Physics, Chemistry, and Dynamics of Interplanetary Dust
ASP Conference Series, Vol. 104, 1996
Bo A. S. Gustafson and Martha S. Hanner (eds.)

Accuracy of a Velocity/Trajectory Sensor for Charged Dust Particles

Siegfried Auer

1906 Paris Court, Bowie, MD 20716, USA

Abstract. A VELOCITY/TRAJECTORY cosmic dust sensor of the CHARGE-SENSING type was tested at the Heidelberg dust accelerator facility, using micron-sized particles. The full-scale (0.4m x 0.4m x 0.3m) model displayed capabilities for providing accuracies to 0.1% in speed and 0.1° in angle relative to the spacecraft at high signal-to-noise (SNR) ratios. The particle's trajectory within the sensor can be located with an accuracy of 0.3mm.

1. Introduction

Planetary scientists have long sought space experimental data that would provide an accurate correlation between a captured (impacted) cosmic dust particle and its recent trajectory (or orbital parameters) in order to associate the particle with its parent body. Orbital evolution calculations have shown that most particles could be classified as asteroidal or cometary (in origin) provided the particle's speed relative to the spacecraft is determined to an accuracy of <10% and its angle to an accuracy of <5°. Furthermore, distinction of individual, collisionally produced asteroid families is possible with trajectory accuracies of <1% in speed and <1° in angle (Zolensky, 1994). In addition, it would greatly simplify the task of locating a captured particle on the target plate if the position of its trajectory could also be determined.

Among trajectory sensors, the charge sensor is considered scientifically superior to other similar sensor systems (Zolensky, 1994). It is non-destructive and can, in principle, achieve quasi-unlimited accuracy. Two prior versions of this sensor have demonstrated accuracies of 1% in speed and 1° in angle (Auer, 1975). From the theory based on the design of the present version, Auer et al. (1994) estimated an error of 0.3% in speed and 0.2° in angle at a low SNR=2.5. For micron-sized cosmic dust particles, SNR≈2.5 is indeed expected and the errors will be experimentally determined in the near future. In this paper, however, we present experimental results indicating errors of about 0.1% in speed, 0.1° in angle, and 0.3mm in position for highly charged particles (SNR≈2000).

2. Experiment Description

The tests were performed at the Heidelberg dust particle accelerator facility. The particle beam consisted of individually accelerated iron microspheres with diameters of about 0.1-10μm, speeds of 1-30km/s, and positive surface charges ranging from 1-1000fC.

The sensor was mounted on a platform that provided rotation (up-down) and translations in x and y, but no position monitoring. Unable to rotate through many accurately known angles (which would be required for a full-scale calibration), we chose two, not accurately known but stable, positions. In the first position, the particle beam was almost parallel to the sensor axis; in the other, the particles entered the sensor at a high angle. In each position, the standard deviation of the angles, as derived from the sensor output, was taken as an indication of the angular accuracy.

Figure 1 shows a schematic cross section (not to scale) of the sensor model. Grids G_1 and G_2 consist of wire mesh (mesh size 1mm) and are electrically grounded. Each of rod assemblies, R_1 through R_4, consists of 12 thin (1mm), parallel, equidistant, conductive rods mounted on an insulating frame. Each rod consists of a carbon fiber-vinylester composite and is electrically connected to one of 4 charge amplifiers. Rods within each assembly are also electrically connected to the amplifiers according to the following scheme:

rod	#1	2	3	4	5	6	7	8	9	10	11	12
amp.	*#1*	*2*	*3*	*1*	*2*	*4*	*1*	*3*	*4*	*2*	*3*	*4*

With 3 rods per plane (12 rods total) connected to an amplifier, the measured amplifier noise (rms) is equivalent to about 600 electrons or 0.1fC. The sensor's aperture is 0.4m square and its depth D=0.3m. Let the coordinates and time of the trajectory's intersection with the k-th rod plane be x_k, y_k, z_k, t_k; and with G_1 and G_2 be x_0, y_0, z_0, t_0, and x_5, y_5, z_5, t_5, respectively; where $z_0=0$, $z_1=0.045$m, $z_2=0.105$m, $z_3=0.195$m, $z_4=0.255$m, and $z_5=D$ are the positions of G_1, R_1, ..., R_4, and G_2 along the sensor's z-axis.

