JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE START PROGRAMME

Gas leak measurement in straw detector

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Abstract

In this paper, we study the design and leak tightness testing of detectors built on the basis of thin-film drift tubes widely used in particle physics. The main components of the detector design used to make tubes are discussed.

Special attention is paid to leak analysis, which is crucial to ensure the reliability of detectors used in high energies and high background radiation environments. The results of the study emphasize the importance of high-quality assembly and testing of detectors in achieving high measurement accuracy in modern physical experiments.

CONTENTS

Introduction

Gas coordinate detectors have been the basis of the tracking systems of modern physical installations for decades, but despite this fact, they continue to be actively developed. In recent years, their modifications, such as time projection detectors (TPCs) and detectors with sub-millimeter recording elements based on gas electron multipliers (GEM and Micromegas), have become widespread. The special interest in these detectors lies in the fact that they can operate under high-load conditions and are characterized by good radiation resistance and spatial resolution of about 100 microns. However, typical drift chambers based on metal drift tubes effectively covering large areas are also undergoing a rebirth with the advent of thin-film drift tube (straw) technology, which allows to use more flexible design solutions that offer low cost per unit of sensitive area and have such an important advantage as a small amount of substance in the core. These features of straw tubes have led to their active use in search experiments aimed at the registration of super rare decays and the search for manifestations of new physics, where special requirements are imposed on the "transparency" and efficiency of tracking systems.

1. Detectors based on thin-film drift tubes (straw detectors)

Thin-film drift tube detectors are devices used in high-energy physics to detect and measure charged particles. They operate on the principle of ionizing gas (usually an Ar/CO2 mixture in a ratio of 80/20% or 70/30%) located inside a tube and measuring the resulting electrical signals.

When a charged particle passes through the tube, it collides with gas molecules, causing ionization. As a result, ions and electrons are produced.

Under the influence of an electric field, electrons produced as a result of ionization begin to drift to the anode tube, while ions move to the cathode.

As electrons move toward the anode, they collide with other gas molecules, causing additional ionization. This process is called avalanche multiplication and results in significant signal amplification.

An electrical pulse is generated when the electrons reach the anode. It can be recorded and analyzed.

Drift tubes are often used in accelerators and other experiments designed to detect and analyze particle traces. They can also be part of complex systems, such as spectrometers, where particle energy needs to be accurately measured.

Drift tubes are relatively simple to manufacture and operate. They provide consistent results in a variety of conditions.

In some cases, they may be less sensitive than other types of detectors, such as scintillation or semiconductor detectors. Regular calibration is required for accurate measurements.

Figure 1 shows a straw detector with a working area of 200x200 mm, consisting of 64 thin-film drift tubes connected to two 32-channel motherboards that provide high voltage supply to the straw and retrieve information from them. 32-channel amplifiers are connected to the power boards. When conducting experiments, 64-channel time-to-digital converters (TDCs) will be connected to the motherboards.

