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ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ
ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ
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Monte-Carlo Simulation of Hadronic Showers

Part I: Comparison with Experiment

ЦНИИатоминформ
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ՀԱԴՐՈՆԱՅԻՆ ՀԵՂԵՂՆԵՐԻ ԽԱՂԱՐԿՈՒՄԸ ՄՈՆՏԵ-ՔԱՐԼՈ ԵՂԱՆԱԿՈՎ

ՄԱՍ I. MARS10 ԾՐԱԳՐԻ ՀԱՇՎԱՐԿՆԵՐԻ ՀԱՄԵՄԱՏՈՒԹՅՈՒՆԸ ԳԻՏԱՓՈՐՁԵՐԻ ԱՐԴՅՈՒՆՔՆԵՐԻ ՀԵՏ

MARS10 ծրագրով [1] խաղարկված են հադրոնային հեղեղներ եւ կատարված են համեմատություններ բարձր էներգիայի արագացուցչային տարբեր գիտափորձերի արդյունքների հետ: Դիտվել են գիտափորձերի եւ խաղարկման արդյունքների լավ համաձայնություններ: MARS10-ն արագ եւ հուսալի միջոց է հադրոնային հեղեղների միջին բնութագրիչների թվային հետազոտման համար:

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ

ԵՐԵՎԱՆ 1992

1. Introduction

In the first part of this work we consider the comparison of results obtained by the MARS code with experimental data. In the [illegible] we present the results for various calorimetric devices which are operating or under construction in the multi-TeV energy range. It is worth to notice [illegible] development of hadronic showers in condensed medium [illegible] the help of MARS code was considered and discussed in reference [1], along the results of other authors with the purpose demonstrating the quality of these codes. These are both differential and integral characteristics of hadronic showers which are in agreement. A short review of the results obtained using three [illegible] programs via [illegible] [2], CASIM [3] and MARS [illegible] which are [illegible] the design problems of accelerators, is presented in reference [3]. The quantities for comparison are the basic ones common to the output of codes: the star density, $S(r)$, and the energy deposition [illegible]. As it is concluded in [3], the results agree very well for [illegible] conditions and over a wide energy range. This is gratifying [illegible] the rather different models of production and transport used [illegible].

The code was written at [illegible] Madison in mid 70-ies and [illegible] extensively modified and [illegible] by the IHEP (Serpukhov) [illegible] the past years. A weighted Monte-Carlo algorithm is used in [illegible] then only the average characteristics of the shower can be [illegible]. Typical computing times are of the order of an hour on [illegible] logarithmically with the incident energy.

The purpose of the present work was mostly to [illegible] ourselves with the MARS10 code in practice. We have simulated [illegible] calorimetric experiments on the accelerators and made comparison of the results.

2. The Prototype of CHARM Calorimeter [6,7]

The layout of the calorimeter is given in fig. 1 (see ref.-s [6,7] for details). We have calculated pion induced longitudinal shower profiles in a Marble/Al/scintillator sandwich with a geometry corresponding to that presented in fig. 1. The experimental[7] and the calculated shower profiles for 1, 2, 3, 5 and 6GeV pion induced showers are given in fig. 2. As it is seen from the figures the agreement is quite good.

3. The CDHS Calorimeter Prototype [8]

This is an Iron/Scintillator total absorption calorimeter. Figure 3 shows the details of it's structure (see ref.[8]). We have calculated the development of hadronic showers initiated by 10GeV pions for 10, 20 and 30MeV energy cutoffs. The comparison between the experimental[8] and calculated shower profiles is shown in fig. 4. It can be seen, that the shower attenuation slope depends on this cutoff value. For 30MeV cutoff the agreement with the experimental data is satisfactory.

It's worthwhile to mention that the value of the energy cutoff is to be adjusted empirically. There is no simple and direct connection between this Monte-Carlo cutoff and the actual cutoff imposed by the detection system.

4. The HEAO Calorimeter [9,10]

This was a Tungsten/Scintillator sandwich calorimeter designed for Mission A of HEAO.The prototype was exposed to particle beams at SLAC and FNAL. The arrangement of the apparatus in the experiment at SLAC is shown schematically in fig. 5(for a detailed description see ref. [11,12]).The average number of equivalent particles has been calculated for 5, 10 and 15GeV/c pion induced cascades. The comparison of our Monte-Carlo results with the experimental data in units of the average energy loss of sea-level cosmic ray muons is presented in fig. 6. As it is seen from the figure the agreement is good.

5. The Prototype of an Iron/Scintillator Sampling Total Absorption Detector for Neutrino Experiments at FNAL [13,14]

The schematic view of the scaled-down calorimeter is shown in fig. 7. The experimental data[13,14] was obtained with a momentum and sign selected secondary beam, which at energies above 100GeV was primarily composed of hadrons(mostly protons and pions for positive sign selection and mostly pions for negative sign selection) with a small muon contamination.

In our Monte-Carlo calculation we used protons and positive pions with equal weight to simulate the case with positive hadrons and a pure beam of negative pions to simulate the negative hadrons. Proton and pion cascades do not differ drastically at high energies and the kaon contamination of the beam is supposed to be negligible, so this assumption is valid.

The fractional energy depositions along the calorimeter depth for 100, 200 and 250GeV negative hadrons are given in fig. 8, and that for 150 and 200GeV positive hadrons in fig. 9. The agreement with the experimental data[13,14] is satisfactory.

6. Iron and Lead Sandwiched with X-Ray Films [15]

The X-ray film chambers were exposed in the 300GeV proton beam at CERN[15]. The schematic view of the chamber is shown in fig. 10(see ref. [15] for details).

Our calculations of the longitudinal development of 300GeV proton induced cascades in the iron absorber are in a good agreement with the experimental curves from ref. [15], which are given in fig 11 a). There is a disagreement between the calculated and the experimental profiles for 300GeV proton induced cascades in lead absorber(see fig. 11 b)). As it can be seen from the figure the Monte-Carlo curve is systematically higher by a factor of about 1.5. Variation of the Monte-Carlo energy cutoff from 10MeV to 50MeV does not change the situation.

The lateral development of the same cascades were also analysed. The calculated and the experimentally measured longitudinal profiles for various distances from the shower axis are given in fig. 12(iron absorber) and fig. 13(lead absorber). Here also the Monte-Carlo results are in good agreement with the experimental data for the case of the iron absorber, while for the lead absorber the agreement is unsatisfactory. This circumstance is also noted by the authors of ref. [16] using a different Monte-Carlo code.

7. CONCLUSION AND ACKNOWLEDGEMENTS

The comparison of the experimental data and the results obtained using MARS10 code shows good agreement. MARS10 is a fast and reliable instrument for numerical studies of the average characteristics of hadronic showers.

We would like to thank N. Mokhov and A. Uzunyan from IHEP(Serpukhov) who made available for us the 10-th version of MARS. We would like to thank also our numerous friends and colleagues from the Cosmic Ray Department of YerPI for many useful and stimulating discussions. Last but not least, our acknowledgements go also to A. Adjemyan, N. Akopov and H. Kerobyantsyan from the YerPI computer center.

