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Current Status of Beamline 1A Optics

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Abstract: This note summarizes the current status of BL1A optics, serving as a reference and starting point of a future design.

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1 Introduction

The beamline 1A (BL1A) has been in operation for nearly 50 years. But it was not intensively investigated until 2009, with a goal to reproduce the beam sizes measured at profile monitors along the beamline [1]. Since then, efforts were made in two aspects: one was surveying the distances [2, 3] between elements in the front end section, i.e. from combination magnet to T1 target, because there remained inconsistencies of $20 - 30$ mm in the longitudinal locations of some magnets and diagnostics. These inconsistencies are not trivial because the quadrupole magnets are strongly powered, thus very sensitive to the beam envelope downstream. The other effort was struggling with the harp monitors [4, 5], trying to acquire stable and reliable data of beam profiles for accurate calculation of the beam sizes. But the outcome appeared disappointing; the existing harp monitors are very inefficient and hardly usable, because: (1) they have very poor signal-to-noise ratio, making it very hard to discern the beam tails/halos; (2) different wires show different responses to the beam density, causing bad distortions to the beam profile and therefore resulting in wrong beam sizes; (3) some monitors are either too narrow to cover the full beam size, or too wide between neighbouring wires to see the beam distribution. Although the pseudo wire scanner procedure (i.e. by steering the beam across the harp) [6] seems feasible, in practice it is inefficient because it is too slow and also is highly limited by the available steerer-monitor combinations. As a consequence, the measured beam size (2rms) often has big uncertainty; one should not be surprised to see a discrepancy of $\pm 50\%$ between the measured beam sizes and the calculated envelopes. Nevertheless, we managed to establish a standard tune for the beamline operation.

2 Standard Tune

The 480 MeV standard tune that we have established for the BL1A is described in details in the `TRANSOPTR` file in Appendix. Fig. 1 shows the calculated beam envelopes and dispersions through the beamline. The initial condition of the beam dumped on the stripper foil but before undergone scattering is obtained from `COMA` [7] simulation, given below:

$$
\begin{aligned}
\alpha_x &= -0.73\,, \\
\beta_x &= 3.50\,\mathrm{m}\,, \\
\epsilon_x &= 0.75\,\pi\mathrm{mm\text{-}mrad}\,(4\mathrm{rms})\,, \\
\alpha_y &= 2.3\,, \\
\beta_y &= 24.7\,\mathrm{m}\,, \\
\epsilon_y &= 0.93\,\pi\mathrm{mm\text{-}mrad}\,(4\mathrm{rms})\,, \\
\Delta p/p &= 0.064\%\,(2\mathrm{rms})\,, \\
\eta &= -1.55\,\mathrm{m}\,, \\
\eta' &= -0.055\,, \\
\theta_{scatt} &= 0.19\,\mathrm{mrad}\,(2\mathrm{rms,\ in\ plane})\,,
\end{aligned}
$$

where η and η' denote the beam positional and angular dispersions separately, and θ_{scatt} denotes the scattering angle of 480 MeV H-minus beam traversing a carbon foil of typical thickness of 1.5 mg/cm^2.

