

# **g4beamline** and E05-115

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## Abstract

The **g4beamline** program was used to determine whether fringe fields could cause problems in Jlab's hall C experiment E05-115; it provides an easy method of applying the power of Geant4 to accelerator physics applications.

## Introduction

Large high energy and nuclear experiments typically use the Geant4<sup>1</sup> toolkit to model their detectors; it models most of the processes by which particles and photons interact with matter and contains detailed models of particle production through nuclear and electromagnetic interactions. Most large experiments invest man-years of effort constructing simulations based on the toolkit.

Many particle accelerators tend to be rather long skinny devices that can be represented by fairly simple geometric shapes. For these accelerator applications it is very convenient to have an interface which requires no C++ programming and only needs a simple single text input file to describe the system. The **g4beamline** program was written by T.Roberts of Muons, Inc. specifically for this purpose.<sup>2</sup>

A.Bogacz suggested that **g4beamline** would be useful to estimate the deflection of the electron beam due to stray fields in the upcoming hall C experiment E05-115.<sup>3</sup>

## Geometry and Fields

The drawing of the experiment in Figure 1 shows the locations of the major components in the hall. In this drawing, Z is to the right, and X toward the top of the page. Y is  $Z \times X$ . The upper spectrometer is the HES (electron) spectrometer and is tilted out of the horizontal plane, the lower is the HKS (kaon) spectrometer. The target is at the entrance of the splitter magnet and the beam enters at an angle from the left. The primary electron beam is deflected by the splitter magnet into the Z direction and to the electron dump. The small beam line at  $14.7171^\circ$  with respect to the electron dump line is the photon beam line.

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1 <http://www.geant.org>

2 <http://g4beamline.muonsinc.com>

3 A.Bogacz, *private communication*

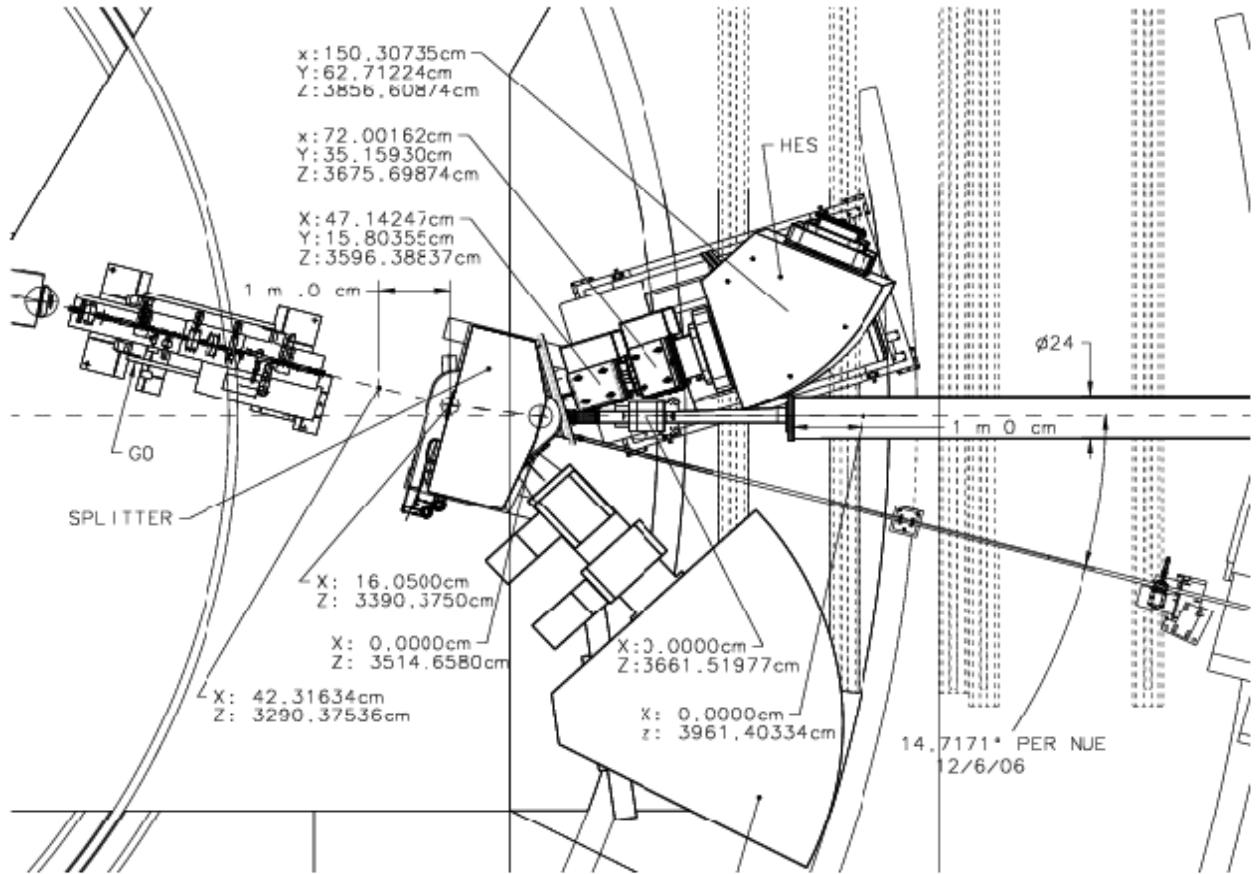


Figure 1. Layout of the E05-115 experiment.

The two quadrupoles of the HES are close to the electron beam line, and so their stray magnetic fields could deflect the electron beam. To determine if that is the case, one can use `g4beamline` to simply track the electrons through the magnetic fields.

To help verify the position of the fields, it is convenient to place some objects in the model; the splitter magnet, the two quadrupoles, the electron and photon dumps. The approximate dimensions of the magnets were just measured off the drawings.

