T_1 study of the CH2 reference cells

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October 12, 2011

1 Introduction

Five CH_2 reference targets were made using a single batch of high density CH_2: a BNL-type CH_2 target and 4 JLab-type targets called #1, #2, #3 and INFN. Their designs are given in [1]. During the various polarimetry studies done on the BNL-type and the JLab-type #1 and #2 targets, the polarization seems to track instantaneously changes in magnetic field or temperature, see for ex. the temperature studies reported in [1]. This indicates very short T_1 from these targets (significantly less than a minute). The NMR apparatus presently used (as of 2011) is not designed to measure such short T_1 so the actual values are unknown. Since target #3 and INFN were made of the same CH_2 rod, we expected them to have the same T_1. However, target #3 seems to display a longer T_1 while the INFN target seems to have the expected very short T_1. The sequence of fabrication of the various targets is the following. The BNL-type target was made first, followed by targets #1 and #2 machined at the same time. Targets #3 and INFN were made at the same time several months later.

Because it is unexpected that T_1 differs between these targets, especially between targets #3 and INFN which were made at the same time and with the same CH_2 material, many tests were conducted to make sure that what was seen in the target #3 data was indeed due to a long T_1 and not another effects. In this note, we present the analysis of the data taken on target #3 for such studies and we give an estimate of the T_1 of the various targets. The reason for the larger T_1 for target #3 is so far not understood.

2 Data

Earlier runs were taken with target #3 (RF power study runs), but no effect due to a long T_1 was noticed, see 2. If these runs were taken after that the cell has been under the nominal B-field long enough (a few minutes), then the T_1 effect would not be noticeable.

Run #	T^o	CH_2 target	cycles	B-span	B-center	$T_{up,down}$	freq./phase	H T_1	purpose/comments
177267855	4.26K	#3 w/ all cooling wires	5	200G	2850	16s	12317/140^o	-	Stopped after a few cycles when T_1 effect was noticed
177268484	4.26K	#3 w/ all cooling wires	3	200G	2850	16s	12317/140^o	-	Check if varying NMR strength for run above is b/c varying Q (b/c RF circuit not at TE yet)
177268945	4.27K	#3 w/ all cooling wires	524	200G	2850	16s	12317/140^o	8.1±1.4min	Baseline run for cooling wire study.
177380853	4.27K	#3 w/ all cooling wires	270	200G	2850	16s	12317/140^o	8.1min	T_1 effect study. Field set to 0 for 2h30 before starting run.
177409234	varies	#3 w/ all cooling wires	41	330G	2950	31s	12317/140^o	6.9±1.4min	Larger B span to include fluorine. Started at 4.3K and ended at 1.8K
177415064	1.85K	#3 w/ all cooling wires	9	330G	2950	31s	12317/140^o	12.9±2.0min	T_1 effect study at 1.85K, including H and F.
177417061	1.85K	#3 w/ all cooling wires	59	330G	2950	31s	12317/140^o	12.9±2.0min	T_1 effect study at 1.85K, including H and F. 3-pin tool pulled up by 6 inches. End of run at 4.3K
177327937 condition 1	1.86K	#3 w/ all cooling wires	40	200G	2850	16s	12317/140^o	13.74±1.4min	Decaying signal. Stduy done in [4]
177425030	4.27K	no target	43	330G	2950	31s	12317/140^o	-	F signal study and check for remaining HD.
177438462	4.27K	#3 w/ 1/2 cooling wires	11	330G	2950	31s	12317/140^o	2.0±0.7min	T_1 effect study with half cooling wires removed.
177439952	4.27K	#3 w/ 1/2 cooling wires	1000	330G	2950	31s	12317/140^o	-	Baseline run for cooling wire study. In TE condition
177667669	4.27K	#3 w/ 1/2 cooling wires	103	330G	2950	31s	12317/140^o	2.0±0.7min	Same as above.
177706303	4.27K	#3 w/ 1/2 cooling wires	41	330G	2950	31s	12317/140^o	2.0±0.7min	Same as above, but w/ 3-pin tool installed
177715565	4.27K	#3 w/ 1/2 cooling wires	378	200	3611	16s	15500/0^o	~2.0±0.7min	run off RF-circuit resonance to check if time dependence comes from Q-curve change. Last 35min of data not usable (PD fill)
177872537	4.27K	#3 no cooling wires	551	200	2850	16s	12317/140^o	2.0±0.7min	T_1 effect study with no cooling wires.
177927640	4.27K	#3 no cooling wires	6	200	2850	16s	12317/140^o	2.0±0.7min	T_1 effect study with no cooling wires.
177929878	1.90K	#3 no cooling wires	63	200	2850	16s	12317/140^o	2.0±0.7min	T_1 effect study with no cooling wires at different temperature.

Table 1 contines next page.

Run #	T^o	CH_2 target	cycles	B-span	B-center	$T_{up,down}$	freq./phase	H T_1	purpose/comments
177960074	4.28K	#2 no cooling wires	480	200	2850	16s	12317/140^o	too small to measure	T_1 effect study with no cooling wires.
178014325	4.28K	#2 no cooling wires	6	200	3000	16s	12317/140^o	-	Fluorine study
178016448	1.8K	#2 no cooling wires	40	200	2850	16s	12317/140^o	2.3±0.7min	T_1 effect study with no cooling wires.
178040926	4.28K	#2 no cooling wires	5	200	3020	16s	12317/140^o	-	Fluorine study
178120005	4.28K	#3 CH_2 with #2 ring	4	200	2850	16s	12317/140^o	~4.1±0.7min (short measurement)	Study if the brass ring of the target is responsible for time dependence. PD Temperature was 4.28 but record indicate 1.8K (?)
178131520	4.28K	#3 CH_2 with #2 ring	613	200	2850	16s	12317/140^o	-	baseline measurement. PD Temperature was 4.28 but record indicate 1.8K (?)
178275290	4.28K	#3 CH_2 with #2 ring	34	200	2850	16s	12317/140^o	4.1±0.7min	T_1 study. PD Temperature was 4.28 but record indicate 1.8K (?)
178280329	1.79K	#3 CH_2 with #2 ring	11	200	2850	16s	12317/140^o	4.1±0.7min	Same as above at different temperature
178284996	1.85K	#3 CH_2 with #2 ring	17	200	3020	16s	12317/140^o	-	Fluorine run.
178297345	1.78k	no target	21	200	3020	16s	12317/140^o	-	Fluorine run without target
178308804	4.3K	"INFN" CH_2 target	507	200	2850	16s	12317/140^o	-	Study with different target. TE measurement
178359590	4.2K	"INFN" CH_2 target	37	200	2850	16s	12317/140^o	too small to measure	T_1 study with different target
178364581	1.8K	"INFN" CH_2 target	112	200	2850	16s	12317/140^o		Same as above at 1.8K (moved back to 4.2K after sweep #20)

All the data where taken at -5dBm with the white cable. We conservatively estimated the uncertainty on T_1 to be ±1 cycle time

3 T_1 estimates

3.1 Run 177268945

From run 177268945, T_1 is about 8.1min, see Fig. 1. The signal evolution was fit with the form $P_{TE}(1-e^{-t/T_1})$, with P_{TE} the TE polarization given by the later sweeps. The possible RF losses are accounted by adding a negative slope to the form $-\alpha t$. There is no visible effect of RF losses *in terms of slope* because of the small value of T_1. However, RF losses are present for this target as discussed in [2]). Furthermore, the rise of the signal near cycle 490 is because the run was paused between cycles 491 and 492 for 1h30min. Polarization losses due to RF were recovered (about 10%, see [2]). The run might have been paused when the field was at its highest value (end of sweep, 3050 Gauss), contributing to a further 7% enhancement of the signal. Those effects would account for the total ~20% enhancement of the signal after the 1h30 pause.

3.2 Run 17738053

A fit of run 17738053's data using the same parameter confirms the 8.1min value of T_1 see Fig. 2. (The apparent loss of polarization during the up sweep near sweep #32 is not understood but is not physical. It may be due to a software of hardware glitch during the sweep).

3.3 Run 177409234

Run 177409234 was done at two temperatures: it started at 4.3K and stopped at 1.8K. We do not have TE value with Tup=31s but it can be deduce from the former runs at Tup=16s by scaling their TE value by 16/31 [2]. The each sweep takes 1.58min. The run indicates a T_1 $\sim$3.5cycle~6.9min.

3.3.1 Hydrogen data

We get T_1 $\sim$3.5cycle~6.9min.

3.3.2 Fluorine data

The fluorine NMR peak was also covered and the data indicate that Fluorine too has a T_1 long enough to be visible by our NMR apparatus. It appears that the fluorine has a double peak structure, see Figs. 4 and 5. This structure must be due to the inhomogeneity of the magnetic fields (lower field at the level of the coil holder): Part of the Fluorine sees a lower magnetic field and produces the left (right) peak seen for the down (up) sweep. The Fluorine signal is clearly growing with time but it is unclear whether this growth is exponential (T_1 growth) and whether the two peaks grow at the same rate. Since F is not used as a reference and since it is not the purpose of this note, we did not analyzed the fluorine time evolution.

3.4 Run 177415064 and Run 177417061

Data from run 177415064 are not sufficient to determine T_1 since 9 cycles were not enough to reach TE. However, we can use the next run (177417061) to determine the value of the polarization at TE. The two data sets yield longer T_1 values compared to 4.3K runs, as shown in Fig. 6. Fit of the 1.8K data of run 177417061, see Fig. 6, indicates a longer lifetime of 12.9min. This longer lifetime may be due to a temperature dependence of T_1.

A similar T_1 estimate from a decaying signal was found using run 177327937, see [4].

