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Estimation of the magnetic longitudinal gradient between the pick-up coils

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Abstract

We present here the estimation of the longitudinal gradient between the pick-up coils from dedicated NMR measurements performed in the EEL test lab and in Hall A. We find a longitudinal gradient in Hall A smaller than 5 mG/cm.

1 Effect of the longitudinal gradient

A longitudinal magnetic gradient along the pick-up coils may cause a broadening of the Helium NMR signal and a reduction of its height. Without any longitudinal gradient, we know how to modelize the NMR signal S as a function of time :

$$S(t) = \frac{H_1}{\sqrt{H_1^2 + (\alpha t)^2}} \tag{1}$$

where H_1 is the RF field and $\alpha = 1.2\text{G.s}^{-1}$ is the ramp speed. Now, we can introduce a longitudinal magnetic component b which will cause the spins to go through the resonance at different times. As suggested by E154, let's assume a square distribution normalized to 1 for b and extended from $-b_0$ to b_0. In this case, the NMR signal expression as a function of time becomes :

$$S(t) = \frac{1}{2b_0} \int_{-b_0}^{b_0} \frac{H_1}{\sqrt{H_1^2 + (\alpha t - b)^2}} db \tag{2}$$

Assuming $H_1 = 90.8$ mG, as measured during E94010 [1], figure 1 and figure 2 show you the graphical representation of the NMR signal as a function of time and of b_0. The broadening and the height reduction effects are evident.

It is important to estimate the value of the longitudinal gradient if we wish to modelize correctly our NMR measurements. However, the gradient, if it exists, is expected to keep the same magnitude for the water NMR signals and for the NMR Helium signals, so that the effect of broadening and height reduction may be neglected when calibrating the Helium measurements with the water measurements.

2 Principle of measurement

The evolution of the helium NMR signal height as a function of the RF field H_1 depends strongly on the value of b_0, as can be seen from figure 3. Consequently, measuring this height dependence with H_1 will lead us to the estimation of b_0, and consequently will give the longitudinal gradient.

The series of measurements will start with a measurement of the NMR signal amplitude at the nominal RF field, that is $H_1 = 90.8$ mG. Then the RF field will be decreased to a lower value, and the amplitude will be measured again. Then, a new measurement will be performed at the nominal field. The RF field will then be lowered again to a smaller value than the previous one, and will be followed by another measurement at the nominal field. This sequence is necessary to take into account the AFP losses occuring during the successive NMR measurements. It is also important to keep the cell temperature stabilized during the measurements, to minimize any Helium density change.

We have performed several sets of measurements but will present only the most significant ones :

- first estimation in the EEL target test lab, by I. Kominis and G. Cates.
- second and final estimation in Hall A, during February 1999 dedicated measurements, returning to E94010 experimental conditions (holding field orientation and coil temperature stabilization).

The data taken have been corrected for several effects :

- take into account the NMR signal residual in both lock-in channels [2].
- correct for the signal shaping due to the lock-in time constant [3], table 1, table 2.

The function used to fit to the experimental measurements after correction (also called rescaling in this note) must have an analytical expression ; the height of the NMR signal at the resonance (occuring at $t = 0$) as a function of H_1 is given by :

$$S(t=0) = \frac{1}{2b_0} \int_{-b_0}^{b_0} \frac{H_1}{\sqrt{H_1^2 + b^2}} db \tag{3}$$

whose analytical expression is :

$$S(t=0) = \frac{H_1}{b_0} ArcSinh\left(\frac{b_0}{H_1}\right) \tag{4}$$

which can also be written :

$$S(t=0) = \frac{H_1}{b_0} Ln\left(\frac{b_0}{H_1} + \sqrt{1 + \frac{b_0^2}{H_1^2}}\right) \tag{5}$$

That expression will then be used to fit to our measurements, using a scaling factor and b_0 as free parameters.

