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CONSTRUCTION AND MANUFACTURE OF LARGE SIZE STRAW-CHAMBERS OF THE COMPASS SPECTROMETER TRACKING SYSTEM

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We report the construction and preliminary testing of 3.6 and 3.2 m long straw tube drift chambers consisting of 672 and 864 channels, respectively. The design considerations, the development of several new techniques are described. The 15 two-layer straw drift chambers have been built for the experiment COMPASS at CERN.

Представлена конструкция и результаты предварительного тестирования дрейфовых камер на основе тонкопленочных трубок (строу) длиной 3,6 и 3,2 м. Каждая камера содержит 672 и 864 канала считывания информации соответственно. Рассмотрена конструкция и технология сборки камер, обладающие некоторой новизной. Пятнадцать двухслойных строу-камер изготавливаются для эксперимента COMPASS в CERN.

INTRODUCTION

The use of a large size straw-chamber was suggested as the one most satisfying all requirements of the planned experiments in the tracker structure of the constructed wide-aperture magnetic spectrometer COMPASS [1].

The tracking system using ST2 straw-chambers consists of five modules, each containing three chambers for determination of the X, Y and V (an inclination of 10°) coordinates. Thus, fifteen two-layer straw-chambers with a sensitive area of about 3.2×2.8 m (Table 1) are installed in a small beam space. This sets restrictions on a maximum thickness of each chamber up to a size of 40 mm. The radiation length of the chambers is optimized to a minimum size. Besides, their central part does not contain some matter. To maintain a good efficiency in high radiation beams, the maximum drift length for the central part of the chambers about 1.18 or 1.37 m wide is limited to 3 and 5 mm for the left and right peripheral parts of the chambers. The spatial resolution should be better than 200 microns at a detection efficiency of more than 95 % for charged particles.

The research of straws has been carried out and the prototype with a sensitive size of 2.4×1.2 m has been developed at the Laboratory of Particle Physics, JINR [2, 3]. During a beam test at CERN, the research of this prototype has made an opportunity to construct similar straw-chambers.

1. PROTOTYPE OF THE STRAW-TRACKER

The developed prototype [3] contained two layers of thin-film drift tubes (straws) 2.4 m long. The straws of each layer strengthened by carbonic fibers were glued together in a uniform plane. Two straw-planes tightly pasted in a common frame were assembled of 1.5 m aluminium plates located across the straws and connected with two carbon-plastic profiles 2.5 m long. The inner diameter of 2×97 straws contained in the central part of the prototype was 6.030 ± 0.005 mm. The left and right parts comprised 2×31 straws with an inner diameter of 9.530 ± 0.005 mm (Fig. 1). To eliminate left-right uncertainty for determination of the coordinates of detected particles, the straws of the first layer were shifted to those of the second one by a half-diameter step.

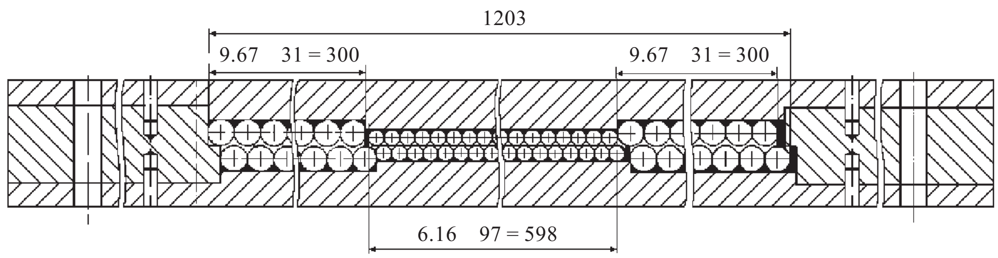


Fig. 1. Cross section of the ST2 detectors prototype

The central area of the prototype 200×200 mm in size was insensitive to charged particles. It was provided with internal mylar tubes 4 mm in diameter and about 200 mm long installed on the anode wires of each straw in this zone [2].

The beam test of the prototype at CERN has shown that a spatial resolution of 150–200 microns can be obtained for straws about 3 m in length and 6–10 mm in diameter. The design and manufacturing technology of the prototype were further used as the basis to construct ST2 chambers.

