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MEASUREMENT OF THE TOTAL AND PARTIAL $\bar{p}p$ CROSS SECTION BETWEEN 1901 AND 1950 MeV(*)

CERN-Liverpool-Mons-Padova-Roma-Trieste Collaboration

V. CHALOUPKA*, H. DREVERMAN, F. MARZANO**, L. MONTANET and P. SCHMID
CERN, European Organization for Nuclear Research, Geneva.

J.R. FRY, H. ROHRINGER and S. SIMOPOULOU
University of Liverpool, Liverpool.

J. HANTON, F. GRARD, V.P. HENRI, H. JOHNSTAD, J.M. LESCEUX and J.S. SKURA
Université de Mons, Mons.

A. BETTINI, M. CRESTI***, L. PERUZZO and P. ROSSI
Istituto di Fisica dell' Università and INFN, Padova.

R. BIZZARRI and M. IORI
Istituto di Fisica dell'Università and INFN, Roma.

E. CASTELLI, C. OMERO and P. POROPAT
Istituto di Fisica dell' Università and INFN, Trieste.

ABSTRACT

The presence of a structure in the $\bar{p}p$ total cross section at 1930-1940 MeV, with a narrow width of 9 MeV is confirmed. The interpretation of the effect as a single, non interfering, resonance is made difficult by the comparison of the elastic scattering with the charge exchange cross sections.

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* Now at SLAC.
** On leave of absence from INFN, Sezione di Roma.
*** Now at CERN Geneva, Switzerland.

LM/jr

A recent counter measurement of the $\bar{p}p$ and $\bar{p}d$ total cross sections performed at BNL by Carroll et al[1] between 360 and 1050 MeV/c has indicated the presence of a structure at a $\bar{p}$ momentum of 475 MeV/c, corresponding to a mass of 1932 ± 2 MeV for the $\bar{p}p$ system, with a Breit-Wigner width of $\left(9 \pm {}^{4}_{3}\right)$MeV (corresponding to 40 MeV/c for the $\bar{p}$ momentum) and a cross section of $\left(18 \pm {}^{6}_{3}\right)$mb over a smooth background. Since the momentum lost by a 475 MeV/c antiproton in their 30 cm long liquid hydrogen target was 50 MeV/c, antiproton in their 30 cm long liquid hydrogen target was 50 MeV/c, the momentum of the interacting $\bar{p}$'s was known with an uncertainty larger than the quoted width. This could then be significantly smaller than 9 MeV, as is, on the other hand, indicated by the error attached to it.

A narrow effect at the same mass has also been reported in a bubble chamber study of $\bar{p}d$ reactions[2] and other experiments indicate the existence of structures in the $\bar{p}p$ backward elastic cross section in this mass region[3]. In general, searches for narrow heavy resonances, in particular in the $\bar{N}N$ system, have been simulated by the recent discovery of the J-Ψ objects. Also, a theoretical model, derived from NN interaction, suggests the existence of several low lying resonances in the $\bar{N}N$ system[4] while others postulate the existence of exotic $\bar{N}N$ states[5].

We have measured the $\bar{p}p$ interaction between 306 and 551 MeV/c (1901 and 1950 MeV of total cm energy) in an experiment designed to achieve an experimental resolution small compared to the width quoted in ref. (1). We used a separated antiproton beam which entered the visible region of the CERN 2m hydrogen bubble chamber with a momentum of(571.2 ± 5.5)MeV/c. The antiprotons stopped in the liquid hydrogen after a path of(132.5 ± 0.5)cm if they came to rest. Therefore all the antiprotons were seen to interact in the chamber, either in flight or annihilating at rest. The magnetic field in the chamber was reduced to 0.5 T to keep the trajectories well inside the fiducial volume and a superconducting field-shielding tube[6] was used to provide a field-free path for the low energy primaries.

