SLAC-PUB-5232
March, 1990
(E)

Review of Straw Chambers*

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Abstract

This is a review of straw chambers used in the HRS, MAC, Mark II, Mark III, CLEO, AMY, and TPC e^+e^- experiments. The straws are 6-8 mm in diameter, operate at l-4 atmospheres and obtain resolutions of 45100 microns. The designs and constructions are summarized and possible improvements discussed.

Straw or thin walled tube chambers for high resolution position measurements of charged particles are extensively used in high energy physics experiments. In this paper a concise review is made of chambers for e^+e^- colliding beam experiments and a discussion of future applications is considered. These include the straw chambers used in the HRS[1], MAC[2], Mark II[3], MarkIII[4], CLEO[5], AMY[6] and TPC[7] experiments. Experiences from construction and operation will also be described. This review is organized into first a discussion of the general features, design layout and mechanical aspects, the operation and calibration and future considerations.

1. General Features

Straw or tube chambers are basically proportional chambers constructed with a single anode wire centered in a aluminized plastic tube forming the grounded cathode. In Table 1 is a summary of several straw detectors. The typical sizes of the tube are several millimeters to a centimeter in diameter. The straw is made usually of aluminized mylar several mils thick wrapped with two strips glued together in a barber pole strip fashion. The chambers are operated from 1-4 atmospheres and obtain resolutions of 45-100 microns[8]. This is achieved by

Invited paper to the 5th International Conference on
Instrumentation for Colliding Beam Physics, Institute of Nuclear Physics,
Novosibirsk, U.S.S.R., March 15-21, 1990

*Work supported in part by the National Science Foundation and by the Department of Energy contracts DE-AC03-76SF00515, DE-AC02-76ER01195, DE-AC03-81ER40050, DE-AC02-87ER40318 and DE-AM03-76SF000324

Table 1. Summary of Operating Straw Chambers

Group	HRS	MAC	MarkII	MarkIII	CLEO	TPC	AMY
Dia(mm)	6.91	7.9	8.0	8.0	5.9-7	8.0	5.3-5.9
Length(cm)	41-46	43	75	84	51	40-60	56
wire dia (pm)	20	30	20	50	15	30	16
straw thickness (μm)	85	100	75	75	32	100	38
no. of straws	352	324	552	640	192	964	144
gas	At/Et	$ArCO_2CH_4$	Ar/Et	Ar/Et	Ar/Et	$ArCO_2CH_4$	Ar/Et
operating HV(KV)	1.65	3.9	1.9	3.9	1.6-1.67	4.0	1.75-1.8
pressure (atm)	1	4	1	3	1	4	1.5
resolution(μm)	100	45	90	49	90	50(>1mm)	85

operating the cell at very high gain (10^7-10^8) in order to detect the time of the arrival of the first electron from the ionization path of the charged tracks. In the e^+e^- colliding beam experiments the straws are placed around the beam pipe and provide high precision position measurements near the interaction vertex.

1.1 Advantages

The advantages of a straw chamber when compared to multiwire chambers are;

1) The straw chamber is inexpensive, robust and relatively simple to construct.

2) The damage and possible down time caused by wire breakage is minimal since the broken wire is isolated in the tube cell and will only need to be disconnected.

3) The effects of signal cross talk are minimized as the straw cathode provides a complete ground shield between nearby wires.

4) The problems of electrostatic alignment distortions are minimal when the anode is kept reasonably centered in the straw.

These last two features allow the powerful simplification, in the off-line analysis, that the

anode forms a straight line between the two endpoints of cell. Also since the tube is cylindrically symmetric the closest distance of approach of the tracks is independent of the incident angle of the track. This is particular useful for very curved tracks and in high magnetic fields where ExB effects are large.

1.2 Disadvantages

The main disadvantage of a straw chamber is the amount of material the straw introduces into the chamber. This causes more multiple scattering and reduces the momentum resolution. However, in thin walled tubes the amount of radiation length for a 50 micron thick mylar straw of 8 mm diameter is comparable to that of Argon gas at 4 atmospheres pressure. In some designs from the AMY[6] and Novosibirsk[9] groups, the straw itself is pressurized and the only multiple scattering is from the straw itself since the requirement of an outer pressure vessel (Carbon Fiber is typically .2% R.L.) is removed. In addition, the Novosibirsk group has reported the construction of thin mylar straws of 25 micron thickness which would translate into only 0.0174% R.L. per straw.

2. Design Layout and Mechanical Aspects

The design and layout of straws are usually in a close pack configuration around the beam pipe. In Figure 1. is shown the layouts for the different experiments. The close packing provides a gapless coverage. A difficulty of continuous close packing is the requirement of straw tubes of varying radii. The AMY detector has varying tube radii in order to reduce the gaps when the layer radii are fixed. The other chambers vary the radii of the layer to fill the spaces with straws of equal diameter. A problem with this arrangement is when a track passes through the center of one straw (where the resolution is very poor) it will then continue into the gap between the straws of the next layer there by providing a poor measurement in one layer and none in the next. In the Mark III detector a partial solution to this problem was the intentional layout of a pair of layers shifted by half a diameter of a cell. Hence when a radial track passes through the center of one straw it will pass midway between the center and the wall of the straw in the next layer there by providing a high resolution measurement.

2.1 Mechanical Considerations

The main technical problem in a straw chamber is keeping the straw straight and the wire centered in the straw. If the wire is offset from the center of the tube or the tube is not straight, the wire can be electrostatically deflected and the electric drift field may change

along the length of the cell. This is especially a serious problem for very thin tube and/or long tubes (>1m). The formula[10] for the sag caused by an off centered wire in the straw is ;

$$h \cong \frac{L^2 \delta V^2 (4\pi\varepsilon)}{(9.8)(16)TR^2\left[\cosh^{-1}(R/2r)\right]^2}$$

where L= wire length (m), T= wire tension(Kgm),R=tube radius(m),r=wire radius(m), V=voltage, δ=displacement or off-set from the tube center(m) and h = wire deflection in the middle of the tube (m). Using a standard straw cell configuration of 75 cm length, 100 micron offset, 4 KV voltage, 100 gram tension, 4 mm radius and 15 micron wire radius, we obtain an electrostatic offset of 13 microns. The formula[11] for the sag , caused by gravitation, of a tube rigidly fixed at each end is,

$$y = \frac{L^4 \rho}{192ER^2}$$

where L is the length in inches, ρ is the density of the tube material in lbs/in, E the modulus of elasticity in lbs/in^2 and R the tube radius in inches. Using a choice of parameters of $\rho=5\times10^{-2}$ lbs/in^2 for the mylar density, E=550,000 lbs/in^2, and R=.1358 in (6.9 mm dia.) and L=16 inches, we obtain 43 microns. This sag varies as the forth power of length and inversely as the square of the radius. It also is independent of the straw thickness. Figure 2 contains the drawing for wire deflection and tube sag.

