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Target density from pressure curves for E01-012

P. Solvignon
Temple University, Philadelphia, PA 19122
E-mail
solvigno@jlab.org

1 Introduction

In order to evaluate the pressure under running conditions of the gases contained in the polarized ^{3}He target, data are taken with a reference cell filled with N_2 or ^{3}He gas at different pressures. The interpolation or extrapolation of these data to the yield from the polarized ^{3}He target should give an accurate measurement of this gas pressure inside the cell.

2 Pressure curves

Since the reference cell and the polarized target cell are practically identical, the acceptance is assumed to be the same in both cases. Depending of gas thicknesses, the collisional loss creates a shift of the elastic peak. It is corrected by aligning all elastic peaks before applying the cuts.

The yield is calculating as followed:

$$\mathrm{Yield} = \frac{\mathrm{PS}}{\mathrm{Q/e\ LT}\ \epsilon_{\mathrm{det}}\ \mathrm{L_{tg}}} \mathrm{N_{acc}} \tag{1}$$

Where PS is the prescale factor, Q/e is the number of incident electrons, LT is the data acquisition livetime, ϵ_{det} is the product of all detector efficiencies for the cuts chosen, L_{tg} is the target chamber length and N_{acc} is the number of good events passing all the cuts.

Uncertainty calculation

$$P(\mathrm{atm}) = \frac{\mathrm{Y(nb)} - \mathrm{a_0}}{\mathrm{a_1}} \tag{2}$$

$$\left(\frac{\Delta \mathrm{P}}{\mathrm{P}}\right)^2 = \frac{(\Delta \mathrm{Y})^2 + (\Delta \mathrm{a_0})^2}{(Y - a_0)^2} + \frac{(\Delta a_1)^2}{a_1^2} \tag{3}$$

2.1 Nitrogen filling density in Pol. ^{3}He cell Duke

Duke nitrogen filling density is 0.0846 amg (N_2) at 0°C [1]. A 5% uncertainty is considered on this quantity. The pressure in atm is calculated with:

$$\mathrm{P(atm)} = \frac{2.6868 \times 10^{19}}{0.101325} \mathrm{\ k\ T\ } \rho(\mathrm{amg}) \tag{4}$$

P = (0.168±0.008) atm at 0°C

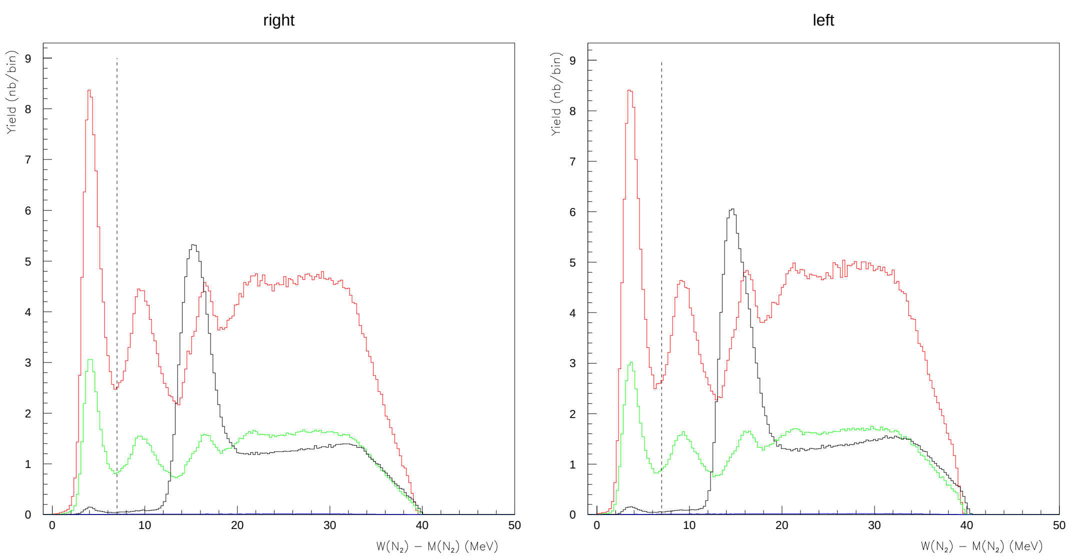

Figure 1: Cut on nitrogen elastic peak: $0.0 < W_{N_2} - M_{N_2} < 7.0$ MeV.

