

"Acceleration"

Muon Acceleration :beyond first demonstration

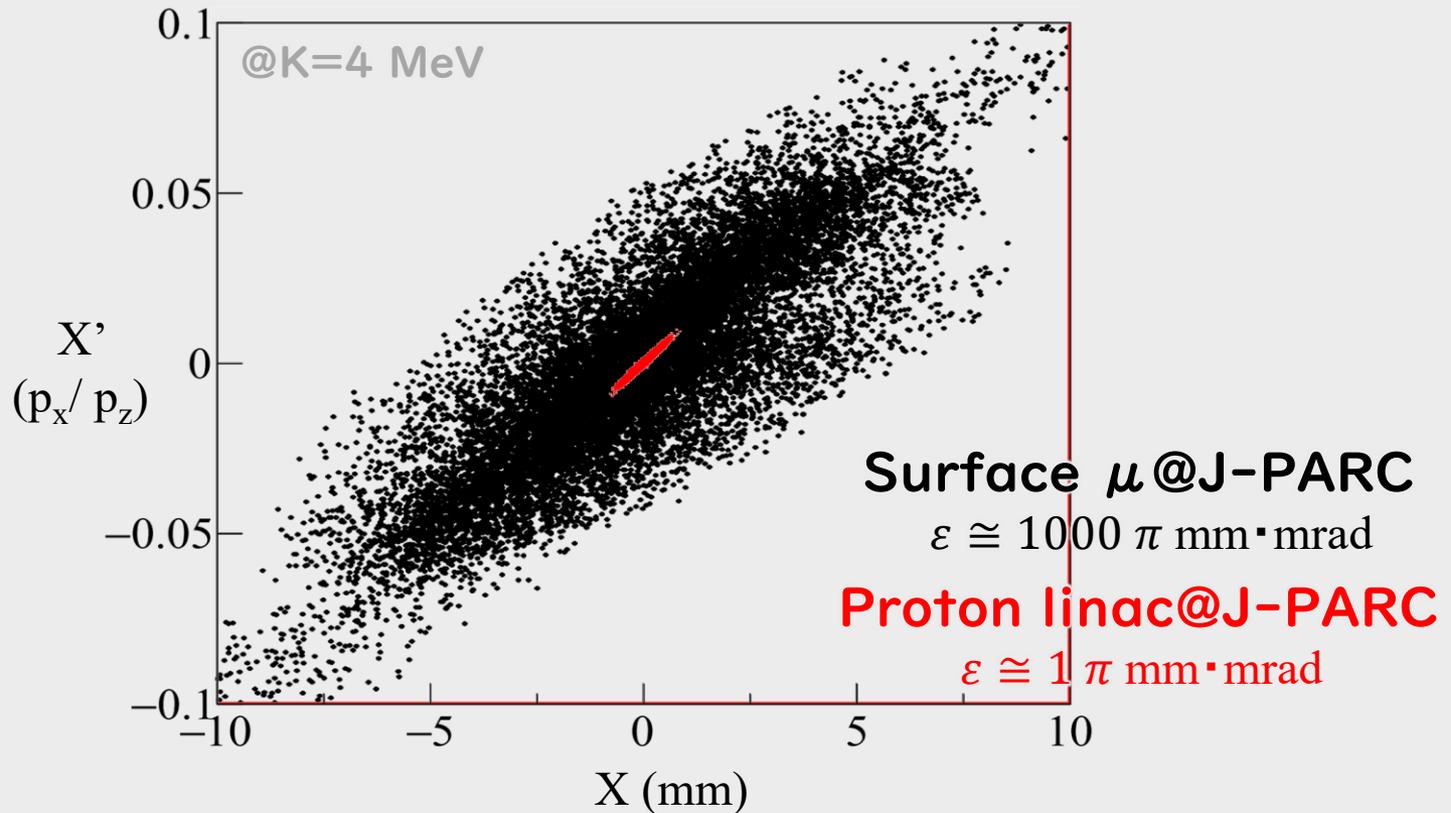
KEK Acc. Masashi Otani

March 3rd, 2026

1. Introduction
2. Beyond 0.1 MeV
3. Beyond 4 MeV
4. Beyond 200 MeV
5. Summary

Introduction

The large phase-space volume (\sim emittance ε) is the most significant bottleneck for muon science.



Muon cooling and acceleration are necessary to overcome this limitation.

linac 400 MeV



RCS 3 GeV

MR 30 GeV



Neutrino

MLF

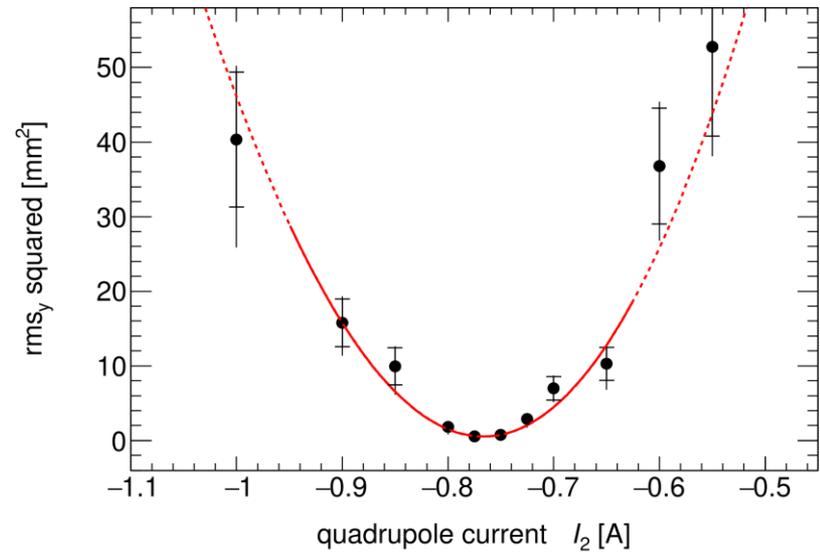
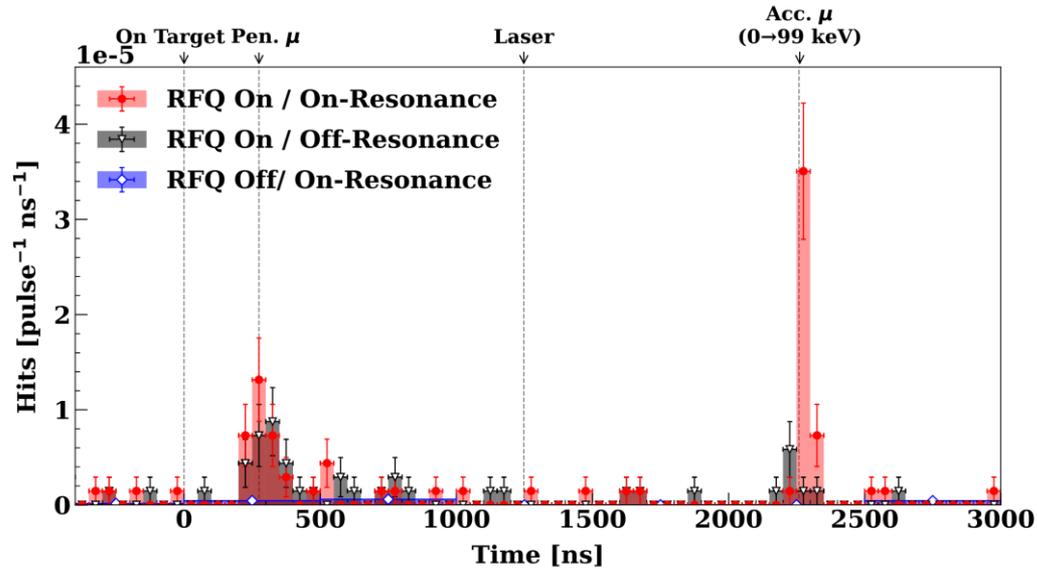
Hadron

