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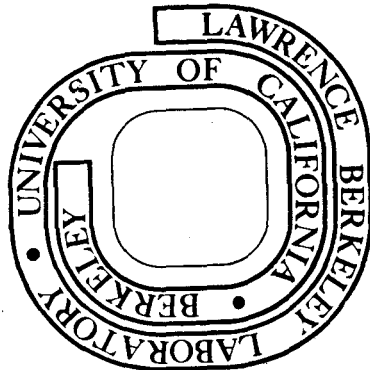
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EXPERIMENTAL STUDY OF $\bar{p}n$ ANNIHILATIONS BETWEEN 1.0 AND 1.6 GeV/c

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Abstract

$\bar{p}n$ annihilations into three and five charged mesons with or without neutrals have been studied in order to measure the contributions of the various final states to the 5.5 mb enhancement discovered in the total $I = 1 \bar{N}N$ cross section at 2190 MeV total CM energy. Fits have been performed to the cross sections as functions of the incident \bar{p} momentum with background plus a resonant term. The fits show enhancements in several final states, the statistically most significant one being in the reaction $\bar{p}n \rightarrow \pi^+ 2\pi^-$ (0.51 ± 0.13 mb over a background of 1.4 mb). Less significant effects are also found in all other pionic annihilation final states regardless of their G-parity.

1. Introduction

We report a study of the $\bar{p}d$ interactions at \bar{p} momenta of 1.0, 1.1, 1.2, 1.3, 1.4, 1.5 and 1.6 GeV/c, in the 81 cm CERN bubble chamber filled with deuterium.

The experiment was designed to study the $I = 1$ $\bar{p}n$ interaction in the region of the broad enhancement found by Abrams et al.⁽¹⁾ at a total CM energy of 2190 MeV, in the $\bar{p}p$ and $\bar{p}d$ total cross sections. The height of the enhancement, in the $I = 1$ $\bar{N}N$ cross section, was 5.5 mb over a background of about 100 mb. More recently, Alspector et al.⁽²⁾ studying $\bar{p}p$ cross sections found an enhancement at the same energy with a cross section of about 2.3 mb, in agreement with the $\bar{p}p$ data of Abrams et al.

The energy region around 2190 MeV, commonly referred to as the "T region", has been the object of several experimental studies. Experiments have been performed to see whether the enhancement in the $\bar{N}N$ cross section in this region could be ascribed to the formation of a resonance, or whether it could be due to some threshold effect, in particular, the production of the $\bar{\Delta}N$ and $\Delta\bar{N}$ final states, whose threshold lies at about the same energy.⁽³⁾

The results indicate that:

- a) the single pion production ($\bar{\Delta}N$ or $\Delta\bar{N}$ threshold effect) cannot be responsible for the enhancement. This is true for $\bar{p}p$ interactions⁽⁴⁾ as well as for $\bar{p}n$ interactions.⁽⁵⁾
- b) For $\bar{p}p$ annihilations, only weak evidence has been found for structure in any of the final states analyzed so far.^(4,6,7,8)

- c) For $\bar{p}n$ annihilations, in the cross sections for the production of resonances, no evidence has been found of structures capable of explaining a significant part of the 5.5 mb enhancement. ⁽⁹⁾

In the following we shall give the details and present the results of an analysis of the $\bar{p}d$ interactions resulting in a final state containing a proton stopping in the chamber and an odd number of charged mesons (prongs). We shall give the topological cross sections for both odd and even topologies and the $\bar{p}n$ reaction cross sections for final states containing an odd number of charged mesons with and without neutrals. Results on the production of one pion ⁽⁵⁾ and on the cross sections for production of resonances ⁽⁹⁾ have already been published. A preliminary analysis of the data to be discussed in this paper has been presented at the 1971 EPS Conference. ^(10a) The present analysis replaces entirely the preliminary one. More details on part of this analysis can be found in ref. (10b).

We shall also present in this paper the results of fits to the data of an incoherent superposition of background and two Breit-Wigner functions, one at 2190 MeV, the other at 2350 MeV (the second $I = 1$ enhancement observed by Abrams et al. ⁽¹⁾ whose low energy tail extends into our energy range). To decrease the uncertainty in the energy dependent background function we included in the fit the data of Eastman et al. ⁽⁸⁾ who performed an experiment similar to ours at higher \bar{p} momenta.

2. Exposure and Scanning

The exposure consisted of 370,000 pictures of the CERN 81 cm bubble chamber filled with deuterium. The primaries were antiprotons

of seven different momenta from 1.0 to 1.6 GeV/c in steps of 0.1 GeV/c. The Fermi motion of the neutron in the deuterium nucleus gives a spread in the total $\bar{p}n$ center of mass energy equivalent to a spread of the beam momentum of about ± 60 MeV/c. The details of the exposure are given in Table 1. Two different beam set-ups were used, one for 1.0 and 1.2 GeV/c, the other for the rest of the pictures.

The pictures were scanned at Padova, Pisa and Torino, for all interactions within a fiducial volume 40 cm long in the chamber and all entering beam tracks were counted. Interactions were recorded according to the number of "prongs". In our terminology a prong is any track emerging from the interaction vertex which cannot be identified as a proton stopping in the liquid. A "spectator" (or recoil) proton is then not called a prong if it stops in the chamber but is if it leaves the chamber. The raw scan data were corrected for the three effects:

a) Contamination of the beam. We measured the fraction of "light" particles among the beam tracks by searching for delta-rays. This contamination turned out to be 3% at 1.0 GeV/c, 9.7% at 1.2 GeV/c, and less than 0.5% at the other momentum settings. At 1.2 GeV/c the 9.7% contamination was estimated to consist of 6.2% μ 's and 3.5% π 's from interactions of tracks with delta-rays. Using this information and the known π^-d topological cross sections for that energy we corrected the 1.2 GeV/c data. For the 1.0 GeV/c data, we used for the correction a similar composition of the contamination. No corrections were applied to the rest of the data.

b) Scanning efficiencies. By rescanning about 10% of the film (36,000 pictures) we determined our scanning efficiency, which is 81%

for the 0-prongs and about 93% for each of the other topologies. The inefficiency for the 0-prongs is due to actual losses. For the other events we found that some were listed under different topologies in the two scans. The overall scan efficiency for non-zero-prong events is 96%. We did not determine the efficiency for counting beam tracks but assumed it to be equal to 100% for the purposes of comparing our raw total cross sections with the more accurately measured cross sections of Abrams et al.⁽¹⁾.

c) Small angle one-prong interactions. The efficiency for detecting small angle one-prong interactions decreases rapidly as the projected angle approaches zero. From a study of this efficiency performed at all beam momenta,⁽¹¹⁾ we estimate that the number of events lost for this reason is $9 \pm 2\%$ of the total number of events found. To this accuracy, the fraction lost is independent of beam momentum.

3. Total and Topological Cross Sections

Cross sections were determined independently for scans made at the three different labs. The resulting total cross sections agree among themselves and the combined results are shown in fig. 1. The errors shown take into account statistics and the uncertainties in the corrections described above but they do not reflect uncertainties in our beam track scan. For comparison we show in fig. 1 also the more accurately determined cross section of Abrams et al.⁽¹⁾. The agreement is good if one allows for the systematic difference in the overall normalization of about 6%.

For the purpose of calculating the topological cross sections, we normalized the total cross sections for each lab separately to the $\bar{p}d$

total cross section of Abrams et al.⁽¹⁾. The three sets of topological cross sections were then compared and found to be statistically compatible for each topology. The weighted averages are shown in fig. 2 and table 2.

A comparison of our even prong (0,2,4,6) cross sections with the corresponding topological cross sections measured in $\bar{p}p$ interactions reveals differences due in part to scanning techniques and in part to the presence of the spectator nucleon.

For our zero-prong cross section we find essential agreement with $\bar{p}p$ experiments. Averaged over the momentum range of our experiment we find 7.7 ± 0.2 mb compared to 7.4 ± 0.1 mb for published $\bar{p}p$ experiments.^(4,6) This agreement may just be a fortuitous cancellation of various effects.

For 2-prong cross sections no meaningful comparison can be made. In $\bar{p}p$ experiments, small angle scatters with no visible recoil are taken as two-prong events and constitute a large fraction of the cross section. The corresponding elastic scatters are classified by us as one prong.

Our 4-prong and 6-prong cross sections are higher than those in hydrogen^(4,6,12,13) (by about 4.5 mb for the 4-prong and 3 mb for the 6-prongs, at all beam momenta). As a check on what the excess events are, we have measured and analyzed a sample of 6-prong events at 1.6 GeV/c where our 6-prong cross section is about two times the $\bar{p}p$ cross section. We had a cross section for events with a proton in the final state of 3.5 ± 0.3 mb. These events are $\bar{p}n$ annihilations with protons that have been called prongs in the scan. Most of

them are probably due to initial or final state scattering on the proton. In addition to scattering, some transfer of events to even prong topologies takes place just because the spectator proton has sufficient momentum from its motion in the deuteron to be called a prong. Based on the McGee wave function for the deuteron⁽¹⁴⁾ we estimate that this effect contributes less than 1 mb to the 4- and 6-prong cross sections.

The experiment of Eastman et al.⁽⁸⁾ includes the measurement of $\bar{p}d$ topological cross sections at 1.6 GeV/c. Their definition of "prongs" in scanning differs from ours in such a way that we can only make a comparison of the summed 3- plus 4-prong and 5- plus 6-prong cross sections. In these two cases the experiments agree within the quoted errors (54.2 ± 1.2 mb and 17.0 ± 0.6 mb respectively for ref. 8 and 55.2 ± 0.6 mb and 17.8 ± 0.3 mb respectively for this experiment).

4. Measurements and Processing

All 3- and 5-prong events and 1-prong events with projected scattering angle larger than 20° (as measured in scanning) were selected for measurement on the Berkeley Spiral Reader. We shall consider here only the analysis of the 3- and 5-prong events of the final states that can be obtained from them.

After measurements the events were processed with the POOH-TVGP-SQUAW program chain. All events that could not be processed successfully were remeasured once. The overall passing rate was 80% for the 3-prongs and 70% for the 5-prongs. The failures were due to one of the following causes:

- a) the operator at the Spiral Reader rejected the event because it was

mislabelled or could not be found in the picture or for similar reasons (17% of the failures);

- b) processing failed due to an operator's mistake in the measurement, often a failure to "flag" the stopped proton track (10%);
- c) the filter program could not find or sort out the tracks, in general because of the poor quality of the picture (21%);
- d) the geometry program could not reconstruct a track (11%);
- e) the interaction primary had a momentum or a direction not in agreement, within errors, with the average of the beam (24%);
- f) the kinematics program could not find a successful fit or perform for the event a successful missing mass calculation (17%).

The hypotheses tested by the fitting program were: production of pions, annihilations into pions, annihilations into K's and pions. Results on the production of one pion have already been published.⁽⁵⁾ Production of more than one pion is negligible, even at our highest momentum (1.6 GeV/c). We shall therefore, concern ourselves only with annihilations.

The results of the fits were used for a first assignment of the events to the various reactions on an event-by event basis according to the following criteria:

- a) no event was accepted if some of the quantities (momenta or angles) were not measured or were measured poorly, so that the missing mass squared could not be computed. This happened for 3% of the fits.
- b) Events were accepted as good fits if the confidence level was larger than 10^{-5} for 4c fits with only π 's in the final state (4π), 10^{-3} for

1c fits with only π 's ($1c\pi$) and 10^{-2} for fits with K's in the final state.

- c) Any event that had a good fit to a $4c\pi$ hypothesis was accepted as a $4c\pi$ (i.e. all ambiguities between a $4c\pi$ and any other hypothesis was resolved in favor of the $4c\pi$. When either a higher confidence level cut for $4c\pi$ or a choice based on best confidence level between $1c\pi$ and $4c\pi$ was tried some events were found in the $1c\pi$ sample with a distribution in mm^2 vs missing energy that was peaked around zero in both variables. In general, the lower confidence level for the $4c\pi$ hypothesis for these events could be correlated with a rather large unmeasured spectator momentum (75 to 150 MeV/c).

