Spin Relaxation and Mechanical Spin Pump in Superfluid ^{3}He-A$_1$

A. Yamaguchi, S. Murakawa, Y. Aoki, H. Ishimoto
H. Kojima

Institute for Solid State Physics, University of Tokyo;
Rutgers University;
Tokyo Institute of Technology;
University of Hyogo

PSM2010, Yokohama, March,2010

Thanks to

- **Experiments at ISSP**
  - **K. Kimura, S. Kobayashi, K. Suzuki, M. Arai**
    (Former Graduate and Undergraduate Students)
  - **R. Masutomi** (Former Post Doc at Rutgers Univ.)
- **Theoretical Suggestion**
  - **A.J. Leggett, K. Nagai, T. Takagi, H. Ebisawa**

- **Financial support**
  - **“Research project of PSM”**

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Outline

1.Introduction

– Superfluid A_1 phase; Hydrodynamics in A_1

2.Early Experiment

– Magnetic Fountain Effect, Spin Relaxation;

3.Spin Pump Experiment

– Polarization Enhancement, Spin Relaxation

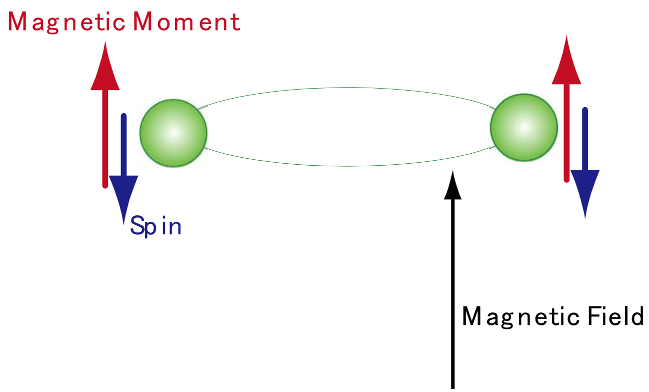
4.Summary

– Summary, Future Aspect

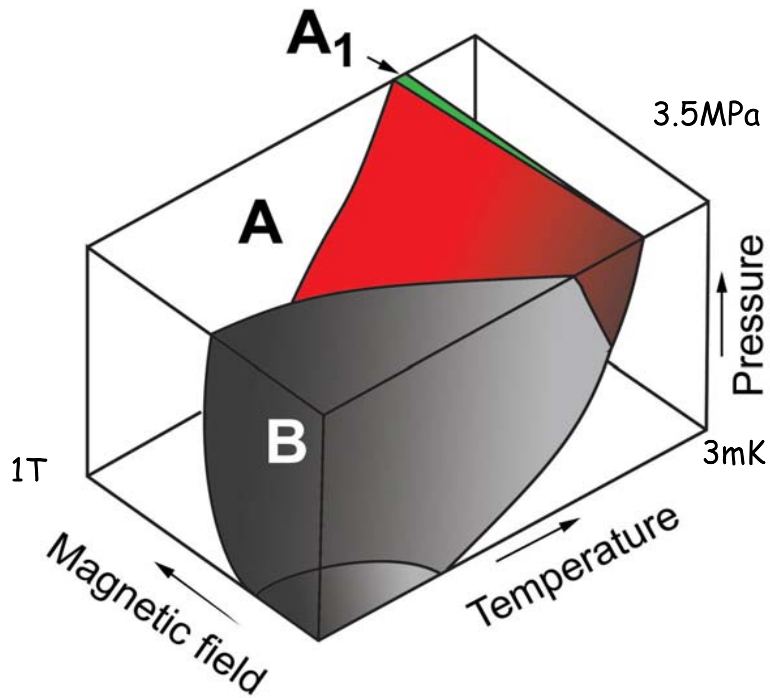
1. Introduction

Superfluid ^{3}He A_1 phase

- **One phase among multiple p-wave superfluid phases of liquid ^{3}He**
- **It only appears in magnetic field.**
- **The condensate is believed almost totally spin polarized. (consists of up-spin cooper pairs)**
- **Characteristic hydrodynamics, such as "Magnetic Fountain Effect"**



Definition of up-spin cooper pair



Magnetic Fountain Effect

- **Magnetically accelerated superfluid ^{3}He in A_1**

$$\frac{\partial v_s}{\partial t} = -\frac{1}{\rho}\nabla P - \sigma \nabla T - \frac{\gamma\hbar}{2m}\left[\left(\frac{\gamma}{\chi}\right)\nabla S - \nabla H\right]$$

M.Liu (1979)

Simply,

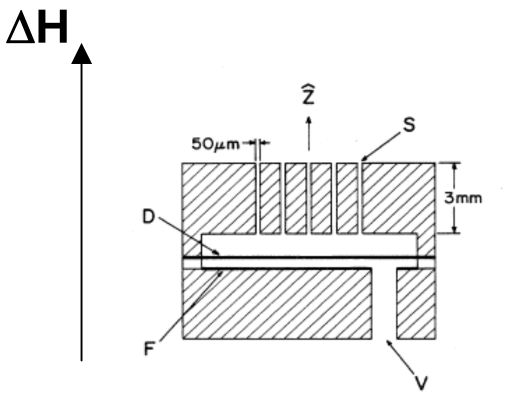
$$\frac{1}{\rho}\nabla P = \frac{\gamma\hbar}{2m}\left[\nabla H - \left(\frac{\gamma}{\chi}\right)\nabla S\right]$$

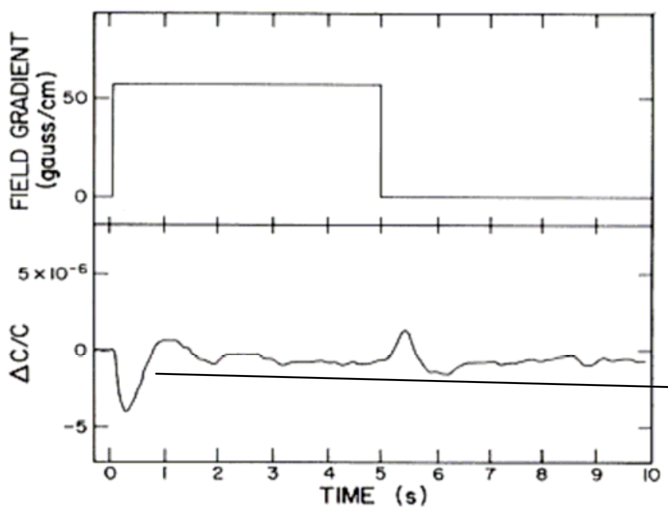
Spin Pressure

Pressure

Internal Magnetic Field

(ignoring small temperature gradient and acceleration terms)





