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14 October 1982LONGITUDINAL DRIFT AND FINE dE/dx SAMPLING IN VARIOUS GAS MIXTURESI. Lehtaus, R. Matthewson and W. Tejessy
CERN, Geneva, SwitzerlandSummary

Results of measurements realized at 15 GeV/c in a tagged $e/\pi/p$ beam are presented. A longitudinal drift detector of 88 cm total length consisting of 16 stages of 4.7 cm drift each was used. Fast shaped signals from the detector were processed in a set of Flash ADC's with 25 ns sampling interval, corresponding to 0.3 - 2.6 mm distance in the drift space. Resolution and particle separation efficiency obtained in mixtures of Ne + 10% C_3H_8 , Ar + 5% C_3H_8 , Ar + 20% CO_2 , C_3H_8 + 20% C_2H_6 and in pure CH_4 are compared to the performance of a classical method of charge integration over large samples.

1. Introduction

A potential improvement in the efficiency of particle identification by using many very fine sampling intervals in ionization measurements was suggested at BNL [1], following the attempts to detect individual ionization clusters when drifting along the particle trajectory [2]. Recently, several experiments were realized in order to investigate the performance of longitudinal drift detectors with "fine" sampling. A single 5.1 cm gap [3] and a 2-stage detector with 2 x 3 cm drift [4] were used by two groups in Japan. Results from a BNL collaboration using a 10-stage detector with folded 10 x 2 cm drift (6-stages instrumented) [5] are now available. We present here some new results (first measurements in Ne + 10% C_3H_8 were published already [6]) from a 16-stage device with 4.7 cm of longitudinal drift per stage.

Improvements of resolving power by about a factor of two were quoted from the small prototype measurements [3-5] when extrapolated to 1 m of total track length. Various versions of the original BNL fast amplifiers [7] (shaped pulse FWHM of ~ 20 ns) were used in those experiments. The sampling interval was 40 ns (~ 1.4 mm samples in Ar + 10% CH_4) [3,4] and 2 x 10 ns (~ 0.5 mm samples in Ar + 20% CO_2) [5] respectively. The gas gains were above 10^4 .

Our previous results [6] measured in similar conditions with 88 cm total detector length gave, in a Ne mixture, a performance comparable to what is expected from a detector of this size using charge integration and large samples. Our aim now was to verify this tendency in two different Ar mixtures (with fast and slow drift velocity) and in several hydrocarbons.

2. Experimental arrangement

The geometry of the detector is shown schematically in fig. 1 for two stages from the total of 16. The ionization deposited in the 4.7 cm of drift space between the 25 μ thick aluminium foil HV electrode and the separation grid was drifted along the particle trajectory into proportional cells of 0.8×0.8 cm² section. The 15 cm long HV and field wires are 50 μ in diameter, the signal wires are of 10 μ diameter silver plated tungsten. Another foil electrode separates the adjacent stages. Uniform drift field is maintained by a cage structure formed by tubular brass electrodes. The total detector length is 88 cm without the gas-tight box. The measurements were performed in a 15 GeV/c unseparated tagged $e/\pi/p$ beam. The beam direction was perpendicular to the wires. The triggering scintillation counters were 0.6 cm wide, aligned on the central cells, and 3 cm long covering the middle part of the wires. A veto scintillation counter guarding the full detection area was used to remove background and multiple hits.

A modified circuit of the original fast amplifier developed at BNL [7] was connected as close as possible to the signal wire of each cell. The Gaussian shaping amplifier was replaced by repeating the final stage of the front amplifier. Six distributed integrating time constants were added to the system. The first three of these were incorporated in the grounded-base preamplifier (5 ns each); the fourth and fifth are in the tandem final stage and are 10 ns. Lastly, the connecting coaxial cable between the amplifier output and the ADC served as the final stage of integration. When excited by an input delta function, the shaped output pulse had a rise time of 18 ns, fall time of 26 ns and a FWHM of 32 ns. For a step function, the signal droop over 5 μ s was 2%. Single electron cell response produced a positive 7 mV output signal when the chamber was operated at a gas gain of 10^4 and the r.m.s. noise was 1300 electrons referred to the amplifier input.

The output signals were transmitted via coaxial cable to a 16 channel, 6-bits, ECL Flash ADC system which was operated continuously with a sample interval of 25 ns. Each FADC has a fast ECL, 256 bit deep, RAM buffer into which data was stored upon receipt of a trigger from the scintillation counters. The same trigger also served to clock the beam tagging system. Aperture time of the FADC (Siemens SDA 6020) was 2 ns with an uncertainty of 25 ps. The coaxial cable delay guaranteed seeing several samples of the base-line prior to the

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signal. All the amplifiers were biased to have an offset of + 28 mV at the output, so that the base-line stood at a count of 7 at the FADC. If, therefore, the chamber was operated at a gas gain of a little more than 10^4 the single electron response would produce a count of 9 and a ten electron cluster a count of 27. The r.m.s. noise level was ± 1.5 counts and the droop over 5 μ s was -1.