2. DESIGN OF THE CHAMBERS AND ASSEMBLY METHOD

2.1. General Principle. As with the prototype, each two-layer chamber contains straws with an inner diameter of 6.02 mm in their central part and with an inner diameter of 9.53 mm for the other area. The straws are stuck and glued together as a uniform plane, and the two planes shifted by the value of straw radius are pasted on the appropriate aluminium elements of the chamber frame (Fig. 2); and pasting is tight in the direction orthogonal to the arrangement of the straws. At a subsequent assembly, this allows one to make two gas-tight volumes used to blow out both straw-planes with a working gas mixture (Fig. 3). Motherboards for anode voltage feed to each straw of both planes and information readout from them are mounted as a continuation of the Al element frames on the one side of the straw-planes and motherboards for straw anode termination on the opposite side. Low-voltage feed buses and connectors for readout cards are then placed. It should be noted that the termination of 2×64 straws in the area of the central insensitive zone is carried out from their internal ends and readout from the opposite sides of the chamber. The total thickness of the frames of each chamber is 40 mm. Table 1 presents geometric dimensions of the module chambers.

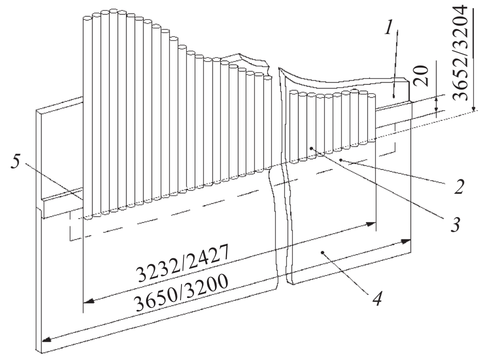


Fig. 2. Glueing the straw-plane with the orthogonal Al rods oriented across the straws: *1* — bottom element of the Al frame made with an accuracy of better than 0.1 mm; *2* — boundary dimensions of the future total gas volume; *3* — straw-plane; *4* — Al element used to place peripheral elements of the chamber; *5* — area of tight strong pasting the straw-plane with the Al element

As distinct from the prototype, a moisture-proof varnish is not applied to the straw-plane, and the straws are not reinforced with carbon wires. Four carbon-plastic strips, tensioned and fixed in the frame elements and pasted to each straw, are placed across the straws. To install an individual straw in the frame, a tension of about 1.0 kg [4] is required for keeping its cylindrical shape. The installation of monolithic straw-planes into the chamber frame allows one to lower significantly a load on the frame elements, but it imposes certain requirements for plane manufacturing technology.

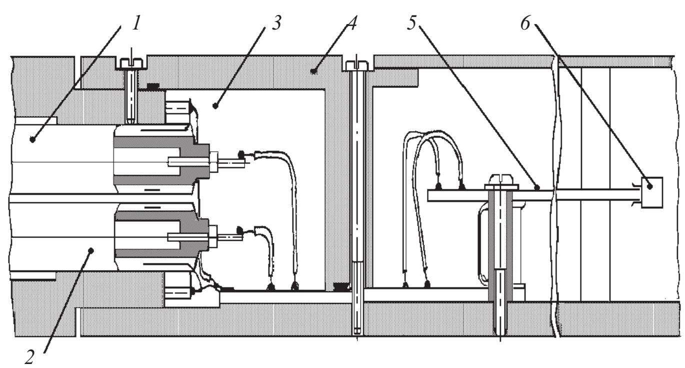


Fig. 3. A scheme of the gas volume and a peripheral part of the chamber: *1, 2* — bottom and top straw-planes; *3* — gas volume; *4* — demountable cover of the gas volume; *5* — readout; *6* — connector used to install a readout map

Table 1. **Parameters of the X, Y and V chambers of a ST2 module**

Type	Sensitive area, mm	Length of straws, mm	Number of straws with different outer diameter 6.144 mm	9.654 mm	Number of readout channels	Overall dimensions, mm
Y	3254×2427	3652	320	256	704	4567×3160
		1752	128			
X	2802×3232	3202	380	384	892	4117×3570
		1523	128			
V	2802×3232	3202	380	384	892	4117×3570
(10°)		1523	128			

2.2. Straw. Coated kapton-kapton ($2K_{\mathrm{Coated-C}}$) straws with an inner and outer graphite cover similar to those in TRT ATLAS [5] were used to construct the prototype. To manufacture the ST2 chambers, straws made by the LAMINA firm ($KK_{\mathrm{Loaded-C}}$) and also mylar-capton straws ($MK_{\mathrm{Loaded-C}}$) were used in part. These straws were wound of two strips: an external strip of kapton HN50 (or mylar) film 12 microns in thickness and an internal one of conducting kapton XC-160 film [6] 40 microns in thickness with a graphite loading. In all cases, the thickness of the straw walls was close in value. The best mechanical properties of «symmetric» ($2K_{\mathrm{Coated-C}}$) straws, wound up of equal-in-thickness strips should be noted. Each type of straws has its disadvantages. Some of them should be noted:

