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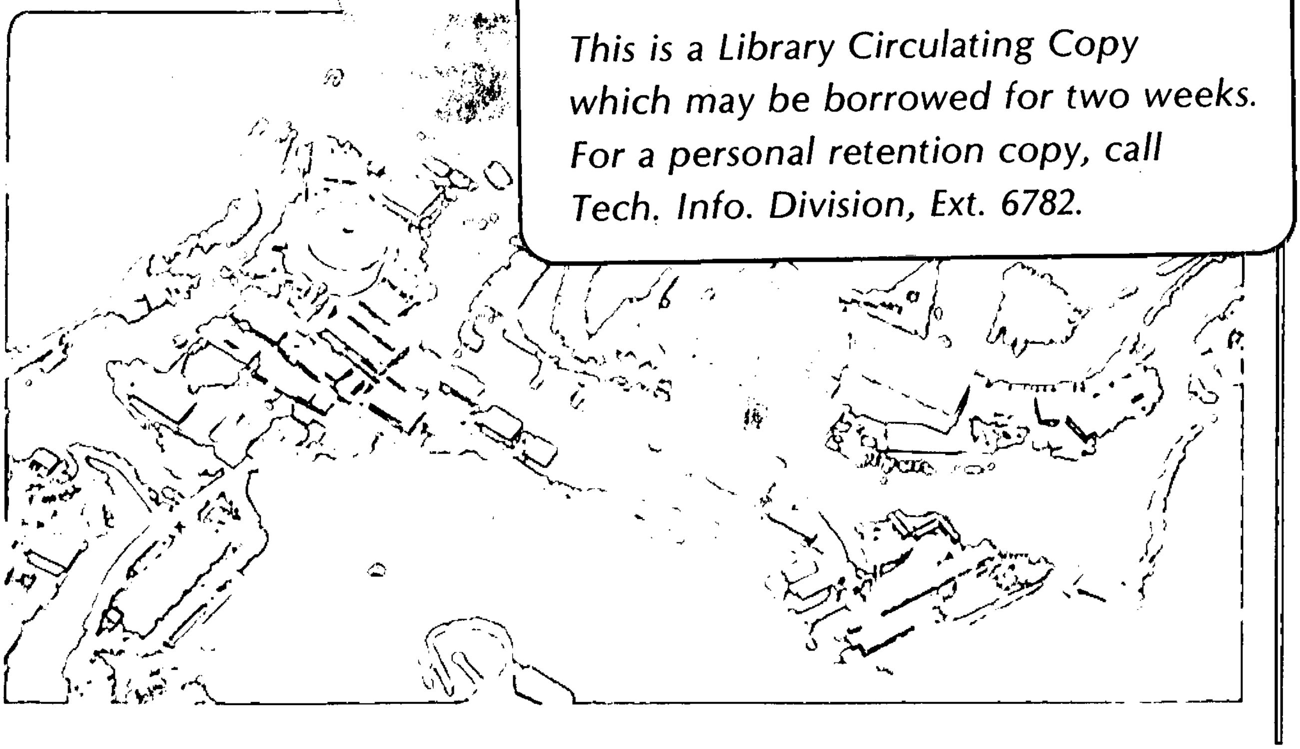

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Design of a Lead Glass Drift Calorimeter with MWPC Detection*

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A drift collection calorimeter having a combined radiator and field shaping structure made of lead glass tubing is described. A high resistance metallic layer is formed by reduction of the lead oxide at the surface of the glass and forms a continuous voltage divider for drift field shaping. The energy resolution of such a calorimeter is modeled, for several configurations, by the Monte Carlo technique.

1. Introduction

Calorimeters offer many attractive features as particle detectors. They are sensitive to neutral particles as well as to those carrying a charge. The size of the detector needed to achieve a given fractional energy resolution scales as log E while the size of the equivalent magnetic spectrometer scales as $\sqrt{E}$. Transverse segmentation of the device allows good position and angular resolution, and longitudinal segmentation allows the differences in shower development to be exploited for particle identification.

