SIMULATIONS OF LOW ENERGY Au^{78+} LOSSES IN RHIC*

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Abstract

The 2019 RHIC Run BES-II program [1] features the commissioning of the Low Energy RHIC electron Cooling (LEReC) Project [2, 3], which uses electron cooling techniques to compensate for intra-beam scattering and thus to improve the luminosity lifetime. During RHIC operations at 3.85 GeV/u (beam energy) with LEReC, one needs to ensure that the electron beam energy is properly matched for cooling purposes: if so, some of the circulating Au-79 ions can recombine with an electron, turning into Au-78 and circulating with a large momentum offset. Part of the LEReC commissioning steps is therefore to drive a maximized number of Au-78 ions towards a chosen location of the RHIC mechanical aperture to generate particle showers that can be detected by a Recombination Monitor (RM) outside the cryostat. This article introduces the baseline lattice design, then discusses the few scenarios considered for optimizing Au-78 losses at a given location. Each scenario is then simulated using new tracking tools for generating beam loss maps. Results from operations with the selected lattices are also presented.

INTRODUCTION

With the 2019 RHIC Run, LEReC entered the commissioning phase of the project. The goal at the onset of this run was to demonstrate electron cooling of Au-79 ion beams using RF based acceleration of electron bunches [2]. Figure 1 presents a schematic view of the LEReC layout.

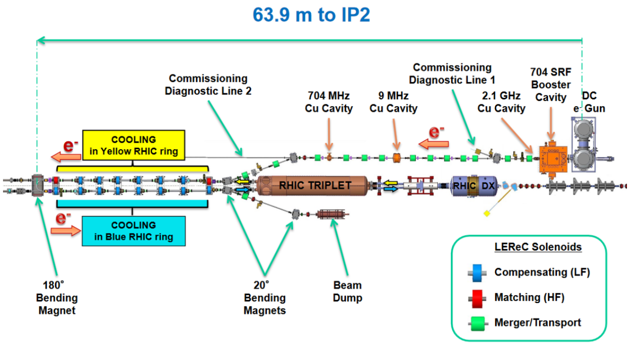

Figure 1: Schematic view of the LEReC layout in and around the RHIC beamlines [2].

On top of the specific lattice requirements for the electron layout, there are prerequisites to the linear optics of the Blue and Yellow ion beam lattices in order to achieve electron cooling: preliminary calculations for LEReC demand that the transverse beam size of the ion bunches matches that of the electron bunches while in the cooling section. Additionally, the electron beam relativistic factor γ_e must be matched to the Au ion beam one γ_{Au} with a precision better than $5.0 \cdot 10^{-4}$ [3]. There is one byproduct of the cooling process that can help fine tune the LEReC RF cavities to that accuracy level: inside of the cooling section, some of the Au-79 ions can recombine with an electron, which turns them into Au-78 ions and gives them a small momentum offset $(\delta p/p)_R = 0.0128$.

Because of this offset, one can design a distortion wave for the dispersion function D_x such that it generates closed orbit oscillations with an amplitude derived from $(\delta p/p)_R$ large enough to drive the recombined Au-78 ions into the physical aperture of the arc downstream of the cooling section for each lattice (Blue or Yellow) but not so large that circulating Au-79 ions with the largest momentum spread at the edges of the bunch length would also get lost. At this location a device (Recombination Monitor, RM) [4] would be installed to detect the resulting particle showers, generating the signal needed to adjust γ_e.

It is relevant to point out that this particular lattice design is only intended to be used as a LEReC commissioning tool to properly set up the electron beam energy for the 2019 program. As such, and for brevity reasons, only the Yellow lattice design will be discussed in the following since it is the one for which the cooling section is closest to a RHIC arc thus presenting the biggest challenge for linear optics manipulation when generating a closed D_x bump for localized orbit excursion. Similar results were achieved for the Blue lattice.

