EDM実験に向けた高精度磁力計に関して

吉見　彰洋

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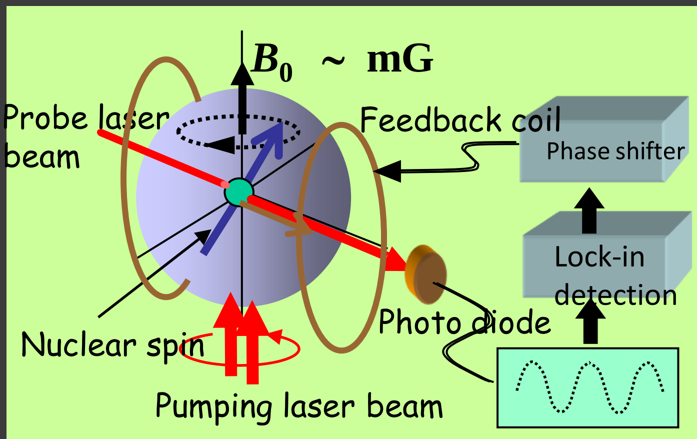
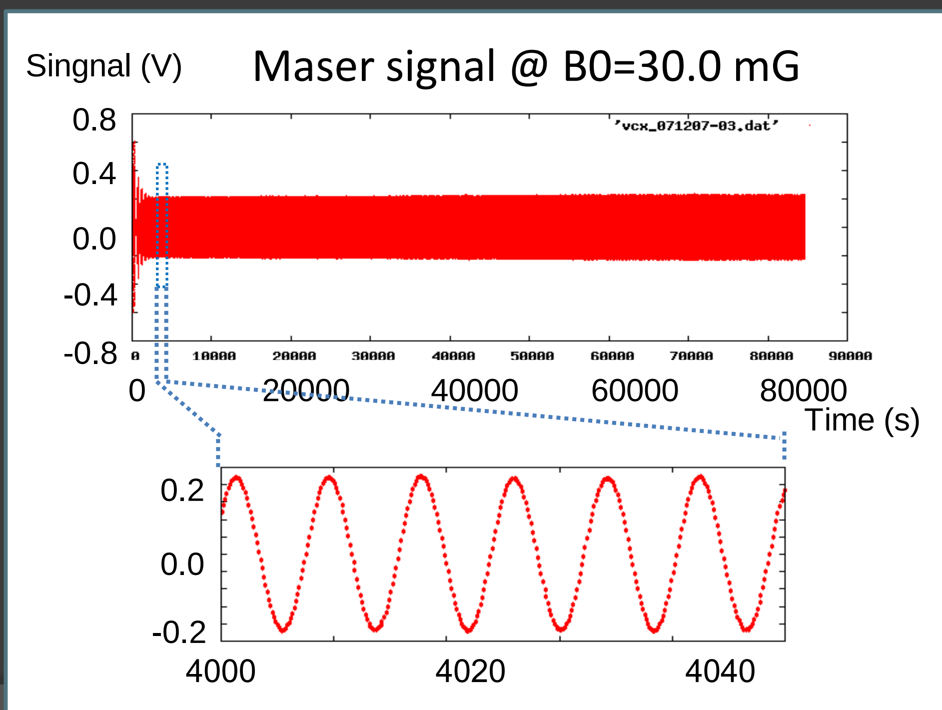
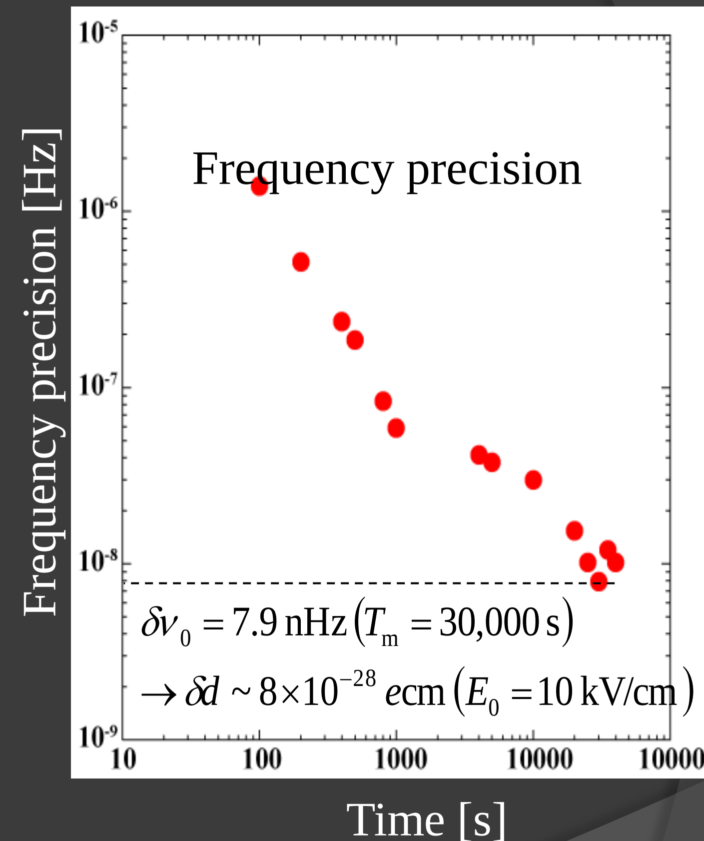
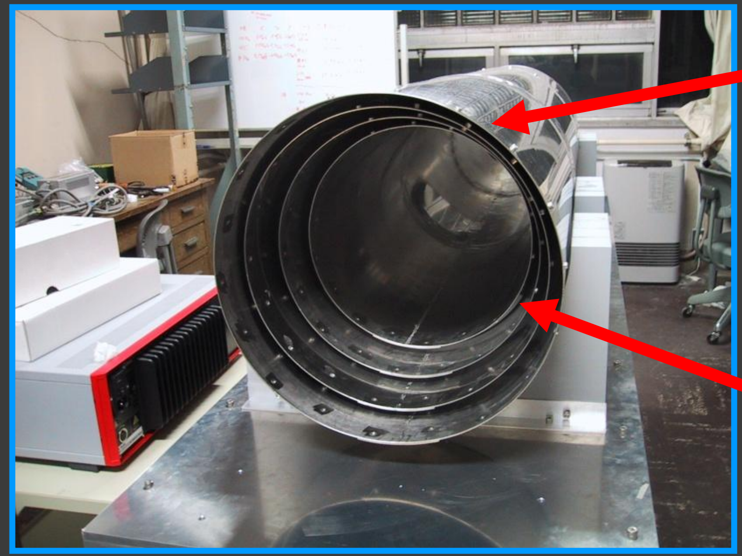
KUR workshop, 2012/2/26

