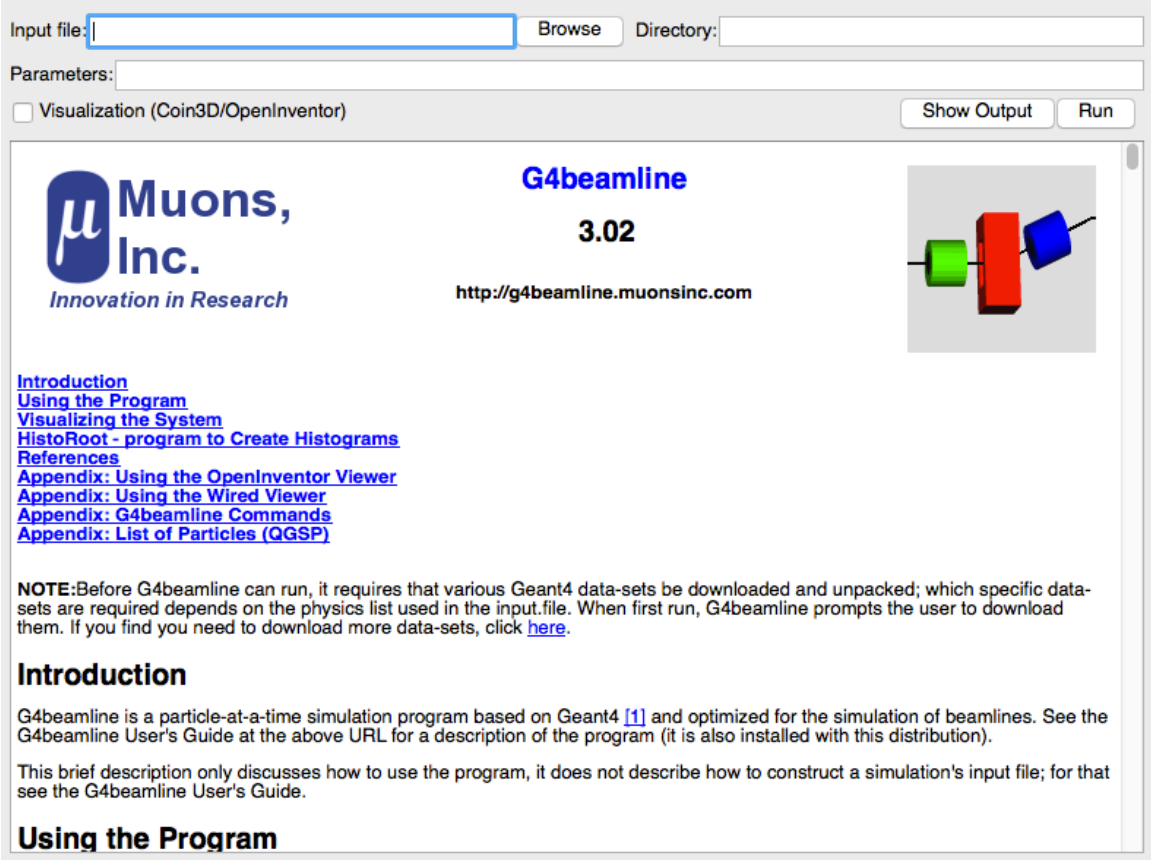
Accelerator Fundamentals Homework 4

1. For this problem, we will revisit the LHC FODO cell from yesterday's homework. This time we'll use the g4beamline simulation program to run the simulation and the HistoRoot program to analyze the data. These programs are installed on the lab computers and the computer lab computers, and there are instructions on how to install them on your own computer on the website. My instructions will assume you are running it on a lab computer, so the details may be different on your computer. G4beamline runs by reading a simple script. Like the MADX simulation, you can download the Main Ring example at the website, under the homework section. I'll assume that you rename it "lhc.g4bl" and then modify it for your purposes. Unlike MADX, G4Beamline uses full quad lengths, and places them at the full half-cell separation (i.e. no explicit "drifts"). Note that the units are a little weird: lengths are in mm, both for the dimensions and for the particle distributions. Angular distributions are in radians. Energy, etc, are in MeV, and magnetic gradients are in T/m, as usual.
    a. Modify the file to reflect the lengths, gradients, and particle distributions that you calculated for the LHC FODO cell in yesterday's homework.

