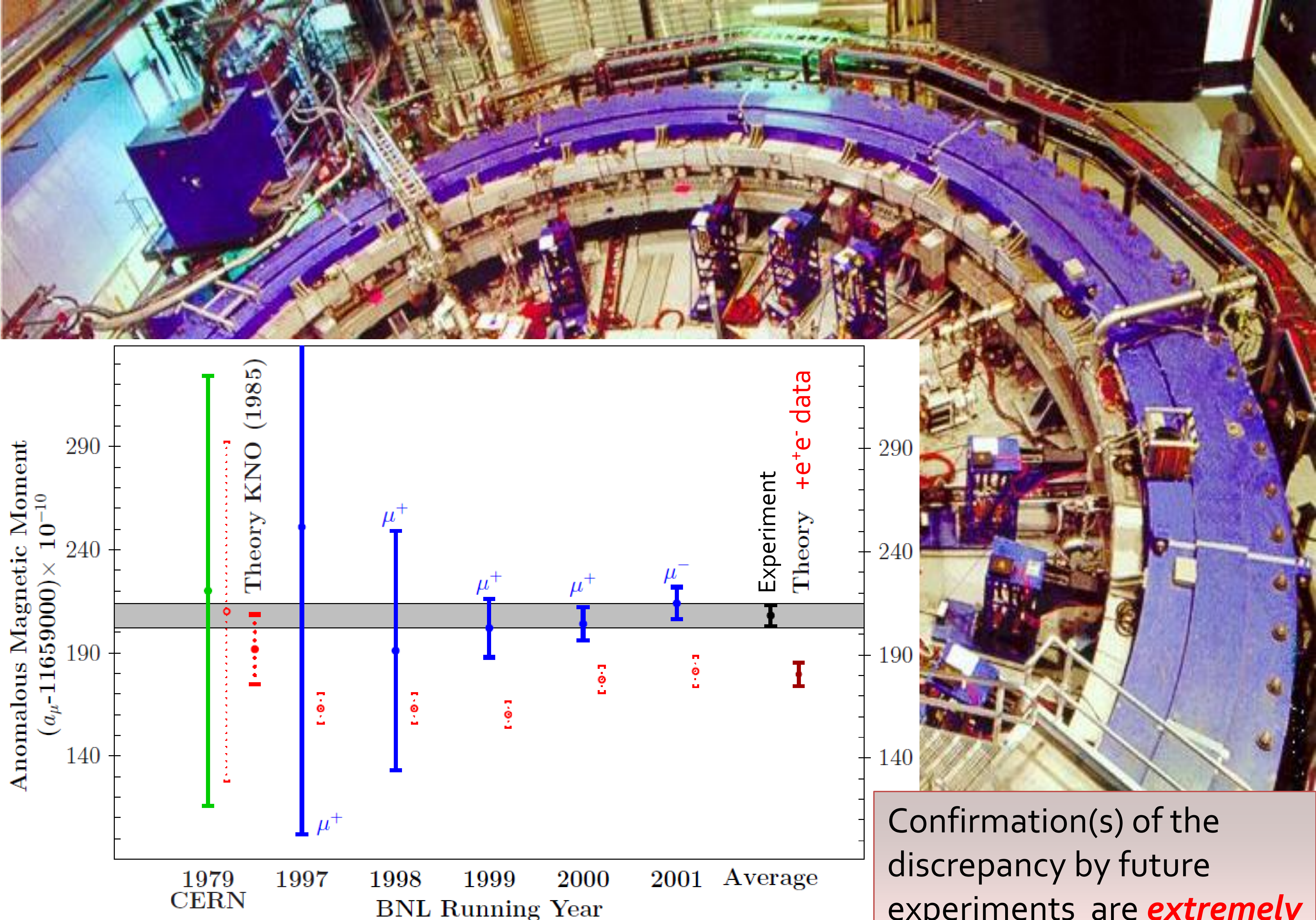
Measurement of muon g-2 and EDM with an ultra-cold muon beam at J-PARC

September 15, 2010

Tsutomu Mibe (KEK)
for the J-PARC muon g-2 collaboration

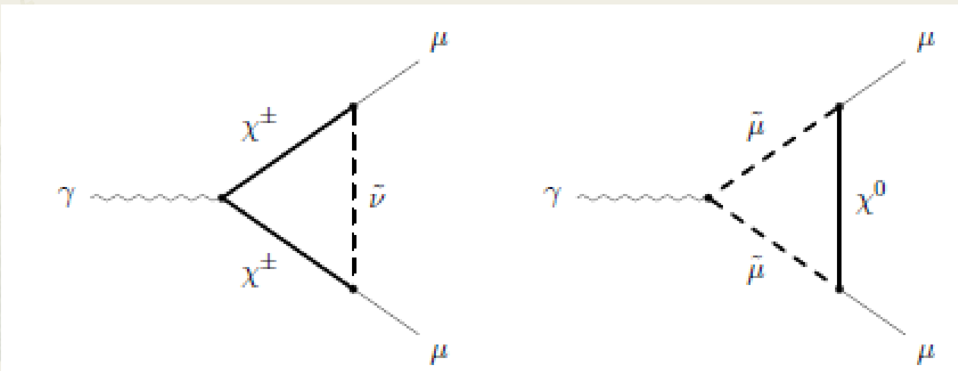


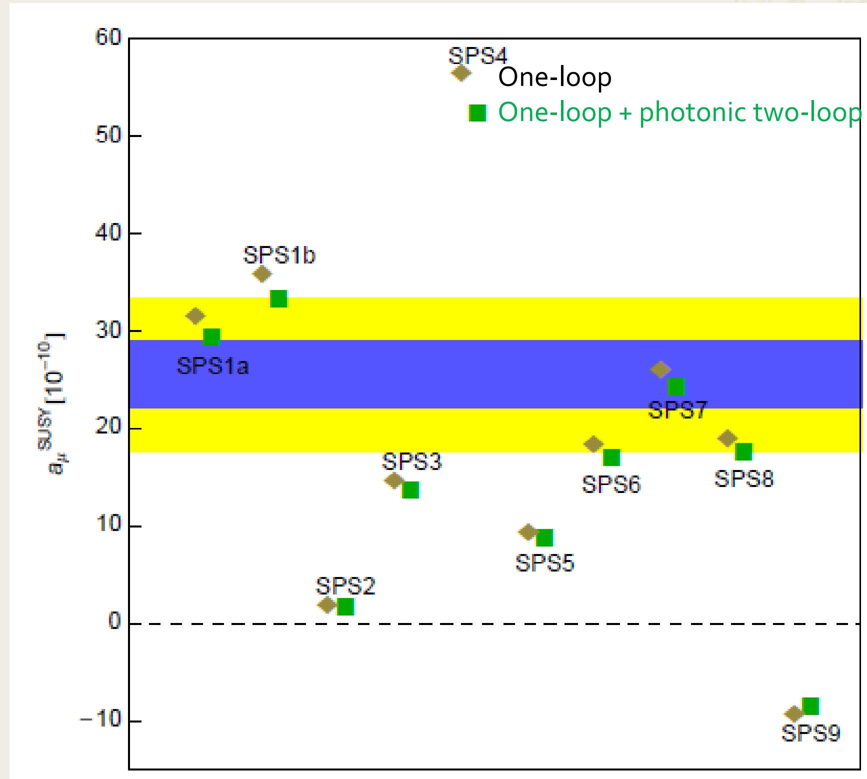
Courtesy F. Jergerlehner, arXiv:0902.3360

Confirmation(s) of the discrepancy by future experiments are ***extremely*** important.

Natural explanation?

Weitershausen, Schafer, Stockinger-Kim, Stockinger
Phys.Rev.D81:093004 (2010)





- Contributions from SUSY diagrams covers the E821 deviation.
- Strong sensitivity to tanβ

$$a_\mu^{\mathrm{SUSY}} = (\mathrm{sgn}\mu) \times 13 \times 10^{-10} \times \left(\frac{100\mathrm{GeV}}{\tilde{m}}\right)^2 \tan\beta$$

  - Complementary to LHC searches.

Muon anomalous spin precession in B and E-field

- Precession frequency

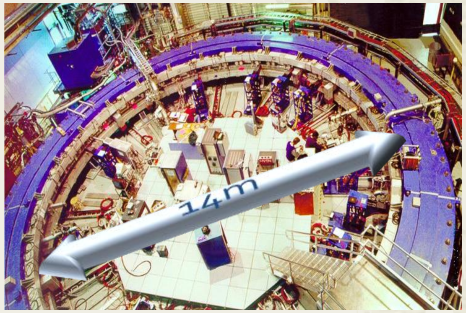
$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

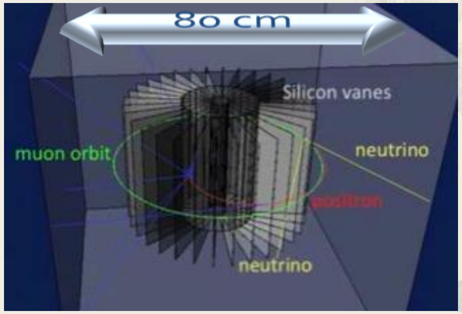
- Focusing **electric field** to confine muons in the storage ring.
- At the **magic momentum**
  - $1/(\gamma^2-1) = a_\mu$
  - $\gamma = 29.3$, $p = 3.094$ GeV/c

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

With present upper limit, EDM term can safely be neglected in g-2 measurement.

New approach: Going to lower momentum





- Disadvantages
  - No longer at magic momentum.
  - Muon decays more quickly.
- … However, experimental apparatus can be **compact**.
  - Better accuracy of B-field, e.x. 1 ppm local accuracy acheived in MRI magnet
  - Stronger B-field, i.e. more precession
  - Better environmental control
    - temperature, EM noise shielding etc.
  - Completely different systematics than the BNL E821 or FNAL
- Ok, but how do we deal with the $\beta \times E$ term?
  - **Zero electric field**

Another way to vanish the βxE term

Zero Electric field (E = 0)

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

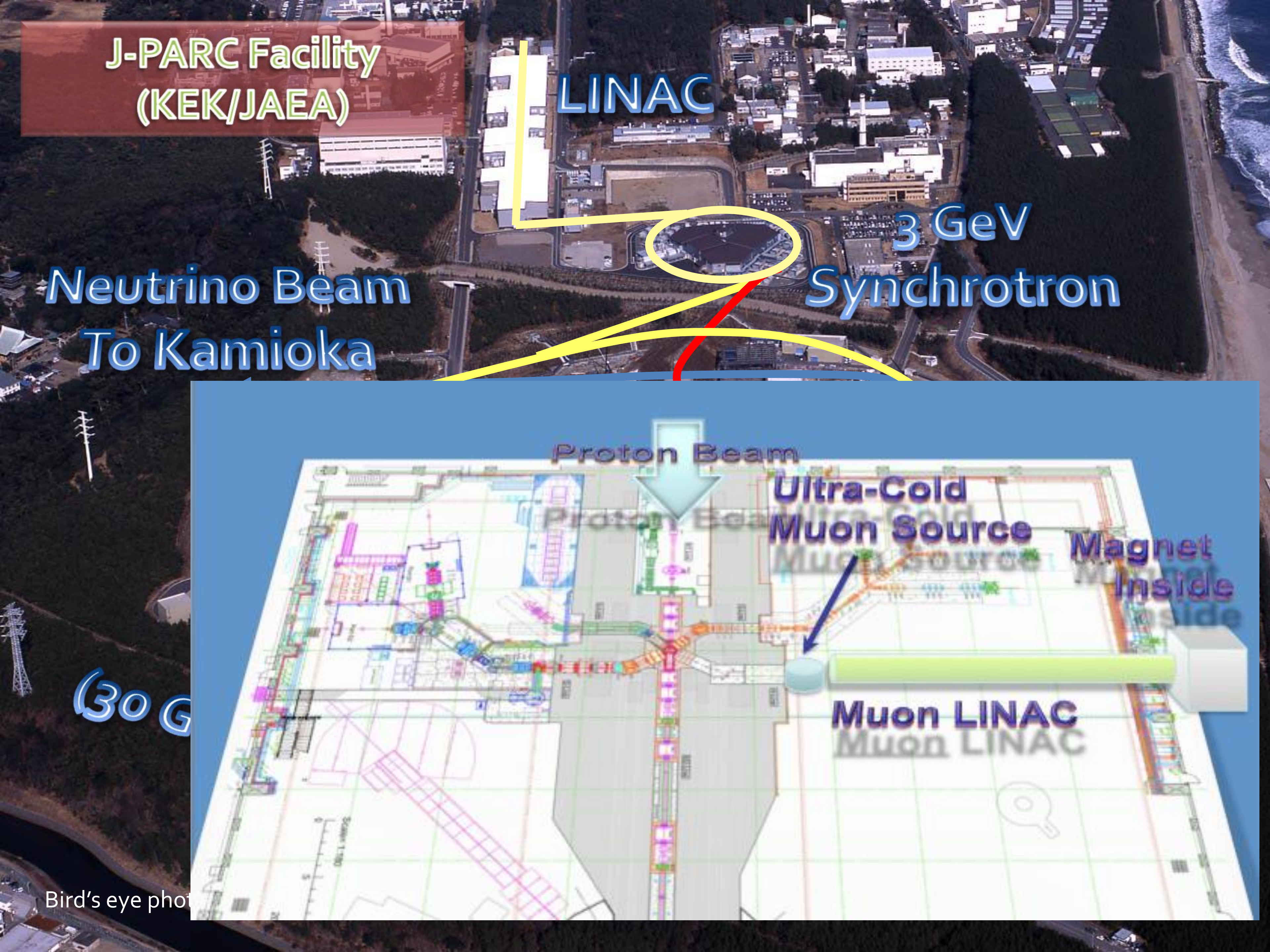
$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$

