BEAM-BEAM WITH A FEW LONG RANGE ENCOUNTERS AT SHORT DISTANCE*

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Abstract

The high nominal luminosity of the LHC requires a large number of bunches spaced by about 25 ns. To prevent more than one head-on collision in each interaction region, a total crossing angle of 0.285 mrad is necessary, and the bunches experience around 30 long range (LR) interactions per IP with at mean separation of 9.5 σ. For the LHC luminosity upgrade, there are two possible scenarios: the early separation scheme and low Piwinski angle (LPA) scheme. In the early separation scheme, a few long range interactions need to be tolerated, this paper the discuss the possibility of having a few LR encounters at a minimum separation smaller than the 9 σ, and present observations from other hadron machines with a smaller beam separation.

INTRODUCTION

In the LHC there is a total 120 LR interactions with 30 LR per interaction point. In simulations these interactions create a diffusive aperture around 6 σ. In order to overcome this aperture limitation and also increase the luminosity two different scenarios were propose: the early separation scheme and the LPA scheme with LR wires compensators.

In the early separation scheme a dipole (D0) is installed at a distance between 2 and 9.5 meters from the IP. With this setup the crossing angle would be zero (in the case of 2 meters separation) or reduced (in the case of the 9.5 m separation) which would lead to a gain in luminosity of 110% or 65 % respectively. However both setups reduce the nominal minimum bunch separation around the IP from 9.5 σ to between 3 to 5 σ. Simulations show that these few LR encounters does not reduce the diffusive aperture.

In the second scheme, more indicated for long bunches with 50 ns spacing, a wire is installed near each IP to compensate for the LR interactions. This setup could compensate for the tunes changes due to the LR and simulations show that it could increase the diffusive aperture by 1 up to 2 σ.

Given the two possible upgrades scenarios it is important to know whether a few long-range encounters could be accepted without limiting the lifetime or the dynamic aperture. A possible investigation of the effect is to look into the limitations of other hadron machines like Tevatron, RHIC and SPS with a few LR interactions and/or the wire compensators. A description of the RHIC wire experiments is also shown and comparison with simulation results is presented

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OBSERVATIONS OF A FEW LONG RANGE INTERACTIONS AT THE TEVATRON

In the Tevatron each bunch experiences 70 LR interactions at each turn. Different from the other colliders, these interactions are distributed around the machine and not localized in the interaction regions. There are 138 locations where these interactions can take place and the sequence of 72 out of 138 is different for each bunch, hence the effects changes from bunch to bunch. These parasitic collisions limit the dynamic aperture and lifetime, and thereby the luminosity.

Experience shows that a minimum separation smaller than 5-6 σ causes losses there are unacceptable. The emittance blow-up cause by the beam-beam interactions is reduced by increased that Helix field and thus increasing the minimum separation from 4 σ to 6 σ (Figure 1).

