Studies on ~~field error in storage ring~~ and field measurement

This is not mentioned

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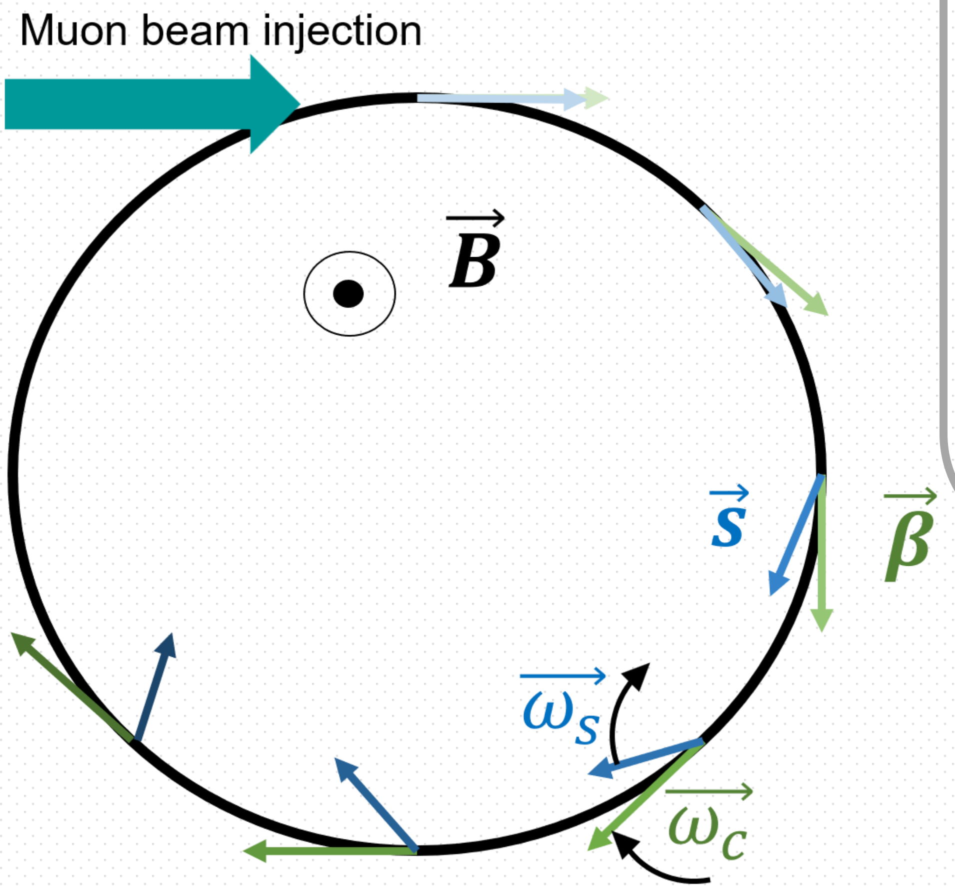
Importance of uniform magnetic field



Spin precession of muon

We do not use $\vec{E}$ for beam focusing

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

g-2 term EDM term

$$a_\mu = \frac{g-2}{2} \quad \eta = \frac{2m_\mu c}{e} d_\mu$$

$\vec{B}$ must be uniform because

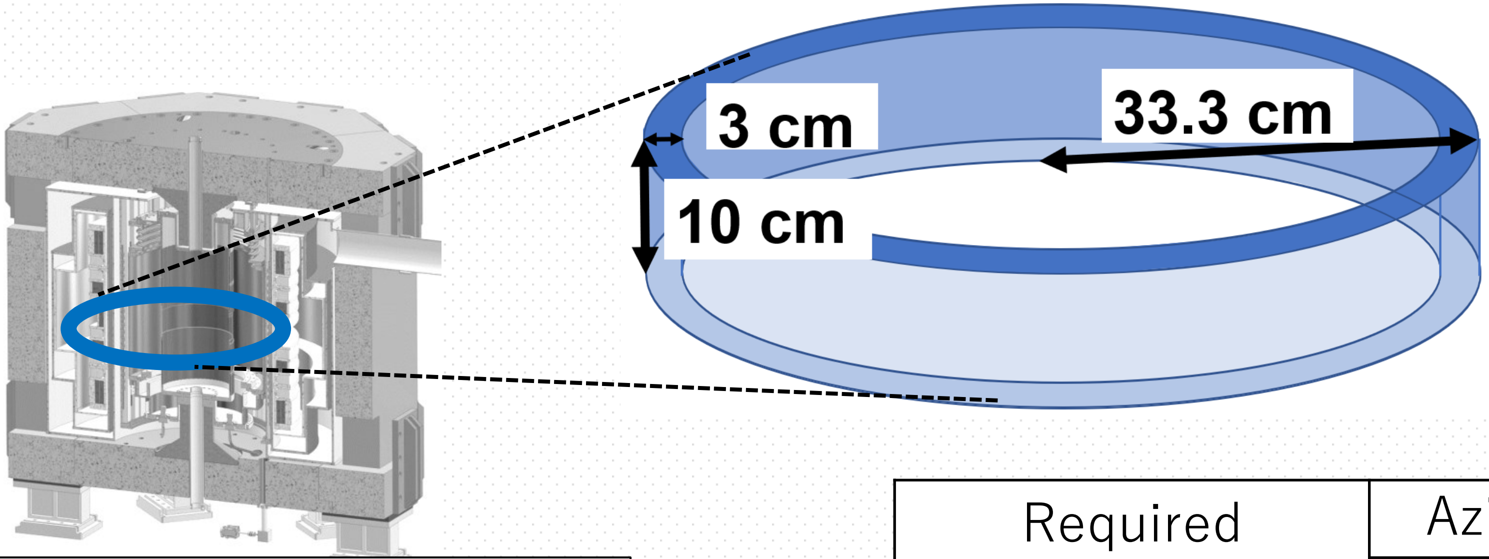
$\vec{\omega} \propto a_\mu, \eta,$ and $\vec{B}$

