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X-Ray Rates in Scintillating Fibers Placed Near the BNL ATF RF Gun

K.T. McDonald
Princeton University, Princeton, NJ 08544
H.G. Kirk, X.J. Wang
Brookhaven National Laboratory, Upton, NY 11973

Abstract

Scintillating fiber detectors 1 mm in diameter and 30 cm long experienced x-ray rates of about 1000 photoelectrons per 5-ns interval when placed near a 2856 MHz rf cavity operating at a field of 110 MV/m. The rate varied as the 10.8 power of the cavity field, so detection of single minimum ionizing particles above the x-ray background would only be possible for cavity field below about 50 MV/m. Since the peak energy gain of electrons crossing the cavity is about 3 MeV, which is similar to the gain per cell in an ionization cooling channel, these results suggest that it will be difficult to detect single muons in scintillating fibers at an ionization cooling channel operating at peak field.

1 Introduction

A key technology for a muon collider [1] or a neutrino factory based on a muon storage ring [2] is ionization cooling [3, 4, 5], in which ionization loss in a medium reduces both the transverse and longitudinal momentum of a penetrating charged particle. For subsequent use of a beam based on this technique, longitudinal momentum is restored by means of rf cavities.

This simple technique has never been explicitly demonstrated in the laboratory (for MeV-scale energies), and particularly not with components representative of a practical ionization cooling channel. Therefore, an R&D program is underway to develop prototype components for ionization cooling, with the goal of testing these in a muon beam [6]. To reduce costs, and to permit full measurements of the 6-D phase space of a muon beam, a demonstration of ionization cooling can be made by detailed measurements of individual muons before and after a cooling apparatus [7], and the phase-space history of a muon bunch reconstructed in software.

An initial proposal to implement a so-called single-muon cooling demonstration using gaseous tracking detectors [8] was criticized as being vulnerable to severe backgrounds in the tracking devices due to x-rays from the necessarily high-gradient rf cavities of the cooling apparatus. A test of x-ray dose in thermoluminescent detectors placed near a 1300 MHz rf cavity operating at peak fields of 110 MV/m confirmed a high x-ray flux [9]. This result dampened the enthusiasm for single-particle ionization cooling demonstrations that contain rf cavities.

Recently, the concept of a single-particle ionization cooling demonstration using rf cavities has been revived [10], with a tracking device based on 1-mm-diameter Bicron BCF-12 scintillating fibers [11]. As these fiber as sensitive to x-rays, the question remains as to their viability in the proposed ionization cooling demonstration.

Therefore, tests of Bicron BCF-12 scintillating fibers are underway at various rf cavities. The present report concerns x-ray backgrounds detected at a 2856 MHz rf cavity operating at up to 110 MV/m field, namely the rf gun of the BNL Accelerator Test Facility [12, 13].

2 Results

The BNL ATF rf gun is sketched in Fig. 1. Two BCF-12 scintillating fibers, each 30 cm long, were wrapped around the beampipe at distances about 30 and 60 cm from the rf gun.