Sampling in gaseous media has advantages over sampling with scintillators or Cherenkov radiators. The low cost per sampling channel and the geometrical simplicity of a gas detector (wire chamber) as compared to photo multiplier tubes allows a high degree of segmentation. It is also much easier to instrument regions where high magnetic fields exist. The major disadvantage of gas sampling calorimeters is their inherently poorer energy resolution which requires a longitudinal sampling density three times greater than an optical device of comparable resolution. This results in the need for large amounts of readout electronics, albeit at a low cost per channel, and a large number of fragile, easily broken, difficult to repair wires.

The required number of wires can be reduced to a very modest number in designs known as "drift collection calorimeters"(1) or "high density projection chambers."(2) In these schemes ionization produced in a gas sampled radiator is drifted over a fairly long distance to a separate wire plane a la ISIS(3) or TPC.(4) Digitization of the drift times allows the reading out of a complete "image" of the shower with a high degree of segmentation via a modest number of wires. We report here on the design of a drift calorimeter in which the radiator and drift field structure are combined in the form of lead glass tubes coated with a highly resistive layer. The predicted performance of such structures is studied by Monte Carlo simulation.

2. The proposed lead glass drift calorimeter

The combined radiator/drift field shaping structure proposed here is an adaptation of converters used in our group's past efforts in instrumentation for positron emission tomography.(5) Tubes of high density (80% PbO) lead glass are fused together with their axes perpendicular to the direction of incident radiation as shown in Figure 1. The glass has a density of 6.3 g/cc and a radiation length of 1.3 cm. The tubes we considered had inner diameters which varied from 3 to 10 mm and wall thicknesses of 1 or 2 mm. The resistive metallic layer which acts as a continuous voltage divider for drift field shaping is made by reducing a surface layer of the PbO to metallic lead by heating in a hydrogen atmosphere. This procedure is described in detail in reference (5) and in other references contained therein. Typical layers had resistances of 50-200 MΩ/sq and were uniform among the tubes to within ±10%. Scaling up the dimensions of these converters(5,6) and drawing on other authors' studies of drifting in extreme aspect ratio geometries(1,7,8) we believe that, with the proper choice of gas mixture, pressure, and inside tube diameter, one should be able to employ the proposed structure with drift path lengths of up to 50 cm without degradation of calorimeter performance due to electron loss.

The chemical reduction of PbO on the glass surface is a convenient method of providing a uniform resistive layer to define the potential everywhere on the surface of the drift structure. It is particularly convenient for small diameter tubes where such methods as coating uniformly with resistive inks would prove difficult. The use of such continuous electrodes to avoid field distortions due to the edges of discrete electrodes and the presence of nearby conductors is of great importance in avoiding loss of electrons while drifting in long, narrow spaces.(9)

The use of tubes rather than planar drift spaces has some advantages in itself. The fused mass of tubes provides a rigid self-supporting structure and makes a more compact calorimeter. The tubular configuration gives a large surface-to-volume ratio which reduces the loss of energy trapped unseen in the radiator and the consequent degradation of resolution. Further improvement in the energy resolution is obtained from the tubes' limiting of track length variations in the direction transverse to the tube axes. This reduces the fluctuation due to the wide angular distribution of the very soft shower electrons in the sampling gap. These fluctuations have been shown to be a major contribution to the loss of resolution in gas sampling devices.(10)

The wire chamber used to read out the calorimeter may be oriented with the anode wires either parallel or perpendicular to (as shown in Fig. 1) the direction of development of the shower. In the orientation shown, longitudinal segmentation is obtained by reading out individual wires, and transverse segmentation (in the vertical direction) is obtained by digitizing the drift time using some externally supplied START signal. Segmentation in the remaining transverse direction, along the wires, can be accomplished either by charge division along the wire or delay line readout of a cathode segmented in that direction. Our thinking favors the latter method because of the delay line's superior spatial resolution and superior capability of resolving closely spaced tracks.

The wire chamber may be operated either in the standard proportional mode or in one of the modes in which the pulse height is saturated, e.g. the "self-quenched streamer" mode(11). In the former the signal collected from each wire is proportional to the amount of energy deposited in the tubes sampled by that wire. Thus for energy measurement, the calorimeter is not troubled by many overlapping tracks in a very high energy shower, but the resolution is degraded by the Landau fluctuations in the energy deposited by each track. In the saturated modes, one uses "digital samplng"(12) in which the measured signal is proportional to the number of tracks. This eliminates the deleterious effect of Landau fluctuations but may cause the energy response of the calorimeter to saturate at high energies due to overlapping tracks' being registered as single particles traversing the tubes.

