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Correction of Wire Positions in Nose Cone Prototype

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INTRODUCTION

In this short note the experience of the first attempt to correct the positions of the wires in the Nose Cone Prototype (NCP) of the CLAS Drift Chamber (DC) is described. The NCP data were used to test the Drift chamber Reconstruction software (DR package), which is planned to be used for the Cosmic Muon Calibration of DC.

The DR package adopts the strategy of the SDA Reconstruction Package [1] in the first stages of the reconstruction, but uses different algorithms. The reconstruction starts with the segment extraction routine (DRSEGM). Let us start with definitions in the routine. If a charged particle crosses a superlayer of DC (6 superlayers for each of 6 sectors; 2-nd, 3-d, and 5-th are axial and 1-st, 4-th, and 6-th are stereo), then the hits along the track are combined in SEGMENTS (SDA notation). Each superlayer consists of layers (first superlayer has 4 layers, other have 6 layers). If the the track is not perpendicular to the layer then there can be more than one hit in the same layer. In this case the hits of one layer are combined in CLUSTERS. So the SEGMENTS consist of CLUSTERS. If segments overlap with each other in such a way that the same cluster can be considered to be a member of different segments, then overlapping segments are combined in SUPERCLUSTERS of segments. As a result: HITS are combined in CLUSTERS in one layer (i-1, i, i+1 is one cluster; i-2, i-1, i+1, i+2 - two clusters because of the break in i-th position); CLUSTERS are combined in SEGMENTS in one superlayer, corresponding to the segment of the track crossing the superlayer; overlapping SEGMENTS create SUPERCLUSTERS of segments (there can be fake SEGMENTS initiated by δ-electrons and by noise).

To define segments, the DRSEGM subroutine uses an Artificial Neural Network (ANN) method, which can be defined like a Chain Perceptron Method. This linear algorithm is fast and does not demand a learning period. The idea of the algorithm is to consider a segment as a straight line segment. Creating a bank of hit projections along the lines with different slopes, it is possible to find narrow spikes which define different segments. But one real line segment can create spikes for different slopes. For the same hit-set the DRSEGM algorithm defines the most narrow spike and suppresses the reflections of the same line segment in different slopes. After the segments are defined they are combined in SUPERCLUSTERS for possible compatability with SDA.

The differences with SDA should be spelled out to avoid misunderstanding:

(*i*) what is defined in DR as a SUPERCLUSTER is called a CLUSTER in SDA;

(*ii*) the CLUSTER (DR definition) position in the layer is twice as accurate as in SDA, where it is defined by wire number (cluster center can be between wires);

(*iii*) the DRSEGM subroutine provides a center of segment position and a straight line approximation in addition to the pattern recognition information.

The second subroutine of the DR reconstruction is the DRLINK subroutine, which links segments to form a full track. This subroutine is supposed to be used only for Cosmic Muon Calibration and will not be discussed in this paper. The only feature of the algorithm which should be mentioned is the lack of predefined templates, which are characteristic of the SDA algorithm. It uses the nonlinear (circles instead of lines) ANN algorithm to link appropriate segments in one track.

For the NCP data only the software dealing with one superlayer was used. The main purpose of the DR software application was to test the segment reconstruction and straight line fitting algorithm for real noise conditions and physics backgrounds for Cosmic Muons. NCP data were found to be very useful for the algorithm improvement and can be used for the further improvement (in particular for the three-dimensional reconstruction of the track in one DC Region). The application was so successful that the algorithm was applied to the calibration of the NCP.

Time-to-distance transformation.

The transformation of TDC values to Distances of Close Approach (DCA) is the responsibility of the DC group. The transformation depends not only on the slope of the track, but on the position along the wire (spread time along the wire) and the magnetic field. Experimentally this dependence was investigated in [2] and it was independently simulated in more detail, for different magnetic fields using the GARFIELD program [3]. In this paper we will consider only TDC (it will be referenced like t) to DCA (it will be referenced like d) transformation for zero magnetic field.

