J-PARC muon *g*-2 experiment

Takayuki YAMAZAKI (KEK IMSS/J-PARC)

on behalf of

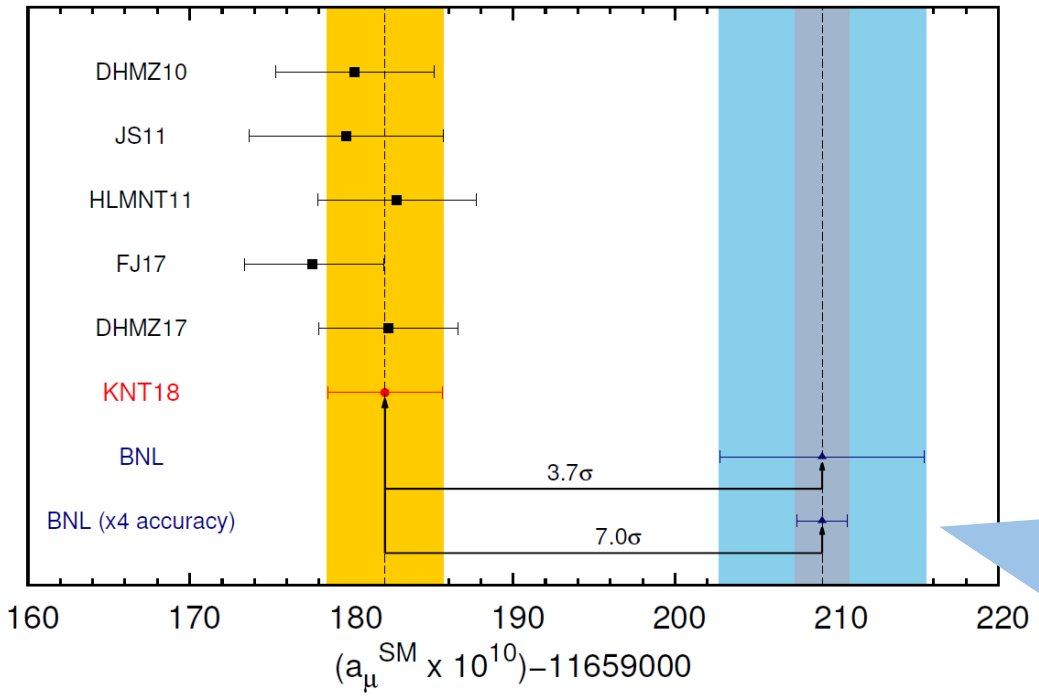
The J-PARC muon g-2/EDM collaboration

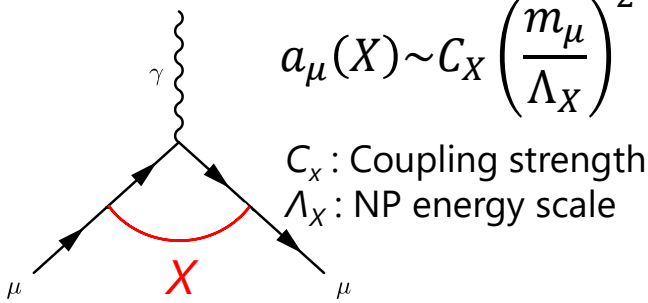
Outline

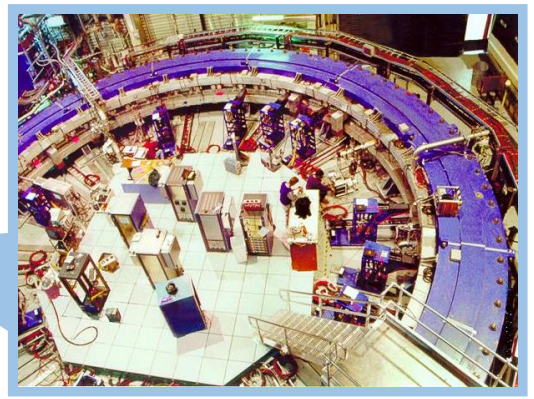
- Project overview
- Current status
  - Construction of muon beamline for g-2 (H-line)
- Summary

>3σ discrepancy of muon *g*-2

- Muon *g*-2 is one of the most sensitive targets to explore new physics
  - Precise experiment (BNL E821) : 0.5ppm
  - Precise theoretical calculations : 0.3ppm (PRD97, 114025 (2018))
- According to a recent theoretical calculation, the discrepancy between experiment and SM theory is 3.7σ → **New physics?**

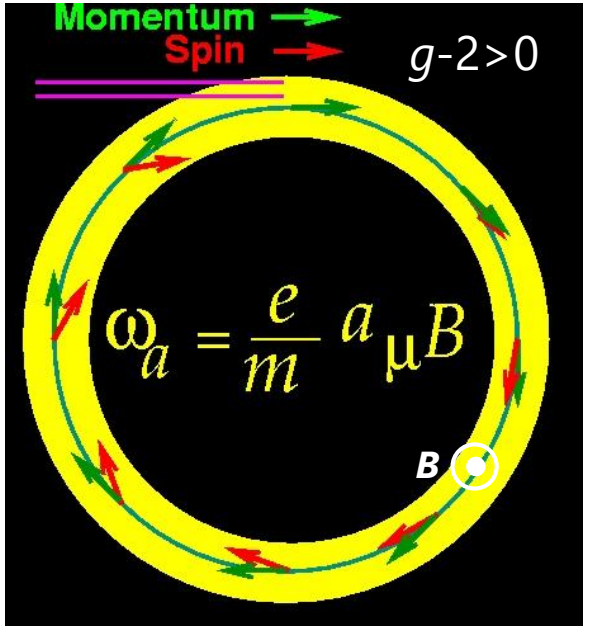






Muon g-2 experiment

- Measurement principle
  - ✓ Store a polarized muon beam in a uniform magnetic field ***B***
  - ✓ Detect decay e^+ to measure spin precession frequency $\boldsymbol{\omega}_a$



- $\boldsymbol{\omega}_a$ under ***B*** and ***E*** field is

$$\boldsymbol{\omega}_a = -\frac{e}{m_\mu}\left[\underbrace{a_\mu \boldsymbol{B}}_{g\text{-}2} - \underbrace{\left(a_\mu - \frac{1}{\gamma^2-1}\right)\frac{\boldsymbol{\beta}\times\boldsymbol{E}}{c}}_{\text{Effect of } \boldsymbol{E} \text{ field}} + \underbrace{\frac{\eta_\mu}{2}\left(\boldsymbol{\beta}\times\boldsymbol{B} + \frac{\boldsymbol{E}}{c}\right)}_{\text{EDM}}\right]$$

Elimination of *E*-field effect is necessary for precise measurements

FNAL E989 / J-PARC E34

- Their difference is the way to eliminate ***E***-field effect.

$$\boldsymbol{\omega}_a = -\frac{e}{m_\mu}\left[\underbrace{a_\mu \boldsymbol{B}}_{g\text{-}2} - \underbrace{\left(a_\mu - \frac{1}{\gamma^2-1}\right)\frac{\boldsymbol{\beta}\times\boldsymbol{E}}{c}}_{\text{Effect of } \boldsymbol{E} \text{ field}} + \underbrace{\frac{\eta_\mu}{2}\left(\boldsymbol{\beta}\times\boldsymbol{B} + \frac{\boldsymbol{E}}{c}\right)}_{\text{EDM}}\right]$$

$\gamma = 29.3$ ($P = 3$ GeV)
"Magic momentum"

$E = 0$ at any γ
Super-low emittance muon beam

$$\boldsymbol{\omega}_a = -\frac{e}{m_\mu}\left[\underbrace{a_\mu \boldsymbol{B}}_{g\text{-}2} + \underbrace{\frac{\eta_\mu}{2}\left(\boldsymbol{\beta}\times\boldsymbol{B} + \frac{\boldsymbol{E}}{c}\right)}_{\text{EDM}}\right]$$

