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MASTER

Proportional Chambers and Multiwire Drift Chambers at High Rates+

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The high event and particle rates expected for ISABELLE intersecting storage rings raise the question whether PWC's and drift chambers, now widely in use in experiments, still can operate under such conditions.

The space charge produced by the positive ions of the avalanche drifting away from the anode may reduce the gas gain and in this way affect the energy loss measurement. In addition, the avalanche, as long as it is close to the wire, may produce dead zones which cause efficiency loss. Deposits from the quenching process on the anode limit the liftetime of the chamber. These effects depend on the number of avalanches produced per length of wire $\mathcal{N}$ and the size of the avalanche Q, i.e. on the number of positive ions created in an avalanche. Therefore the important parameter for the following discussion is the product $Q\mathcal{N}$.

The minimum Q will be determined by the type and noise level of preamplifiers used. Examples will be given for a typical low noise amplifier as well as for a typical integrated "cheap" amplifier. The rate/wire length $\mathcal{N}$ will depend on the chamber arrangement, wire spacing, etc. Three different cases are considered:

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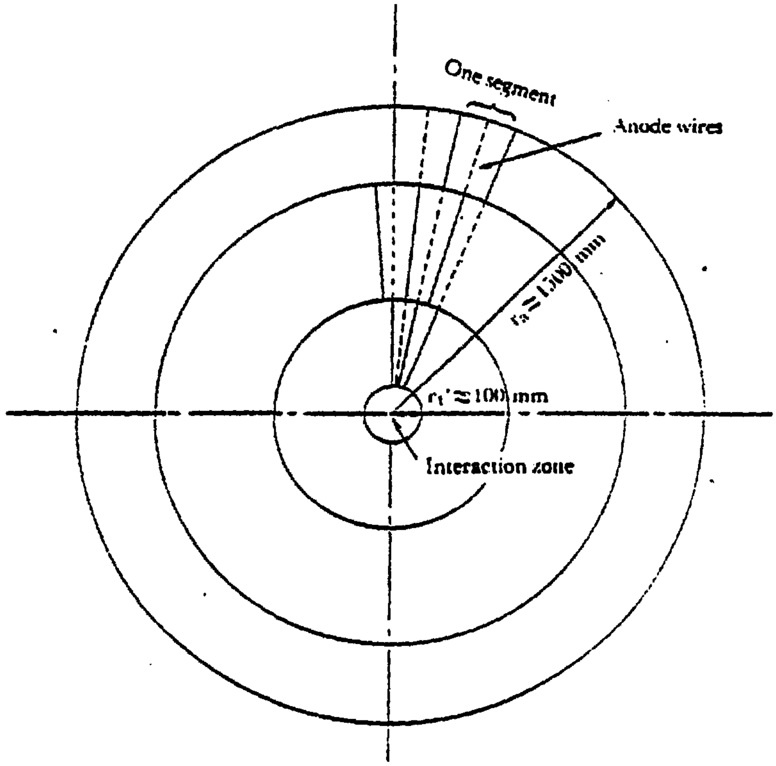

Figure 1. Cylindrical drift chamber arrangement, type "bicycle."

1. A chamber of the type "bicycle" (Figure 1) with 32 cells in the circumference. The acceptance is $\theta = 45° \ldots 135°$ with respect to the beam axis (region I in Figure 2).

2. The cylinder cone, as described in 1., is filled with conventional drift chambers of 1 cm wire spacing (Figure 3).

3. Chambers with 1 cm or 0.4 cm wire spacing in the small angle region (region II in Figure 2).

PULSE HEIGHT REDUCTION

A reduction in pulse height is caused by the total amount of space charge drifting away from the anode. Since the drift time of the positive ions to the counter walls (0.5 . . . 10 cm away) takes 0.5 . . . 10 msec, a large amount of charge is accumulated, reducing the field near the anode over a larger region (of the order of cm), thus reducing the gas amplification for a certain region by a constant fraction.

Hendricks[1] has calculated and measured this effect for cylindrical counters. The reduction of field strength near the wire can be expressed as a drop in effective anode voltage ΔV.