3 Results

Using the method described before, we may only extract the longitudinal magnetic gradient extending along the pick-up coil length L, which is about 10 cm. So the longitudinal gradient measured in Hall A can be estimated from :

$$\frac{dB_z}{dz} \equiv \frac{2b_0}{L} = 4.2 \pm 0.5 mG/cm \tag{6}$$

For comparison, we had in the EEL test lab :

$$\frac{dB_z}{dz} \equiv \frac{2b_0}{L} = 3.1 \pm 0.2mG/cm \tag{7}$$

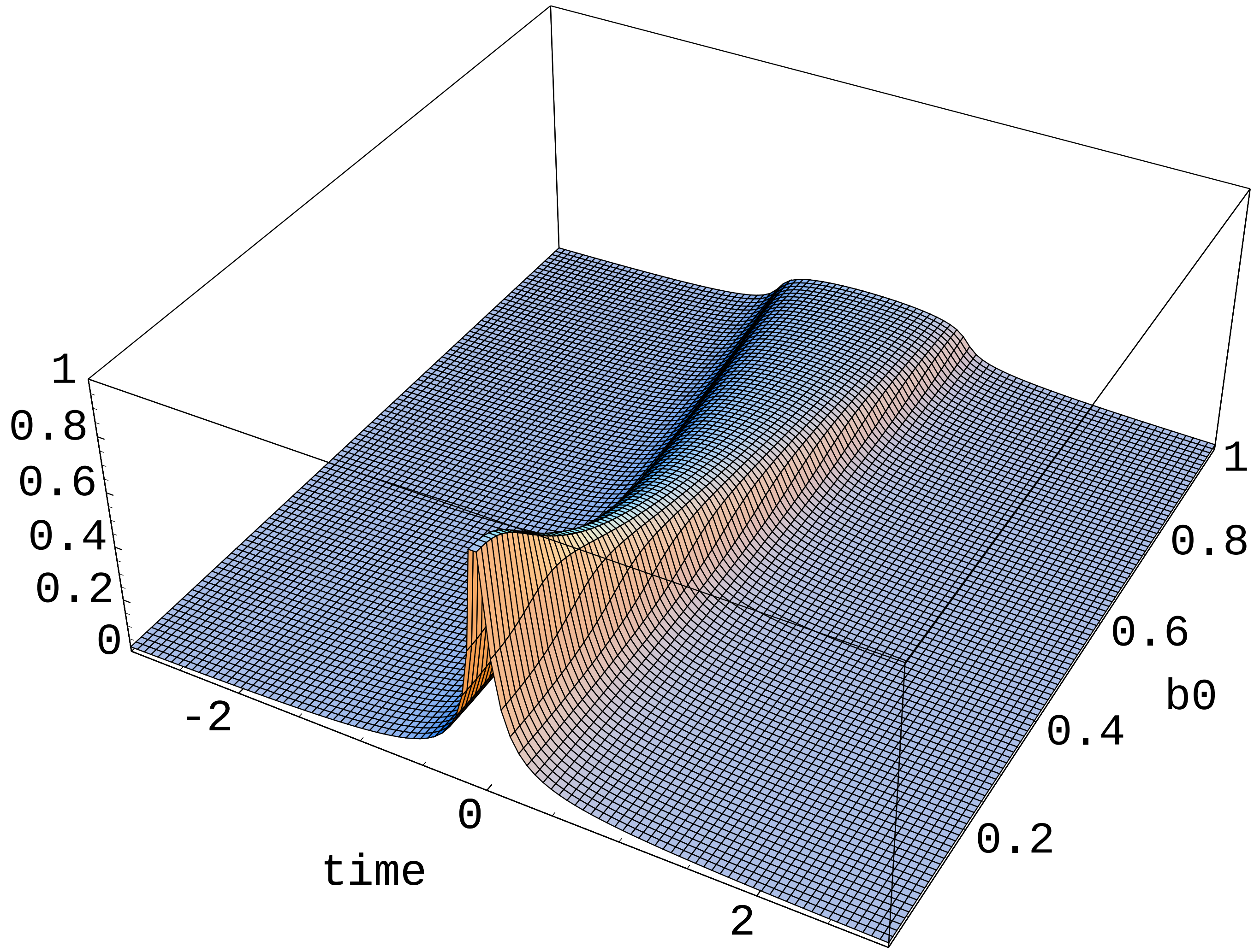

Figure 1: Evolution of the Helium NMR signal height as a function of time and as a function of the magnetic boundary b_0, expressed in G.

