Status of the muon g-2/EDM experiment at J-PARC.

B.Shwartz (on behalf of E34 collaboration)

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Anomalous magnetic moments (PDG)

Particle	Experiment $a_l = (g-2)/2$	SM
e	0.001 159 652 180 91 (26) 0.001 159 652 180 62 (12) (PDG24)	0.001 159 652 181 64 (76) Limited by α precision
μ	0.001 165 920 89 (64) (2020) 0.001 165 920 71.5 (14.5) (2024)	0.001 165 918 23 (43) (2020) 0.001 165 920 33 (62) (2024)
τ	>-0.052 and <0.013 (95%)	0.001 177 21(5)

a_e tests QED to the precision of the fine structure constant α.

a_μ is more sensitive to heavy particle exchanges by a factor of $(m_\mu/m_e)^2$ ~42,000.

2

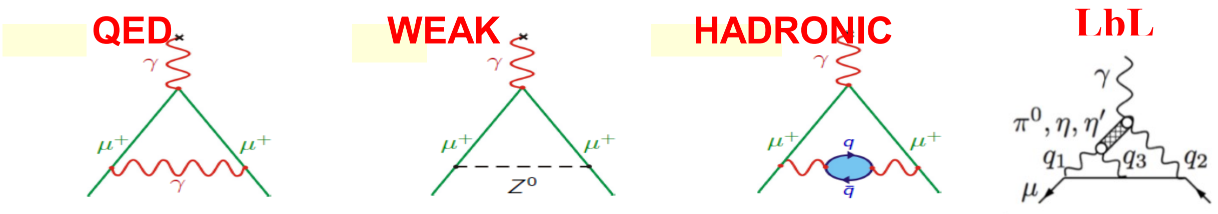
Muon anomaly, $a_\mu=(g-2)_\mu/2$: SM calculations and experiment

$$a_\mu^{theory(SM)} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$$

Two approaches for estimating the HVP contribution:
Dispersion relations (w/ inputs from ee → hadrons data)
Lattice QCD

$$a_\mu^{had} = \frac{\alpha^2}{3\pi^2}\int_{4m_\pi^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

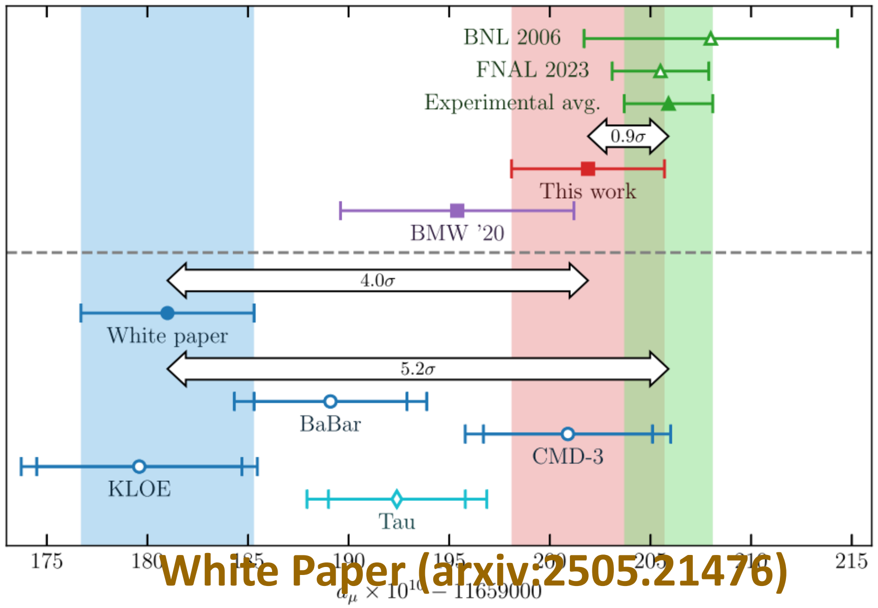
$$R(s) = \frac{\sigma(e^+e^- \to \gamma^* \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



Contribution	Value $\times 10^{11}$
QED	116 584 718.931(104)
Electroweak	153.6(1.0)
HVP (e^+e^-, LO + NLO + NNLO)	6845(40)
HLbL (pheno + lattice + NLO)	92(18)
Total SM Value Section	116 591 810(43)
Exp. (E821) - SM	279(76)

$\pi^+\pi^-$~ 73 %, $\pi^+\pi^-\pi^0$ ~7%

FNAL 0.001 165 920 71.5 (14.5) (2025)



White Paper (arxiv:2505.21476)

$e^+e^-\to\pi^+\pi^-$ PRD 109 112002 (2024)

The table is from:

"The anomalous magnetic moment of the muon in the Standard Model",
T. Aoyama et al., Physics Reports 887 (2020) 1–166

J-PARC muon *g*-2/EDM experiment

The only experiment to check FNAL/BNL *g*-2 results

Excellent sensitivity to muon EDM about 100 times better than the previous limit (sensitivity : 1.5×10^{-21} e × cm)

Non-zero EDM indicates T-violation. (It is equivalent to CP-violation in CPT theorem.)
Upper limit : $d < 1.8 \times 10^{-19} e \cdot$ cm 95% C. L. by BNL E821.

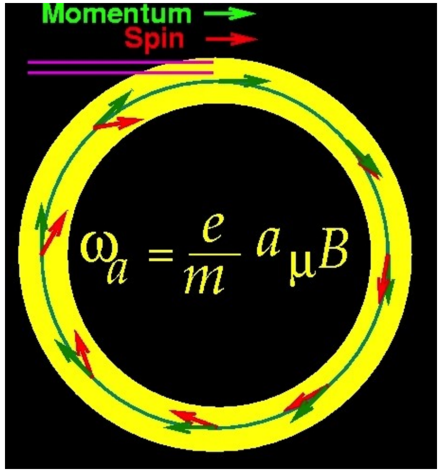
Features:

Low emittance muon beam
No strong focusing & good injection eff.
Compact storage ring

Collaboration:

146 members from Canada, China, Czech, France, India, Japan, Korea, Netherlands, Russia, USA, UK

Muon g-2 and EDM measurements



In uniform magnetic field, muon spin rotates ahead of momentum due to g-2 ≠ 0

general form of spin precession vector:

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

BNL E821 approach

J-PARC approach

γ=30 (P=3 GeV/c)