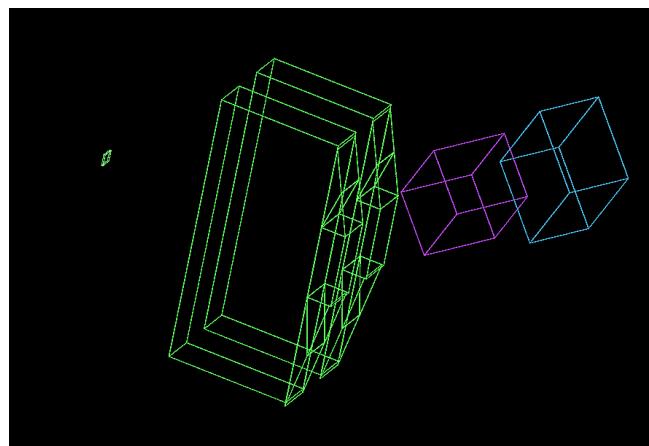


Figure 2. Wireframe display of the splitter magnet and quadrupoles.

This version of `g4beamline`, 1.12, can create rectangular (“box”), cylindrically symmetric (“tub”), and isosceles triangular right prism (“trap”) solids; latter versions will incorporate considerably more flexibility.<sup>4</sup><sup>5</sup> Various solids can be put together to form a group, and groups can be grouped together. The group can then be placed anywhere in the model in any orientation any number of times.

The splitter is modeled as two identical iron poles; the return yokes are not present in this model, but could easily be added. The quadrupoles are just blocks of iron. Figure 2 shows the model of the splitter and quadrupoles in position. Each dump is just a virtualdetector; an empty volume of space used for tracking. In addition, another thin virtual detector representing a beam position monitor (BPM) was placed in the electron beam line to help determine the angle of the downstream electron beam. The input file `hks14b.in` appears in the Appendix I.

The magnetic fields were generated using TOSCA<sup>6</sup> only in the nominal plane of the beam ( $Y=0$ ).<sup>7</sup> The files were converted into a format suitable for `g4beamline` as described Appendix II.

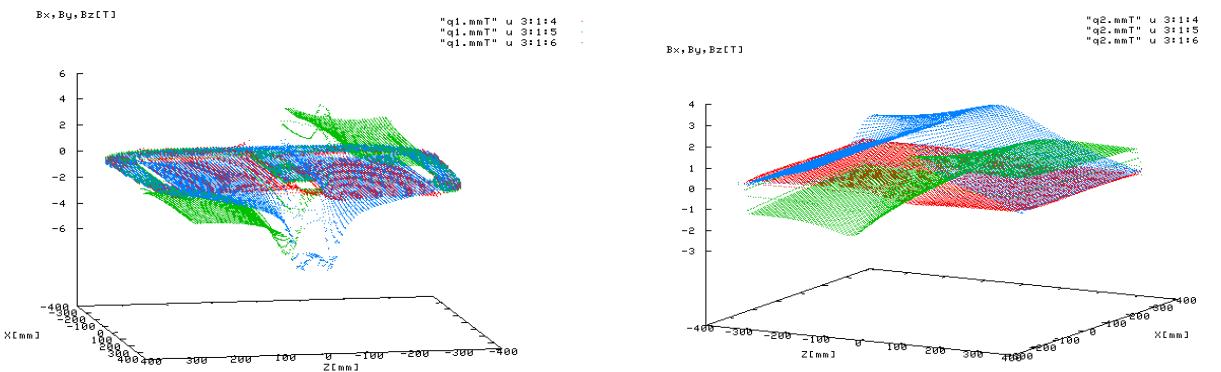


Figure 3a. Plots of the hes-q1 and hes-q2 field maps.

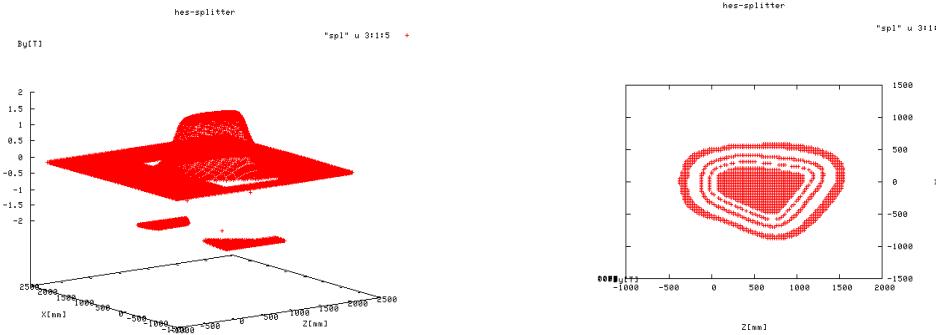


Figure 3b. Plots of the splitter field map.

4 G4beamline User's Guide 1.09, Tom Roberts, Muons, Inc. <http://g4beamline.muoninc.com>

5 T.Roberts, *private communication*

6 <http://www.vectorfields.com/>

7 S.Lassiter, *private communication*

Note that while the splitter map has approximately the same orientation as the splitter in the hall with its entrance face along the Y axis , the quadrupole maps have their major axis along X, so an extra 90° rotation is added to align the quadrupoles in the input file.

At this point, the model is ready to go. A target was also described in the model, but was commented out of the file for simplicity.

## Tuning and Testing

This input file expects several external variables be set on the command line; they are EXTbm\_X, the offset from the nominal beam starting X, EXTbm\_dXdZ, the offset from the nominal beam angle (expressed as a tangent), EXTj\_spl, the splitter current relative to nominal, EXTj\_q1, the 1<sup>st</sup> quadrupole current relative to nominal, and EXTj\_q2, the 2<sup>nd</sup> quadrupole current relative to nominal.

