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COSMIC RAY GROUP

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A MEASUREMENT OF THE SPECTRUM OF COSMIC RAY ELECTRONS BETWEEN 20 MEV AND 4 BEV IN 1968 - FURTHER EVIDENCE FOR EXTENSIVE TIME VARIATIONS OF THIS COMPONENT

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ABSTRACT

The intensity and spectrum of cosmic ray electrons from 20 MeV to 4 BeV has been measured at a depth of 2.5 g/cm^2 at Ft. Churchill in the summer of 1968 at a time when solar modulation effects had reduced the sea level neutron monitor rate by $\sim$ 12% below its sunspot minimum value. The instrument used and its calibration were identical to that used in previous flights to study electrons at this location in 1965 and 1966. The total electron intensity at 2.5 g/cm^2 atmospheric depth at energies $\gtrsim$ 2 BeV in 1968 was essentially the same as that observed in 1966, however at lower energies the intensity was greatly reduced in 1968. This reduction was a factor of 4 in the 200-400 MeV range. Atmospheric growth curves were used to determine the contribution of atmospheric secondary electrons. The deduced extra-terrestrial electron intensity appears to be a factor $\sim$ 7 lower in 1968 than in 1966 at energies just above 200 MeV. At higher energies the decrease becomes less - the intensity is a factor of two lower at 1 BeV and above 2 BeV the extra-terrestrial intensities are the same to within 10-20% in the two years. These results confirm earlier measurements of the solar modulation of electrons made in 1965-1966. The energy dependence of the electron modulation is essentially the same in the 1966-1968 period as was measured in 1965-1966.

INTRODUCTION AND DISCUSSION OF INSTRUMENT

We have measured the intensity and spectrum of cosmic ray electrons from 20 MeV to 4 BeV on a balloon flight from Ft. Churchill on July 31, 1968. The measurements were made with a 5 element telescope containing a lead glass Cerenkov total energy spectrometer and a gas Cerenkov detector. A diagram of the instrument used is shown in Figure 1. This is the identical instrument to the one we have used for electron measurements in the summers of 1965 and 1966 at Ft. Churchill. Its operation and response to electrons have been discussed previously. (Webber and Chotkowski, 1967 a,b). We shall try to explain the instrument as briefly as possible here so that the reader may better understand the results.

Vertically incident particles trigger a counter telescope consisting of plastic scintillation counters S_1 and S_2. The geometrical factor of this telescope is 5.2 ± 0.1 st cm^2. The counter S_2 acts to "stop down" the lead glass detector and the gas Cerenkov detector. For all telescope events, a notation is made as to whether the gas Cerenkov counter G, the guard counter C, and the penetration counter P have fired. In addition, the pulse height of the S_1 scintillator is measured to 128 channel accuracy, the pulse height of the lead glass Cerenkov total energy spectrometer L, to 256 channel accuracy, and the pulse height of the penetration counter also to 256 channel accuracy.

As a result of the guard and penetration criteria, there are 4 classes of events for each G and $\bar{G}$ event -- a total of 8 classes of events. For each of these classes a two dimensional pulse height matrix with coordinates S_1 and L is printed out. In addition, matrices with coordinates L and P are printed out for each class of events.

The gas Cerenkov counter is 60 cm in length and filled with Freon, at a pressure of 1 atmosphere. This provides an effective threshold energy $\sim 30\ m_oc^2$ for all particles.

The particles to be detected are required to pass through 3.0 g/cm^2 of matter (mostly Al) to make a telescope coincidence, $S_1\ S_2$, and an additional 1.2 g/cm^2 to reach the lead glass total energy spectrometer. The minimum energy electrons that can trigger the telescope is thus $\sim$ 6 MeV, although because of scattering, this lower limit is not well defined. The lead glass counter (Schott SF 6-FA) has a total thickness of 10 cm or 6.6 radiation lengths and contains 53 g/cm^2 of material, of which 36 g/cm^2 of slightly more than 6 radiation lengths is lead. The probability that a proton interacts in passing through this detector is approximately 0.35. Thus, most protons with energies great enough to trigger the gas Cerenkov detector will not interact and will therefore reach the penetration counter P and give a pulse in the lead glass spectrometer which is a measure of a single relativistic particle traversing the entire thickness of this counter. This important feature may be used to compare in-flight and ground calibration of the energy response of the lead glass spectrometer.

Consider now the operation of the telescope and the significance of the various classes of events that are observed. From the point of view of studies of the electron component, the most important single classification of events is connected with the triggering of the gas Cerenkov detector. This sorts the particles into those above (G events) and below ($\bar{G}$ events) the gas Cerenkov energy threshold of $\sim 30\ m_oc^2$.

Next there is the classification of events as to whether the penetration counter is triggered (P events) or not ($\bar{P}$ events). Measurements indicate that for an electron cascade, the probability that at least one particle will penetrate the 6.6 radiation lengths of the lead glass counter and thus reach the penetration counter becomes > 0.1 at an incident electron energy $\simeq$ 100 MeV, increasing to 0.5 at $\simeq$ 500 MeV. Thus low energy (< 500 MeV) electrons will essentially be G$\bar{P}$ events. Sea level measurements confirm that all protons and mesons accompanied by a gas Cerenkov pulse will reach the P counter directly or through their progeny and be classed as GP events. The simultaneous pulse height measurement in the plastic scintillator S_1, the lead glass total energy spectrometer, L, and the penetration counter, P, eliminates any possible ambiguity between high energy electrons and extremely energetic protons and mesons, all of which will give GP events. It is estimated that for a Cerenkov threshold, $E_c \simeq 30\ m_oc^2$, proton and meson events comprise only about 10% of the GP events at 2-4 g/cm^2 atmospheric depth, a dominant fraction of the remaining events being electrons of energy $\geq$ 300 MeV.

Certain types of non-telescope events can cause confusion, particularly when measurements are made near the top of the atmosphere where nuclear interacting particles are predominant. To discriminate against such events, an anti-coincidence counter completely surrounds the gas Cerenkov detector and its phototube and extends down to the bottom of the lead glass. With this configuration, the probability that a shower particle from an electron passing through the telescope triggers the anticoincidence counter C is < 10% at all energies, thus no important fraction of the true electron events are lost.

At the same time, interactions in the lead glass of energetic protons passing through the telescope geometry are mainly recorded as C events.

Of particular interest is the relationship between the Cerenkov pulse from the lead glass counter L and the incident electron energy. This calibration has been obtained using the measurements of electron showers in a virtually identical lead glass spectrometer by Heusch and Prescott (1964). A most useful way of treating this problem is in terms of the total track length of all shower electrons (above the Cerenkov threshold of 200 KeV) relative to the track of a single relativistic particle passing through the entire detector. It suffices to point out here that the shower from a 240 MeV electron gives a pulse equivalent to that of a single particle traversing the entire detector (≡ 1x min). The energy response of this counter becomes somewhat non-linear above 500 MeV due to the fact that a greater percentage of the shower energy is not contained within the lead glass element. As a result the maximum pulse size that can be handled by the pulse height analyzer, which corresponds to a pulse equal to 12 times that for a traversal of the detector by a single minimum ionizing particle, is equivalent to a shower from a 4000 MeV electron. This is the maximum energy for which the differential electron spectrum can be obtained using the pulse height measurement in the lead glass spectrometer.

The matrix with coordinates of L output vs P output provides a further check of the energy as deduced from the lead glass spectrometer as well as a confirmation of the electronic nature of the shower. According to calibration and to shower theory, for the average electromagnetic shower a nearly linear relationship exists between the L output and the P output. For example for an L output of 4x a minimum ionizing particle traversal (electron energy = 1060 MeV), the average pulse in the penetration counter is 2.9x minimum; for an L output just at saturation (12x minimum) the P output is 10.7x minimum.

For saturated lead glass pulses the use of the pulse size in the penetration counter provides the capability of extending the electron spectrum above 4 BeV. In addition the relationship between the L output and the P output provides effective discrimination against the small fraction of proton interactions that do not trigger the guard counter and therefore contaminate the high energy electron flux. The electron spectrum we derive in the 4-20 BeV range from this data will be discussed in a separate publication.

THE BALLOON FLIGHT AND GENERAL FEATURES OF THE DATA

The details of the balloon flight made with this electron telescope on July 31, 1968 are given in Table I along with the details of the earlier flights made in 1965 and 1966. Of particular interest is the scaled Mt. Washington neutron monitor rate at the times of the flights. In 1966 this rate was $\sim$ 2372 c/hr a decrease of 3.6% from the rate at the time of the 1965 flight. At the time of the 1968 flight the average neutron rate was 2210 c/hr a further decrease of 7.1%. The total decrease of > 10% between the 1965 and 1968 flights is characteristic

TABLE I

DETAILS OF BALLOON FLIGHTS WITH ELECTRON DETECTOR

Date	Launch Time (UT)	Altitude	Time at Altitude	Mt. Wash N. M.
July 28, 1965	1900	3.8 g/cm^2	8 hrs.	2451
July 25, 1966	2000	2.5 g/cm^2	12 hrs.	2369
July 31, 1968	1230	2.5 g/cm^2	9 hrs.	2210

of the effects of the 11 year solar modulation of cosmic rays. The time periods prior to each of the flights showed no unusual fluctuations attributable to short term solar modulation effects.

Previous experience with counter telescopes and ion chambers flown on balloons at high latitudes has shown that a 10% decrease in neutron monitor intensity near sea level will be accompanied by a substantial change in the total intensity of particles measured near the top of the atmosphere. Regression curves between the neutron monitor rates and ion chamber rates near the top of the atmosphere for example indicate that the % change in counting rate near the top of the atmosphere is $\sim$ 4x as great as at sea level. This is, of course, expected because of the energy of response of these instruments at these locations.

The total intensity of all telescope events as a function of altitude for the three flights is shown in Figure 2. It is evident that we are observing the expected large effects of solar modulation in the upper atmosphere. The changes we observe are consistent with those observed in the past for ion chambers and counter telescopes for a sea level neutron monitor decrease $\sim$ 10%. We consider this to be evidence that the telescope was operating properly on all flights including the one in 1968.

Of further interest is Figure 3 which shows the fraction of all events that trigger the gas Cerenkov detector as a function of altitude for all flights. Near sea level where energetic muons above the gas Cerenkov threshold are quite abundant and up to altitudes corresponding to $\sim$ 100-300 g/cm^2 residual atmosphere where the secondary electron component reaches its maximum intensity, this ratio stays between 0.3 and 0.4. It drops rapidly near the top of the atmosphere to a value ~ 0.1 at 2.5 g/cm^2. This behavior is qualitatively what is expected as more of the events at high altitude become due to the abundant low energy primary cosmic radiation.

Notice that in the 1968 flight this ratio is noticeably larger at high altitudes. We believe that this reflects the "hardening" of the radiation in the upper atmosphere and is directly attributable to the effects of solar modulation which preferentially remove the low energy cosmic rays.

It is this 10% of all events, those above the gas Cerenkov threshold, totaling some 300 particles/m^2-ster-sec in 1968, that are of primary interest, for it is these events that are mainly caused by electrons with energies above $\sim$ 15 MeV.

