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BL1A Simulation Model in G4Beamline

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Abstract: This report documents the G4Beamline model that has been developed for Beam Line 1A, incorporating its magnetic components, field strengths, and layout in a 3D geometry setting. The origin and pre-processing of beam data for input to G4Beamline is also documented.

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1 Introduction

Beam line 1A (BL1A) transports 480 MeV protons from the cyclotron to the UCN beam line (BL1U), muon production targets T1 and T2, the 500 MeV Isotope Production Facility, and finally to the Thermal Neutron Facility (TNF). The simulation code REVMOC has been the reference simulation code for the design and operation of this beam line, with treatments of scattering and energy loss in T1 and T2, as well as detection of proton losses at defined apertures throughout the beam line. The limitations of REVMOC and the availability of Geant4-based beam line simulations has prompted this development of a new BL1A model using the G4Beamline code, which due to its fully 3D geometry, as well as advanced scattering and energy loss treatments, provides more accurate and detailed estimates of losses (and their consequences) than REVMOC. There is also the potential for more advanced simulations including steerers and element misalignments, that go beyond the scope of REVMOC and may be of use in optimising the performance of BL1A, reducing losses and improving the beam transmission to the TNF.

This report also documents the origin and pre-processing of the beam data that is used in the G4Beamline application, where REVMOC is used for beam generation and tracking through the fringe field of the cyclotron.

A single input file is used in G4Beamline to specify beam and field inputs, the beam line component and geometry definitions (with the exception of the T2 section geometry provided by Syd Kreitzman), and all the run steering and output mechanisms. The Appendix to this report contains an annotated listing of the complete input file for BL1A, as well as the T2 section geometry file.

2 Reference Run and Its Components

In conjunction with this document a set of "reference run" files has been created. This comprises a complete set of input and output files for the most recent and fully realised BL1A model, as well as the data sets and conversions involved in preparing beam data for G4Beamline. The reference run is intended to be self-contained and reproducible.

Here are the roles of the codes used in the reference run.

REVMOC	Generates beam distributions at the extraction foil, tracks through the foil and the cyclotron fringe field.
revmoc2g4bl	Converts REVMOC beam data to a BLNtuple file for input to G4Beamline.
G4Beamline	Using the REVMOC beam data, tracks from the combination magnet entrance through to the TNF target.

Here, for simplicity, we have used an existing REVMOC run, provided by Yi-Nong Rao[4], to track the beam through the foil and the fringe field of the cyclotron, represented by a transfer matrix fitted to beam measurement data. This pre-tracking could also be done using ACCSIM, with its more accurate single-scatter model for the foil, but for this application scattering effects in the foil are exceedingly small in comparison to those of the thick targets T1 and T2, and the small increase in large-angle scattering losses seen with ACCSIM would be virtually insignificant in the heavily shielded environment of BL1A.

The following describes each file in the Reference Run.

`revmoc/bl1a.in` This is a REVMOC run for the whole of BL1A, included for reference and as a test of the new refurbished version (see below) of REVMOC.

`revmoc2g4bl/bl1a.in` Input file for REVMOC, comprising only the extraction foil and a transfer matrix representing the cyclotron fringe field.

`revmoc2g4bl/coords.out` Output file of the beam coordinates from REVMOC (symlinked to `fort.4`).

`revmoc2g4bl/revmoc2g4bl.f` Converter program: reads REVMOC beam data on `fort.4` and outputs BLNTuple file for G4Beamline on `fort.3`.

`bl1a.in` Main input file for G4Beamline: reads the beam data from `fort.3`. Includes the beam line geometry (except for the T2-CollimatorA-CollimatorB section), and output and run commands.

`T2CollEDIT.g4bl` An edited and excerpted version of the T2-CollimatorA-CollimatorB section, based on the geometry provided by Syd Kreitzman, merged into the input stream by an `include` commend in `bl1a.in`.

`bl1a.log` Output to the terminal during the G4Beamline run, including input and derived parameters, the layout process, the tracking process, and names of output files.

