TRACKING OF ELECTRONS CREATED AT WRONG RF PHASES IN THE RHIC LOW ENERGY COOLER

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Abstract

The RHIC Low Energy Cooler will be based on a 400 keV DC electron gun with a photo-cathode and a 2.2 MeV SRF booster cavity. Electrons which leave the cathode at the wrong time may be decelerated and turned around in the booster and return to the cathode with energies up to 1 MeV. On the way back these electron will encounter the defocusing EM fields up to nine following electron bunches.

Such electrons may be created for various reasons: Cosmic rays, stray laser light including a catastrophic failure of the laser timing system or as secondaries of returning electrons. We present tracking results from the GPT program [1] and discuss the consequences for the machine protection system.

The results are qualitative, not quantitative, since the sources and numbers of the stray electrons are unknown.

INTRODUCTION

There are various reasons for the emission of electrons from the cathode at the wrong time: they may be created by stray laser light, or they may be secondary particles from cosmic rays or back-bombarding ions or other electrons. Another reason would be a catastrophic failure of the laser timing system.

In [2] we investigated the trajectories of such stray particles to determine where the electron would impact the accelerator. There are two critical locations. One is the cathode, especially the activated area of the cathode. A strong bombardment would destroy the activation and make it necessary to replace the cathode frequently. The other is the cryostat of the booster cavity, where a strong bombardment would increase the helium consumption and may lead to quenching of the cavity.

We concluded that the bombardment of the cathode can be greatly reduced by moving the activated area off center and we included dipole correctors to allow such operation. Very little bombardment was calculated for the cryostat and it was not considered a problem.

However, the simulations did not include the effect of the EM fields of the regular bunches as those bunches pass the slowed down or turned around stray particles. This omission is remedied in this report.

The second question we tried to answer is the effect of a failure of the laser timing system, i.e. how much power is delivered to hot spots when the laser is out of phase with the RF phase.

LOSSES FROM STRAY ELECTRONS

For the first task we tracked a bunch with 50000 particles and the length of a full RF wave length until all particles are lost. We limited the calculations to the first 4 meters of the beam line, since we are mostly interested in beam loss near the DC gun and the SRF. Figure 1 shows that part of the beam line.

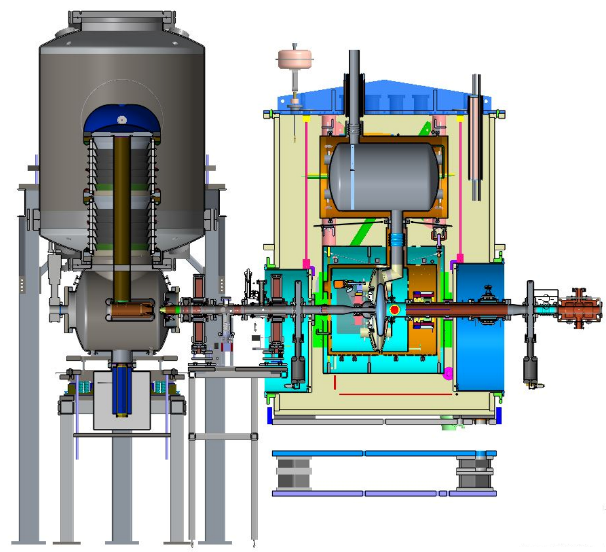

Figure 1: Section of the LEReC considered in this simulation.

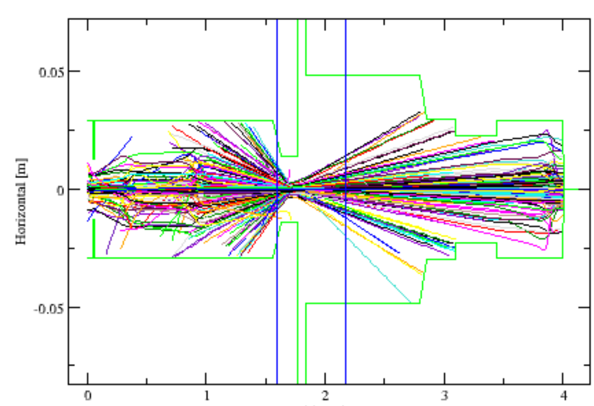

Figure 2: Traces of electrons emitted from the cathode at random phases. The green outline indicates the beam pipe aperture, the blue lines show the position of the cryostat.

