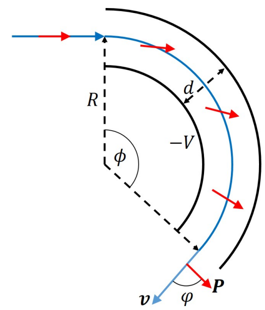

Figure 14: Electron beam trajectory and spin procession in electrostatic field in the spin rotator

For 300 keV beam, $\gamma = 1.587$, thus $V = 244.513\frac{d}{R}(kV)$.The typical aperture d is 10 cm, R is 1 meter, then the bending plates will be applied ±24.4 kV.

2.6.3 Design for scattering chamber

The calculated sherman function and differential cross section for scattering with gold nuclei is shown in Figure 11. The detectors are usually set at the scattering angle with maximum Sherman function. For the kinetic energy of the electron beam is 300 keV, the scattering angle at the maximum Sherman function $\theta = 136^{\circ}$, with the maximum Sherman function $S(\theta) = 0.4665$.

This Sherman function $S(\theta)$ is only known for single scattering, however the practical Sherman function S_{eff} is always smaller than $S(\theta)$ because of the effects of multiple and plural scattering in the target foil which is sensitive to the thickness of the target foil. Thus, the practical effective Sherman function is also a function of the thickness of the target foil.

The way to achieve the effective Sherman function is: first, determining the theoretical Sherman function $S(\theta)$ for single scattering process; second, correctly measuring the Asymetry for all targets with different thickness by achievement of pure energy spectra; and third, extrapolating the foil thickness to zero to compare with $S(\theta)$.

The detector count rate (R) is evaluated by

$$R(\theta) = I(\theta)\rho_{Au}d_{foil}\frac{N_A}{M_{Au}}\frac{I_{beam}}{e}\Delta\Omega \tag{2.8}$$

Time needed to measure beam polarization of P to statistical error of $\Delta P/P$ is evaluated by

$$T = \frac{2N}{R} \approx \frac{1}{2R(\Delta A)^2} = \frac{1}{2R(S(\theta)\Delta P)^2} \tag{2.9}$$

For $\Delta\Omega = 0.18msr$, $R(136^{\circ}) = 1.69 \times 10^3 Hz/(nA \cdot \mu m)$, and the corresponding count time $T = 1.36s$ for $\Delta P = 0.1\%$.

2.7 Wien filter

A spin rotator is necessary in preinjector to rotate the electron beam spin direction from longitudinal to transverse. The Wien filter could rotate the electron spin direction at low energy and has advantage on large energy acceptance compare to arcing spin rotator. Our conceptual design of the wien filter is similar to that of Mainz and Jlab. Opera 3D was used to model and generate 3D statics electric and magnetic field. Simulated fields were used in GPT to track a 10 nC, 1.2 ns bunch through the filter. In order to rotate the spin 90 degrees, the particles travel through a distance in homogenous magnetic and electric fields. The B field and E fields are perpendicular to each other and both are perpendicular to the direction of particle trajectory. Since spin precesses around the magnetic field, a transverse B field (in the Y direction) will align the particle spin from longitudinal (Z direction) to transverse ZX plane. However, a Y directional B field alone will also deflect the particle in the X direction. To nullify this displacement, a X directional E field is applied. Figure 1 shows the model of the wien filter generated in Opera 3D.

2.7.1 Opera 3D and GPT simulation

In a cross electric and magnetic field, for the the particle to have no deflection, the force equilibrium condition leads to

$$\vec{E} = \vec{B} \times \vec{v} \tag{2.10}$$

Using the above equation, the spin rotation angle, Θ, can be calculated from the Thomas-BMT equation as,

$$B \cdot L = mc\gamma^2 \beta\Theta/e \tag{2.11}$$

where L is the effective magnetic field length,γ is the relativistic Lorentz factor and $\beta = \mathrm{v/c}$. In our particular case, the electron energy is 350 keV, $\gamma = 1.168$ and $\beta = 0.8048$. Using these values and the required $\Theta = 90^\circ$, the paramters B, L and E were calculated and shown in table 2.6. Since the bunch charge is high, there is a risk of beam loss over long distances without a focusing lens. Hence, we decided to use three wien filters, each corresponding to a 30 degree rotation over 0.5 m of effective length. Solenoids and X-Y trim magnets were used before each of the filters to ensure no beam loss and on axis trajectory. For a specific value of L and B, the electric field can be calculated using equation 2.2. In order to chose a realistic value of L and E, we need to consider that the bunch charge is 10 nC which is orders of magnitudes higher compared to Mainz or Jlab. Space charge forces would be dominant leading to beam loss over long distance without a focusing solenoid. We also need to have a higher gap length between the electrostatic condenser plates. However the gap cannot be too high since that would mean higher and higher voltage and we are limited by the available HV feedthrus. Therefore, we decided to apply three wien filters, each for 30 degrees rotation, in series. The wien filter parameters used in the simulation are listed in table 2.6.