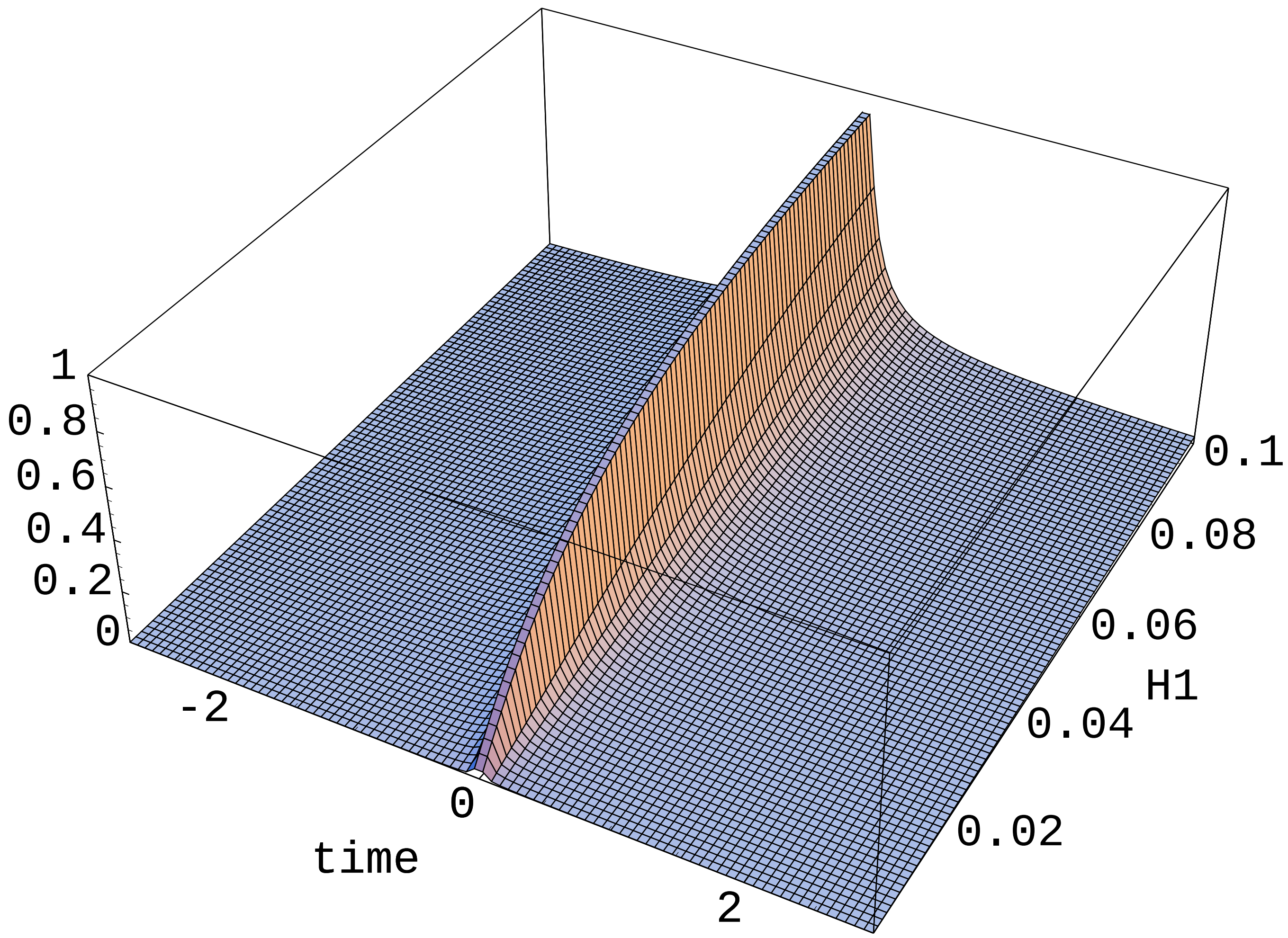

Figure 2: Evolution of the Helium NMR signal height as a function of time and a function of the RF field H_1, expressed in G, for $b_0 = 30$mG. Our measured value for H_1 is $H_1 = 90.8$ mG.

