magnetic field stability

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an amplitude of a magnetic field of iron core electric magnet changes even under constant current. Its underling physics still remains ***puzzle***.

magnet stability of a cyclotron has been in dispute

at AGOR, Osaka, JAEA

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TEMPERATURE DEPENDENCE OF THE AGOR MAGNETIC FIELD

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It has been found necessary to change the magnet currents gradually during long term operation of the AGOR cyclotron due to temperature changes in the iron, which are caused by the correction coils. These changes influence the magnetization in various ways: through a change in susceptibility, saturation magnetization, and through a change in metal density. Based on long term measurements of the magnetic field as function of temperature, a thermal model has been made, which is compared with theoretical estimates.

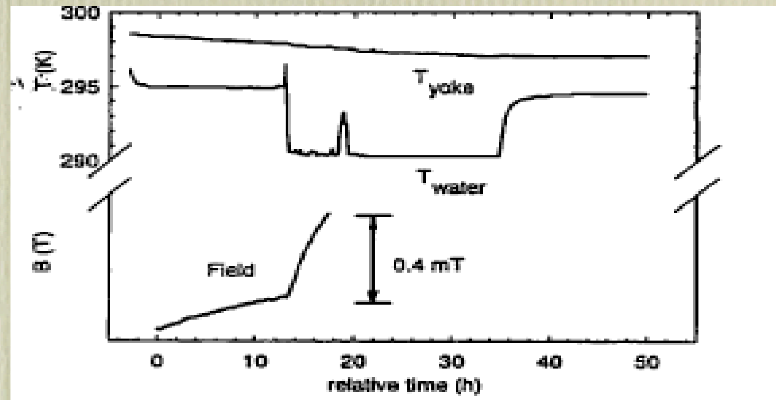


Figure 2: Response of the central field to a step in temperature.

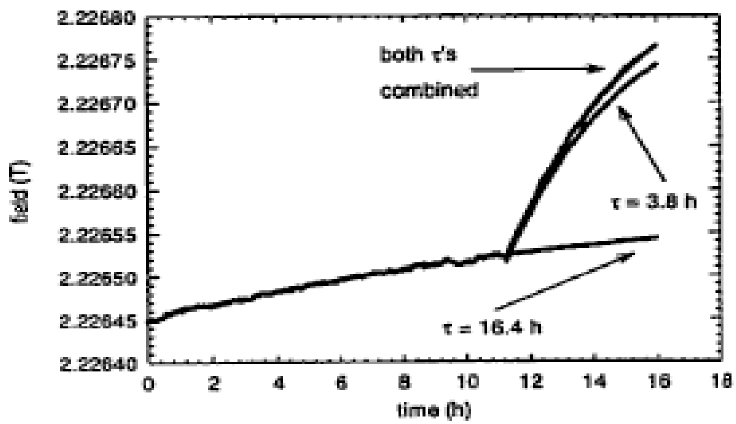


Figure 3: Temperature drift in more detail.

reached. For temperatures well below T_c, the temperature dependence of this process was found by Bloch:

$$M(T) = M_0 \left[1 - c\frac{1}{nS}(k_B T)^{3/2}\right]$$

Here M_0 is the magnetization at zero temperature, n is the (number) density of the spins, S the value of the spin, T the temperature, and c a material constant, depending on the (lattice) structure of the material and the coupling between the spins.

For iron, we have

$$\frac{c}{nS}k_B^{3/2} = 3.4 \cdot 10^{-6}\ K^{-3/2}$$

so that the room temperature coefficient of M_0 is $9 \cdot 10^{-5}$. We have done measurements at our 190 MeV proton field, where the iron contributes 1.27 T, so that we expect a temperature dependence of -0.11 mT/K

once there was a standard theory:

1) Bloch Equation for magnetization of iron:

$M(T)=M_0\ (1-3.4\ 10^{-6}\ K^{-1.5}\ T^{1.5})$

M_0 magnetization a zero temperature

dB/B/dT= **-90 ppm/K**

2) Volume effect: spin density

$$M_0\ (T)= M_0\ (T_0)(1-\ 3.6\ 10^{-\blacksquare}(T-T_0))$$

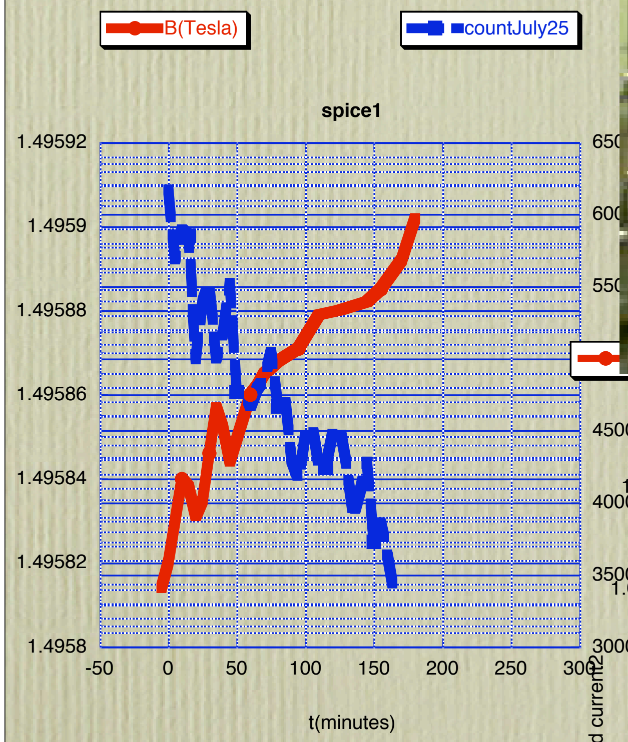
dB/B/dT=-36 ppm/K

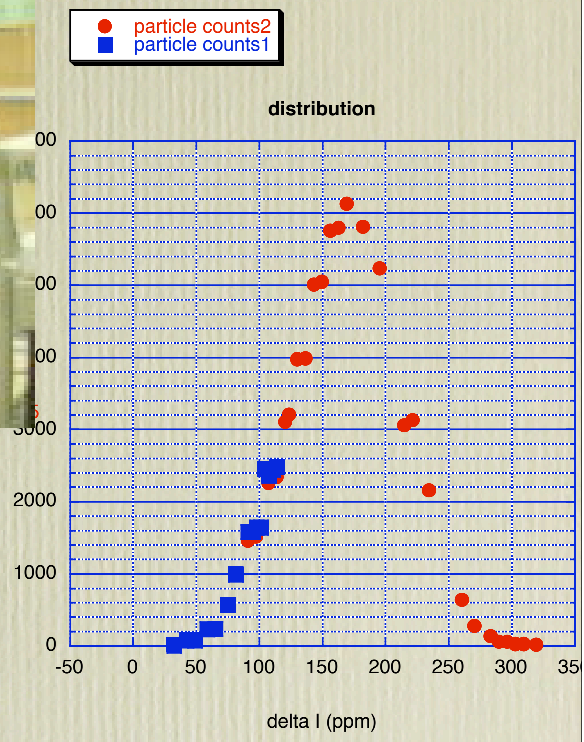
3) Physical change of Gap length and Magnet length:

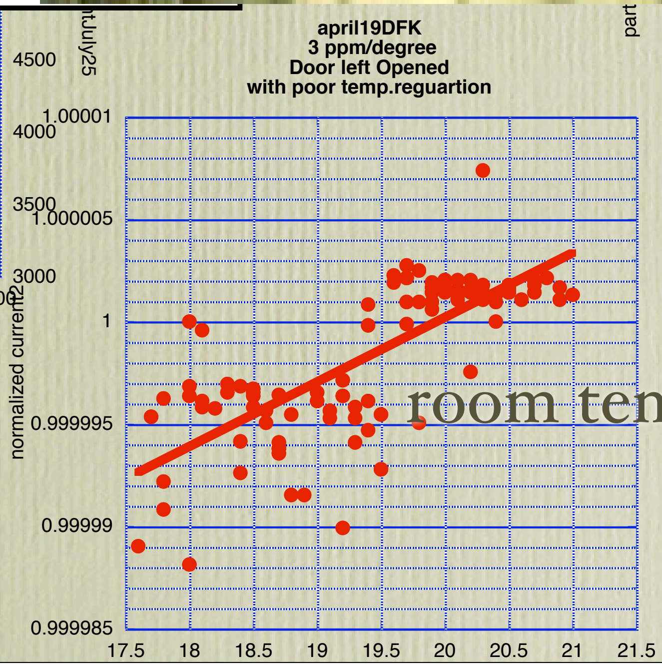
for gap,linear expansion temp.coefficient= -12 ppm /K

