DEUTSCHES ELEKTRONEN – SYNCHROTRON DESY

DESY 89-104
August 1989

MC-Simulations with EGS4 for Calorimeters with Thin Silicon Detectors

G. Lindström, M. Eberle, I. Fedder,
E. Fretwurst, V. Riech, M. Seidel

I. Institut für Experimentalphysik, Universität Hamburg

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 89-104
August 1989

ISSN 0418-9833

Workshop on Calorimetry for the SSC, Tuscaloosa/Alabama, March 1989

MC-Simulations with EGS4 for Calorimeters with Thin Silicon Detectors

G. Lindström, M. Eberle, I. Fedder, E. Fretwurst, V. Riech and M. Seidel
I. Institut für Experimentalphysik, Universität Hamburg, FRG *)

ABSTRACT

Extreme care has to be taken for realistic simulations of the energy response of an electromagnetic calorimeter if thin silicon detectors are being employed. For EGS4 it is very important to use the ESTEPE-option, and special attention has to be paid to the ECUT parameter. Agreement between experiment and simulation was achieved for ESTEPE less than 1% and ECUT below 100keV. This is demonstrated for the energy deposition of 1MeV electrons in a single silicon detector as well as for the electron ranges in aluminum. The correct treatment of low energy electrons results in an excellent reproduction of the experimental energy response for electromagnetic calorimeters including the "G10-effect" recently much discussed in connection with a possible e/h-tuning in silicon instrumented hadronic calorimeters.

INTRODUCTION

The use of silicon detectors in high energy physics has gained increasing importance during the last years. One of the more recent applications is their employment as active devices in sampling calorimeters (1). An example is the H1-PLUG-calorimeter, for which our group is responsible (2). The SICAPO-collaboration (SIlicon CAlorimeter and POlarimeter) at CERN investigates the general performance of silicon instrumented calorimeters using different geometries and absorbers (3). During this conference a hermetic silicon instrumented hadronic calorimeter was proposed for the SSC (4). One of the major questions in using silicon instrumented hadronic calorimeters is whether compensation (e/h = 1) may be obtainable. It has been shown experimentally that a considerable reduction of the electromagnetic response can be achieved by inserting suitable low Z layers (e.g. G10) between the absorber plates and the silicon detectors (2),(3). This

*) work supported by BMFT under contract 05 4HH19 P

effect, which shifts the e/h- ratio into the right direction, may be understood as resulting from the enhanced absorption of low energy electrons (local hardening effect).

As a tool for development and design of such calorimeters reliable MC-simulations are essential. The typical detector thickness of only 200-400 µm requires a careful choice of parameters, relevant especially for the correct treatment of low energy particles. On this approach we started with the most simple case, i.e. the energy deposition of monoenergetic electrons in a single thin layer of silicon, which could be compared to existing experimental data . On the basis of these results the response of electromagnetic test calorimeters was then studied. Both investigations were performed with the widely used EGS4 code (5).

ENERGY DEPOSITION AND RANGE OF LOW ENERGY ELECTRONS

EGS4 contains three parameters, which are crucial for the correct treatment of low energy electrons in thin layers. These are:

- ECUT: energy threshold for electron-tracking; when a particle gets below ECUT, its kinetic energy is deposited.
- ESTEPE: fractional energy loss per step.
- AE: energy threshold for δ-ray production; interactions, which would produce secondaries below AE, are treated as continuous restricted energy loss.

It was found sufficient to choose ECUT in a way that the equivalent electron range is short compared to the layer thickness. Therefore, ECUT was set to 10 keV, which belongs e.g. to a range of appr. 1 µm in silicon. Further calculations have shown that the results are not sensitive on even higher ECUT-values, as long as the range condition mentioned above is fulfilled. We observe a strong dependence of the deposited energy for electrons with 1 MeV kinetic energy in a 400 µm silicon layer on the parameter ESTEPE above 1%, which can be explained in the following way. The EGS code contains a path length correction algorithm, which leads to an overestimation of the energy loss for large steps. In addition, the Moliere algorithm as an approximation for multiple scattering is better for small steps. With respect to the parameter AE it is of course much better to perform the calculations with explicit δ-ray production and hence choose AE as low as possible.