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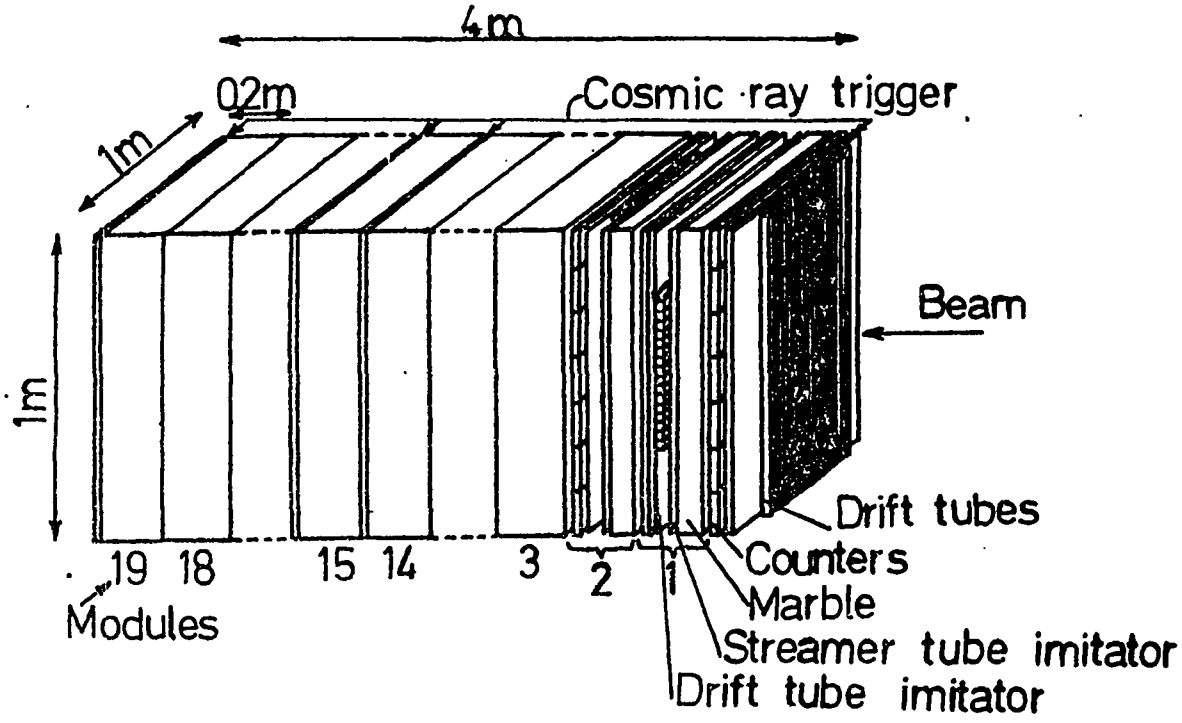
4m
02m
Cosmic ray trigger
1m
1m
Beam
Drift tubes
Counters
Marble
Streamer tube imitator
Drift tube imitator
19
18
15
14
3
2
1
Modules

