Development of 17T-NMR system for measurement of polarized HD target

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Outline

- Introduction of
  polarized HD target in Osaka
- 17 Tesla portable NMR system

Introduction

1. Polarized HD target
for hadron physics
From 2007
Present talk

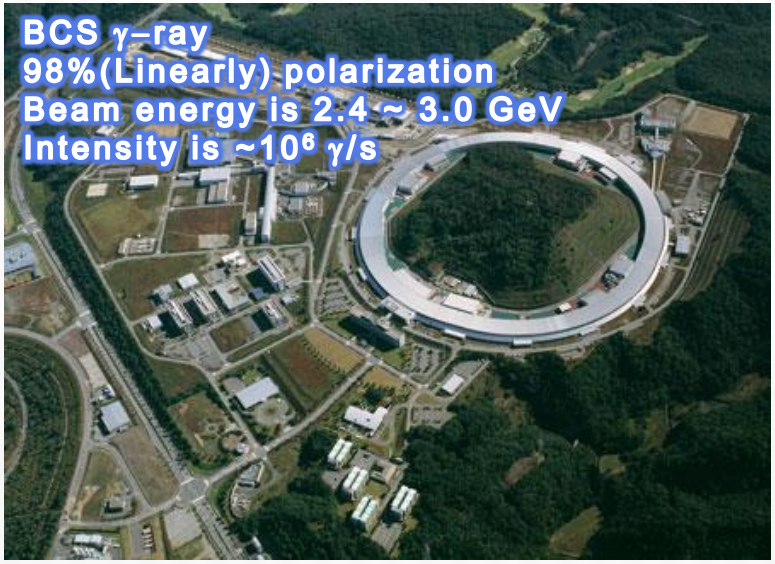
2. Hyprer polarized 3He
for polarized source of MRI
From 2009

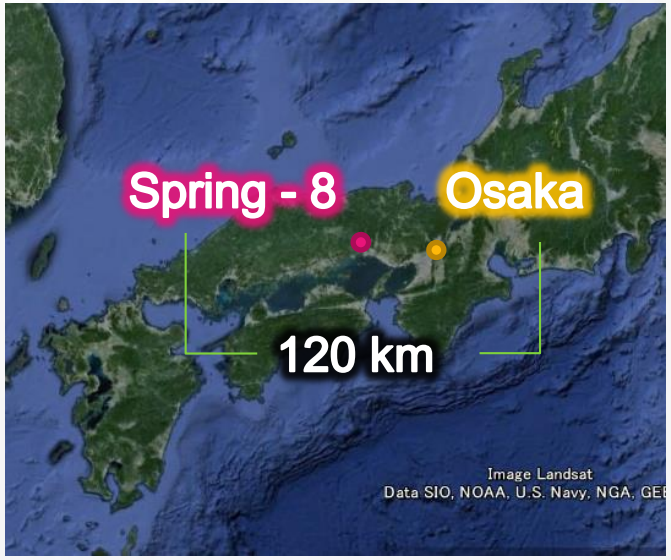
Introduction of Spring-8

The hadron photoproduction of the ϕ, K, η, and π^0 mesons is studied by using linearly polarized photon beams with energies of E γ = 1.5 ~ 2.9 GeV at SPring-8 (LEPS).
These hadron photoproduction experiments have been carried out with unpolarized target.
We plan to carry out hadron photoproduction experiments by using polarized photon beams and the polarized target.

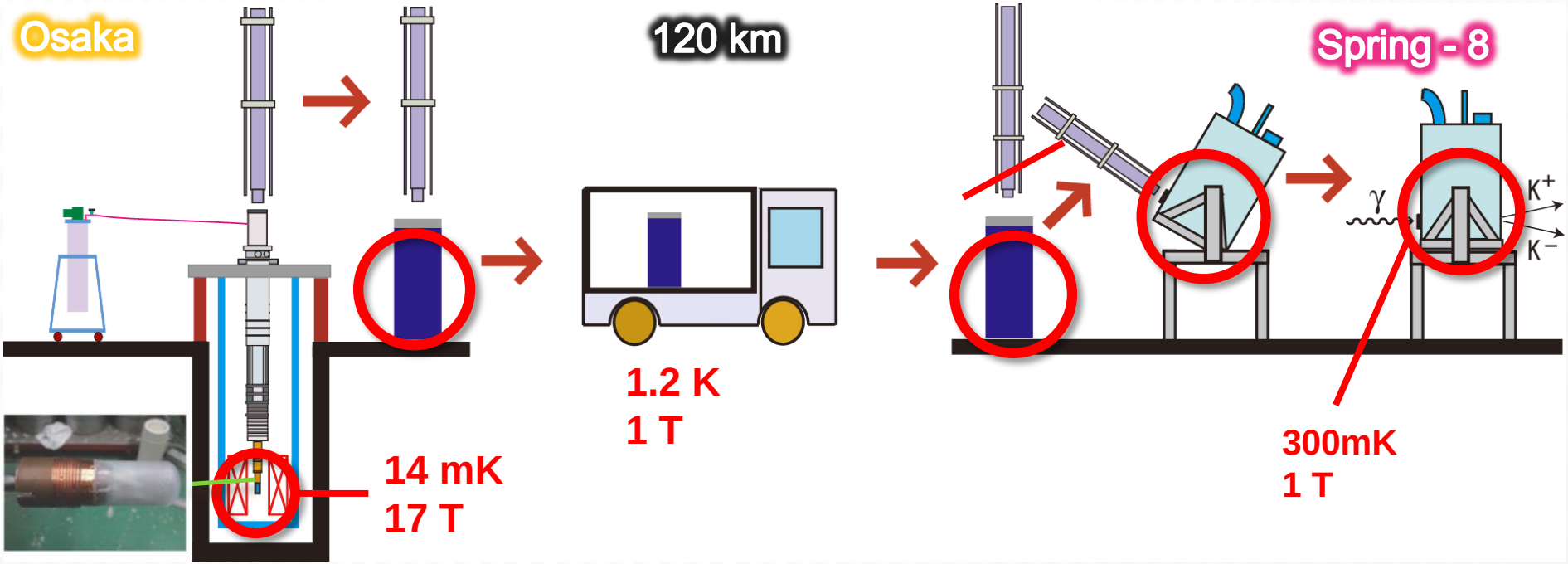
Objective

Development of the polarized Hydrogen-Deuteride (HD) target
for double-polarization Experiments in LEPS.





