SDC-91-00047

SDC
SOLENOIDAL DETECTOR NOTES

A Jet-Cell Design for the SDC Muon Chamber

S. Odaka

June 14, 1991

June 14, 1991

A Jet-cell Design for the SDC Muon Chamber

Shigeru ODAKA

KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken 305, Japan

A jet-chamber-like cell design is proposed for the SDC muon chamber. It is shown that a sufficiently uniform drift field can be formed with a very small number of electrodes and high voltage values. A perfect projective arrangement of the drift cells can be accomplished with this design at any location in the muon chamber system.

1. Conceptual thoughts

A stand-alone capability of momentum measurement and event triggering is an essential requirement to the muon detector system of SDC. The present conceptual design requires a relatively good spatial resolution to the muon chambers, about 250 μm per station (superlayer). The spatial resolution of muon chambers has been an order of 1 mm in most of the detectors for collider experiments having been built so far. Hence the above requirements would not be satisfied with a simple extension of previous experiences, not only in the alignment technique but also in the chamber-cell design itself.

A simplicity of the structure is an important issue when one designs a large chamber system. Tube chambers would be the best choice in this respect. However simple tube-chambers generally suffer from a high voltage problem. A special care is usually needed when the voltage is higher than 5 kV. This restriction, if this is considered as a restriction, results in a limitation of the electric field. For tubes larger than several cm in width and height, it is almost impossible to achieve a field strength of 1 kV/cm on the tube wall, where the field strength is minimum, within the above restriction. The field strength of about 1 kV/cm is required or desired for most of chamber gasses, in order to operate the chamber in a velocity-

saturating region and to reduce the diffusion effect. P10, Ar/Methane (90/10), or similar mixtures must be the only choice for such large tube-chambers. Of course, there is no choice in fast gasses as far as we know. These restrictions eventually limit the size (cross section) of tubes, especially when there is a constraint on the maximum drift time. Therefore it is not always guaranteed that there exists an acceptable design. People who would like to propose a simple tube-based design have to show a realistic cell design including a gas choice, first of all.

The above restrictions can be eased by adding some electrodes for field shaping. The effective electric field can be made narrower, and resultantly the field can be made stronger with additional electrodes. The field lines can be shaped almost parallel to each other if several electrodes are added. However this kind of field configuration shows a significant incident-angle dependence of the spatial resolution. The resolution unavoidably gets worse as the incident angle becomes larger. This effect may be quite significant for the muon chambers of SDC, especially for θ-chambers, since the incident angle of high momentum muons into muon-chamber superlayers is as much as 60° near the edge of the barrel region. Thus, it is desired that the electrodes are arranged so that the field lines always face the interaction point. Although such an arrangement is possible, the design would be much complicated or much space-consuming. Further, the field-shaping electrodes, which are usually made of printed circuits, may cause other problems, such as a leakage current and a layout of voltage-divider resistors. Gas sealing may also be a big problem for any tube-based designs unless the tubes are sealed individually.

In order to achieve an overall resolution of 250 μm, the alignment of chambers or, explicitly to say, the alignment of sense wires has to be fairly better than the overall resolution required. Some modularization must be needed to accomplish such a good alignment over a huge system extending more than 30 m. Of course, the placement within a module must be better than the accuracy required to the entire system. A common-endplate design, where the wires in a module are placed on a common endplate, is favorable in this respect, even if a tube-based design is applied. An accuracy better than 100 μm can easily be achieved over several meters with an ordinary NC-machining. Once a common-endplate design is chosen,

advantages of tube-based designs become smaller and many problems may arise on gas sealing and construction procedure.

In this report we would like to initiate a new approach to the SDC muon chamber. The design that will be shown in the following is based on a large-chamber concept, where each module mentioned above is constructed as one large drift chamber. There appears a wide variation of the cell design, once tube-based designs are abandoned. We chose a jet-chamber-like cell structure. From a point of view for triggering, sense wires are desired to be aligned on the lines pointing to the interaction point (projective geometry). A jet-chamber-like structure is a straight-forward solution to this requirement. Besides, it holds many advantages described for field-shaped tube chambers. A constant drift velocity of jet chambers may provide another advantage for triggering.

