MULTIWIRE PROPORTIONAL QUANTAMETERS

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The performance of multiwire proportional shower counters is predicted using Monte Carlo calculations. Results are compared with existing devices and methods for optimization of the energy resolution are proposed.

1. Introduction

For many modern high energy physics experiments, electromagnetic shower sampling devices are indispensable for identification, localization and energy measurement of electrons and photons.

In this context, the use of multiwire proportional chambers (MWPC) as sampling devices received early interest¹). It emerged, however, that in this case the energy resolution is inferior to scintillator or liquid argon sampling detectors. This was claimed²) to be due to energy loss fluctuations (delta ray statistics) in the gaseous detector medium.

Nevertheless, in view of expenses and technical problems posed by the competing methods, the multiwire quantameter remains an attractive choice. Recently some very big detectors using this principle have been proposed³) or are under construction⁴).

If the use of shower simulation programs has been proven to be very useful in the design and optimization of some sampling detectors⁵), this is not yet true for multiwire quantameters. In this paper, it will be shown that the quantameter response can be reliably calculated by Monte Carlo methods. The better understanding of the basic operation will lead to some straightforward optimization methods which should significantly improve the energy and space resolution.

2. Some basic properties of electromagnetic showers

In the following, shower properties will be calculated for a "standard" lead-proportional chamber detector with 48 samples in a total depth of 16 radiation lengths (X_0), i.e. a sampling thickness $t = \frac{1}{3} X_0$. The Monte Carlo routine originating from Nagel⁶), and recently rewritten at SLAC⁷), will be used.

2.1. ENERGY DISTRIBUTION OF SHOWER ELECTRONS

The routine follows the shower electrons down to kinetic energies of 1 MeV. Indeed, in multiwire quantameters one is worried about low energy secondaries, since the range cut-off in the gas is as low as a few tens of keV.

In fig. 1, curve a, the kinetic energy distribution of shower electrons is shown for 1 GeV incident energy in the standard detector. The hand-drawn extrapolation to lower energies is somewhat steeper than the form $(E+16 \text{ MeV})^{-2}$ used by previous authors⁸) and predicts about 25–30% of all shower electrons to be below the 1 MeV cut-off. Only very few of them will however contribute large mean energy losses as indicated by the dE/dx curve shown in the same figure. In fact the maximum energy loss, as given by range in a chamber gap of about 1 cm, is of the order 5–10 times the minimum ionization, at energies around 50 keV. Electrons of such low energies will be effectively suppressed by the chamber cathodes made of metallized foil or aluminium in most practical detectors. This is shown in fig. 1, curve

Fig. 1. (a) Kinetic energy distribution of shower electrons in the standard detector at 1 GeV incident energy. (b) Same for 0.5 mm Al facing of lead converter plates. (c) Mean energy loss of shower particles in the detector gas as function of energy, referred to minimum ionization loss.

b, which gives the energy distribution for a 0.5 mm aluminium facing of the lead converter plates. To include a reasonable number of very low energy electrons in the calculation, all energies were lowered by 1 MeV for the calculation of the mean energy loss (see below). Still, the total number of shower electrons is somewhat low and therefore the sampling fluctuations will be slightly overestimated by the program.

2.2. ANGULAR DISTRIBUTION OF SHOWER ELECTRONS

The angular distribution of shower electrons is presented in fig. 2a for the standard detector. A strong peak along the shower axis (angle 0°) is evidenced. However, there is considerable spread in the angle and about 12% of all electrons are back scattered into the sampling gap. For low energy electrons, $E < 3$ MeV, the peak at zero degrees vanishes and a $\cos^2$ -distribution is approached. This is expected⁹⁾ from multiple scattering arguments. Also the electrons below the 1 MeV cut-off are therefore assumed to follow this type of distribution.

The wide spread of electron angles corresponds to large fluctuations in track length in the sampling device, which deteriorates the energy resolution. This is of course true for all sampling detectors. However, the strong correlation between energy and angular distribution favours detectors with sufficiently thick layers of dense sampling media. Here, the energy deposit of small angle electrons in the sampling gaps becomes comparable to the total energy of those at large angles.

This is demonstrated by fig. 3, where the energy resolution of a lead-liquid argon quantameter, with lead arrangement corresponding to the standard

Fig. 2. (a) Angular distribution of shower electrons. (b) Same for electron energies below 3 MeV.

Fig. 3. Energy resolution of standard detector with liquid argon sampling for 1 GeV incident energy as function of liquid argon thickness.

detector, is calculated as a function of liquid argon layer thickness. In this case, sufficient thickness means a few mm of liquid argon. Since the multiwire quantameter corresponds practically to zero sampling thickness, it is clear that a much inferior energy resolution is to be expected from this effect alone.

3. The response of the multiwire quantameter

Each shower electron creates a proportional chamber signal according to its energy and track length. The resulting Landau distribution is simulated in the following simplified way: Primary ionization electrons are drawn from a Poisson distribution with a mean given by the dE/dx of the shower electron (fig. 1), its track length and the gas used. Each primary is given kinetic energy following an E^{-2} law and creates secondaries according to the mean energy needed per ion pair in the

Fig. 4. Energy loss distribution in 1.6 cm of A-50% ethane gas. Histogram: measured distribution. Insert: calculated fwhm of energy loss distribution as function of gas thickness, compared to measurement¹¹⁾.

gas. The calculated Landau distribution is shown in fig. 4 for a 50% argon–50% ethane mixture. It compares favourably with a measured spectrum in the same gas¹⁰). Its width as function of track length reproduces the measurements by Aderholz et al.¹¹), as shown in fig. 4.