Transportation of HD target



HD target is cooled and polarized inside dilution refrigerator for 3 month.
NMR measurements are required at various points denoted by ○.
Portable NMR measurement system has been developed for handy transportation.

Polarized HD target

HD is heteronuclear diatomic molecule consisted by hydrogen and deuteron

Polarized method

We use the statistical method by cooling down and keeping the HD target at 10 mK with 17 Tesla for a few months (Brute-force method).

Advantage and disadvantage

Advantage: Dilution factor is good. (the number of H's / the number of nucleons)

HD = 1/3(33.3%), NH_3 = 3/17(17.6%), $C_4H_{10}O$ = 10/74(13.5%)

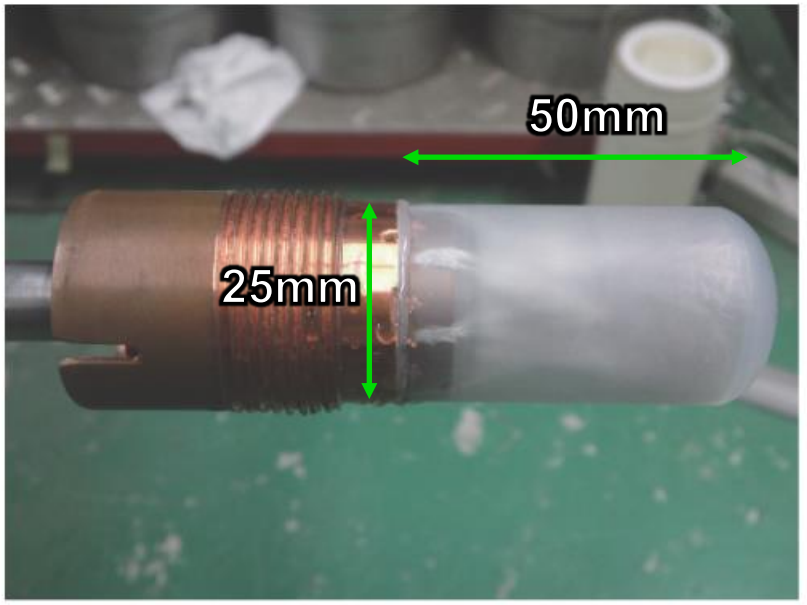
Disadvantage: The HD target needs thin aluminum wires (at most 20% in weight) to improve the cooling power to solid HD.

Size of Target

Diameter is 25 mm. Length is 50 mm.

Relaxation time

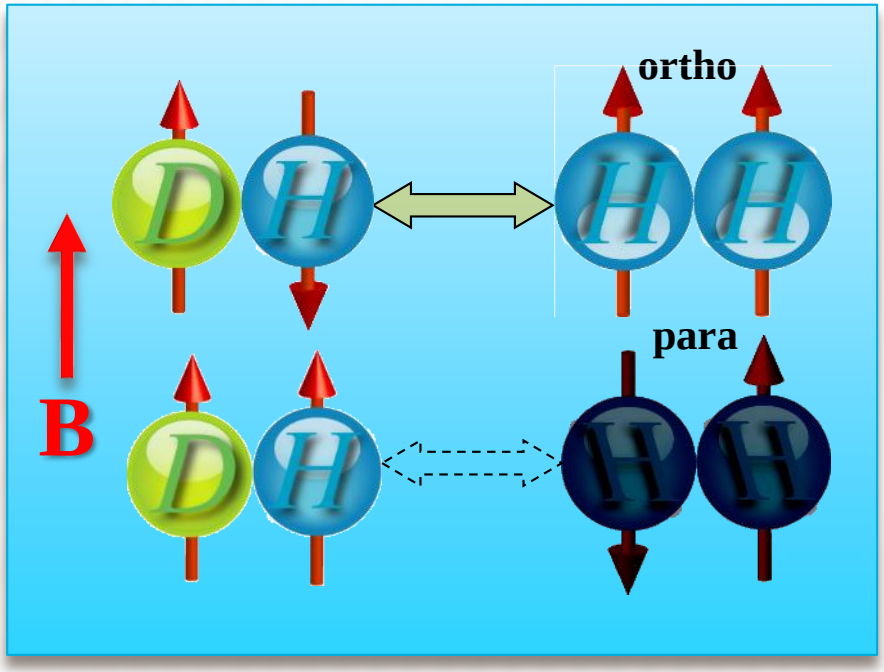
Under the condition of the experiment (T=300 mK and B=1 Tesla) ,
the relaxation time is possible to be longer than several months .