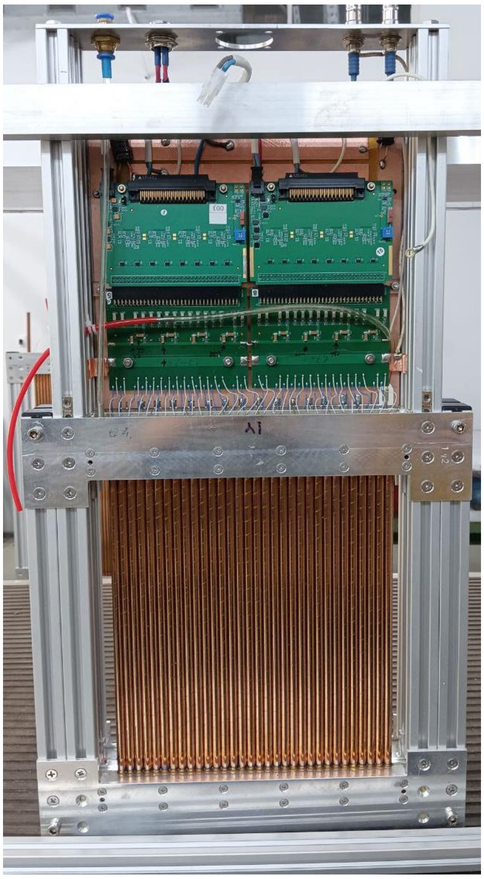
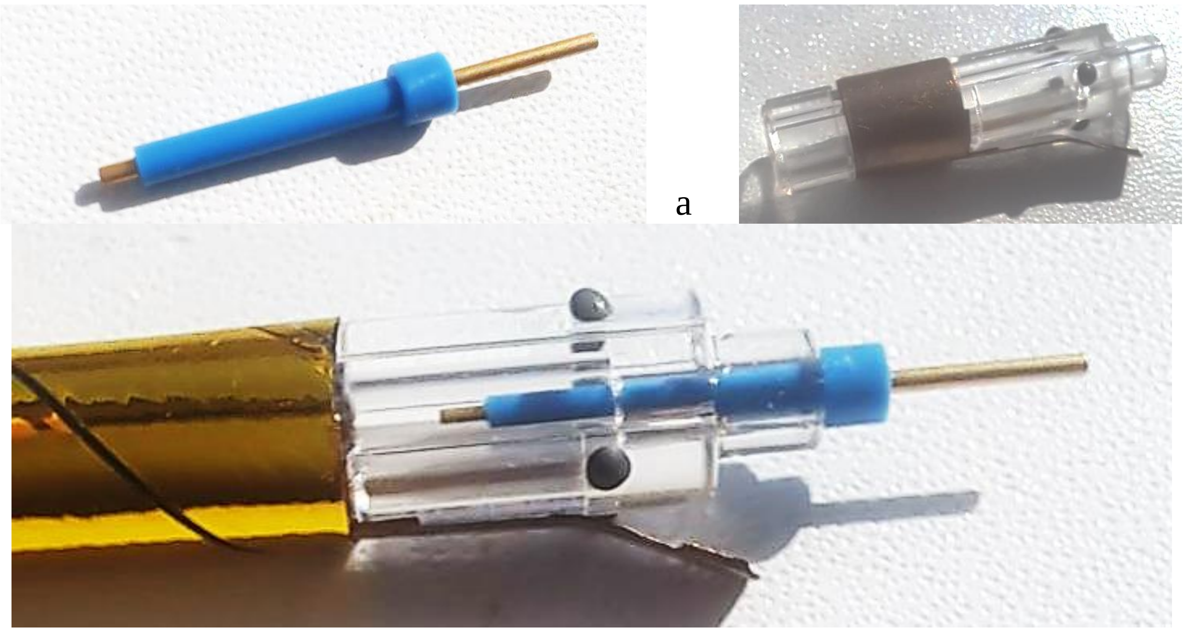


Figure 1: Overall view of the assembled detector based on thin-film drift tubes for the test area of the NICA-SPD experiment in Dubna.

2. Thin-film drift tube design

A thin-film drift tube (straw) consists of a precision polymer tube, the inner surface of which is conductive and serves as a cathode, with an anode wire installed along the axis of the tube, the ends of which are crimped in capillary tubes (pins), secured with plastic ring bushings (end plug). Anode wires must be tensioned (tension of 60–90 g) to reduce gravitational and electrostatic offset from the straw axis [5]. An overall view of the assembled tube is shown in Figure 2.



a b c

Figure 2: a) A crimp pin for securing the anode wire; b) A plastic ring bushing (end plug) with ring spring for grounding the straw cathode; c) Overall view of the assembled straw tube.

According to their mechanical characteristics, thin-film polymer tubes can be divided into two types: asymmetrical and symmetrical. An asymmetrical tube is formed by using ultrasonic welding technology and metallized lavsan (Mylar) tape of the required width. At the welding point, the metallization is sublimated, forming a longitudinal non-conductive seam of 0.5–1 mm width on the tube. Figure 3 shows an overall view of a symmetrical tube made by winding two polyimide (Kapton) strips shifted between each other by half their width, as well as a section of the straw wall [1]. The strips of the inner layer of the tube wall have a conductive coating on their inner surface and a layer of hot-melt adhesive on the outer surface, while the strips of the outer layer are metallized and covered with hot-melt adhesive on their inner surface. Tube winding is carried out on a heated calibrated rod, while two layers of its wall are thermally glued together at the same time. Polyimide (Kapton) has better radiation resistance, and lavsan (Mylar) has lower hygroscopic expansion and gas permeability. An overall view of the machine used for the production of thin-film polymer tubes is shown in Figure 4 [4].