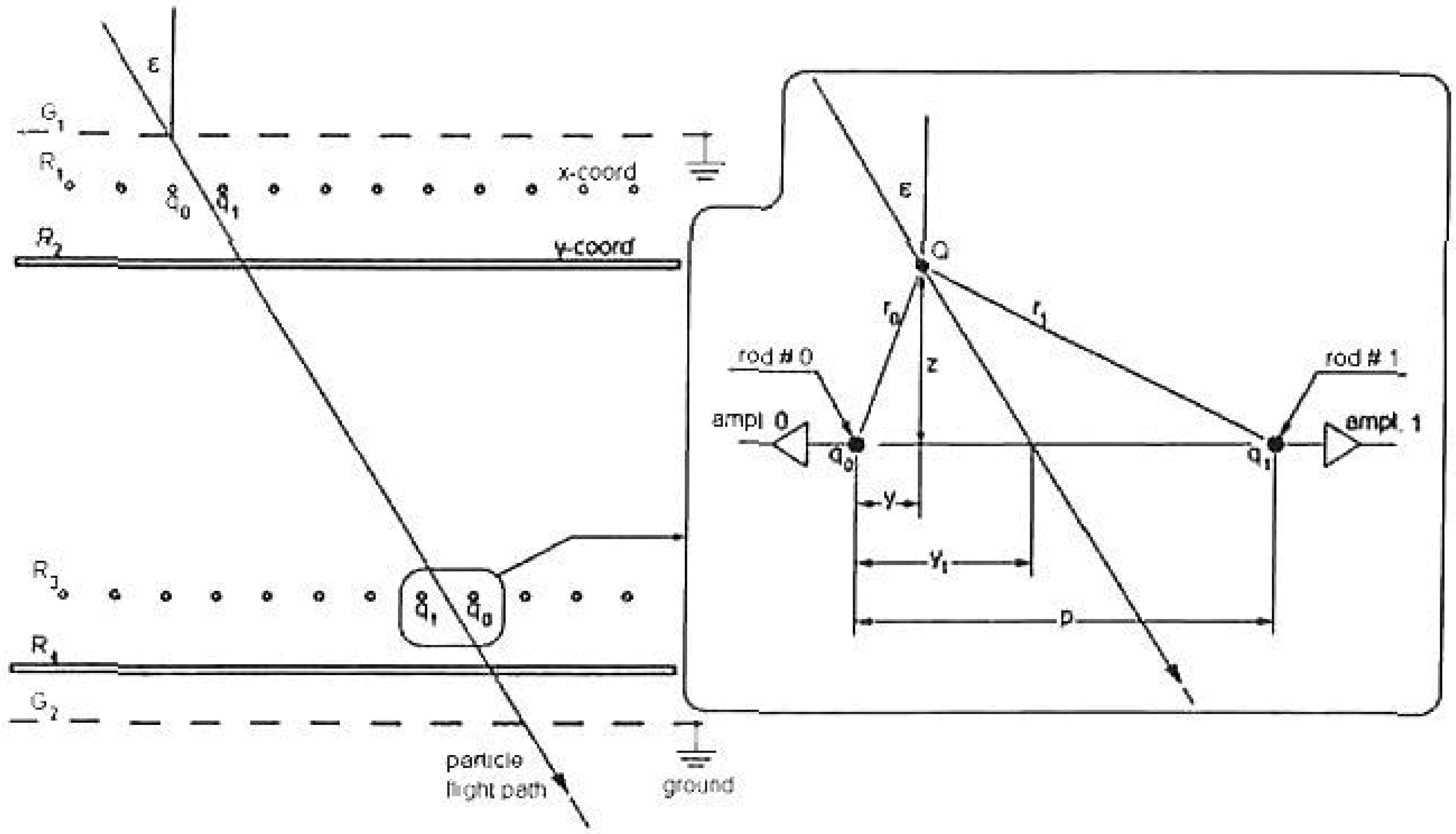

Figure 1. Schematic cross section of velocity/trajectory sensor.