J-PARC@Tokai, Japan

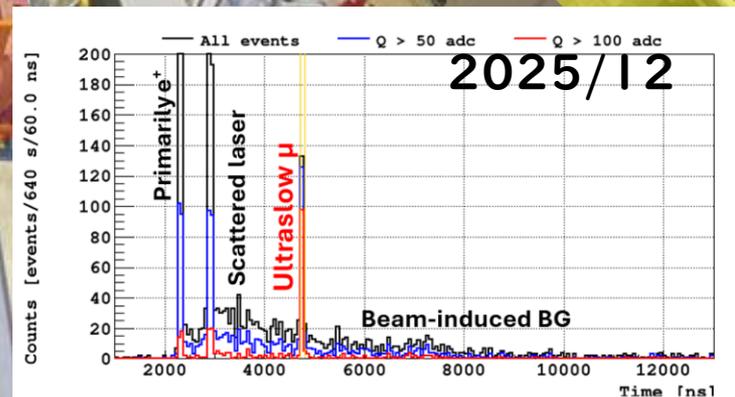
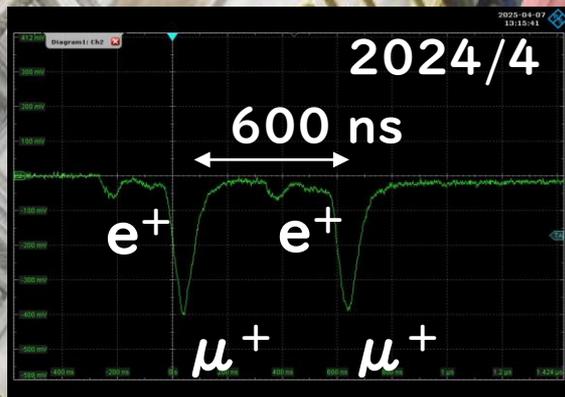


TOF

Q-scan (Y)



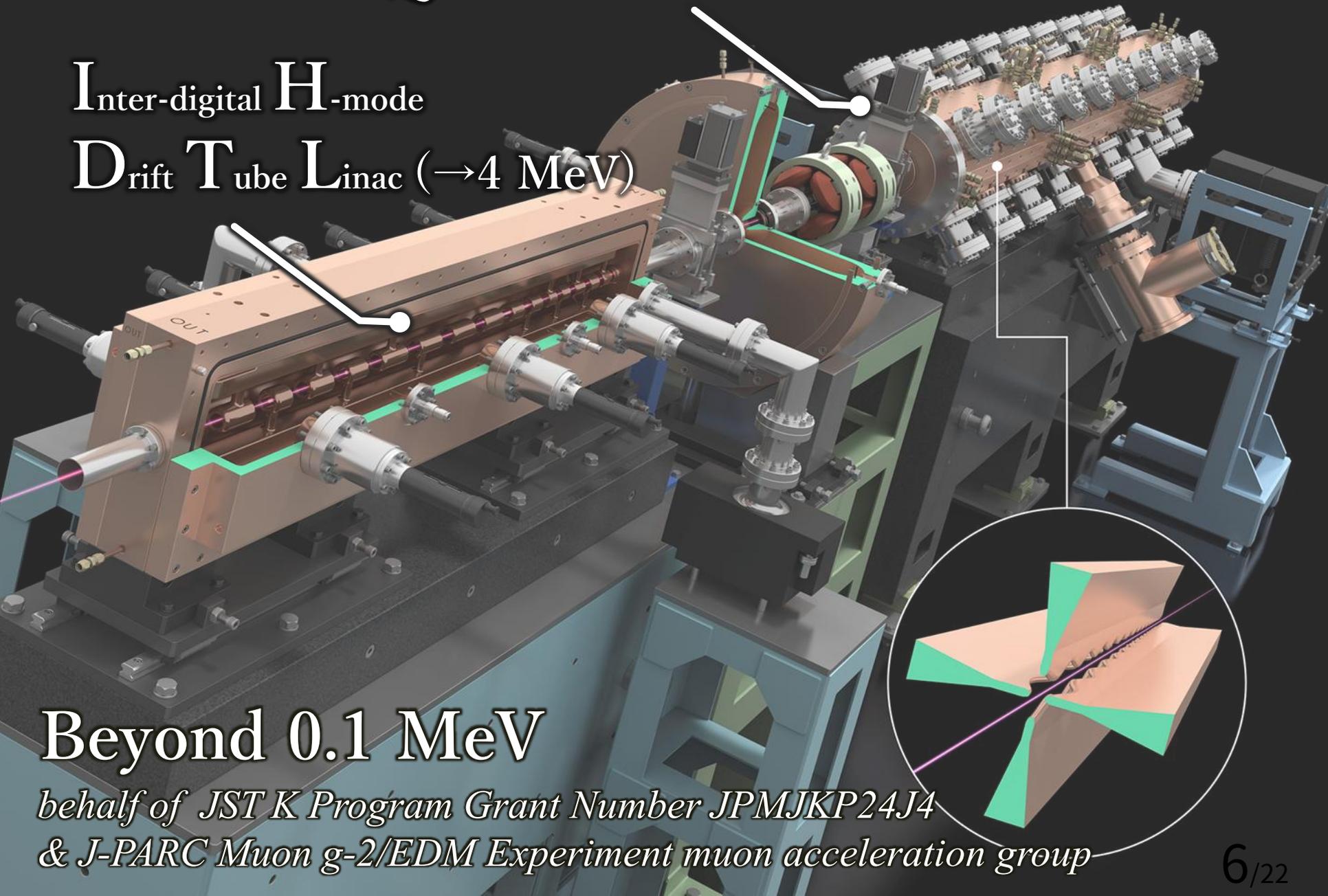
First demonstration of μ^+ cooling and acceleration:
 $\epsilon_{\text{norm.}} \sim 10^2 \rightarrow > 1 \pi \text{ mm mrad}$ and energy $\rightarrow 0.1 \text{ MeV}$



Radio-Frequency Quadrupole linac ($\rightarrow 0.3$ MeV)

Inter-digital H-mode

Drift Tube Linac ($\rightarrow 4$ MeV)



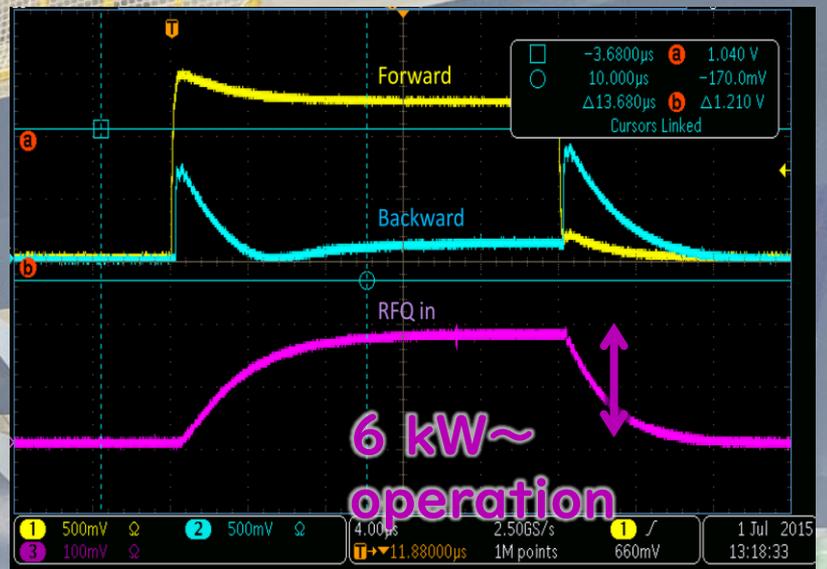
Beyond 0.1 MeV

behalf of JST K Program Grant Number JPMJKP24J4

& J-PARC Muon g-2/EDM Experiment muon acceleration group

H2 in Dec. 2025

- RFQ was successfully installed at the end of 2025.
- Demonstrated the operation (2015 @ J-PARC LI Bld.)



