Jefferson Lab
E01-012 Analysis Report 05
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Target density during E01-012

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Abstract

The different steps to extract the target density during E01-012 are presented in this note.

1 Introduction

2 Cell characteristics

Table 1 summarized the cell characteristics of Duke and Exodus, the two cells used during E01-012. V_{pc}, V_{tc} and V_{tot} are the pumping chamber, target chamber and total volumes respectively. Table 2 and Fig. 1 give the position of the RTDs. The pick-up coils have a length of 11 cm.

Table 1: Cell characteristics

cell name	target chamber length (cm)	V_{tot} (ml)	V_{pc} (ml)	V_{tc} (ml)	density (amg)
Duke	39.4	199.9	113.8	82.6	9.180
Exodus	39.6	192.4	103.9	84.7	9.617

Table 2: RTD positions (in cm).

cell name	RTD#1	RTD#2	RTD#3	RTD#4	RTD#5
Duke	15.2	8.9	1.0	-8.9	-15.2
Exodus	-14.6	-8.0	0.8	8.0	14.6

Table 3: RTD temperature before heating up the oven (in °C).

cell name	RTD#1	RTD#2	RTD#3	RTD#4	RTD#5	RTD#6	RTD#7	oven
Duke	24.3	24.0	23.8	23.9	24.3	24.5	27.1	25.1
Exodus	25.7	21.8	22.0	22.0	21.8	22.5	22.4	(24.2)

RTDs can have different reading offsets so it is important to write down their readings before any heat or cooling are applied (table 3). For Duke, by comparing RTD#6, RTD#7 and the oven RTD (these 3 RTDs are in the sealed oven) we should correct all the RTD#7 reading by -2.3°C. Morever after the second installation of Duke, one of RTD#1 wires was cut. From test done in November 2001, the readout offset from an RTD with three wires

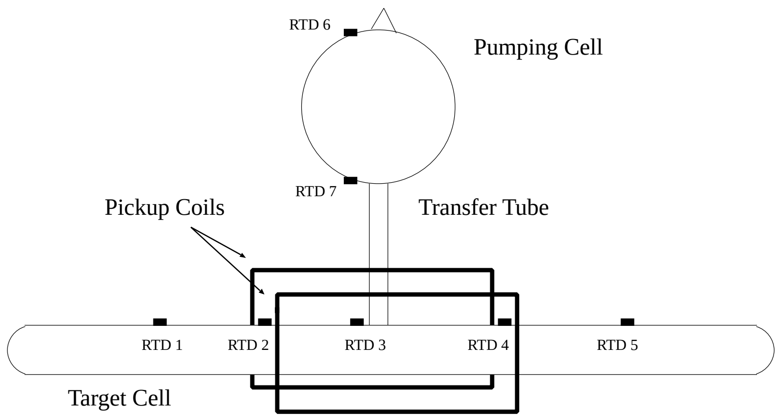

Figure 1: RTD positions. The positions of the RTDs were inverted between the two cell: RTD#5 was upstream for Duke and was downstream for Exodus.

is +3°C. So we will substract this offset for all RTD#1 data. For Exodus, we compare all target chamber RTDs readback, and found that RTD#1 should be corrected by -3.8°C. The oven RTD at the beginning of the running with Exodus is not reliable due to damage caused by Duke rupture.

3 List of changes

- *01/05/03 at 5:40pm* → cooling jets turned on during cosmics runs.
- *01/08/03 at 6:06am* → notice long. laser #6 was off. This is not a problem because we started running pol.^{3}He at 9:51am (run# 1188/20188).
- *01/09/03 at 11:00am* → control access to realign lasers. Notice trans. laser #1 is not working but don't know for how long ??? → need to check runs# 1238/20238, 1239/20239, 1240/20240: only runs at 270° before the control access.
- *01/09/03 at 6:08pm* → notice long. laser #7 was at 15A. Not a problem because only cosmic runs were taken so far.
- *01/13/03 at 3:00pm* → wavelength adjustment during control access:

- T#1: Temperature changed from 19.0°C to 19.8°C
- T#2: Temperature changed from 9.9°C to 9.6°C
- T#3: Temperature changed from 11.5°C to 11.6°C
- L#7: Current changed from 40.0A to 38.8A. Temperature changed from 9.7°C to 9.6°C

Last run before change: 1317/20317
First run after change: 1318/20318

- *01/14/03 at 6:53am* → wavelength adjustment during optics runs: all laser temperatures were raised by 0.2°C.

  Last run before change: 20330
  First run after change: 20331

- *01/19/03 at 1:36pm* → transverse lasers at 15A. Need to check runs# from 1429/20429 to 1436/20436.

- *01/27/03 at 12:00pm* → wavelength adjustment during energy change:

  - L#5: 39.3A (no change) and 13.2°C
  - L#6: 39.2A (before was 38.0A) and 10.1°C
  - L#7: 38.8A (before was 39A) and 9.3°C

  Last run before change: 1579/20579
  First run after change: 1594/20594

- *02/03/03 at 10:30am* → wavelength adjustment during beam study:

  - L#5: no change
  - L#6: 10.1°C to 9.5°C
  - L#7: 9.3°C to 9.8°C

  Last run before change: 1710/20710
  First run after change: 1720/20720

- *02/04/03 at 12:00pm* → wavelength adjustment during beam study:

  - T#1: from 19.5°C to 18.5°C

  - T#2: from 9.6°C to 8.9°C
  - T#3: from 11.6°C to 11.0°C

  Last run before change: 1754/20754
  First run after change: 1757/20757

- *02/05/03 at 11:00am* → wavelength adjustment during beam study:

  - L#7: from 9.5°C to 10.1°C

  Last run before change: 1774/20774
  First run after change: 1775/20775

- *02/06/03 at 2:20pm* → Duke ruptured.

