To Dubna-2007 Workshop

On behalf of the COMPASS collaboration

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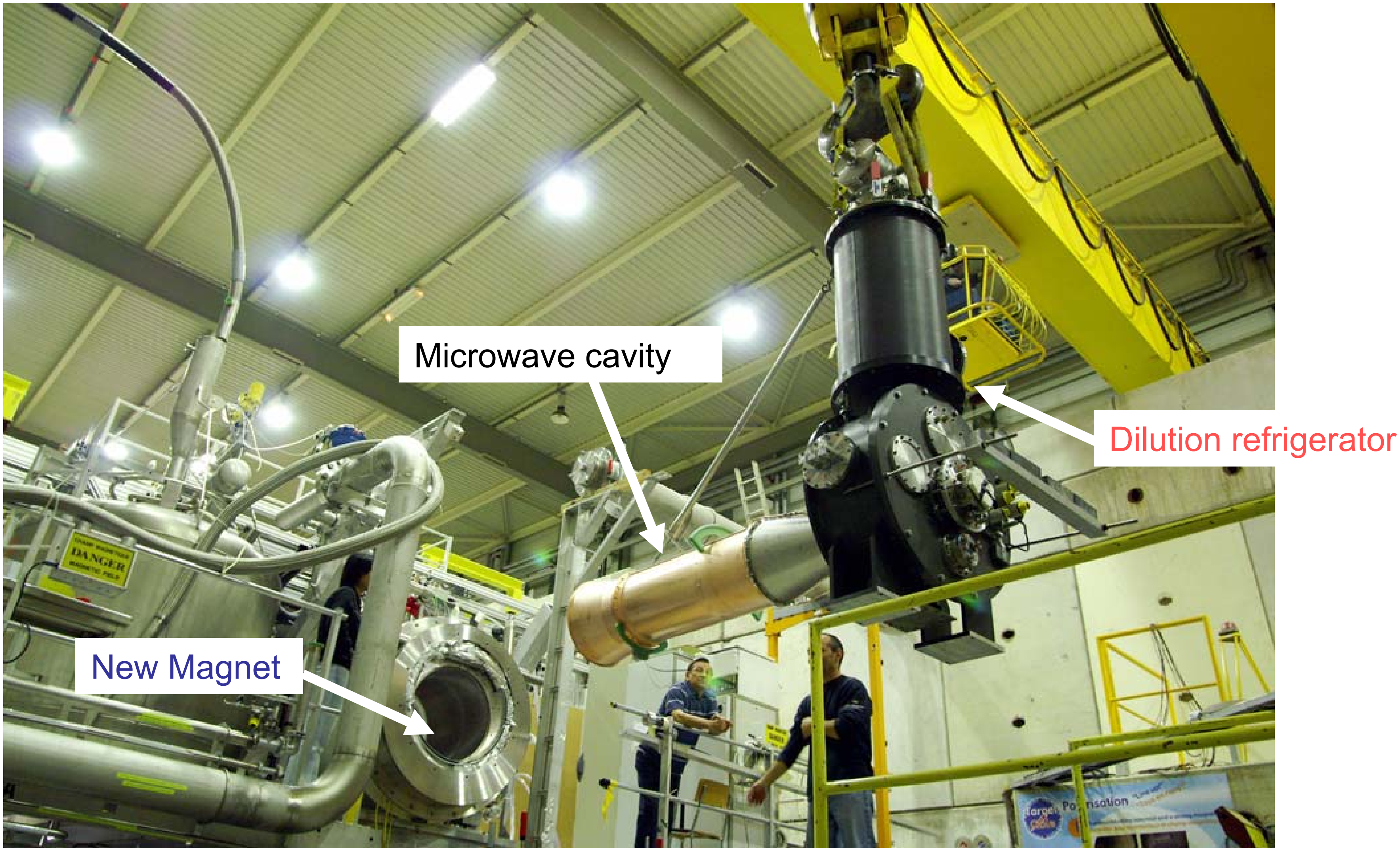
Nonlinear Magnetic Phenomena in Highly Polarized Target Materials

We briefly summarize and survey nonlinear magnetic phenomena observed at high nuclear polarizations