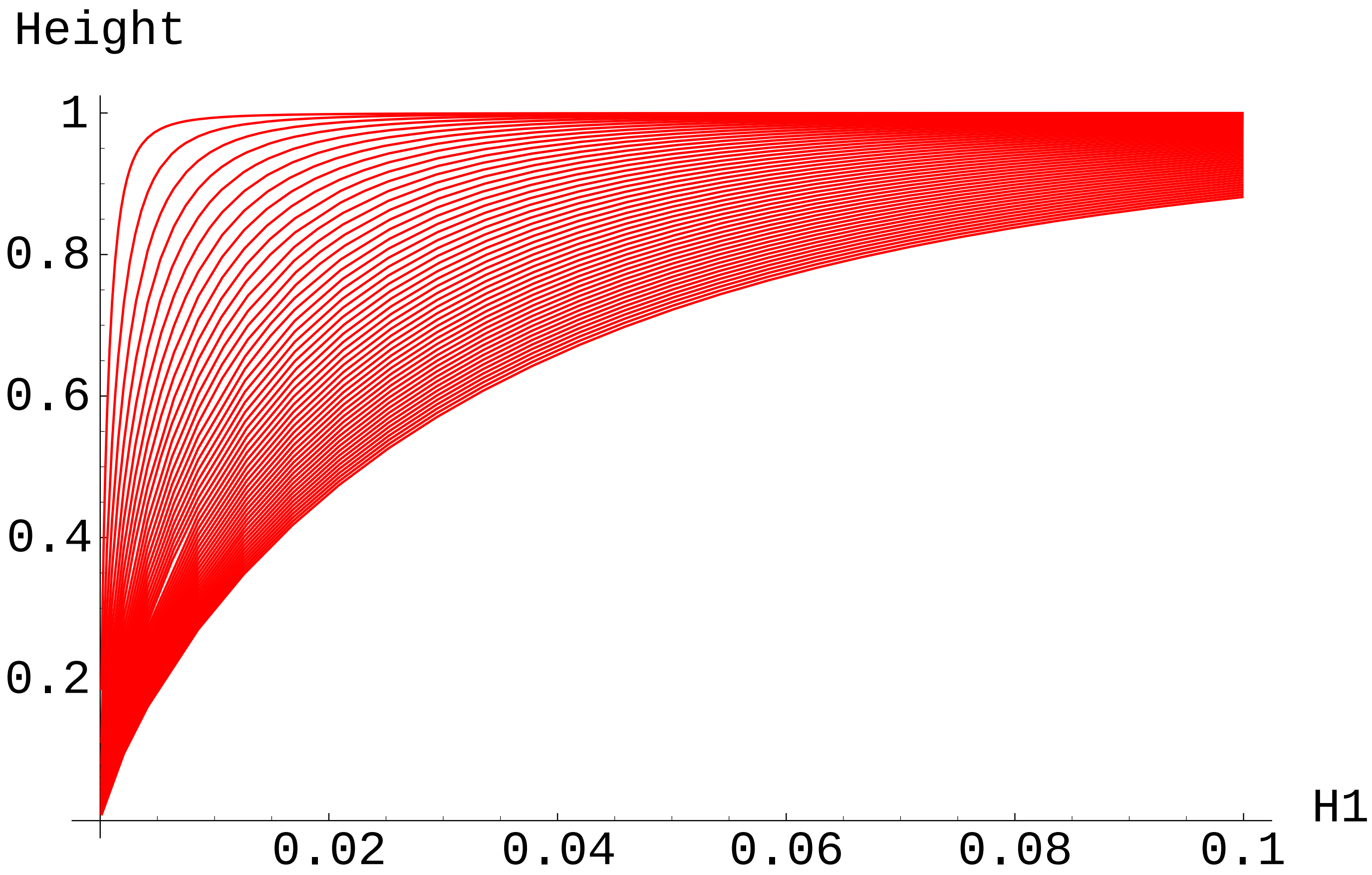

Figure 3: Evolution of the Helium NMR signal height as a function of the RF field H_1, expressed in G. The different curves are obtained for several values of b_0.