  Last run will Duke: 1800/20800.

4 Temperature tests

4.1 Polynomial fit

In order to evaluate the target chamber temperature, I use a polynomial fit $f(x) = a + b \cdot x + c \cdot x^2 + d \cdot x^4 + e \cdot x^5$ and then integrate on the length between the data points. The term in x^3 was replaced by a term in x^5 in order to avoid a dramatic behavior of the fit when the RTD#4 data were missing (see fig. 3). Also this function works well also in the normal conditions of 5 RTDs on the target chamber.

Then the temperature inside the pumping chamber and the target and pumping chamber densities can be predicted [1] as followed:

$$T_{pred} = \frac{V_p\, T_t^{on}}{\frac{S_{He}^{off}}{S_{He}^{on}} \frac{T_t^{on}}{T_t^{off}} \frac{T_c^{off}}{T_c^{on}} \left[V_{tot} + V_p\left(\frac{T_t^{on}}{T_p^{off}} - 1\right)\right] - V_{tot} + V_p} \tag{1}$$

$$n_p = \frac{n_0}{1 + \frac{V_t}{V_{tot}}\left(\frac{T_{pred}}{T_t^{on}} - 1\right)} \tag{2}$$

$$n_t = \frac{n_0}{1 + \frac{V_p}{V_{tot}}\left(\frac{T_t^{on}}{T_{pred}} - 1\right)} \tag{3}$$

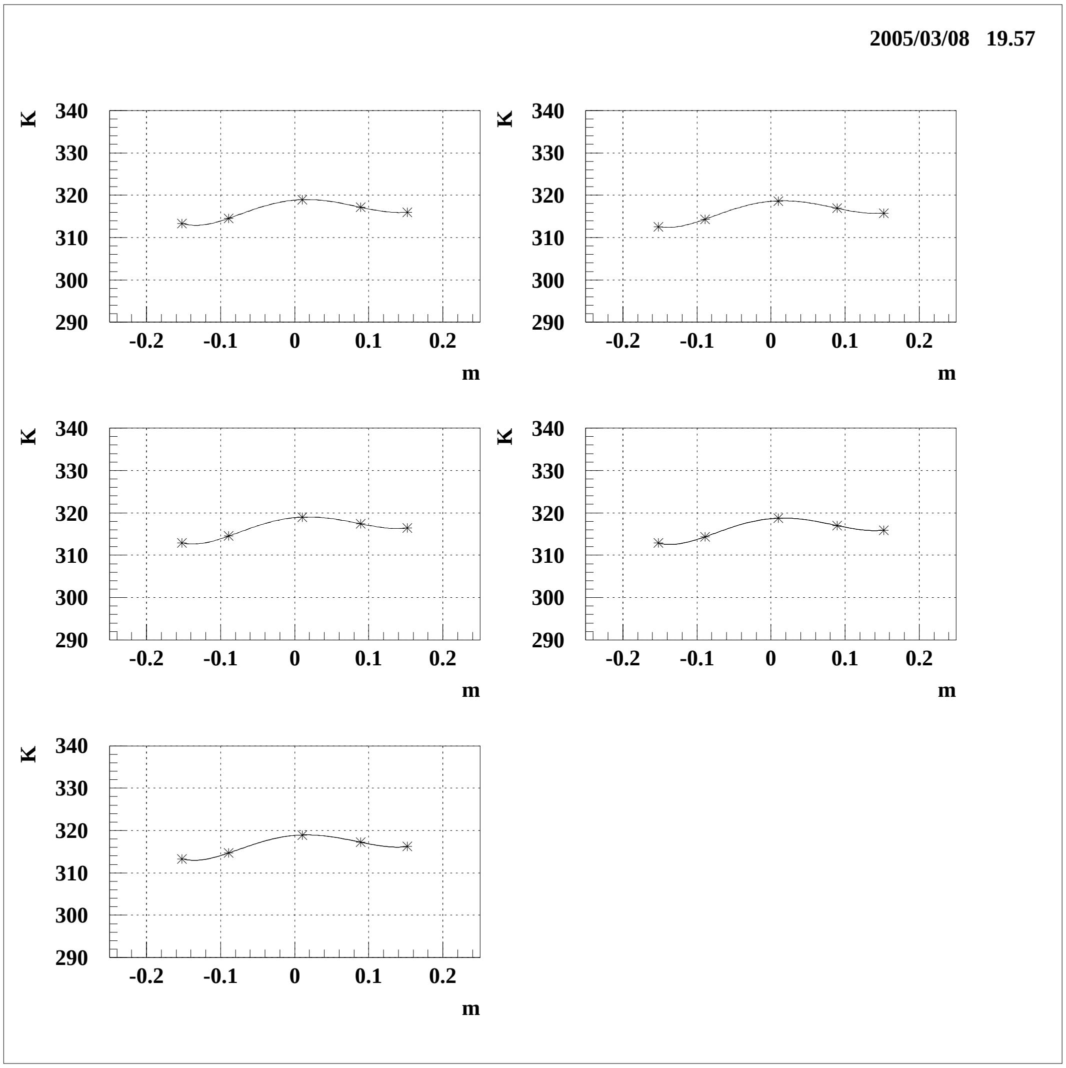

Figure 2: Fit of the target chamber RTD readings for the 5 NMR measurements of January 6 temperature test.