FNAL E989
Improvement of the BNL method

$$\boldsymbol{\omega}_a = -\frac{e}{m_\mu}\left[\underbrace{a_\mu \boldsymbol{B}}_{g\text{-}2} + \underbrace{\frac{\eta_\mu}{2}\boldsymbol{\beta}\times\boldsymbol{B}}_{\text{EDM}}\right]$$

J-PARC E34
New method with different systematics

Super-low emittance muon beam is the key technique for the J-PARC E34 experiment

J-PARC *g*-2 experiment (E34)

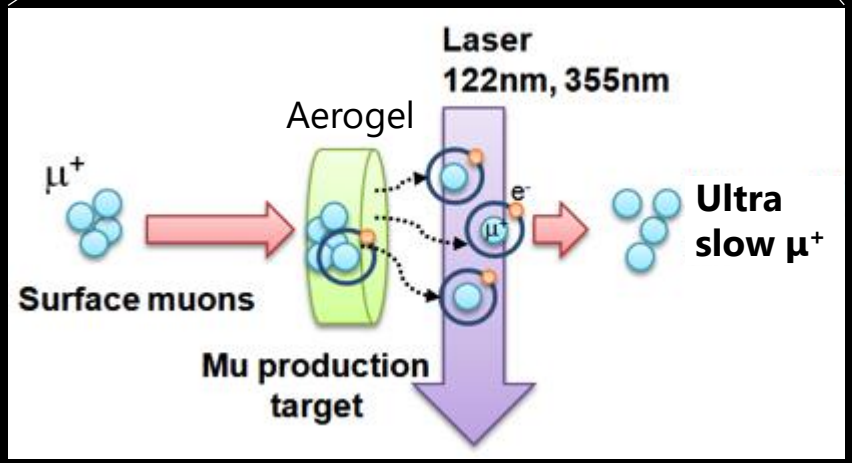
3 GeV proton beam
(1MW, double pulses, 25Hz)

Production target

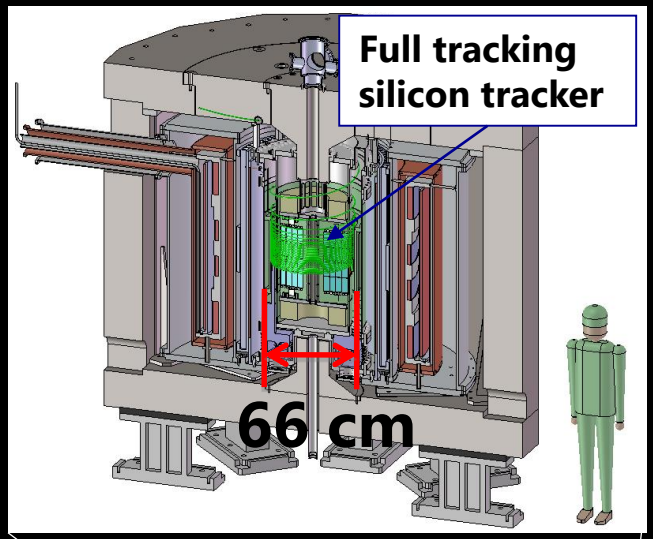
Muonium production target
(300 K ~ **25 meV**)

Surface muon beam (**4 MeV**)
ε~1000 π mm・mrad

Ultra slow μ^+ production by Resonant Laser Ionization of Muonium (~10^6 μ^+/s)



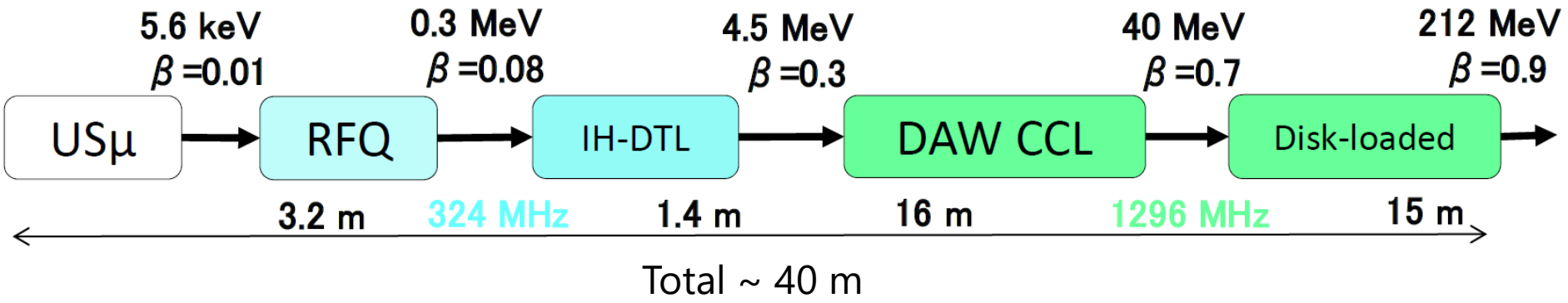
Re-acceleration LINAC
(~ **200 MeV**)
ε~1 π mm・mrad !



Compact storage magnet
(3T, ~1ppm local)

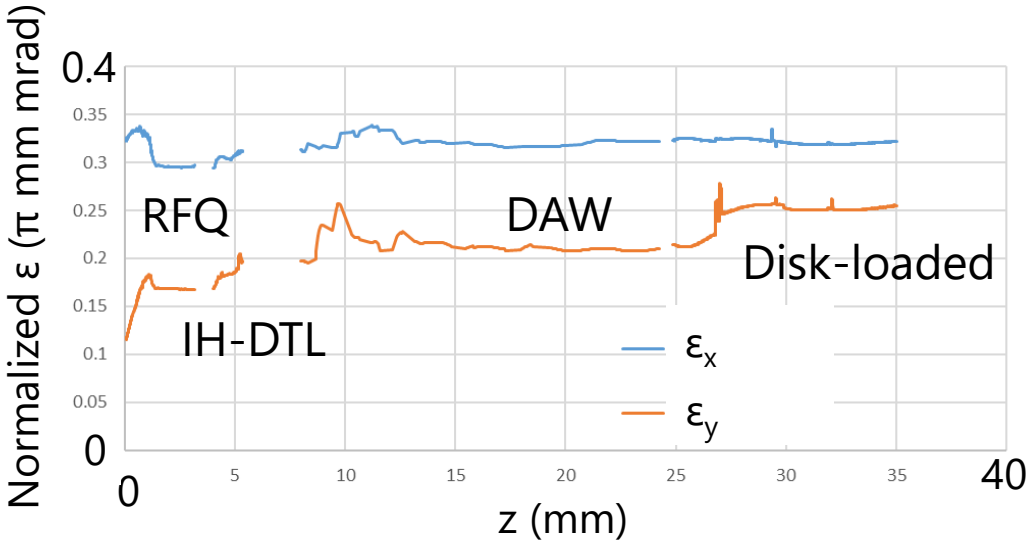
Target precision
$\Delta(g\text{-}2) = 0.1$ ppm
$\Delta EDM = 10^{-21}$ e・cm

