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ESTIMATE OF PARTICLE FLUXES (≥1 MeV) IN A HIGH -Z BEAM DUMP BY INCIDENT PROTONS AT FERMILAB ENERGIES

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Introduction

This TM reports on a calculation of particle fluxes in a large, high -Z target by incident protons at Fermilab energies, since intense particle fluxes might be of interest in testing materials for radiation damage, e.g., materials with practical application in thermonuclear reactors[1]. There are various other uses as well[2] which might be exploited if the creation of such a facility is justified by the energy research objectives.

The Monte Carlo code normally employed at Fermilab for shielding design, CASIM[3], has a rather high momentum cut-off for particles which are followed by the calculation. Typically a value of 0.3 GeV/c (~50 MeV nucleon kinetic energy) is used. Effects of lower energy neutrons are included, e.g., in estimates of radiation dose, by assuming the high energy flux is part of an equilibrium spectrum. This procedure clearly cannot be applied to the present problem.

A general revision of CASIM to incorporate lower energy particles, while highly desirable for a variety of problems has not yet been tackled. For the present purpose a rather crude "patch"

has been applied which allows to lower the momentum cut-off from an equivalent 50 MeV down to 1 MeV for neutrons. Production (and removal) characteristics were taken to be those of a high -Z target without being entirely specific, (its properties are taken alternatively from ^{208}Pb and ^{238}U depending upon availability). The production model is briefly summarized below. More accurate and specific information might be obtained by combining a suitable low energy code with a program such as CASIM. There are various ways this might be accomplished. For future more detailed studies this might be indicated. The present study was undertaken only to impart a rough idea of the magnitude of particle fluxes and of the shapes of neutron (and charged particle) spectra.

Production Model

The production model employed in the program CASIM is sufficiently documented elsewhere[3]. Briefly it is the sum of two terms. The first represents the incident particles re-emerging from the collision (leading particles) along with particles (pions) created in the collision. These particles are selected from distributions predicted by the model of Hagedorn and Ranft[4] which reproduces experimental data quite well. The second term represents additional nucleons (other than the collision partner) knocked out of the nucleus. These additional nucleons are selected from distributions given by Ranft and Routti[5], which are simple analytical expressions based on the intranuclear cascade calculations of

Bertini[6]. The numbers of outgoing particles are adjusted to enforce energy conservation in each collision (taking duly into account the energy carried off by subthreshold particles, energy losses due to binding energy and nuclear excitation).

In extending the program to include lower energies, first the cut-off momentum for all particles was lowered to 0.1 GeV/c (~5 MeV for nucleons). Next, some changes are made in the term describing knock-out particles. These changes are based on Bertini's calculations for ^{238}U and ^{208}Pb. A more thorough revision may be desirable for future calculations. In addition, and perhaps of most importance for the present purpose, a third term is added representing evaporation neutrons (≥1 MeV). Their number and average energy are again taken from Bertini's calculation. It appears they can be well fitted to an exponential distribution with a slope varying slowly with incident energy. The evaporation neutrons are assumed to be emitted isotropically in the laboratory. For nucleons incident below 50 MeV <u>all</u> outgoing particles are assumed to have the same exponential energy distribution; direct knock-out neutrons are merely added to the total. Between the lowest incident energy of Bertini's calculations (25 MeV) and the present cut-off (1 MeV) the numbers and spectra of low energy neutrons are chosen so as to be consistent with a recent evaluation of ^{238}U inelastic scattering cross sections[7]. Fission has been entirely neglected. Unless one wishes to concentrate on very low energy neutrons in large volumes this is probably justified[8]. The high energy total inelastic

cross section assumed is the value calculated for ^{208}Pb with slight adjustments at lower energies. The density of the medium is taken to be 12 $g \cdot cm^{-3}$. To estimate albedo beam particles are brought 20 cm into the cylinder before interacting. The beam is of square cross section measuring 0.1 cm on the side.

Results

As is customary in this type of calculation, results are expressed in star densities (i.e., densities of nuclear interactions). These may be converted into fluxes upon multiplication by the interaction length ($\simeq$15 cm, though slightly energy dependent) and by the incident particle current ($\sim 5 \cdot 10^{12} sec^{-1}$ typically at Fermilab). Also as per custom momentum spectra of interacting particles are presented. The star densities are averaged over finite volumes (4 cm longitudinally and 2 cm in radial extent) covering the entire cylinder. The innermost radial region is further subdivided into five annular regions. To estimate momentum spectra the volumes are typically much larger (40 cm longitudinally and 20 cm radially).

Fig. 1 shows a computer prepared plot of contours of equal total star density, i.e., summed over all particles (neutrons, $p > .043$ GeV/c and changed particles $p > 0.1$ GeV/c where p is the momentum) for 400 GeV/c protons incident on the large target. Because of finite bin size and other limitations, this plot does not accurately reveal the high intensity contours close to the

beam axis. Table I lists the total star densities near the beam axis. As can be seen some very intense fluxes ($\sim 2 \cdot 10^{14}$ cm^{-2} sec^{-1} at the maximum) can be expected over areas as large as 0.5 cm.

Figs. 2-4 show some momentum spectra of interacting neutrons in various regions of the target. Tables II-IV list, for a few of the regions shown in Figs. 2-4, in addition to the neutrons the charged particle spectra. These charged particle spectra might be a rather annoying contamination in certain applications.

For a pencil beam incident on a homogeneous target, which is approximately the case calculated here, it can easily be shown that for materials close in nuclear and atomic properties, but differing in density the flux at position $\vec{r}$, obeys the scaling law

$$\Phi_a(\vec{r}) = \Phi_b(\rho_a\vec{r}/\rho_b)\cdot(\rho_a/\rho_b)$$

where Φ_a, Φ_b are the fluxes in materials a and b respectively and ρ_a, ρ_b are the corresponding densities.

From the above then at least a first impression can be gained about the capabilities and limitations of such a facility. If further calculation is desired, revising the low energy part of the production model is almost mandatory. Also, other information (besides fluxes and spectra) could be generated such as heat generated in the target. But these are perhaps best postponed until the present results have been examined.