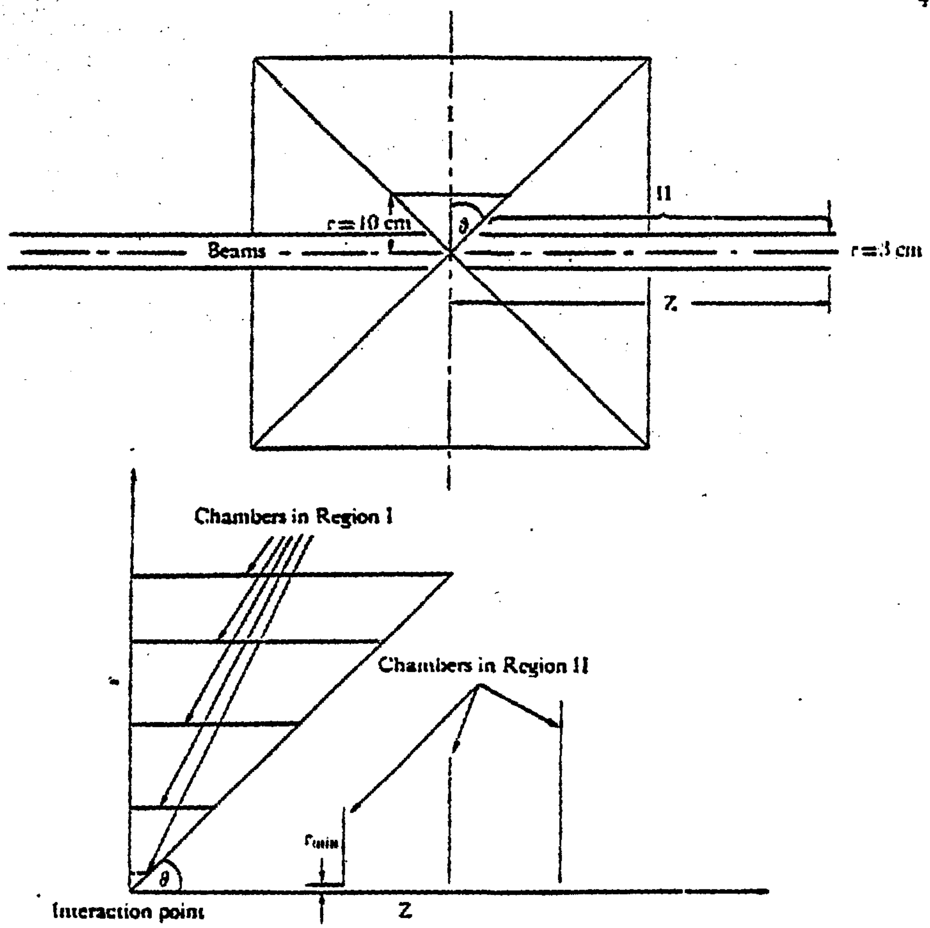

Figure 2. Side view of detector. I: large angle region, II: small angle region.

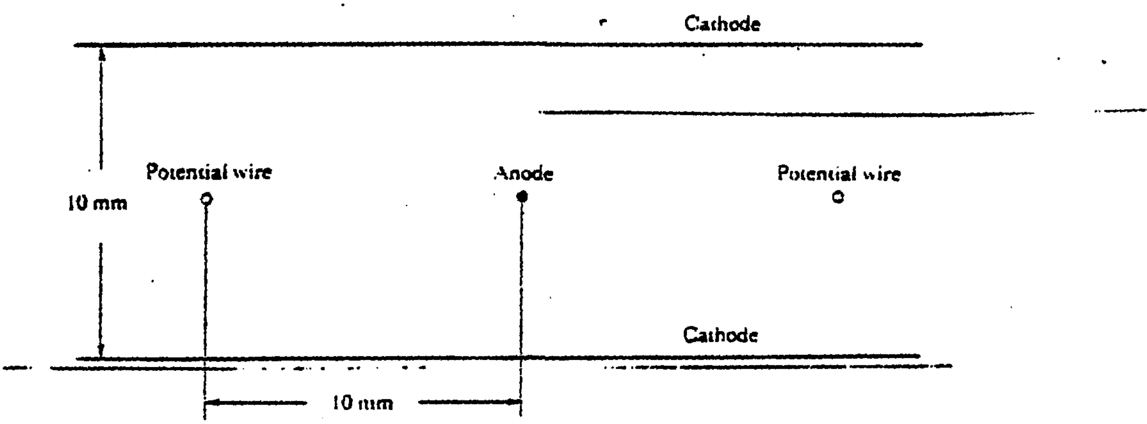

Figure 3. Simple cell of multiwire drift chamber.

$$\Delta V = QN \frac{p \ln(r_a/r_i)}{8\pi^2 \varepsilon_0 \mu V} r_a^2 \tag{1}$$

with Q the charge of the positive ions in one avalanche, N the particle rate per wire length, p gas pressure, μ the mobility of the ions and V the applied voltage. r_i and r_a are the radaii of the central wire and the outer shell, respectively. For our rough calculations it is sufficient to assume a dependence of the gas amplification factor G as follows:

$$G = \exp[k(V - V_0)] \tag{2}$$

where k and V_0 are constant values given by the geometry, gas composition, etc. Combining (1) and (2), one obtains for the relative gas gain

