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LOW PRESSURE AVALANCHE DETECTORS IN RELATIVISTIC HEAVY ION EXPERIMENTS

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Large area, low mass, multiwire avalanche chambers have been developed for relativistic heavy ion experiments. These detectors handle large multiplicities of charged particles and provide position, time of flight and ΔE-information over a large dynamic range.

1. Introduction

Low pressure avalanche counters, especially the double-grid type [1,6], have proved to be useful detection devices in low and intermediate heavy ion physics [2]. Their main advantages are good timing resolution, high count rate capability, insensitivity to radiation damage and the possibility to cover large solid angles with excellent spatial resolution. We report here on the development and performance of a multiwire avalanche chamber (MWAC) system that has been incorporated into the Plastic Ball setup [3] at the Bevalac for the purpose of measuring projectile fragments. In this application the demands on the system are significant, in terms of both particle multiplicity and the large variation in the energies deposited in the detector by the various possible charged fragments. The dynamic range for energy loss determination must accommodate the various projectiles (and their fragments) which are available at the Bevalac, (i.e projectile energies from ~ 80 to 2100 MeV/nucleon and projectile masses from ^{12}C to ^{238}U). In addition the detector system must operate in the environment of a large multiplicity of particles with one and two charges associated with these heavy fragments.

The MWAC-system to be described below consists of two types of counters (see fig. 1). One of these counters, the zero degree detector, is a multiplane, two-step avalanche detector used for observing projectile fragments. This counter is positioned 7.2 m downstream from the target where it covers the angular range of $\pm 2°$. There are two counters of the second type, called beam counters, which provide tracking of the incoming beam particles, a necessary requirement at the Bevalac where especially the low energy beams have a rather large emittance that would otherwise contribute uncertainties to the scattering angle. The design chosen for these beam counters was a single stage, double-grid avalanche counter. With this device the mass of the detector can be kept to a minimum to avoid nuclear interactions with the beam and the count rate capability is sufficient to handle our beam fluxes of up to 10^6 particles/(s cm^2).

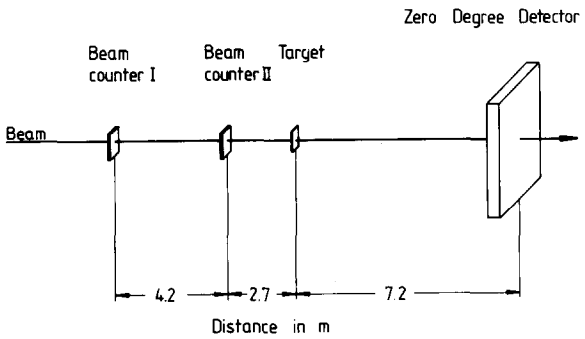

Fig. 1. Arrangement of the wire chambers in the beamline.

2. General description of the counters

2.1. The beam counters

The beam counters are composed of a central electrode plane with a readout plane on either side followed by gas containment films. The readout planes consist of gold plated tungsten wires (diameter = 20 μm) spaced 1 mm apart and located at a distance of 3 mm from the

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central plane. The readout is configured with two wires per pad with each pad connected to an amplifier (see sect. 3). The amplifier is connected via 70 m of RG-58 cable to a CAMAC LRS 2282-ADC. The orthogonal arrangement of the two readout planes gives the two dimensional position of the detected beam particles over an active region of 10×10 cm^2.

Two types of central electrode planes were tried. One version of the beam detector (type A) uses a wire central electrode plane identical in construction to the readout planes with 1 mm spaced gold plated tungsten wires. The other version (type B) has a central plane composed of a 2 μm mylar foil stretched and glued to an epoxy resin frame (Stesallit) (see sketch in fig. 2). The film was made conductive by evaporating a 60 μg/cm^2 layer of gold on both sides and connecting the two gold surfaces electrically. The external layer on each side of the detector is a 2 μm mylar gas containment window. The mechanical design of the detector is simplified by using a vacuum tight sandwich type construction in which the frames carrying the electrodes are glued in a stack. This arrangement eliminates the need for an external vacuum container and allows direct connection of the amplifiers to the position readout pads (see fig. 3). The total effective thickness of this counter (foil design) is less than 600 μg/cm^2.

