Beam optics calculation of proton beam line with TRANSPORT

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Optics calculation of proton beam line for an AC dipole section is performed with TRANSPORT. In this report, the result is shown.

I. GEOMETRY AND CONSTRAINS

A geometry of an AC dipole section is shown in fig. 1. In this figure, Q_n and B_n are quadrupole magnets and dipole magnets (AC dipoles). Proton beam of point source is made parallel at the AC dipole with a doublet Q and focused at a collimator with another doublet Q. This beam line section is symmetric with respect to the collimator. At the AC dipole, the beam profile should be less than 10 mm×50 mm as shown in fig. 1, because of a limitation of stored energy of the magnet.

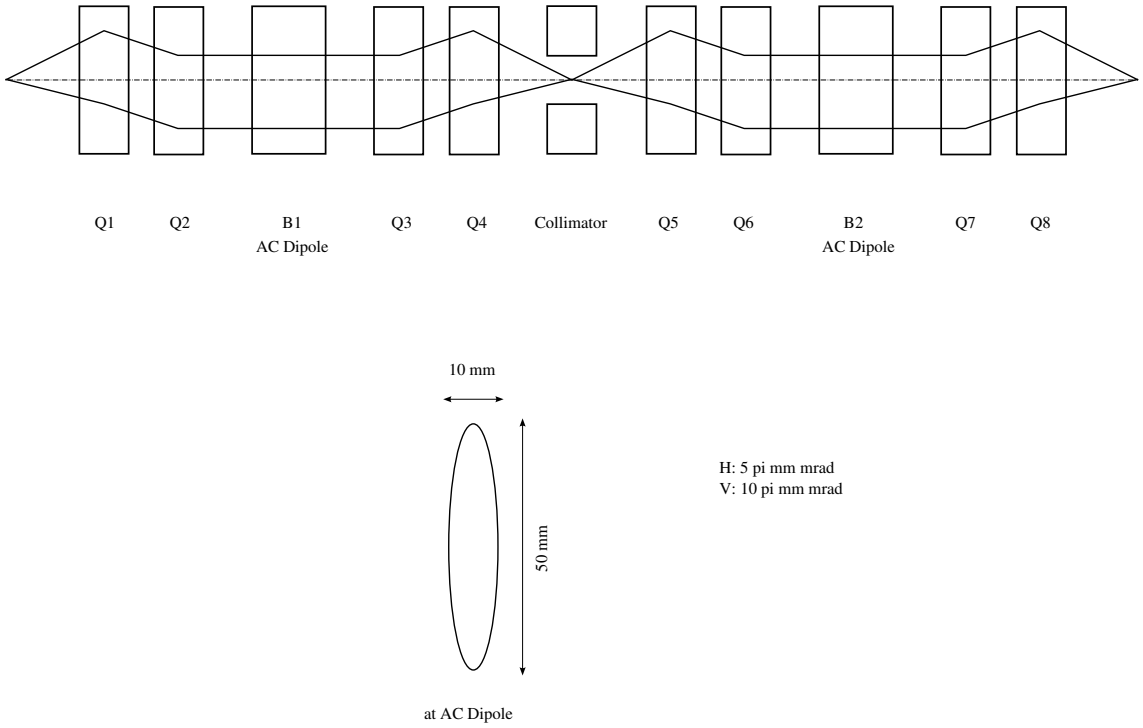

FIG. 1: AC dipole section

In this calculation, field gradient of the quadrupole magnets are varied while positions of the optics elements are fixed. The field gradient and length of Q_1 and Q_2 are same as those of Q_3 and Q_4, respectively. The magnetic field of the AC dipole is set to zero. Proton beam is used with momentum of 8 GeV/c.

Constrains in this calculation are,

$$R_{22} = 0.0 \quad \text{at } B_1, \tag{1}$$
$$R_{44} = 0.0 \quad \text{at } B_1, \tag{2}$$
$$R_{12} = 0.0 \quad \text{at collimator}, \tag{3}$$
$$R_{34} = 0.0 \quad \text{at collimator}. \tag{4}$$

Here, R_{ij} are components of transfer matrix. These constrains mean that the point source beam is made parallel at the AC dipole (B_1) and focused at the collimator. The calculation has been stopped at 1st order.

