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THE MYLAR STRAW TUBES: MECHANICAL PROPERTIES AND BEAM TEST RESULTS

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Abstract

Ammosov V.V. et al. The mylar straw tubes: mechanical properties and beam test results: IHEP Preprint 93-116. – Protvino, 1993. – p. 12, figs. 12, refs.: 3.

Durability, deformations and test results with hadron beam are described here for blocks of straw tubes made of mylar with ultrasonic welding. The thickness of one layer of tubes is less than $10^{-3} X_0$. Mylar tubes allow one to have both anode and strip read-out. Data on two-track resolution for tubes with "field-shaping" are given.

The mylar straw tubes seem to permit to create a high rate and low cost tracking detector of large area.

Аннотация

Аммосов В.В. и др. Дрейфовые трубки из лавсана: механические свойства и результаты испытаний на пучке: Препринт ИФВЭ 93-116. – Протвино, 1993. – 12 с., 12 рис., библиогр.: 3.

Приведены данные как по прочности и деформациям так и по результатам испытания в адронном пучке блоков трубок, изготовленных из алюминизированного лавсана с помощью ультразвуковой сварки. Толщина одного слоя трубок меньше $10^{-3} X_0$. Показана возможность считывания как анодного сигнала, так и индуцированного сигнала со стрипов. Приведены данные по межтрековому разрешению для трубок с полезадающими электродами.

Представляется, что лавсановые трубки являются хорошим кандидатом для создания трековых детекторов большой площади при низкой стоимости изготовления.

INTRODUCTION

The **future** experiments demand large area chambers for inner and muon tracking system. Usually, the choice of the detector is based on the following principles:

- intrinsic spatial resolution in bending coordinate must be about 100 μm. The opposite coordinate readout is desired.
- high rate capacity ($10^4 Hz/cm^{-2}$). The association of particle arrival time with beam crossing is needed.
- small amount of matter to decrease the conversion of gammas and multiple scattering.
- high radiation hardness.
- modularity and safety of chamber construction.

It seems, that mylar straw tubes (MST) can satisfy all demands above. Technology of the MST manufacturing with ultrasonic welding was described in ref.[1]. One layer of several tubes is produced from two sheets of metallized or carbonized mylar with doing a set of parallel straight welding seams. The diameter of a tube is determined by the step between two adjoining seams. After thermal treatment at $t \sim 160^0 C$ with overpressure inside tubes a layer of tubes becomes stiff, and further the tubes go on keeping cylindrical form without any overpressure. The thickness of mylar sheet is $50-100$ μm, so thickness of one MST layer is less than $10^{-3} X_0$.

We have created equipment for the production of the MST layers with length, L, up to 2.5 m and with diameter, D, varying from 5 to 40 mm. The number of tubes in one layer (block) is $8-32$ for $D = 20-5$ mm, respectively. A ready-made detector can consist of one or several blocks of tubes.

The design of the double layer ready-made module based on 2×8 tubes with $D = 20\ mm$ is shown in fig.1. Two blocks of tubes are mounted between two plastic endplates. Endplates have channels for the gas flow and holes for mounting plastic plugs. The plastic plugs are glued into endplates. To have a contact with cathodes, brass collars are inserted in tube ends and glued with conductive compound. The tungsten wires with diameter $d = 50\ \mu m$ are strung through brass pins with a hole of $100 \pm 5 \mu m$ diameter. The accuracy in manufacturing of details allows one to keep space between wires with 25 μm accuracy. The upper limit high voltage for operation with construction shown in fig.1 is about 5 kV. The construction may be used at overpressure up to 3 atm.

1. MECHANICAL FEATURES OF A BLOCK OF TUBES

First, we tested the quality of the welding seam between the tubes. The seam quality depends on the mylar thickness, mylar quality and conditions of welding. Table 1 shows durability (kg/cm) of seam for different thicknesses, h, of mylar.

Table 1.

$h, \mu m$	35	50	70	100
kg/cm	0.5 ± 0.2	2.4 ± 0.4	3.2 ± 0.3	3.1 ± 0.4

Tests of tubes with 20 mm diameter showed that they kept overpressure up to 3 atm.