LATTICE DEVELOPMENT

One needs to first establish what the baseline lattice design at 3.85 GeV/u is first. The most straightforward way to do so is to utilize the injection energy ($E = 10$ GeV/u) from the previous RHIC physics run with Au-79 ions and scale the magnet settings to the low energy setpoint, then modify the arc quadrupole magnets to achieve the dedicated working point [1]. Table 1 lists some of the main machine parameters specific to the 3.85 GeV/u setup, and Fig. 2 displays the Yellow linear optics functions at various locations of interest.

For the purpose of electron cooling, the $\beta_{x,y}$ functions for Au-79 would need to be constant along the cooling section, but the matching requirements to the rest of the ring along with a reduced aperture for the beam pipe around IP2 pushes the design towards minimizing the derivative of the parabolic functions $\alpha_{x,y}$ instead. A similar argument applies to the dispersion D_x and its derivative D'_x, and Fig. 2 shows the results of taking both beam size and dispersion into account when matching the linear optics.

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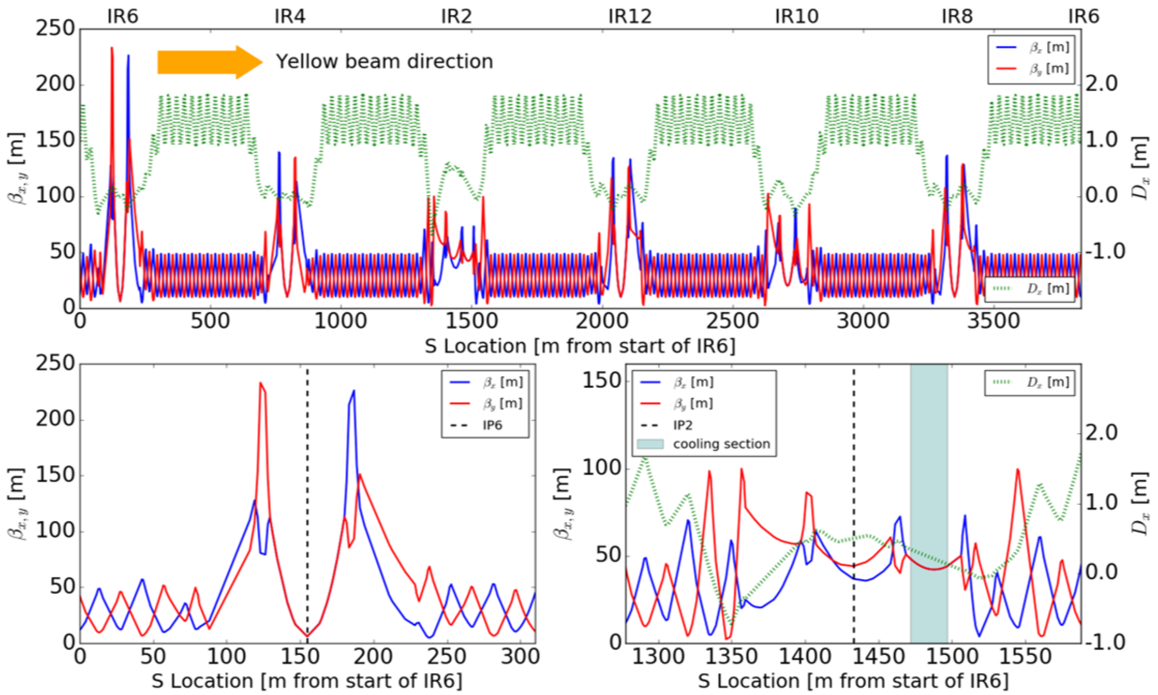

Figure 2: Top: linear optics functions $\beta_{x,y}$ and D_x of the Yellow lattice for Au-79 ions at 3.85 GeV/u. Bottom: zoom into the STAR (left) and LEReC (right) straight sections: the interaction points IP6 and IP2 (respectively) are marked, and the cooling section is also highlighted. The zoom into the LEReC section shows the shape of the dispersion function D_x for completeness.