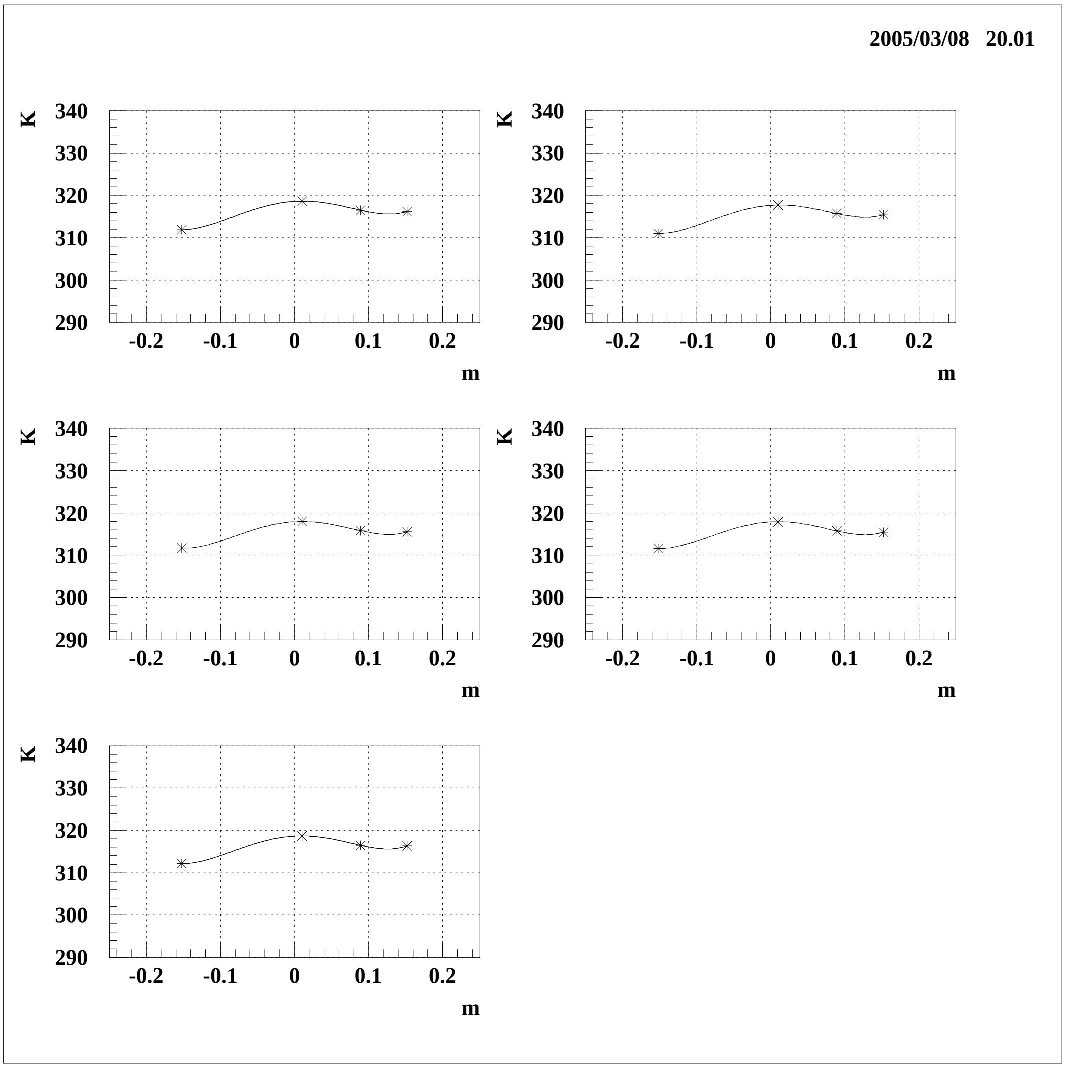

Figure 3: Fit of the target chamber RTD readings for the 5 NMR measurements of January 16 temperature test. Note that RTD#4 is missing.