References

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Table Captions

I. Total star densities (stars/cm^3·inc·proton) near the beam axis as a function of depth and radial coordinates.

II. Momentum Spectra (stars/cm^3·GeV/c·inc·proton) for central regions ($r < 20$ cm) between depths of 0 to 20 cm (measured from point where beam begins to interact, see text).

III. See Table II, but for depth from 60 to 100 cm.

IV. See Table II, but for depth from 140 to 180 cm.

TAR DENSITY IN UNITS OF STARS/(CM3*INC.PARTICLE) AS A FUNCTION OF DEPTH(DOWN) AND RADIUS(ACROSS) IN CM
OR PARTICLES OF KIND 4
1=PRCTCNS,2=NEUTRONS,3=PICNS,4=ALL STARS,5=ENERGY DENSITY IN GEV/(CM3*INC.PARTICLE),6=RELATIVE ERROR OF ALL STAR DENSITY)

		0.0	0.4000	0.8000	1.2000	1.6000
		0.4000	0.8000	1.2000	1.6000	2.0000
-20.00	-16.00	0.611E-02	0.497E-02	0.264E-02	0.120E-02	0.285E-02
-16.00	-12.00	0.802E-02	0.995E-02	0.298E-02	0.203E-02	0.443E-02
-12.00	-8.00	0.277E-01	0.835E-02	0.325E-02	0.494E-02	0.572E-02
-8.00	-4.00	0.398E-01	0.128E-01	0.122E-01	0.116E-01	0.894E-02
-4.00	0.0	0.964E-01	0.384E-01	0.237E-01	0.158E-01	0.174E-01
0.0	4.00	0.648E 00	0.143E 00	0.869E-01	0.723E-01	0.445E-01
4.00	8.00	0.121E 01	0.415E 00	0.181E 00	0.114E 00	0.976E-01
8.00	12.00	0.158E 01	0.550E 00	0.327E 00	0.215E 00	0.166E 00
12.00	16.00	0.245E 01	0.861E 00	0.459E 00	0.494E 00	0.349E 00
16.00	20.00	0.218E 01	0.955E 00	0.541E 00	0.423E 00	0.325E 00
20.00	24.00	0.221E 01	0.886E 00	0.581E 00	0.484E 00	0.328E 00
24.00	28.00	0.234E 01	0.108E 01	0.725E 00	0.546E 00	0.424E 00
28.00	32.00	0.210E 01	0.105E 01	0.767E 00	0.553E 00	0.440E 00
32.00	36.00	0.241E 01	0.114E 01	0.817E 00	0.556E 00	0.508E 00
36.00	40.00	0.218E 01	0.119E 01	0.797E 00	0.599E 00	0.489E 00
40.00	44.00	0.216E 01	0.123E 01	0.918E 00	0.630E 00	0.534E 00
44.00	48.00	0.196E 01	0.121E 01	0.768E 00	0.672E 00	0.585E 00
48.00	52.00	0.171E 01	0.993E 00	0.766E 00	0.679E 00	0.556E 00
52.00	56.00	0.176E 01	0.106E 01	0.733E 00	0.651E 00	0.475E 00
56.00	60.00	0.148E 01	0.894E 00	0.664E 00	0.542E 00	0.482E 00
60.00	64.00	0.153E 01	0.104E 01	0.746E 00	0.579E 00	0.512E 00
64.00	68.00	0.119E 01	0.740E 00	0.677E 00	0.485E 00	0.393E 00
68.00	72.00	0.104E 01	0.698E 00	0.605E 00	0.466E 00	0.385E 00
72.00	76.00	0.818E 00	0.708E 00	0.518E 00	0.432E 00	0.360E 00
76.00	80.00	0.876E 00	0.647E 00	0.500E 00	0.437E 00	0.328E 00
80.00	84.00	0.870E 00	0.572E 00	0.449E 00	0.346E 00	0.272E 00
84.00	88.00	0.645E 00	0.570E 00	0.527E 00	0.394E 00	0.341E 00
88.00	92.00	0.667E 00	0.485E 00	0.400E 00	0.289E 00	0.292E 00
92.00	96.00	0.577E 00	0.385E 00	0.351E 00	0.314E 00	0.274E 00
96.00	100.00	0.480E 00	0.367E 00	0.336E 00	0.262E 00	0.286E 00
100.00	104.00	0.541E 00	0.452E 00	0.322E 00	0.294E 00	0.235E 00
104.00	108.00	0.444E 00	0.372E 00	0.269E 00	0.207E 00	0.189E 00
108.00	112.00	0.351E 00	0.327E 00	0.248E 00	0.198E 00	0.177E 00
112.00	116.00	0.290E 00	0.264E 00	0.254E 00	0.262E 00	0.161E 00
116.00	120.00	0.273E 00	0.282E 00	0.233E 00	0.169E 00	0.165E 00
120.00	124.00	0.220E 00	0.202E 00	0.195E 00	0.181E 00	0.134E 00
124.00	128.00	0.296E 00	0.120E 00	0.125E 00	0.131E 00	0.108E 00
128.00	132.00	0.165E 00	0.127E 00	0.132E 00	0.119E 00	0.109E 00
132.00	136.00	0.208E 00	0.173E 00	0.103E 00	0.993E-01	0.867E-01
136.00	140.00	0.151E 00	0.121E 00	0.114E 00	0.901E-01	0.786E-01
140.00	144.00	0.992E-01	0.842E-01	0.872E-01	0.742E-01	0.727E-01
144.00	148.00	0.156E 00	0.104E 00	0.715E-01	0.621E-01	0.595E-01
148.00	152.00	0.828E-01	0.857E-01	0.727E-01	0.625E-01	0.451E-01
152.00	156.00	0.572E-01	0.906E-01	0.461E-01	0.495E-01	0.583E-01
156.00	160.00	0.885E-01	0.520E-01	0.595E-01	0.528E-01	0.347E-01
160.00	164.00	0.749E-01	0.541E-01	0.708E-01	0.380E-01	0.435E-01
164.00	168.00	0.783E-01	0.409E-01	0.441E-01	0.313E-01	0.450E-01
168.00	172.00	0.456E-01	0.247E-01	0.400E-01	0.407E-01	0.397E-01
172.00	176.00	0.296E-01	0.449E-01	0.273E-01	0.309E-01	0.292E-01
176.00	180.00	0.332E-01	0.214E-01	0.285E-01	0.172E-01	0.247E-01