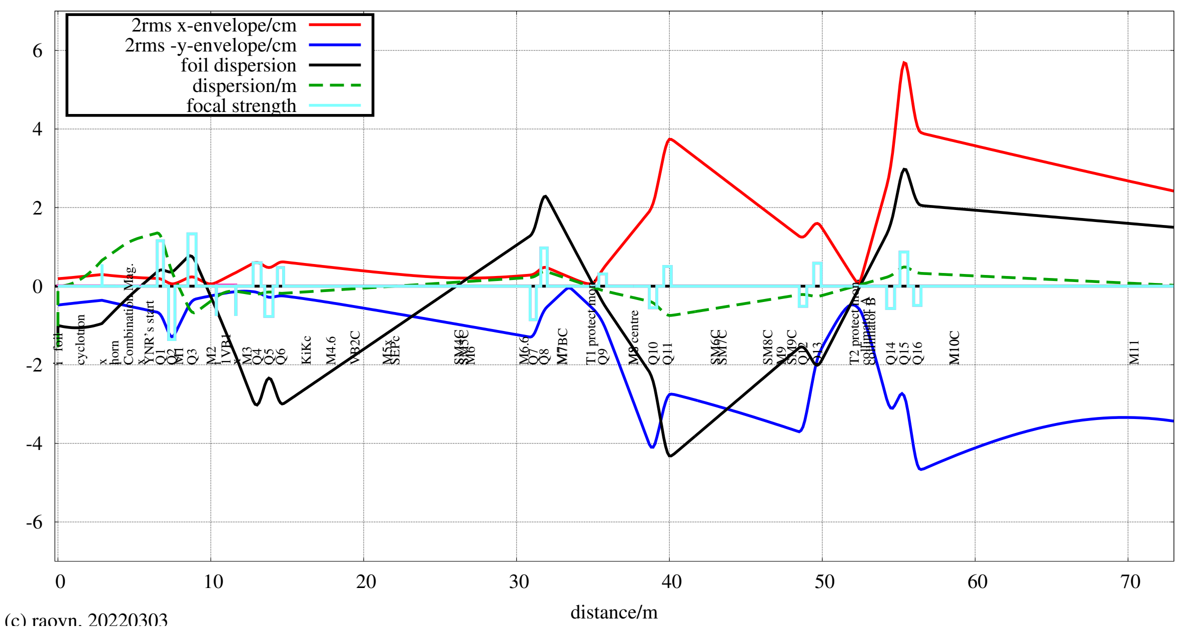

Figure 1: *Beam envelopes and dispersions starting from the stripper foil throughout BL1A. Here the "foil dispersion" in black is calculated from* $(R_{11}D + R_{12}D' + R_{16})/D$*, where* $D = -3.1\,m$ *and* $D' = -0.30\,rad{=}-3.0\,mrad/\%$ *are the cyclotron positional and angular dispersions at the foil location,* R_{11} *(dimensionless) and* R_{12} *(in cm/mrad) are the R-matrix elements; while the "dispersion/m" in green is simply the R-matrix element* R_{16} *in meter (i.e. cm/%). Thus, the black curve reveals a magnification of beam position shift due to average energy change of the beam at foil caused by for example the foil heating and curling. The T1 and T2 are 12 mm and 50 mm long Beryllium targets separately.*

There are a few points we have to note about the variability of this tune:

- The T2 Beryllium target may possess different lengths, e.g. 0, 12 mm, 50 mm or 100 mm, depending on the user's dictation. These cases have been simulated with `G4beamline` [8, 9], concerning the issues of Coulomb scattering, energy loss and energy loss straggling. In brief, for different thicknesses of T2 target, the last triplet (Q14−Q16) is the only knob that one can use to match the beam size into the TNF target.
- The fore-mentioned initial condition is derived from a typical operation mode of the cyclotron where the BL1A is as a single user taking all the beam of high energy, plus that the extraction foil is fully dipped into the circulating beam vertically. This yields a maximum vertical emittance, minimum horizontal emittance and minimum energy spread (and tail). But, this condition changes with the extraction split ratio between BL1A and BL2A, also changes with the position of stripper foil relative to the circulating beam in the vertical direction (due to variations in the B_r trim coil settings of cyclotron). The emittance in either plane can differ from the typical value by a factor of 1.6 [10, 11]. As a result of these changes, the beam profiles and halos down to BL1A can vary noticeably, in particular at T1 and T2 as seen from the target protect monitor. These changes are reflected by the fact that operators have to tweak the beamline quads in order to fix the spot sizes at T1, T2 as well as the spill monitor trips. But such a tweak is within $\pm 3\%$.
- The optics from T1 to T2 is a π section in both x and y planes, so whatever beam sizes attained at T1 are attained at T2 too. However, if it's necessary one can tweak Q12 and Q13 for fine-adjustment of beam sizes (and halos) at T2. This adjustment requires iteration because it has cross-talk between the two planes.