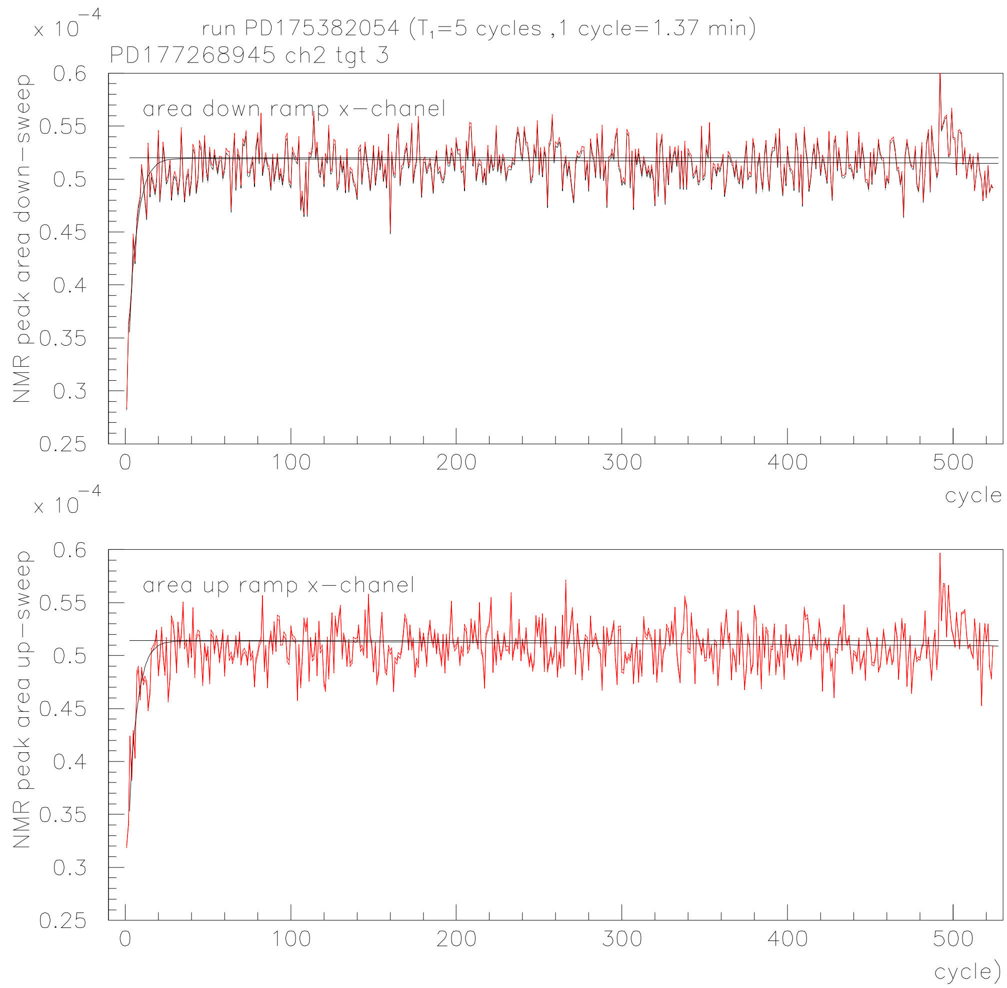


Figure 1:
Evolution of the NMR signal strength with time for run 177268945 (red line). The top plot is for the down sweep and bottom plot for the up sweep. The effects of T_1 is seen for the 20 first sweeps. A fit to the signal evolution (black line) yields a T_1 of about 5 cycles, with each cycle lasting 1min37s, that is a $T_1 = 8.1$ minute. The horizontal black line is the estimated value of the TE.

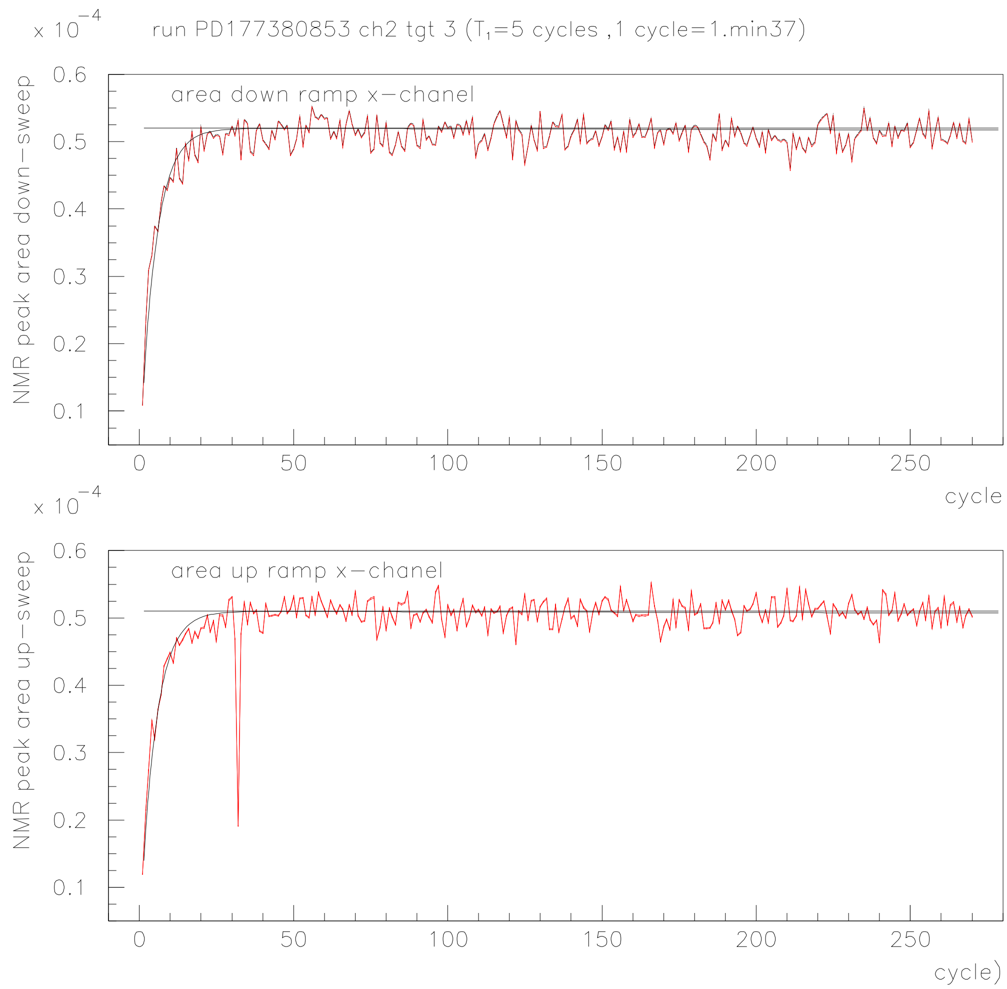


Figure 2:
Same as Fig. 1 but for run 17738053.

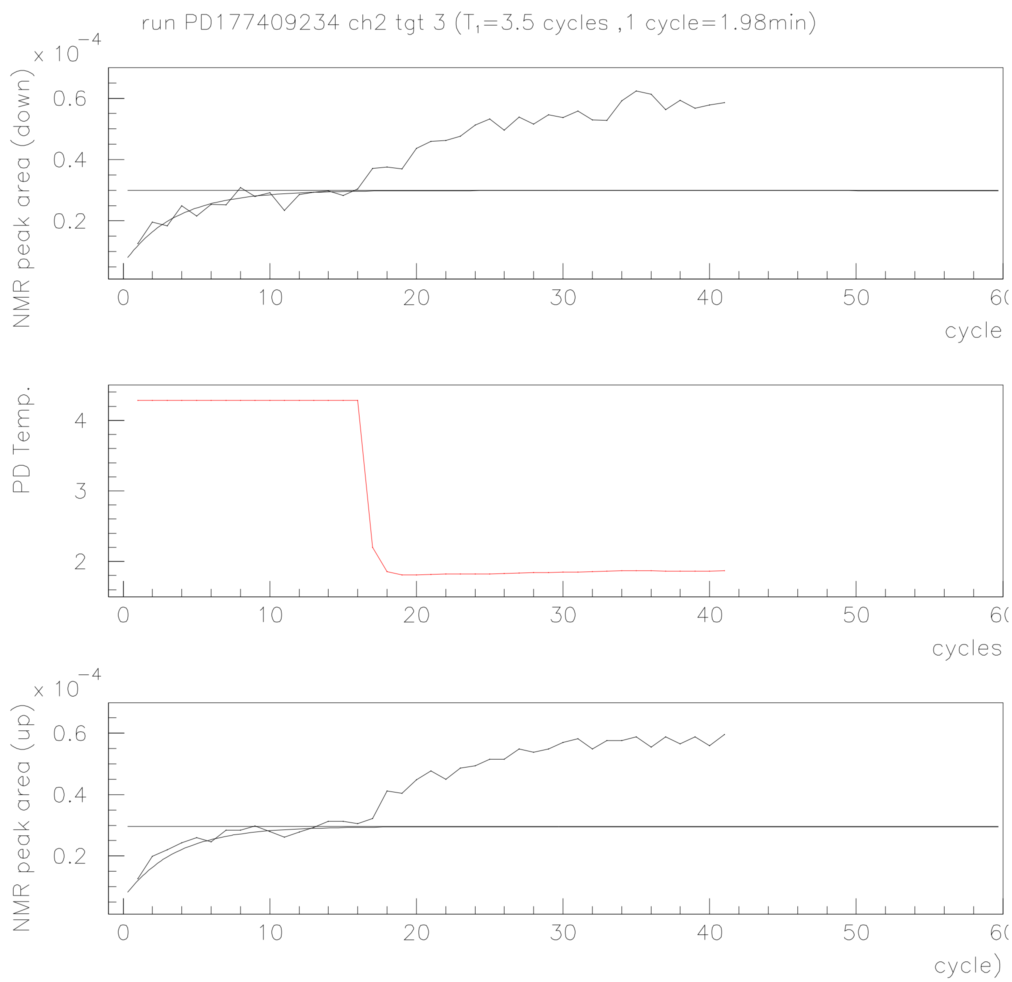


Figure 3:
Left panel: Same as Fig. 1 but for run 177409234. The jerky black line is the signal after temperature "correction (see text for details). The fit was performed on data prior the temperature change (cycle 16). Fluorine data from the same run.

