Comparison between MCNP6.2 and Fluka in energy deposition simulation for a thin Titanium window

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We have done essentially the same simulation using two different simulation packages, MCNP6.2 [1] and Fluka (2011.2x) [2]. In the simulation, gold ion beams with Gaussian distributions in both transverse directions (x and y) are impinged upon the surface of the RHIC beam dump (at 10 o'clock) which is made of carbon/graphite and is 50.8 cm (20 inches) in length. A thin window made of Titanium alloy, with a thickness of 0.15748 cm or 0.062 inches in the beam direction (z), is behind the beam dump which is where we measure the energy deposition by gold ions and other particles from fragmentation and any scattering processes.

In this study, we have used a case from eRHIC where the total beam energy is 110 GeV and the combination of different emittances and β functions in horizontal and vertical directions lead to expected beam sizes σ (rms) of 0.6376 mm in x (horizontal) and 0.3813 mm in y (vertical), which were used as the σ's of the Gaussian distributions of the gold ion beams in x and y respectively.

The input files for both MCNP6.2 and Fluka simulation are shown at the end of this document. In fact, we have imported the input file from MCNP6.2 into the software tool of Fluka, Flair (2.3.0) [3], which would produce an input file with the proper geometry for Fluka. It was then necessary to modify the material information, beam parameters, scoring cards and other cards (such as START and STOP) necessary for Fluka to run, as Flair only seemed to convert the geometry portion of MCNP6.2 properly but not for other cards.

In the MCNP6.2 simulation, we have divided the transverse cross-section of the thin window into a grid of 200 and 250 divisions in x and y coordinates respectively and used the "mesh tally" (in MCNP6.2) to evaluate the energy depositions, as one may see from the MCNP6.2 input file. We then found the line of x or y coordinates (i.e., a series of x-coordinates for a fixed y or a series of y-coordinates for a fixed x) with the overall maximum energy deposition and made double Gaussian fits in each line/coordinate. The fit results can be seen in Figure 1.

We have done the corresponding Fluka simulation with the input file shown at the end of this document and made the same grid and divisions on the cross-section of the thin window. After plotting the result in Flair, one would obtain a text file with the x and y coordinates plus the energy deposition and uncertainties (in %). We then followed a similar procedure as described above and performed similar double Gaussian fits in x and y coordinates. The fit results from this simulation can be seen in Figure 2.

The analyses have been done with the purpose to determine whether the energy deposition would damage the thin window. The most vulnerable place of the thin window is in the center of the Gaussian distribution where the largest energy depositions lies. Therefore, the emphasis is to best fit the center of the Gaussian distributions. We have used double Gaussian for fitting as one Gaussian is for the original Gaussian beam whereas the other Gaussian is for the broadened beam profile (after passing through about 50.8 cm of graphite).

[1] https://rsicc.ornl.gov/codes/ccc/ccc8/ccc-850.html
[2] http://www.fluka.org/fluka.php
[3] http://www.fluka.org/flair/

