EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP-To be specified
To be specified

DIRAC Collaboration status report to SPSC, October 2020

L. Nemenov (JINR), on behalf of the DIRAC Collaboration

CERN-SPSC-2020-021 / SPSC-SR-276
01/10/2020

1 K^+K^- pair analysis in the effective mass region near $2m_K$

The results of experimental K^+K^- pairs analysis in the effective mass region near 2 Kaon masses were presented in the DIRAC annual report in October 2019. The experimental data were analysed (Coulomb approach) proposing point-like pairs production and only Coulomb interaction in the final state (Fig.1(a)).

In the present report are shown the results of a more detailed investigation (detailed approach) taking into account the point-like and non point-like K^+K^- pair generation, Coulomb and strong interaction in the final state (Fig.1(b)). In this analysis the three different theoretical models: Achasov, Martin and ALICE collaboration were used.

The K^+K^- pairs experimental distributions were evaluated by subtraction of $\pi^+\pi^-$, $p\bar{p}$ and accidental pairs background using setup detectors and time of flight measurement. The residual background was evaluated and subtracted using different dependence of K^+K^- and backgrounds pairs from Q. The complete analysis used a more precise description of the background than in the 2019 report.

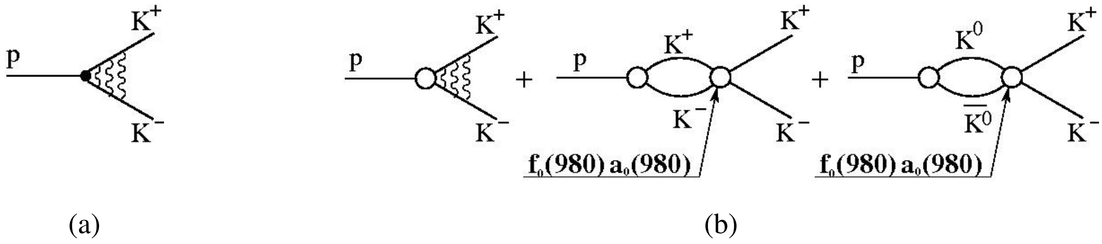

Fig. 1: The K^+K^- production processes. a) point-like production and Coulomb interaction in the final state, b) point-like and non point-like pair generation with Coulomb and strong interaction in the final state.

1.1 Coulomb analysis

In the Coulomb analysis the K^+K^- pairs numbers were evaluated from the experimental Q_L and Q distributions which have different shapes.

On Fig.2 is shown the Q_L spectrum of 70%, 50% and 30% subsamples for the RUNs 2009 and 2010. Each subsample was obtained by subtraction of the background from the experimental distributions with 70%, 50% and 30% of the K^+K^- pairs. Simulated distributions of K^+K^- pairs (Coulomb approach) and residual background of $\pi^+\pi^-$ and $p\bar{p}$ pairs are fitted the experimental spectrum in the interval $0 < Q_L < 100 MeV/c$. The red line is the K^+K^- distribution, the black line is the sum of K^+K^- and residual background. In the subsamples 70% and 30% the residual background is small and the lines

