Accelerator/Decelerator of Slow Neutrons

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Collaboration

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and

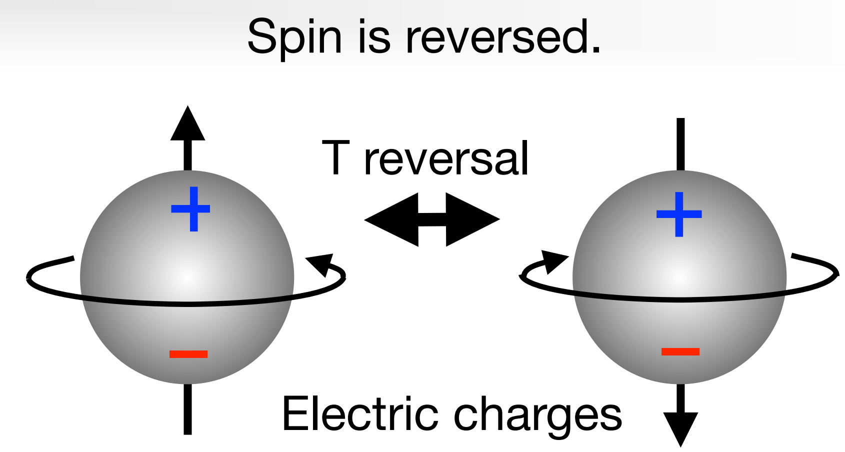
NOP collaboration (Neutron Optics and Physics)

fot nuclear & particle physics using neutrons.

Contents

Motivation Neutron EDM

Neutron Electric Dipole Moment (nEDM) signals the violation of time-reversal (T) invariance.

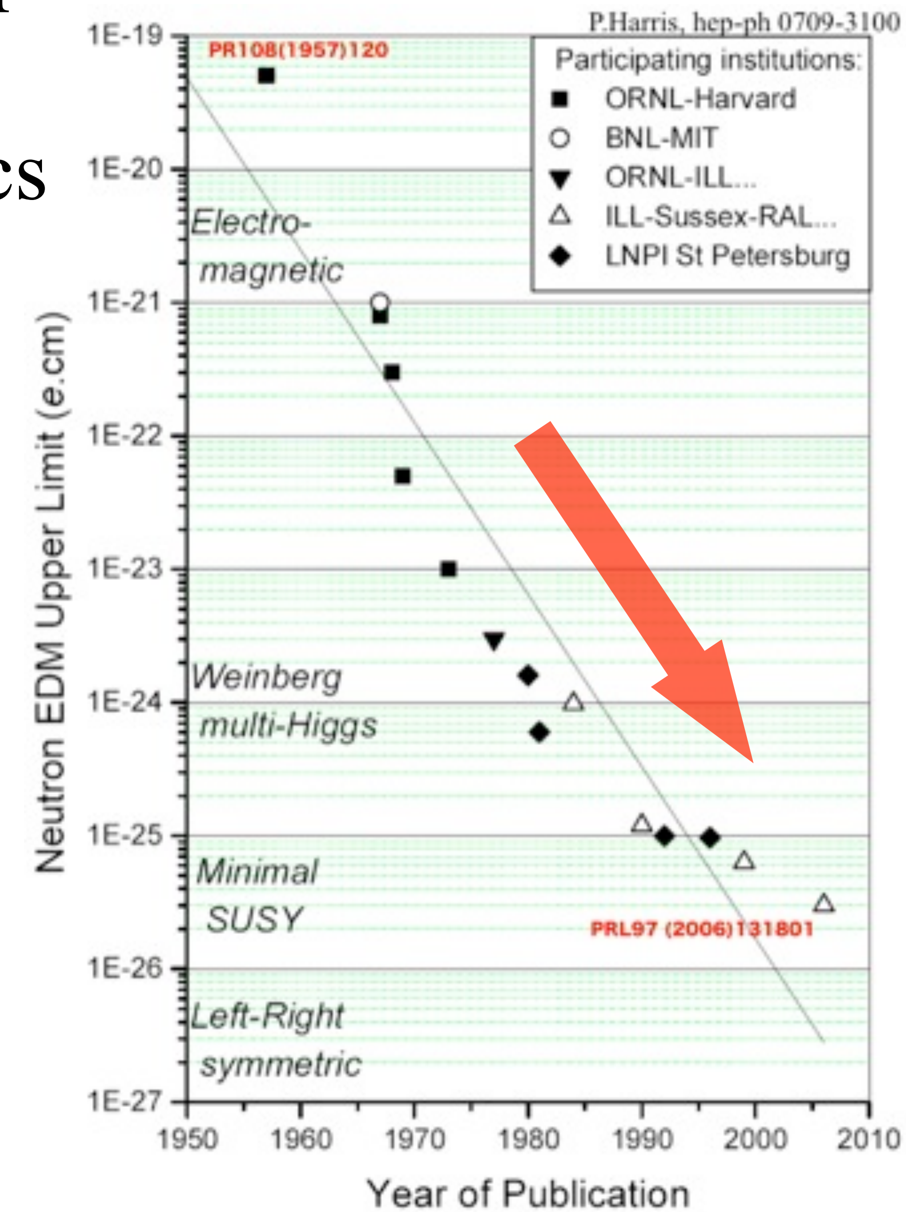


Present upper limit $|d_n| < 2.9 \times 10^{-26}\ e\ \mathrm{cm}$

is approaching to the predictions of some physics beyond the standard model of particle physics.

Standerd Model : $|d_\mathrm{n}| \sim 10^{-32}\ e\ \mathrm{cm}$

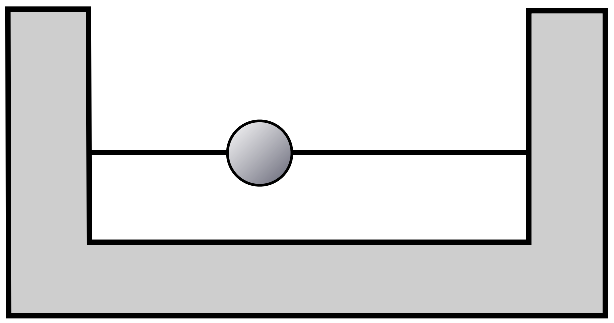
New Physics (SUSY ...) : $|d_\mathrm{n}| \sim 10^{-27 \sim -28}\ e\ \mathrm{cm}$



More precisely !

Motivation UCN

Very slow neutrons (Ultra Cold Neutrons : UCNs) can be stored in bottle by reflections off the material wall.

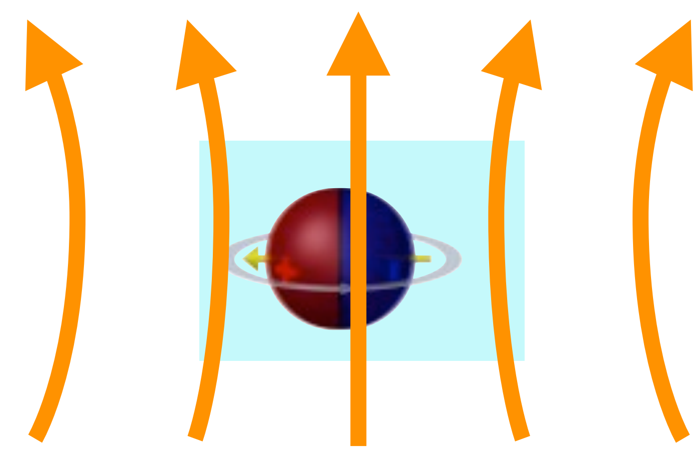


UCNs : energy < 200 neV
velocity < 7 m/s

Change of precession frequency according to the direction of electric field is measured.

$$\frac{\omega_\pm}{2\pi} = \boxed{3 \times 10^1 \frac{B}{1\mu T}} \pm \boxed{5 \times 10^{-8} \frac{d_n}{10^{-26}\mathrm{e}\cdot\mathrm{cm}} \frac{E}{10\mathrm{kV/cm}}}$$

