HD Spin Manipulations by Saturated Fast Passage in the Production Dewar

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1 Introduction

High RF power is needed for efficient spin manipulations. However, in order to not heat the HD too much, one should maximize the RF transmission rather than the generated power. To achieve this, operations should be done on the emitter coil frequency. This is a small resonance sitting on the left of the transmitter resonance and usually not visible during frequency scans. In addition, in order to narrow the NMR signals and hence reducing the duration of the sweeps and increasing the efficiency, the magnetic field has to be as low as possible, keeping in mind that a too low magnetic field increases the T_1 of the H and D and thus induces polarization losses. An adequate range is 300-500 Gauss. To match this range with the emitter coil frequency, the circuit characteristic is changed with capacitors (contained in the "capacitor box"). Varying the capacitor values allows to tune the circuit to match the low field/ emitter coil frequency conditions.

Add description of SFP, AFP, Spin Flip here.

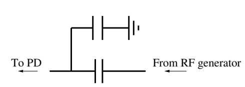
2 Procedure

X. Wei's procedure.

3 First test (Sept. 15th 2011 to Sept 20th 2011).

The test was done on HD target 19.

In order to tune the RF circuit, identify and enhance the emitter coil resonance, the capacitor box was inserted just between the RF switching box and the RF in cable going to the PD. Figure 1 is a schematic of the capacitor box. The value of the serie capacitor was 2000 pF and the value of the paralell capacitor was 1180 pF.

Figure 1: 

Capacitor box for RF circuit tuning.

3.1 Emitter resonance

The figure 2 shows frequency scans done with the capacitor box. Two methods were used to determine the position of the emitter resonance. They give 2.167MHz (subtraction of RF scan with emitter amplitude shifted away) and 2.125 MHz (subtraction of a Lorentzian+linear background).

