DEVELOPMENT OF ULTRACOLD NEUTRON ACCELERATOR FOR TIME FOCUSING OF PULSED NEUTRONS

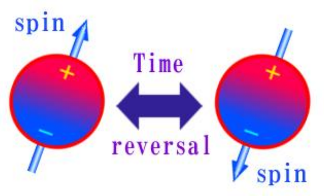
S. Imajo [A], Y. Iwashita [B], K. Mishima [C], M. Kitaguchi [D], H. M. Shimizu [D], T. Ino [C], S. Yamashita [E]

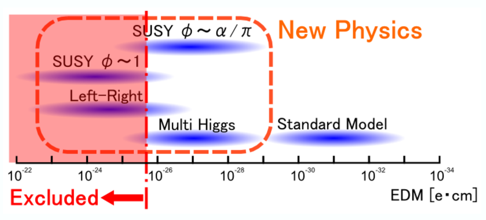
Dep. of Phys. Kyoto Univ. [A], ICR, Kyoto Univ. [B], KEK [C], Dep. of Phys. Nagoya Univ. [D], ICEPP, Univ. of Tokyo [E]

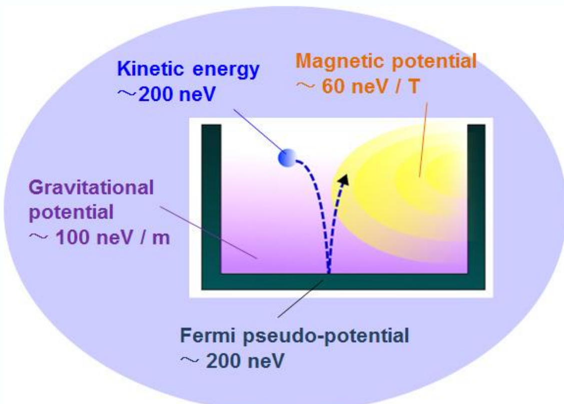
Abstract

Low energy neutron accelerator can be developed by the combination of an adiabatic fast passage spin flipper and a gradient magnetic field. Neutrons have magnetic moments, so that the accumulated potential energies they receive are not cancelled before and after passage of a magnetic field and their kinetic energies change finally in case their spins are flipped in the field. At present most measurements of the neutron electric dipole moment (nEDM) are carried out by storing ultracold neutrons (UCN), whose kinetic energies are lower than approximately 300 neV, in a small experimental bottle to reduce systematic errors. Therefore UCNs as dense as possible are required. Spallation neutron sources of low repetition frequency can generate extremely dense neutrons, however, the pulsed neutrons with several velocities are diffused in guide tubes under the long beam intervals. In order to time-focus such UCNs upon the bottle mouth by controlling their velocities and improve the storage density of UCNs at nEDM experiments in those facilities, we demonstrated the neutron accelerator. Currently we have developed the advanced version which makes it possible to handle broader kinetic energy range. The design and measured characteristics are described.

