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Optic model for the septum magnet without median plane symmetry

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Abstract: This note studied the transfer matrix of the septum magnet in BL1U using 2 methods, one is calculated using the vertically shifted semi-analytical vector potential of the fringe field of the symmetrical bending magnet, and the other is by tracking particles using zgoubi.

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1 Introduction

TRIUMF BL1U is a primary beamline, which delivers 500 MeV proton beams onto a spallation target in the Ultra Cold Neutron facility (UCN). It shares the beam with the other primary beamline BL1A. The 500 MeV proton beam up to hundreds μA is extracted into BL1V from TRIUMF main cyclotron. BL1U brunches off from BL1V by using a kicker magnet. The beam is kicked upward by 12 mrad to enter the gap of the following septum. A Lambertson type septum magnet is used in BL1U to bend the beam to the left by about 9 degrees. The beam outside the kicking period passes through the hole in the septum yoke, where the magnetic field is zero. Thus, the beam outside the kicking period could be delivered into BL1A. Figure 1 shows the Opera-3D model of the septum magnet. There is no median plane symmetry in the magnet geometry model.

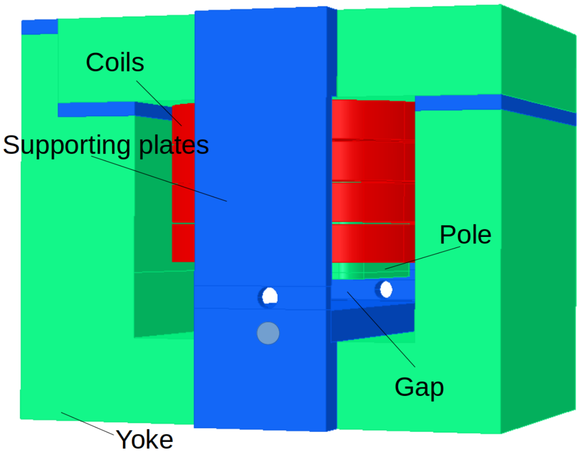


Figure 1: Model of the BL1U septum magnet.

Fig. 2 shows the magnetic field along the reference orbit in the septum magnet.

2 Optic model

2.1 Field without median plane symmetry

For conventional bending magnet, by median plane symmetry, the magnetic field along the reference orbit is in the only vertical direction. However, when there is no median plane symmetry, the field contains a longitudinal component.

Derived from the multipole vector potential expression in the Coulomb gauge[1], the vector potential of a rectangular dipole magnet with median

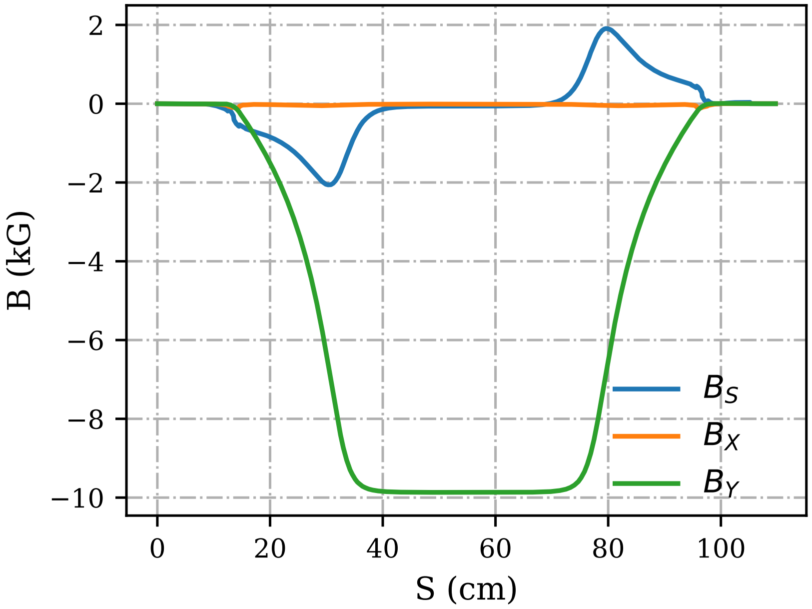


Figure 2: Magnetic field along the reference orbit. The non-zero longitudinal field B_s is caused by the asymmetrical structure of the upper and lower pole of the magnet. The equipotential surface of the magnetic scalar potential on the median plane tilts up on both ends of the magnet.

plane symmetry is written as [2]

$$\begin{aligned} A_x &= \frac{1}{2}(x^2 - y^2)[\frac{1}{2}B_0'(s) + ...] \\ A_y &= xy[\frac{1}{2}B_0'(s) + ...] \\ A_s &= -x[B_0(s) - \frac{1}{8}(x^2 + y^2)B_0''(s) + ...] \end{aligned} \tag{1}$$

where $B_0(s)$ is the on axis magnetic field in the vertical direction. $'$ here donates a derivative with respect to s. If we shift the reference coordinate system vertically by y_0, the vector potential could be written as

$$\begin{aligned} A_x &= \frac{1}{2}(x^2 - y^2 - 2y_0y - y_0^2)[\frac{1}{2}B_0'(s) + ...] \\ A_y &= x(y + y_0)[\frac{1}{2}B_0'(s) + ...] \\ A_s &= -x[B_0(s) - \frac{1}{8}(x^2 + y^2 + 2y_0y + y_0^2)B_0''(s) + ...] \end{aligned} \tag{2}$$

