DE/DX MEASUREMENT WITH FINE SAMPLING

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Introduction

Improvability of particle separation by means of fine dE/dX sampling brings forth an idea of central tracking detector with particle identification capability in the colliding beam experiment. Ludlam et al.[1] (hereafter referred as BNL measurement) at the first time reported their test results on the dE/dX measurement with the sub-mm sampling intervals, which indicated that the particle separation could be improved appreciably compared to that obtained with the ordinary sampling intervals (1-2 cm). As a result, total gas thickness could be much reduced and particle separation in the relativistic rise region could be realized even with a 1 m long chamber at an atmospheric pressure. However, for a practical application of this method, following basic features have to be further investigated.

The length of drift space:
With the longer drift space, the total number of sense wires can be reduced, but particle separation would become worse because of the diffusion and attachment of drifting electrons.

The width of unit cell:
The linear relation between the distance of the ionization point and the drift time to the sense wire is distorted because of the cylindrical electric field around the sense wire, and this distortion may deteriorate resolution of dE/dX measurement for inclined tracks against the drift field.

The effect of magnetic field:
The above effect would be much enhanced in the magnetic field because of the distorted trajectory of drifting electrons.

Readout electronics:
Sophisticated readout electronics for signal shaping and fast-sampling of pulse amplitudes are required. For the large-scale application, more than 10^4 wires may be used and the construction cost is dominated by the cost of fast Flash ADC and fast shift registers. Therefore, simpler and cheaper electronics have to be considered from the viewpoint of economical compromise.

Gain variation, cross talks, etc:
These effects would deteriorate particle separation in a large-scale multi-layer detector.

With above in mind, we have investigated the fine dE/dX sampling method with a longitudinal drift chamber (LTD) having a longer drift space and with simpler readout circuits than BNL's. Here, results obtained without magnetic field are presented.

Description of the Apparatus

Beams

A series of measurements were done using electron and pion beams of 500 MeV/c, which were obtained from the bremsstrahlung beam at the 1.3 GeV electron synchrotron of Institute for Nuclear Study. At this momentum, dE/dX for pion is at its minimum and that for electron is in the Fermi plateau region. So, our results can be compared directly with the BNL's.

Chamber

The LTD, as shown in Fig.1, has a drift region of 51 mm long and twelve cells of 10 mm × 10 mm for gas amplification. Applied electric field on the drift region was about 0.8 KV/cm and electron drift velocity was about 35 mm/μs in the gas mixture of 90% Ar + 10% CH_4. Applied high voltage on sense wires was 1.55 KV which resulted in gas amplification gain of about 2×10^4.

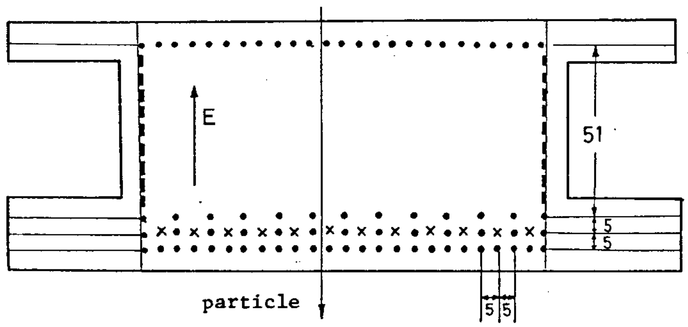

Fig.1. Scheme of our longitudinal drift chamber (LTD).

