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Low-Power Test of Bridge Coupler Connected to Tank in Disk-and-Washer Structure for Muon Acceleration

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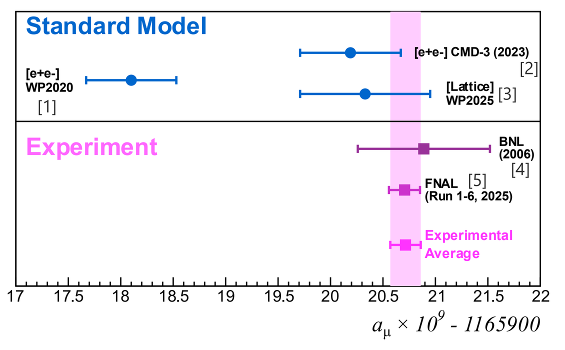
Abstract A muon linear accelerator is under development at J-PARC for precise measurement of the muon anomalous magnetic moment ($g-2$) and search for the electric dipole moment (EDM). The disk-and-washer (DAW) structure is employed to accelerate muons from 30% of the speed of light (kinetic energy = 4 MeV) to 70% (40 MeV) at 1296 MHz. The muon DAW consists of tanks accelerating the muons and bridge couplers that couple the tanks and focus the beam using an internal quadrupole doublet. A bridge coupler prototype was fabricated and tested at low power. This Low-power test focused on measuring resonant frequencies, Q-value, and electric field distribution. Furthermore, the bridge coupler prototype was connected to a tank prototype and tested at low power to understand the effects of the connection. This paper summarizes these results and discusses the prospects for actual machine production.

Muon $g-2$/EDM

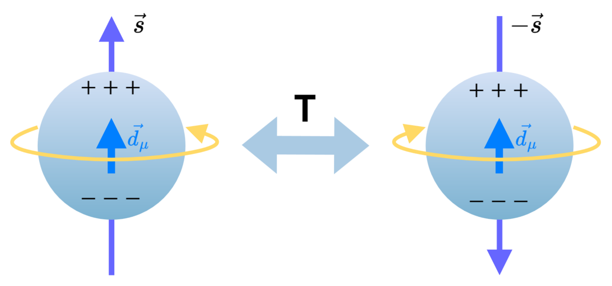
Anomalous Magnetic Moment ($g-2$)



Theoretical values and experimental values may differ.

Sign of New Physics?

Electric Dipole Moment (EDM)