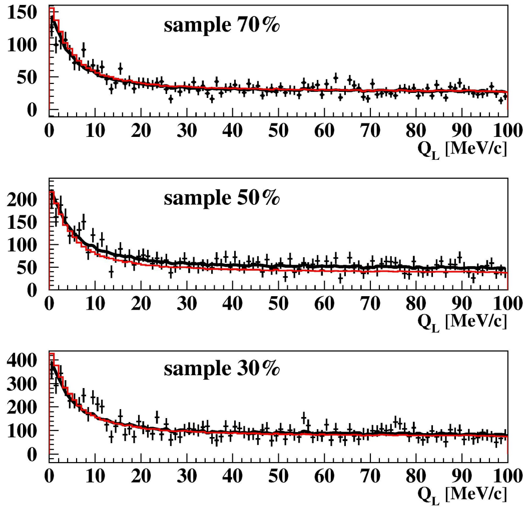

Fig. 2: Q_L distributions of the subsamples 30%, 50% and 70% for the RUNs 2009 and 2010. Simulated distributions of K^+K^- (Coulomb approach) and residual background of $\pi^+\pi^-$ and $p\bar{p}$ pairs are fitted to the experimental spectrum in the interval $0 < Q_L < 100 MeV/c$. The red line is the K^+K^- distribution, the black line is the sum of K^+K^- and residual background. In the subsamples 70% and 30% the residual background is small and these lines practically coincide. For K^+K^- pairs in the region of $Q_L < 10 MeV/c$ the Coulomb enhancement is clearly visible, whereas the residual background is uniform.

coincide. For K^+K^- pairs in the region of Q_L smaller than $10 MeV/c$ the Coulomb enhancement is clearly visible whereas the residual background is uniform.

Table 1: Matching pair numbers for Q and Q_L distribution analyses. The errors of K^+K^- and background values are the same.

year	cut on ToF	distribution	K^+K^-	$\pi^+\pi^-$ & $p\bar{p}$ background
2009 + 2010	70%	Q	3900 ± 410	-110
		Q_L	3930 ± 580	-140
	50%	Q	5320 ± 730	1100
		Q_L	5460 ± 1020	960
	30%	Q	11220 ± 1370	180
		Q_L	10750 ± 2020	300

It is seen from Table 1 that the K^+K^- pairs numbers defined on Q and Q_L distributions do not differ significantly.

1.2 Detailed analysis

The distributions in r^*, the distance between K^+ and K^- in their c.m.s. connecting with the K mesons from the decay of short-lived sources and long-lived resonances is described as the sum: $w_g * Gauss + w_{K^*} * K^*(892) + w_\Lambda * \Lambda(1520) + w_\varphi * \varphi(1020)$.

The first term describes the contributions of the short-lived sources approximated by Gaussian with the radius $r_0 \approx 1.5 fm$, the other terms describe the contributions of the three resonances. The w_i are the relative contributions of the different sources in K^+K^-pairs production; the sum of w_i is equal to unity. The weight values and their errors were evaluated. The analysis was performed for the three sets of w_i.

The first extreme set (0.00, 0.76, 0.10, 0.14) maximises contributions of the $K(892), \Lambda(1520)$ and $\varphi(1020)$ resonances producing the largest value of the average r^*; the third extreme set (0.57, 0.35, 0.06, 0.02) maximises the role of the short-lived K^+K^- pair sources generating the minumum value of the average r^* and the second set (0.10, 0.76, 0.08, 0.06) uses the intermediate values of w_i.

The distributions in Q (fitting curves) were calculated for each year and each set, using three theoretical approaches of Achasov, Martin and ALICE. The experimental data of the 70% subsample were analysed by a dedicated fitting curve with $\pi^+\pi^-$ and $p\bar{p}$ background. The results are shown in the Table 2.

The difference between extreme yield values gives the maximum numbers of systematic errors in connection with the uncertainty of r^* distribution. The maximum errors values are $\pm 70, \pm 55$ and ± 40. These systematic errors are significantly smaller than the errors in Table 2. Therefore for the analysis using two other experimental subsamples only the intermediate distribution on r^* was used.

The results of 70%, 50% and 30% subsamples are presented in the Table 2. It is seen that for any subsample the Achasov approach gives the residual background deflection from zero significantly larger than Martin and ALICE calculations. The large level of residual background can be considered as the result of insufficient accuracy of the fitting curve describing of K^+K^- distribution in Q.