measured value

target

Storage magnetic field @ J-PARC

Magnetic field with a good uniformity will be achieved by using **ultra-cold muon beam** and storing it in **compact region**.



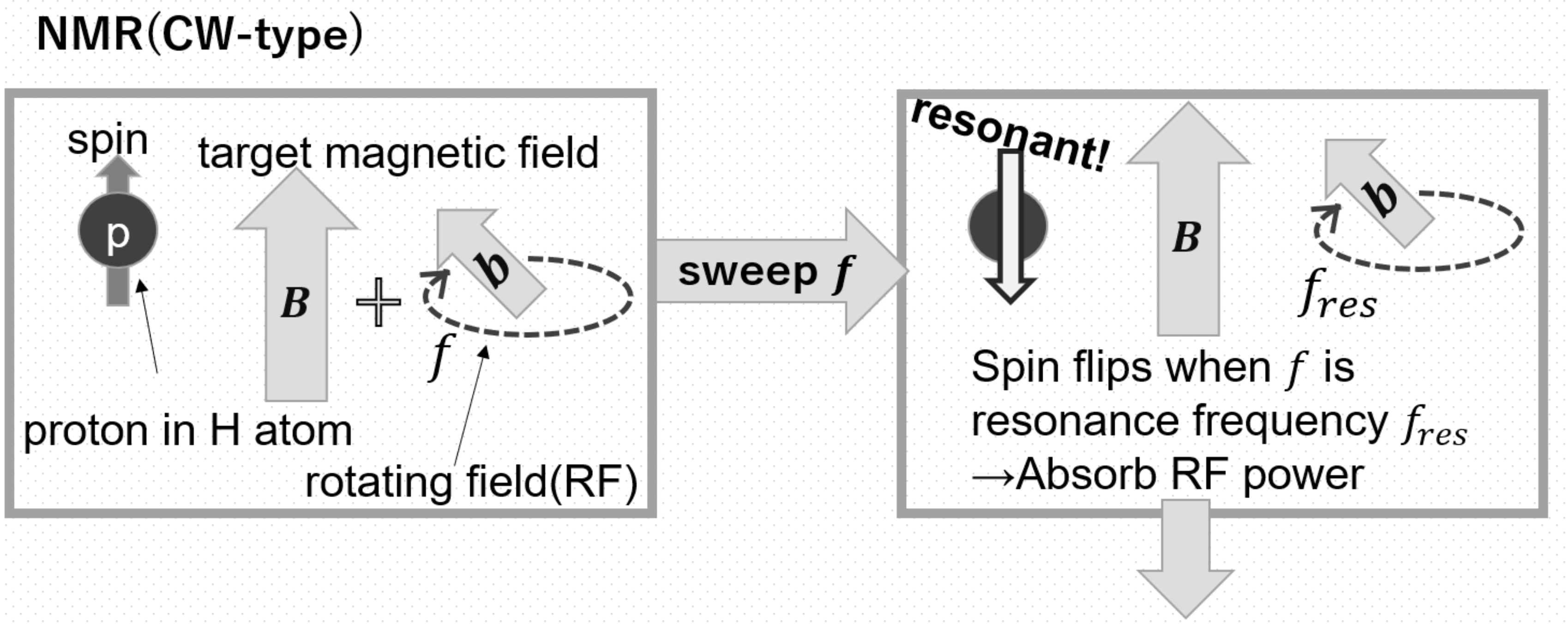
Storage region @ J-PARC

3 T solenoid magnet for muon storage driving persistent current mode

Required uniformity [ppm]	Azimuthal average	±0.1
	Local	±1

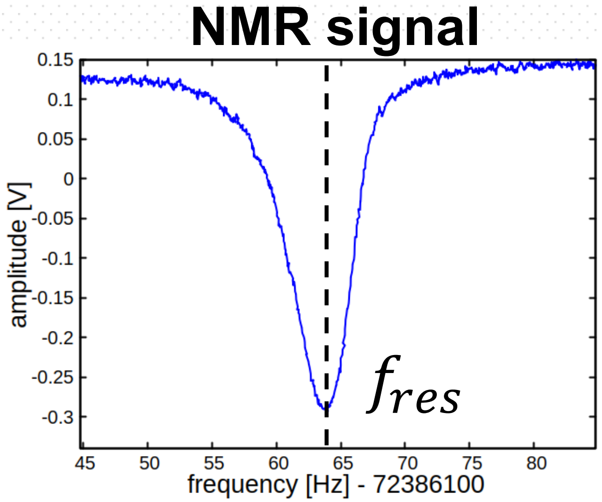
Magnetometer for uniform field

Magnetic field in storage region has to be measured with a precision of 10 ppb.
→We selected NMR magnetometer for its absolute precision.
developing magnetometer optimized to measurement environment

