DOE/ER/40445--38

DE93 007299

A Search for the Production of Direct Leptons in Nucleon-Nucleus and Nucleus-Nucleus Collisions

Progress Report for the period
April 1, 1992 - December 1, 1992

Grant DE-FG05-88ER-40445

Submitted by

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December 15, 1992

Prepared for the Division of High Energy
and Nuclear Physics
United States Department of Energy

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Introduction

The purpose of this report is to describe activities performed by the Intermediate Energy Nuclear Physics Group (IENPG) at the Louisiana State University (LSU) under the terms of grant DE-FG05-88ER40445. This report covers the eleven month interval between approximately December 1, 1991, and November 1, 1992.

The IENPG currently comprises undergraduate John Hellman; graduate student Jiangchen Yu; staff associate Susan Hall; technician Ying-chao Wang; senior postdoctoral research associate Zhi-fu Wang; and principal investigator P. N. Kirk. The undergraduate, Mr. John Hellman is now a junior. The graduate student, Mr. Jiangchen Yu, is in his first year in the graduate program at LSU. Zhi-fu Wang will soon complete the fifth year of his tenure in the IENPG.

On a less happy note, we regret to inform the DOE of the imminent departure of graduate student Weiping Xiao. Mr. Xiao was unable to resist temptation in the form of an industrial salary. He is moving his family to Austin, Texas, in order to accept a lucrative offer of employment from an industrial firm there. We will miss his quiet, modest, effective presence here, and we wish him good fortune in his new activities.

Publications

During the calendar year 1992 two papers that were supported in part by grant DE-FG05-88ER40445 appeared in print. They are:

1. Evidence for Hard Scattering of Hadronic Constituents of Photons in Photon-Photon Collisions at TRISTAN, R. Tanaka, et al., Phys. Lett. B 277, 215 (1992)

2. Measurements at 0° of Negatively Charged Particles and Antinuclei Produced in Collisions of 14.6 GeV/c Si on Al, Cu, and Au Targets, M. Aoki, et al., Phys. Rev. Letters 69, 2345 (1992)

In addition a third paper resulting from work of the DLS Collaboration has been accepted for publication although it has not as yet appeared in print. It is:

3. Dielectron Yields in p + d and p + p Collisions at 4.9 GeV, H. Z. Huang, et al., Phys. Lett. B (in press)

The following paper was returned to the editors of Physical Review C on October 20. All changes and modifications recommended by the referees were incorporated into the text, and we are confident that it will be accepted for publication in its present form. However, we have not as yet been notified of its acceptance. The paper is:

4. Measurement of Low Mass Dielectron in Niobium-Niobium Collisions at 1.05 A GeV, S. Beedoe, et al., submitted to Phys. Rev. C

The following paper has been submitted for publication to the editors of Physics Letters B, but reports from the referees have not as yet been received. The paper is:

5. Systematics of Subthreshold Pion Production as a Function of System Mass, J. Miller, et al., submitted to Physics Letters B

Finally, a sixth paper has been prepared for publication but has not as yet been submitted. The paper is:

6. Relative Dielectron Yields in p + p and p + d Interactions for $E_{beam} = 1.0$ to 4.9 GeV, W. K. Wilson, et al.

Xerox copies of papers numbered 2, 3, and 4 were submitted along with last year's progress report. Xerox copies of papers numbered 1, 5, and 6 will be submitted concomitantly with this report under identification numbers DOE/ER/40445-35 through DOE/ER/40445-37.

Ongoing Activities of the IENPG

In this section of our progress report we shall describe the achievements of the group during the year that has elapsed since the submission of last year's progress report. In order to avoid needless repetition we shall refer the reader to specific sections of earlier reports for details. Specifically we suggest that the reader have at his disposal copies of reports DOE/ER/40445–30 and DOE/ER/40445–34, which are the progress reports submitted by this group in December, 1990, and in December, 1991, respectively. We shall also refer to the renewal proposals that accompanied those progress reports.

(a) contributions to the AMY Collaboration

Our participation in the AMY Collaboration was described in report DOE/ER/40445–30, beginning with section (d) on page 27. In addition we discussed the fast preamplifiers that were designed and built here at LSU beginning on page 3 of report DOE/ER/40445–34. We are happy to announce that Zhi-fu Wang did indeed fly to KEK during January, 1992, in order to repair the broken preamplifiers. The repairs were effected in short order, as one might expect from the man who has become known as the "Wizard of LSU".

The paper to which we referred in the last paragraph that begins on page 4 of report DOE/ER/40445–34 exists only in skeletal form, but it does exist. Unfortunately the person who was responsible for describing the performance of the complete system under actual operating conditions, Dr. Robert Walker, left AMY in order to work at the Fermi Laboratory. Although we rejoice in Dr. Walker's good fortune, his unanticipated departure complicated our efforts to finish the paper. Recently Dr. Leigh Chinitz has been assisting us in analyzing

data logged with the front tracking chambers and in extracting numbers for the efficiency and resolution of the chambers. The paper will be finished prior to the departure of Dr. Chinitz in May, 1993.

(b) the transverse energy, or E_t, detector

The transverse energy detector was described in section (c) of report DOE/ER/40445–30. The discussion, complete with two photographs and a schematic drawing of the device, begins on page 19. The E_t detector was also discussed briefly beginning on page 4 of report DOE/ER/40445–34.

The experiment in which the E_t detector was used has been completed. The concluding report was recently published in Physical Review Letters and is listed as item #2 under the heading "Publications" of this report.

A description of the design of the transverse energy detector and its operating characteristics under actual experimental conditions will appear in a second paper that will be written by Jack Engelage and by the author. The second paper will be comprise a description of all the apparatus that was used in this experiment and will be published in Nuclear Instruments and Methods. Dr. Engelage and the author had reserved one week in October, following the Sante Fe meeting, in which to write and to edit this paper. Unfortunately a financial crisis of unprecedented proportions at LSU forced the author to cancel the trip. The meeting will be rescheduled for early 1993.

(c) the production of subthreshold pions

The concluding report for this experiment has been written and appears as item #5 in the list of publications above.

(d) the Di-Lepton Spectrometer (DLS)

The focus of our activities is now, and has been for years, the Di-Lepton Spectrometer (DLS) at the Lawrence Berkeley Laboratory. Our contributions to the DLS Collaboration have been described in previously submitted progress reports and most recently in section (d) of last year's report. We ask the reader to direct his attention to the second and third paragraphs on page 8 of last year's report. The text begins "On February 25 - 26, 1991,...". The spare planes that are referenced in that text were built here and shipped to LBL in early 1992. They proved to be more than useful, and the decision to invest our time in their construction will stand out conspicuously as one of our better decisions, as we shall now explain.

The most recent experimental run on the DLS began in the middle of September and lasted until the middle of October. Dr. Wang and the author prepared the front drift chambers meticulously before the run, and the chambers were in superb shape by the time data logging

began. The two weeks between the beginning of the run and October 2 were possibly the most productive period of data logging in the history of the DLS. All the apparatus was finely tuned and, to all appearances, functioning perfectly. However, during the shutdown that had been scheduled for the weekend of October 3 - 4, there was an accident of some sort in the experimental cave. For whatever reason, numerous wires within the left front drift chamber were broken, so that we were not able to resume data logging on Monday morning. Frantic attempts to repair the chambers in place not only failed but were counterproductive. Additional wires in other planes were broken, and the collaboration was forced to remove the chamber from the entrance aperture of the magnet for repairs.

Because the spare planes were already on site and ready for installation we were able to recover from the accident within 72 hours. Had there been no spare planes we would have lost two weeks' of data logging. The remainder of the run was smooth and productive, but incidents such as this do prompt some reflection on the roll of luck in human affairs.

Publications #3, #4, and #6 in the list above are based upon the work of the DLS. Despite the imminent departure of Dr. Huang from the group and the attempts of several others to secure more permanent positions elsewhere, we believe that the work of the DLS Collaboration is being brought to a successful and responsible conclusion. We shall return to this issue in the renewal proposal that accompanies this progress report.

(e) the single-lepton experiment

For several years the IENPG has been the only member of the TASS Collaboration that has been actively engaged in the analysis of data that were logged in that experiment. This analysis has been discussed in the last two or three progress reports, and we shall assume the reader's basic familiarity with the experiment and the analysis. Specifically we shall assume that the reader has reviewed section (e) of last year's progress report and pages 3 - 6 of last year's renewal proposal.

Page 9 of last year's progress report, beginning with the paragraph "There followed the most frustrating...", is particularly pertinent to this discussion, as is the paragraph on page 6 of last year's renewal proposal that begins "In contrast to the situation...". As we review these words we are reminded of Thomas Hardy's dark remark "Like flies to wanton boys, so are we to the gods. They smite us as they will." At the time we wrote last year's reports we had no reason at all to expect a repetition of the problems with computers that so bedeviled us during the preceding year – no reason at all.

Nonetheless, on approximately the ides of March, 1992, the members of the local cluster began to replace a hopelessly obsolete 750 with a shiny new VAX 4000. The installation of the 4000 was believed to be straightforward and was scheduled to last for three days. We regret to inform the reader that our cluster was not fully operational until the end of August, more than 5 months later. This was truly an installation from hell, and the toll on our collective psyches was horrific. The problem was that the new VMS software was not compatible with

the specific configuration of our cluster. The most distressing manifestation of the problem was that inordinate times, say, 20 minutes, were required to copy files of trivial lengths from one disk to another. Larger files required correspondingly longer transmission times. The problem was quickly traced to the software, and the Digital Equipment Corporation, much to its credit, readily assumed responsibility. Engineers from DEC worked long hours to analyze the problem and to modify the software, and we take pleasure in recording our thanks to DEC at this time. Nonetheless, no quantity of graciousness and professional behavior from DEC will restore to us the 5 months of lost time. There is no just compensation for lost time, even in principle, and this is the point we want to emphasize.

We are by no means the only persons who have been adversely affected by the software associated with the 4000. We have listened to colleagues who live all over the world discuss essentially the same problem. The issue here is not the existence of a problem with new software, about which we can do nothing, but rather our ability to respond effectively to the problem. Most of my colleagues, both American and foreign, are fortunate enough to employ at least one fully qualified systems programmer, and these happy people were not as seriously affected by the problem as were the members of the local cluster. Our inability to respond effectively, in my opinion, is directly traceable to the lack of a qualified systems programmer in our employ, and I would like to remind the reader of a particularly prophetic paragraph in last year's progress report.

> *The point of this discussion, however, is that there exists within the IENPG and also within the local cluster a great need for the services of an authentic, properly trained specialist in computer science. We believe that no harm whatsoever would have resulted from altering the size of the process section table on each of the affiliated workstations within the local cluster. Of course, in the absence of direct experimental evidence we have no way to prove this belief, and the system manager surely acted properly in protecting what he perceived to be the stability of the system. Nonetheless we believe that if there had been in our employ during that time a properly trained expert this entire episode, which costs us five months and unprecedented frustration, would have lasted five days or less. It is certainly true that expertise is expensive, but as our experience so clearly demonstrates the lack of expertise may be, and often is, equally expensive.*

We are as familiar as anyone else with the financial stresses of our times. We are aware of the budget deficit and of the necessity for self-imposed financial restraint. Nonetheless we contend that in times of financial stress there can be no more efficient use of money than expenditures which benefit not just one group but many different groups simultaneously, and we ask the reader to reconsider our request for assistance in this regard. We shall return to this request in the renewal proposal that accompanies this report.

Despite the difficult circumstances of the past year we managed, mostly by laborious transfer of our programs to other computers, to complete a considerable amount of work, and we are

pleased to present results at this time.

As the reader may possibly recall, our progress report for the year 1991 ended with a mystery. Graphs representing the correction factor for pion decay exhibited strange behavior at low momentum. Specifically, the results displayed in figs 17 and 18 on pages 27 and 28 of last year's report exhibit abrupt rises at low momentum. Beginning with the last paragraph on page 23 of last year's report we suggested an explanation for this odd behavior, and we are delighted to report that the analysis offered there has been verified by this year's calculations. On the following pages we present graphs that are analogous to figs 13 - 18 of last year's report.

Figures 1 - 4 are included here for the sake of completeness only. Their interpretation is identical to the interpretation of figs 13 - 16 in last year's report. The correction factor, which was defined on page 23 of last year's report, is dramatically different, however, and we ask the reader to compare figs 5 and 6 in this year's report with figs 17 and 18 of last year's report. One sees that the correction factor **turns downward at low momentum just as we predicted last year.** These are gratifying results indeed, and we take great pleasure in presenting them. Our skepticism of the last year's results turned out to be justified, and our analysis of the problem has been confirmed. We take pleasure in presenting in fig 6 the correction factor for pion decay in our apparatus.

We also have solved another straightforward but important problem during the past year. The charged pion decays into an electron and a neutrino with a branching ratio of 1.267×10^{-4}. In principle, at least, electrons that are produced through this decay contaminate the data sample, and one must calculate the extent of the contamination. It is a straightforward matter to simulate this decay to any desired degree of accuracy, and we have completed this calculation during the preceding year. The results of our simulation are presented in fig 7.