DERIVATION OF THE ELECTRON SPECTRUM AT 2.5 g/cm^2

Among those events triggering the gas Cerenkov detector the electrons give a unique signature. First they must be members of the minimum ionizing distribution as measured in the S_1 scintillator. Second the electrons and the ensuing shower will not trigger the guard counter. Protons with $E \gtrsim 30\ m_oc^2$ that pass through the entire telescope and do not interact will also satisfy both of the above criteria. However, they will be easily distinguished from electrons since they will give well defined pulses corresponding to a single minimum ionizing particle traversal in both the lead glass Cerenkov spectrometer <u>and</u> the penetration scintillator. The intensity of these protons is measured to be 20 $\pm$ 2 particles/m^2-ster-sec which when corrected for the fraction of protons that interact gives a tot‹ˀ flux of 34 ± 4 protons/cm^2-ster-sec above an effective cut-off energy of 30 $m_o c^2$.

All other particles that satisfy the rather simple criteria listed above are then considered to be electrons and they are placed into various energy intervals according to the energy-pulse height calibration of the lead glass Cerenkov spectrometer. The response of this element ranges from essentially zero pulse height to a pulse height ∿ 12x that for a single minimum ionizing particle traversal. This defines an energy range from ∿ 15 MeV (gas Cerenkov threshold) to ∿ 4 BeV corresponding to showers with average values of $\langle N_e \rangle$ between 0 and 12. The passage of non-interacting minimum ionizing protons and helium nuclei at 4x minimum serves to provide an inflight energy calibration of this detector relative to the ground calibration. This energy calibration is identical for all flights. Therefore spectral or intensity changes cannot be due to differences in energy-pulse height calibration between the flights.

In Table II we show the number of electron events obtained in each pulse height interval in the lead glass spectrometer during the floating portion of the 1968 flight. The total of all P and $\bar{P}$ events directly gives the differential intensity of electrons in the appropriate energy intervals as listed. This differential spectrum is given in Figure 4. Also shown in this figure is the electron spectrum obtained in 1966 derived in exactly the same way and using the identical energy (pulse height) intervals.

It is evident that a substantial decrease in electron intensity has occurred in 1968 at all energies $\lesssim$ 2 BeV. The integral intensity

TABLE II

ELECTRON EVENTS OBSERVED IN 1968
LISTED ACCORDING TO PULSE SIZE IN LEAD GLASS
COUNTER AND ACCORDING TO PENETRATION CRITERIA

Pulse Size in L (x minimum)	Corresponding Energy (MeV)	$\bar{P}$ (Events)	P (Events)	Intensity (particles/ m^2-ster-sec)	Extrapolated Intensity (particles/ m^2-ster-sec)
0 - 0.16	15 - 40	402	4	31.8	
0.16 - 0.37	40 - 90	210	5	17.3	11.6
0.37 - 0.58	90 - 140	97	4	7.9	4.4
0.58 - 0.79	140 - 190	83	5	6.9	3.1
0.79 - 1.00	190 - 240	44	8	4.1	1.5
1.0 - 1.5	240 - 360	86	21	8.4	2.7
1.5 - 2.0	360 - 490	45	21	5.2	1.8
2 - 3	490 - 765	40	32	5.7	2.3
3 - 4	765 - 1060	27	35	4.9	2.5
4 - 5	1060 - 1375	22	35	4.5	3.0
5 - 6	1375 - 1700	19	33	4.1	3.2
6 - 7	1700 - 2140	11	31	3.3	2.9
7 - 8	2140 - 2400	5	23	2.2	1.9
8 - 10	2400 - 3150	4	42	3.6	3.3
10 - 12	3150 - 3950	1	27	2.2	2.0
> 12	> 3950	4	105	7.6	6.8

above this energy is almost unchanged for the two years. Note that the fractional decrease reaches a maximum at energies just above 200 MeV, at still lower energies the decrease is actually somewhat less. We believe that this is directly related to the effects of the geomagnetic cut-off at Ft. Churchill, which in the daytime is approximately 160 MeV for electrons (Webber, 1968).

The electron intensities measured at 2.5 g/cm^2 depth contain both primary electrons and secondary electrons generated in the first few g/cm^2 of the atmosphere. Since the solar modulation effects have evidently greatly depleted the intensity of cosmic ray protons relative to 1965-1966 it is evident that the production rate of atmospheric electrons should be reduced as well. Therefore before we can relate the changes in electron intensity observed at 2.5 g/cm^2 depth to changes in the electron flux incident on the top of the atmosphere we must determine the contribution of secondary electrons produced in the atmosphere above the telescope.

CORRECTION FOR ATMOSPHERIC SECONDARIES

The most satisfactory method of of obtaining the atmospheric secondary electron contribution utilizes the experimentally determined electron intensity-depth curves in the uppermost 100 g/cm^2 of atmosphere. This procedure has been used for our 1965 and 1966 flights and by other workers as well (eg. L'Heureux and Meyer, 1968, Simnett, 1968).

The following considerations are made in the derivation of the atmospheric secondary electron flux.

1) At 0 g/cm^2 of residual atmosphere the secondary electron flux is zero.

2) Between 0 and 10 g/cm^2 the growth of secondary electrons is linear with atmospheric depth. The theoretical calculations of Perola and Scarsi, (1966), and Verma (1967a) predict this behavior. At depths > 10 g/cm^2 the secondary electron flux will begin to approach equilibrium but will continue to increase smoothly.

3) At some depth the contribution to the total electron flux from electrons incident on the top of the atmosphere becomes negligible compared with the contribution from atmospheric secondaries. This depth will obviously depend on energy. For lower energies the attenuation length of primaries is so short and the buildup of atmospheric secondaries so rapid that the effects of the extra-terrestrial component are nearly obscured at a depth $\sim$ 10 g/cm^2. Even at energies > 1 BeV the extra-terrestrial component is overwhelmed by atmospheric secondaries at $\sim$ 20-30 g/cm^2 depth.

The electron growth curves in the atmosphere for various energy intervals are shown in Figures 5-9. According to the above arguments any decrease in the slope of growth curve with increasing altitude is indicative of an extra-terrestrial component. Above $\sim$ 1 BeV such behavior is quite clearly observed. At lower energies the decrease in slope is much less evident particularly in the energy intervals from $\sim$ 120-500 MeV in 1968. This is indicative of a very small flux of extra-terrestrial electrons at these energies in 1968. Also shown in the figures is the linear extrapolation of the atmospheric secondary electrons to the top. The absolute value of this linear growth curve gives the atmospheric secondary production function for electrons for a particular year at a given energy. It is obvious that this production has decreased substantially at all energies in 1968 as compared with 1966.

In Figure 10 we show the atmospheric production function as a function of energy derived from the growth curves obtained in 1966 and 1968. The theoretical electron production functions of Verma (1967a) and Perola and Scarsi (1966) appropriate to the full cosmic ray spectrum present at sunspot minimum are also shown in the figure. As we pointed out earlier (Beedle and Webber, 1968) our data in 1966 appears to be in somewhat better agreement with the calculations of Verma (1967) particularly at energies $\lesssim$ 100 MeV where the difference between the two theoretical predictions is significant. In 1968 the atmospheric production function is notably lower than in 1966; on the average 30-40% lower at energies $<$ 200 MeV and 10-25% lower at higher energies. Although this reduction is obviously related to the solar modulation of the proton and heavier nuclei components of cosmic rays we are unaware of calculations of the expected effect of this modulation on the production of secondary electrons therefore it is not possible to compare our decrease observed in 1968 directly with theory. Some decrease in the production function for secondary electrons should certainly be expected, however, and it is clear that when correcting for the production of atmospheric secondary electrons account must be taken of this reduction due to solar modulation.

Other experimental deductions of the atmospheric electron production function using intensity-depth curves are shown in Figure 10. In general these results are in good agreement with our 1966 results as might be expected since they were made at roughly the same level of solar modulation.

THE DERIVATION OF THE EXTRA-TERRESTRIAL ELECTRON SPECTRUM

The spectrum of electrons incident on the top of the atmosphere may be obtained by subtracting the contribution of atmospheric electrons at the float altitude and then correcting the remaining flux to the top of the atmosphere. This was relatively easy to do in 1965-1966 since a marked flattening of the intensity-depth curves was clearly evident near the top of the atmosphere. As a result the contribution of atmospheric secondaries to the total electron intensity at float altitude was $<$ 40% at all energies. In 1968, in the range above 500 MeV and at energies $<$ 120 MeV the flattening of the intensity-depth curves in the uppermost 10 g/cm^2 of atmosphere is also quite evident. The atmospheric secondary electron flux accounts for $<$ 50% of all electrons observed at 2.5 g/cm^2 depth in 1968 in these energy intervals and the extrapolation to the top of the atmosphere can be made quite accurately. In the energy range 120-500 MeV the decrease in slope arising from a component incident on the top of the atmosphere is very small indeed. Over this energy range nearly 2/3 of all electrons observed at 2.5 g/cm^2 can be attributed to atmospheric secondaries. The extra-terrestrial intensity that is finally deduced in this range is obviously strongly dependent on the production function taken for the atmospheric secondaries. If only the 1968 data were available a good argument could be made for the near total <u>absence</u> of primary electrons in this energy range. The consistency between growth curves obtained in 1966 and 1968 and the day-night measurements made in 1966 allow us to ascribe more confidence to atmospheric correction made in 1968. We do believe that the intensity of electrons incident on the top of the atmosphere in this energy range is finite and is reasonably given by the data points in Figure 11. In any case the differential intensities in the 120-500 MeV range presented in Figure 11 represent firm upper limits as to the electron flux incident on the top of the atmosphere.

The most striking feature of the 1968 electron spectrum at the top of the atmosphere is the large reduction in intensity over the 1966 data also shown in Figure 11. However, the integral intensity > 2 BeV is the same to within ∿ 10% for the two years. At lower energies the intensity in 1968 is progressively depressed from that in 1966-reaching a maximum of a factor of almost 7 at energies just above 200 MeV. The differential spectrum in 1968 appears, in fact, to go through a broad maximum in the range 1-2 BeV-much like the spectrum for cosmic ray protons. Below about 500 MeV the electron spectrum measured in 1968 begins to rise again.

At Ft. Churchill geomagnetic cut-off effects play an important role in understanding the origin of the electrons of energies $\lesssim$ 200 MeV incident at the top of the atmosphere. Observations by Jokipii et al. (1967) and during our flight in 1966 (Webber, 1968) have established the diurnal nature of these cut-off variations. Briefly the situation is as follows. In 1966 the average daytime cut-off near Ft. Churchill was measured to be ∿ 160 MeV for electrons. During the night this cut-off dropped precipitously to a value $\lesssim$ 10 MeV.* As a result, in the daytime, primary electrons are allowed by geomagnetic theory to arrive at Ft. Churchill down to energies just above the cut-off - at lower energies there is a transition to electrons trapped in the

*During 1967 Israel and Vogt (1968) measure daytime cut-offs of 90 ± 20 MeV and a nightime cut-off $\lesssim$ 17 MeV for electrons near Ft. Churchill.

earths magnetic field - the so called re-entrant albedo. Only the electrons above $\sim$ 160 MeV incident on the top of the atmosphere in 1966 as shown in Figure 11 are therefore truely extra-terrestrial. During the night, because of the decrease in cut-off, the re-entrant albedo in the energy range 10-160 MeV is replaced by the primary electron flux that can now arrive from outside of the earths magnetic field. Using measurements at night, the spectrum of primary electrons can and has been extended to lower energies (eg. Jokipii et al. 1967, Webber, 1968).