Electronics

Sampling time interval of 40 ns was chosen because of easiness to obtain commercially available Flash ADC (TRW TDC-1014J), and this choice helped to simplify the readout circuit. As for pulse shaping, only a long signal tail with time constant of about 200 ns had to be filtered out in our case. On the otherhand, BNL's 10 ns sampling required to suppress two signal components with time constant of larger than 10 ns. Then,

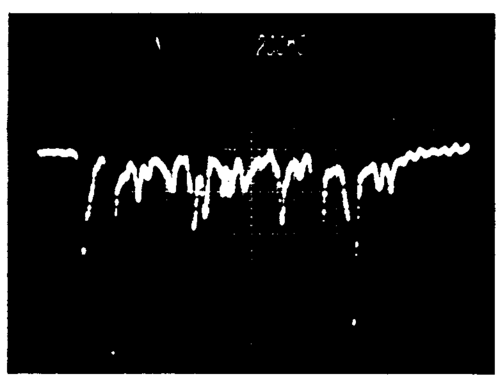

Fig.2. Input signal to FADC for the pion of 500 MeV/c. Vertical scale is 200 mV/div. and horizontal scale is 200 ns/div.

we used a fast and low noise pre-amplifier developed by Boie et al.[2] by modifying it to match with 40 ns sampling interval.[3] Only one pole-zero shortening filter with time constant of 60-70 ns was used instead of two pole-zero's and a semi-Gaussian integrater in BNL's. A semi-Gaussian integrater with time constant of 15 ns was introduced on a particular channel to study its effect. Observed equivalent noise charge of the pre-amplifier was about 4000 electrons. A limiter was also introduced to prevent overload of succeeding amplifier for large pulses. Amplitudes of the signal from the amplifier were sampled by 6-bit FADC with the dynamic range of -1.1 V and digitized data were stored on three dual shift registers (TRW TDC-1005J). The offset level of +100 mV was applied on FADC in order to study the detailed behaviour of small amplitude noises. Fig.2 shows an input signal to FADC for the pion passing through the LTD.

Gain Monitoring

We used ^{55}Fe X-rays irradiating a particular sense wire to monitor the long term gain drift of the system. The pulse height spectrum for X-rays were measured between the beam spill cycles with LeCroy QVT module. We observed gain variation of 1-2% for whole test period and it was corrected at the off-line analysis.

Analysis and Results

Accumulated signal shape

Fig.3 shows an accumulated signal shape for pion events. The smaller pulse height at the leading edge

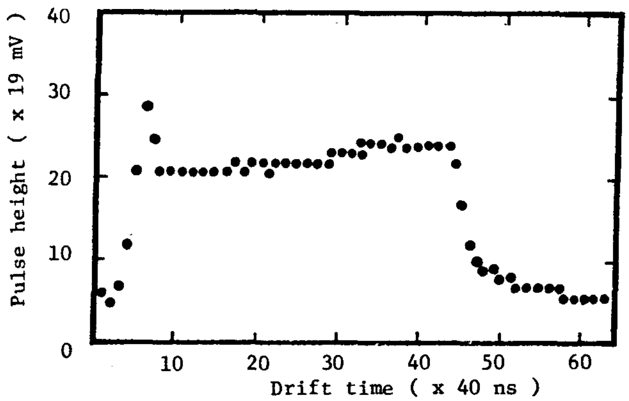

Fig.3 Accumulated signal shape for pions.
One horizontal bin represents the sampling time interval of 40 ns and one vertical bin represents FADC resolution of 19 mV that corresponds to dE/dX of about 15 eV. The offset of +100 mV can be seen.

compared with BNL's can be attributed to the effects of pulse height limitation by FADC dynamic range, different gas mixture and unadjusted timing of the leading edge. The long plateau region of about 1.4 μs corresponds to the drift region of 51 mm in the LTD. Slow rise of the average pulse height in the plateau is seen and this will be discussed later.

In the following, we analyzed the samples in the whole plateau region between the bin number 11 and 40 in Fig.3. This sampling range corresponds to the drift time of about 1.2 μs and to the gas thickness of 42 mm, which occupies 70% of the total thickness of our chamber and this percentage is quite large compared to 31% of BNL's.

Pulse height distributions

Pulse height distributions for pions and electrons with 40 ns sampling are shown in Fig.4 together with Landau distribution functions whose parameters were chosen to fit the data at smaller energy loss side. Single sample resolution W/E_0, where W is the FWHM of the pulse height distribution and E_0 is the most probable energy loss, is plotted in Fig.5. Our data for gas thickness of 1.4 mm is on the linearly extrapolated line from the wide samplings in the figure.[4] The measured ratio of the most probable energy losses for electrons and pions of 500 MeV/c is 1.7 ± 0.1, which is lower than the predicted value of 2.0[5].

