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Scattering of 0.8 GeV Protons from Lead-208, Carbon-12, and Carbon-13

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SCATTERING OF 0.8 GEV PROTONS FROM LEAD-208,
CARBON-12, AND CARBON-13

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ABSTRACT

The first angular distributions for elastic scattering of 0.8 GeV protons from ^{12}C , ^{13}C , and ^{208}Pb , obtained using the High Resolution Spectrometer (HRS) at the Clinton P. Anderson Meson Physics Facility (LAMPF) at the Los Alamos Scientific Laboratory, are presented. A brief description is given of an analysis of the elastic scattering data in terms of the Kerman-McManus-Thaler formalism with spin dependent nucleon-nucleon amplitudes. The data is shown to be sensitive to details of proton and neutron matter distributions. The proton distributions as determined by electromagnetic probes are used along with the available spin independent nucleon-nucleon scattering amplitudes. Preliminary analyzing power measurements are used to fix the spin-dependent amplitudes. The neutron distributions are adjusted to fit the data. Inelastic scattering of protons, exciting the first two states of ^{208}Pb and many states in ^{13}C and ^{12}C , is analyzed in terms of the distorted wave Born approximation (DWBA). The model of coupling a $1/2^-$ neutron to the excited states of ^{12}C is found to explain some of the ^{13}C excited states. Using this model a new assignment of $J^\pi = 7/2^+$ has been made to the 11.9 MeV state of ^{13}C . A coupled channels calculation using a 0^+ , 2^+ , 4^+ rotational band is found to explain the 4^+ , 14.1-MeV state in ^{12}C .

CHAPTER I

INTRODUCTION

Physicists have long felt that intermediate energy nucleons (> 200 MeV) should be a valuable probe of the nucleus. At these energies, the wavelength of the incident nucleon becomes comparable with or smaller than the average spacing between nucleons in a nucleus. For an 800-MeV proton $\lambda = h/p = 2\pi(197.3)/1463 = 0.85$ fm, compared to an average spacing of about 1.8 fm. The nucleon-nucleon cross sections are small at these energies so that the mean free path of a nucleon in the nucleus is fairly large. Thus it may be possible that the positions of nucleons in the nucleus, that is, detailed nuclear matter distributions may be extracted from a careful analysis of the scattering data.

The charge distributions in nuclei have been measured quite accurately by electromagnetic probes,¹ so that the distribution of protons is well known and can be kept fixed in the analysis of data which is sensitive to nucleons in the nucleus. Experiments which have attempted to measure the neutron distribution in lead and carbon include $\pi^\pm$ total cross sections,² alpha scattering,³ and bremsstrahlung-weighted cross sections.⁴ Elastic and inelastic $\pi^\pm$ differential cross sections should also be sensitive to the neutrons.^{5,6} The measurements tend to give conflicting results, with most having little sensitivity to the details of the neutron distribution. Recent measurements of proton-nucleus elastic scattering at incident proton energies near 1 GeV have reawakened interest in what can be learned concerning the nuclear matter distribution from hadron scattering. When such data extend to high enough momentum transfer, the angular distributions display considerable sensitivity to rather fine details of the proton and neutron distributions.

Analysis of existing 1-GeV Saclay data⁷ lends substance to these expectations. The resulting angular distributions are predominantly diffractive and fall off rapidly. This peaking of the cross sections at forward angles, plus the characteristic Fraunhofer diffractive maxima and minima support the claim that the data are sensitive to the "size" of the scatterer. The Saclay data stop at relatively small momentum transfers, usually about 3 fm^{-1} . The data at forward angles is found to be sensitive to the size, but not to the details of the matter distributions.

It was felt that similar data should be taken at 0.8 GeV proton energy during the initial experiment using the High Resolution Spectrometer (HRS) at the Clinton P. Anderson Meson Physics Facility (LAMPF) of the Los Alamos Scientific Laboratory. A comparison can then be made to see if the results of the analyses are very sensitive to the incident beam energy. The data were extended to larger momentum transfers, and thus should be more sensitive to details of the matter distributions. The targets chosen (^{208}Pb , ^{12}C , and ^{13}C plus nickel isotopes) also provide a good test of the system.

The kinematic correction for a heavy target such as ^{208}Pb is small so that the initial resolution for this target should be good. On the other hand, the diffraction pattern has more structure for increasing mass so that the ^{208}Pb data provide a good test of the angular resolution. ^{12}C and ^{13}C provide a better test of the kinematic corrections, although high energy resolution is not necessary in order to resolve the individual states. Good angular resolution is also not required for the carbon isotopes as the angular distributions have a broad oscillating pattern. The energy resolution observed was 80 to 140 keV for ^{208}Pb , and 200 keV and greater for ^{12}C and ^{13}C . The full width at half maximum (FWHM) of the angular resolution was measured to be 0.10 to 0.13 degrees. The ^{208}Pb

differential cross sections extend to 3.9 fm^{-1} , while that for the carbon isotopes reach 4.5 fm^{-1} .

The analysis of the elastic scattering data was carried out in the partial-wave formalism involving the Schrödinger equation with exact relativistic kinematics.^{8,9} The proton-nucleus optical potential was obtained from the Kerman-McManus-Thaler (KMT) expansion¹⁰ in the rearrangement discussed by Feshbach, et al.¹¹ The KMT approach provides a formal theory of the nucleon-nucleus optical potential, in which the optical potential operator is expanded in terms of the two-nucleon scattering operator, and evaluated inside the target nucleus. The resulting T-matrix describing elastic scattering in general involves matrix elements of the potential operator between all target nucleus states and with all orders of excitation present in general. The first order optical potential is obtained by ignoring all matrix elements involving an excited state. The resulting potential involves only the ground state matter densities and the proton-nucleon scattering amplitudes inside the nucleus.¹⁰ Even though the imaginary central potential dominates the calculations, one must treat the smaller first-order terms (i.e. the real central, the spin-orbit, and the Coulomb) correctly if unambiguous matter distributions are to be extracted.⁸

The potential obtained in the analysis of the elastic data is then used in a distorted wave Born approximation (DWBA) analysis of the inelastic data.⁹ The collective excited states are sensitive to derivatives of the matter densities, and thus provide a more rigid test of the theoretical approach than the elastic angular distributions alone.

In addition to the 3^- , 2.62-MeV state in ^{208}Pb and the 2^+ , 4.4-MeV, 0^+ , 7.6-MeV, and 3^- , 9.6-MeV states in ^{12}C which have been reported by Saclay,⁷ and extensively analyzed,^{8,9,12-17} angular distributions have also been obtained for the 5^- , 3.2-MeV state in ^{208}Pb , the 4^+ , 14.1 MeV state in ^{12}C , and the $1/2^+$,

3.1-MeV, $3/2^-$, 3.7-MeV, $5/2^+$, 6.9-MeV, $5/2^-$, 7.6-MeV, and $7/2^+$, 11.9-MeV states in ^{13}C .

As is well known from low energy inelastic scattering results, the inelastic angular distributions are indicative of the orbital angular momentum transfer involved in the reaction. For a nonzero plus ground state there is an ambiguity in the total transferred angular momentum, and a microscopic analysis is preferred. Instead, a similar macroscopic analysis is used for the ^{13}C data as for that of ^{12}C and ^{208}Pb . The model used is that of a $1/2^-$ neutron coupled to the known excited states of ^{12}C . From the 2^+ and 3^- states this model gives states of $J^\pi = 3/2^-, 5/2^-, 5/2^+$, and $7/2^+$. The 3.7- and 7.6-MeV states are well explained by this model using a transferred $\ell=2$.

A new assignment of $7/2^+$ to a state at 11.9 MeV is made on the basis of this model with $\ell=3$. A $5/2^+$ state with the appropriate strength does not appear in the spectra.

The one-step DWBA calculation does not explain the angular distribution of the 4^+ state in ^{12}C . A coupled channels calculation, assuming that the 0^+ , 2^+ states of ^{12}C comprise an abbreviated rotational band explains the data.

The experimental conditions are discussed in the next chapter. The method of obtaining cross sections from the data is described in Chapter III. In Chapter IV the theoretical analysis of the elastic data is discussed, along with that of the excited states. Chapter V contains an estimate of the errors.

CHAPTER II

EXPERIMENTAL METHODS

A. THE PROTON BEAM

The experiment described here was done using the High Resolution Spectrometer (HRS) at the Clinton P. Anderson Meson Physics Facility (LAMPF). The Facility utilizes a two-staged linear accelerator (linac) that can simultaneously accelerate both protons (H^+) and negative hydrogen ions (H^-), with a duty cycle of six percent (one hundred and twenty 500 microsecond macropulses per second).

The first stage, an Alvarez drift tube structure operating at 201.25 MHz, accepts ions from two of three injectors (the third is an H^- polarized source), accelerates them to 100 MeV, and feeds them to the main accelerator. The frequency of this section of the linac, 805 MHz, was chosen to be the fourth harmonic of the first stage. This decision was based on analyses similar to those of Wheeler and others at Yale,¹⁸ who found that during acceleration the phase spread damps to about one-fourth of the phase acceptance at injection. This reduced phase spread can fit into the phase acceptance of another linac having four times the frequency of the drift tube section. The 805 MHz section is a side coupled cavity, standing-wave linac developed at Los Alamos.¹⁸ The final beam energy is stepwise variable from 0.1 GeV to 0.8 GeV. During the experiment described here, the beam energy was 0.8 GeV.

The H^+ , H^- beams are magnetically separated in the switchyard, with the H^+ beam traveling down Line A where there are about eight experimental facilities. The H^- beam travels down Line X where there are five different strippers for beam phase space tailoring. Most H^- ions that intersect a stripper lose both electrons, and the resulting H^+ ions can then be magnetically separated from the remainder of the H^- beam. Three strippers trim the x,y spread of the beam, a fourth the momentum spread, while the fifth, a selection of wires and foils of varying

widths (0.1 to 100 mils), provides the desired amount of H^+ beam for Area C, the location of the HRS. The unstripped beam goes down Line B to two additional facilities.

A plan view of Line C is shown in Fig. 1. A procedure has been developed for preparation of the beam in Line X for simultaneous input to Lines B and C.¹⁹ The beam must enter Line C along its optic axis. If not, there is no satisfactory way to correct it and still achieve the desired beam constraints. The beam is bent a total of 120° in a 54.6-meter flight path down Line C, until it strikes the target located in a 1-meter radius scattering chamber. The "unscattered" beam proceeds to a beam dump, while the HRS detects particles scattered to the left. In the HRS, particles are bent vertically through 150° , about 20 meters to the focal plane where their time of flight (TOF), pulse height, and focal plane coordinates (x,y, x angle, and y angle) are measured.

Line C can be considered as consisting of a separation section, a dispersion section, and a matching and twisting section.²⁰ The separation section consists of bending magnets LCBM01-03, and quadrupole doublet LCQM01,02. LCBM01, 02, 03 bend the beam 1° , 1° , and 4° respectively. The doublet provides a small x spot at the entrance to the dispersion section. Point-to-point focusing ($\langle x|\theta \rangle = 0$) from the stripper to the entrance point is required so that the spot position depends only on stripper location and not on input beam angle. Since a vertical wire stripper is used, the Line C beam spot will not move, even if the H^- beam is not stable. The other constraint on the doublet is to make the smallest possible y spot midway between LCBM04,05 (the dispersion section). At 15 kilogauss LCBM04,05 each bend the 0.8 GeV proton beam 57° . The dispersion at the focus of LCBM05 is 9.03 cm/% in the horizontal plane.

As is discussed in the next section, the HRS operates in the VHV configuration, that is vertical dispersion, horizontal scattering, vertical analysis; thus

Figure 1

A plan view of beam line "C", which provides for a vertical dispersion matched beam on target, for use with the HRS.

the beam dispersion must be rotated from the horizontal plane to the vertical plane without mixing of the phase space. Quadrupole magnets LCQM04-08 are rotated 45° from the normal quadrupole position, and comprise the twister section. This section can be considered in the thin lens approximation to also provide an adjustment of the focus at the target.

LCQM03, 09, 10, 11 comprise the dispersion matching section of Line C. For elastic scattering of 800-MeV protons at small angles, or large angles on a heavy target such as ^{208}Pb , the dispersion required on target is 22 cm/%. Once a "good" solution is achieved, that is, once Line C has been tuned for proper dispersion matching, then the dispersion can be varied with one "knob", adjusting LCQM03, LCQM09, and LCQM11, where LCQM09 and LCQM11 are changed oppositely by the same amount and the ratio of the change of LCQM03 to LCQM09 is a constant. TRANSPORT²¹ runs have verified that this knob works over the dispersion range 18 to 25 cm/%. This adjustment of dispersion can be performed while keeping the x size at the target constant and a focus in y. The TRANSPORT²¹ matrix for Line C from stripper to target for dispersion equal to 22.5 cm/% is

1.6E-03	1.8E-03	7.2E-02	-1.08	0.0	- 1.0E-02	(2.1)
3.0E-03	3.4E-03	1.12	-2.71	0.0	- 1.9E-02	
8.8E-02	-1.2E-02	1.8E-04	-1.2E-04	0.0	22.5	
8.9	10.1	6.0E-05	06.2E-05	0.0	-50.4	
20.52	22.59	0.0	0.0	1.0	3.55	
0.0	0.0	0.0	0.0	0.0	1.0	

B. THE SPECTROMETER

The HRS consists of one quadrupole and two dipole magnets (QDD) with a 75° bend in each dipole. A section view of the HRS is shown in Fig. 2. It is designed to measure the two-body reaction $B(A,C)D$; e.g., a proton beam A, strikes

A section view of the HRS, in which the VHV mode of operation, as discussed in the text, is evident.

Figure 2

a target B with C the detected particle and D the residual nucleus. The reaction may be completely specified by knowledge of the energy and direction of the incident and outgoing particles A and C. The HRS operates in the VHV, energy loss configuration. The energy loss mode is based on the fact that the state of the residual nucleus can be determined by the measurement of the momentum difference between the incident and outgoing particles.²² This may be accomplished by proper dispersion matching between the beam line and the spectrometer optics. Thus all scattered particles having the same energy loss are recombined on a line in the spectrometer focal plane. Using the TRANSPORT²¹ notation (R_{11} = spectrometer magnification, R_{36B} = dispersion of the beam, R_{16S} = dispersion of the spectrometer) the first order condition that the final state detected at a position X at the focal plane of the spectrometer be independent of the incident or final momenta is given by

$$R_{11} * R_{36B} / R_{16S} = (P_{Ac} / P_{Co}) * (\partial M / \partial P_A) / (\partial M / \partial P_C) \quad (2.2)$$

$$= \text{RATIO}$$

where the "o" subscript stands for "central" momenta. Since R_{11} and R_{16S} are fixed, the dispersion of the beam line must be varied as the kinematic factor, RATIO, of the reaction of interest varies. The value of RATIO is ~ -1.0 for the $^{208}\text{Pb}(p,p)$ reaction. The variance of RATIO with scattering angle can be found in the kinematic tables in Appendix I. The TRANSPORT²¹ matrix from target to focal plane is²²

-0.825	-0.005	0.0	0.0	0.0	18.244	(2.3)
-3.972	-1.238	0.0	0.0	0.0	15.951	
0.0	0.0	-0.033	0.193	0.0	0.0	
0.0	0.0	5.16	-0.076	0.0	0.0	
-5.73	-2.25	0.0	0.0	1.0	-12.32	
0.0	0.0	0.0	0.0	0.0	1.0	

Thus from 2.2 and 2.3, with $RATIO = -1.0$, $R_{36B} = 22.11 \text{ cm/\%}$.

In the VHV mode in which the HRS operates, the measurement of scattering angle is decoupled from the momentum analysis, in first order. As can be seen in 2.3, there is point-to-point focusing in the vertical plane (X) and nearly parallel-to-point focusing in the horizontal plane. Thus at the focal plane, for a heavy target, the vertical position is the momentum loss while the horizontal position is the scattering angle. Light targets, with large $dE/d\theta$, require a kinematic correction in converting position into momentum loss and angle. With parallel-to-point focusing in y, an extended target can be used and still allow precise angular measurement since all particles which emerge from the target in a given direction will come to the same y focus independent of y position in the target.

In order to measure small angle scattering with good resolution, the angular dispersion must also be matched. There is no tune of Line C to do this, which leads to some small angular uncertainties.²⁰ The angular momentum mismatch is such that the largest error in the scattering angle, which would occur for zero degree scattering is about 5 mrad.

The angular resolution can be measured by determining the energy resolution for p + p elastic scattering. The total energy resolution is made up of many terms adding in quadrature. For a hydrogen target the dominant term is $(dE/d\theta \cdot \Delta\theta)$ so that $\Delta\theta$ is less than or equal to $\Delta E / (dE/d\theta)$. At 15° , ΔE is equal to 1 MeV, $dE/d\theta$ is 10 MeV/degree, so that $\Delta\theta$ is 0.10° (1.7 mrad). At 30° the numbers as

listed above are 1.8 MeV, 14 MeV/degree and 0.13° (2.2 mrad). In all of the angular distributions measured in this experiment, the cross sections have been averaged over at least 0.19° (3.27 mrad).

The largest term contributing to the energy resolution for a hydrogen target should be from the dispersion mismatch. For all of the data, the dispersion matching was set for $RATIO = -1$. For the 15° and 30° runs, $RATIO = -0.95$ and -0.85 respectively. The uncertainty in energy resolution as $RATIO$ differs from -1.0 is given by

$$\Delta E = P * (dM/dP) (1 + RATIO) (\Delta P/P) \quad (2.4)$$

For an 800 MeV proton beam, P is 1463 MeV/c, $dM/dP \sim 0.82$, and $\Delta P/P \sim 0.15\%$ for the observed 3-cm beam spot. Thus for $RATIO = -0.85$, $\Delta E = 270$ keV. This added in quadrature with the term greater than 1 MeV is negligible, so that the angular resolution is about 2 mrad.

A simple method for setting the fields of the spectrometer magnets was developed. The first time the magnets are turned on after a failure (magnet crash) the fields are cycled three times. A cycle is defined as running the current from zero to the maximum (B is saturated) and back to zero current. The field can be found from the following. If B is the magnetic field in kilogauss, r the radius of curvature (meters), and p the momentum of the particle (here charge = 1) in GeV/c, then

$$Br = (1/0.0299792)*p = 33.35646 p \quad (2.5)$$

For $r = 3.5$ meters

$$B_{HRS} = 9.53042 p \quad (2.6)$$

For an 800-MeV proton beam elastically scattered at 0° , B_{HRS} equals 13.94 kilogauss.

The magnets are set for the proper central momentum of the reaction of interest by a digital voltmeter (DVM), which reads to 0.01 millivolt the voltage across the magnet windings. Nuclear Magnetic Resonance (NMR) probes are located at the center of each dipole. In comparing, at excitation of 4 and 14 kilogauss, the average field as measured by the NMR in the "good" region (center 14 inches of the magnets, $B_{1,2}$, to the average field in the magnets as determined from complete maps, one obtains the following approximate relationship, with magnet fields in kilogauss,

$$\begin{aligned} \text{HSBM01, } B_1 &= B + 0.0006(B-4) \\ \text{HSBM02, } B_2 &= B + 0.00108(B-4) \end{aligned} \tag{2.7}$$

Polynomial fits to the average NMR scan as a function of the DVM were computed. The data was obtained by setting the magnets for a particular DVM and waiting until the field reached its steady state. The NMR was manually moved in increments by a stepping motor controlled in the Line C counting house (CCH), read out on a Spectromagnetics Gaussmeter Model 5300, and averaged over a scan. The data, which can be found in Appendix III, were broken up into the linear region below 10 kilogauss, the proton elastic region and the deuteron region greater than 14 kilogauss, in order to facilitate fitting. The DVM values are then obtained for a desired reaction from the kinematics program KINREL.²³ With this procedure a "peak" could be consistently kept at the same x position on the focal plane, as the scattering angle was changed. By a peak we mean protons of a certain momentum loss which correspond to a particular quantum state of the residual nucleus. Notice from Eq. 2.6 that a change in the field of 9.5 gauss changes the central momentum by 1 MeV/c.

C. TARGETS

The ^{208}Pb target was enriched to 99.14% (^{204}Pb less than 0.005%, ^{206}Pb = 0.17%, ^{207}Pb = 0.69%). The total target is $233.4 \text{ mg}/22.25 \text{ cm}^2$, or $\rho t = 10.40 \text{ mg}/\text{cm}^2$.

The $156 \text{ mg}/\text{cm}^2$ ^{13}C target was enriched to 83% by weight, with 15% ^{12}C , and 2% ^1H . There was some slight absorption of water as can be seen in the presence of small ^{16}O peaks in the spectra. The isotopes of interest thus had the following values of $A/\rho t$: $^{13}\text{C} = 0.1004$, $^{12}\text{C} = 0.513$, and $^1\text{H} = 0.321$.

The ^{12}C and ^1H targets were actually one target of Pilot B scintillator. The $86 \text{ mg}/\text{cm}^2$ target had an $A/\rho t = 0.1544$ for ^{12}C , 0.1344 for ^1H , and 1.2% by weight ^{13}C .

The multiple scattering contribution to the angular resolution can be calculated as in ref. 24 to give a projection of the $1/e$ scattering angle of 0.29, 0.41, 0.32 mrad for the ^{208}Pb , ^{13}C , and ^{12}C targets.

Using Vavilov's theory²⁵ for the Landau contribution to the energy resolution gives 60 keV FWHM for the thick ^{13}C target, with 155 keV full width tenth maximum.

D. RESOLUTION

Since this was the initial experiment using the HRS, and resolution was not critical for the targets used, only one dispersion matched solution was used for the experiment. Resolution of 80-120 keV full width half maximum (FWHM) for peaks in the $^{208}\text{Pb}(p,p)$ spectrum was routinely observed. The thicker targets of $^{12,13}\text{C}$, where the dispersion mismatch becomes greater for increasing scattering angle and where the angular resolution mismatch is a problem, the resolution was approximately 200 keV at the forward angles and worsened at the back angles. Data was taken with no windows between the injector and the exit of

HSBM02 for the smallest angle until 24.5_{lab}° . A gradual pressure gradient for the vacuum was used with about 10^{-4} torr at the scattering chamber and spectrometer, to about 10^{-6} torr at the end of Line X. Vacuum problems with the sliding seal of the scattering chamber forced the use of windows for the data taken at angles 24.5_{lab}° and greater. Two windows (7 mil, Kapton and 10 mil, mylar) isolated the scattering chamber, which contained helium gas, from the beam line and the spectrometer. A 10-mil mylar window was placed over the entrance to the spectrometer.

The resolution of the system was fine tuned by observing the resolution of an elastic peak and adjusting the line C focus on target, with a linear combination of LCQM01,02 or adjustment of the HRS quadrupole. Fine tuning of the twister, and of the beam line dispersion improved the resolution slightly. Tailoring the phase space of the beam with strippers in Line X also helped. Correlations (other than kinematic) between the focal plane position x and the scattering angles θ and ϕ and the y position were searched for by looking at two-dimensional dot plots, and none were found at the 200-keV level.

The twister was adjusted by observing the beam on a Pilot B scintillator target until the dispersion had been rotated into the vertical plane and the x spot size was narrow. The "twist" is very sensitive to adjustment of the quadrupoles, as was also seen in TRANSPORT²¹ calculations.

The dispersion was adjusted to give the best resolution for a heavy target. A small momentum stripper was used to reduce the momentum spread of the beam until about a 1/2-cm beam spot on target was observed. A full stripper was used to select all of the remaining H^{-} beam. Different momentum components of the beam could be selected by movement of the momentum stripper, which, of course, resulted in a vertical movement of the beam on target. The dispersion "knob" was adjusted so that the different momentum protons, that were elastically scattered from the target into the HRS, were all brought to the same x position

at the focal plane. The resolution was improved and remained unchanged when the momentum stripper was opened up to give the normal momentum spread on target.

The x focus on the focal plane of the HRS can be checked by viewing a dot plot of the target excitation versus the vertical angle at the focal plane. If there is a focus, then the two quantities should be uncorrelated. The sensitivity can be checked by varying a constant in the analyzer that gives the position of the front chamber with respect to the focal plane. With the quadrupole set for the correct focus a change in ± 1 cm of this variable can not be detected by eye. A 5-cm change is easily detected resulting in a slope of 7 keV/mrad.

E. BEAM MONITORS

The result of any scattering experiment depends upon an accurate determination of the beam current. Since the HRS is a new facility on a tight budget, the construction of a moderately expensive Faraday cup for absolute beam monitoring has been delayed. Instead it was decided to make use of the fact that an absolute measurement of the $p + p$ elastic cross section has been made at LAMPF by Willard, et al.²⁶ Thus, in addition to our data, the proton-proton elastic cross section was also measured (CH target).

