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MISSING MASS SEARCH FOR NEGATIVE CHARGE BOSONS WITH MASSES BETWEEN 2 AND 12.5 GeV

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Abstract

A missing mass search has been made for negatively charged boson resonances, B^-, produced in the reaction $\pi^- p \rightarrow B^- p$ at beam momenta of 40, 100, 200, and 240 GeV. Approximately 600,000 events were included in the final mass spectra. In the mass region, $2 \leq M_B \leq 12.5$ GeV, no statistically significant enhancements were observed. The 5 s.d. upper limit on the production of narrow resonances is of the order of $10 \mu b$.

We have conducted a search, at Fermilab energies, for charged bosons (B^-) by the missing mass technique, using a π^- beam incident on a liquid hydrogen target. The four momenta of the incident pion and the recoiling proton were measured for the reaction:

$$\pi^- + p \rightarrow p + \text{Anything } (X^-). \qquad (1)$$

From these measurements, the invariant mass squared, M^2, of X^- was determined. The resulting X^- mass spectrum was inspected for irregularities such as bumps or steps due to B^- production which might appear above the expected slowly varying continuum. This technique is particularly sensitive to the existence of narrow resonances produced as two body final states, B^-p, although new states might also be detected as threshold effects. The sensitivity to a new state depends on the production process but is independent of its decay modes. The sensitivity is limited by the presence of the smooth continuum. At low energies, structures in the M^2 spectrum from B^- states corresponding to the ρ, A_1, A_2 and R, have been observed by this method [1,2]. The mass range, however, has been limited in these measurements to less than 5 GeV. In this experiment we extended the mass range to 12.5 GeV, thus spanning the region that had been suggested for gluons [3].

The recoil proton spectrometer, which is described in detail elsewhere [1] consisted of four wire spark chambers to determine the particle trajectory, and five identical plastic scintillation counter arrays to identify the proton and measure its energy. Each array consisted of three counters of area 12.7 cm x 61 cm. The first counter (dE), of thickness 1.3 cm, measured the energy loss

and time of flight of the recoil particle. It was followed by a 28.6 cm thick counter (E) that measured the energy of particles which came to a stop in it. Another 1.3 cm thick counter behind it was used as an anticounter to assure that the recoil particle had stopped in the E counter. A multi-wire proportional chamber was added in front of the spark chambers to restrict recorded events to those in which a recoiling particle originated in the target and passed through the spectrometer aperture. The entire spectrometer was mounted on a platform that could be rotated around an axis perpendicular to the beam direction.

The spectrometer had horizontal and vertical apertures of approximately 18° and 26° and a solid angle of approximately 80 millisteradians in the laboratory frame. Protons with kinetic energies between 53 and 213 MeV, corresponding to four momentum transfer squared, -t, between 0.1 and 0.4 GeV^2, were detected. The missing mass squared resolution was, in terms of the beam momentum P_b:

$$\Delta M^2(\text{rms}) \simeq 0.005\ P_b\ \text{GeV}^2, \qquad (2)$$

which implies $\Delta M/M \cong 1\%$ for the high mass regions of each spectrum. Beam hodoscopes were used to measure the incident beam particle momenta to $\sim 0.2\%$, angles at the target to ~ 0.2 mrad, and the transverse coordinate to $\sim$ 2mm. The beam spot at the target varied as $(P_b)^{-1}$ and was less than $\sim$ .5 cm (FWHM) at 100 GeV. Three threshold Cerenkov counters, an electron shower counter, and muon counters located behind $\sim$ 6m of Fe were used to determine the π^- abundances in the various beams.

A proportional chamber located $\sim$ 10m downstream from the

target measured elastically scattered pions in coincidence with recoil protons. These events, in which the angles of the elastically scattered pion were measured in addition to the angles and energy of the recoil proton, provided calibrations of the beam momentum, the recoil proton kinetic energy, and the scale of the missing mass spectrum.

