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ABSTRACT

Straw chambers have been shown to have good position resolution. By virtue of their cylindrical geometry they are capable of operating in vacuum, which opens the interesting possibility of tracking with a minimum of material. The feasability of constructing a large surface straw chamber has been studied. A prototype chamber with 2.4 m long straws capable of operating in vacuum has been developed and tested in beams at CERN.

(Submitted to Nucl. Instrum. Methods in Phys. Research)

1. Introduction

In the past several years, a number of straw chambers have been developed for high precision charged particle position measurement in high energy physics experiments. (See ref. [1] for a review of the characteristics of the various straw chamber developments.) Most of these developments have been for vertex chambers at e^+e^- colliders where resolutions of 40-100 μm have been obtained. A straw chamber consists of a set of thin walled conducting tubes, each with a central anode wire, has the interesting potential that it could be operated in vacuum. Whereas a large surface wire chamber certainly cannot withstand a large pressure change across its thin mylar windows. This potential to run in vacuum could be exploited for a variety of purposes: a) a reduced contribution of multiple scattering on charged track measurement; b) a smaller conversion probability for rare decay experiments; and c) allow the use of xenon filled straws of a transition radiation detector to operate in vacuum or in a light (helium) atmosphere. The present study has been primarily concerned with the development of a large surface straw chamber for track position measurement.

The study of a large surface straw chamber was originally motivated by the potential reduction in multiple scattering in a future ϵ'/ϵ experiment at CERN. In the NA31 experiment, the $K_L \rightarrow \pi^+\pi^-$ decays occur in vacuum and the charged particles pass through a 1 mm kevlar window into a helium tank where two conventional planar drift chambers measure the pair of charged tracks.[2] In order to limit the number of 3-body K_L decays in the final $\pi^+\pi^-$ sample, the distance, d_{tar}, of the measured charged track plane to the production target is used. Events with a large d_{tar}, indicating missing p_t, are removed. The resolution in d_{tar} is ultimately limited by the multiple scattering in the kevlar window, helium and wire chambers. The component of the d_{tar} resolution coming from multiple scattering is equivalent to about 400 μm coordinate measurement resolution in the two wire chambers. Removing the kevlar window and helium would improve the multiple scattering component of the d_{tar} resolution by a factor of 2, as long as the coordinate measurement resolution is about 100 μm.

A large surface straw chamber, for example 2.4 m x 2.4 m, requires the use of straws which are several times longer than those which have been used in vertex chambers. As well, the straw walls should be kept as thin as possible to minimise the amount of multiple scattering due to the chamber itself. Long straws have nonegligible wire sagittas due to gravity and potentially have important electrostatic wire displacements depending on the form of the straws. The electrostatic behavior of the wire in a straw has been studied, including the effects of the deformation of the straw tube from a rigid cylinder. A full length 2.4 m prototype chamber, allowing for the straws to be operated in vacuum, has been constructed and tested in beams at CERN. Both the individual wire resolution as well as the relative wire positions have been measured with the prototype chamber under a variety of conditions.

2. Electrostatic displacement of the wire in a straw

A gold-plated tungsten wire of length 2.4 m which is held horizontally at maximum tension (below the elastic limit, ~120 g for r_{wire} = 15 μm), has a sagitta due to its own weight of about 80 μm, independent of wire diameter (sagitta $\propto$ tension^{-1}*length^{2}). With reasonable mechanical tolerances and no applied voltage, the relative position of the anode wires in each straw can be maintained to a few tens of microns. However, the sagitta of a thin mylar straw is significantly larger than 100 μm. Fig. 1 shows the measured sagitta vs tension of a 2.4 m straw with a 25 μm thick wall, supported only at both ends. Also given is the corresponding change in length of a straw. At 1 kg, which is about the elastic maximum, a straw has a sagitta of 700 μm. In order to understand the influence of a sagging straw on the position of its central wire, a program was setup to calculate and verify with measurements the wire sagittas arising from the electrostatic forces of a straw tube.

