A New Generation of Muon g-2/EDM Experiment at J-PARC

DESY Seminar

April 27, 2010, Hamburg, Germany

Naohito SAITO (KEK)

Collaboration

- 63 members
- 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. Kamitani, Y. Kamiya, S. Komamiya, K. Koseki, Y. Kuno, O. Luchev, G. Marshall, Y. Matsuda, T. Matsuzaki, T. Mibe, K. Midorikawa, S. Mihara, 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, B. Shwartz, K. Tanaka, N. Terunuma, D. Tomono, T.Toshito, 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

Outline

- Why Muon g-2 and EDM?
- Current status of Muon g-2 (BNL-E821)
- New Experiment at J-PARC
- EDM
- Summary

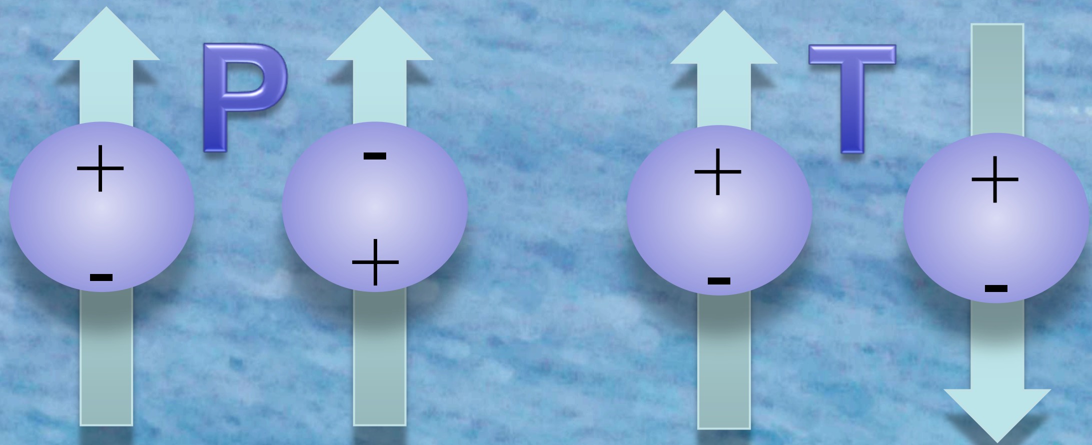
Muon Dipole Moments

- Magnetic and Electric DMs: both related to Spin of the Particle
  - Fundamental physics observable for elementary particles
  - ex. Electron g-2 (measured down to 0.28 ppt) provides the best determination of fine st. const. (0.37 ppb)
- Play important role in the test of fundamental symmetries

If EDM nonzero, T is violated

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

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



Muon magnetic moment

- Magnetic moment and spin can be related as

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

$\vec{\mu}$: magnetic moment
$\vec{s}$: spin
g : gyromagnetic ratio

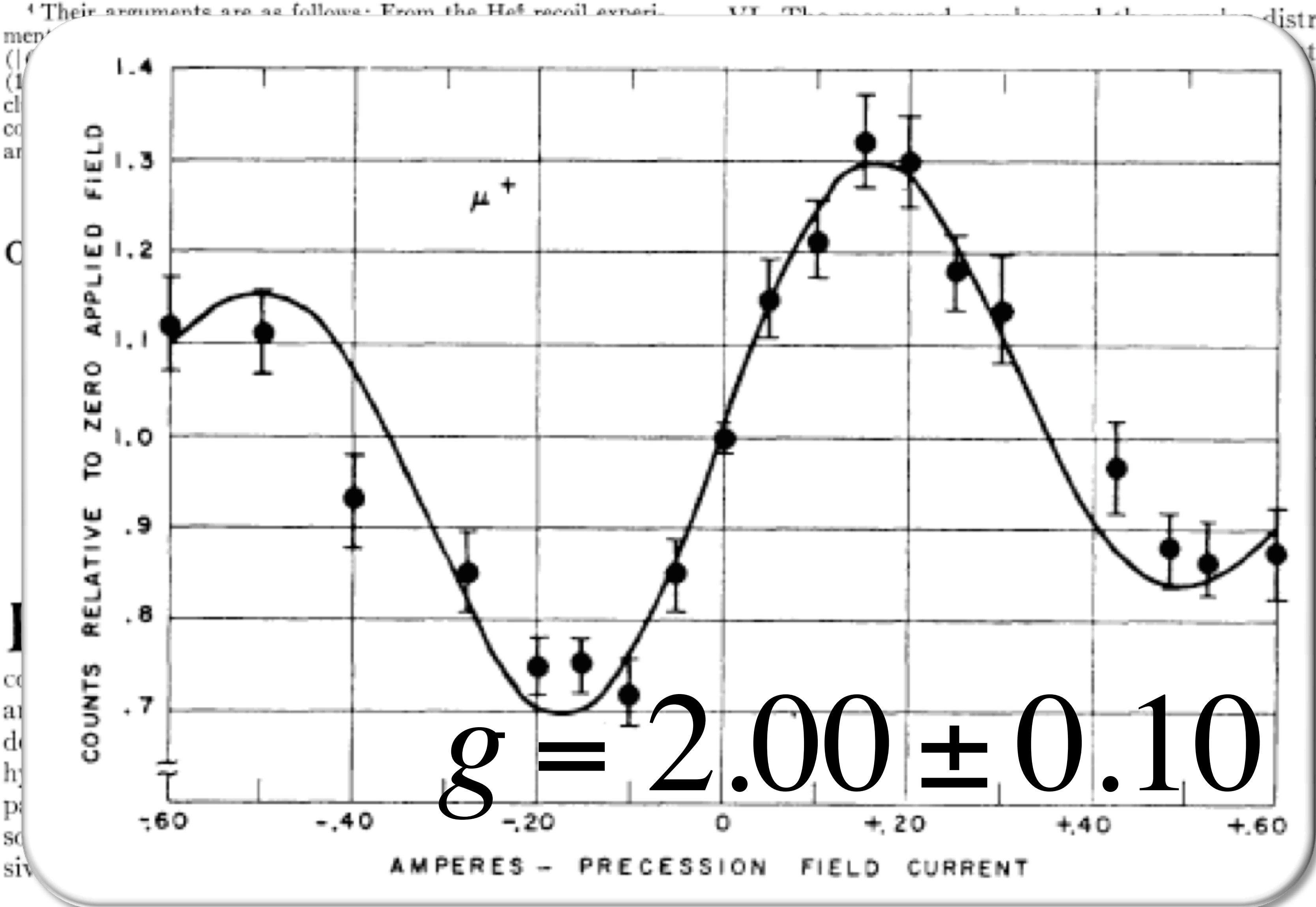
- Dirac equation predicts g=2 → a=0

$$\mu = (1+a)\left(\frac{e\hbar}{2m}\right) \qquad a = \frac{g-2}{2}$$

a=1.2e-3 for e, μ, …
a=1.8 for proton

- Radiative corrections (including NEW PHYSICS) would make g≠2 → a≠0

$$\left(\frac{m_\mu}{m_e}\right)^2 \sim 40{,}000 \qquad \left(\frac{m_\tau}{m_\mu}\right)^2 \sim 290$$



$$\mu^+ \rightarrow e^+ + 2\nu. \quad (2)$$

They have pointed out that parity nonconservation implies a polarization of the spin of the muon emitted from stopped pions in (1) along the direction of motion and that furthermore, the angular distribution of

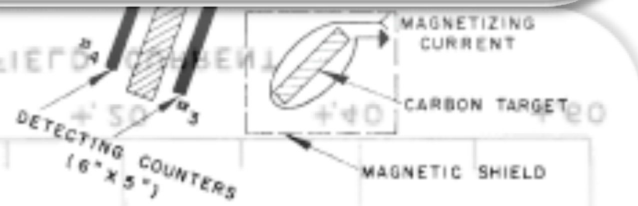


FIG. 1. Experimental arrangement. The magnetizing coil was

Discovery of a≠0

PHYSICAL REVIEW VOLUME 118, NUMBER 1 APRIL 1, 1960

Accurate Determination of the μ^+ Magnetic Moment*

R. L. Garwin,† D. P. Hutchinson, S. Penman,‡ and G. Shapiro§
Columbia University, New York, New York

(Received August 4, 1959)

Note added in proof.—Experiments which have recently been reported to us [J. Lathrop, et al. and A. Bearden et al., Phys. Rev. Letters (to be published)] indicate a mass value of $M_\mu = 206.76_{-0.02}^{+0.03} M_e$. This yields a value of $g_\mu = 2(1.00113_{-0.00012}^{+0.00016})$. Although the assigned … slightly greater than above, it is to be no… new result represents a direct measurement rather than a lower limit. The agreement

0.0011623

$$a(\mathrm{QED}) = \frac{1}{2}\frac{\alpha}{\pi} + C_4\left(\frac{\alpha}{\pi}\right)^2 + C_6\left(\frac{\alpha}{\pi}\right)^3 + C_8\left(\frac{\alpha}{\pi}\right)^4 + C_{10}\left(\frac{\alpha}{\pi}\right)^5 + \cdots$$

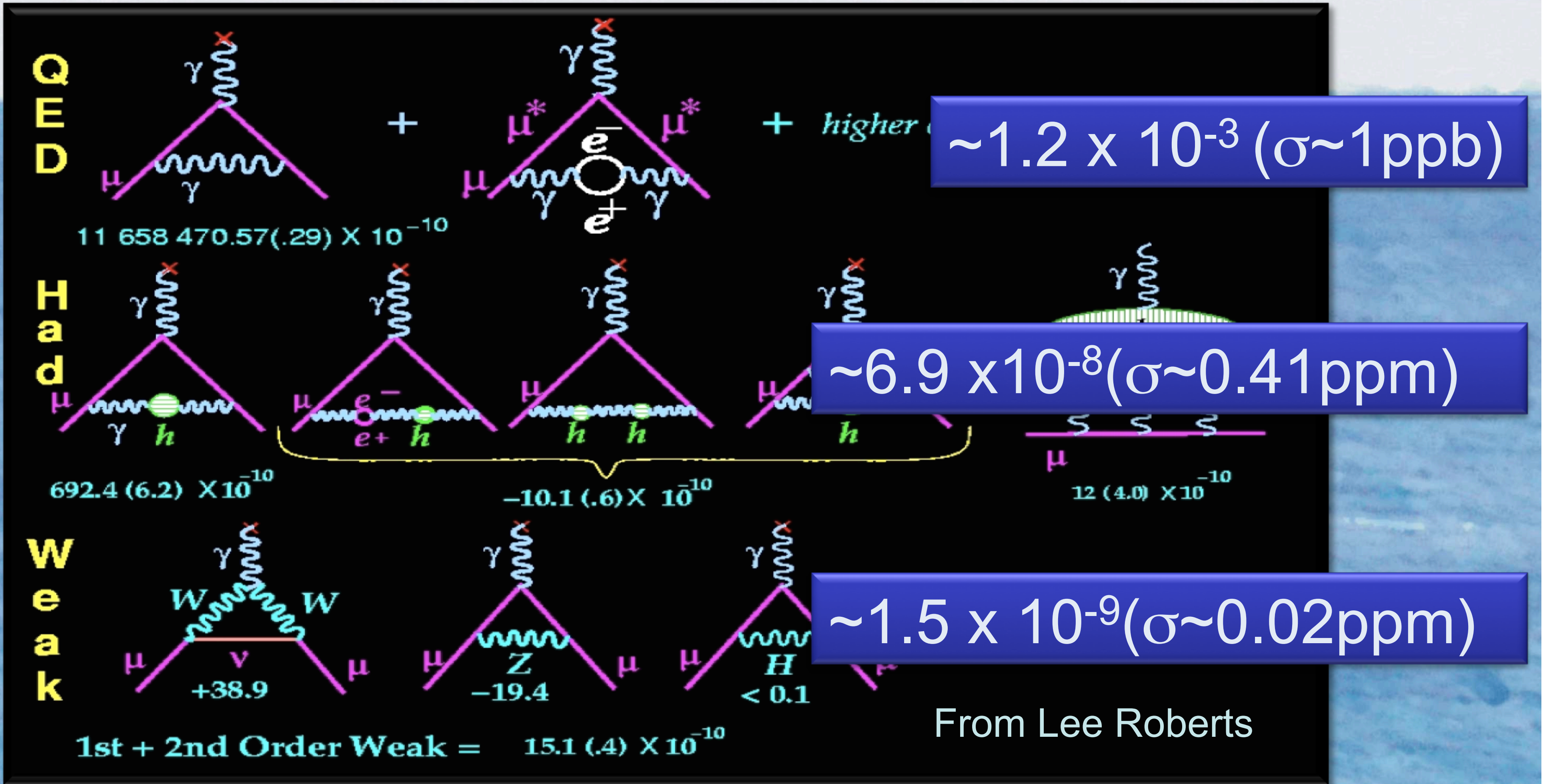
electromagnetic properties of the muon, therefore, acquire increased interest as a further test of the identity of the interactions of the two particles.

Quantum electrodynamics[2] makes the prediction

… using an analog time-to-height converter to record the distribution in time of the emitted electrons, achieved an accuracy of 0.7%. A resonance technique, in which the muons were stopped in a large static magnetic

SM Contribution to a≠0

- **Any particle which couples to muon/photon would contribute : QED >> Hadron > Weak**

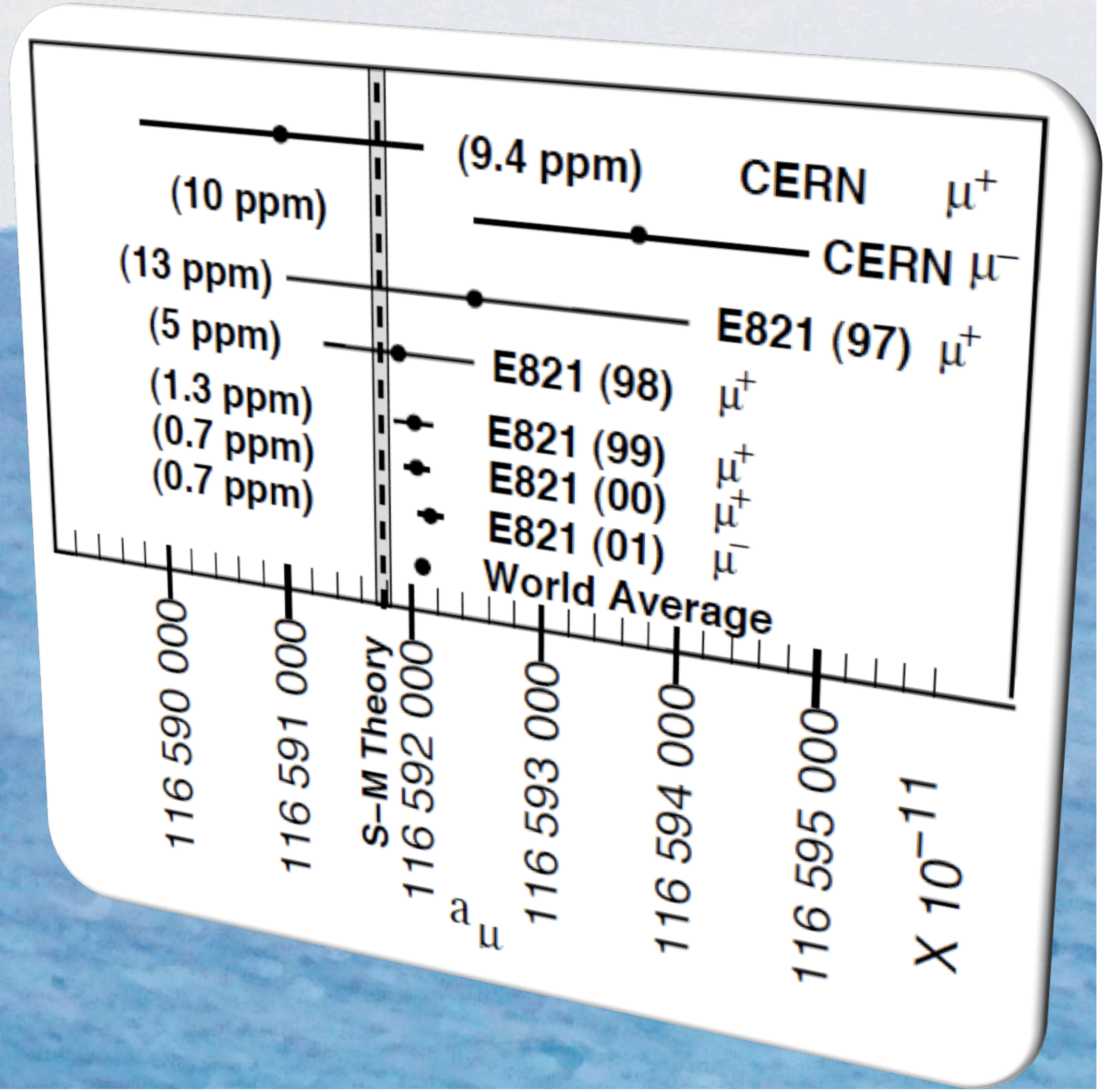


“Final Report” from BNL E821

$$\Delta a_{\mu}^{(\text{today})} = a_{\mu}^{(\text{Exp})} - a_{\mu}^{(\text{SM})} = (295 \pm 88) \times 10^{-11}$$

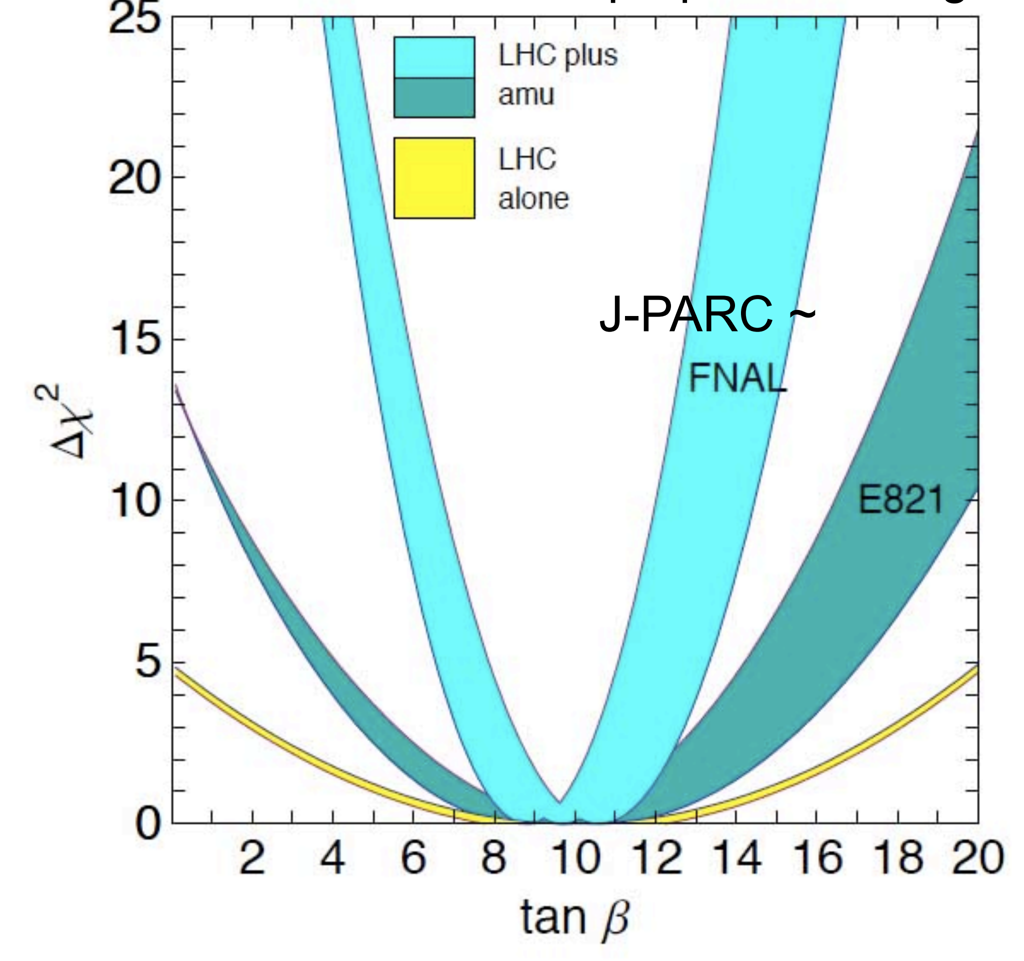
- E821 at BNL-AGS measured down to 0.7 ppm for both μ + and μ−
- 3.4 sigma deviation from the SM
  - SM prediction OK?
  - New Physics?
- Need to explore further
- Preferably

NEW METHOD!



Muon g-2 in the LHC era

Form Fermilab proposal "New g-2"



- **Even the first SUSY discovery was made at LHC, the muon g-2 measurement remains unique to determine SUSY parameters: μ and tan β**

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

Muon Spin precession

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

$\eta :\ d_\mu = \frac{\eta}{2}\left(\frac{e}{2m}\right)$ Electric Dipole Moment

$$d_e = (6.9 \pm 7.4)\times 10^{-28}\, e\cdot\mathrm{cm}$$

Expected to be

$$d_\mu < (1.5 \pm 1.4)\times 10^{-25}\, e\cdot\mathrm{cm}$$

Measured to be

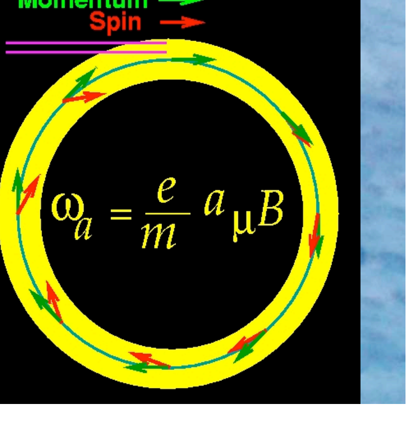
$$d_\mu = (3.7 \pm 3.4)\times 10^{-19}\, e\cdot\mathrm{cm}$$

$$a_\mu - \frac{1}{\gamma^2 - 1} = 0$$

$$\gamma_{\mathrm{magic}} = 29.3$$

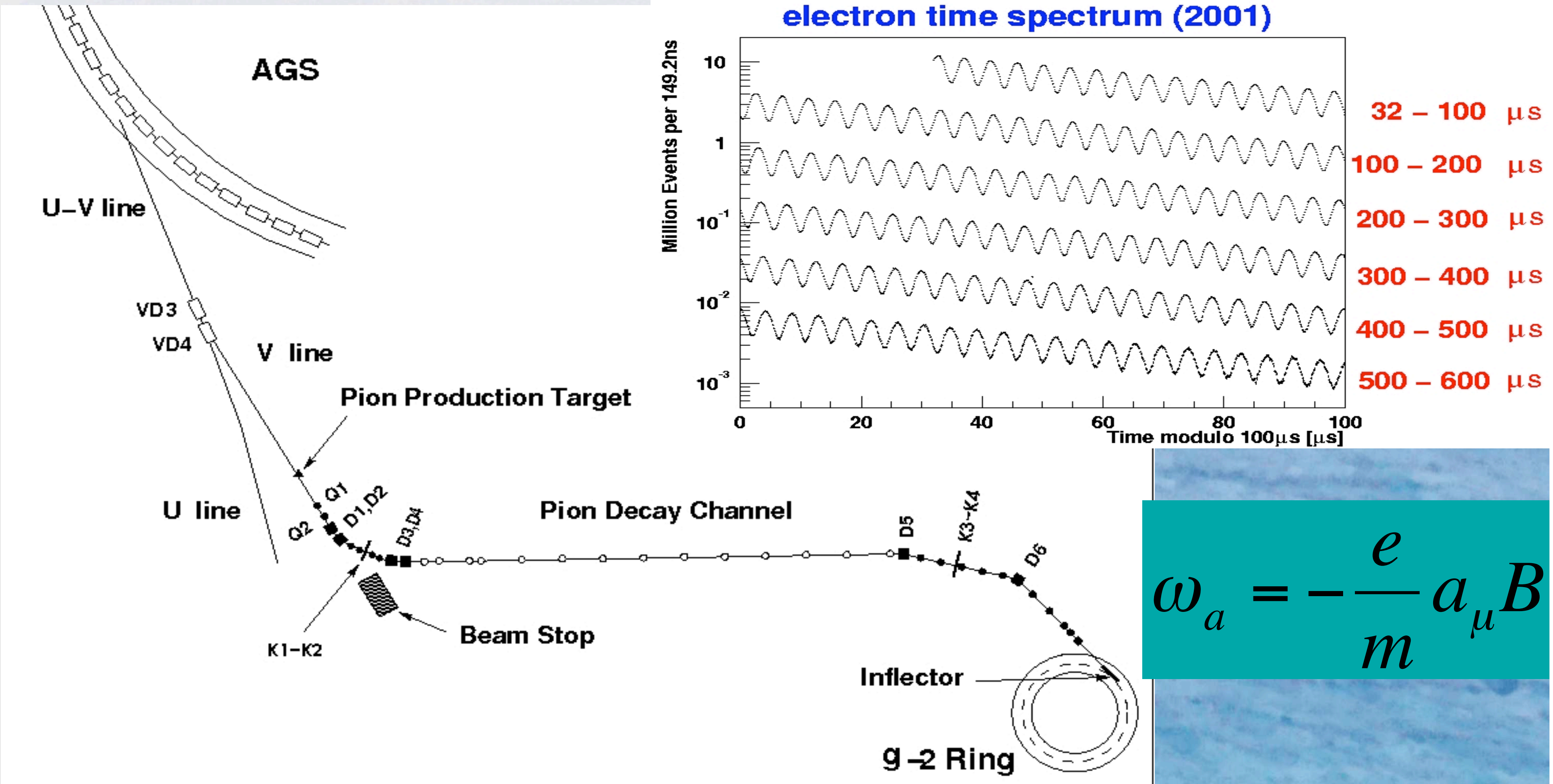
$$p_{\mathrm{magic}} = 3.09\ \mathrm{GeV}/c$$

$$\vec{\omega}_a = -\frac{e}{m} a_\mu \vec{B}$$



How it is Measured?

