DESIGN AND PERFORMANCE OF THE CLEO dE/dx SYSTEM *

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Summary

The dE/dx particle identifier described herein is a pressurized multi-wire proportional chamber system of modular construction. Residing in the outer detector portion of the CLEO detector at the Cornell Electron Storage Ring (CESR), it can separate pions, kaons and protons in the non-relativistic region, identify electrons with high efficiency, and provide several standard deviation separation of kaons/protons from pions in the region of relativistic rise. We will review the most crucial features of its design and construction, and discuss the methods used to control its electronic and gas-dynamic behavior. Finally, we show examples of its actual performance in the CLEO experiment.

Historical Development The dE/dx Project

The CLEO collaboration comprising physicists from Cornell, Harvard, Rochester, Rutgers, Syracuse, and Vanderbilt Universities, was formed in 1977 to design, construct, and operate a magnetic experiment at the yet-to-be-constructed Cornell Electron Storage Ring (CESR).

The obvious importance of charged particle identification in e^+e^- physics prompted an early decision to reserve ~1 meter of radial space just outside the central detector for either a) a threshold Cherenkov detector or b) a suitable dE/dx system.

The potential of a dE/dx detector incorporated within the CLEO experiment led to a research investigation which began with a basic experimental study of the feasibility of dE/dx measurements, and later concentrated on the actual design, construction, and testing of a practical dE/dx detector. Tests on a small 17-gap chamber were performed in 1977, with a goal of determining optimum pressure, gas fill, wire spacing, etc. In July 1978, a prototype of the final design was tested in a BNL test beam, giving 3 standard deviation separation of pions from kaons at 4 GeV/c. In the spring of 1979, a test of a portion of the actual system was made in a secondary electron beam from the Cornell 12 GeV electron synchrotron. By January, 1980, one quarter of the entire CLEO dE/dx system was installed and operational. Data from actual high energy physics running was taken through July 1981 and physics results obtained. The CLEO data is described later. The entire complement of eight octants has now been installed.

Design Considerations

CLEO

The CLEO detector was designed to function usefully without its final particle identification system. Any design for the dE/dx system must live within the constraints imposed by the global detector.

Figure 1 shows a cross section of the CLEO detector perpendicular to the direction of the beam. Figure 2 shows a cross section of CLEO parallel to the beam direction. While a technical description of the CLEO detector is available elsewhere, we will briefly recapitulate its salient points here.[1]

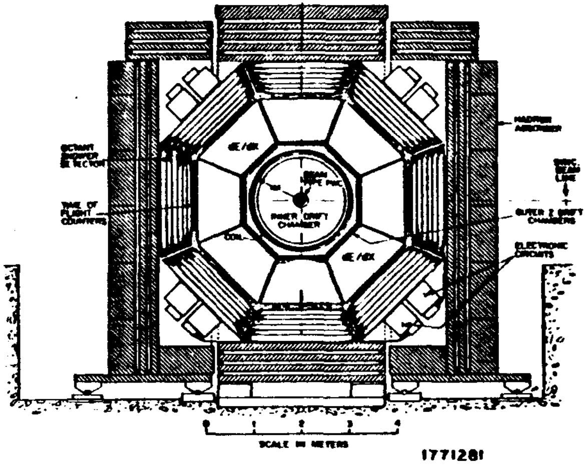

Fig. 1. View of CLEO dectector perpendicular to beams.

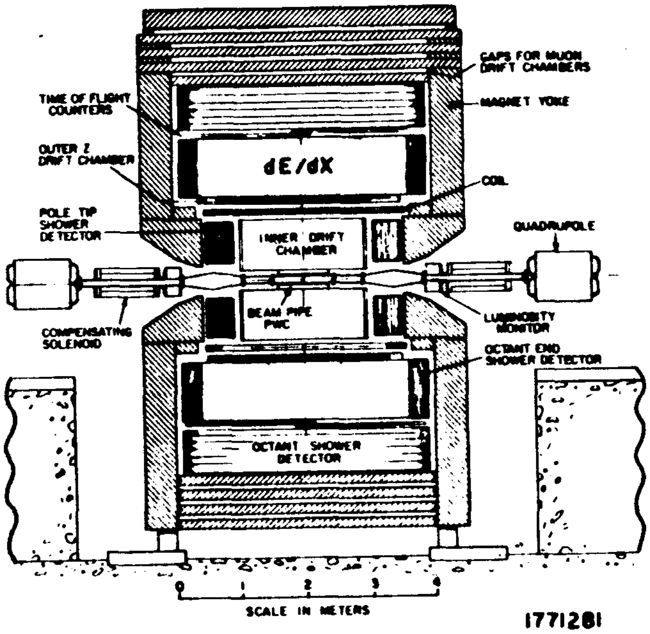

Fig. 2. View of CLEO along beam.

