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1. INTRODUCTION

The necessary existence of material in front of the first active element in a calorimeter will degrade the performance of that device. The question is by what factor. The follow up question is what can be done to minimize the damage. These questions are usually of primary importance for liquid argon calorimetry because of the necessity of containment dewars [1]. However, the problem is universal. For example, the Solenoid Detector Collaboration, SDC, has proposed a superconducting coil which would be placed in front of the EM calorimeter. Although much effort has been made to minimize the depth of material in the coil, still the resolution and linearity must be optimized if the SDC goal of precision electromagnetic (EM) calorimetry is to be realized.

2. THE SCALE FOR EM RESOLUTION OF THE CALORIMETER

The calorimeter simulation studied here is a schematic realization of the SDC EM calorimeter. The array which was put into EGS4 was a stack consisting of Al, 10.68 cm thick, followed by scintillator, 2.5 mm thick and Pb 3.175 mm (1/8") thick repeated 50 times. This stack is ~ 25 Xo thick which will allow a study of the exit leakage fluctuations. The Al is a reasonable representation of the current design of the SDC coil [2]. The stack is very similar to those given in the Conceptual Design Reports, CDR, recently completed for both SDC liquid argon and SDC tile/fiber scintillator options [3]. The appropriate vacuum space between the solenoid coil and the first active element of the EM stack has been defined.

The scale for resolution is set by the Physics of interest. A typical mass scale is set by $E_t \sim M_Z/2 \sim 50$ GeV with a resolution goal of $dE/E < \Gamma_Z/(2.4*M_Z) \sim \alpha_W/2.4 \sim 1\%$. The basic EGS4 resolution for this EM stack is $dE/E \sim 0.12/\sqrt{E_t}$. It is expected that with this good intrinsic resolution, the thickness of scintillator needs to be increased to 4 mm. That increase will lead to a light yield of ~ 4 p.e./mip/tile or ~ 400 p.e./GeV [4]. A 4.0 mm thick SCSN-81 "sigma" tile coupled to a XP2081 photomultiplier tube after 4 m of clear fiber yields ~ 4 p.e./mip/tile [3] for example. Note that a 1 GeV electron produces 400 p.e. which has a statistical accuracy of 5%. Therefore, photostatistics will contribute a stochastic term coefficient of 5%. Folding in quadrature with the 12% term due to sampling fluctuations, we expect a net 13% stochastic term coefficient.

The constant term has a magnitude set by the nonuniformity of the medium. The SDC goal is to control transverse nonuniformities to < 2% using an optimized optics scheme [5]. Longitudinal nonuniformities come from absorber thickness variations and variations in tile/fiber light output. The goal is to control both these effects to < 2% which leads to 2 contributions to the constant term each of size < 0.5%. The combined constant term, folding all nonuniformities, including relative calibration, in quadrature is designed to be less than or = 1%.

Therefore, the relative contribution of the stochastic and constant terms becomes equal at 169 GeV. Note that, with the axial barrel plates, the resolution is roughly, $dE/E = 0.13/\sqrt{E_t} \oplus .01$. The stochastic term is a function of E_t and not E with this absorber geometry. Since one of the Physics scales for E_t is $M_Z/2$, it is very valuable to minimize the stochastic term because it dominates the resolution at the Z mass scale. At that scale, the stochastic term alone causes a resolution, $dE/E \sim 1.8\%$ which exceeds the natural width of the Z. Therefore, reducing the effect of the solenoid coil to the absolute minimum is called for, since the resolution already exceeds the Z natural width. Similar considerations apply in the case of a search for a light Higgs boson decaying to 2 photons. The Higgs width is small with respect to resolutions, so that signal/noise is defined by the resolution of the calorimeter.

In a previous study, it was concluded that the solenoid coil, without massless gap corrections, did not begin to degrade the resolution unless the solenoid thickness exceeded ~ 2 Xo [6]. Since the design is ~ 1 Xo, the effects are expected to be small for the massless gap corrections. For the case of 2 photon decays of a light Higgs boson, the resolution is directly proportional to the signal/noise for the search [7]. Therefore, there is a premium on EM resolution in addressing this Physics topic.