σ/E and R

A one-meter long track was simulated by using 720 samples of 40 ns intervals from the successive events.

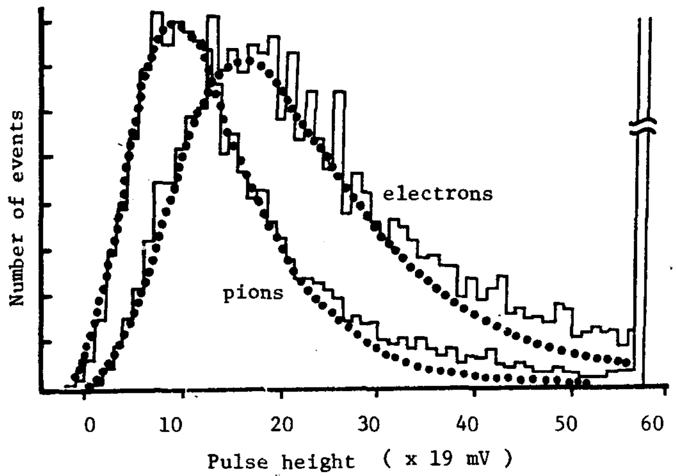

Fig.4. Pulse height distributions for pions and electrons of 500 MeV/c. Dotted curves are Landau distribution functions. +100 mV offset is subtracted.

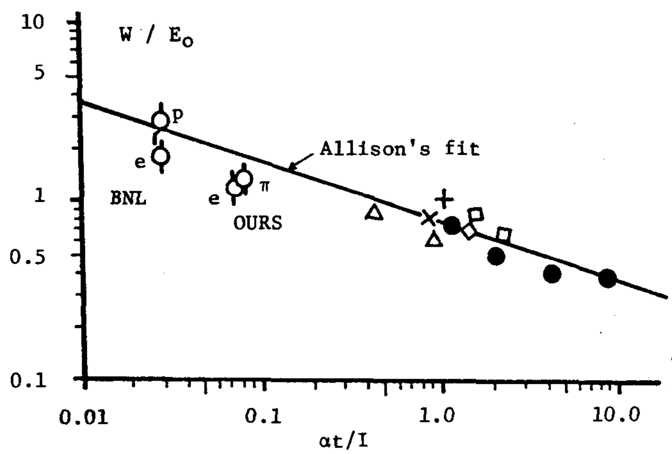

Fig.5. Single sample resolution W/E_0.
ϕ are data points of our and BNL measurements. Other data and Allison's curve are referred from ref.4.

Fig.6 shows the r.m.s. resolution σ/E of the truncated mean energy loss for a one-meter-long track as a function of the sample retention. The resolution for pions is worse than that for electrons and which might be due to the relatively large electronics noise contribution for pions. Relativistic rise R ($=E_e/E_\pi$) is shown in Fig.7.

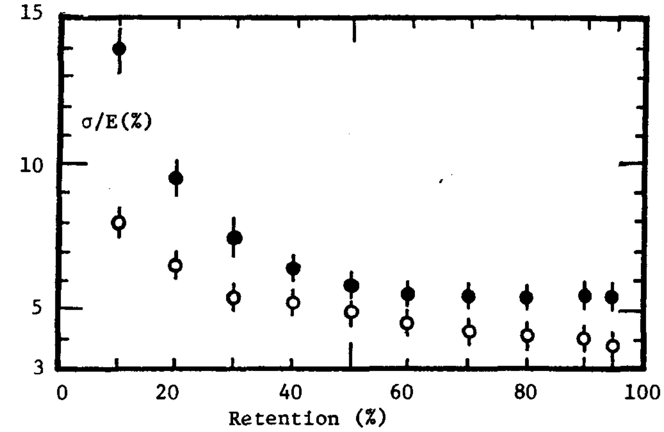

Fig.6. σ/E of the truncated mean energy loss for a one-meter-long track as a function of the sample retention.
♦ is for pions and ϕ is for electrons.

