The Kaon identification system of the NA62 experiment

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Abstract. The main goal of the NA62 experiment at the CERN SPS is to measure the branching ratio of the ultra-rare $K^+ \to \pi^+ \nu\overline{\nu}$ decay with 10 % accuracy. This can be achieved by detecting about 100 Standard Model events with 10% background in 2 - 3 years of data taking. NA62 is exposed to a 750 MHz high-energy unseparated charged hadron beam, with a 6 % kaons component, and uses kaon decay-in-flight technique. Precise timing matching of the incident kaon and of the downstream charged track is essential to reject accidental coincidences when working in such a high rate environment. This is achieved by the kaon tagging system KTAG, which identifies kaons with an efficiency higher than 95 % and provides precise time information with a resolution better than 100 ps. KTAG re-uses the Cherenkov radiator and optics of a CEDAR, a ring-focusing Cherenkov detector designed for MHz beam intensity in the 1970s. To reach the required performance, KTAG is equipped with new photon detectors, electronics readout, mechanics, cooling and safety systems.

1. The NA62 CERN Experiment

The NA62 experiment is located at CERN in the North Area and uses the primary 400 GeV proton beam from the SPS to produce a secondary unseparated charged hadron beam. The beam line layout and the detector setup have been optimized to study $K^+ \to \pi^+ \nu\overline{\nu}$ decays [1] based on decay-in-flight technique of high momentum (75 GeV/c) kaons. To reach a sensitivity to branching ratio of $\mathcal{O}(10^{-10})$, the rate of kaons decaying must be $\sim$5 MHz. As only 10 % of the kaons decay in the 65 m fiducial region between the upstream and downstream detectors, a 50 MHz beam of K^+ is required. It is obtained with the secondary beam from the SPS which has a rate of 750 MHz, and consists of 6 % K^+, 24 % p, 70 % π^+. It is therefore essential to provide an accurate timing ($\sim$ 100 ps) of the incoming kaon to precisely match the particles from the decay, and to avoid wrong association below the 1% level. To identify $K^+ \to \pi^+ \nu\overline{\nu}$ signal events and suppress background, NA62 uses techniques based on kinematic properties and particle identification. To reduce the background due to neutral pions (π^0 decaying to photons) and muons in the final state, hermetic coverage enables vetoing of photons and muons. Details about the already achieved performance and sensitivity can be found in [2]. In 2012, a technical run was carried out to study the performances of NA62 sub-detectors and finalize their design, in particular these of KTAG [3]. A pilot run took place in autumn 2014 to commission the sub-detectors and readout system. KTAG was fully commissioned and its performance found to

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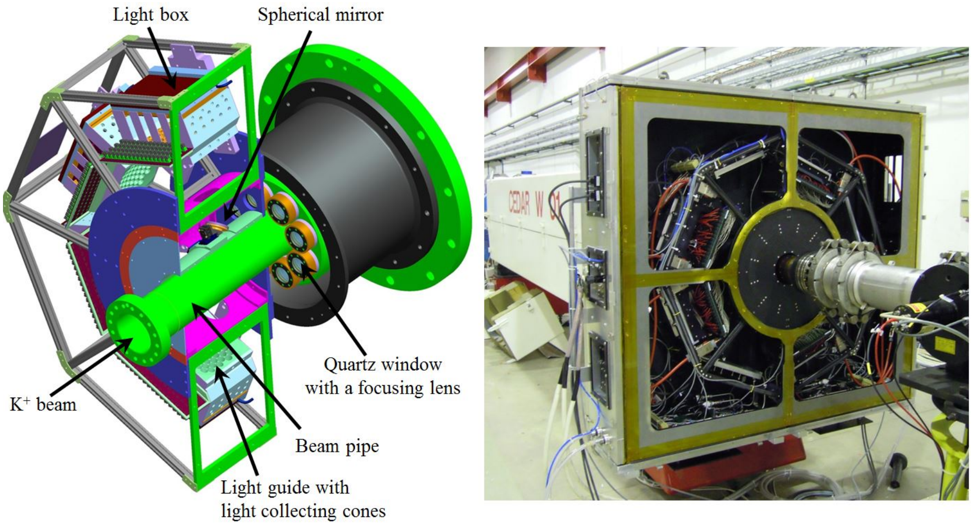

Figure 1. Left: Drawing showing the upstream part of the CEDAR and the KTAG photon detection system. Right: KTAG and CEDAR installed in the NA62 beam line during the 2012 test run.

meet the design requirements. In June 2015, NA62 began to take physics data, and will continue throughout 2018.