Approximately five million triggers (π in, proton out) were recorded. In analyzing the data the following cuts were made:

(a) The production point of the event was restricted in order to exclude events from the target windows and walls. (b) To identify the recoil particle as a proton and to exclude protons which suffered a nuclear interaction in the stopping scintillators, consistency between the measured proton energy and its measured dE/dx was required. (c) The extrapolated position of the proton track at the rear of the stopping counter was restricted to insure that it lost all its energy in the counter.

The recoil proton spectrometer had a horizontal aperture of $\sim 18^{\circ}$ and data were taken at 5° intervals. This procedure provided significant overlap in the data taken at the various spectrometer settings. Mass spectra obtained at incident momenta of 40, 100, 200 GeV are shown in Fig. 1, and Table 1 lists the number of events accumulated and the M^2 ranges of our data at each beam momentum. The mass spectra were corrected for: a) geometrical acceptance of the spectrometer and spark and proportional chamber inefficiencies; b) losses from nuclear interactions of the recoil protons; c) attenuation of the incident beam over the 60 cm length of the target; d) recoil protons produced by secondary hadrons made in the hydrogen; e) contamination of the π^- beam by K^-, $\bar{p}$, μ^- and e's.

The measured cross sections in the overlap regions were independent of the setting of the recoil spectrometer, the target response was flat for purely elastic events, and there was excellent agreement between our measurements of elastic $\pi^- p$ scattering and the measurements of others [4], both in magnitude and $|t|$ dependence. We estimate that the overall normalizations of the spectra are correct to better than $\pm$ 10% and that the distortions to the shape of the spectra are less than $\pm$ 5%.

There is no apparent structure in the boson mass region $2 \leq M_{B^-} \leq 12.5$ GeV. The continuum for $M^2 \geq .1\ P_b\ \mathrm{GeV}^2$ can be adequately fit with a quadratic polynomial in M^2 of the form

$$d^2\sigma/dtdM^2 = P_1 + P_2M^2 + P_3M^4 \qquad (3)$$

where P_1, P_2, P_3, are fit parameters [5].

Upper limits for the production of resonance-like states have been established by assuming that such objects exist, with given mass and width, and by asking with what strength they could be produced consistent with the data. Fits were therefore made that included, in addition to the continuum (Eq. 3), a Breit-Wigner term of the form

$$BW = \frac{A\Gamma^2 M_B^2}{(M^2-M_B^2)^2 + \Gamma^2 M_B^2}, \qquad (4)$$

where M_B and Γ are the mass and width of the resonance and A is a fit parameter. The experimental resolution in M^2 was folded into the fitting function as a Gaussian distribution. The data were examined by stepping through values of M_B^2 covering the measured

range for $M^2 > 4$ GeV^2. Fits were done using resonance widths $\Gamma/2 = \Delta M^2/10$, ΔM^2, $5\Delta M^2$ and $10\Delta M^2$, with ΔM^2, the experimental resolution, given by Eq. (2).

The parameter A, determined by the fits, was consistent with zero, within two standard deviations (s.d.). This confirmed the results of the previous fits (eq. 3) and of the visual inspection, namely, that the data did not exhibit structure above M = 2 GeV. The error in A, also fit determined, set upper limits on the resonance production differential cross section $d\sigma_B/dt$. The results of this procedure for the case $\Gamma/2 = \Delta M^2/10$, i.e. where the resonance width is much smaller than the experimental resolution, are given in Table II. The 5 s.d. upper limits on $d\sigma_B/dt$ are shown in column 4 as obtained for the values of M_B^2 given in column 3. Figure 2 shows how the limits of Table II have to be scaled if the assumption is made that the state is broad ($\Gamma \gtrsim \Delta M^2$).

Upper limits on the total cross sections σ_B for the production of high mass states are calcuated from $d\sigma_B/dt$ under the assumption

$$\sigma_B = (d\sigma_B/bdt)\exp(-bt) \qquad (5)$$

Such limits are given in the last column of Table II. The constant b has been taken as b = 5 GeV^{-2} which is the measured t-dependence of the continuum. Under this assumption the results for the three t ranges t_1, t_2, t_3 could be combined, lowering the 5 s.d. limits on σ_B by a further factor ~ 1.5 beyond those given in the table.