Two distinctive features of this experiment are worth mentioning:

a) It can yield an absolute measurement of the $\bar{p}p$ total and topological cross sections as functions of the $\bar{p}$ momentum, if the primary tracks are picked up at their entrance into the visible region of the chamber and followed up to the interaction point, where position and type of the interaction are recorded; in this way all relative normalization problems are avoided.

b) The residual range of the antiproton at the interaction point is a precise measurement of its energy. The spread of the length distribution for antiprotons annihilating at rest is a measurement of the energy resolution. The r.m.s. spread turned out to be (3.5 ± 0.5)cm, in agreement with the nominal spread of the beam momentum and corresponding to an energy resolution of $\pm$ 1.5 MeV at 1930 MeV total cm energy.

This way of measuring energy and energy resolution checked with the mass-dependent fits on the measured primary tracks and with the information obtained on the primary momentum from the elastic scattering events.

The events were scanned for and measured with different techniques in the various laboratories. At CERN and at Mons a manual scanning was performed on the interactions. The beam tracks entering the fiducial region were then counted and a one-to-one correspondence was required between interactions and entering primaries. The events were then automatically measured, at CERN on ERASME and at Mons on SWEEPNIK. At Padova the entering primaries were picked up automatically on one view by PEPR and followed automatically up to the interaction point where the operator identified the topology of the interaction, recorded its position and, for elastic scattering events, started the automatic following of the secondary $\bar{p}$. Measurement on the second view started at the interaction point, where the operator checked the topology assignment.

The procedures described above insure that the scanning efficiency is topology independent, except for small angle scatterings (see below). The measured events were processed with the HYDRA chain[7] that reconstructed successfully the space coordinates of all the interaction points and 98.6% of the primary tracks selected for measuring at the chamber entrance. The effect of this 1.4% loss was taken into account in the determination of the cross sections, using the fact that for all events the position of the interactions was known.

The scanning efficiency for elastic scattering events is low at small angles. We therefore rejected all events with $\theta < 6.4^{\circ}$ ($\cos\theta^{*} > 0.975$) thus removing also most of the Coulomb scattering events. Above the cut-off angle the losses are small ($\sim$ 3%) and confined to a narrow interval of azimuthal angle and have been corrected for. After this correction, the angular distributions were extrapolated to 0° by a fit to an exponantial distribution in $\cos\theta^{*}$[8], subdividing the elastic events in five energy intervals. The variation of the angular distribution with energy is smooth enough to allow this grouping in energy of the events. For each interval the extrapolated cross section at 0° agrees with the limit given by the optical theorem. The overall correction is (13 ± 2)% of the number of elastic scattering events with $\theta > 6.4^{\circ}$ and has no significant energy dependence.

The most delicate problem we had to face concerns the beam contamination due to antiprotons with abnormally low momenta (low energy tail). Since all antiprotons coming to the end of their range annihilate giving an interaction which is indistinguishable from one in flight, even a very small low energy tail can give a non negligible contribution to the annihilation cross section, especially in the low energy region. This contamination is largely due to that fraction of the antiproton beam which does not enter the chamber through the thin window (5mm steel). To purify the beam we introduced the following criteria: position and direction of the antiproton at the entry of the fiducial region had to be such that it would not leave the visible volume of the chamber before stopping, even if it did not interact in flight. Moreover, the antiproton trajectories were extrapolated upstream to check that they entered through the region of constant thickness of the window. These cuts eliminated about 20% of the events, leaving a total of 205,000 $\bar{p}p$ interactions between 570 MeV/c and rest. We also tried more severe cuts on the entrance parameters, which however had no effect on the cross sections.

The efficiency of the cuts was also controlled by applying them to a proton beam of similar characteristics, sent into the chamber during the run with the same beam settings. These protons also, apart from a small fraction that scatter elastically, stop in the expected region, with a spread in the length distribution corresponding to the nominal momentum spread.

To estimate the importance of a possible residual contamination we measured the distribution of the curvatures for the last 40 cm of all the antiproton tracks annihilating in different regions of the chamber. Comparing this distribution with the one measured for annihilations at rest we were able to estimate the contamination, which was found to be negligible for masses larger than 1920 MeV, equal to (4±1)% between 1910 and 1917 MeV, to (7±4)% at 1905 MeV and to (18±9)% at 1901 MeV. All the results presented below have been corrected for the contamination.