3. THE EM RESOLUTION WITH MASSLESS GAPS

The material stack was studied by using the EGS4 program, with electrons of 12.5, 25, 50 and 100 GeV incident at 90 degrees (normal incidence) and 30 degrees (60 degree angle of incidence). For each energy and angle the profile of energy in each layer for each event was stored on tape/disk. This scheme allowed us to generate only once; subsequent studies of weighting of the "massless gap", exit weighting, transverse nonuniformity, or longitudinal nonuniformity can all be made by manipulating the stored EGS4 output.

An example of the output is shown in Fig. 1. The profile is for 12.5 GeV incident electrons, e, at 30 degrees, which means photons at an angle of 30 degrees to the beam axis or 60 degrees to the angle of normal incidence to the stack. Note the "blip" due to the solenoid, at the first active layer. The Al sampling fraction is different from the 1/8" Pb of the rest of the EM stack. Obviously, the first layer of scintillator should be weighted correspondingly. The fractional resolution, dE/E, as a function of that weight, WT, is shown in Fig. 2 for 12.5 GeV e incident at 30 degrees. There is a clear minimum at WT ~ 3. Note that 12.5 GeV is expected to be the lowest e energy which SDC will trigger on. It is expected that the effect of the coil will be most pronounced at low energies. At high energies, the EM shower penetrates much deeper into the EM stack. The resolution at optimal weight is not noticeably degraded from the expected value of $\sim 12\%/\sqrt{E_t}$.

The question of possible nonlinearities induced by the nonuniform medium was also studied. In Fig. 3 is shown the fractional mean nonlinearity as a function of weight for 12.5 GeV e incident at 90 degrees. The relevant scale is the maximum allowable constant term for SDC which is 1%. Clearly, at the WT which minimizes the resolution, the nonlinearity does not exceed this value.

For liquid argon one can contemplate a separate readout for the massless gap with an adjustable gain. For the tile/fiber scintillator option, fiscal constraints impell one toward attempting to pick an energy independent weight, and merely optically "oring" the light output into the EM phototube input. In the simplest case, the weighting would also be independent of angle. For this reason angles of incidence of 60 degrees (30 degrees wrt the beam axis) were studied as that is the extreme angle of incidence of particles which strike the SDC solenoid as presently designed.

The composite set of results for all angles and energies is shown in Fig. 4. The plot is the scaled energy resolution $dE/E \sqrt{E_t}$ as a function of weight, WT, for all energies and angles of incidence. Clearly, an energy independent weight of ~ 1.75 can be chosen which does not degrade the EGS4 expectation of 12% in any significant way. Since the thickness of Al (coil) and scintillator both scale with incident angle, one might expect that the optimal massless gap weight would be independent of angle. Indeed, a glance at Fig. 4 shows that this is the case.

An optimal weight of WT = 1.75 may then be chosen independent of energy and angle. This choice can be realized simply by making the first tile/fiber assembly a factor = WT thicker. As seen in Fig. 4, the "massless tile" yields an EM resolution which is not compromised with respect to the ideal EGS4 stack result. For the choice of weight, $\langle WT \rangle = 2$, the fractional mean nonlinearity, $[\langle E \rangle - E_o]/E_o$ is plotted as a function of energy for angles of 90 and 30 degrees in Fig. 5. The scale for this nonlinearity as a function of angle is the resolution itself, $dE/E = 0.12/\sqrt{E_t} \oplus .01$. Clearly, the differential nonlinearity induced by the weighting procedure is acceptable; it nowhere exceeds the resolution.

4. SUMMARY AND CONCLUSIONS

The question of massless gaps has been studied for the SDC tile/fiber scintillator calorimeter option. It is found that a first active element weight of 1.75 can be chosen independent of angle and energy. That choice leads to a resolution which does not degrade the resolution expected for SDC EM calorimetry, $dE/E = 0.12/\sqrt{E_t} \oplus .01$. The induced nonlinearity due to this weighting procedure is not comparable to the intrinsic energy resolution of the SDC EM calorimetry. Therefore, the adoption of the simplest possible massless gap scheme is sufficient for the purposes of maintaining the resolution made available by fine grained (~ 1/2 X_o) sampling.

