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**Design and Construction of a Spectrometer
Facility and Experiment for Intermediate Energy
Proton Scattering on Helium**

by

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ABSTRACT OF THE DISSERTATION

Design and Construction of a Spectrometer Facility and Experiment for Intermediate Energy Proton Scattering on Helium

by

Robert Menuhin Rolfe

Doctor of Philosophy in Physics

University of California, Los Angeles, 1976

Professor George J. Igo, Co-Chairman

Professor Charles A. Whitten, Co-Chairman

The goal of the research which forms this dissertation was to investigate proton scattering on nuclei at intermediate energies and in particular to investigate proton scattering on helium. This naturally broke down into three logically distinct sections. The first deals with a theoretical investigation of the helium nucleus and the nature of the intermediate energy interaction; the second discusses design and optimization of an energy-loss spectrometer facility for proton-nucleus scattering; and the third describes the unique superfluid helium target and experimental design.

The first section is the theoretical description of the scattering process. The approach is the "High Energy Approximation".

Within the framework of this model the elastic scattering of protons on helium nuclei is investigated and compared to published experimental data. This is done to determine the extent to which the helium nuclear wave function can be established distinctly from the fundamental proton-nucleon interaction. In order to separate the wave function from the fundamental interaction, the model wave functions for the helium nucleus are compared with the charge form factor as determined from published electron-helium scattering data. The results of these calculations constrained the parameters of the model wave functions for helium in a consistent fashion for both strong interaction scattering and electromagnetic scattering probes.

The second section of the research involved the participation in the design and construction of an energy-loss spectrometer facility to study proton-nuclear scattering in the incident kinetic energy range of 200-800 Mev. The system design goal had been set at 30 Kev in the missing mass. In order to achieve this resolution a detailed high order data analysis scheme was devised and then studied in a Monte Carlo fashion. The results of these studies showed that on heavy nuclei a missing mass resolution of 30 Kev was obtainable. This implies that nuclear states separated by 30 Kev or more can be identified in the final state.

The second important investigation was to determine how to use and optimize HT windings which had been embedded in all of the large dipole magnets in the system. A mathematical procedure was developed and experimentally tested. This procedure showed that magnetic field integrals could be adjusted for small corrections with weak radial

dependencies with random errors better than 10^{-5} fractional error in magnetic field integrals. The procedure required a computer controlled data acquisition system for magnetic field measurements and a mini-computer for optimization of the magnets with the acquired data.

The third major investigation in the spectrometer facility was the optimization of the large beam line dipole magnets consistent with the design goals of the facility. This was done by a combination of pole face shimming, remachining of the field clamps on either end of the magnets, and finally using HT windings to provide correction for field level dependent errors in the desired field line integrals.

The third and final section of the research involved the design and construction of the experimental apparatus unique to proton-helium scattering. This was a superfluid helium target. The superfluid was chosen because of its well known density on the saturated vapour pressure curve and also for its huge heat conductivity which makes possible the use of the large beam currents available at the spectrometer facility. The target was designed around an earlier helium reservoir constructed at the Lawrence Berkeley Laboratory. The original reservoir was for normal liquid helium. The target is unique in that it is mostly helium which is seen by the beam and at the same time the target is only 2. cm thick. The target is also unique in that its geometry is well known because it is a cylindrical shape. The design considerations which differ from standard spectrometer facility equipment are also discussed in this section.

PART 1

THEORETICAL DISCUSSIONS AND RESULTS

Chapter 1

Introduction to Potential Scattering

The problem of elastic scattering from a localized potential $V(\vec{r})$ can be solved within the framework of the Schrodinger equation.

$$\text{eq. 1 } (\nabla^2 + k^2) \Psi(\vec{r}) = \frac{2m}{\hbar^2} V(\vec{r}) \Psi(\vec{r}) .$$

We can write down the asymptotic solution as (GL 59):

$$\text{eq. 2 } \lim_{|\vec{r}| \rightarrow \infty} \Psi(\vec{r}) = e^{i \vec{k} \cdot \vec{r}} + f(\theta) \frac{e^{i k r}}{r} .$$

The first term in equation 2 represents the incident wave and the second term represents the scattered wave modulated by the scattering amplitude $f(\theta)$. The elastic cross section is then given by:

$$\text{eq. 3 } \frac{d\sigma}{d\Omega} = |f(\theta)|^2 .$$

The Green's function for equation 1 is found by solving:

$$\text{eq. 4 } (\nabla^2 + k^2) G(\vec{r}, \vec{r}') = \frac{2m}{\hbar^2} \delta(\vec{r} - \vec{r}') .$$

The integral solution to the Schrodinger equation can then be written as:

$$\text{eq. 5 } \Psi(\vec{r}) = e^{i \vec{k} \cdot \vec{r}} + \int G(\vec{r} - \vec{r}') V(\vec{r}') \Psi(\vec{r}') d\vec{r}' .$$

The asymptotic expression of equation 5 is (G1 59):

$$\text{eq. 6} \quad \lim_{|\vec{r}| \rightarrow \infty} \Psi(\vec{r}) = e^{i\vec{k} \cdot \vec{r}} - \frac{2m}{\hbar^2} \frac{e^{ikr}}{r} \int e^{-i\vec{k}' \cdot \vec{r}'} V(\vec{r}') \Psi(\vec{r}') d\vec{r}'$$

Equation 6 along with equation 2 leads immediately to the result:

$$\text{eq. 7} \quad f(\theta) = \frac{-2m}{4\pi\hbar^2} \int e^{-i\vec{k}' \cdot \vec{r}} V(\vec{r}) \Psi_{\vec{k}}(\vec{r}) d\vec{r}.$$

where $\cos(\theta) = \vec{k}' \cdot \vec{k} / |\vec{k}'| |\vec{k}|$ and $|\vec{k}'| = |\vec{k}|$ define elastic scattering. The total cross section can be expressed in terms of the forward amplitude by the optical theorem which can be derived by requiring the probability current to have zero divergence (G1 59):

$$\text{eq. 8} \quad \sigma = \frac{4\pi}{k} \text{Im}(f(0)).$$

Chapter 2

High Energy Approximation; Potential Scattering

The High Energy Approximation for particle scattering was first derived by Professor Glauber and was well presented in (C1 59). In order to pick out the needed results from Glauber's theory, We will follow a short parallel development of the needed results of the High Energy Approximation.

We first write down the one-dimensional result for the High Energy Approximation. We start again with the Schroedinger equation:

$$\text{eq. 9 } \left(\frac{d^2}{dx^2} + k^2 \right) \psi(x) = \frac{2m}{\hbar^2} V(x) \psi(x) .$$

The assumptions made are that $V/E \ll 1$ and $ka \gg 1$. V is the characteristic strength of the potential. E is the incident particle kinetic energy. k is the incident particle wave number and a is the characteristic range of the potential. $V/E \ll 1$ means that the potential is a perturbation on the incident particle's trajectory. This leads to forward scattering. $ka \gg 1$ says the de Broglie wavelength of the incident particle is much shorter than the region of variation of the potential.

With these assumptions the approximate solution to the Schroedinger equation is:

$$\text{eq 10 } \psi(x) = e^{ikx} f(x)$$

where $f(x)$ is a function that varies slowly over a particle's

wavelength. The general form of the expression for the approximate wave function results from the assumption $\sqrt{E} \ll 1$. The condition on $\rho(x)$ results from the requirement $ka \gg 1$. Putting the trial solution back into equation 9 and neglecting double differentiation of $\rho(x)$, leads to the simple formal solution:

$$\text{eq. 11} \quad \rho(x) = e^{-i/\hbar v \int_{-\infty}^x V(x') dx'}$$

Now with the formal representation for $\rho(x)$, the wave function becomes

$$\text{eq. 12} \quad \psi(x) = e^{ikx - i/\hbar v \int_{-\infty}^x V(x') dx'}$$

Expanding $\rho(x)$ in a power series leads to an expansion parameter $\sqrt{a/\hbar v}$. We arrived at the form $\rho(x)$ from the requirement that $ka \gg 1$. Convergence of the power series leads to the inequality:

$$\text{eq. 13} \quad k \gg \frac{V}{\hbar v},$$

which leads to the condition non-relativistically $\sqrt{E} \ll 1$.

It has therefore been demonstrated that the assumption $ka \gg 1$ does demand $\sqrt{E} \ll 1$ for the approximate wave function.

The fact that $\sqrt{E} \ll 1$ implies forward scattering can be shown by writing:

$$\text{eq. 14 } \psi(x) = e^{ikx} \rho_+(x) + e^{-ikx} \rho_-(x).$$

This equation differs from the forward term by additional terms of order $\sqrt{E}$ and $1/ka$.

The three dimensional result can be directly written down:

$$\text{eq. 15 } \rho(\vec{x}) = e^{-i/hv \int_{-\infty}^z V(x, y, z') dz'}.$$

So that the approximate wave function becomes:

$$\text{eq. 16 } \psi(x, y, z) = e^{ikz - i/hv \int_{-\infty}^z V(x, y, z') dz'}.$$

The same requirements remain on the solution in three dimensions, that is $ka \gg 1$ and $\sqrt{E} \ll 1$.

Inserting this wave function into equation 7 leads to an expression for the scattering amplitude. If we assume $e^{i[(\vec{k}-\vec{k}') \cdot \vec{R}z]} \approx 1$,

which amounts to neglect of terms of order $\Theta^2 kd$, where d is the range over which $V\rho$ varies, then the amplitude becomes:

$$\text{eq. 17 } f(\vec{k}, \vec{q}) = \frac{\kappa}{2\pi i} \int e^{i(\vec{k}-\vec{k}') \cdot \vec{b}} \left[e^{-i/hv \int_{-\infty}^{\infty} V(\vec{b} + \hat{k}z') dz'} - 1 \right] d^2b.$$

This is the Glauber result for potential scattering. $\vec{q}$ is defined in equation 18 and is the three-momentum transfer.

eq. 18 $\vec{q} = \vec{k} - \vec{k}'$

$\hat{k}$ is the unit vector in the z direction and $\vec{b}$ is the vector in the direction perpendicular to the incident beam, i.e. $\vec{b} = (x, y)$.

We can define the integral over the potential to be a phase shift function $\chi(\vec{b})$:

eq. 19 $\chi(\vec{b}) = -\frac{1}{\hbar v} \int_{-\infty}^{\infty} V(\vec{b} + \hat{k}z) dz$.

Then equation 17 becomes:

eq. 20 $f(\kappa, \vec{q}) = \frac{\kappa}{2\pi i} \int e^{i\vec{q} \cdot \vec{b}} [e^{i\chi(\vec{b})} - 1] d^2b$.

The restriction on the expressions to this point are $v/E \ll 1$, $\kappa a \gg 1$, and $\Theta^2 \kappa d \ll 1$.

It is often convenient to define a profile function $T(\vec{b})$:

eq. 21 $T(\vec{b}) = - (e^{i\chi(\vec{b})} - 1)$.

The Glauber potential scattering result now looks very simple:

eq. 22 $f(\kappa, \vec{q}) = \frac{\kappa}{2\pi i} \int e^{i\vec{q} \cdot \vec{b}} T(\vec{b}) d^2b$.

This result is crucial to solving the many particle system because

we can invert the integral, i.e. take its fourier transform, and express the profile function for potential scattering in terms of the scattering amplitude. Knowing the nucleon-nucleon scattering amplitude allows the immediate generation of the profile function for nucleon-nucleon scattering.

Chapter 3

High Energy Approximation; Many Particle System

The results contained in this chapter serve as a framework to calculate proton-helium elastic scattering in chapter 5 and chapter 6. They are from references (G1 59) and (G1 67).

We can generalize equation 7 to include scattering from bound particles:

$$\text{eq. 23 } F_{fi}(\vec{k}, \vec{k}) = \frac{\kappa}{2\pi i} \int e^{i\vec{q} \cdot \vec{b}} u_f^*(\vec{w}) V(\vec{r} - \vec{w}) \psi_{k,i}(\vec{r}, \vec{w}) d\vec{r} d\vec{w}.$$

Using the Glauber wave function this expression becomes:

$$\text{eq. 24 } F_{fi}(\vec{k}, \vec{q}) = \frac{\kappa}{2\pi i} \int e^{i\vec{q} \cdot \vec{b}} \langle f | T(\vec{b} - \vec{s}) | i \rangle d^2 b.$$

This simply means the profile function is averaged over the wave functions of the initial and final states of the bound particle.

The generalization of this result to the many particle system requires one assumption. The phase shifts produced by each particle add together coherently. This only requires that the profile function of equation 24 be modified to be:

$$\text{eq. 25 } T(\vec{b}, \vec{s}_1, \vec{s}_2, \dots, \vec{s}_A) = 1 - e^{i \sum_{j=1}^A \chi(\vec{b} - \vec{s}_j)}.$$

This gives us the necessary expression from which to start the evaluation of proton-nucleus scattering:

$$\text{eq. 26 } f_{fc}(\vec{k}, \vec{q}) = \frac{-k}{2\pi i} \int e^{i\vec{q} \cdot \vec{b}} \langle f | T(\vec{b}, \vec{s}_1, \dots, \vec{s}_A) | i \rangle d^2b.$$

The final limitation we must impose is that the particles are not too far separated or the approximate wave function breaks down. This leads to the requirement $R \ll Ka^2$, where R is the nuclear radius. To see that this is a reasonable requirement look at the case of proton scattering on carbon. $R_{12C} = 1.4A^{1/3} = 3.2 \text{ fm}$. Assume $K = 1463 \text{ MeV}/c / \hbar c = 7.5 \text{ fm}^{-1}$. For the nucleon-nucleon interaction $a \sim 2 \text{ fm}$, then $Ka^2 \sim 30 \text{ fm}$ and $R \sim 3.2 \text{ fm}$.

To demonstrate that multiple scattering is indeed accounted for we rewrite the nuclear profile function $T(\vec{b}, \vec{s}_1, \dots, \vec{s}_A)$ as:

$$\text{eq. 27 } T(\vec{b}, \vec{s}_1, \dots, \vec{s}_A) = 1 - \prod_{j=1}^A [1 - T_j(\vec{b} - \vec{s}_j)]$$

This reduces to:

$$\begin{aligned} \text{eq. 28 } T(\vec{b}, \vec{s}_1, \dots, \vec{s}_A) = & \sum_{j=1}^A T_j(\vec{b} - \vec{s}_j) \\ & - \sum_{j < m} T_j(\vec{b} - \vec{s}_j) T_m(\vec{b} - \vec{s}_m) \\ & + \dots \text{ higher terms} \end{aligned}$$

We develop a sum of terms of alternating sign. For instance, double scattering subtracts for shadowing, assuming only single scattering.

Chapter 4

Charge Form Factor Calculation

In the chapter we will attempt to understand proton scattering on helium in a self-consistent way with electron elastic scattering results on helium. The charge form factor measured in electron scattering is used to uniquely define the helium wave function. This wave function along with results from nucleon-nucleon scattering and the results from the preceeding chapters will completely define the calculation with no free parameters.

Equation 26 can be written in a slightly more explicit notation:

$$\text{eq. 29} \quad f(\vec{k}', k) = \frac{k}{2\pi i} \int d^2b \, e^{i(\vec{k} - \vec{k}') \cdot \vec{b}} \times \left\{ \int |\Psi(\vec{q}_1, \dots, \vec{q}_A)|^2 \prod_{i=1}^A [1 - T_i(\vec{b} - \vec{s}_i)] d^3q_i - 1 \right\}$$

where $\vec{b}$ is the impact parameter, and $\vec{s}_i$ is the projection of the nuclear particle coordinate in the plane of the impact parameter. If we define $\vec{w}_j = \vec{b} - \vec{s}_j$, we can relate the fundamental amplitude to the nuclear profile function:

$$\text{eq. 30} \quad f_j(\vec{k}', k) = \frac{ik}{2\pi} \int e^{i(\vec{k} - \vec{k}') \cdot \vec{w}_j} T(\vec{w}_j) d^2w_j.$$

Within the high energy approximation this expression can be inverted (G1 59):

$$\text{eq. 31} \quad T_j(\vec{w}) = \frac{1}{2\pi i k} \int e^{-i\vec{s} \cdot \vec{w}} f_j(\vec{s}) d^2s.$$

$\vec{\delta}$ is the momentum transfer for the nucleon-nucleon amplitude.
 Let $\vec{\delta} = \vec{k} - \vec{k}'$ where $\vec{k}$ is the incoming wave vector and $\vec{k}'$ is the outgoing wave vector. We can rewrite the expression in the curly brackets in equation 29 assuming $|\psi|^2$ is a product of single particle densities $\rho(\vec{q}_i)$:

$$\text{eq. 32 } \left\{ \right\} = \left\{ \prod_{i=1}^A \left[1 - \int d^3 q_i \rho(\vec{q}_i) T_i(\vec{b} - \vec{s}_i) \right] - 1 \right\}.$$

The terms in the product are all the same, so define:

$$\text{eq. 33 } c_i(\vec{b}) = \left[\int d^3 q_i \rho(\vec{q}_i) T_i(\vec{b} - \vec{s}_i) \right].$$

Then the curly brackets become:

$$\text{eq. 34 } \left\{ \right\} = - \left(1 - \prod_{i=1}^A [1 - c_i(\vec{b})] \right).$$

In this calculation we assume an uncorrelated wave function given by the single particle densities. Furthermore we assume the proton scattering on nuclear protons or nuclear neutrons is the same free particle interaction. With these assumptions the amplitude in equation 29 becomes:

$$\text{eq. 35 } f_{\vec{k}}(\vec{\delta}) = \frac{i k}{2\pi} \int d^2 b e^{i \vec{\delta} \cdot \vec{b}} (1 - [1 - c_i(\vec{b})]^A).$$

Let us assume the following functional form for the nucleon-nucleon amplitude:

$$\text{eq. 36} \quad f(k, \delta) = \frac{(i + \alpha) k \sigma_T}{4\pi} e^{-a\delta^2/2}.$$

The profile function becomes independent of K and is:

$$\text{eq. 37} \quad \Gamma(w) = \frac{(1 - i\alpha)\sigma_T}{4\pi a} e^{-w^2/2a}.$$

We now need the link between the single particle densities and the charge form factor:

$$\text{eq. 38} \quad \rho(\vec{r}) = \frac{1}{(2\pi)^3} \int d^3q e^{i\vec{q} \cdot \vec{r}} F(\vec{q}).$$

The charge form factor was measured and an analytical fit reported (Fr 67)

$$\text{eq. 39} \quad F(\vec{q}) = [1 - (c^2 q^2)^6] e^{-B^2 q^2}.$$

The constants found were $C = .316 \text{ fm}$ and $B = .681 \text{ fm}$.

The key to solving this problem analytically is to note that:

$$\text{eq. 40} \quad F(\vec{q}) = \left[1 - c^{2n} \frac{\partial^n}{\partial (-B^2)^n} \right] e^{-B^2 q^2}.$$

The final result of this calculation was coded in Fortran and run on a CDC 6600 at Brookhaven National Laboratory. In Figure 1 is shown the result at $P_{Lab} = 1.7 \text{ GeV}$ compared with experimental

Figure 1

data (Pa 67). On the curve is also shown the Glauber result if the single particle density is just a Gaussian with radius determined from electron scattering. The calculation doesn't do badly. However it clearly misses the maximum after the first dip and leaves the data where it predicts a second maximum. The calculations of the next chapter were an attempt to investigate the use of correlated wave functions to account for the problems in the fit of Figure 1. It is necessary to note that some additional data were reported in the literature (Ba 74a). However these data were at slightly higher energy (1.05 Gev) and disagreed with the data of (Pa 67). The point of these calculations was not to make final explicit determinations of the amplitudes and wave functions involved, but to understand the range of variation various calculations would introduce and hence test the sensitivity of the scattering on details of the nucleon-nucleon scattering and correlations in the helium nuclear wave function. It is interesting to note that in (Ig 75) the author observes that if a small angular shift is introduced into the data of (Pa 67), then the data sets agree quite well except for the depth of the first minimum.

Chapter 5

Jastrow Wave Function Calculation

In this chapter we investigate a special correlated wave function in the High Energy Approximation. In the last chapter we investigated a wave function of simple single particle densities as determined from electron scattering.

$$\text{eq. 41} \quad |\phi_{He}|^2 = \prod_{i=1}^4 \rho(\vec{r}_i)$$

We will now put explicit correlations in the wave function and see what effect they have on the calculated charge form factor, single particle density, and the proton-helium scattering cross section. The wave function is called the Jastrow wave function. If we try to simultaneously require the Jastrow description fit charge form factor and strong interaction scattering we will have a tight constraint on the parameters of the wave function. The Jastrow wave function is:

$$\text{eq. 42} \quad |\Psi(\vec{r}_1, \dots, \vec{r}_N)|^2 = |\phi_{JM}(\vec{r}_1, \dots, \vec{r}_N)|^2 \prod_{J>K} (1 - h_{JK})$$

ϕ_{JM} is an independent particle wave function. We choose Harmonic Oscillator wave functions:

$$\text{eq. 43} \quad |\phi_{JM}|^2 \propto e^{-r_1^2/R^2 - r_2^2/R^2 - r_3^2/R^2 - r_4^2/R^2}$$

The terms h_{JK} take into account short range repulsive

correlations (Cz 67a). h_{JK} is defined as:

$$\text{eq. 44} \quad h_{JK} = e^{-\vec{r}_{JK}^2 / b^2}$$

where $\vec{r}_{JK} = |\vec{r}_J - \vec{r}_K|$. The choice of parameters R and b will be required by the best fit to the charge form factor. In reference (Ci 69) the best parameters found were $R = 1.16 \text{ fm}$ and $b = .734 \text{ fm}$. The author also found that he could neglect higher order terms in the product $\prod_{J>K} (1 - h_{JK})$. He only kept terms linear in h_{JK} and fit the electron scattering form factor. In reference (Cz 67a) the same kind of approximation was made for a Glauber calculation. So our first approximation is:

$$\text{eq. 45} \quad \prod_{J>K} (1 - h_{JK}) \simeq 1 - \sum_{J>K} h_{JK}.$$

The approximate wave function should be normalized.

$$\text{eq. 46} \quad |\psi|^2 = N^2 / |\phi_{Jm}|^2 (1 - \sum_{J>K} h_{JK}).$$

Hence demand that:

$$\text{eq. 47} \quad \int |\psi|^2 d\vec{r}_1 d\vec{r}_2 d\vec{r}_3 d\vec{r}_4 = 1.$$

Insert equation 46 into equation 47 and the result for N^2 becomes:

$$\text{eq. 48} \quad N^2 = 1 / \left[|\phi_{Jm}|^2 (1 - \sum_{J>K} h_{JK}) d\vec{r}_1 d\vec{r}_2 d\vec{r}_3 d\vec{r}_4 \right].$$

All of the integrals involving h_{JK} will be equal because of symmetry in the $|\phi_{Jm}|^2$. Thus choose $J=2$ and $K=1$ and multiply by the number of such terms. Then N^2 becomes:

$$\text{eq. 49} \quad N^2 = 1 / \left[\int |\phi_{Jm}|^2 d\vec{r}_1 d\vec{r}_2 d\vec{r}_3 d\vec{r}_4 - 6 \int |\phi_{Jm}|^2 h_2 d\vec{r}_1 \dots d\vec{r}_4 \right]$$

Putting in the explicit functional forms and referring to Appendix A we find:

$$\text{eq. 50} \quad N^2 = 1 / [I_1^4 - 6 I_2 I_1^2]$$

If we refer to Appendix B for the definition of constants we can then write N^2 as:

$$\text{eq. 51} \quad N^2 = 1 / [C_1^4 - 6 C_2 C_1^2]$$

We now can start the calculation of proton-helium scattering.

In particular we start with equation 29 in the last chapter and recall $\vec{w} = \vec{B} - \vec{S}_J$, and $\vec{S}_J$ is the projection of $\vec{r}_J$ on the plane perpendicular to $\vec{K}$. Also recall $\vec{A} = \vec{K} - \vec{K}'$ is the three momentum transfer in the lab system. We need in addition equation 30 of the last chapter to define the fundamental amplitude.

$f_J(\vec{K}', \vec{K})$ is the fundamental amplitude of the incoming proton on the J th particle of the target nucleus helium. Equation 31 shows us how to invert equation 30. Thus we need explicit equations for the fundamental amplitudes $f_J(\vec{K}', \vec{K})$.

In this calculation we will assume the proton-proton amplitude is the same as the proton-neutron amplitude. Then we can drop the subscript J on the fundamental amplitude. We will use an amplitude given in (Cz 67c).

$$\text{eq. 52} \quad f(\delta) = \frac{(1 + \alpha(\delta))}{4\pi} k \sigma_T e^{-\frac{1}{2} a \delta^2};$$

where $a = 5 \text{ GeV}^{-2}$, $\alpha(\delta) \equiv \alpha = -.33$, and $\sigma_T = .0438$ barns.

σ_T is an average of proton-proton total cross sections and proton-neutron total cross sections. The resultant profile function is given in equation 37 in the last chapter. Define C a constant.

$$\text{eq. 53} \quad C = \frac{(1 - i\alpha)\sigma_T}{4\pi a}.$$

Then the profile function becomes:

$$\text{eq. 54} \quad T(\vec{w}_J) = C e^{-w_J^2/2a}.$$

So the resulting amplitude for proton-helium scattering is:

$$\text{eq. 55} \quad f_K(\vec{\Delta}) = \frac{\kappa}{2\pi i} \int d^3b e^{i\vec{\Delta} \cdot \vec{b}} \left\{ \frac{1}{V} \frac{1}{2\pi} \int_{J=1}^4 [1 - C e^{-w_J^2/2a}] d\vec{r}_J - 1 \right\}.$$

The integrals are all symmetric with respect to interchange of the J's.

Therefore $1 - \sum_{J \neq K} h_{JK}$ can be rewritten as $1 - 6h_{21}$. Now

inserting the wave function we get:

$$\text{eq. 56 } F_K(\vec{A}) = \frac{KN^2}{2\pi i} \int d^2b e^{i\vec{A} \cdot \vec{b}} \left\{ \left[e^{-\sum_{i=1}^4 r_i^2/R^2} (1-h_{21}) d\vec{r}_1 d\vec{r}_2 d\vec{r}_3 d\vec{r}_4 \right. \right. \\ \times \left[1 - \sum_{j=1}^4 c^j e^{-w_j^2/2a} + \sum_{j>k} c^2 e^{-w_j^2/2a - w_k^2/2a} \right. \\ - \sum_{j>k>m} c^3 e^{-w_j^2/2a - w_k^2/2a - w_m^2/2a} \\ \left. \left. + \sum_{j>k>m>n} c^4 e^{-w_j^2/2a - w_k^2/2a - w_m^2/2a - w_n^2/2a} \right] \right\}.$$

The integrals can be expanded and the amplitude can be written as:

$$\text{eq. 57 } F_K(\vec{A}) = \frac{KN^2}{2\pi i} \int d^2b e^{i\vec{A} \cdot \vec{b}} \{ T \}$$

where T is defined as:

$$\text{eq. 58 } T = \int d\vec{r}_1 d\vec{r}_2 d\vec{r}_3 d\vec{r}_4 e^{-\sum_{i=1}^4 r_i^2/R^2} (1-h_{21}) \\ \times \left[-c e^{-w_1^2/2a} - c e^{-w_2^2/2a} - c e^{-w_3^2/2a} - c e^{-w_4^2/2a} \right. \\ + c^2 e^{-w_1^2/2a - w_2^2/2a} + c^2 e^{-w_1^2/2a - w_3^2/2a} \\ + c^2 e^{-w_1^2/2a - w_4^2/2a} + c^2 e^{-w_2^2/2a - w_3^2/2a} \\ + c^2 e^{-w_2^2/2a - w_4^2/2a} + c^2 e^{-w_3^2/2a - w_4^2/2a} \\ - c^3 e^{-w_1^2/2a - w_2^2/2a - w_3^2/2a} \\ \left. - c^3 e^{-w_1^2/2a - w_2^2/2a - w_4^2/2a} \right]$$

$$\begin{aligned}
& - C^3 e^{-w_1^2/2a - w_3^2/2a - w_4^2/2a} \\
& - C^3 e^{-w_2^2/2a - w_3^2/2a - w_4^2/2a} \\
& + C^4 e^{-w_1^2/2a - w_2^2/2a - w_3^2/2a - w_4^2/2a} \Big] .
\end{aligned}$$

In order to evaluate these integrals we will find five basic integrals.

They are defined in Appendix A along with their solutions. We can define all of the integrals with a symbol f_{ij} where i indicates the multiple scattering term 1,2,3,4 and j indicates uncorrelated piece if it is 0, and the correlated piece if it is 1. Our problem becomes one of noting down f_{i0} and f_{i1} for $i=1,2,3,4$. Let us examine f_{10} :

$$\text{eq. 59} \quad f_{10} = \frac{KN^2}{2\pi i} \int d^2b e^{i\vec{\Delta} \cdot \vec{b}} [I_{10}] ,$$

where I_{10} is:

$$\begin{aligned}
\text{eq. 60} \quad I_{10} &= \int d\vec{r}_1 \dots d\vec{r}_4 e^{-\sum_{i=1}^4 r_i^2/R^2} \left[- C \sum_{i=1}^4 e^{-w_i^2/2a} \right] \\
&= -4C I_1^3 I_3 .
\end{aligned}$$

Thus f_{10} becomes:

$$\text{eq. 61} \quad f_{10} = \frac{KN^2}{2\pi i} \int d^2b e^{i\vec{\Delta} \cdot \vec{b}} (-4C I_1^3 I_3) .$$

By the same process we can write down the answer to each f_{i0} :

$$\text{eq. 62 } f_{20} = \frac{\kappa N^2}{2\pi i} \int d^2 b e^{i \vec{\Delta} \cdot \vec{b}} (6 C^2 I_1^2 I_3^2) ,$$

$$\text{eq. 63 } f_{30} = \frac{\kappa N^2}{2\pi i} \int d^2 b e^{i \vec{\Delta} \cdot \vec{b}} (-4 C^3 I_1 I_3^3) ,$$

and

$$\text{eq. 64 } f_{40} = \frac{\kappa N^2}{2\pi i} \int d^2 b e^{i \vec{\Delta} \cdot \vec{b}} (C^4 I_3^4) .$$

We can easily see the expressions for the part of the amplitude linear in the correlations h_{JK} :

$$\text{eq. 65 } f_{11} = \frac{\kappa N^2}{2\pi i} \int d^2 b e^{i \vec{\Delta} \cdot \vec{b}} (6 C (2 I_4 I_1^2 + 2 I_2 I_3^2)) ,$$

$$\text{eq. 66 } f_{21} = \frac{\kappa N^2}{2\pi i} \int d^2 b e^{i \vec{\Delta} \cdot \vec{b}} (-6 C^2 (I_5 I_1^2 + 4 I_4 I_3 I_1 + I_2 I_3^2)) ,$$

$$\text{eq. 67 } f_{31} = \frac{\kappa N^2}{2\pi i} \int d^2 b e^{i \vec{\Delta} \cdot \vec{b}} (6 C^3 (2 I_5 I_3 I_1 + 2 I_4 I_3^2)) ,$$

and

$$\text{eq. 68} \quad f_{41} = \frac{k N^2}{2\pi i} \int d^2 b e^{i \vec{A} \cdot \vec{b}} (-b c^4 (I_5 I_3^2)) .$$

We must finally evaluate the integrals over $d^2 b$. All of the integrals will be of the form:

$$\text{eq. 69} \quad I_6 = \int d^2 b e^{i \vec{A} \cdot \vec{b} - x b^2} .$$

In the Appendix A the solution to equation 69 will be found.