Starting from the beamline and progressing outward the first detector elements are cylindrical multiwire proportional and drift chambers for precision tracking of charged particles. These are embedded in a magnetic field produced by a 3 meter long 2 meter diameter solenoidal magnet coil. At the ends of the solenoid are shower counters to detect and measure photons at small angles to the beam.

Outside the magnet coil, the detector is divided into 8 octants. Each octant is self-contained including its electronics and may be removed and operated independently if need be. Within each octant are a set of three drift chambers for measuring the exit position of particles emerging from the magnet coil, particle identification elements including a time-of-flight system, and photon shower detectors consisting of

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*Work supported by National Science Foundation.

proportional-wire tubes interleaved with lead sheets. Beyond the octants themselves are the rectangular iron muon filters which completely enclose the experiment.

Implications for dE/dx Design

The volume in each octant is ~5 m^3.Our test studies indicated that we required ~100 ionization samples along the particle path as well as pressurized operation to achieve a final resolution of ~5% in our estimation of the "most probable energy loss." We rejected the notion of an ISIS type chamber, with large drift distances, as requiring excessively high voltages and gas purity, both risky, high technology burdens. We were left, then, with the twin problems of very many wires and pressure containment.

When the number of wires in the total system is considered, it turns out to be impractical to construct a monolithic system. In a monolithic design, every wire would have to be precisely located in a large unit frame. The total number of wires in a system with arrays of 100 proportional wires repeated every 2.5 cm for ~3.0 m along the beam line is ~12,000. Thus we find that by itself, the construction effort for one octant's dE/dx system alone would be comparable to that for a large drift chamber. Moreover, there is no point in insisting on a monolithic structure.

We therefore envision a dE/dx module as a single array of proportional wires complete with high voltage foils. The modules may then be stacked as necessary to make the complete system. As a position accuracy is concerned it should suffice to know the position of the track to ~1 cell width in either direction. Thus, the modules do not have to be too carefully located with respect to one another. The only precision wire spacing necessary is that within a module, and small displacements in the radial direction of one module's set of wires with respect to another module's set of wires will not be noticed.

Two additional arguments in favor of a modular design are: 1) in principle the modules are independent and can be isolated, thus avoiding disabling the entire device in the event of a local failure, 2) Obvious mass production techniques may be used to advantage.

Mechanical Design

The basic detecting module is shown in exploded view in Fig. 3. The cross-section of the frames and their method of joining them together is shown in Fig. 4. The trapezoidal frame is formed from 3 mm thick extruded aluminum channel. The cathode planes are 0.4 mm thick copper-clad circuit board material (FR4). The cathode planes are rigidly attached to the frames by means of studs swaged into the aluminum and by epoxy. Their high strength gives the frames resistance against expansion under pressure: they form a series of internal struts. Gas tight seals are formed by a combination neoprene o-rings and a layer of two-component RTV. (General Electric RTV-77, a viscous compound.)

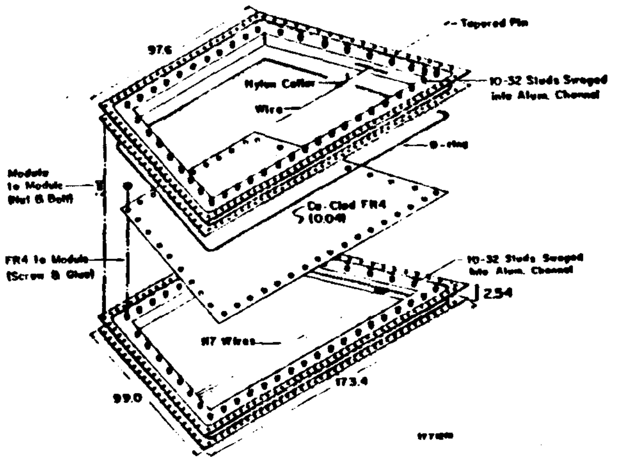

Fig. 3. Exploded view of dE/dx module (units are cm).