A problem which may arise in our design is a complexity of the cell structure. Jet chambers usually need many electrodes for field shaping. Is it a common requirement to any designs based on the jet-cell concept? In the following, by using a field calculation and a drift simulation, we demonstrate that a sufficiently uniform electric field can be formed with a very small number of electrodes, and that a complete projective geometry can be accomplished at any location with the basic cell design unchanged. In the following discussions we restrict ourselves to the θ-chambers in the barrel region. The stand-alone capability required to the muon detector system is concerned with the θ-chambers only, and a similar or, maybe, simpler design can be applied to the other chambers.

2. Optimization of cell parameters

The cell structure that we have chosen is schematically shown in Fig. 1. The sense plane is composed of 4 sense wires and 5 potential wires. The sense wires are located every 1 cm. A guard wire is placed in each side of the sense plane, 5 mm apart from the nearest potential wire, for cell termination. Cathodes are assumed to be made of planes. The distance between the sense plane and the cathode plane, the maximum drift distance, is chosen to be 4 cm at the center of the sense plane according to the LoI. Both the sense plane and the cathode plane are arranged in an

exact projective geometry. Resultantly, the cathode and ground planes form a tilted and slightly wedge-shaped boundary of drift cells.

The cathode planes have to be sufficiently wider than the effective drift volume in order to form a uniform drift field. The full height of the drift volume can be expressed as

$$h = w \sin \theta + 2l \cos \theta , \tag{1}$$

where w is the full width of the sense plane and l is the maximum drift distance. The angle θ is the polar angle where the cell is located. The height of the cathode, $h_{cathode}$, has to be larger than h. The definitions are schematically shown in Fig. 2. If we substitute w = 5 cm and l = 4 cm into Eq. (1), h has a maximum value of 9.4 cm at θ = 32°. The polar angle to be covered with the barrel muon chambers extends down to θ = 30°, approximately. Hence we have chosen $h_{cathode}$ to be 10 cm in the present study. The distance between the upper and lower ground planes is chosen to be 12 cm, in order to keep 1 cm gaps between the ground plane and the cathode plane.

The thickness and the voltage of the electrodes used in the following study are listed in Table 1. The voltages of the sense wire and the cathode plane were determined for an ideal jet-cell having a 1 cm sense-wire spacing and a 4 cm drift distance. The charge densities on the sense and potential wires and on the cathode planes are subject to the following relation in ideal jet-cells:

$$\lambda_{sense} + \lambda_{potential} + 2w_{cell}\sigma_{cathode} = 0, \tag{2}$$

where w_{cell} is the width of each drift cell (= 1 cm). The required strength of the drift field, E_{drift}, determines the charge density on the cathode plane. The charge ratio,

$$R_{potential} = \frac{\lambda_{potential}}{\lambda_{sense}}, \tag{3}$$

determines the focusing property of drift lines. The voltages listed were obtained for the condition, E_{drift} = 1 kV/cm and $R_{potential}$ = 1/3. The wire thicknesses listed in Table 1 were also used as input constraints of the calculation.

The voltage to be applied to the guard wires was optimized so that the electric field in the effective drift region should be as uniform as possible, by using a field calculation based on the exact cell geometry. The optimum

value listed in Table 1 eventually corresponds with the voltage of the sense wire in the present choice of the wire thicknesses. In this optimization and in the following simulations, the cathode and the ground planes are simulated with wires having the circumference equal to the wire spacing, so that the relation between the charge density and the voltage is identical to that of the plane to be simulated. The equi-potential contours for the cell parameters thus optimized are shown in Fig. 3 for the cells in a layer at $R \cong$ 7.1 m (just inside of the toroid). The results are shown for two extreme Z location, $Z \cong 0$ (center) and 10 m (near the edge). The field shape looks fairly good even at $Z \cong 10$ m, though we can see a small distortion due to an asymmetric arrangement of the cathode planes.

3. Drift simulation

The field quality of the drift cells described in the above was studied in detail by using a drift simulation. As an example, the HRS-gas, Ar/CO_2/Methane (90/9/1), was taken for the drift gas in this study. The drift paths of electrons simulated are illustrated in Fig. 4 for two cells at $Z \cong 0$ and 10 m in a layer at $R \cong 7.1$ m. The drift paths are almost parallel to each other in the cell at $Z \cong 0$, while a slight reclining can be seen in the cell at $Z \cong 10$ m.