Electric dipole moment

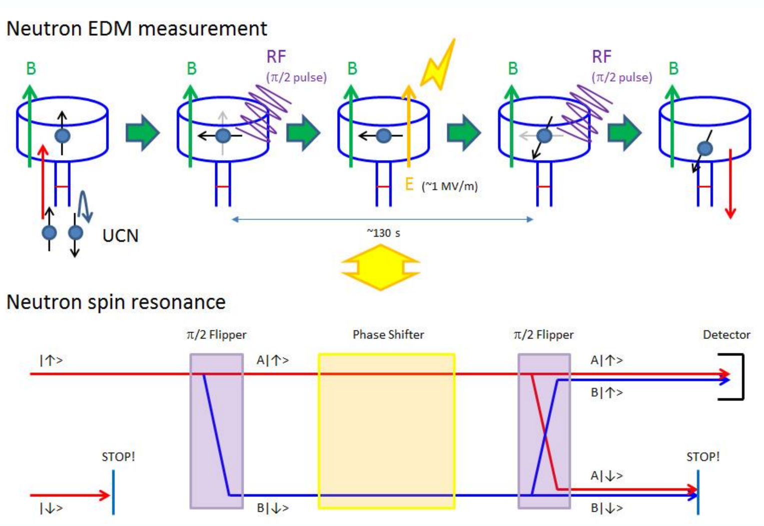




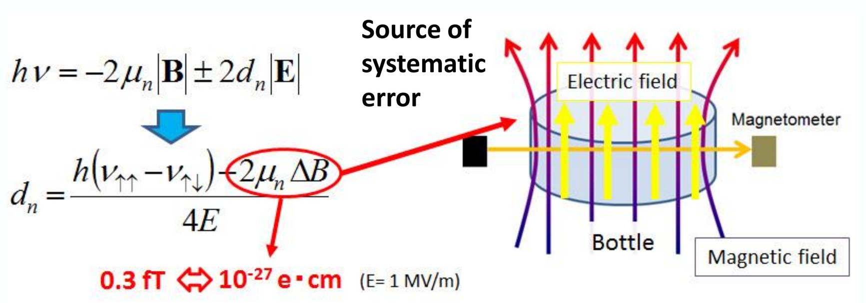


A non-zero neutron electric dipole moment (nEDM) implies the **breaking of time-reversal invariance** and the larger nEDM than the prediction of Standard model, which is 10^{-30} to 10^{-32} e・cm, is the evidence of new physics.

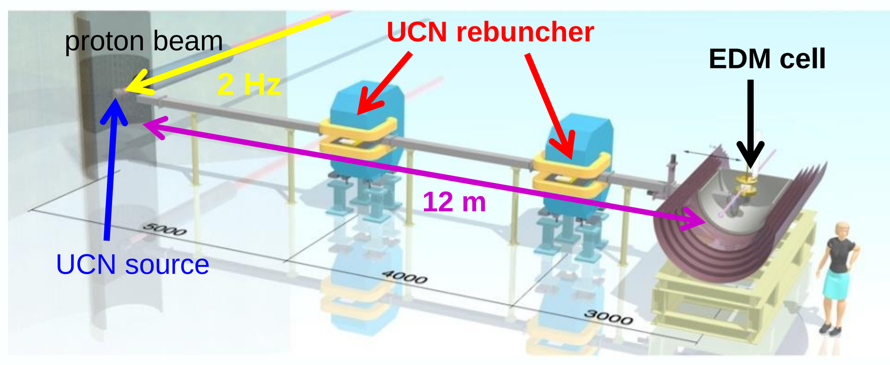
In nEDM experiment polarized ultracold neutron (**UCN**), whose kinetic energy is **100-200 neV**, is stored in an experimental bottle.



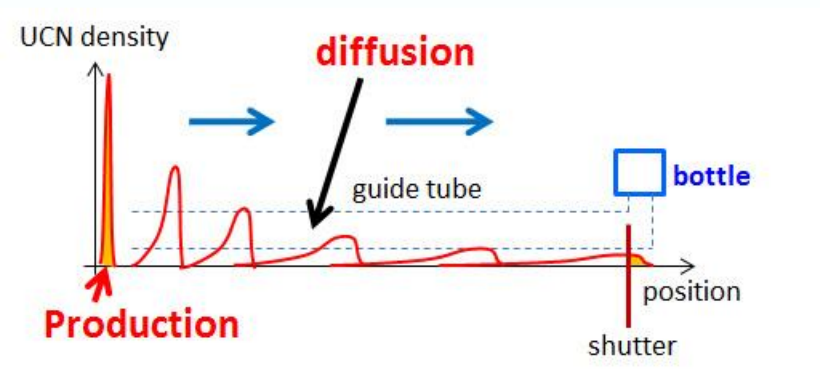
The bottle should be small in order to decrease the systematic error due to nonuniform electric and magnetic field, so that **highly dense UCN is required.**