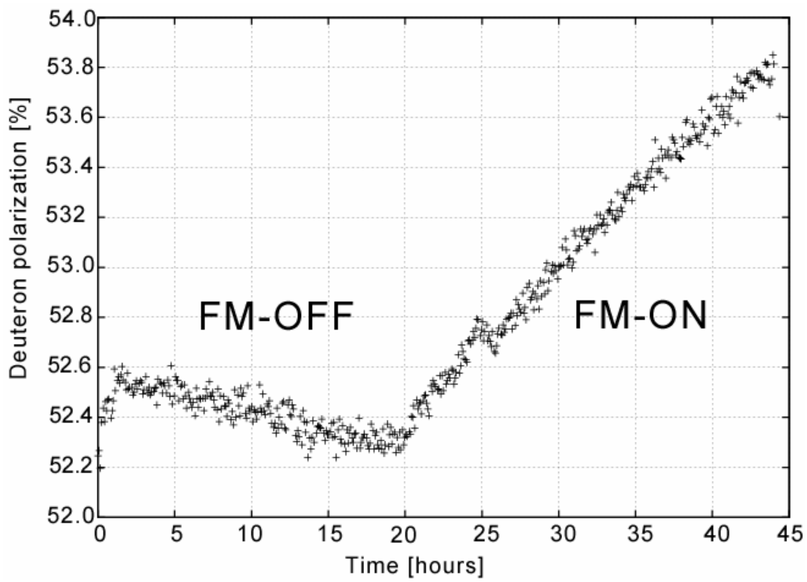
1. **Frequency modulation effect**
2. **Distortions of the NMR line shape**
3. **Polarization by cross relaxation between nuclear species in NH3**
4. **Maser and superradiation phenomena**
5. **Detection of the electromagnetic radiation emitted by negatively polarized nuclei at low magnetic fields**

COMPASS polarized target mounting



Frequency modulation effect

In a target polarized by the Dynamic Nuclear Polarization (DNP) method the frequency modulation effect enables record polarizations as the result of the multimode irradiation of the target material at about 0.1 K temperatures.



This plot shows the build-up of deuteron polarization in LiD over time with and without FM

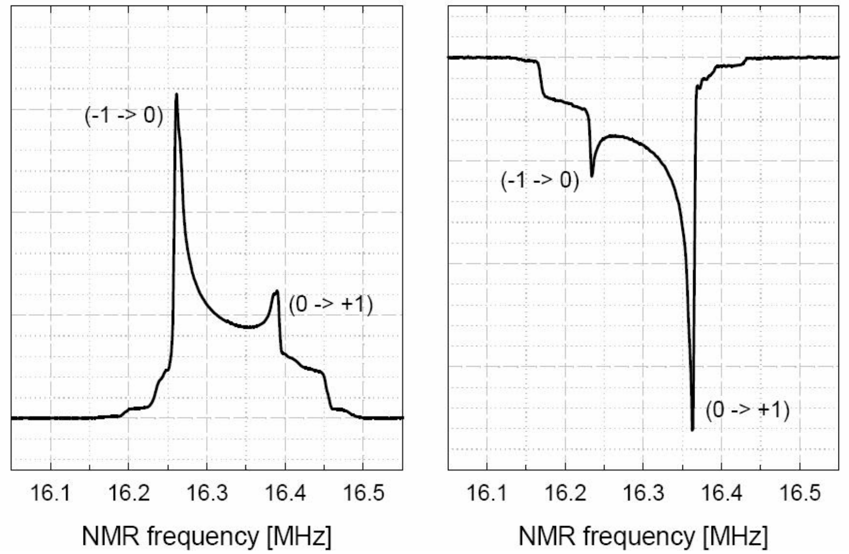
See about FM: →

Y.F. Kisselev, Nucl. Instr. And Meth., A 356, 99 (1995);

Y. F. Kisselev et. al., Proceeding of the 11_th Int. Workshop on Polar. Sources and Target, Tokyo. Japan, 14 -17 Nov. 2005, p.63.

Distortions of the NMR line shape

The high nuclear polarization causes the strong asymmetry of the NMR line shape of deuterons.

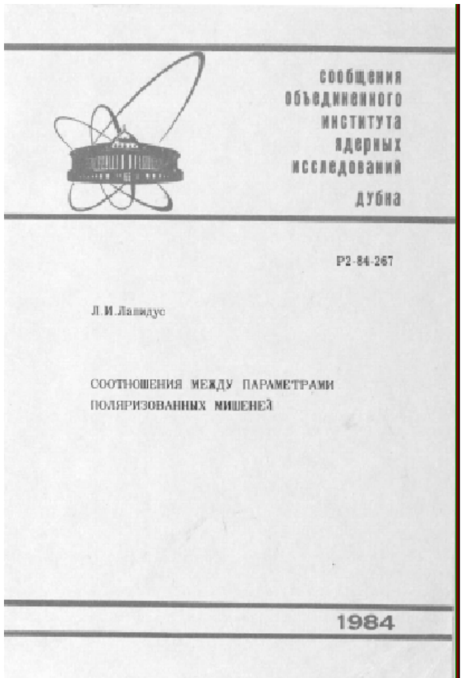


NMR-signals of D-propanediol (left) and D-butanol (right) with record polarizations of -81 % and +80 %, respectively

(Bochum, Germany, S.T. Goertz et al., NIM A 526 (2004) 43-52).