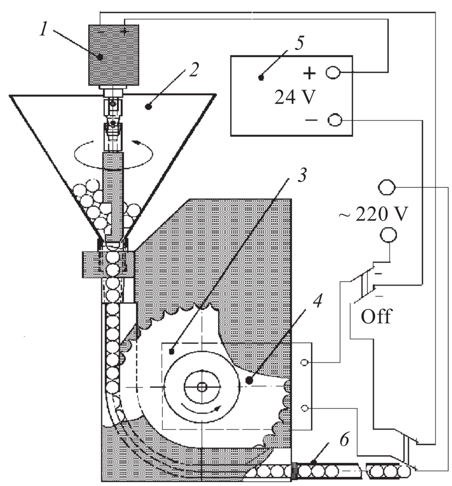
— an increased tendency to the Malter-effect [7] for ($KK_{\mathrm{Loaded-C}}$) and ($MK_{\mathrm{Loaded-C}}$) straws because of the production technology of conducting kapton loaded film;

— some probability to fall off a graphite cover when spacers are being mounted into the $2K_{\mathrm{Coated-C}}$ straws;

— low adhesion of ($MK_{\mathrm{Loaded-C}}$) straws to glue at their pasting.

The straws with an internal diameter of 6.02 (-0; $+0.025$) and 9.53 (-0; $+0.025$) mm and a wall thickness of 0.062 mm were used. However, the accuracies of the inner diameter were really within (-0.01; $+0.035$).

2.3. Straw-Planes. Before assembling the plane or its fragments, each straw was filled with precision steel balls 6.010 ± 0.003 and 9.525 ± 0.003 mm in diameter for a straw of the corresponding diameter. In this case, the balls were carried automatically, and it took about 2 min to fill the straw 3.6 m long. Then, the plane fragment was assembled on a precision table, and one straw after another were pressed to a precision ruler. After that, all neighbouring straws were glued together. For this, Ruetadur SL/Ruetapox L20 (Bakelate AG) glue was used, and the amount of the used glue did not exceed 60 % of the weight of the pasted straws. Schemes of the devices, developed for this, are given in Figs. 4 and 5. In addition, four carbon 0.5×9 mm strips were pasted at equal distances to fix the fragment width on one of their sides in the direction orthogonal to the straw. After the balls were removed, three fragments (a central one, consisting of 6.02 mm diameter straws, and also left and right fragments comprising straws 9.53 mm in diameter) were mounted in a common straw-plane on a large precision table. The step uniformity of positioning each straw in a fragment depends on the accuracy of plastic rods used as plug elements and also on the precision of straw production: it is within 0.1 mm. Each ready-made plane is tightly pasted



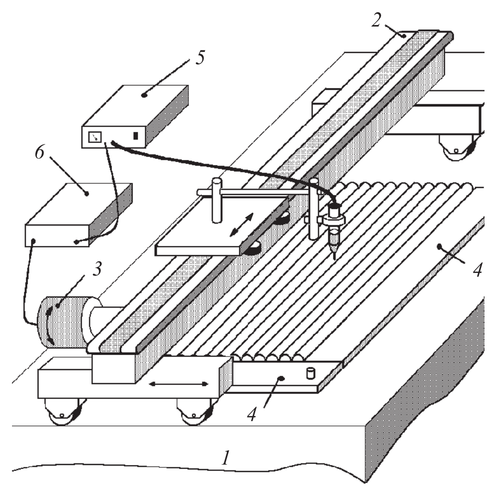


Fig. 4. Kinematics of filling the straw with precision balls. The mixer with engine (*1*) and volume (*2*) containing precision balls; pushing gear (*3*) with engine (*4*); power unit (*5*); straw (*6*)

Fig. 5. Kinematics of gluing a fragment of the straw-plane. Precision table (*1*); linear module (*2*) with engine (*3*) used to move a syringe with glue along the straws; precision rulers (*4*); glue dispenser (*5*); control block (*6*)

to two Al rods. Then, the two-layer chamber is assembled and is prepared to install anode wires in the straws. Araldite 2011, BK-9, and ALK-5 [8] are used to glue the planes.

