IMPROVED $K_{\rm S}$ TAGGING PROCEDURE AND ITS IMPACT ON PHYSICS AT KLOE-2*

M. Silarski

on behalf of the KLOE-2 Collaboration

The Marian Smoluchowski Institute of Physics, Jagiellonian University
Łojasiewicza 11, 30-348 Kraków, Poland
and
Laboratori Nazionali di Frascati dell'INFN
Via E. Fermi, 40, 00044 Frascati, Italy

(Received October 24, 2014)

The KLOE experiment at the DAΦNE ϕ-factory performed precise studies of charged and neutral kaon physics, low energy QCD, as well as tests of CP and CPT invariance. For the new run, the KLOE has been upgraded by adding new tagger systems for the $\gamma\gamma$ physics, the inner tracking chamber and two calorimeters in the final focusing region. We are also improving on kaon identification techniques, in particular algorithms for the $K_{\rm S}$ meson tagging. In this article, we discuss the impact of the improved tagging procedure on studies of the $K_{\rm S}$ decays.

DOI:10.5506/APhysPolB.46.25
PACS numbers: 13.20.Eb, 13.25.Es

1. Introduction

The ϕ meson produced in e^+e^- collisions at DAΦNE is in a pure $J^{\rm PC} = 1^{--}$ state. Thus, neutral kaon pairs are in an antisymmetric state which can be expressed in the ϕ rest frame as

$$|i\rangle = N \cdot \left[|K_{\rm S}(\vec{p})\rangle \, |K_{\rm L}(-\vec{p})\rangle - |K_{\rm L}(\vec{p})\rangle \, |K_{\rm S}(-\vec{p})\rangle \right] , \quad (1)$$

where $\vec{p}$ denotes the momentum of each kaon and N is a normalization factor [1]. Since e^+e^- beams collide in the horizontal plane at small angle, $K_{\rm S}$ and $K_{\rm L}$ are produced almost back-to-back, with total momentum, $P_{\rm T} \sim 15$ MeV$/c$. Therefore, observation of a $K_{\rm L}$ ($K_{\rm S}$) meson ensures (tags) the presence of the $K_{\rm S}$ ($K_{\rm L}$) flying in the opposite direction and the kinematical closure can be used to determine the momentum of tagged kaons. Thus, at DAΦNE we obtain pure $K_{\rm S}$ and $K_{\rm L}$ beams with precisely known momenta and flux, which can be used to measure absolute branching fractions [2]. The tagging is performed mainly by the reconstruction of the $K_{\rm L}$ interaction in the calorimeter ("$K_{\rm L}$ crash"), which provides a very clean identification of the $\phi \to K_{\rm S}K_{\rm L}$ events. The other method is based on reconstruction of the $K_{\rm L}$ decay inside the drift chamber which may significantly increase the tagging efficiency.

2. $K_{\rm S}$ tagging via detection of the $K_{\rm L}$ in the KLOE calorimeter

At KLOE, about 60% of produced $K_{\rm L}$ mesons reach the calorimeter where they can interact [2]. Thanks to the excellent time resolution of the KLOE calorimeter and the low velocity of kaons, one can use the Time-of-Flight technique to tag the $K_{\rm S}$ meson. Adding the information about the position of the energy release ($K_{\rm L}$ cluster), the direction of the $K_{\rm L}$ flight path can be determined with a good precision. In Fig. 1, we present distribution of $\cos\theta_{\rm rel}$, *i.e.*, cosine of an angle between reconstructed and true $K_{\rm L}$ direction for a sample of simulated $\phi \to K_{\rm S}K_{\rm L}$ events. The full width at half maximum corresponds to about 1°. This allows to determine $K_{\rm L}$ kinematics and, knowing the total energy and momentum from the analysis of Bhabha scattering events, to determine the four-momentum of the tagged $K_{\rm S}$ meson.