3. The shower Monte Carlo

The Monte Carlo program used to simulate the performance of our proposed calorimeter was the Electron Gamma Shower (EGS) code of Ford and Nelson.(13) EGS is currently being used to study a variety of problems in accelerator, high energy and medical physics. Details concerning the code and its application are described elsewhere.(14)

For the problem at hand, the tube geometry was approximated by alternating slabs of lead glass and gas regions, with the effective dimensions chosen to give the same average cross sectional area of gas and solid material when viewed from the edge of the slabs (or tubes). The track length restriction that would be imposed by the tubes in the direction transverse to the tube axes was retained by appropriately limiting the energy deposition along the track. The effect of Landau fluctuations was also included. Details of these procedures are given elsewhere.(15)

The simulated calorimeter was taken to have transverse dimensions of 50×50 cm^2 and to be 15 radiation lengths in average longitudinal depth. The gas filling was taken to be P-30 (70% Ar - 30% CH_4).

4. Monte Carlo results

The EGS program was run for various tube diameters, wall thicknesses, and gas pressures with incident electron energies of 1, 2, 4 and 10 GeV. Figure 2 shows a typical EGS prediction for the energy deposited in the gas by 4 GeV electrons incident on 15 radiation lengths of 10 mm inner diameter tubes having 1 mm thick walls and filled with P-30 gas at atmospheric pressure. The longitudinal development of the 4 GeV electron shower is shown in Figure 3. Also shown in this figure are experimental results reported by Anderson et al.(16) Their test calorimeter had a similar arrangement of radiator and gas sampling regions to that of the proposed lead glass device. Their sampling was however carried out by wires inside each tube rather than by the drift collection techinique. The similarity of the EGS results to the experimental measurement provides support that the Monte Carlo technique is successfully modeling the calorimeter response.

The fractional energy resolution (σ/E) is plotted in Figure 4 in terms of the incident electron energy for the tube geometry described above (10mm/1mm/1atm.). The resolution is plotted as a function of $\frac{1}{\sqrt{E}}$ in order to observe any deviation from the expected straight line through the origin. The errors on these points were obtained by dividing the EGS runs, for each energy, into six runs of 150 to 700 incident showers each. Each data point and error bar corresponds to the mean and standard deviation of the mean for the six runs at that energy. The curves shown are one and two parameter fits of the form $\frac{\sigma}{E} = \frac{\alpha_1}{\sqrt{E}}$ and $\frac{\sigma}{E} = \frac{\alpha_1}{\sqrt{E}} + \alpha_2$. In this case, and in all the other geometries studied, the two-parameter prescription provides a better fit to the data and is therefore the most appropriate form to use with a counter having these dimensions. The deviation of the high energy points from a straight line through the origin, as expected from the usual model, may be attributed to fluctuations caused by leakage out the back of the device.

Table 1 provides a summary of the results of running EGS for several geometries and gas pressures. The energy resolution as a function of incident energy is presented in terms of both one and two parameter fits. The energy resolutions obtained for gas fillings at atmospheric pressure are comparable to those claimed for existing gas sampling devices.(17) As would be expected, the resolution shows a trend towards improvement as the fraction of sampling gas to radiator is increased. This improvement must be balanced against the necessary increase in longitudinal size of the device in order to provide sufficient radiator to contain the showers. The results at higher than atmospheric pressure suggest a method of achieving very good resolution with reasonably compact structures.

5. Conclusion

Lead glass tubes with a resistive metallic surface layer provide an elegant method of constructing combined radiator and field shaping structures for drift collection calorimeters. Such structures have some advantages over conventional designs. Monte Carlo studies indicate that energy resolutions that are comparable to other gas sampling calorimeters may be achieved, with the promise of considerable improvement when the device is pressurized.