Our Workshop is devoted to the blessed memory of Prof. L.I. Lapidus.

The important formulas for the calculation of the polarization and alignment were obtained in his last publication.



Сообщения
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Р2-84-267

Л.И.Лапидус

СООТНОШЕНИЯ МЕЖДУ ПАРАМЕТРАМИ
ПОЛЯРИЗОВАННЫХ МИШЕНЕЙ

1984

Well known that, in the case of a week quadrupole interaction, the nuclear polarization of S=1 is calculated by the formula:

$$P_1 = \frac{4\tanh^2 \frac{x}{2}}{3+\tanh^2 \frac{x}{2}} \quad ,$$

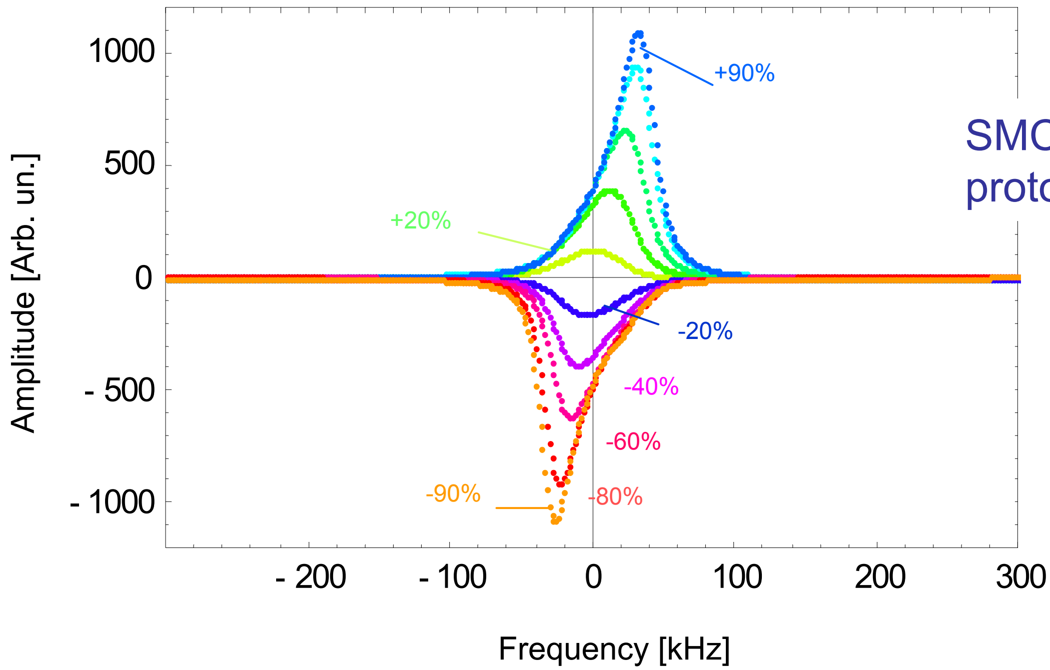
where *x* is the ratio of Zeeman to Boltzmann energy. The general formula was obtained by L. I. Lapidus in 1984 :

$$P_N = P_1\left[1-\frac{(1-\tanh^2 \frac{x}{2})(1-e^{-y})}{1+2e^{-y}+(2e^{-y}-1)\tanh^2 \frac{x}{2}}\right] \quad ,$$

where *y* takes into account the quadrupole interaction. For the fist time, I verified this formula for N_{14} –nuclei in NH_3. It gives 1.46 correction factor at zero polarization which is in an excellent agreement with our data.

Distortions of the NMR line shape

A strong signal asymmetry was also seen for the case of dipole-dipole interaction between the three protons in the NH3 target material



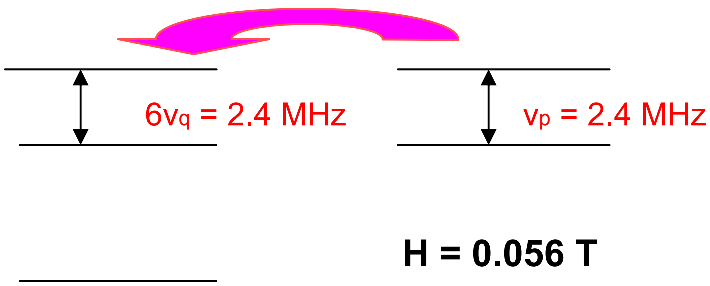
SMC-NH3 - spectra at different proton polarizations.