3 Challenges and Future Improvements

There are a number of challenges associated with current BL1A configuration and optics. Potential improvements are proposed accordingly.

- The BL1A upstream two triplets (Q1−Q3 and Q4−Q6) are shared and bound by BL1A and BL1U two lines, so they are not freely tunable parameters. Moreover, the BL1U optics has very little flexibility to adjust the spot size at UCN target because it does not have enough quadrupole magnets of its own. As a result, we'll have to: (1) establish a new tune for the 1A quads Q4−Q6, plus (2) interlock the 1U quad 1UQ1 operating range, to allow for a desired large enough beam spot created at the UCN target and BL1U window with the present optics layout. This means that for the BL1A we are left with only 2 dependent knobs namely Q7,Q8 that we could use for adjusting the spot size at T1 as per user's requirements. But, these 2 knobs do not necessarily work out, because they are so close to each other that the betatron phase advance between them is too small.

  In addition, between Q6 and Q7, it is a very long drift of 16 meter. As a result, by the time the beam gets to Q7, its vertical size blows up > 1.2 cm (2rms), 3 times larger than the intrinsic size; the resultant beam halo in the vertical direction becomes very broad, causing spills and spill monitor trips. An improvement for this issue would be to add up 2 quads in between to augment focusing and make the beamline better tunable.

- The last triplet Q14−Q16 suffers from cooling degradation (due to clogging of the cooling channels in the magnet coils), especially Q15 has the highest excitation. During the past 5 years production runs, the lowest setting of Q15 was 778 A. This occurred only when T2 & T1 both targets were running with 12 mm Beryllium. Whereas the highest setting reached 850 A when a thicker target (50 mm) was used at T2.

  To mitigate the issue, one can't simply turn off Q15 and then run Q14, Q16 as a doublet and still can get beam into TNF, even if we reverse Q16 polarity. That would cause significant beam spills and even temperature rise on the collimator. The spill monitor trips in that area have become the limiting factor for BL1A operation, unless one would accept higher losses and adjust the interlock levels to create more headroom for the operation. Replacing the triplet with two doublets would be more optimal configuration for the final leg of the BL1A optics because it would equalize the current density among the quadrupoles. Currently the middle quad runs at much higher excitation ($> 60\%$) than the outer two.

- The misalignment in T2 area (including T2 protect monitor, T2 target and collimators A & B) is a big issue, causing TNF neutron flux reduction and substantial beam losses on the collimators (accordingly a large number of spill monitor trips) as well as excessive radiation, therefore limiting the maximum operational current to be $< 120\,\mu$A. Such a misalignment is deemed in an order of a few millimetre rather than in a centimetre range [12].

- There are other aspects of BL1A that are non-optimal. First, the design was based upon an incorrect understanding of the cyclotron beam. This arose from an error in the original beam tracking code (`STRIPUBC`) that tracked from the stripper to the combination magnet [13]. Second, the beamline could be made doubly achromatic with respect to circulating beam, i.e. cancelling the "foil dispersion" as shown in Fig. 1. This would make the beam position insensitive to small fluctuations in the stripper position, obviating ongoing steering corrections as the foil heats and ages.

- Currently, we are missing stable and reliable BPM's and profile monitors in BL1A. The reasonable number of BPM's for the BL1A would be 6, while we have recently installed only 3 monitors. Regarding the profile monitor, we ask for a new type of wire scanner which is capable of measuring x and y profiles of the 480 MeV proton beam with intensity varying from 10 nA up to $150\,\mu$A with sufficiently good signal-to-noise ratio. The measurement of low intensity beam (<100 nA) is essential for routine check of the beamline tune, especially when the machine just starts up from shutdown or maintenance. Whereas the measurement for high intensity beam ($> 10\,\mu$A) is necessary for accurate characterization of the beam property under realistic operational condition of the machine.

