Spacal alignment and calibration

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The main purpose of my work was alignment and calibration of Spacal - the backward detector which is used in the H1 experiment. Fundamental tool applied to perform these tasks was H1OO Analysis Environment. The article contains short introduction to the H1 experiment, description of the Spacal detector and presentation of the results I have reached during my stay at DESY-Zeuthen.

1 Introduction

1.1 HERA and H1 experiment

The Hadron-Electron-Ring-Anlage HERA consists of two separate, 6.3 km long storage rings designed to accelerate 820 GeV protons and 30 GeV electrons (or positrons). Two big detectors were built in the eighties which use HERA in its *ep* colliding mode. These are located in the North Hall (H1) and in the South Hall (ZEUS).

The H1 was designed as a general purpose detector to study high-energy interactions of electrons and protons at HERA.

The H1 detector is arranged cylindrically symmetric around the beam axis. The imbalance in the energy of the electron and the proton colliding beams implies that the detector is better instrumented in the outgoing proton direction, which defines, by convention, the positive Z direction of the H1 coordinate system. The components of the detector situated on the positive side from the interaction point are referred to as "forward". Similarly the negative side is referred to as "backward". The region around the interaction point is called the "central" part of the apparatus.

The H1 detector is composed of central and a forward tracking chamber system surrounded by electromagnetic and hadronic calorimeters: a Liquid Argon calorimeter in the central and forward directions and a Lead-Fiber calorimeter (Spacal) in the backward part. A superconducting coil outside the Liquid Argon calorimeter provides a uniform magnetic field. In the forward direction the measurement of muons is performed by drift chambers placed in a toroidal magnetic field.

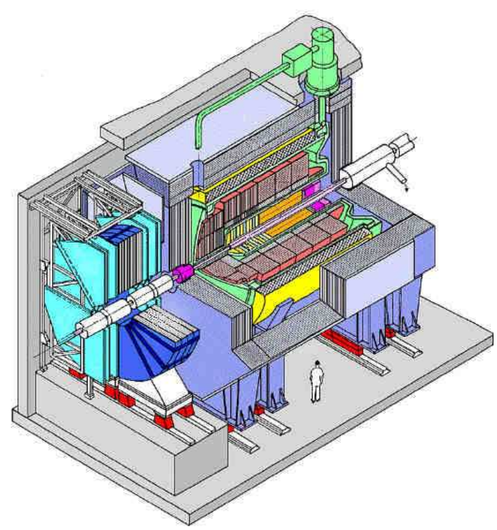

Fig. 1: *The H1 detector - 3D view.*

1.2 Backward Detectors

For kinematic reasons the backward detectors are the most important parts of H1 detector for the measurement of deep inelastic scattering at low $Q^2 \leq 120 GeV^2$. The scattered electron is identififed as a cluster in the backward electromagnetic calorimeter. The angular measurement of the scattered electron relies mainly on the impact point determination in the backward tracking chamber.

Tab. 1: *Backward tracking chamber.*

BDC	
Radial coverage	6.5 - 70.5 cm
Spatial resolution	0.3 mm
Average reconstructed track multiplicity in 5 cm distance around the calorimeter cluster	11.5

Backward Drift Chamber (BDC)

The backward drift chamber (BDC) is subdivided into 8 octants consisting of 4 double layers. The signal wires are strung in polygons around the beam axis in order to optimize the θ resolution. The double layers are rotated by $11.25°$ to obtain some measurement of ϕ. Each signal wire is contained in a separate cathode cell.

The spatial resolution for individual hits is 0.3 mm, leading to a θ resolution better than 0.5 mrad if no showering occured in the material between the vertex and the BDC.

Spacal calorimeter

The Spacal calorimeter comprises the electromagnetic and hadronic sections and the backward plug. The electromagnetic part of the Spacal consists of 1192 cells with an active volume of $4.05 \times 4.05 \times 25 cm^3$ each. A transverse view of the calorimeter is given in Fig. 2. The cells are made of grooved lead plates and scintillating fibers with a diameter of 0.5 mm. The scintillation light of each cell is converted into an electric pulse using photomultiplier tubes (PMT). The active length of the electromagnetic Spacal corresponds to 27.47 radiation lengths and 1 hadronic interaction length. The angular coverage of the calorimeter is $153° < \theta < 177.8°$.

The hadronic part of the Spacal comprises 136 cells of $12 \times 12 \times 25 cm^3$ providing one nuclear interaction length. The fibers are of the same type as in the electromagnetic section but have a larger diameter of 1 mm.