We conclude that there is no evidence for the production of resonance-like enhancements in the data. In the boson mass region $2 < M_B - < 12.5$ GeV the 5 s.d. upper limit on the production cross

section of narrow states produced as B^-p is of the order 10 μb.

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TABLE I.

P_b (GeV)	Events	M^2 intervals measured (GeV^2)
40	114×10^3	-9 to 23
100	216×10^3	-15 to 78
200	290×10^3	-50 to 131
240	21×10^3	-20 to 50; 67 to 158

TABLE II.

P_b (GeV)	t range	M_B^2 $(GeV)^2$	$d\sigma_B/dt(\mu b/GeV^2)$ (5 s.d.)	$\sigma_B(\mu b)$ (5 s.d.)
40	t_1	5.5	36	15
		9.5	27	12
		13.5	37	15
	t_2	5.5	26	18
		9.5	21	15
		13.5	21	15
		17.5	31	21
	t_3	5.5	27	31
		9.5	17	20
		13.5	18	21
		17.5	28	32
		21.5	37	43
100	t_1	16	23	10
		25	27	12
		34	18	10
	t_2	16	25	17
		25	16	11
		34	24	17
		43	22	15
	t_3	16	16	18
		25	13	15
		34	15	17
		43	15	18
		52	21	24
200	t_1	42	21	9
		60	21	9
		78	44	18
	t_2	42	16	11
		60	15	10
		78	15	10
		96	23	16
	t_3	42	13	16
		60	12	14
		78	13	15
		96	14	16
		114	18	20
240	t_3	139	59	68

1) D. Bowen et al., in Experimental Meson Spectroscopy - 1972, AIP Conference Proceedings No. 8, edited by K.W. Lai and A.H. Rosenfeld (American Institute of Physics, New York, 1972), p. 215. Bowen et al., Phys. Rev. Lett. 30, 332 (1973) and references cited therein.

2) Y.M. Antipov et al., Phys. Lett. 40B, 147 (1972)

3) M.S. Chanowitz and S.D. Drell, Phys. Rev. Lett. 30, 807 (1973)

4) For elastic scattering, in the four momentum transfer interval to from .1 to .4 GeV^2, in our P_B range,

$$\Delta\sigma = \int_{\Delta t} a e^{-bt}$$

is independent of P_B. We find b = 8.4 GeV^{-2}, $\Delta\sigma$ = 1.33 mb, with the main error systematic and of order 3% in b and 5% in $\Delta\sigma$. The Fermilab Single Arm Spectrometer results (Phys. Rev. Letters 35, 1195 (1975)) yield b = 8.2 GeV^{-2}, $\Delta\sigma$ = 1.3 mb, in excellent agreement with our data.

5. C.F. Boyer, Ph.D. thesis, Northeastern University, 1976 (unpublished). For comparisons of the continuum spectra to triple Regge models see G.J. Blanar, Ph.D. thesis, Northeastern University, 1975 (unpublished). For comparisons of the continuum spectra of π^-, π^+, p on p, d to each other see M.F. Tautz, Ph.D. thesis, Northeastern University, 1976 (unpublished).

TABLE CAPTIONS

TABLE I. Data Summary. Number of events at each beam momentum that survive all selection criteria and are within $.1 \leq |t| \leq .4$ GeV^2.

TABLE II. Upper limits on the production of narrow resonances. For beam momenta P_b (column 1) and t ranges $.1 < -t_1 < .2$ GeV^2, $.2 < -t_2 < .3$ GeV^2, $.3 < -t_3 < .4$ GeV^2 (column 2), 5 s.d. upper limits on the resonance rpoduction cross section $d\sigma_B/dt$ are given in column 4 for several values of M_B, the central mass of the assumed resonance. The total resonance production cross section σ_B (column 5) has been calculated from $d\sigma_B/dt$ assuming eq. 5, with $b = 5$ GeV^{-2}.

FIGURE CAPTIONS

Fig. 1 Mass squared spectra at 40 GeV incident momentum, (a), 100 GeV (b), 200 GeV (c), for three t-ranges.