Table 6: Parameters for wien filter

Bunch charge	Bunch Length	L	E_x	B_y	HV gap
10 nC	1.2 ns	0.5m	0.98MV/m	0.00407T	5 cm

The E and B fields were simulated in Opera 3D and then transported to GPT for particle tracking. The fields on the Z axis through the center of the wien filter is shown in figure 2.10. The generated fields corresponds to a rotation of 30 degrees over 0.5 meter of effective length. The E fringe fields have a shorter extension compared to the B fringe fields. This leads to a kick in the X direction to the beam on the entry and exit of wien filter. This kick can be minimized by optimizing the electrodes' geometry. For this simulation, the geometry was optimized to achieve down to 2mm of kick in the x direction.

Figure 2.11 shows the central beam trajectory of the bunch through the three wien filters, solenoids and trim magnets. Solenoid to solenoid distance is 1 m and three solenoids are used at locations before

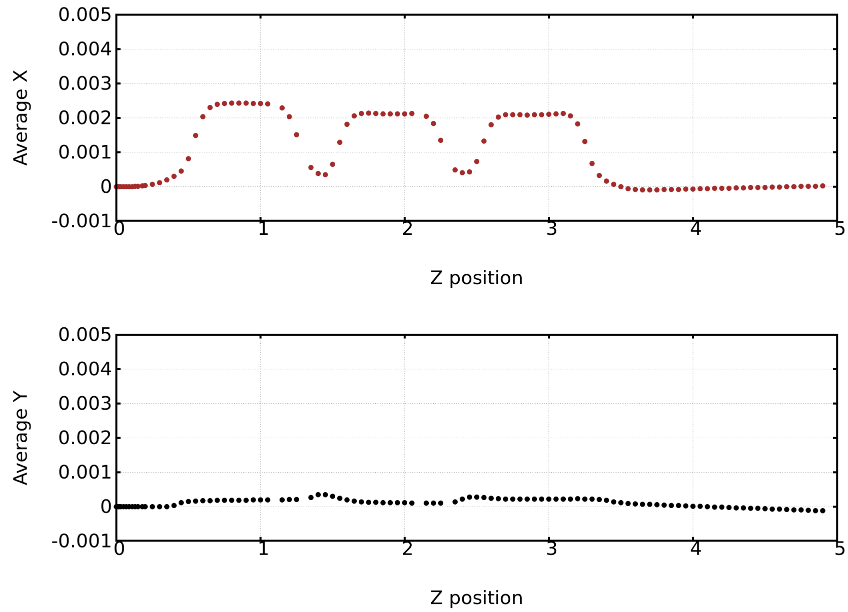

Figure 15: Average beam position of a 10 nC 1.2 ns bunch through the wien filters, simulated using GPT

