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Evaluation at the Medium Energy Region for Pb-208 and Bi-209

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Abstract

Medium energy nuclear data in the 1-1000 MeV range is necessary to accelerator applications which include spallation neutron souces for radioactive waste treatment and accelerator shielding design, medical applications which include isotopes production and radiation therapy, and space applications. For the design of fission and fusion reactors, the nuclear data file for neutrons below 20 MeV is available and well evaluated. Evaluated nuclear data for protons and data in the medium energy region, however, have not been prepared completely. Evaluation in the medium energy region was performed using the theoretical calculation code ALICE-P or experimental data. In this paper, the evaluation of neutron and proton induced nuclear data for Pb-208 and Bi-209 has been performed using ALICE-P, empirical calculations and new systematics for the fission cross section. The evaluated data are compiled for possible inclusion in the ENDF/B-VI High Energy File.

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1. Introduction

Many applications, such as spallation neutron souces for radioactive waste treatment, accelerator shielding design, medical isotopes production, radiation therapy, the effects of space radiation on astronauts and their equipment, and the cosmic history of meteorites and other galactic substances, need medium energy nuclear data in the 1-1000 MeV range. For the design of fission and fusion reactors, the nuclear data file for neutron below 20 MeV is well evaluated such as Japanese Evaluated Nuclear Data Library, version 3 (JENDL-3)/1/ in Japan, Evaluate Nuclear Data File, part B, version 6 (ENDF/B-VI)/2/ in the United States, and so on. Nuclear data for protons and data in at the medium energy region, however, have not been prepared completely, except those for iron/3/.

Evaluation in the medium energy region might be performed by using theoretical calculation codes or based on experimental data. The calculation codes usable at the medium energy are HETC/4/ using Monte Carlo techniques based on intranuclear cascade/5/, ALICE/6/ and GNASH/7/ using evaporation and preequilibrium theory, and PNEM/8/ using systematics for neutron emission cross sections. They have been compared by Pearlstein/9/ in calculated results, running time, and so on. ALICE/6/ has been modified to ALICE-P by Pearlstein/3/ and for this study the 1989 version of ALICE/10/ was modified to ALICE-P. The modifications consist mainly of changes in optical model parameters and the calculation of inverse cross sections. The ALICE-P variables and parameter options refered to in this report are the same variables contained in the 1989 version of ALICE.

In this paper, the evaluation of neutron and proton induced nuclear data for Pb-208 and Bi-209 has been performed using mainly ALICE-P and nuclear systematics. Different systematic schemes were compaired. A methodical search for the best ALICE-P parameters have been carried out. ALICE-P has default options for the mass formula, level density formula, mean free path, exciton starting points for preequilibrium calculation and some systematics for nucleon emission spectra. The combination of these options and parameters were considered and compared with the Pearlstein's systematics for neutron emission spectra. Experimental data of fission cross section for several isotopes near lead in the energy range from 50 MeV to 9 GeV was reviewed, and new systematics for the fission cross section was derived.

2. Consideration of Mass Calculations

ALICE-P code has a default option for mass calculation, which is without the pairing correction and shell effect. The calculated results for isotope production cross sections did not reproduce most parts of the experimental data, especially at threshold energies (dependent on Q-values). On the other hand, the ten latest mass formula have been introduced in the Atomic Data and Nuclear Data Tables (vol.39, No.2 (1988)) which also contains a table of the mass values predicted by each formula. The comparison of the ten mass values included in that table and the binding energies calculated by using them were performed as well as the ALICE-P options.

The comparison of the mass values calculated by Pape and Antony/17/, Dussel et al./18/, Moller and Nix/19/, Moller et al./20/, Comay et al./21/, Stapathy and Nayak/22/, Tachibana et al./23/, Spanier and Johannson/24/, Janecke and Masson/25/, and Masson and Janecke/26/

with the experimental data of Wapstra et al./27/ was performed for all mass ranges using as criteria for suitability the chi-square, the largest different ratio between the values of mass formula and Wapstra mass, availability to predict mass values and binding energies necessary for ALICE-P calculations.

The mass formulas of Moller and Nix, and Moller et al. have larger chi-square values than the others. The small difference between the values of mass formula and Wapstra were given by Pape and Antony, Dussel et al., Comay et al., and Janecke and Masson. The results of the mass values near Bi, which are the isotopes necessary for ALICE-P calculation of proton induced reactions in a Bi-209 target, i.e. Z=76-84, 22 isotopes for each Z, are almost satisfied except for those masses of Pape and Antony. The calculated results of the binding energy distributions compared with those calculated from the Wapstra masses show the values of Pape and Antony, and Satpathy and Nayak are not acceptable. The mass formulas of Pape and Antony, Dussel et al., Moller and Nix, Spanier & Johannson, and Masson and Janecke are not acceptable since they can not predict all binding energies needed.

From the above discussion, the predicted values of Janecke and Masson is the best. Figure 1 shows the result of comparison of the ALICE-P calculation using default option (MC=0, MP=0), Janecke and Masson mass formula, and the Wapstra masses. The result of Janecke and Masson mass formula is closer to Wapstra's and it can reproduce the experimental data.

3. The Sensitivities of Parameters

ALICE-P has default options but a lot of options can be selected by users. However, it is difficult to decide what values are suitable to the individual problems. The case of the mass formula has been already considered and the most applicable set selected in chapter 2. Although the mass option was fixed, the other options in order to adjust or get the final values for evaluation still remains to be selected. Those are the level density formulation, parameter for level density, mean free path and exciton starting points, and comparison between systematics.

Firstly, the sensitivities of the above options and parameters were considerd by using the experimental data of neutron double differential cross section (DDX) and angular integrated neutron emission spectra (SDX) for Bi-209/28/ and Pb-208/35-40/. Since the results are predominantly a mass rather than an element effect/8/ it was not felt necessary to weight calculations for Pb-206, 207, and 208 by their isotopic abundances. The summary of these parameters are in Table 1. The considered parameters were level density parameter (a=A/PLD), and exciton starting points (TD, EX1, EX2) and the calculated multiplier of mean free path (1.0+COST) in ALICE-P. The formulations of level density, which were Fermi Gas Model, the method of Ramamurthy/31/ and Liquid Drop Model, was compared, and the difference of results calculated by ALICE-P, the systematics of Kalback-Mann/29,30/ (an ALICE option) and Pearlstein was examined.

The results of comparison between three methods for level density illustrate that the differences are very small, especially the results of the Ramamurthy's and the liquid drop are same in this case. The formulation of level density does not affect the results at least in the case of targets in the lead region and high proton incident energies. The comparison between three values of level density parameter (a=A/PLD) for three method, which are PLD=8.0, 9.0, and 10.0, was performed. The results are similar to each other. Although the calculated cross sections tend to have smaller gradient with smaller PLD, they have similar shapes and the difference is only a few percents. The calculations of DDX and SDX are not sensitive to the choice of level density parameter.

The effect of different initial exciton number (TD) is examined by using TD=3.0, 5.0 and 7.0. TD=3.0 is the default value of ALICE-P and means two particles and one hole state. The shape of cross section depends on the TD value and the gradient of curve is smaller while the TD value is smaller. The shape of TD=3.0 is the most suitable to experimental data. The examination of the dependence on neutron fraction to initial exciton number (EX1), which are 0.7, 0.82, and 0.9, while TD is equal to 3.0. EX1=0.82 is the ALICE-P default value. The larger value of EX1 gives larger neutron emission cross section. That is reasonable since EX1 is the fraction of neutrons. However, that difference is not very big.

For mean free path, the mean the correction factors to ALICE-P calculation for the calculated mean free path multiplier (1.0+COST) are chosen as COST=0.0, 0.5, and 1.0. In general, larger values of COST gives a flatter shape and this parameter influences the shape. The shape for COST=0.0 seems to be the best fit to experimental data.

The angular distributions using the systematics of Kalback-Mann and Pearlstein were compared with the ALICE-P calculation and experimental data in Figs. 2-9. The solid line is the ALICE-P calculations, and the dashed and dash-dotted lines are the systematics of Kalback-Mann and Pearlstein, respectively. As shown in Fig. 2, the results using the Kalback-Mann systematics have a similar overall shape compared to the ALICE-P calculation. The results of Pearlstein's systematics give much closer values to measured cross sections than the others except for some irregular peaks that are introduced. Figures 3 and 4 show the results of Ep=11.0 and 25.5 MeV, respectively, and the three calculated results do not reproduce the experimental data. Since the Pearlstein's systematics/8/ developed at energies above 100 MeV did not reproduce the data below 100 MeV, the systematics below that energy were modified to improve the agreement as shown in Figs. 5 and 6. As illustrated in Figs. 7-9 for Ep=318, 590 and 800 MeV, respectively, the Pearlstein's systematics can almost reproduce them during the other two calculations do not agree with them.

The similar study has been performed by comparing the results with the experimental data of isotope production cross sections for Bi-209/11,13-16, 32-34/. As the result of comparison between three methods for level density, the differences are small, except for the low energy region of (p,n) reaction. However, the Ramamurthy and liquid drop model give similar results even for the (p,pxn) reactions with large x values. The choice of level density does not affect the results of (p,xn) reactions, and the effect continues to (p,pxn) reactions with larger x values and probably higher multiplicity particle emission reactions. The results of comparison between three values of level density parameter (a=A/PLD) for three methods, which were selected as PLD=9.0, 8.0 and 10.0, show that they have similar shapes and the difference is only a few percents, although the calculates cross sections tend to have smaller gradient in smaller PLD. The isotope production cross section is not sensitive to level density parameter. The results for more particle emission give the rather big differences, about 5%.

The difference from initial exciton number (TD) is shown in Fig. 10. The solid, dashed and dash-dotted lines mean TD=3.0, 5.0 and 7.0, respectively. In the case of (p,xn) reaction cross section as shown in Fig. 10, larger TD values give sharper peaks and the values of cross sections decrease according to the energy increase rapidly. The peak values are smaller while the TD is smaller. In the case of (p,pxn), the situation is similar, except the peak values are larger with smaller TD with small x values. The shape of TD=3.0 is the most suitable to them. That means TD=3.0 is physically correct for the exciton starting point. Figure 11 show the dependence of neutron fraction to initial exciton number (EX1) while TD is equal to 3.0. The solid, dashed and dash- dotted lines are EX1=0.82, 0.90, and 0.70, respectively. The larger value of EX1 gives larger (p,xn) cross section and smaller (p,pxn) cross sections. That is reasonable since EX1 is the fraction of neutrons.

In general, a larger value of the calculated mean free path multiplier (1.0+COST) gives larger cross sections in the case of less particle emission and smaller in that of more particle emission. In the case of (p,pxn), the peak energy shifts with incleasing COST value, especially higher x values. This parameter affects to the shape and useful to change the fraction of isotope production cross sections, such as that of (p,xn) and (p,pxn) cross sections according to x value.

The results by using systematics of Kalback-Mann and Pearlstein were compared with the ALICE calculation. Three systematics give much close values of isotope production cross section.

4. The Study of Systematics for Fission Cross Section

The calculation of fission cross section by ALICE-P takes a lot of time, which is two order times without fission calculation. Researching experimental data of fission cross section for several isotopes at the energy range from 50 MeV to 9 GeV, and parameter search of fitting equations to reproduce the experimental data have been performed. For the fitting equation, the following was selected.

$$S = P(1)*[1-\exp\{-P(2)*(Ep-P(3))\}] \qquad (1)$$

where S is the fission cross section in mb, Ep is the proton energy in MeV, and P is the fitting parameter. In attaching pictorial meanings to the parameters in eq.(1), P(1) is the saturating cross-section, P(3) is the apparent threshold energy, and P(2) is the saturating rate. Experim ntal data which were very different from the average were omitted from the fitting calculation. The experimental data and the fitted results are summarized in Tables 2 and 3, for Pb-208 and Bi-209, respectively. The results for several isotopes are summerized in Table 4 by using the experimental data/41-55/.

Based on above parameterization, a study of creating systematics was carried out. For the parameters P(i), the following systematics was considered, since they are almost on the linear line as the function of Z**2/A in semi-log plot;

$$P(1) = Y*\exp[Q(1)*X+Q(2)] \qquad (2\text{-}1)$$
$$P(2) = Y*\exp[Q(3)*X+Q(4)] \qquad (2\text{-}2)$$
$$P(3) = Y*\exp[Q(5)*X+Q(6)]*1.E\text{-}3 \qquad (2\text{-}3)$$
$$X = Z**2/A \qquad (3)$$
$$Y = A**(2/3) \qquad (4)$$

where Q(i) are fitting parameters, Z is the atomic number, and A is the mass number. The factors X and Y physically mean proton form-factor and surface terms, respectively. For the systematics study, the weighting function was choosen unity (equal weight), since the result of parameters P(i) for each isotope was obtained from much different number of measurements and the parameter errors were not according to the number of measurements.

The fitted results of above parameters, except for W, were used for the systematics study of eqs.(2), since the result for W did not appear to be part of the same systematics. The result of systematics and chi-square per freedum are shown in Table 5, and the parameters calculated by systematics are shown in Tables 6-8. Figure 12 shows the systematics with the best fit parameters. In figures 13 and 14, the fission cross sections for Pb-208 and Bi-209 calculated by systematics are shown. The solid and dash-dotted lines are the calculated fission cross section by using the systematics of eqs.(2) and the best fit parameters, respectively. The systematics gives the good agreement with the experimental data below 1 GeV. The neutron induced fission was found to be about 1/2 proton induced fission in the case of Bi-209. Therefore, in generating the neutron library, the fission cross section was taken to be 1/2 the proton induced value. By using this systematics, the fission cross sections, for which there are no experimental data, can be obtaind below 1 GeV in this mass region. The formula is useful calculating the fission cross section easily and producing evaluation of nuclear data.

5. Calculated Results

Based on previous discussions, the nuclear data of Pb-208 and Bi-209 for proton and neutron insident reaction at the energy region 1.E-5 eV to 1000 MeV were calculated by using ALICE-P and systematics. For the neutron incident data, below 20 MeV, ENDF/B-VI data/56/ were used. For protons and for neutrons above 20 MeV, the total (for neutrons), elastic and reaction cross sections are calculated by the ALICE-P optical model/3/. Elastic scattering angular distributions are based on a diffraction model/57/ amended for relativistic effects and empirical fits to high energy data. Figures 15-51 show the calculated results that make up the final evaluation together with experimental data.

6. Conclusion

In the comparison of mass values calculated by ten mass formulas with the Wapstra mass, the values of Janecke and Masson have the best result. The ALICE-P calculation was performed by using these values. The sensitivites of parameters for level density, mean free path and exciton starting points were studied as well as level density formulatin and applicability of systematics of Kalback-Mann and Pearlstein were examined. The difference between the three methods calculating level density, which are the Fermi Gas Model, the method of Ramamurthy and the Liquid Drop Model, is small at least for targets in the lead region. The level density parameter (a=A/PLD) dose not affect to the results as long as using above three formulations. The results of using different exciton starting points (TD) affect both the shape and magnitude of DDX and SDX. The best starting exciton number is TD=3.0. The results are not sensitive to the fraction parameter of neutrons (EX1) and protons (EX2). The multiplication factor for mean free path (1.0+COST) affects to the shape of DDX and SDX. It seems that the default value, COST=0.0, gives the best result. The calculations using systematics of Pearlstein have good overall agreement with the magnitude and shape for the DDX and SDX experimental data.

The study of systematics for fission cross section in the region of 29 < (Z**2)/A < 33 have been performed. The systematics gives good agreement with the experimental data below 1 GeV. By using this systematics, the fission cross sections, which do not have experimental data, can be obtained below 1 GeV in this mass region. The formula is useful in calculating the fission cross section easily and producing evaluation of nuclear data.

Based on the above discussions, evaluated nuclear data files for Pb-208 and Bi-209 for proton and neutron insident reaction at the energy region 1.E-5 eV to 1000 MeV were calculated by using ALICE-P and systematics. The evaluated data are compiled in ENDF-6 format and are submitted for consideration for the ENDF/B-VI High Energy File.

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Table 1 The Summary of Examined Parameters

	LDOPT	PLD	TD	EX1	EX2	COST	IADST	ESYS
Level Density (Fermi Gas Model)								
	0*	9.0*	3.0*	0.82*	1.18*	0.0*	1*	250*
	0*	8.0	3.0*	0.82*	1.18*	0.0*	1*	250*
	0*	10.0	3.0*	0.82*	1.18*	0.0*	1*	250*
Level Density (Ramamurthy)								
	1	9.0*	3.0*	0.82*	1.18*	0.0*	1*	250*
	1	8.0	3.0*	0.82*	1.18*	0.0*	1*	250*
	1	10.0	3.0*	0.82*	1.18*	0.0*	1*	250*
Level Density (M-S Liquid Drop Model)								
	2	9.0*	3.0*	0.82*	1.18*	0.0*	1*	250*
	2	8.0	3.0*	0.82*	1.18*	0.0*	1*	250*
	2	10.0	3.0*	0.82*	1.18*	0.0*	1*	250*
Exciton Starting Points (TD=3.0)								
	0*	9.0*	3.0*	0.82*	1.18*	0.0*	1*	250*
	0*	9.0*	3.0*	0.90	1.10	0.0*	1*	250*
	0*	9.0*	3.0*	0.70	1.30	0.0*	1*	250*
Exciton Starting Points (TD=5.0)								
	0*	9.0*	5.0	1.20	1.80	0.0*	1*	250*
	0*	9.0*	5.0	1.10	1.90	0.0*	1*	250*
	0*	9.0*	5.0	1.30	1.70	0.0*	1*	250*
Excit on Starting Points (TD=7.0)								
	0*	9.0*	7.0	1.60	2.40	0.0*	1*	250*
	0*	9.0*	7.0	1.80	2.20	0.0*	1*	250*
	0*	9.0*	7.0	1.40	2.60	0.0*	1*	250*
Calculated Multiplier of Mean Free Path								
	0*	9.0*	3.0*	0.82*	1.18*	0.0*	1*	250*
	0*	9.0*	3.0*	0.82*	1.18*	0.5	1*	250*
	0*	9.0*	3.0*	0.82*	1.18*	1.0	1*	250*
Systematics								
ALICE-P	0*	9.0*	3.0*	0.82*	1.18*	0.0*	1*	900
Kalback-Mann	0*	9.0*	3.0*	0.82*	1.18*	0.0*	3	900
Pearlstein	0*	9.0*	3.0*	0.82*	1.18*	0.0*	1*	50

* ALICE-P and PEND6 default values. PEND6 is the compilation code from the calculated results of ALICE-P to ENDF-6 format.

LDOPT : the selection of the level density formula.
PLD : input valuable for level density parameter (a=A/PLD).
TD : exciton starting point.
EX1 : the fraction of neutron for particle exciton.
EX2 : the fraction of proton for particle exciton.
COST : the multiplication factor for the calculated mean free path (1.0+COST).
IADST : the selection of the systematics for particle emission spectra.
ESYS : the border energy to use Pearlstein's systematics. Above ESYS [MeV], Pearlstein's systematics is automatically choosen in the code PEND6.

Table 2 Experimental Data and Fitted Results for Pb-208

POINT	X	D	D-ERROR	ref.	FIT	FIT-ERROR
1	7.000E+01	1.380E+01	8.000E-01	41	1.439E+01	1.766E-02
2	1.000E+02	3.660E+01	1.600E+00	41	3.387E+01	3.743E-02
3	1.500E+02	4.600E+01	6.000E+00	45	5.985E+01	9.763E-02
4	1.550E+02	6.230E+01	2.600E+00	41	6.207E+01	7.769E-02
5	2.000E+02	7.550E+01	3.100E+00	41	7.945E+01	1.068E-01
6	2.800E+02	1.060E+02	1.100E+01	45	1.013E+02	1.284E-01
7	3.600E+02	1.000E+02	5.000E+01	45	1.152E+02	1.850E-01
8	3.900E+02	1.300E+02	1.500E+01	45	1.190E+02	1.548E-01
9	5.900E+02	1.440E+02	1.800E+01	46	1.330E+02	1.939E-01
10	6.000E+02	1.340E+02	1.800E+01	43	1.334E+02	2.104E-01
11	6.000E+02	1.440E+02	2.000E+01	52	1.334E+02	1.957E-01
12	6.600E+02	1.210E+02	2.000E+01	45	1.352E+02	2.444E-01
13	1.000E+03	1.320E+02	1.300E+01	51	1.390E+02	2.524E-01
14	1.000E+03	1.420E+02	1.400E+01	51	1.390E+02	2.347E-01
15	2.000E+03	1.390E+02	2.000E+01	52	1.397E+02	2.454E-01
16	2.900E+03	1.490E+02	2.300E+01	46	1.397E+02	2.289E-01
17	3.000E+03	1.350E+02	2.600E+01	52	1.397E+02	2.526E-01

VARIANCE = 8.63
CHISQUARE PER DEG OF FREEDOM= 0.922

Table 3 Experimental Data and Fitted Results for Bi-209

POINT	X	D	D-ERROR	ref.	FIT	FIT-ERROR
1	7.000E+01	5.190E+01	3.400E+00	41	5.522E+01	6.925E-01
2	1.000E+02	1.034E+02	6.500E+00	41	8.496E+01	7.461E-01
3	1.320E+02	1.250E+02	6.250E+01	42	1.111E+02	9.419E-01
4	1.400E+02	9.300E+01	4.650E+01	45	1.168E+02	1.360E+00
5	1.500E+02	1.030E+02	1.200E+01	45	1.236E+02	1.325E+00
6	1.540E+02	1.450E+02	7.250E+01	42	1.262E+02	9.665E-01
7	1.550E+02	1.364E+02	4.900E+00	41	1.268E+02	1.034E+00
8	1.580E+02	1.470E+02	7.350E+01	42	1.287E+02	9.772E-01
9	1.760E+02	1.570E+02	7.850E+01	42	1.393E+02	1.001E+00
10	1.820E+02	1.470E+02	7.350E+01	42	1.426E+02	1.095E+00
11	1.920E+02	1.470E+02	7.350E+01	42	1.478E+02	1.131E+00
12	2.000E+02	1.589E+02	6.900E+00	41	1.518E+02	1.069E+00
13	2.170E+02	1.730E+02	8.650E+01	42	1.595E+02	1.013E+00
14	2.320E+02	1.550E+02	7.750E+01	42	1.657E+02	1.148E+00
15	2.420E+02	1.500E+02	7.500E+01	44	1.695E+02	1.191E+00
16	2.520E+02	1.750E+02	8.750E+01	42	1.730E+02	1.021E+00
17	2.620E+02	1.900E+02	9.500E+01	42	1.764E+02	9.368E-01
18	2.800E+02	1.660E+02	1.100E+01	45	1.819E+02	1.056E+00
19	2.880E+02	2.020E+02	1.010E+02	42	1.841E+02	8.594E-01
20	3.020E+02	1.870E+02	9.350E+01	42	1.878E+02	9.086E-01
21	3.030E+02	1.600E+02	8.000E+01	44	1.881E+02	1.060E+00
22	3.360E+02	1.970E+02	9.850E+01	42	1.955E+02	8.027E-01
23	3.550E+02	1.600E+02	8.000E+01	44	1.992E+02	9.398E-01
24	3.730E+02	1.700E+02	8.500E+01	44	2.022E+02	8.383E-01
25	3.900E+02	1.700E+02	1.500E+01	45	2.048E+02	7.932E-01
26	4.270E+02	1.900E+02	9.500E+01	44	2.096E+02	6.203E-01
27	4.500E+02	2.000E+02	1.000E+01	44	2.121E+02	5.375E-01
28	4.500E+02	2.200E+02	1.100E+01	44	2.121E+02	4.886E-01
29	4.500E+02	2.100E+02	4.000E+01	46	2.121E+02	5.119E-01
30	4.800E+02	2.140E+02	2.000E+01	45	2.148E+02	4.417E-01
31	5.640E+02	2.190E+02	2.000E+01	45	2.201E+02	2.905E-01
32	5.900E+02	2.150E+02	1.075E+01	45	2.213E+02	2.604E-01
33	5.900E+02	2.170E+02	2.500E+01	46	2.213E+02	2.580E-01
34	6.000E+02	2.200E+02	3.000E+01	46	2.217E+02	2.050E-01
35	6.000E+02	2.160E+02	8.000E+00	47	2.217E+02	2.088E-01
36	6.600E+02	2.180E+02	2.000E+01	45	2.236E+02	1.609E-01
37	1.000E+03	2.900E+02	4.000E+01	46	2.273E+02	1.306E-01
38	1.000E+03	2.620E+02	5.000E+01	48	2.273E+02	1.445E-01
39	1.000E+03	2.900E+02	4.000E+01	49	2.273E+02	1.306E-01
40	2.000E+03	2.700E+02	4.000E+01	46	2.278E+02	1.445E-01
41	2.000E+03	2.550E+02	4.000E+01	48	2.278E+02	1.530E-01
42	2.000E+03	2.700E+02	4.000E+01	49	2.278E+02	1.445E-01
43	2.900E+03	2.270E+02	3.300E+01	46	2.278E+02	1.719E-01
44	3.000E+03	2.130E+02	4.000E+01	48	2.278E+02	1.832E-01
45	5.000E+03	2.800E+02	4.000E+01	46	2.278E+02	1.394E-01
46	5.000E+03	2.800E+02	4.000E+01	49	2.278E+02	1.394E-01
47	9.000E+03	2.700E+02	4.000E+01	46	2.278E+02	1.445E-01
48	9.000E+03	2.700E+02	4.000E+01	49	2.278E+02	1.445E-01

VARIANCE = 26.1
CHISQUARE PER DEG OF FREEDOM= 0.941

Table 4 The Summary of Fitted Parameters and their Corrilation

Isotopes	P(1)	P(2)	P(3)*1.E+3
Ta-181	24.5 +- 2.5		
	-0.31	190.0 +- 19.0	
	-0.75	-0.34	1.52 +- 0.01
W	66.1 +- 0.1		
	0.00	50.1 +- 4.6	
	-0.44	0.08	1.67 +- 0.04
Re	33.7 +- 1.1		
	0.12	140.0 +- 7.0	
	-0.66	0.16	1.51 +- 0.07
Pt	62.8 +- 0.1		
	0.15	94.4 +- 0.6	
	-0.53	0.30	2.44 +- 0.02
Au-197	83.0 +- 8.3		
	0.01	70.0 +- 7.0	
	-0.61	0.23	3.61 +- 0.03
Pb-206	141.0 +- 0.1		
	0.20	51.1 +- 0.2	
	-0.33	0.42	10.80 +- 0.07
Pb-207	134.0 +- 0.1		
	0.20	47.3 +- 0.1	
	-0.37	0.36	6.97 +- 0.05
Pb-208	145.0 +- 0.2		
	0.05	49.9 +- 0.1	
	-0.59	0.50	5.31 +- 0.01
Bi-209	217.0 +- 0.5		
	0.00	36.6 +- 1.2	
	-0.43	0.46	7.82 +- 0.13

Table 5 The Results of the Systematics Study

Parameters	Fitted results
Q(1)	5.75637E-01 +- 3.90613E-04
Q(2)	-1.72680E+01 +- 2.95076E-02
XI	9.99627E-01
Q(3)	-4.56190E-01 +- 7.05967E-03
Q(4)	1.52102E+01 +- 1.84684E-01
XI	1.35614E-01
Q(5)	5.49152E-01 +- 6.18542E-04
Q(6)	-1.94530E-01 +- 6.12872E-02
XI	1.22823E-02

NOTE : The corrilations between Q(1) and Q(2), Q(3) and Q(4), and Q(5) and Q(6) have values of 1.00.