Nuclear Spin Maser with Polarized ^{129}Xe at low field





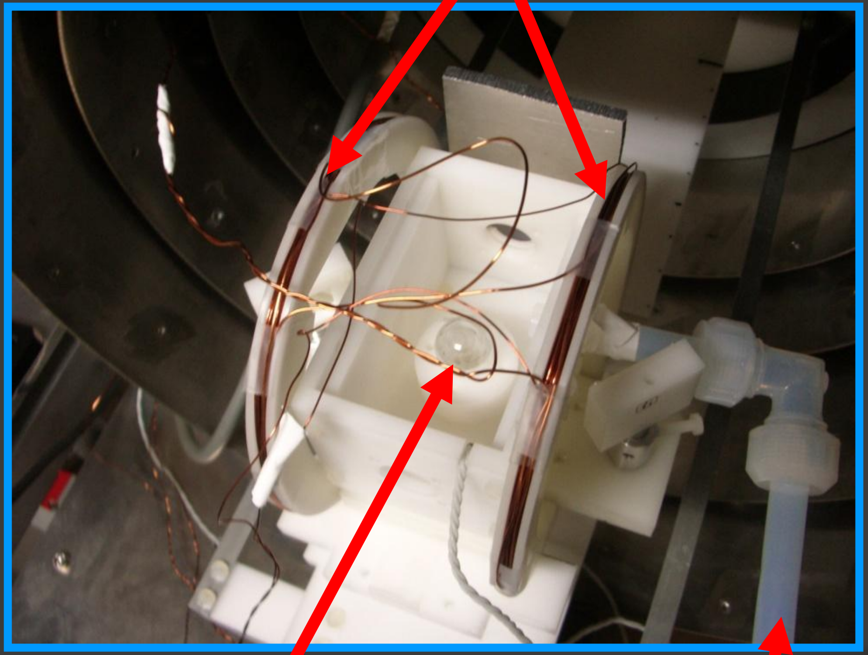




Magnetic shield (4 layers)
ϕ: 400 mm, L = 1600 mm for the outermost layer

Solenoid coil
ϕ: 254 mm, L = 940 mm

Feedback coil

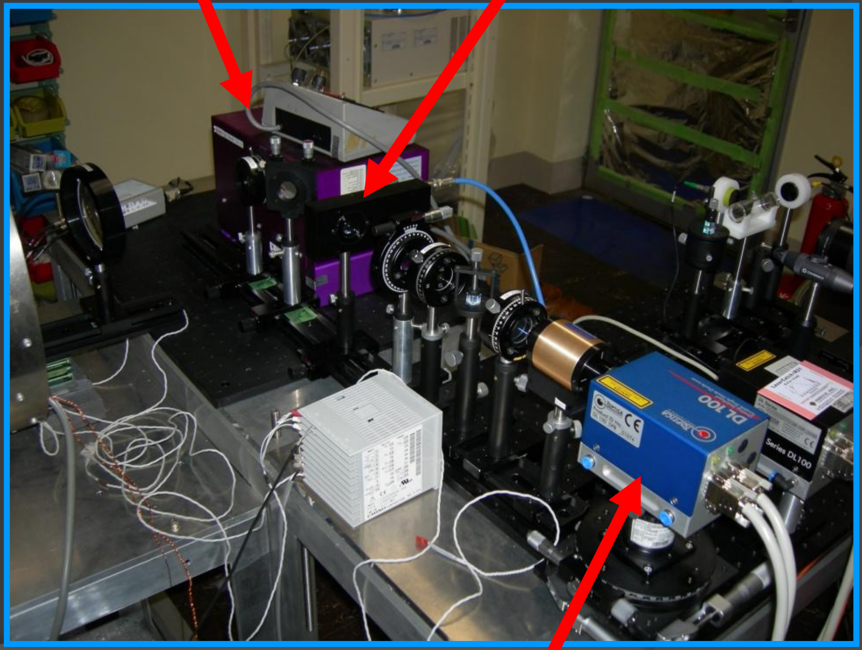


^{129}Xe gas cell

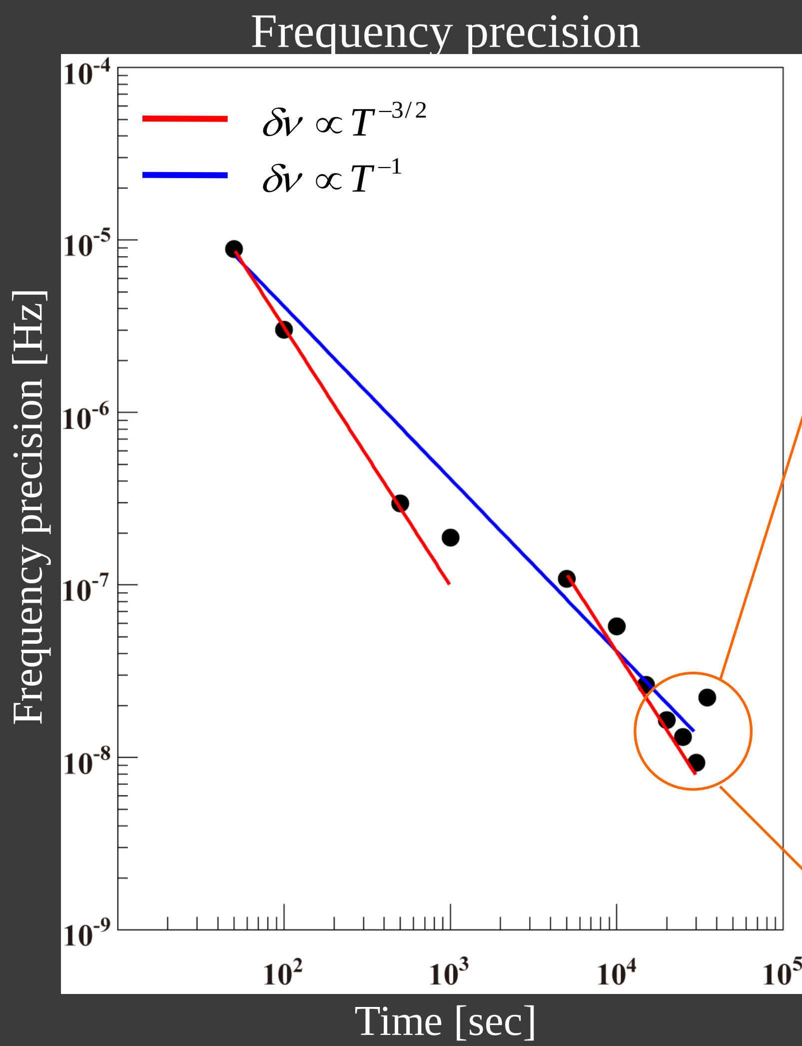
Heater - tube

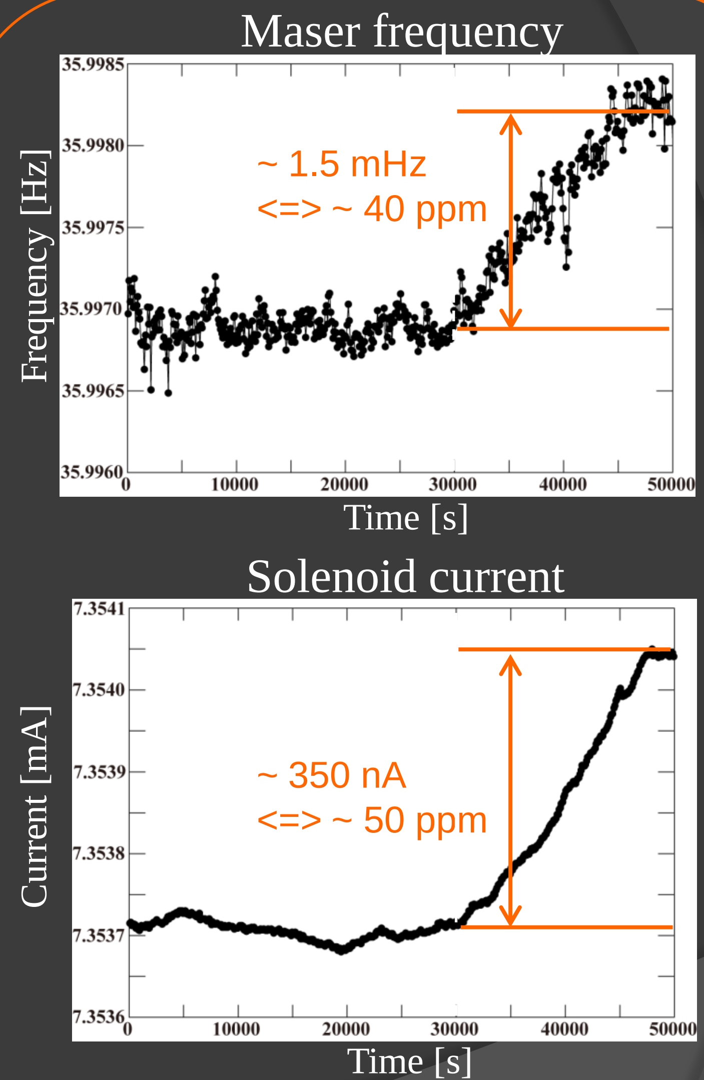
Pumping laser

PEM



Probe laser

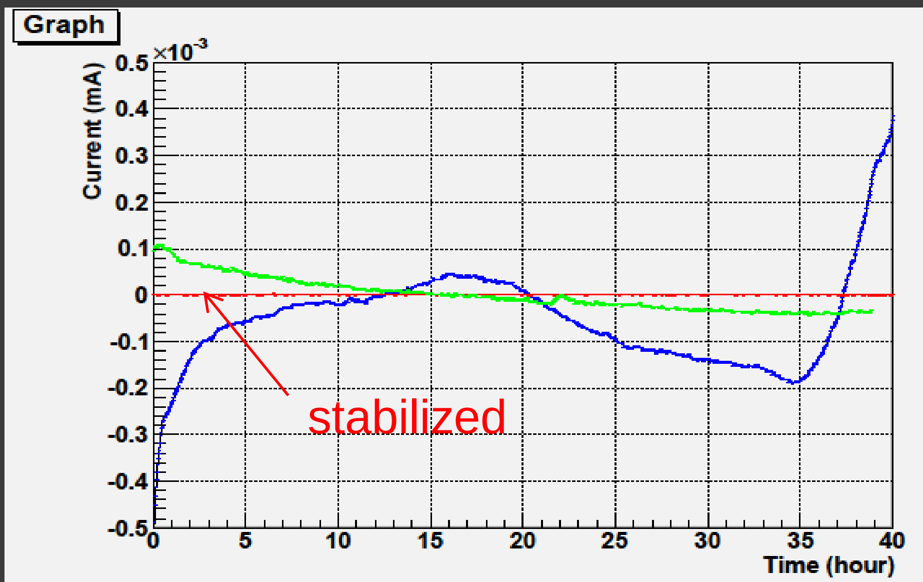


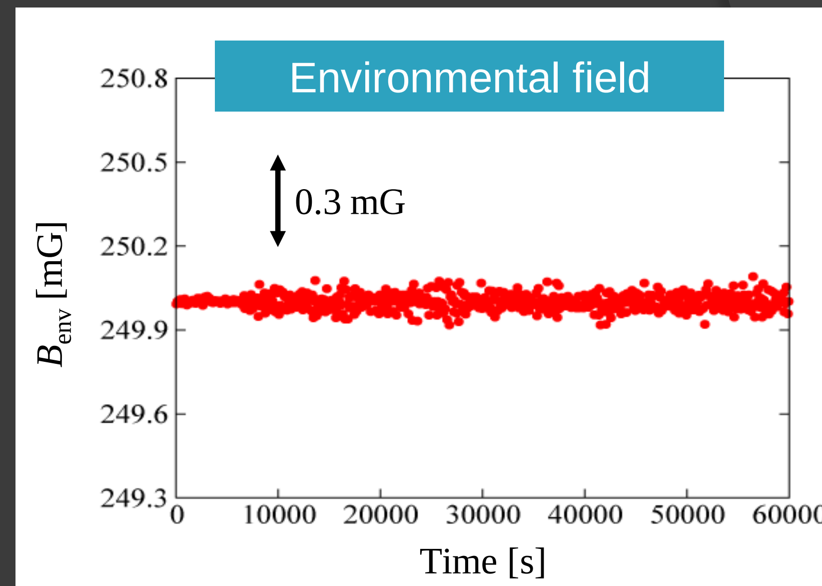


ソレノイド電流のドリフトによる
周波数ドリフト

Stabilization of B0-current source

Correction to environmental field fluctuation





Current fluctuation: 1 ppm

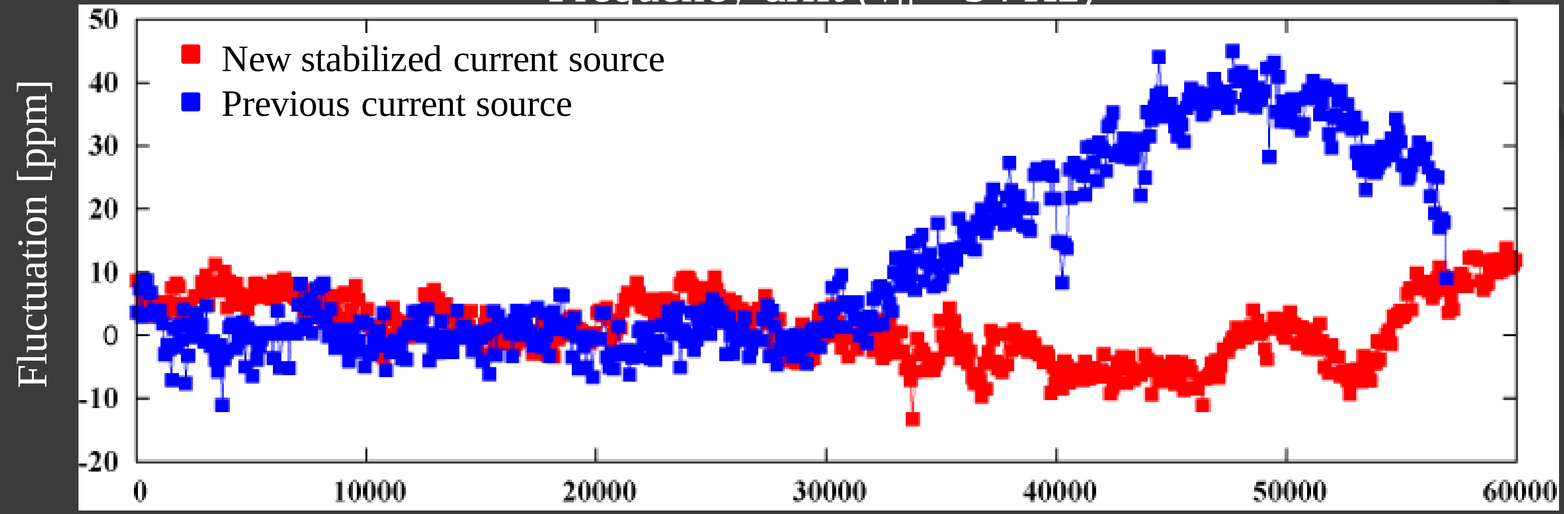
B0=30 mG → δB = 30 nG

Outside the magnetic shield:
δB = 50-100 μG

→ inside the magnetic shield

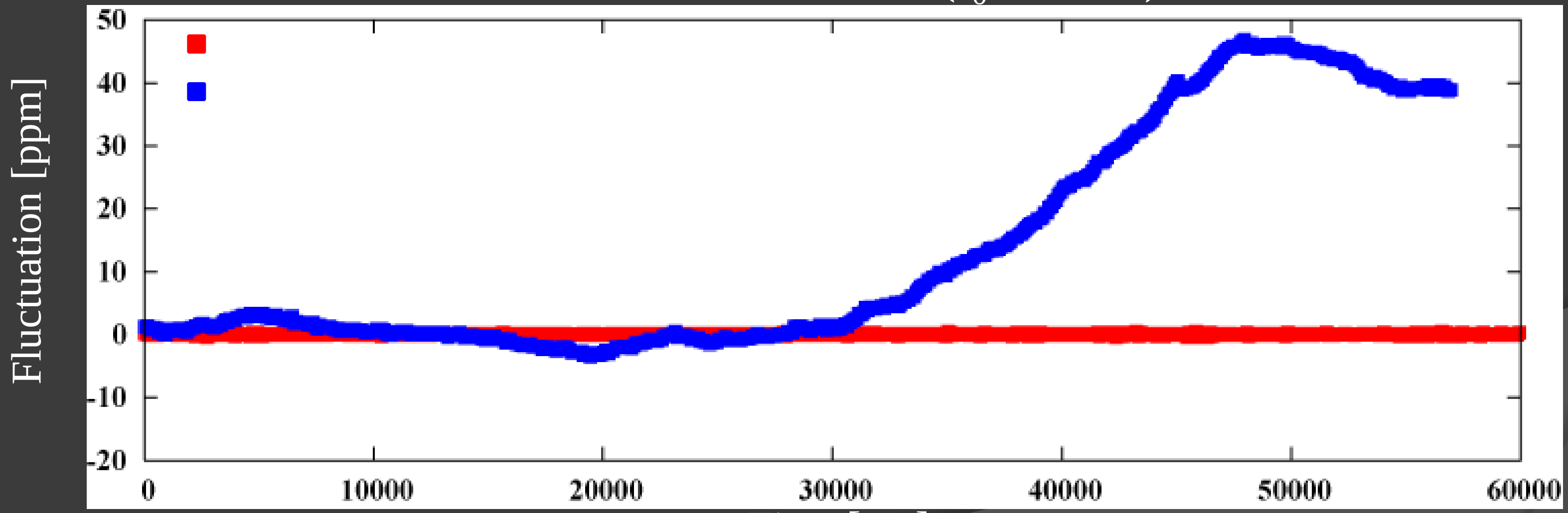
δB = 50-100 nG

Frequency drift (ν_0 ~ 34 Hz)