$$\frac{G}{G_0} = \exp[-F(p,\mu,V,r_a/r_i)\, r_a^2\, QN \tag{3}$$

with

$$F(p,\mu,V,r_a/r_i) = \frac{kp \ln(r_a/r_i)}{8\pi^2 \varepsilon_0 \mu V}$$

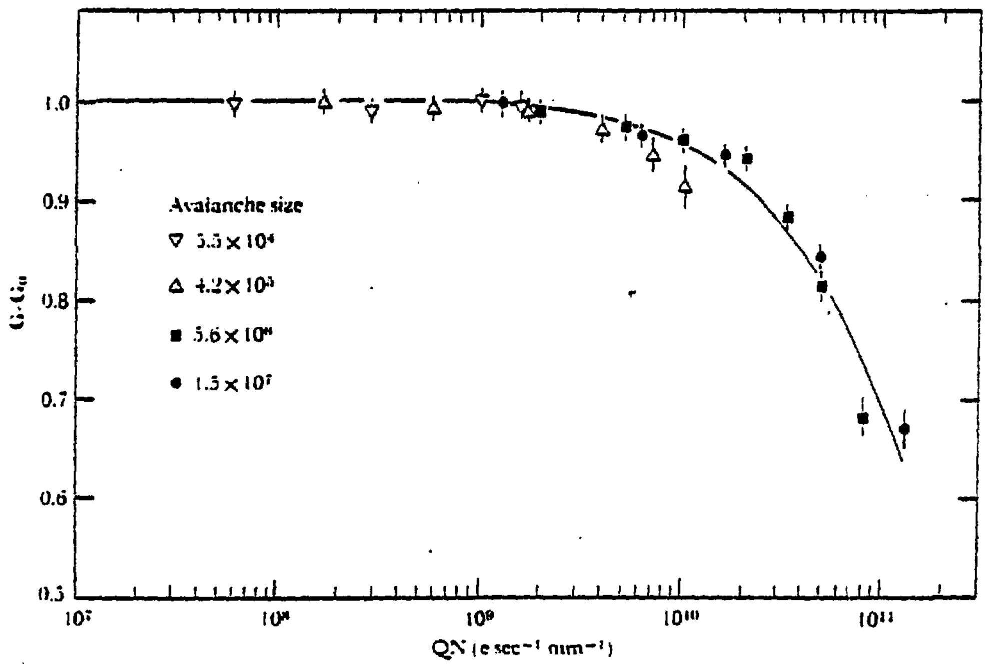

Figure 4. Relative gas gain G/G_0 (G_0: gas gain at zero rate) vs QN (Q: avalanche size; N: rate/wire length). Measured with ^{55}Fe.

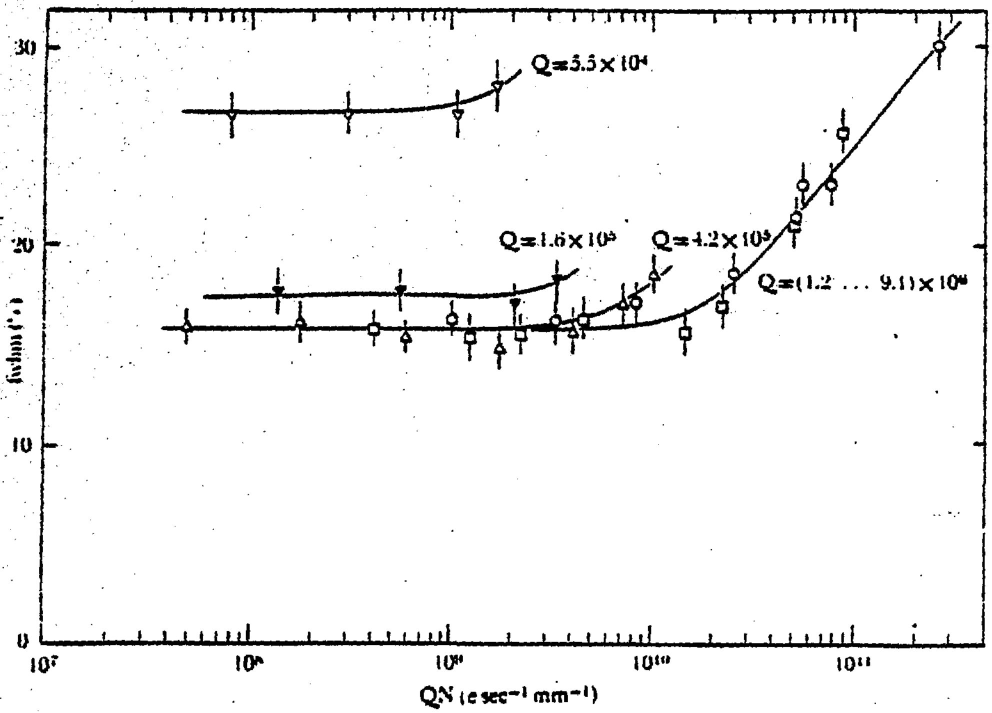

Figure 5. Line width of ^{55}Fe (fwhm) vs QN.

$F(p,\mu,V,r_a/r_i)$ will not vary more than a factor of about two, since μ changes only very little with the choice of gas, and for V/p the freedom of choice is limited for practical reasons. The most important design parameter is r_a which enters as the square. In mutiwire drift chambers with a rectangular unit cell (Figure 3) this quantity is approximately the distance from anode wire to cathode or potential wire. In other words, the gap should not be too wide and the maximum drift path short.

