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Section A

Time resolution of ionization chamber filled with liquid krypton and xenon

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The noble liquid calorimeters of particle detectors are generally regarded to be "slow" devices and have practically not been used in time measurements. But in principle they can have a resolution at the level of ns due to their stability. This paper presents results of measurements of time resolution for a test ionization chamber filled with liquid krypton and xenon and irradiated by cosmic rays. A time resolution of the order of 10 ns is obtained.

1. Introduction

Liquid calorimeters of radiation detectors are usually regarded to be "slow" devices because of their signal rise time of the order of microseconds. Generally the cryogenic calorimeters are the multilayer stacks of plane ionization chambers filled with liquid argon, krypton and xenon. The main feature of these detectors is high time stability of the signals due to absence of charge multiplication and to stability of parameters of the liquid. It gives hope to achieve a time resolution of the order of nanoseconds and use it in experiments, for example, to separate events produced in different beam collisions in colliders.

It is well known [1] that if the time resolution is determined by noise it can be obtained from the expression:

$$\sigma_t = \sigma_n/(\mathrm{d}A/\mathrm{d}t) \simeq \sigma_n \tau_{fr}/A_{\max}, \quad (1)$$

where σ_n is the r.m.s. value of noise, τ_{fr}-signal rise time and A-signal. Therefore, short signals with high amplitude and with a minimum of noise are needed. In practice these demands are in contradiction.

This paper presents the results of time resolution measurements in a test plane ionization chamber filled with liquid krypton and xenon and irradiated by cosmic muons.

2. Experimental

The test chamber was placed inside the cryostat [2], which includes two vessels: an inner vessel of 3 l volume inside the evacuated one. The inner vessel was thermostabilized with an accuracy better than 0.1 K with the help of a thermal screen between the vessels cooled by liquid nitrogen and with the heater on its surface. Before the measurements the inner volume was baked together with all its contents at ~ 100°C at vacuum of about 10^{-3} mm Hg during two days.

The four-layer stack of plane double gap ionization chambers with cathodes placed between anodes was submerged in the liquid xenon or krypton at temperature of 162 K and 124 K, respectively. The 10×10 cm^2 electrodes of the chambers were made of 0.5 mm foiled G-10 with a gap between anode and cathode equal to 1 cm. The working voltage was equal to 1 kV and 2 kV for xenon and krypton runs. At this field strength the drift velocities of electrons are practically saturated [3,4]. To search the dependence of time resolution on energy deposited by particle in the chamber the cathodes of upper three layers were joined together and, therefore, we have two test chambers: one consists of three upper layers and another one of one single layer. The capacitance of these chambers including read-out cable capacitance was equal to 220 pF and 120 pF, respectively.

The attenuation length for electrons in liquids was checked by the X-ray technique in a additional ionization chamber on the bottom of the inner vessel. The gas purification system allows to obtain an attenuation length at the level of 10–20 cm [2] but after liquefaction of gases inside the vessel with such porous material as G-10 it equals to about 6 cm for krypton and only 0.12 cm for xenon. Thus in the krypton run we can have full amplitude of the signal but in xenon only 0.25% [5].

The scheme of electronics is presented in fig. 1. Signals from the chambers were processed by charge sensitive preamplifiers with FETs of SNJ903L type as an input and a RC–CR pulse shaper with a time constant can be varied from 0.5 μs up to 7 μs to search the dependence of resolution on signal filtration.

The ~ 1 V amplitude of the preamplifier output signal was recorded by a 12-bit peak ADC to make off-line corrections for amplitude variation. The form of the pulse was recorded by an 8-bit ADC to calculate the maximum of the signal derivative and to find the best level of signal discrimination.

The time resolution of the chambers corresponding to a given fraction of amplitude was determined as a "jitter" of the time delay measured by the TDC between the "start" signal from the scintillation counters placed above and under the cryostat and "stop" signals from the discriminator with thresholds fixed at 0.1; 0.3; 0.5 and 0.8 V. The input signal of the discriminator was the preamplifier output.

The electronic noise of the preamplifiers connected to upper and lower chambers as a function of shaper constant τ is presented in fig. 2. In the noise measurements the charge equal to ionization charge produced by particle traversing the chambers with a form emulating the shape of the current was injected into the FET input. In our measurements the electronic noise determines the time resolution of chambers filled with liquid xenon.

