# HERMES Summer Student Programme report
# Beam position analysis in target cell

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# 1 The HERMES detector

HERMES stands for **HERA** **ME**asurement of **S**pin and it is one of the main experiments at HERA, the big e-p collider at DESY. It analyzes the spin structure of the nucleon, i.e. measuring structure functions, for example the spin-dependent structure functions ($g_1^n$, $g_1^p$) of the proton and neutron.
The main physical process of the experiment is deep inelastic scattering (DIS, figure 1) of beam electrons($e^-$) or positrons ($e^+$) on polarized ($\vec{\mathrm{H}}$, $\vec{\mathrm{D}}$, $\vec{\mathrm{He}}$) or unploarized ($H_2$, $D_2$, $^3He$, $N_2$) targets in the 40cm long and 2.9cm wide target cell.

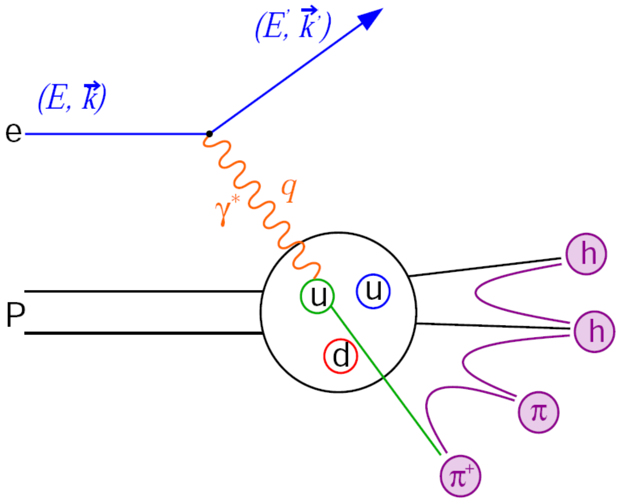



Figure 1: Deep Inelastic Scattering Process

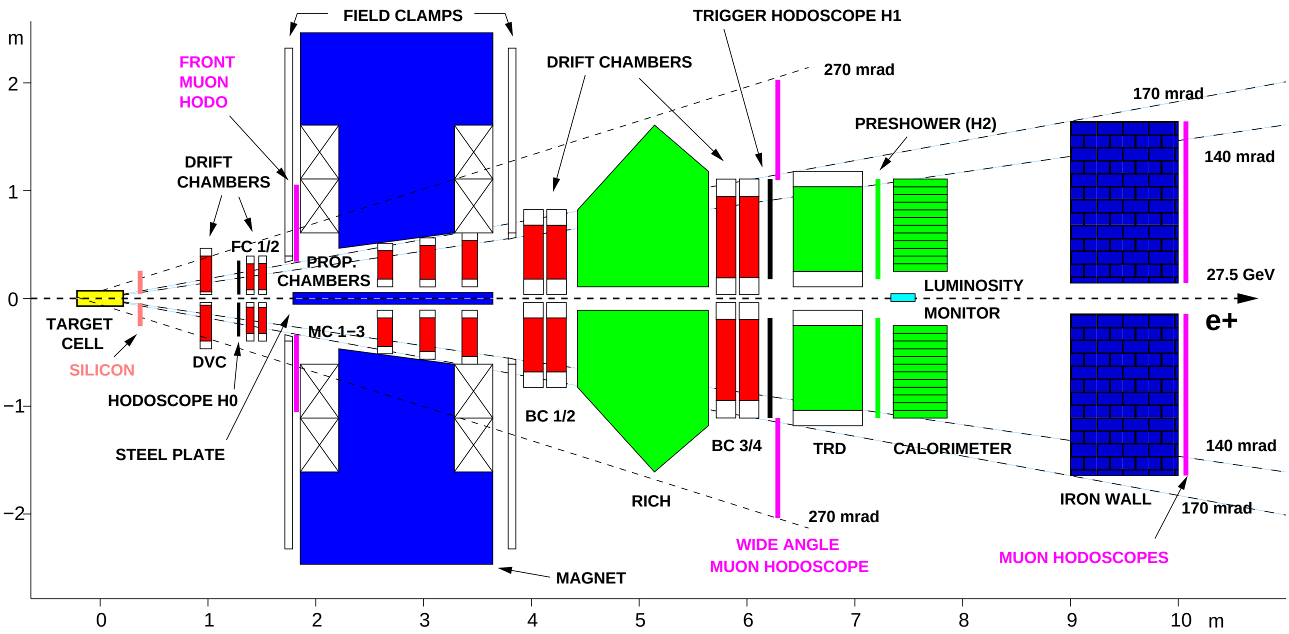



Figure 2: The HERMES detector

The most important kinematic variables are (M is the mass of the nucleon):

| | | |
|---|---|---|
| $Q^2 =$ | $-q^2 = -(\vec{k} - \vec{k'})^2$ | squared four-momentum transfer |
| $\nu =$ | $E - E'$ | total energy transfer (in the labaratory system) |
| $x =$ | $\frac{Q^2}{2M\nu}$ | fraction of nucleons momentum carried by struck quark |
| $z =$ | $\frac{E_{hadron}}{\nu}$ | Hadronic energy compared to total energy transfer |