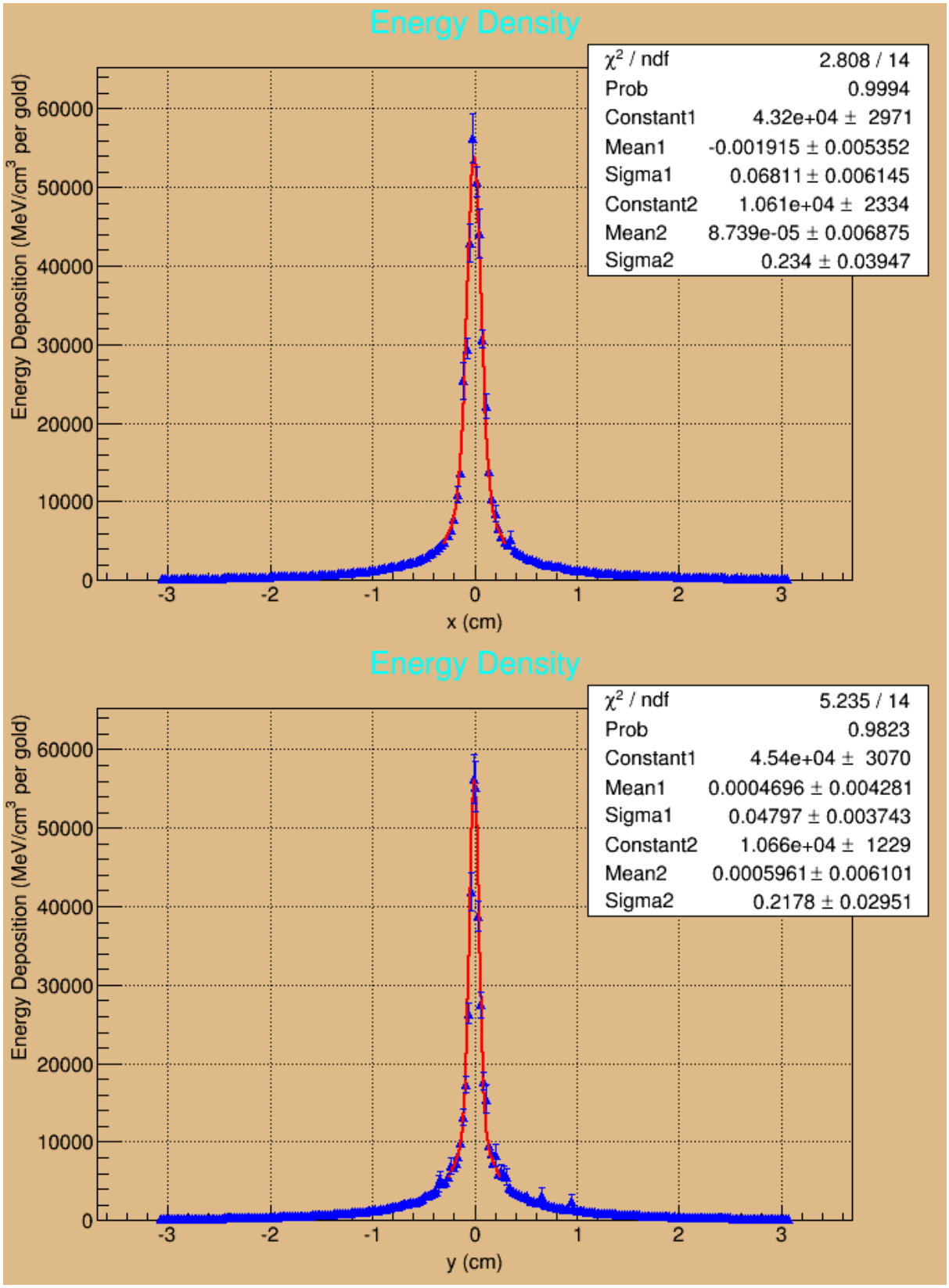

Figure 1: Double Gaussian fit results for the energy depositions in horizontal (x) and vertical (y) coordinates, in the MCNP6.2 simulation. Energy unit is in MeV.