The main solutions to keep the tube straight are a) to use short tubes, b) to slightly stretch the tubes and c) to glue the entire tube assembly in order to add rigidity to all the tubes. The HRS and MAC detectors had relatively short tubes. The Mark II and Mark III tubes were stretched. The AMY straws were glued side by side.

2.2 High Pressure Considerations

The high pressure chambers were built by the MAC, Mark III, TPC and AMY groups. The Mark III chamber was built directly on the Be beam pipe whereas the MAC and TPC chambers were built on a thin Be pipe liner and after assembly it was slid on to the Be beam pipe.

The AMY detector was constructed using pressurized tubes. These tubes of polycarbonate were pressurizable to 4 atmospheres and during actual running they were operated at 21 psi. In an early Mark III design using mylar straws, high pressure tubes were tested and observed to function up to 4 atmosphere but later the design was abandoned when it did not ap-

pear feasible to insure 100% safety against breakage at 4 atmospheres. In these designs the tube connection to the feed through at high pressure is very difficult to solve.

A difficult technical problem in high pressure chambers is getting the HV signal out through the high pressure wall. The method used in the MAC, Mark III and TPC chambers was to epoxy the coaxial cable through the aluminum pressure wall. The coaxial braid was exposed and potted with epoxy through the pressure wall. Occasionally at high pressure the gas would flow through the cable causing a small continuous leak. High pressure high voltage coaxial connector are commercially available but they are expensive and too large to use in a densely packed configuration.

In the MAC, TPC and Mark III high pressure chambers, getting the gas to flow at a rate more than that allowed by diffusion in the straw is difficult. The only method to force fresh gas into the tube cell is to cycle the chamber pressure up and down. This procedure although straight forward requires many pressure cycles to flush the tube gas out completely. This takes away useful running time and may cause added mechanical stress on the straws. The procedure must be performed slowly otherwise the tube may be over pressurized and cause a tube breakage.

2.3 Straw Material

The straw material in the TPC and Mark III chambers was aluminized mylar. The tubes were made of two mylar strips of 25 and 50 micron thickness. The mylar strips had an aluminum film of .3 microns thick and was exposed on the inside and outside of the tube. The AMY detector had straws that were made with aluminized polycarbonate, 12.5 microns thick with two outer layers of mylar, each 12.5 microns thick. The aluminum on the polycarbonate was .1 microns thick. The aluminum of .3 micron was the maximum that the manufacturer was able to put on the mylar. The advantages of thicker aluminum are are better lifetimes and better robustness against damage from sparking. When the Aluminum layer is too thin, it could burn off (as an Aluminum strip fuses does) during a spark and if both ends of the inner Aluminum surface burn off, the inner Aluminum will float and eventually cause a slow charge up followed by a spark.

The American groups had an American vendor who assembled the straws by gluing two mylar strips over a rod. A Novosibirsk group[9] has developed a technique to assemble a straw with only a single mylar strip. They used ultrasonic wielding to a single layer that was slightlty overlapping with itself over the spiral. This produced relatively thin tubes of less than

25 microns thickness that was pressurable to 3 atmospheres.

2.4 Feed through and Endplate designs

The feed through designs from the different detectors are shown in Figure 3. The plastic feed throughs are usually slotted to allow gas flow into the tube. In the MAC, Mark III and Mark II designs the straw is attached with conducting epoxy on to an aluminum ring which is attached to the aluminum plate directly or with a spring. In the Mark III design the straws are precisely cut and the Aluminum rings are glued to each end with the feed throughs inside the straw. The feed throughs are then pulled through and the straws are slightly stretch such that the Aluminum ring butts up against the Aluminum end plate wall. The Mark II feed through screws into the aluminum ring and this allows adjustable tube tension. In the Mark II design the tube cathodes are at negative High Voltage potential whereas all the others designs have a grounded cathode straw and the anode at positive high voltage.

3. Operation and Calibration

The construction of most of these detectors achieved placement accuracies of 25-50 microns. The electronic calibrations were achieved to a level of a few tenths of a nanosecond. For most running periods, the chambers were operated with a single mixture of gas to allow a single set of calibration constants.

3.1 Off-line Analysis

The off-line analysis to improve the resolutions from 100 microns to below 50 microns is quite complex. The problems include finding the t_0 pedestal per wire, the time to distance conversion, and the survey alignment. The jitter caused by the preamp rise time, transit time, and beam crossing time can affect the resolution. Because 50 microns of drift is about a nanosecond, all the corrections must achieve a few tenths of a nanosecond to obtain an overall resolution below 50 microns. The off-line analyses use Bhabha events and cosmic rays. The TPC group[12] has performed an extensive off-line analysis to extract the best possible resolution from their chamber. The calibration constants for each wire were (1) t_0 pedestal, (2) two survey constants to obtain the correct angle. (3) a velocity correction to correct the gas temperature difference in each straw and (4) a coefficient α for a parabolic ϕ correction ($\alpha(z-z_{center})^2$) to correct for wire bowing. The time to distance relation was the same for all wires. The overall resolution for r>1 mm is 30-40 microns. The Mark III and MAC chambers

obtain similiar resolutions. In Figures 4 and 5 are the resolutions as a function of distance to the wire and as a function of the anode voltage.

3.2 Gas and lifetime considerations

Most chambers are using Argon/Ethane in a 50/50 mix. This gas has a very linear time to distance conversion and the resolution near the wire is not too poor. Other gases use the Argon/CO_2/Methane in a 50/49/1 mixture. This gas is safe and the life times are better than those of the Argon Ethane mixtures but the time to distance conversion is nonlinear and the resolution near the wire is worse.

