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Simulation of the injection in the SLS storage ring

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1 Intention

We want to predict the performance of the injection system of the SLS. We are interested in investigating four different cases that will provide insight to the possible problems that we can face during the machine operation. This four scenarios are:

1. The ideal case (the injected beam is the reference point and with the reference optic parameters, no errors in the lattice).
2. Injection of an ideal incoming beam in a SLS lattice with the usual set of errors and correction system [3].
3. Injection of an ideal incoming beam into a ideal SLS lattice, where we have included random roll errors in the injection kickers, with a large rms value, in order to check the tolerance of the system.
4. Realistic case: the injected beam has a small deviation from the ideal parameters, the errors assumed in the second case, and a realistic roll angle error in the kickers.

2 Description of the injection system

The layout of the injection system (kickers and septum) is the one described in the June 24 memorandum by C. Gough, and is show in 1. The figure shows the bumped stored beam, the injected beam and the septum. The bump half time sine time is 6μs, and the kickers are active 4 turns. The position and maximum deflection angle (turn 0) of the kickers are given in Table 1. The stored bumped orbit corresponding to the four turns while the kickers are active is show in figure 2. The parameters for the septum are given in Table 2, and the parameters for the injected beam in Table 3.

3 Simulation with Tracy

We have used **Tracy** [2], to simulate the injection process. It will be simulated using the following steps:

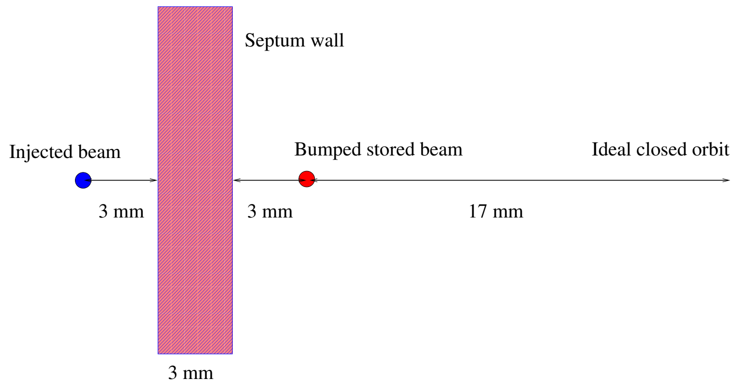

Figure 1: Layout at the exit of the septum.

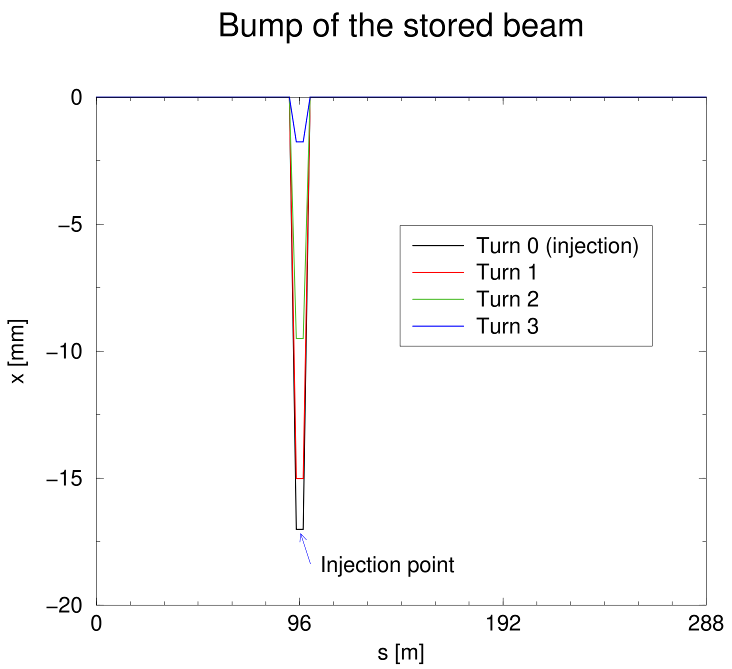

Figure 2: Bumped orbit for the active kicker time.

	Position [m]	Deflection [mrad]
Kicker 1	91.095	-5.288
Kicker 2	94.31	5.288
Kicker 3	97.68	5.288
Kicker 4	100.8955	-5.288

Table 1: Position of the kickers

Position (start)	96.03 m
Length	0.8 m
Thickness	3.0 mm
Distance septum to beam axis	20 mm

Table 2: Septum parameters

- Simulate the injection of a particle by tracking it from the exit of the septum to the end of the lattice, with the right kickers settings.
- Track that particle along the machine while the kickers are active (the following three turns).
- Track a beam of particles around that reference particle. This beam will be represented by an ellipse in phase space with the parameters given in 3.
- Evaluate the acceptance required to capture the above mentioned beam.
- Track the reference particle for a number of turns of the order of one damping time (9 ms at 2.4 GeV) around the machine, including radiation and cavity effects. We will track the particles 15000 turns.

For some of the process we can use the standard **Tracy** library calls for tracking. However, we will need to provide new routines for the the ellipse tracking and the evaluation of the physical acceptance, but is quite straight forward to write those.

For all the calculations, the effects of the RF cavities and the radiation have been included.

β_x	3 m
α_x	0
Emittance	10 nm-rad
Distance to the septum	3 mm
Angle of divergence	-0.8 mrad

Table 3: Injected beam parameters.

4 Ideal case

This case corresponds to an injected reference particle with the ideal input coordinates an ideal beam ellipse, being injected in the machine, without any kind of errors, neither in the lattice or the incoming beam.

The figure 3 shows the trajectory in the horizontal plane of the incoming beam for the injection turn, the following three turns (while the injection kickers are active), and the first turn with the kickers turned off. As can be seen, the particle stays comfortably inside the limits of the vacuum pipe (± 32.5 mm)

The figure 4 plots the behavior of the injected beam, the reference particle and the stored beam in the horizontal phase space for the first ten turns after injection, at the end of the septum. As can be seen from the plot, the small emittance of the injected beam (10 nm-rad) makes it relatively easy to inject the beam without touching the septum wall, providing for a large injection efficiency. The figure 5 shows the phase space plot for the reference injected particle, at the start of the lattice (not at the end of the septum) for a 15000 revolutions. The damping of the particle is clear, as can be seen from the reduction of the oscillation amplitude.