References

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1b. J. Proudfoot et al., Symposium on Detector Research and Development for the Superconducting Supercollider, Ed. Bombeck, Kelly and Yost, October 15-18, 1990, Ft. Worth, Texas.

2. Letter of Intent by the Solenoidal Detector Collaboration, Nov. 30, 1990, SDC-90-00151.

3a. Calorimeter Conceptual Design, Tile/Fiber Scintillator Option, Sept. 3, 1991.

3b. Calorimeter Conceptual Design, Liquid Argon Option, August 5, 1991.

4. CDF Endplug Prototype, J. Freeman, private communication.

5. J. Freeman, as discussed in Ref. 3a in the section on Optics Design.

6. D. Green, Effect of Inert Material on ZZ Mass Resolution for $H \rightarrow ZZ \rightarrow eeee$, April 1991, FNAL-TM-1736.

7. SDC Calorimeter Design Requirements, Aug. 5, 1991, Ed. J. Siegrist.

Figure Captions

1. Energy deposit in each layer of a Pb sampling calorimeter for 12.5 GeV electrons incident at 30 °.

2. Fractional energy resolution, $dE/E \sqrt{E_t}$, as a function of the weight, WT, of the first active layer for 12.5 GeV electrons incident at 30°.

3. Fractional mean energy nonlinearity, [<E(WT)>-Eo]/Eo , as a function of weight, WT, of the first active layer for 12.5 GeV electrons incident at 90°.

4. Scaled fractional energy error, $[dE/E] \sqrt{E_t}$, as a function of weight, WT, for incident electrons of 12.5 +, 25 o, 50 Δ, and 100 [], GeV electron energy at angles of;

   a. 30°
   b. 90°

5. Fractional mean energy nonlinearity, [<E(WT)>-Eo]/Eo, as a function of incident energy, E, at a fixed weight of WT = 2 for angles of 30° +, and 90° [].

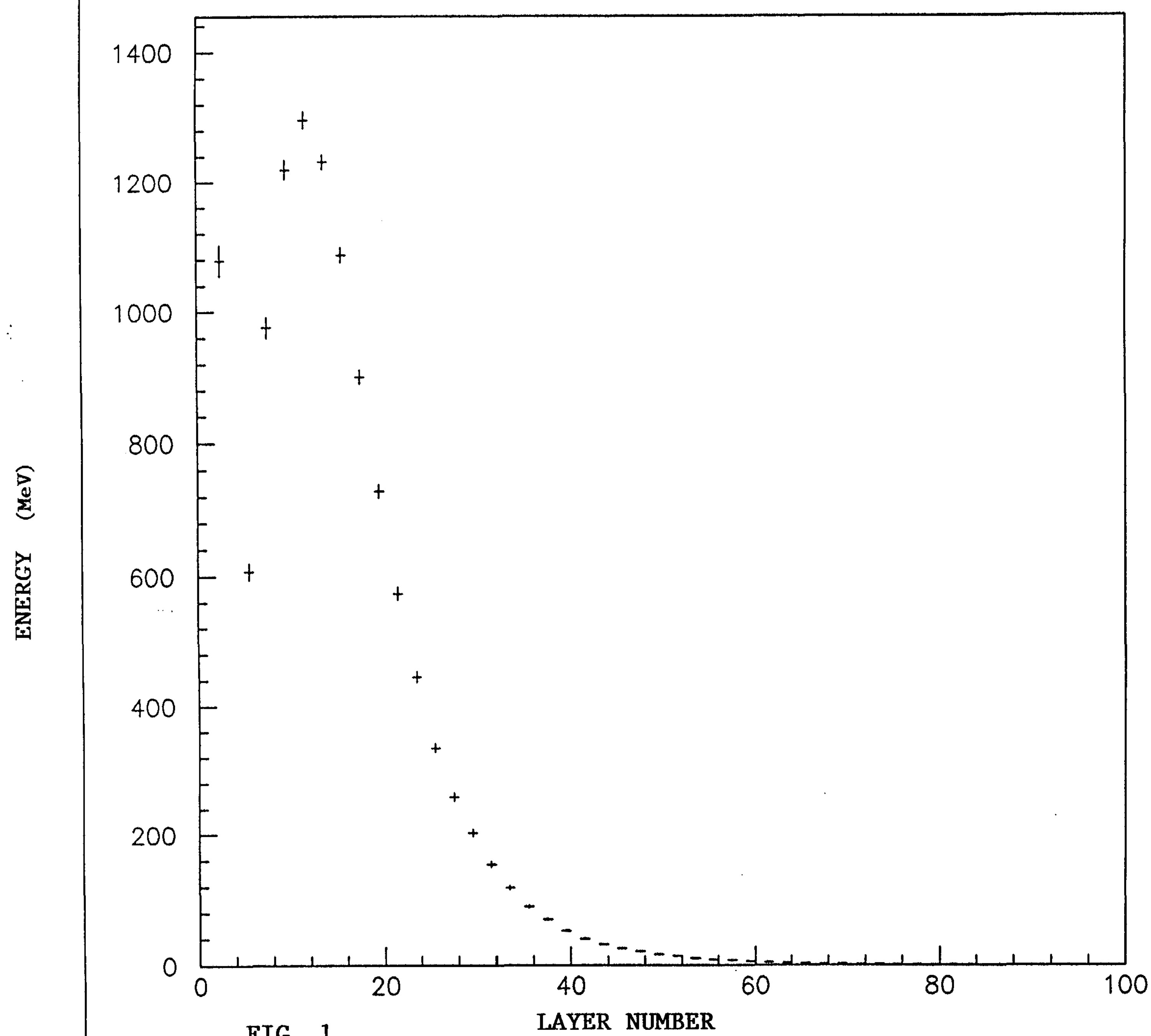
ENERGY (MeV)
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
LAYER NUMBER