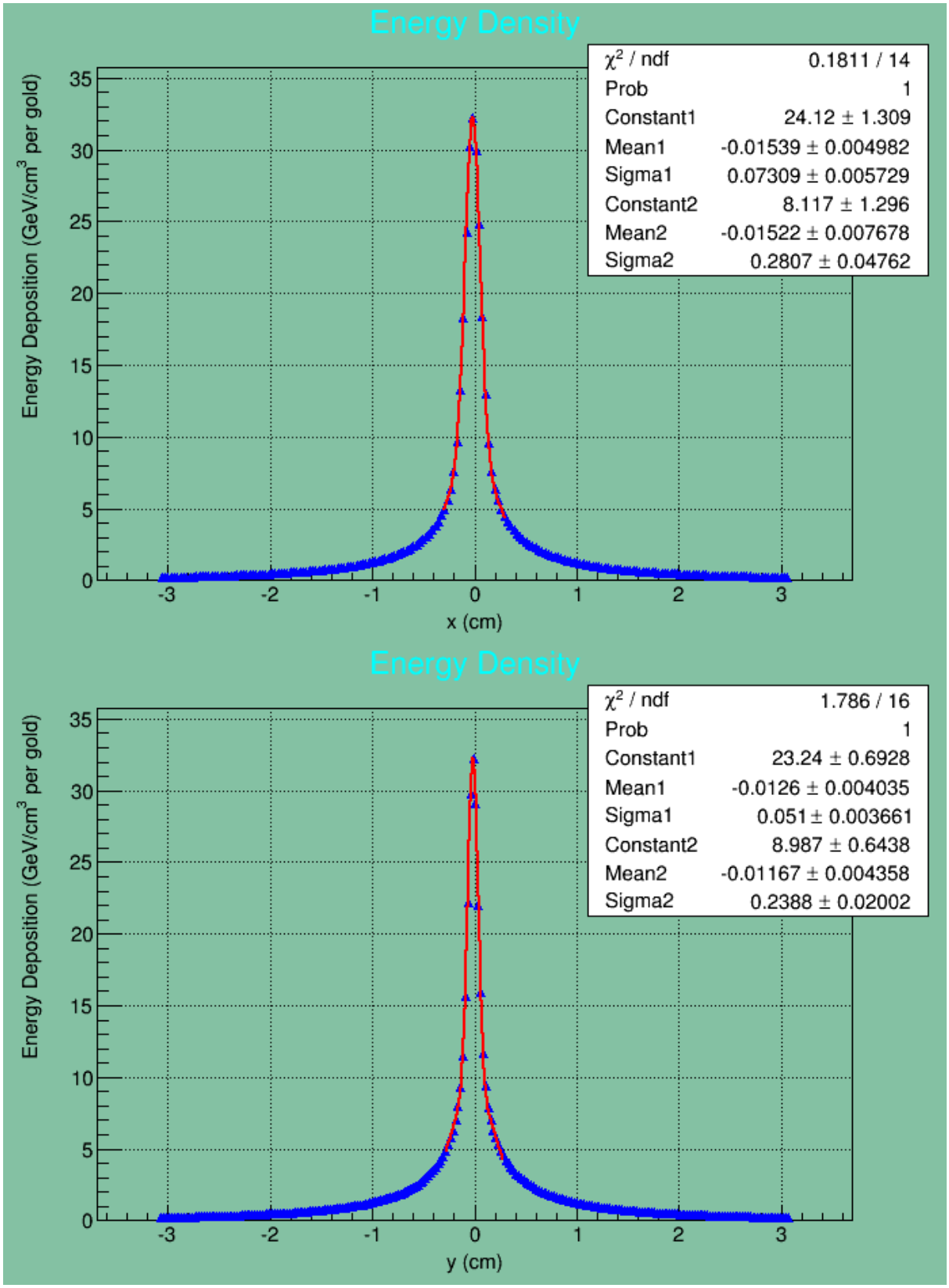

Figure 2 : Double Gaussian fit results for the energy depositions in horizontal (x) and vertical (y) coordinates, in the Fluka simulation. Energy unit is in GeV.

