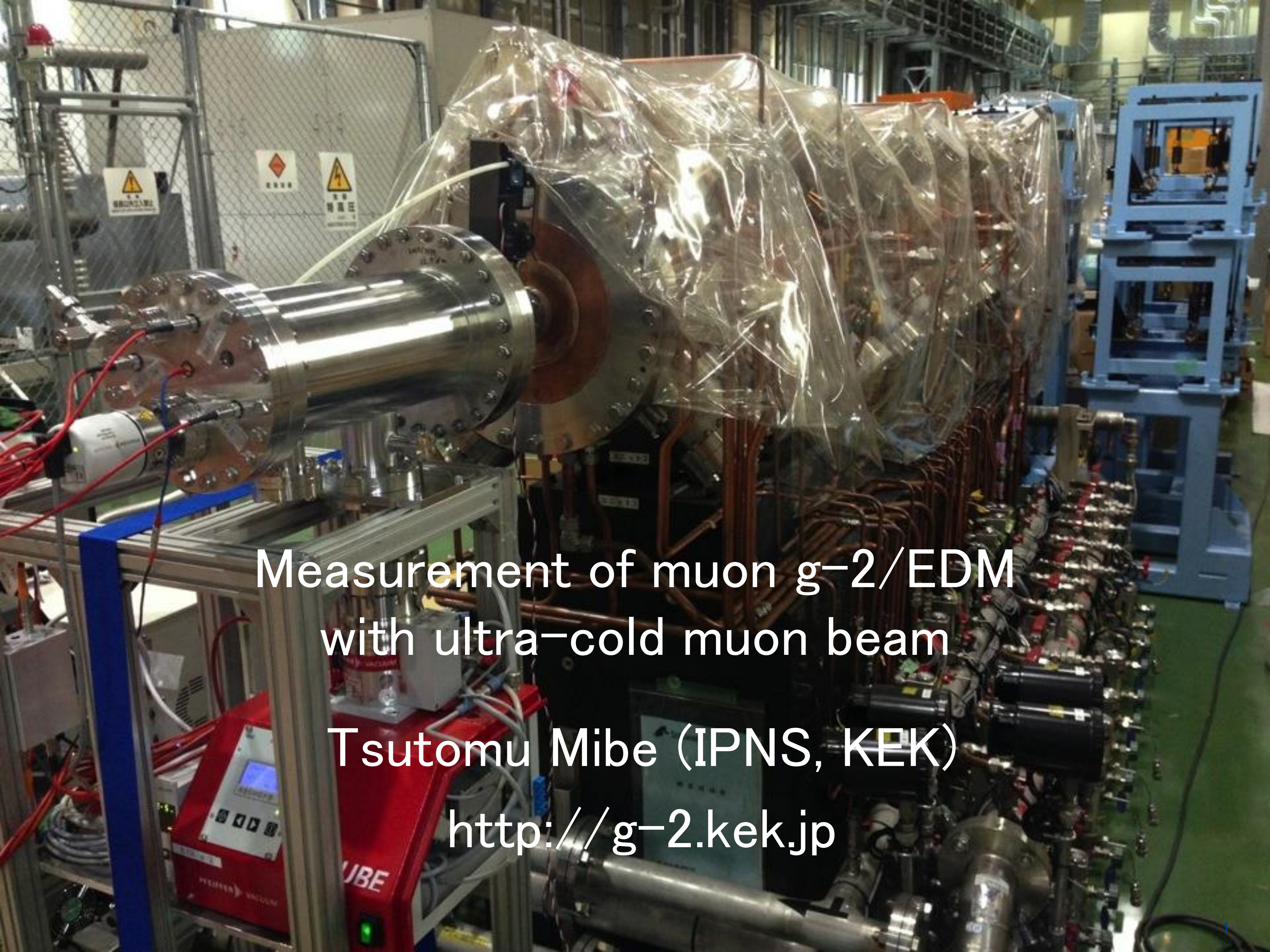


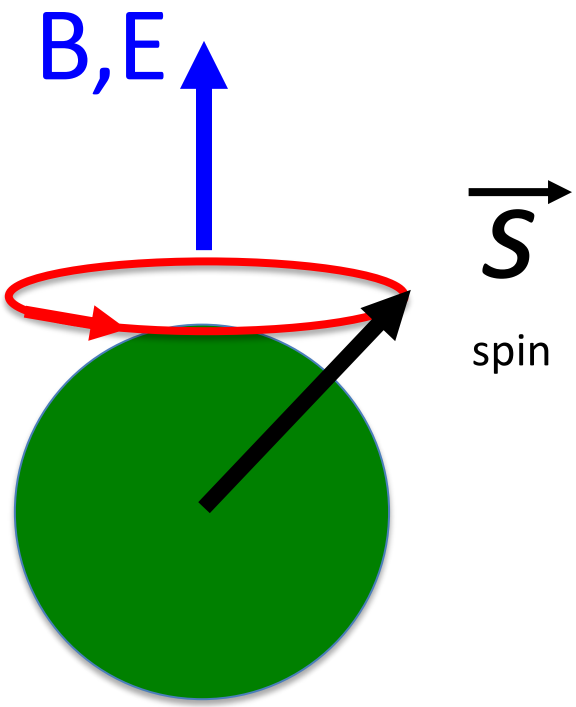
Measurement of muon g-2/EDM with ultra-cold muon beam

Tsutomu Mibe (IPNS, KEK)

http://g-2.kek.jp

Particle dipole moments

$$\mathcal{H} = -\vec{\mu} \cdot \vec{B} - \vec{d} \cdot \vec{E}$$



Magnetic Dipole Moment

$$\vec{\mu} = g \left(\frac{q}{2m} \right) \vec{s}$$

CP even

Electric Dipole Moment

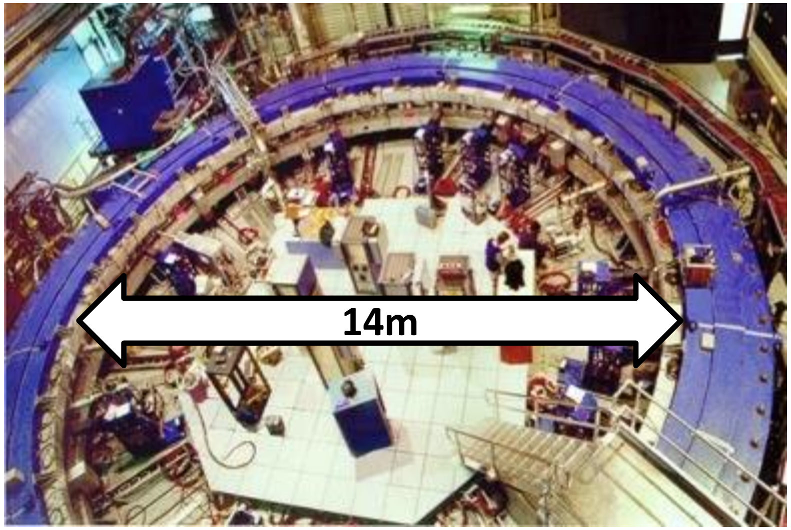
$$\vec{d} = \eta \left(\frac{q}{2mc} \right) \vec{s}$$

CP odd

Why g-2 and EDM with new method?

