1987

NASA/ASEE SUMMER FACULTY RESEARCH FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

ANALYSIS OF RELATIVISTIC NUCLEUS-NUCLEUS INTERACTIONS IN EMULSION CHAMBERS

Prepared By: Stephen C. McGuire
Academic Rank: Associate Professor
University and Department: Alabama A&M University Department of Physics

NASA/MSFC:
Laboratory: Space Science
Division: Astrophysics
Branch: High Energy

NASA Colleague: Thomas A. Parnell
Date: August 7, 1987

Contract No.: The University of Alabama in Huntsville NGT-01-008-021

XXIV
TABLE OF CONTENTS

Page No.

ABSTRACT ........................................ iii
ACKNOWLEDGEMENTS .............................. iii
LIST OF FIGURES ................................. iv
I.  INTRODUCTION ................................ 1
II.  OBJECTIVES .................................. 3
III. EXPERIMENT DESCRIPTION .................. 4
IV.  DATA REDUCTION METHODS ................. 5
     a.  Determination of Emission Angles .... 5
     b.  Calculation of Linear Momenta ....... 7
V. SOFTWARE DEVELOPMENT ..................... 9
VI. CONCLUSIONS AND RECOMMENDATIONS ...... 10
VII. REFERENCES .................................. 11
     APPENDIX A .................................. 16

XXIV-i
ABSTRACT

We report on the development of a computer-assisted method for the determination of the angular distribution data for secondary particles produced in relativistic nucleus-nucleus collisions in emulsions. The method is applied to emulsion detectors that were placed in a constant, uniform magnetic field and exposed to beams of 60 and 200 GeV/nucleon $^{16}$O ions at the Super Proton Synchrotron (SPS) of the European Center for Nuclear Research (CERN). Linear regression analysis is used to determine the azimuthal and polar emission angles from measured track coordinate data. The software, written in BASIC, is designed to be machine independent, and adaptable to an automated system for acquiring the track coordinates. The fitting algorithm is deterministic, and takes into account the experimental uncertainty in the measured points. Further, a procedure for using the track data to estimate the linear momenta of the charged particles observed in the detectors is included.
ACKNOWLEDGEMENTS

The author expresses his appreciation to Thomas A. Parnell and James H. Derrickson for serving as technical monitors during his appointment as a NASA/ASEE Summer Faculty Fellow. Thanks also go to Yoshiyaki Takahashi for helpful discussions regarding the construction and performance characteristics of the emulsion detectors, to Fred Berry for assistance with the computer system, and to Taka Tabuki for providing experimental data for testing the software. Lastly, the financial support of the NASA/ASEE Summer Faculty Fellowship Program, Gerald F. Karr, director and Ernestine Cothran, co-director, is gratefully acknowledged.
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.</td>
<td>Sketch of the experimental arrangement showing the approximate dimensions of the detector</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.</td>
<td>Cross sectional view of the chamber configuration designated as 5A2 for the EMU05 experiment</td>
<td>13</td>
</tr>
<tr>
<td>Figure 3.</td>
<td>Coordinate system diagram illustrating the use of track coordinates to obtain emission angles.</td>
<td>14</td>
</tr>
<tr>
<td>Figure 4.</td>
<td>Schematic diagram used to show how the radius of curvature is related to the measured distances, ( \Delta x_i ).</td>
<td>15</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

In this paper we report on the development of a data analysis method for the rapid determination of the azimuthal and polar emission angles of particles produced in nucleus-nucleus collisions observed in emulsion chambers exposed to relativistic \(^{160}\) beams. The method makes use of the track coordinate \((x,y,z)\) data that is presently obtained by visual inspection of the developed emulsion plates, using scanning microscopes. Although our initial application focusses on studying charged pions, the method is applicable to data for any emitted particle. The results of this work will be applied to the analysis of heavy ion cosmic ray interactions that are observed in emulsion chambers flown at high altitudes\(^1\). Events from these cosmic ray experiments are especially valuable since they often occur at energies that are substantially greater than those readily achievable with present-day particle accelerators.