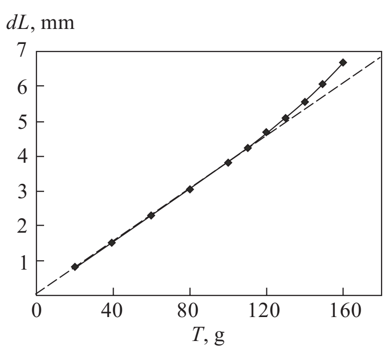


Fig. 6. Dependence of linear lengthening of a 1 m long anode wire on its tension

2.4. Straw Internal Elements. The type 861 (Luma firm) gold-plate tungsten wire 30 microns in diameter is used as anodes for thin-film drift tubes. Figure 6 shows the value of wire elongation depending on wire tension.

The limit of elastic deformation is about 120 g. Polycarbonate end-plugs made by the method of pressure moulding are used to fix the wires at the straw ends (Fig. 7). These elements are inserted into the straw against their stop. This excludes their displacement later on. The diameters of the end-plugs are 9.5 ($+0$; -0.022) and 6.0 ($+0$; -0.018) mm for the corresponding straws. There are grooves on the outside surface of the end-plugs to connect the internal straw volume to that common to all the straws; this gas manifold is used for their blowdown. There is also a gutter to install a ring contact spring which allows one to connect the cathode to the common «ground» of the chamber. These elements are identical to all straws except those located in the central insensitive zone. The straw-chamber is placed in the vertical position, and the wire passes through the end-plugs and the tube. The wire goes through the Cu pins [9, 10] inserted in the end-plugs. The top pin is then crimped, the wire is tensioned to 90 g, and the bottom pin is finally crimped after.

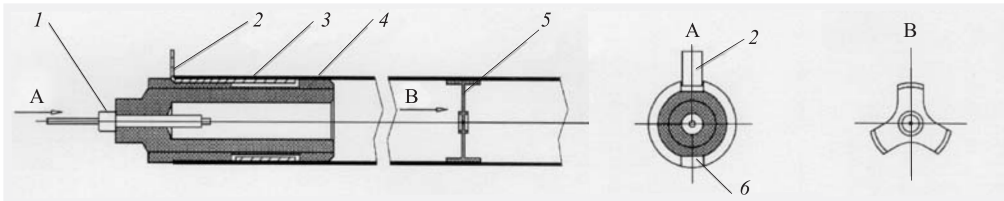


Fig. 7. A scheme of straw (*1*) with inserted end-plug (*2*) and spacer (*3*). Pin (*4*) for fixing an anode wire, ring spring (*5*) for grounding the straw cathode, gas channel (*6*)

To decrease a gravitational and electrostatic displacement of the wires, four spacers with central hole 0.1 mm in diameter also made of polycarbonate by the method of pressure moulding are placed at equal distances (Fig. 7). To reduce an insensitive zone in the vicinity of the spacers, their dimensions and mass are minimized, and so their diameters are 9.49 ($+0$; -0.022) and 5.97 ($+0$; -0.018) mm and the mass of one spacer is 25 and 15 mg for the straws of the corresponding diameter. The spacers are pasted on the anode wires with Araldite 2013 glue before mounting the wires in the straws. The use of special tables for these operations provides an exact spacer position for all the chambers.

A typical distribution of wire tension after their installation is given in Fig. 8. It is seen that the tension is within 90 ± 10 g for approximately 95 % wires and within 90 ± 15 g for all the wires. All the straws are checked after their complete assembly and electrical soldering of the chamber. During this check, about 2–3 % anode wires are mainly replaced because of their breakage or fouling on the spacer.