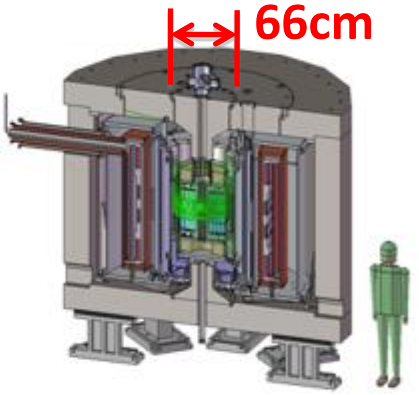
- **BNL E821**
  - a_μ = 11 659 208.9 (6.3) x 10^{-10}
    - 0.46ppm (stat.) + 0.28ppm (syst.) = 0.54ppm
    - **3σ deviation from SM**
    - **→Stat. dominant**
- **FNAL E989**
  - Recycle major parts of the muon storage ring.
  - **Will become online in 2017-**
- **J-PARC E34 (new method)**
  - **Brand-new concept**
  - **Ultra-cold muon beam + Compact storage ring + Spin flip**

BNL E821 / FNAL E989



P= 3.1 GeV/c , B=1.45 T

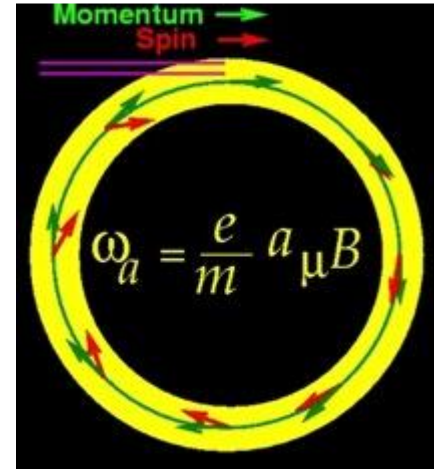
J-PARC E34



P= 0.3 GeV/c , B=3.0 T

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
γ=30 (P=3 GeV/c)

J-PARC approach
E = 0 at any γ

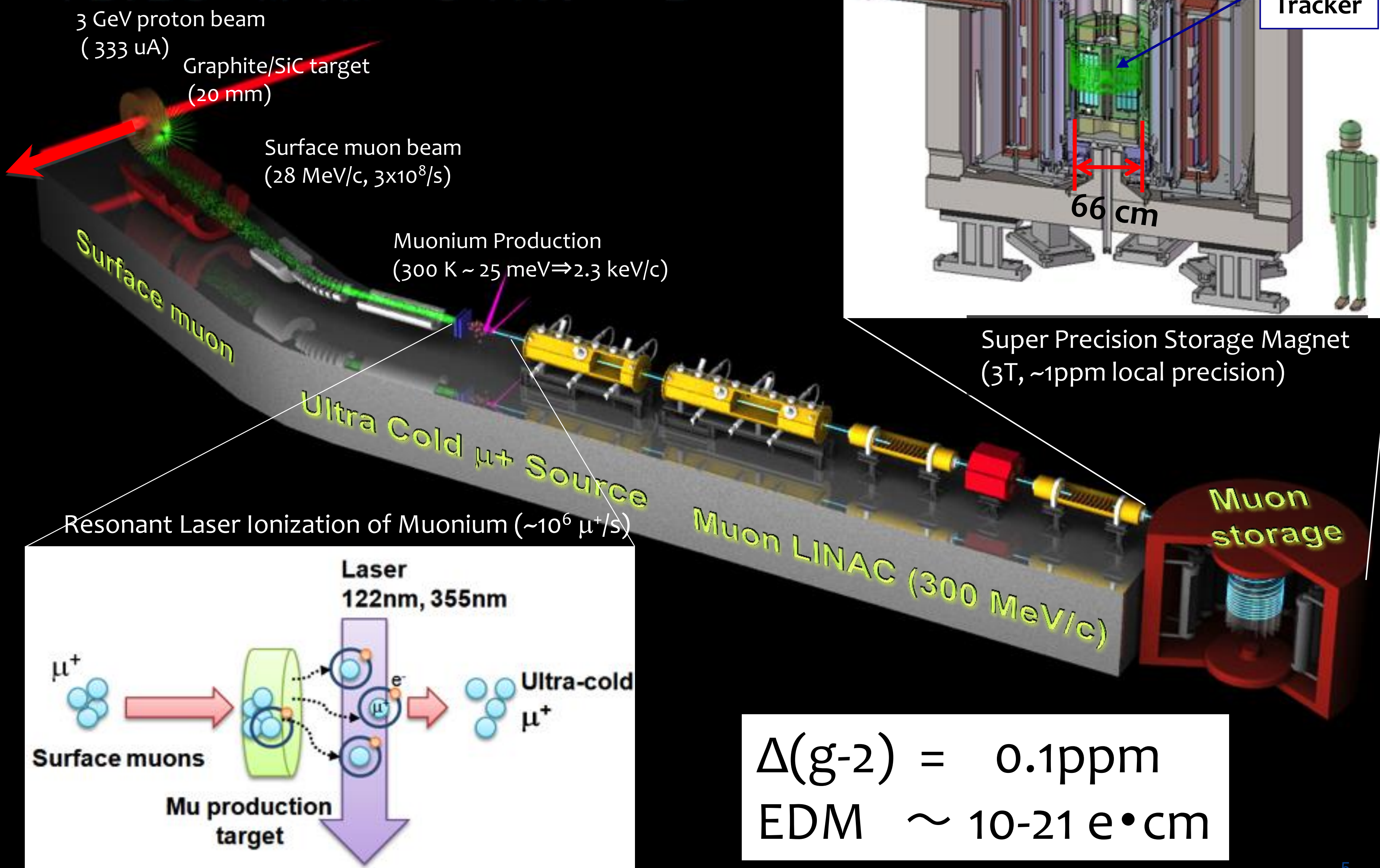
$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