The concern was thus on good relative beam monitors, which has led to a number of monitors utilizing different techniques. For relative beam current, a split secondary emission monitor (SEM) was located about 4 m downstream of the target and two ion chambers (IC1,2) which operate at low pressure (approximately 50 mm of Hg; Ar, 90%, CO₂, 10%) positioned inside, near the exit, of the 1 m radius scattering chamber. Monitors of the beam-target interaction consisted of two, 4-detector (scintillators) counter telescopes which were positioned outside the scattering chamber to view the target at 45° and 120° with respect to the beam direction. For small scattering angles, the scattering chamber is rotated 40° which places these monitors at 85° and 80° respectively. Since the beam

intensities are also reduced, the monitor telescopes are of little value for small angles. Also for angles less than 10° the SEM must be removed, while IC1,2 can remain in the beam until scattering angles of less than or equal to 5° . A polarimeter²⁷ installed upstream of the target after LCQM11, after this experiment was completed, has helped the monitor problem at small angles. Problems with "noise" in the SEM and IC1,2 was reduced by replacing power supplies with batteries. IC2, with 50-mm ArCO₂ and -300 V, was found to have a gain of approximately 3%, and was linear from about 1 pA of beam to about 10 nA where it saturated. The reason that it saturates so soon is thought to be that the voltage is not enough to collect all of the charge before significant recombination occurs. A smaller beam spot and thus larger charge density causes the ion chamber to saturate sooner. At about 10-mm ArCO₂, IC2 would avalanche. The leakage current was less than or equal to 0.1 pA in the SEM, and up to 1 pA for the ion chambers.

The monitor telescopes each consisted of four scintillators. They give some indication of the beam quality (straightness and halo) in the scattering chamber region. The criteria²⁸ for the design of the telescopes was that:

- they be directional,
- the four-fold coincidence should be sensitive to a 12 cm x 1 cm beam spot at the target,
- not be geometrically sensitive to alignment, and
- the third counter serves to define the solid angle.

The third counter is 2.54 cm square located about 152 cm from the target. Thus for a point on the target, the solid angle equals $A/r^2 \sim 0.28$ msr. The front monitor telescope suffers from rate problems at the highest beam levels. The singles rate in the front scintillator in this telescope is 3.3×10^6 /sec for a 60 nA proton beam on a 10 mg/cm^2 , ²⁰⁸Pb target.

ORTEC Model 439 current digitizers were used to integrate the SEM and the IC_{1,2} signals and gave one pulse for 10^{-10} Coulombs of integrated charge. The gain of the SEM was measured to be 0.42 ± 0.04 .

F. SCINTILLATION COUNTERS

Besides the monitor telescopes, scintillators are used for time of flight (TOF) and pulse height information for particle identification (PID) at the HRS focal plane, and as vetoes for unacceptable events. The TOF scintillators S_2 , S_3 , and S_4 are shown in Fig. 3, along with the vetoes $V_{1,2}$, which are positioned so that the solid angle for the TOF system and the chambers is the same for particles that do not go through either veto. Other vetoes are scintillator jaws $J_{1,2}$ located between HSBM01,02. This position is where the R_{12} term is a maximum through the HRS, but R_{16} is still "small". Their separation along with $V_{1,2}$ defines the angular acceptance in the plane transverse to the scattering plane. Thus particles which traverse the "good" region of the fields in the dipoles can be preferentially chosen.

A PID dot plot for $p + {}^{13}\text{C}$ at 35°_{lab} is shown in Fig. 4a. The distance from S_2 to S_4 is 206 cm. S_2 and S_6 are separated by 51 cm while S_3 and S_4 are 15 cm apart. The 2 m flight path plus the pulse height in $S_{3,4}$ provides good PID (separates minimum ionizing, π , p, d, and t) for a variety of experiments at the HRS which includes the elastic scattering at 800 MeV as discussed here,²⁹ plus ${}^4\text{He}(p,p)$ from 14.5° to 155°_{lab} ,³⁰ and the measurement of the quasi-elastic cross section up to the pion production threshold.³¹ The TOF is derived from an S_2 start and an $S_3 \cdot S_4$ stop time. The pulse height used is the geometric average of the four signals from $S_{3,4}$. Straggling in the scintillators results in a tail on the pulse height as described by Vavilov,²⁵ which can be seen in Fig. 4. The ellipses seen around the particle types in the figure, are used for computer

Figure 3

The detector arrangement at the exit of the HRS is shown, with particles traveling along the z axis from right to left in the figure. The particle identification is provided by scintillators S_2 , S_6 , S_3 , and S_4 . Delay line chamber DL1 is located at the focal plane of the HRS, except for a rotation about the center.

Figure 4b

The number of protons relative to the number of events is plotted as a function of the laboratory scattering angle.

Figure 4a

A dot plot of the particle identification signals for 800-MeV protons on ^{13}C , with the HRS set for elastic scattering at a laboratory scattering angle of 35° .

software identification, and are valid for a range of protons from $p + {}^{208}\text{Pb}$ at small angles to $p + p$ scattering at 30° .

Other experiments⁷ have not used a particle identification system. That this will limit the experiment to forward angles is evident in Fig. 4b where the number of protons relative to the total number of events is shown as a function of the laboratory scattering angle. At 35° only one fourth of the events are protons.

The PID system also provides strobe signals to indicate and define an event. This allows a cross section to be measured. Not every event can be analyzed and/or written on tape, but every event as defined by the PID system is read into a scaler. The total number of events divided by the number of events processed (where in replaying data the "must process" mode is used for all events written on tape) is the correction factor for the system dead time.

The $J_{1,2}$ ($V_{1,2}$) signals are used to generate a latch that tags an event for software rejection. In this experiment the signals into the latch were 100 ns (20 ns) long. This has been reduced to 20 ns for both. For our maximum beam rate of 60 nA on ${}^{208}\text{Pb}$, this required an additional correction factor for accidental vetoes of 1.09. This is discussed further in the singles rates section.

The fast electronics for the PID system, shown in Fig. 5 are located at the detector area on the main frame of the HRS. The various time delays represented by rectangles are remotely controllable from CCH. The basic timing scheme uses amplified anode signals from $S_{2,6,3,4}$ phototube pairs, with leading-edge discriminators (squares in the figure). An anode and discriminator signal are sent from the HRS directly to CCH, where they are used to set up the time signals read into the computer. The discriminator signal in the fast electronics is then fed into coincidence units where coincident pairs are formed,

Figure 5

A schematic of the fast electronics located near the exit of the HRS. Standard logic symbols are used.

$S_3 = S_{3U} \cdot S_{3D}$, $S_{34} = S_3 \cdot S_4$, etc. The signals from the fast electronics and the chambers are transmitted to CCH via 100 m cables (usually 50 Ω).

All of the scintillator phototube voltages were set as follows: first the individual tubes were plateaued using the ratio of the number of singles detected per unit beam. A reaction that "lights up" the entire focal plane such as the quasi-elastic peak of $^{12}\text{C}(p,p)$ is useful here. Scintillator pairs were then checked. The entire coincidence system was checked by looking at the number of events per unit beam and varying each tube voltage as well as the programmable delay times. The dimensions of the scintillators and the tube voltages used are found in Table I.

In order to test the efficiency of the TOF system, small test scintillators were placed in the center of S_2 and S_4 . The $(S_2 \cdot S_3 \cdot S_4 \cdot S_6 \cdot \text{TEST})/\text{TEST}$ was 100% to 1 part in 3000.

Note, if one wants to use a chopped RF beam for timing, the TOF from target to focal plane for 1463 MeV/c protons and deuteron's is about 36 ns. The chopper at LAMPF can run at 40 ns or 80 ns. Thus the HRS requires the use of the 80 ns chopper.

G. CHAMBERS

Position sensitive multiwire proportional chambers with delay line readouts are used for measuring the focal plane position and angles. A diagram of the chambers and the TOF system is found in Fig. 3. The chambers are two dimensional with anode wires in one direction and cathode wires in the other.³²

Fast (2.5 ns/cm) printed circuit delay lines (copper or teflon glass laminate) are used for both the cathode and anode planes, providing the two dimensional readout for each chamber. The delay line and wire planes are mounted on opposite sides of aluminum "window frames" with an anode-cathode plane separation of

usually 8 mm. Fast signals are generated from the ends of the delay lines using leading edge discriminators, then transported to CCH where they are used as stops for a multichannel CAMAC TDC. The start time is provided by the TOF system (can include one or more of the chambers). Time sums and differences for the signals from each delay are formed in the computer (PDP11/45). A time/sum check is formed by subtracting the sum of the cathode times from the sum of the anode times for each event. This cancels drift time and uncertainties in the start time and provides a sharp time peak (about 1 ns FWHM) at a time equal to the difference in anode and cathode delay line lengths.

Delay line 1 (DL1) is positioned near the focal plane of the spectrometer (the chamber is rotated about the focal plane to perpendicularly intersect the particle paths). DL4 is used with DL1 to measure x and y angle at the focal plane. DL1,3,4 each consist of two delay lines in the x (momentum) direction. These cathode wires are spaced every millimeter. One delay line is ± 15 cm about the center while the other consists of two coupled delay lines that extend ± 30 cm about the center line. The y direction (angle) is the anode plane and has a 3-mm spacing (0.094° or 1.64 mrad). DL2 is the calibration chamber and has 4-mm spacing in the x direction and 1-mm spacing in y.

The chambers could be plateaued for protons by bench testing using electrons which are also minimum ionizing particles. The result was checked, after the scintillators were plateaued, when the chambers were in place at the exit of the HRS.

After the chambers have been positioned properly, the high voltages plateaued, and the discriminators set, the time differences must be calibrated to give x and y positions. The spectrometer is set for the quasi-elastic region of the $^{12}\text{C}(p,p)$ reaction, so that the entire focal plane is illuminated. One tape of data is taken for future calibration work. Using the PID, only protons are

included in the analysis. Gates are set on the delay line time/sum checks, and on 15 wires (every 40 mm) in the x direction of DL2. A gate on the time sum of this chamber is set so that only events that are "near" wires are used in the calibration. By looking at events in DL1,4 that pass the tests, one gets peaks in the time difference of these chambers that correspond to the projection of the calibration chamber position on DL1,4. The projected position must be corrected for the dispersion for precise work (about a 1% correction for DL1 and 3% for DL4). The projected time difference peak centroids are obtained using PEKFIT.²³ A polynomial fitting routine program (PWRFIT) is used to find position as a function of time difference. For this experiment the analyzer used only a linear relationship, although the chi-squared of a quadratic was considerably better. Nonlinearity constants are adjusted at this time. One example is to adjust two constants in an algorithm³² that makes the "wires" parallel when looking at a dotplot of the time difference in y (or x) versus the time sum.

The chambers performed well with high singles. The rates in the scintillators and the chambers defined the limiting beam used here, with minimal shielding in place, to be 60 nA. The singles rate in the chambers and scintillators for a 60 nA beam on ^{208}Pb at 28°_{lab} are given in Table II. Notice that the chamber efficiency has fallen from essentially 100% to about 80%.

H. ANALYSIS SYSTEM

The data acquisition system is located in CCH and consists of a PDP11/45 computer, which runs under the RSX-11D operating system (124 K of fast core memory) and the following peripheral devices: three IBM 729/VI tape drives (7 track), which have since been replaced by 9-track drives, two Tektronix 4010 storage tube graphic terminals, one LA30S Decwriter, one Versatec printer-plotter with a copy option for the 4010's, three 10^6 word disks, a bi-Ra micro-programmed branch driver (MBD) which can control up to 7 CAMAC crates, and two

CAMAC crates. The MBD is a standard LAMPF item. Data is acquired by the MBD during a beam pulse and then transferred to the computer during the time between pulses. The general data acquisition program "Q"³³ is used.

The analysis program³⁴ uses the raw event parameters (i.e., pulse height, TOF, time signals from the chambers) along with calibration constants and backward TRANSPORT²¹ coefficients³⁵ to calculate arithmetic and geometric means of individual and groups of scintillators, TOF between combinations of scintillators, combination of the times out of the chambers, focal plane coordinates (x,y,x angle, y angle), momentum loss, target coordinates (x angle, y, y angle), space scattering angle, and the target nucleus excitation. Ref. 35 describes most of the equations used, along with a discussion of the angular uncertainties.

As a result of experience gained in the first year of experiments, a program that calculates at the end of a "run", correction factors, scattering angle, relative cross section, and polarization asymmetries (if applicable), has been implemented.²³

A relativistic two-body kinematic program KINREL²³ is available which includes parameters for setting the spectrometer magnets. The results for the reactions of interest, along with a short explanation is found in Appendix I.

Another useful program which has been extensively rewritten,²³ is the peak fitting program PEKFIT. The version used here included options of up to a quadratic equation fit to the background for subtraction, and no fit to the net peak, a fit to a single peak with two Gaussians, and a fit to two peaks with the same or with different widths. Of the states to be discussed the first three states of ²⁰⁸Pb, the first two of ¹²C, and the ¹³C ground state (θ_{lab} greater than 18.5°) were "clean" and required no fit. The others required a background subtraction or a double peakfit to states in spectra "gated" on scattering angle. Since any fit which uses a chi-squared optimization will be small, the sum of

the double peakfit was scaled by the total number of counts minus the fit to the background (the average correction was about 3%).

Two reviews that describe the "ideal" HRS data acquisition and PID systems before experiments were begun have just recently been distributed.^{36,37} These systems have undergone major revisions, with experience. The PDP11/45 was found to interfere with accelerator operations, when interfaced with the 840 computer through an 11/10 computer, so that this practice was discontinued. Manual operation of NMR's, beam plugs, the target wheel, etc. has been implemented, with the PDP11/45 used exclusively for data acquisition and analysis. The outer time of flight system no longer exists and the multiwire proportional chambers have been replaced with delay line chambers.

I. SINGLES RATES

The flux of background particles in the scintillators and in the chambers defined the maximum beam, with the minimal shielding that currently exists, to be 60 nA. In Table II, the singles rates for the various scintillators and chambers are given for a 60-nA proton beam on ^{208}Pb at 28°_{lab} . Signals from the $J_{1,2}$ counters are fed into a latch which tags events for software rejection. For the given singles rate, the accidental veto correction factor for the 100-ns latch signal from the J_1 counter is $1 + (10^{-7} \text{ sec} \times 0.33 \times 10^6 \text{ \#/sec}) = 1.033$. The total correction for $J_1 \cdot J_2$ is 1.088, while that for $V_1 \cdot V_2$ is 1.005 (20 ns latch). The correction factor for the delay lines was determined by (good proton)/DL1·DL2·good proton) where a good proton is a TOF proton (with no veto). DL1(4) signifies that for an event, two anode and two cathode signals from chamber 1(4) were received by the electronics in the time limit. For the 60-nA beam the chamber correction was 1.2 while the PID system measured dead time was 1.01, giving a total correction of 1.34. The event rate was kept to about 60-80 events/second for all runs. Improvements, such as the shortening of the event

"word" that is written to tape, have allowed an event rate of about 200/second with an acceptable system dead time.

J. SYSTEMATICS

The relative scattering angle as calculated at the focal plane was measured several times. One accurate method was to set the HRS about eight MeV higher than the $p + p$ elastic peak at a given lab angle. The HRS was then moved 1.5° as measured 10.4 m from the pivot where 18.1 cm is 1° . By observing a dot plot of x, y at the focal plane, it was determined that 16 anode wires spaced 3 mm apart was equal to a scattering angle of 1.5° or 1.64 mrad/wire. This determination should be accurate to about 1/2 wire or 3%.

The absolute zero of the scattering angle was measured by taking data at $\pm 12^\circ_{\text{lab}}$, at which the ratio of the $^{12}\text{C}(p,p)$ cross section for the excitation of the 4.4, 2^+ state to the elastic is "V" shaped. The symmetry axis for $+12^\circ$ was found to differ from -12° by two wires so that a correction to the scattering angle was made such that 12° becomes 11.906° . This correction is valid for all data as long as the proton beam is steered along the same line through the target and the position of the anode wires in DL1 remain the same. For each angle the beam steering was checked by the observation of TV's that look at chromium doped aluminum phosphors that are inserted in Line C after LCBM03, LCBM04, LCBM05, LCQM11, at the target, and in front of the SEM (about 3 m downstream of the target). Caution must be used, since the $\pm 12^\circ$ measurement was performed only once. Subsequent measurements using a polarized beam^{27,53} also used this technique and obtained results that are consistent to $\pm 0.05^\circ$. This error contributes to the error in the theoretical analyses as will be discussed in Chapter V.

The relative solid angle of the HRS varies as a function of x position at the focal plane. The HRS field is set so that the central momentum of the proton

beam yields an elastically scattered peak in the center of the focal plane. As will be discussed in the next chapter, the cross sections are normalized to the p+p elastic cross section. The p+p elastic cross section is also centered in the x acceptance of the spectrometer. The problem is relating the cross section for an excited state (for example the 14.1 MeV level in ^{12}C) to the elastic cross section. The correction was empirically measured³¹ by positioning the spectrometer for the first maximum of the ^{12}C elastic; thus the cross section is changing slowly with angle. The HRS magnets are then set for several central proton momenta such that the elastic peak is "swept" across the focal plane. The relative cross section as a function of focal plane position of a peak is thus measured. With no rejection of events due to large x scattering angles, the correction leads to a reduction of the cross section at 14 MeV compared to that at 0 of $(20 \pm 2)\%$.

As should be noted, the data discussed here was taken in two time periods (February and May 1977) during Cycle 12 and 14 at LAMPF. In order to get the elastic peak to center on the focal plane, beam energies of 795 MeV and 790 MeV, respectively, were used in Eq. 2.6. The central beam energy has been observed to vary from cycle to cycle, but is constant to less than 1 MeV over a three week cycle (795, 789, 790, 796, 798 MeV from Cycle 12 to Cycle 16). Of the angular distributions presented here, the forward angles out to 20° were taken during Cycle 12, while the back angles were obtained during Cycle 14. There was overlap at 15° , 18.5° , and 20° for ^{208}Pb and at 18.5° and 20° for carbon. The ^{12}C elastic forward angle data has been supplemented with that obtained using a polarized beam and "better" monitors.^{27,53} The ^{208}Pb elastic was also checked and found to be consistent with the polarized data which was obtained later.

CHAPTER III

DATA ANALYSIS AND RESULTS

A. THE DIFFERENTIAL CROSS SECTION

The differential cross section for a single target nucleus left in a definite final state of excitation E , is equal to the flux scattered into the solid angle element $d\Omega$ at angle θ divided by the incident flux per unit area. Dividing by the number of target nuclei per unit area $[(A/\rho t)/N_0]$ gives the cross section for a target, as long as all of the incident beam passes through the target.

Thus,

$$d\sigma/d\Omega = (I/\Delta\Omega/I_0) [(A/\rho t)/N_0] \quad (3.1)$$

where $d\sigma/d\Omega$ is usually expressed in mb/sr (10^{-27} cm²/sr). The cross section can also be expressed as a function of transferred momentum, $d\sigma/dt$.

In electron scattering, the first order Born approximation with small corrections is valid, so that data taken at different incident energies fall on the same curve when plotted versus the "effective" momentum transfer.¹ Absorption in nucleon-nucleon scattering invalidates the first order Born theory so that the curves at different incident energies are very different when plotted as a function of momentum transfer. In Fraunhofer scattering the cross section is a function of the momentum transfer and the radius of the target. Plotting versus momentum transfer will take out some of the dependence upon the incident energy. Thus, the first minimum of ²⁰⁸Pb, for example, should appear at about the same momentum transfer for 0.8 and 1.0 GeV protons. The tabulated cross sections in Appendix II are given for both center of momentum angle and momentum transfer.

The cross section for p+p elastic scattering is given by the corrected number of events per relative beam times a constant. The determination of this constant, or the normalization of the data, is discussed in the next section.

B. HYDROGEN ELASTIC SCATTERING

Many measurements of the p+p elastic scattering at about 1.463 GeV have been performed,^{26,38-41} yielding data with quoted uncertainties of less than $\pm 10\%$, yet the magnitudes vary by 30% or more, and there are significant differences in the shapes of the angular distributions. Two recent sets of data which have good agreement is that of H. B. Willard, et al.²⁶ taken at 1.463 GeV/c and that of K. Abe, et al.³⁸ taken at 1.4 and 1.5 GeV/c. The total cross section measurements, along with the other data suggests that the first point (10°_{lab}) of Willard's data is small by about 10%. The second point is 3% smaller than Abe's data, while the rest fall in line very well. Willard's data is found in Table III, while that of K. Abe is listed in Table IV. Both sets of data are plotted in Figure 6 for comparison. The normalization of the current scattering data has been measured by taking p+p elastic data at laboratory scattering angles of 15.0, 20.0, 24.5, 26.0, and 30.0°, and comparing to Willard's data.

The p+p data was analyzed using a restricted area of the focal plane. The angle contribution was limited to 20 mrad as compared to 52 mrad for $^{12,13}\text{C}$ and ^{208}Pb . There is no physics in the vertical angle, that is the cross section does not depend upon the particular vertical angles chosen. If the number of events is plotted as a function of the vertical scattering angle, the distribution is "flat" except at the extremes where the finite acceptance of the spectrometer creates "tails" in the distribution. The cut removes these tails leaving the flat part of the distribution, so that the solid angle can be computed easily. The vertical angle is calculated by the analyzer using the measured vertical angle and position at the focal plane, along with the theoretical backwards

Figure 6

The $p + p$ elastic scattering data used to normalize the present experiment is shown. The $pc = 1.405, 1.501 \text{ GeV}$ data are taken from Ref. 38, while the $pc = 1.463 \text{ GeV}$ data are from Ref. 26.

TRANSPORT matrix. Empirical measurements have shown that the calculated vertical angle is linear in the sense that the number of events per vertical angle scales within statistics for any particular peak along the focal plane (for many different vertical angle cuts taken within the flat part of the distribution as discussed above).

There is a fairly large variance in solid angle (or spectrometer efficiency) as a function of momentum across the focal plane. Since $dE/d\theta$ for hydrogen is large for the angles considered here (10-14 MeV/degree), the solid angle correction has a dramatic effect on the relative cross section. In fact, even though the differential cross section is falling, the uncorrected distribution is seen to be constant or rising for a particular spectrometer setting.

The number of events versus scattering angle can be found in two ways. For peaks in the excitation spectrum with no background, such as the first three states in ^{208}Pb , a computer gate can be set on the peak. All of the events that fall in the peak can be analyzed in the computer and plotted versus scattering angle, yielding the angular distribution for a particular spectrometer setting. Alternately, if there is background under the peak and/or another peak nearby, the excitation spectra can be analyzed for each desired range of scattering angles. The number of events in each peak, minus the background is then found using PEKFIT.²³ Due to the large kinematic rotation of the p+p data at the focal plane, only data over scattering angles of 0.94° at each spectrometer setting is usable as compared to 2.06° for heavier targets (mass greater than or equal to 12). The number of events at each angle was found by fitting the quasi-elastic background due to ^{12}C with a quadratic shape and subtracting the fit from the p+p peak in spectra gated on scattering angles covering 0.19° . The number of events is then corrected for the solid angle efficiency.

As mentioned earlier the correction was determined empirically by sweeping the ^{12}C elastic peak across the focal plane, with the HRS set at 15° .³¹ After

correcting the data, a curve was fit to the trend, and unnormalized cross sections were read off the graph and divided into the the data of H. B. Willard, et al.²⁶ Use of the monitor telescope MTR for beam monitoring gives constants for angles 15, 20, 25, and 30° of 144 ± 7 , 150 ± 7 , 148 ± 3 , and 155 ± 5 . Notice that the 15° point is about 3% lower than the other points. The cross section for p+p elastic from the CH target is thus

$$d\sigma/d\Omega_{lab} = (\text{corrected events/MTR}) (149 \pm 6) \quad (3.2)$$

The ^{12}C cross section has been measured using the same CH target. By dividing Eq. (3.1) for ^{12}C by the same relation for ^1H and substituting (3.2) we arrive at the following

$$\begin{aligned} d\sigma/d\Omega(^{12}\text{C}) &= (\text{corrected events/MTR}) * \Delta\Omega(^{12}\text{C}) * 12 \\ &* [\rho t(^1\text{H})/\rho t(^{12}\text{C})] * (149 \pm 6) \end{aligned} \quad (3.3)$$

By using the same target the absolute target thickness cancels, giving $\rho t(^1\text{H})/\rho t(^{12}\text{C}) = 1.12$ for the PILOT B scintillator. The solid angle for ^1H is 0.098 msr while that for ^{12}C is 0.177 msr (data in 0.19° bins), due to the difference in the range of vertical angles that are used. Thus

$$d\sigma/d\Omega(^{12}\text{C}) = (\text{corrected events/MTR}) * (92.7 \pm 4) \quad (3.4)$$

For normalization of the ^{208}Pb and ^{13}C data, the relative beam monitors (SEM, IC1,2) are used to obtain the cross section from the corrected events as compared to the yield and cross section for ^{12}C . The relative target thicknesses are needed here. A more detailed discussion of the extraction of the number of events, for each final state, per relative beam follows.

C. THE EXPERIMENTAL DATA

As mentioned earlier, there are two methods of obtaining the number of events in a "peak" which corresponds to a specific final excited state of the target nucleus. For the ^{208}Pb (p,p) reaction, energy gates are used on each side of a peak. All events falling between these gates are analyzed and summed into scattering angle bins of 0.19° . In Fig. 7, the ^{208}Pb (p,p) spectrum at 30° in the laboratory is shown. This is the limiting cross section for the 10 mg/cm^2 target and a beam of approximately 60 nA. After four hours almost 1000 elastic events were accumulated over the 2° of acceptance. The ratio of peak to background is the worst here, compared to the rest of the ^{208}Pb data. As can be seen in the figure the spectrum is quite "clean", with the background contributing much less than the counting errors, to the error in the number of events. Both the number of elastic events and of $2.6, 3^-$ events were grouped into 0.19° bins, with about 10% statistics for the 3^- data. The 5^- state at 3.2 MeV was extracted with double the bin size and poorer statistics. The 5^- at 3.7 is always smaller than the first 5^- with a ratio of about 0.6. There is no evidence in our spectra for the 4^- state that lies between the two 5^- states, as seen by Wagner, *et al.*⁴² with 35-MeV protons, and a resolution of 5 to 8 keV.