In 1968 the data was obtained during daytime hours therefore only those particles incident on the top of the atmosphere above 200 MeV can certainly be classed as extra-terrestrial - the particles below this energy may be re-entrant albedo. The discontinuous change in the spectrum at $\sim$ 200 MeV is taken to be evidence of this transition. Actually in 1968, because of the large reduction in primary intensity, the intensity of re-entrant albedo is now apparently larger than the primary intensity at energies $\sim$ 200 MeV.

The data shown connected by a dashed line in Figure 11 represents our determination of the spectrum of re-entrant albedo electrons incident at Ft. Churchill in 1966 and 1968. This data is shown separately in Figure 12 along with measurements of the re-entrant albedo at high altitudes by other observers. In 1968 the re-entrant albedo intensity is obviously considerably less than in 1966. This reduction is $\sim$ 25% at energies $\lesssim$ 70 MeV but becomes progressively larger at higher energies. The effects of solar modulation between 1966 and 1968 have clearly reduced the intensities of atmospheric secondary electrons in 1968 and therefore a concomitant reduction of the splash and re-entrant albedo intensities should result. We believe that the decrease in re-entrant albedo below 70 MeV measured in 1968 reflects this.

The reduction of re-entrant albedo electrons in the 70-160 MeV range between 1966 and 1968 is much larger than the corresponding reduction of atmospheric secondary electrons in the same energy range. We believe that this additional reduction of re-entrant albedo electrons in this energy range is related to a poorer magnetic field line connection between northern and sourthern hemispheres coupled with a more diffuse and somewhat lower daytime cut-off in 1968. This would be consistent with the lower daytime cut-off measured by Israel and Vogt (1968) in 1967. In other words all of the splash albedo in this energy range is not managing to reach Ft. Churchill. Such behavior is plausible in view of the increased distortion of the magnetosphere in 1968 related to the enhanced solar wind parameters.

THE FEATURES OF THE PRIMARY ELECTRON SPECTRUM

In figure 13 we show the primary electron spectrum measured in 1966, including the spectrum below $\sim$ 200 MeV obtained from the nigh-time measurements, and the spectrum we measure in 1968 above 200 MeV. The spectrum we measure in 1965 is shown as a solid line.

Our objective is now to reconstruct the low energy portion of the spectrum in 1968-the part we are unable to measure because of cut-off effects at Ft. Churchill. To this end we use the results of Beuermann et al. (1969) obtained at night at Ft. Churchill in the summer of 1968 in a series of flights only a week before ours. In addition the interplanetary electron fluxes between 2.7 and 21.5 MeV measured in 1967 by Simnett and McDonald (1968) are shown. The 1967 observations represent a level of modulation intermediate between 1966 and 1968.

The electron spectrum we measure above in 200 MeV in 1968 appears to fit smoothly onto the spectrum obtained by Beuermann et al. (1969) at lower energies only 1 week earlier. The dashed line in Figure 13 would represent a reasonable extension of our spectrum through the data points of Beuermann et al. We note that the above authors have emphasized the "dip" in the extra-terrestrial electron spectrum occurring between 60 and 110 MeV. In view of our spectral data above 200 MeV and the accuracy of the above authors data point between 110 and 220 MeV this "dip", if real, must represent a very abrupt change in character of the spectrum in this energy range. Since this change is not apparent in the 1966 spectral measurements in this energy range it must be the result of solar modulation effects (as Beuermann et al. note). We will investigate this point more fully in the following section.

The most accurate information on the extra-terrestrial electron spectrum below 10 MeV is that measured in interplanetary space in 1967 by Simnett and McDonald (1968). There is overlap between these interplanetary measurements and those obtained in the atmosphere in the 10-20 MeV range. Taking the data points in this energy range at face value we note a systematic decrease in the differential intensity measured in 1966, 1967 and 1968. In view of the steepness of the spectrum which makes comparison of the separate measurements difficult, and in view of the difficulty of making measurements in the atmosphere at these low energies one is probably not justified in attaching any significance to the actual time variation observed in the 10-20 MeV range. Instead the general agreement of the separate differential intensities should be emphasized along with the manner in which they delineate the rapid rise in the extra-terrestrial spectrum below $\sim$ 30 MeV.

CHANGES IN EXTRA-TERRESTRIAL ELECTRON INTENSITY

We exhibit the fractional modulation of extra-terrestrial electron intensity measured between 1965-1966 and 1966-1968 in Figure 14. Here the fractional modulation, $M = \ln (j_1/j_2)$, where j_1 and j_2 ~~are~~ the differential intensities of electrons measured at times t_1 and t_2. The intensity changes recorded by the Mt. Washington neutron monitor are shown for the two time periods-plotted at a mean response rigidity of 9-10 BV. The 1965-1966 changes have been presented and discussed previously (Webber, 1968). The rigidity (energy) dependence of the 1966-1968 changes appears to be nearly identical to that observed previously. Furthermore the fractional change in intensity between 1966-1968 is $\sim$ 2.5 times as large as between 1965-1966 in agreement with the changes observed by neutron monitors. Above about 500 MeV the modulation is accurately represented by a functional form $\sim$ (energy)$^{-1}$. Below this energy the fractional modulation clearly does not continue to increase but flattens off. This flattening was noted previously in our 1965-1966 comparison.

Consider now the limits on the modulation between 1966 and 1968 that we can set at low energies. The experimental points plotted at energies < 200 MeV in Figure 14 represent the ratio between our 1966 measurements and those of Beuermann et al. (1969) in 1968. There are obviously large uncertainties in this comparison. The dashed line in Figure 14 represents the modulation obtained if we compare the dashed curve in Figure 13 with our 1966 measurements. The consensus of this set of comparisons would be that the fractional modulation of electrons begins to decrease at energies < 200 MeV.

Beuermann et al. (1969) have derived a fractional modulation at energies < 200 MeV by comparing their measured positron spectrum in 1968 with that expected in interstellar space as a result of collisions of cosmic ray nuclei with interstellar hydrogen. The difference in these spectra is attributed to solar modulation. The rigidity dependence of this modulation has the form of curve A in Figure 14. We have divided by 2 the actual modulation derived by Beuermann et al. to normalize it to the modulation we measure between 1966 and 1968. Note that their modulation function also has a maximum in it. This maximum at ∿ 60 MeV is sufficient to produce the "dip" they observe in the extra-terrestrial electron and positron spectra at 60-110 MeV.

It might reasonably be argued that the dashed line and curve A in Figure 14 represent limits on the fractional modulation of electrons at low energies in the 1966-1968 time interval. Both of these curves decrease at lower energies. It is very important to establish whether the fractional modulation of electrons begins to decrease at energies ≤ 200 MeV. There is some supporting evidence to suggest that this does indeed happen. If it were assumed, for example, that the fractional modulation flattened at some constant value at low energies and did not decrease then pronounced long term changes would be expected in the intensities of sub 10 MeV electrons in interstellar space. Cline and McDonald (1968) have pointed out that changes of the order of magnitude to be expected by this degree of long term solar modulation do not seem to occur although "short term" variations of the low energy electron intensity are much in evidence.

The results on the electron modulation that we have just discussed are obviously of importance in understanding the current theories of the solar modulation of energetic galactic cosmic rays. To properly discuss this problem it is necessary to compare, as a function of energy, the electron modulation with the modulation of other cosmic ray nuclei with different charge to mass ratios such as protons and helium. We defer this discussion to a separate paper.

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FIGURE CAPTIONS

Figure 1 Outline drawing of scintillation counter, gas Cerenkov detector, lead glass spectrometer telescope system.

Figure 2 The intensity of all telescope events as a function of atmospheric depth for the 1965, 1966 and 1968 balloon flights.

Figure 3 Relative fraction of gas Cerenkov events as a function of atmospheric depth for the 1965, 1966 and 1968 balloon flights. Ratio is defined as the intensity of gas Cerenkov events/ intensity of all events.

Figure 4 Differential spectrum of all electrons measured at a depth of 2.5 g/cm^2 in 1966 (open diamonds) and 1968 (solid diamonds).

Figure 5 Intensity-depth relations for electrons of energy 60-120 MeV measured in 1965, 1966 and 1968. Nightime intensities measured in 1966 shown as crosses. Growth of atmospheric secondary electrons represented by solid line.

Figure 6 Intensity-depth relations for electrons of energy 120-240 MeV. Symbols the same as in Figure 5.

Figure 7 Intensity-depth relations for electrons of energy 240-500 MeV. Symbols the same as in Figure 5.

Figure 8 Intensity-depth relations for electrons of energy 500-1100 MeV. Symbols the same as in Figure 5.

Figure 9 Intensity-depth relations for electrons of energy > 1100 MeV. Symbols the same as in Figure 5.

Figure 10 A comparison of experimental determinations of the atmospheric production function for secondary electrons and the theoretical calculations. Our data 1966, (open diamonds);1968, (solid diamonds);

L'Heureux and Meyer (1968) □ , Simnett, (1968) +, Fanselow (1968) o, Israel and Vogt, (1968) ◆. Theoretical predictions of Verma (1967a) shown as solid line, Perola and Scarsi (1966) as dotted line.

Figure 11 Intensity of electrons incident on the top of the atmosphere in 1966 (open diamonds) and 1968 (solid diamonds). The spectra of electrons below the daytime cut-off of ∿ 160 MeV at Ft. Churchill are indicated by the dashed lines and crosses.

Figure 12 Intensity of re-entrant albedo electrons measured at Ft. Churchill in 1966 (solid diamonds) and 1968 (open diamonds). Data on re-entrant albedo electrons from other observers include, Verma (1967b)●, Schmoker and Earl (1965) □ , Israel (1968) O . The data of Israel is splash albedo not re-entrant.

Figure 13 Selected measurements of the extra-terrestrial electron spectrum in the range 2 MeV-4 BeV. Solid line represents our measurements in 1965, open diamonds in 1966, and solid diamonds in 1968. Measurement of Simnett and McDonald (1968) at low energies shown as a dotted curve, that of Beuermann et al. (1969) as solid squares. Possible 1968 spectrum shown as dashed curve.

Figure 14 Fractional modulation of electrons observed between 1965-1966 (open circles) and 1966-1968 (solid circles). Solid lines represent modulation ∿ $(\text{rigidity})^{-1}$. See text for discussion of experimental points designated with crosses and for derivations of curve A and the dashed line.