The electrostatic forces on a wire running down the center of a conducting tube can be solved using the method of image charges. The wire when displaced off axis is attracted to the nearest wall. Thus, for a straight horizontal straw the 80 μm sagitta of a wire is increased. Whereas, if the straw is allowed to hang the wire moves above the central straw axis. In this latter case, the electrostatic forces tend to decrease the wire sagitta and eventually the wire moves up past the horizontal axis forming a sagitta in the upwards direction. The wire sagittas for a variety of voltages and straw sagittas have been calculated and are presented in Table 1. The straw tube and wire have diameters of 8 mm and 30 μm, respectively. Lengths of 1.0 m and 2.4 m are given for comparison. The wire is tensioned with 120 g. The sign of the sagitta indicates its direction where negative is downward. The validity of these calculations have been verified experimentally with a 2.4 m stainless steel tube, 8 mm inner diameter, which was fixed to a rigid beam. The tube had a small hole at its midpoint so that a wire sagitta could be measured optically. A 30 μm wire was tensioned to 50 g to allow for sagittas of up to 500 μm which could be accurately measured. The ends of the wire were variously kept at the center of the tube as well as 100, 300 μm vertically off axis. Sagittas were measured for voltages up to 2200 volts and agreed well with calculations where a 20 μm tolerance for the positioning of the wire ends was allowed.

It can be seen that in going from the 1.0 m to 2.4 m lengths, large wire sagittas are possible, especially if the straws are free to hang with sagittas of >600 μm. As will be seen below, the operating range for straws at one atmosphere is 2100 to 2300 volts. Since one wants to maintain the dispersion of wire positions well below the 100 μm level, Table 1 indicates that the straw sagittas as well as their dispersion should be kept to be within about 100 μm. Note that although the position resolution improves for straw pressures above one atmosphere, the required operating high voltage also increases, implying potentially large electrostatic wire displacements. In conclusion, from these calculations it appears that for a straw chamber of 2.4 m in length the straws must be sufficiently supported so that the electrostatic wire displacements do not deteriorate a desired 100 to 150 μm plane resolution. In order to futher test this hypothesis, a full length prototype chamber was built.

3. Development of a 2.4 m prototype straw chamber

3.1 Chamber description

A prototype straw chamber was designed and constructed to measure both the individual straw position resolution as well as the relative position of the wires of several straws. The prototype chamber consisted of 32 straws of 2.4 m length placed in a steel cylinder which could be evacuated, see Fig. 2. The steel tube consisted of three sections of equal lengths. The central section had a porthole with a mylar vacuum window. Surrounding this central section was a inox frame which assured the straightness of the assembled three sections. At each end of the central steel section was a ring containing a precision grid of 100 μm wires to maintain the position of the straws inside the steel tube. At the ends of the two outer steel tube sections were two precision drilled end plates which held and positioned the straws and their anode wires. The end plate showing the straw configuration can be seen in Fig. 3. The test beam normally impinges perpendicularly on six straw planes. The coverage of the straws in each plane is 2/3 so that each particle passes through four straws. The planes are staggered by 1/4 to allow left/right ambiguity resolution. No external track measurement was foreseen so that the individual straw position resolution and the relative wire positions would be obtained by the redundancy in the number of straws hit.

The straws were made of two 12 μm mylar strips (16 mm wide) which were overlapped, helically wound and glued together.[3] The inner strip had been aluminized with a 0.1 μm deposition, resulting in 70 Ω over 2.4 m. Each straw represents 0.027% radiation lengths. The anode wires were gold-plated tungsten of 30 μm diameter. The straws were glued to stainless steel plugs inserted into either end, see Fig. 4. These plugs, which have an external o-ring joint, would pass through the end plates and seal off the cylinder volume for eventual evacuation. Through the center of each plug passed a plastic Noryl feed-through which allowed for wire positioning and gas flow to the straw. During operation gas was flowed through each straw. The inox plugs were threaded at the extreme end to allow the tensioning of the straws.

3.2 Mechanical assembly

Since the 25 μm straws are easily bent and wrinkled, it was necessary to assemble the chamber vertically. A mechanical jig was set up to hold one end plate with the straws hanging vertically. After each straw had end plugs glued and electrical connection checked, they were inserted into the end plate on the jig. Each portion of the cylindrical tube and steel frame was slid over the straws from the bottom, and the jig lifted it up to be attached to the previous part above. After the second end plate was attached and the plugs passed through, the anode wires were threaded through the straws before the plastic feed-throughs were inserted.

