MEASUREMENT OF SCATTERERS THICKNESS

Andrey Dudarev, Mikhail Nikitin

November 28, 2012

Abstract

A set of different material foils is used in DIRAC experiment to define the multiple scattering parameters. Measurements of thickness of these foils are described in this note.

1. Introduction

To provide an important test of the Chiral Perturbation Theory DIRAC experiment aims to measure the S-wave $\pi\pi$ scattering length difference with high precision. Current result [1], based on a sample of 21 227 atomic pairs, is:

$$|a_0 - a_2| = (0.2533^{+0.0080}_{-0.0078}|_{stat}\ {}^{+0.0078}_{-0.0073}|_{syst})M_{\pi^+}^{-1} \tag{1}$$

The largest systematic error comes from a $\sim 1\%$ uncertainty in the multiple-scattering angle inside the Ni target foil. The modern experimental status of the multiple scattering in “thin” samples, presented in scientific literature, does not allow describing of the multiple scattering with necessary precision. Therefore in 2003 the multiple scattering in Ni foil and some other materials were measured at DIRAC setup [2] with precision of ~ 1%.

For further improvement of the systematic error it was decided to continue the multiple scattering measurements in parallel with 2011 data taking. The aim of these measurements is to decrease twice an uncertainty in the multiple-scattering angle inside targets, which were used during the DIRAC data taking.

The projected multiple-scattering angle $\langle\theta_x\rangle^2$ depends on the scatterer thickness x:

$$\langle\theta_x\rangle^2 = \frac{(21\,MeV)^2(m^2+p^2)}{2p^4\beta^2}\frac{x}{X_0}\left(1 + 0.038\log\frac{x}{X_0}\right)^2$$

therefore to improve the accuracy of the DIRAC result we have to know scatterer thickness with a high precision.

For this reason a set of new different foils were ordered at the Goodfellow Company. In addition few foils were taken from old DIRAC target station. List of foils is presented in Table 1.

Table 1. List of foils.

#	Material	Produced thickness, μm	Size, mm × mm	Purity (%)	Notation
	New foils	***(Goodfellow)***			
1.	Beryllium	100	50 × 50	99.8	Be100 #1
2.	Beryllium	100	50 × 50	99.8	Be100 #2
3.	Nickel	50	100 × 100	99.999	Ni50 #1
4.	Nickel	50	100 × 100	99.999	Ni50 #2
5.	Nickel	125	100 × 100	99.999	Ni125 #1
6.	Nickel	125	100 × 100	99.999	Ni125 #2
7.	Platinum	2	50 × 50	99.95	Pt2 #1
8.	Platinum	2	50 × 50	99.95	Pt2 #2
	Old targets				
9.	Beryllium	2000	50 × 50		Be2000
10.	Nickel [3]	100	50 × 50	99.994	Ni100
11.	Platimun	25	50 × 50		Pt25
12.	Titanium	250	50 × 50		Ti250

2. Mean thickness measurements

At the first we determined average thickness by measuring weight and area of foils. For weighing classical analytical balance with accuracy of 0.5 mg was used. The area was determined by a graphical program from scanned foils pictures.

2.1. Weighing

Results of measuring weight with classical analytical balance are shown in Table 2.

Table 2. Results of foils weighting.

#	Scatterer	m_1, g	m_2, g	m_3, g	$\langle m \rangle$, g
1.	Be100 #1	0.4942	0.4942	0.4943	0.4942
2.	Be100 #2	0.4780	0.4780	0.4780	0.4780
3.	Ni50 #1	4.2567	4.2568	4.2568	4.2568
4.	Ni50 #2	4.2398	4.2399	4.2398	4.2398
5.	Ni125 #1	11.5891	11.5890	11.5890	11.5890
6.	Ni125 #2	11.0636	11.0636	11.0636	11.0636
7.	Pt2 #1	0.1112	0.1112	0.1112	0.1112
8.	Pt2 #2	0.1126	0.1125	0.1126	0.1126
9.	Be2000	-	-	-	9.6175
10.	Ni100	-	-	-	2.3986
11.	Pt25	-	-	-	1.3681
12.	Ti250	-	-	-	2.7722

There is different data about values of the density of foil material in different sources. We used data from WebElements (first column of Table 3) to calculate the thickness of foils.

Table 3. Density of foils.