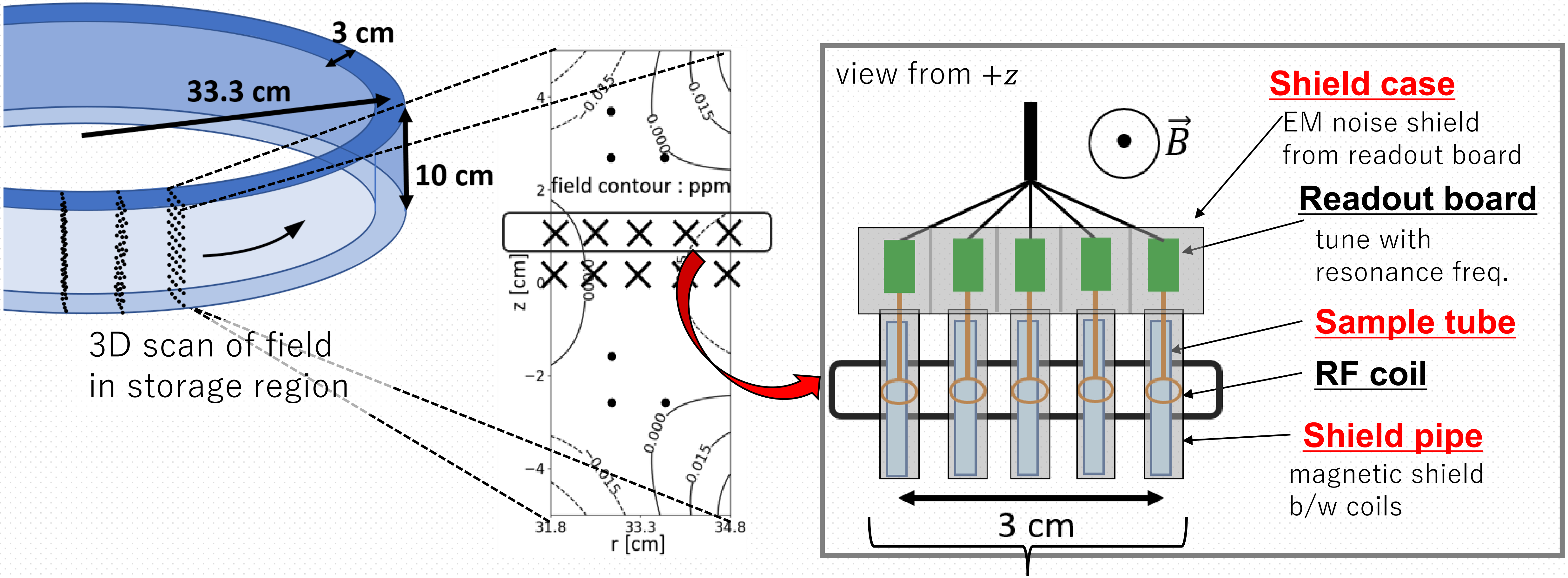


Determine B from

$$hf_{res} = \hbar\gamma_p B \quad (\gamma_p : \text{proton gyromagnetic ratio})$$



Schematic view



5 channels for simple moving mechanism & efficient meas.

Target accuracy :

10 ppb accuracy at every point for <±0.1 ppm uniformity (azimuthal average)

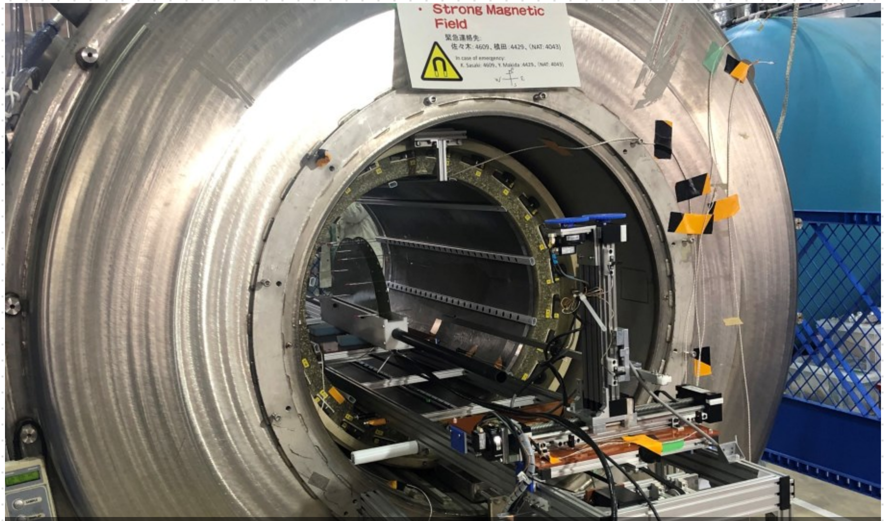
Development items

I am developing NMR magnetometer for g-2/EDM.