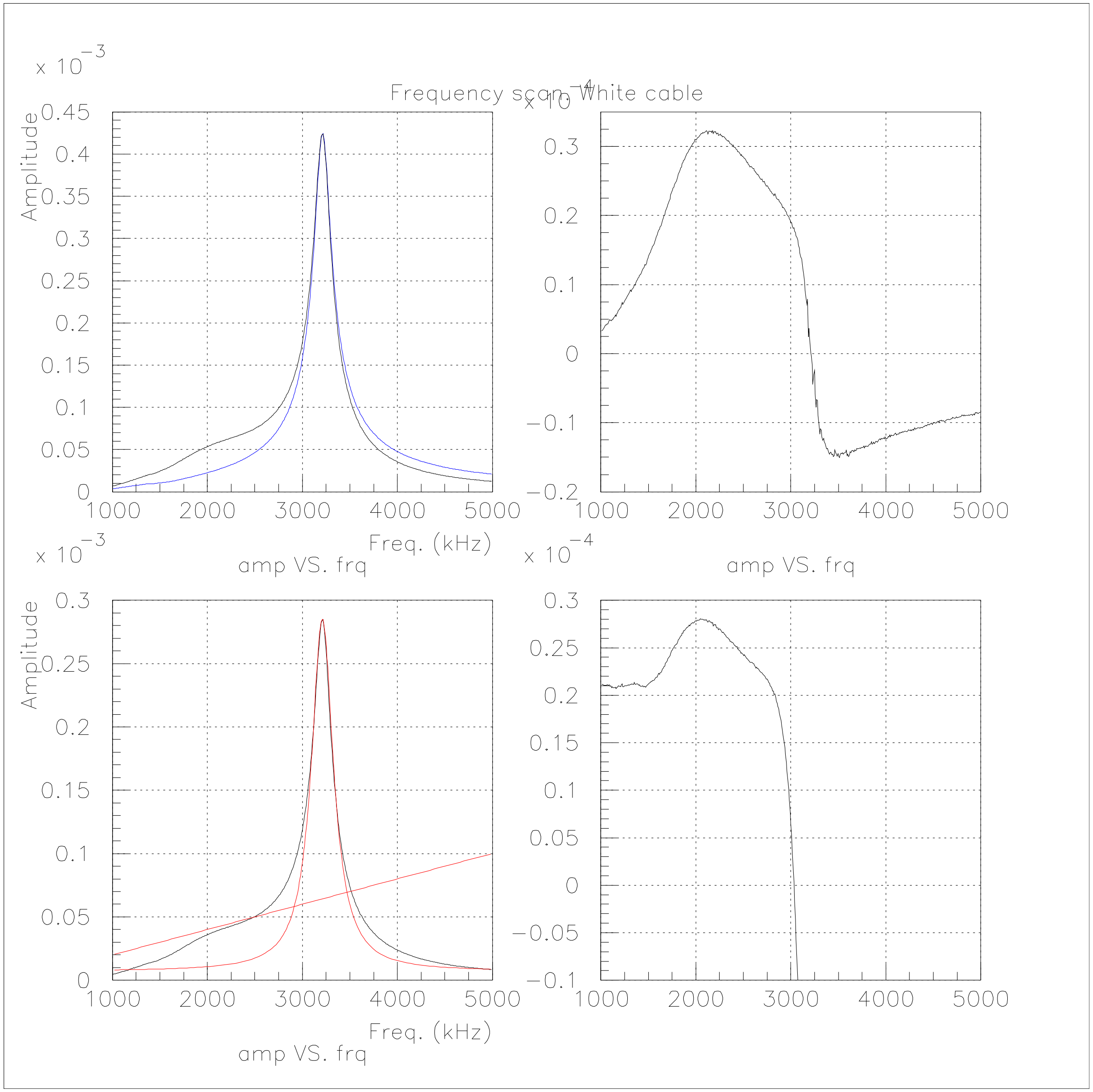
3.2 List of runs

All the runs were done on PD2 with insert 1 and the white RF cables and HD target #19.

We did a set of runs to determine the range in magnetic field for the fastest possible sweeps, in order to minimize the time the target stays under low magnetic field (about 500 Gauss). Good parameters are $B_{center} = 555$ Gauss and $B_{span} = 45$ Gauss. These runs were done with the tuning capacitor box in the circuit.

The integration range is 25 Gauss. D runs are in red, H runs are in blue.

Figure 2:



RF scans. The top left panel shows a scan done with the nominal 2000 pF and 1180 pF values of the capacitors in the capacitor box (black line). The left peak is the emitter coil resonance and the right peak is the receiver coil one. The blue line is for a scan done with the capacitor box without parallel capacitor (emitter peak shifted away to the left). The top right plot gives the subtraction of the blue scan from the black one. Ideally, it should give a pure emitter resonance. The bottom left shows a Lorentzian+linear background fit of the receiver resonance (red line). The bottom right plot gives the subtraction of the red fit from the black data. The scans are done at -25dbm.

Run #	T^o	cycles	B-span	B-center	T_{up}	RF $\lambda/2$ res. freq. & phase @-40dBm	RF $\lambda/2$ res. amp $\times 10^6$V	RF (dBm)	Integral down/up$\times 10^6$	Pol.	Pol. Gain (down up <mean>	comments
192714401	2.025	6	300	18794	31	12372/118.8	9.535	-40	13.009/ 12.842	3.762%/ 3.713%		w/o capa. box
192716052	2.013	3	300	2903	31	12372/118.8	9.535	-40	36.416/ 37.220	3.574%/ 3.652%		w/o capa. box
192730484_1	2.029	1	45	555	16	$12341/-4.83^o$ (used -155^o)	3.862	-45	9.6680/ 7.7153			Before SFP w/ capa. box
192730484_2	2.026	1	300	2903	31	$12341/-4.83^o$ (used -12^o)	3.862	-40	10.969/ 11.217			Before SFP w/ capa. box
192730484_3	2.028	2	300	18794	31	$12341/-4.83^o$ (used -12^o)	3.862	-40	3.876/ 3.885			Before SFP w/ capa. box
192732136	2.037	6	300	18794	31	12337/118.6	9.485	-40	13.025/ 13.176	3.785%/ 3.829%	+0.024% +0.116% +0.071%	After SFP[1] w/o capa. box
192733028	2.035	3	300	2903	31	12337/118.6	9.485	-40	36.568/ 36.193	3.603%/ 3.566%	+0.029% -0.086% -0.029%	After SFP w/o capa. box
192799328	2.016	6	300	18794	31	12364/120.19	9.96	-40	13.617/ 13.229	3.768%/ 3.661%		Before SFP w/o capa. box
192800295	2.016	3	300	2903	31	12364/120.19	9.96	-40	35.987/ 35.517	3.377%/ 3.333%		Before SFP w/o capa. box
192805204	2.025	6	300	18794	31	12366.5/120.05	9.73	-40	13.439/ 13.436	3.808%/ 3.806%	+0.040% +0.145% +0.093%	After SFP[2] w/o capa. box
192806068	2.039	3	300	2903	31	12366.5/120.05	9.73	-40	34.315/ 34.017	3.297%/ 3.268%	-0.080% -0.065% -0.073%	After SFP w/o capa. box
192814578	2.020	6	300	18794	31	12365.0/119.61	10.01	-40	13.479/ 13.661	3.712%/ 3.762%		Before SFP w/o capa. box
192815455	2.023	3	300	2903	31	12365.0/119.61	10.01	-40	34.396/ 33.792	3.212%/ 3.156%		Before SFP w/o capa. box
192820605	2.011	3	300	2903	31	12362.6/119.36	9.848	-40	33.787/ 332.162	3.207%/ 3.053%	-0.005% -0.103% -0.054%	After SFP[3] w/o capa. box
192821037	2.015	6	300	18794	31	12362.6/119.36	9.848	-40	13.457/ 13.443	3.767%/ 3.766%	+0.055% +0.004% +0.030%	After SFP w/o capa. box

