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Preliminary Results from the Beam Test for the SDC Straw-tube Tracking Detector *

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A beam test of the straw-tube tracking detector, developed for the SDC detector at SSC, was carried out at BNL in July 1993. We present the results from our analysis of the beam-test data. The analysis is devoted to the study of the detection efficiency and the spatial resolution in a standard operation condition. The performance is studied for two straw-tube modules employing anode wires of different diameters, 25 and 37 μm. Two methods, a triplet method and a reconstructed-track method, are applied in the analysis.

1. Introduction

The straw-tube tracking detector [1] has been developed for the application to the barrel outer tracker of the SDC detector [2] at SSC. The development has been carried out in collaboration between the institutes listed in Table 1. The proposed detector is composed of five cylindrically concentric superlayers of straw drift tubes. Each superlayer consists of six or eight layers of tubes (8 layers in trigger superlayers and 6 layers in stereo superlayers). The straw drift tube is composed of a Kapton-film tube with thin copper coating on the inner surface and a central anode wire made of tungsten with gold plating. The tubes are all 4 mm in diameter, which allows individual element occupancies to be sufficiently small even in the high-radiation environment at SSC.

The straw tubes are arranged in modules of trapezoidal cross section, each containing about 200 tubes, as shown in Fig. 1. The module is essentially an independent tracking chamber with its own gas and power connections and electronics. The superlayers have the straw-tube modules running either parallel to the beam direction (trigger superlayers) or at a small angle with respect to the beam direction (stereo superlayers). Table 2 summarizes the component information in the final design. A total of 137k straws were planned to be used.

In order to evaluate the performance of the developed straw-tube modules and associated electronics, a beam test was carried out at BNL in July 1993. The beam test was performed in a situation which closely resembles a section of the actual SDC outer tracking system and was expected to provide us useful information for finalizing the design.

The analysis of the beam-test data has been carried out at several institutes in the US and in Japan. Preliminary results from the analysis performed at Tokyo Metropolitan University (TMU) are presented in this report. The analysis was devoted mainly to the study of the detection efficiency and spatial resolution. Further details of the beam test and the analysis are described in ref. [3].

2. Setup of the beam test

Four straw-tube modules of full length (4 m) were used in the beam test. The module shells were made of a carbon-composite-foam sandwich and served as a vessel for the drift gas. One end of the module, the end that would be at the center of the actual detector ($z = 0$), was sealed with a simple endplate with no external connection. A more complicated endplate was attached to the other end, the outer end in the actual detector ($z = 4$ m), to permit all the required connections of signal, gas and high voltage.

The modules were mounted on an aluminum support structure as illustrated in Fig. 2. The placement of the modules simulated the inner 4 superlayers in the proposed layout, though all modules were placed in parallel. The modules were of two types: the stereo modules containing 159 straw tubes and the trigger modules containing 212 straw tubes. Modules 1 and 3 were the stereo type and the others were the trigger type. Another difference between the modules was in the thickness of the anode wires; wires of 25 μm-diameter were strung in modules 1 and 2, while thicker wires, 37 μm in diameter, were used in modules 3 and 4. The entire test stand was mounted on a table capable of moving the modules vertically and horizontally, which allowed all parts of the modules to be put in the beam.

The analog signals from the straw-tube modules were processed with bipolar IC chips (ASD-8) developed at Pennsylvania University for the SDC straw-tube tracking detector [4]. Each ASD-8 chip includes eight channels of amplifier-shaper-discriminator (ASD) circuits. The chips were mounted on circuit boards attached to the endplates of the straw-tube modules. About 500 channels of the straw tubes were

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* Presented by K. Yamauchi.

instrumented with the ASD chips. The output signals of the ASD chips were fed to digitizers through twisted-pair cables.

For the drift-time digitization, we used the TMC-CAMAC modules developed at KEK [5]. The module has 32 input channels and a total of 15 modules were used at the beam test. The TMC (Time Memory Cell) chip, TMC1004, employed in the modules records the history of the input signal by means of a fully digital method, with a r.m.s. time resolution of 0.52 ns. The digitized data were collected via VME by using the SDC portable data acquisition system (UNIDAQ) installed on a UNIX workstation.

3. Analysis of the beam-test data

3.1. General

Although the beam test was carried out in various combinations of the operation condition (gas mixture, applied HVs and discriminator thresholds) and the experimental condition (vertical and horizontal positions and angle of the beam incidence), results are presented in this report only for those data with the discriminator threshold of 3 fC, the gas mixture of CF_4 (80%) + isobutane (20%) and the beam incident angle of 90°, perpendicular to the wire direction.

The measured drift time distribution in a typical run is shown in Fig. 3, where time offsets of individual channels are corrected and an arbitrary overall time offset of 50 ns is added. In order to eliminate spurious hits, we use only those hits contained within the time window, $45 \le t \le 75$ ns, in the following analyses, unless noted otherwise.

The time-to-distance relation was extracted by means of a self-consistency method, in which all the applied HVs were set to the standard values. The relation was found to be well described with a linear function, *i.e.* a constant drift velocity. The obtained results are given in Table 3.