Time [sec]

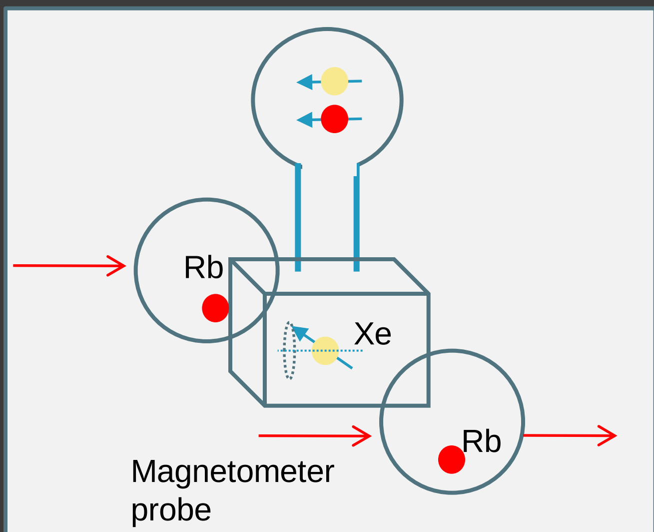
Solenoid current drift (I_0 ~ 7 mA)



Time [sec]

Magnetometer for Low freq-Spin maser EDM experiment

(1) High sensitivity magnetometers



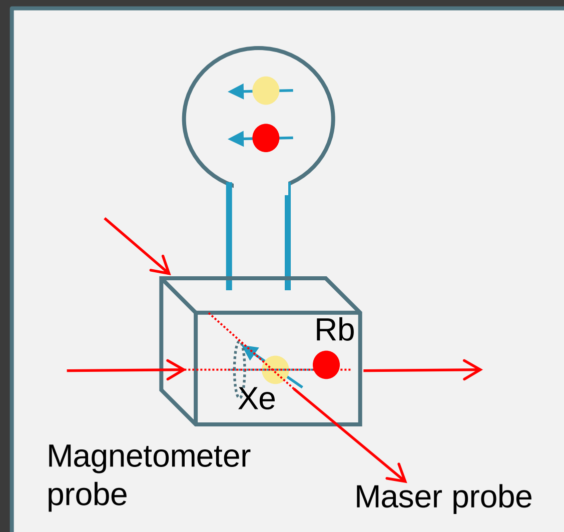
- Not comagnetometer
- Rb magnetometer near maser cell
- Only Xe and Rb (small, and not pol)

$$\delta B = 10^{-11}\ \mathrm{G}/\sqrt{\mathrm{Hz}}$$

100 s –run (if constant):

$$\delta B = 10^{-12}\ \mathrm{G}$$

(2) Rb comagnetometer



- Comagnetometer of Rb
- Only Xe and Rb (small, and not pol)

- Probrem of

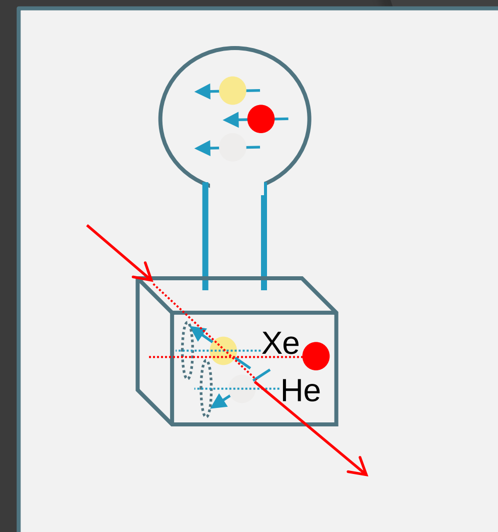
Rb – Xe interaction ?

(→ Low density Xe gas ?)

Polarizability problem

$$\delta B = ?\ \mathrm{G}/\sqrt{\mathrm{Hz}}$$

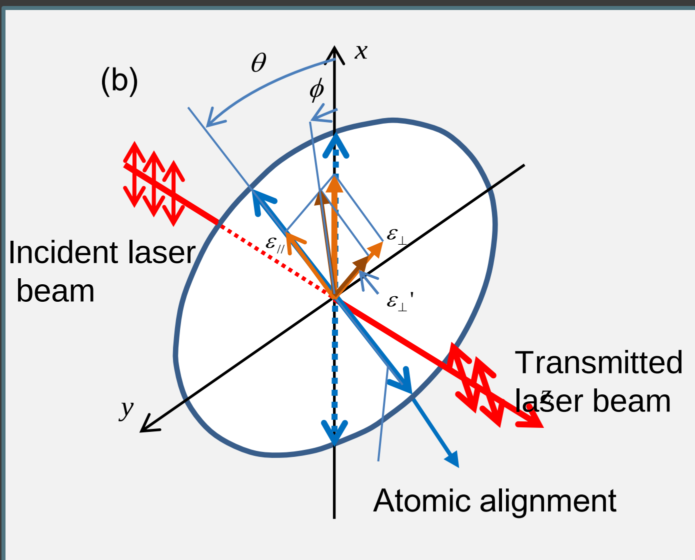
(3) 3He comagnetometer



- Comagnetometer of 3He
- S/N for He precession for laser probing .