To begin, the quads are turned off and the splitter run at the nominal current with a 2500 MeV/c electron beam:

```
$> g4bl hks14.in EXTbm_X=0 EXTbm_dXdZ=0 EXTj_spl=1.0 \
    EXTj_q1=0 EXTj_q2=0 viewer=best
...
cmd: /run/beamOn 10
```

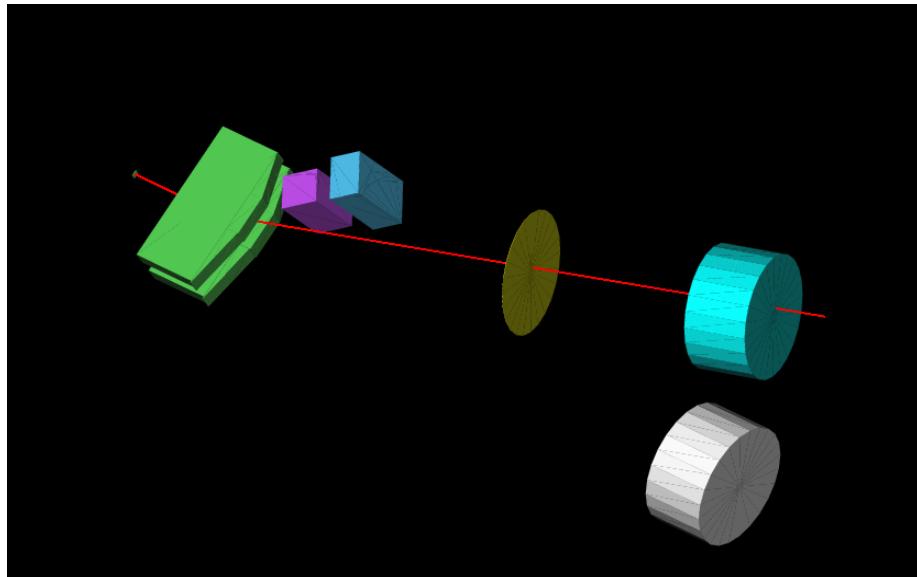


Figure 5. Nominal settings; electrons shown in red.

In Figure 5, the nominal fields and path cause the electron beam to strike the electron dump off center. An simple general purpose optimization tool, kmimf,<sup>8</sup> was used to adjust the entrance angle and fields to best align the beam at the dump. The files are in Appendix III. The best result was EXTbm\_dXdZ=-0.0000203125 and EXTj\_spl=0.9360195844; so the splitter current was scaled

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<sup>8</sup> kmimf 0 . 1, Kevin's minimization in FORTRAN, K.B.Beard, JLAB-TN-07-049

down by that factor for the subsequent work.

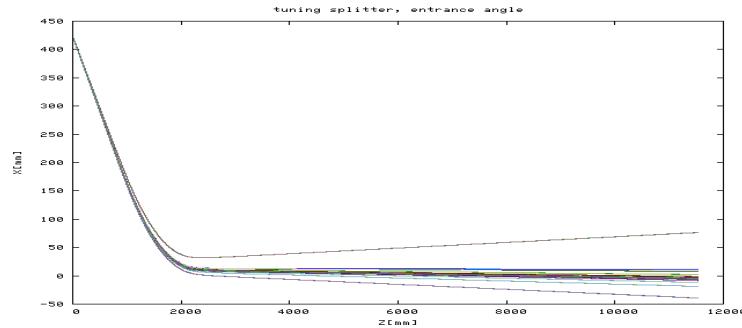


Figure 6. Tuning g4beamline using kmimf.

Using the new value for EXTj\_spl, runs were done with 0x, 1x, and 10x the nominal currents in both quadrupoles. The g4beamline output file AllTrace.txt file contains a detailed history of the particles, so plotting those for each case:

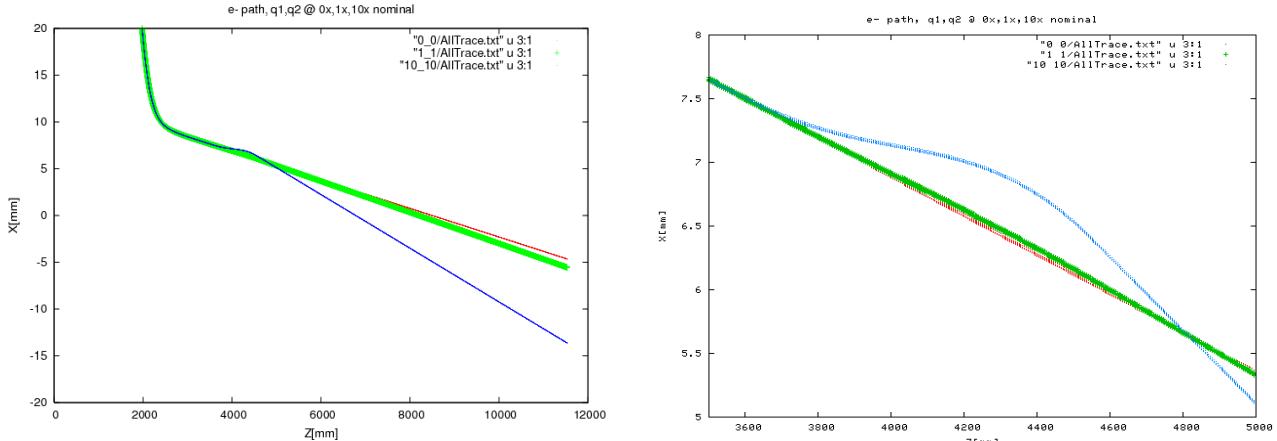


Figure 7a. Electrons' path in the XZ plane with quadrupoles set at 0x, 1x, and 10x their nominal current.

