THE GUN SPECTROMETER DESIGN FOR THE FERMI@ELETTRA PROJECT

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Abstract

In the FERMI linac layout the first spectrometer has been located close to the exit of the photoinjector gun at about 5 MeV. The main purpose of this equipment is measuring the energy and energy spread of the beam. Combining the spectrometer with Yag screens and Cerenkov radiators allows the investigation and characterization of eventual deterioration of the longitudinal profile due to the space charge forces and microbunching instabilities. The design specification of the magnet and multi-particle tracking code simulation results are presented in this paper.

INTRODUCTION

The FERMI photo-injector gun [1] has been built and it is now in the MAX-lab, at Lund, in order to perform RF high power tests and a preliminary commissioning with the driven laser [2]. Diagnostics have been designed and inserted in the gun-to-first accelerating section in order to tune the injector parameters and achieve the specified performance. In this framework the spectrometer at the gun exit plays an important role to accurately know the peak field of the gun accelerating gradient and the injection phase. The energy of the bunch has to be known with an error less than 0.1 %. Figure 1 shows a schematic layout of the gun spectrometer diagnostic beam line. The best spectrometer configuration to guarantee the highest resolution would foresee a quadrupole before the bending magnet [3] but the space budget constraints forced us to remove it. By the way the bunch at the exit of the gun has a correlated energy spread of few percent which allows it to be dispersed enough to satisfy the required resolution. For the same reason even the bending angle can be relaxed and we set it at 60 deg. This choice leads the great advantage to reduce the peak field of the bending magnet and consequently the magnetic fringe fields, which are an issue at 5 MeV.
The beam energy measurements will be performed generally at low charge, but it could be interesting to operate the spectrometer even at high charge, to investigate the effects induced by the space charge forces. Thus to compensate the blow up of the bunch due to the space charge defocusing an additional quadrupole is inserted just at the exit of the bending magnet. Since the bending magnet provides a focusing on the y-plane, it is not necessary to insert a vertical focusing quadrupole.

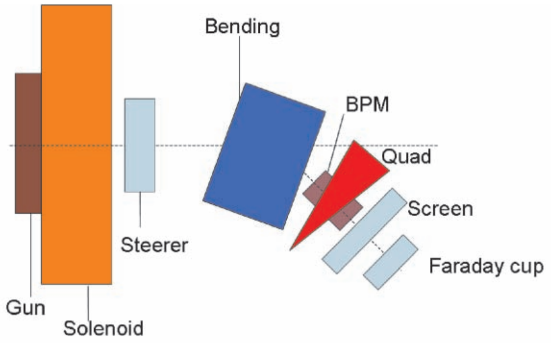

Figure 1: Schematic layout of the spectrometer beam line

MAGNETIC DESIGN

The bending magnetic design has been the result of the optimization and balance of physics requirements and layout constraints. In order to accommodate all diagnostics in between the gun and the first accelerator structure, the trajectories cross is placed at about 1 m from the cathode. Table 1 reports the main bending magnet parameters.

Table 1: Bending magnet main parameters.

Bend angle	60 deg
Magnetic length	0.195 m
Bend radius	0.186 m
Gap Height	42 mm
Nominal peak field (at 5.2 MeV)/ Max. Peak Field (at 7MeV)	0.98 kG/ 1.32 kG
Nominal/Max. Integrated field	181 / 248 $G \cdot m$

One of the main physics request is that particles with the same energy but having a transversal displacement have to be bended in the same way. This means that the quadrupole integrated field along the beam trajectory is specified to be very small, in details of the order of 0.2% with respect to the integrated field on the nominal trajectory. Since the bunch energy is about 5MeV, an accurate study of the quadrupole components even in the fringe fields was carried on. Acting on the chanfer of the iron yoke we minimized the variation between the integrated field sampled by particles on the nominal trajectory and particles on parallel trajectories with a horizontal displacement up to 20mm. Figure 2(a) shows the integrated field variation for three types of chamfer calculated along trajectories parallel to

