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Precise field map measurements for Hall-B Frozen Spin Target Polarizing Magnet

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Polarizing magnet main requirements

In frozen spin mode, the polarizing magnet should provide:

1) Optimal polarizing conditions lasting during polarization process.

2) Fast recovering the optimal polarizing conditions during repolarizing cycles.

3) Precise way of positioning the homogeneous field area over a target area.

Hall-B Frozen Spin Target

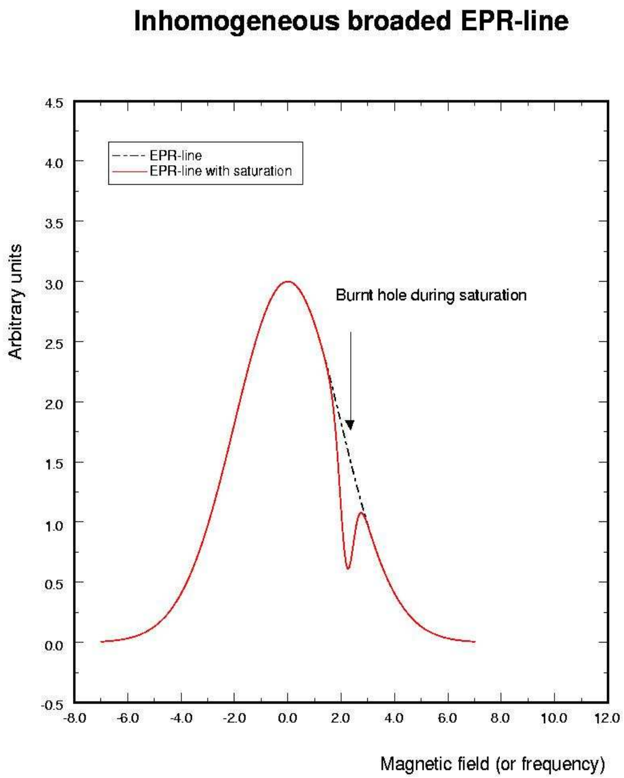
Hall-B Frozen Spin Target will use a dynamic way to enhance
a polarization of target nuclei (DNP technique).

To realize the DNP technique, polarized targets use paramagnetic impurities (unpaired electrons) embedded in a host target material (alcohols with Cr-V, irradiated ammonia, irradiated lithium, etc.).

DNP process is defined by concentration and behavior of those paramagnetic centers (shown by EPR-line shape and width, spectral diffusion rate, etc.).

Thus a choice of a target material (material plus paramagnetic centers) defines DNP process which eventually impacts the experimental setup and in particular the polarizing magnet field requirements.

DNP mechanisms



For the chosen target material, DNP process is defined by concentration and properties of paramagnetic centers:

1) relation between the width σ of the EPR-line
and the nuclear Larmor frequency ω_I;

$\sigma \ll \omega_I$ -- solid effect;
$\sigma > \omega_I$ -- differential solid effect, dynamic cooling,
cross relaxation;

2) rate of spectral diffusion of a saturated transition
inside the broaded EPR-line;

low rate -- differential solid effect, cross relaxation;
high rate -- dynamic cooling.

The paramagnetic centers (PC) of all conventional materials have an EPR-line width σ which is "broad" as compare with the corresponding Zeeman nuclear frequencies ω_I.

Polarization properties of materials with the broad EPR-line

1) Function “polarization value vs magnetic field” has a dispersion shape.

2) Distance between peaks of max polarization $\Delta H = H_+ - H_-$ is defined by DNP mechanism and does not depend on a type of polarizable nuclei.

$$\Delta H \approx \sigma \text{ (EPR-line width)}$$

3) Value of polarization enhancement does not depend on the type of nuclei but EPR-line properties.

Conventional materials

Material	EPR-line Width, σ	Proton Larmor Frequency, 5.0 T ω_i, Mhz	Spectral Diffusion	DNP	Distance between Polarization peaks ΔH, Oe	PC Concentration x 10^{20} cm^3	Reference
Propanediol with EHBA-Cr-V	750 Mhz (270 Oe)	212	High	Dynamic Cooling	270	1.2 – 2.5	Kharkov, [1]
Irradiated ammonia	200 Mhz (70 Oe)	212	Low	Differential Solid effect	90	~ 1.0	Kharkov, [2,3]
Ethandiol, propanediol with Cr-V	230 Mhz (82 Oe)	212	High	Dynamic Cooling	82	0.1 – 0.5	Dubna, [4]

1)A.A. Belyaev et al., Journ. Applied Spectroscopy, 68(4), 2001, p.623.

2) O. Dzyubak, PhD Thesis.