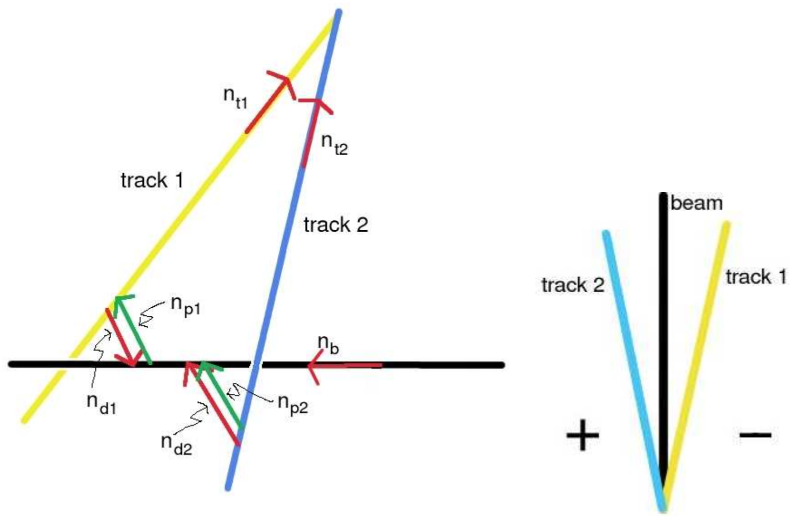
Figure 2 shows a schematic overview of the HERMES detector. The scattered and new produced particles leave hits in the tracking chambers. The hits can be used for a track reconstruction program. After that the tracks are stored in so-called $\mu$dst-files. This files contain all relevant physical information for further analysis.

# 2 Distance between track and z-axis

One can look at the minimal distance (*closest approch*) between the z-axis and the reconstructed track. Using a special definition of distance one can analyze the beam position.

## 2.1 Definition of Distance

In figure 3a the z-axis and two tracks are plotted. They are represented by the (normalized to a unit length) directions $\vec{n_b}$ (z-axis), $\vec{n_{t1}}$ (track 1)and $\vec{n_{t2}}$ (track 2). When calculating the classical scalar distance between any two lines in the three-dimensional space, the distance vector between these two lines is perpendicular to both of them. The distance vector between the z-axis and a track points to the z-axis, by definition.




(a) Geometrical situation (b) Sign of Distance

Figure 3: The distance between the symmetry axis of the experiment z-axis) and a track can be positive or negative, depending on the (anti-)parallel of distance vectors $\vec{d_1}$, $\vec{d_2}$ and the vectors $\vec{p_1}$, $\vec{p_2}$.