Table 4: Results of the temperature tests from polynomial fit.

cell name	date	T_p (K)	T_{pred} (K)	n_t (amg)	n_p (amg)
Duke	jan. 6	454.57	502.88	11.633	7.385
	jan. 7	454.31	501.21	11.587	7.418
	jan. 16	456.39	500.82	11.625	7.391
Exodus	feb. 10	458.03	527.00	12.187	7.501
	feb. 13	457.30	510.14	12.026	7.635

Table 4 summarizes the results of the different temperature tests performed during the experiment. Since T_{pred}=T_p when the lasers are off, an interpolation can be made for any T_p as illustrated on fig. 4 [2]. The fit gives:

$$T_{pred} = 3.12\ T_p - 916.04 \quad \text{for Duke for run before } 1245, 20245 \tag{4}$$

$$T_{pred} = 2.79\ T_p - 774.38 \quad \text{for Duke for run after } 1245, 20245 \tag{5}$$

$$T_{pred} = 4.17\ T_p - 1398.44 \quad \text{for Exodus} \tag{6}$$

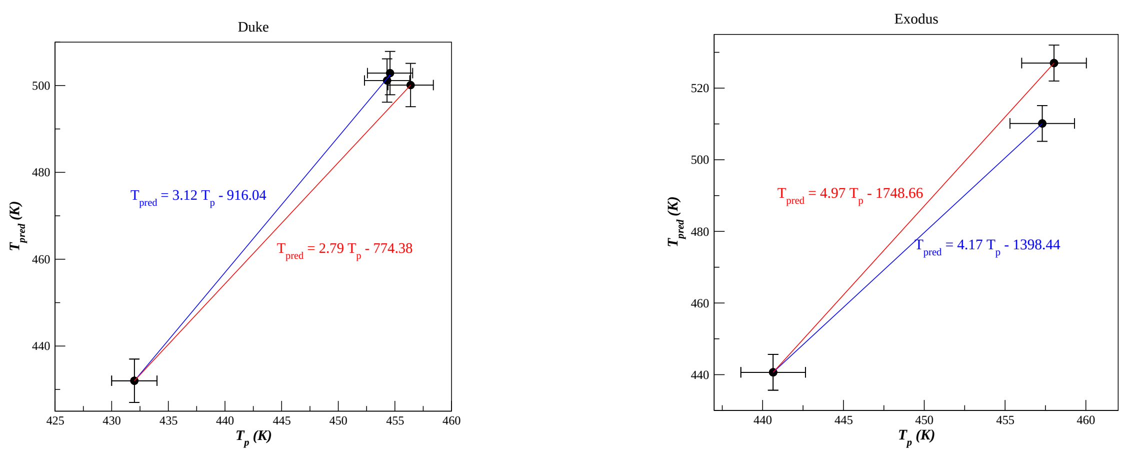

Figure 4: Estimation of the temperature inside the pumping chamber in function of the wall temperature.

Feb. 10 temperature test is not reliable since it was done in a very short time and the temperatures wasn't stable for each NMR measurement. So we won't include it in our analysis.

4.2 Comparison with other methods

For all methods, Eq. 1-3 are used. Only the way by which the target chamber temperature is evaluated changed.

1. Weighted sum from Jensen's thesis:

$$T_c = \frac{1}{2}r3 + \frac{1}{4}(r2 + r4) \tag{7}$$

$$T_t = \frac{6}{40}(r2 + r3 + r4) + \frac{11}{40}(r1 + r5) \tag{8}$$

Table 5: Results of the temperature tests from weighted sum method.

cell name	date	T_p (K)	T_{pred} (K)	n_t (amg)	n_p (amg)
Duke	jan. 6	454.58	503.05	11.650	7.373
	jan. 7	454.31	500.93	11.598	7.411
Exodus	feb. 10	458.04	525.70	12.195	7.495
	feb. 13	457.31	510.65	12.050	7.615

2. Linear fit.

Table 6: Results of the temperature tests from linear fit.

cell name	date	T_p (K)	T_{pred} (K)	n_t (amg)	n_p (amg)
Duke	jan. 6	454.57	503.04	11.636	7.383
	jan. 7	454.31	500.94	11.583	7.422
	jan. 16	456.39	499.91	11.614	7.399
Exodus	feb. 10	458.03	525.53	12.172	7.514
	feb. 13	457.30	510.44	12.026	7.635

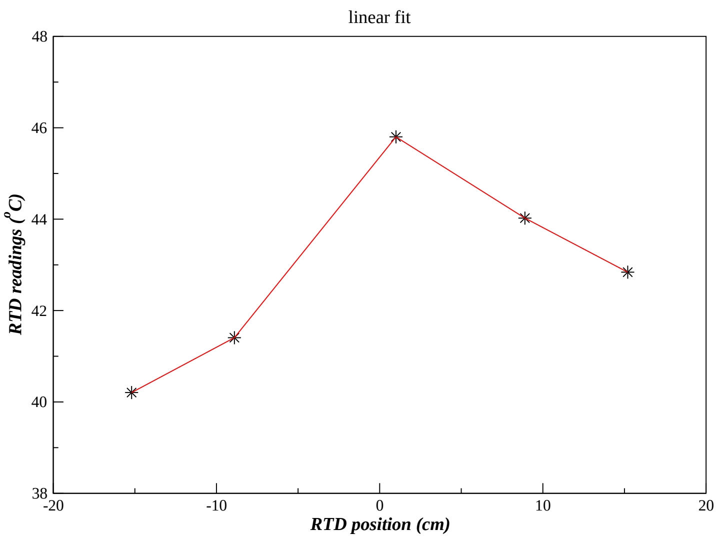

Figure 5: Linear fit of the target chamber RTD readings for one of the temperature test measurements.

Table 7: Comparison of the temperature of the target chamber from the different methods.