In our analysis, studies were made mainly for modules 1 and 3, in order to investigate possible effects of the anode-wire thickness, 25 μm in diameter in module 1 and 37 μm in module 3. The track segment used in the analysis is defined as follows: A 2 mm-wide tracking unit is defined as illustrated in Fig. 4. If we find n or more hits in a certain tracking unit, we call such a set of hits an n-hit track segment.

3.2. Detection efficiency

We studied the HV and z-position (position along the wire) dependence of the efficiency by means of a triplet method. We picked up hits in three contiguous straws aligned along the beam axis, as shown in Fig. 5. Hits in the first and third straws of the triplet were required and the efficiency of the middle straw was studied.

The results obtained for modules 1 and 3 are plotted in Fig. 6 as a function of the applied HV for two z positions of beam incidence, near the center of the straw-tube modules (z = 1.7 m) and close to the readout end (z = 3.45 m). We can see that the efficiency reaches a plateau around 1850 V in module 1 and around 2050 V in module 3. The results for module 3 show a z-position dependence of a few % level in the plateau region, while it is not clear in the results for module 1 although the dependence is obvious at lower HVs. At z = 1.7 m, the (plateau) efficiency was found to be 93% in module 1 at 1950 V and 94% in module 3 at 2150 V.

Another method was applied to study the track-distance dependence of the efficiency in the standard condition, the HVs of 1950 V for module 1 and 2150 V for module 3 and the beam incidence at z = 1.7 m. In this method, tracks were reconstructed by using hits found in other modules than the module under the study. We required that one and only one track segment comprising an appropriate number of hits must be found in each module to be used. In addition, we required that the difference in the vertical position between these track segments should be within a reasonable range. The specific numbers in the selection condition will be given later.

Tracks were reconstructed by fitting the hits in the selected track segments to a straight line. The reconstructed track was extrapolated or interpolated to the module to be studied, and the efficiency was estimated for the straws that were expected to be penetrated by the reconstructed track. The time-window cut described in section 3.1 was not applied, so as to avoid possible small loss of hits in the tails of the time distribution.

In the study of module 1, tracks were reconstructed by using modules 2 and 3. We required a 7-hit track segment in module 2 and a 5-hit track segment in module 3. The vertical position difference allowed for the track segments was chosen to be 2 in the unit of the tracking-unit width, *i.e.* 4 mm.

We introduce a variable dy in order to represent the distance between the track and straw chamber wires. It is defined as

$$dy = y_{\mathrm{track}} - y_{\mathrm{lower}},$$

where y_{track} is the vertical coordinate (y) of the extrapolated track at a certain layer and y_{lower} is the y coordinate of the nearest wire in the lower side of the track in this layer (lower-side straw). This definition is convenient for studying the behavior around the straw boundary. With a perfect alignment, the straw wall should be at dy = 2 mm and the wire of the nearest straw in the upper side (upper-side straw) should be at dy = 4 mm (Fig. 7).

The efficiency was studied for both the lower-side straw and the upper-side straw. The efficiency of the ORed signal was also evaluated. The obtained results are plotted in Fig. 8. We can clearly see a degradation around the wires and the straw-tube boundaries. The efficiency of the ORed signal averaged over the whole track distance is 88%. Note that the boundary effect is smeared by a finite tracking error. The tracking error is expected to be about 200 μm if a spatial resolution of 150 μm is assumed. If we exclude a region around the boundary, $1.5 \le dy \le 2.5$ mm, we obtain an average efficiency of 89% for the ORed signal. Therefore, the degradation due to the straw wall is to be about 1%.

The efficiency obtained here is about 5% worse than the efficiency estimated with the triplet method. The inefficiency around the straw boundary tends to be underestimated in the triplet method due to a geometrical constraint. So that, the triplet method should give somewhat larger efficiency than the method using reconstructed tracks. However, even if we exclude the region around the boundary, there still exists a 4% discrepancy, which is marginal but not negligible.

A similar study was also carried out for module 3. In this study, modules 2 and 4 were used for tracking. A 6-hit track segment was required in each module, and the allowed tolerance in the vertical position was chosen to be 4 tracking units. The obtained results are plotted in Fig. 9. The overall average was found to be 88% and the average excluding the boundary region, $1.5 \le dy \le 2.5$ mm, to be 89% for the ORed signal. These results are in good agreement with those obtained for module 1. The boundary effect is more clearly seen in this result, since the tracking error is smaller. The error is expected to be about 50 μm for a spatial resolution of 150 μm. The disagreement with the results from the triplet method is not negligible also in this result.

3.3. Spatial resolution

The HV and z-position dependence of the spatial resolution was studied by using a triplet method. The definition of the triplet is the same as that used in the efficiency study (Fig. 5). We made a distribution of the triplet time difference, $\Delta t_{\rm triplet}$, defined as

$$\Delta t_{\rm triplet} = (t_1 + t_3)/2 - t_2.$$

The spatial resolution, $\sigma_{\rm triplet}$, was evaluated by multiplying the standard deviation of the $\Delta t_{\rm triplet}$ distribution with a factor of $\sqrt{2/3}$ and with the drift velocity. In this analysis, used were only those hits which belonged to a 6-hit (8-hit) track segment when a stereo (axial) module was studied; *i.e.* no inefficiency was allowed. Further, events were not used if two or more such track segments were found in the straw module under the study.