The term "electron correction factor", as is used in fig 7, perhaps needs some explanation. We shall use the symbol $N_\pi(p)$ to denote the number of pions per unit momentum interval that would be detected in the apparatus if the pion were stable. We define the term $N_e(p)$ to be the number of electrons per unit momentum interval that were produced in the decay $\pi \rightarrow e + \nu$ and detected in the apparatus. The electron correction factor (ecf) is defined to be:

$$\mathrm{ecf}(p) = \frac{N_e(p)}{N_\pi(p)}.$$

This is the quantity that is plotted on the ordinate of fig 7. In particular note that the branching ratio has already been incorporated into the value of the ordinate.

There are two sets of data exhibited on fig 7. We suggest that the reader examine the schematic drawing that is shown on page 35 of report DOE/ER/40445–30 in order to understand the significance of these two sets of data. A charged particle cannot be registered as an

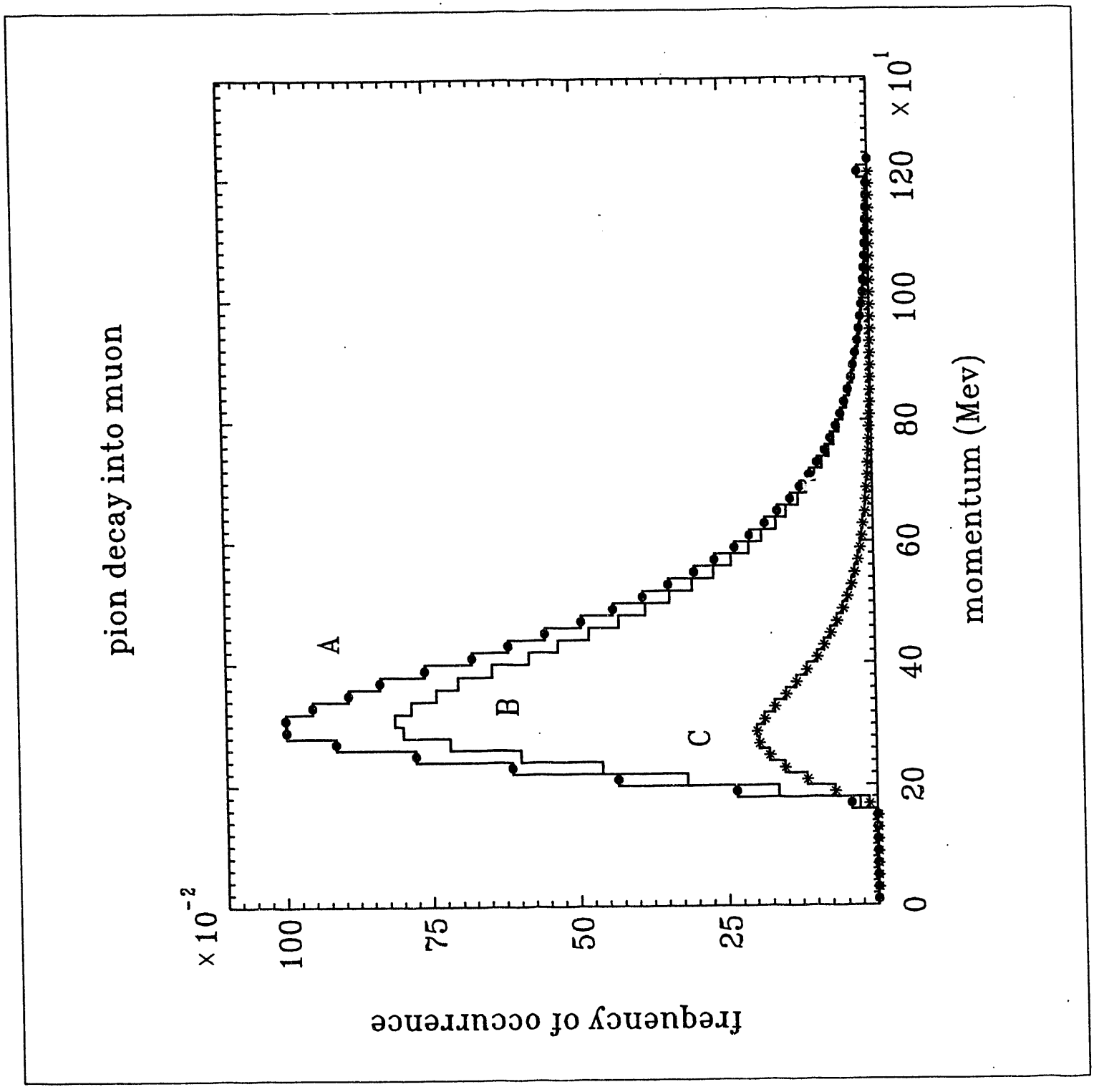
pion decay into muon
frequency of occurrence
× 10^-2
100
75
50
25
0
20
40
60
80
100
120
× 10^1
momentum (Mev)
A
B
C

Fig 1

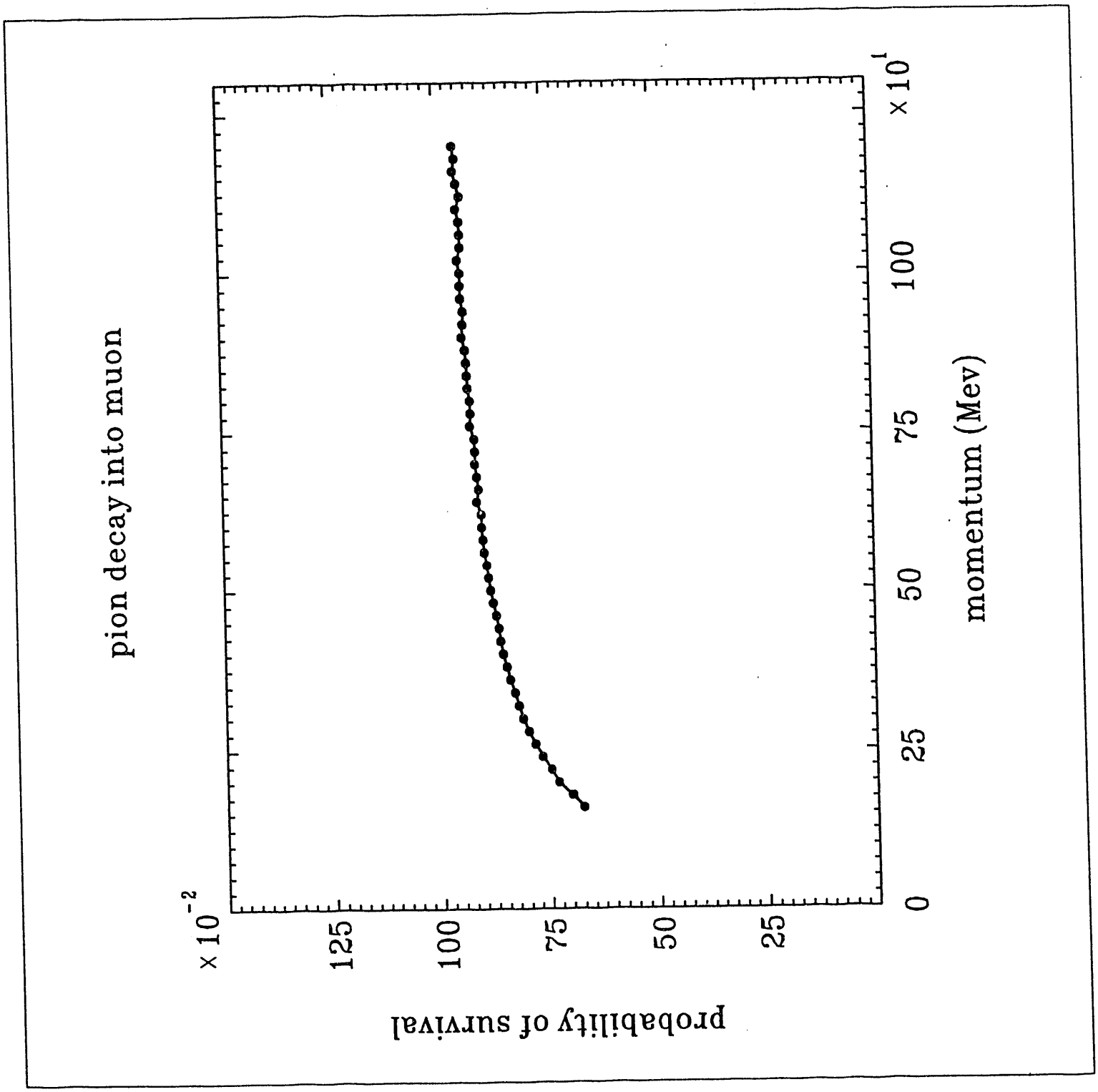
pion decay into muon
probability of survival
× 10^-2
125
100
75
50
25
0
25
50
75
100
× 10^1
momentum (Mev)

Fig 2

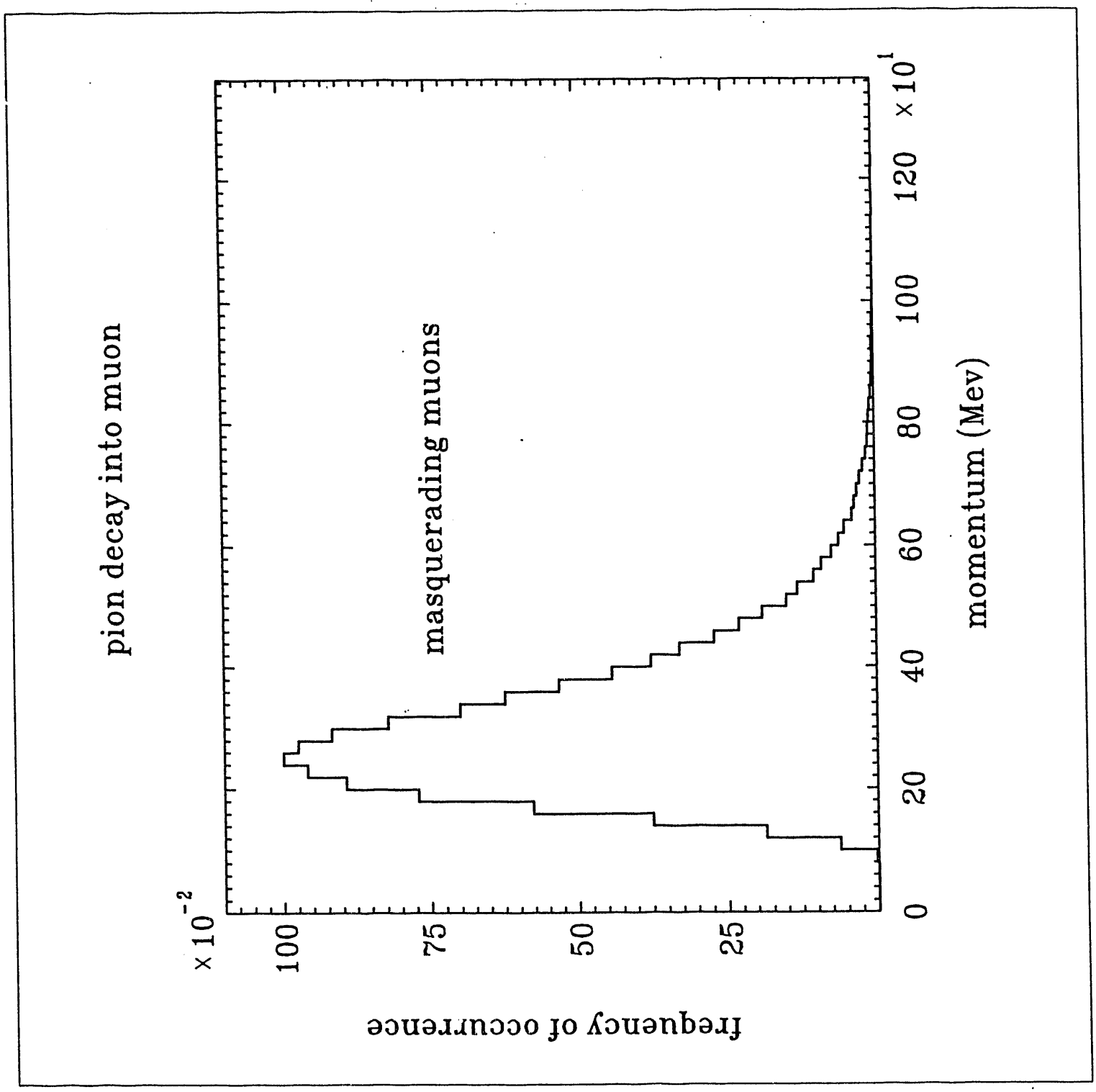
pion decay into muon
masquerading muons
frequency of occurrence
$\times 10^{-2}$
100
75
50
25
0
20
40
60
80
100
120
$\times 10^{1}$
momentum (Mev)