Fig. 5 shows the time-to-distance relations calculated for the tracks traversing a cell parallel to the sense plane. The drift time of the first-arriving electron was taken to be the drift time for the tracks. Note that the relations for 4 sense wires in a cell are drawn in each figure. No apparent difference between the cells and the wires can be seen in these results.

In order to make possible distortions visible, track distances giving a same drift time were compared between the cells and the wires. Fig. 6 shows the differences of the distance with respect to the average in the cell at $Z \cong 0$. The results for the cell at $Z \cong 0$ show practically no difference between the wires, since the resolution of the drift-distance calculation was 10 μm. This means that the cell at $Z \cong 0$ is almost a perfect jet-cell, and a slight wedge shape of the cell boundary is not effective in the chamber performance, at least with the present gas-choice.

On the other hand, some distortions are visible in the cell at $Z \cong 10$ m. However the distortion is only about 150 μm at most. Such a small distortion

never deteriorates the trigger capability. Besides, we can see that the distortion shows a mirror symmetry between the left-side and right-side drift regions, and that the average of the 4 sense wires in this cell almost corresponds with that in the reference cell at $Z \cong 0$. Such a systematic and predictable distortion can be corrected for in software analyses.

4. Summary

A jet-chamber-like cell design was presented for the barrel muon chambers of SDC. It has been shown that a sufficiently uniform drift field can be formed with a very small number of electrodes and with only 3 high voltage values. A perfect projective arrangement of the drift cells can be accomplished with this design at any location of the chambers. A muon chamber system based on this design would satisfy all the requirements on the trigger capability as well as those on the spatial resolution.

It should be noted that the wire thicknesses used in the present study are still tentative. They have to be optimized by the considerations on the gas-multiplication property of a chosen drift gas and on the mechanical and electrical properties of wires. However, possible alternations of the thicknesses never affect the properties of the drift field that we have discussed, since we can adjust the high voltage values so as to keep the basic characteristics, E_{drift} and $R_{potential}$, unchanged.

In the present study we chose the number of sense wires in each cell to be 4. This choice is not essential in our cell arrangement. We obtained almost identical results for a similar cell arrangement consisting of 3 sense wires.

Table 1. The parameters of the electrodes used in the field calculation and the drift simulation.

	diameter (μm)	voltage (kV)
sense	50	+ 2.87
potential	200	0
cathode	(plane)	− 3.23
guard	200	+ 2.87

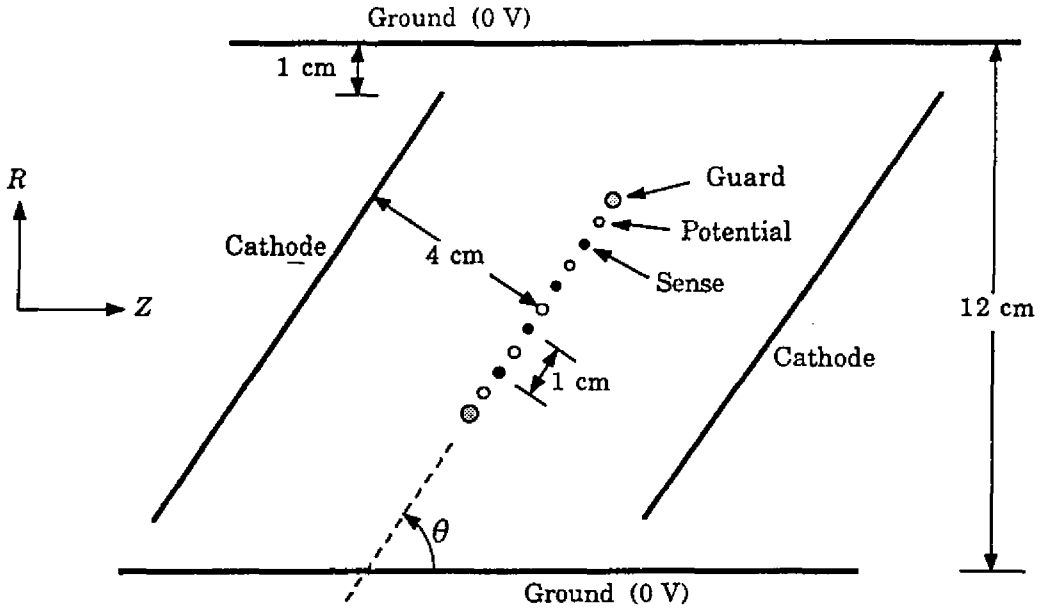

Fig. 1. A schematic drawing of the cell arrangement that we have chosen.

