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# BL4N Simulation Model in G4Beamline

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**Abstract:** This report documents the G4Beamline model that has been developed for Beam Line 4N, 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 4N (BL4N) will transport 480 MeV protons from the cyclotron to an ISOL target in the ARIEL rare isotope beam facility. One of its design goals is to support low-loss operation by utilizing collimation and precision beam tuning to minimize the proton losses due to multiple scattering in the cyclotron extraction foil.

An initial simulation with REVMOC, without collimation, showed losses at certain locations exceeding 1 Watt/meter, indicating that collimation would be necessary to allow sustainable (hands-on maintenance) operation at full beam power. At this point it was decided to pursue a G4Beamline simulation model of BL4N, which would allow more precise detection of losses in a realistic 3D geometry, as well as more accurate physics models of proton scattering and energy loss in the proposed collimator.

Many aspects of the simulation model are described at length in the collimation study reports [1, 2]. This report will therefore be quite brief and will concentrate on describing the components of the simulation, including the pre-processing by ACCSIM.

The Appendix to this report contains an annotated listing of the complete G4Beamline input file for BL4N.

# 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 BL4N 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.

| | |
|---|---|
| COMA | Provides the initial particle data at the location of the extraction foil in the cyclotron. |
| co4accsim | Converts COMA coordinate file into ACCSIM beam input file. |
| ACCSIM | Using the COMA beam data, tracks through the extraction foil and the fringe field of the cyclotron to the beam line entrance, where it outputs the beam data in BLNTuple format for use by G4Beamline. |
| G4Beamline | Tracks the proton beam provided by ACCSIM through the beam line, simulating all proton interactions with the collimator, and recording all proton losses. |
| TRANSOPTR | Used as a reference for the beam line layout, magnetic elements, and their field strengths. |

Since Coulomb scattering in the foil is the principal agent contributing to proton losses, in the ACCSIM run it is treated by an interated single-scatter model, which provides a better description of the large-angle tail than conventional multiple scattering models. Since G4Beamline does not support map-based beam transport, ACCSIM also tracks the extracted protons through the fringe field of the cyclotron, using a matrix representation fitted to beam measurements.

The relevant files for the ACCSIM pre-processing and the G4Beamline simulation itself are as follows:

`coma/input_4revmoc.dat` COMA beam data at the extraction foil (also previously used with REVMOC).

`coma/co4accsim.f` Converts `input_4revmoc.dat` to `coma/fort.4` for input to ACCSIM.

`accsim/bl4n.com` Input file for ACCSIM, comprising the extraction foil and a transfer matrix representing the cyclotron fringe field, with beam input from `fort.4` above.

`accsim/fort.81` Output from the ACCSIM run, in BLNTuple format suitable for input to G4Beamline.

`bl4n.in` Main input file for G4Beamline: reads the beam data from `fort.81`.

`bl4n.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 TRANSOPTR.

`profile.png` Plot of RMS (2 sigma) envelopes of the two codes.

`transoptr/*` The reference TRANSOPTR run for BL4N, from which the element layout and field strengths were obtained.

# 3 G4Beamline Input File

In the Appendix the G4Beamline input file `bl4n.in` is shown in full. This is a complete description of the beam line and all operations to be performed by the program. Running G4Beamline requires only this file and the additional file of initial particle coordinates as generated by ACCSIM.

For additional information on quadrupole types and vacuum chamber dimensions, please consult Reference [2].

# 4 Tuning and Beam Envelopes

The dipoles VB4, B6, B10, B22 and B26 were adjusted using the `tune` command in G4Beamline for centering within 0.01 mm at a strategic location upstream of each dipole. This achieved centering with 0.2 mm throughout the first 70 m of the beam line, and within 1 mm for the last 13 m of the beam line. (see Figure 1).