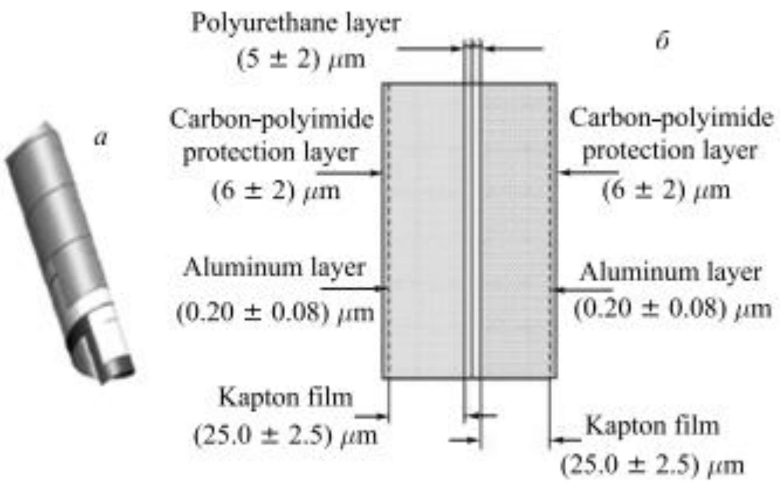


Figure 3. a) Overall view of a symmetrical tube wound from two Kapton strips; b) Cross section of the straw wall.

Figure 4. Overall view of the machine used for the production of thin-film polymer tubes.

Symmetrical tubes are characterized by high cylindricity and uniform diameter regardless of their length. Typically, straws with a diameter of 4 to 10 mm are used [4].

Depending on the straw length, gold-plated tungsten wire with a diameter of 20 to 30 μm with the addition of 3% rhenium, which increases the range of its elastic elongation, is usually used for the anode [4].

3. Straw tube leak tightness testing

Before installation into the detector, all straws undergo testing of various parameters. One of the main tests is a leak test. For example, during the manufacture of ring detectors for the ATLAS LHC installation at JINR VBLHEP, more than 120 thousand reinforced straws with a diameter of 4 mm were tested for leaks. In order to measure the gas leakage, 8 straws were placed inside a sealed box and filled with argon gas at excess pressure relative to the pressure inside the box [2]. The magnitude of the leak was determined by the change in pressure in the box. The results were displayed on the PC display. This complex device can only be used to test straws with a diameter of 4 mm and a limited length. The manufacture and use of such a complex device is justified if there is a large-scale production of the same type detectors.

When carrying out test work at JINR VBLHEP and manufacturing a small number of straw detectors, straws of different diameters and lengths are used. It was necessary to develop a simple and universal device for testing the leakage of original straw tubes with different parameters before using them to manufacture track detectors.

The following scheme was used for straw tube leak tightness testing: a half-metal tube 30 mm long with an outer diameter that fit tightly into the straw was inserted into one end of the straw tube. The other end of this metal tube was attached to a hose that supplied compressed gas and had a pressure gauge for monitoring the pressure in the straw. A solid metal plug was inserted into the straw from the other end. To seal both ends of a straw with metal inserts, sealing clamps called “straw clamps” of the same design, not connected to each other, were used (Figure 5).

