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MULTITUBE PROPORTIONAL CHAMBERS FOR HIGH COUNTING RATES

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ABSTRACT

Proportional chambers made of 3 mm diameter tubes were built and tested in intense particle beams. In the proportional mode the tubes worked satisfactorily at a rate of 2.5×10^6 particles/s and wire, and 4×10^5 particles/s and mm wire. With a suitable gas mixture and pressure, very short pulses with high constant amplitude were obtained.

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1. INTRODUCTION

Proportional counter tubes usually find application at low counting rates, where it is sufficient to have a poor space resolution. The reasons for studying their properties at high counting rates, where good space and time resolution are also important, were the problems encountered with conventional proportional chambers at high counting rates and particle density. Qualitative arguments suggested that a chamber made of layers of thin tubes might, under those conditions, be superior to conventional chambers.

To verify this idea, two prototypes have been built. The first consists of 25 tubes, 100 mm long, having a 3 mm inner diameter and a 4 mm outer one; these tubes are arranged in two superposed interlatched layers in order to achieve 1 mm space resolution. The second prototype consists of 50 tubes, 1 m long, but otherwise identical to the first one. The smaller chamber is equipped with 20 μ m diameter tungsten wire stretched to 0.35 newton; the larger chamber with 30 μ m wire stretched to 1 newton.

Both chambers were initially tested in low- and medium-density beams to evaluate their operating characteristics, and to develop suitable electronics. The final tests were done in a beam of about 10^7 particles/s that was eventually focused on a spot of $5 \times 10 \text{ mm}^2$ at the chamber.

2. WIRE STABILITY IN A TUBE

A stability criterion analogous to that for conventional chambers exists for a tube counter. The electrostatic potential U around a wire of radius a , eccentric by Δ in a tube of radius b , is given by¹⁾

$$U = \frac{U_0}{\ln \left(\frac{b}{a} \right) - \left(\frac{\Delta}{b} \right)^2} \cdot \left[\ln \left(\frac{r}{a} \right) + \frac{\Delta \cdot a}{b^2} \left(\frac{r}{a} - \frac{a}{r} \right) \cos \phi \right].$$

The maximum voltage V applicable to a wire of length ℓ , stretched by a force k newton is

$$V = 3.8 \times 10^5 \sqrt{k} \left(\frac{b}{\ell} \right) \ln \left(\frac{b}{a} \right).$$

This formula was verified by varying the mechanical tension on a wire in a carefully adjusted tube, and measuring the voltage at which the wire flips against the tube wall.

If the initial position of the wire is eccentric by Δ , its equilibrium position in the middle of the tube when the voltage is applied is

$$d = \Delta \left(1 + \frac{1}{\left\{ 1.43 \times 10^{11} \frac{k}{V^2} \left[\frac{b}{\ell} \cdot \ln \left(\frac{b}{a} \right) \right]^2 - 1 \right\}} \right).$$

Before using the 1 m chamber, it was mechanically adjusted in such a way that at least 2500 V could be applied, while the maximum theoretical value was 2650 V. The maximum applied voltage on the 1 m chamber during the tests in the beam was 2100 V, while the 10 cm chamber was operated at up to 3500 V.

3. ELECTRONICS

Both chambers were initially tested in beams of 10^4 to 10^6 particles/(s·cm²). At these rates the properties of the electronics could be adequately studied. As a preamplifier, we chose a fast line receiver (Motorola type MC-10216) which has a bandwidth of 70 MHz. In order to minimize the electronics dead-time, various input circuits were tested. The best results were obtained with an inductance of 0.15-0.5 μ H connected between the amplifier inputs. This, together with the stray capacitances, forms a parallel resonance circuit. Critical damping is provided for by a 100 to 150 Ω resistor in parallel with the inductance.

The effect of the inductance is demonstrated in figs. 1 and 2. Figure 1a shows the signals on the output of the preamplifier and fig. 1b, for comparison, a signal when the inductance is removed. In order to have a better understanding of this effect, the differential equation for the input circuitry was solved numerically (fig. 2). As input, the charge variation on the anode wires due to the drifting clouds of positive ions was used. For comparison, the corresponding signals without the inductance are superposed. The essential features of this circuitry are that

- it has a short time over threshold that depends only slightly on the amplitude;
- there is a positive overswing that reduces pile-up effects in the amplifier chain;
- it is insensitive to the long tail of the chamber pulse;
- the amplitude of a signal from a single electron is almost unaffected by the inductance, i.e. the threshold for full efficiency will not change significantly.

