HIGH GRADIENT RF CAVITIES FOR PHASE SPACE MANIPULATION OF MUONS

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Abstract

A very field gradient cavity of more than 0.5MV/m at 6MHz is required for muons of short lifetime. Because of the high field gradient, a magnetic material load cannot be applied, which is usually used for such a frequency range. Such a low frequency RF system is discussed.

1 INTRODUCTION

In PRISM (Phase Rotated Intense Slow Muons) project [1], the energy spread of muons (20MeV± 50%) that are produced from slow-extracted energetic protons will be reduced by a manipulation of the muon phase space [2,3]. Muons are obtained as decay products from pions that are generated by high-energy protons hitting on a production target. Because the muons are tertiary products, muon beams have very bad quality. A long drift makes a good correlation between the TOF (time of flight) and its energy, where the bunch becomes as long as 20m. Then the large energy spread can be reduced by so-called phase rotation, which decelerates early coming fast muons and accelerates late slow muons. The bunch length corresponds to as low as 6MHz. Because of the short lifetime of muons (~2.2us), the phase space manipulation by the RF cavities has to be finished as quickly as possible, which requires rather high gradient such as 0.5MV/m. Although, magnetic materials are usually used in such low frequency cavities for inductive loads, the high gradient requirement makes it difficult.

2 PRISM/L

While the baseline design of PRISM uses FFAG as the phase rotator, linac based one (PRISM/L) will be treated here, because of the simplicity in describing the cavities. The schematic scheme of PRISM/L is shown in Fig. 1.

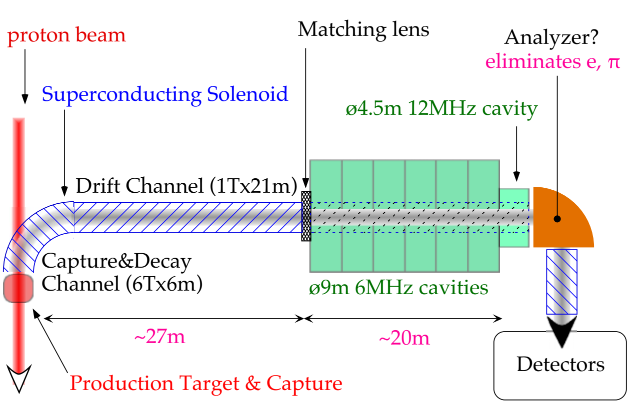

Fig. 1 Schematic view of PRISM/L

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2.1 Target and π Capture-Decay Section

Carbon target is immersed in 6T solenoidal field. Although higher field is preferable to capture as many pions as possible, practical reasons in fabrication and operation of a superconducting solenoid magnet enforce the field level up to 6T[4]. Only pions emitted backwards will be handled because of less radiation compared with the forward area and isotropic distribution of the low energy pions. The collected pions travel in a decay channel of about 6m, where more than 70% of pions are decayed to muons. In order to keep the beam size small, the magnetic field is held 6T up to this point.

2.2 Expansion and Drift Section

Because the momentum transfer from transverse phase space from longitudinal phase space are expected in the decreasing field *B*, where the beam size expands in proportion to $B^{-0.5}$, field level of 6T will be adiabatically decreased to 1T in the drift section. The bore diameter of the drift section becomes 0.6m. Because the time of flight (TOF) develops not as a function of its total momentum but that of longitudinal one, the magnetic field level of the drift section has to be as small as possible. This decreases the stored energy in the solenoid coils and may reduce its cost. A rough simulation result of the muon energy as a function of ToF is shown in Fig. 2. Because of the low energy region (20±10MeV), $\pi \rightarrow \mu + \nu$ decay introduces relatively large disturbance in the correlation. A plot with its ordinates of the longitudinal momentum shows slightly better correlation.

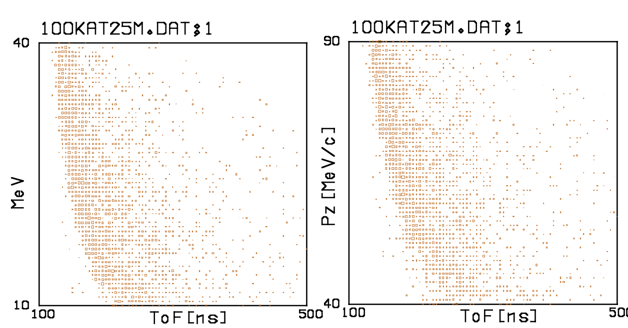

Fig. 2 Energy and longitudinal momentum as a function of TOF after the drift section (25m). Time is measured from the target.