Table I

MOMENTUM SPECTRA OF INTERACTING PARTICLES (STARS/CM3*GEV/C*INC.PTCLE)

	Z FROM 0.0 TO 20.00 CM				Z FROM 0.0 TO 20.00 CM			
	R FROM 0.0 TO 10.00 CM				R FROM 10.00 TO 20.00 CM			
MOMENTUM	PROTONS	NEUTRONS	PIONS	ALL STARS	PROTONS	NEUTRONS	PIONS	ALL STARS
0.01 - 0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.01 - 0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.01 - 0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.02 - 0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.02 - 0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.03 - 0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.04 - 0.04	0.0	0.13E 01	0.0	0.13E 01	0.0	0.12E 01	0.0	0.12E 01
0.04 - 0.06	0.0	0.12E 01	0.0	0.12E 01	0.0	0.86E 00	0.0	0.86E 00
0.06 - 0.07	0.0	0.83E 00	0.0	0.83E 00	0.0	0.53E 00	0.0	0.53E 00
0.07 - 0.09	0.0	0.52E 00	0.0	0.52E 00	0.0	0.34E 00	0.0	0.34E 00
0.09 - 0.11	0.72E-05	0.40E 00	0.68E-04	0.41E 00	0.37E-06	0.17E 00	0.0	0.17E 00
0.11 - 0.14	0.35E-04	0.20E 00	0.14E-03	0.20E 00	0.25E-05	0.74E-01	0.94E-05	0.74E-01
0.14 - 0.18	0.92E-04	0.87E-01	0.45E-03	0.88E-01	0.12E-05	0.28E-01	0.15E-03	0.28E-01
0.18 - 0.22	0.21E-03	0.47E-01	0.70E-03	0.48E-01	0.70E-05	0.15E-01	0.64E-04	0.15E-01
0.22 - 0.28	0.37E-03	0.19E-01	0.24E-03	0.20E-01	0.66E-05	0.72E-02	0.28E-04	0.73E-02
0.28 - 0.35	0.41E-03	0.88E-02	0.48E-03	0.97E-02	0.72E-05	0.35E-02	0.26E-04	0.35E-02
0.35 - 0.45	0.47E-03	0.49E-02	0.36E-03	0.57E-02	0.26E-05	0.26E-02	0.31E-04	0.27E-02
0.45 - 0.56	0.44E-03	0.27E-02	0.46E-03	0.36E-02	0.0	0.66E-03	0.45E-04	0.70E-03
0.56 - 0.71	0.15E-03	0.10E-02	0.41E-03	0.16E-02	0.25E-05	0.22E-03	0.15E-05	0.22E-03
0.71 - 0.89	0.14E-03	0.40E-03	0.39E-03	0.93E-03	0.47E-05	0.69E-04	0.22E-05	0.76E-04
0.89 - 1.12	0.88E-04	0.21E-03	0.29E-03	0.58E-03	0.47E-05	0.38E-04	0.0	0.43E-04
1.12 - 1.41	0.73E-04	0.68E-04	0.26E-03	0.41E-03	0.14E-04	0.25E-05	0.0	0.16E-04
1.41 - 1.78	0.74E-04	0.11E-03	0.21E-03	0.40E-03	0.58E-07	0.21E-05	0.0	0.22E-05
1.78 - 2.24	0.91E-05	0.24E-04	0.12E-03	0.15E-03	0.0	0.0	0.0	0.0
2.24 - 2.82	0.11E-04	0.14E-04	0.11E-03	0.13E-03	0.0	0.0	0.0	0.0
2.82 - 3.55	0.10E-04	0.57E-05	0.59E-04	0.76E-04	0.0	0.0	0.0	0.0
3.55 - 4.47	0.74E-05	0.84E-05	0.51E-04	0.67E-04	0.0	0.0	0.0	0.0
4.47 - 5.62	0.77E-05	0.22E-05	0.47E-04	0.57E-04	0.0	0.0	0.0	0.0
5.62 - 7.08	0.66E-05	0.39E-05	0.32E-04	0.43E-04	0.0	0.0	0.0	0.0
7.08 - 8.91	0.15E-05	0.20E-05	0.27E-04	0.30E-04	0.0	0.0	0.0	0.0
8.91 - 11.22	0.12E-05	0.26E-05	0.13E-04	0.17E-04	0.0	0.0	0.0	0.0
11.22 - 14.13	0.16E-05	0.25E-06	0.11E-04	0.13E-04	0.0	0.0	0.0	0.0
14.13 - 17.78	0.14E-05	0.20E-05	0.79E-05	0.11E-04	0.0	0.0	0.0	0.0
17.78 - 22.39	0.23E-06	0.65E-06	0.87E-05	0.96E-05	0.0	0.0	0.0	0.0
22.39 - 28.18	0.13E-05	0.22E-06	0.45E-05	0.60E-05	0.0	0.0	0.0	0.0
28.18 - 35.48	0.25E-06	0.12E-06	0.36E-05	0.40E-05	0.0	0.0	0.0	0.0
35.48 - 44.67	0.50E-06	0.93E-07	0.26E-05	0.32E-05	0.0	0.0	0.0	0.0
44.67 - 56.23	0.26E-06	0.15E-06	0.19E-05	0.23E-05	0.0	0.0	0.0	0.0
56.23 - 70.79	0.39E-06	0.15E-06	0.83E-06	0.14E-05	0.0	0.0	0.0	0.0
70.79 - 89.12	0.17E-06	0.77E-07	0.61E-06	0.86E-06	0.0	0.0	0.0	0.0
89.12 - 112.20	0.15E-06	0.51E-07	0.38E-06	0.58E-06	0.0	0.0	0.0	0.0
112.20 - 141.25	0.50E-07	0.26E-07	0.18E-06	0.26E-06	0.0	0.0	0.0	0.0
141.25 - 177.83	0.41E-07	0.34E-07	0.68E-07	0.14E-06	0.0	0.0	0.0	0.0
177.83 - 223.87	0.78E-07	0.53E-08	0.91E-08	0.92E-07	0.0	0.0	0.0	0.0
223.87 - 281.84	0.30E-07	0.25E-07	0.0	0.55E-07	0.0	0.0	0.0	0.0
281.84 - 354.81	0.53E-07	0.32E-07	0.0	0.85E-07	0.0	0.0	0.0	0.0
354.81 - 446.68	0.25E-05	0.17E-07	0.0	0.25E-05	0.0	0.0	0.0	0.0
446.68 - 562.34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
562.34 - 707.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
707.94 - 891.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
891.25 - 1122.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table II