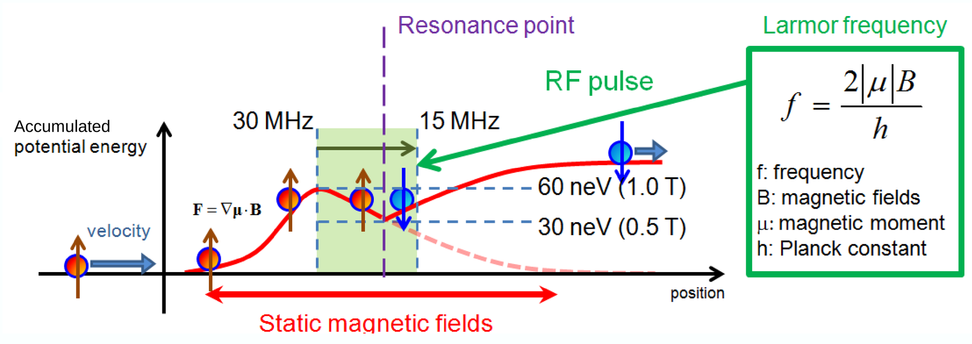
The 1st Rebuncher



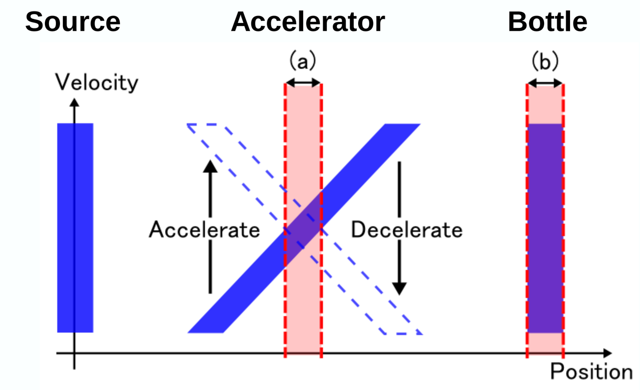
The setting of J-PARC P33



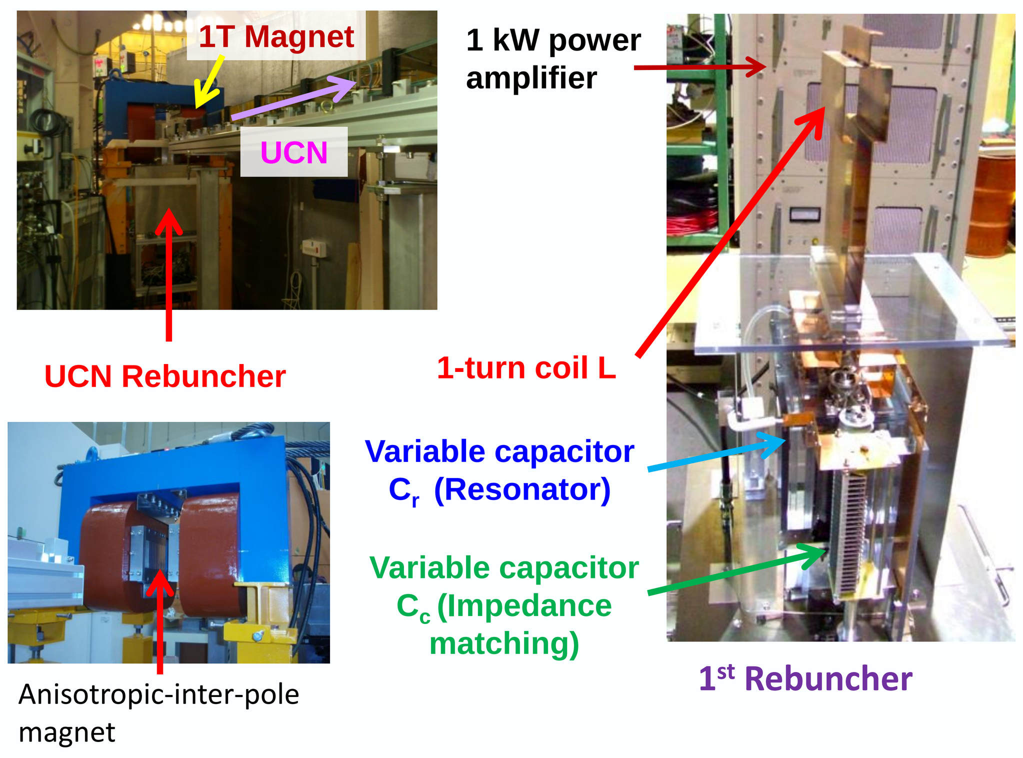
The UCNs produced with pulsed source are diffused during transport according to their own velocity distribution. In order to carry out nEDM experiments with pulsed source efficiently we developed UCN accelerator **(UCN rebuncher)**.

