The J-PARC muon g-2/EDM experiment

Shusei Kamioka

KEK

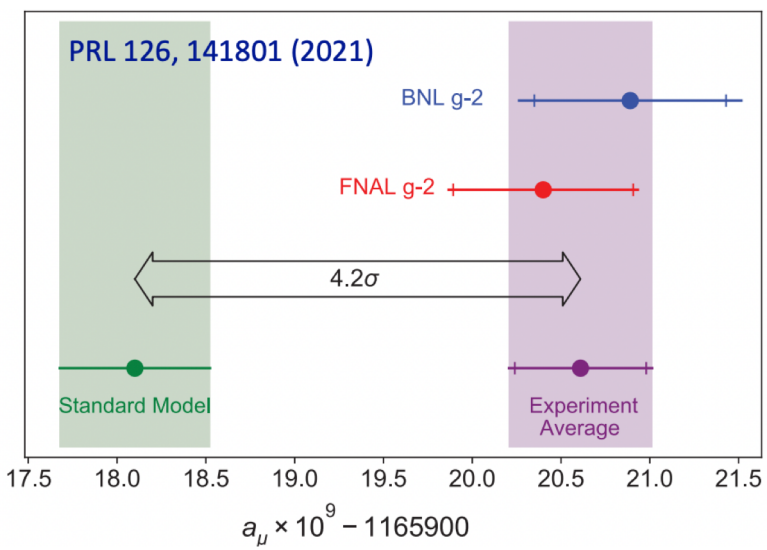
On behalf of the J-PARC muon g-2/EDM collaboration

Muon g-2/EDM

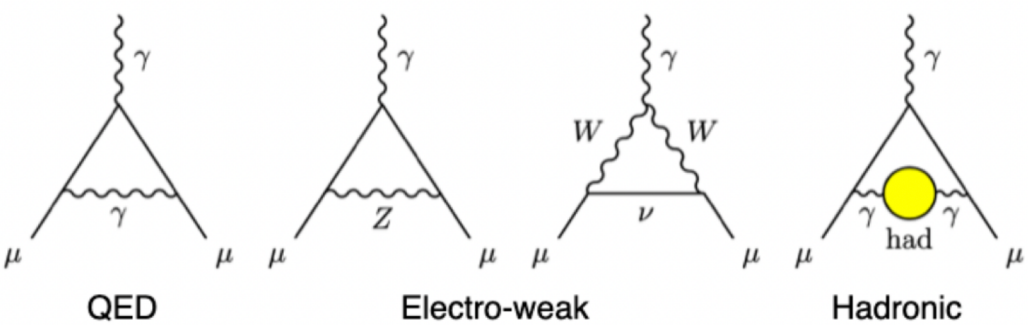
✓ ***Muon anomalous magnetic moment (a_μ)***: Deviation of g_μ from "2"

- $\mu = g\frac{e}{2m}s,\ a_\mu = \frac{g-2}{2}$
- Precisely calculated in the SM → Good Probe for new physics
- *4.2σ discrepancy between the SM calculation and measurements*.

➢ **Verification of this discrepancy from both theoretical & experimental side is important**



Feynman diagrams related to g-2



Muon g-2/EDM

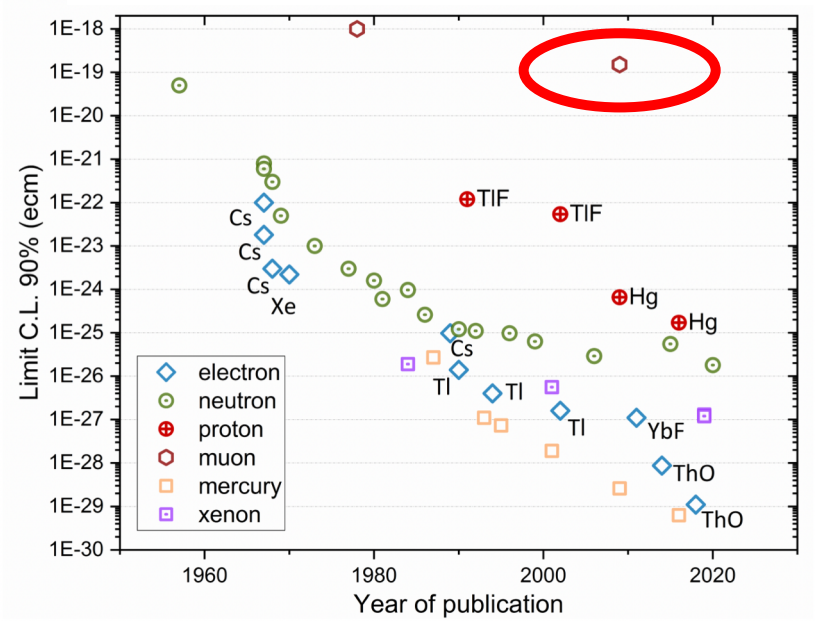
✓ ***Muon electric dipole moment:***

- Can be measured in parallel with g-2
- $d = \eta \frac{e}{2mc} s$

➢ d = 2×10^{-38} e・cm (SM prediction)

- Large EDM indicates T violation = CP violation the lepton sector.
- d < 1.8×10^{-19} e・cm (90% C.L.)