Table 2:

	Achasov K^+K^- (backgr.)	Martin K^+K^- (backgr.)	ALICE K^+K^- (backgr.)	Total events
70% sample				3790
maximum r^*	3190 ± 330	3650 ± 370	3720 ± 380	
intrermediate r^*	3120 ± 320 (670)	3600 ± 360 (190)	3680 ± 370 (110)	
χ^2 2010/2009	$1.03/1.20$	$1.00/1.18$	$1.00/1.18$	
minimum r^*	3050 ± 320	3540 ± 360	3640 ± 370	
50% sample				6420
intrermediate r^*	4340 ± 570 (2080)	4940 ± 640 (1480)	5040 ± 660 (1380)	
χ^2 2010/2009	$0.80/1.04$	$0.79/1.04$	$0.78/1.05$	
30% sample				11030
intermediate r^*	9230 ± 1080 (1800)	10500 ± 1220 (530)	10680 ± 1240 (350)	
χ^2 2010/2009	$0.70/0.89$	$0.68/0.88$	$0.68/0.88$	

Therefore the experimental data will be analysed in ALICE and Martin approximation only. The large residual background in the 50% subsample indicates that this experimental distribution is less reliable than in the two other subsamples.

The Figure 3 shows the experimental distributions in Q, fitting curves describing K^+K^- pairs (ALICE approach), residual ackgrounds and sum of fitting curves and residual backgrounds.

It is seen that for 70% (30%) subsample the fitting curve alone describes well the experimental distribution in the total interval of Q demonstrating that admixture of the residual background to the K^+K^- pairs is relatively small. This result is in agreement with the average level of the residual background, which is equal to 3% (3.2%) of the total number of events in the distribution.

The same analysis was done for the 50% subsample in which the residual background level is larger than that in the two other subsamples. The corrected experimental distributions (ALICE approach) were obtained after background subtraction and is shown in Fig. 4. The red and the blue fitting curves on the Fig. 4 were evaluated from the analysis of experimental distributions with residual background in Coulomb and Martin approaches respectively.

It is seen that Martin fitting curve describes the corrected experimental distribution well. The small

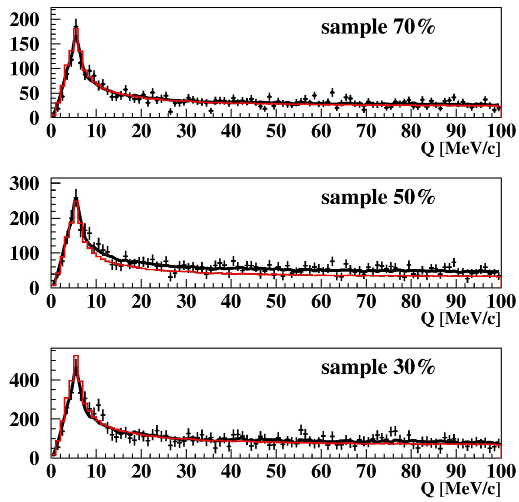

Fig. 3: Q distributions of the subsamples 30%, 50% and 70% for the RUNs 2009 and 2010. Simulated distributions of K^+K^- (ALICE approach), residual background of $\pi^+\pi^-$ and accidental pairs are fitted the experimental spectrum in the interval $0 < Q_L < 100\ MeV/c$. The red line is the K^+K^- distribution, the black line is the sum of K^+K^- and residual background. In the subsamples 70% and 30% the residual background is small and these lines practically coincide.

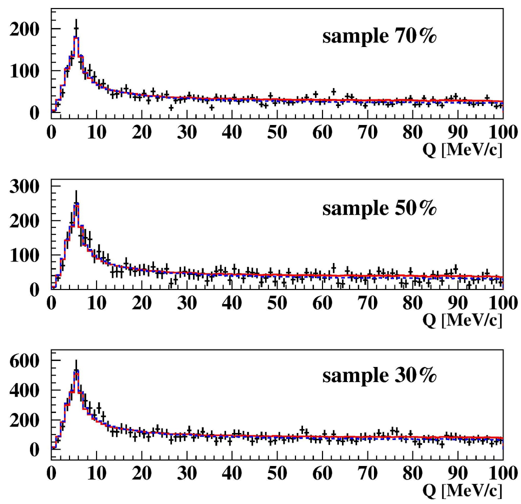

Fig. 4: Q distributions in the interval $0-100\ MeV/c$ of K^+K^- (ALICE approach) of the subsamples 30%, 50% and 70% for the RUNs 2009 and 2010 after residual background subtraction. The red and the blue fitting curves were evaluated from the analysis of experimental distributions with residual background in Coulomb and Martin approaches respectively. It is seen that the difference between these curves is not significant and they describe well "pure" experimental K^+K^- distributions.

difference between Martin and Coulomb approaches in the interval $30-100 MeV/c$ caused by strong K^+K^- interaction in the final state which is taken into account only in Martin approach. The distributions in the interval $0-30 MeV/c$ are presented in Fig. 5.