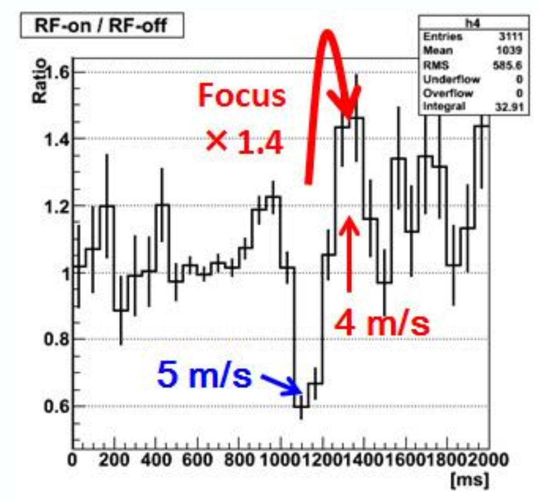


The principle of neutron acceleration



The distribution of neutrons in phase space





Phys. Rev. A **86**, 023843(2012)

We succeeded in focusing UCN.

Now we are developing the next version of this apparatus.

Present status of the 2nd Rebuncher

In order to improve the problems of thw 1st rebuncher we are developing the second rebuncher.

Problems

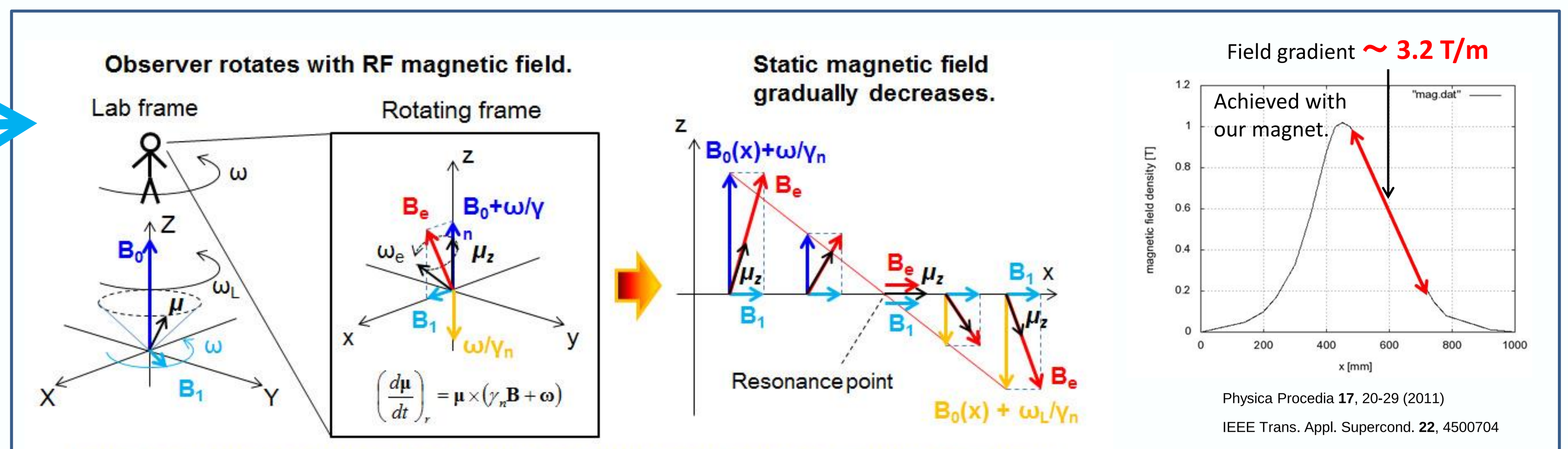
- The spin-flip ratio was ~0.5.
- RF sweep was mismatched with UCN arrival.
- RF frequency range was narrow. (17.5~28.6 MHz)