Dimethyl ether (DME) gas[13] has been tested in the MarkIII and CLEO test chambers. The resolutions at 1 atmosphere were excellent, <40 microns. Also reported by the Novosibirsk group[9] were 20-30 micron resolutions in the region of r>1mm in 10 mm diameter tubes. There were problems[14] of swelling and warping of materials affected by the DME and difficulties of contaminated DME gas that was commercially purchased.

The lifetime of straw chambers has been investigated[15]. It has been found that alcohol or H_20 vapor can be added to increase the lifetime from 0.02 coulombs/cm to roughly .04-.06. In addition flushing gas through the cell is found to enormously improve the lifetime to as much as 1.0 C/cm. In Figure 6 are lifetime measurements for different vapor additives and gas flow rate. In the test cell runs, the high rate flushing of once per minute was done during lifetime runs that were drawing 5 μA over a 10 cm active wire. This would correspond to flushing the straw every time it accumulated 30 micro-coulombs of charge per centimeter of the wire.

4. Future Considerations

Future experiments such as those at SSC[16] could use straw chambers. Straw chambers are not optimized for multi-hit, extremely high resolution (<20 microns), nor extremely high rates. Instead they provide inexpensive chambers with resolutions of about 50 microns that can cover large areas with a reasonable lifetimes.

An obvious choice would be DME since it offers very good resolution at one atmosphere. A large fraction of the cost of the high pressure straw chambers is due to the high pressure requirements. The main problem to solve for DME use is to obtain suitable materials that are not affected by this gas. Possible choices are very thin Aluminum tubes or graphite tubes and sapphire feed throughs.

Another important problem to solve is the construction of tubes in excess of one meter. It may be possible to glue a large array to form a rigid group of straws which could span lengths of several meters with little or no sagging. The AMY detector is such an example on a smaller scale. Also since the sag of the straw is independent of its thickness, it may be possible to construct very thin (< 25 microns) straw in order to further reduce the multiple scattering. Another possible choice could be to obtain hexcell like materials that are very thin but still rigid.

In order to extend the lifetime, there must be gas flow through the tube. A possible solution is to construct an endplate with a built in gas manifold as shown in Figure 7. This could substantially simplify the construction.

Another future improvement could be to shrink the preamp electronics such that it could fit into a region equivalent to that of a straw diameter with a few centimeters length in the endplate wall. Such a system will have two cables exiting each cell, one for the amplified and discriminated signal and the other the DC voltage for the preamp. This would remove the possible cross talk problems.

Acknowlegements

The author acknowledges many useful conversations with H. Kagan, G. Godfrey, G. Lynch, A. Chilingarov, S. Wagner, A. Odian and V. Nagaslaev. And the author would like to thank V. Sidorov and the organizers of the conference for the invitation and an excellent meeting.

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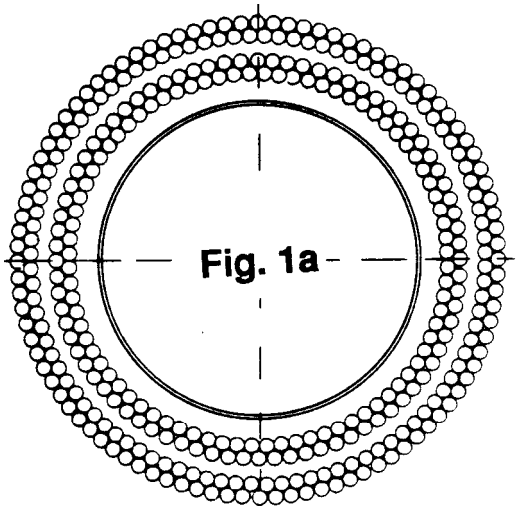


Fig. 1. A 'diagram showing the arrangement of the tubes around the beam pipe

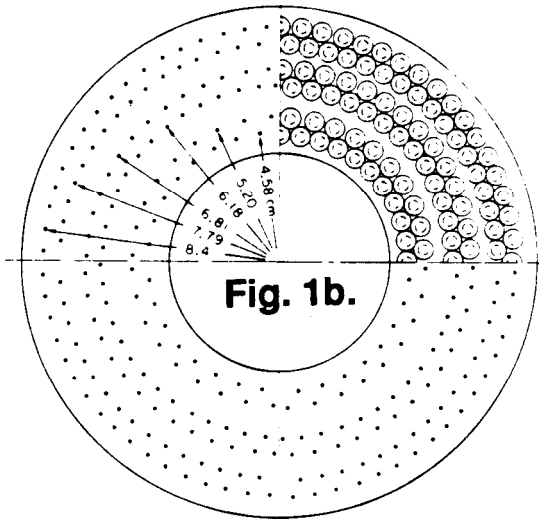


Fig. 2. Layout of the vertex chamber cndplate. showing the arrangement of the six layers of tubes.