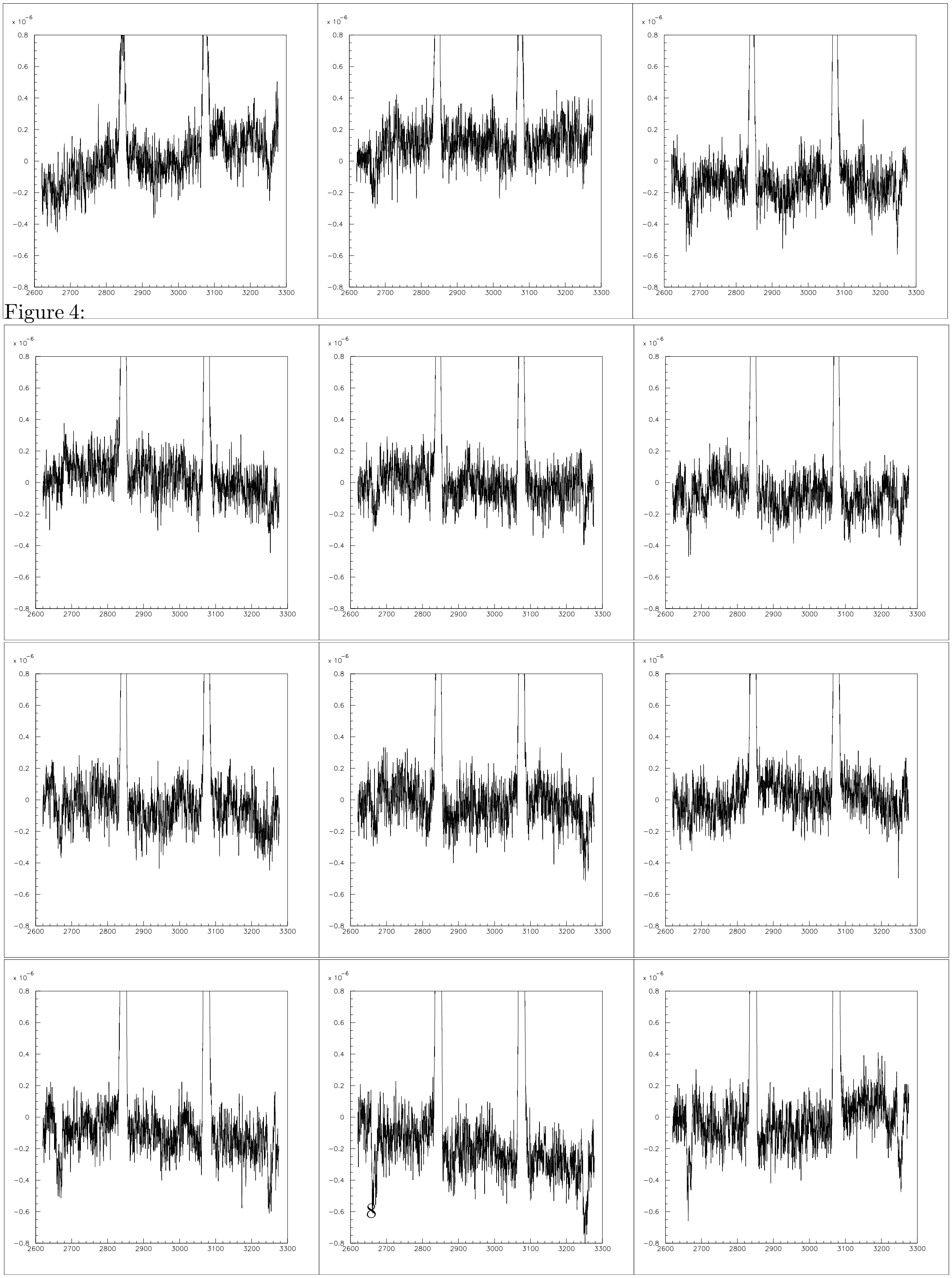
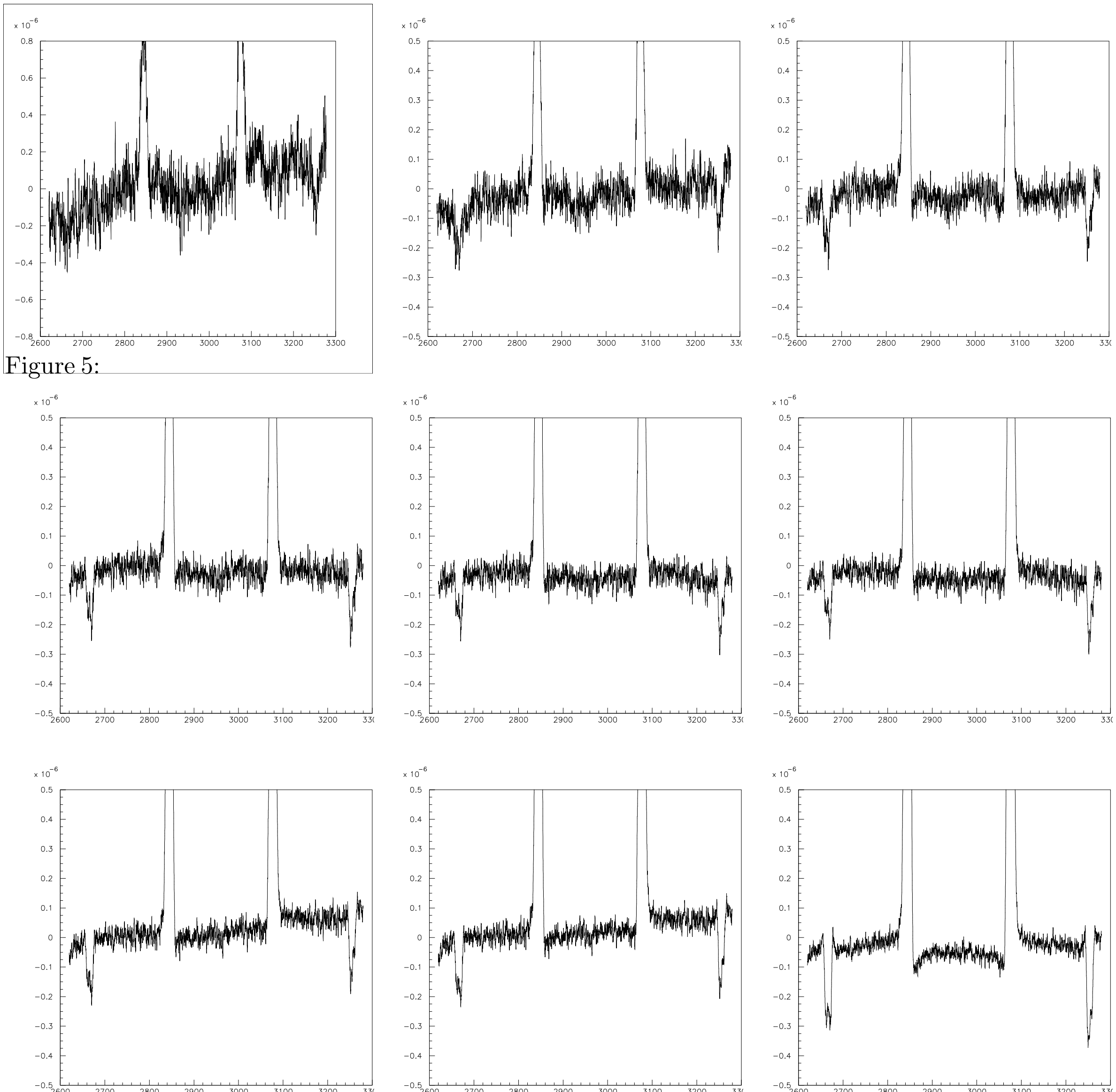


Figure 4: Run 177409234 resonances: top left: first sweep. top center, averaged second sweep, etc... The three bottom plots are for sweep 20, 25 and 30. The larger positive peaks are the Hydrogen NMR peaks.

Figure 5:



Run 177409234 resonances: top left: first sweep. top center, averaged over the 3 first sweeps, top right, averaged over the 6 first sweeps. middle left: averaged over the 9 first sweeps. middle center, averaged over the 12 first sweeps, middle right, averaged over the 15 first sweeps. Bottom left: averaged over the 18 first sweeps. bottom center, averaged over the 21 first sweeps, bottom right, averaged over all the sweeps (41 sweeps). The negative peaks (Fluorine) display a double peak structure, with the **** peaks growing more slowly than the **** one. The larger positive peaks are the Hydrogen NMR peaks.

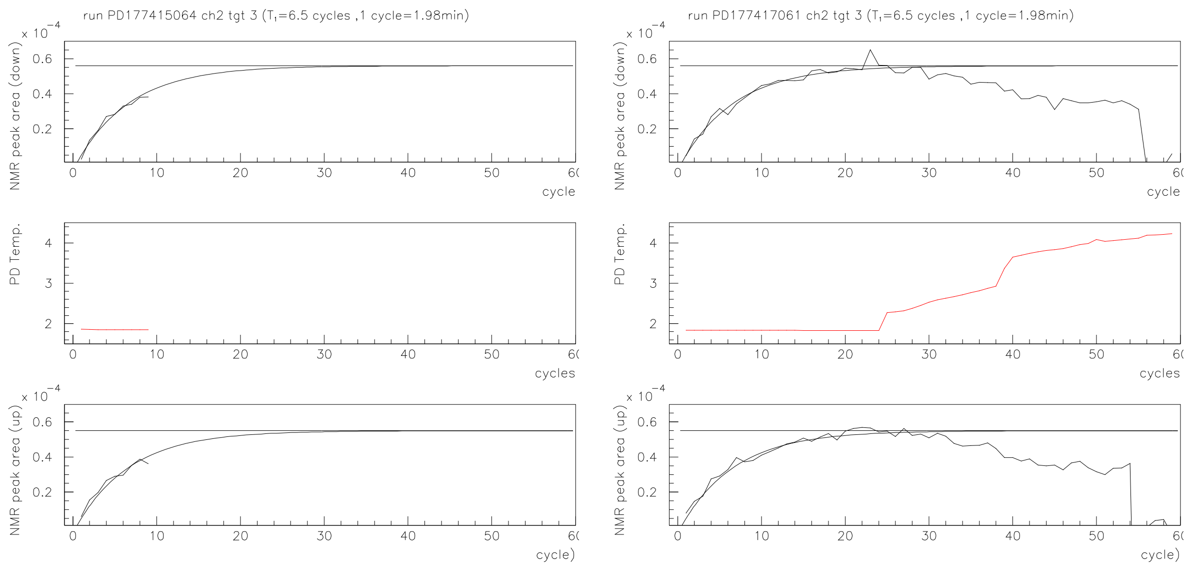


Figure 6:
Same as Fig. 1 but for runs 177415064 (left) and 177417061 (right). The mid-plot displays the PD temperature. The fit for run 177417061 was performed on data prior the temperature change (cycle 24).

3.5 Run 177425030

This run was taken without target, to study the F signal growth and check whether we see residual HD gas from previous HD target condensation. Fig. 7 shows the results of the run. No trace of HD is visible with a 43 sweeps statistics. The fluorine displays the double peak structure but no time evolution is visible on this run, see Figs 8 and 9. It is possible that this is because the run was started after that the F reached TE (no useful information regarding the condition was recorded in the logbook). The F signal is smaller by about a factor 2 compared to F signals from runs done with a CH2 target in, indicating that the coil holder contribute to 50% of the F signal *for a CH2 run* (for a HD run, it will contribute less since a HD target contains more Kel_F)

3.6 Run 177438462

This run was the first one done with half of the cooling wires removed. It allows to check if the time evolution of the signal ("T_1 effect") origin was the cooling wires (e.g. by inducing eddy currents that would warm the target sample). However, the 11 cycles of the run may not enough to reach TE in case of long T_1. Using the subsequent run 177439952 to extract the TE value (3.2×10^{-5} V.[1]), we can extract $T_1 = 2.0$ min, see Fig. 10. The dramatic shortening of T_1 indicates either that the time evolution is link to the cooling wires (***ruled out subsequently***????) or that T_1 for CH2 somehow depends on the history of the sample. For example the shortening of T_1 occurred after the sample was exposed to lower temperatures (1.8K), then warmed up to 4.3K and then to room temperature and half the cooling wires removed.

3.7 Runs 177667669 and 177706303

Run 177667669 and 177706303 confirm the small T_1 value of 2 to 3 min seen in the previous run, see Fig. 11. These runs shows again that the time dependence is not due to the presence of the 3-pins tool.

3.8 Run 177715565

This run was done off-resonance, in order to see whether the time evolution was due to a time change in the RF-circuit resonance. The TE amplitude is much lower and the time evolution of the signal is more difficult to measure due to the larger noise in one hand and the apparently short (few minutes) T_1 value for the runs done with half of the cooling wires removed. It is hard to conclude anything from these data, except that T_1 is short. Using the T_1 value of previous runs provides an acceptable fit of the data, see Fig. 12.

[1] This number is different ****WHY IS THAT???**** to the TE value of 2.5×10^{-5} for target #3 with all wires, taken in the same T_{up} and B_{span}, for example run 177415064 after temperature correction. This was seen in [4] and may be an overall (i.e. angle independent) effect due to cooling wires.