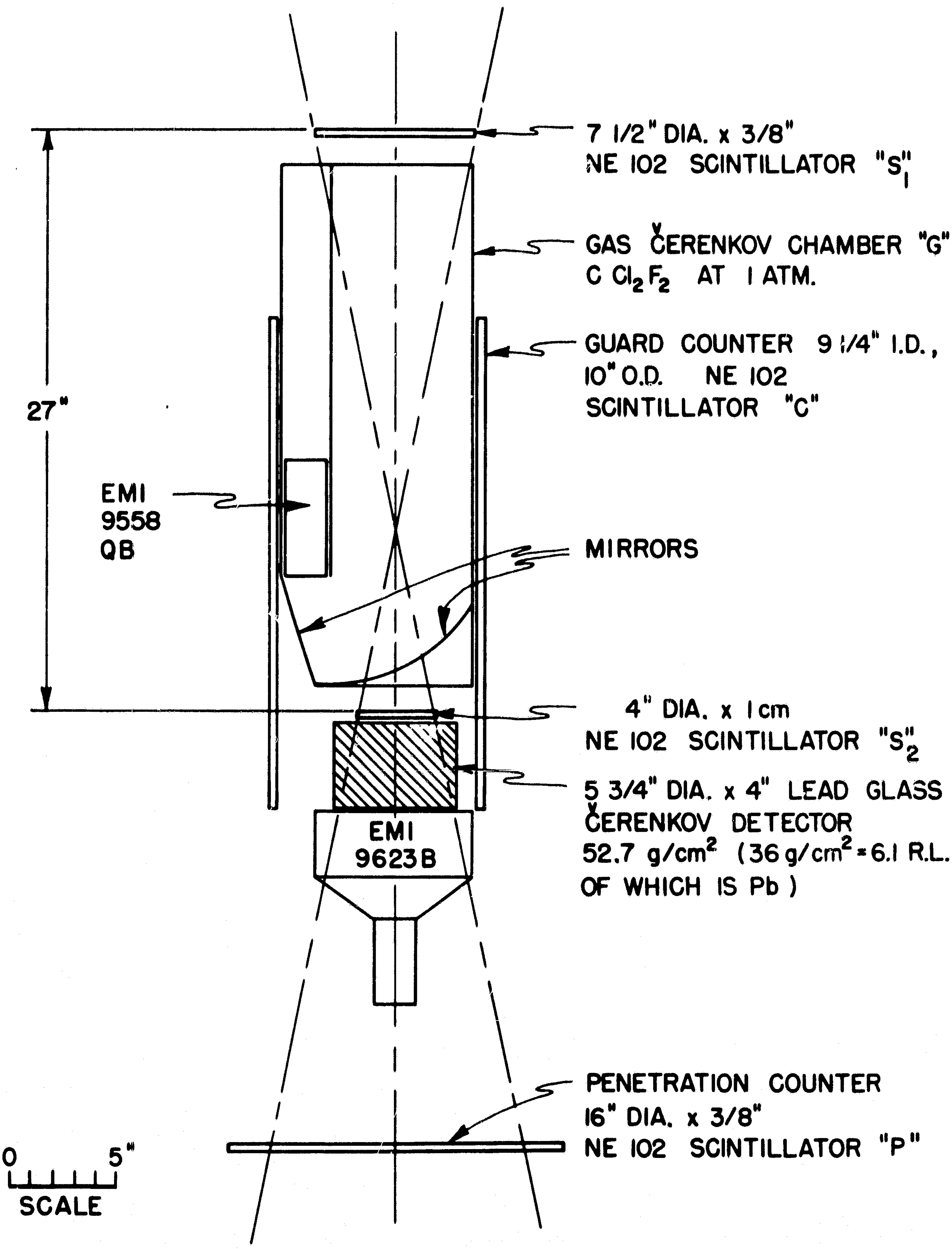
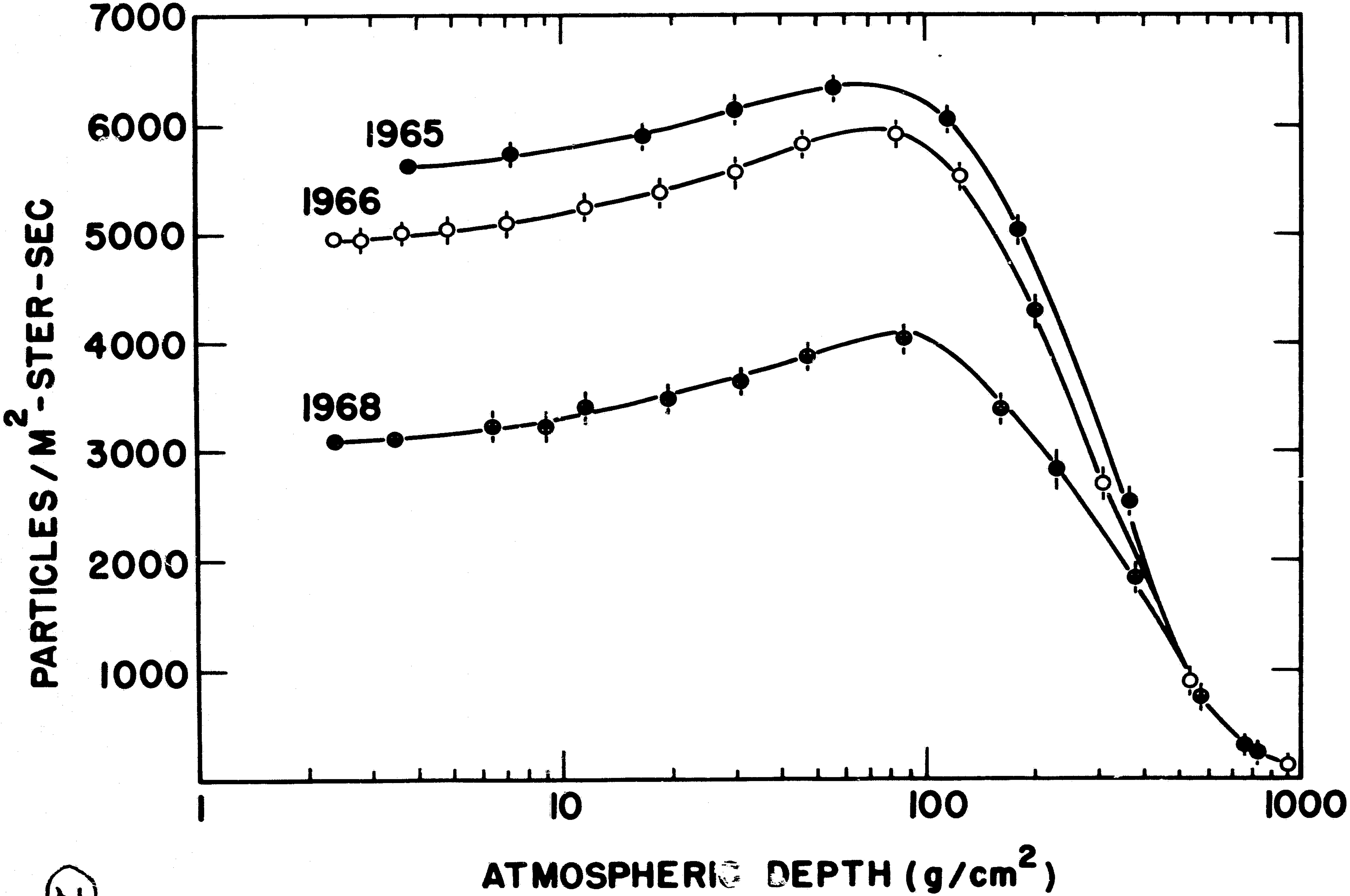
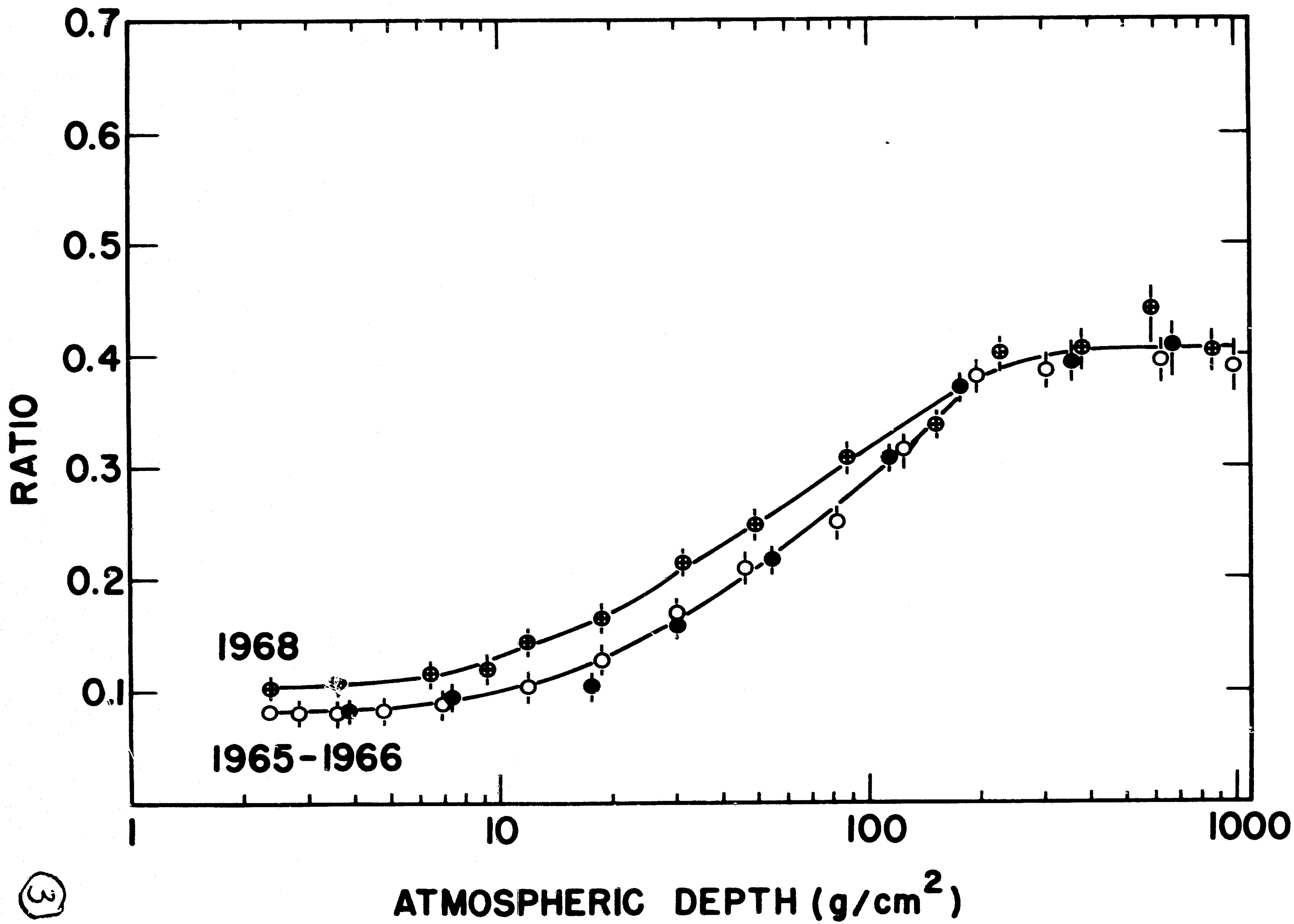

7 1/2" DIA. x 3/8"
NE 102 SCINTILLATOR "S1"
GAS ČERENKOV CHAMBER "G"
C Cl2 F2 AT 1 ATM.
GUARD COUNTER 9 1/4" I.D.,
10" O.D. NE 102
SCINTILLATOR "C"
27"
EMI
9558
QB
MIRRORS
4" DIA. x 1 cm
NE 102 SCINTILLATOR "S2"
5 3/4" DIA. x 4" LEAD GLASS
ČERENKOV DETECTOR
52.7 g/cm² (36 g/cm² = 6.1 R.L.
OF WHICH IS Pb)
EMI
9623B
PENETRATION COUNTER
16" DIA. x 3/8"
NE 102 SCINTILLATOR "P"
0 5"
SCALE