As a final check on the selected $4c\pi$ events, they were re-fit with no constraint on the spectator momentum. The distribution of the resulting spectator momenta is compared with the prediction of the McGee wave function⁽¹⁴⁾ folded with the measurement error for these events in fig. 3. No comparable procedure was possible for events with one or more missing particles.

- d) For the remaining events, all those that gave a fit to a $1c\pi$ hypothesis were accepted as a $1c\pi$, and those that gave a fit to a $4c$ hypothesis with K mesons were accepted as $4cK$. Ambiguities between these two classes were resolved on the basis of the confidence level.
- e) Events that were not a $4c$ or a $1c\pi$ and for which the computed missing mass was consistent with two or more missing π^0 's, were considered as all pion events with more than one neutral ("mm π events").
- f) All remaining events that gave a $1cK$ fit were accepted.
- g) Events that have not been included in any of the previous categories were accepted as "mmK events" if the computed missing mass was compatible with the hypothesis.

The low priority assigned to the $1cK$ hypothesis is due to the fact that the number of K 's produced is small and that for most of them there is ambiguity between various $1cK$ hypotheses and between the $1cK$ and $mm\pi$ hypotheses. For these reasons, all our $1cK$ and mmK cross sections should be considered as lower limits.

The criteria outlined above were not sufficient to discriminate events with a single π^0 from those with 2 or more π^0 's on an event by event basis. The distribution of mm^2 calculated from unconstrained track measurements for the events chosen as $1c\pi$ events according to the above criteria showed a marked skewing towards high mm^2 . We therefore separated the events in these two categories statistically by fitting the combined mm^2 distribution to a theoretical distribution consisting of a delta function near the π^0 mass squared (allowances were made for slight shifts in the experimental π^0 mass) and a 2 body phase space for $2\pi^0$ from threshold to a high mass squared cut off (0.3 GeV^2 for 3-prongs and 0.2 GeV^2 for 5-prongs). The maximum likelihood method was used for fitting and the error in mm^2 was folded with the theory on an event by event basis. Figure 4 shows the resulting fits for 3- and 5-prongs for all momenta. The resulting corrections were sizeable; on the average, 32% of the events originally chosen as $\pi^+2\pi^-\pi^0$ were transferred to $\pi^+2\pi^-mm$ and 15% of the events originally chosen as $2\pi^+3\pi^-\pi^0$ were transferred to $2\pi^+3\pi^-mm$.

5. Reaction Cross Sections

In order to obtain the cross section of the various reactions, we need to know the fraction of events of a given topology that belong to a certain reaction. The events used for the determination of these

branching ratios were those assigned to the hypotheses according to the rules described in the previous section and that satisfied the further condition of having the spectator proton momentum less than 150 MeV/c. That is, we accepted all those "fitted" events that had no visible spectator and those whose visible spectator proton had a momentum, as measured by range, less than 150 MeV/c and discarded all others. This was done in order to reduce the probability that the proton had been involved in the interaction, since we are interested in $\bar{p}n$ annihilations.

From a study of the first and second measurements with successful fits or missing mass calculations we have determined that the combined efficiency of measurement and processing is, to the precision of our measurements, independent of the particular reaction within a given topology for a spectator momentum less than 150 MeV/c.

Using this sample of events we estimate the reaction cross section for each channel as the product of the corresponding topological cross section and the fraction of events in this channel. The cross sections for the various reactions with 3 or 5 charged pions plus zero, one and more than one neutrals, and those for the two reactions with charged K mesons and no neutrals are given as a function of the incoming momentum in table 3.

In trying to derive $\bar{p}n$ cross sections from deuterium data one has to take into account two facts: first, the total $\bar{p}d$ cross section is smaller than the sum of the $\bar{p}p$ and $\bar{p}n$ cross sections due to the fact that part of the beam is absorbed by one nucleon before it can interact with the other (shadow effect); second, some of the annihilations on neutrons really involve interactions with both nucleons, which may be

either annihilations on the neutron with successive interaction of the annihilation products with the proton, or scattering of the antiprotons on the proton and subsequent annihilation on the neutron. We shall call this effect re-scattering.

A first order correction for the shadow effect can be obtained, following Glauber,⁽¹⁵⁾ by assuming that the correction term is inversely proportional to the average inverse square distance between the nucleons in the deuterium nucleus. With this hypothesis, Abrams et al.⁽¹⁾ determined that the $\bar{p}d$ cross section is smaller than the sum of the individual $\bar{p}p$ and $\bar{p}n$ cross sections by an average factor of 1.114 between 1.0 and 1.5 GeV/c. With the further assumptions that the $\bar{p}p$ and $\bar{p}n$ cross sections are equal and that the same factor applies to all topologies, we increase all of our cross sections by 11.4%.

For the rescattering, as we already mentioned (see Sect. 3), some of our $\bar{p}n$ annihilations are to be found in the 4- and 6-prong topologies due to the fact that the proton had enough energy to leave the chamber and was counted as a "prong". If we ignore πN charge exchange reactions (they should result in events changing topologies in both directions tending to cancel)⁽¹⁶⁾ and assume that the elastic πp and initial state $\bar{p}p$ are the dominant effects we can make an approximate correction for this effect. The correction term is computed by requiring that the even prong cross sections in deuterium be equal, after correcting for the shadow effect, to those in hydrogen. In this way, the correction factors by which our three and five prong cross sections should be multiplied are 1.30 and 1.27 respectively. The combined effect of the shadow and rescattering corrections is then to increase

all our cross sections derived from 3-prong events by a factor 1.45 and those from the 5-prong events by a factor 1.41.

The assumption under which these corrections have been estimated are naive and they do not take into account differences in corrections for reactions within a given topology. We therefore apply the correction and warn the reader that there are systematic errors on each reaction cross section that may be large due to unknown details of the rescattering process and the shadow effect.

In figs. 5 to 12 we plot the corrected cross sections. The errors do not include the systematic error due to uncertainties in the above corrections. Whenever possible we have plotted together with our data the data of Eastman et al.⁽⁸⁾. In the next section we will present the results of a fit to these cross sections.

6. Analysis and Conclusions

As can be seen from figs. 5 to 12, several of the reaction cross sections show some structure at or around 1.3 GeV/c. It appears also, however, that no single reaction can be responsible for a bump of a size comparable to that observed by Abrams et al.⁽¹⁾. The largest deviations from a smooth curve are of the order of one mb, and the most significant (in terms of standard deviations) are considerably smaller in absolute magnitude. Even if one tries to combine all the states of equal G parity the situation does not change, either in the size or in the significance of the bumps. Of course a quantitative statement about the presence or height of bumps in the cross section can be made only if one knows the behaviour of background. For this reason we have made a fit to the data of a linear combination of a 2190 MeV Breit-Wigner

resonant term 85 MeV wide and a background term. For the background we have chosen a dependence on the total CM energy such as to obtain the correct general behaviour of the cross section with \bar{p} momentum (see ref. 17). The amount of resonance resulting from the fit depends strongly, of course, on the shape of the background. This in turn, especially on the high mass side of the resonance, depends on the presence of the second bump found by Abrams et al.⁽¹⁾ at 2350 MeV, which, due to its large width of 140 MeV, extends well into our energy region. To optimize our estimate of background we then included in the fit a second Breit-Wigner term at 2350 MeV, 140 MeV wide.

The function we used was of the form:

$$\sigma(E) = A \frac{\text{PhSp}}{pE^b} + B \text{ BW}(2190) + C \text{ BW}(2350)$$

where E is the total CM energy, p is the \bar{p} CM momentum, PhSp is the n -body relativistic phase space for the reaction considered, and:

$$\text{BW}(E_0) = (E_0\Gamma)^2 / [(E^2 - E_0^2)^2 + (E_0\Gamma)^2] .$$

A cross section to compare with our measured cross sections was calculated by folding the above function with the CM energy spread induced by Fermi-motion in the deuteron taking account of the variation of the "flux factor" as well.

We have performed various fits to this functional form. First we have fit our data alone for all the measured cross sections. The result of these fits are given as fit a) in table 4. Because of the limited range of momenta of our data and the fact that the 2350 MeV resonance occurs just above our highest data point we find a strong correlation

between the amount of this resonance and the background term. To decrease this correlation and improve our estimate of the energy dependence of the background we have whenever possible done a second fit including $\bar{p}n$ annihilation cross sections of Eastman et al. ⁽⁸⁾ between 1.6 and 2.9 GeV/c. This second fit we report as fit b) in table 4. The result is, in general, to lower the error on the amount of 2350 and the parameter b as expected. In the case of the $\pi^+ 2\pi^- \pi^0$ final state it was not possible to get a satisfactory fit of type b to the two samples of data. Since we have found this channel most ambiguous with the $\pi^+ 2\pi^- \pi^0$ channel as described in section 4., and the selection criteria of Eastman et al. ⁽⁸⁾ differ from ours, we expect this may be the source of a systematic difference between the two experiments.

In any event, the experiments are certainly subject to systematic normalization difference in each reaction due to the different procedures used to derive the cross sections. For this reason, we have performed a third fit to the combined data allowing for a normalization difference between the two experiments for each final state. The third fit we report as fit c) in table 4.

In that table, one can see from the values of χ^2/ND that the function chosen describes the data well. This is apparent also from figs. 5 to 12, where the solid curves display the result of the indicated fit. The parameter b, which gives the dependence on the CM energy, was left free in the fit and comes out nearly equal for all final states except $2\pi^+ 3\pi^- \pi^0$, where the absence of data at higher energy reduces the lever

arm for a good estimate of the background behaviour. (*) The table also gives the normalization factor between our data and those of ref. 8 for fit c). This factor is significantly different from 1 only in the case of the $\pi^+ 2\pi^- \pi^0$ state, where our cross section is significantly lower than that of Eastman et al. (8).

The first column of the table shows the cross section found by the fits for the BW at 2190 MeV, with its error, computed with the CERN program MINUIT as the change in cross section for a variation of 1 in the χ^2 (one standard deviation). For the purpose of testing the statistical significance of the amount of 2190 in our data we choose fit c) when it exists and otherwise fit a). Fit b) may be used to appreciate the variability of the answer with respect to the relative normalization of the two experiments.

An inspection of the table shows:

- a) the $\pi^+ 2\pi^-$ final state yields the most significant contribution, a 3.9 standard deviations effect: 0.51 ± 0.13 mb, 22% of the total cross section in this channel.
- b) The $\pi^+ 2\pi^- \pi^0$ final state gives the largest cross section of the "pure" final states: 1.20 ± 0.58 mb, a 2.1 standard deviation effect, and 11% of the cross section.
- c) The $2\pi^+ 3\pi^-$ final state shows a 1.6 standard deviation effect: 0.37 ± 0.23 mb, and 8% of the cross section.
- d) The $2\pi^+ 3\pi^- \pi^0$ final state shows a rather large cross section 0.82

(*) Leaving out the phase space factor in the background leads to numerical results differing from those reported by as much as one standard deviation, however no conclusions are changed.

- ± 0.48 mb, a 1.7 standard deviation effect and 9% of the cross section.
- e) The two final states with more than one neutral, $\pi^+ 2\pi^-$ mm and $2\pi^+ 3\pi^-$ mm show rather large effects, 1.81 ± 0.88 mb and 0.74 ± 0.50 mb respectively. Their statistical significance may be misleading because the background estimate for these final states is not too reliable as we lacked data at higher energy.
- f) The final states with K's have a very small cross section and do not make significant contributions to the 2190 MeV bump.

We find then, that a statistically weak signal is present in each of our 6 different pion annihilation channels. One might think that the result was induced by a normalization error - except that the bump in the total cross sections of Abrams et al. ⁽¹⁾ is only about 2.5% of the total signal and our total cross section before normalization to theirs shows a similar size bump. Therefore, our results, which range from 6% to 22% of the respective cross sections, cannot be due to our normalization procedure.