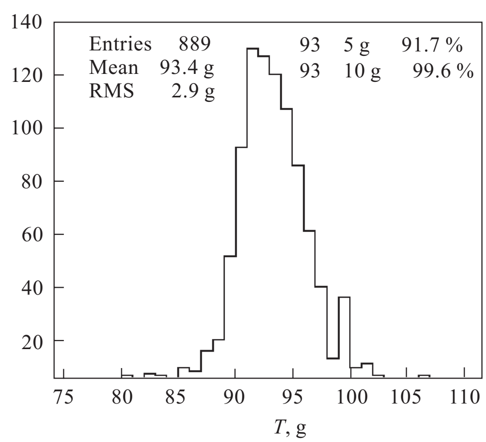


Fig. 8. A typical histogram of wire tension in the chamber

2.5. Central Insensitive Zone. The central 126×194 mm area of each chamber containing no matter is «transparent» for a beam of particles. In this area, two short straws are pasted in the plane instead of one long straw (Table 1). Readout from them is performed from their outside ends. Special polycarbonate end-plugs (Fig. 9) are used for the internal straw ends. Wire crimping pins, a thin-walled (0.1 mm) metal tube used to connect the straw gas volume to the gas manifold and a RC termination chain are linked to the cathode straw. Each plane of the chamber contains two identical gas manifolds which represent two thin-walled fiber-glass laminate boxes $230 \times 15 \times 9$ mm in size. These boxes are connected one to another with two special film tubes. The gas manifolds are placed on metal tubes of the corresponding straws. All connections are tight.

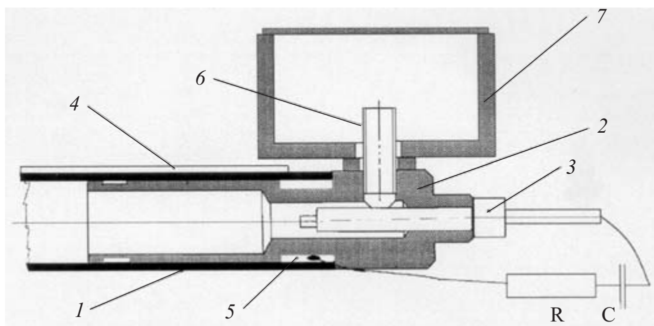


Fig. 9. A scheme of the internal end of straw (*1*) in an insensitive zone; end-plug (*2*) with wire-fixing pin (*3*); fiber glass frame (*4*) 1 mm in thickness, 230×220 mm in size and with an internal hole of 200×200 mm; ring groove (*5*) for hermetic straw sealing and connection of the termination RC chain to the cathode; metal tube (*6*); gas manifold (*7*)

An additional matter is located in the «frame» zone around a beam aperture limited to 126×194 mm and 220×230 mm, respectively. The radiation thickness in this chamber zone is 2.0 % X° when the radiation thickness of the sensitive area is equal to 0.2 % X° (without taking into account a gas mixture in the straws).

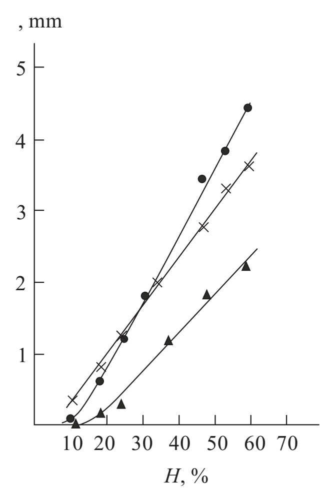
3. DEPENDENCE ON TEMPERATURE AND HUMIDITY

At temperature changes, the difference of expansion coefficients $\Delta\alpha$ for Al and kapton ($23.2 \cdot 10^{-6}$ K^{-1} and $18 \cdot 10^{-6}$ K^{-1}, respectively) leads either to the appearance of an effort, stretching the straws additionally, or to their curvature. The relation between the change of temperature T and a maximum deviation of S from the straightforwardness of the straws of length L not loaded preliminarily is large and can be estimated by the expression:

$$\Delta T = 3S^2/L^2\Delta\alpha.$$

It is obvious that a 1 K temperature increase results in a sagitta of up to 4 mm for a straw length of 3.2 m. In our case, this value decreases to 0.8 mm as we use four orthogonal supporting carbon strips. Besides, an excess of the working temperature of the chamber over the temperature of its assembly leads to some expansion of part of the straw-plane located between the frame Al rods and the neighbouring carbon strips in the direction orthogonal to the straw position. The maximum change of the plane width near the Al rods is about 75 microns per K degree at a straw-plane width of 3.2 m.

