CALIBRATION AND MONITORING OF THE ZEUS URANIUM SCINTILLATOR CALORIMETER AT HERA

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One of the main components of the ZEUS detector at the HERA storage ring is the Uranium Calorimeter (UCAL). It has been running successfully since ZEUS started data taking in 1992. The UCAL is a Uranium-Scintillator calorimeter with equal response for electrons and hadrons ($\frac{e}{h} = 1.00 \pm 0.05$), a linear energy response and a high energy resolution of $\frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E}}$ for electrons and $\frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E}}$ for hadrons. It covers 99.7% of the solid angle and is able to handle bunch crossing rate of up to 10.4 MHz. This performance demands a very precise calibration and a constant monitoring of the detector. In this paper we present the procedure to achieve a calibration accuracy of better than 3% and to maintain it stable to better than 2% for more than10 years.

1. Introduction

The Uranium Sampling Scintillator Calorimeter[1,2,3] (UCAL) is the main calorimeter of the ZEUS experiment[3] at HERA, a electron-proton collider at DESY with a center of mass energy of 324 GeV^2. This calorimeter type is unique in the world. The intrinsic uranium radioactivity and the high uniformity of the signal response over the entire calorimeter allow a simple, accurate and stable calibration, making this calorimeter a central component for all precision measurements of the HERA physics programme. The calorimeter provides precise energy and arrival time measurements which are used for different applications from trigger decisions to jet reconstruction. This contribution describes the methods used to calibrate and monitor the ZEUS Uranium Calorimeter.

2. ZEUS Uranium Calorimeter Architecture

The main design criteria of the calorimeter were as follows:

(1) *high energy resolution* — essential for any high precise measurement;
(2) *high time resolution* — to detect and suppress background like cosmic rays and beam gas events which are out of phase with the bunch crossing;
(3) *good spatial resolution* — to be able to identify efficiently scattered electrons;
(4) *uniformity* — equal signal response throughout calorimeter is essential for any precision measurement
(5) *stability*
(6) *fast response* — to be able to handle the 10.4 MHz of the HERA bunch crossing rate with a minimal readout deadtime.

These requirements are partially achieved by using the sampling principle which allows to tune the electromagnetic and hadronic parts of the hadronic shower to compensate. A small sample depth is used to guarantee a high resolution in electromagnetic shower measurements.

Each layer is made up of 3.3 mm of stainless-steel-clad depleted-uranium and 2.6 mm of SCSN-38 scintillator, corresponds to 1.0 X_0 (0.04 λ_I) and is uniform throughout calorimeter. The thickness of the cladding of the DU is 0.2 mm. Figure 1 shows the ratio $\frac{e}{h}$ of the electron to hadron signals as a function of the energy E_K of the incident particle in the calorimeter.

The UCAL has depleted-uranium (DU) as passive material. It has the advantage of producing slow neutrons by fission which helps in compensating the losses in the hadronic shower. The uranium acts also as an absorber of electromagnetic particles generated in the electromagnetic part of the hadronic shower, enhancing the compensation mechanism. As active material scintillator is used. It contains a large fraction of hydrogen atoms that produces the signal by interacting with the slow neutrons from the hadronic shower.

The calorimeter is divided in three different regions, namely the forward (FCAL), the central (BCAL) and the rear (RCAL) sections, covering the polar angle ranges 2^o - 40^o, 37^o - 129^o and 128^o - 177^o. The FCAL and RCAL are subdivided in 23 modules each and the BCAL is subdivided in 32 modules. Each module consists of towers segmented longitudinally into two parts. The inner part constitutes the electromagnetic section (EMC) with a depth of 25 X_0 (1.1 λ_I) throughout UCAL and the outer one constitutes the hadronic section (HAC) with a depth of 6 λ_I in FCAL, 3 λ_I in RCAL and 4 λ_I in BCAL. The EMCs are further segmented in 4 (2 in RCAL) sections and the HACs are subdivided in 2 (1 in RCAL) sections of 3.0 λ_I in FCAL (RCAL) and 2.0 λ_I in BCAL.