The fact that the signal may be present in several final states of different characteristics, in particular in a 3 pion ($G = -1$) and in a 4 pion ($G = +1$) final states raises the possibility that the 2190 MeV bump may not be due to a single resonance.

Table 4 also shows the amount of the 2190 MeV Breit-Wigner term given by the fit if we combine some of our reactions together. The signal of course becomes stronger, but its statistical significance does not change. One can observe, also, that the sum of all our final states shows a large signal (2.5 mb for the 4c plus 1c cross sections, 5.4 mb if one adds also the mm cross sections, which are, however, unreliable).

This implies that a large part of the 5.5 mb observed by Abrams et al.⁽¹⁾ shows itself in the three and five prong $\bar{p}n$ annihilations although not in any state of definite quantum numbers.

Table 4 shows the results of our fit for the 2350 MeV bump and the results of ref. 8 for the same bump. The two determinations for the same cross section agree within errors. The variability of our results between fits b) and c) shows that they are sensitive to the relative normalization of the two experiments and should be viewed with due caution.

In conclusion, from our analysis of the final states with 3 and 5 charged mesons with or without neutrals, we find that a substantial part of the 5.5 mb bump observed at 2190 MeV in the $I = 1$ $\bar{p}n$ total cross section shows itself in several final states. The most significant bump shows in the $\pi^+ 2\pi^-$ final state, where its cross section is however small (0.51mb). The presence of the bump cannot be excluded in various final states of opposite G parity which leaves its interpretation as a single resonance open to question.

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Figure and Table Captions

- Fig. 1. Total $\bar{p}d$ cross sections for this experiment compared with those from ref. 1 (solid line).
- Fig. 2. Topological cross sections for even prong events (a) and odd prong events (b). See text for our definition of prongs and for details on the way these cross sections have been obtained.
- Fig. 3. Distribution of the momentum of the spectator proton for $\pi^+ 2\pi^-$ (a) and $2\pi^+ 3\pi^-$ (b) final states. The curve is computed using the deuterium wave function from ref. 14 and is normalized to the experimental distributions up to 150 MeV/c.
- Fig. 4. Separation of 1c and mm events. a) $\pi^+ 2\pi^- \pi^0$ and $\pi^+ 2\pi^-$ mm events as a function of mm^2 b) $2\pi^+ 3\pi^- \pi^0$ and $2\pi^+ 3\pi^-$ mm events as a function of mm^2 . Curves show the results of our fit.
- Fig. 5. Reaction cross section for $\bar{p}n \rightarrow \pi^+ 2\pi^-$. The solid line displays fit b) described in the text. The dashed line gives the contribution of the background plus a Breit-Wigner term at 2350 MeV. The dotted line gives the contribution of only the background term.
- Fig. 6. Reaction cross section for $\bar{p}n \rightarrow \pi^+ 2\pi^- \pi^0$. The curves corresponding to fit c) have the same meaning as those in fig. 5.
- Fig. 7. Reaction cross section for $\bar{p}n \rightarrow \pi^+ 2\pi^-$ mm. The curves for fit a) have the same meaning as those in fig. 5.
- Fig. 8. Reaction cross section for $\bar{p}n \rightarrow 2\pi^+ 3\pi^-$. The curves for fit b) have the same meaning as those in fig. 5.

Fig. 9. Reaction cross section for $\bar{p}n \rightarrow 2\pi^+ 3\pi^- \pi^0$. The curves for fit b) have the same meaning as those in fig. 5.

Fig. 10. Reaction cross section for $\bar{p}n \rightarrow 2\pi^+ 3\pi^- \pi^0$. The curves for fit a) have the same meaning as those in fig. 5.

Fig. 11. Reaction cross section for $\bar{p}n \rightarrow K^+ K^- \pi^-$. The curves for fit b) have the same meaning as those in fig. 5.

Fig. 12. Reaction cross section for $\bar{p}n \rightarrow K^+ K^- \pi^+ 2\pi^-$. The curves for fit b) have the same meaning as those in fig. 5.

Table 1. Details of the exposure.

Table 2. Topological cross sections.

Table 3. Reaction cross sections not corrected for shadowing and re-scattering. The correction factors used to obtain the data plotted in figs. 5-12 are 1.45 for the 3-prongs and 1.41 for the 5-prongs (see text).

Table 4. Results of the fits.

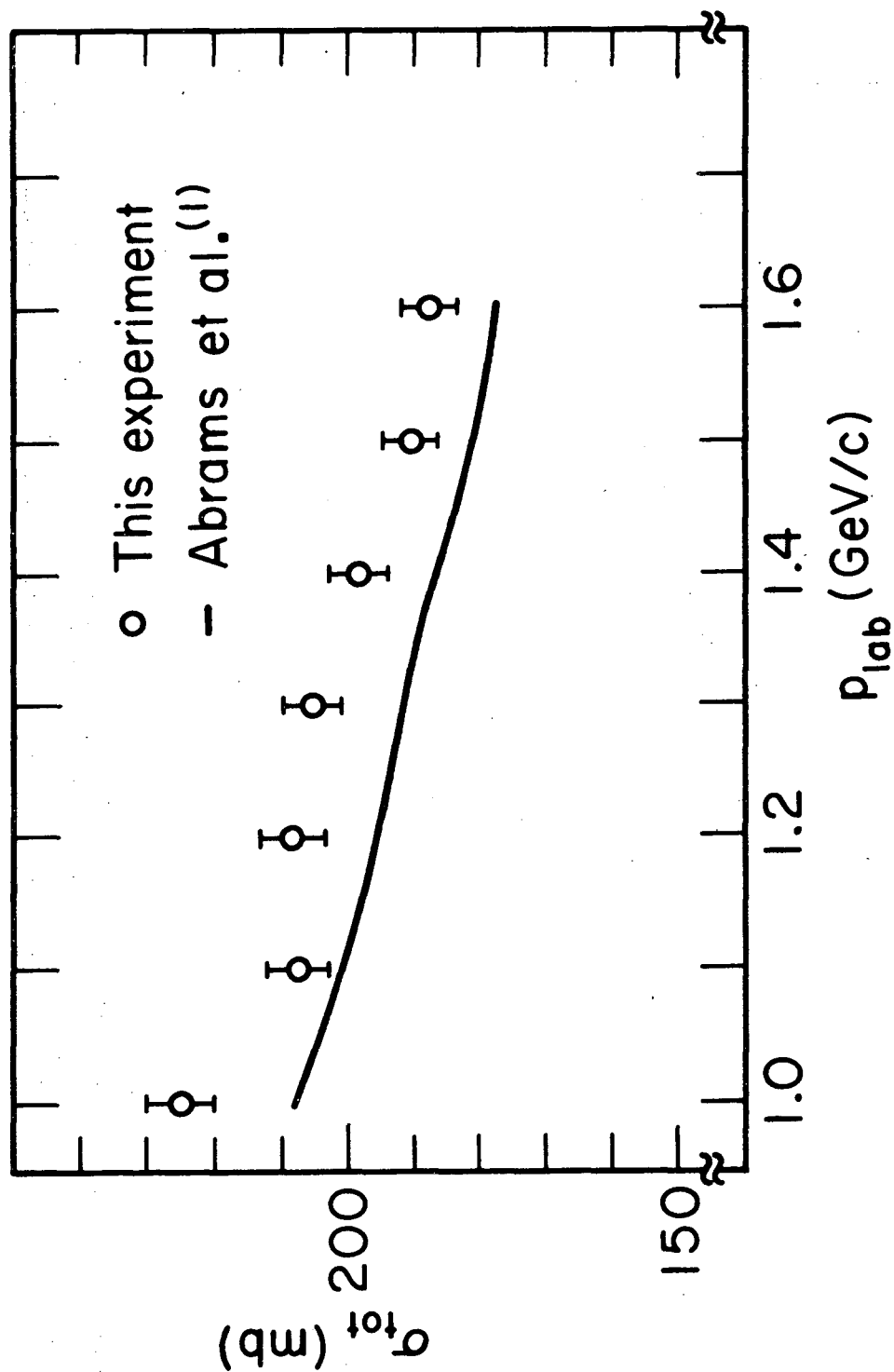
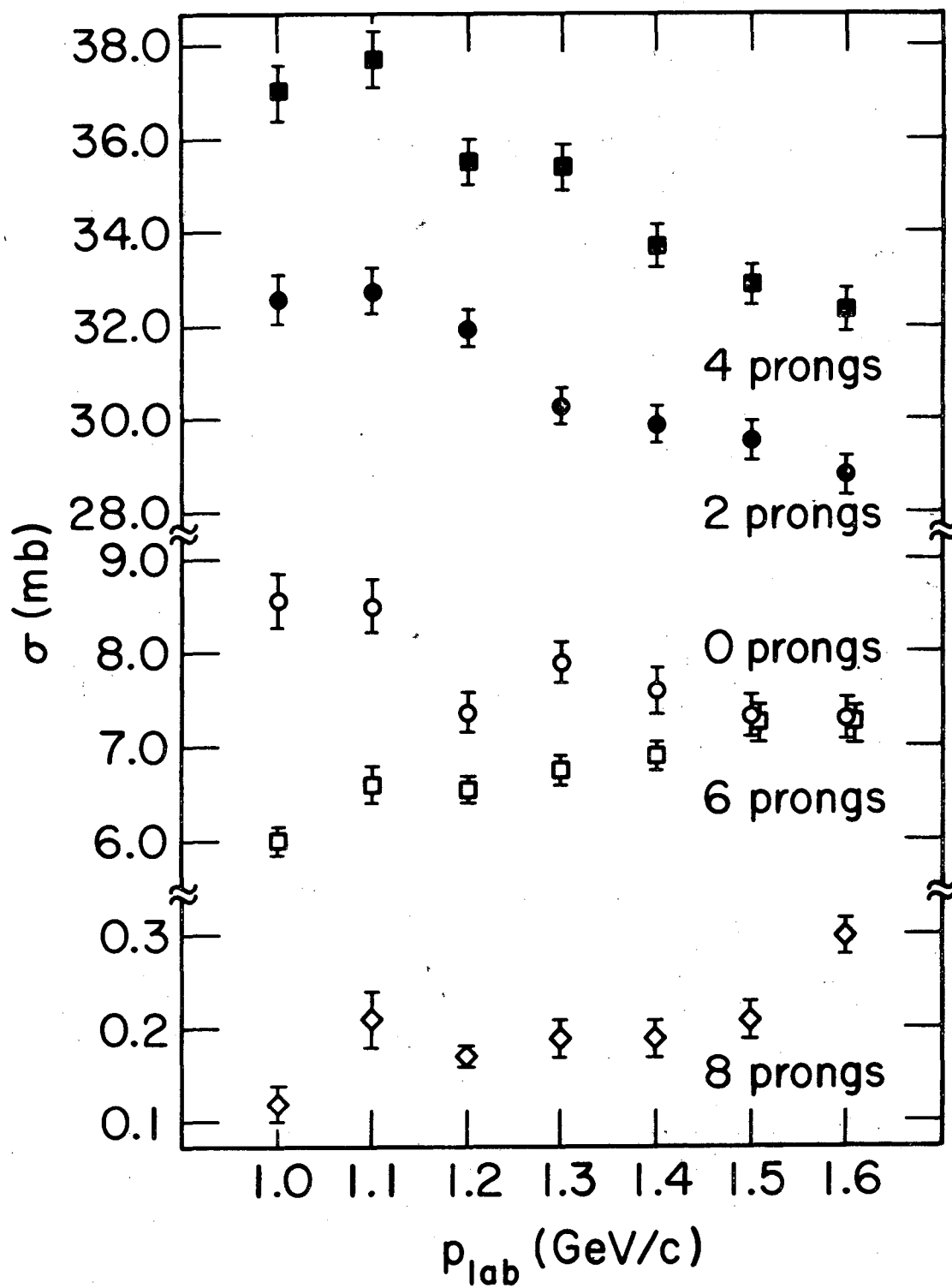