Frozen polarization mechanism

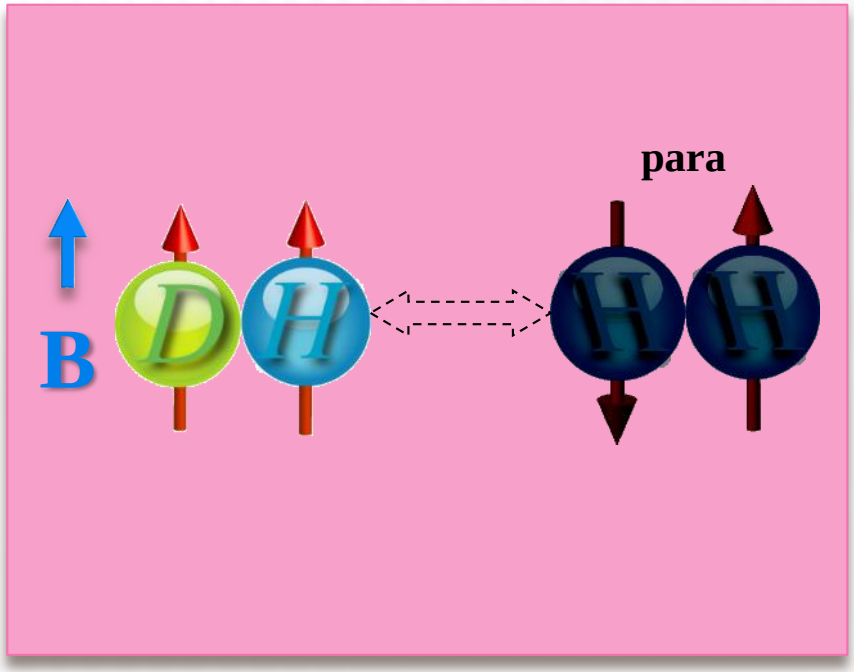
Initial

The polarization of HD is produced by the spin-flip with small concentration of ortho-H_2 (~0.01%) included in HD at 17 Tesla & T=14 mK



After 2 or 3 month

Most of ortho-H_2 has converted to para-H_2. Polarization degree of HD is kept for about one year at 1 Tesla & T=300 mK



Frozen polarization mechanism

Concentration of ortho-H_2

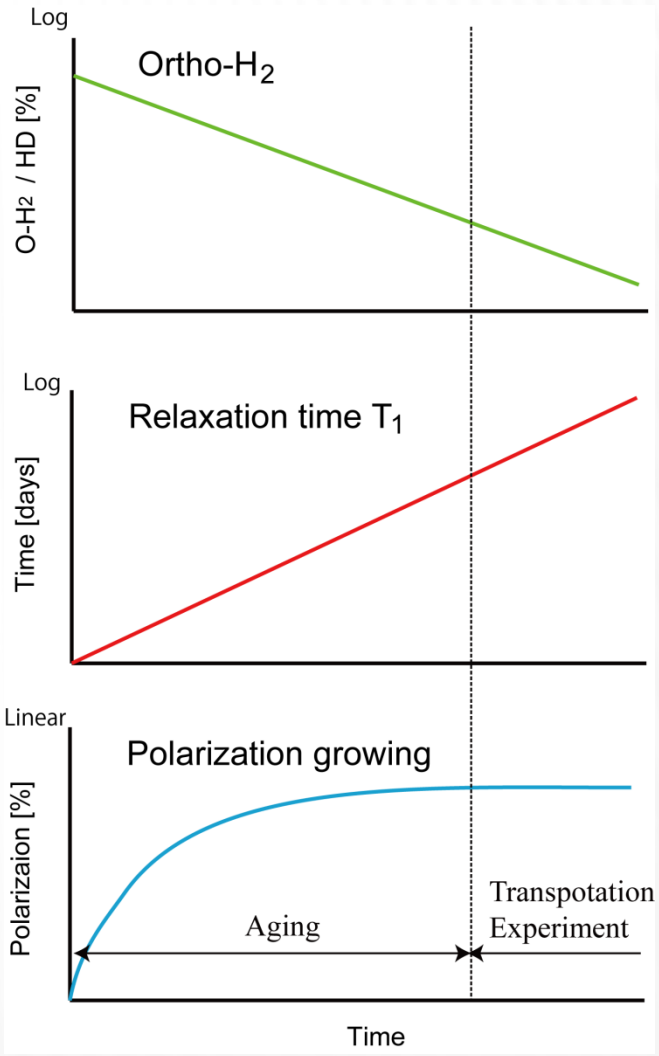
Decrease with time.
Time constant is 6.5 days

Relaxation time

Increase with time. The relaxation time depends on the concentration of ortho-H_2

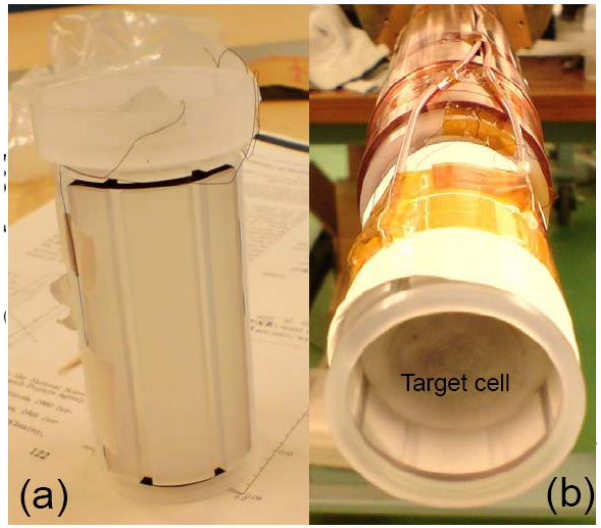
Polarization

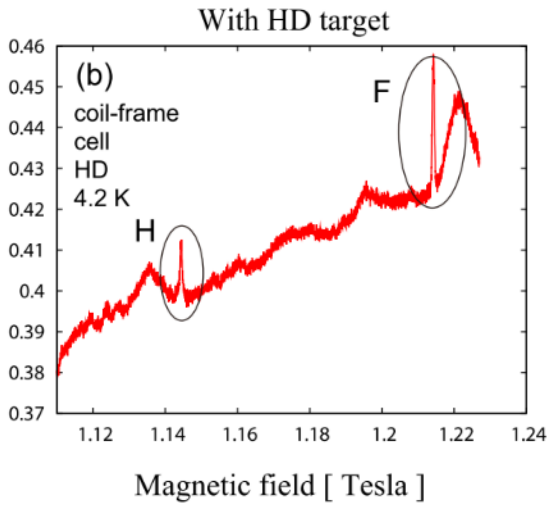
The Polarization grows with time. Growing rate depends on relaxation time.
When the relaxation time is very short, the polarization reaches Thermal Equilibrium

