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University of California

Ernest O. Lawrence Radiation Laboratory

FORTRAN PROGRAM KINE: CALCULATING KINEMATICAL AND DYNAMICAL QUANTITIES FOR PARTICLE INTERACTIONS AND DECAYS

Berkeley, California

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FORTRAN PROGRAM KINE: CALCULATING KINEMATICAL AND DYNAMICAL QUANTITIES FOR PARTICLE INTERACTIONS AND DECAYS

W. Peter Trower

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FORTRAN PROGRAM KINE: CALCULATING KINEMATICAL AND DYNAMICAL QUANTITIES FOR PARTICLE INTERACTIONS AND DECAYS

W. Peter Trower*

Lawrence Radiation Laboratory
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ABSTRACT

FORTRAN program KINE is a calling routine for a collection of seven subroutines. Each subroutine calculates interesting kinematical and dynamical quantities for the particle reaction $1+2 \rightarrow 3+4$ by applying special relativity to the process in the form of the Lorentz transformation. The reaction is completely specified if, in addition to the rest masses involved, two of the physical variables are specified. The subroutines perform calculations for the most useful combinations of these two variables.

I. INTRODUCTION

The application of special relativity to particle interactions is in general a straightforward but often tedious affair. This report describes a computer program KINE, that calculates relativistic kinematics and dynamics of particle interactions and allows the physicist a wide latitude in his choice of input variables and an extensive output that should cover most of his normal needs.

Symbolically the interaction for which KINE is constructed can be written as $1+2 \rightarrow 3+4$, where particle 2 is assumed to be at rest in the laboratory frame. The user specifies his problem by stating the masses of the particles in the reaction. Decays are specified by setting the mass of particle 2 equal to zero. For photoproduction the mass of particle 1 is set to zero. In three-dimensional space, each particle may be described by three variables (for example, $P_x P_y P_z$); this makes a total of nine variables for the reaction, since particle 2 is at rest. But in the reaction plane, each particle can be characterized by a pair of variables, so the number of variables is thus reduced to six. We further have three conservation equations, two in momentum and one in energy, and can arbitrarily specify the direction of particle 1; this leaves only two variables that are necessary to specify this system. KINE has seven subroutines that allow the user to specify the most useful combinations of two variables out of two of three pairs of particle variables: momentum or kinetic energy of 1 in the laboratory or in the center-of-mass frame, momentum or kinetic energy of 3 in either frame, and angle of 3 in either frame.

KINE essentially generates tables of kinematic and dynamic variables. Depending on the input, its output consists of the kinetic energies, momenta, and angles of particles 3 and 4 in both frames, as well as their η, β, and $d\Omega_{LAB}/d\Omega_{c.m.}$. In addition, the η, β, and γ of the center of mass; the relative velocity, phase space, and total opening angle of the final-state particles; and the threshold energy and momenta of the incident particle are calculated.

This program has gone through many stages, programmers, and computers over the last six years.[1] Although it reflects the needs and interests of only one high-energy physics group, it is hoped that it now can serve other groups. A program called RELKIN[2] performs some of the calculations of one of KINE's subroutines; however, RELKIN has the advantage that it can make these calculations for a moving-target particle.

II. THEORY

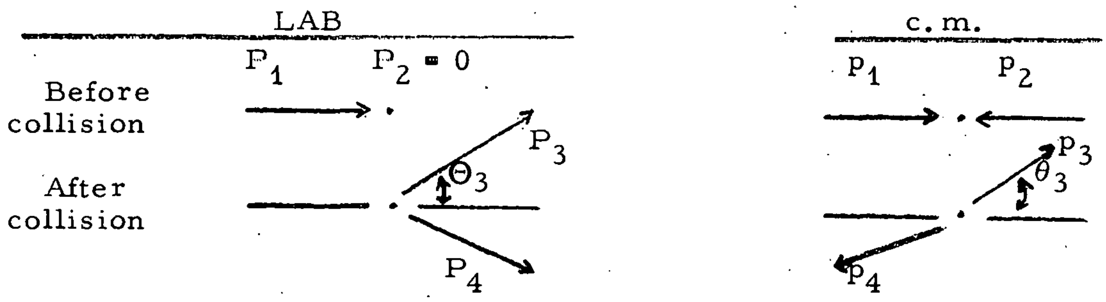
In this report we concern ourselves only with the particle reaction[3] of the form

$$1 + 2 \rightarrow 3 + 4 \,, \qquad (1)$$

where 1 is called the incident particle, 2 is called the target particle, and 3 and 4 are called the final particles. We look at this reaction in two frames of reference, LAB and c.m. In the LAB frame, 1 is moving and strikes 2, which is at rest. This frame is the one that a person is in when he looks at a bubble chamber or spark chamber photograph. The center-of-mass (c.m.) frame is also uniquely defined; it is the frame in which the momentum of 1 is equal in magnitude but opposite in direction to that of 2.

