## Title
Production Cross Sections for Positive and Negative Pi-Mesons by 345 MeV Protons on Carbon at 90 degrees to the Beam



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February 2, 1950

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# Production Cross Sections for Positive and Negative π-Mesons by 345 Mev Protons on Carbon at 90° to the Beam*

C. Richman and H. A. Wilcox

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February 2, 1950

We have recently developed a method for measuring the absolute production cross sections for positive and negative π-mesons when various kinds of nuclei are bombarded with high energy charged particles from the Berkeley 184-inch synchro-cyclotron. In this method the external beam from the cyclotron is allowed to pass through the target to be studied. It is then received in a Faraday cup and is integrated by means of conventional electronic methods. Positive and negative π-mesons produced by the beam leave the target with various energies $E_\pi$ and at various angles θ to the direction of the beam. Absorber blocks are arranged so that mesons leaving the target at any angle θ are stopped in these blocks at depths determined by the energies with which they emerge from the target. The absorber blocks are essentially infinite in extent so that the number of mesons scattered out through the lateral faces is a negligible fraction of the number which stop in the interior. Nuclear emulsions (Ilford C-3, 100 μ thick) are embedded in the absorbers to sample the population of stopped mesons.

The developed emulsions are scanned under high magnification (~ 600x). The ends of the meson tracks are distinguishable from the "background tracks" of other charged particles by their characteristic scattering and rapid change in grain density. In addition, mesons are characterized by the frequent occurence

* A preliminary account of this work was presented at the Physical Society meeting at Stanford University in December, 1949.

of secondary particles at the ends of the tracks. An observed meson is identified as a positive $\pi$ if it gives rise to a $\mu$-meson,[1] and as a negative $\pi$ if it produces a nuclear star.[2] Since negative $\pi$-mesons are known to produce stars in only 73 percent of the cases,[3] we take the true number of negative $\pi$'s to be 1.37 times the number of star producing mesons.

The number of mesons produced in the target per unit energy interval per unit solid angle is calculated from the number of mesons observed per unit volume of emulsion, the stopping powers of the emulsion[4] and the absorber used, and the geometry. The emulsion thickness prior to development has been determined by a simple technique to an accuracy of ± 2 percent.

The absolute differential meson production cross sections as calculated from the above data must be corrected for the number of $\pi$-mesons which are lost through decay in flight; this correction is less than 3 percent for mesons of all energies which we observed. In addition, the absolute cross sections are subject to systematic uncertainties arising from three effects. First, mesons may be lost through large angle nuclear scattering and nuclear absorption in the absorber blocks. The cross section for such events is unknown, but a reasonable estimate for the effect indicates that it would not greatly alter the general character of our results. We make no correction for this effect. Second, small angle scattering near the ends of the meson ranges may give a small systematic

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1 C. M. G. Lattes, H. Muirhead, G. P. S. Occhialini, and C. F. Powell, Nature <u>159</u>, 694 (1947)
C. M. G. Lattes, G. P. S. Occhialini, and C. F. Powell, Nature <u>160</u>, 453, 486 (1947)
J. Burfening, E. Gardner, and C. M. G. Lattes, Phys. Rev. <u>75</u>, 382 (1949)

2 D. H. Perkins, Nature <u>159</u>, 126 (1947)
G. P. S. Occhialini and C. F. Powell, Nature <u>162</u>, 168 (1948)
E. Gardner and C. M. G. Lattes, Science <u>107</u>, 270 (1948)

3 F. L. Adelman and S. B. Jones, Phys. Rev. <u>75</u>, 1468(A), (1949)

4 W. H. Barkas, A. S. Bishop, H. Bradner, and F. M. Smith, Phys. Rev. (in press)

error in the volume density of mesons stopped in the emulsions, because the scattering properties of the emulsions are not identical with those of the absorber blocks. Third, a small but uncertain fraction of the mesons stopped in the emulsion may be missed because of fatigue on the part of the observers or because the meson tracks occasionally occur with unfavorable characteristics for reliable identification. In virtue of these latter considerations we assign the usual statistical probable errors to our relative cross section values, whereas for the absolute values we assign an additional ± 15 percent to take account of the possible systematic errors in the method.