The main parameters of the H1 backward setups are listed in Tab. 1 and 2.

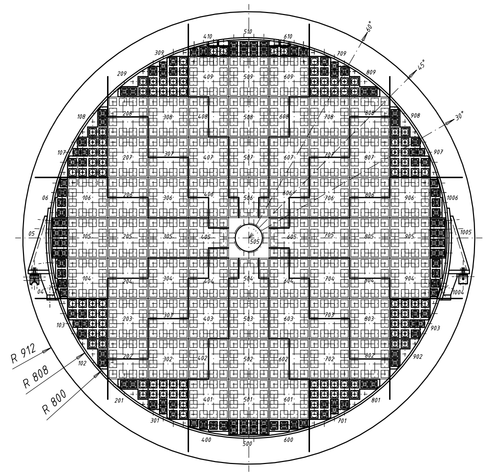

Fig. 2: *Transverse view of Spacal. Small boxes indicate individual cells.*

Tab. 2: *Backward calorimeter.*

Spacal		
	Spacal EM	Spacal HAD
Radial coverage	5.7 - 80 cm	
Sensitive length	$27.5X_0, 1\lambda$	$29.4X_0, 1\lambda$
Moliere-radius	2.55 cm	2.45 cm
Energy resolution at 27.5 GeV	3.0%	
Energy resolution at 2 GeV	5.6%	
Cell size	4.05×4.05	$12 \times 12 cm^2$
Spatial resolution	3.4mm	

2 Spacal alignment

Method used in my analysis is independent of measurement in central tracker. In first step we select QED-Compton events. We require that both: the electron and the photon are reconstructed in Spacal. We demand the total energy of those two particles to be above $25GeV$ and the difference between their azimuthal angles to be close to $180°$. This way we get events with electron and photon moving in oposite directions. Next we connect two clusters created by particles with a line. Each line gives some contribution to 3D histogram, which shows density of the lines.

Fig. 3 shows Spacal before alignment and on Fig. 4 aligned Spacal is shown. Correction factors are the following: $\Delta x = 0.095cm$ and $\Delta y = 0.42cm$.