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Table 1

Gas Pressure	Tube Geometry	Energy Resolution (%) 1 parameter	Energy Resolution (%) 2 Parameter
1 atm.	10 mm i.d. 1 mm wall	$(16.34\pm0.45)/\sqrt{E}$	$(14.59\pm0.74)/\sqrt{E}$ $+ (1.47\pm0.58)$
	4 mm i.d. 1 mm wall	$(19.00\pm0.26)/\sqrt{E}$	$(18.21\pm0.89)/\sqrt{E}$ $+ (0.68\pm0.73)$
	3 mm i.d. 2 mm wall	$(28.16\pm0.35)/\sqrt{E}$	$(27.01\pm0.93)/\sqrt{E}$ $+ (0.82\pm0.63)$
2 atm.	10 mm i.d. 1 mm wall	$(12.90\pm0.94)/\sqrt{E}$	$(9.14\pm0.48)/\sqrt{E}$ $+ (2.90\pm1.19)$
	4 mm i.d. 1 mm wall	$(14.69\pm0.40)/\sqrt{E}$	$(12.9\pm0.15)/\sqrt{E}$ $+ (1.37\pm0.11)$
10 atm.	10 mm i.d. 1 mm wall	$(9.86\pm0.32)/\sqrt{E}$	$(8.80\pm0.73)/\sqrt{E}$ $+ (0.82\pm0.53)$
	4 mm i.d. 1 mm wall	$(10.64\pm0.45)/\sqrt{E}$	$(8.55\pm0.43)/\sqrt{E}$ $+(1.37\pm0.26)$

Figure Captions

Fig. 1	Drift calorimeter with lead glass radiator/drift tube structure and wire chamber readout.
Fig. 2	Typical EGS prediction for 4 GeV electrons incident on 15 radiation lengths of 10 mm i.d. 1 mm wall thickness tubes filled with P-30 gas at 1 atmosphere.
Fig. 3	Predicted longitudinal development of a 4 GeV electron shower as compared with experimental results from a similar geometry.
Fig. 4	Fractional energy resolution as a function of $\frac{1}{\sqrt{E}}$ for 10 mm i.d., 1 mm wall thickness tubes filled with P-30 gas at 1 atmosphere..

