Development of Basic Technologies for g-2 Superconducting Solenoid

Precision Magnetic Field Monitor
~ Seismic Ground Vibration at MLF ~
Conceptual Design of Cryogenic System

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2010/07/06

Contents

- ✧ Introduction
- ✧ Precision Magnetic Field Monitoring System
- ✧ Seismic Ground Vibration and Mechanical Analysis
- ✧ R&D Status of Cryogenic System
- ✧ Summary

Muon Spin Precession

✧ Why at magic gamma?

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

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

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

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

✧ What if no E-field?

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

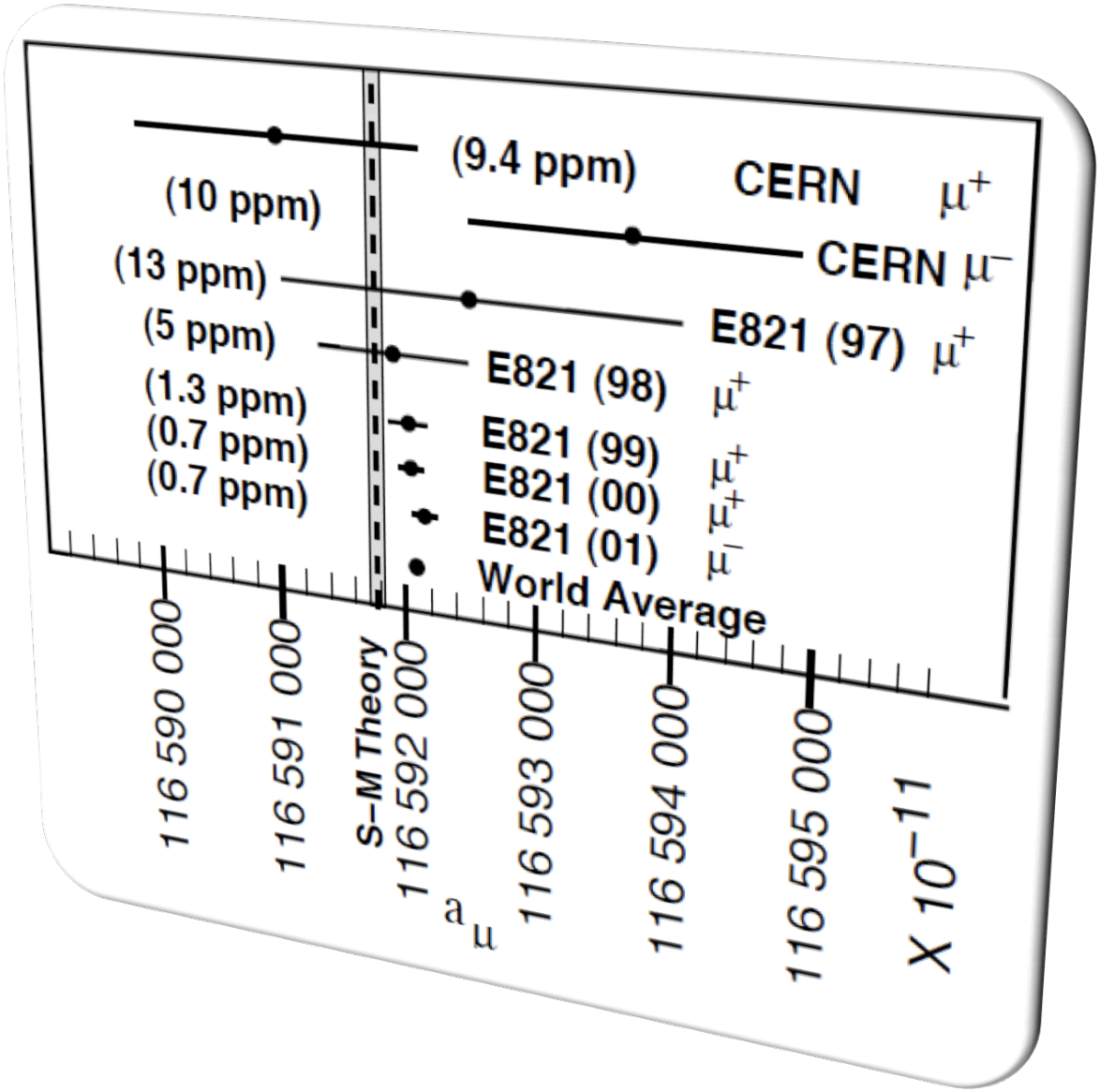
Ultra-Slow Muon Source at J-PARC MLF?

Muon collider technique? Cooling, FFAG etc.

"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 $\mu+$ and $\mu-$
- 3.4 sigma deviation from the SM
  - SM prediction OK?
  - New Physics?
- Need to explore further
- Preferably NEW METHOD!



g-2/EDM experiment

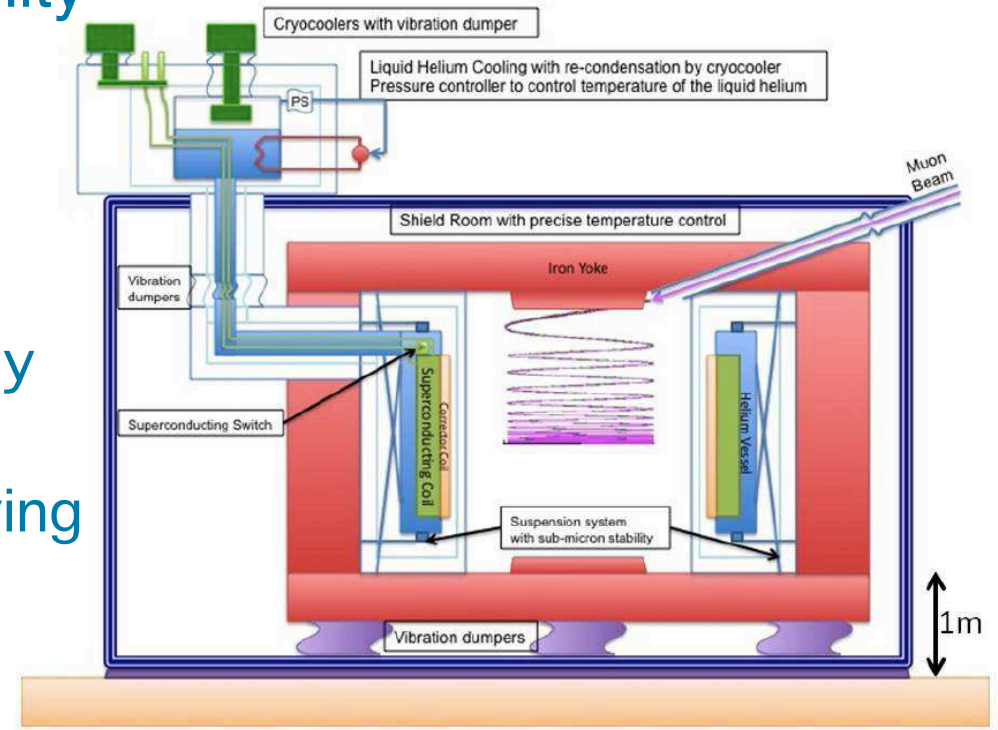
- To measure
  - g-2 below the level of 0.1 ppm
  - EDM with the improved sensitivity by three orders of magnitude

Superconducting solenoid with high magnetic field uniformity is required as a storage ring

- Required specification
  - Storage region :
    - radius : 33.3±5.0 cm
    - height : ±10 cm
  - Field strength : 3T
  - Uniformity : *0.1 ppm !*

SC solenoid for g-2/EDM experiment

✧ Solenoid with very high uniformity



Employ MRI technology

- ❖ 1 ppm MRI at 3T is commercially available
- ❖ could reach 0.1 ppm by modifying MRI technology

✧ Items to be studied

- ❖ Precision field monitoring system
- ❖ Source of error field
  - ➢ Seismic ground vibration
    - -> Low vibration cryogenic system

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Field monitoring system with high accuracy

✧ g-2 solenoid requires the uniformity of 0.1 ppm

-> require the field measurement system with accuracy of 0.1 ppm

⌘ *NMR probe*

❖ 1 ppm NMR probe : commercially available

-> require further fine tuning and modification

❖ Require moving stage covering good field region

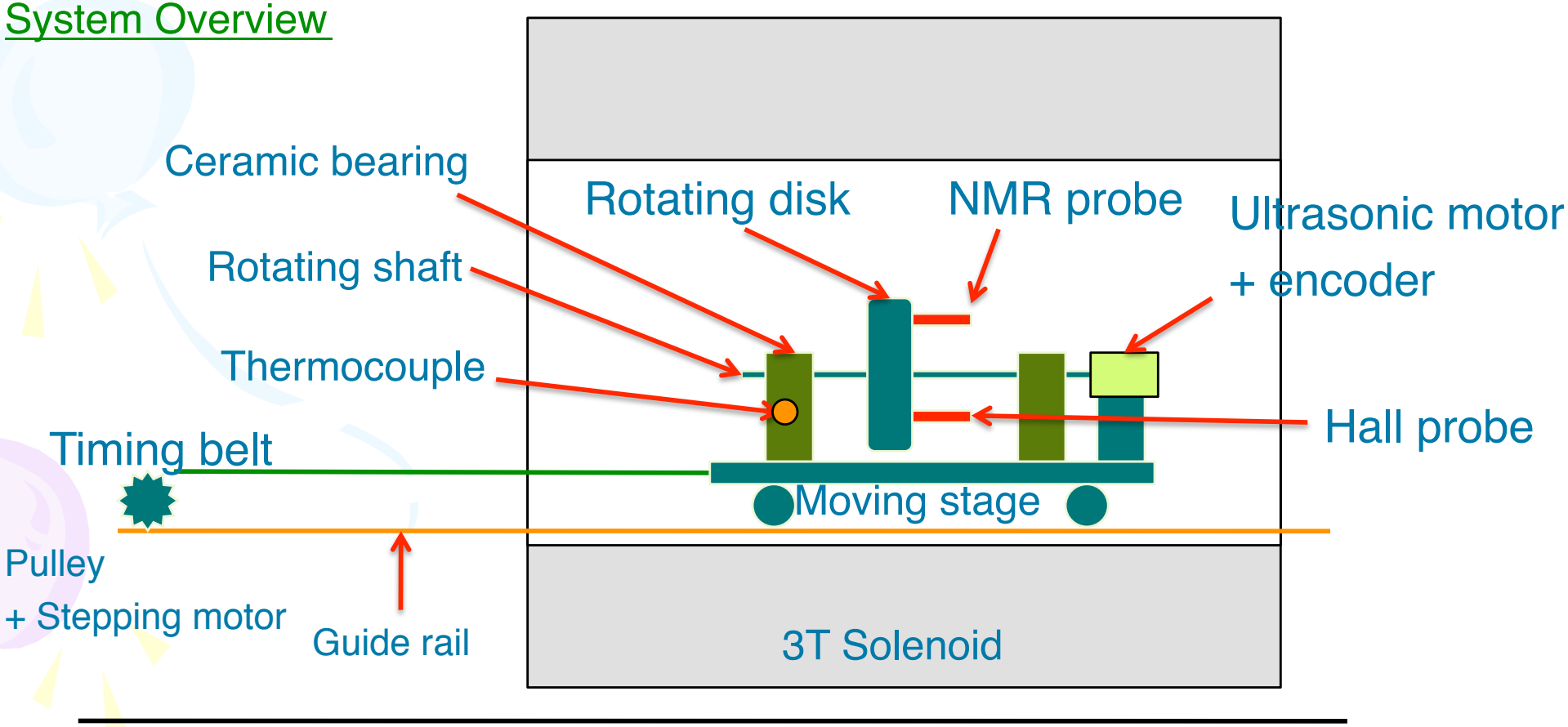
✧ At the beginning

- ✧ Purchased NMR probe with 1 ppm
- ✧ Built prototype of monitoring system
- ✧ Measured 3 T MRI magnet at NIRS

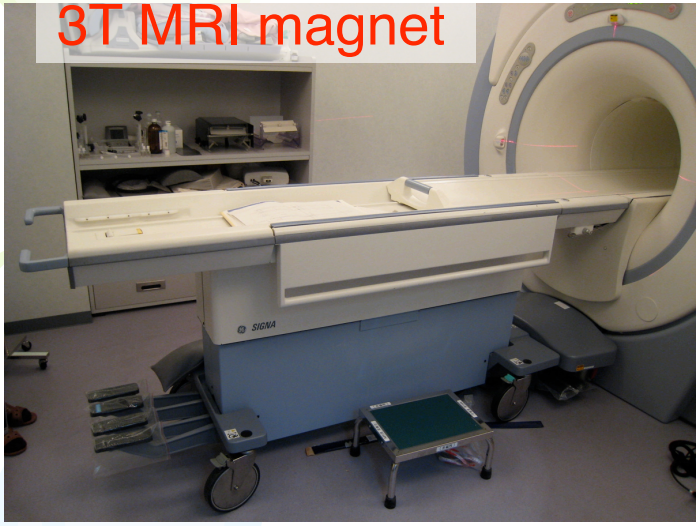
Measurement at NIRS

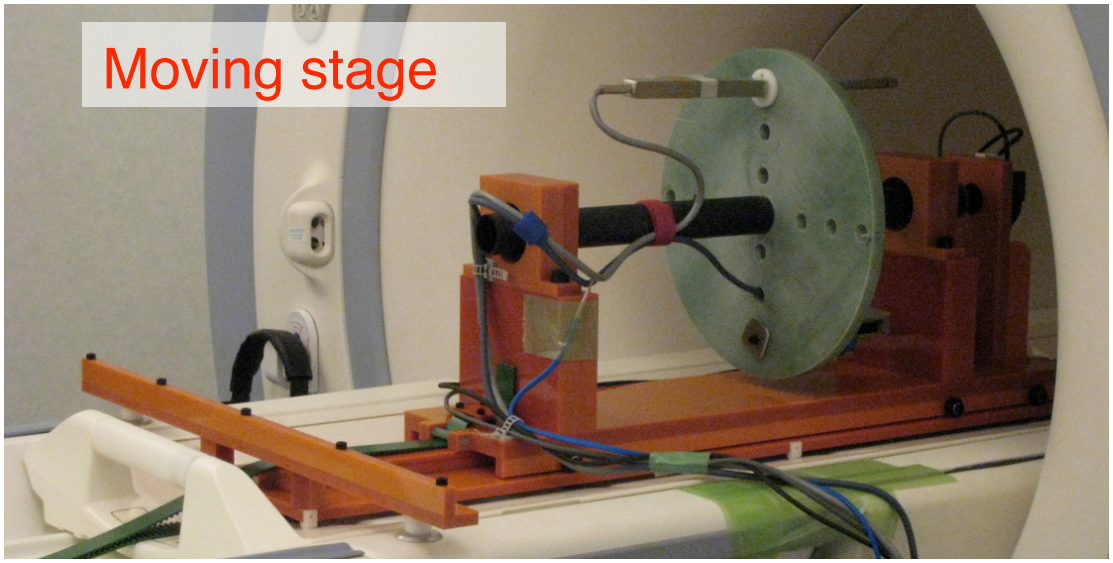
- Objective
  - build and test a prototype of automatic monitoring system for g-2 solenoid.
  - cross-check between NMR probe and Hall probe