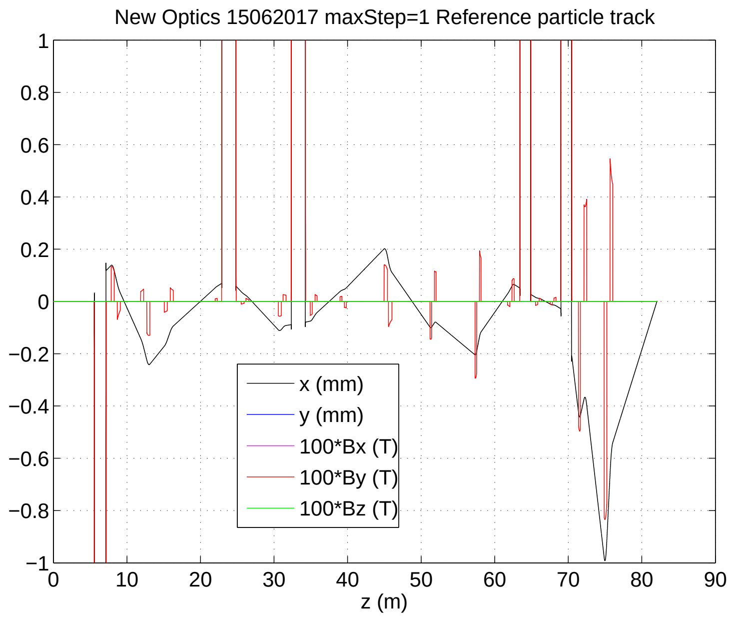


Figure 1: Centering (path of reference particle) after tuning of the four dipoles.

In order to achieve vertical edge focusing consistent with that of TRANSOPTR, the `fringeFactor` of all dipoles was set to 0.25.

Notably, the quadrupole strengths were taken directly from the TRANSOPTR run and did not require any adjustment to achieve good agreement of the RMS beam sizes with those of TRANSOPTR (see Figure 2). However, to achieve this agreement it was necessary to set the `fringeFactor` parameter of all quadrupoles to zero, resulting in a hard-edge field. It is worth mentioning that discontinuities in fields pose no difficulty for Geant4's adaptive stepping methods, which sample the field values at various distances to optimize the step length.

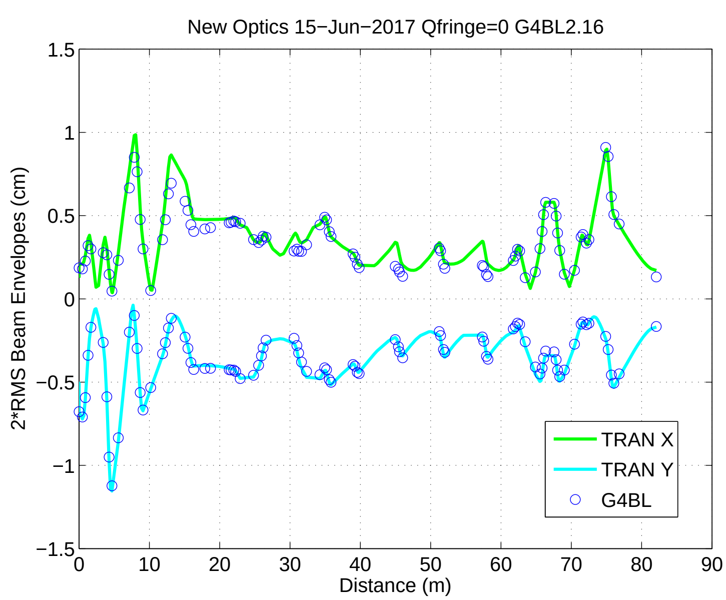


Figure 2: RMS (2 sigma) beam envelopes of TRANSOPTR and G4Beamline.

# 5 Future Applications

In conjunction with the collimation study already conducted with this model, further simulations will undoubtedly be useful for refining the collimator design and investigating the tunability of the beam in the collimator region, once an engineering design is available.

Given the comprehensive set of diagnosics specified for BL4N, it would provide the best available test-bed at TRIUMF for validating G4Beamline and our approach to constructing a simulation and specifying its parameters. Since this is a new beam line, there should be many opportunities for beam experiments providing useful data. Taking advantage of 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, Proton Collimation in Beam Line 4-North (BL4N), TRIUMF Beam Physics Note TRI-BN-16-15 (Revised 2017).
`http://lin12.triumf.ca/text/design_notes/TRI-BN-16-15.pdf`

[2] F.W. Jones, Proton Collimation in BL4N with New Optics, TRIUMF Beam Physics Note TRI-BN-18-04.
`http://lin12.triumf.ca/text/design_notes/TRI-BN-18-04bl4ncollimation2.pdf`