Now, let us adopt a convenient notation in which mass, energy, and momentum are expressed in terms of energy. Let M be an abbreviation for mass Mc^2, and P be an abbreviation for the momentum Pc. Let capital letters refer to quantities relative to the LAB frame and lower-case letters refer to quantities relative to the c.m. frame. Further, let the numerical subscripts designate the specific particle to which the quantity refers.

In summary, we construct the following diagram:



T	Kinetic energy	t
P	Momentum	p
W	Total energy	w
Θ	Angle	θ
Ω	Solid angle	ω

Since two vectors define a plane, we can think of each momentum vector as having only an x and a y component. By conservation of momentum and energy, we can write in the LAB frame the following three equations:

PAGES 3 to 8

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Table IV. Format of outputs.

Type	Line	Word														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A	Master #1	M_1	M_2	M_3	M_4	-	-	-	-	-	v_{rel}	ρ	Θ_3^{max}	Θ_4^{max}	w	-
	Master #2	P_1	T_1	Q	P_1^{Thres}	T_1^{Thres}	p_{in}	p_{out}	-	$*^1$	-	$*^2$	η	γ	β	-
	Data	Θ_3	P_3	η_3	T_3	β_3	$\left(\frac{d\Omega}{d\omega}\right)_3$	θ_3	Θ_4	P_4	η_4	T_4	β_4	$\left(\frac{d\Omega}{d\omega}\right)_4$	Θ_{34}	-
B	Master	M_1	M_2	M_3	M_4	-	-	-	-	-	$*^1$	-	-	Q	T_1^{Thres}	P_1^{Thres}
	Data	$*^2$	$*^3$	$*^4$	β_4	η_4	Θ_4	P_4	T_4	P_1	w	p_{in}	p_{out}	η	γ	β

*The asterisks with superscript numbers are explained in Table III.

ACKNOWLEDGMENTS

Several of KINE's subroutines were originally written by Dr. Jon Peter Berge and Dr. Joseph Schwartz for the IBM 650 computer. Miss Marilyn Gode-von Aesch of this Laboratory and Howard A. Gordon of the University of Illinois have given the author much assistance in expanding these programs and converting them to the IBM 7094, as well as in coding the additional routines. For the interest displayed by Professor Arthur H. Rosenfeld throughout this project, the author is deeply grateful.

This work was performed under the auspices of the U. S. Atomic Energy Commission.

APPENDICES

A. Glossary of Mnemonics Used in KINE

Most of the mnemonics used in KINE are constructed by appropriate combination of the following symbols:

Physical quantity	Particle	System	Magnitude
AM (mass)	1	L (LAB)	X (maximum)
P (momentum)	2	C (c.m.)	N (minimum)
T (kinetic energy)	3		D (increment)
W (total energy)	4		T (threshold)
A (angle)			I (ith iteration)

For example, the P1CT is the threshold value of the momentum of particle 1 in the c.m. system.

The following is a list of terms that are not covered by the table. If they occur for more than one particle, a representative case is given.

BETA = β

BETA3 = β_3

BRUP = $(1+\gamma^2 \tan^2 \Theta_3)$

COS 3L = $\cos \Theta_3$

DOL3C3 = $(d\Omega/d\omega)_3$

DRUP = $\left\{\left(\gamma^2+\eta^2 \dfrac{w_3^2}{p_{out}^2}\right) \tan^2 \Theta_3 + 1\right\}^{1/2}$

