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.

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 $Q^2 \leq 120\text{GeV}^2$. The scattered electron is identified 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.
Spacial alignment

### Tab. 1: Backward tracking chamber.

<table>
<thead>
<tr>
<th></th>
<th>BDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial coverage</td>
<td>6.5 - 70.5 cm</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>Average reconstructed track multiplicity in 5 cm distance around the calorimeter cluster</td>
<td>11.5</td>
</tr>
</tbody>
</table>

**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 $\theta$ resolution. The double layers are rotated by $11.25^\circ$ to obtain some measurement of $\phi$. Each signal wire is contained in a separate cathode cell.

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

**Spacial calorimeter**

The Spacial calorimeter comprises the electromagnetic and hadronic sections and the backward plug. The electromagnetic part of the Spacial 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 Spacial corresponds to 27.47 radiation lengths and 1 hadronic interaction length. The angular coverage of the calorimeter is $153^\circ < \theta < 177.8^\circ$.

The hadronic part of the Spacial 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.

### 2 Spacial 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 Spacial. We demand the total energy of those two particles to be above 25 GeV and the difference between their azimuthal angles to be close to 180°. This way we get events with electron and photon moving in opposite 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 Spacial before alignment and on Fig. 4 aligned Spacial is shown. Correction factors are the following: $\Delta x = 0.095 cm$ and $\Delta y = 0.42 cm$. 

![Transverse view of Spacial. Small boxes indicate individual cells.](image)

### Tab. 2: Backward calorimeter.

<table>
<thead>
<tr>
<th></th>
<th>Spacial EM</th>
<th>Spacial HAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial coverage</td>
<td>5.7 - 80 cm</td>
<td>29.4$X_0$, 1$\lambda$</td>
</tr>
<tr>
<td>Sensitive length</td>
<td>$27.5X_0$, 1$\lambda$</td>
<td>2.45 cm</td>
</tr>
<tr>
<td>Moliere-radius</td>
<td>2.55 cm</td>
<td>2.45 cm</td>
</tr>
<tr>
<td>Energy resolution at 27.5 GeV</td>
<td>3.0%</td>
<td></td>
</tr>
<tr>
<td>Energy resolution at 2 GeV</td>
<td>5.6%</td>
<td>12 × 12cm²</td>
</tr>
<tr>
<td>Cell size</td>
<td>4.05 × 4.05</td>
<td></td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>3.4mm</td>
<td></td>
</tr>
</tbody>
</table>
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:

\[ S(\Delta g_{ic}) = \sum_{ev} (E_{ic}^{\text{ev}} - \sum_{ic} E_{ic}^{\text{ev}} (1 + \Delta g_{ic}))^2 \]  (1)

The first summation is performed over all selected events while the second one extends over all cells included in the electron’s cluster. \( E_{ic}^{\text{ev}} \) defines the energy scale of the event to which the calibration is performed, in our case it is equal to \( E_{DA}^{\text{ev}} \). \( E_{ic}^{\text{calibr}} \) corresponds to the energy measured by the cell \( ic \) for the event \( ev \). This energy includes all corrections done before the final calibration. \( \Delta g_{ic} \) 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:

\[ E_{DA} = \frac{E_{\nu} (1 - y_{DA})}{\sin^2 \frac{\theta_{DA}}{2}} \]  (2)

\[ y_{DA} = \frac{\tan \frac{\theta_{DA}}{2}}{\tan \frac{\theta_{DA}}{2} + \tan \frac{\theta_{H}}{2}} \]  (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:

\[ \delta_{ic}^{ev} = \sum_{ic} E_{ic}^{\text{calibr}} (1 + \Delta g_{ic}^{it}) - E_{ic}^{\text{calibr}} = E_{ic}^{\text{cluster}}(1 + \Delta g_{ic}^{it}) \]  (4)

Here \( it \) denotes the iteration number with \( \Delta g_{ic}^{it} = 0 \) 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:

\[ w_{ic}^{ev} = \frac{E_{ic}^{\text{ev}} (1 + \Delta g_{ic}^{it})}{E_{ic}^{\text{cluster}}(1 + \Delta g_{ic}^{it})} \]  (5)

By construction the sum of the weights \( w_{ic}^{ev} \) 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:

\[ \Delta g_{ic}^{it+1} = \Delta g_{ic}^{it} - (\delta_{ic}^{ev} w_{ic}^{ev}) - 1 \]  (6)

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

3.2 Realization

The calibration according to the method described above has been done using H100 [2] - [4] environment. H100 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 (\( \mu \)ODS and HAT) contain calibrated and selected analysis-ready particle information (\( \mu \)ODS) and event-level information (HAT). \( \mu \)ODS (\( \sim 2 \text{~kB/evt} \)) and HAT (\( \sim 0.4 \text{~kB/evt} \)) 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 contains 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 $\theta_h < 80^\circ$ 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 $\frac{ESpacal}{EDA}$ depends on Spacal radius. $ESpacal$ denotes energy of Spacal cluster and $EDA$ defines energy double angle. We expect the ratio $\frac{ESpacal}{EDA}$ to be close to 1. Error of the ratio is defined as $\frac{ESpacal}{EDA}/\sqrt{N}$, where $N$ denotes number of contributions to the bin.

As one can see on the plot the ratio $\frac{ESpacal}{EDA}$ 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.](image)

**Acknowledgments**

I want to thank all the people in DESY Zeuthen for support during Summer Student Program. I’d like to express a special gratitude to my supervisor Ewelina Lobodzinska for her valuable help and instructions.

**References**

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


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