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RHIC ELECTRON LENSES UPGRADES *

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Abstract

In the Relativistic Heavy Ion Collider (RHIC) 100 GeV polarized proton run in 2015[1], two electron lenses [2] were used to partially compensate for the head-on beam-beam effect for the first time. Here, we describe the design of the current electron lens, detailing the hardware modifications made after the 2014 commissioning run with heavy ions. A new electron gun with 15-mm diameter cathode is characterized. The electron beam transverse profile was measured using a YAG screen and fitted with a Gaussian distribution. During operation, the overlap of the electron and proton beams was achieved using the electron backscattering detector in conjunction with an automated orbit control program.

INTRODUCTION

Figure 1 schematically depicts the layout of the electron lens in the operational synoptic display and the parameters that we used during the 2015 run. At the top of the figure, we show the layout of magnets and their names, including their current controls. Vacuum values and proton-beam losses are also given. At the bottom of the figure, the parameters for the electron beam current, the energy and timing control, as well as the statuses of the e-lens system and the proton beam are displayed.

While in the commissioning run[3] , the electron beam was modulated at the 78 kHz revolution frequency to allow parasitic commissioning with the e-lens acting on only a few ion bunches, for the e-lens operation during the 2015 100 GeV polarized proton run, we used a DC electron beam for beam-beam compensation.

We developed a new lattice for the proton beam based on ATS optics [4], which assures the correct phase advance between the E-lenses and the PHENIX experiment and reduces the second order chromaticity so providing larger dynamic aperture. The lattice has $\beta_{x,y}$ = 15 m at the center of each lens where the electron beam and proton beam collide head-on. We designed a new cathode for the electron beam with a larger radius of 7. 5 mm (formerly, it was 4.1 mm) [5] and machined it to match the size of the proton beam.

After improving the blue superconducting magnet inner cooling system, both the blue and yellow solenoids can run at the design of 6 tesla magnetic field using the RHIC helium system.

NEW CATHODE

For the 2015 polarized proton run, the new cathode with 7.5 mm radius was installed. This cathode is a dispenser cathode [6], which consists of a porous tungsten matrix, impregnated with a barium-based emission-enhancing material.

To activate the cathode material, the pressure near the cathode should be kept below 5×10^{-6} Torr. However, the cathode should in principle be kept at a higher temperature than the rest of the structure during bake-out to avoid the deposition of poisons that may come from out-gassing. These two requirements compete against each other because during the e-lens bake-out, the

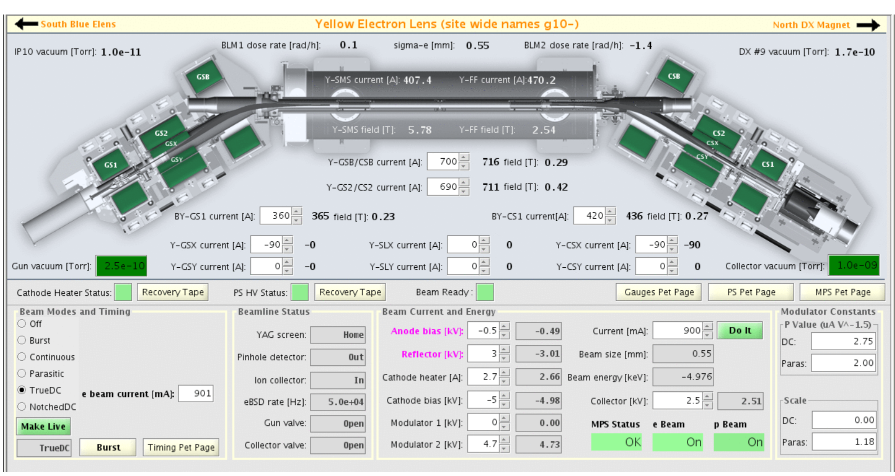

Figure 1: Schematic depiction of the layout and parameters of the electron lens during the 2015 run.

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temperature than the rest of the structure during bake-out to avoid the deposition of poisons that may come from out-gassing. These two requirements compete against each other because during the e-lens bake-out, the vacuum can go as high as 1×10^{-4} Torr for a short period of time. For the 2015 RHIC run, we opted to keep the cathode cold and did not observe any strong evidence of cathode poisoning.