OMENTUM SPECTRA OF INTERACTING PARTICLES(STARS/CM3*GEV/C*INC.PTCLE)

	Z FROM 60.00 TO 100.00 CM				Z FROM 60.00 TO 100.00 CM			
	R FROM 0.0 TO 10.00 CM				R FROM 10.00 TO 20.00 CM			
MOMENTUM	PROTONS	NEUTRONS	PIONS	ALL STARS	PROTONS	NEUTRONS	PIONS	ALL STARS
0.01 - 0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.01 - 0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.01 - 0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.02 - 0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.02 - 0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.03 - 0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.04 - 0.04	0.0	0.35E 01	0.0	0.35E 01	0.0	0.32E 01	0.0	0.32E 01
0.04 - 0.06	0.0	0.31E 01	0.0	0.31E 01	0.0	0.29E 01	0.0	0.29E 01
0.06 - 0.07	0.0	0.23E 01	0.0	0.23E 01	0.0	0.20E 01	0.0	0.20E 01
0.07 - 0.09	0.0	0.16E 01	0.0	0.16E 01	0.0	0.12E 01	0.0	0.12E 01
0.09 - 0.11	0.15E-04	0.91E 00	0.40E-04	0.91E 00	0.46E-05	0.59E 00	0.42E-04	0.59E 00
0.11 - 0.14	0.96E-04	0.46E 00	0.74E-03	0.46E 00	0.26E-04	0.24E 00	0.54E-03	0.24E 00
0.14 - 0.18	0.24E-03	0.21E 00	0.16E-02	0.21E 00	0.74E-04	0.10E 00	0.12E-02	0.10E 00
0.18 - 0.22	0.51E-03	0.93E-01	0.33E-02	0.97E-01	0.13E-03	0.48E-01	0.23E-02	0.50E-01
0.22 - 0.28	0.85E-03	0.42E-01	0.12E-02	0.44E-01	0.25E-03	0.24E-01	0.87E-03	0.25E-01
0.28 - 0.35	0.12E-02	0.25E-01	0.21E-02	0.28E-01	0.23E-03	0.17E-01	0.11E-02	0.18E-01
0.35 - 0.45	0.15E-02	0.14E-01	0.24E-02	0.18E-01	0.26E-03	0.97E-02	0.11E-02	0.11E-01
0.45 - 0.56	0.13E-02	0.95E-02	0.23E-02	0.13E-01	0.36E-03	0.53E-02	0.95E-03	0.66E-02
0.56 - 0.71	0.12E-02	0.56E-02	0.20E-02	0.88E-02	0.46E-03	0.34E-02	0.69E-03	0.45E-02
0.71 - 0.89	0.59E-03	0.21E-02	0.19E-02	0.46E-02	0.22E-03	0.16E-02	0.44E-03	0.22E-02
0.89 - 1.12	0.55E-03	0.18E-02	0.16E-02	0.39E-02	0.18E-03	0.89E-03	0.31E-03	0.14E-02
1.12 - 1.41	0.47E-03	0.80E-03	0.11E-02	0.24E-02	0.78E-04	0.40E-03	0.19E-03	0.67E-03
1.41 - 1.78	0.23E-03	0.53E-03	0.92E-03	0.17E-02	0.42E-04	0.19E-03	0.15E-03	0.39E-03
1.78 - 2.24	0.10E-03	0.20E-03	0.78E-03	0.11E-02	0.22E-04	0.45E-04	0.65E-04	0.13E-03
2.24 - 2.82	0.97E-04	0.94E-04	0.46E-03	0.65E-03	0.14E-04	0.33E-04	0.16E-04	0.63E-04
2.82 - 3.55	0.51E-04	0.82E-04	0.30E-03	0.44E-03	0.13E-04	0.12E-04	0.92E-05	0.34E-04
3.55 - 4.47	0.25E-04	0.20E-04	0.23E-03	0.28E-03	0.20E-06	0.18E-05	0.74E-05	0.94E-05
4.47 - 5.62	0.78E-05	0.95E-05	0.15E-03	0.17E-03	0.33E-06	0.32E-07	0.20E-05	0.23E-05
5.62 - 7.08	0.25E-05	0.49E-05	0.71E-04	0.78E-04	0.91E-08	0.26E-06	0.11E-06	0.38E-06
7.08 - 8.91	0.34E-05	0.79E-05	0.62E-04	0.73E-04	0.22E-07	0.51E-07	0.64E-08	0.79E-07
8.91 - 11.22	0.41E-05	0.42E-05	0.37E-04	0.45E-04	0.14E-08	0.91E-08	0.48E-08	0.15E-07
11.22 - 14.13	0.20E-05	0.99E-06	0.31E-04	0.34E-04	0.0	0.0	0.0	0.0
14.13 - 17.78	0.65E-06	0.67E-06	0.14E-04	0.15E-04	0.39E-09	0.0	0.0	0.39E-09
17.78 - 22.39	0.53E-06	0.29E-06	0.94E-05	0.10E-04	0.0	0.0	0.0	0.0
22.39 - 28.18	0.43E-06	0.62E-06	0.35E-05	0.46E-05	0.0	0.0	0.0	0.0
28.18 - 35.48	0.45E-06	0.22E-06	0.26E-05	0.33E-05	0.0	0.0	0.0	0.0
35.48 - 44.67	0.11E-06	0.31E-06	0.18E-05	0.22E-05	0.0	0.0	0.0	0.0
44.67 - 56.23	0.17E-06	0.21E-06	0.12E-05	0.16E-05	0.0	0.0	0.0	0.0
56.23 - 70.79	0.82E-07	0.12E-06	0.42E-06	0.62E-06	0.0	0.0	0.0	0.0
70.79 - 89.12	0.53E-07	0.61E-07	0.20E-06	0.31E-06	0.0	0.0	0.0	0.0
89.12 - 112.20	0.38E-07	0.19E-07	0.12E-06	0.18E-06	0.0	0.0	0.0	0.0
112.20 - 141.25	0.36E-07	0.33E-07	0.68E-07	0.14E-06	0.0	0.0	0.0	0.0
141.25 - 177.83	0.42E-07	0.14E-07	0.10E-07	0.66E-07	0.0	0.0	0.0	0.0
177.83 - 223.87	0.17E-07	0.12E-07	0.74E-08	0.36E-07	0.0	0.0	0.0	0.0
223.87 - 281.84	0.17E-07	0.11E-07	0.0	0.28E-07	0.0	0.0	0.0	0.0
281.84 - 354.81	0.33E-08	0.91E-08	0.0	0.12E-07	0.0	0.0	0.0	0.0
354.81 - 446.68	0.52E-07	0.18E-08	0.0	0.54E-07	0.0	0.0	0.0	0.0
446.68 - 562.34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
562.34 - 707.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
707.94 - 891.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
891.25 - 1122.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table III