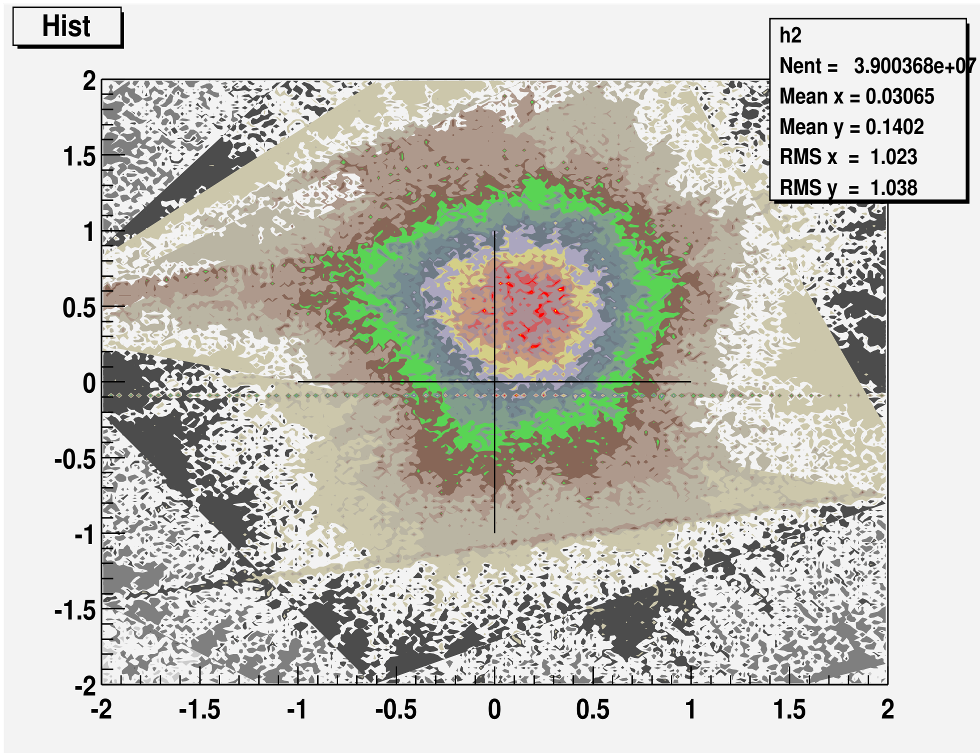

Fig. 3: *Spacal before alignment.*

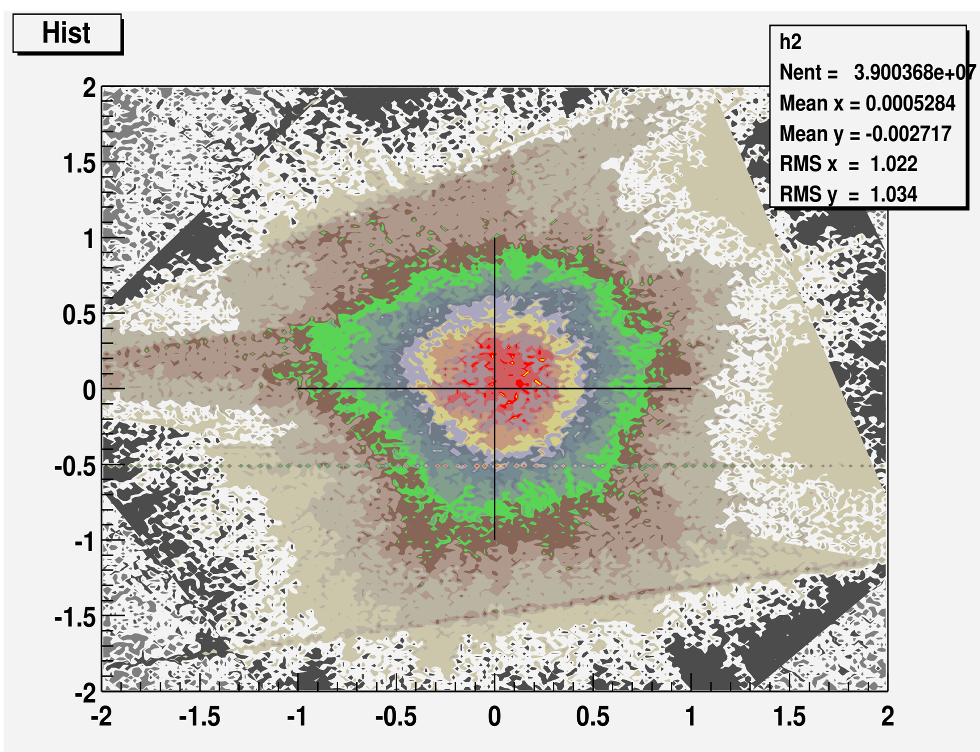

Fig. 4: *Aligned Spacal.*

3 Spacal calibration

3.1 Description of method

The energy measurement in each cell of the calorimeter is performed using photomultiplier tubes individually for each cell. Therefore, altogether 1192 amplification gains have to be known to define the Spacal energy scale.

The situation becomes more complicated as the amplification gains of the photomultiplier tubes can vary with time, changes at the percent level were detected during a few hours of operation. A special LED calibration system was developed in order to detect these variations. Information from LED system is written to the database and used for the Spacal energy reconstruction.

Several methods were proposed for the Spacal energy scale determination. These used cosmic muon events, beam halo muon events and kinematic peak shape calibrations. In my work I have used double angle method introduced in [1].

The Spacal calibration task can be expressed here as a minimization of the functional of the following type:

$$S(\Delta g_{ic}) = \sum_{ev}(E^{ev}_{calibr} - \sum_{ic} E^{ev}_{ic}(1+\Delta g_{ic}))^2 \quad (1)$$

The first summation is performed over all selected events while the second one extends over all cells included in the electron's cluster. E^{ev}_{calibr} defines the energy scale of the event to which the calibration is performed, in our case it is equal to $E^{ev}_{DA} * E^{ev}_{ic}$ corresponds to the energy measured by the cell *ic* for the event *ev*. This energy includes all corrections done before the final calibration. Δg_{ic} is the correction to the amplification gain factor of the cell *ic* to be determined. E_{DA} denotes *energy double angle*. The definition of the E_{DA} is the following:

$$E_{DA} = \frac{E_e(1-y_{DA})}{sin^2\frac{\theta_e}{2}} \quad (2)$$

$$y_{DA} = \frac{tan\frac{\theta_h}{2}}{tan\frac{\theta_h}{2} + tan\frac{\theta_e}{2}} \quad (3)$$

In general minimization of the functional (1) requires to solve a system of 1192 equations with 1192 variables. In principle, it can be done since many of the non-diagonal elements in the correlation matrix are equal to 0.