			Weighted sum		Linear fit		Polynomial fit	
cell	date	meas.#	T_t (K)	T_c (K)	T_t (K)	T_c (K)	T_t (K)	T_c (K)
Duke	jan. 6	1	315.67	317.41	316.48	317.89	316.52	316.46
		2	315.29	317.15	316.18	317.62	316.24	316.26
		3	315.72	317.49	316.55	317.95	316.60	316.45
		4	315.44	317.22	316.27	317.69	316.32	316.26
		5	315.76	317.47	316.56	317.94	316.60	316.56
	jan. 7	1	317.13	318.94	318.01	319.80	317.91	317.85
		2	317.20	319.04	318.12	319.90	318.01	317.64
		3	317.54	319.41	318.46	320.30	318.35	318.11
		4	317.35	319.20	318.28	320.05	318.18	317.87
		5	317.65	319.48	318.56	320.34	318.46	318.16
	jan. 16	1	-	-	316.56	317.80	316.17	316.38
		2	-	-	315.71	316.90	315.28	315.41
		3	-	-	315.98	317.13	315.56	315.77
		4	-	-	315.93	317.10	315.52	315.76
		5	-	-	316.65	317.85	316.26	316.51
Exodus	feb. 10	1	319.93	322.84	321.25	323.51	321.21	321.97
		2	319.28	322.36	320.65	323.07	320.59	321.14
	feb. 13	1	320.08	323.30	321.53	324.46	321.35	324.61
		2	319.55	322.57	320.93	323.64	320.78	324.04
		3	319.65	322.75	321.07	323.83	320.92	324.09
		4	319.51	322.40	320.83	323.43	320.69	323.81
		5	319.65	322.51	320.94	323.56	320.77	323.83
		6	319.25	322.28	320.62	323.34	320.47	323.45

5 Density of the target chamber

5.1 Density extraction for $^3\vec{\mathrm{He}}$ run

To determine the density of the target chamber for each run, we will be using eq. 3 with eq. 4, eq. 5 or eq. 6. The RTD readouts are extracted 8 minutes after the beginning of each run. Thus the temperature had time to stabilize in the case of a change of configuration before the run started.

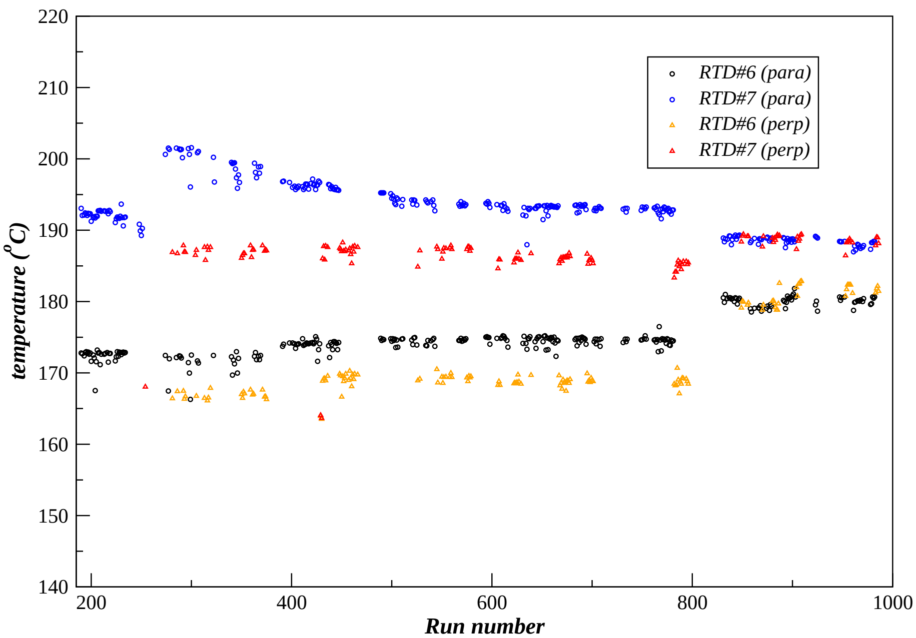

Figure 6: Pumping chamber RTD readbacks for each run.

We can observe a jump in the target chamber temperature (fig. 8) for run numbers between 400 and 500 approximately. This is due to a decrease of the cooling jet flow at this period (see fig. 9).