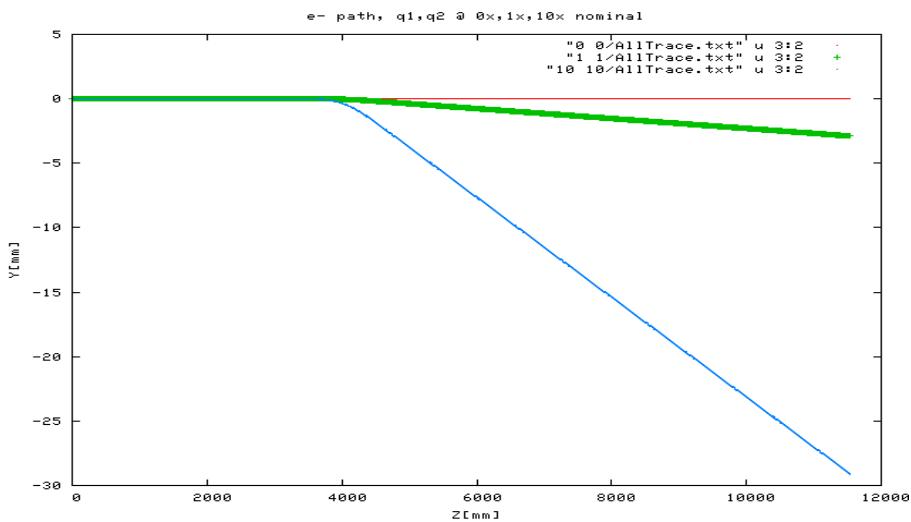


Figure 7b. Electrons' path in the YZ plane with quadrupoles set at 0x, 1x, and 10x their nominal current.

In Figure 7, one can see that the deflection due to the quadrupoles' fringe fields is small (~mm) at the electron dump, but a corrector will be needed.

## Conclusion

This simple model has shown how `g4beamline` may be used to simulate a beam's interactions with various magnetic fields, and that the HES quadrupole fringe fields are a minor perturbation. This simulation is capable of much more.

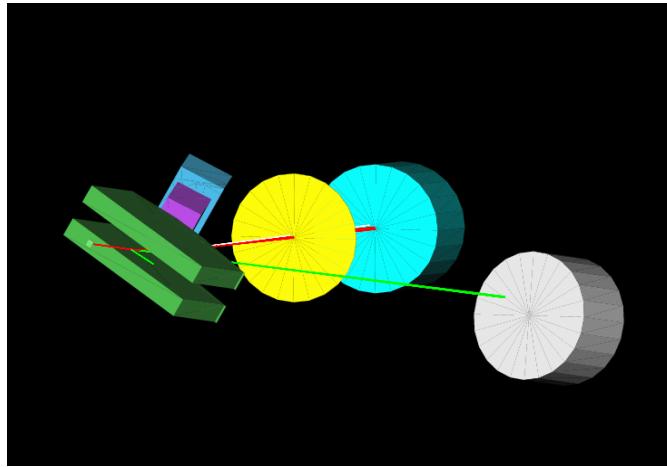


Figure 8. 10 2.5 GeV/c  $e^-$  sent through a  $1\text{ g/cm}^2 {}^{51}\text{V}$  target;  $e^-$  in red,  $y$  in green

For example, a  $1\text{ g/cm}^2 {}^{51}\text{V}$  target placed at the nominal target position produces photons as well as scattered electrons. Many more details could easily be added to the model to calculate the effect of multiple scattering, rates of secondary particles, radiation loads, etc.

Also, `g4beamline` is undergoing constant improvement and acquiring more functionality. For example, newer versions of `g4beamline` have more shapes available, allowing one to greatly simplify the description of the splitter magnet from six shapes (1 box + 5 trap) to a single one (1 extrusion).

## Appendix I. g4beamline input file

The g4beamline input file `hks14b.in` contains numerous comments and various mathematical variables and expressions are used to ensure consistency. In version 1.12 of `g4beamline`, comments must begin in the 1<sup>st</sup> column and empty lines should not contain extraneous whitespace.

It is important to note that objects and groups should never overlap other groups or objects. If they do, objects may appear to display correctly, but the algorithm stepping the particle through space may not find them. It is easy to overlook warnings printed by `g4beamline`, and the result is that particles can pass right through apparently solid objects without seeing them. To avoid this, the target was placed inside the `splitter` group rather than being specified separately.

The `EXT*` variables are not defined within the file, and must be set on the command line.

```
*  
* this is for the HES/HKS experiment in CEBAF hallC  
* for use with g4beamline 1.13  
* KBB, 12sep07, 22oct07  
*  
# required command line parameters  
# EXTbm_X: offset from nominal beam start X  
# EXTbm_dXdZ: offset from nominal beam start dXdZ  
# EXTj_spl: splitter current multiplier  
# EXTj_q1: quad1 current multiplier  
# EXTj_q2: quad2 current multiplier  
*  
*  
# use TJR recommended physics routines  
physics QGSP doStochastics=1  
  
param maxStep=.5  
  
param steppingVerbose=0  
param steppingFormat=TAG,N,GLOBAL,STEP,VOL,B,ID,PROCESS  
  
param deg_per_radian=57.29577951  
  
##### target materials #####  
# natural Li density 5.34g/cc  
# (est. for Li6)  
material Li6 z=3 a=6 density=0.458  
material Li7 z=3 a=7 density=0.534  
#  
# natural B density 2.46g/cc [19.78% boron-10 and 80.22% boron-11]  
# (est for B10, B11)  
material B10 z=5 a=10 density=2.28  
material B11 z=5 a=11 density=2.50  
#  
# natural V density 6.11 vanadium-50 (0.24%) and vanadium-51 (99.76%)  
material V51 z=23 a=50.9414 density=6.11  
#  
material Y89 z=39 a=88.9059 density=4.472  
#  
##### target #####  
#  
# for E05-115, ~100mg/cm2  
#
```

```

param target_thickness_gcm2=1.0
param target_dia=25.4
#
# 100mg/cm2 51V for now
param target_density=6.11
param target_thickness_cm=$target_thickness_gcm2/$target_density
param target_thickness_mm=10.*$target_thickness_cm
#
tubs target material=V51 \
    length=$target_thickness_mm \
    innerRadius=0 outerRadius=$target_dia/2 \
    maxStep=0.01 \
    color=1,1,1

#####
#hallC offsets
#angle between gamma and electron exit beams in degrees
param defl_deg=14.7171
param defl_rad=$defl_deg/$deg_per_radian

param Ox=0 Oy=0 Oz=32903.7536

param E0x=423.1634 E0y=0 E0z=32903.7536
param E1x=160.500 E1y=0 E1z=33903.750
param E2x=0.000 E2y=0 E2z=33146.580

param H1x=471.4247 H1y=158.0355 H1z=35963.8837
param H2x=720.0162 H2y=351.5930 H2z=36756.9874
param H3x=1503.0735 H3y=627.1224 H3z=38566.0874
#
# rotation angle about global Y axis [deg]
param HESw_xz=atan2($H2x-$H1x,$H2z-$H1z)*$deg_per_radian
#
# rotation angle about global X axis [deg]
param HESw_yz=-atan2($H2y-$H1y,$H2z-$H1z)*$deg_per_radian

##### beam position monitor #####
param bpmXmm=0 bpmYmm=0 bpmZmm=39624.0334

#####
#electron dump #####
#distance from point#2 (entrance to splitter) to electron dump
param eDumpDist=10000.
param eDumpXmm=($E2x-$Ox) eDumpYmm=($E2y-$Oy) eDumpZmm=($E2z-$Oz)+$eDumpDist
#####

##### gamma photon dump #####
param gBeamDeg=$defl_deg
param gBeamDist=10802.21
param gBeamRad=$gBeamDeg/$deg_per_radian

param gDumpXmm=($E2x-$Ox)-sin($gBeamRad)*$gBeamDist
param gDumpYmm=$E2y-$Oy
param gDumpZmm=($E2z-$Oz)+cos($gBeamRad)*$gBeamDist
#####

##### splitter magnet #####
#
# approximate measurements of 5 corners of splitter
# measured off of drawing...
#
#outline of splitter magnet going CW; beam enters at 0,0,0
param spl_0z=0     spl_0x=0
param spl_1z=0     spl_1x=1180
param spl_2z=1040  spl_2x=1180

