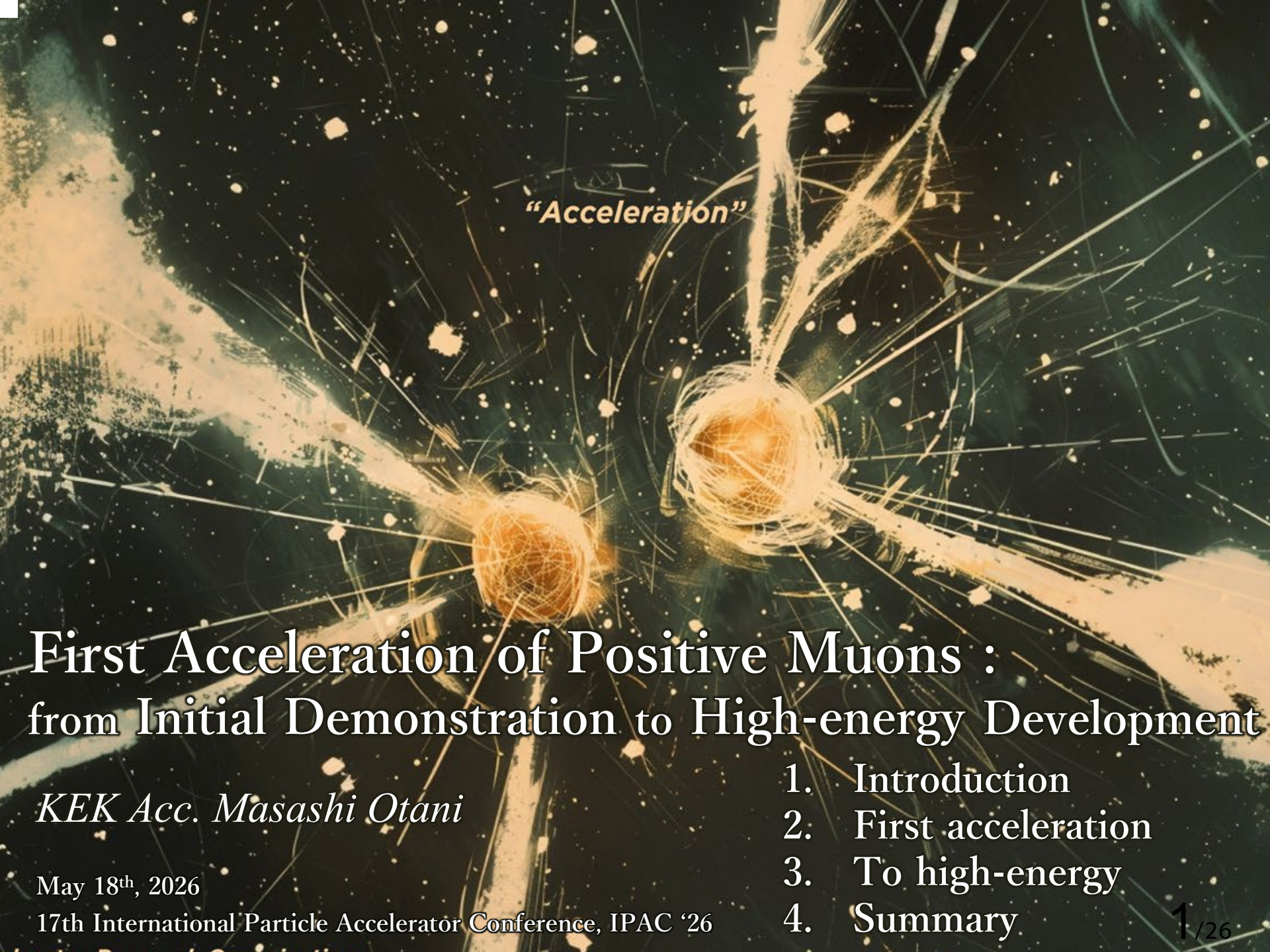



# First Acceleration of Positive Muons : from Initial Demonstration to High-energy Development

*KEK Acc. Masashi Otani*

May 18th, 2026
17th International Particle Accelerator Conference, IPAC ‘26

1. Introduction
2. First acceleration
3. To high-energy
4. Summary

# Why Muon?

Image: The Particle Zoo®

## Electron

Light & Point-like


## Muon

Heavy &
Point-like


## Proton

Heavy &
Composit

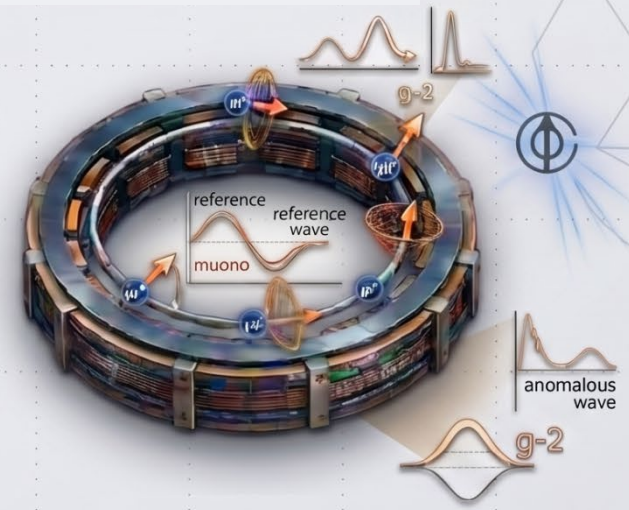

**Goldilocks advantages**

- ✓ Extreme penetration
- ✓ Higher energy reach with compact accelerator

…but lives fast, dies young (2 $\mu$s)…

# Physics Potential

Flavor physics
g-2, EDM...

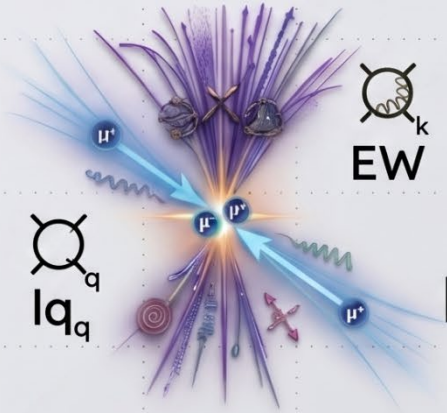



MeV

Material Science
$\mu$SR, ...

Muon Energy Scale

GeV

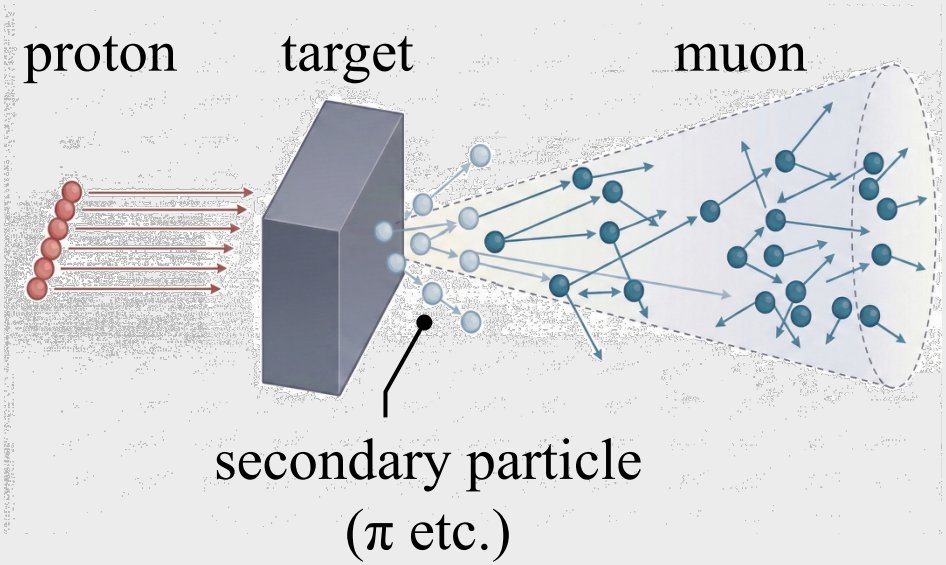


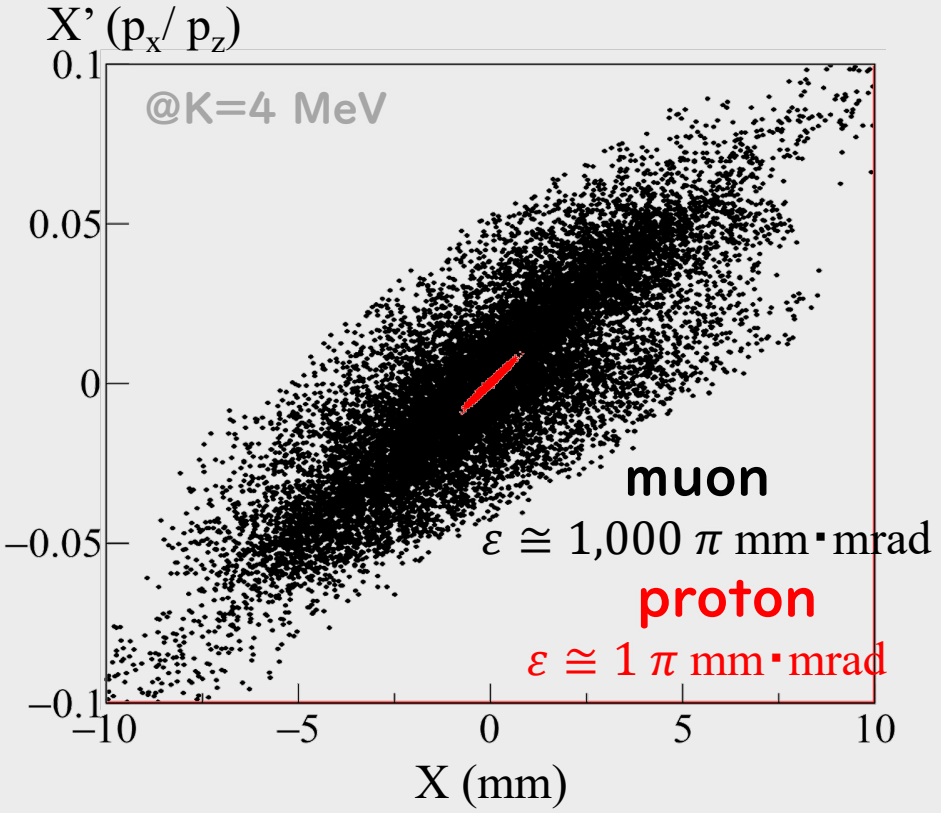

TeV

High energy frontier
$\mu$–e, $\mu$, p collider...

# Key Challenge

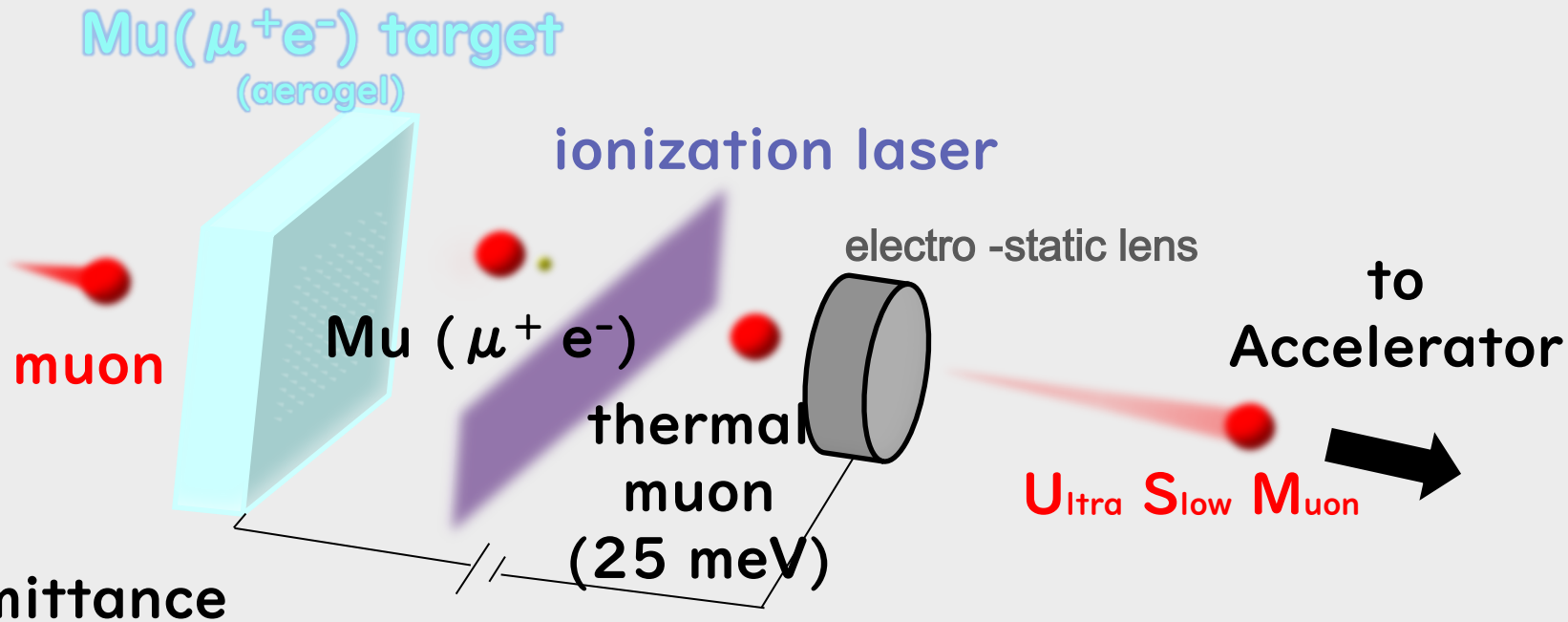
## Emittance compression (Cooling)



