RF SYSTEM CONCEPTS FOR A MUON COOLING EXPERIMENT*

A. Moretti, FNAL, Batavia, IL, USA
J.N. Corlett, D. Li, W.C. Turner, LBNL, Berkeley, CA, USA
H.G. Kirk, R.B. Palmer, Y. Zhao, BNL, Upton, NY, USA

Abstract

Concepts for the rf accelerating cavities of a muon cooling experiment are discussed.

1 INTRODUCTION

The feasibility of muon colliders for high energy physics experiments has been under intensive study for the past few years and recent activity has focused on defining an R&D program that would answer the critical issues.[1] An especially critical issue is developing practical means of cooling the phase space of the muons once they have been produced and captured in a solenoidal magnetic transport channel. Overall six dimensional phase space must be reduced by a factor of 10^5 to 10^6; normalized horizontal and vertical emittance must each be reduced two orders of magnitude, from ~5000πmm-mrad to ~50πmm-mrad. Because of the short muon decay time ionization cooling seems to be the only method that is fast enough; lengths of low-Z absorber alternate with longitudinal rf re-acceleration until the desired cooling is obtained. Initial studies have shown that the entire cooling channel might consist of ~20 modules, each cooling by a factor of ~2. In this paper we describe one of the modules that is under study for transverse cooling. The nominal muon momentum for this module is 163.1 MeV/c, $\beta = 0.839$.

A schematic of a 2m section (one period) of the transverse cooling lattice is shown in Fig. 1. On axis liquid H_2 absorbers with length 64cm provide nominal energy loss 21.6MeV which is to be regained by 1.25m of accelerating cells between absorbers. Beam transport is accomplished with alternating polarity 15T, 20cm bore superconducting solenoids outside the absorbers and matching superconducting solenoids with 38cm bore outside the rf cells. The rms and maximum orbit radii are indicated and require a rather large 16cm aperture in the rf cells.

Having a 16cm aperture for the muon beam leads to rather low cell shunt impedance and very large power to achieve the necessary accelerating gradient if conventional disk coupled cavities are used. We have therefore taken advantage of the low scattering rates of muons in material to design pill box rf cells with thin metal(Be) windows covering the apertures. In addition to increasing the shunt impedance this has the added advantages of (1) putting the maximum accelerating gradient on the beam axis and achieving ~2 times the ratio of accelerating field to maximum field compared to conventional cells and (2) providing considerable freedom in the choice of rf phase advance per cell and cell coupling.

For the rf cell design we have considered traveling and standing wave cases and π, 2π/3, π/2 and π/3 rf phase advance per cell. In order to achieve reasonable power consumption with a traveling wave design required lowering the group velocity to the point where manufacturing tolerances became difficult. We were then led to a side coupled standing wave design with interleaved coupling to allow flexibility in choice of phase advance per cell. Fig. 2 illustrates the accelerating field for (a) π, (b) 2π/3 and (c) π/2 phase advance per cell. For (a) there is a single side structure coupling adjacent cells in the π mode. For (b) there are three side coupling structures connecting three interleaved chains of cells. The interleaved chains are phased 2π/3 apart, adjacent cells within a chain are in the 2π mode. For (c) there are two side coupling structures connecting two interleaved chains of cells. The interleaved chains are phased π/2 apart, adjacent cells within a chain are in π mode. The transit time factor for these three cases is $T = \sin(\phi/2)/(\phi/2) = 0.637$, 0.827 and 0.90 respectively. For a given maximum accelerating gradient. case (c) has 1.4 times the accelerating gradient of (a) and in addition to having larger gradient than (b) has less coupling structure so we have chosen case (c) for most detailed study.

2 DESCRIPTION OF THE RF CAVITIES

Details of the interleaved π/2 cell structure are given in Fig. 3 and Table 1. The rf frequency has been chosen to be 805MHz, the frequency of the FNAL linac. The accelerating field is well approximated by the TM_{010} mode of a cylindrical pill box with the pill box radius R = 14.3cm determined by the first zero of J_0. The pill box length l = 7.82cm is determined by the phase advance and muon velocity; $\pi/2 = (\omega/\beta c)*l$. The side coupling cells are coaxial LC resonators with geometry chosen to match the frequency of the pill box. The Be windows are 125μm thick; chosen to minimize multiple Coulomb scattering emittance growth but not be too fragile. The operating

*Supported by the US DOE under contract numbers DE-AC03-76SF00098, DE-AC02-76-CH00016 and DE-AC02-76-CH03000..