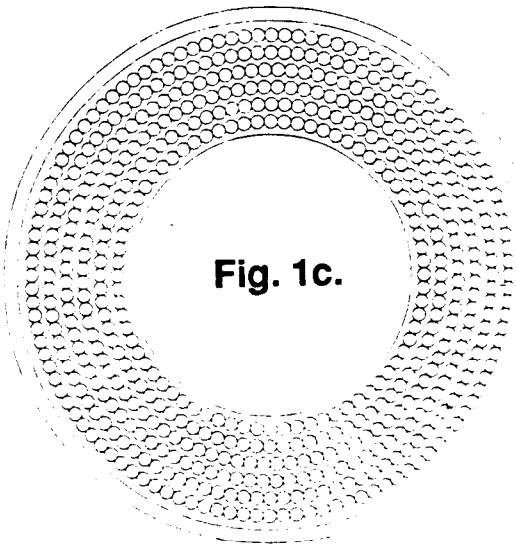
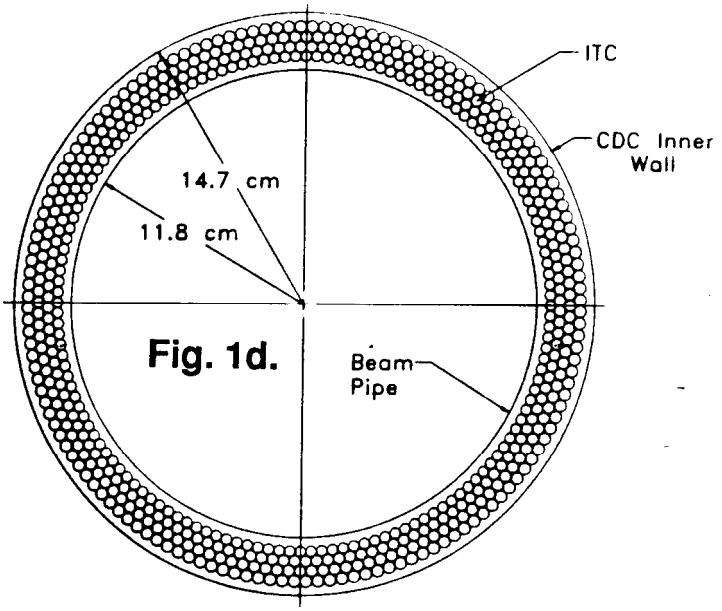


Fig 1 Cross section of the trigger chamber, showing the layout of the cells The small circles denote the cathode tubes



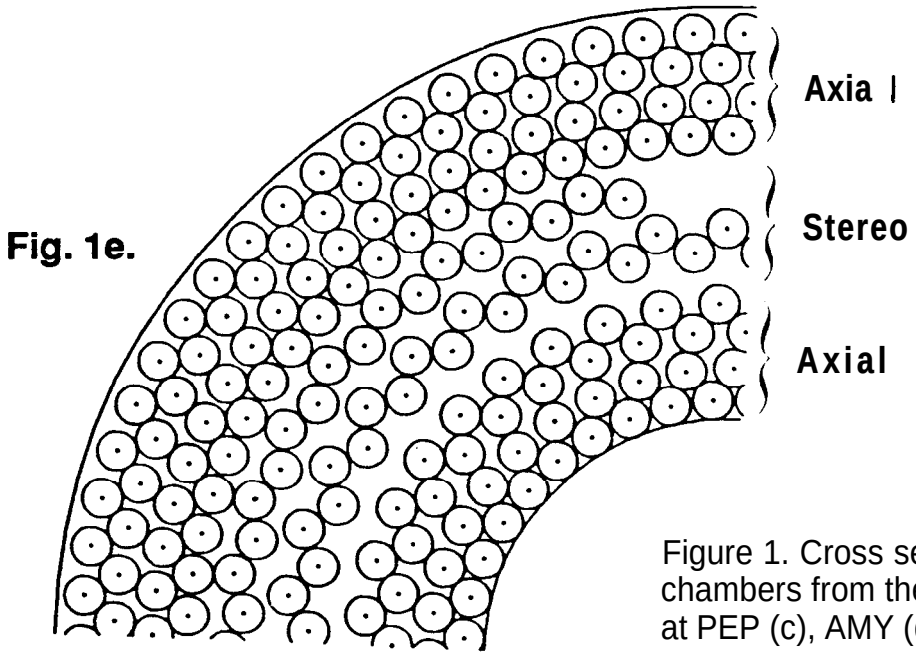


Figure 1. Cross section views of the straw chambers from the HRS (a), MAC (b), MarkII at PEP (c), AMY (d) and Mark III (e) groups.