- Precession frequency (ω_a) of muon spin in the storage ring is measured;



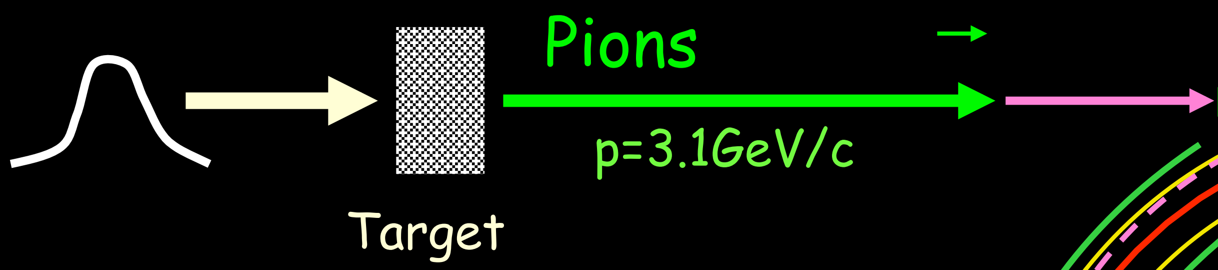
$$\omega_a = -\frac{e}{m} a_\mu B$$

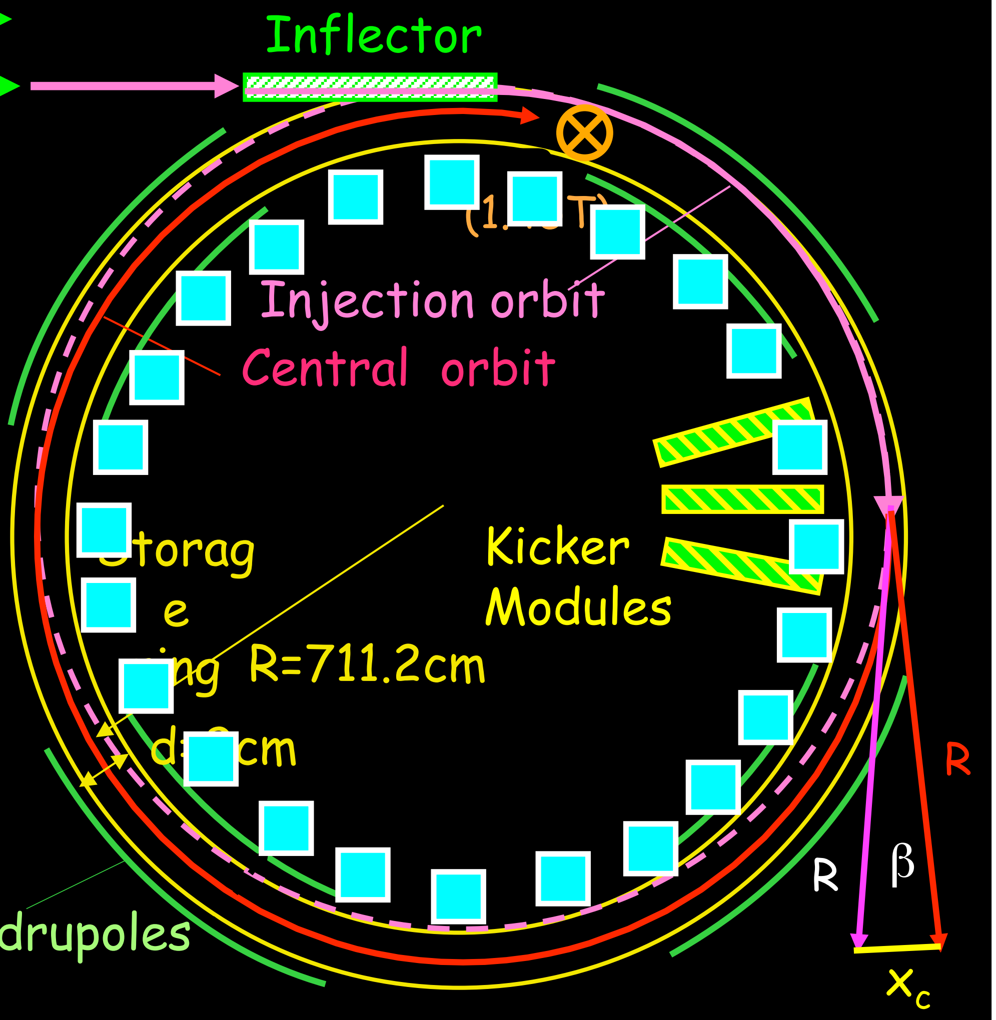

The Muon g-2 Ring
at BNL

Experimental Technique: fill ring, count until all muons are gone; do it again

25ns bunch of
5 X 10^{12} protons
from AGS

$x_c \approx 77$ mm
$\beta \approx 10$ mrad
$B \cdot dl \approx 0.1$ Tm





- Muon polarization
- Muon storage ring
- injection & kicking
- focus with Electric Quadrupoles
- 24 electron calorimeters

$$\vec{\omega}_a = -\frac{e}{m} a_\mu \vec{B}$$

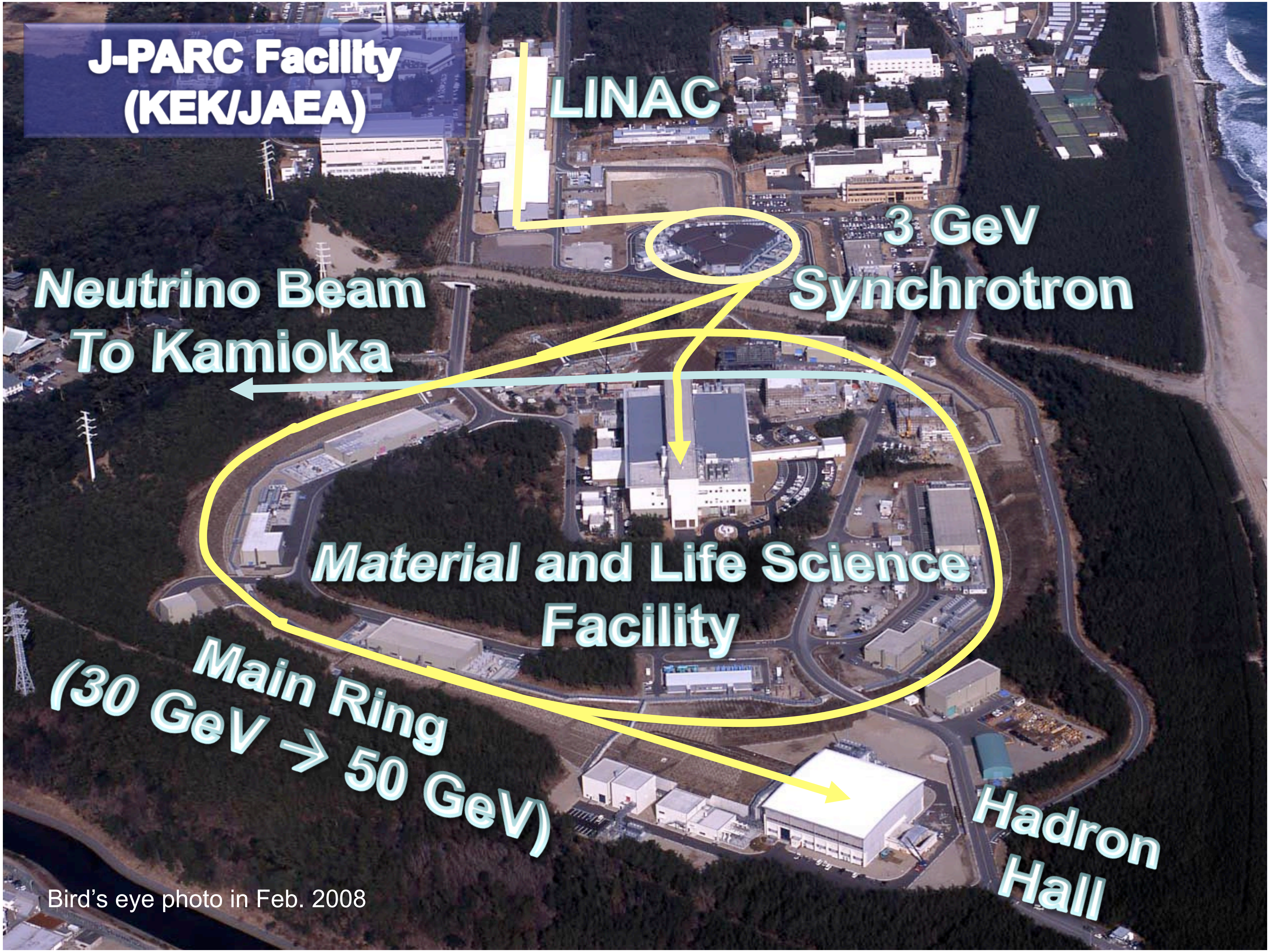
(thanks to Q. Peng)

Systematic Uncertainties

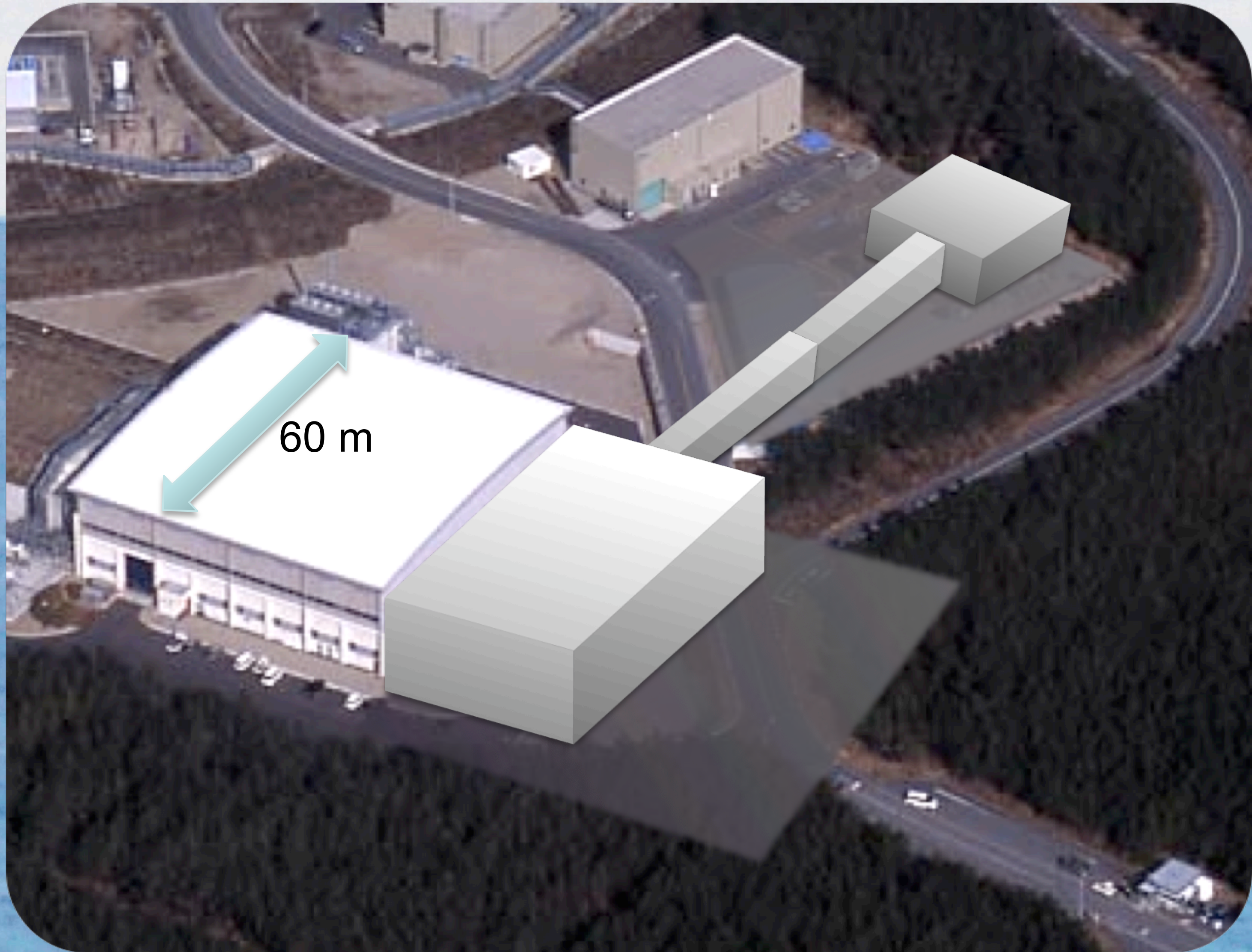
from Final Report of BNL E821

- **Major Sources**
  - Pileup
  - Lost Muons
  - CBO
  - Gain Changes
- **Pion dominates to create "flash"**
- **"Pure" Muon Beam w/ Better Quality**

$\sigma_{\rm syst}\ \omega_a$	R99 (ppm)	R00 (ppm)	R01 (ppm)
Pileup	0.13	0.13	0.08
AGS background	0.10	0.01	‡
Lost Muons	0.10	0.10	0.09
Timing Shifts	0.10	0.02	‡
E-field and pitch	0.08	0.03	‡
Fitting/Binning	0.07	0.06	‡
CBO	0.05	0.21	0.07
Gain Changes	0.02	0.13	0.12
Total for ω_a	0.3	0.31	0.21


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

Parking Lot Solution?



Shipping to J-PARC

- Estimated to be $2.5M
- Need to be refined

Brain-storming!

- **Why at magic gamma?**

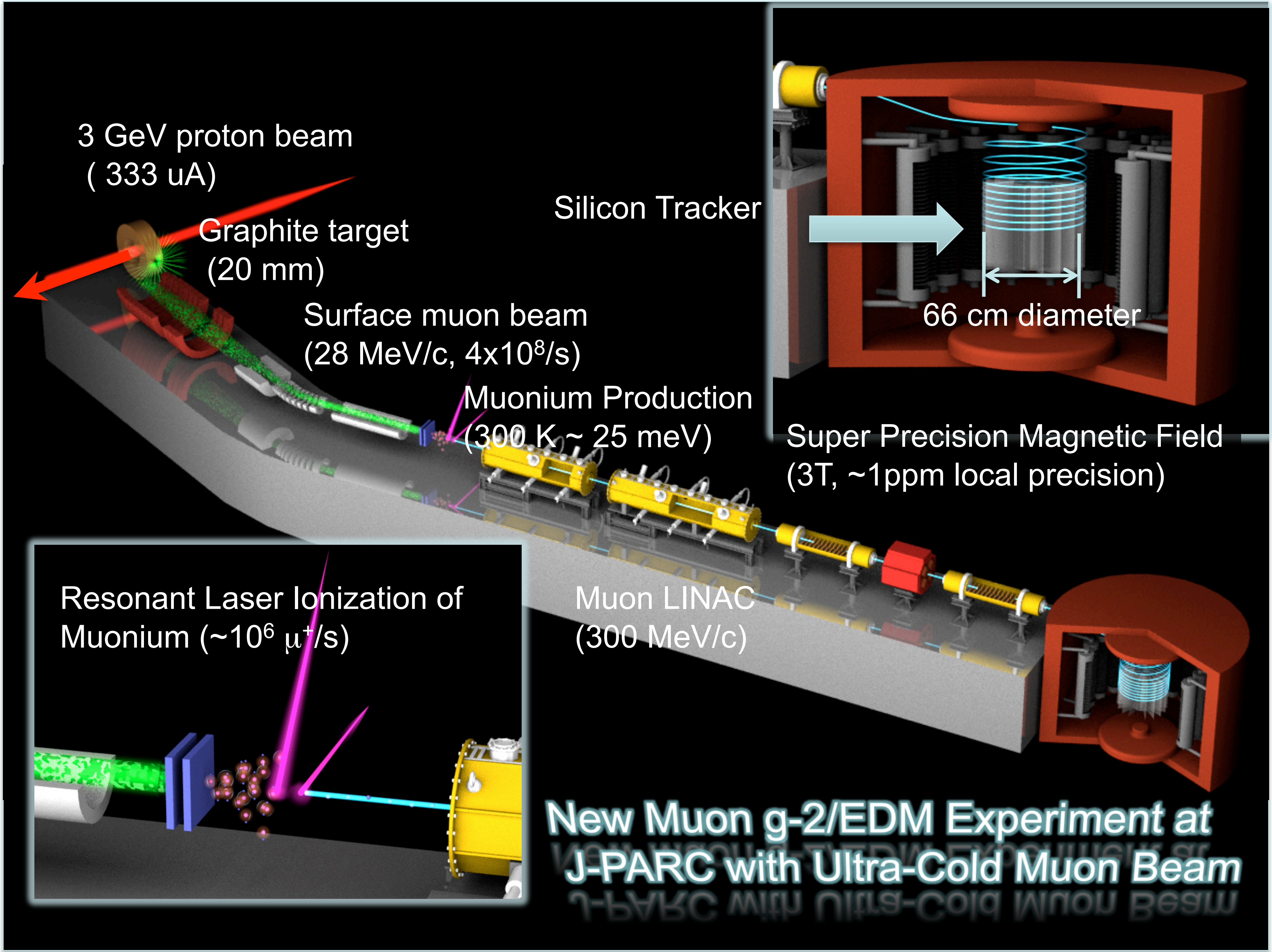
$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \ldots + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \ldots\right)\right]$$

- **What if no E-field?**

⇒requires ultra cooled muon beam Δp/p << 1e-5

Ultra-Slow Muon Source at J-PARC MLF?

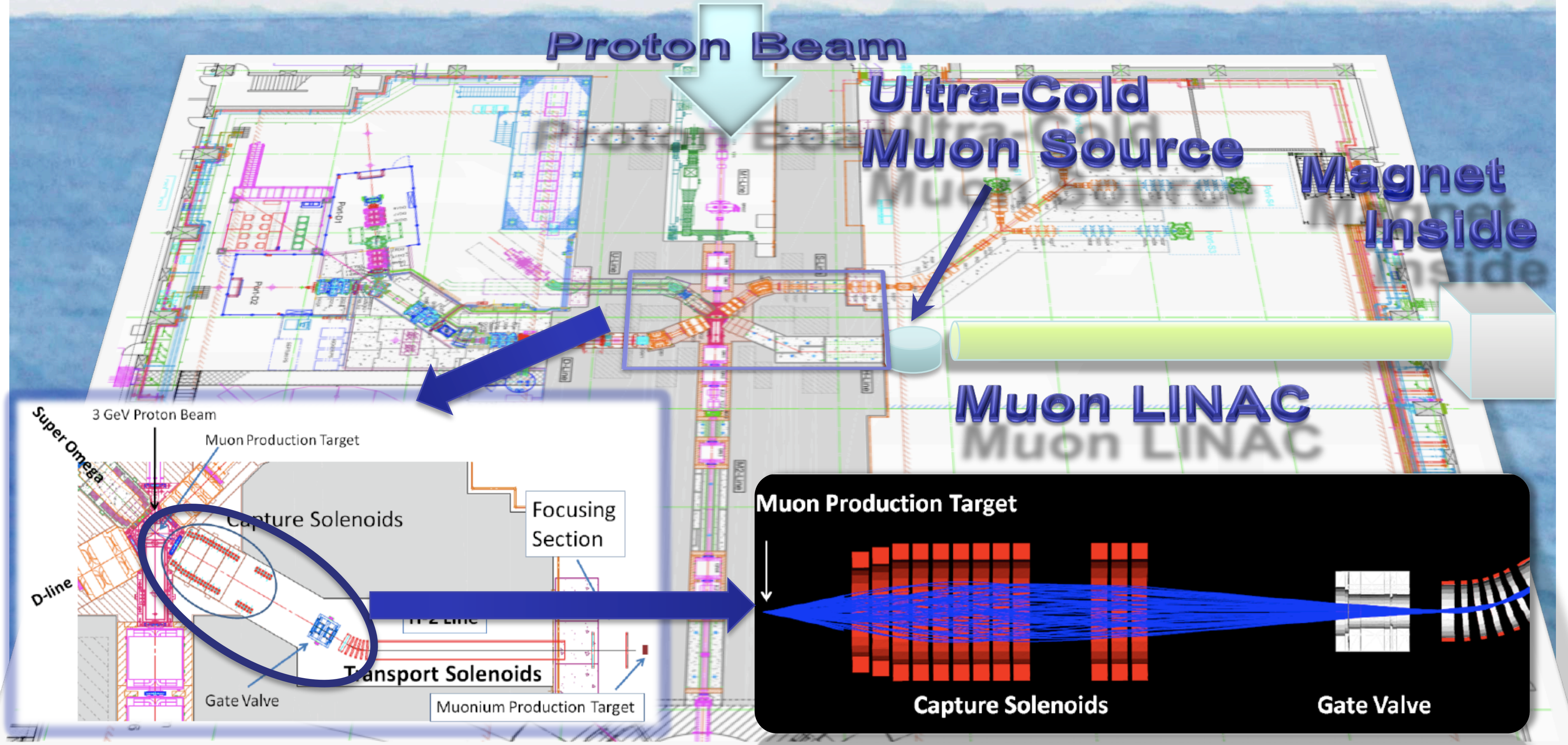
Muon collider technique? Cooling, FFAG etc.