Table 6 The Data and the Results for P(1) Calculated by Systematics

POINT	X	D	D-ERROR	FIT	FIT-ERROR
1	2.944E+01	2.450E+01	1.225E+00	2.323E+01	8.949E-01
2	3.024E+01	3.370E+01	1.100E+00	3.749E+01	1.708E+00
3	3.120E+01	6.280E+01	1.000E-01	6.717E+01	2.970E+00
4	3.168E+01	8.300E+01	4.150E+00	8.916E+01	3.978E+00
5	3.264E+01	1.410E+02	1.000E-01	1.597E+02	7.581E+00
6	3.248E+01	1.340E+02	1.000E-01	1.463E+02	6.685E+00
7	3.233E+01	1.450E+02	2.000E-01	1.341E+02	5.187E+00
8	3.296E+01	2.170E+02	5.000E-01	1.939E+02	7.289E+00

CHISQUARE PER DEG OF FREEDOM= 9.50E+03

Table 7 The Data and the Results for P(2) Calculated by Systematics

POINT	X	D	D-ERROR	FIT	FIT-ERROR
1	2.944E+01	1.900E+02	9.500E+00	1.896E+02	7.425E+01
2	3.024E+01	1.400E+02	7.000E+00	1.340E+02	5.106E+01
3	3.120E+01	9.440E+01	6.000E-01	8.934E+01	3.419E+01
4	3.168E+01	7.000E+01	3.500E+00	7.225E+01	3.040E+01
5	3.264E+01	5.110E+01	2.000E-01	4.803E+01	1.869E+01
6	3.248E+01	4.730E+01	1.000E-01	5.178E+01	2.341E+01
7	3.233E+01	4.990E+01	1.000E-01	5.578E+01	2.569E+01
8	3.296E+01	3.660E+01	1.200E+00	4.189E+01	1.996E+01

CHISQUARE PER DEG OF FREEDOM= 9.64E+02

Table 8 The Data and the Results for P(3)*1.E+3 Calculated by Systematics

POINT	X	D	D-ERROR	FIT	FIT-ERROR
1	2.944E+01	1.520E+00	1.000E-02	1.198E+00	7.397E-02
2	3.024E+01	1.510E+00	7.000E-02	1.893E+00	1.871E-01
3	3.120E+01	2.440E+00	2.000E-02	3.306E+00	3.560E-01
4	3.168E+01	3.610E+00	3.000E-02	4.334E+00	4.149E-01
5	3.264E+01	1.080E+01	7.000E-02	7.566E+00	4.261E-01
6	3.248E+01	6.970E+00	5.000E-02	6.961E+00	5.581E-01
7	3.233E+01	5.310E+00	1.000E-02	6.409E+00	6.203E-01
8	3.296E+01	7.820E+00	1.300E-01	9.112E+00	8.556E-01

CHISQUARE PER DEG OF FREEDOM= 2.97E+03

Table 9 Cross Reference of the Experimental Data in Figures

Figure Captions			Ref. No.	Figure Captions			Ref. No.
88	FRB	Fr	77	87	FEI	Bi	35
87	HAM	Ha	36	87	SAN	Mo	78
87	SWR	Ol	173	86	LAS	Me	39
86	SIU	Li	174	85	AE	Ol	175
84	KFK	Fi	40	84		Kh	54
84		Mc	59	84		DG	151
83	MRY	Ka	28	82		Se	74
82	OSA	Ta	191	82	LAS	Bu	192
82	LAS	Bu	193	81		Va	51
81		Va	60	81	AUW	La	143
81	OHO	We	14	81		Wa	152
80	ORL	La	79	80	BOS	Pa	120
80	BRC	Fr	150	80	ANL	Gu	154
80	BRC	Fr	194	80	KGU	Pr	202
79		Ra	61	78	NII	Mi	32
78	RI	Bo	50	78	DEB	Bo	203
78	TUD	Sc	176	78	PAD	Gi	155
77	UFT	Tu	156	77	IJI	Ko	177
77	HAM	Wi	195	77	LAS	Ve	196
76		Hu	48	76	JIA	Be	145
76	PAR	Ra	178	75		Ca	62
75	CNM	Ma	157	75	ORL	Ha	158
75	KTY	Br	179	75	ELU	De	197
74	NII	Mi	13	74		Va	63
74	NBS	Sc	80	73	RI	By	41
73	BET	Gr	81	73	BET	Gr	82
73	PTN	Sc	83	73	PAD	Dr	159
72		Br	46	72		Re	64
72	CCP	Ma	146	72	GIT	Ha	147
72		Bo	153	72	AMS	Ku	160
71	MIL	Bi	14	71		Re	52
71		Me	65	71	BNW	Fo	84
71	KOS	An	85	70		Me	75
70	ANL	Sm	161	69		Hu	47
69		Me	66	69	OAU	Ro	86
69	ORL	Mi	87	69	AE	Ho	180
68		Ma	49	68	USA	Sc	88
68	FRK	Ba	148	68	KFK	Ci	162
67	PAR	Be	11	67		Th	58
67	ANL	Ha	89	67	WIS	Ca	90
67	BOS	Ch	121	67	FTI	Du	163

Table 9 (Continued)

Figure Captions			Ref. No.	Figure Captions			Ref. No.
67	KUR	Go	164	67	MUN	Fe	198
66		Ko	45	66		Ki	67
66	CSE	Ga	91	66	MIT	Be	122
65		Po	68	65	CCP	De	123
65	JNE	Ma	165	65	LAS	Da	166
65	DKE	Wi	181	65	FEI	Ka	182
64	TCP	Da	12	64	CHI	Pi	15
64		Tu	69	64	KUR	Go	183
63		Wi	70	63	LSU	Ha	92
62	ANL	Wi	33	62	BOS	Mi	93
62	VIR	Hu	184	61	HAR	Bo	94
61	CCP	De	124	60		Me	71
60	LRL	Pe	95	60	CRC	Cr	185
59	COL	Hu	34	59		Go	72
59	RIC	Bo	125	59	TNC	Bo	186
58	COL	We	96	58	LAS	Co	97
58	LRL	Br	98	58	LVN	Ve	99
58	CCP	Le	126	58	LRL	Ma	127
58	LVN	De	167	58	LRL	Ba	189
58	CCP	Fl	199	58	LRL	As	200
57	LVP	As	100	57	IFU	St	128
57	LRL	Ma	129	57	FEI	Po	187
57	LAS	Ro	190	57	LAS	Ro	201
56	AEC	Be	16	56		St	42
56		Cu	76	56	ICP	Kh	101
56	FEI	Po	130	56	HAR	Mo	131
56	IFU	St	132	56	KUR	Fl	133
56	LAS	Be	134	56	OXF	Vo	135
55		Jo	44	55	DUB	Dz	102
55	HRV	Cu	103	55	IFU	Pa	136
55	LAS	Wa	137	55	LAS	Be	138
55	LAS	Gr	139	55	LAS	Al	140
55	RIC	Ta	141	55	NRL	Mc	168
55	CCP	Go	204	54	HRV	Hi	104
54	BAR	Sn	169	54	WIS	Wa	188
53	HAR	Ta	105	53	LAS	Ne	106
53	LAS	Da	107	53	ROM	Ag	108
53	CRC	Pa	149	53	BRK	Li	170
52	ANL	Go	109	52	LAS	Co	110
52	LAS	Ph	142	52	WIS	Mi	171
51	BRK	De	111	51	CAR	La	112
51	CAV	St	113	50		Ju	43
50	BRK	Hi	114	50	BRK	De	115
50	BRK	Fo	116	50	BRK	De	117
50	BRK	Br	118	49	BRK	Co	119
48	WIS	Ba	172				

FIGURE CAPTIONS

Fig. 1 Calculated results using ALICE-P mass option (MC=0, MP=0), mass formula of Janecke and Masson, and Wapstra mass comparing with the experimental data for Bi-209 (p,2n) reaction.

Fig. 2 Difference between the ALICE-P calculation and the two systematics comparing with the experimental data of DDX at 90 MeV and 20 deg. for Bi-209.

Fig. 3 Difference between the ALICE-P calculation and the two systematics comparing with the experimental data of SDX at 11 MeV for natural lead.

Fig. 4 Difference between the ALICE-P calculation and the two systematics comparing with the experimental data of SDX at 25 MeV for natural lead.

Fig. 5 Calculated results using improved Pearlstein's systematics comparing with the experimental data of SDX at 11 MeV for natural lead.

Fig. 6 Calculated results using improved Pearlstein's systematics comparing with the experimental data of SDX at 25 MeV for natural lead.

Fig. 7 Difference between the ALICE-P calculation and the two systematics comparing with the experimental data of DDX at 318 MeV and 7.5 deg. for natural lead.

Fig. 8 Difference between the ALICE-P calculation and the two systematics comparing with the experimental data of DDX at 590 MeV and 90 deg. for natural lead.

Fig. 9 Difference between the ALICE-P calculation and the two systematics comparing with the experimental data of DDX at 800 MeV and 30 deg. for natural lead.

Fig. 10 Difference between the exciton starting points comparing with the experimental data of Bi-209 (p,3n) reaction.

Fig. 11 Difference between the neutron fraction for the exciton starting points comparing with the experimental data of Bi-209 (p,3n) reaction.

Fig. 12 Fitted results for parameters of fission cross section.

Fig. 13 Calculated results for Pb-208 fission cross section using the systematics.

Fig. 14 Calculated results for Bi-209 fission cross section using the systematics.

Fig. 15 Evaluated result for Pb-208 (p,2n) cross section.

Fig. 16 Evaluated result for Pb-208 (p,3n) cross section.

Fig. 17 Evaluated result for Pb-208 (p,4n) cross section.

Fig. 18 Evaluated result for Pb-208 (p,non) cross section.

Fig. 44 Evaluated result for Pb-208 DDX of neutron at 25 MeV and 105 deg.

Fig. 45 Evaluated result for Pb-208 DDX of neutron at 25 MeV and 150 deg.

Fig. 46 Evaluated result for Pb-208 SDX of neutron at 25 MeV.

Fig. 47 Evaluated result for Pb-208 DDX of neutron at 318 MeV and 7.5 deg.

Fig. 48 Evaluated result for Pb-208 DDX of neutron at 590 MeV and 30 deg.

Fig. 49 Evaluated result for Pb-208 DDX of neutron at 590 MeV and 90 deg.

Fig. 50 Evaluated result for Pb-208 DDX of neutron at 590 MeV and 150 deg.

Fig. 51 Evaluated result for Pb-208 DDX of neutron at 800 MeV and 30 deg.

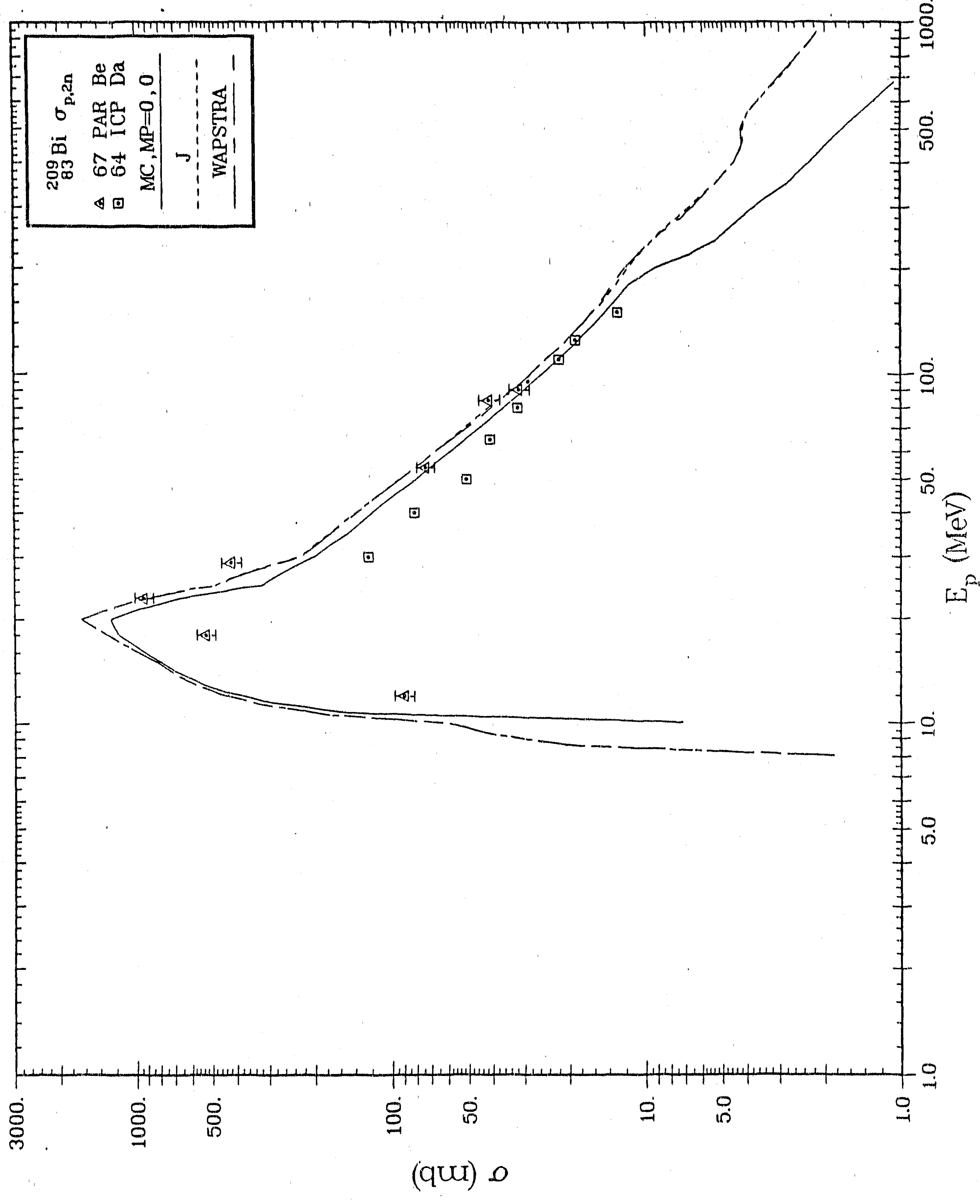
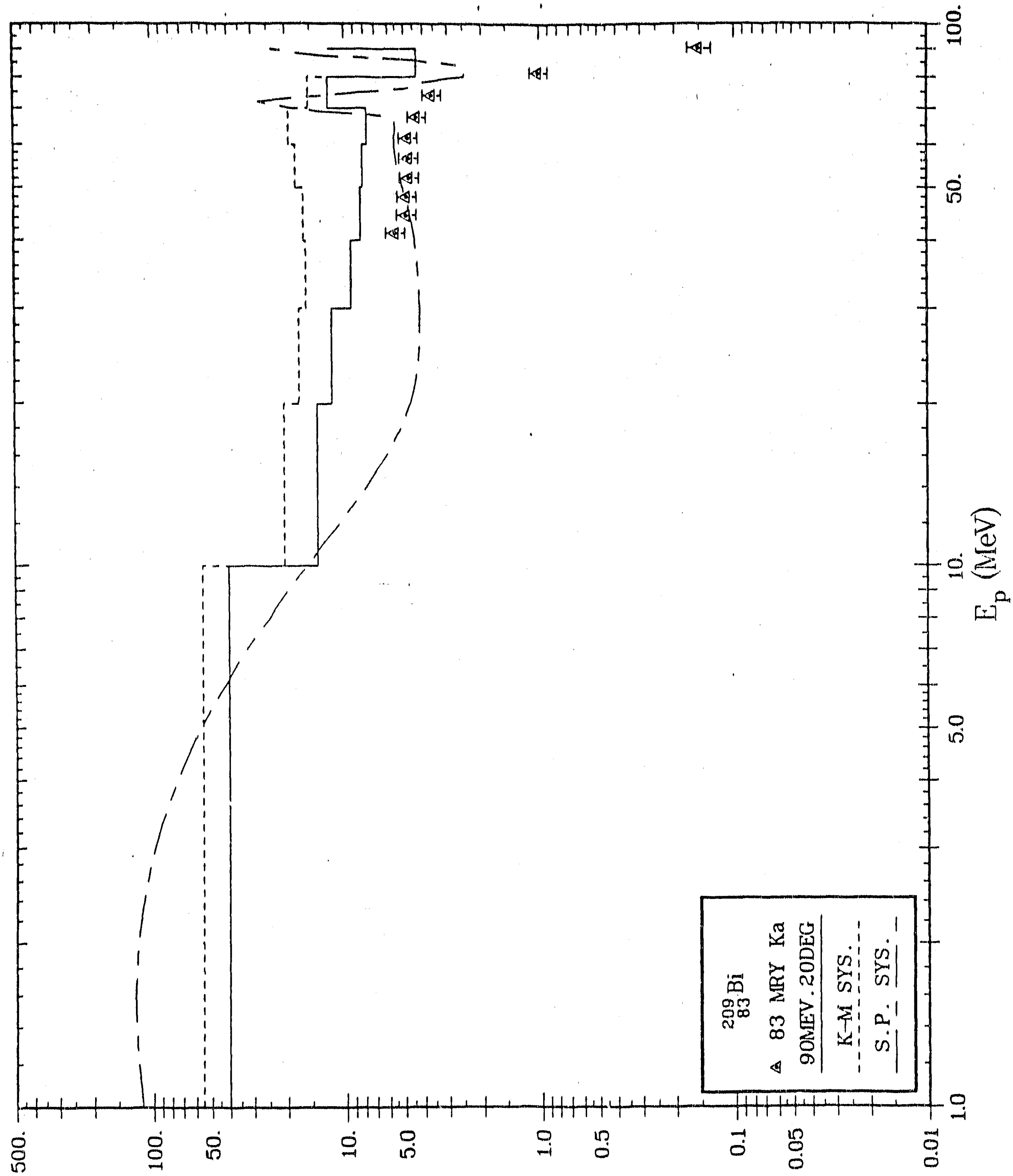
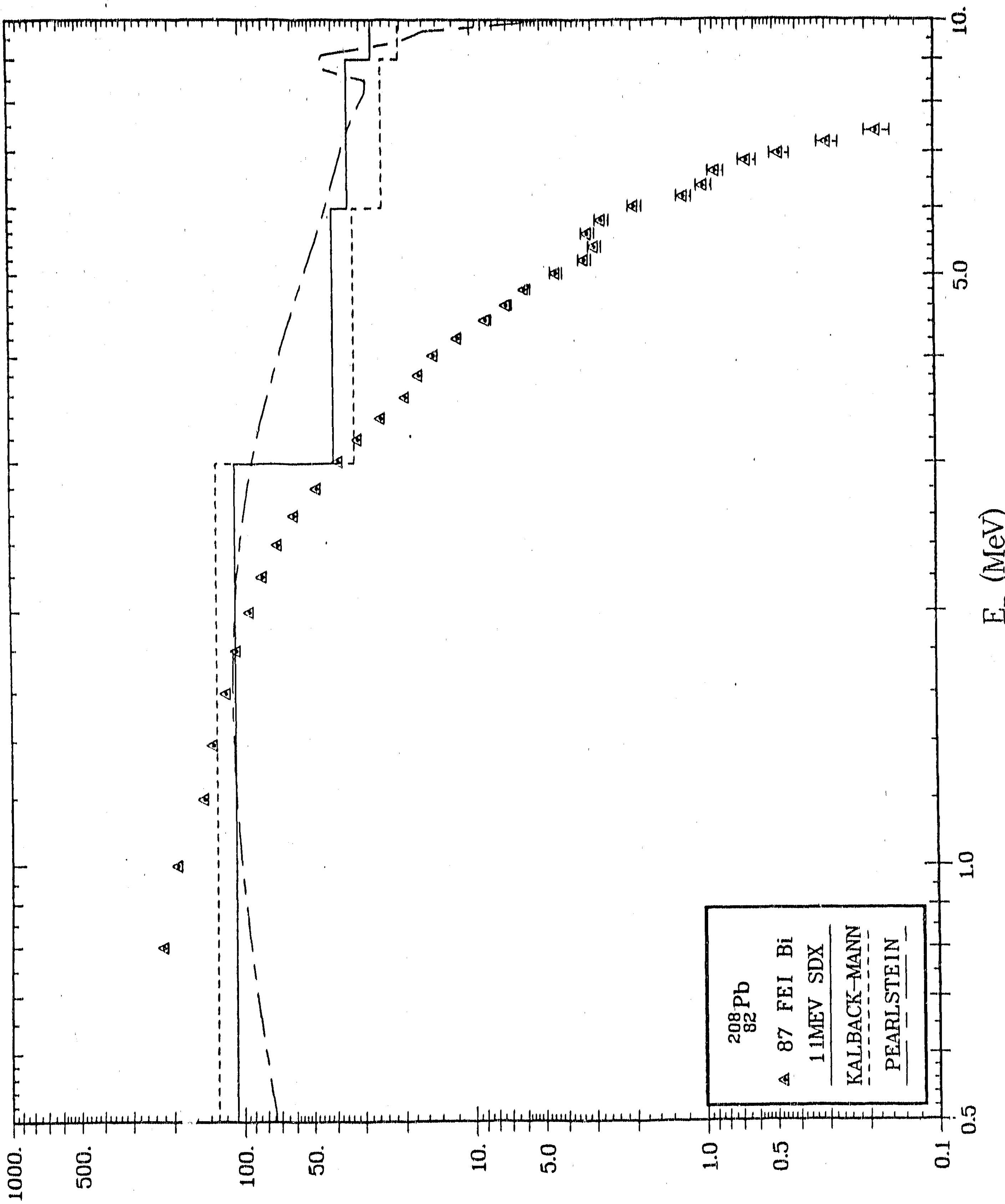


Fig. 1



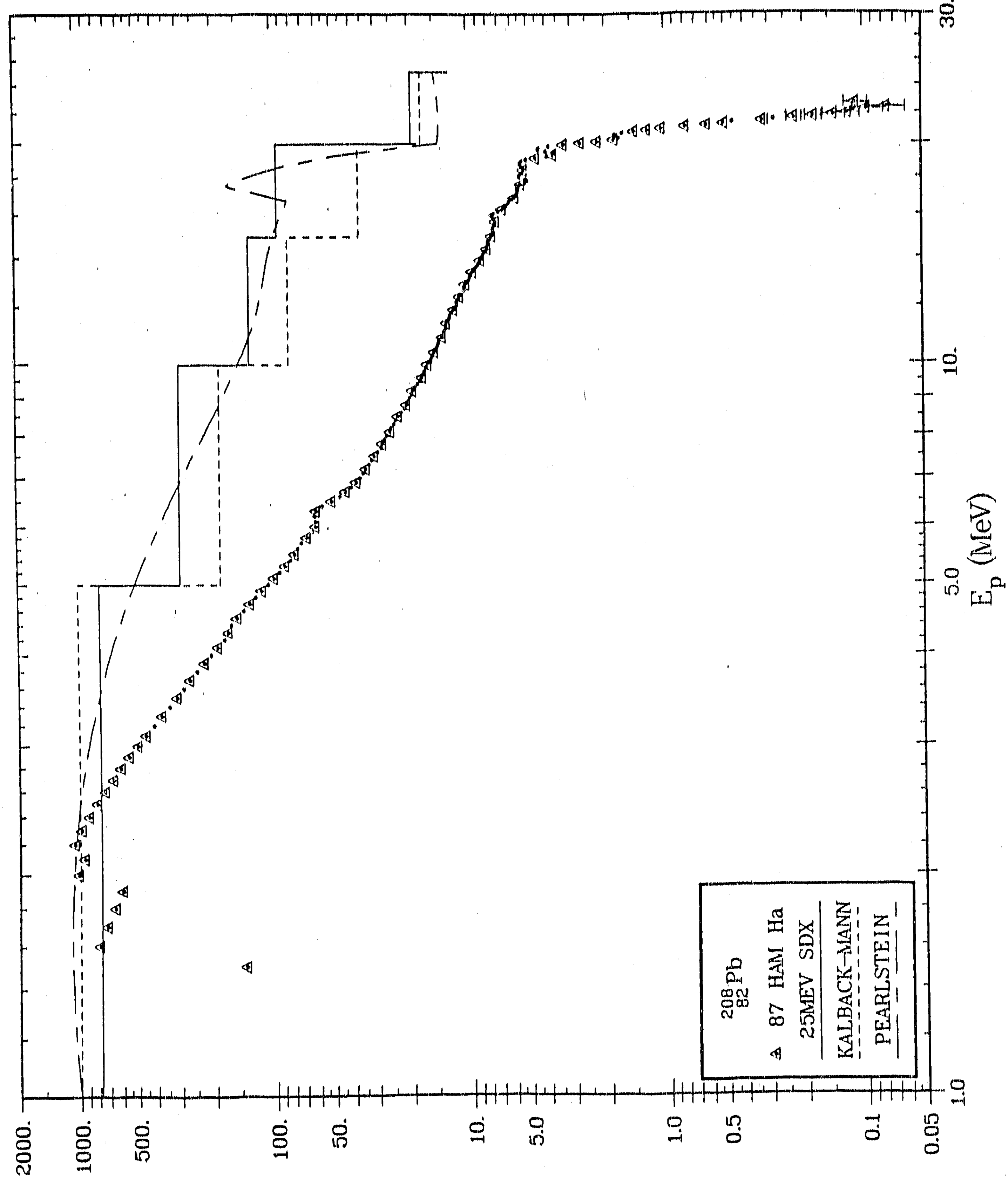
$^{209}_{83}$Bi
83 MRY Ka
90MEV.20DEG
K–M SYS.
S.P. SYS.
E$_p$ (MeV)
1.0
5.0
10.
50.
100.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01

Fig. 2



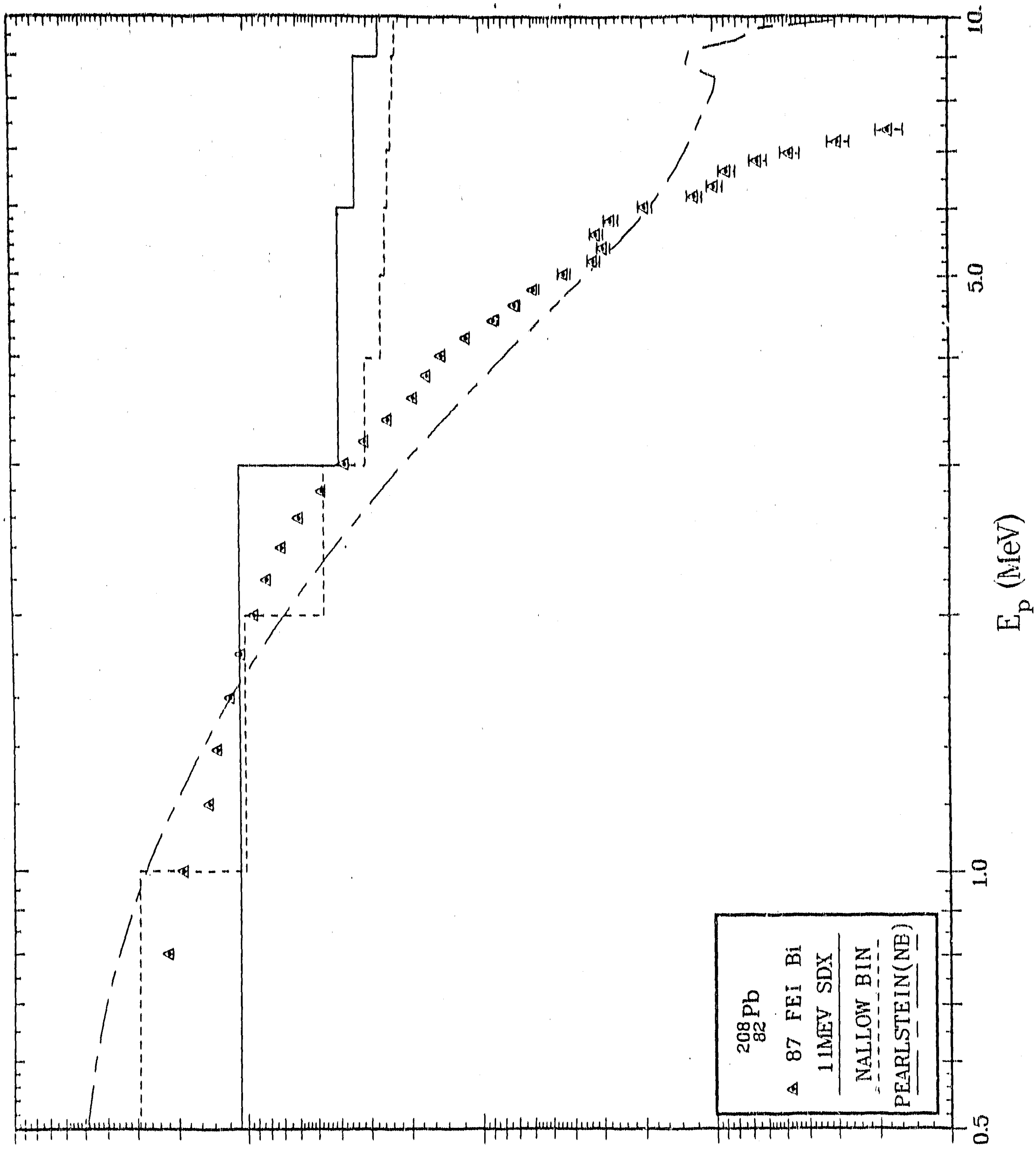
$^{208}_{82}Pb$
87 FEI Bi
11MEV SDX
KALBACK-MANN
PEARLSTEIN
E_p (MeV)
1000.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.5
1.0
5.0
10.