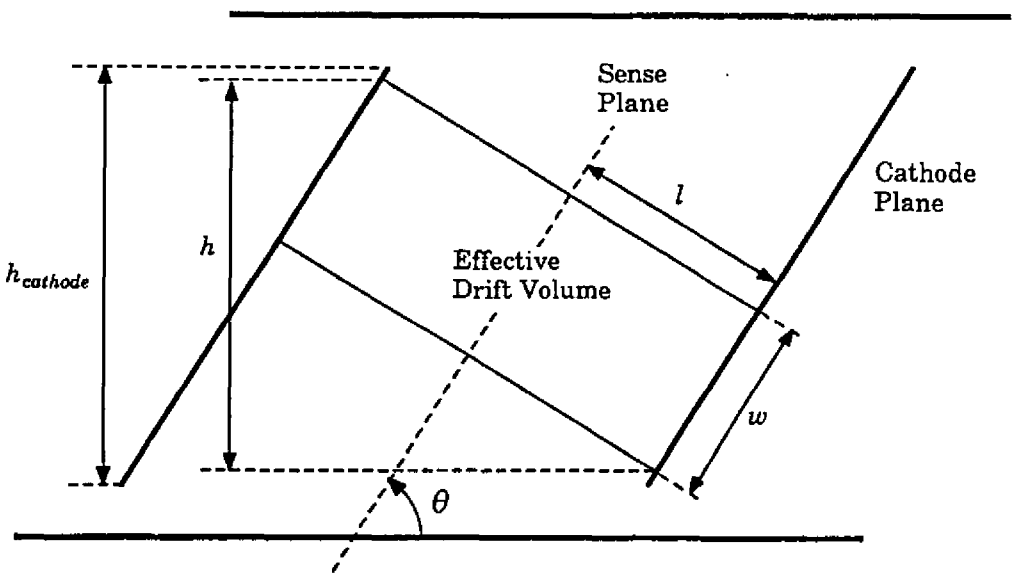

Fig. 2. A picture to show the relation between the size of the effective drift volume and the full height of the cathode plane required.

