Prototyping of a disk-loaded structure for muon acceleration

MOPL172

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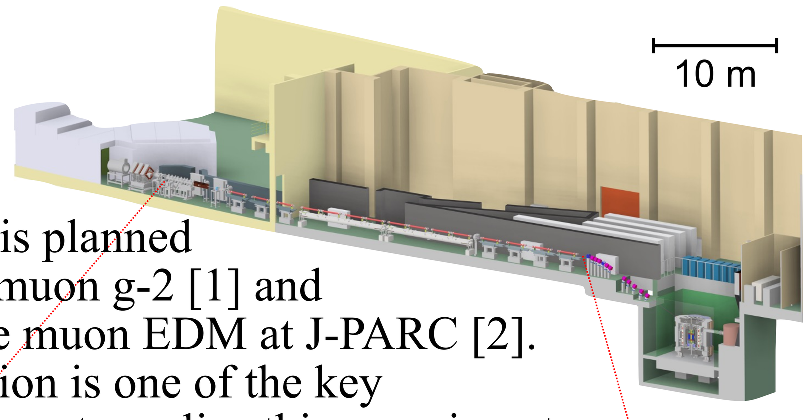
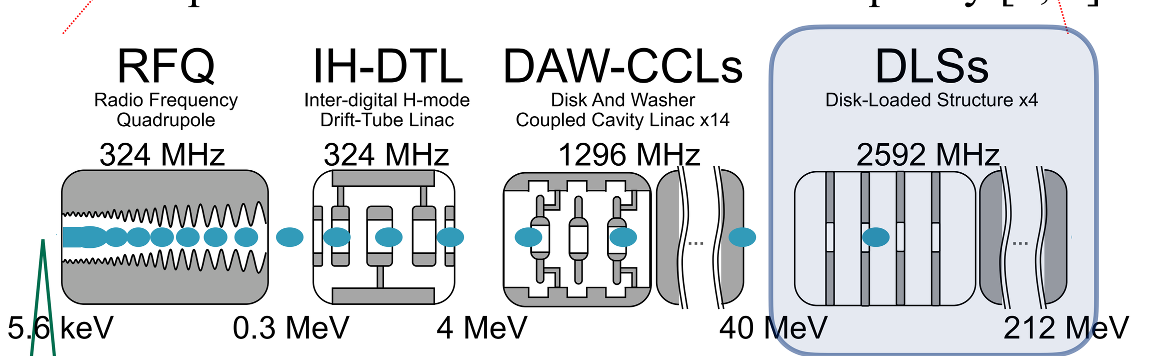
Abstract

The muon linear accelerator is under development at J-PARC for precise measurement of muon anomalous magnetic moment and electric dipole moment. Four 2592 MHz disk-loaded structures (DLSs) operating in the TM01-2π/3 mode take charge of the acceleration of high-velocity muon from 70% to 94% of the speed of light. They have disk-iris apertures tapered to generate a quasi-constant gradient of 20 MV/m. Gradual variation in disk space at each cell is one of the structural features of the DLS for muon to synchronize the accelerating phase with the changing speed of muon. Therefore, the dimensions of both end cells are significantly different. Two prototypes of RF couplers and two 9-cell reference cavities with shapes of the end cells of the DLS at the first stage have been fabricated and tested. We validate our design RF parameters and establish a method for tuning the DLS in this paper.

Motivation



- ❖ An experiment is planned to measure the muon g-2 [1] and to search for the muon EDM at J-PARC [2].
- ❖ Muon acceleration is one of the key development items to realize this experiment.
- ❖ The required beam quality is as follows
  - a low transverse normalized emittance: ~1.5π mm mrad
  - a small momentum spread: < 0.1% (RMS) at 300 MeV/c
- ❖ An unprecedented muon linear accelerator is under development to achieve the desired beam quality [3, 4].



