DESIGN AND SIMULATION OF EMITTANCE MEASUREMENT WITH MULTI-SLIT FOR LEReC *

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Abstract

To improve the luminosity of beam energy scan of low energy Au-Au collision, a electron machine is under construction to cool ion beams in both RHIC rings with pulsed electron beam. Over the course of the project, a multi-slit device is needed to characterize the transverse beam emittance of three energies, 0.4, 1.6 and 2.6 MeV. This report shows the optimization and compromise of the design, which include the slit width, slit spacing, and drift space from the multi-slit to the downstream profile monitor.

INTRODUCTION

Mapping the QCD phase diagram is one of the fundamental goals of heavy-ion collision experiments [1]. In the past, Au-Au collision with various energies (Beam Energy Scan/BES-I) has been provided for the experiments in RHIC [2]. Driven by the physics and BES-I results, future physics program with higher luminosity goals called BES-II is proposed for Au-Au center-of-mass energy below 20 GeV [3]. The role of electron cooling [4] for the lowest energy points is to counteract intrabeam scattering (IBS): this prevents transverse emittance growth and intensity loss from the RF bucket due to the longitudinal IBS.

An electron accelerator (Fig. 1) is being constructed to provide Low Energy RHIC electron Cooling (LEReC) and will provide a beam to cool both the blue and yellow RHIC ion beams by co-propagating a 10~50 mA electron beam of 1.6~2.6 MeV [5] with the ion beams. The electron accelerator consists a DC gun which provides 0.4 MeV beam and a Booster cavity which provides an energy gain of either ~1.2 or ~2.2 MeV.

Over the course of the project, beam emittance measurement is required for three beam energies, 0.4, 1.6 and 2.6 MeV in the injection line [6]. Due to space and budget limitation, it's desirable to use a single device for all the measurements. Since the beam is space charge dominated, the multi-slit and single slit options are considered to avoid the complication of space charge force.

EMITTANCE MEASUREMENT OVERVIEW

The principle of emittance measurement with multi-slit was presented in [7]. The electron beam was intercepted by the multi-slit flag so that emittance dominated beam-lets pass through and project onto the downstream profile monitor (PM). Based on the width of the individual stripes on the profile monitor and some geometrical information, the beam emittance at the flag can be reconstructed.

With a single slit device, one can either move the slit across the beam or move the beam relative to the slit and record multiple snap shots of the projected stripe on the downstream monitor. The advantage of a single slit device is that the step size (equivalent to the slit spacing in multi-slit device) is adjustable, and there is no concern of stripes overlapping with each other on the profile monitor like for the multi-slit case. However, it requires additional hardware to move the beam or the flag with good precision.

SIMULATION

To optimize a multi-slit design common for all the three energies, we started to optimize the individual design for each energy. In the following simulations, the beam distributions were from the output of PAMELA simulation with space charge.

There are some general design considerations for optimization of the multi-slit device. The thickness of the flag should be large enough to stop most of the particles. The slit width should be small, negligible compared to the size of the stripes on profile monitor. The ratio of slit width to thickness should not be smaller than the divergence of the beam. The drift space should be enough for beam-lets to diverge, not too much that the stripes on the profile monitor overlap with each other. The downstream profile monitor should be large enough for diverged beam-lets.

The projection of the stripes on the profile monitor and its multiple Gaussian peak fit for energy of 0.4 MeV are shown in Fig 2. Only 7 main beam stripes were projected in the horizontal plane. The slit width was 0.15 mm, slit spacing was 2.5 mm and the drift space was 2 m. A 2 inch size profile monitor is required at this energy to accommodate the entire beam.

The projection of the stripes on the profile monitor and its multiple Gaussian peak fit for energy of 1.6 MeV are shown in Fig. 3. The slit width was 0.15 mm, slit spacing was 1.2 mm and the drift space was 1 m. The particles with large horizontal displacement have larger uncorrelated beam divergence due to space charge force. The drift length was chosen so that the visible stripes are not overlapping with each other. The stripes even further away from the center will overlap.

The projection of the stripes on the profile monitor and its multiple Gaussian peak fit for energy of 2.6 MeV are shown in Fig. 4. The slit width was 0.15 mm, slit spacing was 2 mm and the drift space was 2 m. With higher energy, the beam divergence is smaller so that with limited drift length

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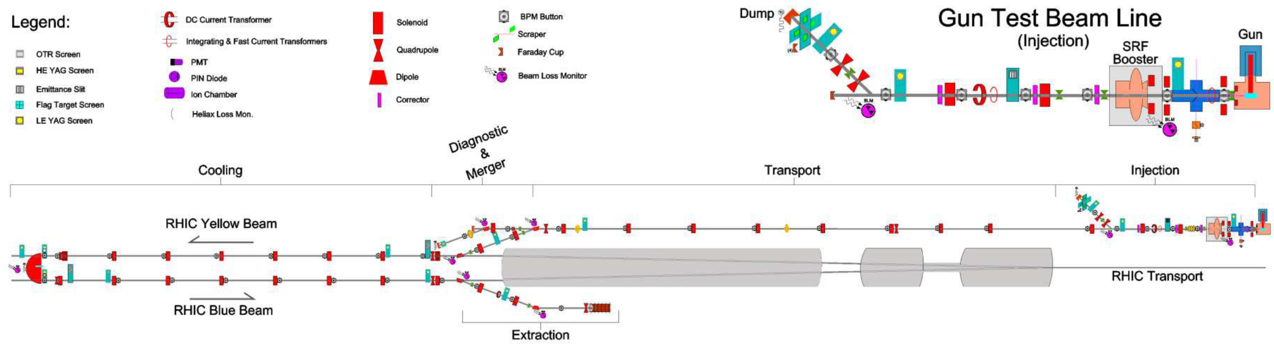

Figure 1: Layout of LEReC electron accelerator showing the five sections. An enlarged view of the injection section as it will be set up during the Gun Test is shown on the right.