Table 1: Values of the variables used in the calculation of the yield.

run#	type	PS	LT(%)	ϵ_{det} (%)	Q(mC)
1167/20167	empty ref.	2/2	98.20/89.82	97.39/97.66	3.9480/3.9525
1168/20168	ref. N_2 (37psig)	8/8	99.19/96.63	95.34/96.42	4.0457/4.0500
1169/20169	ref. N_2 (146psig)	18/18	97.97/91.50	92.57/94.00	3.8503/3.9749
1209/20209	pol. ^{3}He	4/4	83.54/80.19	95.42/96.74	3.8735/3.7919

2.1.1 Radiative corrections

Due to the difference of gas and glass thicknesses between all the configurations used to perform pressure curve measurements, radiative corrections must be applied. In order to evaluate the radiative factors between the polarized cell and the reference cell, a monte-carlo is used. The simulation contains the nitrogen elastic form factors in order to evaluate the cross sections. Thus a correction for thickness differences can be applied as followed [2]:

$$\sigma_{c,ref} = \sigma_{ref} \frac{\sigma_{pol}^{MC}}{\sigma_{ref}^{MC}} \tag{5}$$

2.1.2 Pressure curve fit

- <u>Right</u>: Yield(nb) = $-0.024(\pm 0.003) + 7.357(\pm 0.017)$ P(atm)
- <u>Left</u>: Yield(nb) = $-0.026(\pm 0.003) + 8.714(\pm 0.017)$ P(atm)

After averaging both arms' pressure, we obtain P = (0.159±0.001) atm at 320K ⇒ d_N = (0.136±0.001) amg or d_{N_2} = (0.068±0.001) amg. This result is to be compared with the filling density extrapolated to the running conditions: P = (0.199±0.010) atm at 320K ⇒ d_N = (0.170±0.009) amg or d_{N_2} = (0.085±0.005) amg. The two results differ by 20%. Since it is such a small quantity, small yield variation can generate a large variation in the pressure. Since very good care [1] was taken during the filling of the polarized target cell, the filling density will be the one used in the E01-012 analysis.

Table 2: Radiation lengths used in the radiative corrections.

Arm			RIGHT				
run #	filling	<P> (psig)	$N^{bef}_{X_0}$	$N^{aft}_{X_0}$	$N^{bef}_{d_0}$	$N^{aft}_{d_0}$	σ^{MC} (nb)
1167	empty	-14.7	2.234×10^{-3}	7.797×10^{-2}	0.071	1.598	1465.6
1168	N_2	36.5	3.866×10^{-3}	7.826×10^{-2}	0.147	1.611	1452.9
1169	N_2	141.8	7.224×10^{-3}	7.885×10^{-2}	0.306	1.639	1434.3
1209	$^3\vec{He}$	11.5 amg	2.545×10^{-3}	7.857×10^{-2}	0.098	1.613	1458.6
Arm			LEFT				
run #	filling	<P> (psig)	$N^{bef}_{X_0}$	$N^{aft}_{X_0}$	$N^{bef}_{d_0}$	$N^{aft}_{d_0}$	σ^{MC} (nb)
20167	empty	-14.7	2.234×10^{-3}	8.629×10^{-2}	0.071	1.760	1405.6
20168	N_2	36.5	3.866×10^{-3}	8.658×10^{-2}	0.147	1.773	1393.1
20169	N_2	141.8	7.224×10^{-3}	8.717×10^{-2}	0.306	1.801	1372.0
20209	$^3\vec{He}$	11.5 amg	2.545×10^{-3}	8.019×10^{-2}	0.098	1.645	1443.8

Table 3: without collisional loss corrections but with a shift (in MeV) applied to match elastic peaks.