The results obtained for modules 1 and 3 are plotted in Fig. 10 as a function of the applied HV. We can clearly see an improvement of the resolution as the HVs are increased. The results for module 1 show a reasonable agreement with the results reported previously [6]. The z-position dependence is not clear, mainly because the available data points are limited. On the other hand, the results show a significant difference between module 1 and module 3. In the standard condition, the HVs of 1950 V for module 1 and 2150 V for module 3 and the beam incidence at $z = 1.7$ m, the obtained resolution is 165 μm in module 1 and 224 μm in module 3.

The spatial resolution in the standard condition was studied as a function of the track distance by using a reconstructed-track method. The selection applied was the same as that used in the triplet method. Tracks were reconstructed by fitting hits in the studied module, excluding the hit in the layer under the study.

We introduce a variable $dy_{\rm residual}$ to represent the distance between the track and the measured position. It is defined as

$$dy_{\rm residual} = D_{\rm drift} - X_{\rm fit},$$

where $D_{\rm drift}$ is the drift distance in the vertical coordinate (y) extracted from the measured drift time, and $X_{\rm fit}$ is the y-coordinate difference between the reconstructed track and the wire position (track distance). The study was made for hits in layers 3 and 4 since the tracking error is minimum in these layers. The obtained $dy_{\rm residual}$ distributions are shown in Fig. 11.

From a simulation, we found that there is a relation between the standard deviation of $dy_{\rm residual}$ ($\sigma_{\rm residual}$) and the spatial resolution (σ_x) as

$$\sigma_{\rm residual} = 0.002 + 1.08\,\sigma_x\ (\mathrm{mm}),$$

for layers 3 and 4. The spatial resolution extracted by using this relation is plotted in Fig. 12. We can see a small degradation of the resolution around the wire. Comparing the data of $0.0 \le X_{\rm fit} \le 0.5$ with those of $1.5 \le X_{\rm fit} \le 2.0$, the degradation was found to be about 10% for both modules. The average resolution was obtained to be 173 μm for module 1 and 224 μm for module 3.

Since the $\Delta t_{\rm triplet}$ and $dy_{\rm residual}$ distributions are not pure Gaussian, a systematic uncertainty at a level of 10% should be postulated to the resolution results. Taking such uncertainty into consideration, the results from both analysis methods are in a reasonable agreement, while the difference between module 1 and module 3 is significant.

4. Summary and discussion

Analyzing data from the beam test at BNL, we studied the detection efficiency and the spatial resolution of the prototype straw-tube tracking detector developed for the SDC detector at SSC. The performance was studied for two straw-tube modules employing anode wires of different diameters, 25 and 37 μm. Two methods, a triplet method and a reconstructed-track method, were applied in the analysis.

Using a simple triplet method, we found that the detection efficiency reaches a plateau around 1850 V in the straw tubes with 25 μm wires (module 1) and around

2050 V in those with 37 μm wires (module 3) in the standard threshold setting, 3 fC, and with normal incidence of the beam. In the standard operation and experimental condition (HVs of 1950 V for module 1 and 2150 V for module 3 and normal beam incidence near the center of the straw-tube modules), the detection efficiency was found to be 93% for module 1 and 94% for module 3; *i.e.* no significant wire-diameter dependence was observed.

We have clearly observed a degradation of the efficiency around the straw-tube boundary and the wires, by using a reconstructed-track method. The average efficiency was found to be 88%, and the inefficiency due to the straw boundaries to be about 1%, for both modules 1 and 3 in the standard condition. The obtained average efficiency is somewhat smaller than that from the triplet method. We infer that the results from the reconstructed-track method must be more reliable, since the used sample is more clearly defined and is expected to be free from any bias.

The observed efficiencies are, in any case, appreciably worse than the expectation and results from cosmic-ray tests of about 97%, a few % inefficiency due to the boundary. Noise pick-up, cross talk or contamination in the drift gas may have deteriorated the efficiency at the beam test. The reasons need to be clarified by further studies.

Concerning the spatial resolution, two analysis methods give consistent results. However, we observed a significant difference between the modules, *i.e.* a wire-diameter dependence of the resolution. The average resolution was measured to be about 170 μm for module 1 and 220 μm for module 3 in the standard condition. The result for module 1 is roughly consistent with results from cosmic-ray tests of about 150 μm, while the result for module 3 employing thicker wires, 37 μm in diameter, is significantly worse. Further studies need to be carried out to find the reason and to optimize the chamber design.

One of the main purposes of the beam test at BNL was to operate the developed straw-tube detector system including associated electronics of a large number of channels in a realistic environment, in cooperation between many institutes participating in the development. The beam test was quite successful from this point of view. On the other hand, as described above, unexpected problems were found in the obtained data. Further studies are necessary to solve the problems. Although SSC has been terminated, they will give valuable information for future application of this type of detector to other experiments.

References

[1] Conceptual Design Report for the Modular Straw Outer Tracking System, SDC-91-00125 (January 21, 1992).

[2] SDC Technical Design Report, SDC-92-201 (April 1, 1992).

[3] K. Yamauchi, Master Thesis (Tokyo Metropolitan University, 1994).

[4] F. M. Newcomer *at al.*, Nucl. Instr. Meth. A283 (1989) 806.