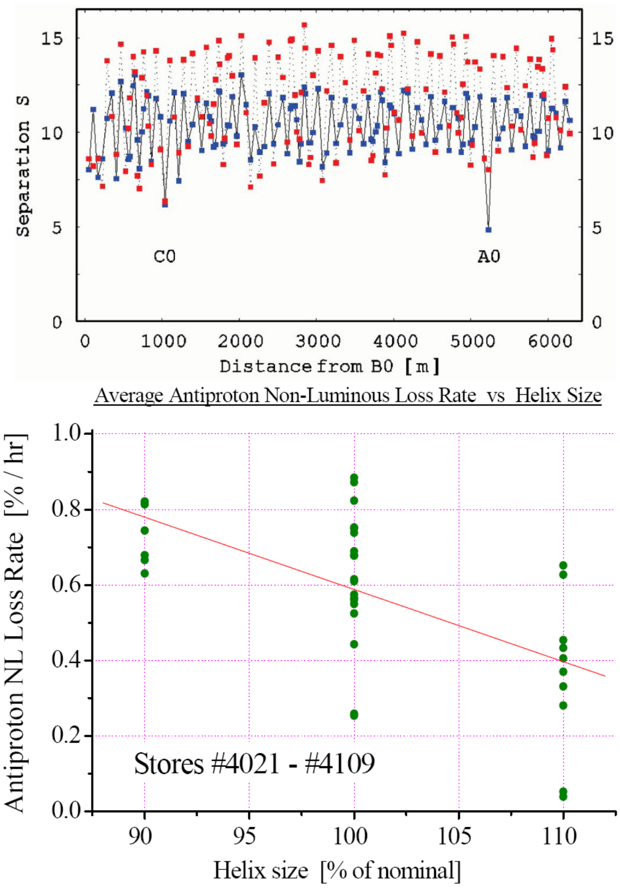

Figure 1: Increase in the Helix separation field increases the minimum separation from 4 to 6 σ [5] (top), and increase in the antiproton lifetime [3] (bottom).

WIRE EXPERIMENTS AT THE SPS

There are two sets of wires already installed is the SPS that can create LR-like interactions. Experiments with that wire show that an excitation corresponding to 9 LR-like encounters at 4.3 σ and the ultimate bunch charge did not show any observable beam loss. It is possible to correct the effect of one set of wires with the second set, as shown in Figure 2, indicating the ability to compensate for LR interactions.

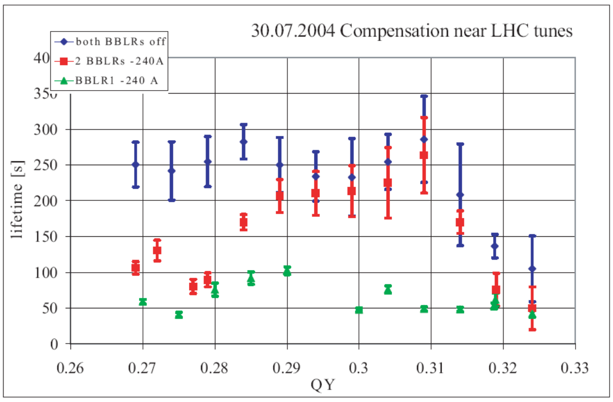

Figure 2: Experiments at the CERN SPS indicating that it is possible to compensate for LR-like interactions wire the wires [6].

EXPERIMENTS AT RHIC

Like in the LHC, LR interactions in RHIC are localized in the IRs, but with a bunch spacing of 108 ns (currently nominal operation) there are no LR interactions under current operations conditions. For eRHIC a bunch spacing of 72 ns is considered which would lead to 2 LR interactions per IP.

Experiment with one long range interaction

Experiments where performed with protons at 100 GeV and the beam were driven near a resonance in order to enhance the effect of the LR interaction and the Yellow beam was moved closer to the Blue beam. As shown in Figure 3, losses start around 4 σ.

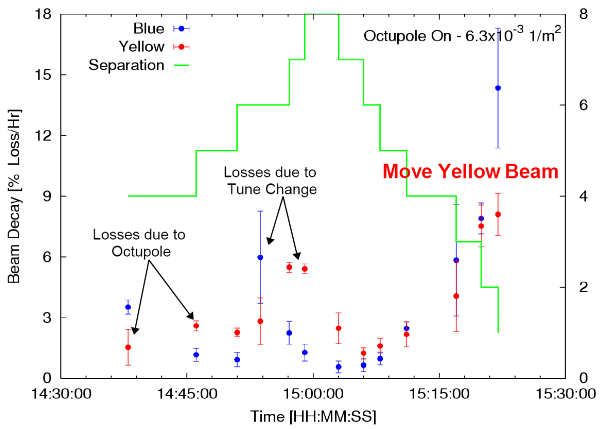

Figure 3: Experiment at RHIC with 1 LR interaction. The Yellow beam was moved towards the Blue beam. The losses start at a separation of 4 σ.

We also simulate this 1 LR interaction at 5 σ separation comparing the effect on the diffusive aperture with the nominal tunes and the ones used at the experiment (Figure 4) showing that for the nominal operation the diffusive aperture is around 10 σ. We also simulate the diffusion as a function of the minimum separation (Figure 5).