1)Power: AFP Attn=0dB, Amplification Box Dial=1.85. 5 cycles.
2)Power: AFP Attn=0dB, Amplification Box Dial=2.46. 5 cycles.
3)Power: AFP Attn=0dB, Amplification Box Dial=2.46. 4×5 cycles .
Note: running at Tup=16s may have set us off resonance.

3.3 SFP conditions

The SFP were done with a magnetic field corresponding to H for the emitter coil resonance frequency (2Mhz), times 1.1815, in order to be at the H-D transition field. The Frequency was 2MHz with a 80 Hz modulation of 2kHz, The field was swept from 532 to 577 Gauss at a speed of 0.1 A/min (516 Gauss/min).

3.4 Conclusion

The polarization transfer by SFP is small and changes are within the statistical fluctuation of the signal. But the numerous tests demonstrate that spin transfer is clearly happening: All of the down and up D signals increase after SFP while all but one of the H signals decrease. So 11 out of 12 signals show the expected behavior. Taking the up and down averages, all the 6 signals show the expected behavior. Furthermore, the H polarization loss seems to be twice bigger than the D gain, as expected.

The small change maybe due to the fact that the H and D polarizations are similar or to too low RF power. Formula [1] with $\epsilon = 1/2$ can be used to compute the expected transfers.

- 1^{st} SPF: With initial H and D polarizations of 3.61% and 3.74% respectively, we expected a change H and D polarizations of -0.54% and +0.27% respectively. The lower gain we obtained may indicate that we used too little RF power.
- 2^{nd} SPF: With initial H and D polarizations of 3.36% and 3.71% respectively, we expected a change H and D polarizations of -0.385% and +0.19% respectively. Again, this would indicate too little RF power.
- 3^{rd} SPF: With initial H and D polarizations of 3.13% and 3.74% respectively, we expected a change H and D polarizations of -0.22% and +0.11% respectively. Again, this would indicate too little RF power.

However, it seems that their is no dependence of the (low) efficiency of spin transfer with the power, indicating that the power for the SFP transition is not the reason of the low efficiency. Another possibility is that the inputs (i.e polarizations) of formula [1] are wrong. The calibrations for H and D would have to be wrong differently, since otherwise a common scaling factor in the calibration would factor out of the equations. Taking the ratio of the H and D polarization calibrations as an unknown, we can solve the equations for it. The D/H "recalibration" ratio turns out to be:

- 1.13 (H polarization eq., first FSP)
- 1.23 (D polarization eq., first FSP)
- 1.04 (H polarization eq., second FSP)
- 1.13 (D polarization eq., second FSP)
- 1.11 (H polarization eq., third FSP)
- 1.12 (D polarization eq., third FSP)

4 Sept 22nd 2011 Tests

The test was done on HD target 19.

capacitor box after RF feeding cable and before PD2. switching box with series capa at 2000p and parallel at 2200pF. RF in and out swapped (so emitter coil <-> receiver).