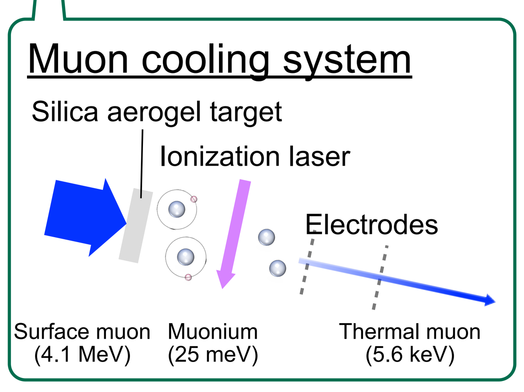
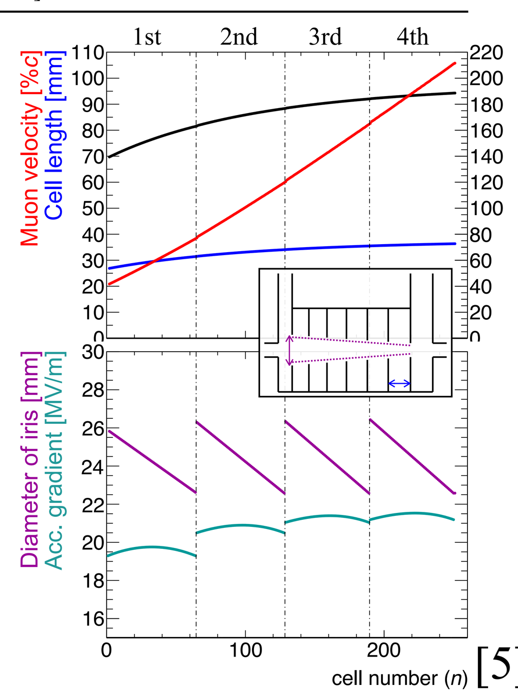


Table 1: Main parameters of the DLS section

Stage	1st	2nd	3rd	4th
Structure type	Disk-loaded traveling-wave quasi-Constant Gradient type			
Operating frequency	2592 MHz			
Accelerating mode	TM01-2π/3			
Muon velocity [%c]	70-82	82-89	89-92	92-94
# of regular cells	63	63	60	60
Length [m]	1.97	2.21	2.23	2.30
Input RF power [MW]	~40			
Gradient [MV/m]	19.6	20.8	21.3	21.4

Muon-dedicated DLS

- ❖ Four muon-dedicated disk-loaded traveling wave structures (DLSs) are responsible for accelerating the muons from 70% to 94% of the speed of light.
- ❖ The disk spacing is proportional to the muon velocity to synchronize the phase velocity of the electromagnetic field in the DLS.
- ❖ The diameter of the iris apertures is tapered to obtain a quasi-constant accelerating gradient.
- → The dimensions of the cells differ significantly at the upstream and downstream ends.
- ❖ The disk spacing is the narrowest and the change is the largest in the first DLS.



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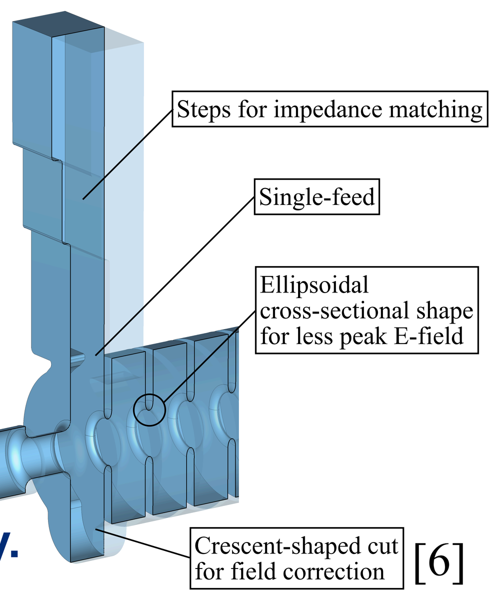
Fabricate prototypes of 1st DLS to verify the feasibility.