[5] Y. Arai and T. Ohsugi, Snowmass 1986, p. 455; and Y. Arai *et al.*, IEEE NS 39 (1992) 784.

[6] D. Rust, Preliminary Results from the Beam Test Prepared for the SDC Subsystem Managers Meeting of Oct. 13, 1993, revised Oct. 15, 1993.

Table 1. The collaborating institutes of the SDC straw tracking group.

Colorado State University
Duke University
Indiana University
KEK
Lawrence Berkeley Laboratory and University of California, Berkeley
Northeastern University
Oak Ridge National Laboratory
Quantum Research Services
Supercomputer Computations Research Institute, Florida State University
Tokyo Metropolitan University
Tokyo University of Agriculture and Technology
TRIUMF
University of Colorado
University of Michigan
University of Pennsylvania
Westinghouse Science and Technology Center

Table 2. The proposed configuration of the SDC barrel outer tracking system.

superlayer	mean radius (m)	channel count	number of modules	layers/ superlayer	$z_{\max}$ (m)	stereo angle (°)
1	0.816	19,504	92	8 (trigger)	2.410	0
2	1.103	19,716	124	6	3.281	+3
3	1.351	32,224	152	8 (trigger)	4.033	0
4	1.488	26,712	168	6	4.033	-3
5	1.631	39,008	184	8 (trigger)	4.033	0

Table 3. The measured time-to-distance relation. A constant drift velocity was assumed.

module	type	wire diameter (μm)	HV (V)	drift velocity (mm/ns)
1	stereo	25	1950	0.112
2	axial	25	1950	0.113
3	stereo	37	2150	0.121
4	axial	37	2150	0.122

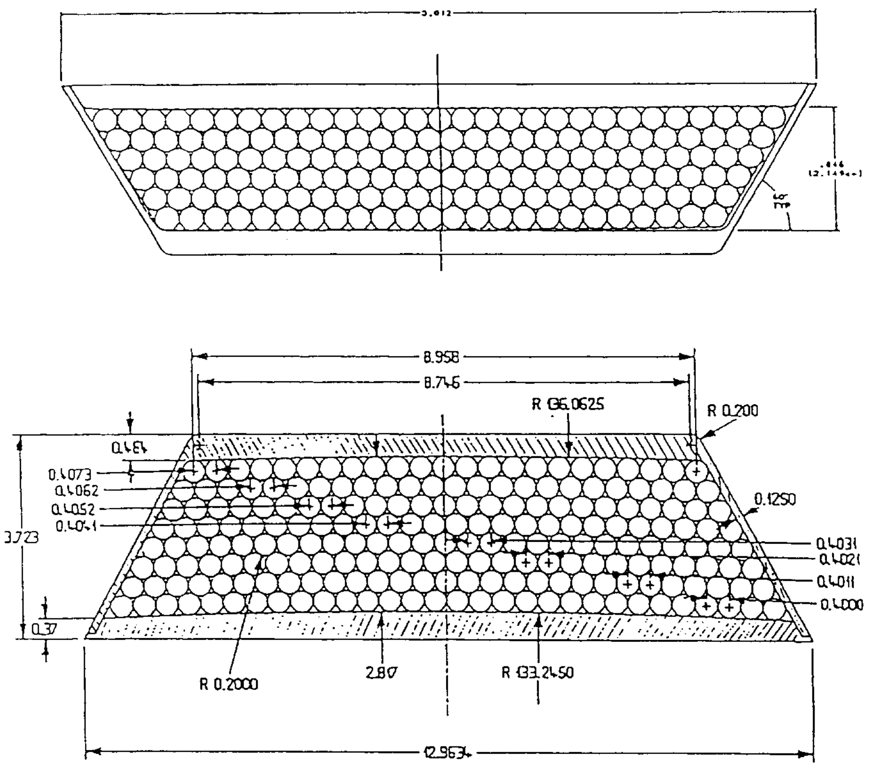


Fig. 1. The basic module design. The two basic designs are shown: a 6 layer module for the stereo superlayers, and an 8 layer module for the trigger superlayers in which all straws are radially aligned.