A TRANSOPTR Code

A.1 Data file:

```
 480.0  0 0 938.28 1 6.5e-12     ! Energy=480 MeV.
 -4 4 1. 3.E-4
 0 0.
 0.0  0.0  0.0  0.0   65.0  0.0635  ! X,XP,Y,YP,dL,dp/p
 1.  1000.  1.  1000.  1.  100. 0. .01
 0
 8
-0.728   -4.7   -0.5   0   !. ALPHAx          (-0.728  is the COMA value of BEAM's alpha)
 3.50     0.0   15.0   0   !. BETAx in meter  ( 3.50m is the ,,, ,,, ,,, of BEAM's beta )
 2.31     0.0    8.5   0   !. ALPHAy          ( 2.31  is ,,, ,,, ,,, ,,, ,,,      ,,,  )
 24.70    1.0   40.0   0   !. BETAy in meter  (24.70m is ,,, ,,, ,,,              ,,,  )
 0.075    0.01   0.2   0   !. Emit_x = cm.mrad (~0.75 pimm-mrad is the COMA value    )
 0.093    0.09   0.15  0   !. Emit_y = cm-mrad (~1 pimm-mrad vert. circulating emittance)
 0.19     0.15   0.4   0   !. transverse scatter 0.19 mrad for 1.367mg/cm^2 carbon.
 0.006    0.006  1.0   0   !. longitudinal scatter 0.006%.  A FREE PARAMETER HERE !.
 1.E-3 2000
 01  0.0  0.98  50
```