Muon acceleration

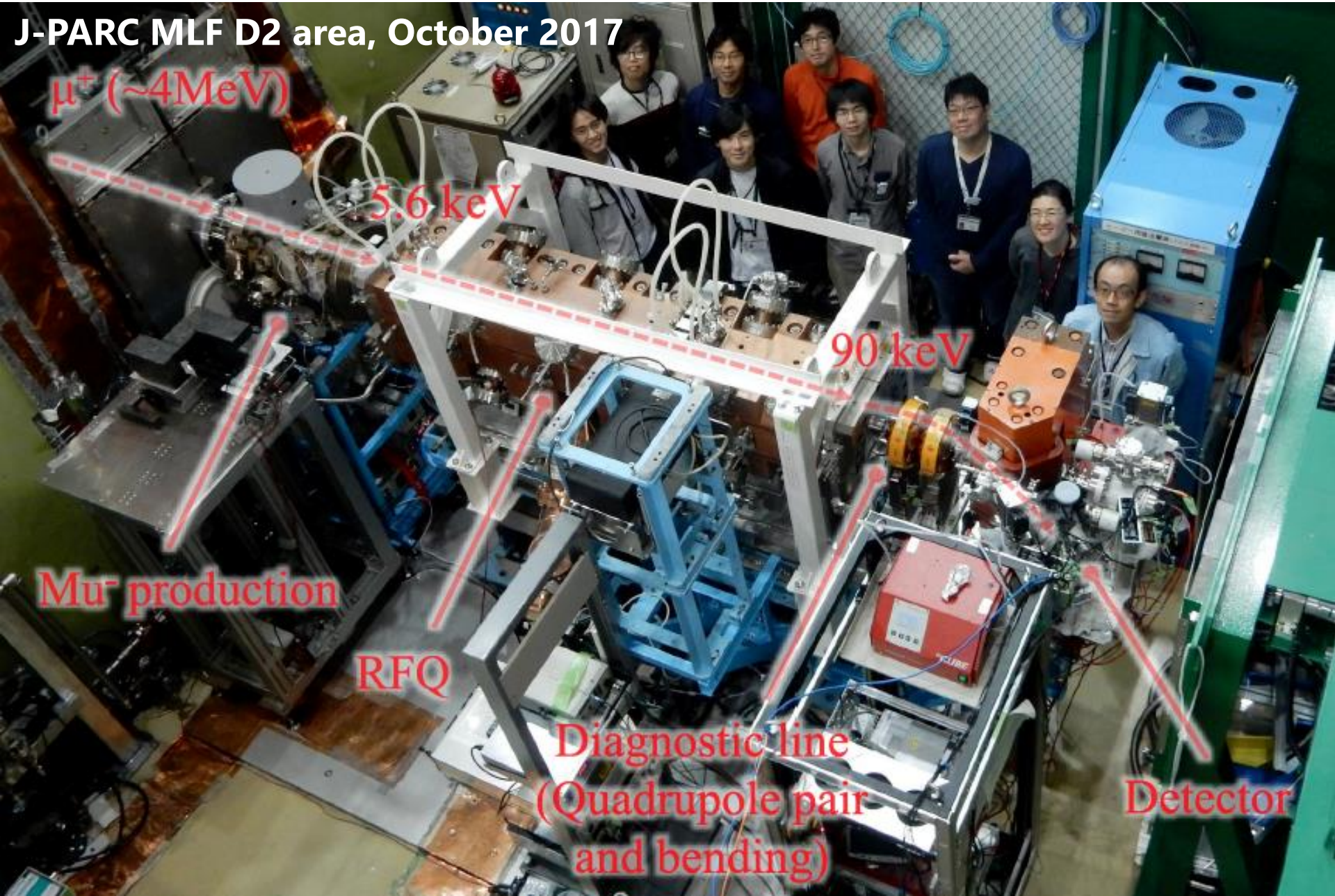


Total ~ 40 m

- Beam acceleration and transportation were simulated from USM source to the exit of muon LINAC, and emittance growth is not significant.



Muon RF acceleration for the first time!



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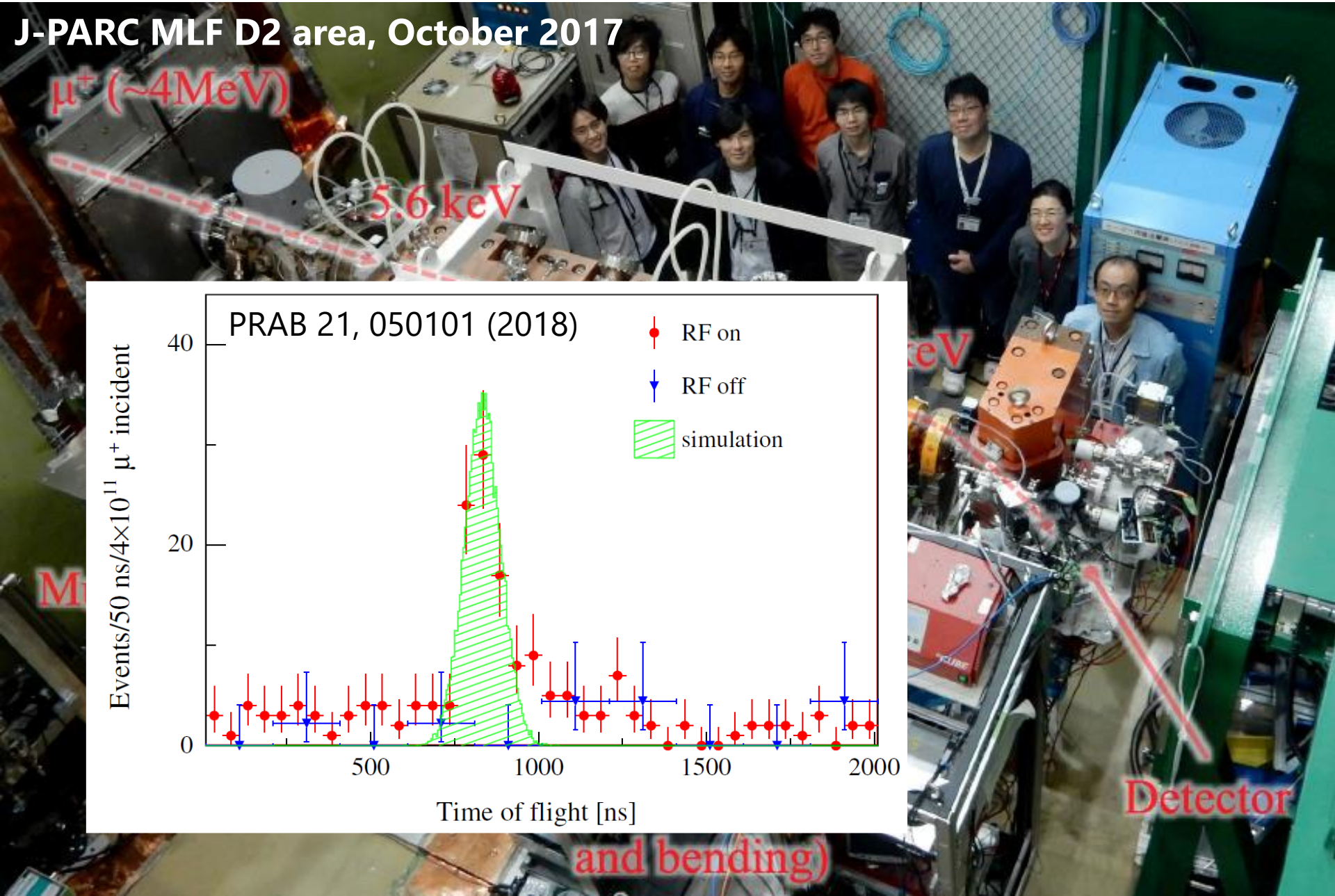
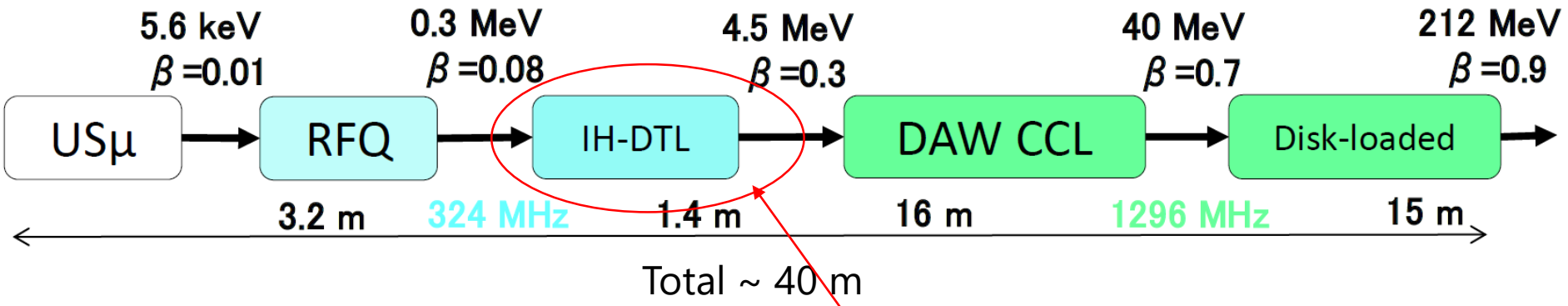
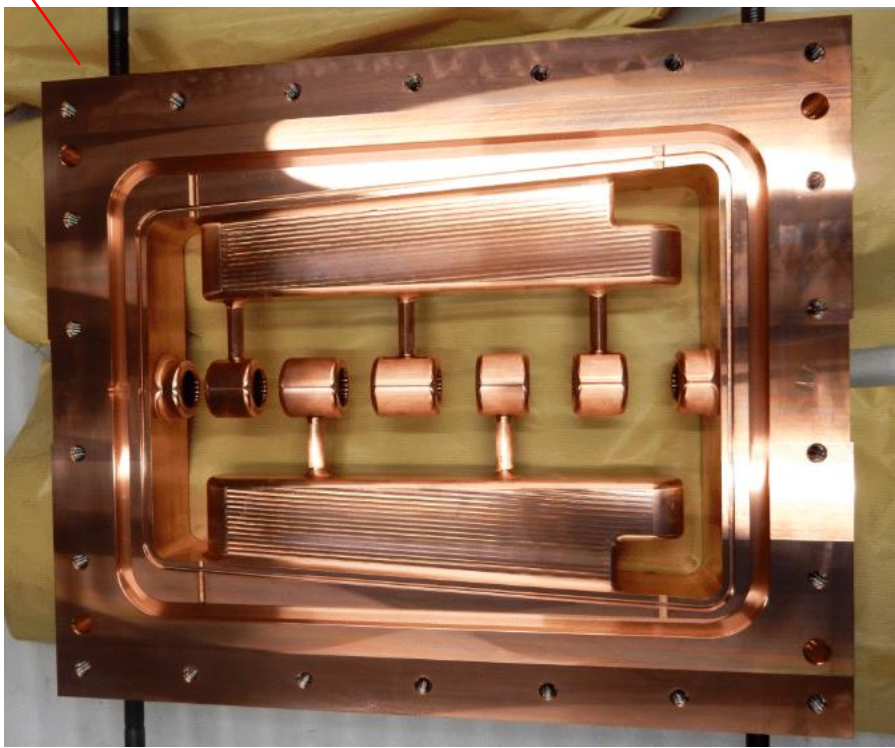