II. CALCULATION RESULTS

Calculated beam profile is shown in fig. 2. Upper plot shows the profile in x direction and lower one shows the profile in y direction. In each plot, three lines are plotted; solid, dash, and dotted-dash lines indicate profiles of a particle injected at initial phases(x, x', y, y') of (0 mm, 5 mrad, 0 mm, 10 mrad), (1 mm, 5 mrad, 1 mm, 10 mrad), and (5 mm, 1 mrad, 10 mm, 1 mrad), respectively. It can be seen that the beam successfully become parallel at B_1 and focused at collimator. The beam size at AC dipole is larger than the aperture, because constrain of the aperture are not included.

In this calculation, field gradient of Q magnets are optimized. And the obtained values are,

$$K_1 = -0.86642 \quad \mathrm{mm}^{-2} \quad (\mathrm{Q}_1, \mathrm{Q}_4), \tag{5}$$

$$K_1 = 0.67171 \quad \mathrm{mm}^{-2} \quad (\mathrm{Q}_2, \mathrm{Q}_3). \tag{6}$$

Here,

$$K_1 = \frac{g}{B\rho}, \tag{7}$$

$$g = \frac{\partial B}{\partial x}. \tag{8}$$

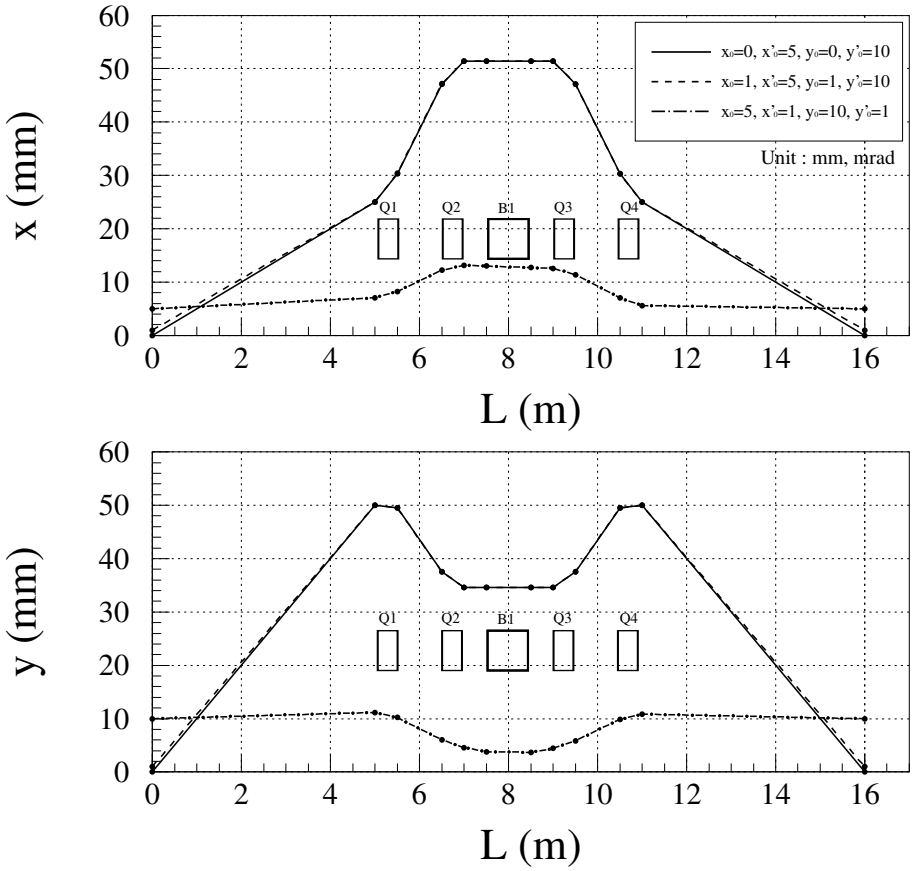

FIG. 2: Beam profile calculated by TRANSPORT.

III. SUMMARY

Calculation of transport matrix of the AC dipole section with TRANSPORT has been performed. With the TRANSPORT, quadrupole component of Q magnet is optimized under the constrains and intended beam optics has

been obtained. The next step would be to optimize not only quadrupole components but the other parameters by inputing more constrains and considering realistic conditions.

