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SIMULATION OF STRAY ELECTRONS IN THE RHIC LOW ENERGY COOLER

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Abstract

The Low Energy RHIC electron Cooler [1], under construction at BNL, accelerates electrons with a 400 kV DC gun and a 2.2 MeV SRF booster cavity. Electrons which leave the cathode at the wrong time will not be accelerated to the correct energies and will not reach the beam dump at the end of the accelerator. They may impact the beam pipe after incorrect deflection in dipoles or after being slowed down longitudinally in the booster while the transverse momentum is not affected. In some cases their direction is reversed in the booster and they will impact the cathode.

We simulated the trajectories of these electrons using the GPT tracking code [2]. 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.

We tracked a bunch with half a million particles and the length of a full RF wave length until all particles are lost. Since we are mostly interested in beam loss near the SRF cavity we did not consider electrons that survive the first 4 meters. Figure 1 shows that part of the beam line. The stray electrons are by definition not inside the regular electron bunch, so the space charge calculation is turned off.

The first calculation starts with a 3 mm radius beam from the center of the cathode holder. From the half million 50% of the electrons make it through the 4 meter mark, 8% return to the cathode, and the remaining 42% are lost on the beam pipe somewhere in between. Again, this assumes that the electrons are created in a continuous stream, which is most likely not correct.

LOCATION OF THE BEAM LOSSES

Figure 2 shows where the 42 % of the electrons are lost. We distinguish between forward going electrons (red curve) and backwards going particles (black curve).

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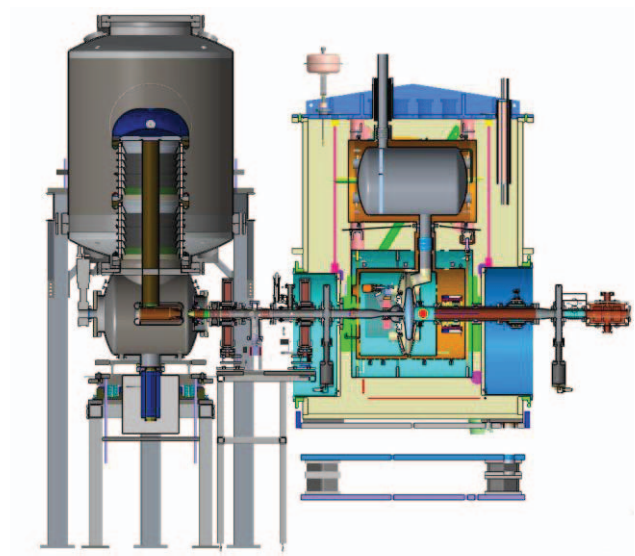

Figure 1: Section of the LEReC considered in this simulation.

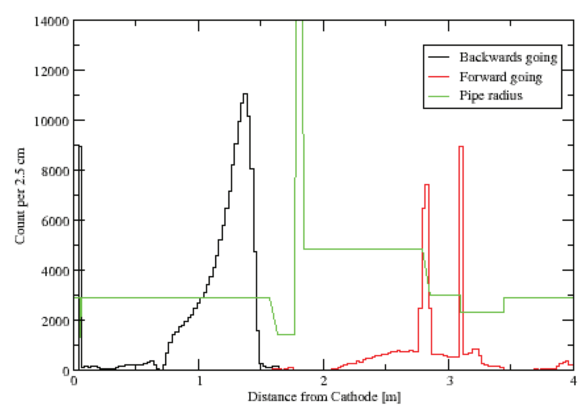

Figure 2: Location of electron losses. Backward going electrons are counted in black, forward going in red.

The green curve shows the beam pipe radius (in arbitrary units, to guide the eye). The spike in the green curve indicates the position of the SRF cavity, which is shown in light blue in Figure 1. The spike in the number of backwards traveling electrons at 0.05 m is caused by electrons impacting the anode of the DC gun.

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.

In the forward direction we have most losses at the pipe radius reduction after the HOM damper, and again at the entrance of the 3rd harmonic cavity, which is used to reduce the energy spread in the beam.

In the backwards direction most losses are close to the upstream gate valve, again just outside the cryostat. The picture does not change significantly when instead of the number of particles the deposited energy is plotted.

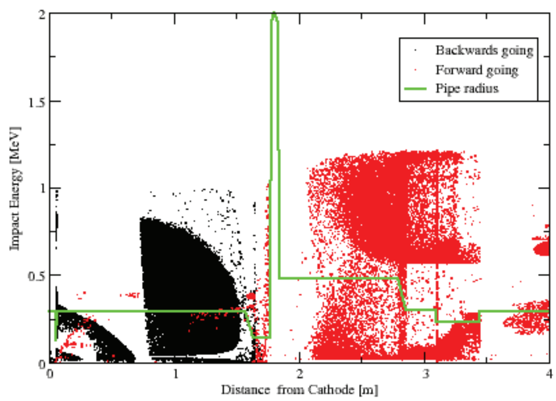

Figure 3: Impact energy of the stray electrons.

Figure 3 shows the impact energy of the stray electrons vs. the impact position. The forward going electrons (red) reach energies up to 1.2 MeV, some backwards going electrons have 1.0 MV.

ELECTRON MULTIPACTORING

It is interesting to study those electrons that reach the cathode with energies up to 0.95 MeV and hit the activated cathode area. They will create secondary electrons, which may be accelerated by the DC voltage and constitute new stray electrons. If the start phase of the electron is right it will come back to the cathode after an integer number of RF cycles and thus create an endless loop of secondary particles. If the secondary yield is greater than one this will cause an electron shower.