As a first approximation the TIME-TO-DISTANCE subroutine provided by DC group was used. A typical event is shown in Fig.1. Straight lines on the figure present the approximation of hits in two different superlayers (prototypes of the superlayer 5 (bottom) and superlayer 6 (top)). In superlayer 6 one can see two background hits, which were originally included in segment, but later were excluded by subroutine DRPURE. The subroutine DRPURE tries to find the best line fit to the existing hits. The strategy of the subroutine is to use a first guess for the track on the basis of the wire-fit (not taking into account the TDC values). After that the distribution of the $d_f - d(t)$ residuals (where d_f is a value obtained as a result of the fit and $d(t)$ is a result of the t-to-d transformation) for all hits in the segment is investigated and the hit with the biggest absolute value of this difference is considered to be noise. After the new fit (without the assumed noise hit) is found, the new distribution of the residuals $d_f - d(t)$ is calculated. If it is narrower than the previous one then the noise status is considered to be valid and the procedure of noise reduction is repeated. In case of the event shown in Fig.1 the noise reduction algorithm was successful twice and two hits were rejected. The reconstructed track segments are quite parallel and shifted (shift is defined by stereo angle). The angle between the two superlayers was the only cut to link track segments in one track in third Region (Region 3 consists of superlayer 5 and superlayer 6) and use it for the calibration.

After the quality of the approximation was tested by the angle-between-lines cut ($\theta \leq 2^o$), the distance from the wire to the line was considered to be the true distance (d_f), and the hits (after noise reduction) were plotted on a $d-t$ plot. Ten plots were used for the calibration. Superlayers 5 and 6 have different average cell radii: r_5=2.074 cm and r_6= 2.235 cm. So the hits for superlayers 5 and 6 were plotted separately. For each superlayer, 5 angular ranges were used:

(0) $\pm 6^o$
(9) from 6^o to 12^o
(15) from 12^o to 18^o
(21) from 18^o to 24^o
(30) from 24^o to 36^o

The plots (in fact two-dimensional histograms for 0 and 30 degrees only) are shown in Fig.2. The events are evenly spread over all 10 plots (4 of which are shown). About 20 000 events were used to make these plots. The two-dimensional histograms were sliced into one dimensional histograms for different t values with a step of 10 ns. Each one-dimensional histogram was fitted by a Gaussian curve to suppress the tails of the background contribution. The centroid of the distribution was defined with the error proportional to the σ of the distribution and inversely proportional to the square root of the statistics. The same inversely proportional dependence is characteristic of the error in σ itself. After that the $d = d(t) \pm \Delta d(t)$ dependence was fit by different functions. The statistics in each one-dimensional distribution is about 400 entries, so the $\Delta d(t)$ value is roughly 20 times smaller then the σ. It means that the reduced χ^2 ($\chi^2_{red} = \chi^2/n_{df}$), where n_{df} is a number of degrees of freedom) should be much smaller than 400. Many different simple approximations were tested and the best one was found to be

$$d = A_1 + t \cdot A_2 + t^2 \cdot A_3 + t^3 \cdot (A_4 + A_5 \cdot slope), \quad (1)$$

where $slope = \frac{dx}{dy}$. For small cell size differences the relation was found to be independent of the cell size. The parameters A_3, A_4, and A_5 are expected to be

t_{max} dependent (similar to the DC group functional dependence [4]). We will come back to the resolution approximation in the next section, where the wire position correction will be discussed.

In this section it should be stressed out that the polynomial fit is good for the $d = d(t)$ fit and bad for the $t = t(d)$ fit. The reason is that the derivative of any polynomial function tends to infinity at infinite x. The same behavior can be seen for the $d = d(t)$ function, while the limit for the derivative of the t=t(d) function tends to be zero.

Wire position correction.

From Fig.1 it is clear that one can use the fit to try to correct the wire position, analyzing the residuals distributions for the fit. E.g. to improve the fit of one can always shift wire position slightly to the right or to the left. Since tracks are mostly vertical, it is possible to correct only x-coordinates. The examples of the residual distributions for different wires are shown in Fig.3. One can see that the distributions are very different: sometimes they are wide, sometimes relatively narrow, and sometimes asymmetric. In all cases the mean value of the shift was used. The difference in the shape can be a consequence of the different distribution of track angles incident upon different wires. A feature of the NCP trigger is the almost 30^o flux of muons. This kind of asymmetric trigger was used to obtain good statistics at 30^o. As far as in addition tracks were demanded in both superlayers, the test conditions for all wires were different.

The correction procedure was iterative. On each step these wires with an absolute value of the shift of more then 100 μm were corrected. The mean shifts of wires are shown in Fig.4. Before the correction it was found that three wires had really big shifts (more then 200 μm, the values are written on the right side of the figure). The rest of the wires were shifted in negative direction. After a few iterations it was found that the axial wires more or less converged , but stereo wires demanded negative correction on each iteration. So the procedure was stopped. It is not clear why stereo wires do not converge, but perhaps the reason is the asymmetry of the muon flux.