Important development items

- Length of sample tube
  - needs to be determined in view of spatial constraint & measurement sensitivity

- Effect of shield case
  - Readout board is set near the coil for high Q value. However, the case's magnetization can affect the measurement.



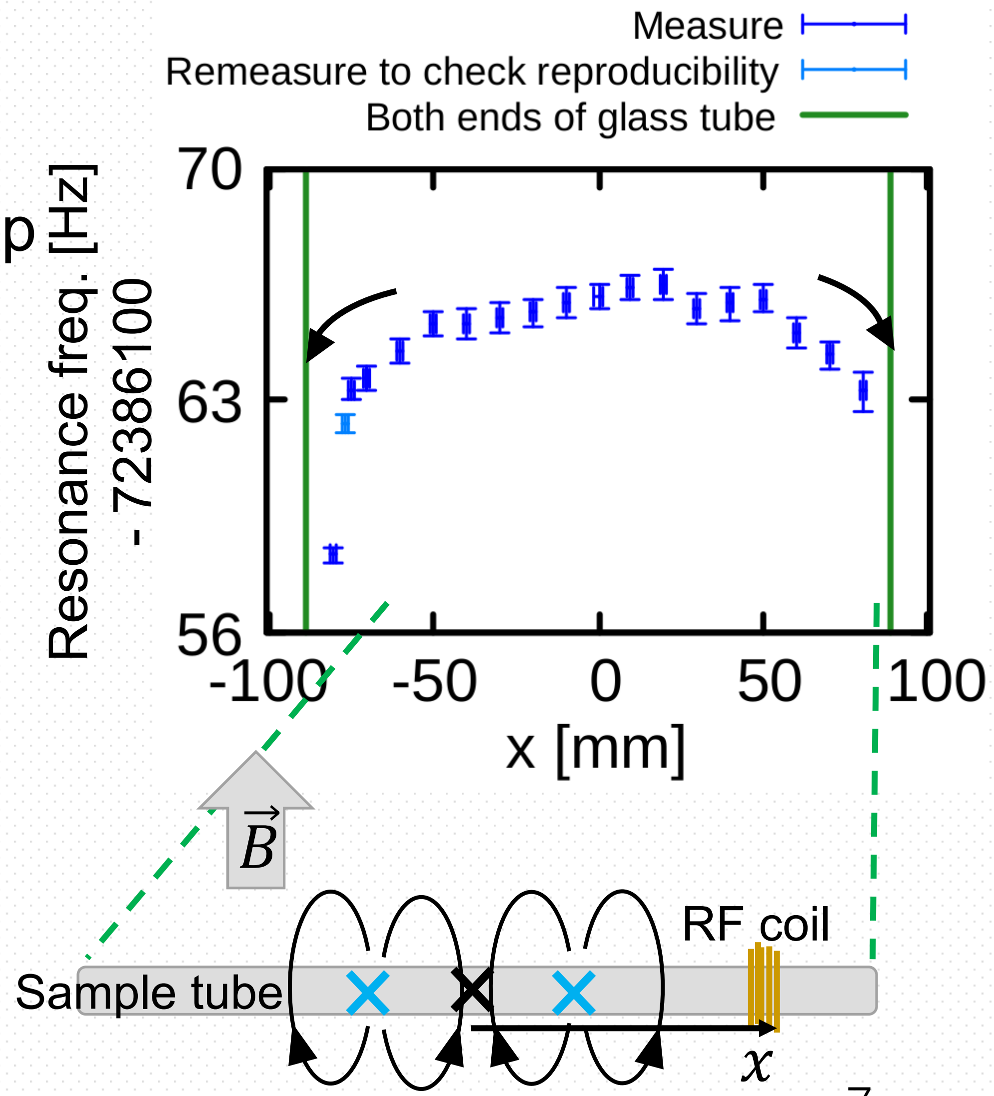
MRI-type magnet for MuSEUM
(K. Tanaka *et al.*, PTEP, vol. 2021, 053C01)

Length of sample tube

Water ($\chi \sim -10^{-5}$) generates surrounding field.
→Field along sample tube can be sidtubed.
→If tube length is not enough, RF coil would pick up resonance signal with various freq.

- Checked that magnetic field begins to decrease from ~30 mm from both ends
- Limited measurement space