A.2 System subroutine:

```
      SUBROUTINE tSYSTEM
      COMMON /BLOC1/ ALPHAx,BETAx, ALPHAy,BETAy,
     $               EmX, EmY,            ! both in cm-mrad;
     $               SCAT, SCATL
      COMMON/PRINT/IPRINT,IQ(8)
      COMMON/CONS/ CONX(8),unitu(8)
      real a1(6,6),a4(6,6)

      data chm/0.0254/

      COMMON/SCPARM/QSC,ISC,CMPS
      iq(1)=6
      cmps=20.

C
C-RYN: Cyc. fringe field R-matrix at 480 MeV:
C      A(1,6) & A(2,6) are positive for it's bent to the right.
C
      data A1/-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/

      wq=0.
      wfr12=1.
      wsize=0.000
      wdisp=1.
```

```
      TH  = 19.8     !! bend angle of B1,  in degrees
      RU  = 3.69338  !! bend radius of B1, in meter.
      THo2= TH/2.
      sagi= RU*tan(THo2/57.29578)

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.

      Q7L = 0.4115
      Q8L = 0.4140

      Q9L = 0.4991

      Q10L = 0.4905
      Q11L = 0.4905

      Q12L = 0.4905
      Q13L = 0.4905

      Q14L = 0.5207
      Q15L = 0.5207
      Q16L = 0.4841

C=====================================
C   1A tune of 480MeV using combo foil
C=====================================
      SM0=8.5
      C1=302.7
      C1=C1-SM0/2.
      C2=356.8
      C3=348.6

      C4=152.5
      C5=196.9
      C6=120.6 !+27.0
      C7=218.6
      C8=249.3

      C9 =290.8

      C10=515.5
      C11=470.0

      C12=480.4
      C13=548.8

C$$$      Q14 is asymmetric too.
C$$$      So is Q16.
```

```
      SM10=10.5
      SM11=36.9
      C14=510.+ SM10/2.
      C15=796.
      C16=427.+ SM11/2.

c fitted for 2AVQ1,2. Assume 1AVQ1,2,7,8 are same
      Q1=  calibq(c1,500.,8912.,380.,-1537.)     ! 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 Q7,8 like Q1,2
      Q7=calibq(c7,500.,8912.,380.,-1537.)
      Q8=calibq(c8,500.,8912.,380.,-1537.)
c fit from the survey of 1AQ16 (that's a guess)
      Q9 =calibq(c9 ,1000.,9899.,-32.,-618.)
      Q10=calibq(c10,1000.,9899.,-32.,-618.)
      Q11=calibq(c11,1000.,9899.,-32.,-618.)
      Q12=calibq(c12,1000.,9899.,-32.,-618.)
      Q13=calibq(c13,1000.,9899.,-32.,-618.)
c Q14,15 were measured Dec./02
      Q14=calibq(C14,1000.,9924.,23.,-362.)
      Q15=calibq(C15,1000.,9924.,23.,-362.)
c fit from survey of 1AQ16 Dec./02
      Q16=calibq(C16,1000.,9899.,-32.,-618.)

      if(iprint.ne.0)write(6,998)q1,q2,q3,q4,q5,q6,q7,q8,q9,
     +               q10,q11,q12,q13,q14,q15,q16
 998  format(/2x,'Quads pole field in Tesla: '/4(1x,F10.5)/
     +             4(1x,F10.5)/4(1x,F10.5)/4(1x,F10.5) )

C=====================
C  Beam line starts
C=====================
      call cic(ALPHAx,BETAx,EmX, ALPHAy,BETAy,EmY)
      call uxyz(0.,2.0864/57.29578,2,dum1,dum2,dum3)
c 2.086 degrees is a fudge.

Consider carefully: do we want to start from zero or start from the machine
C dispersion matrix? For imaging the foil without fuzzing due to momentum spread,
C must also fit R16=0. But this R16 is calculated WITHOUT the machine dispersion.
C So this disp_mat must be commented out.
      call disp_mat_q(-155.,-0.055,0.,0., 0,0) ! calling internal quiet version
                                               ! (uses internal units)

Careful!!! If disp_mat is before addscatter, the dispersion is removed from the
C          cumulative transfer matrix.
      call addscatter(SCAT,SCAT,SCATL,480.)
      call marker ('.   foil')

C  Use STRIPUBC calculated cyc. FF matrix of 480MeV,
```

```
C  which ends at 26.891" downstream from C.M. centreline.
c      call udmat(a4,5.958,0,0) !5.95metres is from the fit
c
c No, use mockup instead:
      call Ea(0.0,6.1900,26.6558,0.0,0.0,2.8,50.0,0.0,wq,0,0)