`g4blenv.dat` Envelope data (RMS X and Y) derived from G4Beamline Zntuples, for comparison with REVMOC and TRANSOPTR.

`env.png` Plot of RMS 2-sigma envelopes of the above three codes.

3 G4Beamline Input File

The beam line elements are mostly derived from Yi-Nong Rao's REVMOC run for BL1A. Due to the storage limitations of REVMOC, he had originally implemented the beam line in three separate REVMOC runs, tied together by coordinate output and input files.

To facilitate this and future work, I first did a review of the REVMOC code (existing in various versions), selected what seemed to be the most authoritative version, and upgraded the code to support much longer beam lines, a larger number of beam particles, and introduced user-settable array dimension parameters, for easy modification in the future.

The REVMOC run provides data for beam pipe sizes as well as the aperture restrictions that exist throughout the line, due to targets, collimators, and so on. In G4Beamline, I tried to flesh out these apertures as part of the 3D geometry of each beam line element. Particular attention was payed to the target regions, and especially the collimators downstream of them, relying on the original drawings of BL1A provided to me. In some other areas the G4Beamline shapes and apertures may be considered somewhat sketchy, due to both the limited detail of the drawings and lack of documentation about the design and purpose of various structures.

The part of the beam line from T2-CollimatorA-CollimatorB to TNF is complete in respect of beam delivery and tuning to the TNF target, but the intervening isotope production target assembly is not yet implemented. The TNF itself includes only the 7 cm radius lead cylindrical target of 25 cm length, without any surrounding geometry.

4 Tuning and Beam Envelopes

The dipole B1 was adjusted using the `tune` command in G4Beamline to achieve centering within 0.4 mm throughout the beam line, at a field strength of 9.557 kGauss (see Figure 1). In

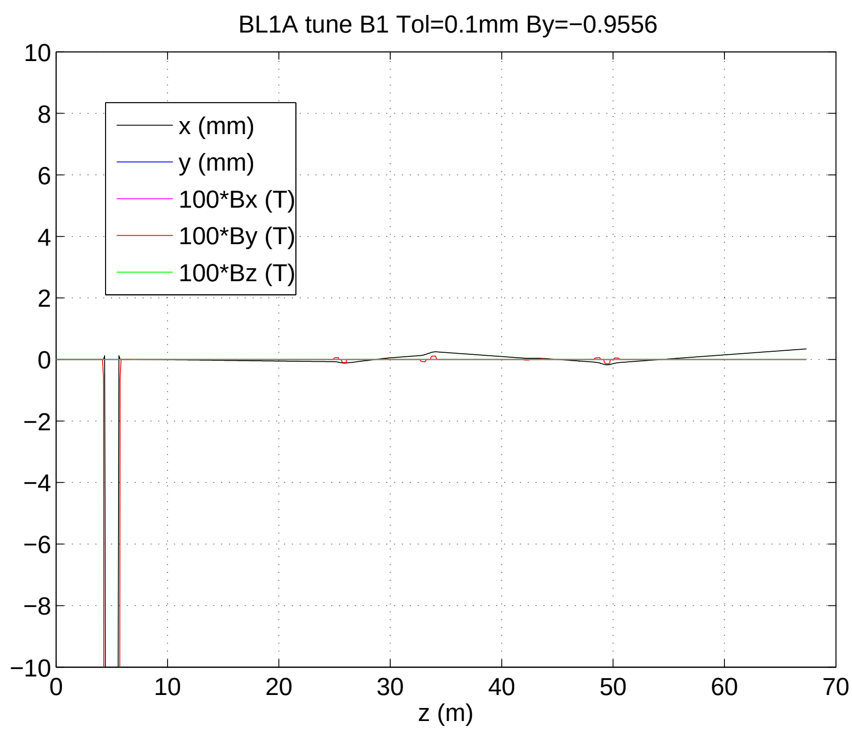

Figure 1: Centering (path of reference particle) after tuning of B1.

order to achieve vertical edge focusing consistent with that of REVMOC, the `fringeFactor` of B1 was set to 0.25.