Longitudinal rigidity of mylar blocks may be useful for creation of light detectors without frames needed to compensate the wire tension. Longitudinal rigidity of one layer of n tubes may be described with:

$$P_k \approx \frac{\pi^2 I_0 E n}{L^2}, \tag{1}$$

where $I_0 = \pi R^3 h$, R- radius of a tube, E- the Young's modulus (for mylar $E \sim 3.5 * 10^7 g/cm^2$). If the squeeze force, P, is less than P_k, a module keeps its form without bending. At $P > P_k$ a module is bent in accordance with:

$$y(x) = \delta_t sin \frac{\pi x}{L}. \tag{2}$$

Open circles in fig.2 show how a bending measured for a block of 8 tubes with $R = 10\ mm$ and $L = 1\ m$ depends on P/P_k. The value of P_k calculated with (1) is about 8.7 kg. Fig.2 shows that the bending starts when $P > P_k$ that is in a good agreement with (1). If, however, a block of tubes has initial bending, all squeeze forces even less than P_k cause an additional bending. Black circles in fig.2 are drawn for the case when the block of 8 tubes ($R = 10\ mm$) had initial bending of 0.4 mm.

Formula (1) demostrates that rigidity of mylar blocks can be improved with the use of multilayer modules.

Fig.3 shows elongation of the tubes as a function of the longitudinal straining force. Double layer module (2×8 tubes, $D = 20\ mm, L = 1\ m$) was used for this test. At force of 15 kg the elongation is $\sim$ 200 μm.

2. TUBE DEFORMATIONS AND DETECTOR STABILITY

We have measured (without any preliminary selection) few 1 m blocks consisting of 8 tubes with $D = 20\ mm$ and have found that mean deviations from straightness is $0.16 \pm 0.02\ mm$, from roundness is $0.10 \pm 0.05\ mm$. The maximal deviation from straightness found in the direction perpendicular to the block plane for one of the blocks was $0.33 \pm 0.23\ mm$.

Mylar tubes bend under force of gravitation. For module consisting of N layers with n tubes in one layer the gravitational sagitta is:

$$s_g^t \cong \frac{0.2L^4}{ER^2(2N^2+1)} . \tag{3}$$

As an example, a double layer module consisting of 2×8 tubes with $D = 20\ mm$ and $L = 2\ m$ has $s_g^t \sim 100\ \mu m$.

It is clear, that all deformations of a tube lead to electrostatic deflection of the anode wire and thus to instability. The equality of electrostatic force and the restoring force of wire tension may be presented as:

$$T\frac{d^2\delta_w}{dx^2} = -\frac{2\pi\varepsilon_0 V^2 \Delta}{R^2(lnR/r)^2}, \tag{4}$$

where δ_w is the wire deviation, δ_t is the tube deviation, $\Delta = \delta_t - \delta_w$ is eccentricity, r is the wire radius, $\varepsilon_0 = 8.85\ pF/m$, T is the wire tension. The limit on voltage when electrostatic force cannot exceed the restoring force is

$$V < V_0 = \sqrt{\frac{T}{2\pi\varepsilon_0}\frac{\pi R}{L} ln\frac{R}{r}} . \tag{5}$$

If the tube bending may be described with (2), the anode wire bent due to electrostatic force in accordance with:

$$\delta_w = \delta_t(1 - (\frac{V_0}{V})^2)^{-1} sin\frac{\pi x}{L}. \qquad (6)$$

Fig.4 shows δ_w as a function of δ_t. The data were obtained for $D = 20\ mm$ at $V/V_0 = 0.205$. The line in this figure is what comes from (6) at $x = L/2$. There is a good agreement between the data and calculation.

Thus, one may conclude, that deformations found for the manufactured blocks can cause the wire deflection less than $\sim 100\ \mu m$.

The maximal working voltage is limited by the wire vibration at V_c. The dependence of V_c on δ_t has been studied in [3] for the tubes with 6.35 mm diameter. Assuming the linear dependence on the tube radius δ_t(R), one can obtain the following relation between δ_t and V_c: $\delta_t^m \cong 2.52R(V_c/V_0+1)\times \times(V_c/V_0-1)^2$.