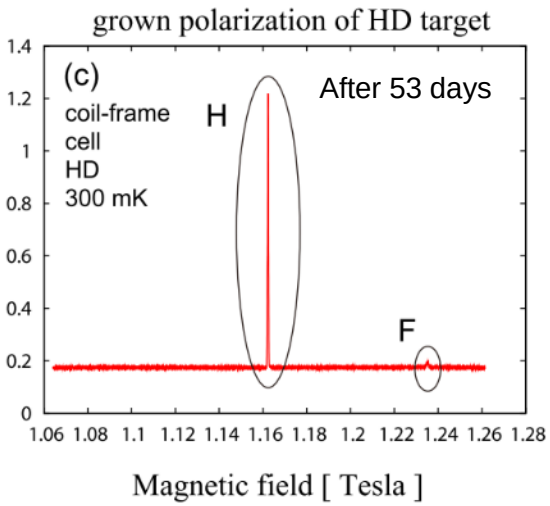


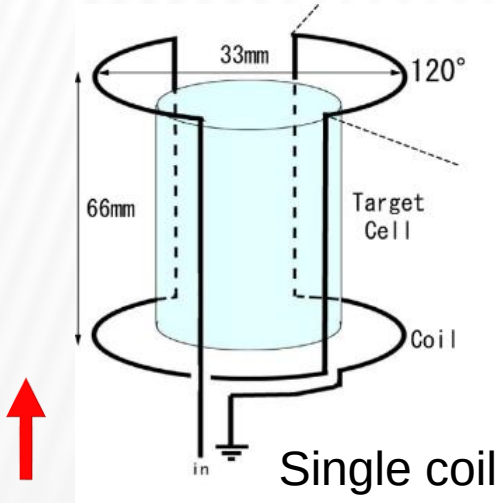
Initial concentration of o-H_2 is important for the polarization degree and relaxation time of HD target. Optimal concentration of ortho-H_2 is 0.02%?

Measurement of NMR spectra









Magnetic field
～1.0 Tesla

Freq.
～42MHz

NMR signals obtained at 4.2 K as a calibration point
(Polarization = 0.024%)

Meas. Environment
- Temperature：4.2 K
- Magnetic field：1 Tesla

NMR signals obtained after polarization production.
Polarization : 40.8±2.3%
Relaxation : 112.8±0.1 days

Meas. environment
- Temperature：300 mK
- Magnetic field：1 Tesla

We only observe the NMR signal before and after

Production results

	Term	Aging time	Temp.	Magnetic	ortho-H_2	Pol.	Relax.
1st	2008 Dec – 2009 Jan	53 days	14 mK	17 T	unknown	40%	100 days
2nd	Failed						
3rd	2012 Aug – Sep	53 days	15 mK	17 T	0.06%	30%	70 days
4th	2013 Jul – Sep	53 days	18 mK	17 T	0.1%	18%	60 days
5th	2014 Feb – Mar	30 days	28 mK	16 T	no meas.	42%	30 days
6th	2014 Dec – Mar	53 days	36 mK	17 T	0.2%	45%	14 days

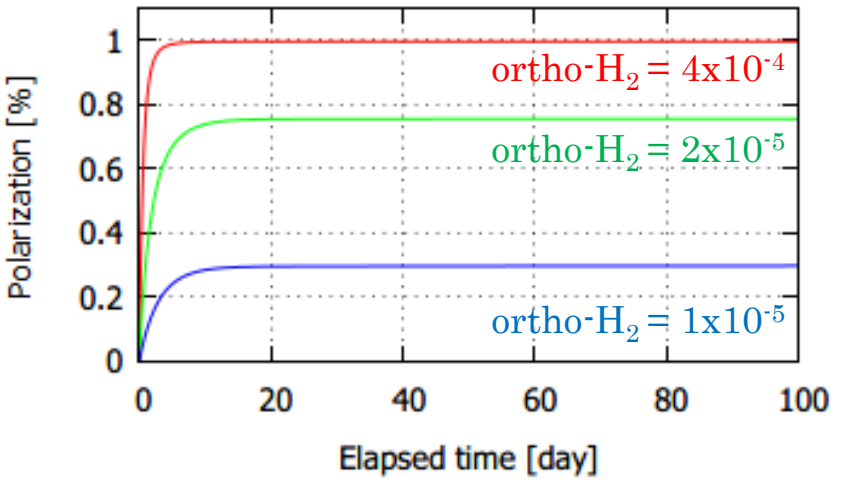
*The concentration of ortho-H_2 is changed every production test.
*From 2008 to 2012, we were developing the other cryostat, instruments and so on.

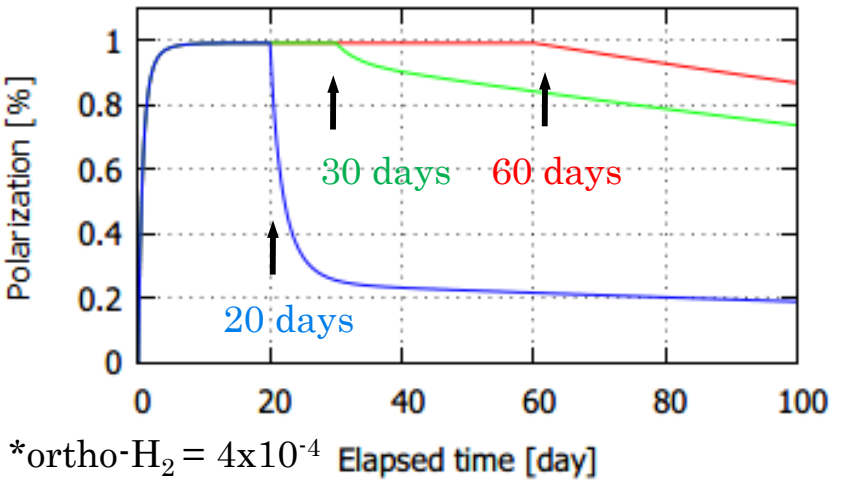
Calculation of polarization growing

This is model equation for polarization growing.

$$T_1 = \frac{\alpha\beta}{\alpha/\gamma + N_0^2 exp(-t/\delta)^2}, \qquad P(t) = 1 - exp\left\{\frac{N_0\delta}{2\alpha\beta}(exp(-t/\delta)^2 - 1) - \frac{t}{\beta\gamma}\right\}$$

N_0 : Initial ortho-H2 amount
α : Ortho-H2 concentration parameter
β : Temperature parameter
γ : T_1 saturation parameter
δ : Time constant of ortho-para conversion (6.5 day?)