The detectors are operated with n-heptane at pressures of 1.5–3 mbar. Pressures are differentially controlled with input and exhaust needle valves. Isobutane

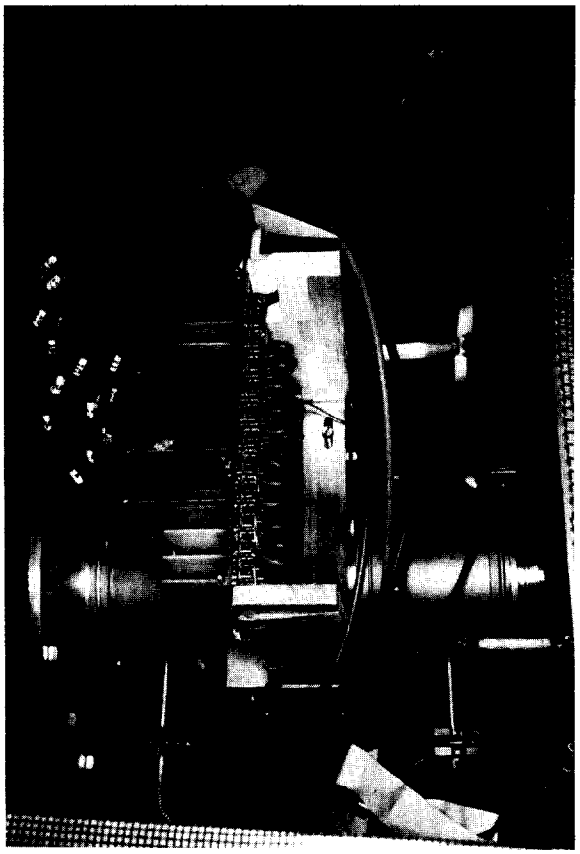

Fig. 3. A beam counter with preamplifiers mounted in the beamline.

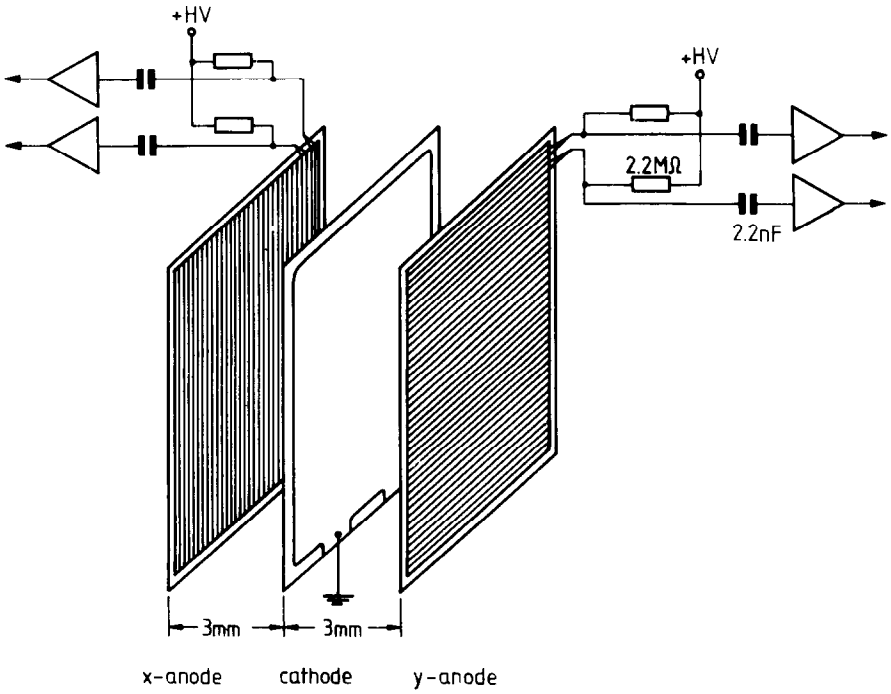

Fig. 2. Schematic view of the beam counters (foil design) and the readout electronics for two of the pads.

was also tested as a counter gas, but this gave a 40% lower pulse height than the heptane.

2.2. The zero degree detector

At Bevalac energies the projectile fragments are concentrated in a rather small solid angle around the beam direction. This imposes several requirements on a detector designed to measure these fragments:

- high counting rate capability (the detector is exposed to the beam),
- detection capability for large particle multiplicity,
- good spatial resolution,
- ability to measure time of flight (TOF) and energy loss.