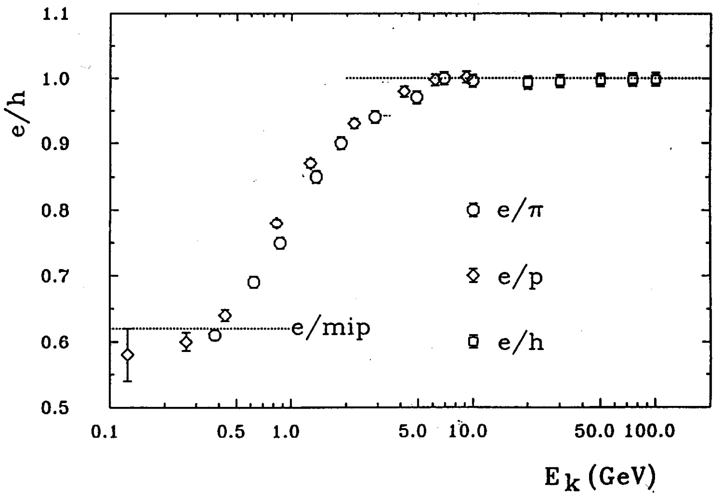

Figure 1. The ratio $\frac{e}{h}$. The calorimeter is fully compensating for energies above 5 GeV and approaches the electron to mip ratio at low energies.

Due to the compensation and uniformity, the calorimeter has a high hadronic energy resolution of $\frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E}}$. The electromagnetic energy is measured with a resolution of $\frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E}}$. The UCAL can also measure the time with a resolution better than 1 ns and the position with a precision better than 1.3 cm vertically and 0.8 cm horizontally. This allows a good identification of the scattered electron in DIS process and an efficient suppression of background events out of phase with the bunch crossing.

3. Calorimeter Readout

The calorimeter readout[4] is designed such as to ensure a very stable system able to handle a high bunch crossing rate with very low deadtime.

The light of each EMC and HAC cells is collected by 2 wave-length shifter guides (WLS) mounted at the two sides of a tower. The light is then sent to a photomultiplier (PMT) that is connected to a front-end card where the signal is splitted 5-fold:

- to two shaping-sampling with different (high and low) gains;
- to a current sum node, serving the Calorimeter First Level Trigger (CFLT);
- to a current integrator averaging the input current over 20 ms and providing the uranium calibration signal measurement;
- to a termination resistor.

The signal is sampled and stored in a 58 cells deep pipeline chip continuously clocked at the 10.4 MHz bunch crossing rate until a first level trigger occurs. Then the readout stops for 10 μs and 6 samples for each gain are transferred to a 8 cells deep buffer chip clocked at 0.6 MHz to the digital cards (DC's). This scheme allows 5 μs for a trigger decision and leads to a deadtime of 1% for a first-level trigger rate of 1 kHz.

Each DC has 4 analog-to-digital converters (ADC's), a digital signal processor (DSP) and a memory in which the calibration constants are stored. The latter are used subsequently in the DSP's to correct the 12-bit digitization results from the ADC's and to reconstruct the time and energy to be used in the second-level trigger and to be sent to an event builder.

The 12-bit digitization, along with the 2 gain scales, allows an effective dynamic range of 17 (15) bits in FCAL and BCAL (RCAL). The dynamical range (high gain)(low gain) per Calorimeter cell is (0-24 GeV)(0-530 GeV) in FCAL, (0-18 GeV)(0-380 GeV) in BCAL and (0-18 GeV)(0-90 GeV) in RCAL, while the noise level is dominated by the uranium activity (UNO) of $\approx$15 ($\approx$25) MeV in the EMC (HAC) sectors.

4. Calibration Method and Monitoring

The calibration[5] of the calorimeter is based on its uniformity and on the natural uranium activity (2-10 MHz per calorimeter cell) that provides the absolute energy calibration. A total of 16 modules were examined in test beams at CERN[2], where the construction tolerance and its implication on the uranium signal calibration was extensively investigated. An averaged non-uniformity of less than 1% were measured, the main contribution occurring in regions across the modules and towers boundaries. Cell-to-cell calibration was measured to be better than 1.5% (2%) for EMC (HAC) sections. The nominal UNO currents are chosen such that the response of each cell to mip's scales with the number of layers in the cell.

The calibration constants were transported from test beam to ZEUS and then a set of corrections are applied in order to keep the UNO current at the nominal level. The corrections are obtained from a full electronic calibration, an adjustment of the high-voltage applied to the PMT's and a measurement of offline energy normalization factors.

In the full electronic calibration, the calibration constants are adjusted for the front-end cards and the digital cards. A digital-to-analog converter (DAC) on board of each front-end card allows to set a very precise reference voltage used to measure the pedestal and gain of the pipeline and buffer chips. In addition this voltage is injected into the buffer-multiplexer and used to measure the ADC-to-VOLT constants. A very stable and known amount of charge is used to calibrate the gain of the shapers. Finally, the uranium noise offset is measured. All the constants are subsequently stored in the DSP on board of each digital card, as already mentioned in the previous section. The constants are found to be stable to much better than 1% over a week. Figure 2 shows a schematic of a front-end card.