The resolution of the chamber, approximated by a third power polynomial is shown in Fig.5. The four curves correspond to the four approximations. The two dimensional plots were approximated before and after by the DC group function and by 5-parameter polynomial function before and after correction. One can see that there is no big influence of the correction on the mean resolution.

The conclusion is that the method is adequate for big errors in geometry (more than 200 μm) and is not effective for small shifts, which can be a consequence of the systematics. In any case for the wire position correction an isotropic muon flow is preferable.

Simultaneous t-to-d and wire correction procedure.

After the wire position corrections did not converged with the DC group function, the procedure of the simultaneous t-to-d calibration and wire position correction has been used. It means that each time new parameters of the relation (1) were corrected together with the wire correction procedure. The final proposed corrections for the wires are shown in Fig.6. The top histogram shows the proposed corrections for the axial wires (it is converged), and the bottom histogram shows the proposed corrections for the stereo wires. It is still necessary to correct positions for stereo wires, but unfortunately there is some constant drift of all wires, that is why the process of correction was stopped at this point. The possible drift is a real problem for the final possible correction procedure. E.g. one can imagen a shift of all detector by 1 mm and nothing in reconstruction procedure will be wrong. There should be a method, which would exclude this degree of freedom. In particular one can find out the mean value of the shift over all wires and subtract it from each proposed correction.

I would like to thank Mac Mestayer for a fruitful discussion and smart advices and to Gerard Gilfoyl for a help in obtaining data from NCP.

