$^3P_1$ and $^1D_2$ amplitudes. This behavior, already present in the "box diagram," is clearly due to the opening of inelastic channels. We do not wish to enter the controversy about whether these should be called resonances.[13]

In conclusion, we have shown that, using OPE forces and the isobar model, a relativistic unitary theory of N-N scattering and single pion production at intermediate energies can adequately describe the inelastic cross section. To fit the elastic data, however, will require more detailed dynamics. Combining this three-body theory with what is known from one-boson-exchange potentials at lower energies should permit the extension of our understanding of nucleon-nucleon dynamics into this region. In particular, the spin-dependent cross sections around 1 GeV promise to be a very interesting testing ground for any model.

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Coherent Dissociation of Neutrons on Nuclei at 100 – 300 GeV/*c*

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We have studied the coherent dissociation of neutrons into $p\pi^-$ systems, for a variety of nuclear targets, at incident momenta up to 300 GeV/c. Using a model incorporating both electromagnetic and hadronic production, we have extracted total cross sections for scattering of unstable $p\pi^-$ systems on nucleons.

We have studied the dissociation of neutrons into $p\pi^-$ systems on the nuclear targets Be, C, Al, Ti, Cu, Ag, Ta, and Pb, for neutron momenta in the range 100–300 GeV/c. These measurements differ from those we made using a hydrogen target[1,2] in that no total-absorption calorimeter was present at the downstream end of the apparatus, and the use of a solid target precluded any measurement of the recoiling nucleus. Similar studies of neutron and proton dissociation at lower energies have been reported previously in the literature.[3] Although, for brevity, we shall often refer to $p\pi^-$ systems as N^*'s, this should not imply that these systems are necessarily resonant or of unique isotopic spin.

We restrict our discussion to N^*'s with invariant masses (m) in the range 1.165 to 1.85 GeV. Below 1.140 GeV, the very small opening angle of the proton and pion degrades the mass resolution and causes reconstruction losses which are difficult to assess in an accurate manner. Above 1.165 GeV, the mass resolution is ~15 MeV (standard deviation), the reconstruction efficiency is ~97%, and the spectrometer acceptance is always larger than 50% and, typically, about 75% for $m < 1.85$ GeV. All cross sections have been corrected for acceptance, as well as for losses due to δ rays striking the veto counters around the target [(5–11)%], and for small spark-chamber inefficiencies (typically 5%). Target-out corrections ranged from 4% to 20%, depending on mass range and specific target. The absolute normalization of the data is estimated as ± 10%, and relative normalization between elements as ± 3%.

A final, potentially important, correction to the data is the background due to other dissociation processes, such as $n+A\to p\pi^-\pi^0+A$, or $n+A\to n\pi^+\pi^-+A$, and that due to incoherent $p+\pi^-$ production. Assuming that the ratio of cross sections for neutron diffraction dissociation into two particles and into three particles is comparable to that observed for proton dissociation at lower energy,[3] we estimate that for small four-momentum transfers, $t'=|t-t_{\rm min}|<0.03$ (GeV/c)^2, such backgrounds are approximately 15% for $m<1.3$ GeV, and about 5% at the highest masses.

Coherent dissociation can proceed either through the strong nuclear force or through an electromagnetic interaction between the incident neutron and the nuclear Coulomb field. The atomic number dependence of the coherent diffractive production reaction, $n+A\to p\pi^-+A$, is strongly affected by the total cross section of the produced $p\pi^-$ system on nucleons. The nuclear diffractive cross section for a given mass range (Δm) and t' range ($\Delta t'$) is given in the optical model by[4]

$$\sigma_{\rm diff}(\Delta m,\Delta t')=\int_{\Delta m}dm\int_{\Delta t'}dt'|f_H(t')\cdot AF(\sigma_1,\alpha_1,\sigma_2,\alpha_2,c,a,t',m)|^2, \tag{1}$$

where $|f_H(t')|^2\equiv C_0\exp(-bt')$ is the cross section on hydrogen.