FIG. 1

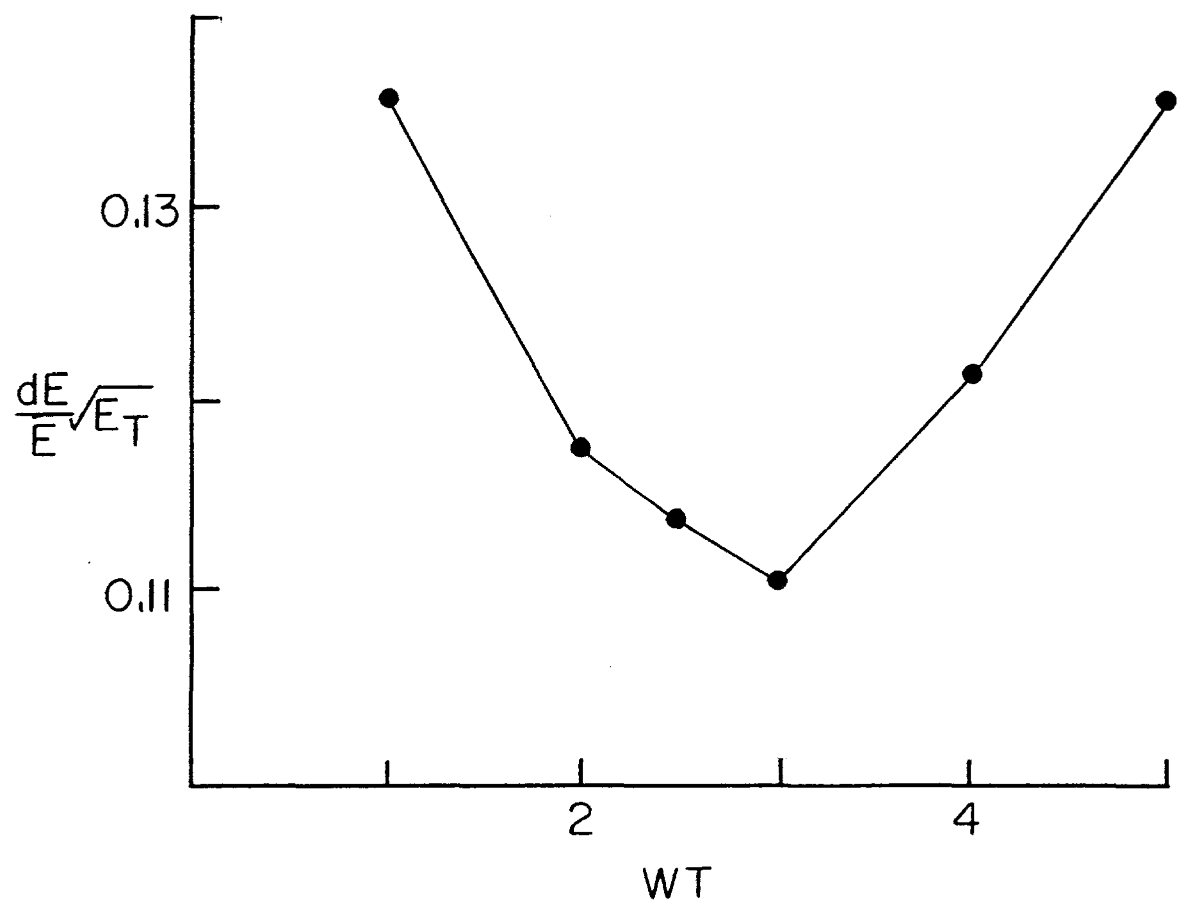

