KTAG: The Kaon Identification Detector for CERN Experiment NA62

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Abstract

In the study of ultra-rare kaon decays, CERN experiment NA62 exploits an unseparated monochromatic (75 GeV/c) beam of charged particles of flux 800 MHz, of which 50 MHz are K^+. Kaons are identified with more than 95% efficiency, a time resolution of better than 100 ps, and misidentification of less than 10^{-4} using KTAG, a differential, ring-focussed, Cherenkov detector. KTAG utilises 8 sets of 48 Hamamatsu PMTs, of which 32 are of type 9880 and 16 of type 7400, with signals fed directly to the differential inputs of NINO front-end boards and thence to TDC cards within the TEL62 system. Leading and trailing edges of the PMT signal are digitised, enabling slewing corrections to be made, and a mean hit rate of 5 MHz per PMT is supported. The electronics is housed within a cooled and insulated Faraday cage with environmental monitoring capabilities.

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1. Introduction

CERN experiment NA62 is dedicated to the study of ultra-rare decays of the K^+ in the pursuit of physics effects beyond the standard model (SM). The flagship decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ has a branching fraction (BF) predicted to be $\sim 10^{-10}$ with an uncertainty of less than 10% [1], [2] and the collaboration will identify more than 100 such decays during data-taking in 2015 – 2017. In order to reduce background below 10% of the signal, NA62 uses low-mass tracking detectors, which enable tight kinematic constraints, hermetic photon vetoes, hadronic and muon calorimeters, a ring-imaging Cherenkov Detector [RICH] to discriminate decay pions from muons and timestamp them, and KTAG to identify and timestamp the parent K^+ forming $\sim$ 6% of the 800 MHz unseparated beam. The momentum and angles of the K^+ are measured to high precision (0.2% and 20 μrad, respectively) by the Gigatracker (GTK) consisting of 3 planes of pixel detectors separated by pairs of dipole magnets. A timing resolution of $<$ 100 ps for both KTAG and RICH reduces considerably the background from overlapping beam particles, while high efficiency ($>$ 95%) for detecting kaons, together with low misidentification ($< 10^{-4}$) of pions also enables KTAG to remove the background from beam-gas interactions.

2. Design and Operation of KTAG

KTAG (Figure 1) utilises the ring-imaging optics, gas volume (1.1 m^3 of N_2 at 1.74 bar) and variable optical diaphragm of the CERN CEDAR-W detector [3]. Its design requires the beam particles to be parallel to the optical axis of CEDAR and this requires both the beam to be highly parallel ($<$ 100μrad) and CEDAR to be aligned parallel to the beam with similar angular accuracy. Cherenkov light exits CEDAR through 8 quartz windows, is focused onto 8 spherical mirrors and reflected radially outwards into 8 Light boxes enclosed in an insulated, cooled, Faraday enclosure flushed with N_2. The entrance to each box is a light guide consisting of a matrix of closely spaced, conic sections cut into an aluminium plate forming a spherical section with centre of curvature at the virtual focus of the Cherenkov light. The interior of each cone is lined with aluminized Mylar, and 48 Hamamatsu PMTs [32 R9880 and 16 R7400] are set into the outer curved surface of the light guide to mate precisely with the cones. A blue LED coupled to 8 optical fibres illuminates the spherical mirrors, and hence the 8 sets of PMTs, and is used to test the complete chain of readout electronics independently of a particle beam. Additionally, the LED enables long-term monitoring of the performance of the PMTs and optics with a view to fault diagnosis and the measurement of any degradation in performance.

Differential signals from the anode and last cathode of each PMT are read into front-end boards consisting of a mother board with 64 analogue differential inputs and outputs, an ELMB for remote control and services, and 8 mezzanines each with a NINO ASIC. The LVDS outputs feed into a 128-channel TDC board enabling the times of leading and trailing edges of the signal to be measured and thereby enabling slewing corrections to be implemented. Figure 2 shows the reconstructed hit-time distribution, with the improvement in PMT resolution to 300 ps as T_0 and slewing corrections are implemented. Further details of the electronics are given in [4]. On average, 20 photo-electrons are detected per kaon with an average rate of 4 MHz/PMT and a kaon timestamp of $\sim$ 70 ps. The detection efficiency of KTAG was measured using identified K^+ decays to $\pi^+\pi^0$ during autumn 2014 and found to exceed 95% when requiring Cherenkov light in coincidence from at least 4 octants,

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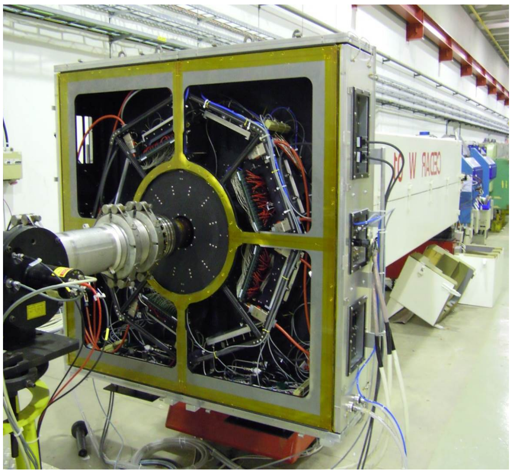

Figure 1: KTAG installed on the NA62 beamline.

in agreement with MC simulations.