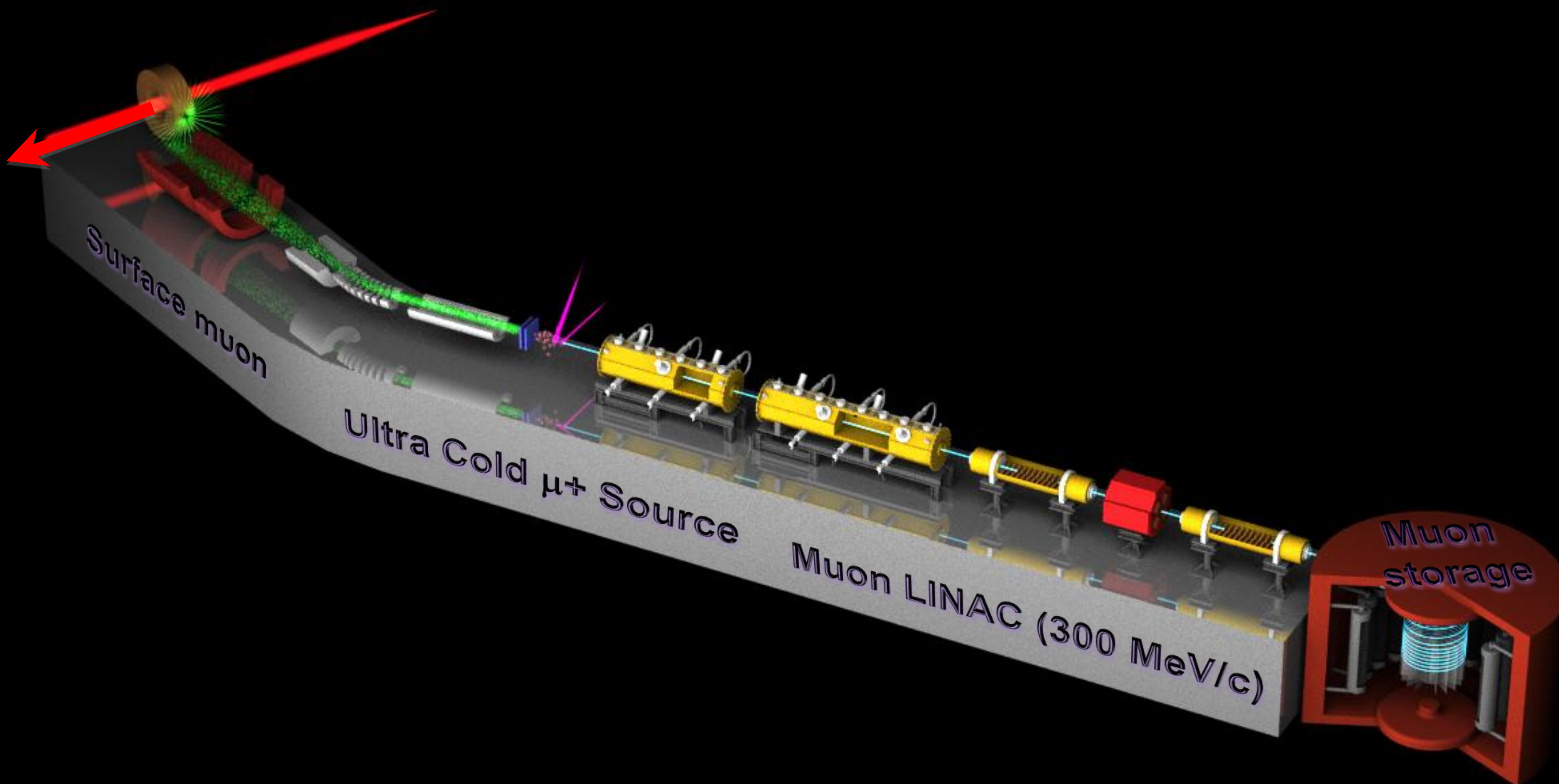
Equations of spin motion is as simple as at the magic momentum

Fine, but how do we confine muons without focusing E-field?

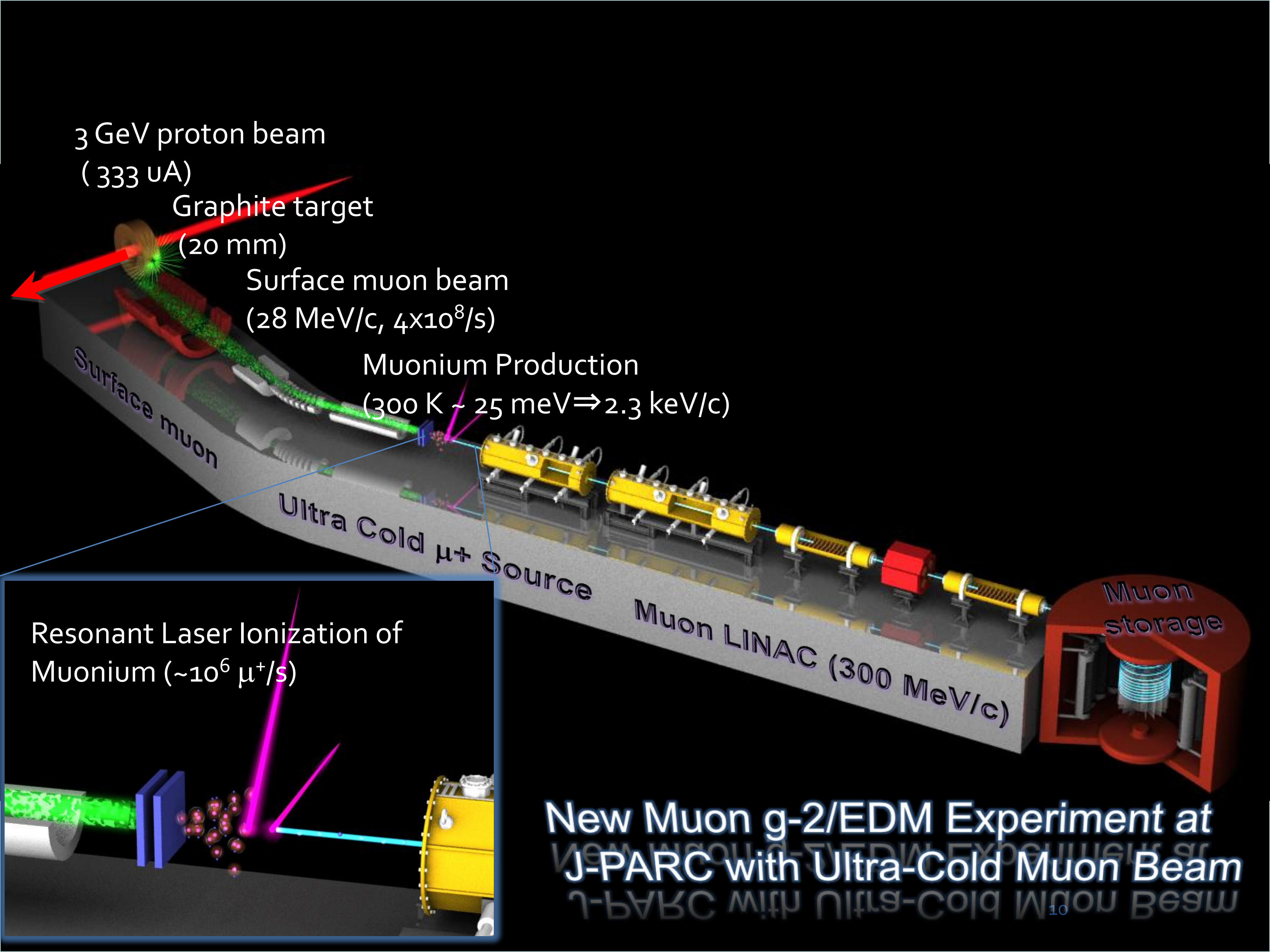
→ **Ultra-cold muon beam ($p_T/p < 10^{-5}$)**

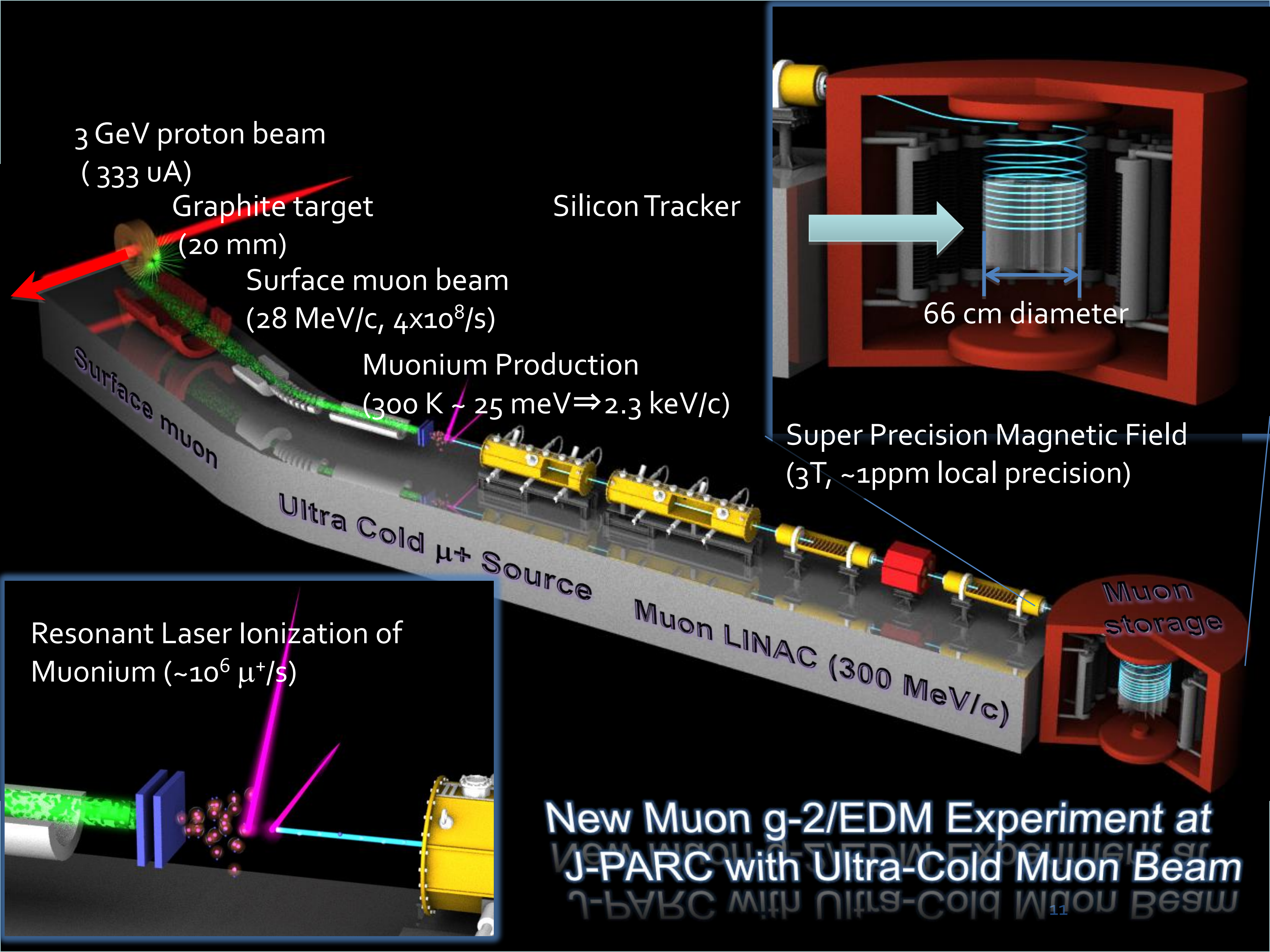

J-PARC Facility
(KEK/JAEA)
LINAC
3 GeV
Synchrotron
Neutrino Beam
To Kamioka
Material and Life Science
Facility
Main Ring
(30 GeV → 50 GeV)
Hadron Hall
Bird's eye photo in Feb. 2008