Rue, and Kojima PRB 28.6582(1983)

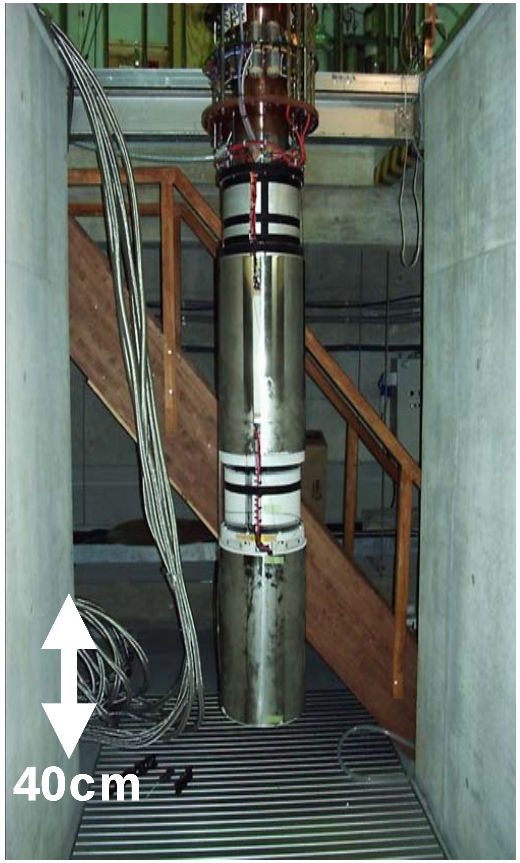
Spin relaxation

2. Early experiment

Motivation

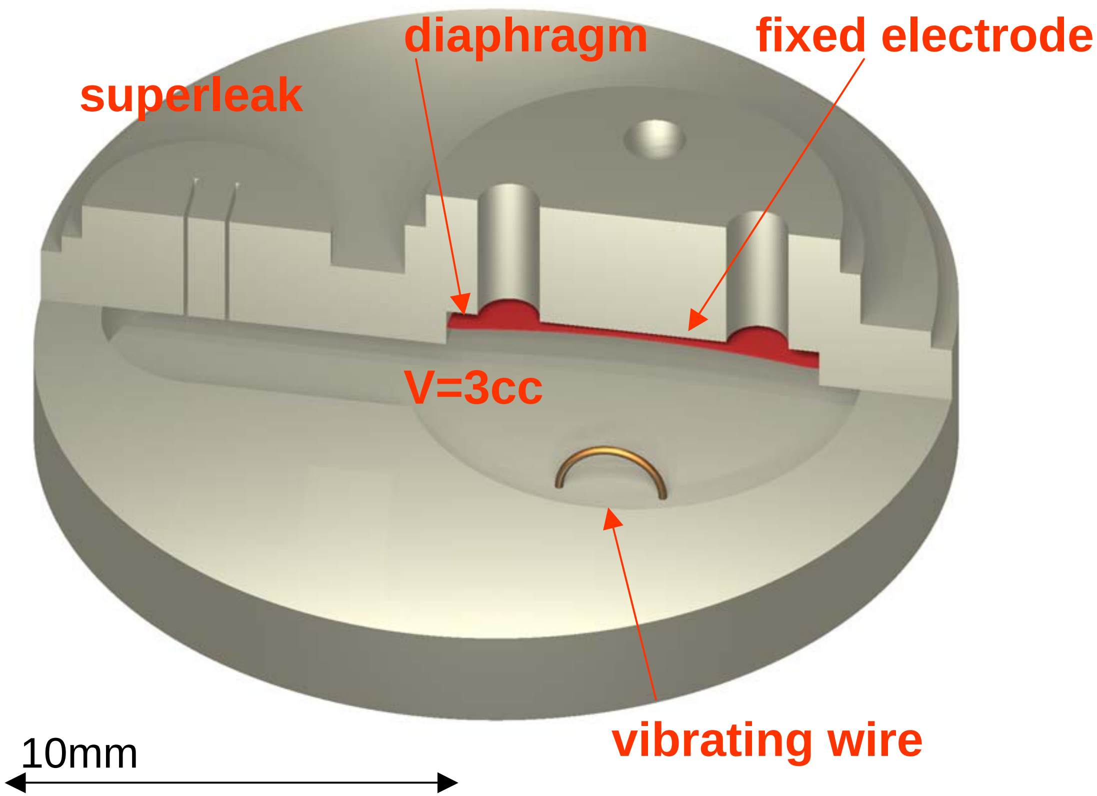
To investigate Magnetic Fountain Effect
in homogeneous and large magnetic field