Fig. 3



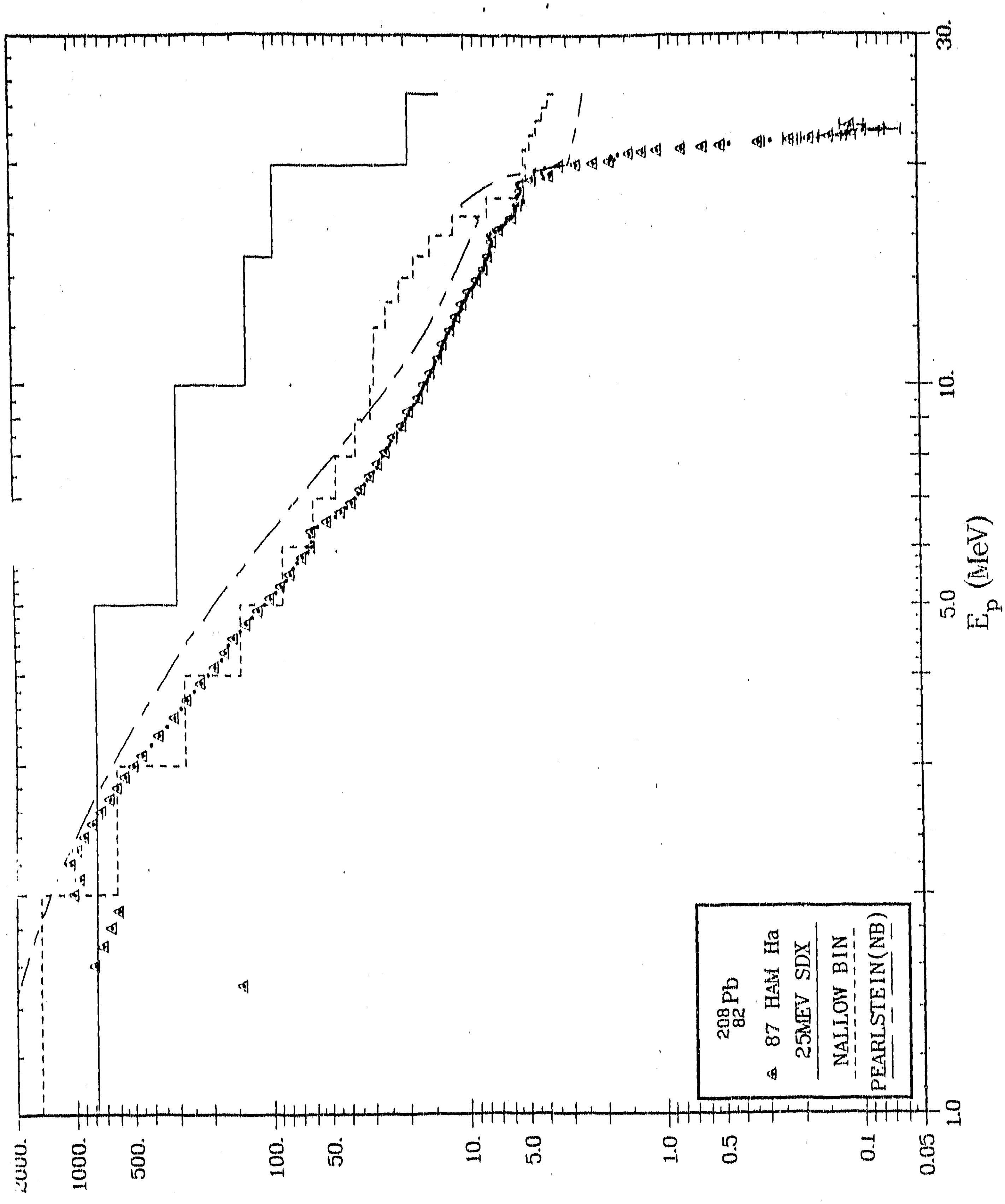
2000.
1000.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
1.0
5.0
10.
30.
E_p (MeV)
$^{208}_{82}Pb$
87 HAM Ha
25MEV SDX
KALBACK-MANN
PEARLSTEIN

Fig. 4



208 82 Pb
87 FEI Bi
11MEV SDX
NALLOW BIN
PEARLSTEIN(NE)
E_p (MeV)
0.5
1.0
5.0
10.
1000.
500.
100.
50.
10.
5.0
1.0
0.5
0.1

Fig. 5



$^{208}_{82}Pb$
87 HAM Ha
25MEV SDX
NALLOW BIN
PEARLSTEIN(NB)
E_p (MeV)
1.0
5.0
10.
30.
1000.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05

Fig. 6

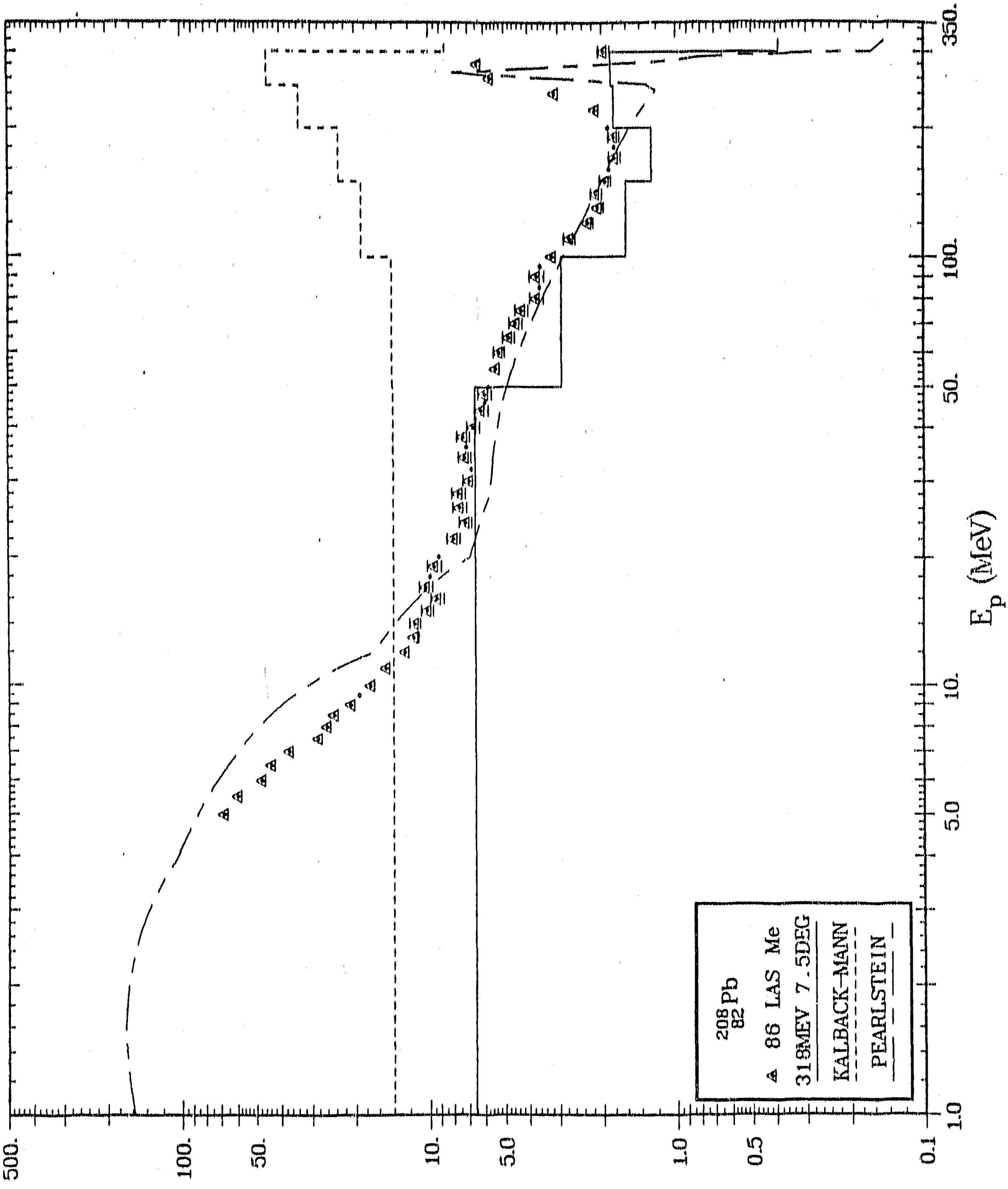

500.
100.
50.
10.
5.0
1.0
0.5
0.1
1.0
5.0
10.
50.
100.
350.
E_p (MeV)
208 82 Pb
86 LAS Me
318MEV 7.5DEG
KALBACK–MANN
PEARLSTEIN

Fig. 7

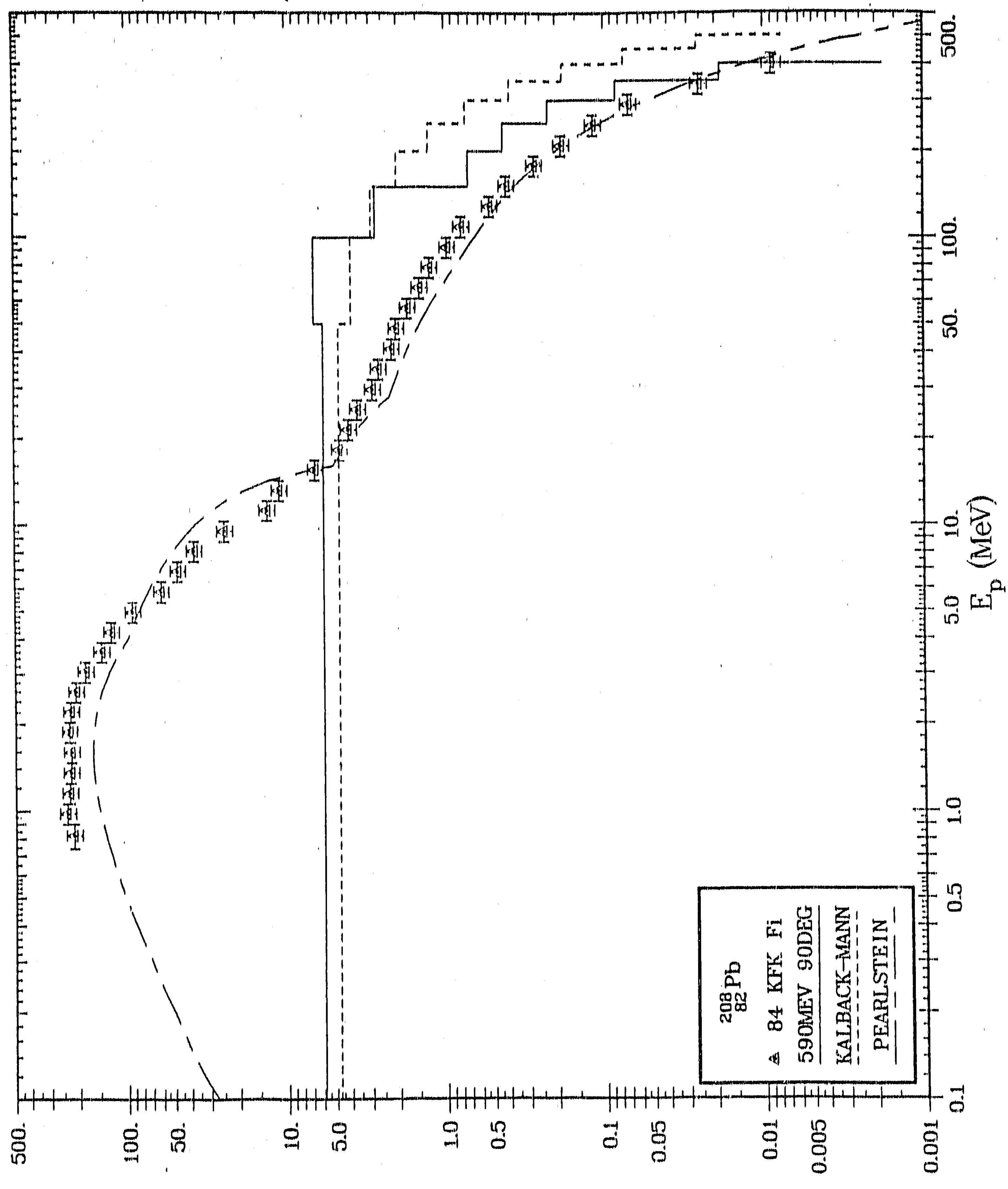
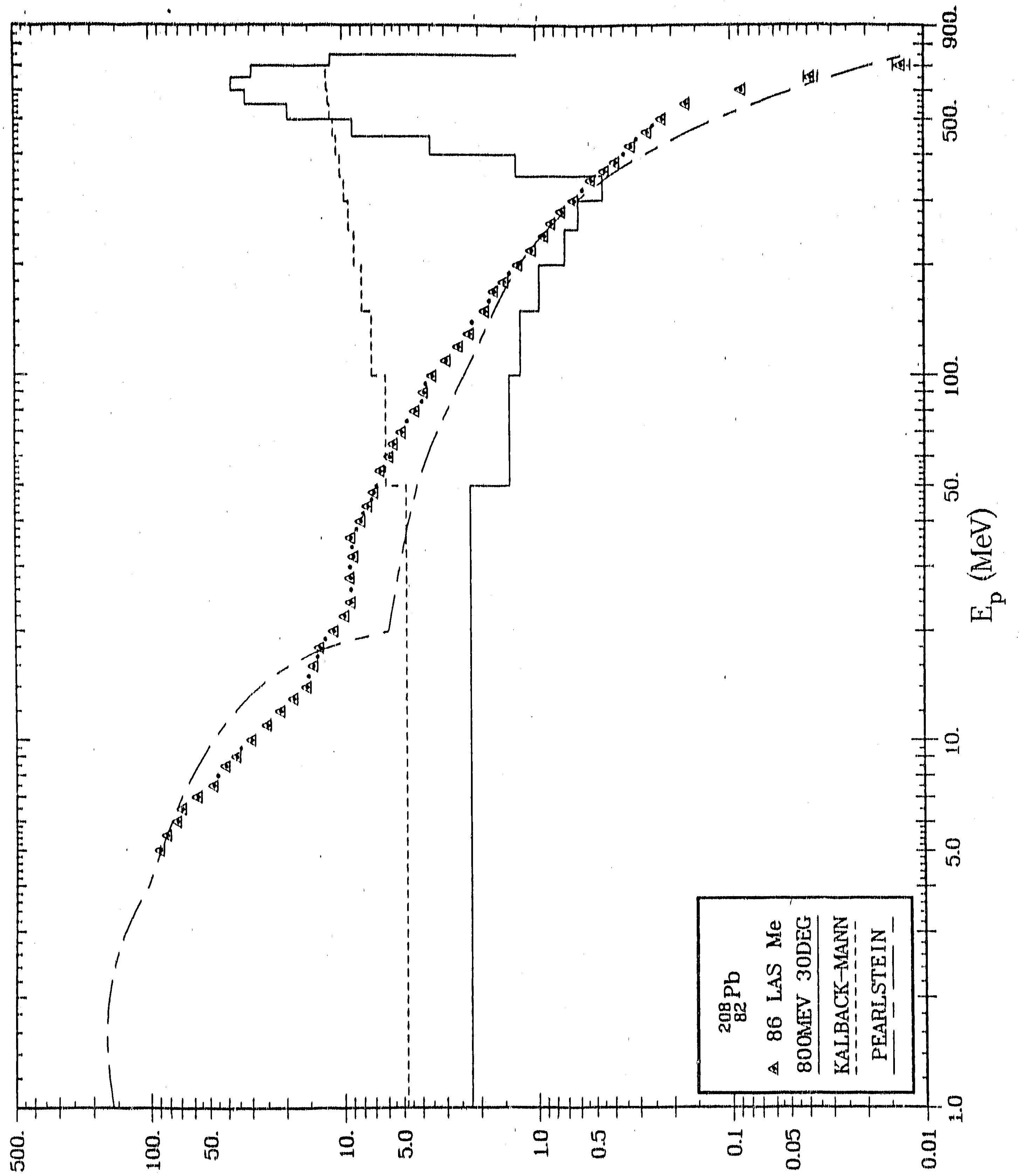
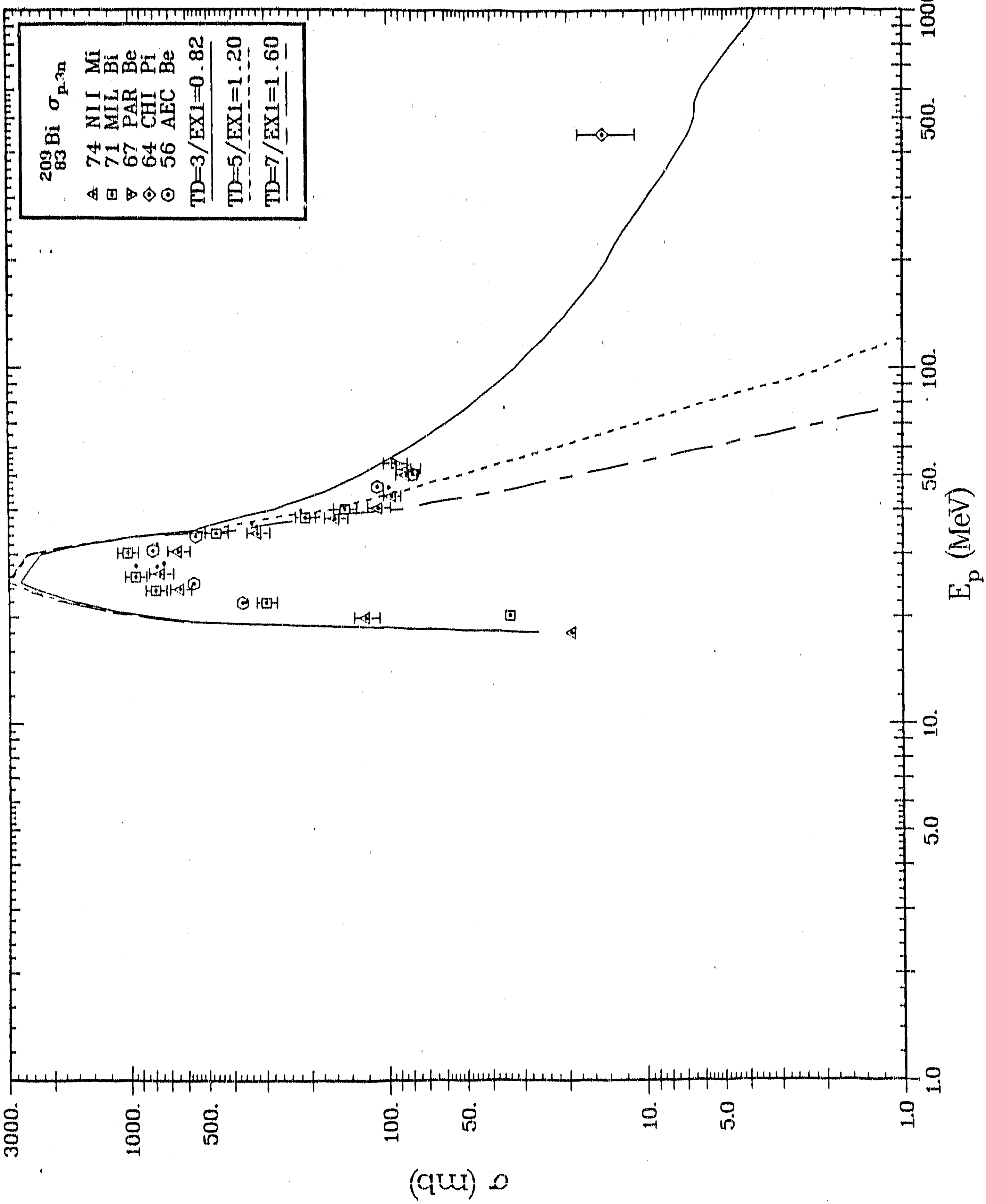

208 82 Pb
84 KFK Fi
590MEV 90DEG
KALBACK-MANN
PEARLSTEIN
E p (MeV)
0.1
0.5
1.0
5.0
10.
50.
100.
500.
0.001
0.005
0.01
0.05
0.1
0.5
1.0
5.0
10.
50.
100.
500.

Fig. 8



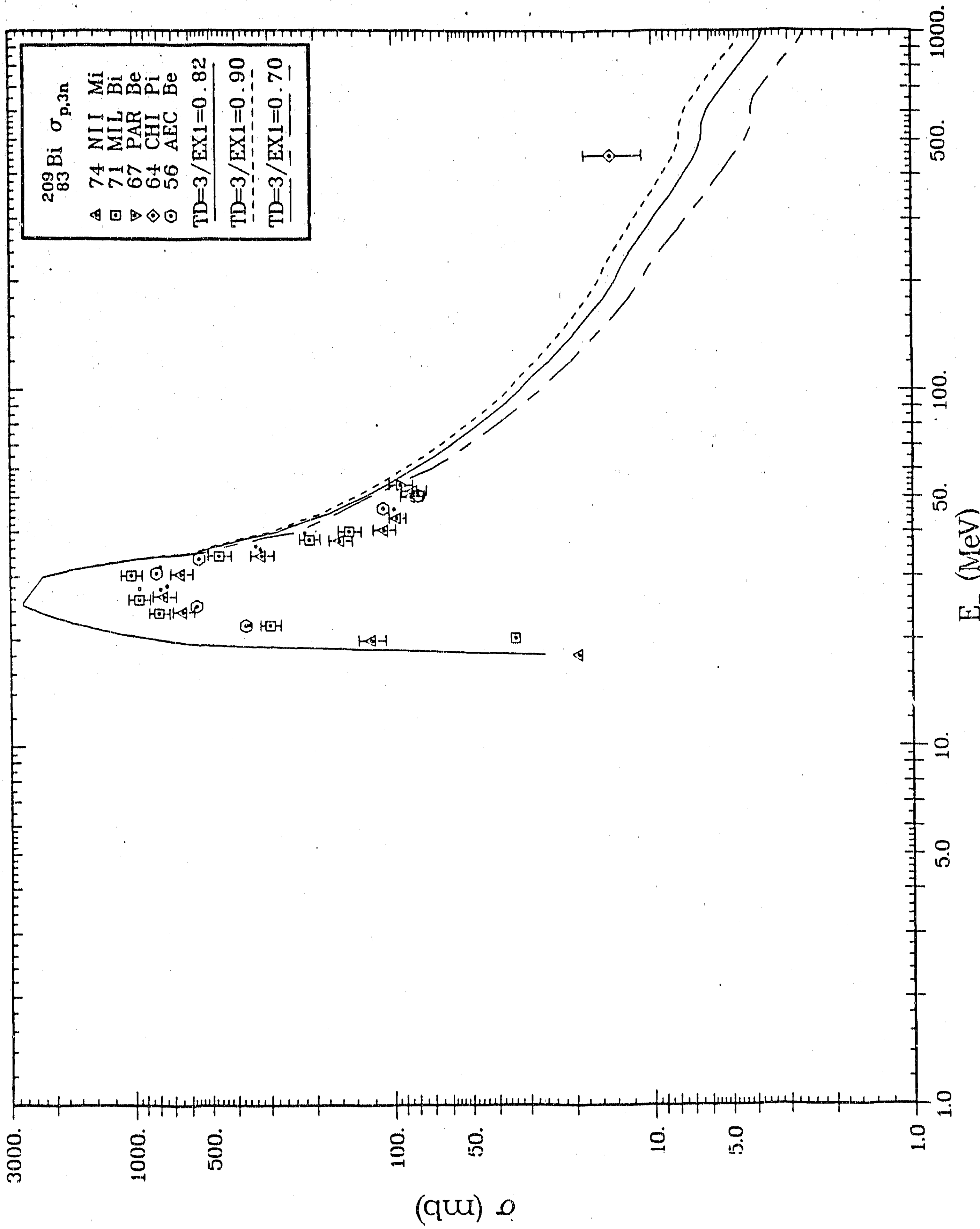
$^{208}_{82}$Pb
86 LAS Me
800MEV 30DEG
KALBACK-MANN
PEARLSTEIN
E_p (MeV)
1.0
5.0
10.
50.
100.
500.
900.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01

Fig. 9



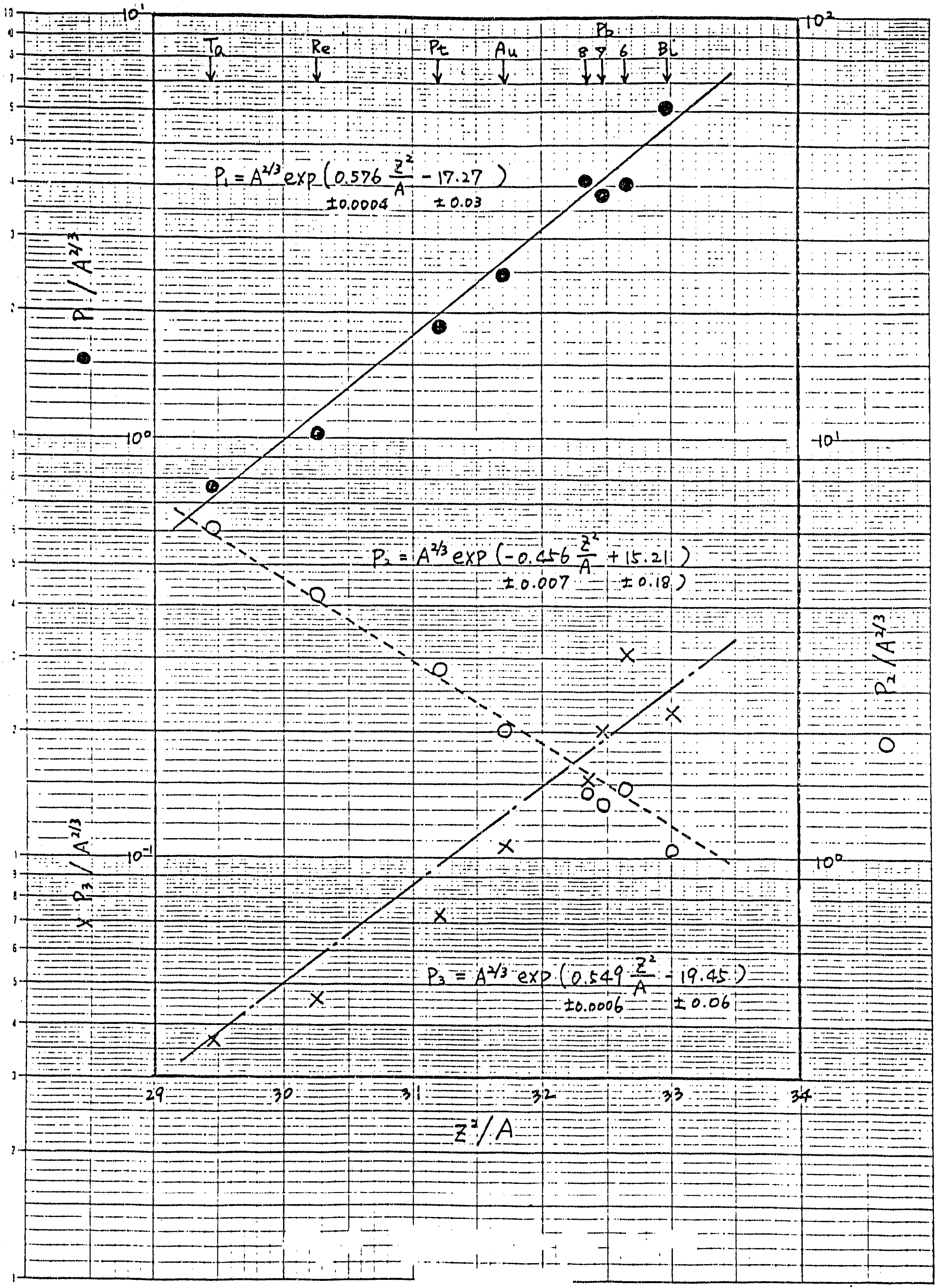
$^{209}_{83}$Bi $\sigma_{p,3n}$
74 NII Mi
71 MIL Bi
67 PAR Be
64 CHI Pi
56 AEC Be
TD=3/EX1=0.82
TD=5/EX1=1.20
TD=7/EX1=1.60
E_p (MeV)
σ (mb)
3000.
1000.
500.
100.
50.
10.
5.0
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 10



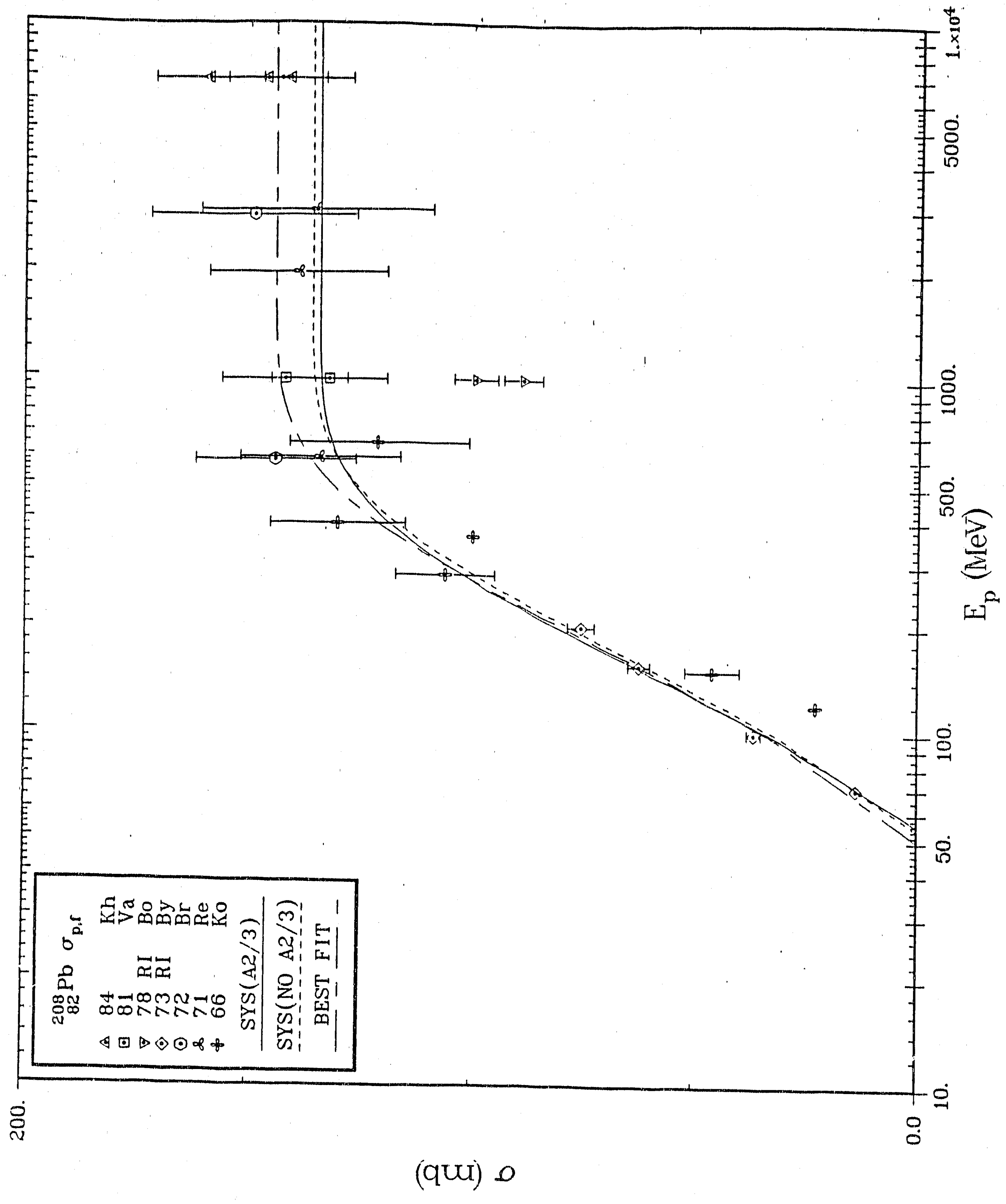
209 83 Bi σ p,3n
74 NII Mi
71 MIL Bi
67 PAR Be
64 CHI Pi
56 AEC Be
TD=3/EX1=0.82
TD=3/EX1=0.90
TD=3/EX1=0.70
σ (mb)
E p (MeV)

Fig. 11



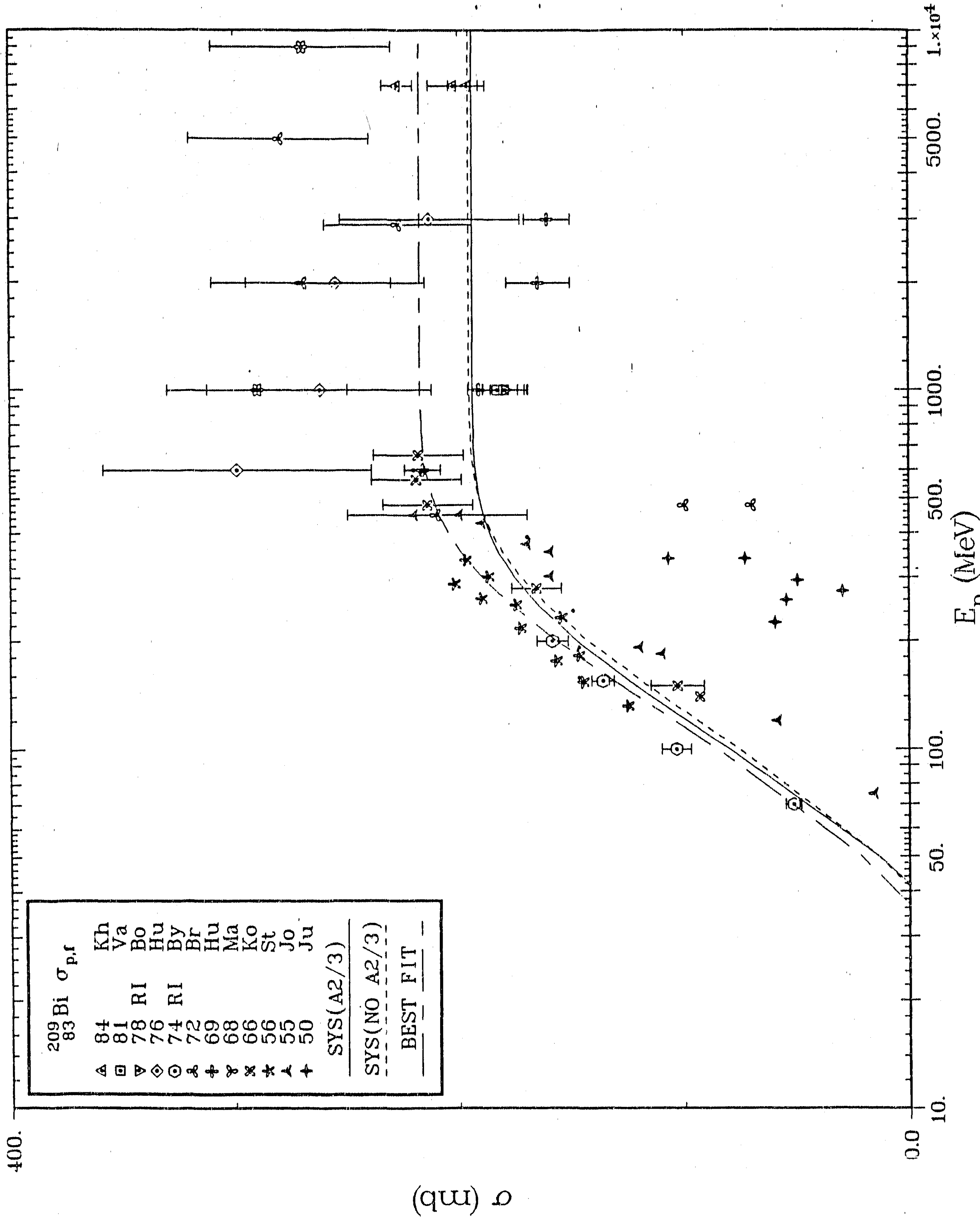
Ta
Re
Pt
Au
Pb
8 7 6
Bi
$P_1 = A^{2/3} \exp(0.576 \frac{Z^2}{A} - 17.27)$
±0.0004 ±0.03
$P_2 = A^{2/3} \exp(-0.456 \frac{Z^2}{A} + 15.21)$
±0.007 ±0.18
$P_3 = A^{2/3} \exp(0.549 \frac{Z^2}{A} - 19.45)$
±0.0006 ±0.06
● $P_1 / A^{2/3}$
O $P_2 / A^{2/3}$
× $P_3 / A^{2/3}$
10^1
10^0
10^{-1}
10^2
10^1
10^0
29
30
31
32
33
34
Z^2/A