4.1 Emitter resonance

Figure 3 shows frequency scans done with the capacitor box. The two methods used to determine the position of the emitter resonance give similar results: 1.769MHz (subtraction of RF scan with emitter amplitude shifted away) and 1.777 MHz (subtraction of a Lorentzian+linear background).

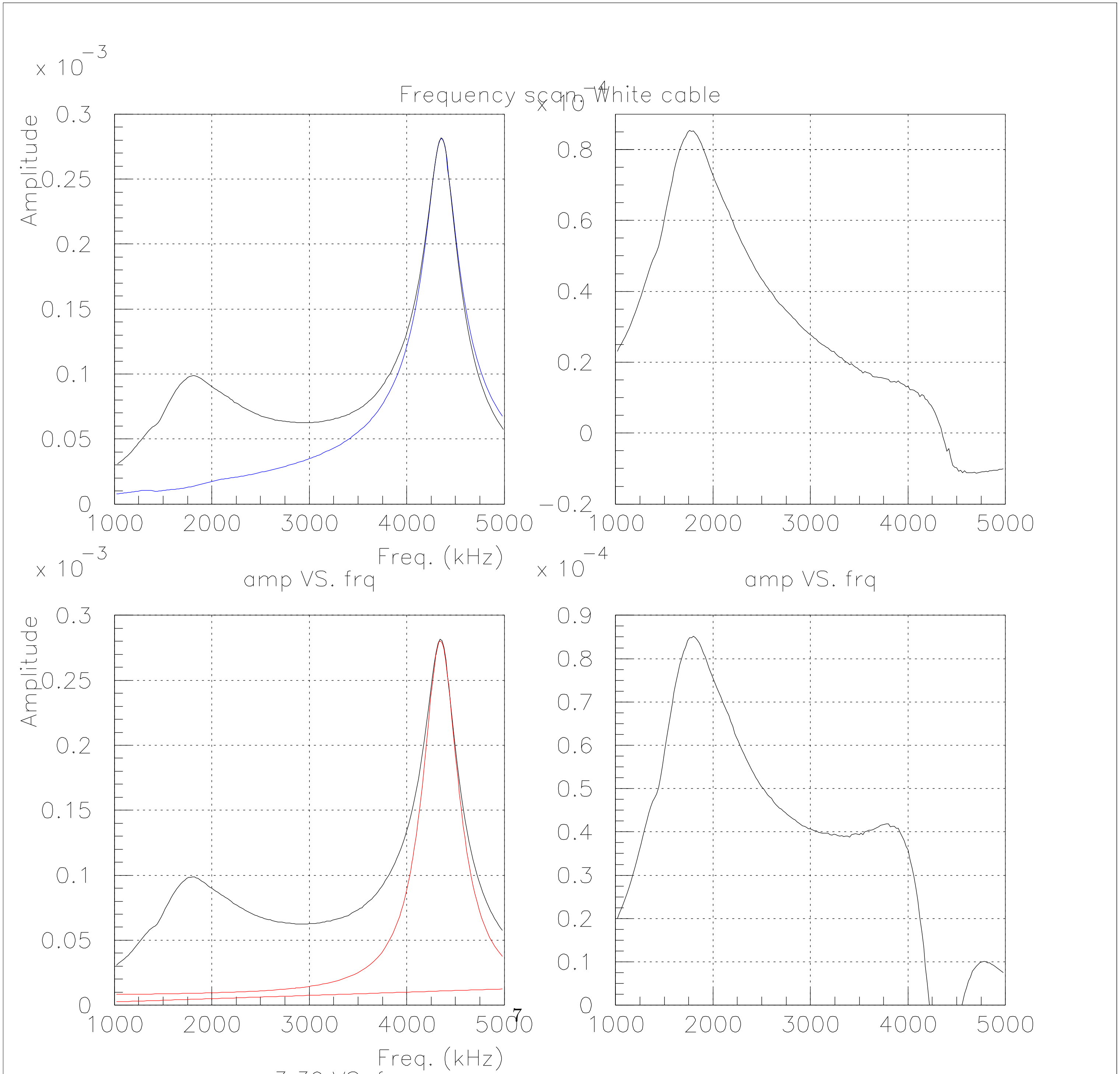
4.2 List of runs

All the runs were done on PD2 with insert 1, the white RF cables and HD target #19. D runs were averaged over 6 cycles and H runs over 3 cycles. Bspan was 300 Gauss and $T_{up,down}$=31s. Because of small NMR signals (the receiver coil is now twice smaller than the emitter coil), we chose the NMR frequency to correspond to the receiver coil resonance rather than the $\lambda/2$ resonance. All the runs were done with the tuning capacitor box in the circuit.