ISSP large 15 T sc magnet and nuclear demagnetization refrigerator

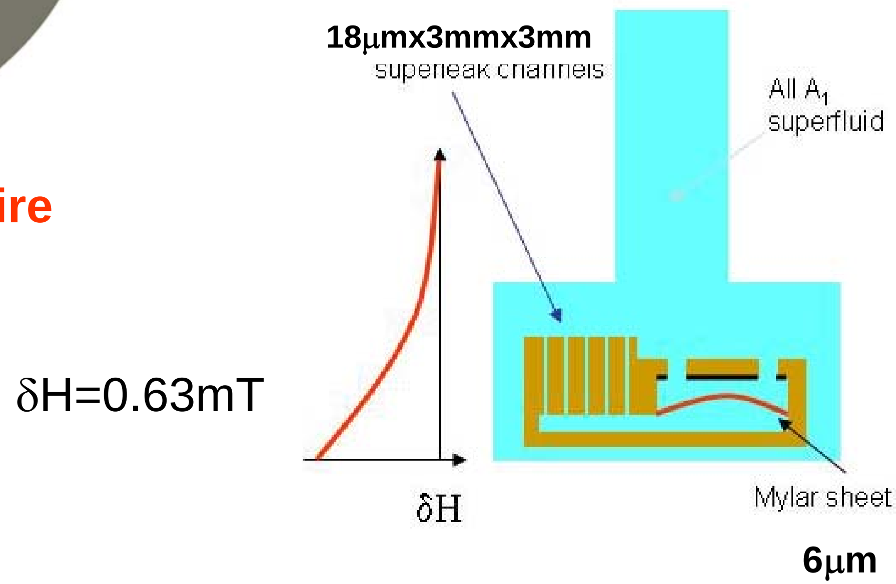


Experimental Cell –Magnetic Fountain Effects

Detector chamber



Outer chamber



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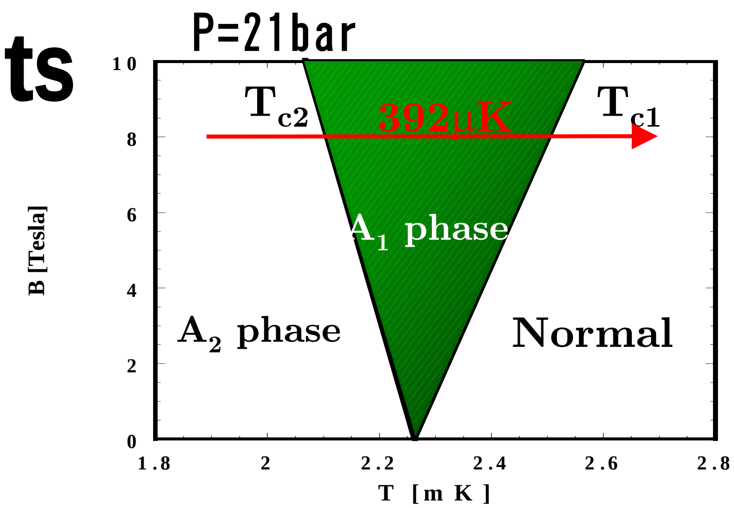
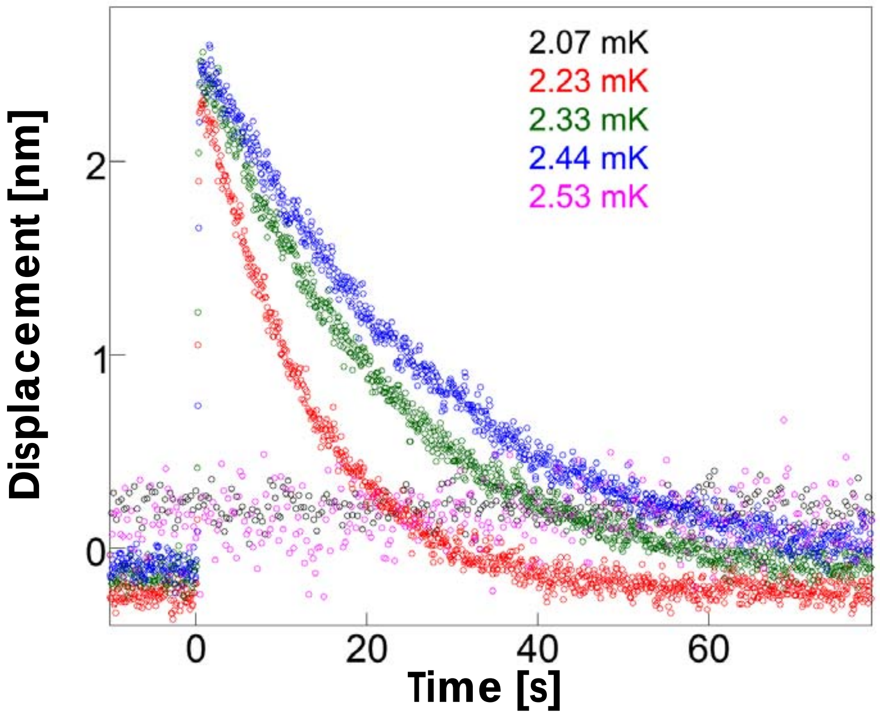
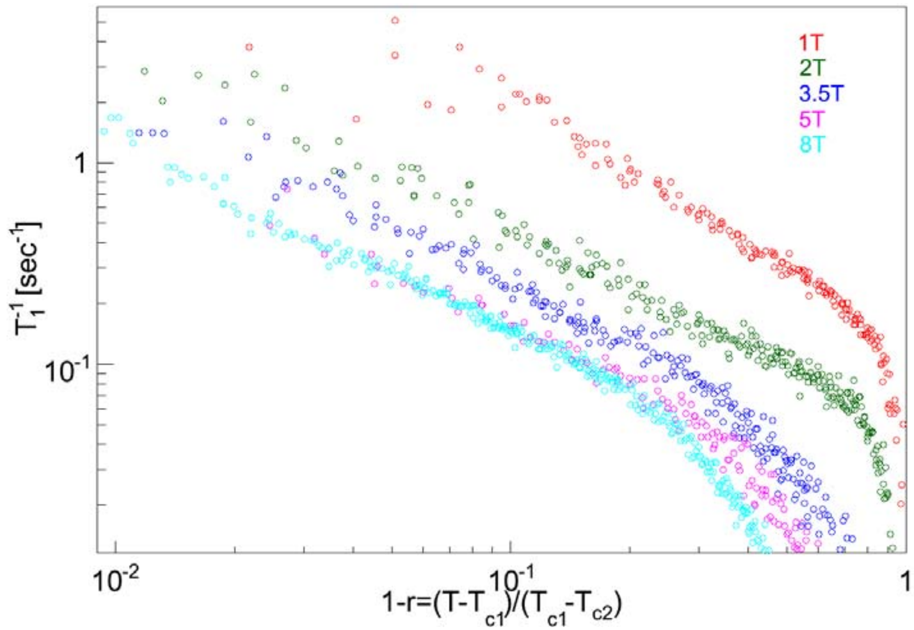
MEF experiments: Results



T-dependence at B=8T, P=21bar



T-dependence of spin relaxation rate at P=21bar



Displacement

~ Magnetic Fountain Pressure

Pressure relaxation

~Spin relaxation

(accounts for normal fluid flow, etc)

Minority Spin Condensate

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Theoretical Prediction

Monien and Tewordt (1985)
Schopohl, Marquardt and Tewordt (1984)