1 μT **1fT equiv.**

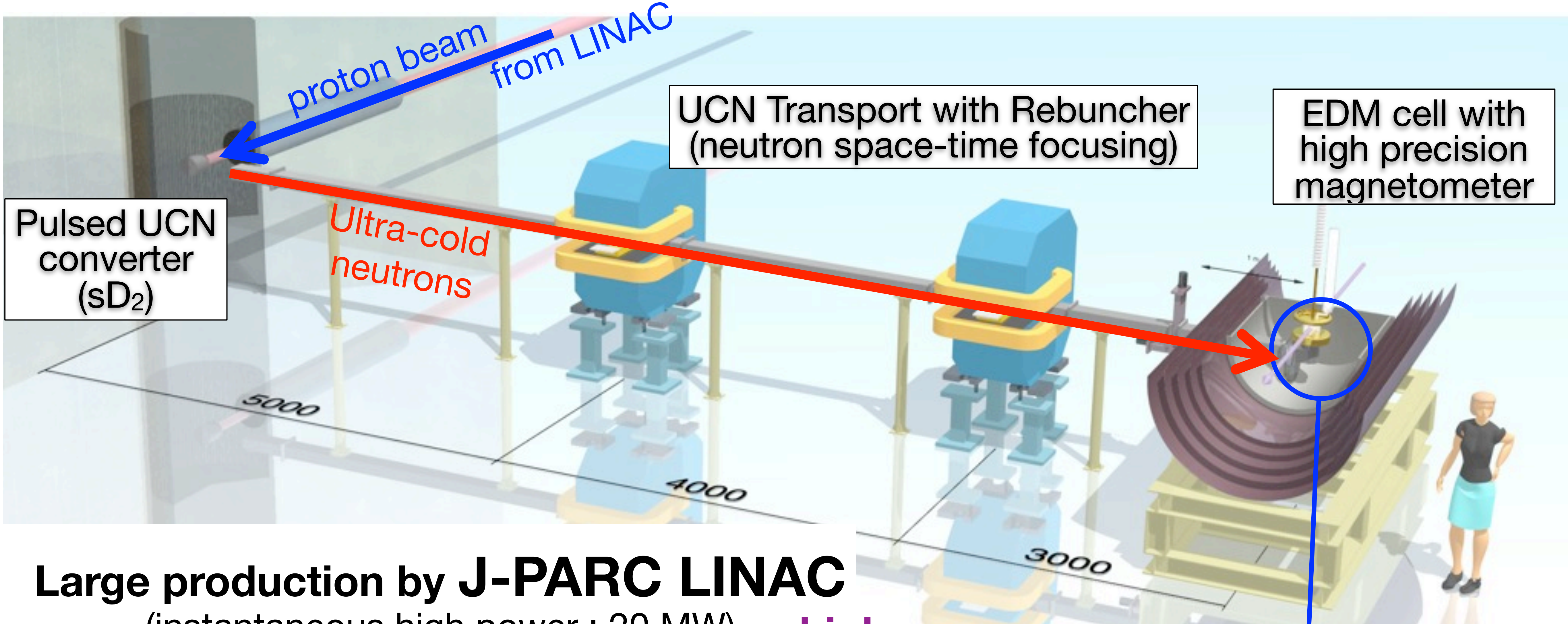


Small storage area is better.

Neutron density is important to reduce the systematic errors.

More Dense UCNs !

Motivation nEDM at J-PARC (P33)



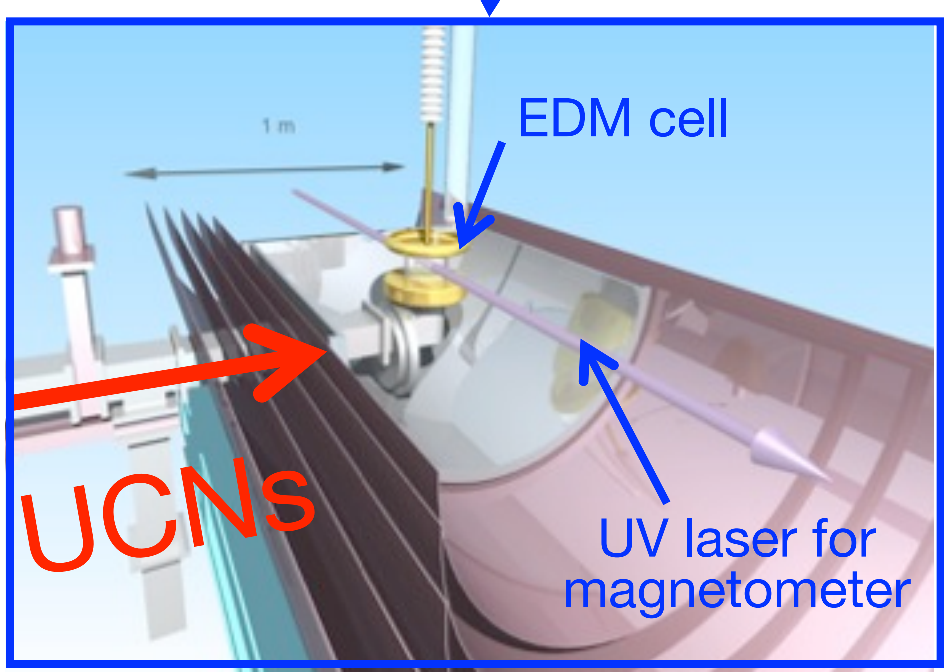
Large production by J-PARC LINAC
(instantaneous high power : 20 MW)
\+
Transport optics
(focusing with pulsed neutron decelerator)
\+
High precision measurement
(magnetometer using UV laser)

high density

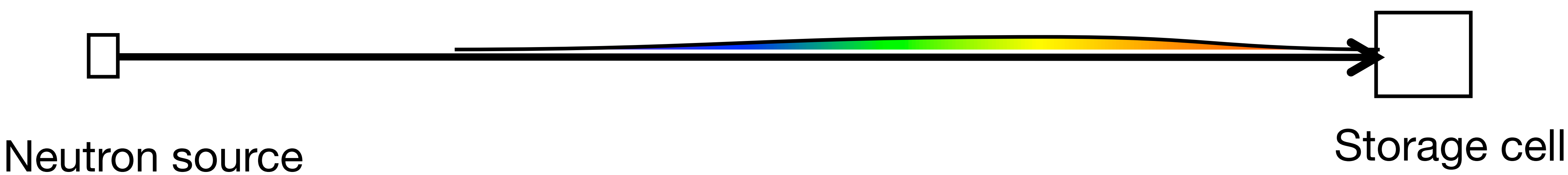
small systematic errors

⇨ **10^{-27} e cm (phase1, 5 years)**

⇨ **10^{-28} e cm (phase2)**



Motivation nEDM at J-PARC (P33)