[3] 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`

[4] 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/`

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

# Appendix: BL4N beam line definition

```
* Beam Line 4N  F.W. Jones TRIUMF
*  +++  VERSION 2 based on new quadrupole layout,  +++
*  +++  vacuum chamber dimensions, and optics.     +++
*  +++  JUNE 2017                                  +++
*
*  LAYOUT based on TRANSOPTR 15-JUN-2017
*       ALL fringe fields
*       Beam generated by COMA
*       FOIL to CYCFF exit pre-tracked by ACCSIM
*  QUADRUPOLE settings from TRANSOPTR data.22
*
*  +++  4 INCH APERTURE TO END OF Q14  +++

physics QGSP_BIC doStochastics=1

##### NO SECONDARIES #####
trackcuts killSecondaries=1

# Mean P from REVMOC at cyclotron FF exit.
# Run using Accsim-foil-scattered rays
param -unset pMomentumRef=1063.1830066

# BEAM.....

# Distribution file generated by ACCSIM
beam ascii \
     filename=/home/g4beamline/BL4N/accsim-matrix/wholebeam-1M-2.5mg/fort.81 \
     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 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.....

# REVMOC ref momentum for bends is 1.062854GeV/c

# VB4

# Bend g/2=??cm L=1.5628914m B=9.8236971kG
# Bend angle 24.8126 degrees per DN-13-13
# Edge angles are 20 and 4.8126 degrees

tune VB4By z0=50 z1=20000 initial=-0.966497 step=0.01 \
   expr=x1 tolerance=0.01 maxIter=100

param LVB4=1562.8914
genericbend VB4 fieldWidth=1000 fieldHeight=102 fieldLength=$LVB4 \
        fringeFactor=0.2 \
   ironColor=1,0,0 ironWidth=1000 ironHeight=1000 ironLength=$LVB4

# Existing vacuum box approximated
param oheightVB4=4*25.4
box boxVB4 height=$oheightVB4 width=6*76 length=$LVB4 \
        material=ss  color=.2,.2,.2,.9
box boxVB4i height=2.345*25.4 width=6*76-4 length=$LVB4 \
        material=Vacuum  color=’’
place boxVB4i parent=boxVB4
place boxVB4 parent=VB4

tubs pipe-CYCFF-VB4 innerRadius=48.7 outerRadius=50.8 length=5580 \
        material=ss  color=.2,.2,.2,.9

# B6 and B10
# Bend g/2=??cm L=1.9038051m B=14.6258640kG
# Bend angle 45 degrees per DN-13-13
# Edge angles are 22.5 degrees

tune B6By z0=22000 z1=27000 initial=1.42574 step=0.01 \
   expr=x1 tolerance=0.01 maxIter=100
tune B10By z0=28000 z1=37500 initial=1.42571 step=0.01 \
   expr=x1 tolerance=0.01 maxIter=100

param LB610=1903.8051
```

```
genericbend B610 fieldWidth=1000 fieldHeight=3*25.4 fieldLength=$LB610 \
        fringeFactor=0.2 \
   ironColor=1,0,0 ironWidth=1000 ironHeight=1000 ironLength=$LB610

# Torus 2.87 inch inner diameter and 0.065 inch wall thickness
param iheightB610=2.87*25.4
param hchordB610=$LB610/2
param radiusB610=$hchordB610/sin(pi/8)
param sagB610=\
$radiusB610-sqrt($radiusB610*$radiusB610-$hchordB610*$hchordB610)
torus pipe-B610 innerRadius=$iheightB610/2 \
      outerRadius=$iheightB610/2+0.065*25.4 \
      majorRadius=$radiusB610 initialPhi=-22.5 finalPhi=22.5 \
      material=ss  color=.2,.2,.2,.9
place pipe-B610 parent=B610 x=-$radiusB610+$sagB610 rotation=x+90

tubs pipe-B6-B10 innerRadius=48.7 outerRadius=50.8 length=32351-24811 \
        material=ss  color=.2,.2,.2,.9