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

FNAL E989

J-PARC E34

New Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam



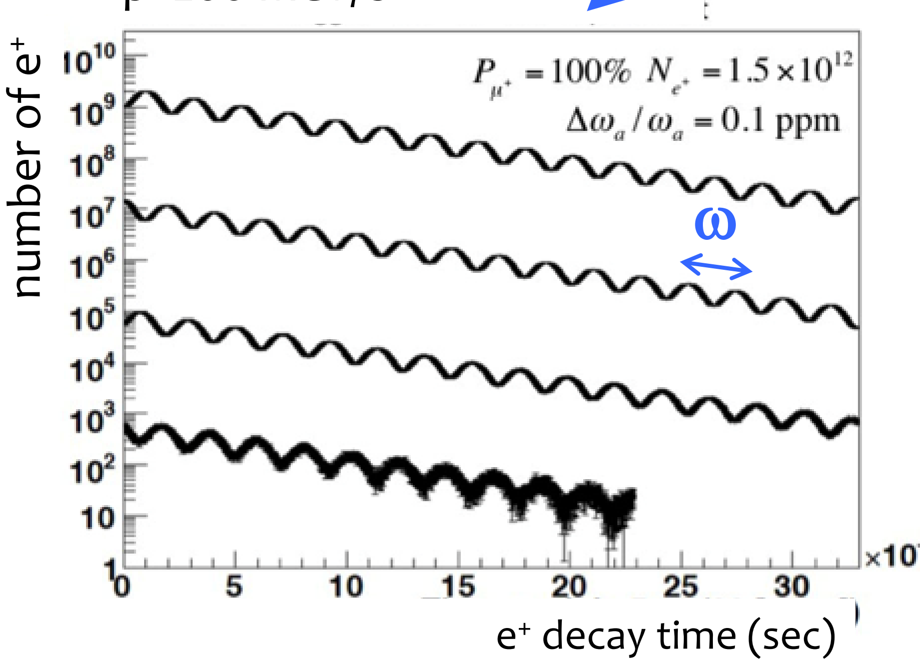
Δ(g-2) = 0.1ppm

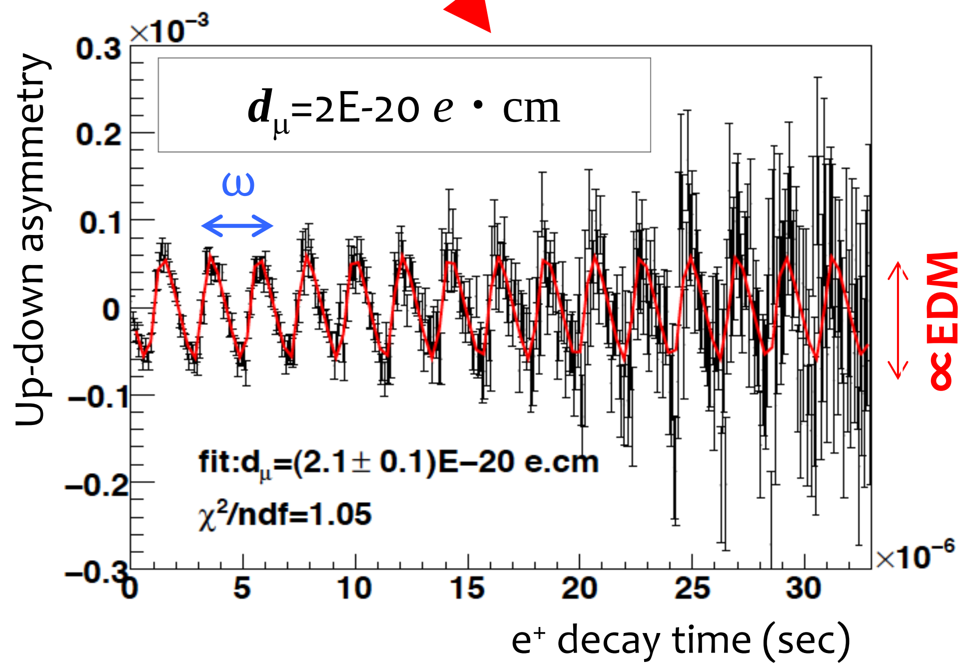
EDM ～ 10-21 e•cm

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

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

p>200 MeV/c





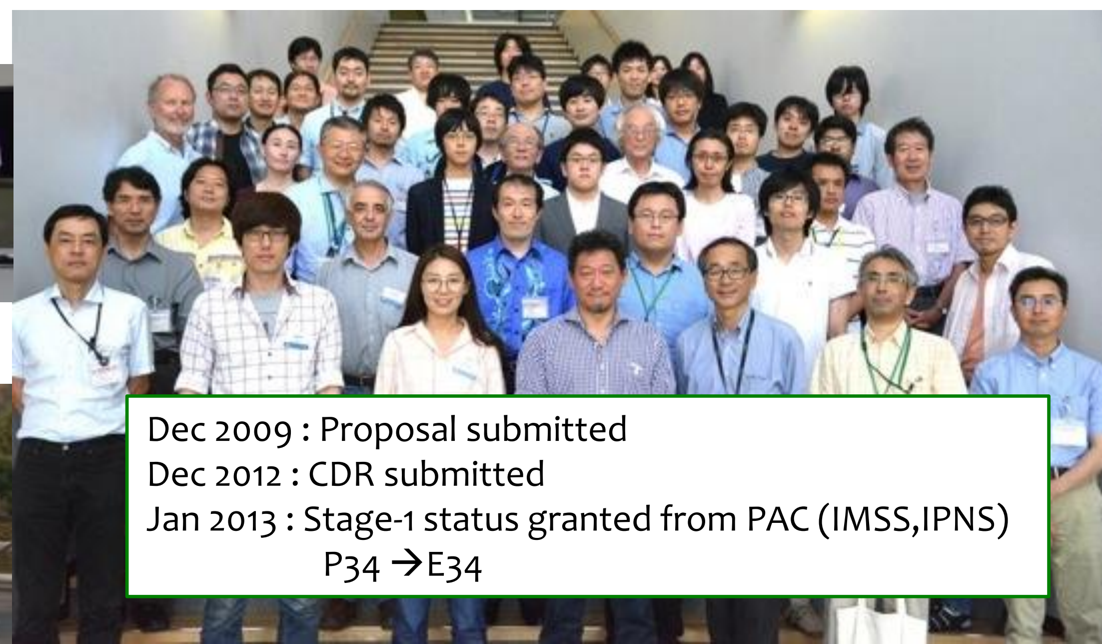
E34 collaborators

- **Collaborators**
  - Proposal (2009) 72
  - Conceptual Design Report (2011) 92
  - Technical Design Report (2015) 136 (16 graduate students)
    (27 also in COMET)
- **9 countries, 49 institutions**
  - Canada, China, Czech, France, Japan, Korea, Russia, UK, USA (in alphabetical order)

J-PARC 2014.9

KAIST (Korea) 2014.11

J-PARC 2015.6



Dec 2009 : Proposal submitted
Dec 2012 : CDR submitted
Jan 2013 : Stage-1 status granted from PAC (IMSS,IPNS)
P34 → E34

TDR

Technical Design Report
for
the Measurement of the Muon Anomalous
Magnetic Moment $g-2$ and Electric
Dipole Moment at J-PARC

May 15, 2015

prepared by 136 authors

Summary

In summary, this experiment intends to reach statistical uncertainties for muon $g-2$ of 0.37 ppm and for muon EDM of $1.3 \times 10^{-21} e \cdot \text{cm}$, during an acquisition time of 2×10^7 seconds of high-quality data, with a completely new experimental technique based on an ultra-cold muon beam and a compact storage ring. We will show in this document that our current understanding of the available beam power, the efficiency of the ultra-cold muon source, the muon acceleration, injection, and storage, and decay detection, all indicate that this is achievable. The statistical reach in the quoted running time is lower than we originally proposed. However, the $g-2$ sensitivity, even at this level, should exceed that of BNL E821 and provide an independent test of the three to four sigma discrepancy with the Standard Model prediction. Moreover, it would reduce the existing upper limit for the muon EDM by a factor of about 70. In the process of achieving these important goals, we would also be able to identify and understand any systematic uncertainties that may have to be reduced before attaining the final goal as originally proposed. In parallel, we will continue R&D, especially on the ultra-cold muon source intensity, to further improve the sensitivity to the final goal of 0.1 ppm for $g-2$.

- TDR describes a technical design to achieve measurement of muon g-2 and EDM beyond BNL E821 precision.