3 GeV proton beam
(333 uA)
Graphite target
(20 mm)
Surface muon beam
(28 MeV/c, 4x10⁸/s)
Muonium Production
(300 K ~ 25 meV)
Silicon Tracker
66 cm diameter
Super Precision Magnetic Field
(3T, ~1ppm local precision)
Resonant Laser Ionization of
Muonium (~10⁶ μ⁺/s)
Muon LINAC
(300 MeV/c)
New Muon g-2/EDM Experiment at
J-PARC with Ultra-Cold Muon Beam

Possible Location at MLF

- Hi-momentum port?
  - Large acceptance preferred
  - LINAC ~30 m
  - Magnetically Shielded Room : 5x5x5 m^3

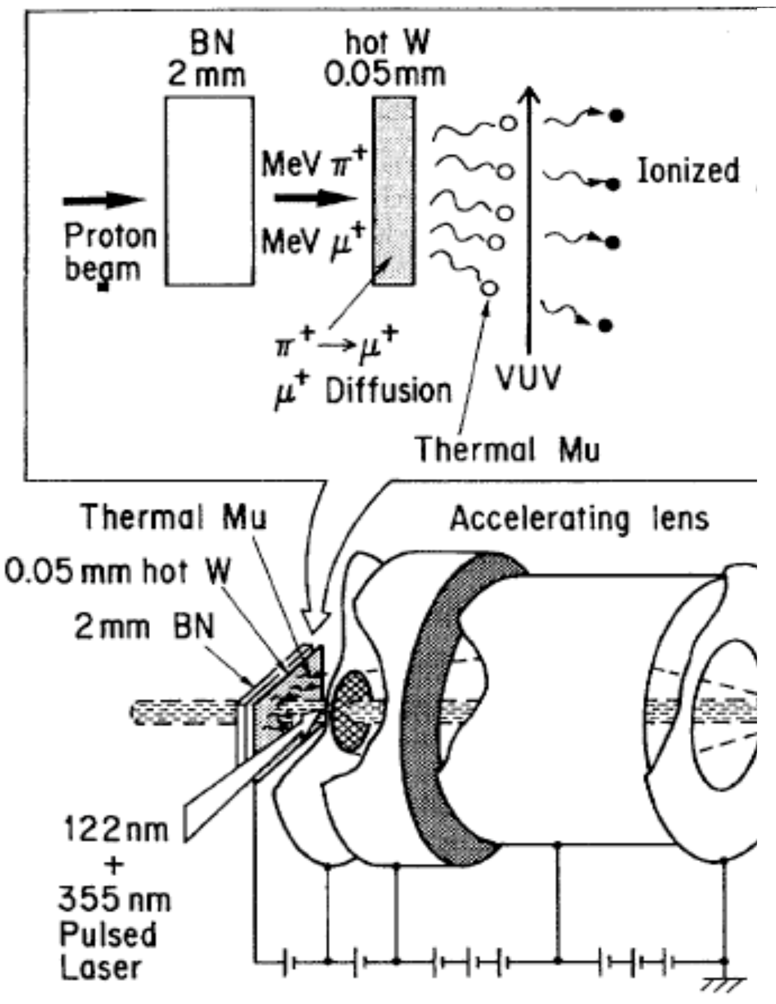
Service Lines (Power, Cryo etc) should be also considered…

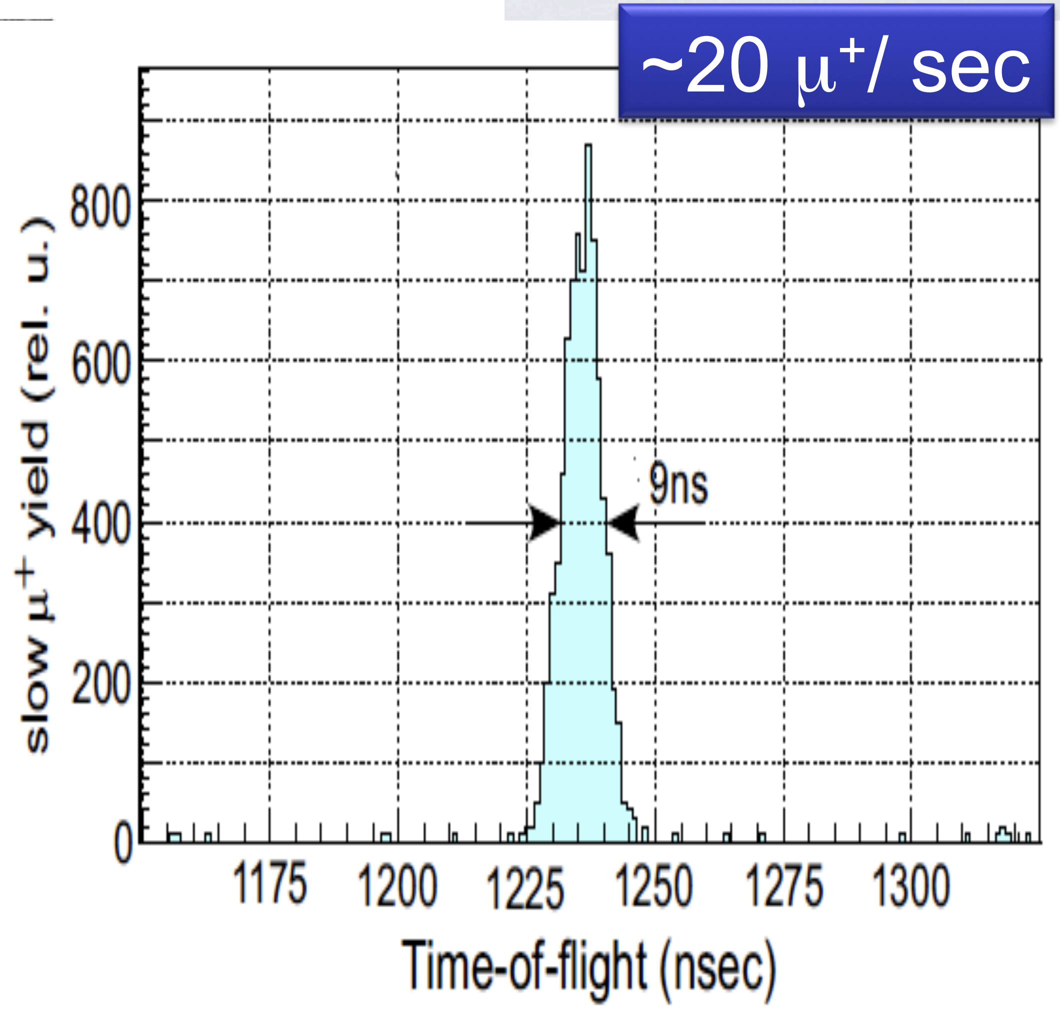


Ultra-Slow Muon Source

Steven Chu, A.P. Mills, A.G. Yodh, K. Nagamine, Y.Miyake, T. Kuga, PRL 60 (1988) 101
K.Nagamine et al. PRL 74 (1995) 4811
Y.Matsuda et al. NP B(Proc) 155 (2006) 346

- Laser Ionization of Muonium





Intense Ultra Slow Muon Source @J-PARC

From Miyake-san

At J-PARC, Aiming at;

1) **Repetition Rate**
   25 Hz (At RIKEN-RAL *50 Hz*) factor ***2 times***

2) Surface Muon Yield by **Super Omega Channel**
   4.0×10^8 /s / 1.2×10^6 /s (RIKEN-RAL) = ***333*** *times*

3) Lyman-α Intensity by **Laser Development**
   100 μJ/p / 1 μJ/p (RIKEN-RAL) = ***100*** *times*

Our Goal of Ultra Slow Muon Yield is

20 /s x 2 x 333 x 100 = 1.3×10^6/s (10^4/s without Laser Developments)

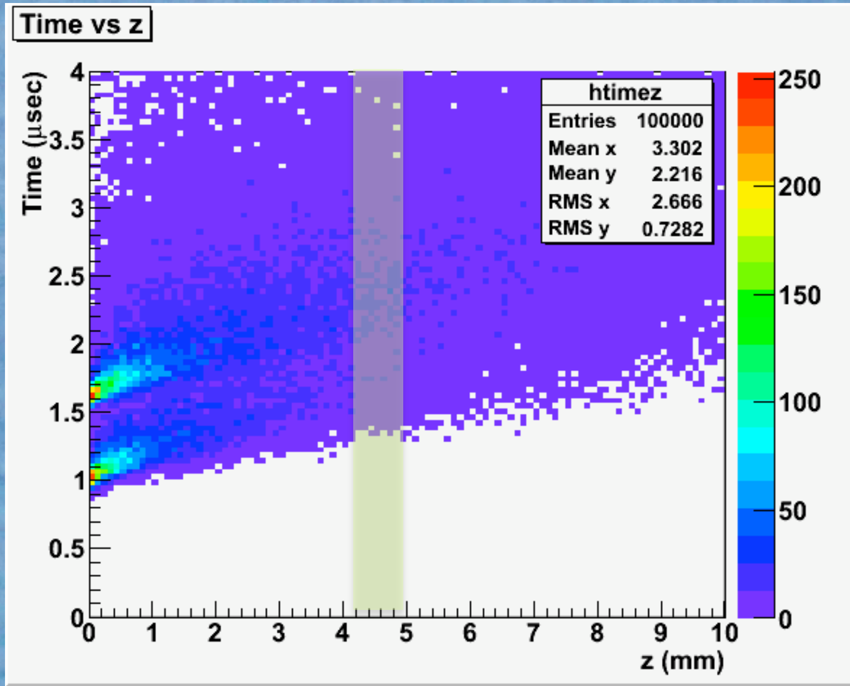
Riken-RAL Slow Muon Intensity

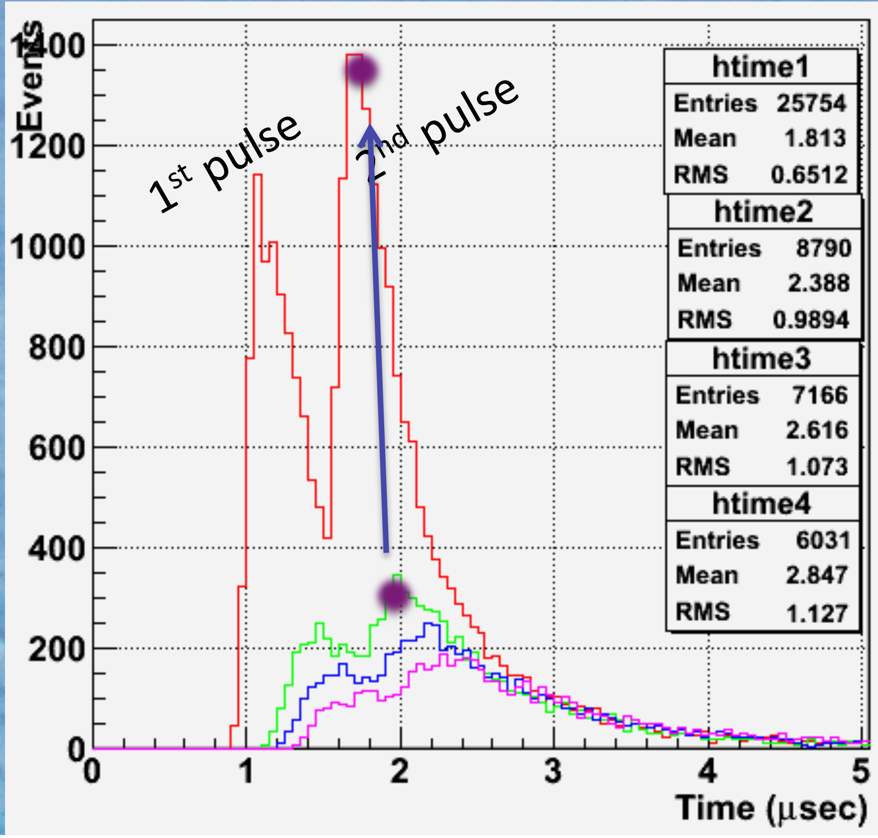
Maximum J-PARC Slow Muon Intensity

Muonium Production @ TRIUMF

- Optimize Mu production for Muon g-2 Exp. S1249
  - Spokespersons: K. Ishida and T. Mibe
  - Find the best target material
  - Measure Space-time distribution of Muonium
  - Received "high-priority approval"
  - Run in this summer

APPROVED



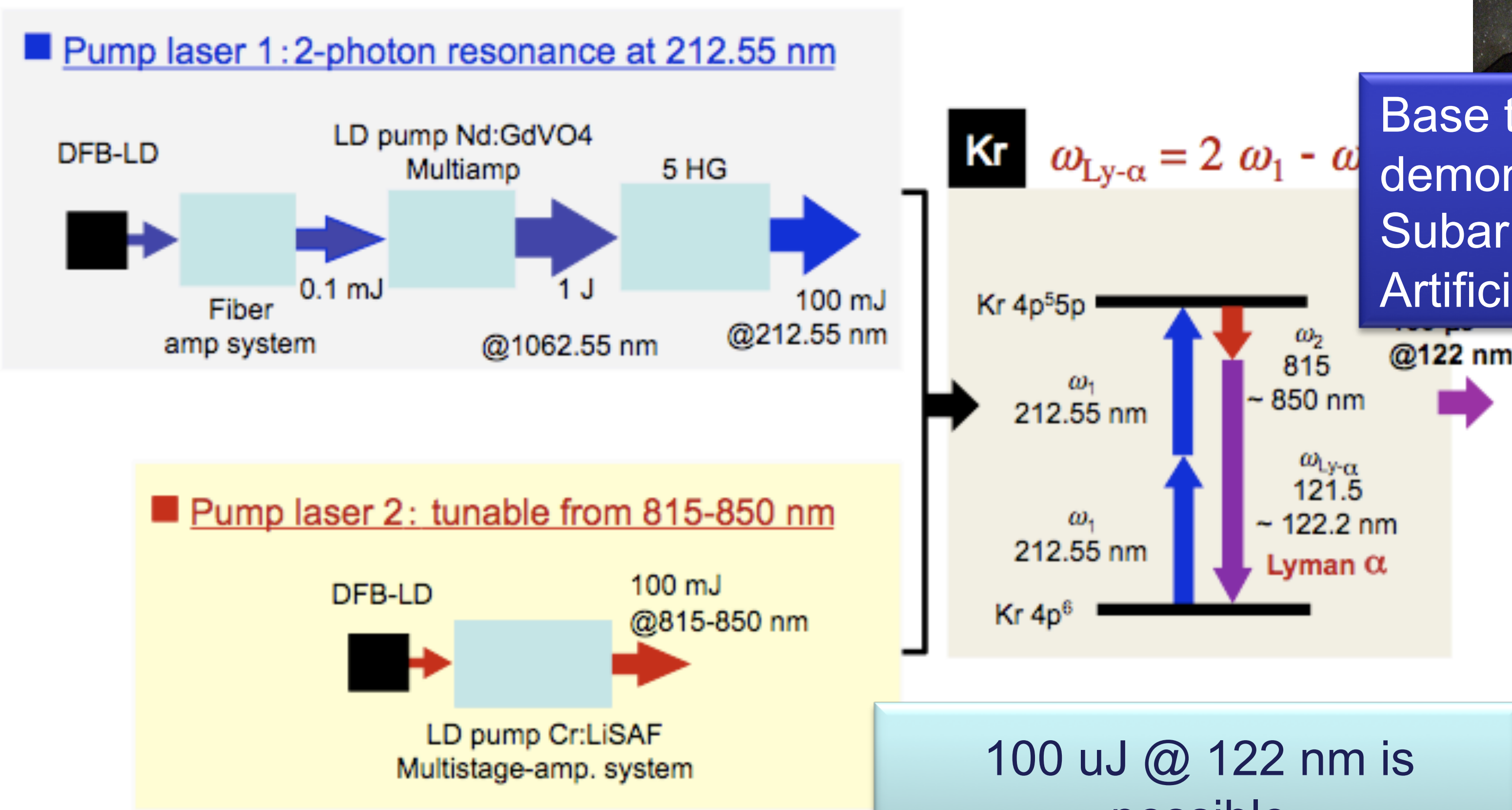


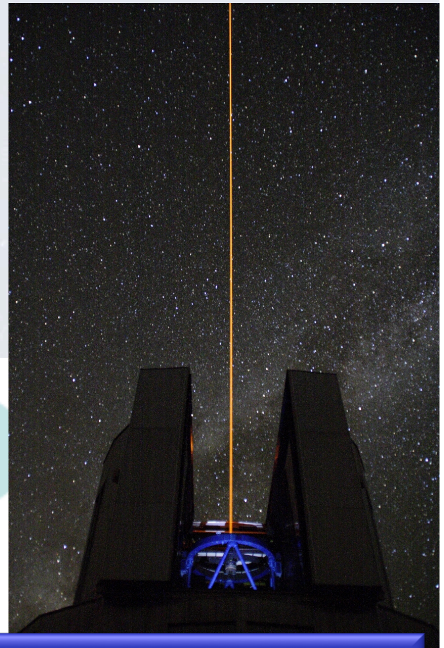
Laser Improvement

M. Iwasaki, S. Wada, N.F. Saito, K.Yokoyama, P. Bakule, et al.

- **Laser is setup at RIKEN**
- **To be tested at RAL in coming JFY**

Schematic Diagram





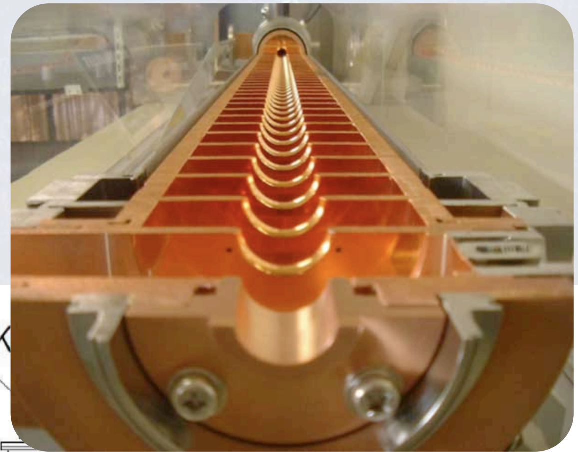
Base technology is demonstrated at Subaru Observatory's Artificial "Guide-Star".

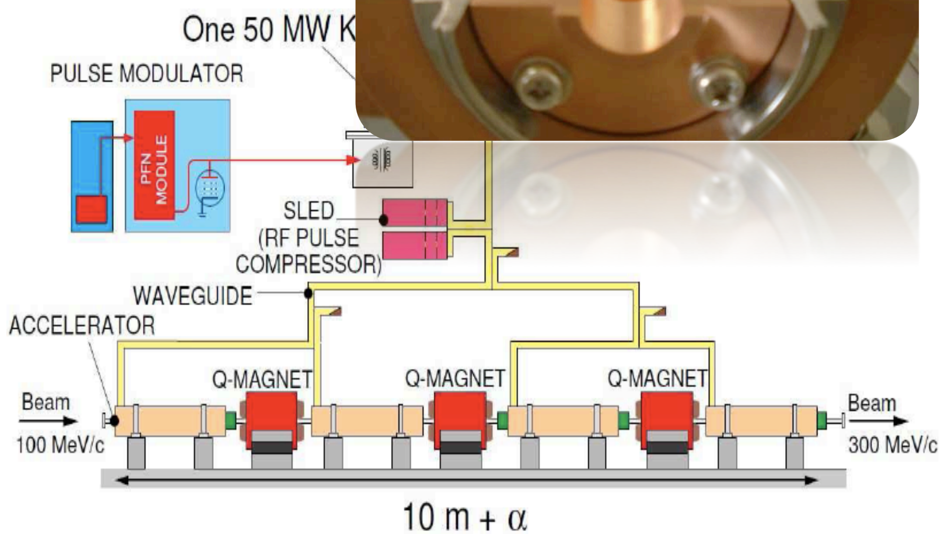
100 uJ @ 122 nm is possible

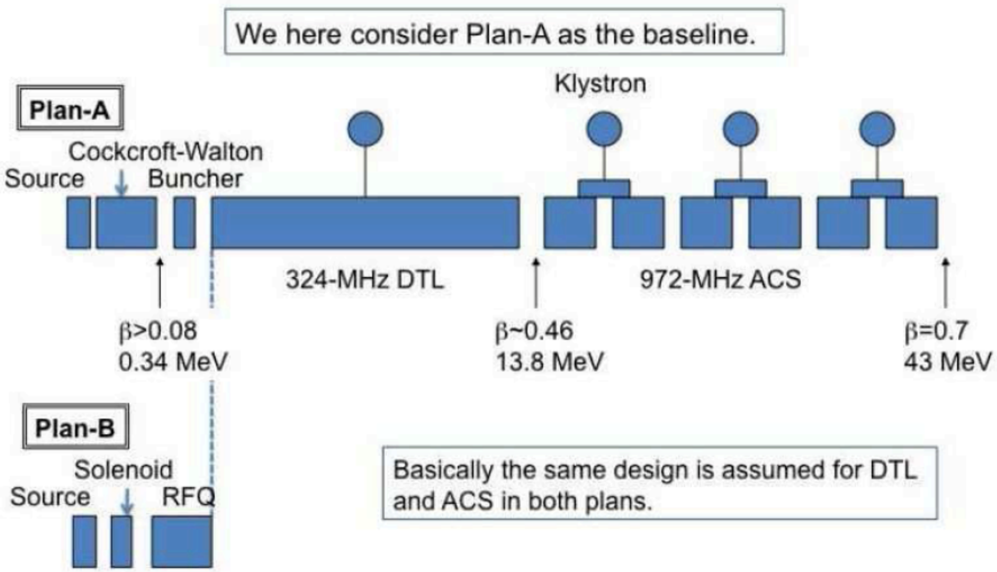
LINAC configuration

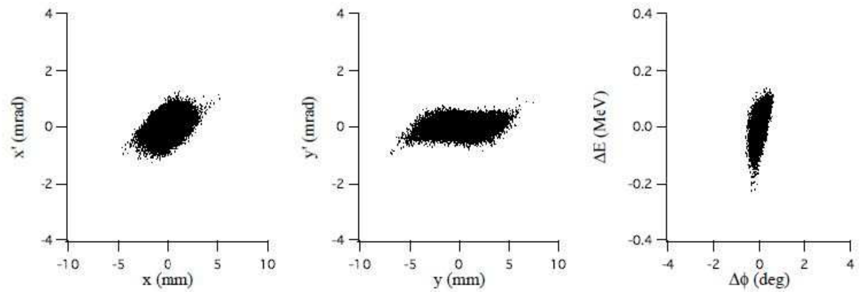
M. Ikegami, T. Kamitani, M. Yoshida

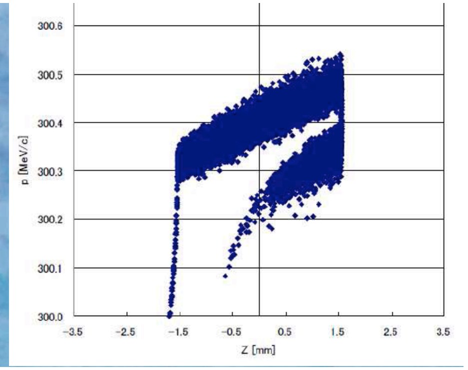
- **Low-beta (proton like) LINAC →**
  Hi-beta (electron like) LINAC
- **Connected at beta = 0.7**











Storage Field with Ultra-Precision

- BNL-E821 achieved precision such a large magnet (14 m – diameter)
  - Local uniformity ~ 100 ppm → 0.1 ppm integrated field
- Smaller Ring with Hi Field just matches with MRI technology
  - Active shimming – 1 ppm local uniformity
  - High field (~ 7 T) with large gap (~ 40 cm) is possible