$B_0(s)$ is the magnetic field on the median plane axis, which is not the reference axis in the shifted coordinate system. Magnetic field on the new reference axis calculated from the curl of the vector potential is written as

$$\begin{aligned} B_x &= -4x_0 y_0 B_0''(s) \\ B_y &= B_0(s) - \frac{3}{8} y_0^2 B_0''(s) \\ B_s &= y_0 B_0'(s) \end{aligned} \tag{3}$$

2.2 Transfer Matrix in the Fringe Field

The general hamiltonian in the cartesian frame, using the distance s as the independent variable in a static magnetic field is given by

$$H = -\frac{qA_s}{P_0} - \sqrt{(1+\sigma)^2 - (P_x - \frac{qA_x}{P_0})^2 - (P_y - \frac{qA_y}{P_0})^2} \tag{4}$$

where P_x, P_y are the canonical momenta scaled by a reference momentum P_0, $\sigma = (P - P_0)/P_0$. Without momentum spread, we expand the Hamiltonian but throwing out the constant

$$H = -\frac{qA_s}{P_0} + \frac{1}{2}(P_x - \frac{qA_x}{P_0})^2 + \frac{1}{2}(P_y - \frac{qA_y}{P_0})^2 \tag{5}$$

For the sector dipole magnet case, where the fringe field is symmetrical with respect to horizontal axis x, the Hamiltonian truncated at second order is written as

$$H = \frac{x[B_0(s) - \frac{1}{8}(y+y_0)^2 B_0''(s)]}{B\rho} + \frac{1}{2}[P_x - \frac{x^2 - (y+y_0)^2 B_0'(s)}{4B\rho}]^2 + \frac{1}{2}[P_y - \frac{y_0 x B_0'(s)}{2B\rho}]^2 \tag{6}$$

For linear motion, the transversal 4 × 4 infinitesimal transfer matrix is calculated as

$$F = JH \quad = \begin{bmatrix} 0 & 1 & K & 0 \\ -0.5K^2 & 0 & F & K \\ -K & 0 & 0 & 1 \\ F & -K & -1.5K^2 & 0 \end{bmatrix}, J = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{bmatrix} \tag{7}$$

where H is a Hessian matrix of the Hamiltonian, $K = \frac{y_0 B_0'(s)}{2B\rho}$, $F = \frac{y_0 B_0''(s)}{4B\rho}$, $B\rho$ is the magnetic rigidity of the beam. Substitute the magnetic field on the new reference axis in eq.3. The parameters in the matrix is $K = \frac{B_s(s)}{2B\rho}$, $F = \frac{B_s'(s)}{4B\rho}$.Thus we can directly use the magnetic field on the reference axis to calculate the transfer matrix instead of B_0, the magnetic field on the virtual symmetric plane axis.

The transfer matrix of the fringe field could be get by solving $M(s) = I + F(s)ds$ numerically. The transfer matrix of the whole septum magnet is calculated as

$$\begin{aligned} \mathrm{M} &= \mathrm{M_{ex}M_bM_{en}} \\ &= \begin{bmatrix} 1.0000 & 0.1099 & 0.0131 & 0.0004 \\ 0.0006 & 1.0000 & 0.2382 & 0.0132 \\ 0.0131 & 0.0004 & 0.9707 & 0.1091 \\ 0.2382 & 0.0132 & -0.5292 & 0.9707 \end{bmatrix} \end{aligned} \tag{8}$$

Check the symplectic of the transfer matrix,

$$\mathrm{M^TJM - J} = \begin{bmatrix} 0.0000 & 0.9351 & -0.3950 & -0.0072 \\ -0.9351 & 0.0000 & -0.0525 & -0.0038 \\ 0.3950 & 0.0525 & 0.0000 & -0.1807 \\ 0.0072 & 0.0038 & 0.1807 & 0.0000 \end{bmatrix} \times 10^{-5} \tag{9}$$

The non-negligible r23 and r41 terms in the transfer matrix are resulted from the shifted median plane, which is not simply an effect from the longitudinal field as in a solenoid.

2.3 Matrix calculated by zgoubi code

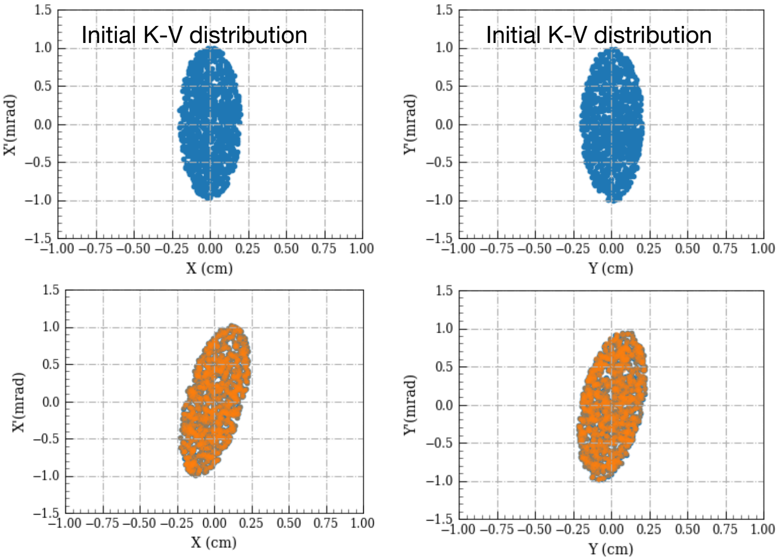
For a soft edge magnet, the more accurate way is to track the particle through the 3D field and calculate the transfer matrix from the particle's coordinate before and after the magnet.