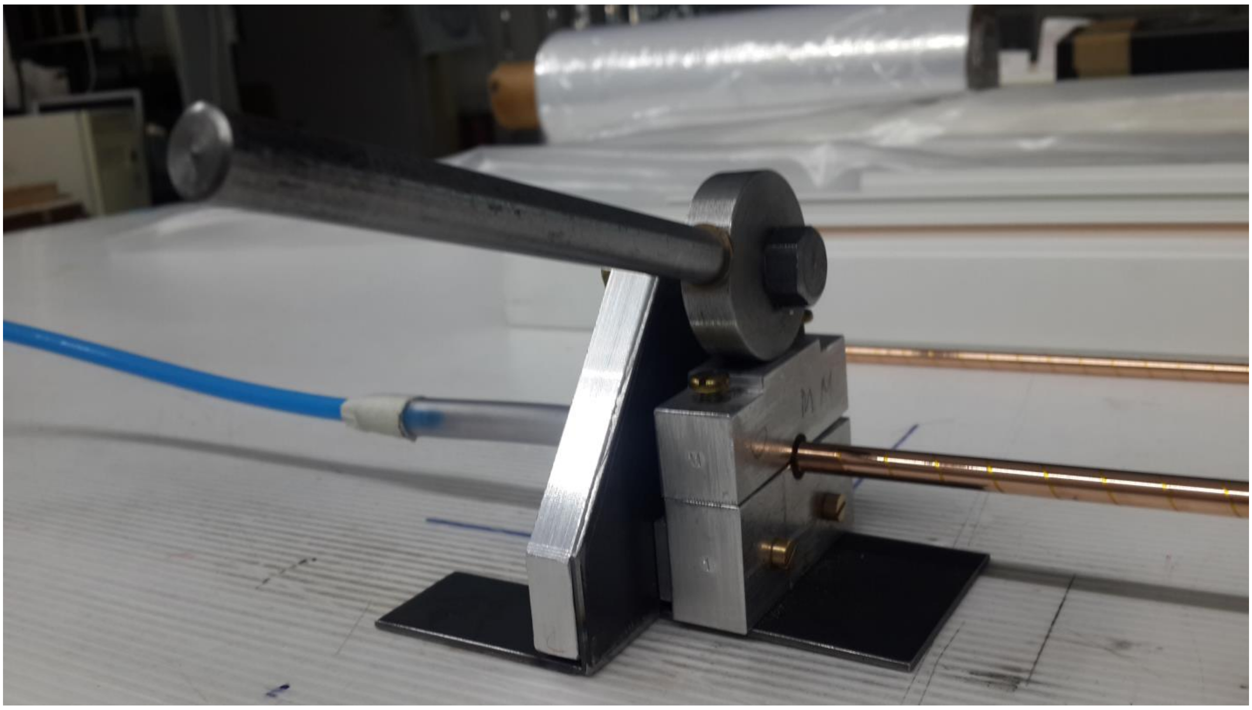


Figure 5. “Straw clamps”.

As can be seen in Figure 5, the straw is connected to a compressed gas supply hose. There are two clamps installed on the “straw clamp” — an unmovable lower one and a movable upper one, both with a cylindrical recess in the middle corresponding to the diameter of the straw being tested. These recesses are covered with a sealing rubber or silicone material. A matching pair of easily replaced clamps is used for straws of different diameters. This helps to increase adaptability of the device as it can be used to test straws of various diameters and lengths.

Figure 6. Overall view of the assembly for testing the leak tightness of straw tubes.

Figure 6 shows an overall view of the assembly for testing the leak tightness of straws with a diameter of 6 mm and a length of 2.5 meters, manufactured at JINR VBLHEP. To conduct the test, compressed gas is supplied under a high (for thin-film straw tubes) excess pressure of 2 atm. A valve switches off the compressed gas supply to the assembly (a hose with a pressure gauge and a straw with clamps), while the pressure gauge monitors the pressure in the straw. In case there is some kind of leak tightness defect in the straw, the pressure quickly drops to zero within a maximum of 5 seconds. Such straws are discarded. After testing is completed, the pressure in the assembly is released, and it is disassembled.

The straw was kept under a pressure of 2 bar for 15 seconds. This time is enough for even a very small leak to manifest itself. The average time for testing one straw is 2-3 minutes, which allows to check a significant number of straws in a short time.