3. Results

Figure 2 shows an example of the 4 output signals for a particle with a charge of 207fC (i.e., SNR=2070). The signal duration is $T = t_5 - t_0 = 88.62\mu s$. D/T equals v_z, the velocity component parallel to the sensor axis. The error in the entry (and exit) time is σ_t = 20-60ns as can be seen in the insert. The error in speed is derived from σ_t as $\sigma_v/v = \sigma_t\sqrt{2}/T$ = 0.03-0.10%. In fact, the 4 values of T derived independently from the 4 signals agree within 0.09%.

In order to determine the trajectory, we first calculated $t_k = t_0 + z_k T/D$. Second, 16 amplitudes $q_i(t_k)$ of the 4 signals at each t_k were calculated by averaging over 11 signal samples closest to t_k. Third, we sorted the signals according to their relative amplitudes at each t_k and from that sequence identified the rod closest to the trajectory. For example in Figure 2, one finds that at t_1=37μs, q_4 is largest, q_2 second, q_3 third, and q_1 smallest. From this we conclude that the particle can only have passed between rods 9 (amp.#4) and 10 (amp.#2), closer to 9 than to 10. Rods 8 and 11 (amp.#3) were further away and rod 7 *(amp.#1) the furthest. Fourth, we took the ratio of the largest and second largest* amplitudes, $q_m(t_k)$ and $q_n(t_k)$, and obtained the distance, d_k, between the point of rod plane crossing and the closest rod as

$$d_k \approx p/[1+q_m(t_k)/q_n(t_k)], \qquad (1)$$

where p = 30 mm is the rod spacing. This formula follows from equation 2 of Auer et al. (1994). Fifth, each of the coordinates x_1, y_2, x_3, and y_4 of the 4 rod plane crossings was calculated from d_k and the known position of the closest rod. Sixth, we obtained the angle ε_x *between the trajectory and the y-z plane from* $\tan\varepsilon_x = (x_3 - x_1)/(z_3 - z_1)$ *and the angle* ε_y between the trajectory and the x-z plane from $\tan\varepsilon_y = (y_4 - y_3)/(z_4 - z_3)$.