Our studies showed that the signal asymmetry is proportional to the proton polarization.

Polarization by cross relaxation between nuclear species in NH3

This method can be applied for the fast polarization of nuclei with a small magnetic moment and a strong quadrupole interaction. For example N_{14} –nuclei in NH3 are directly polarized up to only 14 % polarization at 2.5 T and about 0.1 K.

At the same conditions the proton polarization reaches almost 100 %.



In 0.056 T field N_{14}-quadrupole and Zeeman proton splitting are equalized and the fast cross-polarization between N_{14} and 1H enlarged N_{14} polarization from 14 to 50 %.

See about FM:

B. Adeva, Ch. Dulya, J. Kyynäräinen et al., CERN Preprint, Geneva, 16 June 1997, CERN-PPE/97-66.

F.S. Dzheparov and Yu.F. Kisselev, Pis'ma Zh. Eksp. Teor. Fiz., vol. 68, 539 (1998)

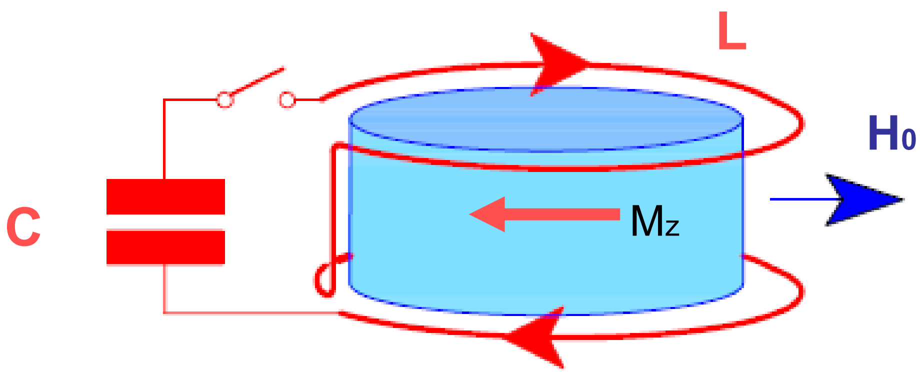
Maser and superradiation phenomena

Used Bloch and Kirchhoff equations one can show that under condition

$$T_2^{-1} = \frac{1}{2}\mu_0 \eta Q \left|M_z\right|,$$

<N. Blombergen and R. Pound, Phys. Rev., 95, 1954, 8].

where μ0 and η are constants, Q is the quality factor and Mz is the nuclear magnetization, the



resonant circuit, tuned on the nuclear Larmor frequency, has no losses.

Such a circuit must ring at the resonant frequency if any change of the magnetic flux .

The maser and superradiation were investigated in the papers below:

See a bout FM: ➡

P. Bösiger, E. Brun, D. Meier, Phys. Rev. Let, **38**, 602 (1976);

P. Bösiger, E. Brun, D. Meier, Phys. Rev., A **20**, 1073 (1979);

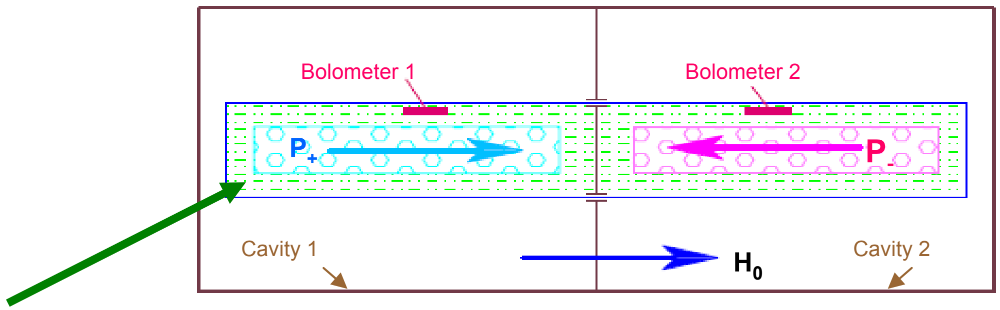
Yu.F. Kisselev et al., Zh. Eksp. Teor.. Fiz., **94,** 344 (1988);

L.A. Reichertz et al., Nucl. Instr. And Meth., A 340, 278 (1994).

Detection of the electromagnetic radiation by negatively polarized nuclei at low magnetic fields

To understand more about spin oscillations, Let's consider the COMPASS 2001-2004 experiment

(SPIN-2004, Trieste, Italy, Y. Kisselev et al., p. 816.)