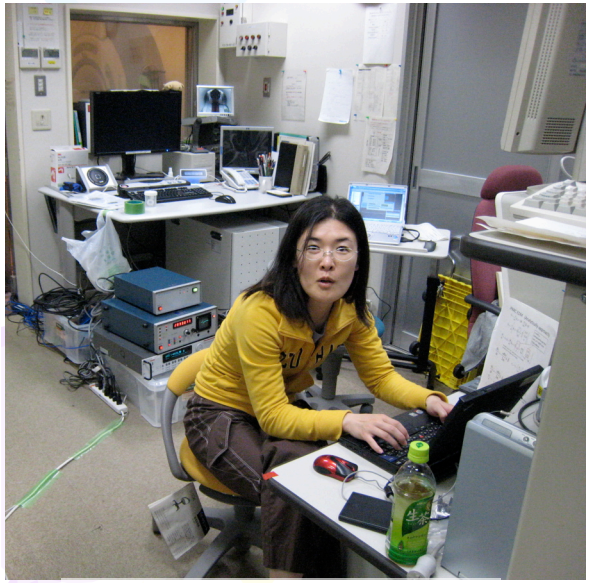
System Overview



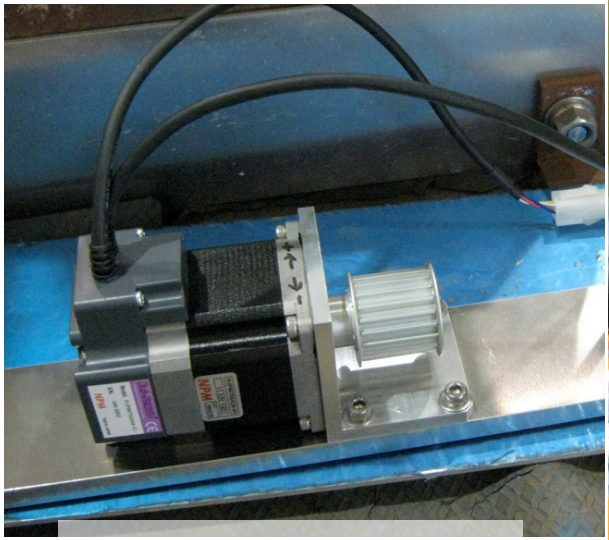
Monitoring System Photos @ NIRS



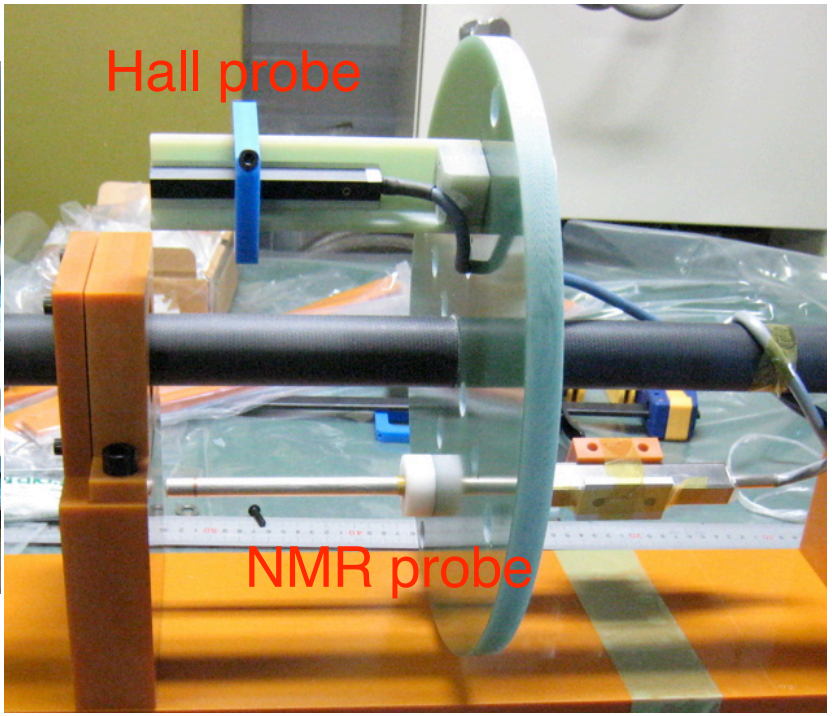




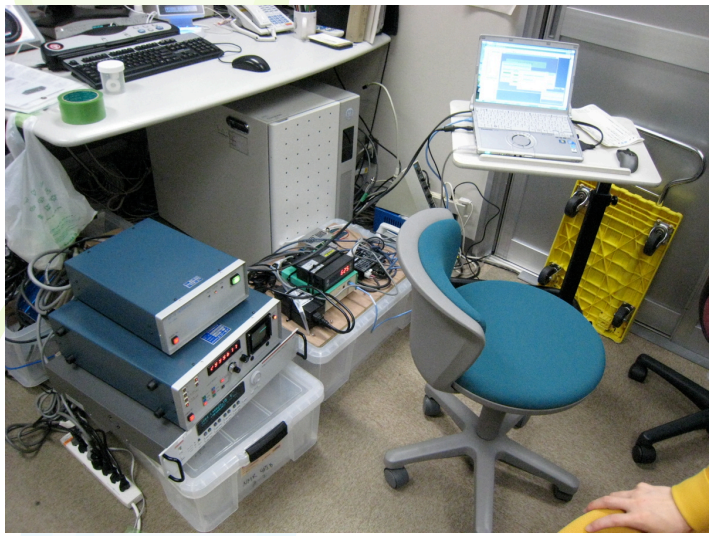
Control room

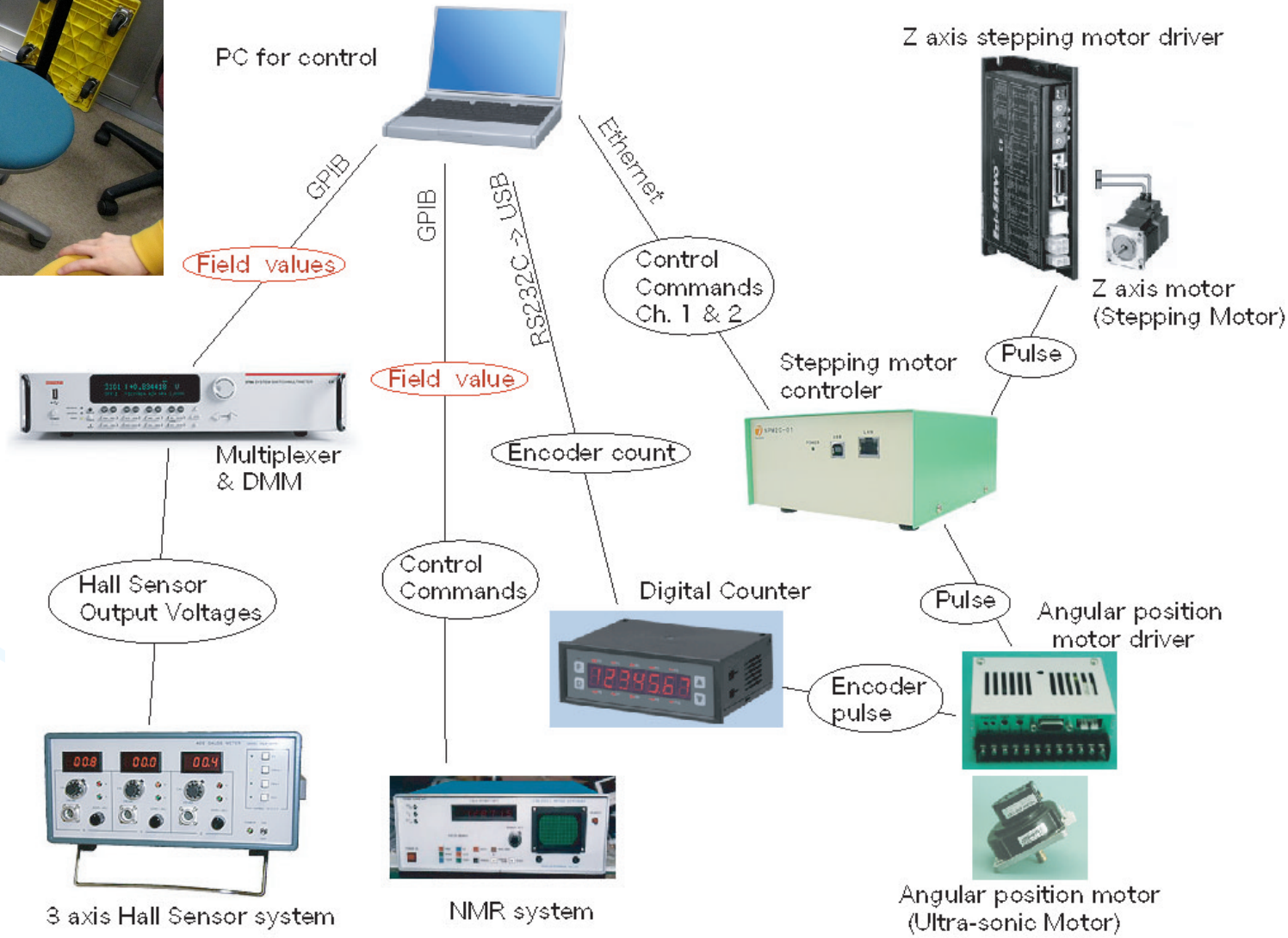


Stepping motor



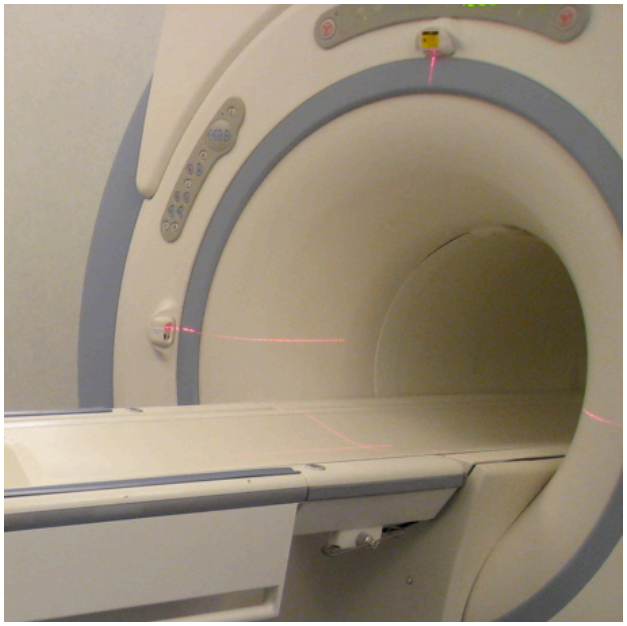
Control system





Measurement Procedure

1. set probes manually on the rotating disk
   - r=35, 75, 115 mm
2. align the guide rail along the magnet axis using line laser and a water level
3. move the stage so that the sensors are at the magnet center (z = 0 mm)
4. run the measurement sequence
   1. angle : 45 degree step
   2. z position :
      -20,20,40,60,80,100,120,140,160,180,200,250,300,350,400,450,500,600,700 mm
   3. read the output of probes 5 times at each position
5. change radial position and repeat 1 ~ 5

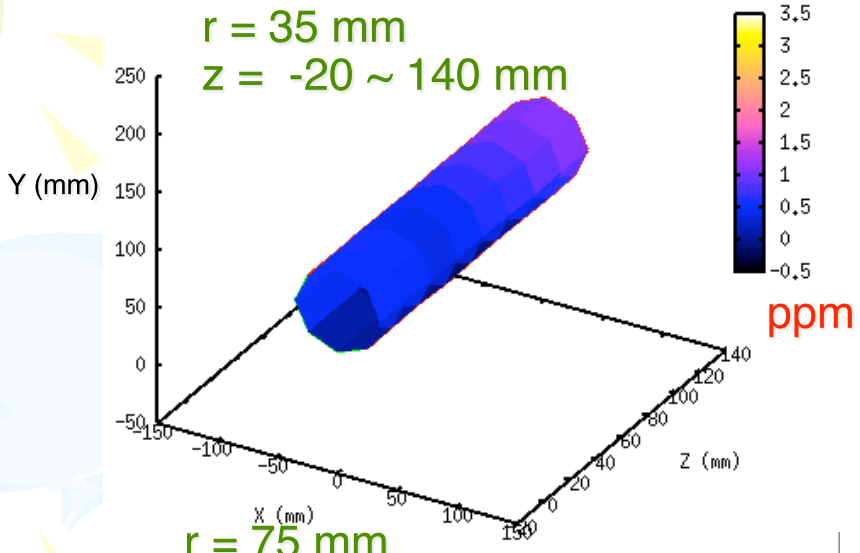


1 sequence : ~4 hours

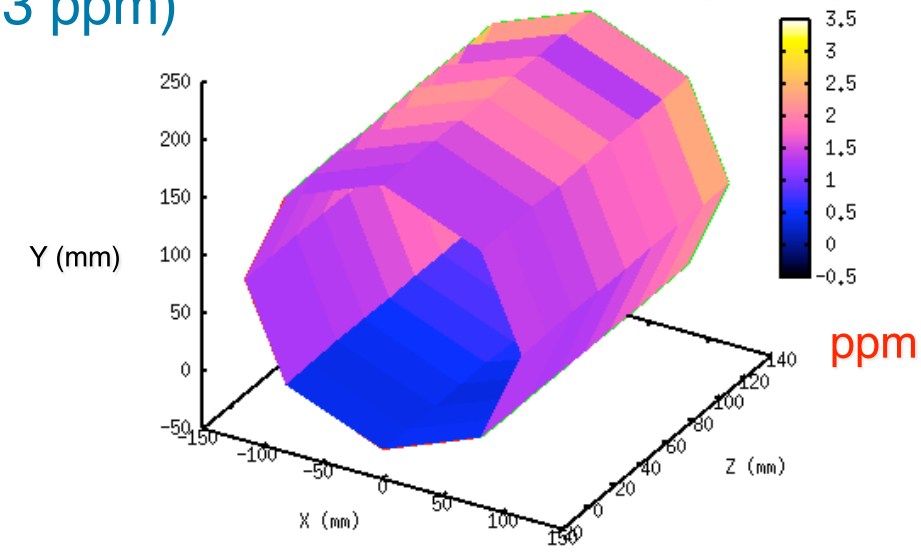
Results ~ NMR probe

- rotating axis : X=0, Y=+ 90 mm
- reference field : 2.99967450 T @ X, Y, Z = 0 mm
- output value : very stable (< ±0.3 ppm)