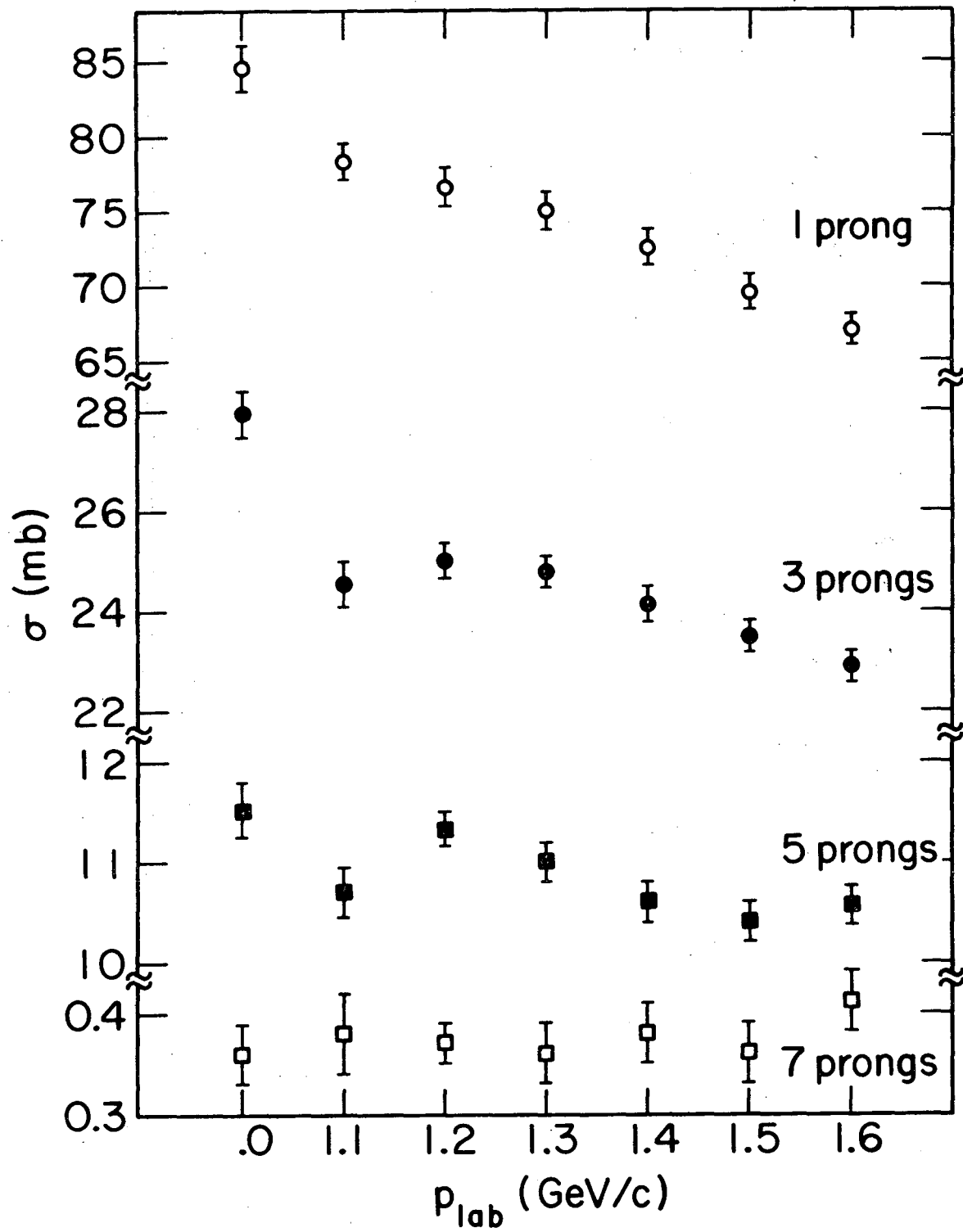
Fig. 1

XBL748-3963



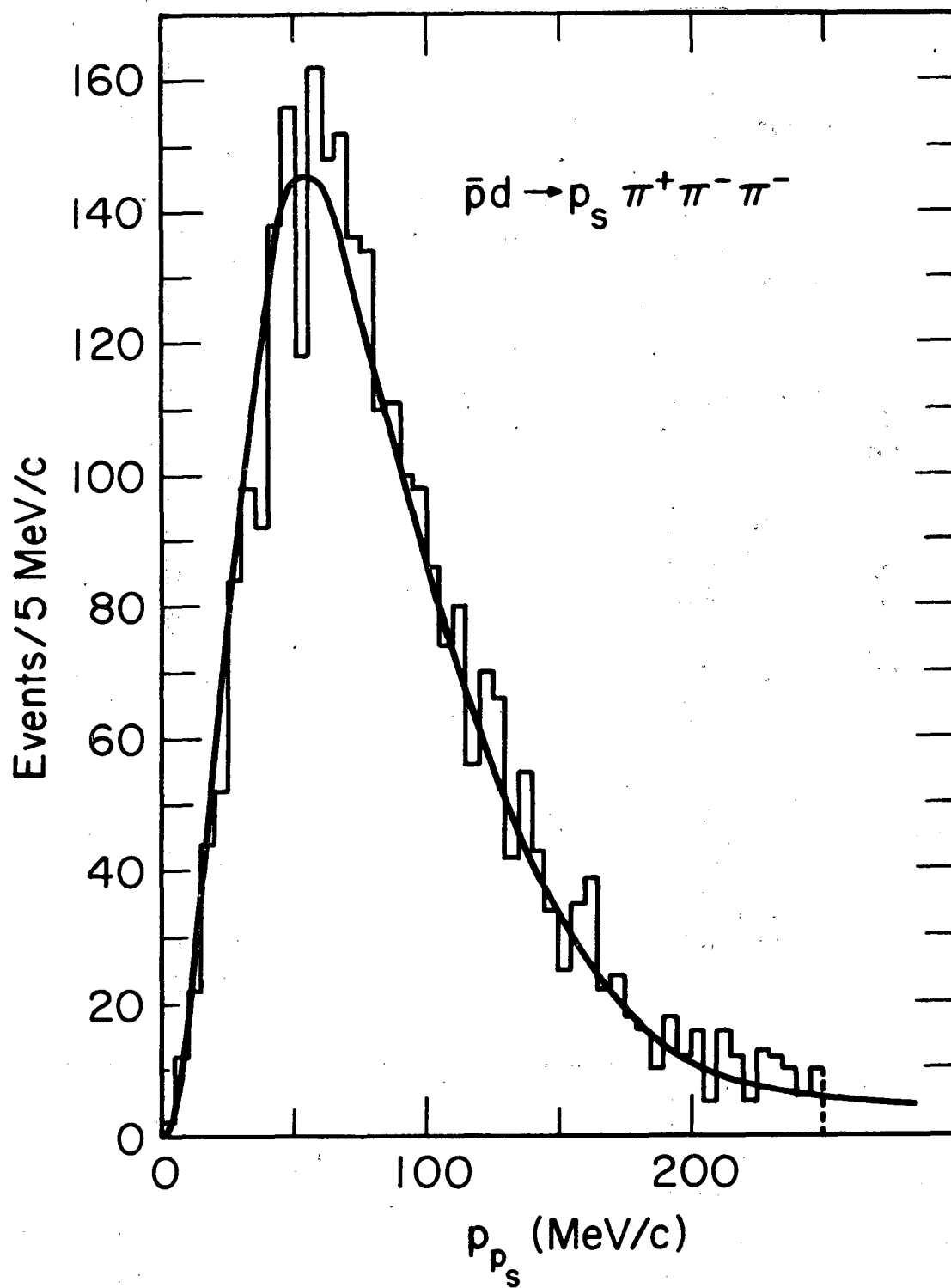
XBL 748-3962

Fig. 2a



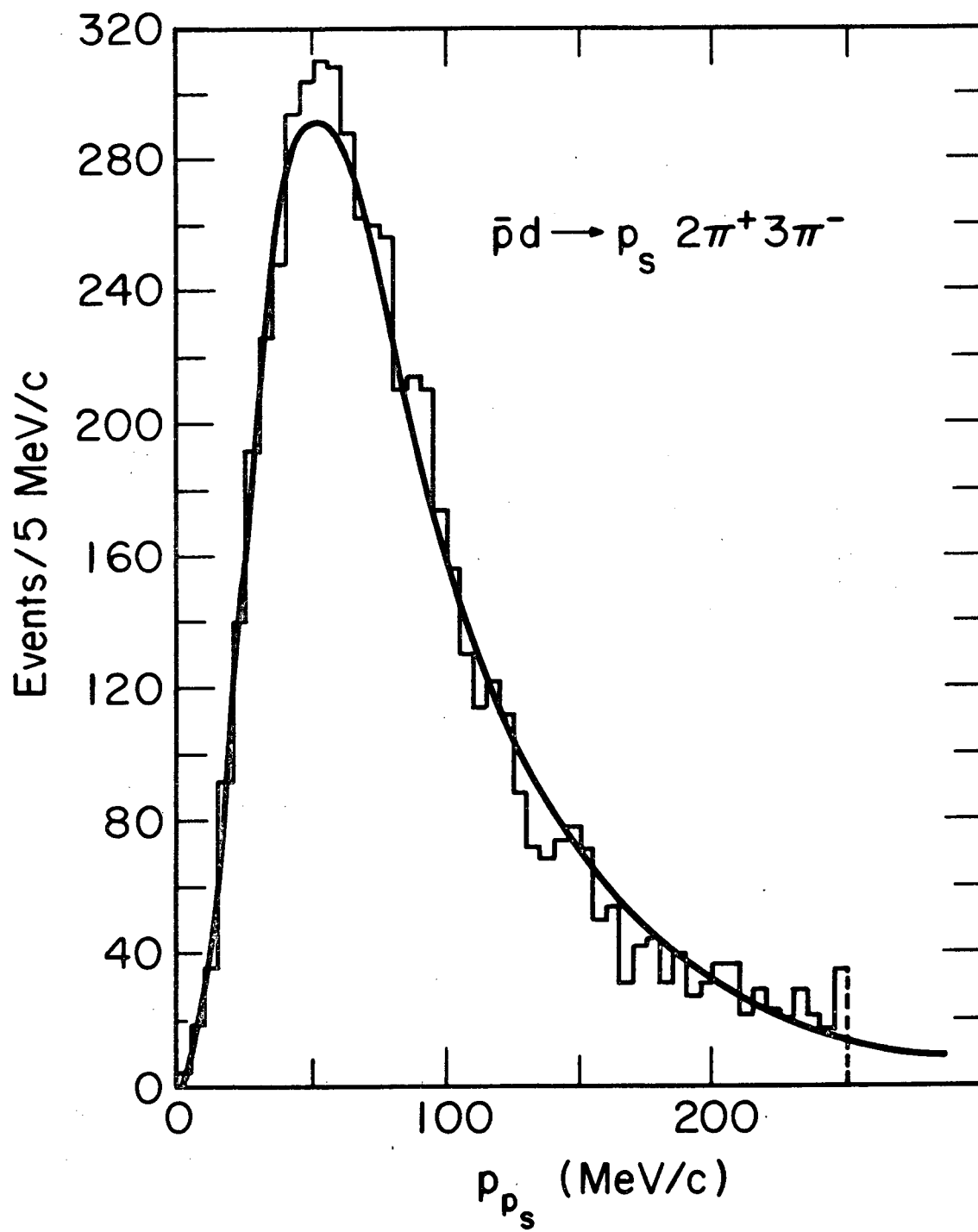
XBL748-3961

Fig. 2b



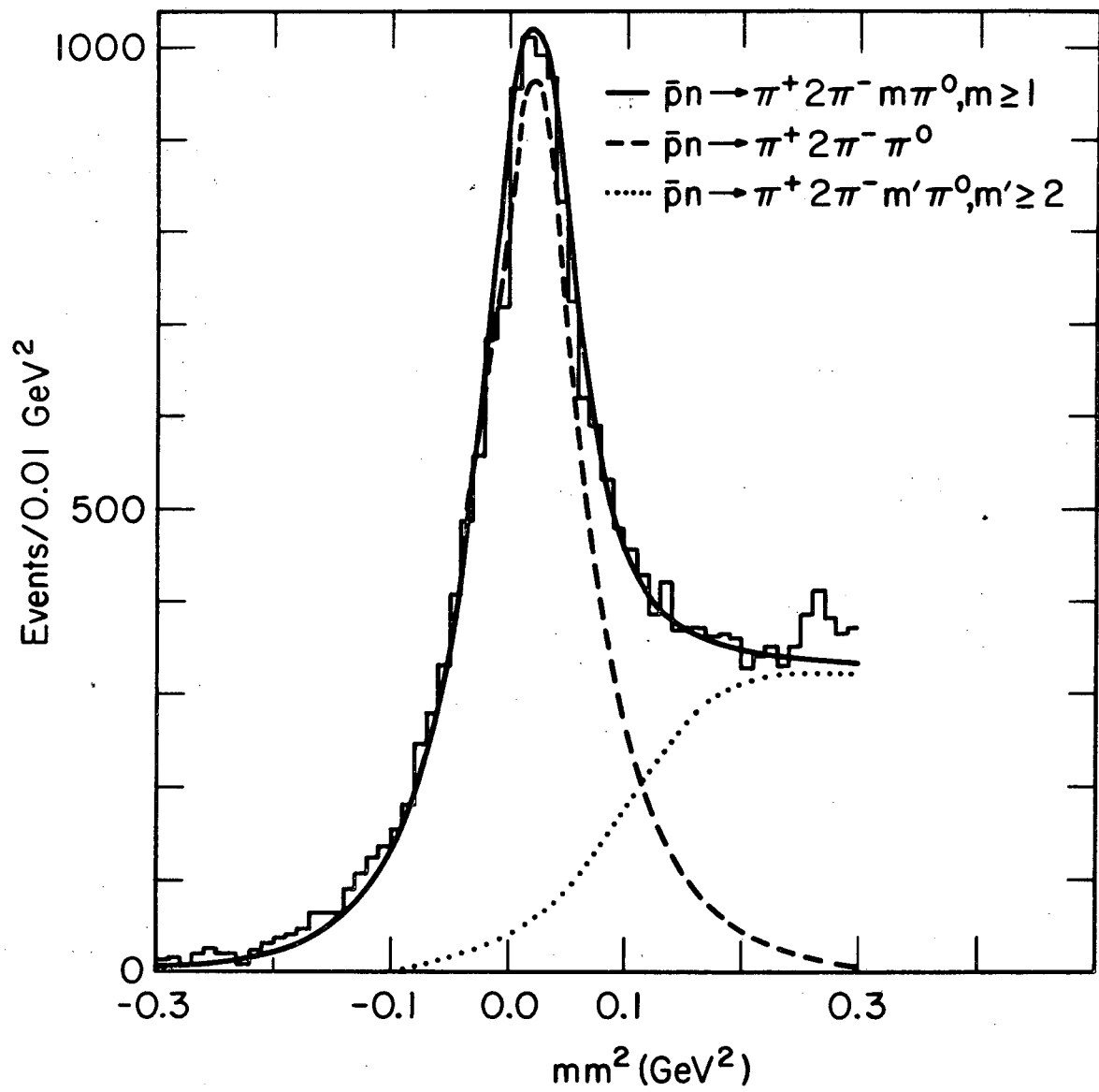