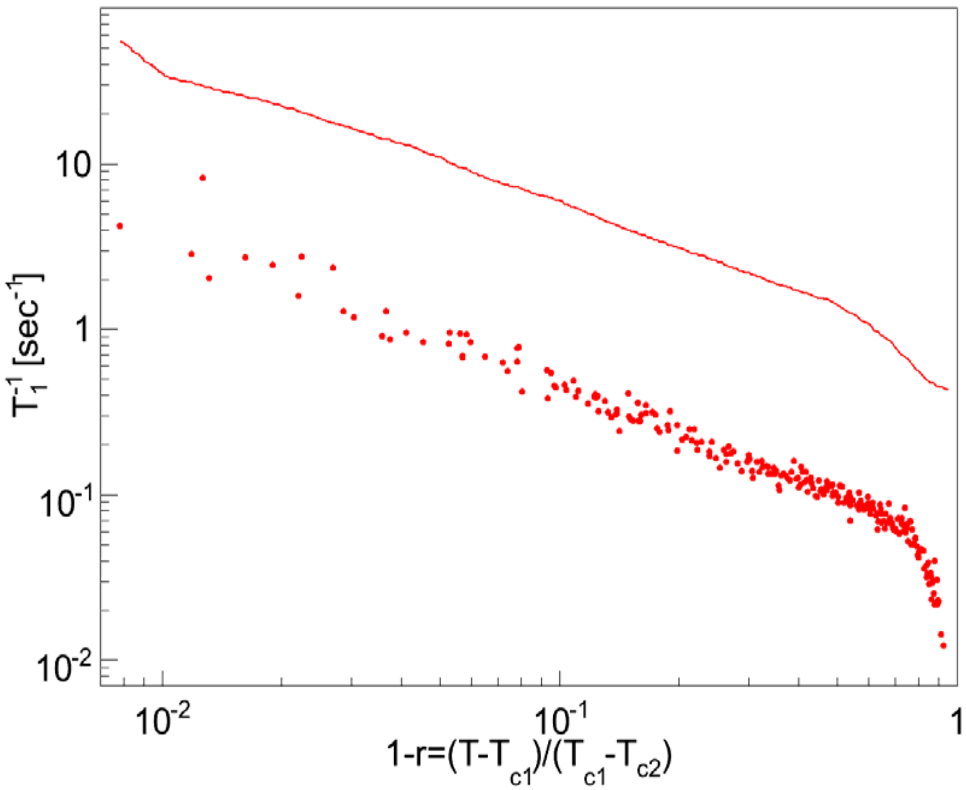
Existence of M.S.C. with opposite ↓↓ spin pairs and energy gap $\Delta_{\downarrow\downarrow}$
(because of stabilization from dipolar energy)

M.S.C is very small ~order of 10-3
M.S.C. increase near T_{c2}

→ **Intrinsic relaxation (Leggett-Takagi Theory)**

Relaxation Rate

— calculated from MSC theory
● observation



T-dependence =good agreement,
value = ten times smaller

3. Spin pump experiments

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Basic Idea

Almost totally spin polarized condensate

+

Force the condensate to pass through the superleak

Superleak = Spin filter

Schematic View

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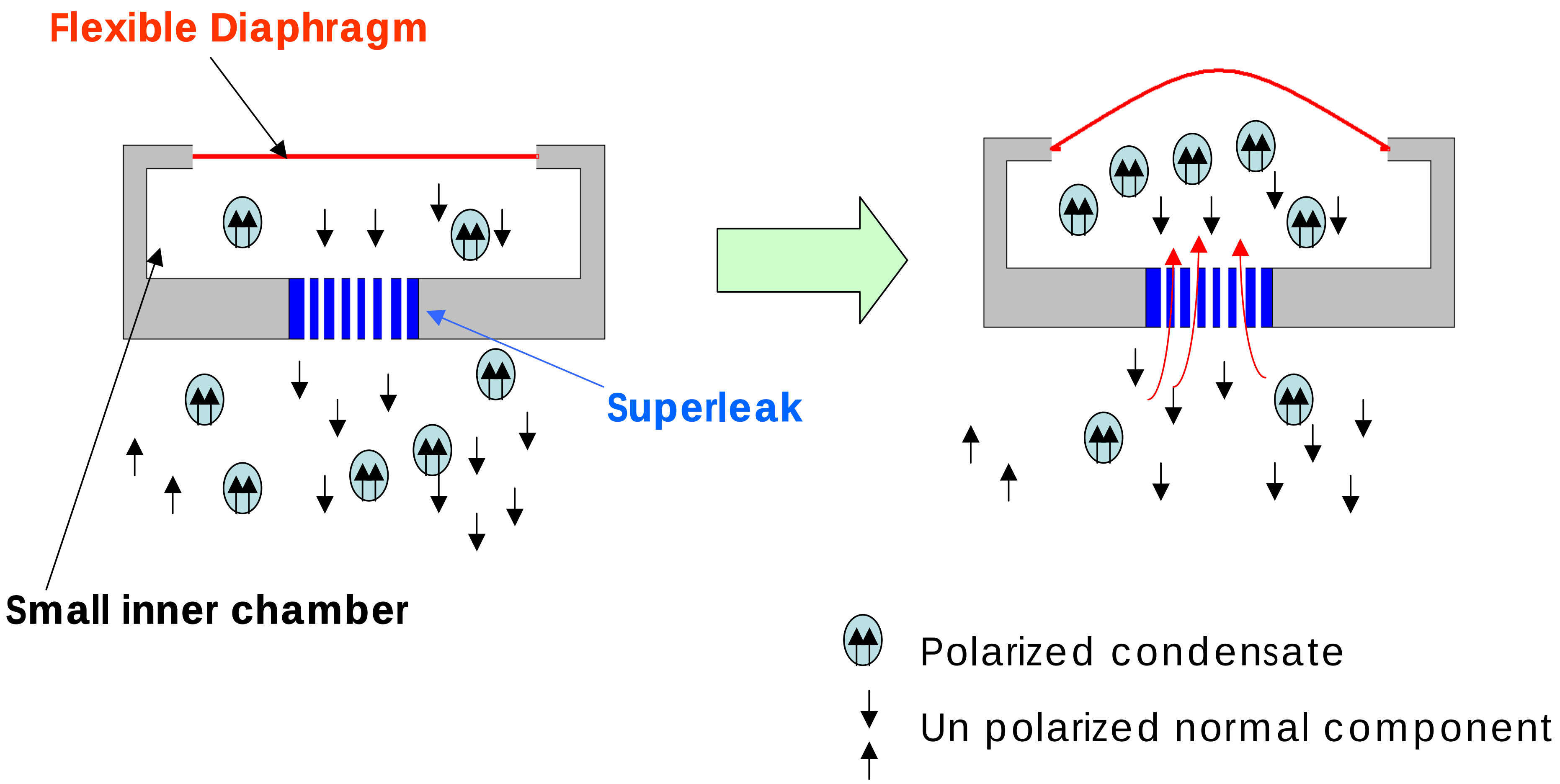