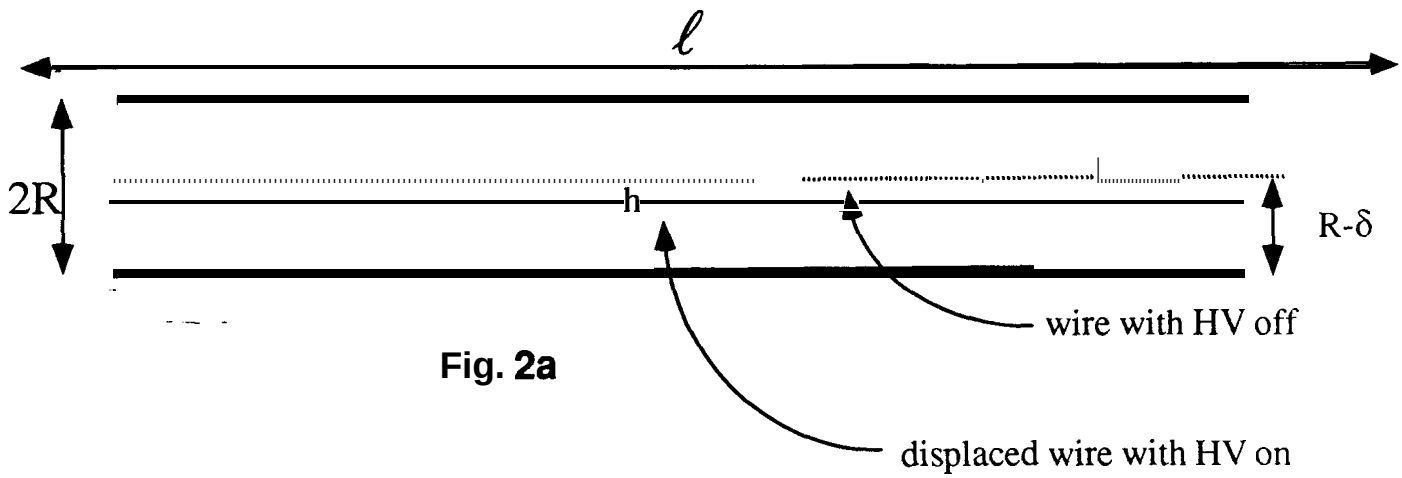


Fig. 2a

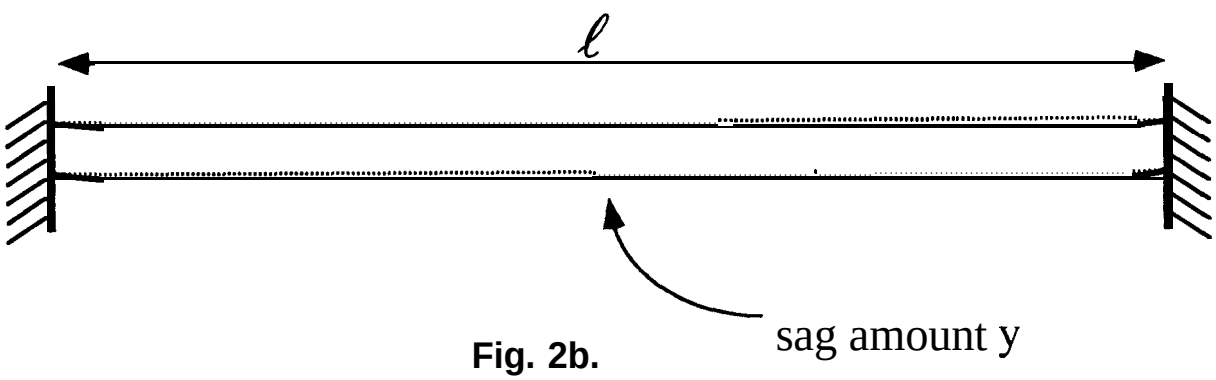


Fig. 2b.

Figure. 2 Drawing of wire sag caused by a wire off-center in the straw (a) and a drawing of straw sag (b). See the text for the symbols in the drawings and the relevant formulas.

Fig. 3a

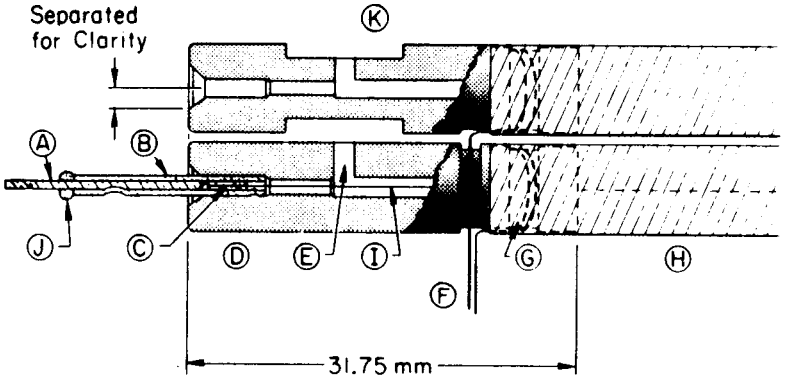


Fig. 3b

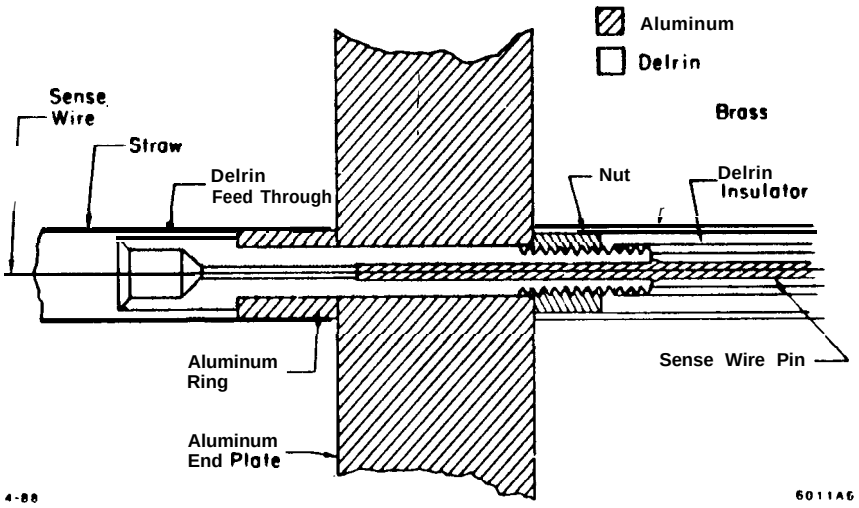


Fig. 3c

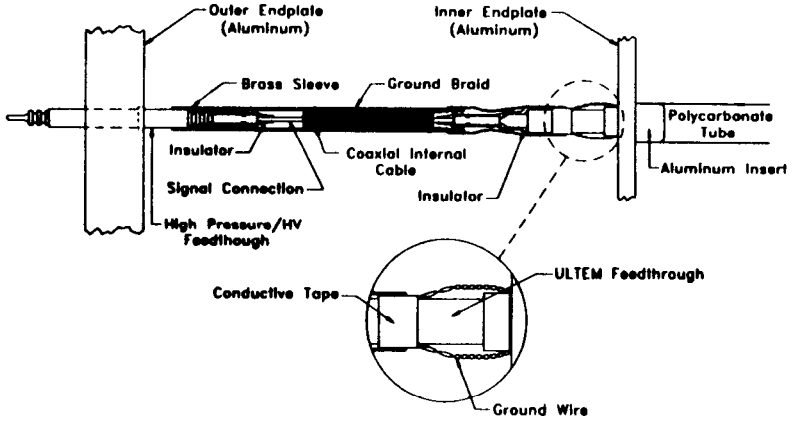


Fig. 3d

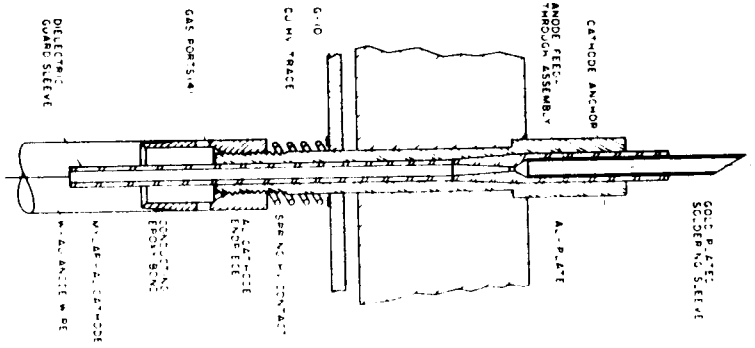


Figure 3. Feed though designs for straw chambers from the HRS (a), MAC and Mark III (b), AMY (c) and Mark III at PEP (d) groups.