FIG. 2

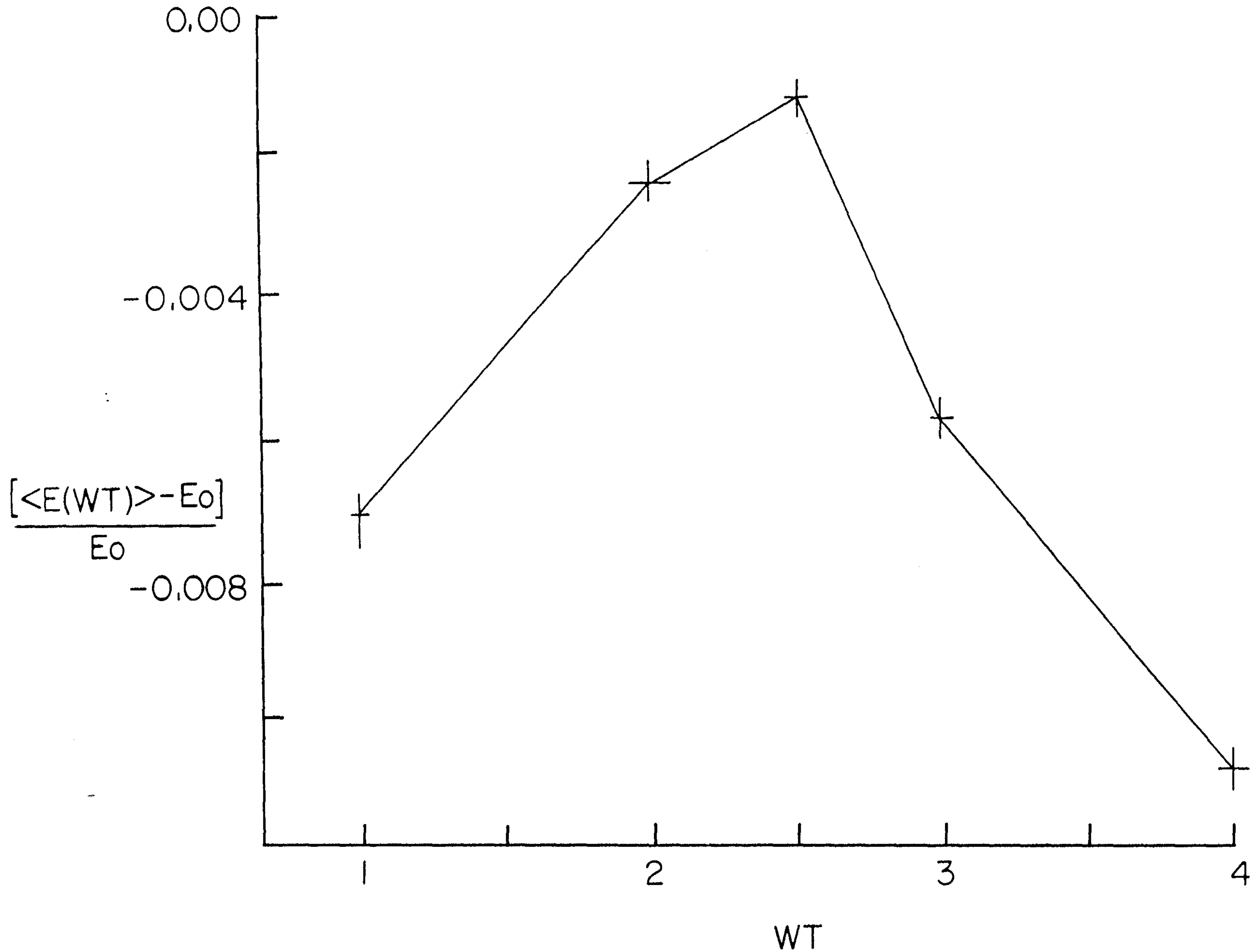