References

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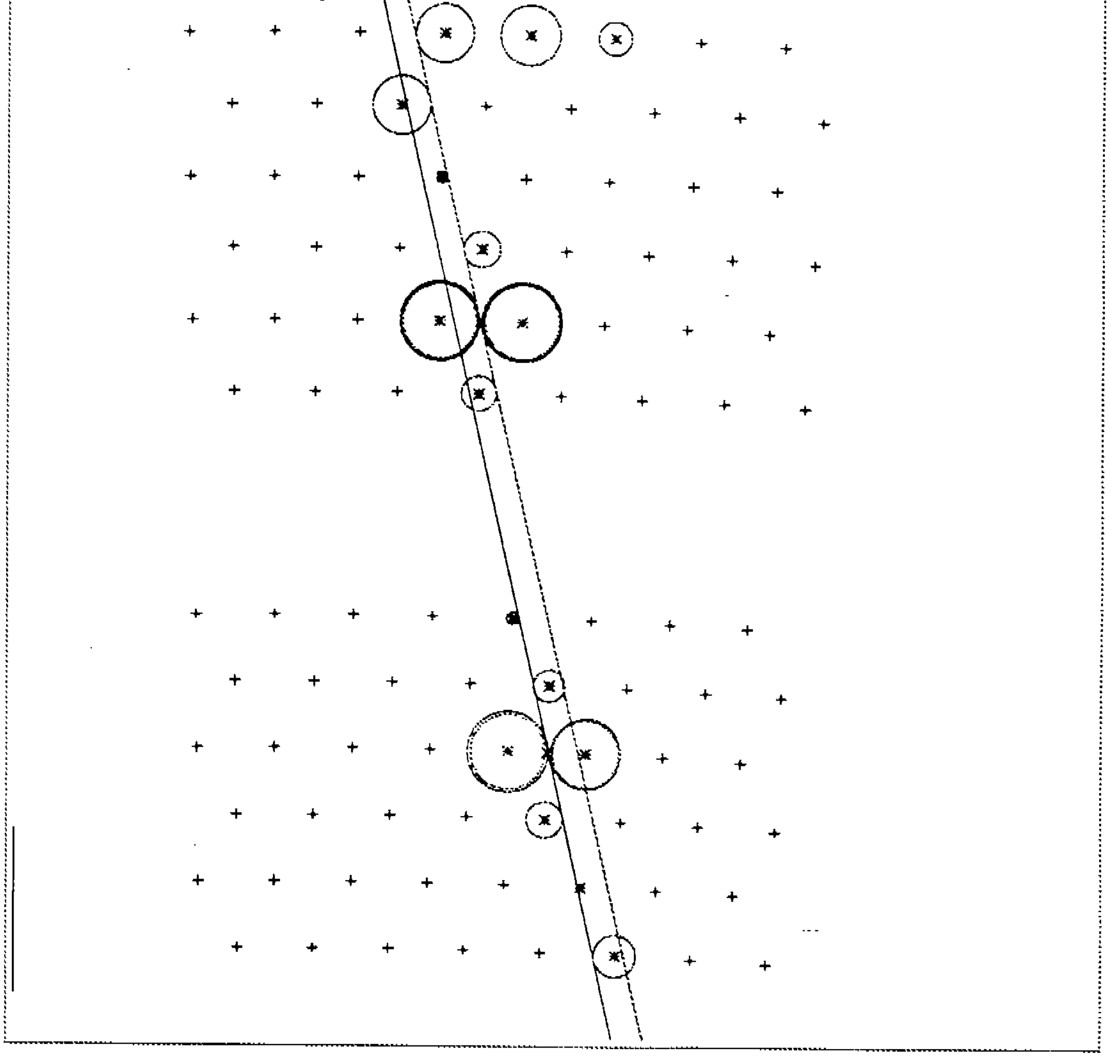
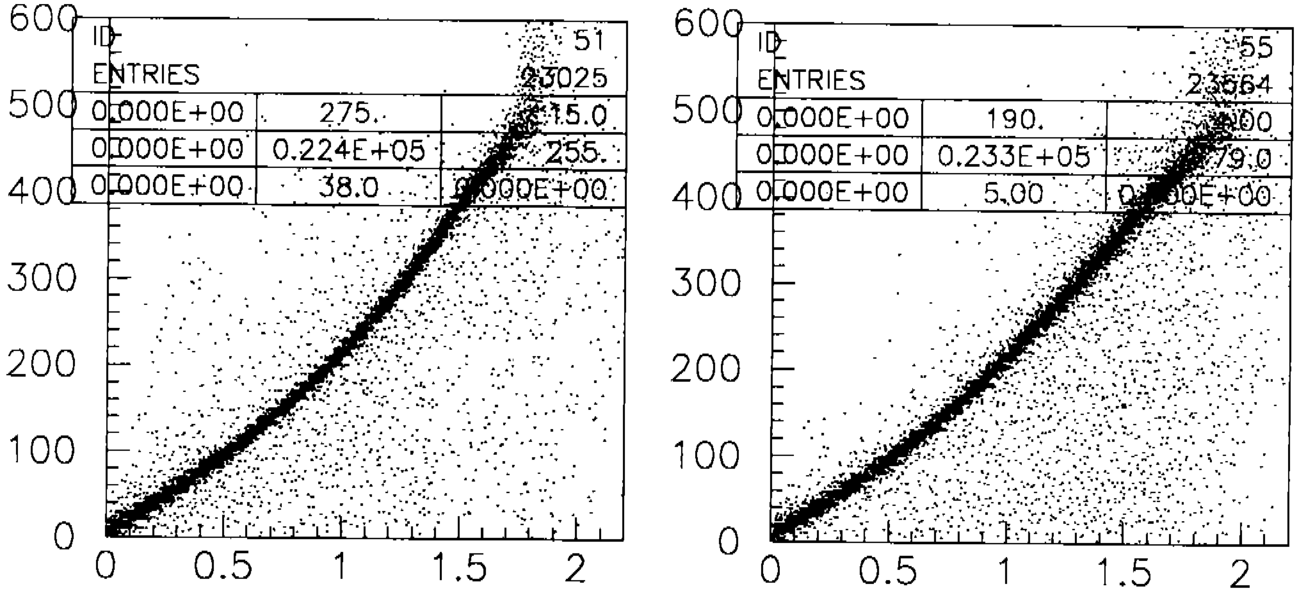