Goals

- Spin-flip ratio ~1.
- Matched.
- 6~30 MHz

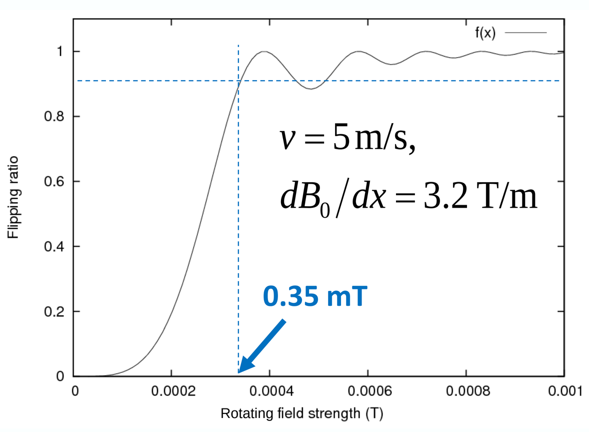
Energy control range : ±70~114 neV → ±24~120 neV

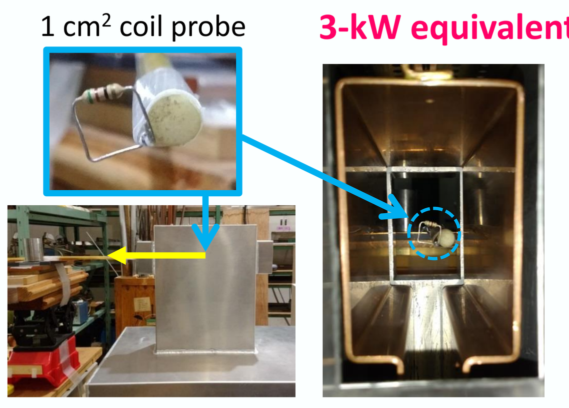
AFP-NMR

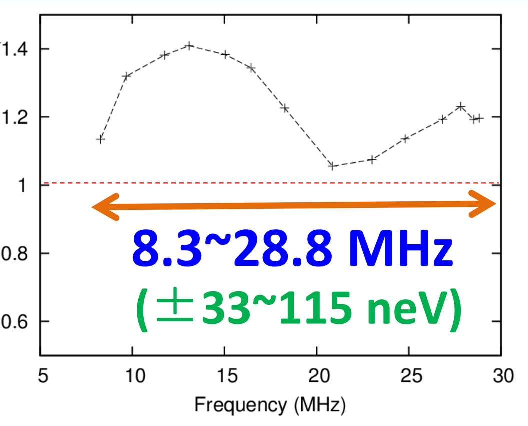


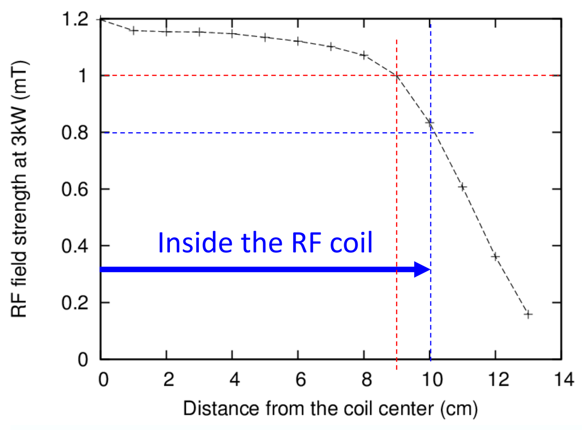
v : a neutron velocity
B_0 : static magnetic flux density
B_1 : rotating magnetic field strength
x : propagating direction of a neutron
γ_n : gyromagnetic ratio of a neutron

$$p = 1 - \frac{1}{1+k^2}\sin^2\left(\frac{\pi}{2}\sqrt{1+k^2}\right), \quad k = \frac{-\gamma_n B_1^2}{dB_e/dt} \geq \frac{-\gamma_n B_1^2}{dB_0/dt} = \frac{-\gamma_n B_1^2}{v\, dB_0/dx}$$