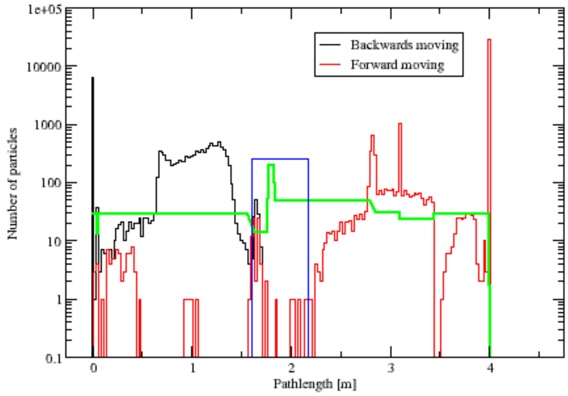

Figure 3: Location of electron losses without space charge. Backward moving electrons are counted in black, forward moving in red. The green curve shows the beam pipe radius (in arbitrary units, to guide the eye) and the blue box shows the location of the cryostat. The spike in the green curve indicates the position of the SRF cavity, which is shown in light blue in Figure 1.

Figure 2 shows the traces of electrons and Figure 3 shows where the electrons are lost if there are no space charge forces. A significant number of the electrons return to the cathode or strike the anode of the DC gun, which is located at 0.05 m.

There are only small losses inside the cryostat. The booster cavity was built as an SRF electron gun which was converted into a cavity by removing the cathode insert. At the location of this cathode insert the beam pipe diameter is restricted and we expected losses, but these simulations show that this does not constitute a problem.

All electrons that travel past the 4 meter make are included in the spike at the end. Figure 4 shows the loss position as a function of the start phase.

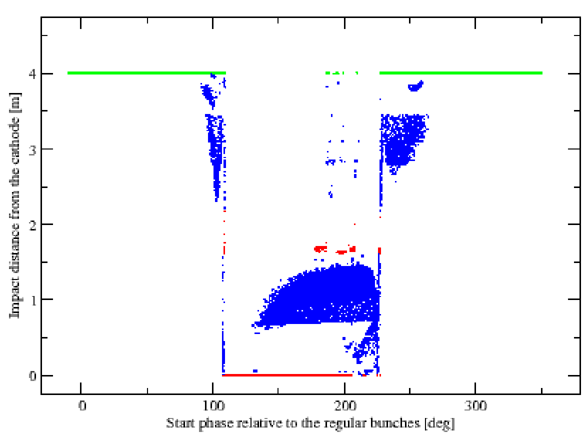

Figure 4: Loss location vs. start phase without space charge. In green electrons that impact the beam pipe, in red electrons that hit the cathode or cryostat and in green electrons that are inside the pipe after 4 meters.

Figure 5 shows the effect of the space charge forces on the stray electrons. Ten additional regular bunches follow the 50000 test particles and provide a defocusing kick to those electrons that slowed down or turned around. In the GPT program these bunches are defined as independent sets using the "setparticles()" call, so that the space charge are performed for each bunch separately.

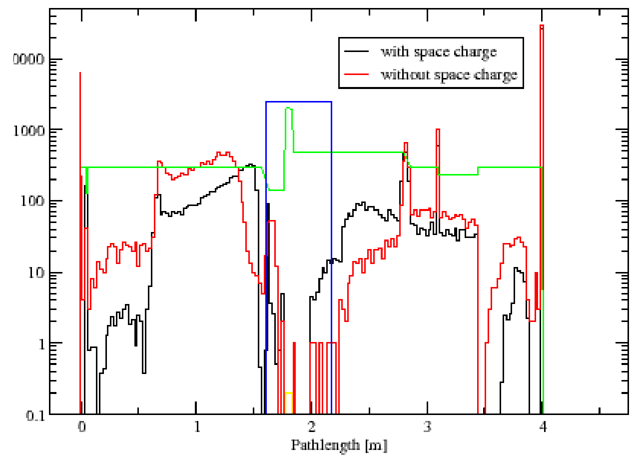

Figure 5: Loss locations with (red) and without (black) space charge.

As expected the defocusing causes more electrons to impact the beam pipe instead of returning to the cathode. The increase is significant before and after the cavity cryostat, but the fear that the space charge deflects a large number of electrons into the cavity could be laid to rest.

LASER TIMING FAILURE

For the investigation of the laser timing failure we let us guide by the previous calculation and consult Figure 4 to select two cases: One with a phase shift of 200 degrees where the cavity is affected and one with a shift of 120 degrees where the majority of the electrons return to the cathode. In both cases we track twenty regular bunches (130 pC, 80 ps) and observe the behaviour of bunch 10.