Instead the following iterative procedure can be used here. For each event, the event pull is introduced:

$$\delta_{ev} = \frac{\sum_{ic} E^{ev}_{ic}(1+\Delta^{it} g_{ic})}{E^{ev}_{calibr}} = \frac{E^{ev}_{cluster}}{E^{ev}_{calibr}} \quad (4)$$

here *it* denotes the iteration number with $\Delta^1 g_{ic} = 0$ for the first iteration. The relative contribution of the cell j to the event pull is given by the fraction of energy deposited in it:

$$w^{ev}_j = \frac{E^{ev}_j(1+\Delta^{it} g_j)}{E^{ev}_{cluster}} \quad (5)$$

By construction the sum of the weights w^{ev}_j for any event is equal to 1. Finally, the weighted pull average over all events with removing of outliers can be calculated and the correction of all cell amplification gain factors can be expressed as follows:

$$\Delta^{it+1} g_j = \Delta^{it} g_j - (\overline{\delta_{ev} w^{ev}_j} - 1) \quad (6)$$

The iterative procedure is continued until $\max_j(\overline{\delta_{ev} w^{ev}_j}) < 0.002$. Normally, 3 - 4 iterations are needed.

3.2 Realization

The calibration according to the method described above has been done using H1OO [2] - [4] environment. H1OO Analysis Environment stores data in three-layer system. The lowest level (ODS) is produced from DST or POT, so content of the ODS is 1-to-1 equivalent to the DST. Two additional layers (μODS and HAT) contain calibrated and selected analysis-ready particle information (μODS) and event-level information (HAT). μODS ($\sim$ 2kB/evt) and HAT ($\sim$ 0.4 kB/evt) are much smaller in size than the ODS, allowing a substantially faster selection of the events.

To persistently store information that is not already on the official data layers, one can add a so-called "user tree" and fill it with information of his choice for a subsample of the events contained in the three official layers.

The first step of my work on calibration was creation of a UserTree, which containes some selected information about clusters, cells and tracks in detector. Then using method described at the begining of the section the Spacal calibration was performed.

Data used for Spacal calibration were carefully preselected in order to provide high efficiency of the method. Firstly, a cut $\theta_h < 80°$ was applied which selected events from the low $y < 0.15$, kinematic peak region. We demanded the energy of the cluster to be between 20 GeV and 32 GeV. The energy of the hottest cell should be above the 60% of the total cluster energy, this way we got rid the hadronic background.

Result of the Spacal double angle calibration is shown on Fig. 5. The graph shows how ratio $\langle\frac{ESpacal}{EDA}\rangle$ depends on Spacal radius. *ESpacal* denotes energy of Spacal cluster and *EDA* defines energy double angle. We expect the ratio $\langle\frac{ESpacal}{EDA}\rangle$ to be close to 1. Error of the ratio is defined as $\langle\frac{ESpacal}{EDA}\rangle/\sqrt{N}$, where N denotes number of contributions to the bin.

As one can see on the plot the ratio $\langle\frac{ESpacal}{EDA}\rangle$ is really centered around 1. Some fluctuations of the ratio are due to the very limited statistics. Production of UserTree takes a lot of time so only about 1200 very carefully selected events (from 2.5 mln in UserTree) were used for the calibration. A larger statistic should limit errors and eliminate fluctuations.

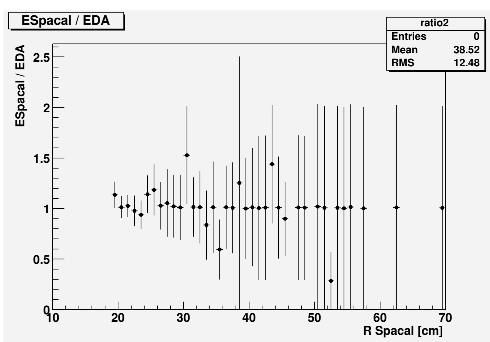

Fig. 5: *ESpacal / EDA.*

Acknowledgments

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References

[1] A. A. Glazov, *Measurement of the Proton Structure Functions* $F_2(x, Q^2)$ *and* $F_L(x, Q^2)$ *with the H1 Detector at HERA*

[2] The H1OO Group, *The H1OO Physics Analysis Project*

[3] The OO Project Team, *Introduction to the H1OO Analysis Environment*

[4] *ROOT - An Object-Oriented Data Analysis Framework, Users Guide 3.05*