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EXCITATION FUNCTION FOR THE C^{12} (π^-, π^-n)C^{11} REACTION*

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The excitation function for the reaction C^{12} (π^-, π^-n) C^{11} has been measured for pion laboratory energies from 50 to 1610 MeV. The cross sections were found to peak at 200-MeV incident pion energy corresponding to the free particle π^-n (π^+p) resonance at 200 MeV.

Because of the short mean free path for pions in nuclear matter, simple nuclear reactions of the type Z^A (π^-, π^-n) Z^{A-1} and Z^A (π^-, π^-p) $Z-1^{A-1}$ are presumed to occur by single collisions on the surface of the nucleus. Both collision partners and any created particles escape from the nucleus without transferring energy to other nucleons in the nucleus. If energy transfer did occur, other nucleons would be emitted, and the simple reaction product would not be observed. This mechanism can be tested by comparing an experimental excitation function for a Z^A (π^-, π^-n) Z^{A-1} reaction with the excitation function for free-particle scattering of negative pions on neutrons. If the $J = T = 3/2$ resonance at 200 MeV in π^-n scattering appears as a peak at the same energy in the Z^A (π^-, π^-n) Z^{A-1} excitation function, then the reaction should proceed by a direct pion-neutron collision, in contrast to the incident pion's interacting with the nucleus as a whole. The only effect of the other nucleons is to provide the potential well in which the struck neutron moves.

We chose C^{12} as the target nucleus because of the short half life of C^{11} and because a convenient electronic method of detecting the decay of C^{11} was available. Carbon-12 in the form of polystyrene-terphenyl scintillator was bombarded with π^- mesons at the 184-in. cyclotron and at the Bevatron. The plastic scintillator was then mounted on a photomultiplier tube and the positrons from C^{11} decay were counted.

The pion beam was monitored by two plastic scintillator counters whose pulses were led to a fast-coincidence circuit and 40-Mc scaling system. The second counter defined the beam accepted by the monitor system. The plastic targets were taped to the rear side of the second counter and were the same diameter so that any pions passing through the second counter had to pass through the target also. Coincidence losses in this system were measured at the same beam level before and after target runs. Corrections due to coincidence loss typically were less than 10%. Pion beams of about 10^6 pions per min. over a 31.7 cm^2 area were commonly used. The pions were produced when the 730-MeV internal proton beam of the 184-in. cyclotron bombarded a Be target.

Muon contamination in the pion beam did not contribute to C^{11} production, but muons were detected by the counter telescope. The corrections for muons produced before the bending magnet were determined by range measurements in Cu and CH_2, and the corrections for muons produced after the bending magnet were determined by calculation. To correct for C^{11} activity produced by stray background in the meson cave, identical plastic scintillator targets were placed just out of the beam, irradiated for various periods, and counted in the C^{11} detection system. The C^{11} contribution from stray particles varied from about 50% at a pion energy of 50 MeV to less than 1% at a pion energy of 400 MeV.

Since the targets were 1-in.-thick, the cross sections were measured as a function of lucite thickness placed before the target, in order to determine the effect of secondary particles produced in the target itself. By extrapolation to zero target thickness, the correction for internally produced secondaries was found to be about 4% at 304 MeV. The dependence of this correction on energy is not known, so that it was assumed to be constant for a given amount of beam through the target.

The decay curve obtained by positron counting showed but one component --a 20.4-min. activity due to C^{11}. This decay curve was extrapolated to the time at the end of bombardment to obtain the initial activity, from which the cross section was calculated. The detection efficiency for C^{11} was determined in a separate experiment in which the source strength of C^{11} in plastic scintillator was measured by a beta-gamma coincidence technique. The counting rate of this source was then measured in our positron-detection system, and the efficiency was found to be 83±3%.

Measured cross sections are presented in Table I. The uncertainty in energy is due to the energy spread of the beam and to the energy lost in the target. The C^{12} $(\pi^-, \pi^- n)$ C^{11} excitation function is plotted in Fig. 1 along with the total cross section for $\pi^- n$ scattering (equal to the $\pi^+ p$ cross sections by charge independence.) The resonance for the reaction C^{12} $(\pi^-, \pi^- n)$ C^{11} is broader and lower than the free-particle $\pi^- n$ scattering resonance. This may be attributed to the neutron momentum distribution within the C^{12} nucleus.

Figure 2 shows a comparison of the C^{12} (p, pn) C^{11} and C^{12} $(\pi^-, \pi^- n)$ C^{11} cross sections plotted versus incident-particle momentum. The (p, pn) reaction is known to proceed by a direct-collision mechanism above 250 MeV.[1]

Because both the C^{12} (p, pn) C^{11} and C^{12} (π^-, π^-n) C^{11} reactions show the same momentum dependence, the reaction mechanism must be similar. The C^{12} (π^-, π^-n) C^{11} reaction follows a similar energy dependence as the free-particle π^-n cross section; therefore this mechanism must involve a direct collision between the incident particle and a neutron of C^{12}. This is true for proton energies as low as 70 MeV and for all pion energies above threshold. With suitable approximations, calculations show that the maximum probability for this type of reaction is for a collision to take place on the surface of the nucleus in order that all collision partners escape without further interactions.[2,3]

FOOTNOTE AND REFERENCES

*Work done under the auspices of the U.S. Atomic Energy Commission.