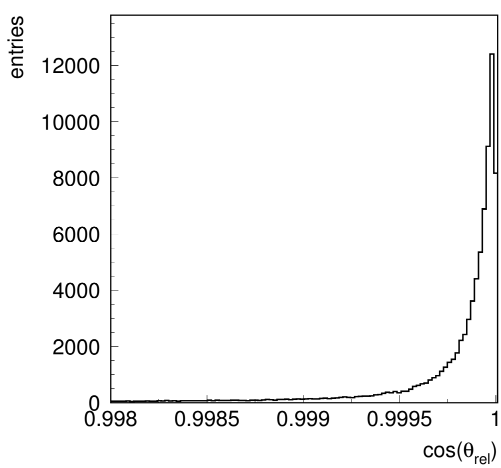

Fig. 1. Distribution of the angle between true and reconstructed $K_{\rm L}$ direction for a sample of simulated $\phi \to K_{\rm L}K_{\rm S}$ events. The full width at half maximum of the distribution corresponds to the accuracy of $\sim 1^\circ$.

The identification of the K_L interaction in the calorimeter is performed after tracks reconstruction and after applying the track-to-cluster association procedure. A sequence of cuts is then applied to reject events with K_L decay inside the drift chamber [3]. For each event, we look for the K_L clusters in the calorimeter taking into account only clusters not associated to any track. For these clusters, we calculate the particle velocity defined in the laboratory frame as $\beta_{cl} = R_{cl}/(c\,t_{cl})$, where R_{cl} is the distance from the e^+e^- interaction point to the reconstructed position of the cluster center, t_{cl} stands for the measured time of flight of the particle, and c is the speed of light. It is used to select clusters corresponding to K_L with $\beta_{cl} \sim 0.22$ (see Fig. 2). To reject delayed clusters due to charged pions for which the track-to-cluster association procedure failed, we require an energy deposition of at least 100 MeV. Kaons from the ϕ decay are mostly emitted at a large polar angle so that the background can be additionally suppressed selecting only "K_L crash" clusters in the barrel calorimeter [4]. The small remaining background contamination originates from $\phi \to K^+K^-$ decays and cosmic muons entering KLOE through the intersection between the barrel and endcap calorimeters. As one can see in Fig. 2, this contamination is characterized by a flat β_{cl} distribution.

The efficiency of this tagging procedure depends on the requirements on K_L velocity and cluster energy, and is in the range of 23–34% [5–10]. It is worth mentioning that, according to the KLOE Monte Carlo simulations, about 30% of K_L interactions reconstructed in the calorimeter fulfill the KLOE trigger conditions allowing for a search of the $K_S \to$ *invisible* decays which, if observed, would be an unambiguous signal of physics beyond the Standard Model [11].

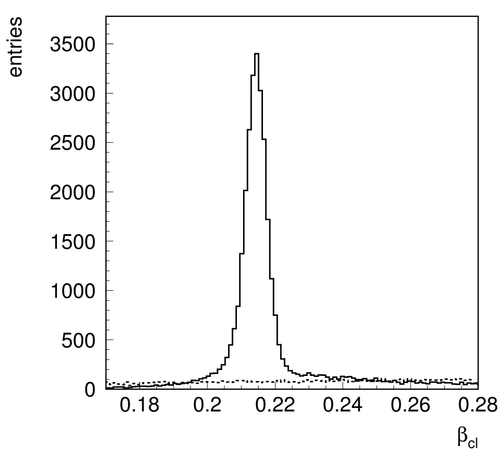

Fig. 2. Simulated distributions of the reconstructed K_L velocity β_{cl} for a sample of the $\phi \to K_S K_L$ events (solid histogram) and background (dashed histogram).

3. $K_{\rm S}$ tagging with $K_{\rm L}$ charged decay reconstruction

Charged $K_{\rm L}$ decays in the KLOE drift chamber which are rejected by the "$K_{\rm L}$ crash" algorithm can also be used to tag $K_{\rm S}$ [12]. This can be done by looking for an isolated vertex or chain of vertices inside the drift chamber which are reconstructed outside a sphere of 30 cm radius around the interaction point. In addition, each track associated to the vertex should not point to the interaction region. More detailed description of the analysis cuts can be found in Ref. [12].