The main difference between the two tracks is, that track 1 is located behind the z-axis, but track 2 is located in front of the z-axis, for the chosen view in figure 3a. But we can also calculate another vector which is perpendicular both to the track and the z-axis. We can determine the vector by calculating the cross product of track- and z-axis-vector:

$$\frac{\vec{n_b} \times \vec{n_{t1}}}{|\vec{n_b} \times \vec{n_{t1}}|} = \vec{n_{p1}}$$

$$\frac{\vec{n_b} \times \vec{n_{t2}}}{|\vec{n_b} \times \vec{n_{t2}}|} = \vec{n_{p2}}$$

Deviding by the length again gives unitary vectors $\vec{n_{p1}}$ and $\vec{n_{p2}}$. For track 1 $\vec{n_{p1}}$ and $\vec{n_{d1}}$ are antiparallel, for track 2 $\vec{n_{p2}}$ and $\vec{n_{d2}}$ are parallel. Because the vectors are normalized to one, the scalar product gives:

$$\vec{n_{p1}} \cdot \vec{n_{d1}} = -1$$

$$\vec{n_{p2}} \cdot \vec{n_{d2}} = +1$$

Now the positiv scalar distance can be multplied by these sign-factors, and the distance becomes positive or negative, depending, where the track is located compared to the z-axis. This fact is illustrated in figure 3b.
An additional but important remark: The scalar distance would be unchanged under a $\phi$-rotation of $\pi$ but the sign is changing (*Antisymmetry*).

## 2.2 Distribution of Distances

Analysing the data from *g1Track table* and *smTrack table* from the $\mu$dst-files, one finds a distribution of the distance when analysing a big enough amount of data (Figure 4).

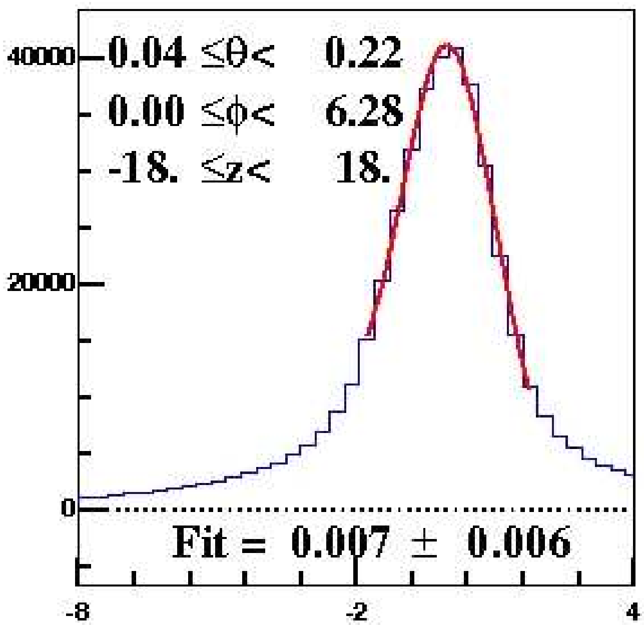



Figure 4: Distribution of Distance for the HERMES production 97d1

In this example Data from the year 1997 is plotted, or, more precisely, data from the production 97d1. The distance is given in millimeters. The distribution fits a gaussian, because also the distribution of the beam density is gaussian. A fit around the peak is quite easy to manage. Four different fiting parameters were used ($a_1$, $a_2$, $a_3$, $a_4$) to approximate the distribution $f(d)$:

$$f(d) \approx a_1 e^{-\frac{(d-a_2)^2}{2a_3}} + a_4$$

$a_1$ gives us the height, $a_2$ the position of the maximum value and $a_3$ the width of the distribution. The constant term ($a_4$) comes from the background and is quite easy to handle around the peak but not so easy to handle far away from the peak. But, anyway, to find the mean value of the gaussian-like distribution, only a fitting around zero is necessary. The mean value then represents the position of the beam in the target cell.