[1] S. Singh and J. M. Alexander, "A Recoil Study of the Reaction C^{12} (p, pn) C^{11}", Lawrence Radiation Laboratory Report UCRL-9911, October 24, 1961.

[2] T. A. J. Maris, P. Hillman, and H. Tyrén, Nuclear Phys. 7, 1 (1958).

[3] P. A. Benioff, Phys. Rev. 119, 324 (1960).

Table I. Cross sections for the reaction $C^{12}(\pi^-, \pi^- n)C^{11}$.

Incident-pion energy (MeV)	Cross section (mb)	
53 ± 5	3 ± 2	
60 ± 6	11 ± 2	
80 ± 8	39 ± 3	
127 ± 11	56 ± 4	a
179 ± 10	68 ± 6	
212 ± 10	68 ± 6	
245 ± 10	61 ± 6	
304 ± 9	42 ± 4	
342 ± 10	37 ± 4	
373 ± 10	30 ± 3	
423 ± 10	26 ± 8	
1000	18	b
1610 ± 20	21 ± 5	c

[a] The Pion beam was monitored by means of a calibrated ion chamber.

[b] This cross section was measured by A. M. Poskanzer, J. B. Cumming, G. Friedlander, J. Hudis, and S. Kaufman [Bull. Am. Phys. Soc. 6, 38 (1961)].

[c] The counter telescope was not used for this cross section. The pion flux was calculated from data supplied by Segrè group experimenters for the pion beam at the Bevatron.

FIGURE LEGENDS

Fig. 1. Cross section for C^{12} $(\pi^-, \pi^- n)$ C^{11} reaction plotted versus incident pion energy. The smooth curve is the total cross section for $\pi^- n$ free-particle scattering, which is equal to the total cross section for $\pi^+ p$ scattering by charge independence.

Fig. 2. Cross section for C^{12} $(\pi^-, \pi^- n)$ C^{11} reaction plotted versus the momentum of the incident pion. The smooth curve is the cross section for C^{12} (p, pn) C^{11} reaction plotted versus incident proton momentum. Data are taken from J. B. Cumming, G. Friedlander, and C. E. Swartz, Phys. Rev. 111, 1386 (1958) and other references listed therein.

