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On the e/h Ratio of the Electromagnetic Calorimeter

Y.A. Kulchitsky [1]

Joint Institute for Nuclear Research, Dubna, Russia
Institute of Physics, National Academy of Sciences, Minsk, Belarus

Abstract

The method of extraction of the e/h ratio for electromagnetic compartment of combined calorimeter is suggested and the non-compensation was determined. The results agree with the Monte Carlo prediction and results of the weighting method for electromagnetic compartment of combined calorimeter. The new easy method of a hadronic energy reconstruction for a combined calorimeter is also suggested. The proposed methods can be used for combined calorimeter, which is being designed to perform energy measurement in a next-generation high energy collider experiment like ATLAS at LHC.

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[1] E-mail: Iouri.Koultchitski@cern.ch

1 Introduction

The future experiment ATLAS [1, 2] at the Large Hadron Collider (CERN) will include a combined calorimeter [3] with in the central region the two separate units: the liquid-argon electromagnetic calorimeter [4] and the iron-scintillating hadronic calorimeter [5, 6, 7, 8].

For many tasks of calorimetry it is necessary to know a non-compensation of combined calorimeter compartments. As to the hadronic calorimeter there is the detailed information about the e/h ratio presented in [5, 9, 10]. But as to the electromagnetic calorimeter [11] reliable information practically absent.

The aim of the present work is to develop the method for the determination of the electromagnetic compartment non-compensation and compares results of this method with results of weighting method [12, 13] and Monte Carlo prediction [14] for the same calorimeter. The new method of an energy reconstruction for combined calorimeter is also presented. For detailed understanding of performance of the future calorimetry the combined calorimeter setup has been made consisting of the liquid-argon electromagnetic calorimeter inside the cryostat and downstream the iron-scintillating hadronic calorimeter [15, 16, 17].

2 Method

The response, R, of a calorimeter to a hadronic shower is the sum of the contributions from the electromagnetic, E_e, and hadronic, E_h, parts of the hadronic shower energy, $E = E_e + E_h$, [18]

$$R = e \cdot E_e + h \cdot E_h \ , \tag{1}$$

where e (h) is the energy independent coefficient of transformation electromagnetic (hadronic) part of a shower energy to response. Therefor an incident energy is

$$E = (1/e) \cdot (e/\pi) \cdot R \ , \tag{2}$$

where

$$\frac{e}{\pi} = \frac{e/h}{1 + (e/h - 1) \cdot k \cdot \ln(E)} \ , \tag{3}$$

$f_{\pi^0} = k \cdot \ln(E) = E_e/E$ is a fraction of electromagnetic energy. In the case of a combined calorimeter the incident energy is deposited into an electromagnetic compartment, E_{em}, into a hadronic compartment, E_{had}, and into a dead material between the two calorimeters, E_{dm}. Using relation (2) the following expression has been obtained:

$$E = E_{em} + E_{dm} + E_{had} = \frac{1}{e_{em}} \left(\frac{e}{\pi}\right)_{em} R_{em} + E_{dm} + \frac{1}{e_{had}} \left(\frac{e}{\pi}\right)_{had} R_{had} \ , \quad (4)$$

where R_{em} (R_{had}) is response of a electromagnetic (hadronic) calorimeter compartment, $1/e_{em}$ [16, 19] and $1/e_{had}$ [16] are the energy calibration constant for electromagnetic and hadronic calorimeter.

The Eq. (4) is the basic formula for the new, non-parametrical, method of a hadronic energy reconstruction for a combined calorimeter. This method does not require the determination of any parameters by a minimisation technique and uses known e/h ratios and electron calibration constants. In the right side of the Eq. (4) an energy is under a logarithmic function therefore for achievement of convergence with an accuracy of $\approx 1\%$ is sufficiently only the first approximation. The obtained reconstruction of the mean values of energies is within $\pm 1\%$ and this accuracy can be compared with results from Ref. [20, 16]. The fractional energy resolution is comparable with the benchmark method result [16]. The method can be used for the fast energy reconstruction in the trigger.

From expression (4) the value of the $(e/\pi)_{em}$ ratio can be obtained

$$\left(\frac{e}{\pi}\right)_{em} = \frac{E_{beam} - E_{dm} - E_{had}}{R_{em} \cdot (1/e_{em})} \ . \quad (5)$$

The $(e/h)_{em}$ ratio can be inferred from (3), where E is the beam energy. For calculation of the E_{had} the value $(e/h)_{had}$ [9] was used and E in the (3) is the energy deposited in the hadronic calorimeter, $k = 0.11$ [14]. The term E_{dm} is taken similar to [16, 15]: $E_{dm} = (1/e_{dm}) \cdot \sqrt{E_{em,l} \cdot E_{had,f}}$, where $E_{em,l}$ is an energy released in a last depth of an electromagnetic calorimeter and $E_{had,f}$ is an energy released in a first depth of a hadronic calorimeter. The validity of this approximation has been tested by the experimental study [17, 16] and by the Monte Carlo simulation [21, 22].