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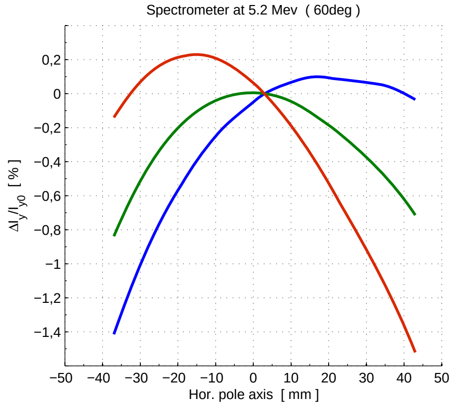
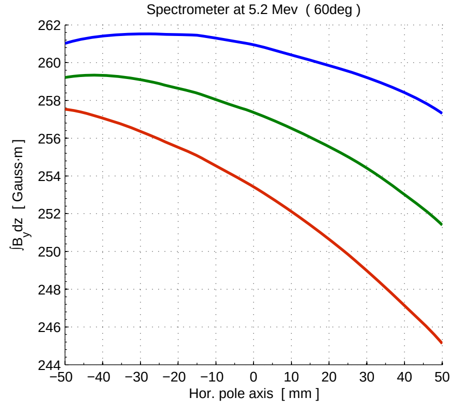
the nominal one: to minimize this integrated field variation, we have to impose a quadrupole component along the z-axis, as shown in figure 2(b).



(a) where $I_0 = \left(\int B_y dl\right)_{x=x_0}$ and $\Delta I_y = \int B_y dl - I_0$



(b)

Figure 2: Integrated quadrupole field variation along parallel trajectories (a) and along z-axis (b) for three different dimensions of the trapezoidal chamfers.

The optimized magnet design is reported in figure 3.

TRACKING CODE SIMULATION

Tracking code simulations of electron bunches coming from the FERMI gun at different injection phase and energy have been performed by using GPT [4]. We used the 3D magnetic fields provided by TOSCA [5] to evaluate the fringe fields effects.

A low charge flat-top bunch launched with RF gun phase varying from -8deg to +8deg with respect to the nominal one has been tracked along the spectrometer beam line. The horizontal profile at the spectrometer screen and the energy distribution along the bunch are reported in Figure 4.

The good linearity between the screen images and the energy spread is proved by the correlation between the Figure 4(a) and Figure 4(b).

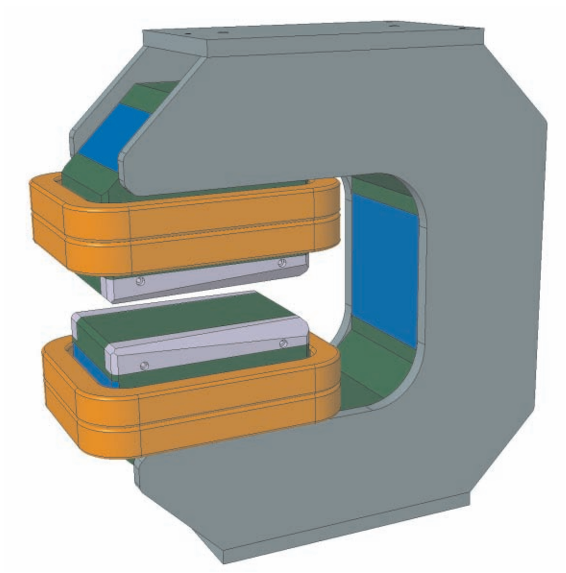
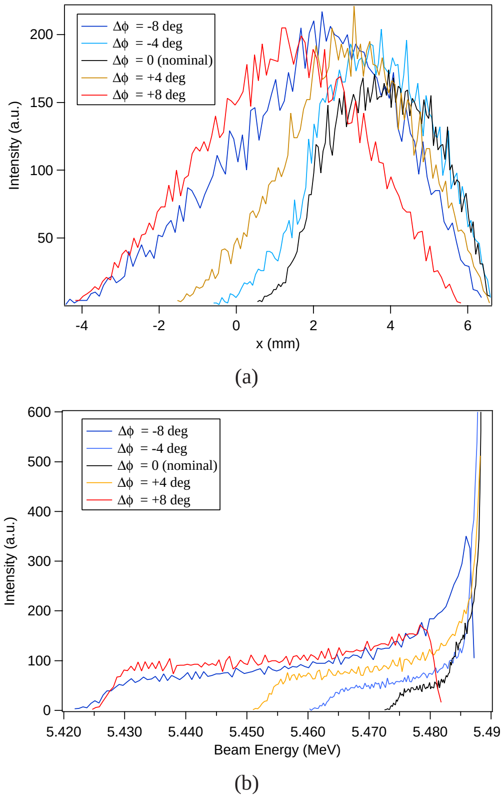


Figure 3: 3D bending magnet design.