The eikonal approximation for the nuclear form factor F which we use is discussed in the paper by Kölbig and Margolis.[4] We have used $c=1.12A^{1/3}$ fm and $a=0.545$ fm for the parameters describing the nuclear half-density radius and skin thickness, respectively. The total neutron-nucleon cross section (σ_1) and the ratios of the real to imaginary parts of the forward elastic amplitudes for both the incoming and outgoing systems (α_1, α_2) have been fixed at 39 mb and 0, respectively.[5] In comparing this model to experimental results, it is common to take C_0, b, and σ_2 as free parameters. These parameters are somewhat coupled, and a reduction in the value of C_0 can often be accommodated, without a large increase in the χ^2 for a fit, by a corresponding reduction in σ_2. We have fixed the values of C_0 and b to be those directly measured in the hydrogen experiment.[1]

In the absence of interference between the two production processes,[6] the additional contribution to coherent dissociation from Coulomb production, for a target of charge Z, is

$$\sigma_{\rm Coul}(\Delta m,\Delta t)=\int_{\Delta m}dm^2\int_{\Delta t}dt\,\frac{Z^2\alpha}{\pi}\,\frac{\sigma_\gamma(m)}{(m^2-m_n^2)}\,\frac{t'}{t^2}\,|F_{\rm em}|^2, \tag{2}$$

where $\sigma_\gamma(m)$ is the cross section for $\gamma+n\to\pi^-+p$, at the γ-n center-of-mass energy specified by m.[7] The detailed definition of the electromagnetic form factor $F_{\rm em}$ is given in Fäldt[8] and Bemporad *et al.*[9] Because Coulomb production occurs primarily at large distances from the nucleus,[10] this contribution to the coherent cross section is essentially independent of any reasonable variation of the parameters σ_1, σ_2, α_1, α_2, c, and a.

Figure 1 serves to indicate the sensitivity of the data to σ_2. Figure 1(a) displays the t' dependence in Cu for neutron momenta between 200 and 260 GeV/c, and for $1.35<m<1.45$ GeV; Fig. 1(b) provides, for the same mass and momentum band, the dependence of the cross section on A. The solid curves represent the sums of the calculations for $\sigma_{\rm diff}$ (as a function of σ_2) and $\sigma_{\rm Coul}$. The Coulomb contribution alone is shown as a dashed line. In all of our calculations we have included the effects of finite experimental resolution in t'.[11]

Figure 2 shows the mass spectra for two different regions of t': (a) $t'<0.001$ (GeV/c)^2 where Coulomb production is most important, and (b) $0.005<t'<0.03$ (GeV/c)^2, which, particularly for the lower-Z targets, includes most of the coherent signal. The data in Fig. 2 indicate substantial Coulomb production of $\Delta(1236)$, especially at small t', where the cross section is also ap-

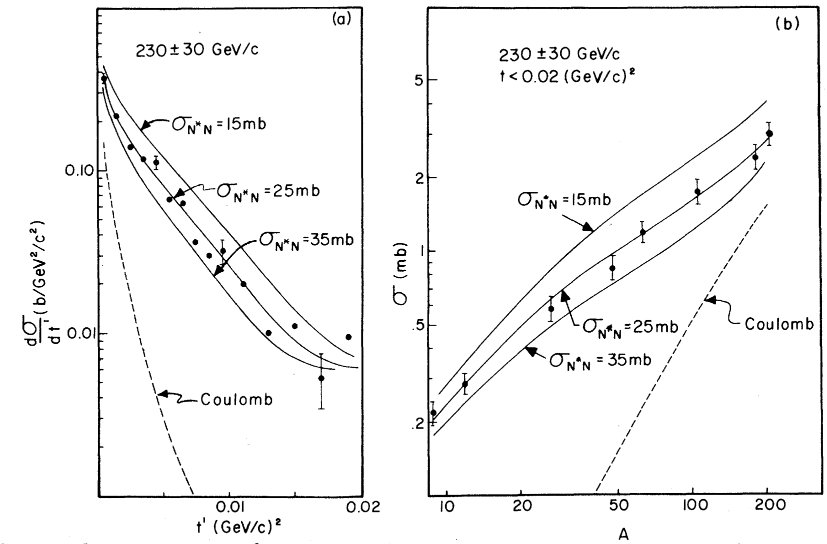

FIG. 1. (a) Differential cross section for neutron dissociation into $p\pi^-$ on copper, for 1.35 GeV < m < 1.45 GeV. (b) A dependence of the cross section for the same mass range as in (a). The solid and dashed curves are based on calculations discussed in the text. (Typical error bars are shown on the data points.)