      call BEND(6.1900,26.6558,0.0,"cyclotron")
      call Ea(-59.6871,6.19,26.6558,0.0,0.3,2.8,50.0,0.0,wq,0,0)

      call BEND(101.0,0.9018,0.0,"horn")

      call DRIFT(-0.6136,"   .")

      call Ea(9.8441,-8.8900,-9.8441,0.0,0.3,0.0,5.0,0.0,wq,0,0)
      call BEND(-8.8900,-9.8441,0.0,"Combination Mag.")
      call Ea(0.0,-8.8900,-9.8441,0.0,0.3,0.0,5.0,0.0,wq,0,0)

      call DRIFT(0.5845,"YNR's start")

      call print_transfer_matrix ! To compare (if you're skeptical).
      call matout(-1) !transpose

      call fringeq(0.35,0.00,0.24,-0.40)        ! 4Q14/8

      call dr( 1.4145-26.891*chm-Q1L/2.,    0,0)
C  1415mm from crossover to Q1 centre,
C  Matrix A goes past crossover by 26.89 inches.
      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  ")
      call print_transfer_matrix

C---------------
C  monitor 1VM1
C---------------
C      call fit(1,1,1,fitx ,wsize,1)
C      call fit(1,3,3,fity ,wsize,1)
C      call fit(2,1,2,0.,1.,1) !stripper image

      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( 1.2549-Q3L/2.,   0,0)
C>>>  Here is the center-line of SM1V.
      call drift(0.,     "M2  ")
      call print_transfer_matrix

C---------------
C  monitor 1VM2
C---------------
C      call fit(1,1,1,fitx ,wsize,1)
C      call fit(1,3,3,fity ,wsize,1)

      call dr(0.9847-sagi,  0,0)
```

```
      call ea(THo2, RU, TH,  0.,0., 2.8,5.,0.,wq,0,0)
      call bend(-RU, -TH,  0.,"1VB1")   ! B1 bend to the left (negative bend)
      call ea(THo2, RU, TH,  0.,0., 2.8,5.,0.,wq,0,0)

      call drift(57.*chm-sagi-2.875*chm,  "M3  ")
C--------------------------------------------------------------------
C  monitor 1VM3: wire plane is 2.875" upstream of the centreline of
C  the box of 9.5" long.
C--------------------------------------------------------------------
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.,     0,0)
      call drift(0.,    "KiKc")
C>>>  Here is the center-line of BL1U kicker.

      call drift( 6.9338-5.2512 - 2.875*chm,  "M4.6")
      call print_transfer_matrix
C---------------------------------------------------------------------
C  monitor 1VM4.6: wire plane is 2.875" upstream of the centreline of
C  the box of 9.5" long.
C---------------------------------------------------------------------
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 ")
      call print_transfer_matrix
C>>>  Here is the EXIT (NOT the centreline) of 1AM5 box.
      call dr( 11.0528-10.5562,  0,0)
      call drift(0.,    "SEPc")
C>>>  Here is the centreline of BL1U septum magnet.
      call DR((400.3125-334.75+171.9375+30.)*chm - (11.0528-8.4468),0,0)
      call drift(0.,    "SM4C")
C>>>  Here is the center-line of SM4.
      call dr( (42.375-30.)*chm,   0,0)

      call drift(0.,    "SM5C")

C>>>  Here is the center-line of SM5.

      call DRIFT( (62.375-42.375)*chm - 2.875*chm,   "M6  ")
C---------------------------------------------------------------------
C  monitor 1AM6: wire plane is  2.875" upstream of the centreline of
C  the box of 9.5" long.
C---------------------------------------------------------------------
```

```
C      call fit(1,1,1,fitx ,wsize,1)
C      call fit(1,3,3,fity ,wsize,1)

      call DRift( 2.875*chm+(160.25-62.375+37.25)*chm, "M6.6")
      call dr( (61.-37.25)*chm-Q7L/2., 0,0)
      call MQUAD(-Q7, 5.156,   Q7L, wq,"Q7  ")        ! 4Q14/8
      call dr( (88.875-61.)*chm-Q7L/2.-Q8L/2.,  0,0)
      call MQUAD( Q8, 5.156,   Q8L, wq,"Q8  ")        ! 4Q14/8
      call drift( (136.75-88.875)*chm-Q8L/2.-2.875*chm, "M7  ")

C-------------------------------------------------------------------