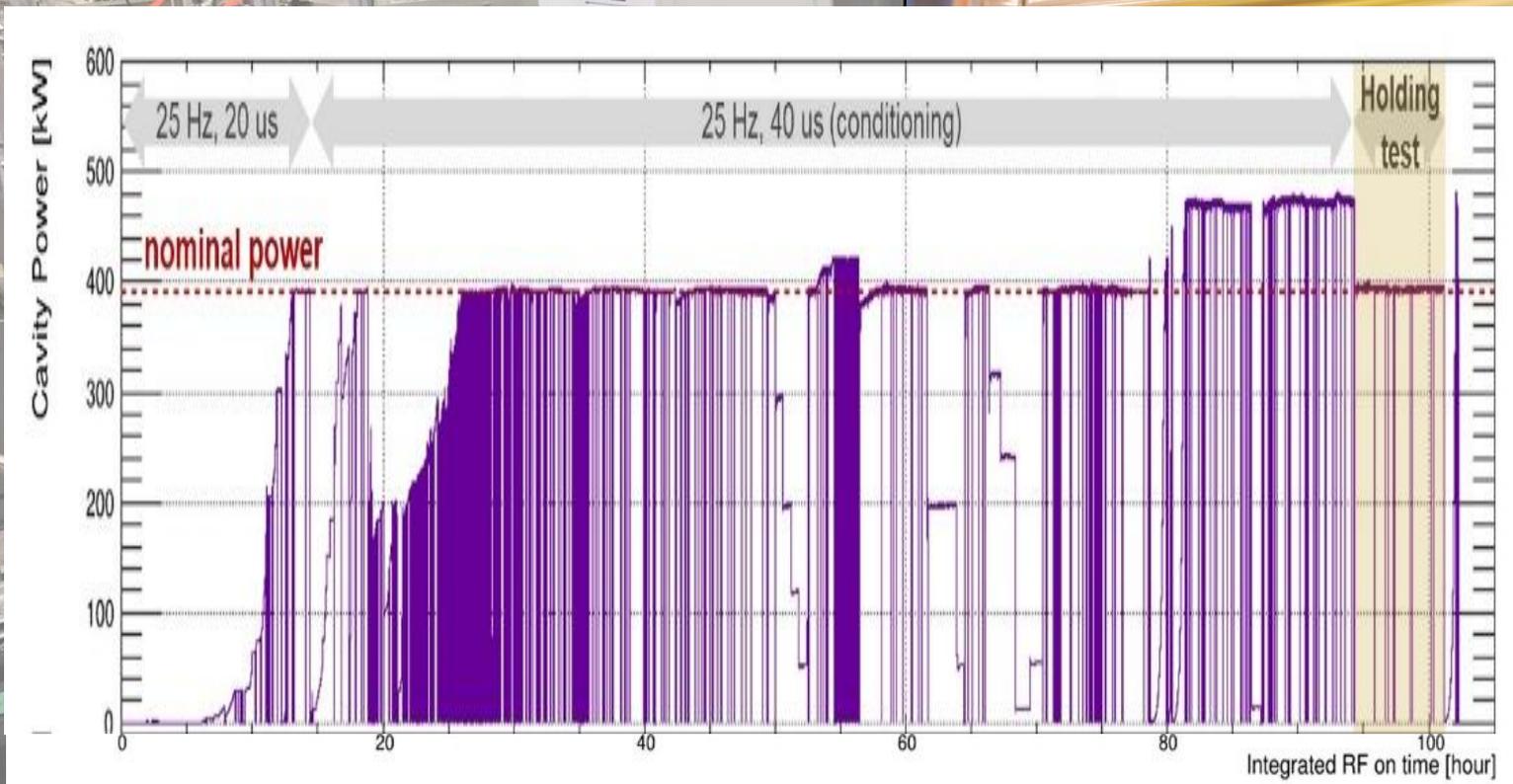
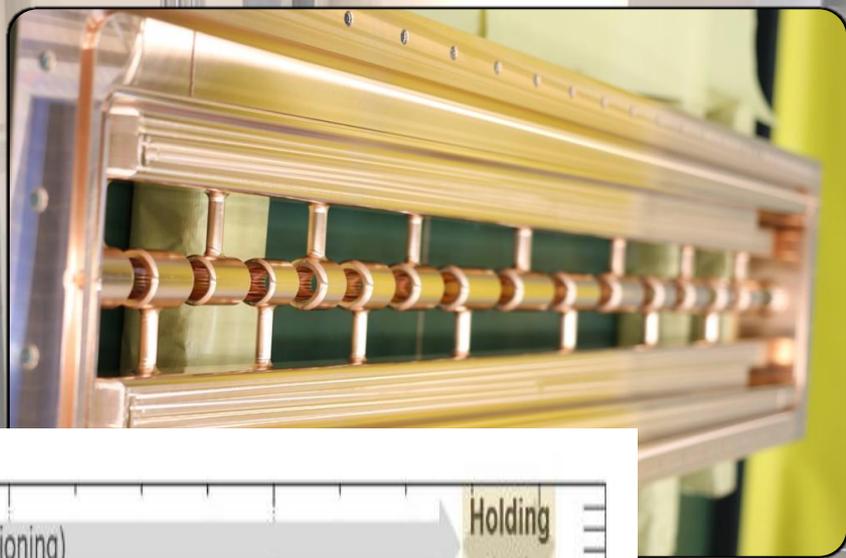
0.3 MeV

Ultra-Slow μ

Surface μ

Acceleration will be demonstrated in FY2026

IH-DTL



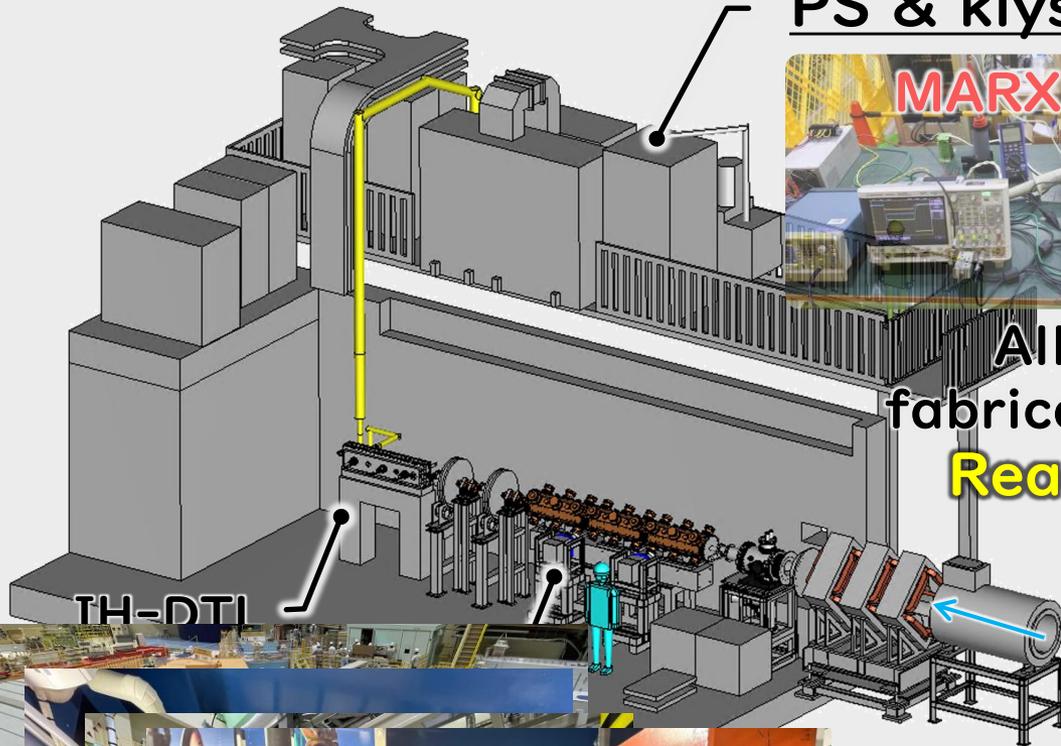
**Demonstrated the operation.
Acceleration will be demonstrated in FY2027**

Power, Control, and Infrastructure

PS & klystron



All the boards have been fabricated and are being tested.
Ready in the end of FY2026

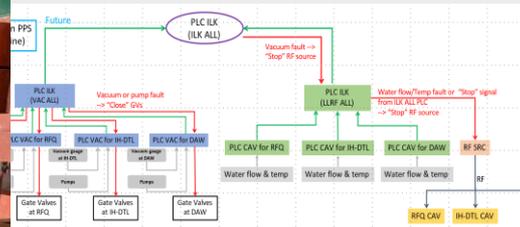


Control System



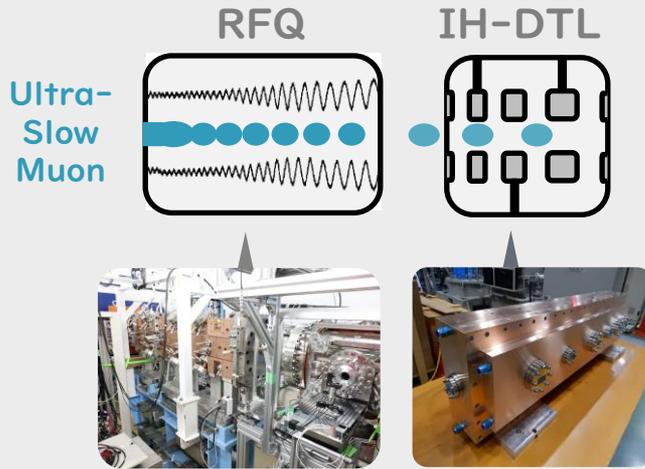
Various on-site works are in progress.