For this example the fitted mean value is almost zero which should not be a surprise but it is not obvious, as we will see in a moment. In this plot the whole kinematic range ($0 < \phi < 2\pi$, $0.04 < \theta < 0.22$, $-18cm < z < 18cm$) of all leptons was put in.

# 3 Dependencies

Now one can look at different cuts on the position variables, for example.

## 3.1 Dependence on the Azimuthal Angle $\phi$

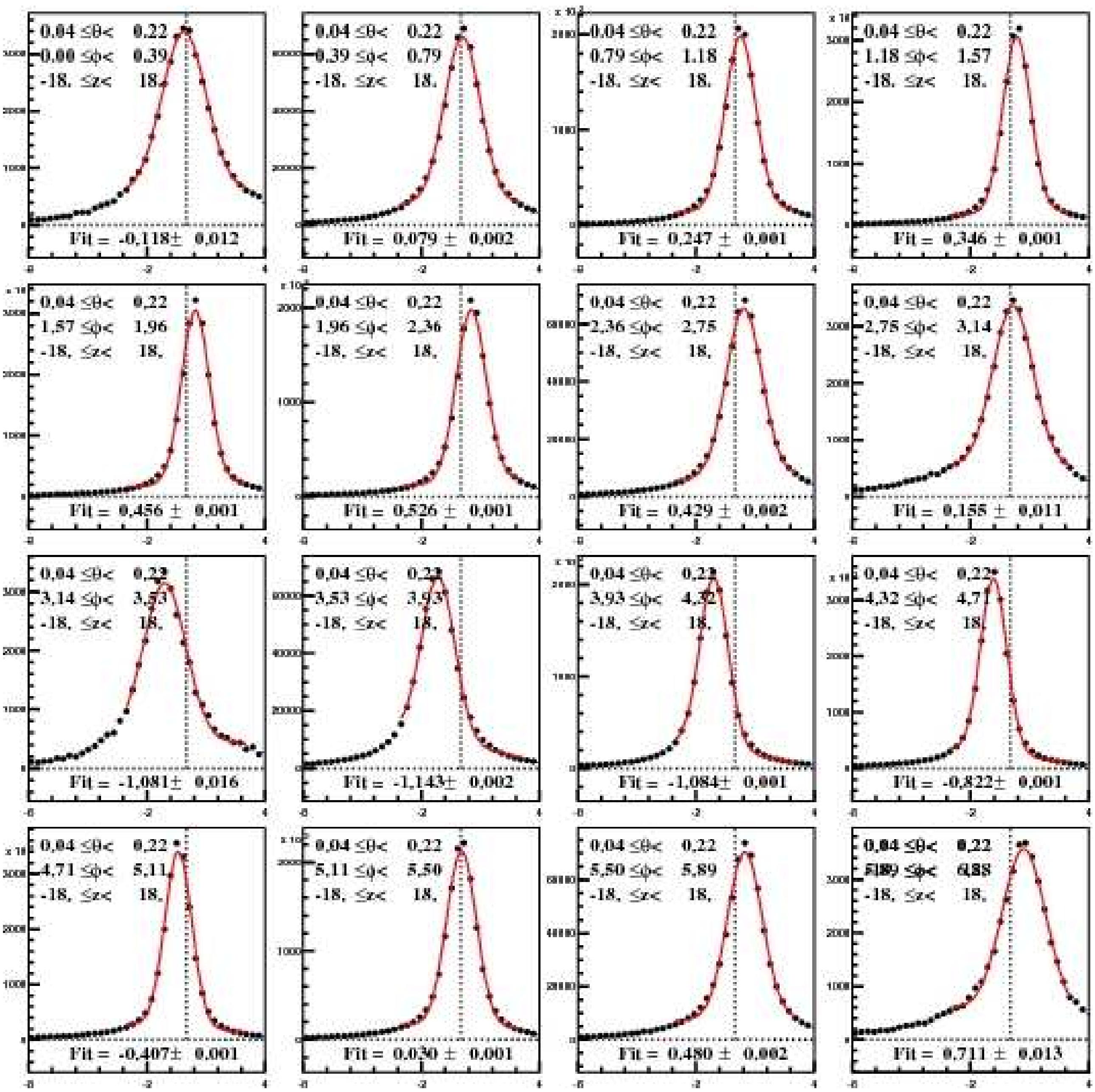
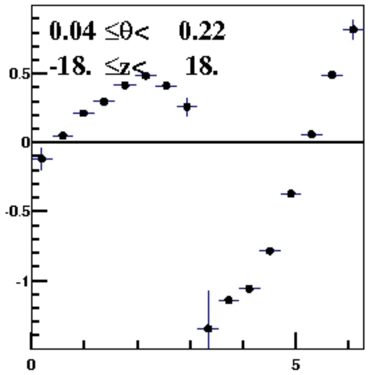
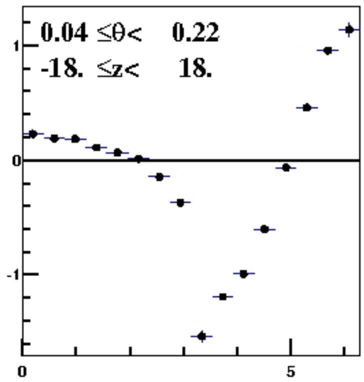