C  monitor 1AM7: wire plane is 2.875" upstream of the centreline of
C  the box of 9.5" long.
C-------------------------------------------------------------------
C      call fit(1,1,1,fitx ,wsize,1)
C      call fit(1,3,3,fity ,wsize,1)

      call drift( 2.875*chm,   "M7BC")
C>>> Here is the centreline of the box of 1AM7.
C-RYN 2015-Nov-27: In terms of D-3503 provided by D.Rowbotham, the distance between
C                  the centreline of 1AM7 box and the centreline of T1 is 6'+5.5"=77.5".
C
C                  According to I.Earle, "The T1 protect monitor is approximately 12.5cm
C                  upstream of the centre-line of the T1 target. The T1 profile monitor
C                  wire plane is at the same position as the centre-line of the T1 target
C                  once it is moved into position".

      call drift( 77.5*chm-0.125,"T1 protect mon.")
C>>> Here is the T1 protect monitor.

      call print_transfer_matrix

      call drift(0.125,"    ")
C>>> Here is the centreline of T1 target, also is the wire plane of MT1.
      call vective(1)

C-------------
C monitor T1
C-------------
C      call fit(1,1,1,fitx , wsize,1)
C      call fit(1,3,3,fity , wsize,1)

C      call drift(0.0,  "T1CL")
C     At T1, 2RMS scatter additions in user units
      call addscatter2(6.2, 6.2, 0.126, 480.-5.1) !! scatter thru a 12mm long Be target.

C-RYN 2015-Nov-27: In terms of D-3503 provided by D.Rowbotham, the distance between
C                  the centreline of T1 and the centreline of 1AQ9 is 2'+1.625"=25.625".

      call dr( (25.625*chm - Q9L/2.),   0,0)
      call fringeq(0.26,0.00,0.11,-0.38)
      call MQUAD(Q9,10.48,  Q9L,  wq,"Q9  ")
      call drift( (79.75*chm - Q9L/2. - 0.0266),  "M8  ")
C--------------------------------------------------------------------------------
C  monitor 1AM8:  wire plane is 1.047"=0.0266m upstream of the centreline of the box.
```

```
C-------------------------------------------------------------------------------------
C      call fit(1,1,1,fitx ,wsize,1)
C      call fit(1,3,3,fity ,wsize,1)

      call drift(0.0266,"M8 centre")
C>>>  Here is 1AM8 box centre line.
      call dr( (50.0625*chm - Q10L/2.),   0,0)
      call MQUAD(-Q10,10.480, Q10L,  wq,"Q10 ")
      call dr(  (37.*chm - Q10L/2. - Q11L/2.),   0,0)
      call MQUAD( Q11,10.480, Q11L,  wq,"Q11 ")

      call dr( (64.40*chm - Q11L/2.),  0,0)
      call dr(  33.47*chm,  0,0)
      call dr(  25.75*chm,  0,0)
      call drift(0.,                 "SM6C")
C>>>  Here is the center-line of SM6.
      call dr(  17.*chm,    0,0)
      call drift(0.,                 "SM7C")
C>>>  Here is the center-line of SM7
      call dr(  90.25*chm,   0,0)
      call drift(  27.564*chm ,      "SM8C")
C>>>  Here is the center-line of SM8

      call drift(  29.625*chm," ")!       "M9CL")
C-RYN 2009-Nov-02  The distance between Q11CL and M9CL is uncertain but should
C                  be around 7.3m (as scaled from dwgs D-3511,3512).
C>>>  Here is 1AM9 box centre line.
      call drift(5.25*chm,   "M9  ")
C---------------------------------------------------------------------------------------
C  monitor 1AM9:  wire plane is 5.25"=0.13335m downstream of the centreline of the box.
C---------------------------------------------------------------------------------------
C      call fit(1,1,1,fitx ,wsize,1)
C      call fit(1,3,3,fity ,wsize,1)

      call dr(  32.0625*chm - 5.25*chm,  0,0)
      call drift(0.,                 "SM9C")
C>>>  Here is the center-line of SM9.

      call dr(  (28.8125*chm  - Q12L/2.),  0,0)

      call MQUAD(-Q12,10.480,  Q12L, wq,"Q12 ")