The straws were tensioned to 1 kg and the wires to 120 g. The wire tensions were later verified by finding the normal vibrational modes of the wires using a wave generator and a small magnet.

4. Beam test of prototype

4.1 Electronics and readout

The electronic readout chain consisted of preamplifier/discriminator followed by a Lecroy 2228 CAMAC TDCs. A M68000 processor with two Mbytes of memory in a VME crate served as the 'online' computer which under OS9 provided the necessary monitoring and data acquisition. A Vaxstation 2000 connected to the VME crate via Ethernet was used for data storage and analysis.

Each straw was terminated at one end and readout with the 32 channel preamplifier/discriminator, recuperated from the CELLO drift chamber. The preamplfier/discriminator was run typically with a threshold of 10^5 electrons. In order to obtain the maximum resolution, the straws were run in limited streamer mode where gains were typically 10^7 - 10^8 (see ref. [4] for a description of straw chamber operation in limited streamer mode). However running at the highest gains was somewhat limited by cross talk on the preamp card which tended to fire adjacent electronic channels.

The Lecroy TDCs had a 0.2 nsec resolution or 10 μm in argon/ethane. The start time of the TDCs was given by the double coincidence of a pair of 5 cm x 5 cm scintillators in front of the chamber vacuum window. The data acquisition was able to handle about 100 tracks every 2 sec SPS burst.

4.2 Tests and results

The main interest in the long straw prototype tests was to reproduce the nice spatial resolution seen in previously constructed straw vertex chambers and as well to study the behavior of wire positions in the 2.4 m straws. The following various operating conditions were possible. The chamber was supported so that the central region of the straws would remain in the beam while the orientation of the straws could be varied from horizontal to vertical. This allowed the study of relative wire positions with and without the gravitational displacement of the straws and wires. As well, the chamber could be rotated along its cylindrical axis so that tracks could traverse parallel to a plane of six straws or normal to six planes of 5 or 6 straws (see Fig. 3). The former position was used for quick online investigation of resolution and wire positions — triplets of times could be used to eliminate systematics of t_0's, time to drift variations, etc. The latter orientation was used for the analysis of the interwire spacing. The straws were capable of being pressurized to two atmospheres absolute, which should improve the spatial resolution through increased ionisation statistics and less diffusion. And the cylindrical steel tube could be evacuated to see whether wire positions were affected, eg. through the deformation of the straws. The change in pressure across the straw membrane was limited to one atmosphere because the straws tended to deform nonelastically at two atmosphere pressure difference.

The straw chamber was assembled, mounted and brought up to high voltage at Orsay and initial tests to debug electronics and data acquisition were performed with cosmic rays. After assembly the relative position of the straws was optically measured to be within about 100 μm of the expected separation. (Recall that the straws were supported by two planes of precision grids.) It was not possible to measure the straw sagitta relative to the ends. The chamber was then transported to CERN for beam tests.

4.2.1 Resolution measurements

The straw chamber was operated with a 50/50 Argon/Ethane gas mixture. A beam of 80 GeV/c pions which illuminated the 5 cm wide set of straws was used for all measurements. With the chamber oriented so that the straws lined up with the pion beam, the resolution was measured using the time of straw triplets: $(t_3 - t_1)/2 - t_2$, assuming 50 μm/nsec as the drift velocity. Given in Fig. 5 are the resolutions obtained versus high voltage for both the one and two atmosphere tests. One sees that in both cases there is a strong high voltage dependence and that a resolution of about 100 μm resolution per straw can be obtained. In the one atmosphere tests the maximum high voltage was limited to 2300 volts because the large signals were beginning to trigger most of the channels via the electronics cross talk, and in the two atmosphere case the high voltage did not exceed 3 kV because various wires began to exhibit large displacements (see below). (From ref. [4] one would expect a limiting resolution of about 80 (50) μm at one (two) atmosphere.)