J-PARC Facility
(KEK/JAEA)
LINAC
3 GeV
Synchrotron
Neutrino Beam
To Kamioka
(30 G
Proton Beam
Ultra-Cold
Muon Source
Magnet
Inside
Muon LINAC
Bird's eye phot

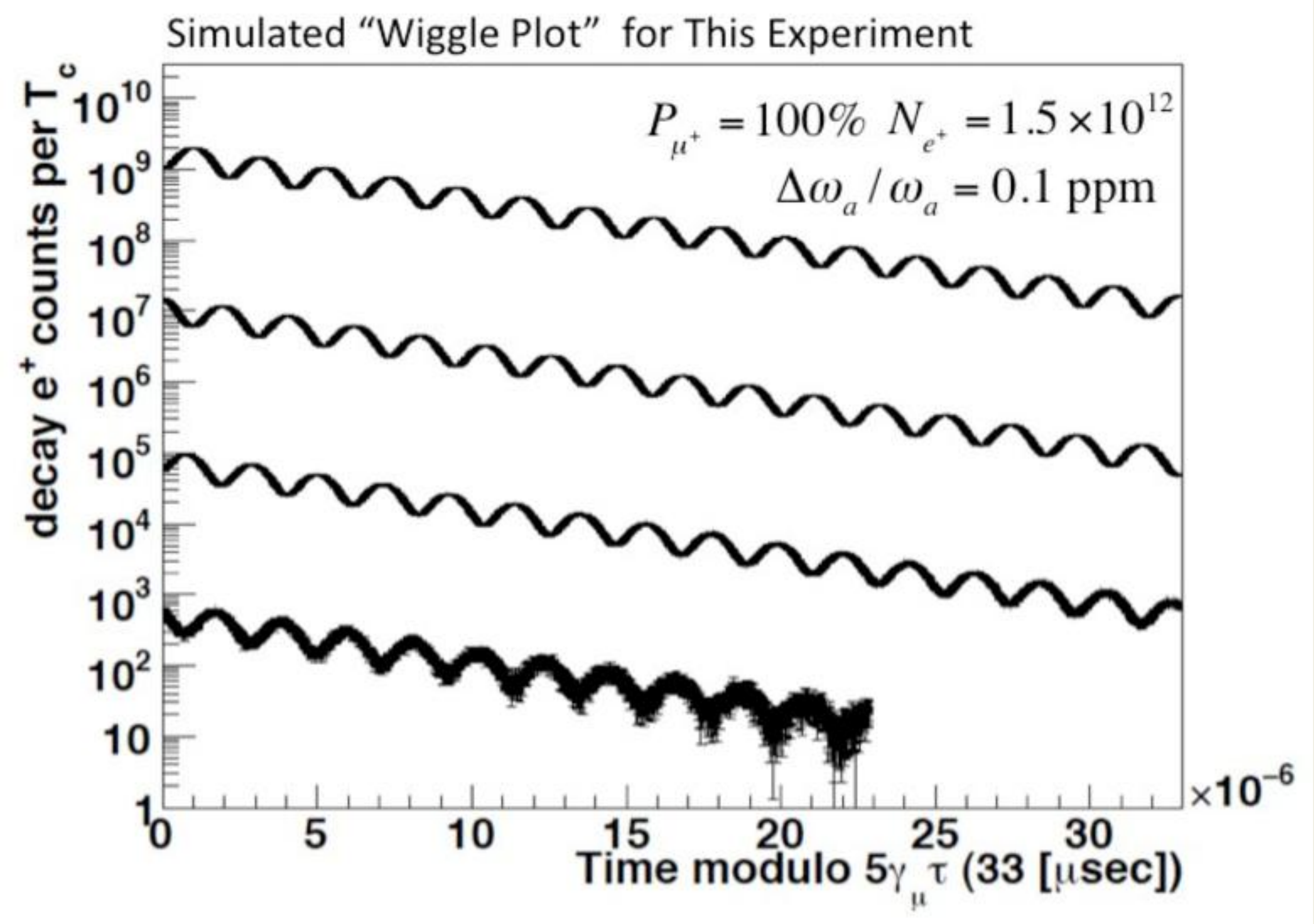


New Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam


3 GeV proton beam
(333 uA)
Graphite target
(20 mm)
Surface muon beam
(28 MeV/c, 4x10^8/s)
Muonium Production
(300 K ~ 25 meV⇒2.3 keV/c)
Surface muon
Ultra Cold μ+ Source
Muon LINAC (300 MeV/c)
Muon storage
Resonant Laser Ionization of
Muonium (~10^6 μ+/s)
New Muon g-2/EDM Experiment at
J-PARC with Ultra-Cold Muon Beam


3 GeV proton beam
(333 uA)
Graphite target
(20 mm)
Surface muon beam
(28 MeV/c, 4x10^8/s)
Muonium Production
(300 K ~ 25 meV⇒2.3 keV/c)
Silicon Tracker
66 cm diameter
Super Precision Magnetic Field
(3T, ~1ppm local precision)
Surface muon
Ultra Cold μ+ Source
Muon LINAC (300 MeV/c)
Muon storage
Resonant Laser Ionization of
Muonium (~10^6 μ+/s)
New Muon g-2/EDM Experiment at
J-PARC with Ultra-Cold Muon Beam

Positron decay time spectrum



BNL, FNAL, and J-PARC

	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		None
# of detected μ+ decays	5.0E9	1.8E11	1.5E12
# of detected μ- decays	3.6E9	-	-
Precision (stat)	0.46 ppm	0.1 ppm	0.1 ppm

J-PARC g-2/EDM collaboration

- 71 members (…still evolving)
- M. Aoki, P. Bakule, B. Bassalleck, G. Beer, A. Deshpande, S. Eidelman, D. E. Fields, M. Finger, M. Finger Jr., Y. Fujirawa, S. Hirota, H. Iinuma, M. Ikegami, K. Ishida, M. Iwasaki, T. Kakurai, T. Kamitani, Y. Kamiya, N. Kawamura, S. Komamiya, K. Koseki, Y. Kuno, O. Luchev, G. Marshall, M. Masuzawa, Y. Matsuda, T. Matsuzaki, T. Mibe, K. Midorikawa, S. Mihara, Y.Miyake, J. Murata, W.M. Morse, R. Muto, K. Nagamine, T. Naito, H. Nakayama, M. Naruki, H. Nishiguchi, M. Nio, D. Nomura, H. Noumi, T. Ogawa, T. Ogitsu, K. Ohishi, K. Oide, A. Olin, N. Saito, N.F. Saito, Y. Sakemi, K. Sasaki, O. Sasaki, A. Sato, Y. Semeritzidis, K. Shimomura, B. Shwartz, P. Strasser, R. Sugahara, K. Tanaka, N. Terunuma, D. Tomono, T.Toshito, K. Ueno, V. Vrba, S. Wada, A. Yamamoto, K. Yokoya, K. Yokoyama, Ma. Yoshida, M. H. Yoshida, and K. Yoshimura

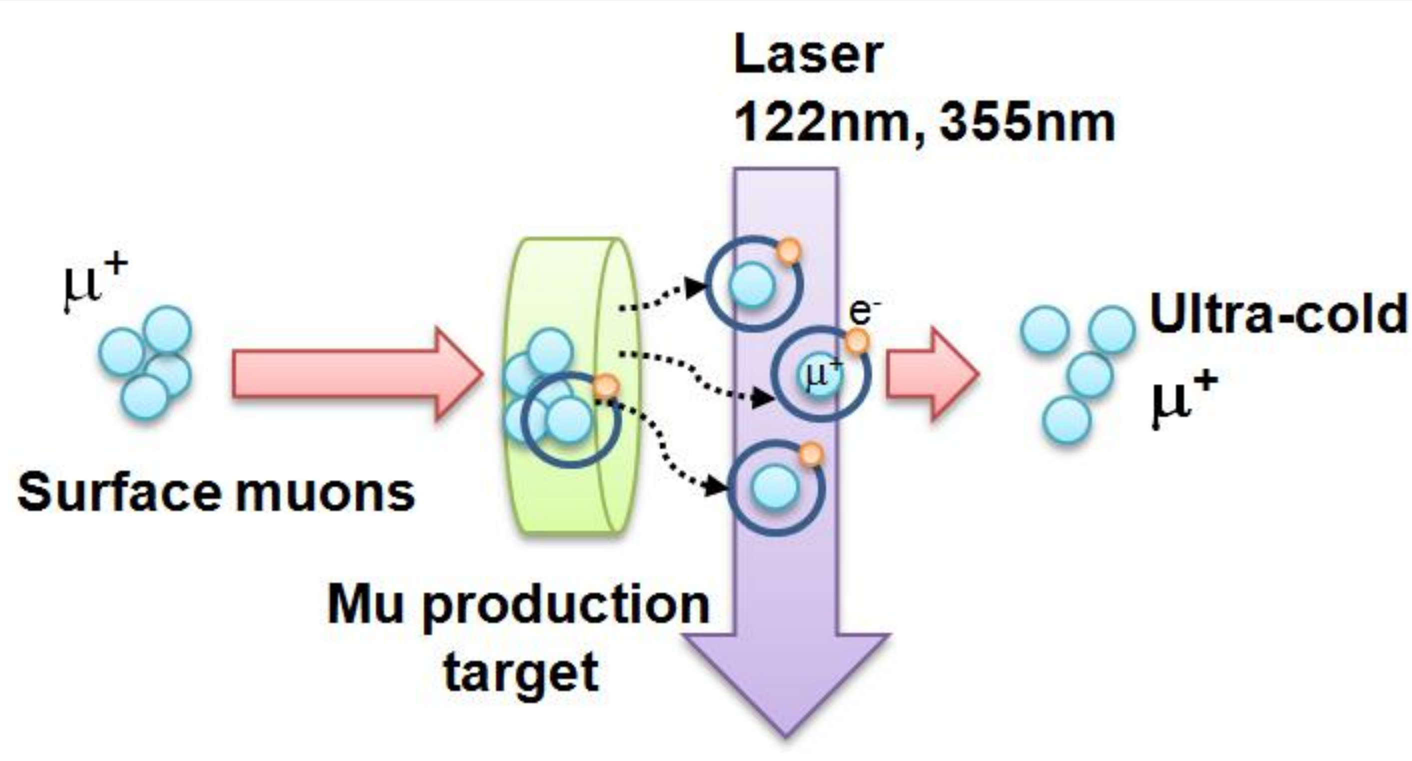
- 18 Institutions
- Academy of Science, BNL, BINP, UC Riverside, Charles U., KEK, NIRS, UNM, Osaka U., RCNP, STFC RAL, RIKEN, Rikkyo U., SUNYSB, CRC Tohoku, U. Tokyo, TRIUMF, U. Victoria
- 6 countries
- Czech, USA, Russia, Japan, UK, Canada