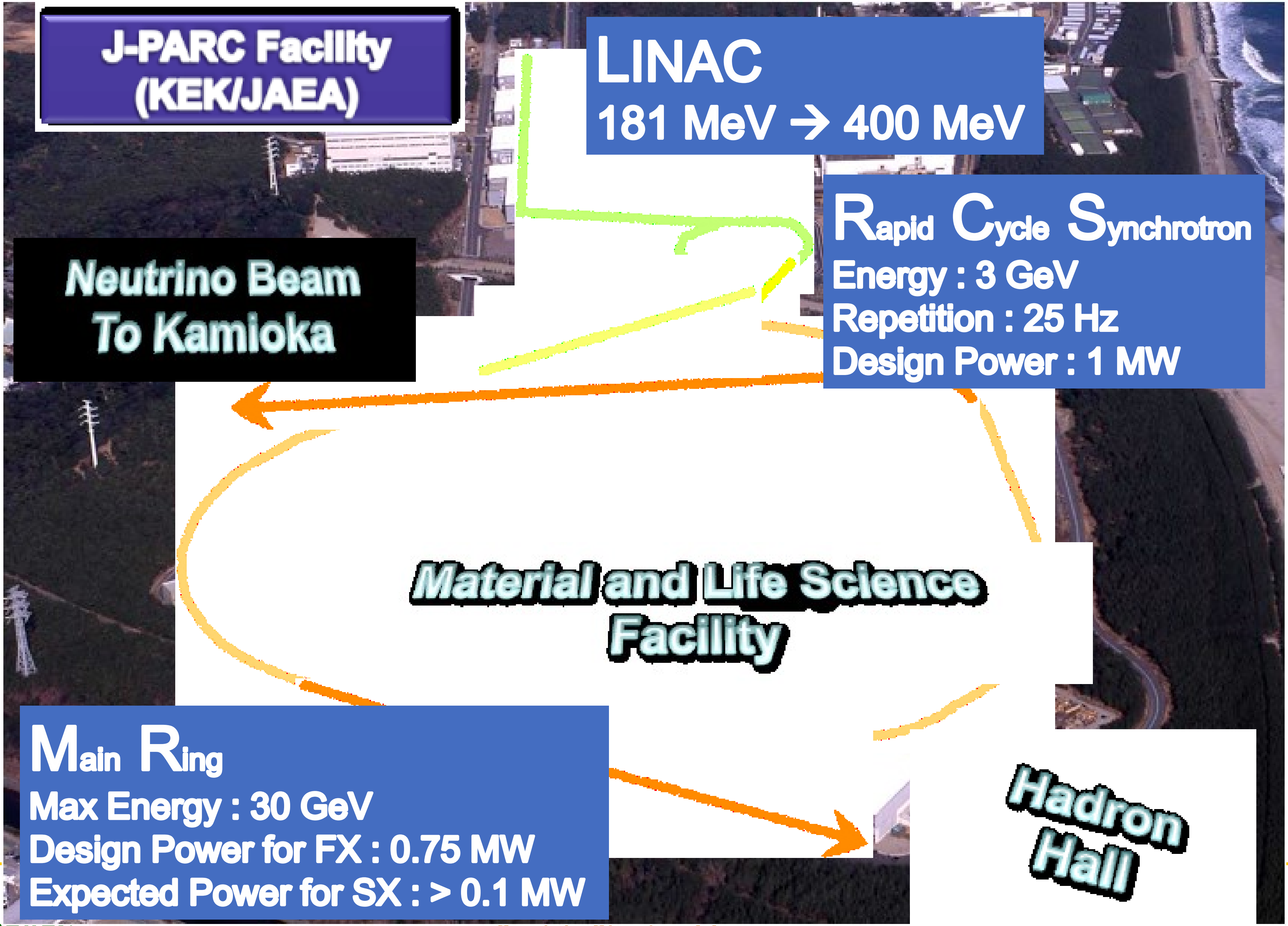
FNAL E989

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

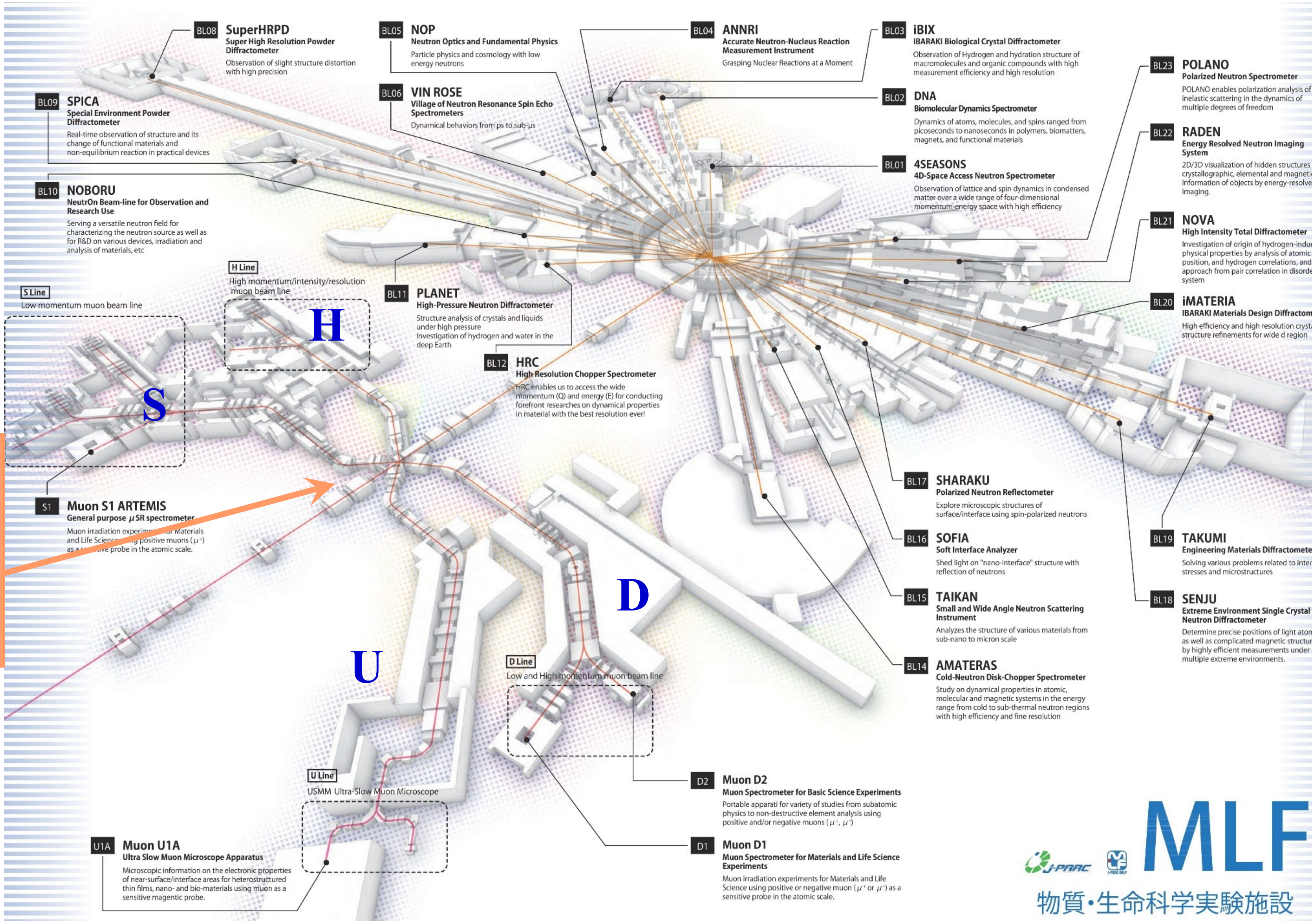
J-PARC E34

E = 0 at any

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

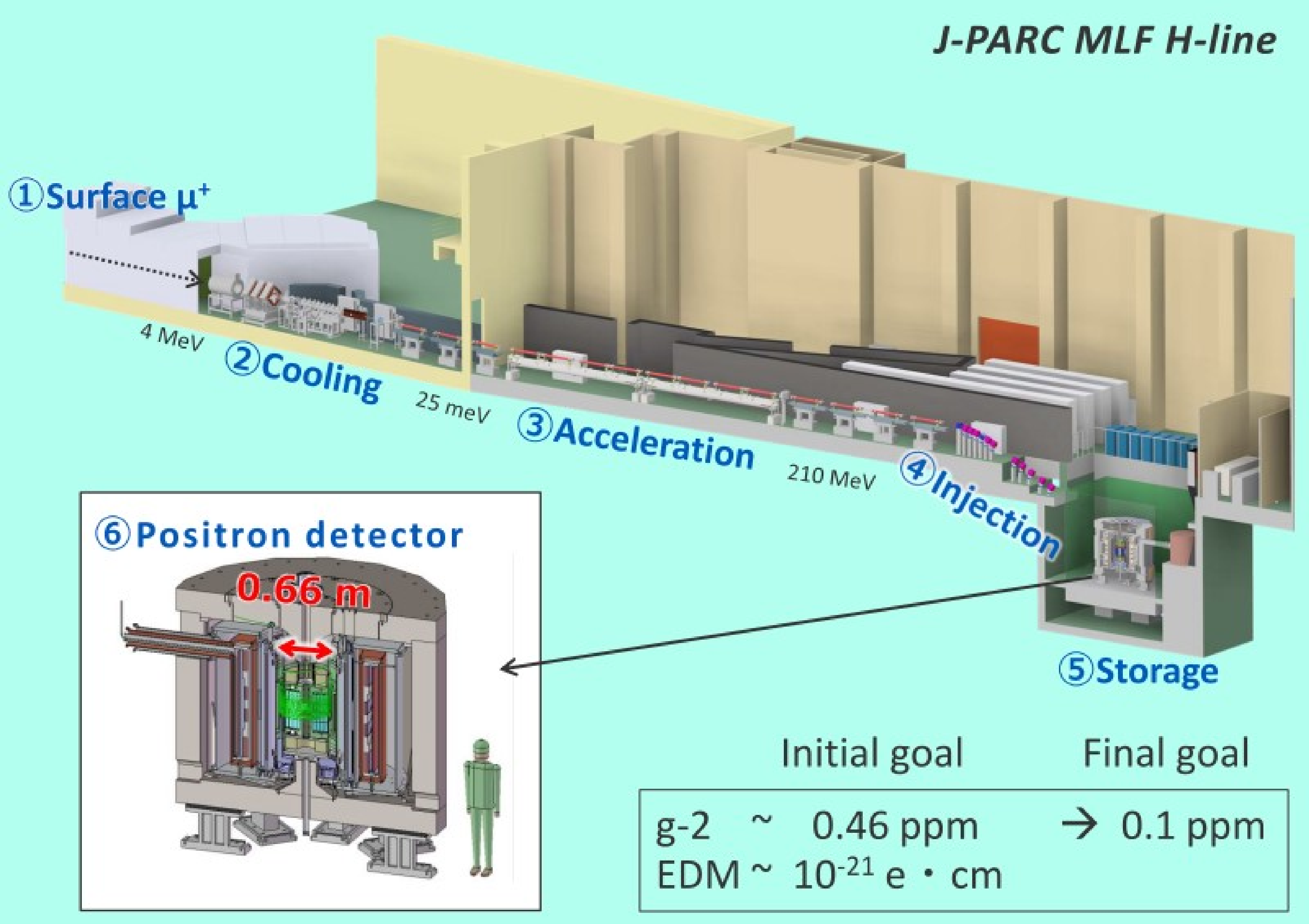

J-PARC Facility
(KEK/JAEA)
LINAC
181 MeV → 400 MeV
Rapid Cycle Synchrotron
Energy : 3 GeV
Repetition : 25 Hz
Design Power : 1 MW
Neutrino Beam
To Kamioka
Material and Life Science
Facility
Main Ring
Max Energy : 30 GeV
Design Power for FX : 0.75 MW
Expected Power for SX : > 0.1 MW
Hadron
Hall

Proton beam 3 GeV, 1 MW
2×10^{15} p/s, 5% interact in graphite target $\rightarrow 2\times10^{9}$ surface muons/s



① Muon Beam Line and experimental area
② Thermal muon
③ Muon linac
④ Injection
⑤ Storage
⑥ Detector

- Construction of facility has been started in 2022.
- Aiming for data taking from 2030.