The gas gain variation has been measured (Figure 4) for a multiwire drift chamber with a geometry given in Figure 3. At $QN=2\times10^9$ e mm^{-1} sec^{-1} a change of gas gain of 1% is noticed. With a low noise amplifier[2] the chamber can operate at an avalanche size of $Q=3\times10^5$ e* which does not noticeably affect the pulse height resolution of about 15% fwhm for the ^{55}Fe (5.89 KeV) – line (Figure 5). The corresponding tolerable particle rate will be $N=7\times10^3$ mm^{-1} s^{-1}. For higher rates, up to $N=3\times10^4$ s^{-1} mm^{-1} the pulse height drops, but the resolution of the ^{55}Fe-line still is good, indicating that the chamber is still working in the proportional mode. For dE/dx measurement, in principle, the shift of gas gain can be corrected.

In a drift chamber arrangement of the type "bicycle" with a simple configuration of the anode wires in one cell, (e.g. Figure 1) the quantity r_a of Eq. (3) is much

*With a load capacity of 40 pF the noise is $Q_{rms}=1.5\times10^3 e$. A clipping time of 100 nsec is assumed.

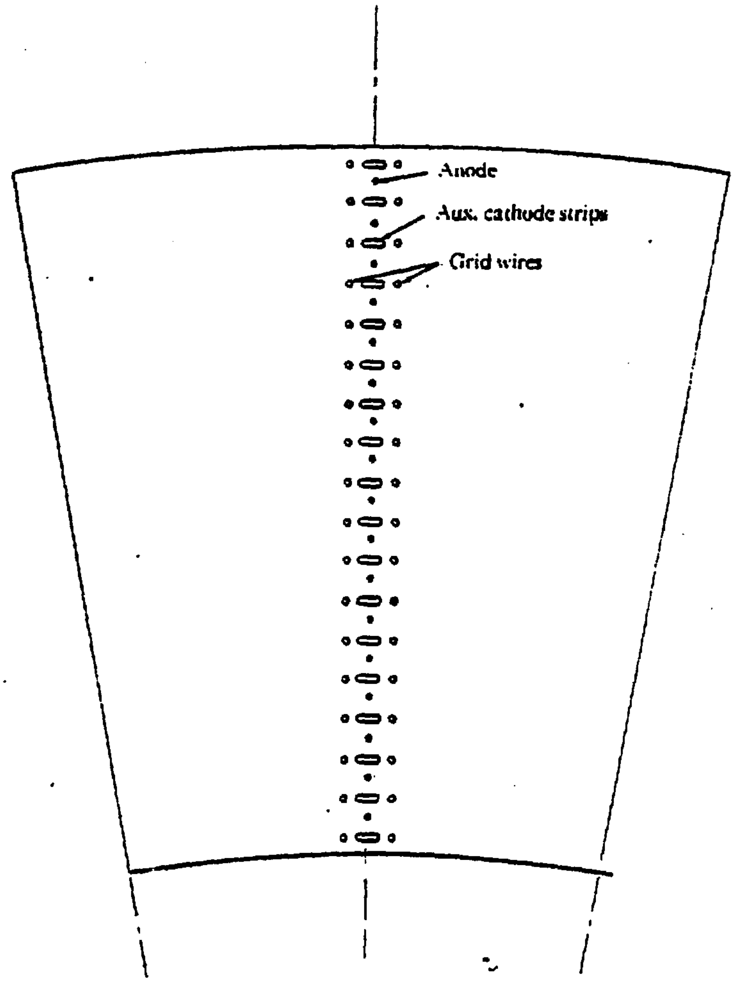

Figure 6. One segment of the chamber arrangement of Figure 1.

larger (7.5 cm). The resulting space-charge effect will be intolerable. The introduction of a grid at a distance of 0.5 to 1 cm from the anode wires (Figure 6) will reduce the effect approximately to the value of the 1 cm chamber.

EFFICIENCY LOSS

As long as the chamber gives an output signal proportional to the energy loss of the ionizing particle, an efficiency loss should not be observed, provided the threshold is lowered by the same fraction as the gas gain drops. This holds up to $Q/V = 10^{10}$ e mm^{-1} s^{-1}. An efficiency loss, however, is possible, if one assumes a completely dead region at the location of the avalanche as long as the avalanche is close to the anode. The measurements of Schultz[3] seem to indicate the existence of such an effect (Figure 7) since the lines (dashed) for constant efficiency loss do not cross the curves for the pulse height at the same pulse height value. On the other hand, the high value

