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Investigation of systematic errors of metastable “atomic pairs” number

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Abstract

Sources of systematic errors in analysis of data, collected in 2012, are analysed. Estimations of systematic errors in a number of “atomic pairs” from metastable $\pi^+\pi^-$ atoms are presented.

1 Introduction

For analysis of systematic errors it is needed to take into account that DIRAC setup has been updated for searching metastable atoms. The main modification is two layer target system: Beryllium target (106.4 μm), crossed by primary proton beam, is a source of particles, including metastable atoms - $\pi^+\pi^-$ atoms in states with non-zero orbital momentum; Platinum foil (2.1 μm) in 10 cm downstream, which is not crossed by primary proton beam, but crossed only by secondary particles, generated in a Beryllium target. Metastable atoms are ionized in Platinum and form “metastable pairs”.

In the gap between Beryllium and Platinum, permanent magnet has been installed. Magnetic field of this magnet (main projection is horizontal) shifts measured value of Q_Y by 12.9 MeV/c for pairs oppositely charged pairs, generated in Beryllium target, and by 2.3 MeV/c for pairs generated in Platinum foil. As result peak of “metastable pairs” is shifted by 10.6 MeV/c relative to peak, formed by “Coulomb” and “atomic” pairs, generated in Beryllium. It means that shape of background distribution in the signal region is close to phase space and influence of the setup resolution over Q (and Q-projections) is not essential for “Coulomb” and “atomic” pairs. Only difference of shapes for experimental and simulated distributions of “metastable pairs” could provides systematic effects, which are described in the next sections.

2 Λ correction

Uncertainty in a measurement of Q_L is induced by accuracy of spectrometer magnet magnetic field map, description of multiple scattering in Aluminum membrane (just after magnet) and geometry, multiples scattering and resolution of DC chambers. This error is corrected with calibration based on Λ-decay position and width [1]. Width of distribution over effective masses is defined only by resolution of detectors due to very low decay width of the particle. Comparison of widths for experimental and simulated distributions shows that experimental distribution is wider [1]. It means that errors of laboratory momentum reconstruction are underestimated for Monte-Carlo events. It is shown [1], that this effect could be compensated by additional smearing for reconstructed momenta P^{rec} of simulated particles, using equation:

$$P^{smeared} = P^{rec} \cdot (1. + Cf \cdot N(0., 1.)) \,, \tag{1}$$

here N(0.,1.) is a normal distribution centered at 0. with unity width parameter, Cf is a coefficient, which estimated [1] to be:

$$Cf = 0.0007 \pm 0.0004 \,. \tag{2}$$

Uncertainty of coefficient Cf leads to systematic error σ_{Λ}^{syst}. To estimate it two sets of simulated distributions have been prepared: with and without correction (Eq. 1), using coefficient Cf (Eq. 2). Differences of "metastable pair" numbers obtained in these two cases have been multiplied by relative accuracy of Cf (0.57). Estimations of σ_{Λ}^{syst} are presented in Table 1 for one-dimensional analysis (distributions over $|Q_L|$ with different criteria on $Q'_T = \sqrt{Q_X^2 + (Q_Y - 2.3)^2}$), two-dimensional distributions (over $|Q_L|, Q'_T$), and two-dimensional distributions with additional bins of distributions over Q_Y in a ranges: $10. < Q_Y < -4.5$, $4.5 < Q_Y < 10.$ MeV/c, with criteria $|Q_X| < 2.$ MeV/c, $|Q_L| < 2.$ MeV/c. These bins improve accuracy of measurement for fraction of "non-Coulomb" pairs, because shape of "Coulomb" and "non-Coulomb" pair distributions over $|Q_L|$ are very similar in the region $Q'_T < 2.$ MeV/c.

3 Uncertainty in Platinum foil thickness

The main source of uncertainty in Q_T measurement is accuracy of Pt foil thickness measurement [2]. Metastable atoms, generated to an acceptance of the DIRAC setup, crosses Platinum foil in the square 3.4×3.4 mm^2 in the centre of one side of the Pt foil #2 [2]. Measured thicknesses of these regions are: 1.8, 2.1, 2.2, 2.3 μm. So, uncertainty of thickness is 0.3 μm .