The influence of all investigated parameters on the energy deposition in a single silicon detector is contained in table 1. With the optimized values for ECUT = 10 keV, ESTEPE = 1% and AE = 10 keV we succeeded in reproducing the experimental energy spectrum obtained for 1MeV electrons in a 530 µm silicon detector (6) with high accuracy (fig.1). In addition the extrapolated range of electrons between 100 keV and 5 MeV in aluminum was simulated using similar parameters. Also in this case very good agreement between the semiempirical formula (7) and the MC-result is obtained (fig.2).

Table 1
Summary of results from the study of the influence on the parameters ECUT, ESTEPE and AE. For 1 MeV e^- and 10 MeV e^- in 400 μm of silicon the MEAN- and MOP-values are given. All values in keV. From top to bottom:
(a): variable ECUT for ESTEPE = 1%, AE = 10 keV (b): variable ESTEPE for ECUT = 10 keV, AE = 10 keV (c): variable AE (and ECUT) for ESTEPE = 1%

(a)

	1 MeV		10 MeV	
ECUT	MEAN	MOP	MEAN	MOP
10	202.9	118	139.6	113
100	204.3	118	139.8	113
500	223.0	118	142.3	113

(b)

	1 MeV		10 MeV	
ESTEPE	MEAN	MOP	MEAN	MOP
0.2	201.7	118	138.9	113
0.5	201.8	118	139.5	113
1.0	202.9	118	139.6	113
2.0	205.9	123	139.1	113
5.0	214.9	128	140.0	113
10.0	229.8	143	140.4	113
20.0	236.7	153	140.9	113

(c)

	1 MeV		10 MeV	
AE=ECUT	MEAN	MOP	MEAN	MOP
10	202.9	118	139.6	113
100	205.1	138	139.4	128
500	219.5	153	143.6	138

ELECTROMAGNETIC RESPONSE OF SILICON SANDWICH CALORIMETERS

Some test experiments have been performed with small silicon instrumented calorimeters using lead and copper as absorbing materials. 1 X_o sampling was used with 400 μm fully depleted silicon detectors of 62 mm diameter each. The overall length corresponded to 12 X_o (Cu/Si) resp. 18 X_o (Pb/Si) and the lateral dimension was 90x90 mm^2. DESY test beams with electron energies between 1 and 6 GeV were used (8). These data were then taken as a confidence check for relevant simulations. As for the energy deposition of low energy electrons in a single layer the influence of the parameters ECUT and ESTEPE was investigated. But in contrast to the discussion given in the

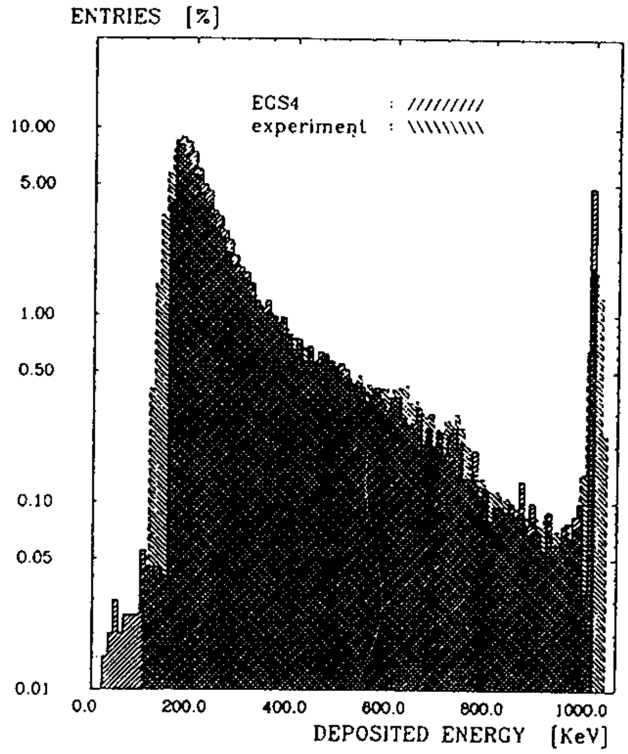

Fig. 1 Spectrum of deposited energy of 1 MeV e- in 530 μm of silicon: comparison between experiment and EGS4 (ESTEPE = 1%, ECUT = 10 keV, AE = 10 keV). Extracted results are:

	experiment	EGS4
MEAN	304 ± 1.5 keV	313 ± 1.5 keV
MOP	169 ± 10 keV	174 ± 10 keV
Entries (MOP)	8.2%	8.8%
Entries (FAP)	3.6%	4.8%

preceding paragraph we have now to deal with a much more complicated case, i.e. two different media (absorber and detector) as well as many samplings instead of only one layer. The parameter choice for the absorber resp. detector may influence each others effect on the energy response and hence has to be investigated separately.

For a correct treatment of the response to low energy electrons it is necessary to choose a low ECUT value not only in the active silicon but also in the adjoining passive absorber layers. But in order to reduce the CPU time the absorbers were subdivided into a bulk part with ECUT = 500 keV and two surface layers (on the front and rear side of each detector) with an ECUT value identical to that in silicon. The thickness of the surface layers was 500 μm, which is certainly enough to stop 500 keV electrons. Therefore, no error is introduced by choosing the high ECUT-value in the bulk part. Fig. 3 shows the dependence of the visible energy on ECUT in both surface layers and silicon detectors. For the investigated Cu/Si and Pb/Si calorimeters the visible energy becomes approximately independent of this

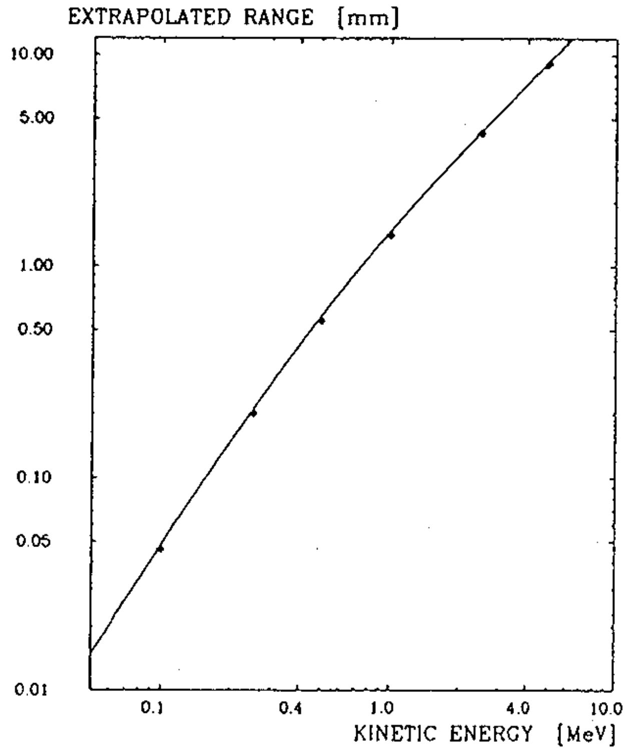

Fig. 2 Extrapolated range of electrons in aluminum for ESTEPE = 0.8% (symbols) and semiempirical formula (line)