ETA = η

FRUP = $-\dfrac{\gamma \eta w_3}{p_{out}} \tan^2 \Theta_3$

GAMMA = γ

IA = Integral value of Q

IN = input-tape designation

IO = output-tape designation

PCIN = p_{in}

PCOUT = p_{out}

PS = phase space

Q = Q value

R = number of degrees in a radian

SAP 4 = $\left\{\dfrac{1}{\beta^2 - \beta_4^2}\right\}^{1/2}$

SIN 3L = $\sin \Theta_3$

SIS = $w_3^2 - M_3^2$

B. LISTING OF MAIN PROGRAM

```
C       MAIN PROGRAM
        COMMON X,AM,P1L,A3C,A3L,P3L,P1C,IO,R
        DIMENSION X(4),AM(4),P1L(3),A3C(3),A3L(3),P3L(3),P1C(3)
        IN=2
        IO=3
        R=57.29578
     10 L=0
      3 READ INPUT TAPE IN,1,N,(X(I),I=1,4)
      1 FORMAT (I1,9X,4F10.0)
        L=L+1
        IF(N-1) 43,43,39
     39 DO 40 I=1,4
        IF(X(I)) 42,40,40
     40 CONTINUE
        IF(X(3)) 42,42,41
     41 IF(X(2)-X(1)) 42,42,43
     42 WRITE OUTPUT TAPE IO,6
      6 FORMAT(34H1ERROR IN DATA. EXECUTION DELETED.)
        GO TO 5
     43 GO TO (11,12,13,14,15,16,4,4,4),N
     11 DO 21 I=1,4
     21 AM(I)=ABSF(X(I))
        GO TO 3
     12 M=1
        IF (X(4)) 100, 32, 100
     32 DO 22  I=1,3
     22 P1L(I)=X(I)
        GO TO 51
     13 DO 23 I=1,3
     23 A3C(I)=X(I)
        GO TO 51
     14 DO 24 I=1,3
     24 A3L(I)=X(I)
        GO TO 51
```

```
 15 M=3
    IF (X(4)) 100,35,100
 35 DO 25  I=1,3
 25 P3L(I)=X(I)
    GO TO 51
 16 M=1
    IF (X(4)) 100,36,100
 36 DO 26  I=1,3
 26 P1C(I)=X(I)
    GO TO 51
  4 WRITE OUTPUT TAPE IO,2
  2 FORMAT(43H1 DATA CARD HAS INCORRECT ASSIGNMENT NUMBER)
  5 READ INPUT TAPE IN,1,N,(X(I),I=1,4)
    IF(N-1) 5,50,5
 50 L=1
    GO TO 11
 51 IF(L-2) 52,53,54
 52 GO TO 3
 53 K=N
    GO TO 3
 54 GO TO (4,55,58,61,62,59),K
 55 GO TO (4,4,56,57,60,4),N
 56 CALL ALPHA
    GO TO 10
 57 CALL BETA
    GO TO 10
 58 CALL GAMMA
    GO TO 10
 59 CALL DELTA
    GO TO 10
 60 CALL EPSIL
    GO TO 10
 61 CALL ZETA
    GO TO 10
 62 CALL ETA
    GO TO 10
100 DO 101 I=1,2
101 X(I) = SQRTF(X(I)**2+2.0*AM(M)*X(I))
102 GO TO (4,32,4,4,35,36),N
    END
```

