Development of Disk-and-Washer cavity for muon acceleration

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Muon g-2

- Measured by BNL around 2000, an anomaly observed exceeding $3\sigma$ that cannot be explained by the standard model.
- Long standing anomaly (~20 yrs), in spite of careful studies on every aspect.
- Suggesting the existence of new physics?

A comparison of recent and previous evaluations of $a_{\mu}^{SM}$ by BNL E821. Main uncertainties in previous measurements comes from muon beam.

$3.7\sigma$
J-PARC E34

Reduce beam-derived systematic error, which was the main factor in previous experiments.

<table>
<thead>
<tr>
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<th>Previous Exp.</th>
<th>J-PARC E34</th>
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<tbody>
<tr>
<td>g-2</td>
<td>0.54 ppm.</td>
<td>0.1 ppm</td>
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<tr>
<td>EDM</td>
<td>$0.2 \times 10^{-19}$</td>
<td>$1 \times 10^{-21}$</td>
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Using method different from the conventional experiment (BNL / FNAL).

→ $\mu$ cooling & acceleration

1/1000 emittance

Conventional method

0.66 m
Muon acceleration

- The muons need to be accelerated in a sufficiently short time compared to the muon lifetime of $2.2 \mu s$ to suppress the decay loss.
- A muon linac enables this quick acceleration.

Realized by a hybrid of a proton accelerator (low to medium $\beta$) and an electronic accelerator (high $\beta$)
RFQ is used by scaling the cavity developed for J-PARC H⁻ by mass ratio.
Newly developed acceleration cavity other than RFQ exclusively for muons.
→ Cavity R&D is essential!
Disk-and-Washer cavity

DAW: Disk-and Washer  CCL : Coupled Cavity Linac

DTL : 0-mode

$\beta \lambda (\Delta \phi = 2\pi)$

At High $\beta$, the drift tube becomes longer and the acceleration efficiency drops.

The coupled-cavity linac (CCL) consists of a linear array of cavities coupled together to form a multicavity accelerating structure.

Acc. cell
Coupling cell

DAW cavity

- High efficiency acceleration with high shunt impedance
- First application to $\beta < 0.4$


Thomas P. Wangler, "RF Linear Accelerators" 1st edit.

DAW is one of the CCL
Design study

Cavity design

2D calculation by SUPERFISH

Optimized four parameters, disk radius / width / washer radius / gap lengths

Beam dynamics design

DAW parameters

- Frequency [MHz]: 1296
- Total length [m]: 16
- Input energy [MeV]: 4.5
- Output energy [MeV]: 40
- Gradient [MV/m]: 5.6
- Tank numbers: 15
- Power [MW]: 4.5

Cavity (10 cells) \times 15 \quad 16.3 \text{ m}

Q doublet \times 14 (4.5\beta\lambda)

Making sure the adjacency mode is not near 1296 MHz

Calculation example at $\beta = 0.3$
Beam simulation

Beam simulation was performed using the electromagnetic field calculation results based on the cavity design.

Evaluate emittance growth through DAW

![Graph showing emittance growth through DAW](chart)

- **X**: 0.36 \( \pi \) mm mrad
- **Y**: 0.21 \( \pi \) mm mrad

Implemented SUPERFISH + PARMILA design parameters in General Particle Tracer

No significant increase in emittance was occurred with no error.

Error study using PARMILA

![Graph showing error study using PARMILA](chart)

- \( \Delta \varepsilon_x \)
- \( \Delta \varepsilon_y \)
- \( \Delta \varepsilon_z \)

RF phase error 1° + Amplitude error 1% + Alignment error of quadrupole magnet

I think it is achievable (50 \( \mu \)m)

Emittance increase is less than a few percent within achievable alignment error range
Development status

- Detailed design is underway for real-machine production (first 2 tanks).
- Design study of RF window
- Pressure distribution estimation for pumping port design
- Design study of quadrupoles
Summary

• I’m developing “Disk-and-Washer cavity” for muon g-2 / EDM precision measurement experiments.

• To reduce beam-derived systematic error, which was the main factor in previous experiments, $\mu$ cooling & acceleration with Linac are essential.

• Newly developed acceleration cavity other than RFQ exclusively for muons.

• The basic design has already been completed, and detailed design is underway for real-machine production.