Table 1: Low Energy RHIC Machine Parameters for Au-79 Beams. Values are Specific to the Yellow Lattice

E	3.85 GeV/u
Tunes $Q_{x,y}$	28.09 / 29.08
β^*(IP6)	6.0 m
Momentum spread	$\pm 6.6 \cdot 10^{-4}$
LEReC Section	
$\beta_{x,y}$ [cooling]	42.0–49.0 m
D_x [cooling]	0.13–0.50 m

One can then generate a closed dispersion bump downstream of IR2 with minimal distortion to the rest of the linear optics functions: much like a closed orbit 4-bump would be constructed, the set of four QGT quadrupole magnets located in the IR2-to-IR12 arc that is designed for γ-transition crossing can be modified (i.e. rewired) to provide enough free parameters to a MAD-X [5] matching algorithm. The linear optics along the cooling section cannot get modified by this rematching if one wants to keep the cooling as efficient as possible: the boundary conditions are therefore taken at the exit of electron-ion common section of the lattice. The closing boundary condition is then taken at the location of the Q4 quadrupole in sector 12, the symmetric point with respect to the arc.

Rather than calculate the required Au-79 D_x amplitude change, MAD-X can perform the calculations for the recombined Au-78 by applying the momentum offset $(\delta p/p)_R$ to the lattice described above and move the resulting closed orbit towards the inner edge of the physical aperture of the machine to force particle losses in that region. Figure 3 presents the results of the algorithm, as well as a simulated orbit for a recombined Au-78 ion exiting the cooling section at X = 0.0 mm. In that plot, this trajectory is compared to the closed orbit for Au-79 ions at the edge of the bunch. The initial condition taken for the Au-78 tracking correspond to a synchronous, on-axis Au-79 ion, therefore representing the position of the centroid of a virtual bunch of Au-78 ions. One can clearly see that the distortion in D_x is contained within the arc immediately downstream of the cooling section. The corresponding trajectory of recombined Au-78 ions is orders of magnitude larger than the off-momentum closed orbit of Au-79 ions, maximizing the signal-to-noise ratio for the Recombination Monitor (RM). Figure 3 also points out the suggested location for the RM i.e. where the horizontal orbit excursion is the largest: on the plot, it corresponds to an arc quadrupole magnet, YO1-QF14, with $\hat{x}_{78} \approx 34.2$ mm. This simulated position of the virtual Au-78 centroid particle is very close to the mechanical aperture of this type of RHIC magnet, listed at $r_Q = 34.5$ mm, thus ensuring that as many

