SPIN@USPAS Summer 2021
Graduate "Polarization in MultiGeV RLAs " Homework

HOME WORK 1

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The purpose of this homework is to optimize the transport in a RLA in order to maximize the polarization at one or more experimental halls.

Due date is June 18, 2021. Grading is on a scale of 0 to 20 pts, points per questions are given in the writeup below.

In a RLA, the spin is prepared and manipulated in the injector proper at low energy using a combination of Wien filters and solenoids. It is usually injected longitudinaly parallel or anti-parallel to the beam. The precession across the machine is calculated and the rotation necessary to achieve maximum polarization in the halls is applied in the injector.

1/ Recall that the Thomas BMT equation which governs the evolution of the spin through the machine can be written as

$$\frac{d\tilde{\mathbf{S}}}{dt} = \frac{q}{m_0\gamma}\vec{\mathbf{S}} \times \vec{\mathbf{\Omega}} \tag{1}$$

$$\vec{\mathbf{\Omega}} = (1 + a\gamma)\vec{B_\perp} + (1 + a)\vec{B_\parallel} \tag{2}$$

We will use the CEBAF accelerator as an example of an RLA machine. It is designed to deliver up to 100 μA of continuous electron beam (CW) with polarization of up to 86%. The beam is generated at the cathode of an electron gun by shinning a circularly polarized laser light on it. The electrons produced by photoemission are polarized longitudinally (by virtue of conservation of helicity).

Figure 1 gives the topology of this machine. After the beam is generated in the injector it is accelerated by traversing two linacs oriented in opposite directions and connected by recirculating arcs bending horizontally 180 degrees. This can occur up to five times (10 linac traversals). At each pass, one of the beam bunches (We will consider three bunch trains for simplification) can be kicked and extracted towards a switchyard which further bends it into the chosen hall by +37.5 degrees for Hall A and -37.5 degrees for Hall C.

for the remainder of this exercise, we will denote the accelerating gains in the injector, north linac and south linac by E_0, E_1 and E_2 respectively and the bending on the east, west and beam swichyard areas by θ_1, θ_2 and θ_h.

2/ **1 Pt** Using equation 2 write the expression for the spin angle precession. Show that by using the notations above, it can be rewritten as

$$\phi_n = \frac{a}{m_e}[(n\theta_1 + (n-1)\theta_2)E_0 + \frac{n}{2}((n+1)\theta_1 + (n-1)\theta_2)E_1 + \frac{n(n-1)}{2}(\theta_1 + \theta_2)E_2 + (E_0 + n(E_1 + E_2))\theta_h] \tag{3}$$

What assumptions did you have to make to write the equation in this form?