The anode wire displacement changes the drift function. Computations with GARFIELD show that the maximal error in determinating the coordinates for the case when $\Delta = 1\ mm$ is $\sim 300\mu m$ for $Ar + CO_2$ (80 : 20)% and $\sim 140\mu m$ for $Ar + Isobutane$ (60 : 40)%.

3. TEST RESULTS

Various modifications of the mylar tube modules were tested in the hadron beam of the U70 accelerator.

First, the anode wire read-out was studied using the module which consisted of one layer of 64 tubes with $D = 10\ mm$ and length of 1 m. The beam direction was in the plane of the tubes and was perpendicular to the wires. Since a beam particle crosses all tubes it allows one to find the tube efficiency and spatial resolution. The tube gases were mixtures $Ar + CO_2$ (80 : 20)% and $Ar + Isobutane$ (C_4H_{10}) (60 : 40)%. Fig.5 shows the setup for this test. The preamplifier had a gain of 38 $mV/\mu A$, rise-time of 10 ns and $ENC \sim 2000e^-$. The discriminator threshold was $2\mu A$. LeCroy 2228 and 2249 convertors were used to registrate time of hit and amplitude from the anode.

Fig.6 shows the tube efficiency as a function of the anode voltage for both gas mixtures. The data for $Ar + CO_2$ are given with circles, triangles represent the result for $Ar + C_4H_{10}$.

The data on the amplitude analysis obtained for $Ar + C_4H_{10}$ are shown in fig.8. This figure demonstrates how the signal amplitude changes when the proportinal mode transforms into the limited streamer mode (LSM). Obtained at $V = 2.6\ kV$ fig.8a shows the amplitude spectrum for the proportinal mode.

At $V = 2.75\ kV$, as fig.8b shows, a fraction of the LSM signal may already be seen. Fig.8c demonstrates that at $V = 2.9\ kV$ there exists pure LSM.

To estimate spatial resolution, hits from the tubes were approximated with a straight line. Spatial resolution as a function of the high voltage is given in fig.7 (circles) for $Ar + CO_2$ and (triangles) for $Ar + C_4H_{10}$. The best coordinate resolution of $120 \mu m$ was achieved for $Ar + C_4H_{10}$ in LSM.

We studied the aging of aluminized tubes in LSM. At integral charge of 1.5 C/cm^2 no changes in behaviour were noticed.

To study the strip read-out we used a double layer module made of 2×8 tubes with $D = 20\ mm$ and $L = 1\ m$. Both layers consisted of tubes which had a window (8 mm width) free of metallization. Both layers of the tubes were supplemented with an external strip panel (see fig.9) to registrate an induced signal and so to measure the coordinate along the anode wires. The strip width was 5 mm. The beam direction was perpendicular to the tube layers of tubes and strip panels. The coordinate of a hit was recontructed by amplitude analysis independently for the "left" and "right" panels of the strips. By comparison between the coordinates, x_1 and x_2 from two strip panels one can estimate an accuracy of the coordinate determination. Fig.10 shows the values of $(x_1 - x_2)$ obtained for $Ar + C_4H_{10}$ at $V = 3.3\ kV$ in LSM. Systematic difference between x_1 and x_2 is caused by the $\sim 1\ mm$ shift along tubes between the strip panels. From Gaussian fit of the data (curve in the figure) the spatial resolution was estimated as $\sim 320\ \mu m$.

Preliminary results have been obtained on improving the multitrack resolution for the anode read-out. For this study we used a block of tubes prepared from two sheets of mylar with special metallization: the cathode in the tubes was in a form of separated strips along the tubes. This gives a possibility to change the shape of the field inside the tubes to reduce variations in electron arrival time. Fig.11a,b shows drift lines and output signals from two tracks spaced by 3 mm. Fig.11a,b are the result of the GARFIELD simulations[2] for a tube with "field shaping". Fig.12 gives preliminary experimental result on the two track resolution. It shows the difference between times of two hits distinguished with those tubes. Tubes with $D = 20\ mm$ and $L = 1\ m$ filled with $Ar + C_4H_{10}$ were used. For the gas mixture used the time resolution of $\sim 40 nsec$ correspondes to the coordinate resolution of $\sim 2\ mm$.