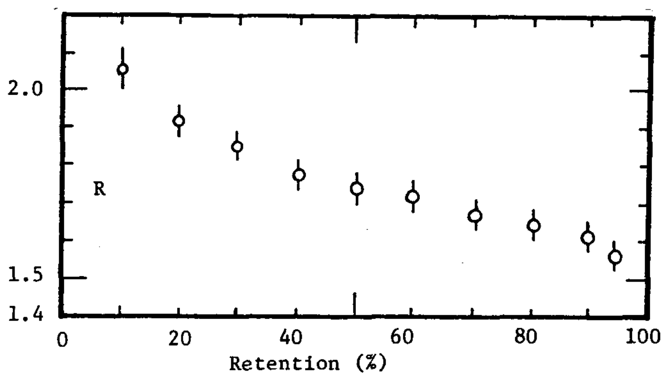

Fig.7. Relativistic rise of the energy loss v.s. retention for 1.4 mm sampling intervals

Particle selectivity S

A figure of merit S as a measure of particle separation is defined as

$$S = \frac{|E_e - E_\pi| - (\sigma_e + \sigma_\pi)}{<\sigma>}$$

where $<\sigma>=(\sigma_e+\sigma_\pi)/2$, E_X and σ_X are the mean of the truncated energy loss for a one-meter-long track of particle X and its standard deviation, respectively. Fig.8 shows distributions of truncated mean pulse heights for pions and electrons with the retention rate of 60%. Fig.9 is a relation between S and retention rate, where the plateau of $S \simeq 8$ can be seen at retention rate from 40% to 90%.

S in the narrow plateau region

The plateau region of the accumulated signal shape was divided into three regions to examine the dependence of S on the drift length. Same S values of about 10 was obtained over three regions. This increment of S value can be understood from the fact that the uniformity of the average pulse height is better in the narrow region. Slow rise of the plateau as seen

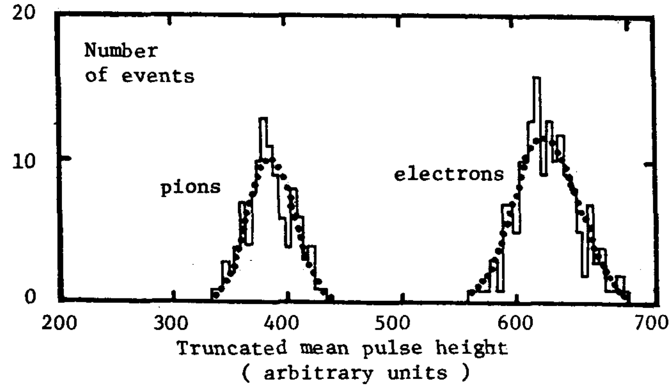

Fig.8. Distributions of truncated mean pulse heights for one-meter-long tracks with retention of 60%, of pions and electrons at 500 MeV/c. Dotted curves are fitted Gaussian distributions.

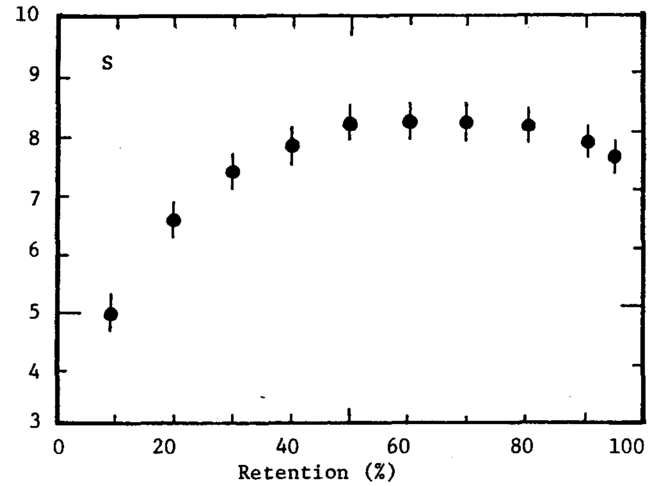

Fig.9. Relation between S and retention rate for one-meter-long tracks, where samples from the whole plateau region were used.