The ^{208}Pb elastic differential cross section seen in Fig. 10 drops nearly eight orders of magnitude from center of mass (cm) angles 2° to 31° , and exhibits eight minima in the diffractive pattern. The first minimum is shallow, probably due to Coulomb effects, while the next three have maximum/minimum ratios of about two. This ratio decreases slowly with increasing angle. The last point at an angle of 31.1° cm corresponds to a momentum transfer of 3.9 fm^{-1} . This momentum transfer localizes the reaction in space by the uncertainty principle, $\Delta p \cdot \Delta x = h$, giving $\Delta x = 2\pi(197.3)/777.8 = 1.6 \text{ fm}$. The data should then be sensitive to structure in the matter distribution of this size or larger. In

Figure 7

The spectrum from the $^{208}\text{Pb}(p,p)$ reaction at a laboratory scattering angle of 30° . This is the limiting cross section for the 10 mg/cm^2 target and a beam of 60 nA. Angular distributions have been obtained for the elastic and the excited states at 2.6 and 3.2 MeV.

Table V are listed several of the "stronger" states in ^{208}Pb , with parameters from Wagner⁴² and from intermediate energy analyses. The results are discussed in the next chapter.

Spectra at two angles from the ^{12}C (p,p) reaction are shown in Fig. 8. The elastic and the 2^+ state at 4.4 MeV are free enough from background that energy gates may be used to extract cross sections. Three body exit channels open up just below the 0^+ state at 7.7 MeV. A quadratic fit to the background is subtracted from the peaks corresponding to the 0^+ , 7.7 MeV, the 3^- , 9.6 MeV, and the 4^+ , 14.1 MeV final states. The approximate background under the 3^- and 4^+ is shown by dashes in the figure. Besides background from three-body channels, there are many broad states evident. In Table VI are listed relevant excited states in ^{12}C . Many of the numbers including the energies and widths of the states are taken from F. Ajzenberg-Selove's compilation.⁴³ The resolution is a parabolic function with the minimum at the center of the excitation spectrum. This gives several hundred keV worse resolution for the 4^+ state which has a natural width of 258 keV. The best resolution obtained was about 450 keV for this state. The 13.4 MeV state with a width of about 375 keV is seen as a shoulder under the 4^+ state. Care must be taken so that this shoulder is subtracted correctly. Evidence of the 10.3 MeV (3 MeV wide), 10.84 MeV (315 keV) and the 11.2 MeV (430 keV) states is seen in the spectra at different angles. Care must be taken so that the data from the 3^- state at 9.64 MeV does not contain contributions from these states.

The ^{12}C and ^{13}C elastic data, Figs. 11 and 17, extend to about 40°_{cm} (momentum transfer of 4.5 fm^{-1}), or into the region of the third minimum. The first minimum and corresponding maximum has a ratio of almost four while the second is just over one. The ^{12}C and ^{13}C cross sections have about the same shape out to the first maximum where they begin to differ with the ^{13}C having a smaller slope.

Figure 8

Two spectra from the $^{12}\text{C}(p,p)$ reaction are shown. Angular distributions have been obtained for the elastic and the excited states at 4.4, 7.7, 9.6, and 14.1 MeV.

At the back angle the ^{13}C cross section is about five times larger.

As seen in the tabulated data Appendix II, there is a drop in the error in the cross section for the ground state in ^{13}C at a scattering angle of $\theta_{\text{cm}} = 17.67^\circ$. The kinematic separation of 0.8 MeV at this angle between the ^{12}C and ^{13}C elastic states has finally made it possible for the HRS to completely resolve the two. For center of mass angles smaller than 17.67° , the ^{12}C elastic must be subtracted from the $^{12}\text{C} + ^{13}\text{C}$ elastic yield. The yield from the 15% ^{12}C in the 156 mg/cm^2 ^{13}C target (subscript 13) is computed from that of the CH target (12) by corrected yield of ^{12}C in $^{13}\text{C} =$

$$\rho t_{13}/\rho t_{12}) * (\text{Beam}_{13}/\text{Beam}_{12}) (CF_{12}/CF_{13}) * \text{yield}_{12} \quad (3.5)$$

where CF is the correction factor for obtaining the total number of events from the number of analyzed events. For the two targets used here t_{13}/t_{12} is 0.301.

Two spectra for ^{13}C (p,p) are found in Fig. 9. The data from the excited states in ^{13}C suffer more from interference with each other than that from ^{12}C . The contaminant from the 2^+ state in ^{12}C is resolved from the 3.68, $3/2^-$ state in ^{13}C at 10° . The kinematic shift at 35° is such that the 2^+ interferes with the 6.85, $5/2^+$ and the 7.55, $5/2^-$ states. Otherwise a double peak fit can be used to obtain the data for the 3.086, $1/2^+$ and the 3.68 MeV states, and for the 6.85 MeV and 7.55 MeV states. The 3.086 MeV state is a single particle $2s$ state.⁴⁵ Its cross section is about an order of magnitude smaller than the 3.68 and 7.55 states which can be treated as states resulting from the coupling of a $1/2^-$ neutron to the 2^+ state in ^{12}C . A $1/2^-$ neutron coupled to the 3^- state in ^{12}C would give two states of J^π , $5/2^+$ and $7/2^+$. The angular distribution for the state at 11.9 MeV is that for an $\ell = 3$ transfer giving a probable $7/2^+$ assignment. One of the $5/2^+$ states at 3.85 and 6.86 MeV could be a single particle state while the other

Figure 2

Two spectra from the $^{13}\text{C}(p,p)$ reaction are shown. Angular distributions have been obtained for the ground state and the excited states at 3.1, 3.7, 6.9, 7.6, and 11.9 MeV.

Figure 10

The $^{208}\text{Pb}(p,p)$ elastic differential cross section obtained in this experiment. The analyzing power is taken from Refs. 27 and 53.

Figure 11

The $^{12}\text{C}(p,p)$ elastic differential cross section obtained in this experiment. The analyzing power is taken from Refs. 27 and 53.

could be the collective state. Both states have small cross sections. The 3.85-MeV state is barely evident in the tail of the 3.68-MeV state. A cross section has been extracted for the 6.86-MeV state. The peak to background ratio is about 1 for many of the angles, and the state is not evident in the spectra at angles much forward of 20° . Table VII includes the features of the ^{13}C excited states, with the energies and widths from F. Ajzenberg-Selove.⁴⁴ Very few proton + ^{13}C experiments have been performed, with the only recent experiment performed at less than 40 MeV,⁴⁵ and no deformation parameters for the collective states seem to be available.

CHAPTER IV

THEORETICAL ANALYSIS

A. ELASTIC SCATTERING

Although recent electron scattering studies show considerable sensitivity to details of nuclear charge distributions,⁴⁶⁻⁴⁸ these studies have the limitation that they probe only the electromagnetic form factors of the nucleus,¹ that is, the charge distribution along with the magnetic distribution of any unpaired neutrons. Recent measurements of proton-nucleus elastic scattering at incident proton energies near 1 GeV have reawakened interest in what can be learned concerning the nuclear matter distribution from proton scattering. References 8, 49, 50, and 51 are examples of recent theoretical papers on this subject. When such data extend to high enough momentum transfer [$>0.3(\text{GeV}/c)^2$], the angular distributions display considerable sensitivity to rather fine details of the proton and neutron distributions, including density fluctuations in the nuclear interior, as shown here. The experimental data is shown in Figs. 13 through 19 together with results of a preliminary analysis. The analysis of the elastic scattering was carried out in the partial wave formalism, solving the Schrödinger equation with exact relativistic kinematics.⁹

$$\left[\frac{d^2}{dr^2} - \ell(\ell+1)/r^2 - 2\mu U_{j\ell}(r)/\hbar^2 + kn^2 \right] \chi_{j\ell}(r) = 0 \quad (4.1)$$

where kn is the relativistic proton-nucleus center of mass momentum, the reduced energy $\mu = \xi_1 \xi_2 / (\xi_1 + \xi_2)$ and ξ_i is the total energy of particle i (proton or target nucleus) in the proton-nucleus center of mass system. The microscopic proton-nucleus optical potential was obtained from the Kerman-McManus-Thaler expansion¹⁰ in the rearrangement discussed by Feshbach, et al.¹¹ In this approach, to first order in intermediate excitations of the target nucleus, the

proton-nucleus optical potential is given in terms of the proton-nucleon scattering amplitudes and the matter density distributions of the target nucleus.¹¹

The ingredients which are needed to predict the angular distribution and polarization of medium-energy protons elastically scattered by a target are:

1) the Coulomb interaction; 2) a realistic set of nucleon-nucleon scattering amplitudes including spin effects; 3) the nuclear matter densities of the target; and, 4) effects of nucleon-nucleon correlations and other higher-order processes, if any. The first three, in particular, have a large effect on the calculated angular distributions.^{11,51}

In a partial-wave formalism, the Coulomb interaction is simple to treat properly, and its effects are well understood. The nucleon-nucleon scattering amplitudes are rather poorly known, particularly the ratio of the real to imaginary part of the spin-independent amplitude and the entire spin-dependent part of the amplitude. These uncertainties, and to a lesser extent the unknown effects of correlations, severely limit the sensitivity of the analysis to the details of the nuclear matter densities in which one is particularly interested. Measurement of the analyzing power, along with the elastic cross section, provides information which may be used to remove much of the uncertainty as regards spin-dependence.

The general spin-dependent form for the nucleon-nucleon amplitudes is adopted:

$$t_{pj}(q^2) = t_{pj}^0(q^2) + i t_{pj}^s(q^2) (\vec{\sigma}_p + \vec{\sigma}_j) \cdot \hat{n} \quad (4.2)$$

where j stands for proton or neutron, $\vec{q} = \vec{k}_i - \vec{k}_f$ and $\hat{n} = (\vec{k}_i \times \vec{k}_f) / |\vec{k}_i \times \vec{k}_f|$.

The parametrization adopted is,⁵² with M the nucleon mass,

$$t_{pj}^o(q^2) = (ik_o \sigma_{pj}^T / 4\pi) (1 - i\alpha_{pj}) \exp(-B_{pj} q^2) ,$$

$$t_{pj}^s(q^2) = (ik_o \theta_{pj} / 4\pi) (q^2 / 4M^2)^{1/2} (1 - i\alpha_{spj}) \exp(-B_{spj} q^2)$$
(4.3)

In principle, the twelve parameters of Eq. 4.3 may be determined by fitting proton-nucleon angular distributions and polarizations at a laboratory energy of 800 MeV. The calculations are essentially the same as those of Kujawski and Vary,⁵² except that we used spin-dependent nucleon-nucleon parameters extracted from 800 MeV proton-nucleon data and from a preliminary analysis of proton-nucleus analyzing power measurements.⁵³ Keeping the total cross sections σ_{pp}^T and σ_{pn}^T fixed at 4.73 and 3.80 fm², respectively, we fit the data of Ref. 54 using Eq. 4.3 to obtain $\alpha_{pp} = 0.056$, $\alpha_{pn} = -0.196$ and $B_{pp} = 0.09$ fm², $B_{pn} = 0.12$ fm² (see Fig. 12). Besides the ¹²C, ¹³C, and ²⁰⁸Pb elastic data, these same parameters are also used to fit ⁴⁰Ca, ⁵⁸Ni, ⁹⁰Zr, ¹¹⁶Sn, and ¹²⁴Sn (Refs. 53 and 55) at 800 MeV.

With only $p + p$ and no $n + p$ polarization data available at 800 MeV, the values of θ_{pj} , α_{spj} , and B_{spj} are adjusted for a first-order empirical fit to preliminary proton-nucleus polarization data at 800 MeV.⁵³ For simplicity the spin-dependent parameters are assumed to be the same for protons and neutrons, so that at least partly because of isotopic effects, they differ from nucleus to nucleus. The values used are found with the density parameters in Table VIII. The ¹³C asymmetry was measured over a limited range around 20° to 25°, and found to be almost identical to ¹²C; so the same spin parameters were used.

The general form for the proton and neutron density distributions was chosen to be a three-parameter Fermi distribution with an oscillatory Gaussian

Figure 12

The fit to the proton-nucleon data using the spin-dependent form for the nucleon-nucleon amplitude as given in Eq. 4.3. The total cross sections, σ_{pp}^T and σ_{pn}^T , are fixed at 4.73 and 3.80 fm². The fit uses $\alpha_{pp} = 0.056$, $\alpha_{pn} = -0.196$, $B_{pp} = 0.09$ fm², and $B_{pn} = 0.12$ fm². The data are from Refs. 26 and 54.

correction term

$$\rho_j(r) = \rho_{oj}[(1+w_j r^2/R_j^2)/\{1+\exp((r-R_j)/z_j)\}] + s_j \cos(m_j r - \phi_j) \exp(-d_j(r-r_{oj})^2)] \quad (4.4)$$

for j = proton or neutron. The oscillatory second term^{46,48} is required only for ^{208}Pb where the data extend beyond a momentum transfer squared of $0.6(\text{GeV}/c)^2$, and are therefore sensitive to such fluctuations of the density distributions. The ^{12}C and ^{13}C data require a Gaussian correction term with no oscillation; thus $m = \phi = 0$. The strengths of the correction terms are such that they make just a few percent change in the folded matter distributions.

The proton charge density as determined by electron scattering^{1,46-48} was numerically unfolded to yield the proton point density parameters used in Eq. 4.4. As usual, ρ_{oj} was obtained by normalizing to the proper number of target protons. The electron scattering data that is used extends to about 3.5 fm^{-1} on ^{13}C and 4.0 fm^{-1} on ^{12}C , and 3.7 fm^{-1} on ^{208}Pb . The experimental single proton charge distribution used fits the $e^- + p$ scattering data to greater than 3 fm^{-1} .

The point-proton matter distributions were kept fixed (except for the case of ^{208}Pb) for the rest of the analysis. Corresponding neutron density parameters, as well as the three spin dependent parameters, θ_p , α_{sp} , and B_{sp} (see Eq. 4.3) were searched to provide simultaneous fits to both the angular distributions and the analyzing powers, with the results listed in Table VIII. Notice that a positive value of α_{sp} is required to fit the polarization data. A negative sign results in a fit that is out of phase near the maxima of the measured asymmetries. This is in disagreement with those (Refs. 52, 56, 57) who have used a real and imaginary part of the spin orbit potential with different signs.

For ^{208}Pb , the data extend to larger momentum transfers than do corresponding electron-scattering data. Therefore corrections to the matter densities were estimated roughly in a eikonal approach, by Fourier-transforming the square root of the ratio of the experimental cross section to the one calculated with a three-parameter Fermi density. As in Eq. 1 of Ref. 46, a small oscillatory correction results. The wavelength of the oscillation, $2\pi/m$, is 2.5 fm compared to a sensitivity in the data, as discussed earlier, of $\Delta x_{\text{vh}}/\Delta p \sim 1.6$ fm. The same correction is made to both proton and neutron point densities. The correction does not affect the fits to the available electron-scattering data. Without the correction, there is a discrepancy in slope and phase between the proton data and the calculation, starting at 20° and becoming progressively worse as the scattering angle increases. The correction changes the folded neutron distribution by about 0.5% with no change in the rms radius. From the analysis the difference between the neutron and proton rms radii, Δr_{np} , is 0.20 fm (see Table VIII), which is in fair agreement with results of a spin-independent Glauber analysis by Ahmad,⁴⁹ 0.26 fm, and of a spin-dependent KMT analysis by Ray and Coker,⁸ 0.25 fm, both using 1 GeV Saclay cross section data. The results all agree with recent Hartree-Fock predictions⁵⁸⁻⁶⁰ which give $\Delta r_{\text{np}} = 0.20\text{-}0.225$ fm, and disagree with some recent Glauber analyses⁶¹ of cross sections taken at Gatchina at 1 GeV, yielding a difference of $\Delta r_{\text{np}} = 0.04 - 0.06$ fm,⁵⁰ and with pion total cross section measurements.²

For ^{12}C the resulting rms proton matter radius is 2.319 fm. After adjusting the corresponding parameters of the point/neutron distribution to obtain the fit shown in Fig. 15 by the solid curve, it is found that any neutron distribution with $\langle r^2 \rangle^{1/2} \approx 2.325$ fm gives a good fit to the data up to the second maximum (18°). If the known proton density fluctuation⁴⁸ in the interior region was not included, along with a similar shaped correction to the neutron density,

Figure 13
 The angular distributions for the ^{208}Pb ground state and excited states at 2.6 and 3.2 MeV are given, along with theoretical fits as discussed in the text.

^{208}Pb ELASTIC SCATTERING

Figure 14

The theoretical fit to the $^{208}\text{Pb}(p,p)$ elastic analyzing power as discussed in the text. The taken are taken from Refs. 27 and 53.

Figure 15

The angular distributions for proton elastic scattering from ^{12}C and ^{13}C are presented along with an analysis that is discussed in the text.

^{12}C ELASTIC SCATTERING

Figure 16

The theoretical fit to the $^{12}\text{C}(p,p)$ elastic analyzing power as taken from Refs. 27 and 53.

poor fits to the data beyond 25° [$-t \approx 0.3(\text{GeV}/c)^2$] were obtained. The strength of the Gaussian correction is such that it makes about a 3% change at the surface and 10% at the origin of the folded density for ^{12}C , and changes the rms radius by 0.04 fm.

The results of this analysis may be compared with those of Ahmad⁴⁹ for 1 GeV cross section data, particularly since both analyses begin with the same charge distribution as above. The good fits obtained here, compared to the relatively poor fits of Ahmad and others, are presumably due to the inclusion of spin effects and also to a freer search on the neutron density parameters. Both analyses yield $\Delta r_{np} \approx 0$, but the present analysis implies quite different shapes for proton and neutron matter densities, as seen in Table VIII.

A similar statement can be made about the sensitivity of the ^{13}C fit to the data beyond 25° . This is the first measurement of proton elastic scattering at intermediate energies on this nucleus. As can be seen in Table VIII, the proton rms radius is almost identical to that of ^{12}C , but the neutron rms radius is 0.16 fm larger. Since ^{12}C and ^{13}C are not spherical nuclei, they are not usually included in Hartree-Fock calculations, although G. Ripka has presented a Hartree-Fock theory of deformed, light nuclei.⁶² It is hoped that this data will stimulate more work along these lines.

Since in the present analysis, the neutron parameters and (relatively independently) the parameters of the spin dependent parts of the nucleon-nucleon scattering amplitudes, have been freely searched, it would be unwise to conclude that there is not some partial compensation for omission in the analysis of small effects, such as those due to correlations and other multistep processes. This is particularly true for ^{12}C . Although it seems likely that the extracted Δr_{np} is not affected by these uncertainties in general,⁵¹ a final conclusion

must await analyses including all effects known to be significant. Here, the importance of the analyzing power data and simultaneous analysis of analyzing power and angular distribution data, in reducing the larger uncertainties in nuclear matter density parameters, should be stressed.

B. INELASTIC SCATTERING

The inelastic scattering data for protons incident on ^{12}C , ^{13}C , and ^{208}Pb at 800 MeV, along with a distorted wave Born approximation (DWBA) analysis⁹ are found in Figs. 13, 17 and 18. The values of the collective parameters $\beta_\ell R$ used, are found in Tables V, VI, and VII.

The DWBA calculations for the inelastic proton scattering cross section require no adjustable parameters, and use as input only two items of physical information: the optical potential that describes the elastic scattering data, and the usual collective parameter $\beta_\ell R$, which can be obtained from many low-energy analyses of inelastic data. As is well known from low energy inelastic scattering, the angular distributions are indicative of the transferred angular ℓ , with the first maximum occurring at a larger angle as ℓ is increased. The DWBA T-matrix is given by

$$T^{\text{DWBA}} \sim \langle \chi_f^{(-)} | F_\ell | \chi_i^{(+)} \rangle \quad (4.5)$$

where the distorted waves, $\chi^{(\pm)}$, are obtained from the solution of Eq. 4.1 for elastic scattering and the inelastic form factor for transferred angular momentum ℓ is given by

$$F_\ell(r) = \beta_\ell R_0 (2\ell+1)^{-1/2} d/dr U_{j\ell}(r) \quad (4.6)$$

where $U_{j\ell}(r)$ is the first order KMT potential in Eq. 4.1 which fits the elastic scattering data. The optical potential, real and imaginary central parts, real

Figure 17

The angular distributions of protons exciting the 4.4, 7.7, 9.6, and 14.1 MeV states in ^{12}C are shown, along with the results of DWBA analyses as discussed in the text.

Figure 18

The angular distributions of protons exciting the 3.1, 3.7, 6.9, 7.6, and 11.9 MeV states in ^{13}C . The DWBA fits shown, assume the weak-coupling model as discussed in the text.

and imaginary spin orbit and the Coulomb are fed into the calculation point by point versus the radius, instead of the more familiar functional forms (Woods-Saxon).

As seen in Eq. 4.6 the inelastic form factor is basically the derivative of the optical potential.⁶³ The potential that is used here contains only the real and imaginary central terms, although the Coulomb excitation⁶³ is included. The inclusion of the spin orbit would put the second derivative of the density into the calculation. The second derivative of the optical potential is thought to be smaller than the spin orbit term and has also been left out.

When the ^{208}Pb elastic data were fit before the asymmetries were available, a very weak spin orbit term was used, which resulted in a perfect fit to the 3^- data. The results of the current DWBA calculations for the first two excited states in ^{208}Pb , the 3^- and the 5^- , can be seen as solid lines in Fig. 13.

The $\beta_\ell R$ values are taken from low energy analyses. The same value fits the 3^- data at 1 GeV,^{8,9} but no polarization data existed for these calculations.

Notice that the data is higher than the calculation as the angle increases.

The spin orbit potential is known to become important in this region. If the spin orbit potential is included in the form factor^{64,65} the theoretical curve could move towards the data at the back angles. Verhaar saw this effect in ^{60}Ni for 40 MeV protons (see Fig. 2 of Ref. 65). In general, the deformation of the spin orbit potential must be different from the deformation that is used with central parts of the potential,⁶⁴ so that there is an additional parameter in the calculation. This, however, is a subject for future study.

The fit to the 2^+ state in ^{12}C is found in Fig. 17. The same $\beta_\ell R$ gives a similar fit to the 1 GeV data.⁸ Since the ground state of ^{13}C is $1/2^-$, there is an ambiguity in the j transfer in the inelastic transitions. A microscopic calculation should then be used. The data should still be sensitive to the ℓ

transfer, so that a macroscopic analysis has been made. The model used is a $1/2^-$ neutron coupled to the excited states of ^{12}C . For the 2^+ state this gives $3/2^-$ and $5/2^-$ states. So, using $j = \ell = 2$ for the transfer yields the fits to the $3/2^-$ state at 3.68 MeV in ^{13}C , and the $5/2^-$ state at 7.55 MeV, both found in Fig. 18. Notice that the deformation lengths are 1.44 (1.23) fm for the $3/2^-(5/2^-)$ state as compared to 1.45 fm for the ^{12}C 2^+ state, and that there is the same relative fit to all three states.

The fit for the 3^- state at 9.63 MeV in ^{12}C is found in Fig. 17 with $\beta_3 R$ equal to 1.02 fm. This same value is used for the 1 GeV data.⁸ As discussed in Ref. 8, the inclusion of the Gaussian correction to the density gives the fit a shoulder at about 25° instead of the deep minimum that has been obtained in other analyses (see for example Ref. 49). The state at 11.9 ± 0.1 MeV in ^{13}C , shown in Fig. 18, clearly involves an $\ell = 3$ transfer with $\beta_3 R = 1.14$ fm (as compared to 1.02 fm for the 3^-). This is probably a $7/2^+$ state, although F. Ajzenberg-Selove⁴⁴ does not list it as such. As will be discussed later, the fit to the 6.8, $5/2^+$ state, seen in the same figure, indicates that it is probably not related to the 3^- state.

DWBA or coupled-channels calculations using collective model form factors for the $7.65, 0^+$ state in ^{12}C predict angular distributions which are out-of-phase with the data. Gustafsson and Lambert¹⁷ have shown that form factors which assume particle-hole excitations are able to reproduce both the electron and the proton inelastic scattering data. The same transition densities as given in Ref. 17 are used to obtain the fits shown in Fig. 17. The solid curve results from a two particle-two hole model, while the dashed curve represents the one particle-one hole prediction. Note that the deep minimum at 16° is better reproduced by the two particle-two hole model, as is also the case in Ref. 17.