Using the results of Appendix A and the constants defined in Appendix B we can write down the general expression for f_{i0} $i=1,2,3,4$.

$$\text{eq. 70} \quad f_{j0} = (I_1)^{4-j} D c^j \left(\frac{\pi^{3/2} R}{\mu} \right)^j \frac{\pi}{j!} e^{-\Delta^2 / 4j} (-1)^j \binom{4}{j} .$$

This allows us to write down the result for the uncorrelated wave function directly:

$$\text{eq. 71} \quad f_0 = \frac{D\pi}{\ell} \sum_{j=1}^4 \frac{(-1)^j}{j} \binom{4}{j} \left(\frac{\pi^{3/2} R c}{\mu} \right)^j e^{-\frac{\Delta^2}{4j}} (I_1)^{4-j} .$$

We can test this result with previous calculations by computing only this piece (equation 71) which amounts to a pure Gaussian wave function. However we must be careful to use the correct normalization N^2 in the constant D. Up to this point D is simply defined:

$$\text{eq. 72} \quad D = k N^2 / 2\pi i .$$

Before we go any further, we must note that a recoil correction term must be put in front of each integral (Cz 67a). The derivation of the term can be found in (Ga 57). Including this term we must redefine D :

$$\text{eq. 73} \quad D \equiv \frac{k N^2}{2\pi i} e^{R^2 \Delta^2 / 16} .$$

The Glauber theory was for a nucleus at rest. For small scattering angles $\Delta^2 \approx -t^2$ where t is the four-momentum transfer. Also the Jacobian from laboratory cross section to center-of-mass cross section is k_{CM}^2 / k_{lab}^2 . Thus if we treat k and Δ as though they are in the center-of-mass system we will have the result in that system. This approximation is good over the useful range of the Glauber theory.

We now need the results for the correlated f_{i1} . The results can be simply expressed by defining a function $R(J_1, J_2, J_3, J_4, J_5)$:

$$\text{eq. 74} \quad R(J_1, J_2, J_3, J_4, J_5) = \pi \left[\prod_{i=1}^5 (C_i)^{J_i} \right] \frac{e^{-\Delta^2 / 4 \bar{X}}}{\bar{X}}$$

where $\bar{X} = J_1 E_1 + J_2 E_2 + J_3 E_3 + J_4 E_4 + J_5 E_5$. Then the terms linear in the correlation become:

$$\text{eq. 75} \quad f_{11} = 6DC \left[2R(2, 0, 0, 1, 0) + 2R(0, 1, 2, 0, 0) \right],$$

$$\text{eq. 76} \quad f_{21} = -6DC^2 \left[R(2, 0, 0, 0, 1) + 4R(1, 0, 1, 1, 0) + R(0, 1, 2, 0, 0) \right],$$

$$\text{eq. 77 } f_{31} = 6DC^3 [2R(1,0,1,0,1) + 2R(0,0,2,1,0)],$$

$$\text{eq. 78 } f_{41} = -6DC^4 [R(0,0,2,0,1)] .$$

The final result then is:

$$\text{eq. 79 } f_K(\vec{\delta}) = \sum_{L=1}^4 \sum_{j=0}^1 f_{Lj} .$$

The constants E_1, E_2, E_3, E_4, E_5 are defined in Appendix B.

A Fortran listing of the program code which was used to make the calculations in Figures 2 through 18 is given in Appendix D. The results of the calculation are given in the figures just mentioned. In order to fit the forward peak the correct electron scattering radius had to be used and is labeled on the figures. In a qualitative sense the best simultaneous fit to the form factor and proton-helium scattering comes for $B=55$ fm. The calculation comes shy of fitting the first maximum; however it follows the data quite well to larger t values. On all of the figures except Figure 6 the data plotted is from reference (Pa 67). These curves were made before the data of (Ba 74a). On Figure 6 we have added the data of (Ba 74a) and note a striking improvement of the fit in the region of the first maximum. It is important to note that the calculation in chapter 4 would fit the data of (Ba 74a) even worse than the data of (Pa 67).

It is apparent that the inclusion of Jastrow type correlations

appeared to improve the fit to existing data sets in the region from the first minimum to the second maximum. In addition the correlation length seems to be in good qualitative agreement for simultaneous fit to the charge form factor and proton-helium scattering.

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

PART 2

ENERGY-LOSS SPECTROMETER SYSTEM

Chapter 6

Data Analysis with HRS

The High Resolution Spectrometer Facility (HRS) at Los Alamos Meson Physics Facility (LAMPF) was designed as an energy-loss spectrometer system. It was designed to get momentum resolution for 800 Mev protons of .002%. However this momentum resolution is not available for the full accelerator phase space of 0.5% in momentum. In order to resolve scattering from nuclei with an equivalent resolution of .002% , the system was designed to measure the missing mass (the nuclear state of the recoil particle) to 30 Kev. The information lost is the momentum of the incoming proton. The way the beam line dispersion system and spectrometer are matched precludes measurement of beam momentum to better than the actual spread produced by the accelerator.

The first chapter of this part will explain how this system achieves these design goals. The second chapter explains a technique that can be used to dynamically adjust the large dipole magnets in the system to achieve this resolution over a large range of beam energies and final particle momenta. In the final chapter we present the results on one such typical magnet in the beam line dispersion section.

In Figure 19 is shown a floor plan view of the facility. The facility is rather large on a nuclear physics scale. The "dome" which houses the spectrometer is 46' in radius. The spectrometer depicted in Figure 20 weighs nearly one million pounds including its support structure.

Figure 19

47

The mass of the undetected recoiling nucleus in the reaction:

can be expanded in a Taylor series in the three variables needed to specify that mass. Let us choose P_a the momentum of particle A. Let P_c be the momentum of particle C which is detected in the spectrometer. The third variable is θ the true scattering angle for each event. Define:

M_a = mass of particle A

M_b = mass of particle B

M_c = mass of particle C

M = mass of particle D

The additional subscript o defines that variable to be the central trajectory ray value. For example P_{ao} is the momentum the beam line central ray is tuned for. The Taylor expansion then becomes:

$$\begin{aligned} \text{eq. 80 } m - m_o &= \frac{\partial m}{\partial P_a} (P_a - P_{ao}) + \frac{\partial m}{\partial P_c} (P_c - P_{co}) + \frac{\partial m}{\partial \theta} (\theta - \theta_o) \\ &+ \frac{\partial^2 m}{\partial P_c \partial \theta} (P_c - P_{co})(\theta - \theta_o) + \frac{\partial^2 m}{\partial P_a \partial \theta} (P_a - P_{ao})(\theta - \theta_o) \\ &+ \frac{\partial^2 m}{\partial P_c \partial P_a} (P_c - P_{co})(P_a - P_{ao}) + \frac{1}{2} \frac{\partial^2 m}{\partial \theta^2} (\theta - \theta_o)^2 \\ &+ \frac{1}{2} \frac{\partial^2 m}{\partial P_a^2} (P_a - P_{ao})^2 + \frac{1}{2} \frac{\partial^2 m}{\partial P_c^2} (P_c - P_{co})^2 \\ &+ \frac{1}{6} \frac{\partial^3 m}{\partial \theta^3} (\theta - \theta_o)^3 \end{aligned}$$

+ . . . (the rest of the third and higher order terms).

Calculation of the various kinematic derivatives found in equation 80 is relatively straight forward and tedious. In Appendix E, which lists the Monte Carlo code for the work in this chapter, is contained a subroutine titled HRSKIN. That subroutine calculates all of the kinematic quantities needed for planning or analyzing an HRS experiment.

In the laboratory reference frame conservation of energy and momentum gives:

$$\text{eq. 81} \quad (m_a^2 + p_a^2)^{1/2} + m_b = (m_c^2 + p_c^2)^{1/2} + (m^2 + p_d^2)^{1/2}$$

and

$$\text{eq. 82} \quad \vec{P}_a = \vec{P}_c + \vec{P}_d \quad .$$

The vector relation above gives scalar expressions:

$$\text{eq. 83} \quad p_a = p_c \cos \theta + p_d \cos \phi$$

and

$$\text{eq. 84} \quad 0 = p_c \sin \theta + p_d \sin \phi \quad .$$

In Figure 21 is defined the angles θ and ϕ . We can eliminate the dependence on ϕ and P_d using equations 81, 83, and 84.

$$\text{eq. 85} \quad m = \left[\left[(m_a^2 + p_a^2)^{1/2} - (m_c^2 + p_c^2)^{1/2} + m_b \right]^2 - (p_a - p_c \cos \theta)^2 - (p_c \sin \theta)^2 \right]^{1/2}.$$

If the acceptance of the spectrometer in θ and P_c is small enough we can truncate the Taylor series at some specific order with a well defined error. We will show with our Monte Carlo code that for best resolution scattering on heavy nuclei we need keep only the following terms:

$$\text{eq. 86} \quad m - m_0 = \frac{\partial m}{\partial P_a} (P_a - P_{a0}) + \frac{\partial m}{\partial P_c} (P_c - P_{c0}) + \frac{\partial m}{\partial \theta} (\theta - \theta_0) + \frac{\partial^2 m}{\partial \theta^2} (\theta - \theta_0)^2.$$

Define:

$$\text{eq. 87} \quad \delta_a \equiv \frac{P_a - P_{a0}}{P_{a0}},$$

$$\text{eq. 88} \quad \delta_c \equiv \frac{P_c - P_{c0}}{P_{c0}},$$

and

$$\text{eq. 89} \quad R \equiv P_{a0} \frac{\partial m}{\partial P_a} \bigg/ \left(P_{c0} \frac{\partial m}{\partial P_c} \right).$$

Figure 21

Plan View

and the equation for $M-M_0$ becomes:

$$\text{eq. 90 } M-M_0 = p_{c0} \frac{\partial m}{\partial p_c} (R\delta_c + \delta_c) + \frac{\partial m}{\partial \theta} (\theta - \theta_0) + \frac{\partial^2 m}{\partial \theta^2} (\theta - \theta_0)^2$$

$M-M_0$ is just the excitation of the recoiling nucleus or particle.

Specifically for HRS the only terms measured are the terms in equation 90. Homogeneous higher order terms in $\theta - \theta_0$ are measured. They also contribute in a negligible way to the errors in the system.

In Figure 22 is defined the relevant coordinate systems for the HRS beam line and spectrometer. It is interesting to note that the spectrometer bend is not in the floor plane but in fact in a vertical plane.

The HRS beam line was designed to first order so that:

$$\text{eq. 91 } \begin{bmatrix} X_{out}^b \\ \theta_{out}^b \\ y_{out}^b \\ \phi_{out}^b \\ \rho_{out}^b \\ \delta_a \end{bmatrix} = \begin{bmatrix} 0 & 0 & R_{13} & R_{14} & 0 & 0 \\ 0 & 0 & R_{23} & R_{24} & 0 & 0 \\ R_{31} & 0 & 0 & 0 & 0 & R_{36} \\ R_{41} & R_{42} & 0 & 0 & 0 & R_{46} \\ R_{51} & R_{52} & 0 & 0 & 1 & R_{56} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{in}^b \\ \theta_{in}^b \\ y_{in}^b \\ \phi_{in}^b \\ \rho_{in}^b \\ \delta_a \end{bmatrix}$$

The spectrometer has the following backward first order optics:

Figure 22

In both figures the origin is the center of the target.

$$\text{eq. 92} \quad \begin{bmatrix} X_{in}^s \\ -\theta_{in}^s \\ -y_{in}^s \\ \phi_{in}^s \\ -\ell_{in}^s \\ \delta_c \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & 0 & 0 & 0 & B_{16} \\ B_{21} & B_{22} & 0 & 0 & 0 & B_{26} \\ 0 & 0 & B_{33} & B_{34} & 0 & 0 \\ 0 & 0 & B_{43} & B_{44} & 0 & 0 \\ B_{51} & B_{52} & 0 & 0 & 1 & B_{56} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{out}^s \\ -\theta_{out}^s \\ -y_{out}^s \\ \phi_{out}^s \\ -\ell_{out}^s \\ \delta_c \end{bmatrix}$$

The subscript in refers to the H^- stripper location, which forms the object for the beam line, for beam line variables. For spectrometer variables in refers to the target location. The out subscript refers to the target location for beam line variables and to the focal plane for spectrometer variables. The matrix notation and definition of the various coordinates are in the standard "Transport" notation of Karl Brown. We can now look at various pieces of equations 91 and 92.

$$\text{eq. 93} \quad X_{in}^s = B_{11} X_{out}^s - B_{12} \theta_{out}^s + B_{16} \delta_c$$

In general including higher order terms we have:

$$\text{eq. 94} \quad X_{in}^s = B_{11} X_{out}^s - B_{12} \theta_{out}^s + B_{16} \delta_c \\ + E(X_{out}^s, \theta_{out}^s, y_{out}^s, \phi_{out}^s, \delta_c)$$

$E(x_{out}^s, \theta_{out}^s, y_{out}^s, \phi_{out}^s, \delta_c)$ represents all of the higher order terms needed to define X_{in}^s to any desired precision.

The backward matrices are generated by reversing the order of magnet specifications in the "Transport" or "Enge Ray Tracing" codes.

From equation 91 we have a relation for Y_{out}^b . Including higher order terms it becomes:

$$\text{eq. 95} \quad Y_{out}^b = R_{31} X_{in}^b + R_{36} \delta_a + \eta (X_{in}^b, \theta_{in}^b, y_{in}^b, \phi_{in}^b, \delta_a).$$

Now from looking at Figure 22 we can verify that $X_{in}^s = Y_{out}^b$. If we therefore equate equations 94 and 95 and drop terms that we know are negligible from "Transport" calculations we find:

$$\text{eq. 96} \quad \left(\frac{R_{36}}{B_{16}} \delta_a - \delta_c \right) = \frac{B_{11}}{B_{16}} X_{out}^s - \frac{B_{12}}{B_{16}} \theta_{out}^s + \frac{E}{B_{16}}$$

If the beam line were tuned so that the relation:

$$\text{eq. 97} \quad R = -R_{36}/B_{16}$$

were satisfied where R is defined in equation 89 we would find that the first term in equation 90 is measured in focal plane quantities. Define:

$$\text{eq. 98} \quad \delta_\ell = R \delta_a + \delta_c$$

then:

$$\text{eq. 99} \quad \delta_\ell = \frac{-B_{11}}{B_{16}} X_{out}^S + \frac{B_{12}}{B_{16}} \theta_{out}^S - \frac{\epsilon}{B_{16}}$$

and

$$\text{eq. 100} \quad m - m_0 = P_{c0} \frac{\partial m}{\partial P_c} \delta_\ell + \frac{\partial m}{\partial \theta} (\theta - \theta_0) + \frac{\partial^2 m}{\partial \theta^2} (\theta - \theta_0)^2.$$

The higher order term $E(X_{out}^S, \theta_{out}^S, y_{out}^S, \phi_{out}^S, \delta_c)$ contains a dependence on δ_c . The largest part of δ_ℓ on the average is just δ_c . Thus we can iteratively solve for δ_ℓ by replacing δ_c by δ_ℓ in the higher order terms. This has been done in the Monte Carlo code in Appendix E. Subroutine M in that code contains such an iterative procedure and converges in two to three iterations to a change in δ_ℓ of less than 0.0001%. We must now demonstrate how we calculate the scattering angle from the focal plane quantities.

The spectrometer angles θ_{in}^S and ϕ_{in}^S along with the central ray scattering angle θ_0 in conjunction with the beam line angles θ_{out}^b and ϕ_{out}^b serve to specify completely the scattering angle for each event. The relationship is:

$$\text{eq. 101} \quad \cos(\theta) = \frac{\left[\tan \theta_{in}^S \tan \phi_{out}^b - \tan \phi_{in}^S (\cos \theta_0 \tan \theta_{out}^b + \sin \theta_0) + \cos \theta_0 \right]}{\left[(1 + \tan^2 \phi_{in}^S + \tan^2 \theta_{in}^S)^{1/2} (1 + \tan^2 \phi_{out}^b + \tan^2 \theta_{out}^b)^{1/2} \right]}$$

The derivation of this relationship will be outlined. The arbitrary spectrometer ray is described by X_{in}^S , θ_{in}^S , y_{in}^S , and ϕ_{in}^S . The

arbitrary beam ray is described by X_{out}^b , Y_{out}^b , θ_{out}^b , and ϕ_{out}^b . The scattering angle is the angle θ between the two rays. The scattering angle does not depend on the spatial coordinates in each specification plane for the rays, but rather on the projected angles with which the rays leave the two planes. The angle between the two specification planes is just θ_0 the central ray to central ray scattering angle. Let us then translate each ray to the origin of the coordinate system (i.e. let all X's and Y's be zero). The dot product of $\vec{A}$ and $\vec{B}$ is $\cos(\theta)$ where $\vec{A}$ is the vector representing the beam ray and $\vec{B}$ is the vector representing the spectrometer ray. In order to form the dot product we need to express both vectors in the same coordinate system. In the spectrometer coordinate system:

$$\text{eq. 102} \quad \vec{A}^s = R_{90^\circ}^{z^s} R_{\theta_0}^{y^b} \vec{A}^b .$$

By using a set of rotation matrices $R_{\theta_0}^{y^b}$ and $R_{90^\circ}^{z^s}$, we can transform $\vec{A}^b$ into the spectrometer system.

$$\text{eq. 103} \quad R_{\theta_0}^{y^b} = \begin{bmatrix} \cos(\theta_0) & 0 & \sin(\theta_0) \\ 0 & 1 & 0 \\ -\sin(\theta_0) & 0 & \cos(\theta_0) \end{bmatrix} .$$

$$\text{eq. 104} \quad R_{90^\circ}^{z^s} = \begin{bmatrix} \cos(90^\circ) & \sin(90^\circ) & 0 \\ -\sin(90^\circ) & \cos(90^\circ) & 0 \\ 0 & 0 & 1 \end{bmatrix} .$$

We know that the rays can be normalized vectors (i.e. $\vec{A} \cdot \vec{A} = 1$). This condition along with the projected angles allows us to write down

the representation of each ray in its coordinate system in terms of the previously mentioned angles. Once both rays are expressed in the same system we simply perform the dot product and come up with equation 101.

We can now put this equation in a more useful form. First we note that $\langle \theta_{out}^b \rangle = 0$ and is unmeasured. We also note that for the range of interest for the variable ϕ_{out}^b the following holds:

$$\text{eq. 105} \quad \cos \phi_{out}^b = \frac{1}{(1 + \tan^2 \phi_{out}^b)^{1/2}} .$$

None of the angles would exceed 60 mrad, so we can use expansions for all of the trigonometric functions. We then drop all terms above second order and we find:

$$\text{eq. 106} \quad \cos \theta = \cos \theta_0 - \phi_{in}^s \sin \theta_0 + \theta_{in}^s \phi_{out}^b - \frac{1}{2} \cos \theta_0 [\phi_{out}^b{}^2 + \theta_{in}^s{}^2 + \phi_{in}^s{}^2] .$$

We have studied this relation and found that for random variations over the allowed variable range it predicts θ to better than 0.05 mrad worst case.

From equation 92 we can write the following relations:

$$\text{eq. 107} \quad \phi_{in}^s = -B_{43} \gamma_{out}^s + B_{44} \phi_{out}^s$$

and

$$\text{eq. 108} \quad \theta_{in}^s = -B_{21} x_{out}^s + B_{22} \theta_{out}^s - B_{26} \delta_c .$$

Clearly ϕ_{in}^s is well measured. Unfortunately $B_{26} \delta_c$ is not measured to better than $\pm B_{26} \delta_a$, this turns out to be 30 mrad. θ_{in}^s being an angle projected in a vertical plane will not affect the measure of scattering angle outside of the very forward cone or very backward cone.

In the very forward cone we can correct for this problem by noting that:

$$\text{eq. 109} \quad \phi_{out}^b \approx R_{46} \delta_a$$

Subtract equation 109 from equation 108 and write as follows:

$$\text{eq. 110} \quad \theta_{in}^s - \phi_{out}^b = -B_{21} \chi_{out}^s + B_{22} \theta_{out}^s - B_{26} \left[\frac{R_{46}}{B_{26}} \delta_a + \delta_c \right].$$

If $R_{46} / B_{26} = R$ then the term proportional to B_{26} would be a measured quantity δ_ℓ . This angular dispersion match was achieved in the design of the beam line to a precision such that the largest error in $\theta_{in}^s - \phi_{out}^b$ is about 5 mrad. Hence the zero degree scattering angle has such an error if we use a full phase space beam. By completing the square in equation 106 and ignoring unmeasured terms we find:

$$\text{eq. 111} \quad \cos \theta = \cos \theta_0 - \sin \theta_0 \phi_{in}^s - \frac{1}{2} \cos \theta_0 \left[(\theta_{in}^s - \phi_{out}^b)^2 + \phi_{in}^{s^2} \right].$$

Finally in the forward cone the approximation:

$$\text{eq. 112} \quad \theta^2 \simeq (\phi_{in}^s + \theta_0)^2 + (\theta_{in}^s - \phi_{out}^b)^2$$

works very well. Outside of 10 degrees the approximation:

$$\text{eq. 113} \quad \theta = \theta_0 + \phi_{in}^s$$

works equally well. The spectrometer can never measure further than 170 degrees and hence equation 113 is sufficient all the way back.

In conclusion we have shown how to measure the missing mass and scattering angle in terms of the measured focal plane quantities. In order to verify these expressions including higher orders, a subroutine M was written and then was used to analyze Monte Carlo data. The code was useful in getting the signs correct in the higher order terms. It was also useful to study the optics for different experimental conditions. In Figure 23 is shown the scattering angle calculated in subroutine M subtracted from the Monte Carlo scattering angle. The full width at half maximum (FWHM) is .3 mrad. In Figure 24 is shown the missing mass for protons on helium at $\theta_0 = 5^\circ$. The line width is due to the optical resolution and is 30 Kev FWHM. When effects like multiple scattering in the target are added these spectra would be quite broadened. These curves are output from the Monte Carlo code.

Figure 23

Figure 24

Chapter 7

HT Windings in Dipole Magnets

HT windings were designed into all of the large HRS dipole magnets. In Figure 25 is shown a section view of an H-type magnet. The HT windings are conductors running along the Z-direction parallel to the beam central ray. The slots that they run through are shown in the figure. Each winding was excited with the corresponding winding in the opposite pole face. This preserved midplane symmetry.

The exact way in which these windings were to be used was unclear. Their use depended on the results of field maps of the large dipoles. However an early study was done on the HRS prototype magnet to learn the characteristics of these windings. A nuclear magnetic resonance (NMR) probe was used to measure a transverse field distribution. The NMR measures the average magnitude of the field over the sample. Typical gradients in the field were of the order of 1.0 Gauss per inch. The desired field gradients across the midplane would be better than 0.02 Gauss per inch. It is important to observe that the result shown in Figure 25 is for one value of Z. The probe remains in the midplane scanning across the gap in X measuring a field primarily aligned in the Y direction. If the midplane field would be constant then the field would be constant throughout the homogeneous volume of the magnets. In Figure 26 is shown a field distribution for LCBM05 (see Figure 13 for location of this magnet). This shows the first 27.5° bend of the magnet. We can see that the field is bumpy to the order 10.0 gauss. The bumpyness has no regularity in the sense of having a constant azimuthal dependence. This fact meant

Figure 25

Comparison between the computer prediction and the observed transverse field distribution. The field is uniform to better than two parts in 10^5 over a range of four gap widths in x .

H-Type Magnet showing HT Slots (Section View)

Figure 26

LCBM05 Entrance

15 kg

that using windings which ran parallel to the beam did not allow for corrections to the field which would produce a constant field throughout the volume along the particle's trajectory.

After the HT windings were studied for a few years it became apparent that they could be used to make small field corrections of the order of one part in ten thousand. That correction would be independent of the Z coordinate.

In this chapter we first describe the mathematical technique which was used to adjust the HTs to any desired radial field distribution at one azimuthal location. We then discuss a way to use the HTs to correct for aberrations in the entire magnet. The technique used on the entire magnet was to adjust the effective field boundaries with the HTs after the magnet was optimized with pole face shims and field clamps at the nominal design field. In this way dynamic (field level dependent) effects could be corrected.

Define a function S:

$$\text{eq. 114} \quad S = f(x_1, x_2, \dots, x_n) .$$

The condition for an extremum is:

$$\text{eq. 115} \quad \frac{\partial S}{\partial x_i} = 0 \quad \text{for } i = 1, \dots, n.$$

In particular for HT windings the primary variables x_i can represent the currents in each set of windings. Let the function S describe the difference between what is measured across the magnet gap and

what is desired across the magnet gap. Then by finding the extremum in S we find what currents lead to the desired field distribution. However it is possible to get stuck in a local valley of the function S and not find the true minimum. In practice with the technique described here we found no such effect in hundreds of optimized radial distributions. The function S for the case of HT windings can be written as:

$$\begin{aligned} \text{eq. 116} \quad S = & \sum_I W(I) \left[B_{DES}(I) - B(I, X_1, \dots, X_n) \right]^2 \\ & + \sum_J V(J) \left[X(J) - X_0(J) \right]^2 \\ & + \sum_K \left[2U X(K) - 2U X(P) \delta_{PK} \right] . \end{aligned}$$

$W(I)$ is the relative weight of the fit quality desired at position I.

$B_{des}(I)$ is the desired field at position I.

$B(I, X_1, X_2, \dots, X_n)$ is the B field at position I as a function of the HT currents X_i s.

$V(J)$ is the relative weight on minimizing the variation of $X(J)$ from the original starting value $X_0(J)$.

$X_0(J)$ is the starting values for $X(J)$.

U is a constant describing the relative importance of a constraint that the sum of the HT currents be zero. This could be useful in order not to increase the flux through the yoke.

For the HT windings it would be very difficult to calculate $B(I, X_1, \dots, X_n)$. We can measure through the proper procedure $\partial B(I) / \partial X(J)$. If such a procedure has no hysteresis we can then set the HTs to a desired solution by a number of linear extrapolations to the final

desired solution. We can therefore approximate:

$$\text{eq. 117 } B(I) \simeq B_0(I) + \sum_J \frac{\partial B(I)}{\partial X_J} \Delta X(J) .$$

$$\text{eq. 118 } \Delta X(J) = X(J) - X_0(J) .$$

In any one iteration we measure $B_0(I)$ and the $\Delta B(I)$ and $\Delta X(J)$. $\partial B / \partial X(J)$ turns out to be a very smoothly varying function of main current excitation in the beam line dispersion magnets. Thus one measurement of $\partial B / \partial X(J)$ suffices for all iterations. Put equation 117 into function 116 and minimize S:

$$\begin{aligned} \text{eq. 119 } \frac{\partial S}{\partial X(L)} = & - \sum_I W(I) \left[B_{DES}(I) - B_0(I) - \sum_m \frac{\partial B(I)}{\partial X(m)} \Delta X(m) \right] \frac{\partial B(I)}{\partial X(L)} \\ & + \sum_J V(J) \Delta X(J) \delta_{JL} \\ & + \sum_K (U \delta_{KL} - U \delta_{PL}) . \end{aligned}$$

Define:

$$\text{eq. 120 } Q(L) = \sum_I W(I) \frac{\partial B(I)}{\partial X(L)} \left[B_{DES}(I) - B_0(I) \right] - \sum_K (U \delta_{KL} - U \delta_{PL}) .$$

We can then write equation 119 as:

$$\text{eq. 121} \quad \frac{\partial S}{\partial X(L)} = -Q(L) + \sum_I W(I) \frac{\partial B(I)}{\partial X(L)} \sum_m \frac{\partial B(I)}{\partial X(L)} \Delta X(m) \\ + \sum_J V(J) \Delta X(J) \delta_{JL} .$$

Define:

$$\text{eq. 122} \quad M_{Lm} = \sum_I \frac{\partial B(I)}{\partial X(L)} W(I) \frac{\partial B(I)}{\partial X(m)} + V(m) \delta_{Lm}$$

We can then write:

$$\text{eq. 123} \quad \frac{\partial S}{\partial X(L)} = -Q(L) + \sum_m M_{Lm} \Delta X(m)$$

Requiring $\frac{\partial S}{\partial X(L)} = 0$ for all L leads to:

$$\text{eq. 124} \quad \sum_m M_{Lm} \Delta X(m) = Q(L) .$$

If $\vec{\Delta X}$ is a column vector and $\vec{Q}$ a column vector, then $\vec{M}$ is a matrix and the solution set becomes:

$$\text{eq. 125} \quad \vec{\Delta X} = \vec{M}^{-1} \vec{Q} .$$

In actual practice the last element of column vector $\vec{\Delta X}$ was a fictitious winding with all $\frac{\partial B(I)}{\partial X(p)}$ equal to a constant. This allowed the solution to fit shapes rather than absolute fields which were easily adjusted with the main field windings.

This is the reason for the term $\sum p_k$ in the part of equation 116 which is linear in U.

An additional equation was used which employed the method of LaGrange multipliers to provide an absolute constraint that the sum of the currents be zero. It turned out to be unnecessary in practice. The $\partial B(x)/\partial x(l)$ in the midplane looked like the derivative of a Gaussian centered over the HT winding L.

The procedure derived above was used to obtain the result at the top of Figure 25. The magnet was very bad to start with and after three iterations remeasuring all the derivatives each time we achieved the result shown. This of course was extremely discouraging in one sense. It took days to measure the data necessary to fix the field at just one Z value. When we finally used HT windings again it was under very different circumstances. The field was already good to about one part in ten thousand. At that level we needed to measure the derivatives at only a few main fields and then perform only one iteration to get to the desired result.

We set out to see if we could predict changes in the $\int B_y dz$ along the entire length of the magnets by simply measuring $\partial B(x)/\partial x(l)$ at radial scanning NMR locations. This turned out to be the case. We simply multiplied the length of an HT winding along the pole face by the derivatives measured at an NMR location. This gave us a derivative in the field integral. We then divided this derivative by the average field in the magnet to give us a derivative in effective length for the magnet. We then tuned the effective length of the magnet with HT windings. Figure 27 shows the result of such

an effort. The vertical axis measures thousandths of an inch deviation of the summed field boundarys (effective lengths). The horizontal axis measures the radial deviation from the central ray trajectory. This result was better than one part one hundred thousand root mean square over a region ± 3 . inches from the central trajectory. Overall shifts in the effective field boundary were not measured as well as the relative shapes.