Fig 3

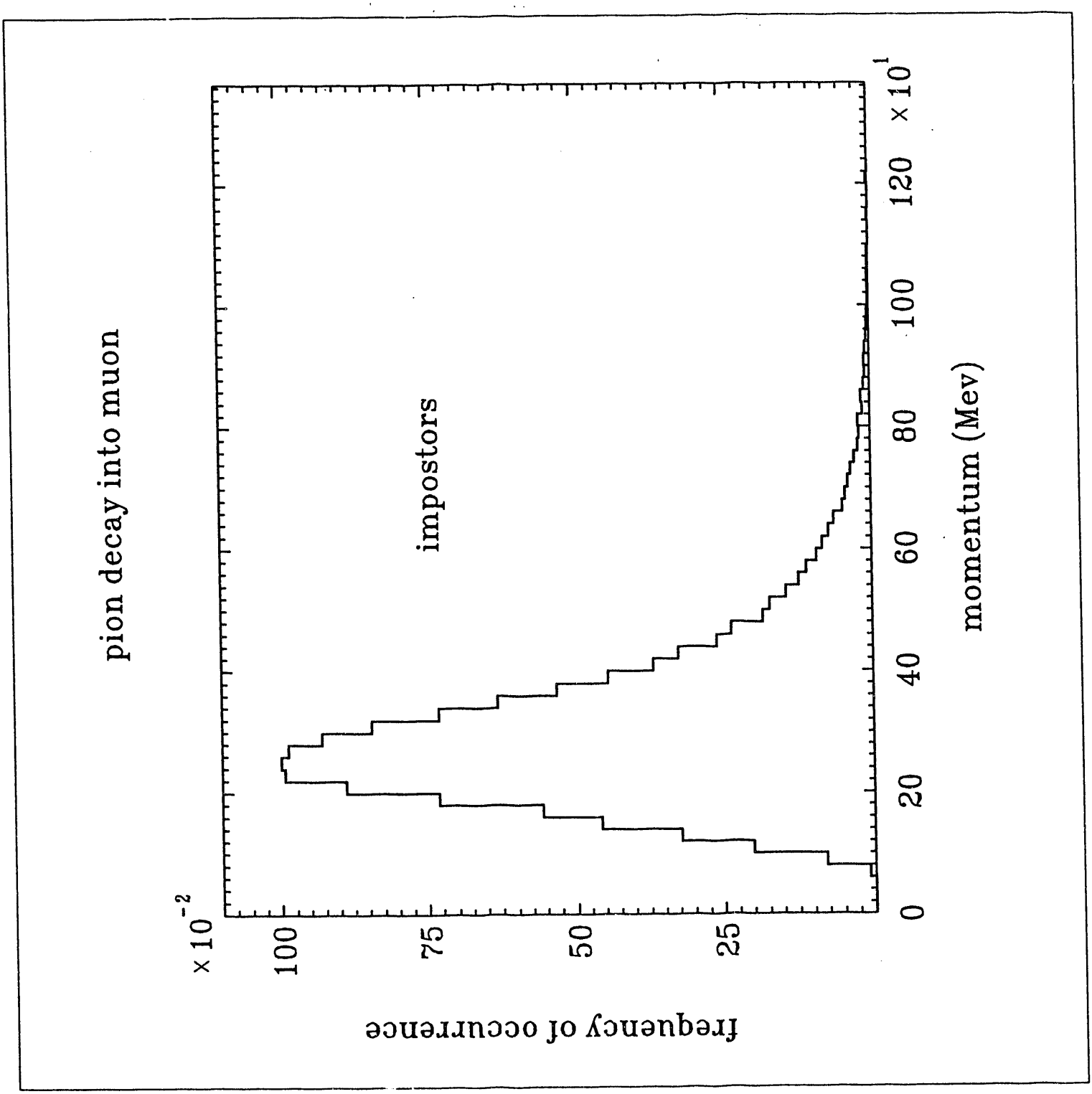
pion decay into muon
impostors
frequency of occurrence
$\times 10^{-2}$
100
75
50
25
0
20
40
60
80
100
120
$\times 10^{1}$
momentum (Mev)

Fig 4

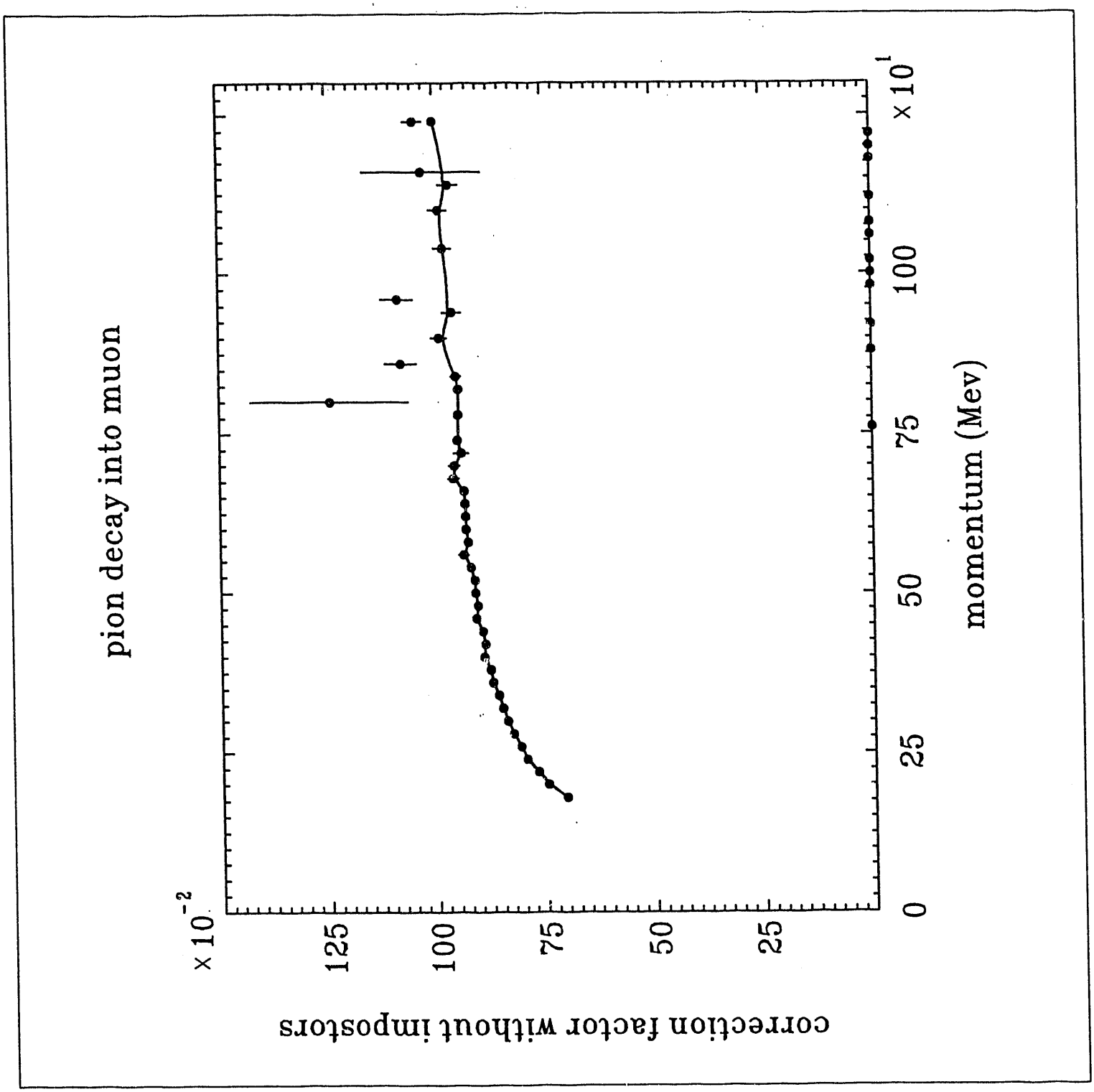
pion decay into muon
correction factor without impostors
× 10^-2
125
100
75
50
25
0
25
50
75
100
× 10^1
momentum (Mev)

Fig 5

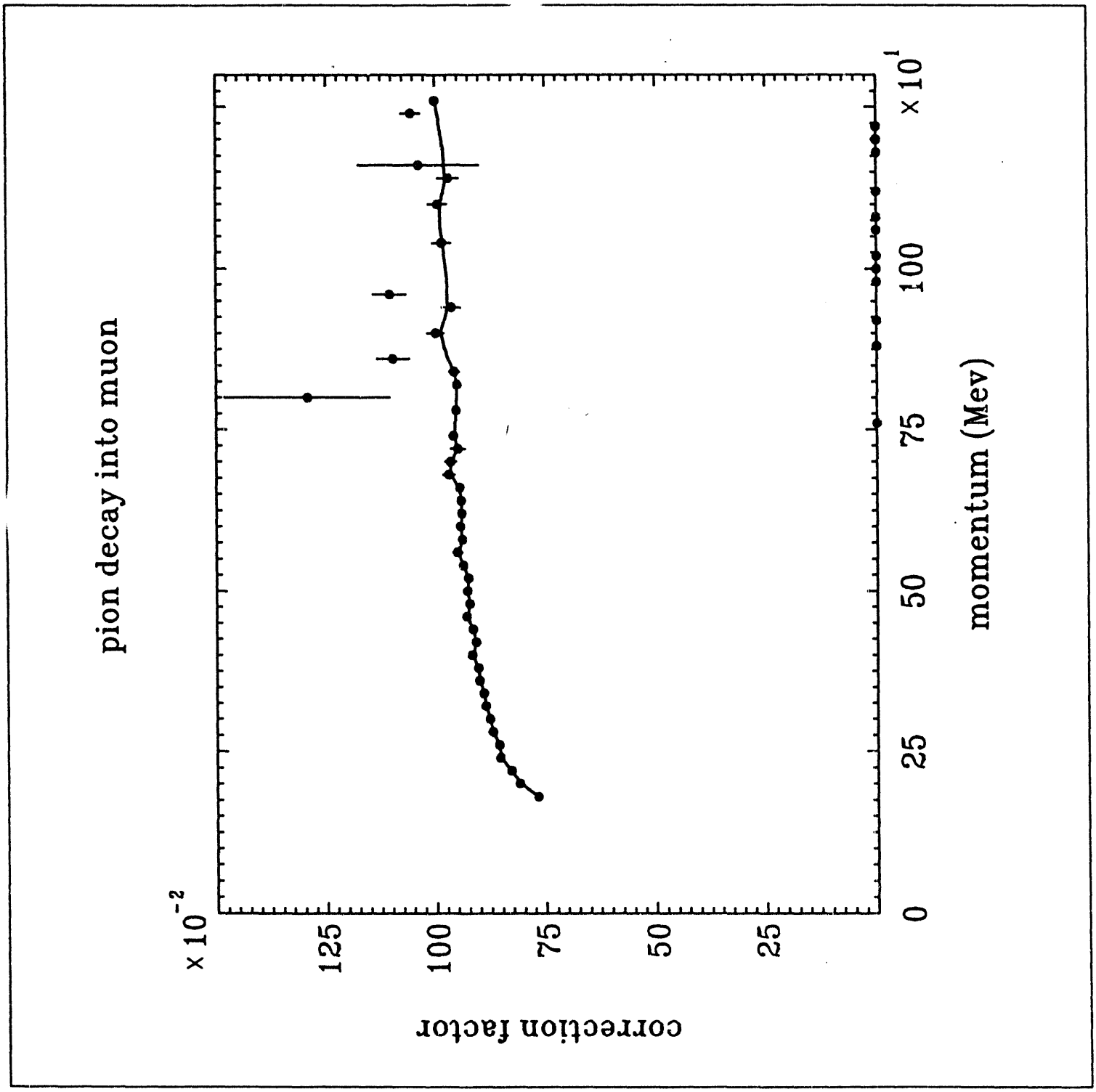
pion decay into muon
correction factor
x 10^-2
125
100
75
50
25
0
25
50
75
100
x 10^1
momentum (Mev)