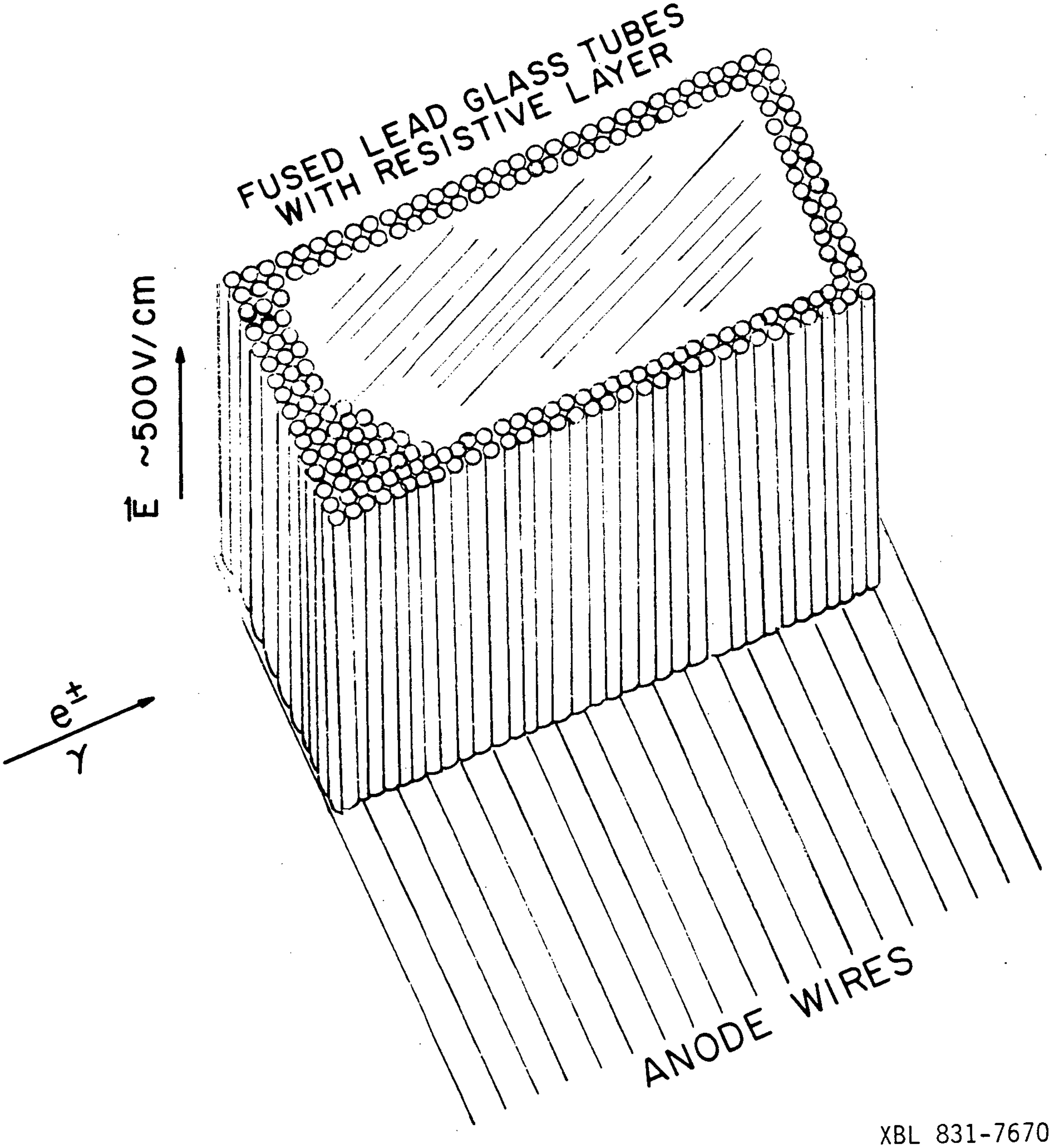

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Fig. 1

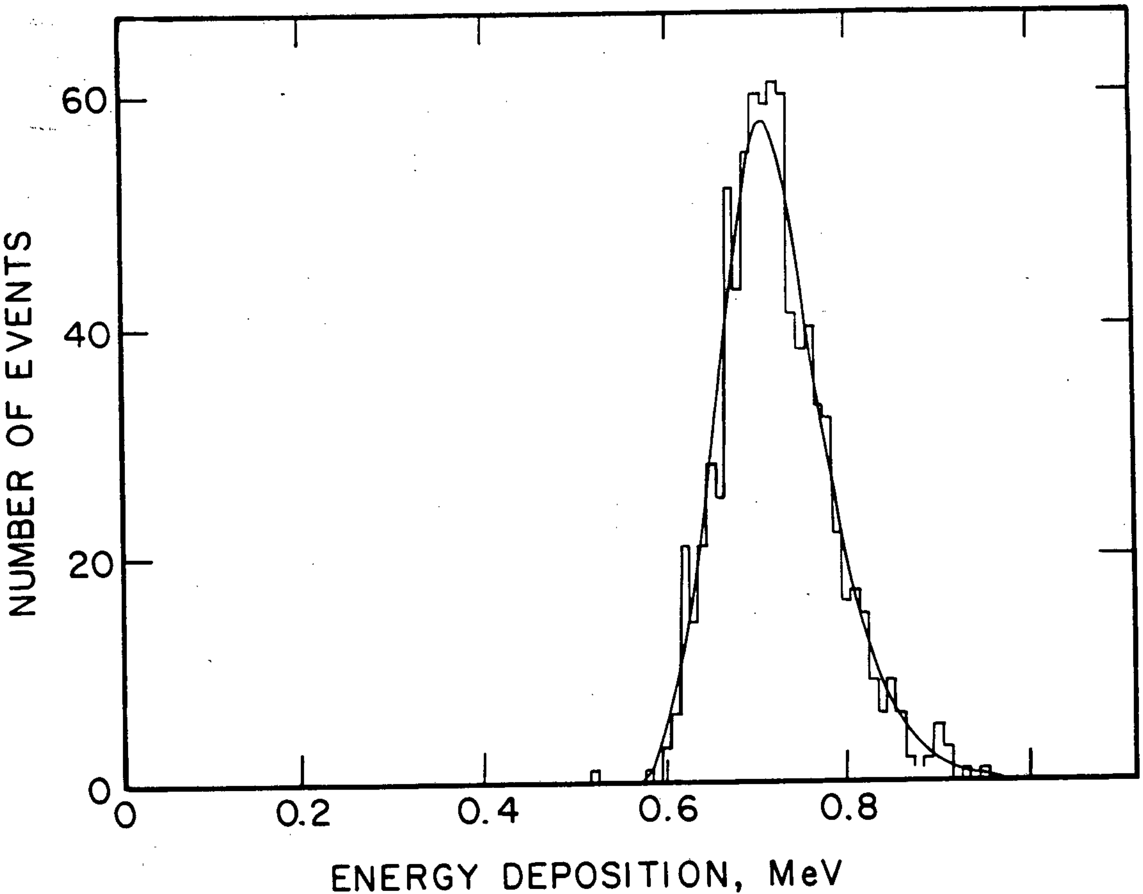