The interactive coding used on the LAMPF Central Control Computer to achieve these results is listed in Appendix F.

Figure 27
ICBM05 summer DSS 15... kilogauss

Chapter 8

Beam Line Dispersion Magnet Optimization

The two large beam line dipoles at HRS are designated LCBM04 and LCBM05. These magnets in relation to the whole system are shown in Figure 19. These magnets each have a bend angle of 57° . The magnets arrived at Los Alamos without field clamps. In order to get 30 Kev resolution with the HRS system the large dipole magnets which produced the dispersion to analyze the beam momentum (see Chapter 6 for beam line requirements) needed fields which fit the design field integrals to better than two parts in one hundred thousand. The approximate length of the magnets from effective field boundaries at entrance and exit was 160 inches. We then see that the boundaries needed to be in agreement with design to the order of three thousandths of an inch. In this chapter we briefly sketch the techniques used to achieve this design goal.

In order to see what we faced initially, examine Figure 28 which shows the total effective length deviation from design for the entire magnet. The curves are labelled in kilogauss. The entire magnet had effective field boundaries which were over 1.0 inches too long and extremely field level dependent. Furthermore they were badly skewed from design values. Essentially the magnets had deviations from design values of about three parts in one thousand. After shimming the pole faces and designing field clamps the results were two orders of magnitude better. We still had not used HT windings. Figure 29 and Figure 30 show the deviation from desired effective field boundaries after the magnets had gone through

(inches) Deviation from desired total effective length.

Figure 28

Figure 99

LCBHQ4 DSS Exit SHIMMED

one year of iterations on field clamp design and positioning and pole face shimming. Figure 29 shows a very stable boundary as a function of magnet excitation. The beam is quite narrow going through the entrance and the effective field boundaries look uniform over the business region to a few parts in one hundred thousand. Some of this early data showed shifts between the two scans of the magnet which made up these curves. That is the reason for the saw tooth structure in some of the curves. Figure 30 shows the exit field boundary deviations. At the low current excitations the boundary looks excellent. As we got to higher field the inner yoke leg and field clamp went into saturation. The saturation effect was also observed on LCBM05. It was solved on LCBM05 with HT windings. This was shown in the last chapter in Figure 27. When HRS is run near the ultimate resolution the HT windings will probably need to be turned on. From both magnets there always remained some saturation in the field clamps at higher fields which resulted in the effective field boundaries moving out 30 to 50 thousandths of an inch from the lowest excitation to the highest. The system was nominally designed for 800 Mev protons which is the highest field measured.

The results for LCBM05 are shown in Figure 31 and Figure 32. Figure 31 shows the total effective length deviation from design at five different field levels. Figure 32 shows the result with the HT windings on at the higher field levels. The results were very encouraging. However until beam was run through the system to test the resolution of the beam line and spectrometer we couldn't be 100% certain that our efforts would do the job required. At the time

units of .001 inches

Figure 31

Central Ray
Radius from Center of Curvature

Figure 32

of writing of this dissertation the best spectrum taken to date had a full width at half maximum (FWHM) of 85 Kev. This used a full phase space accelerator beam and no HT windings on. The detectors at the spectrometer focal plane had an inherent resolution limit of 70 Kev. We can therefore be confident that we have not yet approached the ultimate resolution of the system. Getting that ultimate resolution of 30 Kev will depend on development of focal plane detectors with spatial resolution of .25mm. A typical early HRS spectrum is shown in Figure 33. In this case protons were scattered on Bi²⁰⁹ at 800 Mev. The spectrometer sits at 25° in this run. We can clearly see the elastic peak and observed a resolution approaching that of the detectors. This data explored the entire volume (solid angle) of the spectrometer magnets and the operational volume of the beam line magnets.

The field maps and HT studies were done with a variety of devices and computer systems. In Figure 34 the computer system which acquired HT data on the large spectrometer dipoles and mapped all large HRS dipoles is depicted. This system was under shared use for optimizing four large dipole magnets over a period of two years. In Figure 35 is shown the basic system connections (a block diagram) for the mapping and HT tuning done on LCBM04 and LCBM05. All of the permanent hardware to the HRS system was routed through the Control Computer. The high level software developed for HT tuning was run on the SEL 840. The actual mapping hardware of non-permanent nature was interfaced to the PDP-9 system.

Figure 33

Figure 34

Data Acquisition and Control System

Figure 35

PART 3

EXPERIMENTAL DESIGN AND RESULTS

Chapter 9

Proton-Helium Scattering Design Consideration

The detailed design of the proton-helium scattering experiment is well documented in Appendix G* entitled LAMPF Research Proposals. The first proposal #4 "Large Angle Elastic Scattering from Helium and the Quasi-Elastic Knockout of Alpha Particles by 800 Mev Protons" contains detailed information on the design of the elastic scattering experiment. The LAMPF Program Advisory Committee recommended that the second half of the proposal be resubmitted as a different experiment. This was done and the proposal was entitled "Quasi-Elastic Knockout of Alpha Particles by Medium Energy Protons". This proposal is numbered #177. Proposal #4 did not discuss the experimental technique for the quasi-elastic experiment. Much of the detail discussed in Proposal #177 (which discusses only quasi-elastic scattering) is nevertheless relevant to use of HRS for elastic scattering and hence this proposal is also included in that appendix.

The helium target first proposed for the elastic scattering experiment would have presented difficult problems in normalizing the data. The effective target thickness would have been complicated by not knowing the gas temperature in the ballasted target cell. The best way to get around this problem would have been to build an additional target of Liquid Nitrogen cooled high pressure helium gas. This target could have been used at forward angles to determine the absolute cross section. The relative cross section would have been monitored with scintillator telescopes looking directly at beam target interactions. At these energies (800 Mev protons) it would be

*Los Alamos Scientific Laboratory LAMPF Research Proposals 4 and 177 were included in the original thesis, but are not included in this publication.

difficult to get relative cross sections to better than 5% with the scintillator telescope. This is due to the strong angular dependence of particle production at high energies.

The design of a cylindrical target cell without gas ballast allowed us to avoid the problems of unknown target geometry. However it provided the additional burden of having to know the beam profile. This is because the effective target thickness of a cylinder is a function of displacement from the symmetry axis. In the next chapter we discuss the design of the target and in the subsequent chapter we briefly discuss the beam profile monitor.

Having a known target cell geometry does not solve the entire normalization problem for a liquid helium target. The additional problem is to understand target boiling and how it affects target average density. This problem is eliminated by having a capability of running the helium target as a superfluid. In the superfluid state the liquid would not boil for all reasonable proton current densities on target. This is due to the fact that Helium II has a huge heat conductivity. The second advantage of the superfluid is that the density can be measured to 0.1% by measuring the saturated vapor pressure to 5% in the region of 20mm vapor pressure.

In Figure 36 the kinematic derivative $\partial m / \partial \theta$ for ${}^4\text{He}(p,p){}^4\text{He}$ is shown. In this case the proton is detected in the spectrometer. The effect of the kinematic derivative is to shift the data in energy-loss on the focal plane as a function of scattering angle. In Figure 37 the same curve is shown for the case when the recoiling alpha particle is detected. For the case of the detected alpha

Figure 36

${}^4\text{He}(\text{P,P}){}^4\text{He}$ $T=800$ MEV

θ_{cm} (proton)

Figure 37

particle the kinematic shift can be so severe as to exceed the momentum acceptance of the spectrometer for data still in the solid angle of the device. As a brief application of some of the results in chapter 6, we will present results of a calculation of the expected first order data plot on the focal plane as a function of scattering angle.

Figure 38 shows the HRS focal plane and coordinate system. We know from chapter 6 that we can write:

$$\text{eq. 126} \quad \delta_{\ell} = -\frac{B_{11}}{B_{16}} X_{out}^S + \frac{B_{12}}{B_{16}} \theta_{out}^S,$$

and beyond 10° in the laboratory system we can write:

$$\text{eq. 127} \quad (\Theta - \theta_0) \equiv \Delta\theta = -B_{43} Y_{out}^S + B_{44} \phi_{out}^S.$$

The first order expression for the missing mass is:

$$\text{eq. 128} \quad m - m_0 = P_{c0} \frac{\partial m}{\partial P_c} \delta_{\ell} + \frac{\partial m}{\partial \theta} (\Delta\theta)$$

The coefficients are: $B_{11} = -1.24$, $B_{16} = 22.506$, $B_{12} = -.00548$, $B_{43} = 5.16$, and $B_{44} = -.0328$. Putting these constants in the expressions above yields:

$$\text{eq. 130} \quad \delta_{\ell} \simeq .055 X_{out}^S \quad (\%)$$

and

Figure 38

$$\text{eq. 131} \quad \Delta\theta \approx -5.2 Y_{out}^S \quad (\text{mrad}).$$

which are approximations for δ_ℓ to about .01% and for $\Delta\theta$ to about 1.0 mrad. The units here are the standard "Transport" units with lengths in centimeters, angles in milliradians, and momenta in % deviation from the central ray. In order to put these results back into equation 128 we need units of radians and %/100. We then find that:

$$\text{eq. 132} \quad m - m_0 = p_{c0} \frac{\partial m}{\partial p_c} \left(\frac{.055}{100} X_{out}^S \right) + \frac{\partial m}{\partial \theta} \left(-\frac{5.2}{1000} Y_{out}^S \right)$$

This leads to a slope $S = X_{out}^S / Y_{out}^S$:

$$\text{eq. 133} \quad S \approx 9.4 \frac{\partial m / \partial \theta}{(p_c \partial m / \partial p_c)}$$

If we now multiply equation 133 times to width of the focal plane detectors in Y_{out}^S (assuming that the detectors are near the solid angle limit of the spectrometer) we get the height of the X_{out}^S spot on the focal plane. These results are presented in Figure 39. The helium scattering experiment will use about half of the HRS focal plane in the region of 70° lab angle. In the figure we have assumed that the detector width is 10. cm.

Figure 39

Proton Detected

θ_{lab}	P_c	$\Delta m / \Delta \theta$	$\Delta m / \Delta P_c$	$S=X/Y$	X spot for Y=10 cm.
	MeV/c				cm
10°	1453	-99	-.845	.76	7.6
20°	1423	-191	-.855	1.48	14.8
30°	1376	-270	-.871	2.12	21.2
40°	1316	-332	-.893	2.66	26.6
50°	1247	-375	-.919	3.08	30.8
60°	1175	-399	-.950	3.36	33.6
70°	1102	-406	-.982	3.53	35.3
80°	1031	-398	-1.02	3.56	35.6
90°	965	-379	-1.05	3.52	35.2
100°	906	-350	-1.09	3.33	33.3
110°	853	-314	-1.12	3.09	30.9
120°	808	-274	-1.15	2.77	27.7
130°	770	-231	-1.18	2.39	23.9
140°	739	-186	-1.21	1.96	19.6
150°	716	-140	-1.23	1.49	14.9
160°	699	-94	-1.25	1.01	10.1
170°	690	-47	-1.26	.51	5.1

Alpha Detected

5°	2140	-291	-1.34	.95	9.5
10°	2112	-572	-1.33	1.91	19.1
20°	2002	-1067	-1.29	3.88	38.8
35°	1717	-1536	-1.16	7.25	72.5
45°	1463	-1614	-1.02	10.17	101.7
55°	1172	-1497	-.853	14.1	141.
65°	854	-1207	-.642	21.	210.
75°	519	-781	-.399	35.	350.
85°	174	-270	-.135	108.	1080.

Chapter 10

Development of a Superfluid Helium Target

The virtues of a superfluid target will be demonstrated in the first part of this chapter. The design of the dewar is discussed including its instrumentation. The next most important characteristic is the design of the target flask. The chapter concludes with some operational results for the dewar constructed.

The properties of liquid helium are presented in Figures 40 to 46. The latent heat of vaporization peaks at 20 mm. Hg vapor pressure. In order to give the target its longest holding time we want to run at the peak point on the heat of vaporization curve. Figure 41 shows a property of the superfluid that requires careful construction of the dewar and target flask. The viscosity of the superfluid is very low. Vacuum leaks could be a problem in a poorly constructed system. Figure 43 shows the density of the liquid relative to STP gas density at the saturated vapor pressure. In Figure 46 we show

the important aspect of the density function versus saturated vapor pressure. From 90 mm Hg to 20 mm Hg the density varies only .1%. The main reason for choosing the superfluid in a LAMTF experiment is shown in Figure 44. The thermal conductivity of helium at 1.93°K is huge. This prevents the target from boiling. This is very important to ascertain the density throughout the experiment. The HRS beam seems to be contained in a vertical spot of approximately 2.0 cm and a horizontal spot of .4 cm. Consider a 1.0 microamp beam current on target. That would provide a target heat load of .544 watts over .8 cm^2 (power density .68 watts/ cm^2). Expressed

Figure 40

-41-

UCRL-3421

Latent Heat of Vaporization of Helium from
W. K. Keenan, Helium

Figure 41

Figure 42

Figure 43

Figure 144

Figure 45

Figure 46

in terms of helium consumption at 20 mm Hg (neglecting gas cooling) this would amount to .61 liters/hour of the liquid. If we did not have a superfluid the fluid would have to boil locally where the beam passes through the flask. In our best target run we observed a loss rate of .15 liters/hour (heat of vaporization at 20mm Hg gives .89 watts= 1.0 liters of liquid consumed) which amounts to 130 milliwatts heat leak to the sample with the beam off. The target was run with the flask nude to 300°K. In that case the heat load was equivalent to 1.94 liters/hour. Assuming the difference in rate is due to the super-insulation of the flask and addition of a 77°K shield around the flask, we find a remarkable 1.59 watts heat load from blackbody radiation. This radiation uniformly illuminated the 90 cm² surface of the flask. This amounts to .02 watts/cm². We observed small bubble formation (weak boiling) throughout the target cell. In this case the target was at 4.2°K. With the beam loading we could easily imagine a target cell with nothing but 4.2°K gas in it because of the violent boiling that would occur.

In Figure 47 the helium reservoir less the liquid nitrogen shield and vacuum jacket is shown. The various pieces were put together with pure Indium seals in V-grooves mating flat flanges. After some initial problems these seals were found to be reliable. Indium compresses very much in the V-groove. We calculated a volume change of 40% for the Indium in the seal. After much experimentation we determined that the cross sectional area of the V-groove should be 55% or less of the cross section of the Indium wire. We also found that Indium alloy (Cerroseal) was impossible to work with

Figure 47

Section View
Helium Reservoir and Flask

because it flowed so poorly. The joint would creep for days before setting up with the alloy. With pure Indium, a seal could be torqued initially for a half hour and then retorqued every hour for three hours and would then hold its torque.

The dewar had sufficient redundant instrumentation. Just above the flask were two Germanium resistance thermometers. In Figure 48 we see the calibration of one such thermometer. In Figure 49 we have a plot of this data. This aids in interpolating between calibration points. The helium level sensor was a commercial unit that used a superconducting wire. The sensor was 40 inches long and was mounted so that the top of the sensor coincided with the top of the reservoir. The sensor stuck down into the flask feed tube 16 inches. The unit readout in percent of level remaining. In order to use this information practically, we have taken into account the geometry of the dewar and in Figure 50 show a plot of Level Sensor % versus liters remaining in the target system. The heat load introduced by the Germanium thermometers was typically nanowatts.

The level sensor produced milliwatts. The manufacture recommended against running the sensor in vacuum. It appeared to work very well at 20 mm Hg pressure.

The most unique feature of this target is the target cell design and construction details. In Figure 51 is shown a plan view of the cell. The various materials the beam sees are given on the top of the figure. The beam sees 91.9% helium. The rest of the materials are radiation hard materials designed to withstand intense proton beams. The Kapton should be checked after an early beam run when the

Figure 48

Ge # 1.

[illegible]

Figure 49

Figure 50

Figure 51

<u>material</u>	<u>radius (CM)</u>	<u>thickness (mils)</u>	<u>thickness (CM)</u>
Kapton	1.03	2.0	.0051
metalized Kapton	1.04	.33	.00084
metalized Kapton	1.05	.33	.00084
Aluminum	3.75	.7	.00178

Plan View
Helium Target Cell Detail

accumulated dose is $2.5 \cdot 10^9$ rads. This corresponds to approximately 17 microamp-hours. Typically, HPS running currents will not exceed 50 nancamps in early operation. This should allow 340 beam hours at 50 nancamps. Here we are assuming the beam is spread uniformly over a square centimeter.

The target cell was made in a two step operation. The brass end caps are shown in Figure 52. The .002 inch Kapton was glued to the brass end caps and a .25 inch overlap glued simultaneously. The epoxy used was a 50/50 mixture of Epon 828 and Versamid 125. The first step took about eight hours to prepare after all the materials were together. The flask would then cure in a hollow cylindrical jig which allowed $\pm .0001$ inch clearance between brass, Kapton, and jig. The curing process lasted for 24 hours. The flask was then washed in alcohol to remove the jig assembly. In the second step .003 inch teflon tape was wrapped in a single non-overlapping layer. Both sides of the teflon tape were covered with thin layers of the epoxy mixture and placed over the Kapton which was glued to the brass end caps. Then an aluminum clamp of .8205" ID was placed over the teflon and tightened. This clamp proved necessary for the flask to survive the 60 psi pressure test required by LAMPF. Each flask was leak checked and pressure tested before use (Kapton leaks helium, but the diffusion rate is slow enough to make a leak test meaniful). The clamp was made out of aluminum so that it would tighten as the flask was cooled to cyrogenic temperatures. The flask was then screwed to the feed tube from the resevoir with brass screws with about .125" of steel washers and one lock washer.

Figure 52

This method of using brass screws with steel washers assured that the Indium seal would tighten as the flanges were cooled.

For an 800 Mev proton beam the total multiple scattering should be under 1. milliradians passing through the entire target.

The next four figures (53 through 56) show the results of the two successful helium runs made on the target. During the first run (see Figures 53 and 54) the transfer line was left in the dewar for 1.5 hours. We discovered that this was a tremendous heat leak. The loss rate was 20.8 liters/hour with the transfer line in the dewar. When the transfer line was removed the rate dropped back to 1.97 liters/hour. This rate was primarily caused by the nude target flask. This nude flask allowed the observation of helium conditions in the flask. In the second target run, which was a superfluid run, the target flask was superinsulated with two layers of Kapton superinsulation and the liquid nitrogen jacket was completed with a thin layer of aluminum foil this reduced the heat loss to .15 liters/hour. This leads us to believe that the nude flask has an emissivity of .9 .

In Figures 55 and 56 the superfluid run results are presented. A tremendous amount of helium was used to get near to the lambda point. This should be remedied by pumping at a slower rate until the dewar pressure is near 38 mm Hg . Figure 56 shows the operations as they occurred in time and the associated average loss rates.

($\rho_{\text{eff}} = \rho_0 + \frac{\alpha}{2} \rho_0^2$) となる。ここで、 ρ_0 は平均密度、 α は圧縮率である。

[illegible]

Figure 54

Figure 55

TARGET RUN OF 9-22-76 VACUUM JACKET PRESSURE 6×10^{-6} mm Hg FIRST TWO LAYERS OF SUPER INSULATION AND 77°K AL FOIL											
CLOCK TIME	DECIMAL TIME	Level %	Level in	ΔE	ΔL	Level mm	Ge MI	°K	inches wick	mm Hg	Comments
8:45P	9.75	0	0								Filling
9:52	9.87	60	5.5	.12	-5.5	-46					extract fill tube
10:15	10.15	90	36.	.38	-30.5	-80					stop pump down
10:21	10.35	89.5	36.	.10	0	0					
10:30	10.50	89	35.5	.15	.5	3.33					
10:40	10.57	89.5	35.25	.17	.25	1.47					
10:45	10.75										
10:51	10.85										
10:56	10.93	77	20.5				2200	3.0			
11:06	11.10	74.5	17.5	.17	2.5	14.71	2900	2.67	47	87	
11:12	11.20	72.0	13.5	.10	4.0	40.0	3100	2.60	36	67	
11:18	11.30	70.5	14.0	.10	1.5	15.0	3400	2.47	30	56	
11:27	11.45	68.0	8.5	.15	2.5	16.7	3500	2.40	26.5	49.1	
11:31	11.51	65.0	8.5	.07	0	0	3600	2.40	25.7	47.6	
11:32	11.54	60.0	8.5	.22	0	0	3700	2.38	23.5	43.5	
11:49	11.50	65.2	8.5	.10	0	0	3700	2.38	23.0	42.6	
11:59	11.50	66.0	7.5	.1	1.0	10	3800	2.33	22.3	41.3	
12:06	11.93	65.8	7.4	.03	.1	31.3	3800	2.33	21.4	39.6	
12:08	0.05	63.0	6.2	.12	1.2	10.0	3800	2.33	21.2	39.3	
12:09	0.15	63.0	6.2	.1	0	0	3800	2.33	20.8	38.52	
12:14	0.23	63.0	6.2	.08	0	0	3800	2.33	20.5	37.96	
12:20	0.33	63.0	6.2	.1	0	0	3800	2.33	20.5	37.96	
12:24	0.40	63.0	6.2	.13	0	0	3800	2.33	20.5	37.96	
12:31	0.52	63.0	6.2	0	0	0	3800	2.33	20.5	37.96	
12:47	0.78	63.0	6.2	.26	0	0	3800	2.33	20.5	37.96	
1:25	1.41	60.5	5.5	.64	.7	1.1	3800	2.33	20.5	37.96	
2:10	2.17	58.0	5.0	.75	.5	.67	3900	2.25	20.5	37.96	
2:40	2.67	56.0	4.5	.5	.5	1.0	3900	2.18	20.3	37.59	
2:55	2.92	54.0	4.0	.25	.5	2.0	4500	2.13	19.8	36.7	
3:10	3.17	51.5	4.0	.25	0	0	5000	2.03	15.3	25.3	
3:20	3.33	51.0	3.9	.16	.1	.63	5400	2.02	13.4	24.8	
3:25	3.41	52.5	3.7	.07	.2	2.12	5600	2.00	12.4	23.0	
3:30	3.50	52.2	3.7	.08	0	0	5700	1.95	11.6	21.5	turn off primary pump
3:35	3.58	52.0	3.6	.08	.1	1.25	5900	1.93	11.1	20.6	
3:44	3.73	52.0	3.6	.15	0	0	5900	1.93	11.0	20.4	
4:00	4.00	51.7	3.55	.27	.05	.19	5900	1.93	10.8	20.0	
4:15	4.25	51.0	3.5	.25	.05	.20	5900	1.93	11.2	20.7	
4:40	4.67	50.3	3.45	.42	.05	.12	5900	1.93	10.8	20.0	
6:26	6.43	47.5	3.10	1.76	.30	.17	5900	1.93	11.0	20.4	
8:04	8.07	45.0	2.90	1.64	.20	.16	5900	1.93	10.5	19.4	
8:11	8.18	44.0	2.80	.11	.10	.71	5900	1.93	10.5	19.4	
9:15	9.25	43.0	2.6	1.07	.20	.19	5900	1.93	10.5	19.4	
10:00	10.00	40.0	2.5	.75	.10	.13	5900	1.93	10.5	19.4	
11:00	11.00	0.0	1.8	1.0	.70	.7	6500	1.83	8.5	15.7	

$38 \text{ mm Hg} = 20.57 \text{ "H}_2\text{O} = \lambda \text{ point}$ $.54 \text{ "H}_2\text{O} = 1 \text{ mm Hg}$

Figure 55

Chapter 11

Beam Profile Monitor Design and Development

In order to use the cylindrical superfluid helium target to get absolute cross sections, a method was needed to get the integral of the beam profile over the target geometry. This is because a cylinder changes its effective thickness for a parallel beam as a function of displacement from the symmetry axis. In the scattering chamber the target cylinder sits with its symmetry axis aligned vertically. With the beam profile monitor designed, we measure the beam current in 1mm vertical strips aligned with the symmetry axis of the target. For the kind of beam profiles expected at HRS this would provide absolute cross sections better than 1 % if the per strip resolution was only 5%, as long as the total beam flux was monitored in another way.

A detector choice was made to fit these requirements. It was a multi-wire ion chamber. Each wire had its own complete integrator which could detect currents of 10^{-12} amperes. In Figure 57 is shown the geometry of the chamber relative to the target flask. This is a plan view. Such an ion chamber filled with Argon gas at 560mm pressure would have a gain of about 140 over the incoming current. By varying the absolute gas pressure and type of gas the gain should be adjustable from a maximum of 140 to a minimum of .01 (using Helium gas at 1mm pressure). Ion chambers suffer from non-linear response for large currents. This is due to recombination of the ions before they reach the electrodes. This is essentially a space charge effect. The best way to eliminate this problem is to reduce the gas pressure

Figure 57

PLAN VIEW

.0003" metalized Kapton Gas Window

.0003" metalized Kapton HV plane

Multi-wire
Ion Chamber

17 micron gold-plated tungsten wires

.....

.0003" metalized Kapton HV plane

.0003" metalized Kapton Gas Window

incident beam

so that the peak current per mm^2 is below 1 microampere for Argon gas at 560mm pressure. This is not the beam current but the current collected by the integrator on each wire. In terms of beam current this number becomes approximately 10 picoamperes per mm^2 peak current. Above this current density recombination ruins the linear response of the device.

Each integrator is multiplexed onto an analog to digital converter input line at 40 microsecond intervals. In this way a 25 mm set of wires could be read out in 1 millisecond. As each wire is digitized the data is serial transmitted to the counting house data acquisition computer. The interface was designed to look at the LAEFF beam gate and scale it for a preset number of gates, and then (on the trailing edge of the beam gate) begin a readout cycle.

The integrators were unique in that they could measure currents to a precision of 10^{-12} amperes time average after front end drift corrections were applied. This was done with a \$2.50 operational C-MOS amplifier (RCA CA3130B). The integrators were made with polystyrene low leakage capacitors matched to .1%. The integrator was reset per channel with a C-MOS Quad Bilateral Switch (RCA CD4066). These switches contributed leakage current of the order of a few picoamperes. The bilateral switches cost only \$.50 per quad unit. Each channel was buffered through a voltage follower constructed from inexpensive Raytheon quad operational amplifiers similar to type 741s. This prevented thermal changes in the CA3130s due to varying current loads when the integrator was multiplexed onto the analog to digital converter bus line. The analog to digital converter

was a hybrid Analog Devices ADC 10Z. It had a conversion time of 20 microseconds for 10 bits resolution. The rest of the system used standard TTL logic to send serial data from the data area to the counting house receiver which then transmitted its data to the computer through a CAMAC input register in the data acquisition crate.