	WebElements [4]	Wikipedia [5]	Handbook [6]	Goodfellow	PDG [7]
	ρ, g/cm^3	ρ, g/cm^3	ρ, g/cm^3	ρ, g/cm^3	ρ, g/cm^3
Be	1.848	1.850	1.85	1.848	1.85
Ni	8.908	8.90	8.90	8.90	8.90
Pt	21.090	21.45	21.50	21.45	21.50
Ti	4.507	4.54	4.506	4.5	4.54

2.2. Area measurements

To measure the area we have scanned the foils using a usual scanner. First we made calibration of scanner with ruler to know the pixel size. Results of the scanner calibration along axes *x* (a) and *y* (b) are shown on Fig. 1. Parameter *p1* means that 1 pixel corresponds to 21.2 microns along *x* and 21.0 microns along *y* axes. This allows measuring the area of foils with a high precision. Then we have scanned foils on both sides and calculate the mean square using graphical program.

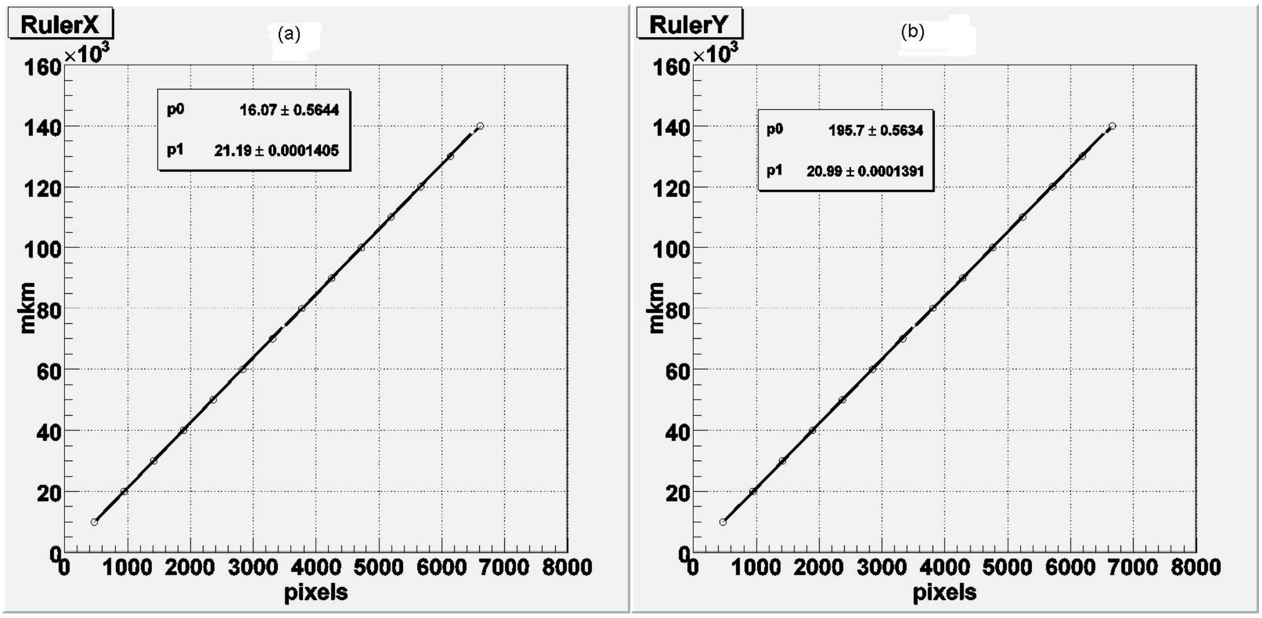

Fig. 1. Scanner calibration.

2.3.Results of the mean thickness measurements

Results are shown in Table 4. In the last column the mean values of the foils thickness are presented. An accuracy of the mean thickness measurements is around 0.1 % due to high precision of mass and square definition.

Table 4. Mean thickness and results of foils square measurements.

#	Scatterer	S_{top}, mm^2	S_{bottom}, mm^2	<S>, mm^2	<t>, µm
1.	Be100 #1	2504.7	2503.8	2504.3	106.8

2.	Be100 #2	2507.2	2503.5	2505.4	103.3
3.	Ni50 #1	10022.9	10016.2	10019.6	47.7
4.	Ni50 #2	9995.1	9996.0	9995.6	47.6
5.	Ni125 #1	10025.7	10024.3	10025.0	129.8
6.	Ni125 #2	10016.0	10005.8	10010.9	124.0
7.	Pt2 #1	2491.8	2493.4	2492.6	2.1
8.	Pt2 #2	2508.6	2503.5	2506.1	2.1
9.	Be2000	2505.5	2495.6	2500.6	2081
10.	Ni100 [3]	-	-	2529.7	106.4
11.	Pt25	2484.6	2473.8	2479.2	26.2
12.	Ti250	2496.5	2501.8	2499.2	246.1