APPENDIX A: INPUT AND OUTPUT FILE

1. Input file

```
'AC Dipole for 8 GeV/c proton beam 1'
0
UMM
EL1: = 5.0;
EL2: = 1.0;
EL3: = 0.5;
EL4: = 5.0;
KF:  = 10.;
KD:  = 10.;
KF2:  = 10.;
KD2:  = 10.;
LIMIT, QUAD, B, ABSOLUTE = 15.0;
PRINT, TRANSPORT, acdp01;
MAGNET, WIDTH = .25, HEIGHT = .25, TYPE = QMAG;
MAGNET, WIDTH = .25, HEIGHT = .5, TYPE = ACDP;
SPEC, HWIDTH=4.0
PLOT, L, XBEAM, YBEAM;
(PLOT, BETAX, BETAY;)
(BEAM, BETAX=15., ALPHAX=0., BETAY=5.88, ALPHAY=0., P0=8.;)
BEAM, X=5, XP=1, Y=10, YP=1,  P0=8.;
DR1:  DRIFT, L=EL1;
Q1:  QUAD, B=10.0, L=0.5, APER=0.15, K1=KF, TYPE=QMAG;
DR2:  DRIFT, L=EL2;
Q2:  QUAD, B=10.0, L=0.5, APER=0.15, K1=KD, TYPE=QMAG;
DR3:  DRIFT, L=EL3;
B1:  RBEND, B=0.0, L=1.0, HGAP=0.5, TYPE=ACDP;
DR4: -DRIFT, L=EL3;
Q3:  -QUAD, B=10.0, L=0.5, APER=0.15, K1=KD2, TYPE=QMAG;
DR5:  -DRIFT, L=EL2;
Q4:  -QUAD, B=10.0, L=0.5, APER=0.15, K1=KF2, TYPE=QMAG;
DR6:  -DRIFT, L=EL4;
VARY, KF;
VARY, KD;
VARY, KF2;
VARY, KD2;
(VARY, EL1;)
(VARY, EL2;)
(VARY, EL3;)
FIT1: FIT, R22=0.0, TOLER=0.001;
FIT2: FIT, R44=0.0, TOLER=0.001;
```

```
FIT3: -FIT, R12=0.0, TOLER=0.1;
FIT4: -FIT, R34=0.0, TOLER=0.1;
SENTINEL
'AC Dipole for 8 GeV/c proton beam 2'
1
DR4: DRIFT;
Q3:  QUAD;
DR5: DRIFT;
Q4:  QUAD;
DR6: DRIFT;
FIX, KF;
FIX, KD;
FIX, EL1;
FIX, EL2;
FIX, EL3;
FIT1: -FIT;
FIT2: -FIT;
FIT3: FIT;
FIT4: FIT;
SENTINEL
SENTINEL
```