Vacuum piping



developing the system with EPICS.
Already in operation for the ultra-slow muon section. 9/22

Up to 4 MeV (Low- β)



High- β
 $(\beta = v/c = 0.3 \rightarrow 0.9)$

~200 MeV

2010

2015

2020

2025

2030

Design · PoP demonstration

Phys. Rev. AB 19 (2016) 040101
 J.Phys.:Conf. 874(2017)012055
 J.Phys.:Conf. 874(2017)012054
 J.Phys.:Conf. 874(2017)012038
 Phys. Rev. AB 21 (2018) 050101
 NIM A 899(2018) 22-27
 J.Phys.:Conf. 1067(2018)052018
 J.Phys.:Conf. 1067(2018)052012
 NIM A 908 (2018) 313-317
 NIM A 937 (2019) 164-167

Design Complete
 PoP with $\text{Mu}^- (\mu ee)$

Low- β

completed

J.Phys.:Conf. 1350(2019)012054
 NIM A 943 (2019) 162475
 NIM A 946 (2019) 162693
 Phys. Rev. AB 23 (2020) 022804
 Phys. Rev. AB 23 (2021) 033403
 JPS Conf.:33 (2021) 011040
 JPS Conf.:33 (2021) 011128
 Phys. Rev. AB 25 (2022) 110101

0.1 MeV
 Realization

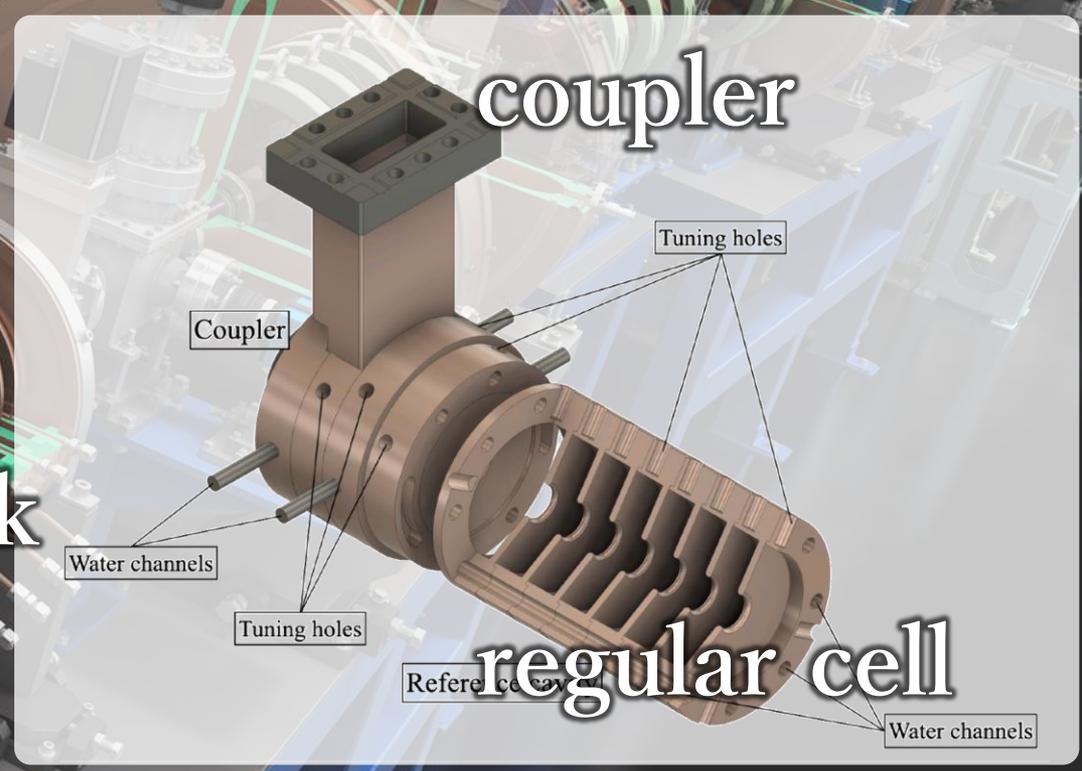
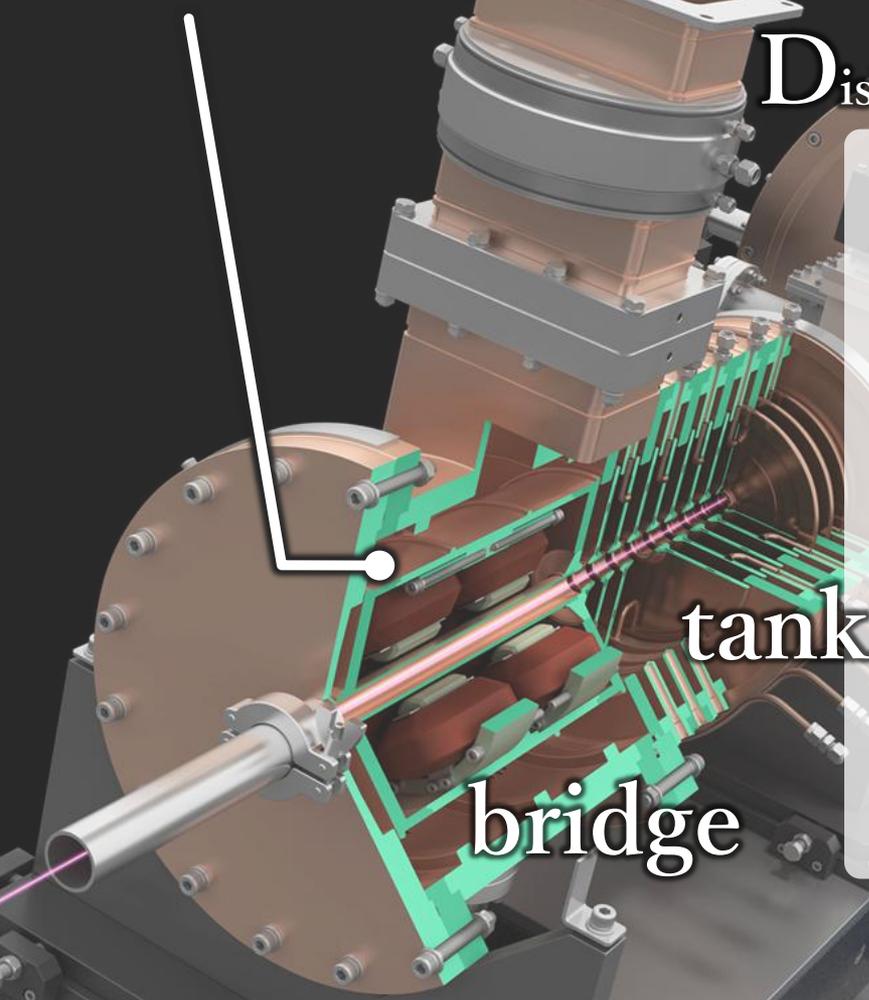
Phys. Rev. Lett. 134 (2025) 245001

Will be realized in FY2027 10/22

Disk And Washer

Coupled Cavity Linac (\rightarrow 30-40 MeV)

Disk Loaded Structure (\rightarrow 200-500 MeV)