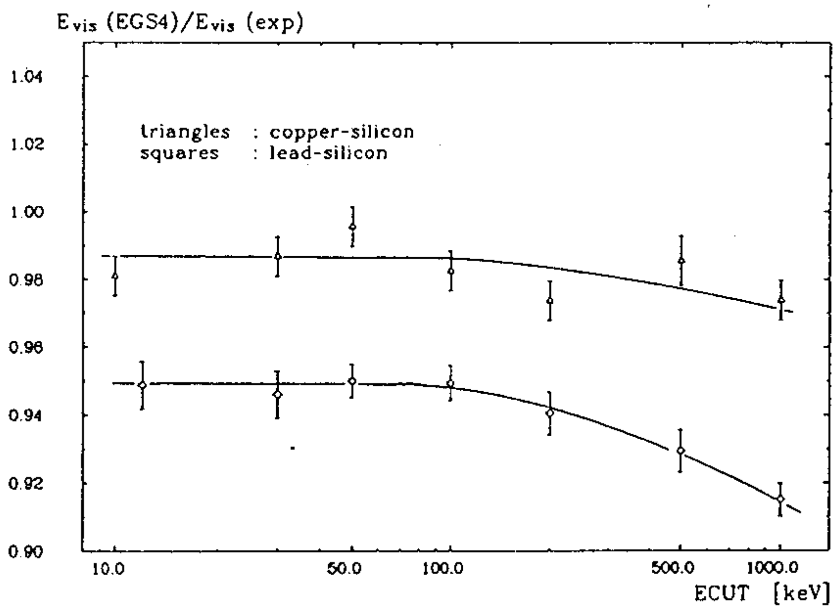

Fig. 3 Simulated visible energy normalized to experimental data of the Cu/Si- and Pb/Si-calorimeter as a function of ECUT both in the surface layers of the absorbers and in the silicon detectors (lines drawn to guide the eye). The other parameters are fixed at:

medium:	Silicon	Copper		Lead	
		bulk	surface	bulk	surface
ECUT		500 keV		500 keV	
ESTEPE	0.8%	0.5%	0.5%	0.6%	0.6%
AE	10 keV	10 keV	10 keV	10 keV	10 keV

parameter below 100 keV, resembling the experimental value within 1.5% for copper and within 5% for lead. For ECUT larger than 100 keV the visible energy is decreasing, because too much energy is dumped in the absorbers. Fig. 4 gives the respective results for the energy resolution. Also in this case the data become constant below ECUT = 100 keV. For higher cuts the fluctuation of the visible energy increases more rapidly than can be explained by the corresponding reduction of the visible energy alone . The observed difference between the asymptotic values and their experimental counterparts is due to instrumental contributions (beam width, noise etc.) not taken into account by the simulations.

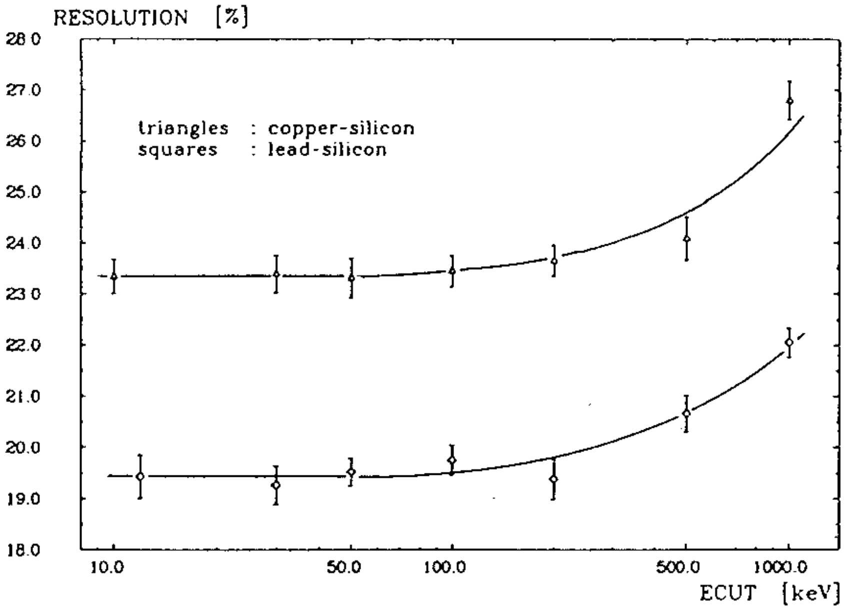

Fig. 4 Energy resolution ($\sigma/E_{vis} \cdot \sqrt{E_e}$) of the Cu/Si- and Pb/Si-calorimeter as a function of ECUT both in the surface layers of the absorbers and in the silicon detectors (lines drawn to guide the eye). The other parameters are fixed at:

medium:	Silicon	Copper bulk	Copper surface	Lead bulk	Lead surface
ECUT		500 keV		500 keV	
ESTEPE	0.8%	0.5%	0.5%	0.6%	0.6%
AE	10 keV	10 keV	10 keV	10 keV	10 keV