In the krypton run there is an additional source of noise from radioactive ^{85}Kr. Small admixture of this long lived isotope with maximum β-electron energy equal to 0.67 MeV gives 326 decays in cm^3 s^{-1} [4], or a decay frequency of 60 kHz in lower and 180 kHz in upper chambers, respectively.

To evaluate fluctuation in signal due to this sort of noise we follow the works [6] regarding spectrometry of high amplitude pulses at presence of high frequency low amplitude background. For pure krypton and RC–CR shaping we obtain:

$$\sigma_r[\mathrm{MeV}] = 0.22\sqrt{tf}. \tag{2}$$

where t is the pulse duration, f the frequency decay in the chamber. The noise calculated from formula (2) is presented in fig. 2. As seen for LKr chambers the time resolution at $\tau > 1$ μs is determined by "radioactivity" noise.

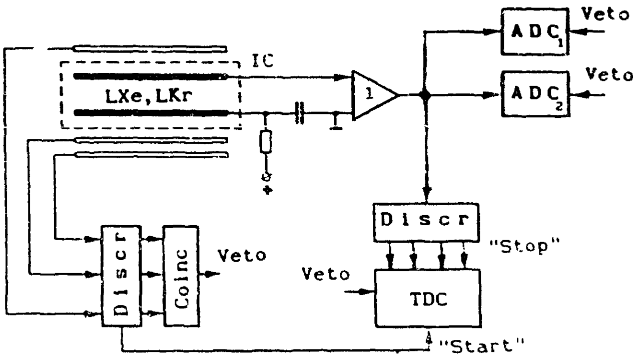

Fig. 1. Scheme of the experiment. Here: IC is ionization chamber stack; 1 – charge sensitive preamplifier followed by RC–CR shaper; ADC$_1$, ADC$_2$ – flash and peak ADC, respectively.

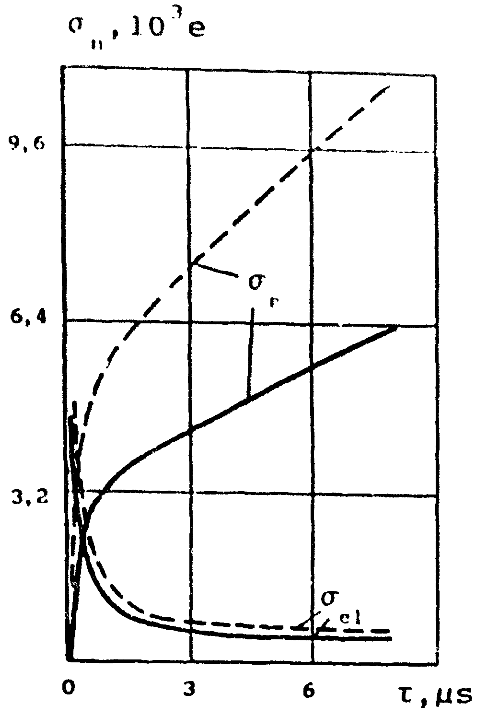

Fig. 2. Dependence of electronic σ_{cl} and "radioactivity" σ_r noises for three layer (dashed line) and single layer chamber as a function of shaper time constant τ.

3. Results and discussion

To eliminate a contamination of the data by the electrons we select the events with amplitude in the region of ∓10% near the most probable energy loss. For these events the measured time delays corresponding to different discriminator thresholds were corrected for amplitude variations of the signals.

Fig. 3 presents the results of measurements obtained at 30% fraction of signal amplitude as a function of shaper time constant. The curves in fig. 3 correspond to time resolution predictions based on electronic noise measurements and "radioactivity" noise calculations from eq (2).

It is seen the best time resolution for Xe case is achieved at $\tau = 1$ μs approximately equal to the electron life time (~ 0.6 μs) and is equal to 9 ns for the upper chamber and to 19 ns for the lower one. At higher τ time resolution is worse due to signal rise time increase but at lower τ due to electronic noise growth. The errors of the points are statistical and equal to about 15%. In the case of pure xenon it is possible to obtain a time resolution of a factor of 3 better due to signal amplitude growth and noise decrease.