in Fig.3 contributes to make the resolution worse when the data in the wider region are used. The origin of slow rise could be attributed to the superposition of remaining signal tails, because an accumulated signal shape for ^{55}Fe X-rays has shown that the tail of 1-2% of its peak amplitude remains at the time 1 μs after the peak.

No appreciable difference between the cases with and without a semi-Gaussian intergrater was observed on every items described above.

S v.s. sample size

The relation between S and the sample size was studied by assembling wider sample sizes with neighbouring 40 ns samples. Data obtained through a channel with a semi-Gaussian integrater were used, because overflowed event rates from the FADC dynamic range are very samll at this channel whose gain was 1/4 of other's. Fig.10 shows S v.s. sample size for samples in the central plateau region from the bin number 21 to 30 in Fig.3. Result of BNL measurement with different gas mixture are also plotted and good agreement between ours and BNL's can be seen.
With 1.4 mm sampling gas thickness (= 40 ns sampling

time interval), improvement of particle separation by a factor of 1.7 has been achieved compared with 21 mm sampling.

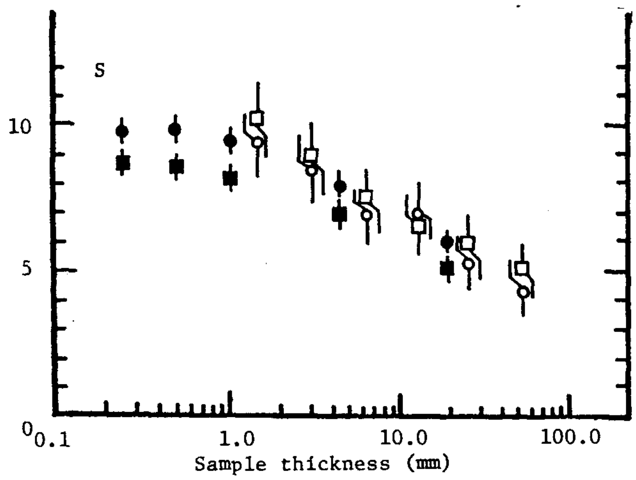

Fig.10. Relation between S and sample size for one-meter-long tracks, where samples from the central plateau region were used.
ϕ and ϕ indicate our measurement with retention rate of 40% and 60%, respectively. ϕ and ϕ indicate BNL measurement with 40% and 60% retention, respectively.

FADC resolution

Effect of FADC resolution on S value was examined by tailering the data with 3, 4 and 5 bit resolutions at the stage of off-line analysis, where the dynamic range of FADC was kept constant (-1.1 V). Almost the same S values were obtained at 4, 5 and 6 bit resolutions, while about 15% deterioration was observed in the case of 3 bit. However, when the dynamic range is reduced to -300 mV, which corresponds to 60% retention for electrons, the S value with 6 bit resolution is reproduced even with 3 bit FADC.

Discussions

Attainable maximum S

We studied attainable maximum S value with 40 ns sampling using samples in the central plateau region. For this purpose, we simulated a one-meter-long track by randomly picking up 40 ns samples from all data, and calculated the truncated means. S value was much improved to about 14.5. Resultant σ/E, R and S are plotted in Fig.11, 12 and 13, respectively. This means that the short range correlation between samples has to be reduced to obtain higher S value. The short range correlation may come from the extended ionizations, diffusion of drifting electrons and the slow responce of electronics circuits. But it is not clear yet at our present understanding.