proximately proportional to Z^2. The calculated contribution from Coulomb production in Pb is shown as a shaded band in Fig. 2(a). The width of the band indicates the uncertainty in the calculation due to the uncertainty in the measurement of $\sigma_\gamma(m)$. The calculation agrees with the Pb data up to a mass of ~ 1.3 GeV, beyond which a contribution from diffractive production becomes apparent. The cross section for diffractive dissociation appears to peak at a mass of ~ 1.35 GeV [see Fig. 2(b)].

The energy dependence of the production cross section is shown in Table I. The cross sections are essentially independent of momentum, except for elements with large Z, where some increase with momentum is expected due to the contribution from electromagnetic production in these elements.

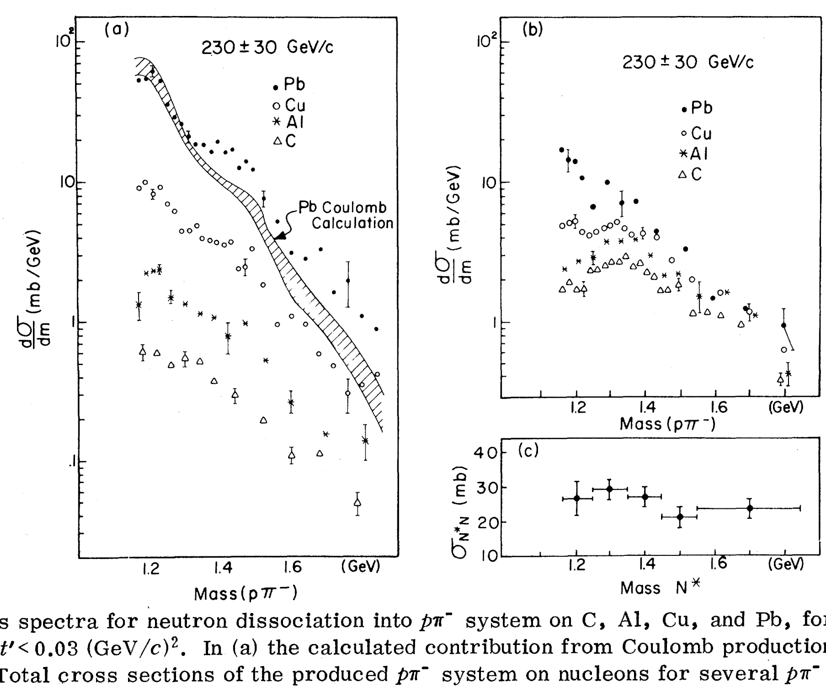

FIG. 2. (a) Mass spectra for neutron dissociation into $p\pi^-$ system on C, Al, Cu, and Pb, for $t' < 0.001$ (GeV/c)^2, and (b) for $0.005 < t' < 0.03$ (GeV/c)^2. In (a) the calculated contribution from Coulomb production in Pb is shown as a shaded band. (c) Total cross sections of the produced $p\pi^-$ system on nucleons for several $p\pi^-$ mass intervals.

TABLE I. Coherent production cross sections for $n+A \to p\pi^- + A$.