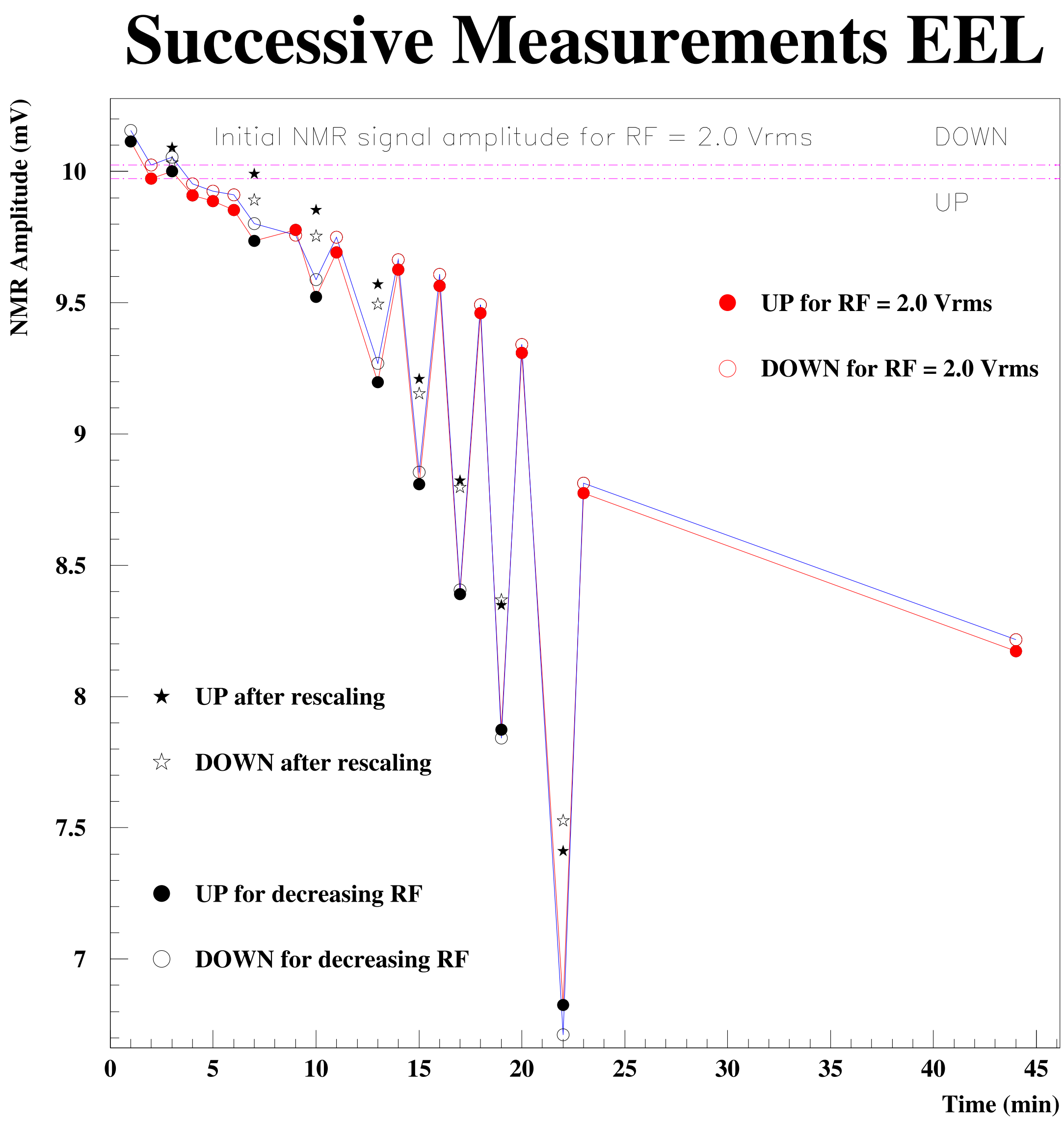

Figure 4: Summary of the measurements performed in the EEL building, for the UP and DOWN NMR ramps. The optimal RF voltage $V = 2.0$ Vrms was corresponding to a RF field of 52 mG. The horizontal dashed lines show you the initial NMR signal height for the first UP and DOWN measurements corresponding to that optimal voltage. Each measurement performed at a higher or lower RF field is rescaled to the initial optimal measurement performed at $V = 2.0$ Vrms from the average of two measurements at $V = 2.0$ before and after the considered measurement.