```

```

param spl_3z=1251 spl_3x=442
param spl_4z=1251 spl_4x=-218
param spl_5z=1056 spl_5x=-1250
param spl_6z=0     spl_6x=-1250
param spl_thick=300. spl_gap=150.

#main box of splitter pole in perpendicular to beam
param spl_main_height=$spl_2z-$spl_1z
param spl_main_width=$spl_1x-$spl_6x
param spl_main_cctx=($spl_1x+$spl_6x)/2
box spl_main \
    length=$spl_thick \
    width=$spl_1x-$spl_6x \
    height=$spl_main_height \
    color=0.3,0.8,0.3 \
    material=Fe \
    kill=1

#tail box
param spl_tail_height=$spl_3z-$spl_2z
param spl_tail_width=$spl_3x-$spl_4x
box spl_tail \
    length=$spl_thick \
    width=$spl_tail_width \
    height=$spl_tail_height \
    color=0.3,0.8,0.3 \
    material=Fe \
    kill=1

#
#
#
#           |
#           |B
#
#           |
# ----- can be made from isolese triangles via trap A,B
#   A          w2=A          w3=B
#           h2=B/2          h3=A/2
#           c2=(A/2,B/4)    c3=(A/4,B/2)
#           r2=0            r3=Y90 (CCW)
#
#upper triangles #2 rot 0, #3 rot Y-90
param spl_tri2w=$spl_2x-$spl_3x
param spl_tri3w=$spl_3z-$spl_2z
param spl_tri2h=$spl_tri3w/2
param spl_tri3h=$spl_tri2w/2

trap spl_tri2 \
    length=$spl_thick \
    lowerWidth=$spl_tri2w \
    height=$spl_tri2h \
    upperWidth=.01 \
    color=0.3,0.8,0.3 \
    material=Fe \
    kill=1

trap spl_tri3 \
    length=$spl_thick \
    lowerWidth=$spl_tri3w \
    height=$spl_tri3h \
    upperWidth=.01 \
    color=0.3,0.8,0.3 \
    material=Fe \
    kill=1

#
#

```

```

# |
# B|
# |
# ----- can be made from isolese triangles via trap A,B
#     A           w5=A          w4=B
#                 h5=B/2        h4=A/2
#                 c5=(A/2,-B/4)   c4=(A/4,-B/2)
#                 r5=0          r4=Y-90 (CW)
#
#lower triangles #4 rot Y90, #6 rot 0
param spl_tri4w=$spl_4z-$spl_5z
param spl_tr5w=$spl_4x-$spl_5x
param spl_tri4h=$spl_tr5w/2
param spl_tri5h=$spl_tri4w/2

trap spl_tri4 \
    length=$spl_thick \
    lowerWidth=$spl_tri4w \
    height=$spl_tri4h \
    upperWidth=1 \
    color=0.3,0.8,0.3 \
    material=Fe \
    kill=1

trap spl_tr5 \
    length=$spl_thick \
    lowerWidth=$spl_tr5w \
    height=$spl_tr5h \
    upperWidth=1 \
    color=0.3,0.8,0.3 \
    material=Fe \
    kill=1

# x diff between beam entrance from geometric center
param spl_offx=$spl_0x-$spl_main_cnx

param spl_grp_L=1+2*($spl_main_height+$spl_tail_height)+1
param spl_tail_midx=($spl_3x+$spl_4x)/2
group splitter_pole length=$spl_grp_L

place spl_main \
    x=-$spl_offx \
    y=0 \
    z=$spl_main_height/2 \
    rotation=X90

place spl_tail \
    x=-$spl_offx+$spl_tail_midx \
    y=0 \
    z=$spl_main_height+$spl_tail_height/2 \
    rotation=X90

place spl_tri2 \
    x=-$spl_offx+$spl_tail_midx+$spl_tail_width/2+$spl_tri2w/2 \
    y=0 \
    z=$spl_main_height+$spl_tri2h/2 \
    rotation=X90

place spl_tri3 \
    x=-$spl_offx+$spl_tail_midx+$spl_tail_width/2+$spl_tri3h/2 \
    y=0 \
    z=$spl_main_height+$spl_tri3w/2 \
    rotation=X90,Y90

place spl_tri4 rotation=X90,Y90 \
    x=-$spl_offx+$spl_tail_midx-$spl_tail_width/2-$spl_tri4h/2 \