Efficiency of this tagging procedure was studied with Monte Carlo simulations for the main $K_{\rm S}$ decay channels. About 30% of generated $K_{\rm L}$ mesons decay inside the KLOE drift chamber and about 55–60% of these decays fulfill the tagging conditions with a small dependence on the $K_{\rm S}$ decay channel (tag bias). Main background source for this tagging algorithm originates from the $\phi \to K^+K^-$ and $\phi \to \pi^+\pi^-\pi^0$ decays giving a few percent contamination.

4. Conclusions and outlook

$K_{\rm S}$ tagging with $K_{\rm L}$ charged decay reconstruction applied together with the $K_{\rm L}$-crash algorithm can increase the statistics for $K_{\rm S}$ branching ratio measurements by a factor of 1.5, which is a significant improvement in view of rare $K_{\rm S}$ decays studies. However, further studies to reject residual contamination from $\phi \to K^+K^-$ are needed for full exploitation of the additional sample. In particular, the evaluation of the impact of tagging with $K_{\rm L}$ charged decay reconstruction on rare $K_{\rm S}$ decays measurements, such as the $K_{\rm S} \to \pi^0\pi^0\pi^0$ and $K_{\rm S} \to \pi^+\pi^-\pi^0$ decays is a first objective of these studies. Improved kaon identification techniques are also important in view of data which have been collected with the KLOE-2 apparatus equipped with the inner tracker [13], new scintillation calorimeters [14, 15] and tagging detectors for $\gamma\gamma$ physics [16, 17]. These measurements will allow to refine and extend the KLOE program on kaon physics and tests of fundamental symmetries as well as the quantum interferometry [18].

The author is grateful to Caterina Bloise for her valuable comments and corrections of the manuscript. This work was supported in part by the EU Integrated Infrastructure Initiative Hadron Physics Project under contract number RII3-CT-2004-506078; by the European Commission under the 7$^{\rm th}$ Framework Programme through the 'Research Infrastructures' action of the 'Capacities' Programme, Call: FP7-INFRASTRUCTURES-2008-1, Grant Agreement No. 227431; by the Polish National Science Centre through the Grants No. DEC-2011/03/N/ST2/02641, 2011/01/D/ST2/00748, 2011/03/

N/ST2/02652, 2013/08/M/ST2/00323, 2013/11/B/ST2/04245, and by the Foundation for Polish Science through the MPD programme and the project HOMING PLUS BIS/2011-4/3.

REFERENCES

[1] A. Di Domenico *et al.*, *J. Phys. Conf. Ser.* **171**, 012008 (2009).

[2] F. Bossi *et al.*, *Riv. Nuovo Cim.* **31**, 531 (2008).

[3] S. Sinibaldi, T. Spadaro, KLOE Memo, 146, 1998.

[4] F. Archilli, Ph.D. Thesis, University of Rome "Tor Vergata", 2011.

[5] M. Silarski, Ph.D. Thesis, Jagiellonian University, 2012 [`arXiv:1302.4427 [hep-ex]`].

[6] F. Ambrosino *et al.*, *Phys. Lett.* **B672**, 203 (2009).

[7] D. Babusci *et al.*, *Phys. Lett.* **B723**, 54 (2013).

[8] F. Ambrosino *et al.*, *J. High Energy Phys.* **0805**, 051 (2008).

[9] F. Ambrosino *et al.*, *Phys. Lett.* **B636**, 173 (2006).

[10] F. Ambrosino *et al.*, *Phys. Lett.* **B619**, 61 (2005).

[11] S.N. Gninenko, `arXiv:1409.2288 [hep-ph]`.

[12] G. Venanzoni, KLOE Memo, 160, 1998.

[13] A. Balla *et al.*, *JINST* **9**, C01014 (2014).

[14] F. Happacher *et al.*, *Nucl. Phys. B Proc. Suppl.* **197**, 215 (2009).

[15] M. Cordelli *et al.*, *Nucl. Instrum. Methods* **A617**, 105 (2010).

[16] D. Babusci *et al.*, *Nucl. Instrum. Methods* **A617**, 81 (2010).

[17] F. Archilli *et al.*, *Nucl. Instrum. Methods* **A617**, 266 (2010).

[18] G. Amelino-Camelia *et al.*, *Eur. Phys. J.* **C68**, 619 (2010).