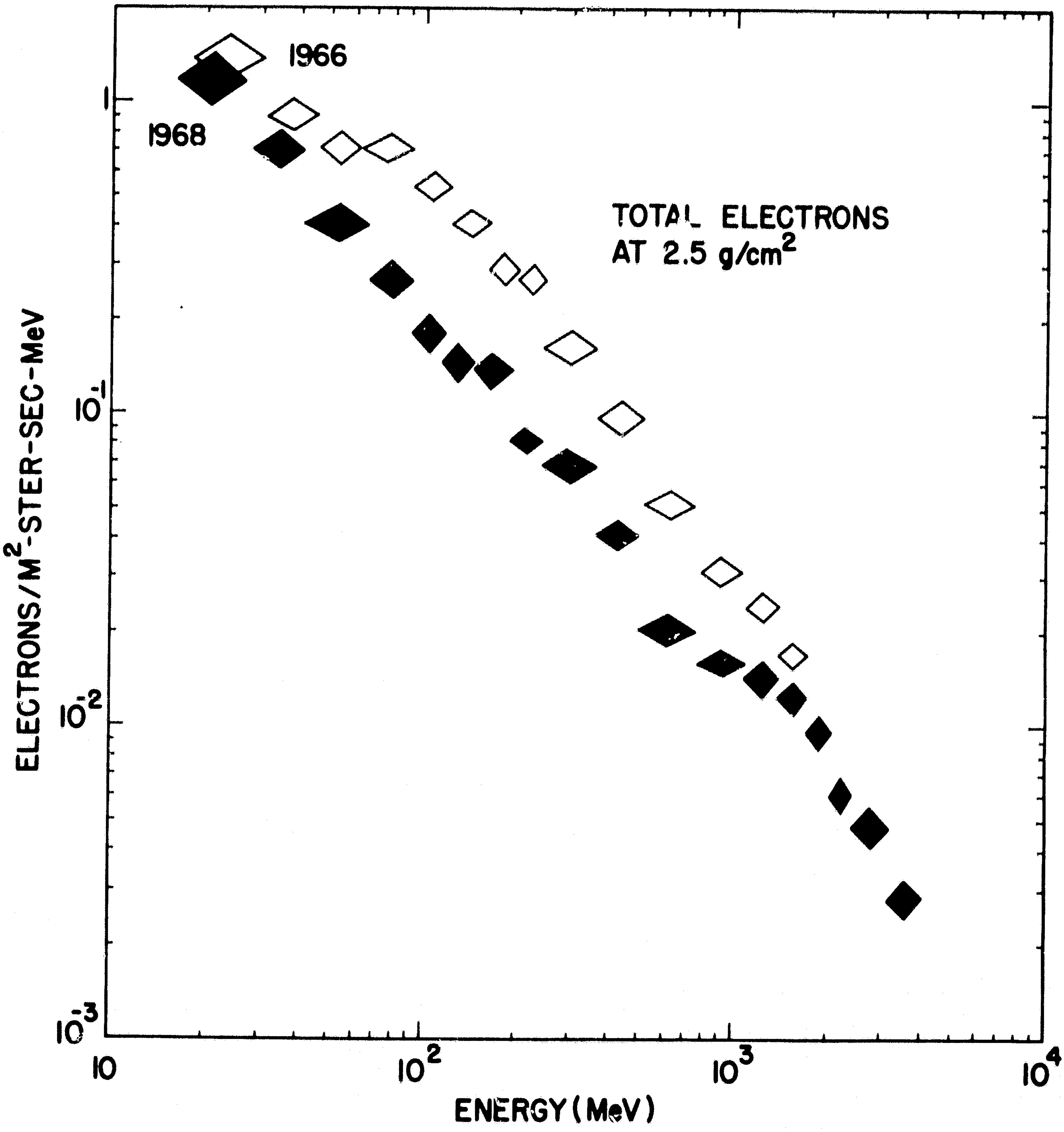
Fig 1

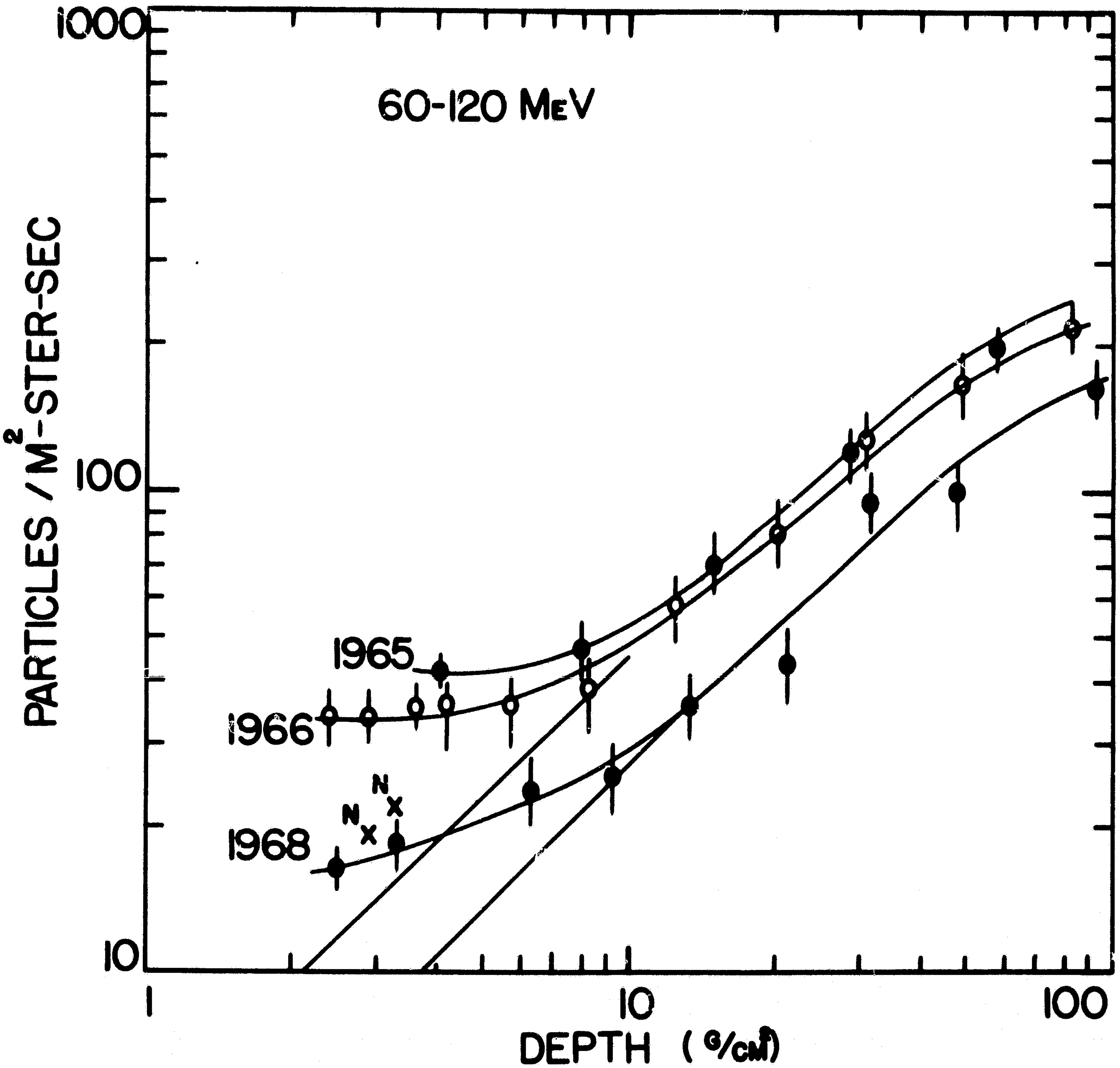

7000
6000
5000
4000
3000
2000
1000
PARTICLES / M^2-STER-SEC
1965
1966
1968
1
10
100
1000
ATMOSPHERIC DEPTH (g/cm^2)

(2)


0.7
0.6
0.5
0.4
0.3
0.2
0.1
RATIO
1968
1965-1966
1
10
100
1000
ATMOSPHERIC DEPTH (g/cm²)

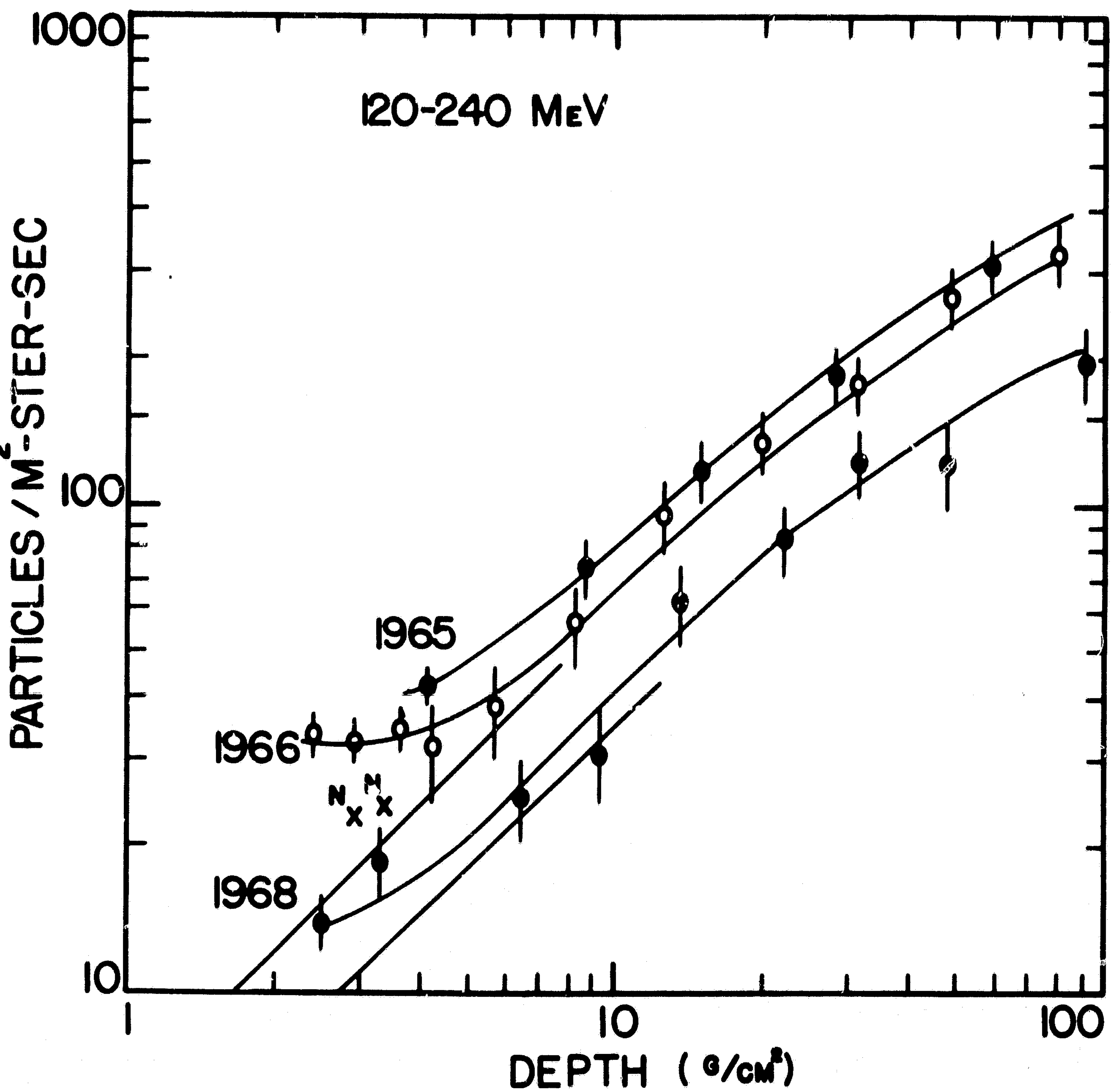
(3)