Muon source

Requrements:

40000 times more muons, and

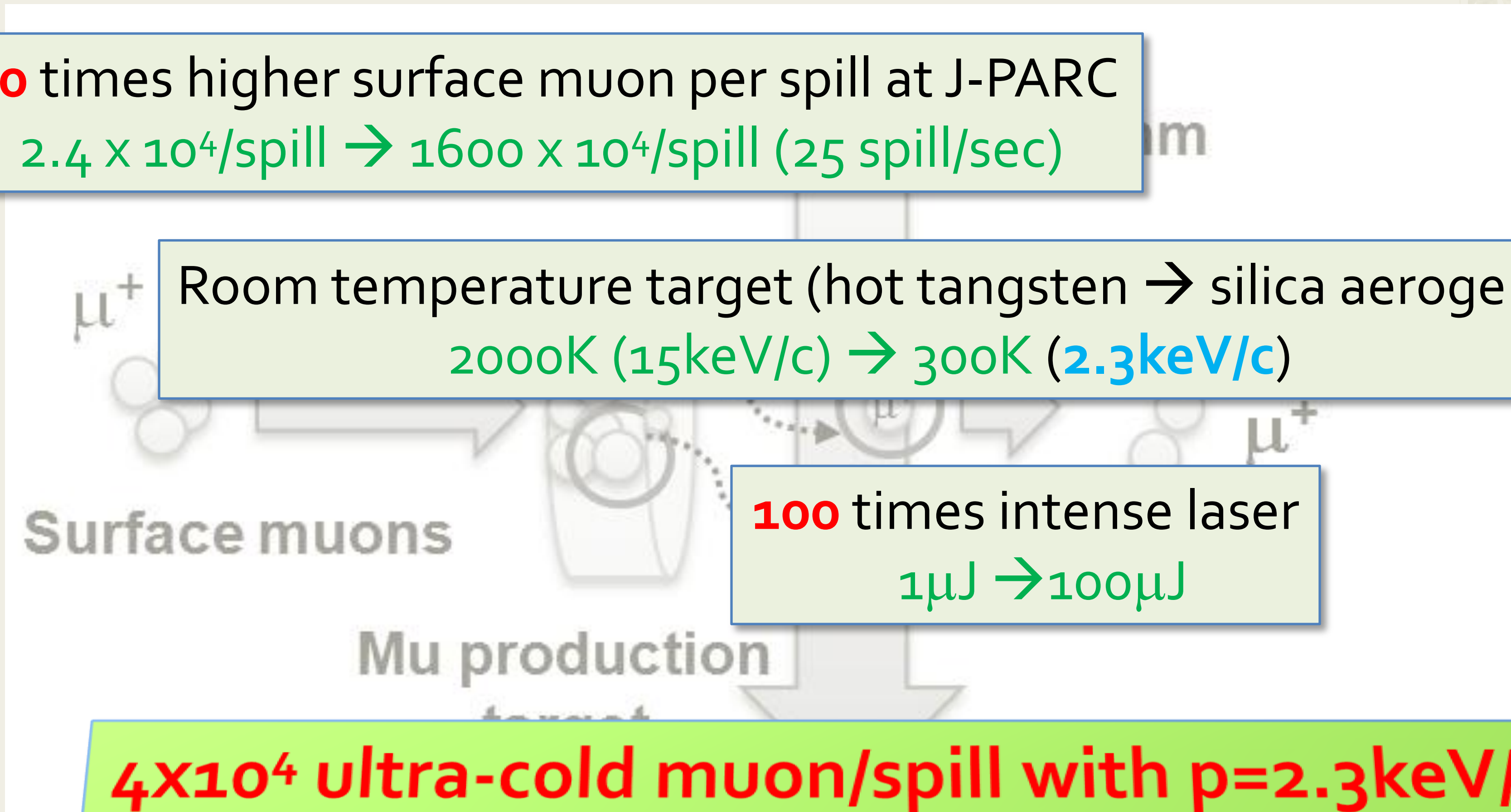
Cooler muon than RAL



Muon source

<u>Requrements:</u>

40000 times more muons, and
Cooler muon than RAL



670 times higher surface muon per spill at J-PARC

2.4×10^4/spill → 1600×10^4/spill (25 spill/sec)

Room temperature target (hot tangsten → silica aerogel?)

2000K (15keV/c) → 300K (**2.3keV/c**)

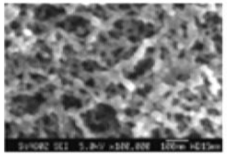
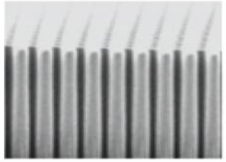
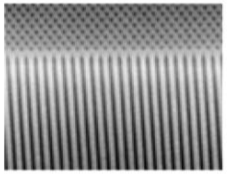
100 times intense laser

1μJ →100μJ

4×10^4 ultra-cold muon/spill with p=2.3keV/c

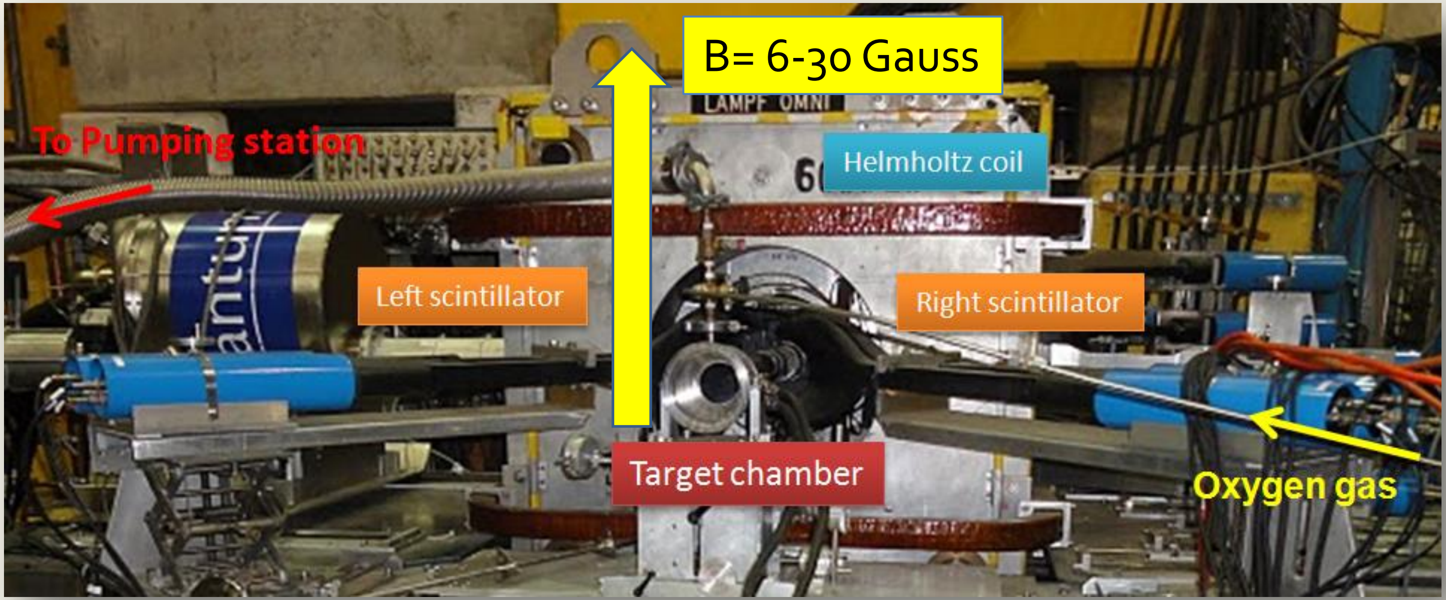
TRIUMF-S1249: Search for muonium emitting material at room temp.

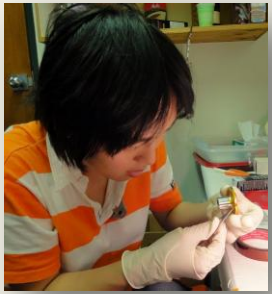
RIKEN/KEK/TRIUMF/U.Victoria

Material	Density (g/cm^3)	Thickness (mm)	Structure	
Silica powders (SiO_2)	0.03, 0.075	37.5	Chain of nano-grains	
Silica aerogel (SiO_2)	0.03, 0.05, 0.11	20	Chain of nano-grain	
Porous Silica (SiO_2)	1.1	0.05 – 0.07	Nano-porous (10 μm pitch)	
Porous Alumina (Al_2O_3)	2.9	0.09 ,0.255, 0.4	Nano-porous (60-450 nm pitch)	

S1249 beam time at TRIUMF M20

June 23 ~ July 1, 2010





target sample

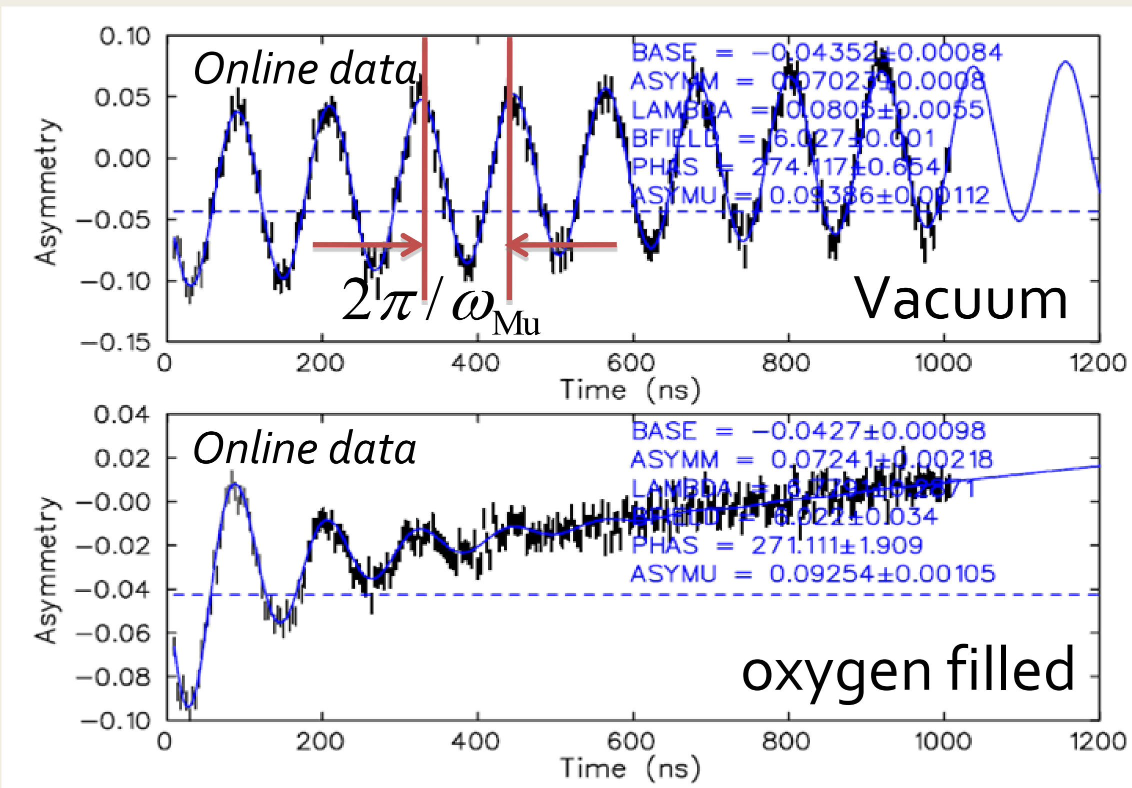
S1249 data : first look

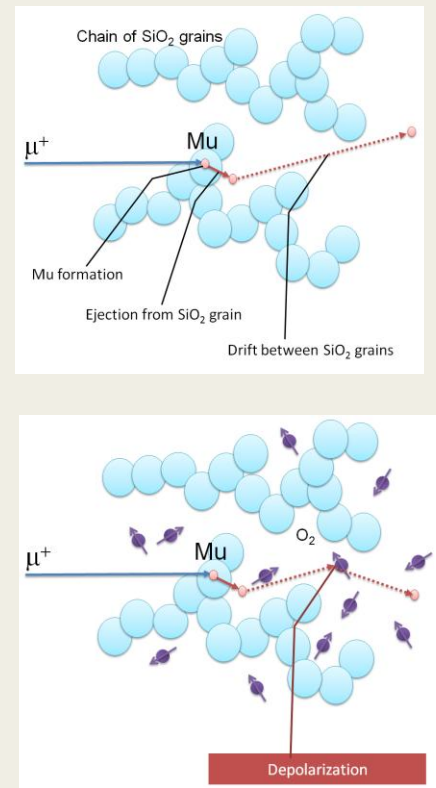
muonium spin rotation | μ spin rotation

L-R asymmetry= $A_{Mu}e^{-\lambda t}\cos(\omega_{Mu}t+\phi_{Mu}) + A_{\mu}\cos(\omega_{\mu}t+\phi_{\mu})+A_{o}$

$$\omega_{\mathrm{Mu}} / \omega_{\mu} = \frac{\mu_{\mu} + \mu_{e}}{2} / \mu_{\mu} \approx \frac{m_{\mu}}{2m_{e}}$$