CONCLUSIONS

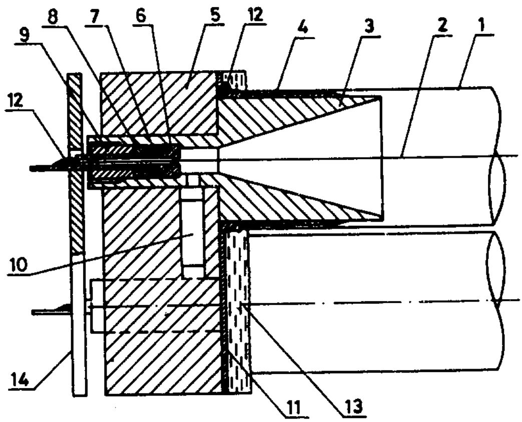
A block of mylar tubes prepared by ultrasonic welding with further heating at $t \sim 160^0 C$ is a very rigid system which gives a possibility to create a low material detectors with length of few meters.

Deviations from ideal cylindrical form found for manufactured tubes are not crucial. Spatial resolution of 120 μm with efficiency close to unit was obtained for the anode read-out.

Mylar tubes may be used as two coordinates detector. Strip read-out allows one to determine coordinate along wires with accuracy of $\sim$ 320 μm.

Multitrack resolution for anode read-out may be improved when tubes with "field shaping" are used. Preliminary result on two tracks resolution is ~ 2 mm.

MST seem to be a good candidate for low-cost, large area tracking detector in future experiments.



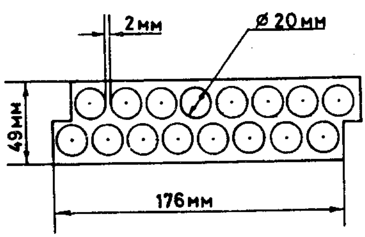


Figure 1. View of the assembled double layer module: 1 – mylar tube, 2 – anode wire, 3 – plastic plug, 4 – brass collar, 5 – plastic endplate, 6 – brass pin, 7 – rubber seal, 8 – brass ring, 9 – bruss nut, 10 – channel for gas, 11 – ground plate, 12 – soldering, 13 – epoxy seal, 14 – HV input board.

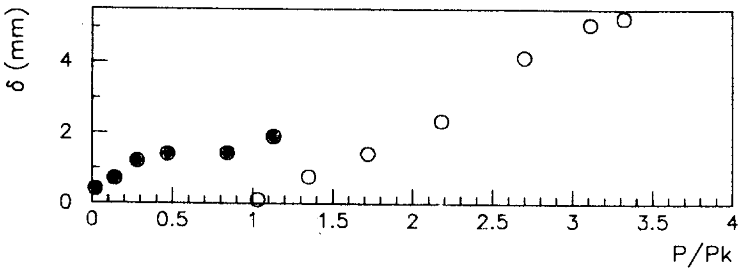


Figure 2. Bending of tubes as a function of the relative longitudinal squeeze force, P/P_k: open circles for the MST block which had no initial bending, black circles for a case when the block had initial bending of 0.4 *mm*.

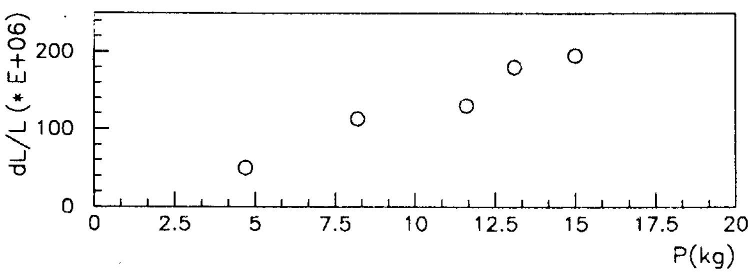


Figure 3. Relative elongation of 1 *m* block of 2×8 tubes with $D = 20$ *mm* as a function of stretch force.