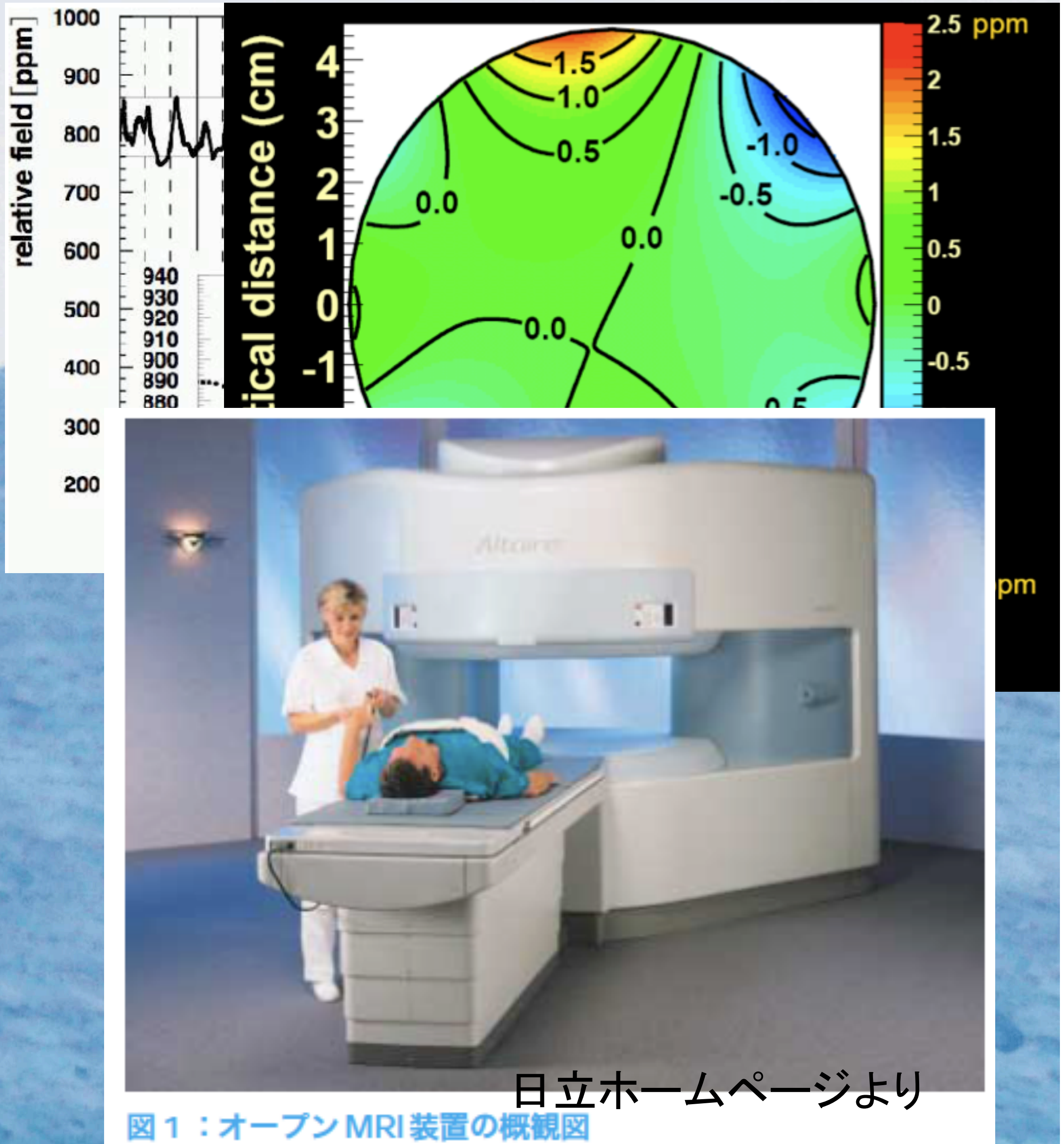
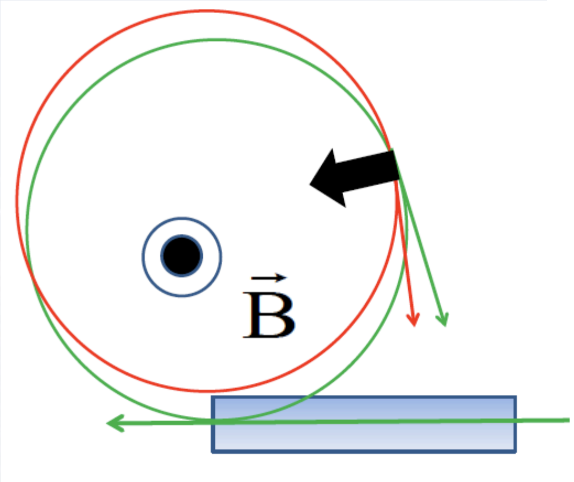


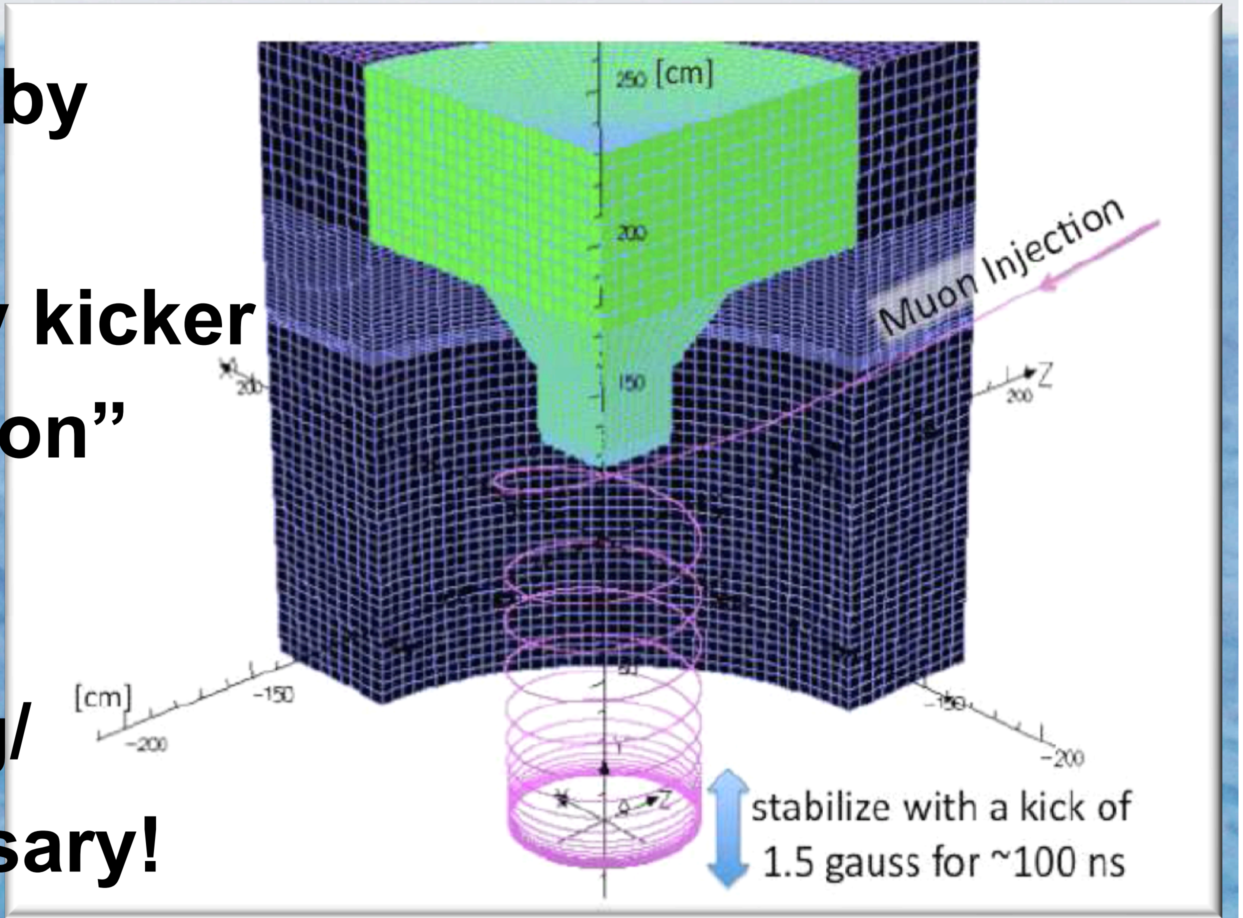
図１：オープンMRI装置の概観図

Spiral Injection Scheme

K. Oide, H. Nakayama and H. Iinuma



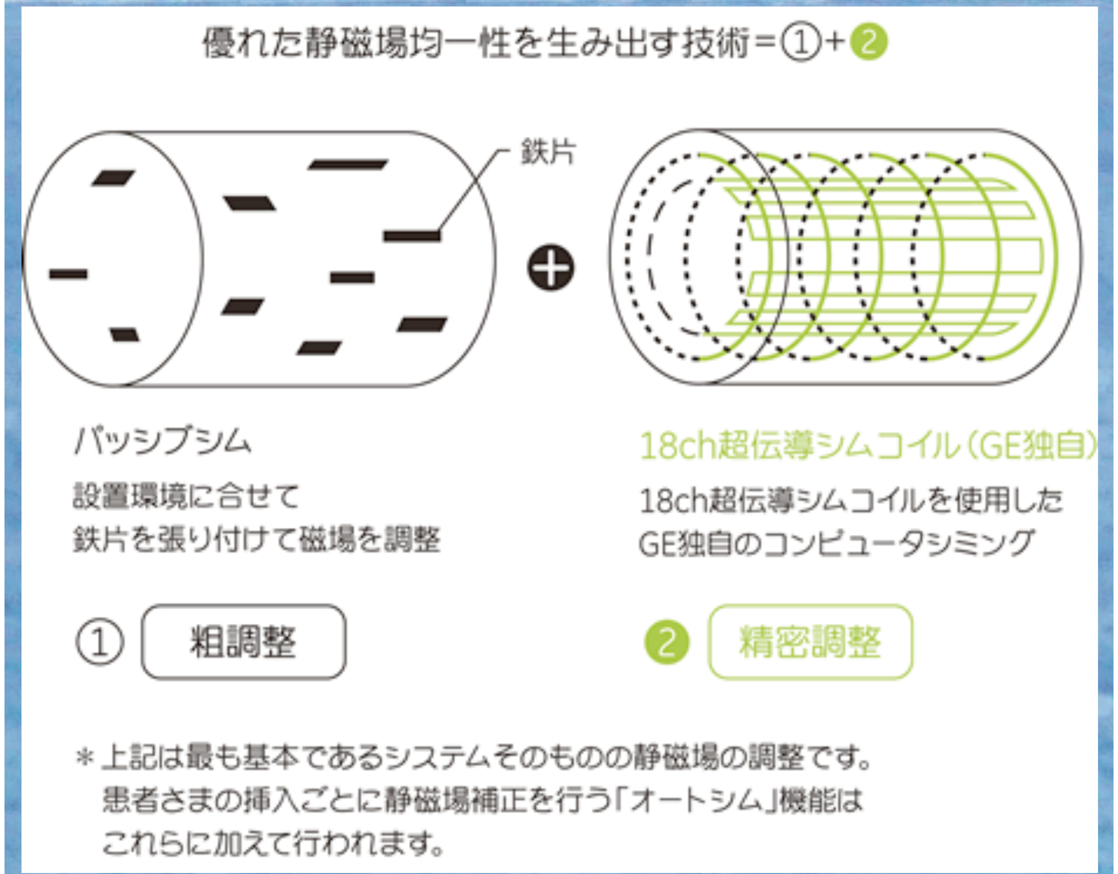
- Inject muon beam with vertical angle to avoid interference in the injection region
- Deflect P_T into P_L by radial field
- Stabilize beam by kicker to "good filed region"
  - Double-kicker or
  - Weak kicker ?
- Better monitoring/ shimming necessary!

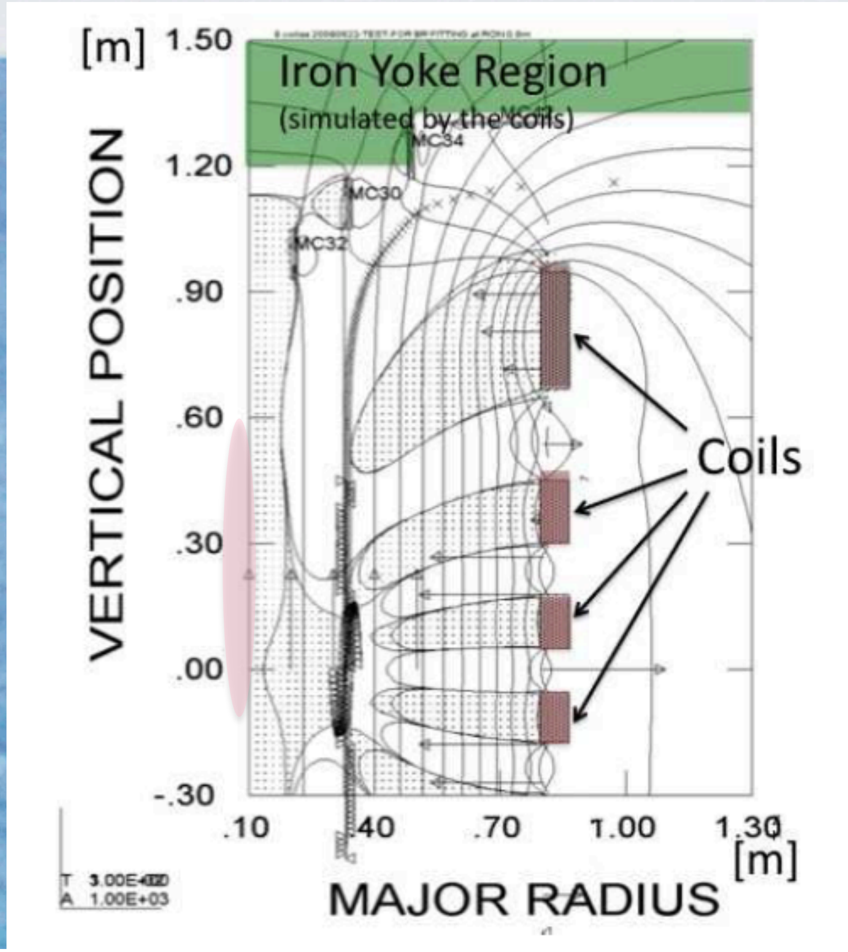


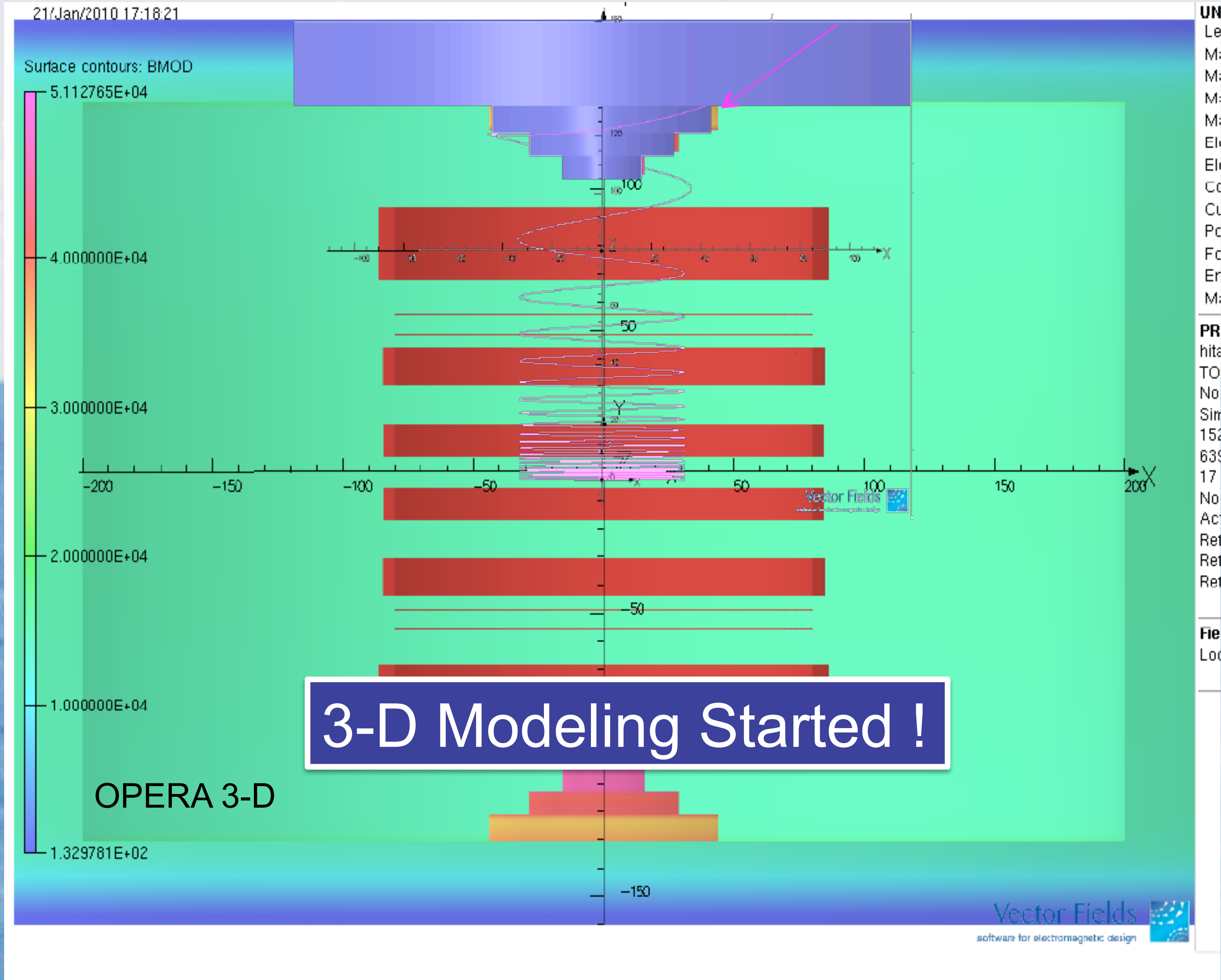
Ultra-Precision Field

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

From GE Website :







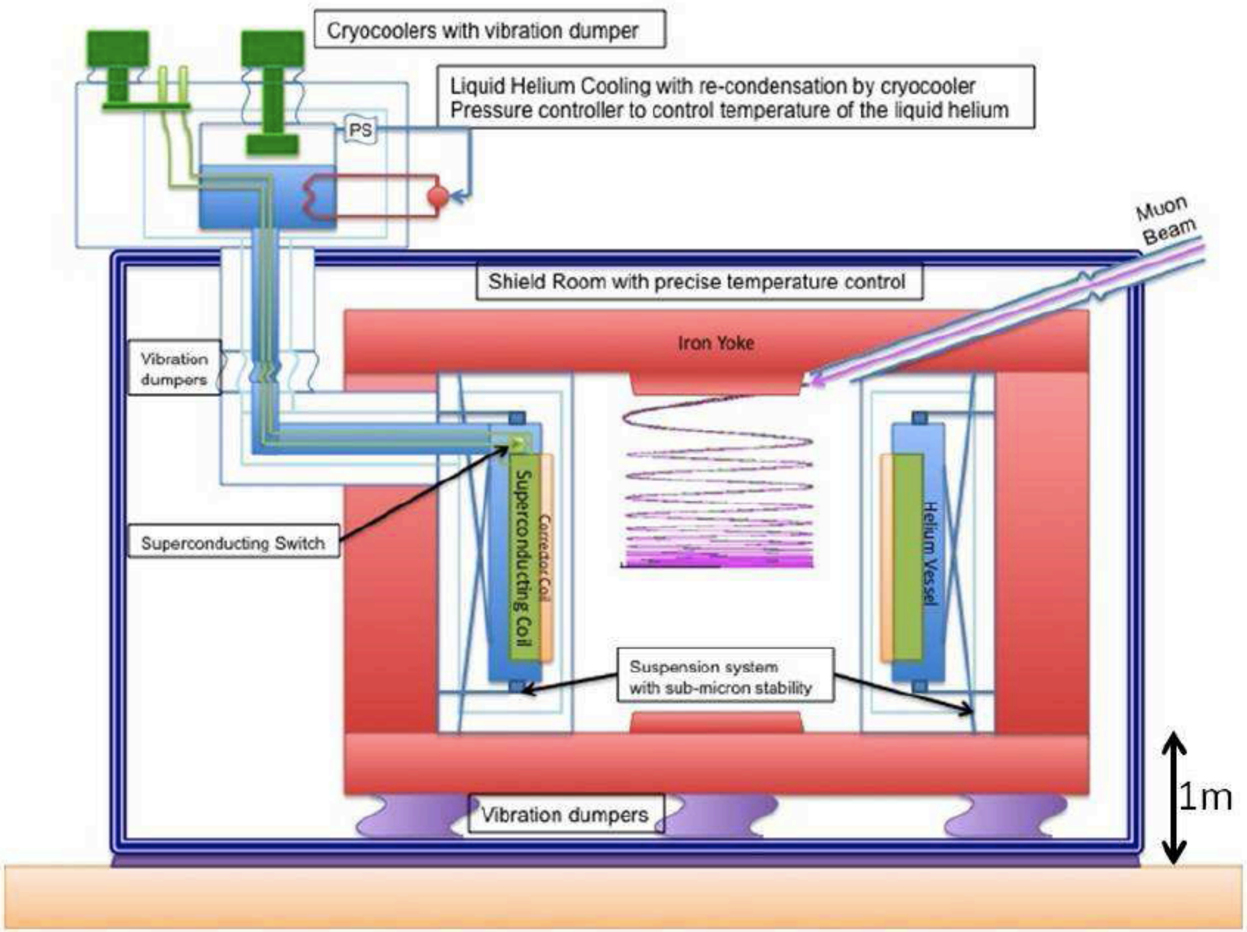
3-D Modeling Started !