The DWBA calculation for the direct step to the 4^+ state at 14.1 MeV in ^{12}C is found in Fig. 17. The two-step process⁶⁶ was thought to be the cause of the large discrepancy. In fact Abgrall, et al.¹⁶ calculated the two-step process and predicted a shape that is similar to our data, but is off in magnitude. What makes this remarkable is that they had only 4 to 6 data points, at 1.0 and 0.8 GeV, that had very large errors, and that lie in the region of the first maximum only. In the model that is used the 0^+ , 2^+ , and 4^+ states are thought to constitute an abbreviated rotational band. The ^{12}C elastic data are then refit using the conventional Woods-Saxon potential forms. For numerical convenience, and because the effect of the spin orbit term in a $0^+2^+4^+$ coupling scheme is expected to be small compared to the multistep domination of the angular distribution, the spin orbit potential strength has been set to zero. In Table IX are found the values of the parameters, i.e. potential strength, radius and diffuseness for the real central, imaginary volume, and surface imaginary scattering potentials. The surface absorption located at $0.48 \cdot (12)^{1/3} = 1.13$ fm is used to "mock up" the Gaussian correction terms to the matter densities, as well as the difference between the three parameter and two parameter Fermi functions. The extreme deformation of the potential shape was handled exactly, rather than in a power series expansion, using the Legendre polynomial expansion procedure discussed by Tamura.⁶⁶ Three curves are shown in Fig. 19 for the 4^+ transition, namely the DWBA result already discussed, and results of two coupled-channels calculations. The dashed curve is the result of a full coupled-channels calculation with $\beta_2 R = -1.36$ fm and $\beta_4 R = +0.10$ fm, which however does not couple the ground state and 4^+ channels to the 2^+ channel. There still exist two paths by which the 4^+ is reached from the entrance channel, one directly via the $\beta_4 Y_4$ term in the optical potential, and another "indirectly" via the $(\beta_2 Y_2)^2$ that appears in the Legendre polynomial expansion.⁶⁶ Thus, in this calculation, the "indirect" step

Figure 19

The results of the coupled-channels calculation, treating the 0^+ , 2^+ , 4^+ states of ^{12}C as an abbreviated rotational band. The details are given in the text.

is due to the deformation of the potential. The solid curve is the result of a calculation that explicitly includes the 2^+ channel, and therefore also the two-step path $0^+ \rightarrow 2^+ \rightarrow 4^+$. Note that while deformation alone is sufficient to give the observed second peak in the angular distribution at 28° , coupling to the 2^+ channel (and thus two-step processes) is required to give the second peak a magnitude which is correct relative to that of the first peak. Also, it is clear that the 4^+ deformation should be opposite in sign to the 2^+ state. The deformed nuclear shape,

$$R = R_0 [1.0 + \beta_2 Y_{20}(\theta) + \beta_4 Y_{40}(\theta)] \quad (4.7)$$

corresponding to $\beta_2 R = -1.36$ fm and $\beta_4 R = 0.0$ and 0.10 fm, has been transformed to rectangular coordinates and plotted in Fig. 20 to show the ground state matter density (with no distinction of protons and neutrons) that is implied by the calculations discussed above. The value of $\beta_4 R = 0.10$ fm, that seems to result in the best fit to the angular distribution, also is seen to have the more believable shape. Fig. 13a of Ref. 62 is very similar except that G. Ripka's Hartree-Fock calculation has $\beta_4 R = 0.0$ fm.

That the $1/2^+$ state at 3.1 MeV in ^{13}C is a single particle state with little, if any collectivity, is evident in the fact that the cross section is an order of magnitude smaller than that of the collective states. The cross section should be computed from the overlap of the 2s state with the ground state, with the same gaussian form for the interaction (see Eq. 4.3) as used to fit the elastic scattering. This requires a significant change to existing theoretical codes, but should be done in the future. Greaves, et al.⁴⁵ measured low energy (30.4 MeV) inelastic proton cross sections and asymmetries for this state, treated it as a 2s $1/2$ single particle state, and obtained relatively good fits.

SHAPE OF CARBON

Figure 20

The ground state deformation that gives rise to the rotational band 0^+ , 2^+ , 4^+ states in ^{12}C is plotted for the values used in computing the curves shown in Fig. 19.

There are two low-lying $5/2^+$ states in ^{13}C , one at 3.8 MeV and the other at 6.8 MeV. The state at 3.8 is small (Fig. 9); just a bump on the tail of the 3.68, $3/2^-$ state. The 6.8 MeV cross section is a factor of ten smaller than that of the collective states. The peak to background ratio is as small as one for some angles, with the tail from the 2^+ state in ^{12}C interfering at back angles and the 7.55 MeV state causing difficulties with the background subtraction at all angles. It may be a d $5/2$ single particle state.

In addition to the angular distributions, polarized proton data exists⁶⁷ for the 2^+ , 0^+ , 3^- and 4^+ states in ^{12}C , between 14° and 25° in the laboratory. The present DWBA calculations without the spin-orbit potential in the form factor does not resemble the asymmetries obtained. A more complete calculation for the ^{12}C and ^{13}C nuclei that can fit the cross sections and analyzing powers should give a better picture of these two complex nuclei.

CHAPTER V

DISCUSSION

A. ERROR ANALYSIS

The errors in the analysis of the elastic scattering data are reflected in the neutron rms radius, since the neutron point matter distribution has been searched in fitting the data. The errors include that in the absolute normalization of the cross section and scattering angle of the proton angular distributions, the error in the charge distribution as determined from electron scattering, and the error in the nucleon-nucleon parameters. For the present, the first-order KMT potential is assumed to be correct, although the effect of neglecting correlations can be estimated.

As seen in Eq. 3.4 the error in the normalization of the ^{12}C is 4% due to the quoted error in the data of Willard, *et al.*,²⁶ Additional error from the relative solid angle is about 3%, for an elastic peak which is centered on the focal plane. The variation of the beam monitor ratios is observed to be 2-3%. The targets are known to be of uniform thickness to 1%. The cross sections were earlier conservatively quoted to be accurate to $\pm 10\%$.²⁹ The above errors added in quadrature add to a little over 6%, although adding them yields 10-11%. An additional error of 2%, due to the uncertainty in the solid angle variation across the focal plane, must be added to the excited states. The error from the background subtraction for the 14.1 MeV state in ^{12}C and the 11.9 MeV state in ^{13}C could be as much as 10%; though this is difficult to determine. The error in B_0R is approximately one-half that of the cross section. This should be about 5% for the excited states, excluding the 14.1 MeV and the 11.9-MeV states where the error is 7 to 8%.

As discussed in Chapter II the scattering angle is known to $\pm 0.05^\circ$. The error in the rms proton radii is given as 0.2% for ^{208}Pb and 1% for ^{12}C and ^{13}C .¹ The nucleon-nucleon parameters are as follows: $\sigma_{pp} = 47.3(+1.3, -0.9)$, $\sigma_{pn} = 38 \pm 2$, $B_{pp} = 0.09 \pm 0.02$, $B_{pn} = 0.12 \pm 0.016$, $\alpha_{pp} = 0.1 \pm 0.2$, and $\alpha_{pn} = -0.35 \pm 0.15$. The values that are used in the present analysis are as above except $\alpha_{pp} = +0.056$ and $\alpha_{pn} = -0.196$.

The uncertainty in angle contributes to the uncertainty in the radii. Diffraction theory gives $R \cdot \sin\theta = \text{constant}$, so that the percent error in $\sin\theta$, taken over the angular distribution, is reflected in the radius. The error for an angular uncertainty of $\pm\Delta\theta$ can be computed from

$$\text{Error} = 1/n \left\{ \sum (\sin(\theta_n + \Delta\theta) - \sin\theta_n)^2 / \sin^2\theta_n \right\}^{1/2} \quad (5.1)$$

Points from 5° to 30° are taken to reflect the range in the data that is well explained by the analysis. For $\pm 0.05^\circ$ this is about 0.19%. The rms radius is related to $(0.6)^{1/2}R$ so that for ^{208}Pb the error is 0.01 fm, and for ^{12}C it is 0.0035 fm. The proton radii are fixed so that the neutrons must take up the error. An estimate of this effect is A/Z times the above, giving 0.025 fm for ^{208}Pb and 0.007 fm for carbon.

The sensitivity of the results to the various parameters was investigated using the chi-squared per point as an indication of the quality of the fit. Three percent error was added to the statistical counting error for each point to account for the systematic error in the relative cross sections. The worst point was not included in the average, so as to better reflect the overall fit. The ratio of the chi-squared, for the various changes in the parameters, to that of the solution discussed earlier, is found in Table X. While fitting the data, the philosophy has been that changes that worsen the fit to the data at small angles, in favor of improving the fit to the data at larger angles, have not been

allowed. Thus, the chi-squared does not tell the whole story, and should only be used as an indication of the sensitivity to changes in the parameters. Since the Gaussian correction terms are small, they have been turned on and off, while the other parameters have been changed by 10%, in most instances. The results are consistent with what has been stated before.

The fits to the angular distributions are very sensitive to the matter radii. The theoretical differential cross section at small angles cannot be adjusted very much so that a change in the normalization worsens the fit in this region. The ^{208}Pb fit is especially sensitive to this. Omission of the Gaussian correction term in the proton matter distributions results in a very large change in the chi-squared due to a shift in angle of the fits after 15° . There does not seem to be a change in the spin independent parameters that would improve the fit for all three nuclei. For example, an increase in B_{pp} or B_{pn} does not affect the ^{12}C fit, improves that for ^{13}C by about 5%, but worsens that for ^{208}Pb by as much as 50%. A study of the nucleon-nucleon amplitudes, including data from the other isotopes, mentioned earlier in Chapter IV, should be done. The spin-dependent parameters are discussed elsewhere.²⁷ They have little effect on the rms radii.⁶⁸

L. Ray⁶⁸ performed an analysis of the errors for ^{124}Sn . The errors from the data normalization ($\pm 10\%$), the angle calibration ($\pm 0.05^\circ$), the proton radius (± 0.007 fm), and the uncertainties in the nucleon-nucleon spin independent parameters, as given above, were included so as to add coherently to the error. Total neglect of the spin-orbit potential caused the neutron radius to decrease by only 0.03 fm so that the uncertainty in the spin-dependent parameters has a negligible effect compared to the other terms. Equivalent fits (the same chi-squared) resulted in a change in the neutron rms radius of 0.03 fm or 0.6%. An exception to this is ^{12}C , for which the fit to the polarized data is not as

good as that for the heavier nuclei. Solutions which give equally bad fits to the data have been found to change the neutron rms radius by 0.1 fm. If the correlations are as big as some theorize, their neglect could have an effect similar to neglecting the spin orbit term, so that the error could be as large as ± 0.06 fm. The simultaneous fitting of cross sections for different isotopes can help fix the nucleon-nucleon parameters, although they only contribute a total of 15%. The uncertainty in the angle gives 46% of the effect, while the normalization contributes 22%. The error in the R_n parameter (Eq. 4.4) is 0.6% while that for z_n is 5.8%. Since the error is dominantly from the angular uncertainty, these percent errors roughly apply to all nuclei. The values of the strength of the spin parameter θ found in Table IX are accurate to $\pm 1 \text{ fm}^2$ or 10%. Model ambiguities are difficult to estimate and must await further study.

B. CONCLUSION

The analysis of the 800-MeV elastic proton scattering data has shown that there is great sensitivity to details of the proton and neutron matter densities. Extracting these details unambiguously is another problem. Recent discussions have shown that it will be some time before the theoretical nuclear physicists agree on what constitutes the "correct" calculation. In the first order KMT approach discussed here, the results are sensitive to the point matter densities, but the accuracy of the calculation is open to discussion. There is a one to one connection between the correction to the neutron density (the Gaussian term in Eq. 4.4) and the difference in the calculation as compared to the data. This correction is unique if the data goes far enough back in angle. The bigger the area in the difference, i.e. the broader the range in momentum transfer that is spanned, then the better defined the transform that yields the correction term. For this reason the ^{12}C and ^{13}C data should be extended to larger momentum transfers. The usual methods of analysis may break down in regions of momentum

transfer $>6 \text{ fm}^{-1}$ where the $p + \text{nucleon}$ reaction reaches its kinematic limit. Thus, "off shell" effects must be accounted for. The data should be fairly easy to obtain, since the maximum beam on the 86 mg/cm^2 CH target was $<4 \text{ nA}$, as compared to 60 nA on the ^{208}Pb target.

It has also been shown that information obtained for collective excited states at low energies can be used along with the potential that describes elastic scattering in DWBA calculations at intermediate energies to obtain absolute fits to the data at these energies. The same deformation lengths can be used for the 2^+ and 3^- states in ^{12}C as those used for the low energy data. The model of coupling a $1/2^-$ neutron to the 2^+ and 3^- state has been shown to explain the resulting $3/2^-$, $5/2^-$, and $7/2^+$ states in ^{13}C , although there is some problem with the $5/2^+$ state.

The inelastic scattering is sensitive to the first derivative of the density, and probably the second derivative through the spin orbit potential. An improvement to be made in the calculation is the inclusion of the spin-orbit potential in the form factor for inelastic scattering. This could result in better fits to the ^{208}Pb inelastic data.

It has been shown that the two-step process dominates the angular distribution of protons exciting the ^{12}C , 4^+ state. It would be very interesting to see the results for another cycle in the diffraction pattern. This data is more sensitive to multistep processes at intermediate energies than any data taken thus far at these energies. More sophisticated coupled channel calculations are probably in order. Unfortunately these calculations are lengthy.

Microscopic calculations are needed for the single particle states in ^{13}C and the 7.7 MeV state in ^{12}C . These require straightforward changes in existing inelastic codes.

The HRS has been shown to be a valuable instrument in obtaining accurate cross sections at intermediate energies and should provide additional interesting data on proton induced reactions in the future.

REFERENCES

1. C. W. De Jager, H. De Vries, and C. De Vries, At. Data and Nucl. Data Tab. 14, 479 (1974); R. Engfer, et al., At. Data and Nucl. Data Tab. 14, 509 (1974); F. Boehm and P. L. Lee, At. Data and Nucl. Data Tab. 14, 605 (1974).
2. B. W. Allardyce, et al., Nucl. Phys. A209, 1 (1973).
3. E. Friedman and C. J. Batty, Phys. Rev. C16, 1425 (1977).
4. R. Leonardi, Phys. Lettrs. 43B, 455 (1973).
5. L. S. Kisslinger, R. L. Burman, J. H. Koch, and M. M. Sternheim, Phys. Rev. C6, 469 (1972).
6. C. L. Morris, Phys. Rev. C13, 1755 (1976).
7. R. Bertini, et al., Phys. Lettrs. 45B, 119 (1973).
8. L. Ray and W. R. Coker, University of Texas Report UTNT-3, Austin (1977).
9. W. R. Coker, L. Ray, and G. W. Hoffmann, Phys. Lettrs. 64B, 403 (1976).
10. A. K. Kerman, H. McManus, and R. M. Thaler, Ann. Phys. (N.Y.) 8, 551 (1959).
11. H. Feshbach, A. Gal, and J. Hüfner, Ann. Phys. (N.Y.) 66, 20 (1971).
12. R. D. Viollier, Ann. Phys. (N.Y.) 93, 335 (1975).
13. I. Ahmad, Nuclear Physics A247, 418 (1975).
14. G. Alberi, M. Gmitro, and L. Hambro, Il. Nuovo Cim. 38, 239 (1977).
15. I. Brissaud, et al., Phys. Lett. 48B, 319 (1974).
16. Y. Abgrall, J. Labarsouque, B. Morand, Nuclear Physics A271, 477 (1976).
17. C. Gustafsson and E. Lambert, preprint (1977).
18. M. S. Livingston, Los Alamos Scientific Laboratory Report LA-5000, New Mexico (1972).
19. E. Dunn, Los Alamos Scientific Laboratory Report LA-6678-PR, New Mexico (1977).
20. H. A. Thiessen, private communication.

REFERENCES (Continued)

21. K. L. Brown, R. Rothacker, D. C. Carey, and C. Iseln, Stanford Linear Accelerator Center Report SLAC-91, Rev. 1 (1974).
22. B. Zeidman, Los Alamos Scientific Laboratory Report LA-4773-MS, Part 1, New Mexico (1971).
23. M. A. Oothoudt, private communication.
24. N. Barash-Schmidt, et al., Rev. Mod. Physics 48, 1 (1976) p. 72.
25. P. V. Vavilov, Sov. Phys. JETP 5, 749 (1957).
26. H. B. Willard, et al., Phys. Rev. C14, 1545 (1976).
27. R. P. Liljestrang, thesis, University of Texas, (1978).
28. C. A. Whitten, Jr., private communication.
29. G. S. Blanpied, W. R. Coker, R. P. Liljestrang, L. Ray, G. W. Hoffmann, D. Madland, C. L. Morris, J. C. Pratt, J. E. Spencer, H. A. Thiessen, N. M. Hintz, G. S. Kyle, M. A. Oothoudt, T. S. Bauer, J. C. Fong, G. Igo, R. J. Ridge, C. A. Whitten, Jr., T. Kozlowski, D. K. McDaniels, P. Varghese, P. M. Lang, H. Nann, K. K. Seth, and C. Glashausser, Phys. Rev. Lett. 39, 1447 (1977).
30. J. Fong, et al., to be published.
31. T. Kozlowski, et al., to be published.
32. C. L. Morris, H. A. Thiessen, and G. W. Hoffmann, I.E.E.E. Transactions of Nuclear Science, San Francisco Meeting, (1977).
33. "Data-Acquisition Program Q," LAMPF (July 31, 1976) unpublished.
34. T. Kozlowski, private communication.
35. R. M. Rolfe, LA-6631-T, Los Alamos Scientific Laboratory, New Mexico (1976), p. 48-62.
36. F. J. Naivar, W. L. Rogers, D. D. Simmonds, J. E. Spencer, N. C. Spencer, and C. F. Stark, LA-6718-MS, Los Alamos Scientific Laboratory, New Mexico (1977).
37. J. C. Pratt, J. E. Spencer, and C. A. Whitten, Jr., LA-6810, Los Alamos Scientific Laboratory, New Mexico (1977).
38. K. Abe, et al., Phys. Rev. D12, 1 (1975).
39. B. A. Ryan, A. Kanofsky, T. J. Devlin, R. E. Mischke, and P. F. Shepard, Phys. Rev. D3, 1 (1971).

REFERENCES (Continued)

40. H. A. Neal, et al., Indiana University Report No. C00-2009.15 (1970), unpublished.
41. D. T. Williams, et al., Rutherford Laboratory Report No. RPP/H/77 (1971) unpublished.
42. W. T. Wagner, G. M. Crawley, G. R. Hammerstein, and H. McManus, Phys. Rev. C12, 757 (1975).
43. F. Ajzenberg-Selove, Nucl. Phys. A248, 1 (1975).
44. F. Ajzenberg-Selove, Nucl. Phys. A152, 1 (1970).
45. P. D. Greaves, V. Hnizdo, J. Lowe, and O. Karban, Nucl. Phys. 179, 1 (1972).
46. J. Heisenberg, et al., Phys. Rev. Lettrs. 23, 1402 (1969).
47. J. Heisenberg, J. S. McCarthy, and I. Sick, Nucl. Phys. A157, 435 (1970).
48. I. Sick and J. S. McCarthy, Nucl. Phys. A150, 631 (1970).
49. I. Ahmad, Nucl. Phys. A247, 418 (1975).
50. G. D. Alkhazov, et al., Nucl. Phys. A274, 443 (1976); Phys. Lettrs. 67B, 402 (1977).
51. E. Boridy and H. Feshbach, Ann. Phys. (1977).
52. E. Kujawski, Phys. Rev. C1, 1651 (1970); E. Kujawski and J. P. Vary, Phys. Rev. C12, 1271 (1975).
53. G. W. Hoffmann, et al., Phys. Rev. Lettrs.
54. J. Bystricki, F. Lehar, and Z. Janout, CEA-N-1547 (E)-Saclay-Aout (1972); O. Benary, L. R. Price, and G. Alexander, Lawrence-Berkeley Laboratory Report UCRL-20000NN, unpublished.
55. L. Ray and G. W. Hoffmann, private communication.
56. K. Kwiatkowski, thesis, University of Maryland (1976) p. 71.
57. L. S. Azhgirey, et al., Nucl. Phys. 43, 213 (1963).
58. J. W. Negele, Phys. Rev. C1, 1260 (1970); Phys. Rev. C9, 1054 (1974).
59. D. Vautherin and D. M. Brink, Phys. Rev. C5, 626 (1972).
60. J. W. Negele and D. Vautherin, Phys. Rev. C5, 1472 (1972).
61. G. K. Varma and L. Zamick, Phys. Rev. C16, 308 (1977).

REFERENCES (Continued)

62. G. Ripka, Advances in Nuclear Physics, Vol. 1, ed. M. Baranger and E. Vogt, Plenum Press, New York (1968), p. 183.
63. T. Tamura, W. R. Coker, and F. Rybicki, Comp. Phys. Comm. 2, 94 (1971).
64. G. R. Satchler, Polarization Phenomena in Nuclear Reactions, ed. H. H. Barschall and W. Haeberli, The Univ. of Wisconsin Press, Madison (1970), p. 155.
65. B. J. Verhaar, Lecture Notes in Physics, Vol. 30, ed. J. Ehlers, et al., Springer-Verlag, Berlin (1973), p. 268.
66. T. Tamura, Rev. Mod. Phys. 37, 679 (1965).
67. R. Liljestrnd, et al., to be published.
68. L. Ray, private communication.

TABLE I: The specifications of the scintillators used in this experiment.

<u>Counter</u>	<u>Material</u>	<u>Size (inches)</u>	<u>Tube Voltages (-volts)</u>
S ₃	NE110	42.0 x 5.5 x 0.375	1780, 1796
S ₄	NE110	42.0 x 5.5 x 0.375	1919, 1851
S ₂	Pilot B	30.0 x 5.5 x 0.375	1879, 1869
S ₆	Pilot F	30.5 x 4.25 x 0.25	1743, 1821
V _{1,2}	Pilot F	5.0 x 7.0 x 0.125	1673, 1701
J _{1,2}	Pilot F	11.0 x 2.0 x 0.25	1767, 1925
MTL			2001, 2056, 2000, 2060
MTR			1937, 1962, 1817, 2036

TABLE II: The single particle rates for a 60 nA beam of 800 MeV protons on ^{208}Pb at a laboratory scattering angle of 28° are given.

<u>Device</u>	<u>Singles Rate ($10^6/\text{sec}$)</u>	<u>Correction Factor</u>
Chambers	0.20	1.20
S_{2U}	0.38	
S_{2D}	0.38	
S_{3U}	1.04	
S_{3D}	0.46	PID = 1.01
S_{4U}	0.77	
S_{4D}	0.76	
S_{6U}	0.75	
S_{6D}	0.49	
J_1	0.33	Accidental vetoes 1.09
J_2	0.53	
V_1	0.12	1.004
V_2	0.14	
MTL1(120°)	0.49	
MTR1(45°)	3.29	

TABLE III: Data from P + P elastic scattering at $p_{\text{c}} = 1.463$ GeV are given as a function of angle and momentum transfer. The data are from Ref. 26. The total uncertainty for each data point is given.

θ_{lab} (degrees)	θ_{cm}	$-t$ $(\text{GeV}/c)^2$	$d\sigma/d\Omega_{\text{lab}}$ (mb/sr)	$d\sigma/d\Omega_{\text{cm}}$ (mb/sr)	$d\sigma/d\Omega$ [mb/(GeV/c) 2]
9.8 ± 0.8	23.3	0.061	46.3 ± 2.2	8.44	70.6
15.0 ± 0.8	35.5	0.139	30.0 ± 1.5	5.76	48.2
20.0 ± 0.9	47.0	0.239	19.55 ± 0.88	4.02	33.6
24.9 ± 1.0	58.0	0.353	11.55 ± 0.27	2.58	21.6
29.9 ± 1.5	69.0	0.481	6.26 ± 0.21	1.55	13.0
34.9 ± 1.1	79.6	0.615	4.11 ± 0.13	1.14	9.54
39.9 ± 1.5	89.9	0.750	3.15 ± 0.10	0.994	8.32

TABLE IV: Data from P + P elastic scattering at $pc = 1.405$, and 1.501 GeV are given as a function of momentum transfer. The data are taken from Ref. 38, and have a 3% uncertainty in normalization.

<u>$pc = 1.405$ GeV</u>		<u>$pc = 1.501$ GeV</u>	
<u>$-t$</u>	<u>$d\sigma/dt$</u>	<u>$-t$</u>	<u>$d\sigma/dt$</u>
0.123	57.2 ± 1.4	0.136	56.1 ± 1.3
0.158	47.3 ± 1.3	0.175	46.0 ± 1.2
0.193	40.0 ± 1.2	0.215	40.3 ± 1.1
0.228	35.0 ± 1.1	0.254	32.1 ± 1.0
0.263	29.4 ± 1.0	0.292	26.1 ± 0.9
0.298	24.5 ± 0.9	0.332	22.9 ± 0.8
0.333	23.0 ± 0.9	0.371	18.9 ± 0.7
0.370	20.0 ± 0.8	0.409	17.0 ± 0.7
0.403	17.7 ± 0.8	0.449	15.3 ± 0.6
0.438	17.2 ± 0.8	0.487	13.1 ± 0.6
0.473	14.2 ± 0.7	0.527	10.0 ± 0.5
0.509	13.0 ± 0.7	0.566	10.2 ± 0.5
0.544	12.1 ± 0.6	0.604	9.16 ± 0.51
0.579	12.4 ± 0.6	0.643	8.24 ± 0.48
0.614	10.3 ± 0.6	0.683	8.99 ± 0.51
0.649	11.3 ± 0.6	0.722	6.89 ± 0.45

Table V. Energy, J^π , and deformation parameters for excited states of ^{208}Pb are taken from Ref. 42. The $\beta_\ell R$ values used in the DWBA calculations as discussed in the text are also given. Only the levels with $\beta_\ell > 0.03$ are given.