Next step



- Demonstration of muon acceleration by IH-DTL



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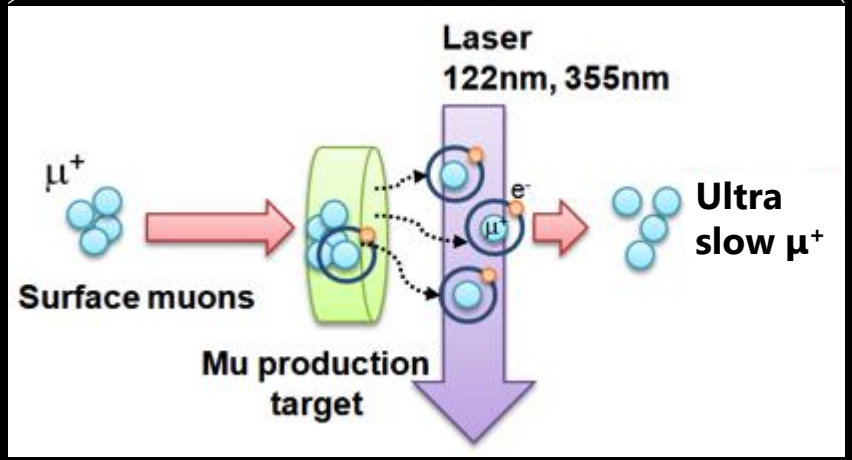

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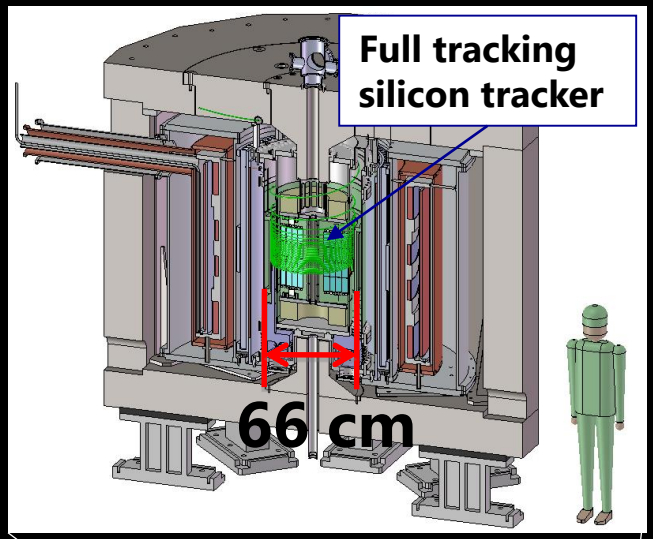

Compact storage magnet
(3T, ~1ppm local)

Target precision
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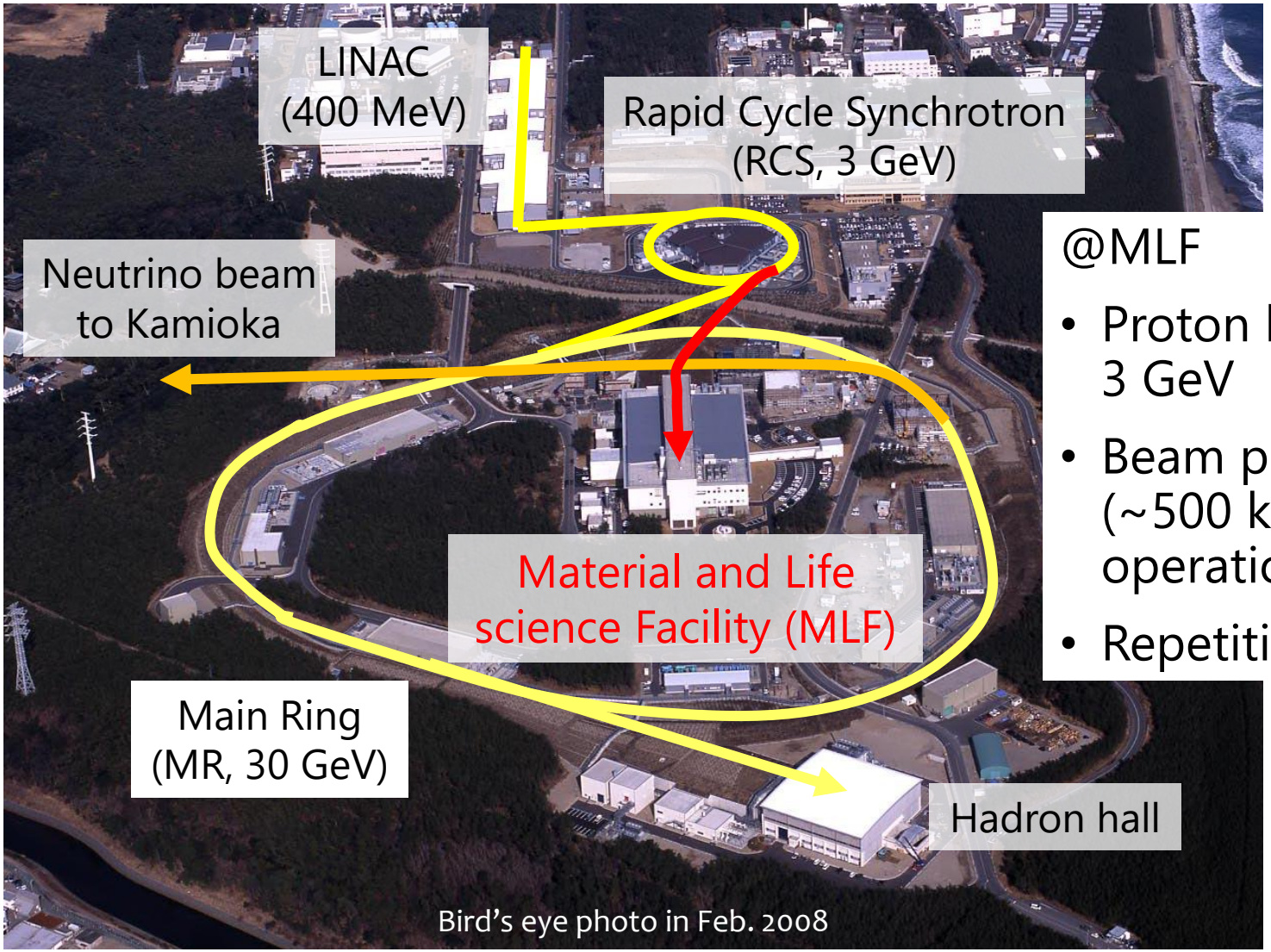
ΔEDM = 10^{-21} e・cm