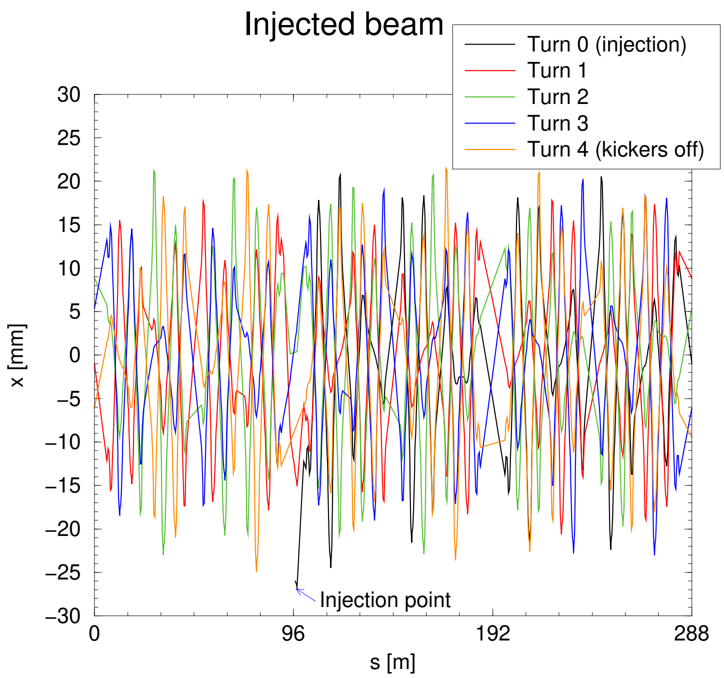

Figure 3: Orbit of the injected beam for the injection turn a nd the following 4 turns.

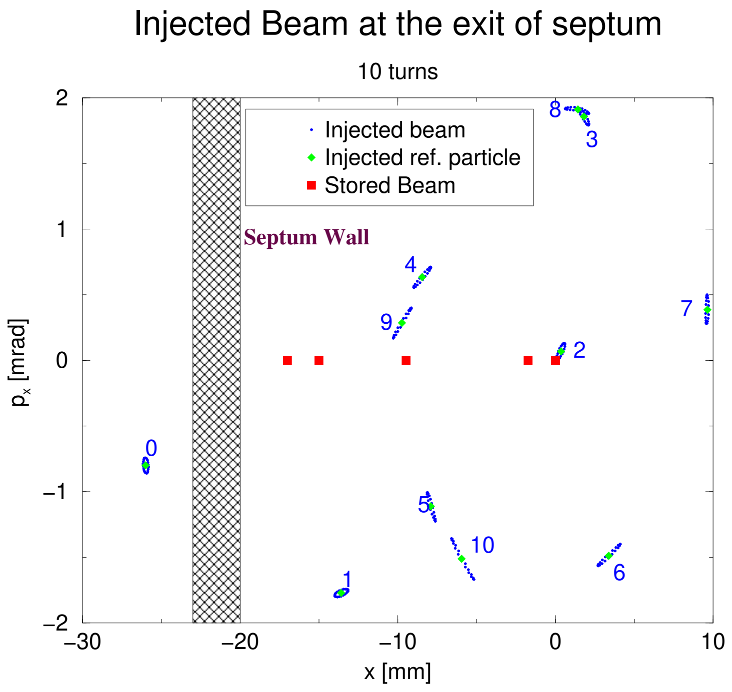

Figure 4: Evolution of the injected beam ellipse at the exit of the septum.

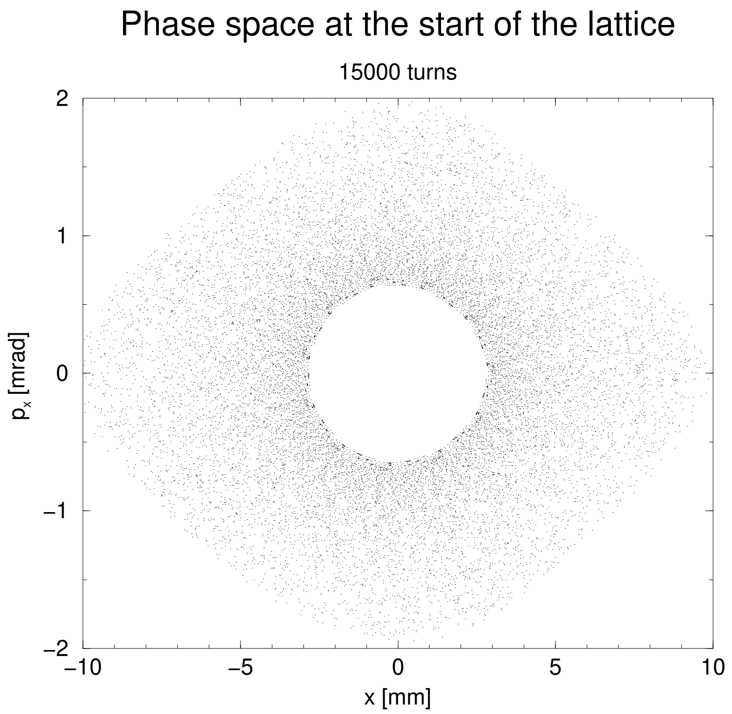

Figure 5: Evolution of the injected beam in phase space for a damping time.

5 Injection in a lattice with errors and correction system

The following step would be to check the tolerance of the proposed injection system to the effect of errors and correction system in the storage ring. In order to do that, we will repeat the simulation in a lattice with the standard set of errors and correction system (as defined in [3]), for the standard error seed (123). This seed provides an average value of the effect of the errors. The rms value of the different kinds of errors included in the simulation are:

- Alignment error of the elements in the girder: 50μm.
- Alignment error of the girders: 300μm.
- Alignment error of the girder joints: 100μm.
- Girder roll angle: 25μrad.
- Element roll angle in girder: 100μrad.