# Novel Cooling Method

## Muonium Laser Ionization

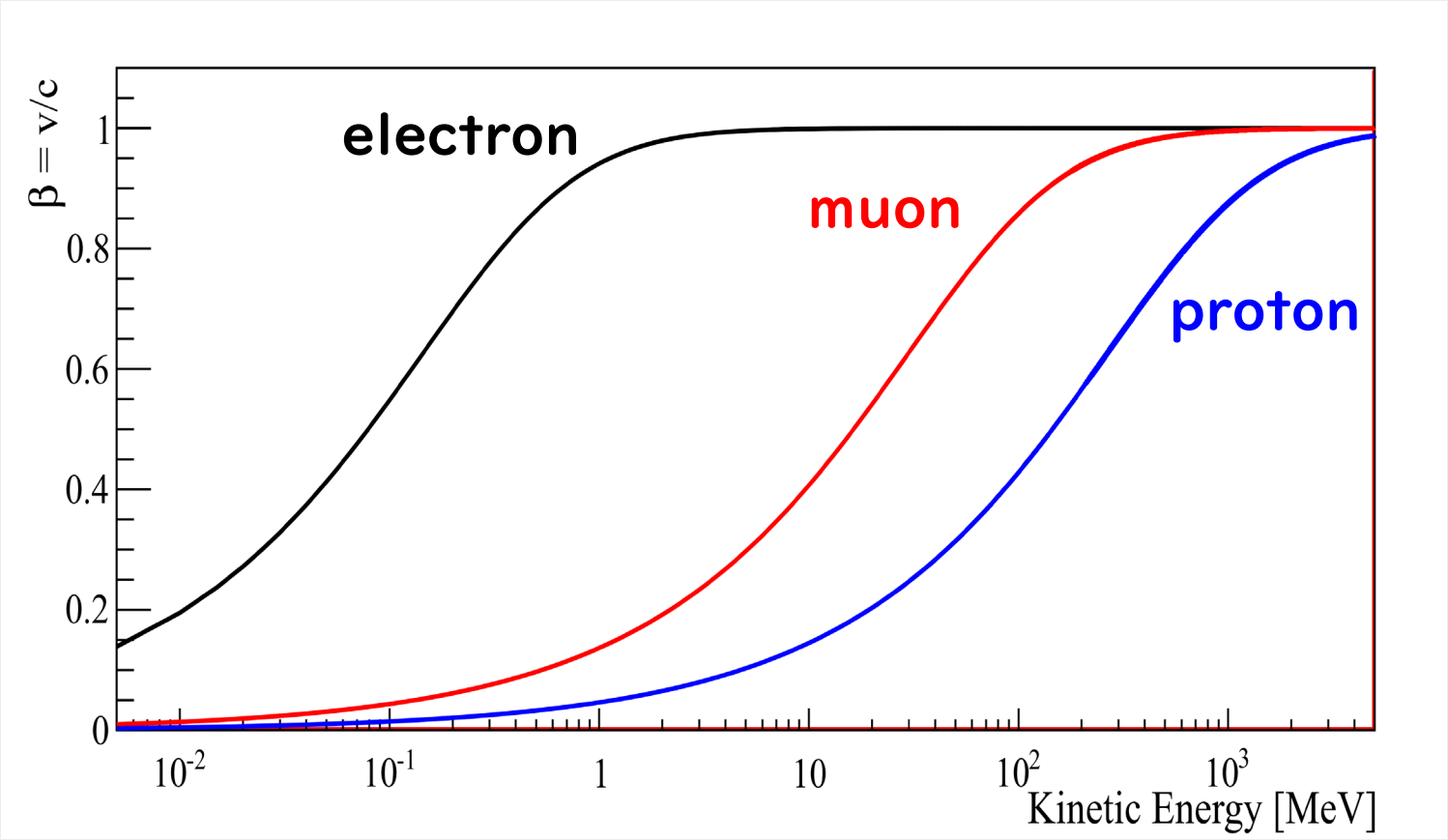



| | |
|---|---|
| 1986-1988 | Observation of Mu in vacuum, Mu ionization (1s-2s) [PRL 56 (1986) 1464, 60 (1988)101] |
| 1995-2008 | ionization (1s-2p), application to $\mu$SR [RRL 74 (1995) 4811, NIMB 266 (2008)335 ] |

# Key Challenge

Rapid acceleration → RF linac

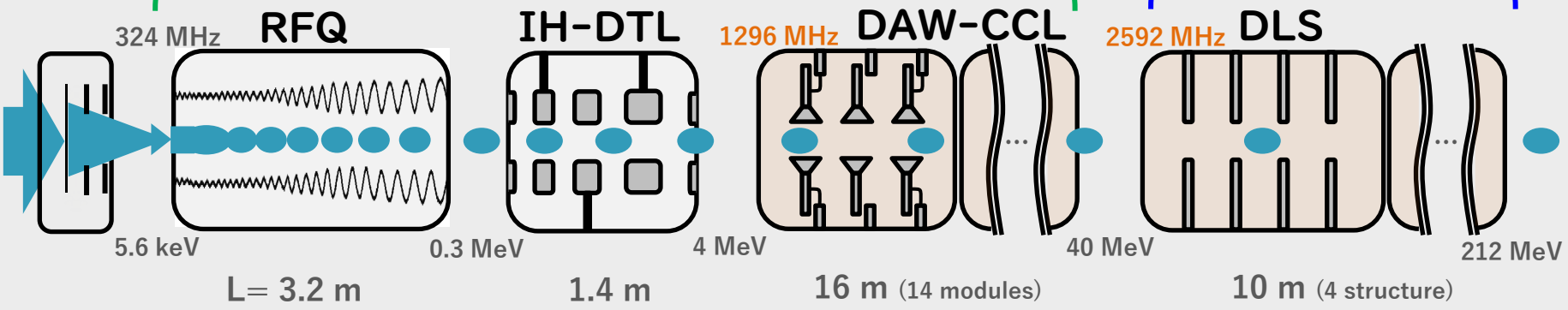
Intermediate mass: Rapid acceleration without instant light speed



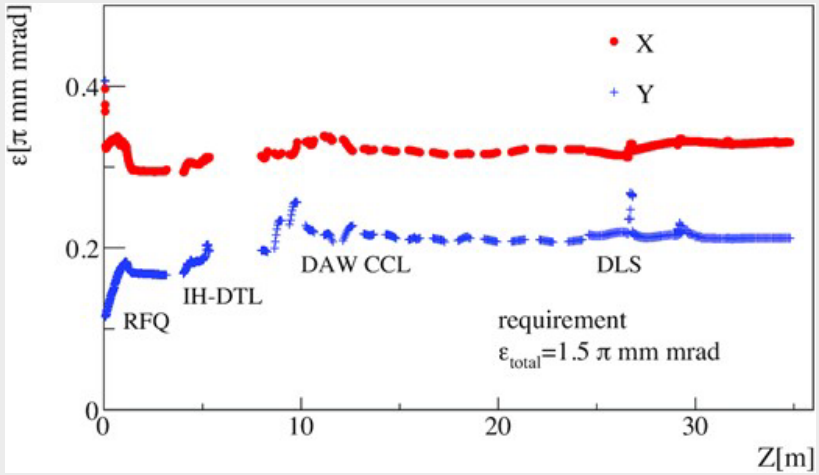

A novel linac dedicated to muon acceleration

# Design

Designed by evolving proven technologies from protons and electrons.



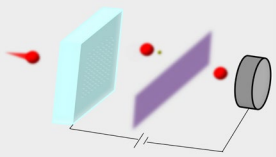

| | |
|---|---|
| Energy [MeV] | 212 |
| Intensity [/s] | $10^6$ |
| Repetition [Hz] | 25 |
| Pulse length [nsec] | ~10 |
| Normalized $\varepsilon_t$ [$\pi$ mm mrad] | ~1.5 |
| $\Delta p$ [%] | ~0.1 |




Rapid acceleration with 0.6 μs (~20% decay) with minimal emittance growth

# History of Developments

2010 2015 2020 2025



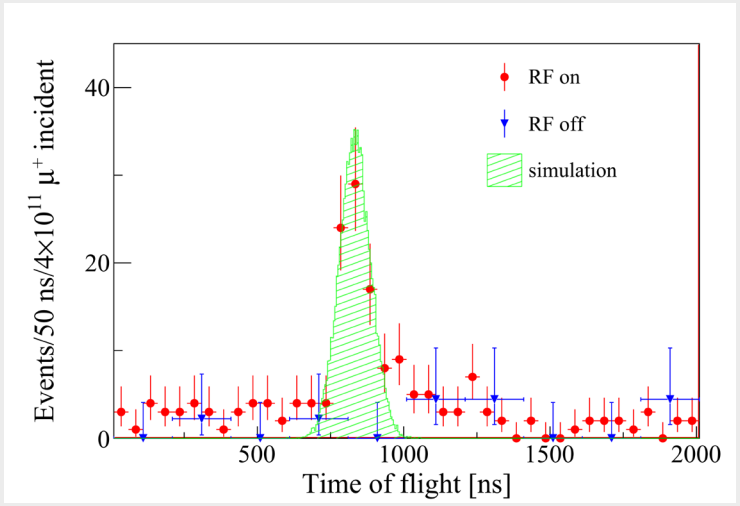
High eff. target → Target optimize → real machine