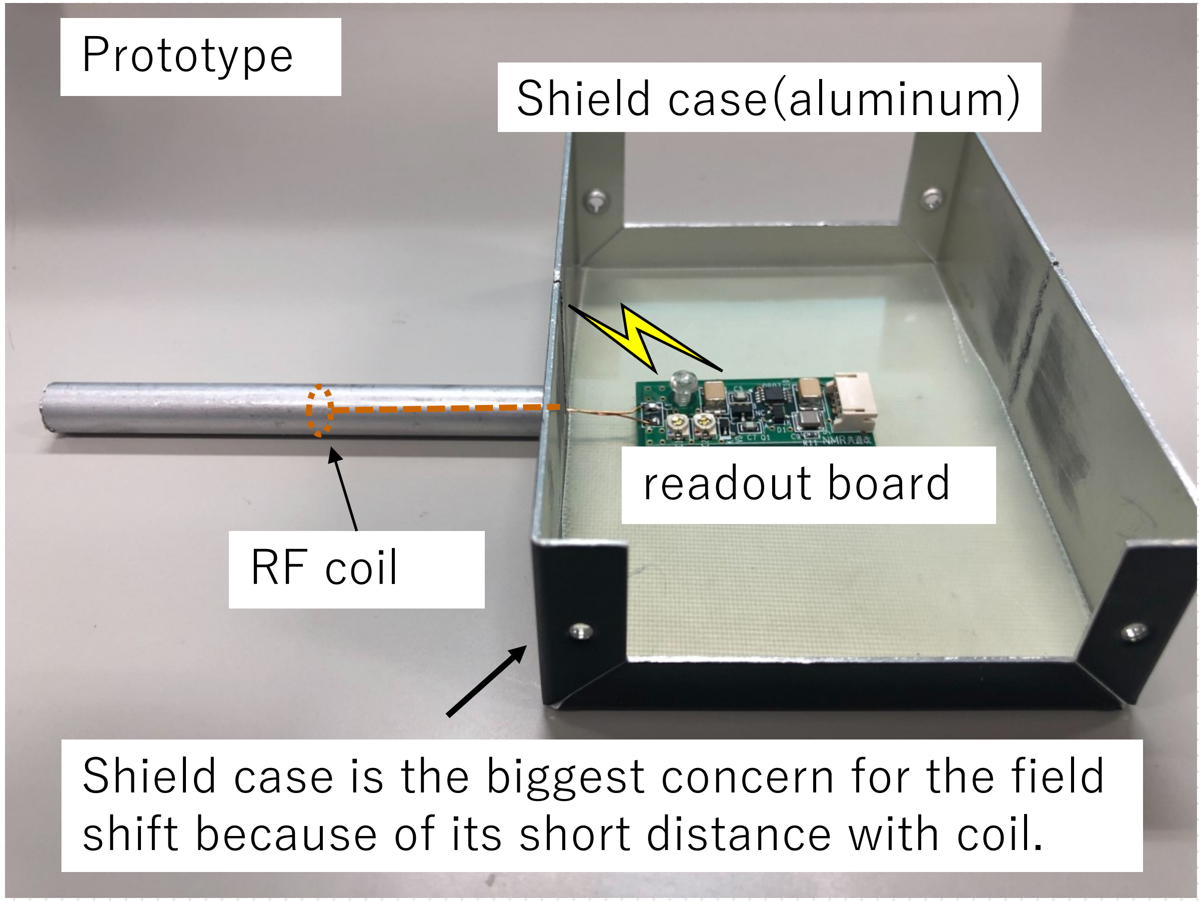
Length is determined to be 90 mm.



Shield case effect

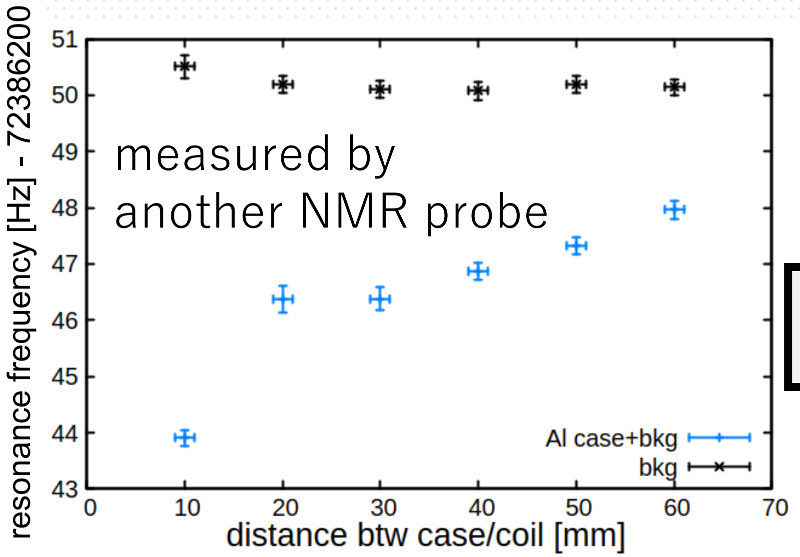
- Readout board is close to RF coil for high Q value of LC resonance.
- EM noise from the readout board is shielded by an aluminum case.