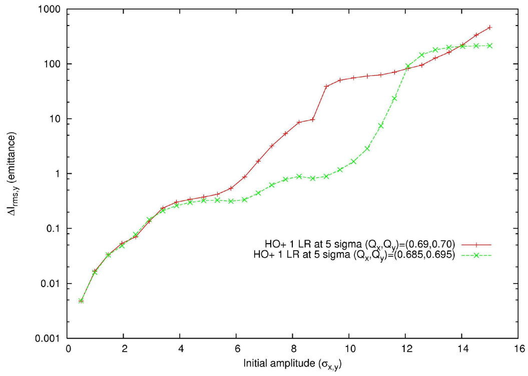

Figure 4: Simulations of 1 LR interaction in RHIC with the nominal tunes and the tunes used in the experiment showing the diffusive border at 10 σ and 5 σ respectively.

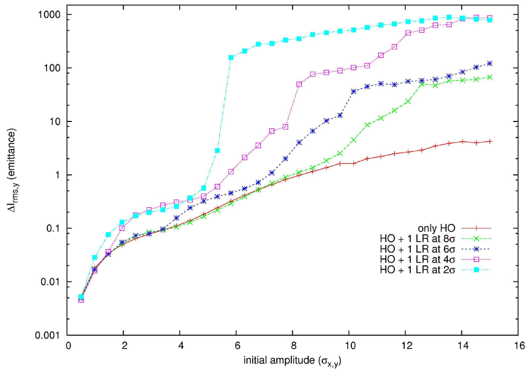

Figure 5: Simulations of 1 LR interaction in RHIC as a function of the beam minimum separation.

Experiments with the wire

In 2006 a set of compensators were installed in RHIC and a set of experiments were carried out at the Au 2007 run at top energy (100 GeV/nucleon). The integrated strength of the wires is: 12.5 Am (=1 LR) and 125 Am (=10 LR). Figure 5 show the schematics of the wires installed in RHIC.

In the experiments we moved the wire towards the beam and measured the losses. The experiments where done using the nominal tunes where we could observe the onset of losses around 5 σ for the Blue beam; and with the tunes swapped when we observed losses around 5 σ for the Yellow beam and 8-9 σ for the Blue beam.

Simulation results indicate that the lifetime has a strong correlation with the wire current and also there a reasonable agreement with the onset of chaos and the diffusive border measured for the 12.5A case [7], as is shown in Figure 8.

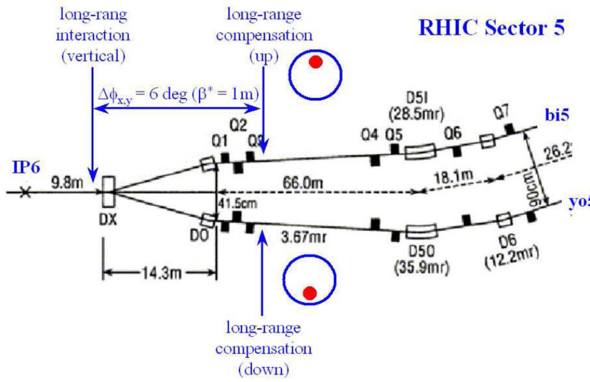

Figure 6: Setup of the wires in RHIC.