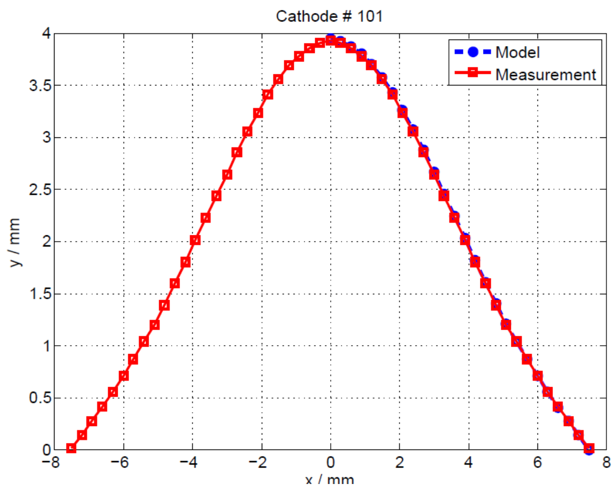

Figure 2: Profile of the cathode and the electron beam.

Figure 2 shows the designed transverse profile of the cathode (Fig. 2, blue dots) and its measured profile (Fig. 2, red squares). Model and measurement are in excellent agreement.

ELECTRON BEAM

The perveances of the electron guns with the pulsed beam are measured as 2.7 $\mu AV^{-3/2}$ and 2.55 $\mu AV^{-3/2}$ for the blue and yellow electron guns, respectively. The design perveance is 3 $\mu AV^{-3/2}$. The perveances of the electron guns are within 10% and 15% of the design value for blue and yellow. The variation in distance between anode and cathode could account for this.

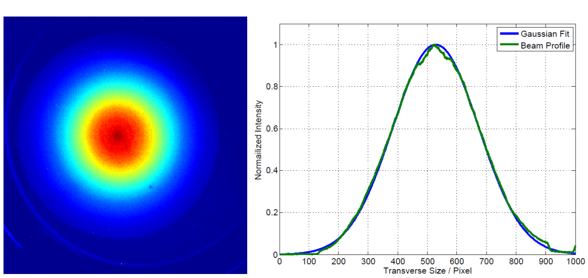

Figure 3: YAG screen e-beam image (left), and profile measurements (right).

The properties of the cathode and the profile of the beam were measured with a YAG screen. The measurement of the electron beam profile (Fig. 3, right green trace) from the YAG screen and its Gaussian fit (Fig. 3, right blue trace) is shown in Figure 3. The measured electron beam profile is well fitted with a Gaussian distribution except for small discrepancies in the center area. The ratio of the measured beam radius to the rms beam size is about 2.7. This value was used for calculating the beam size inside the superconducting solenoid.

EBSD AND BEAM-BEAM ALIGNMENT

For the alignment of the electron and proton beams, the electron backscattering detector (eBSD) [7] is used as the input signal for an automatic steering application. Figure 4 shows that eBSD rate as a function of the proton beam position, as optimized by the IR Steering Application (LISA)

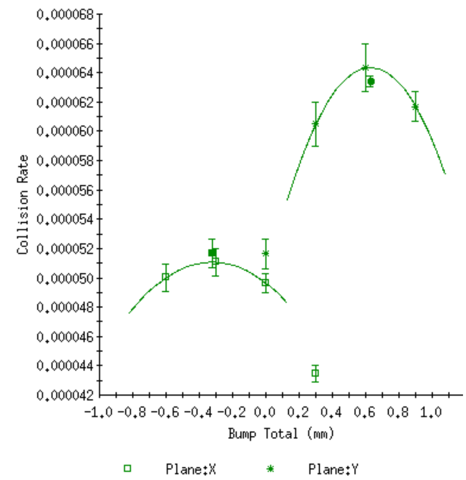

Figure 4: Electron beam and proton beam alignment using the automated steering application.

BLUE DC ELECTRON BEAM OSCILLATION AND INSTABILITY

With the pulsed mode, both blue and yellow electron currents can reach 1 A. For a DC beam, the yellow e-lens can reach 1.1 A. On the other hand, oscillations (Fig. 5) in the blue e-lens DC electron beam were observed when the current was below 200 mA. However, these oscillations could be suppressed by using the split drift tube [8].