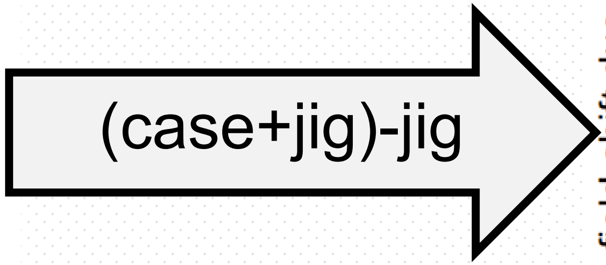
→Mangetic field at RF coil would be shifted by the magnetization of the case.($\chi \sim +10^{-5}$)

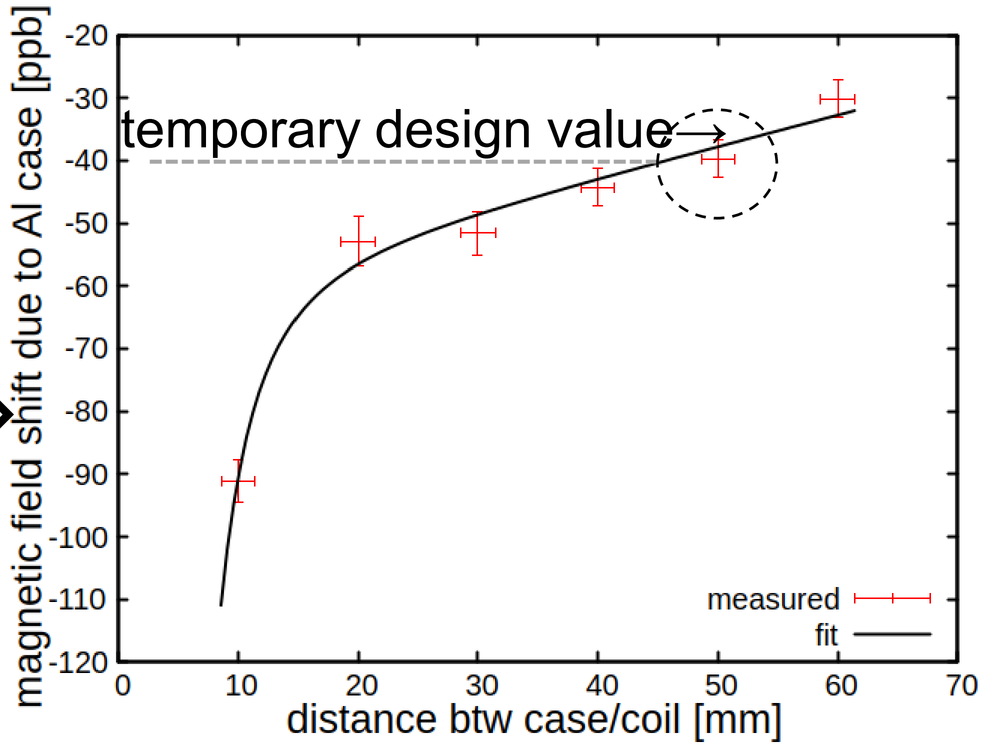


Shield case effect

Measured the shift value of magnetic field at the temporary design value





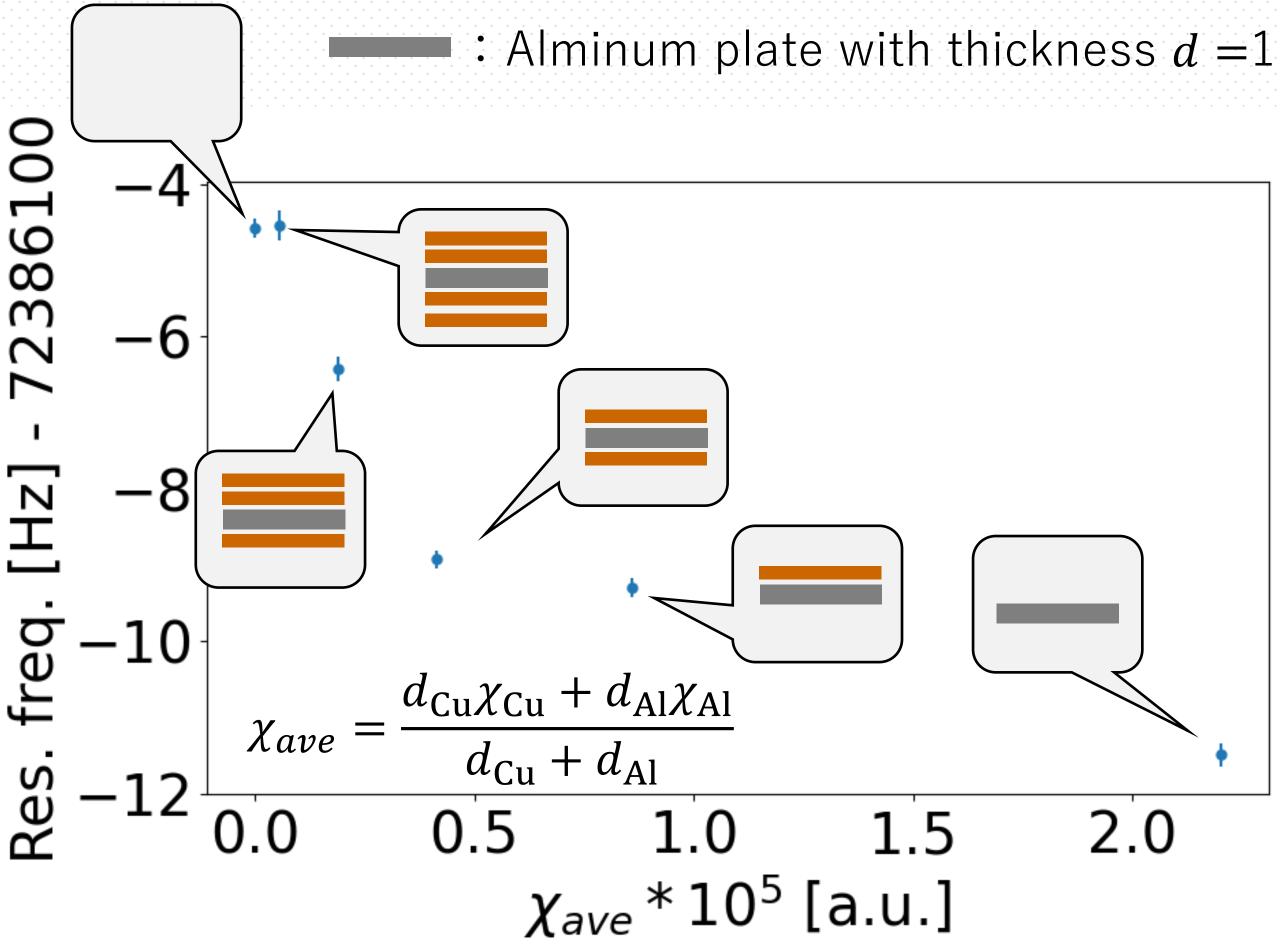


