RF Induced Backgrounds in MICE

J. Norem
HEP Division, Argonne National Laboratory, Argonne IL 60439

D. Li
Lawrence Berkeley National Laboratory, Berkeley, CA 94720

A. Bross, A. Moretti
Fermi National Accelerator Laboratory, Batavia IL 60510

Y. Torun
Illinois Institute of Technology, Chicago, IL 60616

E. McKigney
Imperial College, London, England

(June 30, 2002)

I. MICE OVERVIEW

The goal of the Muon Ionization Cooling Experiment (MICE) is to demonstrate measurable muon cooling effects with realistic hardware, to show that neutrino factories, and eventually muon colliders can be built [1] [2]. A proposal for this experiment will be sent to Rutherford Appleton Lab at the end of 2002. The apparatus will consist of a particle diffuser, an initial spectrometer, rf and absorbers to cool the muons and a final spectrometer and TOF system. This is shown in Fig. 1a. A variety of cooling modules could be used, including curved sections which should provide longitudinal cooling. We have been using an 805 MHz cavity in Lab G of Fermilab to measure dark currents and radiation levels at high rf accelerating fields in the presence of solenoidal magnetic fields. This apparatus is shown in Fig. 1b.

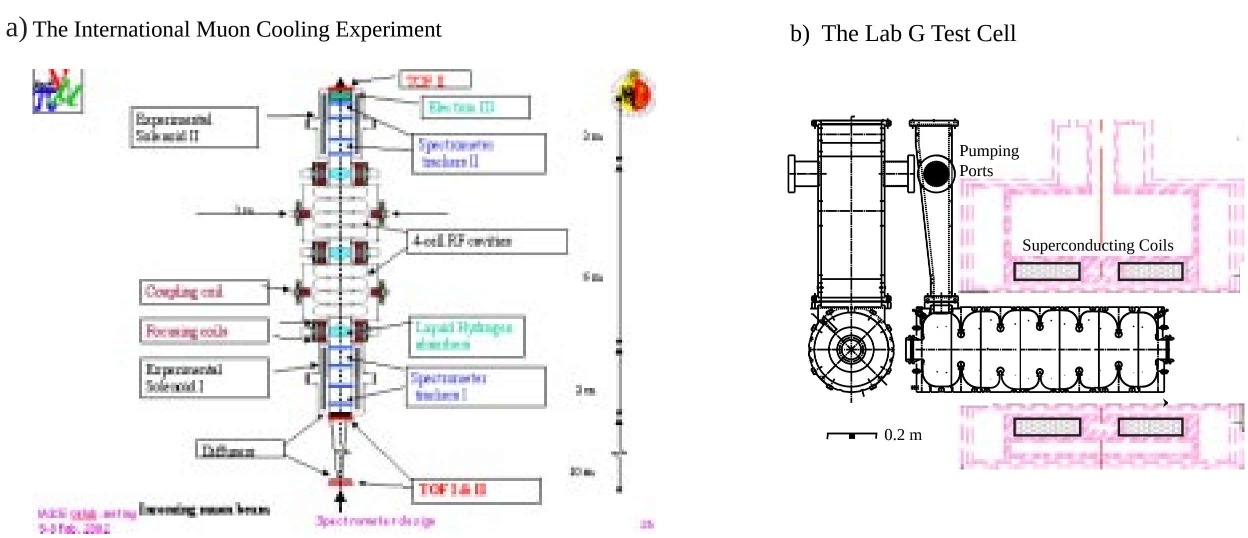

FIG. 1. The MICE experiment, and the test cell used to evaluate rf backgrounds.

The MICE spectrometers will consist of solenoids capable of achieving at least 5 Tesla. These will be matched to the channel under test, to avoid emittance growth at the interface. Two types of tracking detector systems are proposed; one based on scintillating fiber and one based on a Time Projection Chamber read out with a Gaseous Electron Multiplier, which is referred to as a TPG.

The scintillating fiber tracker design (SFT) is based on experience with the D0 detector at Fermilab and the tracker for the MuScat experiment. The SFT would have four planes of three layer crossed fiber doublets in each solenoid, with a total of about 24000 electronics channels. The fibers are round doubly clad plastic scintillating fibers with a polystyrene core. Each detector plane presents about 0.4% of a radiation length to the beam. The light from the scintillating fibers will be coupled into clear fibers and transported out of the solenoid to readout electronics based on Visible Light Photon Counters (VLPCs). The advantages of this system are the ability to operate in a vacuum and a fast response time, and that the electronics can be located away from the experiment and shielded from magnetic fields and RF pickup.

The fiber produces a signal pulse with a time width on the order of 10 nS, and the VLPC can be operated at a rate of 100 MHz. By using timing information to reject hits which do not fall into a trigger window, the SFT can tolerate single hit background rates up to 0.3 MHz, with a probability of overlap with an event of $\leq 1\%$. The conversion efficiency for the background gammas from the cavity in the detector elements is between 1% and 0.1%, depending on energy.

The TPG option is based on experience with the HARP TPC. The idea is to minimize the mass presented to the beam during the measurement process by using only a thin window at the inside end of the channel, and putting the readout at the other end of the chamber. The two sources of background for this tracker are gammas and electrons from the cavity which ionize the tracking gas, and pick-up of the RF in the front-end electronics. Because the TPG is active for the entire spill, these backgrounds will have to be removed using pattern recognition software which reconstructs the helices from individual hits, and rejects noise hits. The rate of background hits which can be tolerated is not known at this time.