A special effect can be observed if ECUT in silicon becomes too large. In normal cases the visible energy follows a gaussian distribution but e.g. for ECUT = 10 MeV it contains several peaks as can be seen in fig.5 . Note that the discrete sharp peaks are approximately 10 MeV apart. Because all particles above 10 MeV can certainly be regarded as mip's, the first peak in the spectrum of the visible energy is composed of showers with energy depositions of mip's only. The second peak contains events with one additional 10 MeV dump. From further MC calculations (9) we know, that the probability of finding a particle in an appropriate energy bin above 10 MeV, reaching the cut energy within the detector is about 50%. Therefore the first and second peak in fig.5 have roughly the same intensity. With a much smaller probability even two or three dumps are observed. Though the mean visible energy is not drastically affected, the rms value deviates of course very much from the realistic case.

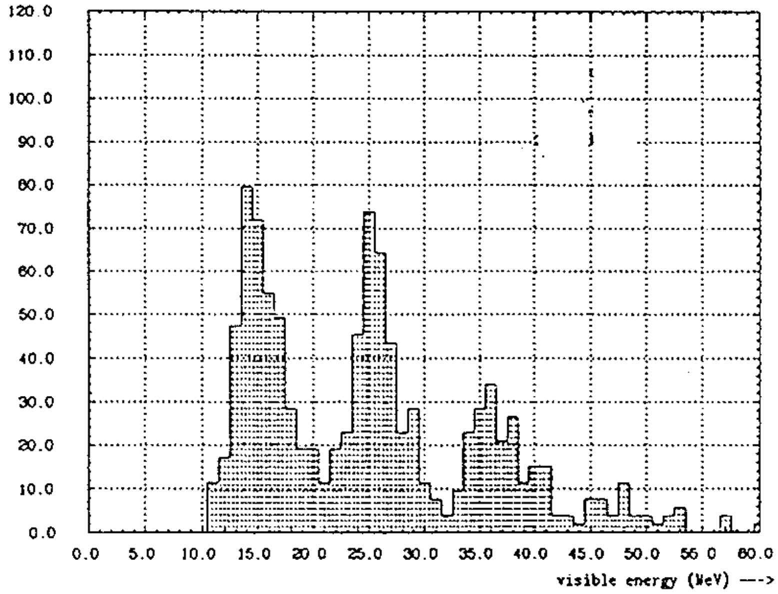

Fig. 5 Spectrum of visible energy of the Cu/Si-calorimeter for incident 4 GeV electrons in the case of ECUT = 10 MEV

For ECUT fixed at 100 keV in the silicon detectors and the surface layers of the absorbers resp. 500 keV in the bulk parts the dependence of the visible energy on ESTEPE in the absorber (bulk and surface parts) was then investigated (figs. 6 and 7). Too large stepsizes overestimate the energy deposition in the absorber and, therefore, less energy is sensed in the silicon detectors. For copper the plateau for the visible energy is reached at ESTEPE = 0,5%. In the case of lead even at ESTEPE = 0,2% the response does not become independent of this parameter. An extrapolation of the simulated curve does, however, match with the experimental value within the same error as for copper. As a compromise between precision and CPU-time consumption ESTEPE = 0,3% was chosen for further simulations with lead as absorber.