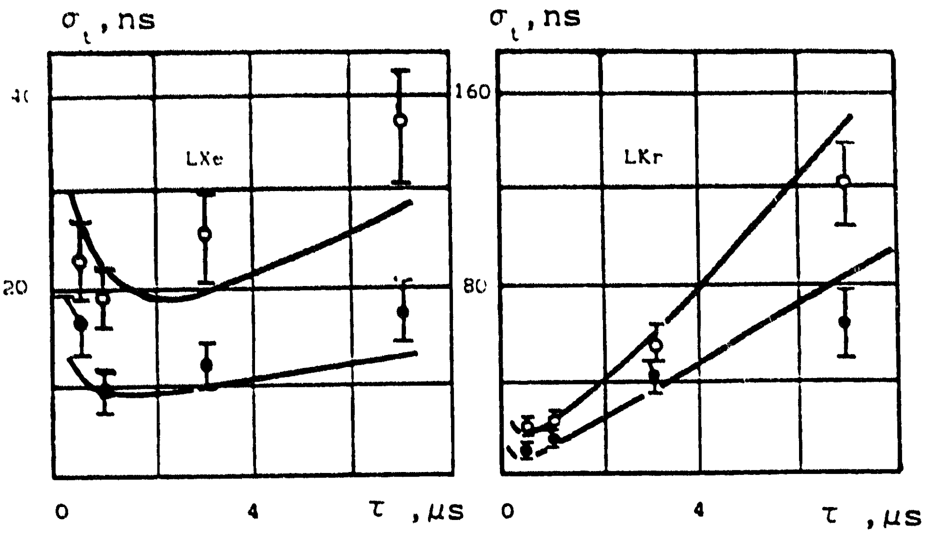

Fig. 3. Time resolution of three layer and single layer (open points) chambers filled by liquid xenon and krypton vs τ.

The best time resolution for LKr filling of the chambers was achieved at $\tau = 0.5$ μs which is significantly smaller than charge collection time (~ 3.5 μs) and is equal to 12 ns for the upper chamber and to 20 ns for the lower one. The resolution is worse at smaller τ due to electronic noise growth and at higher τ due to "radioactivity" noise and signal rise time growth.

It is seen that predictions agree quite well with the data.

Now we can estimate time resolution for a calorimeter prototype [7] using formula (1) and compare the relative parameters for the prototype and for our upper chamber at $\tau = 0.5$ μs. For the case of LKr filling of the prototype the noise-to-signal ratio for both devices is practically the same and signal rise time ratio equal to about 0.07 determines the ratio of their time resolutions. Therefore it is possible to obtain 0.8 ns time resolution detecting single minimum ionizing particles. For the 20 ns signal rise time regime in the calorimeter estimations show that time resolution will be a factor of about 3 worse, but for 1.5 μs rise time corresponding to full charge collection the resolution can be a factor of 3–5 better. These values may be compared to the time resolution of large scintillation counter TOF systems. Time resolution for gammas and electrons must be significantly better because of compact localization of shower energy.

Naturally, these estimations need an experimental confirmation.

4. Conclusions

It is shown that detecting minimum ionizing particles by an ionization chamber filled with liquid xenon or krypton it is possible to achieve a time resolution of about 10 ns. It gives hope to reach a time resolution for liquid calorimeters working on supercolliders at the level of scintillation counter systems.

References

[1] R.N. Krasnokutsky et al., Nucl. Instr. and Meth., 227 (1984) 318.
[2] P.K. Lebedev and S.V. Muraviev, Preprint FIAN, 161, Moscow (1988).
[3] T. Doke, Portugal Phys. 12 (1981) 9.
[4] P.K. Lebedev and S.V. Muraviev, Proc. 5th Int. Conf. on Instr. for Colliding Beam Physics, Novosibirsk, 1990 (World Scientific, 1990) p. 371.
[5] C. Brassard, Nucl. Instr. and Meth. 162 (1979) 29.
[6] W.J. Willis and V. Radeka, Nucl. Instr. and Meth. 120 (1974) 221; and V. Radeka and S. Rescia, Nucl. Instr. and Meth. A265 (1988) 228.
[7] B. Aubert et al., Preprint CERN-PPE/91-73, CERN (1991).