History of direct limit of EDM (arxiv: 2102.08838)



Experimental limit of muon EDM is relatively worse than other EDMs

Experimental method of g-2/EDM measurement

- *Determined from muon spin precession frequency in magnetic field*

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_\eta$$

$$= -\frac{e}{m}\left[a_\mu \vec{B} - \underbrace{\left(a_\mu - \frac{1}{\gamma^2 - 1}\right)}_{=0}\frac{\vec{\beta} \times \vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta} \times \vec{B} + \frac{\vec{E}}{c}\right)\right]$$

- Time dependent spin direction is measured from the decay e+
- **2nd term ∝ E-field is unwanted term to be eliminated**

In the previous and current experiments…

E≠0 for storage.
Magic gamma (p = 3GeV) for elimination of 2nd term.
→ ***"magic gamma approach"***

p= 3.09 GeV/c , B=1.45 T

Another approach

- The elimination of the 2nd term can be also realized by no E-field condition.

E=0 !

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_\eta$$

$$= -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta} \times \vec{B} + \frac{\vec{E}}{c}\right)\right]$$

➢ Even when eliminated, non-zero E-field results in the major collection or systematic uncertainty in magic gamma approach.

Quantity	Correction terms (ppb)	Uncertainty (ppb)
ω_a^m (statistical)	...	434
ω_a^m (systematic)	...	56
C_e	489	53
C	180	13

➢ **With zero E-field, an independent measurement with completely different systematic becomes possible!!**

Key technique: Creation & reacceleration of thermal muon

- μ^+ beam from decay of π has large emittance → E field is required.

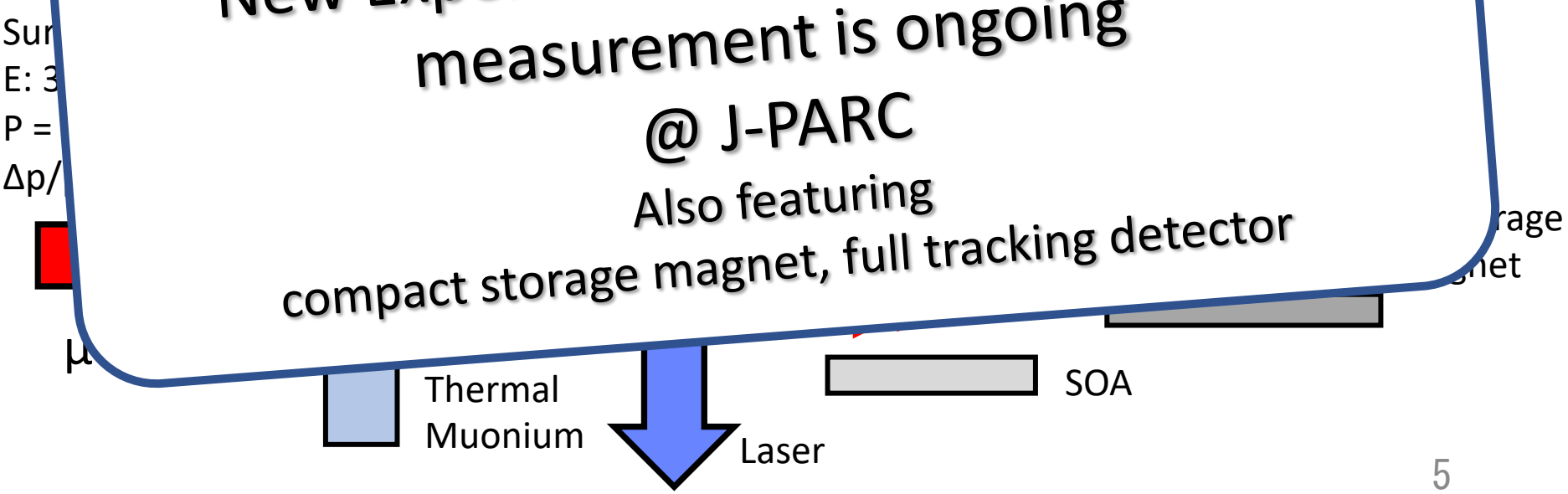
➢ Thermal muon is created by laser ionization of muonium & re-accelerated to produce the low emittance muon beam.