Precise magnetometer with Rb atoms using NMOR

Resonant optical rotation in Rb vapor (NMOR; Nonlinear Magneto-Optical Rotation)



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Sensitive magnetometry based on nonlinear magneto-optical rotation

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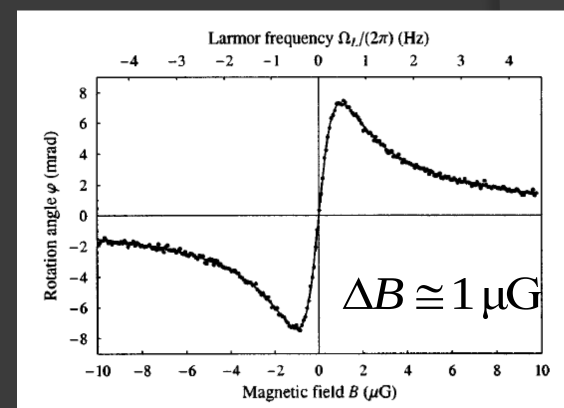
(Received 26 April 2000; published 11 September 2000)

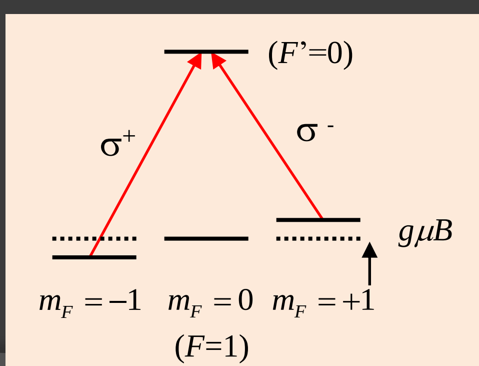
Application of nonlinear magneto-optical (Faraday) rotation to magnetometry is investigated. Our experimental setup consists of a modulation polarimeter that measures rotation of the polarization plane of a laser beam resonant with transitions in Rb. Rb vapor is contained in an evacuated cell with antirelaxation coating that enables atomic ground-state polarization to survive many thousan[…] rrow features ($\sim 10^{-6}$ G) in the magnetic-field dependence of optical […]s scheme to sub-μG magnetic fields as a function of atomic density, light intensity, and light frequency is investigated near the $D1$ and $D2$ lines of ^{85}Rb. It is shown that through an appropriate choice of parameters the shot-noise-limited sensitivity to small magnetic fields can reach 3×10^{-12} G/$\sqrt{\text{Hz}}$.

$$\delta B \sim 10^{-12}\ \text{G}/\sqrt{\text{Hz}}$$

$$\varphi = \frac{\dfrac{2g_F\mu_B B_z}{\gamma_0}}{1+\left(\dfrac{2g_F\mu_B B_z}{\gamma_0}\right)^2}\frac{l}{2l_0}$$

$$\delta B = \left(\frac{d\phi}{dB_z}\right)^{-1}_{B_z=0}\delta\phi$$





G.S.

$$|+\rangle = \frac{1}{\sqrt{2}}\left(|m_F=+1\rangle + |m_F=-1\rangle\right)$$

$$|-\rangle = \frac{1}{\sqrt{2}}\left(|m_F=+1\rangle - |m_F=-1\rangle\right)$$

$$|0\rangle = |m_F=0\rangle$$

Narrow line width (reducing spin relaxation)
Operation at **room temperature**
Operation at **geophysical field range** (mG~G)
(by using modulation of laser property)

NMOR setup

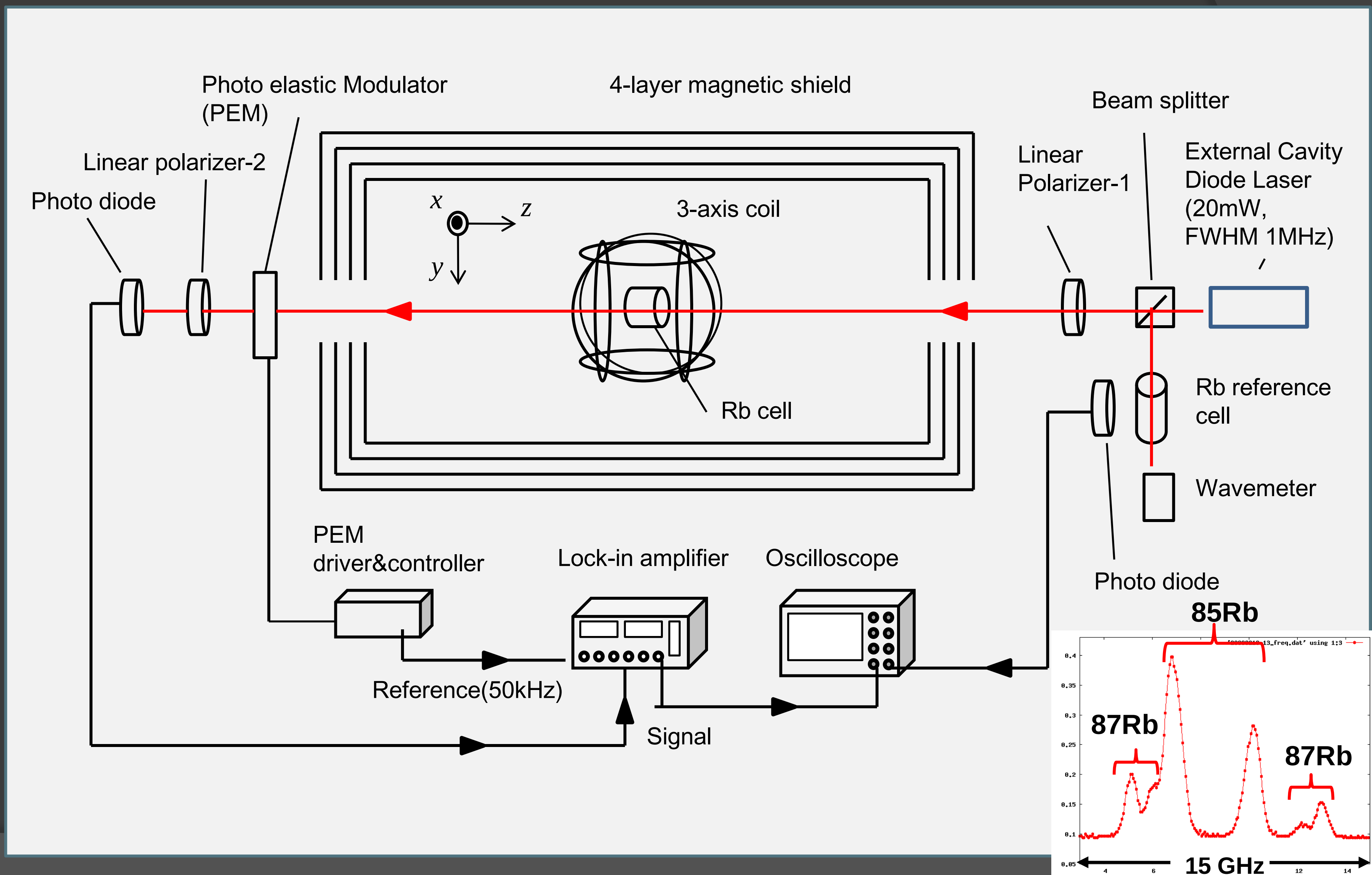
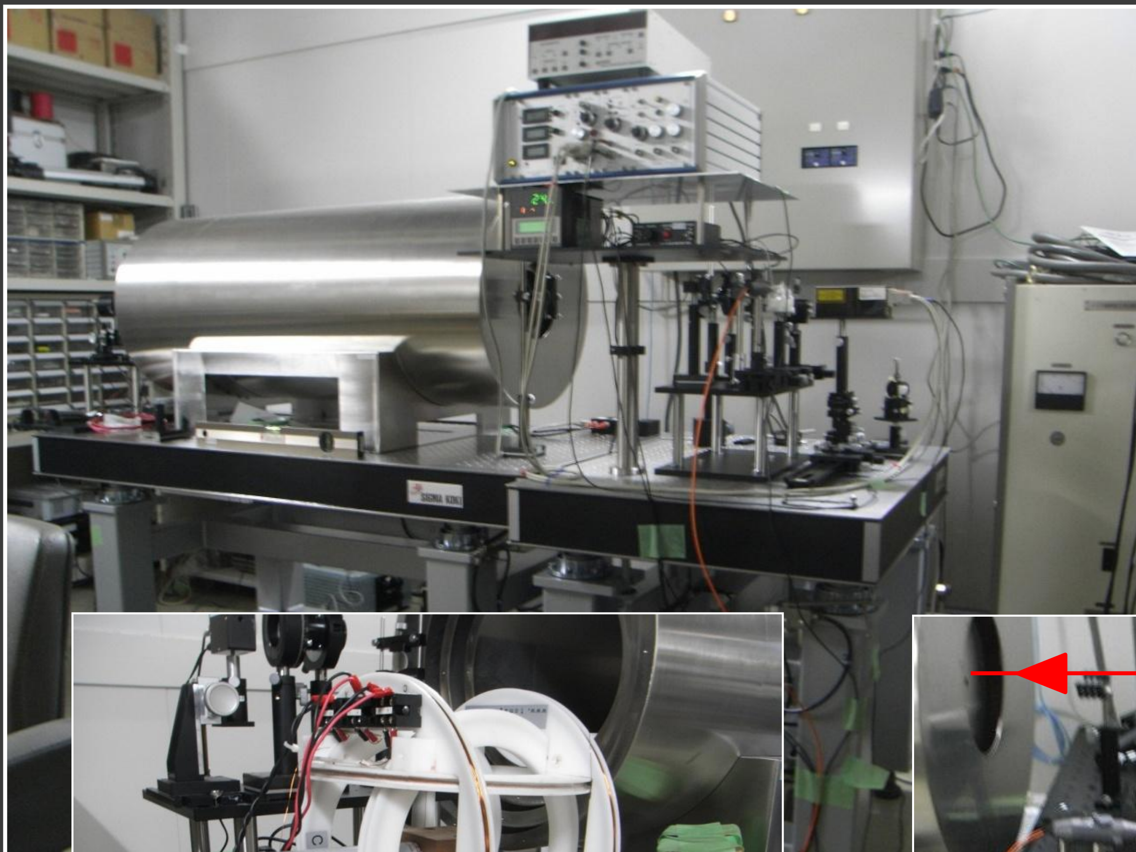
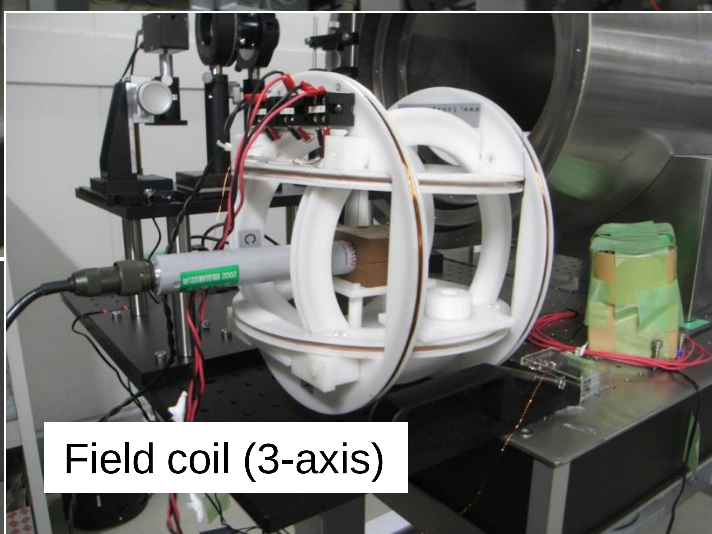
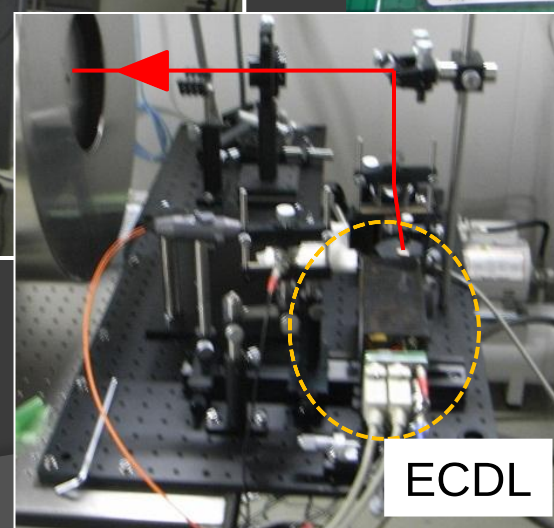