The angular distributions of secondary particles, generated in the collision of two nuclei, contain information on the dynamics of the nuclear interaction process. Events that are characterized by large numbers of secondary particles and large transverse momenta are likely candidates to exhibit new fundamental phenomena. One such phenomenon is a new state of matter, the quark-gluon plasma (QGP), that is expected to occur in relativistic collisions that involve unusually high energy densities\(^2\). Another example rests in the idea that, if the collisions are simple superpositions of proton-like collisions, the produced particles are expected to be emitted isotropically in the center-of-mass frame. In each of these cases, it is very important to examine and understand the angular distributions of particles produced in high energy nuclear interactions, specifically with respect to non-statistical structure that may contain signatures of new physics\(^3,4\).

Emulsion chambers are well established as a tool for observing nuclear interactions involving energetic charged projectiles. They have the advantages of being relatively durable and easy to prepare. They can be used to accurately measure the charge and energy of the primary projectile, in addition to the emission angles associated with fragments
and secondary particles produced for the highest energy nuclear interactions. However, being passive detectors, they require a lengthy and somewhat involved set of developing and scanning procedures in order to obtain the raw data needed for analyzing the events they record. Even after the emulsion plates are developed, considerable laboratory work is needed to obtain angular distribution data.
II. OBJECTIVES

The primary objective of this project is to analyze secondary particle distribution data, recorded in emulsions from the EMU05 experiment, for the existence of non-statistical structures. To accomplish this objective, it was necessary to develop appropriate computer software that could be used to find the azimuthal and polar emission angles from particle track coordinate data. The software includes error analysis, and it has been tested successfully with data for which the results are known. In particular, the angular distributions of charged pions, observed in the EMU05 experiment, are to be examined for deviations from isotropy in the center-of-mass frame.
III. EXPERIMENT DESCRIPTION

For the EMU05 experiment, pulsed beams of $^{16}$O with energies of 60 and 200 GeV/nucleon were provided by the Super Proton Synchrotron (SPS) at the European Center for Nuclear Research (CERN). The pulse duration was 2s with a total intensity of $3 \times 10^3$ ions/cm² pulse. The integrated exposure given to a chamber was $10^4$ ions. The beam size was 2.54cm x 2.54cm (1 sq. in.) and each chamber was exposed to beam spills shifted laterally from each other by 1 cm. Proportional counter measurements at the chamber, located 30 cm downstream from the beamline end, indicated the beam to be 98% pure.

The chamber used in this work consisted of stacked emulsion plates separated by layers of lead, CR39 plastic and polystyrene. A sketch of the experimental arrangement, showing the approximate dimensions of the chamber, is provided in figure 1. The chamber was placed inside a uniform, 1.8 Tesla magnetic field. A cross sectional view of the detector configuration for which our analysis method was developed, is provided in figure 2. In this case, each emulsion plate had a 70 μm base coated on both sides with 50 μm of emulsion. The separation between the emulsion plates is not constant, but gradually increases in the direction of the beam. This facilitates the measurement of the track curvature, the identification of the charge of the emitted particle, and places an upper limit of 10 GeV on the energy of the secondary particles that can be analyzed. Also, lead plates are placed near the front of the detector where the density of emulsion plates is greater to increase the likelihood of collisions there. This feature also improves the accuracy with which the position of the collision vertex and the track angles can be determined.
IV. DATA REDUCTION METHODS

IV.a. Determination of Emission Angles

The method employed to find the polar and azimuthal emission angles consists essentially of fitting the set of position coordinates, \((x_i, y_i, z_i)\), for a given track, to the equation of a straight line. The situation is illustrated in figure 3. The vector \(d\) points in the initial direction of motion of the emitted particle. Since the paths are curved, it is recognized from the outset that this approach can be used to obtain a good estimate of the initial direction of motion of the outgoing particle, at the point of collision. Consequently, only those points closest to the collision vertex are used in the calculation.

First, a fit to the line \(y = a + bx\) is found using the set of points, \((x_i, y_i)\), in the x-y plane. The azimuthal angle, \(\phi\), is then simply obtained from

\[ \phi = \tan^{-1}(b), \]

where \(b\) is the slope of the line. The procedure is repeated for the set of points, \((r_i, z_i)\), in the r-z plane where

\[ r_i = \sqrt{(x_i)^2 + (y_i)^2}, \]

and \(z = c + mr\). The angle \(\theta\) is then obtained from

\[ \theta = \tan^{-1}(m). \]

This procedure is performed for each track associated with the event.