4.2.2 Wire positior measurements

From Fig. 5 one can see that for the two atmosphere tests, 100 μm straw resolution is attained at 3000 volts. Consulting Table 1 shows that at 3000 volts wire displacements of well over 100 μm are possible, depending on the shape of the straws. For the data taken at two atmospheres, the straws were kept vertical to avoid the 80 μm gravitational sagitta of the wires. In overpressuring the straws, they expand and if their lengths are not readjusted, they will be displaced transversly by a few hundred microns. Consequently, in the tests at two atmospheres there were significant wire displacements. For example, some wires were seen to move from under 100 μm in separation to about 300 μm for a corresponding voltage variation from 2600 to 3000 volts.

For the tests at one atmosphere, the typical wire displacements measured at the center of the 2.4 m straws were significantly smaller as compared to the two atmosphere tests. For all tests the voltage was kept at 2150 volts where the resolution per straw is typically 135 μm. (The amount of cross talk on the electronics card made systematic running at 2300 volts impractical.) The relative wire positions are given in Fig. 6 for various operating conditions. In Figs. 6a-c the straws were oriented vertically, at 45° and horizontally, respectively. In Fig. 6d the straws were horizontal with the steel tube evacuated. The rms of these positions is typically 50 μm and represents both the relative mechanical positioning precision as well as electrostatic displacements. It is clear from these plots that a systematic effect due to wire displacements can be maintained at a level which does not limit a desired space point resolution of 100 μm. (Note that there is one wire that is systematically lower than the rest of the wires by about 350 μm in all plots. The cause for this appears to be a mechanical displacement and this wire is not included in the shown rms.)

5. Conclusions

The extrapolation of the operation of short ($\leq$1 m) straw chambers to a larger straws of 2.4 m has proven possible in protoype tests, and space point resolution of 100 μm appears attainable. However, operation of the straws is limited to atmospheric pressure due to electrostatic wire displacements at higher voltages. Future developments towards a full scale 2.4 m x 2.4 m straw chamber would necessitate further considerations on the means to maintain the straws straight. This could be made possible, for instance, by gluing a number of straws together.

6. Acknowledgements

We would like to thank B. Rojat and P. Sauvalle for their work in the study of the electrostatic forces on the wire in a straw, which was conducted as part of their studies at Ecole Polytechnique. Many of the early ideas and designs for the straw fabrication as well as the mechanical connection of the straw and wire to the external frame were conceived by M. Dialinas. The operation of the prototype chamber would have been impossible without the aid of A. Ducorps and A. Krieg and the consultations with R.L. Chase.

7. References

[1] W.H. Toki, *SLAC-PUB-5232* (1988).
[2] H. Burkhardt, et al., *Nucl. Inst. Meth.* A268 (1988) 116.
[3] Fabricated by MICEL 60 rue M. Bonnet, 94230 CACHAN, France
[4] W.W. Ash, et al., *Nucl. Inst. Meth.* A261 (1987) 399.

V_{wire} (Volt)	Straw sagitta (μm) (negative is downward)	Wire sagitta (μm) 2.4 m length	Wire sagitta (μm) 1.0 m length
0.	0.0	-80.	-14.
2000.	+100.0	-135.	-14.
2600.	+100.0	-190.	-14.
3000.	+100.0	-270.	-13.
2000.	0.0	-110.	-15.
2600.	0.0	-130.	-15.
3000.	0.0	-160.	-16.
2000.	-300.0	-20.	-18.
2600.	-300.0	+50.	-20.
3000.	-300.0	+140.	-23.
2000.	-600.0	+70.	-21.
2600.	-600.0	+250.	-25.
3000.	-600.0	+510.	-29.

Table 1: Calculated wire sagitta in horizontal straw tubes of 2.4 m and 1.0 m lengths. $r_{wire} = 15$ μm, $r_{straw} = 4$ mm, $T_{wire} = 120$ g.