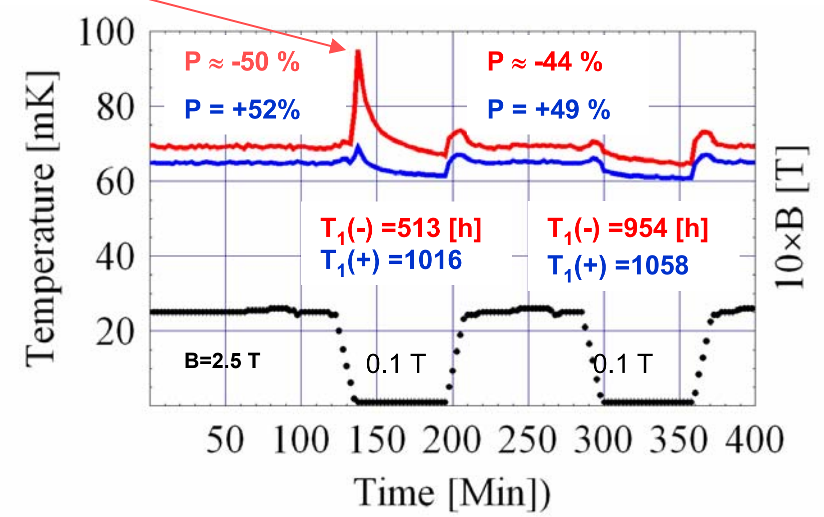


3He/4He mixture, T = 70 mK

Also our study showed that the negative polarization relaxes faster when the deuteron polarization is above 37%

Detection of the electromagnetic radiation by negatively polarized nuclei at low magnetic fields

This signal demonstrates the radiofrequency irradiation emitted by the negatively polarized target material

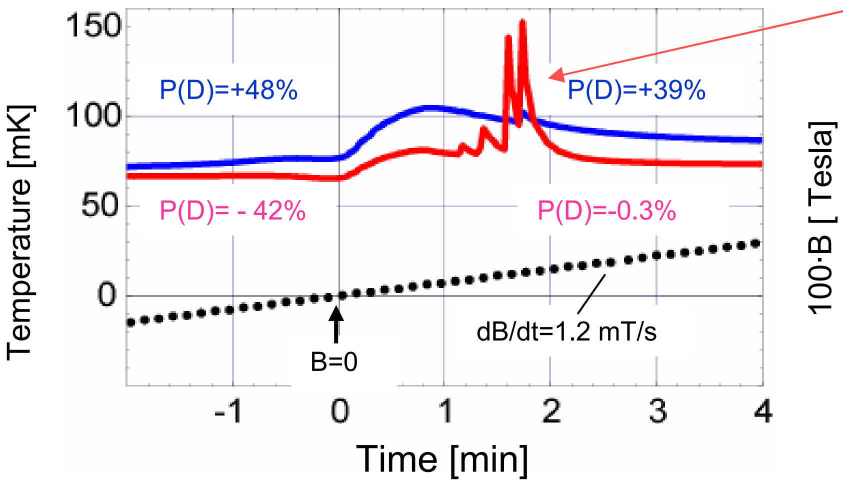


This is really so because our study also showed that the negative polarization relaxes faster when the deuteron polarization is above 37%

In the COMPASS experiments during 2001-2004 we have found out that negative polarization in LiD is lower then the positive one, P= + 57 and P= - 52 %

Detection of the electromagnetic radiation by negatively polarized nuclei at low magnetic fields

The radio-frequency radiation becomes spectrally resolved by changing of the magnetic field from -2.5 T to about +0.15 T.



Here you can see the coherent radiation of D and Li_7 obtained on the COMPASS polarized target at CERN

This is the first observation of the spectrally resolve resonanc radiation emitted when the nuclear Larmor frequency falls within a range of characteristic frequencies of the electron dipole-dipole reservoir.

Resume

The report surveys the further properties of highly polarized nuclear systems:

1 Frequency modulation effect and the distortions of the NMR lineshape promote a further development of the polarized target technique.

2 Maser and superradiation phenomena contribute to the development of quantum statistical physics; they are also serving as unique models for the applied synergetic.

3 It was demonstrated that the electromagnetic radiation from LiD shortens both the relaxation time and the ultimate value of negative deuteron polarization.

4 It was shown that the spectrally resolved selfradiation of spins detected “in-situ” at the very low magnetic field is interesting for further investigations as well as for practical applications in the nuclear spectroscopy.