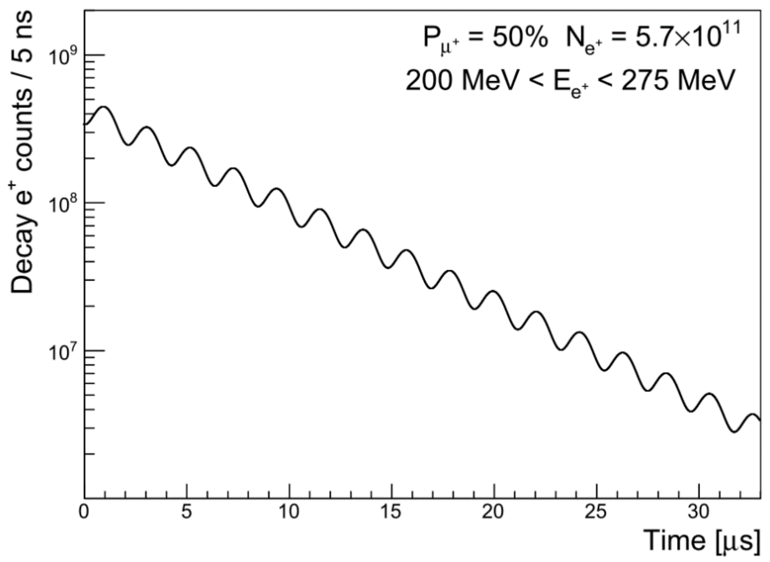


Expected time spectrum of e+ in $\mu^+ \rightarrow e^+\nu\bar{\nu}m$ decay

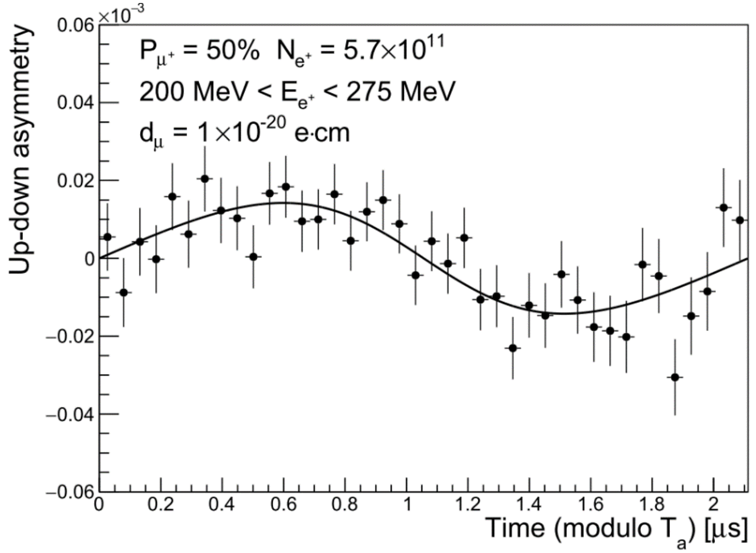
Requirement for zero E-field: Muons should be kept stored without E-focusing
Beam with ultra-small transverse dispersion, i.e. $\Delta p_T/p \sim 10^{-5}$

$$\vec{\omega} = \frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta} \times \vec{B}\right)\right]$$

number of e+, p>200 MeV/c



Up-down asymmetry

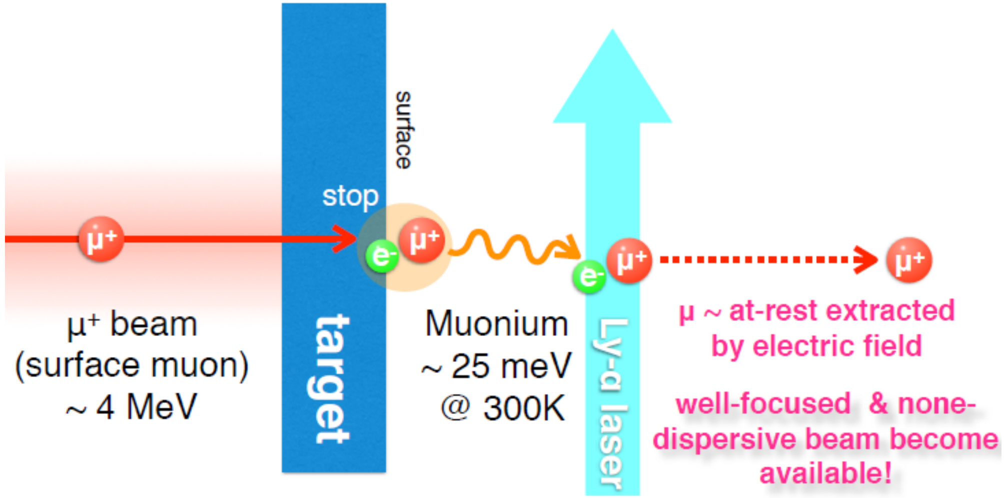


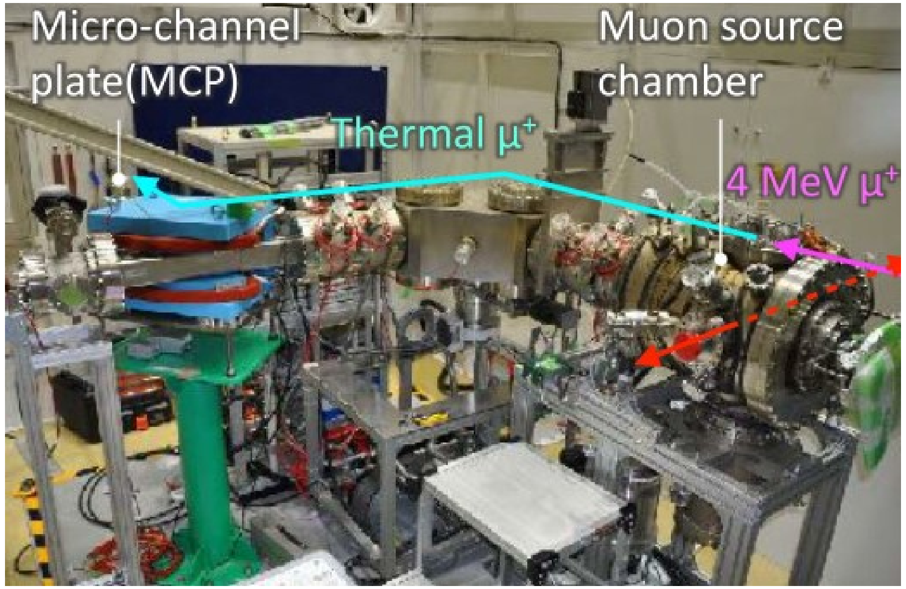
e+ decay time (sec)

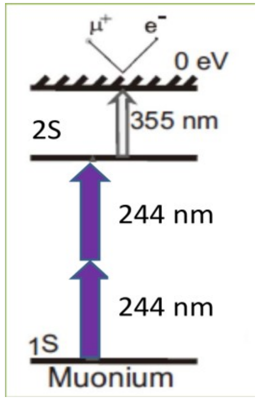
Comparison of experiments

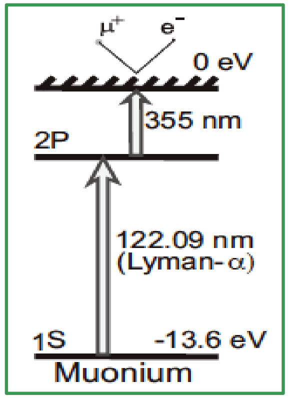
	BNL-E821	Fermilab	J-PARC
Muon momentum	3.09 GeV/c		**0.3 GeV/c**
gamma	29.3		**3**
Storage field	B=1.45 T		**3.0 T**
Focusing field	Electric quad		**Very weak magnetic**
# of detected μ+ decays	5.0E9	1.8E11	**1.5E12**
# of detected μ- decays	3.6E9	-	**-**
Target Precision (stat)	0.46 ppm	0.1 ppm	**0.1 ppm**