PTEP 2014, 091C01
PTEP 2013, 103C01

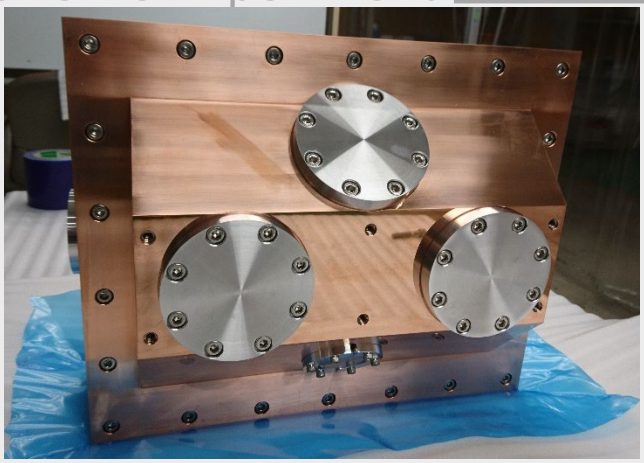
PTEP 2020, 123C01

High-stability laser

Mu 1S-2S Experiment

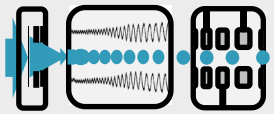



Invited talk in IPAC'18, Y. Kondo



Linac'22 Poster Award, Y. Nakazawa

First Cooling & Acceleration



Design → PoP → real machine

PRAB 19 (2016) 040101

PRAB 21 (2018) 050101
PRAB 23 (2020) 022804

PRAB 25 (2022) 110101
PTEP 2022, 052C01




neutrino

MLF

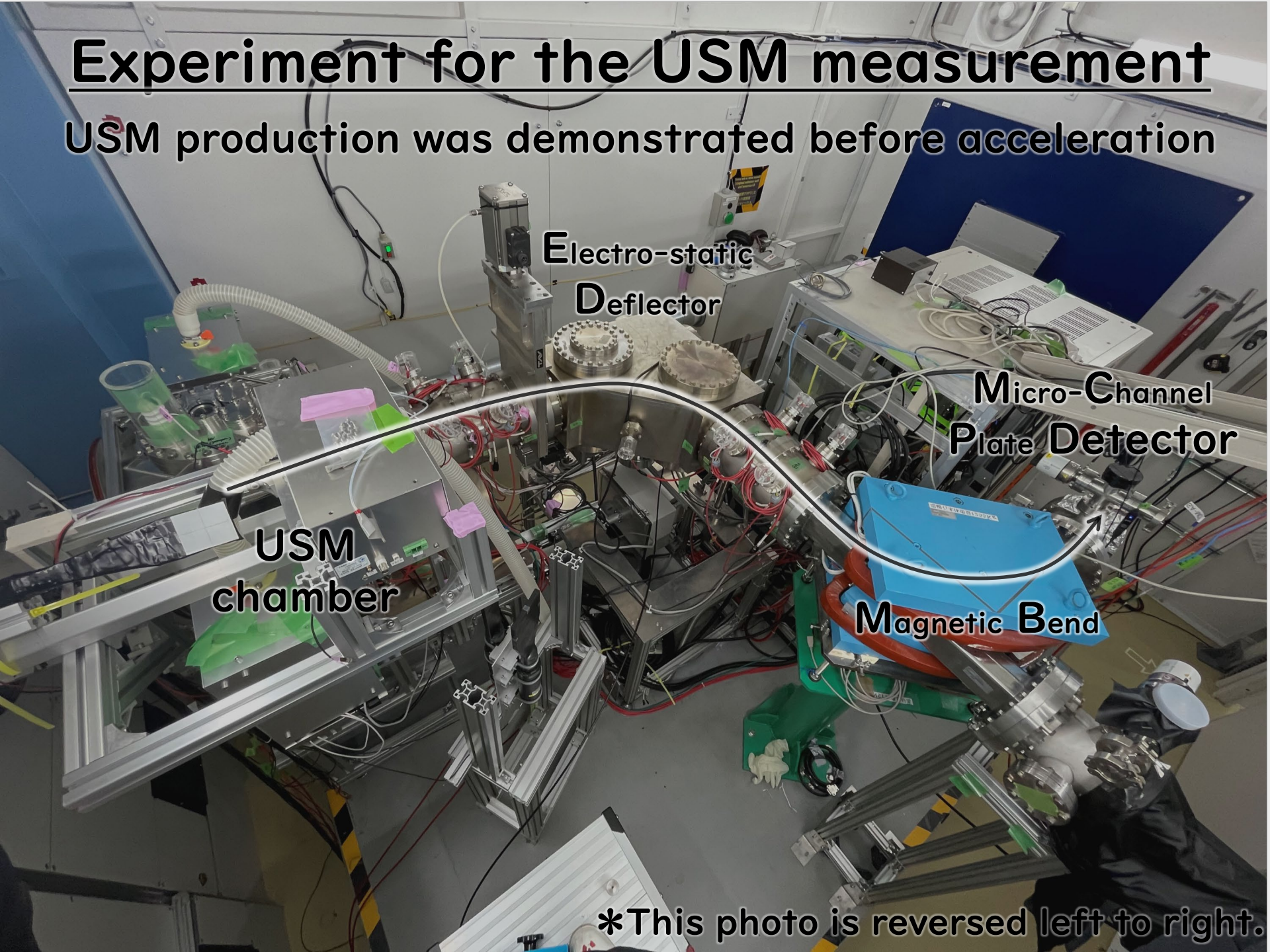
hadron

# Experimental Site


# Experimental Site

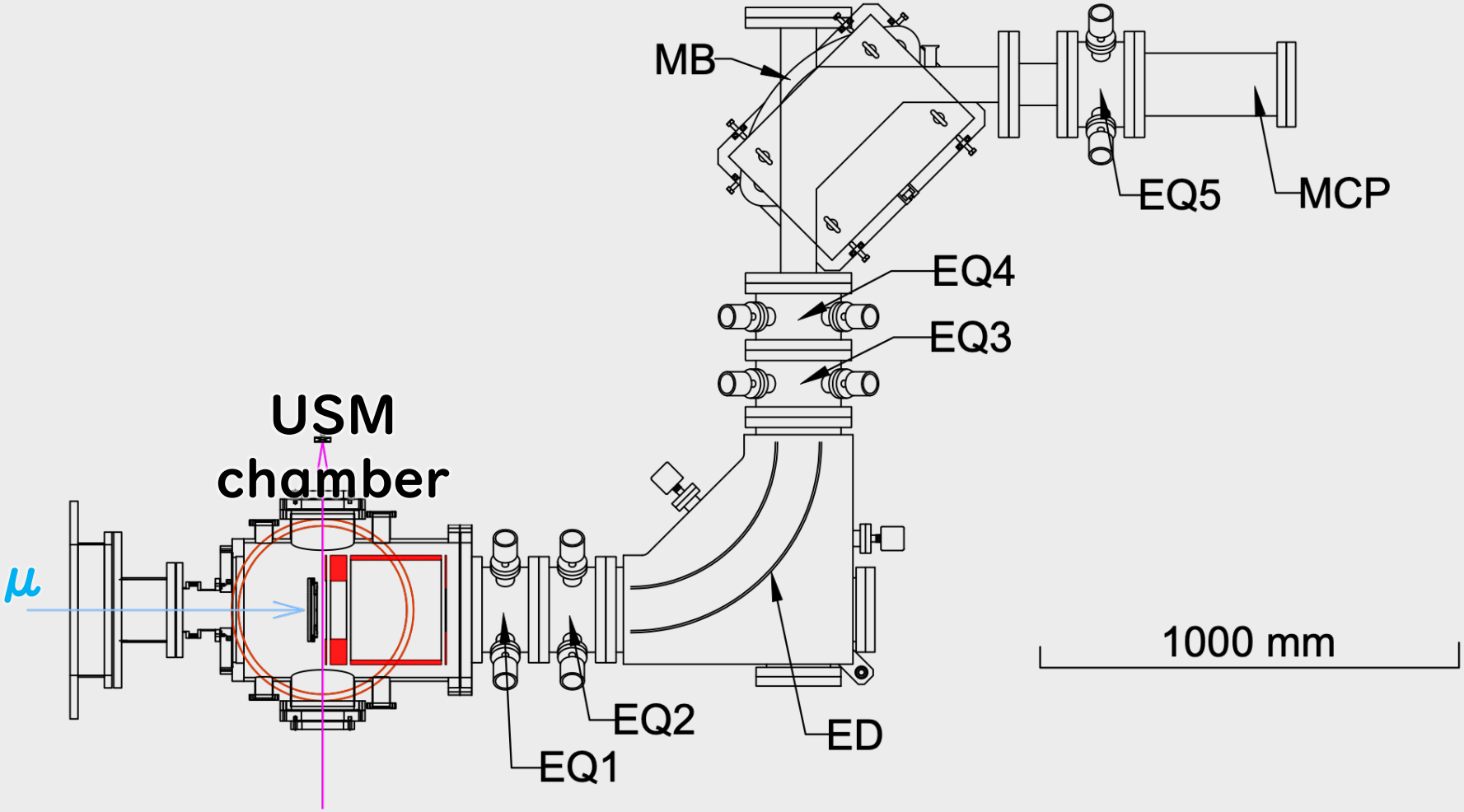
# Experiment for the USM measurement

USM production was demonstrated before acceleration

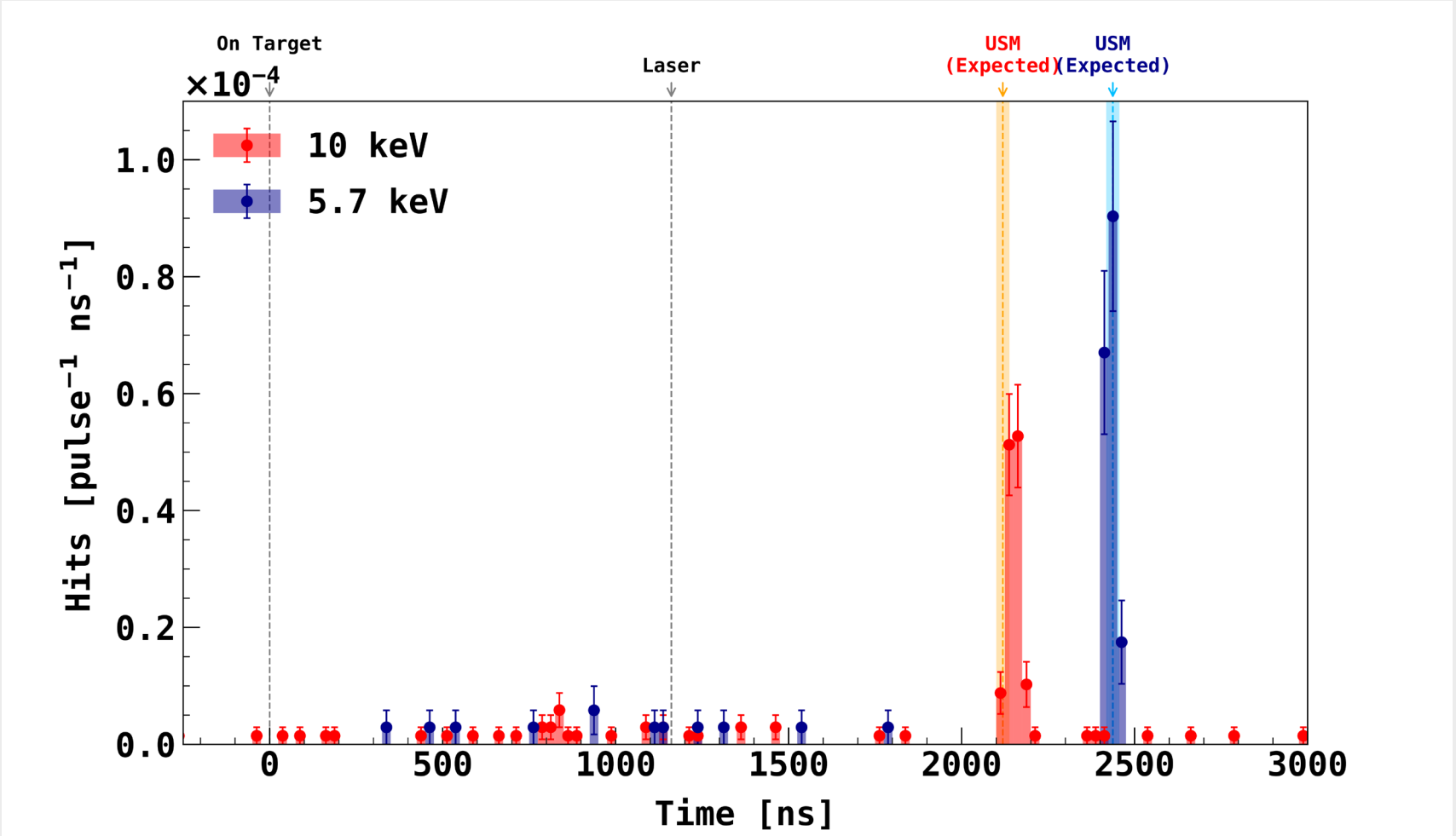