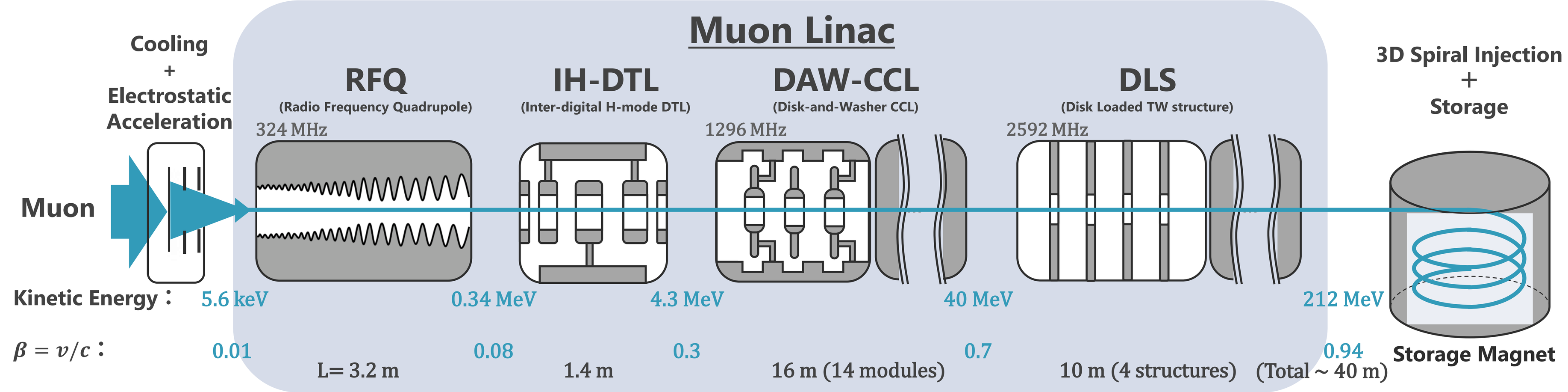


A physical quantity that breaks time-reversal symmetry

Observation = New Physics

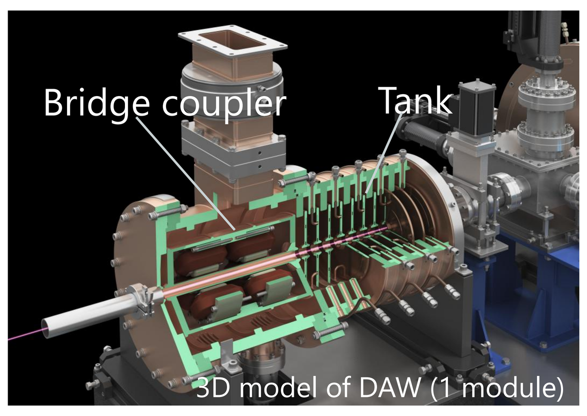
Measurement with muon linac @J-PARC

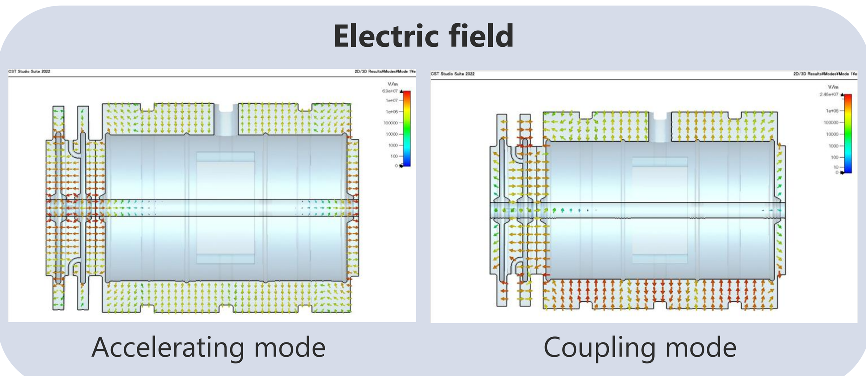
- Precise measurement of muon $g-2$/EDM by novel method [6].
  → Independent verification of $g-2$
- Novel method uses a low-emittance beam by muon cooling and accelerating.
- The muon linear accelerator (linac) consists of four stages suitable for $\beta(=v/c)$ and accelerates muons from $\beta = 0.01$ to 0.94.

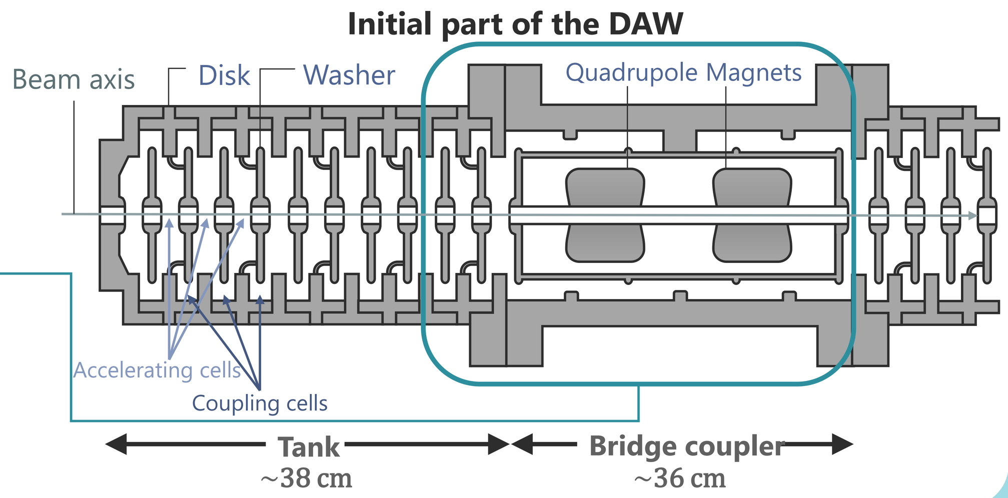


Disk-and-Washer (DAW) CCL

- Third stage ($\beta = 0.3$– 0.7) of muon linac.
- A type of Coupled-Cavity Linacs (CCL)
- The frequencies of the accelerating mode excited in the accelerating cells and the coupling mode excited in the coupling cells must be matched.
- High power efficiency (ZTT) for middle β
- High cell-to-cell electromagnetic coupling
  ▸ High electric field stability
- It consists of accelerating tanks and bridge couplers that couple the tanks and focus the beam.