3. Real thickness measurements

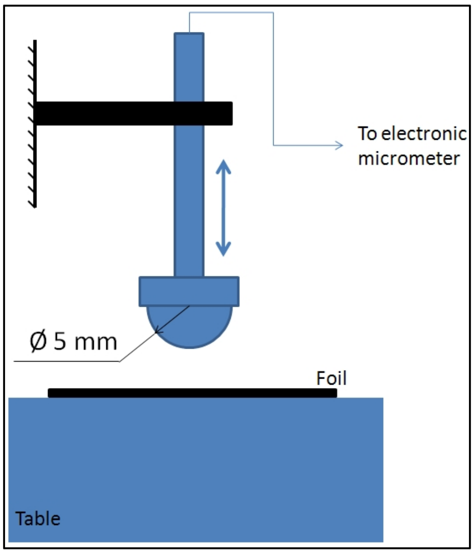

Fig. 2. Scheme of measurement.

In addition we measured thickness on several points using precise electronic micrometer with accuracy of 0.1 μm (at the workshop, CERN Metrology Facilities of EN-MME group). The scheme of measurement is shown in Fig. 2.

Each foil was divided into 25 squares (5×5) and we measure the thickness in the center of each square. The results are shown in Fig. 3. Result for the Ni (109 μm) foil is taken from [3].

The mean thickness, spread and standard deviation were calculated for each foil using 25 measurement points.

To define multiple scattering angles in the experiment we place the scatterer just behind DC3 module in the left arm of DIRAC spectrometer and measure particle track before and behind scatterer. During this analysis only central part of scatterer foil is taken into account (shown as shading square in Fig. 3). Therefore we also calculate the mean thickness, spread and standard deviation for the central part of foils 50×50 mm^2 size (foils 100×100 mm^2 were cut into pieces before placement to the DIRAC setup).

4. Summary

All results (by weighing and real thickness measurement) are summarized in Table 5. One can see in this table that the measured thickness is mostly higher than average values. It can be explained by unevenness of the foil surface. Result of calculation for the central part of foils is shown in blue. The central part of foils looks like more flat, which could be explained by technology of production (rolling method).

109.8	110.7	110.3	109.9	108.3
111.2	111.3	109.1	108.9	108.7
116.4	109.8	109.2	108.6	109.1
113.2	111.5	109.2	109.5	109.6
113.3	112.4	111.6	109.4	110.4

Be 100 µm, #1

107.6	105.7	104.1	105.4	105.8
108.7	106.9	107.8	108.2	106.3
107.9	105.2	106.3	107.2	108.1
107.4	108.6	106.6	108.9	108.2
109.2	105.6	108.2	107.0	107.1

Be 100 µm, #2

1.9	2.0	2.0	2.4	2.6
1.6	1.8	2.2	2.3	2.2
1.5	1.9	2.0	2.2	2.5
1.7	1.9	2.1	2.1	2.5
1.6	1.8	2.0	2.3	2.4

Pt 2 µm, #1

2.4	2.3	2.3	2.3	2.1
2.3	2.3	2.3	2.4	2.2
2.2	2.3	2.1	2.1	2.1
2.0	2.0	2.0	1.8	2.0
1.8	1.7	1.8	1.8	1.8

Pt 2 µm, #2

20.9	24.4	26.0	27.2	27.8
22.1	26.0	26.7	26.5	26.5
21.2	25.6	25.9	28.0	28.7
21.9	26.8	27.2	27.5	28.0
21.7	25.6	27.6	28.3	28.0

Pt 25 µm

247.0	248.8	248.1	248.1	246.9
250.4	253.7	253.5	252.9	251.8
252.1	254.1	254.6	253.5	253.6
249.9	252.5	252.9	253.1	251.3
247.4	245.6	248.3	248.6	247.7

Ti 250 µm

2065.5	2054.2	2051.1	2053.0	2062.9
2065.2	2053.3	2049.1	2051.5	2061.4
2063.7	2052.3	2048.9	2050.4	2063.9
2068.2	2058.8	2055.5	2058.0	2069.1
2069.6	2061.4	2060.3	2067.6	2079.9

Be 2000 µm

110	110	109	109
109	109	109	108
110	110	109	108
109	109	108	107

Ni 109 µm, [3]