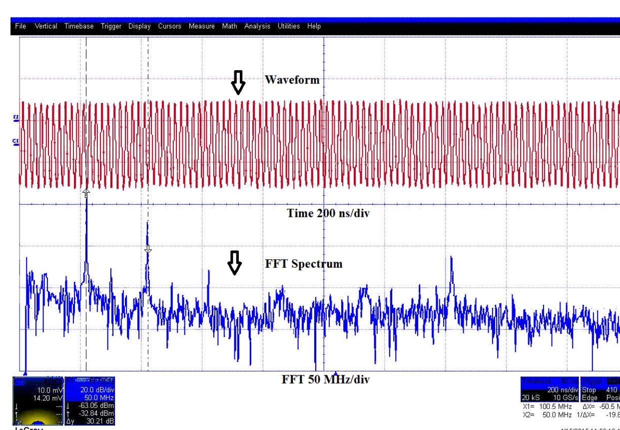

Figure 5: Oscillations in the blue electron beam with 100-mA current. Top is an electron beam waveform, bottom is a spectrum.

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The blue DC beam also has an instability issue if the electron beam current is above 750 mA. This instability results in a reduction in the electron beam current from 750 mA to 650 mA. The anode voltage remains unchanged at that moment. A current above this limit can result in a blue electron beam instability which leads to proton beam loss and/or emittance growth. With a higher collector voltage, this instability can be avoided.

TUNE DISTRIBUTION MEASUREMENT WITH E-LENS

During the 2015 RHIC 100 GeV polarized proton run, the tune distribution was measured when protons collided with electrons, at different electron beam currents and with different electron beam sizes.

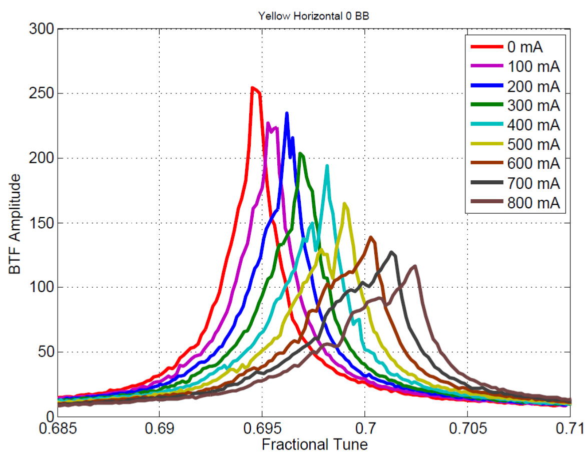

Figure 6: Beam transfer function (BTF) measurements as a function of tune for various e-beam currents.

Figure 6 shows the horizontal tune distribution measurement at different electron beam currents. The measurements were done while the proton beam was colliding with the electron beam only; there were no proton-proton collision at either STAR or PHENIX. The tune shift can be clearly seen from the plot as changing with the increasing electron beam current. The linear tune shift is about 9.2E-3/A and 8.2E-3/A for horizontal and vertical, respectively. These are very close to 8.9E-3/A, the theoretical tune shift. The electron beam size (rms) was about 0.83 mm and the energy was 5 kV.

When the electron beam current is higher, the tune spread, which indicates the de-tuning effect from beam-beam interaction, also becomes larger. This nonlinear effect from the electron beam is designed to compensate the proton-proton beam-beam effect, which has the opposite sign of nonlinear de-tuning.

Figure 7 shows BTF measurements as a function of tune for several e-beam sizes demonstrating the linear tune shift and tune spread. At the same electron beam current, the smaller the electron beam size is, the stronger the beam-beam effect gets. For comparison, the tune without electron beam is also depicted in this plot.

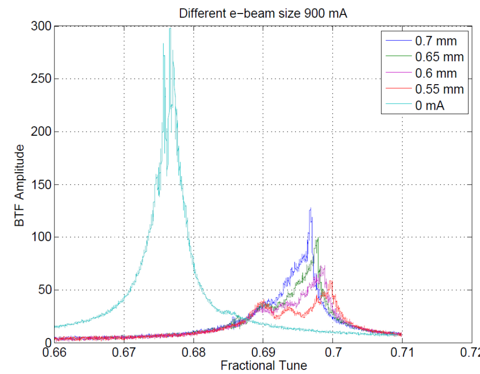

Figure 7: BTF measurements for various e-beam sizes.

SUMMARY AND DISCUSSION

The electron lenses provided in each of the two RHIC accelerators electron beams for every store during the 2015 RHIC run. The electron beam and proton beam were easily well aligned using the new eBSD. Measurements were made to characteristic the electron beam, for example beam profile and beam current.

The blue e-beam issues mentioned above are not yet fully understood but could perhaps be caused by the trapped ions or the reflected electrons from the collector.

In RHIC run 2015, the electron beam and proton beam interaction were measured using BTF beam transfer function measurements, which showed good agreement between measurement and theory in the linear tune shift. Other very recent measurements with e-beam and proton beam interaction will be further studied to analyse the achieved tune spread.

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