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Fig. 2

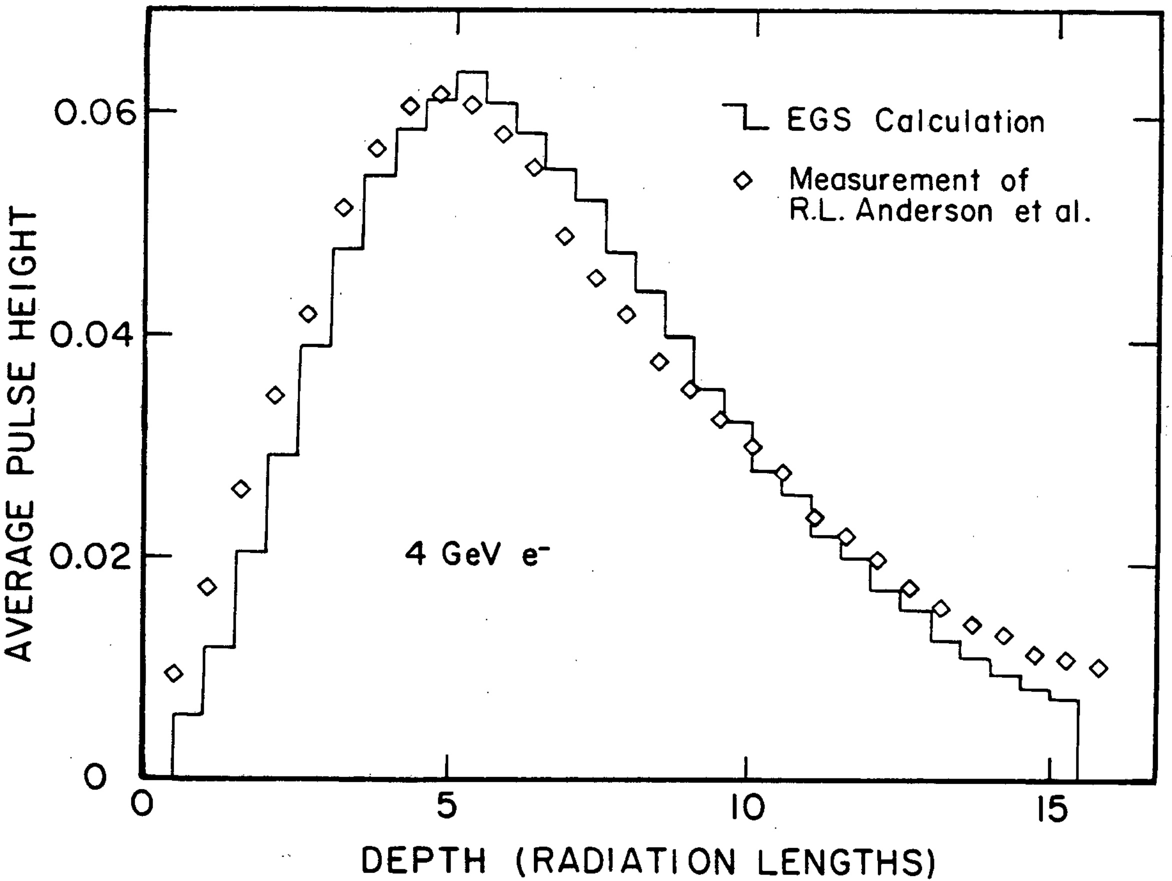

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Fig. 3