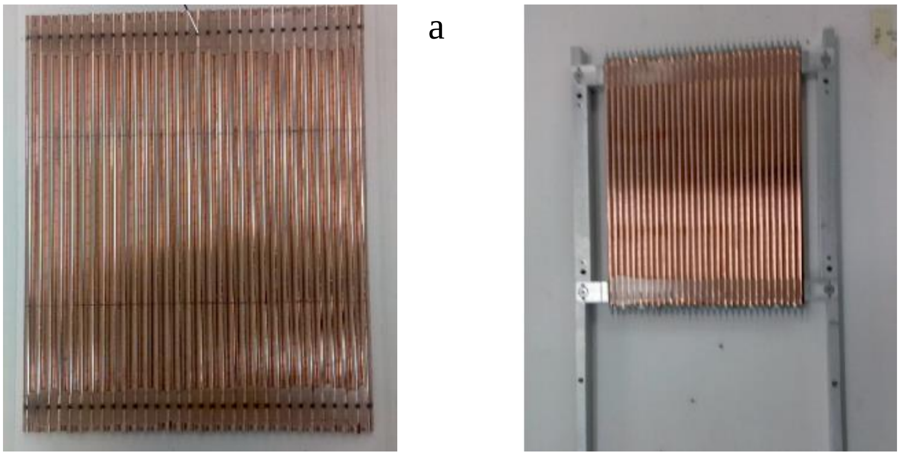
JINR VBLHEP workers tested 900 straw tubes with a diameter of 6 mm, and only 8 of them were defective. This indicates the high quality of the straw tubes. JINR VBLHEP workers also tested the tightness of 400 straws with a diameter of 2 mm and a length of 75 cm and discarded only 3 of them.

These straws (2 mm and 6 mm in diameter) are used to manufacture straw detectors for the NA 64 experiment at CERN [4].

4. Construction of straw chambers for the test zone of the NICA-SPD experiment in Dubna

Each chamber contains two separate planes of tubes glued together, shifted by half the diameter of the tube.

In order to ensure a more even gas supply, as well as to reduce the amount of substance, VBLHEP workers developed a system for injecting gas into the working volume of the chamber through the side walls of the straw. Gas is supplied to each straw plane independently. To do this, a laser beam cuts holes in each straw at both ends in a pre-glued plane of straws (Figure 7, a).



a b

Figure 7. a) Plane of straws with holes cut out for gas injection; b) Plane of straws glued into the frame.

A chamber frame with a slot for supplying the gas mixture is hermetically glued to each assembled layer of straw exactly where the holes were cut out for gas injection. Each plane of the straw is glued into the aluminum elements of the chamber frame, as illustrated in Figure 7 b, and then the two planes are connected into one two-layer chamber with a shift of the planes relative to each other by the straw radius.

After assembling the planes, anode wires are installed inside the straws, the ends of which are crimped in capillary pipes (pins) (Figure 8), secured with plastic ring bushings (Figure 9). Anode wires must be tensioned (tension of 60–90 g) to reduce gravitational and electrostatic offset from the straw axis [5].

5. Assembled straw chamber testing

After assembling straw chambers, it is necessary to test the finished chamber for leaks in the gas system. To do this, the camera is connected to the “gas control panel” (Figure 8, Figure 9).

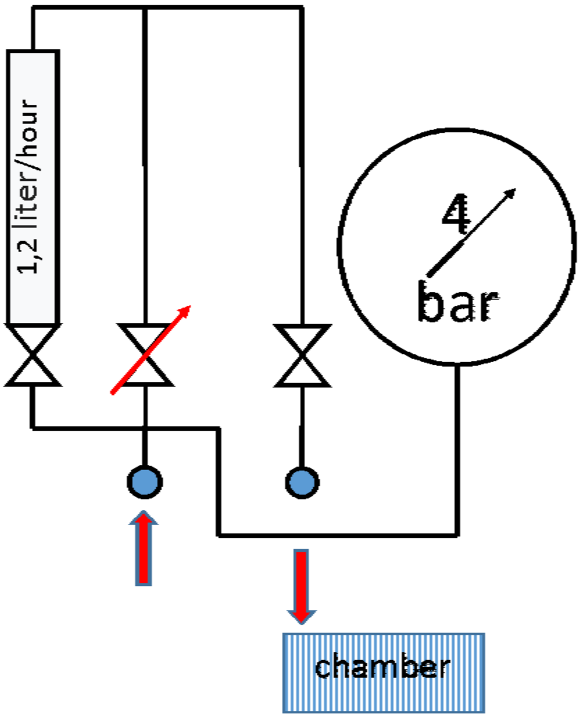


Figure 8. Scheme of the gas control panel.