Fig 6

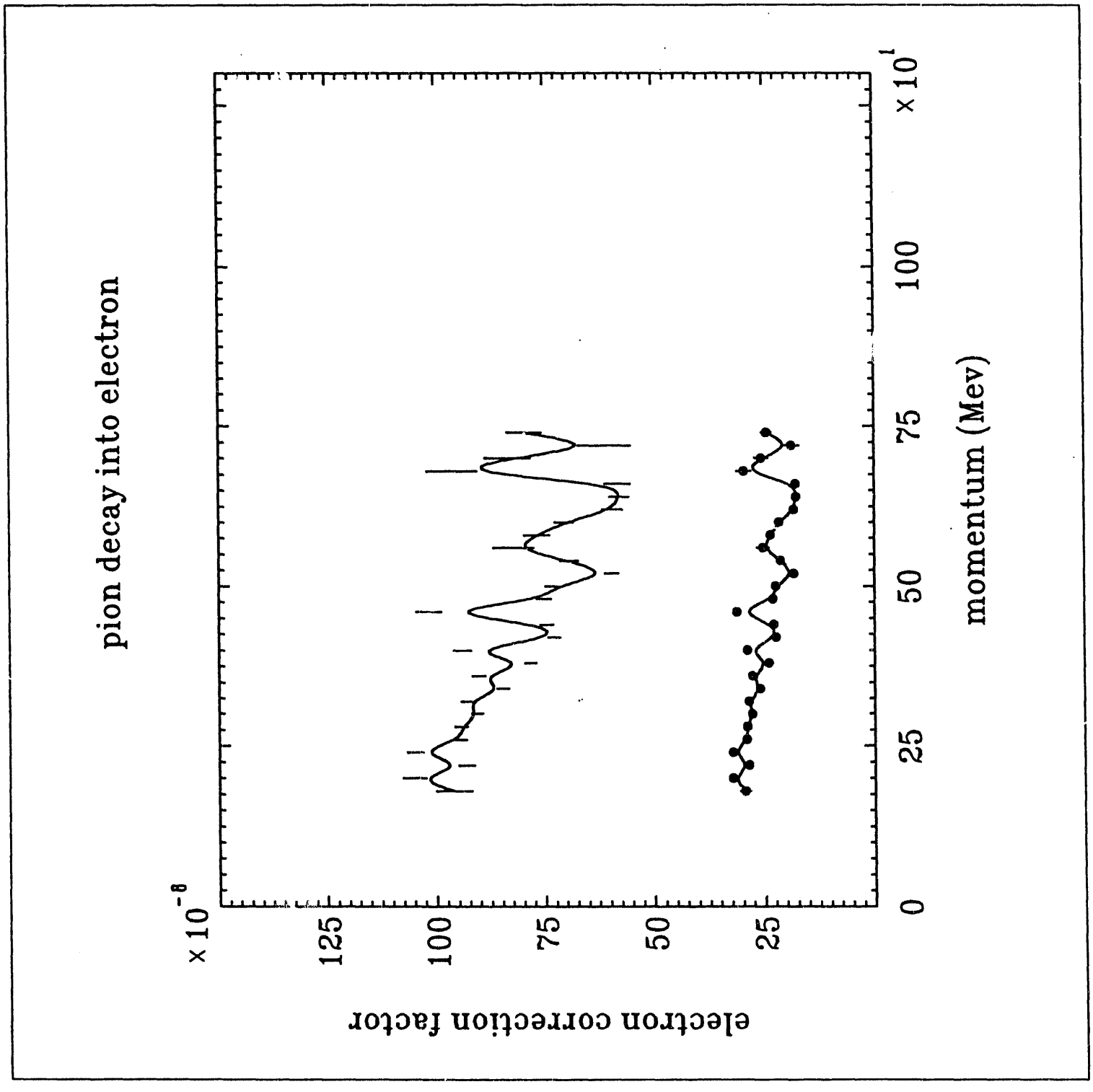
pion decay into electron
electron correction factor
× 10^-8
125
100
75
50
25
0
25
50
75
100
× 10^1
momentum (Mev)

Fig 7

electron in the apparatus unless it should pass through both Cherenkov counters. The solid black circles in fig 7 represent the ecf that is obtained by constraining the point of decay to lie between the target and the entrance aperture to Cherenkov counter C1. The vertical bars represent the ecf that is obtained by constraining the point of decay to lie between the target and the midplane of C1. One sees that even under loose constraints the probability for a charged pion's producing a detectable electron by the electronic decay channel is less than approximately 1×10^{-6}. This number is approximately two orders of magnitude smaller than typical values for the ratio of direct electrons to pions. This is another gratifying result which we are pleased to call to the reader's attention.

The production of kaons is possible at the energies of this experiment. The principal decay mode for charged kaons is $K \rightarrow \mu + \nu$, but the electronic decay mode $K \rightarrow e + \nu$ has been observed with a branching ratio of approximately 1.54×10^{-4}. A fraction of the electrons that are produced through the electronic decay mode of the kaon will be detected in our apparatus, and the number of such electrons must be calculated and subtracted from the data sample. In addition muons that are produced through the decay of the kaon will, with some probability, be detected and incorrectly interpreted as pions. The number of muons that are falsely identified in this way must be subtracted from the sample of detected pions.

During the preceding year we have calculated, by Monte-Carlo simulation, the response of our apparatus to kaon decay, and are pleased to present the results. We exhibit in figs 8 – 11 results that are analogous to those presented in figs 1 – 4. Note that the probability for the survival of the kaon is substantially less than the probability for the survival of the pion, as one might expect from the difference in lifetimes. We show in fig 12 the correction factor for kaon decay. It is important to note that in this case the correction factor is defined as the number of coincidences that are registered and interpreted as being due to the passage of a particle with momentum between p and p + dp divided by the number of kaons that would have been detected with a momentum in this range if the lifetime of the kaon were infinite. *The ratio of cross sections for the production of pions and kaons has not been incorporated into fig 12.* We show in fig 13 the electron correction factor for kaon decay. The two sets of data have the same significance as the two sets of data that are shown in fig 7. The electronic branching ratio for kaon decay has already been incorporate into the value of the ordinate. Even so one sees that the number of detectable electrons that are produced through the electronic decay channel of the kaon is so low as to obviate further discussion of kaon decay.

Because of the severe problems that resulted form our installation of the 4000, we also turned out attention to the calculation of the correction factor for nuclear absorption of pions. We suggest that the reader review the fourth item on page 4 of last year's renewal proposal and also the paragraph on page 5 that begins "Of the remaining four tasks...". The accumulation of the data that are necessary to calculate this correction factor is a task of mind-numbing tedium that is totally lacking in glamour. Nonetheless, the absorption cross sections do exist, and as evidence of our efforts we include in figs 14 – 16 the cross sections for the absorption of pions on ^{9}Be and Carbon. We have, in addition, data on the elastic and inelastic scattering cross sections. In figs 17 – 22 are shown the elastic, inelastic, and total

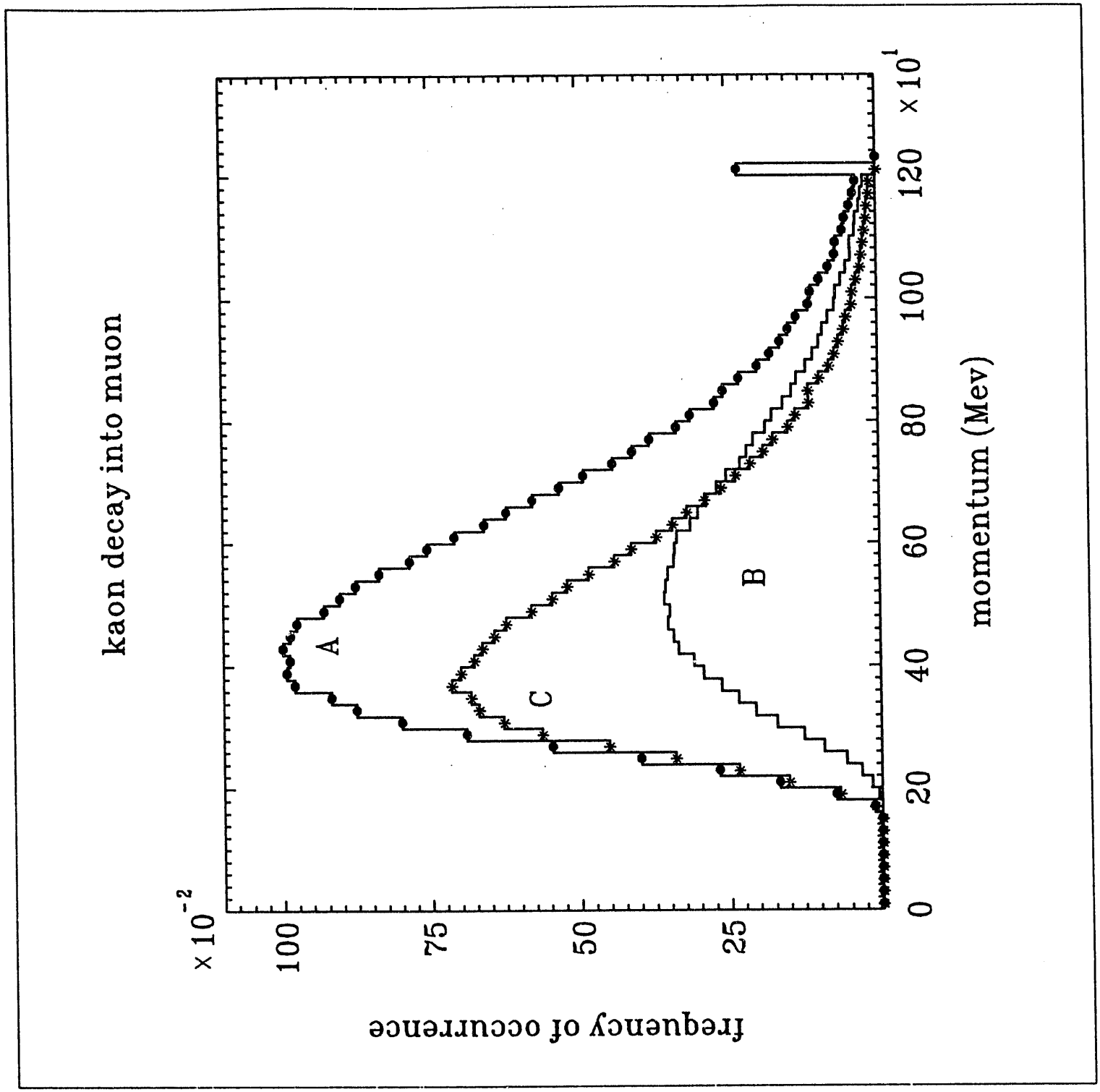
kaon decay into muon
frequency of occurrence
× 10^-2
100
75
50
25
0
20
40
60
80
100
120
× 10^1
momentum (Mev)
A
B
C

Fig 8

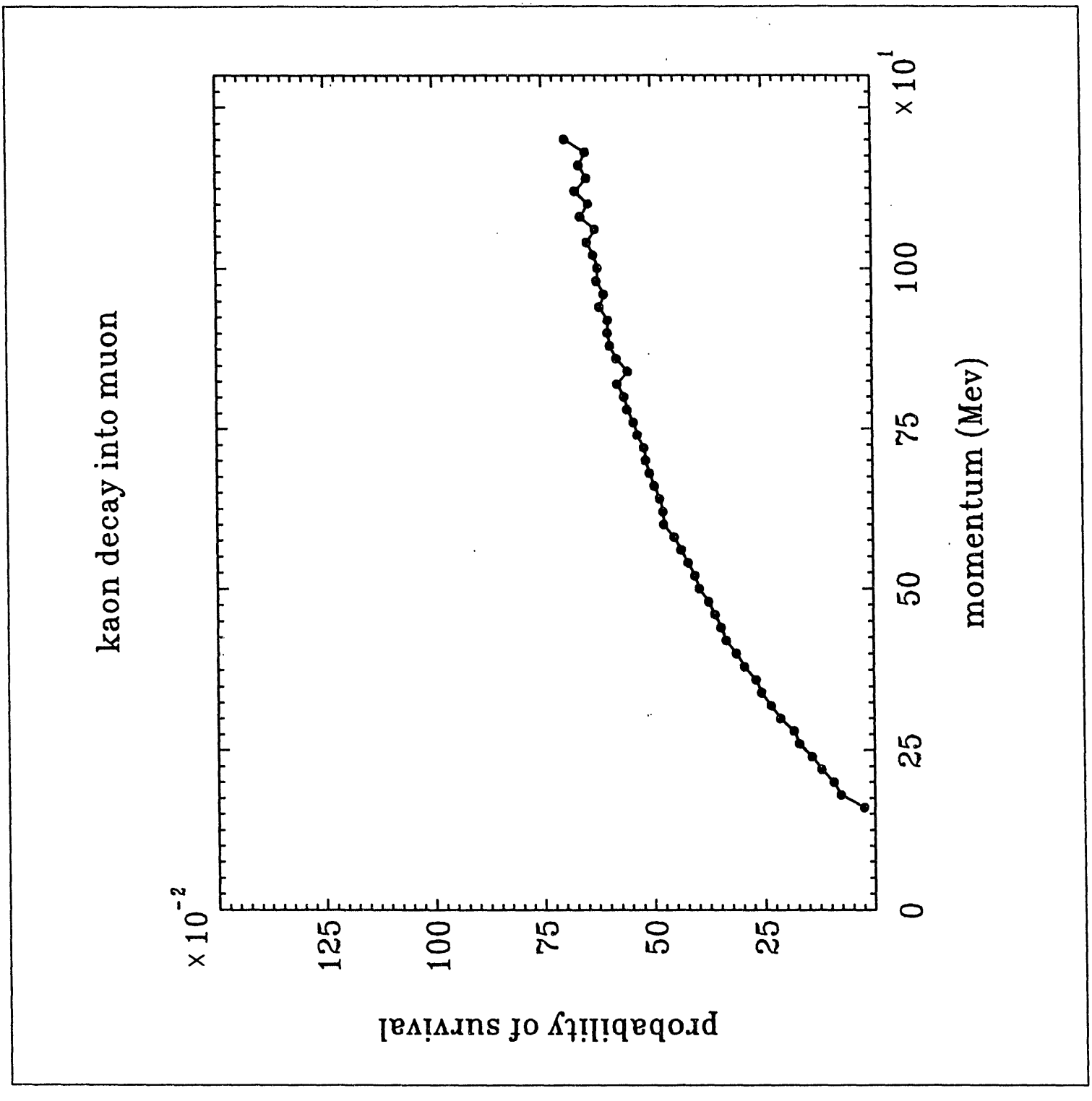
kaon decay into muon
probability of survival
$\times 10^{-2}$
125
100
75
50
25
0
25
50
75
100
$\times 10^{1}$
momentum (Mev)