J-PARC

J-PARC = Japan Proton Accelerator Research Complex

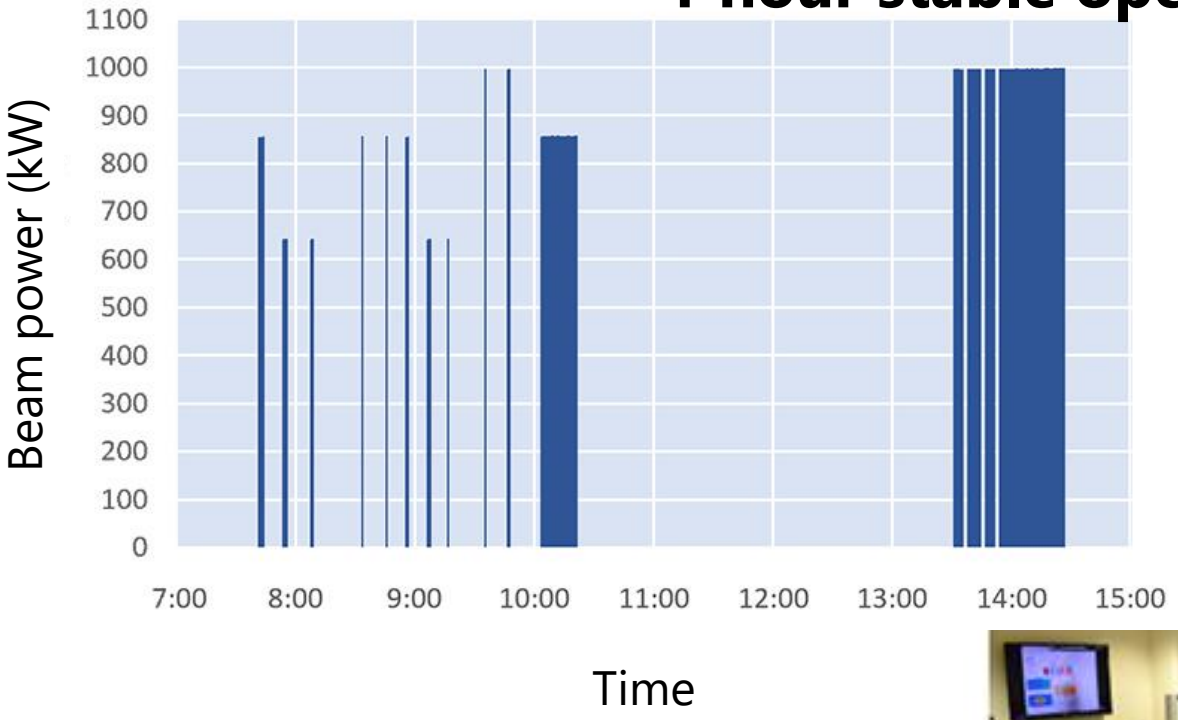


@MLF

- Proton beam energy 3 GeV
- Beam power 1 MW (~500 kW stable operation at present)
- Repetition rate 25 Hz

Success of 1MW stable operatoin

1 hour stable operation!

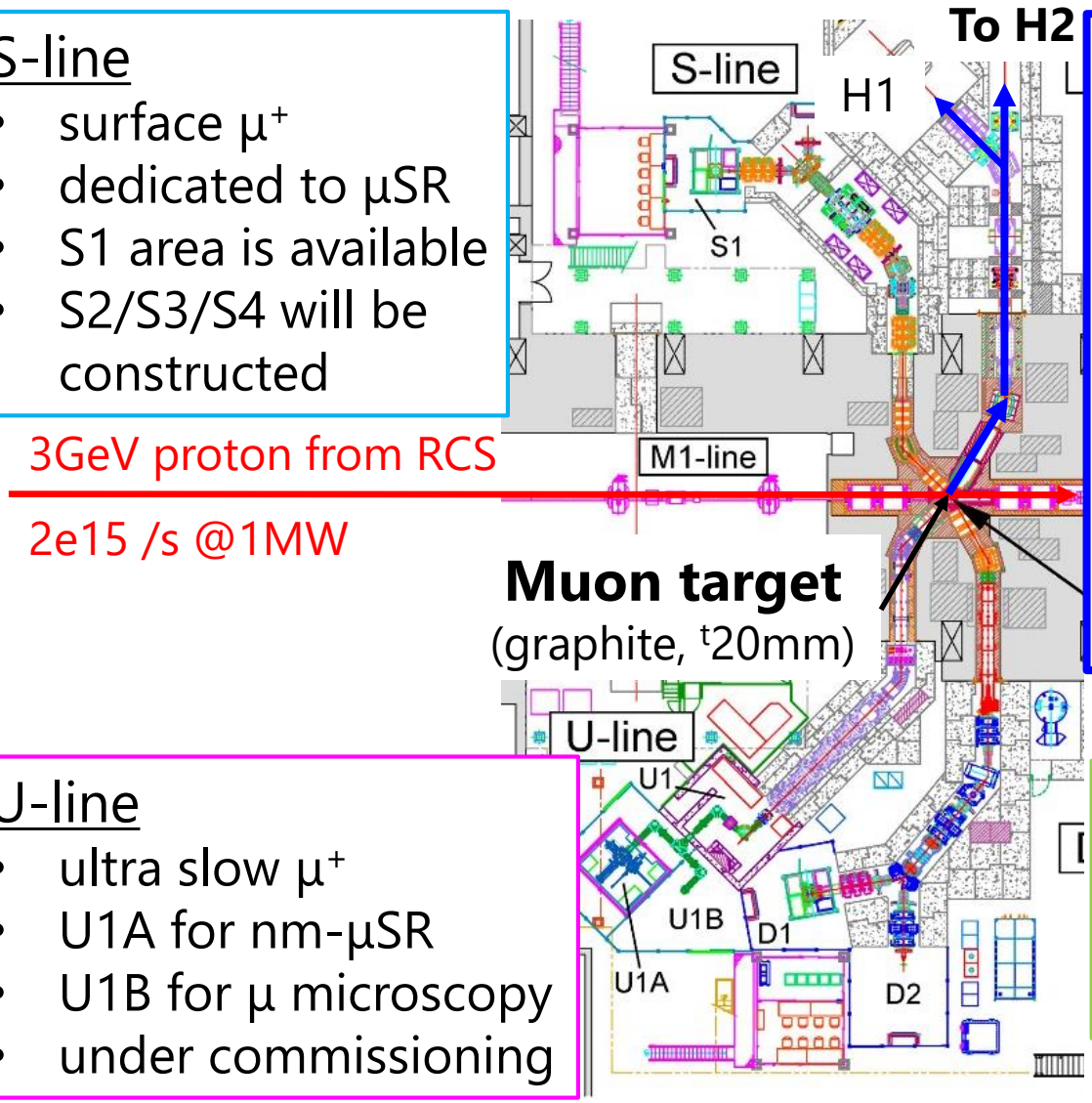


On 3rd July, 2018

J-PARC muon facility

- MUSE (MUon Science Establishment) in the MLF

S-line
- surface μ^+
- dedicated to μSR
- S1 area is available
- S2/S3/S4 will be constructed