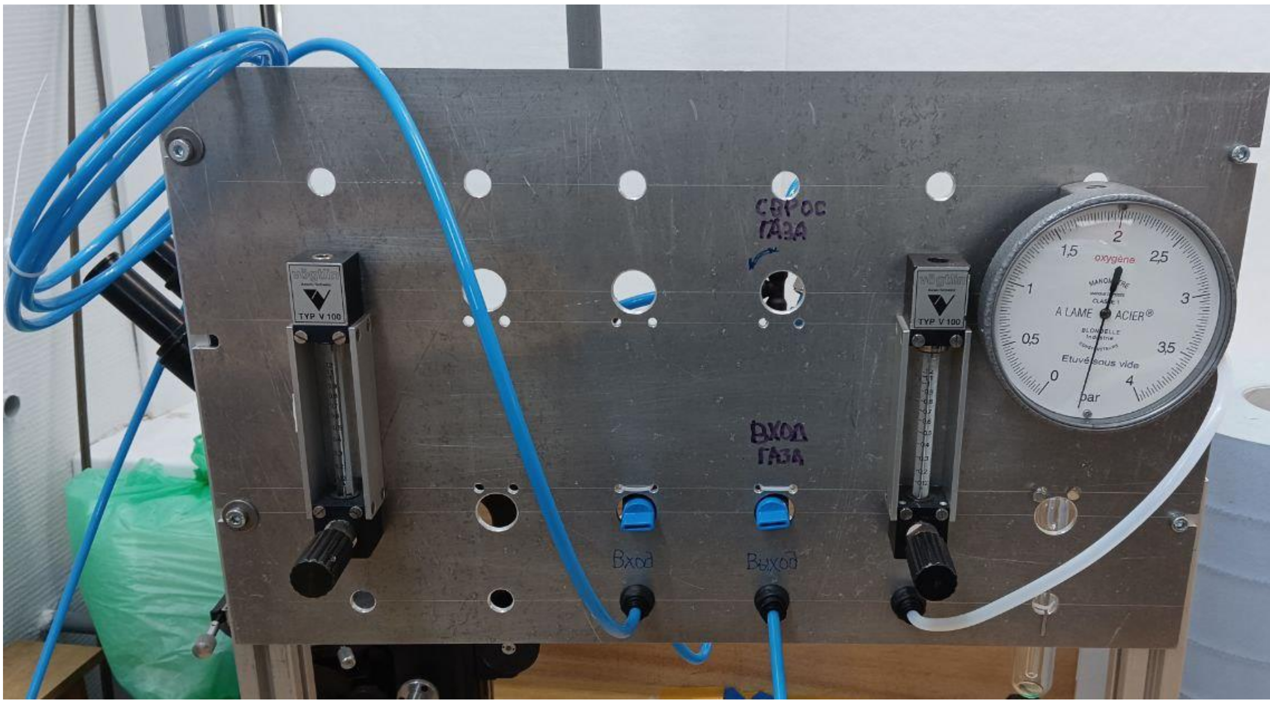


Figure 9. Overall view of the gas control panel.

Since the straw chamber consists of two planes connected into one two-layer chamber with a shift of the planes relative to each other by the straw radius, it is necessary to connect the two layers to each other. The gas system of the straw chamber connected to the gas control panel is shown in Figure 10 and Figure 11.