Fig 9

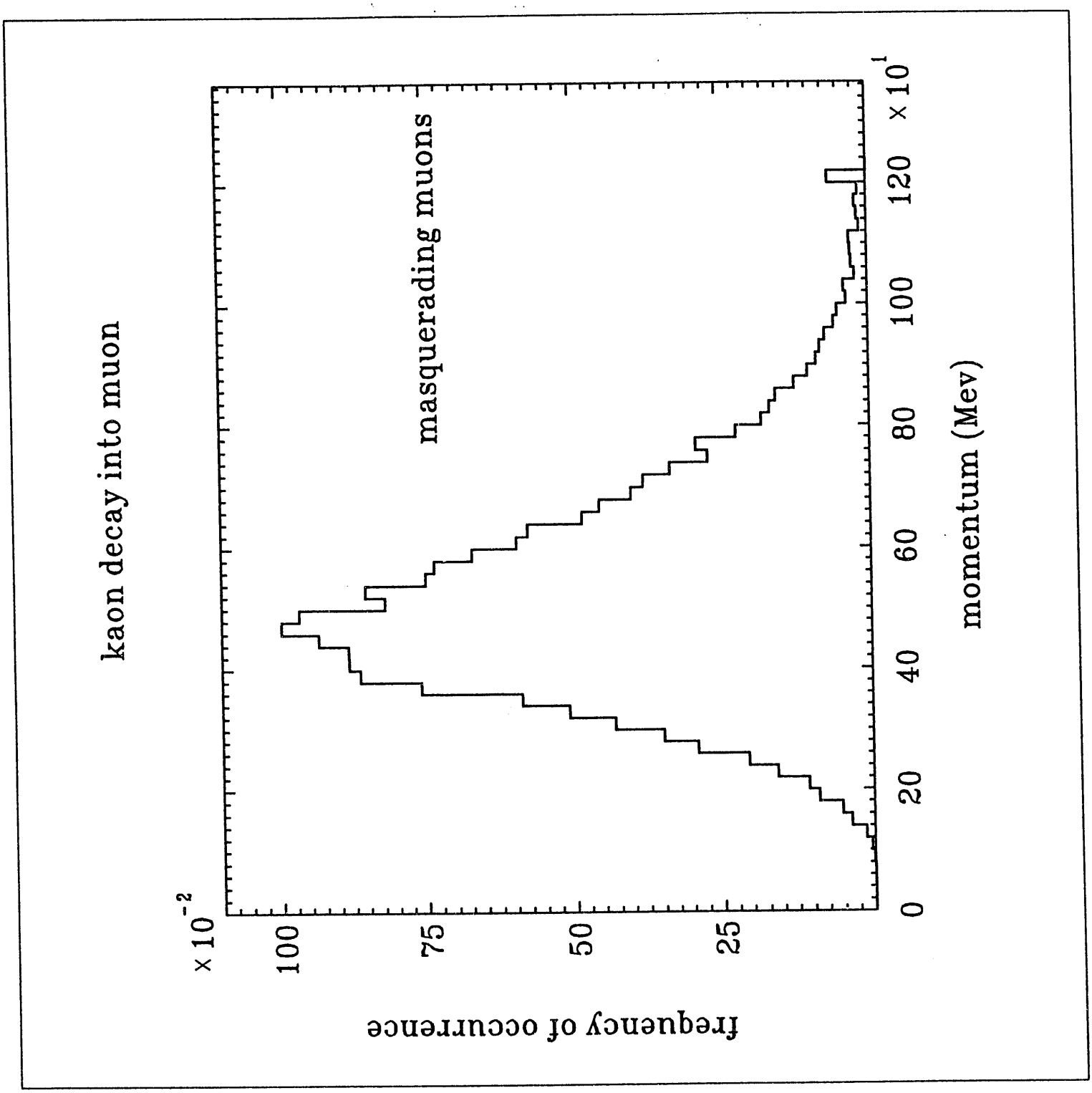
kaon decay into muon
masquerading muons
frequency of occurrence
× 10^-2
100
75
50
25
0
20
40
60
80
100
120
× 10^1
momentum (Mev)

Fig 10

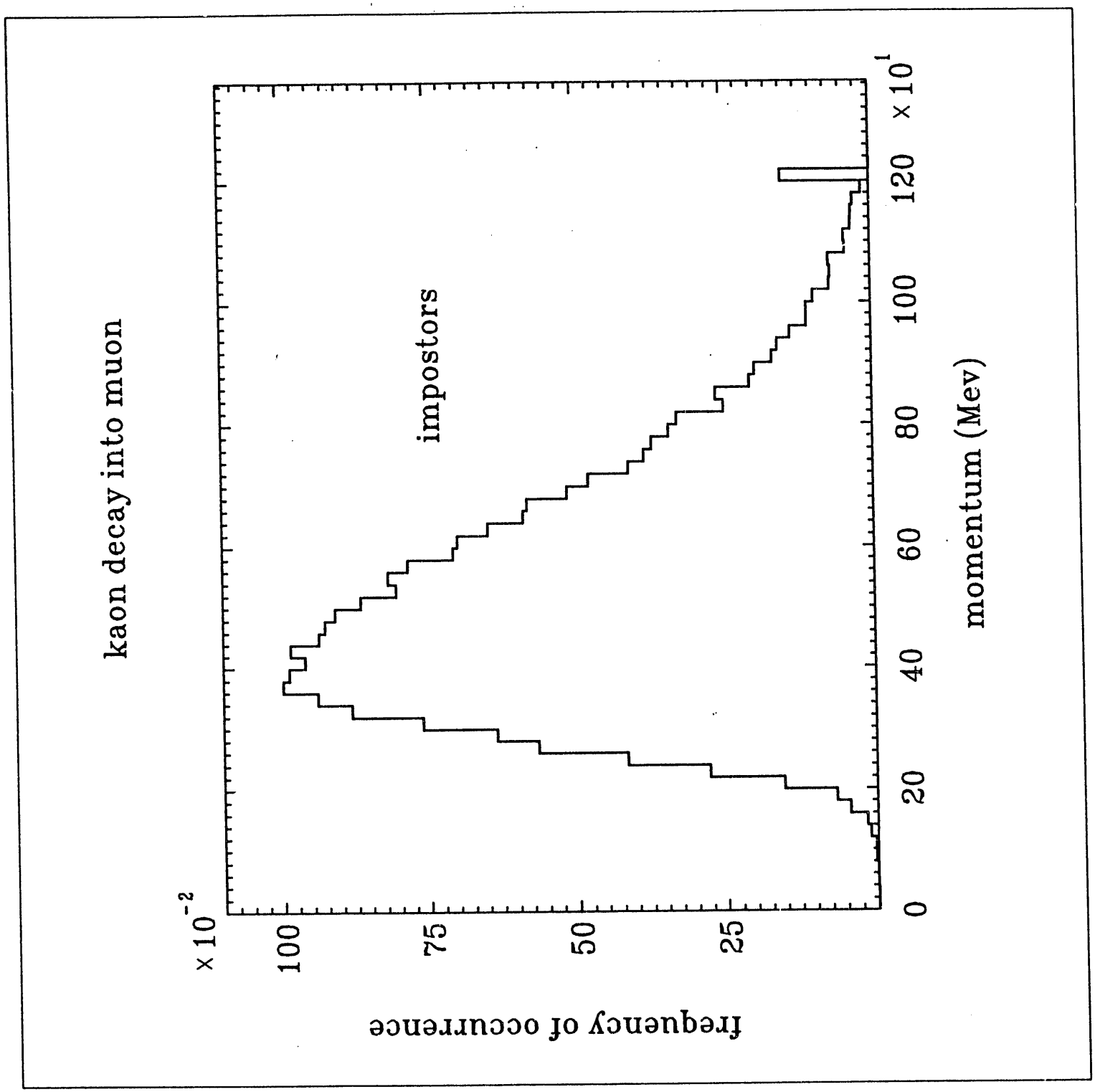
kaon decay into muon
impostors
frequency of occurrence
× 10^-2
100
75
50
25
0
20
40
60
80
100
120
× 10^1
momentum (Mev)

Fig 11

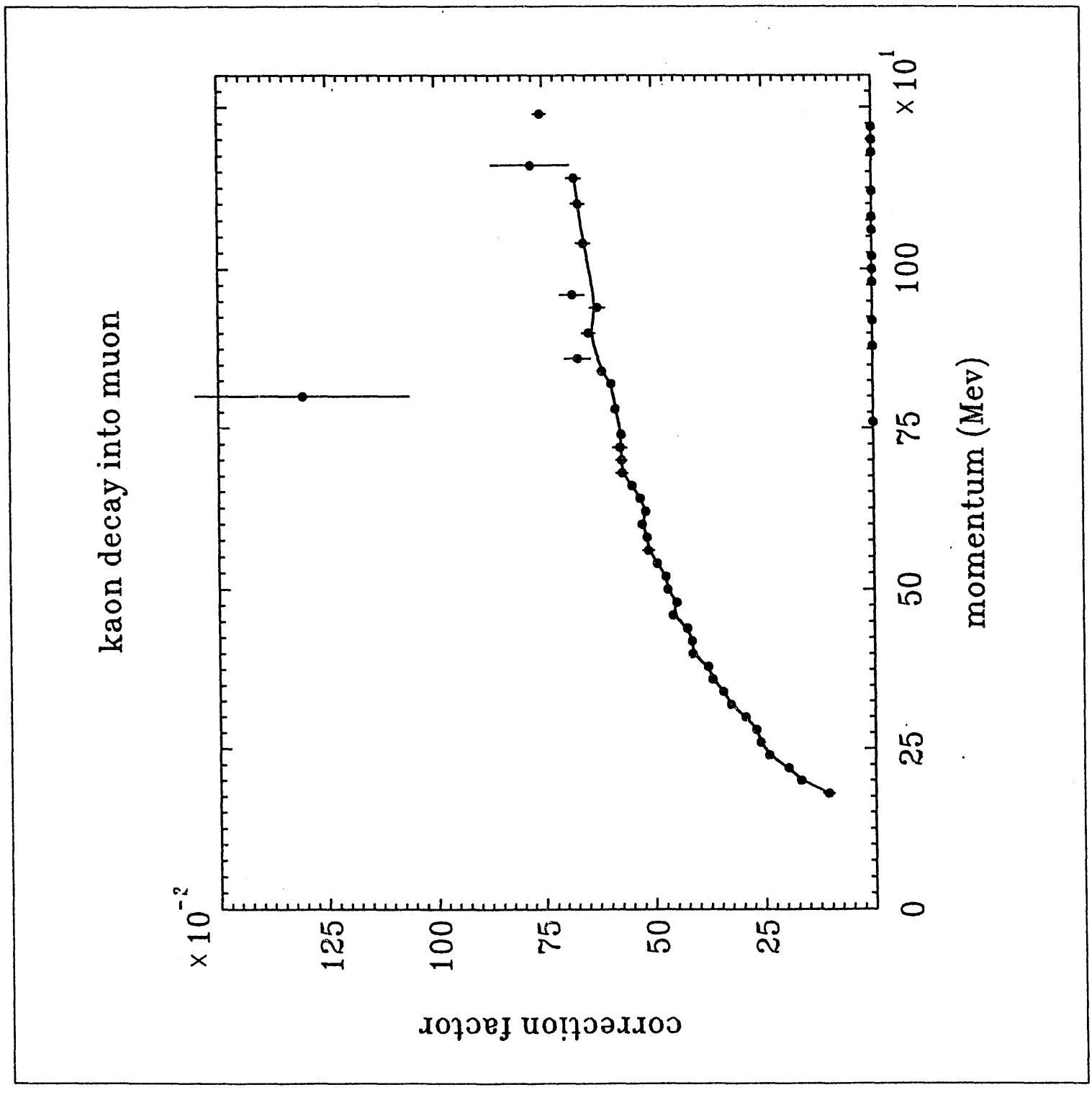
kaon decay into muon
correction factor
x 10^-2
125
100
75
50
25
0
25
50
75
100
x 10^1
momentum (Mev)