The total and topological cross sections, after cuts and corrections, were computed independently for the various laboratories and found to be compatible up to 1950 MeV. Interactions at higher $\bar{p}$ momenta occur very close to the entrance into the visible region and the primary tracks are so short that scanning losses become more likely. For masses lower than 1901 MeV(corresponding to $\bar{p}$ momenta less than 306 MeV/c) the contamination due to the low energy tail of the beam is large and the estimate of the cross section becomes unreliable. The data were then put together and the cross sections computed again for the total sample of 105,00 events in the energy interval 1901 and 1950 MeV. The events have been plotted in equal residual range intervals, 6cm wide. This bin size is chosen to give sufficient statistical accuracy (about 1.4% on the total cross section points) without spoiling the energy resolution. It corresponds to intervals in total cm energy which vary from 2 MeV at the highest energy, to 5.2 MeV at the lowest, being 2.5 MeV at 1936 MeV. Because of the r.m.s. beam spread, 56% of the events in each bin have an energy within the nominal bin limits.

Table 1 gives our measured cross sections and fig. 1 shows the total, elastic, topological and "inelastic" (0 + 2 + 4 + 6 prongs) cross sections as functions of the total $\bar{p}p$ cm energy. The large errors on the two lowest energy points of the total and annihilation cross sections are due to the uncertainty in the contamination correction. Fig. 2 shows the comparison of our results with the data of the BNL experiment[(1)] for the total cross section. Except perhaps for the point at 1931 MeV the agreement is very good and a structure at 1930-1940 MeV is apparent also in our data.

From fig. 1 one can also see that the structure is present both in the elastic and inelastic channels. A previous measurement of these cross section has been performed by the CERN-Rome-Trieste Collaboration (CRT) in a bubble chamber experiment[(9)], of lower statistical significance than ours. Their data give no indication of structures, although the disagreement point-by-point between their total and inelatic cross sections and ours is never statistically significant. For the elastic cross sections, the high energy points of CRT are systematically higher than ours. This difference cannot be explained by the presence of angular biases in scanning, since the slopes of the angular distributions at this energy are very similar for the two experiments. A possible explanation could be a difference in the internal normalization of CRT cross sections, where data for energies above and below 1946 MeV come from different bubble chamber exposures. The comparison of the total cross section of the CRT experiment[(1)] is not in contradiction with this hypothesis.

A fit to our total cross section with a polynomial of the form a +b/p, where p is the laboratory antiproton momentum gives a very low confidence level, 0.8%. Similar fits to the various partial cross sections give also low confidence levels, except for the six prongs, which have, however, very large statistical uncertainties. We tried, therefore, to fit the data assuming an incoherent superposition of the polynomial background with a Breit-Wigner. The fit came out very good and the parameters of the Breit-Wigner in good agreement with those of ref. 1. The fit however gives a very large error to the resonance width (16 ± 11 MeV). This is due to the fact that our highest energy point, at 1950 MeV, lies very close to the observed structure, which makes it difficult to estimate, from our data, the behaviour of the background after the resonant signal has died out. For this reason we tried a new fit, including also the total cross section points of ref. 1 at 564, 593 and 653 MeV/c (1953, 1961 and 1976 MeV respectively). For this purpose the larger experimental resolution of ref. 1 should make no difference, at least for the points measured with the 30 cm long target. The total cross section was assumed to be of the form:

$$\sigma_t = a + b/p + \sigma_t^R \frac{1}{\varepsilon^2 + 1}$$

where

$$\varepsilon = \frac{2}{\Gamma} (M - M_R)$$

and the fit, performed folding in the experimental resolution, gave the following results:

$$a = (57 \pm 3)\text{mb};\ b = (56 \pm 2)\text{mb GeV/c};\ M_R = (1935.9 \pm 1.0)\text{MeV};$$

$$\Gamma = \left(8.8 \begin{array}{l} +\ 4.3 \\ -\ 3.2 \end{array}\right)\text{MeV};\ \sigma_t^R = (10.6 \pm 2.4)\text{mb}.$$

The χ^2 was 10.6 for 16 degrees of freedom. Except for the two background parameters and for the width, these numbers are essentially equal to those obtained with the fit to our data alone.