➢ Low emittance → ***Enables no E field***

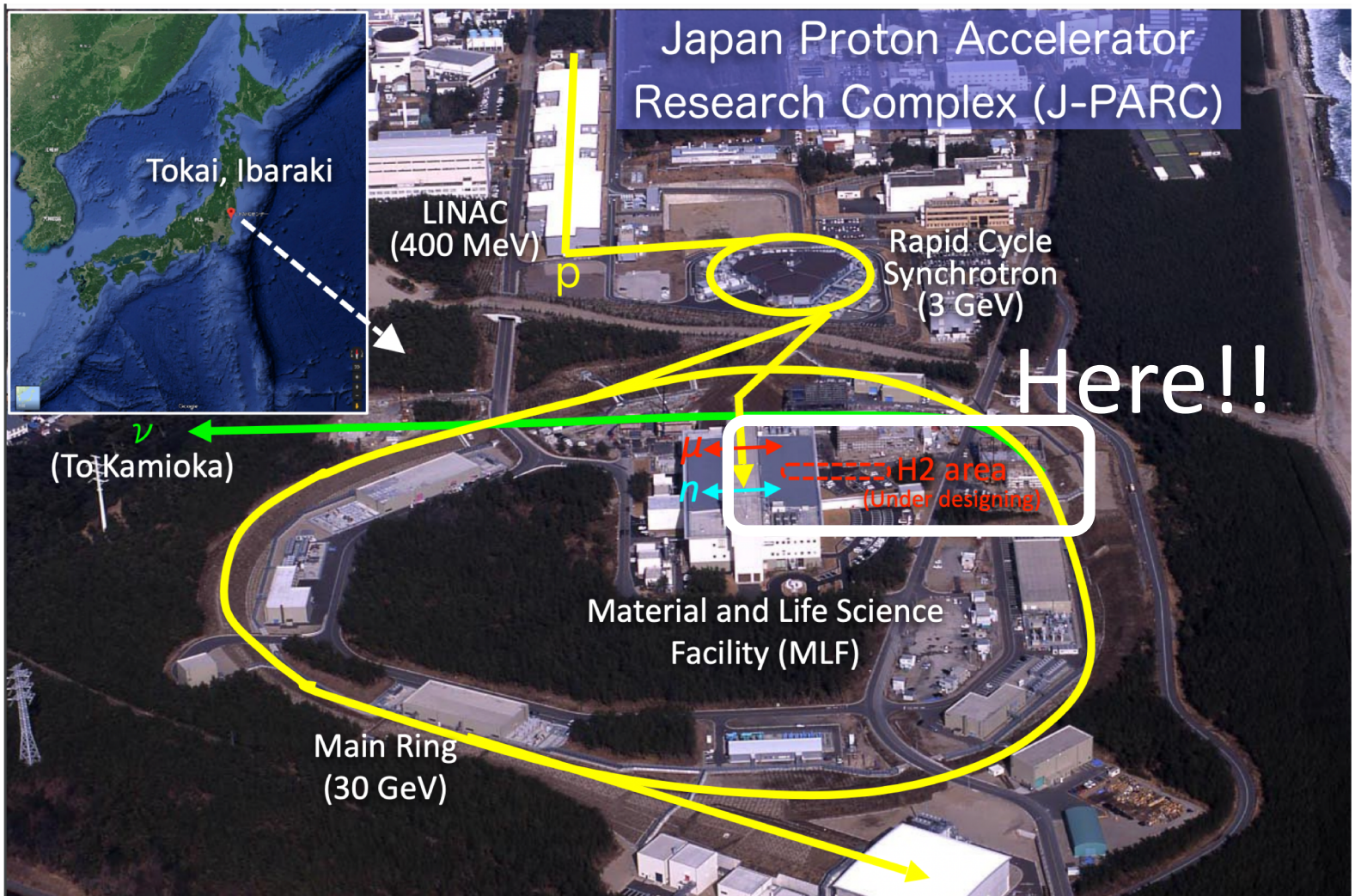
New Experiment featuring zero E-field measurement is ongoing @ J-PARC

Also featuring

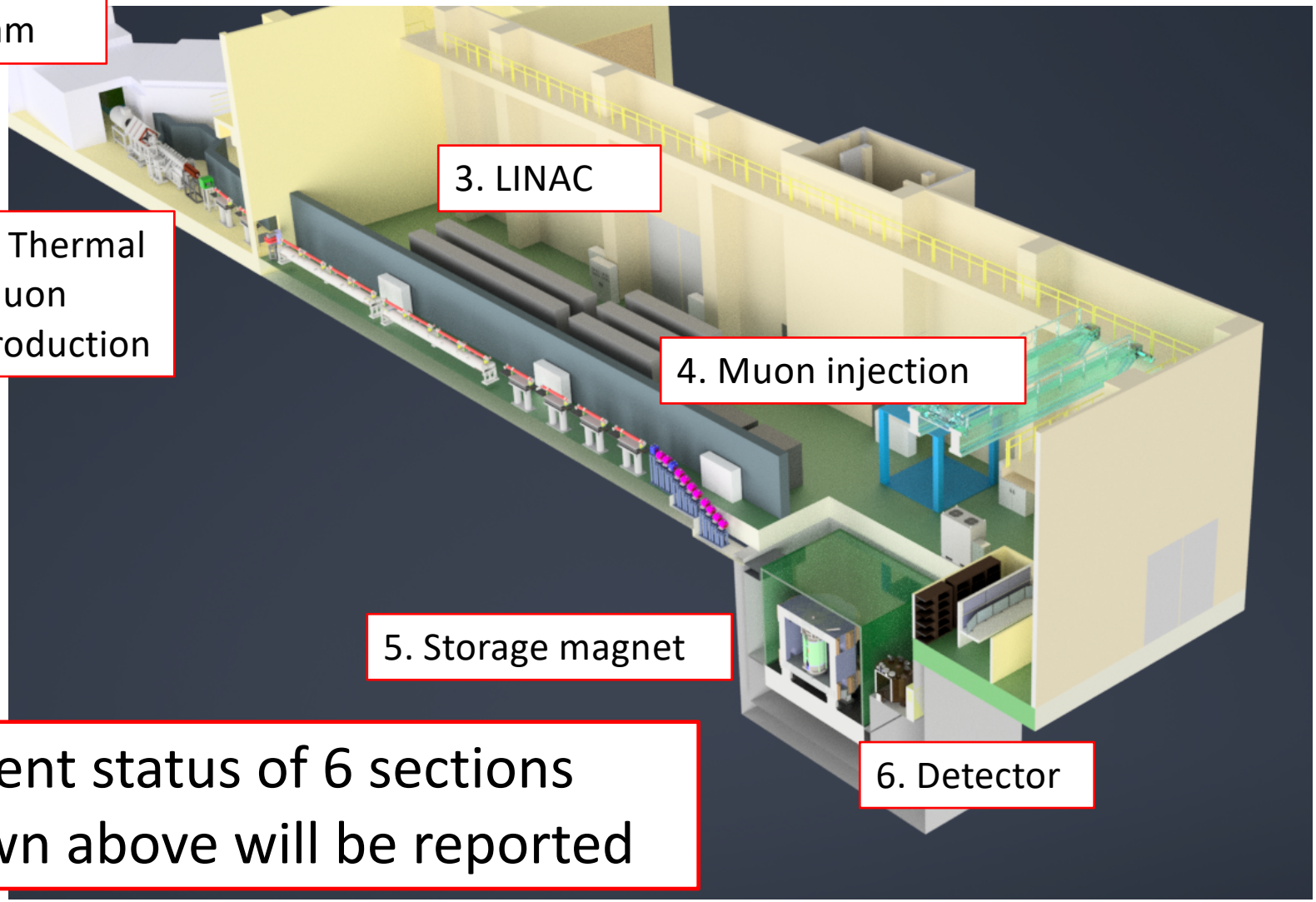
compact storage magnet, full tracking detector