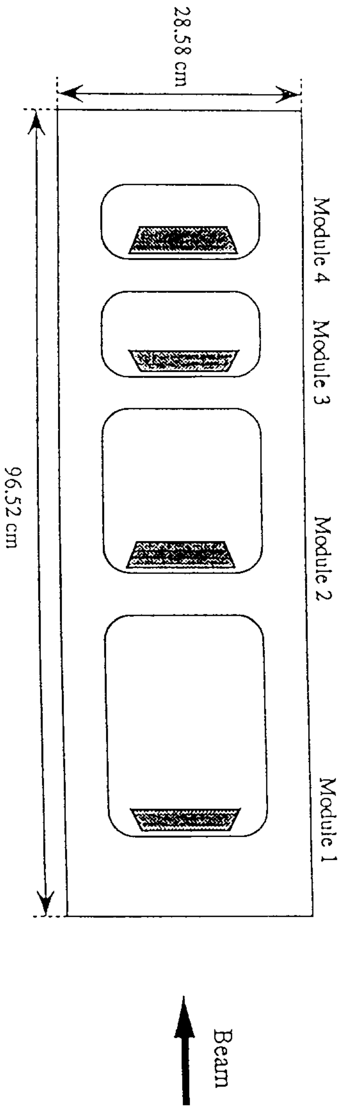
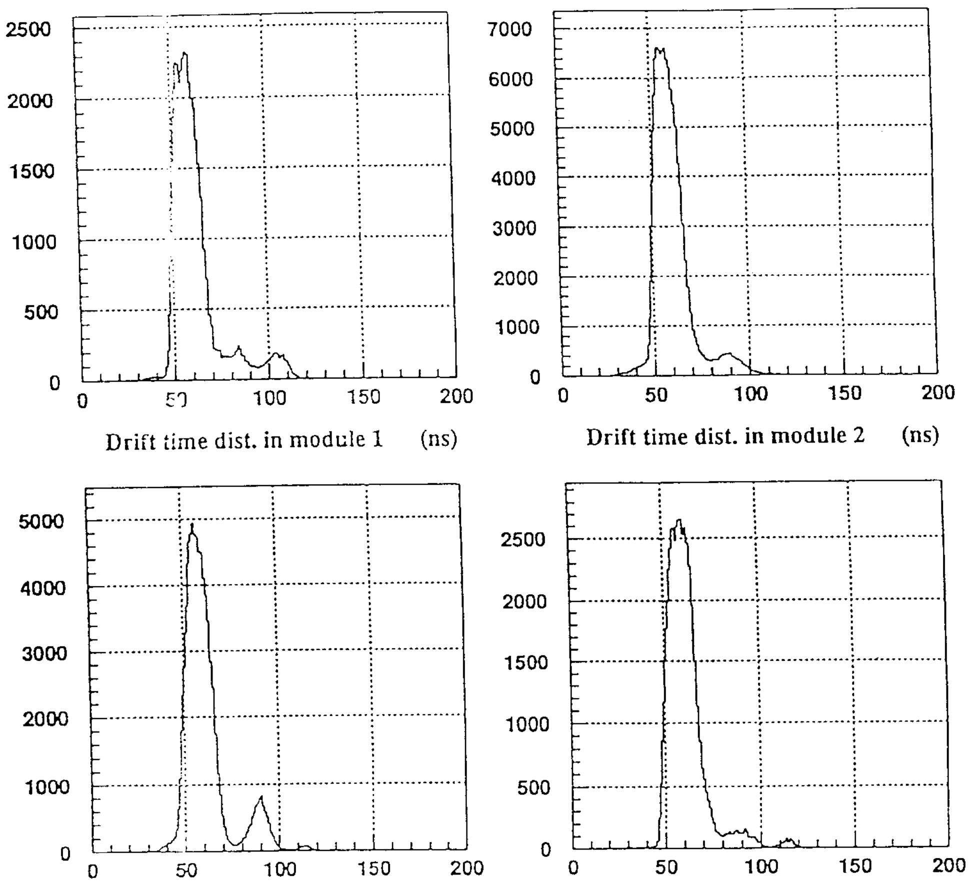


Fig. 2. A schematic layout of the straw-tube modules at the beam test. Four straw-tube modules are mounted on the support structure. Modules 1 and 3 are the stereo type and the other two are the trigger type. The layout approximately emulates the arrangement of inner 4 superlayers in the proposed straw-tube tracking system.



Drift time dist. in module 1 (ns)

Drift time dist. in module 2 (ns)

Drift time dist. in module 3 (ns)

Drift time dist. in module 4 (ns)

Fig. 3. The measured drift-time distribution in a typical run. An arbitrary overall time offset of 50 ns is added.

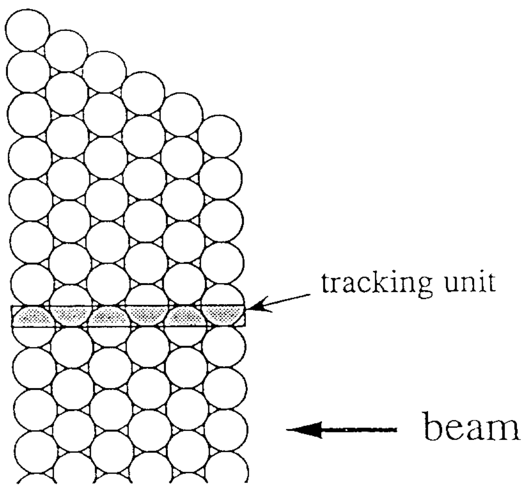


Fig. 4. A picture showing the definition of the tracking unit.

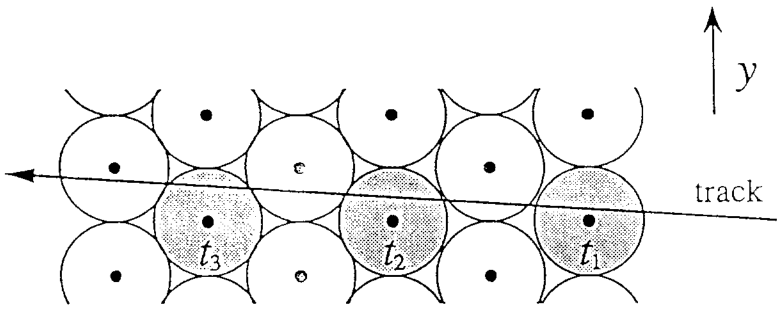


Fig. 5. A picture showing the definition of the straw triplet.