To investigate influence of Platinum foil thickness, experimental data have been analysed with 3 different thicknesses of Platinum foil: 2.0, 2.2 and 2.4 μm. Differences of results have been multiplied by corresponded coefficients to obtain estimation of systematic error σ_{Pt}^{syst}. Results are presented in Table 1.

4 Total systematic error

Both component of systematic error (σ_{Λ}^{syst} and σ_{Pt}^{syst}) are induced by uncertainty of variables values measured in separate investigations (coefficient of additional momentum smearing and thickness of Platinum foil). These are independent processes and total systematic error could be obtained with equation:

$$\sigma^{syst} = \sqrt{(\sigma_{\Lambda}^{syst})^2 + (\sigma_{Pt}^{syst})^2}$$

Values of σ^{syst} are presented in Table 1

Table 1: Systematic errors induced by Λ correction (σ_{Λ}^{syst}), uncertainty of measurement of Platinum foil thickness (σ_{Pt}^{syst}) and total systematic error (σ^{syst}) for analysis with distributions over different variables with different criteria

Variable	Criterion MeV/c	σ_{Λ}^{syst}	σ_{Pt}^{syst}	σ^{syst}
$\lvert Q_L \rvert$	$Q'_T < 2.$	7.9	0.15	7.9
$\lvert Q_L \rvert$	$Q'_T < 1.5$	5.1	0.15	5.1
$\lvert Q_L \rvert$	$Q'_T < 1.$	3.8	0.15	3.8
$\lvert Q_L \rvert$	$Q'_T < 0.5$	1.9	0.15	1.9
$\lvert Q_L \rvert, Q'_T$	$Q'_T < 2.$	4.0	20.	20.
$\lvert Q_L \rvert, Q'_T(Q_Y)$	$Q'_T < 2.$	4.4	22.	23.

5 Hypothetical admixture of “Coulomb pairs”, generated in Platinum foil by proton of primary beam

Another problem is hypothetical admixture of “Coulomb” and “atomic” pairs generated due to interaction of beam halo protons with a Platinum foil. Peak induced by Coulomb interaction in the final state would be at the same point, where “atomic pairs” from metastable atoms. Level of a beam halo and intensity of interaction with the Platinum foil have been investigated [3]. It is shown that flux of particles generated on Platinum foil is practically negligible for its working position. Nevertheless, for additional checking, some amount of “Coulomb pairs” generated of Platinum target have been simulated and using for description of experimental data instead of “atomic pairs” from metastable atoms. “Atomic pairs” from atoms generated on foil are not simulated, because amount of them is small relative to “Coulomb pairs” and their shape is close to one for pairs from metastable atoms.

Table 2 presents results of alternative fit and results of “standard” fit which use “metastable pairs”.

Comparison of results in Table 2 shows that hypothesis of “Coulomb pairs” generated at Platinum foil as explanation of signal is not statistically proved.

References

[1] - A. Benelli, V. Yazkov, DN-2013-03, http://cds.cern.ch/record/1622175

[2] - A. Dudarev, M. Nikitin, DN-2012-09, http://cds.cern.ch/record/1526913

[3] - L.Afanasyiev et al., DN-2013-02, http://cds.cern.ch/record/1636206

Table 2: Amount of “Coulomb pairs” generated at Platinum target N_{CC}^{Pt} used for alternative fit procedure instead of “atomic pairs” from metastable atoms, and χ^2/NDoF of fit in comparison with results of fit used “metastable pairs” n_A^m

Q'_T cut MeV/c	N_{CC}^{Pt} 10^3	(χ^2/NDoF)	n_A^m	(χ^2/NDoF)
Fit over Q_L				
0.5	-0.8 ± 1.3	56/27	152 ± 29	(29/27)
1.0	-2.8 ± 5.4	61/27	349 ± 53	(19/27)
1.5	$-2. \pm 12.$	47/27	386 ± 78	(22/27)
2.0	$25. \pm 22.$	39/27	442 ± 105	(22/27)
Fit over Q_L, Q'_T				
2.0	$-4. \pm 10.$	163/117	407 ± 58	(111/117)
Fit over Q_L, Q'_T (Q_Y)				
2.0	$-0.8 \pm 13.$	238/140	436 ± 57	(138/140)