PART 4

APPENDICES

Appendix A

Integrals for Jastrow Calculation

$$\begin{aligned}
 \text{I} \quad I_1 &= \int d\vec{r} e^{-r^2/R^2} \\
 &= \int d\Omega \, dr \, r^2 e^{-r^2/R^2} \\
 &= 4\pi R^3 \int_0^\infty dw \, w^2 e^{-w^2} \\
 &= 4\pi R^3 \sqrt{\pi}/4
 \end{aligned}$$

$$\underline{I_1 = \pi^{3/2} R^3}$$

$$\text{II} \quad I_2 = \int d\vec{r}_1 \, d\vec{r}_2 e^{-r_1^2/R^2 - r_2^2/R^2 - r_{12}^2/b^2}$$

Examine the negative of the exponent involving the integral over $d\vec{r}_2$.

$$\frac{r_2^2}{R^2} + \frac{r_{12}^2}{b^2} = \frac{r_2^2}{R^2} + \frac{r_2^2}{b^2} + \frac{r_1^2}{b^2} - 2 \frac{\vec{r}_1 \cdot \vec{r}_2}{b^2}$$

$$\text{define } \lambda \equiv \frac{1}{R^2} + \frac{1}{b^2}$$

then we have:

$$\begin{aligned}
 &= \frac{r_1^2}{b^2} + \lambda \left(r_2^2 - 2 \frac{\vec{r}_1 \cdot \vec{r}_2}{\lambda b^2} + \frac{r_1^2}{\lambda^2 b^4} - \frac{r_1^2}{\lambda^2 b^4} \right) \\
 &= r_1^2 \left(\frac{1}{b^2} - \frac{1}{\lambda b^4} \right) + \lambda (\vec{r}_2 - \vec{r}_1 / \lambda b^2)^2
 \end{aligned}$$

So we can now perform the integration over $d\vec{r}_2$:

$$I_2 = \int d\vec{r}_1 e^{-r_1^2/R^2} e^{-r_1^2(\frac{1}{b^2} - \frac{1}{\lambda b^4})} \int d\vec{r}_2 e^{-\lambda(\vec{r}_2 - \vec{r}_1/\lambda b^2)^2}$$

Well the inner integral can be transformed to $d\vec{r}_2'$, $\vec{r}_2' = \vec{r}_2 - \vec{r}/\lambda b^2$:

$$I_2 = \int d\vec{r}_1 e^{-r_1^2 \left(\frac{1}{R^2} + \frac{1}{b^2} - \frac{1}{\lambda b^2} \right)} \int d\vec{r}_2' e^{-\lambda (\vec{r}_2')^2}$$

The integral over $d\vec{r}_2'$ looks like I_1 , if $\lambda = \frac{1}{R^2}$ or

$R = \frac{1}{\sqrt{\lambda}}$ so I_2 becomes:

$$I_2 = \left(\frac{\pi}{\lambda} \right)^{3/2} \int d\vec{r}_1 e^{-\tau r_1^2}$$

where $\tau = \lambda - \frac{1}{\lambda b^4}$ thus:

$$I_2 = \left(\frac{\pi}{\lambda} \right)^{3/2} \left(\frac{\pi}{\tau} \right)^{3/2}$$

$$\begin{aligned} \text{III } I_3 &= \int d\vec{r} e^{-r^2/R^2 - w^2/2a} \\ &= R\sqrt{\pi} \int d^2s e^{-s^2/R^2 - w^2/2a} \end{aligned}$$

$$\text{NOTE: } \frac{s^2}{R^2} + \frac{w^2}{2a} = \mu s^2 + \frac{B^2}{2a} - 2 \frac{\vec{B} \cdot \vec{S}}{2a}$$

$$\text{WHERE: } \mu = \left(\frac{1}{R^2} + \frac{1}{2a} \right)$$

$$\text{SO: } \frac{s^2}{R^2} + \frac{w^2}{2a} = \frac{B^2}{2a} + \mu \left(s^2 - \frac{2 \vec{B} \cdot \vec{S}}{2\mu a} + \frac{B^2}{(2\mu a)^2} - \frac{B^2}{(2\mu a)^2} \right)$$

$$= B^2 \left(\frac{1}{2a} - \frac{1}{4\mu a^2} \right) + \mu \left(\vec{s} - \frac{\vec{B}}{2\mu a} \right)^2$$

DEFINE: $\ell \equiv \frac{1}{2a} - \frac{1}{4\mu a^2}$

$$\frac{s^2}{R^2} + \frac{w^2}{2a} = \ell B^2 + \mu (\vec{s}')^2$$

WHERE $\vec{s}' = \vec{s} - \vec{B}/2\mu a$

So our integral becomes:

$$\begin{aligned} I_3 &= R\sqrt{\pi} e^{-\ell B^2} \int d^2 s' e^{-\mu (s')^2} \\ &= 2\pi^{3/2} R e^{-\ell B^2} \int_0^\infty ds' s' e^{-\mu (s')^2} \end{aligned}$$

$$I_3 = \frac{\pi^{3/2} R}{\mu} e^{-\ell B^2}$$

IV $I_4 = \int d\vec{r}_1 d\vec{r}_2 h_{21} e^{-w_1^2/2a} e^{-\vec{r}_1^2/R^2} e^{-\vec{r}_2^2/R^2}$

Let us begin by evaluating the integral over $d\vec{r}_1$:

$$\begin{aligned} I_{r_1} &= \int d\vec{r}_1 h_{21} e^{-w_1^2/2a} e^{-\vec{r}_1^2/R^2} \\ &= \int d^2 s_1 e^{-w_1^2/2a} \int dz_1 e^{-\vec{r}_1^2/b^2 - \vec{r}_1^2/R^2} \end{aligned}$$

$$\begin{aligned} \text{examine: } \frac{r_2^2}{b^2} + \frac{r_1^2}{R^2} &= \frac{r_1^2}{b^2} + \frac{r_1^2}{R^2} + \frac{r_2^2}{b^2} - 2 \frac{\vec{r}_1 \cdot \vec{r}_2}{b^2} \\ &= r_2^2 \left(\frac{1}{b^2} - \frac{1}{\lambda b^4} \right) + \lambda (\vec{r}_1 - \vec{r}_2 / \lambda b^2)^2 \end{aligned}$$

$$\begin{aligned} \text{so: } I_{r_1} &= \int d^2 s_1 e^{-\omega_1/2a - \lambda(\vec{s}_1 - \vec{s}_2/\lambda b^2)^2} \\ &\times \int d^2 z_1 e^{-\lambda(z_1 - z_2/\lambda b^2)^2 - r_2^2 \left(\frac{1}{b^2} - \frac{1}{\lambda b^4} \right)} \end{aligned}$$

$$\begin{aligned} \text{thus: } I_{r_1} &= e^{-r_2^2 \left(\frac{1}{b^2} - \frac{1}{\lambda b^4} \right)} \int d^2 s_1 e^{-\omega_1/2a - \lambda(\vec{s}_1 - \frac{\vec{s}_2}{\lambda b^2})^2} \\ &\times \int d^2 z_1 e^{-\lambda(z_1)^2} \\ &= \sqrt{\frac{\pi}{\lambda}} e^{-r_2^2 \left(\frac{1}{b^2} - \frac{1}{\lambda b^4} \right)} \int d^2 s_1 e^{-\omega_1/2a - \lambda(\vec{s}_1 - \frac{\vec{s}_2}{\lambda b^2})^2} \end{aligned}$$

$$\text{examine: } \frac{\omega_1^2}{2a} + \lambda(\vec{s}_1 - \vec{s}_2/\lambda b^2)^2 = \frac{B^2}{2a} + \frac{s_2^2}{\lambda b^4} - \frac{\Omega^2}{\epsilon} + \epsilon(\vec{s}_1 - \frac{\vec{\Omega}}{\epsilon})^2$$

$$\text{where: } \epsilon \equiv \lambda + \frac{1}{2a} \quad \text{and: } \vec{\Omega} = \frac{\vec{B}}{2a} + \frac{\vec{s}_2}{b^2}$$

So I_{r_1} becomes:

$$\begin{aligned} I_{r_1} &= e^{-r_2^2 \left(\frac{1}{b^2} - \frac{1}{\lambda b^4} \right)} e^{-B^2/2a - s_2^2/\lambda b^4 + \frac{\Omega^2}{\epsilon}} \int d^2 s_1 e^{-\epsilon(\vec{s}_1 - \frac{\vec{\Omega}}{\epsilon})^2} \sqrt{\frac{\pi}{\lambda}} \\ &= \frac{\pi}{\epsilon} \sqrt{\frac{\pi}{\lambda}} \left(e^{-r_2^2 \left(\frac{1}{b^2} - \frac{1}{\lambda b^4} \right) - B^2/2a - s_2^2/\lambda b^4 + \Omega^2/\epsilon} \right) \end{aligned}$$

Now compute the final integral:

$$I_4 = \int d\vec{r}_2 \left[e^{-\Gamma_2^2 \left(\frac{1}{R^2} + \frac{1}{b^2} - \frac{1}{\lambda b^4} \right) - B^2/2a - S_2^2/\lambda b^4 + \Omega^2/\epsilon} \right] \frac{\pi}{\epsilon} \sqrt{\frac{\pi}{\lambda}}$$

Recall: $\tau \equiv \lambda - \frac{1}{\lambda b^4}$

$$I_4 = \frac{\pi}{\epsilon} \sqrt{\frac{\pi}{\lambda}} e^{-B^2/2a} \int d\vec{r}_2 e^{-\Gamma_2^2 \tau - S_2^2/\lambda b^4 + \Omega^2/\epsilon}$$

DEFINE: $\chi = \lambda - \frac{1}{\epsilon b^4}$

DEFINE: $\Theta = \left(\frac{1}{2a} - \frac{1}{(2a)^2 \epsilon} - \frac{1}{(2a)^2 \epsilon^2 b^4 \chi} \right)$

AND THE RESULT BECOMES:

$$I_4 = \frac{\pi^3}{\epsilon \chi \sqrt{\lambda \tau}} e^{-\Theta B^2}$$

V $I_5 = \int d\vec{r}_1 d\vec{r}_2 h_{21} e^{-\omega_1^2/2a - \omega_2^2/2a - \Gamma_1^2/R^2 - \Gamma_2^2/R^2}$

DEFINE: $K = \left(\lambda + \frac{1}{2a} - \frac{1}{\epsilon b^4} \right)$

$$P = \left(\frac{1}{2a} - \frac{1}{(2a)^2 \epsilon} \right)$$

$$J^{-1} = \left(\frac{1}{2a} + \frac{1}{2a \epsilon b^2} \right)$$

$$\Sigma = \frac{1}{2a} + P - \frac{1}{K J^2}$$

Then

$$I_5 = \frac{\pi^3}{\epsilon \kappa \sqrt{2\lambda}} e^{-\Sigma B^2}$$

$$\text{VI} \quad I_6 = \int d^2 B e^{-\vec{\Delta} \cdot \vec{B} - x B^2}$$

$$\begin{aligned} i \quad \vec{\Delta} \cdot \vec{B} - x B^2 &= -x \left(B^2 - 2i \frac{\vec{\Delta} \cdot \vec{B}}{2x} \right) \\ &= -\frac{\Delta^2}{4x} - x \left(\vec{B} - \frac{i \vec{\Delta}}{2x} \right)^2 \end{aligned}$$

$$\begin{aligned} \text{so: } I_6 &= e^{-\Delta^2/4x} \int d^2 B' e^{-x(B')^2} \\ &= e^{-\Delta^2/4x} \frac{2\pi}{2x} \end{aligned}$$

hence:

$$I_6 = \frac{\pi}{x} e^{-\Delta^2/4x}$$

Appendix B

Definition of Constants for Jastrow Calculation

$\bar{R} = 1.16 \text{ fm}$ Radius used in Jastrow fit to form factor

$b = .734 \text{ fm}$ trial value for Jastrow Correlation Parameter

Δ = momentum transfer in fm^{-1}

k = proton momentum in fm^{-1}

$$a = 5 \text{ GeV}^{-2} = 5 \cdot (.19732)^2 \text{ fm}^2$$

$\alpha = -.33$ ratio of real to imaginary part
of $N-N$ amplitude

$$\sigma_T = 43.77 \cdot 10^{-3} \text{ barns} = 4.377 \text{ fm}^2$$

total p-p cross section averaged
with total p-n cross section

$$C = \frac{(1 - i\alpha) \sigma_T}{4\pi a}$$

$$\lambda = \frac{1}{R^2} + \frac{1}{b^2}$$

$$\tau = \lambda - \frac{1}{\lambda b^4}$$

$$\mu = \frac{1}{R^2} + \frac{1}{2a}$$

$$\ell = \frac{1}{2a} - \frac{1}{4\mu a^2}$$

$$\zeta = \lambda + \frac{1}{2a}$$

$$\chi = \lambda - \frac{1}{\epsilon b^4}$$

$$P = \frac{1}{2a} - \frac{1}{(2a)^2 \epsilon}$$

$$G = \frac{-1}{(2a)^2 \epsilon^2 b^4 \chi} + P$$

$$\kappa = \epsilon - \frac{1}{\epsilon b^4}$$

$$J = \frac{2a}{1 + \frac{1}{\epsilon b^2}}$$

$$\Sigma = \frac{1}{2a} + P - \frac{1}{\kappa J^2}$$

$$E_1 = 0 \quad E_2 = 0 \quad E_3 = \mathcal{L} \quad E_4 = \Theta \quad E_5 = \Sigma$$

$$C_1 = \pi^{3/2} R^3$$

$$C_2 = \left(\frac{\pi}{\lambda} \frac{\pi}{\tau} \right)^{3/2}$$

$$C_3 = \frac{\pi^{3/2} R}{\mu}$$

$$C_4 = \pi^3 / \epsilon \chi \sqrt{\lambda \tau}$$

$$C_5 = \pi^3 / \epsilon \kappa \sqrt{\lambda \tau}$$

if using correlated terms f_{i1} then:

$$N^2 = \frac{1}{(C_1)^4 - 6 C_2 (C_1)^2}$$

if using only uncorrelated terms

$$N^2 = \frac{1}{(C_1)^4}$$

$$\overline{F}(\vec{\Delta}) = \sum_{i=1}^4 \sum_{j=0}^1 f_{ij}$$

$$D = \frac{K N^2}{2\pi i} e^{R^2 \Delta^2 / 16}$$

$$f_{i0} = \frac{D\pi}{E_3} \left[\frac{(-1)^i}{i!} \binom{4}{i} (C_3)^i (C_1)^{4-i} e^{-\Delta^2/4 E_3 i} \right]$$

$$\overline{X} = J_1 E_1 + J_2 E_2 + J_3 E_3 + J_4 E_4 + J_5 E_5$$

$$R(J_1, J_2, J_3, J_4, J_5) = \pi \left[\prod_{L=1}^5 (C_L)^{J_L} \right] e^{\frac{-\Delta^2/4 \overline{X}}{\overline{X}}}$$

$$f_{11} = 6DC [2R(2,0,0,1,0) + 2R(0,1,2,0,0)]$$

$$f_{21} = -6DC^2 [R(2,0,0,0,1) + 4R(1,0,1,1,0) + R(0,1,2,0,0)]$$

$$f_{31} = 6DC^3 [2R(1,0,1,0,1) + 2R(0,0,2,1,0)]$$

$$f_{41} = -6DC^4 [R(0,0,2,0,1)]$$

Appendix C

Determination of Helium Charge Form Factor and Single Particle Density from Jastrow Wave Function

$$F(\vec{q}) = \int d^3r_1 e^{-i\vec{q} \cdot \vec{r}_1} \rho(\vec{r}_1)$$

$$\rho(\vec{r}_1) = \int d^3r_2 d^3r_3 d^3r_4 N^2 \left(\prod_{i=1}^4 e^{-r_i^2/R^2} \right) \prod_{j>k} (1 - h_{jk})$$

$$\text{Approximate } \prod_{j>k} (1 - h_{jk}) \simeq 1 - \sum_{j>k} h_{jk}$$

then:

$$\begin{aligned} \rho(\vec{r}_1) = & N^2 e^{-r_1^2/R^2} (I_1)^3 - 3N^2 (I_1)^2 e^{-r_1^2/R^2} \int d^3r_4 h_{41} e^{-r_4^2/R^2} \\ & - 3N^2 e^{-r_1^2/R^2} I_1 I_2 \end{aligned}$$

so we must evaluate I_7 :

$$I_7 \equiv \int d^3r_4 e^{-r_4^2/R^2 - r_4^2/B^2}$$

perform as in Appendix A:

$$I_7 = e^{-r_1^2 \left(\frac{1}{B^2} + \frac{1}{\lambda B^4} \right)} \left(\frac{\pi}{\lambda} \right)^{3/2}$$

so $\rho(\vec{r}_1)$ becomes

$$\rho(\vec{r}_1) = N^2 (I_1^3 - 3I_1 I_2) e^{-r_1^2/R^2} - 3N^2 I_1^2 \left(\frac{\pi}{\lambda} \right)^{3/2} e^{-r_1^2/R^2}$$

Recall I_1, I_2 are constants, hence:

$$g(\vec{r}_1) = N^2 \left[(C_1^3 - 3C_1 C_2) e^{-r_1^2/R^2} - 3\left(\frac{\pi}{\lambda}\right)^{3/2} C_1^2 e^{-\tau r_1^2} \right]$$

In order to get $F(q)$ we need to perform I_g :

$$I_g \equiv \int d^3 r_1 e^{-i\vec{q} \cdot \vec{r}} e^{-\chi r_1^2} \quad \chi = \text{const} > 0$$

by techniques in Appendix A

$$I_g = \left(\frac{\pi}{\chi}\right)^{3/2} e^{-q^2/4\chi}$$

thus $F(q)$ becomes

$$F(q) = N^2 C_1^2 \left[[C_1^2 - 3C_2] e^{-q^2 R^2/4} - 3C_2 e^{-q^2/4\tau} \right]$$

Appendix D

Listing of Program Code for Jastrow Calculation

```

PROGRAM JASPRO(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE3)
000003 COMMON/DATP1/P1
000003 COMMON/CONST1/E(5),C(5)
000003 COMMON/COM/DELSQ
000003 COMMON/DATA/XCOR(300),YCOR(300)
000003 COMMON/JPAR/R,B,KLAB,A,ALPHA,SIGMAT
000003 COMPLEX EYE,D,F(4,2),FT0,FT1,Z
000003 REAL LAMDA,MU,L,J,N20,N21,KAP,KLAB,K,KCM
000003 DIMENSION BNQM(4)
000003 EYE=(0.,1.,1.)
000003 P1=3.141592653589
000003 DM=.93037,19732
000003 BNQM(1)=4,
000012 BNQM(2)=6,
000014 BNQM(3)=4,
000015 BNQM(4)=1,
000016 CALL PLOTS(0.,0.,5)
000021 R=1.332
000023 DO 300 JCON=1,5
000024 B=.35
000026 R=R+.01
000036 DO 300 XCON=1,5
000031 B=B+.05
000033 WRITE(2,400) R,B
400 000043 FORMAT(1H1,*,R=*,E20.10,*, B=*,F20.10)
000043 KLAB=1.77,19732
000045 A=5,*(1.9732**2)
000047 ALPHA=.,30
000050 SIGMAT=4.377
000052 Z=(1.-EYE*ALPHA)*SIGMAT/(4.*P1*A)
000070 LAMDA=1./R**2+1./A**2
000073 TAU=LAMDA-1./LAMDA**4
000077 MU=1./R**2+1./L2.A)
000103 L=1./L2.A)-1./L4.A**2)
000107 EP1=LAMDA-1./L2.A)
000112 CH1=LAMDA-1./EP1**4)
000116 P=1./L2.A)-1./L4.A**2)
000124 THETA=P-1./L4.A**2)EP1**2)CH1)
000132 KAP=EP1-1./EP1**4)
000136 J=(2.A)/(1.+1./EP1**2)
000143 SIGCAP=P-1./L2.A)-1./KAP**2)
000152 E(1)=0,
000153 E(2)=0,
000154 E(3)=L
000155 E(4)=THETA
000157 E(5)=SIGCAP
000160 C(1)=P1**1.5*R**3
000165 C(2)=(P1**2/(LAMDA*TAU))**1.5
000173 C(3)=P1**1.5*R/MU
000201 C(4)=P1**3/(EP1**4*(SQRT(LAMDA*TAU)))
000210 C(5)=P1**3/(EP1**4*KAP*(SQRT(LAMDA*TAU)))
000220 N20=1./C(1)**4
000223 N21=1./C(1)**4-6.*C(2)*C(1)**2)
000230 ELAB=SQRT(KLAB**2*N20**2)
000235 BETA=KLAB/ELAB**4*DM)
000241 GAMMA=1./SQRT(1.-BETA**2)
000246 KCM=GAMMA*(KLAB*BETA*ELAB)

```

```

000252      K=KCM
000253      WRITE(2,200) LAMUA,TAU,MU,L,EPI,CHI
000272      WRITE(2,200) P,THETA,KAP,J,SICAP
000310      WRITE(2,200) E
000316      WRITE(2,200) C
000324      WRITE(2      1 N20,N21,KLAB,K
000340      200  FORMAT      ,6(E20.13,1X))
000340      TGEV2=0.
000341      DO 100 ICON=1,300
000343      DELSO=TGEV2/(.19732**2)
000346      FT0=(0.,0.)
000350      FT1=(0.,0.)
000353      D=-K*N21+EYE*EXP(1N**2*DELSO/16.)/(2.*PI)
000373      DO 101 I1=1,4
000375      101  F(I1,1)=-D*PI*(-.1)**I1*BNOM(I1)*(2*C(3))**I1*C(1)**(4-I1)-
      1EXP(-DELSO/(4.*E(3)*I1))/(I1*E(3))
000446      F(1,2)=6.*D*Z*(2.*RX(2,0,0,1,0)*2.*RX(0,1,2,0,0))
000472      F(2,2)=-6.*D*Z**2*(RX(2,0,0,0,1)*4.*RX(1,0,1,1,0)*RX(0,1,2,C,0))
000527      F(3,2)=6.*D*Z**3*(2.*RX(1,0,1,0,1)*2.*RX(0,0,2,1,0))
000557      F(4,2)=-6.*D*Z**4*(RX(0,0,2,0,1))
000600      DO 102 I1=1,4
000601      102  FT0=N20*F(I1,1)/N21*FT0
000617      DSDWG=REAL(CONJG(FT0)*FT0)/100,
000630      DSDDG=DSDWG*PI/((K*.19732)**2)
000633      DO 103 I1=1,4
000635      DO 103 I2=1,2
000636      103  FT1=F(I1,I2)*FT1
000653      DSDWJ=REAL(CONJG(FT1)*FT1)/100,
000664      DSDDJ=DSDWJ*PI/((K*.19732)**2)
000667      WRITE(2,104)TGEV2,DELSO,DSDWG,DSDDG,DSWJ,DSDDJ
000707      104  FORMAT(      ,6(E20.13,1X))
000707      XCOR(ICON)=TGEV2
000711      YCOR(ICON)=DSWJ
000713      TGEV2=TGEV2+.01
000714      100  CONTINUE
000716      CALL DISPLAY
000717      300  CONTINUE
000723      CALL FIN
000724      STOP
000726      END

```

```

000010      FUNCTION RX(J1,J2,J3,J4,J5)
000010      COMMON/COMMON1/E(1),C(5)
000010      COMMON/COMMON2/DELSU
000010      COMMON/COMMON3/P1
000010      DIMENSION J(5)
000010      J(1)=J1
000010      J(2)=J2
000010      J(3)=J3
000010      J(4)=J4
000010      J(5)=J5
000010      CAPX=0.
000010      DO 10 I1=1,5
000010      CAPX=J(I1)*E(I1)+CAPX
000010      S=1.
000010      DO 11 I1=1,5
000010      S=S*C(I1)+J(I1)
000010      RX=P1*S*EXP(-DELSU/(4.*CAPX))/C1PX
000010      RETURN
000010      END

```

```

SUBROUTINE DISPLAY
COMMON/ DATA / XCOR(300), YCOR(300)
COMMON/ JP44 / R, R, KLAB, A, ALPHA, SIGMAT
DIMENSION XARRAY(302), YARRAY(302)
REAL KLAB, KTES?
BCD0=10M PLATE
BCD1=10M JASTROW
BCD2=10M JPM2METEND
BCD3=10M (F20M)51
BCD4=10M NS
BCD5=10M NS
BCD6=10M KLAUS
BCD7=10M A
BCD8=10M ALPHA
BCD9=10M SIGMAT
BCD10=10M YARN/STEN
BCD11=10M (GEV/C)**2
DO 10 I=1,300
XARRAY(I)=XCOR(I)
10 YARRAY(I)=4.06101YCOR(I)
XMIN=0.
DX=.25
YMIN=-9.
DY=1.
XARRAY(301)=XMIN
XARRAY(302)=DX
YARRAY(301)=YMIN
YARRAY(302)=DY
CALL LINE(XARRAY,YARRAY,300,1,0,4)
CALL SYMBOL(4.,9.,.3,BCD0,0.,10)
CALL SYMBOL(7.,9.,.25,BCD1,0.,10)
CALL SYMBOL(7.,9.,.25,BCD2,0.,10)
CALL SYMBOL(7.,9.,.25,BCD3,0.,10)
CALL SYMBOL(7.,9.,.25,BCD4,0.,10)
CALL SYMBOL(7.,9.,.25,BCD5,0.,10)
CALL SYMBOL(7.,9.,.25,BCD6,0.,10)
CALL SYMBOL(7.,9.,.25,BCD7,0.,10)
CALL SYMBOL(7.,9.,.25,BCD8,0.,10)
CALL SYMBOL(7.,9.,.25,BCD9,0.,10)
CALL SYMBOL(7.,9.,.25,BCD10,0.,10)
CALL SYMBOL(7.,9.,.25,BCD11,0.,10)
CALL NUMBER(9.5,7.5,.25,R,0.,5)
CALL NUMBER(9.5,7.4,.25,B,0.,5)
CALL NUMBER(9.5,7.,.25,KLAB,0.,5)
CALL NUMBER(9.5,6.6,.25,A,0.,5)
CALL NUMBER(9.5,6.2,.25,ALPHA,0.,5)
CALL NUMBER(9.5,5.8,.25,SIGMAT,0.,5)
CALL AXIS(0.,0.,BCD10,10,10.,90.,YMIN,DY)
CALL AXIS(0.,0.,BCD11,10,12.,XMIN,DX)
KTEST=1.77.19732
IF(KLAB,EO,KTEST) CALL DATPON
CALL PLOT(22.,0.,-3)
RETURN
END

```

```

SUBROUTINE DATPOV
000002      DIMENSION PALEV(40,3)
000002      DIMENSION XARRAY(5),YARRAY(5)
000002      DATA SW /-1, /
000002      XMIN=0.
000003      DX=.25
000005      YMIN=-9.
000006      DY=1.
000010      IF (SW.NE.-1.) GO TO 10
000012      DO 11 I=1,46
000013      HEAD(1,12)(PALEV(I,J),J=1,3)
000026      12  FORMAT(3F20,5)
000026      WRITE(2,14)I,(PALEV(I,J),J=1,3)
000044      14  FORMAT(1H ,15,2X,3(E20,10,5X))
000044      11  CONTINUE
000046      SW=0.
000047      10  XARRAY(4)=XMIN
000051      XARRAY(5)=DX
000052      YARRAY(4)=YMIN
000054      YARRAY(5)=DY
000055      DO 15 I=1,46
000057      XARRAY(1)=PALEV(I,1)
000061      XARRAY(2)=PALEV(I,2)
000063      XARRAY(3)=PALEV(I,3)
000065      YARRAY(1)=ALOG10(PALEV(I,2)+PALEV(I,3))
000072      YARRAY(2)=ALOG10(PALEV(I,2))
000075      YARRAY(3)=ALOG10(PALEV(I,2)+PALEV(I,3))
000102      CALL LINE(XARRAY,YARRAY,3,1,0,4)
000106      15  CONTINUE
000110      RETURN
000111      END

```

```

000003      PROGRAM FORM(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE3)
000003      COMMON/CALC/LAMDA,TAL,N21
000003      COMMON/DATEI/PI
000003      COMMON/CONST1/E(5),C(5)
000003      COMMON/FCM/ELSC
000003      COMMON/LPAR/R,B,KLAB,A,ALPHA,SIGMAT
000003      COMPLEX EYE,D,F(4,2),FT0,FT1,Z
000003      REAL LAMDA,MU,L,N20,N21,KAP,KLAB,K,KCM
000003      DIMENSION ENCM(4)
000003      EYE=(0.,1.)
000006      PI=3.141592653589
000007      DN=.9383/.19732
000011      ENCM(1)=4.
000012      ENCM(2)=6.
000014      ENCM(3)=4.
000015      ENCM(4)=1.
000016      CALL PLCTS(0.,0.,3)
000021      R=1.312
000023      DO 300 LCON=1,5
000024      B=.4
000026      R=H*.01
000030      DO 300 KCON=1,7
000031      B=B+.05
000033      WRITE(2,400) R,B
000043      400      FORMAT(1H1,*,F=*,E23.10,*,B=*,E20.10)
000043      KLAB=1.7/.19732
000045      A=5.*(1.19732**2)
000047      ALPHA=-.30
000050      SIGMAT=4.377
000052      Z=(1.-EYE*ALPHA)*SIGMAT/(4.*PI*A)
000070      LAMTA=1./R**2-1./R**2
000073      TAL=LAMTA-1./((LAMDA*B**4)
000077      MU=1./H**2-1./((2.*1)
000103      L=1./((2.*A)-1./((4.*"L*A**2)
000107      EPI=LAMDA*1./((2.*A)
000112      CHI=LAMTA-1./((EPI*B**4)
000116      P=1./((2.*A)-1./((4.*A**2*EF))
000124      THETA=P-1./((4.*(A*EPI*B**2)**2*CHI)
000132      KAP=EPI-1./((EPI*B**4)
000136      J=(2.*A)/(1.+1./((EPI*B**2))
000143      SIGCAP=P+1./((2.*A)-1./((KAP*J**2)
000152      E(1)=0.
000153      E(2)=0.
000154      E(3)=L
000155      E(4)=THETA
000157      E(5)=SIGCAP
000160      C(1)=PI**1.5*R**3
000165      C(2)=(PI**2/(LAMDA*TAU))**1.5
000173      C(3)=PI**1.5*R/MU
000201      C(4)=PI**3/(EPI*CHI*(SQRT(LAMDA*TAU)))
000210      C(5)=PI**3/(EPI*KAP*(SQRT(LAMDA*TAU)))
000220      N20=1./L(1)**4
000223      N21=1./((C(1)**4-6.*C(2)*C(1)**2)
000230      ELAB=SQRT(KLAB**2+DN**2)
000235      BETA=KLAB/(ELAB*4.*DN)
000241      GAMMA=1./((SQRT(1.-BETA**2))
000246      KCM=GAMMA*(KLAB-BETA*ELAB)

```

```

000252      K=KCM
000253      WRITE(2,200) LAMDA,TAU,MU,L,EPI,CHI
000272      WRITE(2,200) P,THETA,KAP,L,SIGCAP
000310      WRITE(2,200) E
000316      WRITE(2,200) C
000324      WRITE(2,200) R21,N21,KL45,K
000340      200  FORMAT(* J,6(20,13,1X))
000340      CALL PERGITY
000341      CALL FACTOR
000342      300  CONTINUE
000346      CALL FIN
000347      STOP
000351      END

```



```

000002      SUBROUTINE DENSITY
000002      COMMON/CALC/LAMDA,TAL,N21
000002      COMMON/CATF1/F1
000002      COMMON/CCPST1/E(5),C(5)
000002      COMMON/PPAR/R,B,KL19,A,ALPHA,SIGMAT
000002      REAL LAMDA,PLAT,N21
000002      DIMENSION XARRAY(402),YARRAY(402)
000002      ECD0=10+ IENSITY
000003      ECL1=10+ JASTRA
000005      ECD2=10+ PARAPETERS3
000006      ECD3=10+ (FERMIS)
000010      ECD4=10+ R=
000011      ECD5=10+ E=
000013      ECD6=10+ RHC(R)
000014      ECD7=10+ R FM
000016      RAC=0.
000017      DO 10 I=1,400
000020      PART0=(C(1)+3+3.*C(1)*C(2))*EXP(-RAD+.2/R+.2)
000031      PART1=-3.*(PI/LAMDA)+1.5*C(1)+2*EXP(-TAU+RAD+.2)
000045      RHC=N21*(PART0+PART1)
000050      XARRAY(I)=RAC
000053      YARRAY(I)=RHC
000055      RAC=RAC+.01
000057 10 CONTINUE
000060      DO 11 I=1,402
000062      WRITE(2,12)I,XARRAY(I),YARRAY(I)
000075 12 FORMAT(1,15,2(E20.10,5X))
000075 11 CONTINUE
000077      XMIN=0.
000100      EX=1./3.
000101      YMIN=0.
000102      EY=C1
000104      XARRAY(401)=XMIN
000105      XARRAY(402)=EX
000107      YARRAY(401)=YMIN
000110      YARRAY(402)=EY
000112      CALL LINE(XARRAY,YARRAY,4(0,1,0,4)
000116      CALL SYMBOL(4,,9.5,,3,HCE,0,,10)
000122      CALL SYMBOL(7,,9,,25,HCL1,0,,10)
000126      CALL SYMBOL(7,,9.6,,25,HCE2,0,,10)
000132      CALL SYMBOL(7,,9.2,,25,HCE3,0,,10)
000136      CALL SYMBOL(7,,7.9,,25,HCE4,0,,10)
000142      CALL SYMBOL(7,,7.4,,25,HCE5,0,,10)
000146      CALL NUMBER(9.5,7.8,,25,R,0,,5)
000152      CALL NUMBER(9.5,7.4,,25,B,0,,5)
000156      CALL AXIS(0,,0,,ECD6,10,10,,90,,YMIN,DY)
000166      CALL AXIS(0,,0,,ECD7,-10,12,,9,,XMIN,DX)
000176      CALL PLOT(22,,0,,3)
000201      RETURN
000202      END