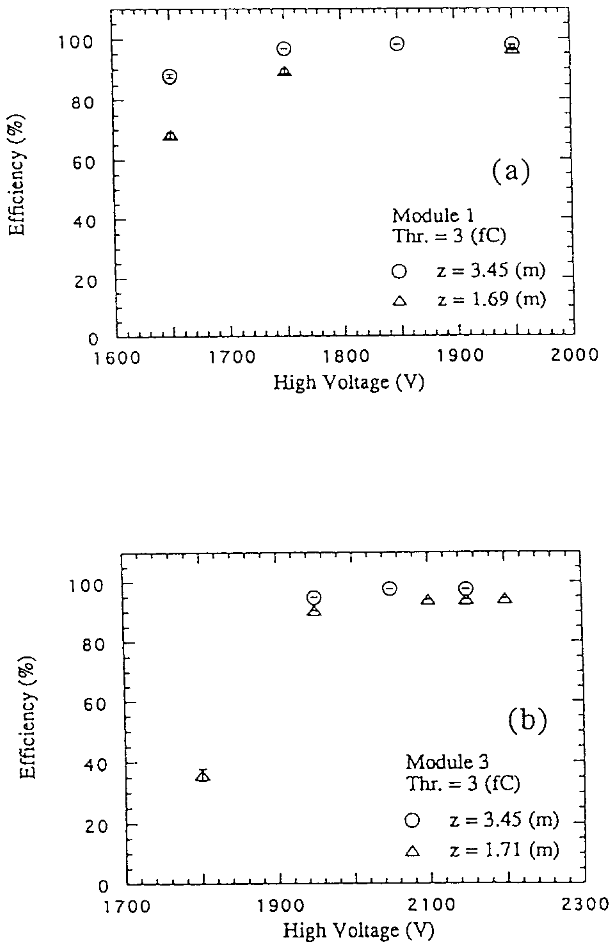


Fig. 6. The average efficiency of each straw, estimated by using a triplet method. Results are presented for (a) module 1 and (b) module 3 as a function of applied HV. The results for two different z positions, z = 1.7 and 3.45 m, are plotted in each figure.

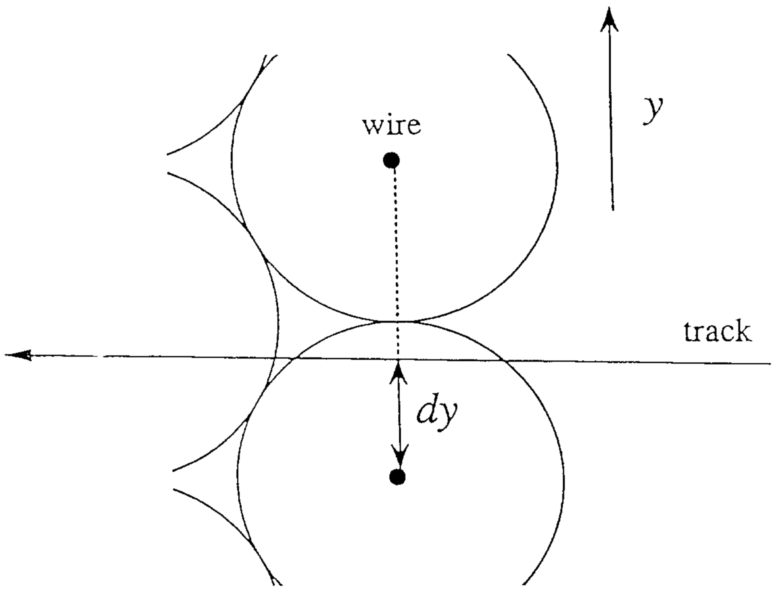


Fig. 7. A picture showing the definition of the track distance, *dy*, which represents the distance between the reconstructed track and the straw chamber wires for the study of the track-distance dependence of the efficiency.