Although systematics with the probe would be calibrated,
the less shift value, the better.

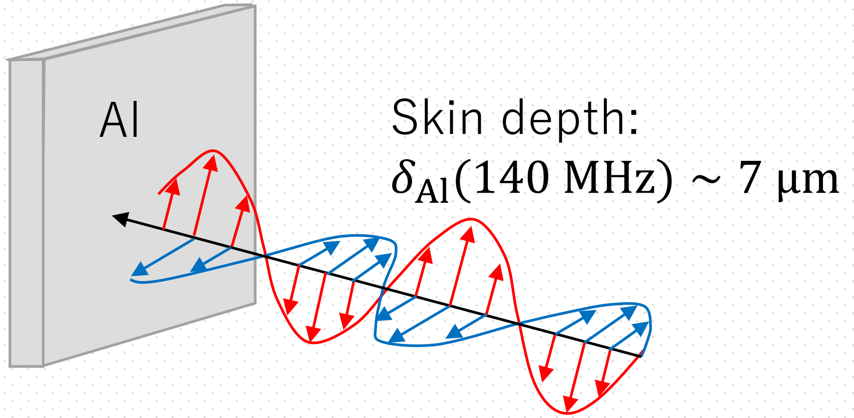
Countermeasure against the effect

: Copper plate with thickness d =0.5 mm ($\chi_{Cu} = -1.0 \times 10^{-5}$)

: Alminum plate with thickness d =1 mm ($\chi_{Al} = +2.2 \times 10^{-5}$)