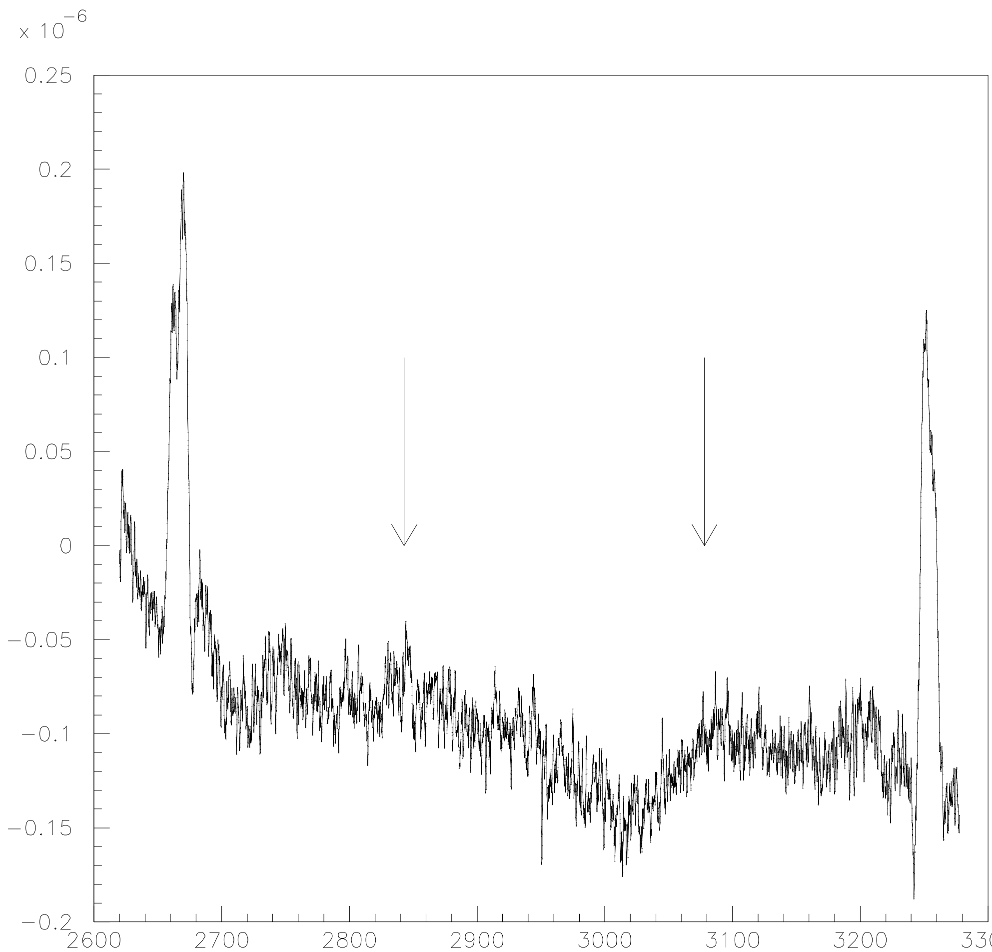


Figure 7:
Averaged of the 43 sweeps for run 177425030. Data were taken without target. The two arrows signals the H peak positions if H would be present (residual HD gas from previous HD target condensation).

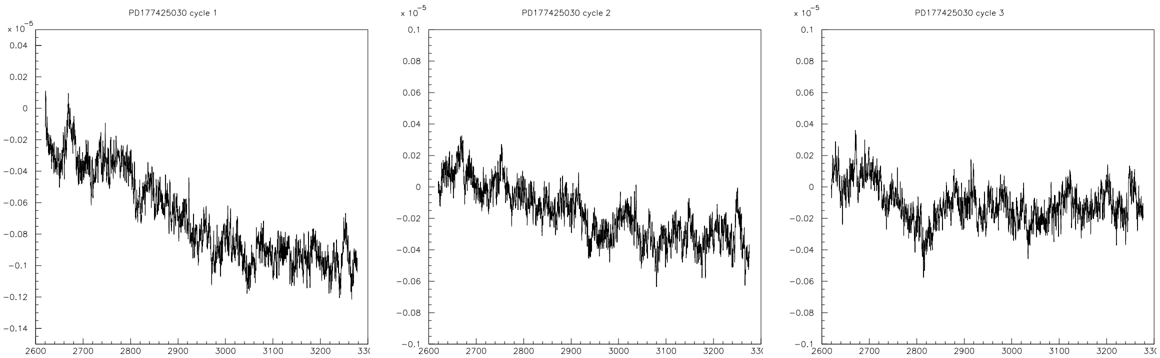
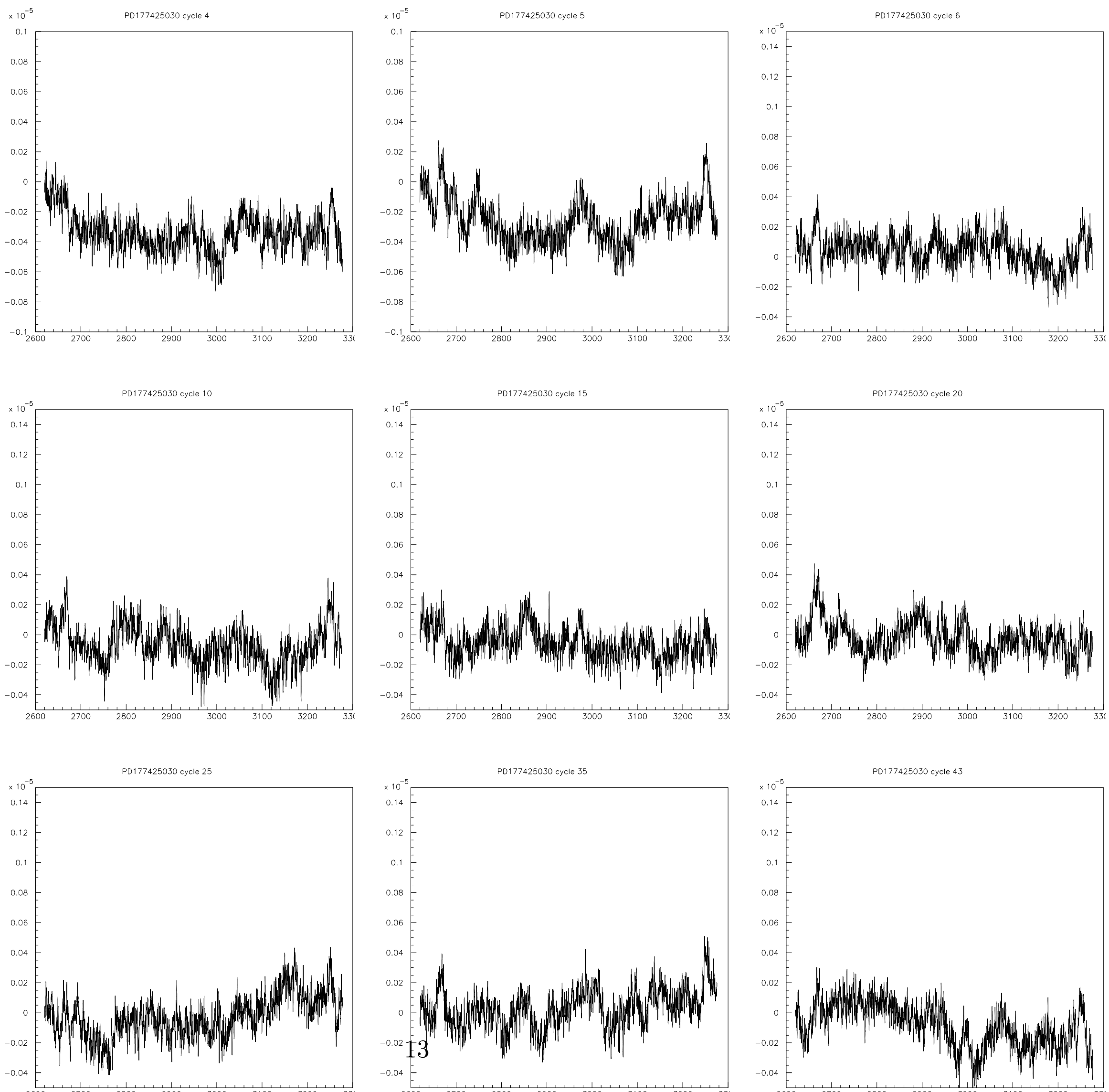


Figure 8:



Some of the individual sweeps for run 177425030.

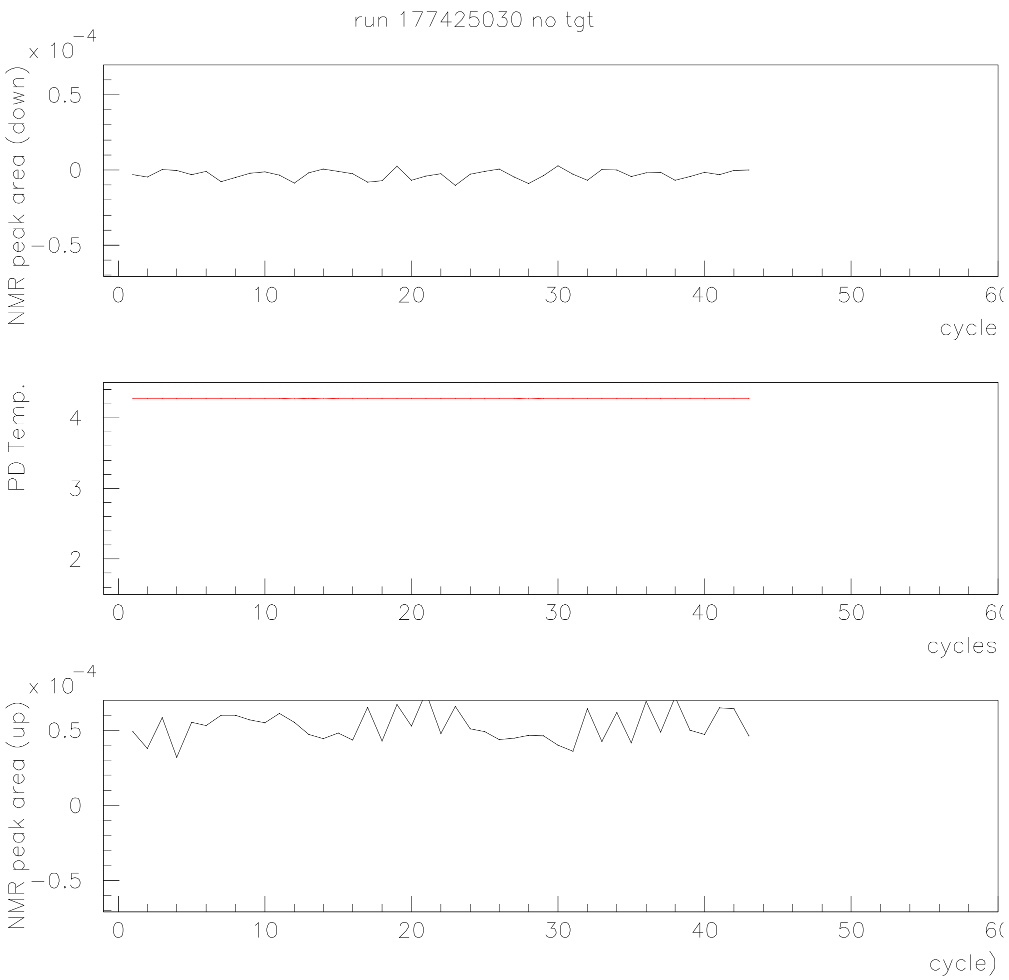


Figure 9:
Evolution of the F signal size for run 177425030.