C. LISTING OF SUBROUTINE ALPHA

```
      SUBROUTINE ALPHA
      COMMON X,AM,P1L,A3C,A3L,P3L,P1C,IO,R
      DIMENSION X(4),AM(4),P1L(3),A3C(3),A3L(3),P3L(3),P1C(3)
      P1LI = P1L(1)
      Q = AM(1)+AM(2)-AM(3)-AM(4)+0.001
      IA=Q
      IF(IA) 100,103,103
  100 W1LT=AM(1)+(((-Q)*(AM(1)+AM(2)+AM(3)+AM(4))))/(2.0*AM(2)))
      P1LT=SQRTF((W1LT+AM(1))*(W1LT-AM(1)))
      T1LT=-AM(1)+SQRTF(AM(1)**2+P1LT**2)
  101 IF(P1LI-P1LT) 102, 104, 104
  102 P1LI=P1L(3)+P1LI
      GO TO 101
  103 P1LT=0.0
      T1LT=0.0
  104 P1L(1)=P1LI
      IF(P1L(2)-P1LI) 10,200,200
   10 WRITE OUTPUT TAPE IO,6
    6 FORMAT(46H MOMENTUM CONSTRAINTS KINEMATICALLY IMPOSSIBLE)
      GO TO 500
C     NEW PASS FOR INDEPENDENT VARIABLE.
  200 A3CI=A3C(1)
      W1L=SQRTF(P1LI**2+AM(1)**2)
      T1L=ABSF(W1L-AM(1))
      W34C=SQRTF(AM(1)**2+AM(2)**2+2.0*AM(2)*W1L)
      W3C=(W34C**2+AM(3)**2-AM(4)**2)/(2.0*W34C)
      W4C=W34C-W3C
      ETA=P1LI/W34C
      GAMMA=(W1L+AM(2))/W34C
      BETA=ETA/GAMMA
      SIS=W3C**2-AM(3)**2
      IF (SIS) 201,201,202
  201 PCOUT=0.0
      BETA3=0.0
      BETA4=0.0
      GO TO 203
  202 PCOUT=SQRTF(SIS)
      BETA4=PCOUT/SQRTF(AM(4)**2+PCOUT**2)
      BETA3=PCOUT/SQRTF(AM(3)**2+PCOUT**2)
  203 PCIN=ABSF(ETA*AM(2))
      IB3=(BETA-BETA3)*10000.0
      IB4=(BETA-BETA4)*10000.0
      VREL=PCIN*(1.0/(SQRTF(AM(1)**2+PCIN**2))+1.0/(SQRTF(AM(2)**2
     1+PCIN**2))) *2.997993E10
      PS=PCOUT*W3C*W4C/W34C
      IF(IB3)204,206,205
  204 A3L(2)=180.0
      GO TO 207
  205 SAP3 =SQRTF(1.0/((BETA+BETA3)*(BETA-BETA3)))
      A3L(2)=ATANF(BETA3*SAP3/GAMMA)*R
      GO TO 207
  206 A3L(2)=90.0
  207 IF(IB4)208,210,209
  208 A4LX=180.0
      GO TO 11
```

```
209 SAP4=SQRTF(1.0/((BETA+BETA4)*(BETA-BETA4)))
    A4LX= ATANF(BETA4*SAP4/GAMMA)*R
    GO TO 11
210 A4LX=90.0
 11 WRITE OUTPUT TAPE IO,1
  1 FORMAT(120H1SUBROUTINE ALPHA       INDEPENDENT VARIABLE=MOMENTUM 1
   1(LAB)           DEPENDENT VARIABLE=ANGLE 3 (CM)                    )
    WRITE OUTPUT TAPE IO,2,(AM(I),I=1,4),VREL,PS,A3L(2),A4LX,W34C
  2 FORMAT(132H-   MASS          MASS          MASS          MASS
   1                       RELATIVE          PHASE       MAX ANGLE     MAX ANG
   2LE     TOTAL /
   3         132H     1           2             3             4
   4                       VELOCITY          SPACE           3              4
   5      ENERGY /
   6         132H   (MEV)        (MEV)         (MEV)         (MEV)
   7                       (CM/SEC)      (MEV-SQ.)       (LAB)         (LAB)
   8       (CM)   /
   91X,4(F7.2,4X),30X,1PE9.3,5X,1PE9.3,4X,0PF6.2,7X,F6.2,3X,F8.2)
    WRITE OUTPUT TAPE IO, 3, ETA, GAMMA, BETA, P1LI, TIL, Q, P1LT, TIL
   1T, PCIN, PCOUT
  3 FORMAT(132H- MOMENTUM    KINETIC       Q       THRESHOLD    THRESHOLD
   1MOMENTUM   MOMENTUM                                    ETA        GAMMA
   2       BETA   /