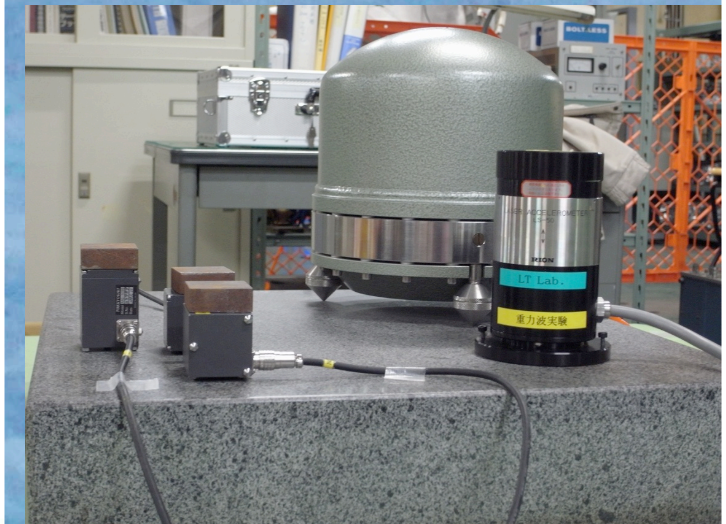
OPERA 3-D

Cryogenic System

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

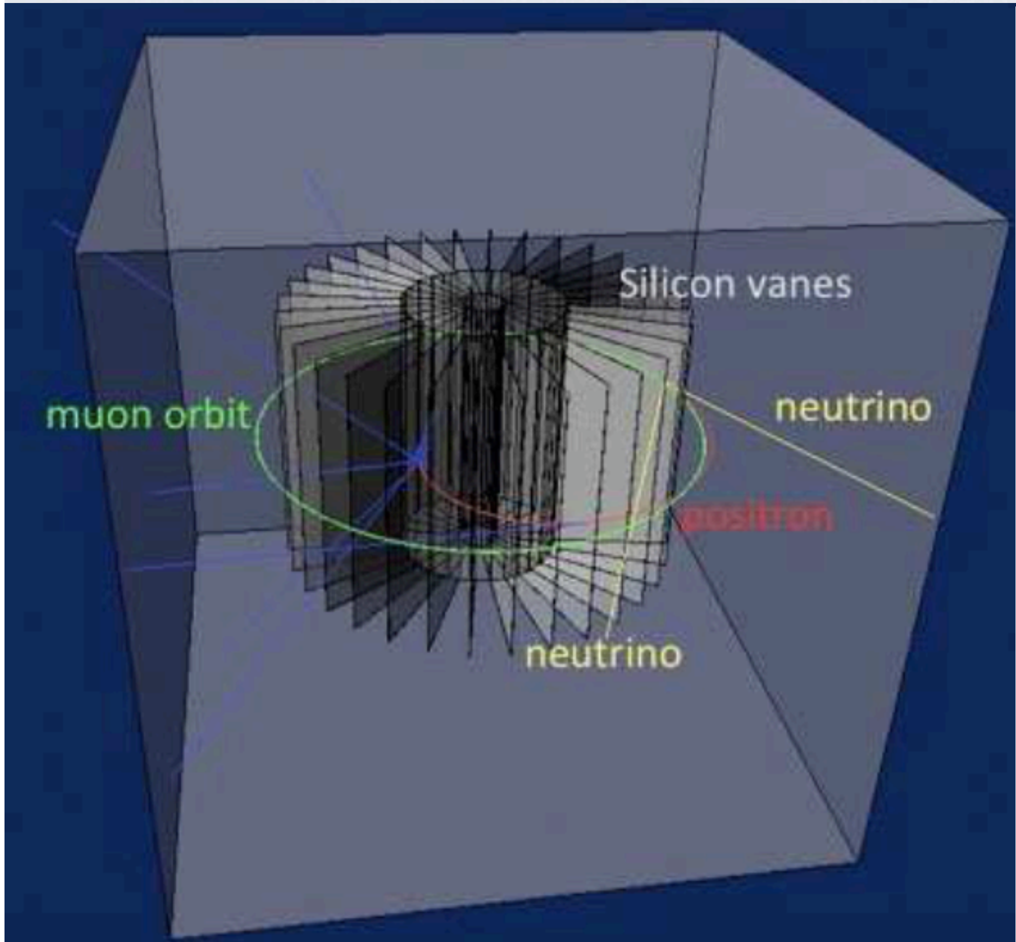
- Conceptual Design developed
- Vibration measurement is ongoing

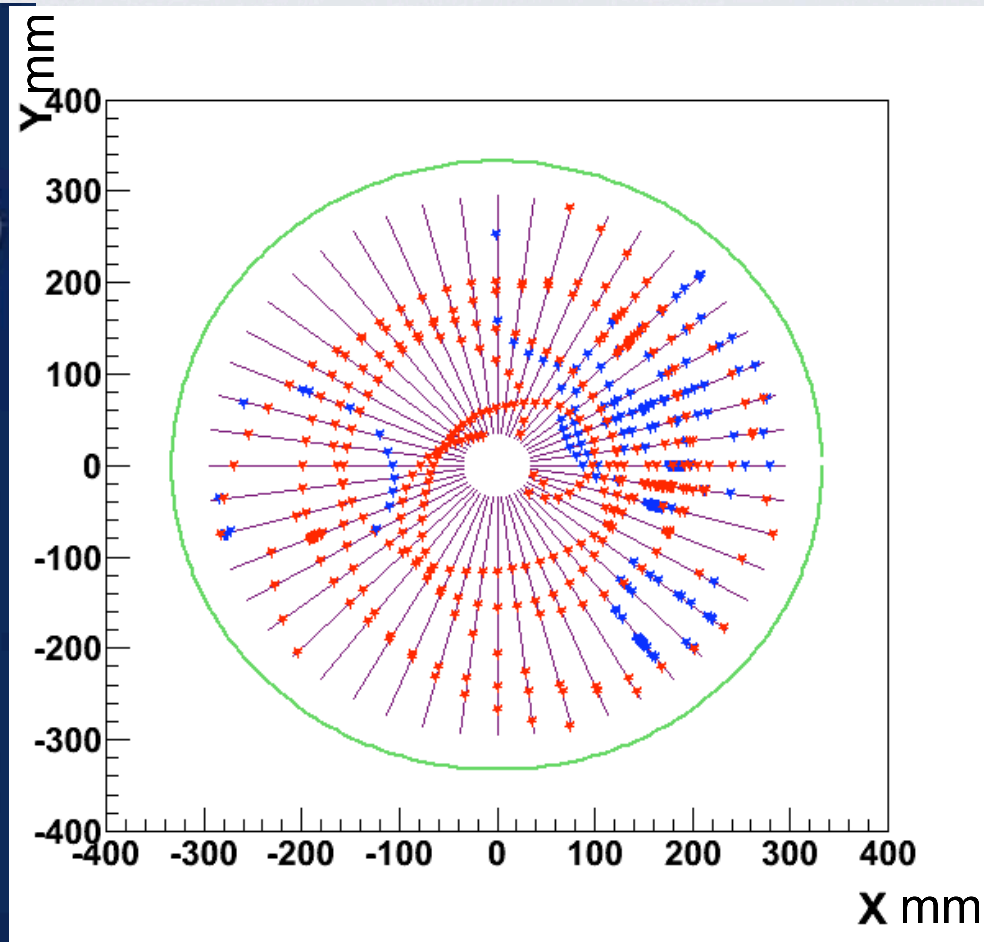




Detector Concept

- Tracking device with hi-rate capability
  - 5 K tracks in 33 micro seconds,
  - ~10 tracks in the first 7.5 nsec period
- Silicon detector would work → Collaboration with ILC started

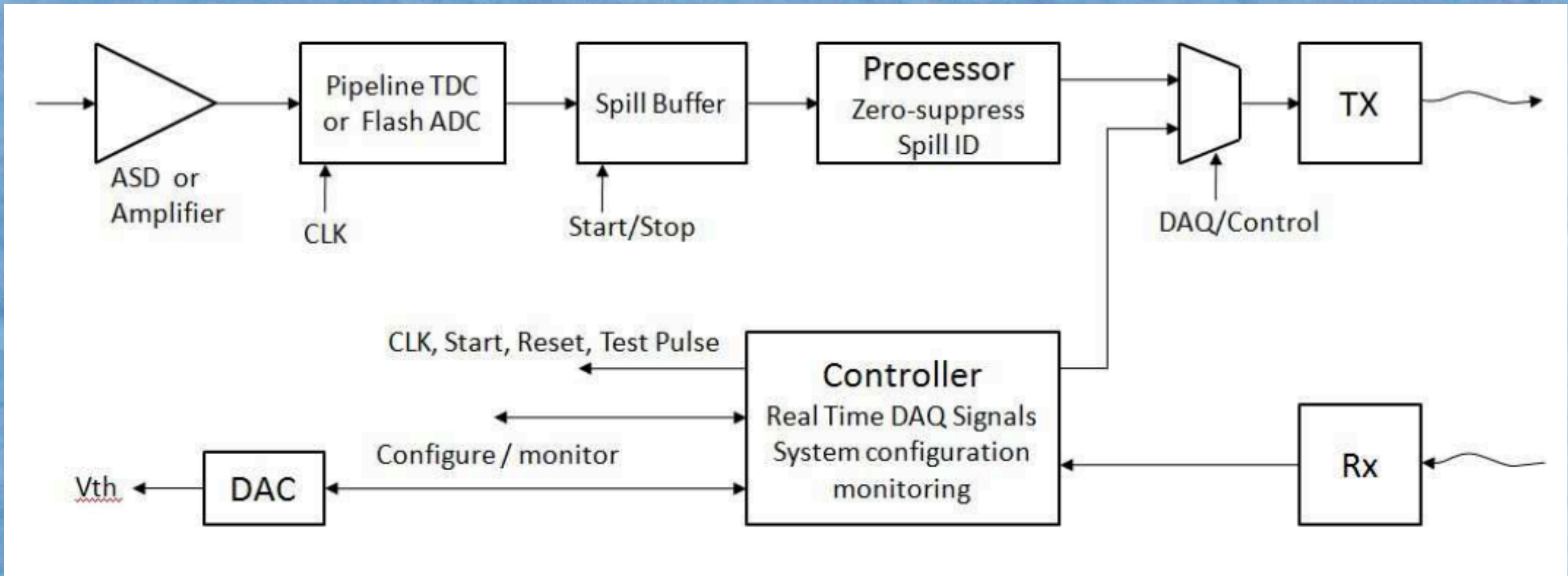




Hit Rate and DAQ Consideration

- About 12 tracks in the first 7.4 nsec
- ~40 hits/track → 500 hits/7.4 ns = 70 GHz
- Over ~100 K channels → 0.7 MHz

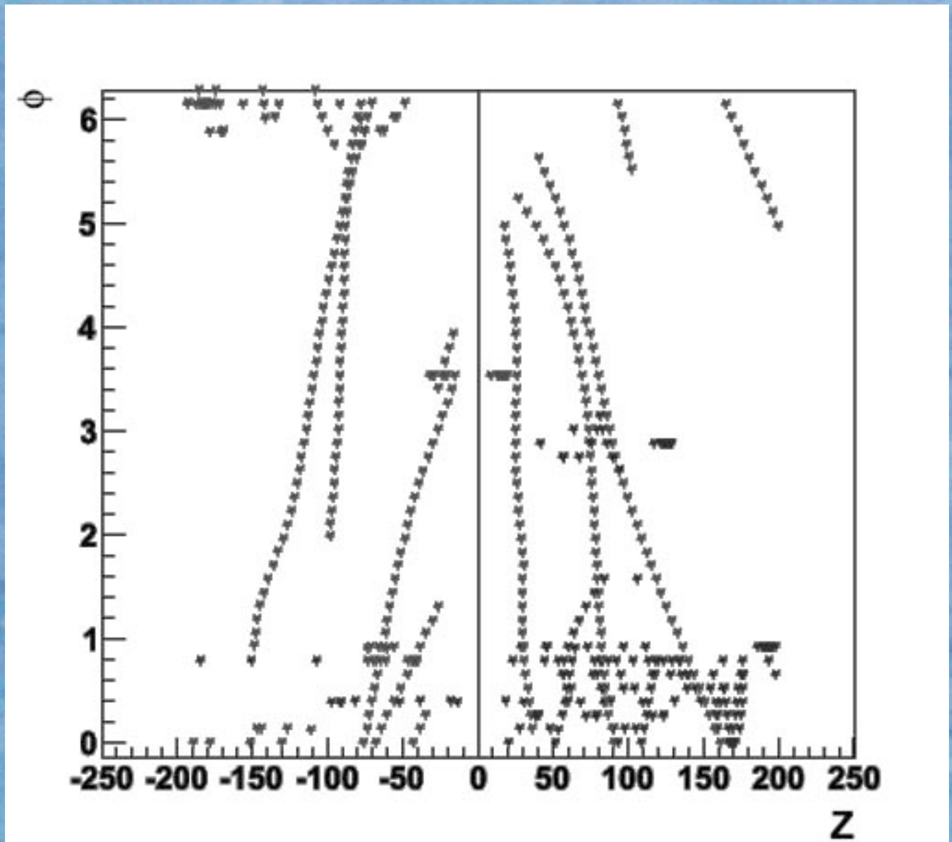
- Data size = 4,000 tracks x 40 hits / 40 ms
  - If address 18 bits (256 Kch), time stamp 18 bits + etc ~ 40 bits / hit → 160 Mb /sec = Back-end DAQ rate

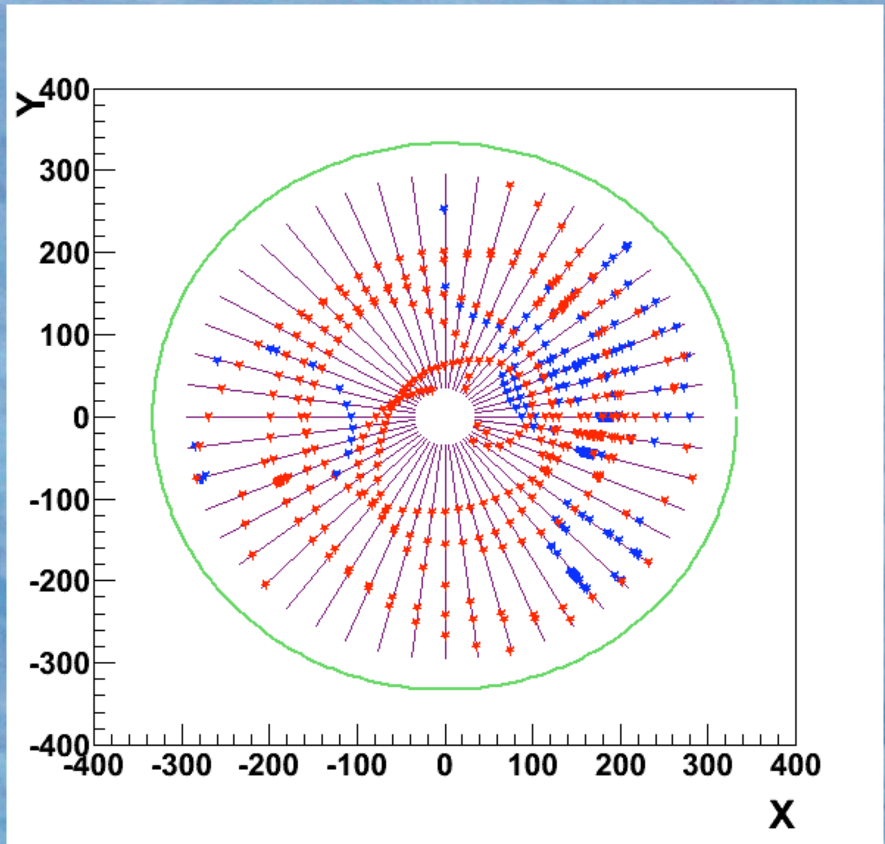


Event Reconstruction

H. Iinuma

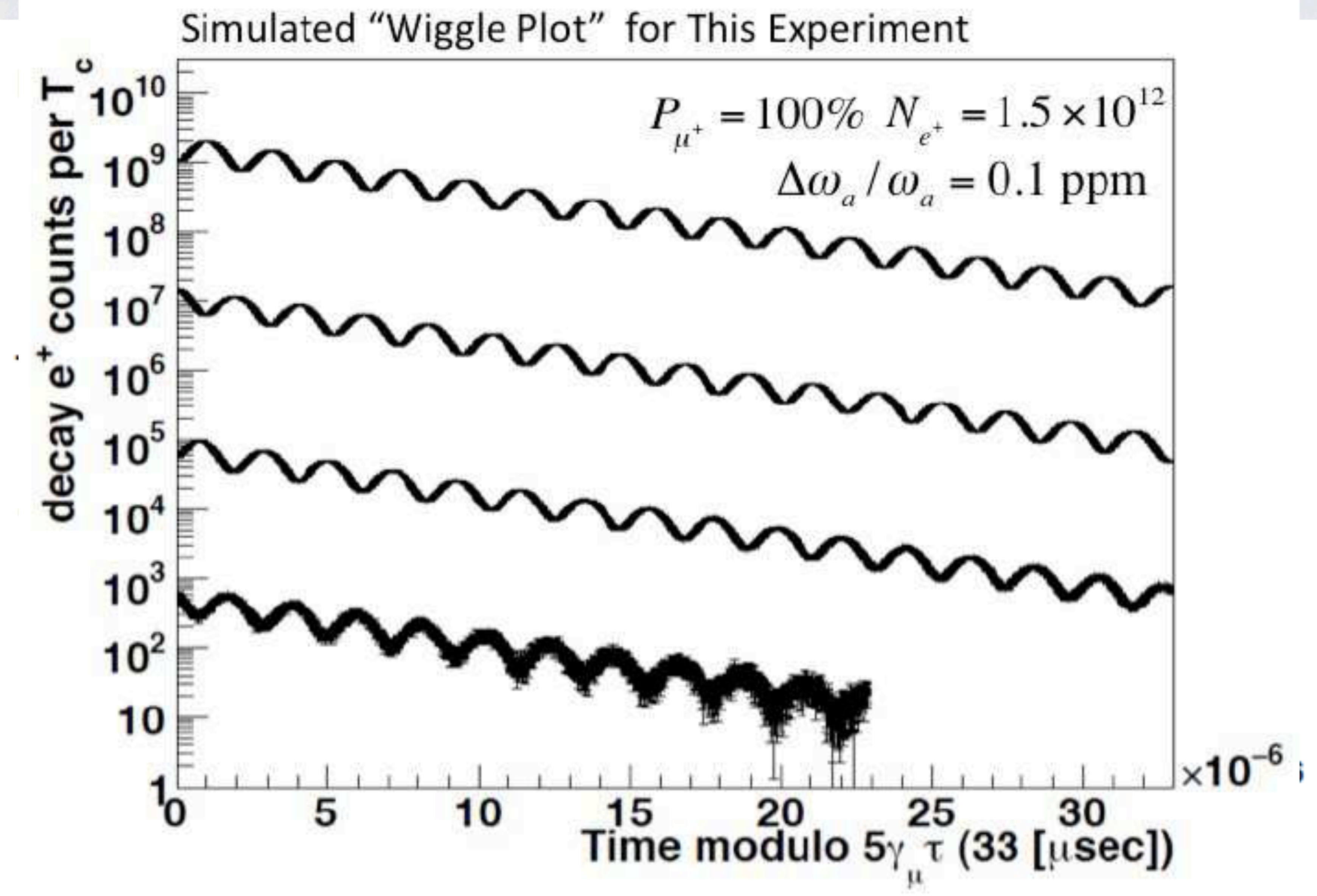
- Simple reconstruction
  - Transform into (r,ϕ) coordinate
  - Hi-momentum track can be identified as consecutive hits in ϕ-z plane





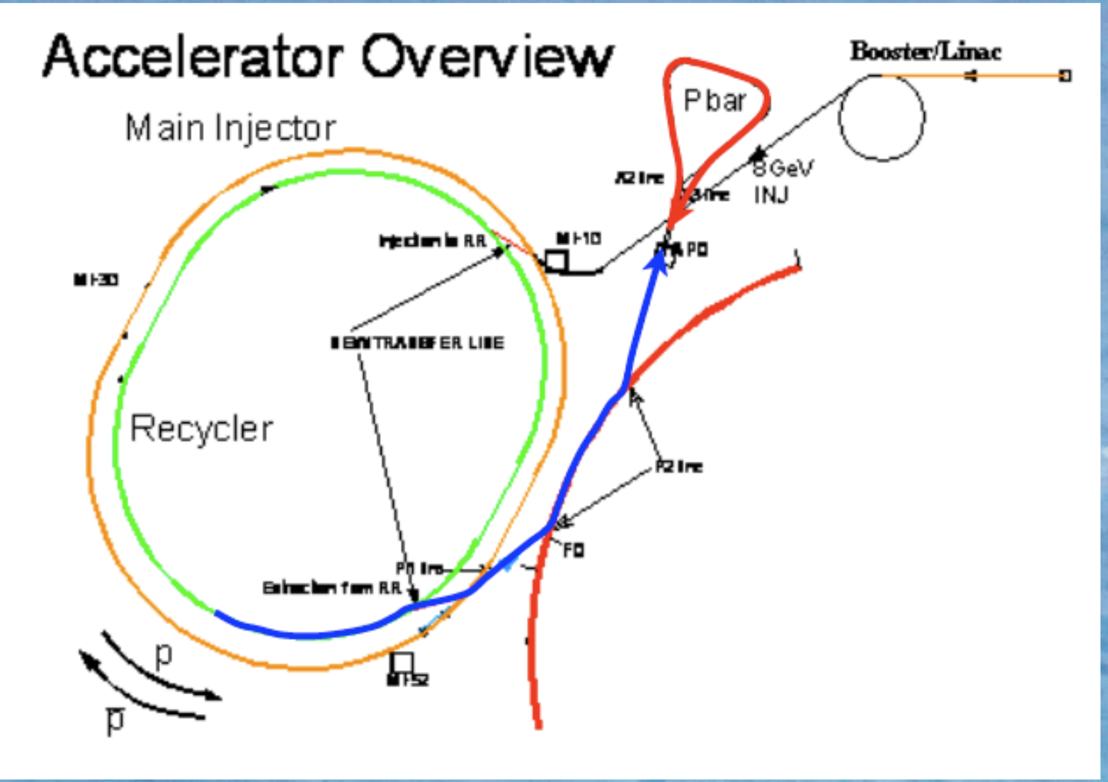
Expected "Wiggle Plot"

- **P=300 MeV/c, B=3T**



Proposal for g-2@Fermilab

- Submitted to Fermilab PAC
  - Contact persons: Lee Roberts (Boston U)
    Dave Hertzog (UIUC)
  - Cost Estimate: ~$20 M (w/ contingency)
  - Discussed at the last PAC (March 4,5)
  - Encouraging message from the lab



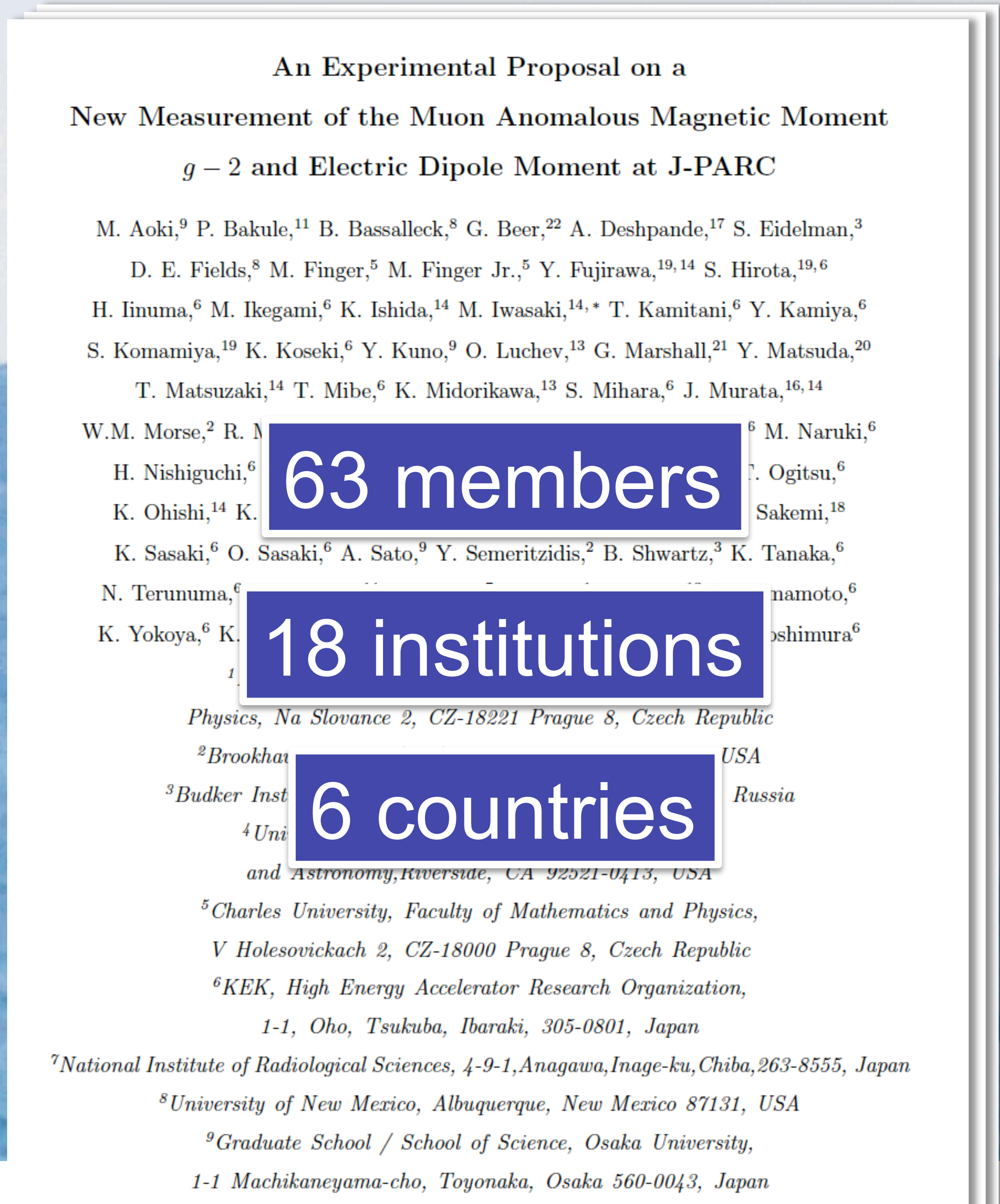
BNL, FNAL, and J-PARC

- complimentary

	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

Proposal to J-PARC PAC

- Submitted to the PAC
- Discussed in the PAC (15-17, Jan., 2010)
- Received strong encouragement and support for further R&D


An Experimental Proposal on a

New Measurement of the Muon Anomalous Magnetic Moment

$g-2$ and Electric Dipole Moment at J-PARC

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D. E. Fields,[8] M. Finger,[5] M. Finger Jr.,[5] Y. Fujirawa,[19,14] S. Hirota,[19,6]

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T. Matsuzaki,[14] T. Mibe,[6] K. Midorikawa,[13] S. Mihara,[6] J. Murata,[16,14]

W.M. Morse,[2] R. N ... [6] M. Naruki,[6]

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K. Ohishi,[14] K. ... Sakemi,[18]

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K. Yokoya,[6] K. ... oshimura[6]

63 members

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6 countries

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EDM

Beginning…

E.M. Purcell and N.F. Ramsey, Phys. Rev. 78 (1950)

On the Possibility of Electric Dipole Moments for Elementary Particles and Nuclei

E. M. PURCELL AND N. F. RAMSEY
Department of Physics, Harvard University, Cambridge, Massachusetts
April 27, 1950

IT is generally assumed on the basis of some suggestive theoretical symmetry arguments[1] that nuclei and elementary particles can have no electric dipole moments. It is the purpose of this note to point out that although these theoretical arguments are valid when applied to molecular and atomic moments whose electromagnetic origin is well understood, their extension to nuclei and elementary particles rests on assumptions not yet tested.

