Secondary Pion Production using the LINAC Beam on Graphite and Tungsten Targets

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Abstract

The Fermilab 400-MeV LINAC primary proton beam can produce precise, single-species secondary beams using a production target in the MeV Test Area experimental hall; specifically, pions from 4 up to 120 MeV kinetic energy. Although graphite is a standard production target material given its ultra-high temperature tolerance and low impact on the post-target primary beam, secondary pion/muon total production cross sections increase approximately as $Z^{1/3}$ for positive muons and $N^{2/3}$ for negative muons. Higher mass targets such as tungsten can potentially increase low-energy mu+ and mu- rates by factors of 3 and 8, respectively. Initial production studies have confirmed higher muon yield from heavy targets (tungsten vs carbon), but also, surprisingly, show significant differences in pion production between modern hadronic models (GENIEhad) and between GEANT and MCNP, state of the art production modeling codes. This project further investigated the production discrepancies between these two target materials and between different physics models with high-statistics runs using the GEANT-based code and G4Beamline to better quantify the results and compare with production data which was obtained using the MTA secondary beamline.

Acknowledgements

I would like to thank Carol Johnstone for giving me the opportunity to participate in the Community College Internship program and for her supervision throughout. I would also like to thank Christopher Izzo for mentoring me throughout G4 Beamline and always being open to my questions. I would not have been able to produce the results I got without the guidance he gave me. Additionally, I would like to thank Kevin Lynch for helping us as a collaborator on the Fermi Grid. Lastly, I want to acknowledge Wesley Winter, Jasmine Tang, and Erica Badaracco, as they were big contributors to my project. Thank you for all the feedback that has been given to me throughout this internship, to all.

Multiple software aided me throughout this project, and I would like to acknowledge them here:

- G4Beamline

- Python Programming Language

- Matplotlib

- Microsoft Office

Table of Contents

1. Introduction

A new secondary beamline was recently installed in the MeV Test Area (MTA) with the intentions of enhancing mu+/mu- production by factors of 3/8 by using a tungsten target versus the traditional graphite (carbon) target using the 400 MeV Fermilab proton LINAC beam. This project consisted of testing various targets to backup this idea, alongside manipulating targets to impact other projects significantly, such as the Muon Catalyzed Fusion experiment.

2. Site Location, Beamline Structure

This section shows the location of the LINAC beam and the build of the MTA Beamline.
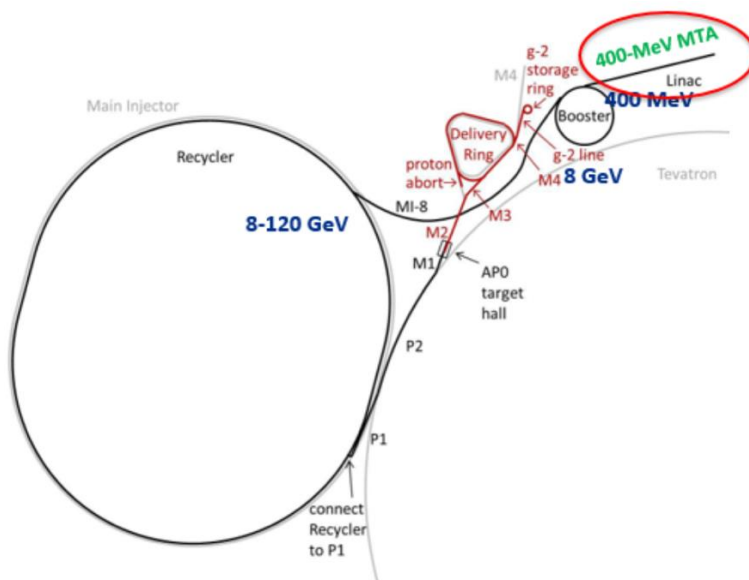
2.1   LINAC Location

Figure 1: MTA & LINAC Location

Figure 1 shows the location of the 400 MeV MTA beamline and the LINAC proton beam. The MTA primary beamline is produced straight from the LINAC proton beam.

2.2   MTA Beamline

Figure 2: MTA Beamline

Figure 2 shows what the MTA beamline looks like.

3. Getting Started (Testing for Efficiency)

The first step of the project was to experiment with G4 Beamline and start testing for efficiency. This section introduces the software and the outlines the basics of target analysis.

3.1 G4 Beamline Introduction

This section elaborates on the capabilities of G4 Beamline and how it was significant to the project. The code for G4 Beamline code incorporates secondary particle production models and predictions/simulations. This allows us to study the performance based on those predictions/simulations. G4 Beamline can be tested in tracking mode with a fixed number of events or in visualization mode in which you are able to see if the target is in the correct place and being properly tracked. It is an easier to use version of GEANT-4 and is optimized for simulating the beamline. It has realistic simulations, does not need C++ programming to be able to use it, and can be used with simple Python programming. The G4 Beamline User Documentation created by Tom Roberts can be found here: https://beamdocs.fnal.gov/AD/DocDB/0079/007950/001/G4beamlineUsersGuide.pdf

Examples of G4 Beamline visualization mode are shown in Figure 3 and Figure 4.