Figures 6 to 11 show the injection scenario for the case considered. The situation in the horizontal plane is almost identical to the previous case. In the vertical plane, the existence of errors couples the horizontal motion into the vertical plane, given rise to a vertical motion. However, the motion is limited to a range of $\pm$ 1.5 mm, well inside the vacuum chamber (even in the small gap undulator section).

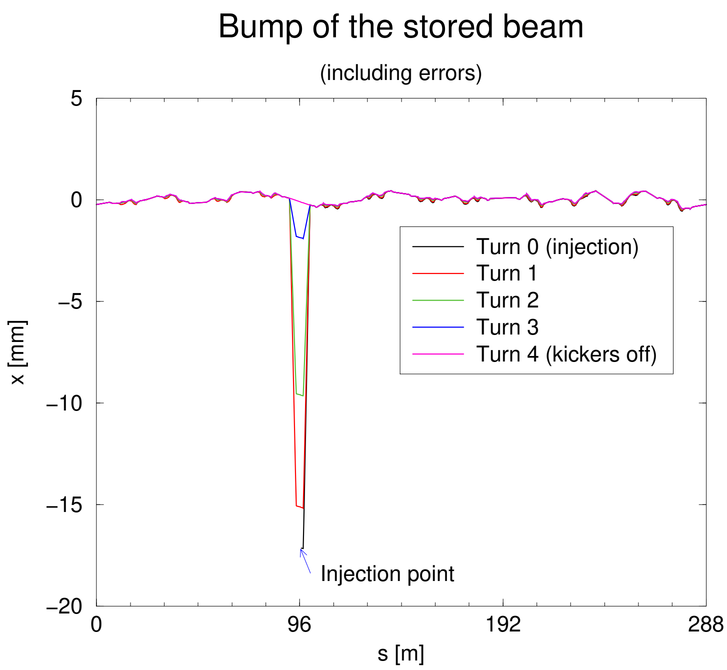

Figure 6: Bumped orbit for the lattice with errors and correction system.

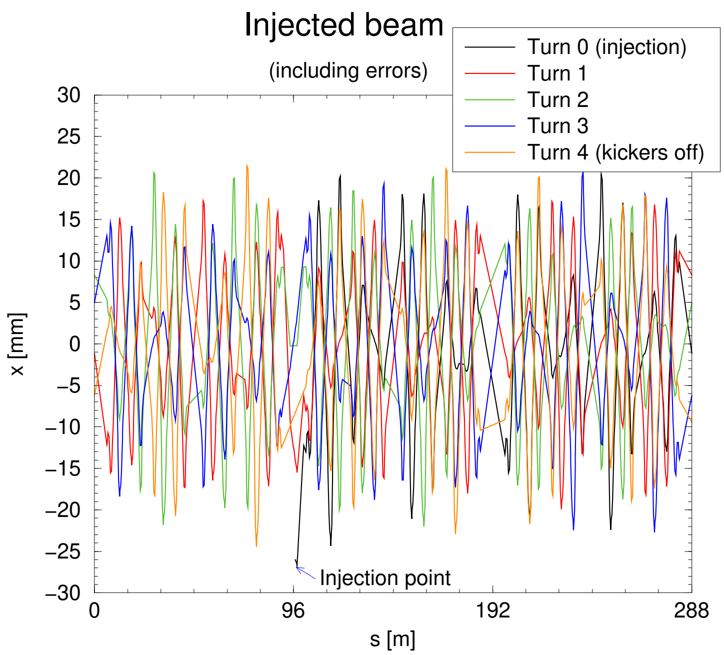

Figure 7: Horizontal orbit of the injected particle for the firsts 5 turns with errors and correction system.

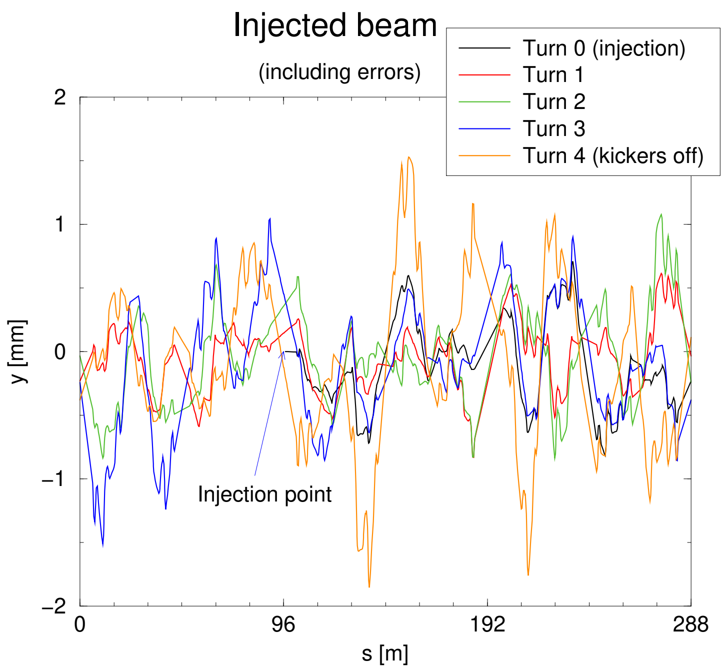

Figure 8: Vertical orbit of the injected particle for the firsts 5 turns with errors and correction system.