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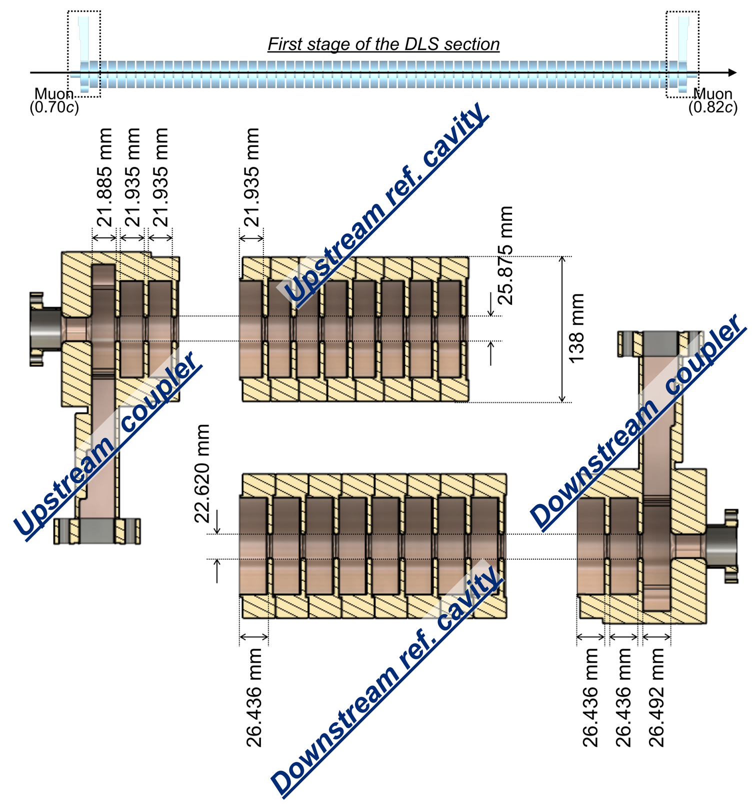
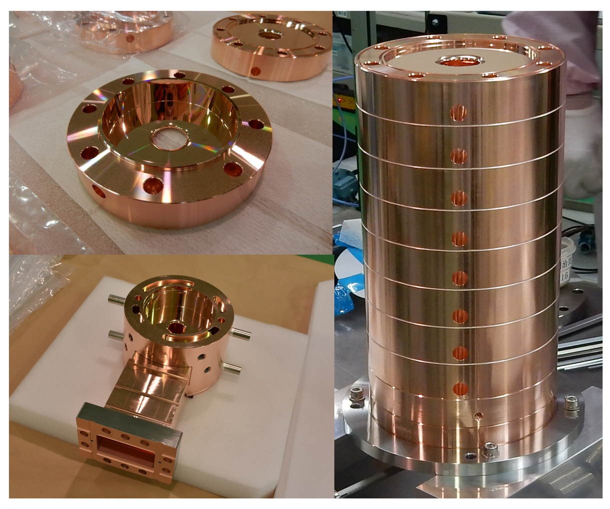
Prototype Fabrication

- ❖ Two 9-cell reference cavities and two RF couplers were fabricated.
- ❖ The coupler is composed of one coupler cell that couples with a single waveguide and two regular cells.
- ❖ The reference cavity is a constant-impedance structure consists of eight regular cells and two half cells.
- ❖ All regular cells have identical dimensions as the adjacent cell of the upstream or downstream coupler cell
  - to validate the RF properties of the regular cells
  - to perform Nodal shift measurements with precisely tuned regular cells



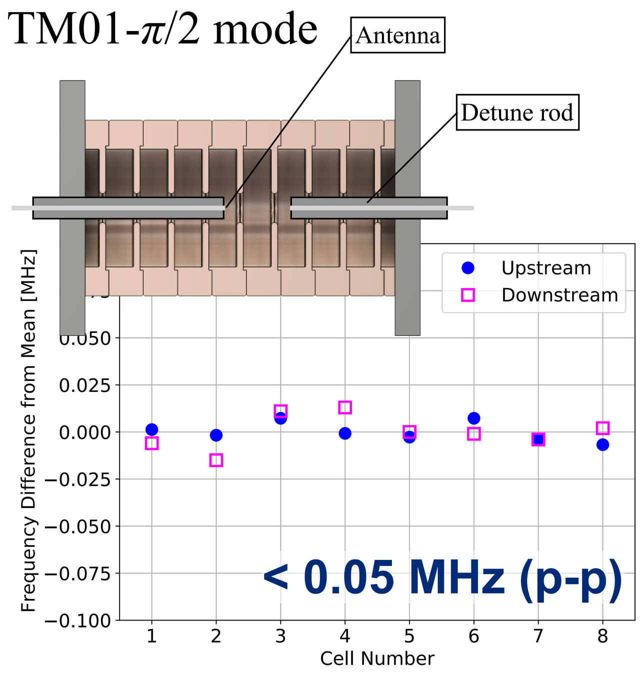
↓ Cup-shaped structure integrating a disk and a cylinder to simplify the construction process and reduce costs.