	RIGHT ARM			LEFT ARM		
	shift	P (atm)	Yield (nb)	shift	P (atm)	Yield (nb)
empty	0.0	0.02±0.02	0.123±0.003	0.0	0.02±0.02	0.148±0.003
37 psig	+0.35	3.48±0.03	26.284±0.089	+0.30	3.48±0.034	30.892±0.094
146 psig	0.0	10.65±0.29	76.705±0.239	0.0	10.65±0.29	91.598±0.234
filling			0.199±0.010			
pol. cell	+0.60	0.152±0.002	1.09675±0.010	+0.80	0.165±0.002	1.408±0.011

2.2 Density of Pol. ^{3}He cell Duke under running conditions

In order to check the density of the polarized target cell under running conditions, data was taken with the reference cell filled with ^{3}He gas at different pressures. Thus a pressure curve can be done as we did for nitrogen and the the projected result can be compared to the polarized target density extracted from the temperature tests [3]: for run # 1209/20209, the target

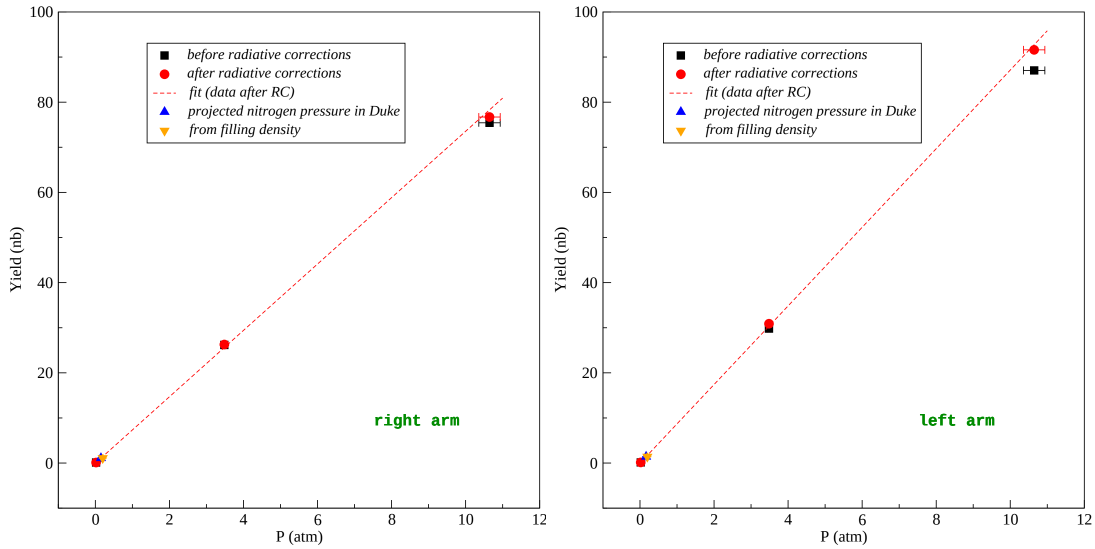

Figure 2: Nitrogen pressure curve

chamber temperature and density were found to be 320 K and 11.5 amg respectively. A conservative 2% uncertainties is considered for this density.

2.2.1 Radiative corrections

The same method is used here as in section 2.2.1 but we now use the ^{3}He elastic form factors in the simulation.

2.2.2 Pressure curve fit

- Right: Yield(nb) $= 0.167(\pm 0.004) + 5.542(\pm 0.003)$ P(atm)
- Left: Yield(nb) $= 0.230(\pm 0.005) + 6.432(\pm 0.003)$ P(atm)

After averaging both arms' pressure, we obtain: P $= (13.28 \pm 0.01)$atm $\Rightarrow$ d $= (11.33 \pm 0.01)$amg. Here only statistical errors are considerated. This value agrees well with the temperature test result: (11.5 ± 0.2)amg. So we will continue to rely on the temperature test density results for data taken with Duke.