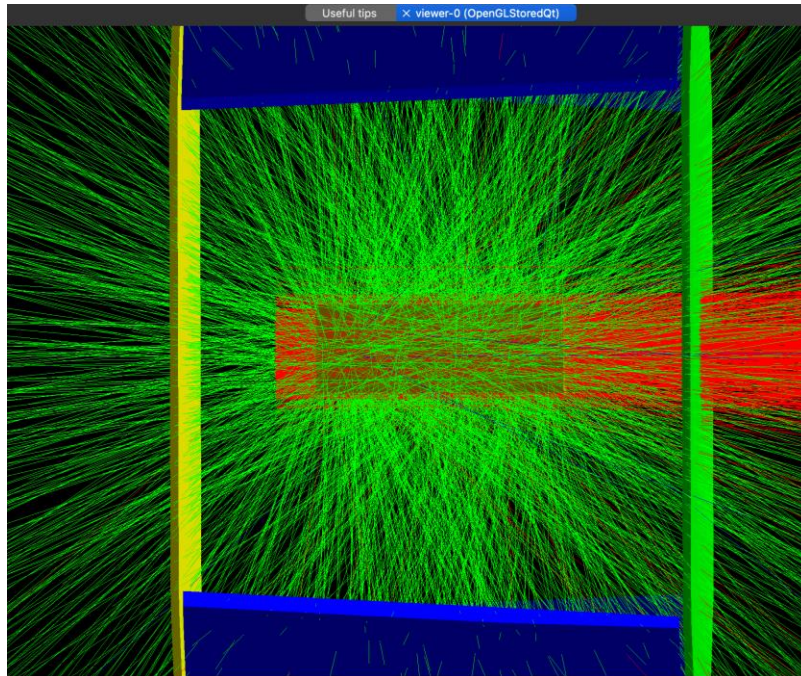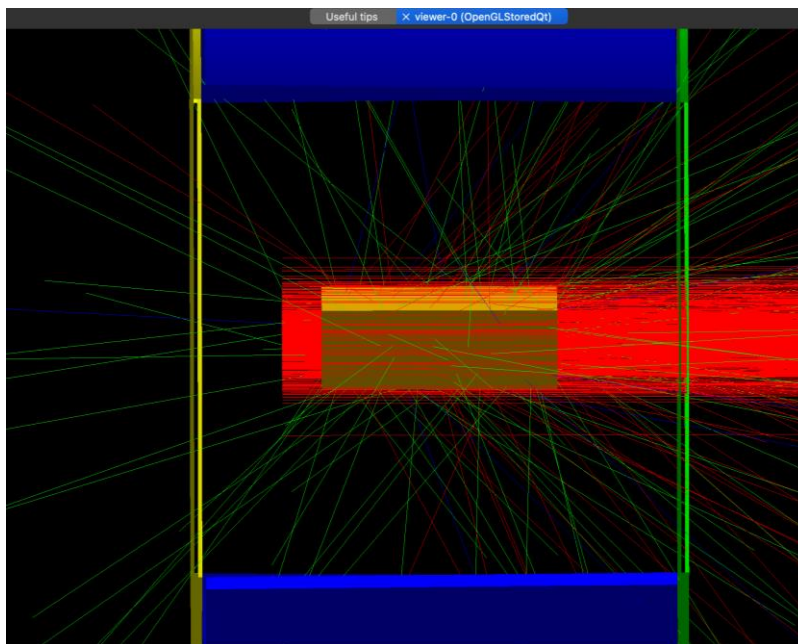*Figure 3: Tungsten - running 1000 events (10.5 mm x 10.5 mm x 30 mm target)*

Figure 4: Graphite - running 1000 events (10.5 mm x 10.5 mm x 30 mm target)

In the images, the lines represent different particles. Protons are red, pions are green, and muons are blue. We use a 10.5 mm x 10.5 mm x 30 mm target with a front detector, back detector, and a cylindrical detector around the sides. The figures above show physical

differences when choosing between the two materials. By using visualization mode, we can go event by event to see where the particles are going.

The program that the simulations in Figures 3 & 4 refer to are from the ProtonsOnTarget.g4bl file. At first, when learning how to use G4 Beamline, I had a problem with outputting the data after the program was done running. This was fixed by adding the command *format=ascii.* An example of the data we get after running the file is shown in DetBackward.txt, DetForward.txt, and DetSideways.txt, which refers to how many pions the back, forward, and sideway detector found during 1,000,000 events. However, the data was far longer than what is reported in the .txt files.