XBL 748-3960

Fig. 3a



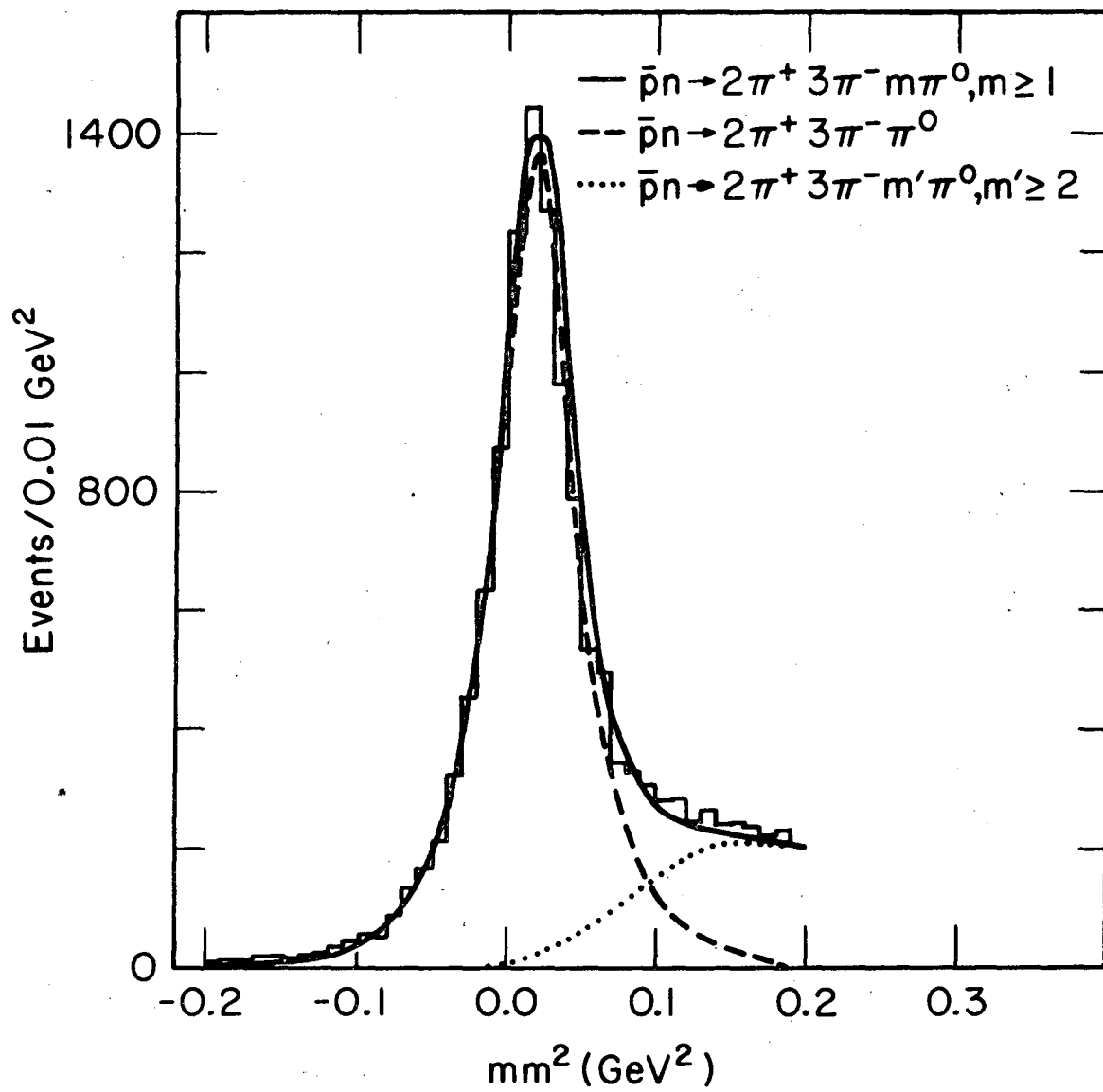
XBL 748-3959

Fig. 3b



XBL 748-3958

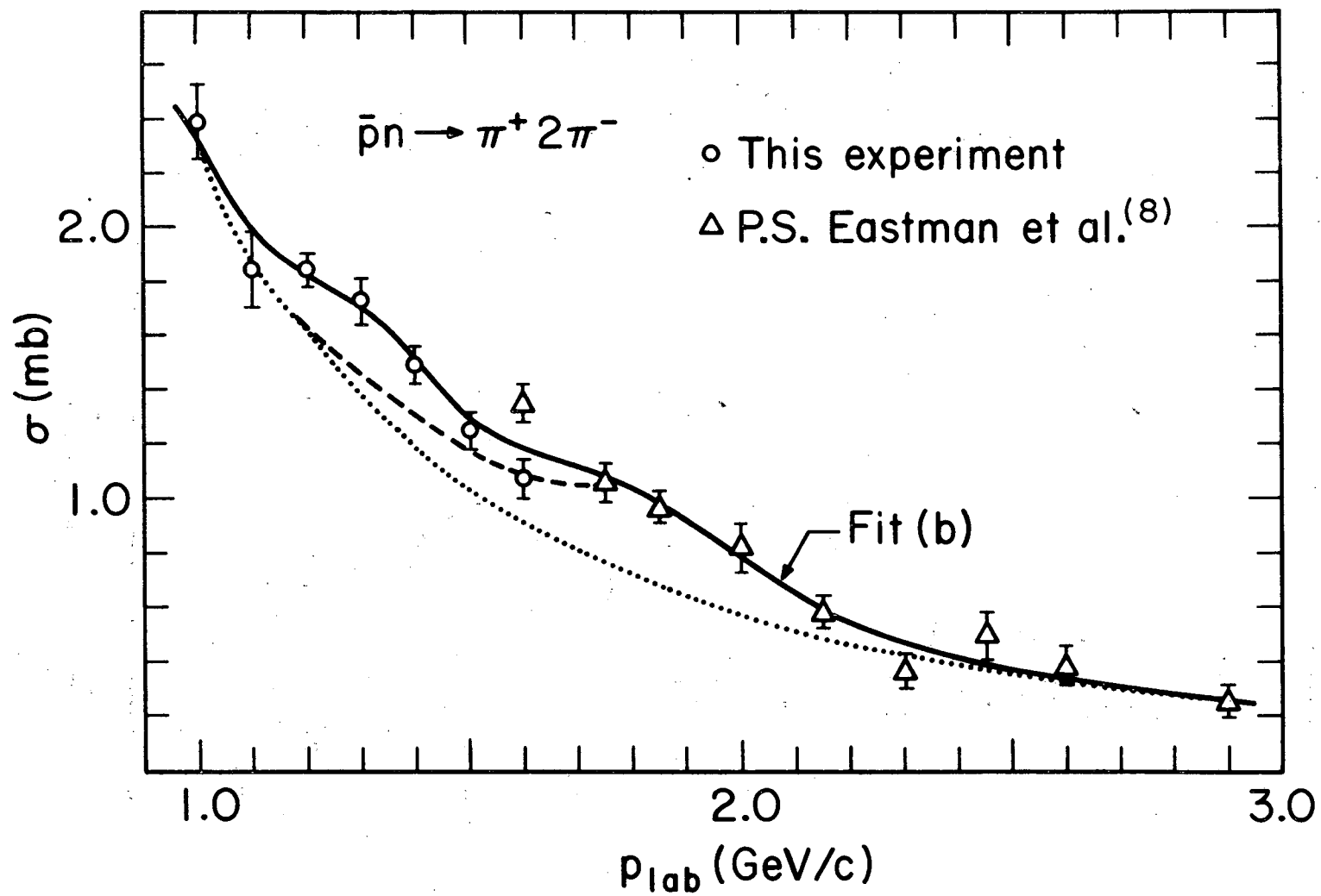
Fig. 4a



XBL748-3957

Fig. 4b

00004205704



XBL748-3956