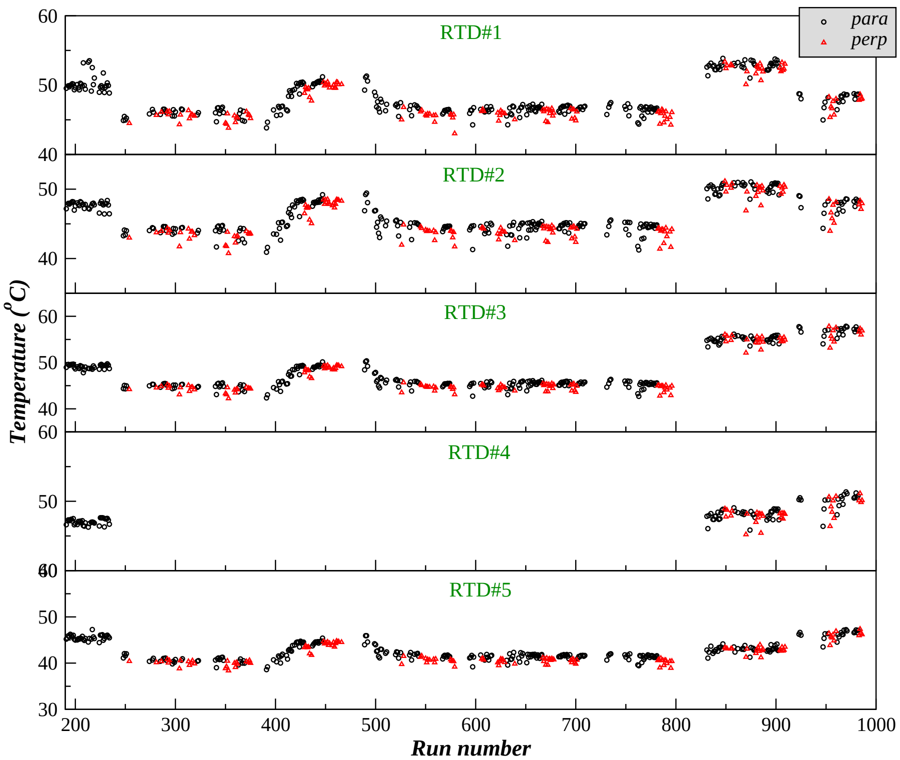

Figure 7: Target chamber RTD readbacks for each run.

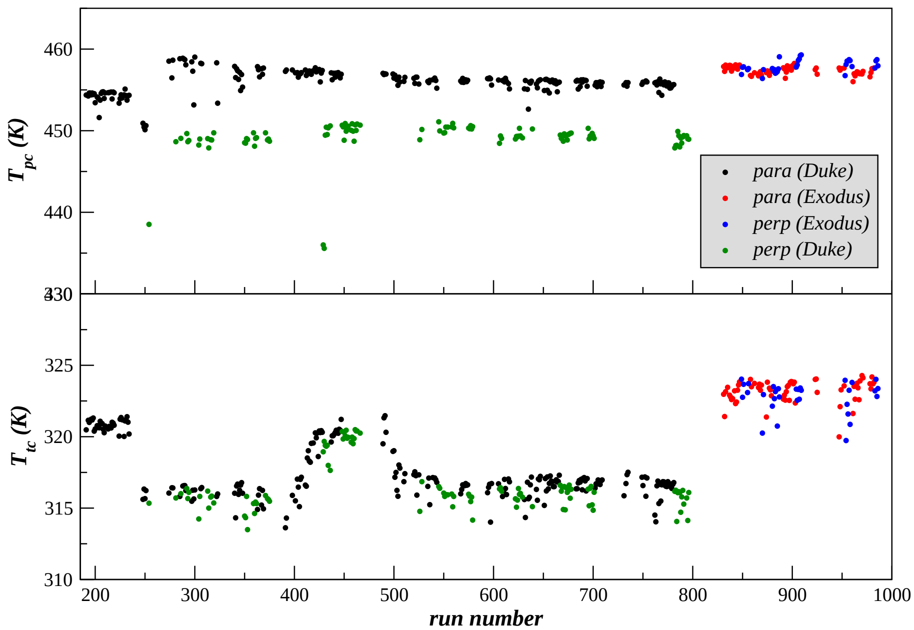

Figure 8: Pumping (wall) and target chamber temperatures.

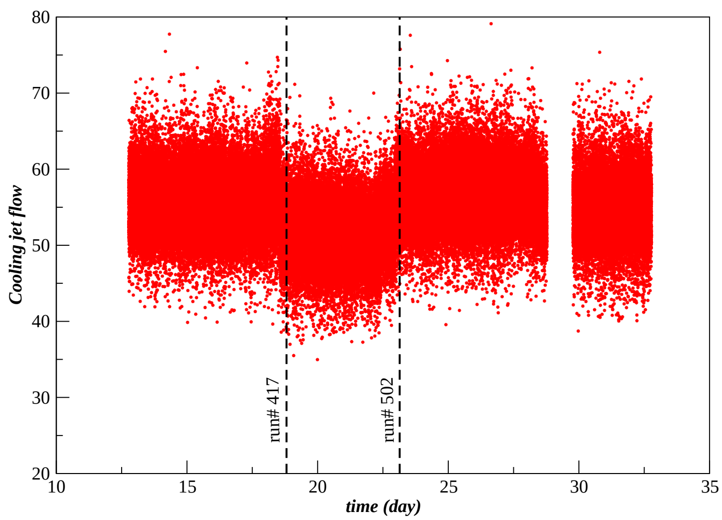

Figure 9: Cooling jet flow during a part of the experiment.