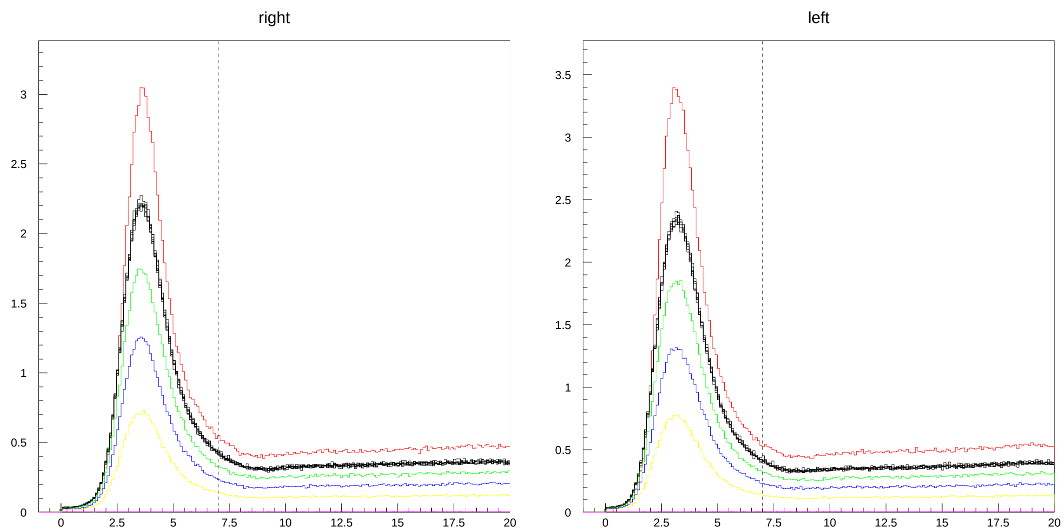

Figure 3: Cut on ^{3}He elastic peak: $0.0 < W_{^3He} - M_{^3He} < 7.0$ MeV.

Table 4: Values of the variables used in the calculation of the yield.

run#	type	PS	LT(%)	ϵ_{det} (%)	Q(mC)
1167/20167	empty ref.	2/2	98.20/89.82	97.39/97.66	3.9480/3.9525
1173/20173	^{3}He (35psig)	3/3	99.03/91.97	96.47/97.53	3.9902/3.9690
1174/20174	^{3}He (72psig)	3/3	98.68/86.81	96.09/97.31	3.5221/3.7349
1175/20175	^{3}He (107psig)	3/3	98.11/81.51	95.72/97.19	2.9242/3.0335
1176/20176	^{3}He (139psig)	6/6	99.31/96.59	95.43/96.86	4.7603/4.8709
1177/20177	^{3}He (140.5psig)	5/5	99.08/94.36	95.45/97.00	4.0079/4.1759
1178/20178	^{3}He (139.5psig)	5/5	99.13/94.36	95.47/96.90	4.0147/4.1630
1179/20179	^{3}He (142psig)	5/5	99.26/93.99	95.52/96.86	2.2024/2.1696
1180/20180	^{3}He (141psig)	5/5	98.97/94.24	95.40/96.93	4.0081/4.1284
1181/20181	^{3}He (141.5psig)	5/5	99.28/94.33	95.40/96.97	4.0100/4.1826
1182/20182	^{3}He (141psig)	5/5	99.13/94.37	95.59/96.96	4.0169/4.1928
1183	^{3}He (140psig)	5	99.09	95.45	4.0137
1209/20209	pol. ^{3}He	4/4	83.54/80.19	95.42/96.74	3.8735/3.7919

Table 5: Radiation lengths used in the radiative corrections

Arm			RIGHT				
run #	filling	<P> (psig)	$N_{X_0}^{bef}$	$N_{X_0}^{aft}$	$N_{d_0}^{bef}$	$N_{d_0}^{aft}$	σ^{MC} (nb)
1167	empty	-14.7	2.234×10^{-3}	7.797×10^{-2}	0.071	1.598	2769.8
1173	^{3}He	35.0	2.352×10^{-3}	7.799×10^{-2}	0.079	1.599	2767.0
1174	^{3}He	72.0	2.441×10^{-3}	7.801×10^{-2}	0.085	1.600	2764.9
1175	^{3}He	107.0	2.524×10^{-3}	7.802×10^{-2}	0.090	1.601	2763.5
1176	^{3}He	139.0	2.601×10^{-3}	7.804×10^{-2}	0.095	1.602	—
1177	^{3}He	140.5	2.604×10^{-3}	7.804×10^{-2}	0.096	1.602	2762.1
1178	^{3}He	139.5	2.602×10^{-3}	7.804×10^{-2}	0.095	1.602	—
1179	^{3}He	142.0	2.608×10^{-3}	7.804×10^{-2}	0.096	1.602	—
1180	^{3}He	141.0	2.605×10^{-3}	7.804×10^{-2}	0.096	1.602	—
1181	^{3}He	141.5	2.606×10^{-3}	7.804×10^{-2}	0.096	1.602	—
1182	^{3}He	141.0	2.605×10^{-3}	7.804×10^{-2}	0.096	1.602	—
1183	^{3}He	140.0	2.603×10^{-3}	7.804×10^{-2}	0.095	1.602	—
1209	$^3\vec{He}$	11.5 amg	2.545×10^{-3}	7.857×10^{-2}	0.098	1.613	2755.2