   3         132H      1         ENERGY1    VALUE    MOMENTUM1    KINETIC
   4    IN         OUT                                       (CM)       (CM)
   5       (CM)   /
   6           79H   (LAB)        (LAB)      (LAB)      (LAB)        ENERGY1
   7   (CM)        (CM)         ,24X,F9.4,2X,F8.4,2X,F8.6/
   81X,F8.2,3X,F8.2,1X,F7.2,3X,F8.2,4X,F8.2,4X,F8.2,3X,F8.2////)
    WRITE OUTPUT TAPE IO, 4
  4 FORMAT(132H  ANGLE   MOMENTUM   ETA     KINETIC    BETA    D OMEGA (LAB
   1)    ANGLE     ANGLE   MOMENTUM   ETA     KINETIC    BETA    D OMEGA (LAB
   2)      TOTAL /
   3         132H     3        3        3     ENERGY3      3     ------------
   4-       3         4        4        4     ENERGY4      4     ------------
   5-      ANGLE /
   6         132H  (LAB)    (LAB)    (LAB)     (LAB)     (LAB)   D OMEGA (CM)
   73     (CM)     (LAB)    (LAB)    (LAB)     (LAB)     (LAB)   D OMEGA (CM)
   84       (LAB) /                 )
C       NEW PASS FOR DEPENDENT VARIABLE
300 COS3C=COSF(A3CI/R)
    W3L=ETA*PCOUT*COS3C+GAMMA*W3C
    W4L=-ETA*PCOUT*COS3C+GAMMA*W4C
    IF(W3L-AM(3)) 301,301,302
301 P3LI=0.0
    T3L=0.0
    GO TO 303
302 P3LI=SQRTF(W3L**2-AM(3)**2)
    T3L=W3L-AM(3)
303 IF(W4L-AM(4)) 304,304,305
304 P4L=0.0
    T4L=0.0
    GO TO 307
305 P4L=SQRTF(W4L**2-AM(4)**2)
    T4L=W4L-AM(4)
    IF(P1LI)500,3307,307
3307 A3LI=A3CI
    A4L=180.0-A3CI
    GO TO 320
```

```
 307 COS3L=(P1LI**2+ P3LI**2-P4L**2) /(2.0*P1LI*P3LI)
     IF (ABSF(COS3L)-0.999995)311,308,308
 308 IF(COS3L)309, 310,310
 309 A3LI=180.0
     GO TO 313
 310 A3LI=0.0
     GO TO 313
 311 SIN3L=SQRTF(1.0-COS3L**2)
     TAN3L=SIN3L/COS3L
     A3LI=ATANF(TAN3L)*R
     IA3LI=A3LI*10.0
     IF(IA3LI)312,3312,313
3312 A3LI=90.0
     GO TO 313
 312 A3LI=A3LI+180.0
 313 COS4L=(P1LI**2-P3LI**2+P4L**2)/(2.0*P1LI*P4L)
     IF(ABSF(COS4L)-0.999995)317,314,314
 314 IF(COS4L)315, 316,316
 315 A4L=180.0
     GO TO 320
 316 A4L=0.0
     GO TO 320
 317 SIN4L=SQRTF(1.0-COS4L**2)
     TAN4L=SIN 4L/COS 4L
     A4L=ATANF(TAN4L)*R
     IA4L=A4L*10.0
     IF(IA4L)318,319,320
 318 A4L=180.0+A4L
     GO TO 320
 319 A4L=90.0
 320 DOL3C3=(PCOUT/P3LI)**3*(GAMMA+(ETA*W3C*COS3C/PCOUT))
     IF(P3LI)321,321,322
 321 DOL3C3=0.0
 322 DOL4C4=(PCOUT/P4L)**3*(GAMMA-(ETA*W4C*COS3C/PCOUT))
     IF(P4L)323,323,324
 323 DOL4C4=0.0
 324 ETA3L=P3LI/AM(3)
     BETA3L=P3LI/SQRTF(AM(3)**2+P3LI**2)
     ETA4L=P4L/AM(4)
     BETA4L=P4L/SQRTF(AM(4)**2+P4L**2)
     A34L=A3LI+A4L
     IF(A34L-180.0)326,325,325
 325 A34L=180.0
 326 WRITE OUTPUT TAPE IO,5,A3LI,P3LI,ETA3L,T3L,BETA3L,DOL3C3,A3CI,A4L,
    1P4L,ETA4L,T4L,BETA4L,DOL4C4 ,A34L
   5 FORMAT(1X,F6.2,1X,F8.2,1X,F6.2,1X,F9.2,1X,F8.6,   F12.5,5X,F6.
    12,1X,F6.2,1X,F8.2,1X,F6.2,1X,F9.2,1X,F9.7,   F12.5,6X,F6.2)
C     INCRIMENT AND TEST VARIABLES.
     A3CI=A3CI+A3C(3)
     IF(A3C(2)-A3CI)400,300,300
 400 P1LI=P1LI+P1L(3)
     IF(P1LI-P1L(2))200,200,500
 500 RETURN
```