As a first application of the method we have chosen to study the positive and negative π-meson production by high energy protons on carbon. The external proton beam of the 184-inch cyclotron was used in this work. The beam current was $\sim 10^{-11}$ ampere; the mean proton energy was 345 Mev with an energy spread of about 2 Mev. Thin graphite targets were used. A preliminary study of the energy and angular distribution of mesons and of the other charged particles coming from the carbon target showed that the simple method described above for determining meson production cross sections is entirely satisfactory for observations at angles from about 60° to nearly 180° to the direction of the beam. For the forward angles, on the other hand, the background on the plates due to the protons scattered by carbon makes scanning very difficult. Hence our first work was confined to an observation angle $\theta = 90^\circ \pm 12^\circ$ to the direction of the beam.

Figure 1 shows the differential cross section $\sigma_+(E_\pi, 90^\circ)$, in $cm^2$ $Mev^{-1}$ $steradian^{-1}$ $nucleus^{-1}$, for the production of positive π-mesons in carbon by 345 Mev protons as a function of the energy of the mesons. This curve is based upon 205 observed π-μ events. The probable errors indicated on the graph are purely statistical in origin and are valid for the relative values of the plotted cross sections. To these errors must be added the above mentioned ± 15 percent to take account of possible systematic errors in the absolute values of the cross sections.

The integral of this curve over meson energy is $(2.0 \pm 0.5) \cdot 10^{-28}$ $cm^2$ steradian$^{-1}$ nucleus$^{-1}$.

Figure 2 shows the cross section $\sigma_-(E_\pi, 90^o)$, in $cm^2$ $Mev^{-1}$ steradian$^{-1}$ nucleus$^{-1}$, for the production of negative $\pi$-mesons in carbon by 345 Mev protons as a function of the meson energy. This curve is based upon 48 observed meson-initiated stars. The remarks about errors made in connection with Figure 1 also apply here. The integral of this curve over meson energy is $(4.0 \pm 1.6) \cdot 10^{-29}$ $cm^2$ steradian$^{-1}$ nucleus$^{-1}$.

Figure 3 gives the ratio $\sigma_-(E_\pi, 90^o)/\sigma_+(E_\pi, 90^o)$ as a function of the energy of the mesons. The probable errors indicated are purely statistical. The average value of this interesting ratio is $0.20 \pm .05$, and although the uncertainties are large owing to the scarcity of negative $\pi$'s, there seems to be some evidence for saying that this ratio falls off at the very high meson energies.

We wish to thank Professor E. O. Lawrence for his constant interest and encouragement during the whole course of this work. We wish also to thank Mr. J. Vale and the cyclotron crew for making the bombardments. This work was sponsored by the Atomic Energy Commission.