# Experiment for the USM measurement

## USM production was demonstrated before acceleration

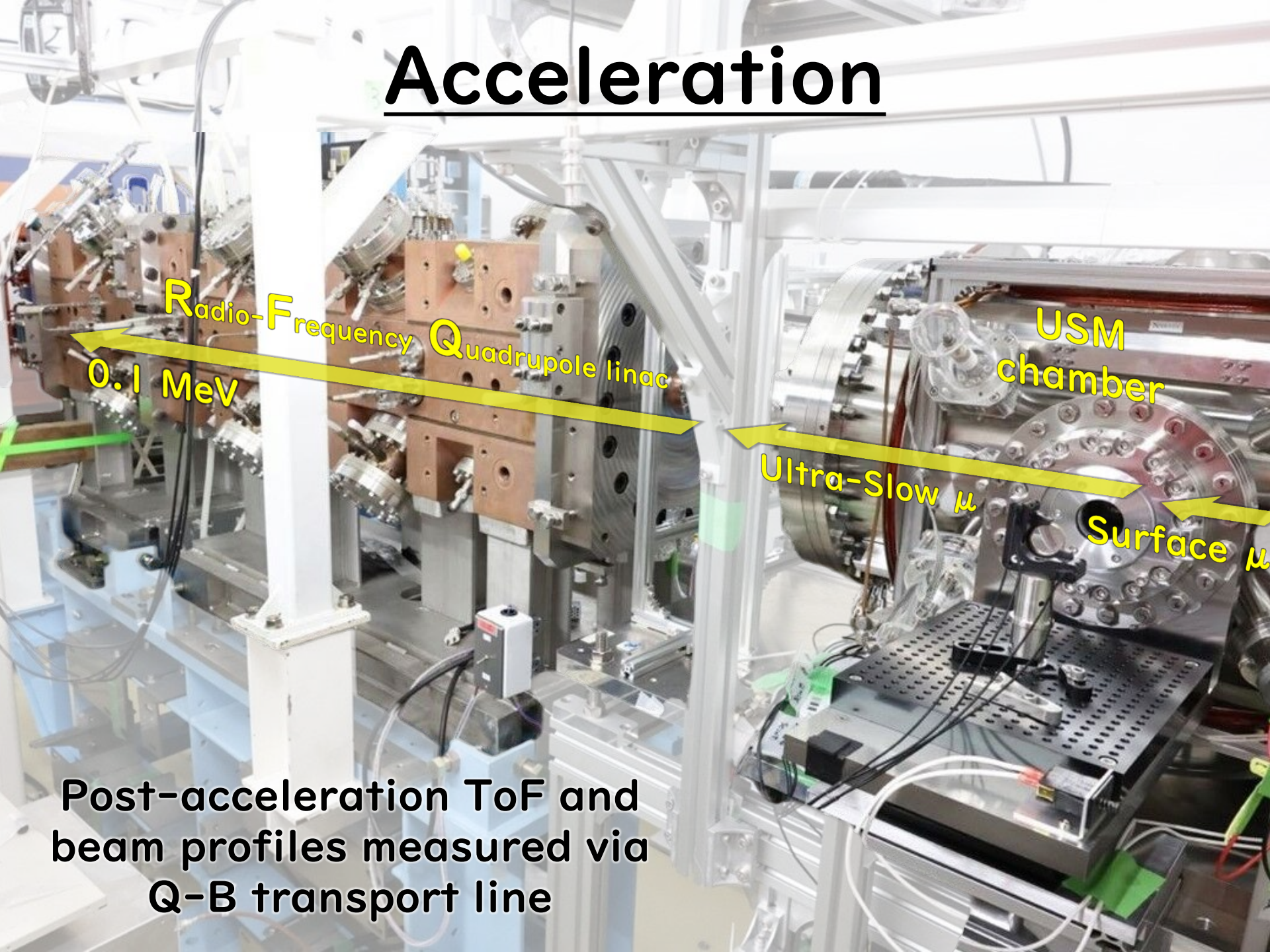


# Result




Successfully demonstrated USM production

# Acceleration

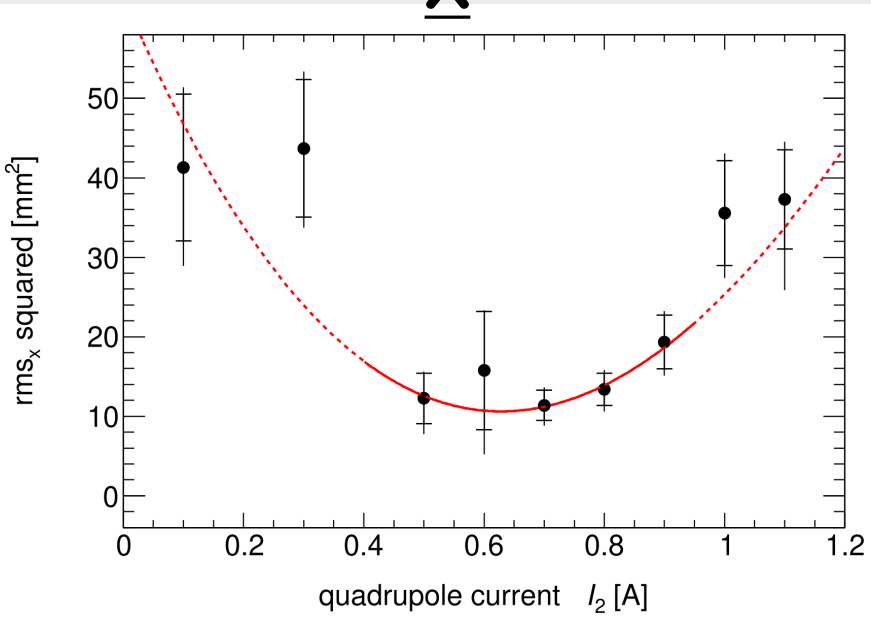



Post-acceleration ToF and beam profiles measured via Q-B transport line

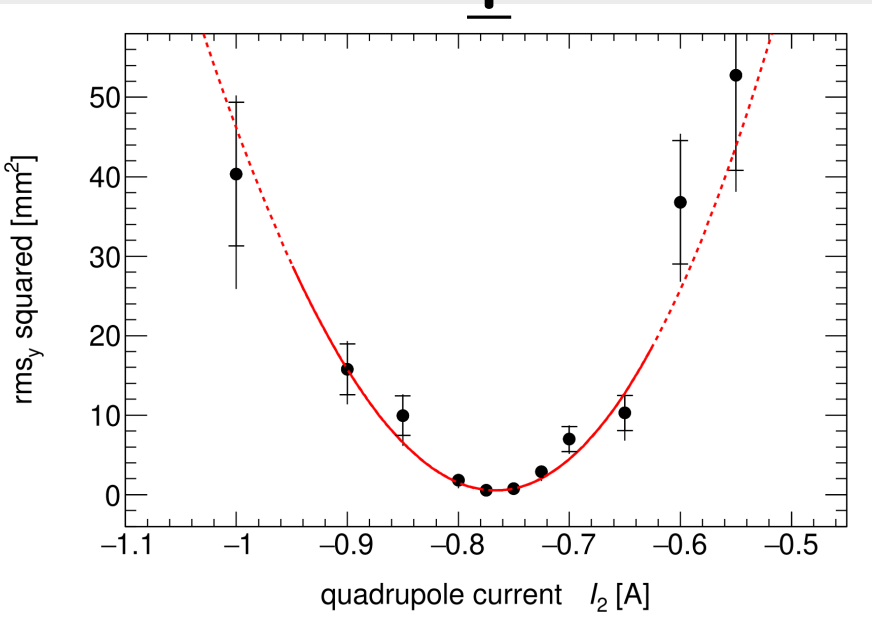
# Result

- Emittance evaluated via Q-scan

X




Y



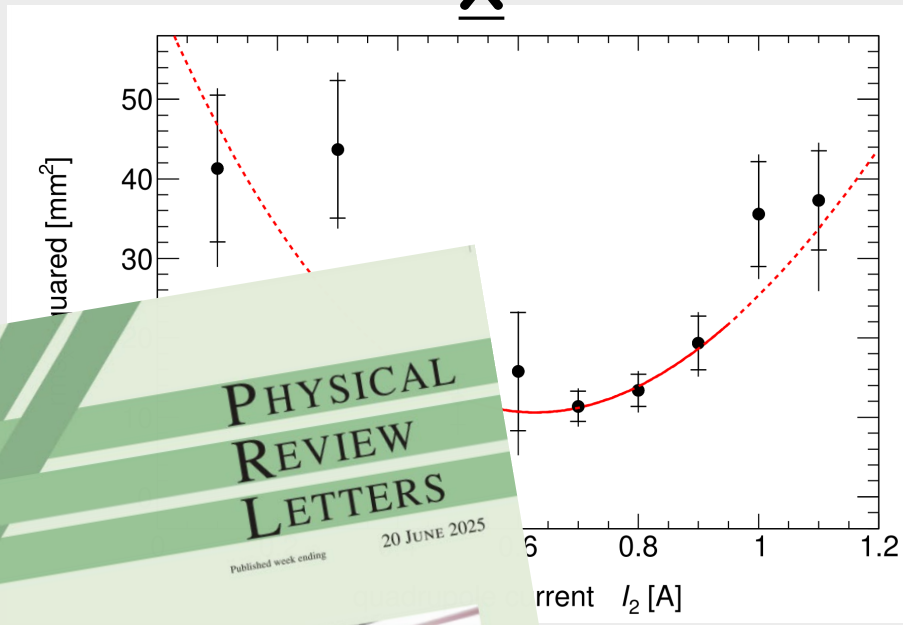

~1000-fold emittance reduction
via cooling and acceleration

PRL 134 (2025) 245001

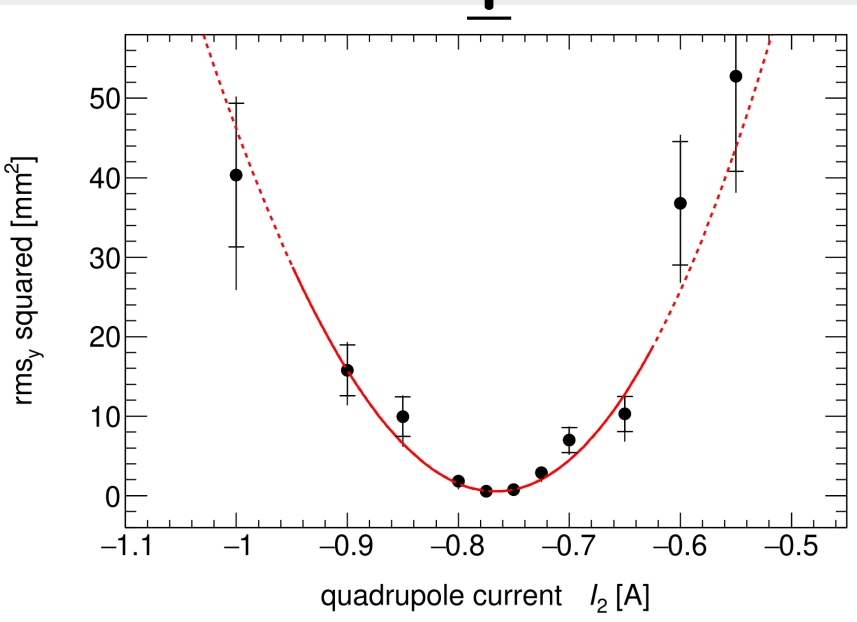
# Result

- Emittance evaluated via Q-scan

X




Y

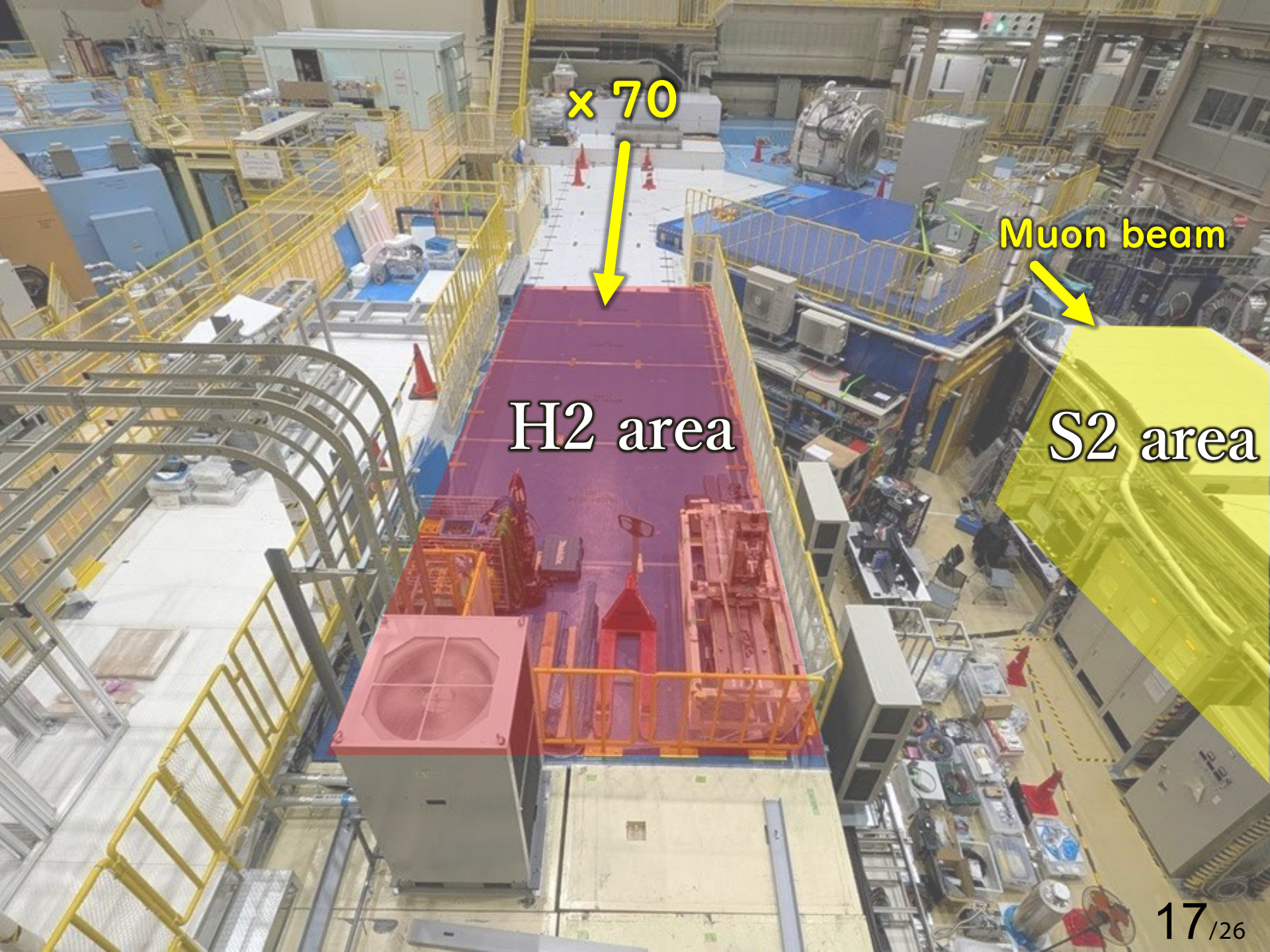


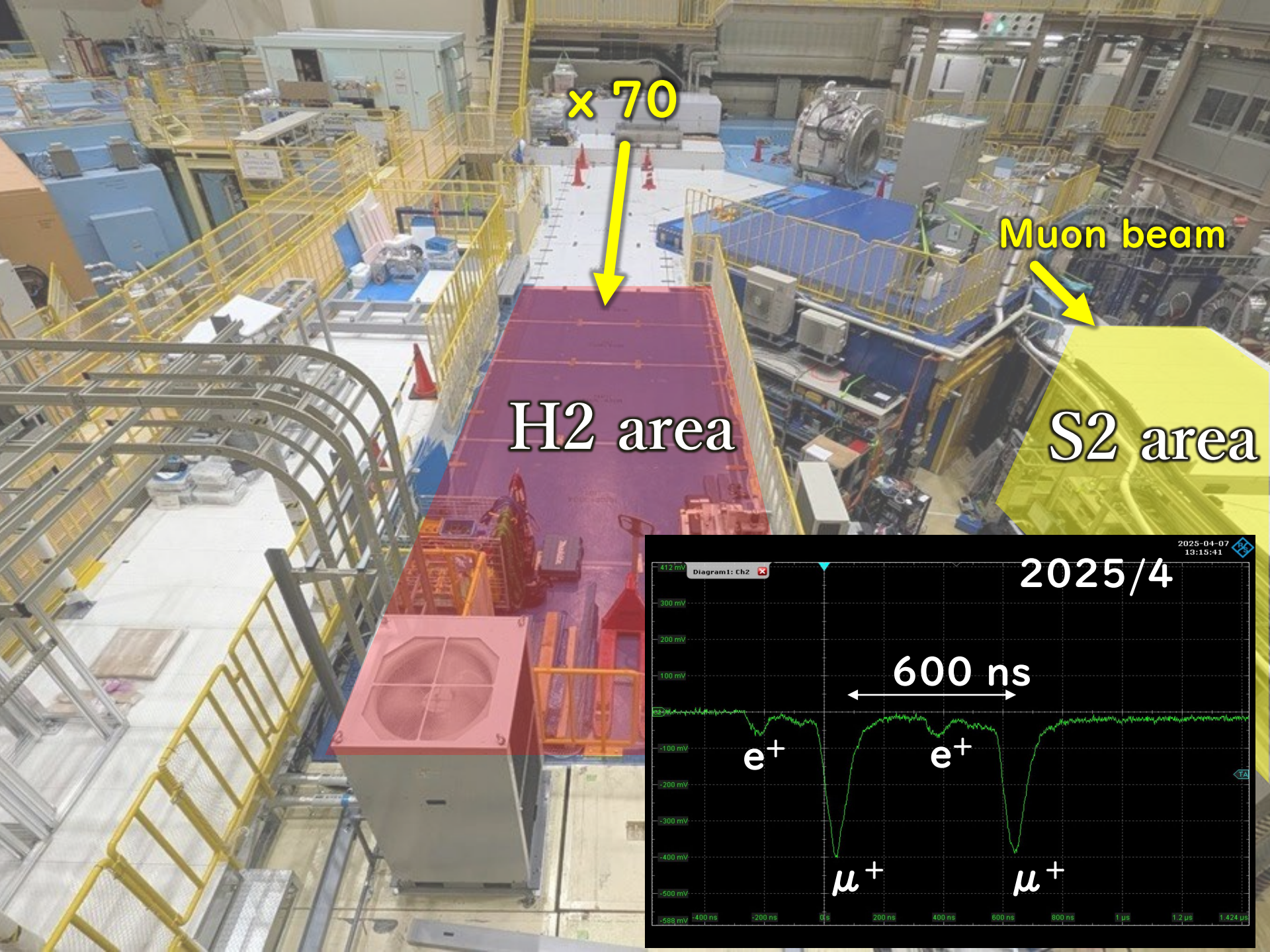