Figure 5: $\phi$-dependence of the distance distribution

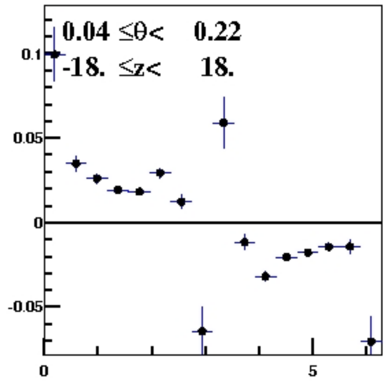
Now we make a cut in the $\phi$-direction and devide the range into 16 bins, 8 for the top $(0-\pi)$ and 8 for the bottom $(\pi - 2\pi)$ side of the detector (figure 5). Now the mean value of the fit is not around zero any more. In the first plot one can see that the average distance is $-0.118$ mm, in the next one the distance becomes positive, in the next one even more positive and the mean fitted distance reaches the maximum in the 6th plot ($d = 0.526mm$). Then it becomes smaller, and so on.




(a) Mean distance vs. $\phi$ for the production 97d1




(b) Mean distance vs. $\phi$ after a repositioning of the beam




(c) Mean distance vs. $\phi$ for MC data

Figure 6: $\phi$-dependence of distance; the mean values of the fits are plotted.

Plotting only the mean values of the fits of the distance in one diagram (figure 6a), one can see a rise and fall of this mean value of distance depending on $\phi$. We can see quite a big gap between top and bottom detector, and the antisymmetry mentioned above, is violated.

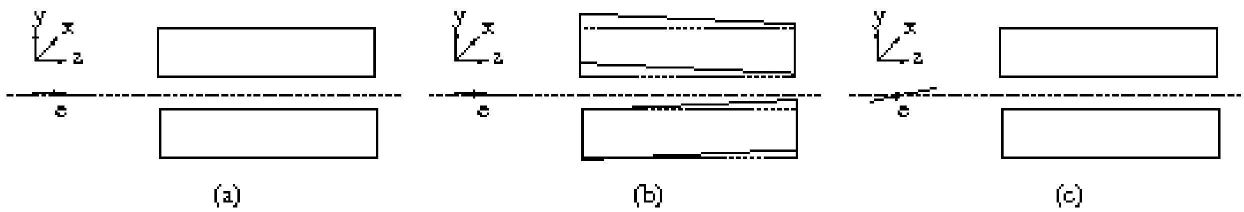



Figure 7: Misalignment, (a) situation without misalignment, (b) misalignment of the detector, (c) misalignment of the beam (slope)

### 3.2 Effects on the $\phi$-Dependence

Now we should find some explanations for the graph (figure 6a) which was discussed before.