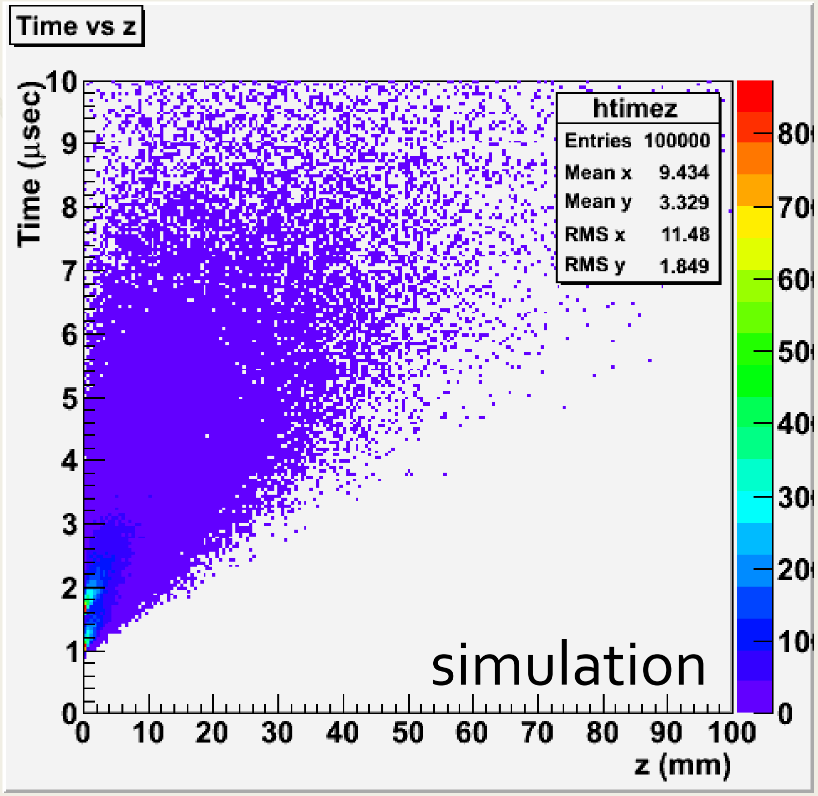
Silica aerogel (0.05g/cm³)

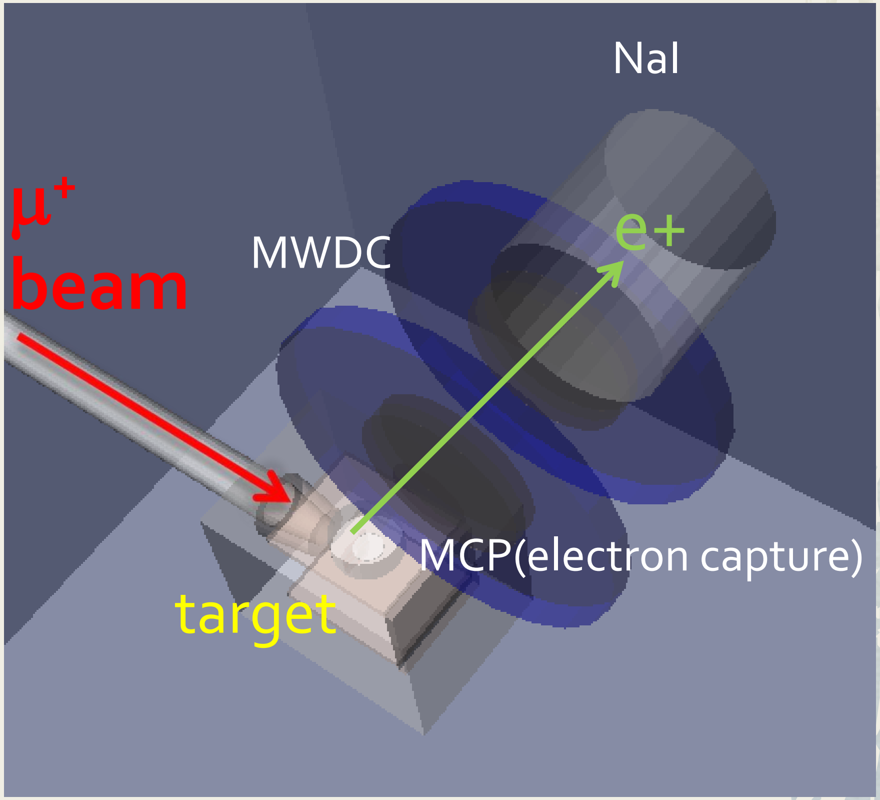




S1249 next step : muonium space-time distribution

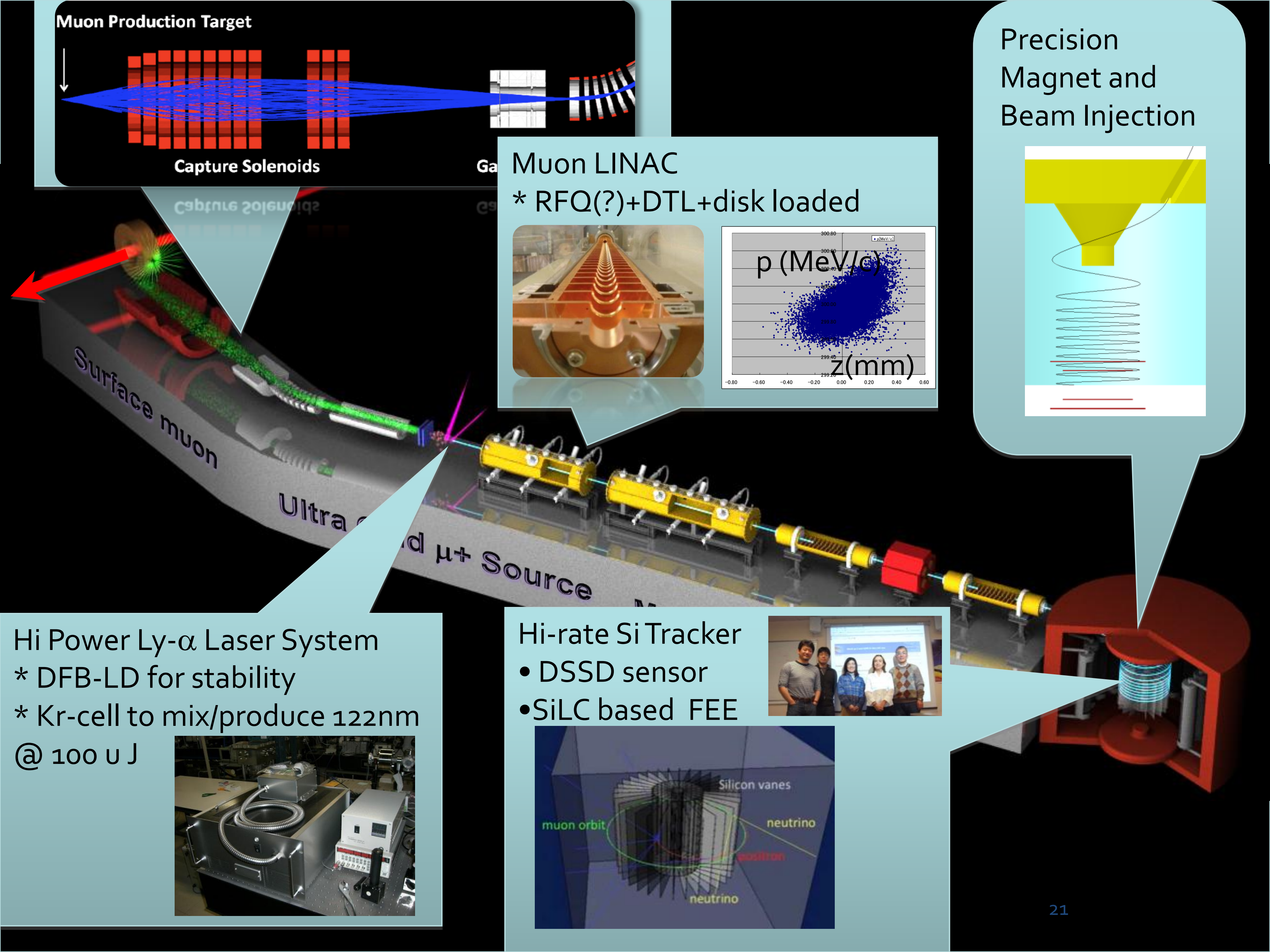
Nov. 18 – 30, 2010





This data will define when and where to shoot the laser.

A test experiment at RAL with new laser & target is planned in 2011.


Muon Production Target
Capture Solenoids
Precision
Magnet and
Beam Injection
Muon LINAC
* RFQ(?)+DTL+disk loaded
p (MeV/c)
z(mm)
Surface muon
Ultra c
d μ+ Source
Hi Power Ly-α Laser System
* DFB-LD for stability
* Kr-cell to mix/produce 122nm
@ 100 u J
Hi-rate Si Tracker
• DSSD sensor
•SiLC based FEE
Silicon vanes
muon orbit
neutrino
positron
neutrino