A multiplane, two-step avalanche design was selected to meet these requirements because detectors of this type have been successfully used at high rates for weakly ionizing particles [2,4,5]. The counter (shown schematically in fig. 4) is composed of 8 planes of 20 μm gold plated tungsten wires with an active area of 48×48 cm^2. Four of these planes (X, Y, Z and W) are sense planes and read out in the same manner as the beam counters. The use of four planes helps to resolve multihit ambiguities in a given wire. In addition to position measurement the X-plane provides time and the W-plane energy loss information of the fragments. The wire spacing in these planes is 1 mm but they are read out more coarsely with 3 wires per amplifier for the X-, Y- and Z-plane and 6 wires per amplifier for the W-plane. The high voltage planes have a higher wire density of 2 wires per mm to reduce the field inhomogeneities. Foil planes are not used in this detector since two stage amplification requires electron transfer through the high voltage planes.

As with the beam counters, a vacuum tight sandwich construction is used, thereby avoiding the difficulty of vacuum feedthroughs for nearly 700 sense leads. The entrance side of the detector gas volume is enclosed by a 3.5 μm aluminum coated mylar foil which is supported by a grid of 350 μm stainless steel wires (3 cm spacing). The last window which must support the external atmospheric pressure, was made as thin as possible to minimize nuclear interactions as the beam and fragments continue on to downstream scintillator detectors.

3. Readout electronics and control system

In order to achieve a high multihit capability, a readout system of many discrete amplifiers was chosen over simpler collective approaches such as delay line or charge division readouts. Two major requirements dictated the development of the preamplifier system at GSI: high packing density and low noise. A high packing density is necessary to accommodate the large number of channels (662) while minimizing the input lead lengths with their associated capacitance and potential for picking up noise. A high density was accomplished by packaging 4 preamplifiers per printed circuit board (see fig. 5) and using surface mounted chips as well as conventional DIL integrated circuits. Each preamplifier occupies an area of 2×5 cm^2. The four-channel pre-

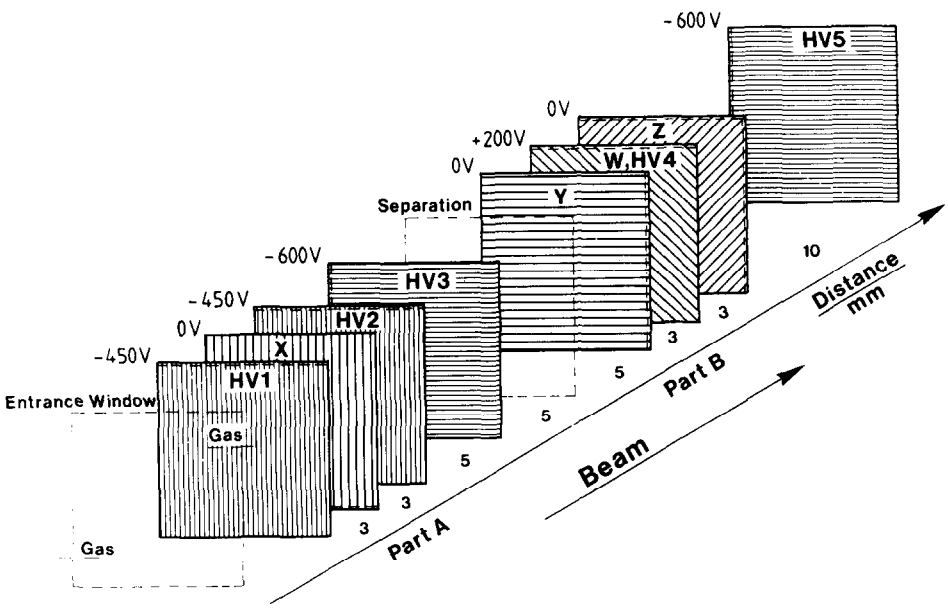

Fig. 4. Schematic diagram of the wire plane configuration in the zero degree detector with typical wire plane voltages.