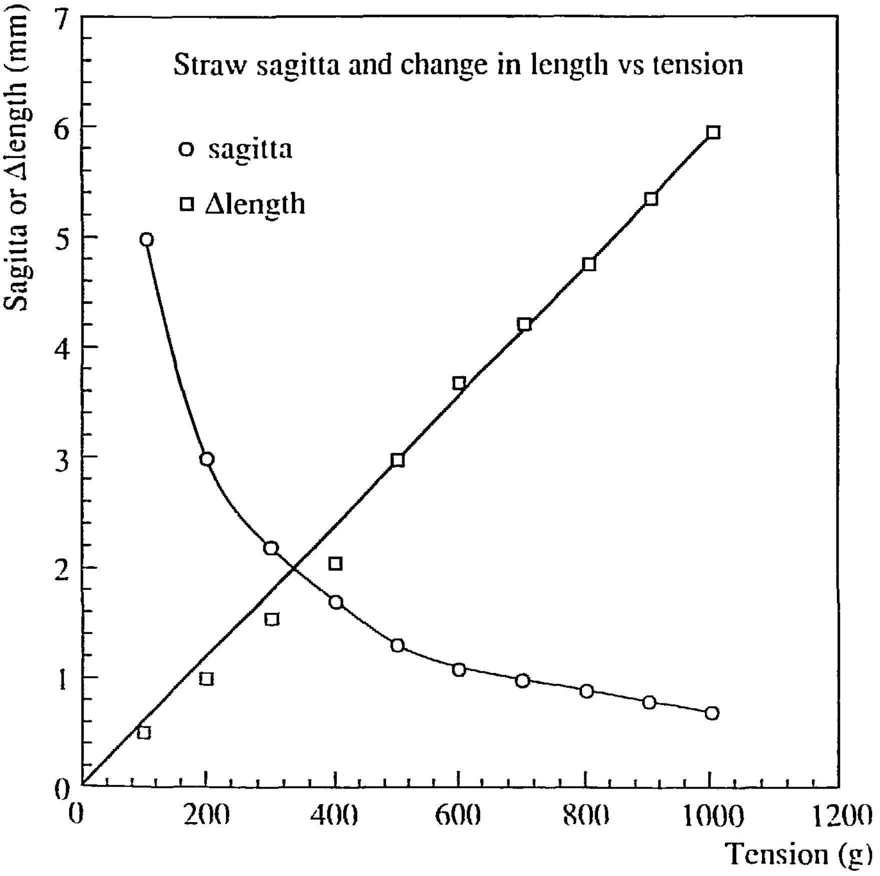


Fig. 1 : The sagitta and change in length as a function of the tension applied to a straw tube: 2.4 m length, 8 mm diameter, and 25 μm wall thickness.

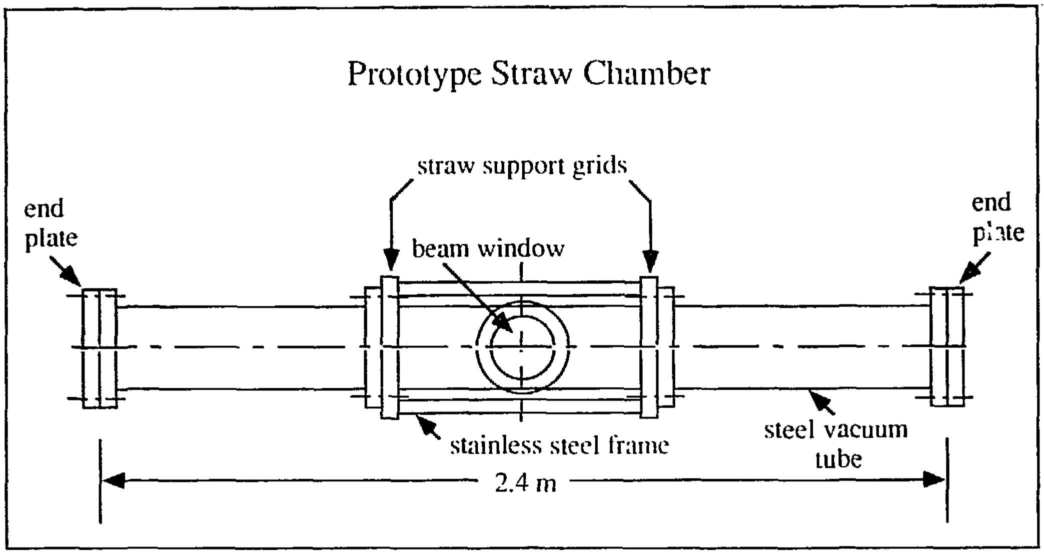


Fig. 2 : Side view of prototype straw chamber vacuum tube.