Fig. 1.1

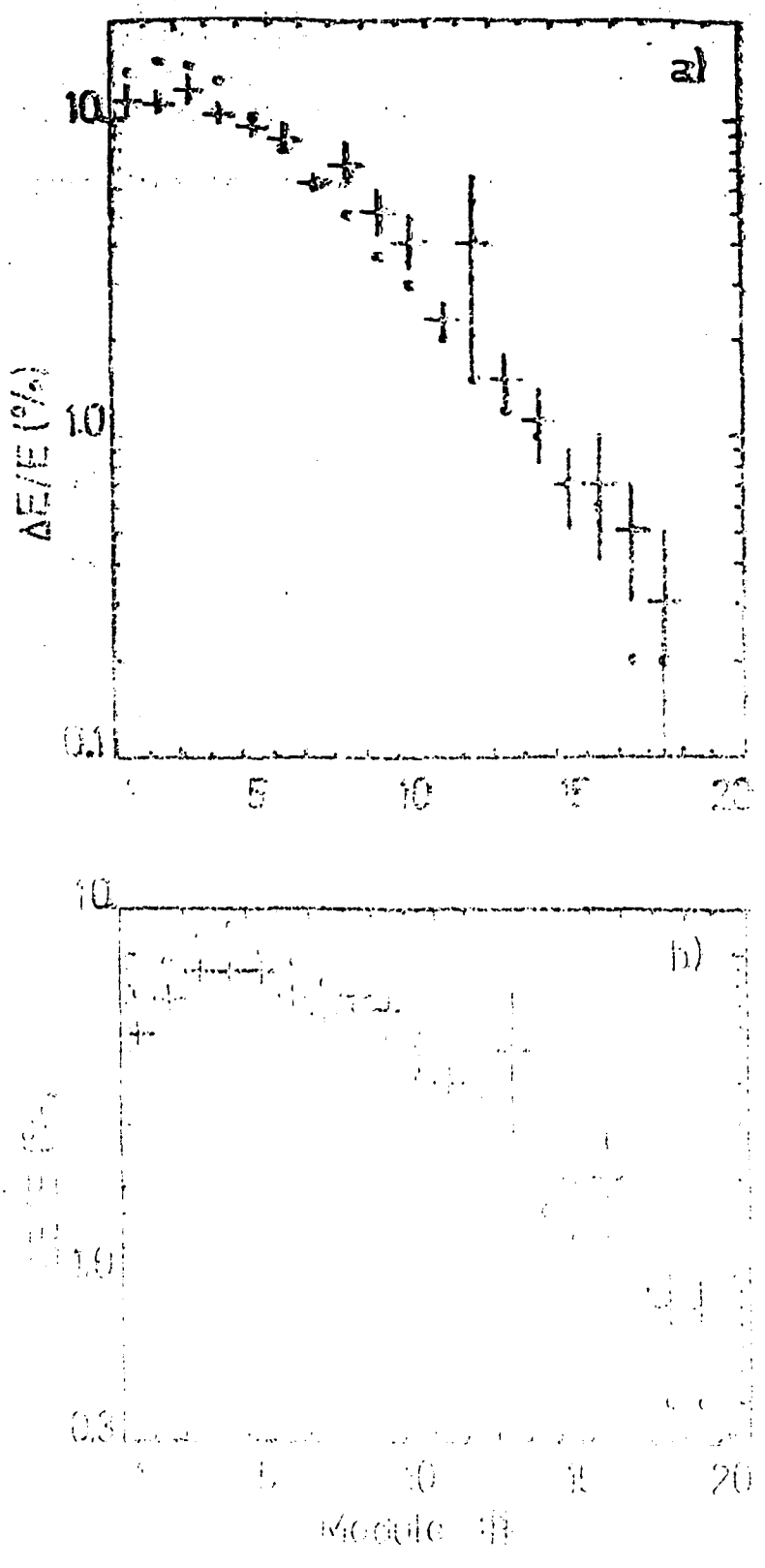

Fig. 1.2

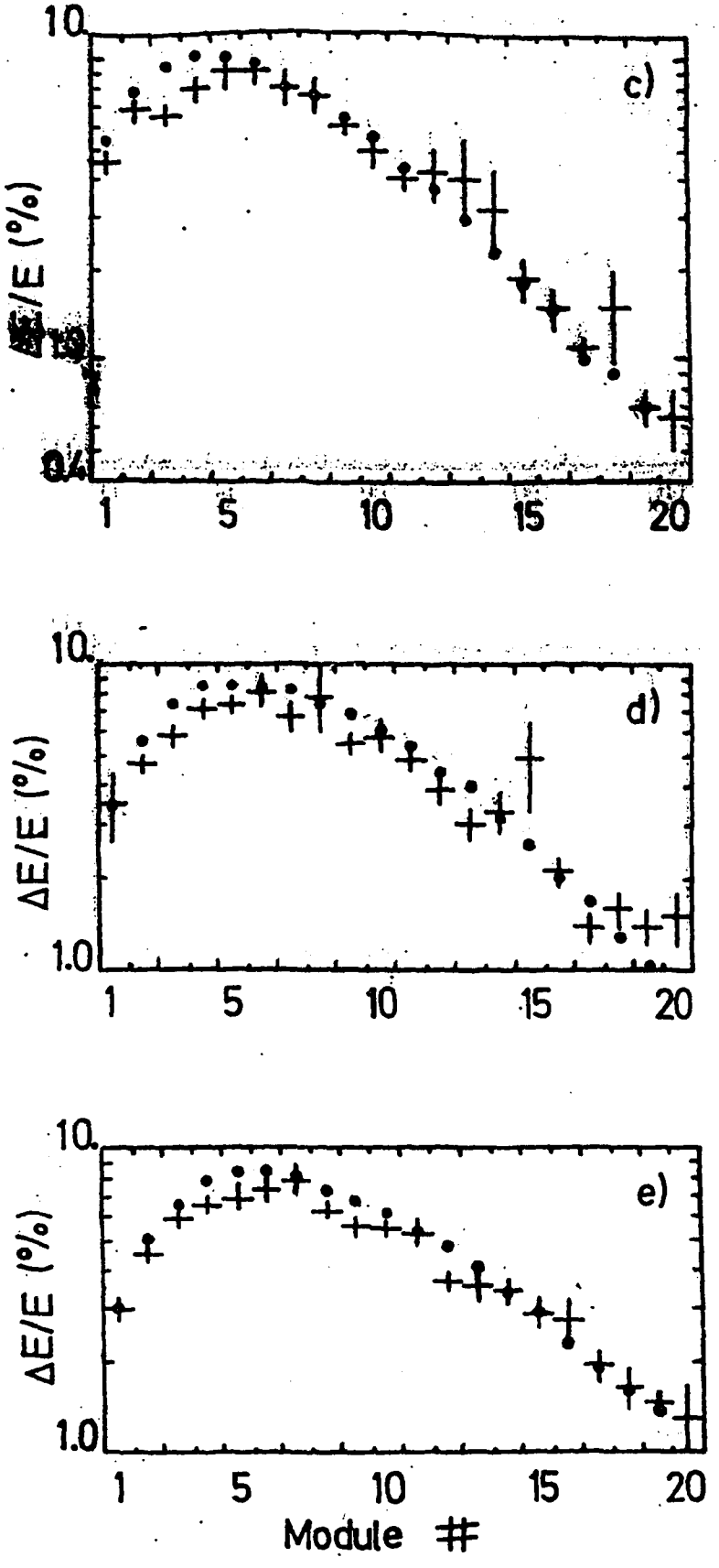

Fig. 1.2

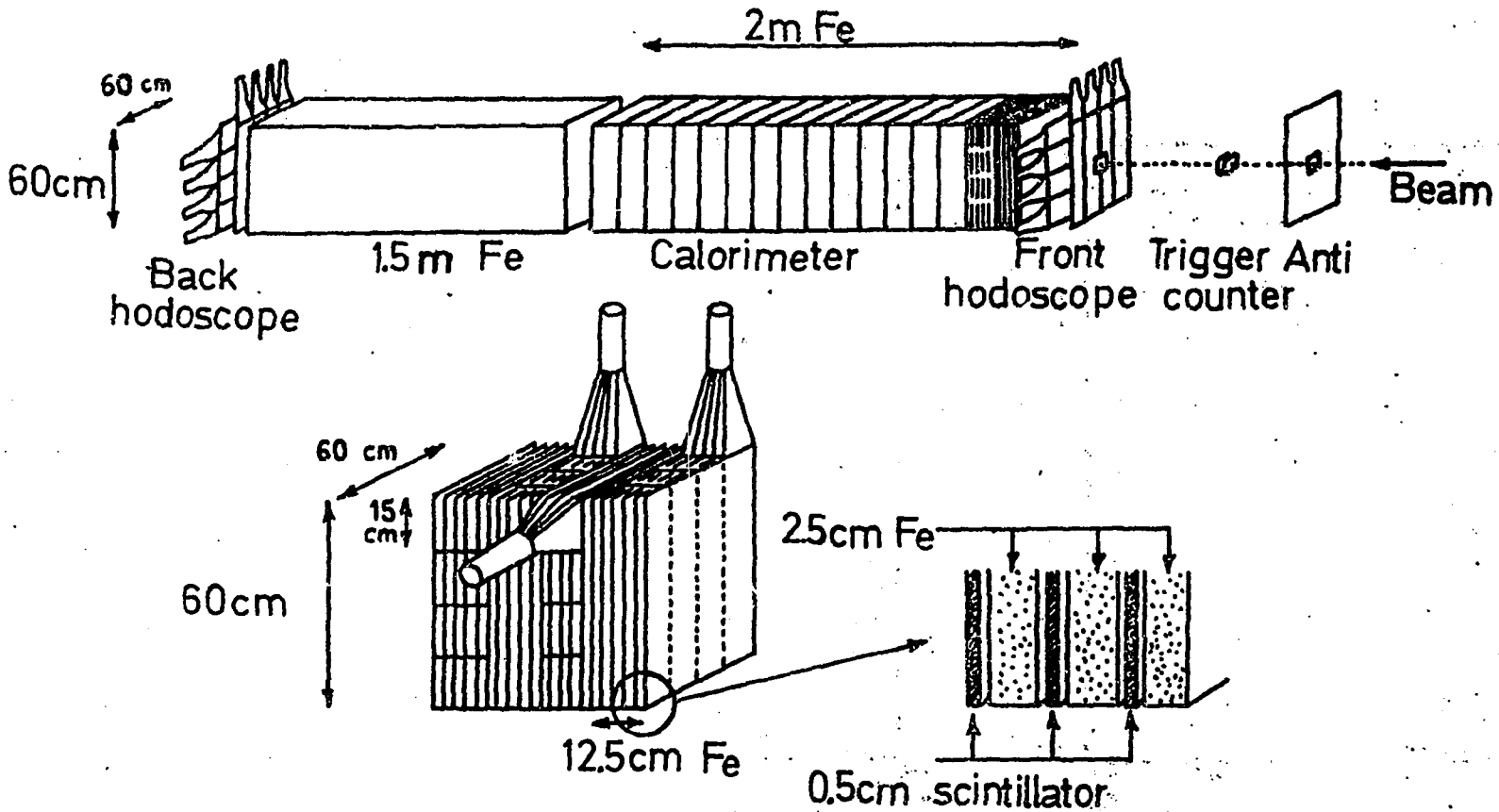
2m Fe
60 cm
60cm
Back
hodoscope
1.5 m Fe
Calorimeter
Front
hodoscope
Trigger
counter
Anti
Beam
60 cm
15
cm
60cm
2.5cm Fe
12.5cm Fe
0.5cm scintillator