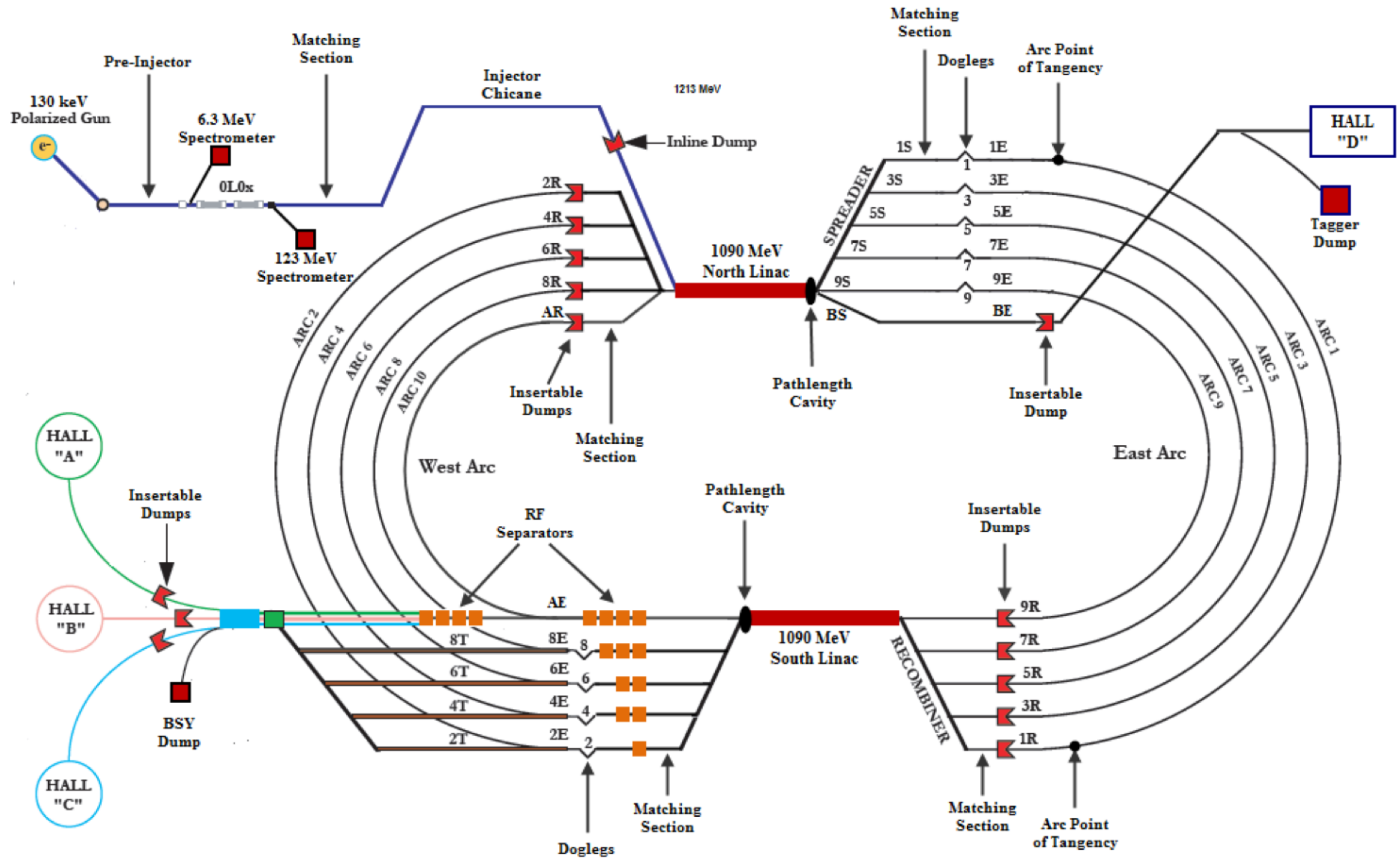

Figure 1: CEBAF recirculator.

3/ **2 Pts** Calculate the horizontal Wien filter rotation needed to maximize the longitudinal spin in Hall A at first pass for linacs set to 700 MeV.

Note that because of geometry constraints in the machine, one has to set the injector acceleration to a fraction 0.1125 of that of the linac gain.

5/ **4 Pts** Consider Hall A and Hall B together. Assuming that we can send both of them to pass 1, show that the condition for maximizing the longitudinal spin in both halls is equivalent to requiring specific linac gains such that the spin precession between these two halls is a multiple of π.

Give the required linac acceleration to achieve this configuration.

Hint: Linac gains can be varied between 500 and 1090 MeV and there is only one such solution in this range.

Finally, calculate the spin rotation which produces maximum polarization in these two halls under the energy gain conditions derived above.

6/ The CEBAF spin manipulation system is made up of two Wien filters and a pair of solenoids. In this exercise we will just consider the evolution of the spin vectors and ignore the transverse matching which is provided by the quadrupoles you see in this schematic in figure 2.

Each Wien filter has an effective length of 0.3095 m. The incoming electron beam is longitudinally polarized with a kinetic energy of 130 KeV. That first Wien filter (dubbed the vertical Wien) rotates spin around an axis perpendicular to the beam direction in the horizontal plane. Each solenoid has a physical length of 5.91 inches. Figure 3 shows the on-axis field normalized for one Ampere.

6.1/ **2 Pts** Calculate the settings required for the electric field and magnetic field in the first Wien filter to rotate the spin vector $\frac{\pi}{2}$ so that it is oriented in vertical. The incoming electron is longitudinally polarized and has a kinetic energy of 130 KeV.

6.2/ **2 Pts** Calculate the settings required in the spin solenoids for the magnetic field to rotate the spin vector back in the horizontal plane and perpendicular to the beam direction.