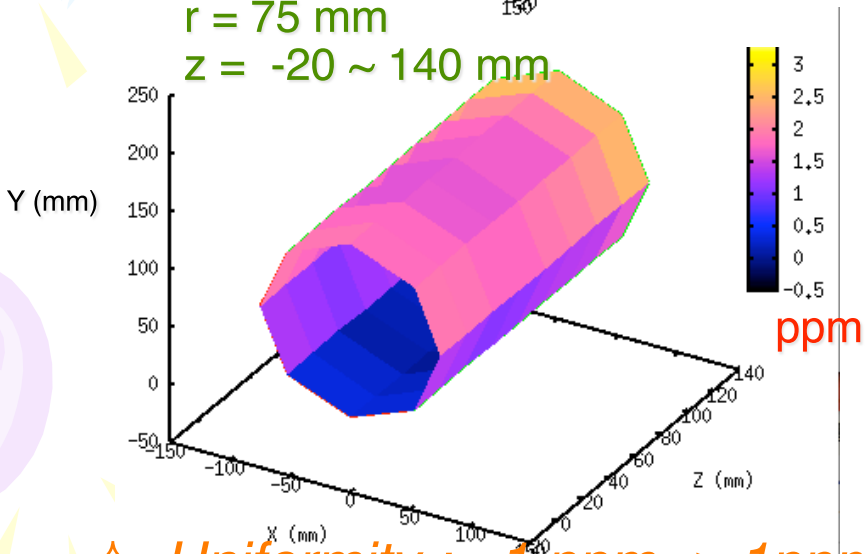
r = 35 mm
z = -20 ~ 140 mm

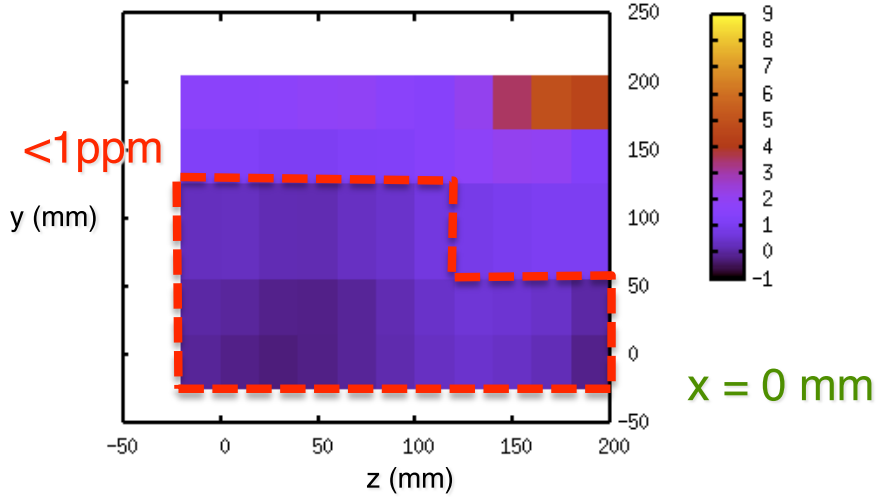


r = 115 mm
z = -20 ~ 140 mm



r = 75 mm
z = -20 ~ 140 mm

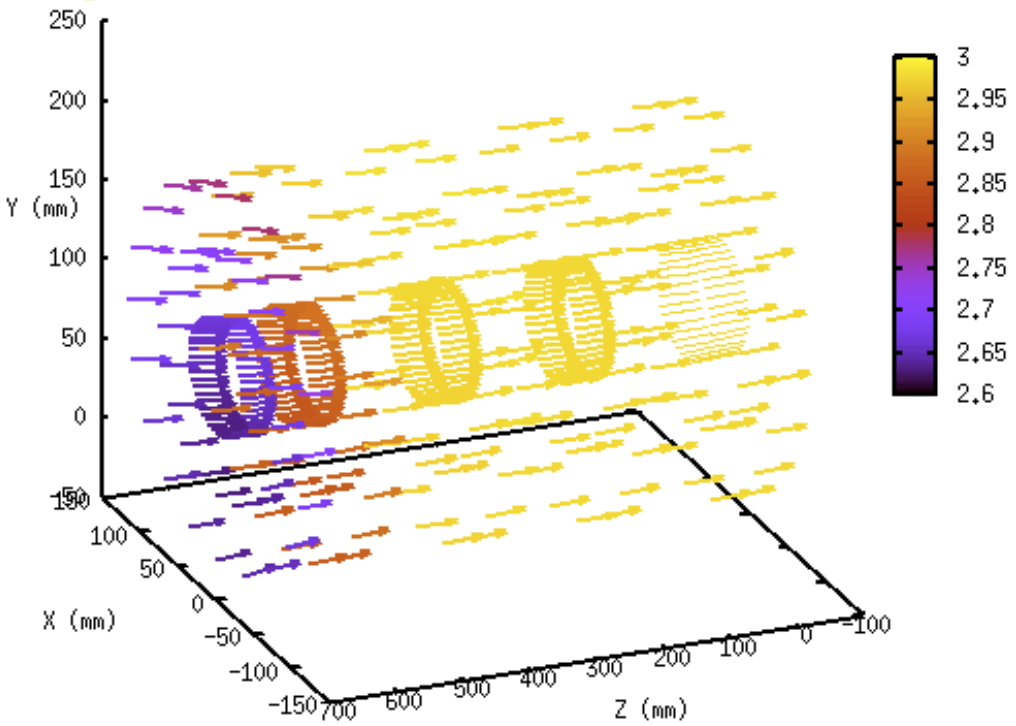




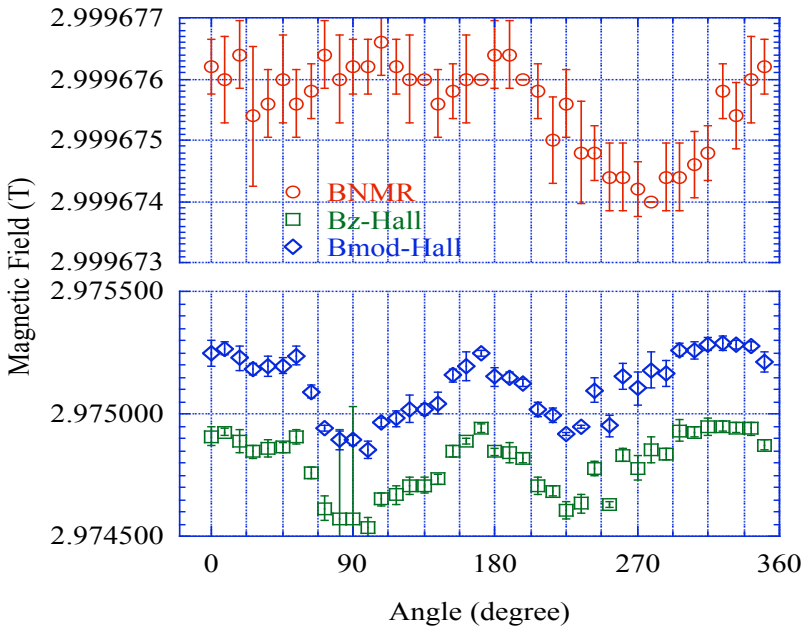
- *Uniformity : ~1 ppm -> 1ppm could be commercially achieved.*

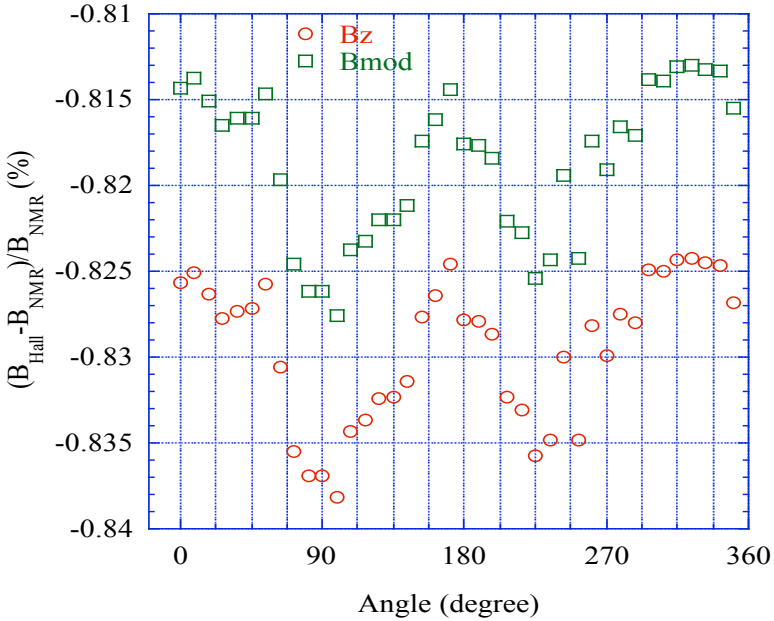
Results ~ Hall probe (1)

Vector Plot



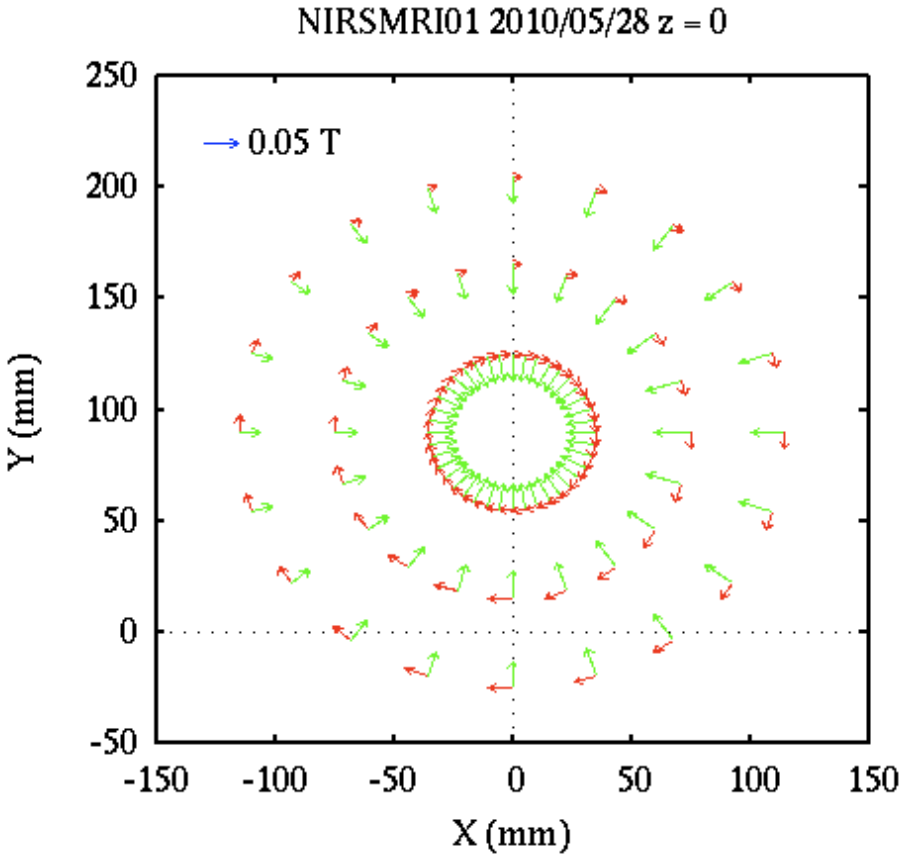
Difference from NMR results

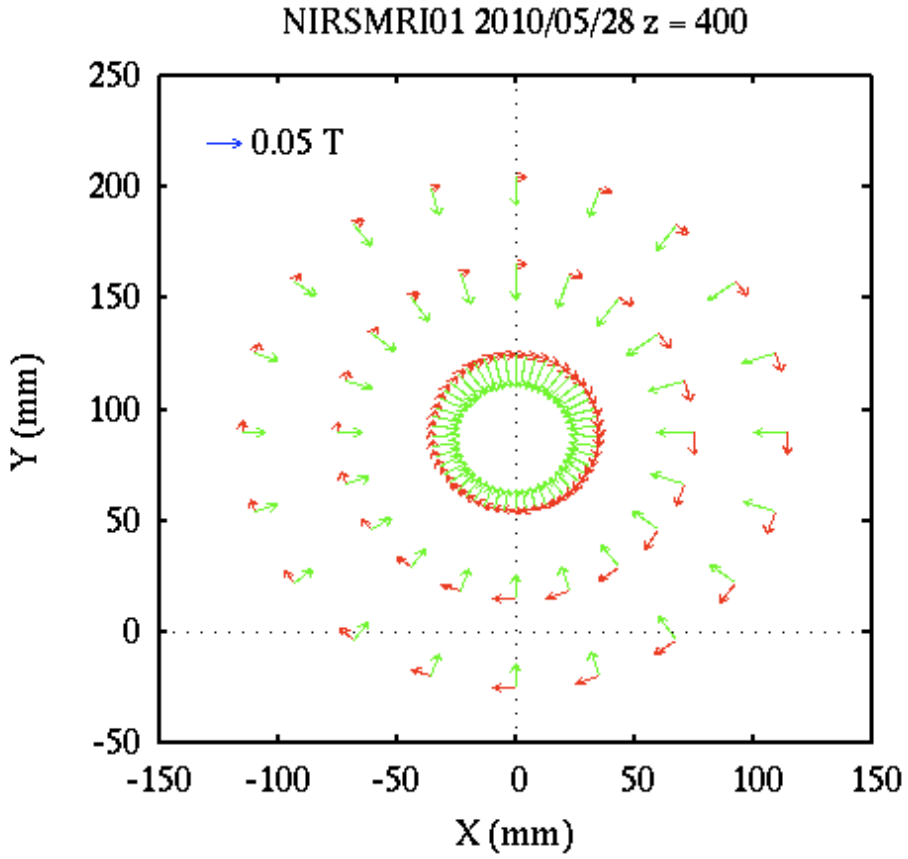




- Temperature dependence of Hall sensors are compensated.
- Hall probe doesn't agree with NMR results : -0.83 %