D. SAMPLE OUTPUTS

TYPE A FORMAT

SUBROUTINE GAMMA   INDEPENDENT VARIABLE = ANGLE 3 (CM)   DEPENDENT VARIABLE = MOMENTUM 1 (LAB)

MASS 1 (MEV)	MASS 2 (MEV)	MASS 3 (MEV)	MASS 4 (MEV)	ANGLE 3 (CM)	Q VALUE (MEV)	THRESHOLD KINETIC ENERGY1	THRESHOLD MOMENTUM1 (LAB)
139.59	938.21	497.80	1115.36	165.00	-535.36	767.75	896.54

ANGLE 3 (LAB)	MOMENTUM 3 (LAB)	KINETIC ENERGY3 (LAB)	BETA 3	ETA 3	ANGLE 4 (LAB)	MOMENTUM 4 (LAB)	KINETIC ENERGY4 (LAB)	MOMENTUM 1 (LAB)	TOTAL ENERGY (CM)	MOMENTUM IN (CM)	MOMENTUM OUT (CM)	ETA (CM)	GAMMA (CM)	BETA (CM)
2.31	237.41	53.72	0.43046	0.477	0.83	662.85	182.10	900.00	1615.15	522.83	37.02	0.55722	1.1448	0.486755
9.15	173.08	29.23	0.32841	0.348	2.09	754.62	231.29	925.00	1629.44	532.60	106.31	0.56768	1.1499	0.493679
15.41	142.13	19.89	0.27455	0.266	2.66	813.86	255.36	950.00	1643.62	542.28	145.93	0.57799	1.1550	0.500418
22.19	121.33	14.57	0.23680	0.244	3.04	863.87	295.42	975.00	1657.68	551.83	177.06	0.58817	1.1601	0.506979
29.66	106.50	11.27	0.20922	0.214	3.32	908.98	323.48	1000.00	1671.63	561.26	203.62	0.59822	1.1653	0.513371
37.77	96.02	9.18	0.18940	0.193	3.55	950.92	350.34	1025.00	1685.47	570.56	227.22	0.60814	1.1704	0.519599
46.31	89.01	7.90	0.17602	0.179	3.73	990.61	376.40	1050.00	1699.21	579.75	248.69	0.61793	1.1755	0.525670
54.95	84.89	7.19	0.16811	0.171	3.87	1028.60	401.89	1075.00	1712.84	588.83	268.53	0.62761	1.1806	0.531589
63.32	83.16	6.90	0.16477	0.167	4.00	1065.26	426.98	1100.00	1726.37	597.81	287.09	0.63718	1.1857	0.537363
71.09	83.33	6.93	0.16510	0.167	4.11	1100.83	451.75	1125.00	1739.80	606.67	304.59	0.64663	1.1909	0.542996
78.07	84.97	7.20	0.16826	0.171	4.20	1135.49	476.29	1150.00	1753.13	615.44	321.21	0.65597	1.1960	0.548493
84.19	87.69	7.66	0.17348	0.176	4.28	1169.39	500.65	1175.00	1766.36	624.11	337.07	0.66521	1.2010	0.553860
89.47	91.18	8.28	0.18016	0.183	4.35	1202.62	524.86	1200.00	1779.50	632.68	352.27	0.67435	1.2061	0.559101
94.00	95.19	9.02	0.18782	0.191	4.41	1235.29	548.96	1225.00	1792.55	641.16	366.89	0.68338	1.2112	0.564220
97.86	99.54	9.86	0.19608	0.200	4.46	1267.45	572.97	1250.00	1805.50	649.55	380.99	0.69233	1.2163	0.569221
101.15	104.11	10.77	0.20470	0.209	4.51	1299.16	596.90	1275.00	1818.37	657.85	394.64	0.70118	1.2213	0.574109
103.98	108.78	11.75	0.21349	0.219	4.55	1330.47	620.78	1300.00	1831.15	666.07	407.87	0.70994	1.2264	0.578888
106.40	113.51	12.78	0.22232	0.228	4.59	1361.42	644.61	1325.00	1843.84	674.21	420.72	0.71861	1.2314	0.583560
108.50	118.24	13.85	0.23109	0.238	4.62	1392.04	668.40	1350.00	1856.45	682.25	433.22	0.72719	1.2365	0.588130
110.32	122.93	14.95	0.23974	0.247	4.65	1422.37	692.17	1375.00	1868.99	690.24	445.40	0.73570	1.2415	0.592601
111.90	127.56	16.08	0.24824	0.256	4.67	1452.42	715.91	1400.00	1881.42	698.14	457.29	0.74412	1.2465	0.596975
113.29	132.13	17.24	0.25654	0.265	4.70	1482.22	739.64	1425.00	1893.79	705.97	468.91	0.75246	1.2515	0.601257
114.51	136.61	18.41	0.26465	0.274	4.72	1511.80	763.35	1450.00	1906.08	713.72	480.27	0.76073	1.2565	0.605449
115.59	141.01	19.59	0.27254	0.283	4.73	1541.16	787.06	1475.00	1918.29	721.41	491.39	0.76892	1.2614	0.609554
116.54	145.31	20.78	0.28022	0.292	4.75	1570.32	810.76	1500.00	1930.42	729.02	502.29	0.77703	1.2664	0.613574