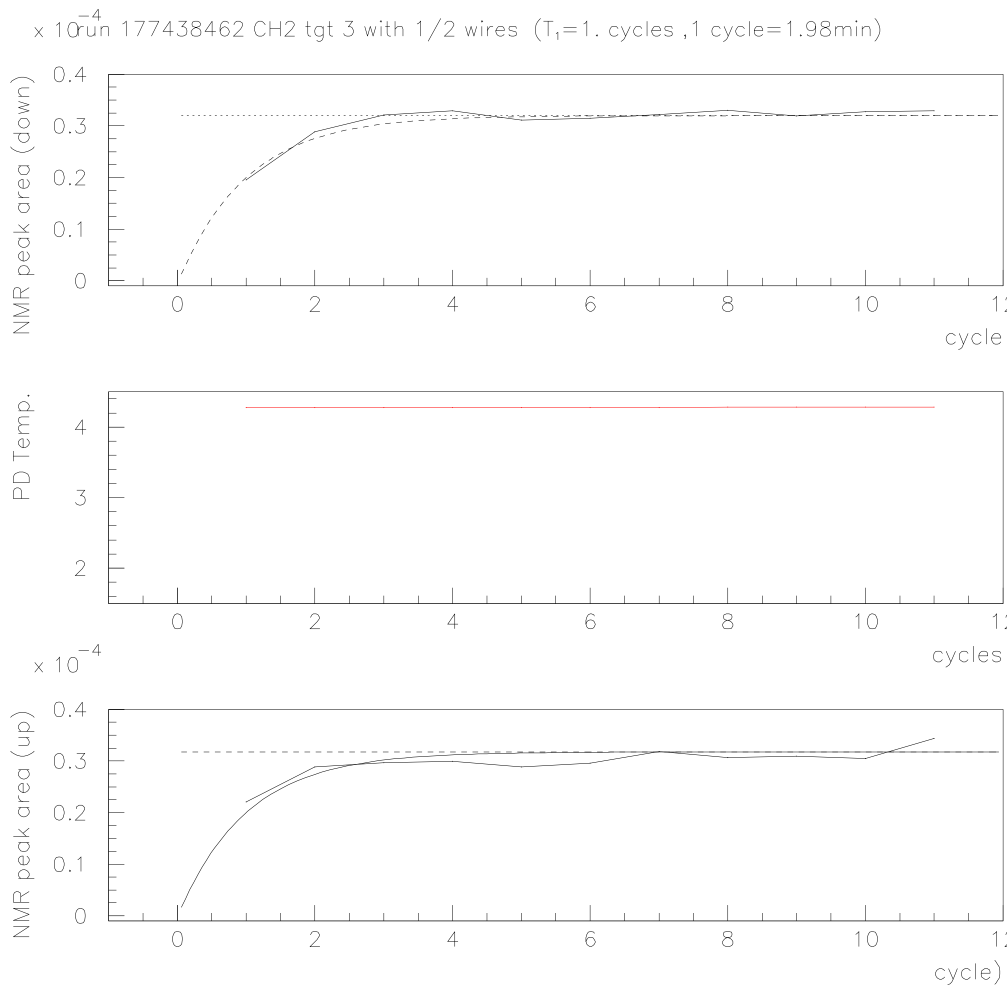


Figure 10:
Evolution of the F signal size for run 177438462.

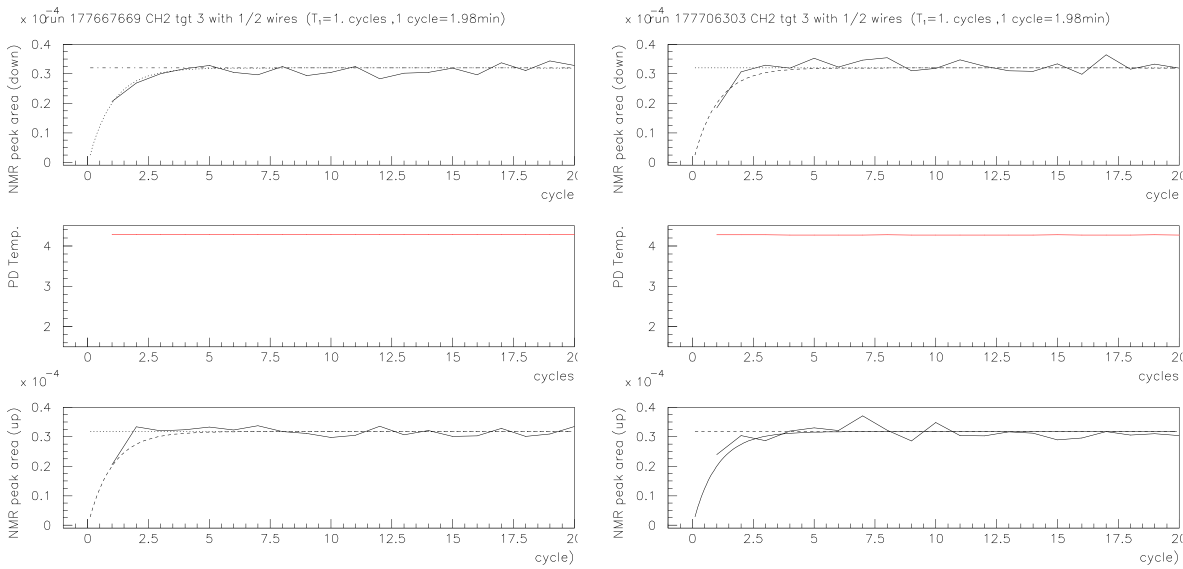


Figure 11:
Evolution of the F signal size for run 177667669 (left) and 177706303 (right).

3.9 Runs 177872537, 177927640 and 177929878

These three runs were taken after removing all cooling wires from the CH2 target. As for the previous runs, they display a short T_1 of about 2 min. There seems to be no temperature dependence of T_1. The TE values for the NMR peak integral (50 Gauss integration range) for run 177872537 done at 4.27K were 5.659×10^{-5}V (down sweeps) and 5.554×10^{-5}V (up sweeps). The TE values for the run at 1.90K were 12.456×10^{-5}V (down sweeps) and 12.237×10^{-5}V (up sweeps). The 1.90K to 4.27K ratio of the NMR peak integrals for the areas are therefore 2.20 (for both down and up sweeps), in good agreement with the curry law predicting 4.27/1.90=2.25. We note that the temperature was not recorded for the 4.27K run and this number is approximate.

3.10 Runs 177960074 and 178016448

Run 177960074 was done with CH_2 target #2. Although the usual procedure of waiting 20min at zero field was followed for this run, no visible time dependence has been seen on this runs (see Fig. for the first 20 sweeps of the run) as well as multiple smaller runs of a few sweeps analyzed online. Run 178016448 done at 1.8K does show a small T_1 estimated at 2.3min, see Fig.).

The fluorine runs 178014325 and 178040926 display no time dependence.

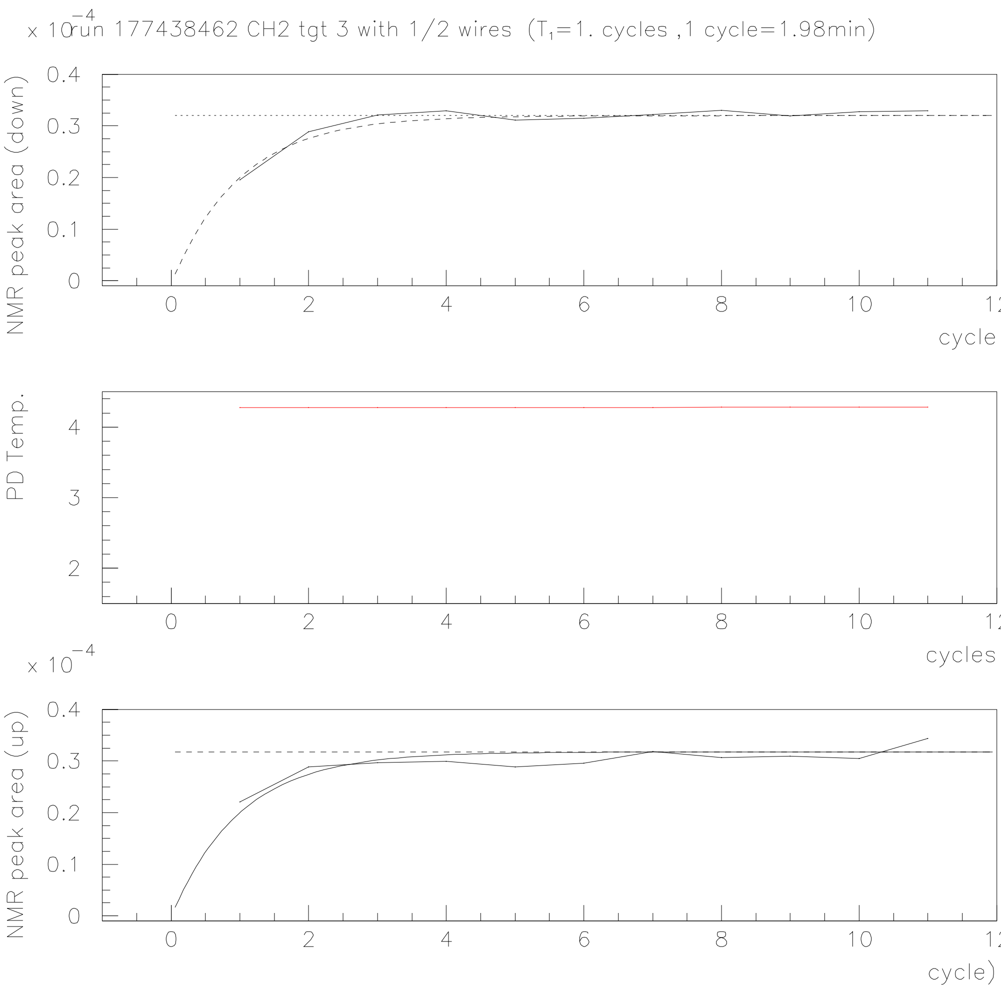


Figure 12:
Evolution of the F signal size for run 177715565.