	BNL E821		J-PARC E34
g-2:	0.46 ppm	→	0.37 ppm (→0.1ppm)
EDM:	0.9 x 10^{-19} ecm	→	1.3 x 10^{-21} ecm

Ultra-cold Muon

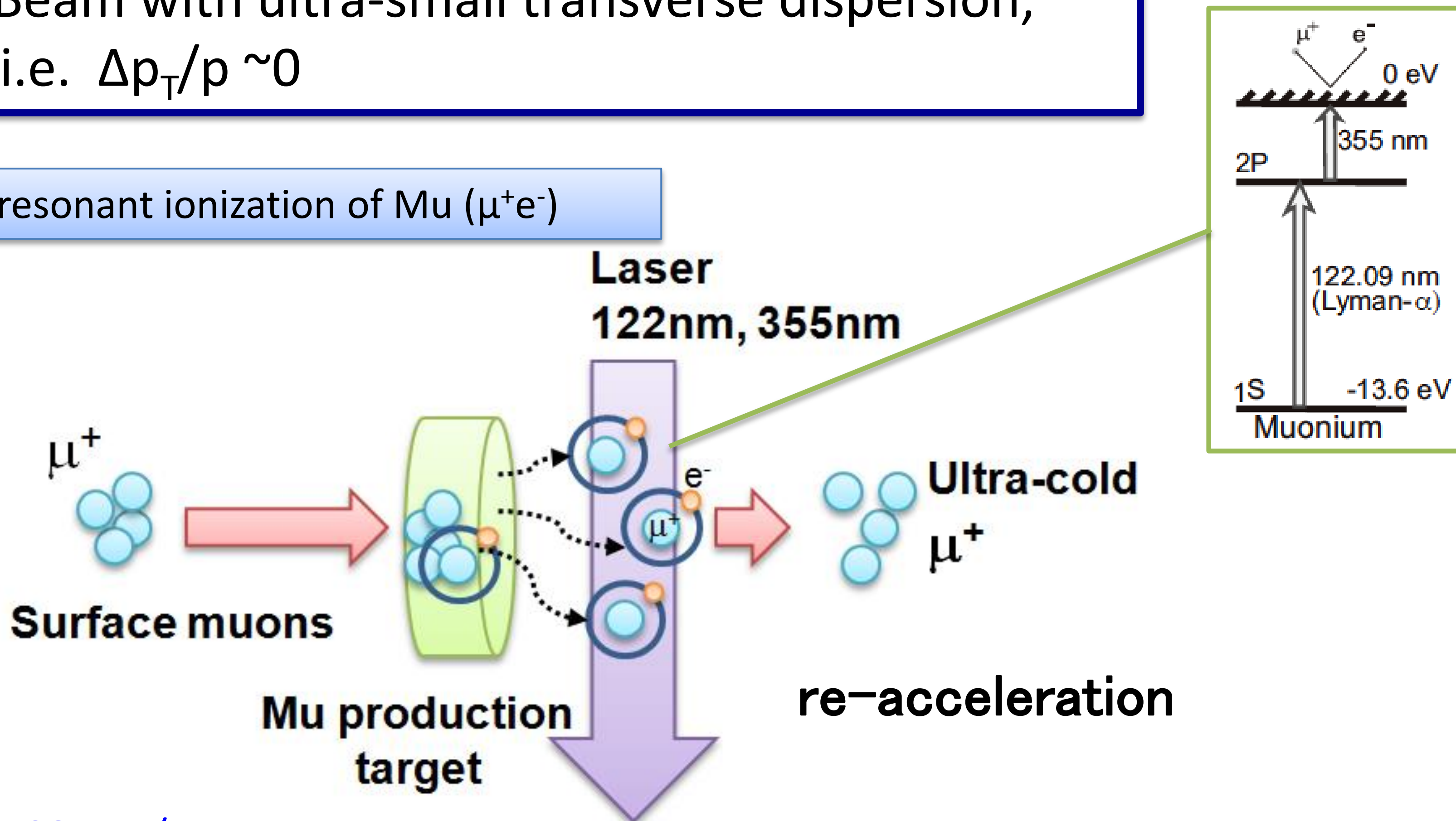
<u>Requirement for zero E-field:</u>

Muons should be kept stored without E-focusing

→ Beam with ultra-small transverse dispersion,

i.e. $\Delta p_T/p \sim 0$

Laser resonant ionization of Mu (μ^+e^-)

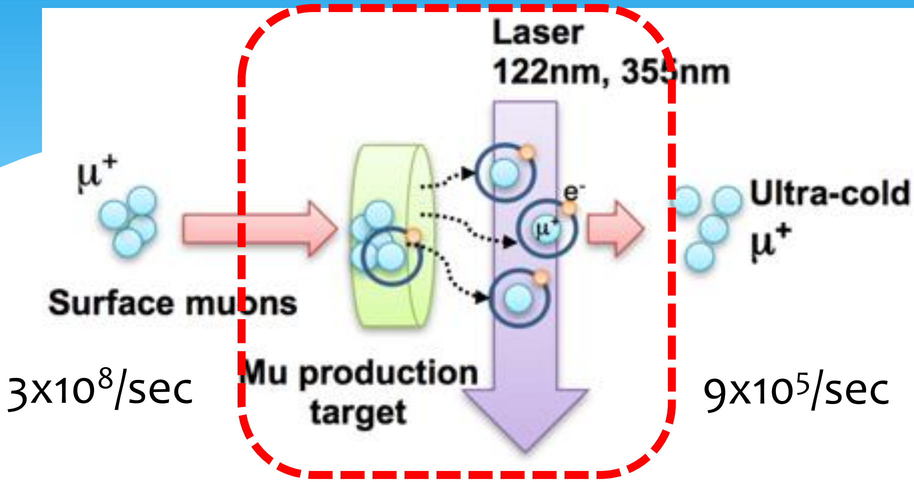


p = 28MeV/c | 3 keV/c | 300 MeV/c

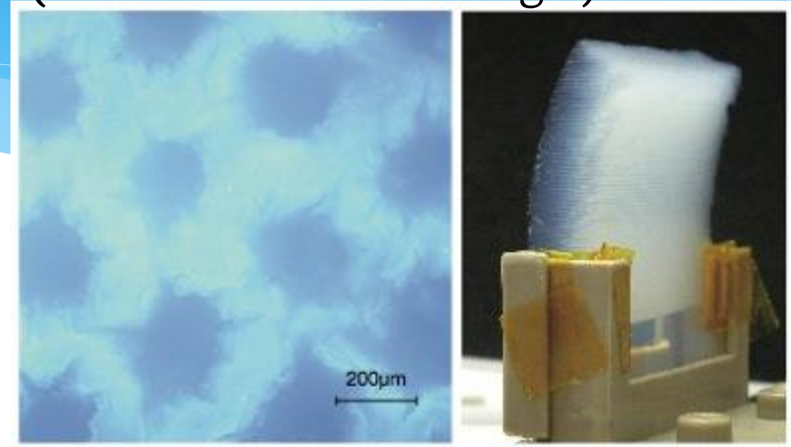
$\Delta p_T/p \sim 3$ keV / 300 MeV =1E-5