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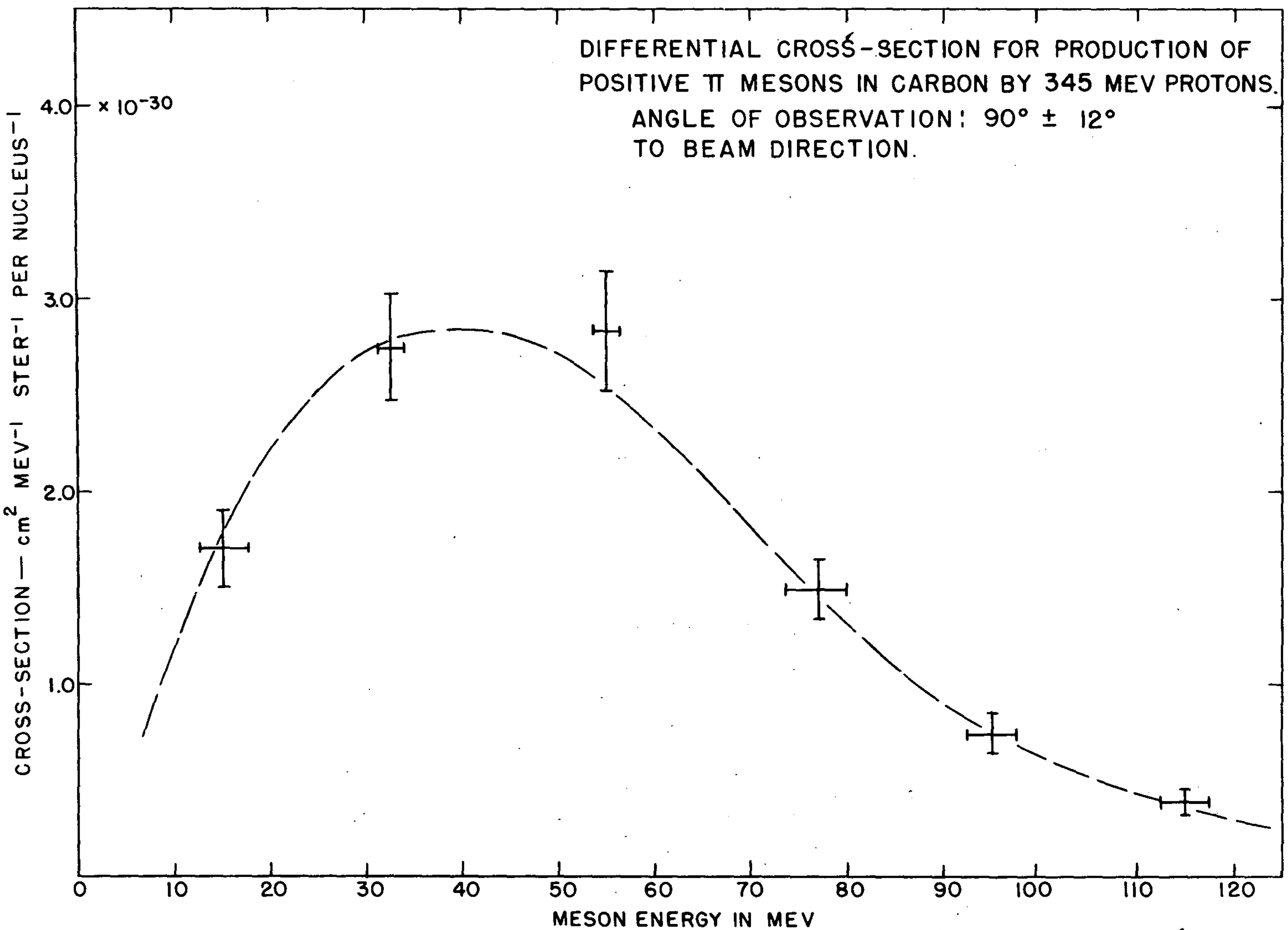


DIFFERENTIAL CROSS-SECTION FOR PRODUCTION OF POSITIVE π MESONS IN CARBON BY 345 MEV PROTONS.
ANGLE OF OBSERVATION: 90° ± 12° TO BEAM DIRECTION.
CROSS-SECTION — cm² MEV⁻¹ STER⁻¹ PER NUCLEUS⁻¹
× 10⁻³⁰
4.0
3.0
2.0
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
MESON ENERGY IN MEV