In this paper, we use the ray-tracing package zgoubi [3] to track the beam through the 3D magnetic field and calculate the transfer matrix. Zgoubi uses a 3-D 27-point grid for interpolation of magnetic field and its second-order derivatives. And the transfer matrix could be calculated automatically in zgoubi by tracking 11 initial particles. In addition, the second-order coefficients could also be calculated in zgoubi by tracking 61 particles. The transfer matrix calculated by zgoubi is given as

$$\mathrm{M} = \begin{bmatrix} 1.0102 & 0.1103 & 0.0187 & 0.0010 \\ 0.1837 & 1.0100 & 0.3676 & 0.0201 \\ 0.0198 & 0.0011 & 0.9679 & 0.1089 \\ 0.3384 & 0.0193 & -0.5794 & 0.9679 \end{bmatrix} \tag{10}$$

Check the symplectic of the transfer matrix,

(a) Small beam size



(b) Large beam size

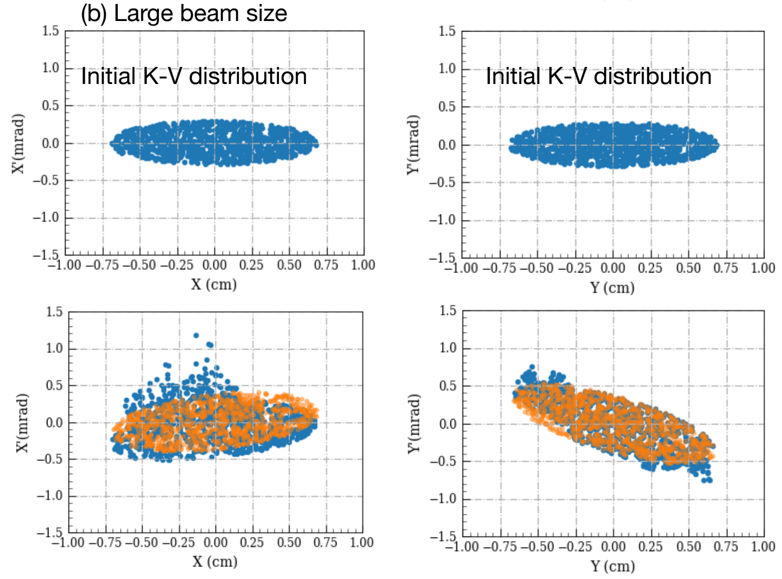
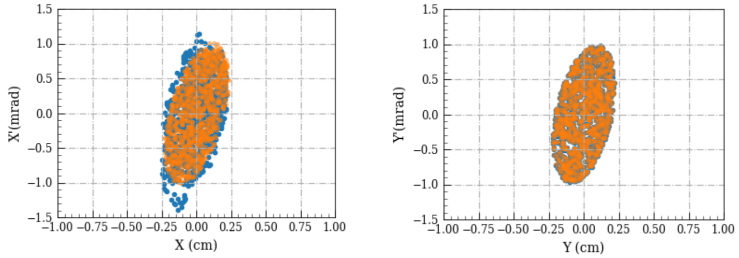
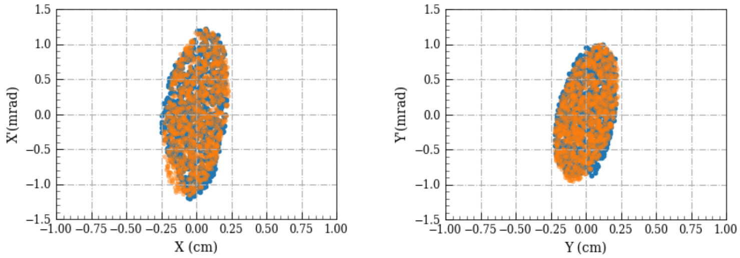


Figure 3: Particle tracking result with different initial beam size. The orange particles are calculated using the transfer matrix, which only includes the linear effect. Blue particles are tracked through the magnetic field numerically. (a) When the beam size (diameter of the K-V distribution) is less than 0.5 cm, the nonlinearity is small. (b) A nonlinearity could be seen when the beam size is larger than 1 cm.

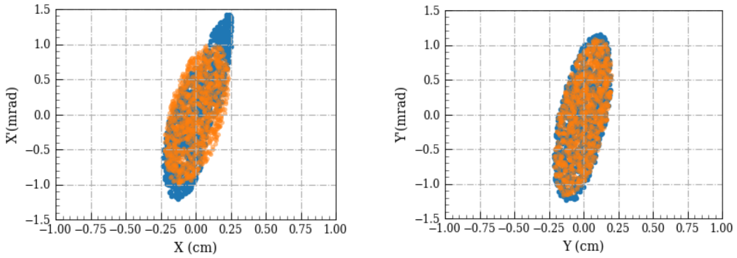
(a) Typical horizontal mis-steering, 0.3 cm



(b) Typical vertical mis-steering, 0.3 cm



(c) Maximum allowed horizontal mis-steering, 1.8 cm



(d) Maximum allowed vertical mis-steering, 1.8 cm

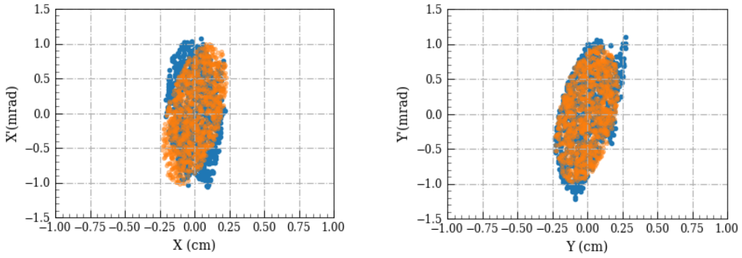


Figure 4: (a) and (b) Even if the beam size is small as Fig. 3(a) initial beam, a typical mis-steering of 0.3 cm can cause a nonlinearity effect. (c) and (d) The radius of the beam pipe inside the septum is 2.33 cm, a mis-steering of 1.8 cm is used to estimate the maximum nonlinearity effect. The distortion of the beam phase plot becomes larger. The horizontal 1.8 cm mis-steering also changes the linear transfer matrix. To reduce the nonlinearity, beam centering is also very important in the septum magnet section.