Fig. 2: Dependence of the resonance cross section limit on the width of the resonance Γ. Horizontal axis shows width in units of the experimental resolution. Ratio of the cross section limit for a resonance of width Γ to that for a narrow resonance (R = .1) shown vertically.

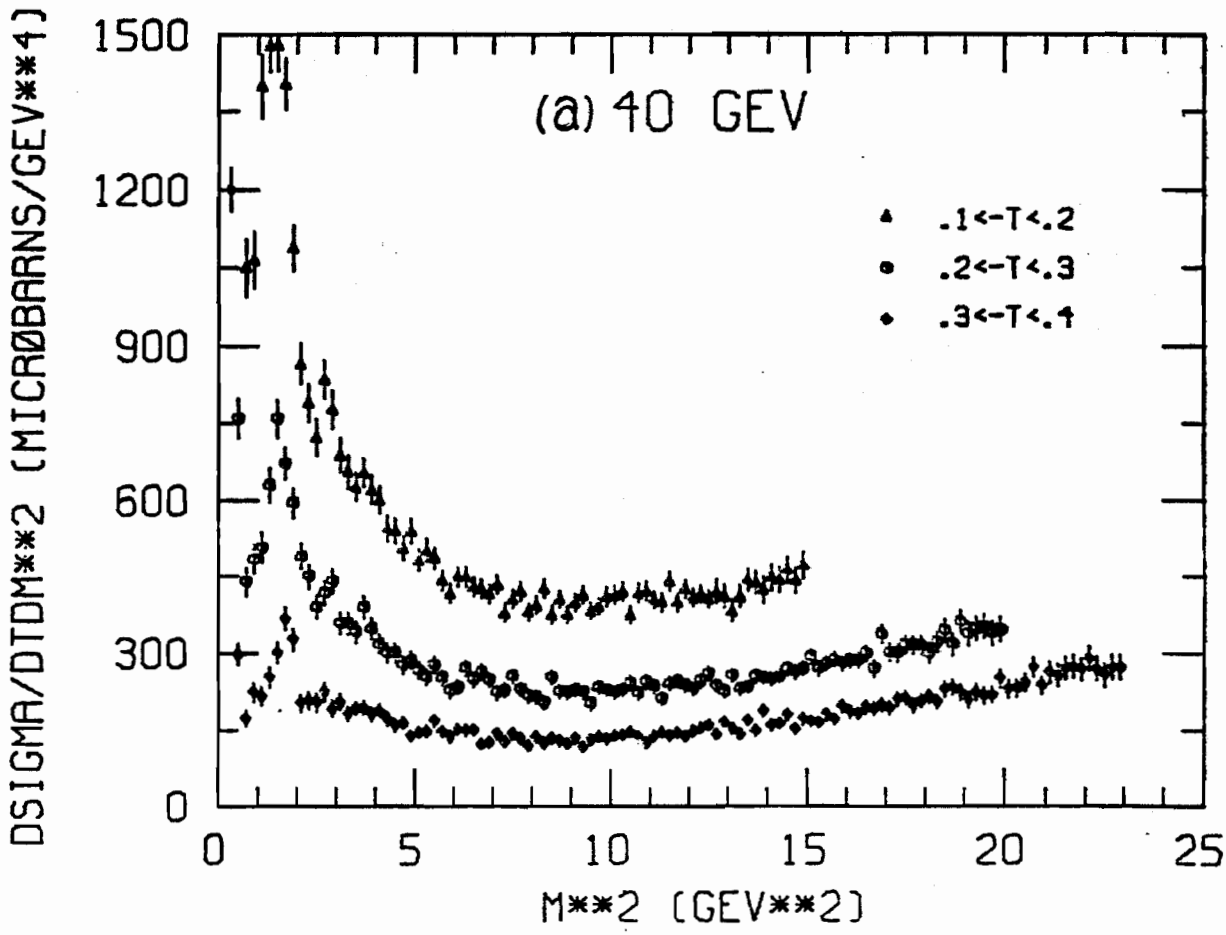
(a) 40 GEV
.1<-T<.2
.2<-T<.3
.3<-T<.4
DSIGMA/DTDM**2 (MICRØBARNS/GEV**4)
M**2 (GEV**2)
0
300
600
900
1200
1500
0
5
10
15
20
25