Arm			LEFT				
run #	filling	<P> (psig)	$N_{X_0}^{bef}$	$N_{X_0}^{aft}$	$N_{d_0}^{bef}$	$N_{d_0}^{aft}$	σ^{MC} (nb)
20167	empty	-14.7	2.234×10^{-3}	8.629×10^{-2}	0.071	1.760	2664.2
20173	^{3}He	35.0	2.352×10^{-3}	8.632×10^{-2}	0.079	1.761	2663.5
20174	^{3}He	72.0	2.441×10^{-3}	8.633×10^{-2}	0.085	1.762	2662.3
20175	^{3}He	107.0	2.524×10^{-3}	8.635×10^{-2}	0.090	1.763	2660.9
20176	^{3}He	139.0	2.601×10^{-3}	8.636×10^{-2}	0.095	1.764	—
20177	^{3}He	140.5	2.604×10^{-3}	8.636×10^{-2}	0.096	1.764	2658.1
20178	^{3}He	139.5	2.602×10^{-3}	8.636×10^{-2}	0.095	1.764	—
20179	^{3}He	142.0	2.608×10^{-3}	8.636×10^{-2}	0.096	1.764	—
20180	^{3}He	141.0	2.605×10^{-3}	8.636×10^{-2}	0.096	1.764	—
20181	^{3}He	141.5	2.606×10^{-3}	8.636×10^{-2}	0.096	1.764	—
20182	^{3}He	141.0	2.605×10^{-3}	8.636×10^{-2}	0.096	1.764	—
20209	$^3\vec{He}$	11.5 amg	2.545×10^{-3}	8.019×10^{-2}	0.098	1.645	2742.6

Table 6: without collisional loss corrections but with a shift (in MeV) applied to match elastic peaks.

	RIGHT ARM			LEFT ARM		
run	shift	P (atm)	Yield (nb)	shift	P (atm)	Yield (nb)
1167/20167	0.0	0.02±0.02	0.275±0.004	0.0	0.02±0.02	0.353±0.005
1173/20173	0.0	3.38±0.07	19.279±0.047	0.0	3.38±0.07	22.597±0.046
1174/20174	0.0	5.90±0.14	33.113±0.065	0.0	5.90±0.14	38.387±0.056
1175/20175	0.0	8.28±0.20	46.047±0.083	0.0	8.28±0.20	53.589±0.067
1176/20176	0.0	10.46±0.48	58.048±0.106	0.0	10.46±0.48	67.224±0.109
1177/20177	0.0	10.56±0.44	58.719±0.106	0.0	10.56±0.44	68.018±0.104
1178/20178	0.0	10.49±0.44	58.343±0.105	0.0	10.49±0.44	67.726±0.104
1179/20179	0.0	10.66±0.20	59.806±0.144	0.0	10.66±0.20	69.194±0.145
1180/20180	0.0	10.59±0.48	58.516±0.105	0.0	10.59±0.48	67.840±0.104
1181/20181	0.0	10.63±0.44	58.767±0.106	0.0	10.63±0.44	68.355±0.104
1182/20182	0.0	10.59±0.41	58.270±0.105	0.0	10.59±0.41	67.705±0.104
1183	0.0	10.53±0.48	58.515±0.105	n/a	n/a	n/a
temp. test	13.48±0.27					
pol. cell	+0.25	13.20±0.02	73.300±0.083	+0.40	13.36±0.02	86.186±0.085

