LIQUID ARGON GAMMA RAY DETECTOR -- VARIATIONS OF THE WILLIS CHAMBER

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ABSTRACT

Application of the liquid argon ionization chamber to gamma ray shower detection is discussed. Several variations are examined, and their merits and deficiencies pointed out. A design which looks promising uses sheets of foil and aluminized strips on mylar as the ion collectors, and detects the current as the output signal.

Willis has pioneered in the development of liquid argon for use in the detection of γ rays and hadrons. He has described a test model which had 200 steel plates, each 22 cm in diameter, 1-1/2 mm thick, spaced 2 mm apart and immersed in liquid argon. Each of the 200 cells represented 0.1 X_o (radiation length) so that there were 20 X_o in all. With a dc potential of about 2 kV between adjacent plates, he had a liquid ionization chamber. A liquid ionization chamber has an advantage over a gaseous one in that more of the energy is lost in a liquid than a gas reducing the fluctuations. The resolution of such a device is improved if the plates are made thinner and proportionately more cells are used. In the chamber described above a σ of 2.6% was obtained for 7 GeV/c electrons. The collection time was 300 ns for the 2 mm gap. It is stated that the addition of a few hundred parts per million of CH_4 speeds the collection time by a factor of three.

The presence of electronegative impurities must be kept very low, less than one part per million in the case of oxygen. It is said that this is not very difficult to start with and that a purifier can maintain this purity easily.

Radeka, who designed the low noise amplifier, used a transformer (25 to 1 step up) to match the 50 nF capacity of the plates to the 30 pF input of the FET amplifier. To get an idea of the signal size, a 1-GeV γ ray produces 0.6 pico-Coulombs on 50 nF giving 12 μ volts on the detector. Transforming this up by a factor of 25 gives 0.3 mV at the input of the amplifier for 1 GeV.

At e^+e^- storage rings the mean momentum of charged π's is about 0.5 GeV/c. If the π^o's had the same mean momentum, γ's of 0.25 GeV/c would be expected and very small pulses would predominate. Furthermore, the energy resolution of these γ's would be poor. The reconstruction of the π^o's would also require spatial resolution. Willis mentioned that plates near shower maximum could be broken into strips to get position resolution.

To utilize the advantages of the liquid argon ionization detector and avoid some of its shortcomings for e^+e^- storage rings, I made a certain number of modifications of it: (1) To improve the energy resolution, thick sampling plates are eliminated so that essentially all the energy is deposited in the argon. This has to be paid for in increased length 10 X_o = 1.4 meters. (2) To obtain spatial resolution, plates have to be subdivided. This has the further advantage of reducing the capacity. My first variation looked very

good until I discovered certain difficulties. One cell of it consisted of two parallel sheets of Al foil 2 cm apart and 1.4 meters long. In between, wires 1.4 meters long separated by 2 cm served as charge-collecting wires. Gamma rays entered parallel to the wires so that most of the energy was deposited near one wire. The capacity of a wire plus the leads amounted to 50 pF. With 1 GeV giving 3 pico-Coulombs, voltages of 60 mV/GeV appeared.

My euphoria vanished when I realized that the system has gross non-uniformities. If a shower develops close to a wire, the voltage is much smaller than for showers near the foils. If the shower spread is not large with respect to the wire-foil spacing, then an averaging is not performed and nonuniformity resulted. The position dependence occurs because the voltage depends on the electron path length to the collector. (The positive ions are not immediately collected.) Consider two parallel plates forming a capacity C and with a voltage between them. Consider three cases in which an ultraviolet photon ionizes an atom of gas between the plates. Case I, the ion pair is at the surface of the negative plate. The voltage change, V, between the plates when the electron is collected but the ion hasn't moved is $V_I = \frac{e}{C}$. Case II, the ion pair is produced in the middle of the gap: $V_{II} = \frac{e}{2C}$. Case III, the pair is produced at the positive plate: $V_{III} = 0$. We see that the effective charge collected and level of voltage depends on the electron path length. The instantaneous current at $t = 0$ is constant, and I shall return to this later. If the voltage is measured, it is evident that an averaging is needed. The easiest method is to have the γ's come in perpendicular to the foils. Wires are bad because again position dependences occur. Thus we are back to the Willis configuration with the plates replaced by foils. However, now the collecting foils can be made of mylar aluminized in desired areas. Strips in X alternated by strips in Y give position resolution. Like strips in depth are connected together to reduce the number of ADC's. Lower capacity yet is possible by aluminizing in squares 2 cm $\times$ 2 cm and connecting the appropriate squares in depth. The voltage output depends on the square of the foil-mylar spacing (the signal increases linearly and the capacity inversely). Thus by increasing the gap from 2 mm to 1 cm a factor of 25 is gained (this has to be paid for in a longer collection time and higher purity). The capacity is 70 pF for 70 2$\times$2 cm squares (both sides) separated by 1 cm from the foil. Without a transformer, 50 mV/GeV is possible. Further, the charge can be transferred from the detector to a capacitor through a FET to be held until multiplexed to an ADC. In this way 100 squares can be digitized serially by one ADC.

The geometry is quite difficult to construct and interconnect however, so that I went back to the geometry with the γ's coming in parallel to the foils. The electron collector now is a sheet of mylar aluminized in strips 2 cm wide on both sides connected together, and 1 cm from a foil on each side. The γ's come in parallel to the strip. The maximum time T_{max} it takes an electron to be collected is 1.5 μsec. The current $I = Q/T_{max}$ has a duration depending on position but not its peak height at $t = 0$. Thus a low input impedance device will measure a fast voltage proportional to the current and hence the energy. The current is ~ 4 μA/GeV. If the device can hold this voltage for ~ 5 msec, it can be read off by an ADC serially. Furthermore the fast pulse can also be used in a sum with other channels to give a total energy trigger out. This geometry is relatively easy to connect to (at the far end, for example), and design for special experiments. For example, the negative high voltage foils do not have to be parallel, but can all aim at the interaction point in storage rings or to the center of a liquid hydrogen target. The sides of the aluminized strips can likewise aim at the interaction point so that the γ's go radially out along a strip, inducing a maximum current in one strip. The typical shower spread should be $\pm$ 1 cm or about one strip.