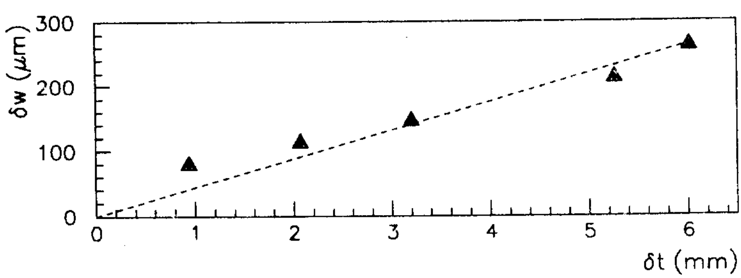


Figure 4. Electrostatic deviation of the wire as a function of the tube bending.

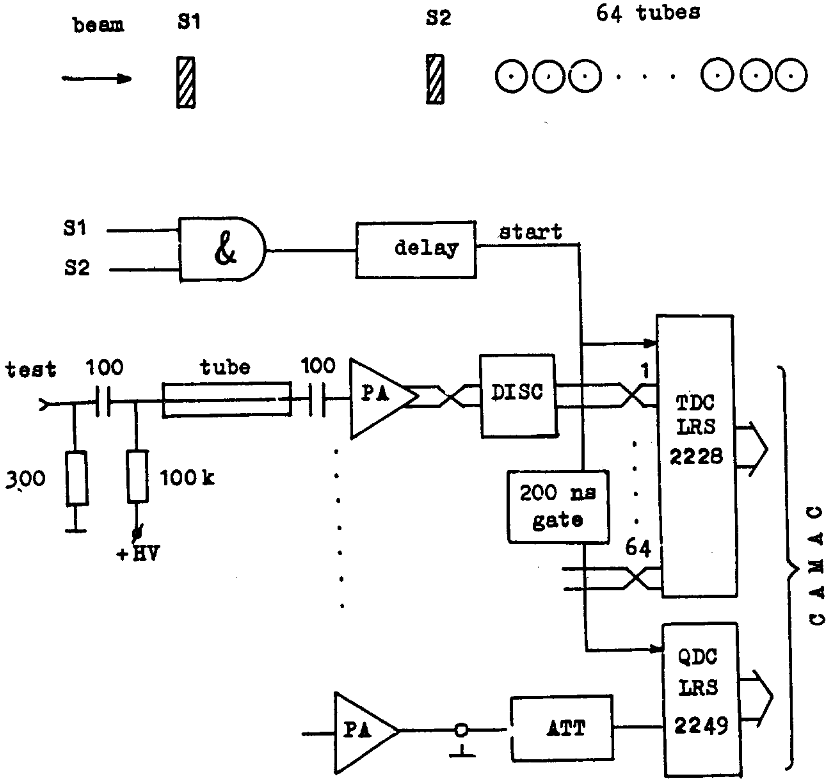


Figure 5. Experimental setup for testing of tubes in hadron beam.

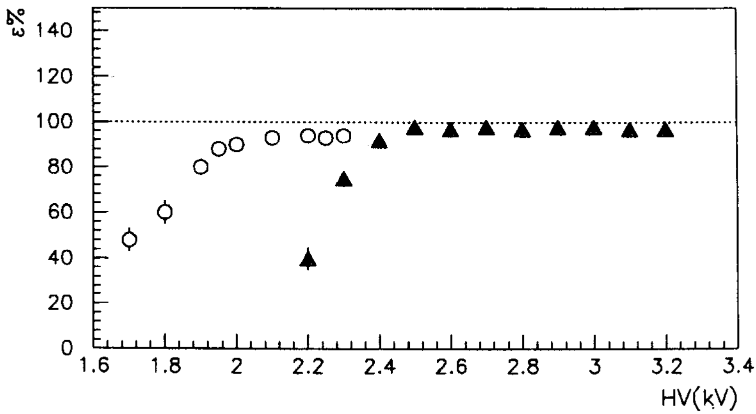


Figure 6. Efficiency of tubes ($D = 10\ mm$) for two gas mixtures, $Ar + CO_2$ (circles) and $Ar + C_4H_{10}$ (triangles), as a function of high voltage.