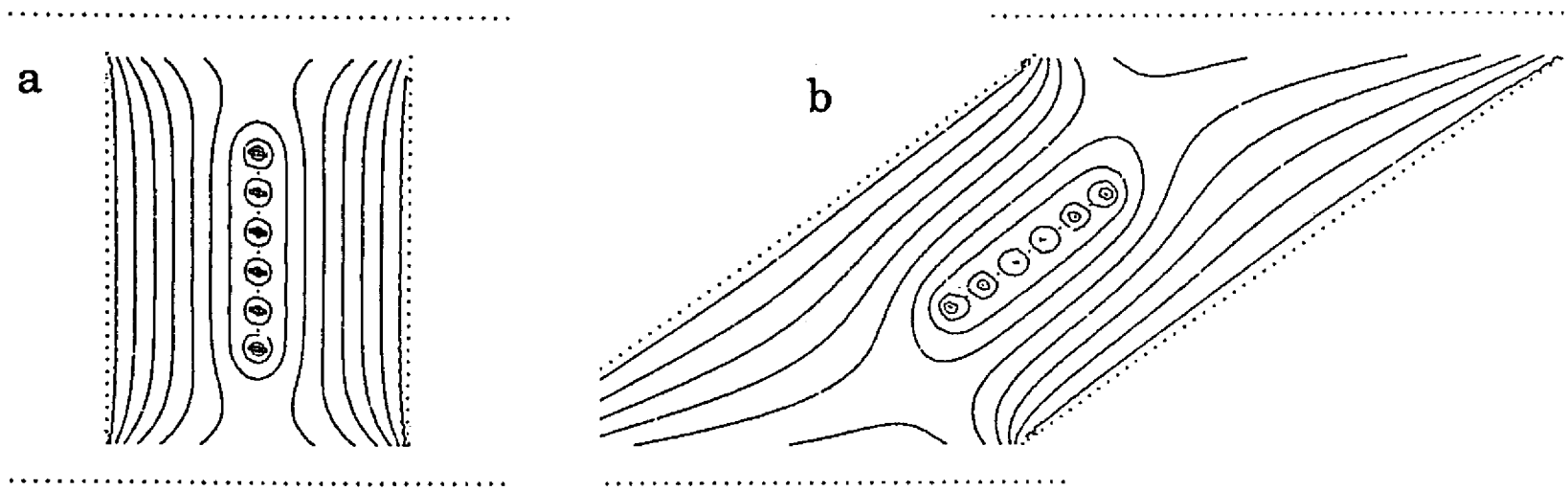

Fig. 3. The equi-potential contours calculated for the cells at $Z \equiv 0$ (a) and 10 m (b) in a layer at $R \equiv 7.1$ m.

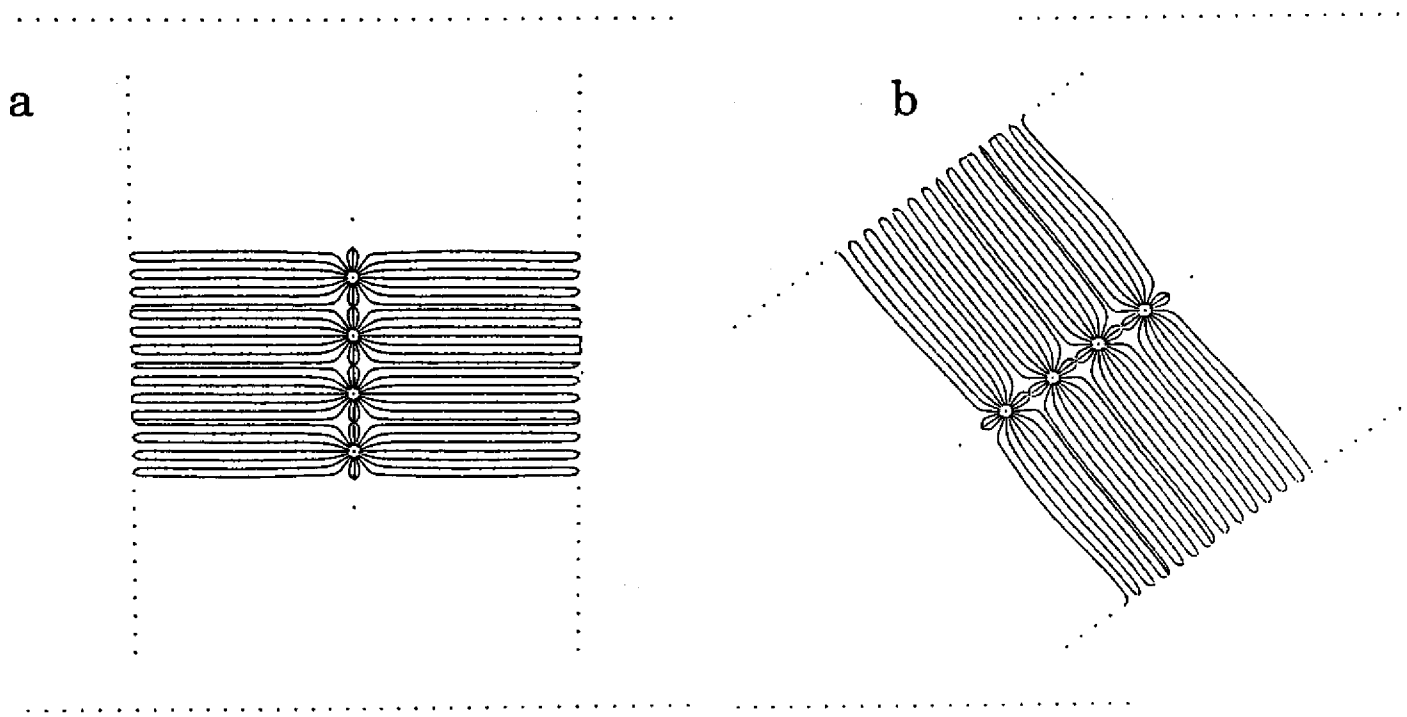

Fig. 4. The electron drift paths simulated for the HRS-gas. Results are shown for the cells at $Z \cong 0$ (a) and 10 m (b) in a layer at $R \cong 7.1$ m. Ticks show the equal drift-time contours of every 100 nsec.