With fixed parameters for the absorbers, finally ESTEPE in silicon was varied (figs. 8 and 9). As to be expected the visible energy depends on this parameter in a similar way as the energy deposition in a single layer (9). This demonstrates the importance of the contribution of low energy particles in case of thin active layers. This can also be seen by looking at the particle flow and visible energy of all electrons traversing a silicon detector: 20% of all particles traversing a detector plane have an energy of less than 1 MeV, but 40% of the total visible energy is caused by these crossings (10). The dependence of the resolution on ESTEPE is not as pronounced (see fig. 9).

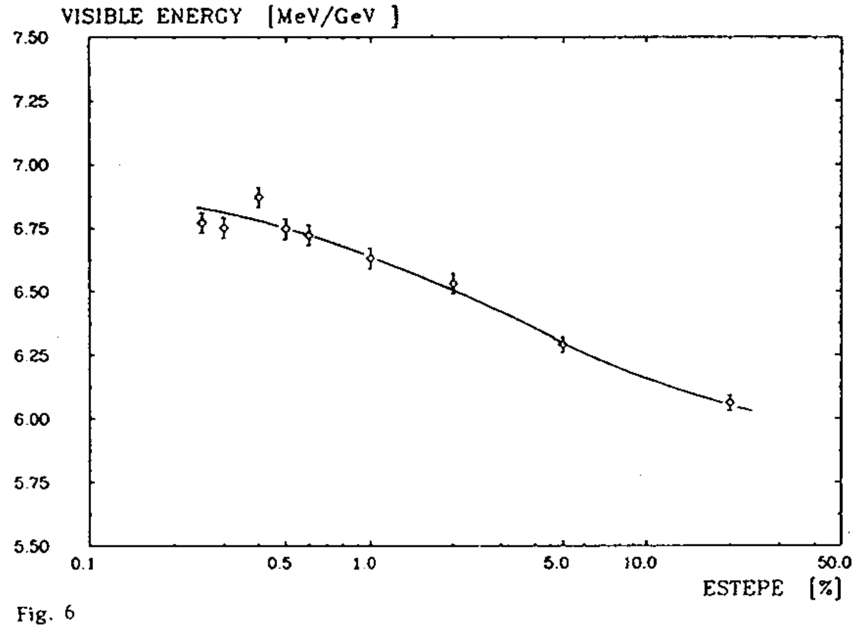

Fig. 6

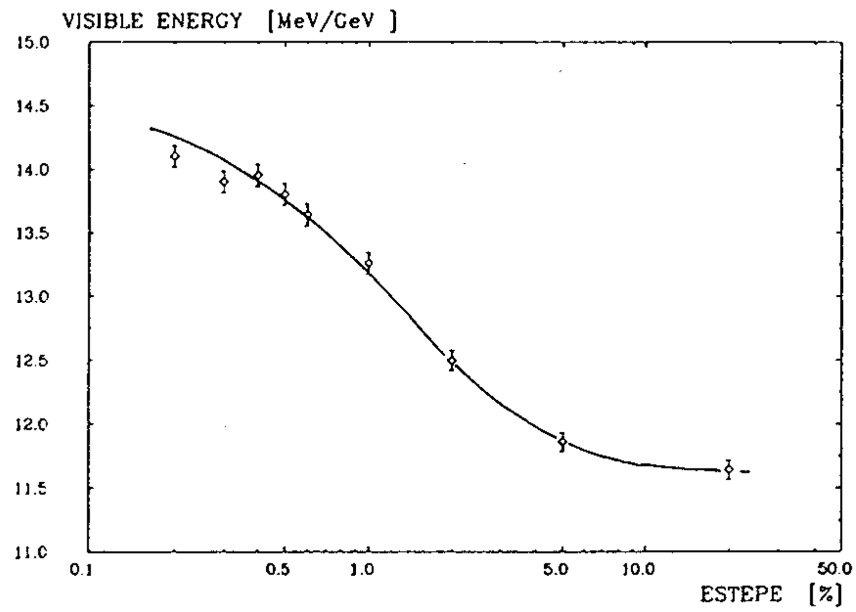

Fig. 7

Fig. 6 and 7 Visible energy in the Cu/Si (Fig. 6) and Pb/Si (Fig. 7) calorimeters as function of ESTEPE in the absorber (Cu resp. Pb ; bulk and surface part). Lines drawn to guide the eye.
Other parameters are fixed at:

medium:	Silicon	absorber bulk	absorber surface
ECUT	100 keV	500 keV	100 keV
ESTEPE	1.0%		
AE	10 keV	10 keV	10 keV