      call dr(  (37.1875*chm - Q12L/2. - Q13L/2.), 0,0)
      call MQUAD( Q13,10.480,  Q13L, wq,"Q13 ")
C-RYN 2009-Nov-05: ACCORDING TO RON KURAMOTO,
C                  THE DISTANCE between Q13CL and T2 PROTECT CL IS APPROX. 95"=2.413m;
C                  THE DISANCCE between T2 PROTECT CL TO T2CL/MT2 IS 12.75"=0.32385m.
C                  (SEE DWG D-3513 THAT RK UPDATED TO ME ON 5-NOV-2009, or SEE E10051).
      call drift( (95.*chm - Q13L/2.),  "T2 protect mon.")
C>>>  Here is T2 PROTECT CENTER LINE.

      thT2 = 12E-3       !!<<< T2 target thickness, in meter.
      call dr( 12.75*chm - thT2*0.5,  0,0)
      call vective(1)
C      call drift(0.,     "T2IN" )
      call dr(thT2*0.5,   0,0)
```

```
C      call drift(0.,     "T2CL")
C--------------------------------------------------
C  monitor 1AMT2 (right at T2 target Centre-Line)
C--------------------------------------------------
C      call fit(1,1,1,XMT2, 4., 1)
C      call fit(1,3,3,YMT2, 4., 1)

      call dr(thT2*0.5,   0,0)
C      call drift(0.,     "T2EX" )

C>>>  Here is the exit of T2 target.
C      call addscatter(18.,  18.,  0.37, 475.-42.8)  !! scattering from 10cm long Be target.
c      call addscatter( 6.2, 6.2,  0.13, 475.-5.1)   !! scattering from 12mm long Be target.
      call addscatter2(12.7, 12.7, 0.26, 475.-21.4)  !! scattering from 50mm long Be target.

C     THE DISTANCE between T2CL and Collimator A Centre-Line is 15.25"
C     in terms of drawing E10051 (dated June 27, 1973).
C     While Collimator A is 25.0cm long (see E-30149, dated OCT.20, 1983).
      call dr(  (15.25*chm - thT2*0.5 - 0.125), 0,0)

C      call drift(0.,     "cAin")
      call dr( 0.125,  0,0)
      call drift(0.,     "collimator A")
      call dr( 0.125,  0,0)
C      call drift(0.,     "cAex")

      call dr( 14.523*chm - 0.125,   0,0)
      call drift(0.,     "collimator B")
C>>>  Here is the THROAT of COL-B (i.e. the location where the COL-B smallest
C     inside aperture occurs.)
      call dr( 32.28125*chm,   0,0)
C      call drift(0.,     "cBex")

      call dr( (18.852*chm - Q14L/2.),  0,0)

C  Q14,15,16 effective lengths as measured Dec./02
      call fringeq(0.17,0.00,0.06,-0.32)
      call MQUAD(-Q14,10.480,  Q14L, wq,"Q14 ")
      call dr( (34.375*chm  - Q14L/2. - Q15L/2.),  0,0)
      call MQUAD( Q15,10.480,  Q15L, wq,"Q15 ")
      call dr( (34.375*chm  - Q15L/2. - Q16L/2.),  0,0)
      call fringeq(0.22,0.00,0.10,-0.35)
      call MQUAD(-Q16,10.480,  Q16L, wq,"Q16 ")

      call dr( (95.625*chm - Q16L/2. - 1.047*chm),  0,0)
      call drift(0.,        "M10 ")
C------------------------------------------------------------------------------------
C  monitor 1AM10: wire plane is 1.047"=0.0266m upstream of the centreline of the box.
C------------------------------------------------------------------------------------
C      call fit(1,1,1,fitx ,wsize,1)
C      call fit(1,3,3,fity ,wsize,1)

      call drift(1.047*chm,   "M10C")
C>>>  Here is the center line of box 1AM10.
```

```
      call drift(11.7475,       "M11 ")
C---------------------------------------------------------
C  monitor 1AM11:  wire plane is at box's centre line.
C---------------------------------------------------------
C       call fit(1,1,1,fitx ,wsize,1)
C       call fit(1,3,3,fity ,wsize,1)

      call drift(113.5*chm,   "TNFc")

C double waist at TNF; desired beam size(full)=4cm*5cm:
C       call fit(1,1,2,0.,wfr12,1)
C       call fit(1,3,4,0.,wfr12,1)
C       call fit(1,1,1,2.0, 1. ,1)
C       call fit(1,3,3,2.5, 2. ,1)

 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
```

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