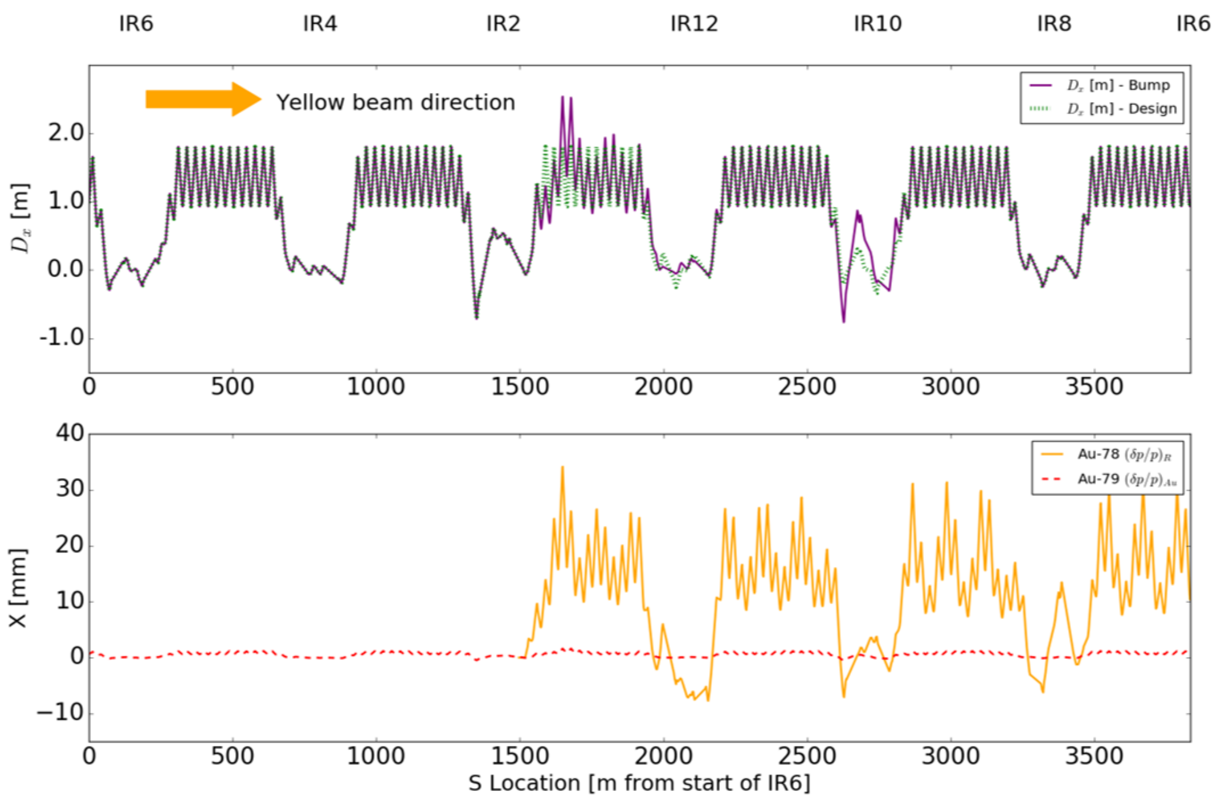

Figure 3: Top: modified D_x to include a closed bump for LEReC commissioning compared to the design settings. Bottom: simulated track for a recombined Au-78 ion escaping the cooling section at X = 0.0 mm. The off-momentum closed orbit for Au-79 ions at the edge of the bunch is shown for reference.

Au-78 ions as possible can be driven into the wall to be detected by the RM for LEReC commissioning.

LEREC COMMISSIONING

A review of the LEReC energy matching commissioning from the perspective of LEReC operations can be found in these proceedings [3]. After initial setup of the RHIC design lattice, further beam setup time was used to ensure that the electron beam and the Au-79 ion beam were overlapping, this time by utilizing the dedicated LEReC beam position monitors. Then the calculated settings for the modified lattice with D_x bump were ramped into, and the process of fine tuning γ_e started. Background levels on the RM signal were initially higher than anticipated, but the changes to the amplitude of the measure signal were still significant to allow for a proper energy scan. Figure 4 shows a sample RF phase scan that clearly shows when the recombined Au-78 ions are produced, demonstrating electron-ion energy matching.

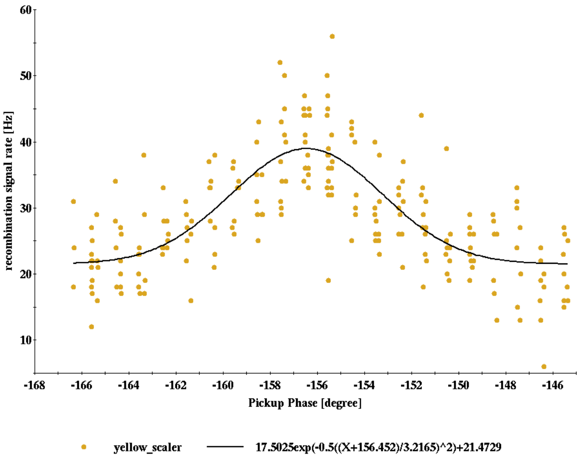

Figure 4: Signal at the Recombination Monitor during a phase scan of the electron RF system for energy matching.

CONCLUSION

As part of LEReC commissioning, a dedicated lattice was created to help drive the losses of recombined Au-78 ions at a specific location where the beam loss signal from the corresponding particle showers can be detected by a dedicated monitor. This allowed to successfully fine tune the LEReC electron beam energy to match that of the circulating Au-79 ions, on the way to the first demonstration of electron cooling of hadron beams.

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