3 Results

The mean values of the $(e/\pi)_{em}$ distributions, derived by (5) and extracting by fitting in the $\pm 2\sigma$ [23], are given in Table 1 and shown in Fig. 1

(black circles) as a function of the energy. The fit of $(e/\pi)_{em}$ values by the expression (3), with two parameters, yields $(e/h)_{em} = 1.74 \pm 0.04$ and $k = 0.108 \pm 0.004$. The value of parameter k is in the good agreement with well known 0.11 [14]. For fixed parameter k the value of non-compensation is $(e/h)_{em} = 1.77 \pm 0.02$. The quoted errors are the statistical ones and obtained from the fit. The systematic error, which is a consequence of the uncertainties in the input constants used in the (5), is estimated to be ± 0.04.

Table 1: The $(e/\pi)_{em}$ ratios as a function of the beam energy.

E	$(e/\pi)_{em}$		
(GeV)	[23]	[12]	[13]
10	1.47 ± 0.03	–	–
20	1.42 ± 0.02	1.47 ± 0.03	1.40 ± 0.03
40	1.33 ± 0.02	–	–
50	1.33 ± 0.02	1.32 ± 0.03	–
80	1.28 ± 0.01	–	–
100	1.28 ± 0.01	1.25 ± 0.02	–
150	1.26 ± 0.01	–	–
180	–	1.16 ± 0.02	–
300	1.19 ± 0.02	0.96 ± 0.02	–
400	–	–	1.10 ± 0.02

In the Ref. [14] showed that the e/h ratio for non-uranium calorimeters with high-Z absorber material is satisfactorily described by the formula:

$$\frac{e}{h} = \frac{e/mip}{0.41 + f_n \cdot n/mip} \;, \tag{6}$$

where f_n is a constant determined by the Z of the absorber (for lead $f_n = 0.12$) [24, 25], e/mip and n/mip represent the calorimeter response to electromagnetic showers and to MeV-type neutrons, respectively. These responses are normalised to the one for minimum ionising particles. The Monte Carlo calculated e/mip and n/mip values [26] for the lead-liquid-argon electromagnetic calorimeter [27] are $e/mip = 0.78$ and $n/mip < 0.5$

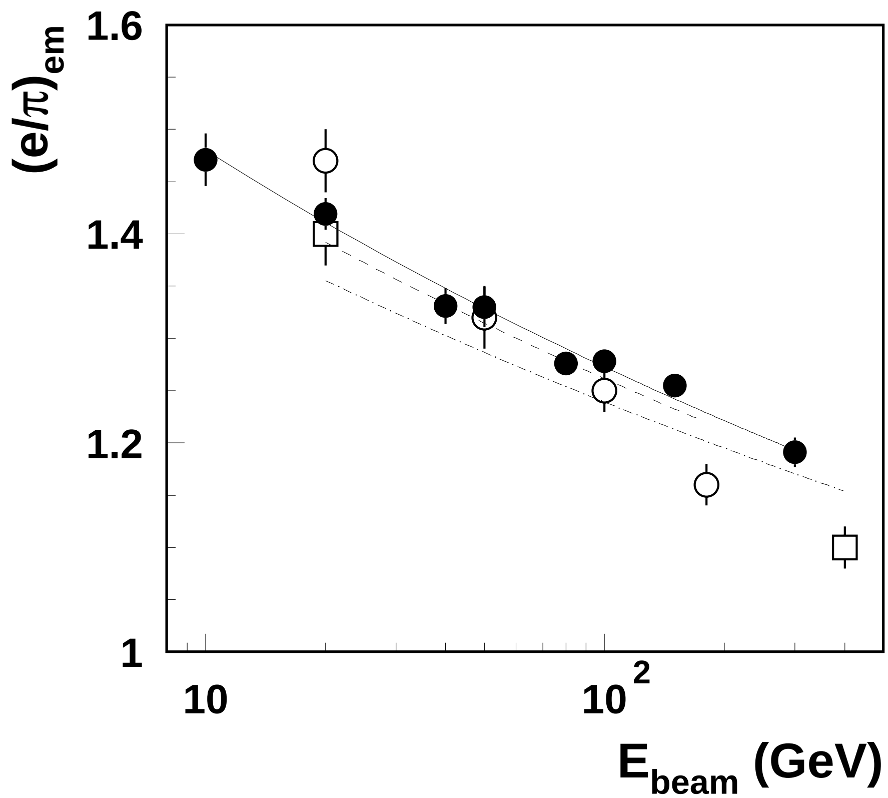

Figure 1: The $(e/\pi)_{em}$ ratios as a function of the beam energy for this method (black circles) and for weighting method (open circles for Ref. [12] and open squares for Ref. [13]). The lines are the result of a fit of Eq. (3) with free e/h parameter and $k = 0.11$: solid line is for the [23] data, dashed line is for the [12] data and dash-doted line is for the [13] data.

and leading to $e/h > 1.66$. The measured value of the $(e/h)_{em}$ ratio agrees with this prediction.