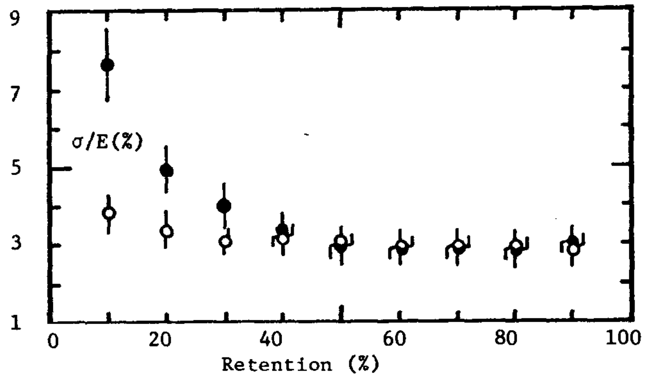

Fig.11. σ/E v.s. retention rate, calculated from randomly picked up samples. ϕ is for pions and ϕ is for electrons.

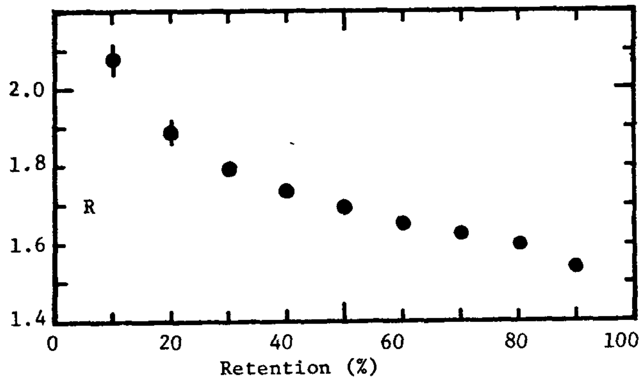

Fig.12. R v.s. retention rate, calculated from randomly picked up samples.

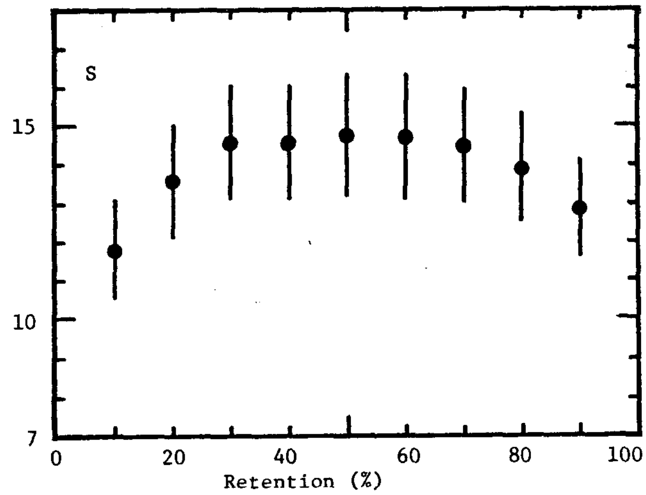

Fig.13. S v.s. retention rate, calculated from randomly picked up samples.

Signal tail suppression

As described above, S value deteriorates about 20%, when samples are taken from the whole plateau region, due to contribution of remaining tails. Then, one more pole-zero filter with time constant of about a few μs might be required for further tail suppression.

δ ray clipping

We examined a δ ray clipping method, reported by Bateman[6], at the stage of off-line analysis. Pulse heights larger than a certain level were replaced by a limited value, and means were calculated including the overflowed samples. Resultant σ/E, R and S for 40 ns samples from the whole plateau region are shown in Fig. 14, 15 and 16, respectively. S value obtained with δ ray clipping is the same with the one with the truncation method. Plateau region of S value appears in the clipping level region between 200 eV and 900 eV of energy losses in gas thickness of 1.4 mm.