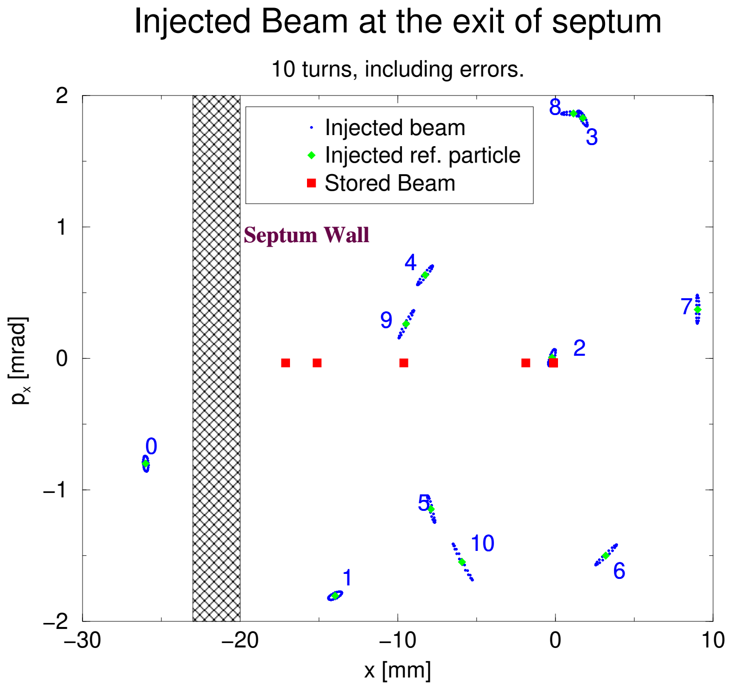

Figure 9: Evolution of the injected beam ellipse at the exit of the septum, for the lattice with errors and correction system.

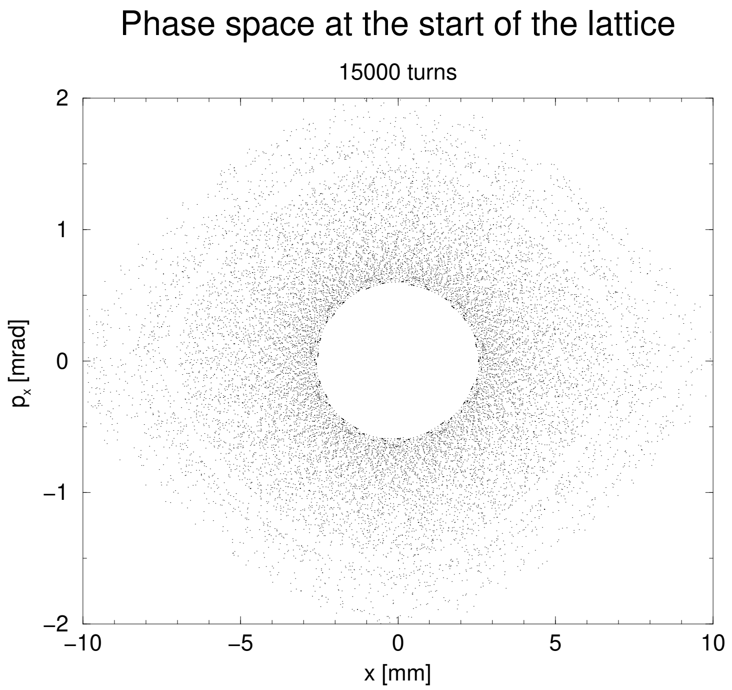

Figure 10: Evolution of the injected beam in the horizontal phase space for a damping time, for the lattice with errors and correction system.

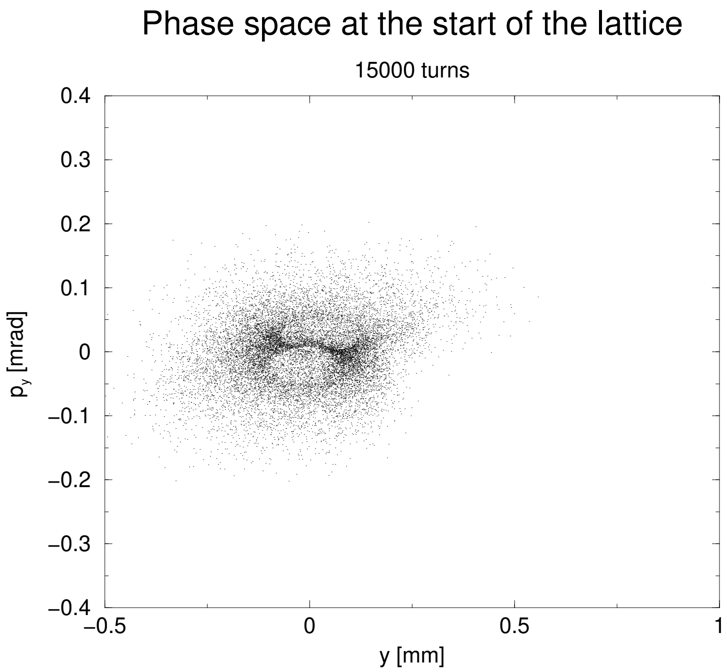

Figure 11: Evolution of the injected beam in the vertical phase space for a damping time, for the lattice with errors and correction system.

6 Injection with roll angle error in the kickers

In this scenario, we want to test the tolerance of the injection system to roll errors in the injection kickers. To simulate an extreme case, we have assumed a large (unrealistic) value for the rms roll angle of 50 mrad. The correction system is not used in this case.

The results of the simulation are show in figures 12 to 17. As we can see, the lattice is very tolerant to the disturbance. The only important effect, as expected, is in the vertical orbit of the injected beam. However, as the expected rms error in the real machine is much smaller (around 5 mrad), it would not compromise the operation of the machine.

7 Injection in a realistic case

The last scenario to consider is a realistic one, were we include the following elements:

- Effect of the errors and the correction system in the lattice (the same that the ones considered in section 5.
- A realistic roll angle error in the kickers, with a rms value of 5 mrad.
- Error in the injected beam, with an average 10% offset respect the ideal case.