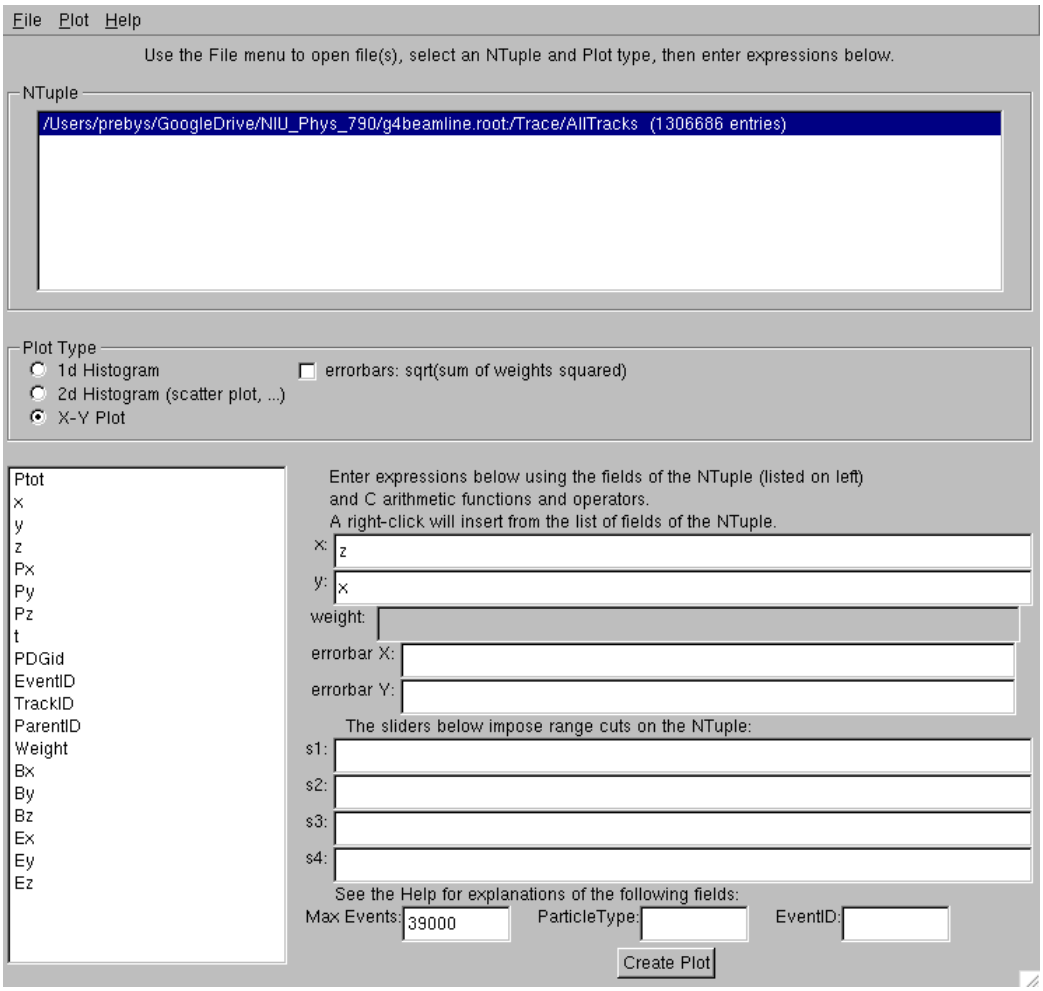
To run G4beamline, invoke the program from the desktop shortcut



The lab computers do not have the visualization option. If your computer has it, please uncheck it, as it will cause the simulation to run 1 event at a time. Browse to select your script file, and click "Run". It will generate 1000 events, which takes a couple of minutes.