Photo elastic Modulator
(PEM)
4-layer magnetic shield
Beam splitter
Linear polarizer-2
Photo diode
Linear
Polarizer-1
External Cavity
Diode Laser
(20mW,
FWHM 1MHz)
x
z
y
3-axis coil
Rb cell
Rb reference
cell
Wavemeter
PEM
driver&controller
Lock-in amplifier
Oscilloscope
Photo diode
Reference(50kHz)
Signal
85Rb
87Rb
87Rb
15 GHz

Setup, Rb cell

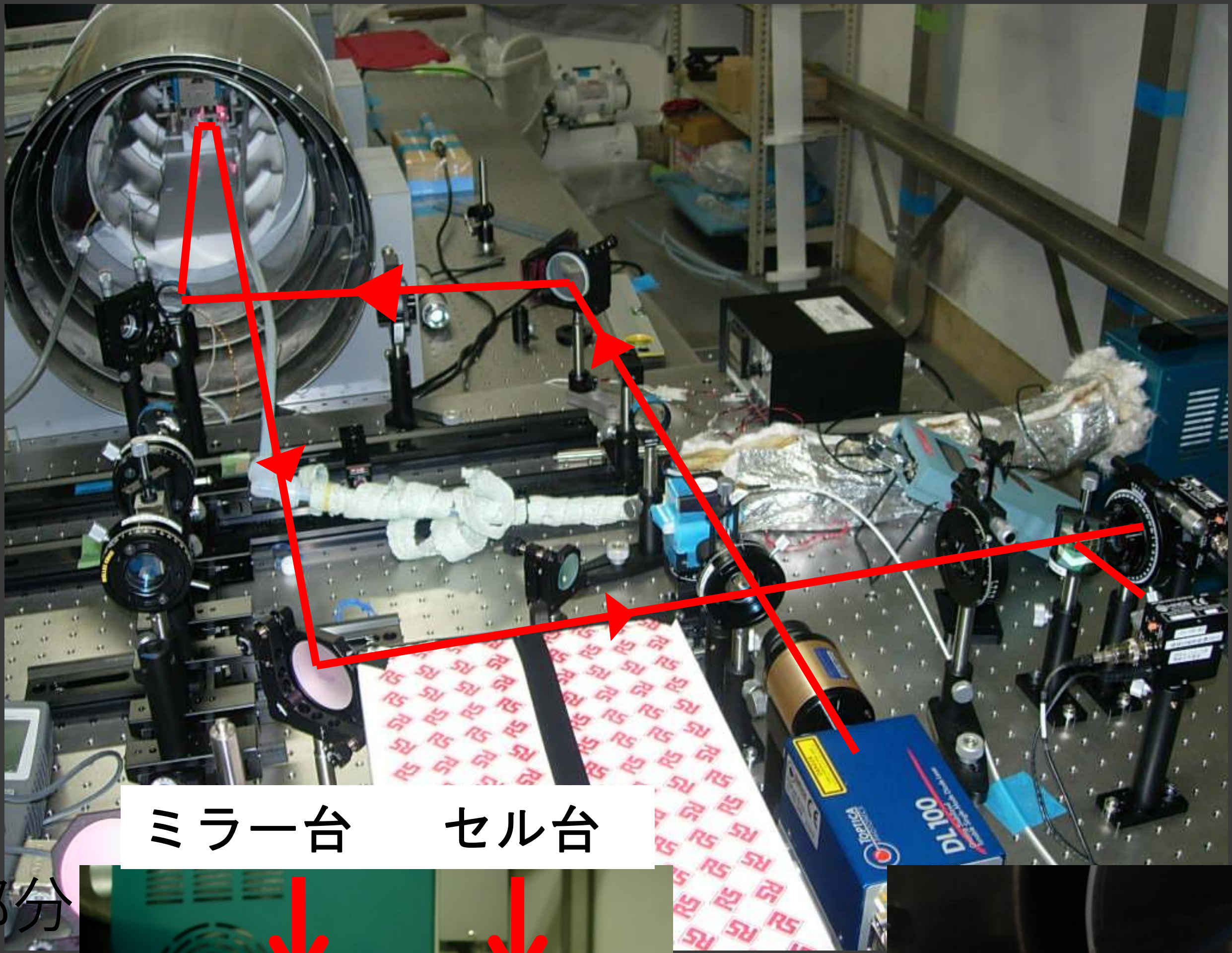




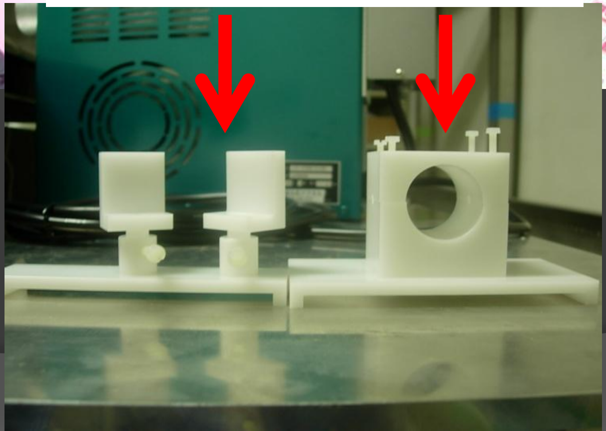


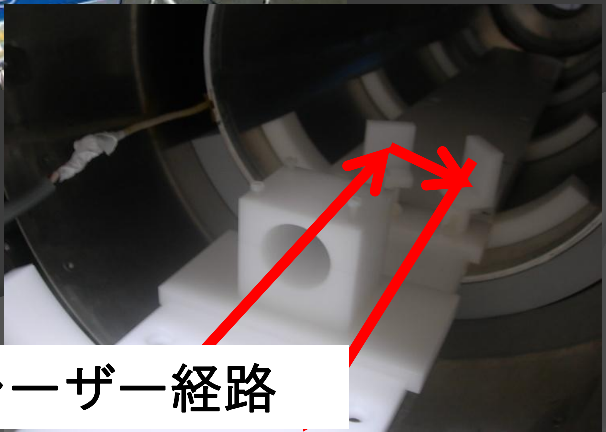
Rb cell with Paraffin coating:
commercial paraffin mixture
(Paraflint) $(CH_2)n$

セットアップ移動：　理研→東工大 (Xe maser setup へのインストール)