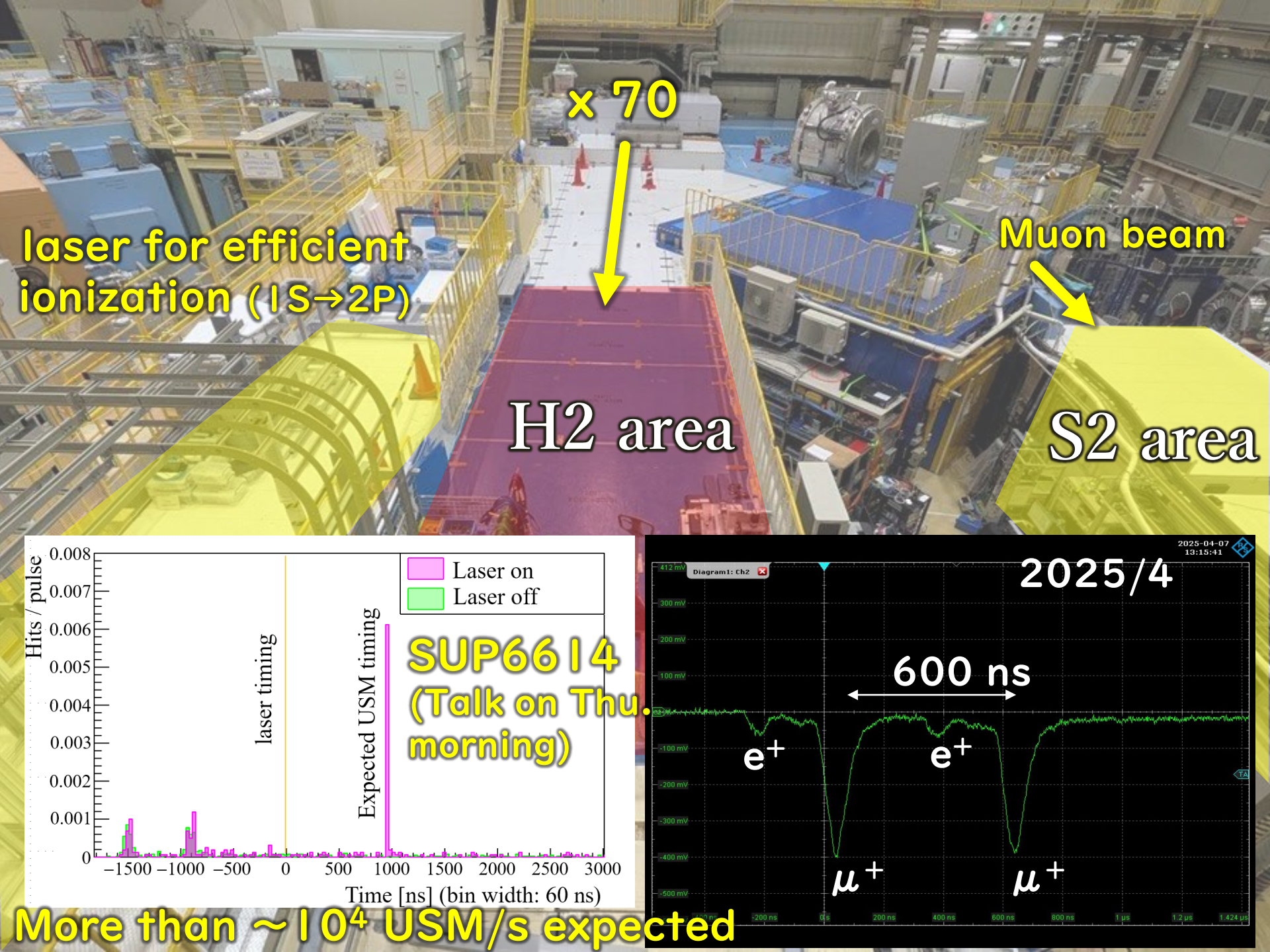
**00-fold emittance reduction**
**cooling and acceleration**

PRL 134 (2025) 245001

Featured as Editors' Suggestion,
Viewpoint, and Journal Cover


× 70
Muon beam
H2 area
S2 area


× 70
Muon beam
H2 area
S2 area
2025/4
600 ns
e+
e+
μ+
μ+



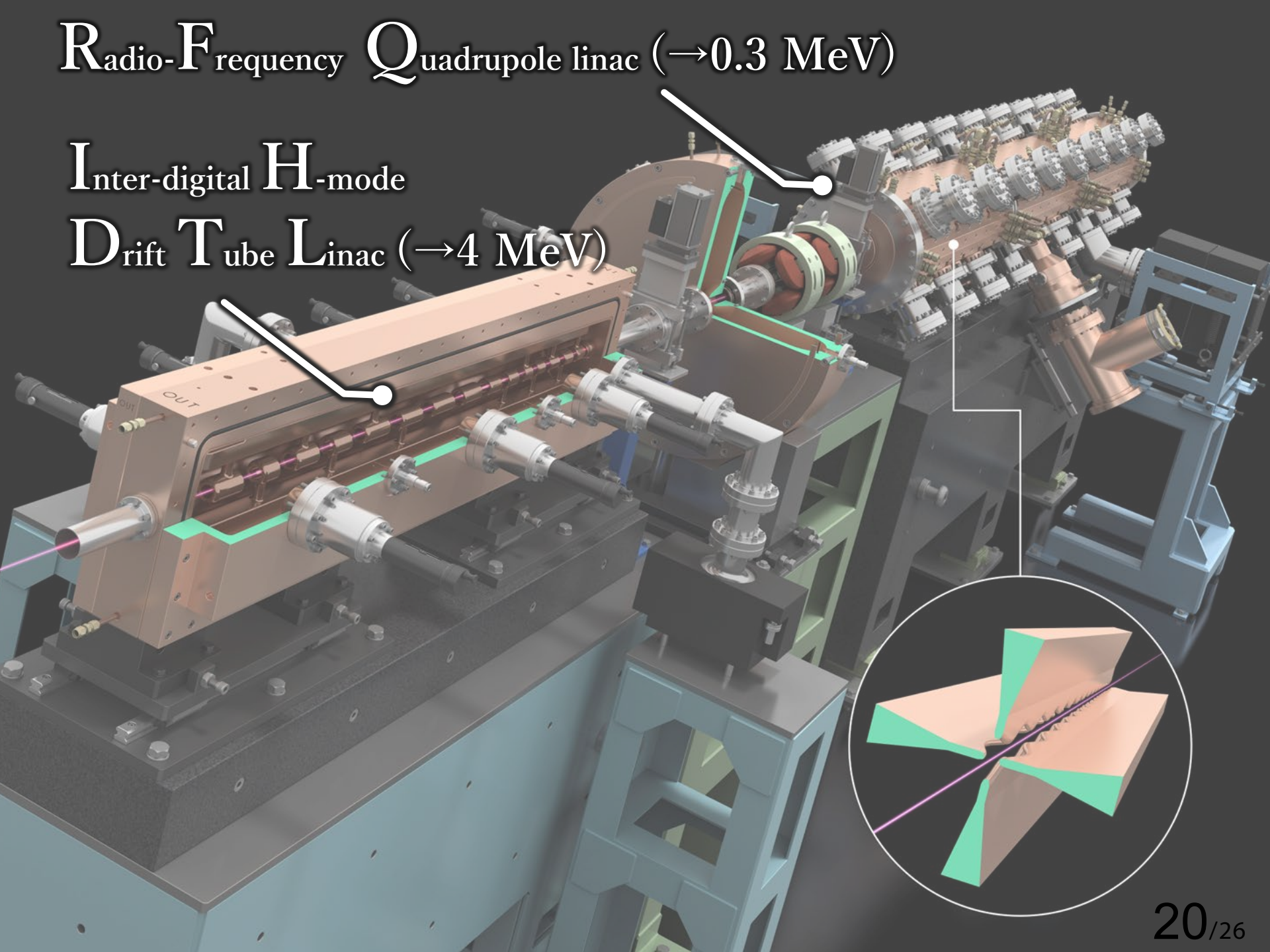




SUP66614 (Talk on Thu. morning)

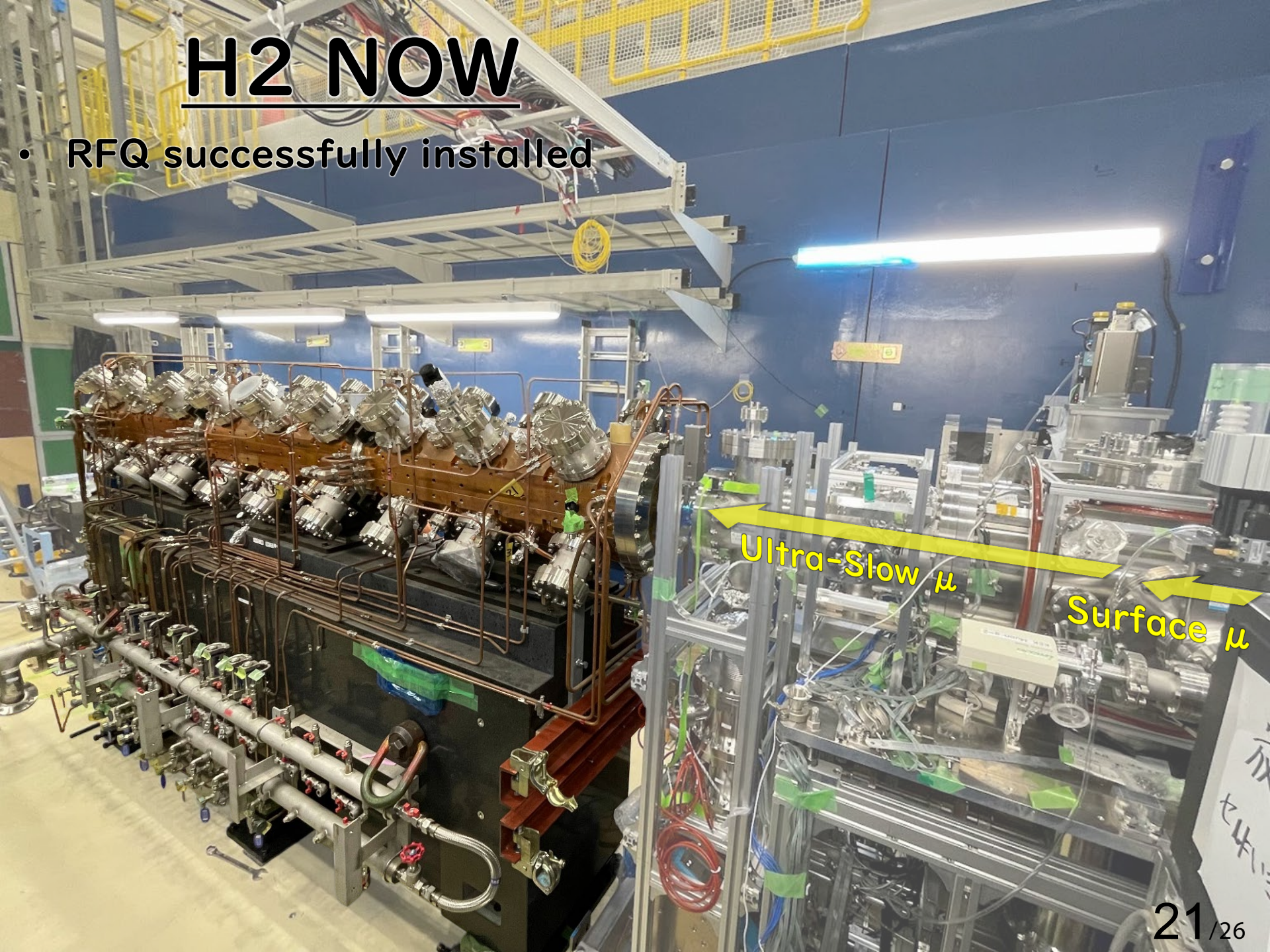



More than ~$10^4$ USM/s expected


Radio-Frequency Quadrupole linac (→0.3 MeV)
Inter-digital H-mode
Drift Tube Linac (→4 MeV)
OUT

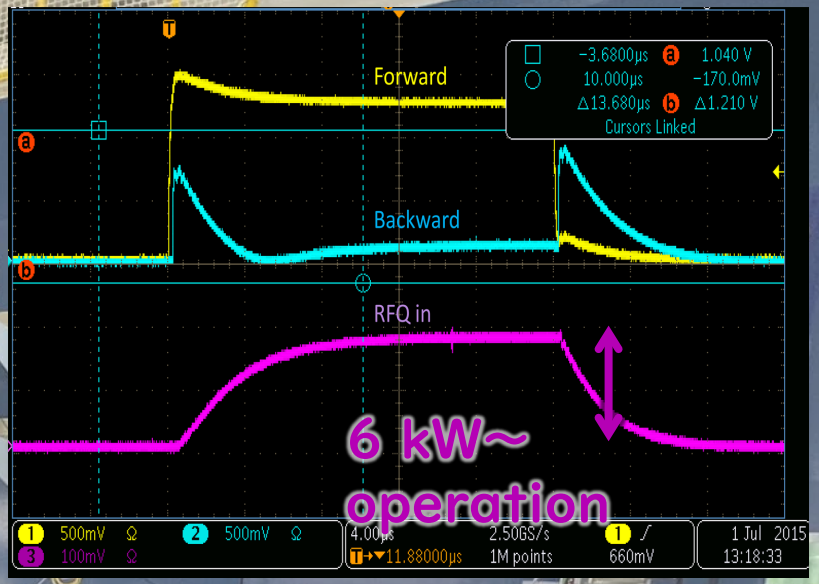
# H2 NOW

- RFQ successfully installed



# H2 NOW

- RFQ successfully installed
- Demonstrated the operation
  (2015 @ J-PARC LI Bld.)