1966
1968
TOTAL ELECTRONS
AT 2.5 g/cm²
ELECTRONS/M²-STER-SEC-MeV
1
10⁻¹
10⁻²
10⁻³
10
10²
10³
10⁴
ENERGY (MeV)



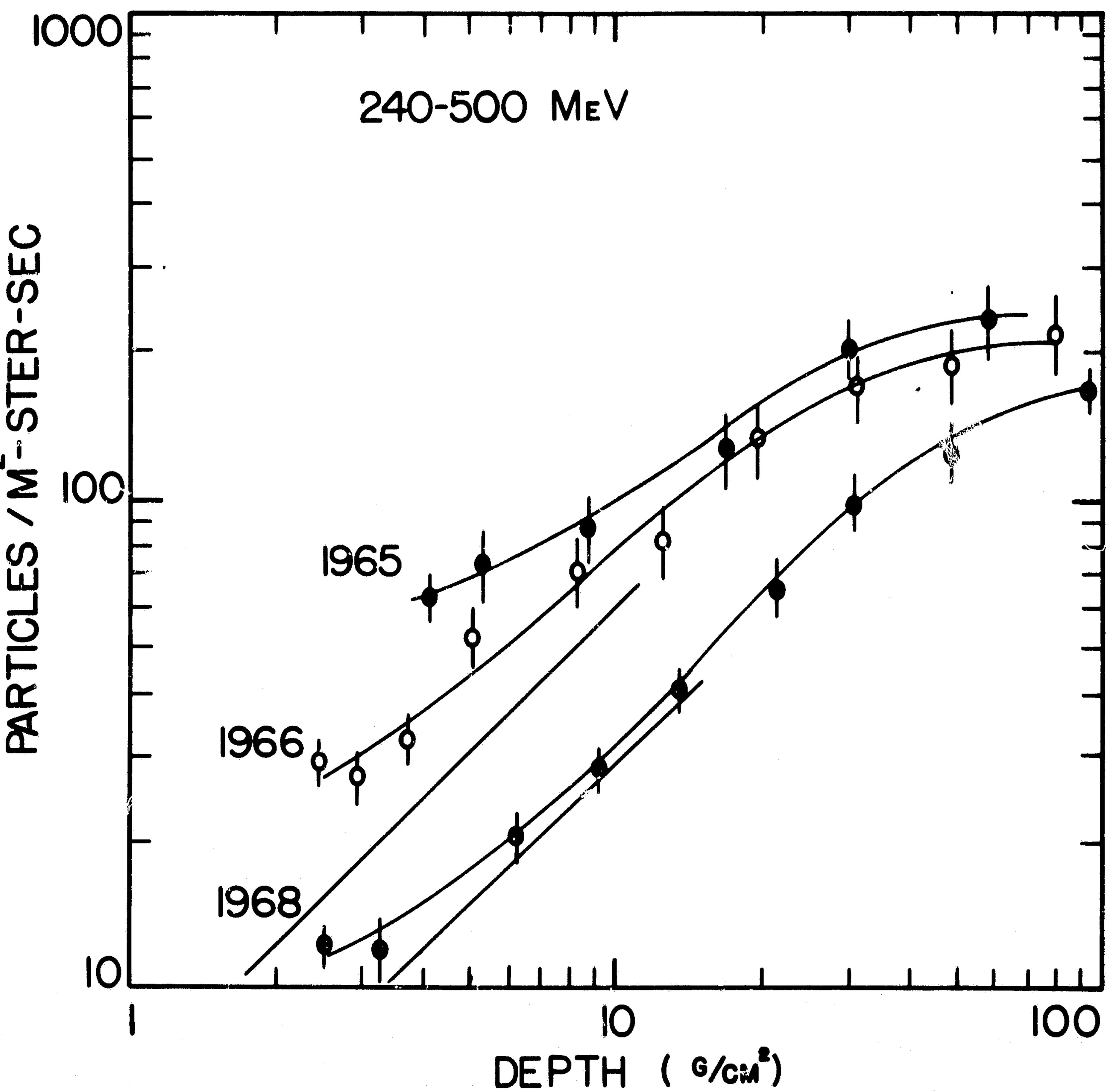
60-120 MeV
PARTICLES / M²-STER-SEC
DEPTH (G/CM²)
1000
100
10
1
10
100
1965
1966
1968
N
X
N
X

5



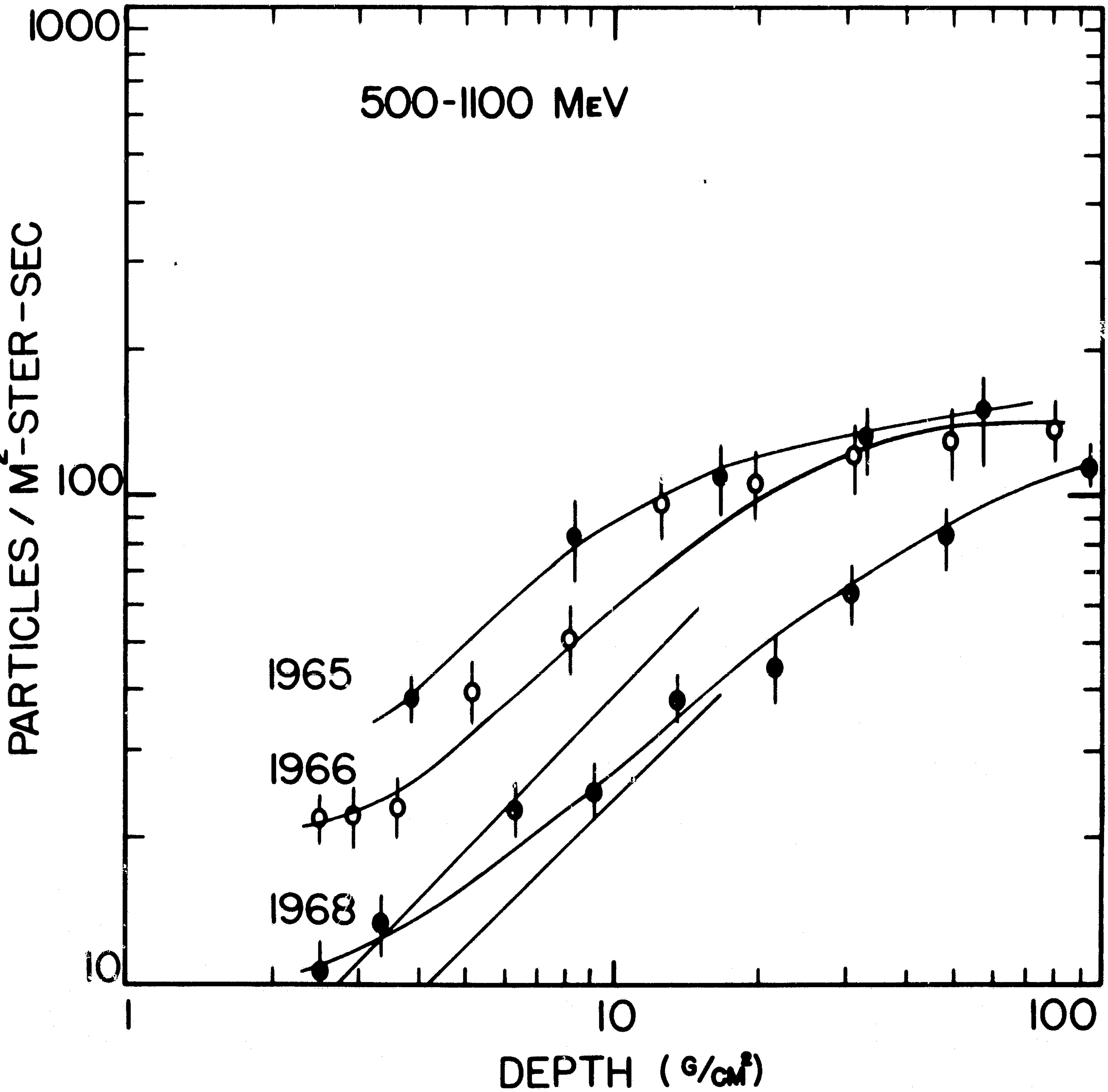
120-240 MeV
PARTICLES / M²-STER-SEC
1000
100
10
1
10
100
DEPTH (G/CM²)
1965
1966
1968
N X
M X