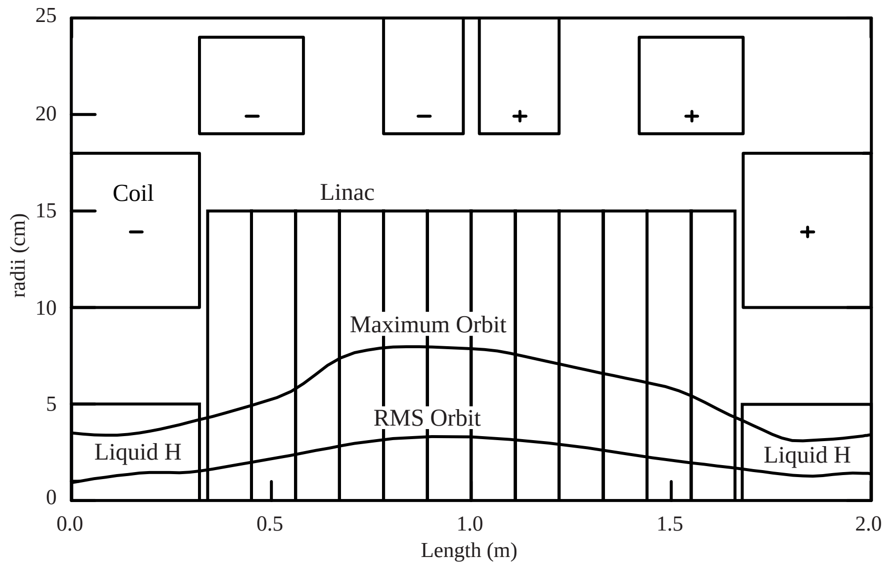

Figure 1: Schematic of a 2m section (one period) of a muon cooling lattice.

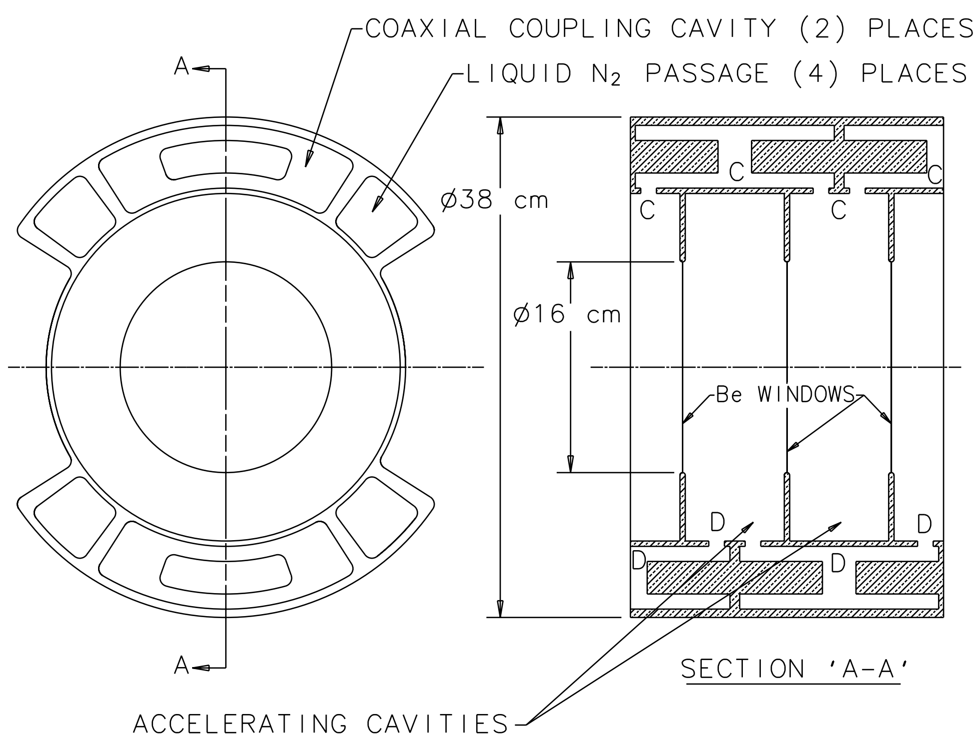

Figure 3: Details of the interleaved π/2 cell structure.