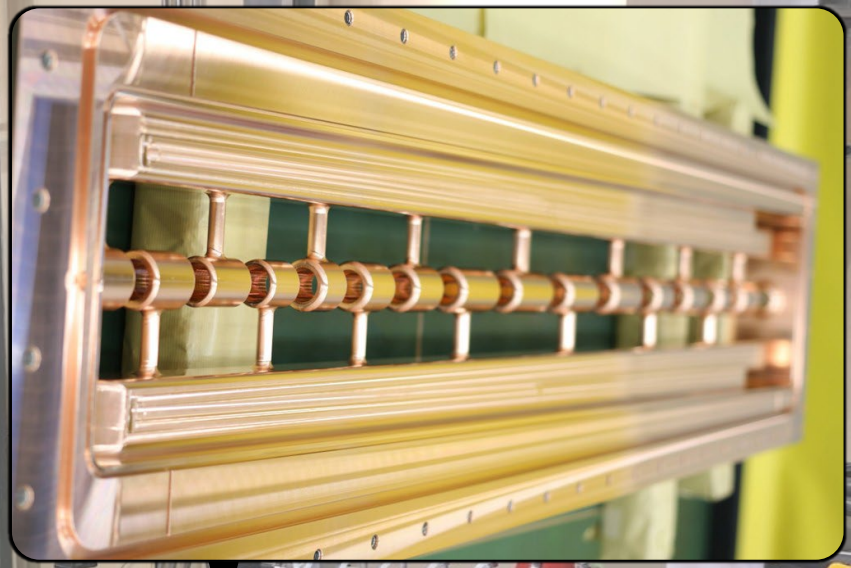

0.3 MeV

Ultra-Slow $\mu$

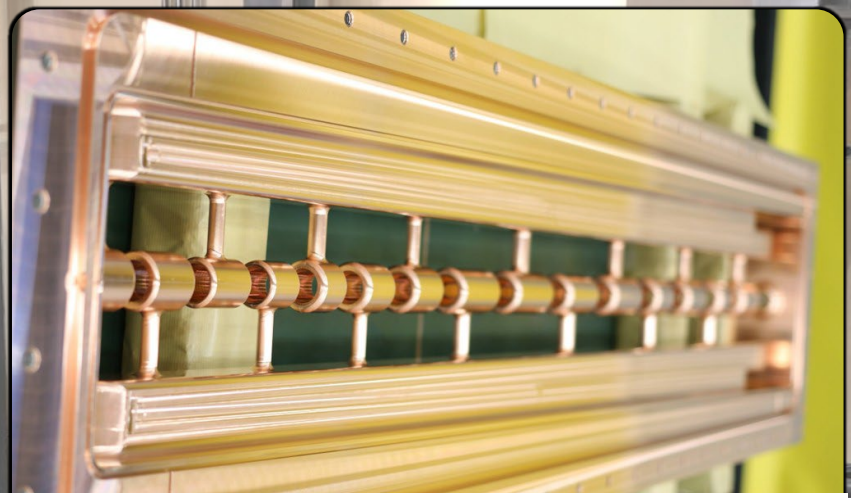
Surface $\mu$

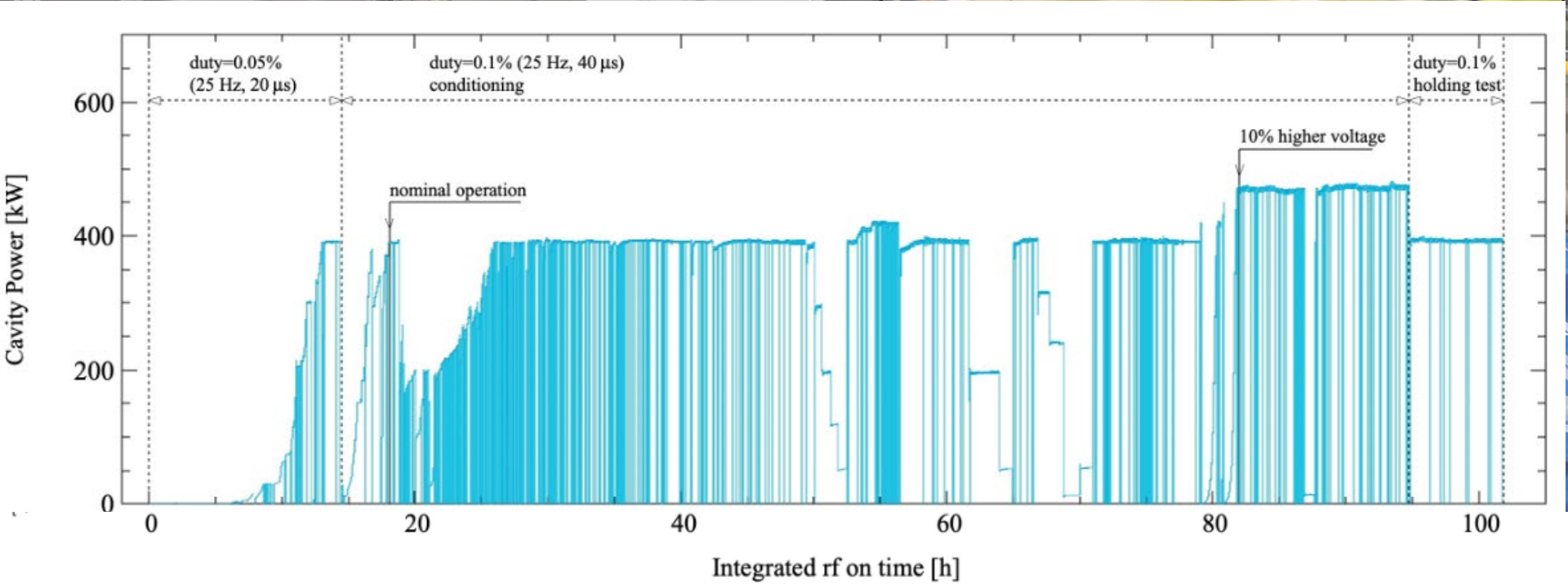
Acceleration will be demonstrated in FY2026

# IH-DTL



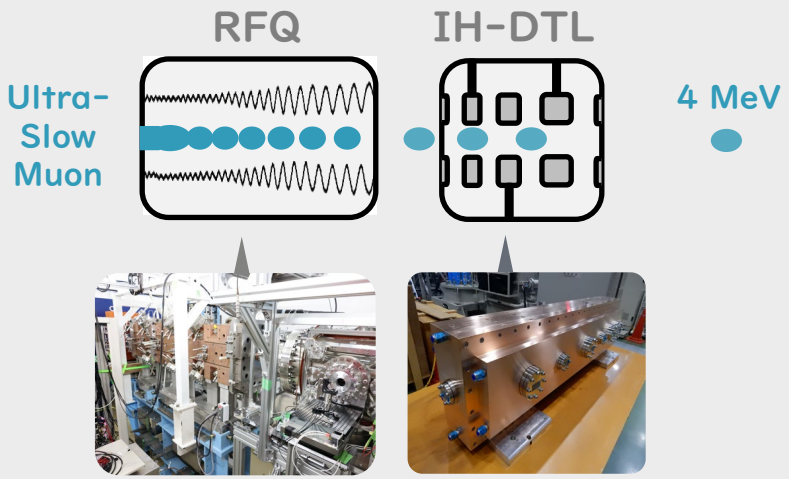
# IH-DTL






Demonstrated the operation.
Acceleration will be demonstrated in FY2027

# Acceleration to 4 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 $Mu^-$($\mu$ee)**

**Low-$\beta$**

**completed**

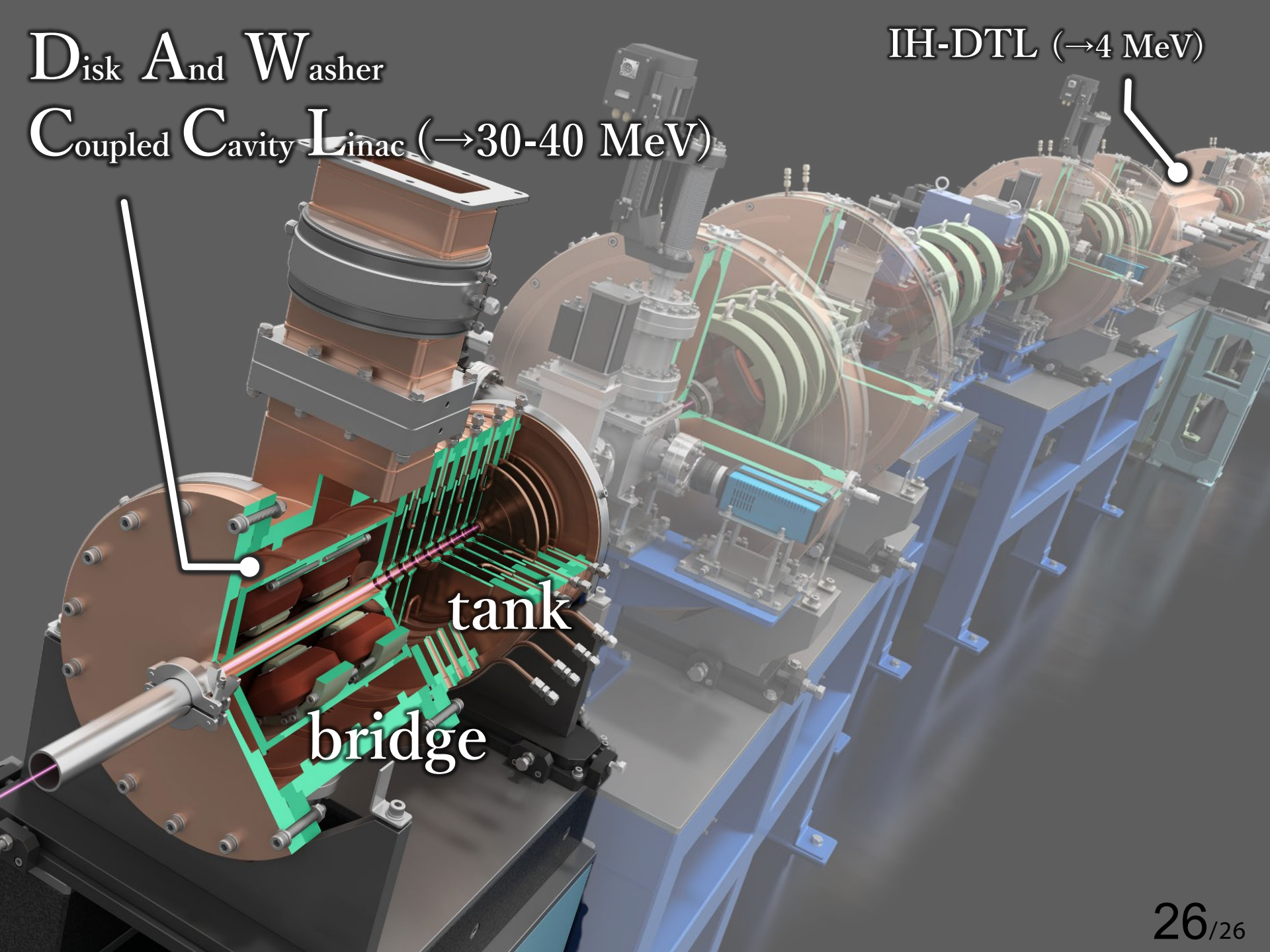
J.Phys.:Conf. 1350(2019)012054
NIM A 943 (2019) 162475
NIM A 946 (2019) 162693
Phys. Rev. AB 23 (2020) 022804
Phys. Rev. AB 23 (2021) 033403
JPS Conf.:33 (2021) 011040
JPS Conf.:33 (2021) 011128
Phys. Rev. AB 25 (2022) 110101