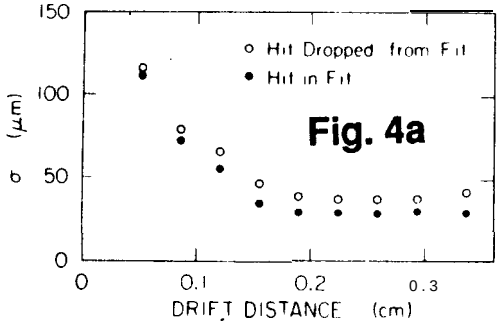
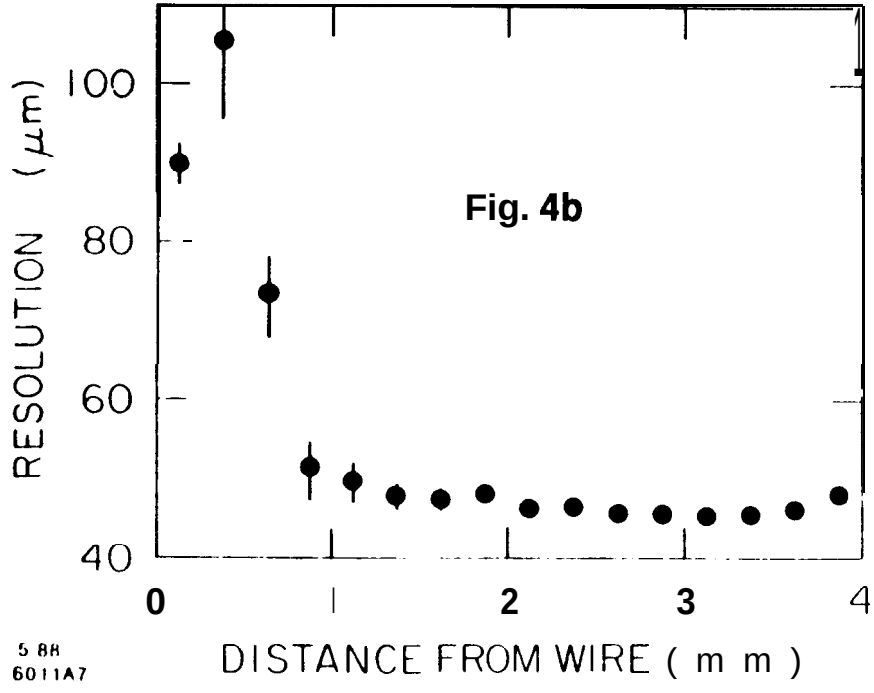


Fig. 20. VC spatial resolution. The fitted σ of the residual distribution is shown as a function of drift distance. Both cases of hit left in the track fit and removed are shown. The true σ is approximately halfway between these two extremes.

Figure 4. Vertex chamber'resolution as a function of distance to the wire from the MAC (a), Mark III (b) and TPC (c) groups.



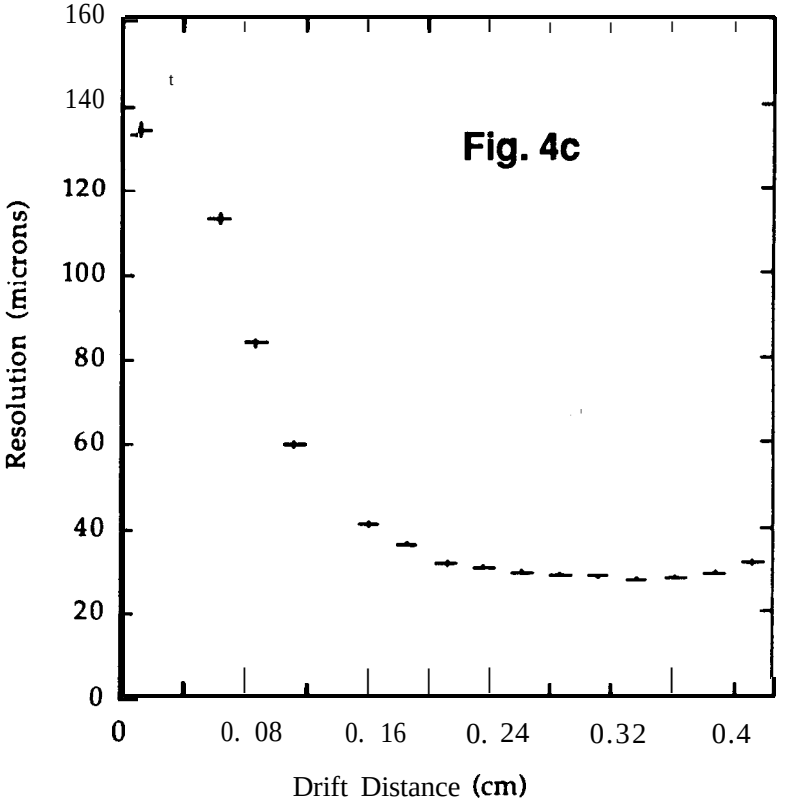


Fig. 5a

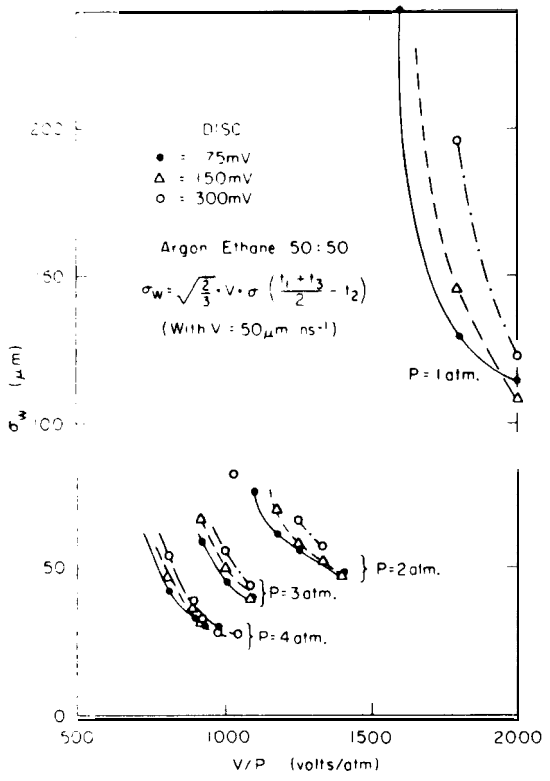


Fig. 13. Average single wire resolution as a function of voltage scaled by pressure for various pressures and discriminator levels. The curves are to guide the eye only.