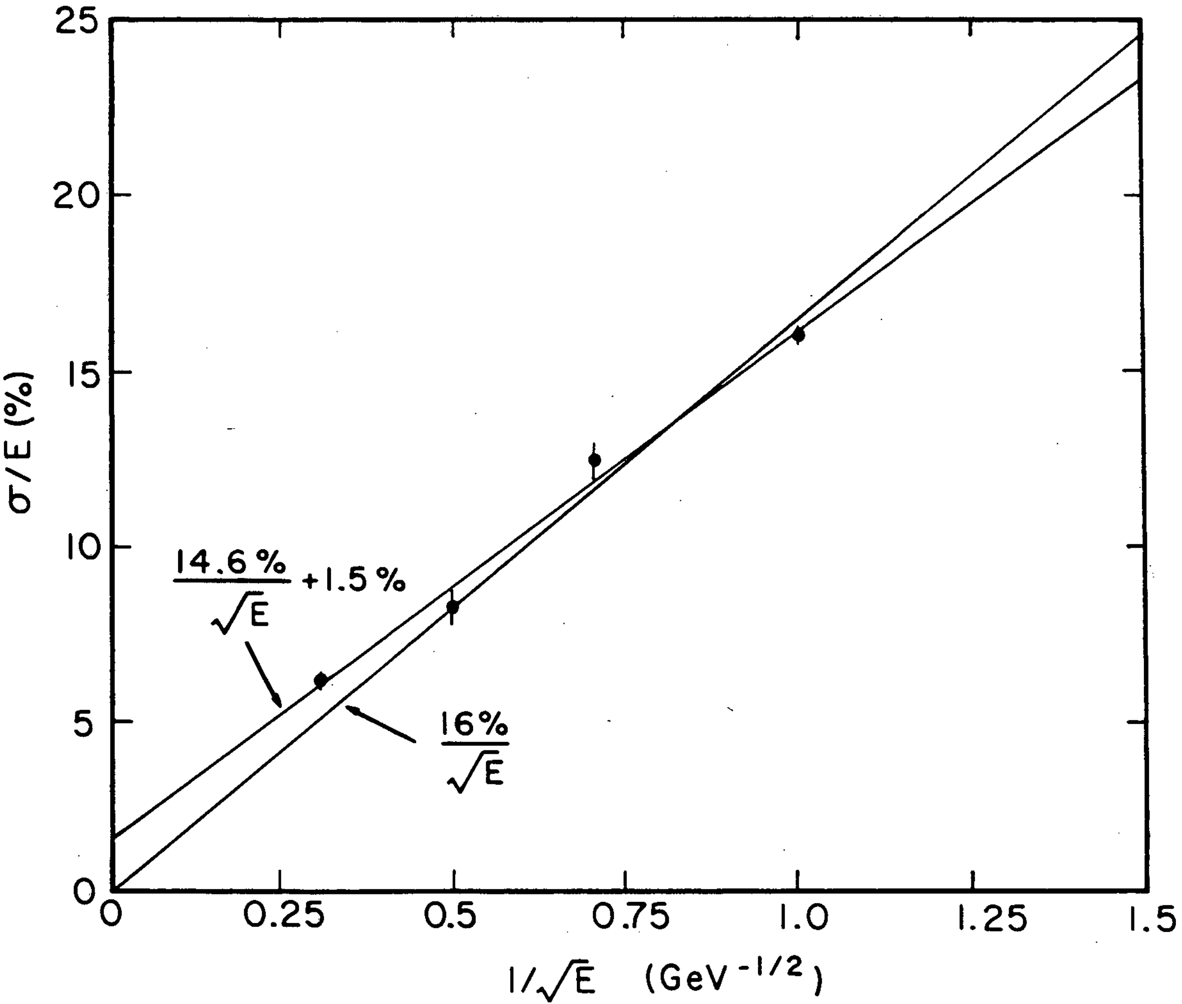

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Fig. 4

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