Fig. 12



$^{208}_{82}$Pb $\sigma_{p,f}$
84 Kh
81 Va
78 RI Bo
73 RI By
72 Br
71 Re
66 Ko
SYS(A2/3)
SYS(NO A2/3)
BEST FIT
200.
0.0
σ (mb)
10.
50.
100.
500.
1000.
5000.
1.x10^4
E$_p$ (MeV)

Fig. 13



209 83 Bi σ p,f
84 Kh
81 Va
78 RI Bo
76 Hu
74 RI By
72 Br
69 Hu
68 Ma
66 Ko
56 St
55 Jo
50 Ju
SYS(A2/3)
SYS(NO A2/3)
BEST FIT
10.
50.
100.
500.
1000.
5000.
1.×10⁴
E p (MeV)
0.0
400.
σ (mb)

Fig. 14

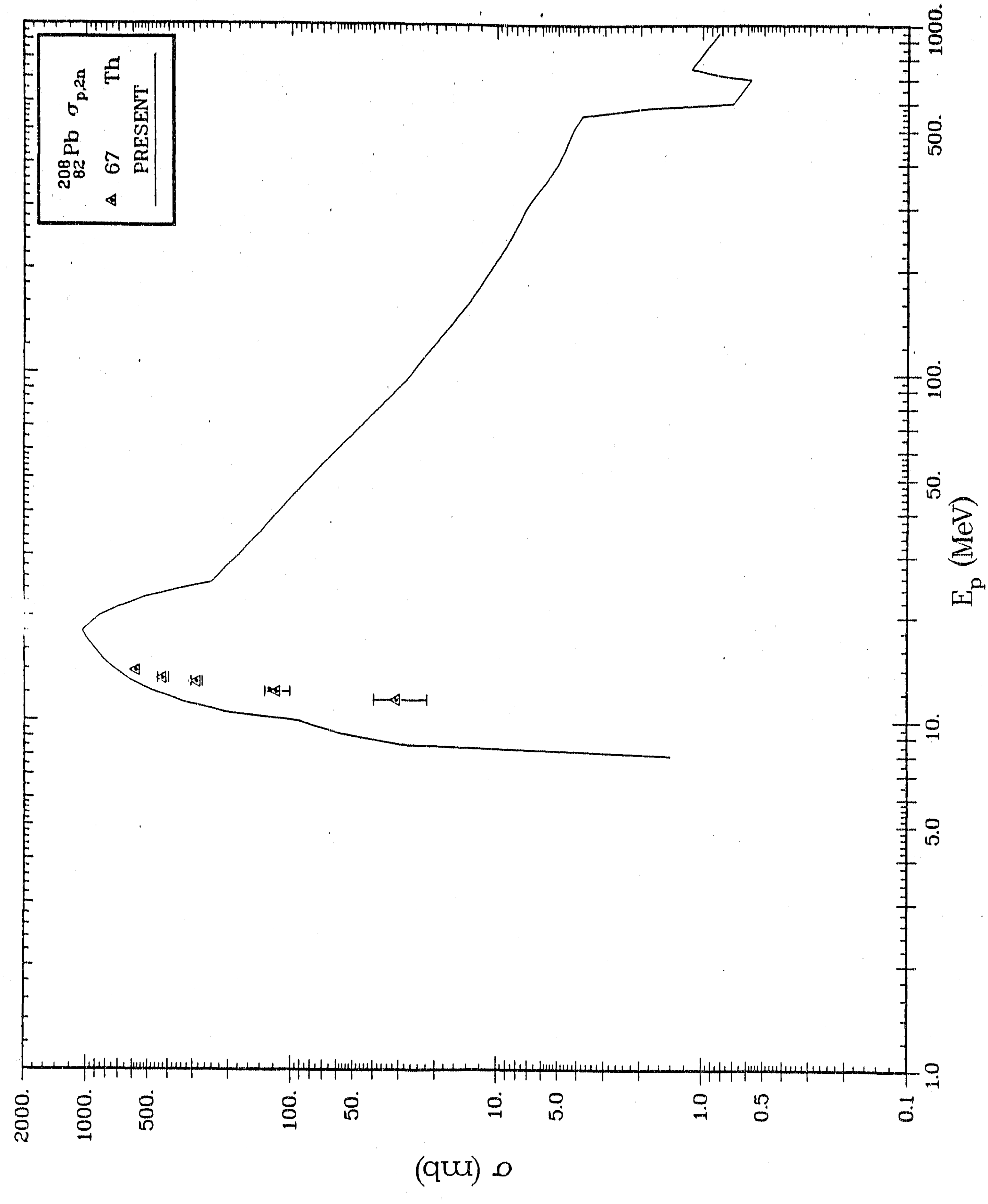

$^{208}_{82}$Pb $\sigma_{p,2n}$
67
Th
PRESENT
E_p (MeV)
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
2000.
0.1
0.5

Fig. 15

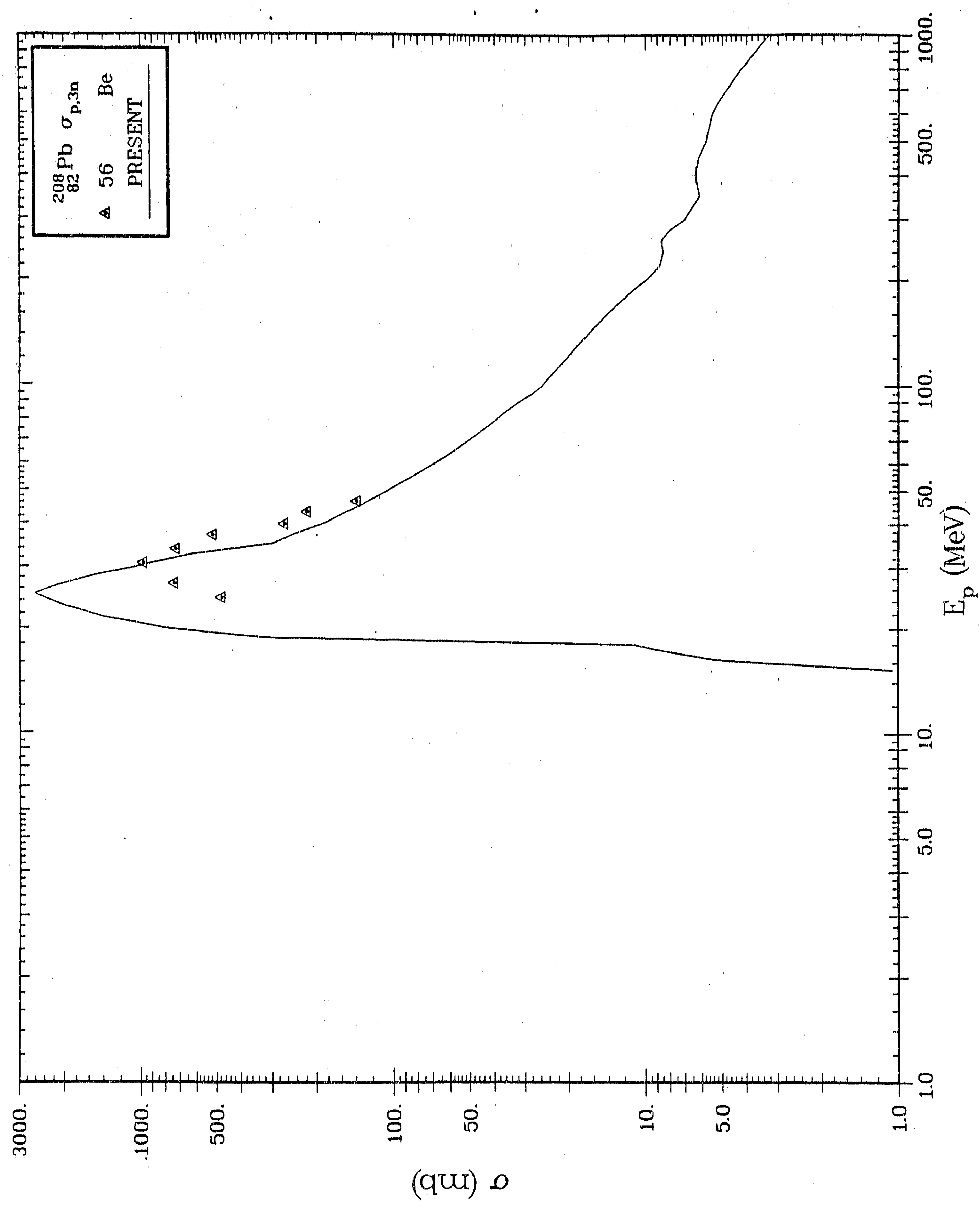
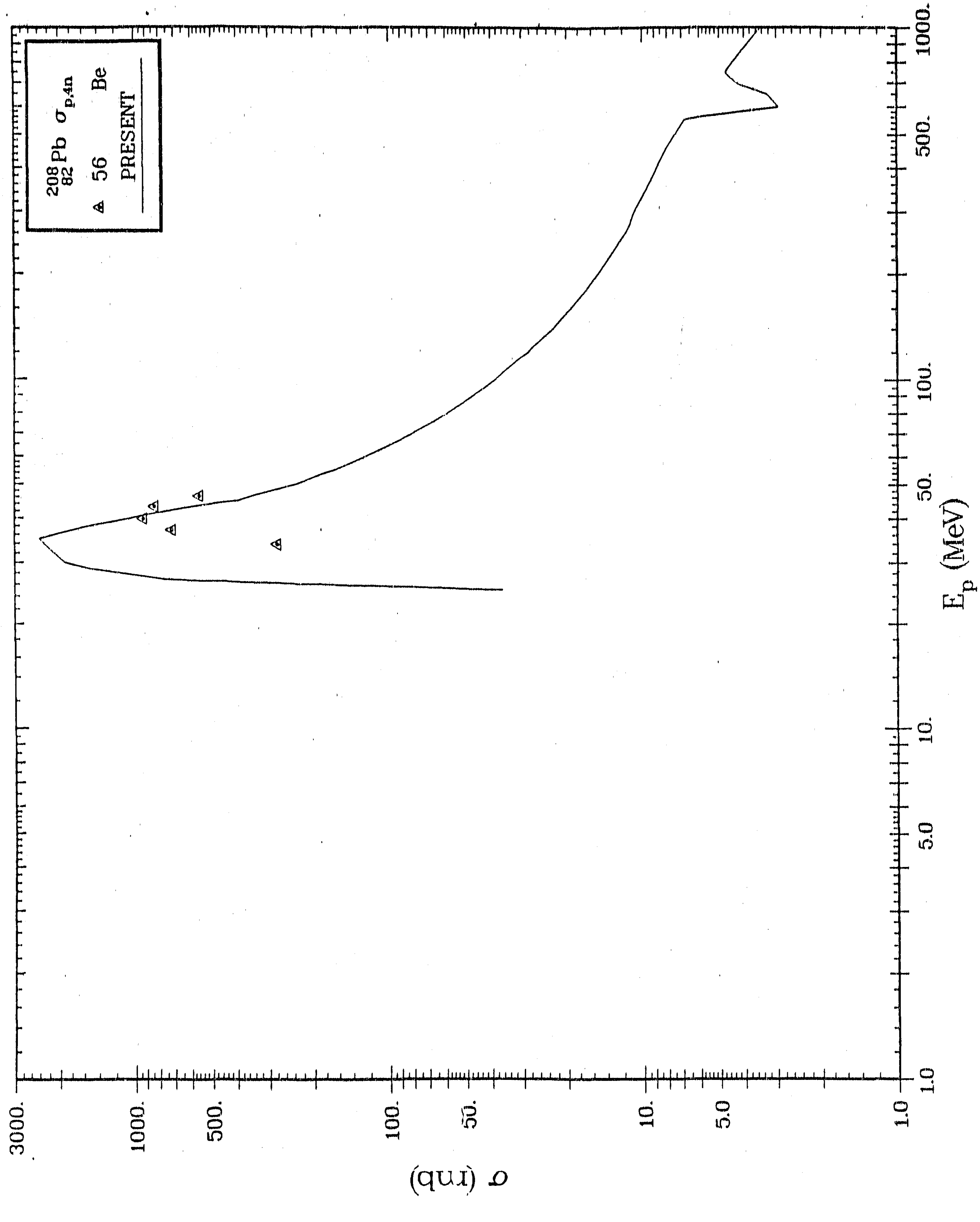
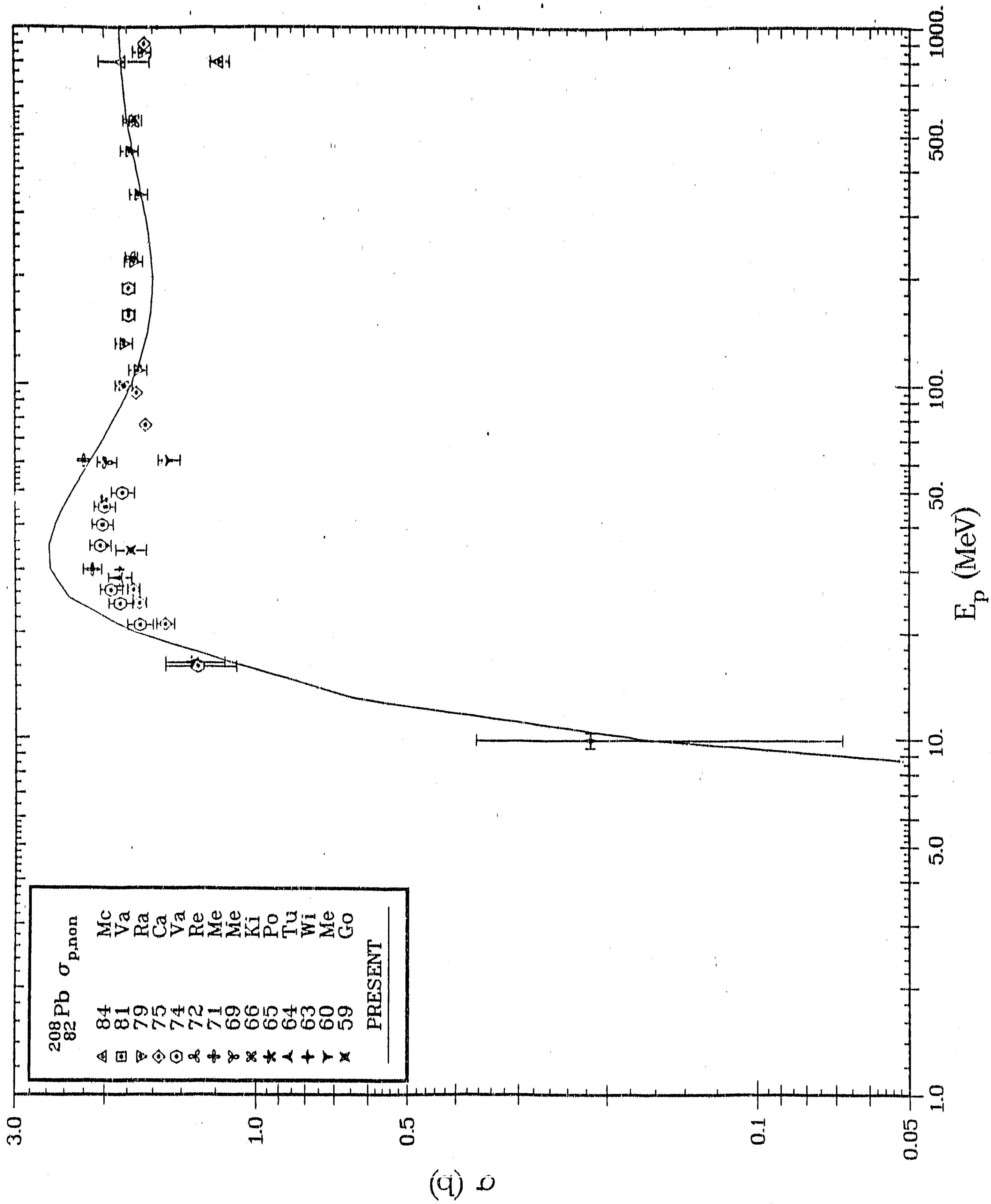

$^{208}_{82}$Pb $\sigma_{p,3n}$
56 Be
PRESENT
E_p (MeV)
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
3000.

Fig. 16



208 82 Pb σ p,4n
56 Be
PRESENT
σ (mb)
E_p (MeV)
3000.
1000.
500.
100.
50.
10.
5.0
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 17



$^{208}_{82}$Pb $\sigma_{p,non}$
84 Mc
81 Va
79 Ra
75 Ca
74 Va
72 Re
71 Me
69 Me
66 Ki
65 Po
64 Tu
63 Wi
60 Me
59 Go
PRESENT
1.0
5.0
10.
50.
100.
500.
1000.
E_p (MeV)
3.0
1.0
0.5
0.1
0.05
σ (b)

Fig. 18

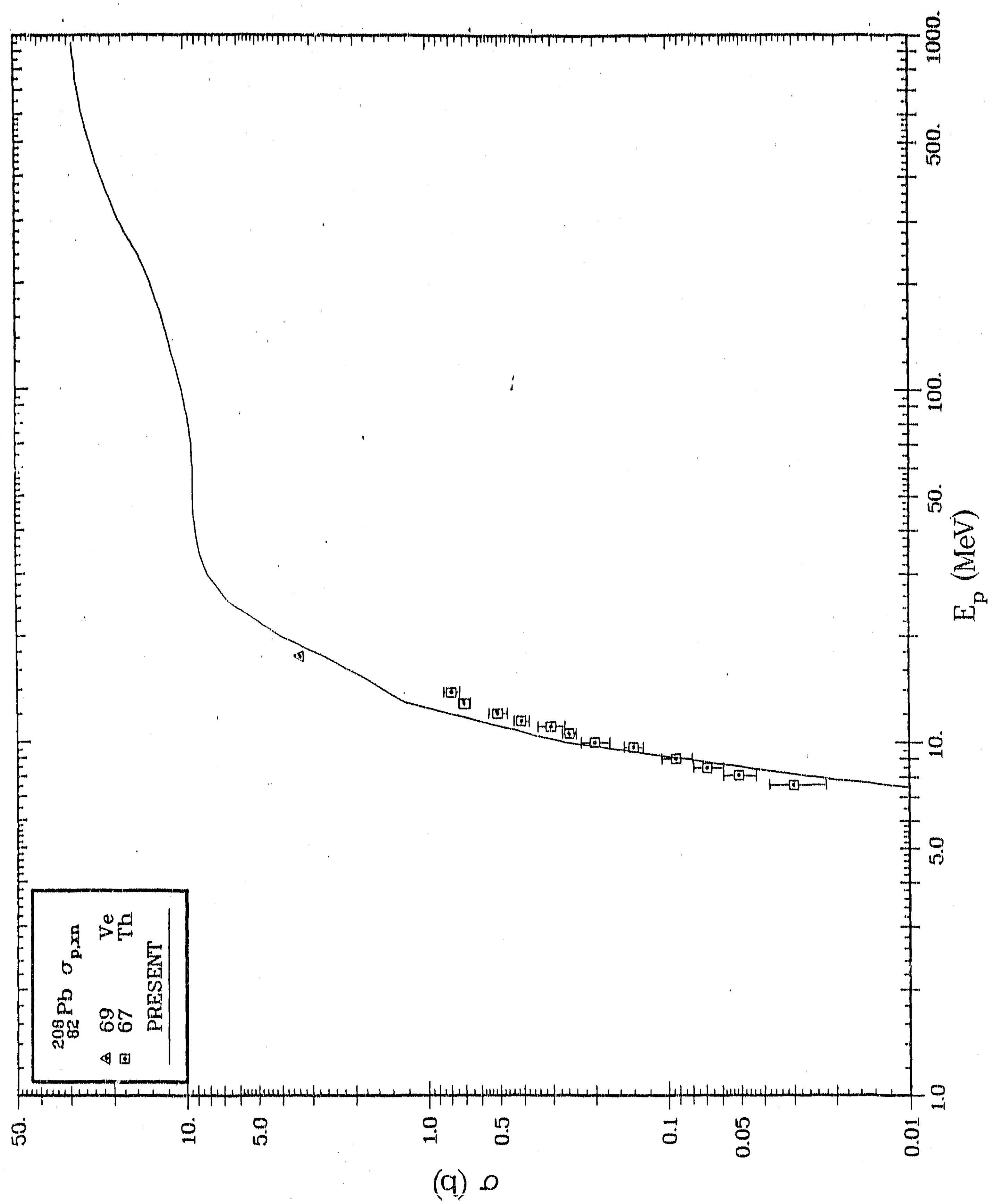

208 82 Pb σ p,xn
69 Ve
67 Th
PRESENT
E_p (MeV)
σ (b)
1.0
5.0
10.
50.
100.
500.
1000.
0.01
0.05
0.1
0.5
1.0
5.0
10.
50.

Fig. 19

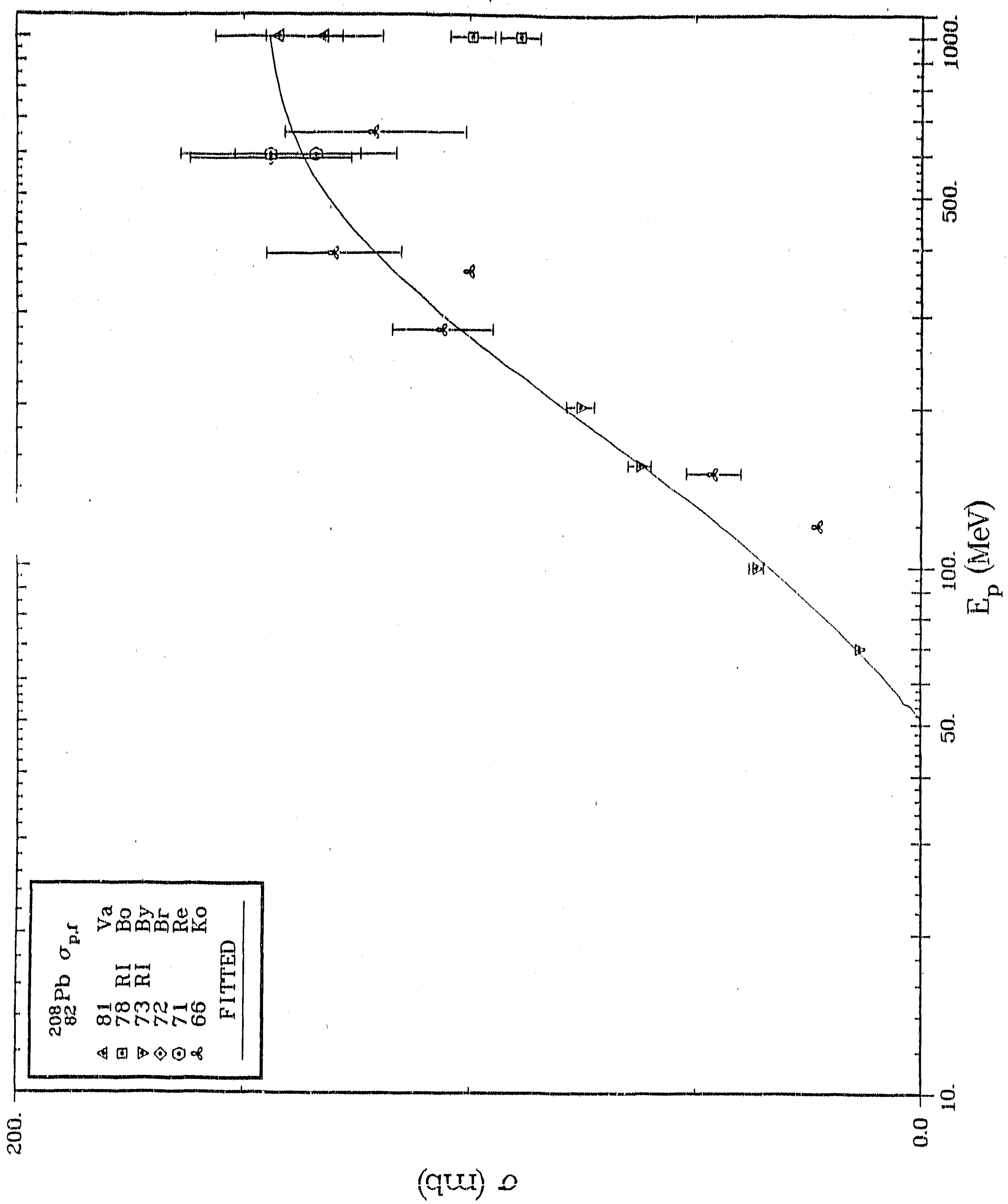
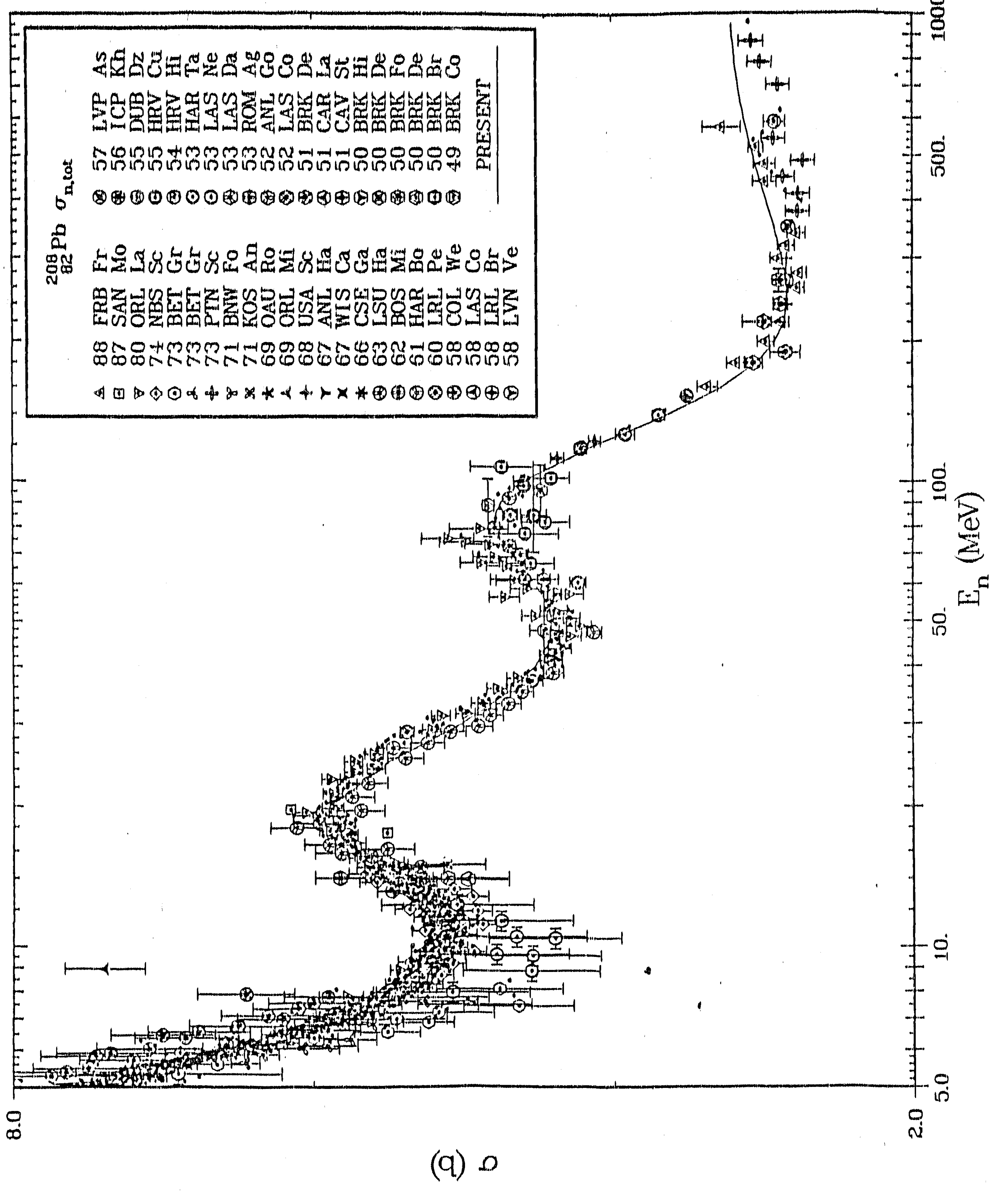
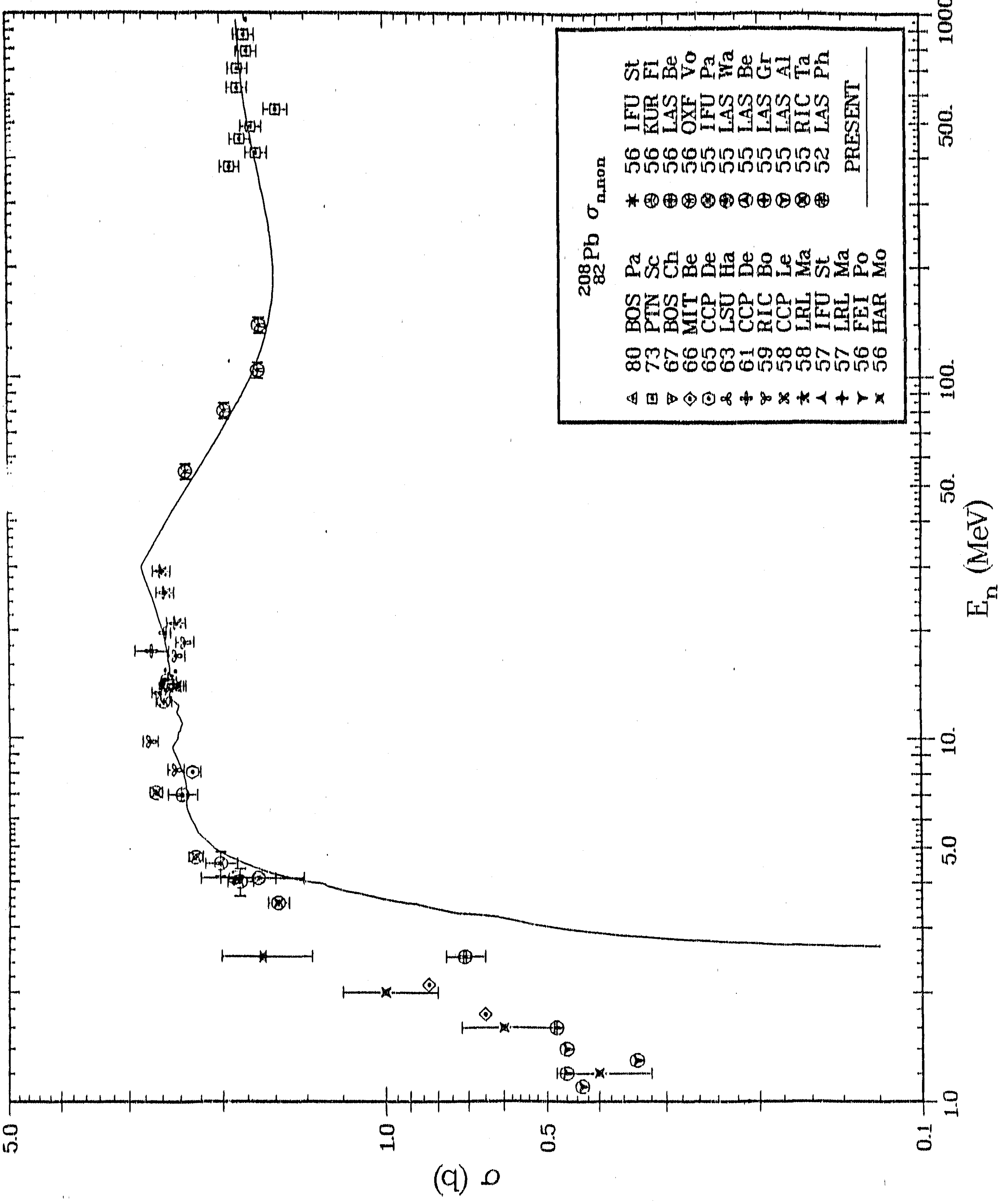

$^{208}_{82}$Pb $\sigma_{p,f}$
81 Va
78 RI Bo
73 RI By
72 Br
71 Re
66 Ko
FITTED
E_p (MeV)
σ (mb)
10.
50.
100.
500.
1000.
0.0
200.