If the enhancement is due to a single resonance of spin J and elasticity $x = \frac{\Gamma_{\bar{p}p}}{\Gamma_t}$, from the measured value of σ_t^R we get:

$$\sigma_t^R/\pi\lambda\!\!\!^{-2} = (2J + 1)x = 0.50 \pm 0.11. \qquad (1)$$

Using the values of M_R and Γ obtained from the fit to σ_t, we also fitted independently the elastic, inelastic, annihilation (2 + 4 + 6 prong) and 0 prong cross sections obtaining:

$\sigma^R_{el} = (7.0 \pm 1.4)$mb	C.L. 40%[10]
$\sigma^R_{inel} = (5.1 \pm 1.9)$mb	C.L. 20%
$\sigma^R_{ann} = (3.2 \pm 1.8)$mb	C.L. 60%
$\sigma^R_{o} = (1.6 \pm 0.7)$mb	C.L. 8%

The most interesting results of these fits are:

a) the large contribution of the elastic channel to the bump,

b) the presence of a signal also in the annihilation channel and

c) the difference between the resonant elastic and 0-prong (78% of which are charge exchange scattering) cross sections.

This disagreement is perhaps stronger than the difference between the fitted values of σ_R(5.4 ± 1.6 mb) indicates. In fact, the two cross sections (see fig. 1) have very different behaviours.

A recent measurement of the 0-prong cross section has been performed by M. Alston Garnjost et al.[11] in a counter experiment. A comparison of our data with theirs is shown in fig. 2. The two experiments agree very well except at 1931-1934 MeV where our data show a sharp "wiggle" not present in the data of ref. 11. However, the experimental resolution of ref. 11 at this energy is such (± 5 MeV or ± 24 MeV/c) as to average over the wiggle region.

The data of ref. 11 support therefore our indication that the charge exchange cross section does not show a resonant signal as strong as that observed in the elastic cross section. We cannot therefore interpret the observed structure as a single, non interfering resonance of definite isospin. Any simple deduction on the value of J or of the elasticity for the resonance is therefore not possible. One might try, however, some speculations. The authors of ref. 1 observe that the existence of two degenerate or nearly degenerate resonances of isospin 1 and 0 is not unlikely, in view of the presence of equal structures in their $\bar{p}p$ and $\bar{p}d$ data. If one assumes that these two resonances exist and have the same J^P, they could interfere destructively to cancel out in the charge exchange and constructively in the elastic scattering. Formula (1) would still be valid, provided one replaced x with the ratio σ^R_{el}/σ^R_t, which, in this case, is equal to the sum of the two elasticities. From our data this ratio turns out to be 0.66 ± 0.20 and would indicate, in this interpretation, a value of 0 for J. However, the presence of a non resonant background for this low J value is hard to exclude. One would have, then, to take into account as well the interference of the two resonances with background. The interference with background, however, could explain all the data even if the resonance is single, but, since the background amplitudes are not known, no conclusions can be drawn in this case on the spin of on the elasticity of the resonance.

Within our statistical accuracy, the angular distributions of the elastic scattering do not show significant changes going through the resonance region. The slopes of the forward peak grow smoothly with increasing momentum in agreement with the results of ref. 9.

In summary our data confirm the existence of a structure in the total $\bar{p}p$ cross section, at(1936 ± 1)MeV, 9^{+4}_{-3} MeV wide and provide evidence for its presence also in the elastic channel. The simultaneous absence of an equal signal in the charge exchange cross section makes the interpretation of the effect as a single non-interfering resonance difficult.

The bubble chamber film used for the present analysis is part of a larger sample on which a search was conducted for structures of width comparable to the experimental resolution (about 2 MeV). No such structures was observed (see for instance "Search for structures in $\bar{p}p$ cross sections in the 1910-1944 MeV mass region" by the CERN-Demokritos-Liverpool-Mons-Padova-Roma-Saclay-Trieste collaboration, presented at the ANL Conference on

"New directions in Hadron Spectroscopy" and at the 1975 EPS Conference on High Energy Physics at Palermo. The same results have also been presented at the Loma-Koli School and at the APS meeting in Seattle). The further analysis required to study the effect of the geometrical cuts and of the beam contamination and for the extrapolation to 0° of the elastic scattering was performed on about two thirds of the original sample.