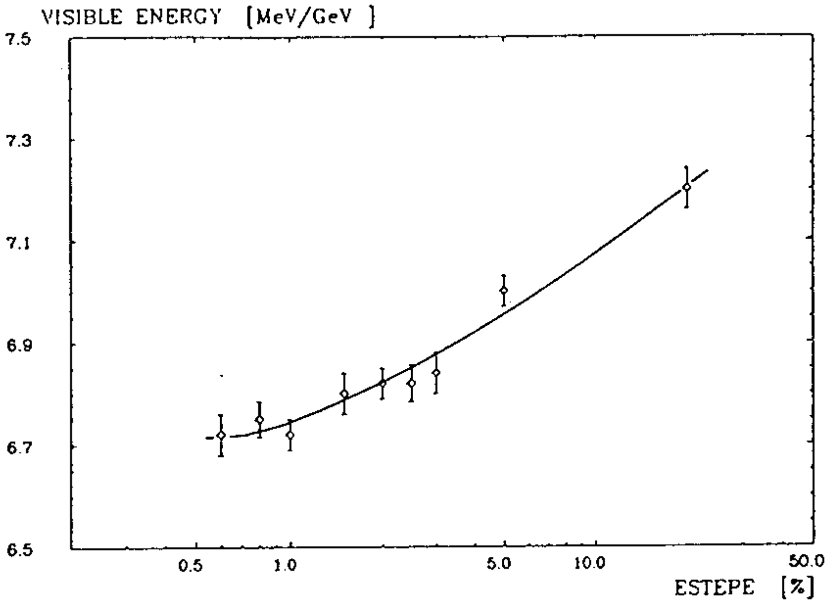

Fig. 8 Visible energy in the Cu/Si-calorimeter as a function of ESTEPE in the silicon detectors (line drawn to guide the eye). Other parameters are fixed at:

medium:	Silicon	Copper bulk	Copper surface
ECUT	100 keV	500 keV	100 keV
ESTEPE		0.6%	0.5%
AE	10 keV	10 keV	10 keV

With the final set of parameters, summarized in table 2 , we get Monte Carlo results, which are shown in comparison with the experimental data in table 3. Taking the remarks, especially for lead, into account the obtained overall agreement is regarded to be excellent. In addition the G10-effect, mentioned above, is very well reproduced.

Table 2
Final set of parameters for EGS4 em simulations

	ECUT [keV]	ESTEPE [%]	AE [keV]
Silicon	100	1.0	10
Copper (surface)	100	0.5	10
Copper (bulk)	500	0.5	10
Lead (surface)	100	0.3	10
Lead (bulk)	500	0.3	10