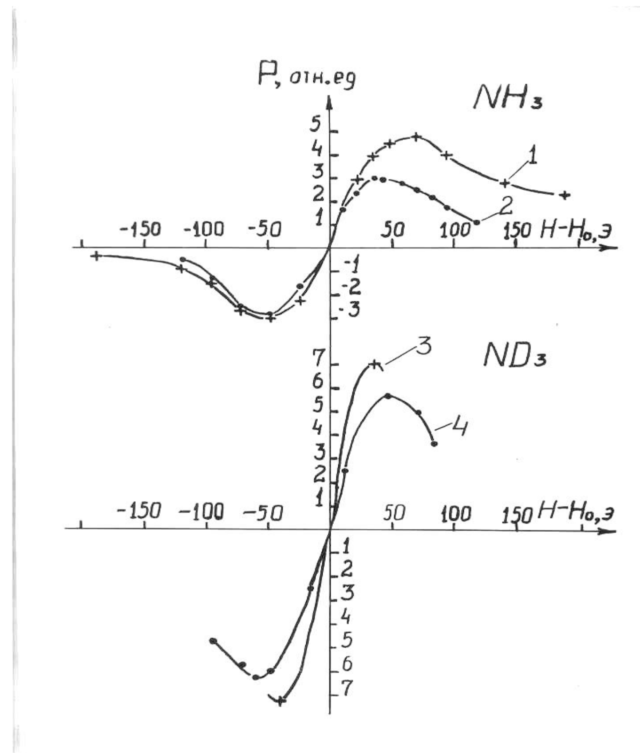
3)A.V. Vertij et al., Sov.Phys.Dokl. 35, 1990, p.899.; A.A. Belyaev et al., AIP Conf. Proc. 187, 1989, p.1336; V.P. Androsov et al., ibid, p.1346;

4) N.C. Borisov et al., Sov.Phys.JETP, 60(6), 1984, p.1291.

Experimental measurements of polarization value vs polarizing field

To prevent polarization “leak”,
a field should be kept under resonance conditions within a tolerance of about

5.0 Oe !



Polarization vs polarizing field (Oe)
(O. Dzyubak, Thesis, 1989)

Field homogeneity requirements
(5.0 Tesla polarizing magnet)

To get the maximum values during polarization process, the magnet field homogeneity over target volume

Cylinder:

D = 15.0 mm
L = 50.0 mm

should be better than

100 ppm !

Recovering the optimal polarizing conditions

"Frozen Spin mode" requires "many" repolarizing cycles during the run period.

Thus before each repolarizing cycle, we should be able to quickly recover optimal field conditions within tolerance:

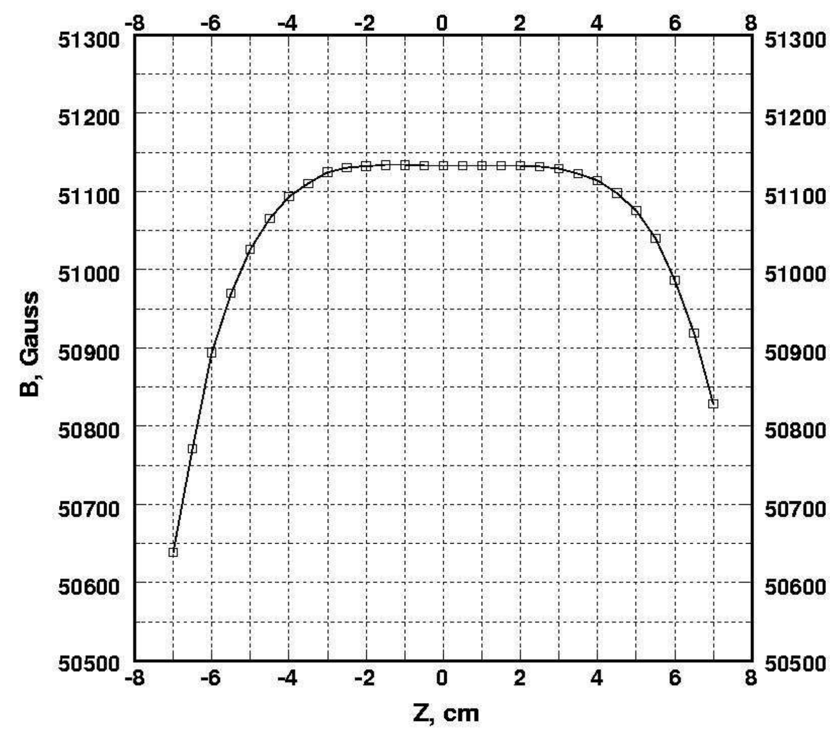
100 ppm !

Cryomagnetics, Inc.

We were only provided
the field map along central axis.

Field map along central axis

(Cryomagnetics, Inc.)



Motivation for field map measurements

- From Cryomagnetics, Inc. we only got a field map along central axis. In fact, we need to know a field homogeneity over a target volume.
- Field map accuracy should be better than 10 ppm.
- After setting up the control system field limits setpoints, we need to know how precisely control system can recover the optimal polarizing field during repolarizing cycles.
- During repolarizing cycles, we need to know what tolerance in positioning a target cell (cryostat tail) relative to the geometrical center of polarizing magnet we can afford.