Figure 4 shows the "round trip" time (in RF degrees) of electrons impacting the cathode as a function of the start phase, where a zero phase indicates the phase of the central particle of the electron bunch. The red lines indicate a round trip time of an integer number of RF cycles.

Fortunately the wide bottom of the curve does not overlay the resonance lines, so there only a few start phases that allow showers. This is mainly a result of the LEReC geometry.

There are several intersections between round trip time and resonance condition lines. The ones with a start phase above 200 degrees are unstable fix points and will not sustain a shower. Only the electrons with a start phase around of 113 degrees may sustain a shower. If an electron leaves the cathode too early, the round trip time is longer and vice versa. The primary electrons will have a kinetic energy of about 70 keV.

The secondary yield at this energy depends on the material in the location of the impact. We have to distinguish between an impact in the activated portion of the cathode and an impact outside this area. In the first case the yield is between 3 and 4 [3], in the second case for stainless steel the yield is greater than 1 between 40 and 1400 keV with a peak of 2 at 400 keV [4].

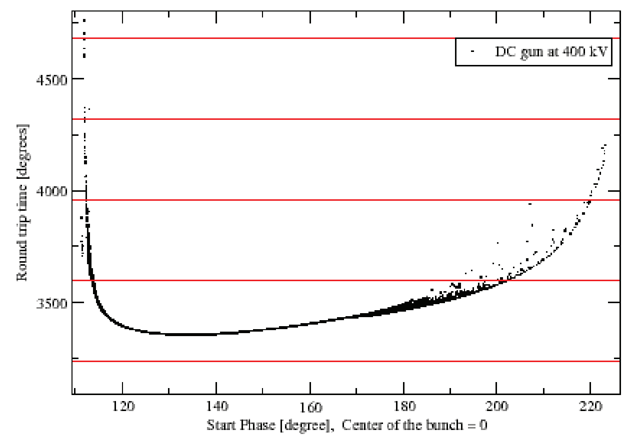

Figure 4: Round trip times of electrons impacting the cathode in degrees vs. start phase.

OFF-CENTER CATHODE AREA

As a remedy for cathode damage it is planned to place the activated area in the cathode off-centre. This is not only beneficial for the prevention of damage from electrons, but also from back-bombarding ions.

Figure 5 shows the impact positions of returning electron on the cathode when the activated area with a radius of 3 mm is centred, figure 6 with a horizontal offset of 6 mm. The red circles indicate the position of the activated area.

However, offsetting the activation area cannot be blindly applied. Figure 7 shows the loss locations with the 6 mm offset. Compared to figure 2 losses have grown at the entrance of the SRF booster cavity. These are backwards going electrons and there is no location where a collimator could be placed to intercept them.

The solution is to find a smaller offset that protects the activation area while not creating an increased heat load in the SRF booster. The optics design for the LEReC has been updated to use an activation area with a radius of 2 mm and an offset of 3mm.

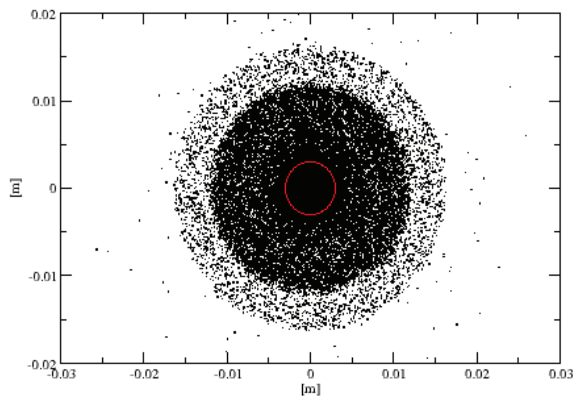

Figure 5: Cathode impact location with an on-centre activated area.

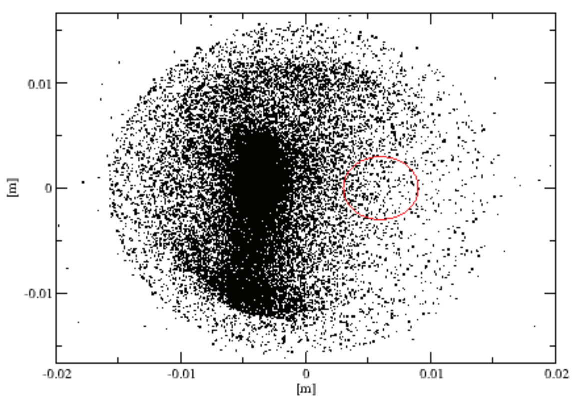

Figure 6: Cathode impact locations with an off-centre activated area.

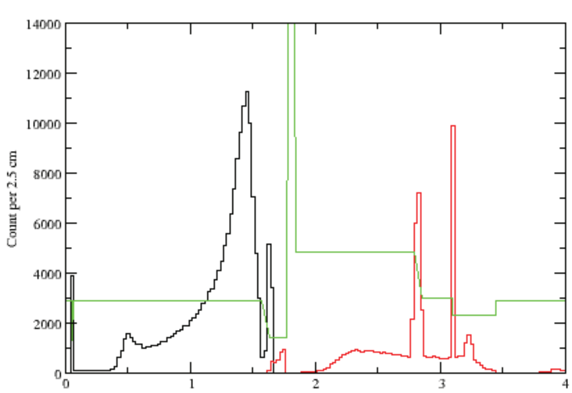

Figure 7: Location of electron losses with a 6 mm offset cathode activation area.

CONCLUSION

We considered two effects of stray electrons in the RHIC low energy cooler: Multipactoring of electrons can be avoided or greatly reduced if the cathode activation area is moved off-centre and a significant heat load in the SRF booster cavity from stray electrons is not expected when the area is moved slightly off-centre.

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