tank

bridge

coupler

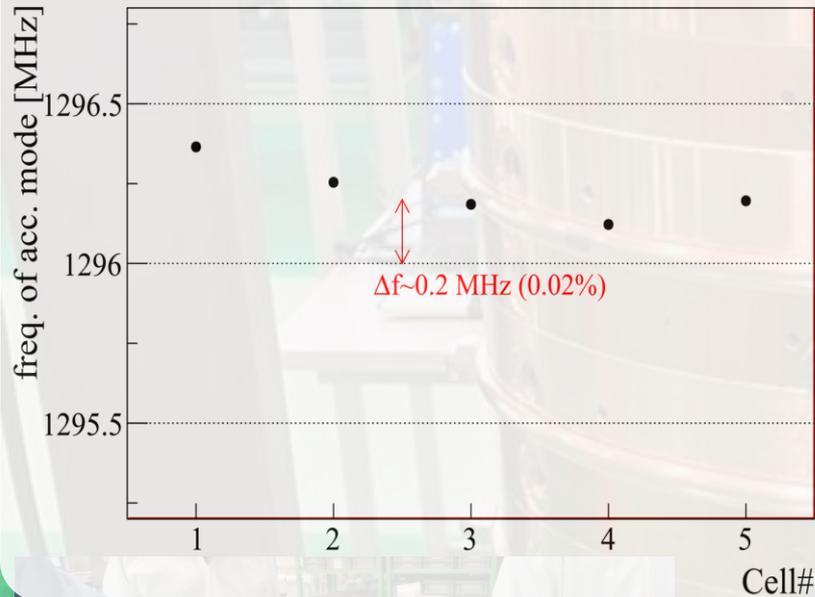
regular cell

Beyond 4 MeV

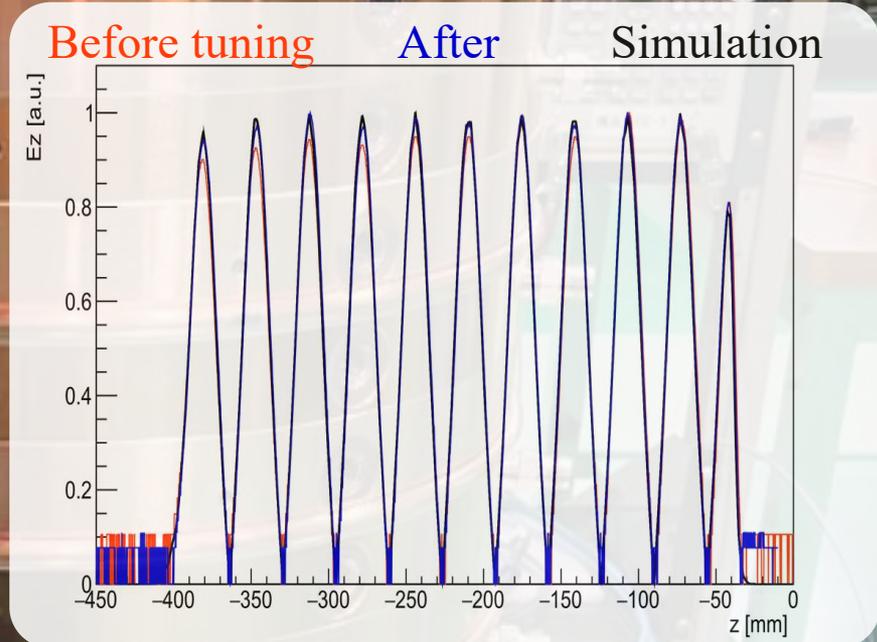
behalf of J-PARC Muon g-2/EDM Experiment muon acceleration group

DAW Tank

Test of each cell



Test with all cell stacking

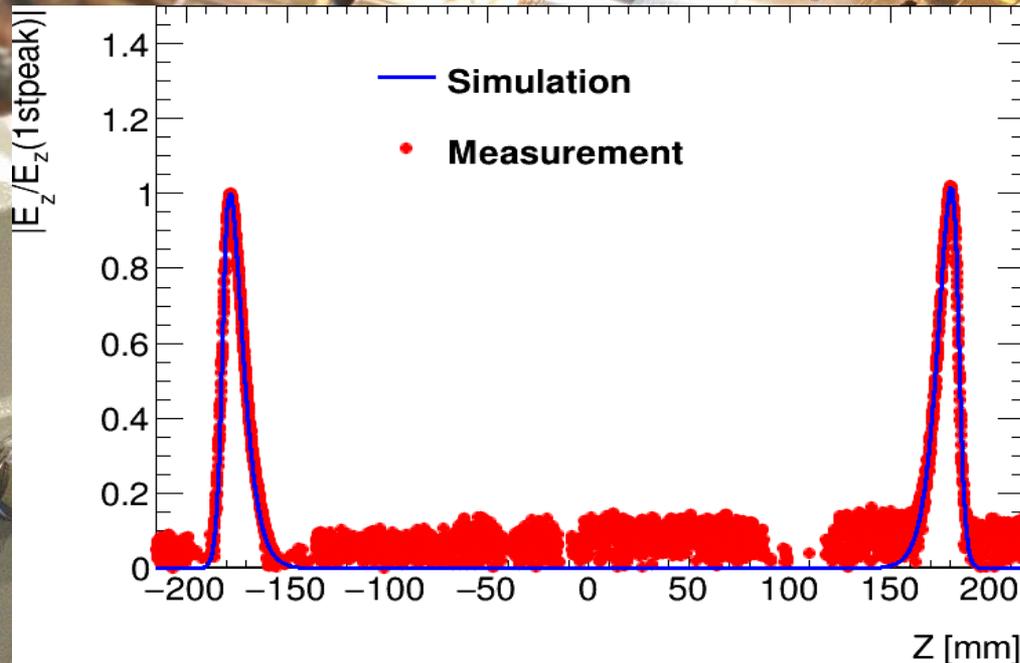


Demonstrated proof-of-principle

DAW Bridge

Bridge
prototype

I-cell
tank

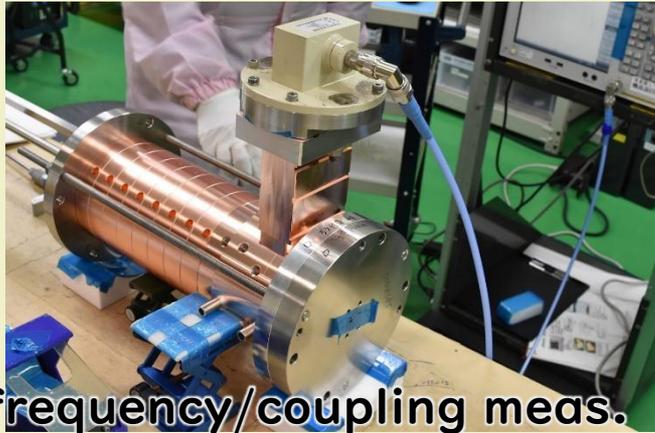


Acceleration field is as expected.

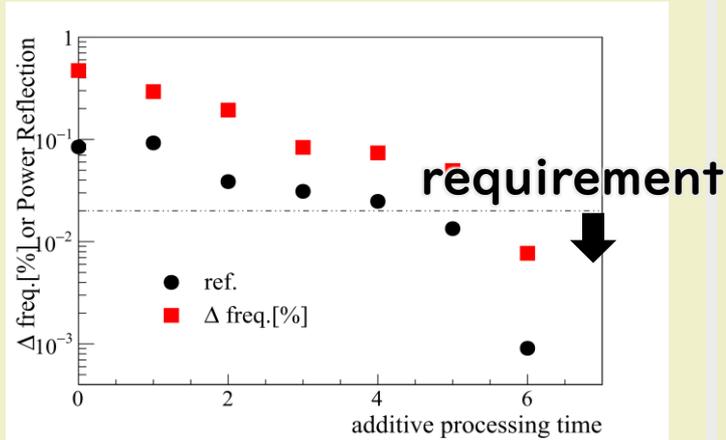
Further developments toward a more efficient structure are being pursued based on prototype experience.

Photo shows assembly in progress

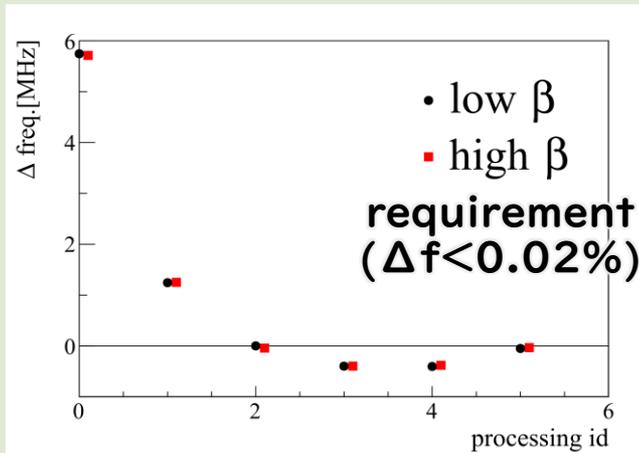
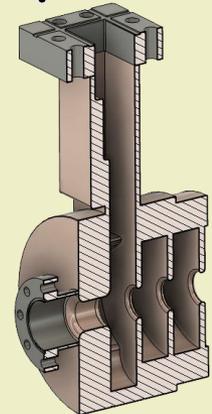
DLS



frequency/coupling meas.