for axial length= +12ppm/K

spice@NIRS



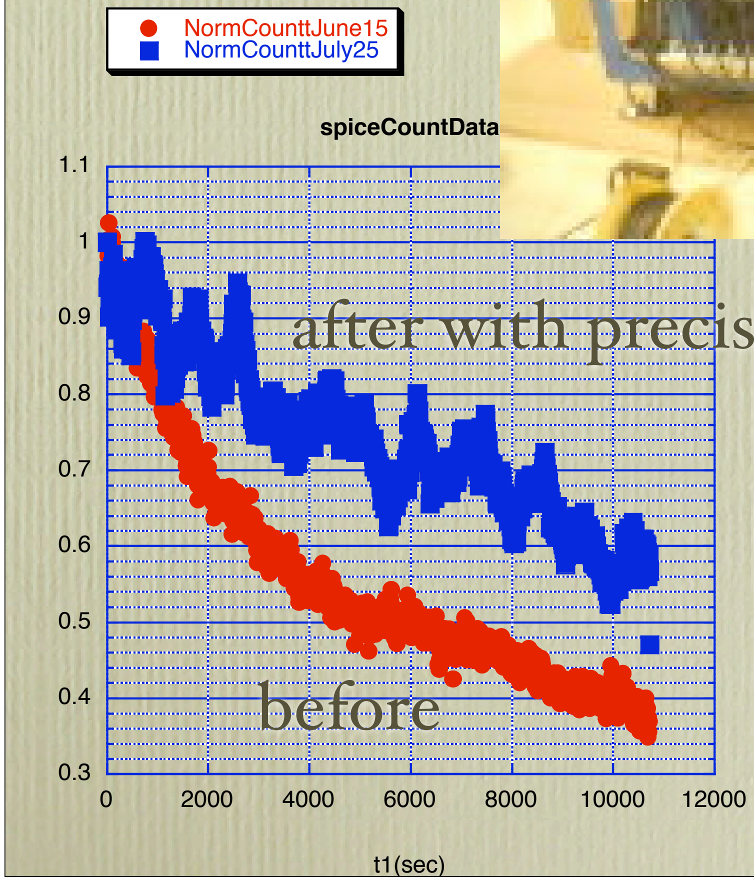


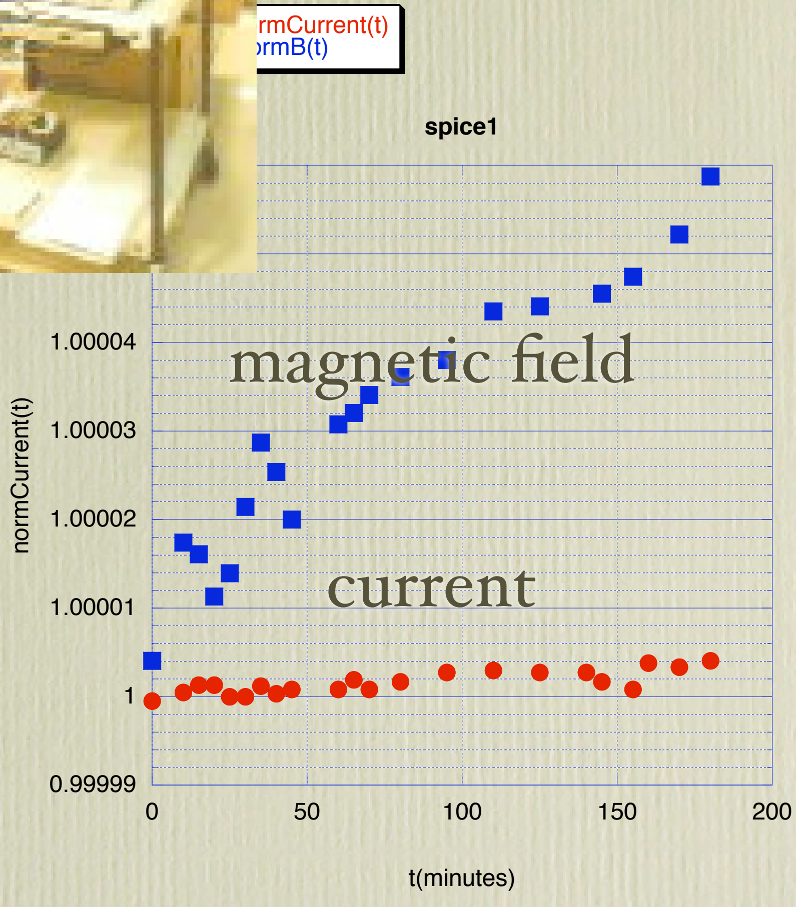