Since G4Beamline cannot fit to statistical properties of the beam, the quadrupoles were hand-tuned to obtain a reasonable level of agreement of the RMS envelopes with those given by REVMOC statistics, as well as those from a TRANSOPTR run for the beam line. This involved a lot of trial and error, as well as some trade-offs between different locations in the beam line. The rapid blow-ups that occur after T1 and T2 are handled by different calculations in all three codes. As seen in Figure 2, the envelopes downstream of T1 are generally within 0.5–1 mm of each other.

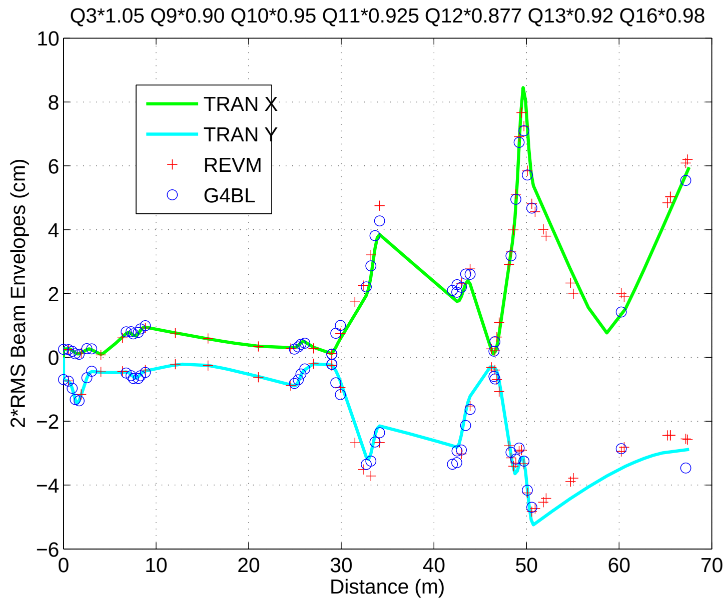

Figure 2: RMS beam envelopes of Transoptr, REVMOC, and G4Beamline. Top line shows adjustments to G4Beamline quad settings.

5 Future Applications

There is evidence that settling of structures in the T2 area, including the T2 monument itself, have had a significant effect on target efficiency and beam losses downstream of T2, resulting in a downward trend of the measured transmission to the TNF target. After photographs of T2 revealed that the beam spot was off center, the vertical position of T2 was adjusted and improved TNF transmission was observed.

Since REVMOC cannot model these kinds of alignment and beam steering issues, the hope is that the G4Beamline model, in which steering magnet settings and element alignments can be easily changed, will eventually help to diagnose the true state of BL1A misalignments and how they influence both the T2 muon production and the reduced transmission to the TNF.

So far, some experiments in G4Beamline with misaligning T2 and its downstream collimators, as well as mis-steering the beam with upstream steerers, have not been very conclusive, in part because it is not obvious what absolute and relative movements in the beam line have occurred in reality. When BL1A was changed to operating with a short 1 cm T2 target instead of the usual 5 cm length, I implemented the same in G4Beamline, but the change in TNF transmission seen in the code did not resemble what was measured. As noted above, the isotope production target module, and other possibly relevant details between T2 and TNF, have not yet been implemented.

Thus the simulation model must be considered a work in progress. There is little doubt that

Geant4 itself is a sound platform on which to build the geometry and track the beam, but validation of the model at the G4Beamline level, via beam experiments, is necessary to go further. This would require a basic familiarity with the code among some group members, with at least one person having more in-depth knowledge and experience in order to design and conduct the experiments.