It is seen that the Martin and Coulomb fitting curves, presented as histograms, are in this region coinciding and describing well the corrected experimental data.

The efficiencies of all cuts are known. Using these efficiencies, the total numbers of detected K^+K^- pairs in 70%, 50% and 30% subsamples were evaluated. They are $40890 \pm 4110, 29650 \pm 3880$ and 38140 ± 4430 pairs respectively.

The background in the 30% subsample is about 19 times larger than in the 70% subsample. Nevertheless

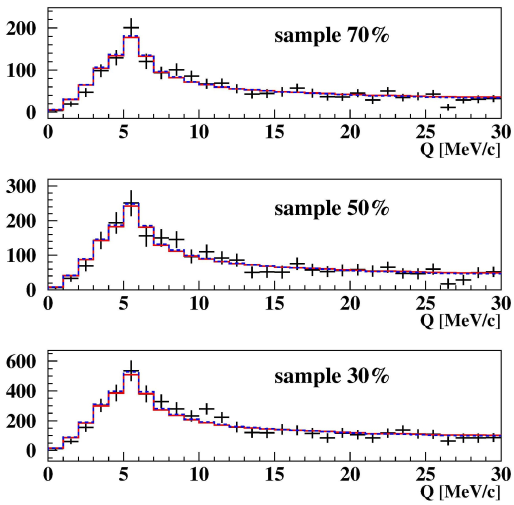

Fig. 5: Q distributions in the interval $0-30\ MeV/c$ of K^+K^- (ALICE approach) of the subsamples 30%, 50% and 70% for the RUNs 2009 and 2010 after residual background subtraction. The red and the blue fitting curves were evaluated from the analysis of experimental distributions with residual background in Coulomb and Martin approaches respectively. It is seen that in this interval of Q the difference between these curves is absent and they describe well "pure" experimental K^+K^- distributions.

the total numbers of K^+K^- pairs are in good agreement demonstrating that the background and residual background subtraction was done correctly. The K^+K^- pairs number in the 50% subsample differs from two others values by 2 standard errors, confirming as mentioned above that experimental data in this subsample is less reliable. The total number of K^+K^- pairs calculated using Martin approach differs from the obtained numbers significantly less than the presented errors.

1. The preprint draft on K^+K^- pairs will be send to the Collaboration before November 2020.
   The preprint publication will be done before April 2021.

2. We plan to evaluate for the first time the number of K^+K^- atoms generated simultaneously with the detected K^+K^- pairs.
   The result of this work will be obtained and published as CERN preprint before October 2021.

2 Proton-antiproton pairs analysis

The shape of detected proton-antiproton pairs on the relative momentum Q is expected to be more sensitive to the size of the particle production region compared to the case of detected K^+K^- pairs. Thus, the study of this shape could open a possibility to evaluate the size of production region of pairs. The pairs distributions on Q will allow to evaluate for first time the number of relativistic proton-antiproton atoms generated simultaneously with the detected proton-antiproton pairs.

The investigation of proton-antiproton system in the region of relative momentum from zero to 100 MeV/c will be finished and published as CERN preprint before October 2021.

3 The short-lived $\pi^+\pi^-$ atom lifetime measurement

Previously, the $\pi^+\pi^-$ pairs from 2008-2010 data were used as a calibration process for the πK and K^+K^- pairs analysis. We expected a better statistics of the $\pi^+\pi^-$ pairs compared to the previously published result. The preliminary results on the measurements of short-lived atom lifetime and $\pi^+\pi^-$ scattering length based on the new data will be presented in October 2021.