REFERENCES

(1) A.S. Carroll et al.; Phys. Rev. Letters 32 (1974) 247.

(2) T.E. Kalogeropoulos and G.S. Tzanakos; Phys. Rev. Letters 34 (1975) 1047.

(3) D. Cline et al.; Phys. Rev. Letters 21 (1968) 1268.
Ch. D'Andlau et al.; Physics Letters 58B (1975) 223.

(4) L.N. Bogdanova et al.; Ann. Phys. 84 (1974) 261.

(5) See for instance P.G.O. Freund, R. Waltz, J. Rosner; Nucl. Phys. B13 (1969) 237.

(6) M. Firth et al.; 1974 International Conference on Instrumentation for High Energy Physics - Frascati.

(7) We acknowledge the important contribution of F. Bruyant who wrote an advanced geometry program for this experiment.

(8) Due to the presence of a strong annihilation cross section the elastic scattering at this energy has a typical diffractive behaviour (shadow scattering).

(9) U. Amaldi et al.; Nuovo Cimento 46 (1966) 171 and
B. Conforto et al.; Nuovo Cimento 54A (1968) 441.

(10) For the fit to σ_{el}^{R} we excluded the lowest energy point whose low cross section made it difficult to fit with a p^{-1} term. The fit with all the points gave the same results as the present fit, but a lower C.L. (1.5%).

(11) M. Alston-Garnjost et al.; Phys. Rev. Letters 35 (1975) 1685. We used for the comparison the sum of the charge exchange and neutral annihilation cross sections.

TABLE 1

P MeV/c	ECM GeV	σ_{el}	$\pm\ \delta\sigma$	σ_{o}	$\pm\ \delta\sigma$	σ_{inel}	$\pm\ \delta\sigma$	σ_{t}	$\pm\ \delta\sigma$
306	1.901	74.7	1.9	22.7	1.4	163.8	18.7	238.5	19.1
336	1.905	75.7	1.9	22.2	1.2	151.0	9.0	226.6	9.6
360	1.910	73.1	1.8	20.6	.9	144.3	4.4	217.4	4.9
381	1.913	71.1	1.7	19.8	.9	131.2	3.4	202.3	3.9
399	1.917	68.0	1.7	19.7	.9	124.8	2.8	192.9	3.3
416	1.920	65.5	1.6	20.8	.9	127.7	2.7	193.2	3.2
431	1.923	66.4	1.6	18.0	.8	122.5	2.5	188.9	2.9
445	1.926	63.6	1.5	19.5	.8	121.0	2.4	184.6	2.9
458	1.929	64.8	1.5	18.3	.8	118.6	2.2	183.4	2.7
471	1.931	64.8	1.5	16.5	.7	113.1	2.1	177.9	2.6
482	1.934	63.7	1.5	20.3	.8	120.0	2.2	183.7	2.6
493	1.936	64.2	1.4	18.2	.7	114.2	2.1	178.3	2.5
504	1.939	60.7	1.4	17.8	.7	113.9	1.7	174.5	2.2
514	1.941	56.5	1.3	18.1	.7	114.7	1.7	171.2	2.1
524	1.943	59.0	1.4	16.9	.6	108.6	1.6	167.6	2.0
533	1.946	55.5	1.3	15.6	.6	105.4	1.6	160.9	2.0
542	1.948	54.9	1.3	16.4	.6	106.5	1.6	161.4	1.9
551	1.950	51.7	1.5	16.8	.8	104.8	2.0	156.5	2.4

Total and partial cross sections, in mb, from this experiment.

FIGURE CAPTIONS

fig. 1 Total, inelastic (0 + 2 + 4 + 6 prongs), elastic and 0, 2, 4, 6 prong cross sections as functions of the total $\bar{p}p$ cm energy. The solid curves on the total, inelastic and elastic cross sections are the results of the fits to background plus resonance (see text). The dashed curves are the polynomial background. The solid curves on the other cross sections are the fits to a polynomial background alone.

fig. 2 Comparison of our total cross sections with those of A. Carroll et al.(1) and of our 0-prong cross sections with those of M. Alston-Garnjost et al.(11).