Muon source

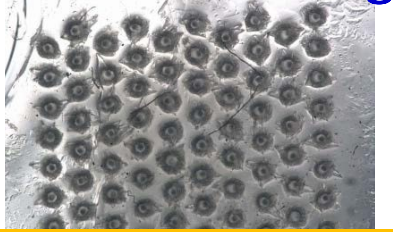






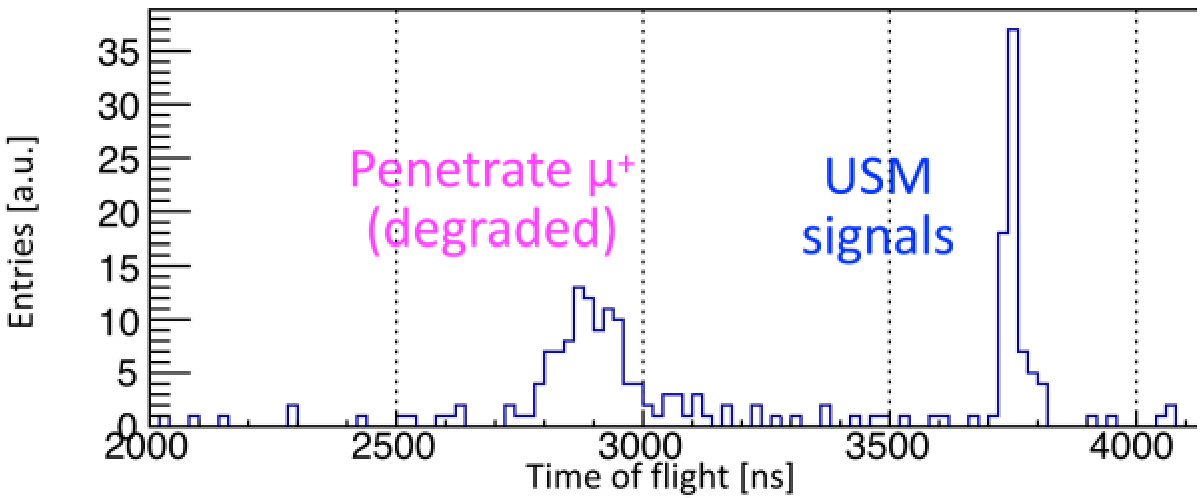


Muonium source: laser ablated silica aerogel

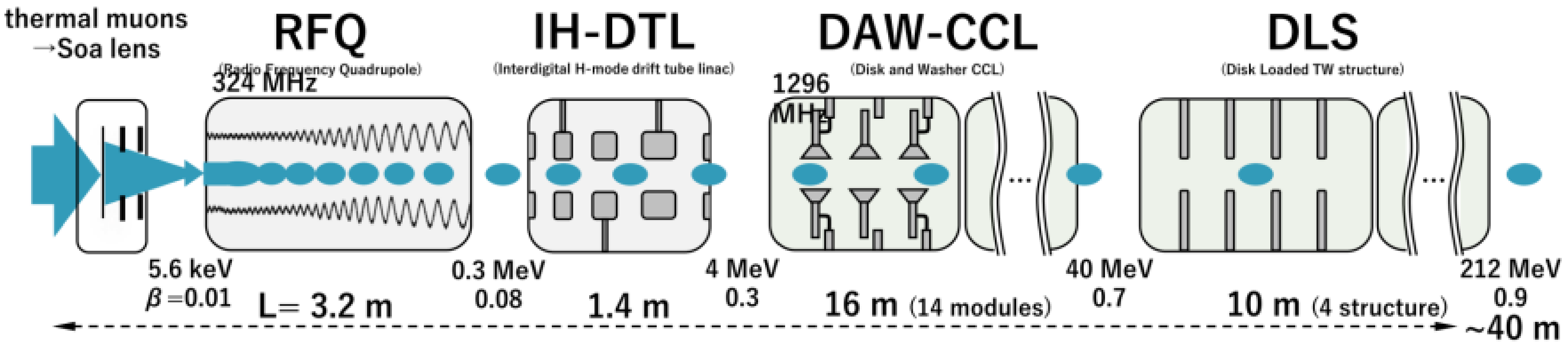


500 μm pitch surface dip

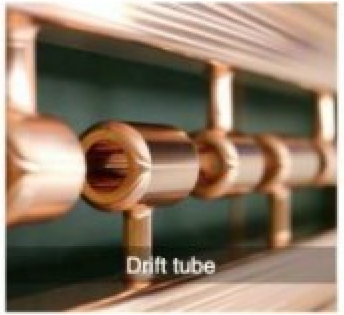
Thermal muons has been successfully observed with real muon source chamber (Mar. 2024).

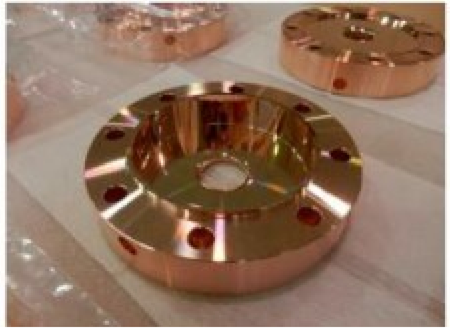


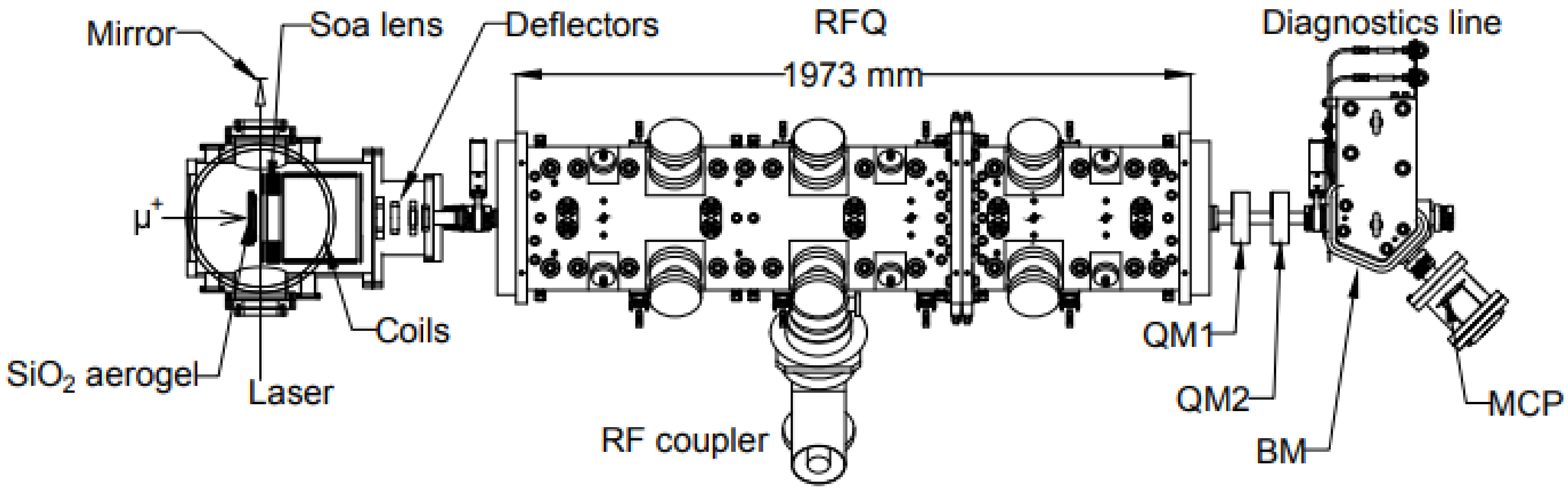
- Thermal muons are reaccelerated up to p=300 MeV/c by muon LINAC.
- – Fast acceleration to avoid muon decay loss, No emittance growth.
- Different types of acceleration cavity to realize fast re-acceleration through wide β region.

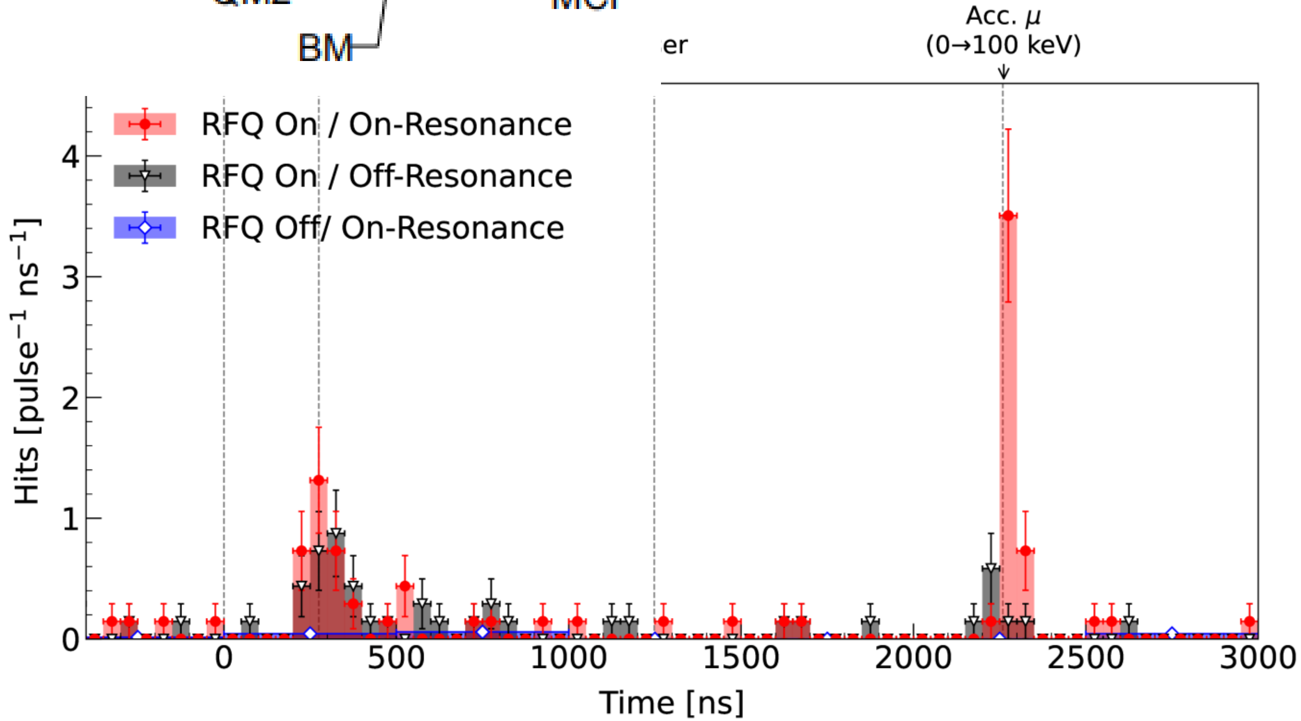


Ready | **Ready**: Acceleration test in 2026/2027 | Ready for production except for bridge coupler | Ready for production except for pulse compressor









Acceleration of thermal muon to 90 keV was demonstrated using prototype RFQ in Apr. 2024.
Phys. Rev. Lett. **134**, 245001

Acceleration up to 4 MeV is in planned for 2026.