The program will produce two files:

- g4beamline.root: This is a file containing tracking information for the first 100 tracks. There are roughly 13000 points per track for this case.
- profile.txt: This file has information on fitted distributions and regular intervals, including the lattice functions. The program doesn't understand beam optics, so it uses the techniques you established in problem 1 to calculate these values.

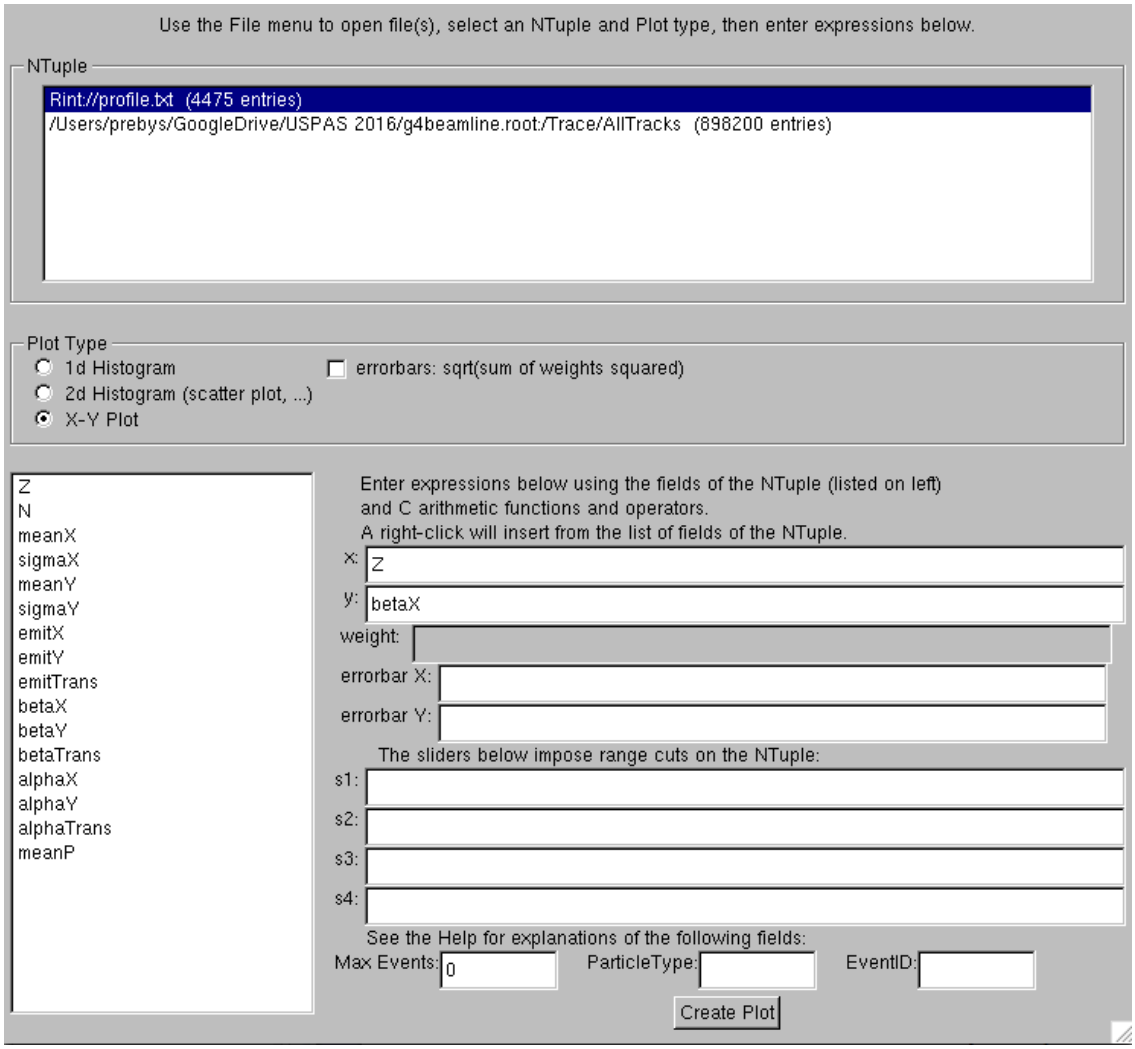


You can analyze these files with the "HistoRoot" program. Start it by clicking the icon. First, open the g4beamline.root file with the file browser[1]. You'll see an "Ntuple" in the list at the top. Select it, and the variables will appear at the left.

[1] For some reason, the lab computers generate an error at this point. Just keep clicking "Try Again", and you'll eventually get the file browser.

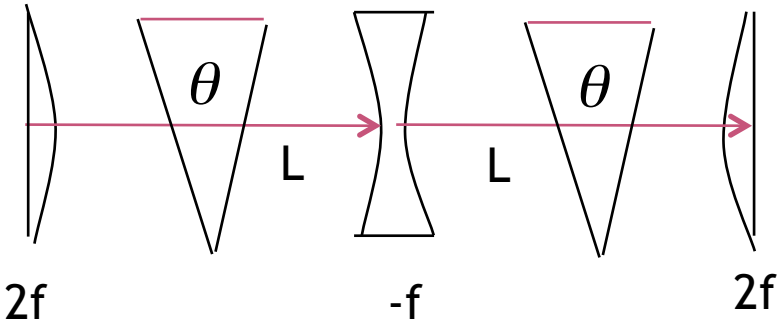
b. Select “X-Y Plot”, and plot *x* vs. *z* (g4beamline uses *z* instead of *s*). Plot the first three events by setting “Max Events” to 39000 (“Events” in this case refer to the individual points on each track.)
c. Clear the “Max. Events” field to plot all points. If you did things right, you should see the periodic behavior of the beam envelope.

Now read in the profile.txt file with the file browser (you will have to explicitly select “.txt” in the file type to see it). A new NTuple “profile.txt” will appear in the list. Select it, and the new variables will appear at the left.



d. Plot *betaX* vs. *Z* and verify that it matches your calculations (this *betaX* is in mm).
e. Plot *alphaX* vs. *Z*.
f. Plot *sigmaX* vs *Z* and compare the maximum and minimum to your calculations.