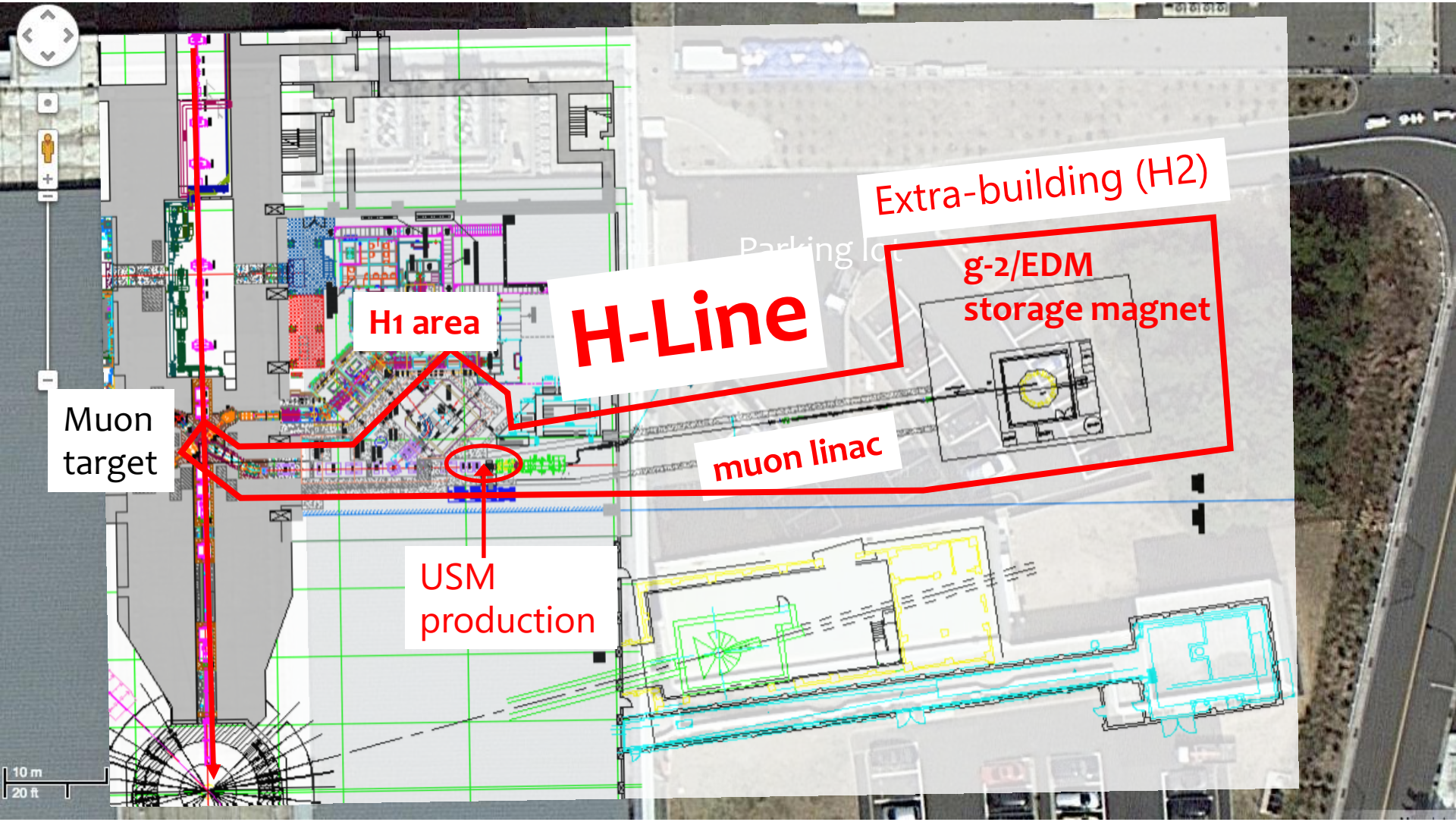


H-line
- **surface μ^+ (>10^8 μ^+/s)**, decay μ^+/μ^-, e^-
- **for high intensity & long beamtime** experiments
- H1 for DeeMe & MuSEUM
- **H2** for **g-2/EDM** & **transmission muon microscopy**
- **under construction**

U-line
- ultra slow μ^+
- U1A for nm-μSR
- U1B for μ microscopy
- under commissioning

D-line
- decay μ^+/μ^-, surface μ^+
- D1 area for μSR
- D2 for variety of science

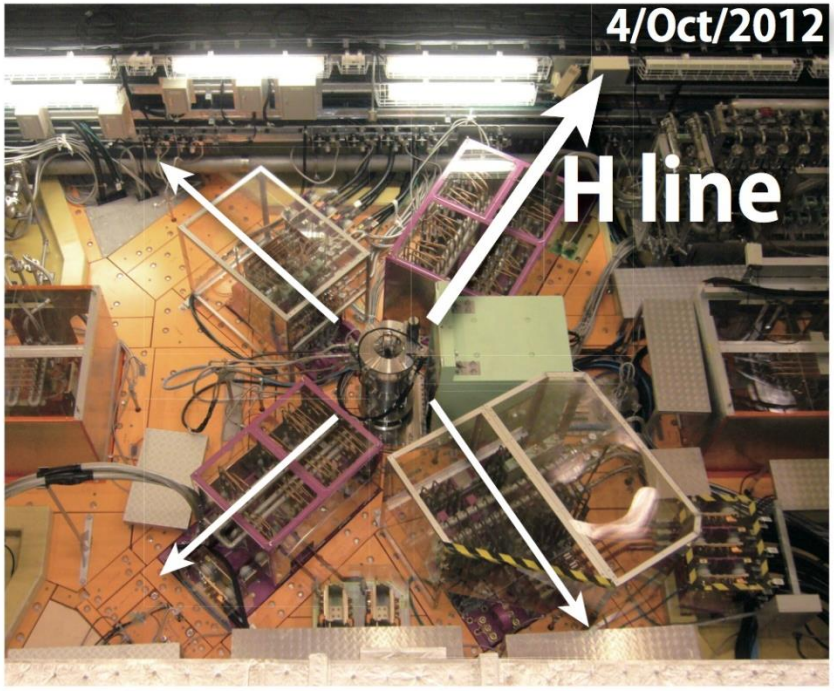
Proposed experimental site (H2)



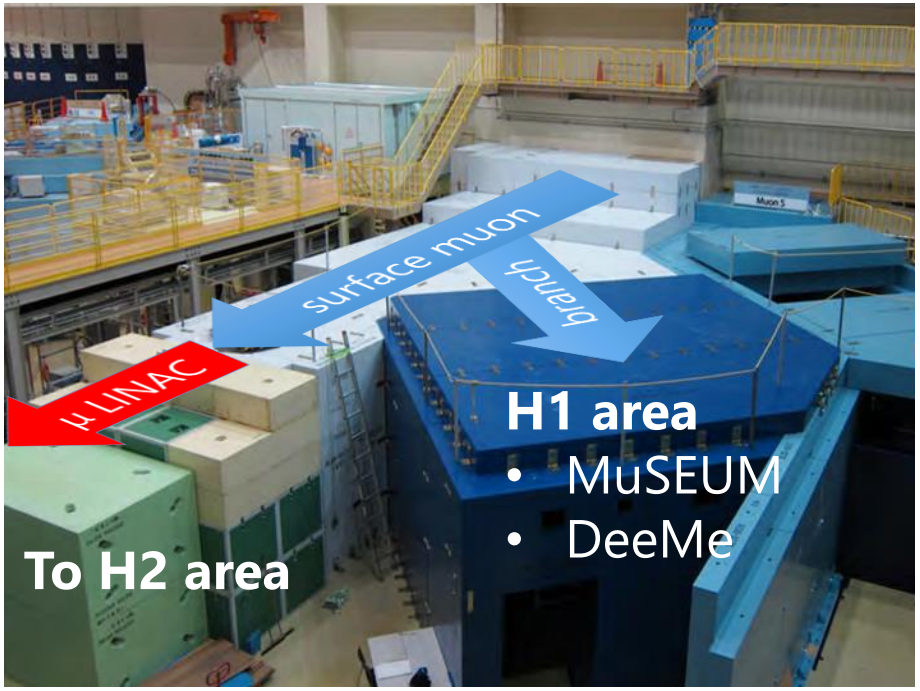
Construction status of H-line

- Frontend devices (magnets, vacuum apparatuses, etc.) were already installed in the proton beam tunnel.
- Beamline shield blocks in the existing experimental hall were installed