<u>Excitation</u>	<u>J^π</u>	<u>β_ℓ</u>			<u>$\beta_\ell R$ (fm)</u>
		<u>(p,p) 35 MeV</u>	<u>(p,p) 54 MeV</u>	<u>(p,p) 800 MeV</u>	
0.0	0^+				
2.6146	3^-	0.120	0.108	0.112	0.747
3.1978	5^-	0.058	0.055	0.056	0.370
3.7087	5^-	0.034	0.035		
4.037	$(7)^-$	0.038			
4.0855	2^+	0.058	0.058		
4.3237	4^+	0.067	0.069		
4.4235	6^+	0.062	0.064		
4.698	3^-	0.033	0.037		
5.072	$(9)^+$	0.039	$(10)^+$ 0.030		
5.087	3	0.033			
5.345	3	0.035	0.039		

Table VI. Energies, J^π , and widths of ^{12}C excited states, as taken from Ref. 43.

The $\beta_\ell R$ values at 1.0 GeV are taken from Ref. 8, while the ones at 0.8 GeV are from the analysis discussed in Chapter IV. $\beta_\ell R$ is measured in fermis.

<u>Excitation</u>	<u>J^π</u>	<u>Γ (keV)</u>	<u>$\beta_\ell R(1 \text{ GeV})$</u>	<u>$\beta_\ell R(0.8 \text{ GeV})$</u>
0.0	0^+	stable		
4.439	2^+	< 1	1.57	1.45
7.655	0^+	< 1	DWBA, CC out of phase	
9.64	3^-	34 ± 5	1.1	1.02
10.3	(0^+)	3000 ± 700		
10.8	1^-	315 ± 25		
11.16	(2^+)	430 ± 80		
11.83	2^-	260 ± 25		
12.71	1^+	< 1		
13.35	(2^-)	375 ± 40		
14.08	4^+	258 ± 15		0.285 (CC $0^+, 2^+, 4^+$)
15.11	$T=1$	< 1		

Table VII. Energies, $2J^\pi$, and widths of ^{13}C excited states, as taken from Ref. 44. As discussed in Chapter IV, there is an ambiguity in the j transfer for the excited states, which makes a macroscopic analysis dubious.

Excitation	$2J^\pi$	Γ (keV)	j, l, s transfer	$\beta_2 R(\text{fm})$
0.0	1^-	stable		
3.086	1^+	< 1	2s single particle state	
3.684	3^-	< 1	2,2,0	1.44
3.85	5^+	< 1		
6.864	5^+	6	3,3,0	(0.343)
			single particle?	
7.49		5		
7.55	5^-	5	2,2,0	1.23
7.677	3^+	72 ± 10		
8.25	3^+	1000 ± 100		
8.86	1^-	161 ± 18		
9.50	(3^-)	< 5		
9.90	3^-	28		
10.46		200		
10.75	7^-	50		
10.81		30		
11.00	(1^+)	37		
11.08	(1^-)	4		
11.72	(3^-)	125 ± 20		
11.97	7^-	150		
12.10	(≥ 7)	125 ± 30		
11.9	7^+		3,3,0	1.14
	5^+		3,3,0	1.32
12.42	$(1,7)^-$	200		
12.81				
13.3		5000 ± 1000		
13.41		60		
13.55				
13.76		350		
14.13		200		
14.39		260		
14.63		210		
14.95		380		
15.109	$T=3/2$	5.9 ± 0.9		

Table VIII. The results of the theoretical analysis discussed in the text. The first eight columns give the numerical values of Equation 4.4. The root-mean-square (rms) radii for the point-nucleon density distributions are listed under $\langle r^2 \rangle^{1/2}$. The quantity $\langle r^2 \rangle_{ch}^{1/2}$ is the rms radius of the charge form factor taken from electron scattering. The last three columns give the numerical values of the spin-dependent parameters, Equation 4.3.

Nucleus	w	R (fm)	z (fm)	k	s	r ₀ (fm)	d (fm ⁻²)	m (fm ⁻¹)	φ (rad)	⟨r ² ⟩ ^{1/2} (fm)	⟨r ² ⟩ ^{1/2} _{ch} (fm)	θ _p (fm ²)	α _{sp}	B _{sp} (fm ²)	
¹² C	p	-0.15	2.42	0.45	1	0.27	1.4	6.9	0.	0.	2.319	2.453	17.6	0.29	0.07
	n	-0.15	2.43	0.46	1	-0.02	2.6	0.33	2.7	1.7	2.393		17.6	0.29	0.07
¹³ C	p	-0.16	2.51	0.41	1	0.33	1.4	6.9	0.0	0.0	2.299	2.434	17.6	0.29	0.07
	n	-0.05	2.30	0.50	1	-0.27	1.0	4.9	0.0	0.0	2.540		17.6	0.29	0.07
²⁰⁸ Pb	p	0.36	6.45	2.65	2	0.030	6.3	0.52	1.4	2.5	5.443	5.502	9.0	0.63	0.20
	n	0.36	6.19	3.13	2	0.13	0.0	0.21	0.0	0.0	5.625		9.0	0.63	0.20

Table IX. Woods-Saxon parameters for $^{12}\text{C}(\text{p},\text{p})$ elastic scattering for use in the JUPITER coupled channel code.⁶⁶ The spin-orbit has been set to zero for reasons as given in the text. The deformation lengths are $\beta_2 R = -1.36$ fm and $\beta_4 R = 0.10$ fm.

	<u>DWBA</u>	<u>CC</u>
V	-5.1	-7.05
r	1.012	0.975
a	0.531	0.447
W_I	79.2	78.6
r_I	0.908	0.911
a_I	0.500	0.427
W_{sf}	18.0	17.9
r_{sf}	0.500	0.506
a_{sf}	0.600	0.500
r_c	1.05	1.08
V_{so}	0.00	0.00
W_{so}	0.00	0.00

Table X. The results of the sensitivity study as discussed in Chapter V. The numbers are the ratio of the chi-squared to that of the solution found in Table VIII. Also the neutron rms radii are given in parentheses. The '*' signifies that the number in Table VIII, or in Chapter IV, has been multiplied by this amount.

	^{12}C	^{13}C	^{208}Pb
Solution chi-squared per point	11.5 (2.325)	8.85 (2.484)	5.66 (5.660)
$d\sigma/d\Omega = 1.1^*$	1.16	0.91	1.67
$\theta = +0.05^\circ$	0.83	0.98	1.11
$\theta = -0.05^\circ$	1.30	1.06	1.08
$V_{\text{so}} = 1.1^*$	1.31	1.45	0.87
$B_{\text{s}} = 1.1^*$	0.98	1.05	1.06
$\alpha_{\text{pp}} = 0.062$	1.01	1.00	1.03
$\alpha_{\text{pn}} = -0.216$	1.00	1.01	0.92
$B_{\text{pp}} = 0.11$	1.02	0.95	1.50
$B_{\text{pn}} = 0.136$	1.01	0.94	1.13
$\sigma_{\text{pp}} = 48.6$	0.87	1.05	0.88
$\sigma_{\text{pn}} = 40.0$	0.82	1.09	0.91
$S_{\text{n}} = 0$	0.62 (2.365)	3.18 (2.453)	----
$S_{\text{p}} = 0$	1.89	8.99	----
$S_{\text{n}} = S_{\text{p}} = 0$	3.01 (2.365)	----	1.02 (5.659)
$z_{\text{n}} = 1.02^*$	1.08 (2.345)	1.04 (2.502)	1.31 (5.687)
$R_{\text{n}} = 1.02^*$	0.89 (2.353)	1.29 (2.508)	1.28 (5.748)
$R_{\text{n}} = 1.004^*$	----	----	1.02 (5.703)
$R_{\text{n}} = 0.98^*$	----	1.07 (2.460)	----
$S_{\text{n}} = 0, R_{\text{n}} = 1.02^*$	0.73 (2.393)	----	----
$\quad, R_{\text{n}} = 1.04^*$	1.03 (2.422)	----	----
$\quad, R_{\text{n}} = 1.06^*$	1.39 (2.451)	----	----

APPENDIX I

KINEMATICS

A. KINREL OUTPUT

The kinematics for the reaction $B(A,C)D$ from the program KINREL.²³

The numbers listed are as follows:

Masses used for the four particles

QA = Charge state of particle A

QC = Charge state of particle C

TA = Kinetic energy of particle A (MeV)

BRHOA = $B \cdot RHO$ of particle A (KG-CM)

BETAA = Beta of particle A (ratio of velocity to light)

1/VA = Inverse of velocity of particle A (NS/M)

T in CM = Kinetic energy in center of mass (MeV)

S = Square of total relativistic energy (GeV^{**2})

EX = Excitation energy of residual nucleus (MeV)

RXN THRESHOLD = Minimum beam energy for reaction to proceed (MeV)

THLC = Lab angle for particle C (degrees)

THCMC = Center of mass angle for particle C (degrees)

TLC = Lab kinetic energy of particle C (MeV)

BRHOC = $B \cdot RHO$ for particle C (KG-CM)

PC = Momentum of particle C (GeV/c)

B = Magnetic field necessary to place particle C at RHO
= 350 CM (KG)

BETAC = Beta of particle C

1/VC = Inverse of velocity of particle C (NS/M)

G = Jacobian connecting lab and cm cross sections

$$= d\sigma_{cm}/d\sigma_{lab}$$

DTC/DTH = Derivative of TC with respect to THLC (keV/degree)

THLD = Lab angle of particle D (degrees)

TLD = Kinetic energy of particle D (MeV)

RATIO = Kinematic factor defined in Eq. 2.2

TBITE = Kinetic energy range covered by focal plane assuming a
4% momentum bite (MeV)

Q**2 = Square of three-momentum transfer (GeV/c)**2

T = Square of four momentum transfer (GeV/c)**2

B. KINEMATIC EQUATIONS

For a reaction $2(1,3)4$, with q-value, Q, the relativistic kinematics in the laboratory reference frame and in the center of mass frame (cm) can be computed starting from the well-known energy relation

$$E = (p^2 + m^2)^{1/2} = T + m \quad (A1)$$

where units of energy are to be used throughout (i.e., $p = pc$, $m = mc^2$).

The various symbols are defined as, E = total energy, T = kinetic energy, p = momentum, m = mass, and c = speed of light in vacuum. Primes are used for the cm expressions. The Lorentz transformation between the two frames is

$$p_x = p'_x, \quad p_y = p'_y$$

$$p_z = \gamma (p'_z + v' E') \quad (A2)$$

$$E = \gamma (E' + v' p'_z)$$

where γ and β are the usual Lorentz parameters. Also

$$E = \gamma m \quad (A3)$$

$$\vec{p} = \gamma m \vec{v}$$

The following equations result:

$$E' = [(m_1 + m_2)^2 + 2T_1 m_2]^{1/2} \quad (A4)$$

$$\text{RXN THRESHOLD} = -Q (1 + m_1/m_2 - Q/2m_2) \quad (A5)$$

$$\vec{p}_1' = m_2 \vec{p}_1/E' \quad (A6)$$

$$\gamma = m_2 + E_1/E' ; \beta = v/c = p/E \quad (A7)$$

$$\vec{v}' = \vec{p}_1/(m_2 + E_1) \quad (A8)$$

$$E_3' = (E'^2 + m_3^2 - m_4^2)^{1/2} E'^2 \quad (A9)$$

The masses are known so that from any energy equation such as A9, the corresponding momentum and kinetic energy can be computed from A1. Let

$$\alpha = v' E_3'/p_3' , \text{ and } \epsilon = 1 + \gamma (\alpha^2 - 1). \quad (A10)$$

Then the center of mass scattering angle (θ_3') can be found from

$$\cos\theta_3' = \frac{-\alpha \gamma^2 \sin^2\theta_3 + s[1 - \sin^2\theta_3 (\epsilon+1) + \epsilon \sin^4\theta_3]^{1/2}}{1 + (\gamma^2 - 1) \sin^2\theta_3} \quad (A11)$$

where for $\alpha < 1$, $s = 1$ for $\theta_3 < \pi/2$ and $s = -1$ for $\theta_3 > \pi/2$. For $\alpha > 1$, there are two solutions, $s = \pm 1$ or ∓ 1 depending on the value of θ_3 . The energy of particle 3 in the lab is given by

$$E_3 = \gamma (E_3' + v' p_3' \cos\theta_3') \quad (A12)$$

and from conservation of energy, $E_4 = E_1 + E_2 - E_3$.

$$\text{Also } \sin\theta_4 = (p_3/p_4) \sin\theta_3. \quad (\text{A13})$$

$$\text{Define } X = \cos\theta \left\{ \frac{d(\cos\theta')}{d(\sin^2\theta)} \right\} \quad \text{which gives} \quad (\text{A14})$$

$$X = \frac{-\alpha \gamma^2 - \cos\theta_3' (\gamma^2 - 1)}{1 + (\gamma^2 - 1) \sin^2\theta_3} \cos\theta_3$$

$$\pm s \frac{2\epsilon \sin^2\theta_3 - \epsilon - 1}{2(1 - \epsilon \sin^2\theta_3)^{1/2} \{1 + (\gamma^2 - 1) \sin^2\theta_3\}} \quad (\text{A15})$$

$$\text{where } s = \begin{cases} +1, \theta_3' < \pi/2 \\ -1, \theta_3' > \pi/2 \end{cases}$$

then

$$\frac{dT_3}{d\theta_3} = 2\gamma v' p_3' \sin\theta_3 X \quad (\text{A16})$$

Also useful is

$$(1/p) \frac{dp}{d\theta} = (E/p^2) \frac{dT}{d\theta} \quad (\text{A17})$$

$$G = \frac{d\Omega}{d\Omega'} = \frac{d(\cos\theta)}{d(\cos\theta')} = -1/(2X) \quad (\text{A18})$$

where

$$\frac{d\sigma}{d\Omega} = G \frac{d\sigma'}{d\Omega'} \quad (\text{A19})$$

The following equations are useful for converting from the center of mass differential cross section, to that as a function of momentum transfer. "t" is the Mandelstam variable corresponding to the square of the four momentum transfer.

Defining the three momentum transfer, q, in the usual way

$$q = (\vec{p}_1' - \vec{p}_3') = p_1'^2 + p_3'^2 - 2p_1' p_3' \cos\theta_3' \quad (\text{A20})$$

then

$$t = -q^2 + (E_1' - E_3')^2 . \quad (A21)$$

For elastic scattering, this reduces to

$$t = -q^2 = -4 p_3'^2 \sin^2(\theta_3'/2) . \quad (A22)$$

One can show that

$$dt = (p_1' p_3'/\pi) d\Omega' , \quad (A23)$$

so that

$$\frac{d\sigma'}{dt} = (\pi/p_1' p_3') \frac{d\sigma'}{d\Omega'} \quad (A24)$$

12C(P,P)12C

12.000000 1.007277 1.007277 12.000000 QA= 1. GC= 1.

QEND= 0.000 MEV

TA= 000.000 MEV BRHOR=4801.044 KGCM

BETAR= 0.842

1/VA=

3.962 NS/M T IN CM= 716.843 MEV

EX= 0.000 MEV RXN THRESHOLD= 0.000 MEV

THLC DEG	THCMC DEG	TLC MEV	BRHOC KGCM	PC GEV/C	B KG	BETAC	1/VC NS/M	G	DTC/DT KEV/DEG	THLD DEG	TLD MEV	RATIO	TBITE MEV	Q**2 (GEV/C)2	T (GEV/C)2
2.00	2.30	799.803	4880.6	1.4632	13.9445	0.842	3.963	0.759	-116	88.84	0.117	-0.999	49.267	0.003	-0.003
4.00	4.39	799.534	4879.2	1.4627	13.9405	0.842	3.963	0.759	-233	87.69	0.469	-0.999	49.249	0.010	-0.010
6.00	6.05	798.951	4876.9	1.4621	13.9349	0.841	3.963	0.759	-348	86.53	1.049	-0.999	49.219	0.023	-0.023
8.00	9.18	798.139	4873.7	1.4611	13.9243	0.841	3.963	0.759	-463	85.38	1.861	-0.999	49.177	0.035	-0.035
10.00	11.47	797.096	4869.5	1.4599	13.9150	0.841	3.963	0.759	-577	84.23	2.904	-0.999	49.123	0.042	-0.042
12.00	13.76	795.628	4864.5	1.4583	13.9086	0.841	3.963	0.759	-690	83.07	4.172	-0.999	49.057	0.053	-0.053
14.00	15.05	794.325	4858.6	1.4566	13.9037	0.840	3.963	0.759	-801	81.92	5.665	-0.999	49.000	0.065	-0.065
16.00	16.33	792.623	4851.1	1.4545	13.9044	0.840	3.963	0.759	-910	80.76	7.377	-0.999	48.931	0.071	-0.071
18.00	17.62	790.694	4844.1	1.4527	13.9061	0.840	3.963	0.759	-1017	79.60	9.397	-0.999	48.859	0.075	-0.075
20.00	18.91	788.553	4835.5	1.4503	13.9094	0.839	3.963	0.759	-1122	78.44	11.736	-0.999	48.781	0.079	-0.079
22.00	20.20	786.204	4826.3	1.4479	13.9133	0.839	3.963	0.759	-1224	77.29	14.447	-0.999	48.691	0.083	-0.083
24.00	21.44	783.654	4816.1	1.4453	13.9180	0.839	3.963	0.759	-1324	76.14	17.536	-0.999	48.591	0.087	-0.087
26.00	22.70	780.907	4805.5	1.4426	13.9233	0.838	3.963	0.759	-1421	75.00	21.000	-0.999	48.484	0.090	-0.090
28.00	23.96	777.971	4793.1	1.4397	13.9295	0.837	3.963	0.759	-1514	73.87	24.939	-0.999	48.371	0.092	-0.092
30.00	25.21	774.850	4781.9	1.4363	13.9368	0.837	3.963	0.759	-1605	72.72	29.350	-0.999	48.253	0.094	-0.094
32.00	26.46	771.552	4767.1	1.4329	13.9452	0.835	3.963	0.759	-1692	71.56	34.349	-0.999	48.130	0.095	-0.095
34.00	27.70	768.083	4754.1	1.4292	13.9541	0.834	3.963	0.759	-1775	70.41	39.917	-0.999	47.997	0.096	-0.096
36.00	28.94	764.452	4739.6	1.4259	13.9635	0.834	3.963	0.759	-1855	69.25	46.148	-0.999	47.855	0.097	-0.097

13C(P,P)13C
 13.003355(1.007277) 13.003355 QA= 1. QC= 1.
 UEND= 0.000 MEV
 TA= 500.000 MEV BRHOA=4881.044 KGCM BETAR= 0.842 I/YA= 3.962 NS/M T IN CM= 722.487 MEV
 S= 189.707 GEV/c²

EX= 0.000 MEV RXN THRESHOLD= 0.000 MEV															
TMLC DEC	THOMC DEG	TLC MEV	BRHOC KGCM	PC GEV/C	B KG	BETAC	I/VC NS/M	G	DTC/DTH KEV/DEG	THLD DEG	TLD MEV	RATIO	TBLTE MEV	Q=0.02 (GEV/C) ²	T (GEV/C) ²
2.00	2.27	799.892	4880.6	1.4632	13.9446	0.842	3.953	0.774	-107	88.86	0.108	-0.999	49.257	0.003	-0.003
4.00	4.55	799.570	4879.3	1.4628	13.9410	0.842	3.963	0.774	-215	87.71	0.430	-0.998	49.251	0.003	-0.010
6.00	6.82	799.032	4877.2	1.4622	13.9349	0.841	3.963	0.775	-328	86.57	0.568	-0.998	49.223	0.003	-0.022
8.00	9.09	798.282	4874.4	1.4613	13.9264	0.841	3.964	0.776	-437	85.43	1.718	-0.999	49.134	0.003	-0.035
10.00	11.36	797.320	4870.8	1.4601	13.9155	0.841	3.965	0.777	-533	84.29	2.600	-0.998	49.074	0.003	-0.053
12.00	13.63	796.149	4865.0	1.4587	13.9022	0.841	3.967	0.778	-637	83.15	3.851	-0.997	49.035	0.003	-0.077
14.00	15.90	794.771	4858.0	1.4571	13.8868	0.840	3.969	0.780	-740	82.01	5.229	-0.995	49.035	0.003	-0.105
16.00	18.16	793.189	4854.0	1.4552	13.8687	0.840	3.971	0.782	-841	80.87	6.811	-0.993	49.020	0.003	-0.127
18.00	20.42	791.407	4847.0	1.4531	13.8485	0.840	3.973	0.784	-949	79.60	8.593	-0.991	49.020	0.003	-0.155
20.00	22.68	789.429	4839.1	1.4507	13.8260	0.839	3.975	0.787	-1037	78.34	10.571	-0.989	49.020	0.003	-0.183
22.00	24.93	787.258	4830.5	1.4481	13.8014	0.839	3.977	0.789	-1132	77.07	12.642	-0.987	49.020	0.003	-0.205
24.00	27.18	784.901	4821.0	1.4453	13.7746	0.838	3.979	0.792	-1224	75.74	14.899	-0.985	49.020	0.003	-0.230
26.00	29.43	782.360	4811.0	1.4423	13.7457	0.838	3.982	0.795	-1314	74.38	17.357	-0.983	49.020	0.003	-0.256
28.00	31.67	779.643	4800.7	1.4391	13.7148	0.837	3.985	0.800	-1401	72.96	20.029	-0.981	49.020	0.003	-0.282
30.00	33.90	776.755	4789.0	1.4356	13.6819	0.836	3.989	0.805	-1485	72.48	22.993	-0.979	49.020	0.003	-0.307
32.00	36.13	773.702	4775.7	1.4320	13.6472	0.835	3.991	0.811	-1567	71.04	26.251	-0.977	49.020	0.003	-0.332
34.00	38.36	770.485	4760.3	1.4281	13.6105	0.835	3.993	0.816	-1644	70.72	29.876	-0.975	49.020	0.003	-0.357
36.00	40.58	767.124	4750.3	1.4241	13.5722	0.835	3.995	0.816	-1719	69.61	32.876	-0.973	49.020	0.003	-0.379

208PS(P,P)208PB
 287.976654(1.007277- 1.007277)207.976654 QA= 1. QC= 1.
 QEND= 0.000+- 0.000 MEV
 TR= 800.000 MEV BRHOA=4861.044 KECM BETAA= 0.842 1/VA= 3.962 NS/M T IN CM= 794.523 MEV
 S=38205.936 GEV**2

EX=	0.000 MEV	RXN THRESHOLD=	0.000 MEV	B	BETAC	1/VC	G	DTC/DTX	THLD	TLD	RATIO	TBITE	D**2	T	
THLC	THMC	TLC	BRHOC	PC	B	BETAC	1/VC	G	DTC/DTX	THLD	TLD	RATIO	TBITE	D**2	T
DEG	DEG	MEV	KECM	GEV/C	KG		NS/M		DEG	MEV			(GEV/C)**2	(GEV/C)**2	(GEV/C)**2
2.00	2.02	799.993	4881.0	1.4633	13.5458	0.842	3.962	0.982	-6	88.99	0.007	-1.0000	49.272	0.003	0.003
4.00	4.04	799.973	4880.9	1.4632	13.5455	0.842	3.962	0.982	-10	87.97	0.061	-1.0000	49.270	0.003	0.010
6.00	6.05	799.939	4880.8	1.4632	13.5446	0.842	3.962	0.983	-26	86.97	0.109	-0.9999	49.267	0.003	0.023
8.00	8.07	799.892	4880.6	1.4631	13.5439	0.842	3.962	0.983	-33	85.96	0.169	-0.9999	49.264	0.003	0.035
10.00	10.09	799.832	4880.4	1.4630	13.5431	0.842	3.962	0.983	-40	84.95	0.241	-0.9999	49.260	0.003	0.054
12.00	12.11	799.759	4880.1	1.4629	13.5421	0.842	3.962	0.983	-46	83.93	0.328	-0.9999	49.255	0.003	0.077
14.00	14.12	799.672	4879.7	1.4628	13.5410	0.842	3.962	0.983	-53	82.91	0.428	-0.9999	49.251	0.003	0.102
16.00	16.16	799.572	4879.3	1.4627	13.5397	0.842	3.962	0.983	-59	81.89	0.541	-0.9999	49.246	0.003	0.127
18.00	18.18	799.459	4878.9	1.4625	13.5383	0.842	3.962	0.983	-65	80.86	0.666	-0.9999	49.241	0.003	0.156
20.00	20.19	799.334	4878.5	1.4623	13.5367	0.842	3.962	0.983	-72	79.82	0.804	-0.9999	49.236	0.003	0.186
22.00	22.21	799.196	4877.3	1.4620	13.5350	0.842	3.962	0.984	-78	78.79	0.953	-0.9999	49.231	0.003	0.216
24.00	24.22	799.032	4876.6	1.4618	13.5332	0.842	3.962	0.984	-84	77.75	1.113	-0.9999	49.226	0.003	0.246
26.00	26.23	798.832	4875.9	1.4615	13.5313	0.842	3.962	0.984	-90	76.70	1.283	-0.9999	49.221	0.003	0.276
28.00	28.24	798.591	4875.2	1.4613	13.5293	0.842	3.962	0.985	-96	75.65	1.467	-0.9999	49.215	0.003	0.306
30.00	30.25	798.323	4874.6	1.4611	13.5270	0.841	3.962	0.985	-101	74.59	1.667	-0.9999	49.209	0.003	0.336
32.00	32.26	797.923	4873.9	1.4608	13.5245	0.841	3.962	0.985	-107	73.52	1.887	-0.9999	49.203	0.003	0.366
34.00	34.27	797.483	4873.2	1.4608	13.5220	0.841	3.962	0.985	-113	72.44	2.117	-0.9999	49.197	0.003	0.396
36.00	36.28	797.003	4872.7	1.4608	13.5195	0.841	3.962	0.985	-119	71.35	2.367	-0.9999	49.191	0.003	0.426

APPENDIX II

TABULATED CROSS SECTIONS

The experimental cross sections as determined in this experiment are given. Listed are the center-of mass angle, the negative of the momentum transfer squared, the momentum transfer in inverse fermis, the center-of-mass cross section as a function of angle and its error, and the cross section as a function of momentum transfer squared and the error.