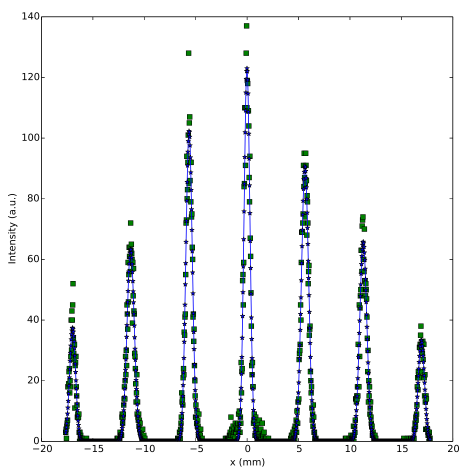

Figure 2: The horizontal projection of the beam stripes on the profile monitor for beam energy of 0.4 MeV, and the multiple Gaussian peak fitting of the projection.

the beam stripes are narrow and have no interference with each other.

The emittances of the three energies are listed in Table 1. The real emittance is calculated from beam distribution of all the particles. The sampled emittance is the one of the particles that pass through the slits. The measured emittance is reconstructed from the image on the profile monitor and other geometrical information. The relative error between the sampled and measured emittances are shown as measurement accuracy. The discrepancy between the real and sampled emittance is resulted from the facts that the particles are under-sampled and only seven beam stripes were included in the analysis. The discrepancy between sampled and measured emittances comes from the facts that the drift length is limited to be 2 m or even less, and the beam stripes were fitted with Gaussian functions which may not be the best description of the distribution, especially with the phase space distribution distorted by space charge force.

As can be seen from Table 1, the measurement using multi-slits with optimized parameters for individual energies is not with high accuracy. A common multi-slit device for all three energies is expected to render even less accurate measurements.

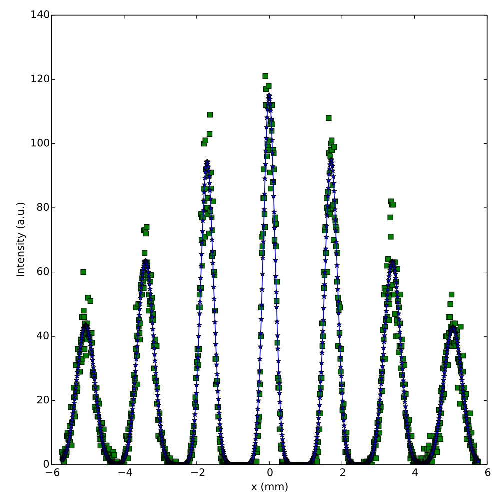

Figure 3: The horizontal projection of the beam stripes on the profile monitor for beam energy of 1.6 MeV, and the multiple Gaussian peak fitting of the projection.

Table 1: Beam Emittance in The Simulation of Multi-slit Emittance Measurement With Design Optimized For Three Individual Energies

	0.4 MeV	**1.6 MeV**	**2.6 MeV**
Real emittance	0.655	0.494	0.317
Sampled emittance	0.630	0.363	0.317
Measured emittance	0.623	0.312	0.369
Measurement accuracy	1.1%	14.0%	16.4%

A single slit device was considered as a better choice in terms of measurement accuracy due to the flexibility of step size and drift length. However, the decision was made to use a common multi-slit device based on schedule and cost limitation.

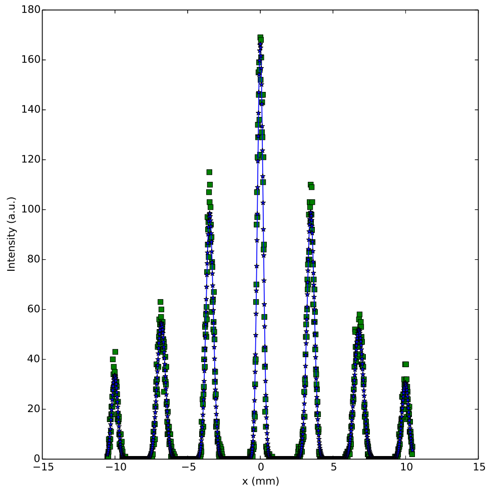

Figure 4: The horizontal projection of the beam stripes on the profile monitor for beam energy of 2.6 MeV, and the multiple Gaussian peak fitting of the projection.

Using a common multi-slit device with slit width 0.15 mm, 1.5 mm slit spacing and 2 m drift length (limited by space), the emittances from the simulation are listed in Table 2.

Table 2: Beam Emittance in The Simulation of Multi-slit Emittance Measurement With a Common Design For Beams of All Three Energies

	0.4 MeV	**1.6 MeV**	**2.6 MeV**
Real emittance	0.655	0.494	0.317
Sampled emittance	0.465	0.437	0.260
Measured emittance	0.465	0.345	0.331
Measurement accuracy	0.0%	21.1%	27.3%

SUMMARY

In order to measure the emittance of three different energies at the injection line of LEReC, multi-slit device for each energy was designed and simulated. The discrepancies of the real emittance, sampled emittance and measured emittance were shown and explained. A common device for all three energies was designed based on the parameters of the three individual designs. The performance was not as good as individual designs as expected. The emittance from the simulation and measurement accuracy for all energies were shown as well. Due to the schedule of the LEReC project and the fact one need to measure the emittance with good precision instead of accuracy, the common multi-slit design was accepted.

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