TYPE B FORMAT

SUBROUTINE ALPHA INDEPENDENT VARIABLE=MOMENTUM 1 (LAB) DEPENDENT VARIABLE=ANGLE 3 (CM)

MASS 1 (MEV)	MASS 2 (MEV)	MASS 3 (MEV)	MASS 4 (MEV)	RELATIVE VELOCITY (CM/SEC)	PHASE SPACE (MEV-SQ.)	MAX ANGLE 3 (LAB)	MAX ANGLE 4 (LAB)	TOTAL ENERGY (CM)
139.59	938.26	497.80	1115.36	4.670E 10	1.703E 05	180.00	31.01	1831.20

MOMENTUM 1 (LAB)	KINETIC ENERGY1 (LAB)	Q VALUE (LAB)	THRESHOLD MOMENTUM1 (LAB)	THRESHOLD KINETIC ENERGY1	MOMENTUM IN (CM)	MOMENTUM OUT (CM)	ETA (CM)	GAMMA (CM)	BETA (CM)
1300.00	1167.88	-535.31	896.45	767.66	666.08	407.92	0.7099	1.2264	0.578877

ANGLE 3 (LAB)	MOMENTUM 3 (LAB)	ETA 3 (LAB)	KINETIC ENERGY3 (LAB)	BETA 3 (LAB)	D OMEGA (LAB) / D OMEGA (CM)3	ANGLE 3 (CM)	ANGLE 4 (LAB)	MOMENTUM 4 (LAB)	ETA 4 (LAB)	KINETIC ENERGY4 (LAB)	BETA 4 (LAB)	D OMEGA (LAB) / D OMEGA (CM)4	TOTAL ANGLE (LAB)
0.	957.15	1.92	581.07	0.887187	0.18163	0.	0.	342.85	0.31	51.50	0.2938178	-1.41565	0.
2.13	955.91	1.92	579.96	0.886941	0.18201	5.00	5.89	346.58	0.31	52.61	0.2967358	-1.35758	8.02
4.27	952.19	1.91	576.67	0.886201	0.18315	10.00	11.43	357.53	0.32	55.90	0.3052538	-1.20162	15.69
6.41	946.02	1.90	571.20	0.884959	0.18506	15.00	16.35	375.06	0.34	61.37	0.3187285	-0.99072	22.76
8.56	937.43	1.88	563.60	0.883197	0.18778	20.00	20.51	398.25	0.36	68.97	0.3362687	-0.76923	29.07
10.72	926.46	1.86	553.93	0.880894	0.19133	25.00	23.86	426.14	0.38	78.64	0.3569055	-0.56734	34.59
12.91	913.20	1.83	542.27	0.878021	0.19576	30.00	26.46	457.81	0.41	90.30	0.3797181	-0.39867	39.36
15.11	897.71	1.80	528.69	0.874541	0.20115	35.00	28.37	492.45	0.44	103.88	0.4039007	-0.26526	43.47
17.33	880.08	1.77	513.31	0.870410	0.20756	40.00	29.69	529.38	0.47	119.25	0.4287835	-0.16330	47.02
19.59	860.42	1.73	496.25	0.865574	0.21508	45.00	30.52	568.05	0.51	136.32	0.4538295	-0.08706	50.10
21.87	838.83	1.69	477.62	0.859970	0.22383	50.00	30.93	607.99	0.55	154.95	0.4786188	-0.03086	52.80
24.19	815.44	1.64	457.58	0.853526	0.23395	55.00	31.00	648.83	0.58	174.99	0.5028313	0.01016	55.19
26.55	790.37	1.59	436.27	0.846155	0.24559	60.00	30.78	690.23	0.62	196.30	0.5262284	0.03983	57.33
28.95	763.75	1.53	413.86	0.837762	0.25897	65.00	30.34	731.92	0.66	218.71	0.5486386	0.06109	59.29
31.40	735.74	1.48	390.52	0.828234	0.27431	70.00	29.70	773.65	0.69	242.05	0.5699437	0.07615	61.10
33.90	706.46	1.42	366.43	0.817445	0.29191	75.00	28.90	815.18	0.73	266.14	0.5900686	0.08664	62.80
36.46	676.06	1.36	341.76	0.805255	0.31212	80.00	27.98	856.32	0.77	290.81	0.6089718	0.09377	64.43