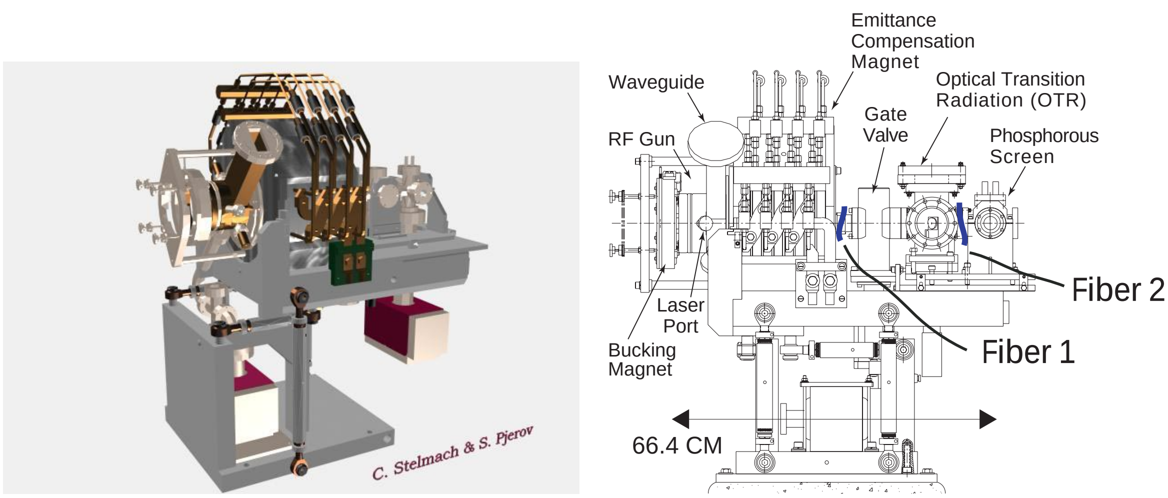

Figure 1: Drawings of the BNL ATF rf gun. Two 30-cm-long BCF-12 scintillating fibers were placed on the output side of the gun, just upstream of the gate valve, and just upstream of the phosphorous screen.

In the proposed ionization cooling experiment, the fibers would be at least 60 cm long, with only $\approx$ 30 cm of liquid hydrogen between them and the rf cavities. As the x-rays must have passed through various copper and stainless-steel walls in the present test before reaching the fiber, the x-ray flux at the fiber is likely more attenuated than would occur in a cooling demonstration.

The scintillating fibers were view by photomultiplier tubes after transmission down 5-m-long lightguides made from 1-mm-diameter clear plastic fiber, Bicron BCF-98. Because of the small diameter of the fibers and the length of the light guides, the number of photoelectrons detected per minimum ionizing particle was only approximately one, as verified by tests with a 1-MeV-β ^{90}Sr source. Nonetheless, substantial x-ray rates were detected from the rf gun, as discussed below.

Both fibers observed qualitatively similar x-ray rates as a function of rf cavity field strength. We only discuss the results from fiber 1 in detail.

Initial measurements were made with the trigger laser off, so the gun was producing no electron beam, and with the emittance compensation solenoid magnet off. At a PMT voltage of 1680 V, the observed peak voltage of the x-ray signal behaved as shown in Fig. 2. Over the limited range of cavity electric field E surveyed, the x-ray rate is well described by a power-law fit of $E^{10.8}$. This is in reasonable agreement with a dependence of E^9 reported elsewhere [9].

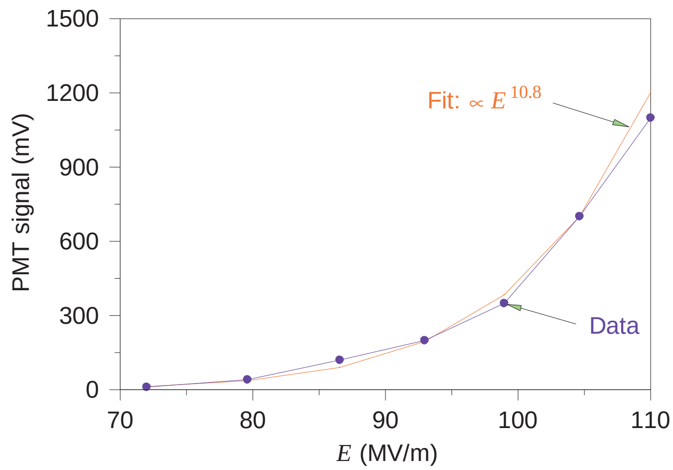

Figure 2: The observed PMT voltage from the x-ray signal in fiber 1 as a function of the peak electric field in the rf cavity, with the electron beam off and the compensating solenoid off.

The PMT signal for the case of $E = 110$ MV/m is shown in Fig. 3. The pulse of rf noise from $t = 1$ to 3 μs is due to the turn-on of the klystron, and is independent of the PMT voltage. The x-ray signal (which varied with PMT voltage) is prominent from $t = 4$ to 5.5 μs, and is slightly narrower than the klystron output pulse width because x-ray production occurs only when the electric field is large inside the rf cavity. The area of the x-ray signal is approximately 1×10^6 mV-ns.