Fig. 20



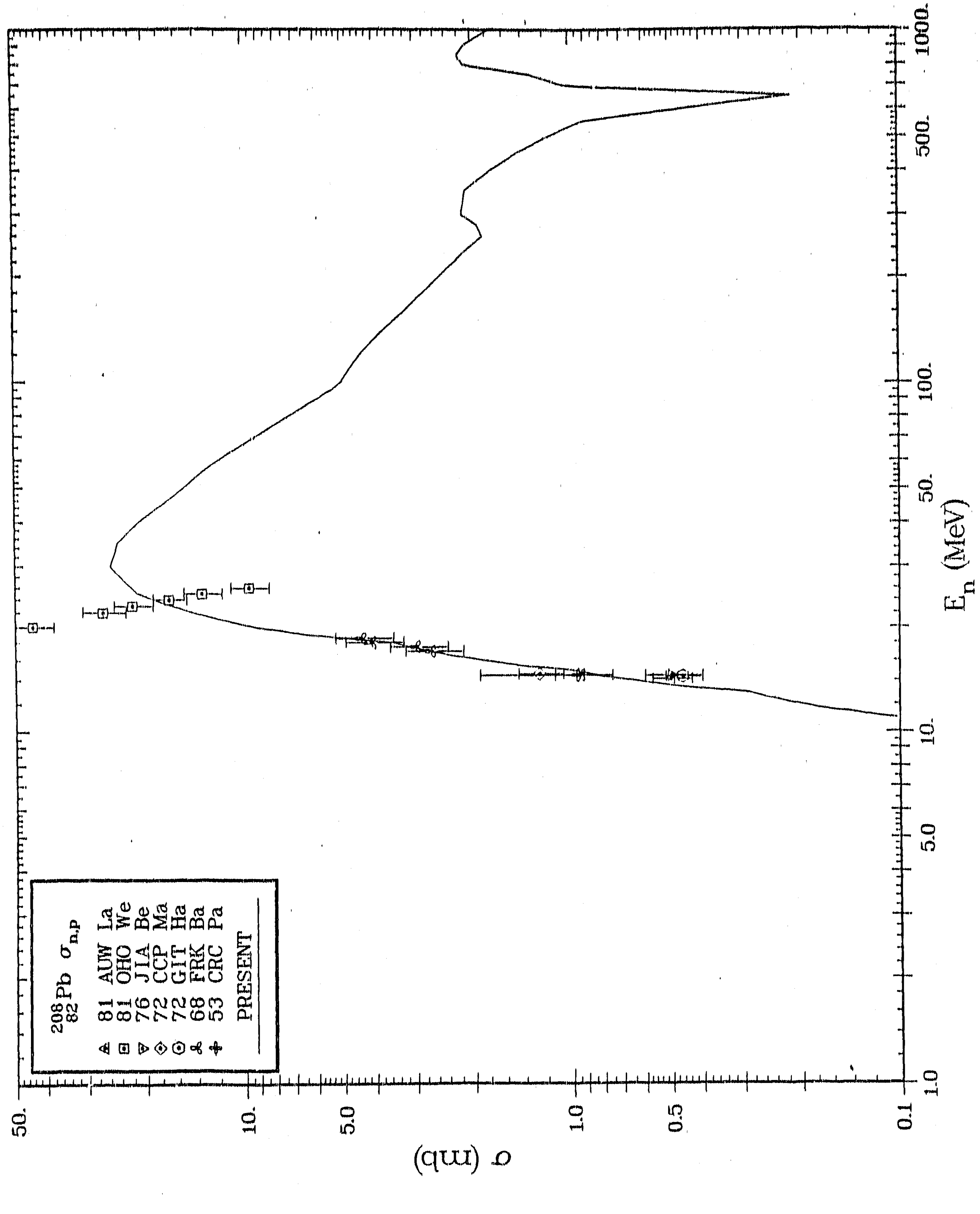
$^{208}_{82}$Pb $\sigma_{n,tot}$
88 FRB Fr
87 SAN Mo
80 ORL La
74 NBS Sc
73 BET Gr
73 BET Gr
73 PTN Sc
71 BNW Fo
71 KOS An
69 OAU Ro
69 ORL Mi
68 USA Sc
67 ANL Ha
67 WIS Ca
66 CSE Ga
63 LSU Ha
62 BOS Mi
61 HAR Bo
60 LRL Pe
58 COL We
58 LAS Co
58 LRL Br
58 LVN Ve
57 LVP As
56 ICP Kh
55 DUB Dz
55 HRV Cu
54 HRV Hi
53 HAR Ta
53 LAS Ne
53 LAS Da
53 ROM Ag
52 ANL Go
52 LAS Co
51 BRK De
51 CAR La
51 CAV St
50 BRK Hi
50 BRK De
50 BRK Fo
50 BRK De
50 BRK Br
49 BRK Co
PRESENT
8.0
2.0
σ (b)
5.0
10.
50.
100.
500.
1000.
E_n (MeV)

Fig. 21



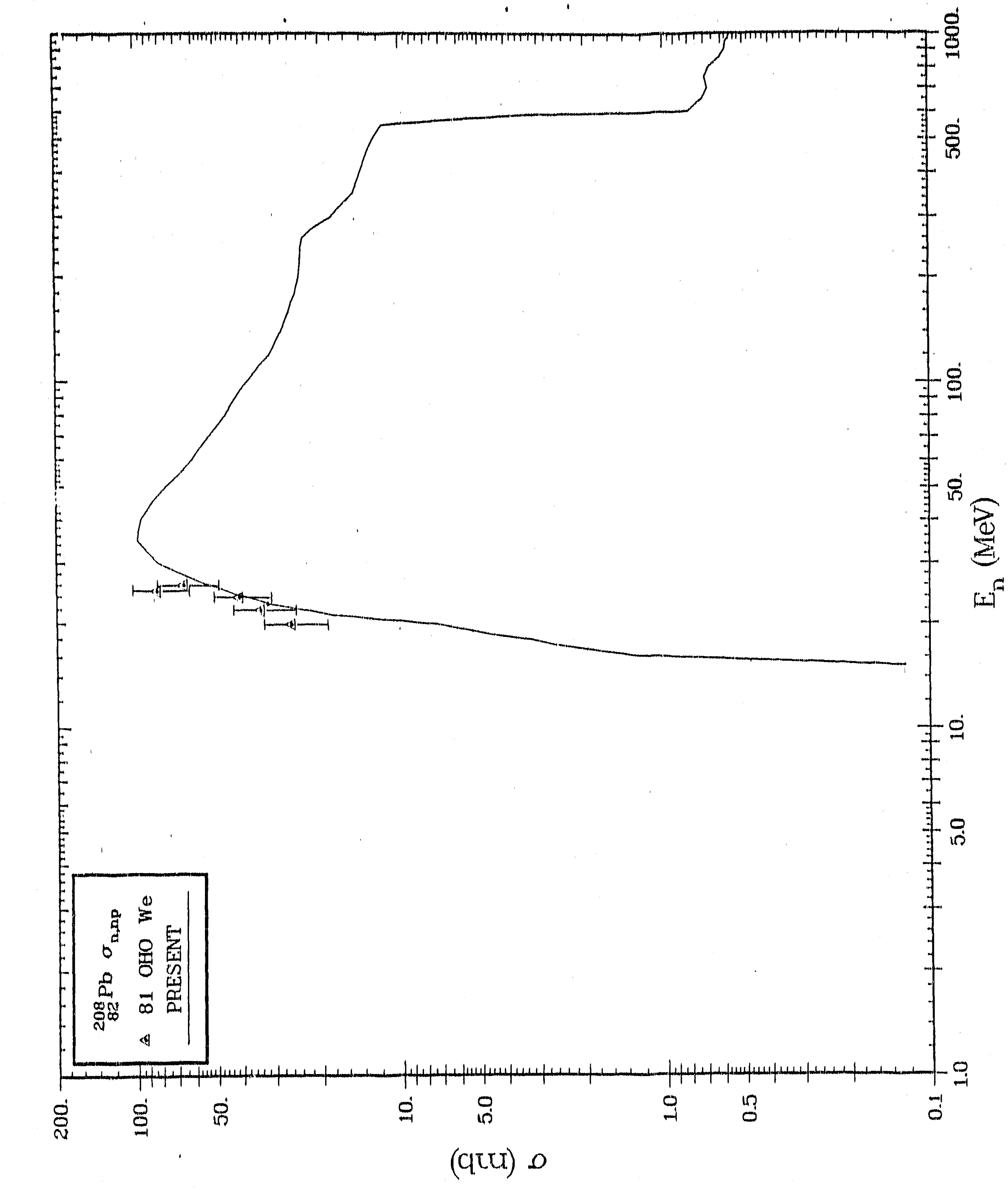
σ (b)
5.0
1.0
0.5
0.1
E_n (MeV)
1.0
5.0
10.
50.
100.
500.
1000.
208 82 Pb σ n,non
80 BOS Pa
73 PTN Sc
67 BOS Ch
66 MIT Be
65 CCP De
63 LSU Ha
61 CCP De
59 RIC Bo
58 CCP Le
58 LRL Ma
57 IFU St
57 LRL Ma
56 FEI Po
56 HAR Mo
56 IFU St
56 KUR Fl
56 LAS Be
56 OXF Vo
55 IFU Pa
55 LAS Wa
55 LAS Be
55 LAS Gr
55 LAS Al
55 RIC Ta
52 LAS Ph
PRESENT

Fig. 22



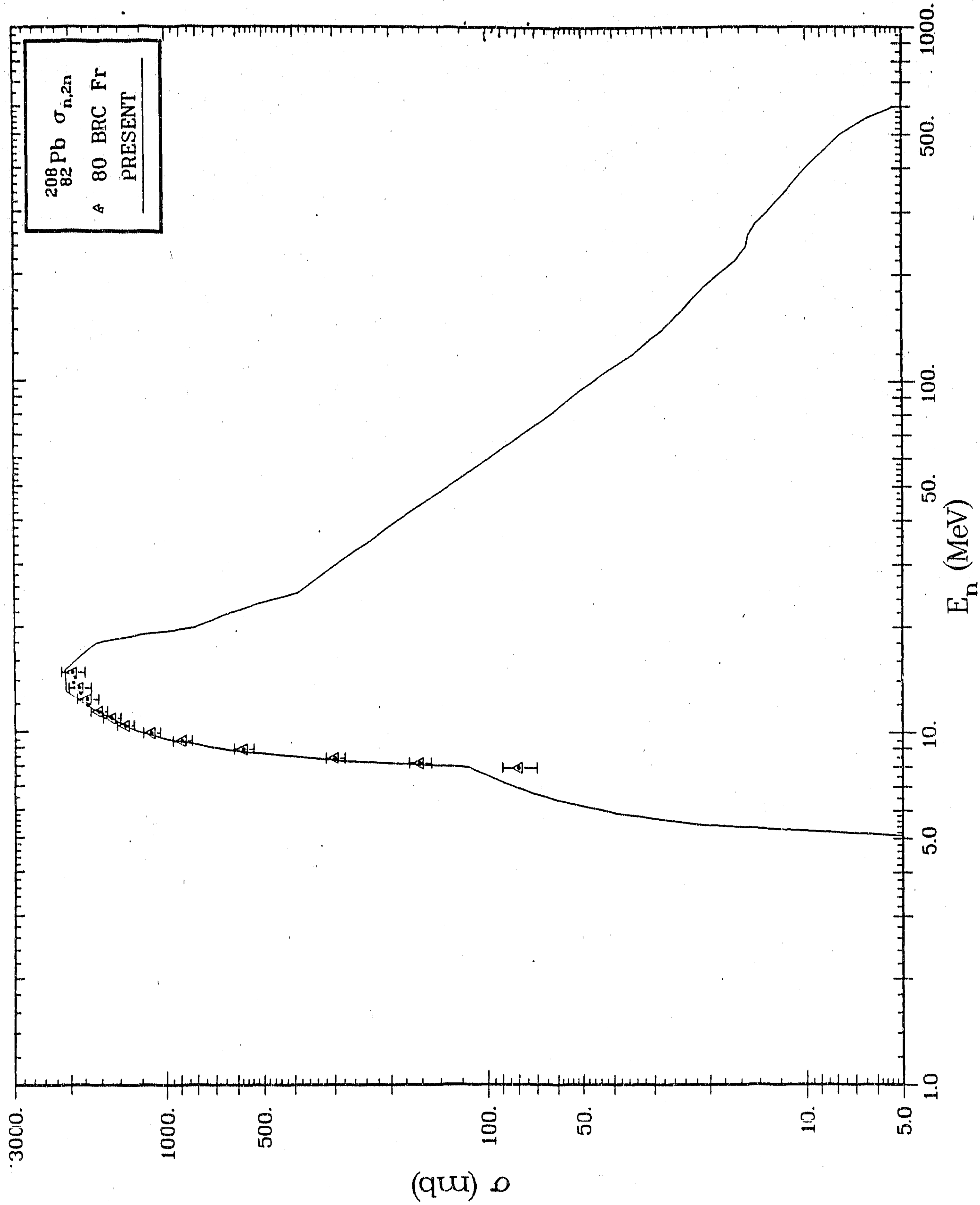
$^{208}_{82}Pb$ $\sigma_{n,p}$
81 AUW La
81 OHO We
76 JIA Be
72 CCP Ma
72 GIT Ha
68 FRK Ba
53 CRC Pa
PRESENT
σ (mb)
50.
10.
5.0
1.0
0.5
0.1
1.0
5.0
10.
50.
100.
500.
1000.
E_n (MeV)

Fig. 23



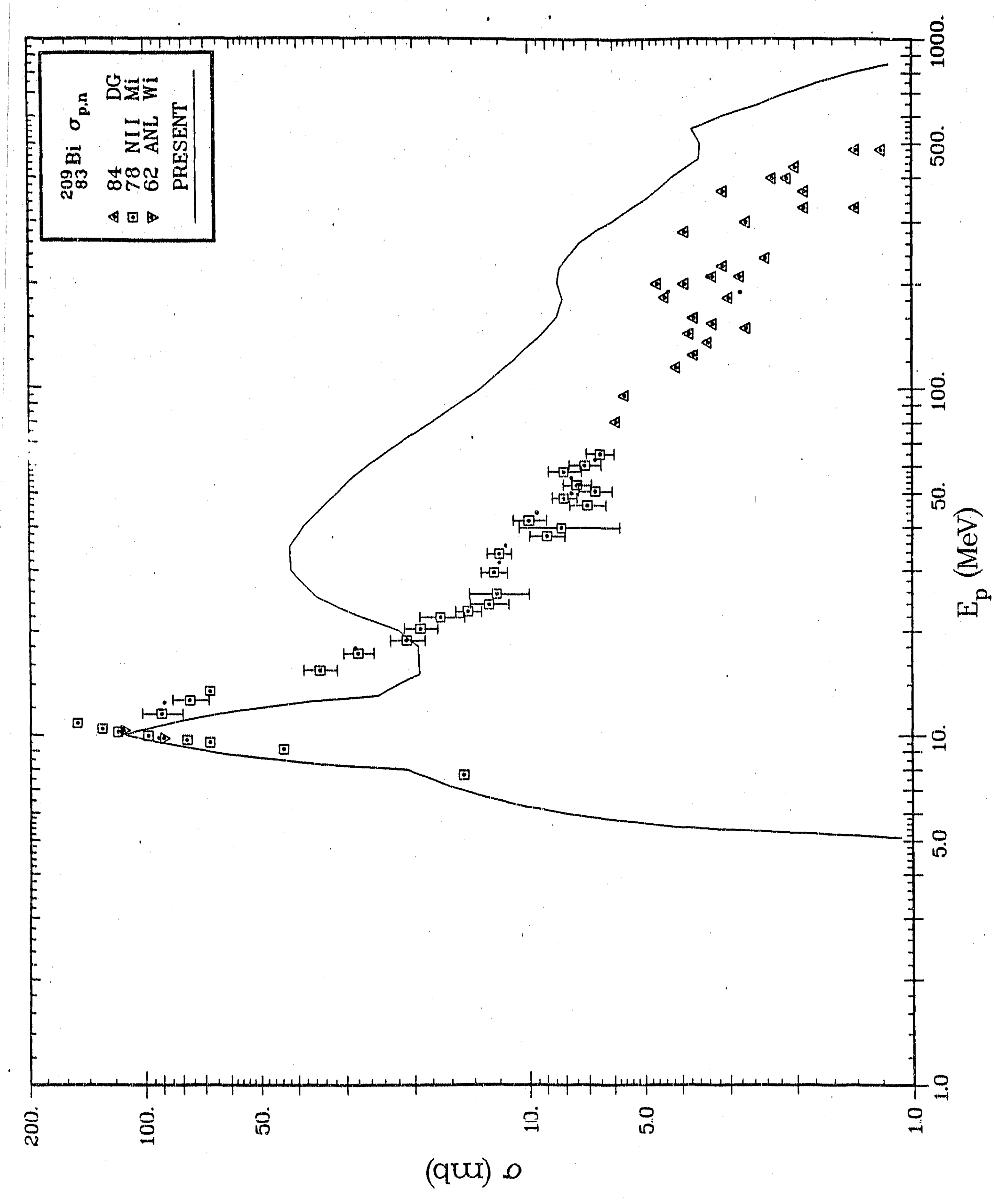
208 82 Pb σ n,np
81 OHO We
PRESENT
σ (mb)
200.
100.
50.
10.
5.0
1.0
0.5
0.1
En (MeV)
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 24



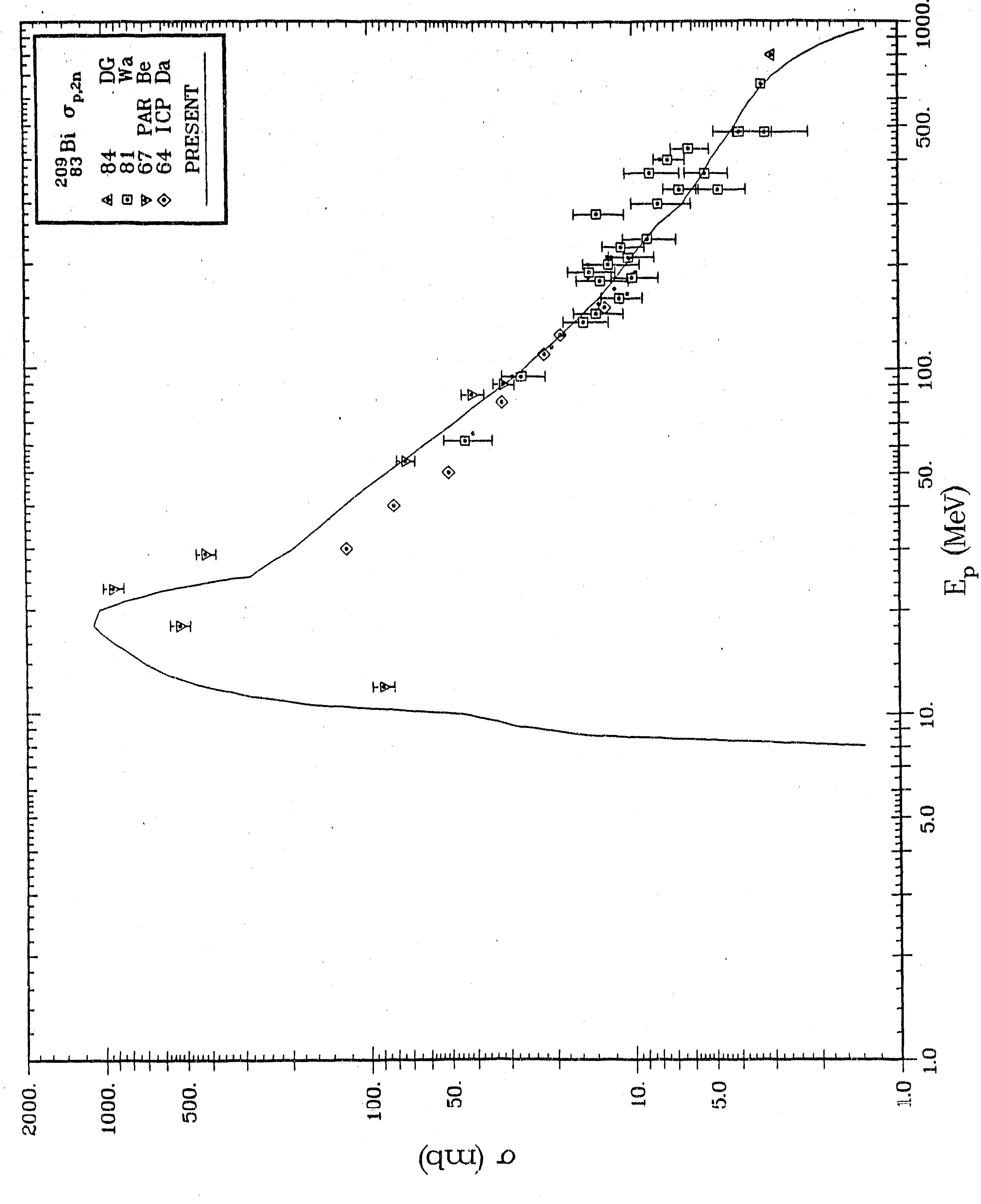
$^{208}_{82}Pb\ \sigma_{n,2n}$
80 BRC Fr
PRESENT
3000.
1000.
500.
100.
50.
10.
5.0
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
E_n (MeV)

Fig. 25



$^{209}_{83}$Bi $\sigma_{p,n}$
84 DG
78 NII Mi
62 ANL Wi
PRESENT
200.
100.
50.
10.
5.0
1.0
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
E_p (MeV)

Fig. 26



$^{209}_{83}$Bi $\sigma_{p,2n}$
84 DG
81 Wa
67 PAR Be
64 ICP Da
PRESENT
E_p (MeV)
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
2000.