Results ~ Hall probe (2)



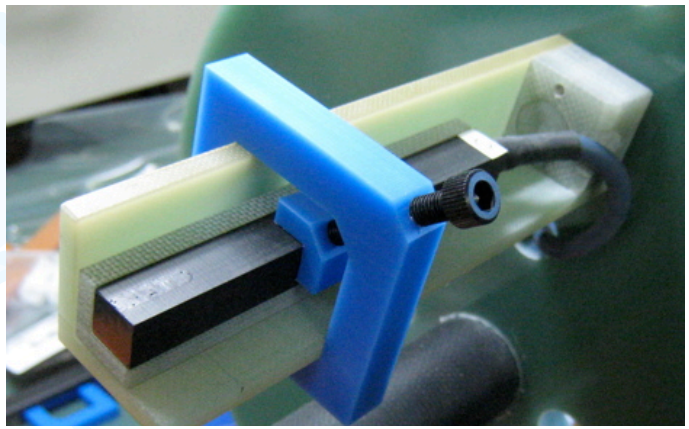


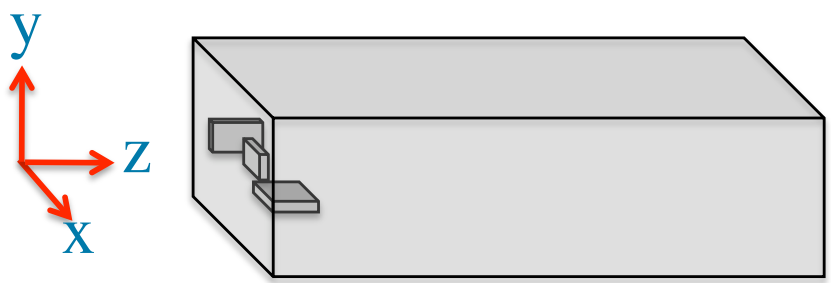
- observe Br and Btheta components systematically.
  - 0.01 ~ 0.05 T

- alignment error of hall probe ?

MFM ~ discussion

- Possible error
  - Hall sensors are not aligned at right angle with z axis.
    - sensors are not mounted at right angle in the epoxy fixture
    - probe is not mounted at right angle on rotating disk





- Manufacturer checked mounting angles
- All sensors are slightly tilted
  - ✓ x: 0.4°, y: 0.7°, z:1.8°

- Apparent Bz = $\frac{\cos(1.8°)}{0.99951}$ x true Bz

MFM ~ discussion

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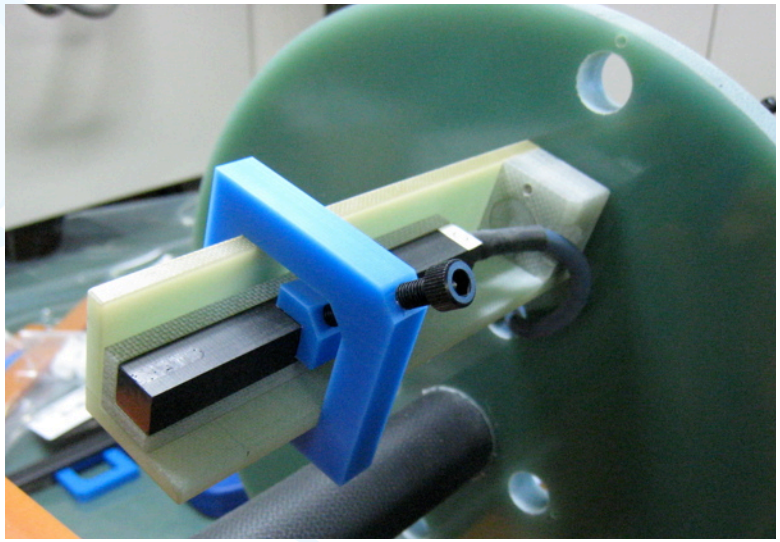
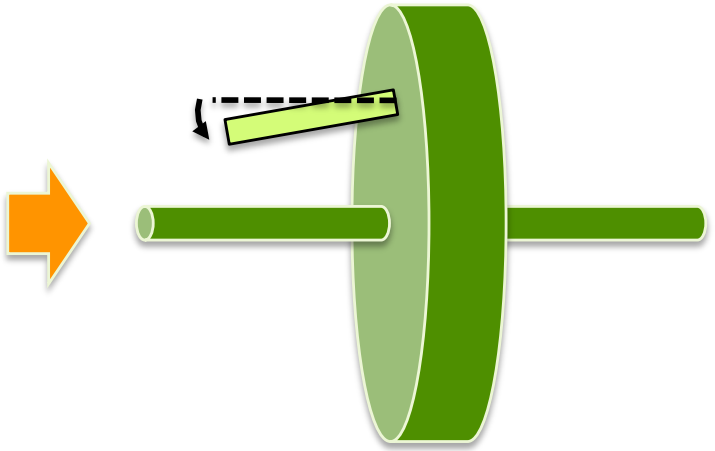
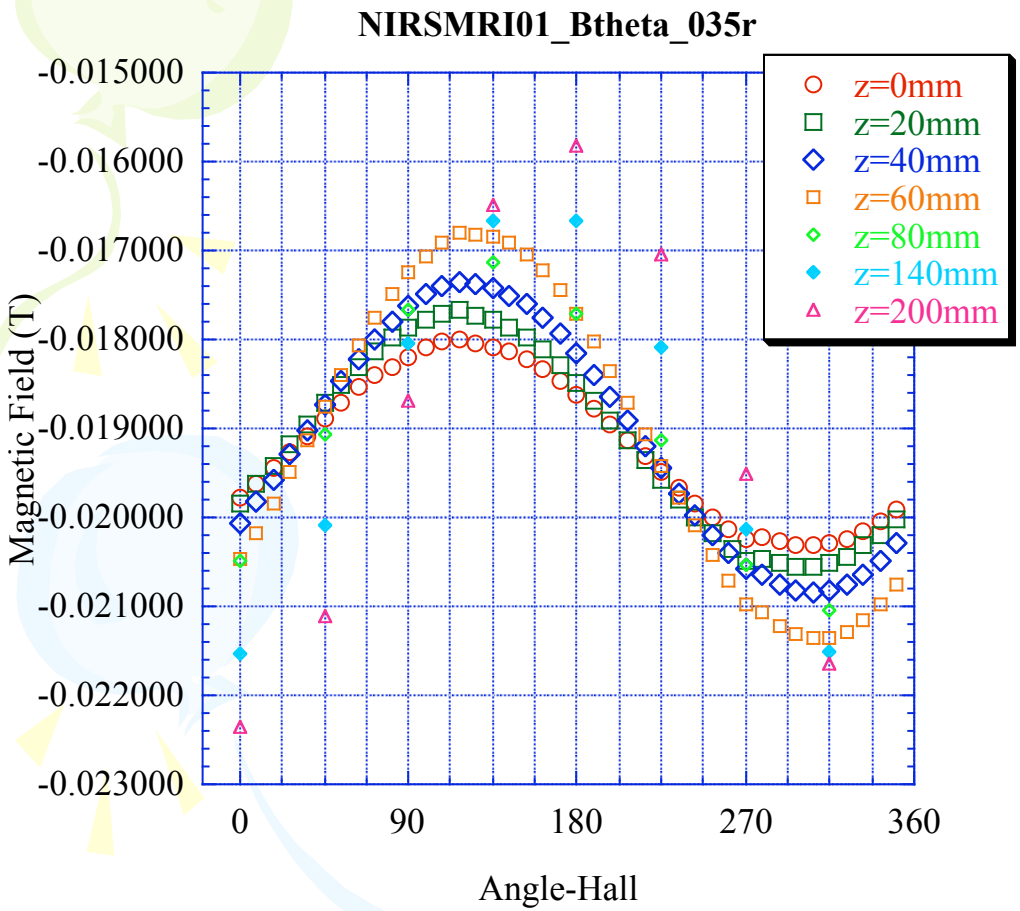
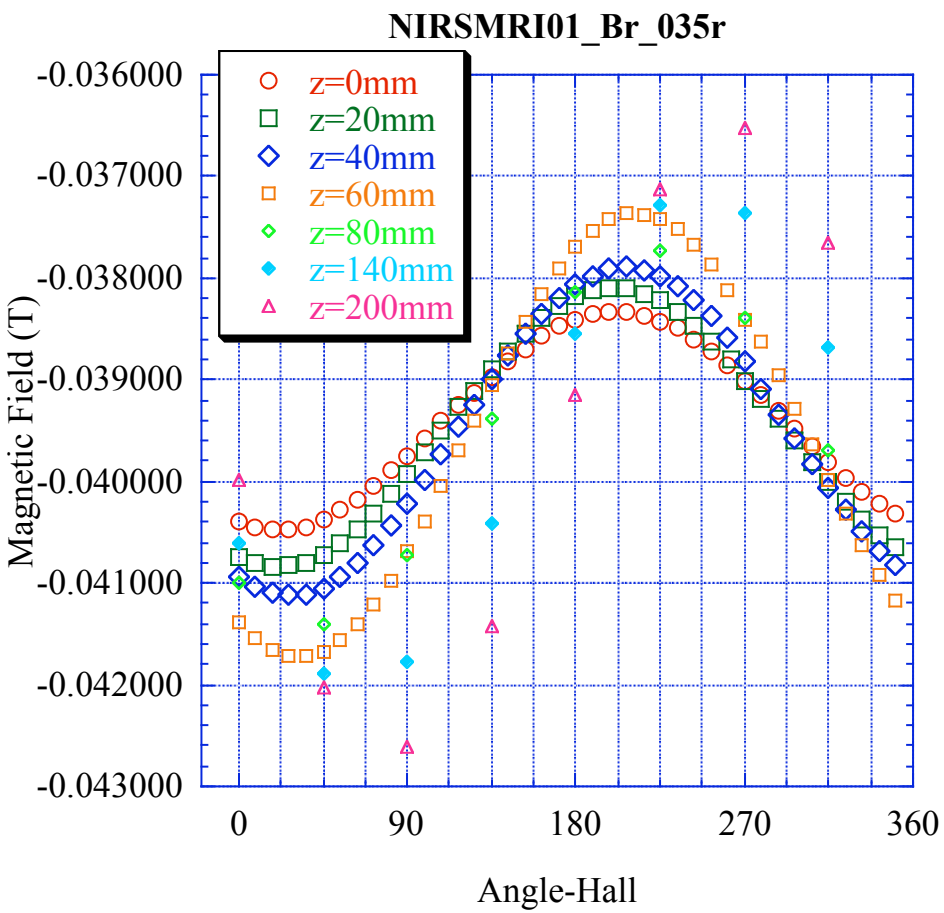




- not check yet : Which is dominant?
- or any other reason ?