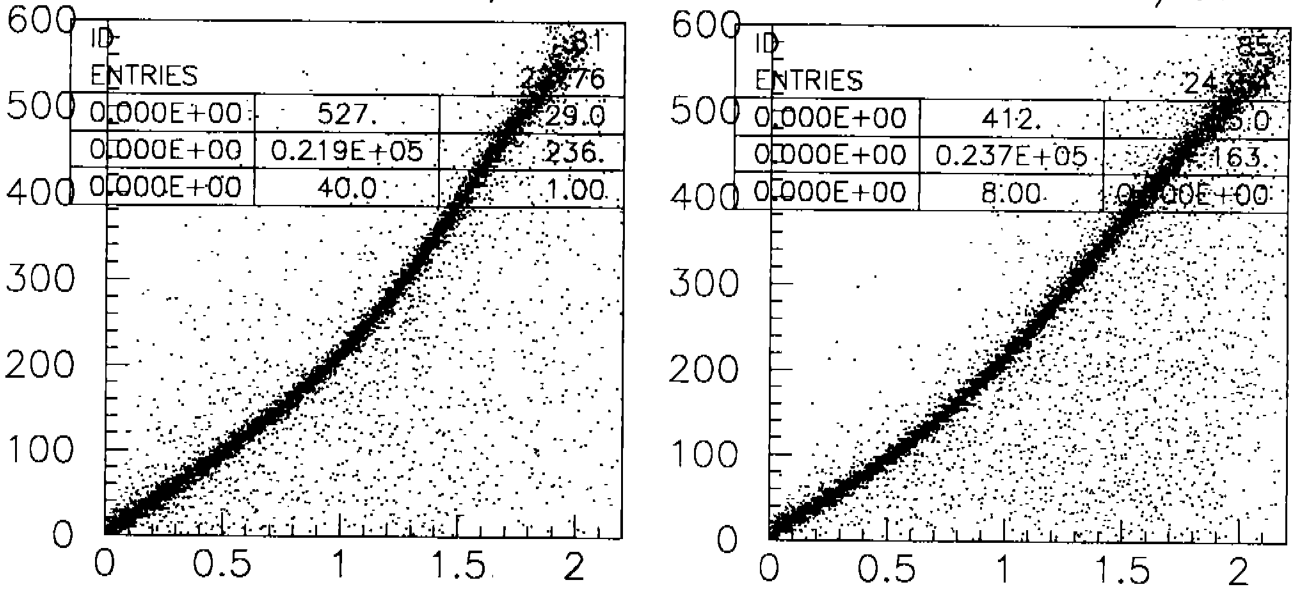
Fig.1. DR reconstruction in NCP

Fig.2. time–distsance plot for different angles and cell sizes
07 means r=2.07, 23 means r=2.23, d in cm, TDC in ns