Fig. 27

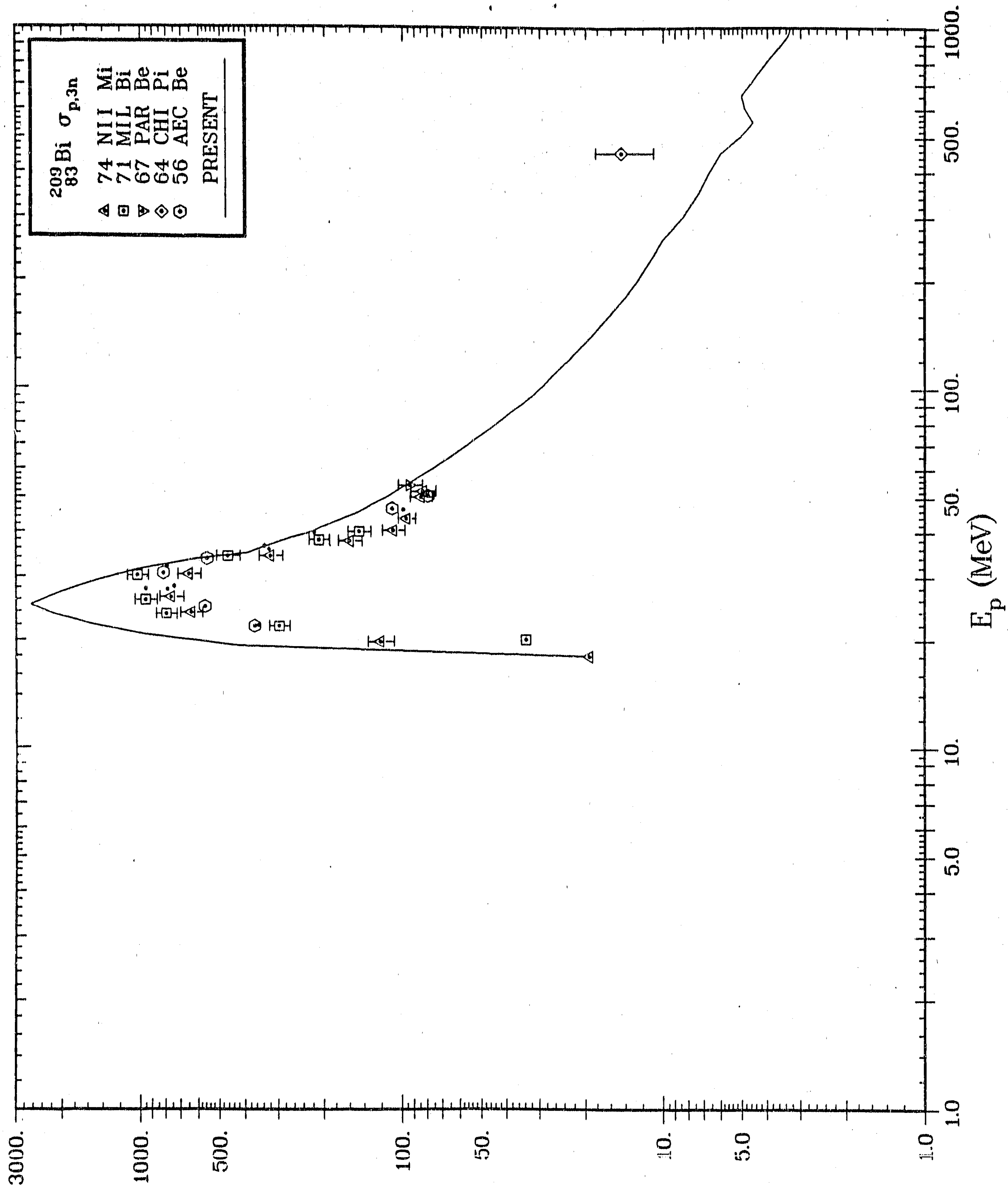
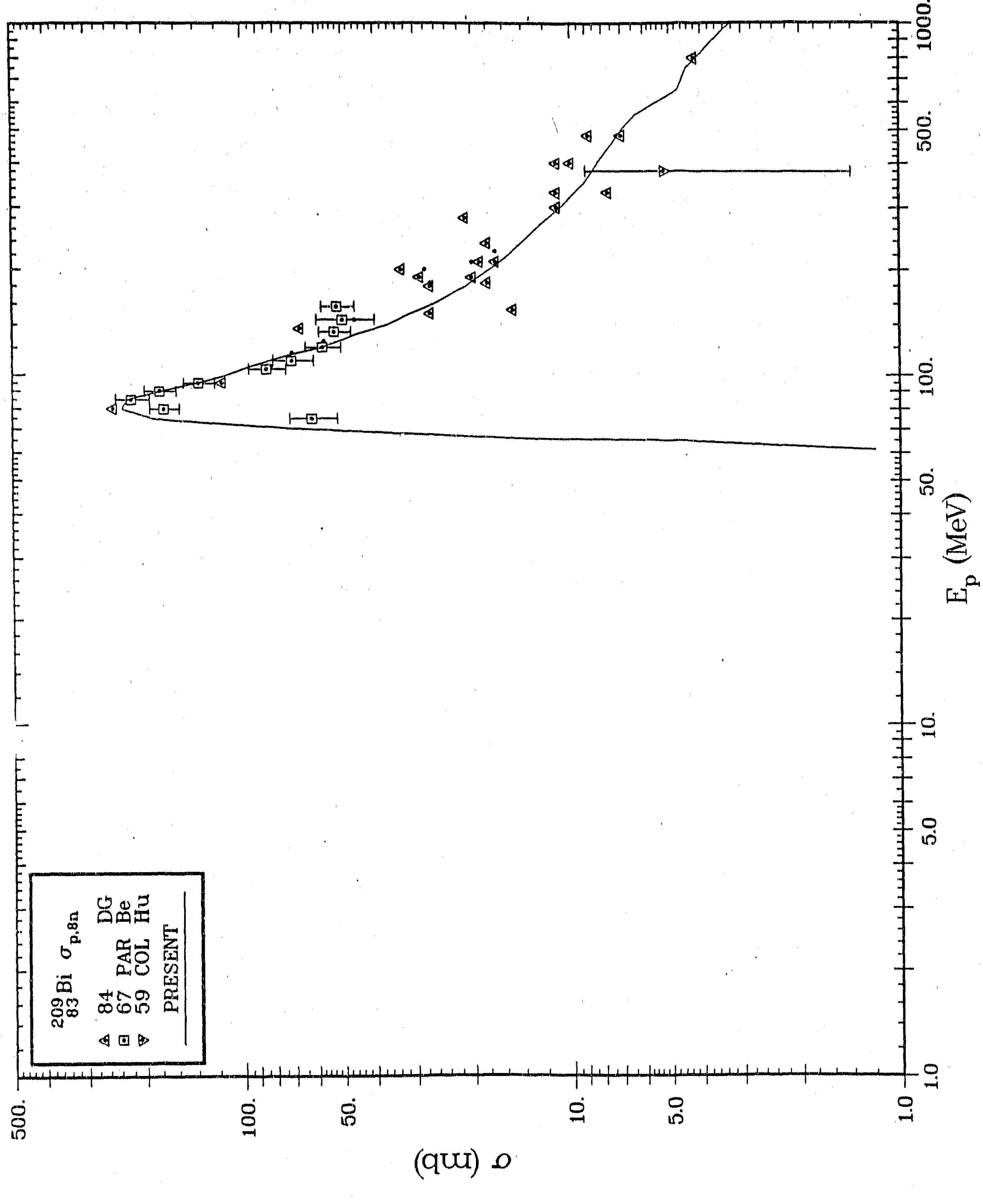
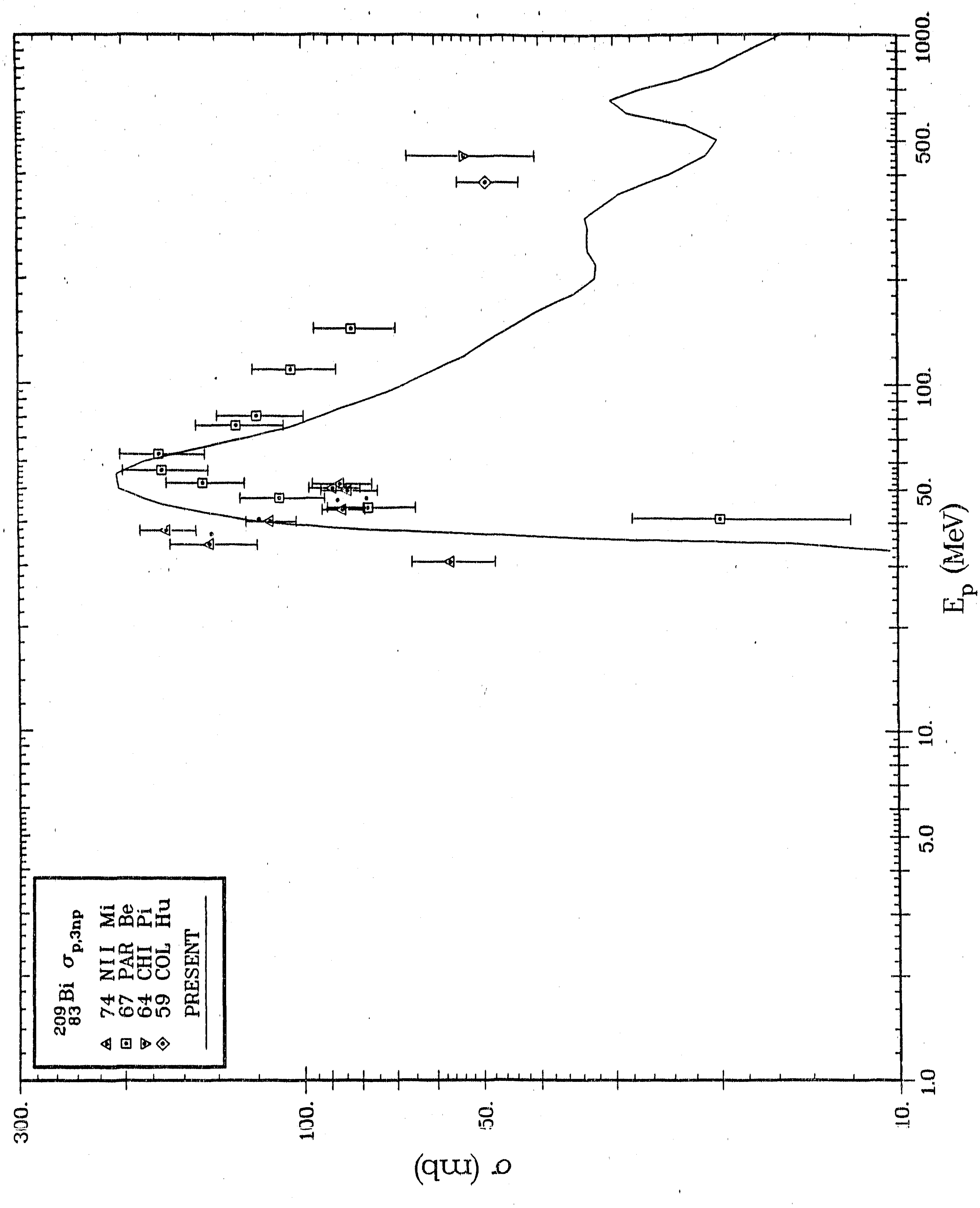

$^{209}_{83}$Bi $\sigma_{p,3n}$
74 NII Mi
71 MIL Bi
67 PAR Be
64 CHI Pi
56 AEC Be
PRESENT
E_p (MeV)
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
3000.

Fig. 28



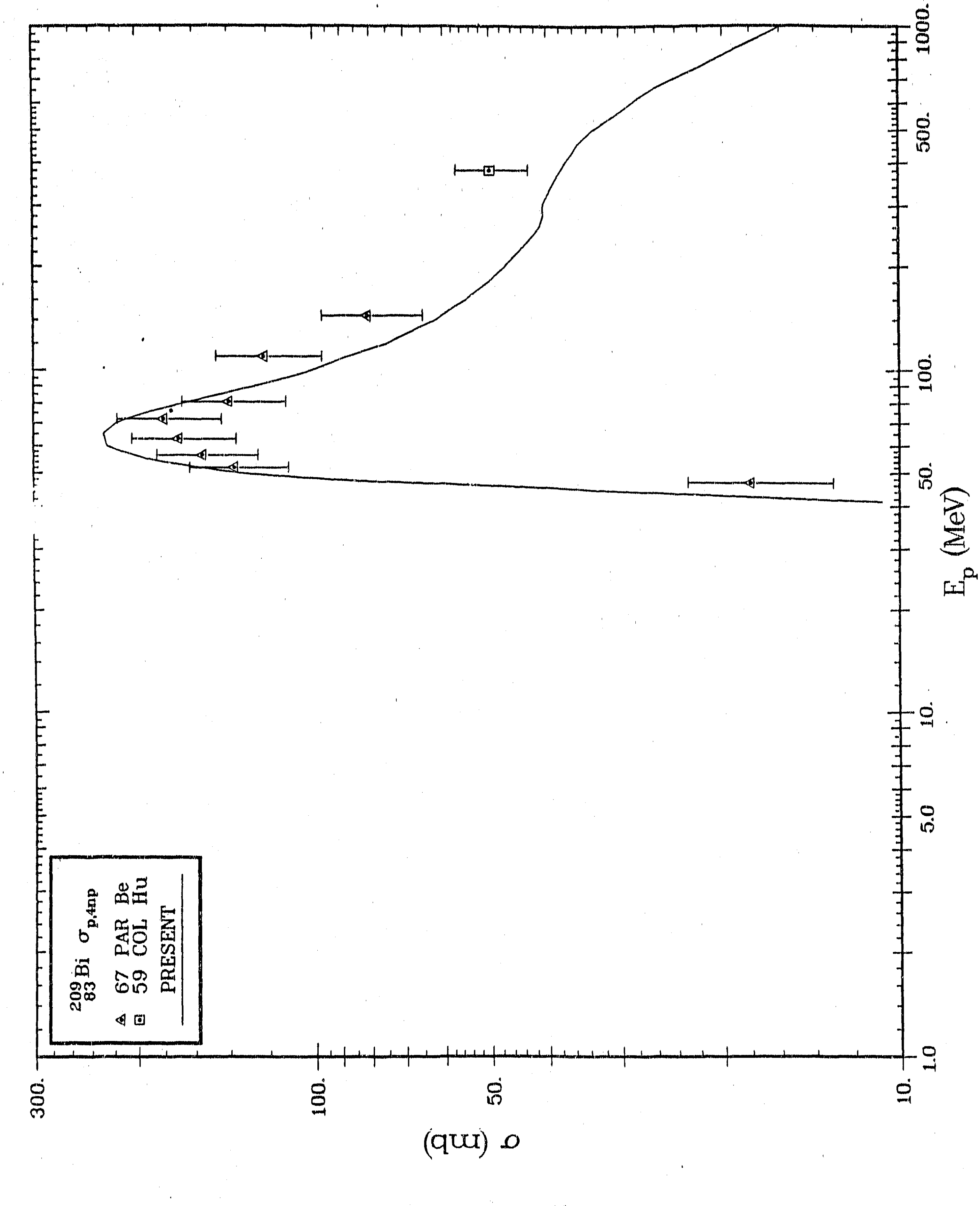
$^{209}_{83}$Bi $\sigma_{p,8n}$
84 DG
67 PAR Be
59 COL Hu
PRESENT
σ (mb)
E_p (MeV)
500.
100.
50.
10.
5.0
1.0
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 29



$^{209}_{83}$Bi $\sigma_{p,3np}$
74 NII Mi
67 PAR Be
64 CHI Pi
59 COL Hu
PRESENT
σ (mb)
E_p (MeV)
300.
100.
50.
10.
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 30



209 83 Bi σ p,4np
67 PAR Be
59 COL Hu
PRESENT
σ (mb)
300.
100.
50.
10.
Ep (MeV)
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 31

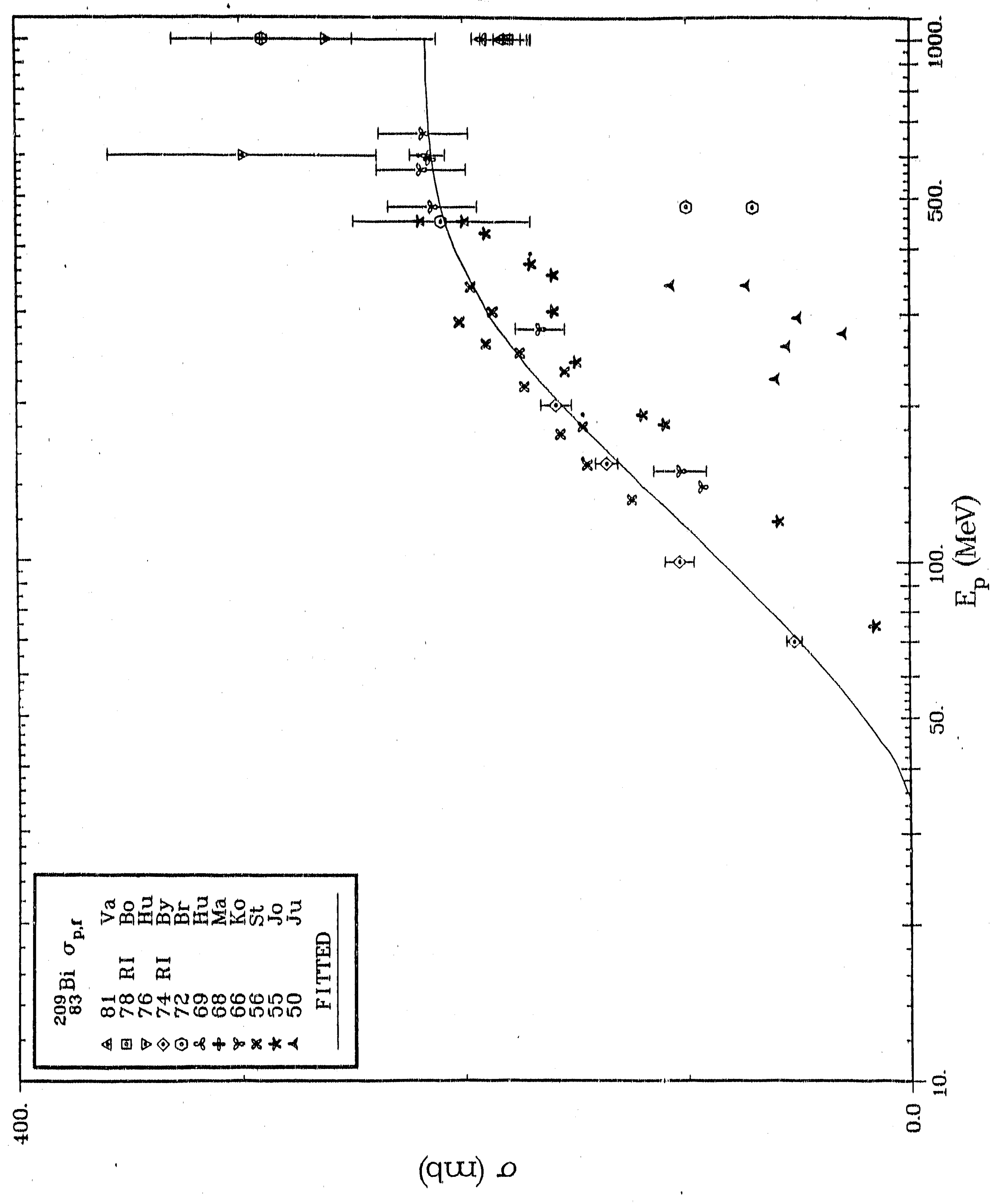
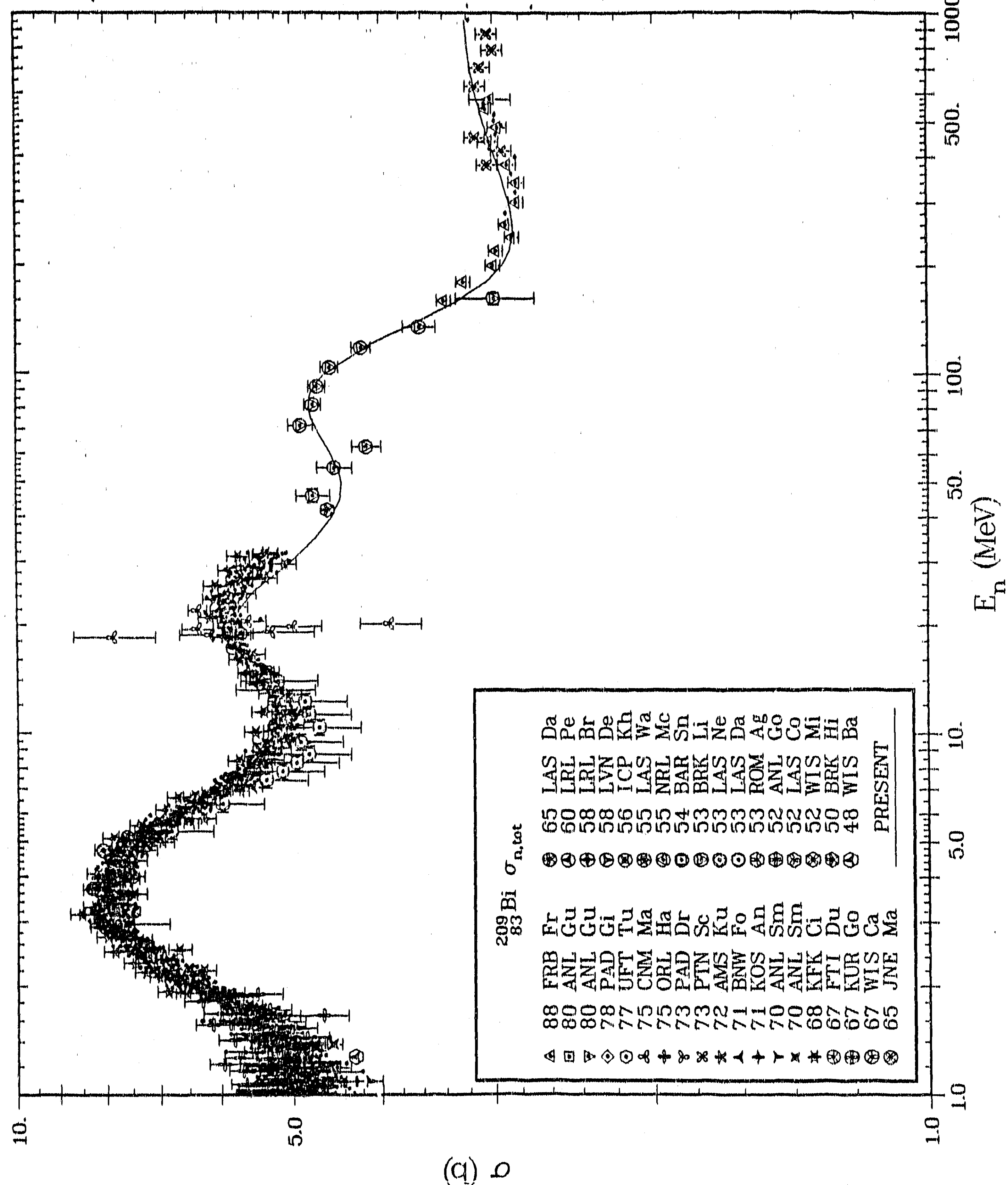
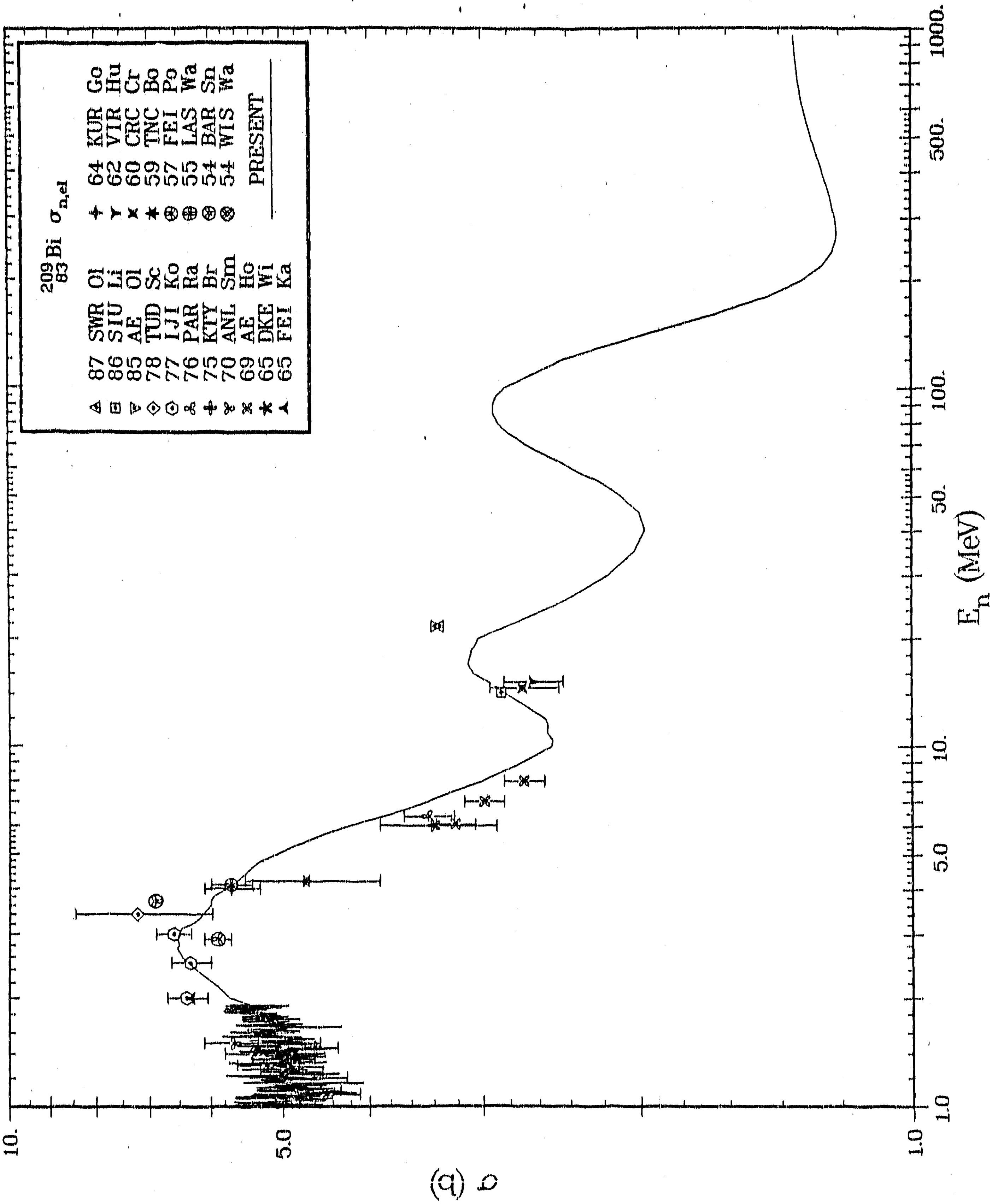

209 83 Bi σ p,f
81 Va
78 RI Bo
76 Hu
74 RI By
72 Br
69 Hu
68 Ma
66 Ko
56 St
55 Jo
50 Ju
FITTED
10.
50.
100.
500.
1000.
Ep (MeV)
0.0
400.
σ (mb)

Fig. 32



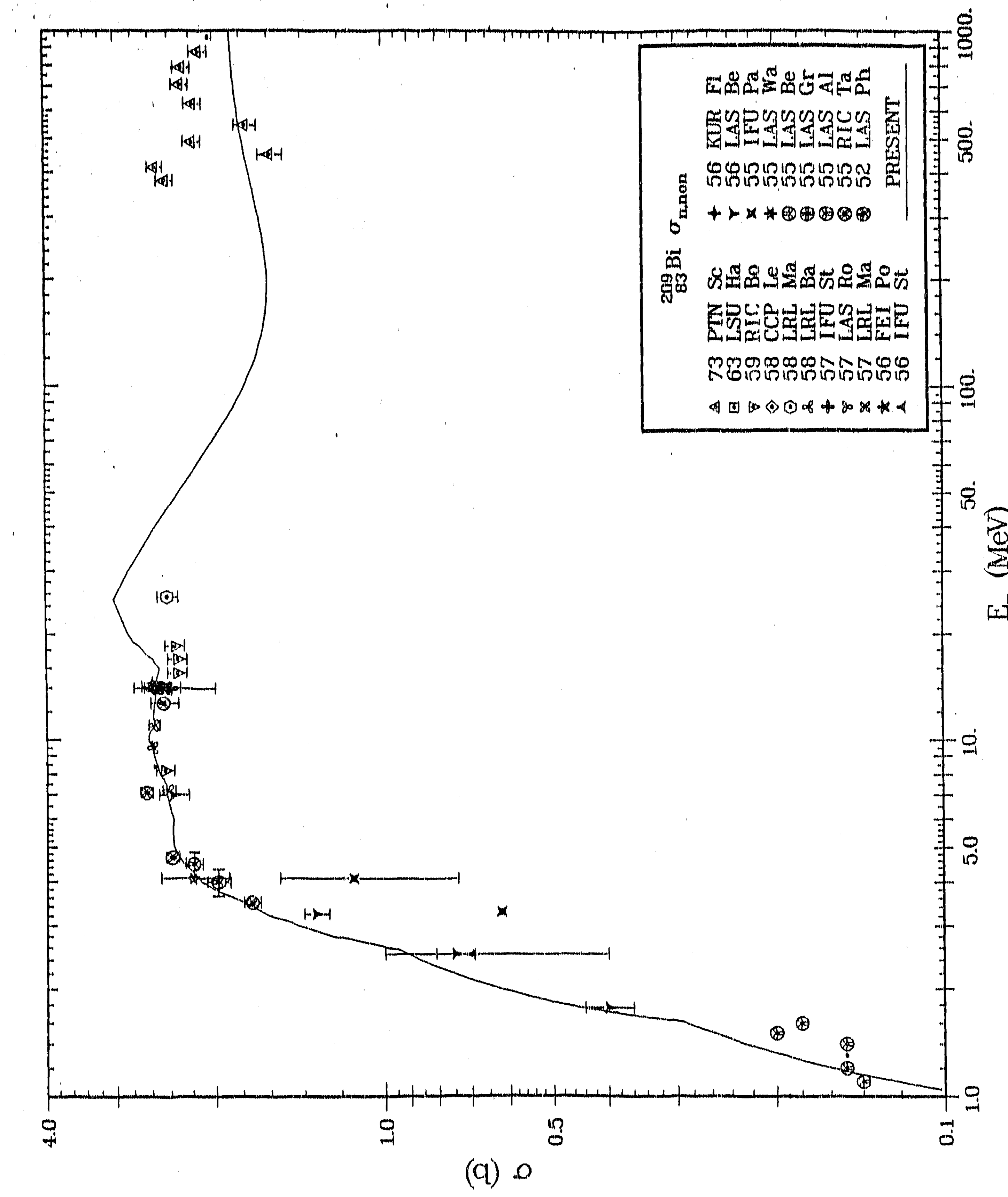
209 83 Bi σ n,tot
σ (b)
10.
5.0
1.0
E n (MeV)
1.0
5.0
10.
50.
100.
500.
1000.
88 FRB Fr
80 ANL Gu
80 ANL Gu
78 PAD Gi
77 UFT Tu
75 CNM Ma
75 ORL Ha
73 PAD Dr
73 PTN Sc
72 AMS Ku
71 BNW Fo
71 KOS An
70 ANL Sm
70 ANL Sm
68 KFK Ci
67 FTI Du
67 KUR Go
67 WIS Ca
65 JNE Ma
65 LAS Da
60 LRL Pe
58 LRL Br
58 LVN De
56 ICP Kh
55 LAS Wa
55 NRL Mc
54 BAR Sn
53 BRK Li
53 LAS Ne
53 LAS Da
53 ROM Ag
52 ANL Go
52 LAS Co
52 WIS Mi
50 BRK Hi
48 WIS Ba
PRESENT

Fig. 33



209 83 Bi σn,el
87 SWR Ol
86 SIU Li
85 AE Ol
78 TUD Sc
77 IJI Ko
76 PAR Ra
75 KTY Br
70 ANL Sm
69 AE Ho
65 DKE Wi
65 FEI Ka
64 KUR Go
62 VIR Hu
60 CRC Cr
59 TNC Bo
57 FEI Po
55 LAS Wa
54 BAR Sn
54 WIS Wa
PRESENT
σ (b)
10.
5.0
1.0
En (MeV)
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 34



209 83 Bi σ n,non
73 PTN Sc
63 LSU Ha
59 RIC Bo
58 CCP Le
58 LRL Ma
58 LRL Ba
57 IFU St
57 LAS Ro
57 LRL Ma
56 FEI Po
56 IFU St
56 KUR Fl
56 LAS Be
55 IFU Pa
55 LAS Wa
55 LAS Be
55 LAS Gr
55 LAS Al
55 RIC Ta
52 LAS Ph
PRESENT
σ (b)
E_n (MeV)
4.0
1.0
0.5
0.1
1.0
5.0
10.
50.
100.
500.
1000.