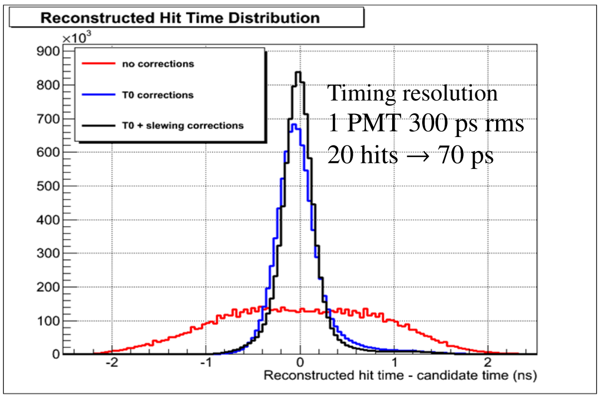

Figure 2: Reconstructed PMT-hit time-distributions.

The discriminatory power against pions of KTAG is shown in Figure 3, where the number of entries is displayed as a function of gas pressure in CEDAR for hits recorded in at least N octants. For fewer than 3 coincident octants the kaon signal is overwhelmed by light leaking into the detector from pions, but for N ≥ 4 clear separation of the pion, kaon and proton peaks is observed. As expected, without KTAG a large amount of non-kaon background data is recorded, which is then removed as KTAG is incorporated into the trigger. Figure 4 shows an example, using minimum bias data, of the relative purity of kaon decay channels to $\mu^+\nu$, $\pi^+\pi^0$, and $\pi^+\pi^+\pi^-$ when the angle between the K^+ and π^+ is plotted as a function of the π^+ momentum for K^+ beam particles selected by KTAG. During the 2014 pilot run KTAG was not included in the trigger and this selection was made offline, but KTAG has now been included in the level-1 trigger for 2015 (and subsequent) data taking, which will improve the trigger efficiency by a factor of ∼ 2.

3. Conclusion

The design and operation of KTAG has been described in the context of the CERN NA62 experiment searching for ultra-rare kaon decays, and evidence presented to show the functionality of KTAG. In particular, charged kaons are identified with more than 95% efficiency, a time resolution of better than 100 ps, and misidentification of less than 10^{-4}

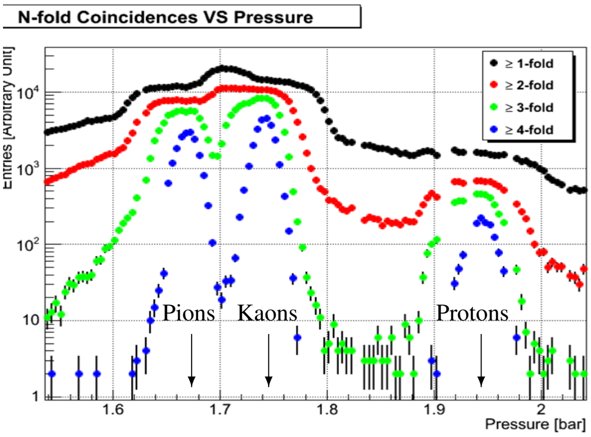

Figure 3: Number of entries as a function of CEDAR pressure for hits recorded in at least N octants. Pion, kaon and proton peaks are clearly visible for $N = 4$.

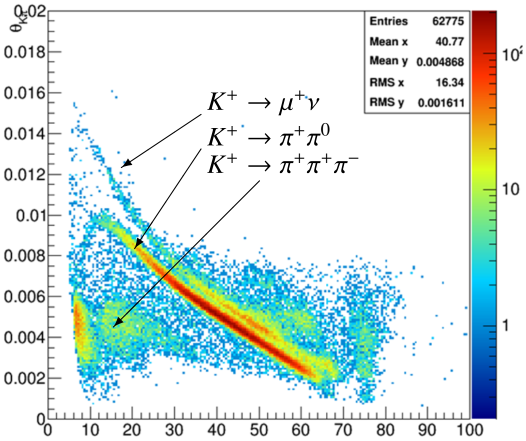

Figure 4: Angle (rad) between the K^+ and π^+ vs π^+ momentum (GeV/c) for K^+ selected by KTAG.

Acknowledgments

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