2.3 Matching and Phase Rotation Section

The ideal correlation function can be fitted by 6MHz and 12MHz components as shown in Fig. 3. Because total voltage of 10MV is too high to generate in a single cavity,

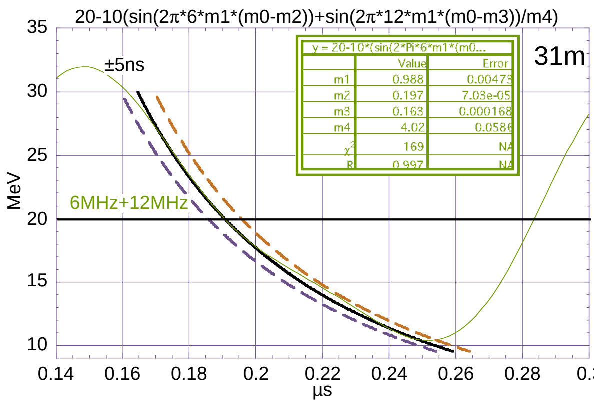

Fig. 3 An ideal Energy to TOF function fitted by 6MHz and 12MHz components.

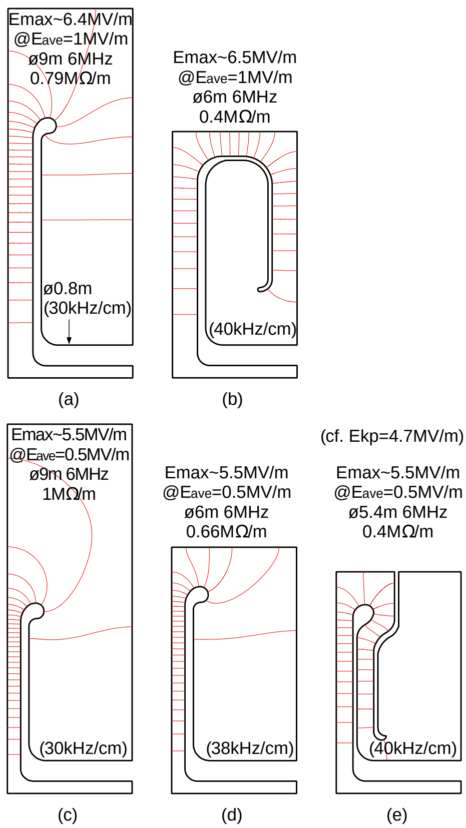

Fig. 4 Candidates for 6MHz cavities. Top two cavities have large gaps and can generate 1MV/m. Bottom three cavities are good for 0.5MV/m.

we need six cavities for 6MHz and one 12MHz cavity. Fig. 4 shows some candidates for the cavity geometry. Top two cavities have large gaps and can generate field gradient of 1MV/m, which corresponds up to 1.4 times of Kilpatrick criterion E_{Kp}. Bottom three cavities are good for 0.5MV/m. The right most one is an extension from the CERN AD cavity [5]. The smaller gap distance has an advantage in reducing the magnetic field dip at the gap. The sensitivity on the resonant frequency is large for the drift tube diameter, because its inductance is important to decrease the resonant frequency. Therefore, the diameter

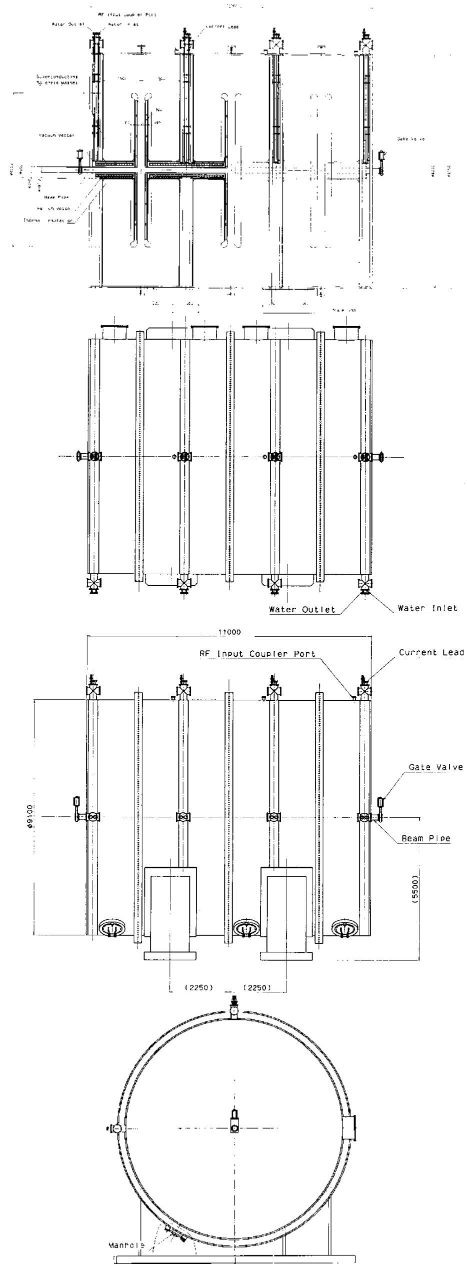

Fig. 5 Rough sketch of the ø9m cavity.

should be as small as possible, in order to reduce the cavity sizes, some of which are already reached ø9m.