The differences in the detector response caused by various gas densities and drift velocity combinations were compensated by adjustments of the gas gain. The data stored in the fast ECL RAM buffers allowed to cover, at 25 ns sampling interval, the full 4.7 cm drift length for drift velocity down to < 1 cm/ μ s. Between consecutive particles these data were transferred to an intermediate 32K byte TTL RAM buffer until the end of the beam spill. There was a possibility to select 64, 128 or 256 samples per particle. This allowed 8 particles per burst for the highest sampling number; for 64 and 128 samples per particle the flux was limited to 16 particles/spill by the capacity of the tagging system buffers. Keeping the 15 GeV/c beam particle flux low avoided space charge build-up from positive ions. Pile-up problems from too close consecutive particles were avoided with the help of a dead-time defining veto.

Between spills the information was read by a dedicated computer, a Nord-10, and transferred after reformatting to 1600 bpi magnetic tape. With up to 4000 bytes/particle the data transfer load was considerable in comparison to integration methods. Concurrently, the information from each full spill was stocked onto disk and sequentially analysed in the time left until the next spill. This allowed a close control of the experimental conditions during the data taking.

3. Results

A typical example of the full registration of one particle passing through a single stage of the device is shown for two different stages in fig. 2, top and centre. The passing particle has been tagged as a pion, the gas mixture was Ar + 20% CO₂, the drift velocity was close to 1 cm/ μ s, so that the 25 ns sample interval corresponded to ~ 0.3 mm in the drift space. The spike at the beginning is caused by the addition of ionization from both sides of the track segment crossing the proportional cell. The peak is limited to a count of 64 by the ADC range (including offset). Summing up corresponding samples from all 16 stages and for many particles for this gas creates the familiar shape shown at the bottom of fig. 2. Summed histograms for various other gas mixtures are given in figs 3-4. Note the differences in length of the plateau due to the different drift velocities. In the summed histograms the offset has been subtracted.

Corrections for the individual stage responses were applied in the off-line analysis. Further corrections were derived from the average response for each gas by splitting the plateau region of the histograms of the accumulated events (figs 2-4) into several intervals and determining the corresponding mean values, which were subsequently used for re-normalization (the improvements due to these corrections were marginal). For further analysis all samples from all stages within the plateau were taken; no cuts eliminating individual strings of samples (e.g. due to high number of overflows, etc.) were allowed, to avoid introduction of bias into the results by

selective cleaning. The final distributions of truncated means, using the 40% smallest values, are plotted in figs 5-9 for all measured gas mixtures. The beam composition during these runs was $\sim 9\%$ protons and roughly equal numbers of the majority particles, pions and positrons.

In table 1 we summarize the results of our measurements. For each gas mixture we indicate the total number of 25 ns samples used per track, the equivalent sample size in the drift space and the total number of beam tracks analysed (this number is not necessarily contained in all the displayed histograms). The particle separation efficiency D/σ is expressed for various pairs of particles as a ratio of the distance between peaks of corresponding truncated mean distributions and the peak widths, using $\sigma = \text{FWHM}/2.36$. Within the experimental errors the Ne mixture gives best results, followed by Ar + 5% C₂H₆. The drift velocity was in those mixtures practically identical at ~ 3.6 cm/ μ s; the specific energy loss in Ar is ~ 2 times higher than in Ne. Ar + 20% CO₂ mixture was measured using $v_d \sim 1$ cm/ μ s. Pure CH₄ (fast, low density) and C₂H₆ + 20% C₂H₄ (slow, density close to Ar mixtures) represent two extremes for investigation of hydrocarbons. The product of number of useful samples and of the equivalent sample size gives the effective detector length which was, in our case, on the average $\sim 2/3$ of the available 88 cm.

For comparison of the results from the longitudinal drift detector with measurements realized, also at 15 GeV/c, using charge integration in 64 x 4 cm samples [8] and 128 x 2 cm samples [9] for the same or similar gas mixtures, we scale the present results to 2.56 m of total detector length [8,9]. As a first (optimistic) approximation, a dependence of the particle identification efficiency on the square root of the effective length could be used. The D/σ values obtained in this way are similar. Note that in the case of the longitudinal drift approach the effective length would have to be increased by 1/3 to obtain the true length.