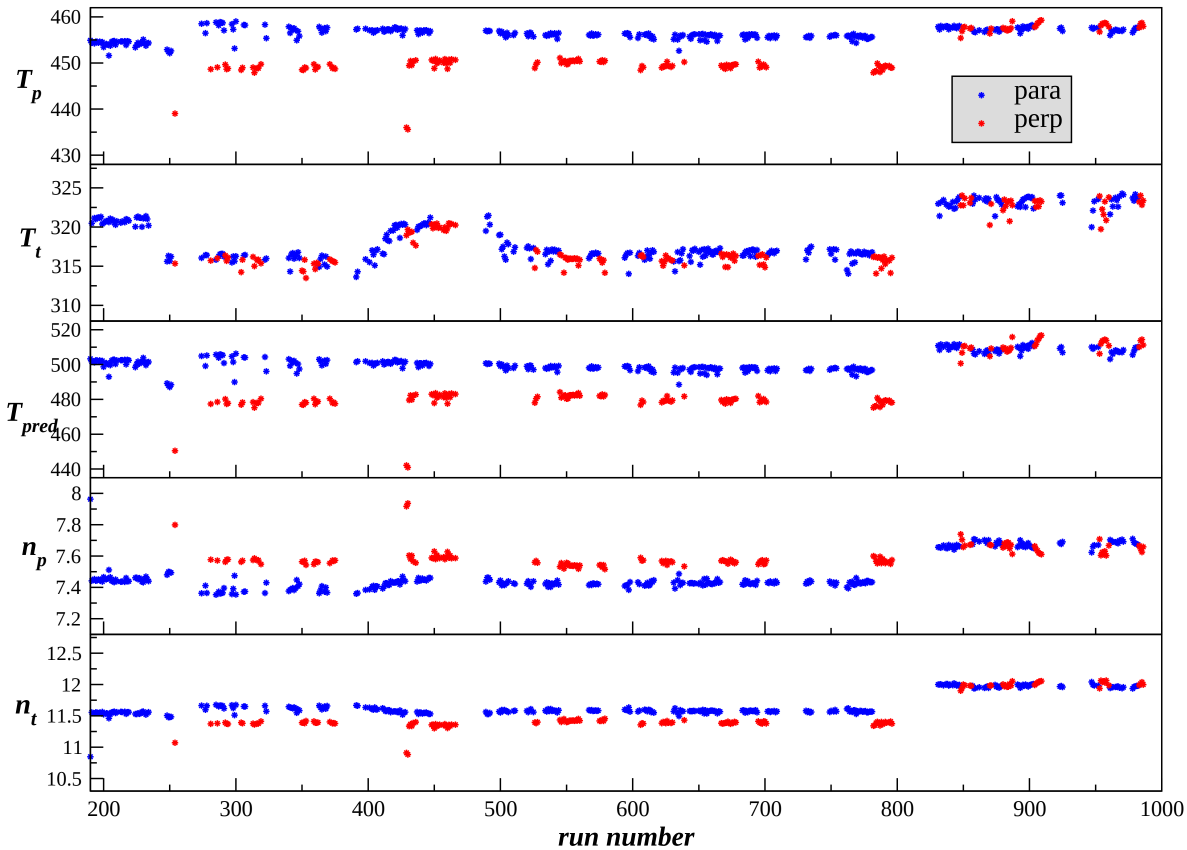

Figure 10: Density for each run.

5.2 Study of the uncertainty on the density

In order to evaluate the density variation due to the uncertainties on the temperature of each target part, the temperature inside the pumping chamber and the pumping and target chamber densities were calculated in several cases as shown in table 8 and table 9.

Table 8: Duke

Variation T_t	Variation T_p	T_{pred} (K)	diff. (%)	n_t (amg)	diff. (%)	n_p (amg)	diff. (%)
0	0	500.82	-	11.625	-	7.391	-
+5	0	500.19	-0.13	11.535	-0.77	7.457	+0.89
-5	0	501.57	+0.15	11.716	+0.78	7.323	-0.92
0	+5	507.08	+1.25	11.691	+0.57	7.342	-0.66
0	-5	494.57	-1.25	11.559	-0.57	7.440	+0.66
+5	+5	506.43	+1.12	11.601	-0.21	7.408	+0.23
-5	+5	507.75	+1.38	11.782	+1.35	7.275	-1.57
+5	-5	493.95	-1.37	11.469	-1.34	7.506	+1.56
-5	-5	495.20	-1.12	11.650	+0.21	7.372	-0.26

Table 9: Exodus

Variation T_t	Variation T_p	T_{pred} (K)	diff. (%)	n_t (amg)	diff. (%)	n_p (amg)	diff. (%)
0	0	510.14	-	12.026	-	7.635	-
+5	0	509.48	-0.13	11.940	-0.72	7.706	+0.93
-5	0	510.83	+0.14	12.113	+0.72	7.563	-0.94
0	+5	516.42	+1.23	12.088	+0.52	7.583	-0.68
0	-5	503.87	-1.23	11.925	-0.84	7.688	+0.69
+5	+5	515.75	+1.10	12.003	-0.19	7.654	+0.25
-5	+5	517.12	+1.37	12.175	+1.24	7.511	-1.62
+5	-5	503.23	-1.35	11.877	-1.24	7.759	+1.62
-5	-5	504.54	-1.10	12.050	+0.20	7.615	-0.26

After taking the standard deviation from all the temperature variation results, we get:

- Duke:

  $T_{pred} = (500.82 \pm 5.82)$ K
  $n_p = (7.391 \pm 0.077)$ amg
  $n_t = (11.625 \pm 0.104)$ amg

- Exodus:

  $T_{pred} = (510.14 \pm 5.84)$ K
  $n_p = (7.635 \pm 0.082)$ amg
  $n_t = (12.026 \pm 0.103)$ amg

Thus the density uncertainties are about 1% relative.