Fig. 1.3

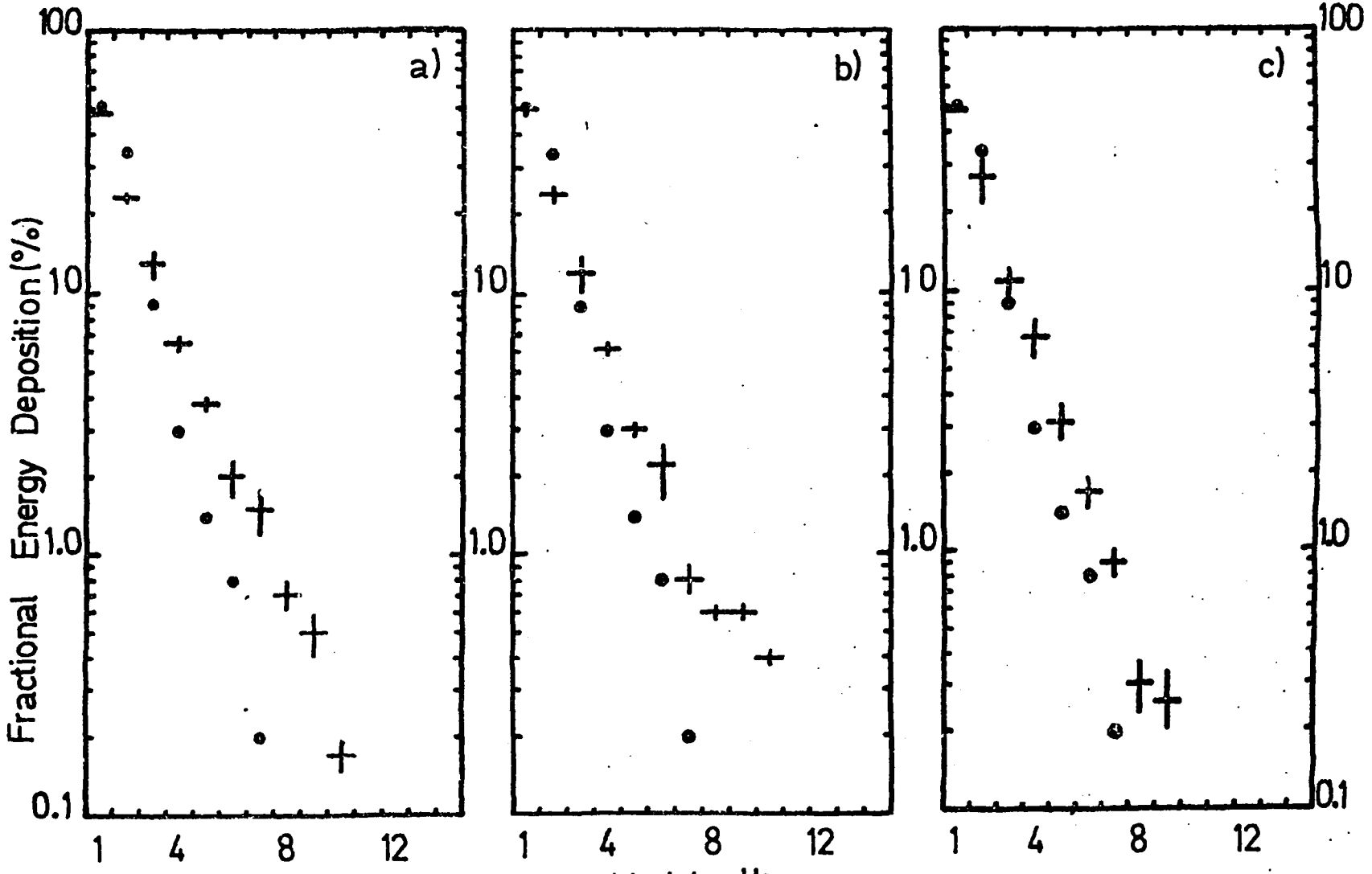

Fig. 1.4

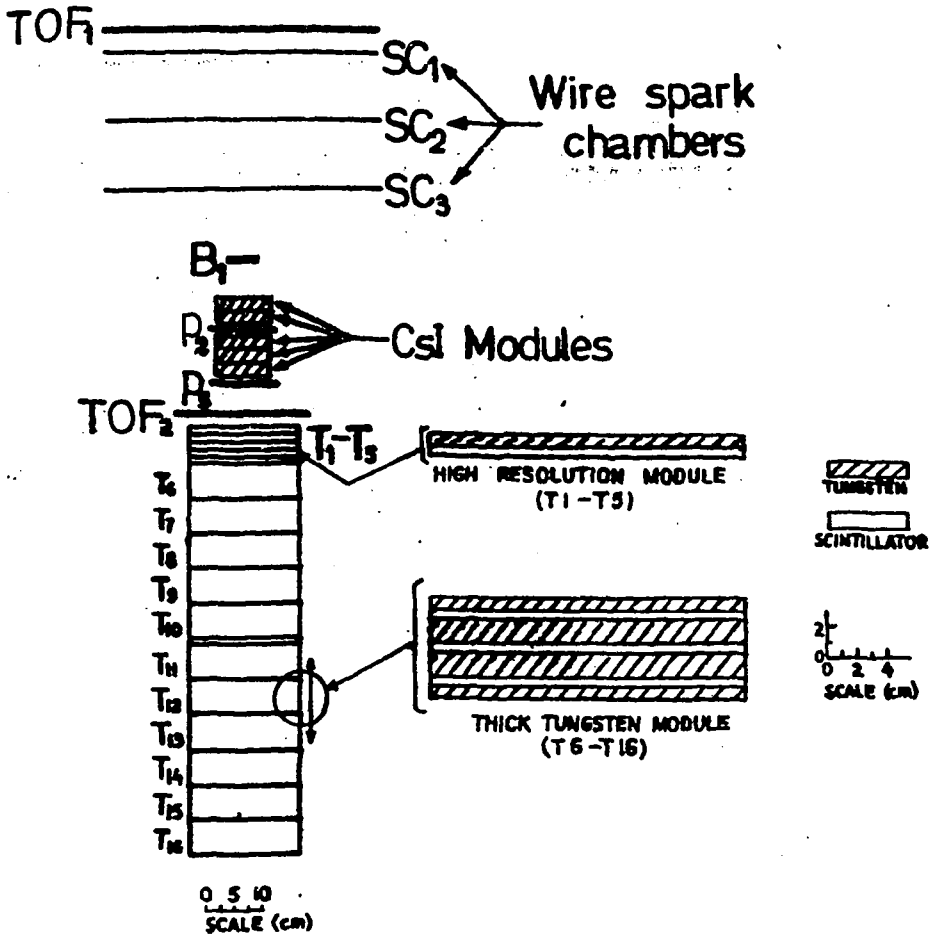
TOF1
SC1
SC2
SC3
Wire spark chambers
B1
B2
B3
CsI Modules
TOF2
T1-T5
HIGH RESOLUTION MODULE (T1-T5)
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
THICK TUNGSTEN MODULE (T6-T16)
0 5 10
SCALE (cm)
TUNGSTEN
SCINTILLATOR
0 2 4
SCALE (cm)