Again, figures 18 to 23 shows the result of the simulation. The beam is still safely injected in the machine. The main difference in this case is a large betatron oscillation in

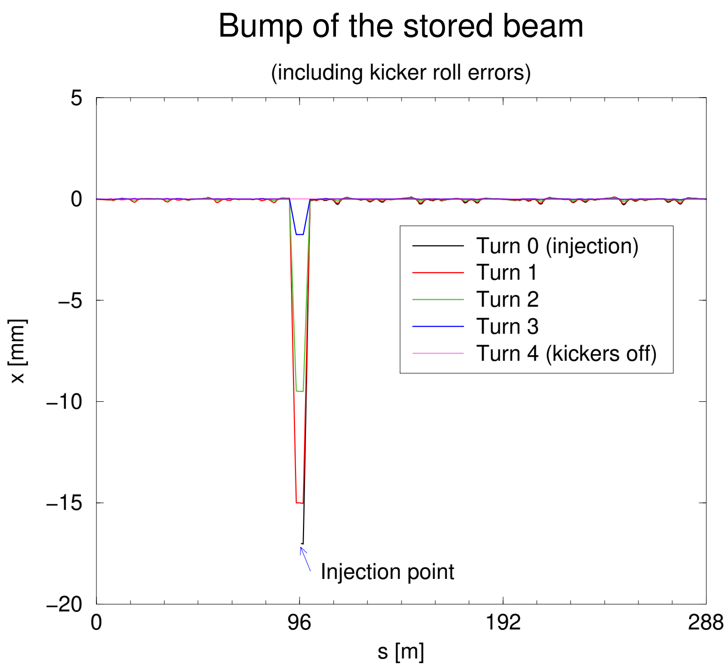

Figure 12: Bumped orbit for the lattice with roll errors in the kickers.

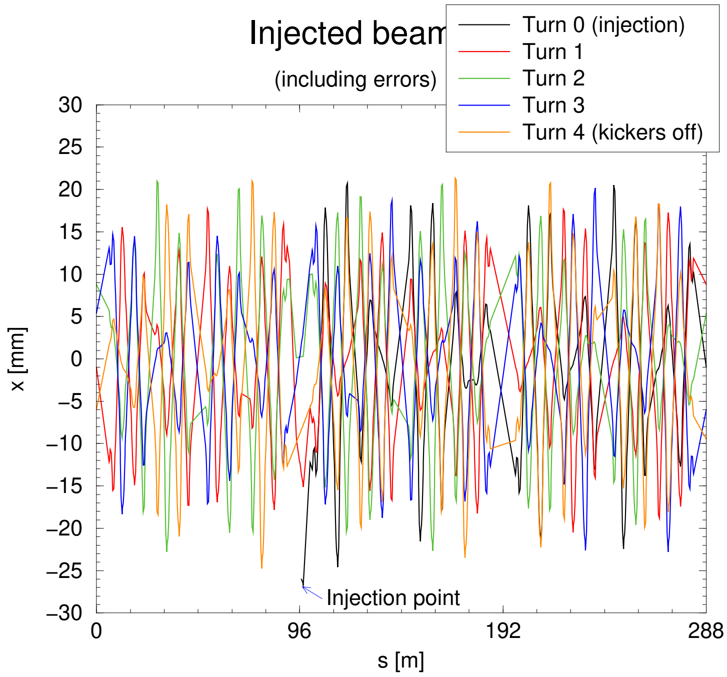

Figure 13: Horizontal orbit of the injected particle for the firsts 5 turns for the lattice with roll errors in the kickers.

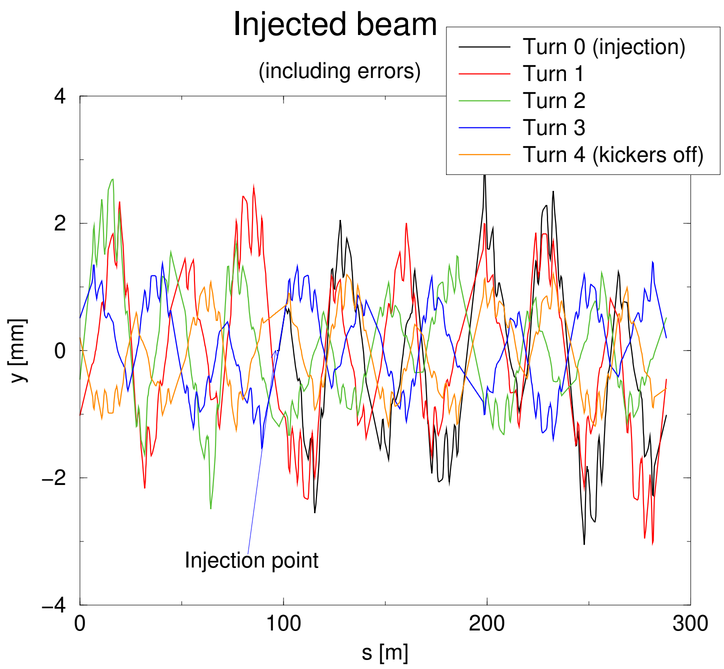

Figure 14: Vertical orbit of the injected particle for the firsts 5 turns for the lattice with roll errors in the kickers.

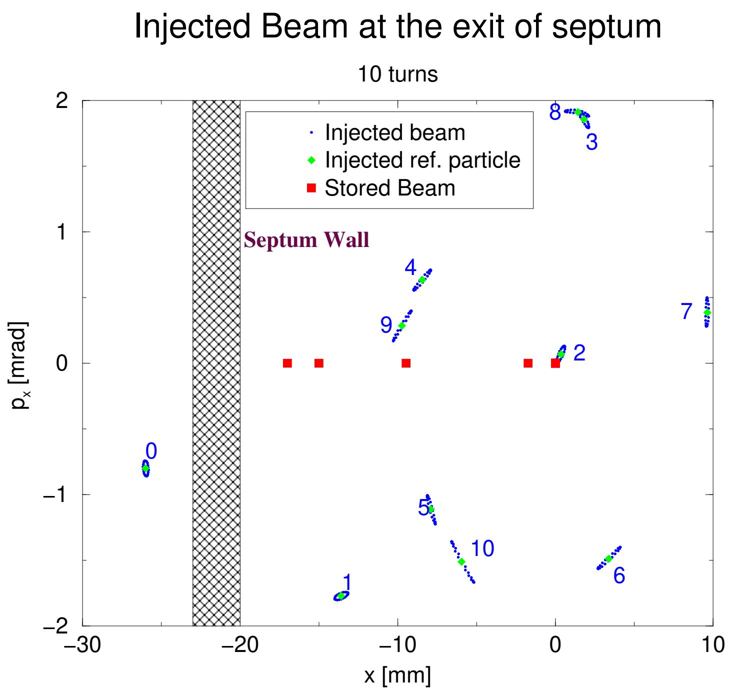

Figure 15: Evolution of the injected beam ellipse at the exit of the septum, for the lattice with roll error in the kickers.