The proportionality of the chamber signal is an important problem, since saturation effects have been shown¹²) to set in already at gas amplifications around 10^3 . The saturation depends very strongly on the track angle relative to the wire direction, and gives rise to additional fluctuations in the quantameter response. It is therefore not advisable to push the amplification into the saturated mode, hoping to decrease the width of the Landau distribution.

From the point of view of collected charge, the multiwire quantameter can work at very low gas amplifications. Calculating the total charge as compared to liquid argon detectors, the loss by the density difference is 800. However, some factor is gained back by the increased sampling gap width (usually factor 5) and the different signal build-up (factor 2 due to ion chamber characteristic of the liquid argon counters). Even taking into account the increased width of the Landau distribution, operation well below the saturation limit is possible if low noise electronics with a charge sensitivity comparable to the liquid argon case is used.

4. Energy resolution

The energy resolution of the standard detector

Fig. 5. Energy resolution of standard quantameter as function of incident energy. The contributions from sampling statistics, track length and Landau distribution are indicated.

Fig. 6. Energy resolution as function of plate thickness for 1 GeV incident energy.

can now be calculated as function of incident energy. To give a reasonable estimate, a cut-off in track length is needed, since otherwise the resolution curve develops a non-Gaussian tail. In the presented calculation a cut-off at 20 times gap width is used.

Fig. 5 shows the energy resolution as given by the different effects mentioned above. The lowest curve corresponds to the fluctuation in the number of shower electrons only. This constitutes the lower limit of resolution obtainable in a sampling detector. The two curves labelled "track length" and "Landau" build up the effective resolution from this optimum. It is seen that the track length fluctuations have a far bigger effect than the energy loss fluctuations. The total resolution follows an approximate $E^{-1/2}$ dependence. The predicted resolution for the corresponding liquid argon detector is also indicated. The resolution as function of sampling thickness t (always for a constant total depth of $16X_0$) is given in fig. 6 for 1 GeV incident energy. Again the expected $t^{1/2}$ dependence is approximately fulfilled.

5. Comparison with existing detectors

Energy resolutions have been calculated for the lead-MWPC sandwich of Nordberg¹) and the iron-MWPC sandwich of Ritson et al.³). These two quantameters are sufficiently different in sampling material and thickness to present a real test of the simulation. Nordberg's device has 19 samples of $0.56X_0$ Pb faced with thin Al sheets. Ritson's detector (proposed as hadron calorimeter) has 36 samples of $1.6X_0$ Fe sandwiched between 1.6 mm Al. In both cases the cut-off in track length is given by the lateral dimension of the device. The

Fig. 7. Comparison of predicted energy resolution (error bars) and experimental results from refs. 1 and 3 (full curves).

aluminium facings, gap dimensions and kind of detector gas have been properly included in the calculation. As shown in fig. 7, the measured resolutions are reasonably well predicted by the simulation program.

6. Optimization

Only little improvement of energy resolution can be expected by reducing the width of the Landau distribution, since it contributes only a relatively small fraction to the total fluctuations. Nordberg¹⁾ tried to pressurize his device without positive result. Certain organic gases are reported to yield narrow energy loss distributions¹³⁾. In these cases, careful studies of saturation properties are needed.

Fig. 8. Energy resolution and total number of sampled shower electrons as function of Al facing thickness.

One can also try to eliminate the low energy, large angle electrons by low Z absorber material (e.g. Al) outside the high Z converter. For almost all practical devices this is anyway needed to obtain the necessary surface quality for the MWPC cathodes. In fig. 8, the influence of Al facing thickness on resolution is shown for the standard detector. The total number of shower electrons is decreasing so fast with increasing Al thickness, that no overall gain in resolution is reached. Nevertheless, it is seen that Al facing up to a few mm thickness does not deteriorate the resolution.

The obvious candidate for optimization is a cut on track length. The calculated gain in resolution by eliminating contributions beyond a certain distance from shower axis is shown in fig. 9. This cut can be achieved both actively, i.e. measuring the

Fig. 9. Energy resolution as function of distance cut (distance in units of gap width).

Fig. 10. Comparison of predicted (error bars) and measured (full curve) energy resolution for the quantameter of Anderson et al.⁴⁾.

space distribution of charge and cutting in distance, or passively by stopping large angle electrons in appropriate absorbers.

At SLAC¹⁰⁾, a lead-MWPC sandwich was developed using cathode readout of two orthogonal coordinates per gap, such that active cutting on pulse height at a distance of 2–3 gap widths from shower axis is possible.

Also at SLAC, Ritson et al.⁴⁾ use channelled Al profiles providing separation walls between adjacent wires, i.e. a proportional tube detector rather than a normal MWPC quantameter. The device is of the lead-MWPC type with 36 samples of $0.47 X_0$. As shown in fig. 10, this detector provides a resolution which is substantially better than the one expected from calculation for the same sampling, but without separation walls. Although the Al channels cut off only along one coordinate, they yield an effective distance cut corresponding to about 4 gap widths.

Evidently, the problem is inviting a clever technical solution, especially in view of the fact that a gain of a factor 1.4 in resolution corresponds to the reduction by a factor of 2 of the number of samples.

7. Conclusion

The detailed response of multiwire proportional quantameters can be understood using Monte Carlo shower generation methods. Apart from the shower electron statistics present in each sampling device, the effective energy resolution is governed by track length fluctuations from the angular distribution of the shower electrons. Energy loss (Landau) fluctuations are relatively less important, they contribute to the same order as the sampling statistics.

The energy resolution can be substantially improved by cutting contributions beyond a certain distance from the shower axis. This cut can be achieved both by measuring the space distribution of charge or by placing appropriate absorbers.

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