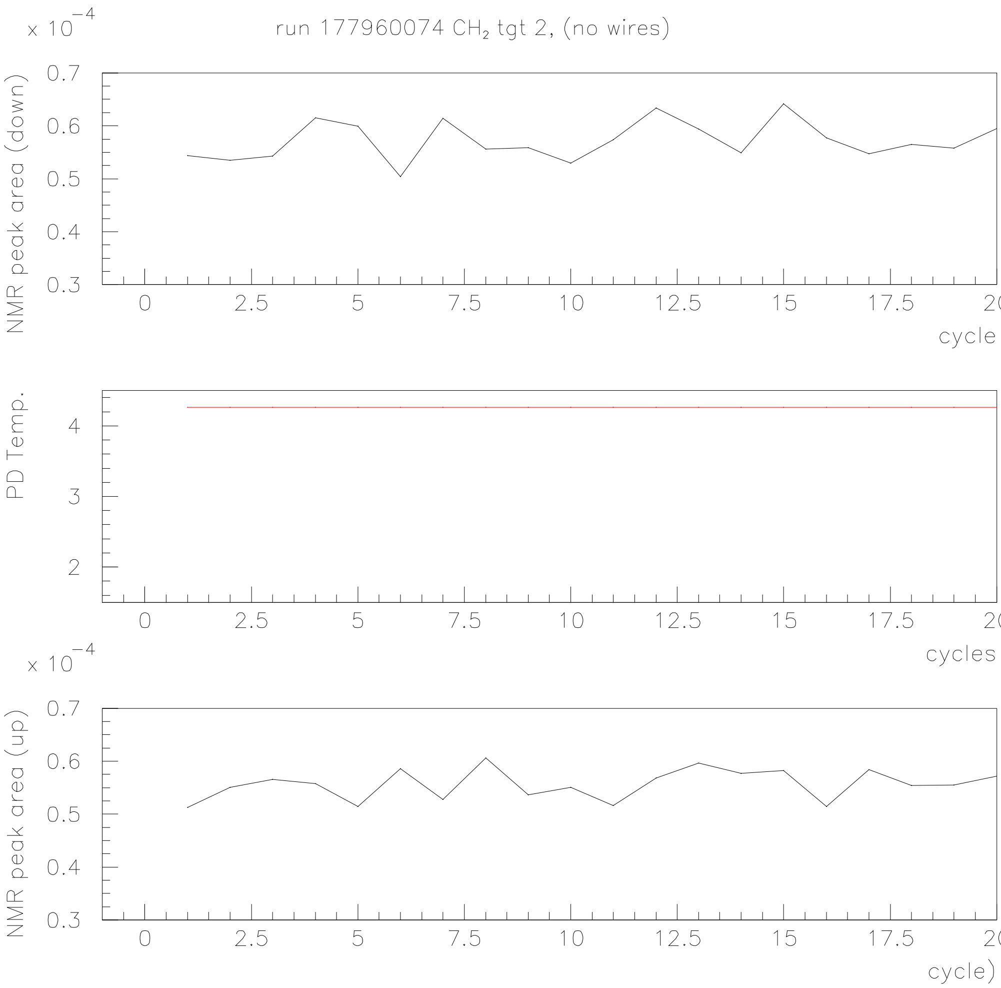


Figure 13:
Evolution of the H signal size for the first 20 sweeps of run 177960074, done at 4.27K. No time dependence of the signal is seen.

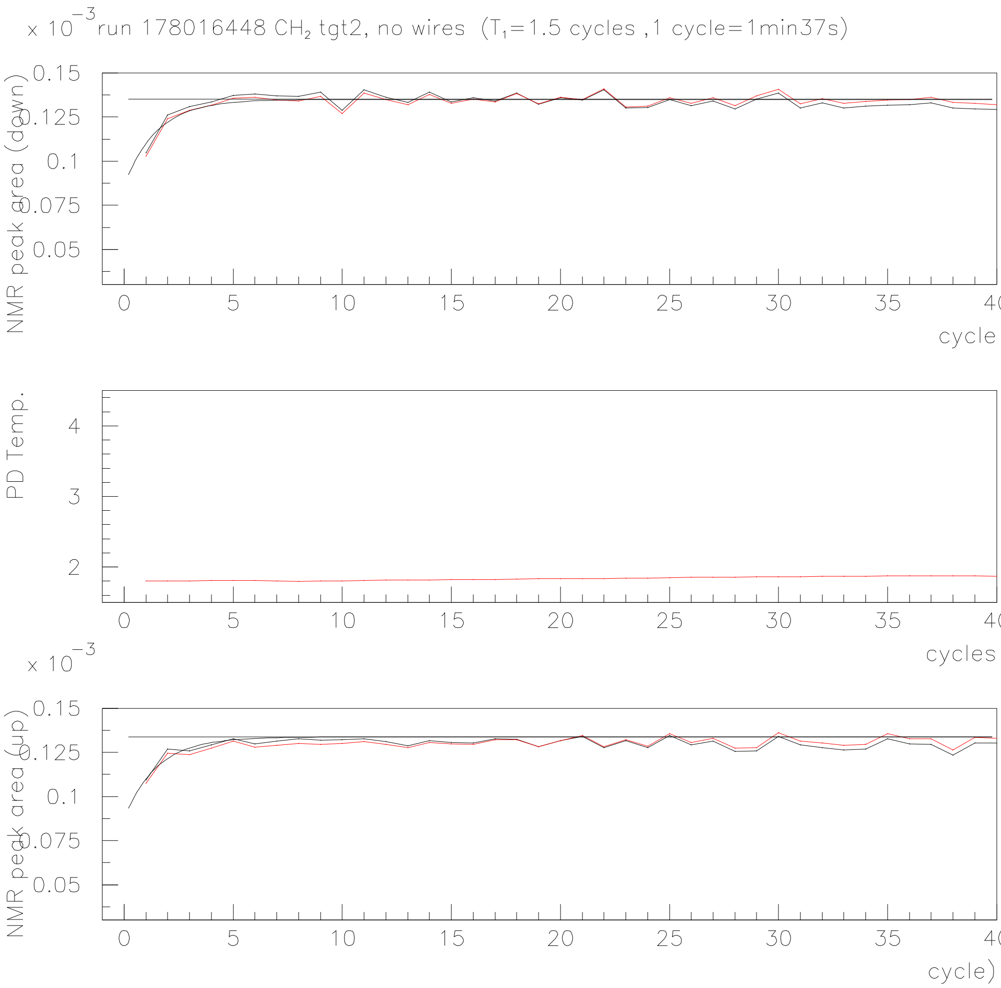


Figure 14:
Evolution of the H signal size for run 178016448. The red signal on the top and bottom plot includes the correction for the temperature drift.

3.11 Runs 178120005, 178131520, 178275290 and 178280329.

These runs were done at 4.3K with the brass ring of target #2 and the CH_2 of target #3. Run 178275290 indicates a T_1 value of 3 cycles (4.1 minutes), see . The short run 178120005 done at 4.3K, indicates (using the TE value from run 178131520) a similar T_1 see Fig. 16. However, this measurement is not precise due to the low number of cycles.

The baseline measurement (run 178131520) gives a TE value of 5.30×10^{-5} V (down sweep) and 5.22×10^{-5} V (up sweep), see fig. 17.

TE measurement for run

A run with the same target was done at 1.8K, run 178280329, and displays the same T_1, see Fig. 18, indicating this time no temperature dependence of the T_1. In addition, the TE value is not the one expected from the baseline run done at 4.3K: The TE value from the last cycles of run 178280329 is about 8.2×10^{-5} V while 12.5×10^{-5} V was expected. ***why is that???***

4 Runs on the "INFN target"

4.1 Comparison with other CH_2 targets

The CH_2 INFN target was made at the same time as target #3 with the same batch of material. Run 178308804 was done at TE to serve as reference. The integral of TE signal amplitude at 4.3K is 5.75×10^{-5} V (down sweeps) and 5.66×10^{-5} V (up sweeps) for an integration over 50 Gauss. On Fig. 19, we compare all the CH_2 targets. The table below gives the run numbers, target type and signal amplitude after correction if the run did not start in TE condition. All the runs used $T_{down,up}$ = 16s. All the signal agree within better than 2%, with the expectation of target #3 with ring #2 ***why??*** (No temperature correction was done because the PD temperature was not logged during these runs. Part of the difference may be explained by a slightly different averaged temperature. We also did not correct for the possible RF losses).

Run number	target	signal (down)	signal (up)
178308804	INFN	5.75×10^{-5} V	5.66×10^{-5} V
178131520	#3 (ring 2)	5.29×10^{-5} V	5.22×10^{-5} V
177960074	#2	5.71×10^{-5} V	5.60×10^{-5} V
177872537	#3 (no wire)	5.67×10^{-5} V	5.56×10^{-5} V
175996735	#1	5.70×10^{-5} V	5.55×10^{-5} V

4.2 T_1 for the "INFN target"

Run 178359590 was done at 4.3K, with the target waiting at zero field for 20 minutes prior starting the run. No time dependence of the signal was seen, see Fig. 20. Run 178364581 was done at 1.8K for the first 20 cycles. Knowing the 4.3K signal amplitude of 5.7×10^{-5} V, the expected signal amplitude is 13.7×10^{-5} V at 1.8K, as measured, see Fig. 21. INFN target seems to display

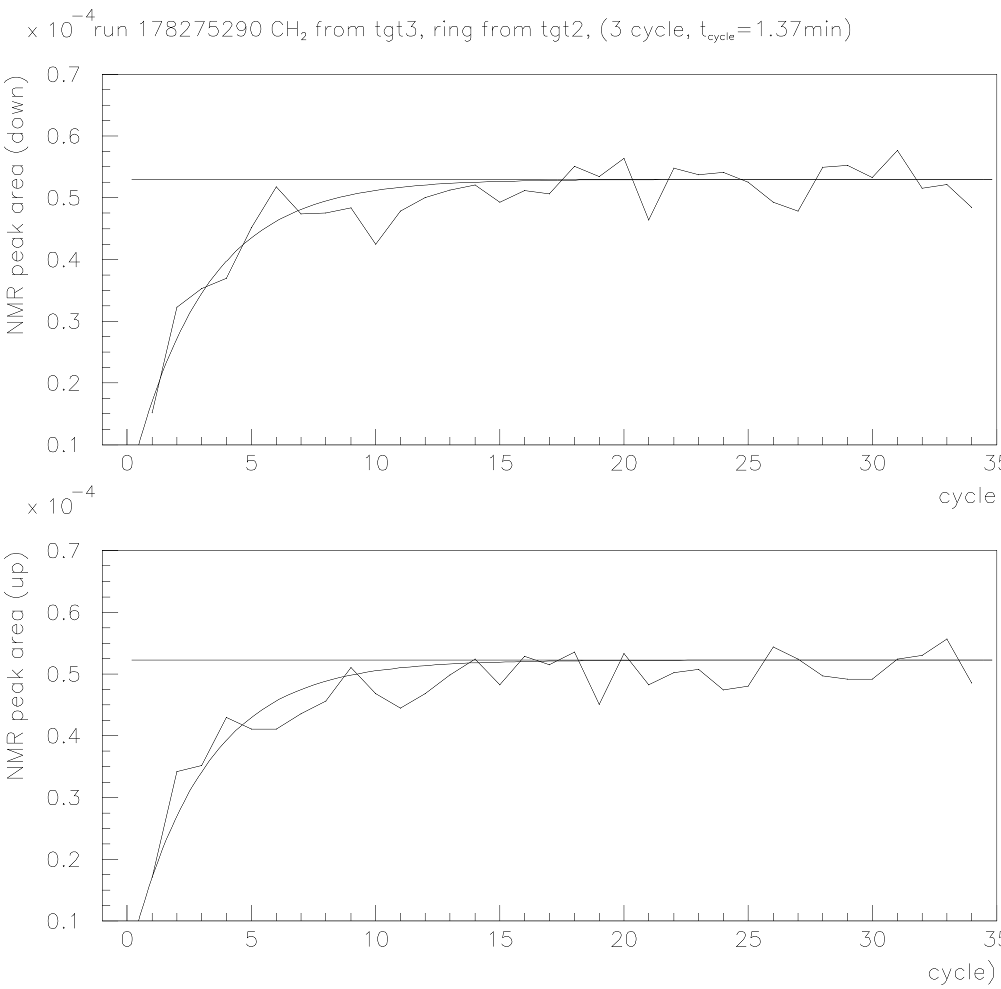


Figure 15:
Time evolution of the H signal measurement for run 178275290.