Dr.t vs d.c.a 00/07

Dr.t vs d.c.a 30/07



Dr.t vs d.c.a 00/23

Dr.t vs d.c.a 30/23

Fig.3. Shift distributions for different wires

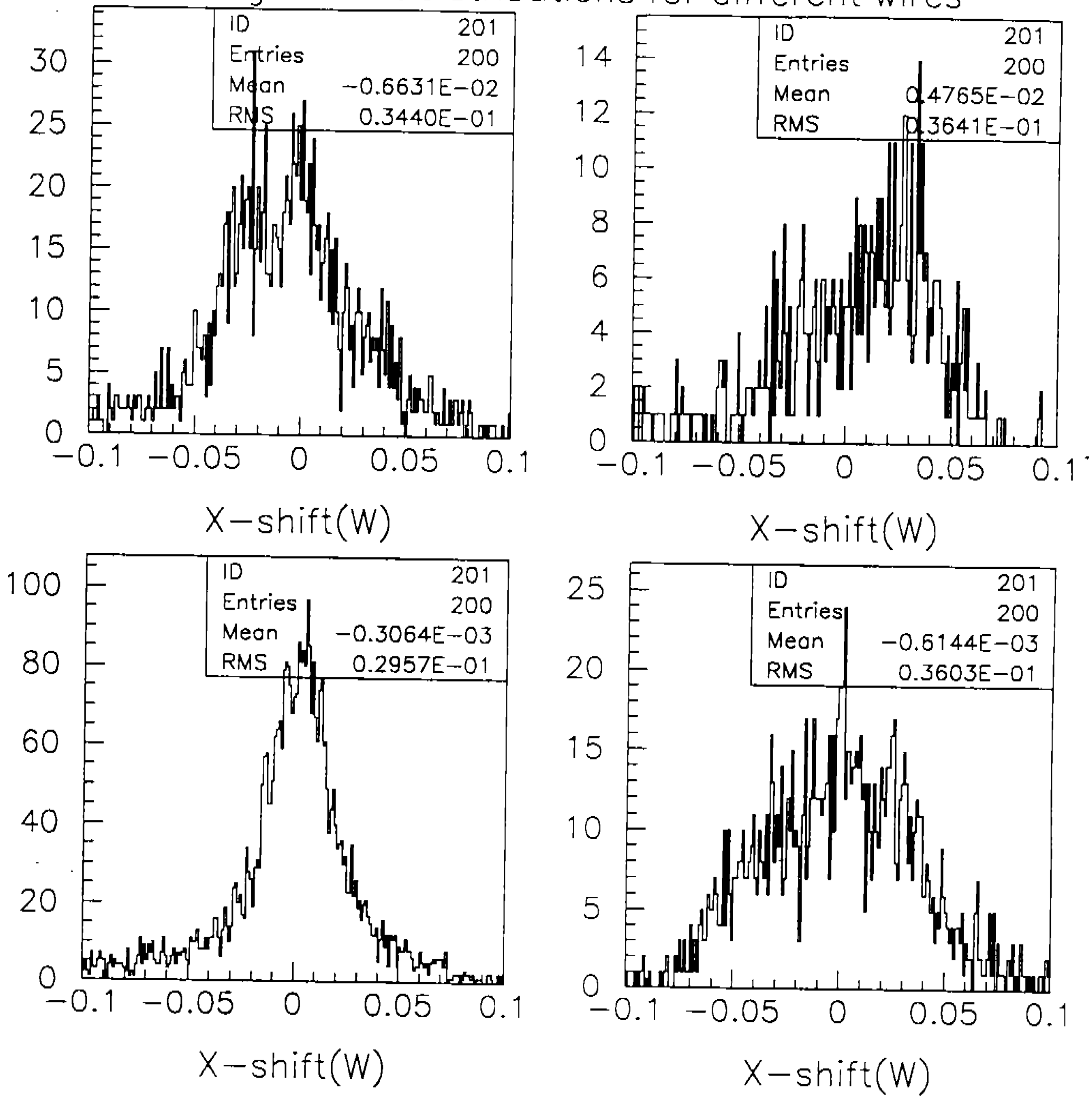