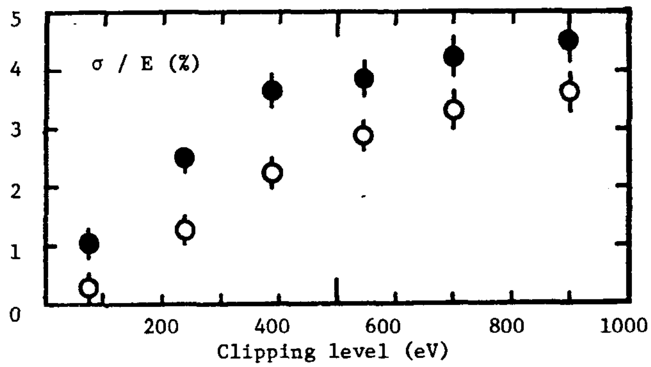

Fig.14. σ/E v.s. clipping level. The latter is presented by the value of energy loss. Retention rate of 50% is corresponding to the clipping levels of about 300 eV for pions and about 400 eV for electrons. ◆ is for pions and ϕ is for electrons.

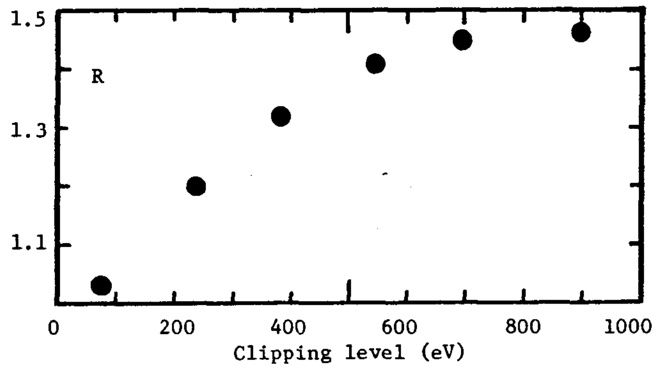

Fig.15. R v.s. clipping level.

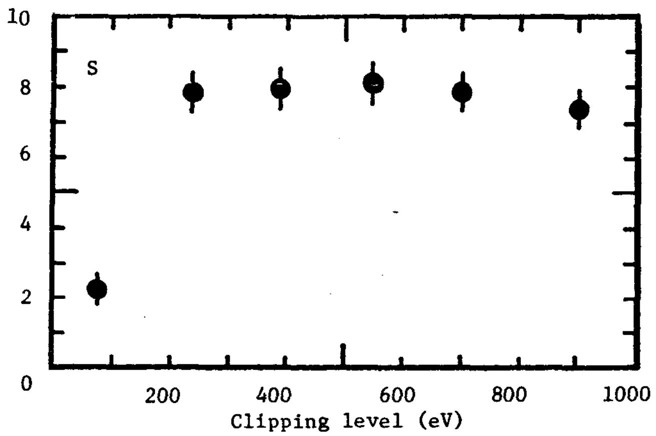

Fig.16. S v.s. clipping level.

Although δ ray clipping technique does not improve S value, it suggests a simpler scheme for readout electronics. Essential points of the electronics for the fine dE/dX sampling are on the fast and low noise amplification, and on the sufficient signal tail suppression both in the truncation and δ ray clipping method. In the latter case, clipping and integration can be done with, for instance, a limiter and an ordinary RC integrator circuits, respectively. Then, FADC and shift resisters which dominate the cost of electronics is not necessarily required.

Summary

With a simpler readout electronics and a longitudinal drift chamber with a longer drift space, improvement of particle separation with the fine dE/dX sampling was obtained. Signal tail suppression is found to be essential to achieve good S values with the longer drift space.

Also it is suggested that the maximum S value of 14.5 would be obtained if the short range correlation between samples are successfully removed.

δ ray clipping technique will make simplification of the readout electronics possible without deteriorating the S value.

Note: A group of KEK[7] also investigated the fine dE/dX sampling with the longitudinal drift chamber similar to ours. They tested the performance with the pion and proton beams of 2 and 3 GeV/c. Their results without the magnetic field are in good agreement with ours and BNL's. In the magnetic field up to 5 KG, no appreciable degradation of the particle separation has been observed, which encourages application of this method to the central tracking detector at the colliding beam experiment.

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