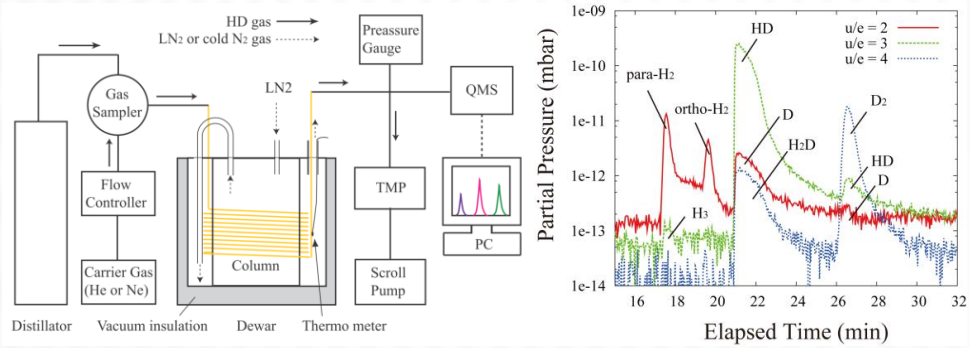
*ortho-H_2 = $4x10^{-4}$

NMR signal is observed before and after the polarization production previously.
I want and need the information of polarization growing curve.
=> Develope the 17 T NMR system and get the parameters of α,β and γ.

HD distiller and gas analyzer

Fortunately we have developed the instruments enable us to control the ortho-H_2 concentration with precise of 0.001%

- The gas analysis system enabled us to observe p-H_2 , o-H_2 , HD, and D_2 separately.
- Components in HD gas enable us to analyze with a high precision of 0.001%
- Distillation term is shorten from 34 days to less than 6 days



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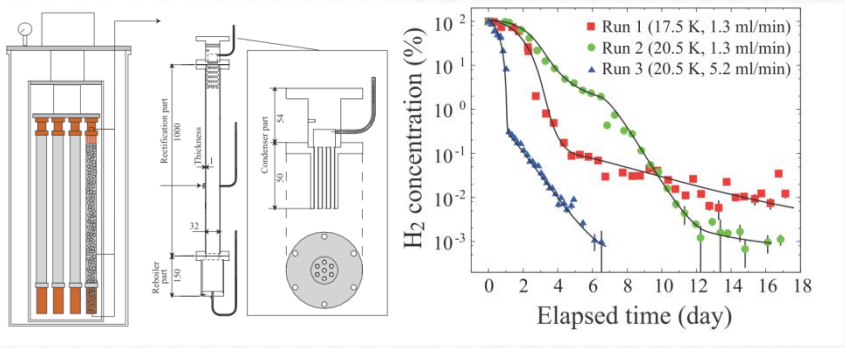

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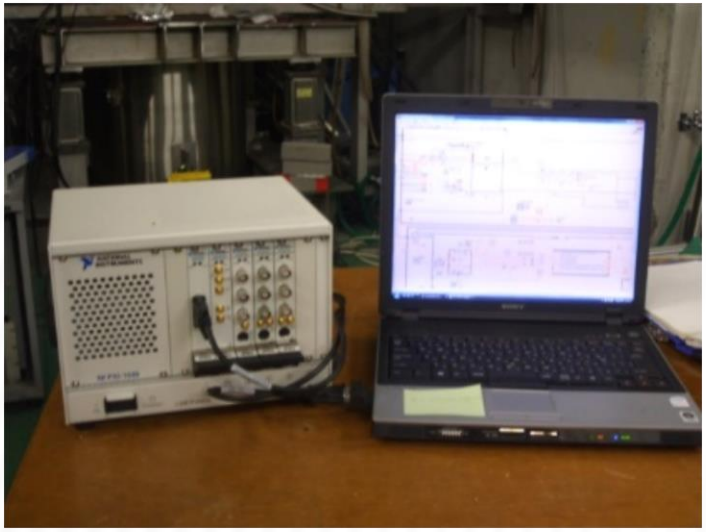
Don't take care to control the initial amount of ortho-H_2

Portable NMR system

Portable NMR system



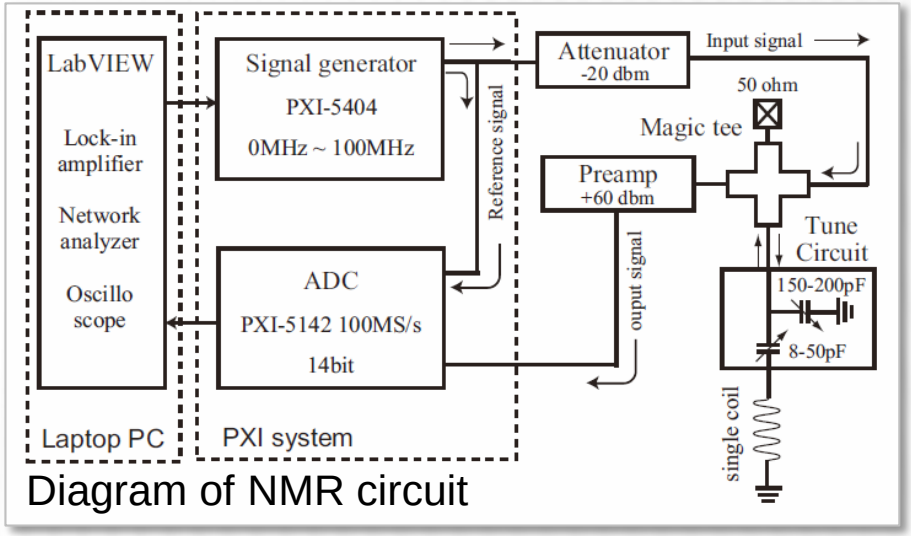


Diagram of NMR circuit

Digital modules

- PXI-1036 Chassis
- PXI-8360 Connection card
- PXI-5404 RF generator (100MHz)
- PXI-5142 Digitizer (100MS/s)