The final tests with the 1 m chamber were done using the electronics shown in fig. 3. To reduce external noise pick-up and cross-talk, the preamplifier card (card 1 in fig. 3) was housed in a metallic box mounted directly on the chamber. The linear, balanced signals were brought to card 2 via a TWP cable, where they were amplified and discriminated. The discriminator threshold may be remotely controlled within a range of 1 to 50 mV. Its nominal value during the tests reported in the next section was 11 mV.

The coupling between the different channels was 5%, measured by injecting calibration pulses onto individual chamber wires. This may explain the rise in the single counting rate in the plateau (see fig. 4).

The chamber signals were stretched to 30 ns, equal to the maximum electron drift-time in the gas. The trigger signal was made as short as would be compatible with the coincidence electronics (~ 10 ns). This minimizes the dead-time effects and double counting simultaneously when updating discriminators and scalers are used, as in fig. 3.

Owing to the statistical distribution of the time of arrival of the electrons from one particle track, there is a small probability that the updating discriminator will be retriggered by late electrons. This effect manifests itself as a shoulder in the trigger delay curve in fig. 5. Alternatively, this shoulder may be due to afterpulses.

4. RESULTS AT HIGH RATES

The final tests with the 1 m chamber were done in a 270 GeV hadron beam behind the NA3 experiment. The beam intensity was about 10^7 particles/s. With the beam focused on the target, the particle density at the chamber was about $10^4/(s \cdot mm^2)$. When it was focused on the chamber itself, a beam density of about $3 \times 10^5/(s \cdot mm^2)$ was obtained.

The trigger was defined by two scintillators, $2 \times 10 \text{ mm}^2$, one 5 m upstream and the other 1 m downstream from the chamber. They defined a 2 mm wide beam used for the efficiency measurements. The precision of the results suffers from the very short test period of two hours in the focused beam, and only a few days parasitic use of the defocused beam.

Figure 4 shows the plateau curves obtained at different beam densities and gas pressures. In those tests the chamber was operated with a gas mixture of about 80% argon, 20% isobutane, 0.1% freon, and isopropyl alcohol vapour. From the figure it can be concluded that the space-charge effects start above 10^5 particles/(s·mm wire), and that 90% efficiency can still be obtained at 10^6 particles/(s·mm wire). A small improvement is obtained with higher pressure, presumably because of the effectively longer plateau. At fixed high voltage the space-charge effect is, as expected, more violent at high pressure owing to the slower drifting of the positive ions.

In a low-intensity beam an efficiency above 99.5% was easily obtained. The missing few percent at high rate are (at least partly) due to an imperfect trigger. If the signals from the tube chamber are properly coded, a full-width space resolution of 1 mm is expected. To verify this, the signals from eight tubes were gated in to a pattern unit. Figures 6a-c show the histograms obtained on the computer display^{*)} under the different conditions. The geometry of the tubes and of the trigger counters is shown in fig. 7.

*) Considering the following detection rules: single but not adjacent wires hit -- stored as individual hits; two adjacent wires hit -- stored as one hit in between. The physical distance between wires is 2 mm, corresponding to two bins.

The registered beam width and accidental rate correspond to what is expected. In fig. 6c the trigger was generated at random. The flat distribution of the accidentals indicates that the true bin width is constant in spite of the round tubes used.

5. RESULTS WITH ARGON-METHANE GAS MIXTURES

Some tests were done with argon + methane mixed in the ratio 59/41 and 41/59 in the 10 cm chamber. Figure 8 shows the plateau curves measured at different pressures. Except for small differences in the plateau voltage, identical results were obtained with both mixtures. In particular, the unexpected poor efficiency at atmospheric pressure is reproducible. Above 3 atm three well-separated modes of amplification exist. A similar effect has previously been observed in magic gas containing freon²⁾ and also in large-diameter proportional tubes³⁾.

The shape of the signals for the three different modes is shown in figs. 9a-c. The amplitude of the signals in mode II is about 80 mV on 100 Ω , and the full width at the base is 20 ns. Therefore they can only be due to electrons drifting across the tube. From the signal width an upper limit of the radial extension of the electron avalanche of 0.5 mm can be deduced. Assuming radial extension of 0.3 mm, the total charge of the avalanche is 1.4×10^{-11} C or 8×10^7 electrons, in good agreement with results in magic gas²⁾. At a particle density of $1.5 \times 10^3/(s \cdot mm \text{ wire})$, 97% efficiency was obtained in this mode of operation. This was verified at low preamplifier gain as well as by making amplitude histograms of the signals. At a particle density of $3 \times 10^4/(s \cdot mm \text{ wire})$ but otherwise at identical conditions, only half of the signals were of type II, while the other half were of type I. This rate effect is well explained by the reduction in effective electric field around the wire during the 30 μs drift-time of positive ions across the tube. At still higher voltage, afterpulsing at 30 ns intervals occurs (fig. 9c) due to photoelectrons from the tube wall³⁾.