```

```

000002      SUBROUTINE FACTOR
000002      COMMON/PATH1/F
000002      COMMON/CC/ST1/E(5),C(5)
000002      COMMON/PAF/R,B,KLAW,A,ALPHA,SIGMAT
000002      COMMON/CALC/LAMBDA,TAL,A21
000002      REAL LAMBDA,KLAW,A21
000002      DIMENSION XARRAY(202),YARRAY(202)
000002      ECD0=10+FF+FACTOR
000003      ECD1=10+JASTERA
000005      ECD2=10+PARAMETERS
000006      ECD3=10+(FEENIS)
000010      ECD4=10+      R=
000011      ECD5=10+      E=
000013      ECD6=10+LOG10(F)
000014      ECD7=10+T*F**2
000016      T=C.
000017      DO 10 I=1,210
000020      PART0=(C(1)+.2+.1.*C(2))*EXP(-T*R+.2/4.)
000032      PART1=-3.*C(2)*EXP(-T/(4.*TAU))
000041      FQ=A21*C(1)+.2*(PART0+PART1)
000045      XARRAY(I)=T
000050      YARRAY(I)=ALOG10(ABS(FQ))
000057      T=T+.1
000061 10      CONTINUE
000063      DO 11 I=1,202
000064      WRITE(2,12)I,XARRAY(I),YARRAY(I)
000077 12      FORMAT(1X,FAC.,15,2(E20,10,5X))
000077 11      CONTINUE
000101      XMIA=0.
000102      EX=2.
000103      YMIA=-5.
000105      EY=5.
000106      XARRAY(201)=XMIA
000110      XARRAY(202)=EX
000111      YARRAY(201)=YMIA
000113      YARRAY(202)=EY
000115      CALL LINE(XARRAY,YARRAY,200,1,0,4)
000121      CALL SYMBOL(4.,9.5,,3,ECD0,0,,10)
000125      CALL SYMBOL(7.,9.,,25,ECD1,0,,10)
000131      CALL SYMBOL(7.,8.5,,25,ECD2,0,,10)
000135      CALL SYMBOL(7.,8.2,,25,ECD3,0,,10)
000141      CALL SYMBOL(7.,7.5,,25,ECD4,0,,10)
000145      CALL SYMBOL(7.,7.4,,25,ECD5,0,,10)
000151      CALL NUMBER(9.5,7.2,,25,R,0,,5)
000155      CALL NUMBER(9.5,7.4,,25,E,0,,5)
000161      CALL AXIS(0.,0.,ECD6,10,10,,90,,YM(N,DY))
000171      CALL AXIS(0.,0.,ECD7,-10,12,,0,,XM(N,DX))
000201      CALL DATPCA
000202      CALL PLCT(22.,0.,-3)
000205      RETURN
000206      END

```

```

SUBROUTINE DATPCA
  DIMENSION PALEV(23,3)
  DIMENSION XARRAY(5),YARRAY(5)
  DATA SH /-1./
  XMIN=0.
  CX=2.
  YMIN=-5.
  CY=5.
  IF (SH.EQ.-1.) GO TO 10
  DO 11 I=1,23
  READ(1,12)(PALEV(I,J),J=1,3)
  12 FORMAT(7F20,5)
  WRITE(2,14)I,(PALEV(I,J),J=1,3)
  14 FORMAT(1H,15,2X,3(F20.10,5X))
  11 CONTINUE
  SH=0.
  10 XARRAY(4)=XMIN
  XARRAY(5)=CY
  YARRAY(4)=YMIN
  YARRAY(5)=CY
  DO 15 I=1,23
  XARRAY(1)=PALEV(I,1)
  XARRAY(2)=PALEV(I,1)
  XARRAY(3)=PALEV(I,1)
  YARRAY(1)=ALCG10(PALEV(I,2)-PALEV(I,3))
  YARRAY(2)=ALCG10(PALEV(I,2))
  YARRAY(3)=ALCG10(PALEV(I,2))
  YARRAY(3)=ALCG10(PALEV(I,2)+PALEV(I,3))
  IF(I.EQ.15) GO TO 15
  IF(I.EQ.16) GO TO 17
  15 CALL LINE(XARRAY,YARRAY,3,1,0,4)
  CONTINUE
  RETRN
  16 YARRAY(1)=ALCG10(PALEV(I,2)-.0019)
  GO TO 15
  17 YARRAY(1)=-5.
  GO TO 15
  END

```

Appendix E

Listing of Elastic Monte Carlo Code

```

          BLANK SUPPRESSION
$CREATE (FS=RMRMC,TYPE=SD,REL=NEVER)
$CREATE (FS=MCBIN,TYPE=SD,REL=NEVER)
$UPDATE (N=RMRMC)
$RUN(I=COMPILE,B=MCBIN,C=BYE)
$FM.
*DECK RMRMC
PROGRAM RMRMC(INP,OUT,FSET1=INP,FSET2=OUT)
DIMENSION HEAD(32)
DIMENSION TITC(8),AC(6,6),BC(6,6,6),CC(50)
DIMENSION TITF(8),AF(6,6),BF(6,6,6),CF(50)
DIMENSION TITB(8),AB(6,6),BB(6,6,6),CB(50)
DIMENSION XFOC(4)
DIMENSION HISTA(212,30),SC(30),OR(30),VAL(30)
COMMON/ALL/TAB(2,40)
COMMON/DATP1/P1
COMMON/VECS/X1(6),X2(6),X3(6),X4(6),X5(6),X6(6)
NT1=1
NT2=2
NB=101
SC(1)=.01
SC(2)=.01
SC(3)=.01
SC(4)=.01
SC(5)=.01
SC(6)=.01
SC(7)=.02
SC(8)=.04
SC(9)=.1
SC(10)=1.
SC(11)=.5
SC(12)=.01
SC(13)=.1
SC(14)=.5
SC(15)=.02
SC(16)=.5
SC(17)=.5
SC(18)=.01
SC(19)=.1
SC(20)=1.
SC(21)=.1
SC(22)=.1
SC(23)=.5
SC(24)=.01
SC(25)=.0001
SC(26)=.001
SC(27)=.0001
SC(28)=.01
SC(29)=.005
SC(30)=1.
DO 50 I=1,30
50 OR(I)=-SC(I)*NB*.5
DO 51 I=1,212
DO 51 J=1,30
51 HISTA(I,J)=0.
CALL READTIT(HEAD,NT1)
CALL WRITTIT(HEAD,NT2)
CALL READKIN(NT1)
CALL HRSKIN
CALL WRITKIN(NT2)
CALL READMAT(TITC,AC,BC,CC,NT1)
CALL WRITMAT(TITC,AC,BC,CC,NT2)

```

```

CALL READMAT(TITF,AF,BF,CF,NT1)
CALL WRITMAT(TITF,AF,BF,CF,NT2)
CALL READMAT(TITB,AB,BB,CB,NT1)
CALL WRITMAT(TITB,AB,BB,CB,NT2)
NR=200
DO 10 J=1,NR
CALL BEAMC(X1)
CALL NAT(X1,X2,AC,BC,CC)
CALL SCATT(X2,X3,TH)
CALL NAT(X3,X4,AF,BF,CF)
DO 100 I=1,6
100 VAL(I)=X1(I)
DO 101 I=1,6
101 VAL(I+6)=X2(I)
DO 102 I=1,6
102 VAL(I+12)=X3(I)
DO 103 I=1,6
103 VAL(I+18)=X4(I)
DO 104 I=1,4
104 XFOC(I)=X4(I)
CALL M(XFOC,AB,BB,CB,DM,DPL,ANG,ITER)
VAL(25)=ANG-TH
VAL(26)=ANG-TAB(2,1)/(180./PI)
VAL(27)=DPL-TAB(2,17)*X2(6)-X4(6)
VAL(28)=DPL
VAL(29)=DM
VAL(30)=ITER
DO 201 I=1,30
IB=(VAL(I)-OR(I))/SC(I)+1
IF(IB.LT.1) IB=1
IF(IB.GT.NB) IB=NB
HISTA(IB,I)=HISTA(IB,I)+1
201 CONTINUE
10 CONTINUE
C PRINT*,HISTOGPAMS
DO 202 I=1,30
PRINT(2,203) I,SC(I),OR(I)
203 FORMAT(1HISTOGPAM *,15,*,BIN=*,F12.6,*,LFT ORIGIN=*,F12.6)
CALL HIST(NB,HISTA(1,I),OP(I),SC(I))
202 CONTINUE
STOP
END
*DECK BEAMC
SUBROUTINE BEAMC(X)
DIMENSION X(6),DX(6),OFFSET(6)
DATA (DX(I),I=1,6)/1.,5.,.35,.3,.05,.1/
DATA (OFFSET(I),I=1,6)/6*0./
CALL RANGEX(X,DX,OFFSET,6)
RETURN
END
*DECK SCATT
SUBROUTINE SCATT(X,Y,ANG)
REAL P1
DIMENSION X(6),Y(6)
DIMENSION RANA(6),OFFSET(6),RANGE(6)
COMMON/ALL/TAB(2,40)
COMMON/DATPI/PI
DATA (RANGE(I),I=1,2)/60.,30./
DATA (OFFSET(I),I=1,6)/6*0./
CALL RANGEX(RANA,RANGE,OFFSET,2)
Y(2)=RANA(1)
Y(4)=RANA(2)
T0=(PI/180.)*TAB(2,1)

```

```

      CALL SANG(X(2),X(4),Y(2),Y(4),TO,ANG)
      CALL P(ANG,X(6),Y(6))
C CALCULATE SCATTERING IN TARGET VOLUME IN A RANDOM FASHION
C ALONG EXTENSION OF PARTICLES TRAJECTORY IN TARGET.
C THE TARGET IS OF THICKNESS T AND ROTATED AT AN ANGLE KI
C FROM THE BEAM LINE COORDINATE SYSTEM OUTPUT PLANE
C THE ANGLE OF ROTATION IS ABOUT THE Y-AXIS AND IS POSITIVE
C IN THE COUNTER-CLOCKWISE SENSE LOOKING FROM ABOVE THE TARGET.
C KI MAY RANGE FROM -90. TO +90. DEGREES. HOWEVER THE SOLUTION
C AT THE TWO EXTREMES DIVERGES. THUS IT IS BEST NOT TO CHOOSE
C KI=90. OR KI=-90.
C
C TARGET ROTATION ANGLE
      KI=-30.
      KI=(PI/180.)*KI
C TARGET THICKNESS IN CM.
      T=2.
C FIND MAXIMUM VALUE OF PARAMETER DEL
      DELMAX=T/2.
      DEL=DELMAX*2.*(RANDOM(D)-.5)
C CALCULATE COORDINATE OF SCATTERING IN TARGET VOLUME.
C ONE CAN CALCULATE THE PATHLENGTH IN THE TARGET BY
C SOLVING THE SAME EQUATIONS FOR DEL=-T/2. THAT GIVES
C THE COORDINATES OF INTERSECTION OF THE ENTERING RAY INTO TARGET.
      ZTAR=(SIN(KI)*X(1)+DEL)/(COS(KI)-TAN(X(2)/1000.)*SIN(KI))
      XTAR=ZTAR*TAN(X(4)/1000.)*X(1)
      YTAR=ZTAR*TAN(X(4)/1000.)*X(3)
C
C EXPRESS TARGET SCATTERING COORDINATES IN SPECTROMETER COORDINATE SYSTEM
      YTARS=-COS(TO)*XTAR-SIN(TO)*ZTAR
      XTARS=YTAR
      ZTARS=-SIN(TO)*XTAR+COS(TO)*ZTAR
C
C NOW PROPAGATE PARTICLE ALONG TRAJECTORY TO SPECTROMETER ENTRANCE
C PLANE Z = 0.
      Y(1)=XTARS-ZTARS*TAN(Y(2)/1000.)
      Y(3)=YTARS-ZTARS*TAN(Y(4)/1000.)
C NOW CHECK ALONG PATH LENGTH DIFFERENCE
      Y(5)=X(5)
C AT THIS POINT IT IS POSSIBLE TO PROPAGATE PARTICLE TO THE ENTRANCE
C OF THE FIRST QUAD IN THE SPECTROMETER AND TEST THAT RAY IS WITHIN
C A SPECIFIED AREA. THIS WOULD BE THE ONLY PROPER WAY OF
C REPRESENTING THE SPECTROMETER ACCEPTANCE. BECAUSE THE ANGULAR
C ACCEPTANCE DEPENDS MUCH ON WHERE IN THE TARGET THE SCATTERING TAKES
C PLACE. THIS IS DUE TO THE EXTREME LENGTH OF THE TARGET.
      RETURN
      END
*DECK P
      SUBROUTINE P(THETAC,DELA,DELC)
      COMMON/DATA/TA,TB,TC,TD,TE,EDD,ERES
      COMMON/ALL/TAB(2,40)
      COMMON/DATP1/P1
      REAL MA,MB,MC,MD,ME
      EA0=TA+TA
      PA0=SQRT(EA0**2-MA**2)
      PA=PA0*(1.+DELA/100.)
      EA=SQRT(PA**2+MA**2)
      MD=MD+EDD
      S=MA**2+MB**2+2.*EA*MB
      DK=S-MC**2-MD**2
      CLOG=(DK**2-4.+(MC*MD)**2)/(4.*S)
      PCCM=SQRT(CLOG)
      ECCM=SQRT(PCCM**2+MC**2)

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      BETA=PA/(EA+MB)
      GAMMA=1./SQRT(1.-BETA**2)
      SOG=1./GAMMA
      TOG=1.-(BETA+COS(THETAC))*2
      A=1.
      B=-2.*BETA+COS(THETAC)*SOG+ECCM/TOG
      C=(MC+12-(SOG+12)*(ECCM**2))/TOG
      ZOG=B*12-4.*A+C
      PC=(-B+SQRT(ZOG))/(2.*A)
      DELC=(PC-TAB(2.3))/TAB(2.3))*100.
      RETURN
    END
    SUBROUTINE SANG(TB,PB,TS,PS,T0,ANG)
C CONVERT ANGLES FROM MILIRADIANS TO RADIANS
      TBR=TB/1000.
      PBR=PB/1000.
      TSR=TS/1000.
      PSR=PS/1000.
      A1=COS(T0)-SIN(T0)*TAN(TBR)
      A2=TAN(TSR)+TAN(PBR)
      A3=-TAN(PSR)+COS(T0)*TAN(TBR)+SIN(T0)
      A=A1+A2+A3
      B=SQRT(1.+(TAN(TSR)+TAN(PBR))**2+(TAN(TSR))**2)
      C=SQRT(1.+(TAN(PBR))**2+(TAN(TBR))**2)
      COSANG=A/C
      ANG=ACOS(COSANG)
      RETURN
    END
*DECK READTIT
    SUBROUTINE READTIT(HEAD,NT)
      DIMENSION HEAD(32)
      READ(NT,100) (HEAD(I), I=1,32)
100  FORMAT(9A10)
      RETURN
    END
    SUBROUTINE WRITTIT(HEAD,NT)
      DIMENSION HEAD(32)
      WRITE(NT,100) (HEAD(I), I=1,32)
100  FORMAT(4(9A10))
      RETURN
    END
*DECK WRITVEC
    SUBROUTINE WRITVEC(X,J,NT)
      DIMENSION X(6)
      WRITE(NT,100) (X(I), I=1,6)
100  FORMAT(1H,19.6(2X)E18.6)
      RETURN
    END
*DECK NAT
    SUBROUTINE NAT(X,Y,A,B,C)
      DIMENSION X(6),Y(6),A(6,6),B(6,6,6),C(50)
      DO 23 I=1,6
        Y(I)=0.
        DO 21 J=1,6
          Y(I)=A(I,J)*X(J) + Y(I)
21      DO 22 L=1,6
          DO 22 K=1,6
            Y(I)=B(I,L,K)*X(L)*X(K) + Y(I)
22      Y(I)=C(I,L,K)*X(L)*X(K) + Y(I)
C****HIGHER ORDER TERMS CAN BE ADDED HERE TO Y(I).****
23      CONTINUE
      RETURN
    END
*DECK READNAT

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SUBROUTINE READMAT(TITLE,A,B,C,NT)
  DIMENSION TITLE(8),A(6,6),B(6,6,6),C(50)
  READ(NT,10) TITLE
10  FORMAT(8A10)
  DO 11 I=1,6
11  READ(NT,12) (A(I,J),J=1,6)
12  FORMAT(6E12,5)
  DO 13 I=1,6
  DO 13 J=1,6
13  READ(NT,12) (B(I,K,J),K=1,6)
C****HIGHER ORDER TERMS CAN BE READ IN HERE****
  DO 14 I=1,50
14  C(I)=0.
C****
  RETURN
  END
*DECK WRITMAT
SUBROUTINE WRITMAT(TITLE,A,B,C,NT)
  DIMENSION TITLE(8),A(6,6),B(6,6,6),C(50)
  WRITE(NT,10) TITLE
10  FORMAT(1H1,8A10)
  WRITE(NT,11)
11  FORMAT(1H0,*(FIRST ORDER MATRIX*))
  DO 12 I=1,6
12  WRITE(NT,13) (A(I,J),J=1,6)
13  FORMAT(1H,6(E12,5,X))
  WRITE(NT,14)
14  FORMAT(1H0,*(SECOND ORDER MATRIX ELEMENTS*))
  DO 15 I1=1,6
  DO 16 I2=1,6
  WRITE(NT,17) (I1,I3,I2,B(I1,I3,I2),I3=1,I2)
17  FORMAT(6(14,I2,I1,E12,5))
16  CONTINUE
  WRITE(NT,18)
18  FORMAT(1H )
15  CONTINUE
  WRITE(NT,19)
19  FORMAT(1H0,*(SELECTED HIGHER ORDER MATRIX ELEMENTS*))
C****HERE ONE CAN PRINT OUT SELECTED HIGHER ORDER TERMS****
  RETURN
  END
*DECK M
SUBROUTINE M(XFOC,B,B2,BH,DM,DPL,ANG,L)
  COMMON/ALL/TAB(2,40)
  DIMENSION B(6,6),B2(6,6,6),BH(50)
  DIMENSION XFOC(4),D(5)
  COMMON/DATPI/PI
C****CALCULATE COS AND SIN OF CENTRAL ANGLE THETA NAUGHT****
  CTH0=COS(TAB(2,1)/(180./PI))
  STH0=SIN(TAB(2,1)/(180./PI))
C****CALCULATE FIRST ORDER DELTA(PL)****
  DPL=-B(1,1)/B(1,6)*XFOC(1)+B(1,2)/B(1,6)*XFOC(2)
C****CALCULATE HIGHER ORDER CORRECTIONS TO DPL****
C****THE PROCEDURE IS ITERATIVE SOLUTION WHERE WE****
C****ASSUME DELTA(PA) SMALL COMPARED TO DELTA(PC)****
C****HENCE DELTA(PL)=DELTA(PC). WHEN HIGHER ORDER****
C****TERMS ARE IMPORTANT THIS IS JUST THE CASE****
  D(1)=DPL
  DO 10 L=2,5
C****
  D(L)=D(1)
  1  -B2(1,1,1)*XFOC(1)**2/B(1,6)
  1  +B2(1,1,2)*XFOC(1)*XFOC(2)/B(1,6)

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1      -B2(1.1.6)**XFOC(1)*D(L-1)/B(1.6)
1      -B2(1.2.2)**XFOC(2)**2/B(1.6)
1      +B2(1.2.6)**XFOC(2)*D(L-1)/B(1.6)
1      -B2(1.3.3)**XFOC(3)**2/B(1.6)
1      +B2(1.3.4)**XFOC(3)**XFOC(4)/B(1.6)
1      -B2(1.4.4)**XFOC(4)**2/B(1.6)
1      -B2(1.6.6)*D(L-1)**2/B(1.6)
C****CHECK CONVERGENCE OF D(L)***
      DEL=ABS(D(L)-D(L-1))
      IF(DEL.LE..000005) GO TO 11
10     CONTINUE
11     CONTINUE
C****COULD PRINT OUT CONVERGENCE INFORMATION HERE****
      DPL=D(L)
C****CALCULATE PHI (SPECTROMETER IN) FIRST ORDER****
      PHISIN=-B(4.3)**XFOC(3)+B(4.4)**XFOC(4)
C****CALCULATE HIGHER ORDER CORRECTIONS TO PHISIN****
      PHISIN=PHISIN
1      -B2(4.1.3)**XFOC(1)**XFOC(3)
1      +B2(4.1.4)**XFOC(1)**XFOC(4)
1      +B2(4.2.3)**XFOC(2)**XFOC(3)
1      -B2(4.2.4)**XFOC(2)**XFOC(4)
1      -B2(4.3.6)**XFOC(3)*DPL
C****CALCULATE PHISIN IN RADIANS****
      PSI=PHISIN/1000.
C****THVER=THSIN-PHIOUT****
      THVER=-B(2.1)**XFOC(1)+B(2.2)**XFOC(2)-B(2.6)*DPL
C****CALCULATE HIGHER ORDER CORRECTIONS TO THVER****
      THVER=THVER
1      -B2(2.1.1)**XFOC(1)**2
1      +B2(2.1.2)**XFOC(1)**XFOC(2)
1      -B2(2.1.6)**XFOC(1)*DPL
1      -B2(2.2.2)**XFOC(2)**2
1      +B2(2.2.6)**XFOC(2)*DPL
1      -B2(2.3.3)**XFOC(3)**2
1      +B2(2.3.4)**XFOC(3)**XFOC(4)
1      -B2(2.4.4)**XFOC(4)**2
1      -B2(2.6.6)*DPL**2
C****CALCULATE THVER IN RADIANS****
      THV=THVER/1000.
C****CALCULATE THE SCATTERING ANGLE USING GENERAL EXPRESSION****
      ANG=ACOS(CTH0-PSI*STH0-.5*CTH0*(THV**2+PSI**2))
C****CONVERT DPL FROM PERCENT TO FRACTION****
      DPLF=DPL/100.
C****COMPUTE D(TH)****
      DTH=ANG-TAB(2.1)/(180./PI)
      DELP=TAB(2.3)*DPLF
C****CALCULATE D(N) TO 4TH ORDER IN DERIVATIVES****
      DM=TAB(2.22)*DELP+TAB(2.23)*DTH
1      +.5*TAB(2.25)*DELP**2
1      +.5*TAB(2.26)*DTH**2
1      +TAB(2.28)*DELP*DTH
1      +1./6.*TAB(2.30)*DTH**3
1      +1./6.*TAB(2.32)*DELP**3
1      +3./6.*TAB(2.33)*DTH**2*DELP
1      +3./6.*TAB(2.39)*DELP**2*DTH
1      +1./24.*TAB(2.40)*DTH**4
      RETURN
      END
*DECK  RANGEN
      SUBROUTINE RANGEN(X,RANGE,BASE,N)
      DIMENSION X(6),RANGE(6),BASE(6)

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      DO 10 I=1,N
      X(I)=PANGE(I)*(RANDOM(D)-.5)+BASE(I)
10    CONTINUE
      RETURN
      END
*DECK HRSKIN
      SUBROUTINE HRSKIN
      COMMON/ALL/TAB(2,40)
      COMMON/DATA/MA,MB,MC,MDD,TA,EDD,ERES
      COMMON/DATB/PA,EA,TH,ECM,PCCM,ECCM,BETA,GAMMA,MD
      COMMON/CAN/ERR(2)
      COMMON/DATPI/PI
      DATA PI/3.1415926536/
      REAL MA,MB,MC,MD,MDD
C
C   HRSKIN CALCULATES TWO-BODY RELATIVISTIC KINEMATICS FOR USE AT LAMPF H
C   THE SYSTEM OF UNITS FOR INPUT AND OUTPUT IS DEGREES FOR ANGLES,
C   MOMENTUM, ENERGY, MASS IN CONSISTENT SET OF UNITS WHERE C=1.
C
C   DERIVATIVES INVOLVING THETA MUST BE MULTIPLIED BY THETA IN RADIANS
C   DERIVATIVES INVOLVING MOMENTA MUST BE MULTIPLIED BY MOMENTA IN UNITS
C   CONSISTENT WITH INPUT UNITS (E.G. MEV/C)
C
C   NOTE THAT FOR EACH LAB ANGLE WE TAKE ONLY ONE CM ANGLE CORRESPONDING T
C   THE LARGEST MOMENTUM IN THE CM SYSTEM AND THE SMALLEST ANGLE
C   BECAUSE THIS PROGRAM IS DEVOTED MAINLY TO THE HRS WE NEED NEVER CONSID
C   THE CASE WHERE WE HAVE TWO CM ANGLES FOR EACH LAB ANGLE.
C   THIS IS BECAUSE WE ARE CONSTRAINED TO PROTON BEAM OF MAX TA=800 MEV.
C   NOTE FURTHER THAT ONE COULD CALCULATE THE OTHER CM ANGLE BY -SORT(ZOG)
C   INSTEAD OF +SORT(ZOG) IN SUBROUTINE COMP(I).
C   NOTE THAT THE JACOBIAN TRANSFORMS LAB CROSS SECTION TO CM CROSS SECTIO
C   PER STERADIAN PER MEV/C.
C   ROBERT H. ROLFE, BNL, SEPTEMBER 1971
C
      TAB(1.1)=10HTheta LAB
      TAB(1.2)=10HTheta CM
      TAB(1.3)=10HPC LAB
      TAB(1.4)=10HTC LAB
      TAB(1.5)=10HPC CM
      TAB(1.6)=10HTC CM
      TAB(1.7)=10HPhi LAB
      TAB(1.8)=10HPhi CM
      TAB(1.9)=10HPD LAB
      TAB(1.10)=10HTD LAB
      TAB(1.11)=10HPD CM
      TAB(1.12)=10HTD CM
      TAB(1.13)=10HBeta CM
      TAB(1.14)=10HGAMMA CM
      TAB(1.15)=10HT MOM TRAN
      TAB(1.16)=10HJACOBIAN
      TAB(1.17)=10HR RATIO
      TAB(1.18)=10HD(PA) MEV
      TAB(1.19)=10HD(PC) MEV
      TAB(1.20)=10HD(TH) MRAD
      TAB(1.21)=10HM/PA
      TAB(1.22)=10HM/PC
      TAB(1.23)=10HM/TH
      TAB(1.24)=10HM/PAPA
      TAB(1.25)=10HM/PCPC
      TAB(1.26)=10HM/THTH
      TAB(1.27)=10HM/PATH
      TAB(1.28)=10HM/PCTH
      TAB(1.29)=10HM/PCPA

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TAB(1.30)=10HM/THTHTH
TAB(1.31)=10HM/PAPAPA
TAB(1.32)=10HM/PCPCPC
TAB(1.33)=10HM/PCTHTH
TAB(1.34)=10HM/PATHTH
TAB(1.35)=10HM/THPCPA
TAB(1.36)=10HM/PCPHPA
TAB(1.37)=10HM/PAPCPC
TAB(1.38)=10HM/THPAPA
TAB(1.39)=10HM/THPCPC
TAB(1.40)=10HM/THTHTHTH
ERR(1)=10HTHETA MAX=