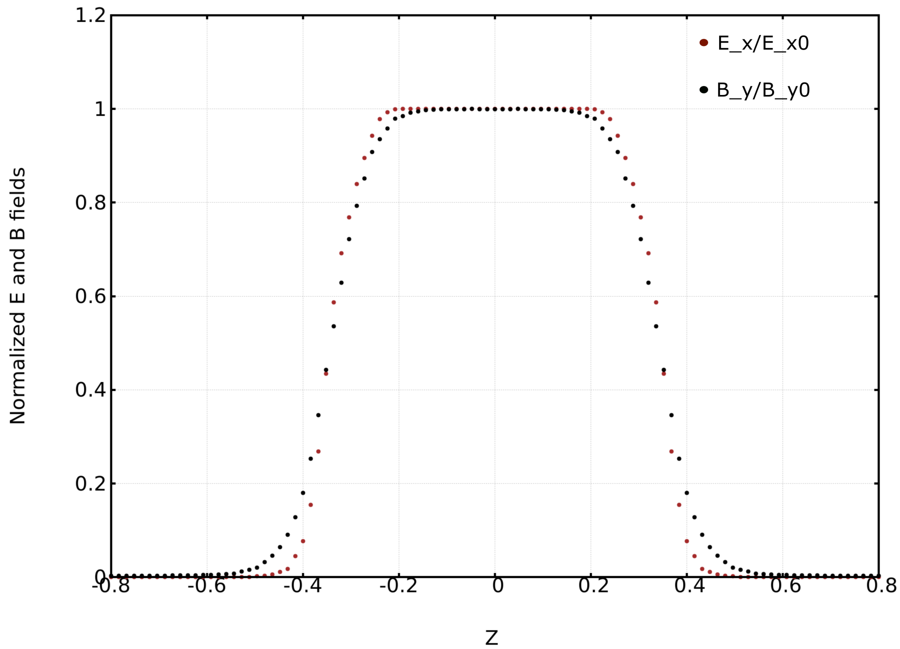

Figure 16: Normalized E and B fields on the axis of the filter, generated using Opera 3D

1st filter, between 1st and 2nd, and between 2nd and 3rd filter. A triplet after the third filter was used to match α and beta functions. The maximum deviation on X axis is about 2.3 mm. The Y trim magnet pairs were used to compensate for the y direction deviation which caused by the overlapping of the wien filter and solenoid fringe fields. The aperture of wien filter is X times of maximum beam size. The transverse emittance increase by X for x direction and Y for y direction when beam pass through the spin rotators.

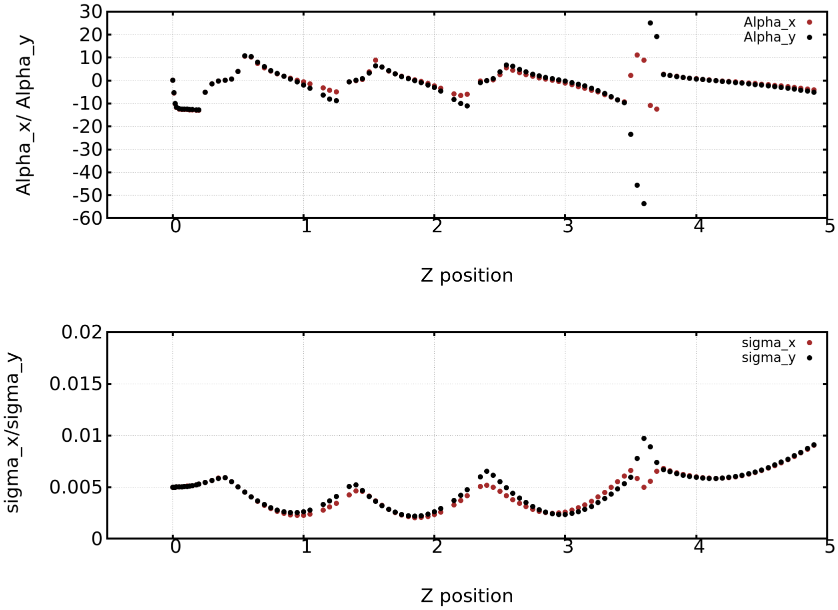

Figure 17: α and σ of the bunch passing through the wien filters

Even the simulation shows the results are promising, we still consider the wien filter is a high risk item. So far, it was not demonstrated for 350 keV and 10 nC beam in a existing machine. We consider it as a back up plan, recently.

2.8 Beam diagnostics Requirement and Instrumentation Specifications

The following parameters should be measured in pre-injector: Charge, bunch length, beam energy, beam profile, beam position and beam loss. In pre-injector, there are two diagnostics beamline, one is after the gun dipole magnets with beam energy of 300-350 keV, another one is after the first spin rotator at 400 MeV.

- BPM

  The four buttons BPMs will be placed after the gun, after first dipole, after the bunching section and between each of TMP Linacs.These BMPs should provide less than $100\mu m$ beam position measurement accuracy. The first BPM buttons will have ion cleaning electrodes for preventing ions from down stream beamline. The acquisition electronics should be capable of 1Hz mode and 28 MHz bunch train mode.

- Current transformers(CT)

  Beam current transformers will provide intensity measurement for the beam in pre-injector. The fast current transformers(FCT) will be install after the gun and before get into the bunching section for both bunch charge measurement and bunch length measurement. The bunch length from the gun is about 1.5 ns. After the bunching section, Integrated current transformer(ICT) will in installed between each Linac tank. The requist measurement accuracy should be less than 1%. The ICT could use for estimating the beam loss after each components.

- Beam profile monitor