# B22 and B26
# Bend g/2=??cm L=1.4384304m B=14.6258640kG
# Bend angle 34 degrees per DN-13-13
# Edge angles are 17 degrees

tune B22By z0=60000 z1=67000-100 initial=1.44162 step=0.01 \
   expr=x1 tolerance=0.01 maxIter=100
tune B26By z0=67000+100 z1=82080 initial=1.44161 step=0.01 \
   expr=x1 tolerance=0.01 maxIter=100
param B2226By=1.45
param LB2226=1438.4304
genericbend B2226 fieldWidth=1000 fieldHeight=102 fieldLength=$LB2226 \
        By=$B2226By fringeFactor=0.2 \
   ironColor=1,0,0 ironWidth=1000 ironHeight=1000 ironLength=$LB2226

# Torus 2.87 inch inner diameter and 0.065 inch wall thickness
param iheightB2226=2.87*25.4
param hchordB2226=$LB2226/2
param radiusB2226=$hchordB2226/sin(17*pi/180)
param sagB2226=\
$radiusB2226-sqrt($radiusB2226*$radiusB2226-$hchordB2226*$hchordB2226)
torus pipe-B2226 innerRadius=$iheightB2226/2 \
      outerRadius=$iheightB2226/2+0.065*25.4 \
      majorRadius=$radiusB2226 initialPhi=-17 finalPhi=17 \
      material=ss  color=.2,.2,.2,.9
place pipe-B2226 parent=B2226 x=-$radiusB2226+$sagB2226 rotation=x+90


# QUADRUPOLES.....
```

```
# Scale factor to get Tesla/meter from pole tip field B0
# See: BL2A notes p28
# Half-gap for vault quads and Q1-Q4 is 5.08 cm
param qsfv=1.9685039
# Half-gap for remaining quads is 3.55 cm
param qsf=2.8169014

param LQ14s8=406.4
genericquad Q14s8 fieldLength=$LQ14s8 ironLength=$LQ14s8 \
      apertureRadius=25.4*4.06/2 ironRadius=914.4/2 \
      ironColor=0,.6,0 fringe=0
param LQ19s8=526.542
genericquad Q19s8 fieldLength=$LQ19s8 ironLength=$LQ19s8 \
      apertureRadius=25.4*4.06/2 ironRadius=914.4/2 \
      ironColor=0,.6,0 fringe=0
param LFQ10s3p6=260.35
genericquad FQ10s3p6 fieldLength=$LFQ10s3p6 ironLength=$LFQ10s3p6 \
            apertureRadius=108/2 ironRadius=914.4/2 \
            ironColor=0,.6,0 fringe=0
param LFQ8p5s8p5=261.8
genericquad FQ8p5s8p5 fieldLength=$LFQ8p5s8p5 ironLength=$LFQ8p5s8p5 \
             apertureRadius=25.4*4.06/2 ironRadius=914.4/2 \
             ironColor=0,.6,0 fringe=0
param LKEK=459.4
genericquad KEK fieldLength=$LKEK ironLength=$LKEK \
            apertureRadius=110/2 ironRadius=914.4/2 \
            ironColor=0,.6,0 fringe=0
param LDanFysikaL5=205.5
genericquad DanFysikaL5 fieldLength=$LDanFysikaL5 ironLength=$LDanFysikaL5 \
             apertureRadius=71/2 ironRadius=914.4/2 \
             ironColor=0,.6,0 fringe=0
param LTUDAS=296.672
genericquad TUDAS fieldLength=$LTUDAS ironLength=$LTUDAS \
             apertureRadius=85/2 ironRadius=914.4/2 \
             ironColor=0,.6,0 fringe=0
param LFQ12s6=357.124
genericquad FQ12s6 fieldLength=$LFQ12s6 ironLength=$LFQ12s6 \
            apertureRadius=25.4*4.08/2 ironRadius=914.4/2 \
            ironColor=0,.6,0 fringe=0

tubs pipe-B10-BPM14 innerRadius=48.7 outerRadius=50.8 length=42145-34255 \
        material=ss  color=.2,.2,.2,.9

# New Optics: Three quad types from here to B22
# KEK quads
tubs pipe-BPM14-Q17 innerRadius=50 outerRadius=52.5 length=51211-42145 \
        material=ss  color=.2,.2,.2,.9
# DanFysika quads
tubs pipe-Q17-Q20 innerRadius=34 outerRadius=35 \
```

```
     length=57936+$LDanFysikaL5-51211 \
     material=ss  color=.2,.2,.2,.9
# TUDA-S quads
tubs pipe-Q20-B22 innerRadius=40 outerRadius=41.5 \
     length=63441-(57936+$LDanFysikaL5) \
     material=ss  color=.2,.2,.2,.9