Muon storage magnet and detector

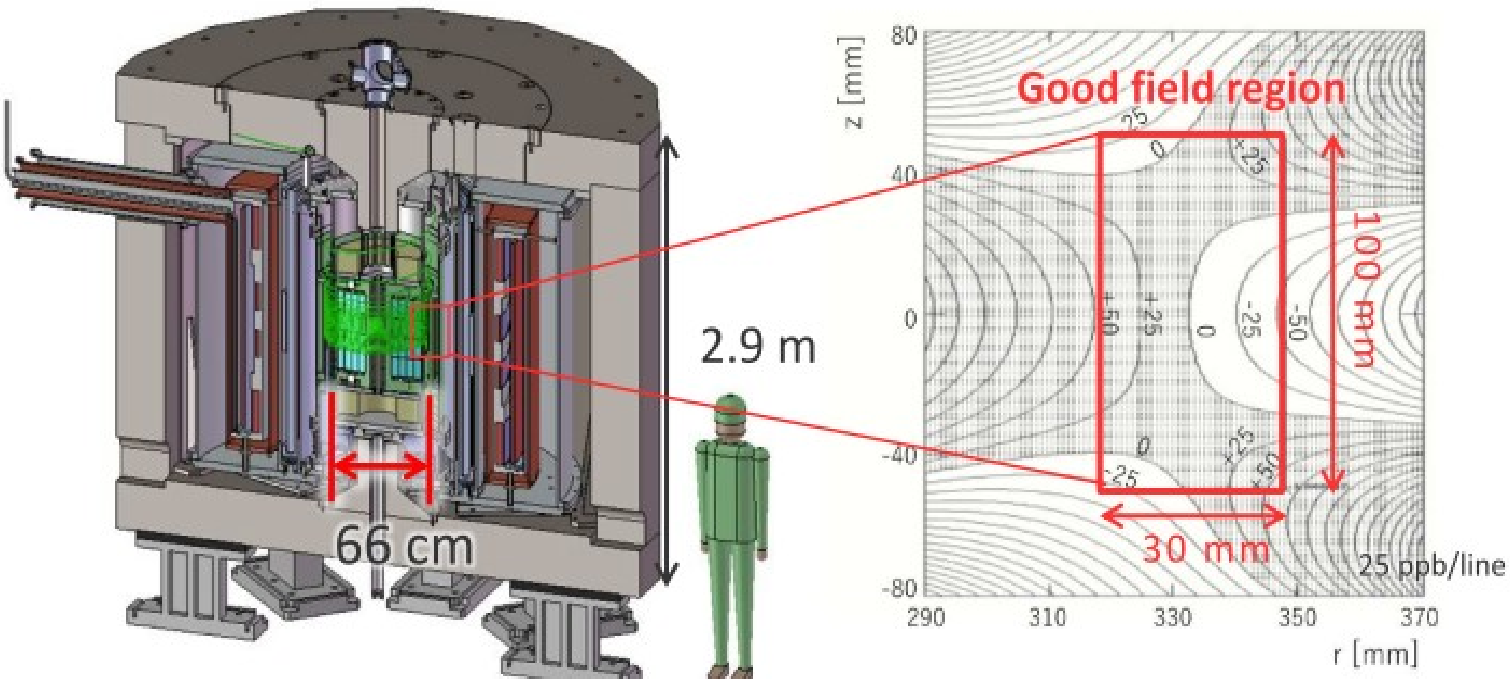


Table 1.2: Specification of the storage field.

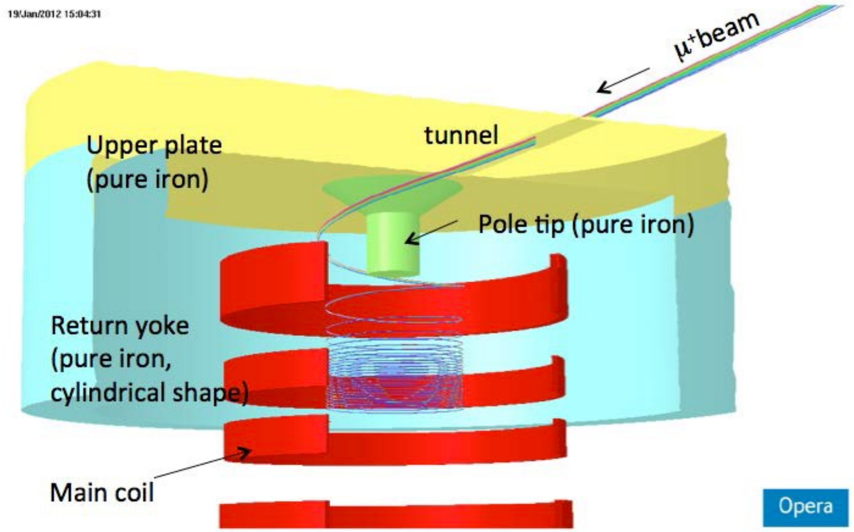
specifications		
field strength		3 T
field uniformity	locally	≤ 1 ppm
	integral	< 0.1 ppm
uniform region	radius	33.3 ± 1.5 cm
	height	± 5.0 cm

B = 3 T, ϕ = 66 cm

- High uniformity of the magnetic field is achieved by shimming.
- Local uniformity of 1 ppm was demonstrated with the magnet used in the MuSEUM experiment.

Muon beam injection and storage

For injection of muon beam into compact storage ring,**3D-spiral injection scheme** has been invented.
Demonstration of the 3D-spiral injection schemeis ongoing with electron beam.
First signal from stored electron beam issuccessfully observed.

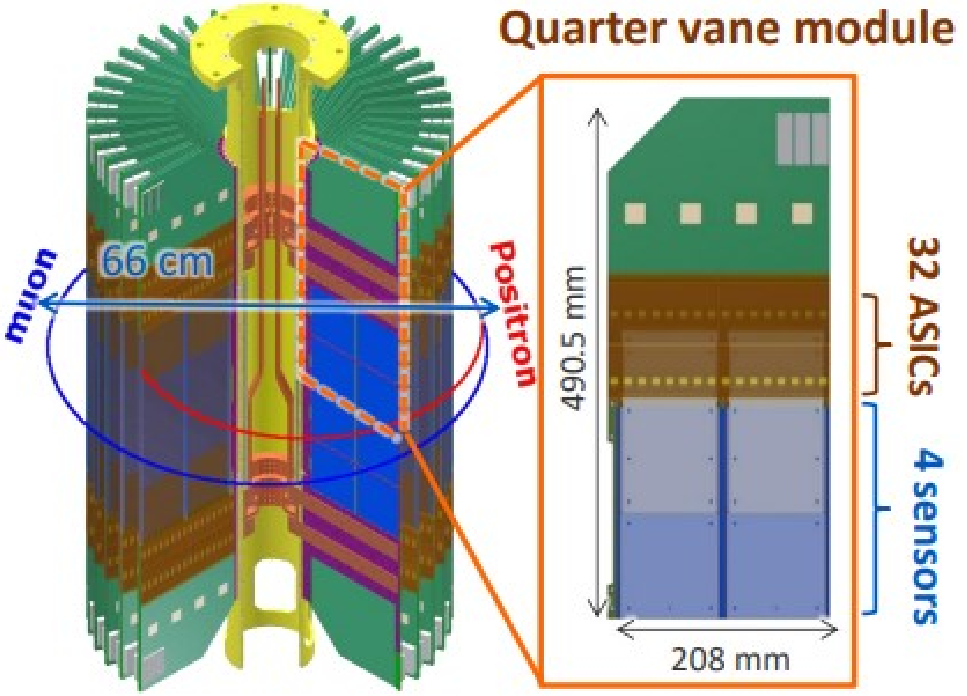


3D spiral injection + kicker (J-PARC E34)

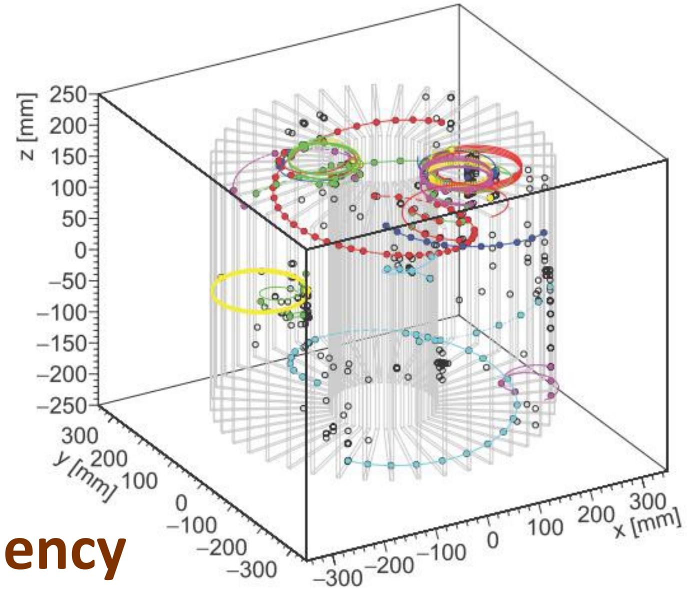
Injection efficiency : ~85%
H. Iinuma et al., Nucl. Instr. And Methods. A 832, 51 (2016)

Positron tracking detector

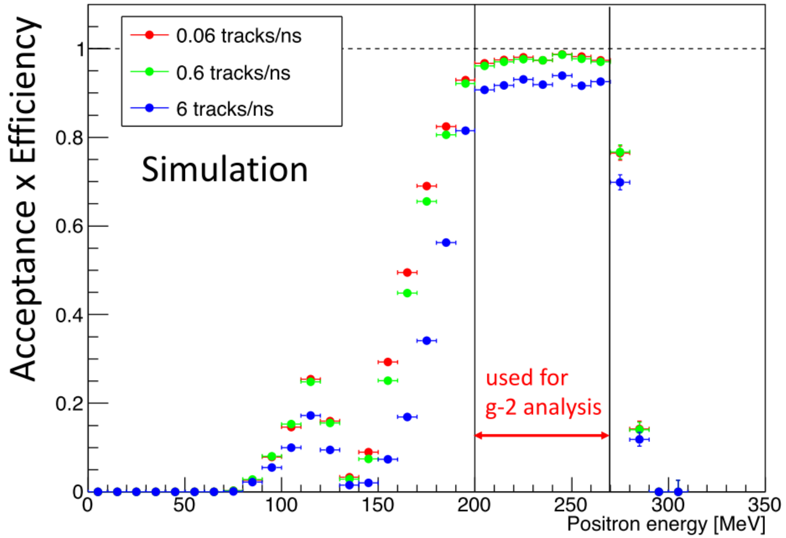
Positron tracks are measured by Silicon-strip detector.Positrons with a momentum of 100-300 MeV/c
High hit rate capability (6 tracks/ns)and stability over early to late rate changes (1.4 MHz → 10 kHz)
Design optimized for pulsed beam.