References

[1] F.W. Jones, Development of the ACCSIM Tracking and Simulation Code, IEEE PAC97, Vancouver, 1997.
`http://accelconf.web.cern.ch/accelconf/pac97/papers/pdf/8P097.PDF`

[2] T.J. Roberts et al., Particle Tracking in Matter-Dominated Beam Lines, IPAC10, Kyoto, 2010.
`http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/tupec063.pdf`
`http://g4beamline.muonsinc.com/`

[3] R. Baartman, TRANSOPTR: Changes since 1984, TRIUMF Beam Physics Note TRI-BN-16-06 (2016).
`http://lin12.triumf.ca/text/design_notes/b2016_06`

[4] Y.N. Rao, private communication.

Appendix: BL1A beam line definition

```
* Beam Line 1A  F.W. Jones TRIUMF
*       T2-CollimatorA-CollimatorB based on
*       geometry by Syd Kreitzman
*
*  LAYOUT based on REVMOC
*       ALL fringe fields
*       Beam generated by REVMOC
*       FOIL and cyclotron fringe field pre-tracked by REVMOC
*  Initial QUADRUPOLE settings from REVMOC

param -unset doStochastics=1
physics QGSP_BIC doStochastics=$doStochastics

# Mean Pz from REVMOC
param -unset pMomentumRef=1063.477423

# BEAM.....

# Distribution file generated by REVMOC2G4BL
beam ascii filename=/home/g4beamline/BL1A/afterCYCFF/REVMOC2G4BL/fort.3 \
   beamZ=0 nEvents=$nEvents

# Calibration file w/single proton and PMomentumRef
#beam ascii filename=fort.81.calib beamZ=0 nEvents=$nEvents

# Test particle file for debug
#beam ascii filename=fort.81.debug beamZ=0 nEvents=$nEvents

# REFERENCE PARTICLE.....

reference referenceMomentum=$pMomentumRef particle=proton beamZ=0 \
   beamX=0 beamXp=0 beamY=0 beamYp=0

# MATERIALS.....

param worldMaterial=Vacuum
#particlecolor proton=1,0,0 plus=1,0,0 minus=0,1,0 neutral=0,0,1
particlecolor proton=1,0,0 neutron=0,1,1 gamma=0,1,0 e-=0,0,1 \
              plus=1,0,1 minus=1,1,0 neutral=0,1,1 reference=1,1,1

# SS from BDSIM (BDSMaterials.cc)
material ss C,0.0003 Mn,0.02 Si,0.0075 P,0.00045 S,0.0003 \
        Cr,0.17 Mo,0.025 Ni,0.12 N,0.001 Fe,0.65545 \
        density=8.0
# Alternative SS from examples/advanced/composite_calorimeter
# AISI Cr-Ni steel, default is type 304.  Weight fractions SDC definition.
#material ss Fe,0.6996 C,0.0004 Mn,0.01 \
```

```
#        Cr,0.19 Ni,0.10 density=8.02

param -unset vacuumColor=0.,0.,0.


# DIPOLES.....

# B1
# Bend g/2=5.08cm L=1.2763m B=9.845kG
# REVMOC ref momentum is 1.09008GeV/c
# Edge angles are 9.9 degrees

tune B1By z0=0 z1=8300 initial=-0.9555 step=0.0001 \
     expr=x1 tolerance=0.1 maxIter=100

param LB1=1276.3
genericbend B1 fieldWidth=1000 fieldHeight=102 fieldLength=$LB1 \
        By=B1By fringeFactor=0.25 \
   ironColor=1,0,0 ironWidth=1000 ironHeight=1000 ironLength=$LB1

tubs pipe-CYCFF-B1 innerRadius=48.7 outerRadius=50.8 length=4360-1 \
        material=ss kill=0 color=.2,.2,.2,.9
tubs pipe-B1 innerRadius=48.7 outerRadius=50.8 length=$LB1 \
        material=ss kill=0 color=.2,.2,.2,.9


# STEERING MAGNETS.....

# 4 INCH
genericbend SMS fieldWidth=150 fieldHeight=102 fieldLength=150 \