CMENTUM SPECTRA OF INTERACTING PARTICLES (STARS/CM3*GEV/C*INC.PTCLE)

	Z FROM 140.00 TO 180.00 CM				Z FROM 140.00 TO 180.00 CM			
	R FRCM 20.00 TO 40.00 CM				R FROM 40.00 TO 60.00 CM			
MCMENTUM	PROTCNS	NEUTRONS	PIONS	ALL STARS	PROTONS	NEUTRONS	PICNS	ALL STARS
0.01 - 0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.01 - 0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.01 - 0.02	0.0	0.C	0.0	0.0	0.0	0.0	0.0	0.0
C.02 - 0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.02 - 0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C.03 - 0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C.C4 - C.C4	C.C	0.25E 00	0.0	0.25E 00	0.0	0.88E-C1	0.0	0.88E-C1
0.04 - 0.06	0.0	0.18E 00	0.0	0.18E 00	0.0	0.55E-01	0.0	0.55E-01
C.C6 - 0.07	0.0	0.12E 00	0.0	0.12E 00	0.0	0.36E-C1	0.0	0.36E-01
0.07 - 0.09	C.C	0.78E-01	0.0	0.78E-01	0.0	0.22E-01	0.0	0.22E-C1
0.09 - 0.11	0.39E-06	0.35E-01	0.67E-05	0.35E-01	0.33E-07	0.87E-02	0.72E-06	0.87E-02
C.11 - C.14	0.14E-C5	0.15E-01	0.42E-04	0.15E-01	0.32E-06	0.43E-02	C.20E-04	0.43E-C2
0.14 - 0.18	0.28E-05	0.56E-02	0.14E-03	0.58E-02	0.60E-06	0.13E-02	0.12E-04	0.13E-02
C.18 - 0.22	0.79E-05	0.21E-02	0.16E-03	0.23E-02	0.11E-05	0.56E-C3	0.14E-04	0.58E-03
0.22 - 0.28	C.19E-C4	0.14E-02	0.77E-04	0.15E-02	0.87E-06	0.59E-C3	0.55E-05	0.60E-C3
0.28 - 0.35	0.14E-04	0.93E-03	0.13E-03	0.11E-02	0.51E-C5	0.50E-03	0.69E-05	0.51E-03
0.35 - 0.45	C.19E-C4	0.99E-03	0.85E-04	0.11E-02	0.29E-05	0.43E-03	0.45E-05	0.44E-C3
0.45 - 0.56	0.20E-04	0.42E-03	0.72E-04	0.51E-03	0.73E-05	0.19E-03	0.33E-05	0.20E-03
0.56 - C.71	C.20E-04	0.22E-03	0.39E-04	0.28E-03	0.13E-C4	0.11E-C3	C.14E-C5	0.13E-03
0.71 - 0.89	C.15E-C4	0.14E-03	0.27E-04	0.18E-03	0.15E-07	0.15E-03	0.96E-06	0.15E-C3
0.89 - 1.12	0.44E-05	0.83E-04	0.19E-04	0.11E-03	0.96E-06	0.34E-04	0.33E-06	0.35E-04
1.12 - 1.41	0.17E-05	0.26E-04	0.11E-04	0.38E-04	0.23E-07	0.57E-C5	0.22E-C7	0.57E-05
1.41 - 1.78	0.26E-05	0.10E-04	0.53E-05	0.18E-04	0.14E-07	0.22E-05	0.21E-07	0.22E-05
1.78 - 2.24	0.44E-06	0.10E-05	0.19E-05	0.34E-05	0.68E-C8	0.15E-C6	0.91E-08	0.17E-06
2.24 - 2.82	C.49E-C7	0.37E-06	0.38E-06	0.80E-06	0.24E-11	0.24E-06	0.14E-C8	0.24E-06
2.82 - 3.55	0.71E-08	0.15E-06	0.94E-07	0.25E-06	0.46E-11	0.17E-07	0.15E-09	0.17E-07
3.55 - 4.47	C.55E-C8	0.13E-07	0.49E-07	0.72E-07	0.0	0.14E-C8	0.C	0.14E-08
4.47 - 5.62	0.17E-C9	0.13E-07	0.19E-08	0.15E-07	0.0	0.65E-11	0.0	0.65E-11
5.62 - 7.C8	C.11E-08	0.13E-08	0.55E-08	0.80E-08	0.0	0.0	C.0	0.0
7.08 - 8.91	C.18E-10	0.43E-09	0.21E-10	0.47E-09	0.0	0.0	0.0	0.C
8.91 - 11.22	0.0	0.17E-10	0.0	0.17E-1C	0.0	0.0	0.0	0.0
11.22 - 14.13	C.0	0.C	0.0	0.0	0.0	0.0	C.0	0.0
14.13 - 17.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.78 - 22.39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.39 - 28.18	C.C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.18 - 35.48	0.0	0.C	0.0	0.0	0.0	0.0	0.0	0.0
35.48 - 44.67	0.0	0.0	0.0	0.0	0.0	0.0	C.0	0.0
44.67 - 56.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56.23 - 70.79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70.79 - 89.12	C.C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
89.12 - 112.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
112.2C - 141.25	C.C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
141.25 - 177.83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
177.83 - 223.87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
223.87 - 281.84	C.C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
281.84 - 354.81	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
354.81 - 446.68	0.0	0.0	0.0	0.0	0.0	0.0	C.0	0.0
446.68 - 562.34	C.C	0.0	0.0	0.0	0.0	0.0	0.0	0.C
562.34 - 707.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
707.94 - 891.25	C.C	0.0	0.0	0.0	0.0	0.C	0.0	0.0
891.25 - 1122.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table IV