**0.1 MeV**

**Realization**

Phys. Rev. Lett. 134 (2025) 245001

**Will be realized in FY2027**


Disk And Washer
Coupled Cavity Linac (→30-40 MeV)
IH-DTL (→4 MeV)
tank
bridge

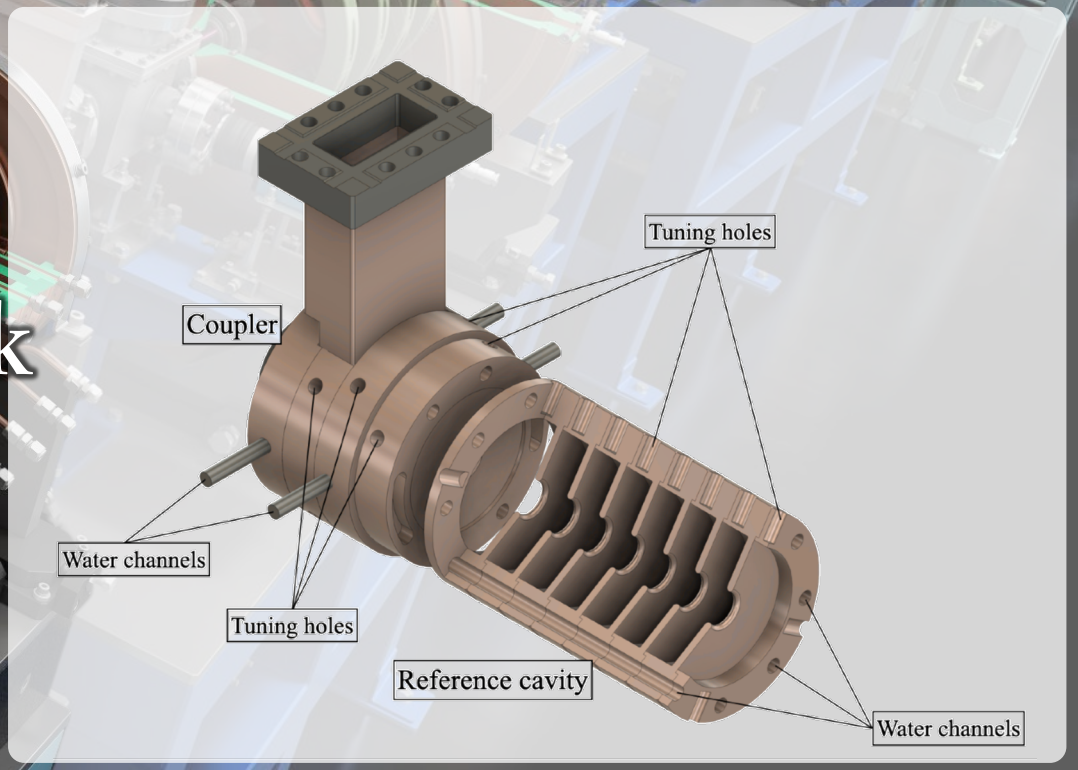
# Disk And Washer Coupled Cavity Linac (→30-40 MeV)

IH-DTL (→4 MeV)

Disk Loaded Structure (→200-500 MeV)

tank

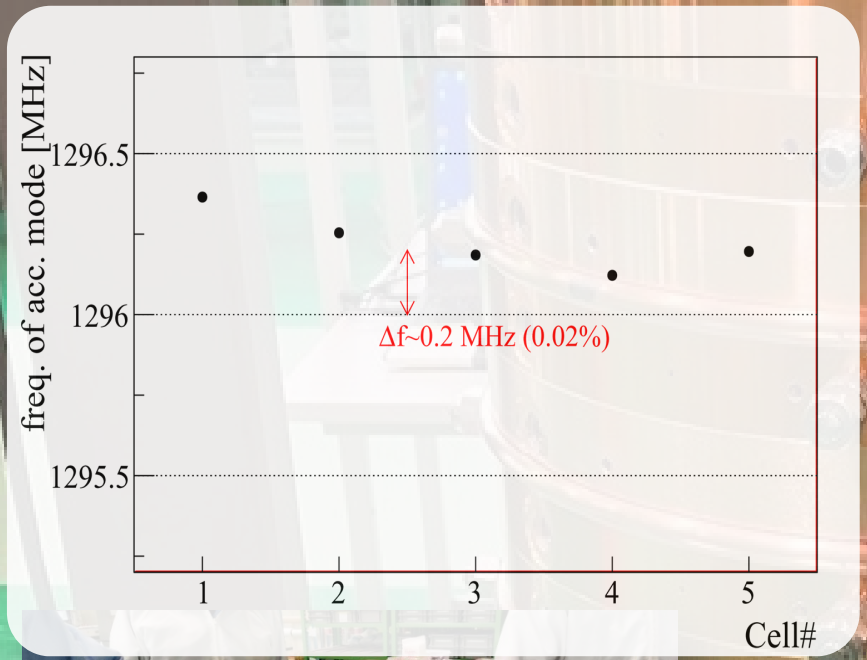
bridge



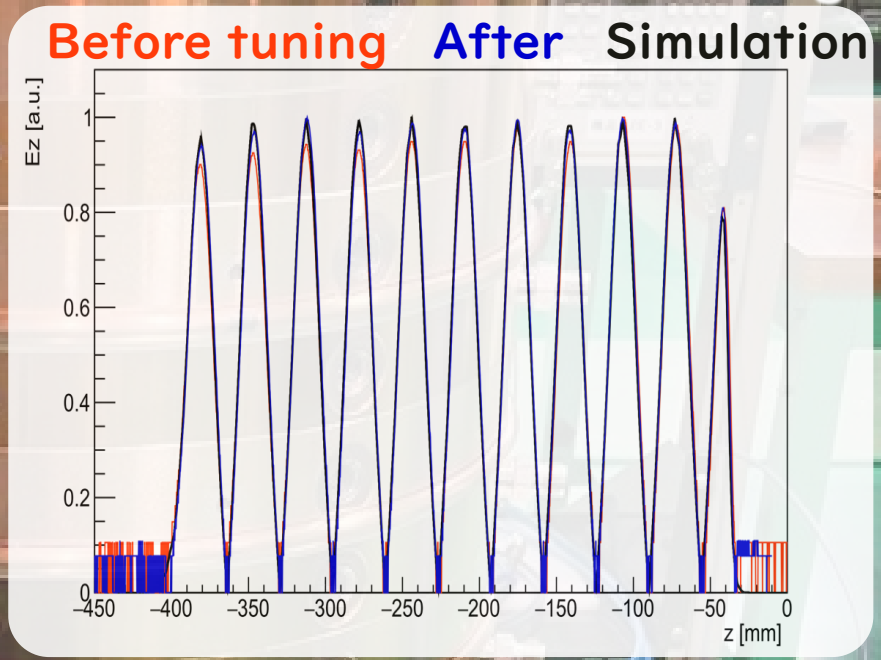
# DAW-CCL

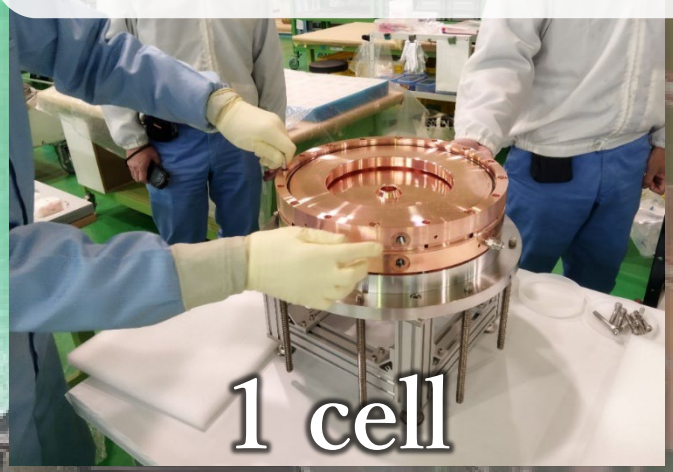
# DAW-CCL

## Test of each cell




## Test with all cell stacking



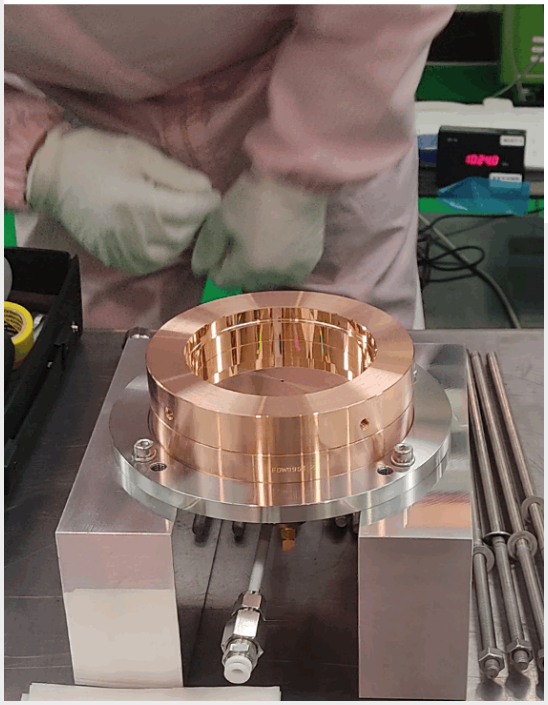



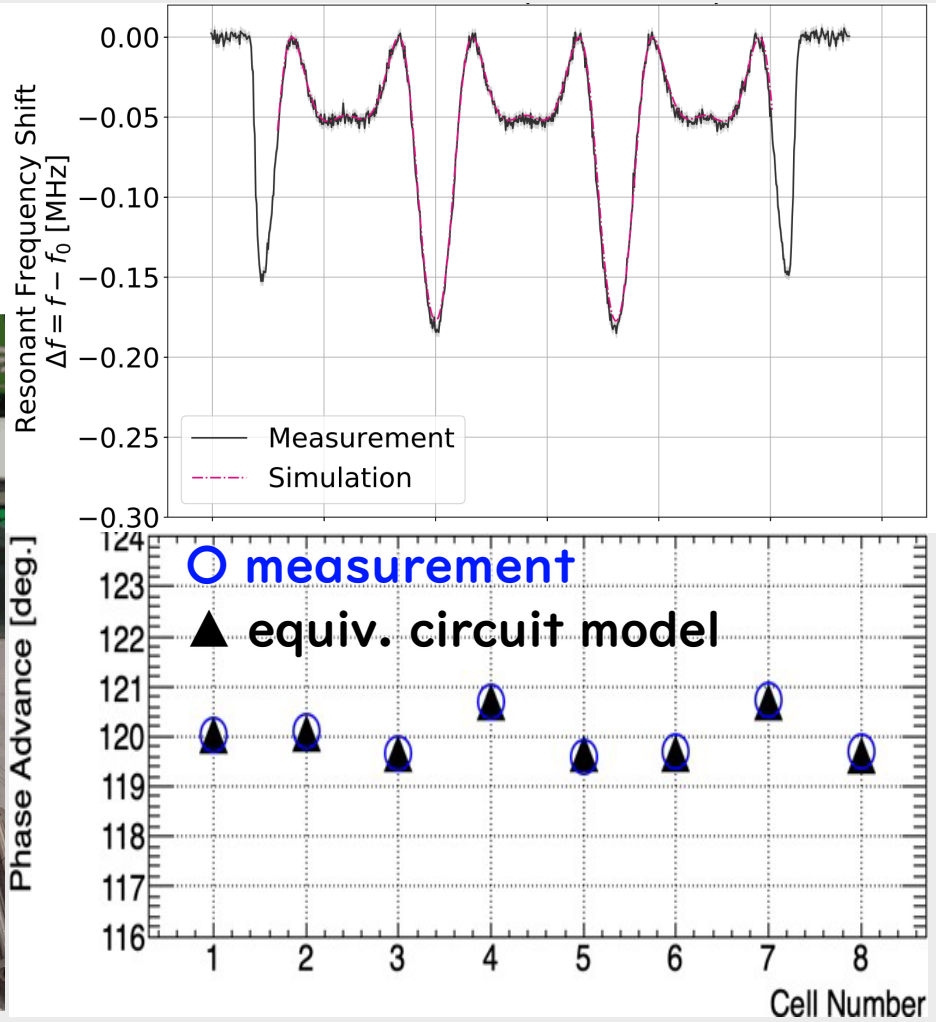

**Demonstrated proof-of-principle**

**Bridge development will be presented in WEP4631 (poster on Wed.)**

# DLS

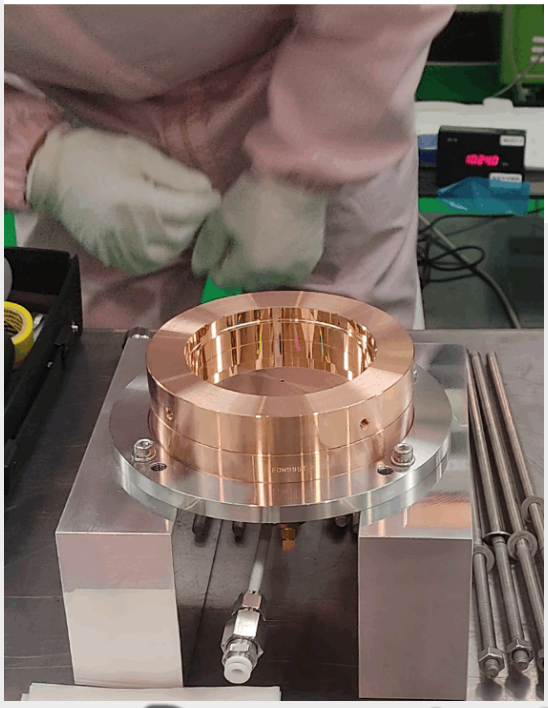
- Novel structure with cell length varying according to velocity ($\beta$=0.6-0.9)