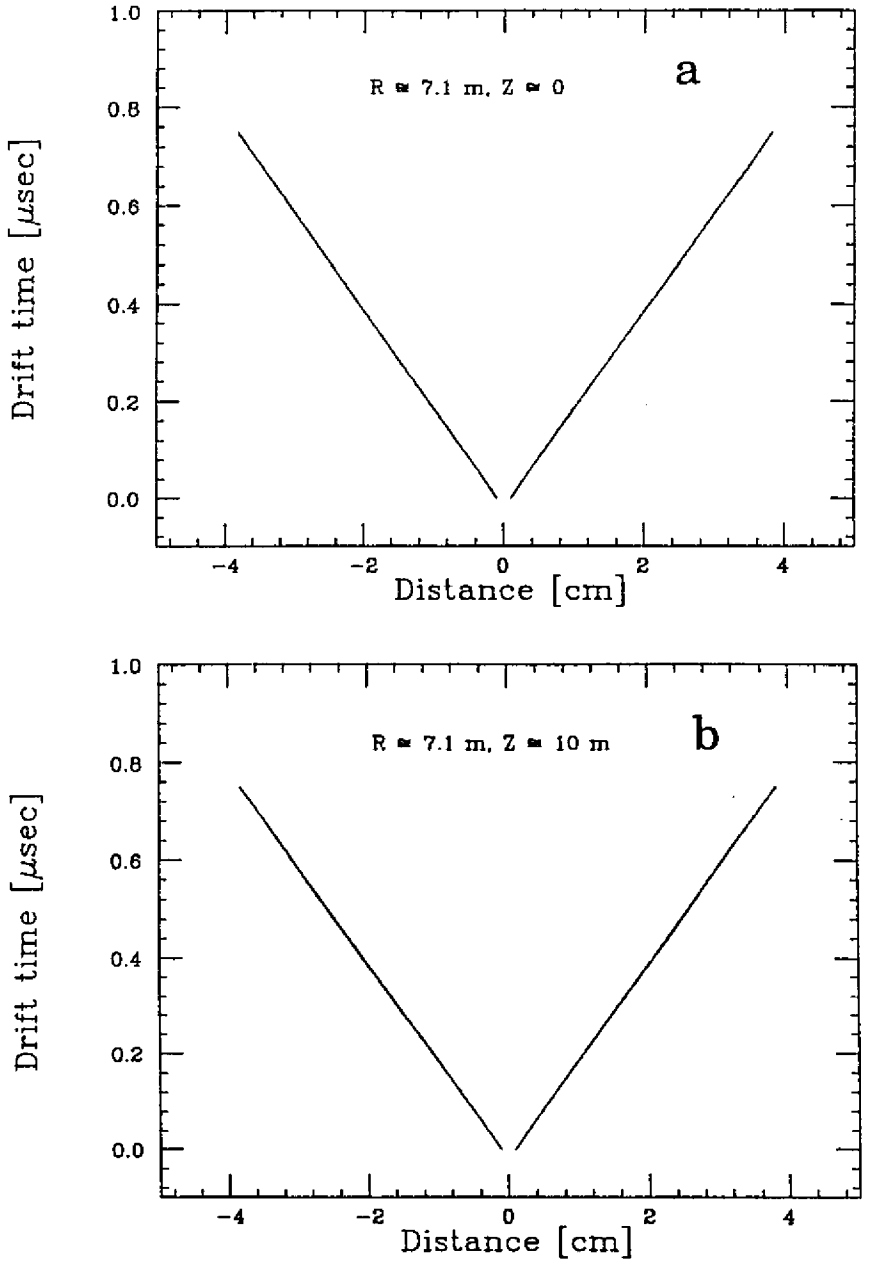

Fig. 5. The time-to-distance relations calculated for the HRS-gas. Results are shown for the cells at $Z \cong 0$ (a) and 10 m (b) in a layer at $R \cong 7.1$ m. The relations for 4 sense wires in a cell are drawn in each figure. The results for the left-side drift region are drawn in the negative side, and those for the right-side drift region in the positive side. The offset of the drift time is chosen so that the drift time is zero at the distance of 1 mm.