Fig.1a

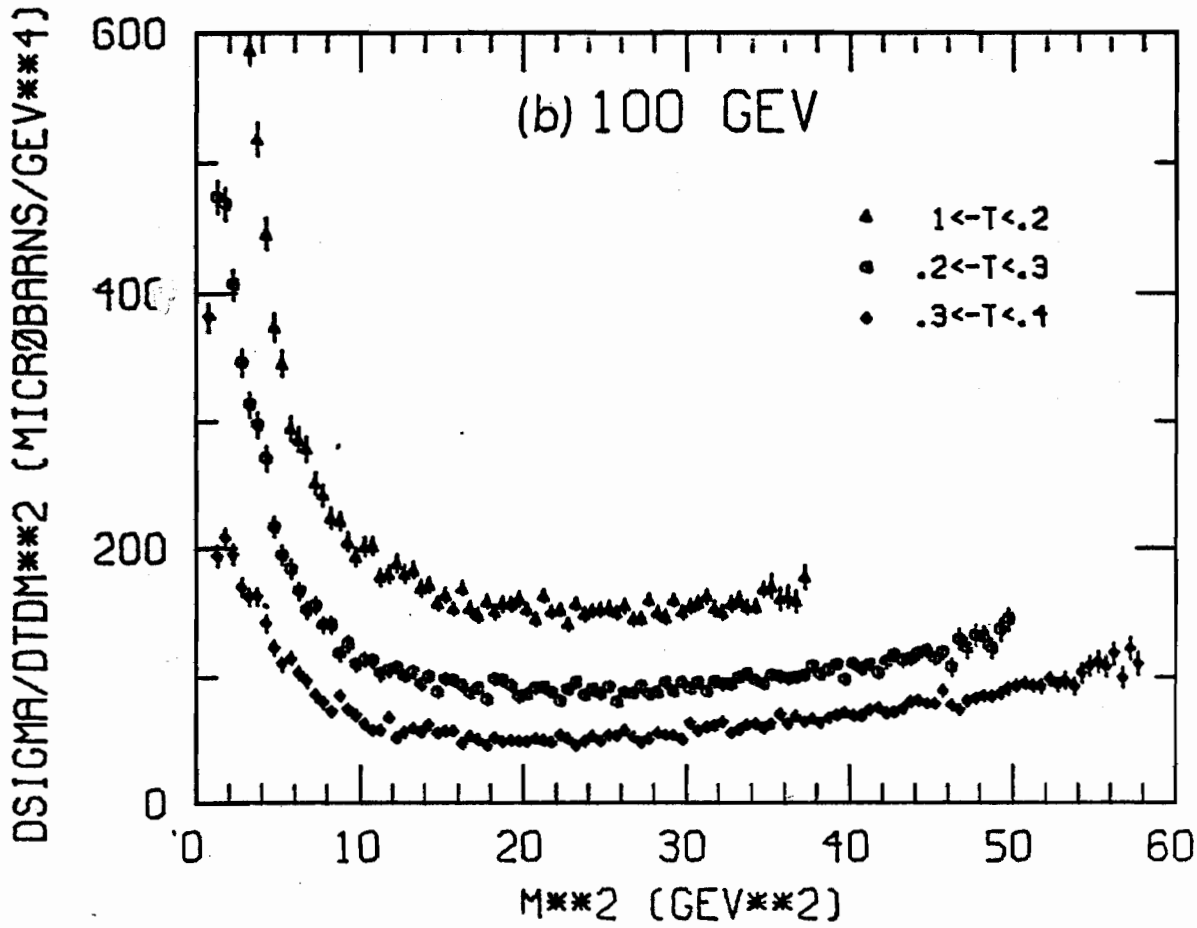
(b) 100 GEV
1<-T<.2
.2<-T<.3
.3<-T<.4
DSIGMA/DTDM**2 (MICRØBARNS/GEV**4)
600
400
200
0
0
10
20
30
40
50
60
M**2 (GEV**2)