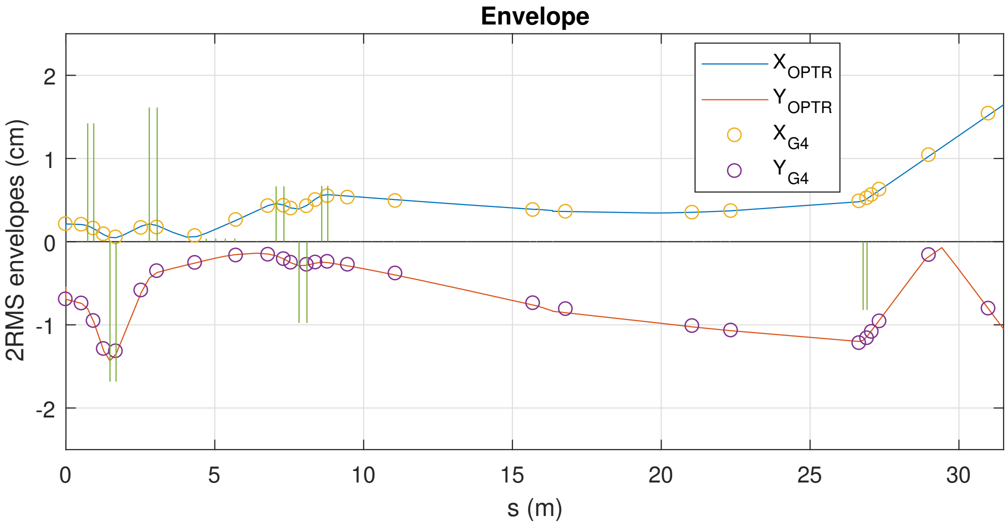


Figure 5: BL1U envelopes. By using the transfer matrix from zgoubi, the TRANSOPTR envelopes agree well with the one calculated using G4Beamline that tracks 1×10^5 particles.

$$\mathrm{M}^{\mathrm{T}}\mathrm{JM} - \mathrm{J} = \begin{bmatrix} 0.0000 & 0.0000 & 0.0289 & 0.0024 \\ 0.0000 & 0.0000 & 0.0023 & 0.0002 \\ -0.0289 & -0.0023 & 0.0000 & -0.0001 \\ -0.0024 & -0.0002 & 0.0001 & 0.0000 \end{bmatrix} \tag{11}$$

The symplectic error is larger than the one calculated using the vertically shifted vector potential. This results from the nonlinearity effect. The difference compared with eq. (9) may be caused by the hole structure at the entry and exit of the magnet. Fig. 3 and 4 show the particle tracking result of an initial K-V beam through the septum magnet.

2.4 Envelope

Fig. 5 compares the envelope results between G4Beamline model and the TRANSOPTR model.

3 Conclusions

For the BL1U septum magnet without median plane symmetry. A non-negligible coupling between momentum and coordinate in different transversal planes is revealed by the transfer matrix calculated from both methods. By using the transfer matrix to model the septum magnet in TRANSOPTR, the beam envelope agrees with the one calculated from G4Beamline, which suggests the linear transfer matrix works well for the BL1U envelope calculation. To reduce the nonlinear effect of the septum magnet, small beam size and good beam centering are required in the septum magnet section.

References

[1] M. Bassetti, C. Biscari, Analytical formulae for magnetic multipoles, Part. Accel. 52 (1996) 221–250.

[2] Y. Cai, Y. Nosochkov, Dynamical effects due to fringe field of the magnet in circular accelerators, in: Proceedings of the 2005 Particle Accelerator Conference, IEEE, 2005, pp. 1907–1909.

[3] F. Méot, The ray-tracing code zgoubi, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 427 (1-2) (1999) 353–356.