Polarization in a small inner chamber should be increased by pumping action

→ **^{3}He SPIN PUMP**

Experimental Cell – Spin pump

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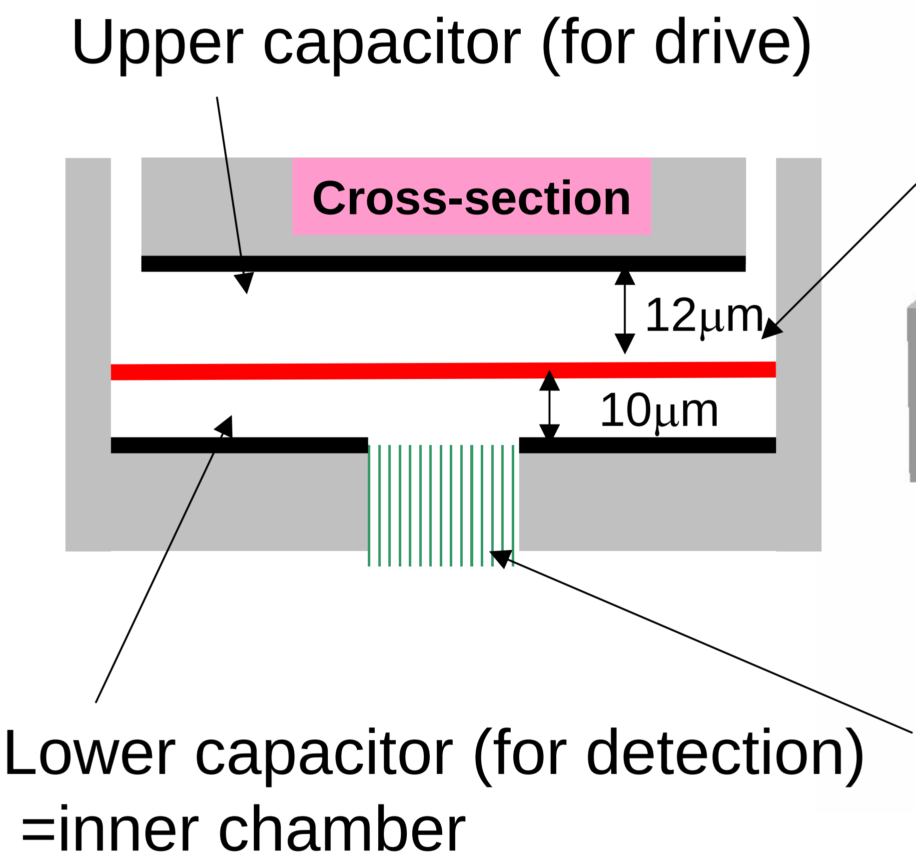