```

```

y=0 \
z=$spl_main_height+$spl_tri4w/2 \
rotation=X90,Y-90

place spl_tri5 \
x=-$spl_offx+$spl_tail_midx-$spl_tail_width/2-$spl_tri5w/2 \
y=0 \
z=$spl_main_height+$spl_tri5h/2 \
rotation=X90
endgroup

group splitter length=$spl_grp_L

place splitter_pole \
x=0 z=0 y=$spl_gap+$spl_thick/2

#
# approximate dimensions of HES Q1
# measured off of drawing...
#
place splitter_pole \
x=0 z=0 y=-$spl_gap-$spl_thick/2

#nominal target
## place target x=0 y=0 z=$target_thickness_mm/2

endgroup
#####
##### HES-Q1 #####
#
# approximate dimensions of HES Q1
# measured off of drawing in E-5-115 proposal -
# simplified to 2 rectangular blocks
#
param hesQ1_overall_length=600
param hesQ1_overall_width=560
param hesQ1_overall_height=1030
param hesQ1_approximate_gap=50

box hesq1_overall \
length=$hesQ1_overall_length \
width=$hesQ1_overall_width \
height=$hesQ1_overall_height \
material=Fe kill=1 color=.8,.3,.1

box hesq1_pole \
length=$hesQ1_overall_length \
width=$hesQ1_overall_width \
height=$hesQ1_overall_height/2-$hesQ1_approximate_gap/2 \
material=Fe \
kill=1 \
color=.3,.5,.1

group hesQ1 length=1+$hesQ1_overall_length+1

place hesq1_pole \
x=0 \
y=$hesQ1_overall_height/4+$hesQ1_approximate_gap/2 \
z=0

place hesq1_pole \
x=0 \
y=-$hesQ1_overall_height/4-$hesQ1_approximate_gap/2 \
z=0

endgroup

```

```

#####
##### HES-Q2 #####
#
# approximate dimensions of HES Q2
# measured off of drawing in E-5-115 proposal -
# simplified to 2 rectangular blocks
#
param hesQ2_overall_length=500
param hesQ2_overall_width=720
param hesQ2_overall_height=1250
param hesQ2_approximate_gap=56

box hesq2_overall \
    length=$hesQ2_overall_length \
    width=$hesQ2_overall_width \
    height=$hesQ2_overall_height \
    material=Fe kill=1 color=.3,.8,1

box hesq2_pole \
    length=$hesQ2_overall_length \
    width=$hesQ2_overall_width \
    height=$hesQ2_overall_height/2-$hesQ2_approximate_gap/2 \
    material=Fe \
    kill=1 \
    color=0,1,.8

group hesQ2 length=1+$hesQ2_overall_length+1

    place hesq2_pole \
        x=0 \
        y=$hesQ2_overall_height/4+$hesQ2_approximate_gap/2 \
        z=0

    place hesq2_pole \
        x=0 \
        y=-$hesQ2_overall_height/4-$hesQ2_approximate_gap/2 \
        z=0

endgroup
#####

##### e- beam #####
#
# beam starts at (423.1634,0,32903.7536)mm in
# in the (0.254047,0,0.967192) direction
# documentation *says* meanXp [radians], but is wrong;
# it is the tangent of angle

#####set.on.command.line##### param beam_xprime_adj=0.0

param global_dXdZ=-tan($defl_rad)
param global_dYdZ=0

param beam_X=$E0x-$Ox+($EXTbm_X)
param beam_Y=$E0y-$Oy
param beam_Z=$E0z-$Oz
param beam_dXdZ=$global_dXdZ+($EXTbm_dXdZ)
param beam_dYdZ=$global_dYdZ

beam gaussian particle=e- nEvents=10 \
    beamX=$beam_X beamY=$beam_Y beamZ=$beam_Z \
    meanXp=$beam_dXdZ meanYp=$beam_dYdZ \
    meanMomentum=2500.0 \
    sigmaP=0. meanT=0. sigmaT=0 sigmaX=.01 sigmaY=.01 sigmaXp=0 sigmaYp=0

particlecolor reference=1,1,1

```

```

reference particle=e-
beamX=$beam_X beamY=$beam_Y beamZ=$beam_Z \
meanXp=$beam_dXdZ meanYp=$beam_dYdZ \
meanMomentum=2500.0

param maxStep=5

##### B-field maps #####
#KBB dimensions of mm & T

#from TOSCA 2D midplane Y=beam of splitter, oriented same as global
fieldmap B_spl file=spl.mmT.go current=$EXTj_spl

#from TOSCA 2D Y=beam cut through tilted Q1, oriented 90deg to global
fieldmap B_q1 file=q1.mmT.go current=$EXTj_q1

#from TOSCA 2D Y=beam cut through tilted Q2, oriented 90deg to global
fieldmap B_q2 file=q2.mmT.go current=$EXTj_q2

#rotation about Y of quad#1 table so axis ~ || z
param Bq1_table_xz=90

#rotation about Y of quad#2 table so axis ~ || z
param Bq2_table_xz=90

param q1Bw_xz=($Bq1_table_xz)+($HESw_xz)

param q2Bw_xz=($Bq2_table_xz)+($HESw_xz)

##### misc #####
# just shows where the beam comes from
box Start width=100.0 height=100.0 length=10 material=Vacuum color=.5,.1,.5

# e beam dump
virtualdetector eDump format=ascii file=edump.txt \
    radius=1000 length=1000 color=0,1,1

#gamma beam dump
virtualdetector gDump format=ascii file=gdump.txt \
    radius=1000 length=1000 color=1,1,1

#beam position monitor
virtualdetector bpm format=ascii file=bpm.txt \
    radius=1000 length=1 color=1,1,0

#####
####verbose##
trace nTrace=10 format=ascii oneNTuple=1 \
    coordinates=global filename=AllTrace.txt

#####
# show nominal beam start
place Start x=$E0x-$Ox y=$E0y-$Oy z=$E0z-$Oz rotation=Y-$defl_deg \
    coordinates=global

#splitter magnet iron
place splitter x=$E1x-$Ox y=$E1y-$Oy z=$E1z-$Oz rotation=Y-$defl_deg \
    coordinates=global

#splitter magnet field
place B_spl x=$E1x-$Ox y=$E1y-$Oy z=$E1z-$Oz \
    rotation=Y-$defl_deg coordinates=global current=$EXTj_spl