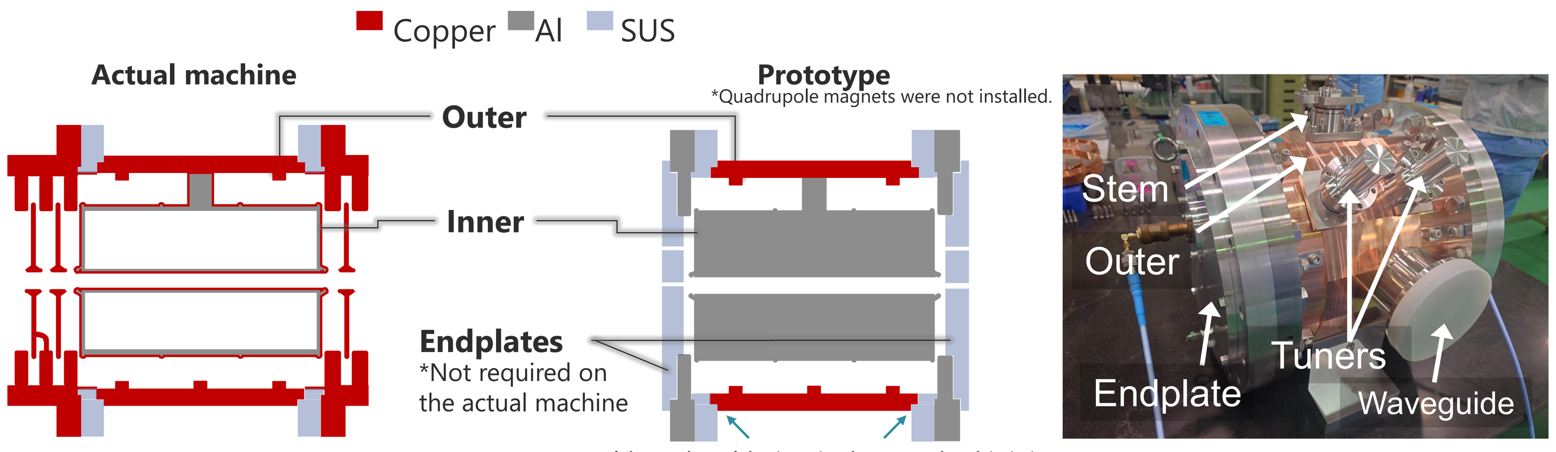
Bridge coupler development

- Fundamental design must be established due to few precedents.
- Completed a design satisfying requirements in simulation[7].

▸ Fabricated a prototype and conducted a low-power test.

Requirement

1. Accelerating mode frequency: 1296 ± 0.01 MHz (Due to cooling-water adjustability)
2. Coupling mode frequency: 1296 ± 4 MHz (Due to beam dynamics)
3. Field flatness of $E_{z(2ndpeak)}/E_{z(1stpeak)}$: $100 \pm 1\%$



Although soldering is the standard joining method, the prototype uses bolt fastening.