3.2   Physics Lists

G4 Beamline gives you access to many physics' lists. To address a physics lists, the command *physics* and the list of all physics list can be found by typing in the *help* command. Our initial studies for π^- production from G4 Beamline use the physics lists QGSP_INCLXX_HP. However, it was determined that different physics list produce difference results. In figure 5, we see that the momentum distribution's shape is consistent throughout each physics list. On the other hand, the yield for π^- has significant larger numbers with the QGSP_INCLXX_HP physics list and the different in yield for π^- between the two physics lists is favored at forward angles and smaller at backward angles.
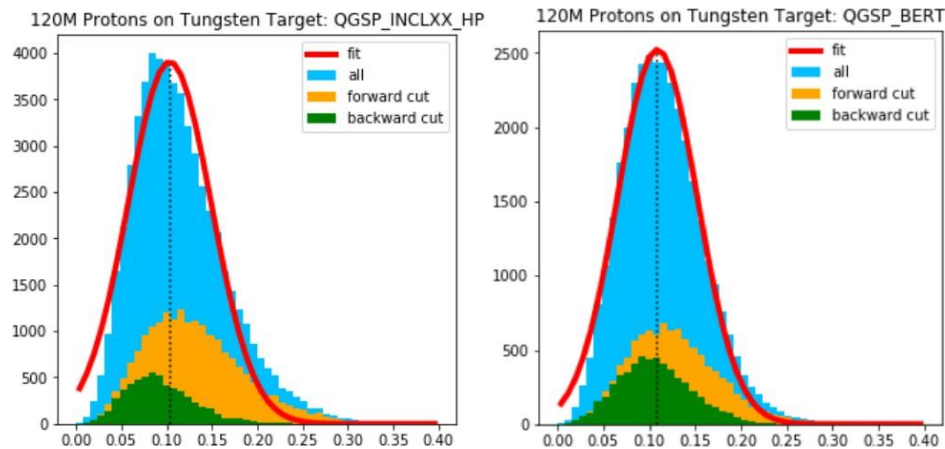

Figure 5: QGSP_INCLXX_HP & QGSP_BERT Momentum Distributions

3.3   Initial Results from G4 Beamline

This section elaborates on some of the results that G4 Beamline has given us. The following graphs in Figure 6 and Figure 7 were computed from Python but the data was pulled straight from G4 Beamline.
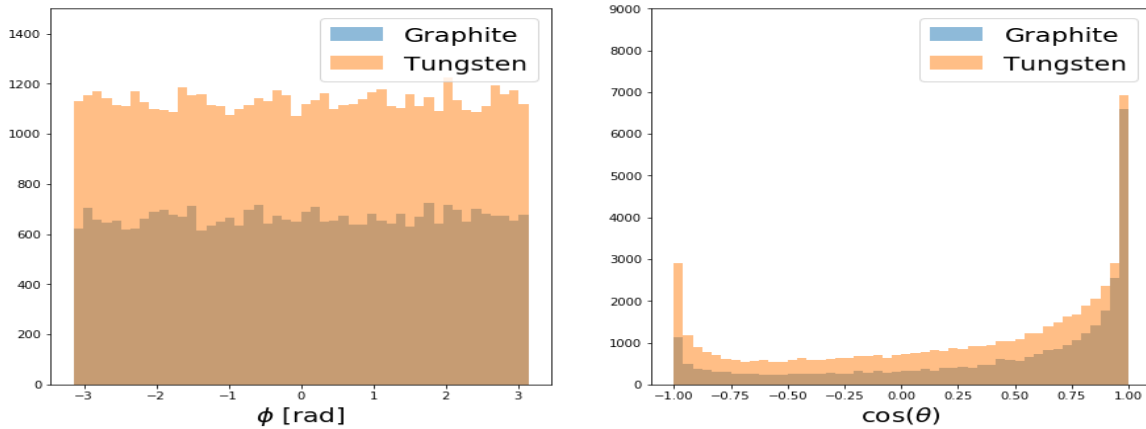
Figure 6: Angular Distribution of Pi- for 120 M Protons on Target
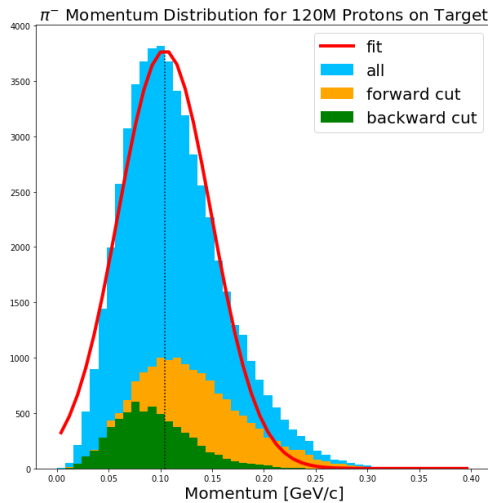
Figure 7: Momentum Distribution of Pi- for 120 M Protons on Target

These production simulations indicated the following:
- Momentum distribution is roughly gaussian, with a peak at about 100 MeV/c.
- π^- azimuthal (vertical angle about the center of the target) (ϕ) distribution is uniform, as expected from symmetry.
- $\cos(\theta)$ distribution peaks strongly at forward angles but also has a smaller peak at backward angles.
- The production rate advantage of using tungsten vs graphite target is apparent in both angular distribution plots – especially pronounced at backward angles.