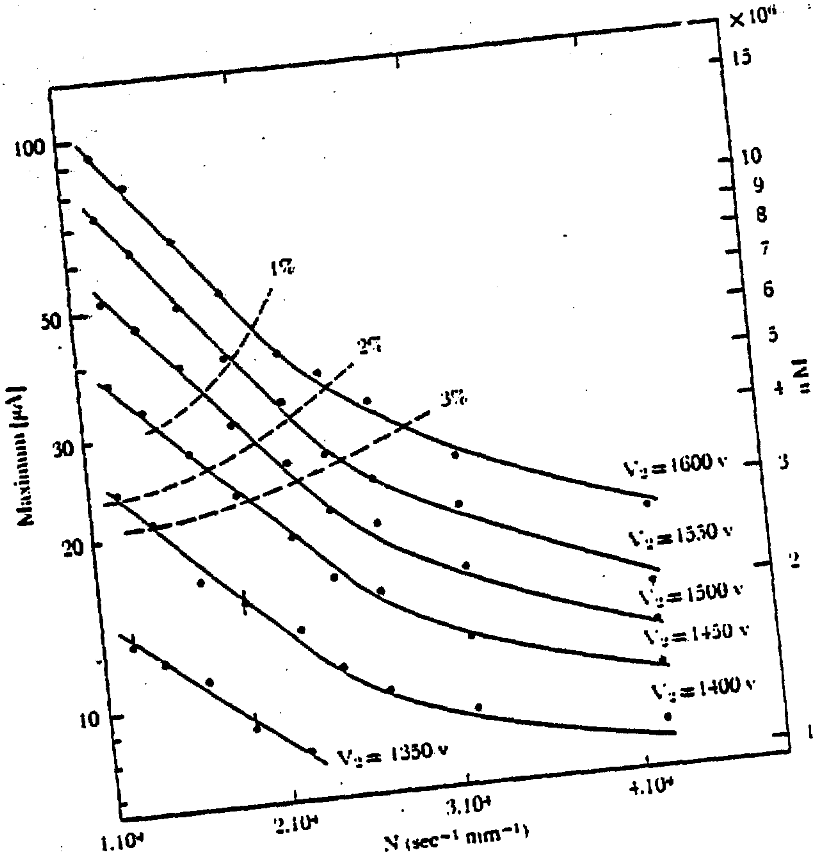

Figure 7. Pulse height vs particle rate/wire length.
Dashed lines: constant efficiency loss. Threshold 10 μA.

for $Q=nM=10^6 \ldots 10^7$ may be responsible for this effect, since saturation in a single avalanche already distorts the pulse height spectrum. Therefore the effect may be much smaller than measured under these conditions where an efficiency loss of 1% is measured for a threshold of 10 μA ($Q_{th}=1.6\times10^6 e$) and an avalanche size $Q_{av}=6\times10^6$ at a rate $N=10^4$ sec^{-1} mm^{-1}. A guess of the rate which would produce the same efficiency loss (1%) in a chamber with much lower gas gain ($W=3\times10^5 e$) and therefore lower threshold ($Q_{th}=3\times10^4$) can be obtained as follows.

A charged particle crossing the chamber just at the position of the wire at an angle to the wire of 90° will leave an ionization chain which drifts towards the same spot on the anode. The avalanche of the electrons that arrive first may produce a dead zone for the electrons arriving later, or reduce at least the gas gain. This produces a nonproportional output with respect to the energy loss. It is known that this occurs at $Q=5\times10^6 e$ for minimum ionizing particles. Using an avalanche size of $Q=3\times10^5 e$ one can conclude that, compared to Schultz's conditions, the primary ionization density can be increased by increasing the particle rate by about one order of magnitude until dead zones at the wire will cause an efficiency loss of 1%.

The rate limit of $N = 10^5\ s^{-1}\ mm^{-1}$ coincides with the number obtained in Chapter (1), which may indicate that the effect broadening the line width there may result from dead spots on the wires as discussed in Chapter (2).

LIFETIME

For reasons of drift as well as for reasons of gas amplification (quenching) the counter gas contains molecular gas which dissociates during operation. Unfortunately deposits are formed on the anode and cathode limiting the useful lifetime of the counter. This effect has been observed and studied extensively in self-quenching Geiger counters (e.g. Ref. 4). The production of a critical amount of deposit on the anode will be in a simple approximation proportional to the integrated amount of free charge Q_{crit} created in the avalanches per wire length.

For Geiger counters a value of $Q_{crit} = 2.5 \times 10^{16} e\ mm^{-1}$ has been found for Argon containing methylal as quencher.[5] Similar results were obtained for a number of other organic quenchers.[6]

Q_{crit} may be different for proportional counters by one order of magnitude since the discharge mechanism is somewhat different than in a Geiger counter and the definition of the critical amount of deposits is different according to whether the counter is used for energy loss measurement or just as a position sensitive detector with relaxed requirements in resolution and efficiency.

Therefore $Q_{crit} = 2.5 \times 10^{16}\ mm^{-1}$ will be used as a typical value and $Q_{crit} = 10^{17}\ mm^{-1}$ as an upper limit.