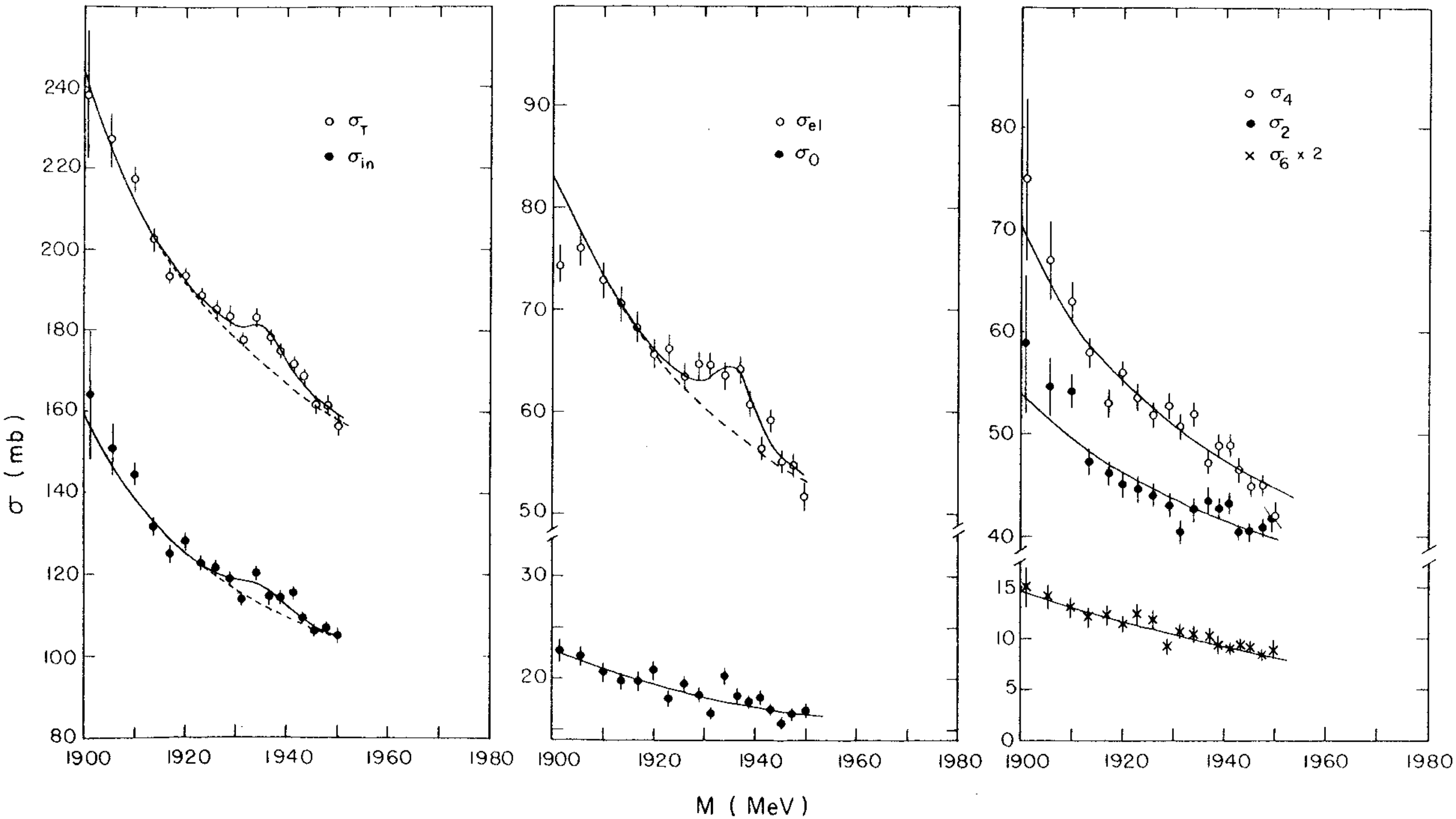

Fig. 1

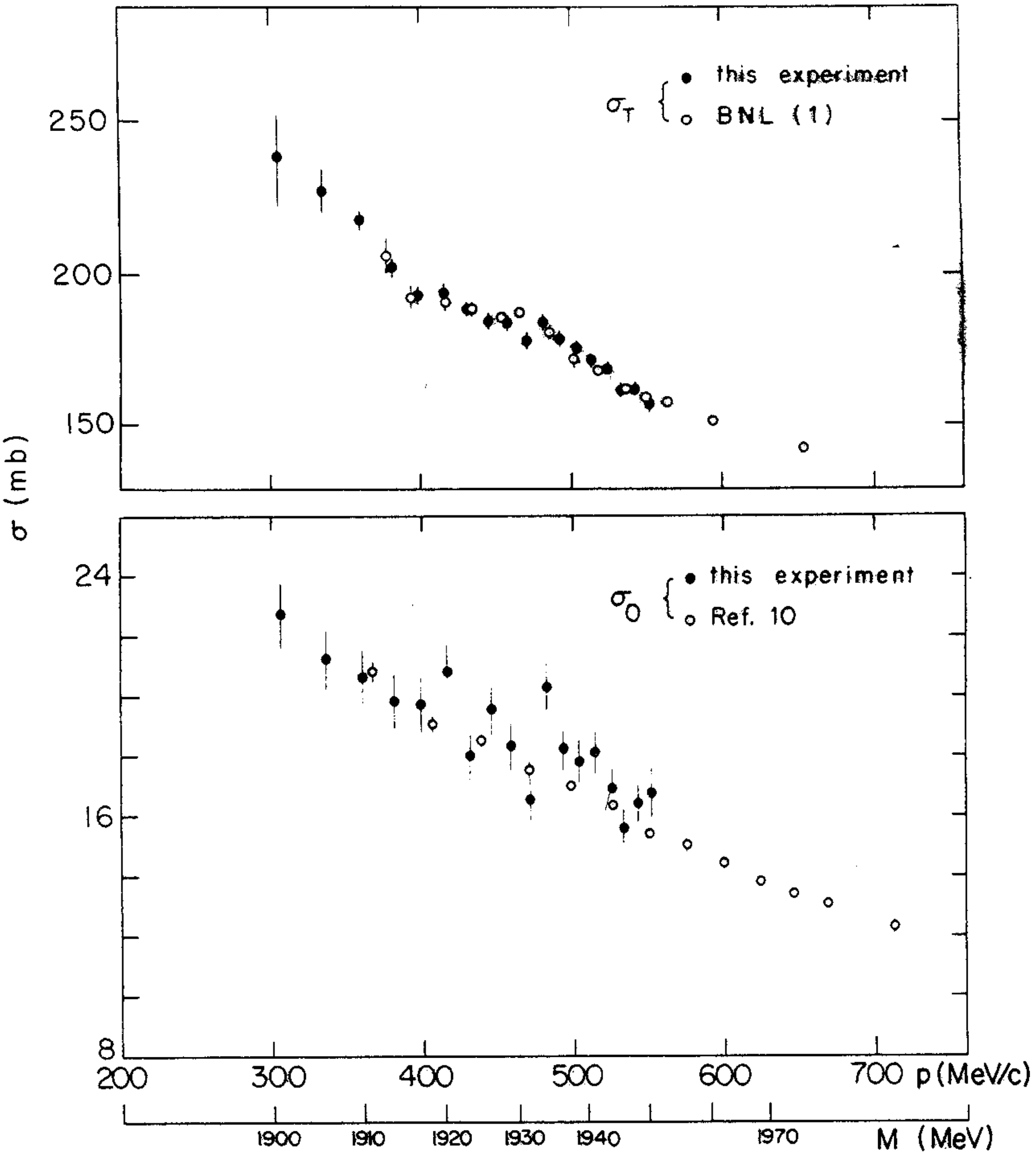
σ (mb)
250
200
150
σT { ● this experiment ○ BNL (1)
24
16
8
σ0 { ● this experiment ○ Ref. 10
200
300
400
500
600
700 p (MeV/c)
1900
1910
1920
1930
1940
1970
M (MeV)

Fig. 2