One form of the argument against the possibility of an electric dipole moment of a nucleon or similar particle is that the dipole's orientation must be completely specified by the orientation of the angular momentum which, however, is an axial vector specifying a direction of circulation, not a direction of displacement as would be required to obtain an electric dipole moment from electrical charges. On the other hand, if the nucleon should spend part of its time asymmetrically dissociated into opposite magnetic poles of the type that Dirac[2] has shown to be theoretically possible, a circulation of these magnetic poles could give rise to an electric dipole moment. To forestall a possible objection we may remark that this electric dipole would be a polar vector, being the product of the angular momentum (an axial vector) and the magnetic pole strength, which is a pseudoscalar in conformity with the usual convention that electric charge is a simple scalar.

The argument against electric dipoles, in another form, raises directly the question of parity. A nucleon with an electric dipole ment would show an asymmetry between left- and right- ...d coordinate systems; in one system the dipole moment

The authors wish to thank Mr. Smith for suggesting an important correction to our original calculation on the neutron-electron interaction experiment.

[1] A typical argument is given by H. A. Bethe, *Elementary Nuclear Theory* (John Wiley and Sons, Inc., New York).
[2] P. A. M. Dirac, Phys. Rev. **74**, 817 (1948).
[3] Havens, Rabi, and Rainwater, Phys. Rev. **72**, 634 (1947).
[4] E. Fermi and L. Marshall, Phys. Rev. **72**, 1139 (1947).
[5] L. W. Alvarez and F. Bloch, Phys. Rev. **57**, 111 (1940).
[6] N. F. Ramsey, Phys. Rev. **76**, 996 (1949).

Weak contribution to $\eta \neq 0$?

- **4^{th} order contributions** F. Hoogeveen, NPB341 (1990) 332

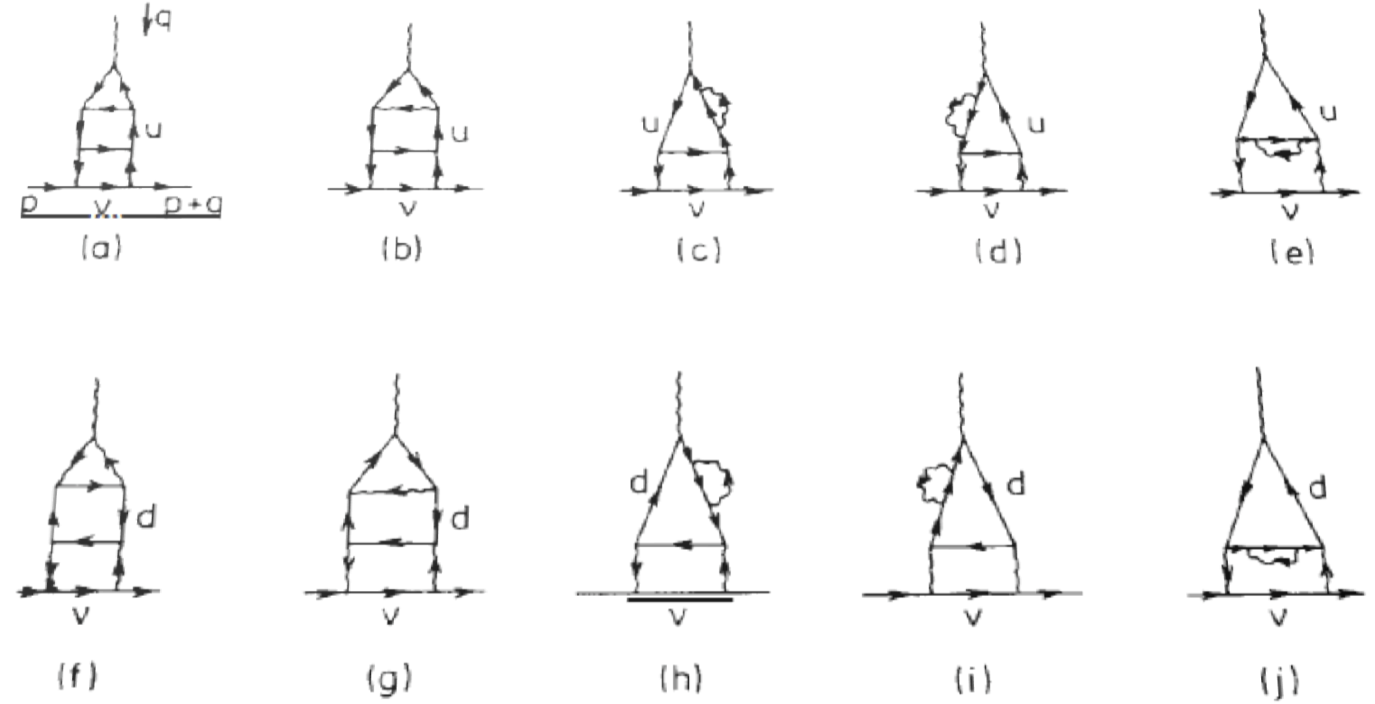


Fig. 4. The ten diagrams which contribute to the edm of the electron. The internal wavy lines are W-propagators.

~2E-38 e cm

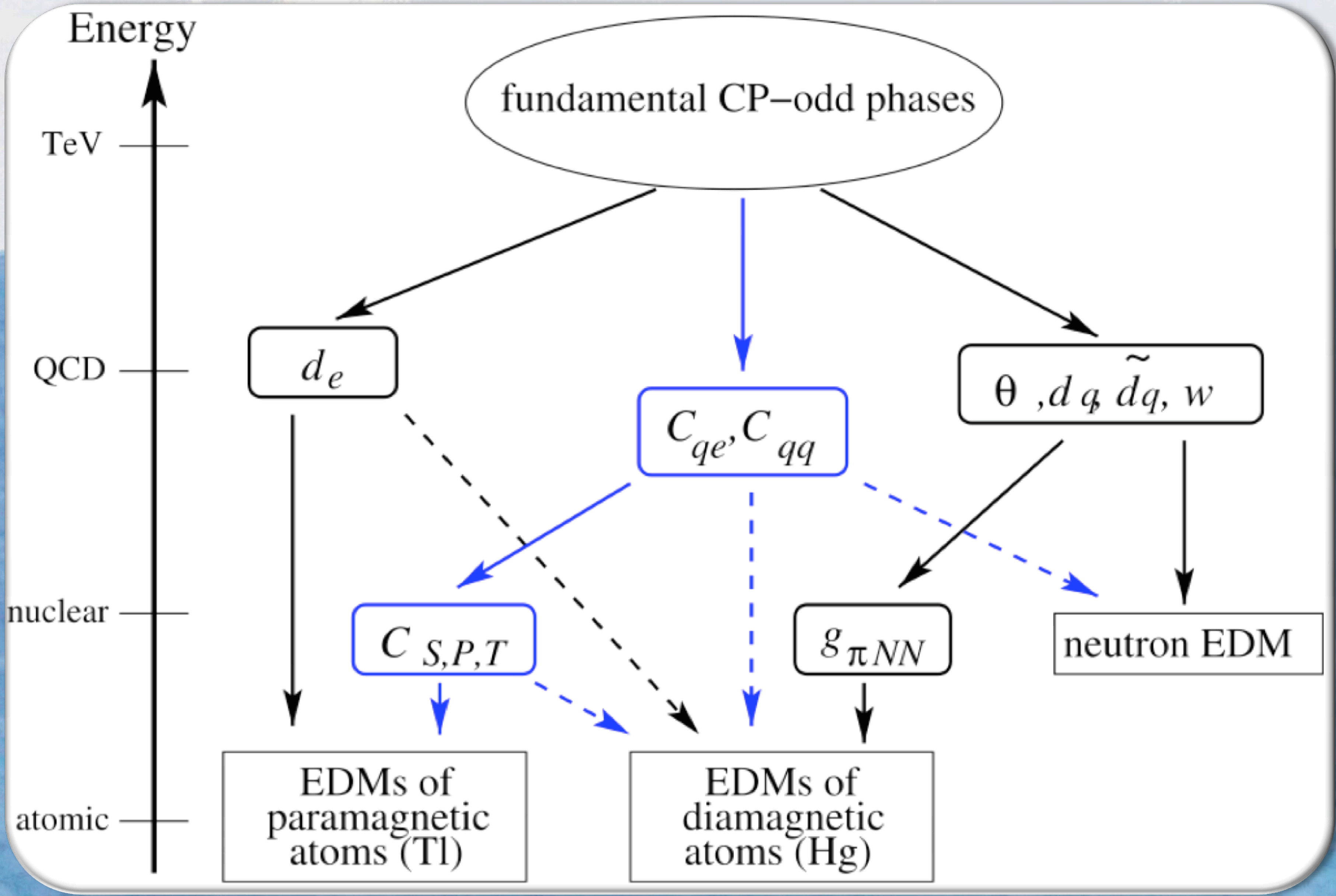
- **New Physics contributions?**

Measurements

- Electron – Penning trap / Atom
  - T-violation search in heavy paramagnetic atoms (EDM)
  - Electron and positron in Penning traps (MDM)
- Muon – Storage ring
  - Decay in flight → storage ring with B and E
- Tau lepton – colliders $e^+e^- \rightarrow \tau^+\tau^-$
  - Pair production kinematic dependence to search for T-odd contribution

Origin of EDM

M.Pospelov and A.Ritz, Ann.Phys. 318 (2005) 119



Current Limits

- **Electron EDM from Atomic EDM Pure lepton contribution can be measured with Muon**

Physical System	Value, Error ($e\cdot$ cm)	Reference
^{199}Hg atom	$(-1.06 \pm 0.49 \pm 0.40) \times 10^{-28}$	[3]
electron	$(0.69 \pm 0.74) \times 10^{-27}$	[4]
neutron	$(-1.0 \pm 3.6) \times 10^{-26}$	[5]
muon	$(3.7 \pm 3.4) \times 10^{-19}$	[6]

Parameter	^{199}Hg bound	Hg theory	Best other limit		
$\tilde{d}_q$(cm) ^{a}	6×10^{-27}	[15]	n:	3×10^{-26}	[3]
d_p(e cm)	7.9×10^{-25}	[16]	TlF:	$6 \times$	
C_S	5.2×10^{-8}	[18]	Tl:	$1.3 \times$	
C_P	5.1×10^{-7}	[18]	TlF:	$3 \times$	
C_T	1.5×10^{-9}	[18]	TlF:	$4.5 \times$	
$\bar{\theta}_{QCD}$	3×10^{-10}	[19]	n:	1×10^{-10}	[3]
d_n(e cm)	5.8×10^{-26}	[16]	n:	2.9×10^{-26}	[3]
d_e(e cm)	3×10^{-27}	[20, 21]	Tl:	1.6×10^{-27}	[3]

^{a}For ^{199}Hg: $\tilde{d}_q = (\tilde{d}_u - \tilde{d}_d)$, while for n: $\tilde{d}_q = (0.5\tilde{d}_u + \tilde{d}_d)$.

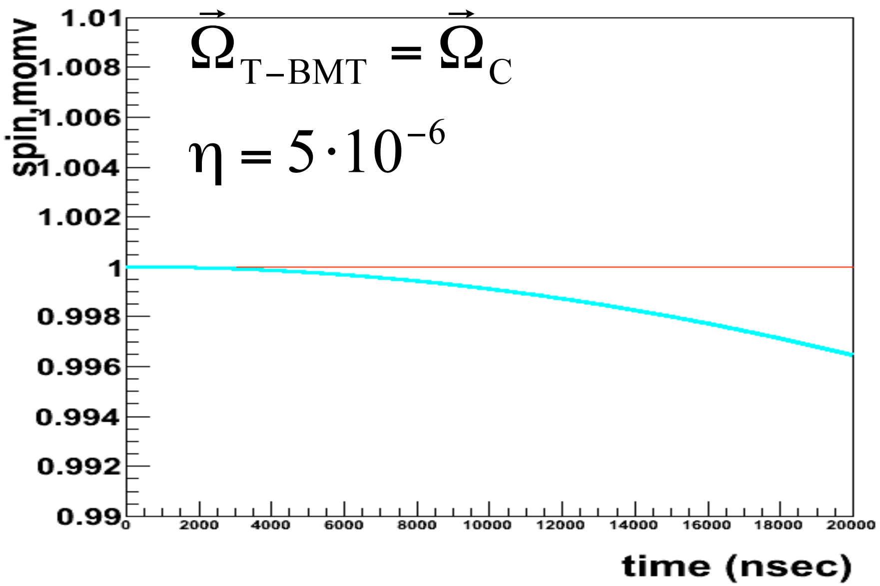
$$-2.2 < Re(d_\tau) < 4.5 \quad (10^{-17} e\,\mathrm{cm}),$$
$$-2.5 < Im(d_\tau) < 0.8 \quad (10^{-17} e\,\mathrm{cm}).$$

Spin Rotation and EDM

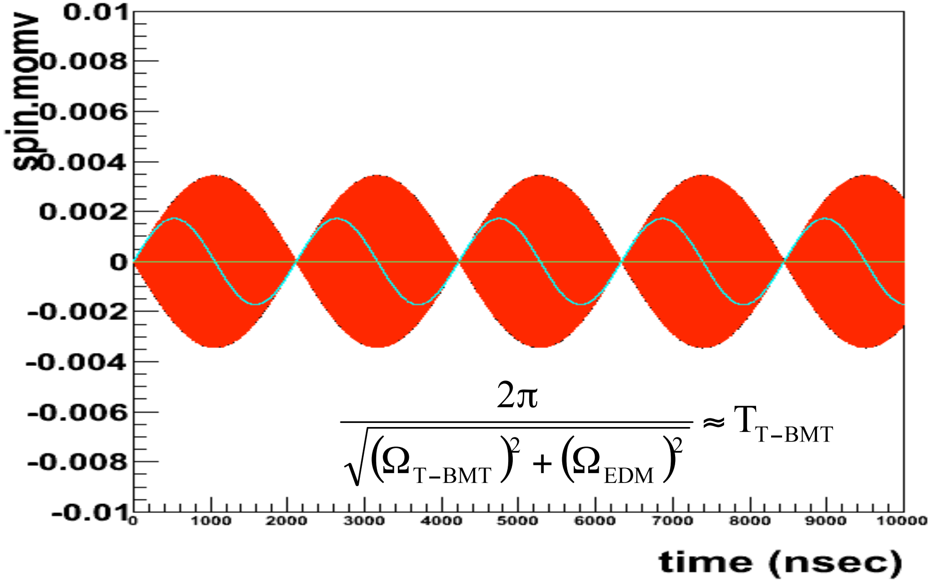
- **Anyway to enhance EDM signal?**

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

Spin Frozen mode

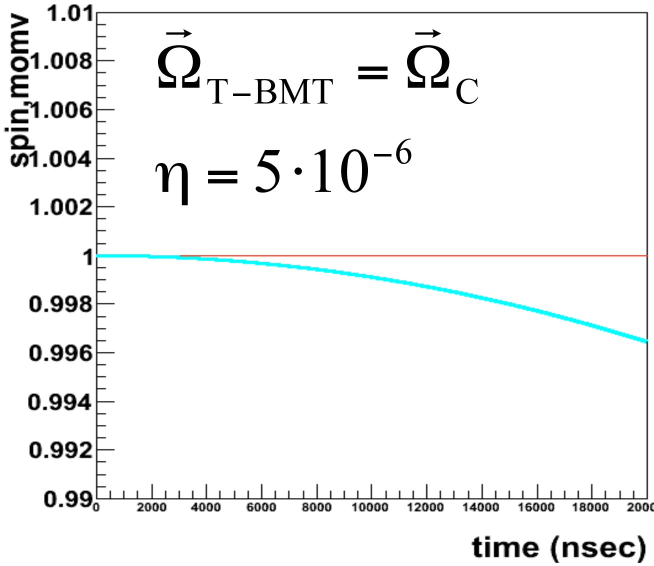


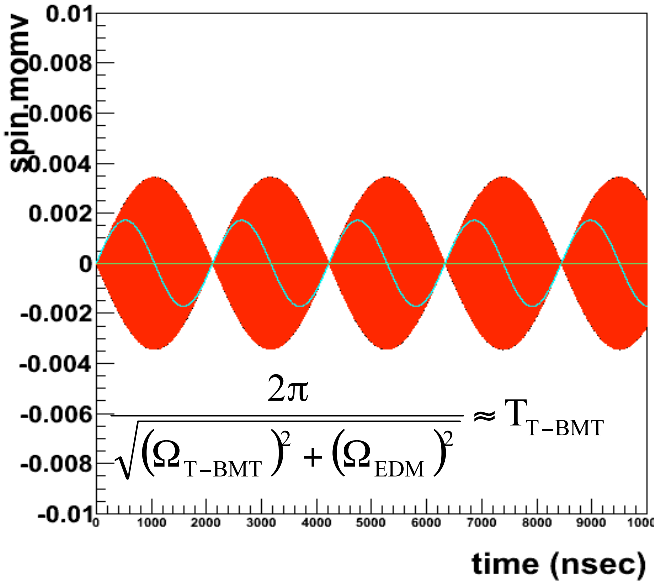
Non-Frozen but E=0, s//B



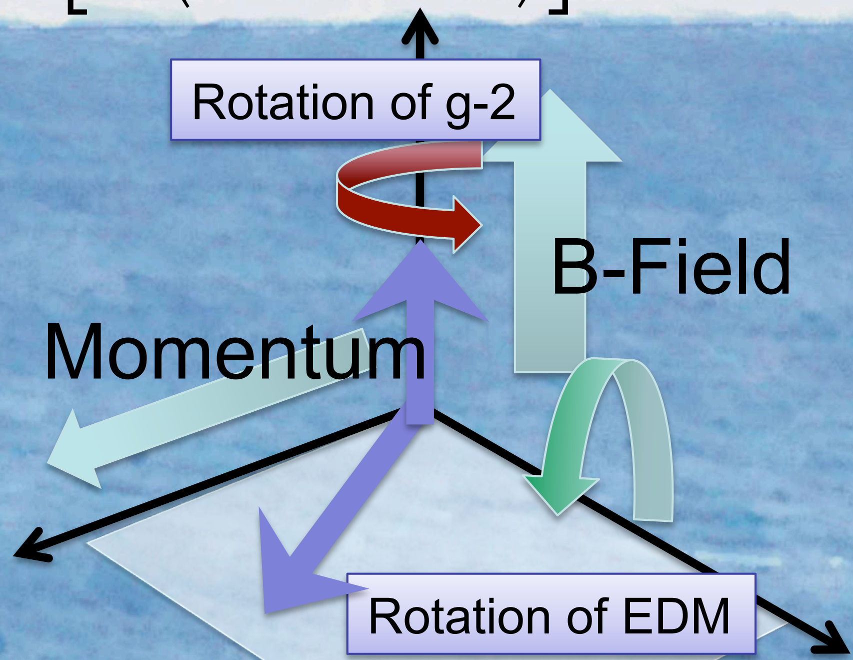
Spin Rotation and EDM

- Rotation axis is orthogonal to g−2 case





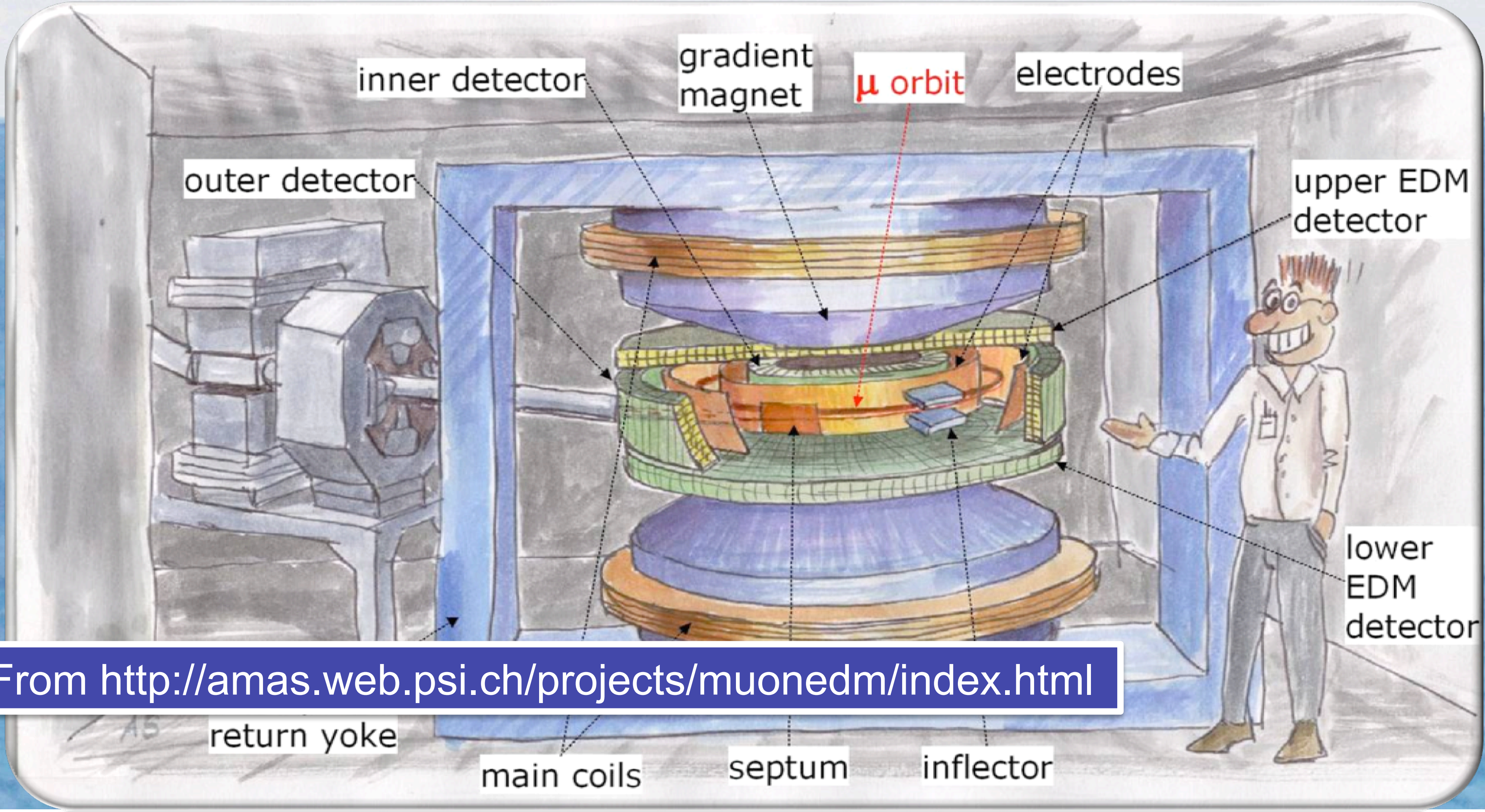
$$\vec{\omega} = -\frac{e}{m}\left[\frac{\eta}{2}\left(\vec{\beta} \times \vec{B} + \frac{\vec{E}}{c}\right)\right]$$



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

Muon EDM at PSI

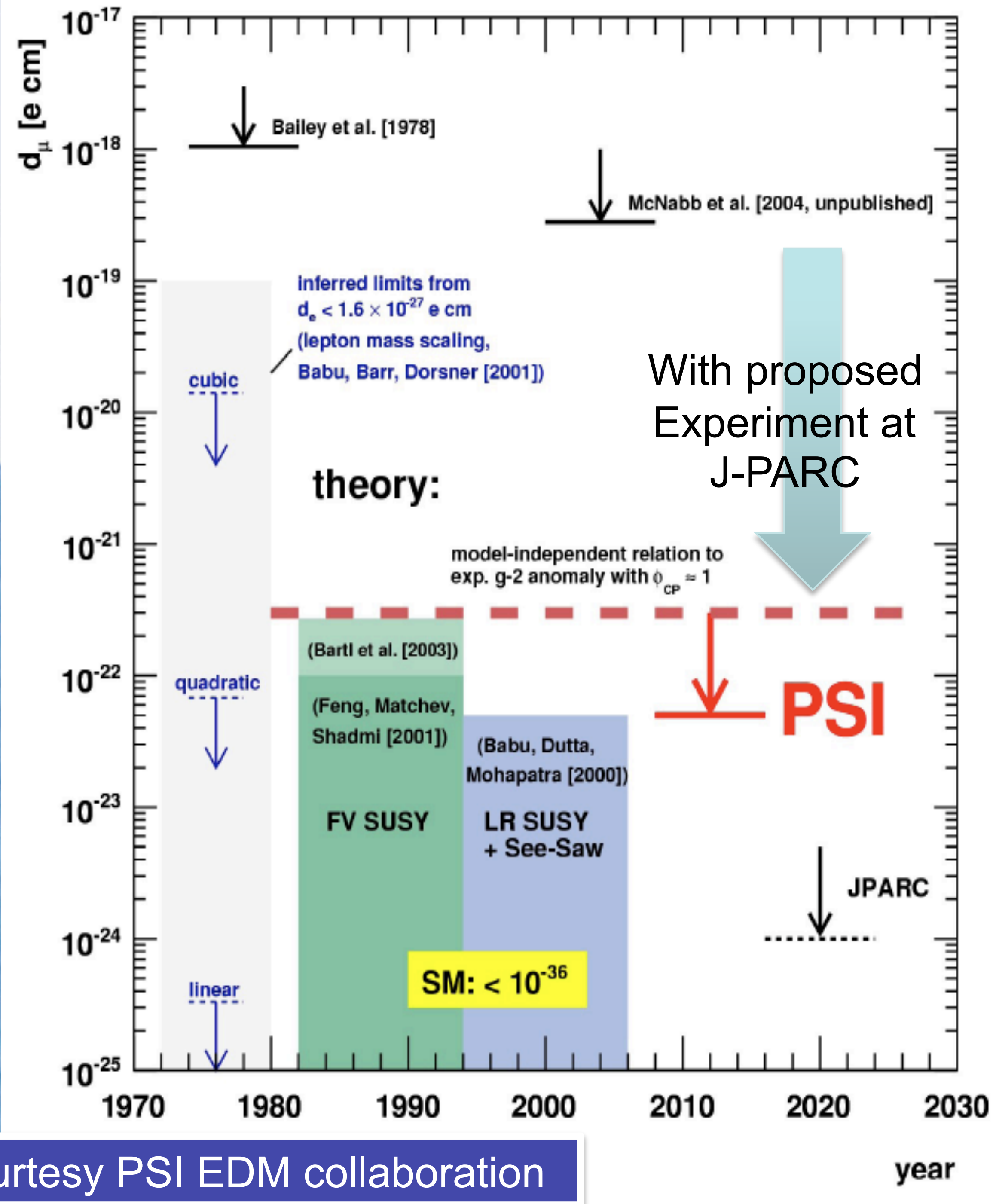
- A nice experimental proposal using "spin frozen" technique!