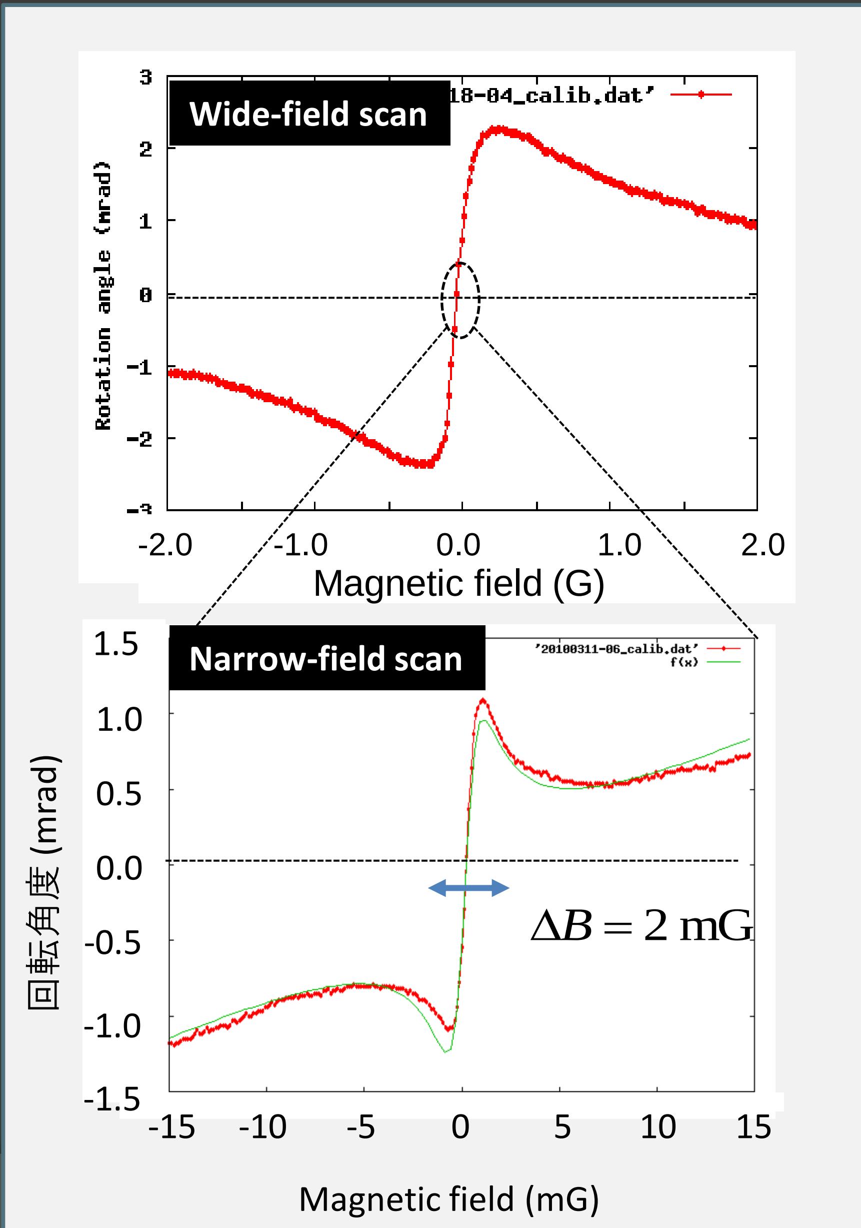


セル部分





NMOR spectrum

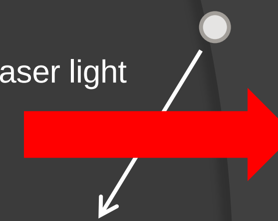


Dispersive function

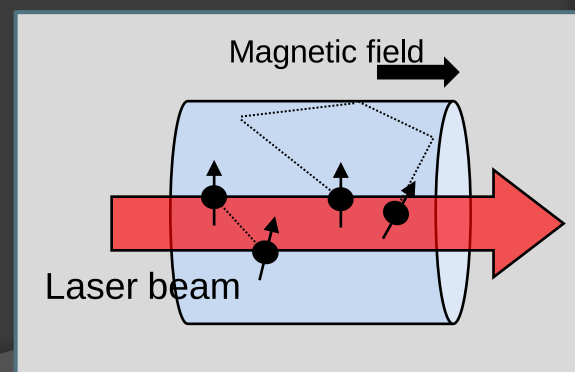
$$\varphi = \frac{\dfrac{2g_F \mu_B B_z / \hbar}{\gamma}}{1 + \left(\dfrac{2g_F \mu_B B_z / \hbar}{\gamma}\right)^2} \frac{l}{2l_0}$$

$$\gamma = 2\pi \times (6.43 \pm 0.03) \times 10^4 \left[\mathrm{s}^{-1}\right]$$

$$\Delta t = 1.25 \times 10^{-5}\ \mathrm{s}$$



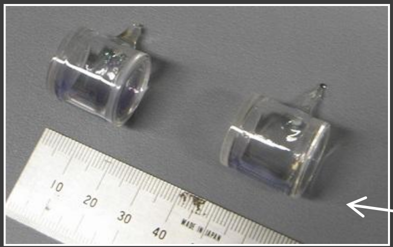
Preservation of atomic spin coherence at wall-collision



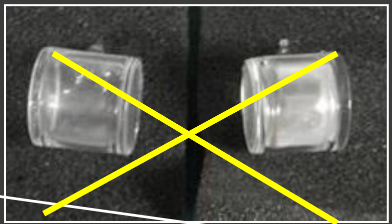
$$(\gamma / 2\pi)^{-1} = \frac{1}{1.65 \times 10^2 [\mathrm{s}^{-1}]} = 6.1 [\mathrm{ms}]$$

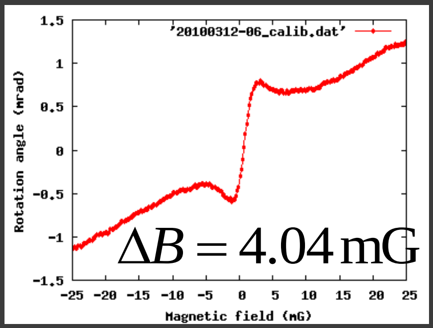
NMOR width (Cell dependence and residual field)

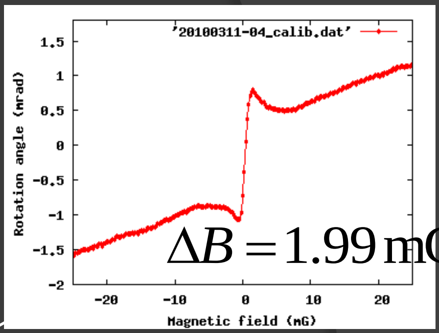
2009

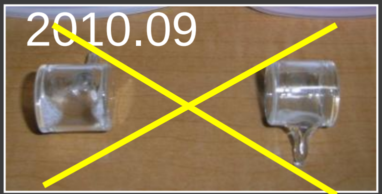


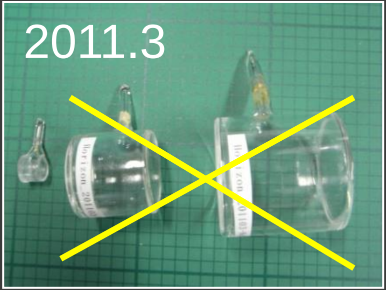
2010.07

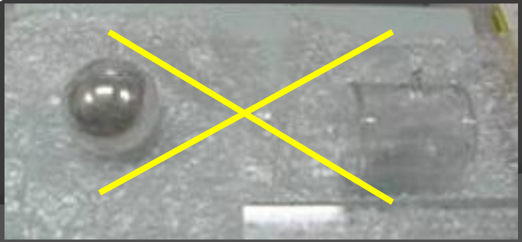








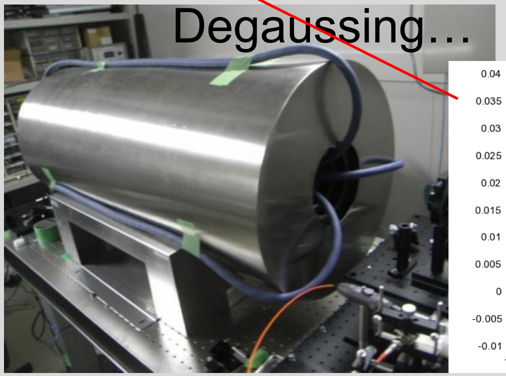


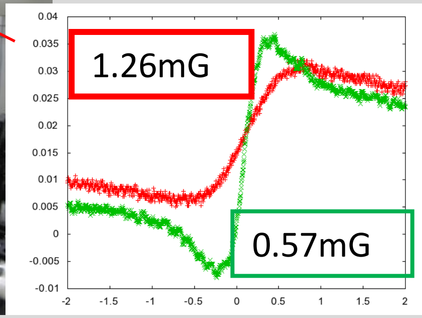


Residual magnetic field

$$\begin{cases} B_x = -235\ \mu\mathrm{G} \\ B_y = -237\ \mu\mathrm{G} \\ B_z = -13\ \mu\mathrm{G} \end{cases} \Rightarrow \begin{array}{l} B_x = -84\ \mu\mathrm{G} \\ B_y = +4\ \mu\mathrm{G} \\ B_z = -45\ \mu\mathrm{G} \end{array}$$

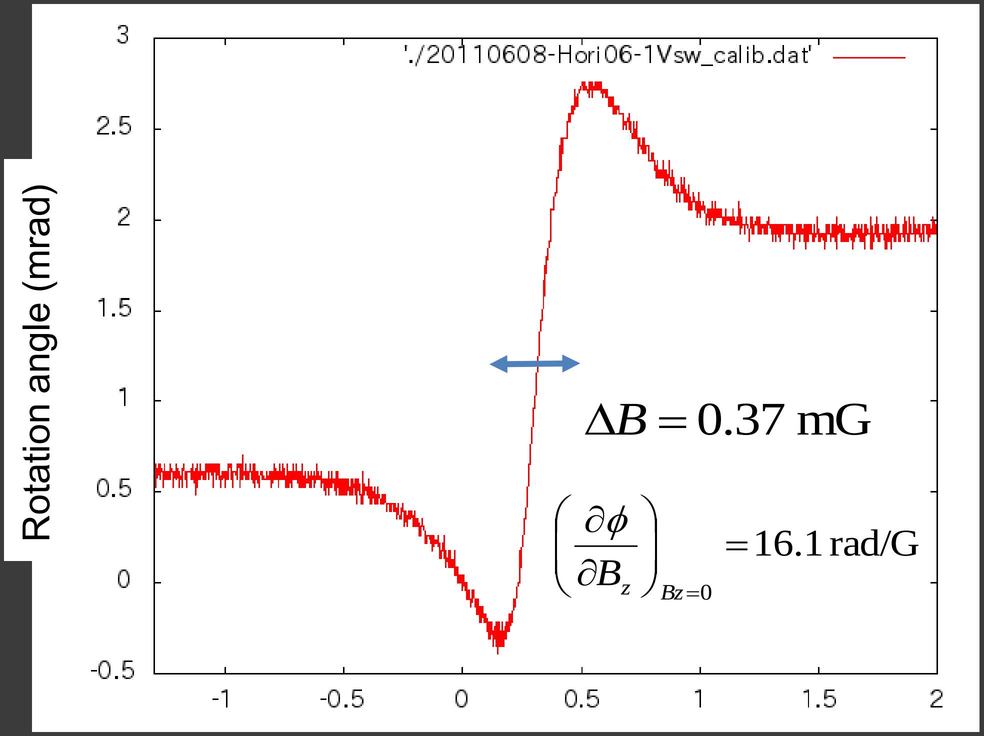
Degaussing…





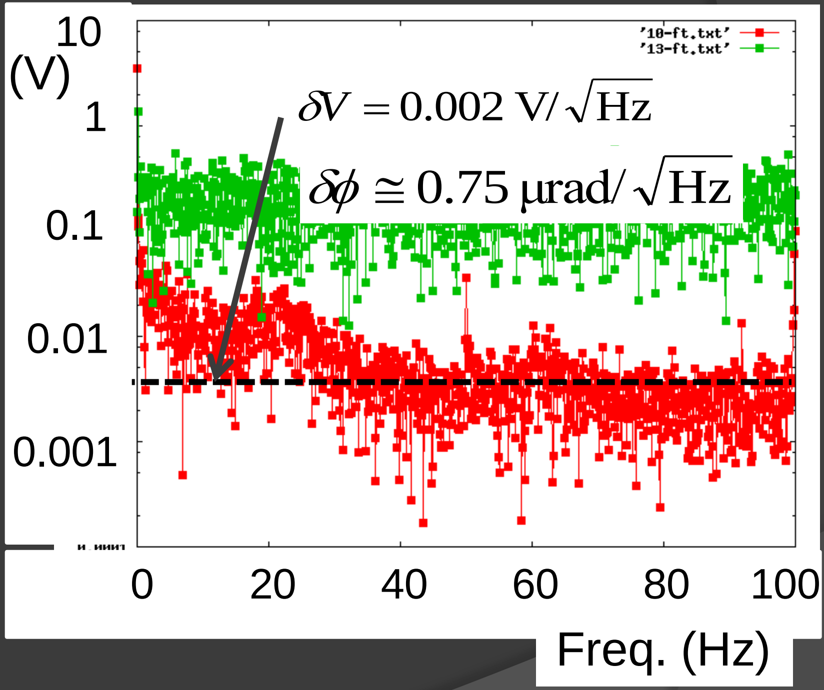
Magnetic sensitivity

NMOR spectrum



Magnetic field (mG)