208PB(P,P) 0.8GEV 0.0,0+

 THETA,CM -T Q DSIG/OMEGA
 DEGREES GEV/C**2 1/FERMI MB/SR

ERROR

 DSIG/DT
 MB/((GEV/C)**2)

ERROR

4.100	.011	.526	3.449E+03	54.0	5.151E+03	80.7
4.290	.012	.550	2.848E+03	49.0	4.254E+03	73.2
4.480	.013	.575	2.853E+03	49.0	4.261E+03	73.2
4.660	.014	.598	3.044E+03	51.0	4.546E+03	76.2
4.850	.015	.622	3.340E+03	52.0	4.988E+03	77.7
5.124	.017	.657	3.819E+03	29.5	5.704E+03	44.1
5.407	.019	.693	3.885E+03	27.2	5.803E+03	40.7
5.686	.021	.729	3.628E+03	28.5	5.418E+03	42.5
5.955	.023	.764	3.250E+03	25.0	4.854E+03	37.4
6.240	.025	.800	2.700E+03	36.0	4.033E+03	53.8
6.440	.027	.826	2.035E+03	32.0	3.039E+03	47.8
6.620	.028	.849	1.609E+03	16.0	2.403E+03	23.9
6.800	.030	.872	1.141E+03	14.0	1.704E+03	20.9
7.000	.031	.898	841	11.0	1.256E+03	16.4
7.180	.033	.921	516	10.0	771	14.9
7.370	.035	.945	363	8.00	542	11.9
7.570	.037	.971	251	7.00	375	10.5
7.760	.039	.995	225	6.00	336	8.96
7.950	.040	1.019	195	6.00	291	8.96
8.130	.042	1.042	254	5.00	379	7.47
8.320	.044	1.066	284	5.00	424	7.47
8.510	.046	1.091	349	5.00	521	7.47
8.700	.048	1.115	388	6.00	579	8.96
8.890	.051	1.139	410	6.00	612	8.96
9.080	.053	1.164	404	6.00	603	8.96
9.270	.055	1.188	431	6.00	644	8.96
9.460	.057	1.212	366	6.00	547	8.96
9.640	.059	1.235	354	6.00	529	8.96
9.840	.062	1.261	278	3.00	415	4.48
10.030	.064	1.285	259	3.00	387	4.48
10.210	.067	1.308	190	5.00	284	7.47
10.400	.069	1.332	136	3.00	206	4.48
10.590	.072	1.357	110	3.30	164	4.93

208PB(P,P) ,0.8GEV 0.0,0*

THETA,CM -T Q DSIG/COMEGA ERROR DSIG/DT ERROR
DEGREES GEV/C**2 1/FERMI MB/SR MB/((GEV/C)**2)

10.780	.074	1.381	70.1	2.40	105	3.58
10.980	.077	1.407	49.4	1.90	73.8	2.84
11.160	.080	1.430	38.4	1.10	57.4	1.64
11.350	.082	1.454	33.9	1.40	50.6	2.09
11.540	.085	1.478	33.6	1.00	50.2	1.49
11.720	.088	1.501	34.8	1.00	52.0	1.49
11.910	.091	1.525	43.5	1.10	65.0	1.64
12.110	.094	1.551	49.2	1.20	73.5	1.79
12.300	.097	1.575	54.4	1.20	81.2	1.79
12.490	.100	1.599	54.0	1.20	80.7	1.79
12.670	.102	1.622	58.4	.910	87.2	1.36
12.870	.106	1.648	55.2	.910	82.4	1.36
13.050	.109	1.671	51.9	.910	77.5	1.36
13.240	.112	1.695	44.6	1.00	66.6	1.49
13.430	.115	1.719	37.2	.910	55.6	1.36
13.620	.118	1.743	31.0	.800	46.3	1.19
13.810	.122	1.767	25.3	.800	37.8	1.19
14.000	.125	1.792	18.1	.600	27.0	.896
14.180	.128	1.815	13.9	.290	20.8	.433
14.380	.132	1.840	10.1	.300	15.1	.448
14.570	.135	1.864	8.51	.250	12.7	.373
14.750	.139	1.887	6.89	.240	10.3	.358
14.940	.142	1.911	6.32	.230	9.44	.344
15.130	.146	1.935	6.73	.230	10.1	.344
15.320	.149	1.960	7.07	.230	10.6	.344
15.520	.153	1.985	8.19	.260	12.2	.388
15.700	.157	2.008	9.09	.170	13.5	.254
16.013	.163	2.048	9.44	.102	14.1	.152
16.260	.168	2.079	9.06	.220	13.5	.329
16.541	.174	2.115	8.65	.123	12.9	.184
16.820	.180	2.150	7.59	.122	11.3	.181
17.109	.186	2.187	5.67	.105	8.47	.157
17.408	.193	2.225	4.00	8.032E-02	5.97	.120

208PB(P,P) ,0.8GEV 0.0,0+

 THETA,CM -T Q DSIG/DOMEGA
 DEGREES GEV/C**2 1/FERMI MB/SR

ERROR

 DSIG/DT
 MB/((GEV/C)**2) ERROR

17.652	.198	2.256	3.18	7.231E-02	4.76	.108
17.881	.203	2.285	2.39	7.641E-02	3.56	.114
18.100	.208	2.313	1.80	8.600E-02	2.69	.128
18.280	.212	2.335	1.29	7.200E-02	1.93	.108
18.470	.217	2.359	1.24	7.100E-02	1.85	.106
18.660	.221	2.383	1.30	7.200E-02	1.94	.108
18.840	.225	2.406	1.20	6.800E-02	1.79	.102
19.040	.230	2.432	1.25	7.100E-02	1.87	.106
19.230	.235	2.456	1.47	4.900E-02	2.20	7.318E-02
19.420	.239	2.480	1.60	5.100E-02	2.39	7.617E-02
19.610	.244	2.504	1.63	5.100E-02	2.43	7.617E-02
19.790	.248	2.526	1.65	6.500E-02	2.46	9.708E-02
19.980	.253	2.550	1.58	6.400E-02	2.36	9.559E-02
20.170	.258	2.574	1.79	6.700E-02	2.67	.100
20.370	.263	2.600	1.47	6.300E-02	2.20	9.409E-02
20.560	.268	2.624	1.31	5.800E-02	1.96	8.663E-02
20.740	.273	2.646	.925	3.200E-02	1.38	4.779E-02
20.930	.278	2.670	.837	3.000E-02	1.25	4.481E-02
21.120	.283	2.694	.580	2.500E-02	.866	3.734E-02
21.300	.287	2.717	.444	2.700E-02	.663	4.033E-02
21.490	.292	2.741	.361	2.500E-02	.539	3.734E-02
21.690	.298	2.766	.301	2.300E-02	.450	3.435E-02
21.880	.303	2.790	.245	1.900E-02	.366	2.838E-02
22.070	.308	2.814	.185	1.700E-02	.276	2.539E-02
22.250	.313	2.837	.177	8.900E-03	.264	1.329E-02
22.440	.319	2.861	.174	8.700E-03	.260	1.299E-02
22.630	.324	2.885	.200	8.900E-03	.299	1.329E-02
22.820	.329	2.908	.196	9.000E-03	.293	1.344E-02
23.010	.335	2.932	.236	9.800E-03	.352	1.464E-02
23.200	.340	2.956	.234	9.800E-03	.349	1.464E-02
23.390	.346	2.980	.235	9.800E-03	.351	1.464E-02
23.580	.351	3.004	.251	1.010E-02	.375	1.508E-02
23.760	.357	3.027	.205	6.200E-03	.306	9.260E-03

208PB(P,P) ,0.8GEV 0.0,0+

THETA,CM -T Q

DEGREES GEV/C**2 1/FERMI

DSIG/COMEGA

MB/SR

ERROR

DSIG/DT

MB/((GEV/C)**2)

ERROR

23.960	.363	3.052	.185	5.900E-03	.282	8.812E-03
24.150	.368	3.075	.165	5.600E-03	.252	8.364E-03
24.330	.374	3.098	.145	7.100E-03	.217	1.060E-02
24.520	.379	3.122	.133	6.700E-03	.199	1.001E-02
24.710	.385	3.146	.106	6.000E-03	.158	8.961E-03
24.900	.391	3.170	7.460E-02	5.000E-03	.111	7.468E-03
25.090	.397	3.193	6.840E-02	4.800E-03	.102	7.169E-03
25.280	.403	3.217	4.940E-02	2.100E-03	7.378E-02	3.136E-03
25.470	.409	3.241	3.760E-02	1.700E-03	5.616E-02	2.539E-03
25.660	.415	3.265	3.340E-02	1.600E-03	4.988E-02	2.390E-03
25.840	.421	3.287	2.760E-02	2.300E-03	4.122E-02	3.435E-03
26.030	.427	3.311	3.320E-02	2.300E-03	4.959E-02	3.435E-03
26.220	.433	3.335	2.390E-02	2.200E-03	3.570E-02	3.286E-03
26.410	.439	3.358	2.930E-02	2.400E-03	4.376E-02	3.584E-03
26.610	.446	3.383	2.950E-02	2.400E-03	4.406E-02	3.584E-03
26.790	.452	3.406	2.790E-02	2.300E-03	4.167E-02	3.435E-03
27.049	.460	3.438	3.246E-02	1.770E-03	4.848E-02	2.644E-03
27.290	.468	3.468	2.940E-02	2.100E-03	4.391E-02	3.136E-03
27.480	.475	3.492	2.630E-02	1.900E-03	3.928E-02	2.838E-03
27.670	.481	3.516	2.430E-02	1.900E-03	3.629E-02	2.838E-03
27.860	.488	3.539	2.270E-02	1.800E-03	3.390E-02	2.688E-03
28.050	.494	3.563	1.930E-02	1.600E-03	2.883E-02	2.390E-03
28.240	.501	3.587	2.100E-02	1.700E-03	3.136E-02	2.539E-03
28.430	.507	3.610	1.370E-02	1.400E-03	2.046E-02	2.091E-03
28.620	.514	3.634	1.120E-02	1.300E-03	1.673E-02	1.942E-03
28.800	.520	3.656	7.300E-03	1.000E-03	1.090E-02	1.494E-03
28.990	.527	3.680	7.800E-03	1.000E-03	1.165E-02	1.494E-03
29.212	.535	3.707	5.381E-03	4.429E-04	8.036E-03	6.615E-04
29.600	.549	3.756	3.400E-03	4.100E-04	5.078E-03	6.124E-04
29.970	.563	3.801	4.200E-03	4.700E-04	6.273E-03	7.020E-04
30.300	.575	3.842	3.600E-03	4.300E-04	5.377E-03	6.422E-04
30.730	.591	3.895	4.700E-03	4.900E-04	7.020E-03	7.318E-04
31.100	.605	3.941	4.000E-03	4.600E-04	5.974E-03	6.870E-04

208PB(P,P),0.8GEV 2.62,3-

THETA,CM -T Q
DEGREES GEV/C**2 1/FERMIDSIG/OMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2) ERROR

4.100	.011	.526	89.5	7.90	134	11.8
4.290	.012	.550	73.7	7.90	110	11.8
4.480	.013	.575	78.9	7.90	118	11.8
4.660	.014	.598	74.6	7.90	111	11.8
4.850	.015	.622	76.2	8.00	114	11.9
5.127	.017	.657	65.7	3.86	98.2	5.77
5.405	.019	.693	62.9	3.23	93.9	4.82
5.680	.021	.728	49.2	3.20	73.5	4.78
5.945	.023	.762	33.4	2.41	49.9	3.60
6.240	.025	.800	18.0	2.50	26.9	3.73
6.440	.027	.826	10.3	2.00	15.4	2.99
6.620	.028	.849	7.82	.901	11.7	1.35
6.800	.030	.872	3.40	.779	5.08	1.16
7.000	.031	.898	4.50	.793	6.73	1.18
7.180	.033	.921	2.90	.700	4.33	1.05
7.370	.035	.945	6.00	1.00	8.96	1.49
7.570	.037	.971	6.00	1.00	8.96	1.49
7.760	.039	.995	13.1	1.40	19.6	2.09
7.950	.040	1.019	14.4	1.40	21.5	2.09
8.130	.042	1.042	19.7	1.00	29.4	1.50
8.320	.044	1.066	18.9	.925	28.2	1.38
8.510	.046	1.091	22.2	1.13	33.2	1.68
8.700	.048	1.115	20.3	1.20	30.3	1.79
8.890	.051	1.139	22.5	1.30	33.6	1.94
9.080	.053	1.164	18.0	1.10	26.9	1.64
9.270	.055	1.188	17.4	1.10	26.0	1.64
9.460	.057	1.212	13.8	1.00	20.6	1.49
9.640	.059	1.235	12.2	.707	18.1	1.06
9.840	.062	1.261	8.69	.590	13.0	.881
10.030	.064	1.285	7.68	.541	11.5	.808
10.210	.067	1.308	4.69	.580	7.00	.866
10.400	.069	1.332	3.27	.420	4.88	.627
10.590	.072	1.357	1.84	.350	2.75	.523

THETA,CM DEGREES	-T GEV/C**2	Q 1/FERMI	DSIG/DOMEGA MB/SR	ERROR	DSIG/DT MB/((GEV/C)**2)	ERROR
17.650	.198	2.255	.290	5.000E-02	.433	7.468E-02
17.809	.202	2.276	.335	2.342E-02	.501	3.498E-02
18.100	.208	2.313	.280	3.400E-02	.418	5.078E-02
18.280	.212	2.335	.360	3.800E-02	.538	5.675E-02
18.470	.217	2.359	.290	3.500E-02	.433	5.227E-02
18.660	.221	2.383	.470	4.400E-02	.702	6.572E-02
18.840	.225	2.406	.440	4.200E-02	.657	6.273E-02
19.040	.230	2.432	.460	5.200E-02	.687	7.766E-02
19.230	.235	2.456	.497	2.786E-02	.742	4.162E-02
19.420	.239	2.480	.465	2.739E-02	.694	4.092E-02
19.610	.244	2.504	.492	2.778E-02	.735	4.149E-02
19.790	.248	2.526	.459	3.400E-02	.686	5.078E-02
19.980	.253	2.550	.422	3.300E-02	.630	4.929E-02
20.170	.258	2.574	.453	3.400E-02	.677	5.078E-02
20.370	.263	2.600	.417	3.300E-02	.623	4.929E-02
20.560	.268	2.624	.330	2.900E-02	.493	4.331E-02
20.740	.273	2.646	.228	1.493E-02	.341	2.229E-02
20.930	.278	2.670	.164	1.232E-02	.245	1.840E-02
21.120	.283	2.694	.138	1.167E-02	.206	1.743E-02
21.300	.287	2.717	8.600E-02	1.100E-02	.128	1.643E-02
21.490	.292	2.741	9.800E-02	1.200E-02	.146	1.792E-02
21.690	.298	2.766	7.100E-02	1.000E-02	.106	1.494E-02
21.880	.303	2.790	6.800E-02	1.000E-02	.102	1.494E-02
22.070	.308	2.814	9.000E-02	1.100E-02	.134	1.643E-02
22.250	.313	2.837	7.895E-02	5.133E-03	.118	7.667E-03
22.440	.319	2.861	8.816E-02	5.268E-03	.132	7.867E-03
22.630	.324	2.885	.101	5.592E-03	.150	8.351E-03
22.820	.329	2.908	.105	6.600E-03	.157	9.857E-03
23.010	.335	2.932	9.990E-02	6.400E-03	.149	9.559E-03
23.200	.340	2.956	.108	6.700E-03	.161	1.001E-02
23.390	.346	2.980	9.790E-02	6.300E-03	.146	9.409E-03
23.580	.351	3.004	9.410E-02	6.200E-03	.141	9.260E-03
23.760	.357	3.027	6.746E-02	3.371E-03	.101	5.035E-03

208PB(P,P),0.8GEV 2.62,3-

THETA,CM	-T	Q	DSIG/DOMEGA	ERROR	DSIG/DT	ERROR
DEGREES	GEV/C**2	1/FERMI	MB/SR		MB/((GEV/C)**2)	
23.960	.363	3.052	5.601E-02	3.036E-03	8.366E-02	4.535E-03
24.150	.368	3.075	4.865E-02	2.857E-03	7.265E-02	4.267E-03
24.330	.374	3.098	3.450E-02	3.900E-03	5.153E-02	5.825E-03
24.520	.379	3.122	2.990E-02	2.900E-03	4.466E-02	4.331E-03
24.710	.385	3.146	2.730E-02	2.800E-03	4.077E-02	4.182E-03
24.900	.391	3.170	1.900E-02	2.400E-03	2.838E-02	3.584E-03
25.090	.397	3.193	1.200E-02	1.900E-03	1.792E-02	2.838E-03
25.280	.403	3.217	1.571E-02	1.371E-03	2.347E-02	2.047E-03
25.470	.409	3.241	1.430E-02	1.305E-03	2.135E-02	1.948E-03
25.660	.415	3.265	1.370E-02	1.277E-03	2.047E-02	1.907E-03
25.840	.421	3.287	1.400E-02	1.600E-03	2.091E-02	2.390E-03
26.030	.427	3.311	1.700E-02	1.800E-03	2.539E-02	2.688E-03
26.220	.433	3.335	2.050E-02	2.000E-03	3.062E-02	2.987E-03
26.410	.439	3.358	1.970E-02	1.900E-03	2.942E-02	2.838E-03
26.610	.446	3.383	1.800E-02	1.800E-03	2.688E-02	2.688E-03
26.790	.452	3.406	1.800E-02	1.800E-03	2.688E-02	2.688E-03
26.980	.458	3.430	1.700E-02	1.800E-03	2.539E-02	2.688E-03
27.236	.466	3.461	1.768E-02	1.185E-03	2.640E-02	1.770E-03
27.480	.475	3.492	1.660E-02	1.500E-03	2.479E-02	2.240E-03
27.670	.481	3.516	1.140E-02	1.200E-03	1.703E-02	1.792E-03
27.860	.488	3.539	1.020E-02	1.100E-03	1.523E-02	1.643E-03
28.050	.494	3.563	1.030E-02	1.100E-03	1.538E-02	1.643E-03
28.240	.501	3.587	7.800E-03	1.000E-03	1.165E-02	1.494E-03
28.430	.507	3.610	5.000E-03	8.200E-04	7.468E-03	1.225E-03
28.620	.514	3.634	3.400E-03	6.900E-04	5.078E-03	1.031E-03
28.800	.520	3.656	3.400E-03	6.900E-04	5.078E-03	1.031E-03
28.990	.527	3.680	4.300E-03	7.600E-04	6.422E-03	1.135E-03
29.211	.535	3.707	3.018E-03	3.322E-04	4.507E-03	4.962E-04
29.600	.549	3.756	3.300E-03	4.100E-04	4.929E-03	6.124E-04
29.970	.563	3.801	3.300E-03	4.000E-04	4.929E-03	5.974E-04
30.300	.575	3.842	4.000E-03	4.400E-04	5.974E-03	6.572E-04
30.730	.591	3.895	3.700E-03	4.300E-04	5.526E-03	6.422E-04
31.100	.605	3.941	2.300E-03	3.400E-04	3.435E-03	5.078E-04

208PB(P,P),0.8GEV, 3.2,5-

THETA,CM DEGREES	-T GEV/C**2	Q 1/FERMI	DSIG/COMEGA MB/SR	ERROR	DSIG/DT MB/((GEV/C)**2)	ERROR
6.700	.029	.859	8.00	.900	11.9	1.34
7.090	.032	.909	9.20	.900	13.7	1.34
7.470	.036	.958	7.10	.800	10.6	1.19
7.860	.040	1.008	6.20	.800	9.26	1.19
8.220	.043	1.054	4.48	.393	6.69	.586
8.600	.047	1.102	2.40	.340	3.58	.508
8.980	.052	1.151	1.00	.220	1.49	.329
9.370	.056	1.201	.480	.150	.717	.224
9.740	.061	1.248	.725	.128	1.08	.191
10.120	.065	1.297	1.10	.200	1.64	.299
10.500	.070	1.345	2.10	.280	3.14	.418
10.880	.076	1.394	2.00	.270	2.99	.403
11.250	.081	1.441	2.04	.159	3.05	.237
11.630	.086	1.490	1.50	.170	2.24	.254
12.010	.092	1.538	1.10	.140	1.64	.209
12.400	.098	1.588	1.40	.160	2.09	.239
12.760	.104	1.634	.776	7.683E-02	1.16	.115
13.200	.111	1.690	.500	8.000E-02	.747	.119
13.520	.117	1.731	.340	6.500E-02	.508	9.708E-02
13.900	.123	1.779	.280	6.000E-02	.418	8.961E-02
14.280	.130	1.827	.346	3.218E-02	.516	4.807E-02
14.660	.137	1.876	.470	4.300E-02	.702	6.422E-02
15.040	.144	1.924	.500	4.400E-02	.747	6.572E-02
15.420	.151	1.972	.520	4.500E-02	.777	6.721E-02
15.800	.159	2.021	.362	2.466E-02	.540	3.682E-02
16.170	.166	2.068	.160	2.200E-02	.239	3.286E-02
16.550	.174	2.116	.120	1.900E-02	.179	2.838E-02
16.940	.183	2.165	8.800E-02	1.600E-02	.131	2.390E-02
17.300	.190	2.211	5.600E-02	1.300E-02	8.364E-02	1.942E-02
17.800	.201	2.275	.122	1.145E-02	.182	1.710E-02
18.190	.210	2.324	.108	1.077E-02	.162	1.609E-02
18.560	.219	2.371	.121	1.106E-02	.181	1.651E-02
18.940	.228	2.419	.135	1.168E-02	.202	1.744E-02

208PB(P,P) 0.8GEV, 3.2*5- THETA,CM -T 0 DEGREES GEV/C**2 1/FERMI	DSIG/COMEGA MB/SR	ERROR	DSIG/DT MB/((GEV/C)**2)	ERROR
19.320	.237	2.467	.158	1.185E-02
19.700	.246	2.515	.128	1.643E-02
20.080	.256	2.563	8.214E-02	1.195E-02
20.460	.265	2.611	6.870E-02	1.195E-02
20.840	.275	2.659	3.254E-02	4.721E-03
21.210	.285	2.706	2.539E-02	4.481E-03
21.590	.295	2.754	3.584E-02	5.974E-03
21.980	.306	2.803	4.481E-02	7.468E-03
22.340	.316	2.848	3.661E-02	2.681E-03
22.720	.326	2.896	4.03 E-02	2.987E-03
23.100	.337	2.944	3.136E-02	2.987E-03
23.480	.348	2.991	2.539E-02	2.987E-03
23.860	.360	3.039	1.729E-02	1.533E-03
24.240	.371	3.087	9.857E-03	1.494E-03
24.620	.382	3.134	8.065E-03	1.494E-03
25.000	.394	3.182	8.961E-03	1.494E-03
25.380	.406	3.230	5.618E-03	7.160E-04
25.750	.418	3.276	7.617E-03	1.045E-03
26.120	.430	3.322	8.663E-03	1.045E-03
26.510	.442	3.371	9.708E-03	1.195E-03
26.880	.455	3.417	5.974E-03	8.961E-04