Figure Captions

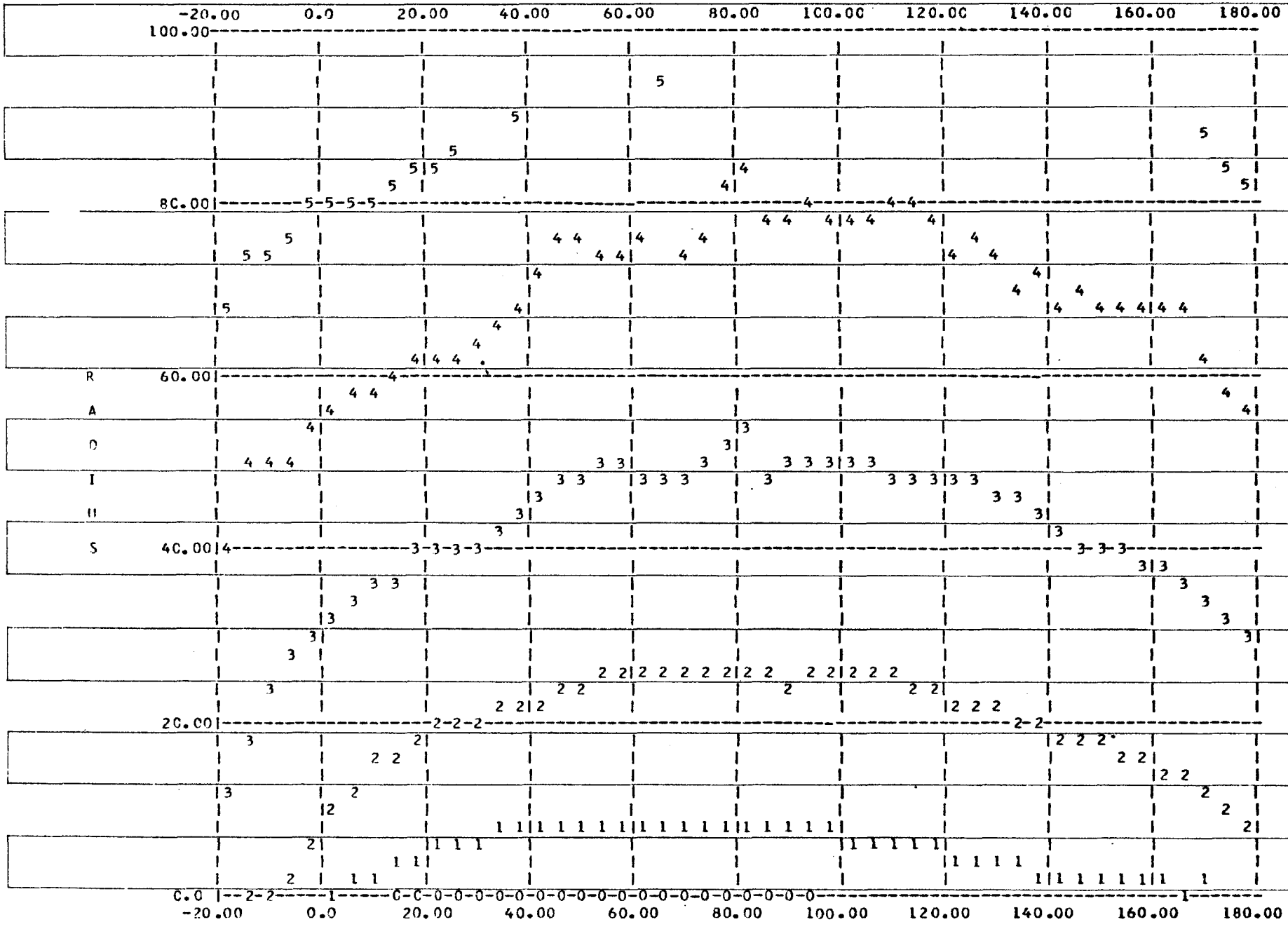
1. 400 GeV/c protons incident on a solid lead target. Contours of equal total star density (above momentum cut-off, see text) in stars/(cm^3·inc·proton).

2. Momentum spectrum of neutrons interacting in six different radial intervals between depths of 0 to 20 cm (measured from point where beam begins to interact, see text), units of stars/(cm^3·GeV/c·inc·proton).

3. See Fig. 2 but for depth from 60 to 100 cm.

4. See Fig. 2 but for depth from 140 to 180 cm.

CONTOURS OF EQUAL STAR(ENERGY) DENSITY, IN UNITS OF STARS(GEV)/(CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR THE INTEGRAL POWERS OF 10



R-LABELS REFER TO SMALLER VALUES OF CORRESPONDING BINS
LEGEND : NUMERICAL SYMBOLS REFER TO THE NEGATIVE POWER OF 10 OF THE STAR(ENERGY) DENSITY E.G., 5 REFERS TO THE 10**-5 CONTOUR
OTHER POWERS OF 10(SYMBOLS) :-10(A),-11(B),-12(C),-13(D),-14(E),-15(F),-16(G),-17(H),-18(I),-19(J)
1(Z),2(Y),3(X),4(W),5(V),6(U),7(T),8(S),9(R),10(Q)

Fig. 1

PLOT OF THE LOG OF THE MOMENTUM SPECTRUM OF NEUTRONS INTERACTING BETWEEN Z= 0.0 AND Z= 20.00 CM
UNITS OF STARS/(CM3*(GEV/C)*INC*PTCLE).