        fringeFactor=1 \
   ironColor=.5,0,0 ironWidth=300 ironHeight=300 ironLength=150

# 8 INCH
genericbend SML fieldWidth=300 fieldHeight=210 fieldLength=150 \
        fringeFactor=1 \
   ironColor=.5,0,0 ironWidth=600 ironHeight=425 ironLength=150


# QUADRUPOLES.....

# Scale factor to get Tesla/meter from pole tip field B0
# See: BL2A notes p28
# Half-gap for all quads is 5.159 cm
# REVMOC half-gap is 5.156cm so needs slight correction
param qsf=1.9383601

# APERTURE INCREASED TO ACCOMMODATE A 5MM THICK VIRTUALDET
genericquad Q apertureRadius=65 ironRadius=914.4/2 \
```

```
        ironColor=0,.6,0 fringeFactor=0.1

param LQ1=403.9
param LQ2=408.9
param LQ3=530.9
param LQ4=523.8
param LQ5=532.1
param LQ6=523.8
param LQ7=411.5
param LQ8=414.0

# LARGE APERTURE QUADS a=10.48cm
param qqsf=0.95419847
genericquad QQ apertureRadius=118 ironRadius=450*1.414 \
ironColor=0,.6,0 fringeFactor=0.1

param LQ9=499.1
param LQ10=490.5
param LQ11=490.5
param LQ12=490.5
param LQ13=490.5
param LQ14=4*130.17
param LQ15=4*130.17
param LQ16=484.10

# DIPOLE FIELDS FOR (future) STEERING WITH QUADS

fieldexpr SQ5H width=2*65 height=2*65 length=$LQ5 By=0
fieldexpr SQ5V width=2*65 height=2*65 length=$LQ5 Bx=0

fieldexpr SQ14H width=2*118 height=2*118 length=$LQ14 By=0
fieldexpr SQ16V width=2*118 height=2*118 length=$LQ16 Bx=0


# TARGETS

# T1  (REVMOC bl1a2T1.in T1 11mm.  1_to_T1.in 10*1mm)
tubs T1 innerRadius=0 outerRadius=101.6 length=11 material=C

# T2  (REVMOC T201-T220 5mm slices)
tubs T2 innerRadius=0 outerRadius=51.0 length=100 material=Be

# TNF see TRIUMF Users Hbk 4.1.3.3
tubs TNF innerRadius=0 outerRadius=70 length=250 material=Pb


# SEPTUM AFTER T1: aperture deltaX 0.75,0.75,0.76 cm

box SEPT length=640 height=2*110 width=2*110 material=Cu \
```

```
    color=1,0,1,0.95
# For unmodified trap:
trap SEPT2 length=200 height=640 \
     upperWidth=100+36.5 lowerWidth=100+59.1+7.6 \
     material=Vacuum
# Modified BLCMDtrap.cc to allow right angular wedge
#trap SEPT2 length=200 height=640 \
#     upperWidth=100+36.5 lowerWidth=100+59.1+7.6 rwedge=1 \
#     material=Vacuum

place SEPT2 parent=SEPT x=-16.65 rotation=X-90


# KINK

box KINK length=10 height=2*110 width=2*110 material=Fe \
    color=1,1,0,0.95
box KINK2 length=10 height=2*100 width=100+61.5 material=Vacuum
place KINK2 parent=KINK x=-19.25


# COL

tubs COL length=5*108 innerRadius=0 outerRadius=97.9 material=Cu \
    color=1,0,1,0.95
param RAP1=61.294 RAP2=74.000
extrusion COL2 length=5*108 \
   vertices=1.000000,-0.000000;0.866025,-0.500000;0.500000,-0.866025; \
            0.000000,-1.000000;-0.500000,-0.866025;-0.866025,-0.500000; \
           -1.000000,-0.000000;-0.866025,0.500000;-0.500000,0.866025; \
           -0.000000,1.000000;0.500000,0.866025;0.866025,0.500000 \
   scale1=$RAP1 scale2=$RAP2 material=Vacuum color=0,0,1
place COL2 parent=COL