Noise spectrum

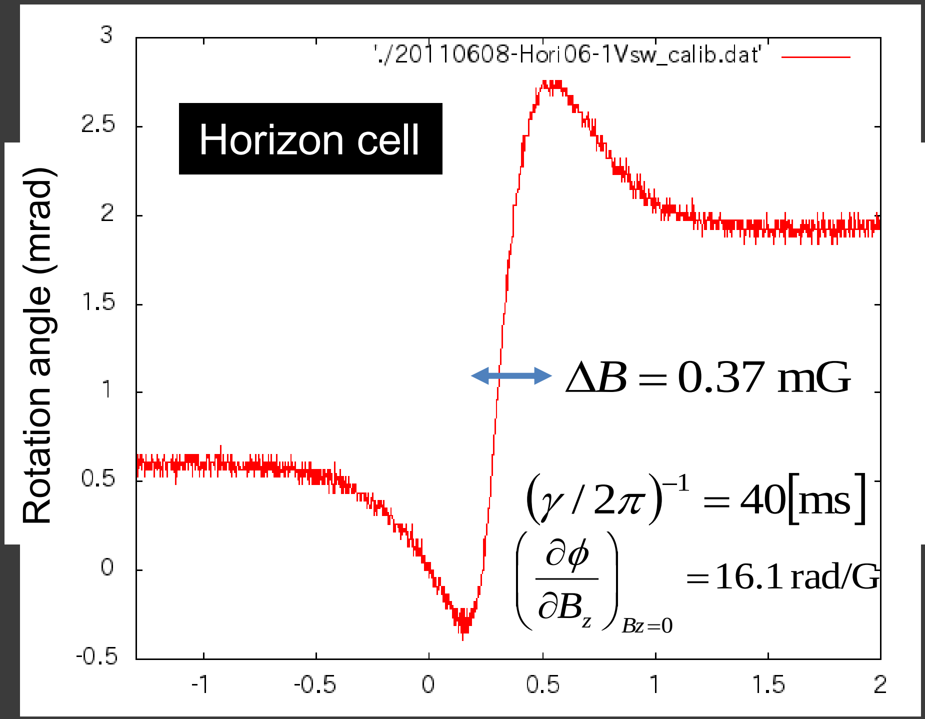


$$\delta B = \frac{7.5\times10^{-7}}{16.1} = 4.7\times10^{-8}\left[\text{G}/\sqrt{\text{Hz}}\right] \cong 50\ \text{nG}/\sqrt{\text{Hz}}$$

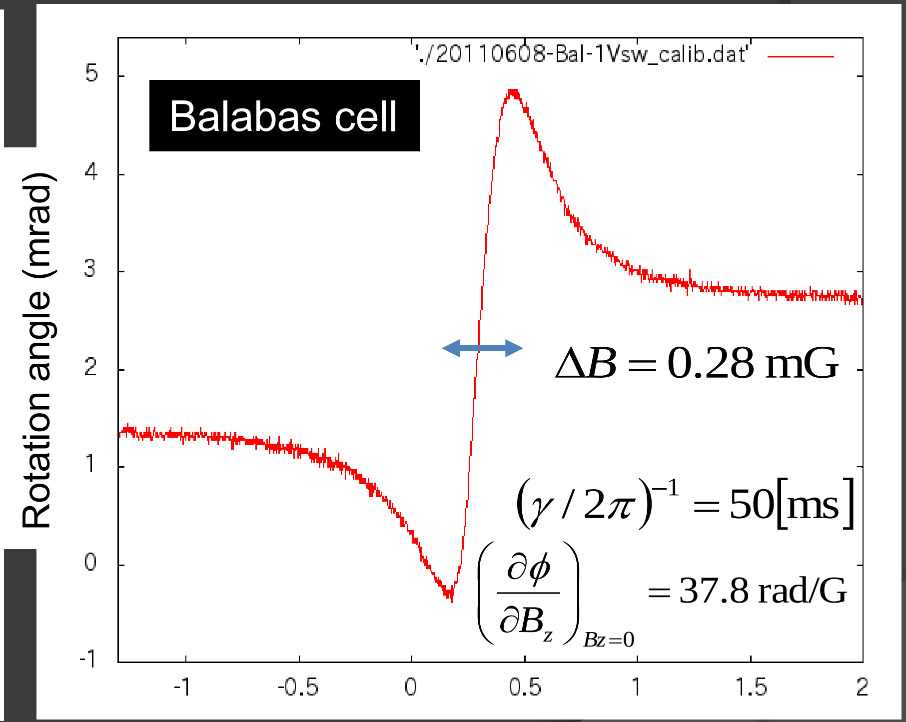
Shot noize limit: ~ O(1nG)

The cell made by Prof. M.V. Balabas : φ60 mm, T1 ~2s.

Thanks to Prof. Hatakeyama



Magnetic field (mG)



Magnetic field (mG)

No large difference in NMOR width

→ Wall performance does not limit the width → residual field…

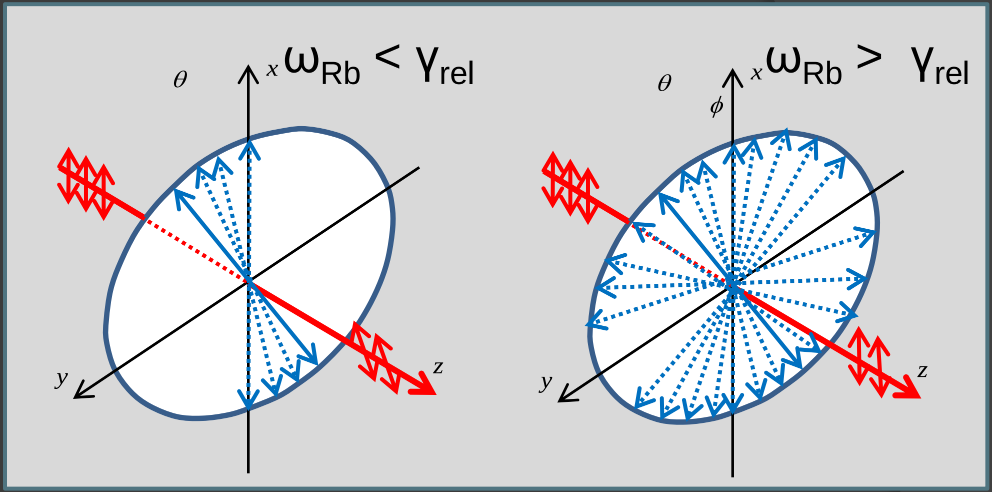
Modulated NMOR - measurement at B0 ~ 10 mG -

NMOR : measurement around B=0[G]