Fig. 1.5

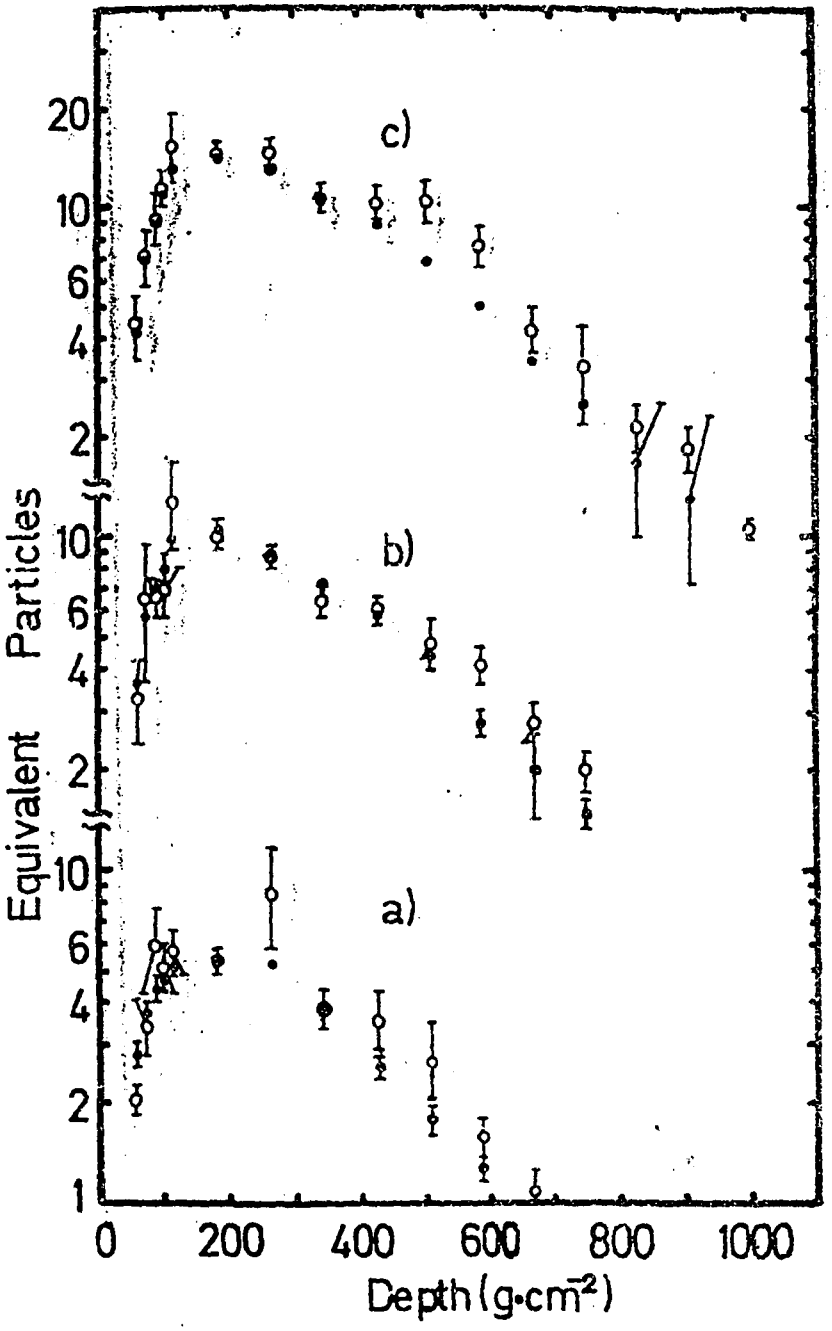
Equivalent Particles
Depth (g·cm⁻²)
a)
b)
c)
0
200
400
600
800
1000
1
2
4
6
10
20

Fig. 1.6

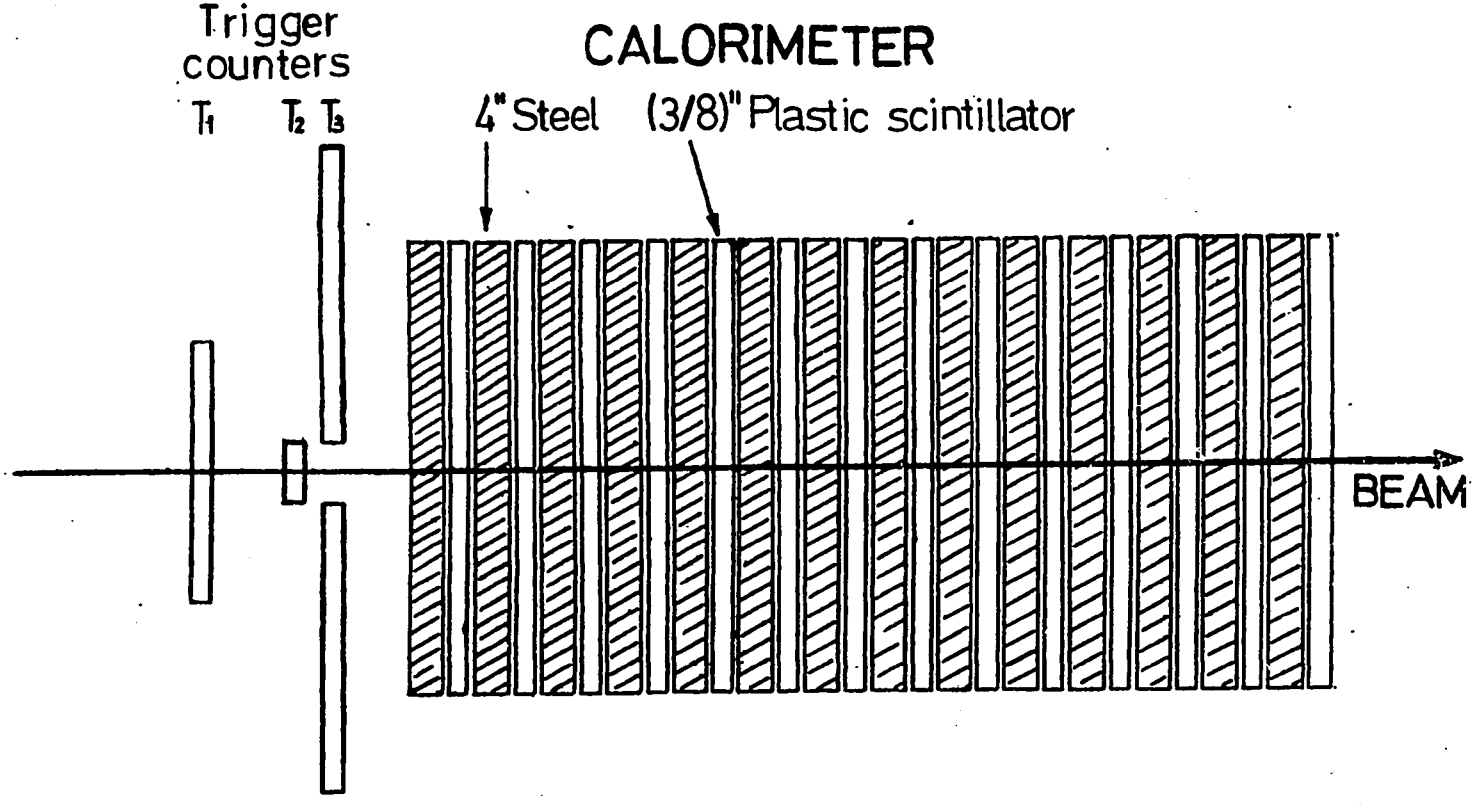
Trigger
counters
T1 T2 T3
CALORIMETER
4" Steel
(3/8)" Plastic scintillator
BEAM