Classification of magnetic measurement methods

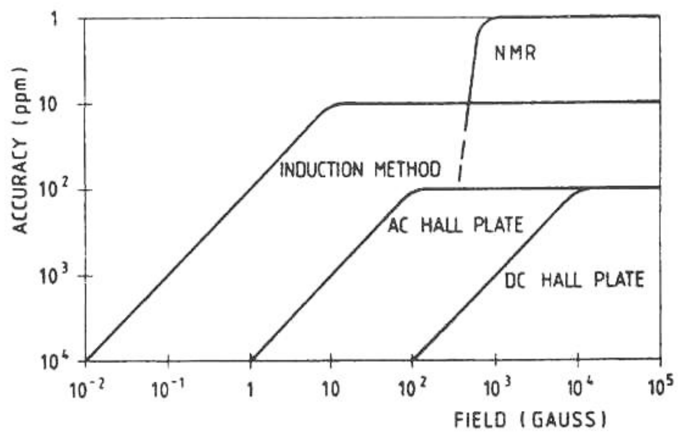


Fig. 1 Measurement methods: accuracies and ranges

Accuracy range:

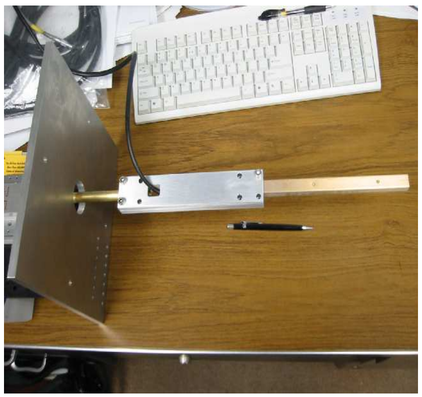
Hall-probe – about 100 ppm
(not sensitive to field inhomogeneity)

NMR-probe – about 1 ppm
(very sensitive to field inhomogeneity)

K.N. Henrichsen (CERN, 1998)