2. Output file

```
 CHANGEDATE(TRMAIN   FORTRAN  19990614 14:55:00)
1
0          "AC DIPOLE FOR 8 GEV/C PROTON BEAM 1                                  "
0          0
           UMM
+                                                                          (   1         )
           EL1: = 5.0;
+                                                                          (   2         )
     5     EL2: = 1.0;
+                                                                          (   3 ELEMENTS)
           EL3: = 0.5;
+                                                                          (   4         )
           EL4: = 5.0;
+                                                                          (   5         )
           KF:  = 10.;
+                                                                          (   6         )
           KD:  = 10.;
+                                                                          (   7         )
```

```
    10      KF2:  = 10.;
+                                                                    (   8 ELEMENTS)
            KD2:  = 10.;
+                                                                    (   9         )
            LIMIT, QUAD, B, ABSOLUTE = 15.0;
+                                                                    (  10         )
            PRINT, TRANSPORT, acdp01;
+                                                                    (  10         )
            MAGNET, WIDTH = .25, HEIGHT = .25, TYPE = QMAG;
+                                                                    (  11         )
    15      MAGNET, WIDTH = .25, HEIGHT = .5, TYPE = ACDP;
+                                                                    (  12 ELEMENTS)
            SPEC, HWIDTH=4.0
+                                                                    (  13         )
            PLOT, L, XBEAM, YBEAM;
+                                                                    (  14         )
            (PLOT, BETAX, BETAY;)
+                                                                    (  14         )
            (BEAM, BETAX=15., ALPHAX=0., BETAY=5.88, ALPHAY=0., P0=8.;)
+                                                                    (  14         )
    20      BEAM, X=5, XP=1, Y=10, YP=1,  P0=8.;
+                                                                    (  15 ELEMENTS)
            DR1:  DRIFT, L=EL1;
+                                                                    (  16         )
            Q1:  QUAD, B=10.0, L=0.5, APER=0.15, K1=KF, TYPE=QMAG;
+                                                                    (  17         )
            DR2:  DRIFT, L=EL2;
+                                                                    (  18         )
            Q2:  QUAD, B=10.0, L=0.5, APER=0.15, K1=KD, TYPE=QMAG;
+                                                                    (  19         )
    25      DR3:  DRIFT, L=EL3;
+                                                                    (  20 ELEMENTS)
            B1:  RBEND, B=0.0, L=1.0, HGAP=0.5, TYPE=ACDP;
+                                                                    (  21         )
            DR4: -DRIFT, L=EL3;
+                                                                    (  22         )
            Q3:  -QUAD, B=10.0, L=0.5, APER=0.15, K1=KD2, TYPE=QMAG;
+                                                                    (  23         )
            DR5:  -DRIFT, L=EL2;
+                                                                    (  24         )
    30      Q4:  -QUAD, B=10.0, L=0.5, APER=0.15, K1=KF2, TYPE=QMAG;
+                                                                    (  25 ELEMENTS)
            DR6:  -DRIFT, L=EL4;
+                                                                    (  26         )
```

```
          VARY, KF;
+                                                                                    (  26         )
          VARY, KD;
+                                                                                    (  26         )
          VARY, KF2;
+                                                                                    (  26         )
    35    VARY, KD2;
+                                                                                    (  26 ELEMENTS)
          (VARY, EL1;)
+                                                                                    (  26         )
          (VARY, EL2;)