Comparing the fit results from the two simulation packages, we look at the peaks of the two Gaussians. Approximately, for the MCNP6.2 fit results, the peaks (which are very close to x=0 or y=0 anyway) in the center are about (43+11 or 54) and (45+11 or 56) GeV/cm^3 per incident gold ion in x and y dimensions respectively. For Fluka, the peaks are about 24+8 or 23+9 or 32 GeV/cm^3 per incident gold ion in x and y dimensions. Therefore, on average, the ratio of the peak energy deposition from MCNP6.2 to that from Fluka is about 55 vs 32. In other words, at the peaks, the energy deposition from MCNP6.2 is about 72% higher than that of Fluka. The thinness of the window can be one factor contributing to this difference. From a web search, I have come across a comparison of energy depositions done by N.V. Mokhov and S.I. Striganov [4] for various software including MCNPX (an earlier version of MCNP6.2), Fluka, GEANT, MARS and PHITS. Though the comparison is for energy depositions due to protons, one can see from the plots in Figure 10 of that paper that the agreement between MCNPX and Fluka would be better in thicker targets than in thinnest target.

This work has been initiated by Wolfram Fischer and Sumanta Nayak when they investigated whether the existing window behind the RHIC beam dump will be good enough for the coming RHIC beam abort system upgrade. A paper including the MCNP6.2 result has been submitted to the 2019 North American Particle Accelerator Conference (TUPLO03).

[4] https://lss.fnal.gov/archive/2007/conf/fermilab-conf-07-009-ad.pdf\

MCNP6.2 input file :

```
Ti window --- Energy deposition by the gold ions
c
c carbon
c
1 1 -1.77 -1     imp:n,h,p,#,z,d,t,s,a,e,/=1
c
c window
c
2 3 -4.76  -2     imp:n,h,p,#,z,d,t,s,a,e,/=1
c
10 0 1 2 -3      imp:n,h,p,#,z,d,t,s,a,e,/=1
c
c outside
c
999 0    3       imp:n,h,p,#,z,d,t,s,a,e,/=0
c
c
=============================================================================

c
=============================================================================
c
c C-C carbon
c
1 rpp 3.18516 9.18464 -2.99974 2.99974 0.381 51.181
c
c steel window
c
2 rpp 3.1115  9.2583  -3.0734  3.0734  52.25288 52.41036
c
3 rpp 3.  10.   -3.5 3.5  0. 55.
c
c
=============================================================================

c
=============================================================================
c
c mode n h
c mode n h p e | /

6
```

```
c
c mode n p h # / | z d t s a e
mode n p h # / z d t s a e
c
c
c graphite
m1 6000 1
mx1:h 6012
mx1:p 6012
c
c
c
c Ti – 15V-3Cr-3Sn-3Al
c
c Aluminum, Al 3.0 %
c Chromium, Cr 3.0 %
c Tin, Sn      3.0 %
c Titanium, Ti 76 %
c Vanadium, V 15%
c
m3 13027 -0.03                                                          $ Al 3%
   24050 -0.0013035 24052 -0.0251367 24053 -0.0028503 24054 -0.0007095 $Cr 3%
   50112 -0.000291  50114 -0.000198  50115 -0.000102  50116 -0.004362     $
   50117 -0.002304  50118 -0.007266  50119 -0.002577  50120 -0.009774     $
   50122 -0.001389  50124 -0.001737                                       $ Sn 3%
   22046 -0.0627    22047 -0.056544  22048 -0.560272  22049 -0.041116     $
   22050 -0.039368                                                       $ Ti 76%
   23050 -0.000375  23051 -0.149625                                      $ V 15%
c
c
c
c 110 GeV/nucleon --- Aug. 24, 2019 : beta_x/beta_y have changed from
c 41/166 m to 9.606/47.703 m
c                              emittance_x = 5 micro-meter and emittance_y = 0.36 micro-meter
c
SDEF erg = 21485160.4 par = 79197 dir = 1 vec = 0 0 1 x=D1 y=D2 z=0.38
      AXS 0 0 1 wgt=1 ccc=10
SP1 -41  0.150152125  6.1849 $sigma=0.063763737cm=>FWHM = 2 sqrt(2 ln 2)sigma
SP2 -41  0.08978407   0.     $sigma=0.038127784cm=>FWHM = 2 sqrt(2 ln 2)sigma
c
c
c
c anti-particle promotion
c
DBCN  26j 1
c
```

```
c RAND  96475763
c
phys:e 100000.
phys:n 10000000. 5j 1
phys:h 10000000. 5j 1
phys:d 10000000.
phys:t 10000000.
phys:a 10000000.
phys:s 10000000.
phys:# 21485160.5
phys:p 10000000. 2j -1
c
c
cut:d j 0.0 0
cut:t j 0.0 0
cut:a j 0.0 0
cut:s j 0.0 0
cut:h j 0.0 0
cut:# j 0.0 0
c
c
c
c phys:n 250000.
c phys:h 250001.
c phys:e 100000.
c phys:p 100000. 2j 1
c
c
+F6 2
c
prdmp 2j 1
c
print
c
c Energy Bins (upper limits)
e0  1. 10. 100. 1000. 10000. 100000. 1000000. 10000000. 30000000. T
c
c e0 1.0e-7 1.0e-5 1.0e-3 .01 .1 1. 2. 20. 150. 1000. 24000. 50000. 100000.
c      200000. 250000 T
c
nps 10000
c
c        Mesh Tally
c
c
tmesh
```