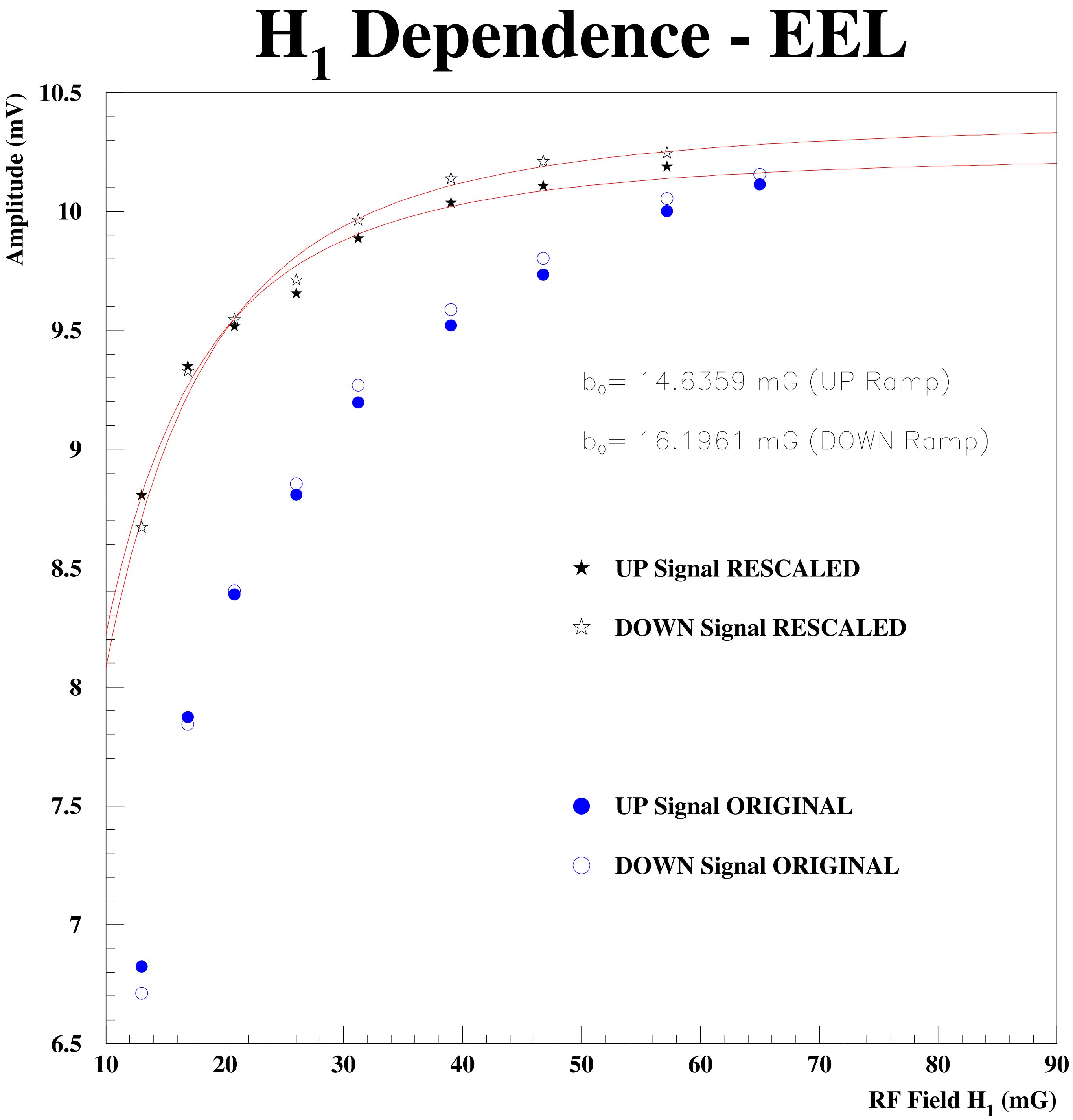

Figure 5: Dependence of the NMR UP and DOWN signal height as a function of H_1. Both original and rescaled measurements are shown. The fit to the UP and DOWN ramps give us an estimation of b_0 in the EEL building.