```

```

#bpm
place bpm x=$bpmXmm-$Ox y=$bpmYmm-$Oy z=$bpmZmm-$Oz coordinates=global

#electron beam dump
place eDump x=$eDumpXmm y=$eDumpYmm z=$eDumpZmm coordinates=global

#gamma photon beam dump
place gDump x=$gDumpXmm y=$gDumpYmm z=$gDumpZmm \
      rotation=Y-$gBeamDeg coordinates=global

#HES-Q1
place hesq1_overall \
      rotation=X$HESw_yz,Y$HESw_xz x=$H1x-$Ox y=$H1y-$Oy z=$H1z-$Oz

## TOSCA 2D field map at Y=beam, sliced horizontally=XZ through tilted Q1
place B_q1 rotation=X0,Y$q1Bw_xz x=$H1x-$Ox y=$H1y-$Oy z=$H1z-$Oz

#HES-Q2
place hesq2_overall \
      rotation=X$HESw_yz,Y$HESw_xz x=$H2x-$Ox y=$H2y-$Oy z=$H2z-$Oz

## TOSCA 2D field map at Y=beam, sliced horizontally=XZ through tilted Q2
place B_q2 rotation=X0,Y$q2Bw_xz x=$H2x-$Ox y=$H2y-$Oy z=$H2z-$Oz

```

## Appendix II. Magnetic field maps

The original 2D field maps from TOSCA, `hes-q1.table`, `hes-q2.table`, `hges-dip.table`, and `Splitter-map.table` were of the form:

*a few comments*

`x_cm y_cm z_cm Bx_T By_T Bz_T Bmod_T`

...

or

*a few comments*

`x_cm y_cm z_cm Bx_T By_T Bz_T`

for example, `hes-q1.table`:

```
1 X [cm]
2 Y [cm]
3 Z [cm]
4 BX [T]
5 BY [T]
6 BZ [T]
7 BMOD [T]
0
-67.0000000000 -23.3295900000 -50.0000000000 -0.281709426728E-02 0.106713049372E-01 0.360821293047E-03
0.110427786892E-01
...
70.0000000000 -23.3295900000 41.0000000000 -0.100440790505E-02 -0.821854399354E-03 0.257351651624E-02
0.288223301501E-02
70.0000000000 -23.3295900000 42.0000000000 -0.117328631944E-02 -0.976278241823E-03 0.242694451728E-02
0.286701581489E-02
70.0000000000 -23.3295900000 43.0000000000 -0.134216473384E-02 -0.113070208429E-02 0.228037251833E-02
0.287749755839E-02
70.0000000000 -23.3295900000 44.0000000000 -0.151104314823E-02 -0.128512592676E-02 0.213380051937E-02
0.29134088212E-02
70.0000000000 -23.3295900000 45.0000000000 -0.167992156263E-02 -0.143954976923E-02 0.198722852041E-02
0.297380516965E-02
70.0000000000 -23.3295900000 46.0000000000 -0.186440334083E-02 -0.161143563140E-02 0.187750106333E-02
0.309802111908E-02
70.0000000000 -23.3295900000 47.0000000000 -0.200439793735E-02 -0.178251347612E-02 0.176480336455E-02
0.321084043504E-02
70.0000000000 -23.3295900000 48.0000000000 -0.193636121229E-02 -0.194599236316E-02 0.163025371350E-02
0.319282135303E-02
70.0000000000 -23.3295900000 49.0000000000 -0.186832448724E-02 -0.210947125020E-02 0.149570406246E-02
0.319024074131E-02
70.0000000000 -23.3295900000 50.0000000000 -0.180028776218E-02 -0.227295013724E-02 0.136115441142E-02
0.320313591419E-02
```

The format required by `g4beamline` is similar, but requires a few header statements. Note that `g4beamline` 1.12 does not support continuations in this format.

A small C program, `summaps`<sup>9</sup>, can manipulate the maps in a number of ways, including weights, sums, reflections, displacements, rotations, and changing the sampling. In this example, however, the fields were considered constant on the Y axis, the sampling made uniform, and the units changed from cm to mm, to produce the fieldmap files `sp1.mmT.go`, `q1.mmT.go`, and `q2.mmT.go`. For example:

<sup>9</sup> <http://www.jlab.org/~beard/UTILITIES/summaps/>

```
$> summmaps -i hes-q1.table -u 10.0 -2D -Y -50:0:2 \
-o q1.mmt -g q1.mmt.go +v
```

```
* summmaps -i hes-q1.table -u 10.0 -2D -Y -50:0:2 -o q1.mmt -g q1.mmt.go +v +v
#
# summmaps v0.2c3 10/18/2007 K.B.Beard, Muons, Inc.
#
# -----input-----
# weight move1st euler move2nd file Xrange Yrange Zrange
# 1.00 0.0:0.0:0.0 0.0:0.0:0.0 0.0:0.0:0.0 "hes-q1.table" X[-67.00:70.00:138] Y[-23.33:-23.33:1] Z[-50.00:50.00:101]
#
#
# -----output-----
# "q1.mmt" X[-670.000:706.587:208] Y[-500.000:0.000:2] Z[-500.000:506.579:152]
#
#
##### misc. notes: #####
##### - inline comments & continuations are not supported #####
##### - in BLFieldMap format... #####
#####
##### maxline=1023 # maximum length of a data line #####
##### g4beamline parameters #####
##### normB=1.0 # B field normalization #####
##### current=1.0 # nominal current - override for scaling #####
param normB=1.0 current=1.0
grid X0=-670.00000 Y0=-500.00000 Z0=-500.00000 nX=208 nY=2 nZ=152 dX=6.618205 dY=250.000000 dZ=6.622230
#
# x[mm] y[mm] z[mm] Bx[T] By[T] Bz[T]
data
-670.00000 -500.00000 -500.00000 -0.002817 0.010671 0.000361
-663.381795 -500.00000 -500.00000 -0.003136 0.010779 0.000363
-656.763591 -500.00000 -500.00000 -0.003456 0.010886 0.000365
...
693.350129 -250.00000 499.956717 -0.001968 -0.002187 0.001321
699.968334 -250.00000 499.956717 -0.001801 -0.002272 0.001362
#####
##### End-of-Data #####
#####
```

In this case, the orientation of the maps was not changed by **summmaps**, and all the rotations were handled in the **g4beamline** input file.