Japan Proton Accelerator Research Complex (J-PARC)



Muon g-2/EDM experiment at J-PARC



Current status of 6 sections shown above will be reported

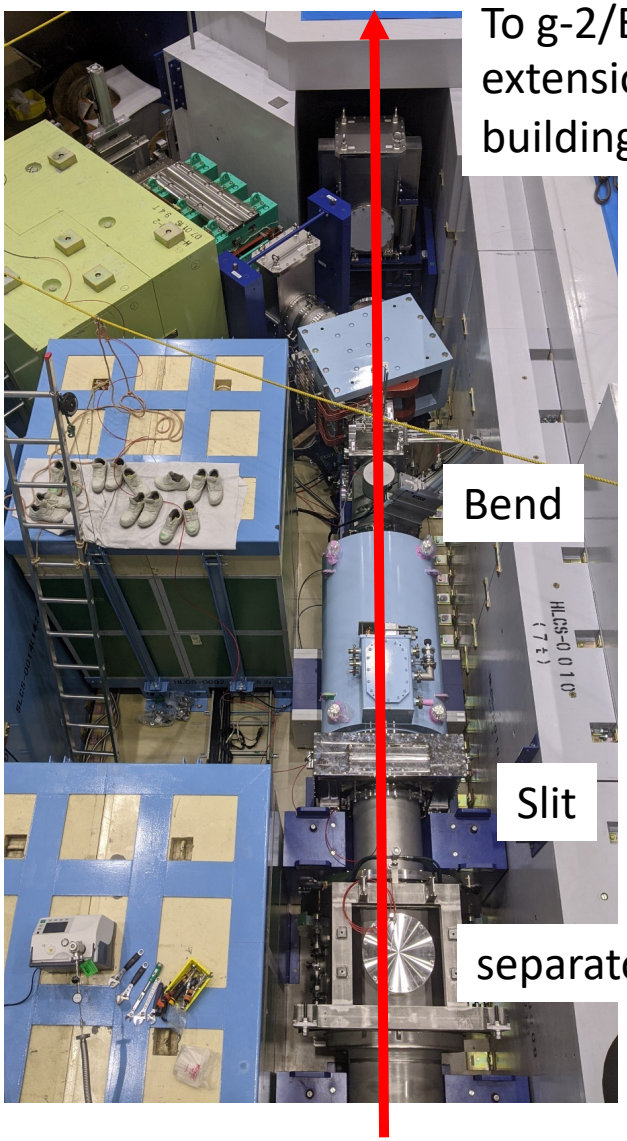
1. Surface μ^+ beam line (H-Line)

- A new beam line is being constructed
- Surface muon beam
  - decayed from π^+ stopped near the surface of the target
  - 100% polarized, monochromatic

➢ Pulsed, **4MeV, 10^8 μ^+/s with 25Hz rep**.

- Commissioning from next year.