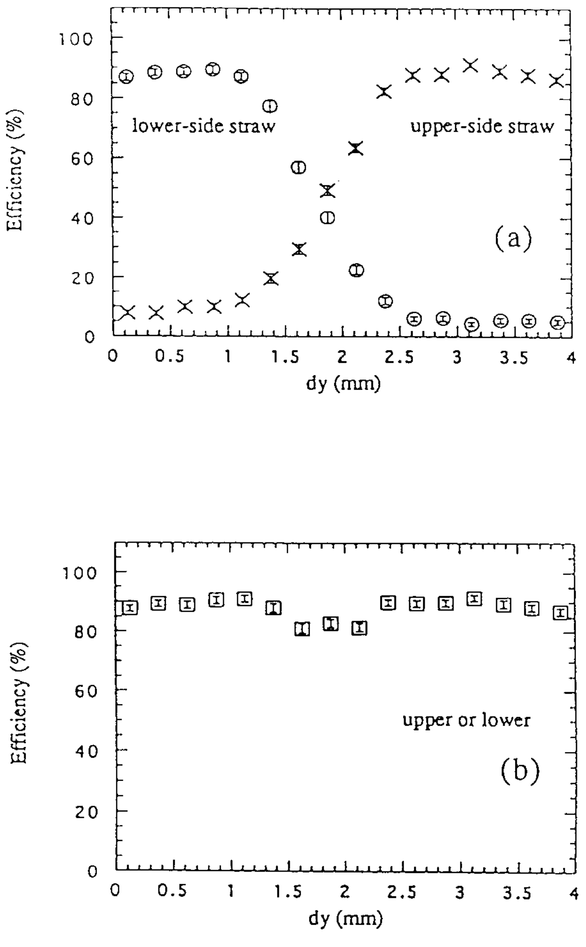


Fig. 8. The efficiency of the straws in module 1 in the standard operation condition, the HV of 1950 V and the discriminator threshold of 3 fC. The results were obtained by using a reconstructed-track method and are presented as a function of track distance. The results for the lower-side straw and the upper-side straw are plotted together in (a), while those for the ORed signal is plotted in (b).

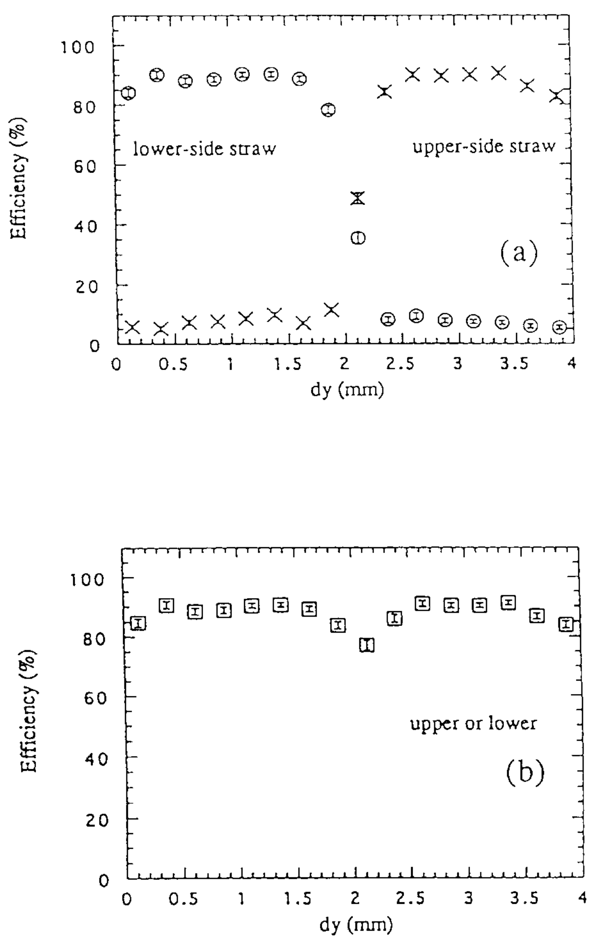


Fig. 9. The efficiency of the straws in module 3 in the standard operation condition, the HV of 2150 V and the discriminator threshold of 3 fC, estimated by using a reconstructed-track method. The notation of the plots is the same as Fig. 8.

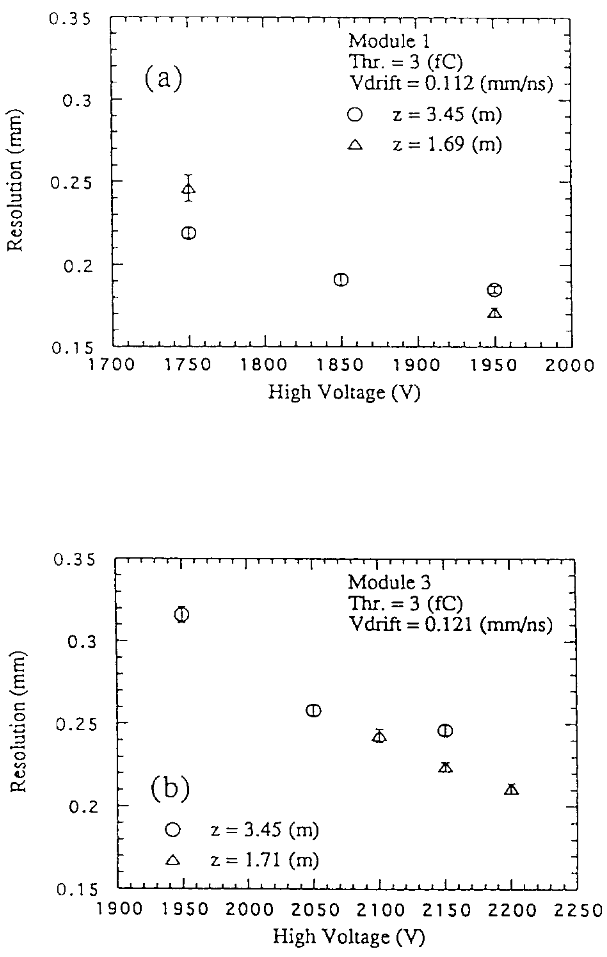


Fig. 10. The average spatial resolution measured by using a triplet method. Results are presented for (a) module 1 and (b) module 3 as a function of applied HV. The results for two different *z* positions, *z* = 1.7 and 3.45 m, are plotted in each figure.