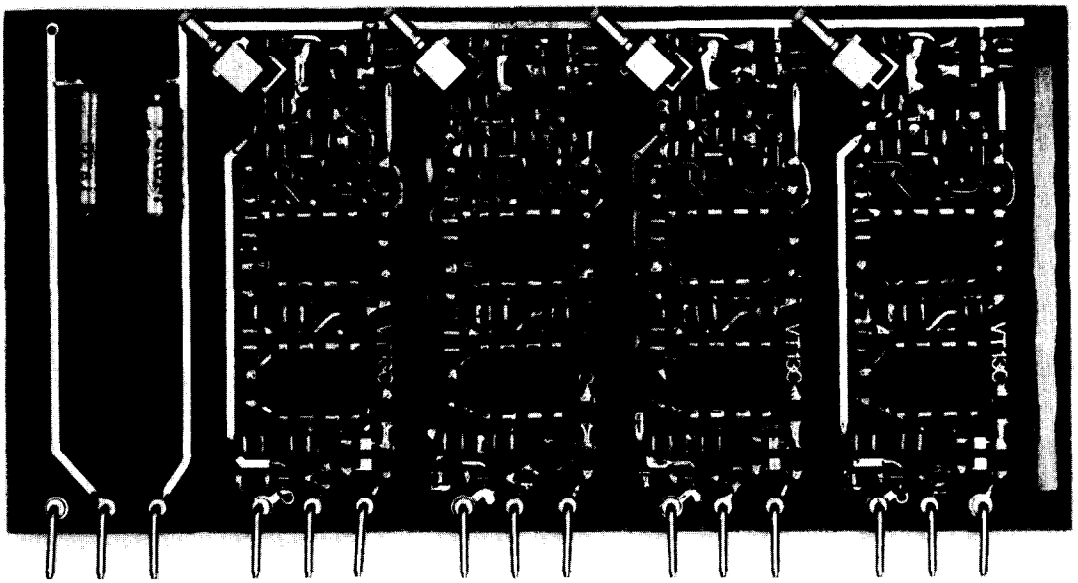

Fig. 5. Printed circuit board of the preamplifier with the shielding cover removed. A match is included to indicate scale.

amplifier board, shielded by a tin plate, is inserted in a motherboard and small jumper clips connect the motherboard to the pads of the counter. With this geometry the total input lead from sense wire to preamplifier is less than 10 cm. A picture of one of the beam counters mounted in the beam line (fig. 3) shows the mechanical arrangement of this system. An additional feature of the counter is a screen wire Faraday cage surrounding the system to shield against RF pick-up.

The low amplifier input impedance of 33 Ω fits best to the high capacities of the long wires. The electron noise charge (ENC) as function of the capacity parallel to the input is

$$\mathrm{ENC} = 1900\ \mathrm{e}^- + 82\ \mathrm{e}^-/\mathrm{pF}.$$

Because of the extremely low slope, the amplifier is very well suited for high capacity applications. The risetime of the output of 3.5 ns and the differentiation time of 50 ns at the input allow high count rates in the detectors which are traversed by the beam. Output pulses of up to −3 V and 3.5 ns rise time are fed into the 50 Ω-RG 58 line. The amplification of these devices is variable within a wide range. A gain of 240, 480 and 920 is used at the different planes of the counters.

A simple pulsing scheme served to monitor the condition of both the electronic channels as well as the wires themselves. This is important considering the large number of wires involved (~ 6150 in the zero degree detector). In this scheme the high voltage planes are pulsed with a −18 V, 1 ns risetime signal, delivered by an avalanche transistor pulser, so that a signal is capacitively induced on the sense wires. The high voltage supplies (Emetron EHV-2002I), biasing the wire planes, are equipped with an adjustable current limit trip and an automatic ramped voltage recovery feature to protect the wires in event of sparking.

4. Operation characteristics

4.1. Beam counters

Prior to using the detectors in heavy ion beams at the Bevalac, both types of counters were tested with a ^{252}Cf fission source and a 5.5 MeV α-source. These tests demonstrated that, of the two, the B type detector (foil design) could be operated without breakdown at significantly higher voltages with a correspondingly higher signal gain (see table 1 and fig. 6). In-beam measurements revealed further, that the permissable operating voltage depends strongly on the charge and energy (i.e. $\mathrm{d}E/\mathrm{d}x$) of the incoming projectile. For instance, it was possible to operate the counter at higher electric field/pressure ratios in a 2100 MeV/nucleon neon beam than in a 150 MeV/nucleon gold beam with its much higher $\mathrm{d}E/\mathrm{d}x$. The optimal gas pressure, yielding the highest pulse heights under stable conditions, was also found to be dependent on both the energy loss of the projectiles in the counter and the beam intensity. Consequently, it was possible to operate the detector, in a stable mode, with a fission source at an electric field/pressure ratio of 700 V/(cm mbar) where the gas gain was observed to be about 4500. However, operating with heavy ion beams required lowering the field with a corresponding drop in gas gain. The test results,