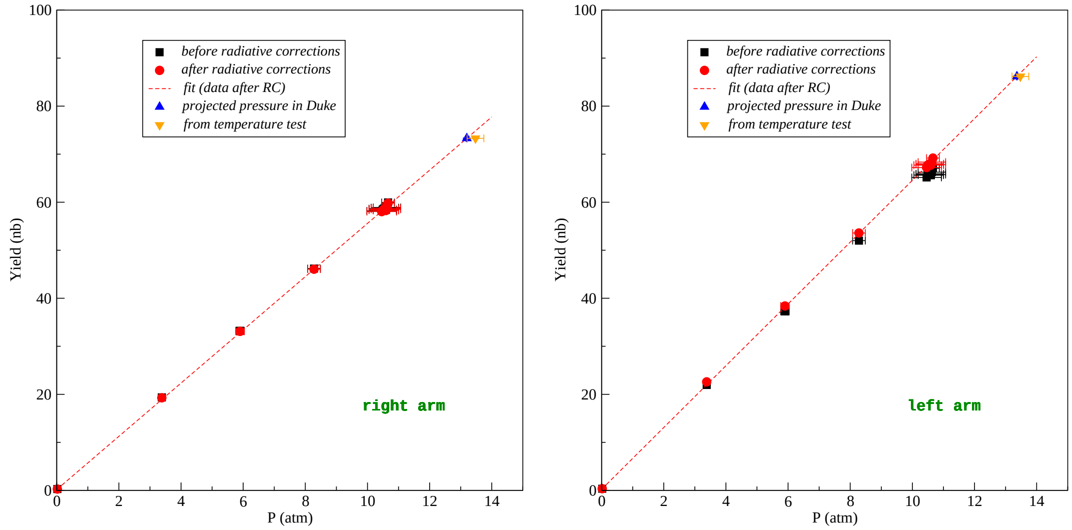

Figure 4: ^{3}He pressure curve for Duke.

2.3 Density of Pol. ^{3}He cell Exodus under running conditions

In the case of Exodus, the temperature test [3] gives:

- for run # 20988, the target chamber temperature and density were found to be 321 K and 12.0 amg respectively.
- for run # 20991, 320 K and 12.0 amg.

A conservative 2% uncertainty is considered for these densities.

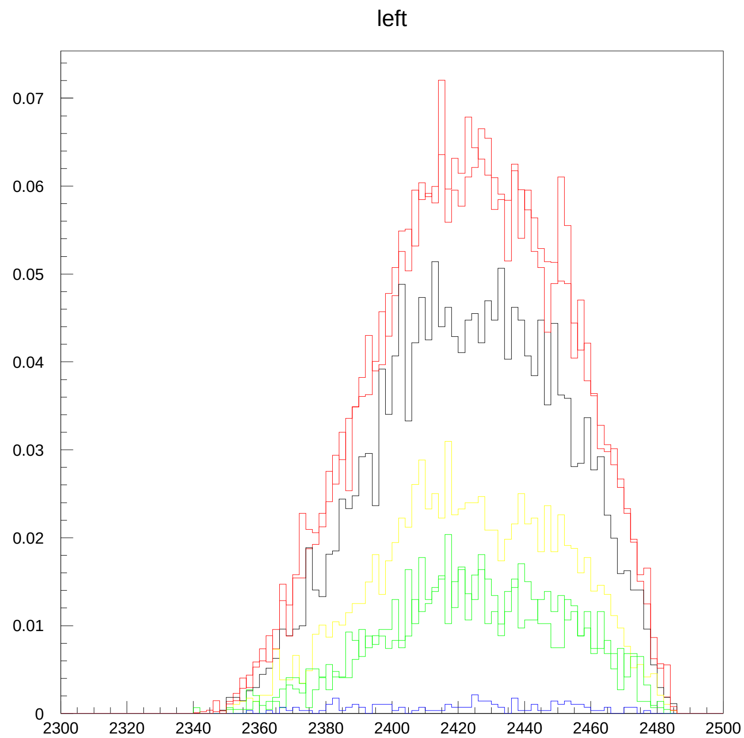

Figure 5: ^{3}He pressure curve for Exodus

Table 7: Values of the variables used in the calculation of the yield.

run#	type	PS	LT(%)	ϵ_{det} (%)	Q(mC)
20992	empty ref.	1	99.03	96.28	0.4425
20995	^{3}He (26psig)	1	98.92	97.14	0.2274
20996	^{3}He (26psig)	1	98.98	95.43	0.3407
20993	^{3}He (66psig)	1	98.53	95.69	0.4548
20994	^{3}He (146psig)	1	90.03	96.70	0.4252
20988	pol. ^{3}He	1	93.91	96.57	1.6497
20991	pol. ^{3}He	1	98.04	97.07	0.4260

2.3.1 Radiative corrections

DIS region (W(nucleon) = 2418.7 MeV): use radiated cross sections generated with modified QFS model [4] at W(nucleon = 2420.0 MeV to estimate thickness difference effects.