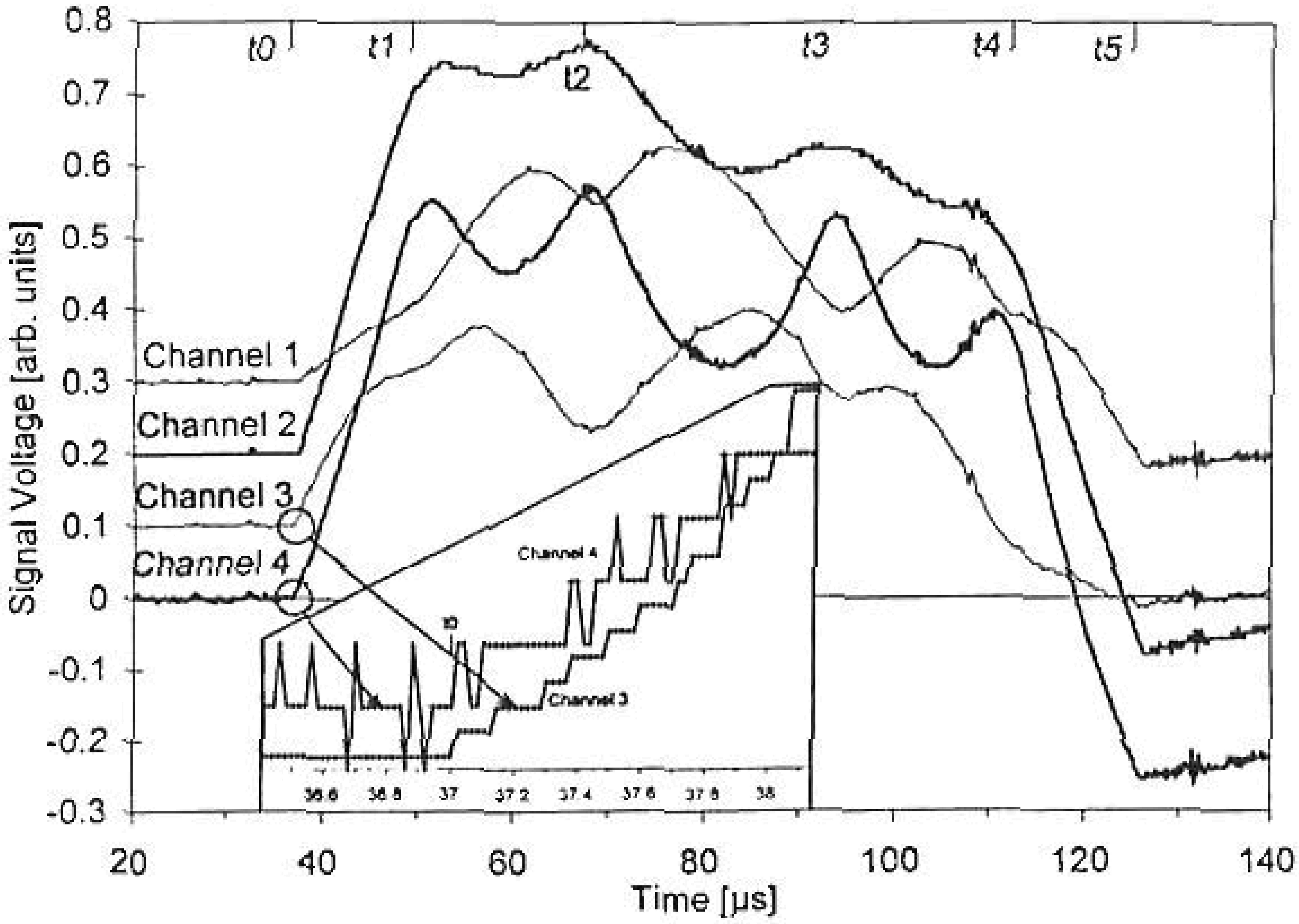

Figure 2. The four sensor output signals from the passage of a single particle. Details of channels 3 and 4 near t_0 are shown in the insert.

Figure 3 depicts the x_1 and y_2 coordinates (solid squares) where the trajectory intersects the R_1 and R_2 planes, respectively, and also the x_3 and y_4 coordinates (crosses) where it intersects the R_3 and R_4 planes, respectively, for the first test run of 25 dust particles with the beam almost parallel to the sensor axis. Notice that the pattern of crosses is similar to the pattern of squares, only shifted toward the lower left. We drew lines between some of the squares and the corresponding crosses to highlight this shift. Each pattern indicates the width of the dust beam, 3-4mm, whereas the shift indicates the distances $x_3 - x_1 = (0.508 \pm 0.072)$mm and $y_4 - y_2 = (0.759 \pm 0.128)$mm which particles travelled as they moved from the front of the sensor to the rear. The angles corresponding to these distances are $\varepsilon_x = 0.194° \pm 0.027°$ and $\varepsilon_y = 0.290° \pm 0.049°$.