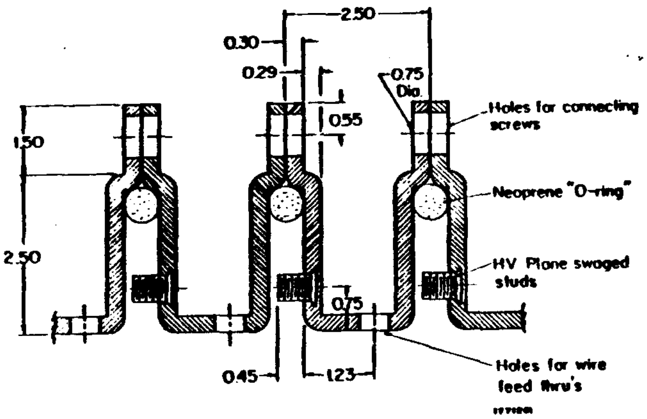

Fig. 4. dE/dx octant: cross section of aluminum U-channel (units are cm).

The 50 μm gold-plated tungsten sense-wires are strung through nylon feed-throughs inserted in precisely placed holes drilled in the web of the u-channels. There are 117 sense wires per module, spaced at ~0.667 cm intervals. The wires are tension to 300 grams, fixed in place by taper pins, line up with a straight edge and glued in place. The taper pins are also used for solder-free connections to the outside world.

The modules are bolted together while the RTV sealant is setting by means of aluminum screws and nuts placed at 5 cm intervals around the periphery of the frames.

An important feature involves gluing small precision-machined lucite blocks between the swaged studs on the parallel sides of the channel. These guarantee an accurate minimum spacing between cathode planes, when the modules are compressed into the full assembly.

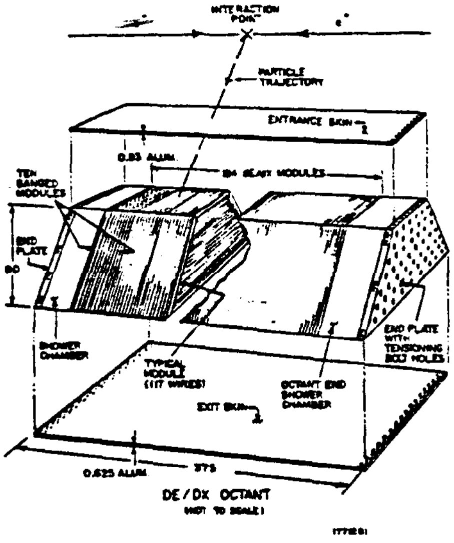

Fig. 5. Exploded view of dE/dx octants (units are cm).

Figure 5 shows the final assembled octant in exploded view. The means of longitudinal pressure containment is clear. (The total force on the ends is

6×10^4 lb.) We can afford to make the end pressure plates very massive because they are located at the edges of the CLEO octants. They are made of 7.5 cm thick trapezoidally shaped steel plates. The two end plates are held together along their parallel sides by two aluminum sheets. The sheet nearest the beam line is .94 cm thick and the other sheet is .63 cm thick. The steel end plates themselves do not come into direct contact with the dE/dx modules. Between the outermost dE/dx module and the pressure plate is inserted a flat aluminum sheet. Contact between the sheet and the end plate is made through a large number of swivel head tensioning bolts. The tensioning bolts are used to squeeze the 124 accordion like modules down to the overall nominal dimension of 3.14 m ±.10cm. Lucite spacer blocks are inserted between the modules; the tensioning bolts are adjusted until the modules are flush against the spacer blocks. On average, the dE/dx system presents only ~.3 radiation lengths of material to a particle coming from the interaction region.

Electrical Considerations

We require that our performance not be compromised by either systematic or unacceptably large statistical variations in the gas-amplification of the wires. Most important has been careful control of wire diameter and maintenance of uniform spacing (wrinkle-free) between cathode planes. We tested several wires in each module to ensure gain uniformity to ±4%. The 60 KeV line from Am^{241} was used to fluoresce the copper clad foils. The primary radiation easily penetrates the aluminum frames. The same technique was used to determine empirically the electrostatic cross-talk between sense wires, by observing the oppositely signed pulses on wires neighboring a struck wire. This cross talk is removed in our hardware by a resistive network which couples the output of all amplifiers in such a way as to cancel the electrostatic chamber effect, as well as circuit board cross talk.