Muonium production

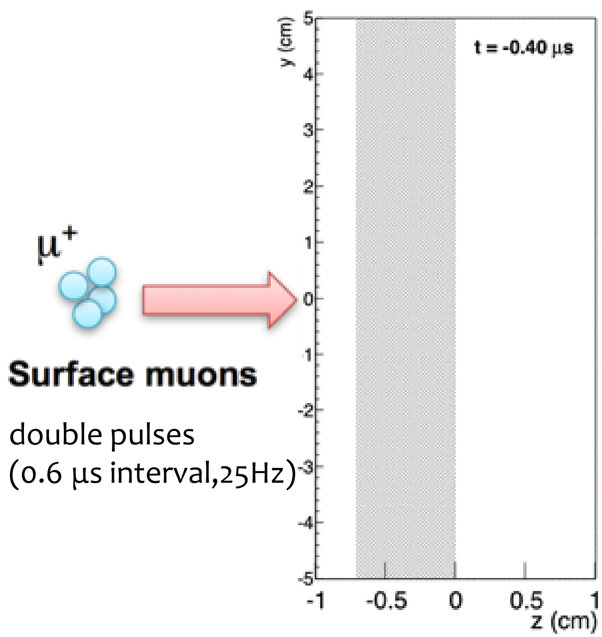
RIKEN, TRIUMF, UVic,
Chiba, Korea U, KEK



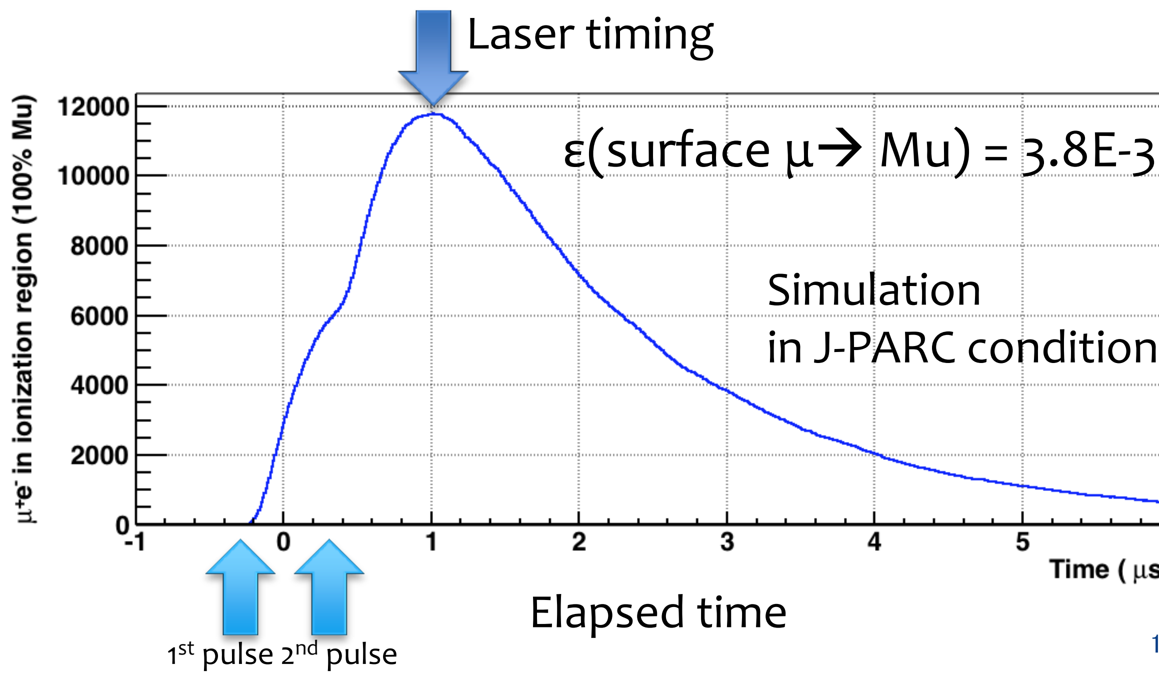
Mu production target
(laser-ablated silica aerogel)