To add, this data is derived from the DetBackward.txt, DetForward.txt, and DetSideways.txt files. The data was taken from G4 Beamline and four new columns were created: P_tot, θ, Cos(θ), and ϕ. P_tot is the pi-'s total momentum, and θ/ϕ describe the angular distribution of the pi-. The original columns that G4 Beamline gave us were x, y, z, Px, Py, and Pz. Any other column was deleted because they were not needed.

The next following lines show how each was calculated.

P_total:

$$P_{tot} = \sqrt{(\frac{Px^2 + Py^2 + Pz^2}{1000})}$$

θ:

$$theta = \tan^{-1}\left(\frac{z}{x}\right)$$

$\cos(\theta)$:

$$\cos(\theta) = \cos\left(\tan^{-1}(\frac{z}{x})\right) * (\frac{z}{|z|})$$

ϕ:

$$\phi = \cos^{-1}(\frac{x}{\sqrt{x^2 + y^2}}) * \left(\frac{y}{|y|}\right)$$

All of these calculations were carried throughout various targets.

4. All Targets Tested

This section outlines the targets that were tested throughout the internship. 400 MeV is the proton's beam kinetic energy, but G4 Beamline takes the beam's mean momentum rather than kinetic energy. The mean momentum for the proton beam with 400 MeV kinetic energy is 954.263 MeV/c, so the mean momentum is set to that. Each script mentioned in this section will include a visualization from G4 Beamline.

4.1 ProtonsOnTarget.g4bl

The first tested was a 10.5 mm x 10.5 mm x 30 mm target. Both were tested with 10,000,000 events. DetBackward, DetSideways, and DetForward are the virtual detectors. DetBackward and DetForward are circular detectors that surround the target, and DetSideways is a hollow cylindrical detector around the target. This can be seen in the visualization mode of G4 Beamline, referenced in Figures 3 & 4. When you run it in G4 Beamline, it simulates the proton beam hitting the target and producing other particles. However, the only one we cared about was pi-. This is why the PDGid is specified as -211, which is the ID for pi-. When recording the data, it ignores all other particles. G4 Beamline then produces the data as text files. The text files were then converted to an Excel file to be able to graph the data. Figures 3 & 4 show a simulation for this file.

4.2   ProtonsOnTarget2.g4bl file

One thing to add is not everyone uses the same angular distributions, so when comparing them to other simulations, you must be careful to make sure you're defining the angles the correct way. An example of this was slice-target geometry that Daniel Kaplan gave to test. The target was angled at 146.4 degrees. When tested with the production modeling software MCNP, Kaplan found that graphite produced more than Tungsten. When the same slice-target geometry was tested with G4 Beamline, tungsten produced more than graphite. This shows the significant differences between using MCNP and GEANT-based code. The results can not necessarily be relied on until further testing.
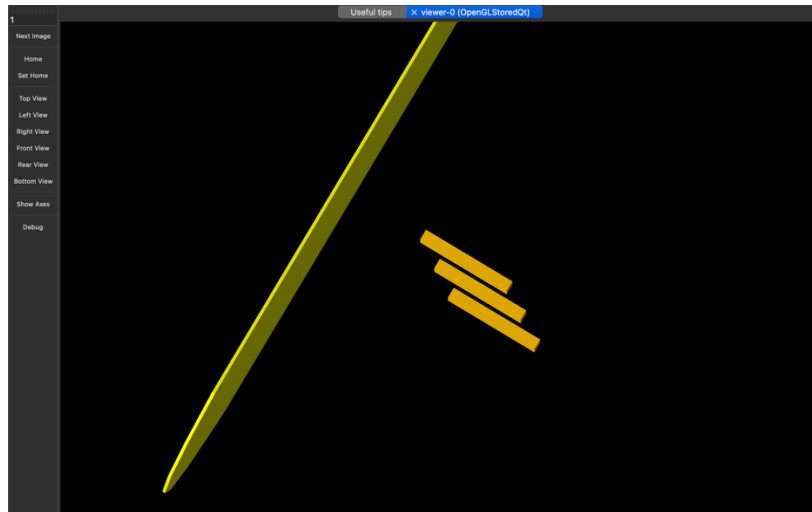
Figure 8: Slice-Target Geometry (3 Slices)