```

C
C

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102 DO 102 J=2.40
TAB(2,J)=0.
TH=TAB(2,1)/(180./PI)
EA=TA+MA
PA=SORT(EA**2-MA**2)
MD=MDD+EDD
S=MA**2+MB**2+2.*EA*MB
ECM=SORT(S)
DK=S-NU**2-MD**2
CLOG=(DK**2-4.*(MC*MD)**2)/(4.*S)
C IF NEGATIVE CLOG REACTION CANNOT PROCEED WITHOUT HIGHER INITIAL ENERGY
IF(CLOG.LT.0.) STOP 1
PCCM=SORT(CLOG)
ECCM=SORT(PCCM**2+MC**2)
BETA=PA/(EA+MB)
GAMMA=1./SORT(1.-BETA**2)
C CALCULATE THETA MAX IN LAB SYSTEM.
VCCM=PCCM/ECCM
DEL=BETA-VCCM
IF(DCL) 97,98,99
97 THMAX=PI
GO TO 96
98 THMAX=PI/2.
GO TO 96
99 TANNIX=VCCM*VCCM/(GAMMA*GAMMA*(BETA*BETA-VCCM*VCCM))
THMAX=ATAN(TANNIX)
GO TO 96
96 ERR(2)=THMAX*(180./PI)
IF(TH.GT.THMAX) STOP 2

```

C
C

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CALL COMP(2)
RETURN
END
SUBROUTINE COMP(1)
REAL JACOB
COMMON/ALL/TAB(2,40)
COMMON/DATA/MA,MB,MC,MDD,TA,EDD,ERES
COMMON/DATB/PA,EA,TH,ECM,PCCM,ECCM,BETA,GAMMA,MD
REAL TA,MB,MC,MD,MDD
COMMON/DATPI/PI
SOG=1./GAMMA
TOG=1.-(BETA*COS(TH))**2
A=1.
B=-2.*BETA*COS(TH)*SOG*ECCM/TOG
C=(MC**2-(SOG**2)*(ECCM**2))/TOG
ZOG=B**2-4.*A*C
IF(ZOG.LT.0.) GO TO 302
PC=(-B+SQRT(ZOG))/(2.*A)

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EC=SQRT(PC**2+MC**2)
TC=EC-MC
DOG=(COS(TH)*PC-GAMMA*BETA*ECOM)/(GAMMA*PCCM)
HOG=ABS(DOG)
IF(HOG.GT.1.) GO TO 302
THCM=ACOS(DOG)
TCCM=ECOM-MC
ANG=TH*(180./PI)
ANGCM=THCM*(180./PI)
JACOB=PC**2/(PCCM*GAMMA*(PC-BETA*EC*COS(TH)))
DMPA=(PC*COS(TH)+PA*(MB-EC)/EA)/MD
DMPC=(PA*COS(TH)-PC*(EA+MB)/EC)/MD
DMTH=-PA*PC*SIN(TH)/MD
R=(PA*DMPA)/(PC*DMPC)
T=MA**2+MC**2+2.*PA*PC*COS(TH)-2.*EC*EA
DPA=ERES/DMPA
DPC=ERES/DMPC
DTH=1000.*ERES/DMTH
DMPAPA=-DMPA*(PC*COS(TH)+PA*(MB/EA-EC/EA))/MD**2+(MB/EA-EC/EA)*(1.
1-(PA/EA)**2)/MD
DMPCPC=-DMPC*(PA*COS(TH)-PC*(EA+MB)/EC)/(MD*MD)-(EA+MB)*(1.-(PC/E
1C)**2)/(MD*EC)
DMTHTH=PA*PC*(DMTH*SIN(TH)/MD-COS(TH))/MD
DMPATH=DMPA*PA*PC*SIN(TH)/MD**2-PC*SIN(TH)/MD
DMPCTH=DMPC*PA*PC*SIN(TH)/MD**2-PA*SIN(TH)/MD
DMPCPA=-DMPC*(PC*COS(TH)+PA*(MB-EC)/EA)/MD**2+(COS(TH)-(PA*PC)/(EA
1*EC))/MD
D3MTT=-3.*DMTH*DMTHTH/MD-DMTH
D3MAA=2.*(DMPA**3)/(MD**2)
1-DMPAPA*DMPA/MD
1-(DMPAPA+(DMPA**2)/MD)*(2.*DMPA/MD+3.*PA/(EA**2))
D3MCCC=2.*(DMPC**3)/(MD**2)-DMPCPC*DMPC/MD
1-(DMPCPC+(DMPC**2)/MD)*(2.*DMPC/MD+3.*PC/(EC**2))
D3MCTT=2.*(DMTH**2)*DMPC/(MD**2)-DMPCTH*DMTH/MD
1+DMPC*PA*PC*COS(TH)/(MD**2)
1+DMTH*PA*PC*SIN(TH)/(MD**2)-PA*COS(TH)/MD
D3MTTT=2.*(DMTH**2)*DMPA/(MD**2)-DMPATH*DMTH/MD
1+DMPC*PA*PC*COS(TH)/(MD**2)
1+DMTH*PC*SIN(TH)/(MD**2)-PC*COS(TH)/MD
D3MTCA=2.*DMTH*DMPC*DMPA/(MD**2)-DMPCTH*DMPA/MD
1+DMPC*PC*SIN(TH)/(MD**2)-DMTH*(COS(TH)-(PA*PC)/(EA*EC))/(MD**2)
1-SIN(TH)/MD
D3MCAA=2.*DMPC*(DMPA**2)/(MD**2)-DMPCPA*DMPA/MD
1-DMPA*(COS(TH)-(PA*PC)/(EA*EC))/(MD**2)
1-(1.-(PA/EA)**2)*(PC/EC)/(EA*MD)
D3MACC=2.*DMPA*(DMPC**2)/(MD**2)-DMPCPA*DMPC/MD
1-DMPC*(COS(TH)-(PC*PA)/(EC*EA))/(MD**2)
1+DMPA*(EA+MB)*(1.-(PC/EC)**2)/(EC*(MD**2))
1-PA*(1.-(PC/EC)**2)/(EC*EA*MD)
D3MTAA=2.*DMTH*(DMPA**2)/(MD**2)-DMPATH*DMPA/MD
1+DMPA*PC*SIN(TH)/(MD**2)-DMTH*(MB-EC)*(1.-(PA/EA)**2)/(EA*(MD**2))
D3MTCC=2.*DMTH*(DMPC**2)/(MD**2)-DMPCTH*DMPC/MD
1+DMPC*PA*SIN(TH)/(MD**2)+DMTH*(EA+MB)*(1.-(PC/EC)**2)/(EC*(MD**2))
D4MTTTT=-3.*(DMTHTH**2)/MD-3.*DMTH*D3MTT/MD
1+3.*(DMTH**2)*DMTHTH/(MD**2)-DMTHTH
PDCM=PCCM
EDCM=SQRT(PDCM**2+MD**2)
TDCM=EDCM-MD
PHICM=PI-THCM
ED=EA+MB-EC
TD=ED-MD
PD2=ED**2-MD**2
IF(PD2.LT.0.) GO TO 302

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PD=SQRT(PD2 )
IF (PD) 302,302,304
304 CONTINUE
COSPHI=(PA-PC*CGS(TH))/PD
XX=ABS(COSPHI)
IF (XX.GT.1.0) GO TO 302
PHI=ACOS(COSPHI)
ANGDCM=PHICM*(180./PI)
ANGD=PHI*(180./PI)
C 303 REST OF CALCULATIONS
CONTINUE
TAB(I,1)=ANG
TAB(I,2)=ANGCM
TAB(I,3)=PC
TAB(I,4)=TC
TAB(I,5)=PCCM
TAB(I,6)=TCCM
TAB(I,7)=ANGD
TAB(I,8)=ANGDCM
TAB(I,9)=PD
TAB(I,10)=TD
TAB(I,11)=PDCM
TAB(I,12)=TDCM
TAB(I,13)=BETA
TAB(I,14)=GAMMA
TAB(I,15)=T
TAB(I,16)=JACOB
TAB(I,17)=R
TAB(I,18)=DPA
TAB(I,19)=DPC
TAB(I,20)=DTH
TAB(I,21)=DNPA
TAB(I,22)=DNPC
TAB(I,23)=DNTH
TAB(I,24)=DNPAFA
TAB(I,25)=DNPCPC
TAB(I,26)=DNTHTH
TAB(I,27)=DNPAFA
TAB(I,28)=DNPCPC
TAB(I,29)=DNPCPA
TAB(I,30)=DSMTTT
TAB(I,31)=DSMAAA
TAB(I,32)=DSMCCC
TAB(I,33)=DSMCTT
TAB(I,34)=DSMATT
TAB(I,35)=DSMTCA
TAB(I,36)=DSMCAA
TAB(I,37)=DSMACC
TAB(I,38)=DSMTAA
TAB(I,39)=DSMTCC
TAB(I,40)=D4MTTTT
302 RETURN
END
SUBROUTINE READKIN(NT)
COMMON/DATA/MA,MB,MC,MDD,TA,EDD,ERES
REAL MA,MB,MC,MDD
COMMON/ALL/TAB(3,40)
C EACH COMMENT DESCRIBES ONE DATA CARD.
C TITLE CARD COLUMNS 1 THRU 80
C MASSES OF PARTICLES A,B,C,D IN F10.3
C INCIDENT ENERGY,ENERGY RESOLUTION,EXCITATION ENERGY,THETA0 IN F10.3
C
COMMON/TIT/HEAD(8)

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```

40  READ(NT,40) HEAD
    FORMAT(8A10)
    READ(NT,30) MA,MB,MC,MDD
    READ(NT,30) TA,ERES,EDD,TAB(2,1)
30  FORMAT(4F10,3)
    RETURN
    END
    SUBROUTINE WRITKIN(NT)
    COMMON/ALL/TAB(2,40)
    CALL PAGTIT(NT)
    DO 201 K=1,40
    WRITE(NT,202) TAB(1,K),TAB(2,K)
202  FORMAT(1H ,A10,2X,G18,7)
201  CONTINUE
    RETURN
    END
*DECK PAGTIT
    SUBROUTINE PAGTIT(NT)
    COMMON/ DATA/MA,MB,MC,MDD,TA,EDD,ERES
    COMMON/TIT/HEAD(8)
    COMMON/CAM/ERR(2)
    REAL MA,MB,MC,MD,MDD
    WRITE(NT,34) HEAD
34  FORMAT(1H1,8A10)
    WRITE(NT,32) MA,MB,MC,MDD
32  FORMAT(1H ,7H  MA=,F11,3,7H  MB=,F11,3,7H  MC=,F11,3,7H  MD=,F11,3)
    WRITE(NT,33) TA,EDD,ERES
33  FORMAT(1H ,17H INCIDENT ENERGY=,F10,3,4X,18HEXCITATION ENERGY=,F9,
    13,4X,18HENERGY RESOLUTION=,F7,3,4X)
    WRITE(NT,35) ERR(1),ERR(2)
35  FORMAT(1H ,A10,F15,6,7)
    RETURN
    END
*DECK HIST
    SUBROUTINE HIST(NXT,PCT,XZERO,XWIDTH)
    C  PLOTTER ROUTINE FOR ONE PAGE HISTOGRAMS
    C  MODIFIED BY C. J. YAPPUSSO AND B. A. MARTIN FEBRUARY 1968
    C  APPLIED MATH DEPT., BROOKHAVEN NATIONAL LABORATORY
    C
    C  RCT IS THE VECTOR WHICH IS TO BE GRAPHED. IT MUST BE OF LENGTH 210 OR
    C  EACH CELL IN THE VECTOR MAY BE OF ANY REASONABLE HEIGHT
    C  WHEN THE VECTOR CONTAINS CELLS WHICH WOULD RESULT IN HISTOGRAM COLUMN
    C  MORE THAN A PAGE IN LENGTH, EACH VALUE OF THE VECTOR IS DIVIDED BY
    C
    C  FRACTIONAL VALUES ARE THEN PLOTTED DISTINGUISHABLY AS FOLLOWS
    C
    C  STEPS X.S.
    C
    C  (INTGR+.51) TO (INTGR+.99) (E.G. .75) GIVES  +11+  H
    C  (INTGR+.5) (E.G. .50) GIVES  +++++  H
    C  (INTGR+.01) TO (INTGR+.49) (E.G. .25) GIVES  +..+
    C  NEGATIVE VALUES (NEGATIVE FREQUENCIES) SHOULD NOT BE USED, SINCE ALL
    C  PLOTTED AS ZERO. THEY WOULD PRODUCE ERRONEOUS VALUES
    C  FOR THE MEAN (WHICH IS INDICATED BY THE LETTER M UNDER THE GRAPH)
    C
    C  RCT(1) IS PLOTTED AS IF IT HELD THE DATA VALUES LYING BETWEEN 0 AND
    C  RCT(2) THE VALUES GREATER THAN 1 AND LESS THAN OR EQUAL TO 2, ETC.
    C
    C  NXT IS THE TOTAL NUMBER OF CELLS IN THE VECTOR. IF NXT IS LESS THAN 1
    C  THEN THE HISTOGRAMS WILL CONSIST OF THREE COLUMN WIDE BARS
    C  IF NXT IS GREATER THAN NUMBS. THE HISTOGRAM BARS WILL CONSIST OF SIX
    C  COLUMNS OF THE LETTER X
    C

```

```

C      XZEPO AND XWDTH HELP DEFINE THE LABLING OF THE COLUMNS ALONG
C      THE BOTTOM OF THE GRAPH
C
C      IF NXT IS NEGATIVE, THE HISTOGRAM WILL CONSIST OF UN-FILLED COLUMNS
C      IF NWDTH IS NEGATIVE, THE NUMBER OF BINS WILL BE HALVED TO ALLOW
C      3 COLUMN WIDE BARS WHEN NXT IS GREATER THAN 35, BUT LESS THAN 71.
C
C      DIMENSION PCT(212),SHT(120),FMT1(8),FMT2(8),FMT3(8),NXL(24)
C      DIMENSION BASE(120)
C      EQUIVALENCE (BASE,SHT)
C
C      IF(IPL-1111)103,120,109
103 IF(IPL-1) 110,120,110
110 CONTINUE
C
C      CONSTANTS DETERMINING HEIGHT AND WIDTH OF PAGE FORMAT
C      HEIGHT=58.0
C      WIDTH=119.0
C      NUM15=WIDTH-13.0
C      NUM35=NUM15/3
C      NBW=WIDTH-8.0
C
C      WORDS FOR GENERATING FORMATS WHICH PRINT Y-AXIS SCALE
C      FMT1(1)=1H(
C      FMT1(2)=6H1H 13,
C      FMT1(3)=4H2H -
C      FMT1(4)=3H1H*
C      FMT1(5)=3H1X,
C      FMT1(6)=6H106A1,
C      THE FIGURE 106A1 MUST BE CHANGED IF THE -WIDTH- OF PAGE CHANGES
C      FMT1(7)=4H2H *
C      FMT1(8)=3H13)
C
C      WORDS FOR USE IN BUILDING THE FORMAT MATRIX (SHT)
C      F1=1H
C      F2=1H
C      F3=1H-
C      F4=1H+
C      F5=1H
C      F6=1H*
C      F7=1H
C      F8=1H
C
C      FA=1H*
C      FM=1HM
C
C      WORDS FOR GENERATING FORMATS WITHOUT Y-AXIS SCALE
C      FMT2(1)=1H(
C      FMT2(2)=3H6X,
C      FMT2(3)=4H2H*
C      FMT2(4)=6H106A1,
C      THE FIGURE 106A1 MUST BE CHANGED IF THE -WIDTH- OF PAGE CHANGE
C      FMT2(5)=4H2H *
C      FMT2(6)=2H3X
C      FMT2(7)=1H)
C
C
C      IRL=1111
C
C      NX COUNTS HORIZONTALLY ALONG X AXIS. NZ COUNTS VERTICALLY UP Y AX
120 NXTT=(NXT+1)/2
C      IF(NXT-NUM15)125,125,121
121 IF(NXTT-NUM15)122,122,124

```



```

122 DO 1231 NX=NXT.211
1231 RCT(NX+1)=0.0
      DO 123 NX=1,NXTT
      NXX=NXX*2
123 RCT(NX)=RCT(NXX)+RCT(NXX-1)
      NXT=NXTT
      G2=2.0
      FX=1H2
      GO TO 126
124 PRINT921
921 FORMAT(10X49HT00 MANY COLUMNS IN DATA VECTOR,CALLED FROM HIST)
      RETURN
125 NXTT=NUM15
      IF( XWDTH) 1251,1255,1259
1251 IF(NXT-NUM35) 1259,1259,1254
1254 IF(NXTT-NUM35) 122,122,1259
1255 XWDTH=1.0
1259 G2=1.0
      FX=1HX
126 PRINT905
      IF(NXT) 127,128,128
127 NSW=1
      NXT=-NXT
      GO TO 600
128 NSW=0
C
C FINDING THE MEAN
600 SUM=0
      XSUM=0
      DO 610 NX=1,NXT
      IF(RCT(NX)) 610,610,605
605 XN=NX
      SUM=SUM+RCT(NX)
      XSUM=XSUM + (XN-0.5)*RCT(NX)
610 CONTINUE
      MEAN=SUM
615 C=SUM/SUM
C
C
129 NC=1
      TOP=0.0
C
C SCALING OF COUNTS IN DATA VECTOR
130 DO 143 NX=1,NXT
      IF(RCT(NX)) 132,131,132
131 RCT(NX)=-2.0
132 CONTINUE
      IF(RCT(NX) - TOP) 1302,1302,1301
1301 TOP=RCT(NX)
1302 IF(TOP-HEIGHT+4.0) 142,142,139
139 DO 140 NB=1,NXT
140 RCT(NB)=RCT(NB)/2.0
      TOP=TOP/2.0
      NC=NC+1
      GO TO 1302
142 CONTINUE
      NTP=TOP/5.0
      NTOP=NTP*5 + 5
      IF(NXT-NUM35) 400,400,155
C THIS LAST STEP DECIDES WHETHER THE GRAPH IS TO BE MADE OF X.S
C OR OF FOUR CHARACTER BARS DEPENDING ON NXT AND WIDTH
C
C SLICING OFF THE TOP OF EACH COLUMN TO BUILD FORMAT MATRIX (USING X

```

```

C
155 DO 165 NX=1,NUM1S
165 SHT(NX)=FB
    DO 300 NZ=1,NTOP
    IF (NZ-NTOP) 180,170,180
170 DO 175 NX=1,NUM1S
175 SHT(NX)=FD
180 R=NTOP-NZ
C
200 DO 250 NX=1,NXT
    IF (RCT(NX)-R) 250,210,204
204 IF (RCT(NX)-R-1.0) 220,205,205
205 SHT(NX)=FX
    GO TO 250
210 SHT(NX)=FX
    GO TO 250
220 SHT(NX)=FH
250 CONTINUE
C
C    PREPARATION OF Y-AXIS SCALE
NYU=(NTOP -NZ)*2***(NC-1)
QNY=NZ
NYD=NZ/5
QNYD=NYD
IF (QNY/5.0-QNYD) 270,275,270
C
C    PRINTING THE HISTOGRAM (USING X-S)
275 PRINTFM1,NYU,(SHT(NX),NX=1,NUM1S),NYU
    GO TO 300
270 PRINTFM2,(SHT(NX),NX=1,NUM1S)
300 CONTINUE
C
C    PRINTING X-AXIS SCALE UNDERNEATH THE HISTOGRAM (USING X-S)
320 NPX=QM+1.5
    JJTOP=NXT/5+2
    DO 333 K=1,JJTOP
    KP=5*(K-1)+1
    BASE(KP)=FB
    BASE(KP+1)=FB
    BASE(KP+3)=FB
    BASE(KP+2)=FB
333 BASE(KP+4)=FB
    NXT2=NXT+7
    DO 335 K=NXT2,NBW
335 BASE(K)=FB
    BASE(NPX)=F70
    PRINT337,(BASE(K),K=1,NBW)
337 FORMAT(1H+5X:12A1)
    DO 345 J=1,JJTOP
    XJ=J
C 345 NXL(J)=(5.0*XJ-5.0)*G2*ABSF(YWDTH)+XZERO
345 NXL(J)=(5.0*XJ-5.0)*G2*ABS (YWDTH)+XZERO
    PRINT 10
347 PRINT902,(NXL(J),J=1,JJTOP)
905 FORMAT(1H0)
902 FORMAT(3X22I5)
    PRINT 931,N500
931 FORMAT(102X10HTOTAL N = 15)
305 RETURN
C
C    SLICING OFF THE TOP OF EACH COLUMN TO BUILD FORMAT MATRIX
C    FOR NXT LESS THAN NUM1S (I.E. USING STEPS , NOT X.S )
400 DO 500 NZ=1,NTOP

```

```

DO 405 NX=1,NUM1S
405 SHT(NX)=FB
IF (NZ-NTOP) 403,406,409
406 DO 408 NX=1,NUM3S
SHT(3*NX+1)=FM
SHT(3*NX)=FA
408 SHT(3*NX-1)=FA
409 R=NTOP-NZ
RCN=-2.0
C
410 DO 450 NX=1,NXT
IF (RCT(NX)-R) 450,411,412
411 NXBT=3*NX+1
SHT(NXBT)=FP
SHT(NXBT-1)=FM
SHT(NXBT-2)=FM
SHT(NXBT-3)=FP
GO TO 450
412 NXBT=3*NX+1
NXBT1=NXBT-1
NXBT2=NXBT-2
NXBT3=NXBT-3
C
440 IF (RCT(NX)-R-1.0) 441,446,446
441 SHT(NXBT)=FP
IF (RCT(NX)-R-0.5) 442,443,444
442 SHT(NXBT1)=FD
SHT(NXBT2)=FD
GO TO 445
443 SHT(NXBT1)=FP
SHT(NXBT2)=FP
GO TO 445
444 SHT(NXBT1)=FI
SHT(NXBT2)=FI
445 SHT(NXBT3)=FP
GO TO 450
446 SHT(NXBT)=FI
IF (RCN-1) 447,448,447
447 SHT(NXBT1)=FM
SHT(NXBT2)=FM
448 IF (RCT(R) 449,450,450
449 SHT(NXBT3)=FI
450 RCN=RCT(NX)
C
C PREPARATION OF Y-AXIS SCALE
NYU=(NTOP -NZ)*2*(HC-1)
QNY=NZ
NYD=NZ/5
QNYD=NYD
460 IF (QNY/5.0-QNYD) 470,475,470
C
C PRINTING THE HISTOGRAM (USING STEPS)
470 PRINTFMT2,(SHT(NX),NX=1,NUM1S)
GO TO 500
475 PRINTFMT1,NYU,(SHT(NX),NX=1,NUM1S),NYU
500 CONTINUE
C
C PRINTING X-AXIS SCALE UNDERNEATH HISTOGRAM(USING STEPS)
510 NPX=3.0*DM + 0.5
NXT2=NXT+1
NXT22=NXT2/2+1
DO 512 K=1,NXT22

```

```

      KT=6*(K-1)+1
      KT1=KT+1
      KT2=KT+2
      BASE(KT)=FM
      BASE(KT1)=FD
      BASE(KT2)=FD
      BASE(KT+3)=FD
      BASE(KT+4)=FD
512  BASE(KT+5)=FD
      NXT6=3*NXT2
      BASE(NPX)=FMM
      PRINT517,(BASE(K),K=1,NXT6)
517  FORMAT(1H+7X110A1)
      JJTOP=NXT/2+1
      DO 500 J=1,JJTOP
      NJ=J
C 520  NXL(J)=(2.0*XJ-2.0)*G2*ABS(XWDTH)+XZERO
520  NXL(J)=(2.0*XJ-2.0)*G2*ABS(XWDTH)+XCEPD
      PRINT 10
      10  FORMAT(1H )
      PRI: T903.(NXL(J),J=1,JJTOP)
903  FORMAT(3X1816)
      PRINT931,NSUM
      RETURN
      END

```

\$FM.

THIS IS A SIMULATED DATA TAPE FOR HRS. P 4HE ELASTIC SCATTERING
WITH NO BROADENING EFFECTS EXCEPT THAT ONLY SECOND ORDER COEFFICIENTS
HAVE BEEN USED FOR BEAM AND HRS. THE BEAM LINE USED TRANSPORT AND
THE SPECTROMETER USED RAY TRACING.

4HE(P,P)4HE

938.2593 129.4409 938.2592 3728.4409

800.

PUNCH

```

      02/01/72 03.46.09.
1.10177E-05-1.15363E-05-1.10273E+00-3.50475E-01 0. 2.34349E-04
1.97177E-05-1.63065E-04-1.52168E+00-1.39047E+00 0. 4.62054E-04
1.33177E-01-4.47750E-06 5.41898E-06-9.37639E-06 0. 2.27729E+01
8.64177E-04 7.47928E+00-1.76281E-05 2.60824E-05 0. -4.58658E+01
2.02977E-01 1.70325E+01 0. 0. 1.00000E+00-2.14543E+00
0. 0. 0. 0. 1.00000E+00
-6.58877E-07
-1.11580E-03-4.72807E-06
9.15677E-01 7.80177E-01 9.42503E-08
7.55493E-01 5.77470E-02-3.43247E-07 2.06349E-07
0. 0. 0. 0. 0.
2.26227E+00 1.89196E+00-2.32813E+00 3.86998E+00 0. 1.27701E+00
-1.17642E-05
-1.99432E-05-8.46537E-06
1.79594E-01 1.55931E-01 1.74470E-07
4.58705E-02 2.79845E-02-6.26175E-07 3.59302E-07
0. 0. 0. 0. 0.
4.12037E+00 3.44569E+00-4.25598E+00 6.92324E+00 0. 2.45469E+00
-1.40706E-02
-3.68240E-02-2.09807E-02
2.01619E-07 1.66227E-07 3.35668E-03
-1.08575E-06-9.08583E-07-7.51301E-03-4.70531E-03
0. 0. 0. 0. 0.
-2.99183E-01-2.52669E-01 1.23099E-01-1.90272E-01 0. -1.16652E-01
-4.98134E-01
-8.06571E-01-3.26499E-01
-3.96338E-07-3.18136E-07-1.33190E-03
3.24758E-05 2.70523E-05-6.59734E-03 3.02935E-02
0. 0. 0. 0. 0.