Values for \(b\) and \(m\) are obtained by the minimization of a chi-square quantity given by
\[ \chi^2(a,b) = \sum_{i=1}^{N} \left( \frac{y_i - y(x_i; a, b)}{\sigma_i} \right)^2, \quad (4) \]

where \( \sigma_i \) is the experimental uncertainty in the \( i \)th point. The resulting conditions,

\[ \frac{\partial \chi^2}{\partial a} = 0 \]

and

\[ \frac{\partial \chi^2}{\partial b} = 0, \quad (5) \]

must be satisfied, and in doing so yield two equations in two unknowns that are readily solvable for the constants \( a(c) \) and \( b(m) \). An estimate of the probable uncertainties in the constants can be obtained if the data are treated as independent with each contributing its own bit of uncertainty to the parameters. Consideration of the propagation of errors shows that the variance, \( \sigma_f \), in the value of any function will be

\[ \sigma_f^2 = \sum_{i=1}^{N} \sigma_i^2 \left( \frac{\partial f}{\partial y_i} \right)^2, \quad (6) \]

where \( f = a(c), b(m) \).

If, however, the individual measurement errors of the points \( \sigma_i \), are not known, then a more accurate estimate of the probable uncertainties in the parameters \( a(c) \) and \( b(m) \) can be obtained via the following procedure. Set \( \sigma_i = 1 \) in equations (4), (5), and (6), and multiply the values of \( \sigma_f \) by the additional factor,

\[ \sqrt{\frac{\chi^2}{N-2}} \]

where \( \chi^2 \) is computed by (4). In essence, this latter procedure is equivalent to assuming that one obtains a good fit.
IV.b Calculations of the Linear Momenta

As suggested in the introduction, it is important to identify those events in which a large amount of linear momentum of the incident projectile is transferred to the target nucleus. This may be done by careful examination of the linear momenta reaction products.

The radius of curvature of the path of a secondary particle is related directly to its linear momentum. To show this, consider the motion of a charged particle in a magnetic field. The magnetic force on the particle is given by

\[ F = q(v \times B), \] (7)

where \( q \) is the charge on the particle, \( v \) is its velocity, and \( B \) is the magnetic field. In the present case, \( B \) is assumed to be uniform and oriented in the positive \( y \)-direction. Thus, the magnitude of the force can be written as

\[ F = qvB\sin(\theta'), \] (8)

where \( \theta' \) is the angle between \( v \) and \( B \), and the direction of \( F \) is everywhere perpendicular to the plane formed by \( v \) and \( B \). The curved motion is described in terms of a centripetal acceleration so that

\[ qvB\sin(\theta') = mv^2/R, \] (9)

where \( m \) is the mass of the particle and \( R \) is its radius of curvature. Since \( p = mv \) is the linear momentum of the particle, we have

\[ p = qBR\sin\theta'. \] (10)

For convenience, equation (10) may be expressed as

\[ p(\text{GeV/c}) = 0.29979 \ q \ B(\text{T}) \ R(\text{cm}) \ \sin\theta', \] (11)

where \( q \) takes on the value \( \pm 1 \) for pions.
We can derive an estimate of $R$ from the measured track coordinates using the scheme illustrated in figure 4. From the figure,

$$L_i = R \sin \alpha_i$$  \hspace{1cm} (12)$$

where $L$ is the distance along the symmetry axis of the detector, in this case the $z$-direction, to the $i$th emulsion plate. Also, note that

$$\Delta x_i = R (1 - \cos \alpha_i) .$$  \hspace{1cm} (13)$$

The quantity $\Delta x_i$ is the perpendicular distance from the beam direction. These last two equations can be combined to give

$$R = \frac{\Delta x_i}{\Delta x_i^2/(1 - \cos (\sin^{-1}(L_i/R)))} .$$  \hspace{1cm} (14)$$