Instrumentation

We made a design and we manufactured two setups



NMR-probe

Probe active area:
4.5 *mm diam*

Covered field area:
20 x 52 mm^2

Hall-probe

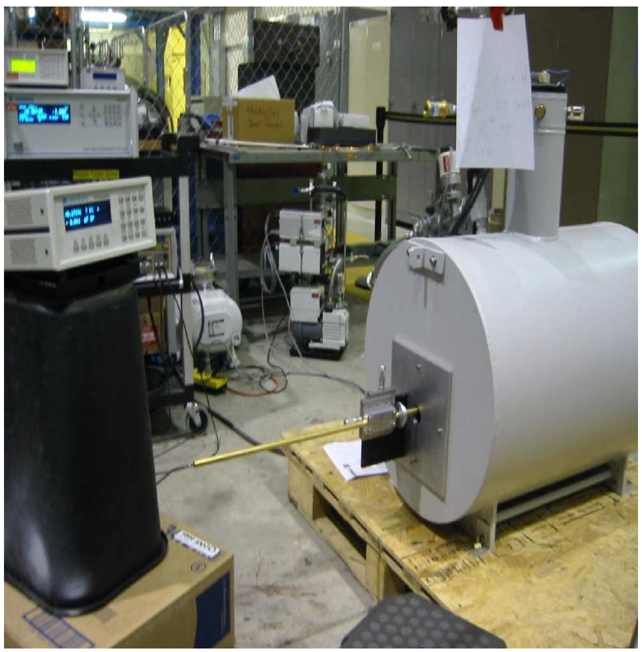
Probe active area:
0.8 *mm diam*