4 Appendix

4.1 TRANSOPTR BL1U sy.f

```
      SUBROUTINE tSYSTEM

      COMMON /BLOC1/
     $               ALPHAx,BETAx, ALPHAy,BETAy,
     $               EmX, EmY             ! both in cm-mrad;
     $              ,C6
     $              ,C1u, C2u
     $              ,Xtgt, Ytgt
     $              ,scatL

      COMMON/PRINT/IPRINT,IQ1,JQ1,IQ2,JQ2,IQ3,JQ3,IQ4,JQ4
      COMMON/SIGS/  SX(6,6),RX(6,6)
      COMMON/VECTORS/VECI(6),VECTOR(6),RVECT(6),NPARAM,IVOPT
      COMMON/CONS/ CONX(8),unitu(8)
      COMMON/VELEM/ VELM(21,9999),NELM
      real a(6,6)
      real b(6,6)
      real RM(6,6)
```

```
      data chm/0.0254/

 10   format(f9.3,f9.2)

C
C Cyc. fringe field R-matrix at 480 MeV:
C
      data A/-0.081,-3.067, 0.000, 0.000,-0.389,  0.000,
     +        0.329, 0.129, 0.000, 0.000,-0.019,  0.000,
     +        0.000, 0.000, 2.017, 3.241, 0.000,  0.000,
     +        0.000, 0.000, 0.882, 1.913, 0.000,  0.000,
     +        0.000, 0.000, 0.000, 0.000, 1.000,  0.000,
     +        1.297, 1.073, 0.000, 0.000, 2.685,  1.000/
C above A(1,6) & A(2,6) are positive for it's bent to thr right.

C
C Septum R-matrix:without rolling
C
C      data B/ 1.01026,  0.18370,  0.01981,  0.33844, -0.15811,  0.00000,
C     +        0.11033,  1.01001,  0.00119,  0.01939, -0.00868,  0.00000,
C     +        0.01870,  0.36761,  0.96794, -0.57949,  0.00025,  0.00000,
C     +        0.00103,  0.02011,  0.10894,  0.96792, -0.00009,  0.00000,
C     +        0.00000,  0.00000,  0.00000,  0.00000,  1.00000,  0.00000,
C     +       -0.08676, -1.58113,  0.00096,  0.01625,  0.00246,  1.00000/

C
C Septum R-matrix: with rolling
C
      data B/ 1.0071,  0.1262,  0.0228,  0.3919, -0.1577,      0,
     +        0.1102,  1.0068,  0.0013,  0.0223, -0.0086,      0,
     +        0.0217,  0.4210,  0.9711, -0.5220, -0.0117,      0,
     +        0.0011,  0.0231,  0.1091,  0.9711, -0.0007,      0,
     +             0,       0,       0,       0,  1.0000,      0,
     +       -0.0866, -1.5778, -0.0056, -0.1032,  0.0025, 1.0000/


      wq=1.
      wsize=0.000

      d2r = 1./57.29578

C  To get output of elements R_11 for purpose of graphing the dispersion:
```

```
      IQ3=1
      JQ3=2
      IQ1=1
      JQ1=6
      IQ4=1
      JQ4=1


C  Quad's effective lengths in meter.
      Q1L = 0.4039
      Q2L = 0.4089
      Q3L = 0.5309

      Q4L = 0.5238
      Q5L = 0.5321
      Q6L = 0.4064    !!<<< Q6 is 4Q14/8 since 2016 March onward.

      Q1uL = 0.2618   !! 4Q8.5/8.5
      Q2uL = 0.2618


C=====================================
C   1A tune of 480MeV on 2014-June-02
C=====================================
      C1=303.5      !! Current in Ampere:   1VQ1 is asymmetrical.
      SM0=19.9
      C1=C1-SM0/2.
      C2=353.1
      C3=336.5

      C4=136.3
      C5=200.0
C$$$      C6=106.5


c fitted for 2AVQ1,2:
      Q1=  calibq(C1,500.,8912.,380.,-1537.)     ! in Tesla.
      Q2=  calibq(C2,500.,8912.,380.,-1537.)
c following calib fits curve in magnet index for 4Q19/8
      Q3 =calibq(C3,500.,8912.,380.,-1537.)
      Q4 =calibq(C4,500.,8912.,380.,-1537.)
      Q5 =calibq(C5,500.,8912.,380.,-1537.)
```

```
      Q6 =calibq(C6,500.,8912.,380.,-1537.)
c Q1u,Q2u are 4Q8.5/8.5 (according to C. Davis):
      Q1u=calibq(C1u,300.,8741.,-132.,-883.)
      Q2u=calibq(C2u,300.,8741.,-132.,-883.)


      if(iprint.ne.0)write(6,998)Q1,Q2,Q3,Q4,Q5,Q6,Q1u,Q2u
 998  format(//2x,'Quads pole tip field in Tesla: '/
     &         4(1x,F10.5)/4(1x,F10.5)//)


C=====================
C  Beam line starts
C=====================
      call cic(ALPHAx,BETAx,EmX, ALPHAy,BETAy,EmY)
      call fip(ETAxu, ETAPxu)
      call disp_mat(ETAxu,ETAPxu,  0.,0., 0,0)


C  Transverse scatter is 0.21 mrad (2rms)
C  Longitudinal scatter is scatL in % (2rms).
      call addscatter(0.21, 0.21, scatL,  480.)
      call vective(1)


      call print_transfer_matrix
C  Use STRIPUBC calculated cyc. FF matrix of 480MeV,
C  which ends at 26.891" downstream from C.M. centreline.
      call umat(a,0,0)
      call print_transfer_matrix


      call fringeq(0.35,-0.03,0.24,-0.40)       ! 4Q14/8

!!=======================================================

      call dr( 1.4145-26.891*chm-Q1L/2.,    0,0)
      call MQUAD( Q1, 5.156, Q1L, wq,"Q1  ")    ! 4Q14/8
      call dr( 0.7477-Q1L/2.-Q2L/2., 0,0)
      call MQUAD(-Q2, 5.156, Q2L, wq,"Q2  ")    ! 4Q14/8
      call drift( 0.4540-Q2L/2.,     "M1  ")
```

```
C---------------
C  monitor 1VM1
C---------------
      fitx=0.30       ! (2rms, half) in cm
      fity=1.37       ! (2rms, half) in cm

      if(iprint.ne.0)write(11,10)velm(7,nelm),fitx
      if(iprint.ne.0)write(11,10)velm(7,nelm),-fity
      call fit(1,1,1,fitx ,wsize,1)
      call fit(1,3,3,fity ,wsize,1)

      call dr( 0.8668-Q3L/2.,  0,0)
c Q3 through Q6 are 4Q19/8; same as 4Q14/8 but 5" longer so fringe field
c should be same according to Doug Evans.
      call MQUAD(Q3, 5.156,  Q3L, wq,"Q3  ")    ! 4Q19/8
      call dr( 0.7882-Q3L/2.,   0,0)
C>>>  Here is the center-line of SM1V
      call dr( 1.2549-0.7882,   0,0)
C>>>  Here is the center-line of M2.
      call drift(0.,     "M2  ")

C---------------
C  monitor 1VM2
C---------------
      fitx=0.24        ! (2rms, half) in cm
      fity=0.54        ! (2rms, half) in cm

      if(iprint.ne.0)write(11,10)velm(7,nelm),fitx
      if(iprint.ne.0)write(11,10)velm(7,nelm),-fity
      call fit(1,1,1,fitx ,wsize,1)
      call fit(1,3,3,fity ,wsize,1)

!!========================================================
      th1  = 19.8     !! bend angle of 1VB1,  in degrees
      r1   = 3.69338  !! bend radius of 1VB1, in meter.
      ea1  = th1/2.
      sag1 = r1*tan(th1/2./57.29578)

      call dr(0.9847-sag1,  0,0)


      call ea(ea1, r1, th1, 0., 0.45,2.8, 10.,0.,0., 0,0)
```

```
      call be(-r1, -th1/2.,  0., 0,0)
      call be(-r1, -th1/2.,  0., 0,0)
      call ea(ea1, r1, th1, 0., 0.45,2.8, 10.,0.,0., 0,0)

      call drift(57.*chm-sag1-2.875*chm,  "M3  ")
C==================================================================
C  monitor 1VM3:  wire plane is 2.875" upstream of the centreline
C==================================================================
C$$$      fitx=       ! (2rms, half) in cm
C$$$      fity=       ! (2rms, half) in cm

C$$$      if(iprint.ne.0)write(11,10)velm(7,nelm),fitx
