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APPLICATIONS OF WIRE CHAMBERS IN HIGH-ENERGY PHYSICS

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My task is to report on recent applications of wire chambers in high-energy physics experiments, that is applications other than the dominant used in providing precise position definition. I will also omit an important application, the use of proportional chambers to identify particles in the region of the relativistic increase in ionization, on the grounds that it is a subject in itself, one that has been thoroughly studied recently. Thus, I will concentrate on the review of two topics, the identification of particles by detection of transition radiation (TR) in proportional chambers, and the increasing use of wire chambers in calorimeter applications.

Proportional chambers are well suited to the detection of X-rays generated by TR. To briefly recall the nature of TR ¹⁾, note that the length required for a Čerenkov radiator to give a certain number of photons grows with the threshold energy E (or $\gamma = E/m$) as γ^2 . For $\gamma \gtrsim 1000$ a threshold detector becomes very long, and a differential detector requires high angular accuracy. On the other hand, the length is proportional to the wavelength of the light used. If, instead of visible or UV photons, one used X-rays, the detector could be a thousand times shorter. However, the index of refraction of available materials is less than one in the X-ray region, making it impossible to satisfy the relation $n\beta > 1$, which allows phase matching between particle and light wave. Fortunately, an alternative possibility is to arrange alternating slabs of low density (helium gas) and high density, low atomic number material (lithium metal foil), so that the light wave phase slips one cycle with respect to the particle while passing through each period of the repeating structure. The photon yield is then approximately the same as from a Čerenkov radiator of the same threshold γ and wavelength. The great reduction in length obtained by utilizing X-radiation allows the construction of experiments with large solid angle, which would otherwise be quite impractical when γ threshold $\gtrsim 10^3$ is required.

The X-rays are typically in the range 3-15 keV, and are emitted at angles of the order of a milliradian with respect to the particle direction. This is just the energy region in which the proportional wire chamber is a very effective X-ray

detector. The different designs for practical detectors derive from their approaches to the problem presented by the fact that the X-rays strike the wire chamber so close to the track of ionization left by the charged particle. They have in common the problems of providing thin windows to allow the transmission of soft X-rays, and of maintaining a constant gain.

The simplest method is to detect the sum of the ionization from the track and the X-rays. This is applicable when the number of X-ray photons from the transition radiator is large enough so that their total ionization is larger than that due to the track, though the Landau tail caused by occasional large energy deposits due to the track constitute an important background. (It is minimized by the use of xenon as the chamber gas, for which the short absorption length allows the use of a small thickness of gas, and thus relatively little ionization loss.) This is the technique which has been used in the experimental applications of TR this far.

The window must be quite thin to allow the passage of 3-5 keV X-rays, for example 10 μm of Mylar with a thin conductive coating of aluminium. It must have helium on one side and a xenon gas mixture on the other, giving rise to a pressure difference. The hydrostatic pressure difference alone sets a limit to the vertical extent of an unsupported window. Two design options exist with respect to the tolerance on the flatness of the window. In the first, the window itself forms the cathode of the proportional wire chamber, and a 10% gain variation limit implies a flatness tolerance of the order of 50 μm . The second possibility is to provide a transparent wire grid as a cathode, with a drift space between this cathode and the window. In this case an important fraction of the X-rays will be converted into photoelectrons in this drift space. It is important that the proper electric field be established in this space, and thus the window surface must still function as an electrode. Though the window flatness tolerance is relaxed somewhat it is important that the window should not touch the grid, which itself must satisfy the tighter tolerance.

Most experimenters have chosen the first option. Here there is a trade off between the unsupported width of the window and the accuracy required of the pressure regulating servo. The first large TR system used in an experiment, an electron pair experiment at the ISR, set the differential pressure variation tolerance at the level (a few mm of H₂O) which can easily be maintained by simple on-off servos, and provided a system of window support adequate to maintain the flatness tolerance while supporting the pressure difference²). This consisted of a set of thin steel cables tensioned against a steel frame and glued to the window, Fig. 1. The required gain uniformity over the surface of the chamber was attained, Fig. 2. In preparing a large TR system for use with the European Hybrid Spectrometer it has been found that a more effective pressure regulating system can be built, allowing the use of relatively large unsupported windows³).

The use of a recirculating gas system incorporating purifiers guards against sudden changes in gain due to changes in gas composition. Slow changes, including those due to atmospheric pressure, are compensated by changing the high voltage by means of a servo system regulated by maintaining a constant pulse height of a peak from a ⁵⁷Fe monochromatic photon source. The performance in identifying particles is shown in Fig. 3.