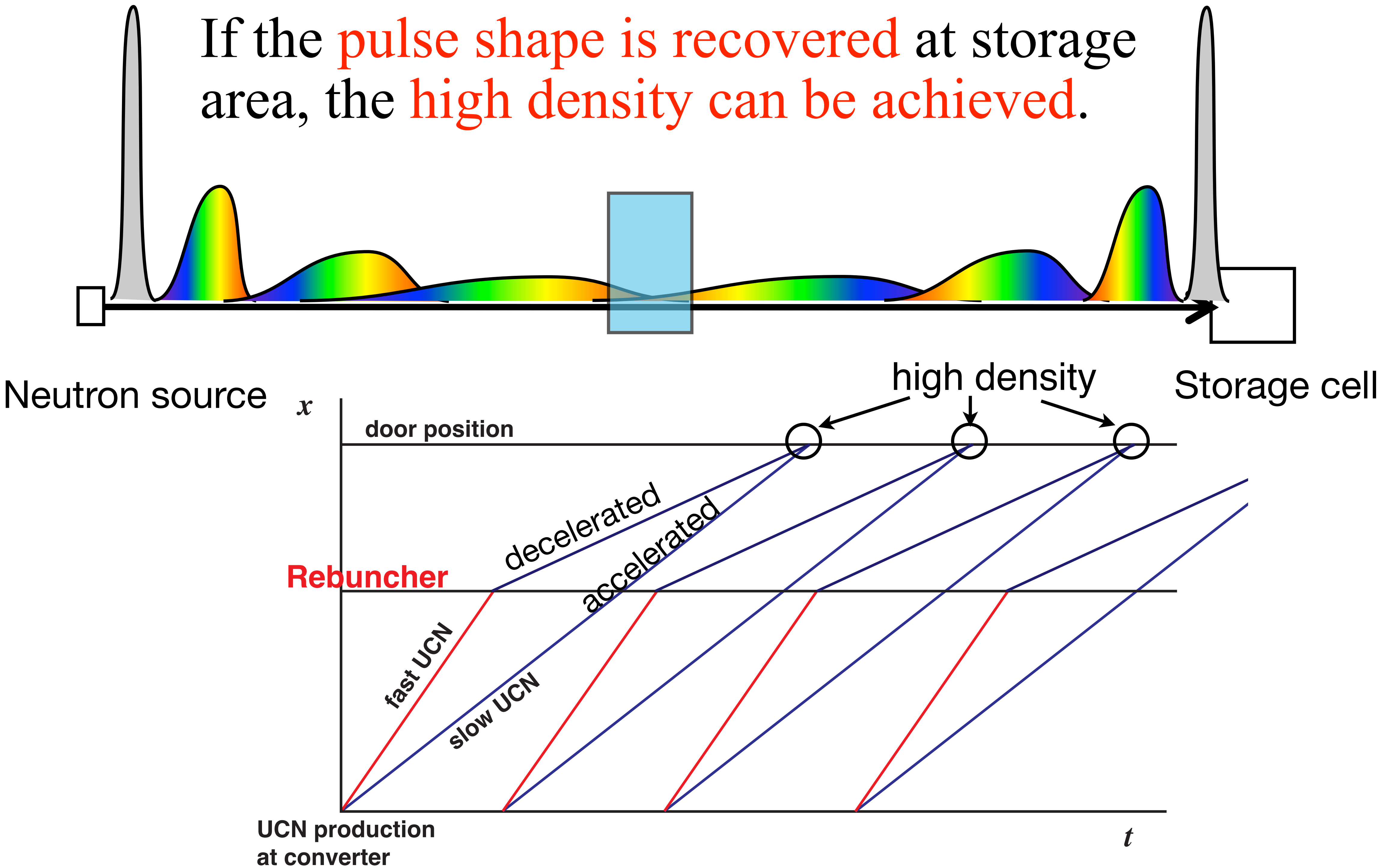
Pulsed UCNs spread spatially,
Density decreases quickly
without any treatment.

Transport without loss of density!

Motivation nEDM at J-PARC (P33)

UCN Rebuncher = Neutron Accelerator

If the pulse shape is recovered at storage area, the high density can be achieved.



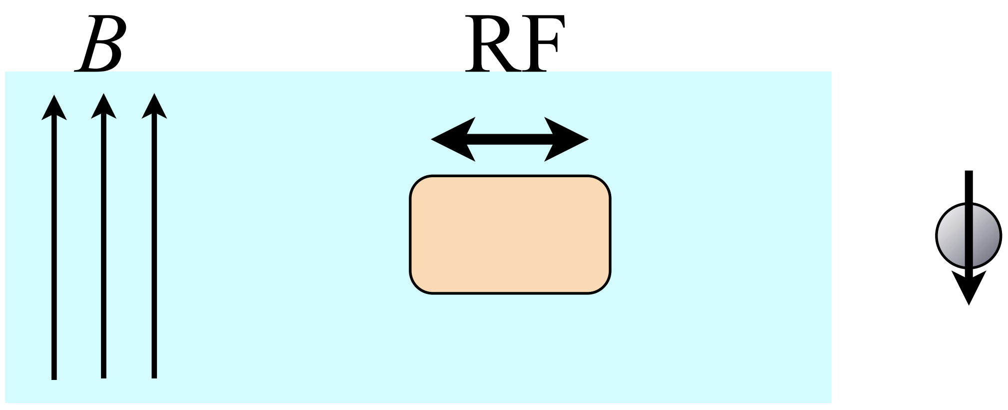
Neutron Accelerator How to

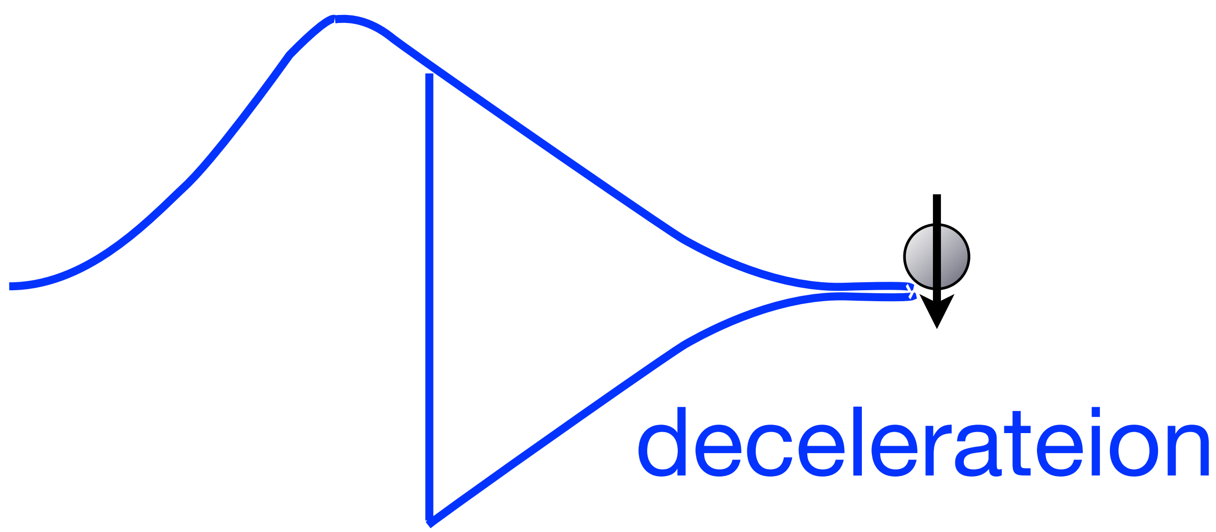
Adiabatic Fast Passage (AFP) spin flipper is used for control of the neutron energy.

RF magnetic field in gradient field gives/removes the energy with spin flip.

$$2\mu B = \hbar\omega$$

30 MHz = 1T = 120 neV





Opposite-spin neutrons are accelerated.