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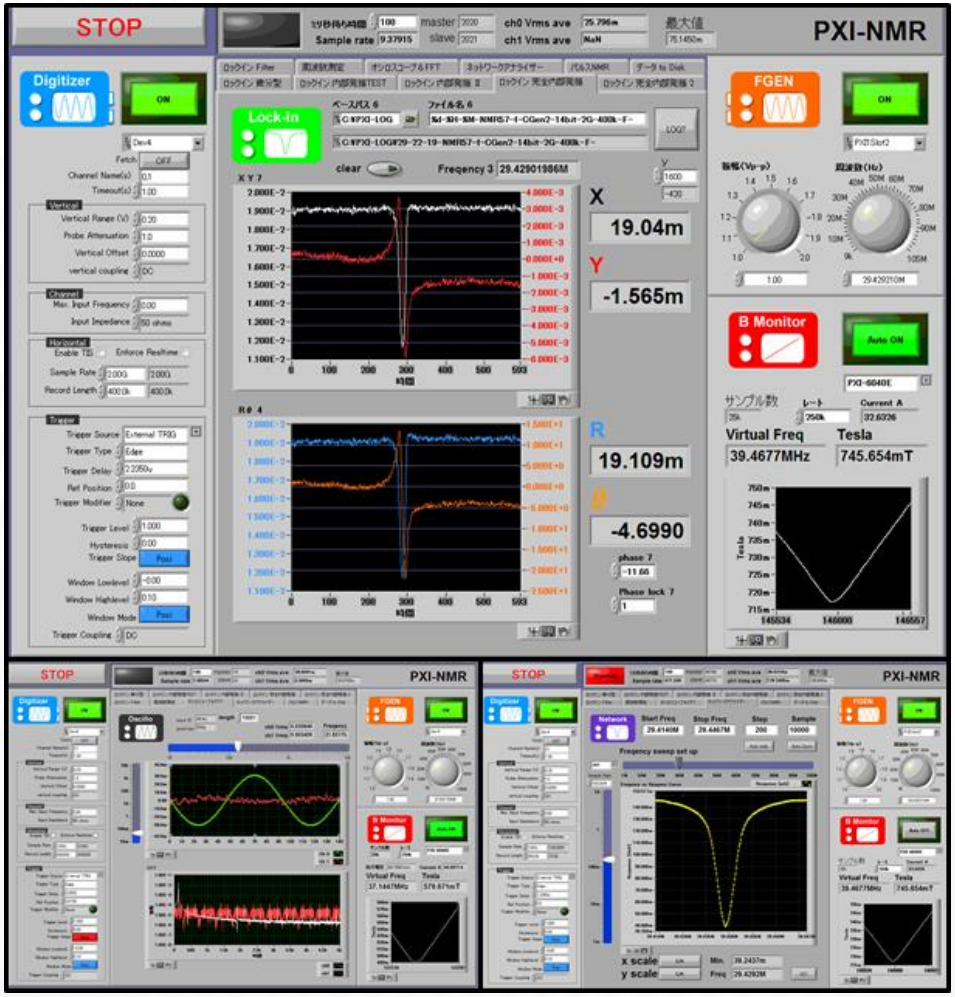
Portable NMR system (PXI-NMR)

Lock-in amp.