In order to verify the resolution dependence on the sample size, in the data for Ar + 5% C₂H₆, 2, 4 and 8 adjacent samples were added in the analysis, giving sample sizes of 0.9 (single sample) to 7 mm. The D/σ ratio remained for π/p separation at 2.7 up to 4 summed samples and was reduced to ~ 2.5 at the sum of 8 samples. This reduction of performance was clearly caused by problems related to a growing influence of the cut-off introduced by the overflow channel for large summed samples.

4. Conclusions

When comparing results obtained in identical conditions using charge integration in 64 x 4 cm and 128 x 2 cm samples and longitudinal drift with fast sampling in a 16 stage detector of 88 cm total length, we found very little difference in performance for corresponding depths. The $e/\pi/p$ relativistic rise ratios are approximately as those found by us using charge integration; an improvement due to increased relativistic rise in the fine samples was not found. The resolutions were, on the average, 12-15% FWHM; the Ne mixture showed the best π/p separation.

Only $\sim 2/3$ of the total length of the detector was available for longitudinal sampling. By definition the longitudinal drift and sampling should be less efficient at higher pressures, so that the

detector cannot be made more compact this way. When adding up to 8 adjacent samples, no marked dependence of the resolution on the sample size has been found.

Some improvement of the performance of this method is certainly possible, e.g. by more refined compensation of base-line shifts and pile-up caused by big signal fluctuations. Attempts to remove the influence of close-range correlations in adjacent samples by using only every n^{th} sample [4] will obviously increase the required detector depth. Some hard problems are related to signal to noise ratio in big systems, differential non-linearity of the FADC's, saturation and space charge caused by high gas gain required for small samples. In the case of inclined and curved tracks the varying interval length during the fine sampling and losses in reconstruction of a track from several sampling channels could only reduce the resolution. The main difficulty seems to arise from strong inter-dependence of the average distance between the primary ionization clusters, electron diffusion during the drift and sampling interval in relation to the drift velocity with respect to the corresponding pulse shaping time constants. All these effects are of the same order. Also, the amount of data to be processed on-line and off-line is considerably increased in the case of the longitudinal drift method as compared to the classical charge integration over large samples.

References

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Table 1 15 GeV/c data; 16 stages; sampling rate 40 MHz

Gas	Total number of samples used	Equiv. sample size (mm)	<40> D/ σ			No. of tracks used
			e/p	e/ π	π /p	
Ne + 0.1 C ₃ H ₈	560	0.9	4.7	1.2	3.5	12 800
Ar + 0.05 C ₃ H ₈	592	0.9	4.2	1.5	2.7	10 600
Ar + 0.2 CO ₂	2128	0.3	3.4	1.4	2.0	11 300
CH ₄	208	2.6	3.1	0.5	2.5	8 000
C ₃ H ₈ + 0.2 C ₂ H ₆	1104	0.5	2.5	0.6	2.0	19 000

Fig. 1 Simplified diagram of two out of the 16 stages of the detector. The alignment of the triggering scintillators on the central cells is schematically shown; the true position of the chamber is between S_1 and S_2 .

Fig. 2 Example of the FADC response over the full drift space (25 ns/bin) in two of the stages (top and centre) for one positive pion passing through the detector; Ar + 20% CO_2 ; 15 GeV/c. The bottom histogram gives the summed response for all stages over many particles.

Fig. 3 The FADC response summed over all stages and many particles for (top) pure CH_4 and (bottom) $\text{Ne} + 10\% \text{C}_2\text{H}_6$; 25 ns/bin.

Fig. 4 The FADC response summed over all stages and many particles for (top) $\text{Ar} + 5\% \text{C}_2\text{H}_6$ and (bottom) $\text{C}_2\text{H}_6 + 20\% \text{C}_2\text{H}_6$; 25 ns/bin.

Fig. 5 Distributions of truncated means (40% smallest values) for protons (+), pions (o) and positrons (•) at 15 GeV/c in $\text{Ne} + 10\% \text{C}_2\text{H}_6$ using 560 samples per track; 40 MHz sampling rate. The inside scale pertains to the protons.

Fig. 6 Distributions of truncated means (40% smallest values) for protons (+), pions (o) and positrons (•) at 15 GeV/c in $\text{Ar} + 5\% \text{C}_2\text{H}_6$ using 592 samples per track.

Fig. 7 Distributions of truncated means (40% smallest values) for protons (+), pions (o) and positrons (●) at 15 GeV/c in Ar + 20% CO₂ using 2128 samples per track.

Fig. 8 Distributions of truncated means (40% smallest values) for protons (+), pions (o) and positrons (●) at 15 GeV/c in pure CH₄ using 208 samples per track.

Fig. 9 Distributions of truncated means (40% smallest values) for protons (+), pions (o) and positrons (●) at 15 GeV/c in C₂H₆ + 20% C₂H₄ using 1104 samples per track.