4.3   50MeV.g4bl

Another idea that was given was based off the results that we need for NK Lab's Muon Catalyzed Fusion experiment. The momentum distribution in earlier results states that there is a peak at 100 MeV. For the Muon Catalyzed Fusion experiment, they desire a peak of 50 MeV. To try to degrade the energy, we can try testing a target that has a few more millimeters of graphite to the left side exterior of the target to degrade the energy. The graphite was placed next to the tungsten target. The dimensions for the Tungsten portion were 30 mm x 30 mm x 15 mm (width, height, length) and the dimensions for the Graphite Portion were 30 mm x 40 mm x 5 mm (width, height, length). Figure 10 shows the simulation with green being graphite and orange being tungsten.
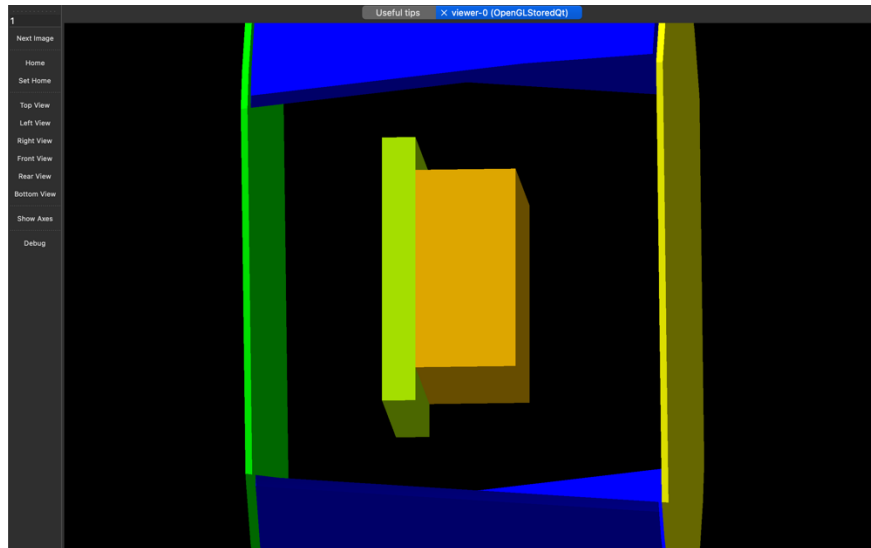
Figure 9: Graphite & Tungsten Combined Target

Unfortunately, it was found that the momentum did not make a shift to 50 MeV/c. The graphite/tungsten target also took significantly longer (8.4 hours) compared to the tungsten target (4.5 hours). The mean for the graphite/tungsten target was about 122 MeV, and the tungsten target mean was about 115 MeV. This means that adding a graphite exterior to a tungsten target potentially increased the energy, though both are still near the 100 MeV peak.

Another example of this was tested but instead of 5mm, we used 10mm. It was assumed that the more graphite added, the more the energy would degrade. This was disproved as well.

5. High-Statistic Runs

Mentioned earlier, in G4Beamline, $1 * 10^6$ or $1 * 10^7$ events are used for efficient computation. However, results need to be confirmed with high statistics run of up to $2 * 10^{13}$ events. The problem is, G4 Beamline only allows up to $2 * 10^9$ events to be executed in one process. In order to get $2 * 10^{13}$, we would have to run the program 10,000 times ($\frac{2*10^{13}}{2*10^9} = 10000$) by hand. One process of $2 * 10^9$ takes a couple of days and then to repeat the process, you would have to run it again, until you run it 10,000 times. Due to this, we run high statistics on the Fermi Grid because $2 * 10^{13}$ events would take almost 50 days to complete if we did it by hand. The Fermi Grid gives us access to run it on multiple computers simultaneously, in order to get through the process quicker.

6. Conclusions & Future Work

To run scripts by hand in G4 Beamline, we need to parametrize the file name where the data was written to avoid overwriting the data from a previous run. However, running it on the Fermi Grid, we are unable to feed it via the command line with g4blplot. To avoid this, a bash script is written to do it for us. The bash script and G4 Beamline script file have been submitted to the Fermi Grid by Kevin Lynch who is a collaborator and has a grid account. Results are pending currently, so this has been left for future work.

Throughout the internship, various amounts of targets were tested to determine whether Tungsten was a better material to use as a target. Each time, it was concluded that Tungsten is a much better choice of material and provided a much larger number of yields for pions. However, there is much more to explore than just the difference between the two target materials. We have also been focusing on trying different shapes and slice-target geometry (much like Daniel Kaplan's example) to establish whether there is a geometry dependence or not. It was also observed that although Tungsten produces larger numbers of pions, it is far quicker to test Graphite. Although Tungsten is a good material to use for the long run, Graphite is faster in getting results. However, the greater yield for Tungsten is worth the time.