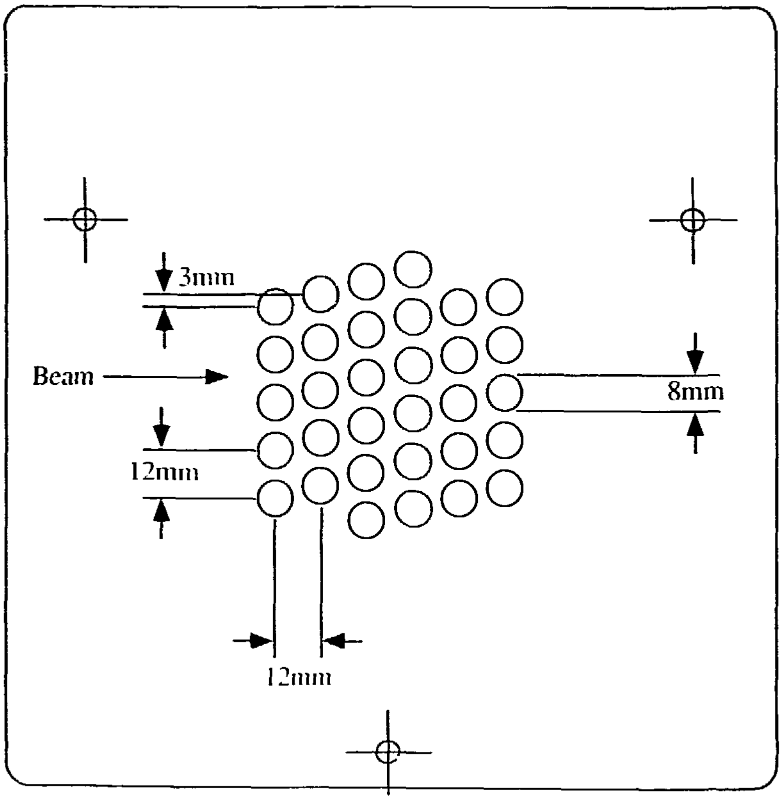
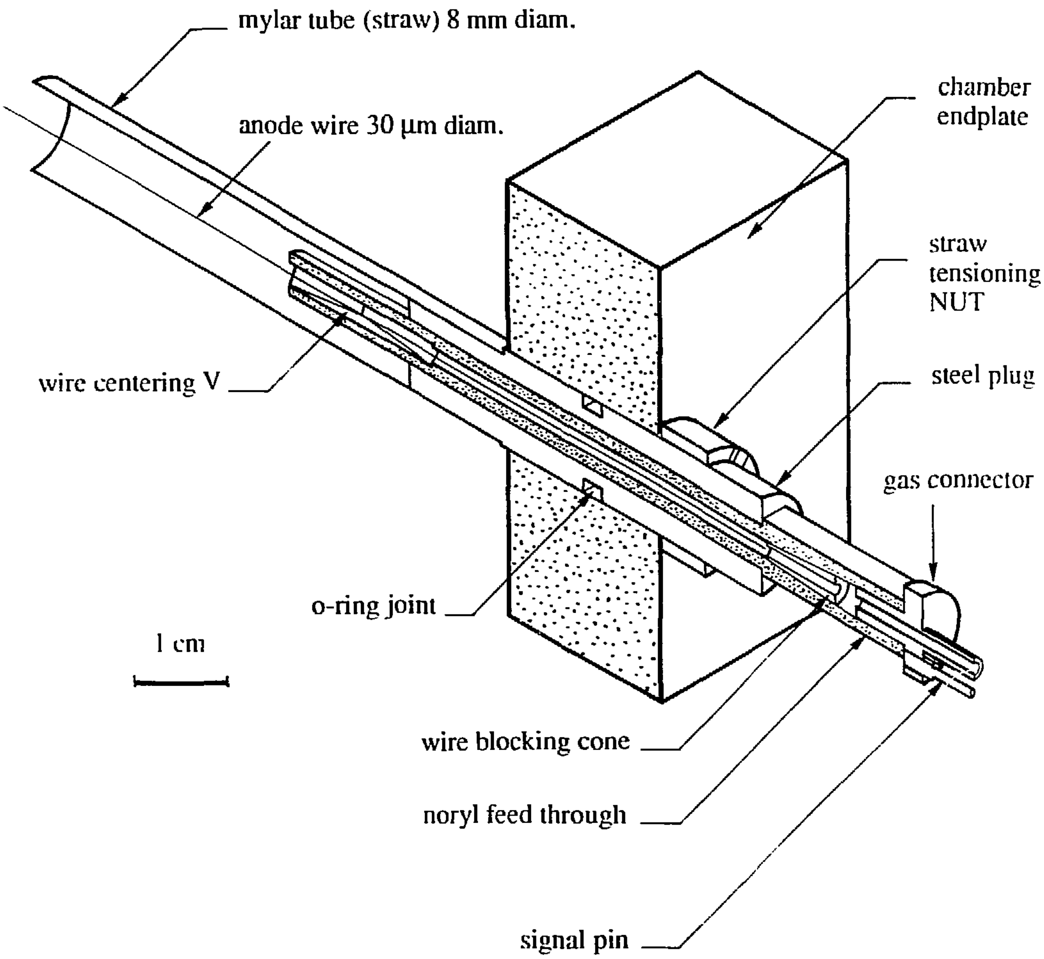