The lifetime of a chamber is given by

$$\tau = \frac{Q_{crit}}{NQ}$$

with Q avalanche size and N the particle rate per wire length. The lifetime at ISABELLE for three examples of chamber arrangement and operation condition is evaluated.

A cylindrical chamber at a radius $r = 10$ cm from the beam and accepting particles in a core of $\theta = 45° \ldots 135°$ form the beam axis (Region I in Figure 2), a total particle rate of $2.5 \times 10^7\ sec^{-1}$ is assumed. For a chamber with $m = 32$ wires, a wire length of $l = 200$ mm and a gas gain resulting in an avalanche size $Q = 3 \times 10^5$ one obtains:

$$\tau = \frac{Q_{crit} \times ml}{QN} = \frac{2.5 \times 10^{16} \times 32 \times 200}{3 \times 10^5 \times 2.5 \times 10^7} = 2.1 \times 10^7\ sec = 8\ months$$

In the small angle region (Region II in Figure 2) the particle flux through the chamber varies as $1/r^2$ where r is the perpendicular distance from the beam (see paper by A. Etkin). At a luminosity of $10^{32}\ cm^{-2}\ sec^{-1}$ the flux would be $6 \times 10^5/r^2$ per cm^2 of chamber.

At a radius of $r_{min} = 3$ cm the flux will be 7×10^4 particles/cm^2. The range of possible chamber arrangements is illustrated in two examples:

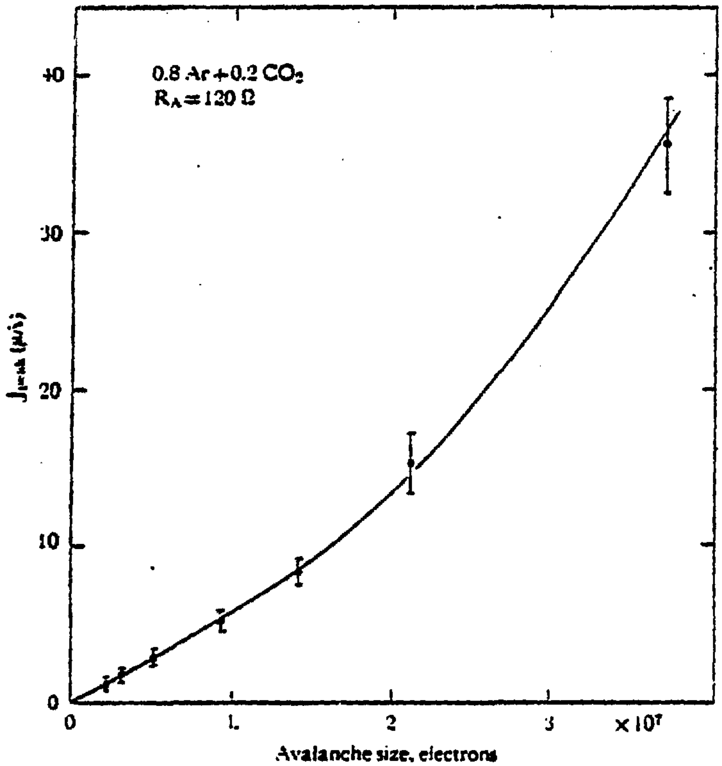

Figure 8. Peak current at the anode vs avalanche size. Measured for most probable pulse height with ^{90}Sr.

1. A conventional wire spacing of 1 cm is considered, which results in $\mathcal{N} = 7\times 10^3$ mm^{-1} sec^{-1}. The use of low noise amplifiers permits the operation of the chamber with an avalanche size of $Q = 3\times 10^5 e$. $Q_{crit} = 2.5\times 10^{16} e$ mm^{-1} is assumed. One obtains

$$\tau = \frac{Q_{crit}}{\mathcal{N}Q} = 1.2\times 10^7 \text{ sec} \approx 5 \text{ months.}$$

2. A wire spacing of 4 mm is considered. This results in $\mathcal{N} = 2.8\times 10^3$ mm^{-1} sec^{-1}. The use of low cost amplifiers may be desirable if a high modularity and therefore a high number of channels are planned (see paper by E.D. Platner). This however results in a much higher necessary gas gain. An amplifier with an input resister of $R \approx 100\Omega$ connected to the anode produces a fast signal with a peak characterized by the value of the current J_{peak}. The relation between J_{peak} and Q is shown in Figure 8 measured with a chamber shown in Figure 3. The full charge Q of the avalanche has been obtained measuring the pulse height with a 10 $M\Omega$ probe and multiplying this value by a factor 1.6 with corrections for the fact that even in this case only incomplete charge collection is measured. If the current amplifier has