History and intended plan

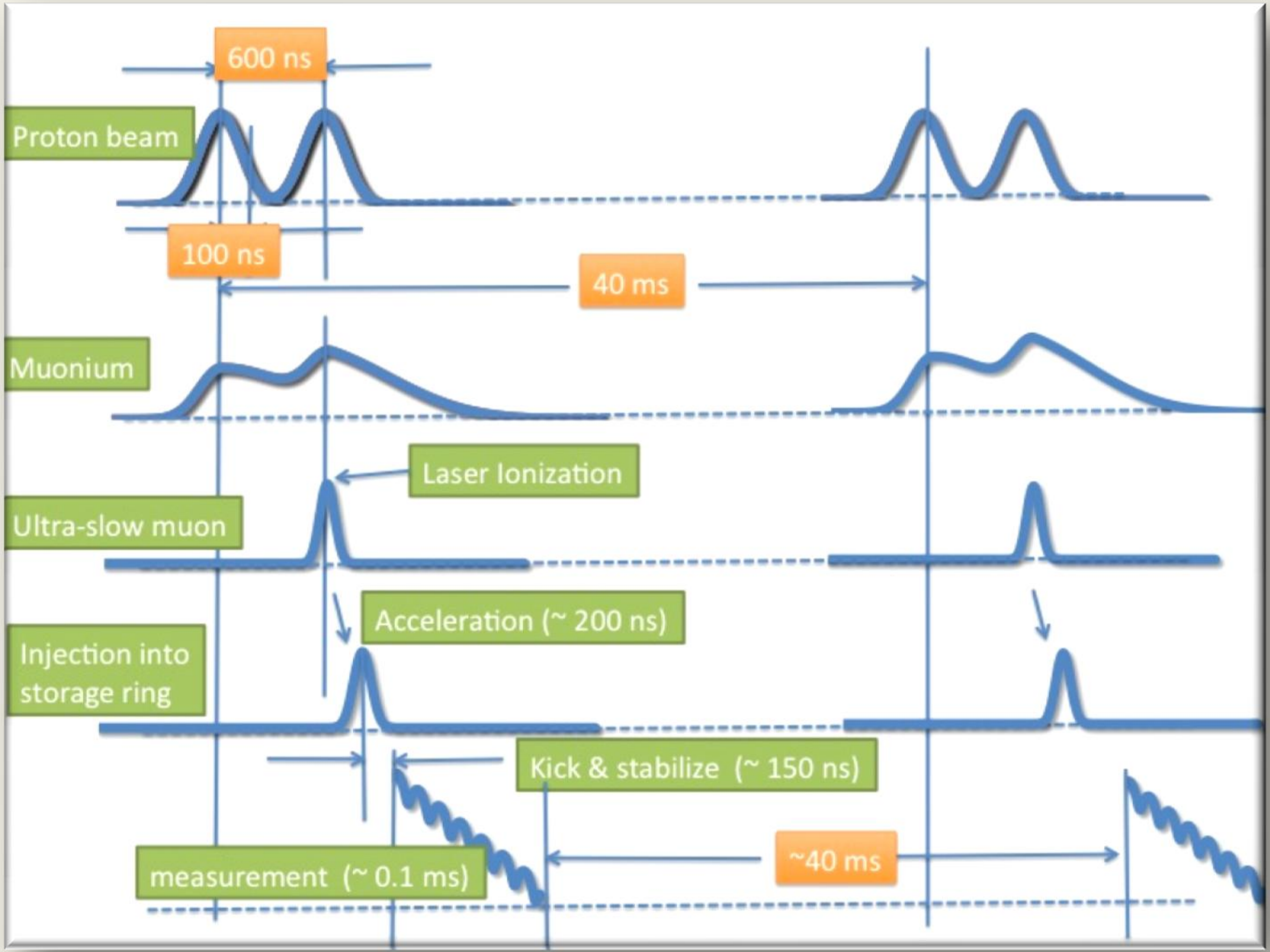
- 2009 June : Letter of intent
- 2009 Dec : Proposal submitted to J-PARC PAC
- 2010 June : 1st collaboration meeting at KEK
- 2010 Dec : Conceptual Design Report
- …
- 2015 : First beam

Summary

- A new muon g-2 experiment at J-PARC:
  - Off-magic momentum
  - Ultra-slow muon beam + compact g-2 ring
  - Complementary to g-2@FNAL
- KEK lab management support R&Ds. There are many progress are being made.

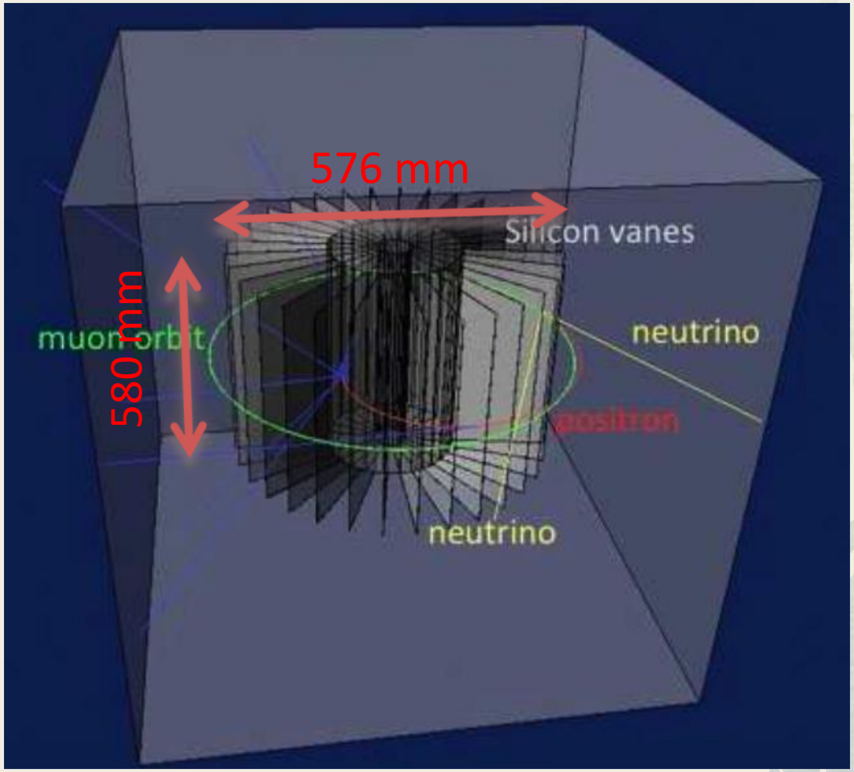
Time structure of the exp.

- Driven by 25 Hz proton beam
- Time-zero defined by Laser Ionization



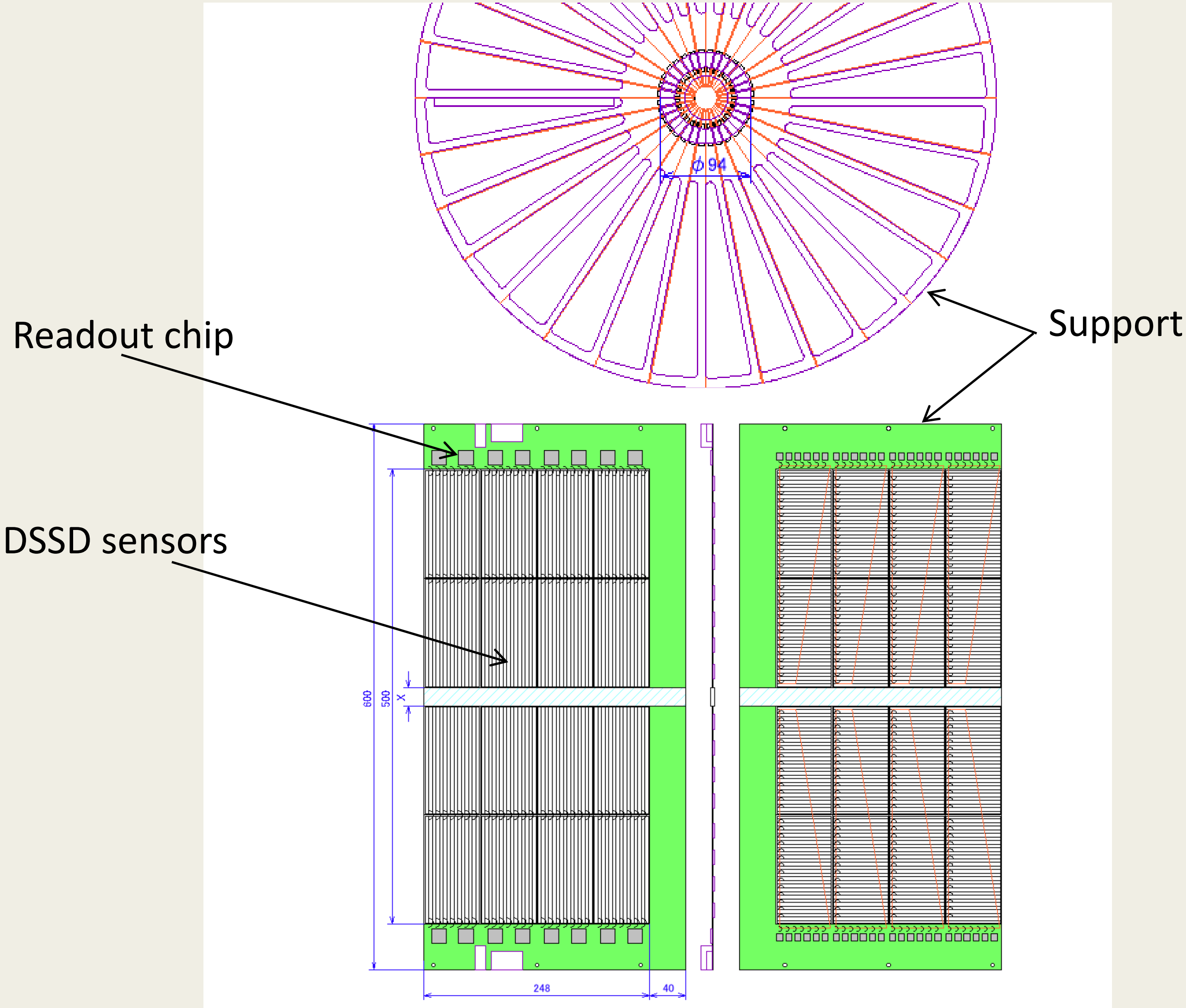
g-2 silicon tracker

- **Detector area**
  - 0.12 * number of vanes [m^2]
  - 2.9 m^2 for 24 vanes
- **Number of sensors**
  - 384 for 24 vanes
- **Number of channels**
  - Assume 0.2 mm pitch
  - 115k for 24 vanes*
    - *288k for multi-segments readout



g-2 silicon tracker

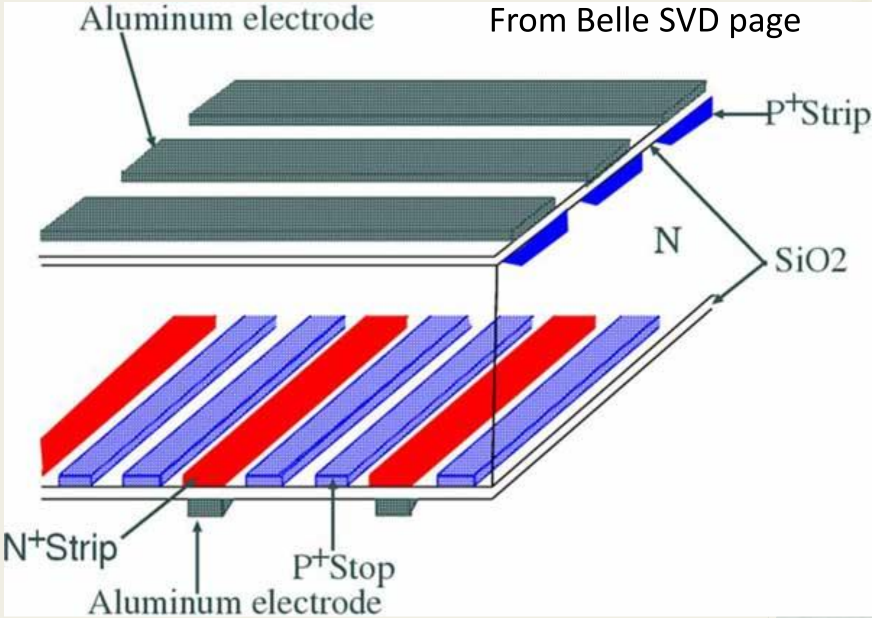
Silicon strip module

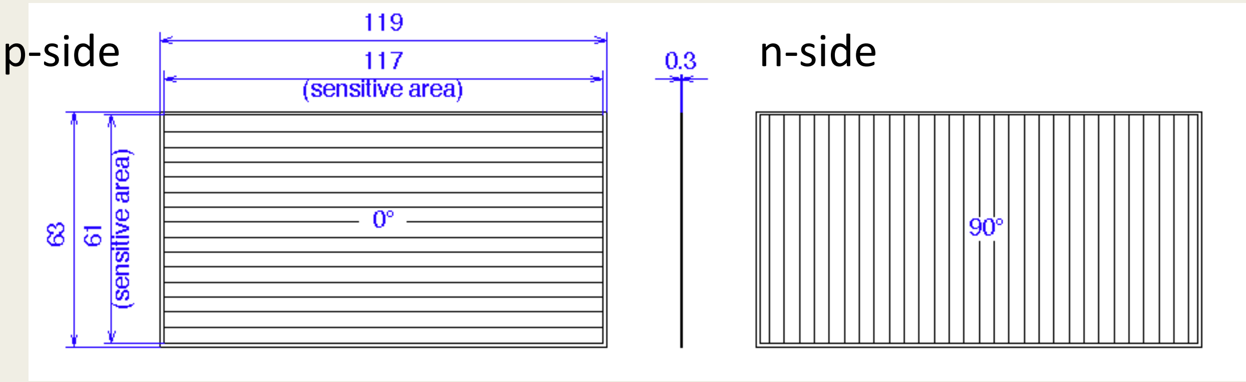


Silicon sensor

- Sensor type : Double-sided SSD
- Chip size : ~12 cm x 6 cm
- Thickness: 320 um
- Readout: AC-couple
- Depletion voltage : 80 V
- Detector capacitance : ~100pF*
- Strip pitch : 200um*

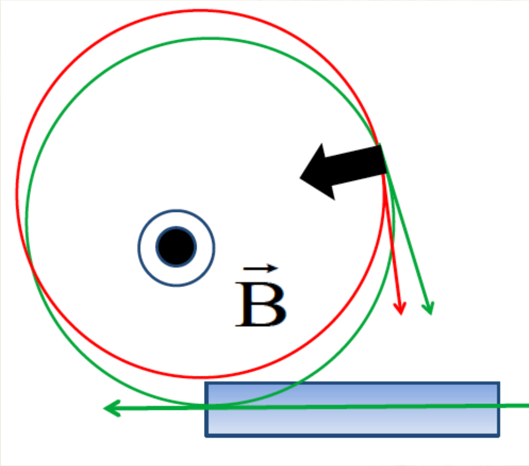
- * to be determined by further studies.