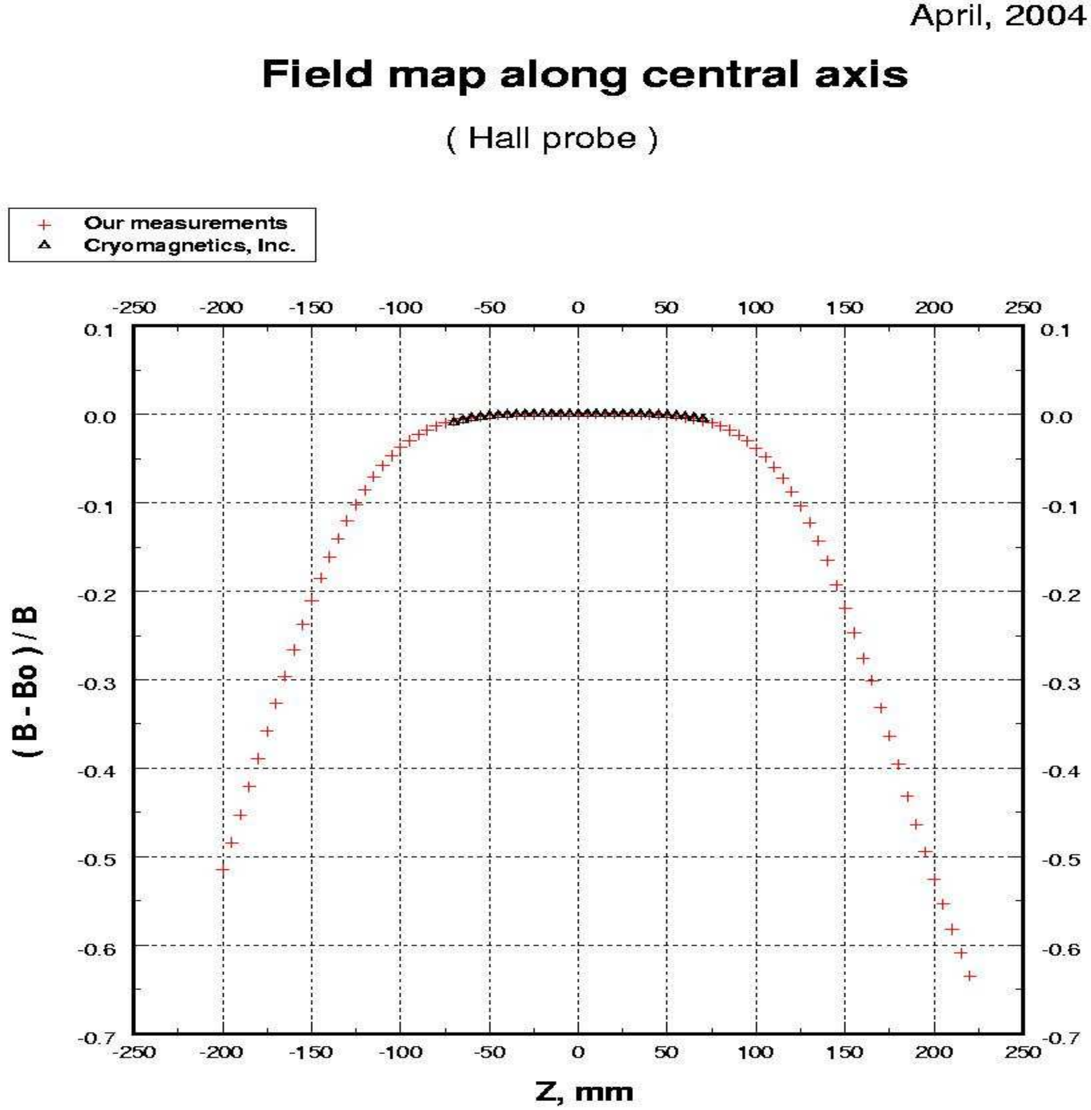
Covered field area:
20 x 120 mm^2

Field along central axis

(2.0 Tesla Hall-probe)

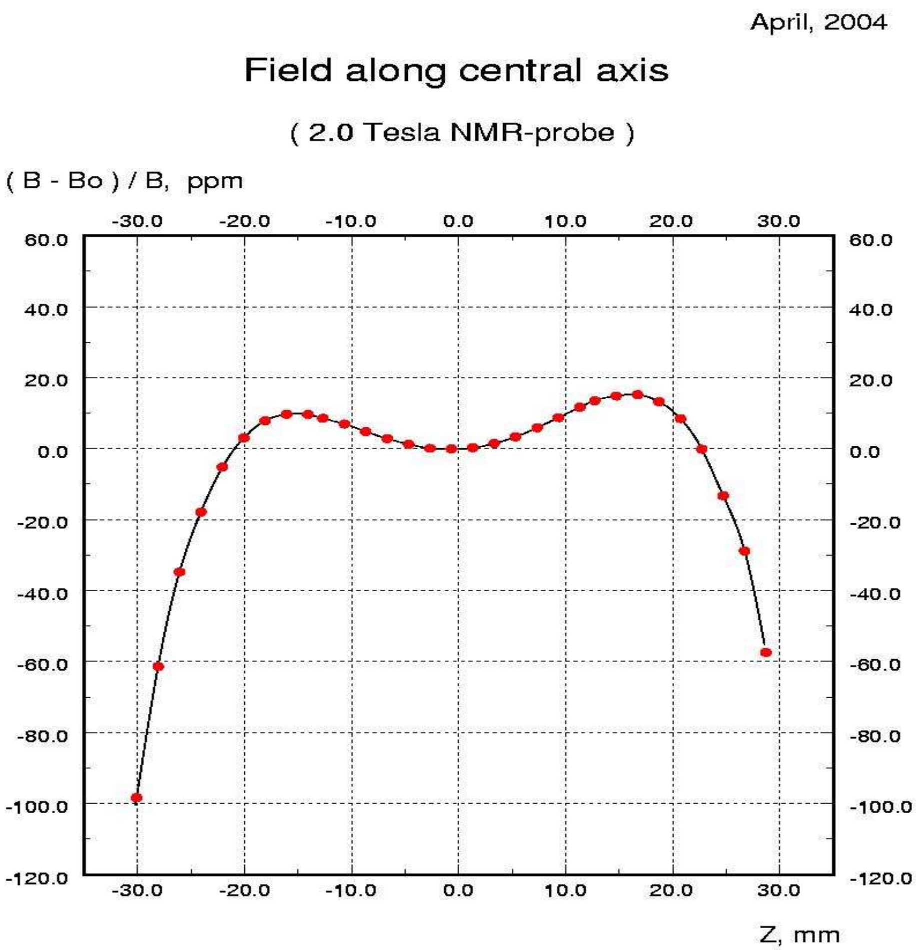
Comparison our measurements with Cryomagnetics, Inc. ones