Neutron Accelerator How to

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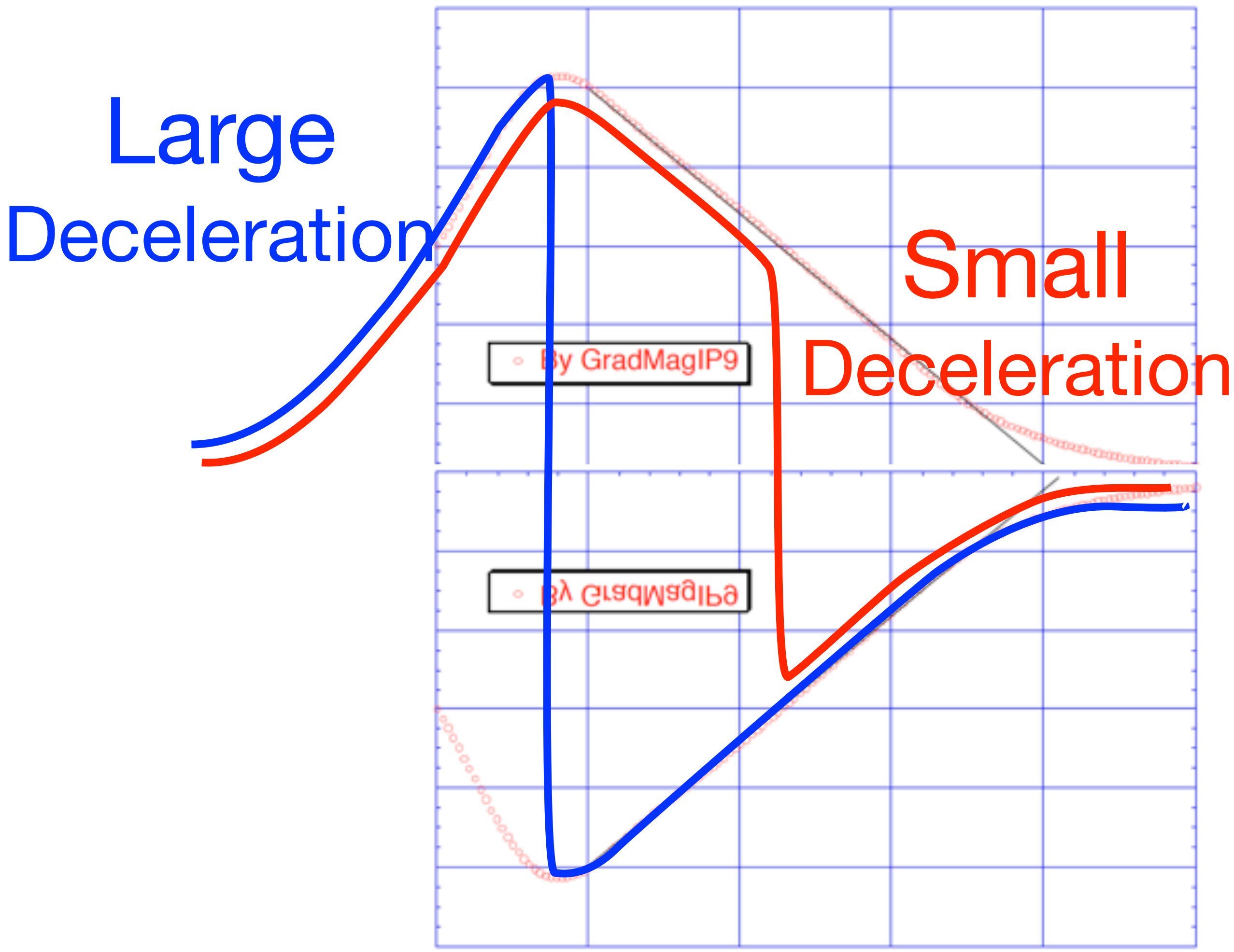


RF magnetic field in gradient field gives/removes the energy with spin flip.

$$2\mu B = \hbar\omega$$

30 MHz = 1T = 120 neV

Faster neutrons arrive early.

Large deceleration = High Freq. RF

Slower neutrons arrive late.

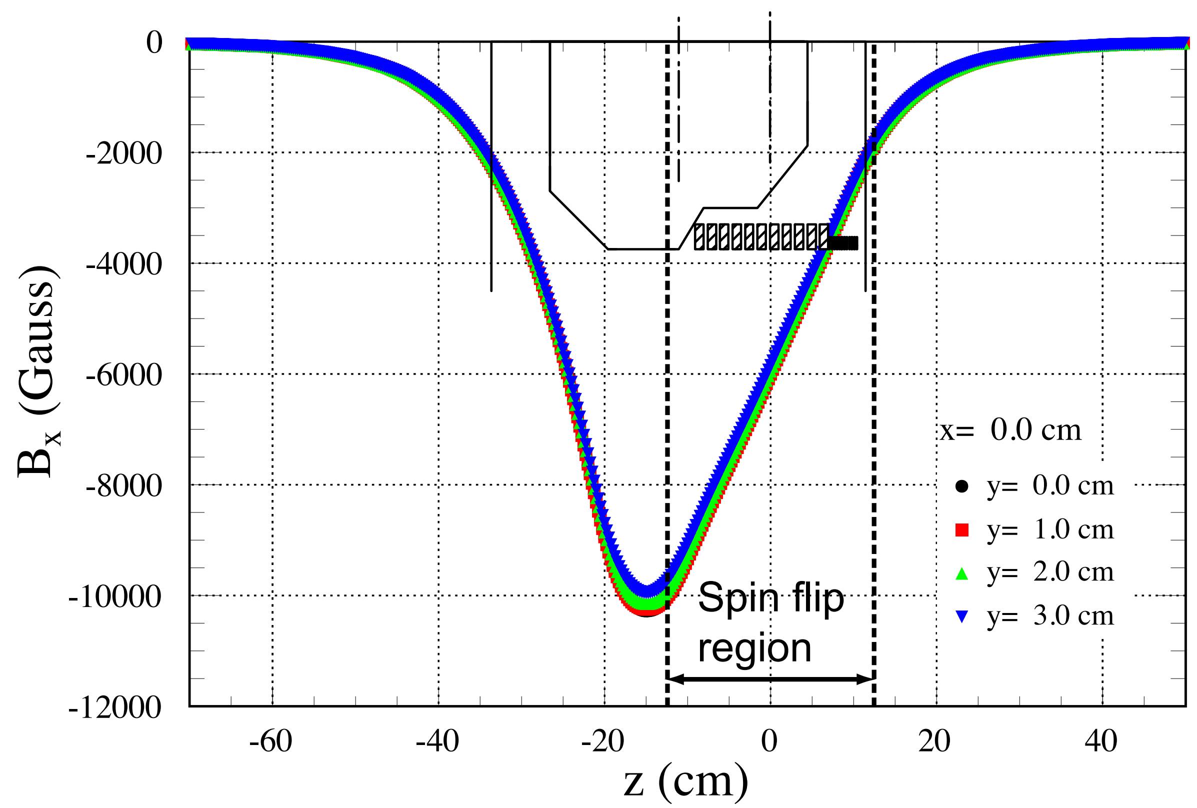
Small deceleration = Low Freq. RF

Energy exchange is proportional to the RF frequency.