room temperature is in good condition

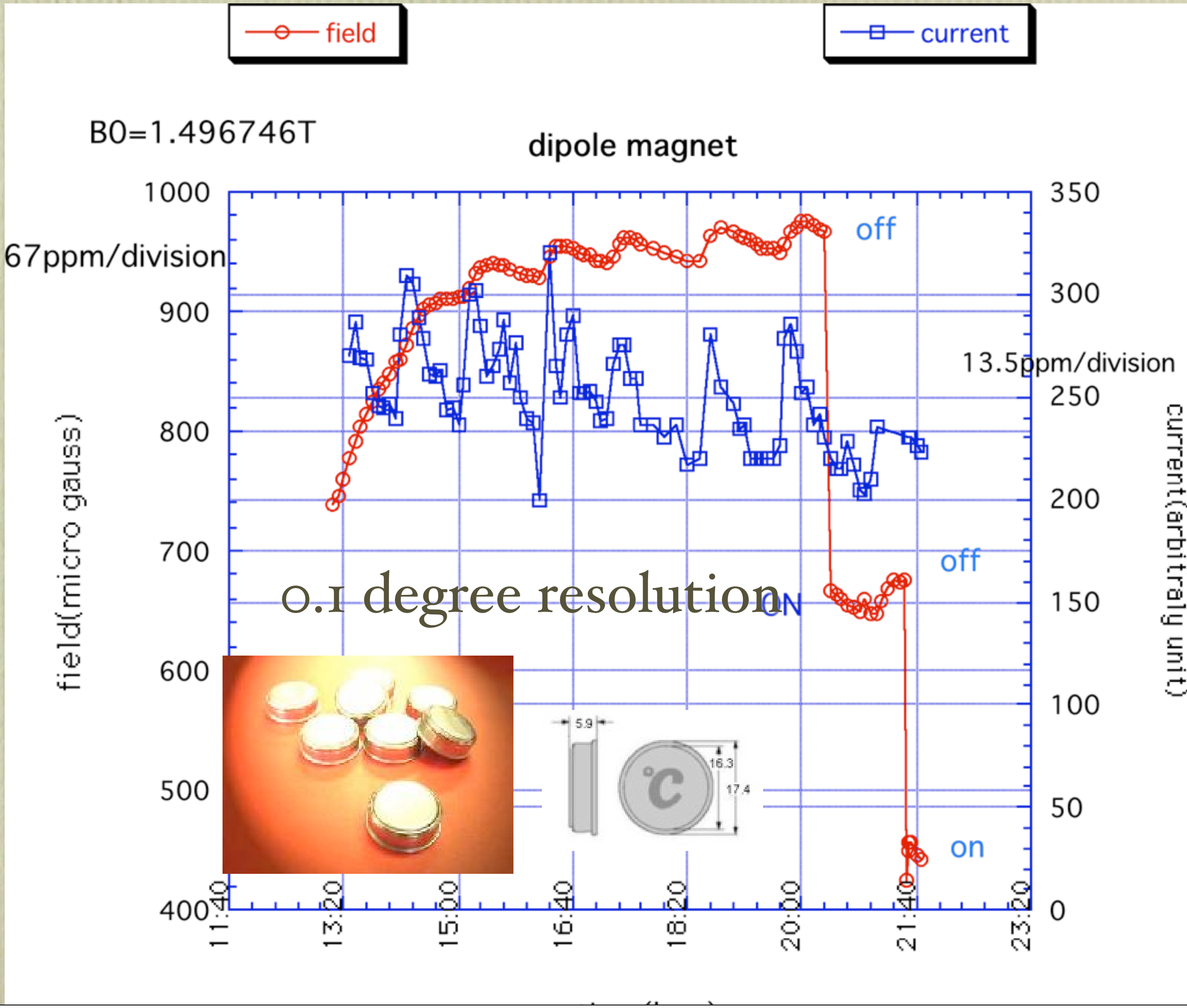
field changes while current is stable @SPICE