Amplifier Performance

Each of the sense wires is ganged to nine neighbors with a simple single filament daisy-chain. The resultant independent groups total 1400 channels per octant. These are connected by ~20 ft. of coaxial cable to the charge sensitive amplifier inputs; each circuit board handles 60 channels.

The amplifiers have a charge gain of about 5 ADC channgels/fC. Our typical signal at a gas gain of ~5×10^3 is 40 fC. The rms white noise is about 1 fC, a negligible amount. With careful shielding and filtering, incidental sources of coherent noise give less than 1 channel, or less than 1% of a single minimum ionizing signal. Gains are calibrated by impressing a small voltage pulse on the cathode planes.

Gas Mixture

The gas used is a 9% CH_4, 91% Argon mixture. Its composition is carefully controlled to $\leq$0.5% in the relative CH_4 concentration. This keeps gain shifts down below 1 percent. We also control the density of the gas mixture by requiring the octant absolute pressure to be strictly proportional to the measured absolute temperature.

Fe^{55} Monitoring

Finally, within each octant we have placed four small Fe^{55} sources, whose spectrum as seem by representative wires is continuously monitored.

CLEO Performance

Fig. 6 shows the appearance of events in a dE/dx octant. The "clean" hit patterns are typical of non-interactive hadrons and muons. The "overlapping" patterns are indicative of interactions, overlapping tracks, or showering electrons.

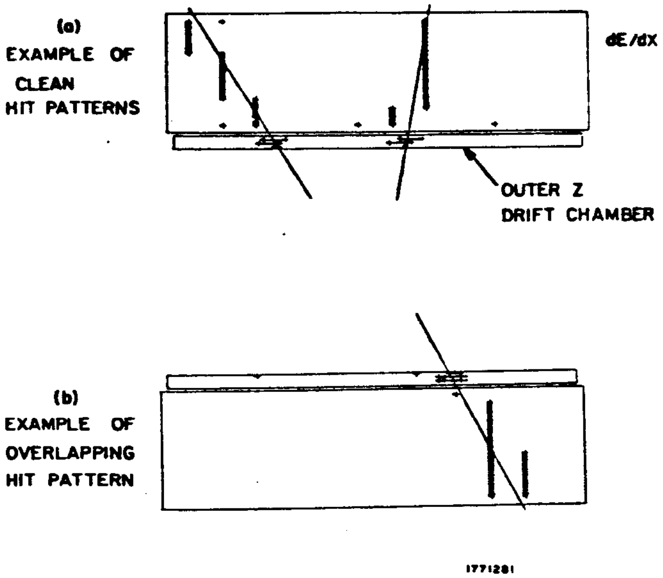

Fig. 6. Examples of (a) clean hit patterns and (b) overlapping hit patterns.

Clean tracks are internally divided into 3 segments. They are retained for hadron identification only if the pulse height distributions of the segments are consistent. The estimate of dE/dx used is the mean of the smallest 50% of the pulse heights (TM50). In Fig. 7, we show the TM50 vs. raw drift chamber momentum for ~9000 clean tracks collected in the summer of 1981. These events, collected during the $\Upsilon(3S)$ running are required to

1) have more than 90 hits
2) to be in the fiducial volume for uniform gain
3) to scatter by no more than 5° from the projected drift-chamber extrapolation.

They are corrected for path length in a trivial way. Clean pion, kaon, and proton bands are evident. We stress that no hypothesis dependent manipulation has been performed, even though the particles pass through the solenoid coil (~30 g/cm^2) at a variety of angles. Figure 8 shows the TM$_{50}$ plots for particles identified by the CLEO time-of-flight system (TOF). The (imperfect) agreement between the devices is quite good, though it is apparent that perhaps 20% of the TOF kaons are in fact dE/dx pions. Such contrasts between redundant detectors are invaluable for understanding true rejection ratios.

Resolution in Practice

Perhaps, the cleanest test of the in site capability of the dE/dx system is provided by QED muons. Except for occasional final state radiation, these low multiplicity non-interacting particles outght to give optimum resolution.