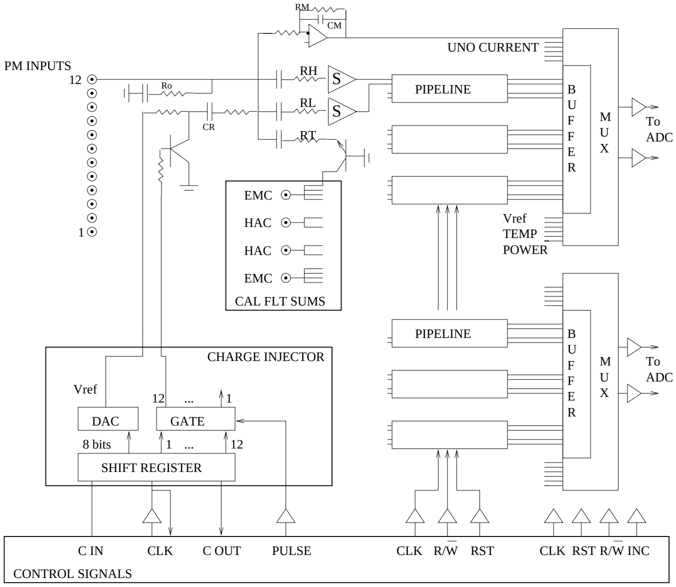

Figure 2. A calorimeter front-end card.

In addition to the full electronic calibration, the high voltages (HV) applied to the photomultipliers are adjusted such that the response of the detector to the UNO current is kept to the nominal one within less than 1%. The uranium current measured at DESY is used for such purpose. Figure 3 shows the relative deviation of a measured UNO current to the nominal one after a HV adjustment. Figure 4 shows the stability of the UNO current measured at different time in a period of 36 days.

Ultimately, the UNO current is recorded daily for use as offline normalization correction factors.

Beside the above corrections, a constant monitoring ensures a good quality of the signal. The calibration stability is checked daily and the bad channels are marked and removed from the readout. Dedicated runs are used for this purpose, namely:

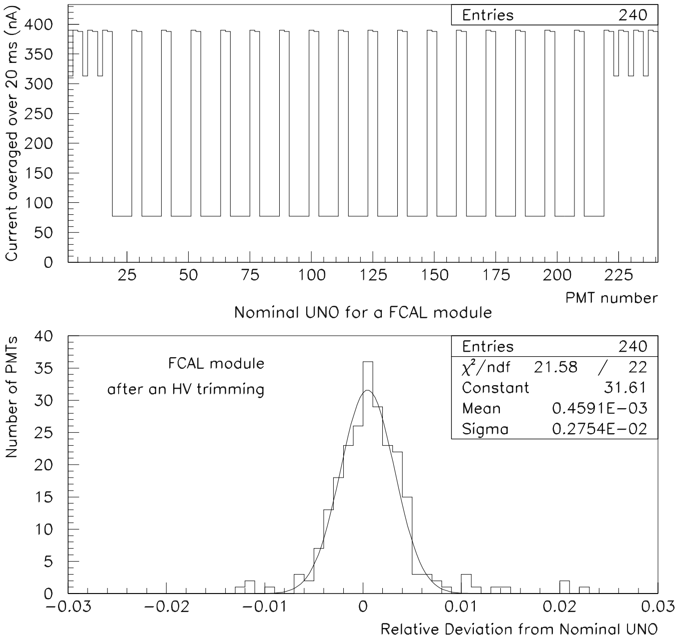

Figure 3. Nominal UNO current measured in test beam for a FCAL module and the relative deviation of a UNO current measured at DESY after a HV adjustment showing an agreement to much better than 1%.

(1) *Pedestal (Ped) runs*;
(2) *Charge injection (Qinj) runs*;
(3) *Uranium noise (UNO) runs*;
(4) *LED runs*;
(5) *Laser runs.*

The pedestal runs are used to check the whole readout chain from the photomultipliers to the digital cards. Any channel with bad pedestal is marked and removed from the readout. The UNO and Qinj runs are used for the same purpose of checking for bad channels. The first monitors the uranium activity tracing down malfunction of photomultipliers or HV systems and the latter checks the stability of the electronic readout. Figure 5 shows the results of the measurement from these three runs. We can clearly recognize single bad channels or groups of them. They are marked and fixed whenever possible.