Fig. 35

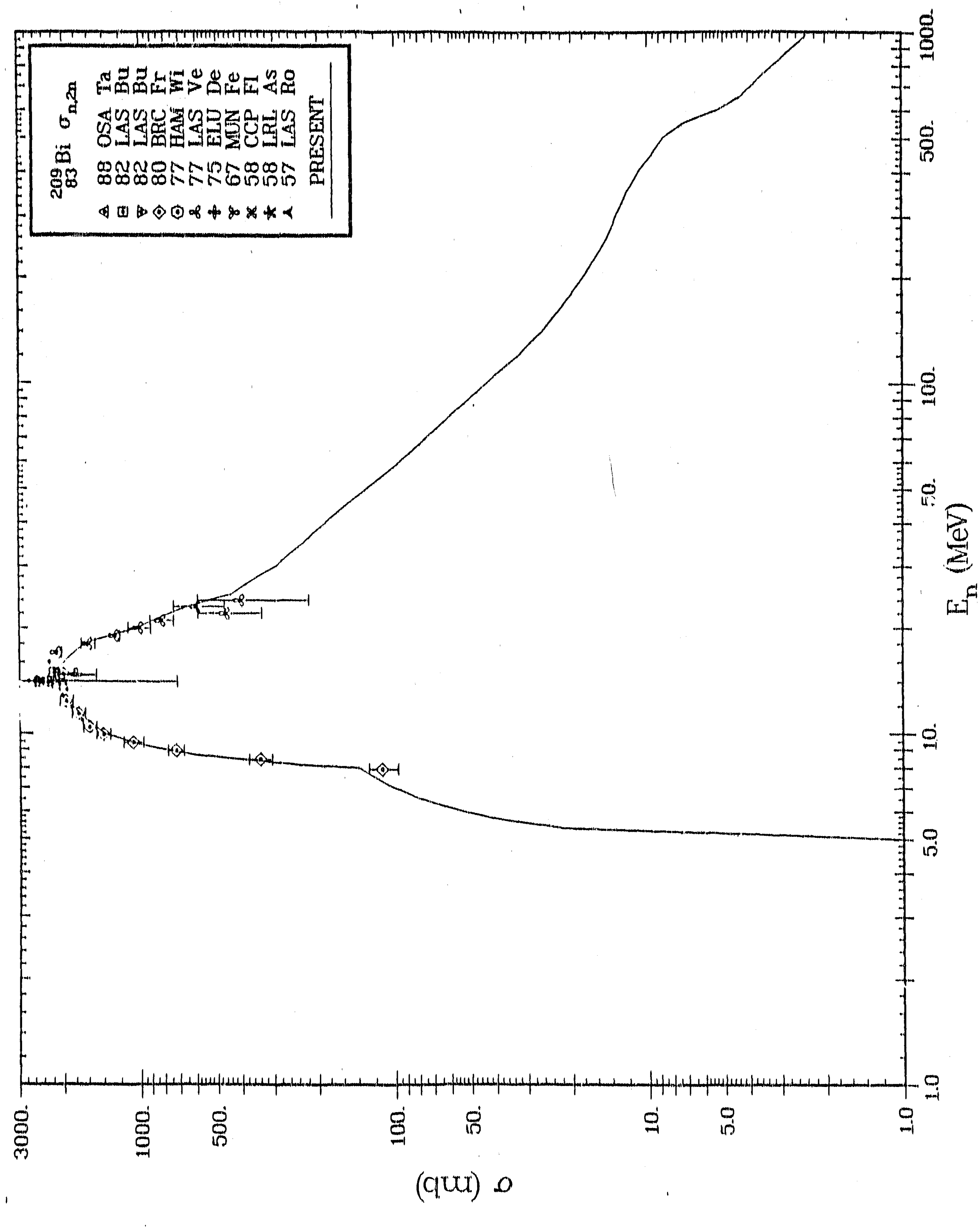
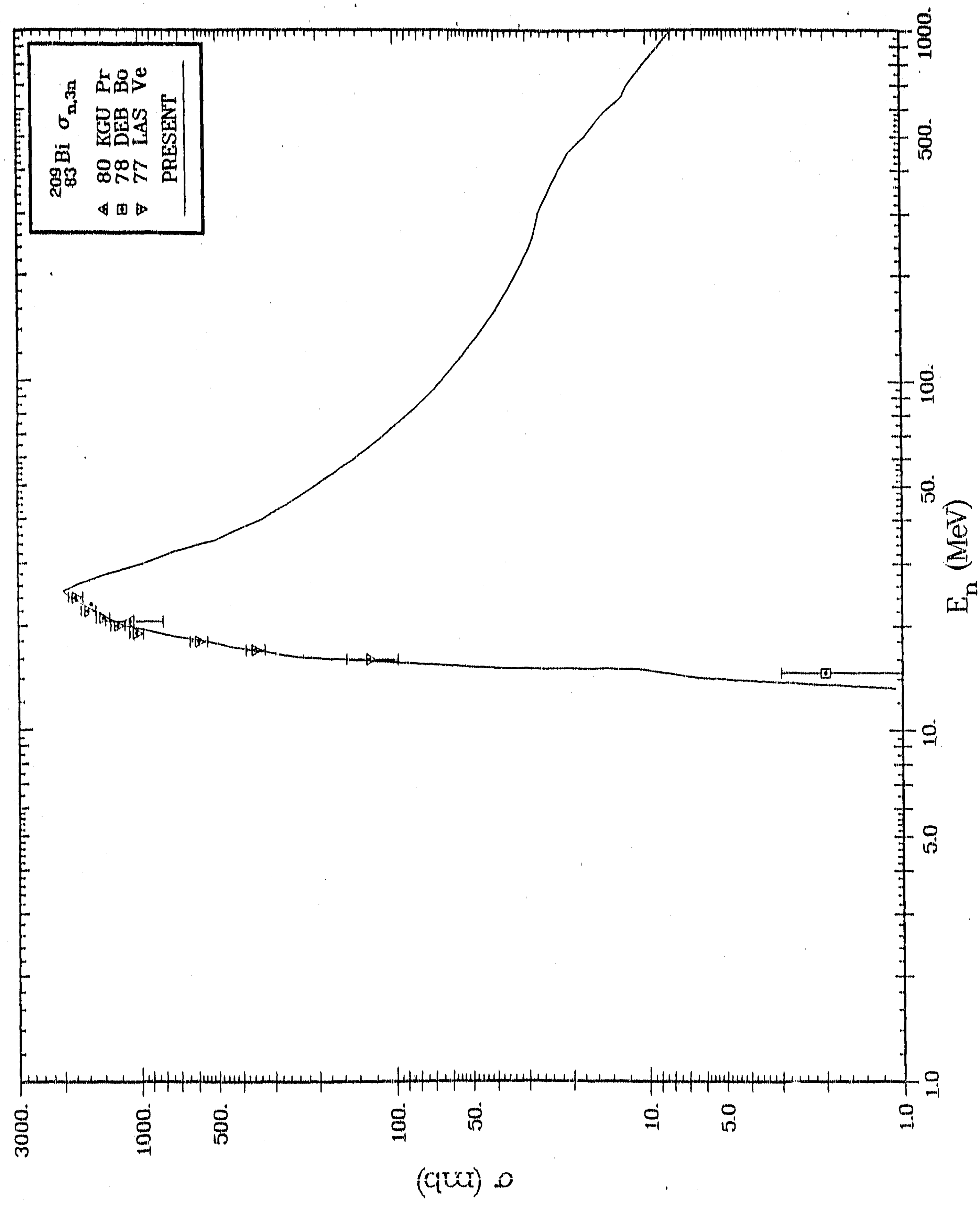
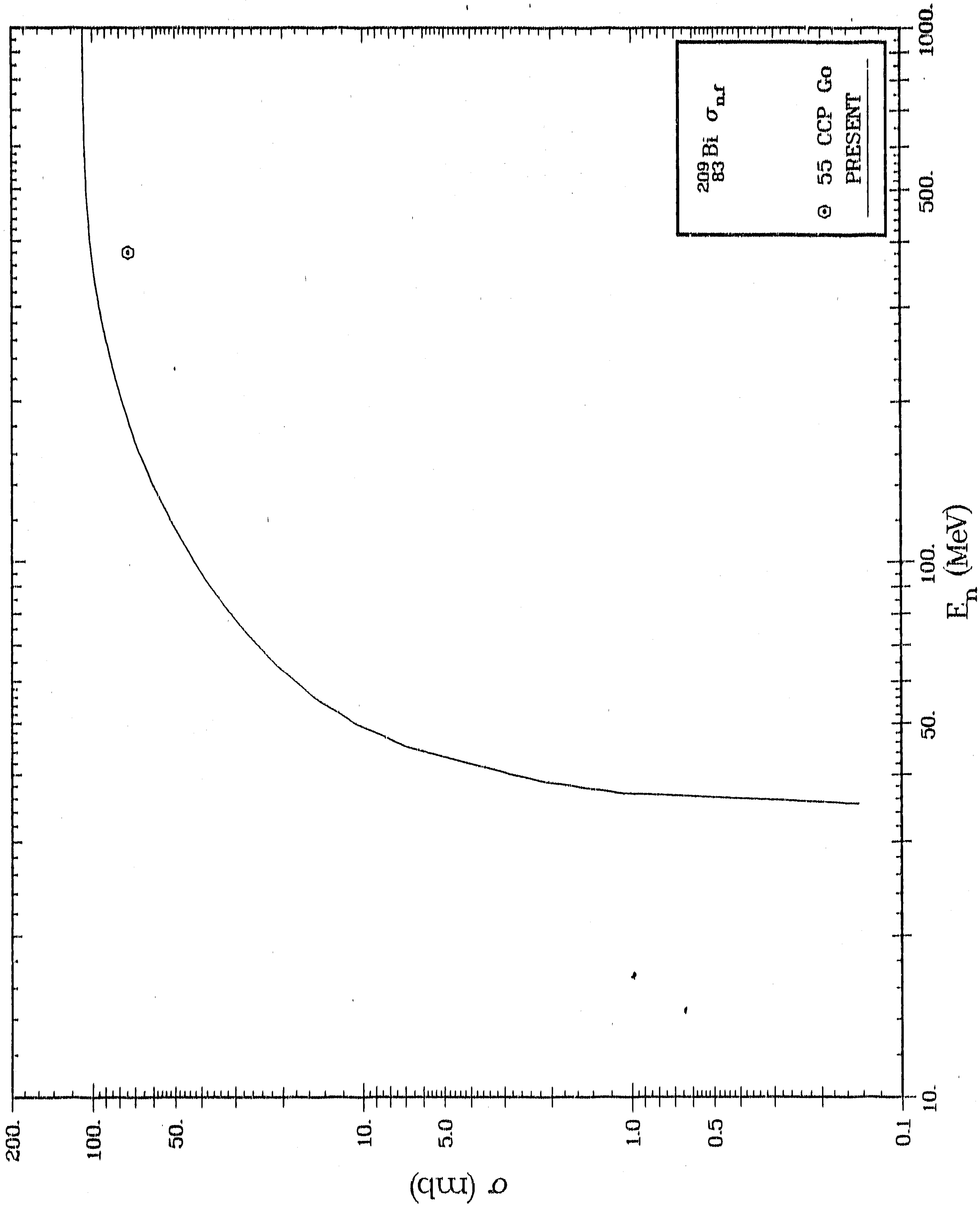

$^{209}_{83}$Bi $\sigma_{n,2n}$
88 OSA Ta
82 LAS Bu
82 LAS Bu
80 BRC Fr
77 HAM Wi
77 LAS Ve
75 ELU De
67 MUN Fe
58 CCP Fl
58 LRL As
57 LAS Ro
PRESENT
E_n (MeV)
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
3000.

Fig. 36



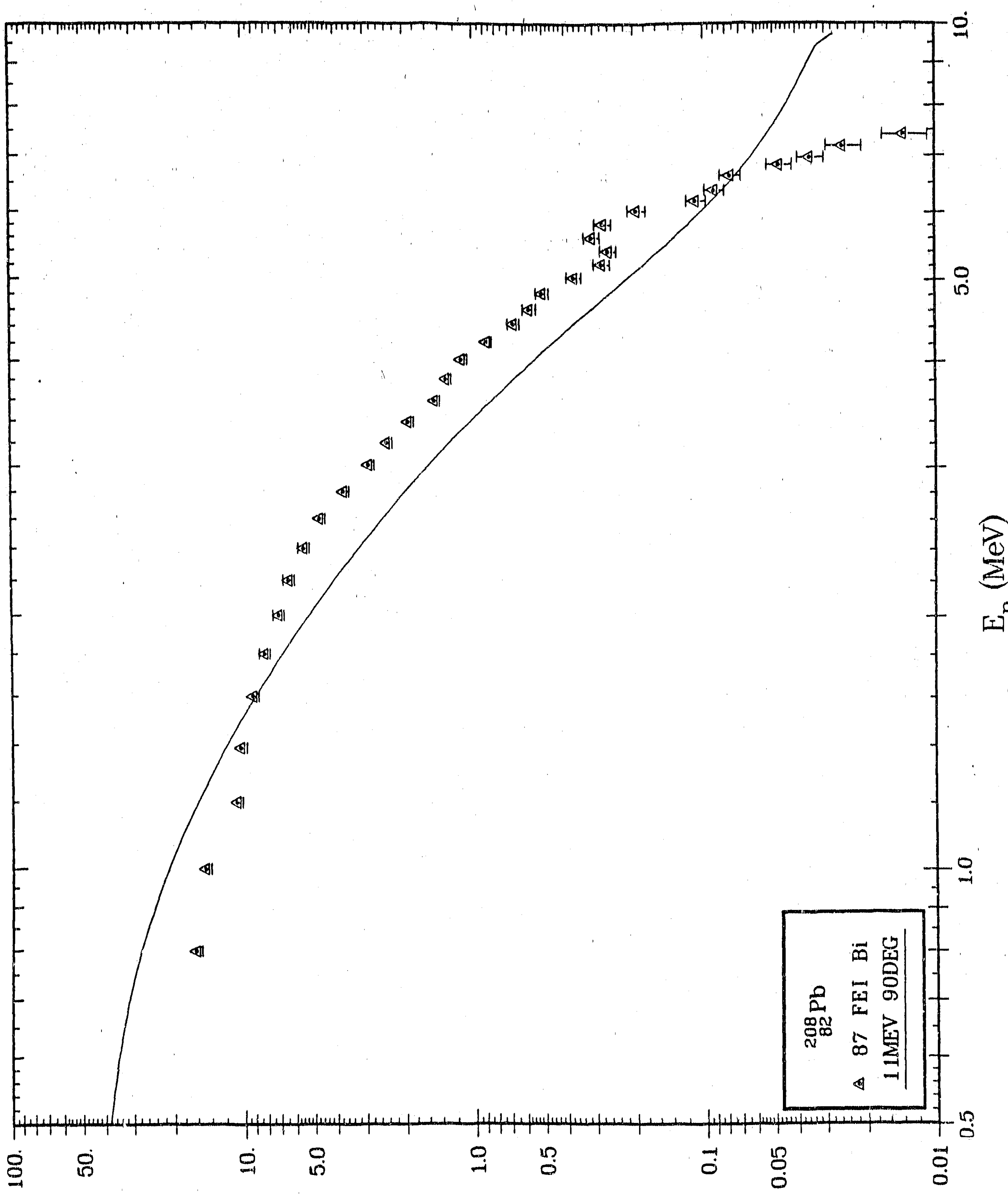
$^{209}_{83}$Bi $\sigma_{n,3n}$
80 KGU Pr
78 DEB Bo
77 LAS Ve
PRESENT
E_n (MeV)
σ (mb)
1.0
5.0
10.
50.
100.
500.
1000.
3000.

Fig. 37



$^{209}_{83}$Bi $\sigma_{n,f}$
⊙ 55 CCP Go
PRESENT
σ (mb)
200.
100.
50.
10.
5.0
1.0
0.5
0.1
E_n (MeV)
10.
50.
100.
500.
1000.

Fig. 38



100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
0.5
1.0
5.0
10.
E_p (MeV)
208 82 Pb
87 FEI Bi
11MEV 90DEG

Fig. 39

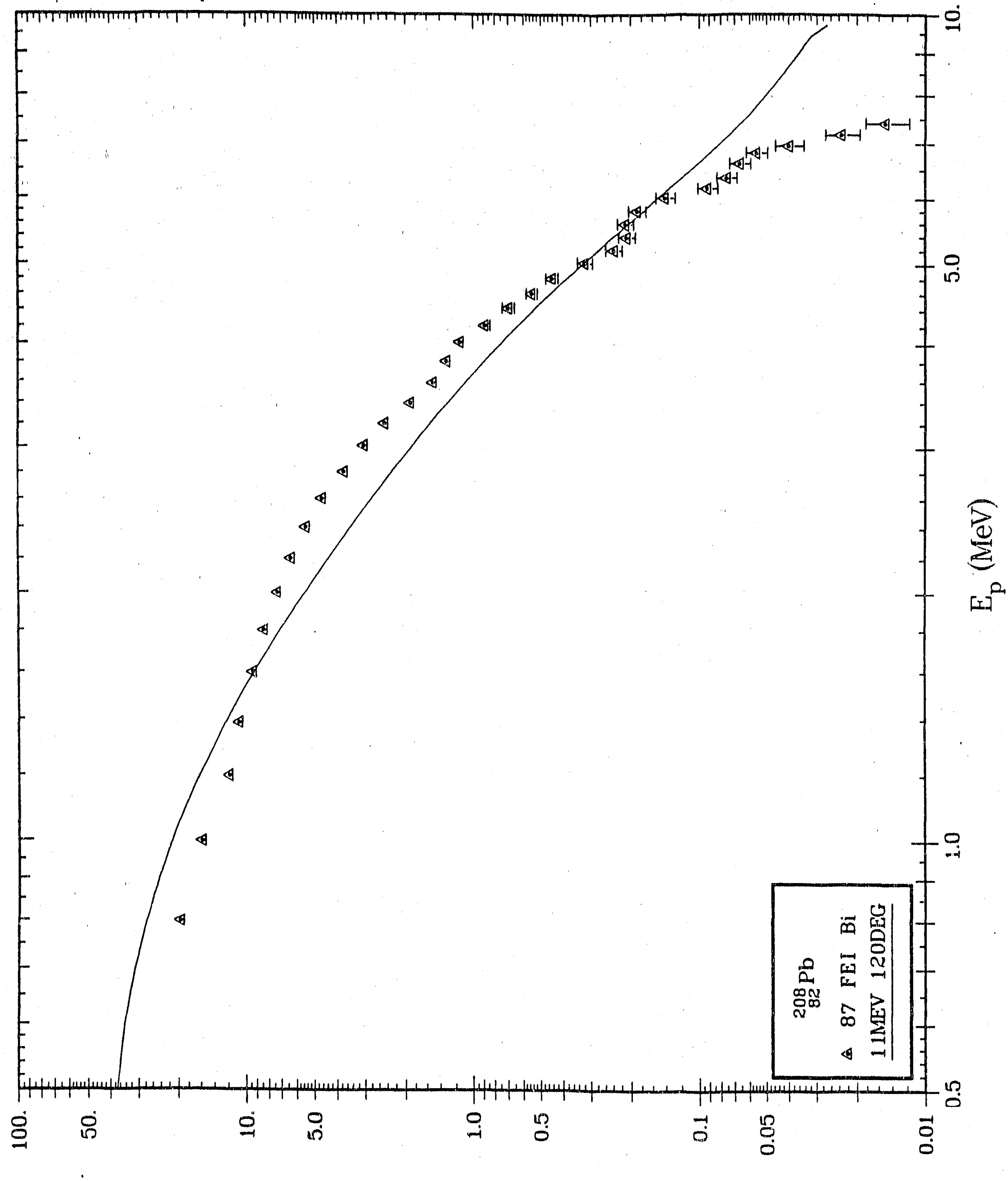
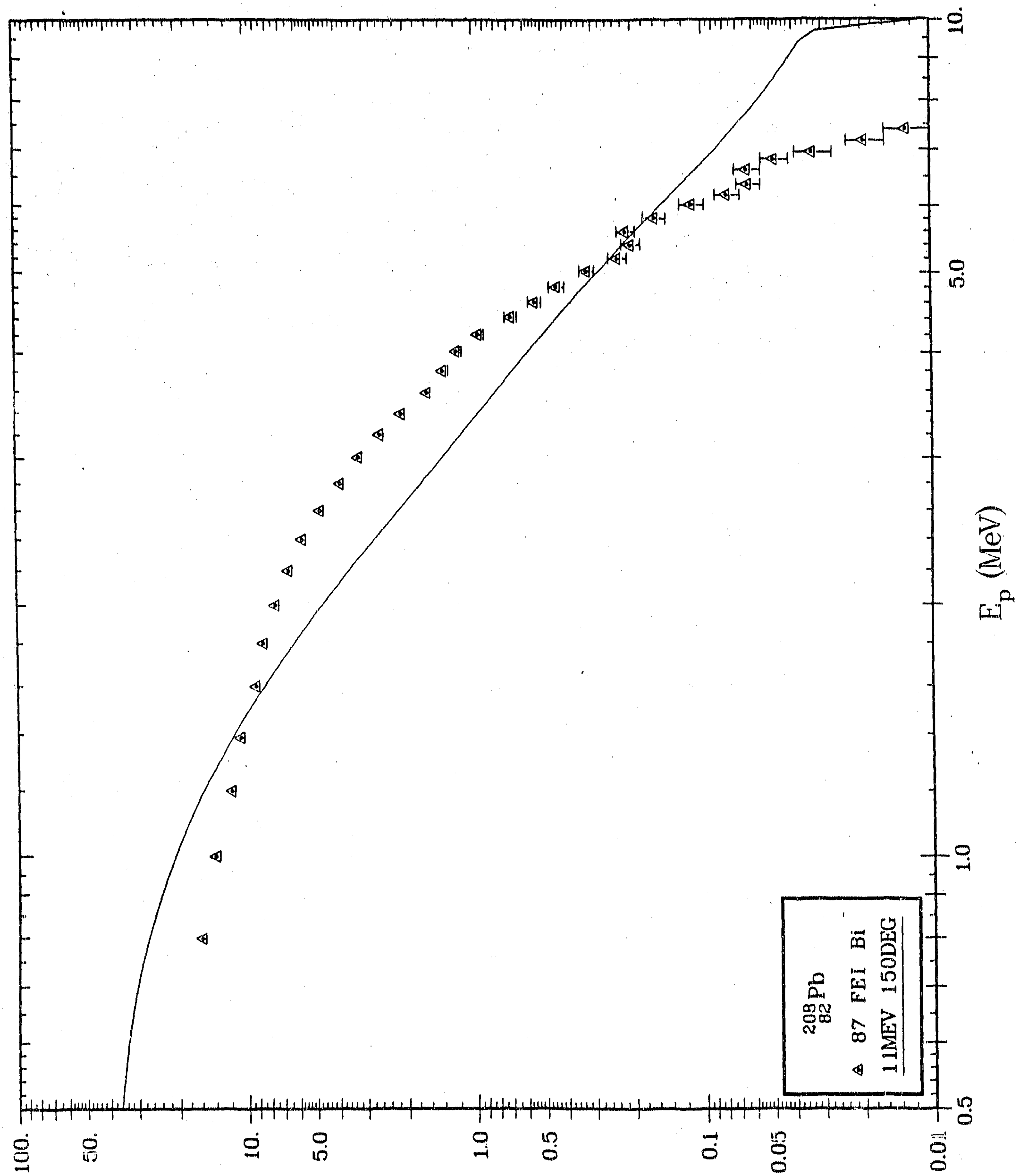
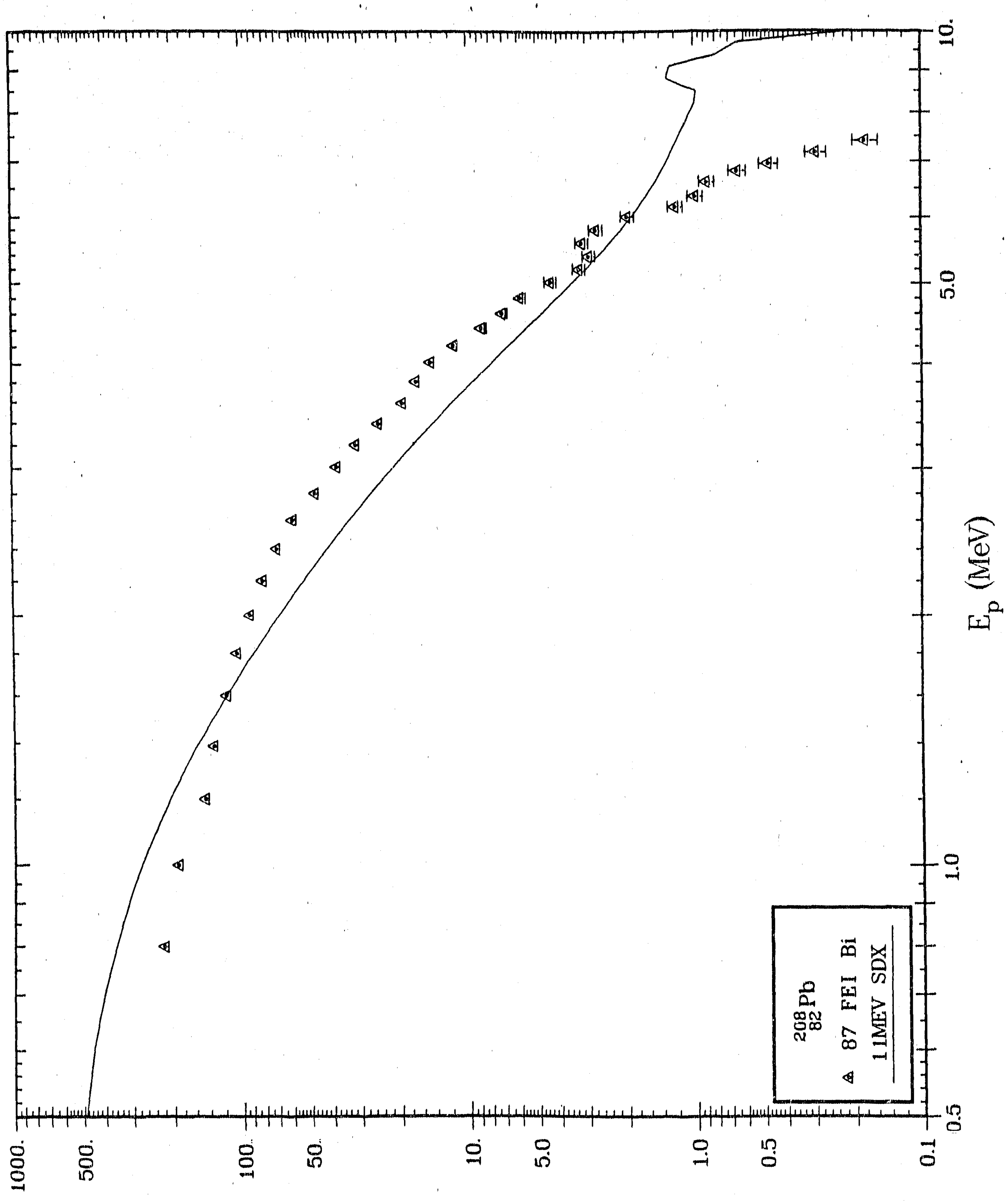

100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
0.5
1.0
5.0
10.
E_p (MeV)
$^{208}_{82}Pb$
87 FEI Bi
11MEV 120DEG

Fig. 40



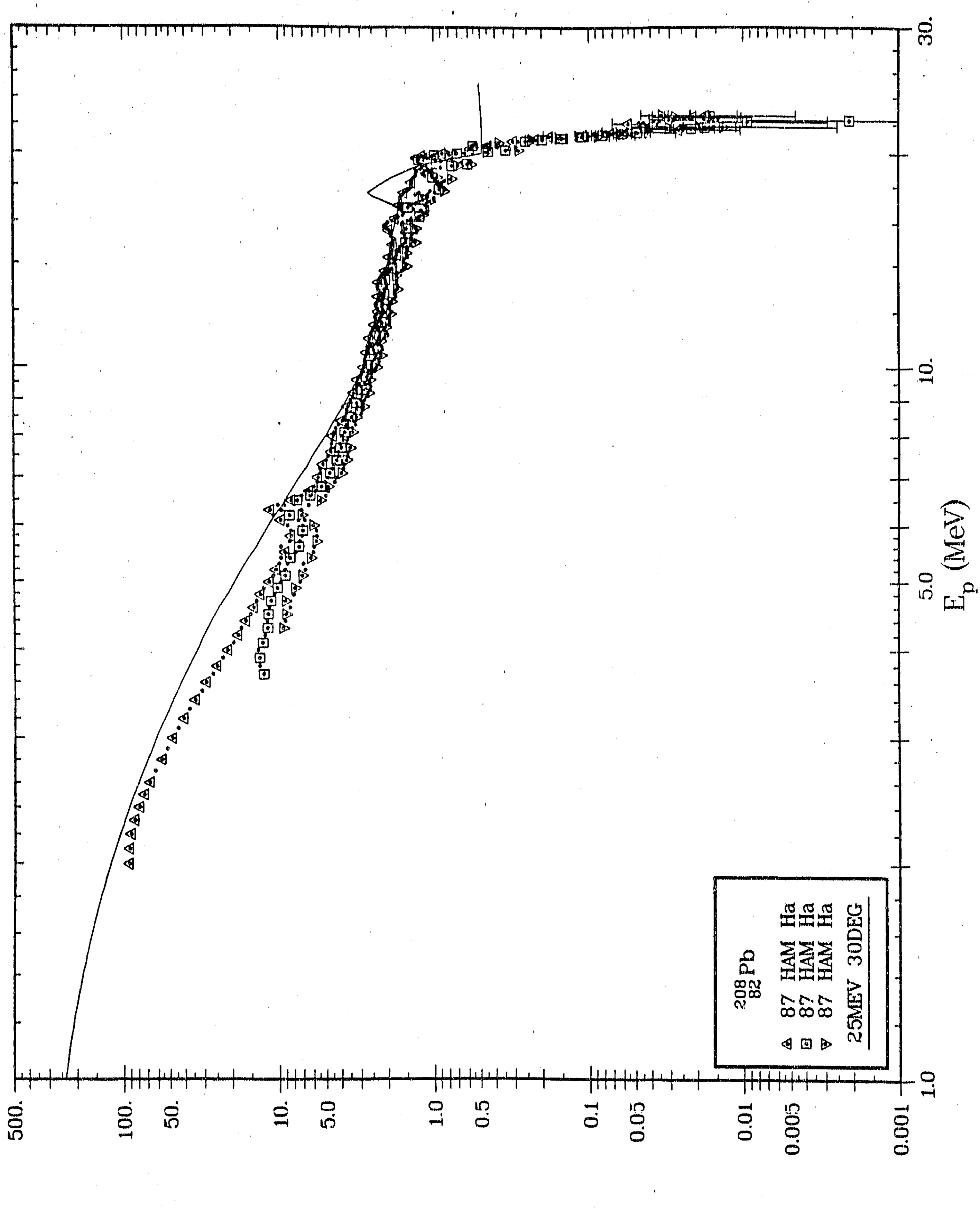
$^{208}_{82}Pb$
87 FEI Bi
11MEV 150DEG
E_p (MeV)
0.5
1.0
5.0
10.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01

Fig. 41



1000.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.5
1.0
5.0
10.
E_p (MeV)
$^{208}_{82}Pb$
87 FEI Bi
11MEV SDX

Fig. 42



500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
0.005
0.001
1.0
5.0
10.
30.
E_p (MeV)
$^{208}_{82}$Pb
87 HAM Ha
87 HAM Ha
87 HAM Ha
25MEV 30DEG