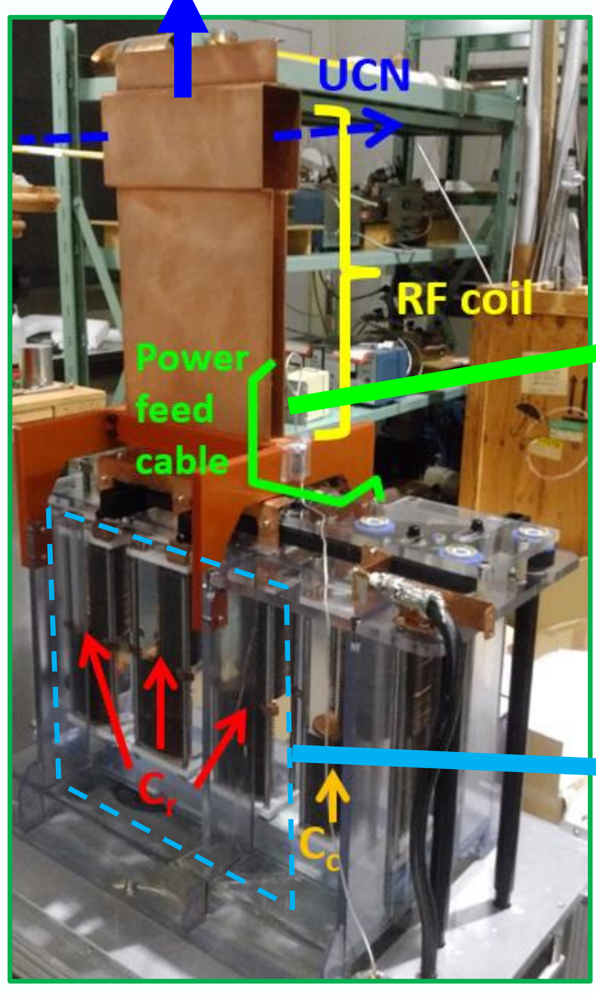




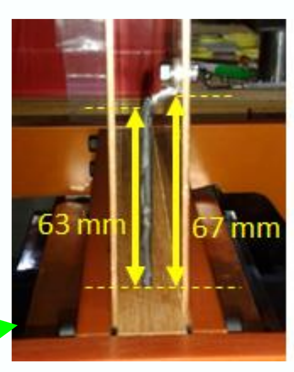




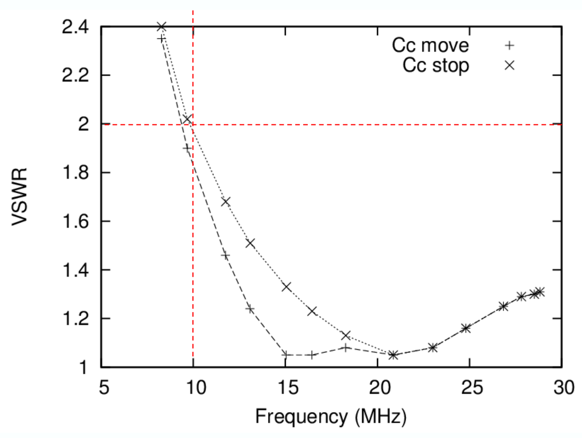
The RF field strength **more than 1 mT will be achieved** inside the approximately entire coil and at the whole frequency range. These were measured with **0.4W** input.