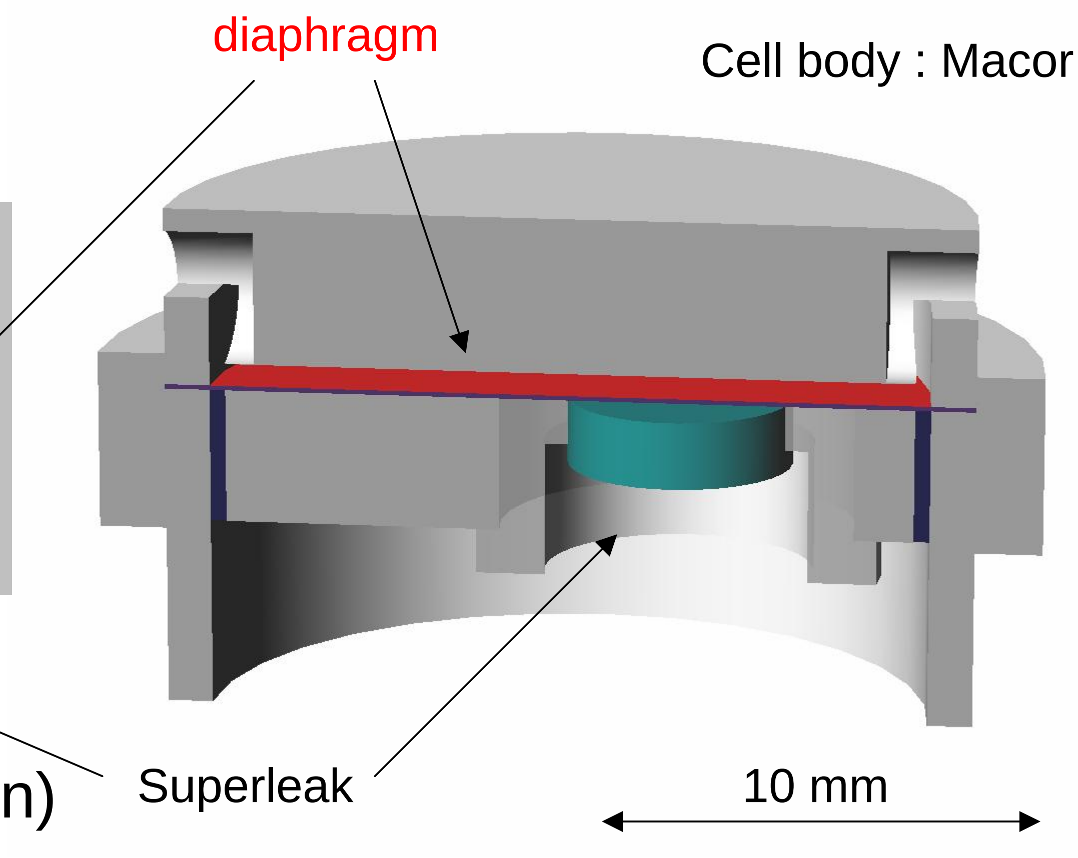

Increasing polarization

$$\Delta S / S \sim \Delta V / V$$

If no spin relaxation

Volume of inner chamber: V=0.016 cm^3

determined by parasitic volume

Diaphragm motion: 1.6 μm at 200 Vdc

Result in A_2 phase, no spin pressure

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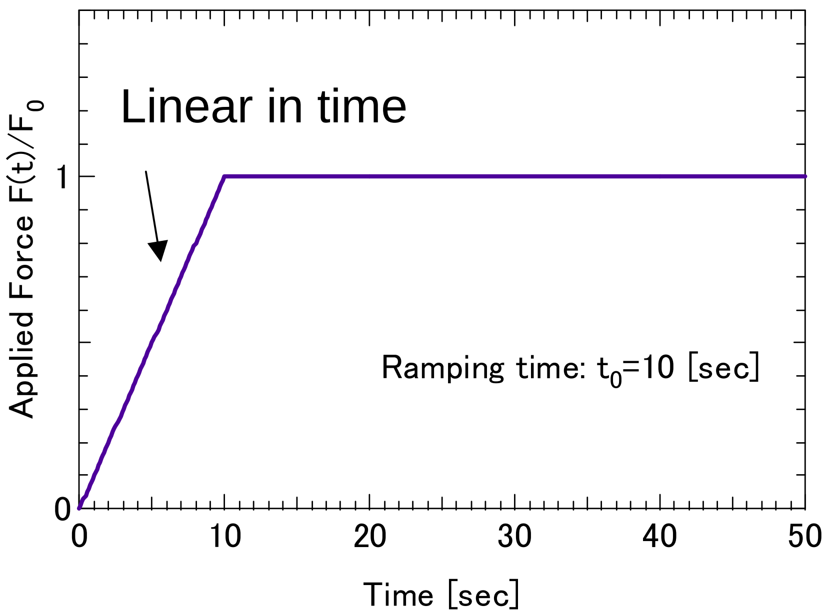
28 bar, 5T, A_2 phase

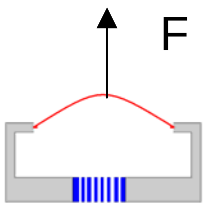
Applied force, F



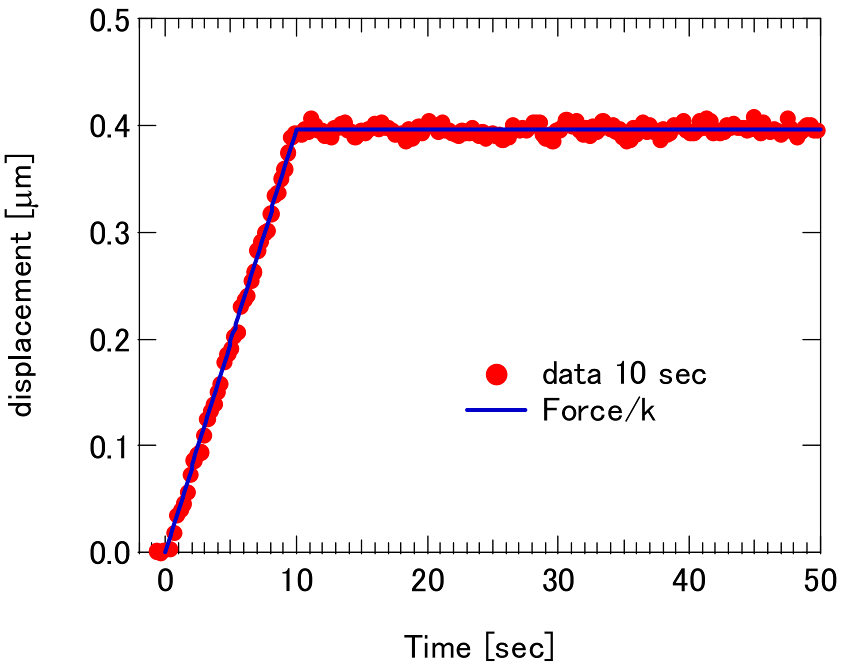
$$F(t) = F_0 \times t / t_0$$

F_0:maximum force

t_0: ramping time



Response, displacement



Determined only by F,
No additional pressure

Result in A_1 phase

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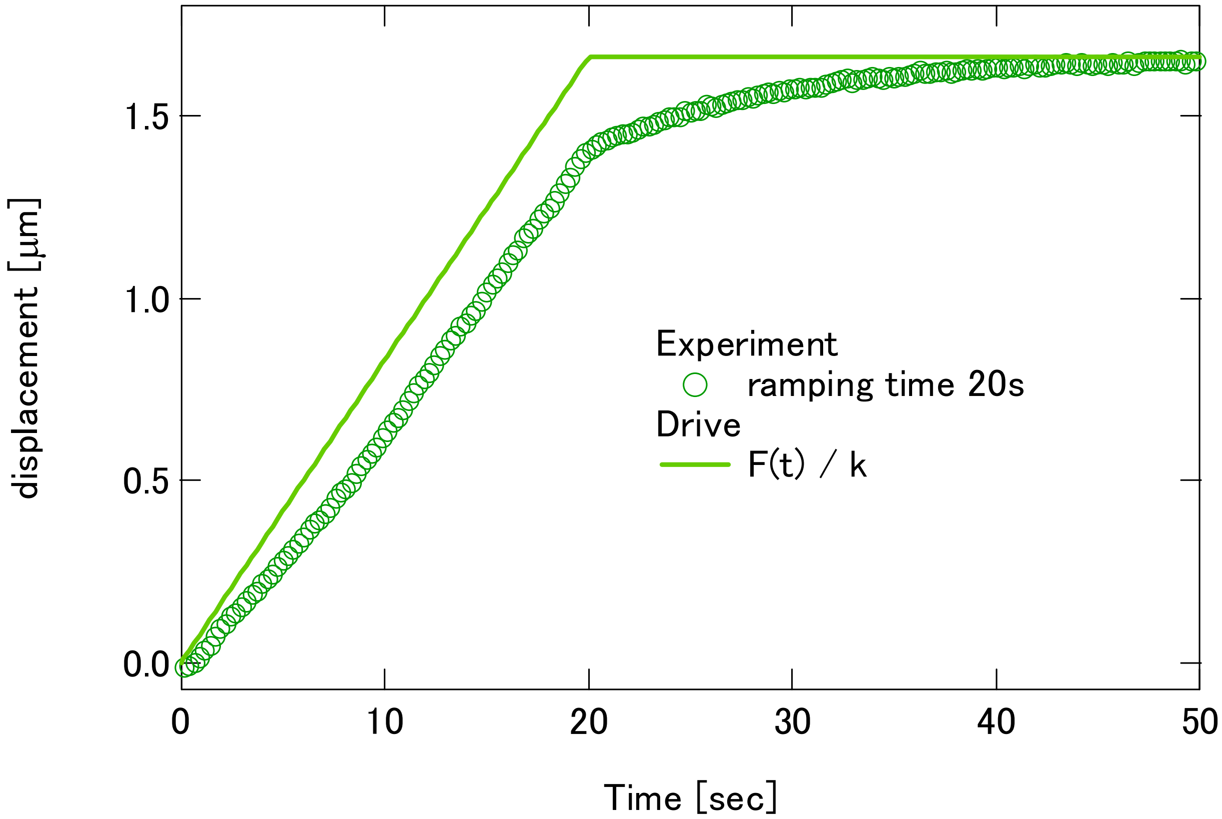
28 bar, 5T, A_1 phase