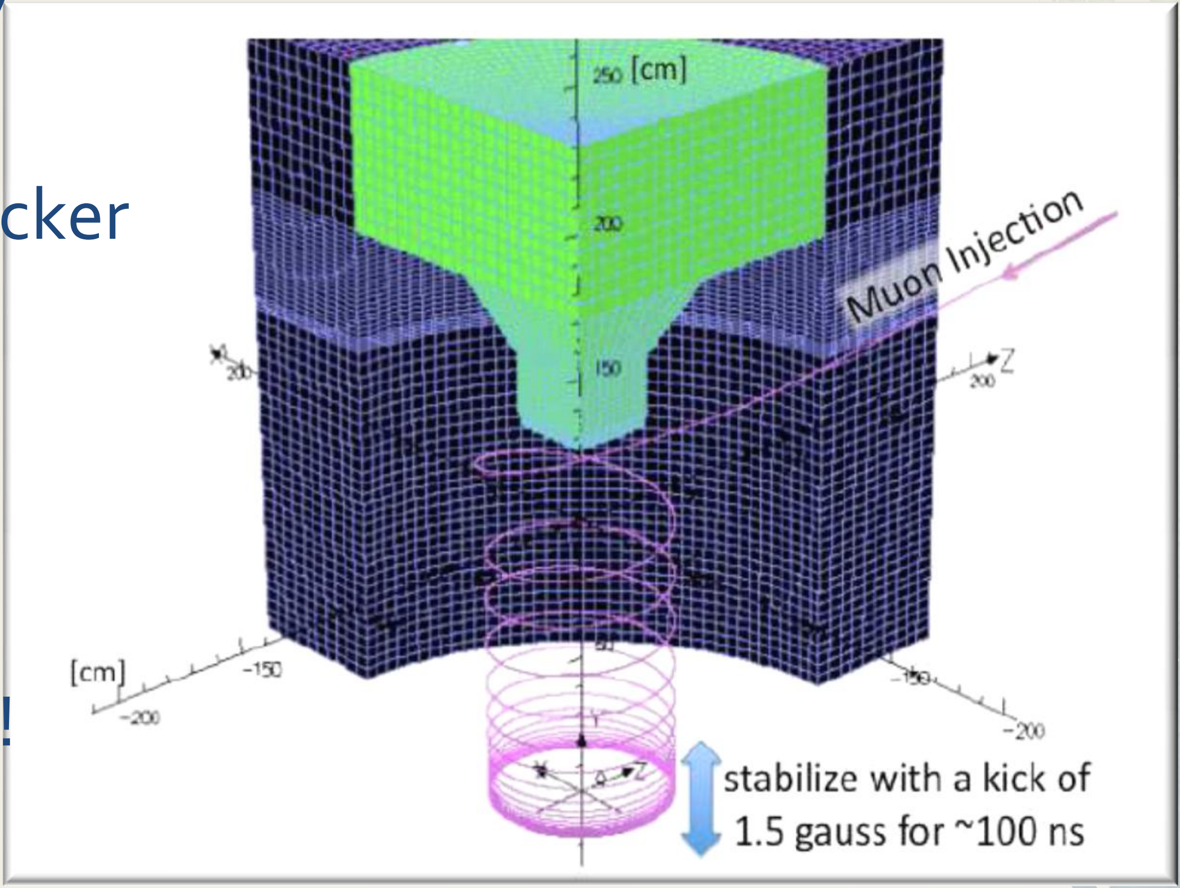


Spiral Injection Schem

K. Oide, H. Nakayama and H. Iinuma



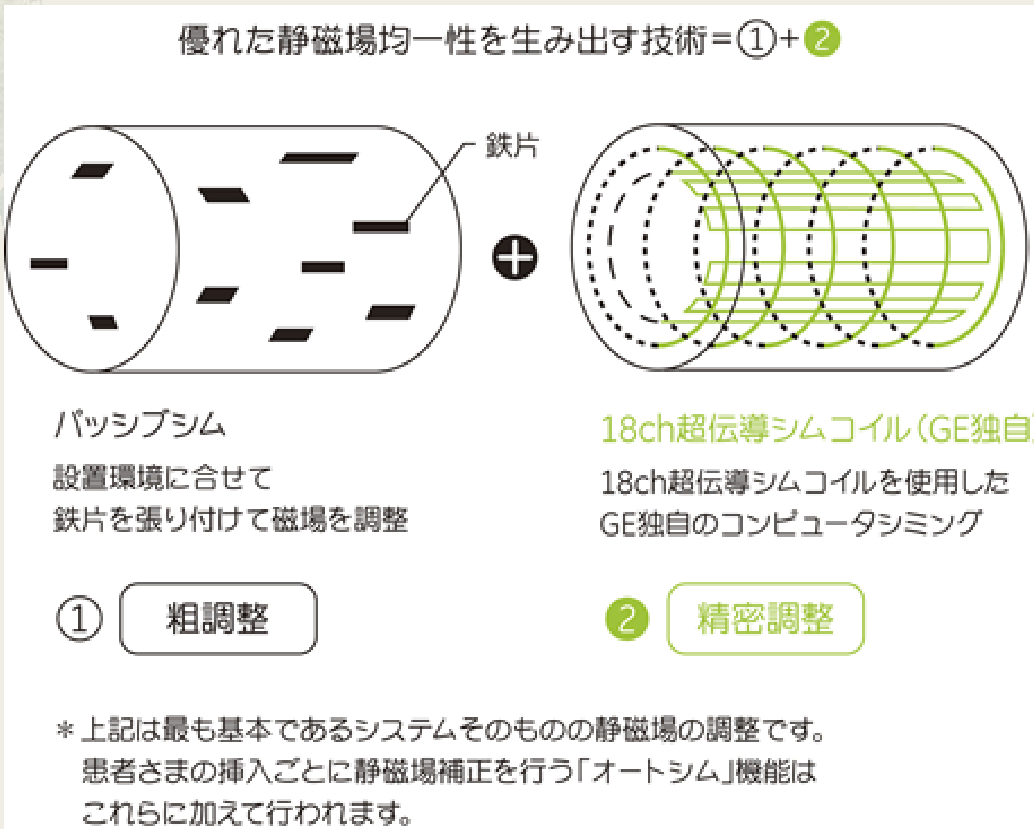
- Inject muon beam with vertical angle to avoid interference in the injection region
- Deflect P_T into P_L by radial field
- Stabilize beam by kicker to “good filed region”
  - Double-kicker or
  - Weak kicker ?
- Better monitoring/ shimming necessary!

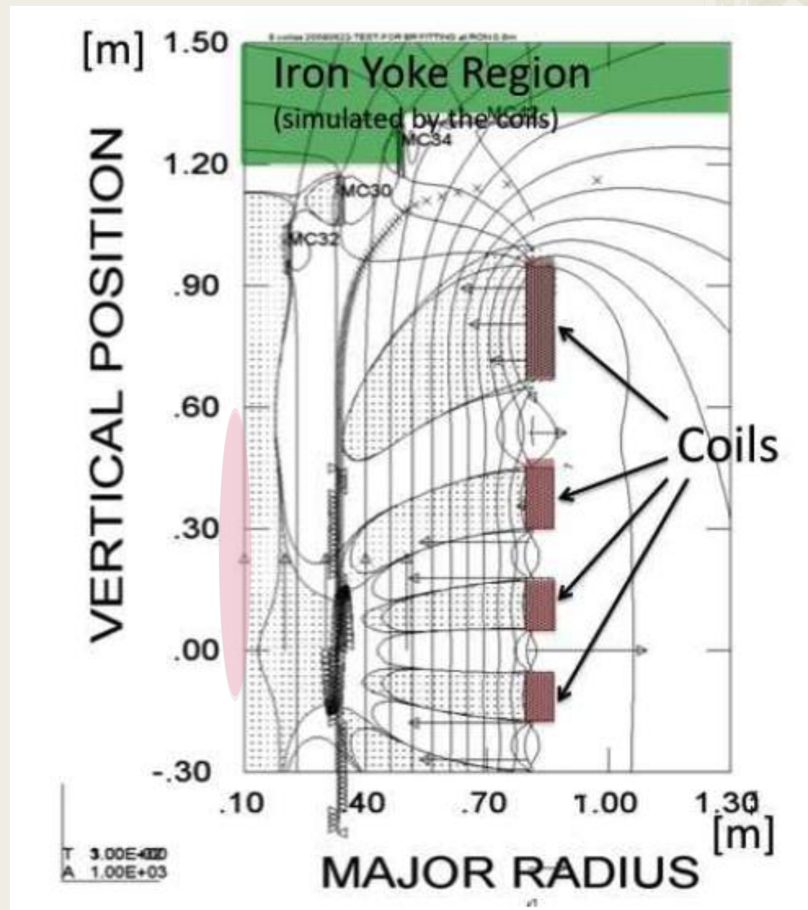


Ultra-Precision Field

- "Active" shimming with current adjustment for separate coils
  - Employed in many MRI

From GE Website :