✧ reference field : 2.99967450 T @ X, Y, Z = 0 mm





✧ z=0mm

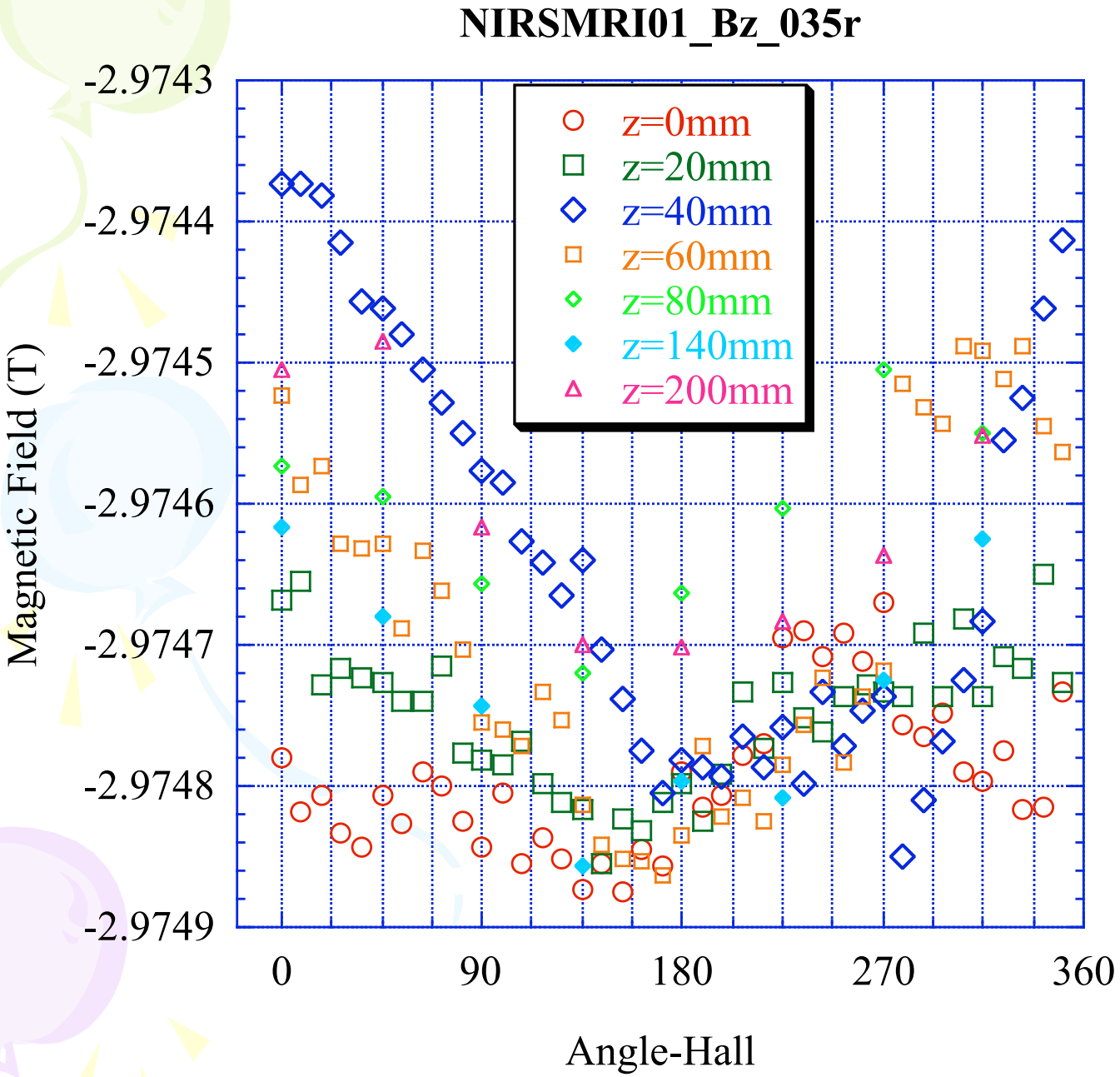
avg: -0.019189
Bx傾き:0.367°

peak-peak: 0.002306463
Bx傾き:0.0441°

✧ z=0mm

avg: -0.039391
By傾き:0.752°

peak-peak: 0.02132238
By傾き:0.0407°



avg: -2.9747938

Bz傾き:7.384°

Summary ~ MFM

- Monitoring system
  - successfully built moving stage system and assemble automatic control system
- NMR probe
  - could measure magnetic field with NMR prove below ±0.3 ppm
- Hall probe
  - not agree with NMR results

- Next study
  - identify the error source of Hall probe measurement
  - study any possible sources of error; kicker, detector, ⋯
  - design moving stage for vertical superconducting solenoid
  - how to calibrate the absolute field value (NMR)
    - no standard magnet of 3 T
    - can get field imaging map of MRI at NIRS -> cross-check
    - check accuracy of main components of NMR
      - RF generator, read-out circuit, purity of NMR sample, ...

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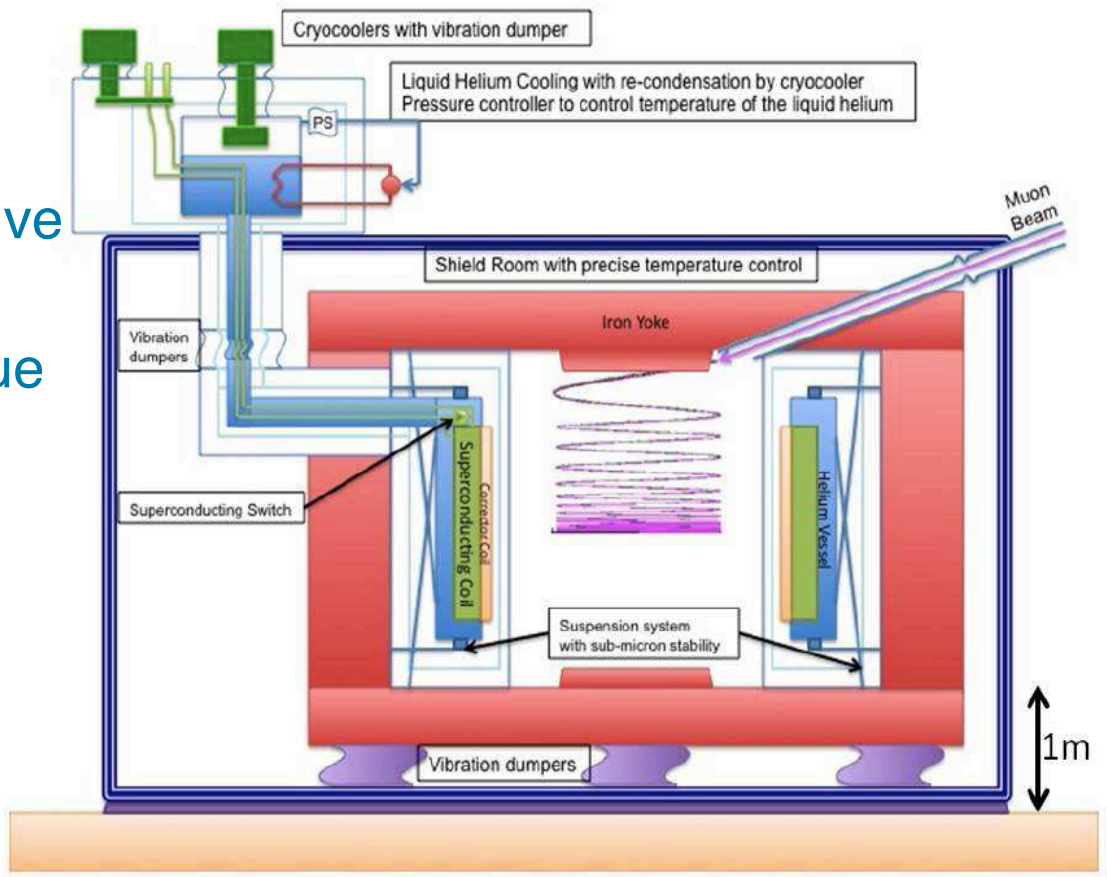
Seismic ground vibration

- Seismic ground vibration is closely related to field uniformity and stability

- Field quality is sensitive to relative position btw yoke and coil
- random & individual vibration due to mechanical resonance

  -> disturb uniform field



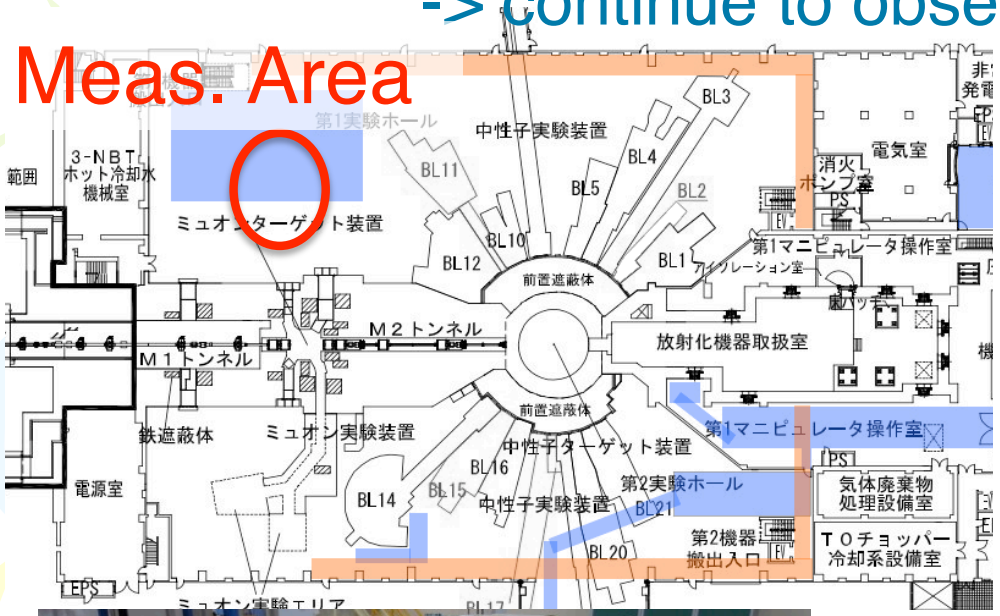
- Started seismic measurement at MLF for later structural analysis

Seismic ground vibration

✧ Measurement : for one week every month

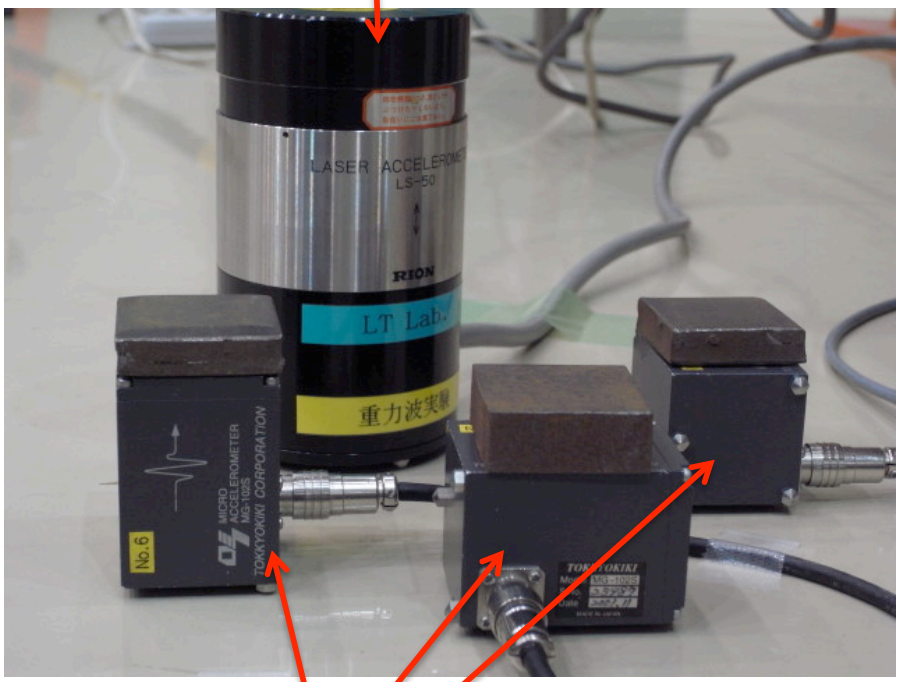
-> continue to observe vibration for one year