+                                                                                    (  26         )
          (VARY, EL3;)
+                                                                                    (  26         )
          FIT1: FIT, R22=0.0, TOLER=0.001;
+                                                                                    (  27         )
    40    FIT2: FIT, R44=0.0, TOLER=0.001;
+                                                                                    (  28 ELEMENTS)
          FIT3: -FIT, R12=0.0, TOLER=0.1;
+                                                                                    (  29         )
          FIT4: -FIT, R34=0.0, TOLER=0.1;
+                                                                                    (  30         )
          SENTINEL
0   30 ELEMENTS USED OUT OF A MAXIMUM ALLOWABLE 4001
   117 NUMBERS USED OUT OF A MAXIMUM ALLOWABLE 12001
1AC DIPOLE FOR 8 GEV/C PROTON BEAM 1

 (  13)  *HWIDTH*                    0.40000E+01
 (  15)  *BEAM*                      8.00000 GEV/C
              0.000 M                                                  0.000   5.000 MM
                                                                       0.000   1.000 MR      0.000
                                                                       0.000  10.000 MM      0.000  0.000
                                                                       0.000   1.000 MR      0.000  0.000  0.000
                                                                       0.000   0.000 MM      0.000  0.000  0.000  0.000
                                                                       0.000   0.000 PM      0.000  0.000  0.000  0.000  0.000
 (  16)  *DRIFT*         DR1         5.00000 M
              5.000 M
 (  17)  *QUAD*          Q1          0.50000 M       10.00000 M   **-2              (    0.31624 M   )
              5.500 M
 (  18)  *DRIFT*         DR2         1.00000 M
              6.500 M
 (  19)  *QUAD*          Q2          0.50000 M       10.00000 M   **-2              (    0.31624 M   )
              7.000 M
 (  20)  *DRIFT*         DR3         0.50000 M
```

```
             7.500 M
 (  21)  *     *        B1            0.00000 MR
 (  21)  *RBEND*        B1            1.00000 M         0.00000 KG        0.00000      (     0.000 M   ,   0.00000 MR  )
 (  21)  *     *        B1            0.00000 MR
             8.500 M
 (  27)  *FIT*          FIT1         R22           0.0     /0.00100        (    49.35461 )
 (  28)  *FIT*          FIT2         R44           0.0     /0.00100        (   487.74222 )
0        *LENGTH*          8.50000 M
0        *CORRECTIONS*
         *NUMBER OF VARIED PARAMETERS =     4 *
         *NUMBER OF CONSTRAINTS       =     2 *

  0.10000E+01 ( 0.24033E+12)  -43.0672   33.7066
 -0.10000E+01 ( 0.17334E+13)   43.0672  -33.7066
  0.50000E+00 ( 0.24033E+12)  -23.5729   14.7627
 -0.50000E+00 ( 0.53702E+12)   23.5729  -14.7627
  0.25000E+00 ( 0.24033E+12)  -13.8648    5.3288
  0.25000E+00 ( 0.14264E+11)    6.4517   21.7430
 -0.25000E+00 ( 0.12028E+13)   -6.4517  -21.7430
  0.12500E+00 ( 0.14264E+11)    6.4298   21.6231
 -0.12500E+00 ( 0.11740E+13)   -6.4298  -21.6231
  0.62500E-01 ( 0.14264E+11)    6.3865   21.3860
 -0.62500E-01 ( 0.11189E+13)   -6.3865  -21.3860
  0.31250E-01 ( 0.14264E+11)    6.3022   20.9237
 -0.31250E-01 ( 0.10179E+13)   -6.3022  -20.9237
  0.15625E-01 ( 0.14264E+11)    6.1415   20.0431
 -0.15625E-01 ( 0.84714E+12)   -6.1415  -20.0431
  0.78125E-02 ( 0.14264E+11)    5.8487   18.4402
 -0.78125E-02 ( 0.59926E+12)   -5.8487  -18.4402
  0.39062E-02 ( 0.14264E+11)    5.3564   15.7491
 -0.39062E-02 ( 0.32192E+12)   -5.3564  -15.7491
  0.19531E-02 ( 0.14264E+11)    4.6302   11.7928
 -0.19531E-02 ( 0.11469E+12)   -4.6302  -11.7928
  0.97656E-03 ( 0.14264E+11)    3.7407    6.9877
 -0.97656E-03 ( 0.24615E+11)   -3.7407   -6.9877
  0.48828E-03 ( 0.14264E+11)    2.8653    2.3623
  0.48828E-03 ( 0.39771E+10)    0.5189  -16.3773
  0.97656E-03 ( 0.19678E+08)   -0.2058   -0.7610
  0.19531E-02 ( 0.25050E+06)   -0.1875    0.1251
  0.39062E-02 ( 0.66199E+03)    0.0073   -0.0061
  0.78125E-02 ( 0.46305E+00)  0.21E-03 -0.16E-03
  0.78125E-02 ( 0.59934E-04)  0.23E-05 -0.18E-05
0        *COVARIANCE  (FIT 0.82540E-07 )
        0.000
```

```
      -0.665       0.000
 (   6)  *PARAM*        "KF    "     -0.86642307E+00
             VARIED
 (   7)  *PARAM*        "KD    "      0.67170852E+00
             VARIED
 (   8)  *PARAM*        "KF2   "      0.10000000E+02