Table 8: Radiation lengths used in the radiative corrections

Arm			LEFT		
run #	filling	<P> (psig)	$N_{X_0}^{bef}$	$N_{X_0}^{aft}$	σ^{QFS} (pb/MeV.sr)
20992	empty	-14.7	2.347×10^{-3}	9.029×10^{-2}	385.25
20995	^{3}He	26.0	2.444×10^{-3}	9.030×10^{-2}	385.48
20996	^{3}He	26.0	2.444×10^{-3}	9.030×10^{-2}	385.48
20993	^{3}He	66.0	2.540×10^{-3}	9.032×10^{-2}	385.71
20994	^{3}He	146.0	2.731×10^{-3}	9.036×10^{-2}	386.16
20991	$^3\vec{He}$	12.0 amg	2.464×10^{-3}	7.226×10^{-2}	383.93
20988	$^3\vec{He}$	12.0 amg	2.464×10^{-3}	7.226×10^{-2}	383.93

2.3.2 Pressure curve fit

Yield(nb) = 0.039(±0.004) + 0.165(±0.002) P(atm)

Table 9: without collisional loss corrections but with a shift (in MeV) applied to match elastic peaks.

run	P (atm)	Yield (nb)
20992	0.02±0.02	0.039±0.004
20995	2.77±0.02	0.521±0.018
20996	2.77±0.02	0.537±0.015
20993	5.49±0.04	0.940±0.018
20194	10.93±0.10	1.801±0.025
temp. test: 20988	14.12±0.28	
temp. test: 20991	14.09±0.28	
20988	14.58±0.18	2.438±0.014
20991	14.56±0.24	2.434±0.029

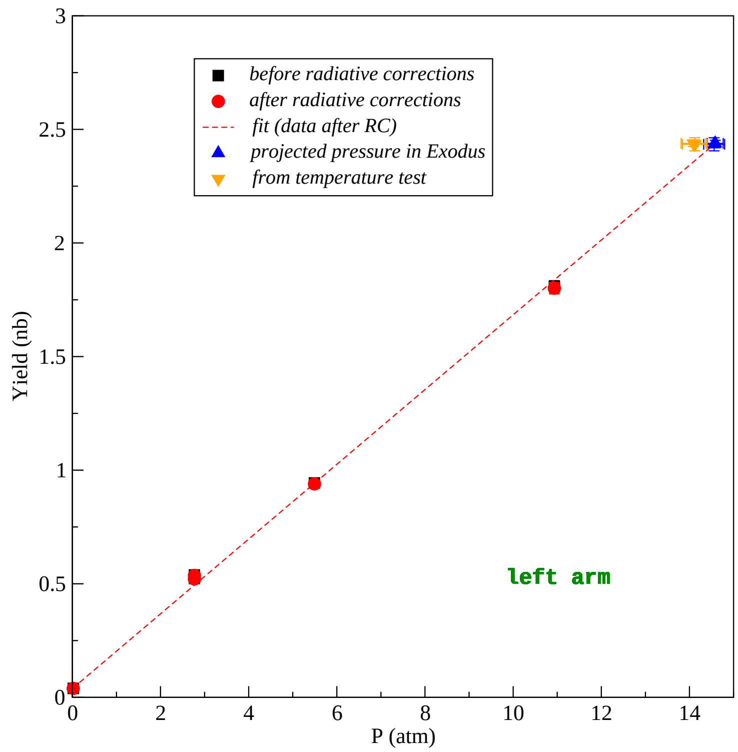

Figure 6: ^{3}He pressure curve for Exodus.

Under running conditions, we obtain:

- Average temperature test: 14.11±0.20 atm ⇒ 12.0±0.2 amg
- Average pressure curve: 14.57±0.14 atm ⇒ 12.4±0.1 amg

Due to the unstability of the oven during the temperature test of Exodus, we will rely on the results from the pressure curve. Thus we will apply a correction of +3% to the densities of each run taken with Exodus.

References

[1] Jaideep Singh, Private communication.

[2] X. Zheng, Ph.D. thesis, MIT, 2002.

[3] P. Solvignon, *Target density during E01-012*, E01-012 analysis report 05, March 2005.

[4] K. Slifer, *Modifications to the QFS and RADCOR codes*, E94010 Technical Note 44 (2003)