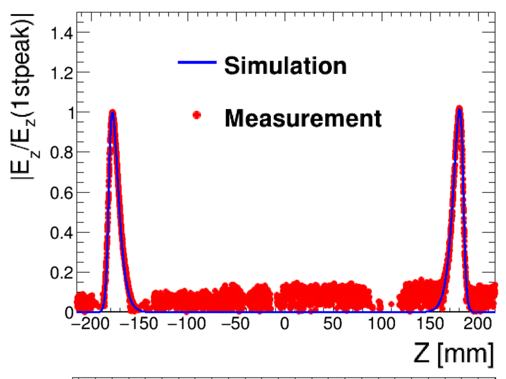
Low-Power Test

RF characteristics

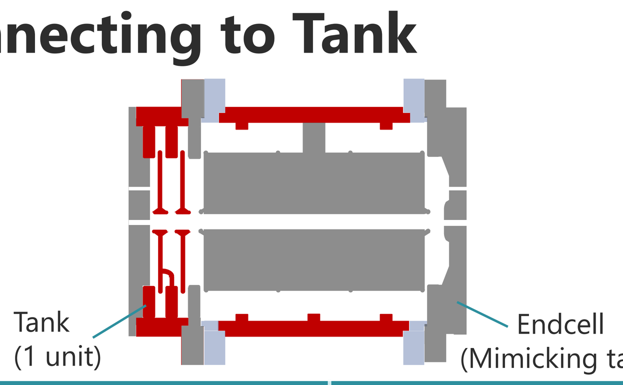
[Note]
- **Test setup Sim. vs. Design targets:** Deviate due to measurement components (endplates, antennas).
- **Sim. uncertainty:** Based on CST mesh convergence.
- **Measured data:** Corrected to actual conditions (vacuum, 30°C).
- **Meas. uncertainty:** Standard deviation of multiple runs (not shown for single trials).

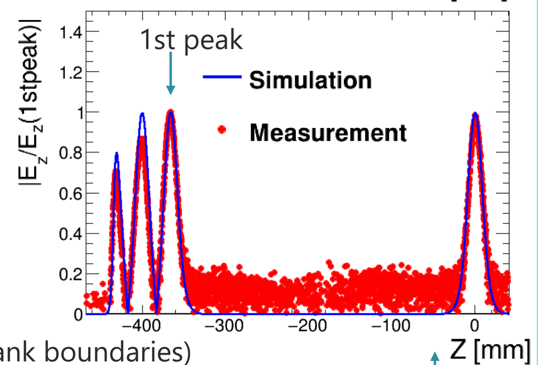
Characteristic	Simulation	Measured
Acc. Mode Freq.	1295.6 ± 0.2 MHz	1294.7 ± 0.1 MHz
Q_0	6184 ± 5	3951
Field flatness of $E_{z(2ndpeak)}/E_{z(1stpeak)}$	101.6 ± 0.5 %	101.4 ± 0.4 %

- Acc. Mode Freq. didn't meet the requirement (± 0.01 MHz).
- Q_0 is small, at about 65% of the simulation value.
- The electric field matched the simulation.



Connecting to Tank





Characteristic	Simulation	Measured
Acc. Mode Freq.	1295.7 ± 0.1 MHz	1297.3 MHz
Q_0	10271 ± 9	269.29
Field flatness of $E_{z(2ndpeak)}/E_{z(1stpeak)}$	99.8 ± 0.1 %	98.7 ± 1.1 %

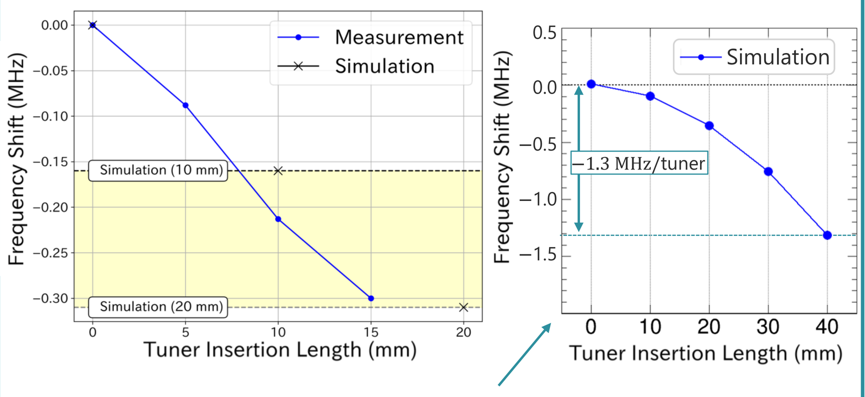
- Verify excitation in accelerating mode.
- Frequency deviation and reduced Q_0 are likely caused by distortion in the prototype tank
  ▸ Re-evaluate with a fully spec-compliant tank.

Discussion

Acc. Mode Freq. & Tuner Study

Current deviation: -0.9 MHz

Simple Tuner (15 mm) **Test:** Measured freq. shifts matched sim. (0.16–0.31 MHz at 10/20 mm depth), confirming the calculation model's validity.