             VARIED
 (   9)  *PARAM*        "KD2   "      0.10000000E+02
             VARIED
1AC DIPOLE FOR 8 GEV/C PROTON BEAM 1

 (  13)  *HWIDTH*                     0.40000E+01
 (  15)  *BEAM*                       8.00000 GEV/C
              0.000 M                                                  0.000   5.000 MM
                                                                       0.000   1.000 MR      0.000
                                                                       0.000  10.000 MM      0.000  0.000
                                                                       0.000   1.000 MR      0.000  0.000  0.000
                                                                       0.000   0.000 MM      0.000  0.000  0.000  0.000
                                                                       0.000   0.000 PM      0.000  0.000  0.000  0.000  0.000
 (  16)  *DRIFT*        DR1           5.00000 M
              5.000 M
 (  17)  *QUAD*         Q1            0.50000 M        -0.86642 M   **-2              (   -2.22707 M   )
              5.500 M
 (  18)  *DRIFT*        DR2           1.00000 M
              6.500 M
 (  19)  *QUAD*         Q2            0.50000 M         0.67171 M   **-2              (    3.06248 M   )
              7.000 M
 (  20)  *DRIFT*        DR3           0.50000 M
              7.500 M
 (  21)  *     *        B1            0.00000 MR
 (  21)  *RBEND*        B1            1.00000 M         0.00000 KG        0.00000      (     0.000 M   ,   0.00000 MR  )
 (  21)  *     *        B1            0.00000 MR
              8.500 M
 (  27)  *FIT*          FIT1         R22           0.0     /0.00100        (  -0.701E-07 )
 (  28)  *FIT*          FIT2         R44           0.0     /0.00100        (  -0.279E-06 )
0        *LENGTH*          8.50000 M
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
 LATDEF [ F] <>  0
 MAD [ F] <>  0
 TRANSPORT [ T] <ACDP01>  6
 STRUCT [ F] <>  0
 ACAD [ F] <>  0
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
1
```

```
0          "AC DIPOLE FOR 8 GEV/C PROTON BEAM 2                                                    "
0          1
           DR4: DRIFT;
           Q3:  QUAD;
           DR5: DRIFT;
           Q4:  QUAD;
    50     DR6: DRIFT;
           FIX, KF;
           FIX, KD;
           FIX, EL1;
           FIX, EL2;
    55     FIX, EL3;
           FIT1: -FIT;
           FIT2: -FIT;
           FIT3: FIT;
           FIT4: FIT;
    60     SENTINEL
0   30 ELEMENTS USED OUT OF A MAXIMUM ALLOWABLE 4001
   110 NUMBERS USED OUT OF A MAXIMUM ALLOWABLE 12001
1AC DIPOLE FOR 8 GEV/C PROTON BEAM 2

 (  13)  *HWIDTH*                    0.40000E+01
 (  15)  *BEAM*                      8.00000 GEV/C
              0.000 M                                                    0.000   5.000 MM
                                                                         0.000   1.000 MR      0.000
                                                                         0.000  10.000 MM      0.000  0.000
                                                                         0.000   1.000 MR      0.000  0.000  0.000
                                                                         0.000   0.000 MM      0.000  0.000  0.000  0.000
                                                                         0.000   0.000 PM      0.000  0.000  0.000  0.000  0.000
 (  16)  *DRIFT*         DR1         5.00000 M
              5.000 M
 (  17)  *QUAD*          Q1          0.50000 M       -0.86642 M   **-2              (   -2.22707 M   )
              5.500 M
 (  18)  *DRIFT*         DR2         1.00000 M
              6.500 M
 (  19)  *QUAD*          Q2          0.50000 M        0.67171 M   **-2              (    3.06248 M   )
              7.000 M
 (  20)  *DRIFT*         DR3         0.50000 M
              7.500 M
 (  21)  *     *         B1          0.00000 MR
 (  21)  *RBEND*         B1          1.00000 M        0.00000 KG       0.00000      (     0.000 M   ,   0.00000 MR  )
 (  21)  *     *         B1          0.00000 MR
              8.500 M
 (  22)  *DRIFT*         DR4         0.50000 M
```

```
             9.000 M
 (  23)  *QUAD*         Q3            0.50000 M        10.00000 M   **-2              (    0.31624 M   )
             9.500 M
 (  24)  *DRIFT*        DR5           1.00000 M
            10.500 M
 (  25)  *QUAD*         Q4            0.50000 M        10.00000 M   **-2              (    0.31624 M   )
            11.000 M