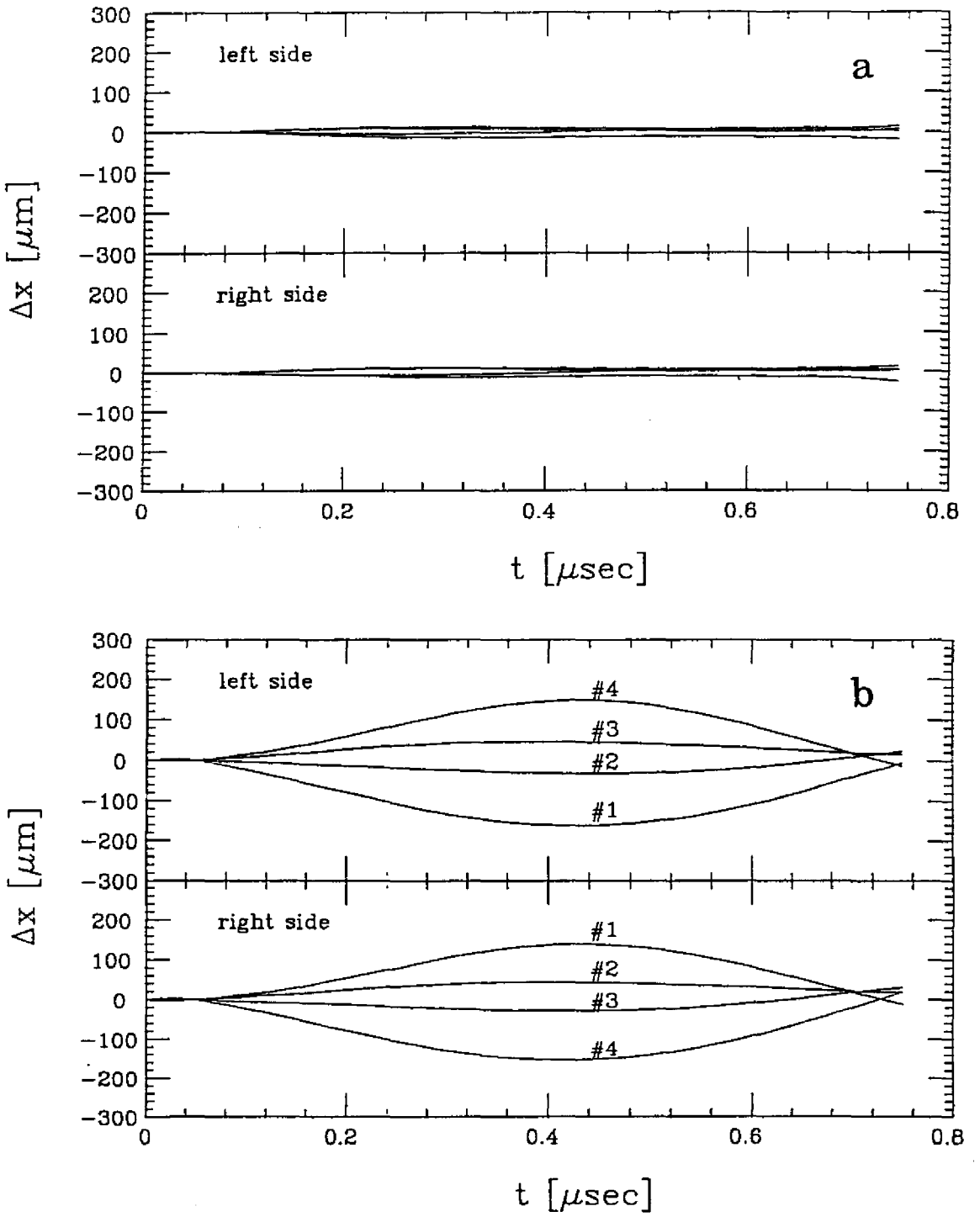

Fig. 6. The track distances giving a same drift time are compared between the sense wires in the cells at $Z \cong 0$ (a) and 10 m (b) in a layer at $R \cong 7.1$ m. Shown are the differences of the distance with respect to the average in the cell at $Z \cong 0$. The HRS-gas is assumed in the calculation. The numbers in (b) represent the sense-wire number counted from inside to outside.