Figure 9 shows the histogram of the muon tracks plotted versus the measured TM$_{50}$ pulse height. In fact, the peak is located within 1% of the expected position, but the width is broader than expected from test beam performance. Both for this sample, and for pions in the neighborhood on minimum ionization, it appears that some systematic broadening of about 3% (in quadrature) is

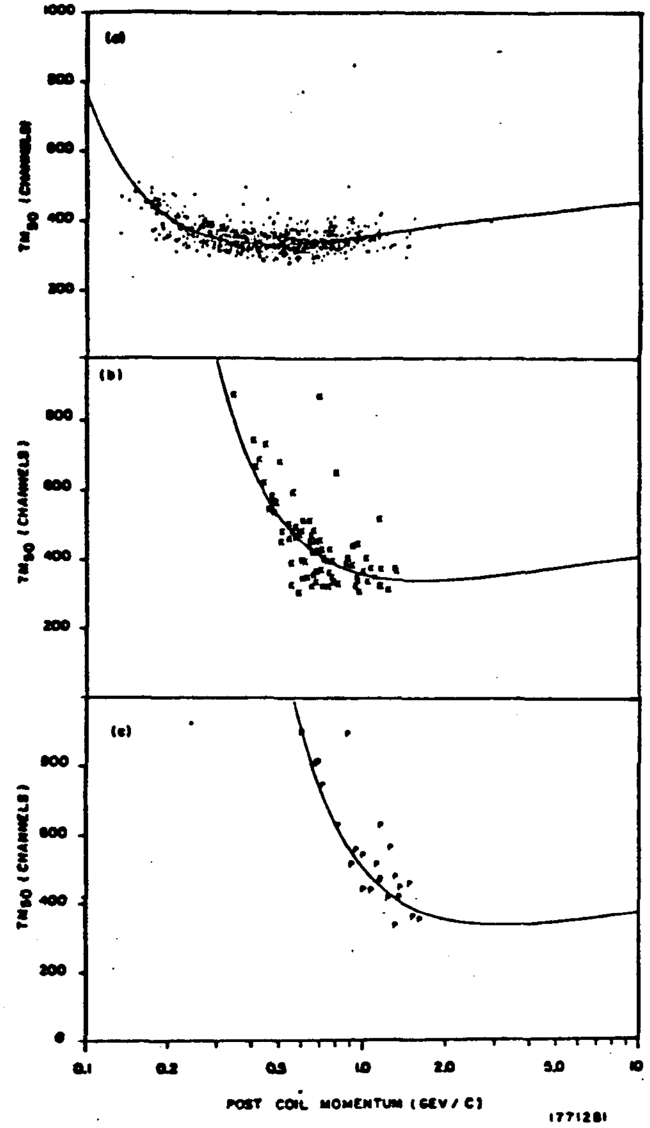

Fig. 8. "Most probable" energy loss (TM_{50}) versus momentum of tracks as measured in the CLEO drift chamber.