From http://amas.web.psi.ch/projects/muonedm/index.html

Muon EDM

- Direct CPV in Lepton Sector
  - CPV Required beyond KM
- Current Exp. Limit ~ 1e-19
- Potential Sensitivity of J-PARC Exp.
  - ~5e-22 @ MLF



Courtesy PSI EDM collaboration

Summary

- We propose New Generation of Muon g-2/EDM Experiment at J-PARC with Novel Technique!
- Intend to start the experiment in 5 years!
- There are many challenges on the way
  - Muon flux
  - High power Lyman-alpha Laser
  - Maximize the muon polarization
  - Muon LINAC
  - Beam monitor of low intensity muon be
  - Ultra-precision field !
  - High-rate tracking system … and many
- We have STRONG SUPPORT from th ab to explore these exciting challenges!
- We would like to invite young scientists to join this challenge!

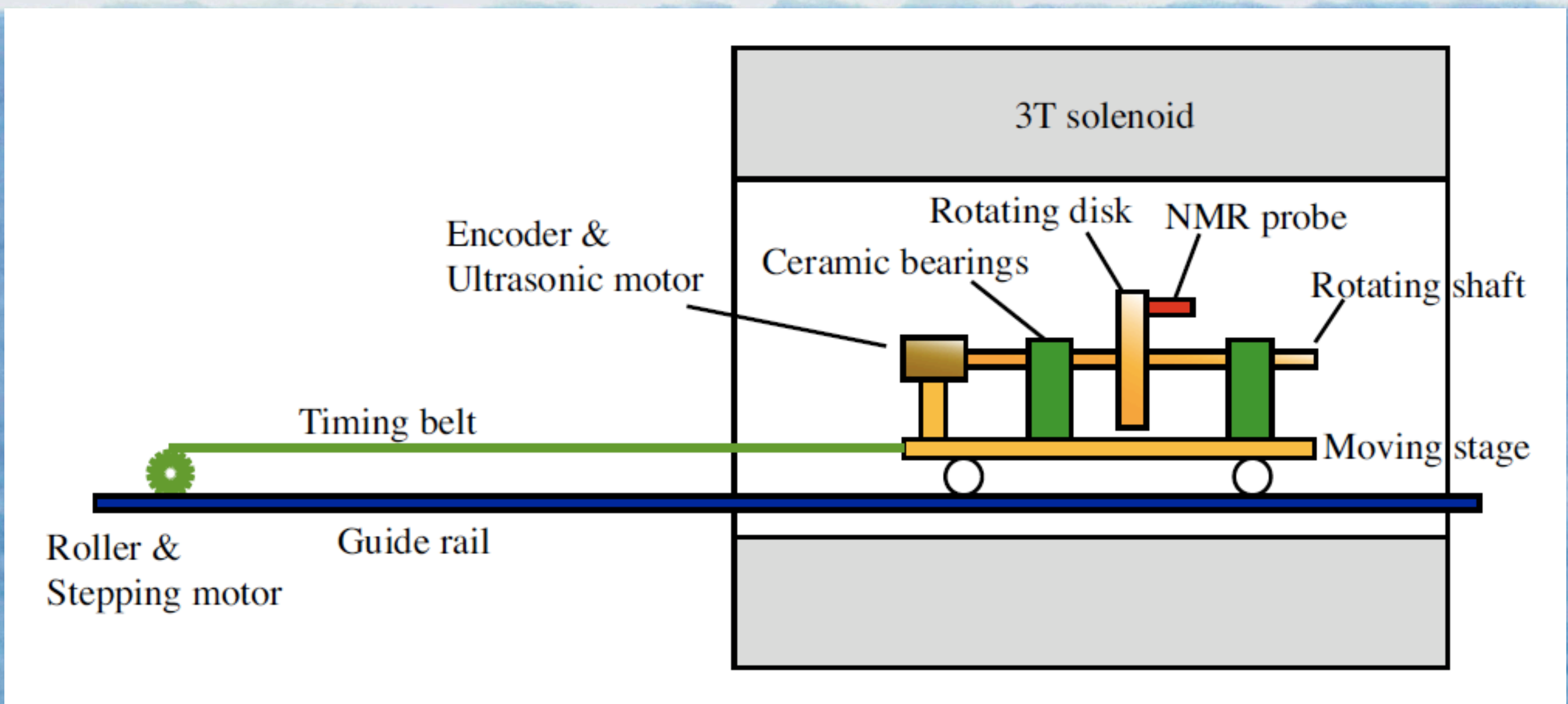
Of course, including young at heart!

backup

Precision Field Monitor

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

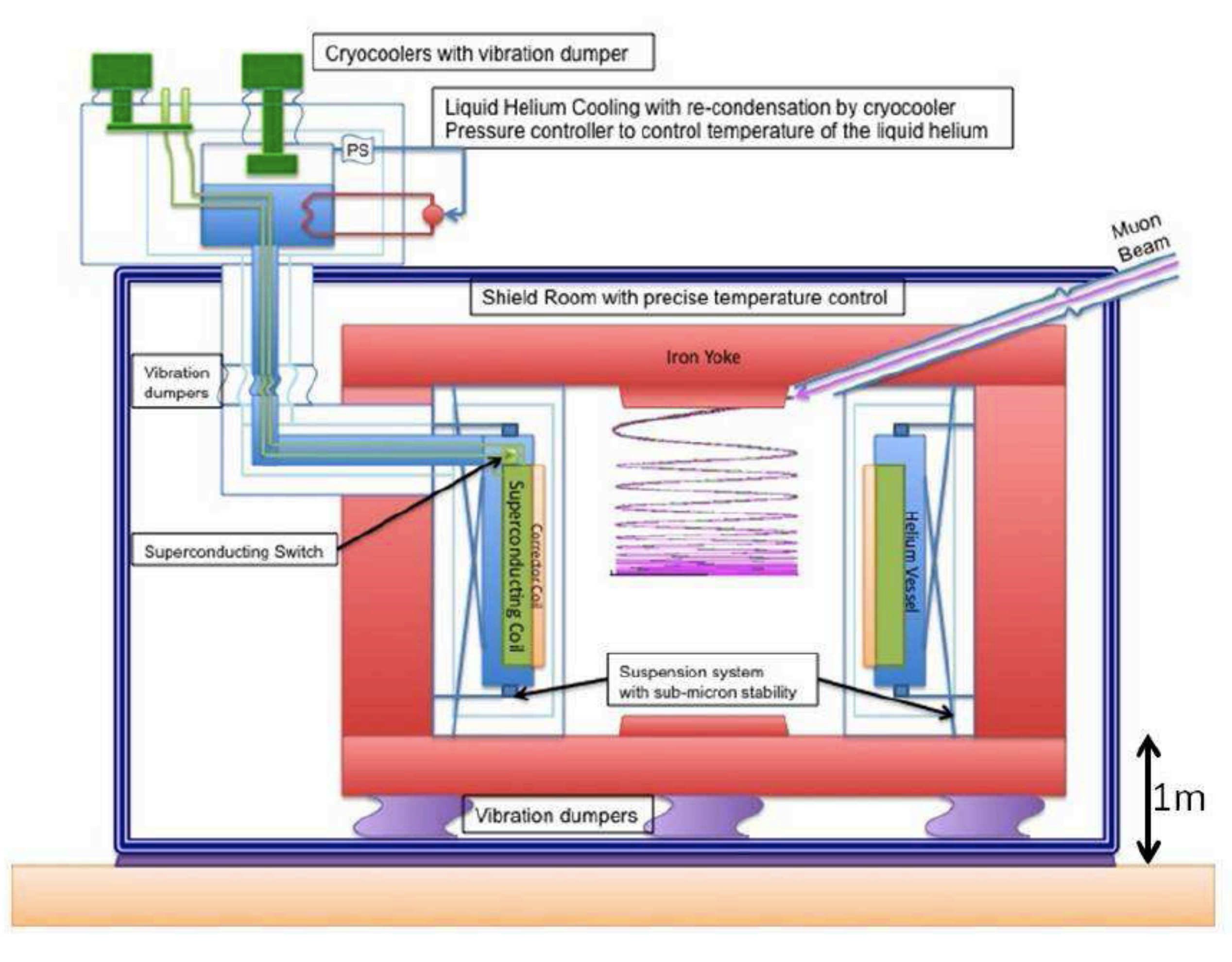
- **Being developed with MRI precision magnet + NMR probes + Hall probes**



Cryogenic System

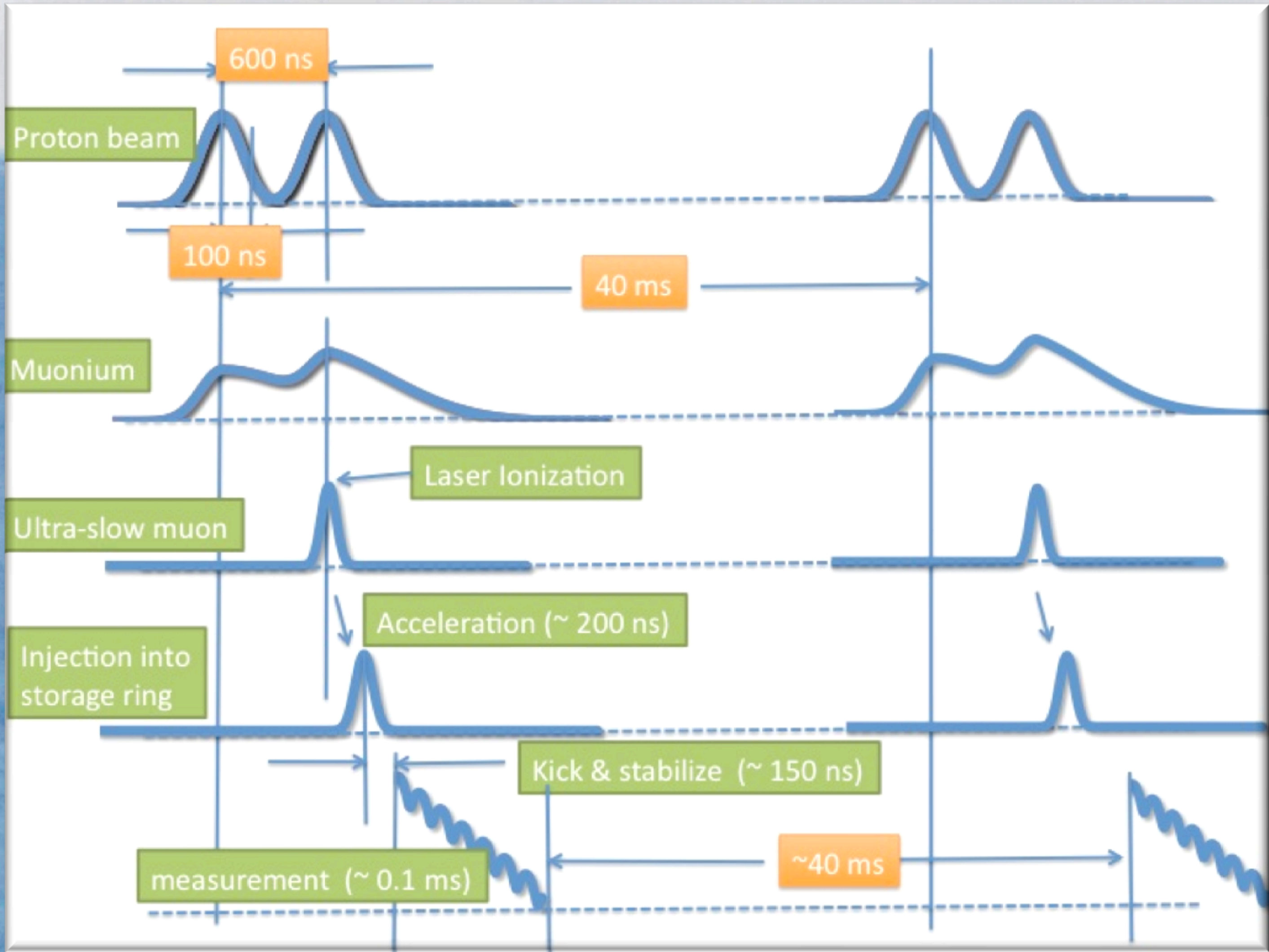
T. Ogitsu, K. Sasaki, K. Tanaka, and A. Yamamoto

- Conceptual Design developed
- Vibration measurement is ongoing



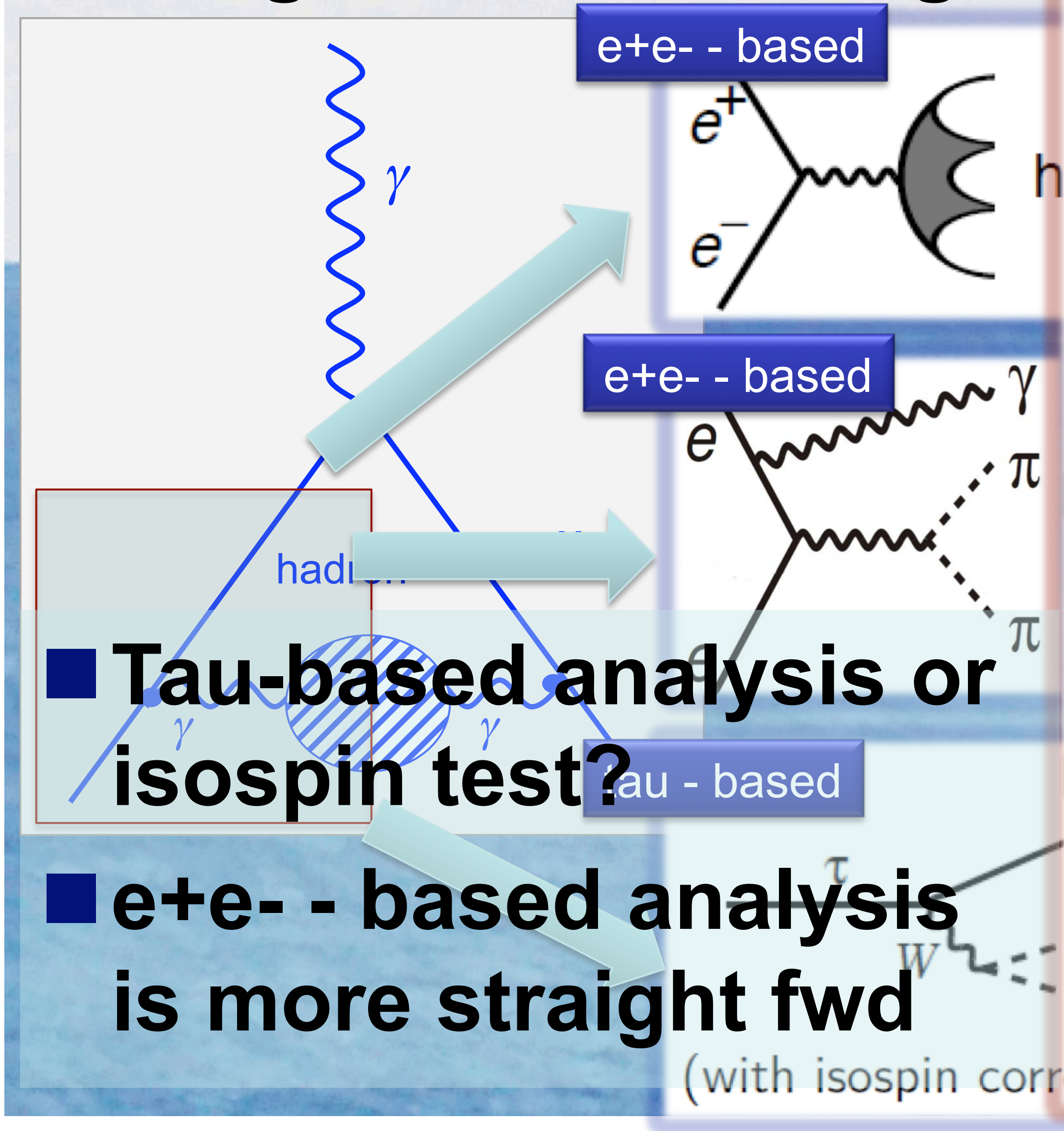
Time structure of the exp.

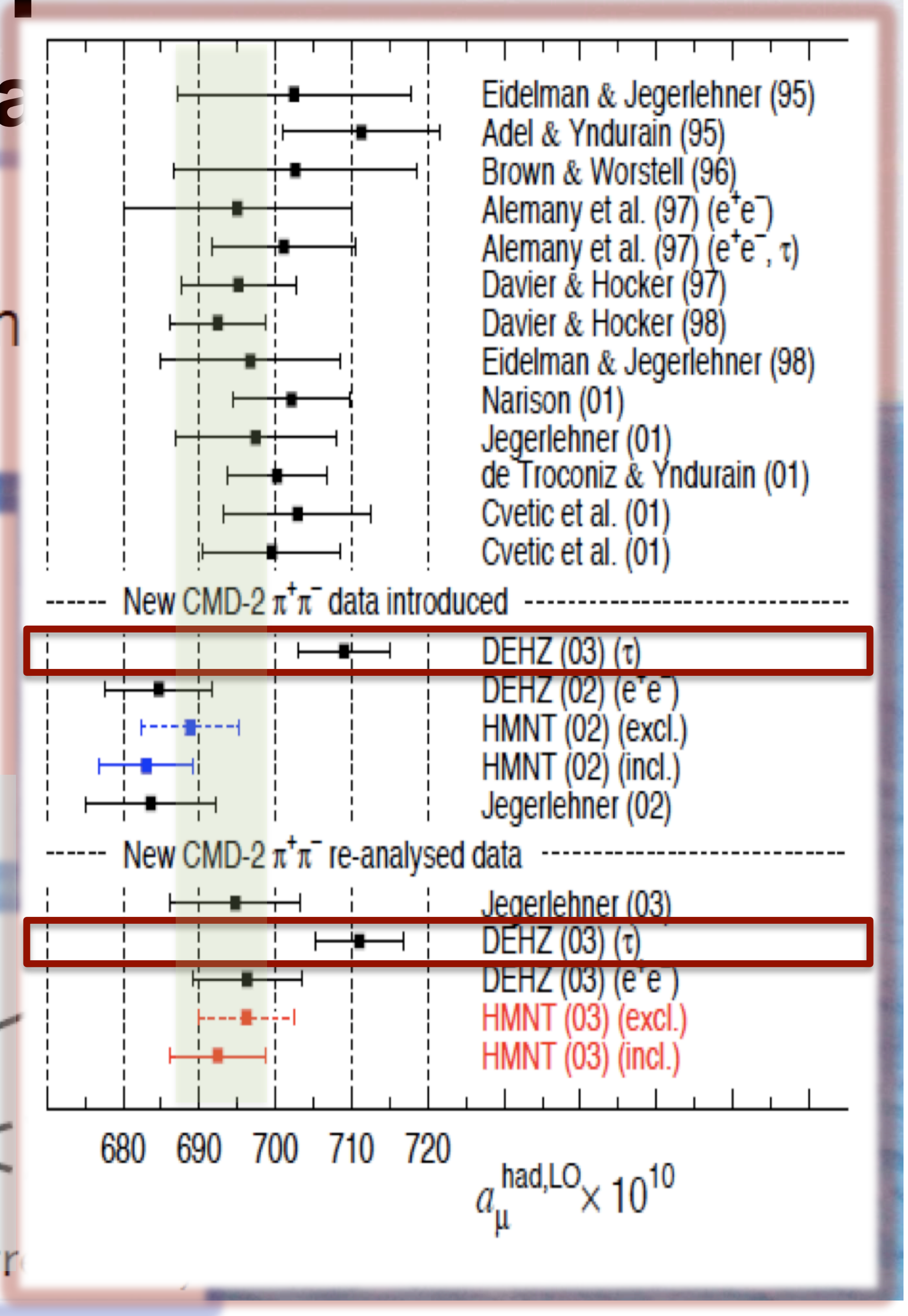
- Driven by 25 Hz proton beam
- Time-zero defined by Laser Ionization



Hadronic vacuum polarization

- Largest cont. among ha



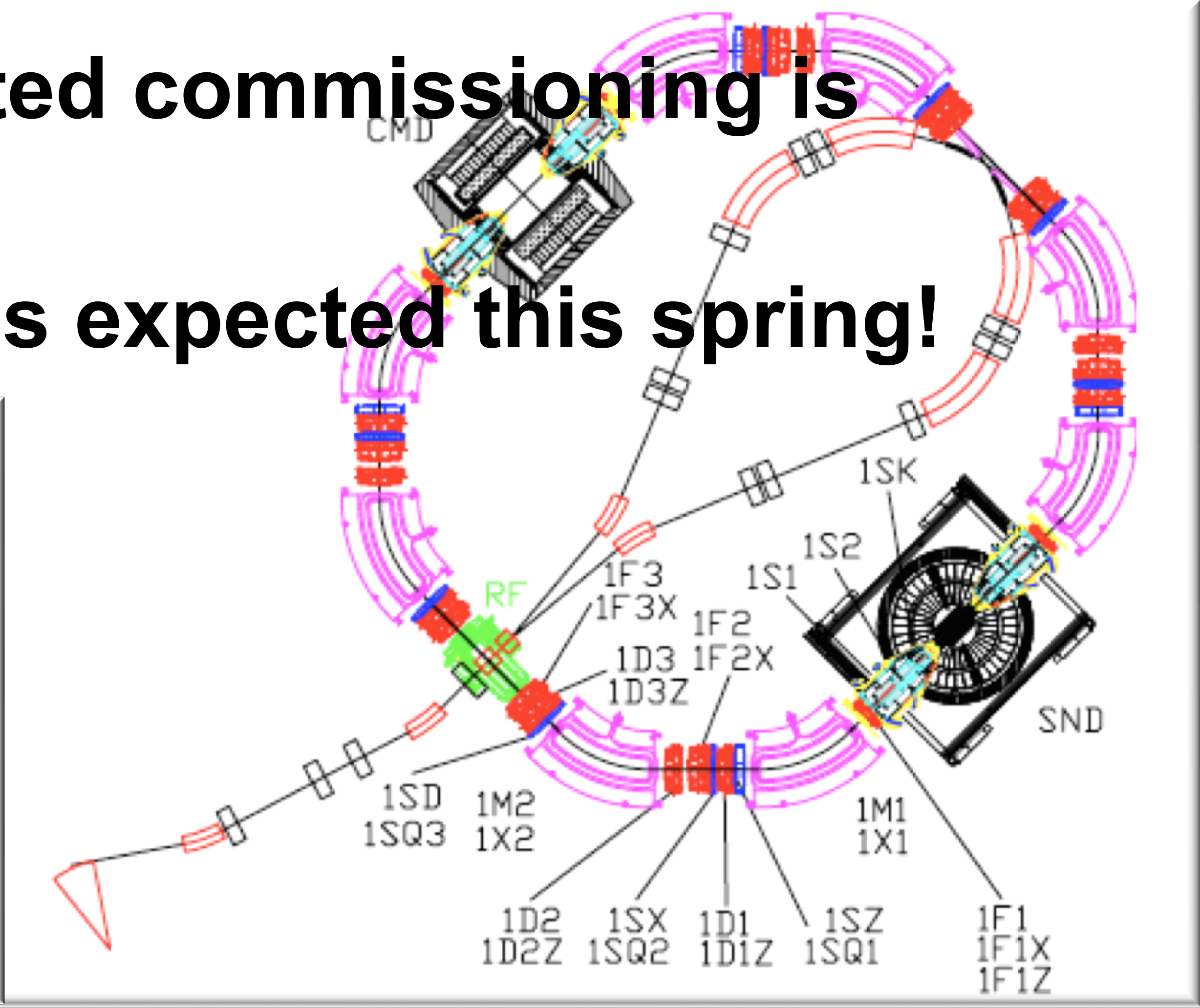


- Tau-based analysis or isospin test?
- e+e- - based analysis is more straight fwd

VEPP-2000 at BINP

- Machine commissioning since 2007
- Detector installed
- Fully integrated commissioning is ongoing
- Physics run is expected this spring!