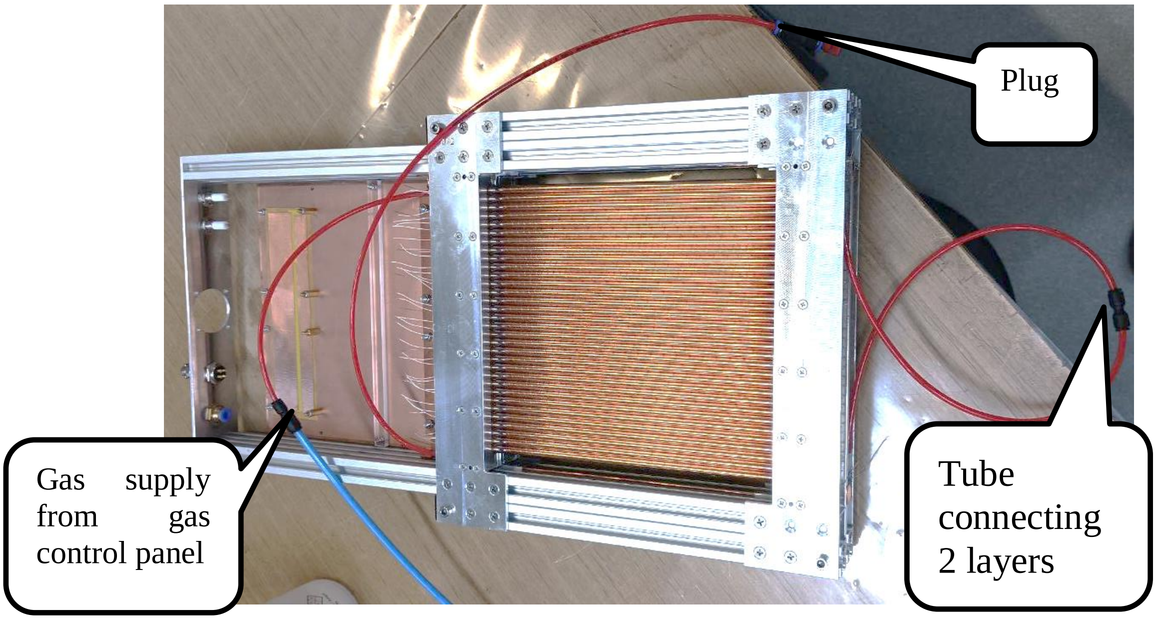


Figure 10. Overall view of the straw chamber connected to the gas control panel.

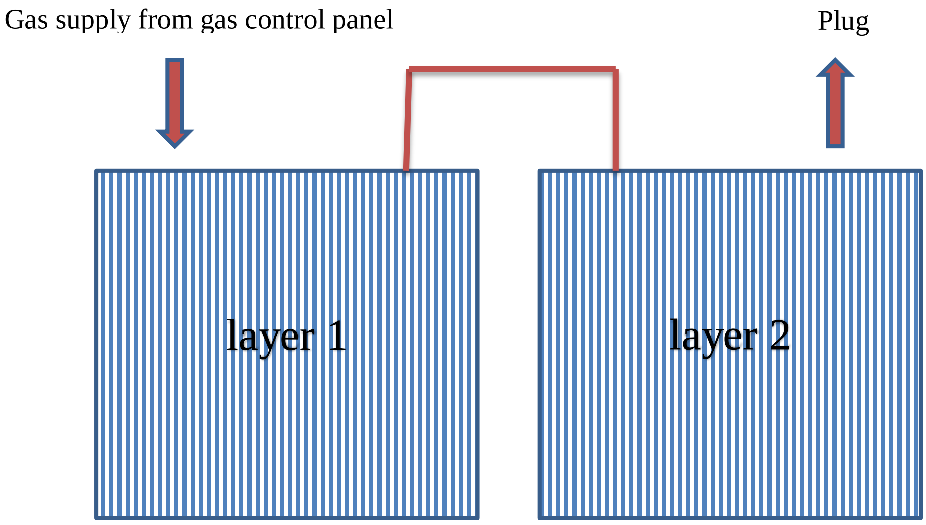


Figure 11. Scheme of the gas system of the straw chamber connected to the gas control panel.

To find the amount of leakage, it is necessary to supply gas under an excess pressure of 1 bar into the chamber using a gas control panel. Then, using a pressure gauge and a stopwatch, it's determined how long it takes for the pressure in the chamber to decrease by a certain amount.