Fig 12

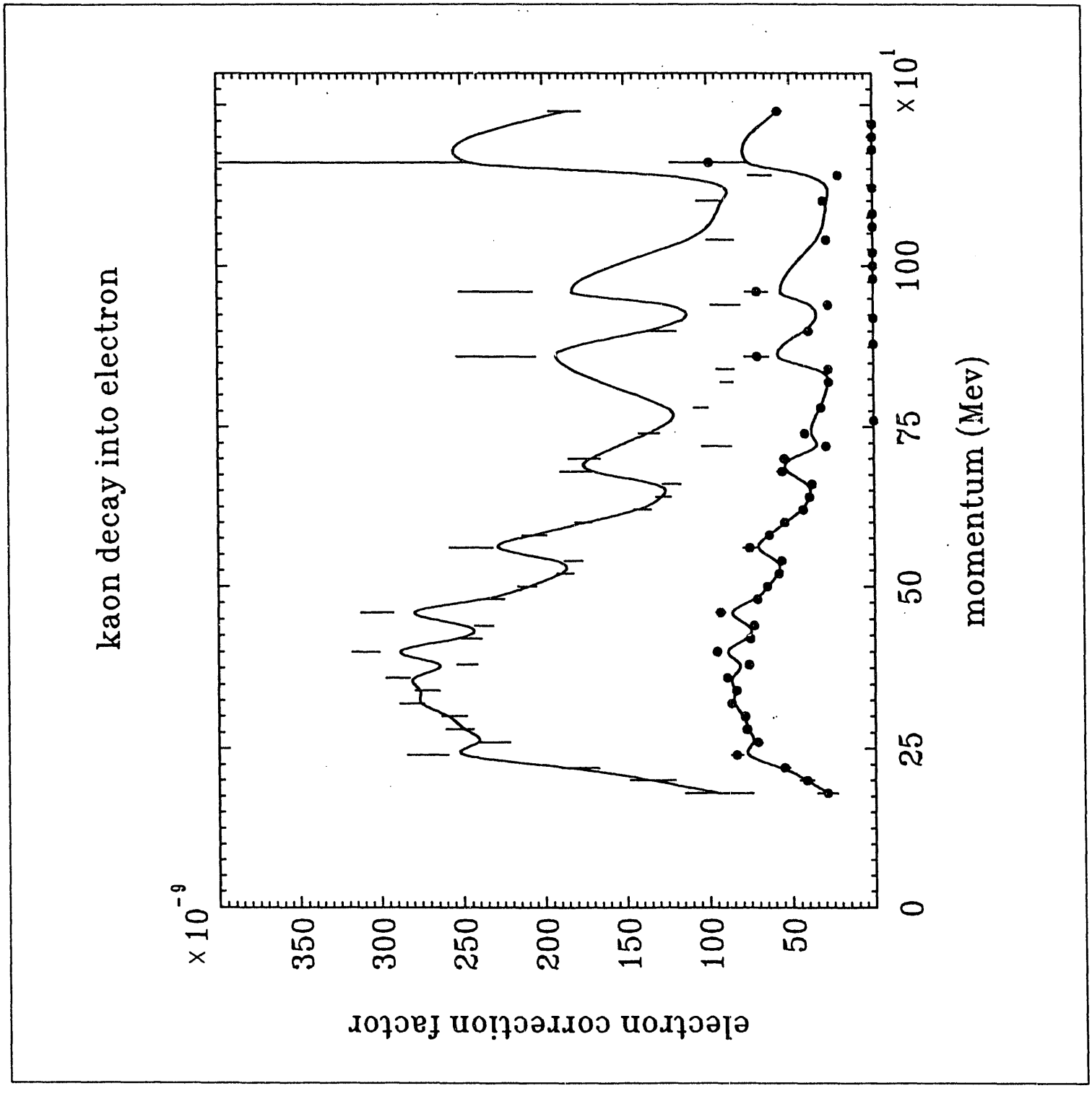
kaon decay into electron
electron correction factor
× 10^-9
350
300
250
200
150
100
50
0
25
50
75
100
× 10^1
momentum (Mev)

Fig 13

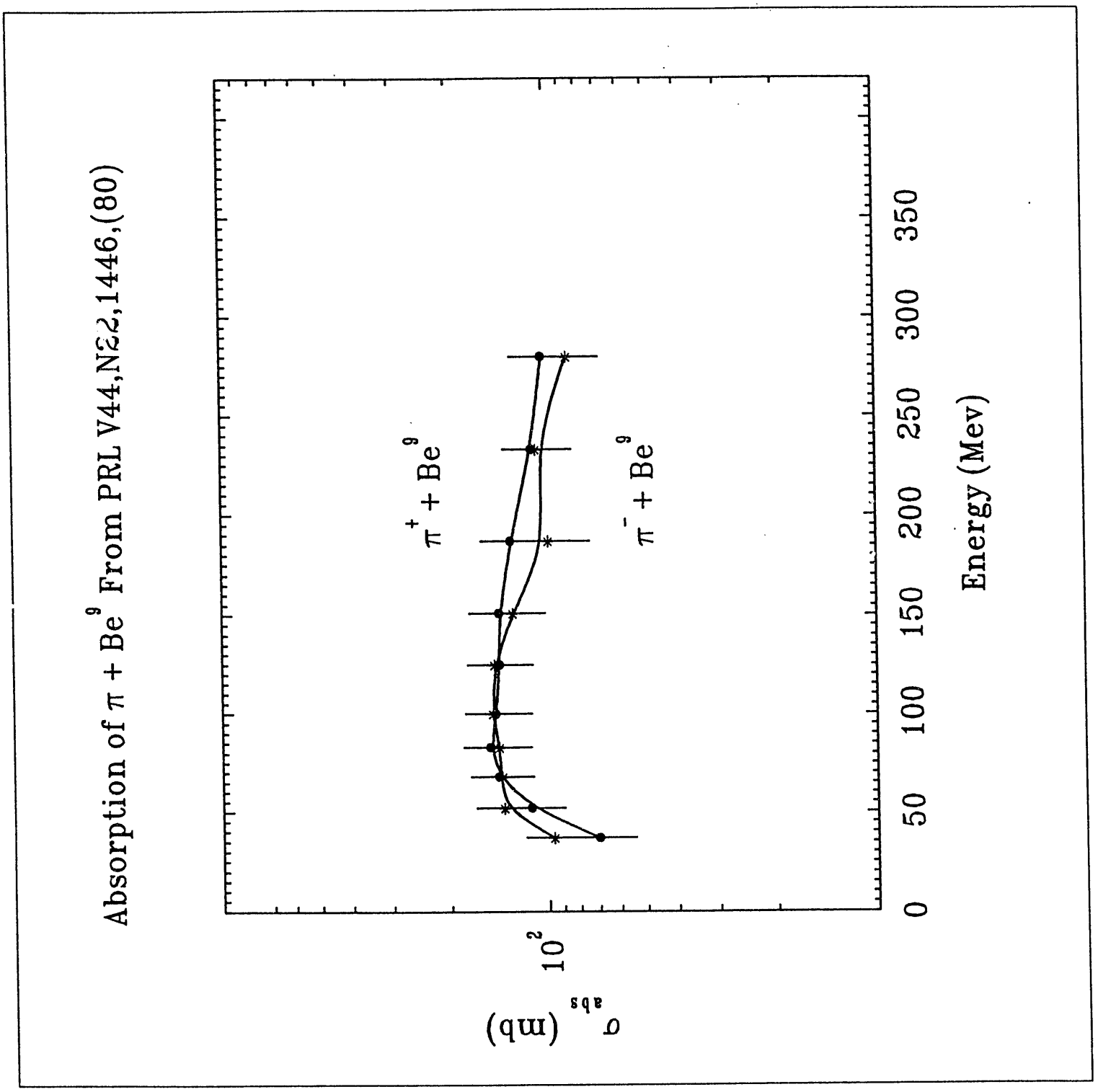
Absorption of π + Be9 From PRL V44,N22,1446,(80)
σabs (mb)
10^2
π+ + Be9
π- + Be9
0
50
100
150
200
250
300
350
Energy (Mev)

Fig 14

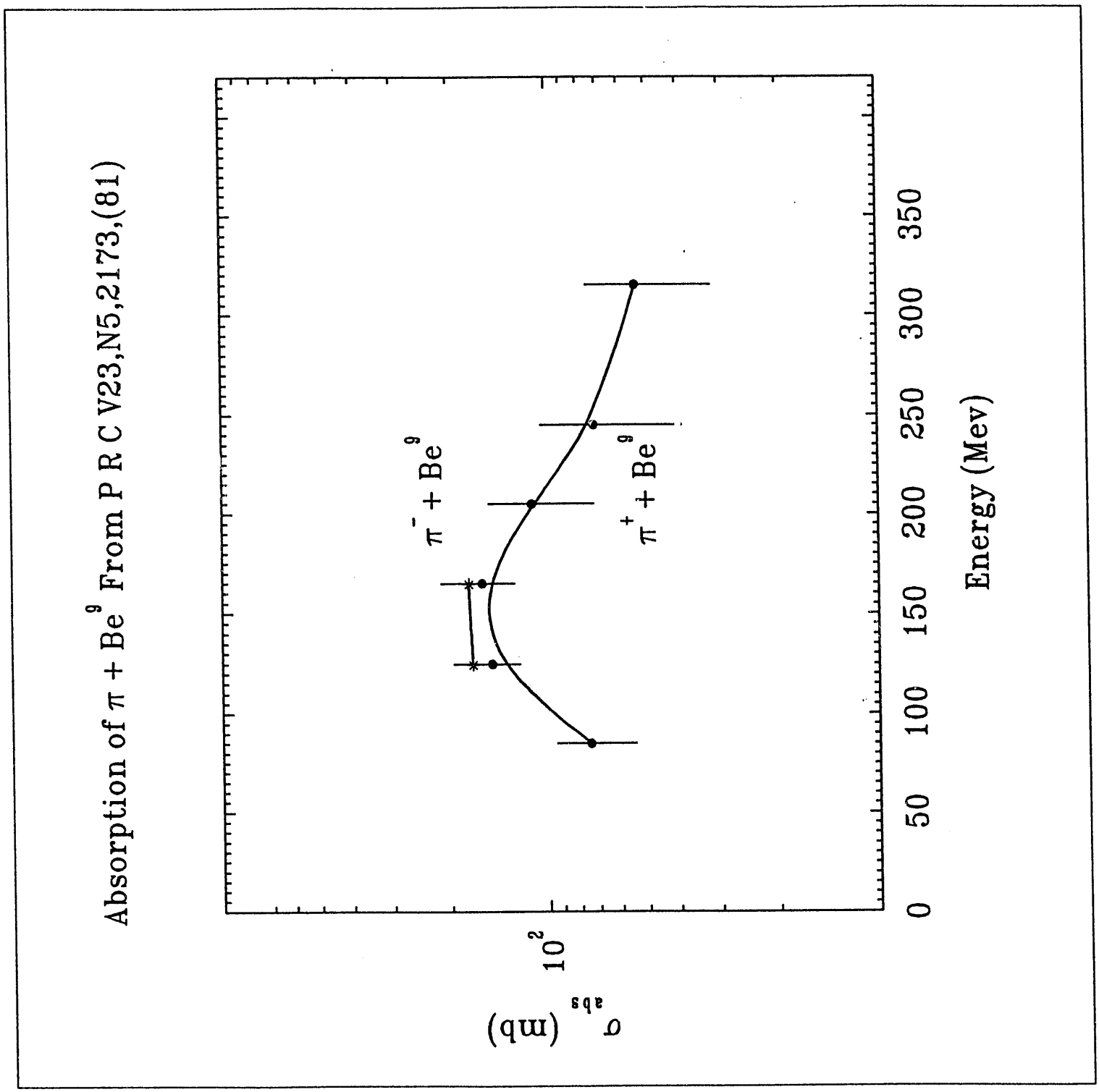
Absorption of π + Be9 From P R C V23,N5,2173,(81)
σabs (mb)
10^2
π- + Be9
π+ + Be9
0
50
100
150
200
250
300
350
Energy (Mev)

Fig 15

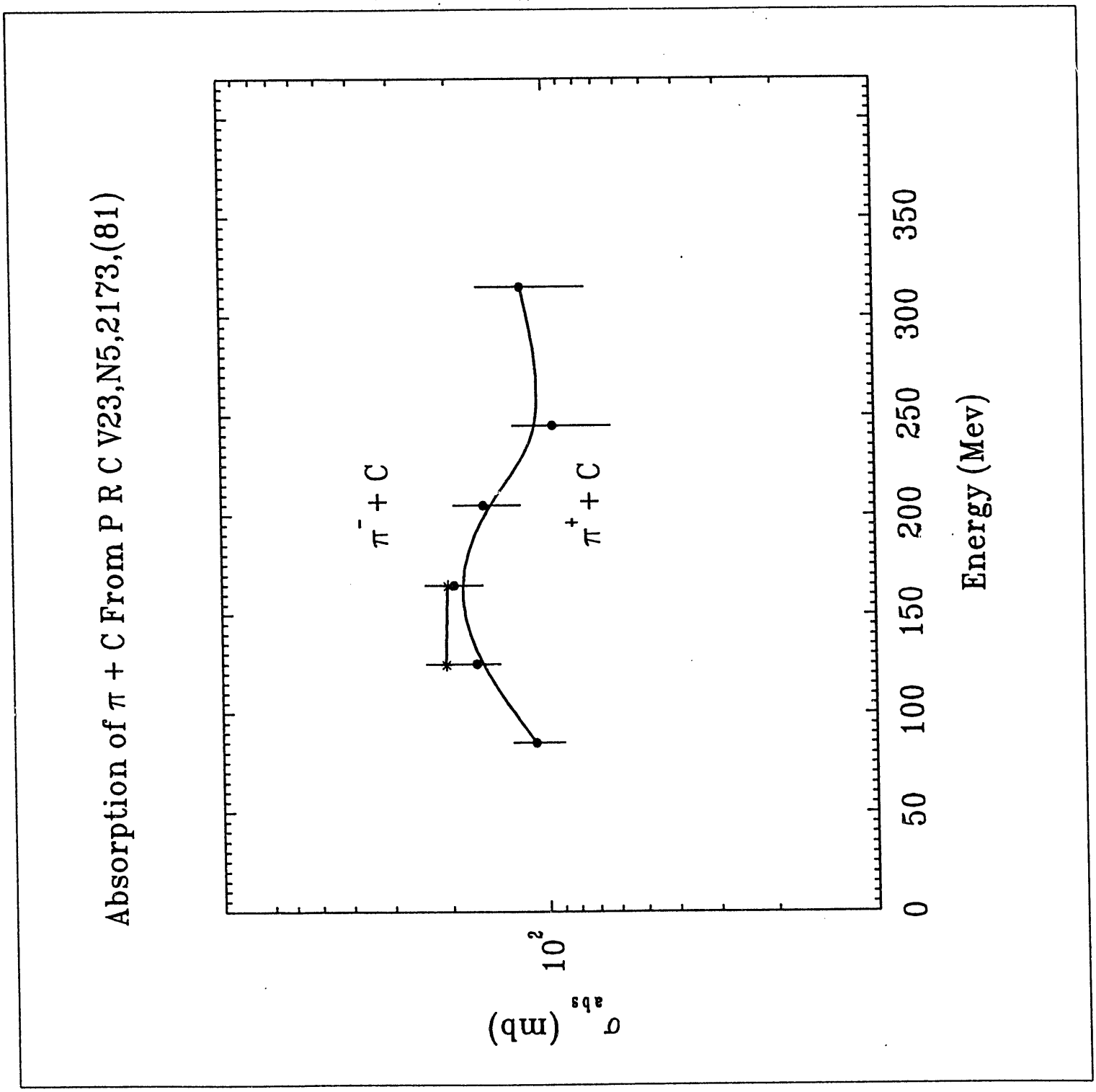
Absorption of π + C From P R C V23,N5,2173,(81)
π⁻ + C
π⁺ + C
σ_abs (mb)
10²
0
50
100
150
200
250
300
350
Energy (Mev)