Since we are interested in obtaining a solution to this last, non-linear equation for $R$ in terms of $\Delta x_i$, this may best be done by approximating the $\cos(x)$ and $\sin^{-1}(x)$ functions by their series forms, i.e.,

$$\cos(x) = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots \bigg| x \bigg| < \infty,$$

$$\sin^{-1}(x) = x + \frac{x^3}{2\cdot3} + \frac{1\cdot3\cdot5}{2\cdot4\cdot5} + \ldots \bigg| x \bigg| < 1 .$$

Using only the first order terms, we obtain

$$R \approx \frac{(L_i)^2}{2\Delta x_i} .$$

Clearly, this approximation is best suited for measurements involving the coordinates of the first few emulsion plates nearest the interaction vertex, and for reaction products with large $p$ values.
V. SOFTWARE DEVELOPMENT

A computer code that makes use of the analysis methods described in the previous section was written for the Commodore AMIGA computer. The code is written in BASIC and is designed to be machine independent. It is expected that the code will be executed under the BASIC interpreter supplied with the computer. For input, the program requires files that contain the track coordinate \((x, y, z)\) data that have been obtained for each event by scanning the developed emulsion plates. At present, the program returns the corresponding angles, \(\theta\) and \(\phi\) for each track, and it also has a provision for estimating the linear momenta of the emitted particles, based upon the track radius of curvature and the magnetic field. Early tests, employing idealized track data, as well as actual track data from a few plates, indicate that the code is operating correctly. A current source listing, to be regarded as preliminary, is provided in Appendix A along with a logic diagram for the code. A detailed description will appear elsewhere, after finalization of the software.
VI. CONCLUSIONS AND RECOMMENDATIONS

Initial development work on the computer software for determining the emission angles and estimating the linear momenta of particles emitted in nucleus-nucleus collisions observed in emulsions has been completed. The software has been tested successfully for correct operation using idealized track data and partial data from the EMU05 experiment. Further testing of the code with complete track data for EMU05 events is recommended to confirm the accuracy of the calculations.

Additional heavy ion experiments involving emulsion chambers of the 5A2 design are planned for the SPS accelerator. The first will employ a $^{32}$S beam and is scheduled for September, 1987. Another will use a $^{208}$Pb beam that is anticipated being available during the Fall of 1989. Also, the High Energy Astrophysics Branch of SSL has been involved over the past 10 years in a collaborative research program, the Japanese American Collaborative Emulsion Experiment (JACEE), the purpose of which is to study charge particle cosmic ray interactions in emulsion chambers flown at high altitude. To date, seven balloon flights have been conducted and data analysis has been completed for five of these. In view of the large amount of data anticipated to be available from these two efforts, it is recommended that an automated system of coordinate data recording be incorporated with the code development work presently underway in order to reduce the time between plate scanning and final analysis of the angular distributions. Such a system will be especially valuable for analyzing events having high multiplicities.

The present method of calculating the emission angles will work best when data are available for a few closely spaced plates near the interaction vertex of the event. It is therefore of interest to explore alternative means of fitting the track data that make use of functions that better represent the curved path. An initial approach would include using higher order polynomial function approximations to the path, and finding the tangent to the curve at the interaction vertex.
VII. REFERENCES


9. AMIGA is the Commodore trade name for this computer.
Magnet Field
1.8 Tesla

Emulsion-Gap Chamber

Oxygen beam

FIGURE 1.
FIGURE 2.
\[ z = c + m \cdot r \]
\[ \theta = \tan^{-1}(m) \]

\[ y = a + b \cdot x \]
\[ \phi = \tan^{-1}(b) \]

FIGURE 3.
FIGURE 4.
APPENDIX A

Logic Diagram and Source Listing of the Track Coordinate Analysis Program
INITIALIZE VARIABLES

DEFINE DETECTOR GEOMETRY

READ INPUT DATA

CHECK VALIDITY OF INPUT DATA

PERFORM FITS TO A STRAIGHT LINE

DETERMINE ANGLES

PRINT $\theta$ AND $\phi$

ESTIMATE THE TRACK CURVATURE

CALCULATE $P_1$ AND $P_{\text{TOTAL}}$

PRINT $P_1$ AND $P_{\text{TOTAL}}$

LAST TRACK?