Event display with 25 muons



Reconstruction efficiency

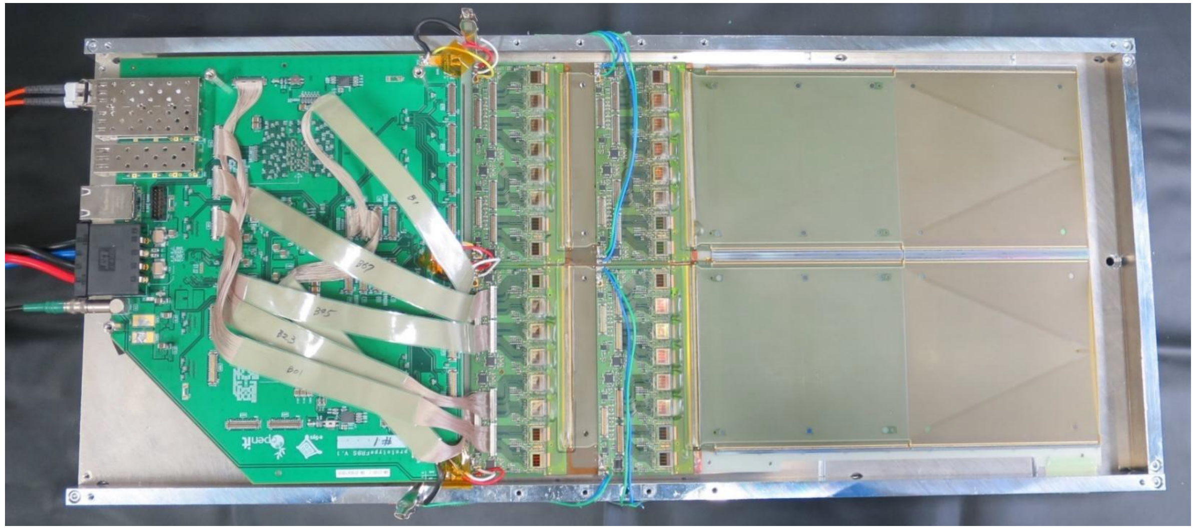


Positron tracking detector

Vanes: 48
Sensor Area : 8.46 m^2
Strips : 811k strips
Maximum Rate : 1.2 GHz

p+-on-n, single-sided
Thickness: 320 μ
Bias Register: 10 MΩ (avg.)
AC coupling: 100 pF

Silicon-strip sensor
Made by Hamamatsu Photonics K.K., S13804
Strip pitch : 190 μm
Mass-production : ongoing



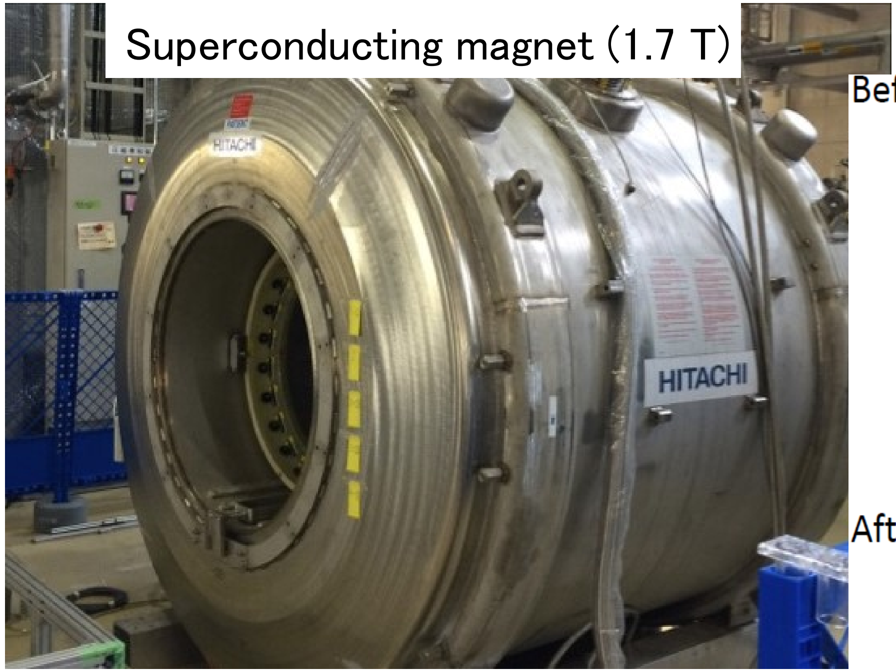
Prototype module “quarter-vane” is assembled.

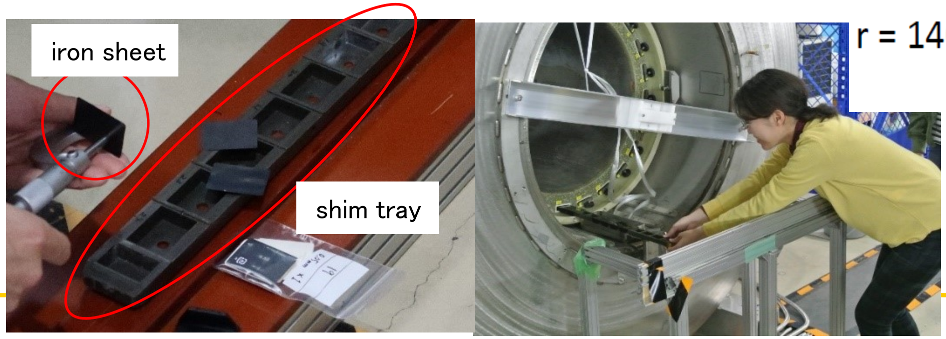
- Various operation test are also performed using the prototype module.

Readout ASIC (SliT)
Silterra180-nm CMOS process
Binary output with sampling interval of 5 ns
Mass-production and QA : done

Magnet shimming test

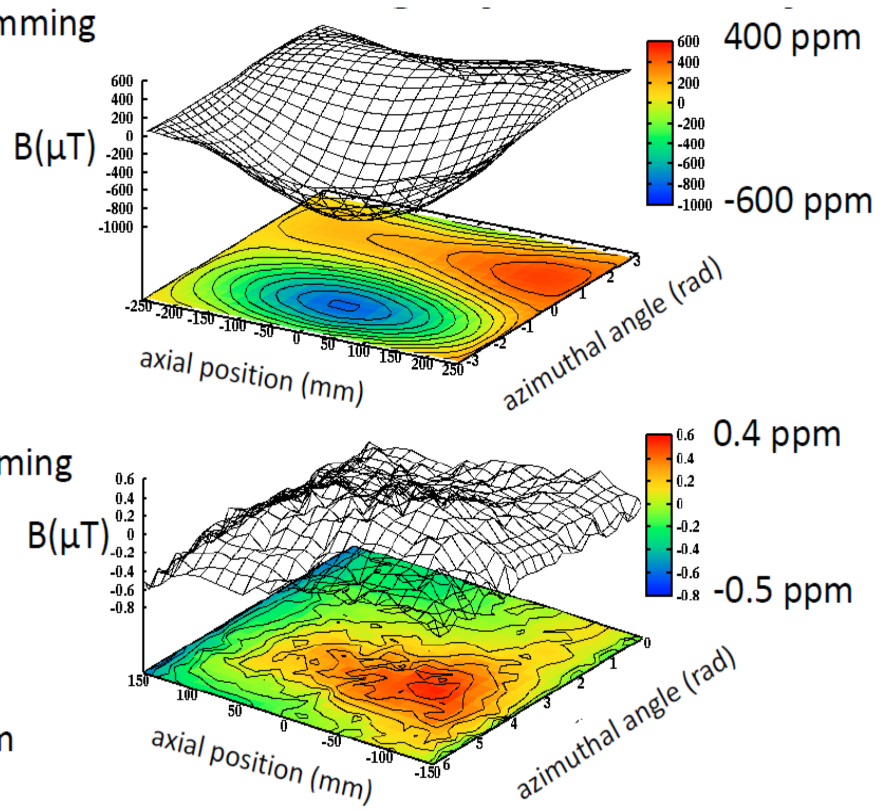
Superconducting magnet (1.7 T)





r = 140 mm

Plots by K. Sasaki



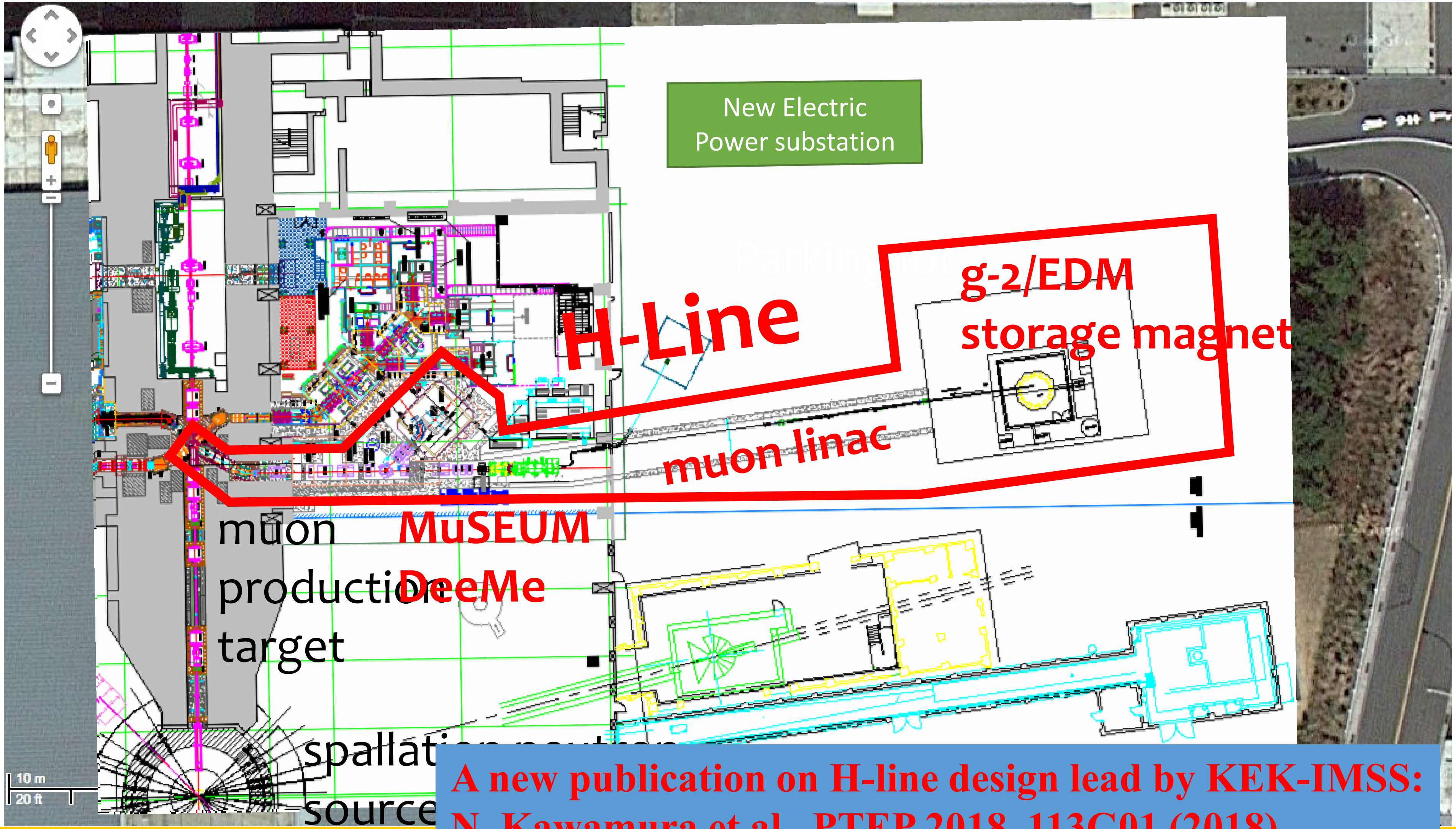
Field uniformity: **0.454 ppm** (peak–to–peak)
on the surface of sphere r=15 cm