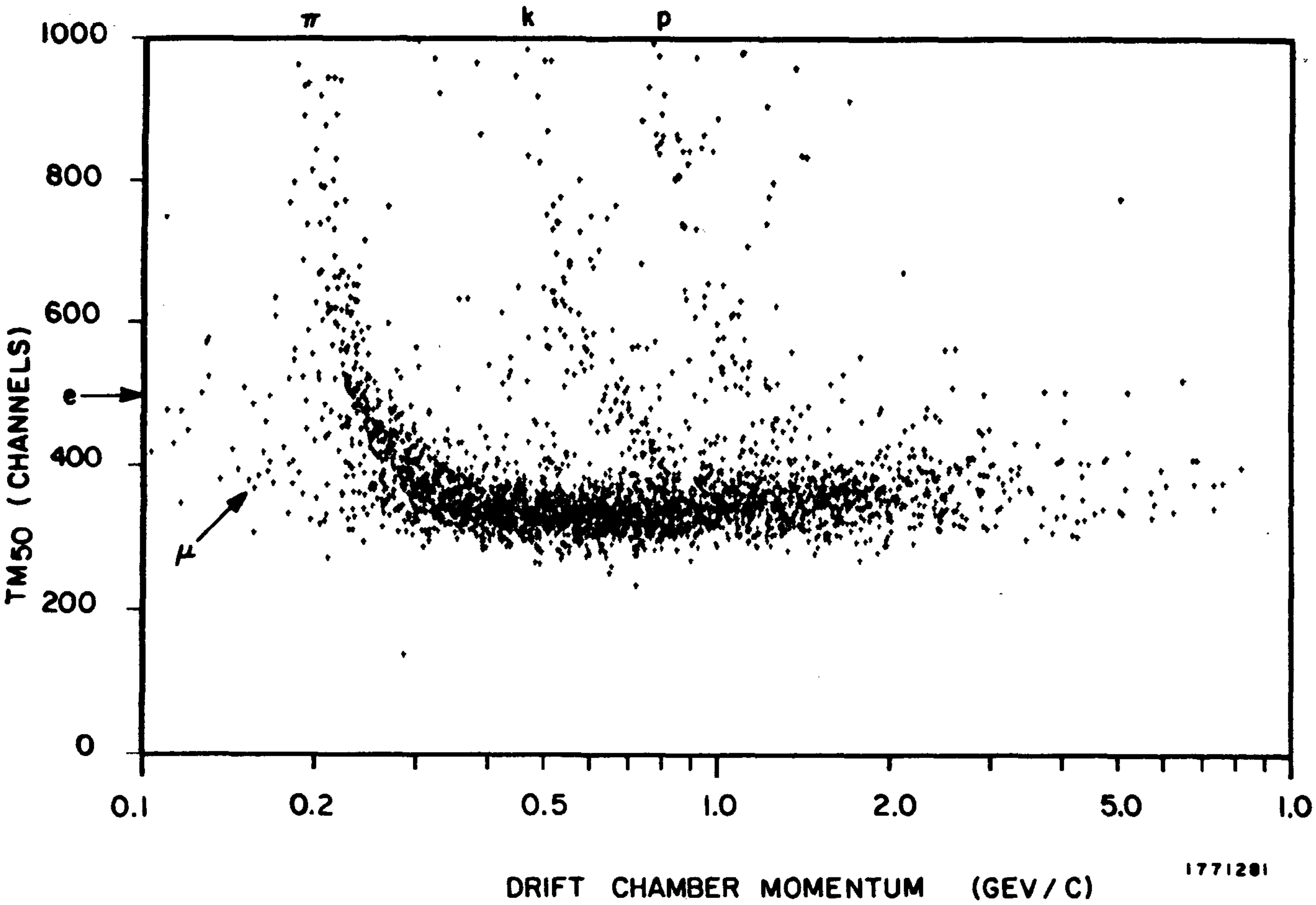

Fig. 7. TM_{50} versus momentum in the dE/dx device for particles identified by the CLEO time-of-flight system as (a) pions, (b) kaons, (c) protons. The curves are the theoretical energy losses expected.

operative. Currently we favor uncompensated variations in gas density as an explanation, but no certain cause has been identified. The resolution is nevertheless adequate to do useful high momentum π/K separation. Heretofore, running at a field of 0.4 Tesla we have been reluctant to trust momentum measurements; with our current 1 Tesla field, and improved tracking and luminosity, we expect to study the relativistic rise region.

Acknowledgements

I would like to give credit to my colleagues in the dE/dx effort at CLEO; particularly to Saj Alam, Sheldon Stone, Dick Talman, Rainer Wilcke, and Tom Gentile. Thanks for support and encouragement are due to Al Silverman and B. D. McDaniel.

Reference

1. See E. Nordberg and A. Silverman, "The CLEO Detector" CBX 79-6, Cornell Laboratory of Nuclear Studies, Cornell University, Ithaca, NY 14853, and S. Stone, Physica Scripta 23, 4:2 (1980) 605.

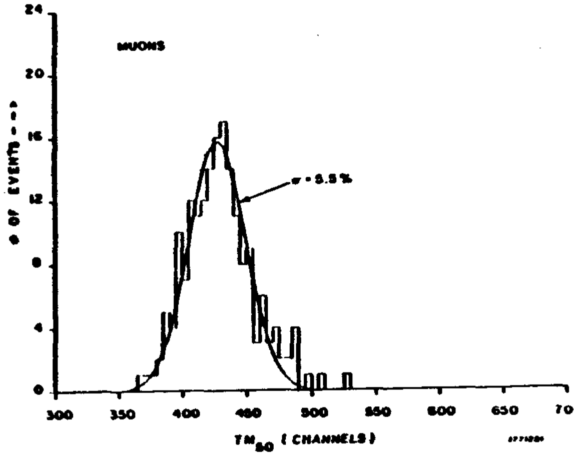

Fig. 9. "Most probable" energy loss for 5.15 GeV/c muons. The curve is a Gaussian of 5.5% r.m.s. fit to the data.