### Appendix III. Tuning with kmimf

The kmimf program runs a script while adjusting parameters; it adjusts those parameters based on the number returned by the script. Generally it is used with two setup files; one specifies the parameters of interest, the other tells the system how to calculate a number.

To adjust the splitter current to put the beam into the center of the electron beam dump, the parameters were specified in adj1.pf:

```
# this file sets up the parameters for a kmimf search
# name          start  step {low-limit high-limit}
#
EXTbm_dXdZ 0      0.01    #tangent of entrance angle
EXTj_spl 0.9360156 0.001  #splitter current
EXTbm_X 0           #beam starting position
EXTj_q1 0.0         #quad1 field
EXTj_q2 0.0         #quad2 field
#
```

and the command script in adj1.if. The latter runs g4beamline, with the current parameters, finds the sums of the squares of the X positions at the bpm and e-beam dumps, and returns that value:

```
# kmimf script - run each cycle
# [each command should end with a ";" - returns ignored]

export TWRK=`autoname -b 1 -f log%04d`; # next dir. of the form wnnnn
                                              # starting w/ "log0001"
                                              # & assign it to shell variable TWRK

mkdir $TWRK;                                # work in that subdirectory

# run case with passed parameters
touch cmd.log;
echo "g4bl hks13.in EXTbm_dXdZ={EXTbm_dXdZ} EXTbm_X={EXTbm_X} EXTj_spl={EXTj_spl}
EXTj_q1={EXTj_q1} EXTj_q2={EXTj_q2}" >> cmd.log;

g4bl hks13.in EXTbm_dXdZ={EXTbm_dXdZ} EXTbm_X={EXTbm_X} EXTj_spl={EXTj_spl}
EXTj_q1={EXTj_q1} EXTj_q2={EXTj_q2} >& $TWRK.log;

# find sum of square of X errors
echo "`txt2rms -NS -i bpm.txt|grep "x "|beshuffled -I 4^2 + \
      `txt2rms -NS -i edump.txt|grep "x "|beshuffled -I 4^2" | bc \
sdup +o err.log;

mv $TWRK.log *.txt $TWRK;
```

The *{variable}*'s within the command script are replaced by their values, all line feeds and \ removed, and the whole string sent at once to the shell. The autoname, beshuffled, sdup, and txt2rms

utilities are used by the script, but many others would serve just as well.<sup>10</sup> The point of the script is return a single number to kmimf. The search was begun with the command:

```
$> kmimf -if adj1.if -pf adj1.pf -m -a 100 -o adj_1.log \
+re adj_1.hnt -F adj_1.fin -v
```

The history was written to adj\_1.log:

```
# kmimf -if adj1.if -pf adj1.pf -m -a 100 -o adj_1.log +re adj_1.hnt -F adj_1.fin -v
# kmimf 0.1f7, 22mar2006
# 10:08:57 Oct 23, 2007
#MINUIT: set warnings|show fcnvvalue|simplex
#SCRIPT-template: export TWRK=`autoname -b 1 -f log%04d`; mkdir $TWRK; touch cmd.log; echo "g4bl hks13.in
EXTbm_dXdZ={EXTbm_dXdZ} EXTbm_X={EXTbm_X} EXTj_spl={EXTj_spl} EXTj_q1={EXTj_q1} EXTj_q2={EXTj_q2}" >> cmd.log; g4bl
hks13.in EXTbm_dXdZ={EXTbm_dXdZ} EXTbm_X={EXTbm_X} EXTj_spl={EXTj_spl} EXTj_q1={EXTj_q1} EXTj_q2={EXTj_q2} >&
$TWRK.log; echo "`txt2rms -NS -i bpm.txt|grep " x "|beshuffled -I 4^2 + `txt2rms -NS -i edump.txt|grep " x "|
beshuffled -I 4^2" | bc | sdup +o err.log; mv $TWRK.log *.txt $TWRK;
#+++starting values: name start step {lowlimit highlimit}
# EXTbm_dXdZ      0.000000E+00      0.100000E-01
# EXTj_spl        0.936016E+00      0.100000E-02
# EXTbm_X         0.000000E+00
# EXTj_q1         0.000000E+00
# EXTj_q2         0.000000E+00
#---
# cycle EXTbm_dXdZ EXTj_spl EXTbm_X EXTj_q1 EXTj_q2 FCN
1 0.0000000000 0.9360156000 0.0000000000 0.0000000000 0.0000000000 0.110786E+02    # 11.078611386239
2 0.0100000000 0.9360156000 0.0000000000 0.0000000000 0.0000000000 0.735407E+04    # 7354.066428365822
3 -0.0040000001 0.9360156000 0.0000000000 0.0000000000 0.0000000000 0.131887E+04    # 1318.870085808032
4 0.0016000000 0.9360156000 0.0000000000 0.0000000000 0.0000000000 0.218177E+03    # 218.177190957782
...
43 0.0000296875 0.9361020844 0.0000000000 0.0000000000 0.0000000000 0.114188E+02    # 11.418840716287
44 -0.0000078125 0.9359202094 0.0000000000 0.0000000000 0.0000000000 0.111403E+02    # 11.140310939502
45 -0.0000578125 0.9359977094 0.0000000000 0.0000000000 0.0000000000 0.111901E+02    # 11.190057910300
```

---

10 [http://casa.jlab.org/internal/code\\_library/casa\\_lib/MISC/DOC/](http://casa.jlab.org/internal/code_library/casa_lib/MISC/DOC/)