Meas. Area



- Laser accelerometer

  v-direct, 0.1 – 100 Hz

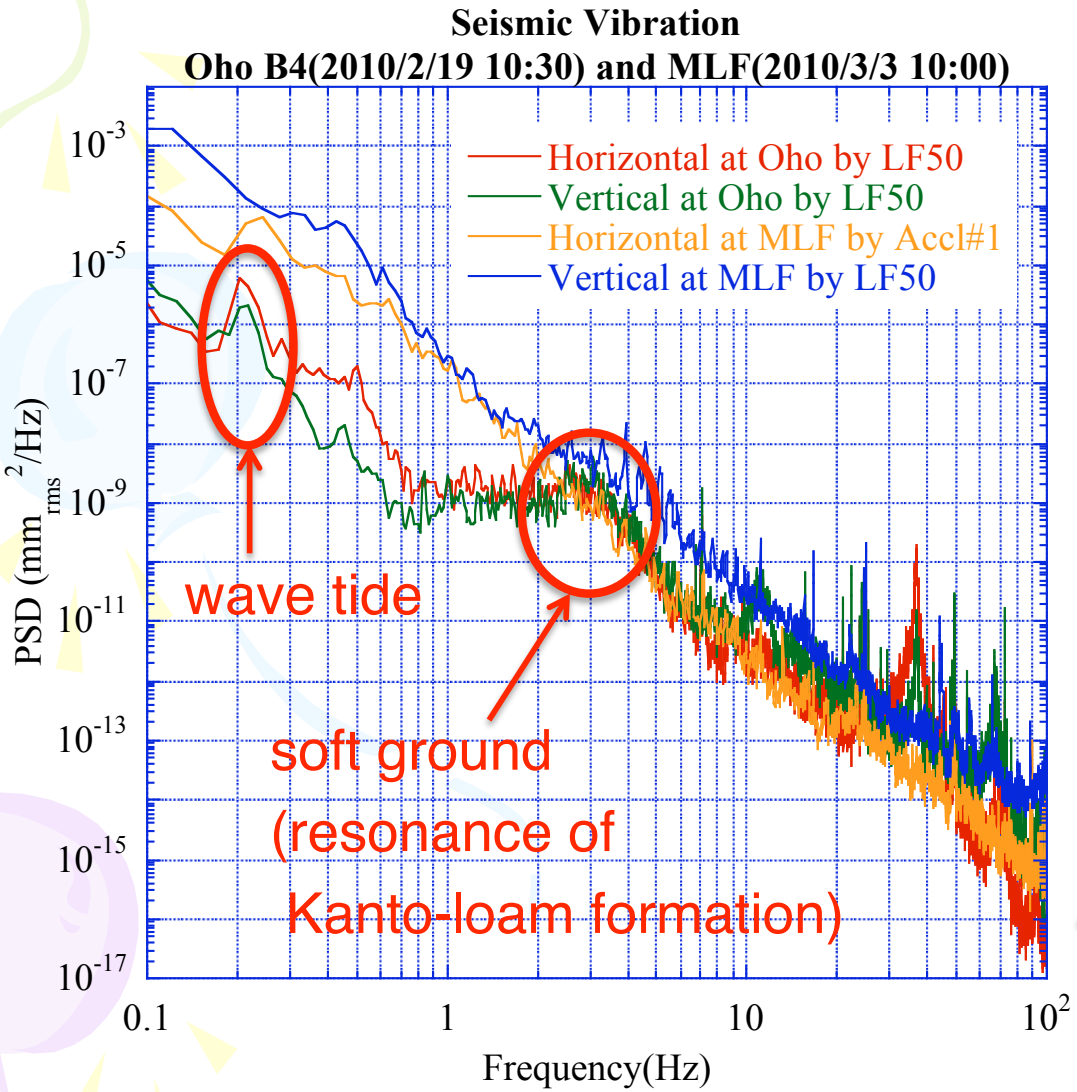


- Servo accelerometer

  x, y, v-direct, 0.1 – 400 Hz

Example of seismic ground vibration

✧ Data at MLF and KEK



At MLF

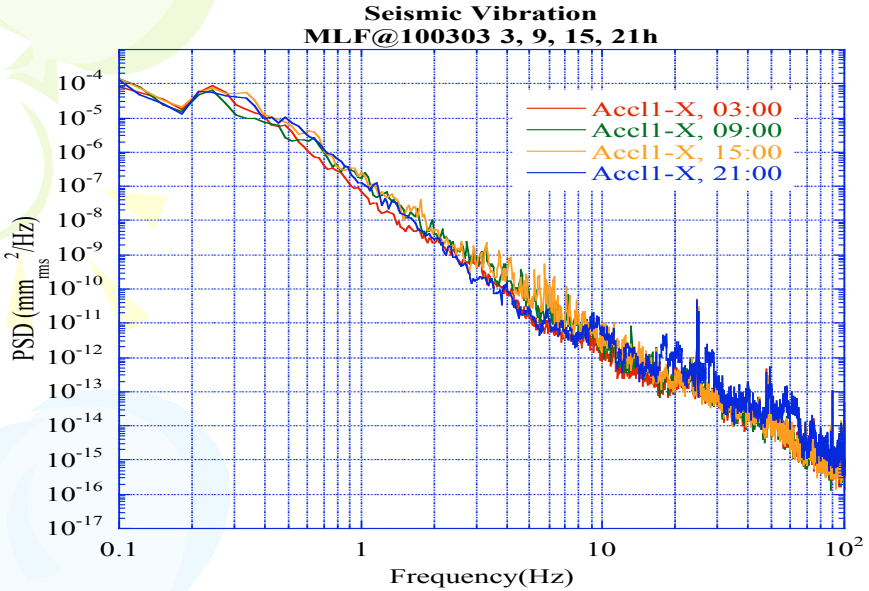
- vibration is larger than KEK, especially below ~3 Hz
- wave tide and soft ground peaks disappear

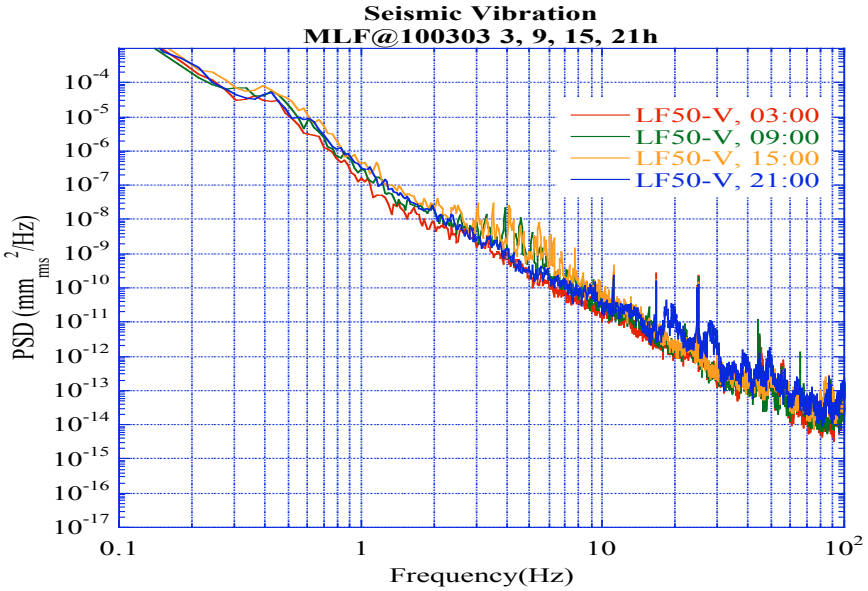
reason???

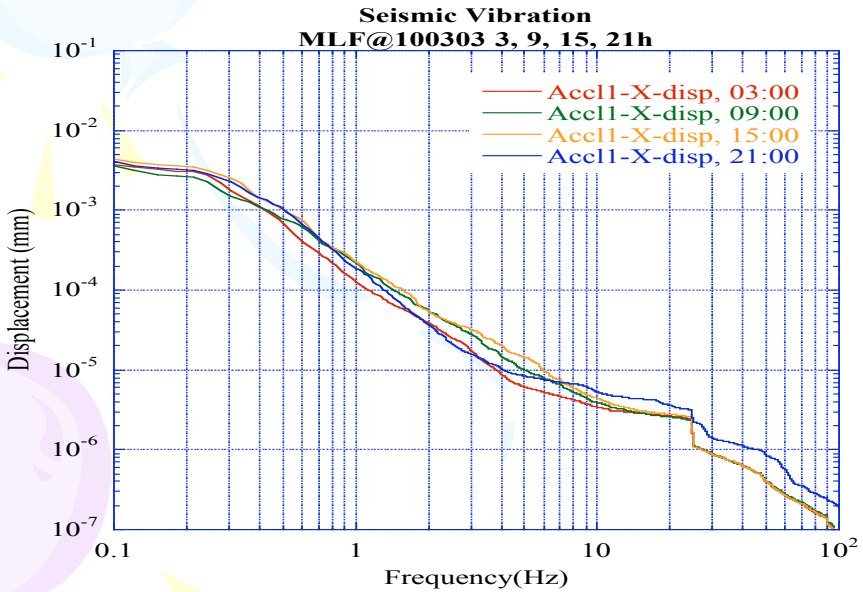
- Ground around J-PARC site
  -> mainly sand