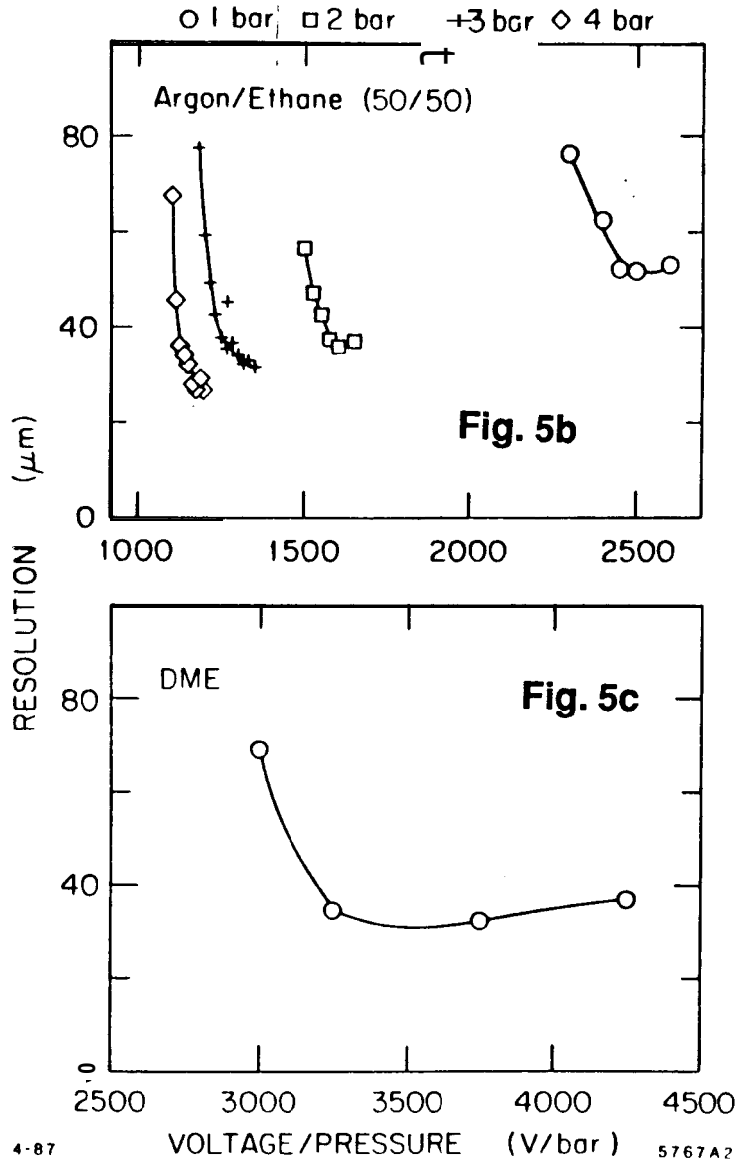


Figure 5. Vertex chamber resolution as a function of voltage/pressure using Argon/Ethane gas from the MAC (a) and Mark III (b) groups and using DME gas from the Mark III (c) group.

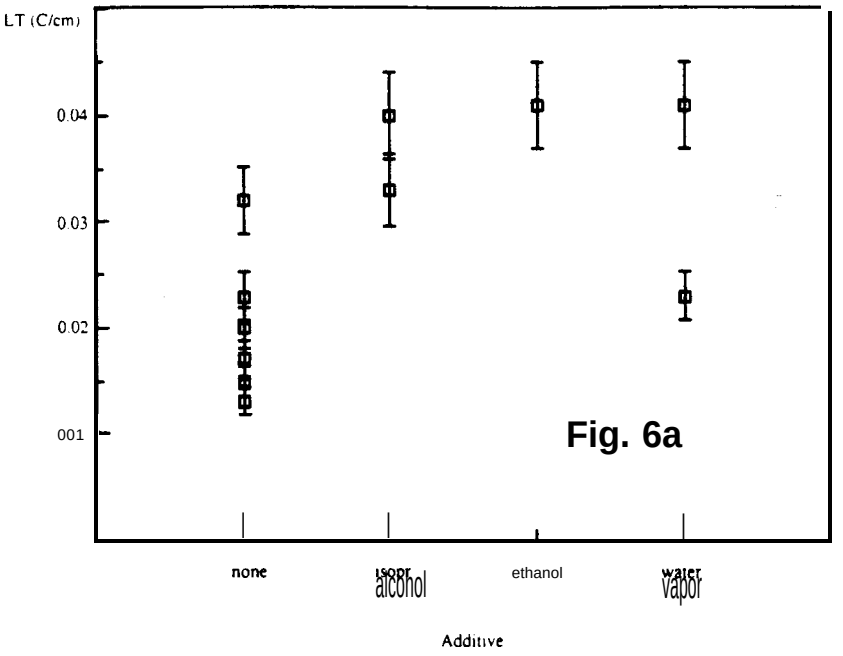


Fig. 3. Lifetime as a function of additives to the argon-ethanc (50/50) gas mixture. The gas mixture was not circulated.