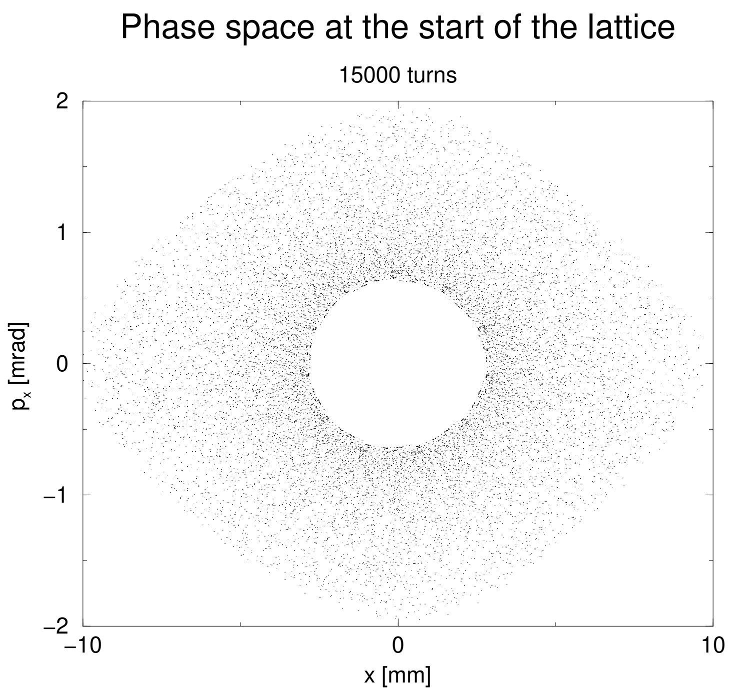

Figure 16: Evolution of the injected beam in the horizontal phase space for a damping time, for the lattice with roll errors in the kickers.

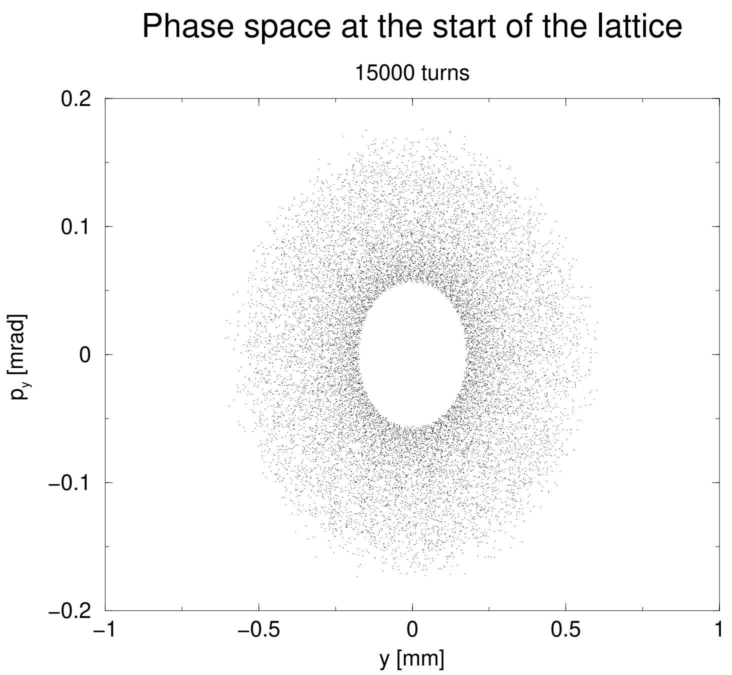

Figure 17: Evolution of the injected beam in the vertical phase space for a damping time, for the lattice with roll errors in the kickers.

the vertical plane, due to the off-axis injection, but the particles remain inside the vacuum chamber.

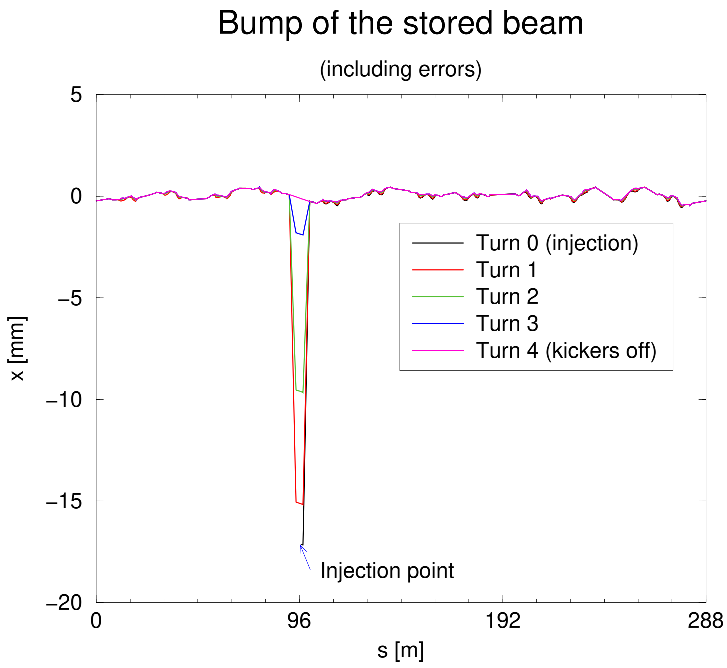

Figure 18: Bumped orbit for the realistic case.