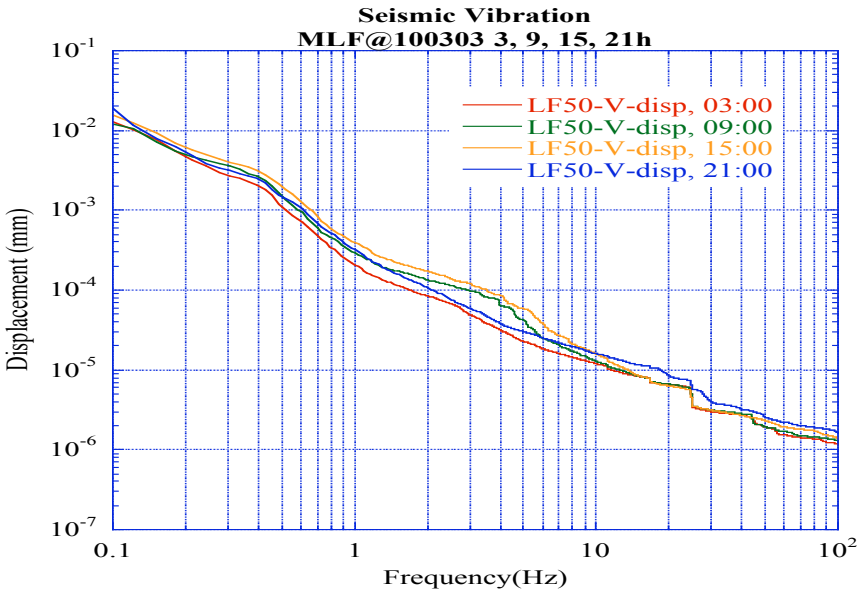
Mechanical analysis with ANSYS

2010/03/03
Accl#1, MLF





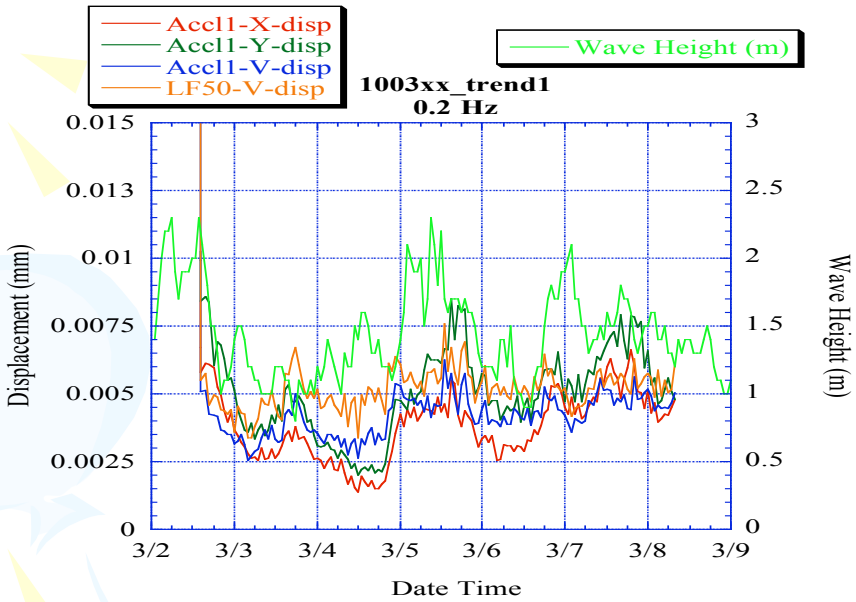


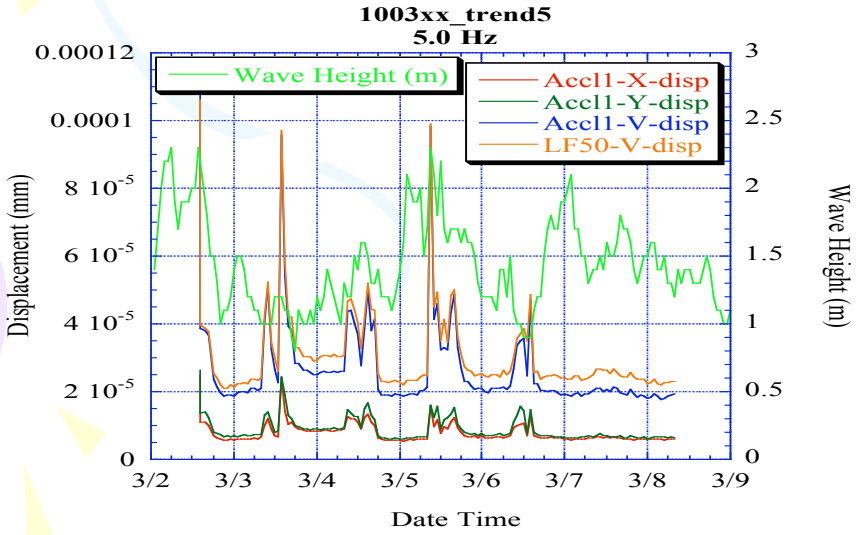


朝昼夜の違いはあまり見られず

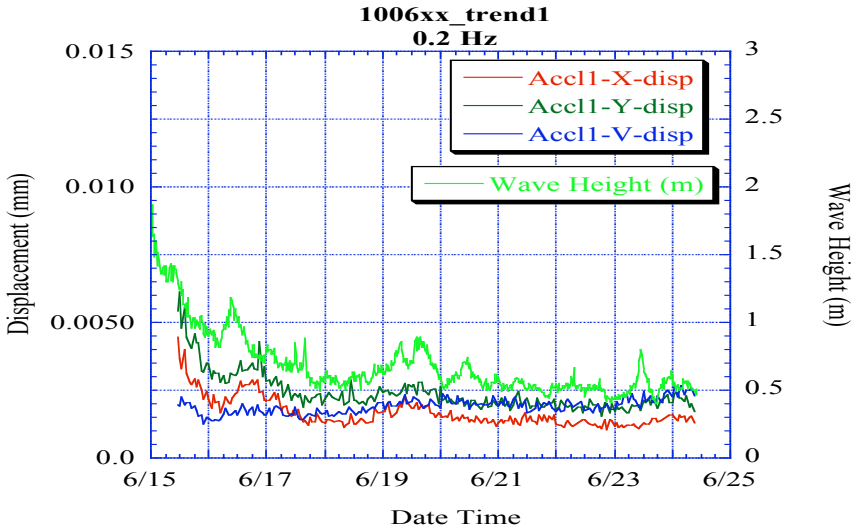
Displacement Trend

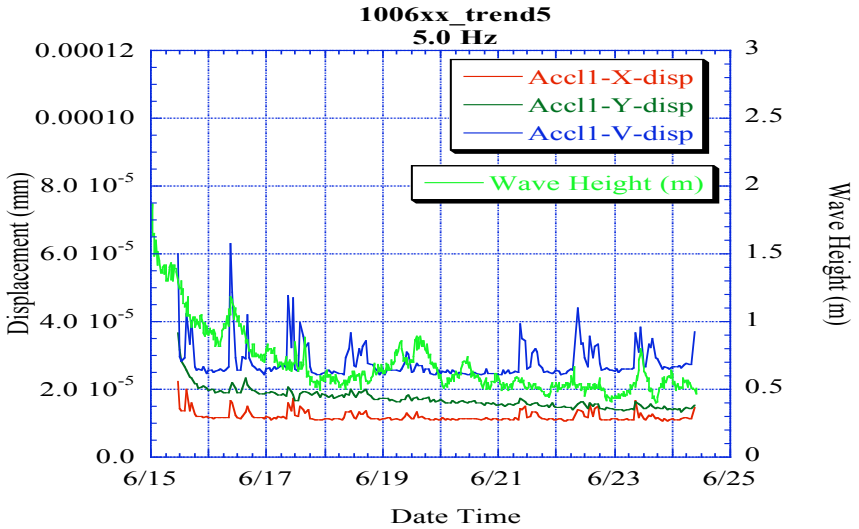
March/2010





June/2010

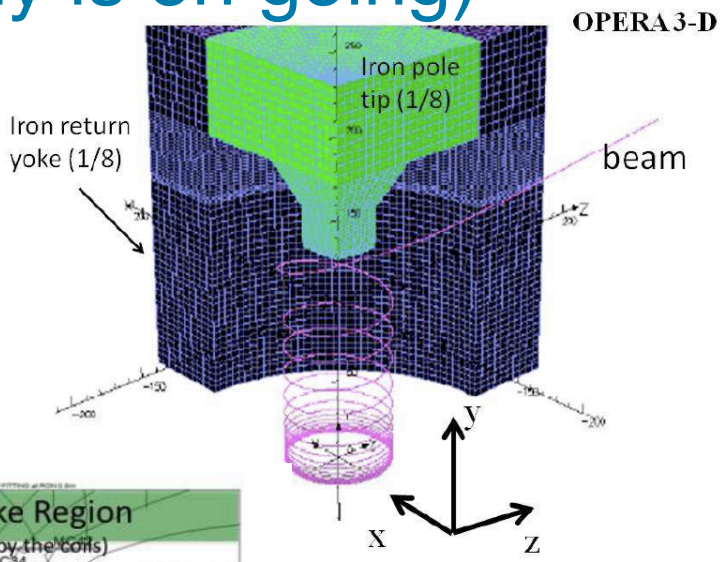


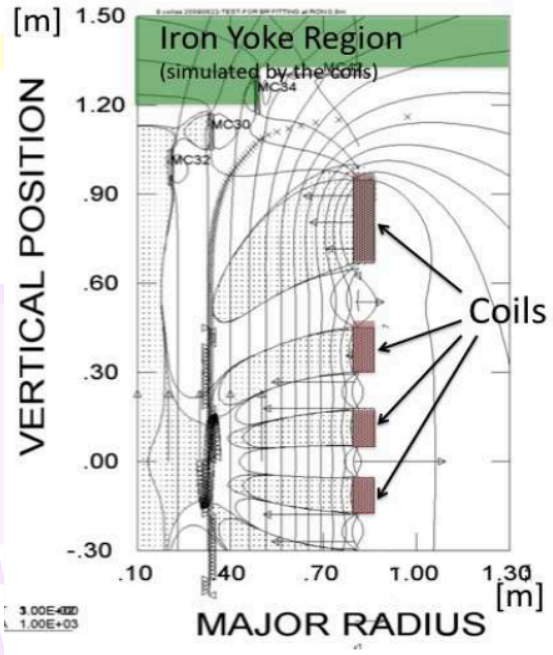


Study of Mechanical Resonance ~ yoke

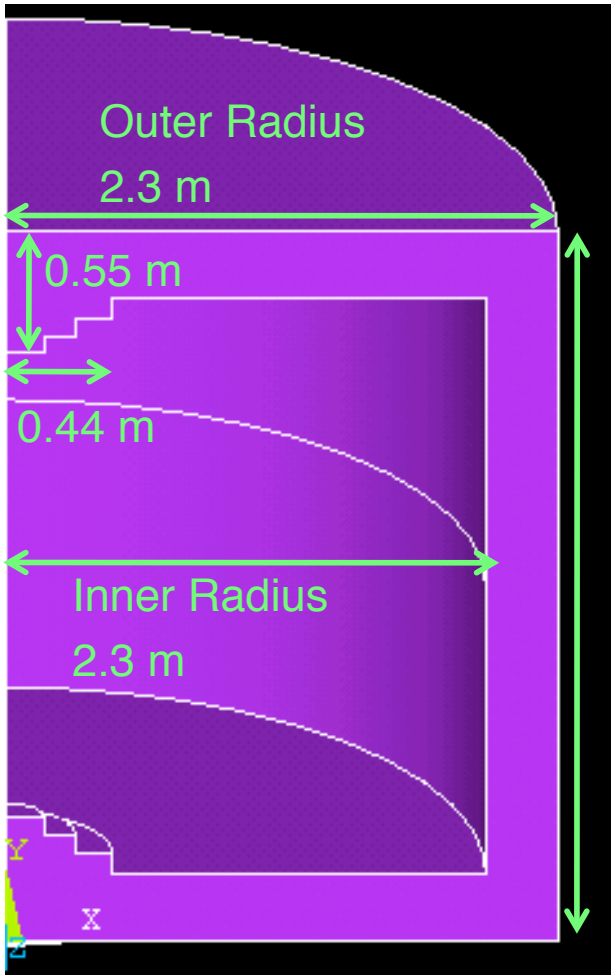
✧ Coil design

(study is on going)



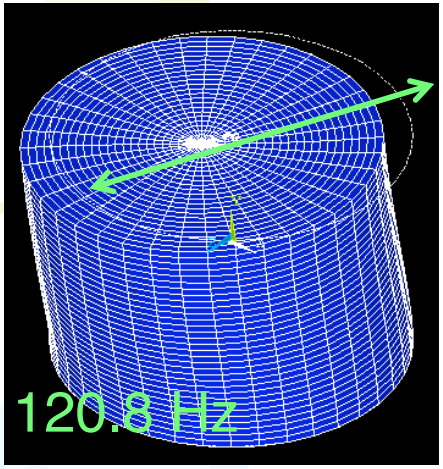


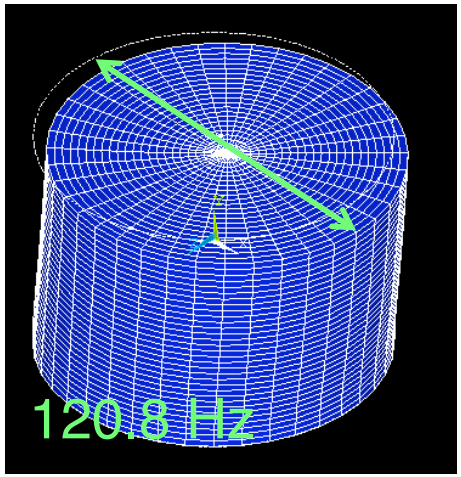
✧ Yoke model (quadrant)

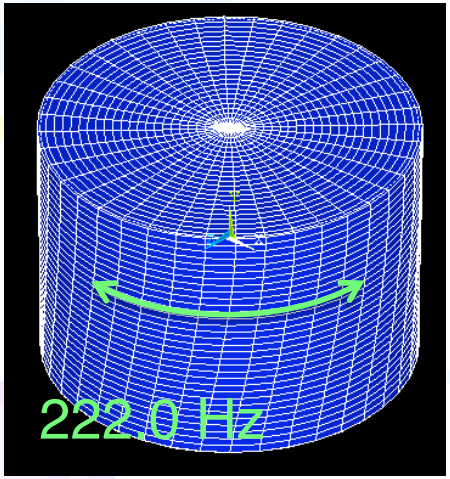


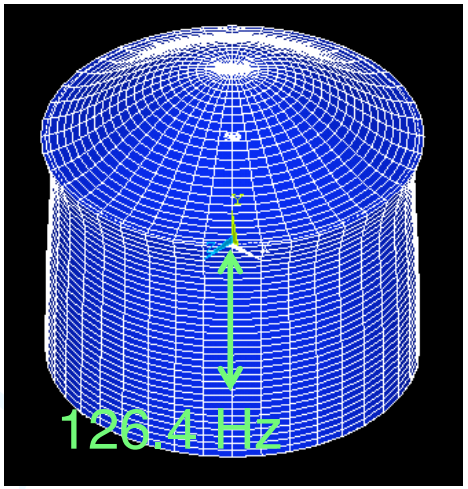
Modal and Spectrum analysis with ANSYS

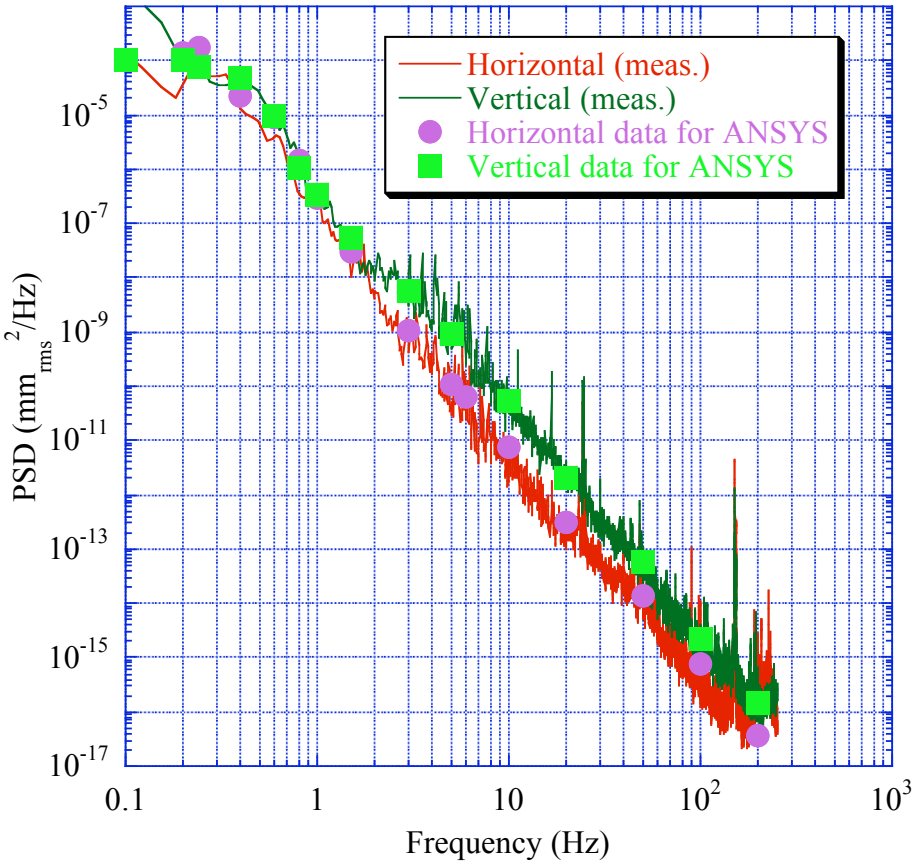
Modal analysis







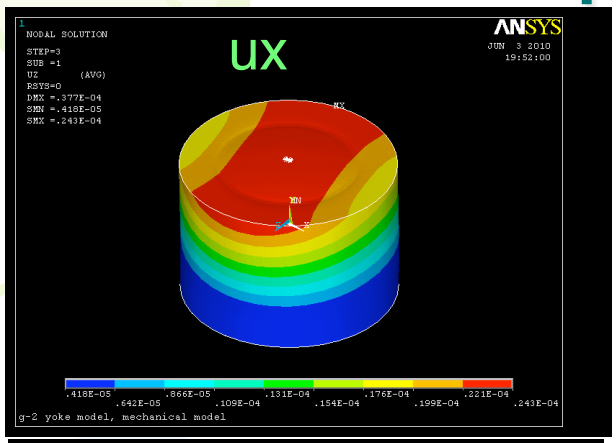


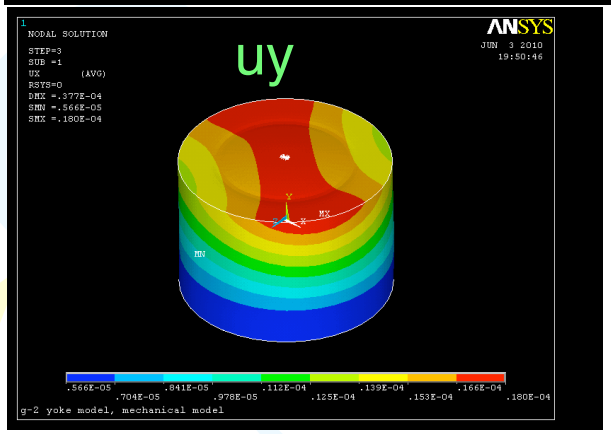


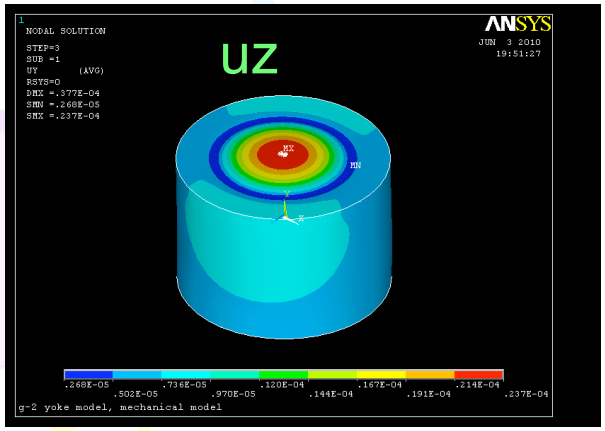
- These four basic mode are applied in the following spectrum analysis

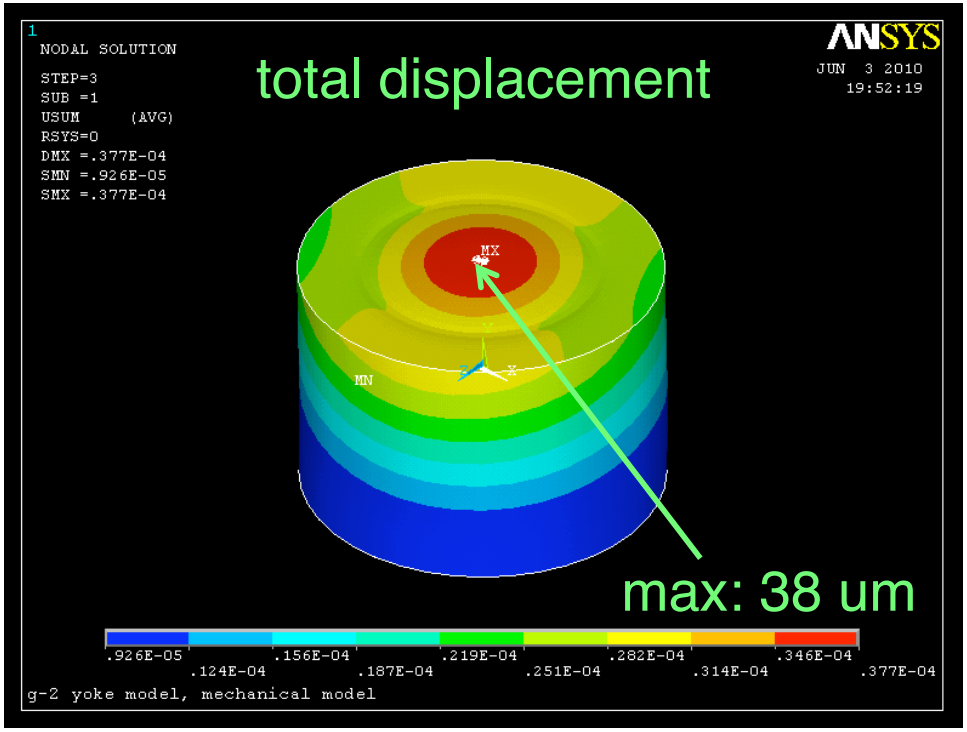
- PSD data for ANSYS are based on measured data at MLF.