Sweeping frequency according to time

Neutron Accelerator

Prototype Static Magnet

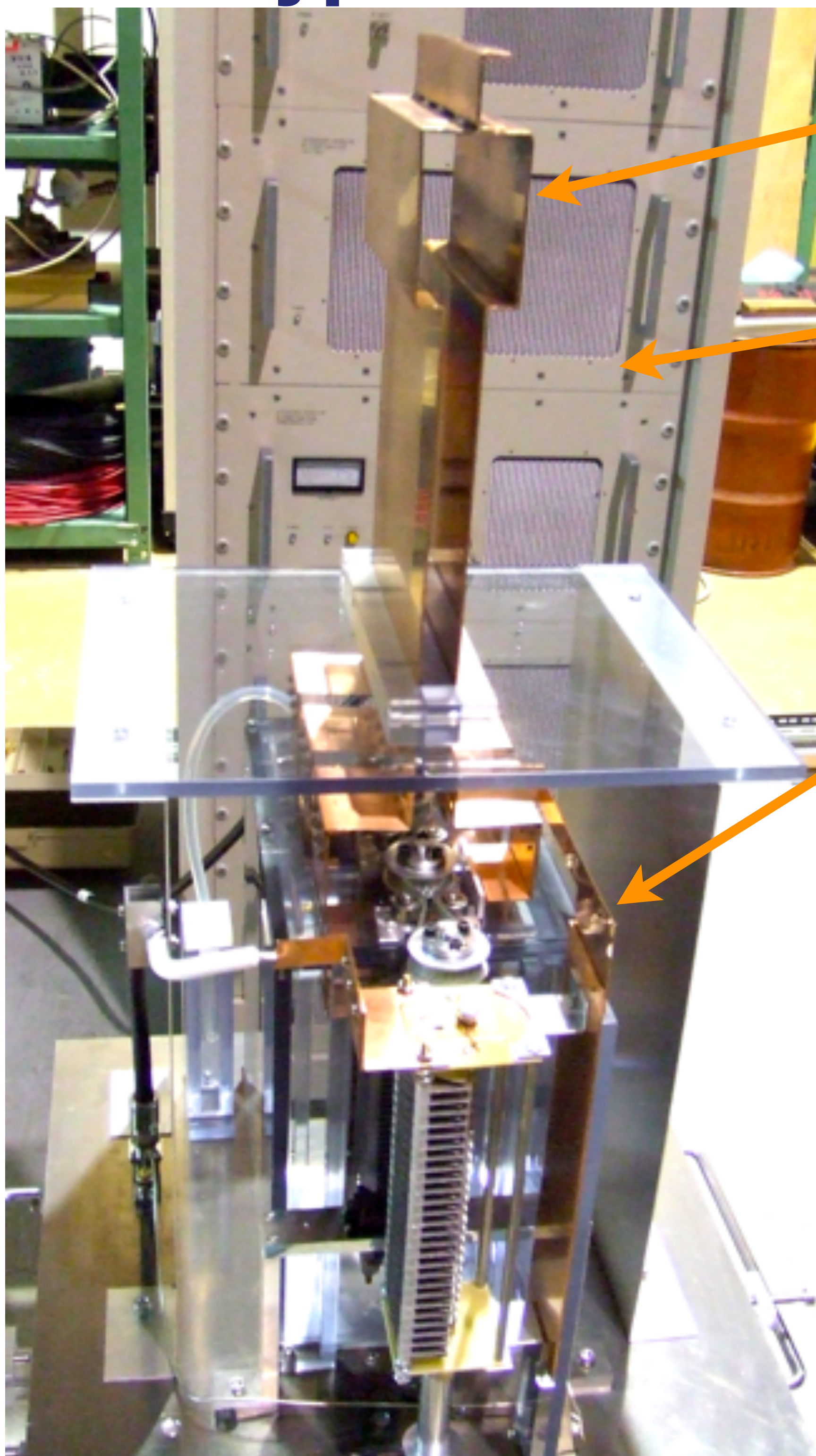


Y.Arimoto, et. al.,IEEE Trans. Appl. Supercond. 22, 4500704 (2012).

Anisotropic inter-poles make homogeneous gradient field.

Neutron Accelerator

Prototype RF

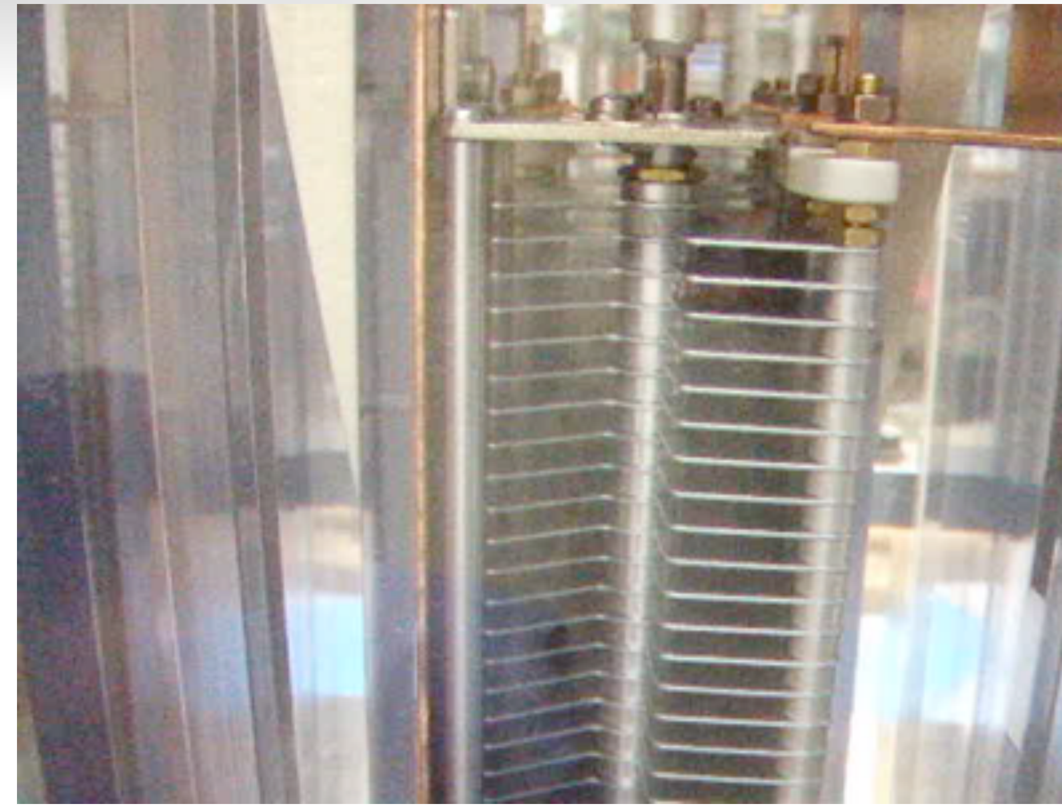


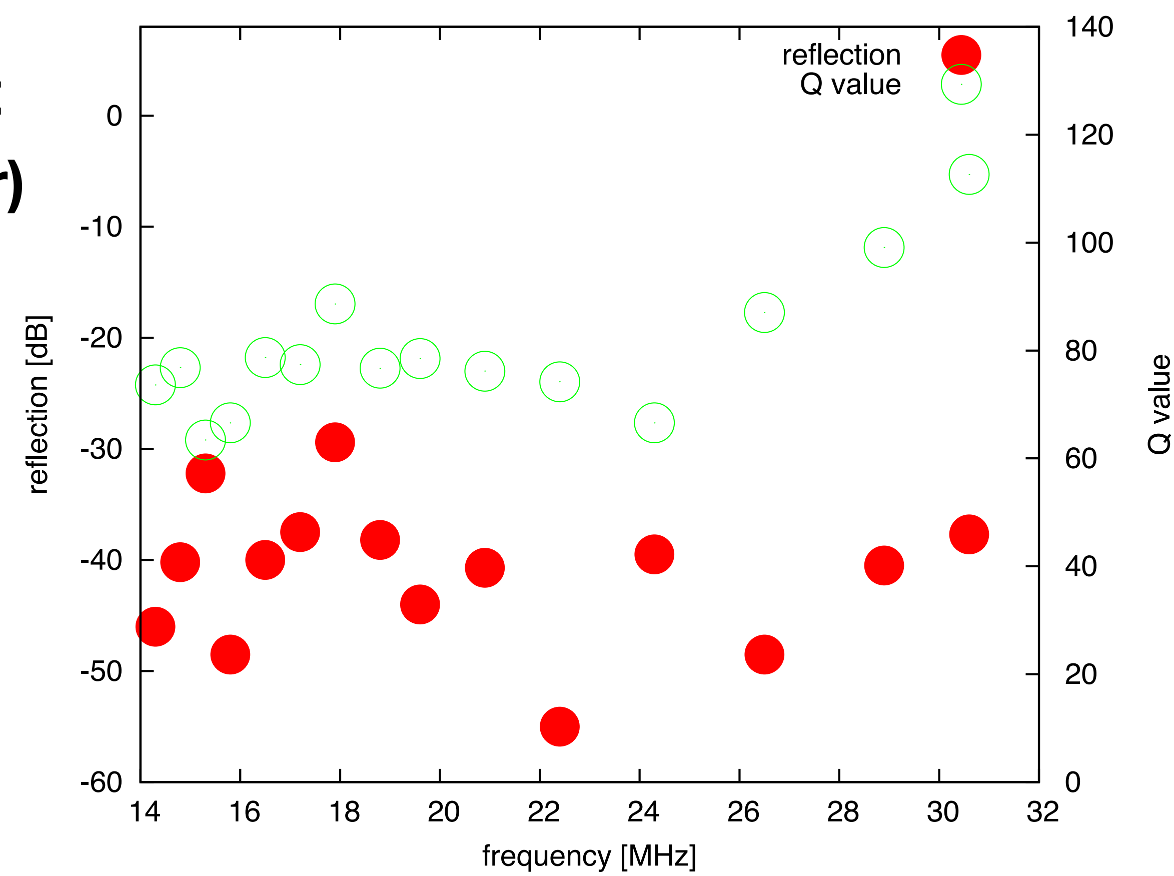
RF coil
(one-turn)