10 chambers were tested for leaks for the test area of the NICA-SPD experiment in Dubna. The amount of leakage was measured during each leak tightness test. The results of one of the camera measurements with the designation 4Y are shown in Table 1.

Table 1. Result of chamber leakage measurement 4Y

Time, sec	Pressure, bar
0	1
84	0.975
148	0.95
195	0.925
295	0.875
346	0.85
463	0.8
591	0.75
732	0.7
895	0.65
1083	0.6
1298	0.55
1523	0.5
1774	0.45
2064	0.4

To measure leakage in cm^3/min, the following formula is used:

$$\mathrm{dV} = \frac{\Delta \mathrm{P}\ (\mathrm{bar}) \cdot \mathrm{V_{chamber}}\ (\mathrm{litre}) \cdot 1000\,\frac{\mathrm{cm}^3}{\mathrm{litre}} \cdot 60\,\frac{\mathrm{sec}}{\mathrm{min}}}{\Delta \mathrm{t}\ (\mathrm{sec})}$$

where ΔP is pressure change; $V_{chamber}$ – chamber volume in liters (in this case, 0.4 litre); Δt – time during which the pressure in the chamber changed.

Differential leakage is represented as a graph (Figure 12).

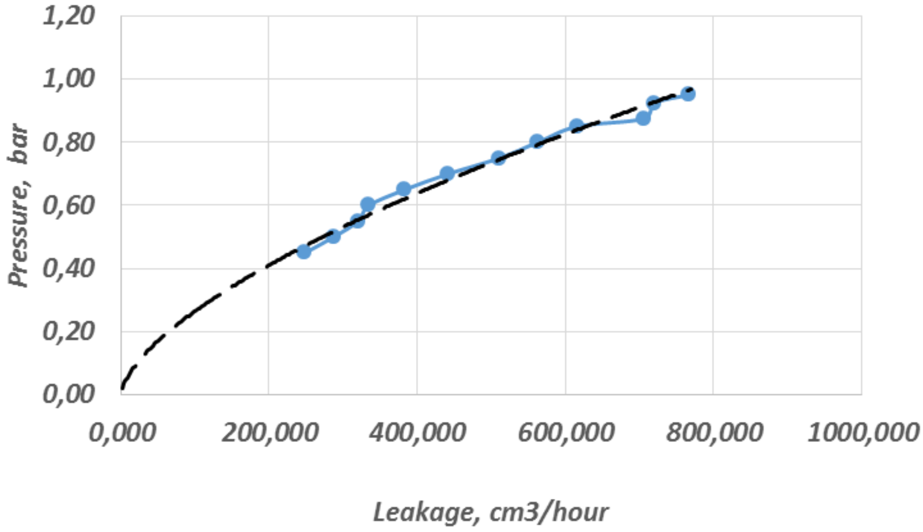


Figure 12. Differential leakage and differential leakage graph extrapolation.

During experiments, the straw chamber is purged with gas at a flow rate of $V_{chamber}$/hour. For normal functioning of the straw detector, the leakage value should be 1% of the $V_{chamber}$. In this case, the chamber volume is 0.4 liters, meaning the leakage value should be less than 4 cm^3/hour or 0.067 cm^3/min.

Leakage is measured under an excess pressure of 1 bar, although straw chambers are usually used at a small excess pressure of the order of 10 mbar. If we extrapolate this graph, we find that the leakage value at an excess pressure of 10 mbar will be equal to 0.58 cm^3/hour, which is less than 4 cm^3/hour. Based on this, we conclude that the 4Y chamber has passed the leak tightness test.

Conclusion

During the JINR summer student program, I was introduced to gas coordinate detectors based on thin-film drift tubes. This is one of the areas of work of the Veksler and Baldin Laboratory of High Energy Physics.

I also gained knowledge in the field of manufacturing and testing straw detectors. I conducted more than 100 leak tests of straw tubes and measured gas leakage values of 10 chambers for the test area of the NICA-SPD experiment in Dubna.

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