6. CONCLUSIONS

The properties of proportional chambers made of 3 mm diameter steel tubes were investigated. The most significant result is the big particle density that

can be handled. In units of particles/(s·mm wire) it is an order of magnitude higher than was previously observed⁴⁾.

The electronic dead-time due to the long tail of the chamber signal could be reduced by connecting inductance between the inputs of the differential pre-amplifier. Counting rates in the range of MHz/wire could be handled with this method.

A full-width space resolution of 1 mm is obtained with two superposed layers of tubes and 4 mm wire spacing in each layer. The time resolution of 30 ns is determined by the electron drift time across the 1.5 mm tube radius. The long plateau observed when the chambers are operated at high pressure suggests that by using tubes of smaller diameter, the space and time resolution would improve.

Operation in an argon-methane mixture at high pressure may have applications where the particle density is not too high. The small dispersion in signal amplitude and big signal-to-noise ratio would make this mode of operation particularly suitable for two-dimensional read-out techniques.

Depending on the ratio of the tube length to diameter and on the operation conditions, intermediate wire supports may be necessary. For 3 mm diameter tubes, 1 m may represent a practical limit without intermediate supports.

Preliminary calculations of space-charge effects, using a formalism similar to that developed for proportional counters⁵⁾, agree with the observed shift of the plateau at the highest rates.

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Figure captions

Fig. 1 : a) Linear signals. Preamplifier gain 32. Horizontal scale: 10 ns/div.
Vertical scale: 20 mV/div.

b) As above but without inductance on the amplifier input. Horizontal scale: 20 ns/div. Vertical scale: 20 mV/div.

Fig. 2 : a) Calculated signal from a single electron and a gas amplification of 10^6 . For comparison, the same signal without the inductance is shown. Input: 100 Ω , 0.47 μ H, and 40 pF stray capacitance.

b) Same as above but with four primary electrons at 8 ns intervals. A gain reduction of 15% is assumed per electron.

c) Eleven electrons at 3 ns intervals.

Fig. 3 : The electronics used for the tests. The top half shows the amplifiers and interconnections. The lower half is a block diagram of the logic used.

Fig. 4 : Plateau curves at different particle rates and densities:

a) Single tube STP.

b) Three tubes OR-ed STP.

c) Single tube, two bars

Curve		$(s \cdot \text{wire})^{-1}$	$(s \cdot \text{mm wire})^{-1}$
0	Defocused	5.5×10^5	1.4×10^4
+	Defocused	1.1×10^6	4.5×10^4
x	Focused	2.3×10^6	4.0×10^5
.	Focused	2.6×10^6	1.0×10^6

The full line is the counting rate.

Fig. 5 : Efficiency as a function of the delay of the counter coincidence.

The beam is centred between two tubes that are OR-ed.

Fig. 6 : Histograms obtained with the pattern unit and the beam centred on one tube:

a) in a defocused beam at $5 \times 10^5/(s \cdot \text{wire})$;

b) in a focused beam at $\sim 2.6 \times 10^6/(s \cdot \text{wire})$;

c) in a defocused beam and random trigger.

Fig. 7 : Chamber and counter geometry.

Fig. 8 : Plateau curves in an argon-methane mixture:

- a) at atmospheric pressure;
- b) at 2 bars;
- c) at 3.5 bars.

Fig. 9 : Shape of the signal in an argon-methane mixture at 3.5 bars. The amplifier input is $100\ \Omega$ and about 20 pF stray capacitance.

- a) Proportional mode, preamplifier gain 64. Horizontal scale: 20 ns/div. Vertical scale: 20 mV/div. Signal amplitudes between 80 and 120 mV are selected by a window discriminator. Applied HV = 2.9 kV.
- b) Most of the signals are of type II. Preamplifier gain 4. Horizontal scale: 20 ns/div. Vertical scale: 50 mV/div. The scope is triggered on the chamber signals. HV = 3.1 kV.
- c) Signals of type III. Preamplifier gain 4. Horizontal scale: 20 ns/div. Vertical scale: 100 mV/div. HV = 3.3 kV.

Fig. 1

Fig. 2

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9