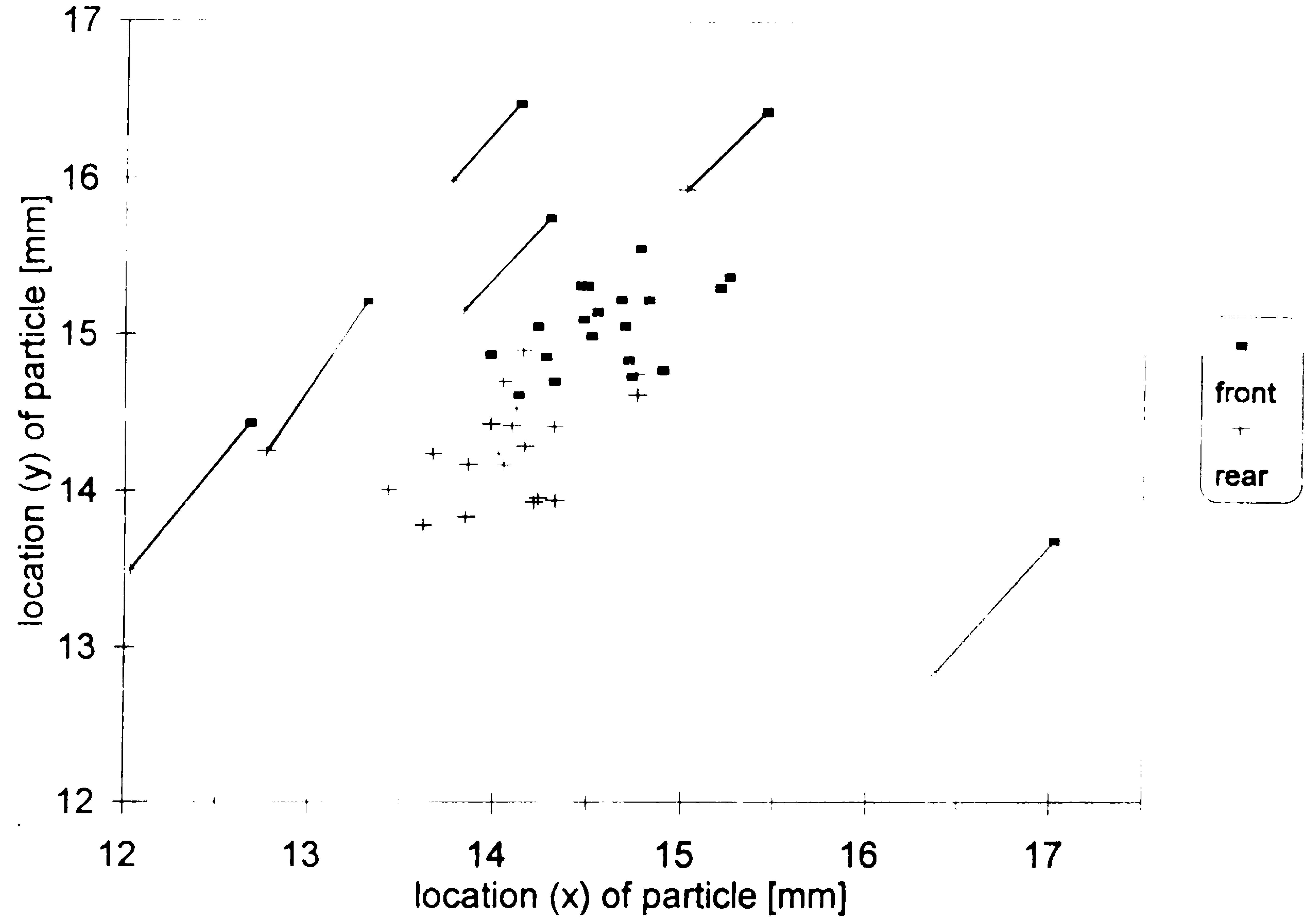

Figure 3 Measured x/y locations in front and rear sections of sensor.

In the second test run of 14 dust particles, the sensor was oriented at a high angle with respect to the particle beam as mentioned. Similar calculations yielded travel distances x_3-x_1=(80.630±0.329)mm and y_4-y_2=(40.445±0.414)mm and angles ε_x=28.259° ±0.097° and ε_y=15.090°±0.147°.

The standard deviations above are due to: errors of the measurement within the sensor; divergence of the particle beam; variations of the sensor orientation; and/or of the rod positions due to mechanical vibrations. Whatever the relative contributions, the errors of the velocity/trajectory sensor are equal to, or less than, the standard deviations and are summarized as follows: **speed:** $\sigma_v/v \leq 0.03$-0.10%, **angle:** $\sigma_\varepsilon \leq 0.03°$-$0.15°$, **position:** σ_x, $\sigma_y \leq 0.07$-0.41mm.

4. Conclusions

The sensor was tested on a dust accelerator in two fixed positions. Well-defined signal durations and the stability of the angular measurements demonstrate an accuracy of 0.1% and 0.1° which more than satisfies the required accuracy of <1% and <1°.

The sensor is simple and rugged and thus well suited for use on the space station or a free flyer. It should be noted that the probability of non-destructive sensing is very high (70-80%) and that the sensor can readily be combined with a particle capture device or with an *in situ* dust composition analyzer.

References

Auer, S. 1975, *Rev. Sci. Instrum.*, **46**, 127
Auer, S. and von Bun, F O. 1994, *LPI Tech. Rpt.* **94-05**, 25
Zolensky, M.E. (ed.) 1994, *LPI Tech. Rpt.* **94-05**, 1