Proton beam tunnel

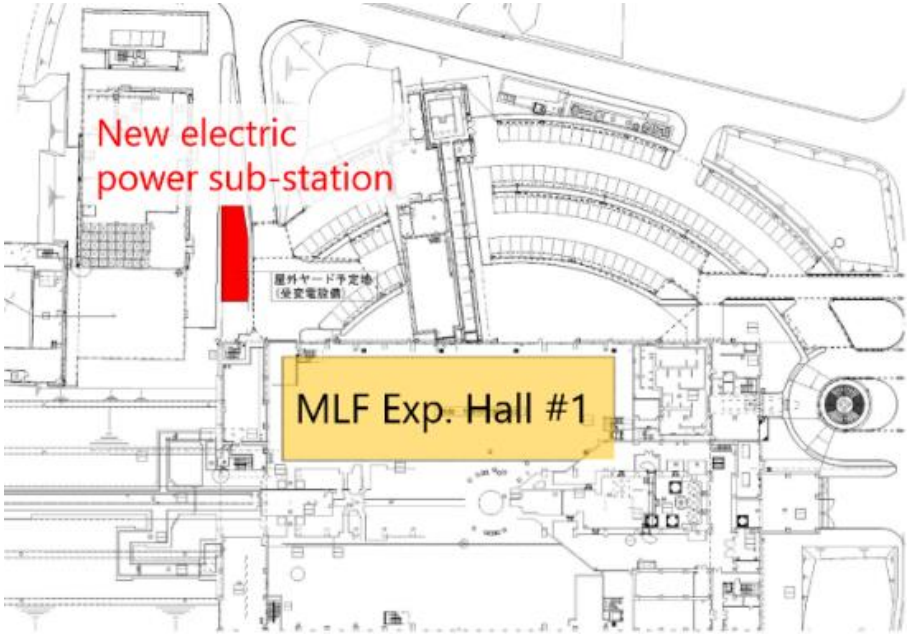


MLF experimental hall #1

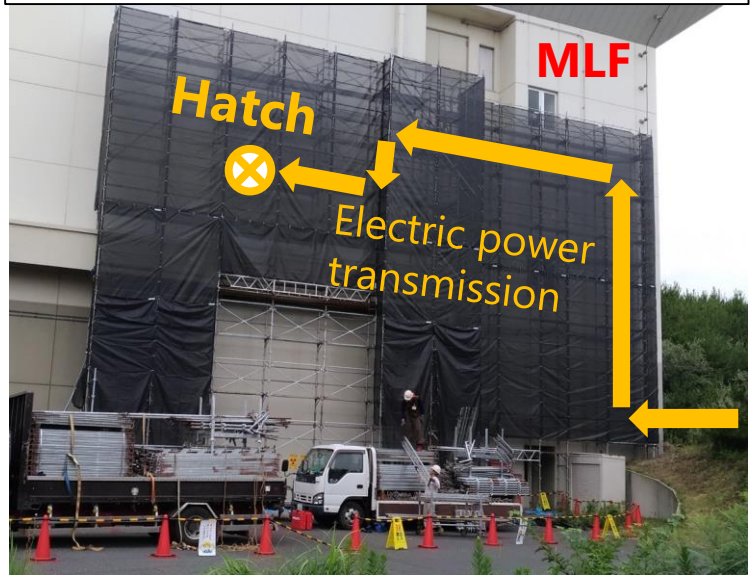


Construction status of H-line

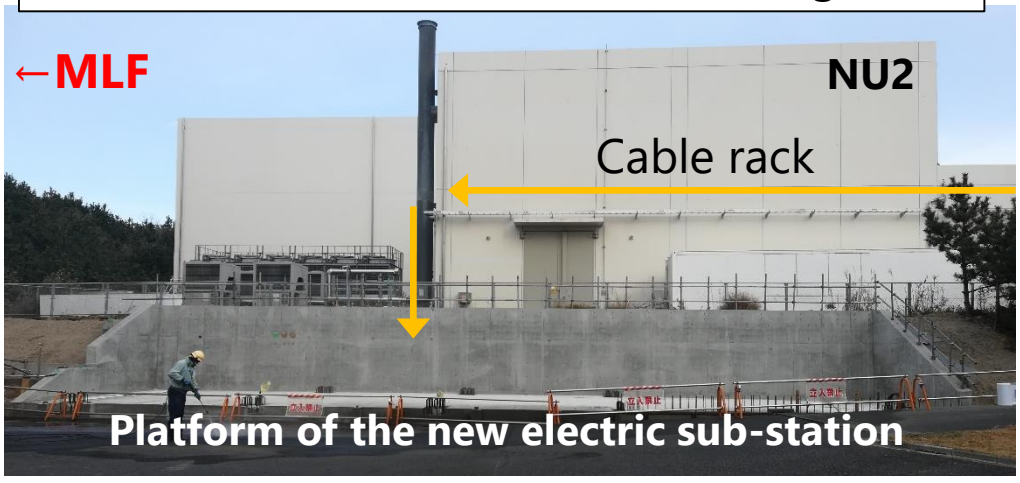
- H-line needs about 5 MW electricity, but the surplus power of the MLF is only 1 MW.
- The construction of the new electric power sub-station is on-going and will be finished in JFY2019.



2017: Renovation of the MLF wall

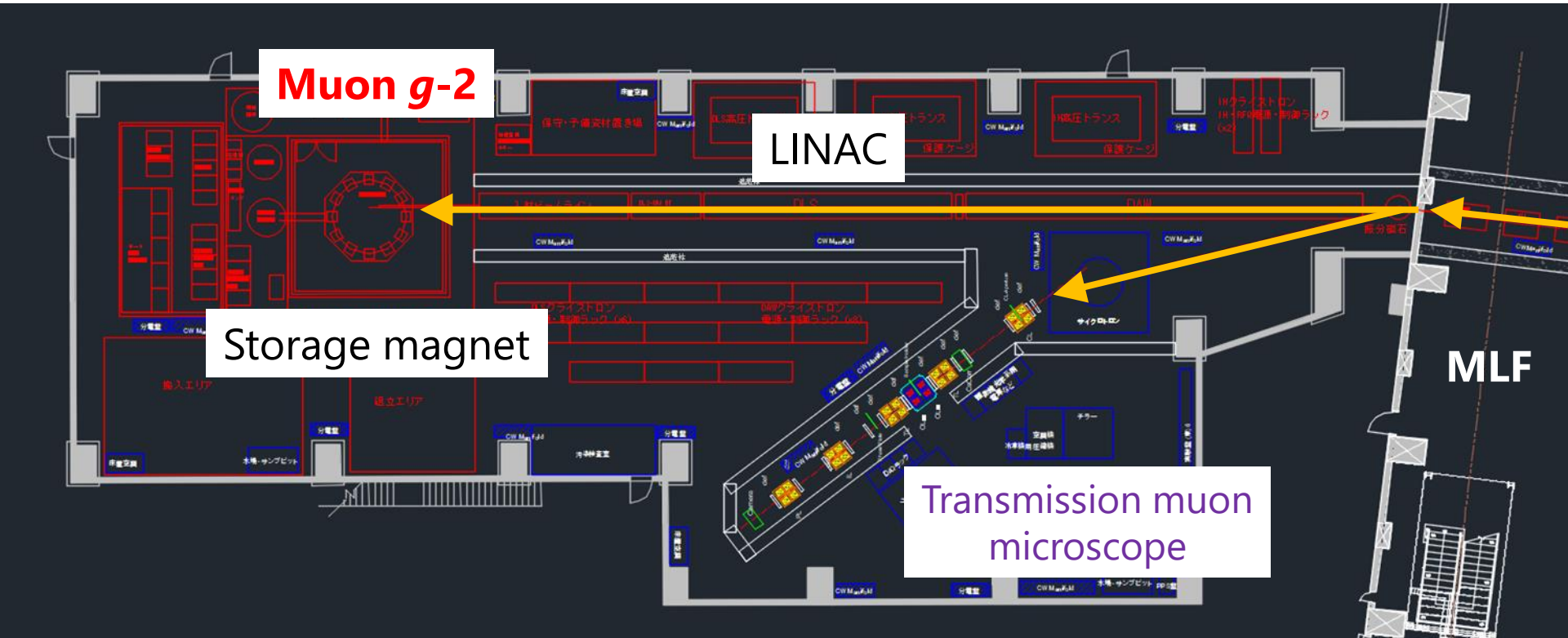


2018: Platform construction & cabling work



H2 area (Extension building)

- H2 area is not only for ***g*-2** experiment but also for **transmission muon microscopy**, which are selected as a KEK-PIP 3rd priority project.
- We are handling tasks necessary to build a new radiation controlled area step by step.