Fig. 5

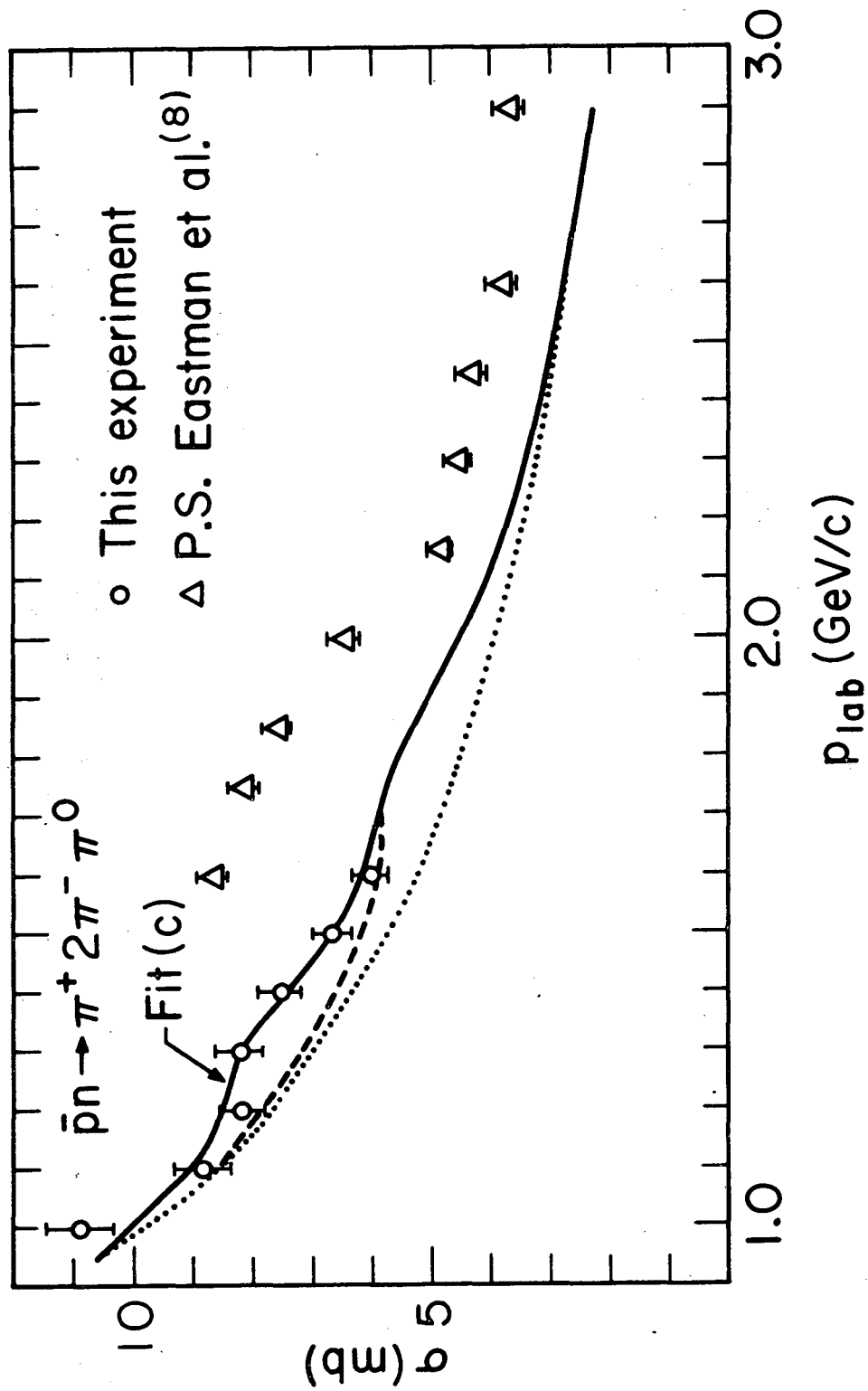
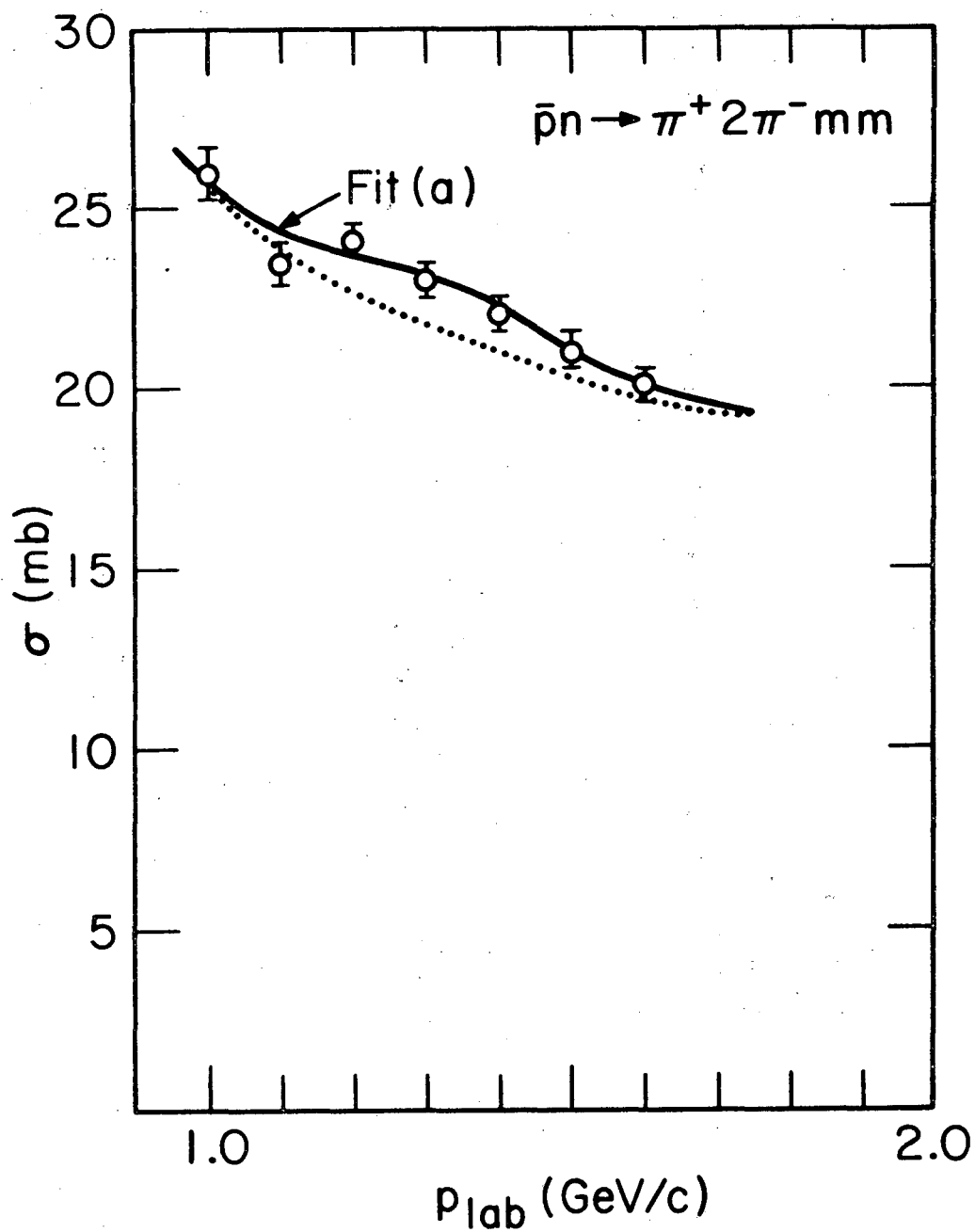


Fig. 6

XBL 748-3955



XBL 748-3954

Fig. 7

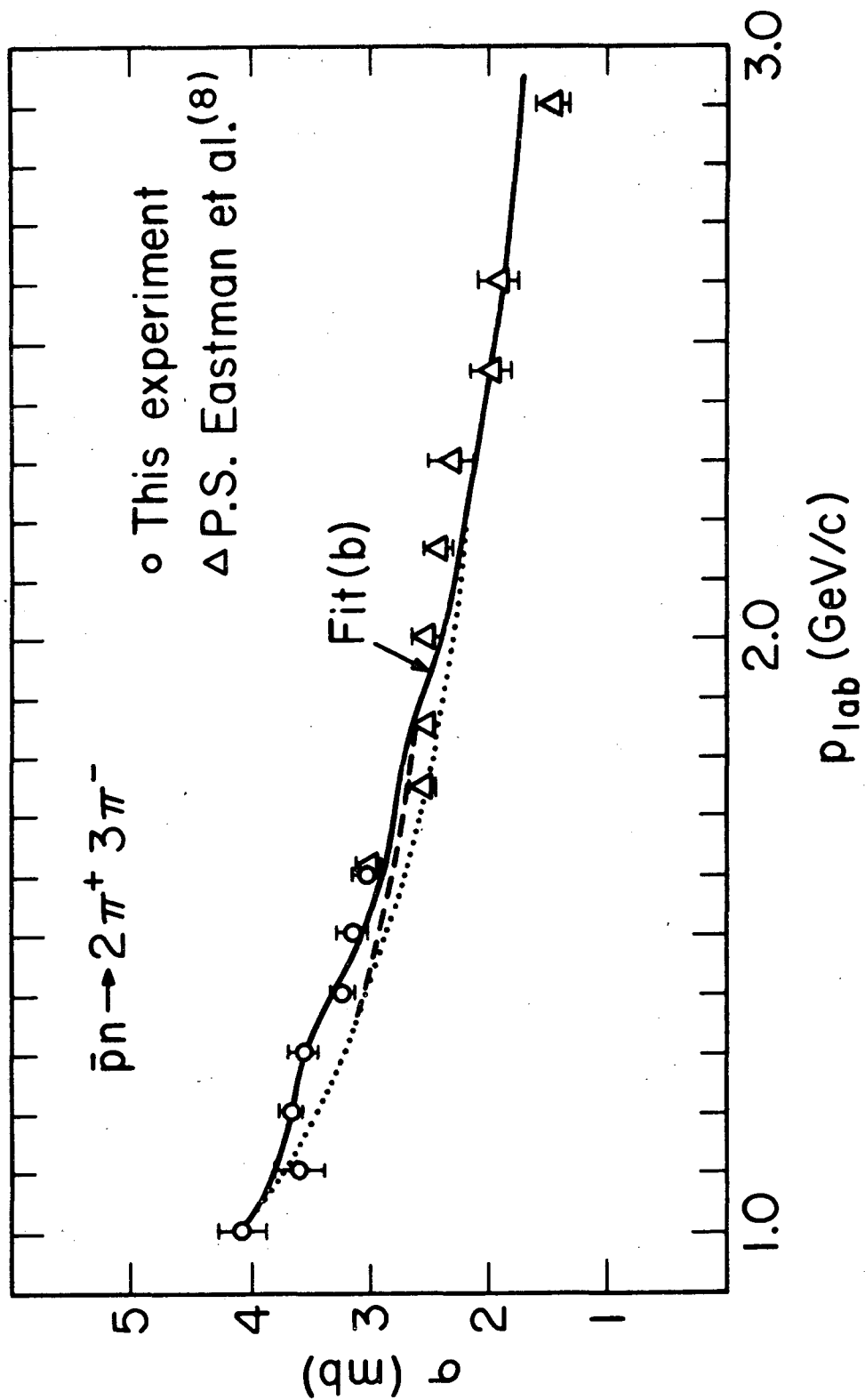
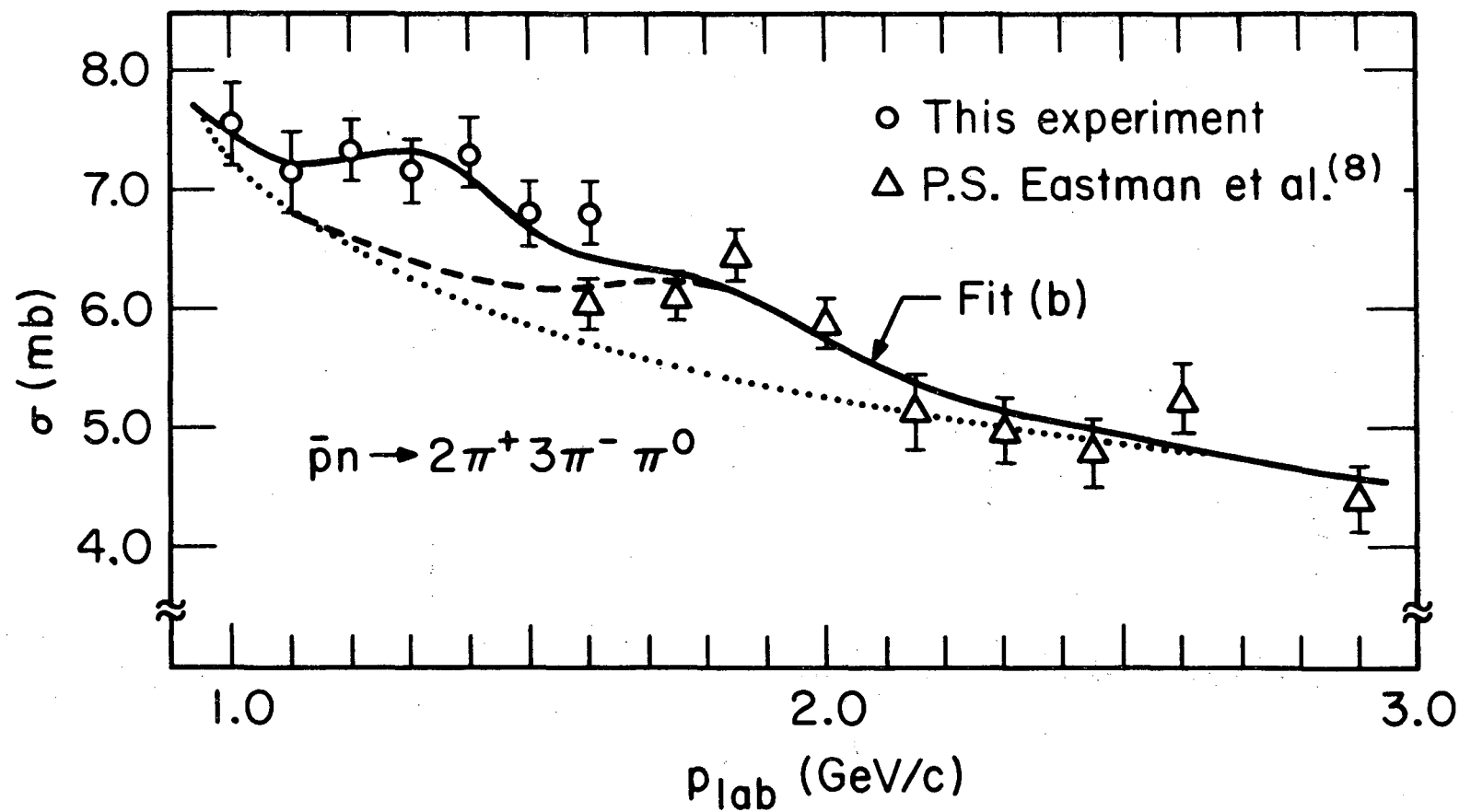