#### 3.2.1 Beam position

If the beam would be exactly in the z-axis, the average distance should be zero. The reason, why it is nonzero, is that the beam position is not along the symmetry axis but shifted in the transversal direction. The $\phi$-value where the distance is zero represents the direction of the beam in the transversal plane and the $\phi$-value where the distance reaches it's maximum gives the scalar deviation from the z-axis:

| d [mm] | $\phi$ [rad] | meaning |
|---|---|---|
| 0 | $\phi_0$ | direction of deviation |
| $\approx 0.5$ | $\phi_1 = \phi_0 + \pi$ | radius of deviation |

#### 3.2.2 Misalignment

One possible explanation why the gap in the mean distance in figure 6a between top and bottom of the detector is so big is that the two parts of the detector are misalignend.
This means that the two parts are not arranged symmetrically around the symmetry axis but shifted (figure 7). So the distance is not *antisymmetrical*.

#### 3.2.3 Tracking

And maybe the tracking itself causes problems and the reconstructed tracks show differences for top and bottom detector.

### 3.3 Dependence on the Longitudinal Positioin in the Target Cell

Another possible dependence is the position in the target cell, $z$. Now we again divide the $\phi$-range into 16 parts but now the mean distances are plotted as a function of z (figure 8).
For some $\phi$-regions we can see a clear raise or fall of the mean distance. In the second picture, for example, the distance is approximatly 0.7 mm for $z = -18$ cm, but only 0.4 mm for $z = +18$ cm. For some other plots it is the other way around.
In principle we can say: We can see a *slope* of the beam because of the z-dependence, but it is not very big. The maximal slope is 0.3 mm for a $z$-range of 36 cm.

### 3.4 Other possible Dependencies

One can also look on other dependencies like the momentum vector $\vec{p}$ which depends not only on $\phi$ but also on $\theta$:

$$\vec{p} = \begin{pmatrix} p \sin\theta \cos\phi \\ p \sin\theta \sin\phi \\ p \cos\theta \end{pmatrix}$$

Or maybe also the charge of the particle can play a role, maybe because of effects on the beam caused by the magnet.
And maybe there are differences between hadrons and leptons too.

## 4 Beam Position Manipulation

After astimating the beam position for the top part of the detector one can take that into account and modify the symmetry axis for the experiment in the code which analyzes the distance. After that we can look again on the disance distribution and the mean distance values. Doing this for the 97d1 production mean distances like in figure 6b can be found.
For the top part the distances become smaller but nonzero because of the other effects mentioned above and because the new beam position was calculated with a very roughly estimation. Nevertheless the concept of beam position manipulation seems to be a adequate concept.

# 5 Monte Carlo Simulations

## 5.1 Dependence on the Azimuthal Angle $\phi$

After analyzing real data one can also look at Monte Carlo (MC) simulated data.
It is very interesting to look at MC data because it is simulated with a beam exactly in the z-direction. So we should expect a mean distance distribution around zero, independent of $\phi$ and $z$. Nevertheless the distance is not exactly zero (figure 6c) but one magnitude of order less than the real data distances. The reason for the non-zero distances is the fact that also in the MC simulations some of the effects mentioned above occur (misalignment, tracking).

## 5.2 Dependence on the Longitudinal Positioin in the Target Cell

For MC data no slope like for real data can be found, because the beam was simulated without slope and it would have been a big surprise if there would be on.