The LED and laser runs measure the light (LED) and laser pulse[3] injected in the WLS guiders and can be used as a double check for the performance of the photomultipliers, the HV system and the electronic readout. They are also used to study the photomultipliers gain stability and linearity over a wide

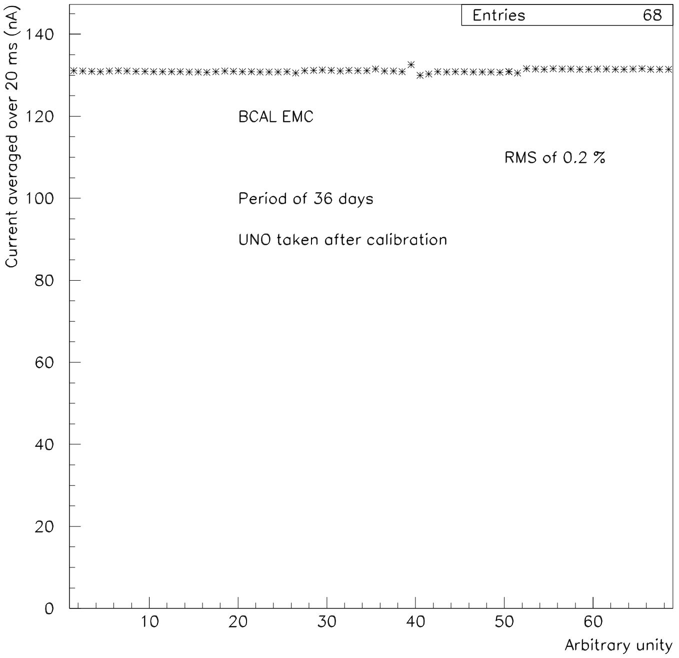

Figure 4. UNO current measured at different time showing high stability.

dynamic range.

As a result of all corrections and monitoring, the calorimeter has typically 2% of the total readout channels declared as bad, the number of bad cells is usually less than 2 and the calibration is stable to $1 - 2\%$.

5. Summary

The calorimeter uniformity and the compensation ensures a high hadronic energy resolution. The natural uranium activity provides the absolute energy scale and an in situ calibration is performed to correct for changes in the readout electronic. The nominal uranium noise current from the test beam measurement is re-established by adjusting the high voltage based on the measured uranium current at DESY. The latter is recorded on daily basis for use as offline normalization factor. A complete monitoring of the readout system is performed and bad channels are removed from the readout.

The calibration is stable to $1 - 2\%$. However it is worth mention that the absolute calibration from the test beam to ZEUS is good only to $3 - 4\%$ which is taken into account by using physics constraints[6].

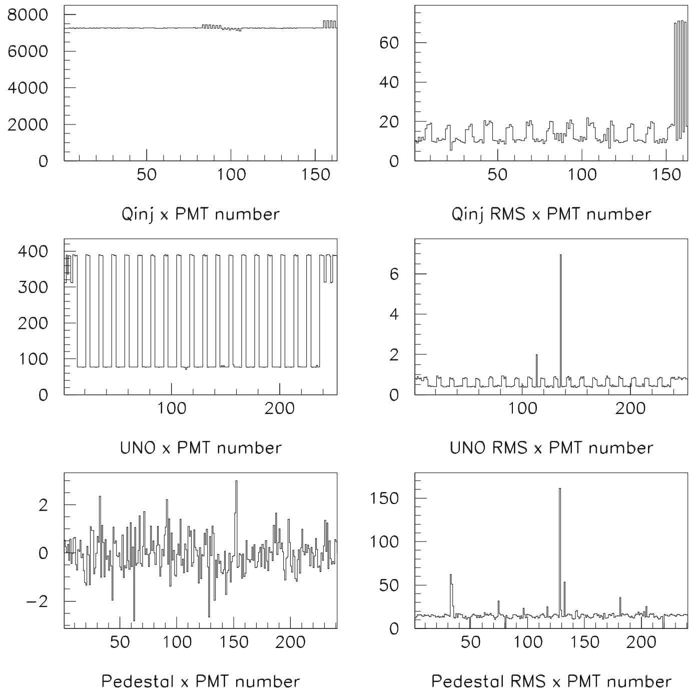

Figure 5. Charge injection, UNO and pedestal runs used to monitor the readout channels. Those ones outside the calibration tolerance are marked as bad and removed from the readout.

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