Phy 790 Accelerator Physics Problem Set

March 20, 2014

We will model a FODO cell which is very close to the actual LHC lattice design.

Part 1: Preliminary Calculations

The LHC is designed to accelerate proton beams to 7 TeV of kinetic energy and collide them. Calculate:

- The momentum p [MeV/c]
- The rigidity $(B\rho)$ [T-m]

Each FODO cell has a full length of 106.9 m (L= 53.45 m) and a phase advance of $\mu = 90°$. Use the equations we derived in class to calculate:

- The required focal length f of the quadrupoles
- The required gradient B' [T/m] of the quadrupoles, given that they are 3.1 m long
- β_{max} at the center of the focusing quads
- β_{min} at the center of the defocusing quads

The *normalized* RMS emittance of the LHC beam is 2.75 μm-radian. Using this and the equation we derived in class, calculate:

- The RMSs of the x and x distributions, σ_x and σ_y [mm].
- The RMSs of the angular distributions $\sigma_{x'}$ and $\sigma_{y'}$.

Part 2: G4beamline Simulation

In G4beamline, set up a beam line as follows:

- Create an LHC quadrupole using the "genericquad" command with
  - ironLength=fieldLength=3100.
  - apertureRadius=28.
  - ironRadius=80.
  - gradient=(what you calculated in Part 1)
- Using these quadrupoles, create 5 LHC FODO cells. Do this by placing 10 of the quadrupoles 53450 mm apart, with the first centered at $z = 0$. The gradients should alternate positive, negative, positive, negative, etc (this is a great opportunity to learn about loops in G4Beamline).
- Create a "gaussian" beam of at least 1000 protons with the sigmaX,sigmaY,sigmaXp, and sigmaYp that you calculated in Part 1.
- Add the following lines to the file

  ```
  trace nTrace=100 oneNTuple=1 primaryOnly=1
  profile zloop=0:500000:100 particle=proton file=profile.txt
  ```

  The first will store full tracking information for the first 100 tracks. This will be stored in the standard ROOT output file in an Ntuple called "AllTracks". The second will generate a text file called "profile.txt" with fitted profiles in both planes every 10 cm, including the calculation of the α and β lattice functions.

Run G4beamline.

Part 3: ROOT Analysis

Using ROOT (or histoROOT) to analyze the output file from the first part:

- Load both the "AllTracks" Ntuple and the profile Ntuple into ROOT. If you're using histoROOT, you can load the profile information straight from the text file. In ROOT, you can import the profile information using the "G4BLProfile" class provided, with

  ```
  root[] .L G4BLProfile.C
  root[] G4BLProfile f("profile.txt");
  root[] TNtuple *n=f.getNtuple();
  ```

- Create a 2D plot to draw on: 0. to 500000. mm in x by -1. to 1. mm in y.[1]
- One at at time, plot the trajectories of the first four or five tracks. You can by plotting x vs z for the AllTracks Ntuple, requiring "EventID==1", "EventID==2", etc, with the "SAME" option to cause it to be superimposed.
- Now superimpose an "envelope" of three times the fitted standard deviation of the beam, from the profile Ntuple, by plotting "3*sigmaX" vs. "Z" and "-3*sigmaX" vs. "Z". What is the relationship of the periodicity of the individual track motion to the periodicity of the beam RMS (hint: think about the phase advance per cell)?
- Superimpose the rest of the tracks.
- Now, in a seperate plot, plot both "betaX" vs. "Z" and "betaY" vs. "Z" for the profile Ntuple. You might want to use different colors to keep them separate.

[1] ROOT makes this seemingly simple operation rather complicated. The easiest way I know to do it is to book an empty TH2F histogram, use SetStats(kFALSE) to turn off the statistics, and plot it.