Delay in diaphragm motion

Pressure difference

$$k\Delta d = F(t) + A \times P_{diff}(t)$$

$$A : area\ of\ diaphragm$$

Spin Pressure

$$P_{diff}(t) = \rho\nu\left(-\frac{\gamma}{\chi}\Delta S(t)\right)$$

Proportional to increase of polarization difference In inner chamber

Polarization

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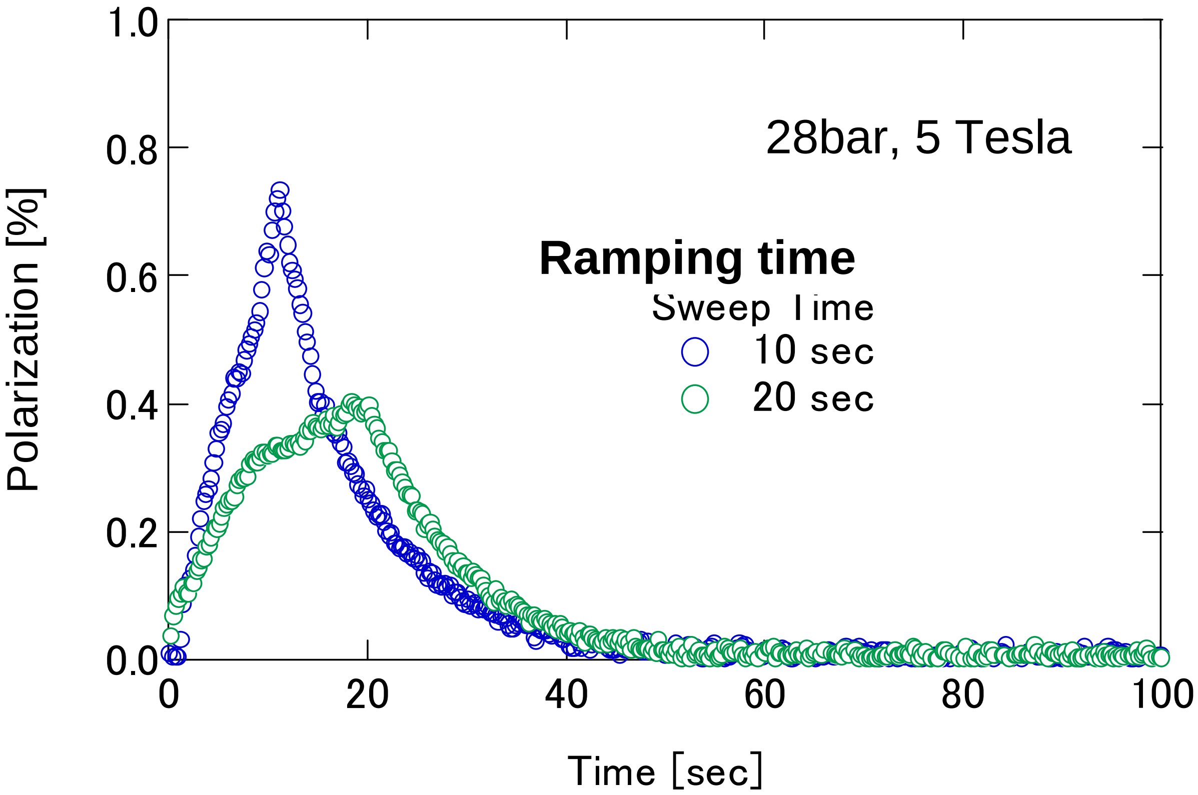


Calculated from difference between data and force

$$k\Delta d = F(t) + A \times P_{diff}(t)$$

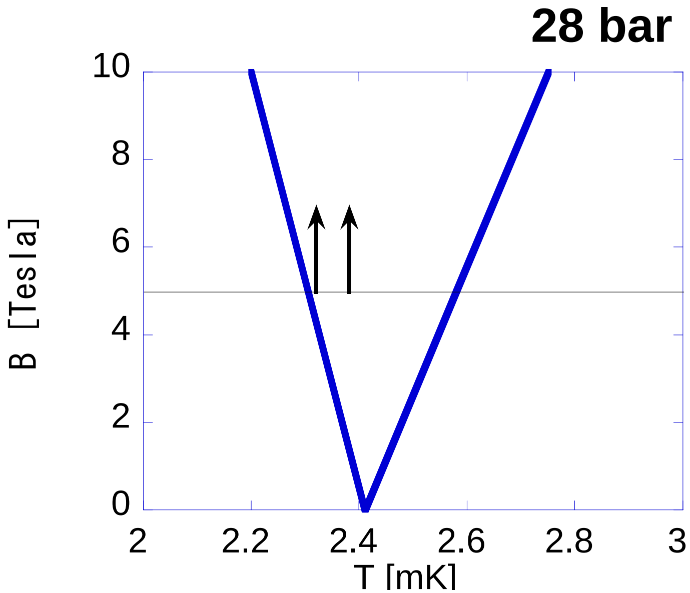
$$P_{diff}(t) = \rho\nu(-\frac{\gamma}{\chi}\Delta S(t))$$