6

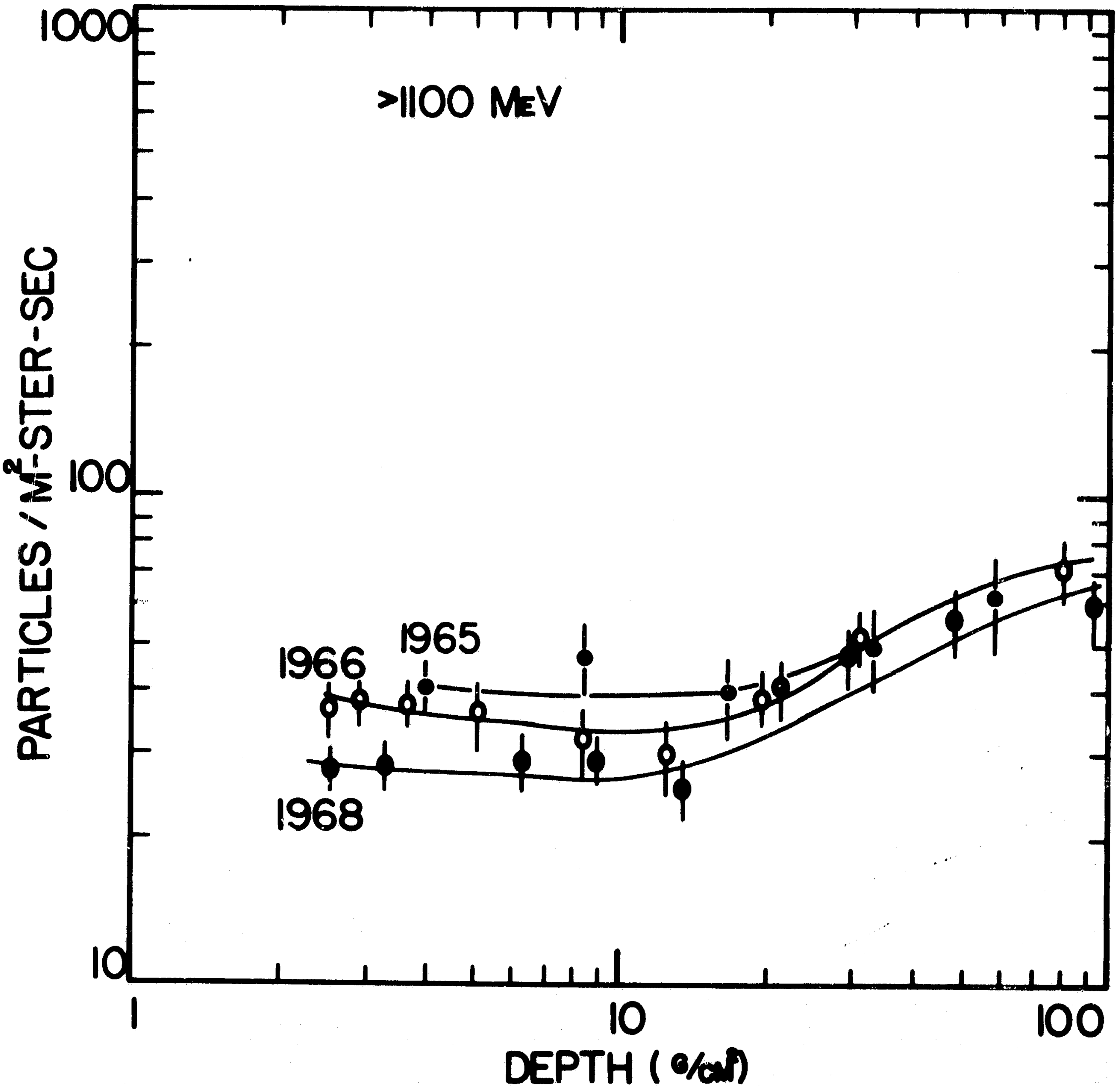


240-500 MeV
1965
1966
1968
1000
100
10
1
10
100
PARTICLES / M^2-STER-SEC
DEPTH (G/CM^2)

(7)

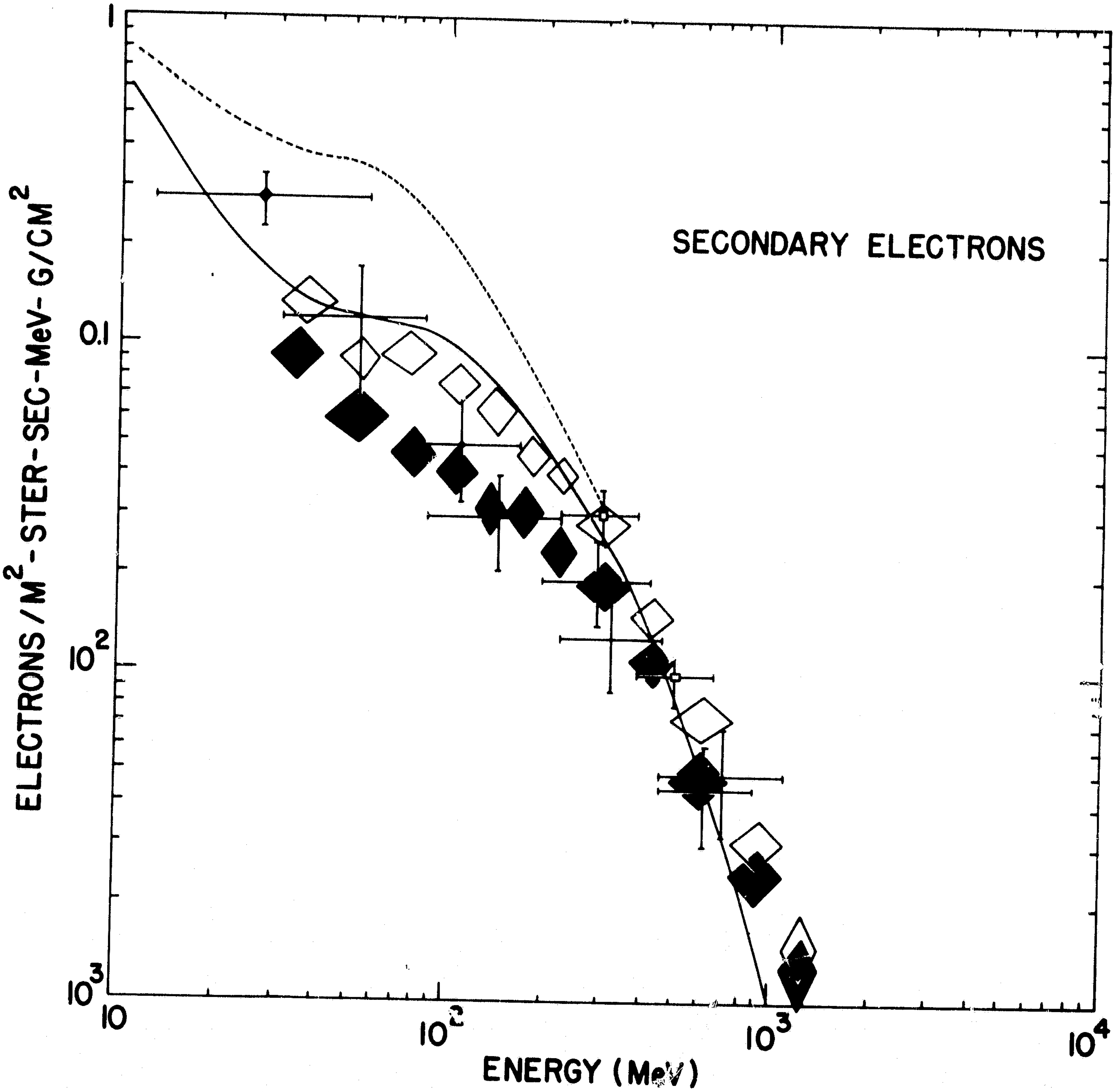


500-1100 MeV
1965
1966
1968
1000
100
10
1
10
100
PARTICLES / M²-STER-SEC
DEPTH (G/CM²)



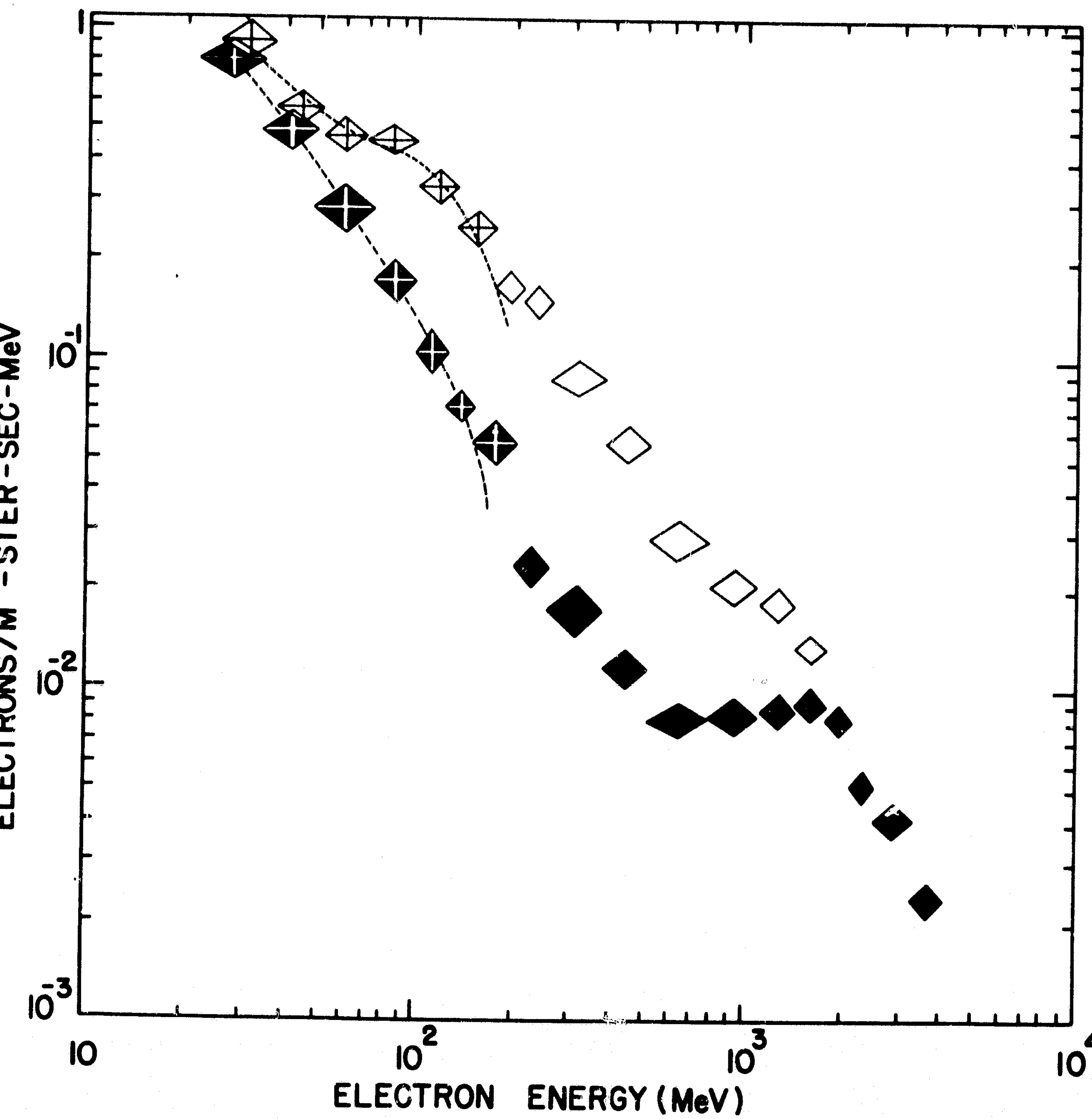
>1100 MeV
1966
1965
1968
1000
100
10
1
10
100
PARTICLES / M²-STER-SEC
DEPTH (g/cm²)

(9)