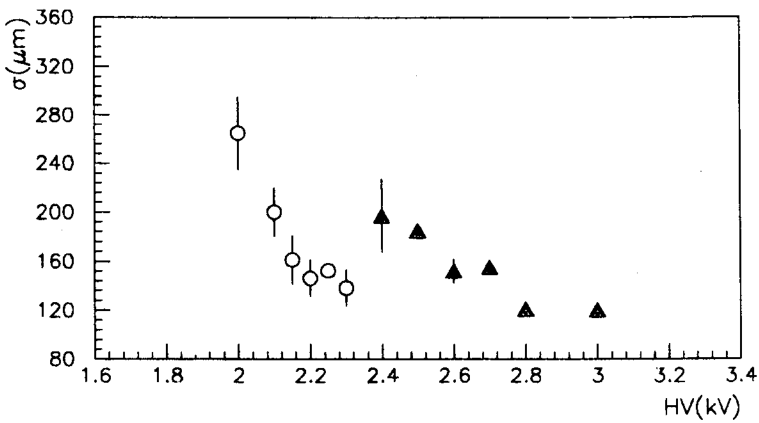


Figure 7. Spatial resolution at anode read-out for the same gas mixtures (as in fig.6) as a function of high voltage.

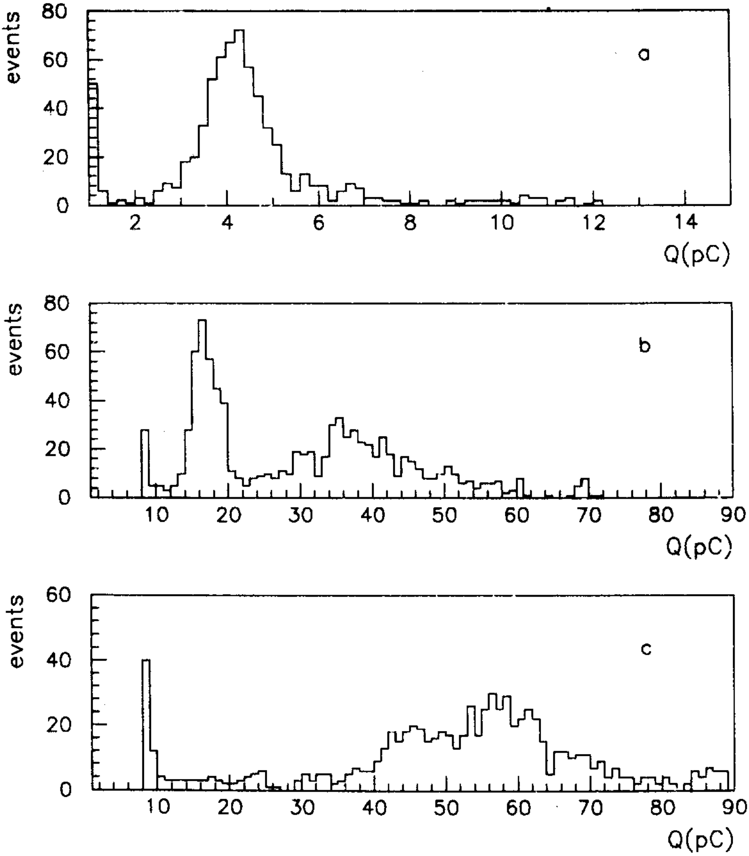


Figure 8. **Amplitude from anode at different voltages, V_t: a) - 2.6 kV, b) - 2.75 kV, c) - 2.9 kV. Tube gas is $Ar + CO_2$.**

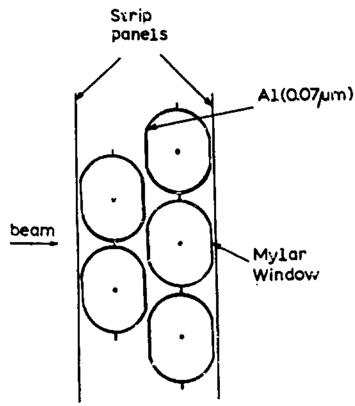


Figure 9. Schematic picture of double layers module supplemented with strip panels.