8 Evaluation of the acceptance

The acceptance required to capture an incoming particle by the stored beam is given by:

$$\mathcal{A}_z = \beta_z \left(p_z^i - p_z^0\right)^2 + 2\alpha_z \left(p_z^i - p_z^0\right)\left(z^i - z^0\right) + \gamma_z \left(z^i - z^0\right)^2 \tag{1}$$

where z stands for the plane where the acceptance is being evaluated, the superscript i for the injected particle and 0 for the stored.

In the case of an injected beam, the acceptance required to capture it is the one of the particle that requires the largest acceptance.

The acceptance required to capture the beam is shown, for the first 10 turns, in figure 24, for the four different scenarios. The dynamic acceptance of the lattice ($\approx$ 35 mm-mrad) is large enough to capture the injected beam. A nice feature of the evaluation of the acceptance by tracking is that we can appreciate the effects of the non-linearities, as can be seen by the change of the acceptance turn to turn.

9 Conclusion

The combination of the low emittance of the injected beam (around 10 nm-rad, one order of magnitude smaller than the provided by a conventional booster), and the high

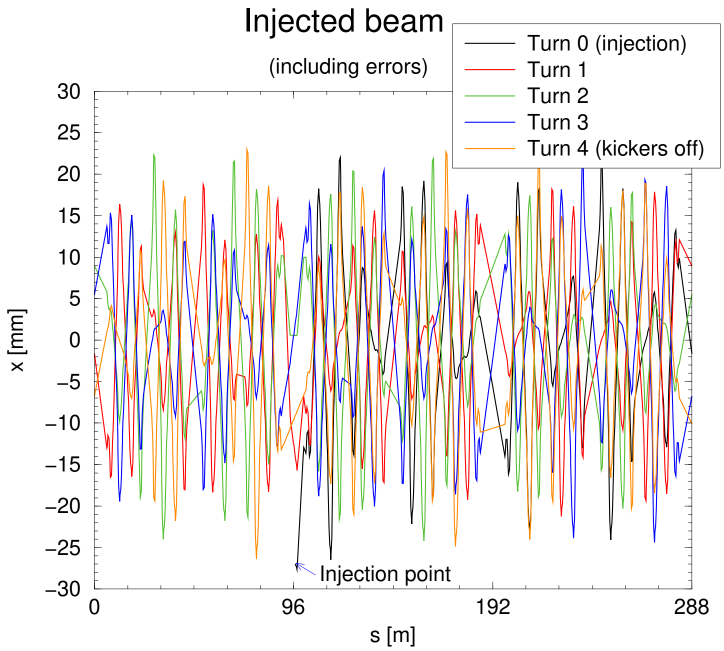

Figure 19: Horizontal orbit of the injected particle for the firsts 5 turns for the realistic case.

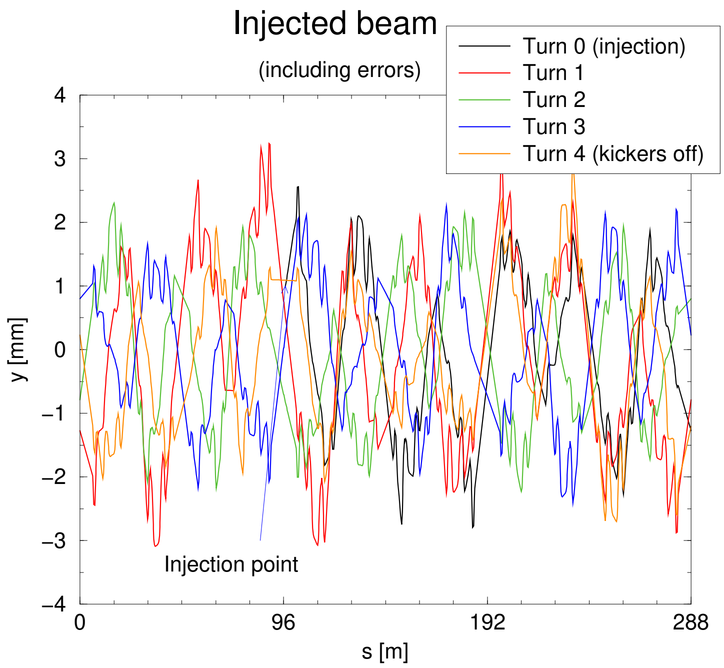

Figure 20: Vertical orbit of the injected particle for the firsts 5 turns for the realistic case.

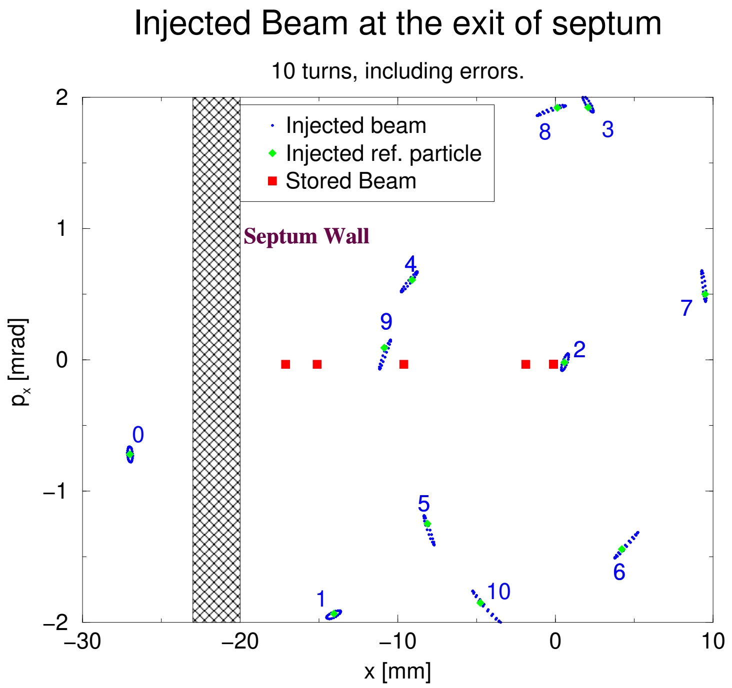

Figure 21: Evolution of the injected beam ellipse at the exit of the septum, for the realistic case.