FIG. 3

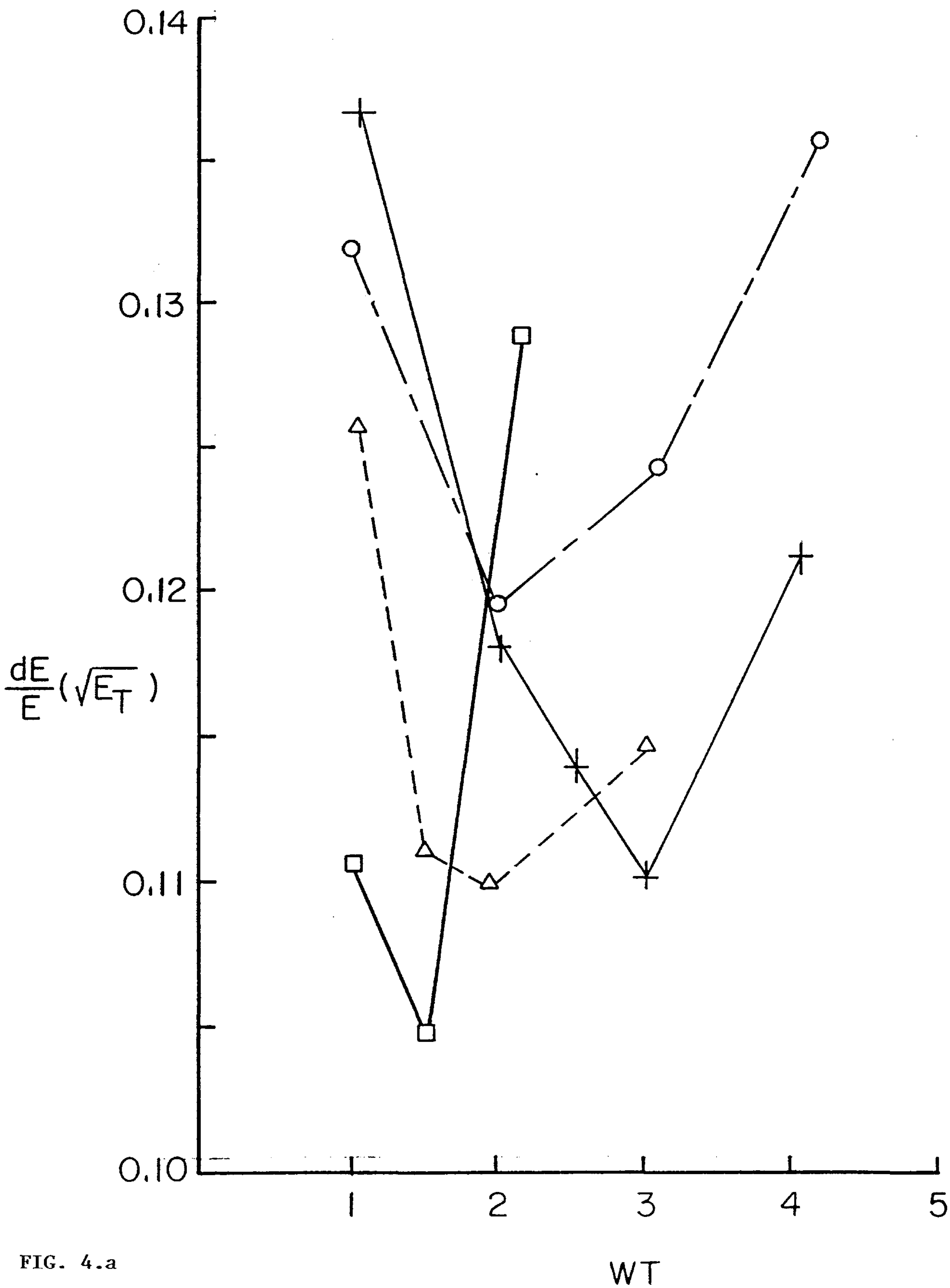

FIG. 4.a