Expected uncertainties

Total number of muons in the storage magnet:	5.2×10^{12}
Total number of positrons:	0.57×10^{12}
Effective analyzing power:	0.42
Statistical uncertainty on ω_a [ppb]:	450
Statistical uncertainty on ω_p [ppb]:	100
Uuncertainties on a_μ [ppb]	460 (stat.)
	< 70 (syst.)
Uncertainties on EDM [10^{-21}e·cm]	1.4 (stat.)
	0.36 (syst.)

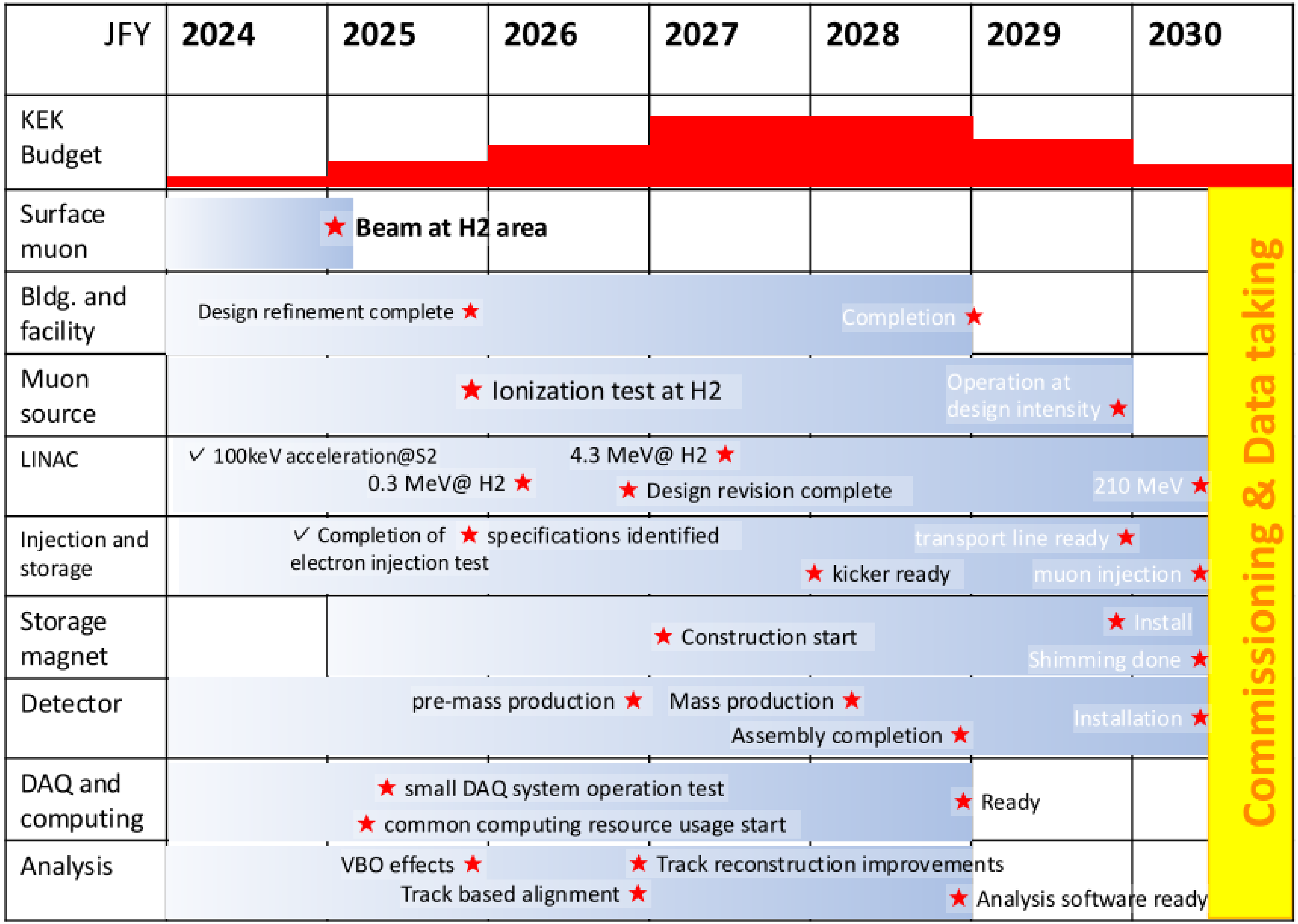
Proposed experimental site (H-line)