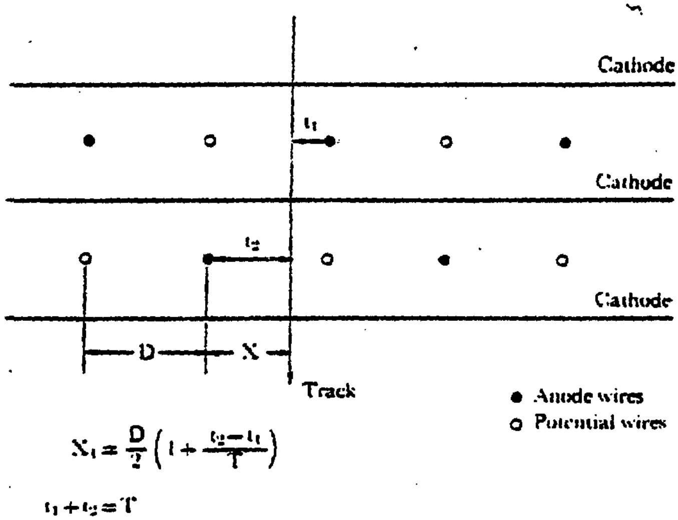

Figure 9. Drift chamber type "double chamber."

a threshold of 1 μA the most probable pulse height must be 10 μA in order to obtain full efficiency and precise drift time measurement. The avalanche size in this case is $Q = 1.6 \times 10^7$. For the lifetime of a chamber under these operating conditions and assuming $Q_{crit} = 10^{17} e\ mm^{-1}$ one obtains $\tau = 2.2 \times 10^6$ sec $= 26$ days.

Possible improvements are already outlined in the early literature. The rejuvenation of an anode wire by heat (current through the wire) has been successfully performed[4] and the use of ammonia as quenching agent[7] shows considerable improvement since the dissociation products do not form solid or liquid deposits. Unfortunately an argon-ammonia mixture does not give a saturated drift velocity and therefore cannot be used in drift chambers. Probably a mixture of Ar-CH_4-NH_3 gives the desired result, since a large fraction of quenching will be due to NH_3 (lowest ionization potential) while CH_4 determines the drift properties.

TIME RESOLUTION

The time resolution characterized by the quantity Δt_r permits one to correlate measured coordinates to tracks of particles crossing the chambers in a time interval between t and $t + \Delta t_r$.

In drift chambers having at least two staggered chamber planes (double wire type[3]) the time of particle passage t_p can be calculated (see Figure 9).

$$t_p = \tfrac{1}{2}(t_1 + t_2 - T)$$

The precision Δt_p is correlated to the space resolution Δs

$$\Delta t_p = 1/V \Delta s.$$

For $\Delta s = 200\ \mu m$ (fwhm) and a drift velocity $V = 5$ cm/μs one obtains $\Delta t_p = 4$ nsec (fwhm). This resolution seems to be appropriate to handle an event of 10^7 sec^{-1}.

MEMORY TIME

The memory time Δt_m, in a PWC or drift chamber given by the maximum drift time, determines how many random tracks are found in an event. Whether good tracks can be reconstructed in the presence of random tracks or are lost depends for a given memory time on the readout system. Two simple cases are considered:

1. Each wire has one TDC which measures the drift time of the first arriving signal with respect to a trigger. The wire spacing is 1 cm in a chamber type shown in Figure 9.

2. The electronics attached to each wire is able to register a large number of stop signals from the wire with a minimum double pulse resolution T_e. The chamber is of the type "bicycle" (Figure 1) and has large drift spaces of $x_{max} = 75$ mm.

In case (1) the situation may occur, where the random particle completely obscures the signals of the wanted particle thus producing an efficiency loss. The probability for such an event is given by (see Ref. 8):

$$W_l = 2n_i T + 3n_i T_e$$

with T_e the minimum double pulse resolution of the amplifier and n_i the rate on one wire.

For the innermost chamber of region I (Figure 2) with $r = 100$ mm, the number of drift spaces $M = 128$, $n_i \times 10^5$ sec^{-1}, $T_e = 100$ nsec, $T = 100$ nsec one obtains $W_l = 10\%$, a number which is clearly too high.

For a chamber with large radius but unchanged wire spacing the rate per dirft space decreases rapidly. At $r = 300$ mm the loss is only 1%.

For the part of the chamber close to the beam in region II (Figure 2) as well as for the innermost chamber in region I the loss W_l has to be reduced by other means.