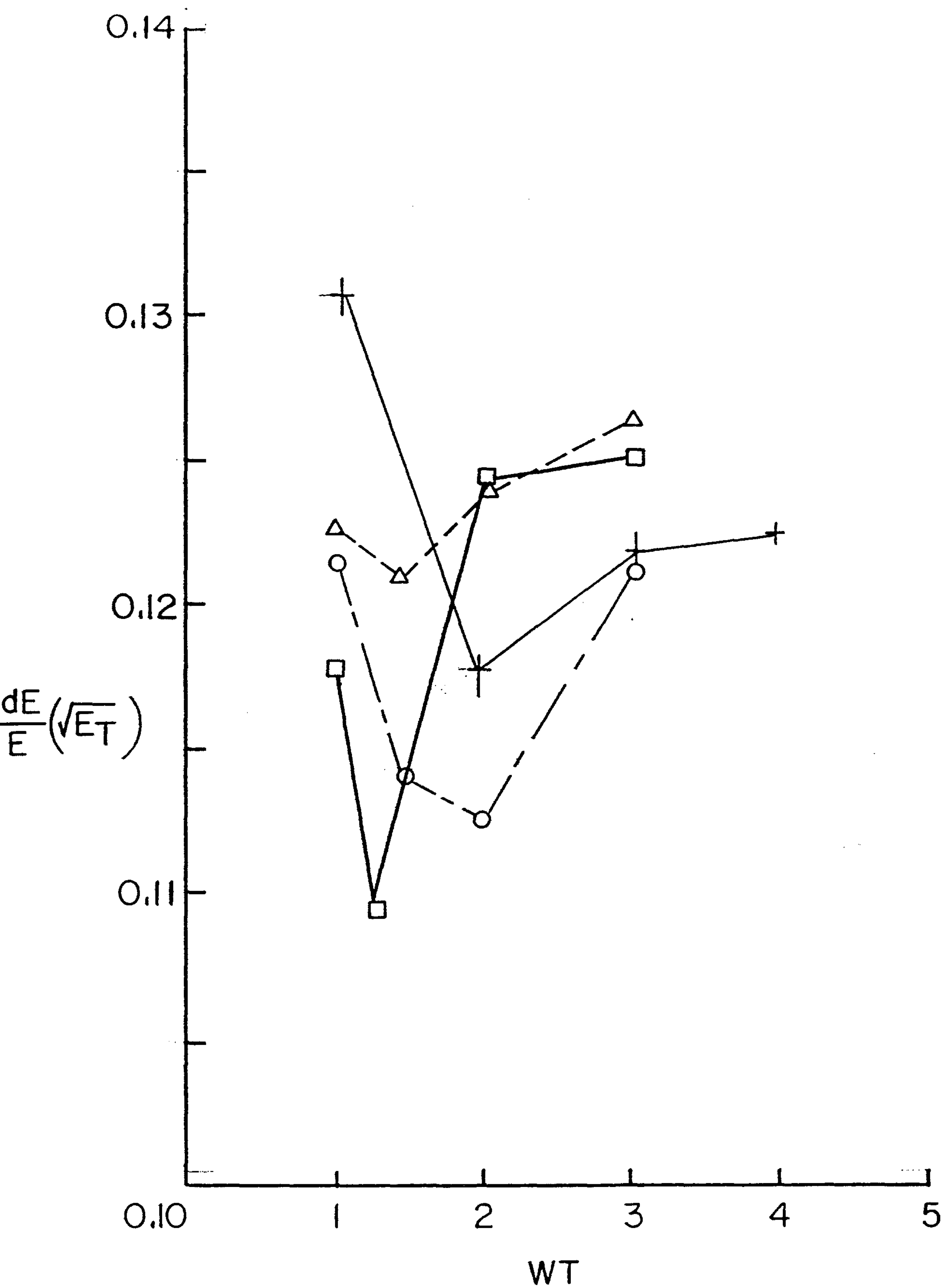

FIG. 4.b