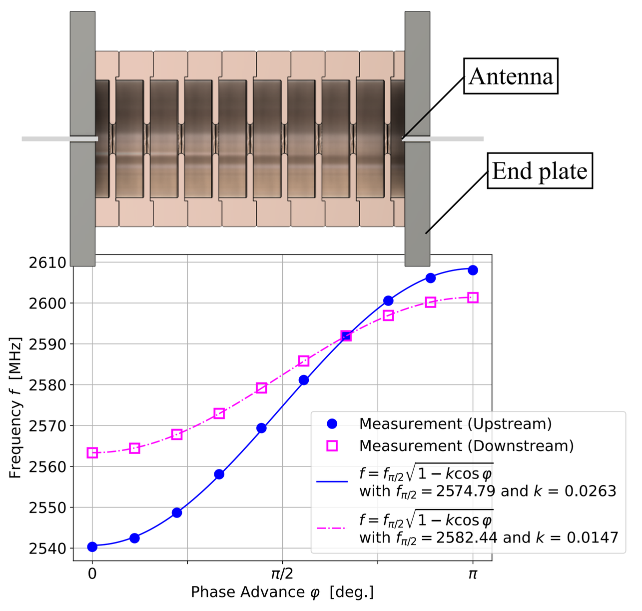
↑ Brazed coupler & ref. cavity. ↑ (oxygen-free copper)

RF Measurements

❖ TM01-π/2 mode



❖ Dispersion curve & Quality factor Q (TM01-2π/3 mode)



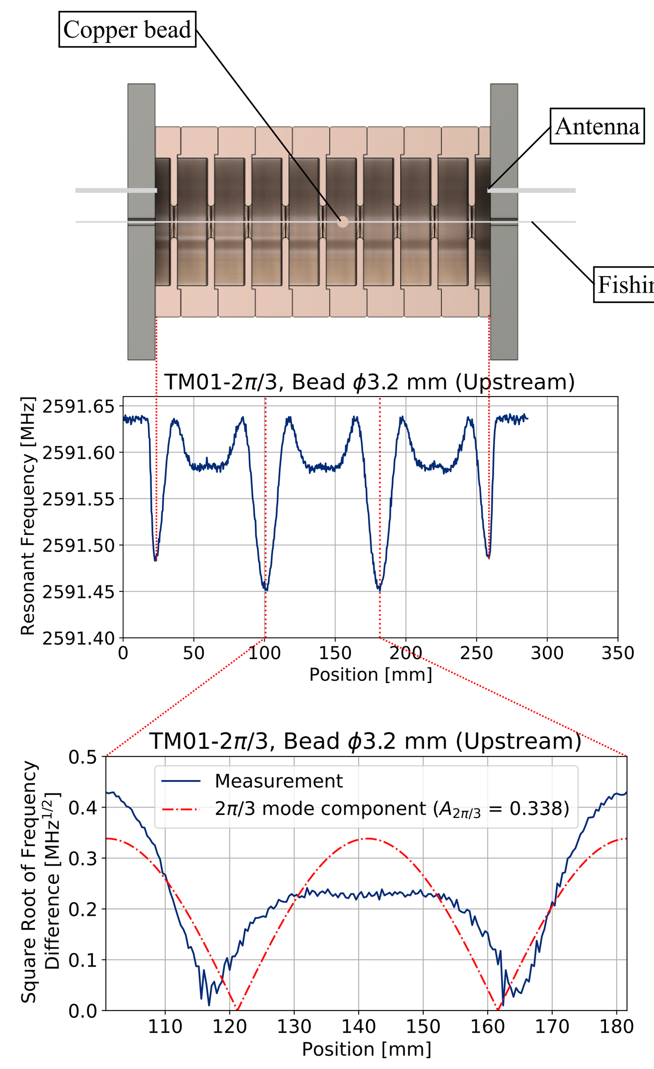
Couplings are as expected.