# COLA is included in T2CollEdit.g4bl

# COLB is included in T2CollEdit.g4bl


# PIPES... 4" and 8" O.D.

# Straight section from B1 exit to T1
param STRL1=28975-5637
# Shorten for box around T1
#param STRL1=28975-5637-50

tubs pipe-B1-T1 length=$STRL1 innerRadius=48.7 outerRadius=50.8 \
        material=ss kill=0 color=.2,.2,.2,.9
```

```
# T1 to SEPT
param LT1SEPT=30351-28986-50
tubs pipe-T1-SEPT length=$LT1SEPT innerRadius=98.6 outerRadius=101.6 \
        material=ss kill=0 color=.2,.2,.2,.9

# Straight section from SEPTUM to T2
param STRL2=46486-30991-50
tubs pipe-SEPT-T2 length=$STRL2 innerRadius=98.6 outerRadius=101.6 \
        material=ss kill=0 color=.2,.2,.2,.9

# T2 to TNF
param LT2TNF=67197-46586-50-50
tubs pipe-T2-TNF length=$LT2TNF innerRadius=98.6 outerRadius=101.6 \
        material=ss kill=0 color=.2,.2,.2,.9


# DETECTORS...
# Detect beam loss for input to FLUKA:

# B1 to T1
virtualdetector SPILL4 format=ascii file=SPILL4.txt \
        length=$STRL1 innerRadius=55 radius=60 \
        color=1,0,1,.95 require=Px*x>0&&Py*y>0
# T1 to TNF
param LT1TNF=67197-28975
#param LT1TNF=67197-28986-50-50
virtualdetector SPILL8 format=ascii file=SPILL8.txt \
        length=$LT1TNF innerRadius=105 radius=110 \
        color=1,0,1,.95 require=Px*x>0&&Py*y>0

box CHECKP width=10000 height=50 \
        length=$STRL1 material=Vacuum \
        color=1,0,1
virtualdetector CHECK format=ascii file=CHECK.txt width=10000 height=50 \
        length=$STRL1 \
        color=1,0,1
place CHECK parent=CHECKP


# Virtual beam spill monitors not currently used

#virtualdetector BSM innerRadius=53 radius=1500 length=500 material=Vacuum \
#        color=red format=ascii referenceParticle=1 kill=0
#virtualdetector BSM height=500 width=500 length=500 material=Vacuum \
#virtualdetector BSM height=150 width=150 length=150 material=Vacuum \


#------------------------------------------------------------
# LAYOUT
```

```
# Beamline definition in centerline (the default) coordinates
#------------------------------------------------------------

# Cyclotron exit (REVMOC)
param SFOIL=0.007324
param SCYCFF=0.01
param SINJ=$SFOIL+$SCYCFF

zntuple format=ascii z=$SINJ referenceParticle=1

place pipe-CYCFF-B1 front=1 z=$SINJ

param S=$SINJ+537.90

zntuple format=ascii z=$S referenceParticle=1
place Q rename=Q1 front=1 z=$S fieldLength=$LQ1 gradient=$qsf*(5.28393) \
      ironLength=$LQ1
param S=$S+$LQ1
zntuple format=ascii z=$S referenceParticle=1

# THE REMAINDER IS LAYED OUT ACCORDING TO REVMOC (1MM PRECISION)

param S=1277

zntuple format=ascii z=$S referenceParticle=1
place Q rename=Q2 front=1 z=$S fieldLength=$LQ2 gradient=$qsf*(-6.10584) \
      ironLength=$LQ2
param S=$S+$LQ2
zntuple format=ascii z=$S referenceParticle=1

param S=2524

zntuple format=ascii z=$S referenceParticle=1
place Q rename=Q3 front=1 z=$S fieldLength=$LQ3 \
      gradient=$qsf*(5.87466)*1.05 ironLength=$LQ3
param S=$S+$LQ3
zntuple format=ascii z=$S referenceParticle=1

param S=4360

corner B1c1 z=$S rotation=Y+9.9