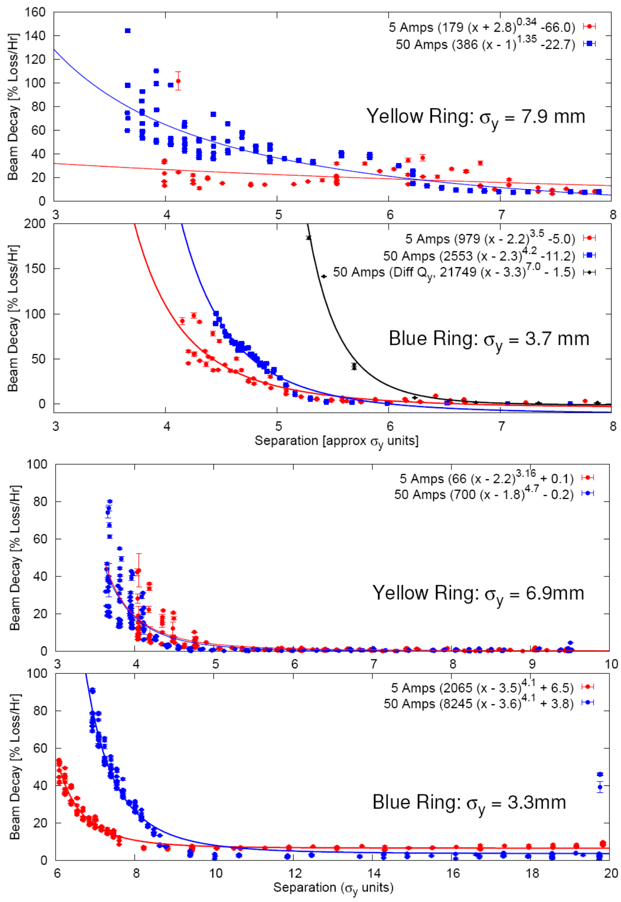

Figure 7: Wire experiments in RHIC. Nominal tunes (top) and tunes swapped (bottom) [7].

CONCLUSION

In the early separation scheme for LHC, the beam has up to 3 LR encounters at a minimum separation of 5 σ. The experience from other hadron colliders can be summarized as:

- Tevatron: 70 LR encounters at a mean separation of 9 σ. Losses start for a minimum separation of 5-6 σ.
- SPS: wire experiments show no observable losses for 9 LR-like interactions at 4.5 σ and for 120 LR-like interactions losses start at 9 σ.
- RHIC: 1 LR interaction show onset of losses at 4 σ. Wire experiments show that losses are very sensitive to the working point and start between 5 and 9 σ separation.

Simulations for the RHIC experiments show agreement with the experimental results and LHC simulations show that the wire compensator should increase the diffusive aperture by 1 to 2 σ, and that a few LR encounters at 5.5 σ does not affect the diffusive aperture.

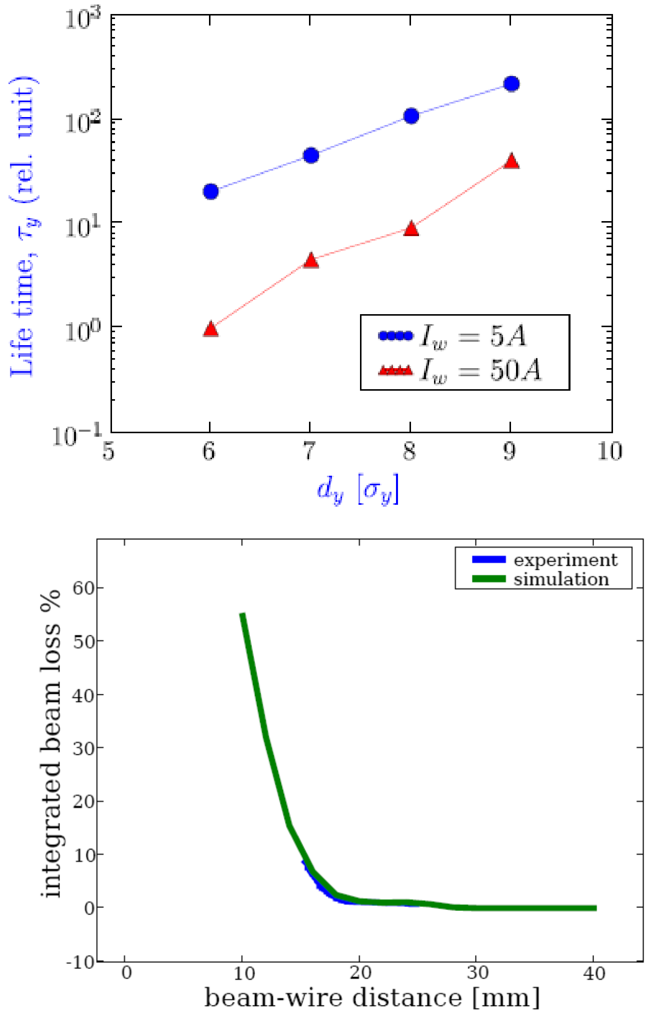

Figure 8: Simulations of the wire experiments in RHIC. Lifetime show a strong dependence with the wire current (top) and for the 12.5 Am case there is a very good agreement between the onset of chaos calculated and the onset of losses measured (bottom) [7].

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