II. DATA

It seems important to understand the sources of radiation produced in rf cavities, since there is some degree of extrapolation involved in the construction of high gradient, 200 MHz, rf cavities. There is a variety of information on the processes producing dark currents and radiation in cavities, some of it comparatively recent. This information implies local surface anomalies are the cause, and the model argues against significant frequency dependence, as parametrized by Kilpatrick. These conclusions are in agreement with a very slow dependence of rf gradient on frequency in superconducting cavities. Recent developments in superconducting rf also imply that breakdown and dark current emission can be improved by well understood techniques, primarily electropolishing and high pressure water rinsing.

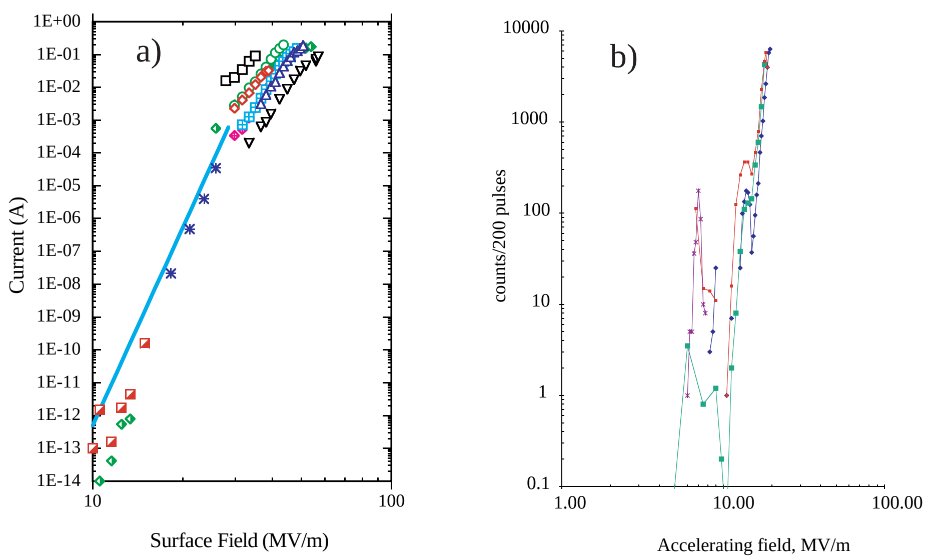

FIG. 2. Data from the open cell(a), and pillbox cavity(b), showing the Fowler Nordheim emission at high fields and low field, presumably multipactor, phenomena. These data were taken with the solenoidal field off.

Fig. 2a shows the results of the open cell studies with and without magnetic field [3]. Fig. 2b shows photomultiplier counts as a function of accelerating field. Results with both the open cell and pillbox cavities seem to show a variety of multipactor phenomena at low gradients which we do not yet understand. The slope at high field is field emission, but the counts at lower field, whose intensity changes with time and accelerating field do not seem to be described in the literature. The peak at the lowest field is very narrow.

The magnetic field also strongly affects dark currents in an rf cavity. The electron orbits are changed, the cavity copper itself is altered by magnetoresisitance and the instrumentation is also affected. Measurements of the affects of the magnetic field have been imprecise, because of the sensitivity of the instrumentation to the field.

Scattering and energy loss will also reduce the flux of dark current and x rays from reaching the detectors. Low energy electrons will be attenuated by the absorbers and deflected by the cusp fields in the FOFO structure. GEANT and ICOOL are being used to simulate this.

III. LIMITS TO THE ACCELERATING FIELD

The limit to the gradient that can be used in the rf cavities is determined by the accelerating gradient producing the maximum tolerable rate of dark current electrons and x rays. There is some uncertainty in this estimate due to lack of knowledge about the copper and Be surfaces in the 200 MHz cavities, transport of electrons and x rays through the system, and the detectors. This section attempts to make conservative assumptions where information is unavailable. The accuracy of these initial estimates should be expected to converge as more information becomes available.

The background rates depend on the tracking technology. The scintillating fiber tracker will consist of 4 planes with a resolving time of 20 ns. We assume a maximum rate of 2-10 background hits in this window, giving rates for recoil Compton electrons of 100 - 500 MHz / plane. The TPG will be live for the entire spill. and will integrate the x rays seen in the fill time of the rf system. We should determine the maximum number of compton recoil tracks in the chamber without additional trackfinding. We thus assume an overall background rate of 100 MHz, or 1 track in 10 ns, in about 0.01 radiation lengths, as the maximum tolerable rate for the spectrometers. A rate of one electron /10 ns corresponds to 0.016 nA. Our data have shown that 10 primary electrons produce roughly one detectable Compton electron when stopped in aluminum or plastic, using a thick scintillator for a detector. Our detectors will be thin, but there may be material nearby.

We can assume that most of the electrons will be diverted by the cusp fields and absorbers, and less than 0.1 of these will enter the spectrometers, about the same as the flux of Compton conversion electrons. The Compton photons will be attenuated somewhat by their angular divergence. The maximum Compton x ray current is then $\sim$0.016 nA, divided by efficiency for x ray production/detection, which we estimate as 0.1, giving a maximum rate of $\sim$0.16 nA, or a maximum accelerating field of about 13 MV/m. This field seems to be greater than the maximum that can be generated by our power supplies at the present time. Nevertheless magnetic field effects, and changes in dark currents due to the use of Be have not been tested with pillbox cavities.

IV. CONCLUSIONS

The conclusions from almost a year operating cavities in Lab G are fairly optimistic. It seems possible to operate the MICE experiment up to gradients of $\sim$13 MV/m if pillbox geometries are used. The primary complication is that the design we plan to use has strong magnetic field, with large, flat Be windows. We are in the process of testing these details.

---

[1] D. Kaplan, This conference.
[2] S. Geer, This conference.
[3] J. Norem, V. Wu, A. Moretti, M. Popovic, Z. Qian, L. Ducas, Y. Torun, and N. Solomey, Submitted to Phys. Rev. ST Accel. Beams (2002), also MUCOOL Note #235 (2002).