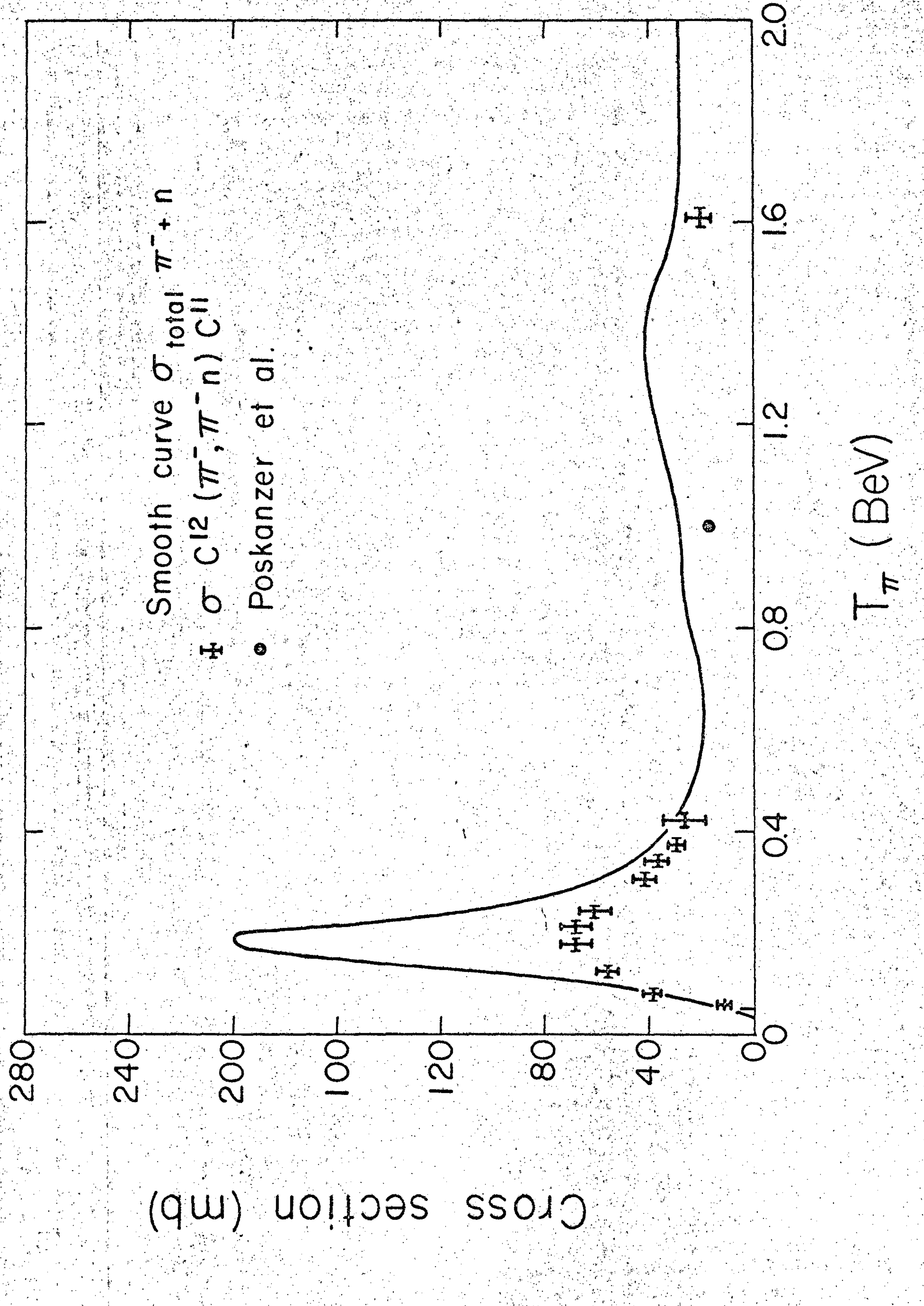

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Fig. 1

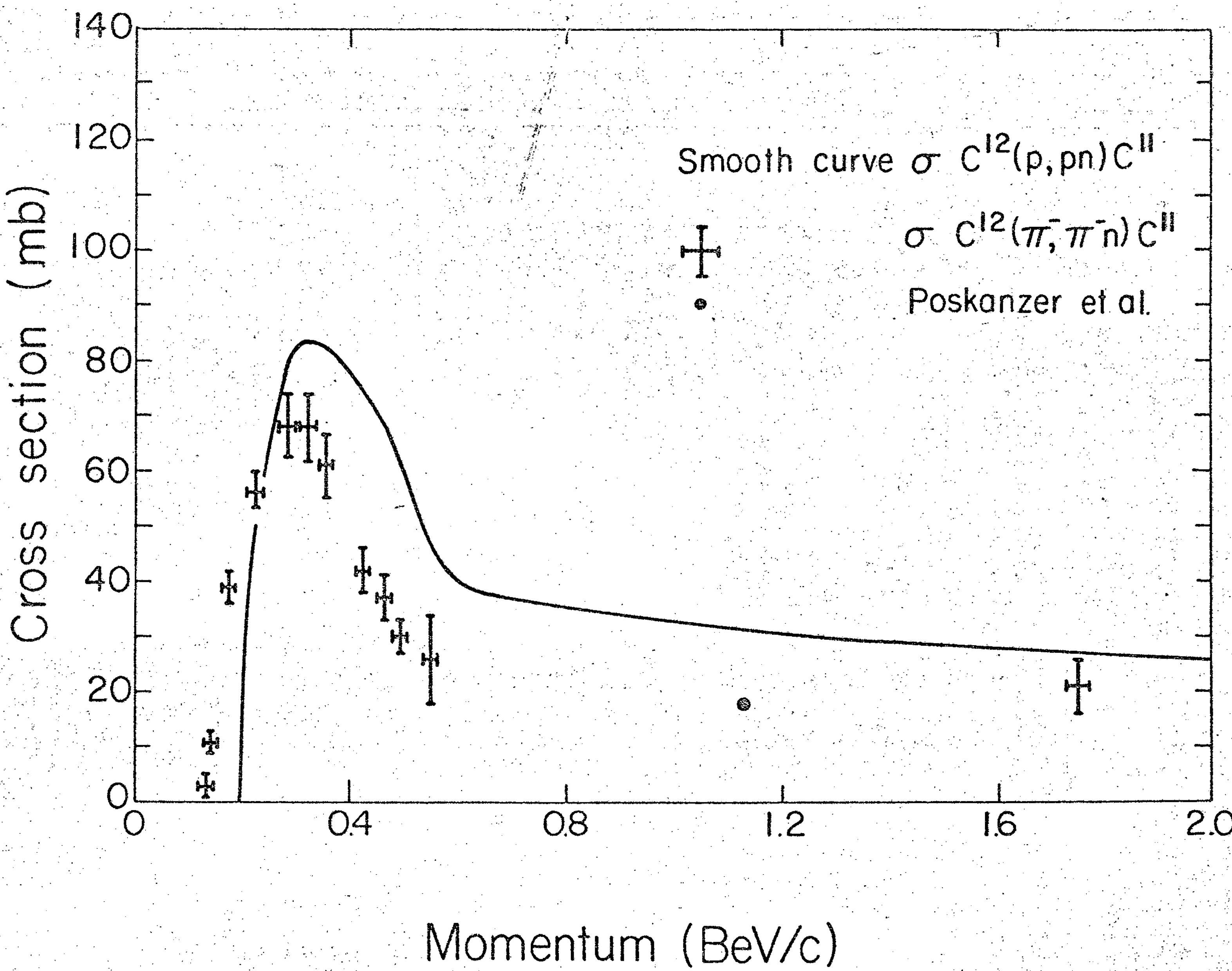

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Fig. 2