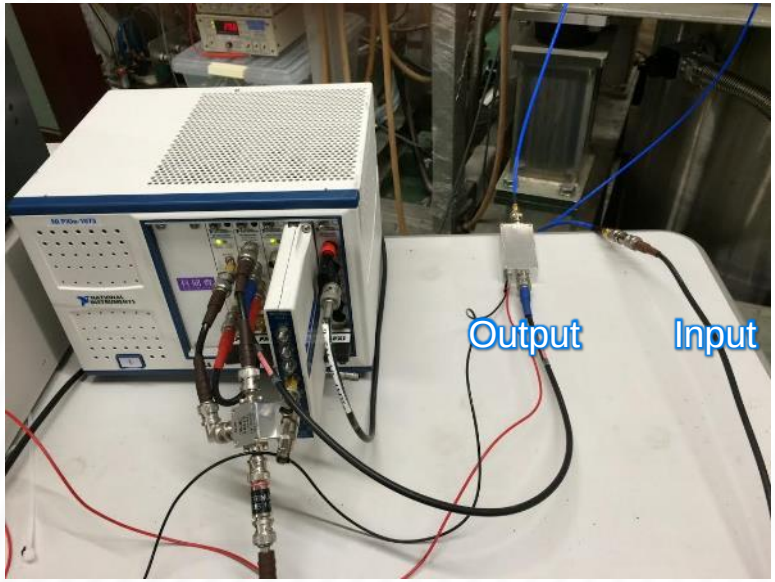
Oscillator & FFT

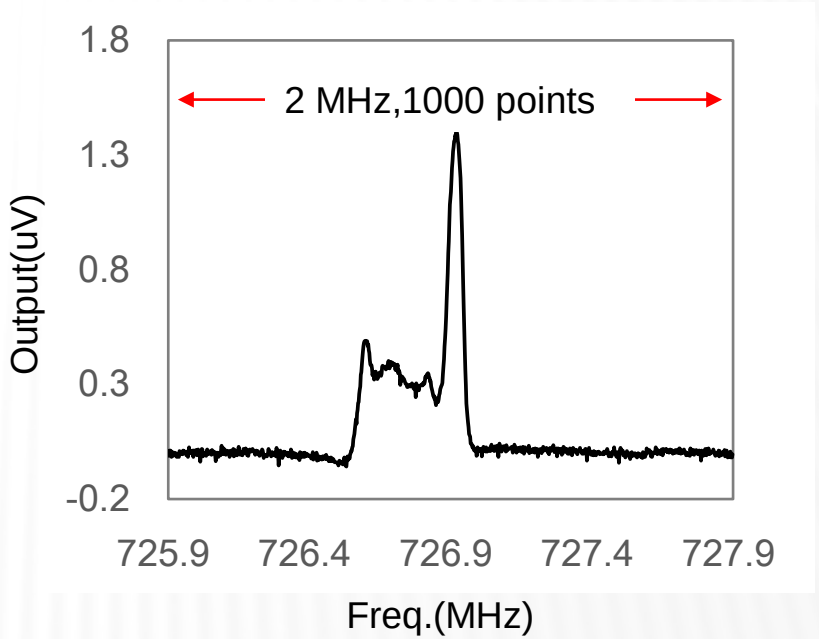
Network Analyze

- Don’t need to disconnect and connect the cable to port of many device.
- Operation trouble shooting is easy.
- The system enable us to measure NMR signal automatically and to custom the measurement

Weight	Size	Cost
7.1 Kg	W 250 D 200 H 200	$15000

17 Tesla portable NMR system





In order to be able to measure the NMR in 17 Tesla,,,

Add these modules

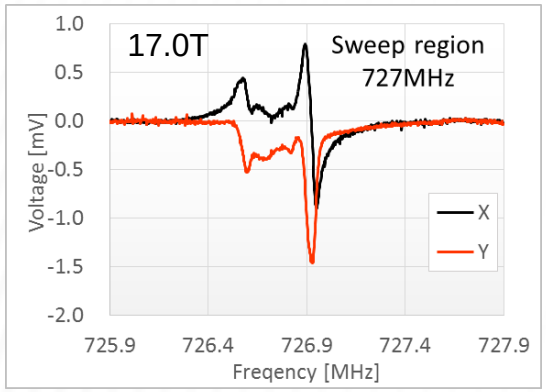
- PXIe-5650 RF generator (1.3GHz)
- PXIe-5162 Digitizer (2.5GS/s)

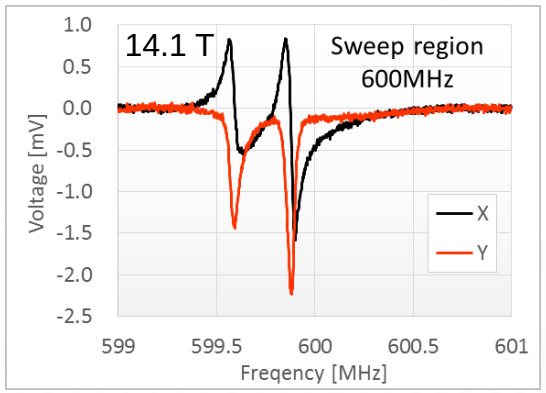
Add the function

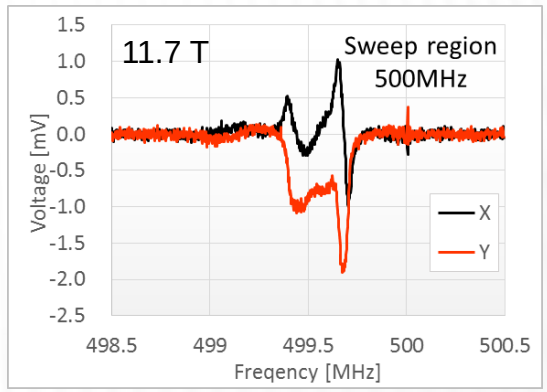
- Frequency sweep method
- Enable the cross coil

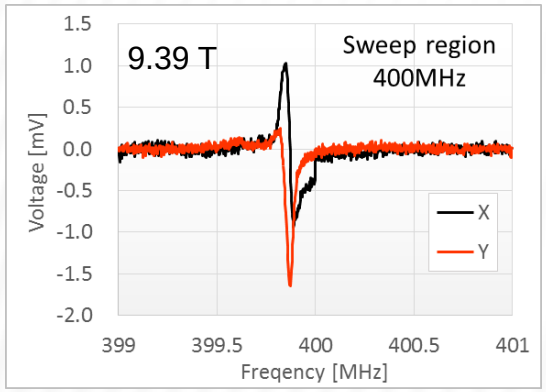
- Sweep region is 726.9+-1MHz
- 240 times integration.（For 4 min.）
- Analog circuit is only preamp for NMR signal.