$M(p\pi^-)$ (GeV)	P_{inc} [a] (GeV/c)	Cross Section [b] (mb) for 0.0 < t' < .03 (GeV/c)^2							
		Be	C	Al	Ti	Cu	Ag	Ta	Pb
1.165-1.25	100-150	.23 ± .03	.32 ± .05	.63 ± .09	1.1 ± .2	1.6 ± .2	2.9 ± .4	4.7 ± .7	5.3 ± .7
	150-200	.22 ± .03	.28 ± .04	.62 ± .09	1.0 ± .2	1.5 ± .2	2.8 ± .4	5.0 ± .7	5.7 ± .8
	200-260	.19 ± .03	.24 ± .03	.50 ± .07	.9 ± .2	1.6 ± .2	3.0 ± .4	6.1 ± .8	7.2 ± 1.0
	260-300	.17 ± .03	.24 ± .04	.56 ± .09	1.2 ± .2	1.7 ± .2	3.4 ± .5	7.9 ± 1.2	8.8 ± 1.2
1.25 -1.35	100-150	.33 ± .04	.46 ± .06	.76 ± .1	1.2 ± .2	1.4 ± .2	2.8 ± .3	3.8 ± .5	3.6 ± .5
	150-200	.27 ± .03	.38 ± .04	.69 ± .09	.9 ± .2	1.5 ± .2	2.4 ± .3	3.2 ± .4	3.6 ± .4
	200-260	.28 ± .03	.39 ± .05	.64 ± .08	.9 ± .2	1.4 ± .2	2.3 ± .3	3.7 ± .5	4.3 ± .5
	260-300	.27 ± .04	.39 ± .05	.81 ± .11	1.1 ± .2	1.6 ± .2	2.9 ± .4	4.6 ± .6	5.2 ± .7
1.35 -1.45	100-150	.30 ± .04	.40 ± .05	.78 ± .10	.8 ± .2	1.4 ± .2	2.0 ± .2	2.5 ± .4	2.6 ± .4
	150-200	.26 ± .03	.37 ± .04	.65 ± .08	.7 ± .1	1.2 ± .1	1.6 ± .2	2.3 ± .3	2.4 ± .3
	200-260	.26 ± .03	.34 ± .04	.63 ± .08	.9 ± .1	1.2 ± .1	1.9 ± .2	2.5 ± .3	3.1 ± .4
	260-300	.27 ± .03	.39 ± .05	.78 ± .10	1.1 ± .2	1.3 ± .2	2.3 ± .3	4.0 ± .6	3.9 ± .5
1.45 -1.55	100-150	.18 ± .02	.28 ± .03	.49 ± .06	.54 ± .08	.9 ± .1	1.1 ± .2	1.6 ± .3	2.0 ± .3
	150-200	.17 ± .02	.19 ± .02	.41 ± .05	.58 ± .08	.8 ± .1	1.1 ± .1	1.5 ± .2	1.7 ± .2
	200-260	.16 ± .02	.23 ± .03	.41 ± .05	.54 ± .07	.8 ± .1	1.2 ± .2	1.8 ± .2	2.1 ± .3
	260-300	.19 ± .03	.22 ± .03	.53 ± .07	.59 ± .10	.9 ± .1	1.7 ± .2	2.5 ± .4	2.5 ± .4
1.55 -1.85	100-150	.21 ± .03	.30 ± .04	.67 ± .09	.80 ± .12	1.0 ± .1	1.4 ± .2	1.9 ± .3	2.1 ± .3
	150-200	.21 ± .03	.29 ± .04	.49 ± .06	.78 ± .11	1.0 ± .1	1.3 ± .2	1.9 ± .3	1.6 ± .2
	200-260	.19 ± .02	.29 ± .03	.50 ± .06	.65 ± .09	.9 ± .1	1.4 ± .2	1.6 ± .2	2.0 ± .3
	260-300	.24 ± .03	.31 ± .04	.70 ± .10	.88 ± .14	1.0 ± .1	1.6 ± .2	2.6 ± .4	2.5 ± .4

[a]The mean values of the incident momenta for the four momentum bands in this table are 127, 176, 230, and 275 GeV/c.
[b]The error contain statistical and systematic contributions, all added in quadrature.