Fig.1b

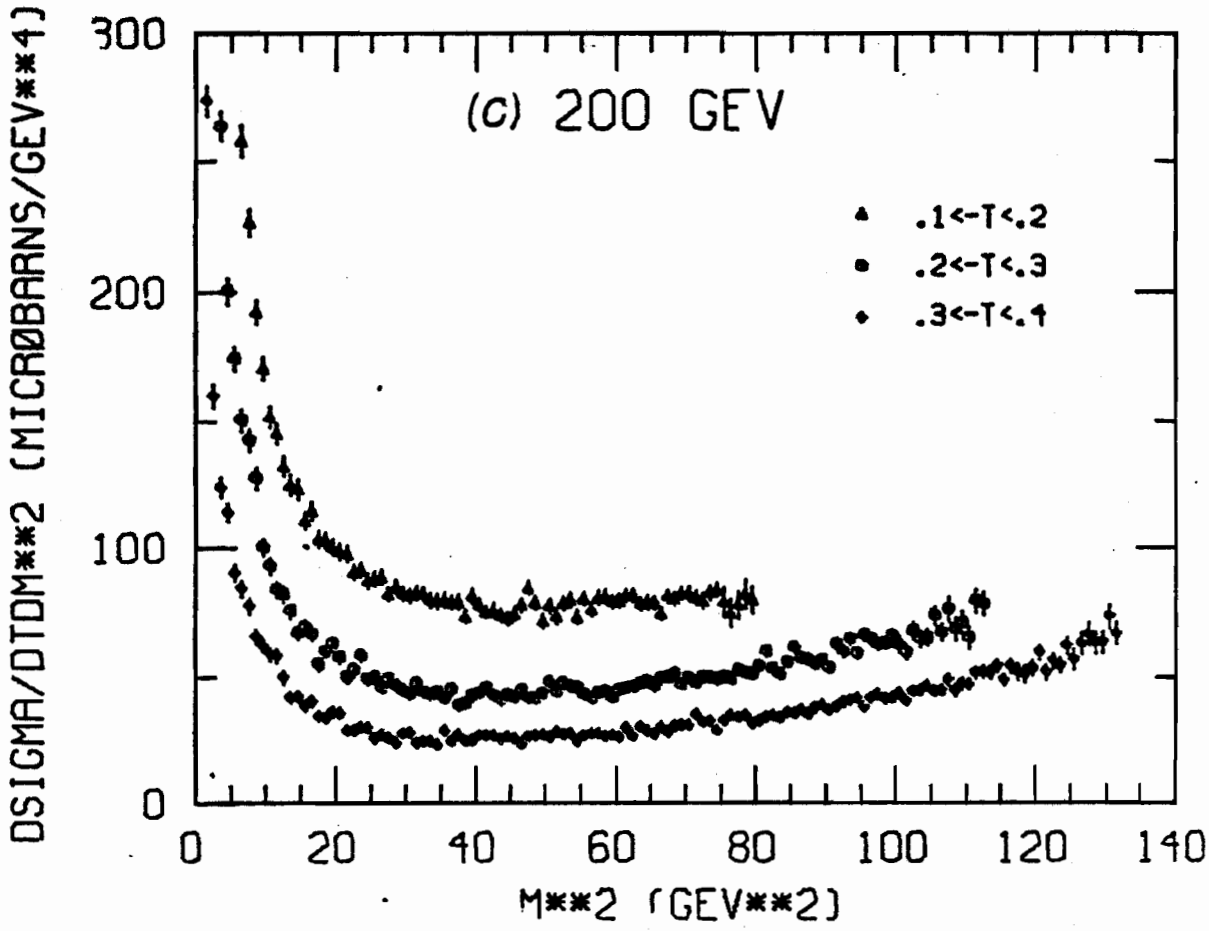
(c) 200 GEV
.1<-T<.2
.2<-T<.3
.3<-T<.4
DSIGMA/DTDM**2 (MICRØBARNS/GEV**4)
M**2 (GEV**2)
0
100
200
300
0
20
40
60
80
100
120
140