At higher magnetic field, optical rotation does not appear

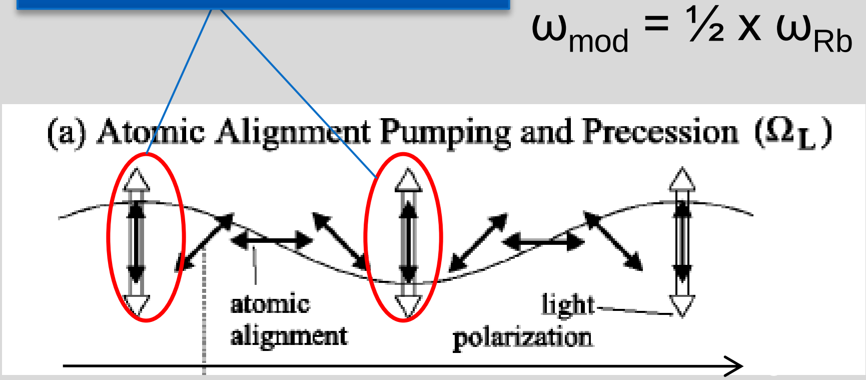
$\omega_{Rb} > \gamma_{rel}$

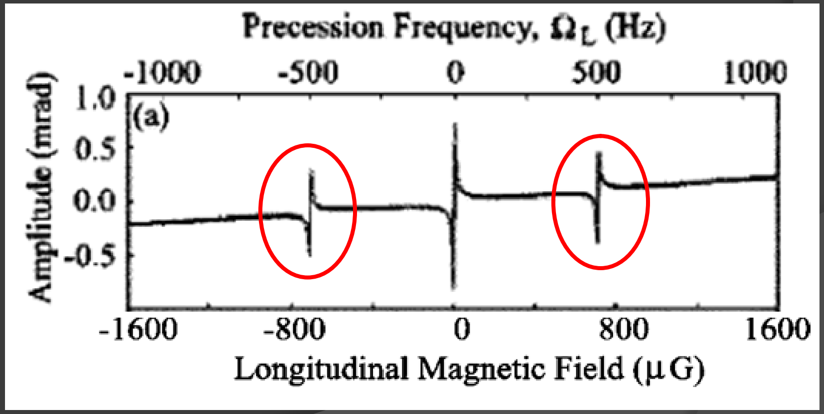
Modulated NMOR



Production of alignment

$\omega_{mod} = ½ \times \omega_{Rb}$



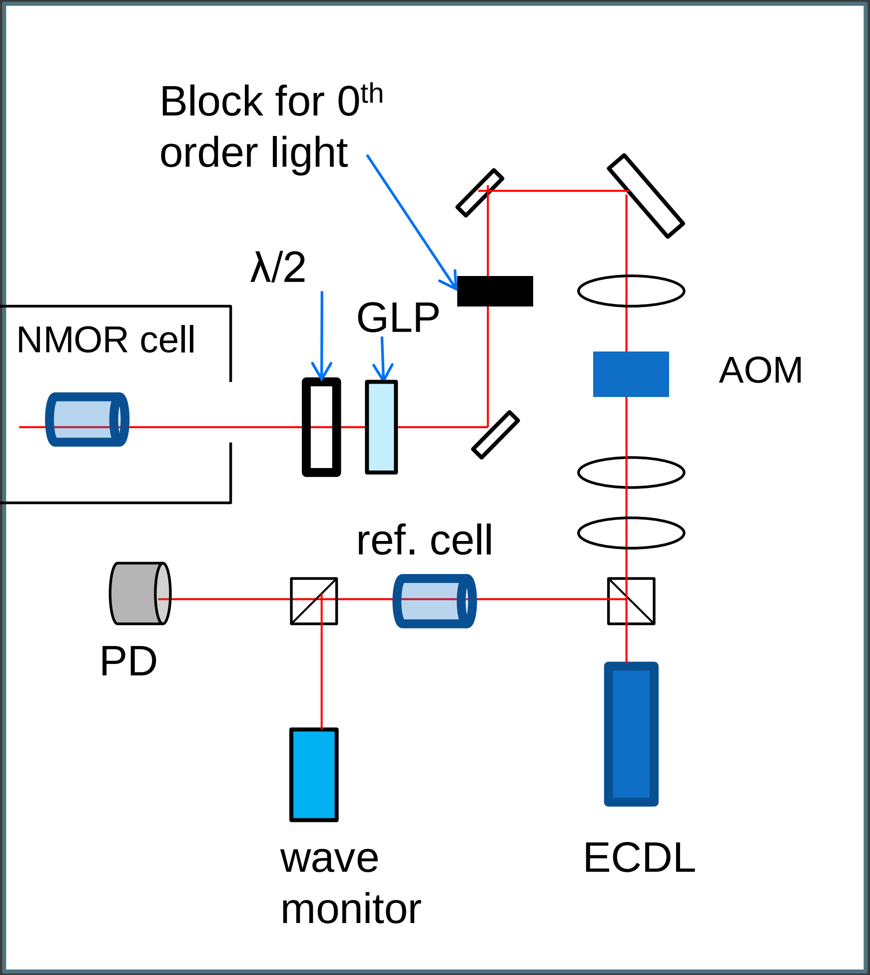


$\delta B = 4.3\times10^{-9}$

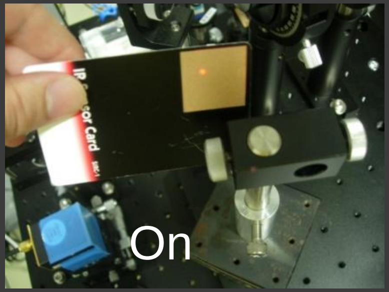
- Frequency modulated
- Amplitude modulated

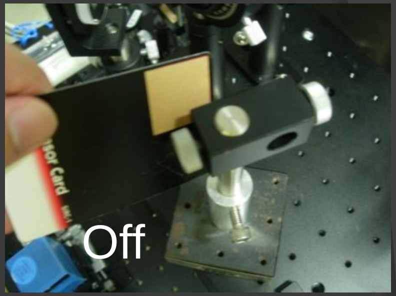
Pustelny *et al*. J.Appl.Phys. 103, 063108(2008)

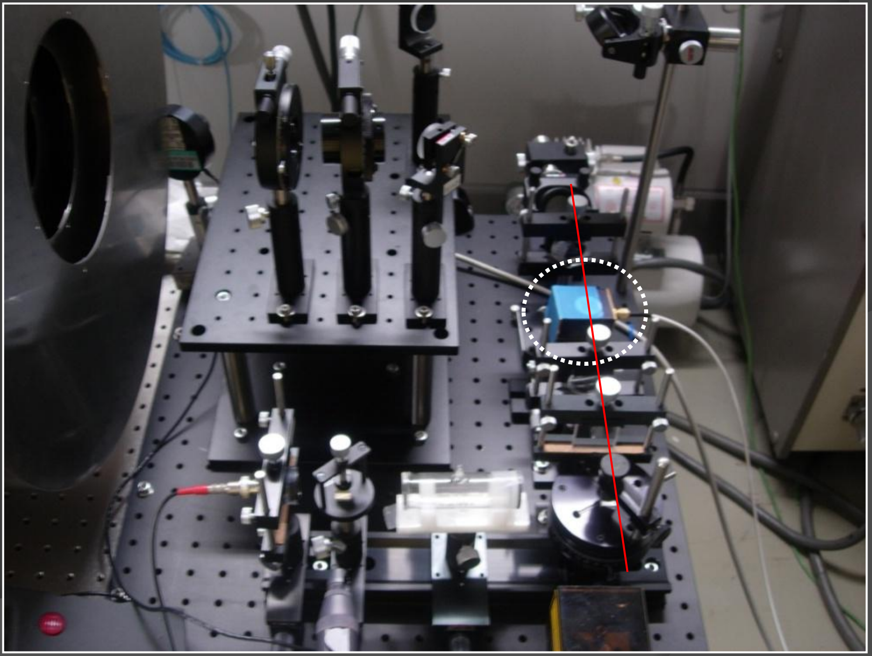
Setup - measurement at B0 = 10 mG -



Amplitude modulation by using
AOM:(Acousto-Optical Modulator)







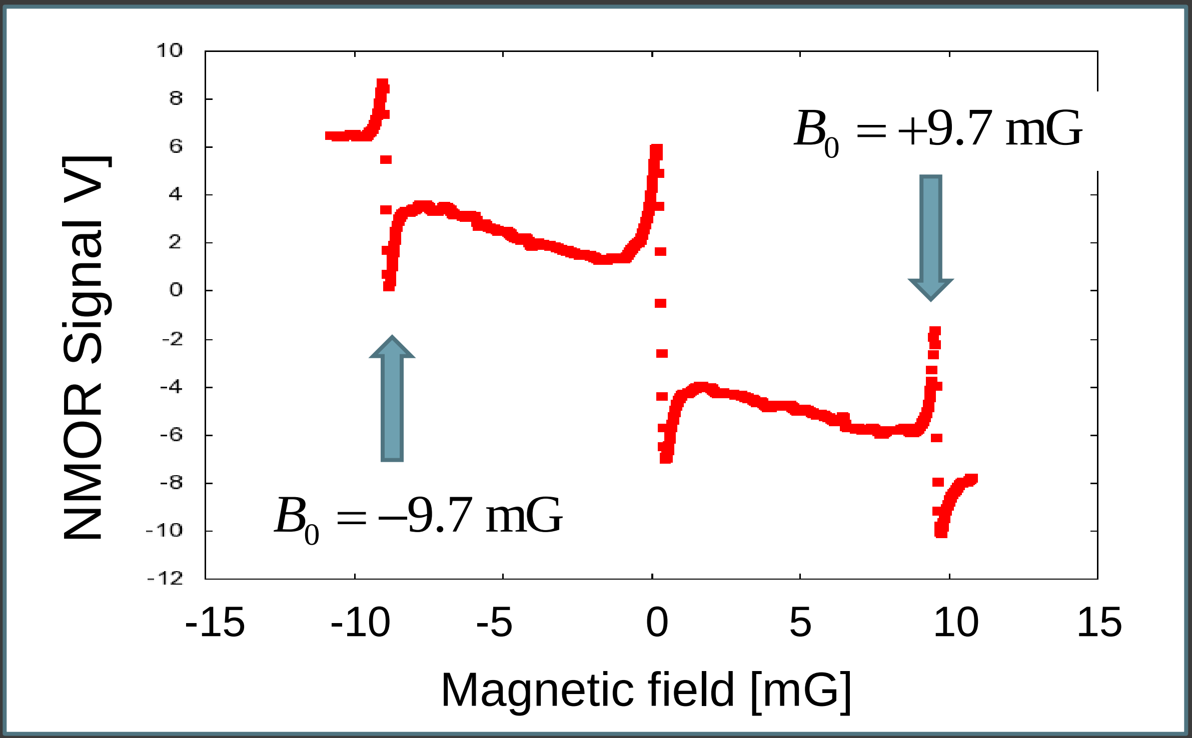
Spectrum - measurement at B0 = 10 mG -

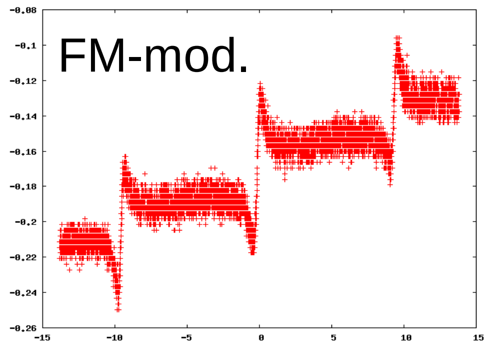
Modulation frequency : 9 kHz (AM)

corresponds to twice the Larmor freq. at B0 = 9.645mG

Magnetic field sweep: -11 mG → +11 mG

$$\nu_F = \frac{g_F \mu_B}{\hbar} = 461.7[\mathrm{kHz/G}] \Rightarrow 4.5000[\mathrm{kHz}]@9.7466\mathrm{mG}$$





Slope =53.5V/mG

Magnetic sensitivity (at present)

$$\delta B = \left(\frac{d\phi}{dB}\right)^{-1}_{B=0} \delta\phi = \frac{2\times 10^{-3}}{53.5\times 10^{3}} \approx 40\left[\mathrm{nG}/\sqrt{\mathrm{Hz}}\right]$$

Summary and Future

- High sensitive magnetometer is inevitable for atomic EDM experiments because main source of frequency stability comes from drifts of magnetic field (applied B_0 or environmental field).
- We have developed the Rb NMOR spectrometer for the operation of magnetometer.
- Operation of modulated NMOR for measurements at B0 = 10 mG.

- Improving NMOR-magnetometer performance;

  Optimization of degaussing procedure;
  Optimization of cancelling field (to << ΔB_z.)
  Improving cell-coating procedure.
  Checking the T1 for the Rb cells

  Noise studies; detection method, electronics, experimental room…

  Introduction to spin maser setup