PROGRAM END

XXIV-17
10 REM****PROGRAM TO CALCULATE THE AZIMUTHAL AND POLAR EMISSION ANGLES FROM THE EMU05 EXPERIMENT DATA.*****
20 REM*************************************************************
30 DIM A(4),X(50),Y(50),Z(50),SIG(50),R(50)
40 XMAX=80000!:YMAX=80000!:ZMAX=47680!
50 ANGFAC=180!/3.14159!:PFAC%=.299?9: BFIELD = 1.8
60 CONST = .299?9: BFIELD = 1.8
70 QP = 1!: QN = -1!
80 OPEN FILENAM$ FOR INPUT AS 1
90 LPRINT "FILENAME=",FILENAM$
100 REM*****READ IN THE TRACK DATA.**************
110 REM*****INITIALS SHOULD BE MICRONS**************************
120 INPUT "FILENAME=",FILENAM$
130 OPEN FILENAM$ FOR INPUT AS 1
140 LPRINT "FILENAME=",FILENAM$
150 REM********
160 LPRT
170 REM******
180 INPUT #1, NRAY%
190 FOR J% = 1 TO NRAY'
200 NPTS% = 0
210 FOR K% = 1 TO 40
220 NPTS% = NPTS% + 1
230 INPUT #1, X(K%),Y(K%),Z(K%),SIG(K%)
240 R(K%) = SQR(X(K%)*X(K%) + Y(K%)*Y(K%))
250 LPRINT USING "########.##"; X(K%),Y(K%),R(K%),SIG(K%)
260 IF X(K%) = -1! THEN NPTS_ = NPTS_ - 1: GOTO 320
270 REM END INNER LOOP
280 NEXT K%
290 REM*****PERFORM FIT TO A STRAIGHT LINE AND******
300 REM***BASED ON THE FITTED DATA, FIND THE EMISSION ANGLES.*****
310 LPRINT "EMISSION ANGLES FOLLOW ...........
320 REM*****BASED ON ITS ESTIMATED RADIUS OF CURVATURE, DETERMINE
330 REM THE LINEAR MOMENTUM OF THE TRACK.*******************
340 FOR IR% = 1 TO NPTS%
350 RI = Z(IR%)*Z(IR%)
360 RI = RI/(2!*X(IRX))
370 R = R + RI
380 NEXT IR%
390 PMOM = CONST*QP*BFIELD*AVR
400 PPR = PMOM*SIN(THETA)
410 PPL = PMOM*COS(THETA)
420 PPRTOT = PPRTOT + PPR
430 PPLTOT = PPLTOT + PPL
440 LPRINT USING "########.##"; PMOM,PPR,PPRTOT,PPL,PPLTOT
450 LPRINT
460 LPRINT
470 REM***********
480 REM*****GET DATA FOR THE NEXT TRACK, OR
490 REM END OUTER LOOP.******************************
500 NEXT J%
510 REM END OUTER LOOP.******************************
520 REM END
530 END
580 REM
1000 REM***SUBPROGRAM TO PERFORM A BEST FIT TO STRAIGHT LINES:
1005 REM IN THE X-Y AND R-Z PLANES. THESE FITS WILL BE********
1010 REM** TO DETERMINE THE AZIMUTHAL AND POLAR EMISSION ANGLES****
1012 REM NOTE:** Y = B*X + A IS THE FORM OF THE STRAIGHT LINE.******
1015 REM*********FIRST CONSTRUCT THE SUMS OVER THE DATA POINTS
1020 REM NEEDED FOR THE CALCULATION OF THE CONSTANTS.******
1030 SX=0:SY=0:S=0:SXX=0:SXY=0
1045 REM****USE ONLY A FRACTION OF THE AVAILABLE POINTS.*****
1050 NPTSH% = NPTS% / PFAC%
1060 FOR J21 = 1 TO NPTSH%
1070 SIGSQR = SIG(J2X)*SIG(J2X)
1080 SXY = SXY + X(J2%)*Y(J2%)/SIGSQR
1090 SXX = SXX + X(J2%)*X(J2%)/SIGSQR
1100 SX = SX + X(J2%)/SIGSQR
1110 SY = SY + Y(J2%)/SIGSQR
1150 S = S + 1/SIGSQR
1170 ****************************
1180 REM**THE NEXT STEP IS TO CALCULATE THE VALUES
1190 REM OF THE PARAMETERS A AND B FOR THE ACIMUTHAL ANGLE.******
1200 DELTA = S*SXX - SX_SX
1210 APHI_i = (SXX*SY - SX*SXY)/DELTA
1220 BPHI = (S*SXY - SX*SY)/DELTA
1230 REM ****FIND THE UNCERTAINTY IN THE A AND B.*****
1240 SIGMAA = SXX/DELTA:SIGMAB = S/SQR(SIGMAB)
1250 SIGMA = S/DELTA:SIGMAB = SQR(SIGMAB)
1270 REM~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
1270 REM****CALCULATE A CHISQUARE VALUE FOR THE FIT.*****
1280 REM AND RE-ESTIMATE THE UNCERTAINTIES IN A AND B.***
1290 SRES=0!
1300 FOR I% = 1 TO NPTSH%
1310 YP = BPHI*X(I%) + APHI
1320 RESI = (Y(I%) - YP)/SIG(I%)
1330 RESI = RESI*RESI
1340 SRES = SRES + RESI
1350 NEXT I%
1360 CHISQR = SRES
1370 EFACT - CHISQR/(NPTSH% - e)
1380 EFACT = SQR(FACT)
1390 SIGMA = SIGMA*EFACT
1400 SIGMAB = SIGMAB*EFACT
1410 REM**********NEXT, CALCULATE THE ANGLE PHI.**********
1415 PHI = ATN(BPHI):PHI = ANGFAC*PHI
1420 LPRINT "A SIGMA  B SIGMAB PHI"
1424 IF (X(1) < 0! AND Y(1) < 0!) THEN PHI = PHI + 180!:GOTO 1929
1425 IF X(1) < 0! THEN PHI = PHI + 180!: GOTO 1929
1426 IF Y(1) < 0! THEN PHI = PHI + 360!: GOTO 1929
1427 REM **********END
1430 LPRINT USING "####.##";APHI,SIGMAA,BPHI,SIGMAB,PHI
1440 LPRINT "R**";
1450 REM**********NOW DO THE SAME FOR THE POLAR ANGLE******
1460 REM *****X --> R AND Y --> Z.**********
1470 SR=0:SZ=0:SSR=0:SRZ=0:S=0
1480 FOR J1% = 1 TO NPTSH%
1490 SIGSQR = SIG(J1X)*SIG(J1X)
1500 SR = SR + R(J1%)/SIGSQR
1510 SRZ = SRZ + Z(J1%)/SIGSQR
1520 SSR = SSR + R(J1%)*R(J1%)/SIGSQR
1530 SRZ = SRZ + Z(J1%)*Z(J1%)/SIGSQR
1530 S = S + 1/SIGSQR
1540 NEXT J1%
1542 REM****FIND THE FITTED CONSTANTS, A AND B FOR THE DETERMINATION OF
1543 REM THE ANGLES.*****