Fig. 3 : Chamber end plate indicating the relative straw positioning.



Cross Section of Straw Connection to Endplate

Fig. 4 : Cross section of feed-through which supports and positions the straw and wire, and allows gas flow through the straw.

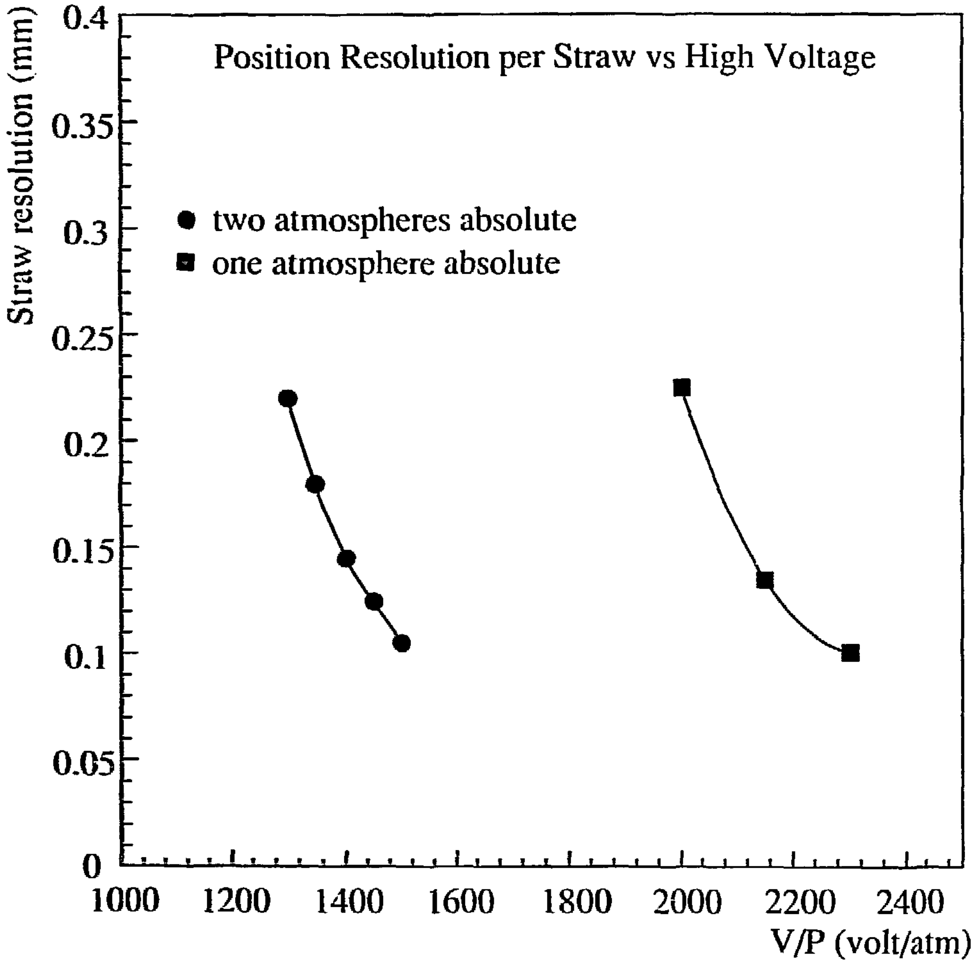


Fig. 5 : Straw position measurement resolutions as a function of high voltage for one and two atmospheres. Note that the maximum high voltage obtainable was limited by electronic crosstalk in the preamplifier.