C$$$      if(iprint.ne.0)write(11,10)velm(7,nelm),-fity
C$$$      call fit(1,1,1,fitx ,wsize,1)
C$$$      call fit(1,3,3,fity ,wsize,1)

      call dr( (2.875+80.1-57.)*chm-Q4L/2.  , 0,0)
      call MQUAD( Q4, 5.156,  Q4L,  wq, "Q4  ")              ! 4Q19/8
      call dr( (110.4-80.1)*chm-Q4L/2.-Q5L/2., 0,0)
      call MQUAD(-Q5, 5.156,  Q5L,  wq, "Q5  ")              ! 4Q19/8
      call dr( 30.*chm-Q5L/2.-Q6L/2.,        0,0)
      call MQUAD( Q6, 5.156,  Q6L,  wq, "Q6  ")              ! 4Q19/8

      call dr( 5.2512-3.5683-Q6L/2.-0.75,     0,0)

      call drift(0.,    "KiKn")
C>>>  Here is the entrance of 1.5m long kicker .
      rK   = 125.                         !! in meter
      thK  = 12.e-3/d2r                   !! in degrees
      eaK  = thK/2.                       !! in degrees.
      call yea(eaK, rK, thK,0.,0.45,2.8, 10., 0.,wq,0,0)
      call ybe(-rK,-thK/2.,  0.,0,0)    !! kick upward by 12mrad.
      call ybe(-rK,-thK/2.,  0.,0,0)
      call yea(eaK, rK, thK,0.,0.45,2.8, 10., 0.,wq,0,0)
      call drift(0.,    "KiKx")
C>>>  Here is the exit of kicker .

      call drift( 6.9338-5.2512-0.75 - 2.875*chm,  "M4.6")
C==================================================================
C  monitor 1VM4.6: wire plane is 2.875" upstream of the centreline
C==================================================================
C$$$      fitx=0.86       ! (2rms, half) in cm
```

```
C$$$      fity=0.31       ! (2rms, half) in cm

C$$$      if(iprint.ne.0)write(11,10)velm(7,nelm), fitx
C$$$      if(iprint.ne.0)write(11,10)velm(7,nelm),-fity
C$$$      call fit(1,1,1,fitx ,wsize,1)
C$$$      call fit(1,3,3,fity ,wsize,1)


      call DRift( 8.4468-6.9338 + 2.875*chm, "VB2C")
      call dr( 10.5562-8.4468,  0,0)
      call drift(0.,    "M5x ")
C>>   Here is the EXIT (NOT the centreline) of 1AM5 box.
      call dr( 11.0528-10.5562-0.27783,  0,0)

      call drift(0.,    "SEPn")
C>>   Here is the entrance of septum magnet.
      rS  = 3.527       !! in meter.
      thS = 9.02666     !! in degrees, to make 9degr bend in H plane.
      eaS = thS/2.      !! in degrees, POSITIVE ea for V. focusing.
      sagS= rS*tan(thS/2.*d2r)

      call uxyzmat(b,rS*thS*d2r,-thS*d2r,12.e-3,0,0)

      call drift(0.,    "SEPx")
C>>   Here is the exit of septum magnet.

      call DR(3.7039-sagS, 0,0)
      call drift(0.,    "CBY0")
C>>>  Here is the center-line of 1UCBY0.
      CALL dr(0.4076,      0,0)
      call drift(0.,    "1UM0")
C=====================
C     monitor 1UHARP0
C=====================
C$$$      fitx=      ! (2rms, half) in cm
C$$$      fity=      ! (2rms, half) in cm

C$$$      if(iprint.ne.0)write(11,10)velm(7,nelm), fitx
C$$$      if(iprint.ne.0)write(11,10)velm(7,nelm),-fity
C$$$      call fit(1,1,1,fitx ,wsize,1)
C$$$      call fit(1,3,3,fity ,wsize,1)
```

```
      r0   = 9.822              !! in meter
      th0  = 7.                 !! in degrees
      ea0  = (7.)/2.     !! in degrees. NEGATIVE ea
      sag0 = r0*tan(th0/2.*d2r)

      call dr( 5.6239-3.7039-0.4076-sag0,   0,0)
      call drift(0.,    "B0n ")
C>>>  Here is the entrance of 1UB0.
      call ea(ea0, r0, th0, 0.,0.45,2.8, 10.,0.,wq,0,0)
      call be(-r0,-th0/2., 0.,0,0)   !! 1UB0 bend LEFT by 7 degrees.
      call be(-r0,-th0/2., 0.,0,0)
      call ea(ea0, r0, th0, 0.,0.45,2.8, 10.,0.,wq,0,0)

      call DR( 5.0882-sag0 - Q1uL/2.,   0,0)

      call fringeq(0.24,-0.09,0.07,-0.36)        !! 4Q8.5/8.5
      call MQUAD( -Q1u, 5.159,  Q1uL,  wq, "Q1u ")
      call dr( 0.4192-Q1uL/2.-Q2uL/2.,         0,0)
      call MQUAD(  Q2u, 5.159,  Q2uL,  wq, "Q2u ")

      call DR( (7.1799-5.5073-Q2uL/2.)/5.,  0,0)
      call DR( (7.1799-5.5073-Q2uL/2.)/5.,  0,0)
      call DR( (7.1799-5.5073-Q2uL/2.)/5.,  0,0)
      call DR( (7.1799-5.5073-Q2uL/2.)/5.,  0,0)
      call DR( (7.1799-5.5073-Q2uL/2.)/5.,  0,0)
      call DRift( 0.,  "1UM2")
C-------------------
C  monitor 1UHARP2.
C-------------------
c$$$      fitx=       ! (2rms, half) in cm
c$$$      fity=       ! (2rms, half) in cm

c$$$      if(iprint.ne.0)write(11,10)velm(7,nelm),fitx
c$$$      if(iprint.ne.0)write(11,10)velm(7,nelm),-fity
c$$$      call fit(1,1,1,fitx, wsize,1)
c$$$      call fit(1,3,3,fity, wsize,1)

      call dr( (9.9357-7.1799)/5., 0,0)
      call dr( (9.9357-7.1799)/5., 0,0)
      call dr( (9.9357-7.1799)/5., 0,0)
      call dr( (9.9357-7.1799)/5., 0,0)
      call dr( (9.9357-7.1799)/5., 0,0)
```

```
      call drift(0.,       "TARG")


      call fit(1,1,1,Xtgt,  wsize, 1)
      call fit(1,3,3,Ytgt,  wsize, 1)
      call vective(10)

 999  RETURN
      END


      real function calibq(cur,scale,b1,b3,b5)
      tmp=cur/scale
      tmp2=tmp*tmp
      calibq= (b1 + (b3 + b5*tmp2)*tmp2)*tmp
      calibq=calibq/10000.   ! Tesla.
      return
      end


      SUBROUTINE fip(ETAxu, ETAPxu)
C  I apply COMA simulation results of (dp/p; D, D').

      COMMON/SIGS/  SX(6,6),RX(6,6)
      COMMON/VECTORS/VECI(6),VECTOR(6),RVECT(6),NPARAM,IVOPT
      COMMON/MOM/P,BRHO,pMASS,ENERGK,GSQ,ENERGKi,charge,current
      COMMON/CONS/CONX(8),unitu(8)
      character*4 unitu

C================================================================
C     In the following, I apply the COMA simulation results of
C               (dp/p, D, D')
C================================================================
C$$$  DPOP    = 0.053
      DPOP    = 0.1
      rvect(6)= DPOP/100.   ! for internal use,
*
*
      rvect(5)= 65.0        ! This rvect(5)=2RMS bunch length in CM.
      rx(5,6) = -0.06
      rx(6,5) =rx(5,6)
```

```
      call resetup

C--------------------------------------------------------------------------------
      D = 2.32            ! This is BEAM's positional DISPERSION,  in meter.
      D =-D               !* D reverses sign because bend to the right.

C--------------------------------------------------------------------------------
      DP = 0.19           ! This is BEAM's angular DISPERSION, in radian.
      DP =-DP             !* DP reverses sign because bend to the right.


C-----------------------------------------
CS3   set up Dispersion:
C     ETAxu  must be in user-specified (x, dp/p) unit, here is cm/%,  i.e. METER.
C     ETAPxu must be in user-specified (x',dp/p) unit, here is mrad/%
      ETAxu = D
      ETAPxu= DP*10.

      return
      end
```