12C(P,P)0.8GEV 0.0,0+

THETA,CM DEGREES	-T GEV/C**2	Q 1/FERMI	DSIG/DOMEGA MB/SR	ERROR	DSIG/DT MB/((GEV/C)**2)	ERROR
2.600	.003	.293	2.807E+03	23.0	5.428E+03	44.5
2.810	.004	.317	2.707E+03	23.0	5.235E+03	44.5
3.030	.005	.342	2.521E+03	22.0	4.875E+03	42.5
3.240	.005	.365	2.376E+03	22.0	4.595E+03	42.5
3.440	.006	.388	2.204E+03	20.0	4.262E+03	38.7
3.670	.007	.414	2.123E+03	20.0	4.106E+03	38.7
3.890	.007	.439	1.959E+03	19.0	3.788E+03	36.7
4.100	.008	.462	1.844E+03	19.0	3.566E+03	36.7
4.320	.009	.487	1.682E+03	18.0	3.253E+03	34.8
4.540	.010	.512	1.582E+03	18.0	3.059E+03	34.8
4.680	.011	.528	1.473E+03	12.0	2.849E+03	23.2
4.890	.012	.551	1.409E+03	12.0	2.725E+03	23.2
5.110	.013	.576	1.301E+03	11.0	2.516E+03	21.3
5.320	.014	.600	1.232E+03	11.0	2.382E+03	21.3
5.540	.015	.624	1.165E+03	11.0	2.253E+03	21.3
5.730	.016	.646	1.061E+03	11.0	2.052E+03	21.3
5.900	.017	.665	970	11.0	1.876E+03	21.3
6.040	.018	.681	895	11.0	1.731E+03	21.3
6.260	.019	.705	819	11.0	1.584E+03	21.3
6.470	.021	.729	749	9.00	1.448E+03	17.4
6.690	.022	.754	702	9.00	1.358E+03	17.4
6.900	.024	.778	637	9.00	1.232E+03	17.4
7.120	.025	.802	570	9.00	1.102E+03	17.4
7.330	.027	.826	528	8.00	1.021E+03	15.5
7.550	.028	.851	466	8.00	901	15.5
7.670	.029	.864	457	8.00	884	15.5
7.960	.031	.897	393	7.00	760	13.5
8.240	.034	.928	335	7.00	648	13.5
8.530	.036	.961	283	6.00	547	11.6
8.820	.038	.993	241	3.00	466	5.80
9.100	.041	1.025	197	2.00	381	3.87
9.390	.044	1.058	164	2.00	317	3.87
9.680	.046	1.090	130	2.00	251	3.87

12C(P,P)0.8GEV 0.0,0+

THETA,CM -T Q

DEGREES GEV/C**2 1/FERMI

DSIG/OMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2)

ERROR

9.960	.049	1.122	106	2.00	205	3.87
10.250	.052	1.154	85.5	1.90	165	3.67
10.530	.055	1.186	62.7	1.00	121	1.93
10.820	.058	1.218	49.1	.900	95.0	1.74
11.110	.061	1.251	35.3	.800	68.3	1.55
11.390	.064	1.282	27.8	.700	53.8	1.35
11.680	.067	1.315	19.5	.500	37.7	.967
11.970	.071	1.347	14.0	.400	27.1	.774
12.250	.074	1.379	7.47	.160	14.4	.309
12.540	.078	1.411	4.93	.140	9.53	.271
12.830	.081	1.444	2.89	.100	5.59	.193
13.110	.085	1.475	1.77	.100	3.42	.193
13.400	.088	1.507	1.21	8.000E-02	2.34	.155
13.680	.092	1.539	1.14	8.000E-02	2.20	.155
13.970	.096	1.571	1.18	5.000E-02	2.28	9.669E-02
14.260	.100	1.604	1.52	6.000E-02	2.94	.116
14.540	.104	1.635	2.03	7.000E-02	3.93	.135
14.830	.108	1.667	2.46	8.000E-02	4.76	.155
15.110	.112	1.699	2.79	9.000E-02	5.40	.174
15.400	.117	1.731	3.28	7.000E-02	6.34	.135
15.690	.121	1.764	3.68	7.000E-02	7.12	.135
15.970	.125	1.795	3.90	7.000E-02	7.54	.135
16.260	.130	1.827	4.28	8.000E-02	8.28	.155
16.540	.134	1.858	4.29	8.000E-02	8.30	.155
16.830	.139	1.891	4.41	8.000E-02	8.53	.155
17.110	.144	1.922	4.40	8.000E-02	8.51	.155
17.400	.149	1.954	4.49	8.000E-02	8.68	.155
17.680	.153	1.986	4.22	8.000E-02	8.16	.155
17.970	.158	2.018	3.98	8.000E-02	7.70	.155
18.260	.164	2.050	3.76	8.000E-02	7.27	.155
18.540	.169	2.081	3.50	7.000E-02	6.77	.135
18.830	.174	2.114	3.31	7.000E-02	6.40	.135
19.110	.179	2.145	3.06	7.000E-02	5.92	.135

12C(P,P)0.8GEV 0.0,0+

THETA,CM -T Q
DEGREE\$ GEV/C**2 1/FERMI

DSIG/DOMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2)

ERROR

26.500	.341	2.961	3.320E-02	1.900E-03	6.420E-02	3.674E-03
26.720	.347	2.985	3.200E-02	1.800E-03	6.188E-02	3.481E-03
26.920	.352	3.007	3.300E-02	1.200E-03	6.382E-02	2.321E-03
27.140	.358	3.032	3.510E-02	1.200E-03	6.788E-02	2.321E-03
27.350	.363	3.055	3.490E-02	1.200E-03	6.749E-02	2.321E-03
27.550	.368	3.076	3.680E-02	1.600E-03	7.117E-02	3.094E-03
27.770	.374	3.101	4.050E-02	1.700E-03	7.832E-02	3.288E-03
27.980	.380	3.123	3.800E-02	1.600E-03	7.349E-02	3.094E-03
28.200	.386	3.148	3.750E-02	1.600E-03	7.252E-02	3.094E-03
28.410	.391	3.171	3.770E-02	1.600E-03	7.291E-02	3.094E-03
28.620	.397	3.193	3.720E-02	9.000E-04	7.194E-02	1.740E-03
28.830	.403	3.216	3.530E-02	1.000E-03	6.826E-02	1.934E-03
29.050	.409	3.240	3.570E-02	1.000E-03	6.904E-02	1.934E-03
29.250	.414	3.262	3.180E-02	1.200E-03	6.150E-02	2.321E-03
29.460	.420	3.285	3.520E-02	1.200E-03	6.807E-02	2.321E-03
29.680	.426	3.309	3.280E-02	1.200E-03	6.343E-02	2.321E-03
29.900	.432	3.333	2.970E-02	1.200E-03	5.743E-02	2.321E-03
30.110	.438	3.356	3.080E-02	1.200E-03	5.956E-02	2.321E-03
30.310	.444	3.378	2.740E-02	1.100E-03	5.299E-02	2.127E-03
30.530	.450	3.402	2.910E-02	1.100E-03	5.627E-02	2.127E-03
30.817	.459	3.433	2.291E-02	6.279E-04	4.430E-02	1.214E-03
31.090	.467	3.463	2.130E-02	8.000E-04	4.119E-02	1.547E-03
31.310	.473	3.486	2.040E-02	7.000E-04	3.945E-02	1.354E-03
31.510	.479	3.508	1.960E-02	7.000E-04	3.790E-02	1.354E-03
31.720	.485	3.531	1.790E-02	7.000E-04	3.462E-02	1.354E-03
31.940	.492	3.555	1.670E-02	7.000E-04	3.230E-02	1.354E-03
32.150	.498	3.578	1.530E-02	6.000E-04	2.959E-02	1.160E-03
32.370	.505	3.601	1.390E-02	6.000E-04	2.688E-02	1.160E-03
32.570	.511	3.623	1.370E-02	6.000E-04	2.649E-02	1.160E-03
32.790	.518	3.647	1.200E-02	6.000E-04	2.321E-02	1.160E-03
33.076	.527	3.678	9.868E-03	3.127E-04	1.908E-02	6.047E-04
33.350	.535	3.707	7.830E-03	3.500E-04	1.514E-02	6.768E-04
33.560	.542	3.730	7.220E-03	3.400E-04	1.396E-02	6.575E-04

12C(P,P)0.8GEV 0.0,0+	Q	DSIG/COMEGA	ERROR	DSIG/DT	ERROR
THETA,CM -T		MB/SR		MB/((GEV/C)**2)	
DEGREES	GEV/C**2	1/FERMI			
33.760	.548	3.752	3.400E-04	1.367E-02	6.575E-04
33.980	.555	3.775	3.300E-04	1.313E-02	6.382E-04
34.190	.562	3.798	3.100E-04	1.197E-02	5.995E-04
34.410	.569	3.822	2.800E-04	9.379E-03	5.415E-04
34.620	.575	3.844	2.800E-04	9.263E-03	5.415E-04
34.820	.582	3.866	2.400E-04	7.039E-03	4.641E-04
35.040	.589	3.889	2.300E-04	6.246E-03	4.448E-04
35.250	.596	3.912	2.200E-04	5.705E-03	4.254E-04
39.070	.727	4.320	1.500E-05	3.036E-04	2.901E-05
40.330	.772	4.454	1.500E-05	2.669E-04	2.901E-05

12C(P,F)0.8GEV 4.43.2+	THETA,CM -T 0	DEGREES GEV/C*2 1/FERNI	DSIG/DOMEGA MB/SR	ERROR	DSIG/DT MB/((GEV/C)**2)	ERROR
6.290	.020	.709	14.2	1.40	27.5	2.71
6.620	.022	.746	18.5	1.90	35.8	3.67
6.950	.024	.783	24.5	2.50	47.4	4.83
8.010	.032	.902	30.6	1.80	59.2	3.48
8.340	.034	.940	29.4	1.80	56.9	3.48
8.660	.037	.975	33.7	2.00	65.2	3.87
8.980	.040	1.011	33.4	2.00	64.6	3.87
9.310	.043	1.049	33.1	2.00	64.0	3.87
11.450	.065	1.289	28.5	.660	55.9	1.28
11.780	.068	1.326	29.1	.660	56.3	1.28
12.110	.072	1.363	25.6	.620	49.5	1.20
12.420	.076	1.398	25.5	.620	49.3	1.20
12.750	.080	1.435	21.2	.560	41.0	1.08
13.170	.085	1.482	17.8	.310	34.4	.599
13.500	.090	1.519	16.0	.290	30.9	.561
13.820	.094	1.554	15.0	.270	29.0	.522
14.140	.098	1.590	13.0	.250	25.1	.483
14.470	.103	1.627	10.6	.240	20.5	.464
14.880	.109	1.673	7.03	.160	13.6	.309
15.210	.114	1.710	5.92	.150	11.4	.290
15.540	.119	1.747	5.37	.140	10.4	.271
15.850	.124	1.781	3.87	.120	7.48	.232
16.170	.129	1.817	3.23	.110	6.25	.213
16.600	.135	1.865	2.50	6.700E-02	4.83	.130
16.930	.141	1.902	2.13	6.700E-02	4.12	.130
17.240	.146	1.936	1.72	5.600E-02	3.33	.108
17.560	.151	1.972	1.30	5.700E-02	2.51	.110
17.880	.157	2.008	.974	4.400E-02	1.88	8.509E-02
18.310	.164	2.056	.665	3.100E-02	1.29	5.995E-02
18.630	.170	2.091	.554	2.800E-02	1.07	5.415E-02
18.950	.176	2.127	.525	2.800E-02	1.02	5.415E-02
19.270	.182	2.162	.513	2.700E-02	.992	5.221E-02
19.590	.188	2.198	.500	2.700E-02	.967	5.221E-02

12C(P,P)0.8GEV 4.43,2*	THETA,CM -T	Q	DSIG/DOMEGA MB/SR	ERROR	DSIG/DT MB/((GEV/C)*2)	ERROR
DEGREES	GEV/C**2	1/FERMI				
31.680	.484	3.527	1.820E-02	6.000E-04	3.520E-02	1.160E-03
32.000	.494	3.561	1.580E-02	5.000E-04	3.055E-02	9.669E-04
32.320	.500	3.596	1.420E-02	5.000E-04	2.746E-02	9.669E-04
32.630	.513	3.630	1.170E-02	4.000E-04	2.263E-02	7.735E-04
33.300	.533	3.702	8.650E-03	2.900E-04	1.673E-02	5.608E-04
33.620	.543	3.736	8.030E-03	2.800E-04	1.553E-02	5.415E-04
33.940	.554	3.771	8.030E-03	2.800E-04	1.553E-02	5.415E-04
34.250	.563	3.804	8.320E-03	2.900E-04	1.609E-02	5.808E-04
34.570	.574	3.839	9.090E-03	3.000E-04	1.758E-02	5.802E-04
34.880	.584	3.872	8.550E-03	2.900E-04	1.653E-02	5.608E-04
38.910	.721	4.303	4.960E-03	1.600E-04	9.592E-03	3.094E-04
39.230	.732	4.337	4.440E-03	1.500E-04	8.586E-03	2.901E-04
39.550	.744	4.371	4.250E-03	1.500E-04	8.219E-03	2.901E-04
39.860	.755	4.404	3.890E-03	1.400E-04	7.523E-03	2.707E-04
40.180	.767	4.438	3.460E-03	1.400E-04	6.691E-03	2.707E-04
40.480	.778	4.470	3.130E-03	1.300E-04	6.053E-03	2.514E-04

12C(P,P)0.8GEV 7.7.0+	THETA,CM	-I	G	DSIG/DOMEGA	MB/SR	ERROR	DSIG/DT	MB/((GEV/C)*#2)	ERROR
DEGREES	GEV/C*#2	1/FERMI							
6.620	.022	.746		4.13		.830	7.99	1.61	
6.950	.024	.783		4.01		.800	7.75	1.55	
7.260	.026	.818		2.83		.710	5.47	1.37	
8.010	.032	.902		5.30		.800	10.2	1.55	
8.340	.034	.940		5.54		.830	10.7	1.61	
8.660	.037	.975		5.06		.760	9.79	1.47	
8.980	.040	1.011		5.13		.770	9.92	1.49	
11.450	.065	1.289		2.66		.250	5.14	.483	
11.780	.068	1.326		2.63		.250	5.09	.483	
12.110	.072	1.363		2.25		.130	4.35	.251	
12.420	.076	1.398		1.84		.130	3.56	.251	
12.750	.080	1.435		1.16		.100	2.24	.193	
13.170	.085	1.482		1.01	6.600E-02	6.600E-02	1.95	.128	
13.500	.090	1.519		.784	6.500E-02	6.500E-02	1.52	.126	
13.820	.094	1.554		.653	5.200E-02	5.200E-02	1.26	.101	
14.140	.098	1.590		.516	5.300E-02	5.300E-02	.998	.102	
14.470	.103	1.627		.212	3.200E-02	3.200E-02	.410	6.188E-02	
16.600	.135	1.865		6.500E-02	1.100E-02	1.100E-02	.126	2.127E-02	
16.930	.141	1.902		9.200E-02	1.400E-02	1.400E-02	.178	2.707E-02	
17.240	.146	1.936		.129	1.600E-02	1.600E-02	.249	3.094E-02	
17.560	.151	1.972		.135	1.700E-02	1.700E-02	.261	3.288E-02	
17.880	.157	2.008		.171	1.800E-02	1.800E-02	.331	3.481E-02	
18.310	.164	2.056		.187	1.600E-02	1.600E-02	.362	3.094E-02	
18.630	.170	2.091		.182	1.600E-02	1.600E-02	.352	3.094E-02	
18.950	.176	2.127		.213	1.700E-02	1.700E-02	.412	3.288E-02	
19.270	.182	2.162		.212	1.700E-02	1.700E-02	.410	3.288E-02	
20.260	.201	2.272		.188	1.200E-02	1.200E-02	.364	2.321E-02	
20.590	.208	2.305		.155	1.100E-02	1.100E-02	.300	2.127E-02	
20.910	.214	2.345		.161	1.100E-02	1.100E-02	.311	2.127E-02	
21.230	.221	2.380		.155	1.100E-02	1.100E-02	.307	2.127E-02	
21.550	.227	2.415		.138	1.000E-02	1.000E-02	.267	1.934E-02	
21.933	.235	2.458		9.711E-02	4.927E-03	4.927E-03	.188	9.527E-03	
22.290	.243	2.497		8.620E-02	5.600E-03	5.600E-03	.167	1.083E-02	

12C(P,F)0.8GEV 7.7,0+

THETA,CM -T Q
DEGREES GEV/C**2 1/FERMIDSIG/DOMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2)

ERROR

22.620	.250	2.534	8.730E-02	5.600E-03	.169	1.083E-02
22.940	.257	2.569	7.400E-02	5.200E-03	.143	1.006E-02
23.260	.264	2.605	6.510E-02	4.900E-03	.126	9.476E-03
23.660	.273	2.649	5.090E-02	2.900E-03	9.843E-02	5.608E-03
24.000	.281	2.686	3.790E-02	2.500E-03	7.329E-02	4.835E-03
24.320	.288	2.722	3.270E-02	2.300E-03	6.324E-02	4.448E-03
24.640	.296	2.757	3.080E-02	2.200E-03	5.956E-02	4.254E-03
24.960	.303	2.792	2.060E-02	1.800E-03	3.984E-02	3.481E-03
25.280	.311	2.827	1.730E-02	1.700E-03	3.346E-02	3.288E-03
25.700	.321	2.873	1.200E-02	9.000E-04	2.321E-02	1.740E-03
26.030	.330	2.910	8.280E-03	7.800E-04	1.601E-02	1.508E-03
26.350	.338	2.945	7.910E-03	7.600E-04	1.530E-02	1.470E-03
26.670	.346	2.980	7.460E-03	7.500E-04	1.443E-02	1.450E-03
26.980	.354	3.014	6.500E-03	6.900E-04	1.257E-02	1.334E-03
27.400	.364	3.060	5.870E-03	5.400E-04	1.135E-02	1.044E-03
27.730	.373	3.096	4.600E-03	4.700E-04	8.896E-03	9.089E-04
28.050	.382	3.131	6.310E-03	5.600E-04	1.220E-02	1.083E-03
28.370	.390	3.166	5.130E-03	5.000E-04	9.921E-03	9.669E-04
28.744	.400	3.207	4.744E-03	3.011E-04	9.174E-03	5.823E-04
29.100	.410	3.246	5.470E-03	4.100E-04	1.058E-02	7.929E-04
29.420	.419	3.281	4.170E-03	3.600E-04	8.064E-03	6.962E-04
29.740	.428	3.316	5.380E-03	4.100E-04	1.040E-02	7.929E-04
30.060	.437	3.351	5.220E-03	4.000E-04	1.009E-02	7.735E-04
30.370	.446	3.384	4.820E-03	3.900E-04	9.321E-03	7.542E-04
31.040	.465	3.457	4.260E-03	2.800E-04	8.238E-03	5.415E-04
31.360	.475	3.492	4.190E-03	2.800E-04	8.103E-03	5.415E-04
31.680	.484	3.527	4.480E-03	2.800E-04	8.664E-03	5.415E-04
32.000	.494	3.561	4.170E-03	2.800E-04	8.064E-03	5.415E-04
32.320	.503	3.596	3.530E-03	2.500E-04	6.826E-03	4.835E-04
32.630	.513	3.630	3.580E-03	2.500E-04	6.923E-03	4.835E-04
33.620	.543	3.736	2.090E-03	1.400E-04	4.042E-03	2.707E-04
33.940	.554	3.771	2.020E-03	1.400E-04	3.906E-03	2.707E-04
34.250	.563	3.804	1.630E-03	1.300E-04	3.152E-03	2.514E-04

12C(P,P)0.8GEV 7.7,0+
 THETA,CM -T Q
 DEGREES GEV/C**2 1/FERMI

DSIG/OMEGA
 MB/SR

ERROR

DSIG/DT
 MB/((GEV/C)**2) ERROR

34.570	.574	3.839	1.650E-03	1.300E-04	3.191E-03	2.514E-04
34.880	.584	3.872	1.270E-03	1.100E-04	2.456E-03	2.127E-04
39.700	.749	4.387	8.200E-05	7.000E-06	1.586E-04	1.354E-05

12C(P,P)0.8GEV 9.63-	G	DSIG/DOMEGA	ERROR	DSIG/DT	ERROR
THETA,CM	-T	MB/SR		MB/((GEV/C)**2)	
DEGREES	GEV/C**2	1/FERMI			
6.730	.022	.758	4.00	7.74	1.93
8.660	.037	.975	6.96	13.5	2.01
8.980	.040	1.011	7.07	13.7	2.03
9.310	.043	1.049	8.06	15.6	2.34
11.450	.065	1.289	11.3	21.9	.774
11.780	.068	1.326	11.0	21.3	.735
12.110	.072	1.363	11.0	21.3	.735
12.420	.076	1.398	10.4	20.1	.735
12.750	.080	1.435	10.5	20.3	.735
13.170	.085	1.482	9.44	18.3	.425
13.500	.090	1.519	8.87	17.2	.406
13.820	.094	1.554	8.95	17.4	.406
14.140	.098	1.590	8.54	16.5	.406
14.470	.103	1.627	7.17	13.9	.348
14.880	.109	1.673	5.47	10.6	.271
15.210	.114	1.710	5.05	9.84	.251
15.540	.119	1.747	4.86	9.40	.251
15.850	.124	1.781	4.13	7.99	.232
16.170	.129	1.817	3.82	7.39	.213
16.600	.135	1.865	3.01	5.82	.155
16.930	.141	1.902	2.66	5.14	.135
17.240	.146	1.936	2.51	4.85	.135
17.560	.151	1.972	2.12	4.10	.135
17.880	.157	2.008	1.76	3.40	.116
18.310	.164	2.056	1.42	2.75	7.735E-02
18.630	.170	2.091	1.07	2.07	7.735E-02
18.950	.176	2.127	1.02	1.97	7.735E-02
19.270	.182	2.162	.745	1.45	6.188E-02
19.590	.188	2.198	.602	1.16	5.608E-02
20.260	.201	2.272	.387	.748	3.288E-02
20.590	.208	2.309	.336	.650	3.094E-02
20.910	.214	2.345	.258	.499	2.707E-02
21.230	.221	2.380	.251	.485	2.707E-02

12C(P,P)0.8GEV 9.63-

THETA,CM -T Q
DEGREES GEV/C**2 1/FERMIDSIG/OMEGA
MB/S

ERROR

DSIG/DT
MB/((GEV/C)**2)

ERROR

21.550	.227	2.415	.200	1.200E-02	.387	2.321E-02
21.870	.234	2.451	.144	1.000E-02	.278	1.934E-02
22.290	.240	2.497	.123	6.700E-03	.238	1.296E-02
22.620	.250	2.534	.102	6.100E-03	.197	1.180E-02
22.940	.257	2.569	8.100E-02	5.300E-03	.157	1.025E-02
23.260	.264	2.605	8.260E-02	5.500E-03	.160	1.064E-02
23.570	.271	2.639	7.130E-02	5.100E-03	.138	9.863E-03
24.000	.281	2.686	7.720E-02	3.500E-03	.149	6.768E-03
24.320	.288	2.722	6.030E-02	3.100E-03	.117	5.995E-03
24.640	.296	2.757	5.590E-02	3.000E-03	.108	5.802E-03
24.960	.303	2.792	4.940E-02	2.700E-03	9.553E-02	5.221E-03
25.280	.311	2.827	3.950E-02	2.500E-03	7.639E-02	4.835E-03
25.700	.321	2.873	2.990E-02	1.400E-03	5.782E-02	2.707E-03
26.030	.330	2.910	2.800E-02	1.400E-03	5.415E-02	2.707E-03
26.350	.338	2.945	2.660E-02	1.400E-03	5.144E-02	2.707E-03
26.670	.346	2.980	2.360E-02	1.300E-03	4.564E-02	2.514E-03
27.036	.355	3.020	1.886E-02	7.270E-04	3.647E-02	1.406E-03
27.400	.364	3.060	1.540E-02	9.000E-04	2.978E-02	1.740E-03
28.050	.382	3.131	1.270E-02	8.500E-04	2.456E-02	1.644E-03
28.370	.390	3.166	9.100E-03	6.600E-04	1.760E-02	1.276E-03
28.779	.401	3.211	4.621E-03	3.749E-04	8.935E-03	7.250E-04
29.100	.410	3.246	4.300E-03	3.600E-04	8.315E-03	6.962E-04
29.420	.419	3.281	4.880E-03	3.900E-04	9.437E-03	7.542E-04
29.740	.428	3.316	3.850E-03	3.400E-04	7.445E-03	6.575E-04
30.060	.437	3.351	2.800E-03	2.900E-04	5.415E-03	5.608E-04
31.040	.465	3.457	1.680E-03	1.700E-04	3.249E-03	3.288E-04
31.680	.484	3.527	1.700E-03	1.700E-04	3.288E-03	3.288E-04
32.000	.494	3.561	1.450E-03	1.600E-04	2.804E-03	3.094E-04
32.320	.503	3.596	1.650E-03	1.700E-04	3.191E-03	3.288E-04
32.630	.513	3.630	1.610E-03	1.700E-04	3.113E-03	3.288E-04
33.300	.533	3.702	2.210E-03	1.400E-04	4.274E-03	2.707E-04
33.620	.543	3.736	2.260E-03	1.500E-04	4.370E-03	2.901E-04
33.940	.554	3.771	2.510E-03	1.500E-04	4.854E-03	2.901E-04

12C(P,P)0.8GEV 9.63-

THETA,CM -T Q
DEGREES GEV/C**2 1/FERMI

DSIG/DCMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2)

ERROR

34.250	.563	3.804	3.040E-03	1.700E-04	5.879E-03	3.288E-04
34.570	.574	3.839	3.220E-03	1.700E-04	6.227E-03	3.288E-04
34.880	.584	3.872	3.190E-03	1.700E-04	6.169E-03	3.288E-04
38.910	.721	4.303	1.380E-03	8.300E-05	2.669E-03	1.605E-04
39.230	.732	4.337	1.060E-03	7.300E-05	2.050E-03	1.412E-04
39.700	.749	4.387	7.290E-04	4.300E-05	1.410E-03	8.315E-05
40.330	.772	4.454	7.640E-04	4.400E-05	1.477E-03	8.509E-05

12C(P,P)0.8GEV 14.1,4+

THETA,CM -T Q

DEGREES GEV/C**2 1/FERM!