7. Appendix
7.1   Protons On Target Simulation: ProtonsOnTarget.g4bl script

```
#  lengths are in mm, fields is Tesla !  Momentum in MeV

#_____
___

#----------------------------- Setup -----------------------------
--#


param nEv=10000000



#physics QGSP_BERT disable=Decay
#physics QGSP_BERT
physics QGSP_INCLXX_HP


#--------------------------- Define World and Beam ----------------
---------#

# Set default environment material
param worldMaterial=Vacuum


#BEAM
# 400 MeV proton beam aimed at target center
```

```
beam gaussian z=-20 meanMomentum=954.263 sigmaP=0 nEvents=$nEv
particle=proton sigmaX=3 sigmaY=3 meanXp=0.0 meanYp=0.0 sigmaXp=0
sigmaYp=0


# Only pay attention to the following particles (saves on
calculation time)
particlecolor proton=1,0,0 pi-=0,1,0 mu-=0,0,1
#trackcuts keep=mu-,pi-,proton



#------------------------- Background Color ---------------------
----#


# Scaling GUI view from pg 19 of the manual

g4ui when=4 "/vis/viewer/scaleTo 2 2 2"


#------------------------- Define Beamline Elements -------------
------------#


# Parameters
param Tw=10.5 Th=10.5 Tl=30
param Tm=W

box Target width=$Tw height=$Th length=$Tl material=$Tm
color=1.0,0.75,0.0

#--------------------- Place Beamline Elements ------------------
---#

place Target rename=target z=0.0

#--------------------- Place Virtual Detectors -----------------
---#

# This virtualdetector catches what comes out of the target to the
back; make it yellow
virtualdetector DetBackward radius=50 length=1 color=1,1,0
require=PDGid==-211 format=ascii
place DetBackward z=-31

# This virtualdetector catches what comes out of the target to the
side; make it blue
virtualdetector DetSideways innerRadius=50 radius=51 length=60
color=0,0,1 require=PDGid==-211 format=ascii
place DetSideways z=0

# This virtualdetector catches what comes out of the target in the
forward direction; make it green
```

```
virtualdetector DetForward radius=50 length=1 color=0,1,0
require=PDGid==-211 format=ascii
place DetForward z=31
```

7.2   ProtonsOnTarget-2.g4bl script for Fermi Grid

```
#  lengths are in mm, fields is Tesla !  Momentum in MeV

#_____
___

#----------------------------- Setup -----------------------------
--#


# Must add kill=$kill_aperture to every element to use this feature.
randomseed time
param kill_aperture=1
param -unset nEv=2000000000



#physics QGSP_BERT disable=Decay
physics QGSP_BERT


#--------------------------- Define World and Beam ----------------
---------#

# Set default environment material
param worldMaterial=Vacuum


#BEAM
# 400 MeV proton beam at 30.6 deg. from secondary-beamline direction
aimed at target center
param -unset angle=30.6
beam gaussian rotation=Y(180+$angle) x=50.9 y=0 z=86.07
meanMomentum=954.263 sigmaP=0 nEvents=$nEv particle=proton sigmaX=3
sigmaY=3 meanXp=0.0 meanYp=0.0 sigmaXp=0 sigmaYp=0


# Only pay attention to the following particles (saves on
calculation time)
particlecolor proton=1,0,0 pi-=0,1,0 mu-=0,0,1
trackcuts keep=mu-,pi-,proton



#--------------------------- Background Color ----------------------
----#
```

```
# Scaling GUI view from pg 19 of the manual

g4ui when=4 "/vis/viewer/scaleTo 5 5 1"


#-------------------------- Define Beamline Elements --------------
-----------#


# Parameters
param Tw=15 Th=30 Tl=30
param Tm=W

param QUADfieldlength13=1076.3
param QUADgradient13=0.140
param QUADironLength13=1076.3

param QUADfieldlength2=1452.6
param QUADgradient2=-0.155
param QUADironLength2=1452.6

param QUADapertureRadius=49.15
param QUADironRadius=50.8

param SOLinnerRadius=20.0
param SOLouterRadius=22.0
param SOLlength=130.0
param SOLmaxZ=64.0
param -unset SOLcurrent=158.2

box Target width=$Tw height=$Th length=$Tl material=Tm
color=1.0,0.75,0.0,.25


genericquad Quad2 fieldLength=$QUADfieldlength2
apertureRadius=$QUADapertureRadius ironLength=$QUADironLength2 \
ironRadius=$QUADironRadius ironColor=0,0,1,.3 \
gradient=$QUADgradient2 fringeFactor=10.0 kill=$kill_aperture


genericquad Quad13 fieldLength=$QUADfieldlength13
apertureRadius=$QUADapertureRadius ironLength=$QUADironLength13 \
ironRadius=$QUADironRadius ironColor=0,0,1,.3 \
gradient=$QUADgradient13 fringeFactor=10.0 kill=$kill_aperture


coil LLS innerRadius=$SOLinnerRadius outerRadius=$SOLouterRadius
length=$SOLlength


solenoid LomaLindaSolenoid coilName=LLS current=$SOLcurrent
color=1,0,0,.3 kill=$kill_aperture
```

```
tubs TargetToSolenoid material=STAINLESS-STEEL outerRadius=70.0
innerRadius=60.0 length=355.6  color=.2,.2,.2,.3 kill=$kill_aperture

tubs SolenoidToQUAD1 material=STAINLESS-STEEL outerRadius=50.8
innerRadius=49.15 length=231.45  color=.2,.2,.2,.3
kill=$kill_aperture

tubs QUADGap material=STAINLESS-STEEL outerRadius=50.8
innerRadius=49.15 length=304.8  color=.2,.2,.2,.3
kill=$kill_aperture

tubs QUAD3ToStraw material=STAINLESS-STEEL outerRadius=50.8
innerRadius=49.15 length=388.9  color=.2,.2,.2,.3
kill=$kill_aperture

tubs Straw material=STAINLESS-STEEL outerRadius=17.525
innerRadius=15.875 length=585.2  color=.2,.2,.2,.3
kill=$kill_aperture



#--------------------- Define Virtual Detectors for scoring -------
----------------#

virtualdetector Det radius=50 length=1 color=1,1,1 material=Vacuum
format=ASCII require=PDGid!=2212

virtualdetector muDet radius=15.875 length=1 color=1,1,1
material=Vacuum format=ASCII require=PDGid!=2212

virtualdetector piDet radius=50.8 length=1 color=1,1,1
material=Vacuum format=ASCII require=PDGid!=2212

virtualdetector solenoidDet radius=31.75 length=1 color=1,1,1
material=Vacuum format=ASCII require=PDGid!=2212

#--------------------- Place Beamline Elements -------------------
---#

place Target rename=target z=0.0 rotation=Y(180+$angle)
place LomaLindaSolenoid z=435.6
place SolenoidToQUAD1 rename=S2Q z=616.325
place Quad13 rename=Q1 z=1270.2
place QUADGap rename=QGap12 z=1960.75
place Quad2 rename=Q2 z=2839.4125
place QUADGap rename=QGap23 z=3718.075
place Quad13 rename=Q3 z=4408.625
place QUAD3ToStraw rename=Q2Str z=5141.225
place Straw z=5628.275

#--------------------- Place Virtual Detectors -------------------
---#
place Det rename=file_name_0 z=5921
```