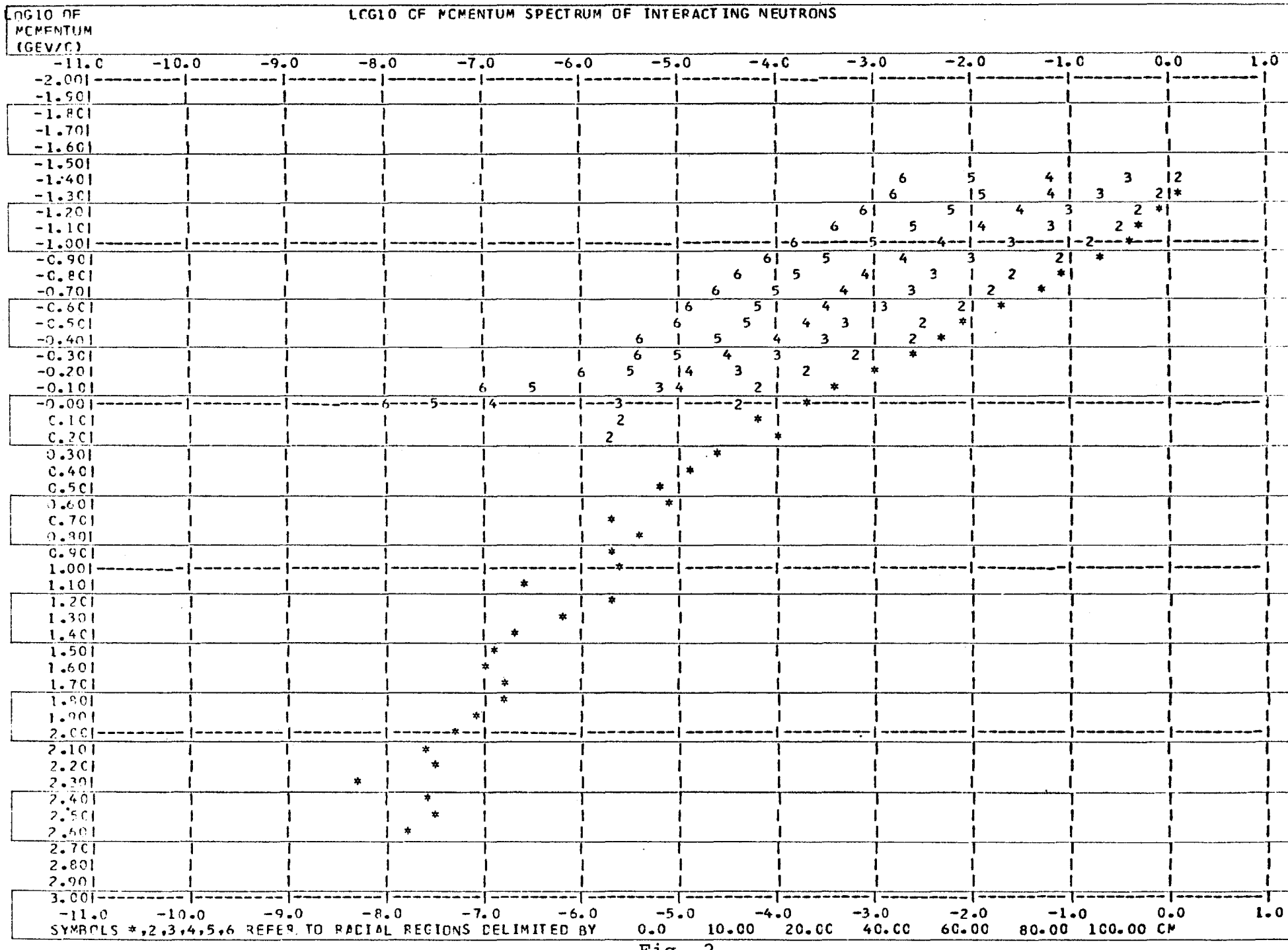


Fig. 2

PLOT OF THE LOG OF THE MOMENTUM SPECTRUM OF NEUTRONS INTERACTING BETWEEN Z= 60.00 AND Z= 100.00 CM
UNITS OF STARS/(CM3*(GEV/C)*INC*PTCLE).

