$a \pm \sigma a(\%)$	$b \pm \sigma b(\%)$	
ST ($\eta = 0.4$)	41.70 ± 0.86	2.21 ± 0.15	9.6
ST ($\eta = 0.6$)	40.09 ± 0.66	2.26 ± 0.04	9.7
WT ($\eta = 0.4$)	40.39 ± 0.89	1.51 ± 0.14	0.5
WT ($\eta = 0.6$)	38.57 ± 0.69	1.51 ± 0.12	1.4

Summary

The ATLAS barrel calorimeters (ps + em + ha) jet calibration was done by different approaches. The standard calibration method gives bad linearity for hadron noncompensated calorimeter. The calibration with weighting technique restores linearity and improves energy resolution. The application of the weighting technique for barrel calorimeter energy reconstruction allows one to achive results :

- barrel calorimeter's linearity is better than:
  0.5% for pseudorapidity value $\eta = 0.4$,
  1.4% for pseudorapidity value $\eta = 0.6$;
- barrel calorimeter's resolution for $\eta = 0.4$ $\eta = 0.6$ is respectively :

$$\frac{\sigma(E)}{E} = \frac{40.4\%}{\sqrt{E}} \oplus 1.5\%\,,$$

$$\frac{\sigma(E)}{E} = \frac{38.6\%}{\sqrt{E}} \oplus 1.5\%\,.$$

Authors thank Marzio Nessi (CERN) who proposed the investigation subject and made the valuable comments during its performing.

References

[1] ATLAS Collaboration, Letter of Intent, *CERN/LHCC/92-4, LHCC/I 2*, 1992;

[2] A.E.Kiryunin, *ATLAS Internal Note CAL-NO-016*, 1993;

[3] W.Braunschweig et al., *Nucl.Instr. and Meth. A265(1988) 419-434*, 1988;

[4] W.Braunschweig et al., *Nucl.Instr. and Meth. A275(1989) 246-257*, 1989;

[5] F.Ariztizabal et al., *Nucl.Instr. and Meth. A349(1994) 384-397*, 1994;

[6] SLUG, DICE, ATRECON manuals, *ATLAS Internal Notes*.

Received by Publishing Department
on December 29, 1994.

Аствацатуров А.Р. и др. E13-94-522
Калибровка ATLAS калориметров при помощи струй

Проведена калибровка калориметров центрального модуля установки ATLAS посредством стандартного метода и техники взвешивания (weighting technique). Метод стандартной калибровки дает неудовлетворительное значение линейности для нескомпенсированного адронного калориметра. Калибровка методом взвешивания позволила восстановить линейность с точностью до 0,5% и улучшить энергетическое разрешение до $38{,}6\%/\sqrt{E} \oplus 1{,}5\%$ при значении псевдобыстроты $\eta = 0{,}6$.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1994

Astvatsaturov A.R. et al. E13-94-522
ATLAS Calorimeters Energy Calibration for Jets

The calibration of ATLAS barrel calorimeters (including preshower system, electromagnetic Liquid Argon calorimeter and scintillating hadron tile calorimeter) was done by standard calibration and weighting technique approaches. The standard calibration gives the bad linearity for hadron noncompensated calorimeter. The calibration with weighting technique, in comparision with standard calibration, restores linearity and improves energy resolution up to $38.6\%/\sqrt{E} \oplus 1.5\%$ for $\eta = 0.6$.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 1994