4.2 TRANSOPTR UXYZMAT.f

```
      SUBROUTINE UxyzMAT(AA,dzed,angH,angV,IVECT,IMAT)

      COMMON/PRINT/IPRINT,IQ1,JQ1,IQ2,JQ2,IQ3,JQ3,IQ4,JQ4
      COMMON/VELEM/VELM(21,9999),NELM
      COMMON/LABELS/start,QNAR,FFIT,skp,Se4,QDOT,LABEL
      CHARACTER*16 start,QNAR,FFIT,skp,Se4,QDOT,LABEL(9999),TAME
      COMMON/SCPARM/QSC,ISC,CMPS
      COMMON/MOM/P,BRHO,PMASS,ENERGK,GSQ,ENERGKI,CHARGE,CURRENT,ENERGKS
      COMMON/ZED/ZINIT,Z
      COMMON/CONS/CONX(8),unitu(8)
      REAL AA(6,6),A(6,6)

      TAME="TMAT"
      if(abs(iprint).eq.1)write(8,333)aa,dzed
 333  format(6x,
     +     'call UdMAT('/6(5x,'+',6(f9.4,','),/),5x,'+',f9.4,',0,0)')

      NELM=NELM+1
```

```
      if(nelm.gt.9999)call abend
      velm(12,NELM)=0
      velm(13,NELM)=0
      velm(14,NELM)=energk
      VELM(9,NELM)=0
c      VELM(7,NELM)=VELM(7,NELM-1)+velm(9,nelm)
      VELM(7,NELM)=z*conx(8)
      if(abs((velm(7,nelm)-z*conx(8))/(1.+velm(7,nelm))).gt..01)
     $     write(6,*)'fix me: z.ne.velm(7) ',velm(7,nelm),z*conx(8)
      if(angV.NE.0.0) THEN
      call uxyz(0,angV/2,1,velm(19,nelm),velm(20,nelm),velm(21,nelm))
      endif
      LABEL(NELM)=TAME
      CALL VECTIVE(0)

      NELM=NELM+1
      if(nelm.gt.9999)call abend
      velm(12,NELM)=0
      velm(13,NELM)=0
      velm(14,NELM)=energk
      VELM(9,NELM)=0
c      VELM(7,NELM)=VELM(7,NELM-1)+velm(9,nelm)
      VELM(7,NELM)=z*conx(8)
      if(abs((velm(7,nelm)-z*conx(8))/(1.+velm(7,nelm))).gt..01)
     $     write(6,*)'fix me: z.ne.velm(7) ',velm(7,nelm),z*conx(8)
      if(angH.NE.0.0) THEN
      call uxyz(0,angH/2,2,velm(19,nelm),velm(20,nelm),velm(21,nelm))
      endif
      LABEL(NELM)=TAME
      CALL VECTIVE(0)

      DO  I=1,6
            DO  J=1,6
               A(I,J)=AA(I,J)/conx(i)*conx(j)
            enddo
            enddo
            IF(ISC.EQ.0)THEN
                 CALL ML(A)
            ELSE
                 CALL EDGEUP(A)
              ENDIF
```

```
      call velmer(TAME,energk,dzed,0.,3,0.,0.)

      NELM=NELM+1
      if(nelm.gt.9999)call abend
      velm(12,NELM)=0
      velm(13,NELM)=0
      velm(14,NELM)=energk
      VELM(9,NELM)=0
c      VELM(7,NELM)=VELM(7,NELM-1)+velm(9,nelm)
      VELM(7,NELM)=z*conx(8)
      if(abs((velm(7,nelm)-z*conx(8))/(1.+velm(7,nelm))).gt..01)
     $     write(6,*)'fix me: z.ne.velm(7) ',velm(7,nelm),z*conx(8)
      if(angH.NE.0.0) THEN
      call uxyz(0,angH/2,2,velm(19,nelm),velm(20,nelm),velm(21,nelm))
      endif
      LABEL(NELM)=TAME
      CALL VECTIVE(0)

      NELM=NELM+1
      if(nelm.gt.9999)call abend
      velm(12,NELM)=0
      velm(13,NELM)=0
      velm(14,NELM)=energk
      VELM(9,NELM)=0
c      VELM(7,NELM)=VELM(7,NELM-1)+velm(9,nelm)
      VELM(7,NELM)=z*conx(8)
      if(abs((velm(7,nelm)-z*conx(8))/(1.+velm(7,nelm))).gt..01)
     $     write(6,*)'fix me: z.ne.velm(7) ',velm(7,nelm),z*conx(8)
      if(angV.NE.0)THEN
      call uxyz(0,angV/2,1,velm(19,nelm),velm(20,nelm),velm(21,nelm))
      endif
      LABEL(NELM)=TAME
      CALL VECTIVE(0)

        return
      END
```