To estimate the value of elongation with increasing humidity, the straws of different types (($2K_{Coated-C}$), ($KK_{Loaded-C}$) and ($MK_{Loaded-C}$)) 3.2 m long and 6.02 and 9.56 mm in diameter were placed in a tight box, where they were under fixed air humidity for a day. Figure 10 shows a straw elongation depending on humidity. It is seen that the value of lengthening is 16.6, 29.2 and 21.0 microns per 1 m for a straw of the ($2K_{Coated-C}$), ($KK_{Loaded-C}$) and ($MK_{Loaded-C}$) types and for a humidity change of 1 %, respectively. The check has shown that the length of the straws is kept after drying them with dry air, i. e., the straws have an elastic deformation range. Figure 11 presents the change of ($KK_{Loaded-C}$) straw length in time at a constant temperature and humidity. The straw 3.2 m long was under a constant load of 12 g. The straw length increased approximately by 2.3 mm after increasing a load by 500 g, and it continued to increase slowly under this load for 5 days. After removing a load of 500 g, the straw length decreased and practically returned to its initial value after 2 days.



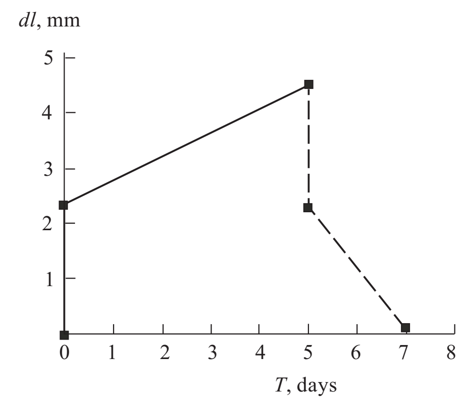


Fig. 10. Lengthening of the 3.2 m long straw depending on air humidity: • — $KK_{Loaded-C}$ straw; × — $MK_{Loaded-C}$; ▲ — $2K_{Coated-C}$

Fig. 11. Lengthening of the 3.2 m long straw under a 500 g load and without it

The presented results show that it is worth-while to install the straw-planes in the chamber frame at a temperature which is no higher than the chamber working temperature and humidity no smaller than it will be further on. It is possible to compensate the difference of working and assembly temperature/humidity by applying additional compressing efforts to the frame Al elements during this procedure.

4. TEST OF THE CHAMBERS

After assembly works, the produced chambers are checked against tightness and functioning of all information channels. As a rule, the value of gas leaks is 50–80 cm^3/min. Note that the gas volume of the chamber (without taking into account the volumes of the gas manifolds) is about 126 l for the X, V chambers and 104 l for the Y chamber.

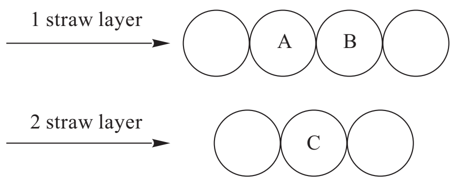


Fig. 12. A scheme of measurement of the cross-talk of the chamber readout channels

The chamber channels are tested with the help of a ^{55}Fe source by a test amplifier. Identity of the following parameters is checked: gas gain uniformity of all the channels at a fixed anode voltage, signal attenuation along the straws, and a level of own noises. The measurements are made at a gas gain of $2 \cdot 10^4$ and 10^5; an Ar/CO_2 (80/20) mixture is used. During the check, the anode wires are replaced by some defective channels.

The cross-talk value was tested for the scheme given in Fig. 12. Using a Fe-55 source or a pulse generator, the values of induced signals for the neighbouring straws were measured. The induced signals of the B and C straws were measured in the percentage of the signals registered for the A straw. The results are given in Table 2. As seen, the readout boards (MB and TB), mounted around the chamber periphery, make a main contribution to the value of an induced signal.

Table 2. **Cross-talk value**

Straw diameter, mm	Scheme of measurement	Cross-talk value, %			
		MB	TB	Straw	Amount
9.56	A–B	0.33	0.45	0.42	1.2
	A–C	0.94	0.51	0.29	1.76
6.03	A–B	0.44	0.40	0.66	1.5
	A–C	1.1	0.55	0.41	2.05

CONCLUSION

The developed design of the large area straw-chambers and the development of their manufacture technology allow one to build 3×4 m tracking straw-chambers at a high accuracy of their manufacturing The coordinate accuracy of the chambers is mainly determined by the parameters of readout electronics and the precision of detector manufacturing. The developed technology provides a production accuracy of better than 100 microns and can be improved using straws having both more precise dimensions and assembly equipment.

Both the performance of assembly works and the operation of the detectors require to keep certain climatic conditions. The stabilization of working temperature should be within one degree K. This is a typical requirement to drift chambers. Air humidity should be within the range determined by the manufacturing technology.

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