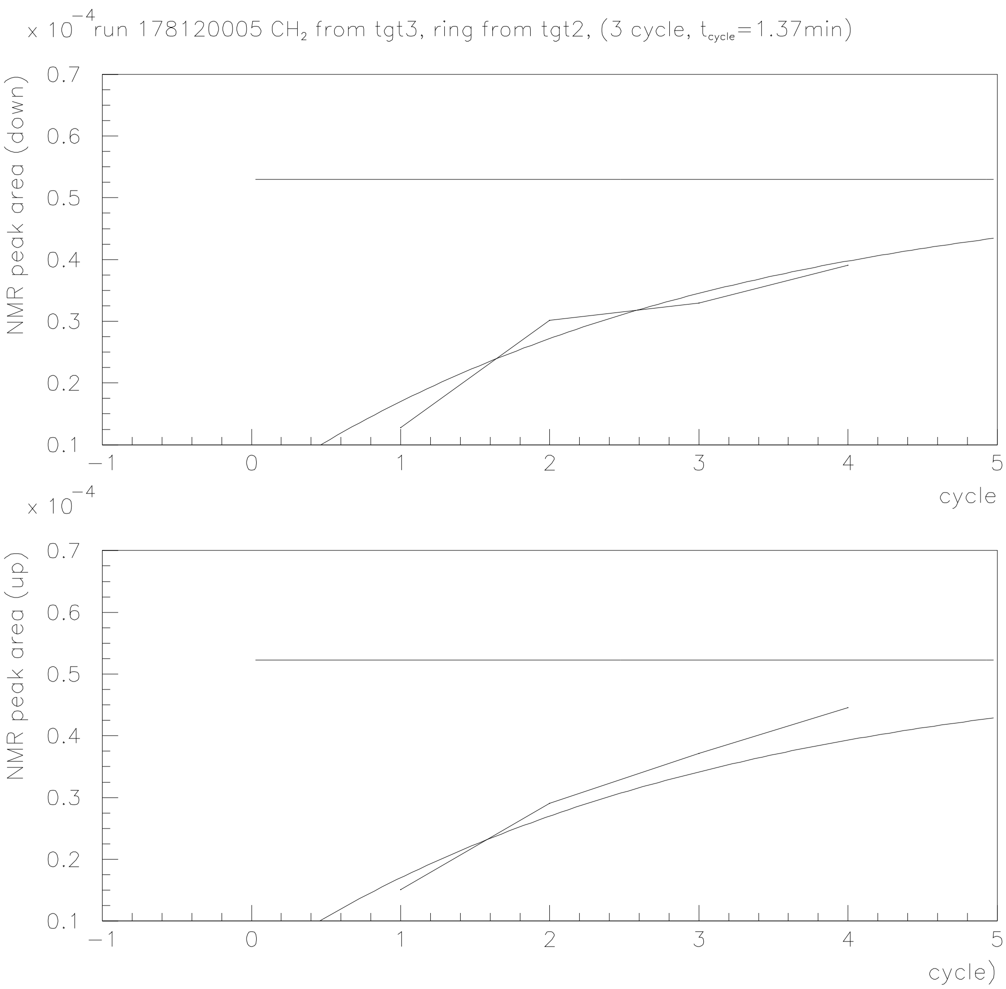


Figure 16:
Time evolution of the H signal measurement for run 178120005.

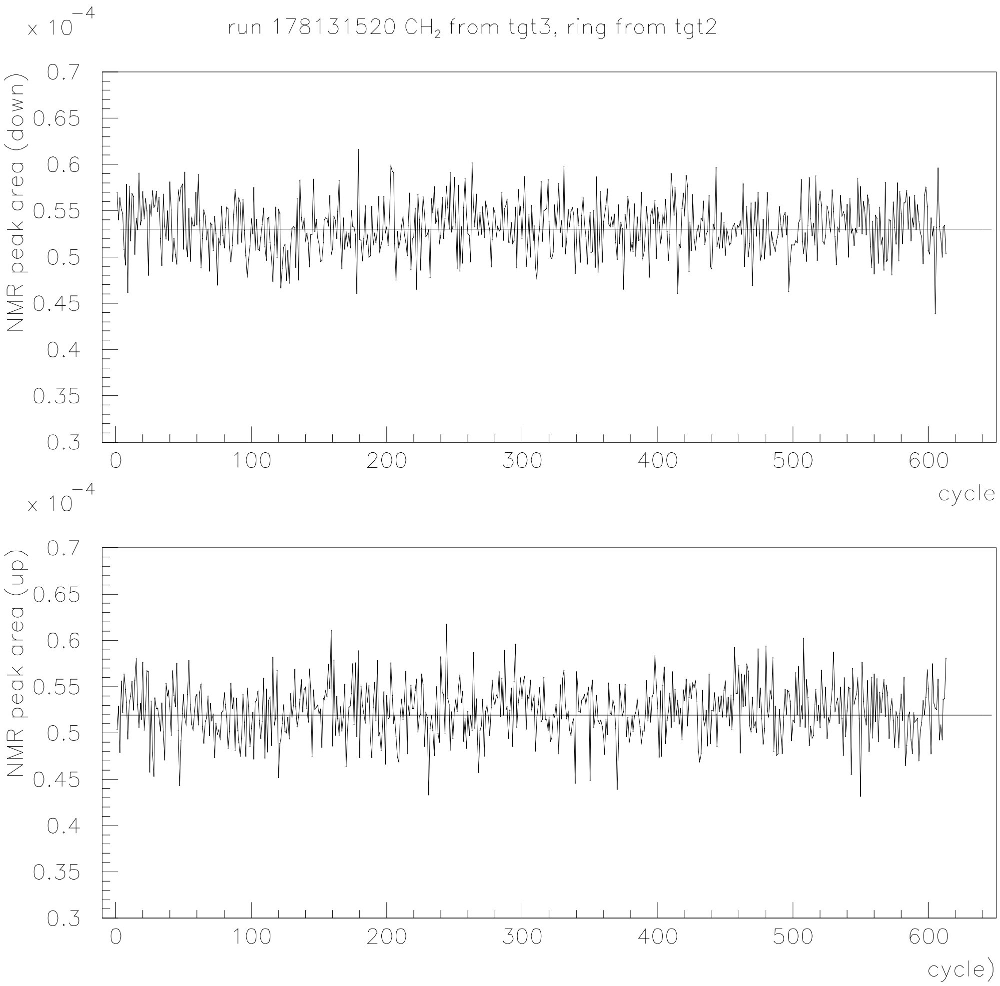


Figure 17:
TE measurement for run 178131520.

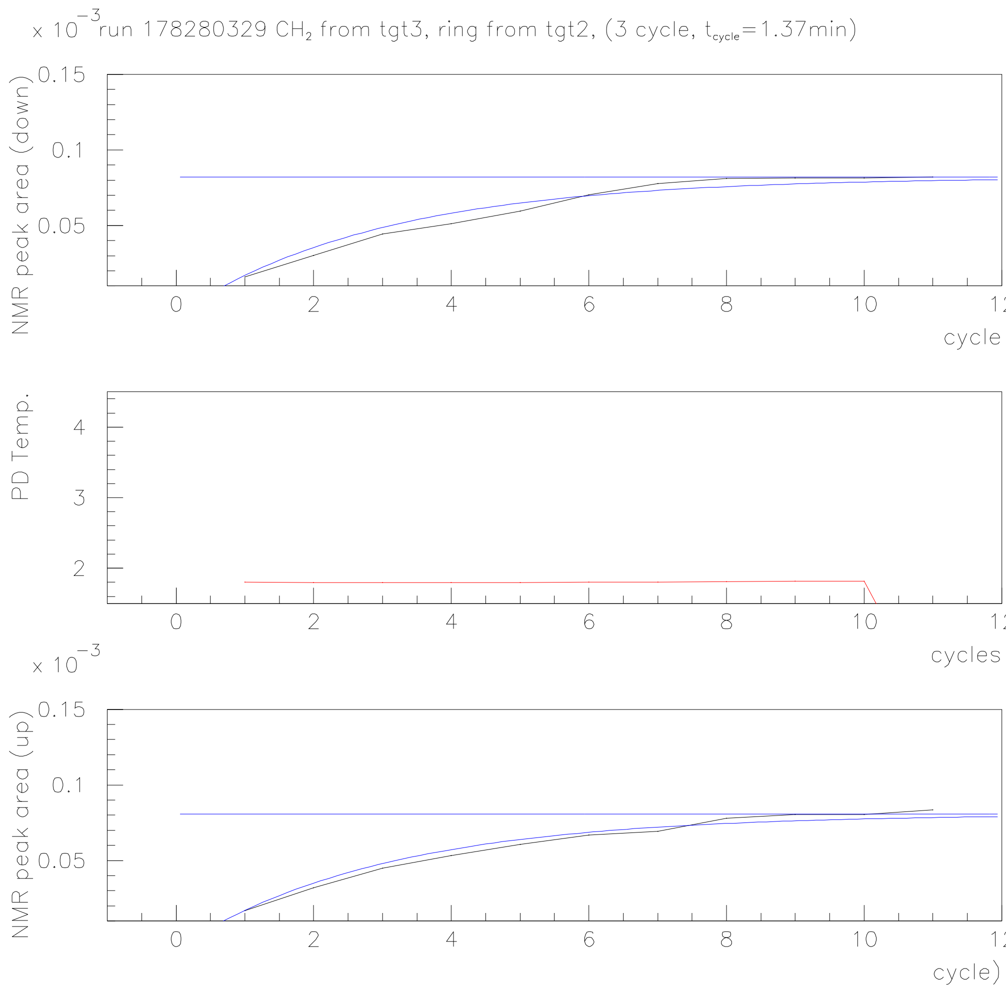


Figure 18:
T_1 measurement, run 78280329.