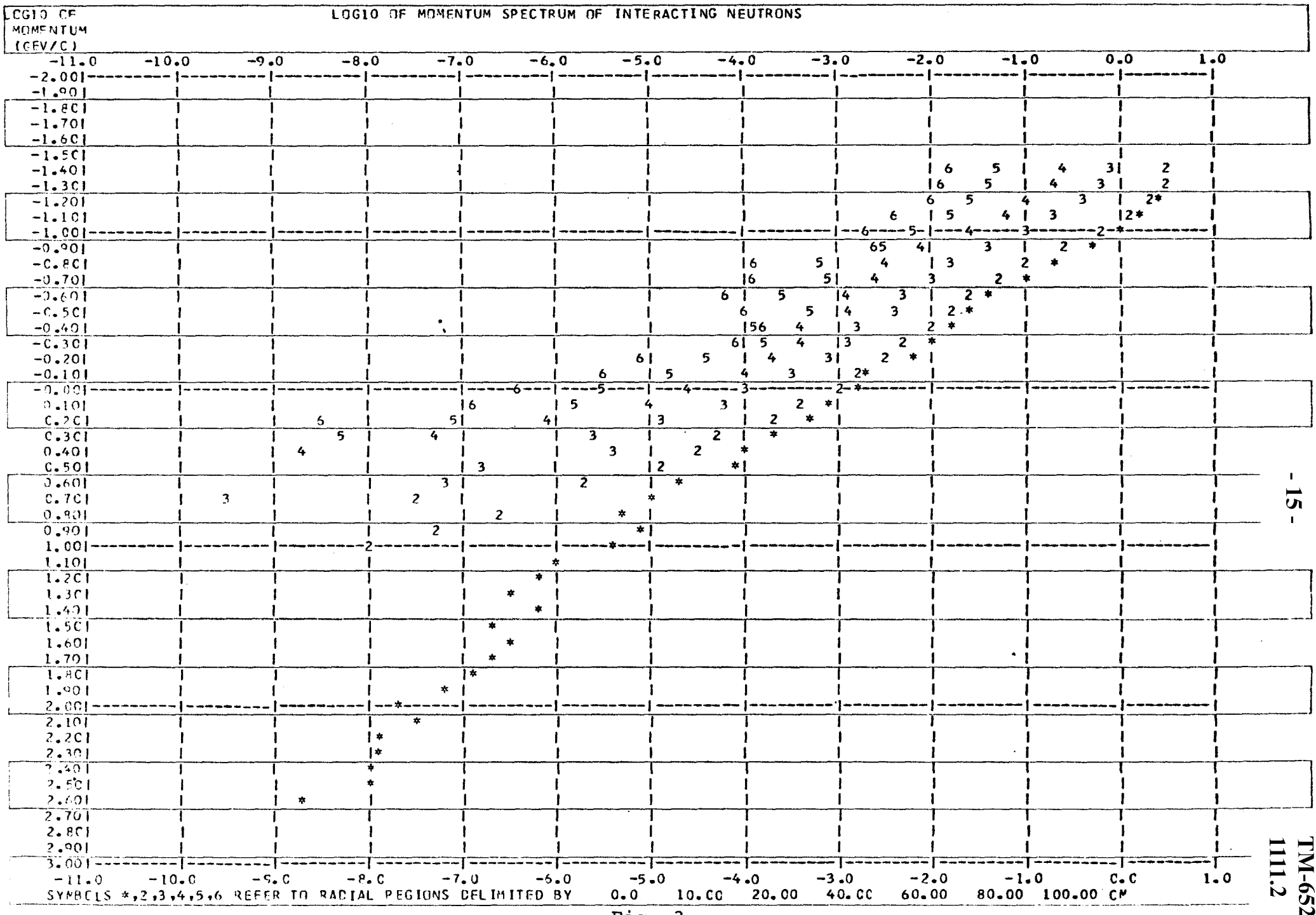


Fig. 3

PLOT OF THE LOG OF THE MOMENTUM SPECTRUM OF NEUTRONS INTERACTING BETWEEN Z= 140.00 AND Z= 180.00 CM
UNITS OF STARS/(CM3*(GEV/C)*INC*PTCLE)

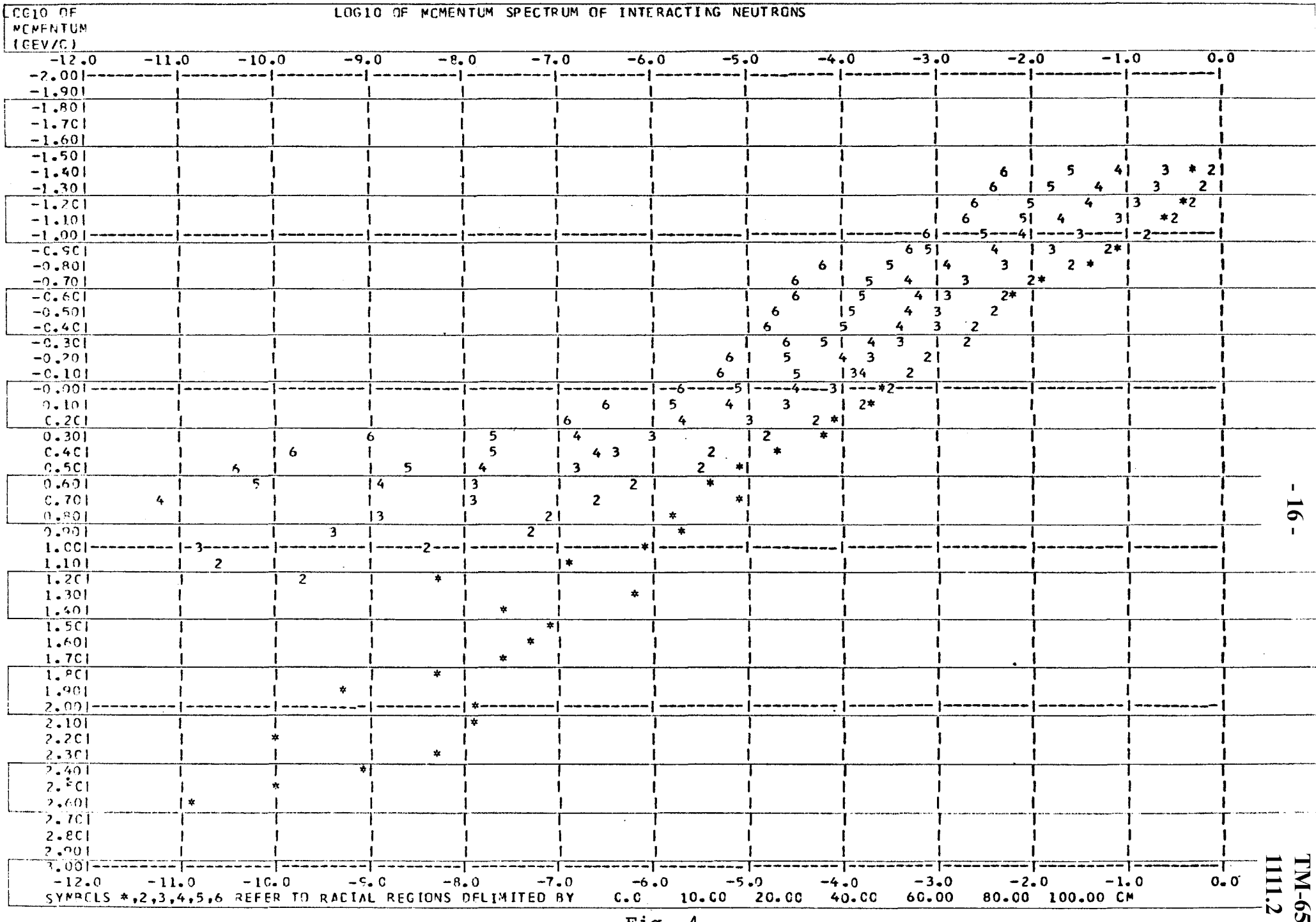


Fig. 4