RF Amp 1kW

Resonance circuit
(Variable capacitor)

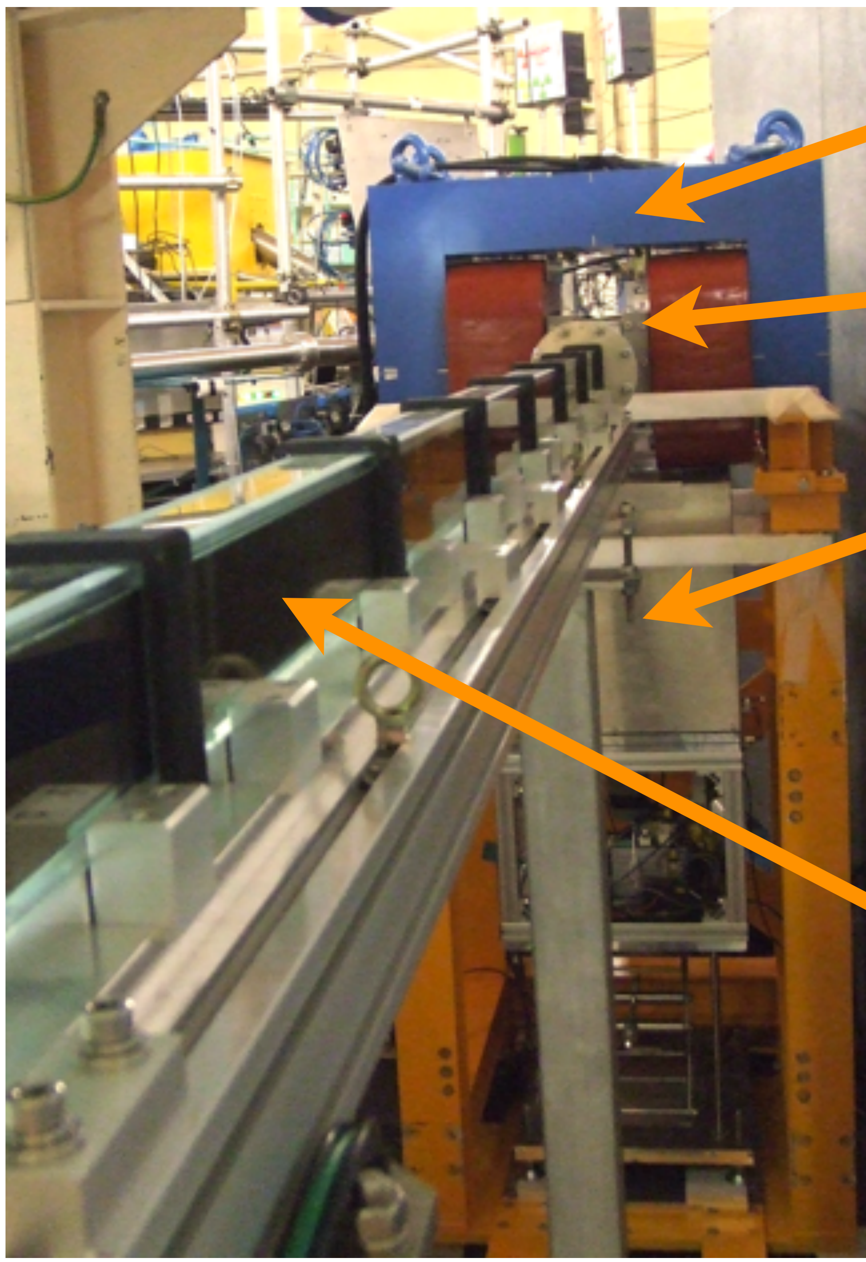
RF matching
15 - 30 MHz

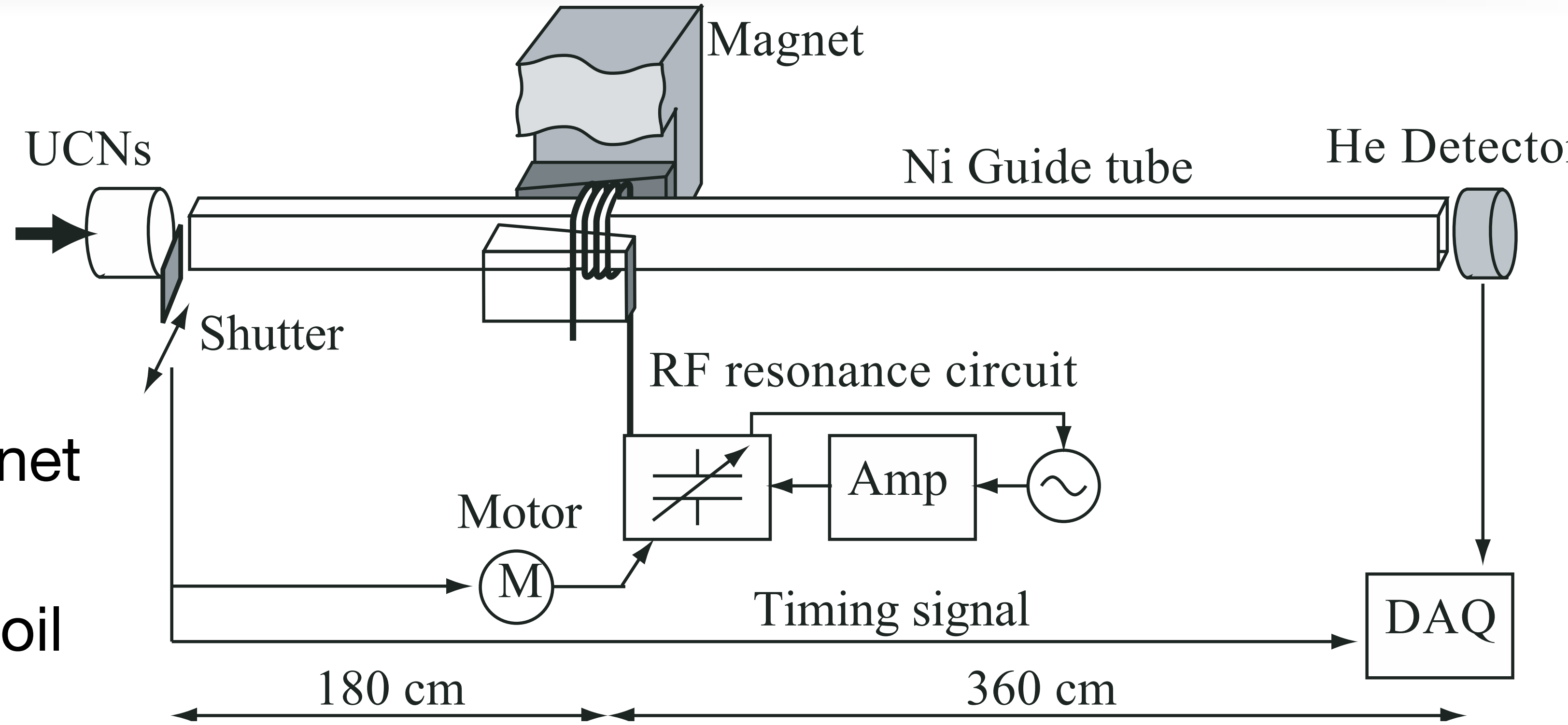




Demonstration of Rebunching