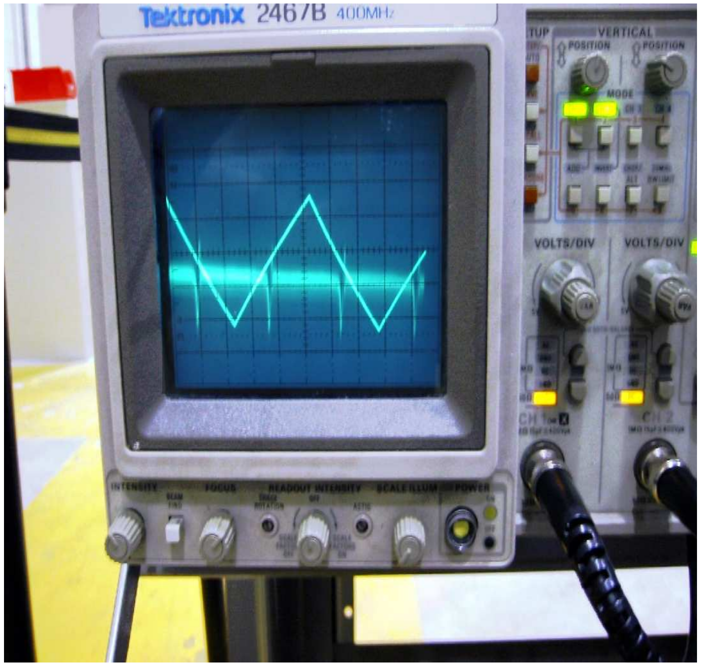




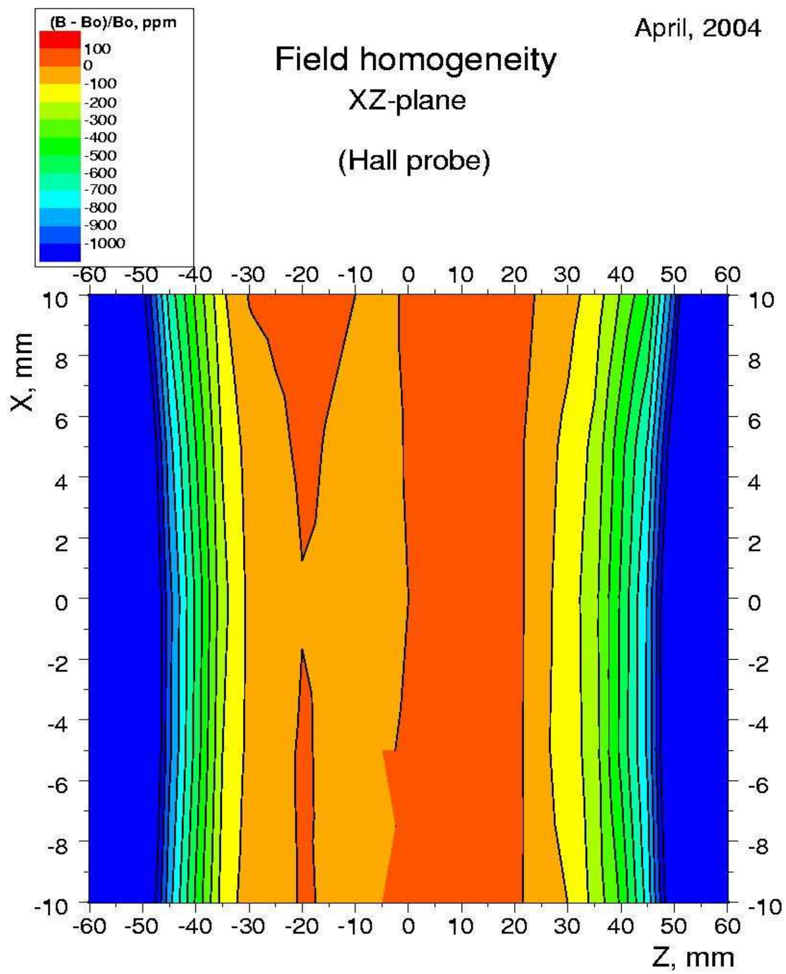
Field along central axis

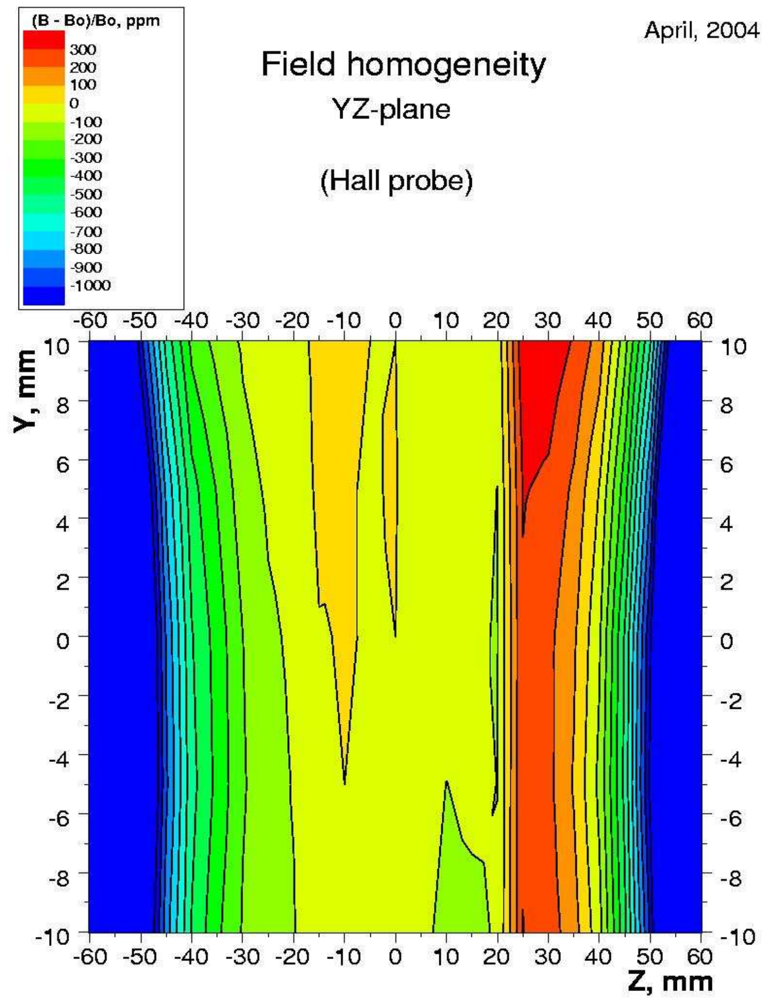
(2.0 Tesla NMR-probe)