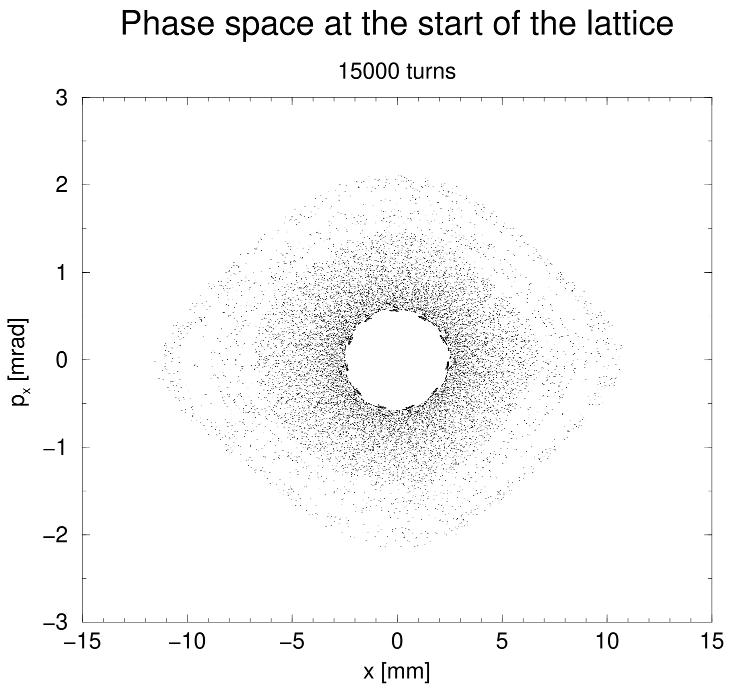

Figure 22: Evolution of the injected beam in the horizontal phase space for a damping time, for the realistic case.

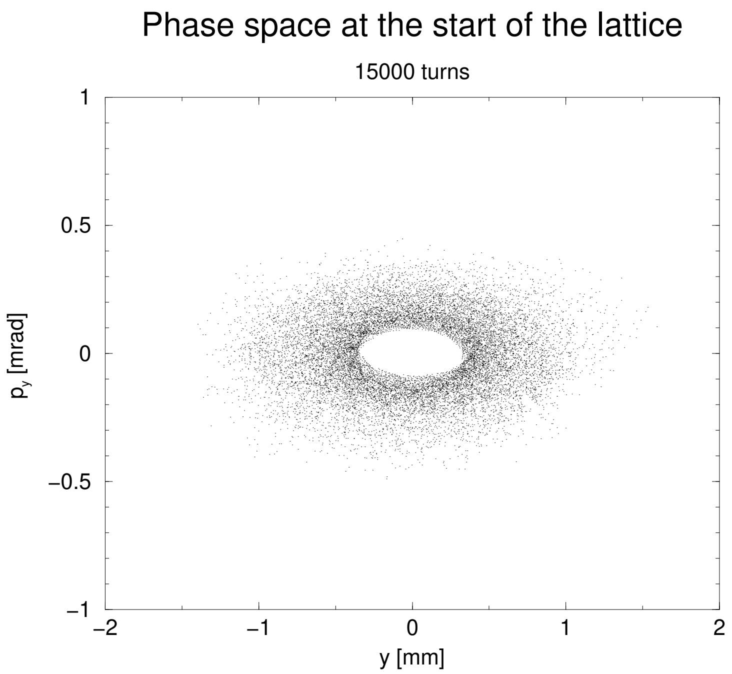

Figure 23: Evolution of the injected beam in the vertical phase space for a damping time, for the realistic case.

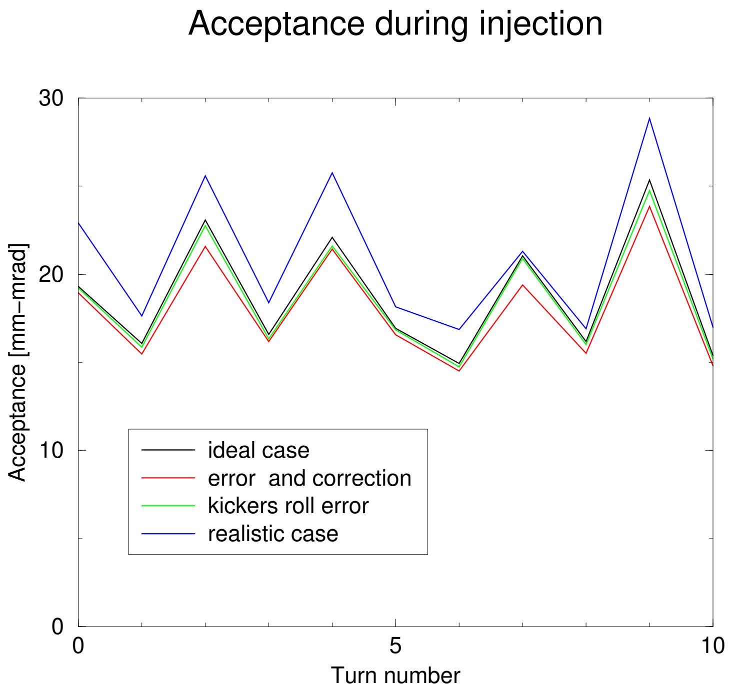

Figure 24: Acceptance required to captured the injected beam.

performance of the injection system, provides for a very reliable injection process. The simulations don't predict any special problem during machine operations.

References

[1] *The SLS Handbook.*

[2] M. Böge, *Update on Tracy-2 documentation*, SLS internal note, SLS-TME-TA-1999-0002.

[3] M. Böge, A. Streun, M. Muñoz, *Studies on imperfections in the SLS storage ring*, SLS internal note, SLS-TME-TA-1999-0004.