# References


[1] K. Ackerstaff et al., *The HERMES Spectrometer*, hep-ex/9806008 (1998)

[2] R. Devenish, *Deep Inelastic Scattering*, Oxford University Press (2003)

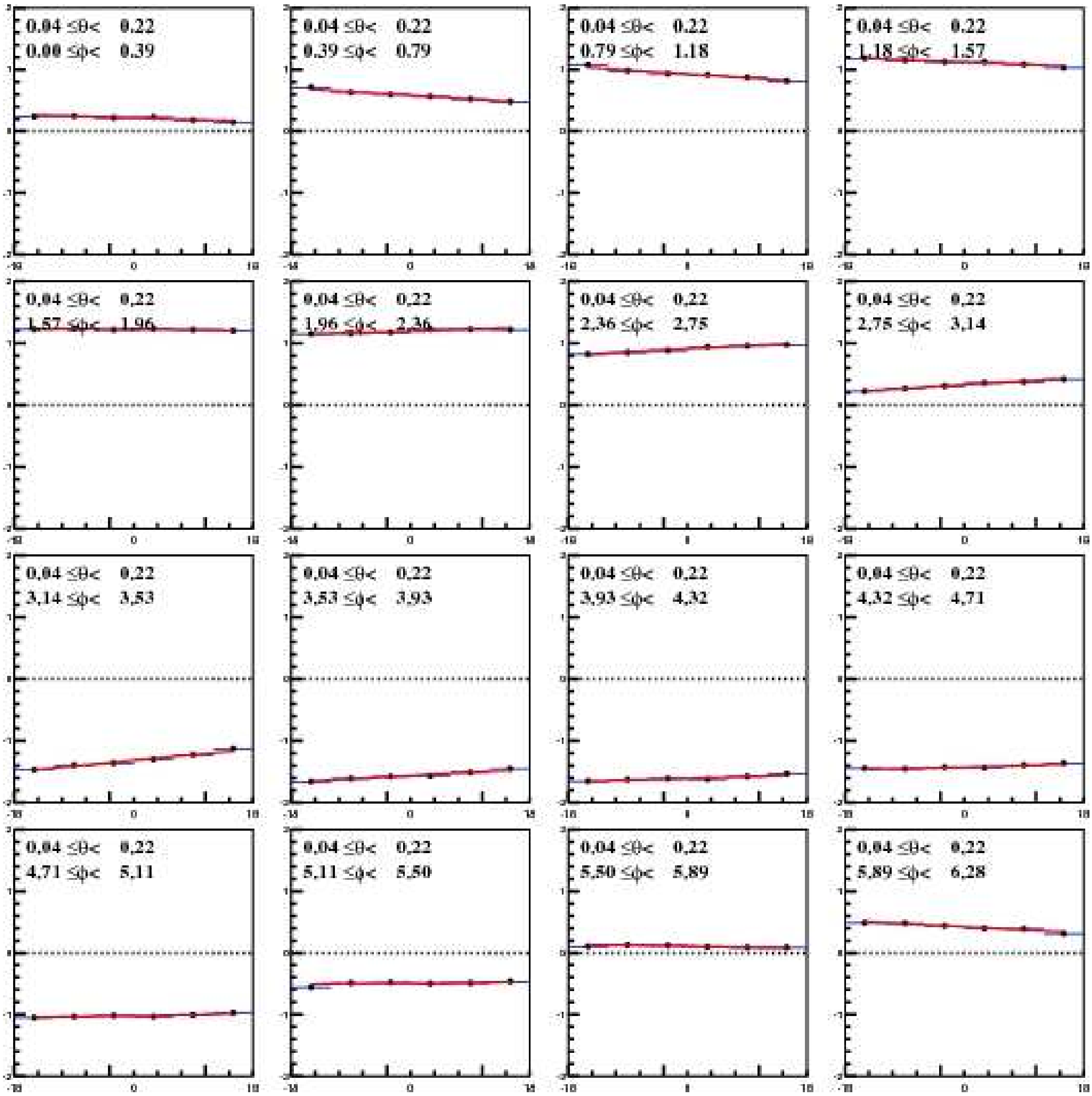



Figure 8: z-Dependence of the distance for the production 00d0