place B1 rename=B1. z=$S+0.5*1276.3
place pipe-B1 front=1 z=$S
param S=$S+1276.3
corner B1c2 z=$S rotation=Y+9.9

param S=6775

zntuple format=ascii z=$S referenceParticle=1
```

```
place Q rename=Q4 front=1 z=$S fieldLength=$LQ4 gradient=$qsf*(2.34704) \
      ironLength=$LQ4
param S=$S+$LQ4
zntuple format=ascii z=$S referenceParticle=1

param S=7545

zntuple format=ascii z=$S referenceParticle=1
place Q rename=Q5 front=1 z=$S fieldLength=$LQ5 gradient=$qsf*(-3.44693) \
      ironLength=$LQ5
place SQ5H z=$S
place SQ5V z=$S
param S=$S+$LQ5
zntuple format=ascii z=$S referenceParticle=1

param S=8312

zntuple format=ascii z=$S referenceParticle=1
place Q rename=Q6 front=1 z=$S fieldLength=$LQ6 gradient=$qsf*(1.90125) \
      ironLength=$LQ6
param S=$S+$LQ6
zntuple format=ascii z=$S referenceParticle=1

# KICKER has simple aperture R=5.08cm -- no material specified
# KIKn
param S=$S+2500.02
# KIKc
param S=$S+750
# KIKx
param S=$S+750
# M5c
param S=$S+2770.80

# SEPTUM has simple aperture R=5.08cm -- no material specified
# SEPn
param S=$S+1479.20
# SEPc
param S=$S+750
# SEPx
param S=$S+750
# M6
param S=$S+2453.20
# M6.6
param S=$S+3505.20
# Whatever
param S=$S+397.51

# SM4 (V)
param S=20289.1
```

```
place SMS rename=SM4 z=$S rotation=z+90 By=0
# SM5 (H)
param S=20603.4
place SMS rename=SM5 z=$S By=0

param S=24941
zntuple format=ascii z=$S referenceParticle=1
place Q rename=Q7 front=1 z=$S fieldLength=$LQ7 gradient=$qsf*(-3.90707) \
      ironLength=$LQ7
param S=$S+$LQ7
zntuple format=ascii z=$S referenceParticle=1

param S=25648

zntuple format=ascii z=$S referenceParticle=1
place Q rename=Q8 front=1 z=$S fieldLength=$LQ8 gradient=$qsf*(4.42756) \
      ironLength=$LQ8
param S=$S+$LQ8
zntuple format=ascii z=$S referenceParticle=1

param S=28975

# T1 10mm
zntuple format=ascii z=$S referenceParticle=1
place T1 front=1 z=$S
param S=$S+10
zntuple format=ascii z=$S+1 referenceParticle=1

place pipe-T1-SEPT front=1 z=$S+50

param S=29401
#param S=$S+415.02

zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q9 front=1 z=$S fieldLength=$LQ9 \
      gradient=$qqsf*(2.84103)*0.90 ironLength=$LQ9
param S=$S+$LQ9
zntuple format=ascii z=$S referenceParticle=1

# SEPTUM
param S=30351
place SEPT front=1 z=$S

# KINK
param S=31465
place KINK front=1 z=$S

# COL1-COL5
param S=31830
```

```
place COL front=1 z=$S

param S=32703

zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q10 front=1 z=$S fieldLength=$LQ10 \
      gradient=$qqsf*(-5.2540)*0.95 ironLength=$LQ10
param S=$S+$LQ10
zntuple format=ascii z=$S referenceParticle=1

param S=33642

zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q11 front=1 z=$S fieldLength=$LQ11 \
      gradient=$qqsf*(4.79243)*0.925 ironLength=$LQ11
param S=$S+$LQ11
zntuple format=ascii z=$S referenceParticle=1

param S=42480

# SM6 (V)
param S=37011.8
place SML rename=SM6 z=$S rotation=z+90 By=0
# SM7 (H)
param S=37443.6
place SML rename=SM7 z=$S By=0