7.3 Bash Script (to avoid overwritten files) for Fermi Grid

```bash
#!/bin/bash
file="test_script.g4bl"

line_number="124"

text_to_insert="file_num_a"


i_start=1
i_end=15
if [ -r "$file" ] && [ -r "$file" ]; then
    # For every i (standing for submission order)
    for (( i = i_start; i <= i_end; i++ )); do

        # on line number #, change file_num_. to file_num_i
        sed -i '' "${line_number}s/file_num_[a-zA-Z0-
9]*/file_num_$i/g" $file

        # print the number on that line for confirmation
        sed -n "${line_number}p" "$file"


        # Add your submission
    done

    # sed -i '' '${line_number}s/.*/${text_to_insert}/g' $file
else
    echo "The file '$file' is either not readable or not writable,
or both."
```

7.4 DetBackward.txt Tungsten

#x	y	z	Px	Py	Pz
#mm	mm	mm	MeV/c	MeV/c	MeV/c
1.70391	17.7572	-30.5	-8.76696	102.228	-92.4622
46.3164	2.3709	-30.5	136.8	-3.94945	-46.9277
5.81074	3.20394	-30.5	19.0353	23.8189	-88.8862
30.0686	-11.2388	-30.5	52.7841	-21.6554	-33.7693
-42.2188	-7.91244	-30.5	-59.1906	-15.8974	-25.1337
-15.6631	1.27933	-30.5	-39.2715	13.2519	-43.2132
4.4038	12.5218	-30.5	20.0188	62.1169	-106.972
-20.9248	23.1818	-30.5	-45.5158	65.3397	-100.775
-31.6306	1.70109	-30.5	-63.1699	-4.02842	-35.9161

-7.92196	-22.6983	-30.5	-9.66542	-43.8683	-33.277
45.9684	6.04657	-30.5	56.8598	8.59888	-35.1335
20.4224	-13.0834	-30.5	81.468	-54.4864	-70.4168
31.6456	8.14271	-30.5	75.9857	30.927	-71.419
6.11371	-3.48553	-30.5	26.6783	-11.6082	-63.7
8.73331	9.48068	-30.5	22.7653	31.0102	-69.7095
3.18108	7.23707	-30.5	-4.90268	33.2419	-65.4124