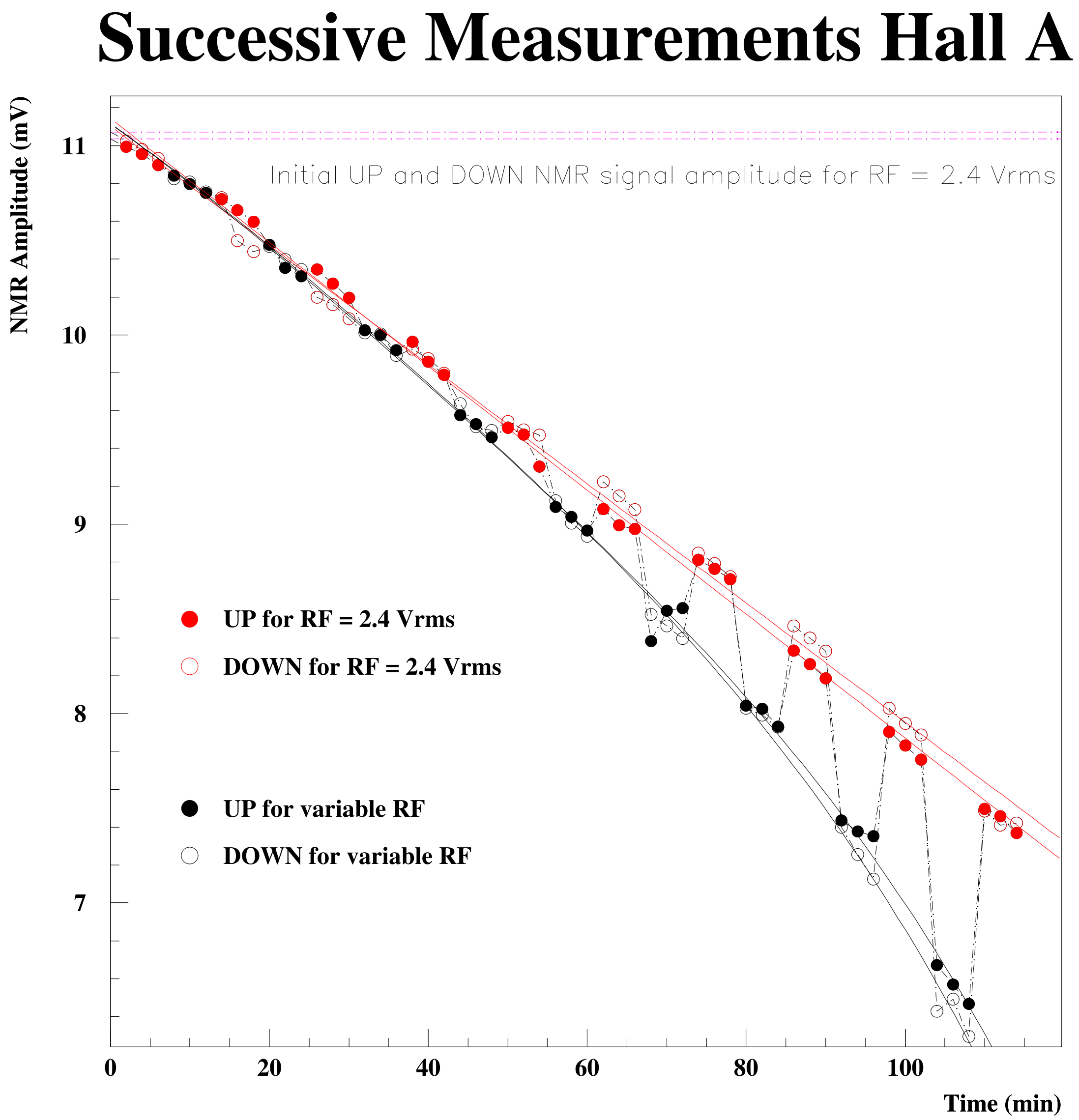

Figure 6: Summary of the measurements performed in Hall A, for the UP and DOWN NMR ramps. The optimal RF voltage $V = 2.4$ Vrms was corresponding to a RF field of 90.8 mG. The horizontal dashed lines show you the initial NMR signal height for the first UP and DOWN measurements. The measuremenst performed at 2.4 Vrms follow nicely a straight line, corresponding to a loss of about 0.03 mV per minute. A fifth order polynomial function is used to fit to the NMR measurements performed at decreasing RF fields. The value obtained from that fit and corresponding to the first measurement only among the three at a given RF voltage is used to extract b_0, since we do not want to take into account the successive AFP losses occuring at smaller values of H_1. The corresponding value of the amplitude at $V = 2.4$ Vrms used to rescale to the inital measurement is obtained from the linear purple fit, taken at the same time.