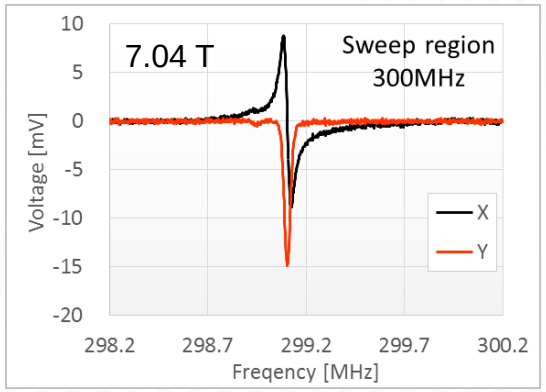
NMR signals from 50 MHz to 100 MHz

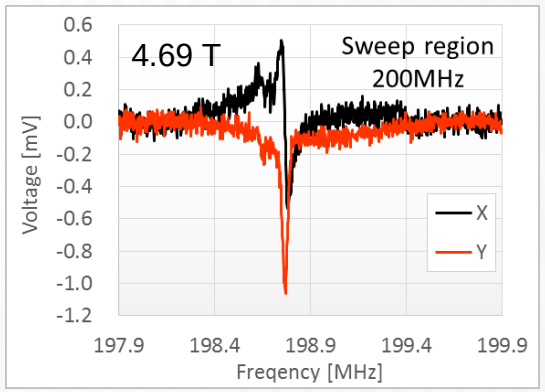


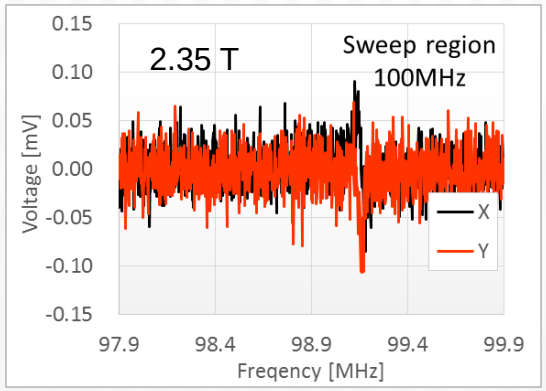


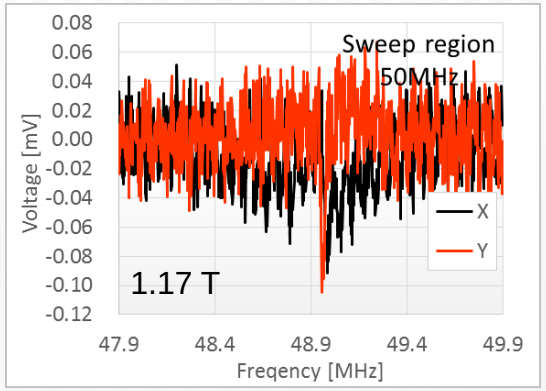








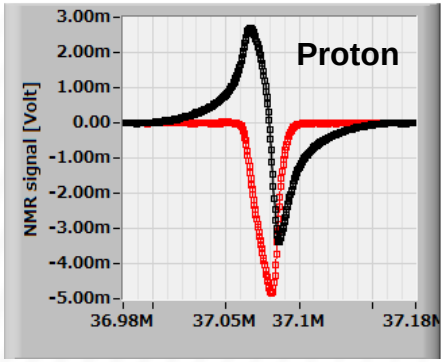


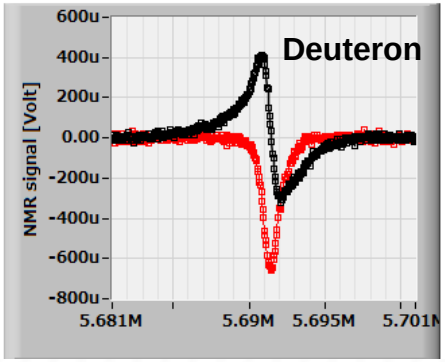


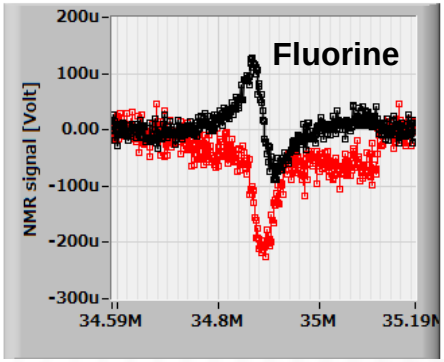
Proton NMR signals.
No frequency restriction
because it does not use Q-meter.

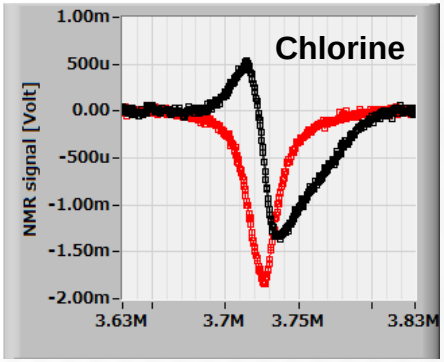
Multi nuclear NMR measurement

17T-NMR system enable us to obtain a several nuclear NMR resonance.
NMR resonance of Hydrogen and Deuteron in HD target is measurable in 17 Tesla.

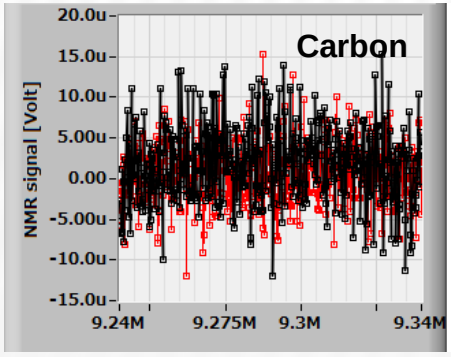


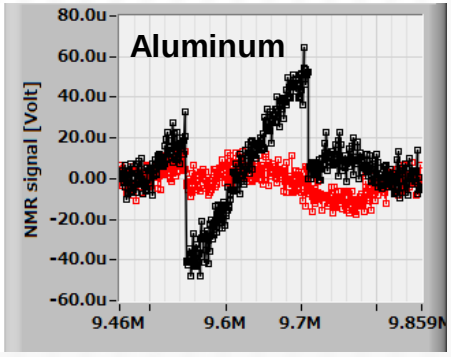






But we can't measure Carbon and Aluminum NMR resonance.
(We use aluminum wire and PCTFE cell)





Summary

- HD group in Osaka University have developed polarized HD target
- Production of the target required for a few month.
- Helium resource and man power resource will be short in the future
- To reduce or optimize the production term, 17T-NMR measurement system was developed.
- 17 T NMR measurement with frequency sweep was succeeded.
- Polarization growing curve have not been acquired yet