We did a set of runs to determine the range in magnetic field for the fastest possible sweeps, in order to minimize the time the target stays under low magnetic field (about 500 Gauss). Good parameters are B_{center} = 511 Gauss and B_{span} =20 Gauss for $T_{up,down}$=31s. These runs were done with the tuning capacitor box in the circuit.

The integration range is 25 Gauss. D runs are in red, H runs are in blue. In the second column, the first temperature indicates the average PD temperature during the measurement. A second temperature indicates the highest PD temperature during the SFP.

(Note. To obtain the correct polarization, we have to account that the raw signal is proportional to the NMR frequency).


Frequency scan: White cable
x 10^-3
Amplitude
Freq. (kHz)
x 10^-4
amp VS. frq
x 10^-3
Amplitude
Freq. (kHz)
x 10^-4
amp VS. frq

Run #	T^o	B-center	RF coil res. freq & phase @-15dBm	RF coil res. amp $\times 10^6$V	RF (dBm)	Integral down/up$\times 10^6$	Pol.	Pol. Gain (down up <mean>	comments
193049709	2.015	6618	4344.4/164.9	266.0	-40	6.841/ 6.824	3.558%/ 3.550%		
193050928	2.016	1022	4344.4/149.6	266.0	-40	15.701/ 15.542	2.792%/ 2.763%		
193058154	2.030 2.121	1022	4344.4/149.6	266.0	-40	15.854/ 15.601	2.819%/ 2.774%	+0.027% +0.011% +0.019%	power: Amp Box dial:1.46, Att. Box: 0db 5 cycles
193058608	2.022 2.121	6618	4344.4/164.9	266.0	-40	6.436/ 6.512	3.347%/ 3.386%	-0.211% -0.163% -0.187%	
193060548	2.082 3.379	1022	4344.4/149.6	266.0	-40	16.159/ 16.063	2.873%/ 2.856%	+0.054% +0.082% +0.068%	power: Amp Box dial:2.46, Att. Box: -5db 5 cycles
193060966	2.009 3.379	6618	4344.4/164.9	266.0	-40	6.628/ 6.676	3.446%/ 3.472%	+0.100% +0.085% +0.093%	
193068606	2.011	6618	4435.2/168.1	319.1	-40	7.883/ 7.920	3.347%/ 3.362%		
193069395	2.013	1020	4435.2/168.1	319.1	-40	19.098/ 19.204	2.756%/ 2.772%		
193073843	2.1634.700	1020	4435.2/168.1	319.1	-40	1.260/ 1.227	0.182%/ 0.177%	Large losses due to high T^0	power: Amp Box dial:2.45, Att. Box: -3db 5×5 cycles. Killed polarization
193074585	2.0004.700	6604	4435.2/168.1	319.1	-25	2.837/ 2.794	0.214%/ 0.211%	Large losses	Killed polarization
193075581	2..009	1020	4435.8/168.0	322.4	-25	5.975/ 6.223	0.177%/ 0.184%		
193078848	2.095	1020	4435.8/168.0	322.4	-25	6.462/ 6.185	0.191%/ 0.183%	+0.014% -0.001% +0.007%	power: Amp Box dial:2.45, Att. Box: -7db 30 cycles
193079294	2.021	6604	4435.8/168.0	322.4	-25	2.785/ 2.444	0.210%/ 0.185%	-0.004% -0.026% -0.015%	

4.3 SFP conditions

The SFP were done with a magnetic field corresponding to H for the emitter coil resonance frequency (1.820Mhz), times 1.1815, in order to be at the H-D transition field. The Frequency was 2MHz with a 80 Hz modulation of 6kHz, The field was swept from 501 to 521 Gauss at a speed of 0.07489 A/min (387 Gauss/min).

4.4 Conclusion

The spin transfer seems to have gone from D to H. This was not expected from formula [1]. We remark that, due to the longer D T_1, the starting polarization was higher for D than H.

Formula [1] with $\epsilon = 1/2$ can be used to compute the expected transfers.