g. Rerun the g4beamline program, but this time put “beamZ=-1550.” on the Parameters line to start the beam at the beginning of the quad instead of the center. Repeat (b)-(f) to illustrate the effect that this mismatch has on the distributions.

2. Starting for the standard FODO cell with bend sectors that we discussed in class



Show that the dispersion is given by

$$D_{F,D} = \frac{\theta L\left(1 \pm \frac{1}{2}\sin\frac{\mu}{2}\right)}{\sin^2\frac{\mu}{2}}$$

(hint: follow the discussion in the "Off Momentum Particles" lecture and use the symmetry to make a simplifying assumption about *D'*)

3. We have a synchrotron that is 3 km in circumference. This synchrotron is initially not accelerating, and we inject protons at K=10 GeV. After they are injected, they are accelerated from 10 to 100 GeV in 1 second, after which they stop accelerating prior to extraction. The RF system has a harmonic of 588, and a total voltage of 1MV. The transition gamma (γ_t) is 25. You may treat the period as approximately constant (v=c) for this problem.
    a. What is the period of the synchrotron [s]?
    b. What is the frequency of the RF system [Hz]?
    c. What is the slip factor η at the injection energy?
    d. What is the slip factor η at the extraction energy?
    e. What is the synchronous phase angle ϕ_s [degrees] at injection, before the beam starts to accelerate?
    f. What is the synchronous phase angle ϕ_s [degrees] just as beam begins to accelerate?
    g. What is the synchronous phase angle ϕ_s [degrees] just before beam stops accelerating?

    (Hint: for parts (e)-(f), be careful that you put the phase angle at a stable point!)