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

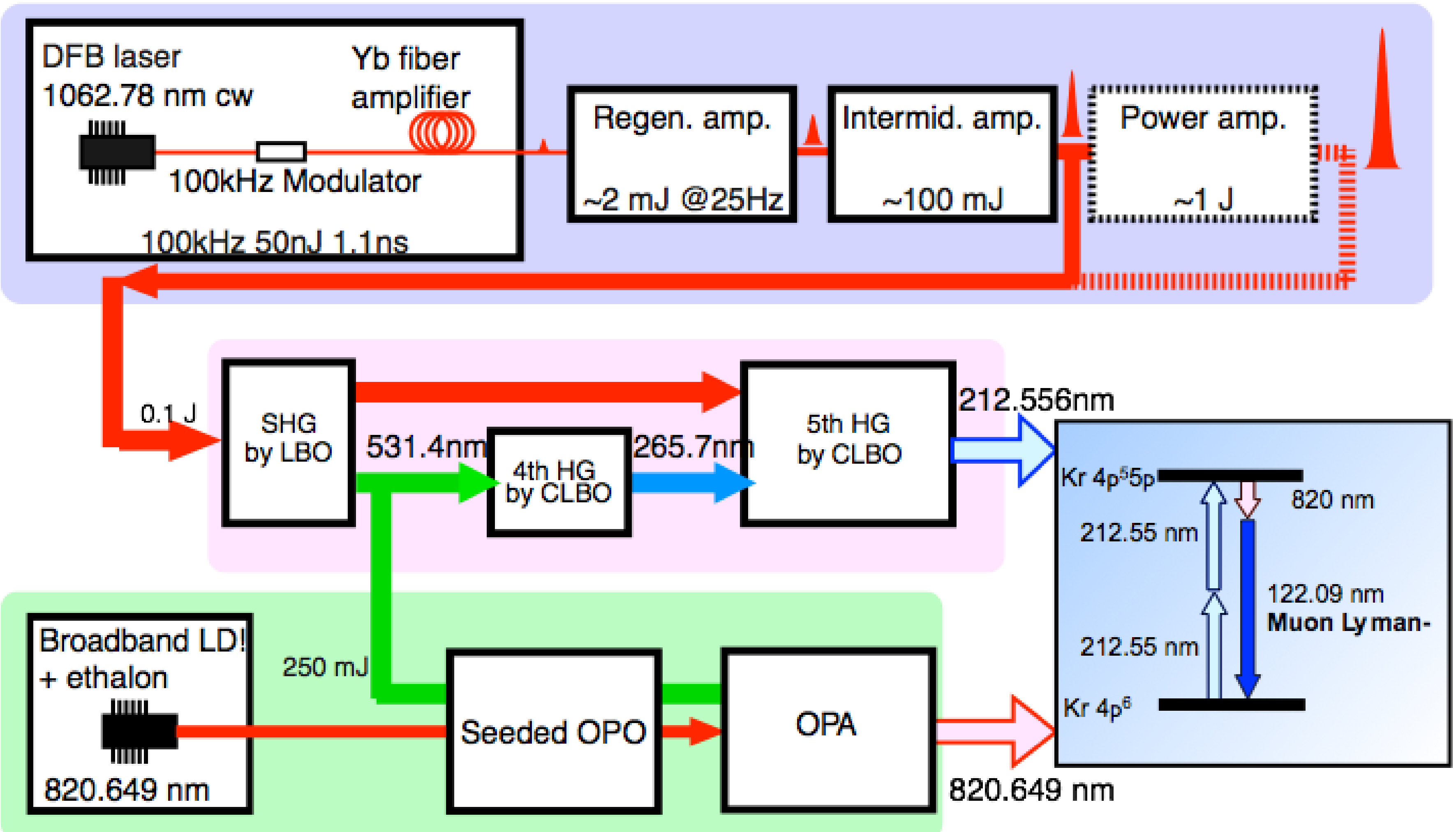


G. Marshall



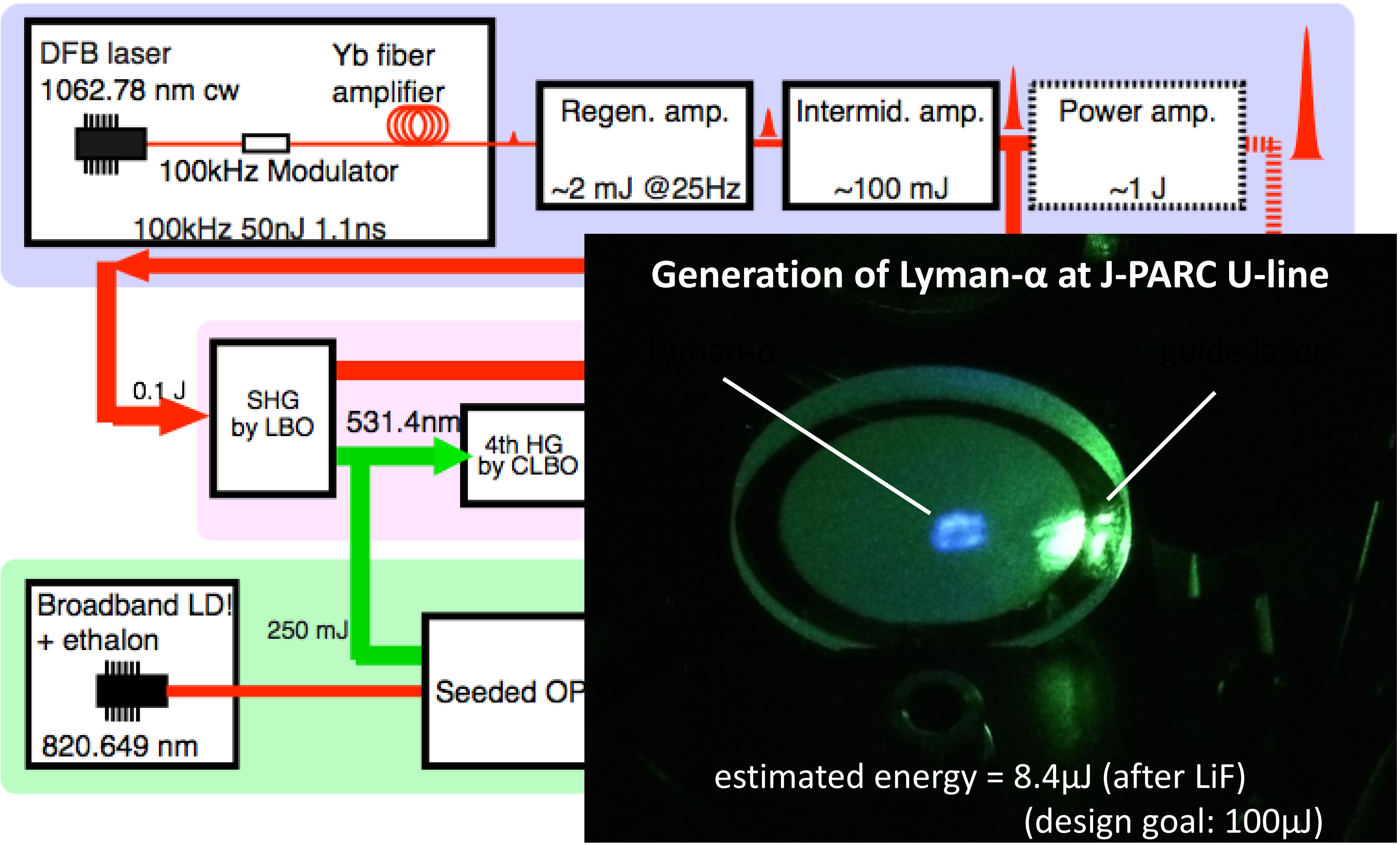
Schematic of laser system

Slide by Satoshi Wada (RIKEN)



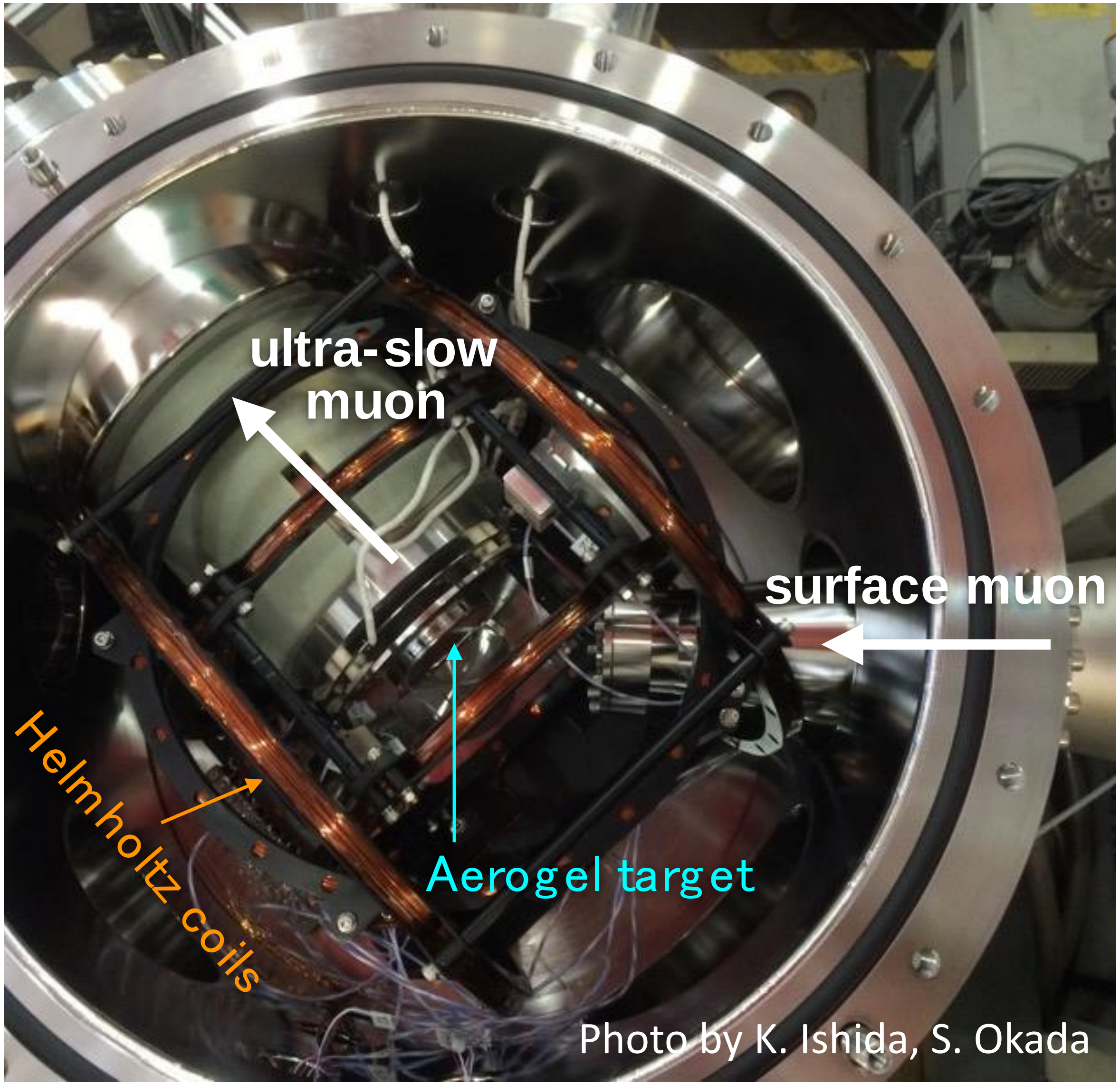
Schematic of laser system

Slide by Satoshi Wada (RIKEN)



The power amplifier (x10) to be installed for higher power.