Initial polarization of liquid ^{3}He =2.2 % at 5Tesla,

Maximum increased polarization 0.8 %

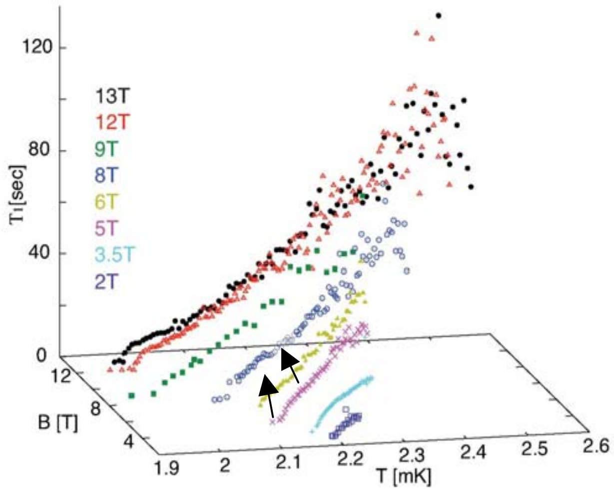
~Increase by 40% from initial polarization

Spin relaxation times at different polarization



Increase by 40% corresponds to 2T

Assuming temperature change negligible



B-dependence of relaxation time in MFE experiments

Spin relaxation time should vary as function of polarization

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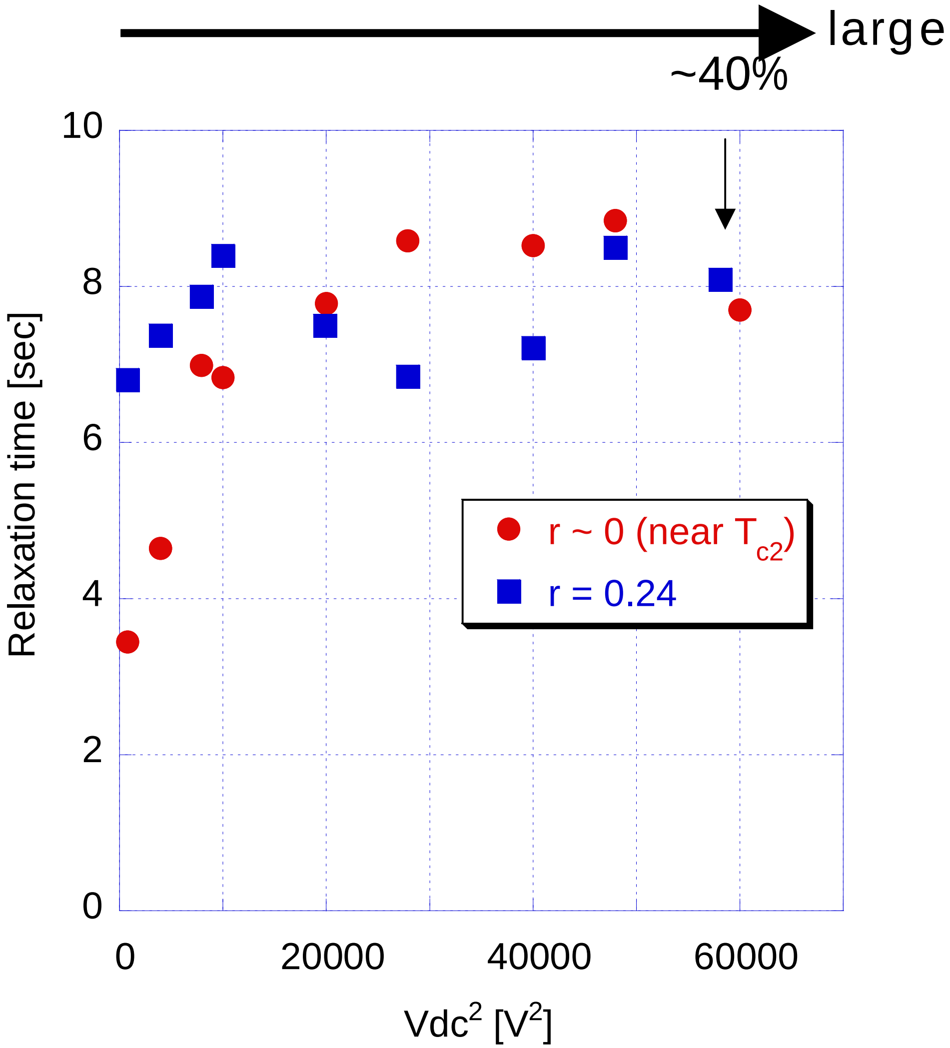
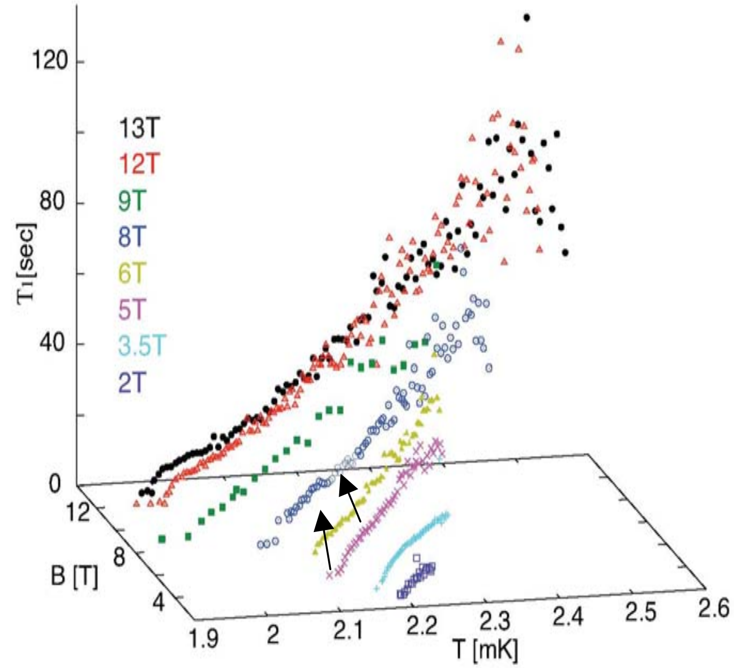
Spin relaxation times at different polarization

Maximum Polarization



diaphragm displacement [a.u]



Consistent with B-dependence of relaxation times

Summary

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- Spin Relaxation in ^{3}He A1 phase
  - In homogeneous and large magnetic fields
  - Temperature dependent spin relaxation rate
  - Comparison with M.S.C theory

- Spin pump experiment
  - Polarization was increased by 40 %, estimated from spin pressure.
  - Polarization dependence of Spin relaxation rate

- Alternative method for spin polarized ^{3}He experiment in "mK" temperature range

- Future Aspects
  - What happens in larger polarized 3He?

    Spin relaxation?, Stability of superfluid phase?