The formula (6) show that e/mip is very important for understanding compensation in lead-liquid-argon calorimeters. The non-compensation increase when the sampling frequency is also increased [24]. A large fraction of the electromagnetic energy is deposited through very soft electrons ($E < 1$ MeV) produced by Compton scattering or the photoelectric effect. The cross sections for these processes strongly depend on Z and practically all these photon conversions occur in the absorber material. The range of the electrons produced in these processes is very short, ~ 0.7 mm for 1 MeV electron in lead. Such electrons only contribute to the calorimeter signal if they are produced near the boundary between the lead and the active material. If the absorber material is made thinner this effective boundary layer becomes a larger fraction of the total absorber mass and the calorimeter response goes up. This effect was predicted by EGS4 simulation [24]. It explains that predictions for the GEM [28] accordion electromagnetic calorimeter (1 mm lead and 2 mm liquid-argon) are the $e/mip = 0.86$ and the $e/h > 1.83$. The Monte Carlo calculations also predict that the electromagnetic response for liquid-argon calorimeters (due to the larger Z value of argon) is consistently large than for calorimeters with plastic-scintillator readout. The signal from neutron (n/mip) suppressed with factor 0.12 and the $n - p$ elastic scattering products do not contribute to the signal of liquid-argon calorimeters. These detectors only observe the γ's produced by inelastic neutron scattering and from thermal neutron capture [24].

In the Refs. [12, 13] the following definition of an e/π ratio for first compartment of the combined calorimeter is adopted. The estimators for pion and electron energies, respectively, are $E = c^{\pi}_{em} \cdot R_{em} + c^{\pi}_{had} \cdot R_{had}$ and $E = c^{e}_{em} \cdot R_{em}$, where R_{em} and R_{had} are responses of elecromagnetic and hadronic compartments of a combined calorimeter, c^{e}_{em} (energy independent within 1%) is the energy calibration constant for the electromagnetic calorimeter, c^{π}_{em} and c^{π}_{had} are weighting parameters for pions. These parameters was find using a minimisation procedure for a energy resolution (σ/E) at every beam energies. In the Ref. [12, 13] an electron/pion ration defined as $(e/\pi)_{em} = c^{\pi}_{em}/c^{e}_{em}$. This definition one can find from (4) for an electromagnetic compartment, where $c^{\pi}_{em} = 1/e_{em} \cdot (e/\pi)_{em}$ and $1/e_{em} = c^{e}_{em}$.

The results of this weighting method for $(e/\pi)_{em}$ rations are given in

Table 1 and shown in Fig. 1 (open circles are for [12] and open squares are for [13]). In the energy region $\leq$ 100 GeV the [23] data are in a good agreement with [12, 13] data and in disagreement for energies $>$ 100 GeV. Fit of the $(e/\pi)_{em}$ values by the expression (3), with two parameters, yields $(e/h)_{em} = 2.28 \pm 0.19$ and $k = 0.143 \pm 0.006$ for [12] data and $(e/h)_{em} = 1.93 \pm 0.13$ and $k = 0.135 \pm 0.007$ for [13] data. Note, that problematical value of $(e/\pi)_{em} = 0.96 \pm 0.02$ at 300 GeV [12] is excluded from the fit. One can see that parameters k are more bigger that its well known value and the $(e/h)_{em}$ are bigger than our result. For fixed parameter $k = 0.11$ the result of the fit are $(e/h)_{em} = 1.73 \pm 0.10$ for [12] data and $(e/h)_{em} = 1.64 \pm 0.18$ for [13] data. In the both cases we calculated errors of the e/h taken into account the values of $< \chi^2 >$. The finding e/h rations are in agreement with our result within error bars. Therefore, one can see that the weighting method leads to distortion of the $(e/\pi)_{em}$ ratios.

4 Conclusions

The method of extraction of the e/h ratio for electromagnetic compartment of combined calorimeter is suggested and the non-compensation was determined. The results agree with the Monte Carlo prediction and results of the weighting method for electromagnetic compartment of combined calorimeter. The new easy method of a hadronic energy reconstruction for a combined calorimeter is also suggested. The proposed methods can be used for combined calorimeter, which is being designed to perform energy measurement in a next-generation high energy collider experiment like ATLAS at LHC.

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