Material and Life science Facility in J-PARC

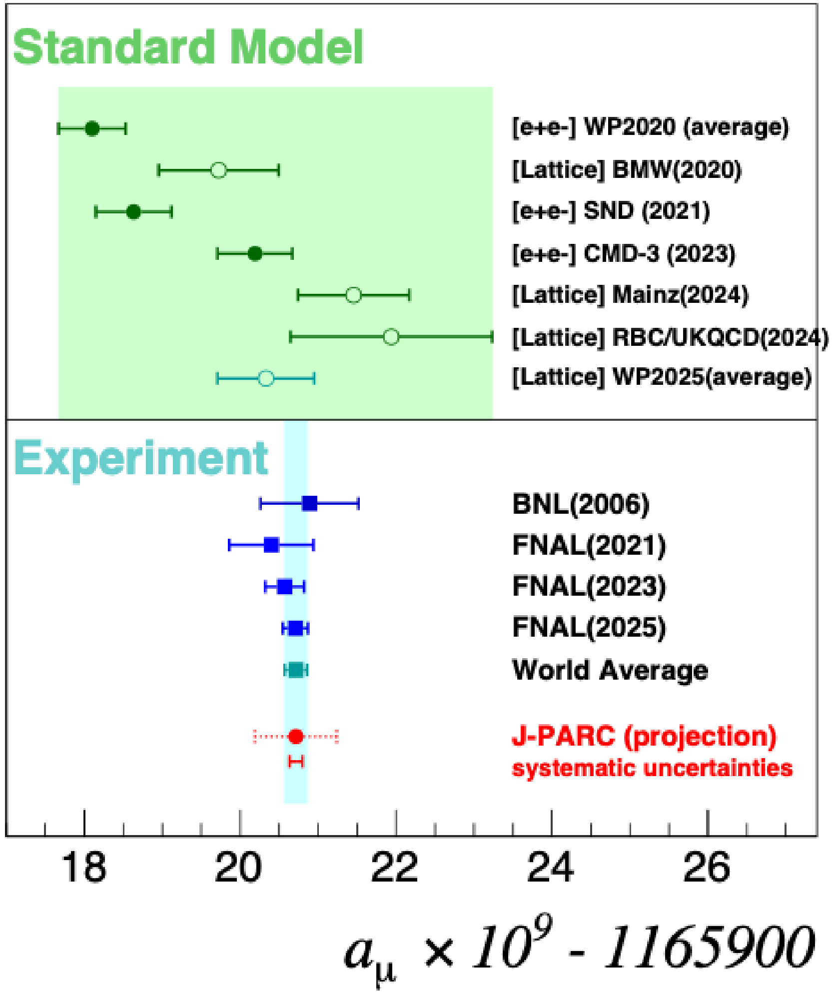


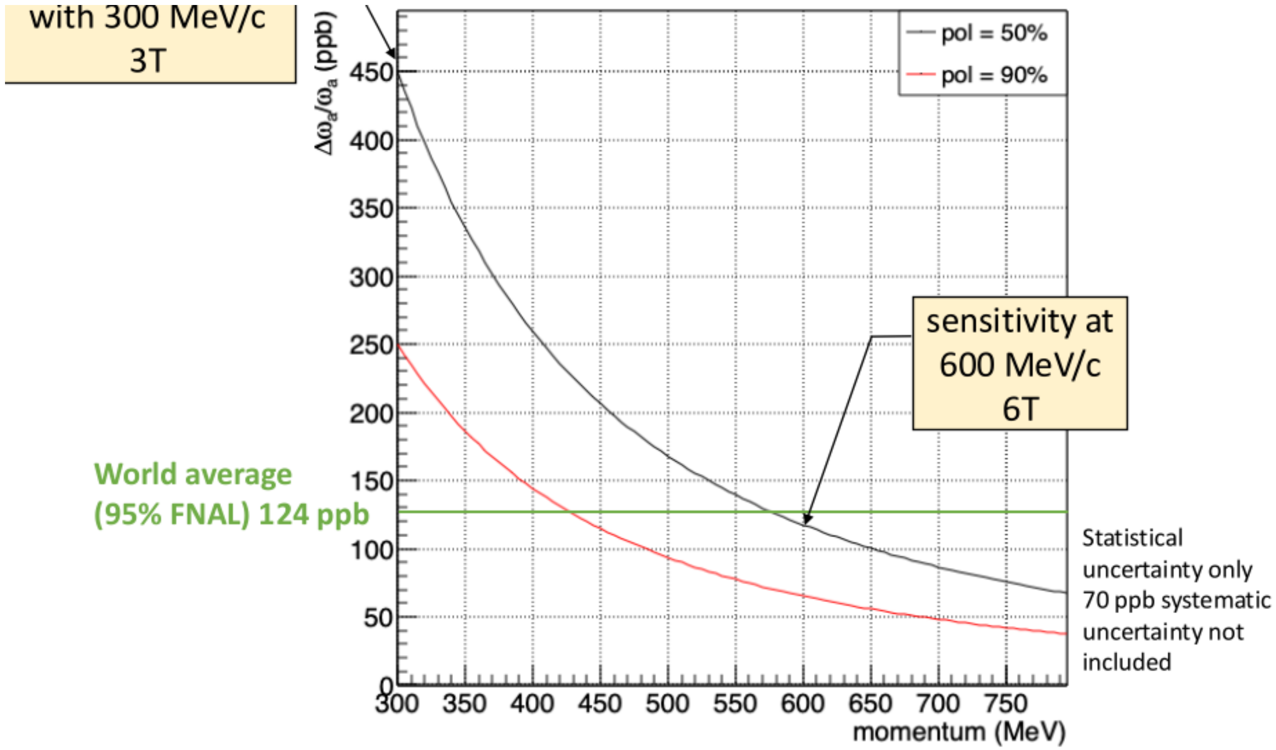
A new publication on H-line design lead by KEK-IMSS:
N. Kawamura et al., PTEP 2018, 113G01 (2018)

Schedule and milestones



Towards higher sensitivities





J-PARC 450 ppb 70 ppb

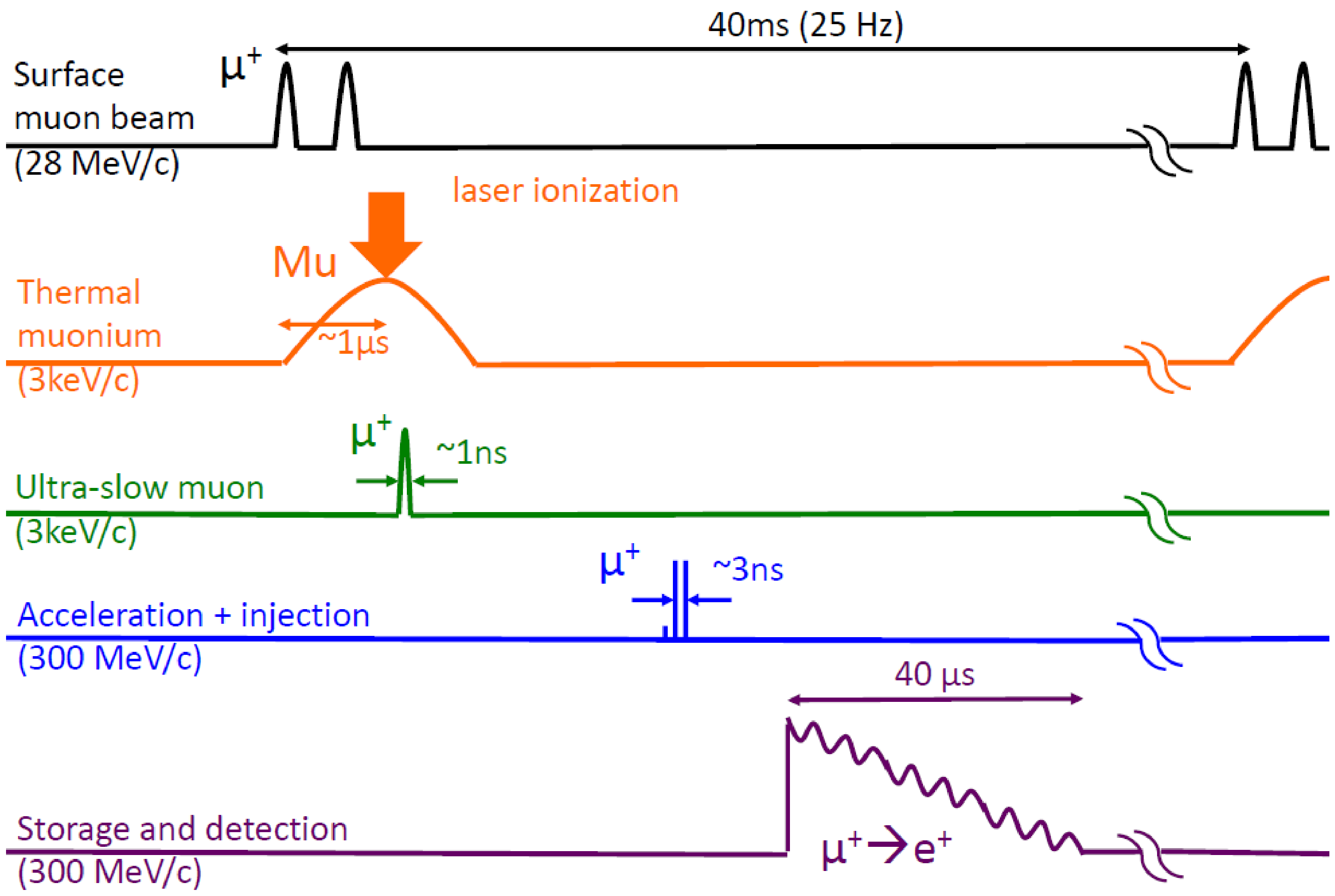
Higher polarization (P)
Higher energy (E)
Stronger magnetic field (B)

Summary

- **E34 project at J-PARC is intended to measure the muon (g-2) and EDM by a method that is completely different from previous experiments**
  - **Re-accelerated thermal muon beam with no strong focusing.**
  - **Compact MRI-type storage ring with a good injection efficiency and high uniformity of local B-field.**
  - **Full-tracking detector with large acceptance**
- **Development of all components of E34 project is ongoing.**
- **First Muon acceleration test has been successfully done**
- **Next task in coming years is the construction of muon beamline (H-line)**
- **First beam to H2 was delivered and acceleration up to 4 MeV is in preparation.**
- **Expecting data taking from FY2030. Intending to reach the BNL precision in ~2 year running.**
- **The monochromatic low-emittance polarized muon beam can be used in other applications and studies like μSR and development of the μe and μ μ collider.**

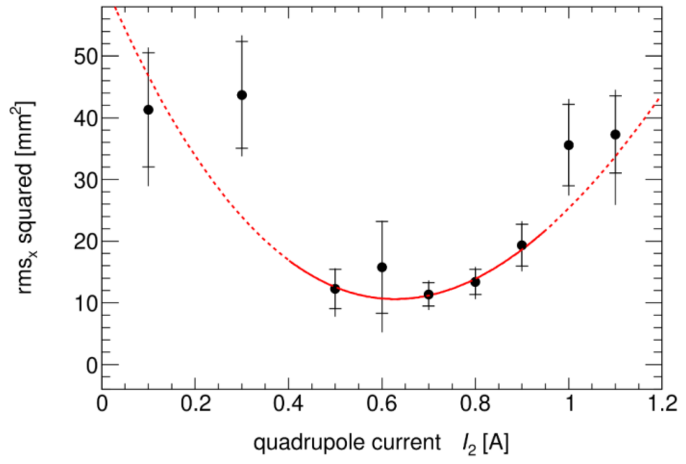
Back up

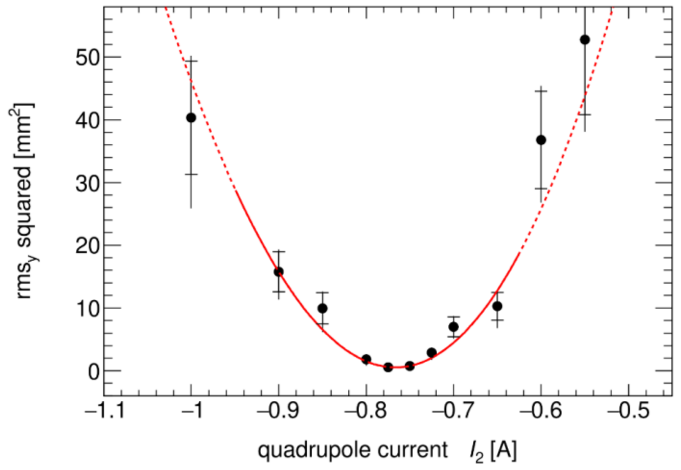
Experimental sequence



Transverse phase-space distribution of the beam was measured by “Q-scan”. Strength of quadrupole field (=focal length) v.s. beam spot sizes

Normalized emittance was reduced with more than two order.





Acceleration up to 4 MeV is in planned for 2026.

before cooling

$\varepsilon_x = 170\ \pi$ mm mrad

x 1/200

after cooling + acceleration

$\varepsilon_x = 0.85 \pm 0.25^{+0.22}_{-0.13}\ \pi$ mm mrad

before cooling

$\varepsilon_y = 130\ \pi$ mm mrad

x 1/400

after cooling + acceleration

$\varepsilon_y = 0.23 \pm 0.03^{+0.05}_{-0.02}\ \pi$ mm mrad