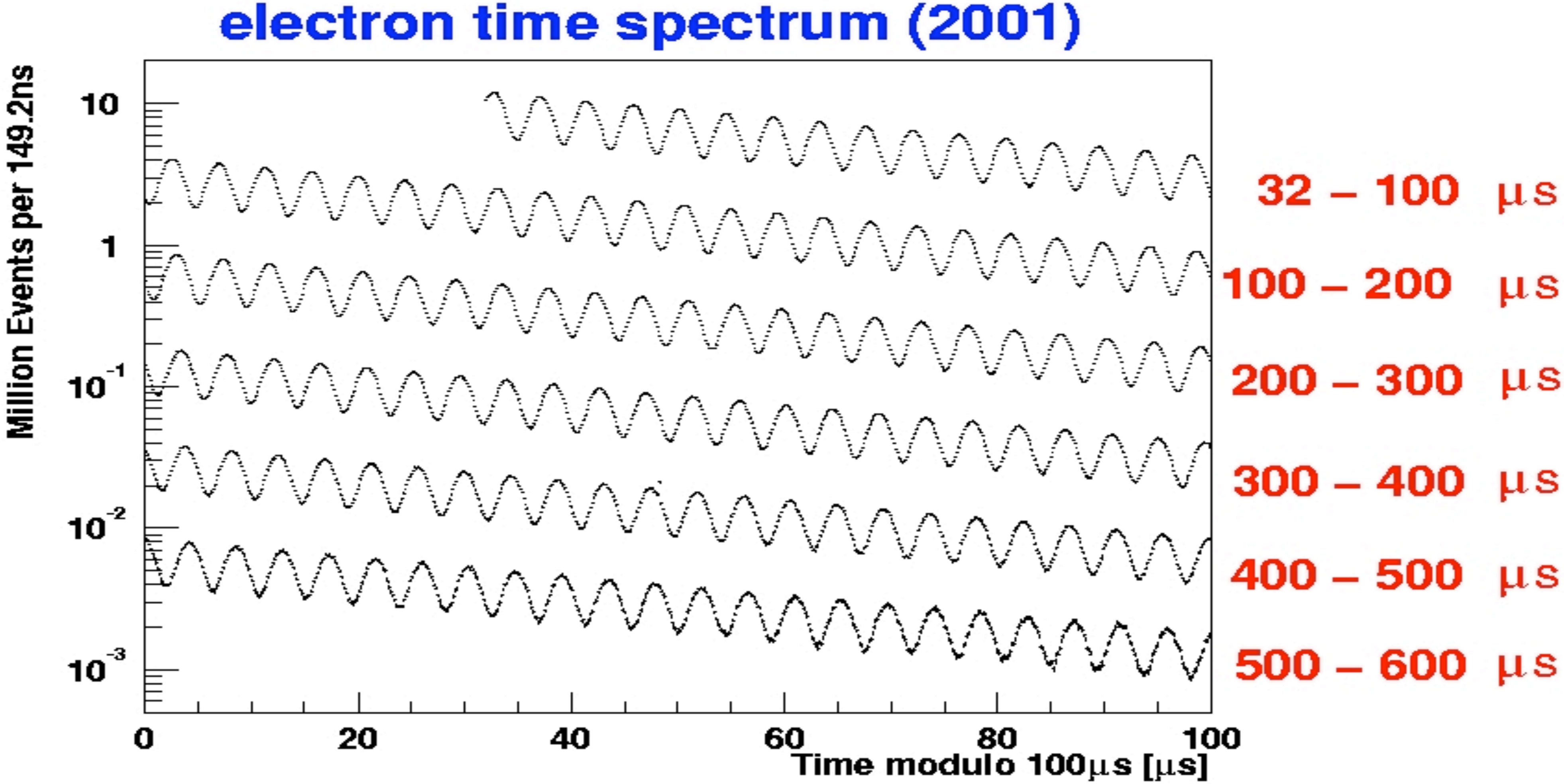
Circumference, m	Π	24.388
RF frequency, MHz	f_0	172.0
RF voltage, kV	V	100
RF harmonic	q	14
Momentum compaction	α	0.036
Synchrotron tune	Q_s	0.0025
Emittances, m · rad	ϵ_x	$2.2 \cdot 10^{-7}$
	ϵ_y	$2.2 \cdot 10^{-7}$
Energy loss per turn, keV	ΔE_0	41.5
Energy spread	σ_E	$6.4 \cdot 10^{-4}$
β at IP, cm	β^*	6.3
Betatron tunes	Q_x, Q_y	4.1, 2.1
Particles per bunch	e^-, e^+	$1.0 \cdot 10^{11}$
Number of bunches		1
Beam-beam tuneshifts	ξ_x, ξ_y	0.075, 0.075
Luminosity per IP, $cm^{-2} \cdot s^{-1}$	L_{max}	$1.0 \cdot 10^{32}$



Signal: Oscillation in hi-E electron

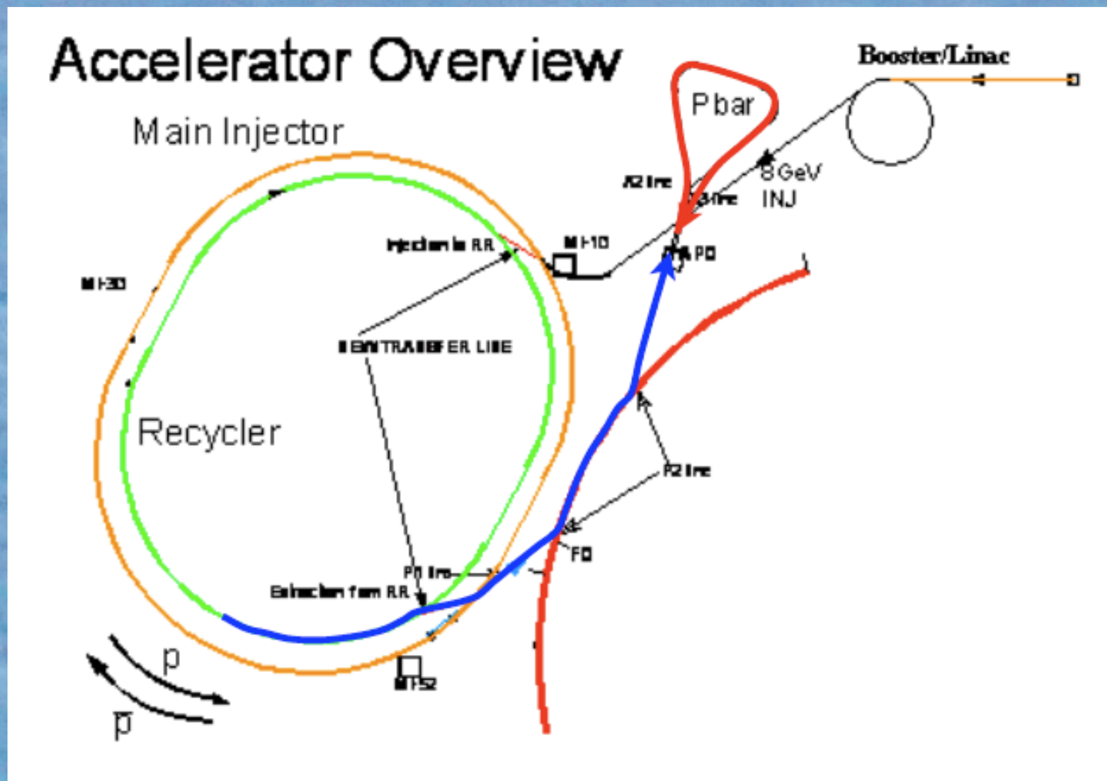
- 4E9 electrons; E > 1.8 GeV

$$f(t) \approx N_0 e^{-\lambda t}\left(1 + A\cos\omega_a t + \phi\right)$$



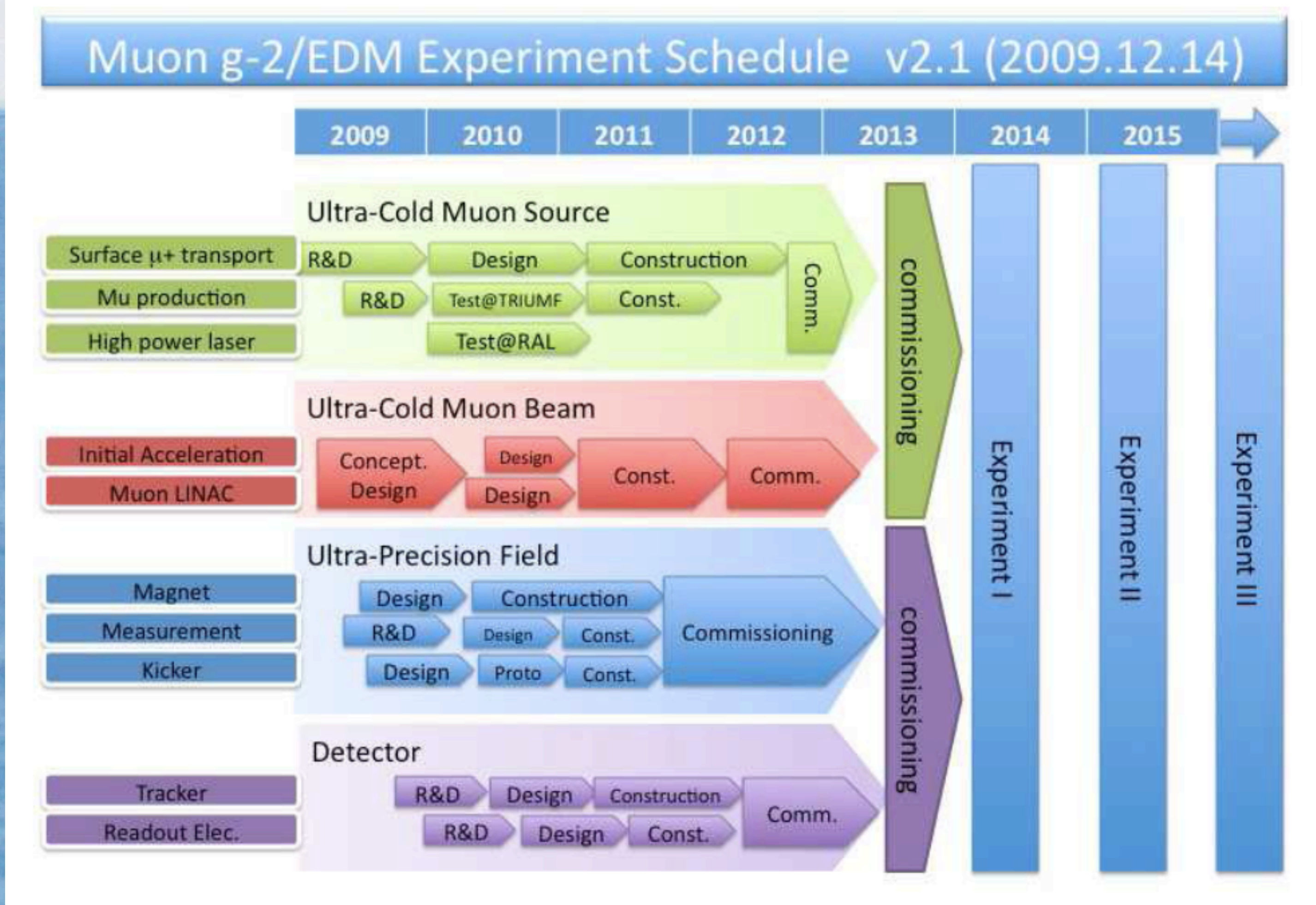
Proposal for g-2@Fermilab

- Submitted to Fermilab PAC
  - Contact persons: Lee Roberts (Boston U)
Dave Hertzog (UIUC)
  - Cost Estimate: ~$20 M (w/ contingency)
  - Discussed at the last PAC (March 4,5)
  - Encouraging message from the lab



Intended Schedule

- **Intend to start the experiment in 5 years**
  - **Similar time scale to the Fermilab proposal**



Cost Estimate

- **Very preliminary…**

TABLE XV: Preliminary estimate of the cost of this experiment.

Item	Cost (Oku-yen)
Surface Muon Transport	Facility
Ultra-Cold Muon Source	
High-power Laser System	3.0
Initial Acceleration System	0.5
Muon LINAC	15
Ultra-precision Magnet	
Solenoid	10
Field Monitor	1
Detector System	
Silicon Tracker	1.5
Readout Electronics	0.5
TOTAL	32 + Facility

Systematic Error on B

- **Smallness of the magnet : advantageous**
- **Absolute calibration is a common issue**

TABLE III: Systematic uncertainties for B.

Source of errors	E821-R01 (ppm)[5]	This experiment (ppm)
Absolute calibration of standard probe	0.05	0.05
Calibration of trolley probes (field measurement on the muon trajectory)	0.09	<0.09
Trolley measurement B_0	0.05	<0.05
Interpolation using fixed probes	0.07	<0.07
Uncertainty from muon distribution	0.03	<0.03
Inflector fringe field uncertainty	0.00	0.00
Others	0.10	–
Total syst. error on ω_p	0.17	<0.07(goal)

Systematic Error on ω_a

- **Mostly eliminated… pileup may be still issue due to hi-rate**

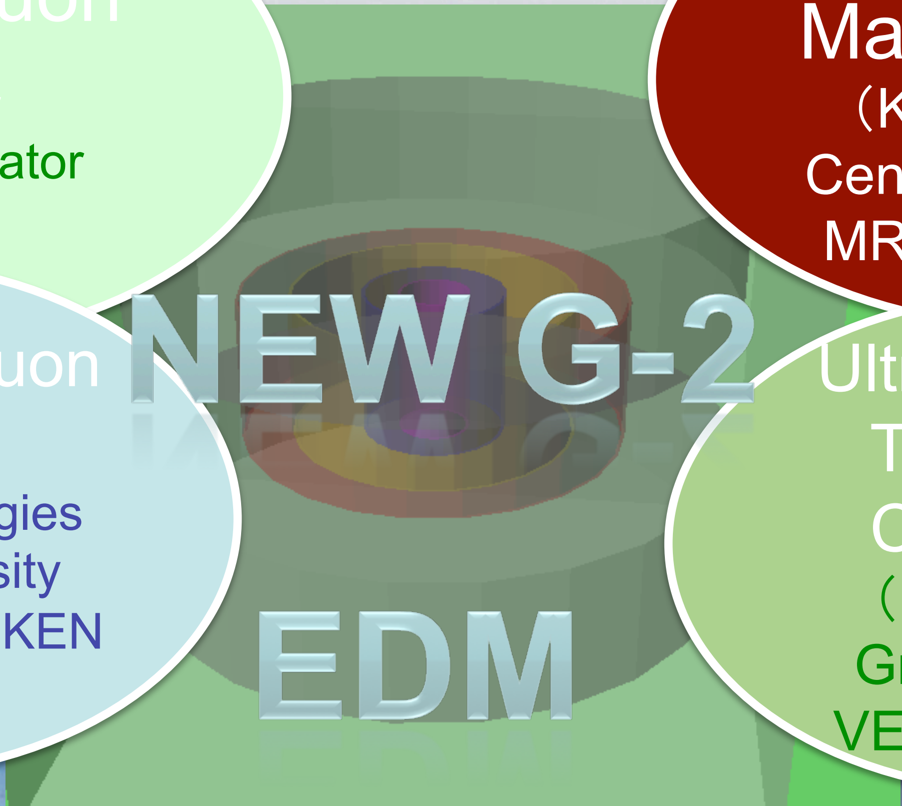
TABLE II: Systematic uncertainties for ω_a. Details are discussed in Sec. X.

Source of uncertainty	E821-R01 (ppm)[5]	This experiment (ppm)
Pileup	0.08	<0.05(goal)
AGS background	< 0.1	0.0
Lost muons	0.09	<<0.09
Timing shifts	< 0.1	<<0.1
E-field, pitch	<0.1	<<0.1
Fitting/binning	<0.1	<<0.1
Coherent Betatron Oscillation	0.07	0.00
Gain changes	0.12	<<0.1?
Others	–	–
Total (ω_a)	0.21	0.07 (goal)

Collaborative Efforts!

R&D of Muon LINAC
（KEK Accelerator Team）

Precision Magnetic Field
（KEK Cryogenic Center / Progress in MRI technologies）

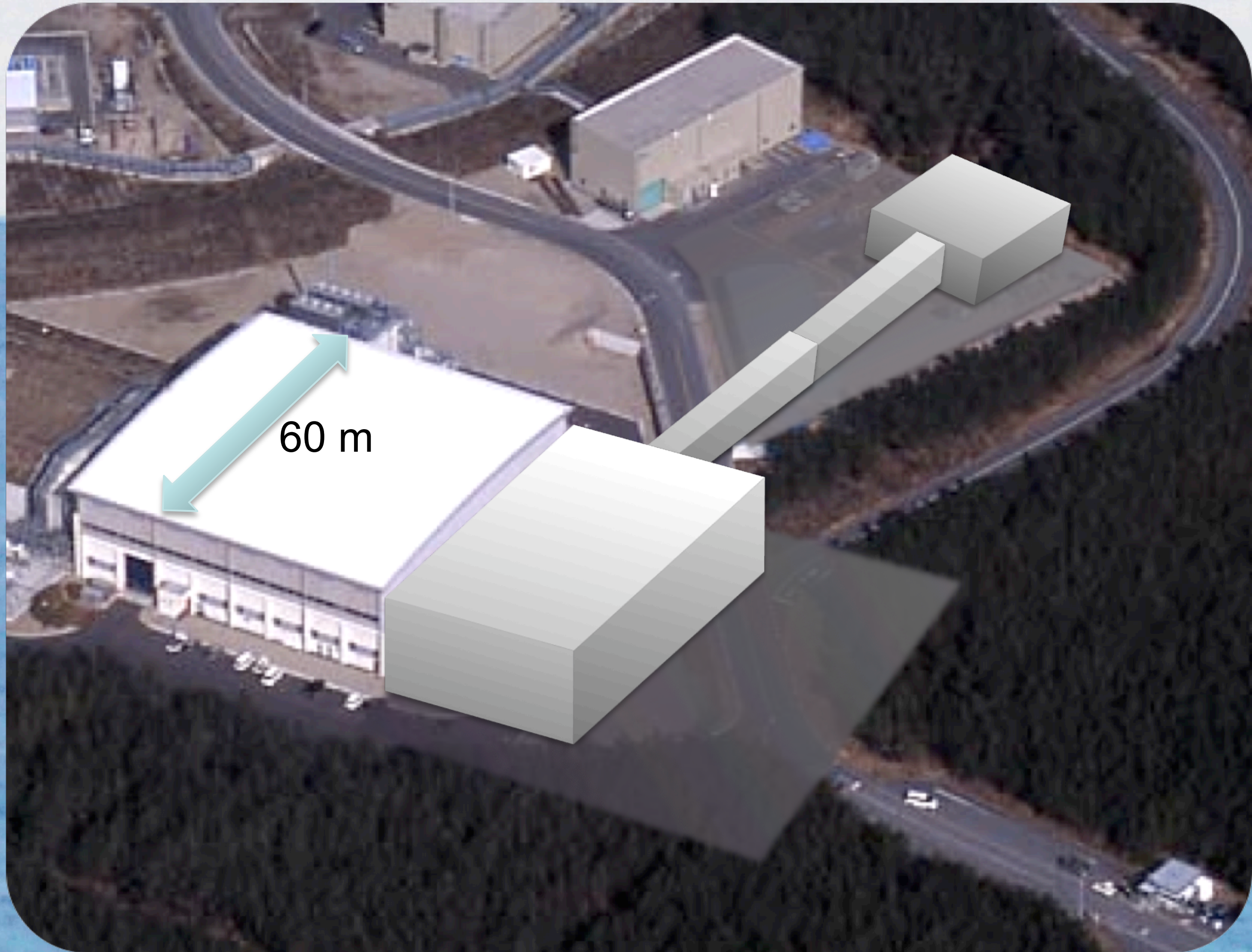


Ultra Cold Muon Source
（Laser technologies and High Intensity Proton Beam : RIKEN and KEK）

Ultra-Precision Theoretical Calculation
（KEK Theory Group & Belle, VEPP, Babar…）

Muon Working Group

Parking Lot Solution?



Shipping to J-PARC

- Estimated to be $2.5M
- Need to be refined

⇒Origin of Matter

- Sakharov's necessary conditions
  - violation of matter number: $0\nu\beta\beta$, pdecay
  - CP violation
  - out of equilibrium
- J-PARC aims to provide answers for
  - How matters (hadrons) are formed?
    - Confinement is understood?
    - How hadron properties are emerged?
  - How matter-dominant universe is emerged?
    - CP violation in quark sector
    - CP violation in lepton sector