Fig. 1.7

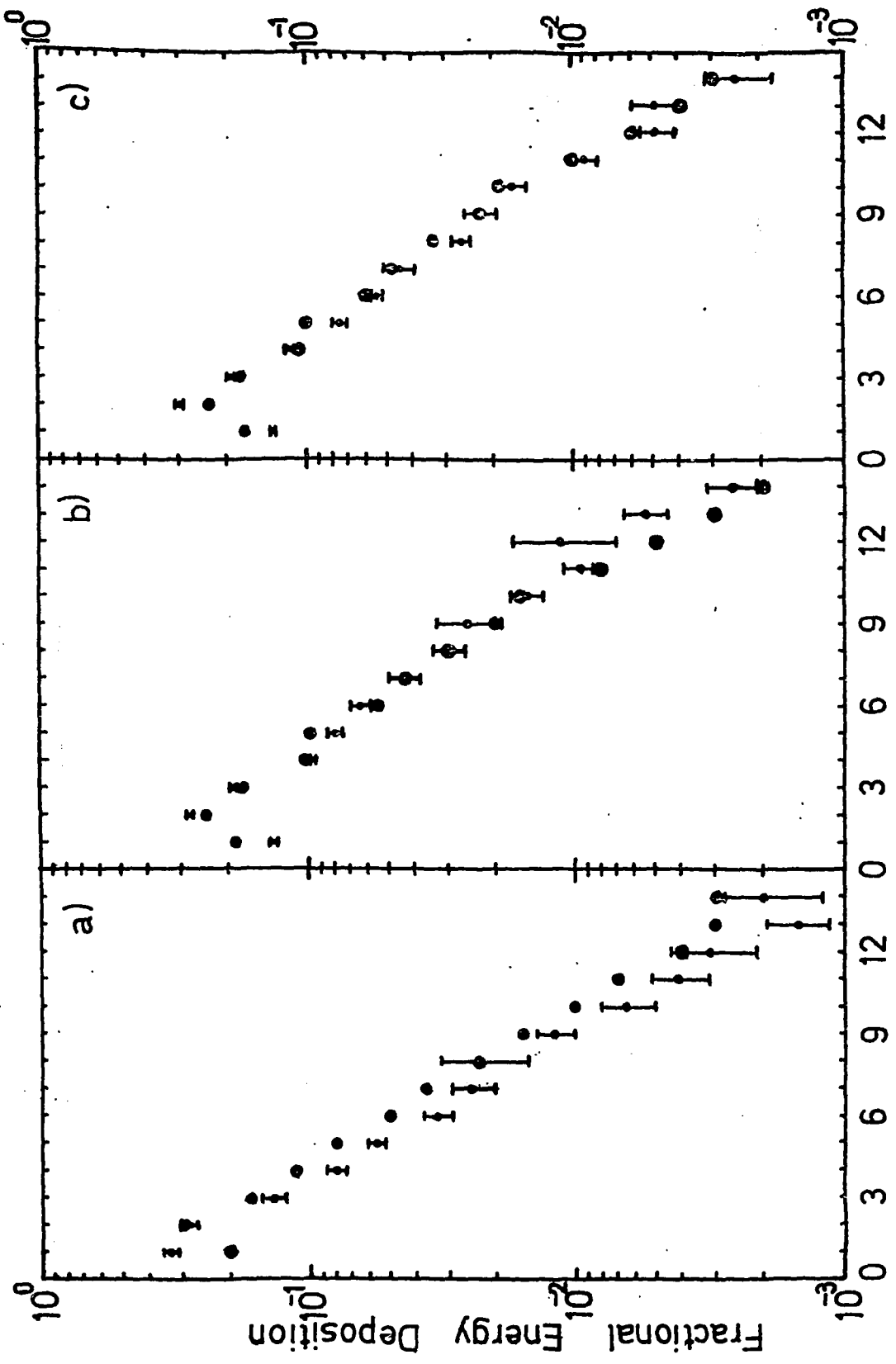

Fig. 1.8

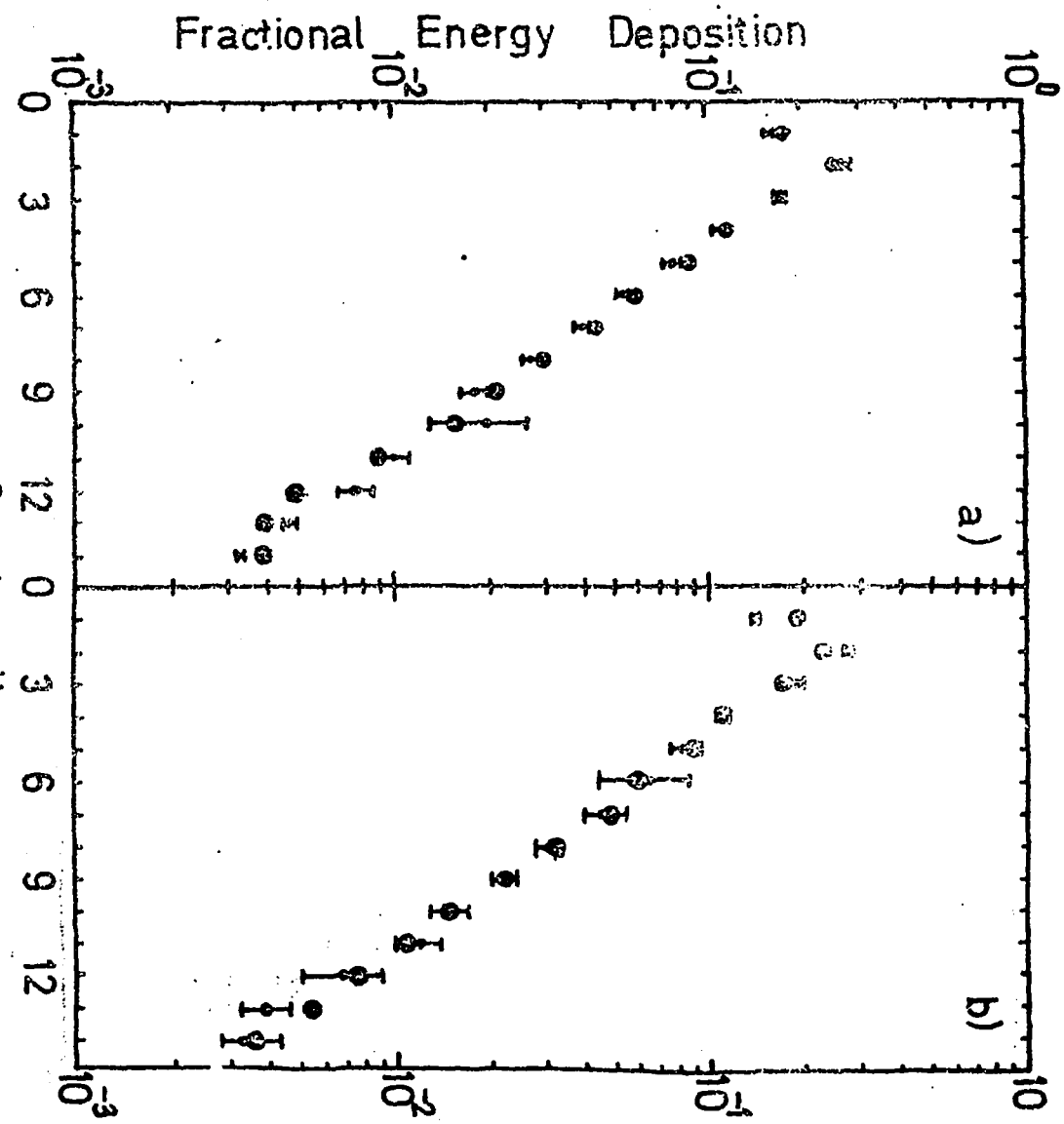
Fractional Energy Deposition
10^{-3}
10^{-2}
10^{-1}
10^{0}
Counter #
0
3
6
9
12
a)
b)

Fig. 1.9

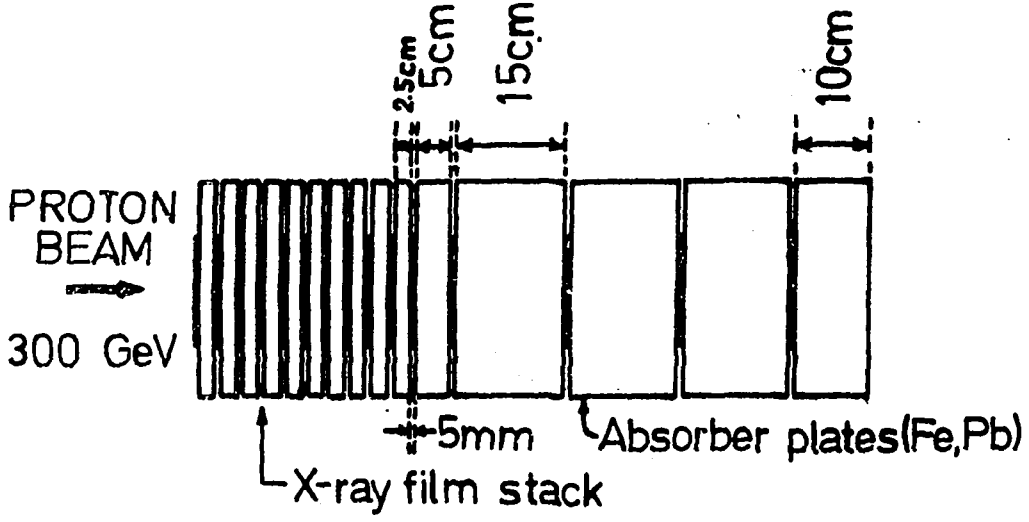
2.5cm
5cm
15cm
10cm
PROTON
BEAM
300 GeV
5mm
Absorber plates(Fe,Pb)
X-ray film stack