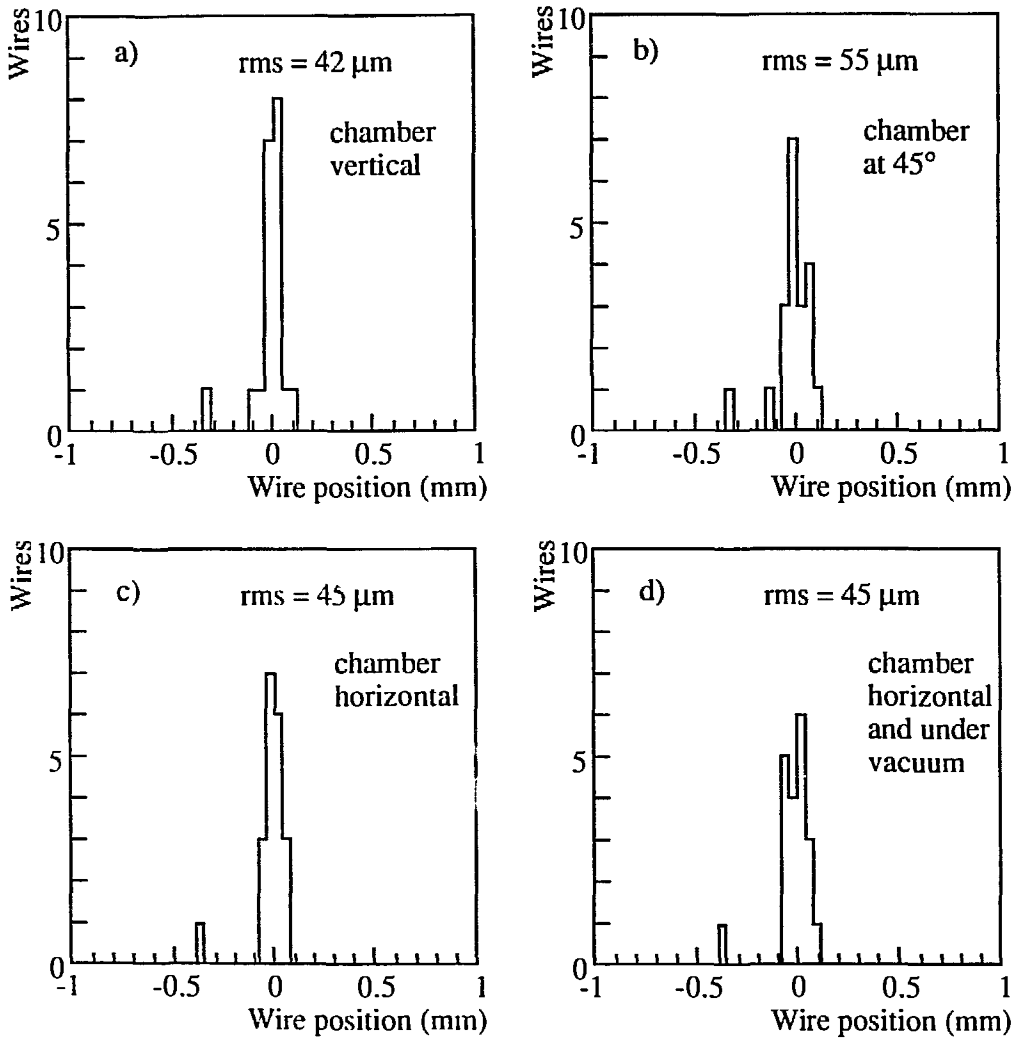


Fig. 6 : Relative wire positions measured at the center of the straw chamber. For a) to d) the straws were oriented vertically, at 45°, horizontally, and horizontally with the steel tube evacuated. The rms of the relative positions is given, excluding the single wire which is off by 350 μm.