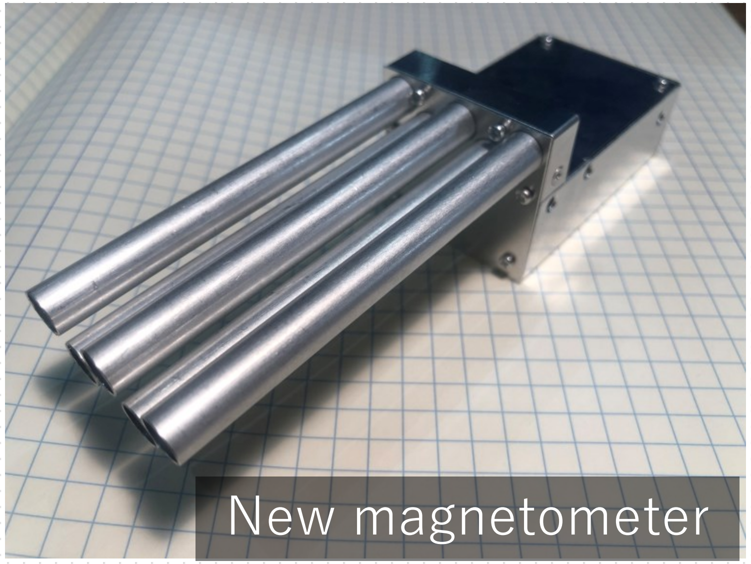
The case can also be thinner

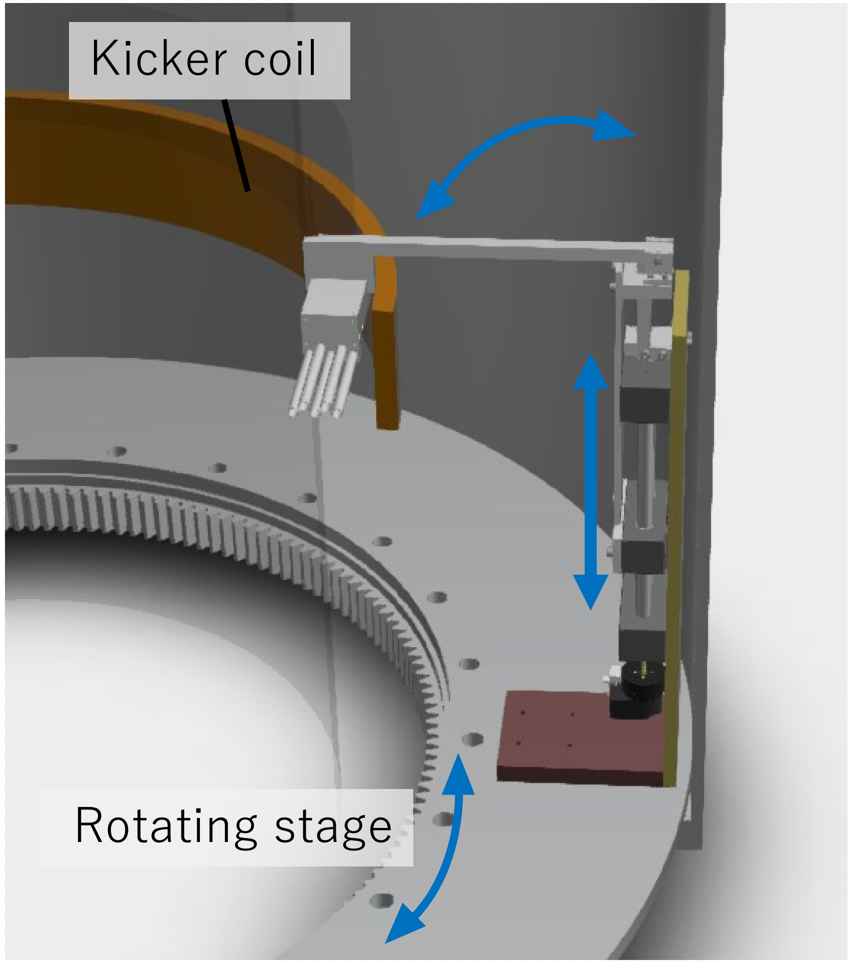


Checked that copper plate, which has -1/2 magnetization as aluminum, can cancel the effect.

Future outlook 1

A new magnetometer was manufactured based on the study. A more practical performance evaluation will be carried out.



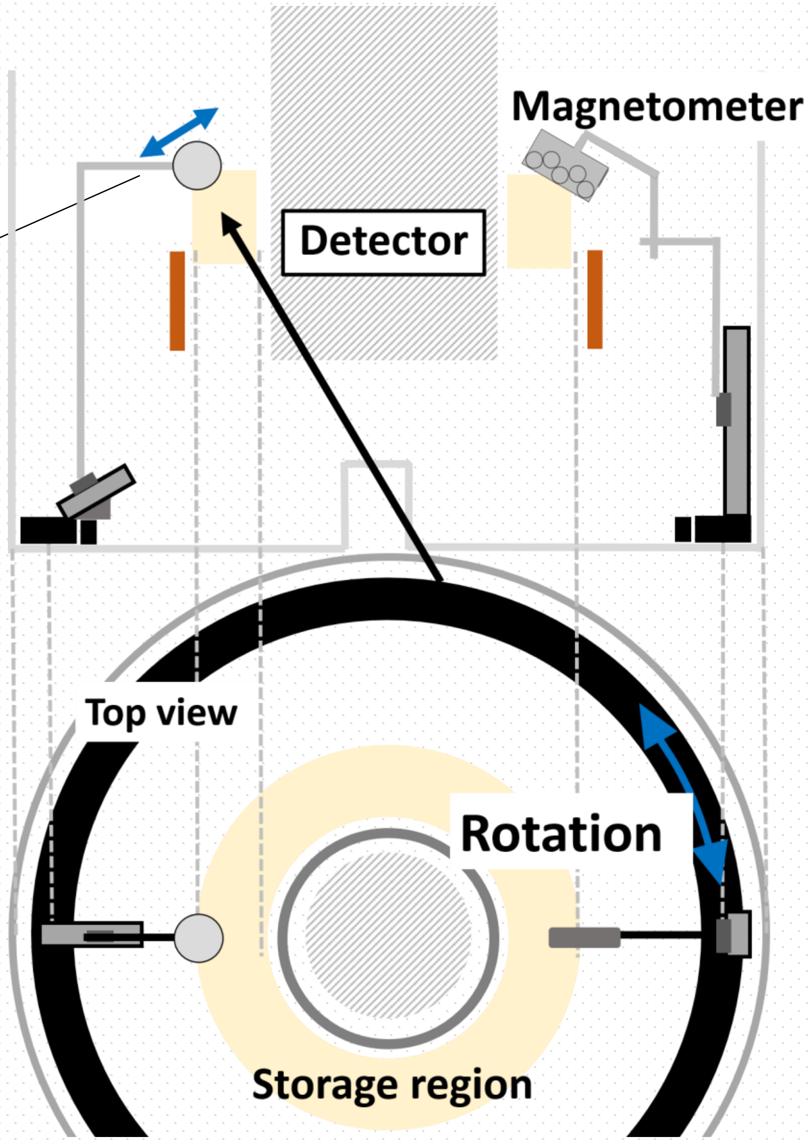


Moving mechanism for field measurement is under discussion.

Future outlook 2

Calibration sequence in magnet is also under discussion.

Calibration probe
Systematics is well estimated.
bigger sample size



Calibration probe measures field at the same point with magnetometer for the calibration.
Diagonal movement for all channels' calibration is under consideration.