Table 3: Comparison of the Simulated and Measured Quality Factor

Parameters	Upstream	Downstream
Simulation w/o end plate	11314	12785
Simulation w/ end plate	9840.2	11210
Measurement w/ end plate	9490.2	10263

96.4% 91.6%

❖ Shunt impedance by bead pull



$$Z = \frac{{A_{2\pi/3}}^2 QL}{4\pi^2 \varepsilon a^3 f_0^2}$$

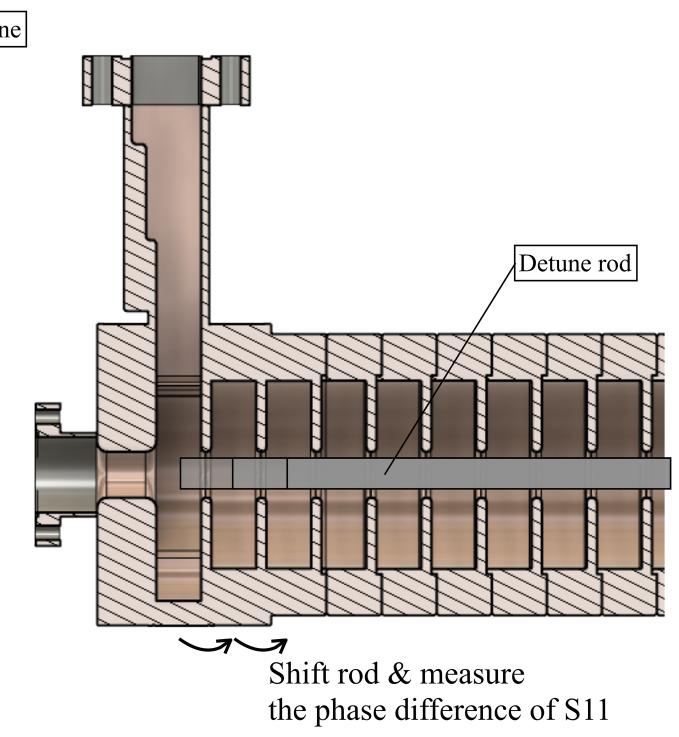
$A_{2\pi/3}$: Fourier series coefficient for the 2π/3 mode
L: length of a reference cavity
ε: permittivity of nitrogen gas
a: radius of the copper bead
f_0: resonant frequency of the reference cavity

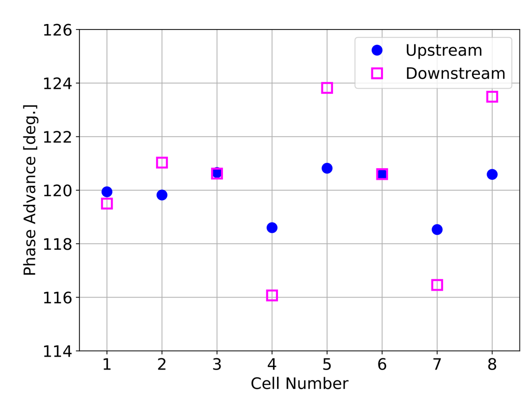
Table 4: Comparison of the Simulated and Measured Shunt Impedance

Parameters	Upstream	Downstream
$A_{2\pi/3}$	0.338	0.356
Measured Q in this setup	9136.3/.870	10362/.877
Measured shunt impedance Z [MΩ/m]	30.3	44.1
Simulated shunt impedance [MΩ/m]	27.56	43.14

❖ Phase advance (Coupler tuning accuracy)

The coupler was tuned using the Kyhl method [7].
The accuracy of the phase difference ~0.5° after tuning.





Nodal shift measurements

Some cells differed significantly from 120°.
Due to imperfect detuning by the rod?

Summary

- ❖ Muon accelerator is under development for J-PARC muon g-2/EDM experiment.
- ❖ Prototypes (reference cavities & couplers) of muon-dedicated DLS were fabricated to verify the feasibility.
- ❖ Frequency and coupling coefficient agreed well, but Q and shunt impedance showed deviation.
- ❖ Tuning by the Kyhl method appeared to be successful, but phase shift was visible in the Nodal shift measurement.

Prospects

- □ Q for downstream ref. cavity: Check RF contacts around half-cells & measure again.
- □ Z: Perform measurements with other bead or with a plunger.
- □ Phase shift: Try to understand this situation using an equivalent circuit model.
- □ Further investigation of beam dynamics that are closer to the actual situation based on these results.

References

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Acknowledgements

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