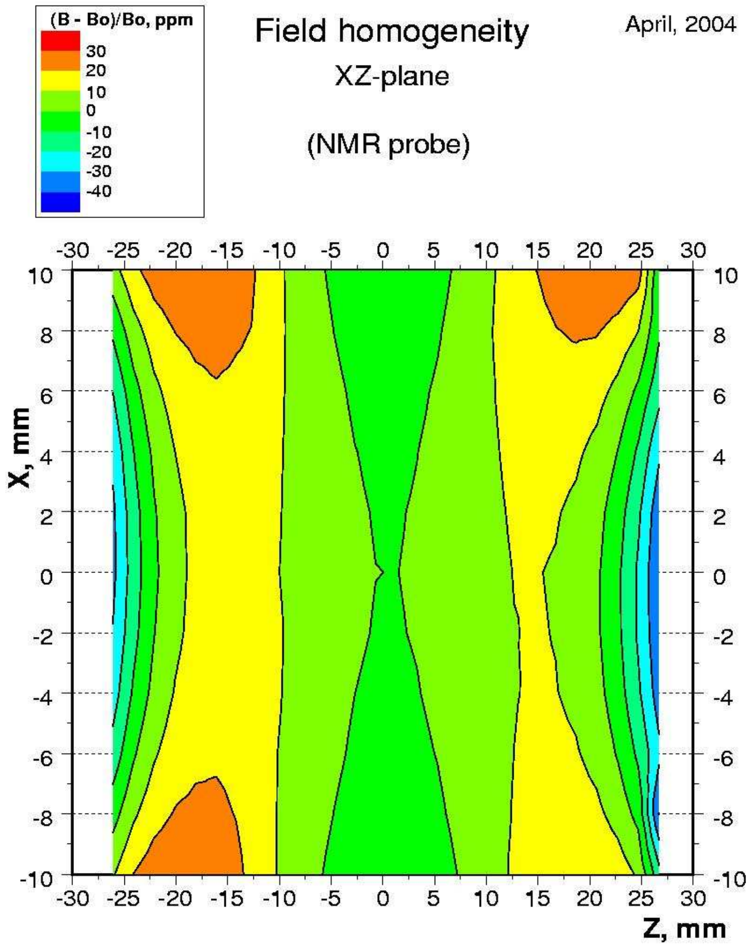


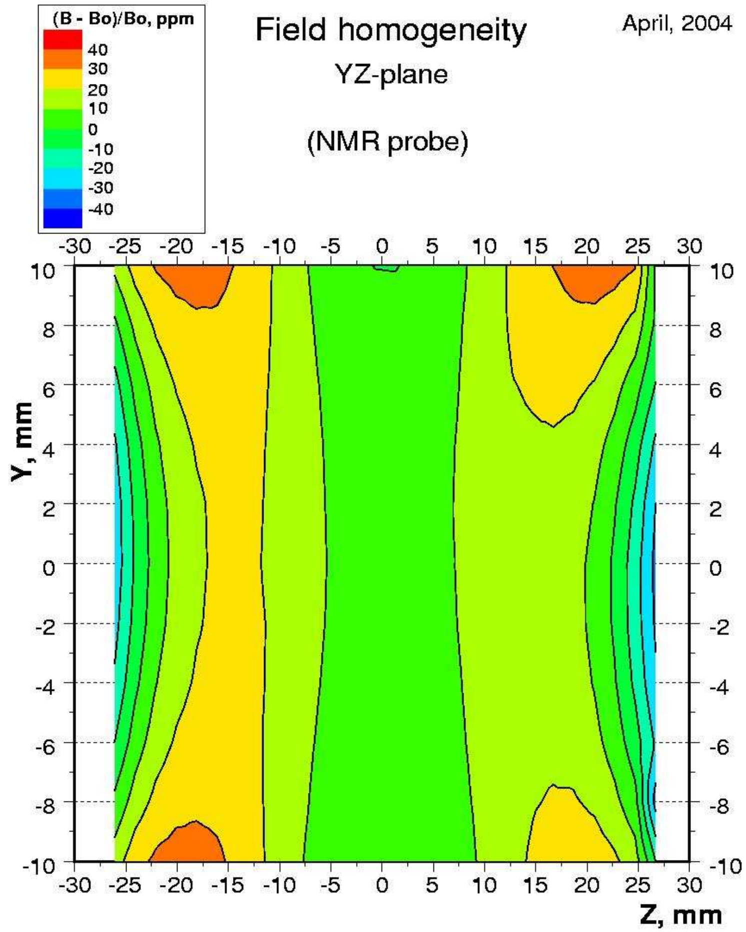
Field homogeneity over 20 x 120 mm^2 area (Hall-probe)