Fig.4. Mean shifts of wires before and after correction

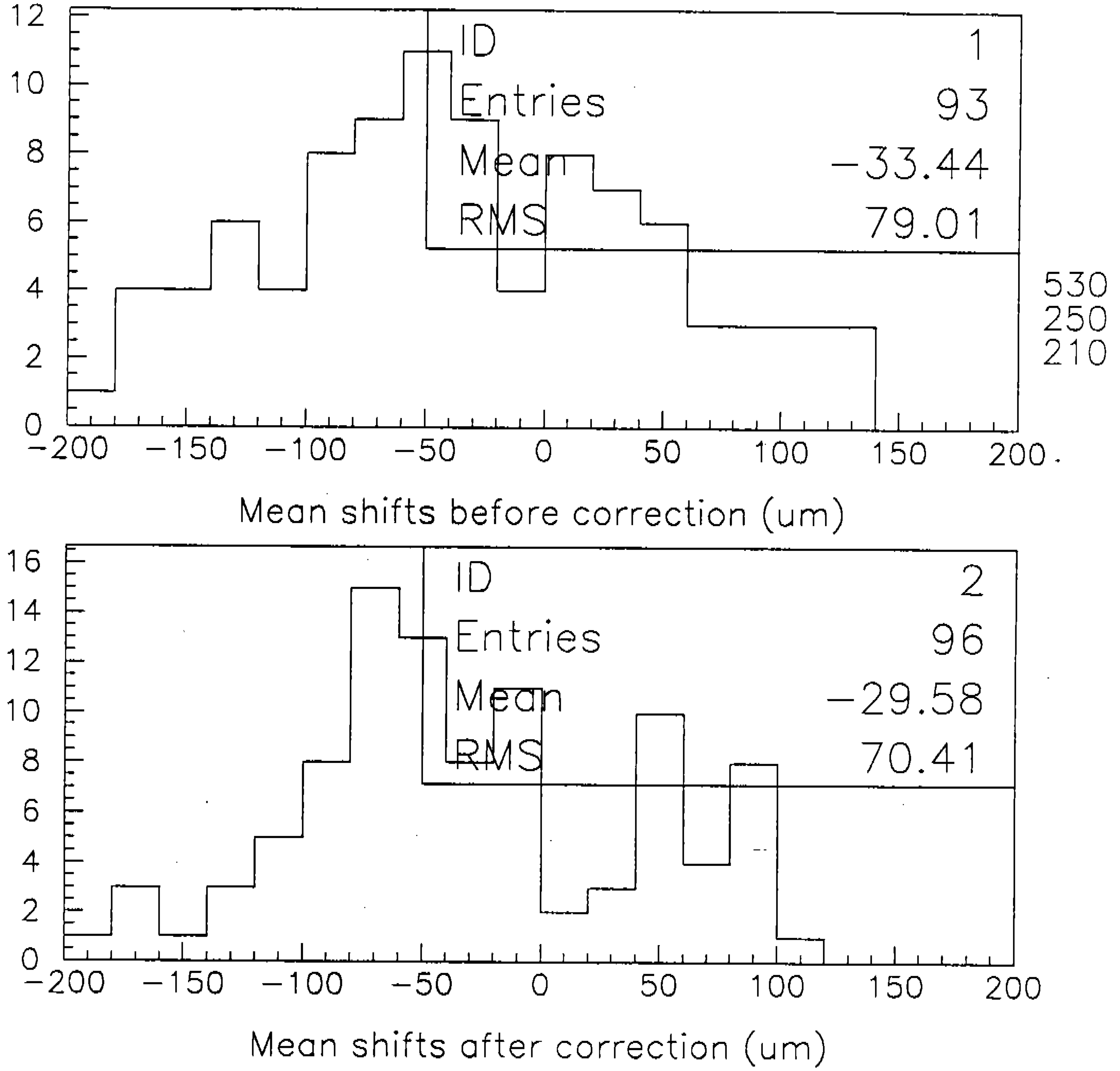


Fig.5. Resolution (.1 mm) as function of Time (100 ns)