7.5 DetForward.txt Tungsten

#x	y	z	Px	Py	Pz
#mm	mm	mm	MeV/c	MeV/c	MeV/c
5.95057	1.90995	30.5	36.4801	12.5963	108.704
46.3318	-7.1808	30.5	159.356	-23.9347	144.195
-21.7507	26.1507	30.5	-39.2436	42.276	67.09
-28.0993	5.38678	30.5	-51.9173	9.76325	84.399
-15.0373	-15.4109	30.5	-26.2442	-20.6636	79.2855
19.6745	-15.9889	30.5	74.1749	-56.2377	84.0576
-25.2745	-30.6331	30.5	-33.4866	-40.6776	45.7465
-26.4535	-23.2268	30.5	-59.6778	-54.3773	77.3455
-9.30058	-16.1563	30.5	-27.5861	-49.3119	67.4007
6.34964	-32.4892	30.5	7.10454	-198.1	242.401
-22.6245	19.167	30.5	-44.3905	32.0483	90.9305
0.878554	11.2831	30.5	-10.8638	96.9024	132.445
21.7375	28.9508	30.5	47.3704	62.7851	83.1215
0.406219	-5.47815	30.5	-4.45703	-59.4804	143.816
-11.7171	0.668865	30.5	-15.3598	6.2062	59.3083
-20.9786	-30.5499	30.5	-49.355	-90.2368	126.881

7.6 DetSideways.txt Tungsten

#x	y	z	Px	Py	Pz
#mm	mm	mm	MeV/c	MeV/c	MeV/c
34.1953	36.4785	3.57464	137.008	156.31	57.688
-12.3353	-48.4545	-12.2716	-7.82896	-49.2708	-4.76151
12.5705	48.394	-13.6901	28.6721	132.153	-10.3971
23.8038	43.9702	-19.3521	94.0388	177.309	-59.0443

28.7424	-40.913	18.013	50.0291	-63.4974	27.6876
49.9442	-2.36239	23.0975	65.9485	-5.92377	18.7352
48.7154	11.2612	-10.2928	99.8083	28.4602	4.23063
18.6127	46.4065	25.9262	28.7089	67.6572	31.872
-4.73225	-49.7756	22.5802	-15.0938	-104.593	56.7738
36.5679	34.0997	-22.4204	70.9077	59.9235	-23.477
-43.1618	25.24	9.24518	-95.5207	45.6635	16.3211
-44.953	21.8913	-11.8502	-62.0374	31.9172	-29.4556
-7.56367	-49.4246	-21.97	-15.0483	-92.2452	-17.6047
49.4875	-7.1406	2.80453	78.8595	-4.25191	-4.36037
-42.827	-25.8041	-3.83293	-118.224	-68.1584	27.0273
-4.24092	49.8198	-12.8976	-1.00923	71.8684	1.65397

7.7   50MeV.g4bl

```
#   lengths are in mm, fields is Tesla !  Momentum in MeV

#_____

#----------------------------- Setup ------------------------------#


param nEv=1000000




#physics QGSP_BERT disable=Decay
#physics QGSP_BERT
physics QGSP_INCLXX_HP



#--------------------------- Define World and Beam ------------------
------#

# Set default environment material
param worldMaterial=Vacuum


#BEAM
# 400 MeV proton beam aimed at target center

beam   gaussian   z=-20   meanMomentum=954.263   sigmaP=0   nEvents=$nEv
particle=proton  sigmaX=3  sigmaY=3  meanXp=0.0  meanYp=0.0  sigmaXp=0
sigmaYp=0


# Only pay attention to the following particles (saves on calculation
time)
```

```
particlecolor proton=1,0,0 pi-=0,1,0 mu-=0,0,1
#trackcuts keep=mu-,pi-,proton




#------------------------ Background Color ------------------------
-#


# Scaling GUI view from pg 19 of the manual

g4ui when=4 "/vis/viewer/scaleTo 2 2 2"



#------------------------ Define Beamline Elements ----------------
---------#


# Parameters
param Tw=30 Th=30 Tl=15
param Tw2=30 Th2=40 Tl2=5
param Tm=W
param Tm2=GRAPHITE

box    Target    width=$Tw    height=$Th    length=$Tl    material=$Tm
color=1.0,0.75,0.0
box    Target2   width=$Tw2   height=$Th2   length=$Tl2   material=$Tm2
color=0.75,1.0,0.0

#-------------------- Place Beamline Elements --------------------
#

place Target rename=target z=0.0
place Target2 rename=target z=10

#-------------------- Place Virtual Detectors --------------------
#

# This virtualdetector catches what comes out of the target to the back;
make it yellow
virtualdetector    DetBackward    radius=50    length=1    color=1,1,0
require=PDGid==-211 format=ascii
place DetBackward z=-31

# This virtualdetector catches what comes out of the target to the side;
make it blue
virtualdetector    DetSideways    innerRadius=50    radius=51    length=60
color=0,0,1 require=PDGid==-211 format=ascii
place DetSideways z=0

# This virtualdetector catches what comes out of the target in the forward
direction; make it green
virtualdetector    DetForward    radius=50    length=1    color=0,1,0
require=PDGid==-211 format=ascii
```

```
place DetForward z=31
```

8. References

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