Studies on laser ionization of muonium at RIKEN-RAL port-3



RIKEN, TRIUMF, UBC, UVic

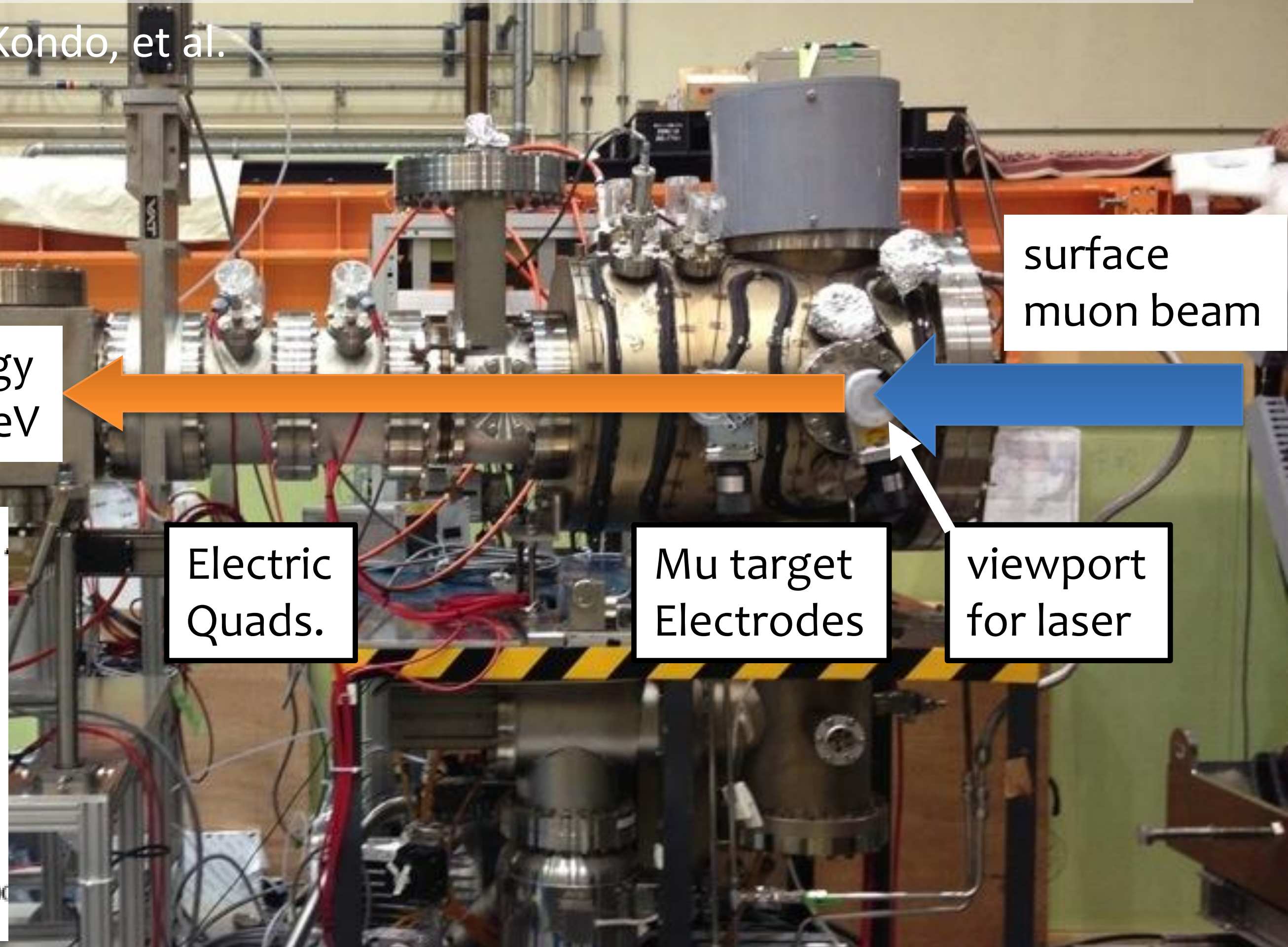
First demonstration of laser ionization of Mu from silica aerogel.

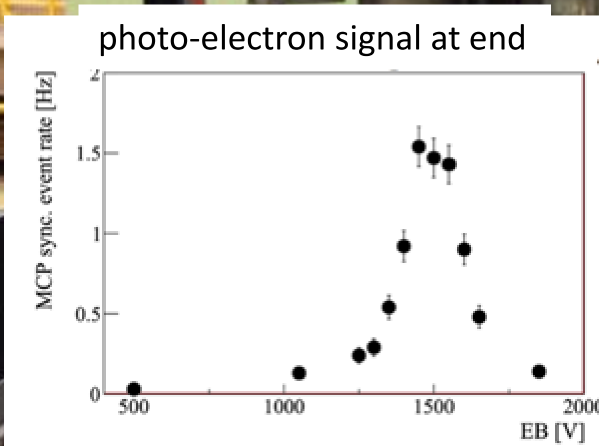
A commissioning run was succeeded. Mu production observed.

Next steps:
Beam tune & BG study (Dec 2015)
laser ionization (2016-)