```

159

150

Appendix F
Listing of HT Optimization Code

```

SJOB(NAME=MPQRJR,CL=U,AC=MP1QRJR,UA=95ICE225 RJP,PR=21,TL 71M,PL=100,MX=76)
  SUBROUTINE MAINMT
    COMMON/ARGS/IA(5),IRRAW(10),IRUN,ISCAN,ITIME(2),INVR,ICFF,NPTS,
    1IAC,IPDS(3),IRG(3),I=IA,INT(PI),IRLANK(4),ISCOPE,ICCI,LOOP,NPG,
    2NSTAT,RDES(3),RRES(3),ANW(1),ADES(9),APRES(9),ANEM(9),A(30),
    3V(4),PCO(3,9),C(1,1),PI(1),PMSP,PMSPH,PMST,NMT,MX,ICD4,IFIC,
    4IRFG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),ICOR(6),IEPT(10)
    IF(IA(1).EQ.2)GO TO 5000
    ICCI=LSL(NPG,12)+NSTAT+2
    GO TO (2001,2002,2003,2004,2005,2006,2007,2008),NPGRET
  5000 CONTINUE
    NPGRET=1
    NSTAT=IA(2)
    NPG=304
    ICCI=LSL(NPG,12)+IA(2)+2
    ISCOPE=IA(2)+12
    IOUT(1)=6
    IOUT(2)=NSTAT+2
    IOUT(3)=304
    IOUT(4)=304
    IOUT(5)=1
    IOUT(6)=5
    LOOP=0
    CALL RESID(NPG,NSTAT,2,5,ICANT)
    IF(ICANT.EQ.1)RETURN
  C
  DO 5001 I=1,4
  5001 IORDER(I)=I
  DO 5002 I=1,10
  5002 IEPT(I)=1
  C INTERNAL DATA
  C DEFAULT TREG,ICEL,NUMNMR
  TREG=2272
  IDEL=34
  NUMNMR=1
  C
  C ICON=1 LAGRANGE CONSTRAINT ON
  C ICON NE 1 CONSTRAINT OFF
  ICON=2
  C
  C IFIC=1 FIELD LEVEL ADJUSTER ON
  C IFIC,NE,1 ADJUSTER OFF
  IFIC=1
  C
  C DESIRED CURRENT DISTRIBUTION
  DO 9 I=1,9
    ADES(I)=0.
    APRES(I)=0.
    ANEM(I)=0.
  9 CONTINUE
  C
  C SPECS ON \ OF MT WINDINGS* MAX 8
  NMT=8
  C SPECS ON \ OF SCAN POSITIONS* MAX 30
  NX=30
  C EPSILONS ELAST IS USED IN CURRENT PREDICTION
  ELAST=1.
  C SET W WEIGHTS
  DO 8 I=1,NX
    W(I)=1.
  8
  C SET V WEIGHTS

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```

      DO 6 I=1,9
      V(I)=2.
C LOAD BDES,BPRES,BNEW WITH ZERO SO NO PROBLEM CALLIN
C AVER IN HEIGHT
      DO 5 I=1,NX
      BDES(I)=0.
      BPRES(I)=0.
      BNEW(I)=0.
5     CONTINUE
C SET DEFAULT BRANCH CONTROL
      DO 15 I=1,6
      IBRAN(I)=1
15    CONTINUE
      IBRAN(4)=0
      IBRAN(5)=0
      DO 14 I=7,10
14    IBRAN(I)=0
      IIN(1)=0
      IIN(2)=0
      CALL FSC(1,1)
      WRITE(ICC1,901)
901   FORMAT(40H***HTRMR
12    CONTINUE
      LOOP=LOOP+1
      CALL FSC(1,11)
      WRITE(ICC1,902)
902   FORMAT(30HBRANCH CONTROL
      CALL FSC(2,1)
      WRITE(ICC1,16)
16    FORMAT(160X)
      WRITE(ICC1,903) (IBRAN(I),I=1,10)
903   FORMAT(10I4)
      READ(ICC1,903)(IBRAN(I),I=1,10)
      CALL NCURSR(NPG,NSTAT,LINE,ICHR)
      IF(LINE,EO.1.AND.ICHR.LE.3)GO TO 709
C ENTER DESIRE*****
      IF(IBRAN(1))701,701,700
700   CALL DESIRE
C ENTER WEIGHT*****
701   IF(IBRAN(2))703,703,702
702   CALL WEIGHT
C ENTER RPRES*****
703   IF(IBRAN(3))705,705,704
704   IA(1)=1019
      IOUT(3)=340
      IOUT(4)=448
      CALL DMOPAN(177,IOUT(1))
      ICCI=LSL(448,12)+NSTAT+2.
      CALL DMOPA(448,IA(1))
      RETURN
2001  IOUT(3)=448
      IOUT(4)=344
      CALL DMOPAN(177,IOUT(1))
C ENTER RDES*****
705   IF(IBRAN(4))707,707,706
706   IA(1)=1019
      IOUT(3)=344
      IOUT(4)=535
      CALL DMOPAN(177,IOUT(1))
      ICCI=LSL(535,12)+NSTAT+2
      CALL DMOPA(535,IA(1))
      RETURN

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```

2000 IOUT(3)=535
      IOUT(4)=344
      CALL DMOPAW(177,IOUT(1))
707  CONTINUE
C  ENTER ROBOI*****
      IF(IIN(1))804,804,202
804  IA(1)=1019
      IOUT(3)=344
      IOUT(4)=460
      CALL DMOPAW(177,IOUT(1))
      ICCI=LSL(460,12)+NSTAT+2
      CALL DMOPA(460,IA(1))
      RETURN
2002 IOUT(3)=460
      IOUT(4)=344
      CALL DMOPAW(177,IOUT(1))
      IIN(1)=1
202  CONTINUE
C  ENTER SMOOTM*****
      IF(IBRAN(5))203,203,200
200  IF(IIN(2))204,204,203
204  IA(1)=1019
      IOUT(3)=344
      IOUT(4)=484
      CALL DMOPAW(177,IOUT(1))
      ICCI=LSL(484,12)+NSTAT+2
      CALL DMOPA(484,IA(1))
      RETURN
2003 IOUT(3)=484
      IOUT(4)=344
      CALL DMOPAW(177,IOUT(1))
      IIN(2)=1
C
203  CONTINUE
C  ENTER RADES*****
      IF(IBRAN(6))800,800,800
800  CALL RADES
801  CONTINUE
C  OFFER DBOI PLOTS HERE
C  ENTER PLDPDI*****
      IF(IBRAN(7))808,808,808
808  IA(1)=1019
      IOUT(3)=344
      IOUT(4)=534
      CALL DMOPAW(177,IOUT(1))
      ICCI=LSL(534,12)+NSTAT+2
      CALL DMOPA(534,IA(1))
      RETURN
2004 IOUT(3)=534
      IOUT(4)=344
      CALL DMOPAW(177,IOUT(1))
809  CONTINUE
C  SOLVE PROBLEM
C  ENTER SOLVE*****
201  IA(1)=1019
      IOUT(3)=344
      IOUT(4)=492
      CALL DMOPAW(177,IOUT(1))
      ICCI=LSL(492,12)+NSTAT+2
      CALL DMOPA(492,IA(1))
      RETURN
2005 IOUT(3)=492

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```

      IOUT(4)=344
      CALL DMOPAN(177,IOUT(1))
C   ENTER OUTHY*****
      IA(1)=1019
      IOUT(3)=344
      IOUT(4)=493
      CALL DMOPAN(177,IOUT(1))
      ICCI=LSL(493,12)*NSTAT+2
      CALL DMOPAN(493,IA(1))
      RETURN
2006 IOUT(3)=493
      IOUT(4)=344
      CALL DMOPAN(177,IOUT(1))
C   OFFER BDES,BPRES,BNEW PLOTS
C   ENTER PLR*****
      IF(1BRAN(8))E07,R07,R06
806  IA(1)=1019
      IOUT(3)=344
      IOUT(4)=525
      CALL DMOPAN(177,IOUT(1))
      ICCI=LSL(525,12)*NSTAT+2
      CALL DMOPAN(525,IA(1))
      RETURN
2007 IOUT(3)=525
      IOUT(4)=344
      CALL DMOPAN(177,IOUT(1))
807  CONTINUE
      GO TO 12
709  CALL CANIO(NPG,NSTAT,2,5)
      RETURN
      END
      SUBROUTINE WEIGHT
      COMMON/IARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
      1INC,IPOS(30),IFG(30),IMAIN,IMT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,
      2NSTAT,RDES(30),RFRFS(30),RNEW(30),ADES(9),APRES(9),RNEW(9),N(30),
      3V(9),RBDI(30,9),DI(10),ELAST,RMSP,RMSB,RMSDI,NHT,NX,ICON,IFIC,
      4IBEG,IOEL,NUMNMR,NPGRET,IOUT(6),IIN(6),ICROER(8),IEPPT(10)
      CALL FSC(1,11)
      WRITE(ICCI,12)
12   FORMAT(3PHW WEIGHTS )
      CALL FSC(2,1)
      WRITE(ICCI,16)
16   FORMAT(16PX)
      WRITE(ICCI,13)(P(1),I=1,NX)
13   FORMAT(30F5,2)
      READ(ICCI,13)(W(1),I=1,NX)
      CALL FSC(1,11)
      WRITE(ICCI,14)
14   FORMAT(30PV WEIGHTS )
      CALL FSC(2,1)
      WRITE(ICCI,16)
      WRITE(ICCI,15)(V(I),I=1,NHT)
15   FORMAT(3E13,6,1X,3E13,6,1X,3E13,6)
      READ(ICCI,15)(V(I),I=1,NHT)
      CALL AVER(BPRES,BNDRM)
      CALL AVER(BDES,BNDRM)
      RETURN
      END
      SUBROUTINE RADES
      COMMON/IARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
      1INC,IPOS(30),IFG(30),IMAIN,IMT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,

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2NSTAT,BOES(30),BPPFS(30),BNEW(30),ADES(9),APRES(9),ANEW(9),W(30),
3V(9),OHDI(30,9),DI(10),ELAST,RMSP,RMSB,RMSOI,NHT,NX,ICON,IFIC,
4IBEG,IOEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPT(10)
DO 100 I=1,NHT
ADES(I)=APRES(I)
100 CONTINUE
CALL FSC(1,11)
WRITE(ICON,101)
101 FORMAT(30HDESIRED CURRENTS )
CALL FSC(2,1)
WRITE(ICON,103)
103 FORMAT(160X)
WRITE(ICON,102)(ADES(I),I=1,NHT)
READ(ICON,102)(ADES(I),I=1,NHT)
WRITE(ICON,102)(ADES(I),I=1,NHT)
102 FORMAT(3F13.6,1X,3E13.6,1X,3F13.6)
RETURN
END
SUBROUTINE DESIRE
COMMON/IARG5/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
1INC,IPDS(30),IBG(30),IMAIN,IMT(8),IBLANK(4),ISCOPE,ICON,LOOP,NPG,
2NSTAT,BOES(30),BPPFS(30),BNEW(30),ADES(9),APRES(9),ANEW(9),W(30),
3V(9),OHDI(30,9),DI(10),ELAST,RMSP,RMSB,RMSOI,NHT,NX,ICON,IFIC,
4IBEG,IOEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPT(10)
CALL FSC(1,11)
WRITE(ICON,10)
10 FORMAT(30HDESIRED )
CALL FSC(1,21)
WRITE(ICON,11)
11 FORMAT(20HNHT,NX,ICON,IFIC )
CALL FSC(2,1)
WRITE(ICON,20)
20 FORMAT(160X)
WRITE(ICON,12)NHT,NX,ICON,IFIC
12 FORMAT(4I5)
READ(ICON,12)NHT,NX,ICON,IFIC
CALL FSC(1,21)
WRITE(ICON,13)
13 FORMAT(20HIREG,IOEL,NUMNMR )
CALL FSC(2,1)
WRITE(ICON,20)
WRITE(ICON,12)IREG,IOEL,NUMNMR
READ(ICON,12)IREG,IOEL,NUMNMR
CALL FSC(1,21)
WRITE(ICON,14)
14 FORMAT(20HELAST )
CALL FSC(2,1)
WRITE(ICON,20)
WRITE(ICON,15)ELAST
15 FORMAT(F10.5)
READ(ICON,15)ELAST
WRITE(ICON,20)
WRITE(ICON,100)(IEMPT(I),I=1,NUMNMR)
100 FORMAT(25HNUMR SHIFTS 112 PER INCH ,3I5)
READ(ICON,101)(IEMPT(I),I=1,NUMNMR)
101 FORMAT(25X,3I5)
RETURN
END
SUBROUTINE AVER(BFIX,BNPM)
DIMENSION BFIX(30)
COMMON/IARG5/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
1INC,IPDS(30),IBG(30),IMAIN,IMT(8),IBLANK(4),ISCOPE,ICON,LOOP,NPG,

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2NS1A1,BDES(30),APPS(30),RNE(30),ADES(9),APPS(9),AKEM(9),M(30),
3V(9),OBSD(30,9),D1(10),ELAST,FWSP,RMSB,PMSDI,WHI,NX,ICON,IFIC,
4REG,IOEL,NUMMR,APGET,IOU(6),IIV(6),IORDER(6),LEPT(10)
8NO9M=9.
DO 601 ILC1,NX
BACKM=BNO9M*9F1X(11)*M(11)
PWX=0.
DO 603 ILC1,NX
RX=B4X*M(11)
BNO9M=B4O9M/RNX
DO 602 ILC1,NX
BFX(11)=BFX(11)+BNO9M
RETURN
END

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$JOB(NAME='MPORJR,CL=U,AC=MP10RJR,UAE091PE225 RJR,PR=21,TL=01M,PL=100,MX=76)
SUBROUTINE RPRES
  DIMENSION NRUN(3)
  DIMENSION RPRES(32),ATEMP(30),NSCAN(3)
  COMMON/IARGS/IA(5),IRPAM(10),IPUN,ISCAN,ITIME(2),INPR,IOFF,NPTS,
  1INC,IPDS(30),IHC(30),IMAIN,IHT(A),IPLANK(4),ISCOPE,ICCI,LOOP,APG,
  2NSTAT,BDES(30),BPRES(30),RNEW(30),ADES(9),APRES(9),ANEW(9),N(30),
  3V(9),DHOI(30,9),DIF(10),ELAST,RMGP,RMSR,RMSD, NMT,NX,ICON,IFIC,
  4IREG,IDEL,NUMNMR,MPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
  RAP=NUMNMR
  CALL FSC(1,11)
  WRITE(ICC1,10)
10  FORMAT(20HRPRES
      )
  CALL FSC(2,1)
  DO 6 I=1,NMT
6    IORDER(I)=I
  WRITE(ICC1,25)
25  FORMAT(160X)
  WRITE(ICC1, 3002)(IORDER(K),K=1,NMT)
3002 FORMAT(10NMT ORDER ,A12)
  READ(ICC1,3003)(IORDER(K),K=1,NMT)
3003 FORMAT(10X,812)
  WRITE(ICC1, 3002)(IORDER(K),K=1,NMT)
  WRITE(ICC1,25)
  NRUN(1)=1
  WRITE(ICC1,2000)NRUN(1)
2000 FORMAT(10NRUN PROMPT,15)
  READ(ICC1,2001)NRUN(1)
2001 FORMAT(10X,15)
  WRITE(ICC1,25)
  DO 39 I=1,3
39  NSCAN(I)=1
  DO 2002 J=1,NUMNMR
  WRITE(ICC1,12)J,NRUN(J),NSCAN(J)
12  FORMAT(10NMR NUM ,15,25X,215)
  READ(ICC1,13)K,NRUN(J),NSCAN(J)
13  FORMAT(10X,15,25X,215)
2002 CONTINUE
  9 CALL RESIO(448,0.6,0.0,ICANT)
  IF(ICANT.EQ.1) GO TO 9
C  LOCATE PROPER FILE FOR REQUESTED RUN
  27 WRITE(ICC1,25)
  WRITE(ICC1,26)
26  FORMAT(19HREWIND TAPE YES NO)
  READ(ICC1,25)
  CALL WCURSR(448,NSTAT,LINE,ICHAR)
  IF(LINE.NE.2) GO TO 27
  IF(ICHAR.GE.10.AND.ICHAR.LE.19) GO TO 31
  IF(ICHAR.GE.14.AND.ICHAR.LE.16) GO TO 30
  GO TO 27
30  CALL REWIND(6)
31  CONTINUE
  DO 32 J=1,NX
32  BPRES(J)=0.
  DO 33 J=1,NMT
33  APRES(J)=0.
  DO 1000 I=1,NUMNMR
  IEOF=0
41  CONTINUE
  CALL ROTP(6,4,1,0,77,81,NWDS,IRUN,IPAR,IECF)
  IF(IPAR.EQ.1) GO TO 100

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      IF(IECF,EO,1,AND,ITFQF,EO,8) GO TO 201
      IF(IECF,EO,1,AND,ITFQF,EO,1) GO TO 202
      GO TO 203
201  ITEQF=1
      GO TO 41
202  CALL REMIND(6)
      ITEQF=2
      GO TO 41
203  CONTINUE
      IF(IRUN,EO,NRUN(I),AND,ISCAN,EO,NSCAN(I))GO TO 99
      GO TO 41
99  CONTINUE
      CALL FSC(2,1)
      WRITE(ICC1,25)
      WRITE(ICC1,14)IRUN,ISCAN,ITIME(1),ITIME(2),ITIME(1),ITIME(2)
10  FORMAT(SMNRUN ,13,AM SCAN ,13,1X,2,1X,Y)
      CALL FSC(3,1)
      WRITE(ICC1,15)INMR,IPOS(1),INC,NPTS
      FORMAT(5MNR ,13,7M IBEG ,15,6M INC ,13,7M NPTS ,13)
15  READ(ICC1,25)
      C PUT SHIFTS IN SCAN IF NECESSARY
      DO 2005 IS=1,NPTS
      IPOS(IS)=IPOS(IS)+TEMP(I)
2005  CONTINUE
      CALL EXTRAX(BTEMP)
      DO 30 J=1,NX
      BPRES(J)=BPRES(J)+TEMP(J)
      DO 34 J=1,NMT
      JUX=IORDER(J)
      VOLT=IHT(JUX)
      VOLT=VOLT/1,RES
34  APRES(J)=APRES(J)+ VOLT
1020  CONTINUE
      DO 35 I=1,NX
      BPRES(I)=BPRES(I)/RAP
      DO 36 I=1,NMT
      APRES(I)=APRES(I)/PAP
      CALL AVER(BPRES,BNORM)
      CALL FSC(2,1)
      WRITE(ICC1,25)
      CALL FSC(4,1)
      WRITE(ICC1,37)BNORM
37  FORMAT(7MNBORM ,F13.6)
      READ(ICC1,25)
      CALL CANIO(448,0.6,0)
      IA(1)=IPIS
      NPGRET=1
      CALL DMOPA(344,IA(1))
      RETURN
100  CALL FSC(4,1)
      WRITE(ICC1,101)
101  FORMAT(40X)
      WRITE(ICC1,102)
102  FORMAT(37MGPARTY FPROBS ON RECORD IGNORE YES NO)
      READ(ICC1,101)
      CALL WCOURS(448,NSTAT,LINE,ICHAR)
      IF(LINE,NE,4) GO TO 100
      IF(ICHAR,GE,32,AND,ICHAR,LE,30) GO TO 41
      IF(ICHAR,GE,36,AND,ICHAR,LE,37) CALL CANIO(448,2,6,0)
      IF(ICHAR,GE,36,AND,ICHAR,LE,37) CALL CANIO(448,NSTAT,2,5)
      IF(ICHAR,GE,36,AND,ICHAR,LE,37) RETURN
      GO TO 100

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END
SUBROUTINE AVER(BFIX,GNORM)
DIMENSION BFIX(32)
COMMON/IARGS/IA(5),IPPAR(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
1INC,IPOS(32),IBG(32),IPAIN,IHT(8),IRLANK(4),ISCOPE,ICCI,LOOP,NPG,
2NSTAT,BDES(32),BPRES(32),BNEW(32),ADES(9),APRES(9),ANEW(9),N(32),
3V(9),DBDI(32,9),DI(12),ELAST,RHSP,RHSE,RMSDI,NHT,NX,ICON,IFIC,
4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPT(10)
BNORM=0.
DO 801 IL=1,NX
801 BNORM=BNORM+BFIX(IL)*V(IL)
RNK=0.
DO 803 IL=1,NX
803 RNK=RNK+V(IL)
BNORM=BNORM/RNK
DO 802 IL=1,NX
802 BFIX(IL)=BFIX(IL)-BNORM
RETURN
END
SUBROUTINE EXTRAK(RLOAD)
DIMENSION BLOAD(32),RPOS(32),RG(32)
COMMON/IARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
1INC,IPOS(32),IBG(32),IPAIN,IHT(8),IRLANK(4),ISCOPE,ICCI,LOOP,NPG,
2NSTAT,BDES(32),BPRES(32),BNEW(32),ADES(9),APRES(9),ANEW(9),N(32),
3V(9),DBDI(32,9),DI(12),ELAST,RHSP,RHSE,RMSDI,NHT,NX,ICON,IFIC,
4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPT(10)
NORDER=3
DO 20 I=1,NPTS
RPOS(I)=IPOS(I)
20 CONTINUE
DO 22 I=1,NPTS
BG(I)=IBG(I)
22 CONTINUE
DO 21 I=1,NX
XBAR=IBEG+(I-1)*IDEL
BLOAD(I)=AKNINT(XBAR,NPTS,NORDER,RPOS,BG)
21 CONTINUE
RETURN
END
FUNCTION AKNINT(XBAR,IN,IM,X,Y)
DIMENSION Y(36),X(30),Y(30)
COMMON/IARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
1INC,IPOS(32),IBG(32),IPAIN,IHT(8),IRLANK(4),ISCOPE,ICCI,LOOP,NPG,
2NSTAT,BDES(32),BPRES(32),BNEW(32),ADES(9),APRES(9),ANEW(9),N(32),
3V(9),DBDI(32,9),DI(12),ELAST,RHSP,RHSE,RMSDI,NHT,NX,ICON,IFIC,
4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPT(10)
CALL FSC(4,1)
N=IABS(IN)
M=IM
IF(M.GE,N.OR,M.GT,A) GO TO 100
9 K=N-1
IF(M.LT,2) GO TO 320
S=X(2)-X(1)
IF(IN.LT,0) GO TO 30
DO 20 I=3,N
Z=(X(I)-X(I-1))/S
IF(Z.LE,0.) GO TO 420
20 CONTINUE
30 IF(S.LT,0.) GO TO 24
DO 20 J=1,N
IF(XBAR.LE,X(J)) GO TO 11

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201 CONTINUE
  J=N
  GO TO 11
20 DO 120 J=1,N
  IF(XBAR,GE,X(J)) GO TO 11
120 CONTINUE
  J=N
11 K=M
  M=M+1
  J=J-M/2
  J=MAX2(J,1)
  J=MIN2(J,N-K)
  MEND=J+K
  DO 121=J,MEND
  KK=I+J+1
  T(KK)=Y(I)
  KKK=KK+M
12 T(KKK)=X(I)-XBAR
  DO 131=1,K
  KK=I+1
  DO 13JJ=KK,M
  JJM=JJ+M
  IMS=I+M
  JMES=JJ+J-1
  IMES=I+J-1
  T(JJ)=(T(I)+T(JJM) -T(JJ)+T(IMES))/(X(JMES) -X(IMES))
13 CONTINUE
  AKKINT=T(M)
  RETURN
420 WRITE(1CC1,1)
1 FORMAT(5X,23MX(1) NOT SEQUENCED OKAY)
  CALL EXIT
300 WRITE(1CC1,2)
2 FORMAT(5X,24MONE DATA POINT YBAR=Y(1))
  AKKINT=Y(1)
  RETURN
100 CONTINUE
  M=N
  IF(M,GT,8)M=8
  WRITE(1CC1,3)M
3 FORMAT(5X,18M TOO LARGE,SET M,15)
  GO TO 9
END
SEJ

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1 JC9(NAME=MPORJR,CL=U,AC=MPJURJR,UA=8910E225 RJR,PR=21,TL=214,PL=100,MX=76)
  SUBROUTINE RD801
  DIMENSION NRUN(3,9)
  DIMENSION RTEMP(3,1),NSCAN(3,9),RINTR1(30),RINTR2(30),AM1(8),AM2(8)
  COMMON/IARG5/I4(5),IPAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
  IINC,IPOS(30),IUC(3),IMAIN,INT(8),IRLANK(4),ISCOPE,ICCI,LOOP,NPG,
  2NSTAT,BDES(30),APRES(30),BNEW(30),ACFS(9),APRES(9),ANEN(9),K(30),
  3V(9),DBDI(30,9),D(10),FLAST,RMSP,RMSB,RMSD1,NHT,NX,ICON,IFIC,
  4IBEG,IOFL,NUMNMR,NPGRET,IOUT(6),IIN(6),ICPDER(8),ITEMP(10)
  RAP=NUMNMR
C COMPUTE FICTIOUS WINDING
  JJ=NHT+1
  DO 5 I=1,NX
5    DBDI(I,JJ)=1.0
C SET UP METHOD OF CALCULATION
C SUBTRACT SUCCESSIVE SCANS ISUC=1
  ISUC=1
  CALL FSC(1,11)
  WRITE(ICC1,10)
10  FORMAT(20HRDBDI)
  CALL FSC(2,1)
  WRITE(ICC1,25)
  WRITE(ICC1,3000)ISUC
3000  FORMAT(6HISUC,12)
  READ(ICC1,3001)ISUC
3001  FORMAT(6X,12)
  NRUN(1,1)=1
  WRITE(ICC1,2000) NRUN(1,1)
2000  FORMAT(10HRUN PROMPT,15)
  READ(ICC1,2001)NRUN(1,1)
2001  FORMAT(10X,15)
  WRITE(ICC1,25)
25  FORMAT(160X)
  ICNT=0
  DO 11 I=1,JJ
  DO 11 J=1,NUMNMR
  NRUN(J,I)=NRUN(1,1)
  ICNT=ICNT+1
11  NSCAN(J,I)=ICNT
  DO 2002 J=1,NUMNMR
  WRITE(ICC1,2003)J,(NRUN(J,L),L=1,JJ),(NSCAN(J,L),L=1,JJ)
2003  FORMAT(10HNMR NUM,15,25X,9I4,4X,9I4,4X)
  READ (ICC1,2004)K,(NRUN(J,L),L=1,JJ),(NSCAN(J,L),L=1,JJ)
2004  FORMAT(10X,15,25X,9I4,4X,9I4,4X)
2002  CONTINUE
9  CALL RESIO(460,0.6,0,ICNT)
  IF(ICNT.EQ.1) GO TO 9
C LOCATE PROPER FILE FOR REQUESTED RUN
27  WRITE(ICC1,25)
  WRITE(ICC1,26)
26  FORMAT(19HREWIND TAPE YES NO)
  READ(ICC1,25)
  CALL NCURSR(400,NSTAT,LTIME,ICHAR)
  IF(LINE.NE.2) GO TO 27
  IF(ICHAR.GE.18.AND.ICHAR.LE.19) GO TO 31
  IF(ICHAR.GE.14.AND.ICHAR.LE.16) GO TO 30
  GO TO 27
30  CALL REWIND(6)
31  CONTINUE
  DO 50 I=1,JJ
  DO 802 IL=1,NX

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882  BINTR2(IL)=0.
      DO 883 IL=1,NMT
883  AM2(IL)=0.
      DO 1000 IN=1,NUMNMR
        ITEOF=0
      41 CONTINUE
        CALL ROTP(6,4,1,2,77,21,NHOS,IPUN,IPAR,IEOF)
        IF(IPAR.EQ.1) GO TO 170
        IF(IEOF.EQ.1.AND.ITEOF.EQ.0) GO TO 201
        IF(IEOF.EQ.1.AND.ITEOF.EQ.1) GO TO 202
        GO TO 203
201  ITEOF=1
      GO TO 41
202  CALL REWIND(6)
      ITEOF=0
      GO TO 41
203  CONTINUE
      IF(IRUN.EQ.NRUN(IN,1).AND.ISCAN.EQ.NSCAN(IN,1))GO TO 99
      GO TO 41
99  CONTINUE
      CALL FSC(2,1)
      WRITE(ICC1,25)
      WRITE(ICC1,14)IPUN,ISCAN,ITIME(1),ITIME(2),ITIME(1),ITIME(2)
14  FORMAT(5HPRN ,I3,4H SCAN ,I3,1X,2,1X,Y)
      CALL FSC(3,1)
      WRITE(ICC1,15)INMR,IPOS(1),INC,NPTS
15  FORMAT(5HNMR ,I3,7H IBEG ,I5,6H INC ,I3,7H NPTS ,I3)
      READ(ICC1,25)
C PUT SHIFTS IN SCAN IF NECESSARY
      DO 2005 IS=1,NPTS
2005  IPOS(IS)=IPOS(IS)+IEMPT(IN)
2205  CONTINUE
      CALL EXTRAX(BTEMP)
      DO 38 J=1,NX
38  BINTR2(J)=BINTR2(J)+BTEMP(J)
      DO 34 J=1,NMT
      JUX=IORDER(J)
      VOLT=IMT(JUX)
      VOLT=VOLT/1,RES
34  AM2(J)=AM2(J)+VOLT
1000 CONTINUE
      DO 35 IL=1,NX
35  BINTR2(IL)=BINTR2(IL)/RAP
      DO 36 IL=1,NMT
36  AM2(IL)=AM2(IL)/RAP
      CALL AVER(BINTR2,BNDRM)
      CALL FSC(2,1)
      WRITE(ICC1,25)
      CALL FSC(4,1)
      WRITE(ICC1,17)BNDRM
37  FORMAT(7HBNDRM ,E13,6)
      READ(ICC1,25)
      IF(1.EQ.1) GO TO 340
      GO TO 400
350  CONTINUE
      DO 351 IL=1,NX
351  BINTR1(IL)=BINTR2(IL)
      DO 352 IL=1,NMT
352  AM1(IL)=AM2(IL)
      GO TO 50
400  CONTINUE
      DO 45 KK=1,NX

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      L=I-1
      OBDI(X,L)=(BINTP2(KK)+BINTR1(KK))/(A*2(L)-AM1(L))
45  CONTINUE
      IF(I5UC,NE,1) GO TO 52
      DO 481 J=1,NX
481  BINTR1(J)=BINTP2(JK)
      DO 482 JK=1,NHT
482  AM1(JK)=A*2(JK)
50  CONTINUE
      CALL CANIO(460,0,6,0)
      IA(1)=1019
      NPGRET=2
      CALL DMOPA(344,IA(1))
      RETURN
100 CALL FSC(4,1)
      WRITE(ICC1,101)
101  FORMAT(0PX)
      WRITE(ICC1,102)
102  FORMAT(374GPARTY ERRORS ON RECORD IGNORE YES NO)
      READ(ICC1,101)
      CALL WCURSR(460,NSTAT,LINE,ICHR)
      IF(LINE,NE,4) GO TO 100
      IF(ICHR,GE,32,AND,ICHR,LE,34) GO TO 41
      IF(ICHR,GE,36,AND,ICHR,LE,37) CALL CANIO(460,0,6,0)
      IF(ICHR,GE,36,AND,ICHR,LE,37) CALL CANIO(460,NSTAT,2,5)
      IF(ICHR,GE,36,AND,ICHR,LE,37) RETURN
      GO TO 100
      END
      SUBROUTINE AVER(RFIX,BNORM)
      DIMENSION RFIX(30)
      COMMON/IAIGS/IA(5),IRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
      1INC,IPCS(30),IBG(30),IMAIN,IHT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,
      2NSTAT,BDES(30),APRES(30),RNEW(30),ADES(9),APRES(9),ANEW(9),W(30),
      3V(9),OBDI(30,9),DI(10),ELAST,RMSP,RMSB,RMSDI,NHT,NX,ICON,IFIC,
      4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
      BNORM=0.
      DO 801 IL=1,NX
801  BNORM=BNORM+RFIX(IL)*W(IL)
      RNK=0.
      DO 803 IL=1,NX
803  RNK=RNK+W(IL)
      BNORM=BNORM/RNK
      DO 802 IL=1,NX
802  RFIX(IL)=RFIX(IL)-BNORM
      RETURN
      END
      SUBROUTINE EXTPAK(LOAD)
      DIMENSION BLOAD(30),RPOS(30),BG(30)
      COMMON/IAIGS/IA(5),IRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
      1INC,IPCS(30),IBG(30),IMAIN,IHT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,
      2NSTAT,BDES(30),APRES(30),RNEW(30),ADES(9),APRES(9),ANEW(9),W(30),
      3V(9),OBDI(30,9),DI(10),ELAST,RMSP,RMSB,RMSDI,NHT,NX,ICON,IFIC,
      4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
      NORDER=3
      DO 20 I=1,NPTS
20  RPOS(I)=IPCS(I)
      CONTINUE
      DO 22 I=1,NPTS
22  BG(I)=IBG(I)
      CONTINUE
      DO 21 I=1,NX

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      XBAR=YBEG+((I-1)*YOFI
      BLOAD(I)=AKNINT(XBAR,NPTS,NORDER,RPOS,BC)
21    CONTINUE
      RETURN
      END
      FUNCTION AKNINT(XBAR,IN,IM,X,Y)
      DIMENSION Y(36),X(37),Y(39)
      COMMON/ARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
      1 INC,TPOS(39),ISG(30),I4AIN,IMT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,
      2 NSTAT,BDES(39),APRES(37),RNEW(39),ADES(9),APRES(9),ANEX(9),M(30),
      3 V(9),DBDI(39,9),DI(10),ELAST,RMSP,RMSH,RMSDI,NHT,AX,ICON,IFIC,
      4 IREG,IOEL,NUMNPR,NPGRET,IOUT(6),ITN(6),IORDER(8),IEMPT(10)
      CALL FSC(4,?)
      N=IABS(1h)
      M = IM
      IF(M.GE.N.OR.M.GT.N) GO TO 100
      9 K=N-1
      IF(N.LT.2) GO TO 300
      S=X(2)-X(1)
      IF(IN.LT.0) GO TO 30
      DO 20 I=3,N
      Z=X(I)-X(I-1)+S
      IF(Z.LE.0.) GO TO 320
20    CONTINUE
      30 IF(S.LT.0.) GO TO 24
      DO 20 IJ=1,N
      IF(XBAR.LE.X(IJ)) GO TO 11
201  CONTINUE
      J=N
      GO TO 11
      20 DO 120 J=1,N
      IF(XBAR.GE.X(J)) GO TO 11
120  CONTINUE
      J=N
      11 K=N
      M=M+1
      J=J-M/2
      J=MAX0(J,1)
      J=MIN0(J,N+K)
      MEND=J+K
      DO 121 I=J,MEND
      KK=I+J+1
      T(KK)=Y(I)
      KKM=KK+M
12  T(KKM)=X(I)-XBAR
      DO 131 I=1,K
      KK=1+I
      DO 13JJ=KK,M
      JJM=JJ+M
      JMS=I+M
      JMS=JJ+J+1
      JMS=I+J+1
      T(JJ)=(T(I)+T(JJM) +T(JJ)+T(JMS))/(X(JMS) -X(JMS))
13  CONTINUE
      AKNINT=T(4)
      RETURN
420  WRITE(ICC1,1)
      1  FORMAT(5X,23MX(1) NOT SEQUENCED OKAY)
      CALL EXIT
300  WRITE(ICC1,2)
      2  FORMAT(5X,24XONE DATA POINT YBAR=Y(I))
      AKNINT=Y(1)

```

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      RETURN
100 CONTINUE
      M=N
      IF(M,GT,6)M=6
      WRITE(1001,3)M
3     FORMAT(5X,18H TOO LARGE,SET M,15)
      GO TO 9
      END
SEJ

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$JOB(NAME=MPORJR,CL=U,AC=MP,PRJR,UA=8910E225 RJR,PR=21,TL=31M,PL=100,MX=76)
      SUBROUTINE OUTH1
      COMMON/ARGSI/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
      INC,IPGS(30),IRG(30),IMATN,INT(8),IRLANX(4),ISCOP,ICCI,LOOP,NPG,
      RNSTAT,BDES(30),BPRS(30),RNEW(30),ADES(9),APRES(9),ANEW(9),W(30),
      JV(9),ORDI(30,9),DI(12),FLAST,RMSP,RMSB,RMSDI,NHT,NX,ICON,IFIC,
      AIBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
C     COMPUTE SUM OF WEIGHTS
      RNK=0.
      DO 602 I=1,NX
602    RNK=RNK+W(I)
C
C     COMPUTE RMSP PRESENT SCAN RMS
      RMSP=0.
      DO 600 I=1,NX
600    RMSP=RMSP+W(I)*(BDES(I)-BPRS(I))**2
      RMSP=RMSP/RNK
      RMSP=SQRT(RMSP)
C     COMPUTE RMS B AND RMS DI
      RMSB=0.
      RMSDI=0.
      DO 561 I=1,NX
561    RMSB=RMSB+W(I)*(BDES(I)-BNEW(I))**2
      RMSB=RMSB/RNK
      RMSB=SQRT(RMSB)
      DO 562 I=1,NHT
562    RMSDI=RMSDI+W(I)*(ADES(I)-ANEW(I))**2
      RNHT=NHT
      RMSDI=RMSDI/RNHT
      RMSDI=SQRT(RMSDI)
      CALL FSC(1,1)
      WRITE(1001,10)
10     FORMAT(20HOUTHT
      CALL FSC(2,1)
      WRITE(1001,25)
25     FORMAT(160X)
      WRITE(1001,11)RMSP,RMSB,RMSDI
11     FORMAT(4H RMS ,3F12.5)
      CALL FSC(3,1)
      JJ=NHT+IFIC
      WRITE(1001,12)(ANEW(I),I=1,JJ)
12     FORMAT(3E13.6,1X,3F13.6,1X,3E13.6)
      CALL FRASE(ISCOP,10UM)
      CALL FSC(1,1)
      CALL FSSS(7)
      WRITE(ISCOP,200)LOOP,(IBRAN(I),I=1,10)
200    FORMAT(5ML00P ,14,8H IBRAN ,1P13)
      CALL FSC(3,1)
      WRITE(ISCOP,201)NHT,NX,ICON,IFIC,ELAST
201    FORMAT(18HNHT NX ICON IFIC ,4I7,8H ELAST ,E13.6)
      CALL FSC(4,1)
      WRITE(1001,202)RMSP,RMSB,RMSDI
202    FORMAT(5H RMSP ,E13.6,6H RMSB ,E13.6,7H RMSDI ,E13.6)
      CALL FSC(5,1)
      WRITE(ISCOP,203)
203    FORMAT(6H HT ,7H ADES,8X,8H APRES,7X,7H ANEW)
      JJ=NHT+IFIC
      DO 204 I=1,JJ
      IQ=6+I
      CALL FSC(IQ,1)
      NUMHT=IORDER(I)

```

```

      IF (IFIC.EQ.1.AND.I.EQ.JJ) NUMHT=JJ
      WRITE(ISCOPE,205) NUMHT, ADES(I), APRES(I), ANE4(I)
205  FORMAT(2X,I2,4X,E13.6,2X,E13.6,2X,E13.6)
206  CONTINUE
      CALL FSC(16,1)
      WRITE(ISCOPE,206)
      FORMAT(9HW, HEIGHTS)
206  CALL FSC(17,1)
      WRITE(ISCOPE,207) (W(I), I=1, NX)
207  FORMAT(10F5,2,/)
      CALL FSC(22,1)
      WRITE(ISCOPE,208)
208  FORMAT(9HW, HEIGHTS)
      CALL FSC(21,1)
      WRITE(ISCOPE,209) (V(I), I=1, NHT)
209  FORMAT(4E15,6,/)
      CALL FSC(23,1)
      WRITE(ISCOPE,210)
210  FORMAT(7HDELTA A)
      CALL FSC(24,1)
      WRITE(ISCOPE,209) (OI(I), I=1, NHT)
      CALL FSC(3,9)
      READ(IIC1,13)
13  FORMAT(1X)
      IA(1)=1019
      NPGRET=6
      CALL DMOPA(344, IA(1))
      RETURN
      END
SEJ