particle count

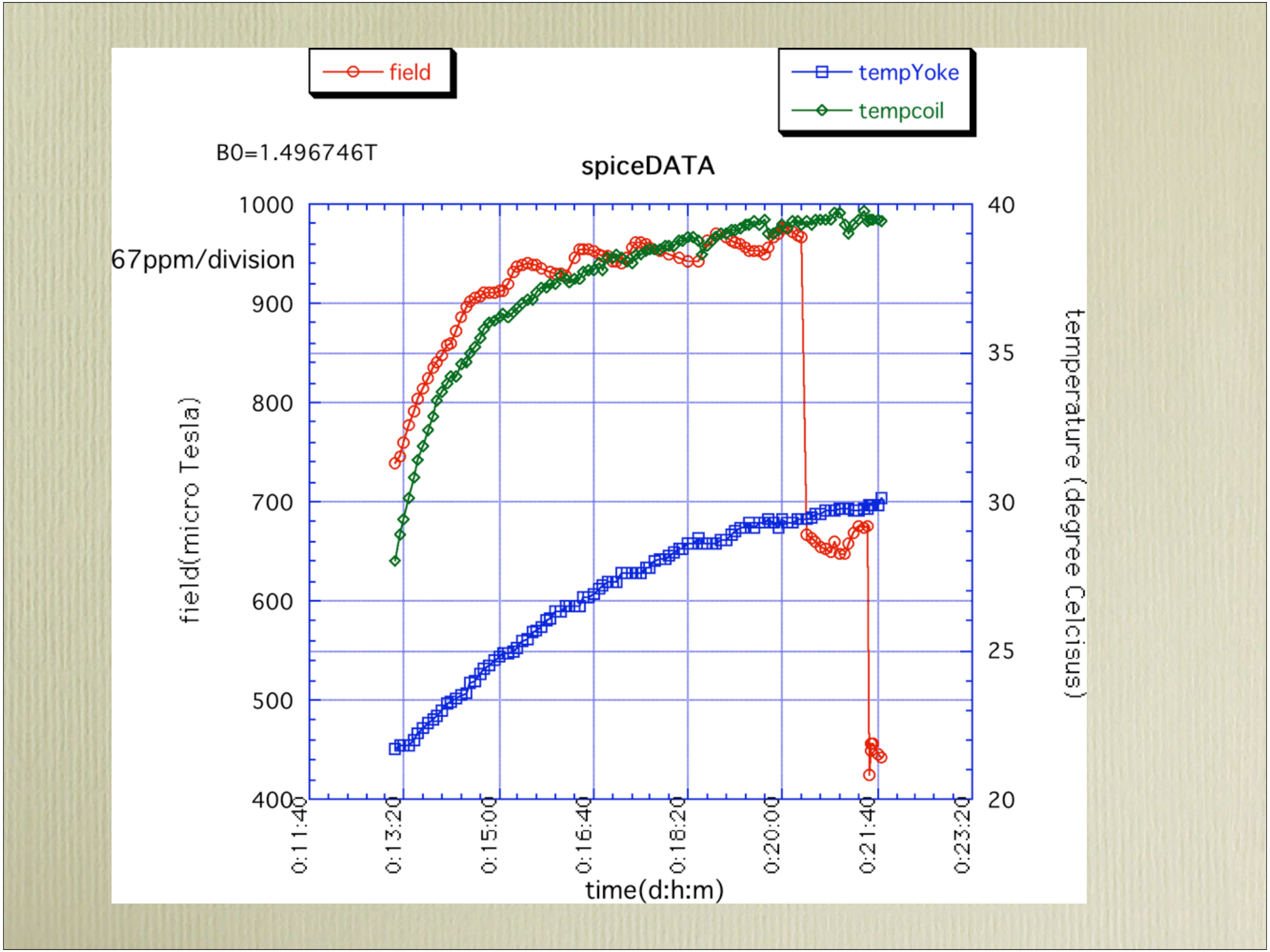


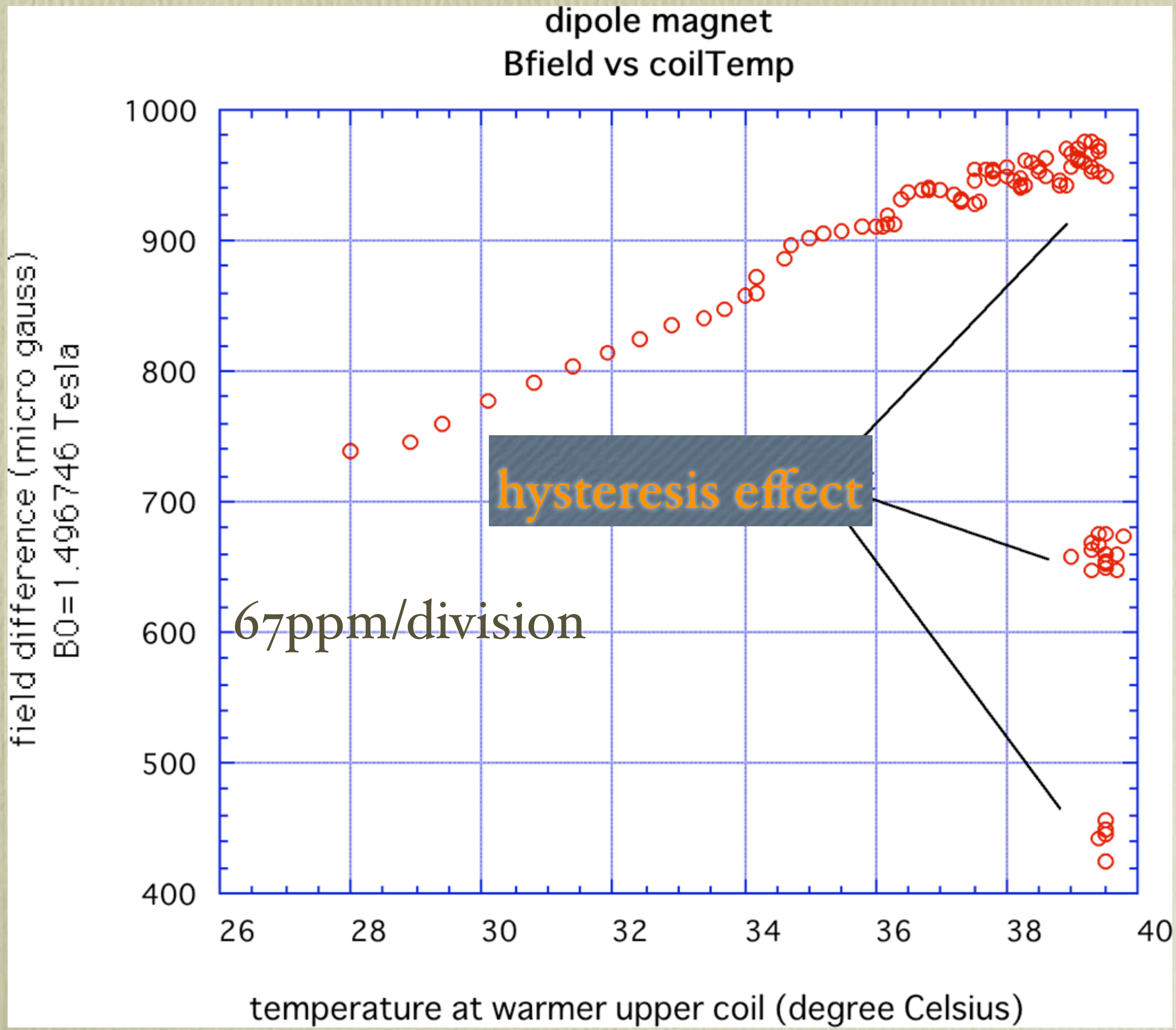


detail study @spice



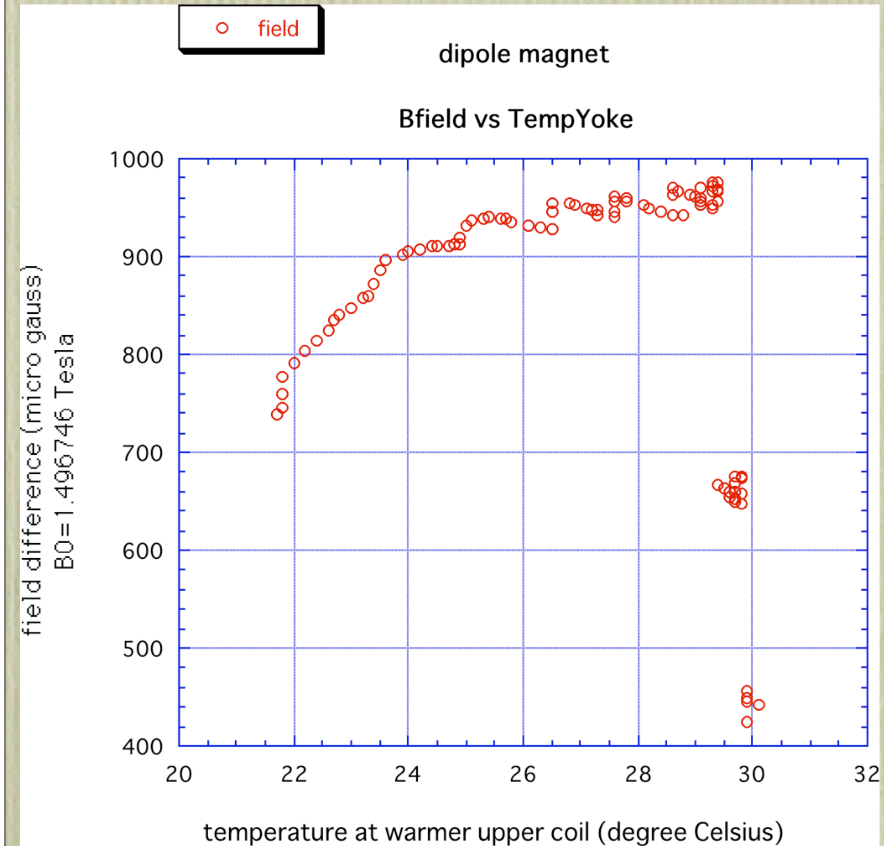
0.1 degree resolution

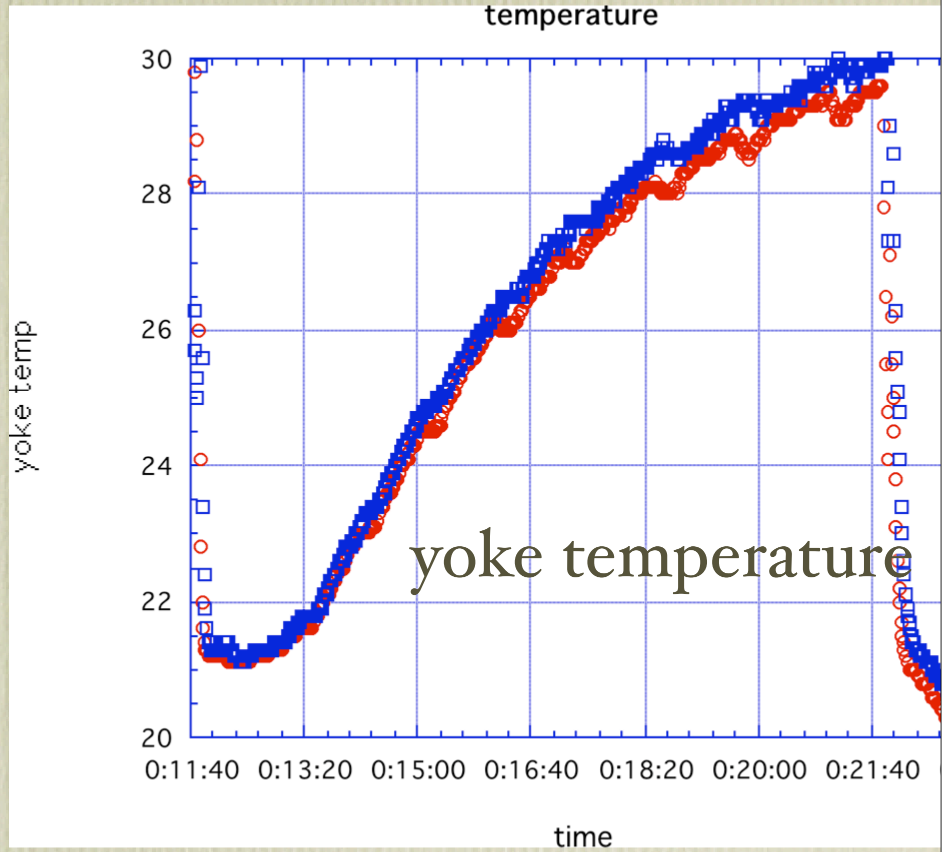

field
tempYoke
tempcoil
B0=1.496746T
spiceDATA
67ppm/division
1000
900
800
700
600
500
400
40
35
30
25
20
field(micro Tesla)
temperature (degree Celsius)
0:11:40
0:13:20
0:15:00
0:16:40
0:18:20
0:20:00
0:21:40
0:23:20
time(d:h:m)



dipole magnet
Bfield vs coilTemp
field difference (micro gauss)
B0=1.496746 Tesla
1000
900
800
700
600
500
400
26
28
30
32
34
36
38
40
temperature at warmer upper coil (degree Celsius)
hysteresis effect
67ppm/division

- there is a fine time structure





conclusion

- Under good air conditioning,the amplitude of the magnetic field is strongly correlated with coil temperature.
- The observed temperature coefficient of the iron core electromagnet is about +14 ppm/degree. It is positive and can not be explained by the standard Bloch theory.
- Note hysteresis effect is larger than the temperature effect. We would monitor B magnet and Q magnet by the NMR.
- Local thermal insulation is economical and recommended.