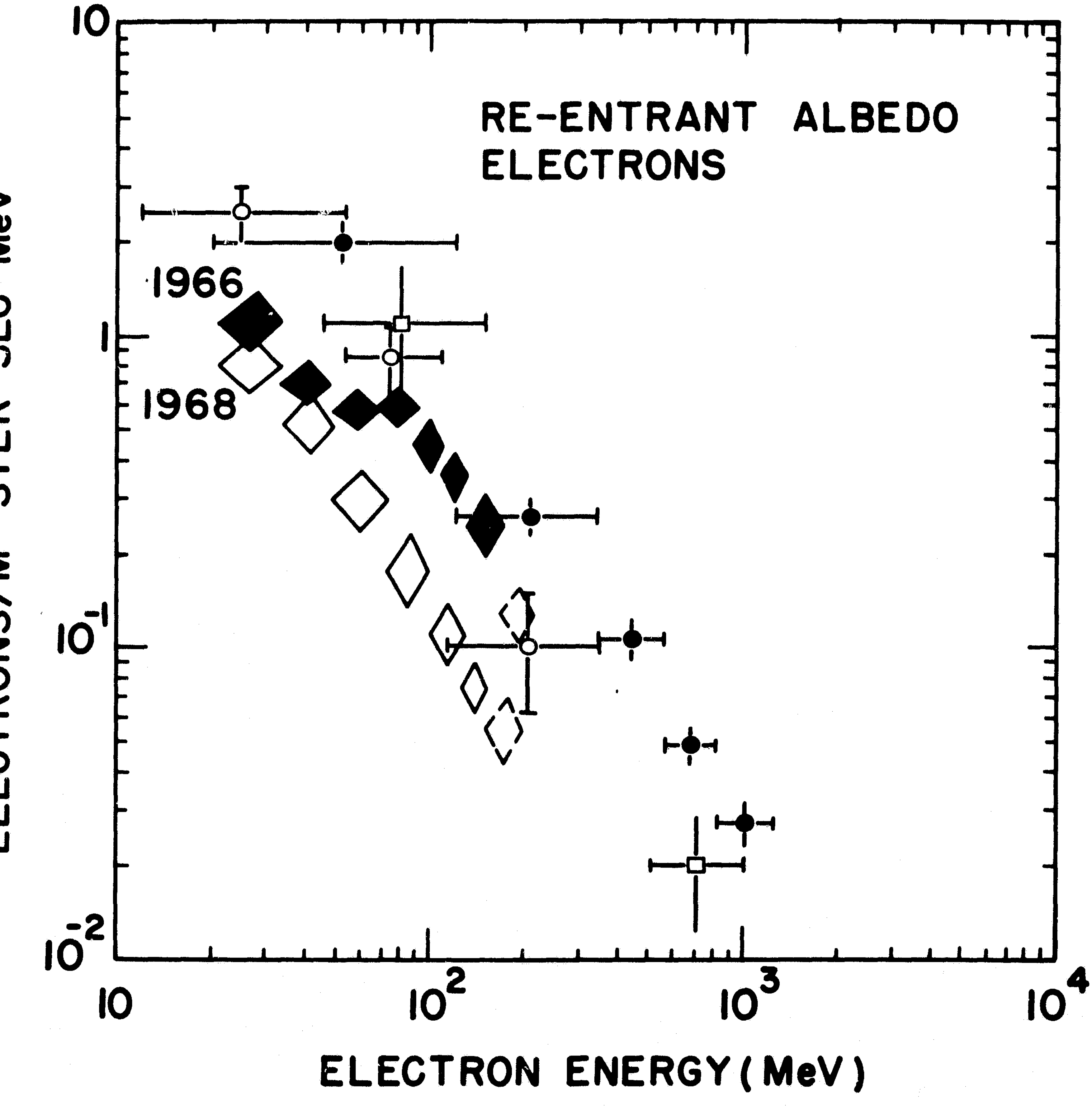
SECONDARY ELECTRONS
ELECTRONS / M^2 - STER - SEC - MeV - G/CM^2
1
0.1
10^{-2}
10^{-3}
10
10^2
10^3
10^4
ENERGY (MeV)

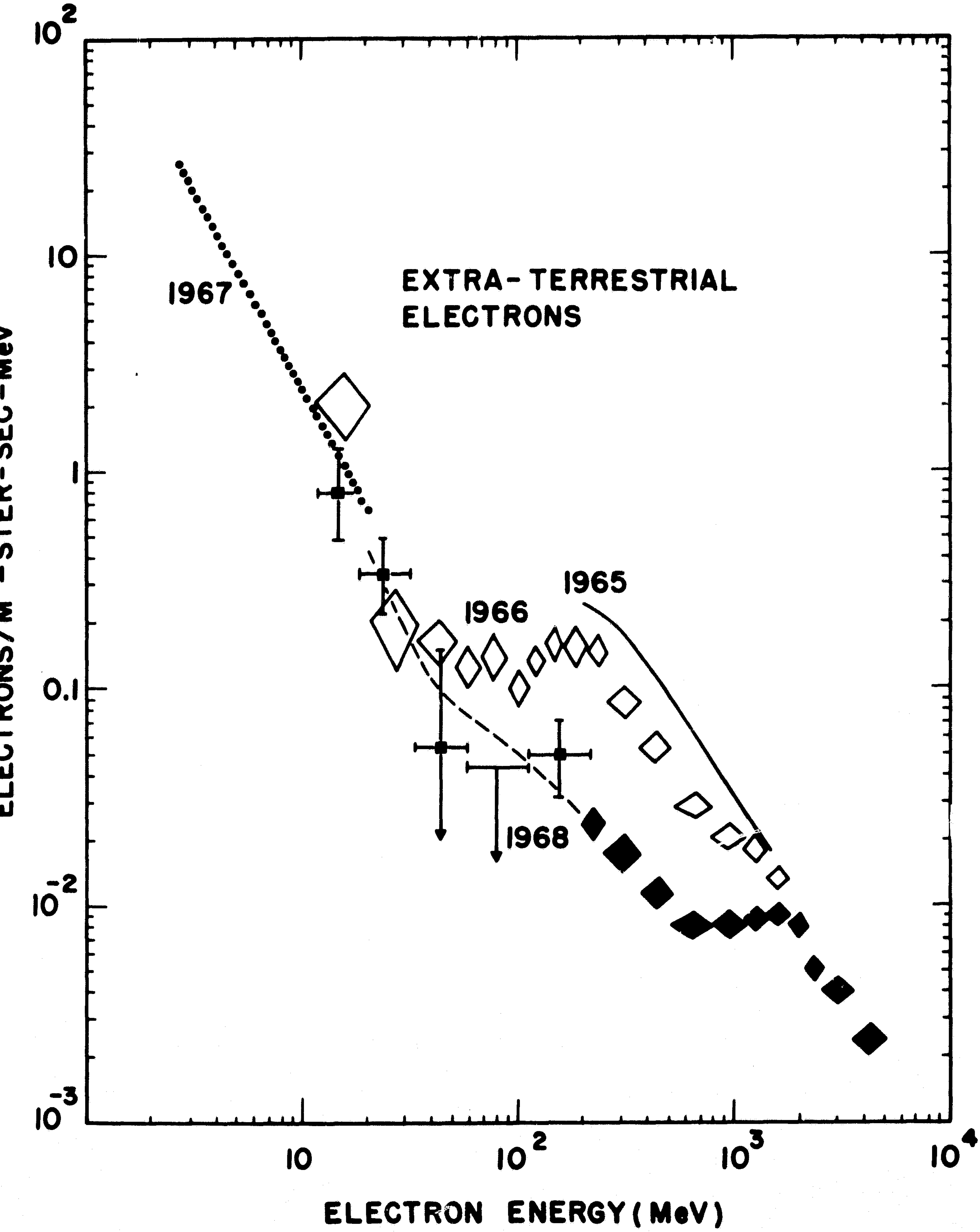
10

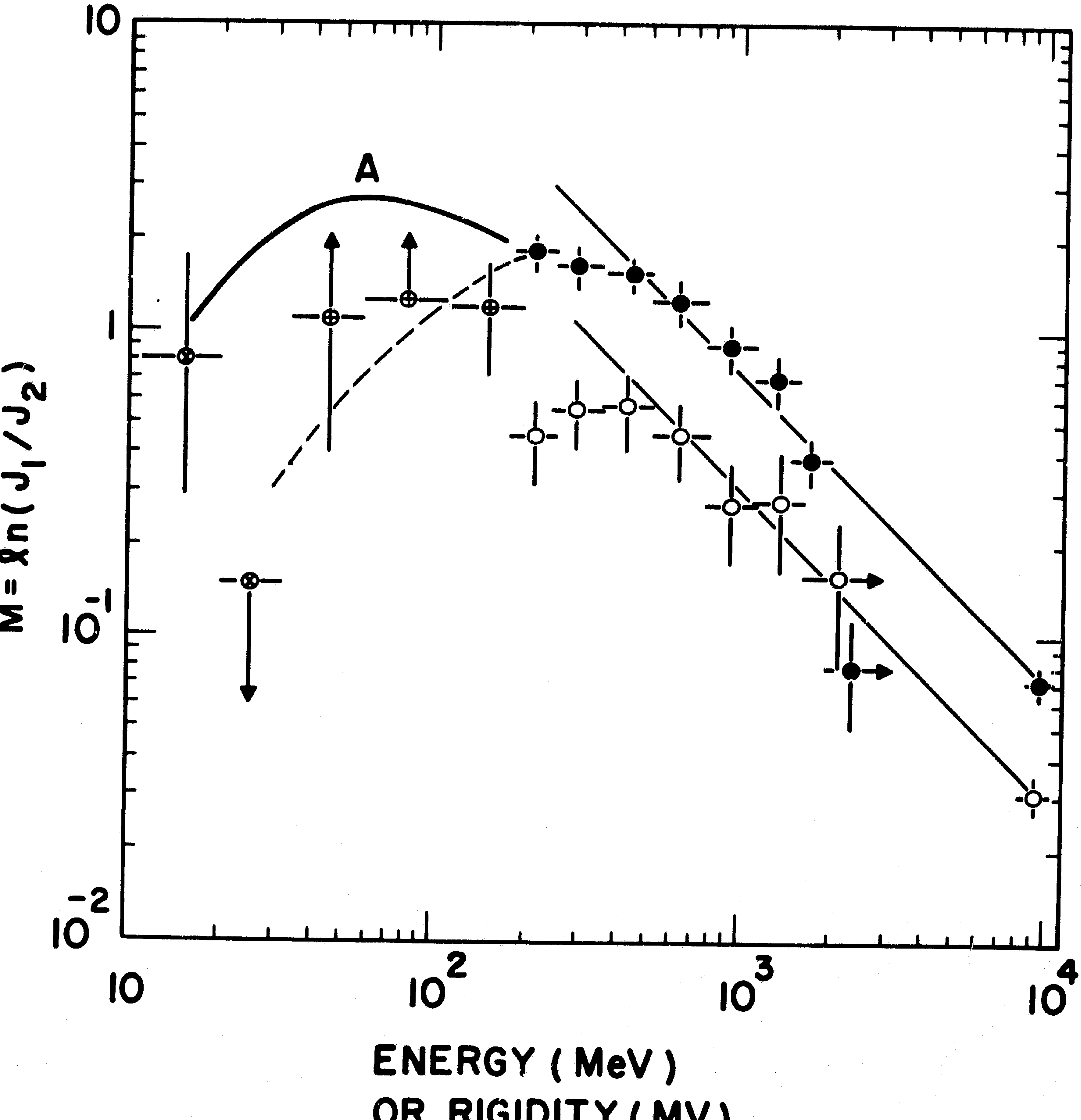


ELECTRONS/M² -STER-SEC-MeV
1
10⁻¹
10⁻²
10⁻³
10
10²
10³
10⁴
ELECTRON ENERGY (MeV)

11


RE-ENTRANT ALBEDO
ELECTRONS
1966
1968
10
1
10^{-1}
10^{-2}
10
10^2
10^3
10^4
ELECTRON ENERGY (MeV)


EXTRA-TERRESTRIAL
ELECTRONS
1967
1966
1965
1968
10^2
10
1
0.1
10^{-2}
10^{-3}
10
10^2
10^3
10^4
ELECTRON ENERGY (MeV)


10
1
10^{-1}
10^{-2}
M = ℓn(J1/J2)
A
10
10^2
10^3
10^4
ENERGY (MeV)
OR RIGIDITY (MV)