➢ Extension building for g-2 experiment is being ready for construction

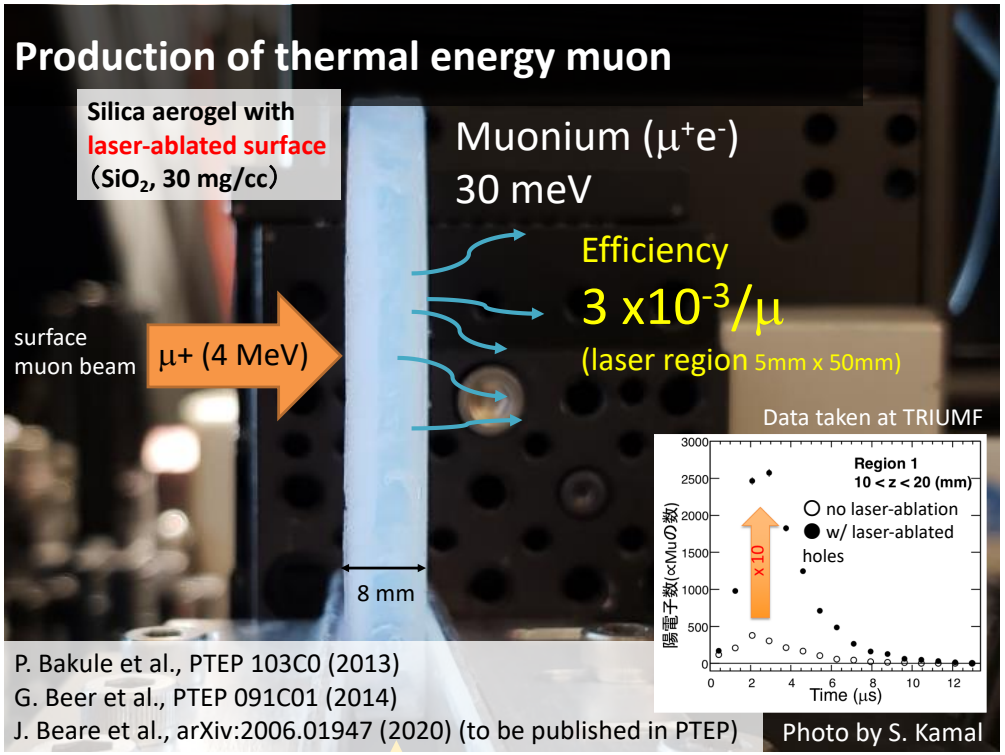


2. Thermal muon production

- Design of muonium emission target & development of ionization laser

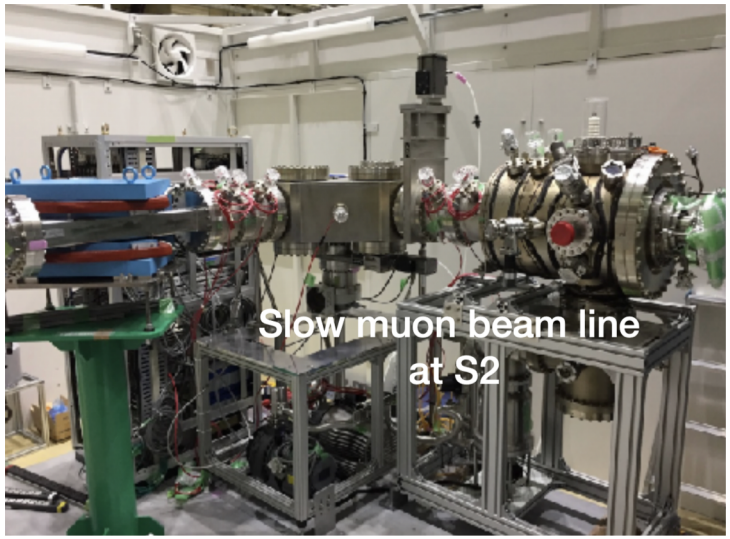
➢ Emission target: novel laser ablated silica aerogel → Eff ~ 3×10^{-3}

➢ Dedicated study of ionization will start from Jun. 2022 at another beam line with the collaboration of Mu spectroscopy experiment.



P. Bakule et al., PTEP 103C0 (2013)
G. Beer et al., PTEP 091C01 (2014)
J. Beare et al., arXiv:2006.01947 (2020) (to be published in PTEP)

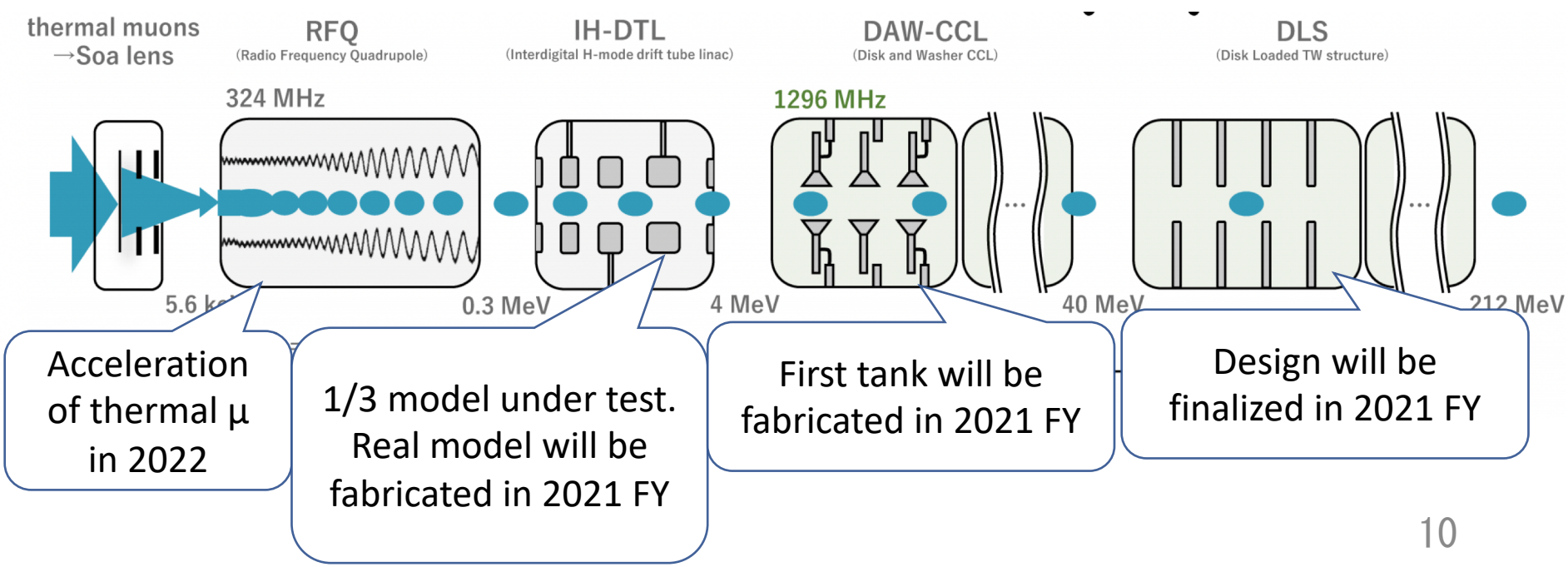
Set up for muonium spectroscopy experiment