A typical single photoelectron signal in the PMT at 1680 V is shown in Fig. 4. Its area is about 5 mV-ns. Hence the x-ray signal shown in Fig. 3 corresponds to about 2×10^5 photoelectrons over a 1.5 μs interval. In, say, a 5-ns window for measurement of a single muon, there would be about 700 photoelectrons. Recall that because of small diameter of the fiber and the long lightguide, the signal due to a single muon is slightly less than one photoelectron. Thus, the x-ray background level is at least 1000 times larger than the single muon signal at the peak field condition of the BNL rf cavity.

Because of the steep dependence of the x-ray rate on cavity field strength, the x-ray level could be reduced to, say, 1/10 of the single muon signal by lowering the cavity electric field to 0.4 of 110 Mv/m = 44 MV/m.

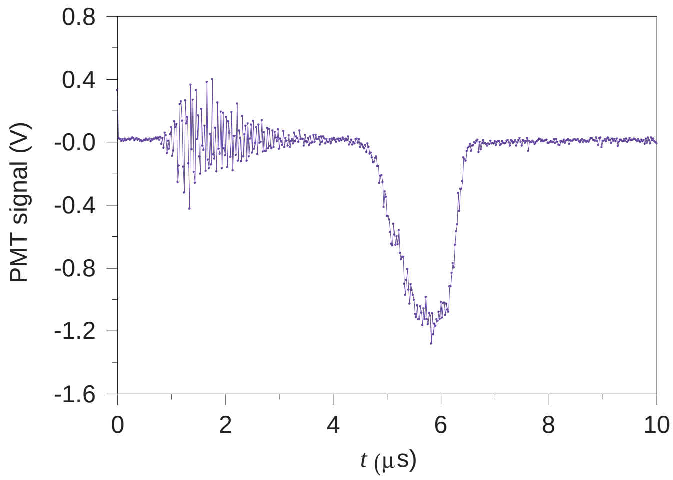

Figure 3: The observed PMT voltage *vs.* time from the x-ray signal in fiber 1 at a peak electric field of 110 MV/m in the rf cavity.

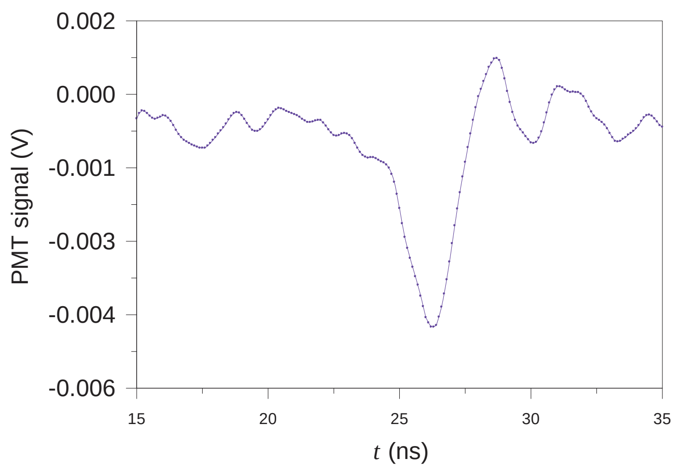

Figure 4: A single photoelectron signal in the PMT at 1680 V.

Note that because of the small size of a 2856 MHz rf cavity, the maximum voltage across the cavity is only about 3 MV when the peak electric field is 110 MV/m. The x-rays are caused by electrons that leave the cavity wall at one point and strike it at another after gaining at most 3 MeV. This gain of 3 MeV per cavity cell is typical of the lower frequency rf cavities forseen in an ionization cooling channel, so the present test is at relevant voltages.

The present result suggests that x-rays are likely to preclude observation of single muons in scintillating fibers near rf cavities in an ionization cooling channel if the cavities are operated at peak field strength. But single-particle measurements may be possible if the cavity field strength is reduced sufficiently.

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