The TR detector described above, designed for e- π separation, would also be a good design for 300-800 GeV, π -K separation. At lower energies, around 100 GeV, the available materials show increasingly strong absorption of the few keV photons from TR, and one must work with smaller numbers of photons. The fluctuations in the track ionization then dilute the effect severely. Adequate particle identification can then be achieved only by repeating radiator-PWC layers many times. In this situation, it is advantageous to try to separate the photon signal from the track ionization background. It has already been pointed out that the photons are emitted at a finite angle, and thus a transverse separation from the track will develop after a certain drift distance. The different characteristics of track ionization and photoelectrons of a few keV allow a differentiation as well by study of the charge distribution along the track. Both methods have been tried, and preliminary results have been obtained.

The method of transverse drift has been tested by Dolgoshein et al.⁴⁾. A free space of about 50 cm gives photon to track separation of the order of a millimeter. The charge in a wire chamber detector drifts transversely to the anode wires, allowing the measurement of the transverse separation projected onto the drift direction. The track and photoelectron charge clusters are measured with a full width resolution of approximately 0.5 mm, limited by diffusion. The collected charge is measured in a flash encoder (multiple time step ADC) with a 20 ns period⁵⁾. The photoelectrons are often not resolved from the track as separate peaks, but appear as a wide cluster, distinguishable from a normal track signal except in the case of a long δ -ray. Figure 4 compares the performance in particle separation using just the total charge information, and using also the angle, or cluster width information.

An alternative studied by the same authors⁴⁾ is the analysis of the longitudinal charge distribution of the track plus photons, as shown in Fig. 5. The ionization along the track occurs in clusters, most commonly corresponding to 200-300 ev, small compared to the energy of the photons ≥ 3 keV. Thus a track with no TR analysed in this manner with a threshold of about 3 keV will show only an occasional response from a δ -ray. The TR photons register as unresolved clusters, up to about 10 keV. Some further information is contained in the position of the clusters with respect to the entrance window. The δ -ray background is uniform across the width of the chamber, but the photons show the attenuation length corresponding to their energy. For example, the low-energy photons, ~ 3 keV, for which the background is largest, are all absorbed in a fraction of the chamber width. A preliminary result with this method is shown in Fig. 6, for a test system not optimized for a detector. The longitudinal drift method seems somewhat more effective than the transverse drift.

An alternative method of obtaining the longitudinal distribution of charge is to provide a chamber with many close spaced anodes, as carried out by Atac. This solution uses less complex electronics, but more channels and connections.

In summary, new wire chamber and electronic techniques promise to make TR detectors more effective, particularly in hadron identification in the few hundred GeV region.

The use of wire chambers in calorimeter applications has increased recently, as experiments have required good spatial resolution over large areas, at relatively low cost. It may be of interest to discuss somewhat the factors which limit the energy resolution of these devices.

First we consider the case of measurement of electromagnetic showers. The typical wire chamber calorimeter then consists of an array of sheets of lead or iron, with the ionization sampled by a plane of wire chambers between each pair of sheets. In the case of ionization sampling by a dense material, such as organic scintillator or liquid argon, we know that the energy resolution is limited by sampling fluctuations. That is, the fluctuations in the fractions of energy deposited in the active material and in the passive material account for the observed fluctuations in the signal from a well-designed calorimeter of this type. This can be checked by measuring the fluctuations in the correlation in signal between different active layers. The fluctuations are dominated by the energy loss processes in the thick plate, where most of the energy is deposited, and are considerably larger than that expected from Landau fluctuations in the energy loss in the active medium. For example, in the common configuration with 1.5 mm lead plates sampled by 2 mm of liquid argon, one measures an energy resolution, equal to the sampling fluctuation of about $\sigma_E = 8\% [E(\text{GeV})]^{-\frac{1}{2}}$.

If the sampling medium is argon gas at 1 atm, the Landau fluctuations are quite important, leading to a calculated and measured resolution about twice as large as the value obtained in the dense liquid argon⁶⁾. It is found possible to control the instrumental effects, for example proportional gain changes along the wire, well enough so that this resolution is not degraded. The density of the sampling medium could be increased by operating at high pressure, but the improvement in resolution is slow enough so that this option is not usually attractive.

The simple scheme of planar absorbers and PWC is adequate for many purposes, but one may ask which variations on it may be advantageous. In cases where a number of close spaced showers must be measured without ambiguities, other PWC wire configurations may be of interest. I have made an investigation using the Monte Carlo shower simulation program EGS, to see if the resolution is affected by the precise geometrical configuration of the absorber and active sampling regions. Consider the configurations shown in Fig. 7. One is the normal arrangement of parallel plates, the other is a checkerboard with exactly the same sampling fraction. The absorber material was iron or lead, and the sampling material was liquid argon, because the EGS program is known to give reliable results for these materials. The result was that the checkerboard was predicted to give a slightly better energy resolution than the iron. The hole arrays were studied as a function of the aspect ratio of the holes, and it was found that the energy resolution is mainly a function of the fraction of the volume represented by the sampling medium, with a small term depending on the surface of the sampling volume, such that the resolution improves by $\sim 10\%$ when the surface is doubled. The checkerboard resolution was studied as a function of angle of incidence of an electron in the plane perpendicular to the axis of the holes, with the result that it was nearly independent of angle except for a narrow band near 45° . This is in contrast to the situation with the parallel plates, where the resolution is degraded if the particles are not normally incident. If the angle is varied in the other plane, the resolution for the checkerboard is broadened by about 50% for angles of 50° with respect to the normal. Such a relatively isotropic response offers interesting possibilities in detector design.