Spectrum Analysis









- 38 um : seems to be small enough
- should analyze the influence on the field uniformity
  - good field region
  - injection region

Summary ~ seismic vibration

- Measurement of seismic ground vibration at MLF
  - clearly different from KEK
    - larger than KEK; especially below 3 Hz
- First mechanical analysis of Iron yoke
  - Displacement of yoke is not so large in the present analysis

- Next study
  - continue to observe the seismic ground vibration at MLF for a year
  - check the influence of the field quality
  - mechanical analysis of coil
  - analyze more detail model.

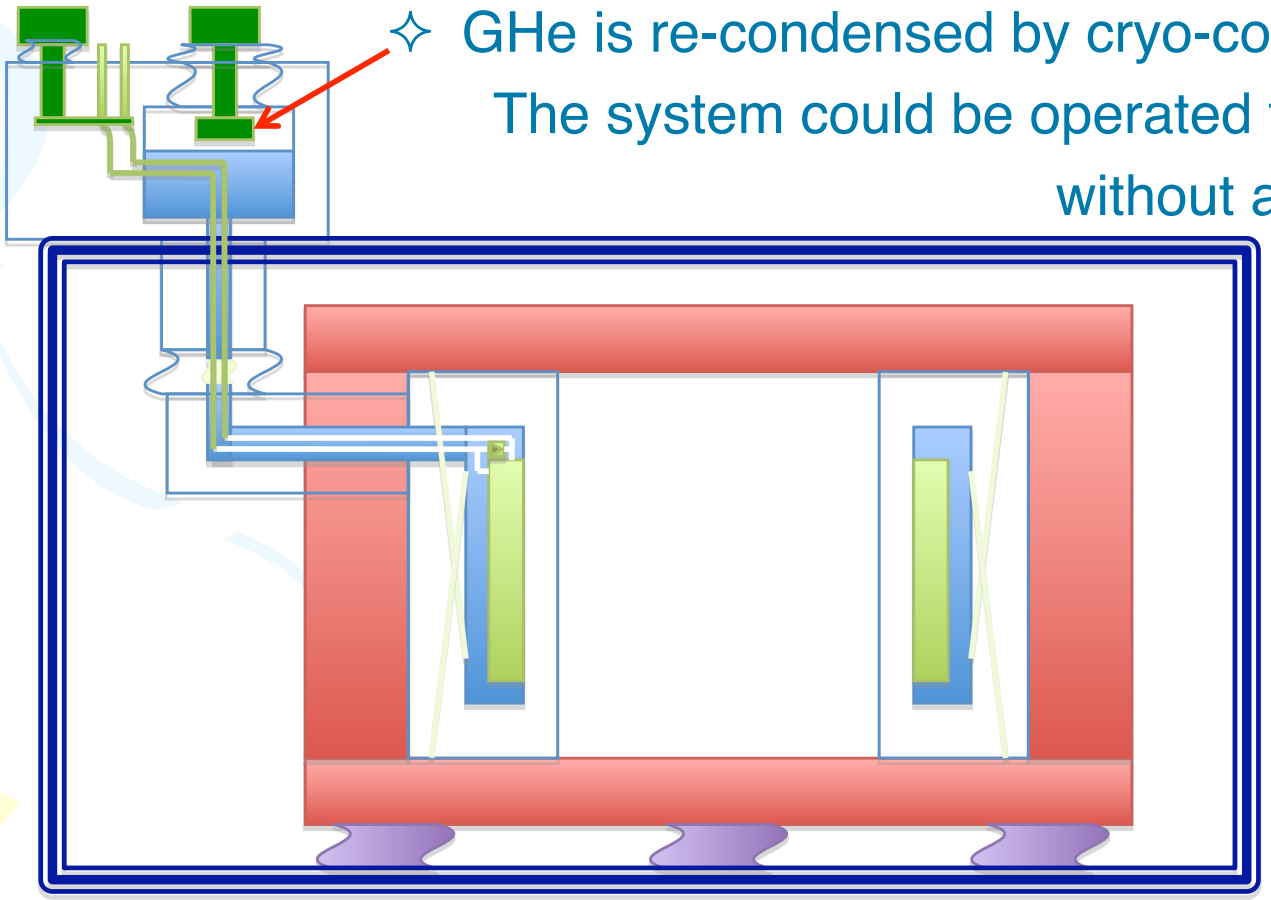
Contents

- ✧ Introduction
- ✧ Precision Magnetic Field Monitoring System
- ✧ Seismic Vibration and Mechanical Analysis
- ✧ R&D Status of Cryogenic System
- ✧ Summary

R&D of Cryogenic System

- Mechanical resonance would affect field quality
  - extra vibration source -> may cause large vibration

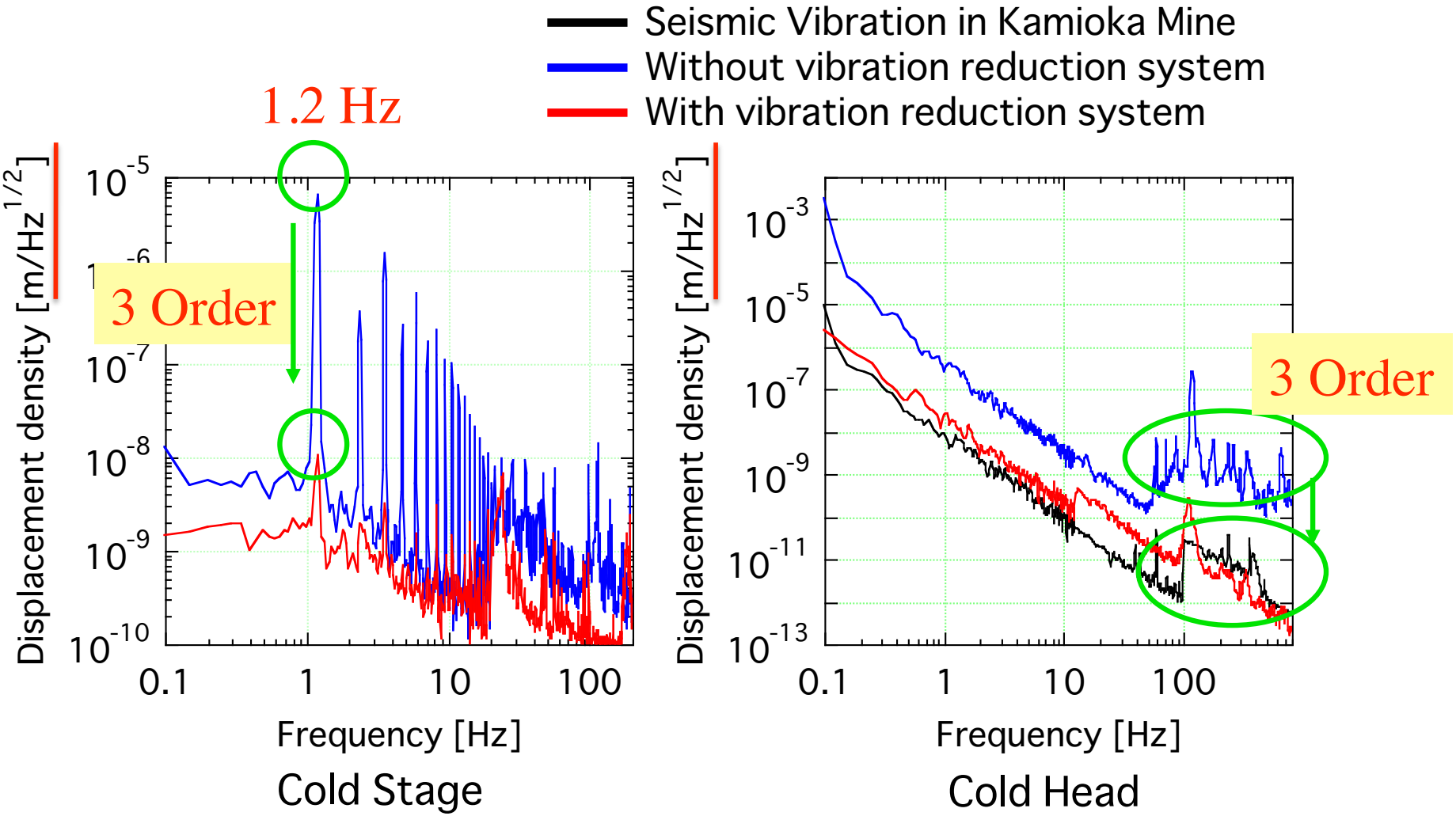
Present design of cryogenic system = thermo siphon



- GHe is re-condensed by cryo-cooler
  The system could be operated for the long term without additional LHe.

Vibration excited by cryocooler

Measured Result (Vertical direction)

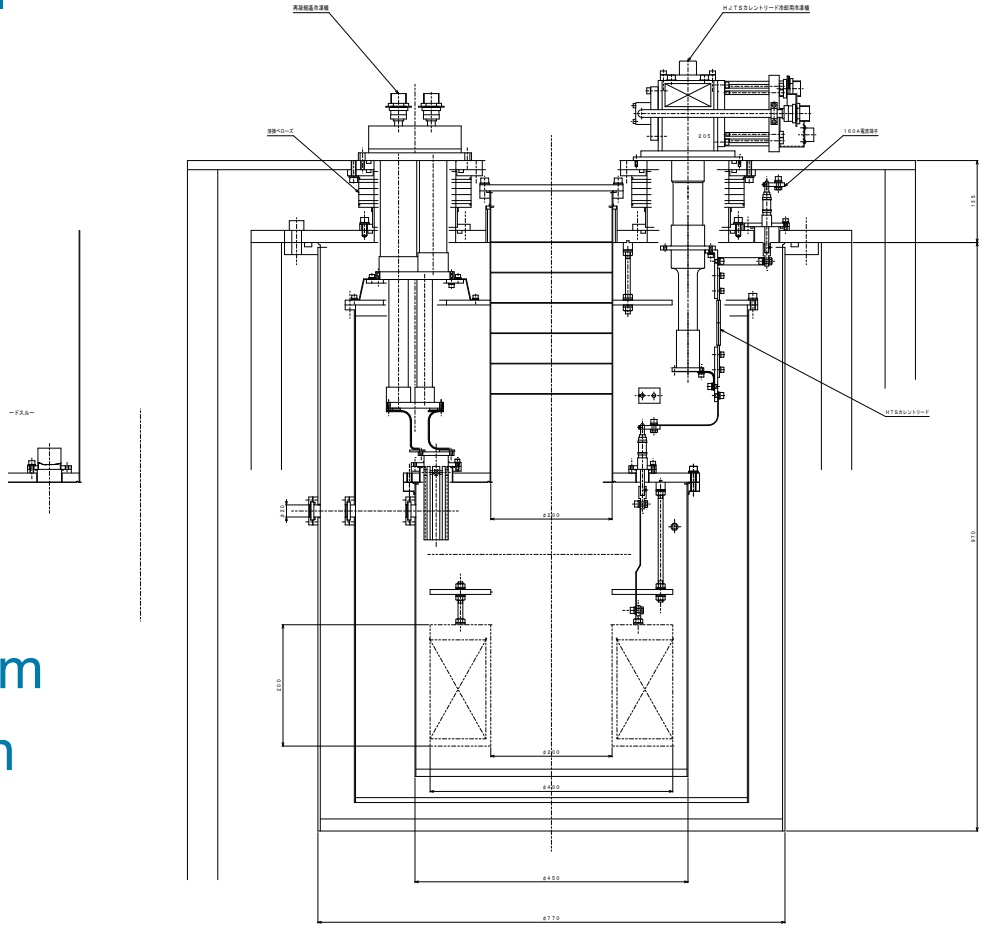


T. Tomaru, Cryogenics 44 (2004) 309.
T. Tomaru, Cryocoolers 13 (2005) 695.
R. Li, Cryocoolers 13 (2005) 703.

R&D of Low vibration cooling system

- R&D project of low vibration cooling system with *thermo siphon loop* has been launched in Cryogenic Science Center of KEK.

- Ultra-low vibration conduction cooling system has been successfully developed in Cryo. Sci. Center.



In one year:

- build prototype of cooling system
- study how to reduce vibration in *thermo siphon cooling system*

Summary

- Magnetic field monitoring system
  - built prototype system and did the first test
  - Some issues come up <- to be studied
    - error source of Hall probe measurement
    - design of monitoring system for actual g-2 solenoid
    - calibration of the absolute field value
- Seismic ground vibration measurement
  - Seismic ground vibration at MLF was measured.
  - made spectrum analysis with Iron yoke based on measured vibration
  - keep to measure vibration and make mechanical analysis with detailed model
- R&D of cooling system
  - launched R&D project of thermo siphon cooling system with low vibration
  - will start quench protection analysis as soon as coil parameters are fixed.

2010年度R&D申請

- ✧ 基礎物性測定装置群の整備および試験 ～15T&10T-Ic測定装置と熱伝導測定装置
  - ❖Ic測定装置および熱伝導測定装置の整備し、測定環境を構築する
    - ◘Ic測定装置@第4低温：15T、10T
    - ◘熱伝導測定装置@第3低温
  - ➢取り合いやサンプル作成用治具などを整備
    - ◘電源配線、底上げ台（第一低温におく場合）
  - ➢全体を整備し、資料をセットすれば測定が開始出来るように、測定系も可能な限り準備
  - ➢場所について、将来的には第一低温に設置希望
  - ➢Nb3AlやMgB2のIc測定
  - ➢シアネートエステルの熱伝導測定