Fig.1c

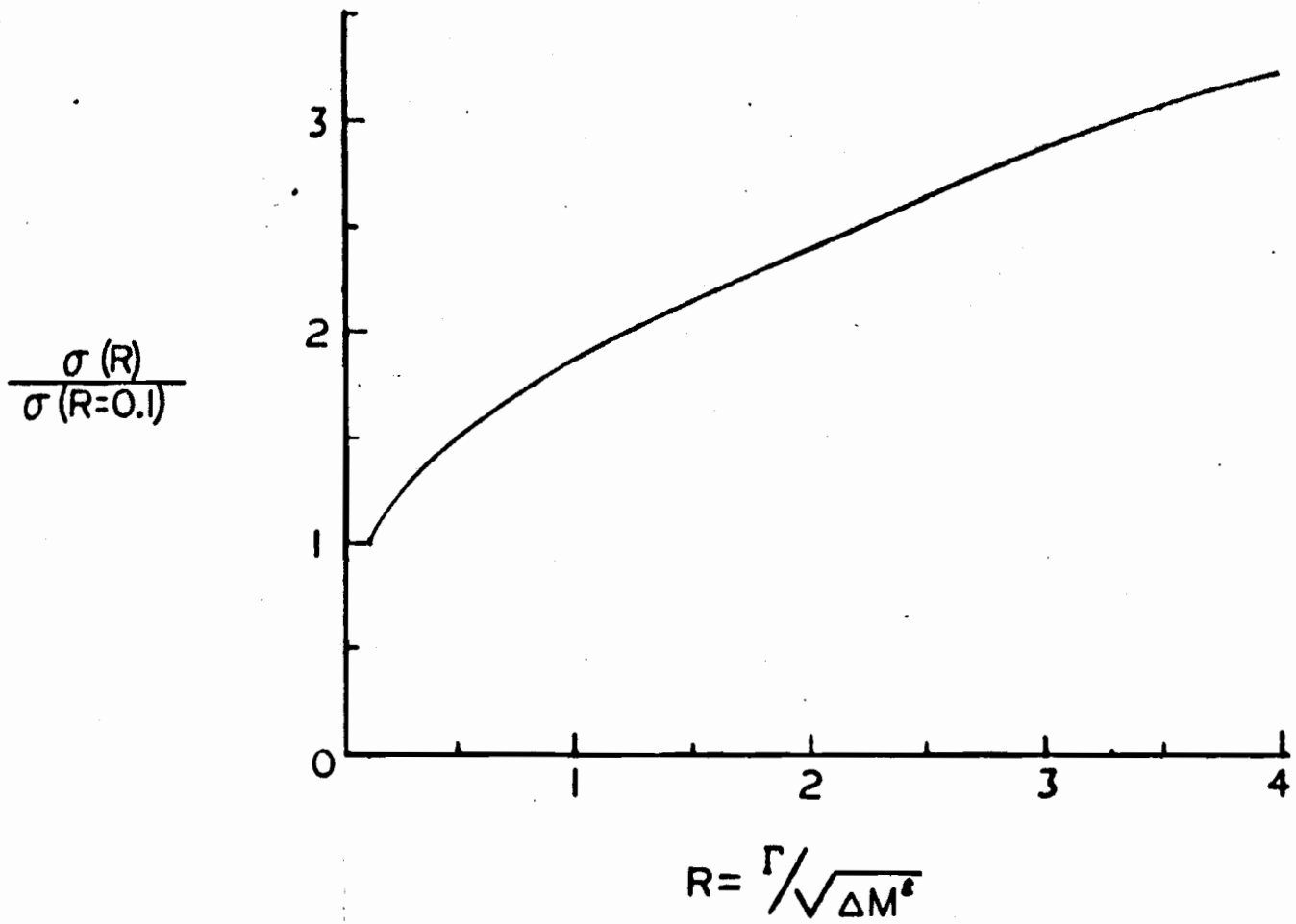

Fig. 2