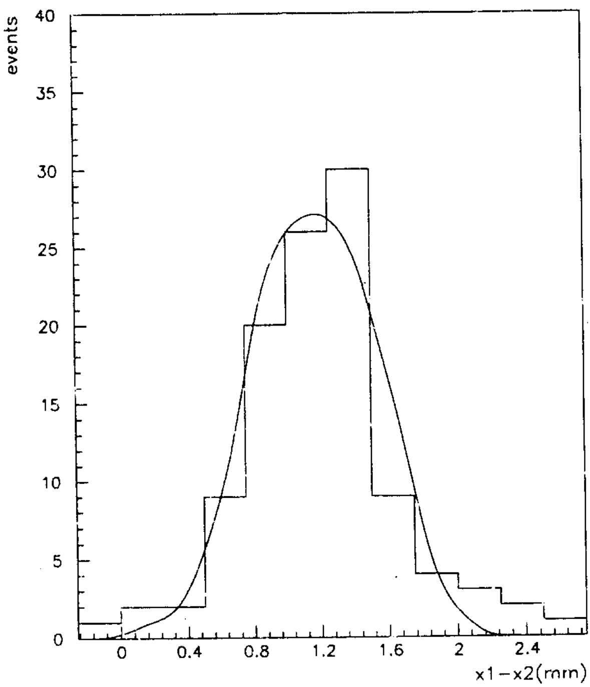
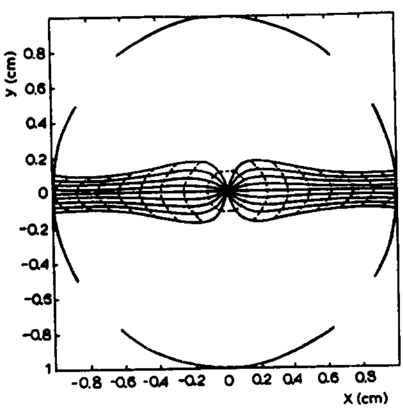


Figure 10. Difference between coordinates of hit extracted from the first and second strip panels. The curve is Gaussian fit.



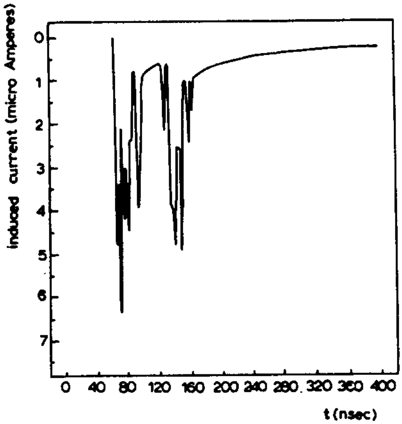


Figure 11. Computations with GARFIELD for a tube with "field-shaping": a) drift lines, b) signals from two simultaneous tracks spaced with 3 *mm*.

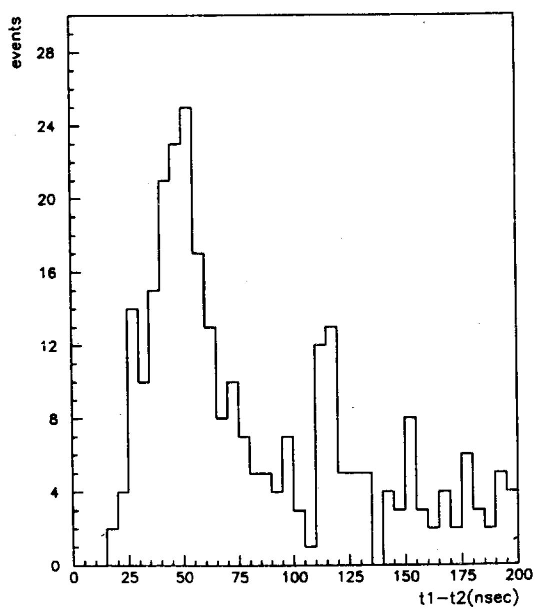


Figure 12. Preliminary result on time resolution for two tracks crossing the field shaping tube.

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