- 1^{st} SPF: With initial H and D polarizations of 2.78% and 3.55% respectively, we expected a change H and D polarizations of -0.08% and +0.04% respectively. Instead, we obtained a gain in H and a loss in D.
- 2^{nd} SPF: With initial H and D polarizations of 2.80% and 3.37% respectively, we expected a change H and D polarizations of -0.18% and +0.09% respectively. Instead, we obtained a gain in H and a loss in D.
- 3^{rd} SPF: The temperature of the target went to 4.7K. This, together with the low (about 500 Gauss) field shortened significantly the T_1 of H and D, resulting in important polarization losses.
- 4^{th} SPF: With initial H and D polarizations of 1.81% and 2.13% respectively, we expected a change H and D polarizations of -0.14% and +0.07% respectively. Again, instead, we obtained a gain in H and a loss in D.

In case of a mistake in one of the calibration, the D/H "recalibration" ratio turns out to be:

- 1.06 (H polarization eq., first FSP)
- 1.23 (D polarization eq., first FSP)
- (H polarization eq., second FSP)
- (D polarization eq., second FSP)
- 1.19 (H polarization eq., fourth FSP)
- 1.16 (D polarization eq., fourth FSP)

5 Sept 23rd 2011 Tests

The test was done on HD target 19.

capacitor box after RF feeding cable and before PD2. switching box with series capa at2000p and parallel at 2200pF. RF in and out swapped (so emitter coil <-> receiver).

6 List of runs

All the runs were done on PD2 with insert 1, the white RF cables and HD target #19. D run were averaged over 6 or 8 cycles and H runs over 3 cycles. Bspan was 300 Gauss and $T_{up,down}$=31s. Because of small NMR signals (receiver coil twice smaller, we ran on coil res rather than $\lambda/2$. All the runs are done with the capa box on the circuit

We did a set of runs to determine the range in magnetic field for the fastest possible sweeps, in order to minimize the time the target stays under low magnetic field (about 500 Gauss). Good parameters are B_{center} = 511 Gauss and B_{span} =20 Gauss for $T_{up,down}$=31s. These runs were done with the tuning capacitor box in the circuit. It turns out the the fast resonance scan

The integration range is 25 Gauss. D runs are in red, H runs are in blue.

Run #	T^o	B-center	RF coil res. freq & phase @-15dBm	RF coil res. amp ×10^6V	RF (dBm)	Integral down/up×10^6	Pol.	Pol. Gain (down up <mean>	comments
193135704	1.997	1020	4345.0/168.3	325.9	-25	6.700/ 6.818	0.972%/ 0.989%		
193136929	2.004	6604	4345.0/168.3	325.9	-25	2.702/ 2.818	1.148%/ 1.198%		Before spin flip
193141980	2.038	6604	4345.0/168.3	325.9	-25	-0.905/ -1.034	-0.385 -0.439		After 1^{st} D spin flip. Power=-20dbm, dial=2.46
193143607	2.027	6604	4345.0/168.3	325.9	-25	0.721/ 0.593	0.306%/ 0.252%		After 2^{nd} D spin flip. Power=-15dbm, dial=2.46
193146835	2.009	6604	4345.0/168.3	325.9	-25	-0.488/ -0.405	-0.208 -0.172		After 3^{rd} D spin flip. Power=-12dbm, dial=2.46
193148583	2.007	1020	4345.0/168.3	326.1	-25	6.581/ 6.566	0.954%/ 0.952%		After erasing D pol. and redoing Fast Res. Scan,
193151682	2.086	1020	4345.0/168.3	326.1	-25	1.848/ 1.545	0.268%/ 0.224%	-0.686% -0.728% -0.707%	After 1^{st} pol. transfer. Power=-7dbm, dial=2.45
193152192	1.996	6604	4345.0/168.3	326.1	-25	0.890/ 0.590	0.378%/ 0.251%	+0.378% +0.251% +0.314%	After 1^{st} pol. transfer
193156985	2.071	1020	4345.0/168.3	326.1	-25	1.451/ 1.601	0.210%/ 0.232%	-0.058% +0.08% -0.025%	After erasing D pol. and 2^{nd} pol. transfer.Power=-7dbm, dial=2.45
193157412	2.021	6604	4345.0/168.3	326.1	-25	0.278/ 0.244	0.118%/ 0.103%	+0.118% +0.103% +0.110%	After erasing D pol. and 2^{nd} pol. transfer

6.1 SFP conditions

The SFP were done with a magnetic field corresponding to H for the emitter coil resonance frequency (1.820Mhz), times 1.1815, in order to be at the H-D transition field. The Frequency was 1.824MHz with a 80 Hz modulation of 6kHz, The field was swept from 504 to 524 Gauss at a speed of 0.07489 A/min (387 Gauss/min).