Figure 2(c) displays the results of our extraction of σ_2. The large uncertainty in σ_2 for the lowest mass band is partly due to the fact that the hadronic component of the cross section, which is sensitive to σ_2, is small compared to the electromagnetic part. Moreover, there is a large uncertainty (± 15%) in the Coulomb calculation for this mass interval due to discrepancies in the various photoproduction experiments.[7] Nevertheless, it is clear that the extracted N^*-nucleon total cross sections are considerably lower, particularly at large masses, than the neutron-nucleon cross section. This result is similar to that reported recently in an investigation of coherent production of $p\pi^+\pi^-$ systems at lower incident momenta.[12]

Finally we point out that σ_2 may be a function of the spin state of the N^*.[13] However, because our neutron beam is unpolarized, we cannot examine the dependence of σ_2 on the specific angular momentum state of the N^*. Furthermore, it has been shown that neglecting possible nucleon helicity-flip contributions to coherent production (as was done in the model of Ref. 4) can lead to an underestimate of the apparent value of the N^*-nucleon total cross section, particularly at larger N^* mass values. Calculations are presently in progress to gauge the sensitivity of σ_2 to such helicity-flip terms in coherent production.

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[5]Small variations in these parameters do not materially affect the determination of σ_2. Because the statistical uncertainty of our data precludes the simultaneous extraction of the α_i and σ_2 projecting from results for

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[11]The spectrometer's angular resolution (55 μrad) was determined by fitting the resolution-broadened Coulomb calculation to the measured differential cross section on Pb, at very small t, for masses near $\Delta(1236)$. We have also included in our analysis effects of multiple Coulomb scattering in the targets.

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Observation of μe Events in $\bar{\nu}$ and ν Interactions in Neon

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Based on four μ^+e^-X and six μ^-e^+X events (with estimated backgrounds 1.1 and 0.6 events, respectively), in the Fermilab 15-in. neon (64 at.%) hydrogen bubble chamber, the fractions of μ^+e^- and μ^-e^+ production relative to $\bar{\nu}_\mu$ and ν_μ charged-current interactions in a broad band $\overset{(-)}{\nu}$ beam are, respectively, $\bar{f} = (0.15^{+0.14}_{-0.08})\%$ and $f = (0.34^{+0.23}_{-0.13})\%$; $\bar{f}/f = 0.45^{+0.6}_{-0.3}$.

Considerable attention has been given to the reaction $\nu_\mu N \to \mu^- e^+ X$ which occurs at a fractional rate $f \sim \frac{1}{2}\%$ of all ν_μ charged-current (CC) interactions.[1] The most popular interpretation of this phenomenon, and of the $\mu^-\mu^+$ events reported in both ν_μ and $\bar{\nu}_\mu$ interactions,[2] is that they are due to the production of charmed particles which decay (semi-) leptonically. A 90%-confidence upper limit of $\frac{1}{2}\%$ was set[3] previously on the fractional rate $\bar{f}$ of the $\bar{\nu}_\mu$ reaction $\bar{\nu}_\mu N \to \mu^+ e^- X$. The ratio of rates $\bar{f}/f$ is expected to be sensitive to the fraction of the nucleon momentum carried by the strange quarks of the sea.[4] We report here a simultaneous measurement of $\bar{f}$ and f which results in a determination of $\bar{f}/f$ relatively free of systematic effects.[5]

The data come from 45×10^3 pictures produced by an exposure of the Fermilab 15-in. bubble chamber (BC) with external muon identifier[6] (EMI) to a one-horn-focused wide-band antineutrino beam produced by 10^{13} (400 GeV) protons/pulse in a 12-in.-long aluminum oxide target. The BC has a 30-kG field and was filled with a heavy mixture of neon and hydrogen (64% Ne atomic fraction). This liquid's short radiation length (39 cm) yields high electron identification and γ-ray conversion efficiencies, and its short interaction length (~ 1.3 m for pions), together with the EMI, permits good separation of muons and hadrons. Because only one horn (downstream) was in place and no plug was inserted into the beam, the flux was such that the relative numbers of CC events which satisfy our cuts[7] are $\bar{\nu}_\mu : \nu_\mu : \bar{\nu}_e : \nu_e = 2.8\times10^3 : 2.3\times10^3 : 36 : 71$; and median event energies and energy distribution rms widths are (in GeV) 30:47:32:32 and 25:46:20:24. This