39.07	644.69	1.30	316.71	0.791506	0.33539	85.00	26.94	896.85	0.80	315.85	0.6266381	0.09844	66.02
41.76	612.50	1.23	291.48	0.776023	0.36228	90.00	25.82	936.60	0.84	341.09	0.6430723	0.10132	67.58
44.52	579.61	1.16	266.24	0.758614	0.39348	95.00	24.62	975.39	0.87	366.33	0.6582944	0.10288	69.14
47.35	546.17	1.10	241.19	0.739075	0.42991	100.00	23.36	1013.03	0.91	391.38	0.6723350	0.10350	70.72
50.27	512.30	1.03	216.52	0.717185	0.47277	105.00	22.05	1049.37	0.94	416.04	0.6852321	0.10346	72.33
53.29	478.13	0.96	192.43	0.692717	0.52367	110.00	20.70	1084.23	0.97	440.14	0.6970287	0.10296	74.00
56.42	443.78	0.89	169.09	0.665441	0.58485	115.00	19.32	1117.46	1.00	463.48	0.7077700	0.10215	75.74
59.66	409.33	0.82	146.68	0.635130	0.65949	120.00	17.91	1148.90	1.03	485.89	0.7175019	0.10115	77.57
63.04	374.89	0.75	125.37	0.601577	0.75230	125.00	16.47	1178.41	1.06	507.20	0.7262700	0.10004	79.51
66.58	340.53	0.68	105.33	0.564607	0.87048	130.00	15.02	1205.86	1.08	527.24	0.7341181	0.09890	81.60
70.32	306.33	0.62	86.70	0.524092	1.02566	135.00	13.55	1231.11	1.10	545.86	0.7410876	0.09778	83.87
74.31	272.36	0.55	69.64	0.479982	1.23758	140.00	12.07	1254.05	1.12	562.93	0.7472168	0.09670	86.38
78.62	238.67	0.48	54.26	0.432325	1.54216	145.00	10.58	1274.56	1.14	578.31	0.7525408	0.09571	89.20
83.38	205.33	0.41	40.68	0.381307	2.01031	150.00	9.08	1292.54	1.16	591.89	0.7570908	0.09481	92.46
88.84	172.43	0.35	29.02	0.327306	2.79703	155.00	7.57	1307.91	1.17	603.55	0.7608942	0.09404	96.41
95.40	140.14	0.28	19.35	0.270986	4.28794	160.00	6.06	1320.59	1.18	613.22	0.7639742	0.09339	101.47
104.00	108.81	0.22	11.75	0.213539	7.61267	165.00	4.55	1330.52	1.19	620.82	0.7663499	0.09287	108.55
116.79	79.35	0.16	6.29	0.157421	16.75366	170.00	3.04	1337.65	1.20	626.28	0.7680361	0.09250	119.83
139.39	54.62	0.11	2.99	0.109068	46.06220	175.00	1.52	1341.94	1.20	629.58	0.7690436	0.09228	140.91
180.00	43.37	0.09	1.89	0.086792	88.47095	180.00	0.	1343.37	1.20	630.68	0.7693788	0.09221	180.00

FOOTNOTES AND REFERENCES

*Present address: Physics Department, Virginia Polytechnic Institute, Blacksburg, Virginia.

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   W. P. Trower and M. Gode-von Aesch, KINE-NINE: A FORTRAN Program to Calculate Particle Kinematics and Present Them in Tabular Form, Alvarez Group Memo 376, 1962 (unpublished).
2. John H. Poirier (Lawrence Radiation Laboratory), RELKIN (unpublished data), 1962.
3. Much of what appears here can be found in J. P. Berge, Special Relativity: Algebra, etc., Alvarez Group Memo 39, 1958 (unpublished).