126.3	124.9	127.8	129.8	128.6
131.1	131.1	133.5	136.6	136.6
132.6	135.0	136.8	138.8	138.8
131.8	132.3	135.2	136.1	136.1
126.7	126.2	131.8	130.0	130.0

Ni 125 µm, #1

121.1	126.7	129.5	126.7	119.3
122.7	126.8	129.1	127.7	121.3
123.0	129.3	129.6	126.1	122.3
123.6	128.8	133.6	129.0	121.6
124.5	131.8	134.4	130.6	123.4

Ni 125 µm, #2

46.4	50.9	53.3	51.5	46.5
47.4	50.6	51.9	50.3	47.0
47.2	49.4	51.1	49.3	47.4
47.5	49.4	49.8	49.1	47.1
47.1	49.5	50.5	49.0	47.1

Ni 50 µm, #1

46.5	46.4	46.7	47.2	47.0
48.7	49.1	49.4	50.1	49.6
49.1	51.0	50.2	51.4	52.6
48.7	50.0	49.3	50.5	51.0
47.1	47.6	47.8	47.2	48.2

Ni 50 µm, #2

Fig. 3. Results of real thickness measurement.

Table 5. Weighed and measured foils thickness.

Foil	$\langle m \rangle$, g	S, mm^2	"Weighted" thickness $\langle t_w \rangle$, µm	Measured thickness $\langle t_m \rangle$, µm	σ, µm	$\sigma/\langle t_m \rangle$, %
Ni 125 µm, #1	11.5890	10025	129.8	132.1±6.9	3.9	3.0
Ni 125 µm, #2	11.0636	10019	124.0	126.5±7.5	4.1	3.2
Ni 50 µm, #1	4.2568	10020	47.7	49.1±3.5	1.9	3.9
Ni 50 µm, #2	4.2398	9996	47.6	48.9±3.1	1.7	3.5
Be 100 µm, #1	0.4942	2504	106.8	110.5±4.0	1.9	1.7
				109.7±1.5	**1.1**	**1.0**
Be 100 µm, #2	0.4780	2505	103.3	107.1±2.6	1.3	1.2
				107.3±1.9	**1.1**	**1.0**
Pt 2.0 µm, #1	0.1112	2493	2.1	2.1±0.5	0.30	14.3
				2.1±0.3	**0.17**	**8.1**
Pt 2.0 µm, #2	0.1126	2506	2.1	2.1±0.3	0.22	10.5
				2.1±0.3	**0.19**	**9.0**
Be 2.0 mm	9.6175	2501	2081	2060±16	8	0.4
				2053 ± 5	**4**	**0.2**
Pt 25 µm	1.3681	2479	26.2	25.8±4.0	2.4	9.3
				26.7 ± 1.2	**0.8**	**3.0**
Ti 250 µm	2.7722	2499	246.1	250.7±5.4	2.8	1.1
				253.4 ± 1.1	**0.7**	**0.3**
Ni 109 µm [3]	2.3986	2530	106.4	108.9 ± 1.5	0.9	8.3
				109.3 ± 0.5	**0.5**	**0.5**

For the foils, which are planning to be used for measuring of multiple scattering angles, one should take into calculations the "weighted" thickness as the best estimation.

For the foils, which were used or are planning to be used as a target in the DIRAC setup, we have estimated the spread of thickness t_c in the central region (~1 cm around the center) of the foils.

Table 6. Thickness of targets in the center region.

Target	$\langle t_w \rangle$, µm	t_c, µm	δ, %
Ni 109 µm [3]	106.4	109.0±0.5	0.51
Be 100 µm, #2	103.3	106.4±0.6	0.56
Pt 25 µm	26.2	26.4±0.8	3.0
Ti 250 µm	246.1	253.5±1.0	0.39

5. References

1. Determination of ππ scattering lengths from measurement of $\pi^+\pi^-$ atom lifetime
   B.Adeva, et al., Phys.Lett.B 704(2011), p. 24-29
2. Pion multiple Coulomb scattering in the DIRAC experiment
   A. Dudarev, et al., DIRAC note 2008-06, http://cdsweb.cern.ch/record/1369639.
3. New Nickel Target, V.Brekhovskikh et al., DIRAC note 2010-05,
   http://cdsweb.cern.ch/record/1369620
4. *http://www.webelements.com/*
5. *http://en.wikipedia.org/wiki/Density*
6. CRC Handbook of Chemistry and Physics, 90th Edition, 2010,
   http://www.hbcpnetbase.com/
7. *http://pdg.lbl.gov/2011/AtomicNuclearProperties/*