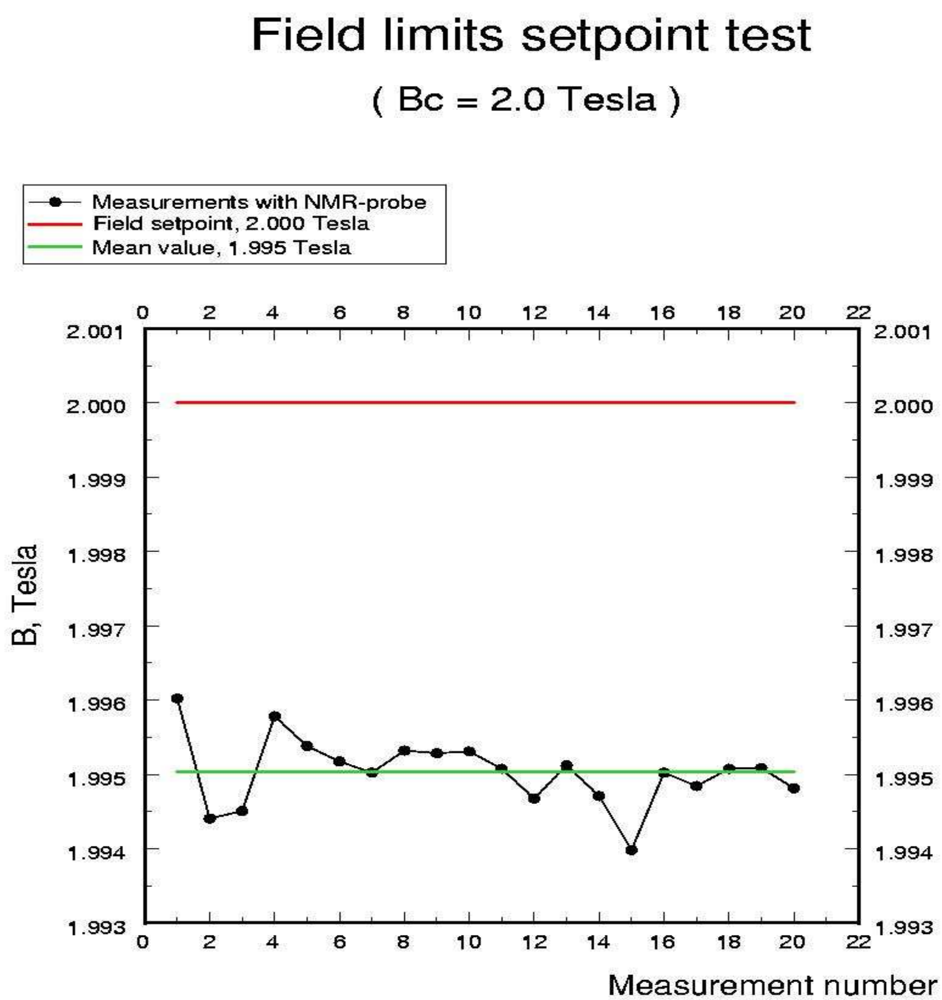


Field homogeneity over 20 x 52 mm^2 area (NMR-probe)





Field limits setpoints of control system



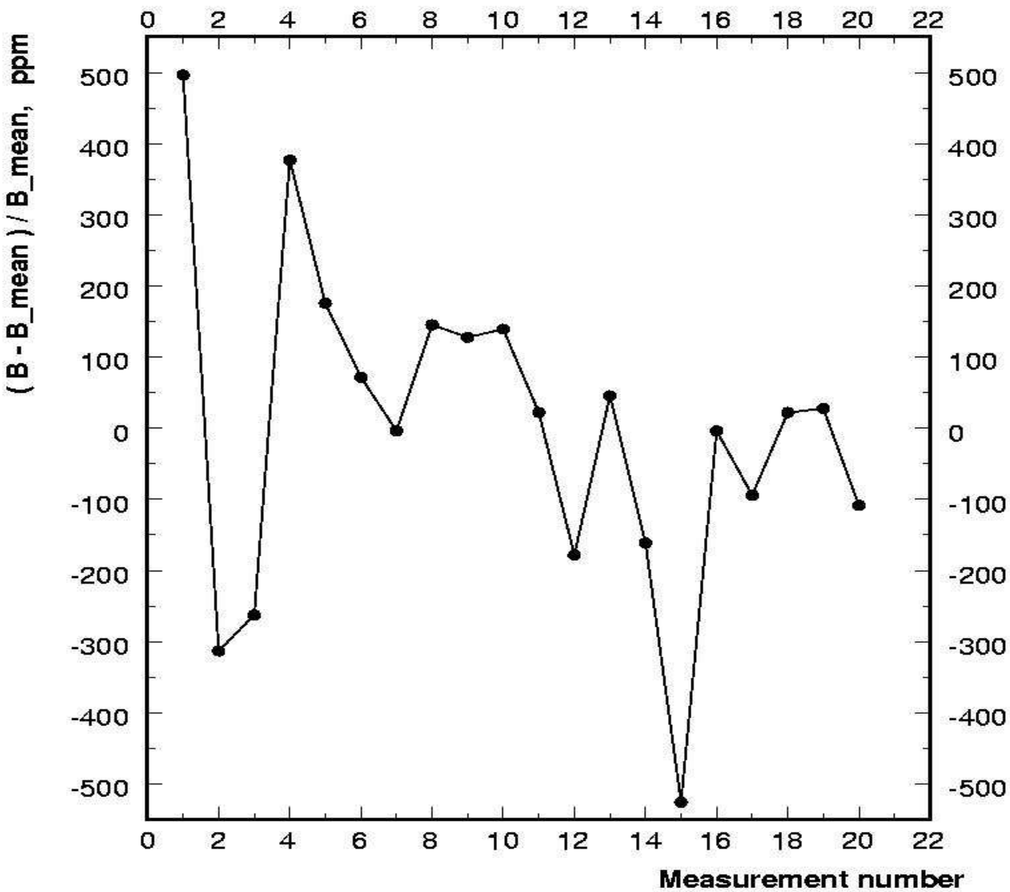
Field limits setpoint
B_c = 2.0 Tesla

Actual field (NMR-probe)
B_c = 1.995 Tesla

Difference ~ ***2500 ppm !***

Control system setpoints stability

Field limits setpoint instability



Control system recovers
the field limits
within tolerance

+/- 500 ppm !

We need 100 ppm !

Conclusions

- Hall-B polarizing magnet is very reliable.
- Homogeneity over the target area, cylinder 20 x 50 mm^2, is better than 40 ppm (vs 100 ppm needed).
- With such a magnet we can use a large variety of target materials.
- We can afford about 3 mm tolerance in positioning target cell (cryostat tail) over the geometrical center of the polarizing magnet. That should be used while making the positioning infrastructure.
- We need a control system which can provide recovering an optimal polarizing field with a tolerance better than 100 ppm !