tubs pipe-B22-B26 innerRadius=40 outerRadius=41.5 length=69019-64879 \
        material=ss  color=.2,.2,.2,.9

# New Optics now large quads here
tubs pipe-B26-ATW innerRadius=48.7 outerRadius=50.8 length=81383-70458 \
        material=ss  color=.2,.2,.2,.9

# COL with TAPER and STRAIGHT section
# Cf REVMOC COLLN COLX
# RAP1 is inner radius of 4" pipe
param RAP1=48.7 RAP2=16
#param RAP1=48.7 RAP2=20.8
param LTAPER=200
#param LTAPER=500
extrusion COL1 length=$LTAPER \
   vertices=1.000000,-0.000000;0.866025,-0.500000;0.500000,-0.866025; \
   0.000000,-1.000000;-0.500000,-0.866025;-0.866025,-0.500000; \
   -1.000000,-0.000000;-0.866025,0.500000;-0.500000,0.866025; \
   -0.000000,1.000000;0.500000,0.866025;0.866025,0.500000 \
   scale1=$RAP1 scale2=$RAP2 material=Vacuum color=0,0,1,.9
param LCOL2=600
#param LCOL2=200
#param LCOL2=500
tubs COL2 length=$LCOL2 innerRadius=0 outerRadius=$RAP2 \
     material=Vacuum color=0,0,1,.9

param LCOL=$LTAPER+$LCOL2
tubs COL length=$LCOL innerRadius=0 outerRadius=97.9 material=Cu \
    color=1,0,1,0.7

place COL1 front=1 z=-0.5*$LCOL parent=COL
place COL2 front=1 z=-0.5*$LCOL+$LTAPER parent=COL

param SCOLFRONT=0.5*(16894+19694-$LCOL)

tubs pipe-VB4-COLL innerRadius=48.7 outerRadius=50.8 length=$SCOLFRONT-7143 \
        material=ss  color=.2,.2,.2,.9
# Q5 and Q6 HERA quads w 105mm OD pipe
tubs pipe-COLL-B6 innerRadius=50 outerRadius=52.5 \
     length=22907-$SCOLFRONT-$LCOL material=ss  color=.2,.2,.2,.9
```

```
# TARGET
param Tlength=24
tubs TARGET innerRadius=0 outerRadius=9.5 length=$Tlength material=Ta \
color=1,0,1 kill=1

# DETECTORS...

# Placeholder for beam spill monitors


#-------------------------------------------------------------
# LAYOUT
# Beamline definition in centerline (the default) coordinates
# S-values are taken directly from TRANSOPTR data.1
#-------------------------------------------------------------

place pipe-CYCFF-VB4 front=1 z=0

# VAULT magnets ...

# S-values from TRANSOPTR replacing those from REVMOC
#    (where different)
# Gradients directly from TRANSOPTR data.22

param S=485
place Q14s8 rename=VQ1 front=1 z=$S gradient=-9.53286

param S=1284
place Q14s8 rename=VQ2 front=1 z=$S gradient=14.9544

param S=3432.9
place Q19s8 rename=VQ3 front=1 z=$S gradient=15.5670

param S=4280.2
place Q14s8 rename=VQ4 front=1 z=$S gradient=-11.6592

param S=5580.4
corner VB4c1 z=$S rotation=Y+24.8126/2
place VB4 rename=VB4. z=$S+0.5*$LVB4 rotation=Y7.5937 By=VB4By
param S=$S+$LVB4
corner VB4c2 z=$S rotation=Y+24.8126/2

place pipe-VB4-COLL front=1 z=$S

param S=7855.8
place Q14s8 rename=VQ5 front=1 z=$S gradient=9.64140

param S=8692.2
place Q14s8 rename=VQ6 front=1 z=$S gradient=-10.1008
```

```
# Foil image
param S=10189

# Tunnel WEST ...

param S=11869
place Q14s8 rename=Q1 front=1 z=$S gradient=-2.68657

param S=12705
place Q14s8 rename=Q2 front=1 z=$S gradient=5.38283

param S=15081
place Q14s8 rename=Q3 front=1 z=$S gradient=2.39969

param S=15898
place Q14s8 rename=Q4 front=1 z=$S gradient=-4.56096

# COLLIMATOR

param S=$SCOLFRONT

zntuple file=PRECOL.txt format=ascii z=$S referenceParticle=1
place COL rename=COLLIM front=1 z=$S
param S=$S+$LCOL
zntuple file=POSTCOL.txt format=ascii z=$S+1 referenceParticle=1