DSIG/OMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2)

ERROR

11.940	.070	1.344	.360	2.500E-02	.696	4.835E-02
13.660	.092	1.537	.382	1.700E-02	.739	3.288E-02
15.370	.116	1.728	.214	1.000E-02	.414	1.934E-02
17.090	.143	1.920	.228	8.000E-03	.441	1.547E-02
18.790	.173	2.109	9.370E-02	3.600E-03	.181	6.962E-03
21.070	.217	2.362	2.860E-02	1.600E-03	5.531E-02	3.094E-03
21.970	.236	2.462	3.190E-02	3.300E-03	6.169E-02	6.382E-03
22.290	.243	2.497	2.240E-02	2.700E-03	4.332E-02	5.221E-03
22.620	.250	2.534	2.170E-02	2.700E-03	4.196E-02	5.221E-03
22.940	.257	2.569	3.630E-02	3.500E-03	7.020E-02	6.768E-03
23.260	.264	2.605	4.580E-02	3.900E-03	8.857E-02	7.542E-03
23.635	.273	2.646	5.183E-02	2.304E-03	.100	4.455E-03
24.320	.288	2.722	5.890E-02	2.900E-03	.114	5.608E-03
24.640	.296	2.757	6.290E-02	3.000E-03	.122	5.802E-03
24.960	.303	2.792	5.830E-02	2.900E-03	.113	5.608E-03
25.280	.311	2.827	5.890E-02	2.900E-03	.114	5.608E-03
25.700	.321	2.873	5.020E-02	1.800E-03	9.708E-02	3.481E-03
26.030	.330	2.910	4.550E-02	1.700E-03	8.799E-02	3.288E-03
26.350	.338	2.945	5.100E-02	1.900E-03	9.863E-02	3.674E-03
26.670	.346	2.980	5.220E-02	1.900E-03	.101	3.674E-03
27.041	.355	3.021	5.173E-02	1.177E-03	.100	2.277E-03
27.400	.364	3.060	5.060E-02	1.500E-03	9.785E-02	2.901E-03
27.730	.373	3.096	5.140E-02	1.500E-03	9.940E-02	2.901E-03
28.050	.382	3.131	5.030E-02	1.500E-03	9.727E-02	2.901E-03
28.780	.401	3.211	5.170E-02	1.200E-03	9.998E-02	2.321E-03
29.100	.410	3.246	5.490E-02	1.200E-03	.106	2.321E-03
29.420	.419	3.281	4.200E-02	1.100E-03	8.122E-02	2.127E-03
29.740	.428	3.316	4.170E-02	1.100E-03	8.064E-02	2.127E-03
30.060	.437	3.351	3.960E-02	1.100E-03	7.658E-02	2.127E-03
30.370	.446	3.384	3.190E-02	9.500E-04	6.169E-02	1.837E-03
31.040	.465	3.457	2.890E-02	6.900E-04	5.589E-02	1.334E-03
31.360	.475	3.492	2.410E-02	6.300E-04	4.661E-02	1.218E-03
31.680	.484	3.527	2.170E-02	6.000E-04	4.196E-02	1.160E-03

12C(P,P)0.86EV 14.1,4+	0	USIG/DOMEGA	ERROR	DSIG/DT	ERROR
THETA,CM -1		MB/SR		MB/((GEV/C)*2)	
DEGREES GEV/C**2 1/FERMI					
32.000	.494	3.561	5.200E-04	3.133E-02	1.006E-03
32.320	.503	3.596	5.200E-04	3.210E-02	1.006E-03
32.630	.513	3.630	4.800E-04	2.669E-02	5.282E-04
33.620	.543	3.736	2.900E-04	1.822E-02	5.608E-04
33.940	.554	3.771	2.500E-04	1.385E-02	4.835E-04
34.250	.563	3.804	2.400E-04	1.274E-02	4.641E-04
34.570	.574	3.839	2.200E-04	1.054E-02	4.254E-04
34.880	.584	3.872	2.000E-04	8.412E-03	3.868E-04
39.230	.732	4.337	1.100E-04	4.931E-03	2.127E-04
39.550	.744	4.371	9.900E-05	3.926E-03	1.914E-04
39.860	.755	4.404	8.600E-05	2.978E-03	1.663E-04
40.180	.767	4.438	9.000E-05	3.288E-03	1.740E-04
40.480	.778	4.470	8.700E-05	3.094E-03	1.682E-04

13C(P,P)0.8GEV,0.0,1/2-
 THETA,CM -T Q
 DEGREES GEV/C**2 1/FERMI

DSIG/COMEGA
 MB/SR

ERROR

DSIG/DT
 MB/((GEV/C)**2) ERROR

10.870	.059	1.236	47.7	2.30	90.5	4.36
11.080	.062	1.259	37.1	2.00	70.4	3.79
11.290	.064	1.283	28.2	1.70	53.5	3.23
11.510	.067	1.308	21.8	1.50	41.4	2.85
11.720	.069	1.332	17.6	1.40	33.4	2.66
11.930	.072	1.356	12.0	1.10	22.8	2.09
12.140	.074	1.379	9.11	1.00	17.3	1.90
12.360	.077	1.404	6.10	.850	11.6	1.61
12.570	.079	1.428	4.47	.440	8.48	.835
12.780	.082	1.452	3.01	.350	5.71	.664
12.990	.085	1.476	2.35	.320	4.46	.607
13.210	.088	1.500	2.12	.370	4.02	.702
13.420	.090	1.524	1.42	.300	2.69	.569
13.630	.093	1.548	1.39	.270	2.64	.512
13.840	.096	1.572	1.46	.270	2.77	.512
14.060	.099	1.597	1.76	.270	3.34	.512
14.270	.102	1.620	2.35	.300	4.46	.569
14.480	.105	1.644	2.63	.250	4.99	.474
14.690	.108	1.668	3.09	.260	5.86	.493
14.910	.112	1.693	3.81	.380	7.23	.721
15.120	.115	1.716	4.12	.400	7.82	.759
15.330	.118	1.740	4.28	.380	8.12	.721
15.540	.121	1.764	4.71	.410	8.94	.778
15.970	.128	1.812	5.16	.360	9.79	.683
16.180	.131	1.836	5.28	.340	10.0	.645
16.390	.135	1.859	5.19	.350	9.85	.664
16.610	.138	1.884	5.47	.350	10.4	.664
16.820	.142	1.908	5.35	.340	10.1	.645
17.030	.145	1.932	5.19	.410	9.85	.778
17.240	.149	1.955	5.12	.330	9.71	.626
17.450	.152	1.979	5.06	.330	9.60	.626
17.670	.156	2.004	4.51	.180	8.56	.341
17.880	.160	2.027	4.39	.180	8.33	.341

13C(P,P)0.8GEV,0.0,1/2- THETA,CM -T Q			DSIG/DOMEGA	ERROR	DSIG/DT	ERROR
DEGREES GEV/C**2 1/FERMI			MB/SR		MB/((GEV/C)**2)	
18.090	.164	2.051	4.32	.180	8.20	.341
18.300	.168	2.074	3.59	.180	6.81	.341
18.510	.171	2.098	3.36	.170	6.37	.323
18.730	.175	2.123	3.25	.170	6.17	.323
18.940	.179	2.146	2.99	.160	5.67	.304
19.150	.183	2.170	2.82	.160	5.35	.304
19.360	.187	2.193	2.62	.150	4.97	.285
19.570	.191	2.217	2.30	.140	4.36	.266
19.910	.198	2.255	1.91	4.270E-02	3.63	8.100E-02
20.140	.203	2.281	1.66	4.400E-02	3.15	8.347E-02
20.350	.207	2.304	1.49	4.100E-02	2.83	7.778E-02
20.560	.211	2.328	1.32	3.800E-02	2.50	7.209E-02
20.770	.215	2.351	1.26	3.700E-02	2.39	7.019E-02
20.990	.220	2.376	1.20	3.600E-02	2.28	6.830E-02
21.200	.224	2.400	.980	3.300E-02	1.86	6.260E-02
21.410	.229	2.423	.838	3.100E-02	1.59	5.881E-02
21.620	.233	2.447	.682	1.300E-02	1.29	2.466E-02
21.830	.238	2.470	.586	1.200E-02	1.11	2.277E-02
22.040	.242	2.494	.546	1.200E-02	1.04	2.277E-02
22.260	.247	2.518	.396	1.100E-02	.751	2.087E-02
22.470	.251	2.542	.365	1.100E-02	.692	2.087E-02
22.680	.256	2.565	.305	1.000E-02	.579	1.897E-02
22.890	.261	2.588	.236	8.000E-03	.448	1.518E-02
23.100	.266	2.612	.222	8.000E-03	.421	1.518E-02
23.310	.270	2.635	.172	5.000E-03	.326	9.485E-03
23.520	.275	2.659	.146	5.000E-03	.277	9.485E-03
23.740	.280	2.683	.119	4.000E-03	.226	7.588E-03
23.930	.285	2.704	.100	5.000E-03	.190	9.485E-03
24.140	.290	2.728	9.200E-02	5.000E-03	.175	9.485E-03
24.350	.295	2.751	8.240E-02	4.700E-03	.156	8.916E-03
24.570	.300	2.776	6.690E-02	4.200E-03	.127	7.968E-03
24.780	.305	2.799	6.790E-02	4.300E-03	.129	8.157E-03
24.980	.310	2.821	5.800E-02	2.200E-03	.110	4.174E-03

13C(P,P)0.8GEV,0.0,1/2- THETA,CM DEGREES	Q -T GEV/C**2	1/FERMI	DSIG/DOMEGA MB/SR	ERROR	DSIG/DT MB/((.EV/C)**2)	ERROR
25.200	.315	2.846	5.910E-02	2.200E-03	.112	4.174E-03
25.410	.320	2.869	5.860E-02	2.200E-03	.111	4.174E-03
25.610	.325	2.891	5.510E-02	2.600E-03	.105	4.932E-03
25.830	.331	2.916	6.620E-02	2.800E-03	.126	5.312E-03
26.040	.336	2.935	6.580E-02	2.800E-03	.125	5.312E-03
26.270	.342	2.964	6.180E-02	2.800E-03	.117	5.312E-03
26.470	.347	2.987	6.180E-02	2.800E-03	.117	5.312E-03
26.670	.352	3.005	6.270E-02	1.700E-03	.119	3.225E-03
26.880	.358	3.032	6.710E-02	1.900E-03	.127	3.604E-03
27.100	.364	3.056	6.440E-02	1.700E-03	.122	3.225E-03
27.300	.369	3.078	6.590E-02	2.300E-03	.125	4.363E-03
27.510	.374	3.102	7.070E-02	2.400E-03	.134	4.553E-03
27.730	.380	3.126	7.640E-02	2.600E-03	.145	4.932E-03
27.940	.386	3.149	7.190E-02	2.400E-03	.136	4.553E-03
28.150	.392	3.172	7.140E-02	2.400E-03	.135	4.553E-03
28.360	.398	3.196	6.100E-02	1.500E-03	.116	2.846E-03
28.570	.403	3.219	6.020E-02	1.400E-03	.114	2.656E-03
28.780	.409	3.242	6.050E-02	1.400E-03	.115	2.656E-03
28.980	.415	3.264	5.410E-02	1.700E-03	.103	3.225E-03
29.200	.421	3.288	5.470E-02	1.700E-03	.104	3.225E-03
29.410	.427	3.311	5.690E-02	1.700E-03	.108	3.225E-03
29.620	.433	3.334	5.460E-02	1.700E-03	.104	3.225E-03
29.840	.439	3.355	5.260E-02	1.700E-03	9.979E-02	3.225E-03
30.040	.445	3.381	4.830E-02	1.600E-03	9.163E-02	3.035E-03
30.250	.451	3.404	4.540E-02	1.600E-03	8.613E-02	3.035E-03
30.547	.460	3.436	3.741E-02	8.883E-04	7.097E-02	1.685E-03
30.810	.467	3.465	3.350E-02	1.100E-03	6.355E-02	2.087E-03
31.020	.474	3.488	3.500E-02	1.100E-03	6.640E-02	2.087E-03
31.220	.480	3.510	3.160E-02	1.100E-03	5.995E-02	2.087E-03
31.440	.486	3.534	3.170E-02	1.100E-03	6.014E-02	2.087E-03
31.650	.493	3.557	2.870E-02	1.000E-03	5.445E-02	1.897E-03
31.860	.499	3.580	2.380E-02	5.400E-04	4.515E-02	1.783E-03
32.070	.505	3.603	2.230E-02	9.200E-04	4.231E-02	1.745E-03

13C(P,P)0.8GEV,0.0,1/2-

THETA,CM -T Q
DEGREES GEV/C**2 1/FERMI

DSIG/COMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2)

ERROR

32.270	.512	3.625	2.000E-02	8.700E-04	3.794E-02	1.650E-03
32.490	.518	3.649	1.700E-02	8.000E-04	3.225E-02	1.518E-03
32.768	.527	3.680	1.325E-02	4.468E-04	2.522E-02	8.476E-04
33.050	.536	3.710	9.710E-03	4.900E-04	1.842E-02	9.296E-04
33.260	.543	3.733	1.000E-02	5.000E-04	1.897E-02	9.485E-04
33.460	.549	3.755	8.670E-03	4.700E-04	1.645E-02	8.916E-04
33.670	.556	3.778	8.230E-03	4.500E-04	1.561E-02	8.537E-04
33.880	.562	3.801	8.080E-03	4.500E-04	1.533E-02	8.537E-04
34.310	.576	3.848	6.380E-03	4.000E-04	1.210E-02	7.588E-04
34.510	.583	3.869	5.200E-03	3.600E-04	9.865E-03	6.830E-04
34.720	.590	3.892	3.990E-03	3.100E-04	7.569E-03	5.881E-04
34.930	.597	3.915	3.430E-03	2.900E-04	6.507E-03	5.502E-04
38.500	.720	4.301	6.200E-04	6.000E-05	1.176E-03	1.138E-04
38.920	.735	4.346	5.400E-04	6.000E-05	1.024E-03	1.138E-04
39.340	.751	4.391	7.200E-04	6.000E-05	1.366E-03	1.138E-04
39.760	.766	4.436	7.600E-04	6.000E-05	1.442E-03	1.138E-04
40.170	.781	4.480	6.900E-04	6.000E-05	1.309E-03	1.138E-04

13C(P,P)0.8GEV 3.1.1/2+ THETA,CM -T Q DEGREES GEV/C*#2 1/FERMI	DSIG/DOMEGA MB/SR	ERROR	DSIG/DT MB/((GEV/C)*#2)	ERROR
11.820	.070	1.343	1.17	5.502E-02
13.530	.092	1.537	.624	2.846E-02
15.230	.116	1.729	.231	1.328E-02
16.930	.144	1.920	7.038E-02	4.743E-03
18.630	.174	2.111	4.193E-02	3.035E-03
20.870	.217	2.363	4.800E-02	2.846E-03
21.930	.240	2.481	4.932E-02	3.035E-03
22.570	.254	2.553	5.615E-02	3.225E-03
23.200	.268	2.623	4.724E-02	3.035E-03
23.620	.277	2.670	3.358E-02	2.277E-03
24.250	.292	2.740	3.965E-02	2.656E-03
24.880	.307	2.810	2.846E-02	2.097E-03
25.300	.318	2.857	2.504E-02	1.897E-03
25.940	.334	2.928	2.011E-02	1.897E-03
26.570	.350	2.998	1.425E-02	1.669E-03
26.980	.360	3.043	1.383E-02	8.537E-04
27.620	.377	3.114	8.575E-03	6.830E-04
28.250	.394	3.183	6.109E-03	5.691E-04
28.670	.406	3.230	4.363E-03	3.984E-04
29.300	.424	3.295	3.472E-03	3.415E-04
29.940	.442	3.370	1.897E-03	2.656E-04
31.540	.489	3.545	1.366E-03	3.794E-04
33.770	.559	3.789	1.766E-03	1.214E-04

13C(P,P)0.8GEV 3.68,3/2-
 THETA,CM -T Q
 DEGREES GEV/C**2 1/FERMI

DSIG/OMEGA
 MB/SR

ERROR

DSIG/DT
 MB/((GEV/C)**2) ERROR

11.080	.062	1.259	9.01	.340	17.1	.645
11.510	.067	1.308	8.02	.320	15.2	.607
11.930	.072	1.356	7.54	.310	14.3	.588
12.140	.074	1.379	7.24	.300	13.7	.569
12.360	.077	1.404	6.53	.290	12.4	.550
12.570	.079	1.428	5.81	.164	11.0	.311
12.780	.082	1.452	5.55	.156	10.5	.296
12.990	.085	1.476	5.21	.154	9.88	.292
13.210	.088	1.500	4.69	.180	8.90	.341
13.420	.090	1.524	4.38	.180	8.31	.341
13.630	.093	1.548	4.16	.170	7.89	.323
13.840	.096	1.572	3.80	.160	7.21	.304
14.060	.099	1.597	3.34	.150	6.34	.285
14.270	.102	1.620	3.13	9.843E-02	5.94	.187
14.480	.105	1.644	3.08	9.371E-02	5.85	.178
14.690	.108	1.668	2.68	8.684E-02	5.09	.165
14.910	.112	1.693	2.46	.110	4.67	.209
15.120	.115	1.716	2.15	.100	4.08	.190
15.330	.118	1.740	1.89	9.600E-02	3.59	.182
15.540	.121	1.764	1.88	9.600E-02	3.57	.182
15.760	.125	1.788	1.54	8.700E-02	2.92	.165
15.970	.128	1.812	1.49	8.500E-02	2.83	.161
16.281	.133	1.847	1.11	2.765E-02	2.10	5.245E-02
16.930	.144	1.920	.765	2.700E-02	1.45	5.122E-02
17.550	.154	1.990	.478	2.100E-02	.907	3.984E-02
17.980	.162	2.038	.332	1.200E-02	.630	2.277E-02
18.630	.174	2.111	.242	1.000E-02	.459	1.897E-02
19.250	.185	2.181	.203	9.600E-03	.385	1.821E-02
20.240	.205	2.292	.175	7.900E-03	.332	1.499E-02
20.870	.217	2.363	.190	8.200E-03	.360	1.556E-02
21.510	.231	2.434	.197	8.300E-03	.374	1.575E-02
21.930	.240	2.481	.185	8.500E-03	.351	1.613E-02
22.570	.254	2.553	.191	8.600E-03	.362	1.631E-02

13C(P,P)0.8GEV 3.68,3/2-
 THETA,CM -T Q
 DEGREES GEV/C**2 1/FERMI

DSIG/DOMEGA
 MB/SR

ERROR

DSIG/DT
 MB/((GEV/C)**2)
 ERROR

23.200	.268	2.623	.185	8.600E-03	.351	1.631E-02
23.620	.277	2.670	.157	7.700E-03	.298	1.461E-02
24.250	.292	2.740	.146	7.200E-03	.277	1.366E-02
24.880	.307	2.810	.127	7.000E-03	.241	1.328E-02
25.300	.318	2.857	.103	4.100E-03	.195	7.778E-03
25.940	.334	2.928	9.140E-02	3.900E-03	.173	7.399E-03
26.570	.350	2.998	6.880E-02	3.500E-03	.131	6.640E-03
26.980	.360	3.043	5.260E-02	1.200E-03	9.979E-02	2.277E-03
27.620	.377	3.114	4.090E-02	1.100E-03	7.759E-02	2.087E-03
28.250	.394	3.183	2.860E-02	9.000E-04	5.426E-02	1.707E-03
28.670	.406	3.230	2.050E-02	6.200E-04	3.889E-02	1.176E-03
29.300	.424	3.299	1.360E-02	5.000E-04	2.580E-02	9.485E-04
29.940	.442	3.370	9.250E-03	1.000E-03	1.755E-02	1.897E-03
30.910	.470	3.476	4.680E-03	2.300E-04	8.878E-03	4.363E-04
31.540	.489	3.545	4.740E-03	2.300E-04	8.992E-03	4.363E-04
32.170	.508	3.614	4.070E-03	2.100E-04	7.721E-03	3.984E-04
33.150	.539	3.721	3.540E-03	3.900E-04	6.716E-03	7.399E-04
33.770	.559	3.789	3.780E-03	4.000E-04	7.171E-03	7.588E-04
34.410	.580	3.859	3.940E-03	4.400E-04	7.475E-03	8.347E-04

13C(P,P)0.8GEV 6.85,5/2+

THETA,CM -T 0

DEGREES GEV/C**2 1/FERMI

DSIG/DOMEGA
MB/SR

ERROR

DSIG/DT
MB/((GEV/C)**2) ERROR

15.230	.116	1.729	3.500E-02	4.000E-03	6.640E-02	7.588E-03
16.930	.144	1.920	1.900E-02	2.000E-03	3.604E-02	3.794E-03
18.630	.174	2.111	8.500E-03	1.000E-03	1.613E-02	1.897E-03
22.570	.254	2.553	4.910E-03	3.400E-04	9.315E-03	6.450E-04
24.250	.292	2.740	4.980E-03	3.300E-04	9.448E-03	6.260E-04
25.940	.334	2.928	3.470E-03	3.300E-04	6.583E-03	6.260E-04
27.620	.377	3.114	3.450E-03	1.500E-04	6.545E-03	2.846E-04
29.300	.424	3.299	2.570E-03	1.100E-04	4.876E-03	2.087E-04
30.910	.470	3.476	1.220E-03	1.200E-04	2.314E-03	2.277E-04
33.150	.539	3.721	6.200E-04	1.500E-04	1.176E-03	2.846E-04
33.770	.559	3.789	4.800E-04	1.600E-04	9.106E-04	3.035E-04

13C(P,P)0.8GEV 7.55,5/2-						
THETA,CM	-T	Q	DSIG/COMEGA	ERROR	DSIG/DT	ERROR
DEGREES	GEV/C**2	1/FERMI	MB/SR		MB/((GEV/C)**2)	
30.910	.470	3.476	5.430E-03	2.400E-04	1.030E-02	4.553E-04
31.540	.489	3.545	4.900E-03	2.300E-04	9.296E-03	4.363E-04
32.170	.508	3.614	3.940E-03	2.100E-04	7.475E-03	3.984E-04
33.150	.539	3.721	4.250E-03	4.400E-04	8.063E-03	8.347E-04
33.770	.559	3.789	4.850E-03	4.900E-04	9.201E-03	9.296E-04
34.410	.580	3.859	4.470E-03	1.900E-04	8.480E-03	3.604E-04

13C(P,P) 11.9 MEV

 THETA,CM -T Q
 DEGREES GEV/C**2 1/FERMI

 DSIG/DOMEGA
 MB/SR

ERROR

 DSIG/DT
 MB/((GEV/C)**2)

ERROR

11.820	.070	1.343	6.03	.600	11.4	1.14
13.530	.092	1.537	4.74	.470	8.99	.892
15.230	.116	1.729	2.30	.230	4.36	.436
16.930	.144	1.920	1.45	.150	2.75	.285
18.630	.174	2.111	.570	5.700E-02	1.08	.108
20.870	.217	2.363	.150	1.500E-02	.285	2.846E-02
22.570	.254	2.553	8.300E-02	8.300E-03	.157	1.575E-02
24.500	.298	2.768	4.720E-02	4.700E-03	8.954E-02	8.916E-03
25.940	.334	2.928	2.560E-02	2.600E-03	4.857E-02	4.932E-03

APPENDIX III

SPECTROMETER NMR CALIBRATION

As discussed in Chapter II, the HRS section, the calibration of the spectrometer dipoles was performed with the dipoles cycled from saturation down to the desired value. The average of an NMR scan is taken to be that for the NMR values every inch from 7 inches to 26 inches. The DVM is then read to 0.01 mV, yielding the following numbers. $\langle B_{\text{NMR}} \rangle$ is in gauss.

<u>HS-BM-01</u>		<u>HS-BM-02</u>	
DVM (mV)	$\langle B_{\text{NMR}} \rangle$	DVM (mV)	$\langle B_{\text{NMR}} \rangle$
335.0	8307.8	333.2	8307.6
344.95	8555.4	342.65	8545.0
365.95	9065.3	399.86	9948.2
499.96	12336.0	466.91	11599.0
501.35	12368.9	499.16	12372.9
504.96	12457.8	502.74	12465.1
530.01	13052.8	529.7	13000.1
531.1	13072.3	549.96	13588.8
559.82	13755.6	559.83	13818.2
569.90	13986.9	563.33	13893.3
		569.90	14045.9
574.91	14099.1	574.81	14157.7
599.76	14650.9	600.0	14707.0
600.1	14659.1	650.20	15775.5
650.02	15722.6	700.32	16769.9
700.03	16685.4	780.36	18047.0
780.32	17979.3		

linear
region

proton
region

deuteron
region