Fig. 8

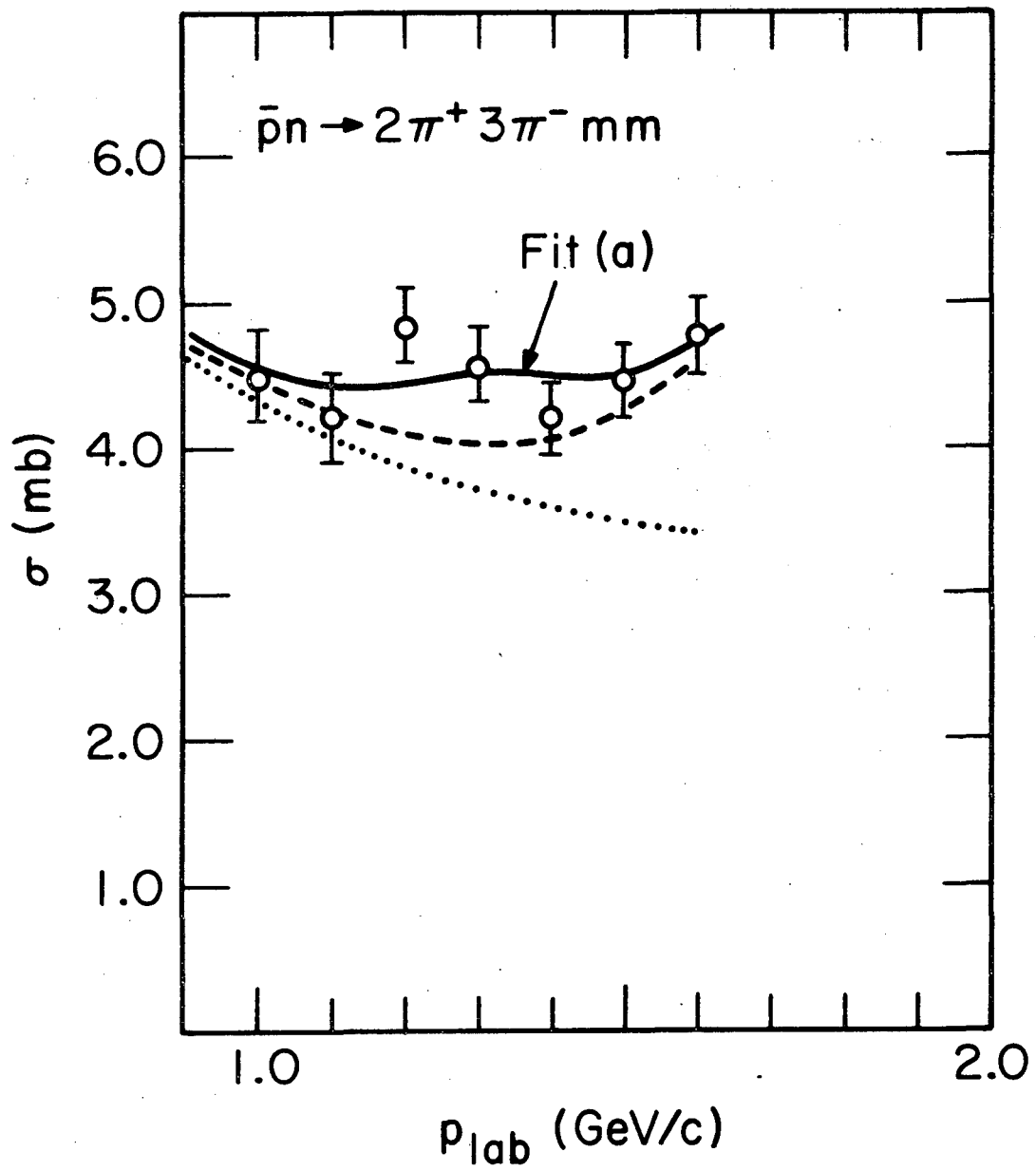
XBL 748-3953

00004203706



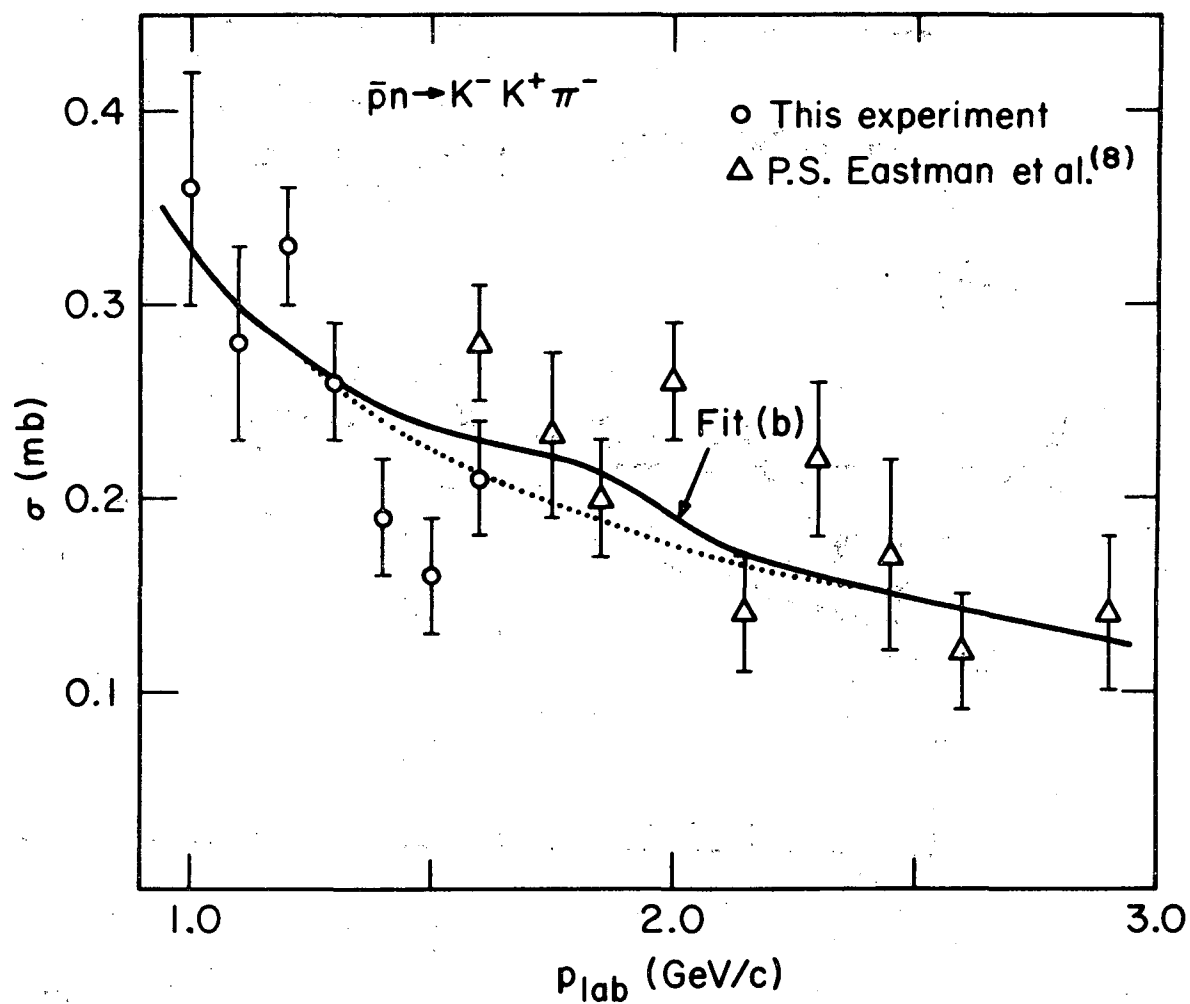
XBL 748-3952

Fig. 9



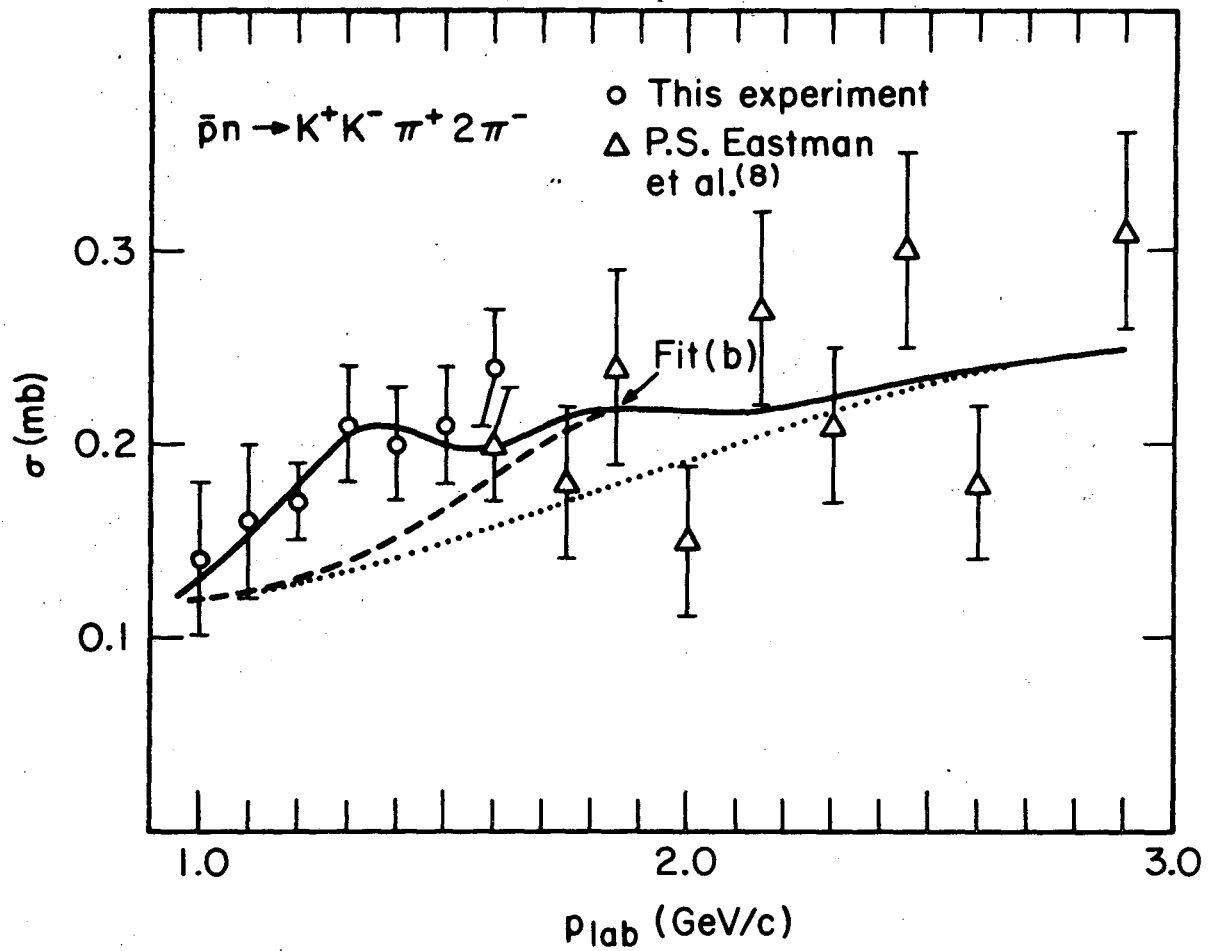
XBL 748-3951

Fig. 10



XBL 748-3950

Fig. 11



XBL 748-3949

Fig. 12

TABLE 1

<i>P_{lab}</i>	<i>E_{c.m.}</i>	<i>No. of pictures</i>	<i>Events/μb^(*)</i>
1.0	2.08	24 000	0.25
1.1	2.12	25 000	0.20
1.2	2.15	130 000	1.40
1.3	2.19	56 000	0.50
1.4	2.22	56 000	0.60
1.5	2.26	46 000	0.50
1.6	2.29	30 000	0.50

(*) *Part of the film has been excluded from measurement due to the bad quality of the picture.*

TABLE 2
TOPOLOGICAL CROSS SECTIONS (mb)

	0	2	4	6	8	1	3	5	7
1.0	8.54 ± .30	32.56 ± .54	36.97 ± .59	5.99 ± .16	0.12 ± .02	84.49 ± 1.44	27.94 ± .48	11.52 ± .26	0.36 ± .03
1.1	8.50 ± .29	32.74 ± .53	37.71 ± .59	6.60 ± .20	0.21 ± .03	78.34 ± 1.38	24.55 ± .44	10.70 ± .26	0.38 ± .04
1.2	7.37 ± .21	31.95 ± .41	35.54 ± .45	6.56 ± .11	0.17 ± .01	76.60 ± 1.29	25.01 ± .33	11.33 ± .17	0.37 ± .02
1.3	7.90 ± .23	30.31 ± .42	35.38 ± .48	6.75 ± .14	0.19 ± .02	74.91 ± 1.29	24.77 ± .36	11.02 ± .19	0.36 ± .03
1.4	7.61 ± .23	29.91 ± .41	33.71 ± .46	6.92 ± .14	0.19 ± .02	72.54 ± 1.25	24.16 ± .35	10.62 ± .19	0.38 ± .03
1.5	7.33 ± .22	29.55 ± .42	32.92 ± .46	7.25 ± .15	0.21 ± .02	69.52 ± 1.23	23.47 ± .35	10.42 ± .19	0.36 ± .03
1.6	7.32 ± .22	28.84 ± .41	32.36 ± .44	7.26 ± .15	0.30 ± .02	66.94 ± 1.21	22.87 ± .33	10.55 ± .19	0.41 ± .03

TABLE 3
REACTION CROSS SECTIONS (mb) uncorrected

	1.0	1.1	1.2	1.3	1.4	1.5	1.6
$p\bar{p}\pi^-$	0.08 ± .02	0.37 ± .05	0.76 ± .03	1.37 ± .07	2.14 ± .09	2.95 ± .12	3.54 ± .13
$\pi^+2\pi^-$	1.65 ± .10	1.27 ± .10	1.27 ± .04	1.19 ± .06	1.03 ± .05	0.86 ± .05	0.74 ± .05
$\pi^+2\pi^-\pi^0$	7.50 ± .38	6.11 ± .32	5.66 ± .25	5.67 ± .27	5.22 ± .25	4.60 ± .23	4.15 ± .21
$K^+K^-\pi^-$	0.25 ± .04	0.19 ± .04	0.23 ± .02	0.18 ± .02	0.13 ± .02	0.11 ± .02	0.15 ± .02
$\pi^+2\pi^-MM$	17.92 ± .48	16.16 ± .43	16.61 ± .33	15.83 ± .36	15.20 ± .34	14.54 ± .34	13.85 ± .32
All other 3pr.	0.54 ± .06	0.41 ± .06	0.48 ± .03	0.53 ± .04	0.40 ± .03	0.38 ± .04	0.39 ± .04
$2\pi^+3\pi^-$	2.87 ± .14	2.54 ± .14	2.59 ± .07	2.52 ± .09	2.29 ± .08	2.23 ± .09	2.14 ± .09
$2\pi^+3\pi^-\pi^0$	5.38 ± .25	5.06 ± .24	5.18 ± .18	5.06 ± .20	5.17 ± .20	4.81 ± .19	4.81 ± .19
$K^+\pi^-K^-2\pi^-$	0.11 ± .03	0.12 ± .03	0.12 ± .01	0.15 ± .02	0.14 ± .02	0.15 ± .02	0.17 ± .02
$2\pi^+3\pi^-MM$	3.18 ± .22	2.98 ± .21	3.42 ± .17	3.23 ± .18	2.97 ± .18	3.16 ± .18	3.37 ± .18

TABLE 4

Final State	fit	BW(2190) mb	% of the cross section	b	scale factor	χ^2/ND	C.L. %	BW (2350)	
								fit	ref.8