Fig 16

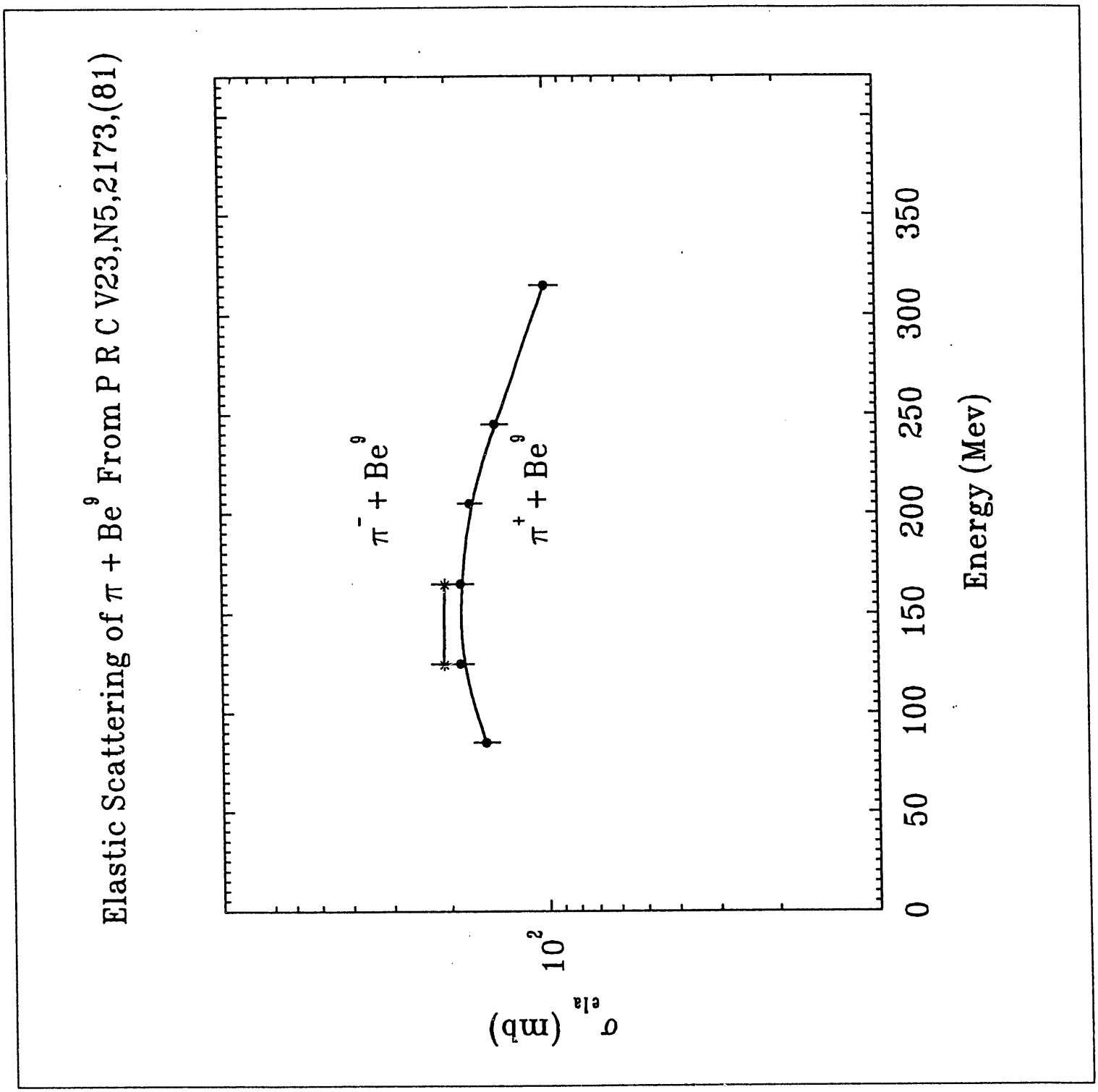
Elastic Scattering of π + Be9 From P R C V23,N5,2173,(81)
π- + Be9
π+ + Be9
σela (mb)
10^2
0
50
100
150
200
250
300
350
Energy (Mev)

Fig 17

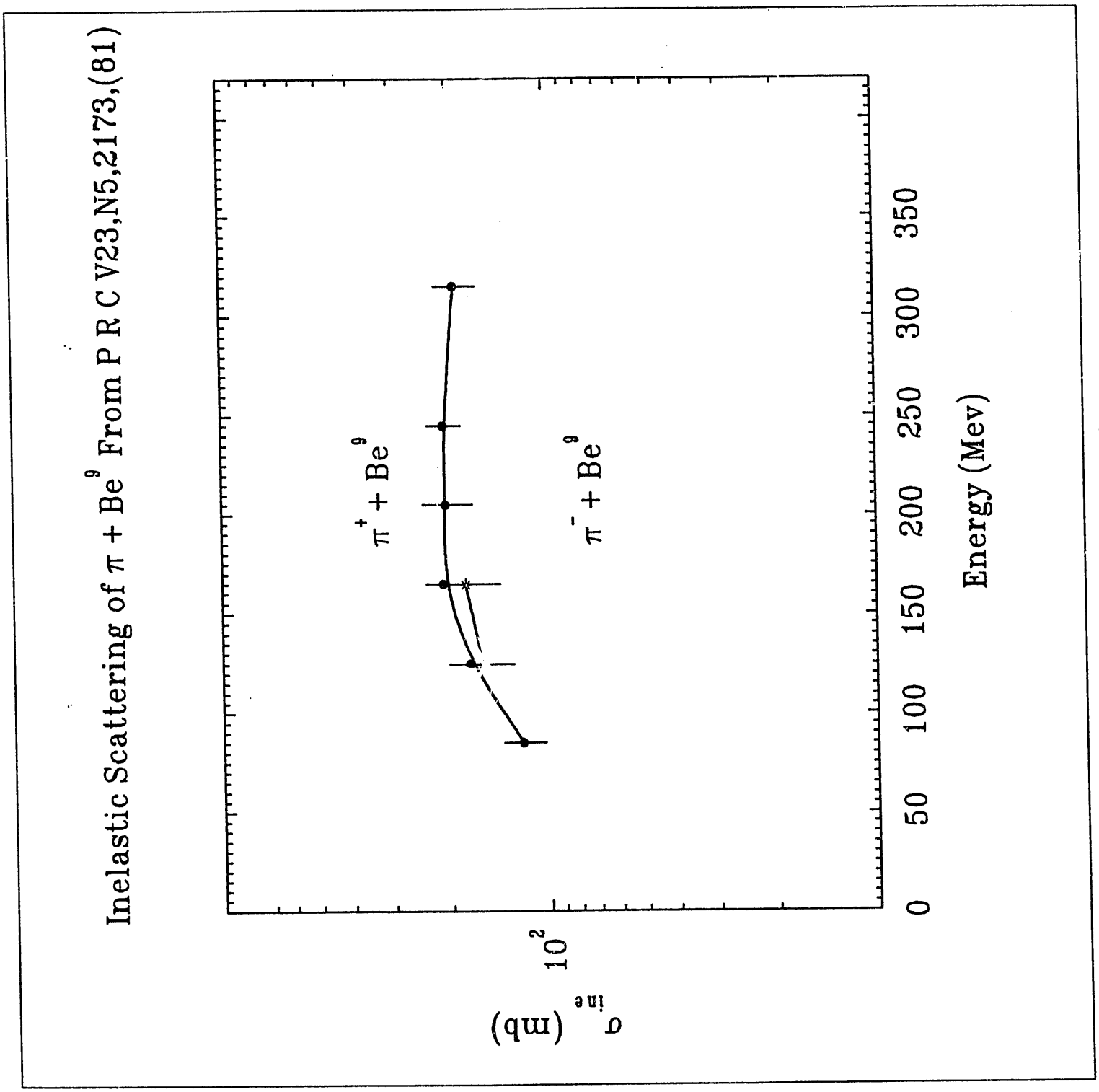
Inelastic Scattering of π + Be9 From P R C V23,N5,2173,(81)
π+ + Be9
π- + Be9
σine (mb)
10^2
0
50
100
150
200
250
300
350
Energy (Mev)

Fig 18

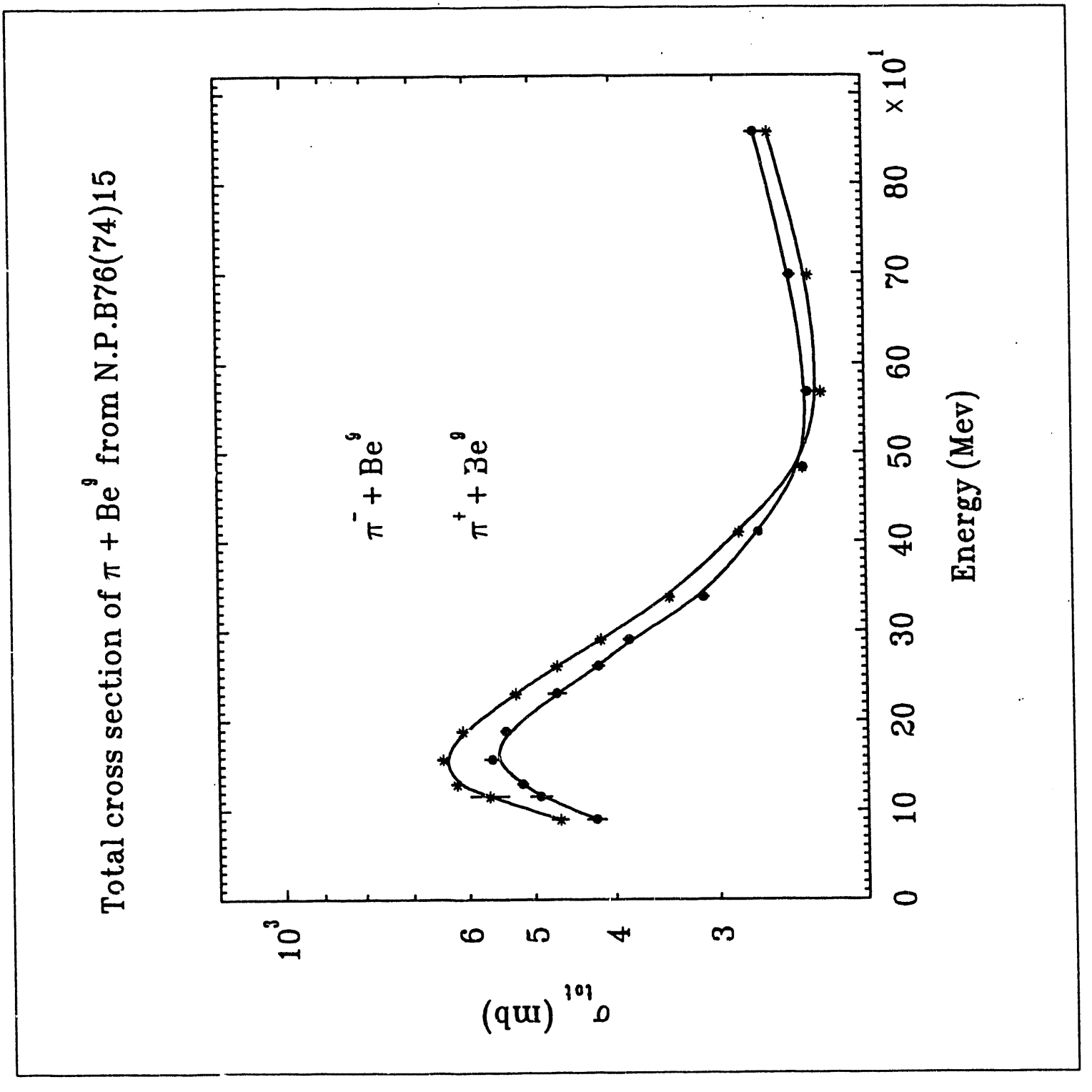
Total cross section of π + Be⁹ from N.P.B76(74)15
π⁻ + Be⁹
π⁺ + Be⁹
σ_tot (mb)
10³
6
5
4
3
0
10
20
30
40
50
60
70
80
×10¹
Energy (Mev)