3. LINAC (Muon acceleration)

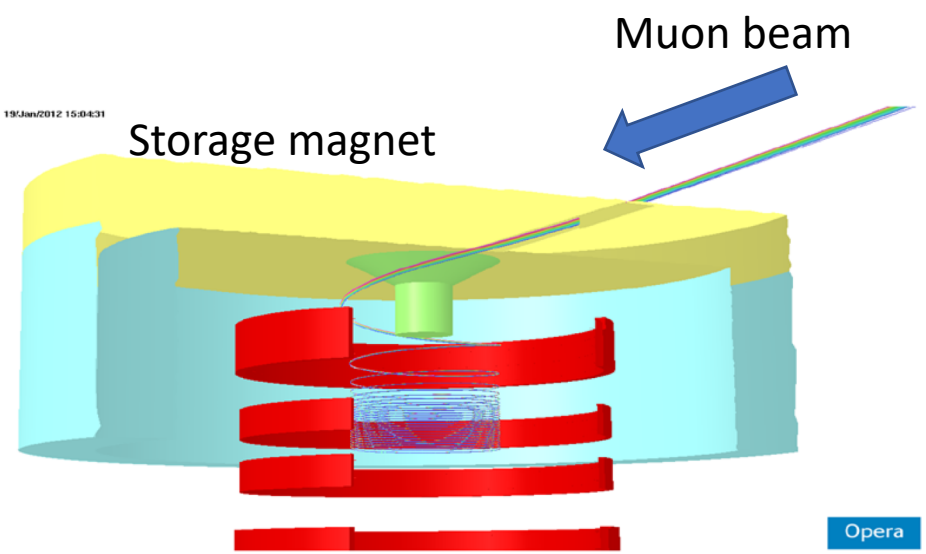
- **Acceleration of the thermal muons suppressing the emittance growth**. (~30meV → 200MeV)
- Demonstration of world first RF acceleration of μ in Mu^- was succeeded in 2018

➢ Fabrication & design of each component is ongoing

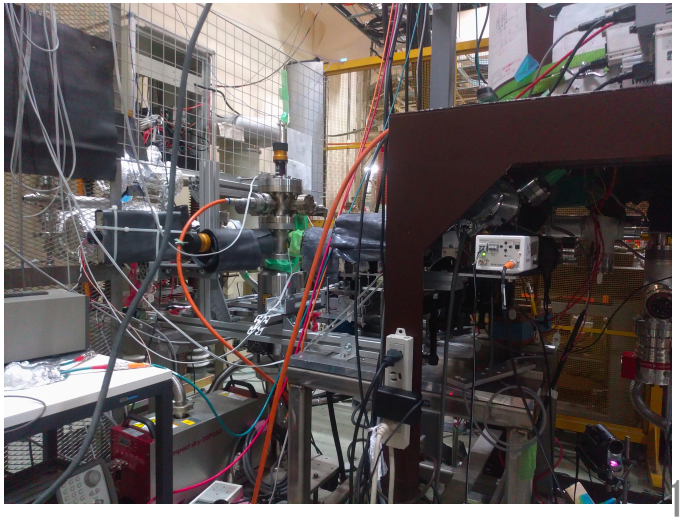


4. Muon injection

- ***New 3D spiral injection scheme*** is being developed for the injection of μ beam to the storage magnet from LINAC
  - enables **injection of muon to smaller muon orbit** (66cm↔14m)
  - High (~90%) efficiency
- Dedicated simulation & first demonstration of the scheme with electrons → **To be performed in this Autumn**



Test bench for 3D injection with electron (electron-gun, kicker, storage magnet)

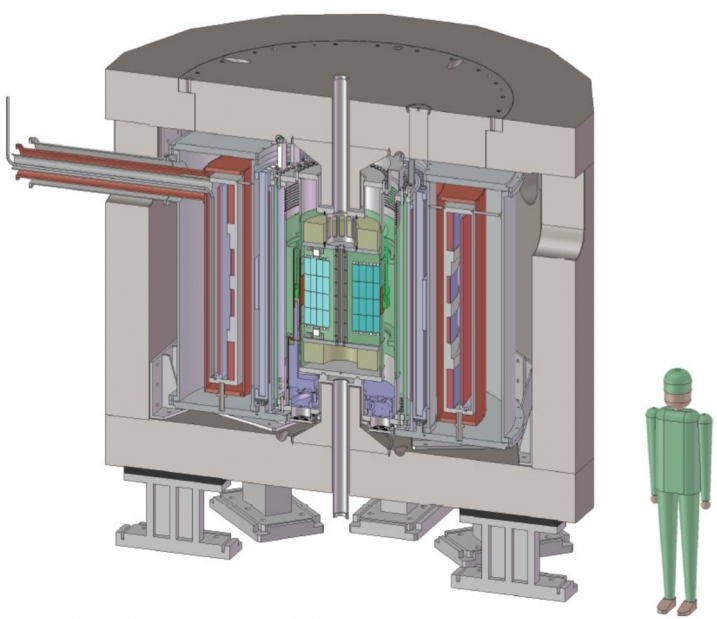


5. Muon storage magnet

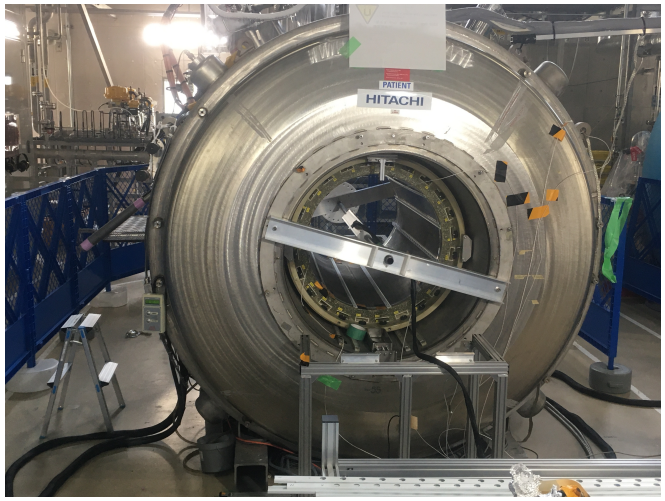
- Utilize small MRI-type solenoid magnet (**3T, ϕ = 66cm << 14m**)

➢ Better field uniformity is expected (**ΔB (local) < 0.2 ppm**)