 (  26)  *DRIFT*        DR6           5.00000 M
            16.000 M
 (  29)  *FIT*          FIT3         R12           0.0     /0.10000        (   507.15640 )
 (  30)  *FIT*          FIT4         R34           0.0     /0.10000        (  1687.88684 )
0        *LENGTH*         16.00000 M
0        *CORRECTIONS*
         *NUMBER OF VARIED PARAMETERS =     2 *
         *NUMBER OF CONSTRAINTS       =     2 *

  0.10000E+01 ( 0.31062E+09)  -43.0644   33.7039
 -0.10000E+01 ( 0.21272E+10)   43.0644  -33.7039
  0.50000E+00 ( 0.31062E+09)  -23.6017   14.7196
 -0.50000E+00 ( 0.13828E+10)   23.6017  -14.7196
  0.25000E+00 ( 0.31062E+09)  -13.9131    5.2708
  0.25000E+00 ( 0.80153E+08)    6.4581   20.7800
 -0.25000E+00 ( 0.12624E+10)   -6.4581  -20.7800
  0.12500E+00 ( 0.80153E+08)    6.4106   20.4484
 -0.12500E+00 ( 0.11875E+10)   -6.4106  -20.4484
  0.62500E-01 ( 0.80153E+08)    6.3183   19.8050
 -0.62500E-01 ( 0.10531E+10)   -6.3183  -19.8050
  0.31250E-01 ( 0.80153E+08)    6.1441   18.5924
 -0.31250E-01 ( 0.83563E+09)   -6.1441  -18.5924
  0.15625E-01 ( 0.80153E+08)    5.8315   16.4279
 -0.15625E-01 ( 0.54296E+09)   -5.8315  -16.4279
  0.78125E-02 ( 0.80153E+08)    5.3191   12.9163
 -0.78125E-02 ( 0.25457E+09)   -5.3191  -12.9163
  0.39062E-02 ( 0.80153E+08)    4.5898    8.0317
  0.39062E-02 ( 0.77055E+08)   -0.0202  -12.5561
  0.78125E-02 ( 0.94763E+07)    0.6957  -10.4007
  0.15625E-01 ( 0.13115E+06)   -1.3326   -0.3221
  0.31250E-01 ( 0.95268E+04)    0.0711    0.1418
  0.62500E-01 ( 0.46094E+04)   -1.2698    0.9330
 -0.62500E-01 ( 0.36353E+05)    1.2698   -0.9330
  0.31250E-01 ( 0.46094E+04)   -0.6943    0.5082
  0.31250E-01 ( 0.27258E+04)   -0.2515   -0.0070
  0.62500E-01 ( 0.19837E+01)   -0.0111    0.0050
  0.12500E+00 ( 0.61847E-03) -0.23E-03  0.73E-04
```

```
  0.12500E+00 ( 0.51927E-07) -0.21E-05  0.73E-06
0        *COVARIANCE  (FIT 0.13785E-09 )
        0.009
       -0.831       0.004
 (   8)  *PARAM*        "KF2   "     -0.86642289E+00
             VARIED
 (   9)  *PARAM*        "KD2   "      0.67170846E+00
             VARIED
1AC DIPOLE FOR 8 GEV/C PROTON BEAM 2

 (  13)  *HWIDTH*                     0.40000E+01
 (  15)  *BEAM*                       8.00000 GEV/C
              0.000 M                                                    0.000   5.000 MM
                                                                         0.000   1.000 MR      0.000
                                                                         0.000  10.000 MM      0.000  0.000
                                                                         0.000   1.000 MR      0.000  0.000  0.000
                                                                         0.000   0.000 MM      0.000  0.000  0.000  0.000
                                                                         0.000   0.000 PM      0.000  0.000  0.000  0.000  0.000
 (  16)  *DRIFT*        DR1           5.00000 M
              5.000 M
 (  17)  *QUAD*         Q1            0.50000 M       -0.86642 M   **-2              (   -2.22707 M   )
              5.500 M
 (  18)  *DRIFT*        DR2           1.00000 M
              6.500 M
 (  19)  *QUAD*         Q2            0.50000 M        0.67171 M   **-2              (    3.06248 M   )
              7.000 M
 (  20)  *DRIFT*        DR3           0.50000 M
              7.500 M
 (  21)  *     *        B1            0.00000 MR
 (  21)  *RBEND*        B1            1.00000 M        0.00000 KG       0.00000      (     0.000 M   ,   0.00000 MR  )
 (  21)  *     *        B1            0.00000 MR
              8.500 M
 (  22)  *DRIFT*        DR4           0.50000 M
              9.000 M
 (  23)  *QUAD*         Q3            0.50000 M        0.67171 M   **-2              (    3.06248 M   )
              9.500 M
 (  24)  *DRIFT*        DR5           1.00000 M
             10.500 M
 (  25)  *QUAD*         Q4            0.50000 M       -0.86642 M   **-2              (   -2.22707 M   )
             11.000 M
 (  26)  *DRIFT*        DR6           5.00000 M
             16.000 M
 (  29)  *FIT*          FIT3          R12           0.0     /0.10000        (  -0.477E-06 )
 (  30)  *FIT*          FIT4          R34           0.0     /0.10000        (   0.107E-05 )
```

```
0        *LENGTH*         16.00000 M
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
 LATDEF [ F] <>  0
 MAD [ F] <>  0
 TRANSPORT [ T] <ACDP01>  6
 STRUCT [ F] <>  0
 ACAD [ F] <>  0
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
```