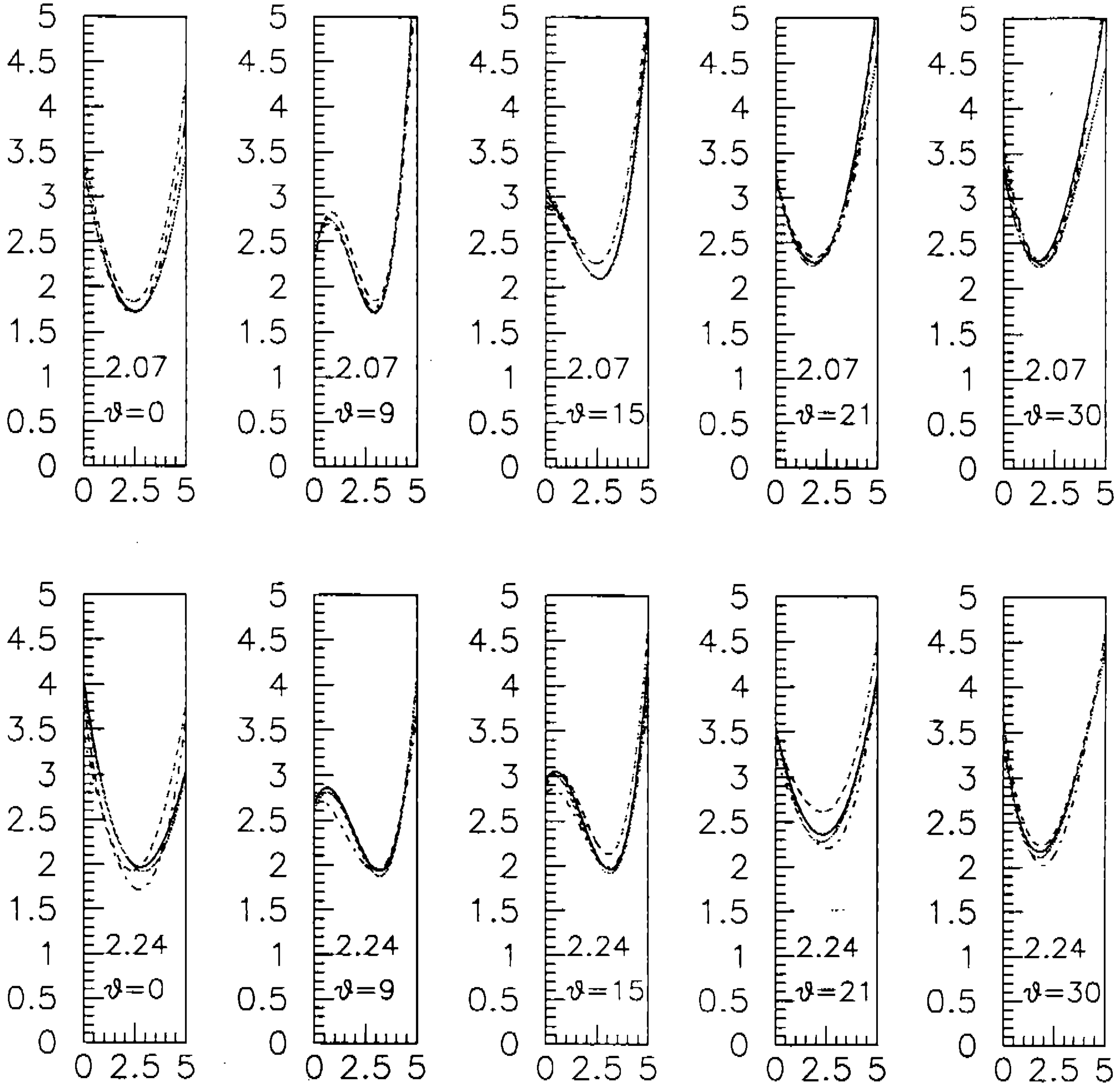


Fig.6. Mean shifts of wires after correction with calibration

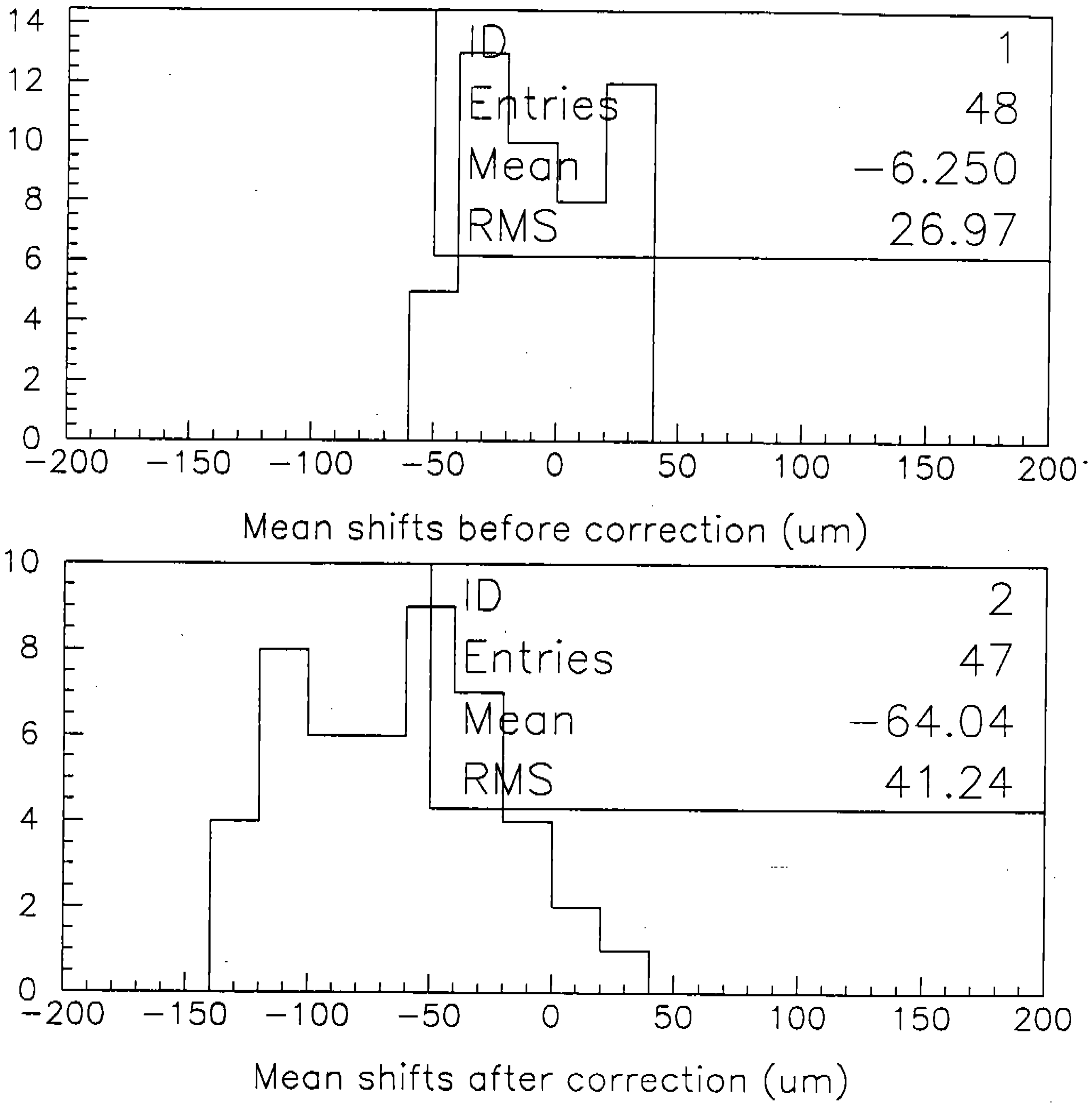


Fig.7. Resolution (.1 mm) as function of Time (100 ns)