Coupler



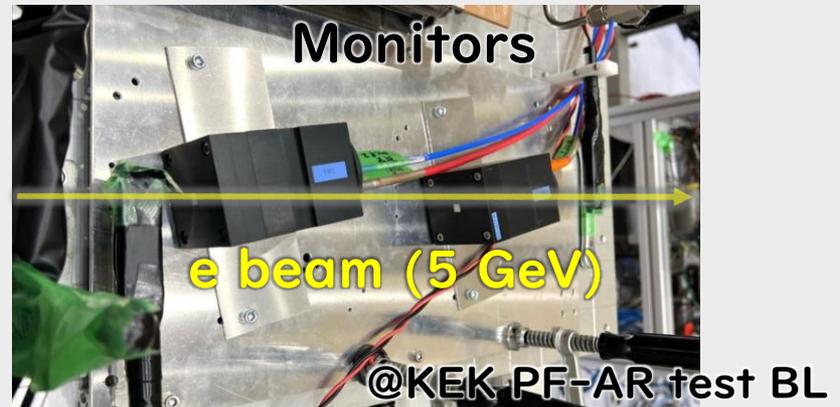
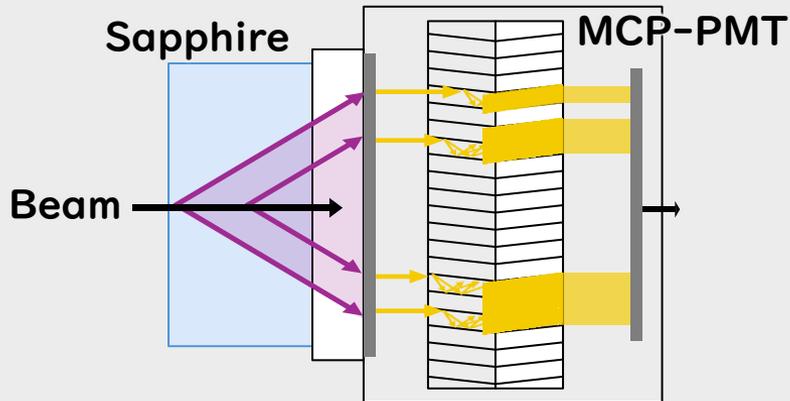
Regular cell



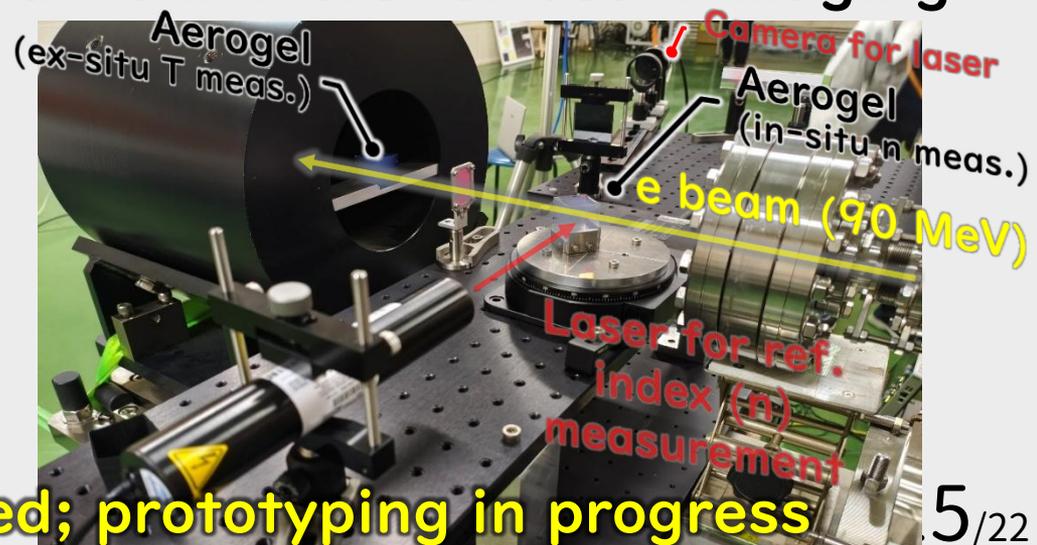
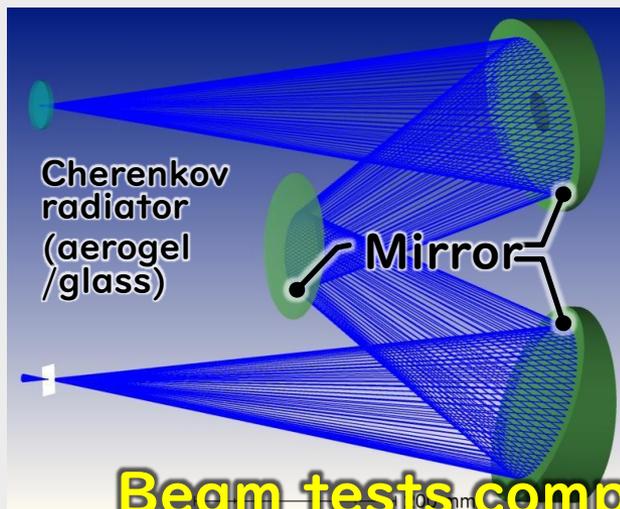
Demonstrated proof-of-principle

Beam Monitors

- Cherenkov monitors are being developed
 - Measured with MCP-PMT using a fast readout circuit

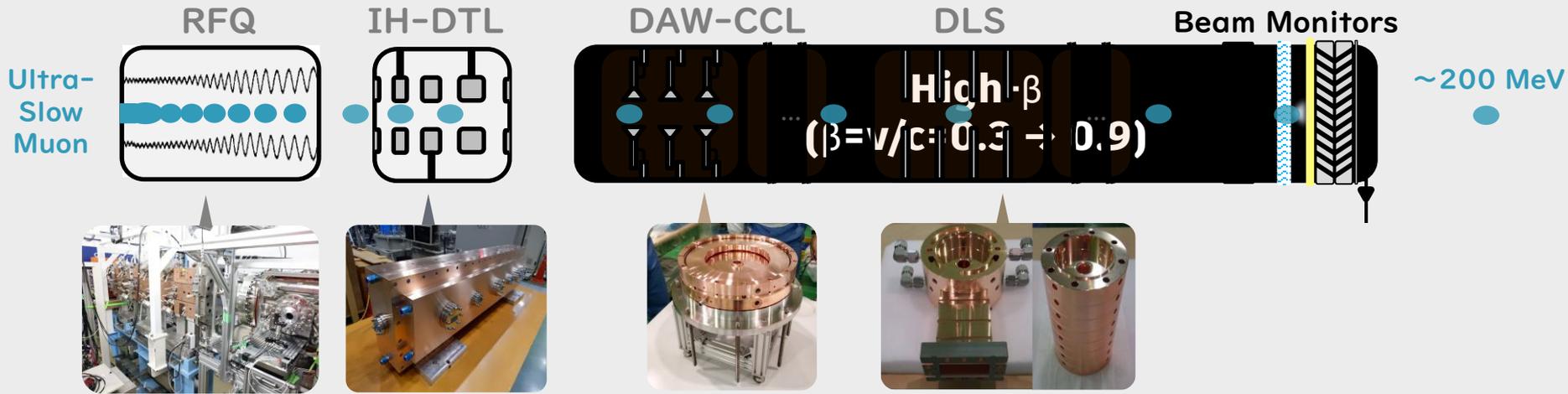


- detected by camera via mirrors for beam imaging.