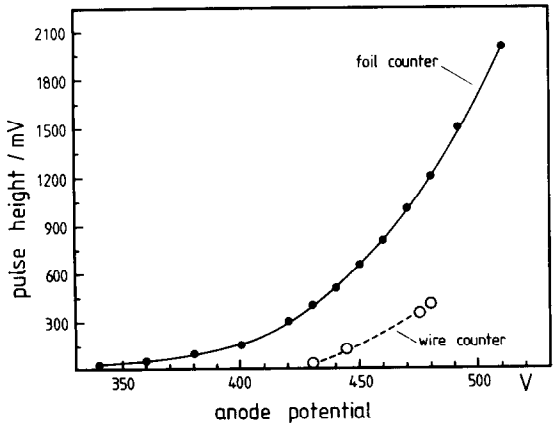

Fig. 6. Pulse height of the beam counter signal for fission fragments as a function of the anode potential. The preamplifier gain in this case was 200.

summarized in table 1 show that:

1. The same voltage applied to both of the beam counters results in much higher signals for type B detector.
2. Type B tolerates a higher electric field than type A.
3. The maximum field strength in type A is independent of the polarity, whereas type B gives satisfactory results only when using the foil plane as cathode.

Through these observations the high performance of the type B detector (the double-grid avalanche counter [1,6]) can be explained by two basic effects:

In low pressure counters the main amplification occurs in the anode–cathode gap, and not, as in wire chambers at atmospheric pressure, directly around the wire. A large drop in potential occurs close to a thin wire and thus a smaller electric field strength is obtained in a gap formed by two wire planes compared to a gap formed by a wire grid and a foil electrode. This is illustrated in fig. 7, where the position dependences of the field strength in the gap of the two beam counter designs (curves A and B) and an equivalent parallel plate counter (made of two evaporated foils) (curve C) is compared. The voltage applied to the cathode is −500 V and the distance between the planes is 3 mm in all three cases. The calculated field strengths, achieved in the center of the gap as $\langle E \rangle = 167$, 142, and 113 V/mm for the different plane combinations, respectively. Following the results of these calculations [7], one can lower the voltage applied to the type B beam counter from 500 to 400 V and still achieve the same field strength in the center of the gap. If, on the other hand, the gas amplification around the wires in the type A detector, which partly compensates the loss of the field strength in the center of the gap, is also taken into account, the different results obtained with the two beam counter designs can be understood quantitatively as well as qualitatively. Low energy secondary electrons emitted by the heavy ion traversing the cathode foil might also contribute to the signal in the foil counter.

The dependence of the maximum field strength on the polarity of the HV planes in the foil–wire but not in the wire–wire design can be assumed to be an effect of the ions released in the sensitive volume. When collect-

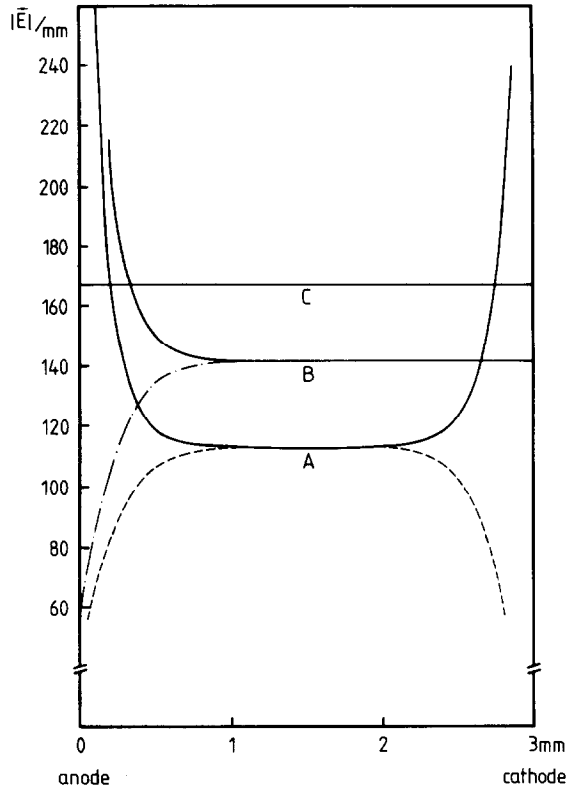

Fig. 7. Position dependence of the electric field strength between two wire-planes (A), a foil and a wire plane (B) and two parallel foils (C). The solid lines are calculated for a field going directly to a 20 μm wire and the dashed lines for a field going to the middle of two adjacent wires of the same plane.