6.3/ **2 Pts** Calculate the settings required in the second Wien filter to achieve the final rotation which rotates the

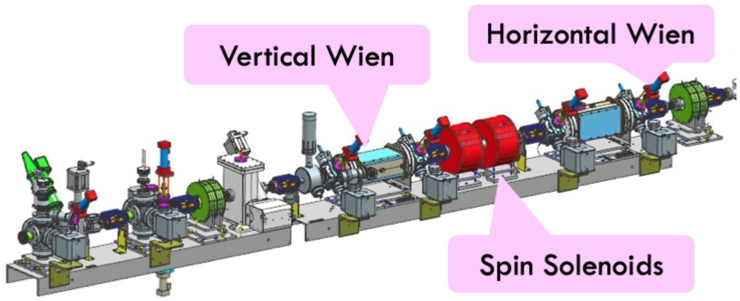

Figure 2: The double Wien filter setup

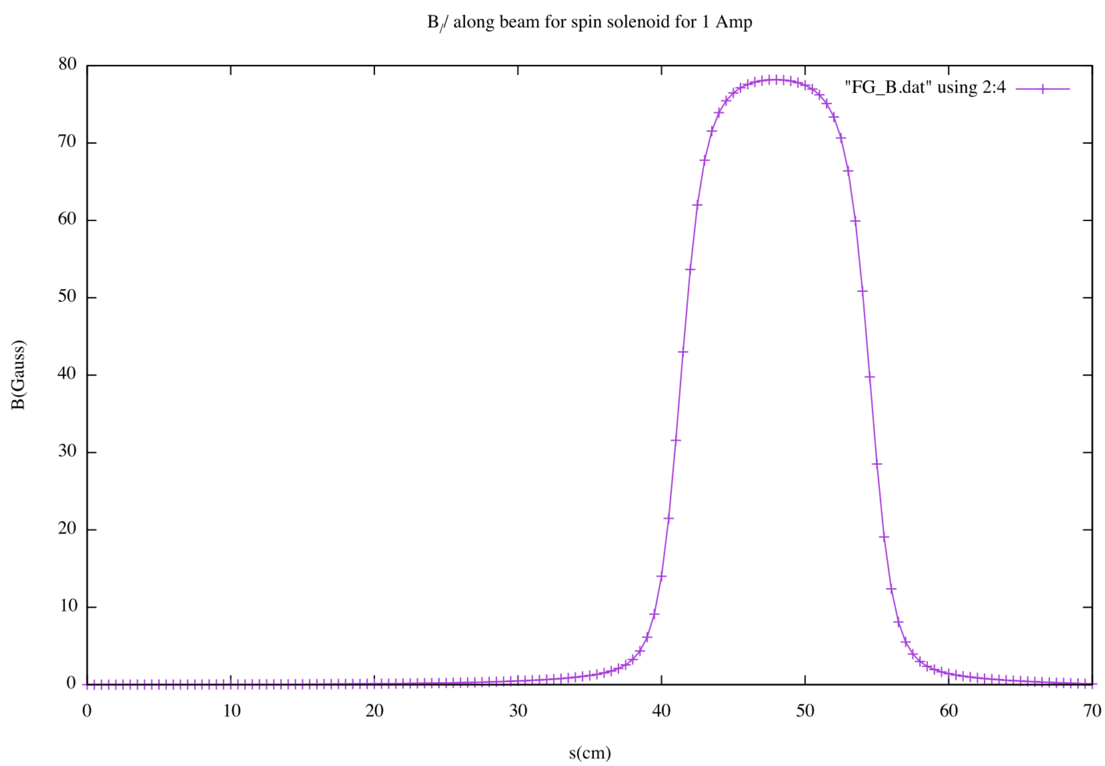

Figure 3: The double Wien filter setup

spin around the vertical axis.

7/ **4 Pts** Construct a zgoubi model for this double wien setup. You can refer to F. Meot's exercise on Wien filters as a starting point. Here, you need two Wien filters and two solenoids. These solenoids can be modeled using a 'SOLENOID' element or alternatively, using the field profile provided and a BREVOL element. A less realistic but easier approach is to use a 'SPINR' to model the solenoids.

Full points for using 'SOLENOID' or 'BREVOL', half points for using 'SPINR' and **4 Pts** bonus if you can give the three solutions.

Check that they all produce the same spin component for a particle injected with Sx=1.0

What are the pro and cons of each method?

8) **2 Pts** using the zgoubi files for Hall A and Hall B at pass 1, edit them to inject the spin vector (SPNTRK command) in the orientation calculated above and accelerate the beam with the gains calculated in 4/. Hints: You can change the incoming reference rigidity. and adjust the SCALING command to set the fields in the injector. The linac gains can be set by using a text editor and substituting the cavity gains by the required gains in the zgoubi file. You will notice there is two types of cavities. Those that are 50 cm long (160 of them) and those that are 70 cm long (40

of them). The file you were provided has been set to accelerate 700 MeV. In order to use another acceleration, simply scale those cavity gradients by newmomentum/700 .

Transport the spin and show that it is maximized for both halls.