Present 2nd Rebuncher



Inductive matching

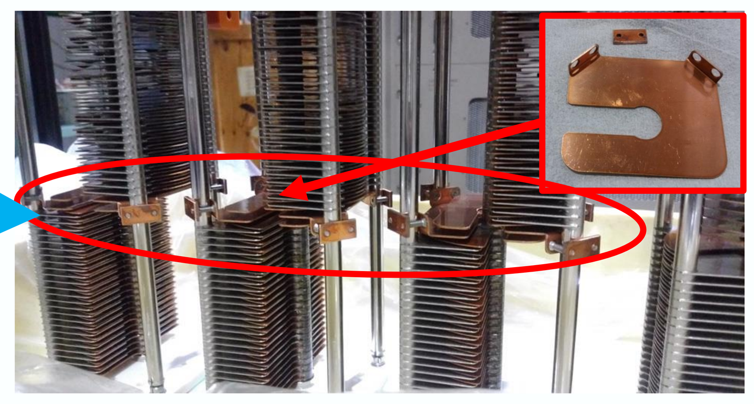


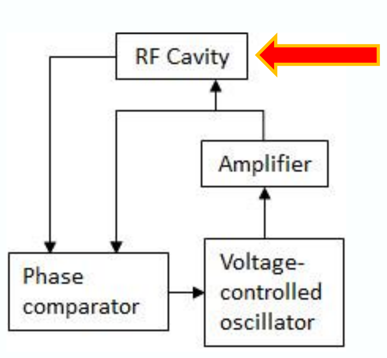
Γ : Voltage reflection coefficient

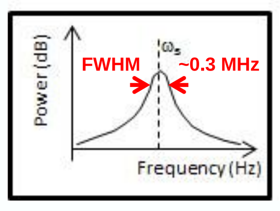
$$\mathrm{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Power reflection < 10%

The **VSWR is good** (under 2) at the frequencies more than 10 MHz.



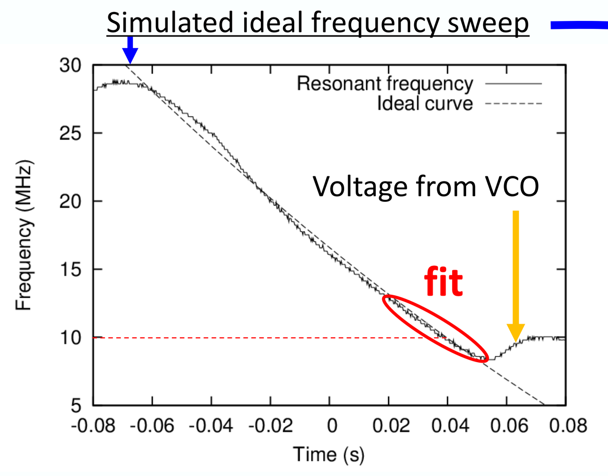




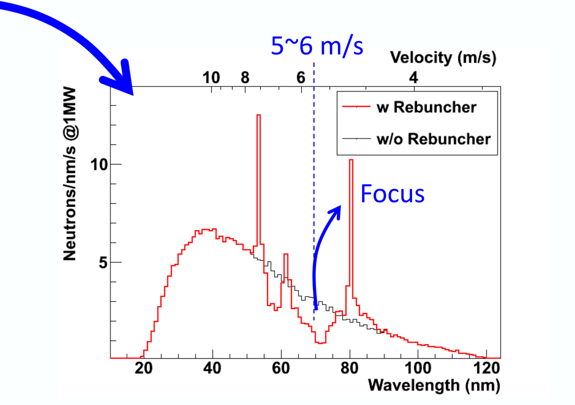
$$Z = \frac{R(1-\omega^2 LC) + i\omega(L+R^2C)}{(1-\omega^2 LC) + 2i\omega RC} \xrightarrow{\omega^2 = 1/LC} Z = \frac{L}{2RC} + \frac{R}{2}$$

The resonant frequencies were adjusted by increasing the capacitance and decreasing the inductance in order to increase the current.

Simulated ideal frequency sweep



The ideal and real RF sweeping curve



(An example. Not the final result.)

Since the resonant frequency is proportional to $C^{-1/2}$, the angular velocity rapidly increases for realizing a linearly decreasing frequency curve. Therefore, **the ideal curve in the range more than 10 MHz can be realized** by fine-tuning the motion of the motors.

The second rebuncher is near completion!

This research was partially supported by Ministry of Education, Science, Sports, and Culture Grants-in-Aid for Scientific Research (A) 23244047 and (A) 26247035, and by the JSPS, Grant No. 23360428, and approved by the Neutron Scattering Program Advisory Committee of IMSS, KEK (Proposal No. 2009S03 and 2014S03).