Fig. 1.10

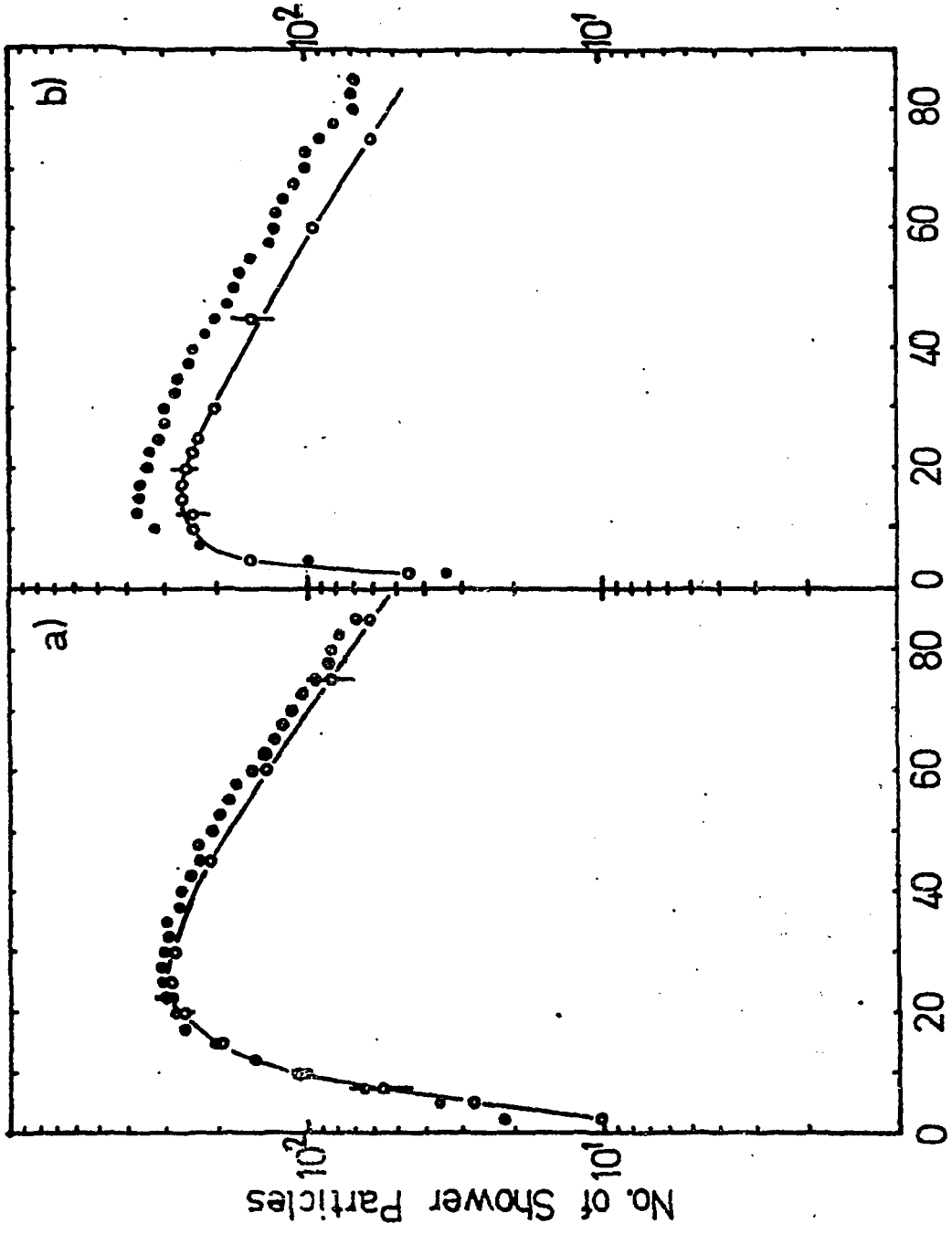

Fig. 1.11

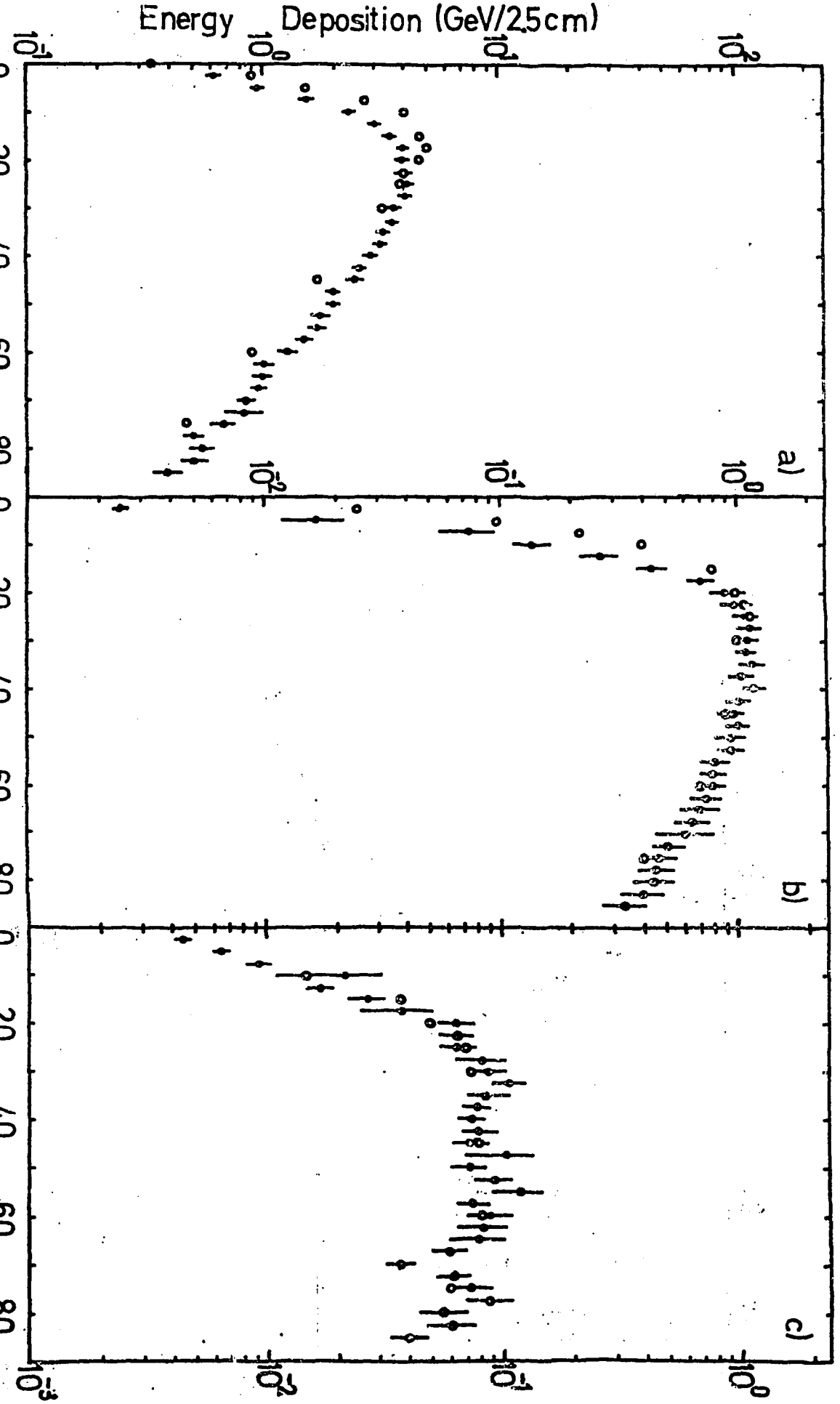

Fig. 1.12

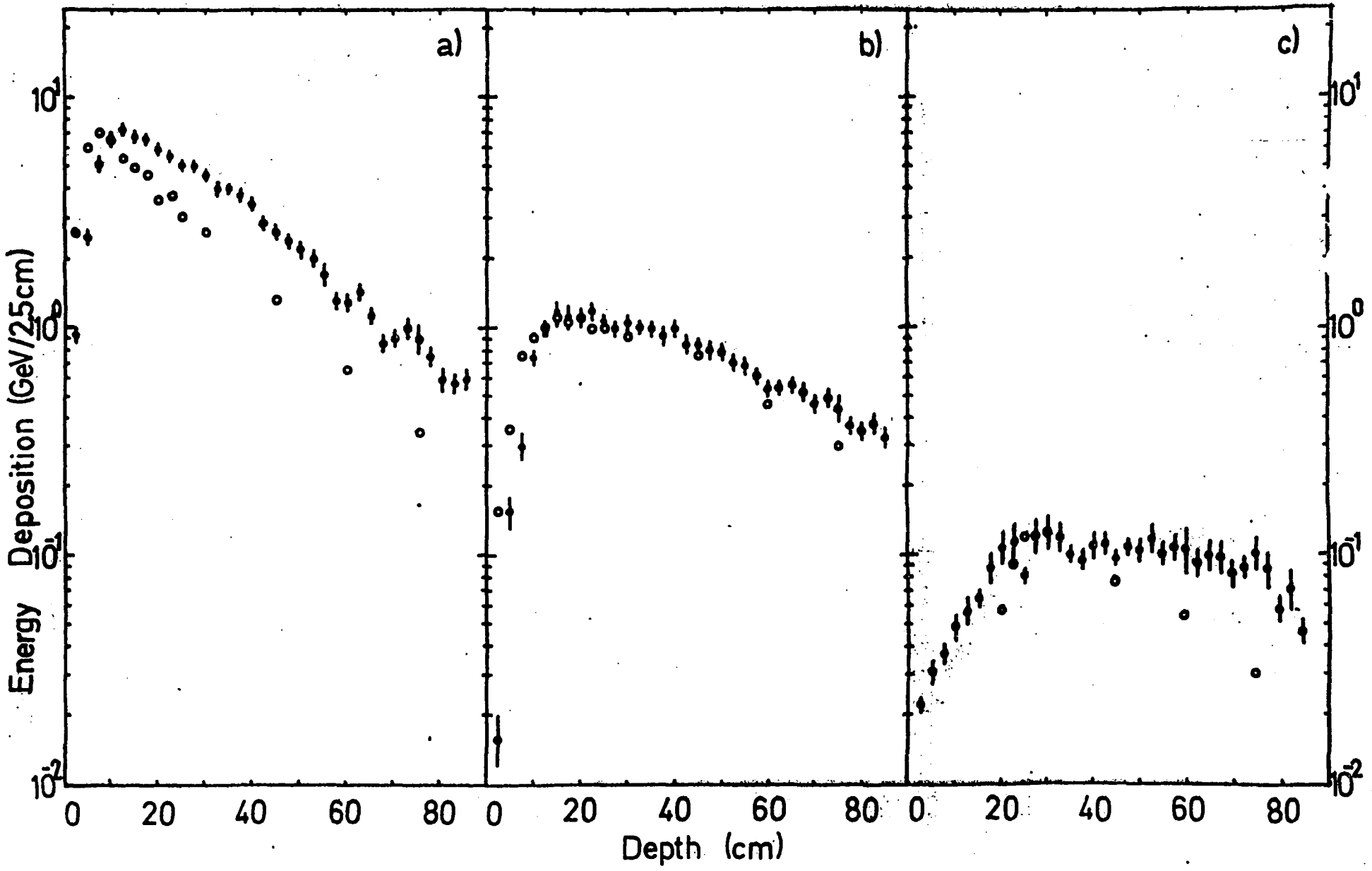
a)
b)
c)
Energy Deposition (GeV/25cm)
Depth (cm)
0
20
40
60
80
10^{1}
10^{0}
10^{-1}
10^{-2}

Fig. 1.13

FIGURE CAPTIONS

[1] Layout of the CHARM prototype calorimeter. Each of the 19 modules consists of 22gcm^{-2} marble, 1.5gcm^{-2} Al and 3gcm^{-2} plastic scintillator.

[2] Fractional energy deposition in the calorimeter modules: ● – exp.[7]; + – MARS10; number of shower histories N=10000, energy cutoff – 30MeV, a) – E_0 = 1GeV, b) – E_0 = 2GeV, c) – E_0 = 3GeV, d) – E_0 = 5GeV, e) E_0 = 6GeV.

[3] Layout of the CDHS calorimeter prototype.

[4] Fraction of the total shower energy detected (● – [8]) and calculated(+ – MARS10) in each calorimeter module, N = 10000, the cutoff energy is a) 10MeV, b) – 20MeV and c) – 30MeV.

[5] Scale drawing of the apparatus and the tungsten modules. SC1, SC2 and SC3 are wire spark chambers; TOF1, TOF2, S2, S5 and S1 are plastic scintillators. Each of the modules T1–T5 consist of 13gcm^{-2} [illegible] layer followed by 6.5mm thick sheet of plastic. Each of the T6–T16 modules consist of 4 layers of [illegible] and 3 sheets of 6.5mm thick [illegible] ranges of calorimeter layers with 26.3gcm^{-2} of tungsten [illegible]