Muon acceleration studies at J-PARC

M. Otani, R. Kitamura, Y. Kondo, et al.

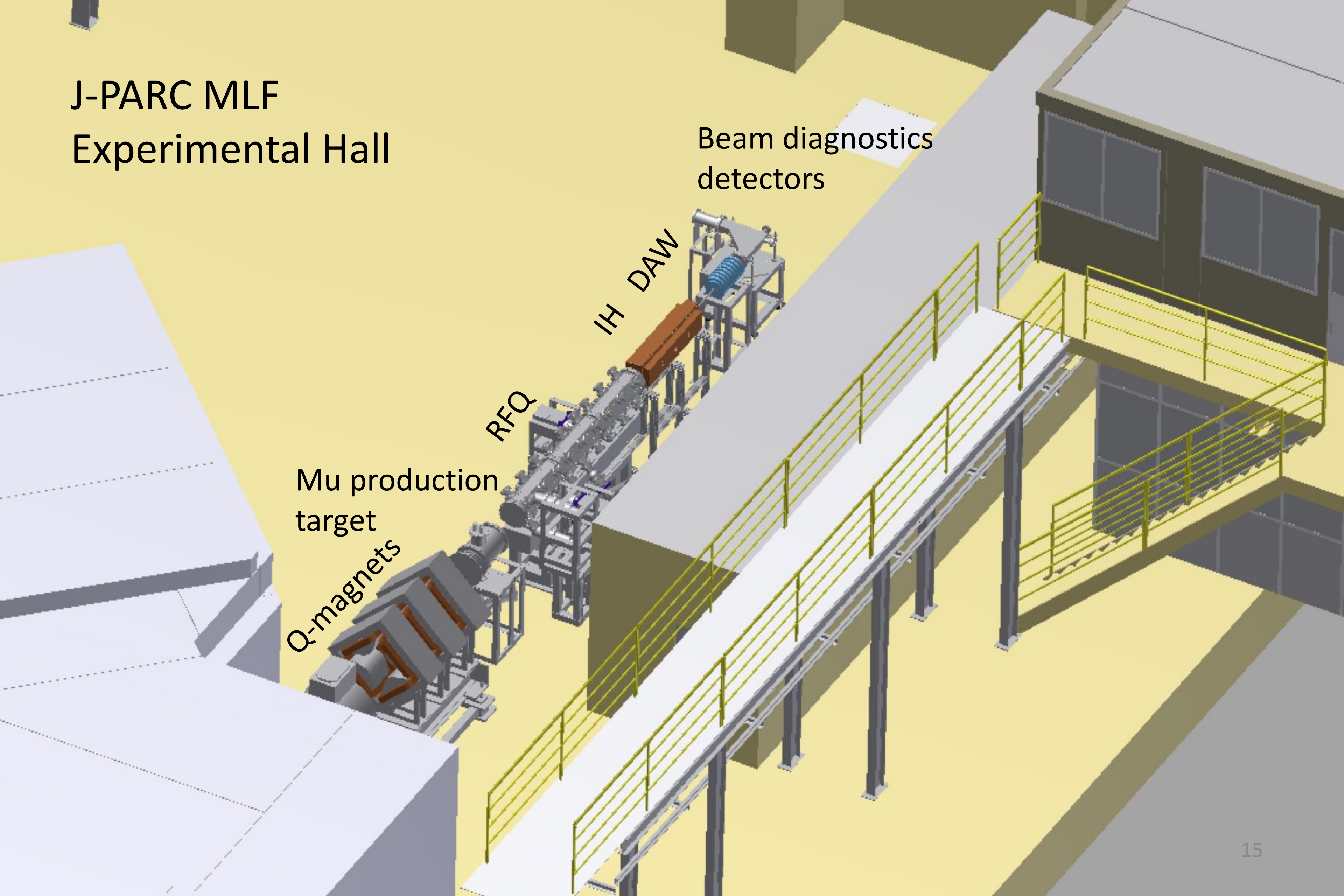




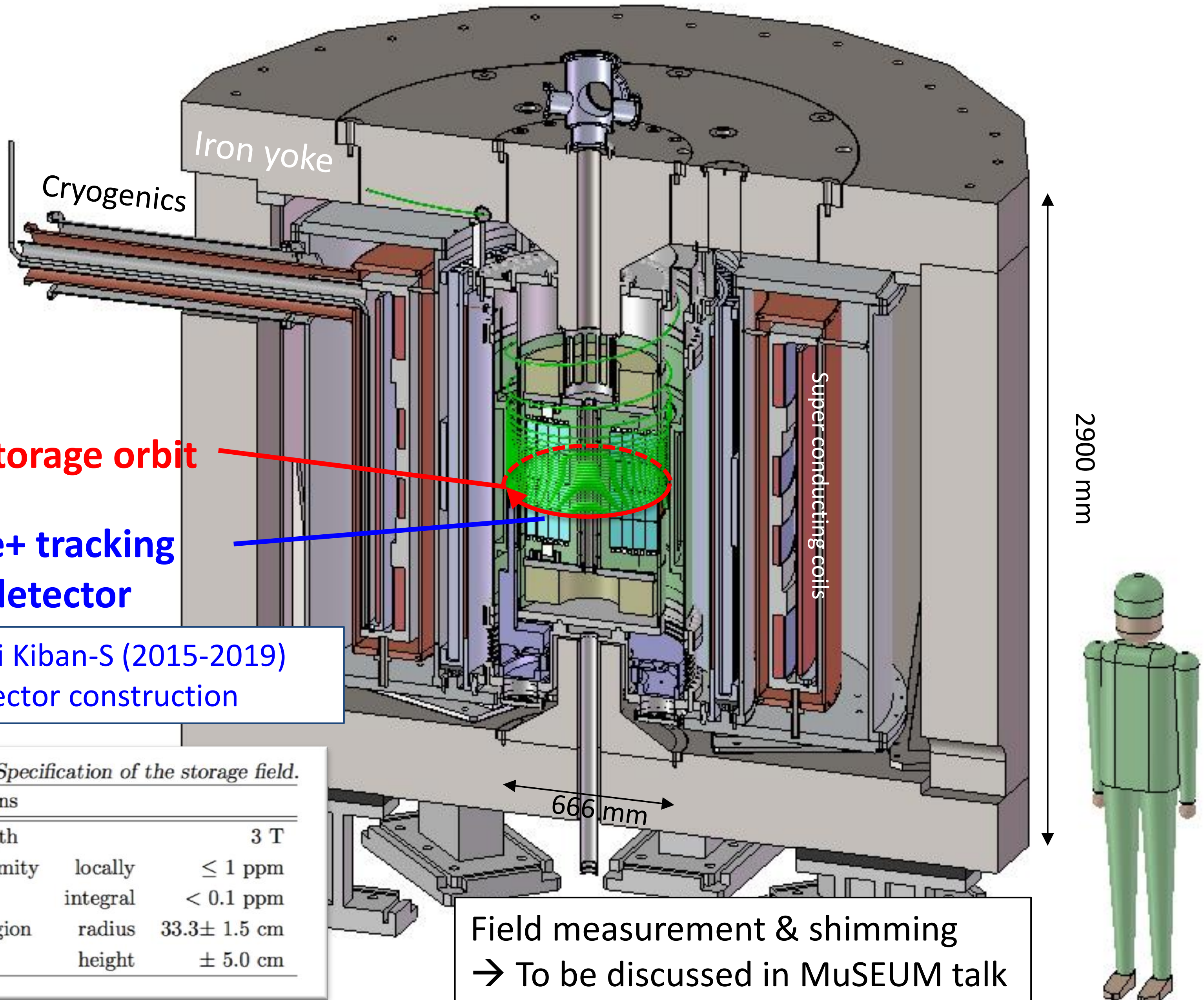
Main apparatus were recycled from RIKEN-RAL port-3

To be commissioned with Mu- at MLF D-line

Layout of the acceleration test



Muon storage magnet and detector



Kakenhi Kiban-S (2015-2019)
for detector construction

Table 1.2: Specification of the storage field.

specifications		
field strength		3 T
field uniformity	locally	$\leq$ 1 ppm
	integral	$<$ 0.1 ppm
uniform region	radius	33.3$\pm$ 1.5 cm
	height	$\pm$ 5.0 cm

Field measurement & shimming
→ To be discussed in MuSEUM talk

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Summary

- A technical design was developed to measure muon g-2 and EDM with ultra-cold muon beam (TDR).
- Data taking can start from 2019 (technically-driven schedule)
- R&D is in the final stage to meet remaining milestones.
- Detector construction fund is partially approved.
- Full approval is being discussed in PACs