(a)

(b)

Figure 4: Horizontal profile at the spectrometer screen (a) and bunch energy distribution (b) for a low charge flat-top bunch tracked through the spectrometer beam line.

Considering the same flat-top bunch but with the nominal charge of 0.8nC, the space charge forces introduce a large defocusing effect. At the nominal RF gun phase, the horizontal displacement increases from about 6 mm (peak to peak) to about 30 mm. Figure 5 shows the horizontal displacement at the spectrometer screen obtained for three RF gun phase. Moreover the space charge forces change the energy distribution in the bunch and this is visible in the $\Delta\phi = -8deg$ case. In fact without space charge the bunch is more displaced when $\Delta\phi = -8deg$ than in the nominal one, while at high charge the situation is reversed.

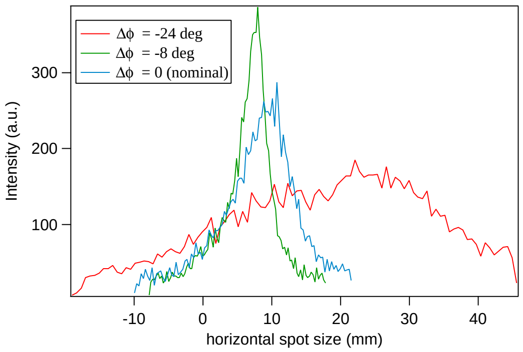


Figure 5: Horizontal displacement at the spectrometer screen for a high charge flat-top bunch.

The relative energy spread of the bunch at the gun exit for $\Delta\phi = -24deg$ is about 10% and it is necessary to switch on the quadrupole of the spectrometer beam line. In this condition when the bunch passes throught the quadrupole, chromatic effects have to be taken into account during the screen images analysis, to accurately evaluate the energy spread.

The nominal electron bunch produced by the FERMI photoinjector is a 800pC-10ps bunch with a ramped longitudinal profile [1, 6, 7] and the spectrometer can be very useful to check and control the efficiency in producing the desired ramping current distribution. In order to avoid distortion introduce by the space charge effects, we consider a low charge bunch with the nominal ramped profile. The RF gun phase is set far off crest to superimpose a very linear energy correlation in the bunch, as shown in figure 6. Particles on the head of the bunch are more energetic so they will be bended less than particles on the tail. Figure 7 shows that the ramped longitudinal profile is reproduced at the spectrometer screen. Since the high resolution of the screen, this measurement resolves the longitudinal profile better than 0.2ps, which is better than a commercial streak camera.

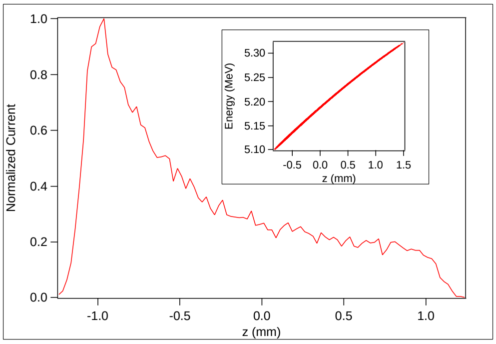


Figure 6: Ramped longitudinal profile and longitudinal phase space of the FERMI bunch at 50cm from the cathode.

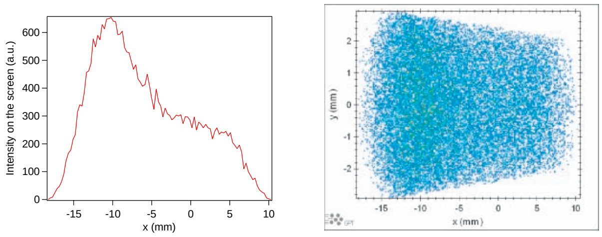


Figure 7: Spectrometer screen image (on the right) and horizontal profile (on the left) resulting from simulation of the ramped profile of Figure 6.

CONCLUSION

The FERMI gun spectrometer bending magnet design and optimization has been carried out. Tracking code simulation of the 3D magnetic field have been performed, and the results show the good linearity between the energy spread of the bunch and the spectrometer screen images. Moreover in the FERMI project case the gun spectrometer can be a valid diagnostic tool to verify and controll the efficiency in producing the desired ramped longitudinal profile.

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