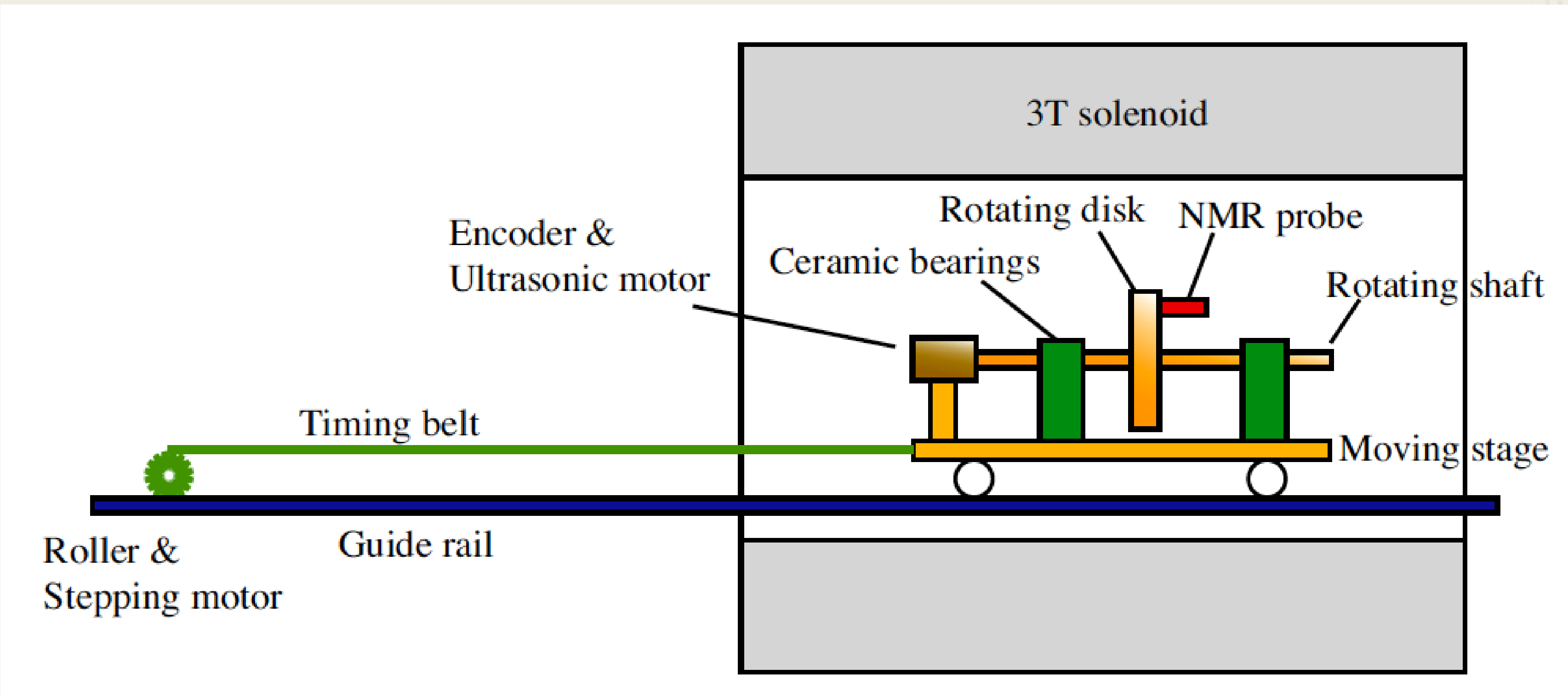




Precision Field Monitor

K. Sasaki, T. Ogitsu, H. Iinuma and A. Yamamoto

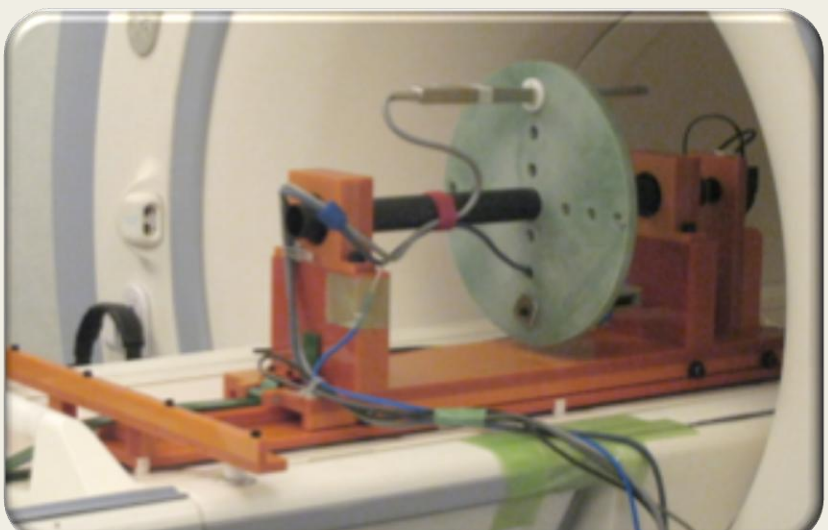
- Being developed with MRI precision magnet + NMR probes + Hall probes



R&D for Precision Field Measurement

K. Sasaki and H. Iinuma et al.

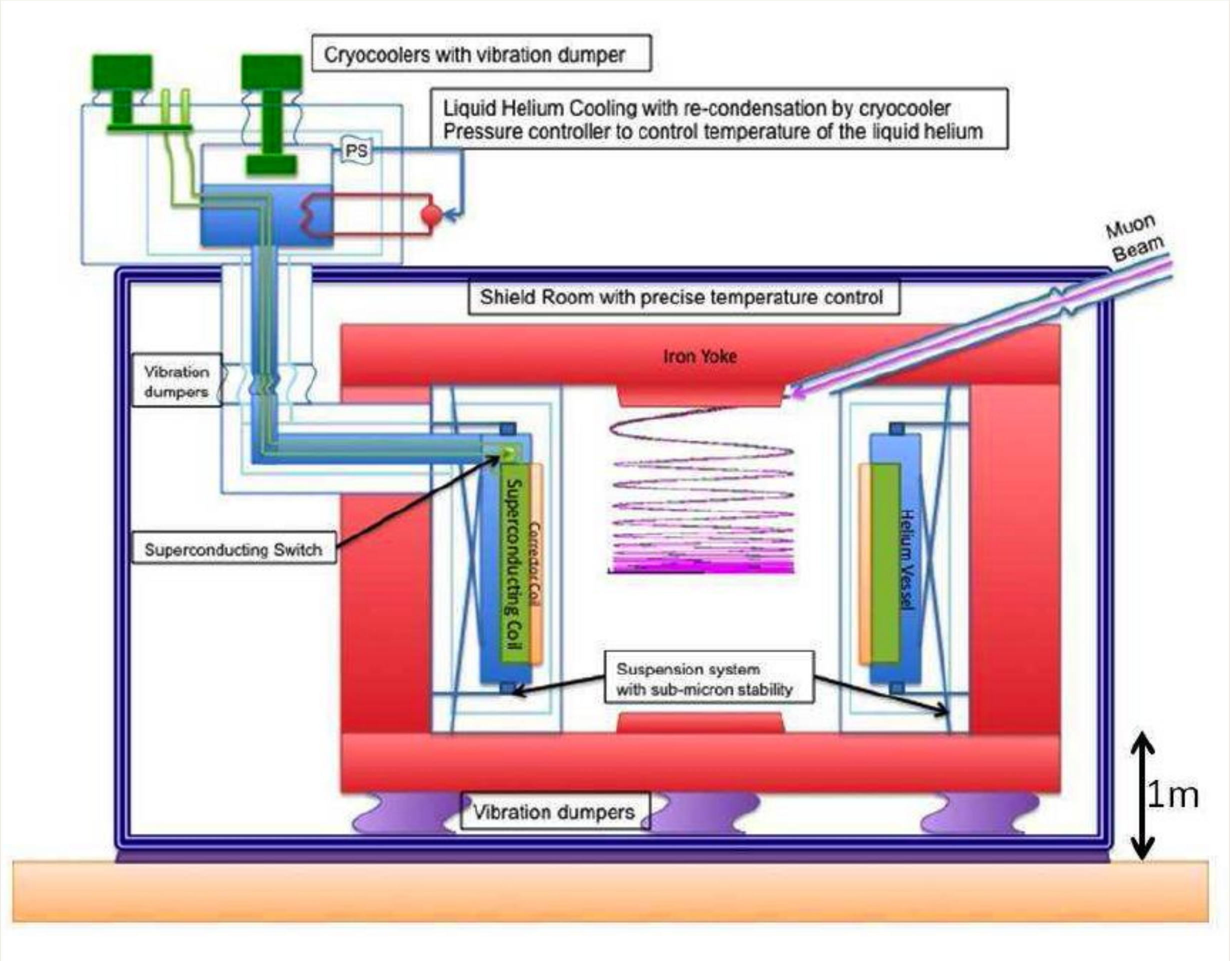
- 3T- MRI at National Institute of Radiological Science done
- NMR and Hall Probes (vector)
- First trial provided < 0.3 ppm stability for NMR (preliminary)
- To be continued



Cryogenic System

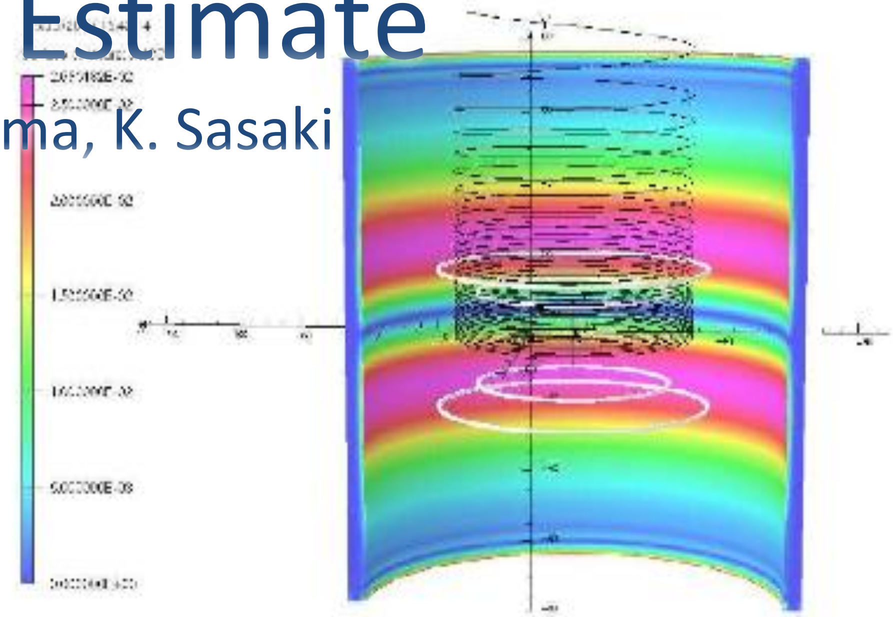
T. Ogitsu, K. Sasaki, K. Tanaka, and A. Yamamoto

- Conceptual Design developed
- Vibration measurement is ongoing

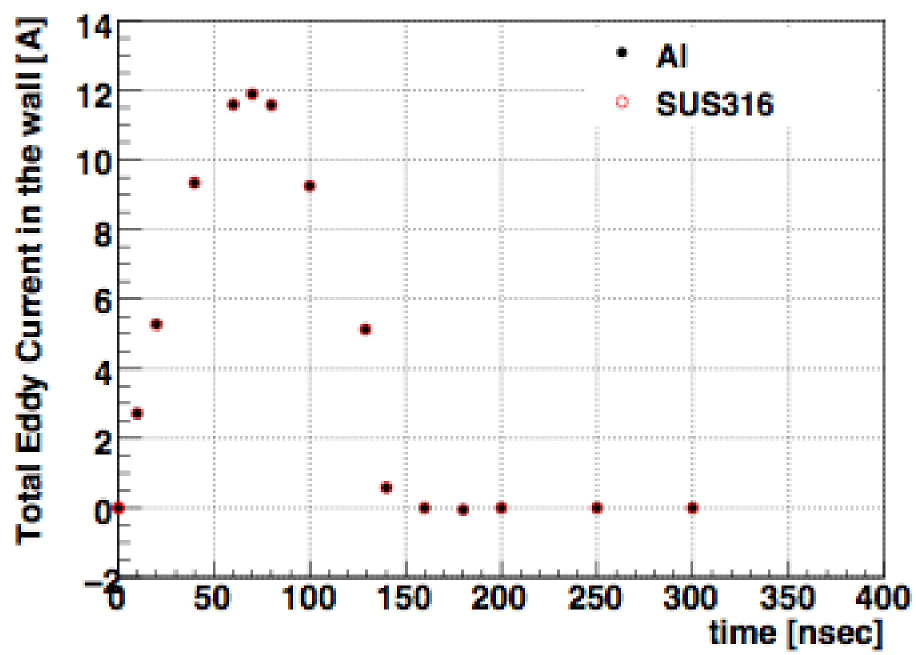


Eddy Current Estimate

H. Nakayama, H. Iinuma, K. Sasaki



- Cryostat wall is assumed to be SUS316 or Al
- Eddy current time profile is similar to Kicker current
- After 150 nsec, no remaining effect
- To be continued



g-2:Stored Energy / Cold Mass

K. Sasaki, T. Ogitsu, et al.

- Not an extreme, but requires serious efforts
  - Material : NbTi /Copper
  - Cu/Sc ratio : 4
  - Central Field:3T
  - Peak Field on Cable: 5.4 T
  - Nominal current : 417 A
  - Stored Energy : 23 MJ
  - Inductance : 264.5 H
  - Total mass : 3.7 t
- Well within current Technology !