Beam tests completed; prototyping in progress

Up to 200 MeV



2010

2015

2020

2025

2030

Design · PoP demonstration

Low- β

Realization

0.1 MeV

PoP with prototyping

High- β

Will be realized in FY' 30~

J.Phys.:Conf. 1350(2019)012097

JPS Conf.:33 (2021) 011129

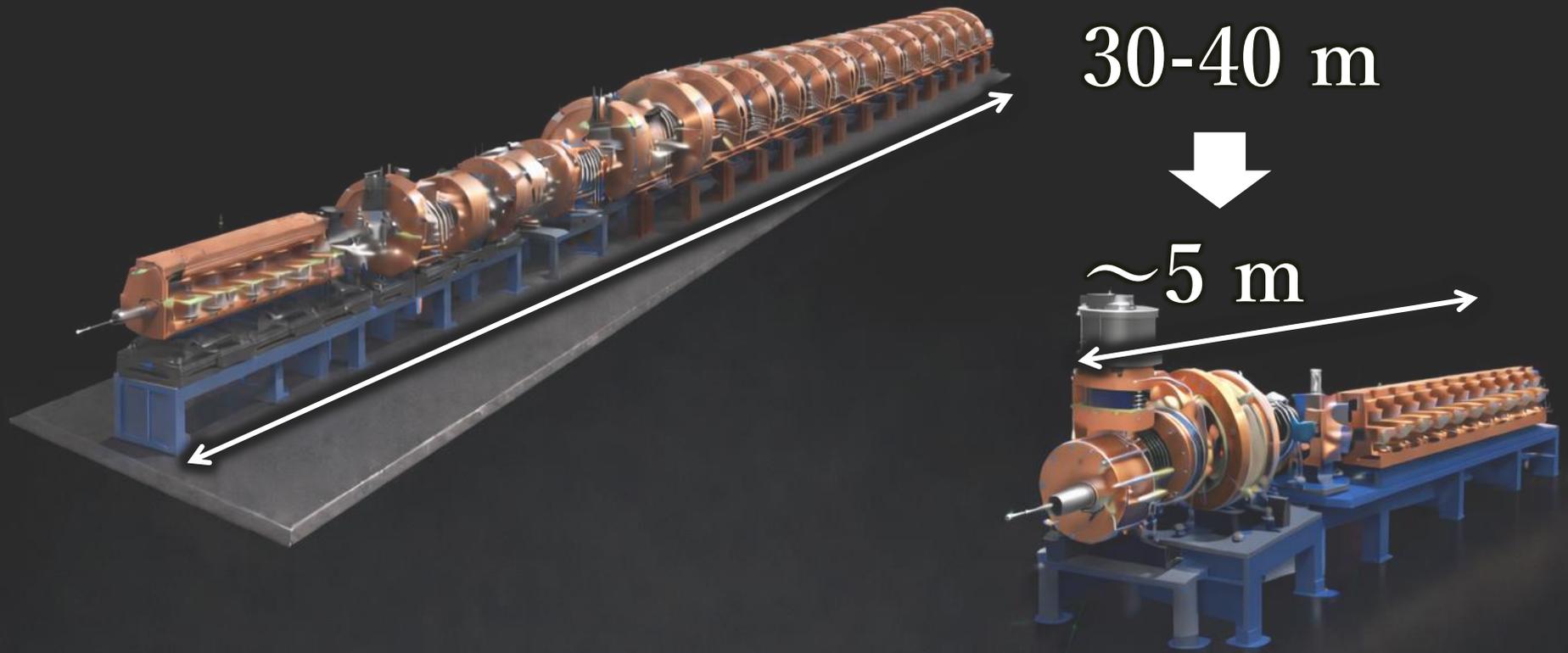
J.Phys.:Conf. 2420 (2023)012038

J.Phys.:Conf. 3094 (2025) 012024

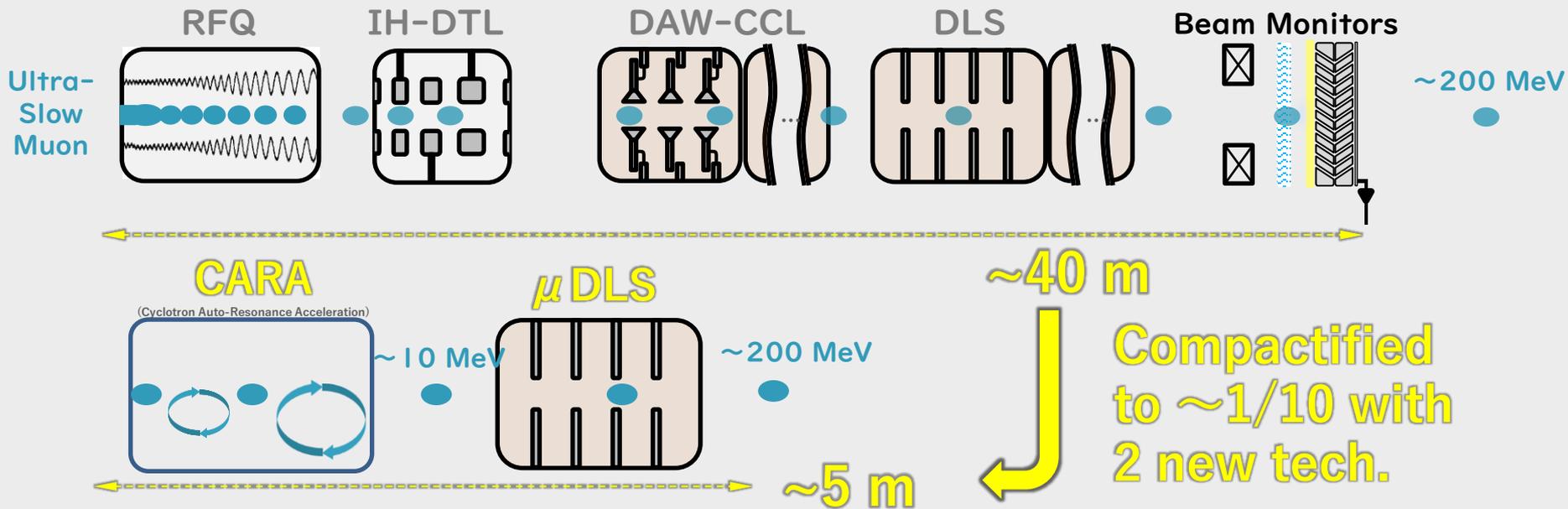
J.Phys.:Conf. 3094 (2025) 012025

NIMA 1083 (2026) 171150

Beyond 200 MeV



Up to 4 MeV (Low- β)



Cyclotron Auto-Resonance Acceleration

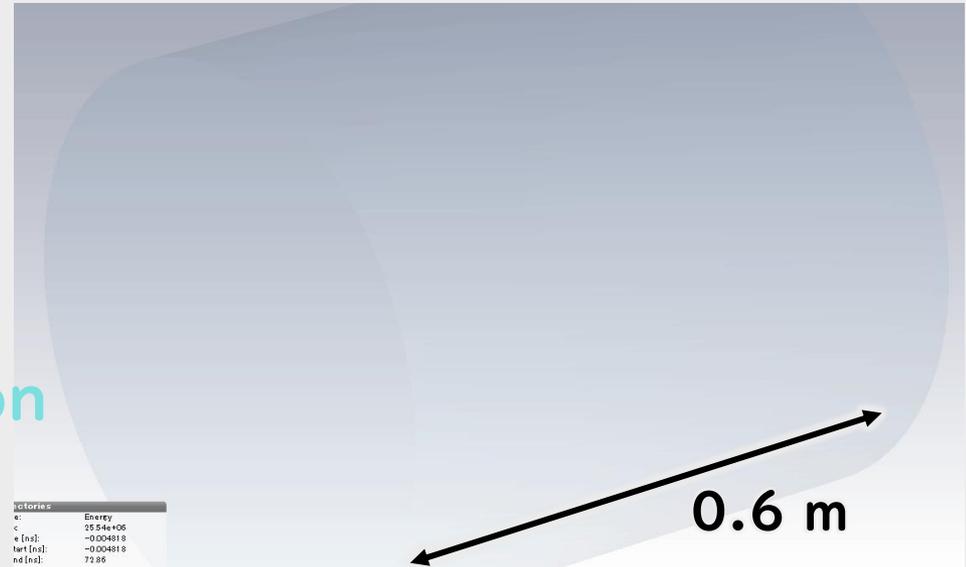
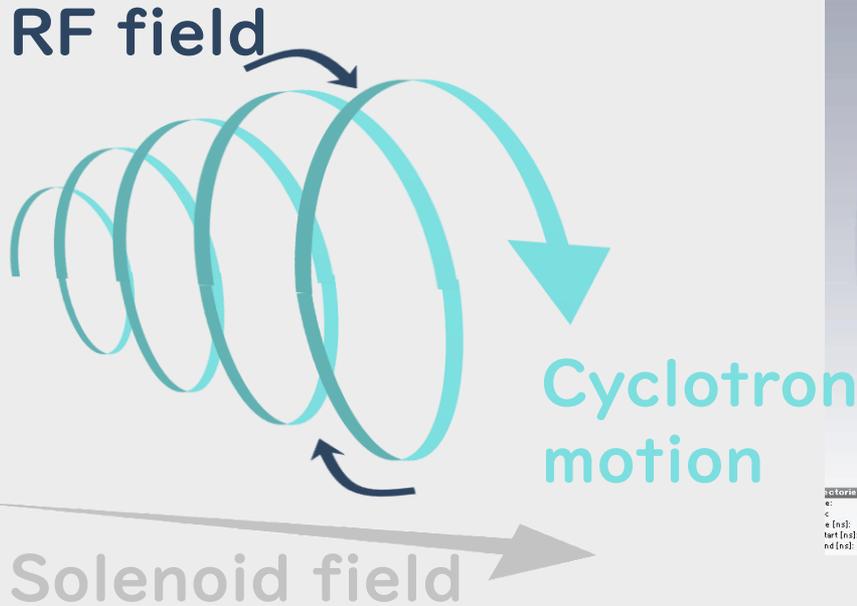
- Verified in electron [PRL 76 (1996) 2718]
- Aims to demonstrated PoP in μ
 - ⊙ Lower applicable energy due to relativistic effects
 - ⊙ Intermediate mass between electron and proton
- Investigated in protons
 - ⊙ $B > 50 \text{ T} @ f = 900 \text{ MHz}$ ($f = eB/2\pi m$)
 - demonstrated of RF acceleration of muons \rightarrow it is now timely to validate this principle