UCN beam line PF2
High Flux Reactor
ILL, France



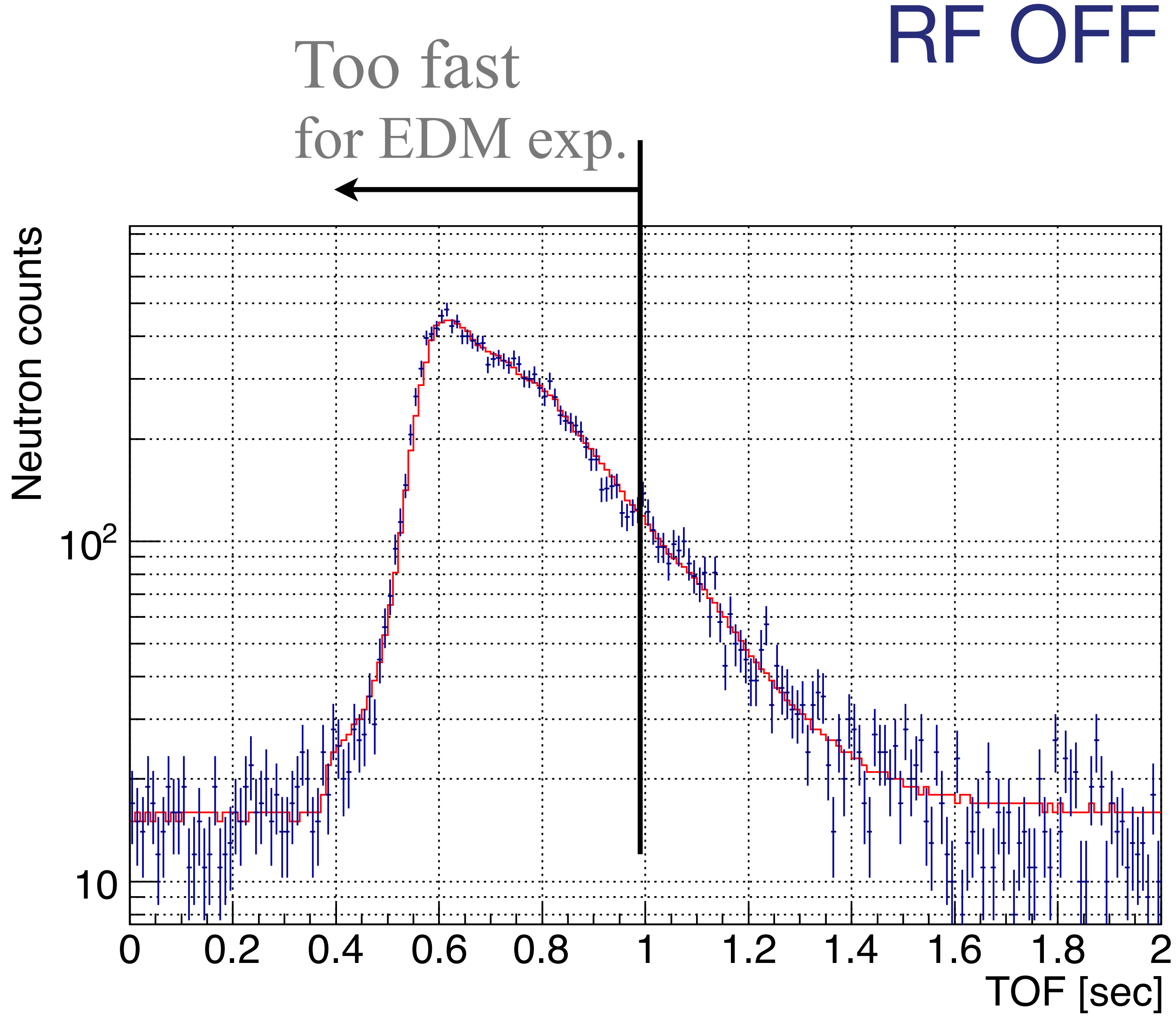


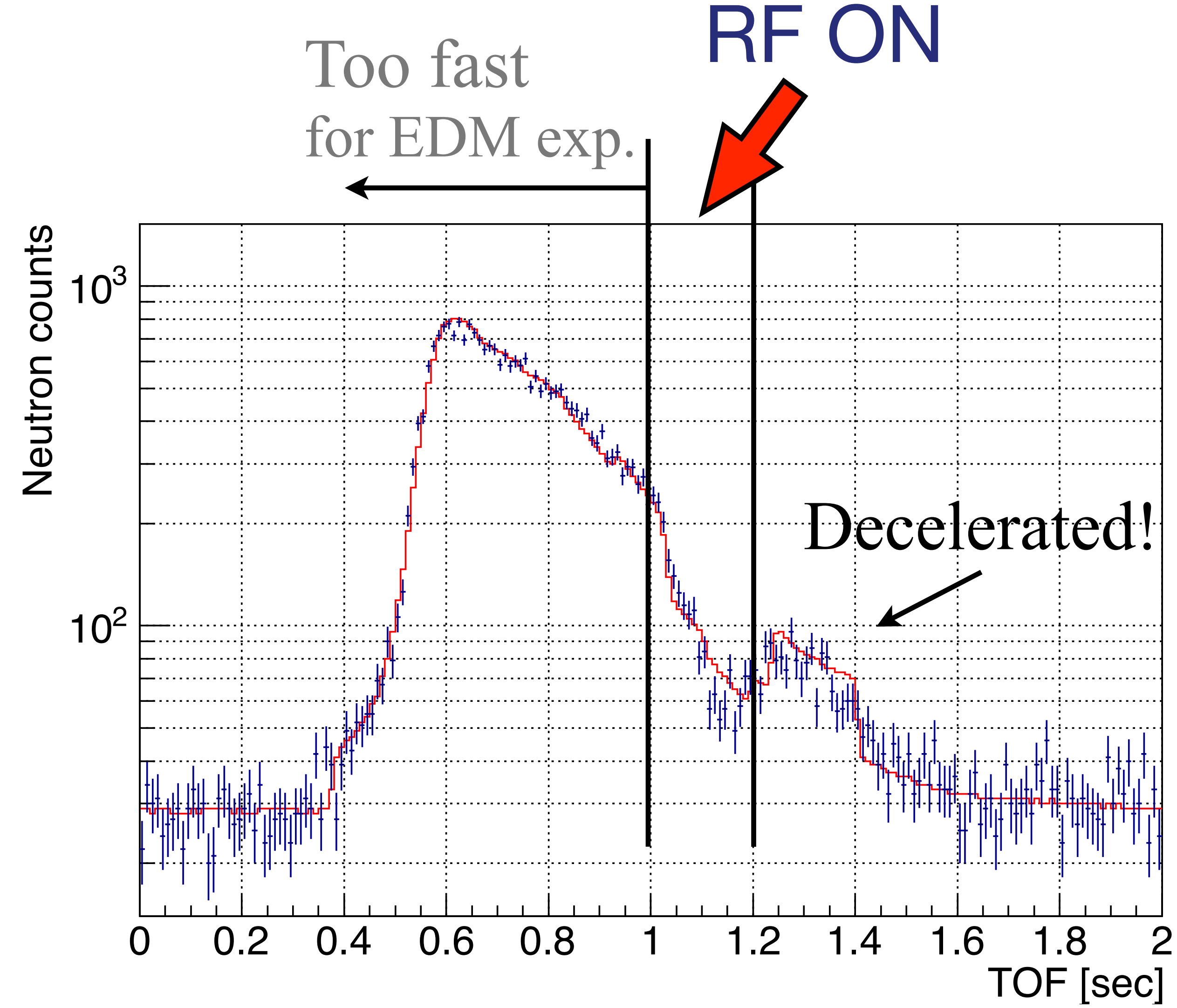
Continuous UCN beam was chopped by shutter to simulate pulsed source.