FIG. 1

OZ 825

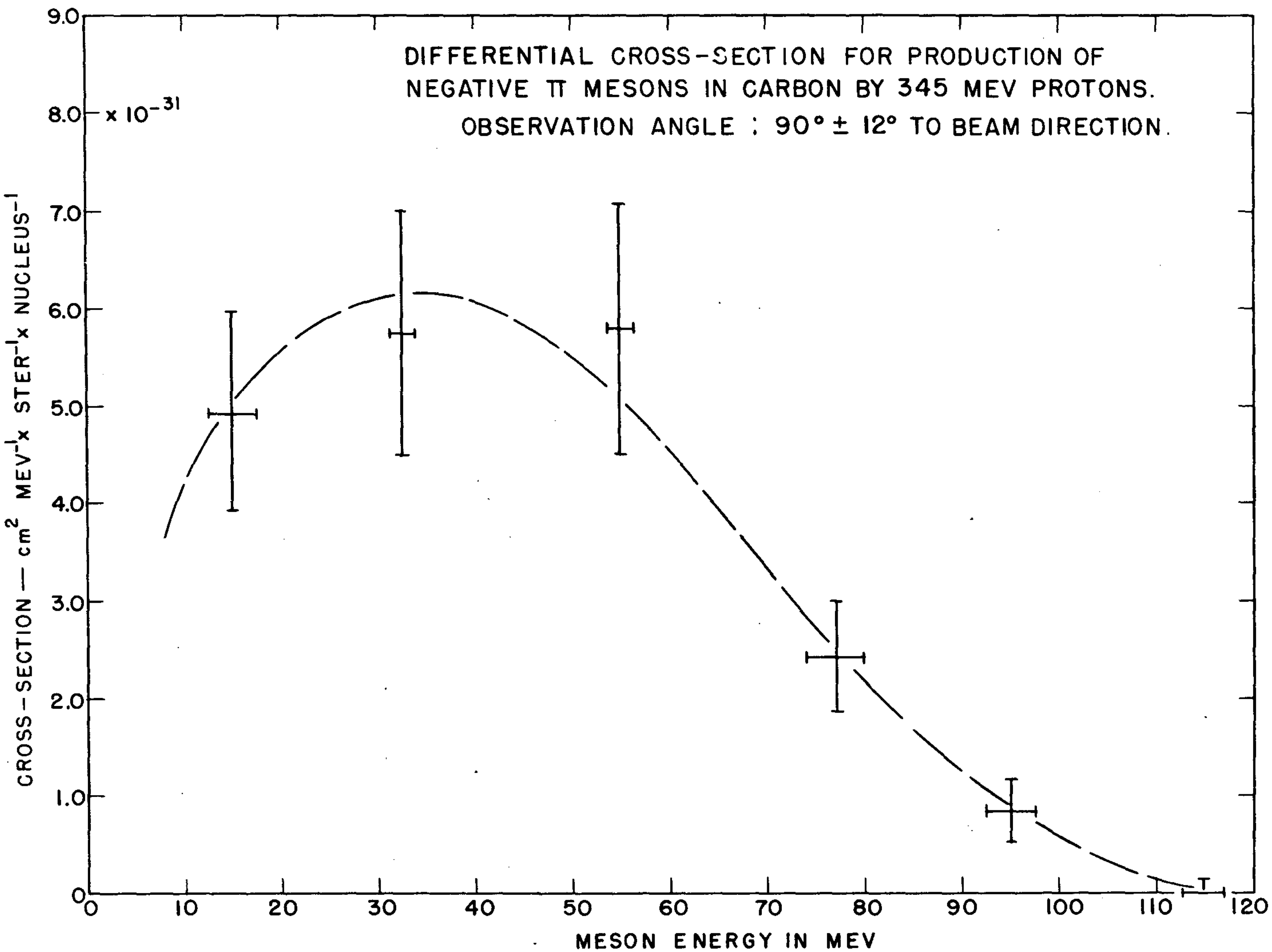
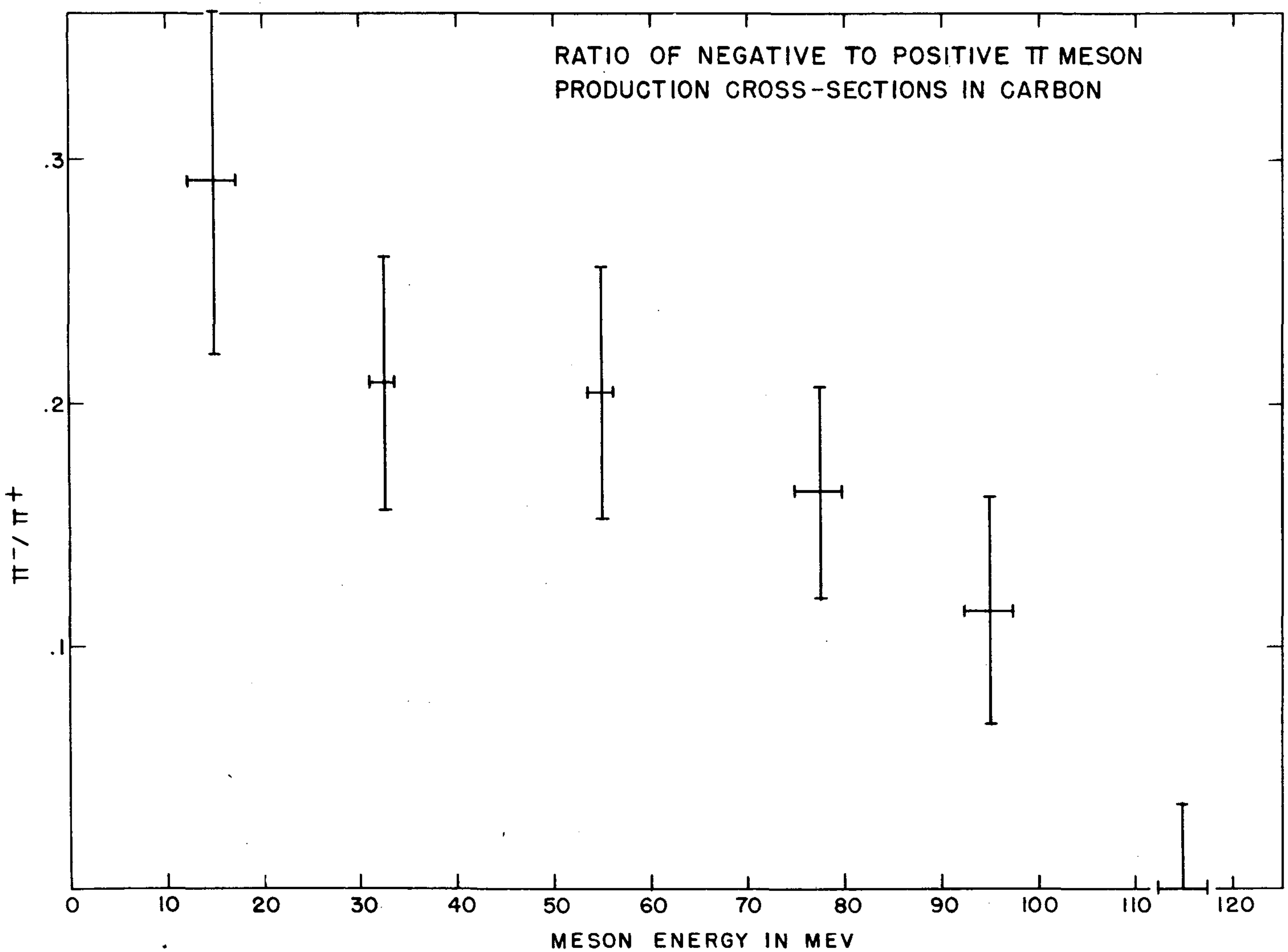

DIFFERENTIAL CROSS-SECTION FOR PRODUCTION OF
NEGATIVE π MESONS IN CARBON BY 345 MEV PROTONS.
OBSERVATION ANGLE : 90° ± 12° TO BEAM DIRECTION.
CROSS-SECTION — cm² MEV⁻¹ x STER⁻¹ x NUCLEUS⁻¹
x 10⁻³¹
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0
10
20
30
40
50
60
70
80
90
100
110
120
MESON ENERGY IN MEV

FIG. 2

OZ 826



RATIO OF NEGATIVE TO POSITIVE π MESON
PRODUCTION CROSS-SECTIONS IN CARBON
.3
.2
.1
π⁻/π⁺
0
10
20
30
40
50
60
70
80
90
100
110
120
MESON ENERGY IN MEV


FIG. 3

OZ 827