History

Date	Events
Jul, 2009	**LOI** submitted to PAC8
Jan, 2010	**Proposal** submitted to PAC9
Jan, 2012	**CDR** submitted to PAC13, Milestones defined.
Jul, 2012	Stage-1 status recommended by PAC15 Stage-1 status granted by the IPNS director
May, 2015	**TDR** submitted to PAC
Oct, 2016	**Revised TDR** submitted to PAC and FRC
Jun, 2016	**Selected as a KEK-PIP priority project (3rd)**
Nov, 2016	**Focused review on technical design**
Dec, 2017	Responses and Revised TDR submitted to PAC
Jul, 2018	**Stage-2 status recommended by PAC**
Nov, 2018	**Stage-2 status recommended by the IPNS director**
Feb, 2019	**Stage-2 status approved by IMSS-PAC (Full approval!)**

The Collaboration

102 members (Canada , China, Czech, France, Japan, Korea, Russia, USA)

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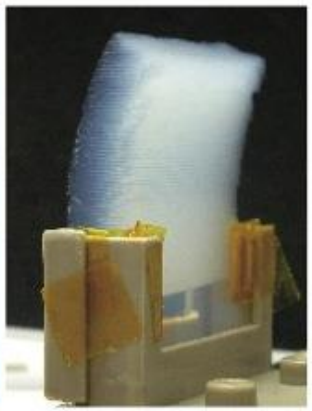
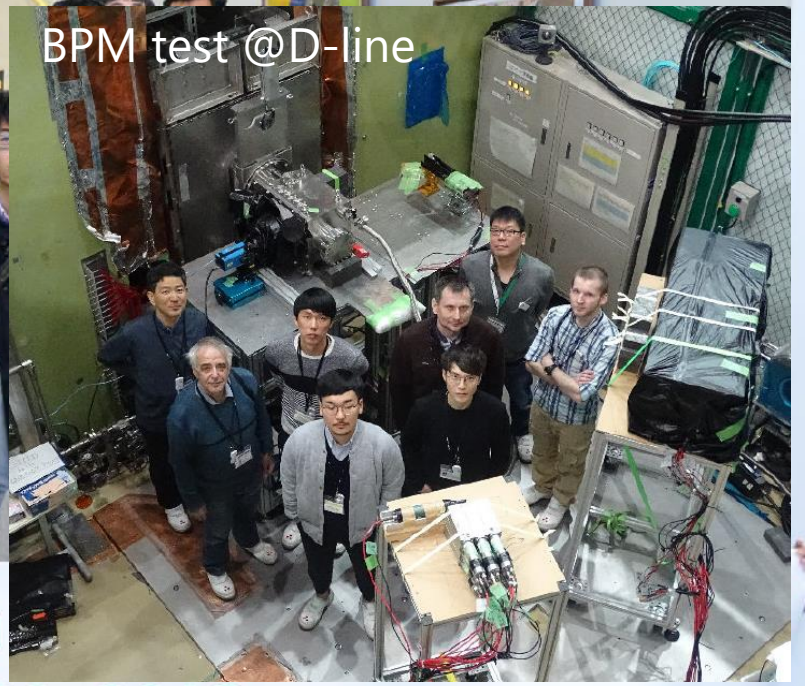
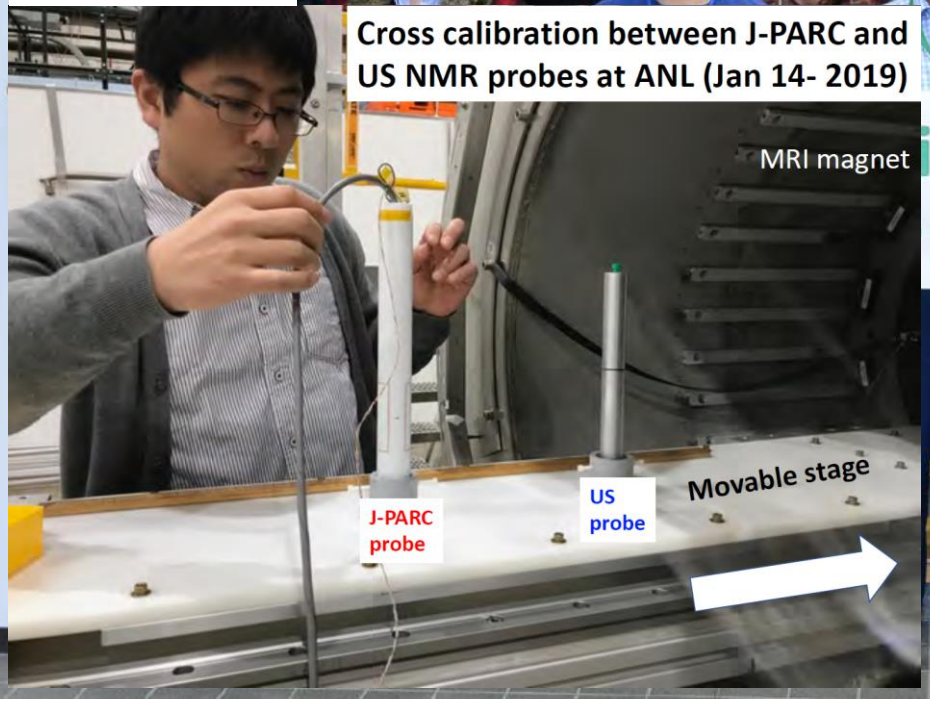


G. Beer et al., Prog.Theor.Exp.Phys. (2014)091C01



NMR probe



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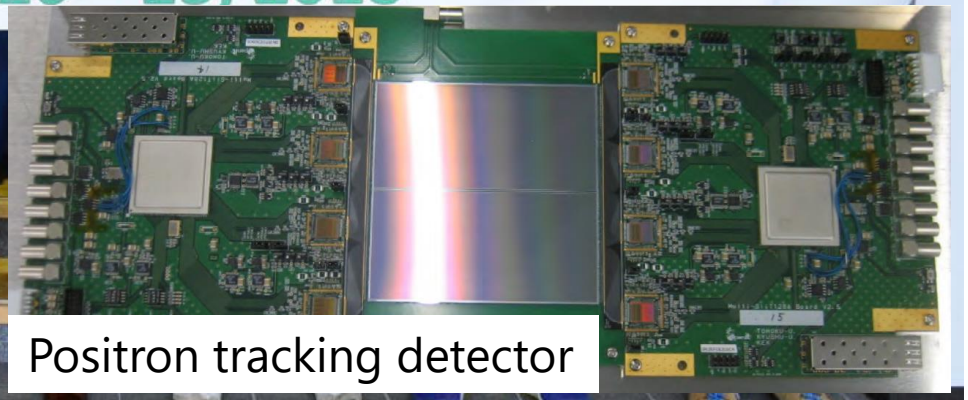
20 – 23, 2018



Positron tracking detector

Summary

- J-PARC g-2 experiment (E34) is under preparation to measure muon g-2 with an independent method using ultra slow muon beam.
- **Fully approved.**
- **Construction phase is on-going.**
  - Main part of H-line will be completed in next JFY at the earliest, which will lead to further development for muon g-2 experiment.

- Further information : http://g-2.kek.jp