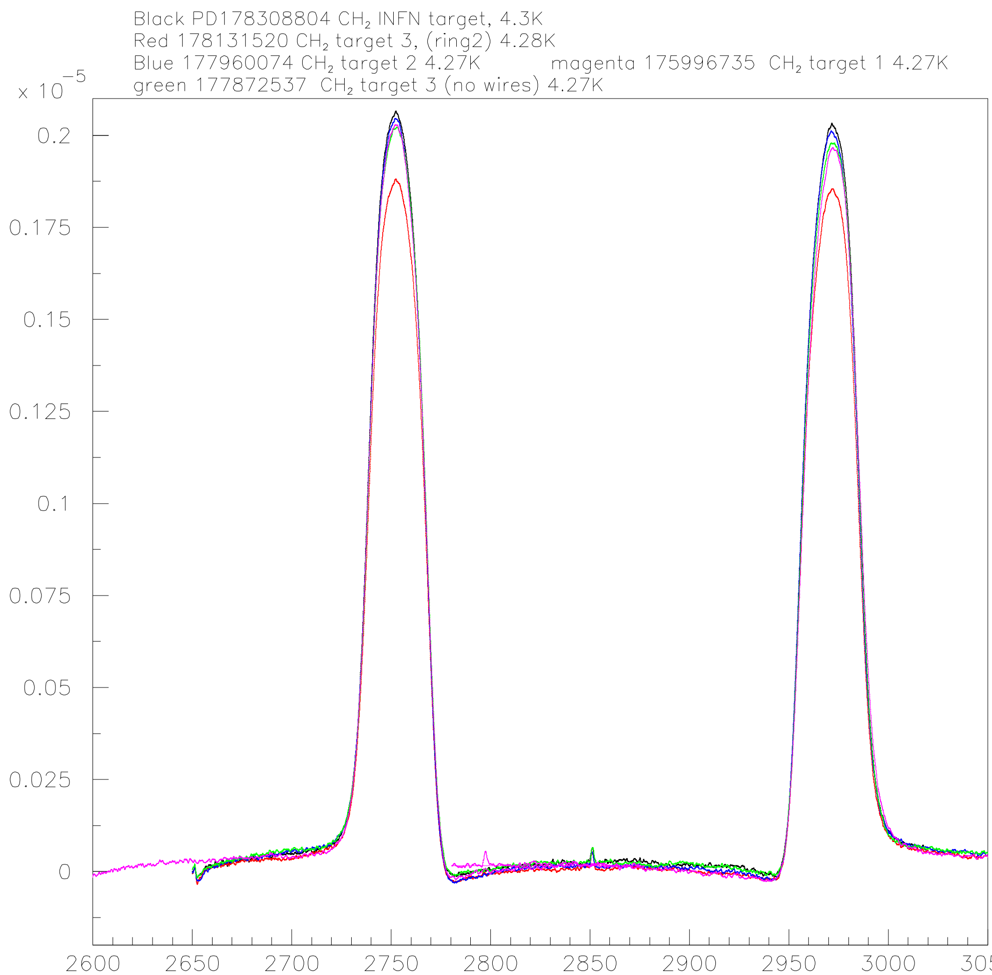


Figure 19:
Comparison of the TE signal from the 4 JLab-type CH_2 targets for runs taken in the PD1 with insert 1. Temperature was approximately 4.3K. The white RF cable was used. Also shown is a run with a combination of target CH_2 material #3 with target ring #2.

a short time dependence at this temperature. We measured a T_1 of about 1.4 minute (0.8 cycles for the down sweeps and 1.5 cycles for the up sweeps).

5 Summary of the test to identify the origin of the polarization lag

The possible other origins for a apparent polarization lag could be:

- Eddy current in the Al, cooling wires warming up the CH2 sample during the fast field rise from 0 Gauss to the nominal ~2800 Gauss. This would have to increase in average the sample temperature by at least a factor 5 to 10 to explain the initial small signal, which is implausible. Furthermore, the almost instantaneous cooling of CH2 cell (see [1]) would suppress this effects. The eddy current hypothesis was experimentally ruled out using:
  - Run 177409234 in which we see that the damping of the NMR signal occurs with Fluorine as well;
  - The damping of the signal was also seen in runs without Al. cooling wires;
  - The effects exist long after the fast rise of the field (see T_1 effect after the 1h30 pause of the run 177409234 near sweep 491);
  - ???dedicated runs T_1 effects seen after the target has been sitting at hight field???
- Magnetization of the 3-pin tool. This was ruled out by run 177417061 for which the 3-pin tool was moved 6cm away from the target. (This was also verified with runs Run 177667669 and 177706303)
- Q-curve shift due to field ramping. Frequency scans were done in stable magnetic field condition and immediately after ramping up the field. No difference in frequency, amplitude of phase of the resonance was seen. Also, a run was done off-resonance. The data seems to indicate that the time evolution is the same, but without great certainty.

6 Conclusion

- CH2 target #3 has a longer T_1. It seems to be temperature dependent ***in some cases***: about 8min at 4.3K and 13min at 1.8K.
- F signal, coming mostly from the coil holder also displays a time dependence.

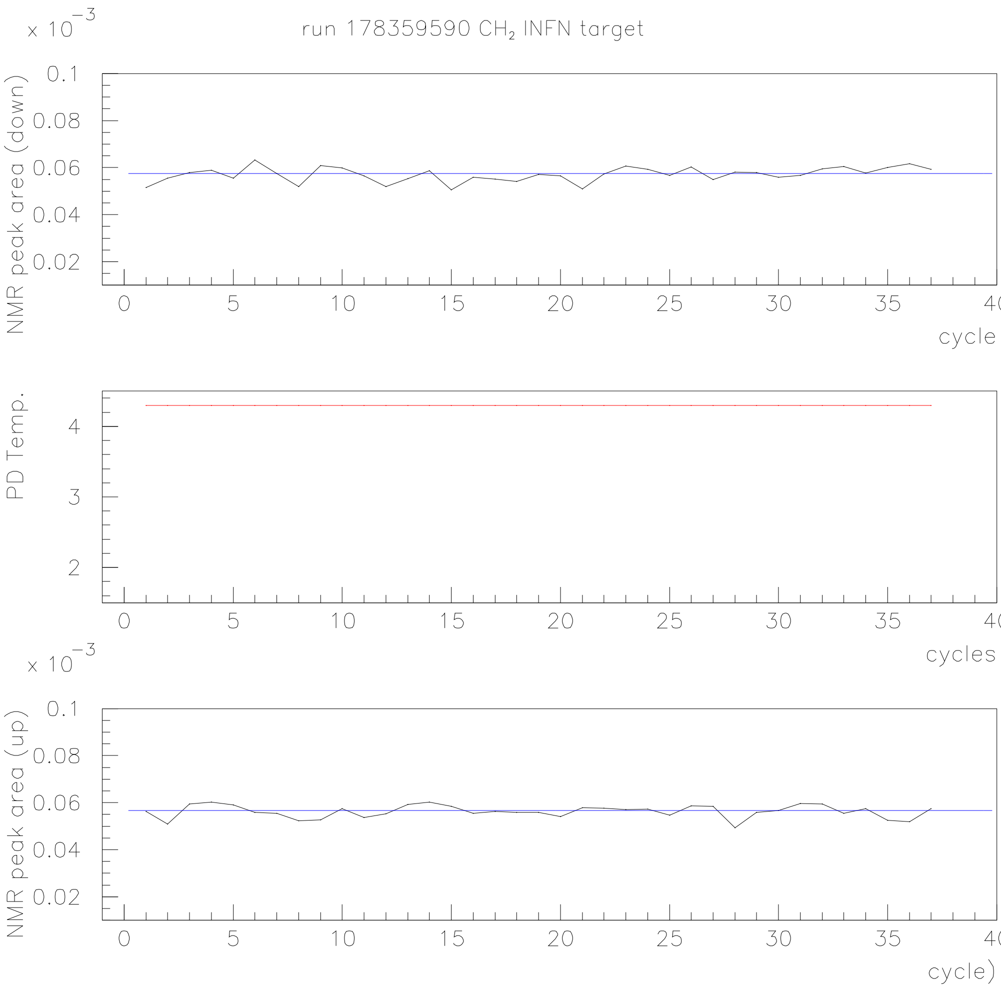


Figure 20:
T_1 measurement, run 178359590 (4.3K run).

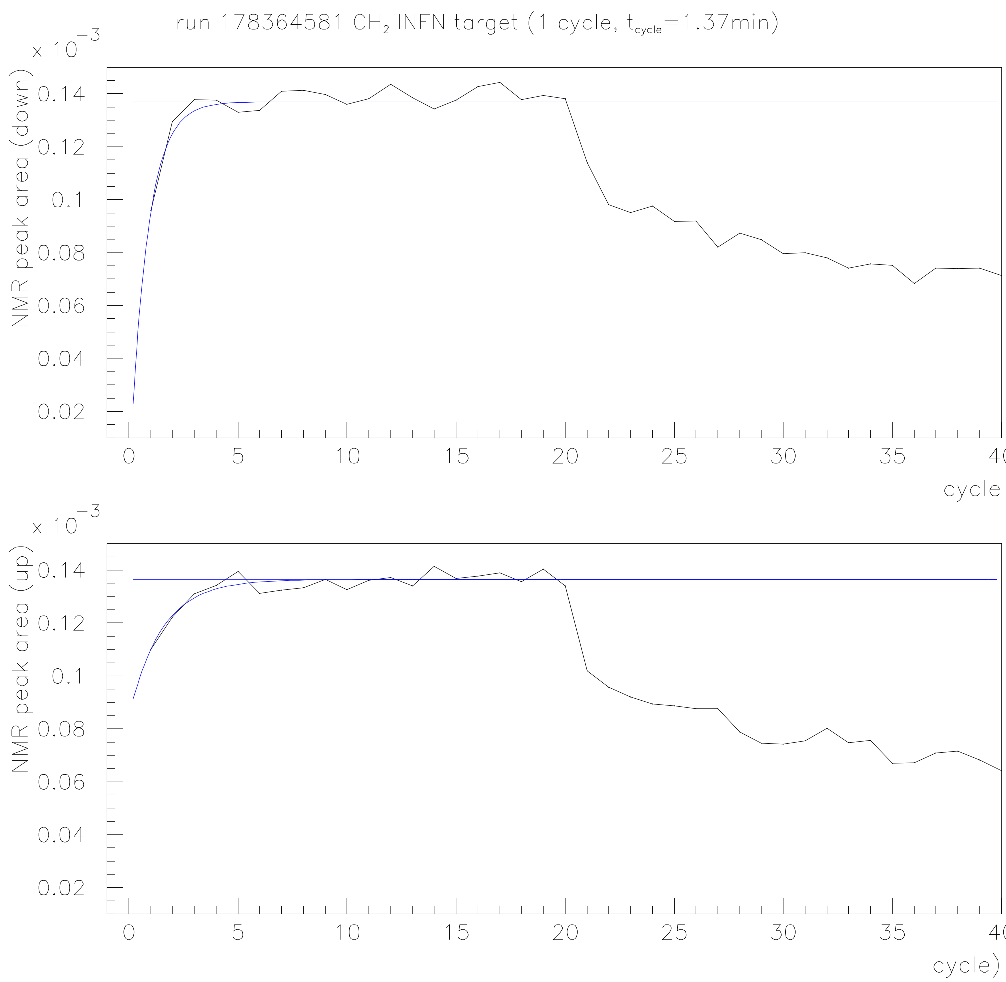


Figure 21:
T_1 measurement, run 178364581 (1.8K run up to cycle 20. The CH_2 sample is warmed up to 4.3K afterward).

References

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