Sweeping RF frequency is synchronized with the shutter.

Demonstration of Rebunching

Results



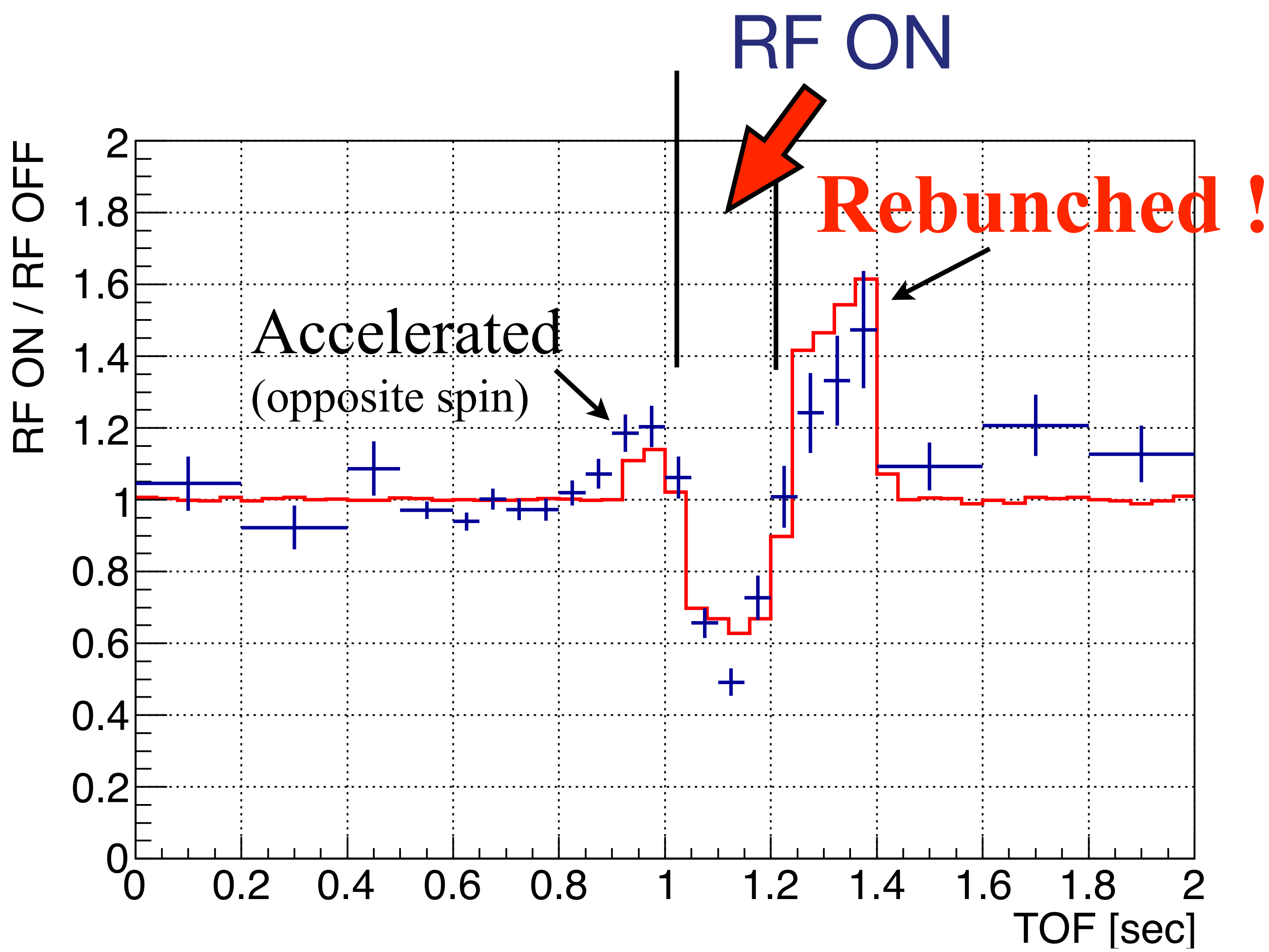


Blue : Exp. Data
Red : Simulation

Y. Arimoto, et., al.,
Phys. Rev. A 86, 023843 (2012).

Demonstration of Rebunching

Results



Blue : Exp. Data
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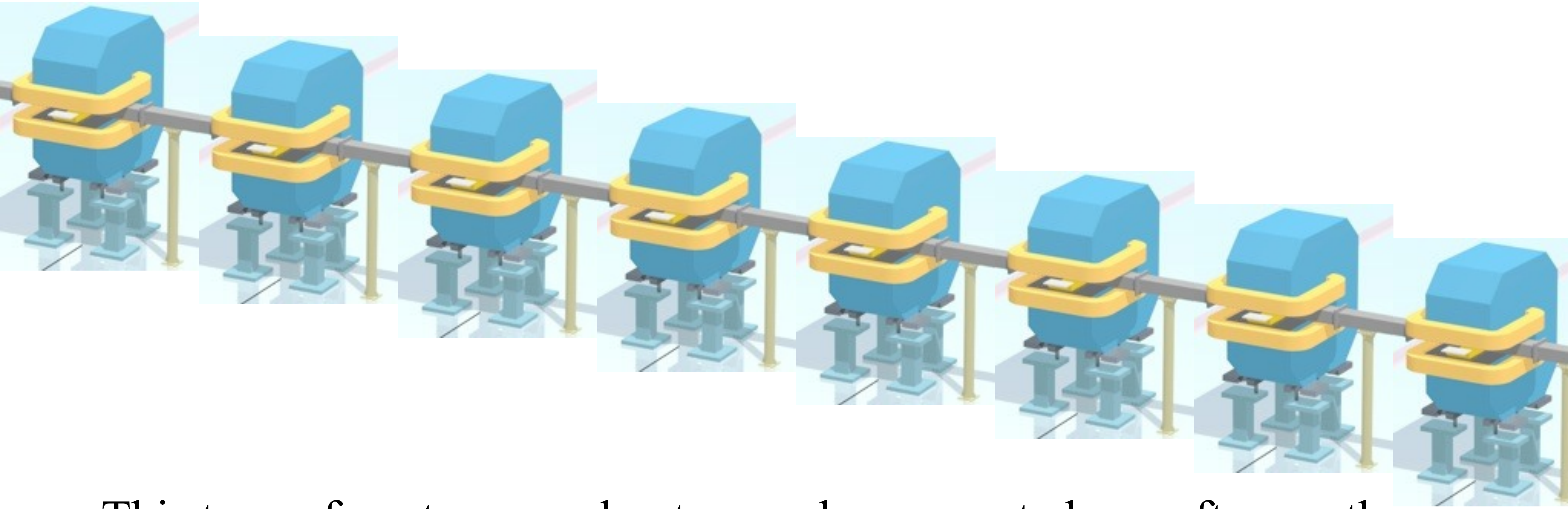
Focusing of UCNs was observed !

Y. Arimoto, et., al., Phys. Rev. A 86, 023843 (2012).

Summary

Now we can control neutron velocity precisely.



This type of neutron accelerator can be connected one after another.

Controllable energy = 120 neV / T / unit

Summary

Neutron EDM (nEDM) signals new physics beyond standard model.

nEDM experiment requires dense Ultra Cold Neutrons (UCNs).

By controlling the energy distribution of UCNs, the pulse shape of the UCNs can be reconstructed at experimental area.

UCN Rebuncher = Neutron Accelerator

Spin flipper with frequency-sweeping RF can be Neutron Accelerator.

We have developed prototype of Neutron Accelerator and demonstrated the space-time focusing.

We are now planning the new nEDM experiment using this focusing technique at J-PARC.