As mentioned before, the drift tubes should hold the solenoid coils, and the bore of the solenoid coils have to be large enough to trap the muons. Thus the magnetic filed of 4T in the phase rotator section is thought to be reasonable. The magnetic field of 1T in the drift section is increased to 4T towards the cavity in the matching section. The solenoid coils are installed in the drift tubes in the six cavities with the gap length of 30cm and the magnetic flux continues throughout the phase rotator. Extra coils in the electrodes can reduce small dips of the magnetic field at the gap. The magnetic force between the coils is almost comparable with the air pressure on the endplates for the ø9m cavities. A rough sketch of the ø9m cavity is shown in Fig. 5. The example has three cavity sections and thus two of them are required to generate the total phase rotation voltage of 10MV.

The muon energy just after the phase rotator as a function of TOF is shown in Fig. 6. Because of the transverse momentum, the median energy is slightly pushed up.

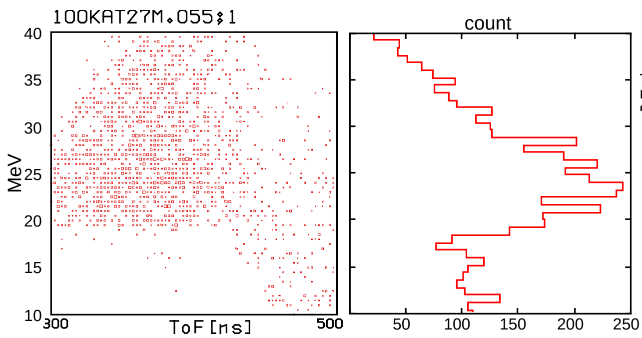

Fig. 6 The muon energy as a function of TOF just after the phase rotator. The weighted projection to the energy axis is also shown.

2.4 Extraction from Solenoidal field

Muons immersed in the solenoidal field throughout the system should be extracted from the field. The muon beam diverges immediately after the solenoid field ended. Thus a reverse field is applied to focus the beam again. Fig. 7 shows the Magnetic field distribution with the reverse field that works as a lens with focal length of about 40cm[6]. This also acts as a field clamp. The origin corresponds to the exit of the phase rotator. The Phase space distributions at 56m and 57m with energy window between 22 to 26 MeV are shown in Fig. 8. Because the energy spread is already compressed at this point, the drift of the phase distribution is fairly straightforward. Additional lens can be placed to manipulate the beam parameter to match the beam to a subsequent section such as momentum analyzer. Because of the linear system, not only electrons but also muons with opposite charge come out from the exit. A device to eliminate such particles has to be incorporated in the system.

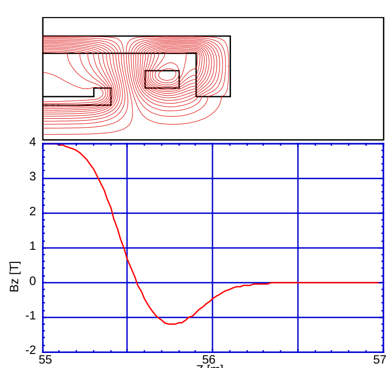

Fig. 7 Magnetic field distribution for refocus the muon beam. The reverse (negative) part acts as a lens with focal length of about 40cm.

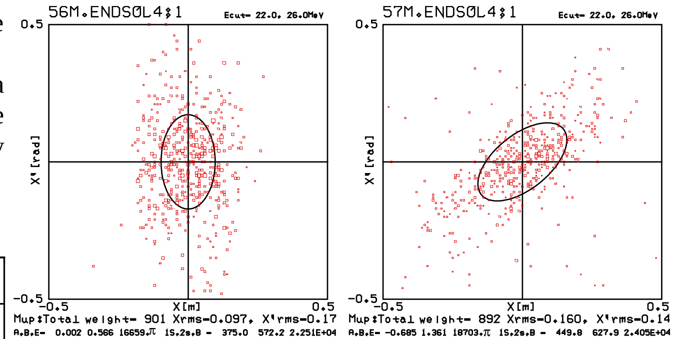

Fig. 8 Phase space distribution at 56m and 57m.

4 DISCUSSIONS

The high gradient makes a use of magnetic material as an inductive load difficult. The air core cavities, however, will have a radius of more than a few meters. For higher energy muons more than 100MeV, high frequency cavities such as 100MHz may be applicable with a high frequency bunching system [7,8]. The low energy muon beam has less quality and such high frequency buncher is difficult to apply. Construction of the huge cavity is under investigation.

5 ACKNOWLEDGMENT

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