Table 1
Performance of the two beam counter designs, obtained with fission fragments at $p = 2.5$ mbar of heptane. The signals are amplified by a factor of 200 [a)]

Foil design (type B)	Wire design (type A)
HV = +430 V	HV = +430 V (max)
Ph = 400 mV	Ph = 30 mV
HV = −510 V (max)	
Ph = 2000 mV	
HV = −395 V (max)	HV = −420 V (max)
Ph = 40 mV	Ph = 30 mV

[a)] HV = potential of the readout planes, Ph = pulse height.

ing the ions on a wire plane at very low operation pressures, the velocity in the vicinity of the thin wires might get high enough to produce secondaries (electrons, photons, etc.) in a collision with the wire, which then leads to sparks. A foil used as cathode plane does not produce this very high local field and the counter can tolerate a higher mid gap field strength without sparking.

Thicker wires spaced closer to each other might yield better performance for the type A design, but at the expense of increased detector mass. A slight improvement of this detector type resulted by biasing the readout plane as well as the central plane onto reversed voltages (last three open circles in fig. 6). Nevertheless, the foil detector must be considered superior and will be the design of choice in future experiments.

The spatial resolution of these counters was studied experimentally with the beam particles passing undeflected through the three counters (two beam counters plus the zero degree detector). A check of the three way consistency gave a spatial resolution of 1.4 mm (fwhm), a value slightly better than the 2 mm pad spacing. We believe this would be improved if the signals were distributed over several pads so that a center of mass analysis could be used more effectively. For our system, however, the small transverse diffusion of the avalanche (about 1.6 mm) [5] causes most of the primary and secondary electrons to be collected on only one or two wires of the anode. The actual data used to find the 1.4 mm resolution value is shown in fig. 8. This figure was generated by comparing the position of the projectile measured in the zero degree counter with the projected position determined from the two upstream beam counters. The figure shows the particle distribution as a function of this difference.

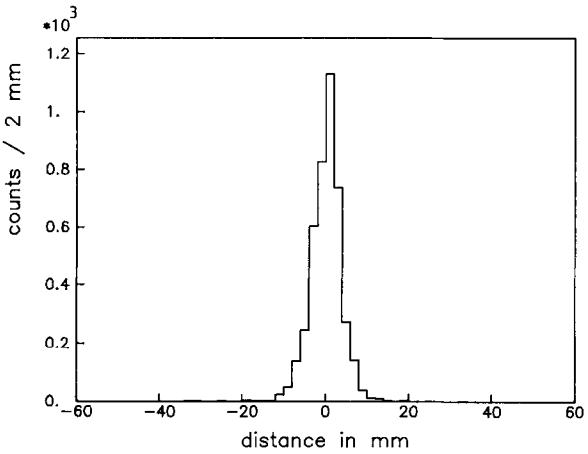

Fig. 8. Number of counts as a function of the separation distance between the actual particle hit position in the zero degree detector and the hit position as projected from the two beam counters. The beam in this case was 150 MeV/nucleon Au and the distance from the midpoint of the beam counter pair to the zero degree detector was 12 m.

4.2. Zero degree detector

The detector is subdivided into two independent parts. The first part of the detector (part A in fig. 4) is a two stage avalanche counter with the designed function of providing both position and timing information. This two stage avalanche operation gives rise to a signal at the X-plane (see fig. 9), which is the sum of the two components. There is an initial sharp peak which comes from the avalanche initiated by the beam track passing from the HV1 plane to the HV2 plane. The second component, a broad plateau extending to later time, comes from two stage amplification where electrons generated in an avalanche between planes labelled HV2 and HV3 drift into the region between planes X and HV2 where a second avalanche amplification occurs. Timing is obtained from the initial peak with its 3–4 ns rise time and the total integrated yield provides a strong signal for the position information.