5.3 Comparison of parallel and perpendicular cross sections

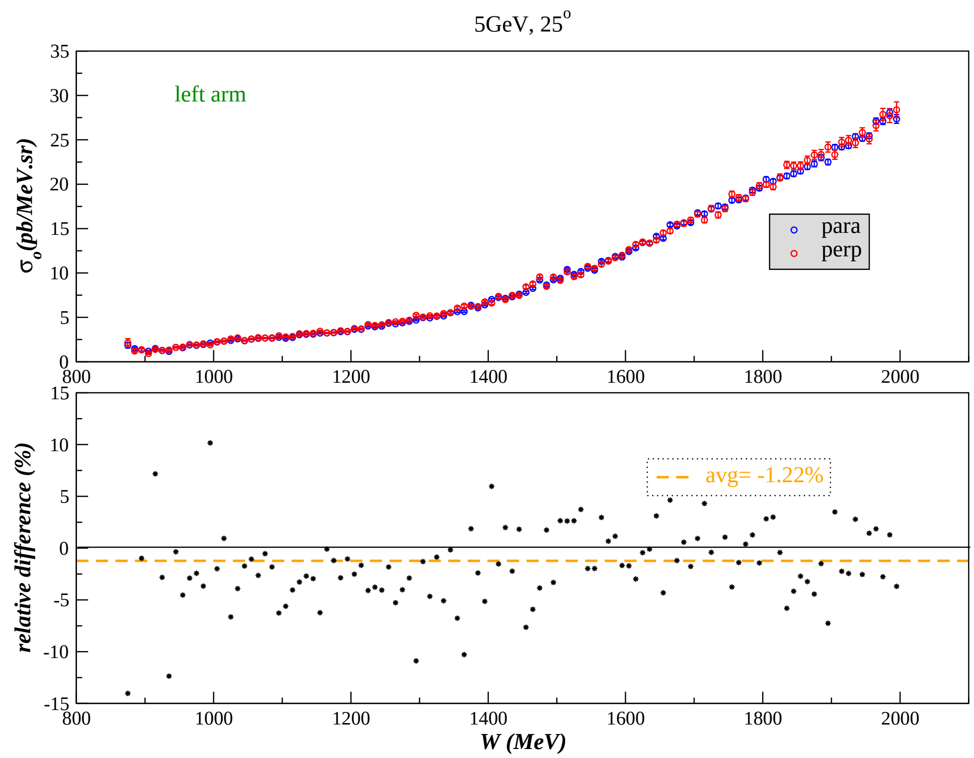

Figure 11: Comparison for perpendicular and parallel cross section for the right arm at 5GeV and 25°. Only Duke was used here.

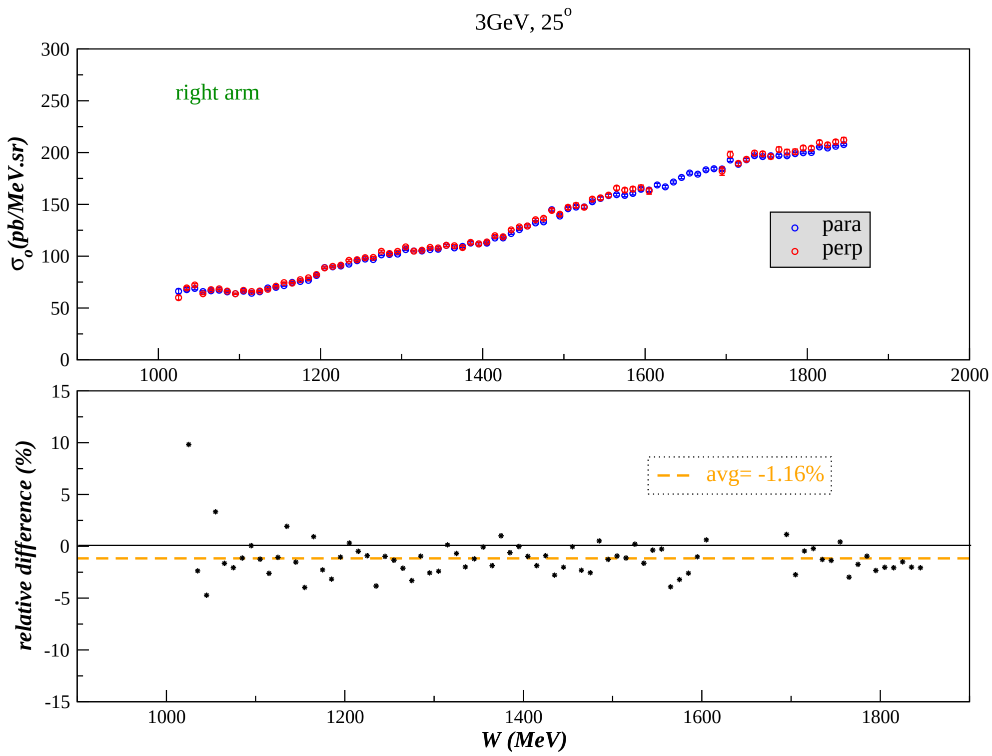

Figure 12: Comparison for perpendicular and parallel cross section for the right arm at 3GeV and 25°. Only Exodus was used here.

The unpolarized cross sections for perpendicular and parallel configurations agree very well. Thus we are confident in the method used to estimate the density of the target chamber during the entire experiment.

References

[1] J.S. Jensen, Ph.D. thesis, California Institute of Technology, 2000.

[2] K.M. Kramer, Ph.D. thesis, The College of William and Mary, 2003.