[6] The average number of [illegible]ent particles in the cascade as a function of [illegible] (● – exp. data, ○ – MARS10). a) 5GeV/c cutoff [illegible] 10GeV/c, cutoff – 50MeV; c) – 10GeV/c, cutoff [illegible]

[illegible] calorimeter.

[illegible] of negative hadrons in iron as a [illegible] data. a) – E_0 = 100GeV, b) – E_0 = [illegible] ● – MARS10, cutoff [illegible]

[illegible] positive hadrons in iron as a [illegible] ● – E_0 = 150GeV, b) – E_0 = [illegible] cutoff 30MeV, N = 5000.

[illegible] chamber

[illegible] as a function of iron + Cu and [illegible] b) absorber only. The primary particle is a 300GeV proton;

solid lines are experiment; ● – MARS10, cutoff – 1Gev for iron, 0.9GeV for lead, N = 10000.

[12] Longitudinal energy deposition in the iron absorber (in arbitrary units) at various radii. a) 0<r<0.5cm, b) 1cm<r<3cm, c) 10cm<r<15cm; o – experiment, ϕ – MARS10.

[13] The same as in figure 12 for the lead absorber.

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МОДЕЛИРОВАНИЕ АДРОННЫХ ЛИВНЕЙ МЕТОДОМ МОНТЕ-КАРЛО
ЧАСТЬ I: СРАВНЕНИЕ РЕЗУЛЬТАТОВ РАСЧЕТОВ ПРОГРАММОЙ MARS IO
С РЕЗУЛЬТАТАМИ ЭКСПЕРИМЕНТОВ
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