Correction Forecast: In this model, simulating the actual tuners (40 mm × 2) provides a ~2.6 MHz tuning range, fully covering the current deviation.

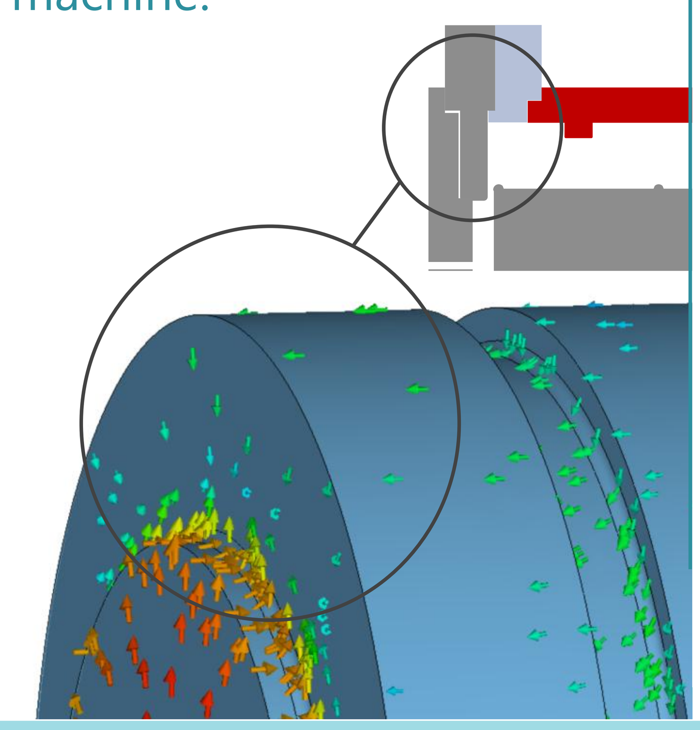
Next Step: Target reachable with precision tuners, requiring actual machine parameter optimization.

Q_0 Degradation

Possible Cause:

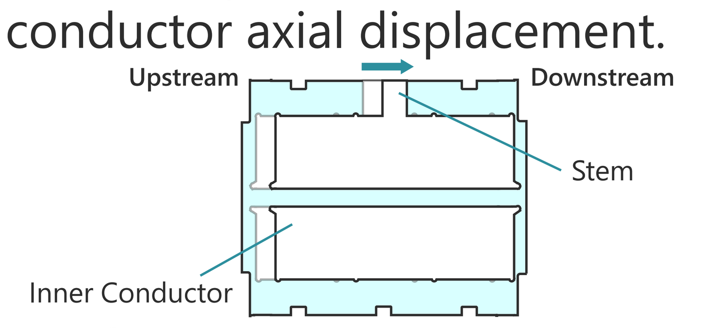
Imperfect Joint Contact
- Wall currents cross the joints.
- ▸ Poor contact might increase RF loss.

Next Step:
Evaluate with the actual machine.

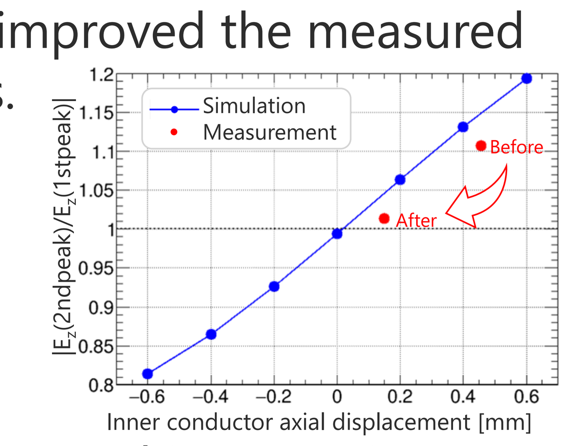


E-Field Flatness Tuning

Sensitivity: ~34%/mm by inner conductor axial displacement.



Verification: CMM-guided tuning improved the measured flatness.



Issue: Manual iteration is impractical (reproducibility & disassembly effort).

Next Step: Introduce a precise axial positioning mechanism.

Conclusion

- Successfully demonstrated the fabrication of a bridge coupler capable of exciting the accelerating mode.
- Identified practical issues in Q_0, tuner optimization, and field-flatness control, providing a basis for final-design bridge coupler fabrication.

References

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