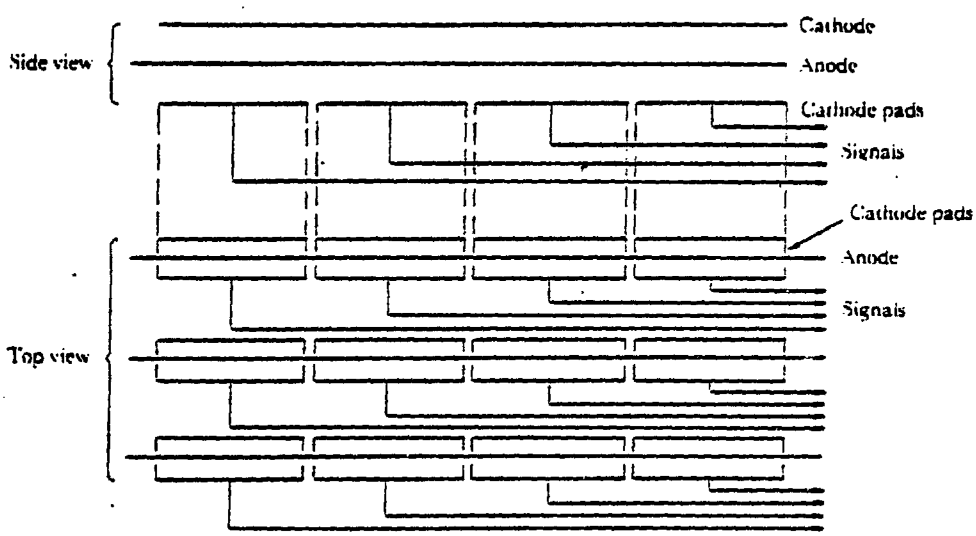

Figure 10. Readout via cathode pads (schematically).

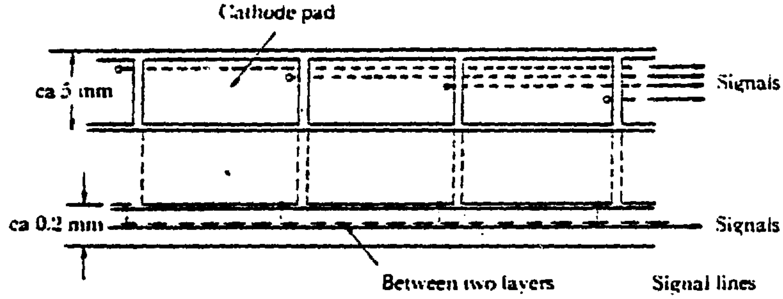

Figure 11. Auxiliary cathode with pads made of PC-foils for segments of type "bicycle.".

With the present knowledge of the drift mechanism and the process of gas amplification only little improvement in T and T_e can be expected. Note that both quantities have to be reduced simultaneously in order to improve the situation considerably. The way proposed here is based on a reduction of n_i by a factor of m by dividing the anode lengthwise in m segments. In order to avoid cutting the anode into m pieces, the readout is done via the induced signals on m cathode pads (Figure 10). For $m=10$ one obtains the desired reduction in efficiency loss below 1% for the chamber in region I at $r=10$ cm. One also has the advantage of an unambiguous measurement of the coordinate along the wire which, although giving only roughly the position, will improve considerably the three-dimensional reconstruction of a multiparticle event. For the part of the chamber close to the beam ($r=3$ cm) in region II cathode pads of about 1 cm × 1 cm* would reduce the rate to $n_i = 7 \times 10^4\ \text{sec}^{-1}$ and the loss would be $W_l = 2\%$. Since the rate decreases rapidly with increasing r there is no need to continue this fine modularity over the whole chamber. The somewhat larger number of amplifier and time encoding circuits are still manageable, especially in the light of new developments of integrated circuits (see paper by E.D. Platner).

In case 2 the rate per wire is independent of the radial position and only determined by the total number of segments (here 32), resulting in a rate of $n_i = 8 \times 10^5$ particles/sec on one wire. Only the electronics dead time determines the efficiency loss $W_l = n_i T_e = 8\%$ for $T_e = 100$ nsec.

Since the situation does not improve with increasing radius, the ability to find hidden tracks relies on the power of a pattern recognition program, fitting short track pieces together and allowing for disappearing parts. The use of segmented auxiliary cathode strips may be considered (Figure 6) between two anode wires. A double layer of printed circuit foil carries the cathode pads ($m=10$) on the outside and has in the middle the lines bringing the signals to the end (Figure 11).

In order to obtain the high time resolution as in case 1 and so solve the right/left ambiguity, at least two rings of segments shifted in an appropriate way have to be used (Figure 1).

*The small cathode pads have low capacity and therefore the same low amplifier noise figure is obtained as for the anode.

CONCLUSION

In multiwire drift chambers a single wire shows space-charge effects reducing the pulse height by 1% at a rate of $\mathcal{N} = 7 \times 10^3$ mm^{-1} sec^{-1}. At a rate of $\mathcal{N} \approx 10^5$ mm^{-1} sec^{-1} an efficiency loss of the order of 1% will be noticed.

The aging effect due to deposits on the anode wire can be reduced using low noise amplifiers and low gas gain to such an extent that a lifetime of about half a year at ISABELLE can be expected. The use of conventional cheap preamplifiers will result in a typical lifetime of about 30 days. Improvements are probable.

The time resolution of $\Delta t_r = 4$ nsec fwhm seems adequate for event rates of 10^7 sec^{-1}.

The memory time $\Delta t_m \geqslant 100$ nsec may cause serious problems for pattern recognition depending on layout and readout. The use of induced signals on cathode pads, thus reading out shorter parts of the wire, can solve the problem.

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