Muon dedicated Disk-Loaded Structure

- Aims to higher acceleration gradient
 - \rightarrow will be applicable to medical p-accelerator

CARA Principle and design

- Synchronization of cyclotron motion with the RF cavity field for acceleration

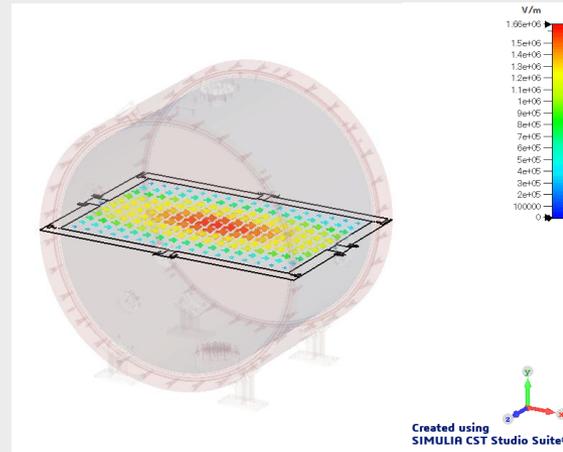
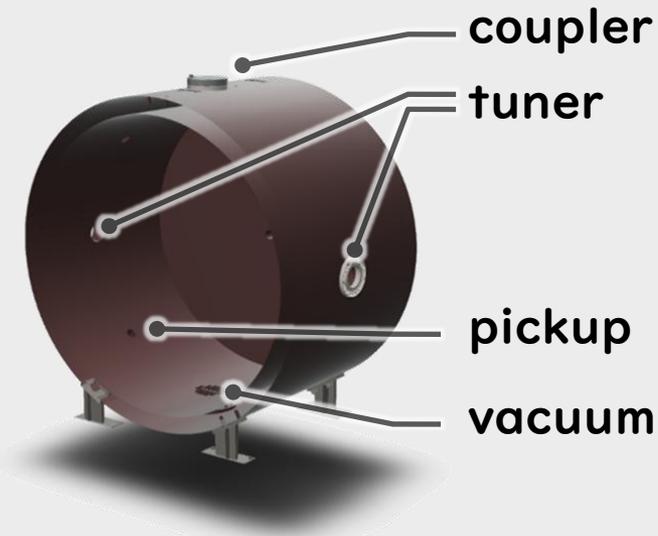


- design different from the well-established electron version is required for muons.
 - Designed at 324 MHz in view of future RF tests.
- Acceleration has been verified for several designs through the field- and beam dynamics simulations

CARA design up to $\sim 0.5c$ (~ 13 MeV) successfully completed

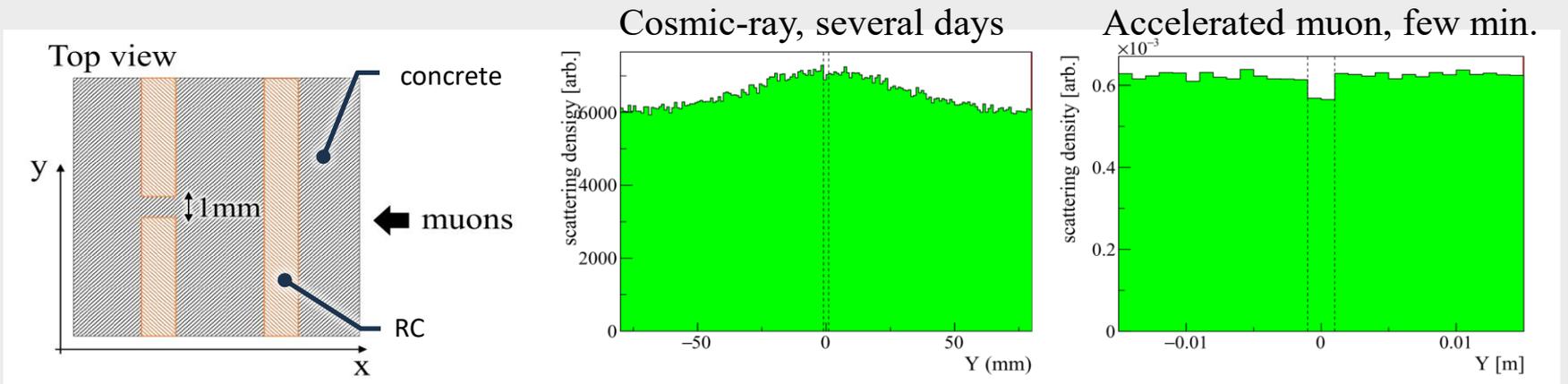
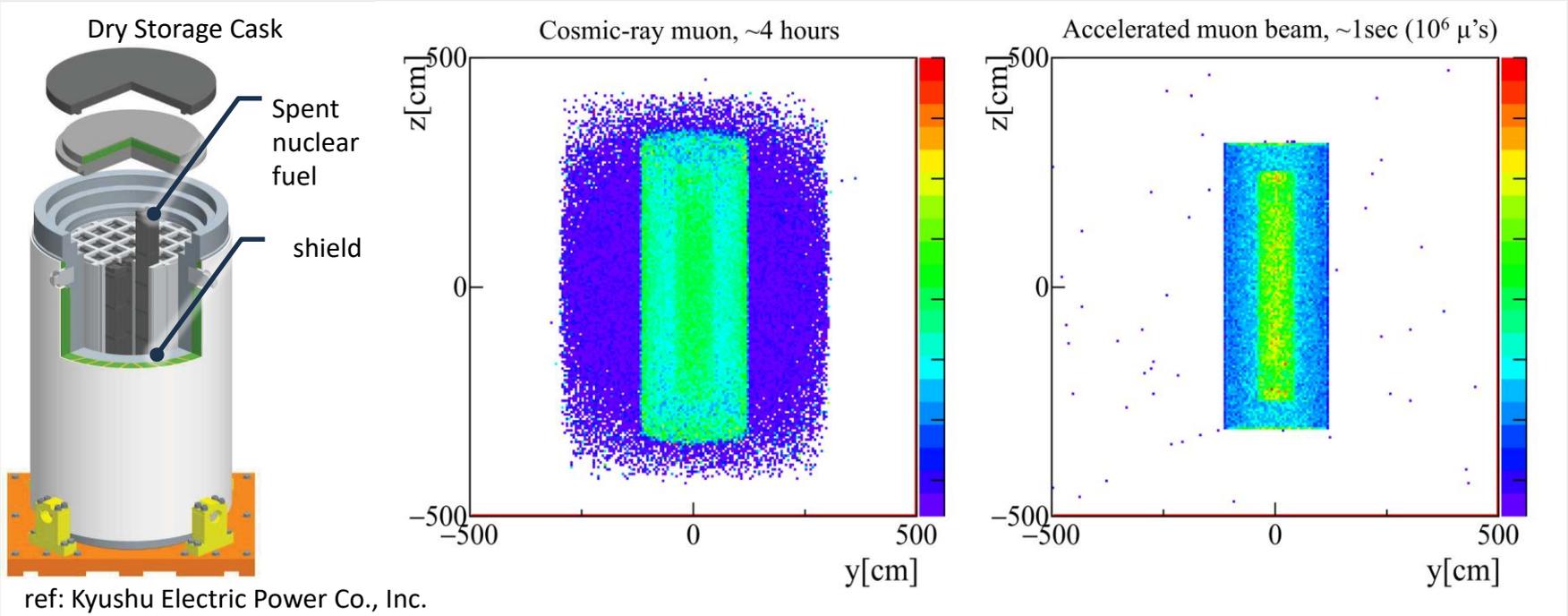
Prototyping

- Manufacturing model incorporating coupler ports for RF power delivery was designed. The simulations confirmed that the required accelerating field distribution is achieved.
- The prototyping was done, and three-dimensional measurements confirmed that the necessary machining precision was attained.



Prototyping was done and test will be soon

Application to the Muon Imaging



Summary

- **~4MeV acceleration will be demonstrated in FY2027.**
- **Key technologies for 4 MeV to ~200–500 MeV acceleration have been demonstrated. We aim to achieve acceleration FY2030~.**
- **Pursuing technologies to reduce the muon accelerator length to ~1/10**