1. Shimming studies in collaboration with Mu-hyperfine spectroscopy experiment : **<0.2ppm @ 1.2T is established**
2. Development of NMR probe & field mapping system



Solenoid magnet for
Mu-hyperfine spectroscopy experiment

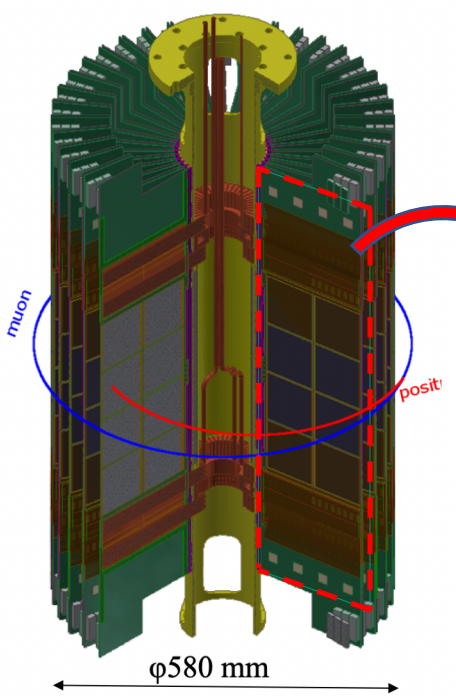


6. Positron tracking detector

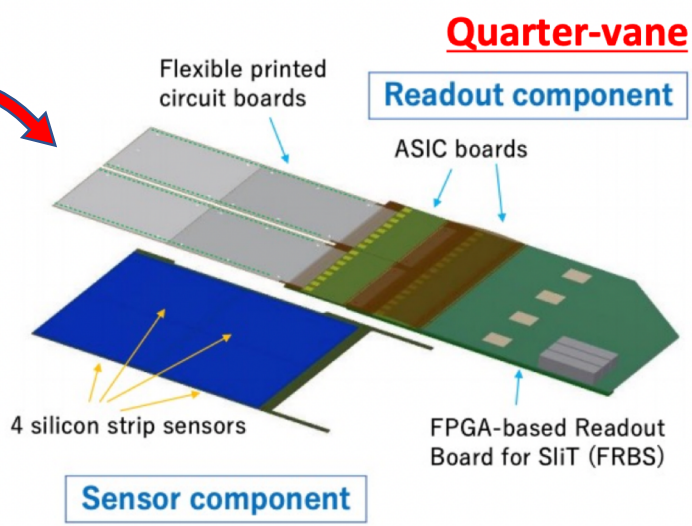
- Direction of spin is measured from momentum vector of decay e^+
  - Detection of e^+ (100MeV < E < 300MeV), reconstruction of p vector, stability over rate change (1.4MHz ~ 14kHz) are required

➢ **New Silicon strip detector is being developed**

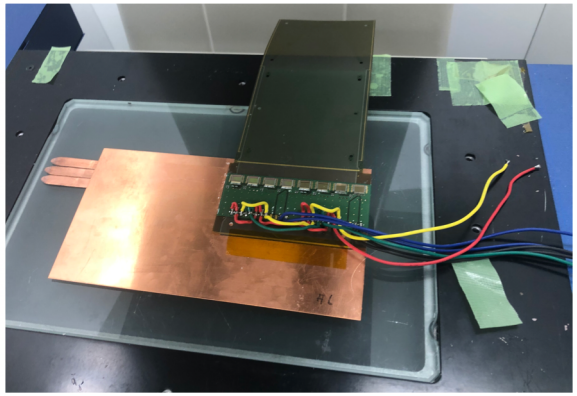
✓ Test assembly & cooling test is ongoing → **Mass production will start from next year.**



Total 40-vanes, composed with 4-quarter vanes

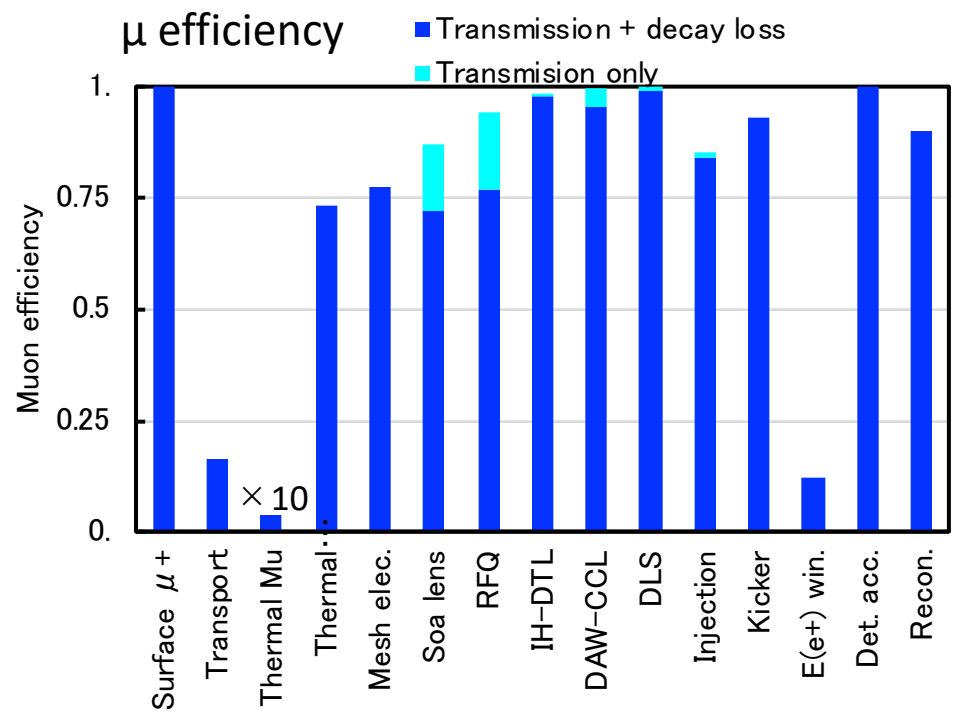


Preparation of cooling test of Quarter-vane



Expected sensitivity

- **Total μ^+ efficiency: 1.3×10^{-4}**
- Assuming 1MW proton beam + 2 year data taking
  - ***g-2***: reach the BNL precision **(450 ppb)**
  - ***EDM***: 1/100 times better sensitivity