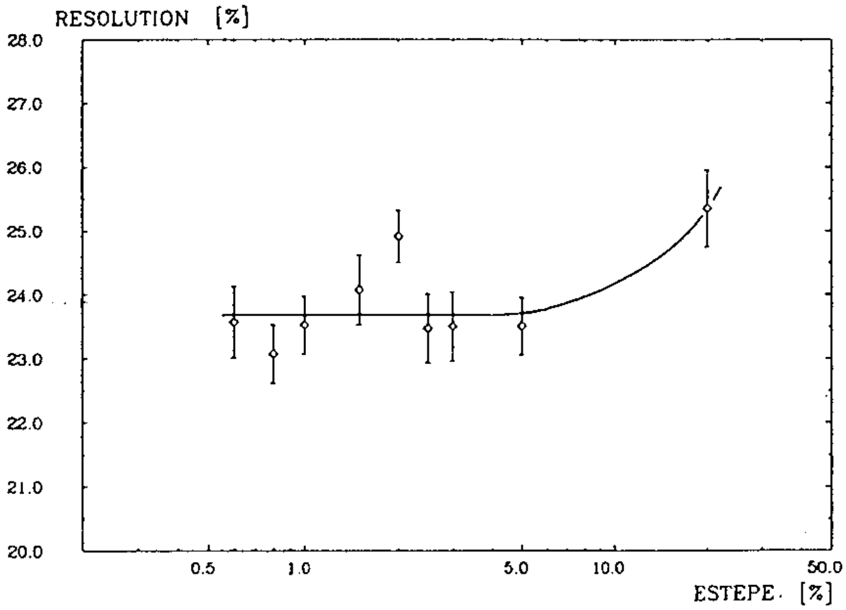

Fig. 9 Energy resolution ($\sigma/E_{vis} \cdot \sqrt{E_e}$) of the Cu/Si-calorimeter as a function of ESTEPE in the silicon detectors (line drawn to guide the eye). Other parameters are fixed at:

medium:	Silicon	Copper bulk	Copper surface
ECUT	100 keV	500 keV	100 keV
ESTEPE		0.6%	0.5%
AE	10 keV	10 keV	10 keV

Table 3
Experimental and simulated response of Cu/Si- and Pb/Si-calorimeters, including three G10-configurations (see text)

Calorimeter Configuration		E_{vis} [MeV/GeV] experim.	E_{vis} [MeV/GeV] EGS4	$\frac{\sigma}{E_{vis}} \cdot \sqrt{E_e}$ [%$\cdot\sqrt{GeV}$] experim.	$\frac{\sigma}{E_{vis}} \cdot \sqrt{E_e}$ [%$\cdot\sqrt{GeV}$] EGS4
Cu/Si	without G10	6.85±0.08	6.70±0.01	25.0±0.6	23.9±0.3
	1.5mm G10 front	6.53±0.09	6.41±0.02	24.8±0.6	22.7±0.3
	1.5mm G10 rear	6.33±0.08	6.21±0.02	25.1±0.6	23.3±0.4
	1.5mm G10 front and rear	6.12±0.07	5.90±0.02	24.5±0.6	22.7±0.5
Pb/Si	without G10	14.44±0.17	13.94±0.03	20.9±0.5	19.3±0.3
	1.5mm G10 front	12.91±0.15	12.29±0.03	20.3±0.5	19.3±0.3
	1.5mm G10 rear	12.13±0.14	11.64±0.03	20.7±0.5	19.3±0.3
	1.5mm G10 front and rear	11.04±0.13	10.58±0.02	20.3±0.5	17.9±0.3

CONCLUSION

It was shown, that the electromagnetic energy response of silicon instrumented calorimeters can be predicted with high accuracy, using the EGS4-code with a careful choice of parameters. The MC-data reproduce existing experimental results on the visible energy and the energy resolution with high accuracy even if additional low Z absorber layers are incorporated (G10-effect). The presented investigations are therefore not only useful in understanding the response of electromagnetic calorimeters but can also be used as a first step for more elaborate MC-simulations of hadronic calorimeters. A more detailed report is published elsewhere (9).

REFERENCES

(1) C. Gößling, Proceedings of the XXIV. Int. Conf. on High Energy Physics, Munich 1988, p. 1208

(2) E. Fretwurst, G. Lindström and V. Riech, Technical Progress Report H1-TR 110, Hamburg 1987

(3) SICAPO-Collaboration, CERN-EP/89-28

(4) J. Brau, this conference

(5) W.R. Nelson, H. Hiroyama and D.W.O. Rogers, SLAC-265 (1985)

(6) M.J. Berger et al., NIM 69 (1969), 181

(7) T. Takata et al., NIM 103 (1972), 85

(8) G. Lindström et al., to be published

(9) M. Eberle et al., internal report H1-05/89-109, Hamburg May, 1989

(10) M. Eberle, Diploma thesis, Univ. of Hamburg, 1989