# SM8 (V)
param S=40436.1
place SML rename=SM8 z=$S rotation=z+90 By=0
# SM9 (H)
param S=42003.0
place SML rename=SM9 z=$S By=0

param S=42480
zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q12 front=1 z=$S fieldLength=$LQ12 \
      gradient=$qqsf*(-4.89035)*0.877 ironLength=$LQ12
param S=$S+$LQ12
zntuple format=ascii z=$S referenceParticle=1

param S=43425

zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q13 front=1 z=$S fieldLength=$LQ13 \
      gradient=$qqsf*(5.66510)*0.92 ironLength=$LQ13
param S=$S+$LQ13
zntuple format=ascii z=$S referenceParticle=1
```

```
# T2 front from REVMOC
param S=46486
zntuple format=ascii z=$S referenceParticle=1

#------------------------------------------------------------#
# BEGIN Syd Kreitzman's T2 ASSEMBLY
# targetNo==1 variant
#------------------------------------------------------------#

include T2CollEDIT.g4bl

# T2 EXIT:
param S=$S+$targetLen
zntuple format=ascii z=$S referenceParticle=1

# From REVMOC for reference...
#param S=$S+2300.02
# T2N
#param S=$S+270.1
# My simple T2
#zntuple format=ascii z=$S referenceParticle=1
#place T2 front=1 z=$S
#param S=$S+100
#zntuple format=ascii z=$S+1 referenceParticle=1
#param S=46799
# COLA
#param S=47061
# COLB

param S=48328

# *NOT* REPLACED BY RAD-HARD QUAD IN SK GEOMETRY
zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q14 front=1 z=$S fieldLength=$LQ14 gradient=$qqsf*(-5.67622) \
         ironLength=$LQ14
place SQ14H z=$S
param S=$S+$LQ14
zntuple format=ascii z=$S referenceParticle=1

param S=49201

zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q15 front=1 z=$S fieldLength=$LQ15 gradient=$qqsf*(8.10748) \
      ironLength=$LQ15
param S=$S+$LQ15
zntuple format=ascii z=$S referenceParticle=1

param S=50092
```

```
zntuple format=ascii z=$S referenceParticle=1
place QQ rename=Q16 front=1 z=$S fieldLength=$LQ16 \
      gradient=$qqsf*(-4.51139)*0.98 ironLength=$LQ16
place SQ16V z=$S
param S=$S+$LQ16
zntuple format=ascii z=$S referenceParticle=1

param S=50935

# S1A-B-C
# 51811.3

# S1D1-2
# 52115.3

# S1E through S3A
# 54752

# S3B1-2
# 55056.8

# S3C-F
# 56276

# S3FL through S4A
# 60236.8

# BEAM SIZE for REVMOC comparison
zntuple format=ascii z=60237 referenceParticle=1

# S4B1-2
# S4C-F
# radd+M11CL+TNFI+WPOS

param S=65526
# WIN1
# RING1-4
# TWX through TNF

param S=67197

zntuple format=ascii z=$S referenceParticle=1
place TNF front=1 z=$S
param S=$S+197.1

# END OF BEAM LINE ELEMENTS

# Long pipes
place pipe-B1-T1 front=1 z=5637
```

```
place pipe-SEPT-T2 front=1 z=30991
place pipe-T2-TNF front=1 z=46486+100+50

# Loss detectors
#place SPILL4 front=1 z=5637
#place SPILL8 front=1 z=28975
#place SPILL8 front=1 z=28975+10+50

#place CHECKP front=1 z=11041.556+50 y=600


beamlossntuple BLNT filename=LostParticles.txt format=ascii

# Only for G4BL 2.16 and above
survey coordinates=centerline filename=bl1a.svy

trace nTrace=1 format=ascii

g4ui when=4 "/run/beamOn 100"
```