place pipe-COLL-B6 front=1 z=$S

param S=21357
place FQ10s3p6 rename=Q5 front=1 z=$S gradient=-0.174155

param S=22007
place FQ10s3p6 rename=Q6 front=1 z=$S gradient=2.00834

param S=22907
corner B6c1 z=$S rotation=Y-22.5
place B610 rename=B6 z=$S+0.5*$LB610 By=B6By
param S=$S+$LB610
corner B6c2 z=$S rotation=Y-22.5

place pipe-B6-B10 front=1 z=$S

param S=25528
place Q14s8 rename=Q7 front=1 z=$S gradient=-2.67106

param S=26178
place Q14s8 rename=Q8 front=1 z=$S gradient=5.05137
```

```
param S=30578
place Q14s8 rename=Q9 front=1 z=$S gradient=5.05137

param S=31228
place Q14s8 rename=Q10 front=1 z=$S gradient=-2.67106

param S=32351
corner B10c1 z=$S rotation=Y-22.5
place B610 rename=B10 z=$S+0.5*$LB610 By=B10By
param S=$S+$LB610
corner B10c2 z=$S rotation=Y-22.5

place pipe-B10-BPM14 front=1 z=$S

param S=34929
place FQ8p5s8p5 rename=Q11 front=1 z=$S gradient=7.00911

param S=35579
place FQ8p5s8p5 rename=Q12 front=1 z=$S gradient=-5.22194

param S=38967
place FQ8p5s8p5 rename=Q13 front=1 z=$S gradient=4.70440

param S=39567
place FQ8p5s8p5 rename=Q14 front=1 z=$S gradient=-4.81876

# BPM14 TRANSITION TO KEK quad 100 mm APERTURE
param S=42145
place pipe-BPM14-Q17 front=1 z=$S

param S=44959
place KEK rename=Q15 front=1 z=$S gradient=6.95273

param S=45559
place KEK rename=Q16 front=1 z=$S gradient=-6.33455

param S=51211

place pipe-Q17-Q20 front=1 z=$S

place DanFysikaL5 rename=Q17 front=1 z=$S gradient=14.3403

param S=51811
place DanFysikaL5 rename=Q18 front=1 z=$S gradient=-14.3403

param S=57336
place DanFysikaL5 rename=Q19 front=1 z=$S gradient=14.3403

param S=57936
```

```
place DanFysikaL5 rename=Q20 front=1 z=$S gradient=-14.3403

place pipe-Q20-B22 front=1 z=$S+$LDanFysikaL5

param S=61752
place TUDAS rename=Q21 front=1 z=$S gradient=-4.59592

param S=62352
place TUDAS rename=Q22 front=1 z=$S gradient=13.3595

param S=63441
corner B22c1 z=$S rotation=Y-17
place B2226 rename=B22 z=$S+0.5*$LB2226 By=B22By
param S=$S+$LB2226
corner B22c2 z=$S rotation=Y-17

place pipe-B22-B26 front=1 z=$S

param S=65544
place TUDAS rename=Q23 front=1 z=$S gradient=-9.70485

param S=66044
place TUDAS rename=Q24 front=1 z=$S gradient=10.7803

param S=67544
place TUDAS rename=Q25 front=1 z=$S gradient=10.7803

param S=68044
place TUDAS rename=Q26 front=1 z=$S gradient=-9.70485

param S=69006
corner B26c1 z=$S rotation=Y-17
place B2226 rename=B26 z=$S+0.5*$LB2226 By=B26By
param S=$S+$LB2226
corner B26c2 z=$S rotation=Y-17

place pipe-B26-ATW front=1 z=$S

param S=71386
place FQ8p5s8p5 rename=Q27 front=1 z=$S gradient=11.1998

param S=72145
place FQ12s6 rename=Q28 front=1 z=$S gradient=-9.90428

param S=74881
place FQ12s6 rename=Q29 front=1 z=$S gradient=8.41439

param S=75688
place FQ12s6 rename=Q30 front=1 z=$S gradient=-8.31017
```

```
# RASTER MAGNET
param S=76803

# ARIEL TARGET WEST

param S=82083
place TARGET front=1 z=$S

# END OF BEAM LINE ELEMENTS

# Loss detectors

beamlossntuple BLNT filename=LostParticles.txt format=ascii \
               require=PDGid==2212&&ParentID==0

trace nTrace=1 format=ascii coordinates=Centerline primaryOnly=1

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

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