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$JCB(NAME=MPORJR,CL=U,AC=MP10RJR,UA=8910E225 RJR,PR=21,TL=01M,PL=100,MZ=76)
  SUBROUTINE PLA
    DIMENSION RPOS(32),IARG(64),ICAR(3)
    INTEGER O
    COMMON/IARG/I(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
    1INC,IPOS(30),IRG(30),IMAIN,IMI(8),IRLINK(4),ISCOPE,ICCI,LOOP,MFG,
    2NSTAT,BDES(30),BPRES(30),BNEW(30),ACES(9),APRES(9),ANEW(9),W(30),
    3V(9),DBDI(30,9),DI(10),ELAST,RMSP,RMSB,RMSDI,NMT,NX,ICON,IFIC,
    4IBEG,IDEL,NUHMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
    EQUIVALENCE(IARG(9),XMIN)
    EQUIVALENCE(IARG(11),XMAX)
    EQUIVALENCE(IARG(13),YMIN)
    EQUIVALENCE(IARG(15),YMAX)
  9  CALL ERASE(ISCOPE,IOUM)
    CALL FSC(1,1)
    CALL FSSS(8)
    ICAR(1)=0(330)
    ICAR(2)=0(243)
    ICAR(3)=0(253)
    WRITE(ISCOPE,10)((ICAR(I),I=1,3),LOOP
  10  FORMAT(5HBDDES ,A1,4H BPRES ,A1,7H BNEW ,A1,6H LOOP ,I4)
    CALL FSSS(6)
    CALL FSC(3,1)
    WRITE(ISCOPE,11)RMSP,RMSB,RMSDI
  11  FORMAT(5HRMSP ,E13.6,6H RMSB ,E13.6,7H RMSDI ,E13.6)
    CALL RESCOM(525,240,ICANT)
    IF(ICANT)12,12,9
  12  CALL LNKCOM(525,ICANT)
    IF(ICANT)13,13,12
  C LOAD Y AXIS
  13  CALL STICOM(BDES,0,180)
  C LOAD POSITIONS X AXIS
    DO 14 I=1,NX
      RPOS(I)=IBEG+(I-1)*IDEL-2048
      RPOS(I)=RPOS(I)/112.
  14  CONTINUE
    CALL STICOM(RPOS,180,60)
  C SET UP IARG FOR 187
    IARG(1)=63
    IARG(2)=0
    IARG(3)=525
    IARG(4)=ISCOPE
    IARG(5)=40
    IARG(6)=1325
    IARG(7)=40
    IARG(8)=900
    XMIN=IBEG-2048
    XMIN=XMIN/112.
    XMAX=IBEG+(NX-1)*IDEL-2048
    XMAX=XMAX/112.
  C COMPUTE RANGE OF B FIELD IN B VECTORS FOR RANGING ON PLOT
    YMAX=BDES(1)
    YMIN=BDES(1)
    DO 15 I=1,NX
      IF(BDES(I).GT,YMAX)YMAX=BDES(I)
      IF(BPRES(I).GT,YMAX)YMAX=BPRES(I)
      IF(BNEW(I).GT,YMAX)YMAX=BNEW(I)
      IF(BDES(I).LT,YMIN)YMIN=BDES(I)
      IF(BPRES(I).LT,YMIN)YMIN=BPRES(I)
      IF(BNEW(I).LT,YMIN)YMIN=BNEW(I)
  15  CONTINUE

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IARG(17)=4
IARG(18)=6
IARG(19)=6
IARG(20)=6
IARG(21)=3
C START CURVE SPECS
C FIRST CURVE
IARG(22)=0(44330)
IARG(23)=0
IARG(24)=0
IARG(25)=0
IARG(26)=0
IARG(27)=NX
IARG(28)=0
IARG(29)=525
IARG(30)=180
IARG(31)=2
IARG(32)=0
IARG(33)=525
IARG(34)=0
IARG(35)=2
C SECOND CURVE
IARG(36)=0(44243)
IARG(37)=0
IARG(38)=0
IARG(39)=0
IARG(40)=0
IARG(41)=NX
IARG(42)=0
IARG(43)=525
IARG(44)=180
IARG(45)=2
IARG(46)=0
IARG(47)=525
IARG(48)=0
IARG(49)=2
C THIRD CURVE
IARG(50)=0(44253)
IARG(51)=0
IARG(52)=0
IARG(53)=0
IARG(54)=0
IARG(55)=NX
IARG(56)=0
IARG(57)=525
IARG(58)=180
IARG(59)=2
IARG(60)=0
IARG(61)=525
IARG(62)=120
IARG(63)=2
CALL DMOPA(187,IARG)
CALL FSC(1,1)
READ(ICC,16)
16  FORMAT(1X)
1001 CALL DELAY(1000)
CALL CANCOM(525,ICANT)
IF(ICANT,EQ,1)GO TO 100
IA(1)=1819
MPGRET=7
CALL DMOPA(340,IA(1))
RETURN

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3EJ  END

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SJOB(NAME=MPDRJR,CL=U,AC=MPDRJR,UA=8910E225 RJR,PR=21,TL=01H,PL=100,MX=76)
SUBROUTINE PLOPDI
  DIMENSION RPOS(30),IARG(64)
  INTEGER 0
  COMMON/IARG5/IA(5),IRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
  1INC,IPOS(30),IHC(30),IMAIN,INT(4),IRLANX(4),ISCOPE,ICCI,LOOP,NPG,
  2NSTAT,BDES(30),BPRFS(30),PNEW(30),ADES(9),APRES(9),ANEW(9),X(30),
  3V(9),DBDI(30,9),DI(10),ELAST,RMSP,RMSB,RMSDI,NMT,NX,ICON,IFIC,
  4IBEG,IDEL,NUHNM9,APCRET,IOUT(6),IIN(6),IOROEN(8),IEMPT(10)
  EQUIVALENCE(IARG(9),XMIN)
  EQUIVALENCE(IARG(11),XMAX)
  EQUIVALENCE(IARG(13),YMIN)
  EQUIVALENCE(IARG(15),YMAX)
  JJ=NMT+IFIC
C COMPUTE RANGE OF DERIVATIVES
  YMAX=DBDI(1,1)
  YMIN=DBDI(1,1)
  DO 8 I=1,NX
    DO 8 J=1,JJ
      IF(DBDI(I,J).GT.YMAX)YMAX=DBDI(I,J)
      IF(DBDI(I,J).LT.YMIN)YMIN=DBDI(I,J)
  8 CONTINUE
  DO 1000 I0=1,JJ
    ICHAR=0(130)
  9 CALL ERASE(ISCOPE,IDUM)
    CALL FSC(1,1)
    CALL FSSS(8)
    JUX=IOROEN(I0)
    IF(IFIC.EQ.1.AND.I0.EQ.JJ)JUX=JJ
    WRITE(ISCOPE,16)JUX,LOOP
  10 FORMAT(4HDBDI,4H HT ,33,6H LOOP ,10)
  11 CALL RESCOM(534,120,ICANT)
    IF(ICANT)12,12,9
  12 CALL LKCOM(534,ICANT)
    IF(ICANT)13,13,12
C LOAD Y AXIS
  13 CONTINUE
    DO 14 I=1,NX
      RPOS(I)=DBDI(I,10)
  14 CONTINUE
    CALL STICOM(RPOS,0,60)
C LOAD X POSITIONS
    DO 15 I=1,NX
      RPOS(I)=IBEG+(I-1)*IDEL-2048
      RPOS(I)=RPOS(I)/112.
  15 CONTINUE
    CALL STICOM(RPOS,60,60)
C SET UP IARG FOR PROGRAM 107
  IARG(1)=35
  IARG(2)=0
  IARG(3)=534
  IARG(4)=ISCOPE
  IARG(5)=40
  IARG(6)=1325
  IARG(7)=42
  IARG(8)=900
  XMIN=IBEG-2048
  XMIN=XMIN/112.
  XMAX=IBEG+(NX-1)*IDEL-2048
  XMAX=XMAX/112.
  IARG(17)=4

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      IARG(18)=0
      IARG(19)=6
      IARG(20)=6
      IARG(21)=1
      IARG(22)=0(46130)
      IARG(23)=0
      IARG(24)=0
      IARG(25)=0
      IARG(26)=0
      IARG(27)=0MX
      IARG(28)=0
      IARG(29)=530
      IARG(30)=60
      IARG(31)=2
      IARG(32)=0
      IARG(33)=530
      IARG(34)=0
      IARG(35)=2
      CALL DMOPA(187,IARG)
      CALL FSC(1,1)
      READ(ICC1,17)
      FORMAT(1X)
1001 CALL DELAY(1000)
      CALL CANCOM(530,ICANT)
      IF(ICANT.EQ.1) GO TO 1001
1000 CONTINUE
      IA(1)=1010
      NPGRET=0
      CALL DMOPA(300,IA(1))
      RETURN
      END
SEJ

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9 JOB(NAMF=MPORJP,CL=U,AC=MP10RJR,UA=891CE225 RJR,PR=21,TL=01M,PL=100,MX=75)
  SUBROUTINE RDES
    DIMENSION NRUN(3)
    COMMON/ARGS/IA(5),IPAN(10),IRUN,ISCAN,ITIME(2),INHR,IOFF,NPTS,
    1INC,IPOS(30),I9G(3),IPAIN,INT(8),IHLANK(4),ISCRPE,ICCI,LOOP,NPG,
    2NSTAT,BDES(30),RPRFS(30),RNEW(30),ADES(9),IPRES(9),ANEW(9),W(30),
    3V(9),ORDI(30,9),DI(10),ELAST,RMSP,RMSH,RMSDI,NMT,NX,ICON,IFIC,
    4IBEG,IOEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IOPDER(8),IEMPTY(10)
    RAP=NUMNMR
    CALL FSC(1,11)
    WRITE(ICC1,10)
10   FORMAT(20HRDES
    CALL FSC(2,1)
    WRITE(ICC1,25)
25   FORMAT(16PX)
    NRUN(1)=1
    WRITE(ICC1,2000)NRUN(1)
2000  FORMAT(10HRUN PROMPT,15)
    READ(ICC1,2001)NRUN(1)
2001  FORMAT(10X,15)
    WRITE(ICC1,25)
    DO 39 I=1,3
39   NSCAN(I)=1
    DO 2002 J=1,NUMNMR
    WRITE(ICC1,12)J,NRUN(J),NSCAN(J)
12   FORMAT(10HNR NUM ,15,25X,215)
    READ(ICC1,13)K,NFUN(J),NSCAN(J)
13   FORMAT(10X,15,25X,215)
2002  CONTINUE
    9 CALL RESIO(535,0.6,0,ICANT)
    IF(ICANT.EQ.1) GO TO 9
  C LOCATE PROPER FILE FOR REQUESTED RUN
27   WRITE(ICC1,25)
    WRITE(ICC1,26)
26   FORMAT(10HREWIND TAPE YES NO)
    READ(ICC1,25)
    CALL WCURSR(535,NSTAT,LINE,ICHAR)
    IF(LINE.NE.2) GO TO 27
    IF(ICHAR.GE.18.AND.ICHAR.LE.19) GO TO 31
    IF(ICHAR.GE.14.AND.ICHAR.LE.16) GO TO 30
    GO TO 27
30   CALL REWIND(6)
31   CONTINUE
    DO 32 J=1,NX
32   BDES(J)=0.
    CO 1000 I=1,NUMNMR
    ITEOF=0
41   CONTINUE
    CALL RDTF(6,4,1,0,77,81,NWDS,IRUN,IPAR,IECF)
    IF(IPAR.EQ.1) GO TO 100
    IF(ITEOF.EQ.1.AND.ITEOF.EQ.0) GO TO 201
    IF(ITEOF.EQ.1.AND.ITEOF.EQ.1) GO TO 202
    GO TO 203
201   ITEOF=1
    GO TO 41
202   CALL REWIND(6)
    ITEOF=0
    GO TO 41
203   CONTINUE
    IF(IRUN.EQ.NRUN(1).AND.ISCAN.EQ.NSCAN(1))GO TO 99

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      GO TO 41
99  CONTINUE
      CALL FSC(2,1)
      WRITE(ICC1,25)
      WRITE(ICC1,14)IRUN,ISCAN,ITIME(1),ITIME(2),ITIME(1),ITIME(2)
10  FORMAT(SMIRUN ,I3,AH SCAN ,I3,I3,2,I3,Y)
      CALL FSC(3,1)
      WRITE(ICC1,15)INMR,IPOS(1),INC,NPTS
15  FORMAT(SMNMNR ,I3,7H IREG ,I5,6H INC ,I3,7H NPTS ,I3)
      READ(ICC1,25)
C PUT SHIFTS IN SCAN IF NECESSARY
      DO 2005 IS=1,NPTS
      IPOS(IS)=IPOS(IS)+IEMPTY(I)
2005 CONTINUE
      CALL EXTRAK(6TEMP)
      DO 30 J=1,NX
30  BDES(J)=BDES(J)+BTEMP(J)
1000 CONTINUE
      DO 35 I=1,NX
35  BDES(I)=BDES(I)/RAP
2008 IADD=0
      WRITE(ICC1,25)
      WRITE(ICC1,2006)IADD
2006 FORMAT(10HADD BPRES ,I3)
      READ(ICC1,2007)IADD
2007 FORMAT(10X,I3)
      IF(IADD.GT.1)GO TO 2008
      IF(IADD.EQ.0)GOTO 2029
      DO 2010 I=1,NX
2010 BDES(I)=BDES(I)+BPRES(I)
2009 CONTINUE
      CALL AVER(BDES,BNORM)
      CALL FSC(2,1)
      WRITE(ICC1,25)
      CALL FSC(4,1)
      WRITE(ICC1,37)BNORM
37  FORMAT(7HBNORM ,E13.6)
      READ(ICC1,25)
      CALL CANIO(535,0,6,0)
      IA(1)=1019
      NPGRET=0
      CALL DMOPA(304,IA(1))
      RETURN
100 CALL FSC(4,1)
      WRITE(ICC1,101)
101 FORMAT(40X)
      WRITE(ICC1,102)
102 FORMAT(37HCOMPATIVITY ERRORS ON RECORD IGNORE YES NO)
      READ(ICC1,101)
      CALL WCURSR(535,NSTAT,LINE,ICHA)
      IF(LINE.NE.0) GO TO 100
      IF(ICHA,GE,32,AND,ICHA,LE,34) GO TO 41
      IF(ICHA,GE,36,AND,ICHA,LE,37) CALL CANIO(535,0,6,0)
      IF(ICHA,GE,36,AND,ICHA,LE,37) CALL CANIO(535,NSTAT,2,5)
      IF(ICHA,GE,36,AND,ICHA,LE,37) RETURN
      GO TO 100
END
SUBROUTINE AVER(BFIX,BNORM)
DIMENSION BFIX(30)
COMMON/IARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
1INC,IPOS(30),IRG(30),IMAIN,INT(8),IBLANK(4),ISCOPE,ICC1,LOOP,NPG,
2NSTAT,BDES(30),BPRES(30),BNEW(30),ADES(9),APRES(9),ANEW(9),W(30),

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3V(9),ORDI(30,9),DI(10),ELAST,RHSP,RHSH,RMSDI,NMT,NX,ICON,IFIC,
4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
  BNORM=0.
  DO 801 IL=1,NX
801  BNORM=BNORM+BFIX(IL)*W(IL)
    RNX=0.
    DO 803 IL=1,NX
803  RNX=RNX+W(IL)
    BNORM=BNORM/RNX
    DO 802 IL=1,NX
802  BFIX(IL)=BFIX(IL)*BNORM
  RETURN
  END
  SUBROUTINE EXTRAK(LOAD)
  DIMENSION BLOAD(30),RPOS(30),BG(30)
  COMMON/IARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
  1INC,IPOS(30),IBG(30),IMAIN,IMT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,
  2NSTAT,RDES(30),BPRES(30),RNEW(30),ADES(9),APRES(9),ANEW(9),W(30),
  3V(9),ORDI(30,9),DI(10),ELAST,RHSP,RHSH,RMSDI,NMT,NX,ICON,IFIC,
  4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
  NORDER=3
  DO 20 I=1,NPTS
  RPOS(I)=IPOS(I)
20  CONTINUE
  DO 22 I=1,NPTS
  BG(I)=IBG(I)
  BG(I)=BG(I)/100.
22  CONTINUE
  DO 21 I=1,NX
  XBAR=IBEG+(I-1)*TOFL
  9LOAD(I)=AMNINT(XBAR,NPTS,NORDER,RPOS,BG)
21  CONTINUE
  RETURN
  END
  FUNCTION AKNINT(XBAR,IN,IM,X,Y)
  DIMENSION Y(30),X(30),Y(30)
  COMMON/IARGS/IA(5),IBRAN(10),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
  1INC,IPOS(30),IBG(30),IMAIN,IMT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,
  2NSTAT,RDES(30),BPRES(30),RNEW(30),ADES(9),APRES(9),ANEW(9),W(30),
  3V(9),ORDI(30,9),DI(10),ELAST,RHSP,RHSH,RMSDI,NMT,NX,ICON,IFIC,
  4IBEG,IDEL,NUMNMR,NPGRET,IOUT(6),IIN(6),IORDER(8),IEMPTY(10)
  CALL FSC(4,1)
  N=IABS(IN)
  M = IM
  IF(M.GE.N.OR."GT.R) GO TO 100
  9 K=N-1
  IF(K.LT.2) GO TO 300
  S=X(2)-X(1)
  IF(IM.LT.0) GO TO 30
  DO 20 I=3,N
  Z=(X(I)-X(I-1))*S
  IF(Z.LE.0.) GO TO 420
20  CONTINUE
30  IF(S.LT.0.) GO TO 24
  DO 201 J=1,N
  IF(XBAR.LE.X(J)) GO TO 11
  401 CONTINUE
  J=N
  GO TO 11
24  DO 120 J=1,N
  IF(XBAR.GE.X(J)) GO TO 11
120 CONTINUE

```

```

      J=N
11  K=M
      M=M+1
      J=J-M/2
      J=MAX0(J,1)
      J=MIN0(J,N-M)
      MEND=J+K
      DO 12 I=J,MEND
      KK=I-J+1
      T(KK)=Y(I)
      KKM=KK+M
12  T(KKM)=X(I)-YBAR
      DO 13 I=1,K
      KK=I+1
      DO 13 JJ=KK,M
      JJM=JJ+M
      JMS=I+M
      JMES=JJ+J-1
      IMES=I+J-1
      T(JJ)=(T(I)+T(JJM)+T(JJ)+T(JMS))/(X(JMES)-X(IMES))
13  CONTINUE
      AKNINT=T(M)
      RETURN
420  WRITE(ICC1,1)
1  FORMAT(SX,23MX(1) NOT SEQUENCED OKAY)
      CALL EXIT
300  WRITE(ICC1,2)
2  FORMAT(SX,24MONE DATA POINT YBAR=Y(I))
      AKNINT=Y(I)
      RETURN
100  CONTINUE
      M=N
      IF(M.GT.8)M=8
      WRITE(ICC1,3)M
3  FORMAT(SX,18MM TOO LARGE,SET M,15)
      GO TO 9
      ENO
SEJ

```

```

SJOB(NAME='PQRJR',CL=U,AC='P12RJR,UAN912E225 RJR,PR=21,TL=01N,PL=100,MN=76)
SUBROUTINE SMOOTH
  DIMENSION ARRAY(10,12),T(10),A(10),Z(10)
  COMMON/IAFGS/IA(5),IBRAN(12),IRUN,ISCAN,ITIME(2),INMR,IOFF,NPTS,
  1INC,IPDS(30),ING(30),IMAIN,INT(8),IBLANK(4),ISCOPE,ICCI,LOOP,NPG,
  2HSTAT,RDES(12),HPRFS(30),PNEM(30),ADES(9),APRES(9),ANEM(9),W(32),
  3VC(9),RSDI(32,9),DT(12),ELAST,HMSR,HMSO,HMSOI,NMT,NX,ICOR,IFIC,
  4IBEG,IOEL,NHMMR,NPCRET,TRUT(6),IIN(6),IORGER(8),IEMPT(10)
  DO 99 I=1,32
    Z(I)=1.
  99 CONTINUE
  NORDER=4
  C THIS SUBROUTINE SMOOTHS THE DBDI BY LEAST SQUARES FIT
  C TO ORDER NORDER,
    CALL FSC(1,11)
    WRITE(ICC1,10)
  10 FORMAT(30H5+GOTH NORDER )
    CALL FSC(2,1)
    WRITE(ICC1,5)
  5 FORMAT(16H )
    WRITE(ICC1,13)
  13 FORMAT(40HNORDER )
    CALL FSC(2,8)
    WRITE(ICC1,11)NORDER
    READ(ICC1,11)NORDER
  11 FORMAT(15)
    CALL FSC(1,11)
    WRITE(ICC1,10)
  10 FORMAT(30HSMOOTH WEIGHTS )
    CALL FSC(2,1)
    WRITE(ICC1,5)
    WRITE(ICC1,12)(Z(I),I=1,NX)
  12 FORMAT(30H5,2)
    READ(ICC1,12)(Z(I),I=1,NX)
  99 DO 1020 KING=1,NMT
  C LOAD T VECTOR
    DO 20 I=1,NORDER
      T(I)=0.
    DO 20 J=1,NX
      XPOS=IBEG+(J-1)*IOFL
  20 T(I)=T(I)+Z(J)*DBDI(J,KING)*(XPOS**([I-1]))
  C LOAD ARRAY I ROW J COL
    DO 22 I=1,NORDER
    DO 22 J=1,NORDER
      ARRAY(I,J)=0.
    DO 22 K=1,NX
      XPOS=IBEG+(K-1)*IOFL
  22 ARRAY(I,J)=ARRAY(I,J)+Z(K)*(XPOS**([I+J-2]))
  C INVERT MATRIX
    CALL INVERT(ARRAY,NORDER)
  C FIND COEFFICIENTS A(I) OF LEAST SQUARES POLYNOMIAL
    DO 151 I=1,NORDER
      A(I)=0.
    DO 151 M=1,NORDER
  151 A(I)=A(I)+ARRAY(I,M)*T(M)
  C NOW LOAD DBDI WITH L.S. POLYNOMIAL
    DO 160 I=1,NX
      DBDI(I,KING)=0.
      XPOS=IBEG+([I-1])*IOFL
    DO 160 J=1,NORDER
  160 DBDI(I,KING)=DBDI(I,KING)+A(J)*(XPOS**([J-1]))

```



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      CALL FSC(1,1)
      WRITE(ICC1,64) KING
000  FORMAT(15,5M00TH A(J) J= ,15)
      CALL FSC(2,1)
      WRITE(ICC1,5)
      WRITE(ICC1,641)(A(J),J=1,NORDER)
001  FORMAT(3F13,6,1X,3F13,6,1X,3F13,6)
      READ(ICC1,5)
1020 CONTINUE
      IA(1)=1019
      NPGRET=3
      CALL DMDPA(304,IA(1))
      RETURN
      END
      SUBROUTINE INVERT(ARRAY,NORDER)
      DIMENSION ARRAY(12,12),IK(12),JK(12)
C INVERT ARRAY MATRIX
      DO 100 K=1,NORDER
      AMAX=0
21  DO 30 I=K,NORDER
      DO 50 J=K,NORDER
23  IF(ABS(AMAX)-ABS(ARRAY(I,J))) 24,24,30
20  AMAX=ARRAY(I,J)
      IK(K)=I
      JK(K)=J
30  CONTINUE
      I=IK(K)
      IF(I=K) 21,51,43
43  DO 50 J=1,NORDER
      SAVE=ARRAY(K,J)
      ARRAY(K,J)=ARRAY(I,J)
50  ARRAY(I,J)=SAVE
51  J=JK(K)
      IF(J=K) 21,61,53
53  DO 60 I=1,NORDER
      SAVE=ARRAY(I,K)
      ARRAY(I,K)=ARRAY(I,J)
60  ARRAY(I,J)=SAVE
61  DO 70 I=1,NORDER
      IF(I=K) 63,72,63
63  ARRAY(I,K)=ARRAY(I,K)/AMAX
70  CONTINUE
71  DO 80 I=1,NORDER
      DO 80 J=1,NORDER
      IF(I=K) 74,82,74
74  IF(J=K) 75,80,75
75  ARRAY(I,J)=ARRAY(I,J)+ARRAY(I,K)+ARRAY(K,J)
80  CONTINUE
81  DO 90 J=1,NORDER
      IF(J=K) 83,90,83
83  ARRAY(K,J)=ARRAY(K,J)/AMAX
90  CONTINUE
      ARRAY(K,K)=1./AMAX
100 CONTINUE
101 DO 130 L=1,NORDER
      K=NORDER-L+1
      J=IK(K)
      IF(J=K) 111,111,105
105 DO 110 I=1,NORDER
      SAVE=ARRAY(I,K)
      ARRAY(I,K)=ARRAY(I,J)
110  ARRAY(I,J)=SAVE

      I=JK(K)
      IF(I=K) 130,130,113
113 DO 120 J=1,NORDER
      SAVE=ARRAY(K,J)
      ARRAY(K,J)=ARRAY(I,J)
120  ARRAY(I,J)=SAVE
130 CONTINUE
      RETURN
      END
      2EJ

```

```

SJOB(NAME=PPCRJR,CL=U,LC=MP(PCRJR,UAEARQ(DEC25 RJR,PR=21,TL=RTM,PL=10P,M=76)
SUBROUTINE SOLVE
DIMENSION ARRAY(10,10),IK(10),JK(10),T(10)
COMMON/1APGS/1A(5),1SRAN(10),1PRUN,1SCAN,1TIME(2),1NMH,1OFF,NMTS,
1INC,1PC(30),1RG(30),1MAIN,1MT(4),1PLAN(4),1COPR,1CC1,1LOCP,1PG,
2NSTAT,5PRES(30),5PRES(30),RAN(30),APFS(9),APRES(9),ANEM(9),H(30),
3V(9),DBDI(30,9),D(10),ELAST,RHSP,RMSD,RMSDI,MT,NX,ICON,IFIC,
4IBEG,1DEL,NMNHQ,1PGRET,1OUT(6),1IN(6),1ORDER(8),1EPT(10)
IF(IFIC,NE.1) IFIC=0
IF(ICON,NE.1) ICON=0
I=NX
JJ=NMT+IFIC
KK=NMT+IFIC+ICON
C LOAD ARRAY MATRIX DEPENDING ON NMT,IFIC,ICON
DO 25 J=1,JJ
DO 25 K=1,JJ
ARRAY(K,J)=0.
DO 325 I=1,II
ARRAY(K,J)=ARRAY(K,J)+DBDI(I,K)*H(I)+DBDI(I,J)
IF(X,EG,J) ARRAY(K,J)=ARRAY(K,J)+V(J)
25 CONTINUE
JEE=JJ+1
DO 326 K=1,NMT
ARRAY(K,JEE)=1.
326 ARRAY(K,JEE)=1.
IF(IFIC,EG.1)ARRAY(JEE,JJ)=0.
IF(IFIC,EG.1)ARRAY(JJ,JEE)=0.
IF(ICON,EG.1) ARRAY(KK,KK)=0.
C COMPUTE COLUMN VECTOR FOR INVERSION
DO 29 J=1,JJ
T(J)=0.0
DO 28 I=1,II
T(J)=T(J)+DBDI(I,J)*H(I)+(PRES(I)-BPRES(I))
28 CONTINUE
T(J)=T(J)+V(J)+(APFS(J)-APRES(J))
29 CONTINUE
IF(ICON,NE.1) GO TO 28
T(KK)=0.
DO 327 I=1,NMT
327 T(KK)=T(KK)+APRES(I)
C INVERT ARRAY MATRIX
28 NORDER=KK
CALL INVERT(ARRAY,NORDER)
C MULTIPLY INVERTED ARRAY BY T VECTOR TO GET SOLUTION
DO 152 I=1,KK
DI(I)=0.
DO 151 M=1,KK
151 DI(I)=DI(I)+ARRAY(I,M)*T(M)
DI(I)=DI(I)+ELAST
150 CONTINUE
DO 215 I=1,NX
BNEH(I)=BPRES(I)
DO 215 J=1,JJ
215 BNEH(I)=BNEH(I)+DBDI(I,J)*DI(J)
DO 216 I=1,JJ
216 ANEM(I)=APRES(I)+DI(I)
1A(1)=1010
NPGRET=5
CALL DMDPA(300,1A(1))
RETURN
END

```

```

      SUBROUTINE INVERT(ARRAY,NORDER)
      DIMENSION ARRAY(10,10),IK(10),JK(10)
C INVERT ARRAY MATRIX
      DO 100 K=1,NORDER
      AMAX=0.0
21      DO 30 I=K,NORDER
      DO 30 J=K,NORDER
23      IF(ABS(ARRAY)=ABS(ARRAY(I,J))) 24,24,30
24      AMAX=ARRAY(I,J)
      IK(K)=I
      JK(K)=J
30      CONTINUE
      I=IK(K)
      IF(I=K) 21,41,43
43      DO 50 J=1,NORDER
      SAVE=ARRAY(K,J)
      ARRAY(K,J)=ARRAY(I,J)
50      ARRAY(I,J)=SAVE
51      J=JK(K)
      IF(I=K) 21,61,53
53      DO 60 I=1,NORDER
      SAVE=ARRAY(I,K)
      ARRAY(I,K)=ARRAY(I,J)
60      ARRAY(I,J)=SAVE
61      DO 70 I=1,NORDER
      IF(I=K) 83,70,63
63      ARRAY(I,K)=ARRAY(I,J)/AMAX
70      CONTINUE
71      DO 80 I=1,NORDER
      DO 80 J=1,NORDER
      IF(I=K) 74,82,74
74      IF(J=K) 75,82,75
75      ARRAY(I,J)=ARRAY(I,J)+ARRAY(I,K)*ARRAY(K,J)
80      CONTINUE
81      DO 90 J=1,NORDER
      IF(J=K) 83,90,83
83      ARRAY(K,J)=ARRAY(K,J)/AMAX
90      CONTINUE
      ARRAY(K,K)=1./AMAX
100      CONTINUE
101      DO 130 L=1,NORDER
      K=NORDER-L+1
      J=IK(K)
      IF(J=K) 111,111,104
103      DO 110 I=1,NORDER
      SAVE=ARRAY(I,K)
      ARRAY(I,K)=ARRAY(I,J)
110      ARRAY(I,J)=SAVE
111      I=JK(K)
      IF(I=K) 130,130,113
113      DO 120 J=1,NORDER
      SAVE=ARRAY(K,J)
      ARRAY(K,J)=ARRAY(I,J)
120      ARRAY(I,J)=SAVE
130      CONTINUE
      RETURN
      END
85J

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PART 5

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