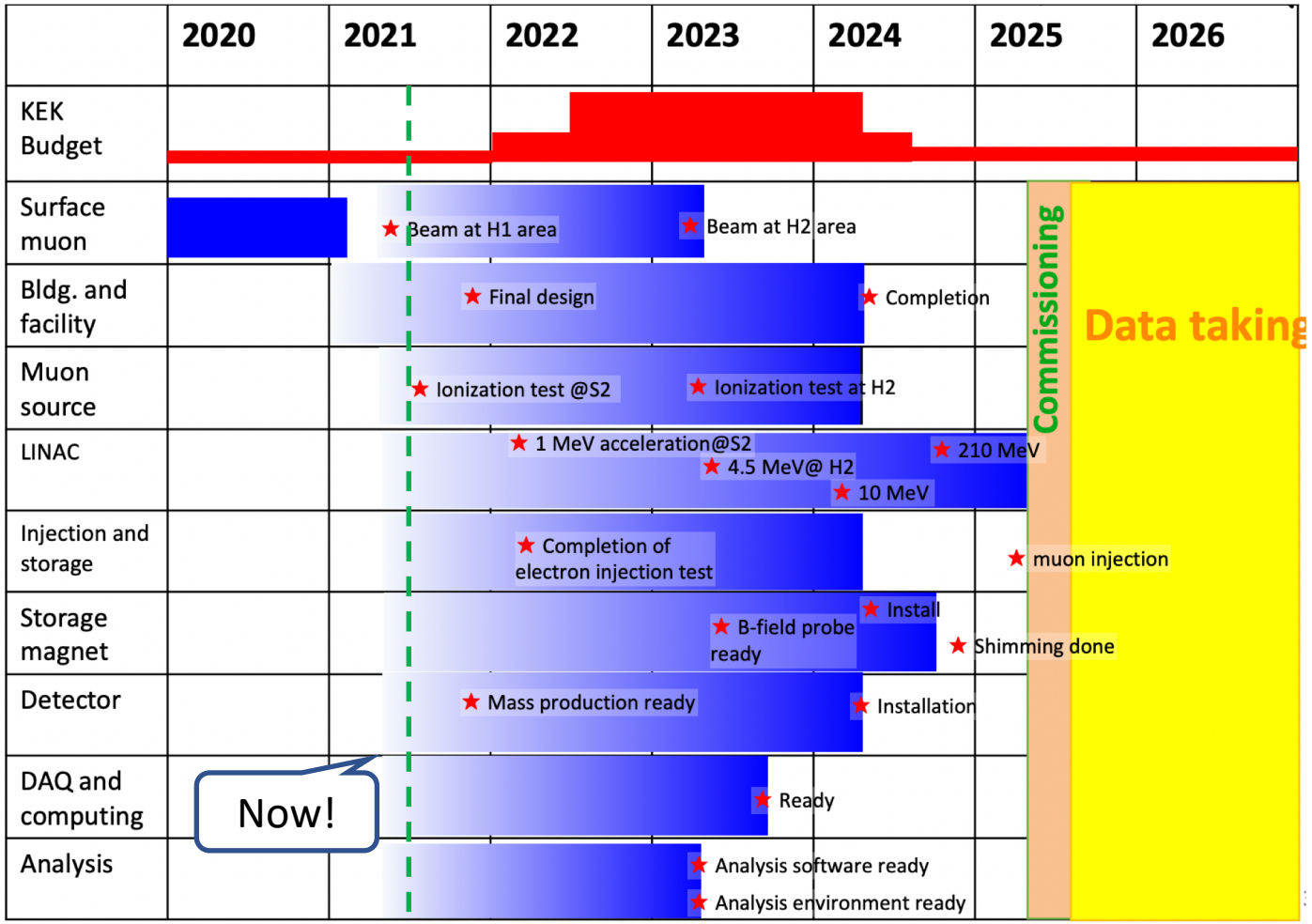
Our systematic goal of g-2 measurement

Anomalous spin precession (ω_a)		Magnetic field (ω_p)	
Source	Estimation (ppb)	Source	Estimation (ppb)
Timing shift	< 36	Absolute calibration	25
Pitch effect	13	Calibration of mapping probe	20
Electric field	10	Position of mapping probe	45
Delayed positrons	0.8	Field decay	< 10
Diffential decay	1.5	Eddy current from kicker	0.1
Quadratic sum	< 40	Quadratic sum	56

Systematic uncertainties will be much smaller than statistical ones.

Intended schedule and milestone

- Start data taking in FY2025.



Summary

- J-PARC E34 experiment intends to measure the muon g-2 and EDM with a new experimental approach.

➢ Different experimental approach from that of the BNL/FNAL experiments.
  - Small-emittance muon beam with no strong focusing
  - MRI-type storage ring with high uniform B-field
  - Full-tracking silicon strip detector

- Experiment is getting ready for realization.

➢ The development and construction is in progress to start data taking in FY2025.

✓ Intending to reach the BNL precision in ~2-year running.