4.3 TRANSOPTR data.dat

```
 480.0  0 0 938.28 1 6.5e-12     ! Energy=480 MeV.
 4 3 1. 0.5E-5
 0 0.
```

```
 0.0  0.0  0.0  0.0   0.0  0.01   ! X,XP,Y,YP,dL,dp/p
 1.  1000.  1.  1000.  1.  100. 0. .01
 5
 1 2 0.0   3 4  0.0    1 6 0.0   2 6 0.0   5 6 0.0
 12
-0.79    -4.7   -0.5    0     !. ALPHAx
 3.14     0.0   15.0    0     !. BETAx in meter
 2.48     0.0    7.5    0     !. ALPHAy
 26.5     1.0   50.0    0     !. BETAy in meter
 0.071    0.01   0.2    0     !. Emit_x = cm.mrad.
 0.11     0.09   0.15   0     !. Emit_y = cm-mrad
 137.27   0.     300.   0     !. C6  in Amp.
 103.6    0.     300.   0     !. C1u in Ampere
 0.0      0.     300.   0     !. C2u in Ampere
 2.0      0.     2.     0     !. Xtgt in cm
 1.0      0.     2.     0     !. Ytgt in cm
 0.045    0.     1.     0     !. scatL, in %
 1.E-4 1000
 01  0.1  0.98  50
```