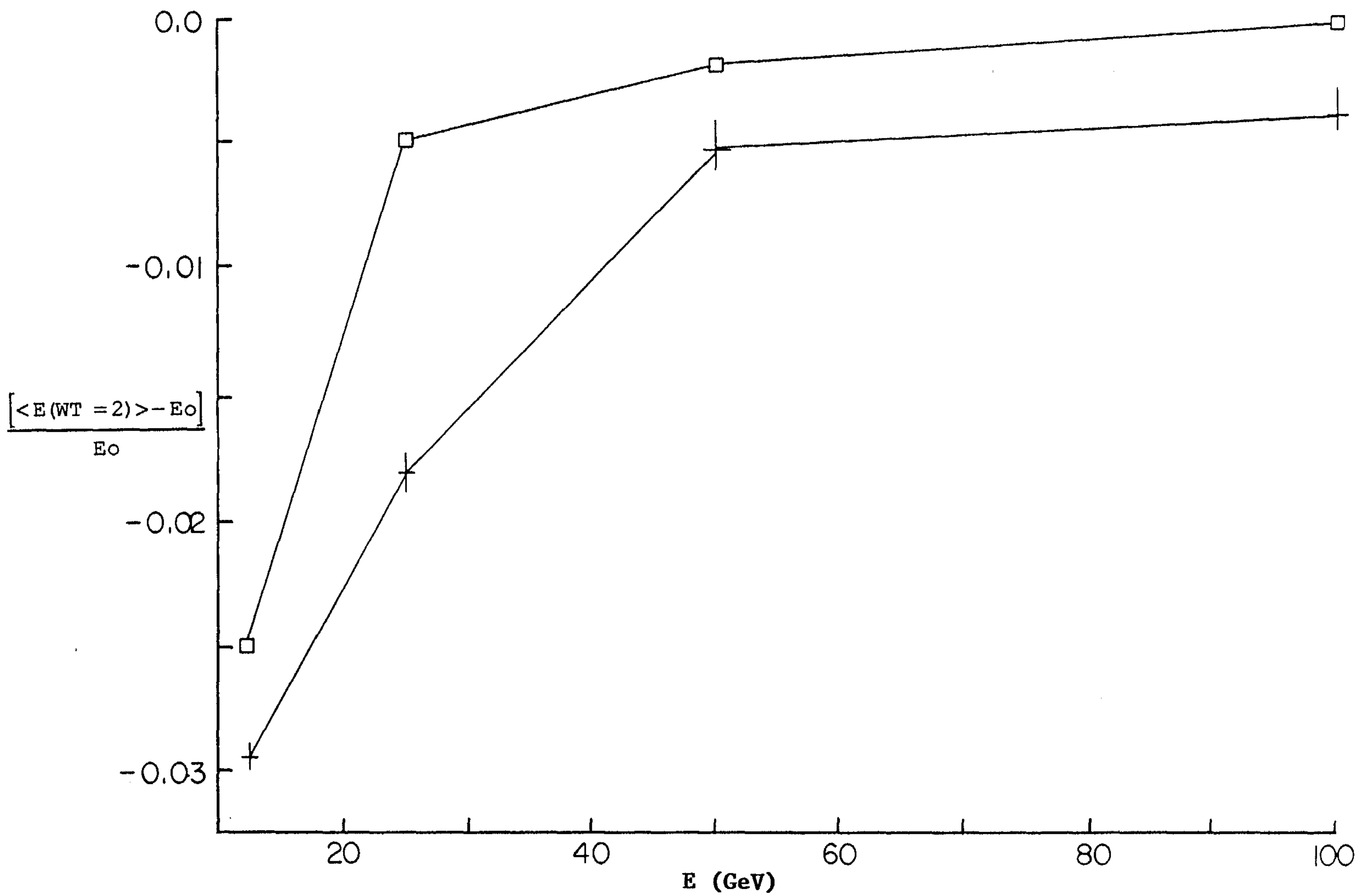

FIG. 5