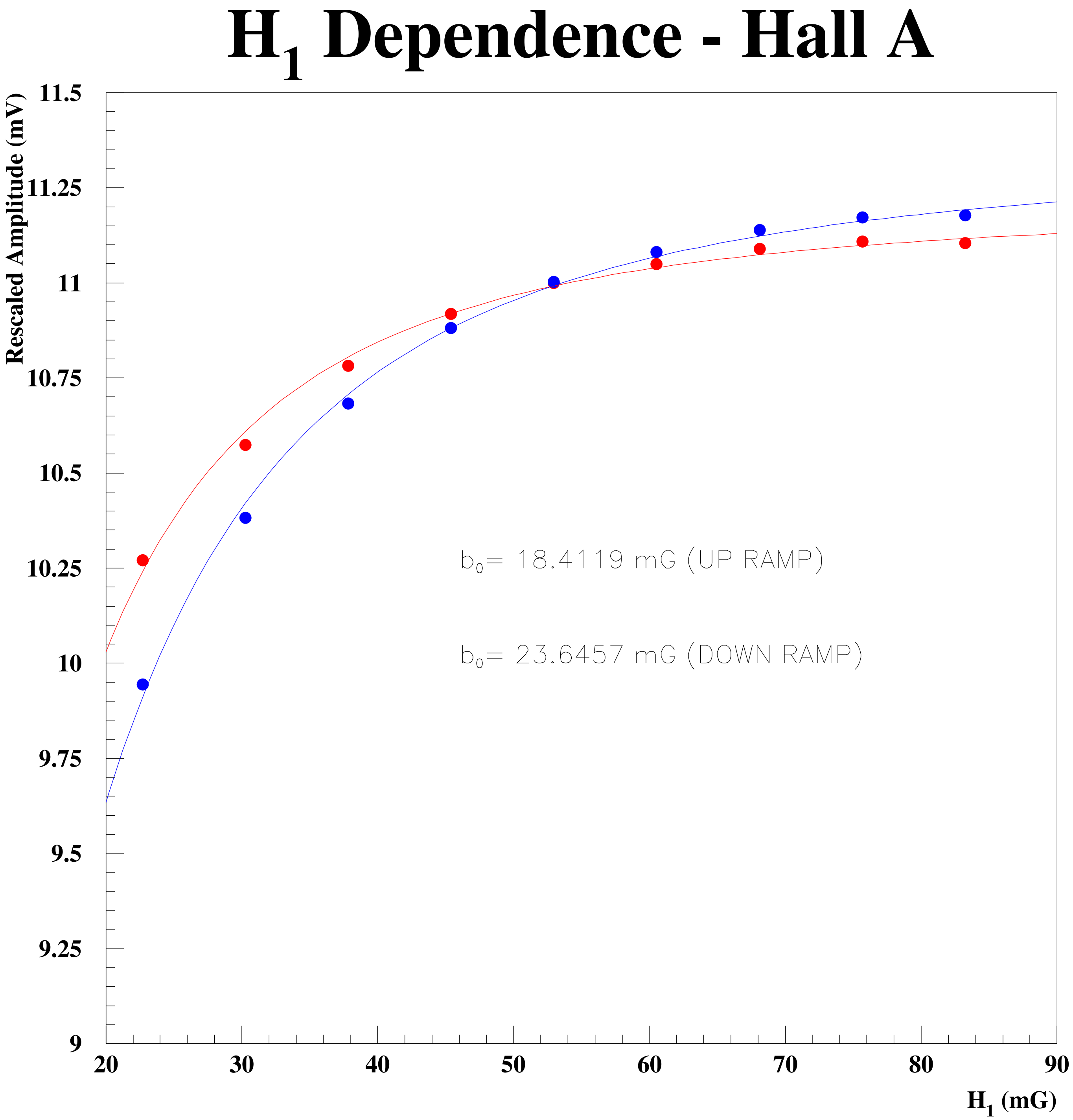

Figure 7: Dependence of the NMR UP and DOWN signal height as a function of H_1. Rescaled measurements obtained from the fifth order fits are shown. The fit to the UP and DOWN ramps give us an estimation of b_0 in Hall A.

Table 1: *Lock-in time constant correction in EEL*

RF Field H_1 (mG) - EEL Data	**Ratio Raw/lock-in - EEL Data**
57.2	1.01554
46.8	1.02199
39.0	1.02907
31.2	1.04117
26.0	1.05469
20.8	1.08187
16.3	1.11734
13.0	1.17005

Table 2: *Lock-in time constant correction in Hall A*

RF Field H_1 (mG) - Hall A Data	**Ratio Raw/lock-in - Hall A Data**
83.2	1.00782
75.7	1.00953
68.1	1.01168
60.5	1.01402
53.0	1.01792
45.4	1.02304
37.8	1.03027
30.3	1.04347
22.7	1.06967

References

[1] E94010 Technical Note 18

[2] E94010 Technical Note 16

[3] E94010 Technical Note 15