Fig 19

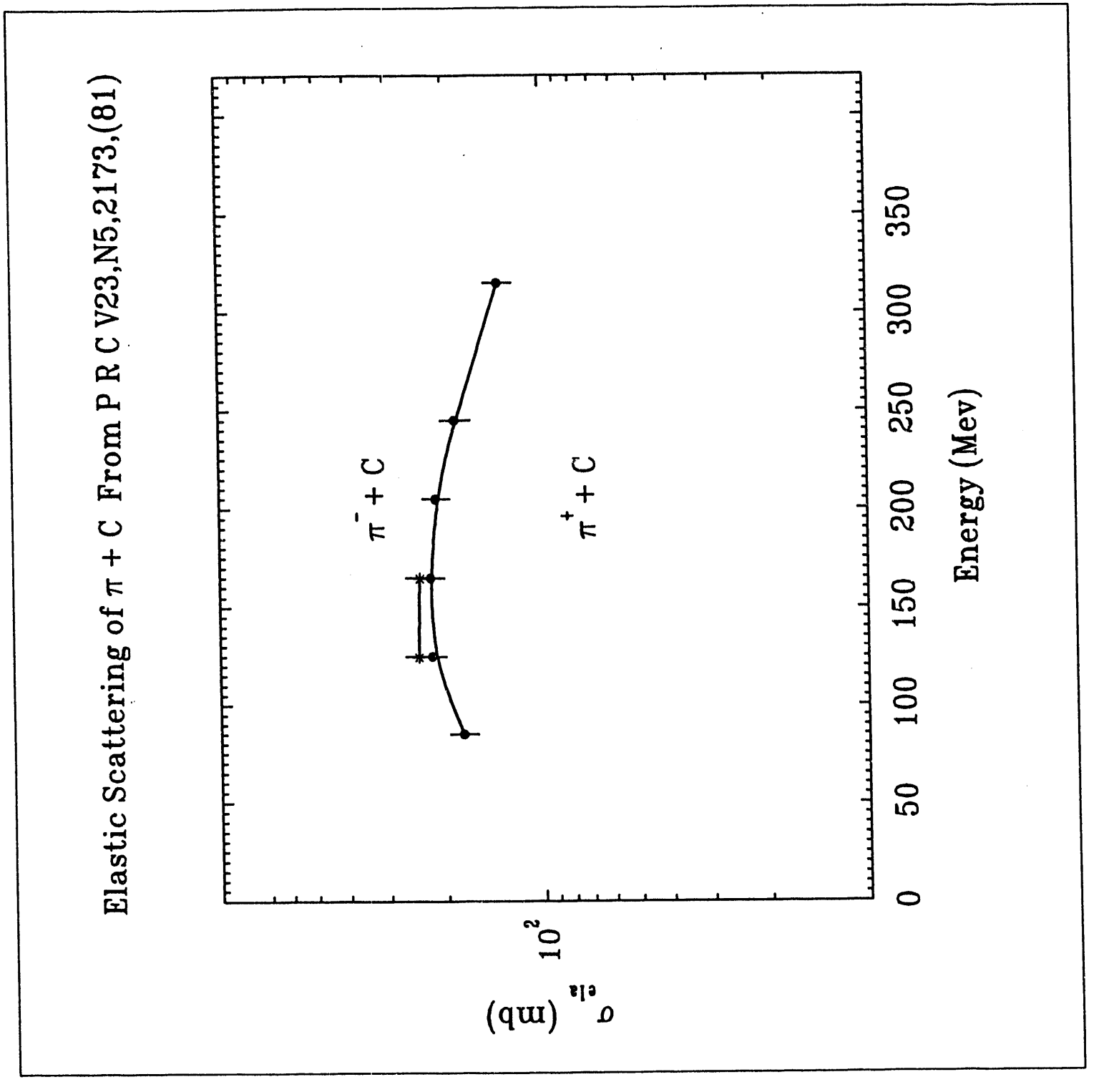
Elastic Scattering of π + C From P R C V23,N5,2173,(81)
π⁻ + C
π⁺ + C
σ_ela (mb)
10²
0
50
100
150
200
250
300
350
Energy (Mev)

Fig 20

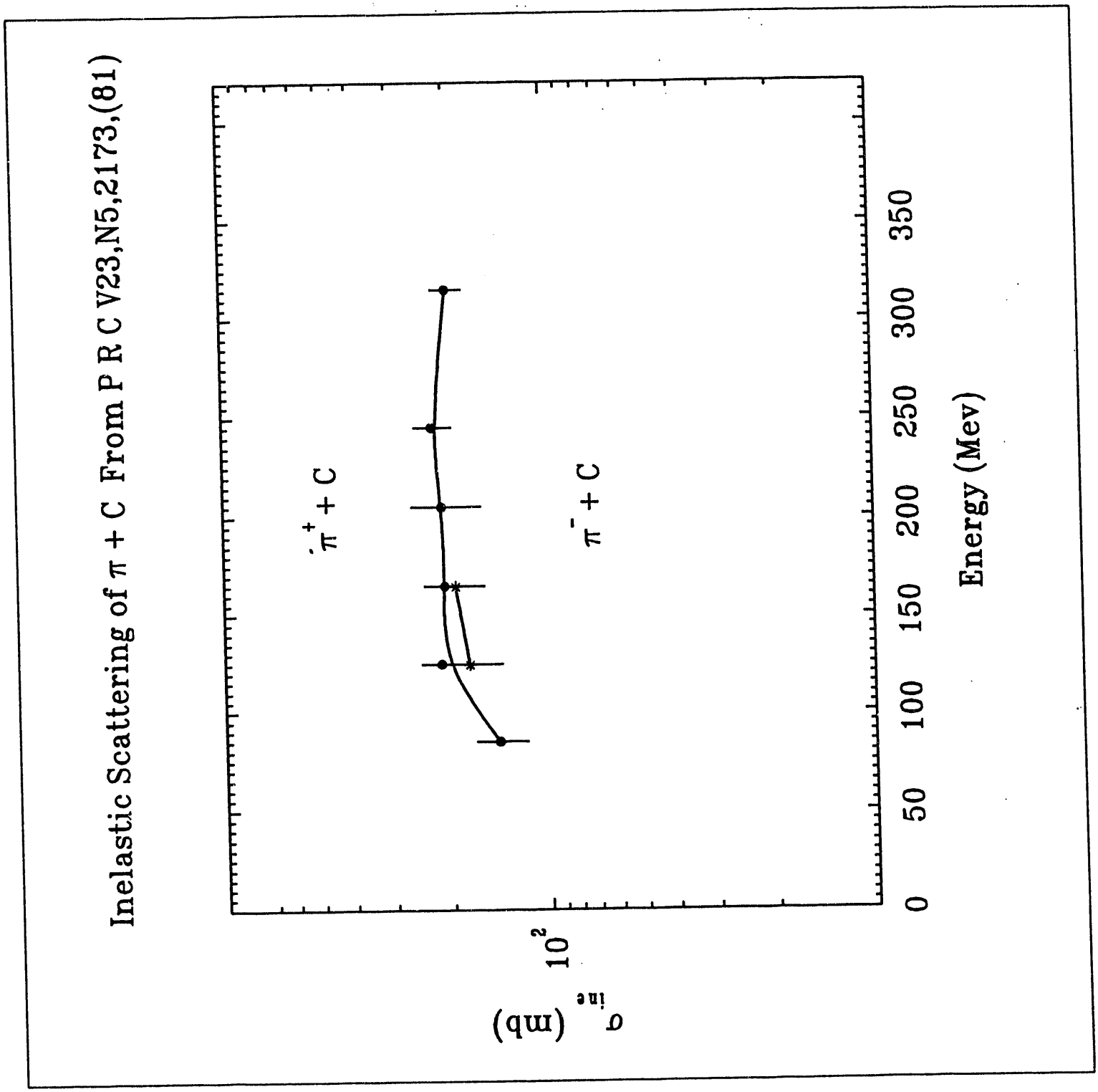
Inelastic Scattering of π + C From P R C V23,N5,2173,(81)
π+ + C
π- + C
σ_ine (mb)
10^2
0
50
100
150
200
250
300
350
Energy (Mev)

Fig 21

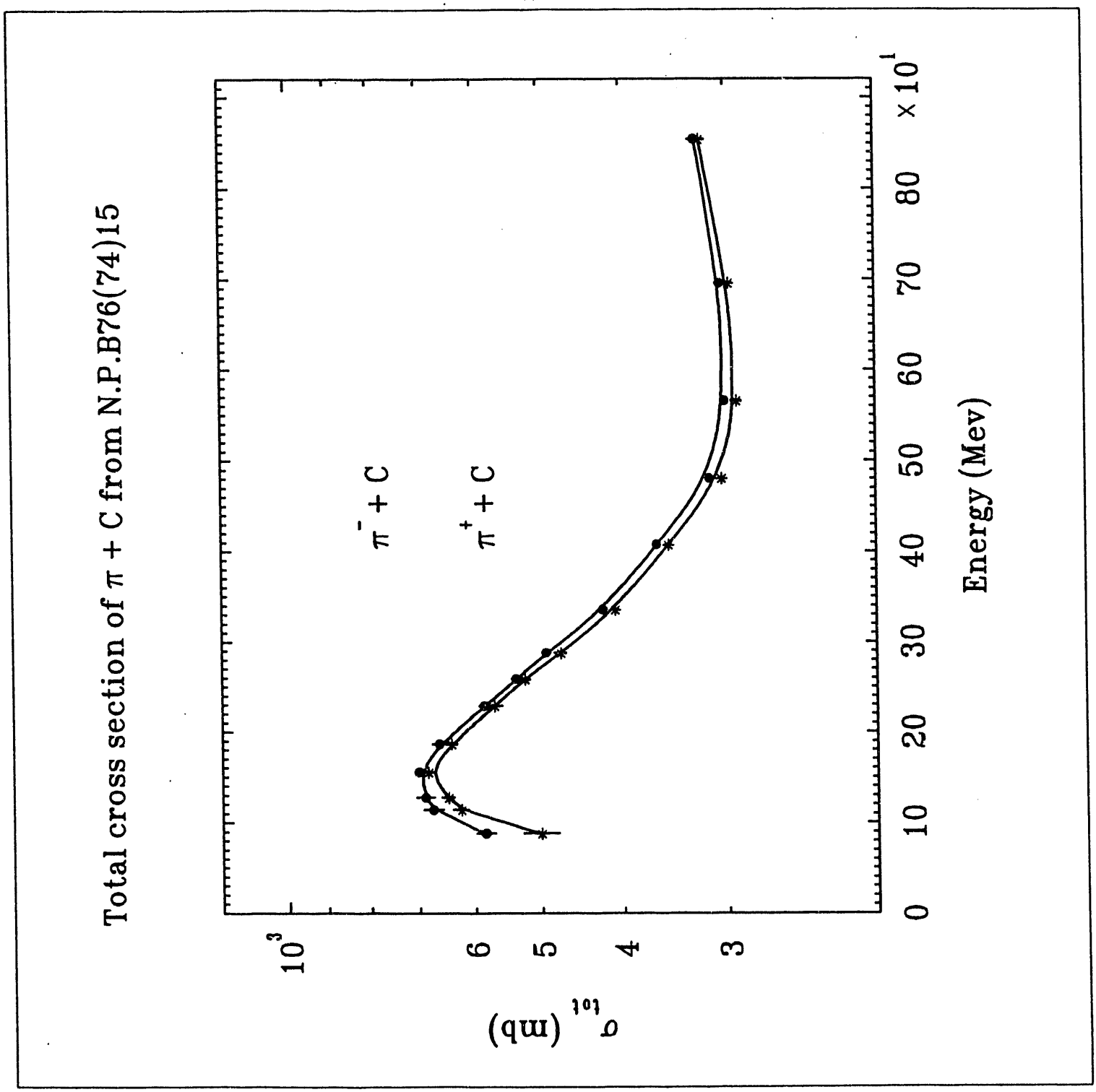
Total cross section of π + C from N.P.B76(74)15
$\pi^- + C$
$\pi^+ + C$
σ_{tot} (mb)
10^3
6
5
4
3
0
10
20
30
40
50
60
70
80
$\times 10^1$
Energy (Mev)

Fig 22

cross sections for pions on ^{9}Be and Carbon. All the data that are necessary for evaluating the effects of secondary interactions are now at our disposal.

(f) affiliation with PHENIX

We are pleased to inform the reader that our application for membership in the PHENIX Collaboration was accepted. At the possible risk of excessive exuberance we wish to record our delight with our new affiliation. The experiment being mounted by this collaboration will become the focus of our efforts within the next year.

(g) content of last year's proposal

We think it possible that the reader might be curious as to the fate of the calculation we outlined in last year's renewal proposal. Beginning on page 6 there is a discussion entitled "The Search for Direct Leptons at the DLS", and in that discussion we outlined a specific calculation which, in our judgement, needs to be carried out. The proposal created within the DLS Collaboration a spirited and occasionally sharp debate. Not all of our colleagues agree with our analysis in detail, but the idea of establishing a fiducial volume carried the day.

Our colleagues pointed out, and we must reluctantly agree, that the computational facilities available at LBL are superior to ours at all times. More importantly, they were vastly superior to ours at the time of the debate because of the problems that resulted from our installing the 4000. Consequently the responsibility for carrying out the calculation devolved onto the able shoulders of our colleagues at LBL.

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