$\pi^+ 2\pi^-$	a	$0.59 \pm^{0.17}_{0.39}$	26	8.5 ± 2.1	—	1.1/3	77	$0.42 \pm^{0.48}_{0.42}$	0.05 ± 0.16
	b	0.33 ± 0.12	15	6.3 ± 0.5	—	15.3/12	22	0.34 ± 0.08	
	c	0.51 ± 0.13	22	7.0 ± 0.6	0.81 ± 0.07	8.3/11	69	0.20 ± 0.09	
$\pi^+ 2\pi^- \pi^0$	a	$2.14 \pm^{0.72}_{0.80}$	13	8.7 ± 2.6	—	2.4/3	49	$2.84 \pm^{1.7}_{2.8}$	1.81 ± 0.51
	b	NO acceptable fit			—	—	—	—	
	c	1.20 ± 0.58	11	6.0 ± 0.3	0.72 ± 0.04	13.7/11	25	1.26 ± 0.29	
$\pi^+ 2\pi^- MM$	a	1.81 ± 0.88	6	$5.6 \pm^{2.0}_{2.8}$	—	3.6/3	31	$0.0 \pm^{5.0}_{0.0}$	—
	b	—	—	—	—	—	—	—	
	c	—	—	—	—	—	—	—	
$2\pi^+ 3\pi^-$	a	$0.51 \pm^{0.63}_{0.51}$	11	$7.3 \pm^{4.3}_{2.3}$	—	1.7/3	63	$0.85 \pm^{0.24}_{0.70}$	negative value
	b	0.38 ± 0.20	8	6.5 ± 0.2	—	13.2/12	36	0.20 ± 0.13	
	c	0.37 ± 0.23	8	6.4 ± 0.3	1.01 ± 0.03	13.1/11	28	0.21 ± 0.16	
$2\pi^+ 3\pi^- \pi^0$	a	$0.89 \pm^{0.75}_{0.82}$	9	$7.6 \pm^{4.2}_{1.2}$	—	1.0/3	81	$0.87 \pm^{0.64}_{0.87}$	1.47 ± 0.73
	b	1.28 ± 0.43	13	8.2 ± 0.2	—	14.7/12	26	0.84 ± 0.25	
	c	0.82 ± 0.48	9	7.8 ± 0.3	1.10 ± 0.04	8.7/11	65	1.29 ± 0.31	
$2\pi^+ 3\pi^- MM$	a	0.74 ± 0.50	12	$12.9 \pm^{7.3}_{3.9}$	—	4.5/3	21	$2.3 \pm^{0.6}_{0.7}$	—
	b	—	—	—	—	—	—	—	
	c	—	—	—	—	—	—	—	
$K^+ K^- \pi^-$	a	$0.04 \pm^{0.09}_{0.04}$	12	$10.6 \pm^{7.4}_{5.2}$	—	6.7/3	8	$0.10 \pm^{0.05}_{0.10}$	—
	b	$0.0 \pm^{0.01}_{0.0}$	0	3.0 ± 0.5	—	26.0/12	1.1	0.03 ± 0.03	
	c	$0.0 \pm^{0.03}_{0.0}$	0	5.0 ± 1.0	0.68 ± 0.12	18.9/11	6	$0.0 \pm^{0.02}_{0.0}$	
$K^+ K^- \pi^+ 2\pi^-$	a	$0.05 \pm^{0.08}_{0.05}$	19	$5.6 \pm^{14.4}_{1.5}$	—	0.4/3	95	$0.09 \pm^{0.12}_{0.09}$	—
	b	0.09 ± 0.05	32	$5.9 \pm^{1.2}_{1.6}$	—	13.0/12	37	0.04 ± 0.04	
	c	$0.04 \pm^{0.06}_{0.04}$	15	$5.3 \pm^{1.3}_{1.5}$	1.30 ± 0.23	11.3/11	42	0.06 ± 0.04	
SUMMED CROSS SECTION FITS									
3π + 5π	a	$0.97 \pm^{0.63}_{0.58}$	14	$7.3 \pm^{4.1}_{2.1}$	—	2.5/3	47	$1.07 \pm^{0.37}_{1.07}$	
	b	0.72 ± 0.24	10	6.5 ± 0.2	—	15.6/12	21	0.53 ± 0.15	
	c	0.81 ± 0.27	11	6.5 ± 0.3	—	13.9/11	24	0.36 ± 0.17	
4π + 6π	a	2.5 ± 2.5	12	$10.4 \pm^{5.7}_{2.1}$	—	2.5/3	47	$3.3 \pm^{4.5}_{3.3}$	
	b	NO acceptable fit			—	—	—	—	
	c	1.59 ± 0.76	8	9.4 ± 0.2	—	13.4/11	27	2.16 ± 0.44	
$3+4\pi$ + $5+6\pi$	a	$5.1 \pm^{2.6}_{5.1}$	18	$11.8 \pm^{2.9}_{3.4}$	—	2.6/3	46	$7.8 \pm^{4.7}_{7.8}$	
	b	NO acceptable fit			—	—	—	—	
	c	2.54 ± 0.81	9	9.2 ± 0.2	—	10.5/11	49	2.51 ± 0.48	
$3\pi MM$ + $5\pi MM$	a	$2.9 \pm^{3.0}_{2.9}$	8	6.0 ± 2.2	—	5.6/3	13	$3.4 \pm^{7.3}_{3.4}$	
	b	—	—	—	—	—	—	—	
	c	—	—	—	—	—	—	—	

* Fit a) Fit to our data only

Fit b) Fit to our data plus those of ref. 8.

Fit c) Same as b) but with a variable scale factor for the data of ref. 8.

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