rmesh3 total
CORA3 3.1115 199i 9.2583
CORB3 -3.0734 249i 3.0734
CORC3 52.25288   52.41036
endmd

Fluka input file :

```
TITLE
Ti window --- Energy deposition by the gold ions
GEOBEGIN                                                COMBNAME
    0    0          Ti window --- Energy deposition by the gold ions
*
==========================================================================
==========
* C-C carbon
* steel window
* 1 RPP 3.18516 9.18464 -2.99974 2.99974 0.381 51.181
RPP S1          3.18516 9.18464 -2.99974 2.99974 .381 51.181
* 2 RPP 3.1115  9.2583  -3.0734  3.0734  52.25288 52.41036
RPP S2          3.1115 9.2583 -3.0734 3.0734 52.25288 52.41036
*
==========================================================================
==========
* 3 RPP 3.  10.   -3.5 3.5  0. 55.
RPP S3          3. 10. -3.5 3.5 0.0 55.
* * Black body
SPH blkbody    0.0 0.0 0.0 100.
END
* carbon window
* 2 2 -7.7  -2     imp:n,h,p,#,z,d,t,s,a,e,/=1
C1           5 +S1
C2           5 +S2
*  outside
*
C10          5 -S1 -S2 +S3
BLKBDY       5 +blkbody -S3
END
GEOEND
ASSIGNMA          M1       C1
ASSIGNMA          M3       C2
ASSIGNMA      VACUUM       C10
ASSIGNMA    BLCKHOLE    BLKBDY
MATERIAL                        1.77                         M1
*  Al 3%
*  Cr 3%
*  Sn 3%
*  Ti 76%
*  V  15%
* golds
*
```

```
*  100 GeV/nucleon --- Aug. 21, 2019 : beta_x/beta_y have changed from 41/166 m to
9.606/47.703 m
*
MATERIAL                  4.76                    M3
COMPOUND      -.03  ALUMINUM     -.03      TIN     -.76  TITANIUMM3
COMPOUND      -.03  CHROMIUM     -.15  VANADIUM              M3
MATERIAL       24.          7.18                    CHROMIUM
COMPOUND        1.    CARBON                          M1
MATERIAL       23.          6.11                    VANADIUM
HI-PROPE       79.     197.
BEAM     -109.06173              -.15015213-.08978407        HEAVYION
BEAMPOS      6.1849      0.0      0.38
USRBIN         10.    ENERGY     -30.    9.2583    3.0734  52.41036
USRBIN       3.1115   -3.0734  52.25288      199.      249.       1. &
* Set the random number seed
RANDOMIZ        1.387873487.
* Set the number of primary histories to be simulated in the run
START         5000.
STOP
```