XXIV-19
DELTA = S*SR - SR*SR
ATHETA = (SRR*SZ - SR*SRZ)/DELTA
BTHETA = (S*SRZ - SR*SZ)/DELTA
REM****NOW FIND THE UNCERTAINTIES IN THE FITTED CONSTANTS.*******
SRES = 0!
SIGMAA = SQR(SRR/DELTA); SIGMAB = SQR(S/DELTA)
FOR I% = 1 TO NPTSH%
ZP = BTHETA*R(I%) + ATHETA
RESI = (Z(I%) - ZP)/SIG(I%)
RESI = RESI*RESI
SRES = SRES + RESI
NEXT I%
CHISQR = SRES
EFACT = CHISQR/(NPTSH% - 2)
EFACT = SQR(EFACT)
SIGMAA = SIGMAA*EFACT
SIGMAB = SIGMAB*EFACT
REM *****NEXT, FIND THE ANGLE THETA.**********************
THETA = ATN(I%/BTHETA); THETA = ANGFAC*THETA
IF Z(1) < 0! THEN THETA = THETA + 180!
LPRINT "SIGMAA B SIGMAB THETA"
LPRINT USING "######.##"IATHETA, SIGMAA,BTHETA,SIGMAB,THETA
LPRINT
RETURN

XXIV-20