The problem of energy resolution in a wire chamber calorimeter has received some study. In an ideal totally active calorimeter, the best resolution would presumably be obtained with a linear response to ionization. However, in such a dilute sampling medium as gas in a wire chamber, the advantages of linearity may be outweighed by the large Landau fluctuations. We might expect that the resolution would improve if the active element counted the electrons passing through,

rather than measuring the ionization. This can be done by operating a wire chamber in the Geiger mode, or by using Conversi flash tubes. However, each counting element covers a finite area. As the energy of the shower increases, the particle density in the core of the shower increases and the loss due to two particles striking the same counting element becomes important. Eventually, the response as a function of energy becomes seriously non-linear, and the resolution is degraded. We might therefore expect that the resolution is improved at low energies by a switch to the counting mode, but that at some higher energy it becomes increasingly bad. This question has been investigated by the TPC^{*)} group at Berkeley, in a calorimeter which can be operated in either the proportional or Geiger modes. To minimize the counting loss effect, the old trick of the "beaded" Geiger counter is used in a modern form, with nylon threads in contact with the anodes at 10 mm intervals to limit the spread of the Geiger discharge to one such segment. The counting element is then 0.6 cm^2 . The expected behaviour of the energy resolution is then observed, as shown in Fig. 8. The improvement in the counting mode at low energies is clear, though the improvement in resolution was not the motivation of the Berkeley work, rather it was the solution of the calibration problem, and the ease of working with large signals⁸⁾. The disadvantage of rapidly worsening resolution at high energies would be serious in many applications. It is an interesting challenge to devise a wire chamber counting technique which would have element areas of 1 mm^2 . This would also be important from the point of view of rate capability.

The Landau fluctuations also adversely affect hadron calorimeters using wire chambers, but another effect can be more serious. This is the presence of densely ionizing evaporation products from nuclear stars. These give large, relatively infrequent signals which add to the fluctuations. Occasionally a star will take place in the gas itself, leading to a tail on the high side of the signal distribution which is most undesirable in many applications. Consequently, it may be expected that the improvements in performance will be more important for hadron

*) TPC: Time Projection Chamber.

calorimeters than for electromagnetic detectors, though no measurements have been reported this far.

REFERENCES

1. J. Cobb et al., Nucl. Instrum. Methods 140, 413 (1977).
2. J. Fischer et al., Nucl. Instrum. Methods 136, 19 (1976).
3. M. Deutschmann and W. Struczinski (private communication).
4. V. Baskakov, V. Chernyatin, M. Deutschmann, B. Dolgoshein, C. Fabjan, V. Fedorov, I. Gavrilenko, V. Kantserov, S. Mailurov, E. Platner, A. Shmeleva, W. Struczinski and W. Willis, CERN/SPSC/79-36; SPSC/P126 (1979).
5. This is a possible application of the electronics described by E.D. Platner, IEEE Trans. Nucl. Sci. NS-25, 35 (1978).
6. T. Kansure et al., Nucl. Instrum. Methods 105, 245 (1972).
7. W. Carithers, C. Day, L. Galtieri, F. Goozen, K. Johnson, H. Videau and W. Wenzel, paper at Fermilab Muon-Neutrino Workshop, Jan. 1980) (private communication by W. Carithers).

Figure captions

- Fig. 1 : An exploded view of a proportional wire chamber for the detection of X-rays from transition radiation, after Ref. 2.
- Fig. 2 : Measurement of the uniformity of response of the chamber pictured in Fig. 1. The shaded region indicates the range among the 80 individual anodes.
- Fig. 3 : The performance of the system of Refs. 1 and 2 in separating electrons and hadrons.
- Fig. 4 : The result of TR detection with track ionization suppression by transverse drift, according to Ref. 4.
- Fig. 5 : The layout of the longitudinal drift chamber for the enhancement of TR signals.
- Fig. 6 : The number of ionization clusters per particle per detector, for 140 GeV π with and without TR. The distribution shown is averaged over ten particles, to simulate the effect of ten sequential detectors. The test set-up is not optimized for the number of photons detected.
- Fig. 7 : The two configurations whose performance was simulated with results reported in the text. The fraction of active sampling material and the elements thicknesses are the same in both cases.
- Fig. 8 : The response of a calorimeter operated in the proportional and Geiger modes. Points are preliminary data from Carithers et al.⁷⁾.

Fig. 1

Fig. 2

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Fig. 4

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Fig. 6

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