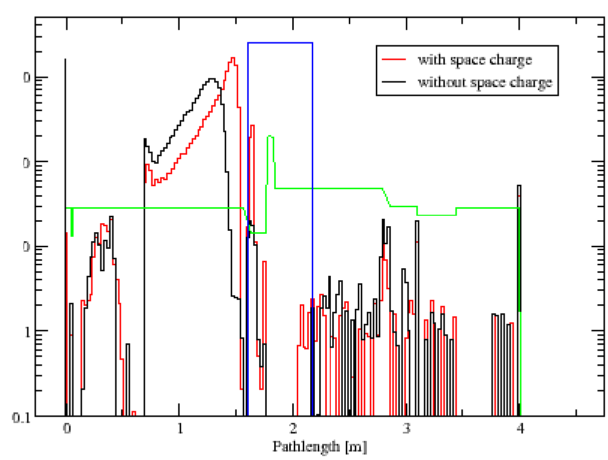

Figure 6: Losses with the laser phase shifted by 200 degrees, with (red) and without (black) space charge.

Figure 6 shows the result of the 200 degree shift. We expect from the choice of the phase shift losses inside the

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cryostat, but also a significant amount outside. This is confirmed by the simulation. We find that the space charge defocusing increases the losses in the cryostat by an order of magnitude, but decreases the losses on the cathode.

Without space charge and a 120 degree phase shift we expect that nearly all electrons will return to the cathode and this is confirmed by the tracks of the particles shown in Figure 7.

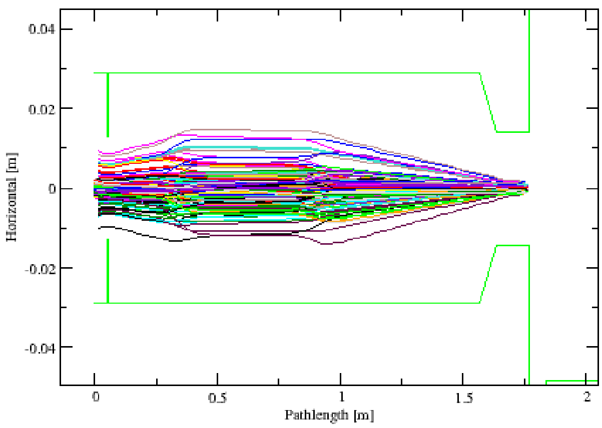

Figure 7: Electron traces with a 120 degree phase shift between laser and RF voltage. The electrons are turned around in the cavity.

The machine protection system for an electron linear accelerator consists often of a pair of DCCTs, one after the gun and one in front of the dump. A difference in the two readings indicates a loss of particles and the beam is turned aborted if the difference exceeds a threshold.

In the case of the 120 degree shift both DCCTs would read zero: the first because the electrons pass through it in both directions and the second because no electrons arrive (Fig. 8). The LEReC machine protection system includes therefore above the “save level” beam current also the laser power and BPM signals to diagnose the health of the beam.

Including the space charge defocusing causes significant losses on the beam pipe between the gun and the acceleration cavity. Also, a fraction of electrons are helped by the longitudinal space charge forces through the cavity and are lost downstream. These losses would trigger a two-DCCT machine protection system.

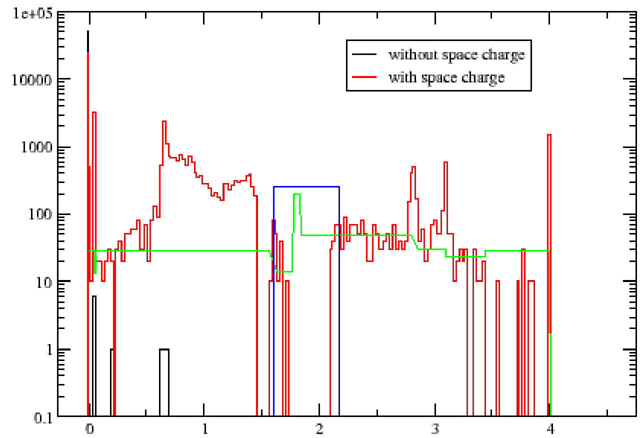

Figure 8: Losses with the laser phase shifted by 120 degrees, with (red) and without (black) space charge.

CONCLUSION

We confirmed that the space charge forces of following bunches do not significantly concentrate lost electrons in unwanted locations, but spread them out over the accelerator. For machine protection purposes this may actually be helpful.

REFERENCES

[1] S. B. van der Geer *et al.*, `www.pulsar.nl`

[2] J. Kewisch, “Simulation of stray electrons in the RHIC low energy cooler”, in *Proc. NAPAC’16*, Chicago, IL, USA, paper WEPOB55, 2017.