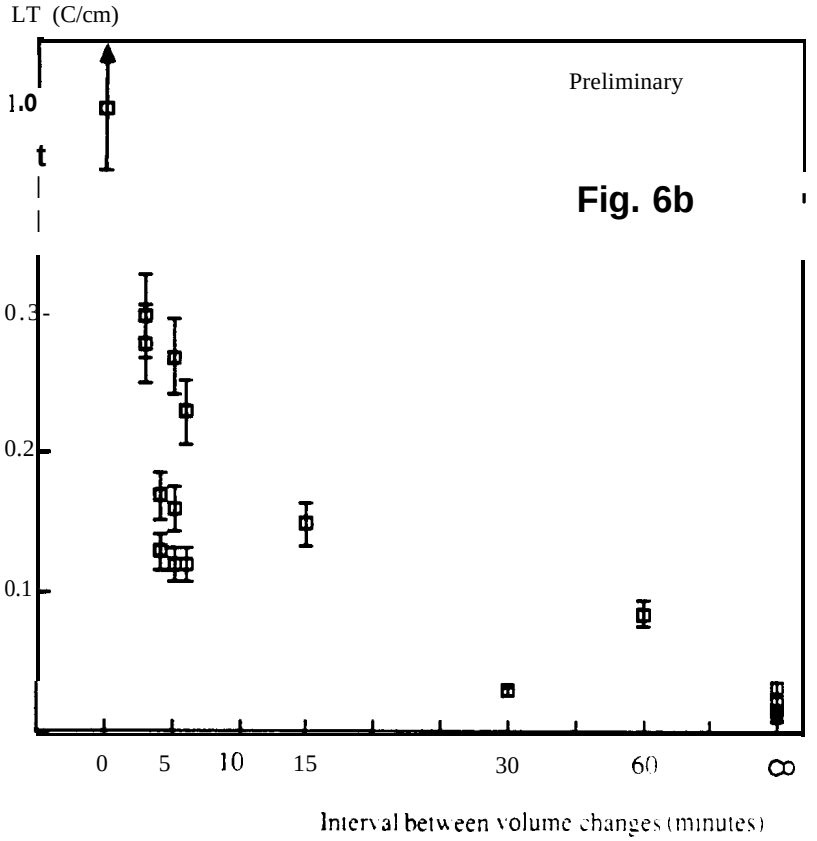
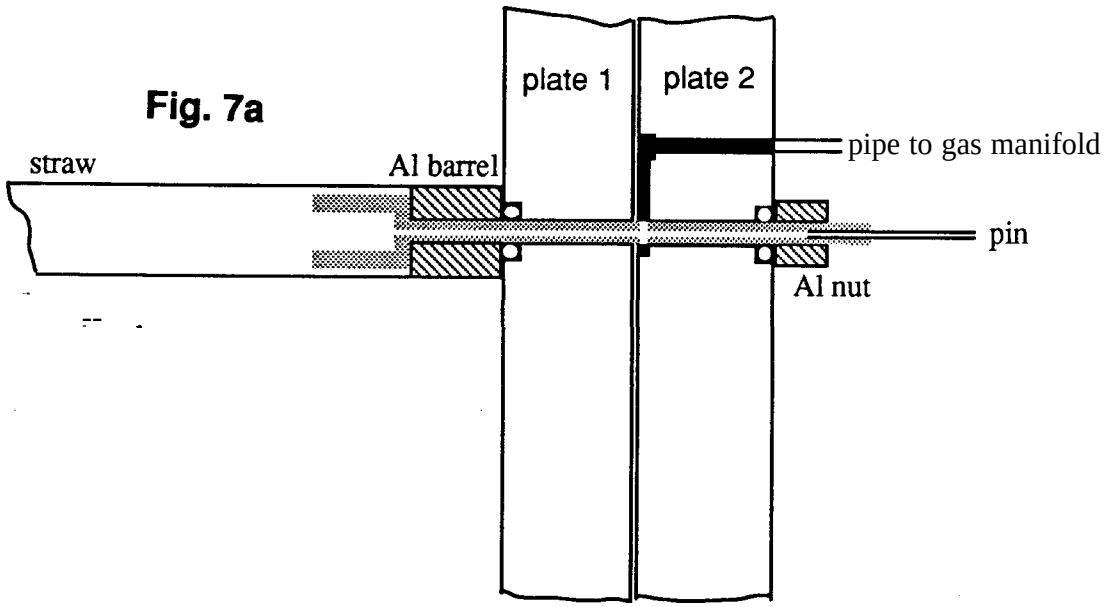


Fig 4 Lifetime as a function of the rate of volume changes (water vapor added)

Figure 6. Lifetime measurements in coulombs per cm for different gas vapor additives to argon/ethane (a) and lifetime measurements as a function of gas interval flushing (b) from the Mark III group.



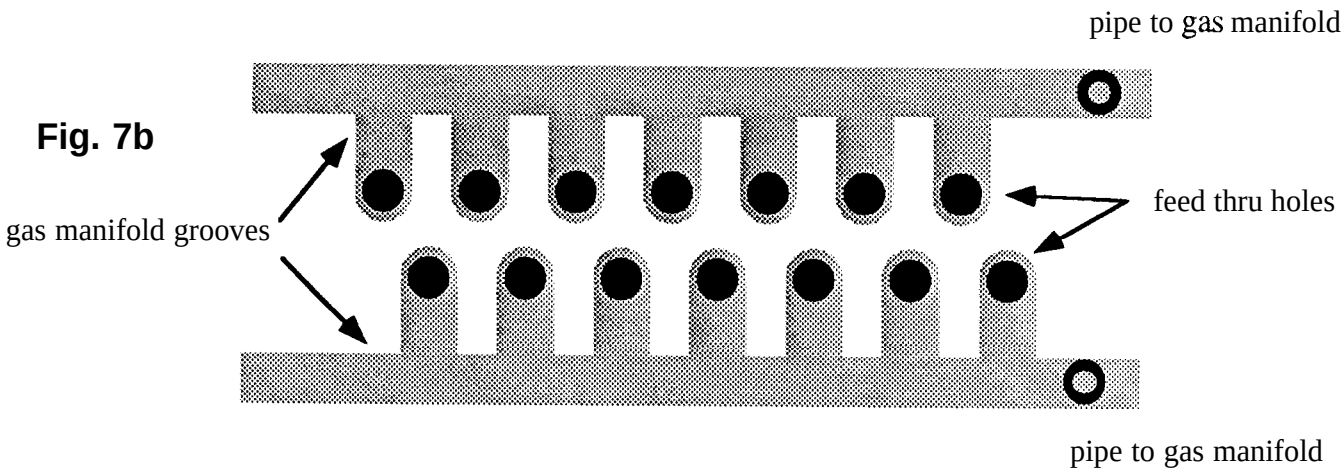


Figure 7. Side view (a) drawing for a gas manifold the endplate and front view (b) of gas manifold grooves in plate 2.