The second part of the detector (part B), designed to obtain dE/dx information, operates in the proportional mode and the planes are arranged to collect charge from a longer ionization path. As in the A part, two stages of amplification are used, but the shape of the signals (see fig. 9) observed at the W sense plane is quite different from the X-plane signal. This is because, in the B part of the detector, the field in the 3 mm gap

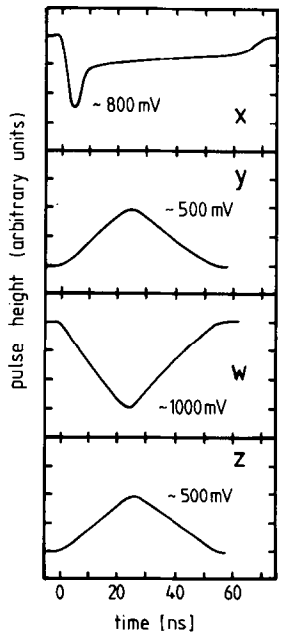

Fig. 9. Shape of the signals, observed at the planes of the zero degree detector.

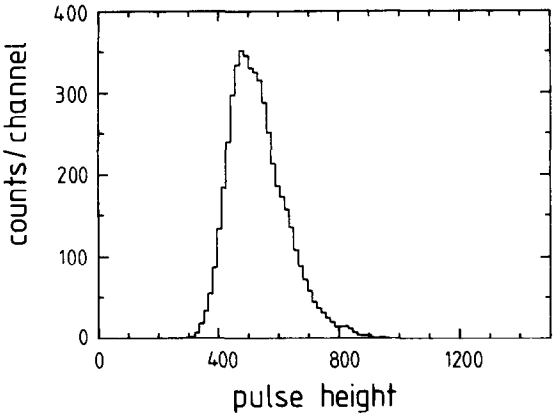

Fig. 10. Energy loss spectrum for 1000 MeV/nucleon Au projectiles at the W-plane of the zero degree detector.

is relatively low compared to the field in the 10 mm gap. Consequently, the slow component is enhanced compared to the initial fast peak that comes from the single stage amplification in the 3 mm region. In addition to the ΔE signal extracted from the W-plane, signals are also extracted from the Y- and Z-planes giving a total of four sense planes for the two parts. By demanding position correlation in these four planes the accidentals due to noise and localized sparks are strongly suppressed.

The zero degree detector performs reasonably well for determining both position and time, but shows poor performance for ΔE. The position resolution is slightly better than the 3 mm pad spacing and the ΔE resolution (a spectrum is shown in fig. 10) is about 40% for a 1 GeV/nucleon Au beam. The measured time resolution relative to the upstream start scintillator is 650 ps (fwhm). This time uncertainty is the result of several contributions, some of which should be reasonably easy to correct. One contribution not easily corrected for is the large RF noise in the Bevalac experimental area which we have not been able to shield against completely. However, uncertainties stemming from the finite signal velocities on the sense wires [8] are, in principle, correctable using the position information. Deviation of the wire planes from parallel is another possible source of position dependent time variation.

4.3. Efficiency determination

The counter efficiencies were determined by measuring coincidences between the gas counters and a plastic scintillator beam monitor. The combined efficiency, for particles triggering the vertical and horizontal planes of a beam counter in coincidence is close to 100% for the Au beams and drops to 30% for less strongly ionizing Ne projectiles. In the latter case a projectile produces only about 20 primary electrons in the sensitive volume, compared to more than 5000 electrons produced by a 100 MeV/nucleon Au-projectile. The detection efficiency of the zero degree counter is somewhat lower because of the additional requirement of correlated hits in the four readout planes. For beams of 184 MeV/nucleon La and 400 MeV/nucleon Au the combined efficiency in the four planes was 94% while the single plane efficiency was 97%.

5. Conclusion

A system of two dimensional position sensitive low pressure avalanche counters with an active area of 10×10 and 48×48 cm^2 was developed and used in relativistic heavy ion experiments. The electronics were designed with individual wire readout thus achieving a high multiplicity capability. The smaller detectors (beam counters) have a position resolution of less than 1.4 mm. The larger detector (zero degree detector) gives position information, with 3 mm resolution, and in addition provides time of flight ($\Delta t = 650$ ps) as well as $\mathrm{d}E/\mathrm{d}x$ for the projectile fragments. The efficiency of beam tracking in the beam counters is 100% for low energy (100–500 MeV/nucleon) high Z-particles and drops to 30% for 2100 MeV/nucleon ^{20}Ne beams with fluxes of 10^5 particles/(s cm^2).

These first promising results plus the attractive features of simple design, easy operation and low mass (600 μg/cm^2) open new possibilities for low pressure avalanche detectors in the field of relativistic heavy ions.

Acknowledgment

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