Fig. 43

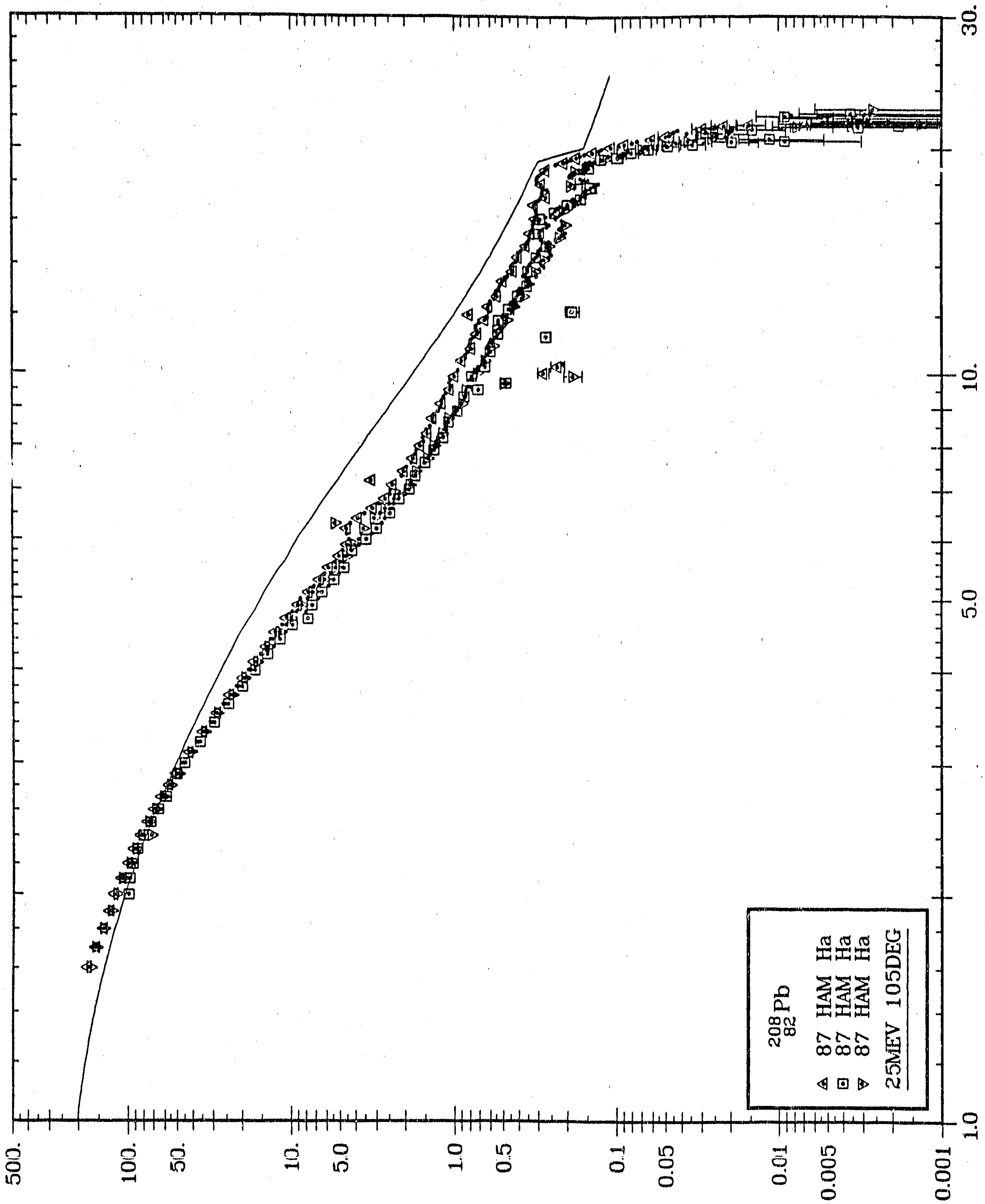
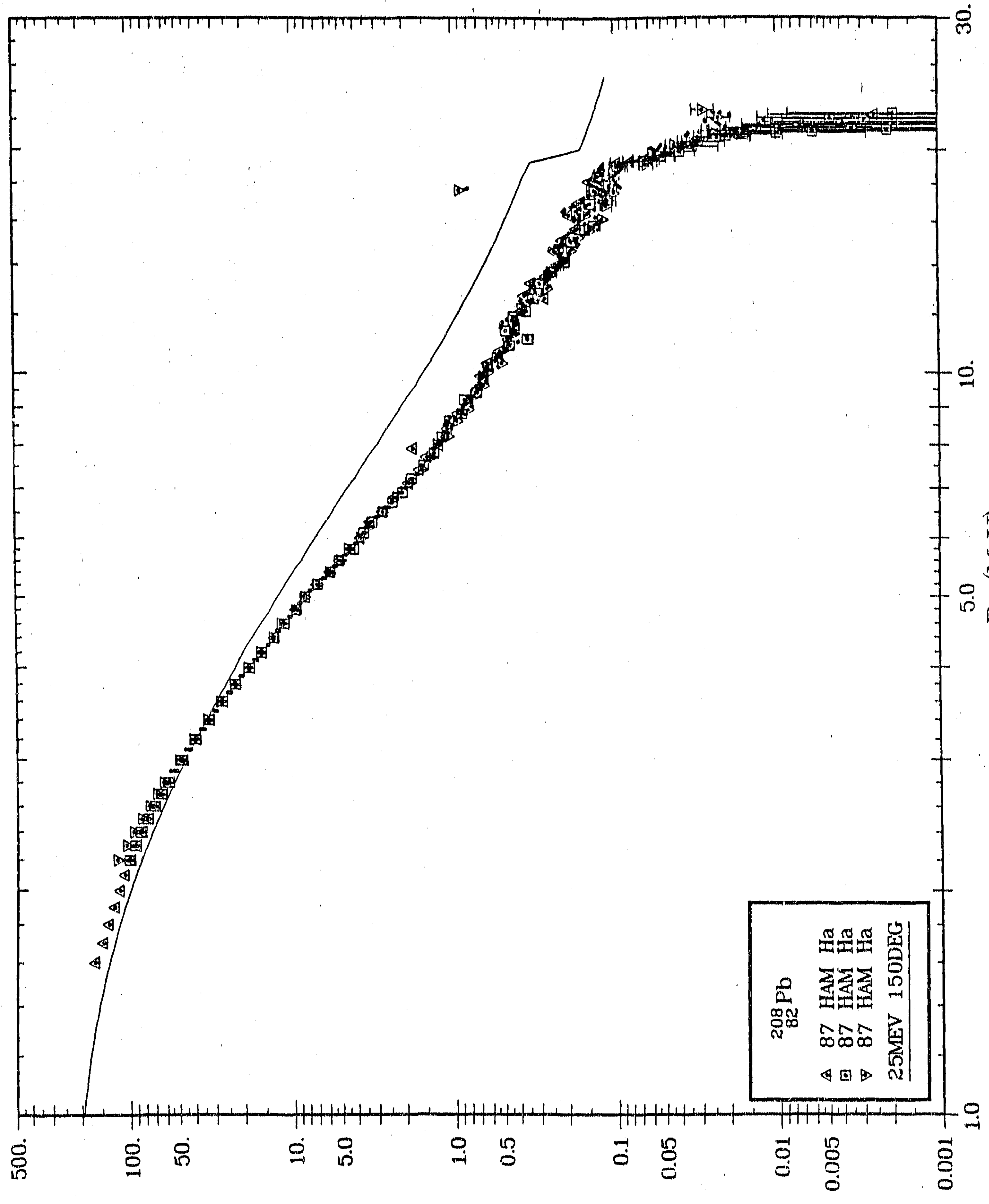
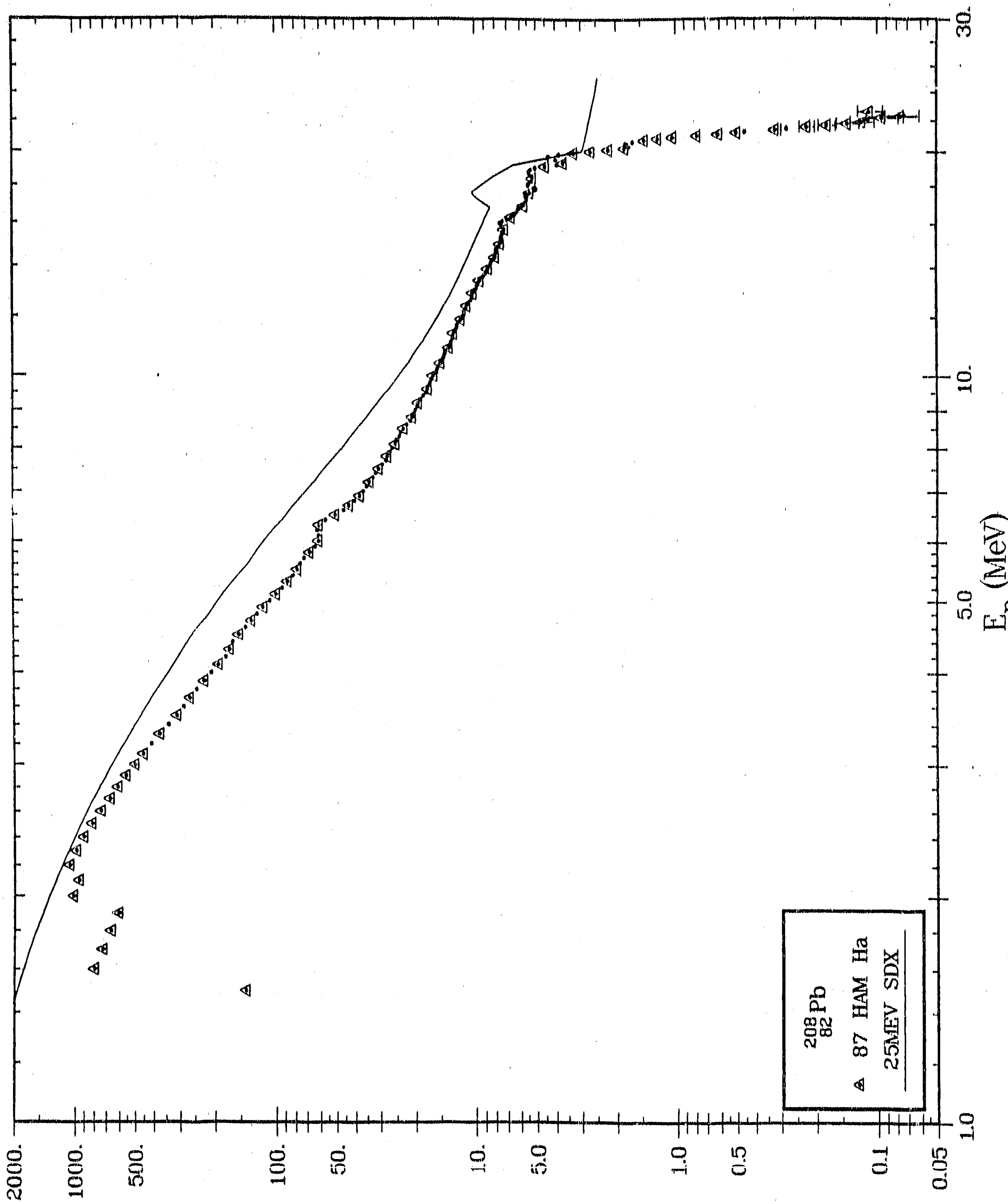

E_p (MeV)
$^{208}_{82}Pb$
87 HAM Ha
87 HAM Ha
87 HAM Ha
25MEV 105DEG
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
0.005
0.001
1.0
5.0
10.
30.

Fig. 44



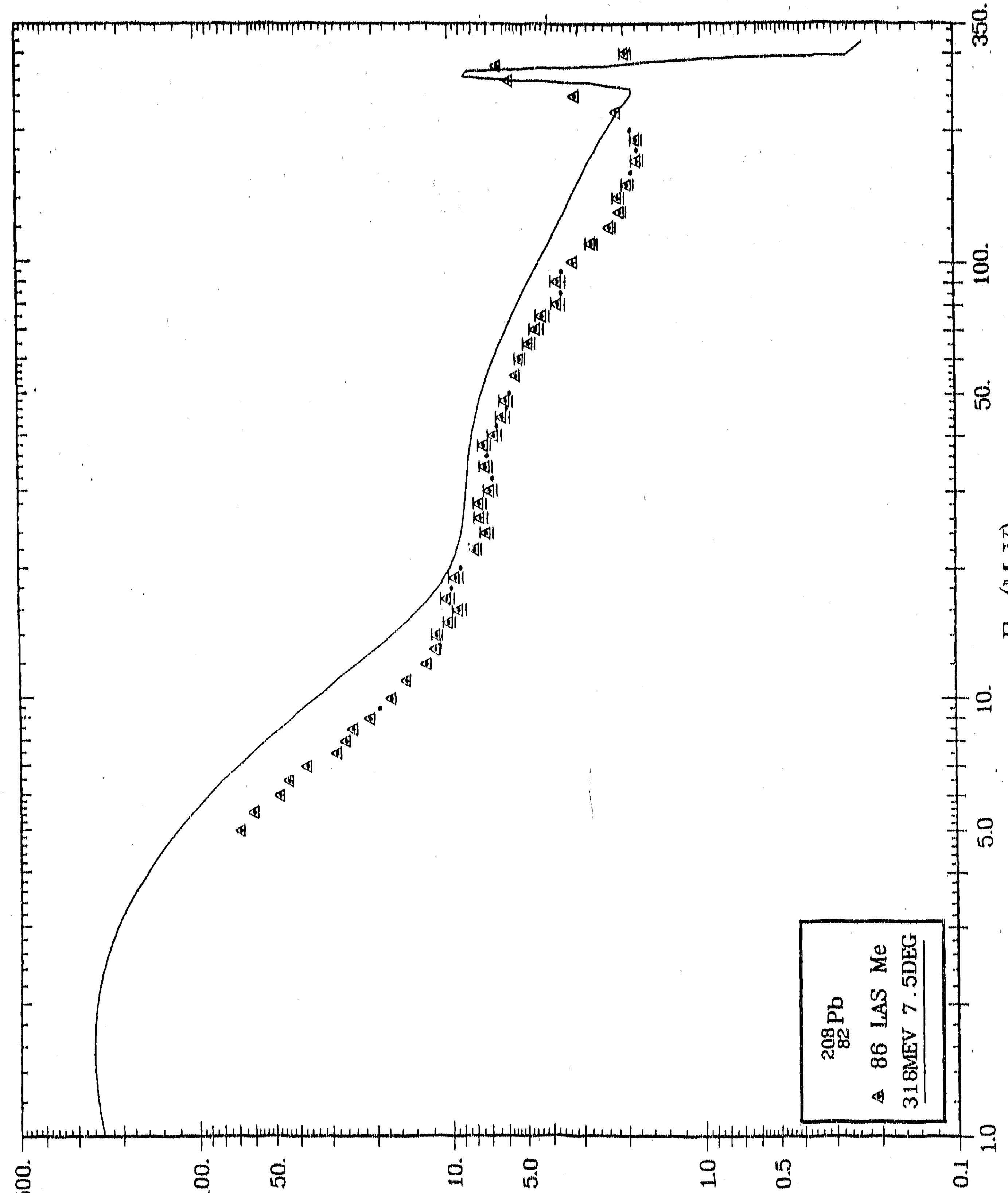
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
0.005
0.001
1.0
5.0
10.
30.
Ep (MeV)
208 82 Pb
87 HAM Ha
87 HAM Ha
87 HAM Ha
25MEV 150DEG

Fig. 45



2000.
1000.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
1.0
5.0
10.
30.
E_p (MeV)
$^{208}_{82}Pb$
87 HAM Ha
25MEV SDX

Fig. 46



500.
100.
50.
10.
5.0
1.0
0.5
0.1
1.0
5.0
10.
50.
100.
350.
E_p (MeV)
$^{208}_{82}$Pb
86 LAS Me
318MEV 7.5DEG

Fig. 47

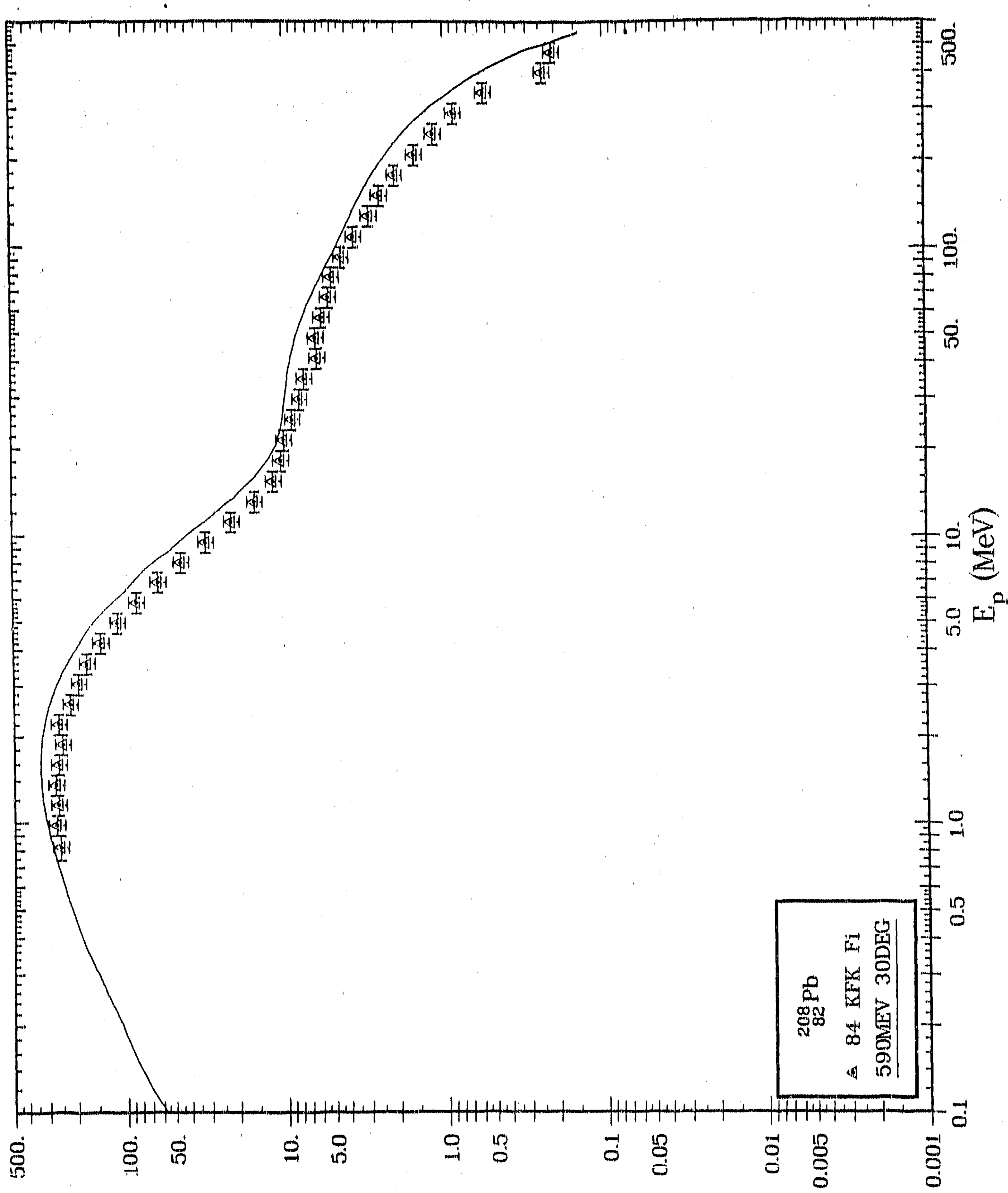
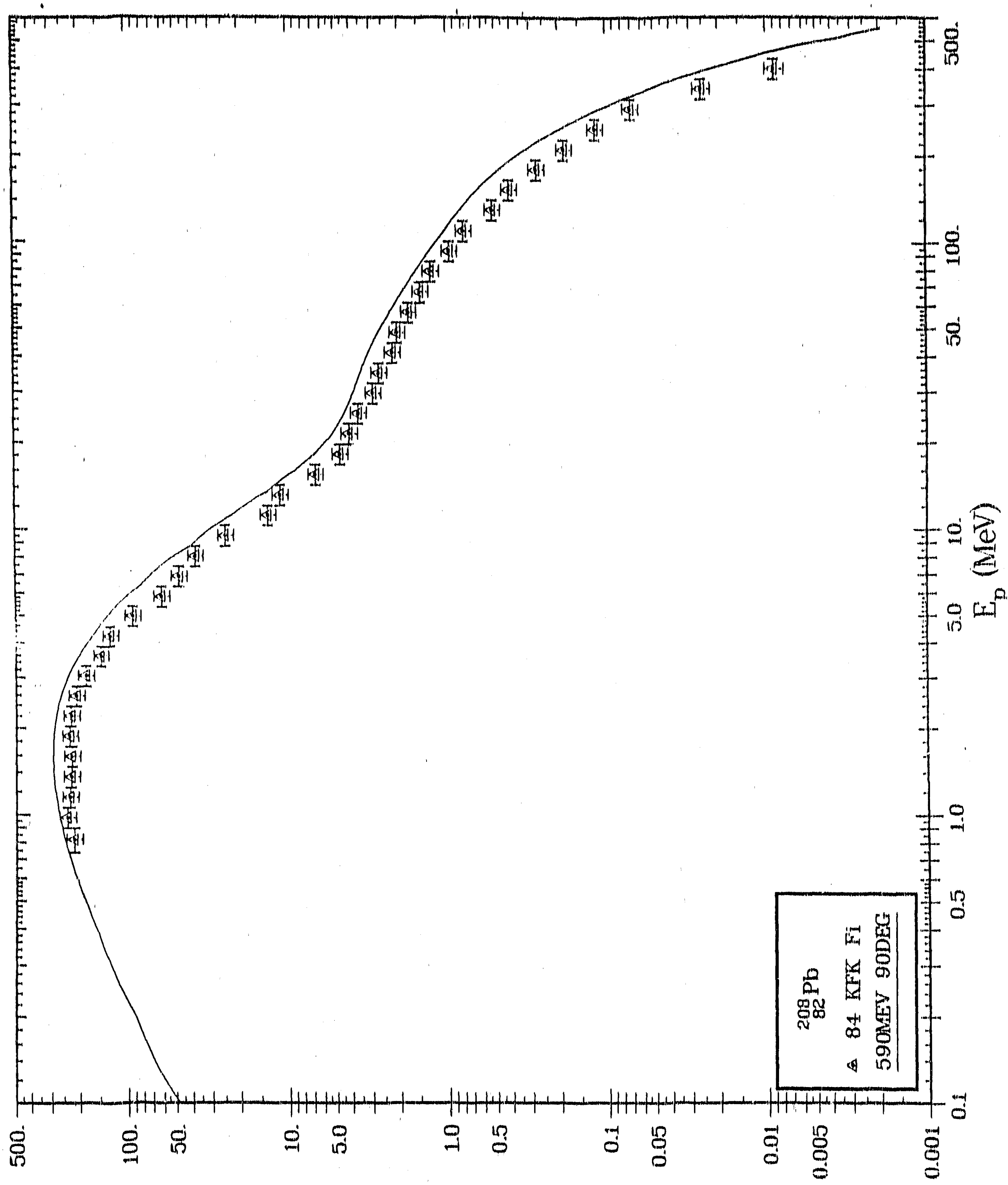
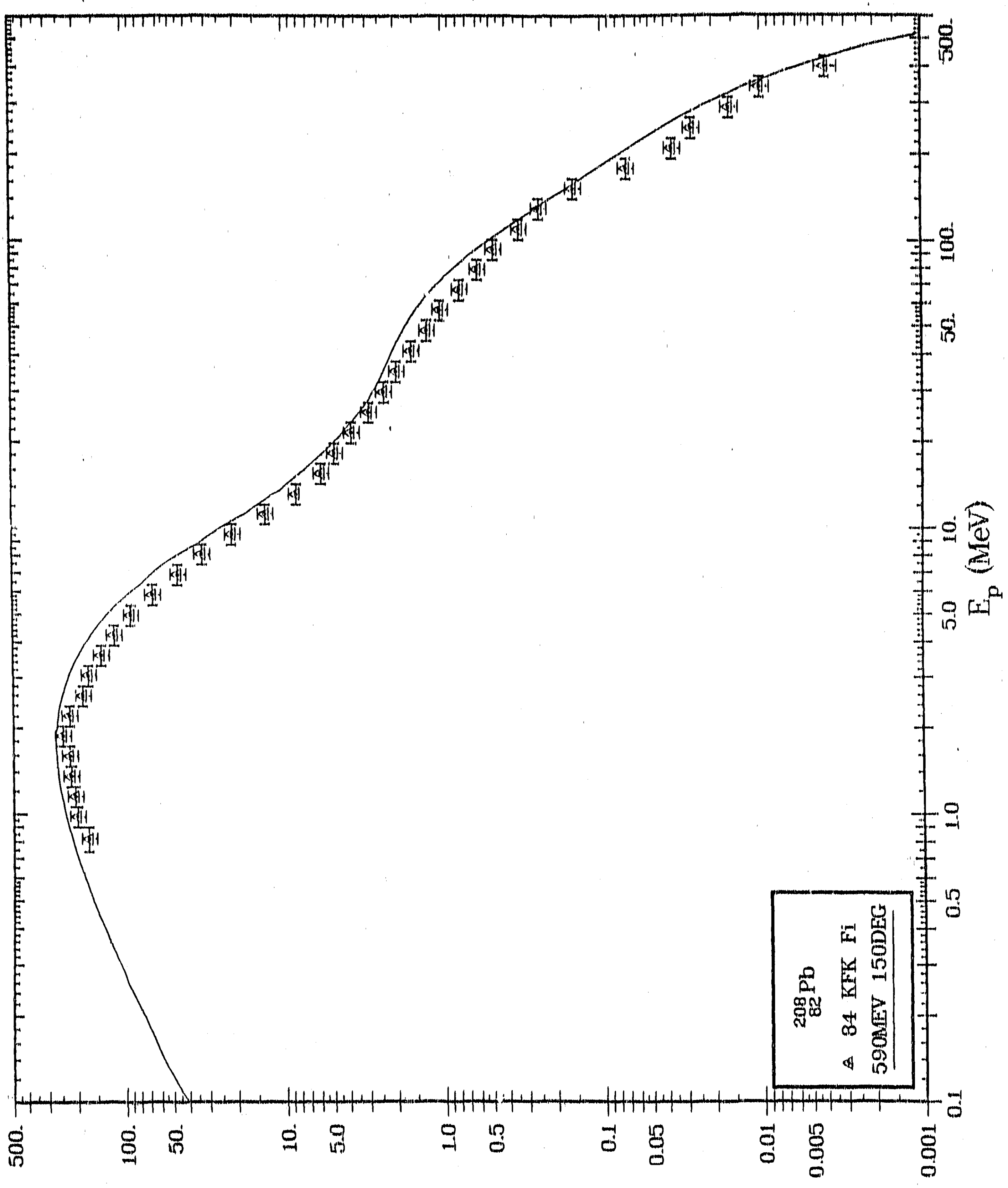

$^{208}_{82}$Pb
84 KFK Fi
590MEV 30DEG
E$_p$ (MeV)
0.1
0.5
1.0
5.0
10.
50.
100.
500.
0.001
0.005
0.01
0.05
0.1
0.5
1.0
5.0
10.
50.
100.
500.

Fig. 48



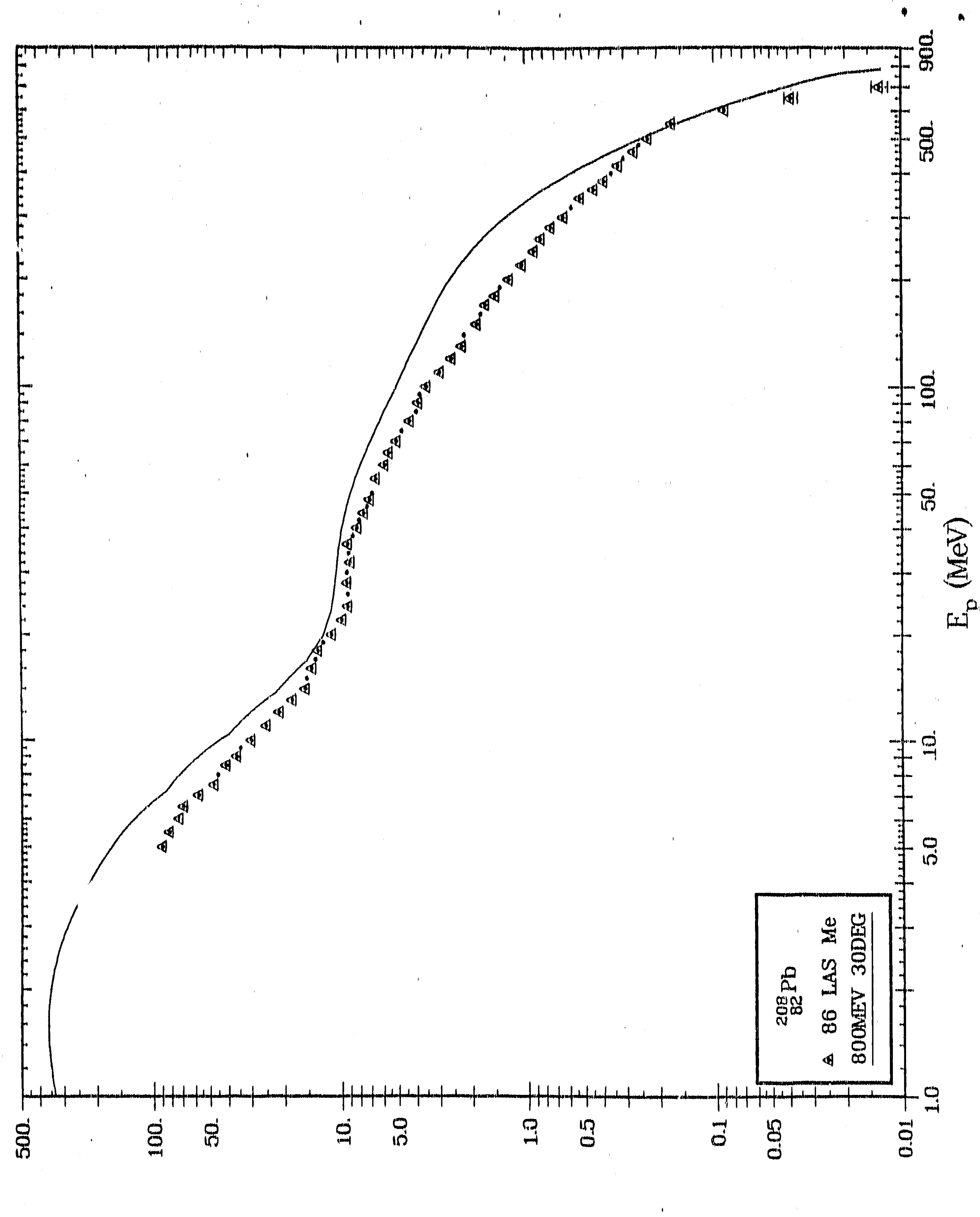
$^{208}_{82}$Pb
▲ 84 KFK Fi
590MEV 90DEG
E_p (MeV)
0.1
0.5
1.0
5.0
10.
50.
100.
500.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
0.005
0.001

Fig. 49



208 82 Pb
84 KFK Fi
590MEV 150DEG
Ep (MeV)
0.1
0.5
1.0
5.0
10.
50.
100.
500.
500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
0.005
0.001

Fig. 50



500.
100.
50.
10.
5.0
1.0
0.5
0.1
0.05
0.01
1.0
5.0
10.
50.
100.
500.
900.
E_p (MeV)
$^{208}_{82}$Pb
▲ 86 LAS Me
800MEV 30DEG

Fig. 51

- END -

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