6.2 Conclusion

There is a clear spin transfer between H and D. Formula [1] with $\epsilon = 1/2$ can be used to compute the expected transfers.

- 1^{st} SPF: With initial H and D polarizations of 0.953% and 0% respectively, we expected a change H and D polarizations of -0.624% and +0.318% respectively.
- 2^{nd} SPF: With initial H and D polarizations of 0.246% and 0% respectively, we expected a change H and D polarizations of -0.164% and +0.082% respectively.

7 Operation on HD target 21a (Sept 29 2011)

The setting was identical to the Sept. 23^{rd} tests. However, the RF power applied (-7dBm on the attenuator box and 2.45 for the amplication box dial) induced a jump of temperature. It went from 2.1K to 3.2K and still rising when the RF was shut down before the end of the first cycle. -10dBm was also tried and was still too large. The appropriate power to keep a reasonable temperature was -12dBmon the attenuator box and 2.45 for the amplication box. The temperature stabilized at 2.8K while the RF was on.

7.1 List of runs

All the runs were done on PD2 with insert 1, the white RF cables and HD target #21a. We used a RF power of -55dBm. H & D have just 1 cycle. Bspan was 200 Gauss and $T_{up,down}$=31s. The runs were done on the receiver coil resonance (freq=4335.4kHz, Amplitude@15dBm=1.103×10^{-4}V, phase=171.4^o.

We did a set of runs to determine the range in magnetic field for the fastest possible sweeps, in order to minimize the time the target stays under low magnetic field (about 500 Gauss). Good parameters are B_{center} = 509 Gauss and B_{span} =20 Gauss for $T_{up,down}$=31s.

The integration range is 25 Gauss. D runs are in red, H runs are in blue.

Run #	T^o	B-center	Integral down/up×10^6	Pol.	Pol. Gain (down up <mean>	comments
193700723	2.110	6608	11.280/ 11.016	12.8%/ 12.5%		Before spin flip
193700922	2.110	1020	115.15/ 113.57	44.1%/ 43.5%		
193702839	2.109	1020	74.495/ 74.507	28.53%/ 28.53%	-15.57% -14.97% -15.27%	After two short tries of pol. transfer. Power=-7dbm or -10dBm, dial=2.45
193703056	2.101	6608	16.667/ 17.193	18.91%/ 19.51%	+6.11% +07.01% +6.56%	
193704280	2.064	1020	53.081/ 52.760	20.33%/ 20.21%	-8.20% -8.32% -8.26%	After SFP@ Power=-12dbm, dial=2.45 5 cycles
193704587	2.041	6608	20.491/ 20.182	23.25%/ 22.90%	+4.34% +3.39% +3.82%	
193705568	2.038	1020	50.780/ 51.429	19.45%/19.70%	-0.88% -0.51% -0.70%	After SFP@ Power=-12dbm, dial=2.45 5 cycles
193705868	2.031	6608	20.315/ 20.476	23.05%/ 23.24%	-0.20% +0.58% +0.19%	
193706764	2.035	1020	50.864/ 50.997	19.48%/ 19.53%	+0.03% +0.17% +0.010%	After SFP@ Power=-12dbm, dial=2.45 5 cycles
193707057	2.021	6608	20.254/ 20.495	22.98%/ 23.26%	-0.007% +0.02% -0.05%	

7.2 Conclusion

There is a clear spin transfer between H and D. Formula [1] with $\epsilon = 1/2$ can be used to compute the expected transfers. With initial H and D polarizations of 43.8% and 12.7% respectively, we expected a change H and D polarizations of -22.85% and +11.43% respectively, that is H=20.95% and D=24.125%, in good agreement with the observation.

discrepancey due to loss or phase that is not too good*

8 Conclusions

References

[1] F. Klein, A. Sandorfi; E06-101 proposal. Appendix A, formula a3. www.jlab.org/exp_prog/proposals/06/PR-06-101.pdf