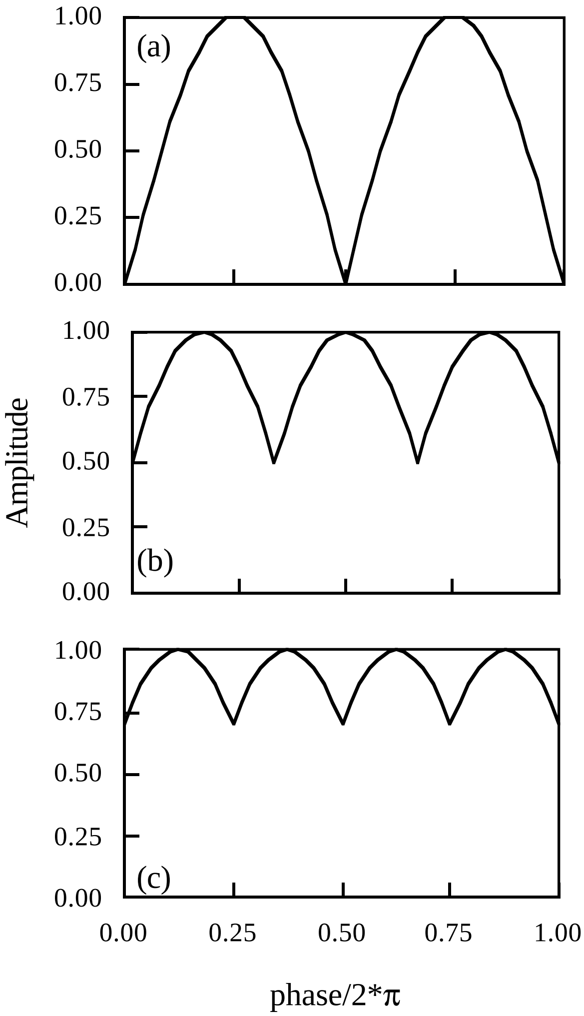

Figure 2: Illustration of the rf accelerating field for interleaved pill box cells with (a) π, (b) 2π/3 and (c) π/2 muon phase advance per cell.

temperature of the cells has been chosen to be LN temperature to decrease the cavity losses by a factor of ~2. This factor is indicated explicitly in the Q and shunt impedance figures given in Table 1. Sixteen of the pill box cells occupy each 2m section, one of which is indicated in Fig. 1. The total rf peak power for a 2m section is then 16x.0782x8.3 = 10.4MW which is a good match to one FNAL linac klystron. The peak accelerating gradient 30MV/m is only slightly higher than the Kilpatrick gradient. The cells would be operated in a 15Hz, 28μsec pulse mode. A single transverse cooling stage would be 22m long; simulations of a such a 22m cooling stage have indicated reduction of transverse emittance from an input value 1400 πmm-mrad to output 650 πmm-mrad, growth of longitudinal emittance from 1000 πmm to 2040 πmm-mrad and overall reduction of 6D emittance by a factor of 2.2.[2] Emittance growth due to scattering in the 176 125μm Be windows has been

Table 1: Cell parameters for the RF structure shown in Figure 3.

Parameter	Value
RF frequency, MHz	805
Cell length, cm	7.82
Cell aperture, cm	16
Cell outer radius, cm	19
Cells per 2m section	16
Q/1000	2x22
Peak axial gradient, MV/m	30
Shunt impedance, MOhm/m	2x54
ZT^2 MOhm/m	2x44
Fill time (3τ), μsec	26
RF peak power, MW/m	8.3
Avg Power(15Hz), kW/m	3.5

calculated to be ~20 πmm-mrad, small compared to the overall emittance reduction by ionization cooling.

3 NEAR TERM EXPERIMENTAL PLANS

An experimental apparatus has been constructed at BNL to measure the resistivity and thermal conductivity of Be samples at room and LN temperatures. A first design of the Be window has been carried out at FNAL. A 3 cell low power rf cavity has been designed at LBNL and will be used to test mechanical stability, Q and tunability at LN temperatures. A 3 cell high power rf cavity with a 5.5T superconducting solenoid will be fabricated at LBNL and tested at FNAL. The high power tests will investigate multipactoring, cavity coupling, window heating and mechnical stability. The time scale for these activities is ~2 years. Beyond that it is planned to incorporate a 10m length of the rf cells desribed in this paper in a demonstration muon cooling experiment described in Ref. 2.

4 REFERENCES

[1] R. Palmer, A. Tollestrup and A. Sessler, Proc. of 1996 DPF,DPB Summer Study “New Directions for High Energy Physics”, Snowmass, CO(1996).
[2] The MUCOOL Collaboration, "Ionization Cooling Research and Development Program for a High Luminosity Muon Collider”, http://www.fnal.gov/projects/muon_collider/