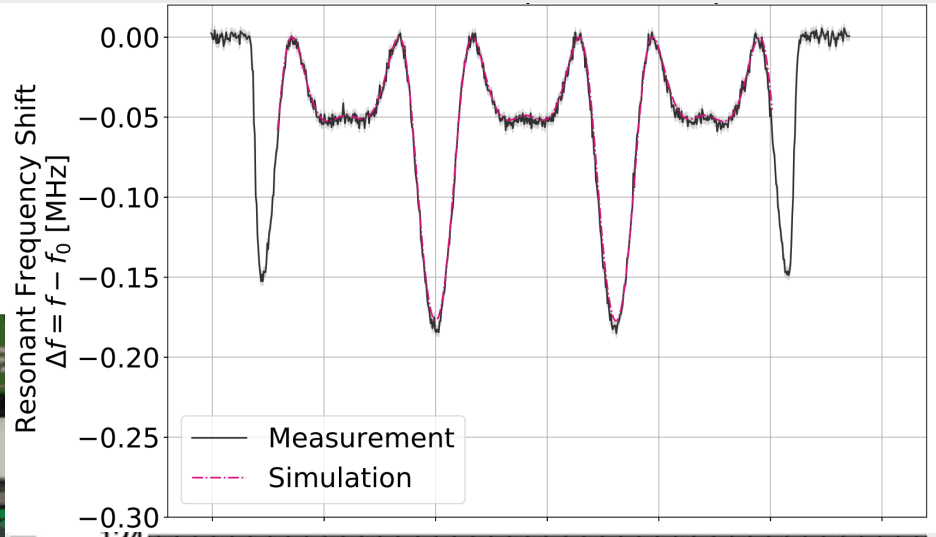


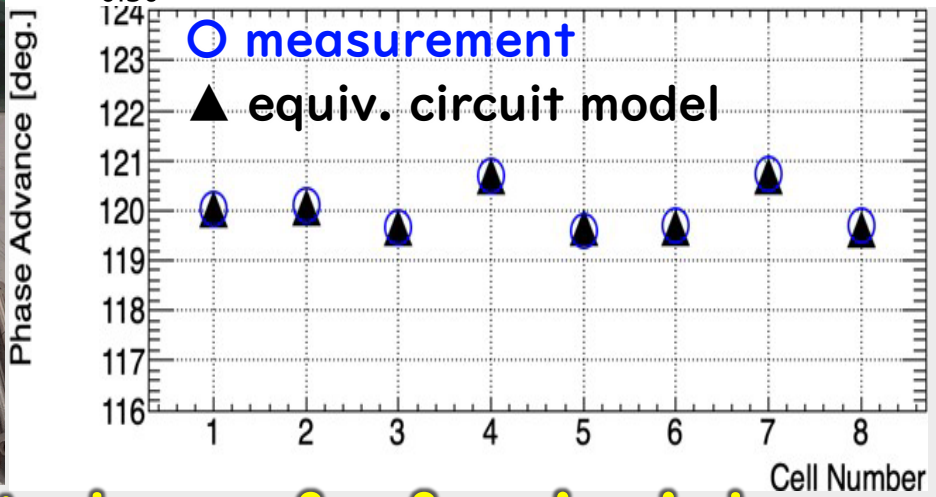


# DLS

- Novel structure with cell length varying according to velocity ($\beta$=0.6-0.9)



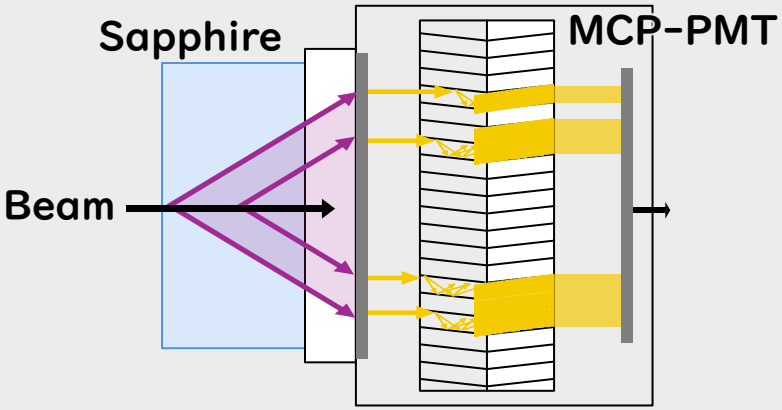



Demonstrated proof-of-principle

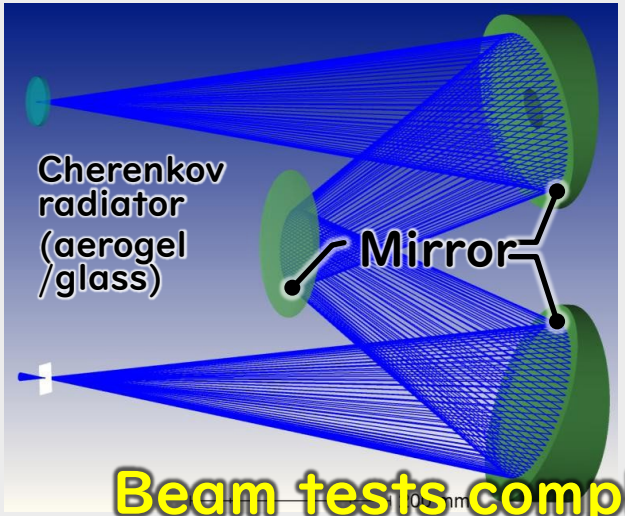
# Beam Monitors

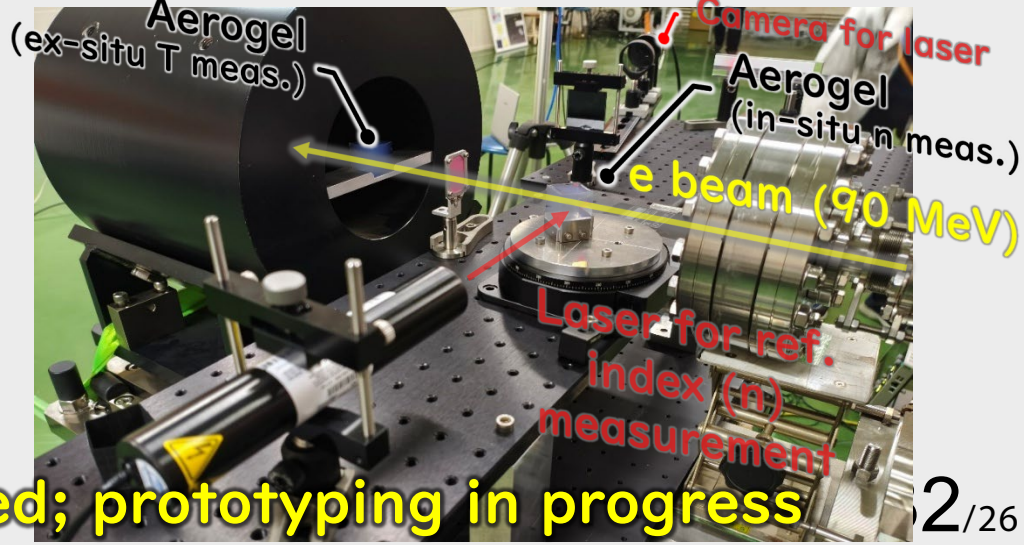
- Cherenkov monitors are being developed
  - Measured with MCP-PMT using a fast readout circuit





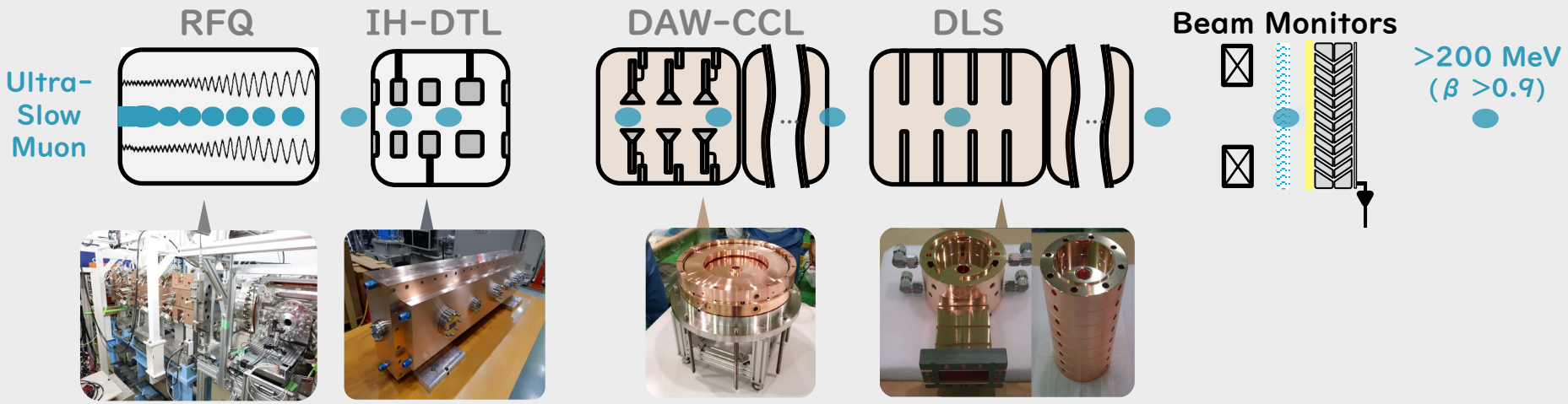
  - detected by camera via mirrors for beam imaging.




Beam tests completed; prototyping in progress

# Acceleration to relativistic velocities




2010 2015 2020 2025 2030

Design・PoP demonstration

Low-β

0.1 MeV

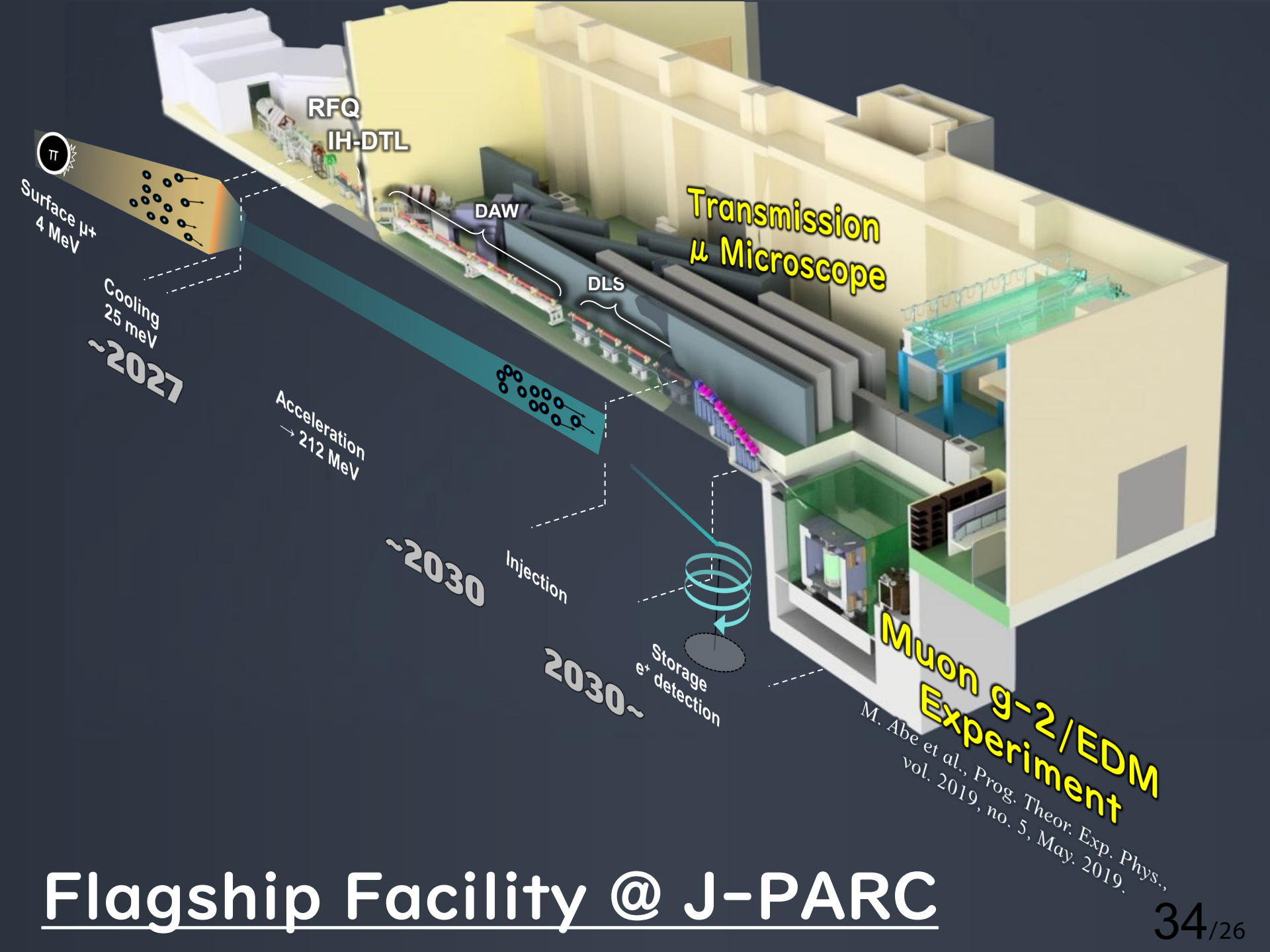
Realization

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




# Flagship Facility @ J-PARC

# Summary

- We have achieved the first demonstration of the positive muon cooling and acceleration to 0.1 MeV.
- Acceleration to 4 MeV with RFQ and IH-DTL will be demonstrated in the coming years.
- Development toward high-energy muon linac (→200-500 MeV) is ongoing, enabling future applications.
- This work establishes a key technology for compact high-energy muon accelerators.

# Acknowledgement

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