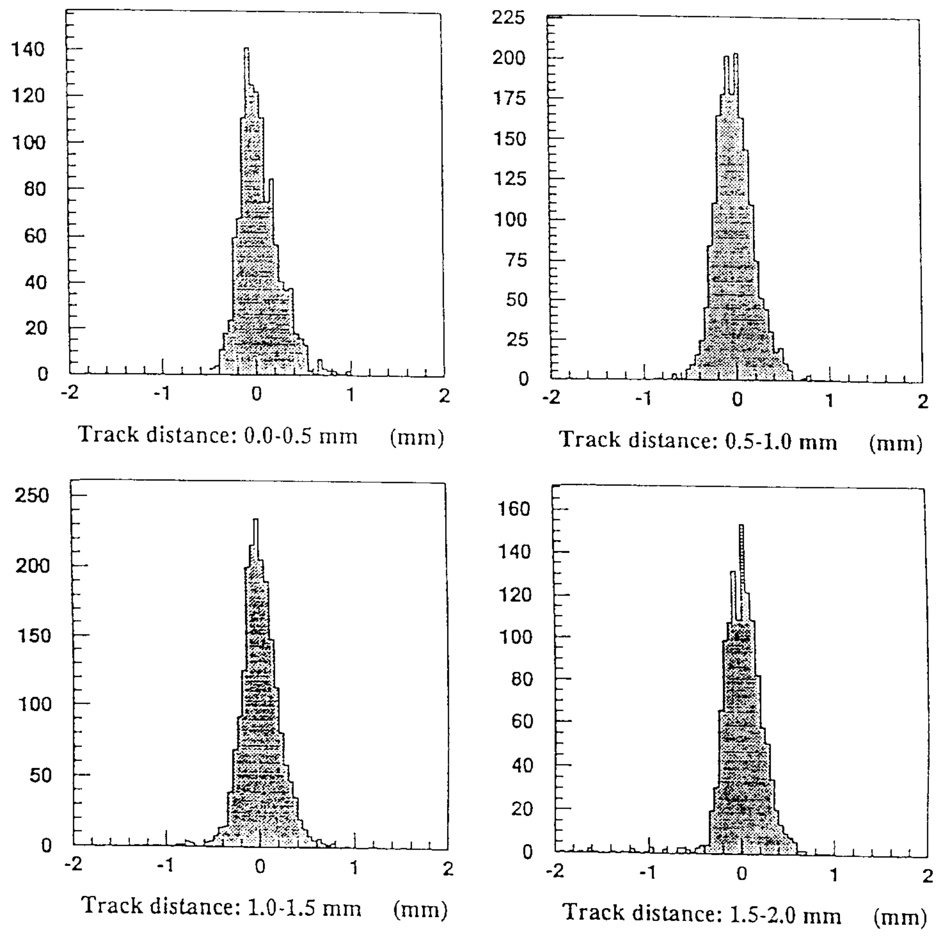


Fig. 11. The dy_{residual} distributions. Results are presented for each track distance for layer-3 or 4 in module 1 in the standard operation condition, the HV of 1950 V and the discriminator threshold of 3 fC.

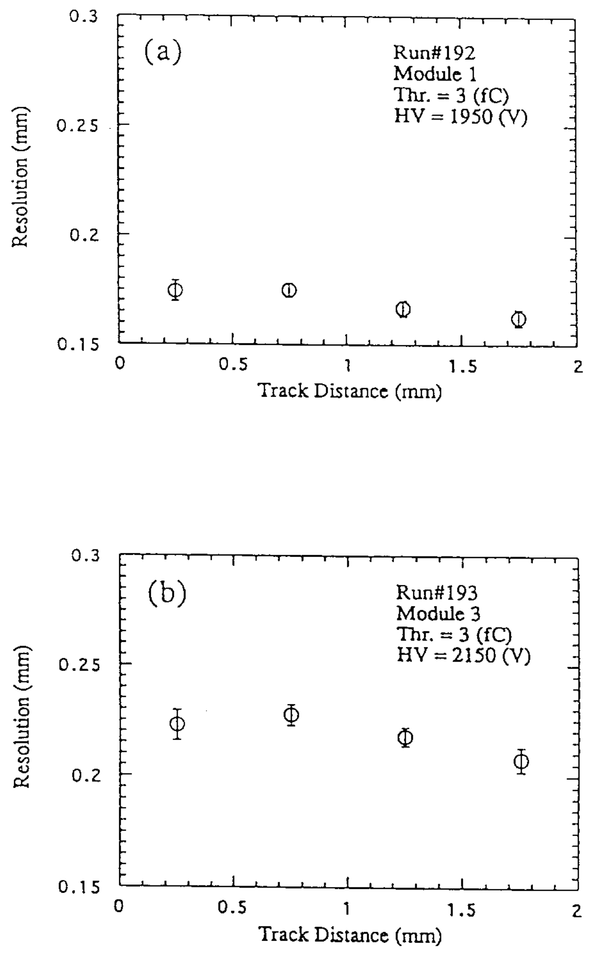


Fig. 12. The spatial resolution as a function of track distance for layers 3 or 4 in (a) module 1 and (b) module 3. The HV was set at 1950 V for module 1 and 2150 V for module 3. The discriminator threshold was set at 3 fC for both modules.