2. The Kaon identification system (KTAG)

The Kaon identification system (Figure 1) is instrumental in suppressing the accidental non-kaon background and defines a precise event timestamp with an accuracy better than 100 ps. KTAG identifies the 50 MHz of K^+ within the 750 MHz unseparated beam.

KTAG is based on a ring-focusing Cherenkov counter (CEDAR for Cherenkov Detector with Achromatic Ring focus [4]) equipped with new photon detectors and read-out system. This counter is optimized to detect Cherenkov light emitted by charged particles traveling together in a parallel beam, with an internal optical system focusing the light in concentric rings on the photon detector plane (Figure 2-left). Proper operation requires the intrinsic beam divergence not to exceed 70 μrad in each transverse direction to the beam axis. The pressure of the radiator gas is then used to distinguish the particles of different velocities and so discriminate between kaons, pions and protons, as shown in Figure 2-right.

The Cherenkov light produced in the gas is reflected by a mirror, passes through a corrector lens and finally through a diaphragm. The lens corrects for the optical dispersion in the N_2 gas and ensures that the Cherenkov light, emitted at all wavelengths, arrives at the same radius on the diaphragm plane. The aperture of the diaphragm is adjusted to detect light emitted by particles, as selected by the chosen gas pressure. As a consequence, photons emitted by other particles hit the diaphragm at a different radius and do not illuminate the PMTs. The pressure scan highlighting the kaon operation pressure is shown in Figure 2-right: the optimal N_2 gas pressure is 1.74 bar to select 75 GeV/c kaons. After the diaphragm, the light passes through additional lenses and light guides to finally reach eight light-boxes where the photon detectors (PMT) are located. These PMTs are hosted in an insulated, cooled Faraday enclosure flushed with N_2. Each box contains 48 Hamamatsu PMTS (32 of R9880 type and 16 of R7400 type). The rate of photons on each PMT is reduced to 5 MHz while PMT signals are read out and digitized in dedicated front end electronic boards, enabling KTAG to handle the high beam flux.

Data recorded in 2014–2015 have been analyzed to assess performance of KTAG. This

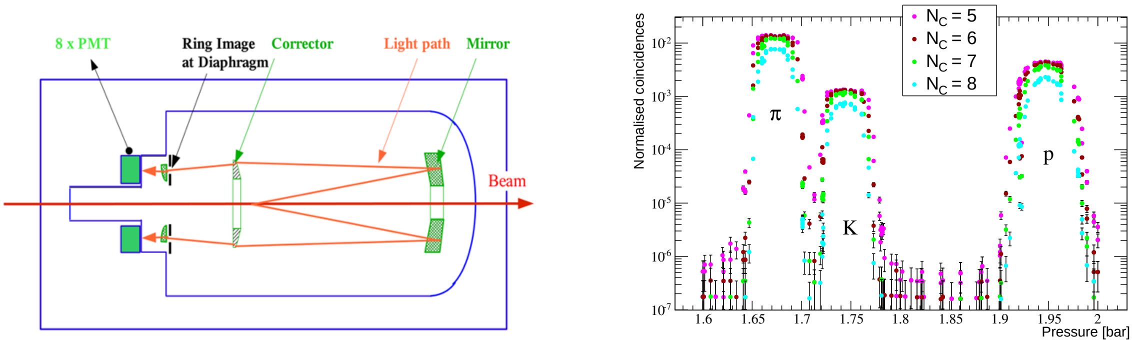

Figure 2. Left: Schematic view of the light path in the CEDAR counter. Right: Result of a pressure scan of the N_2 gas radiator showing the separation between K^+, π^+, p.

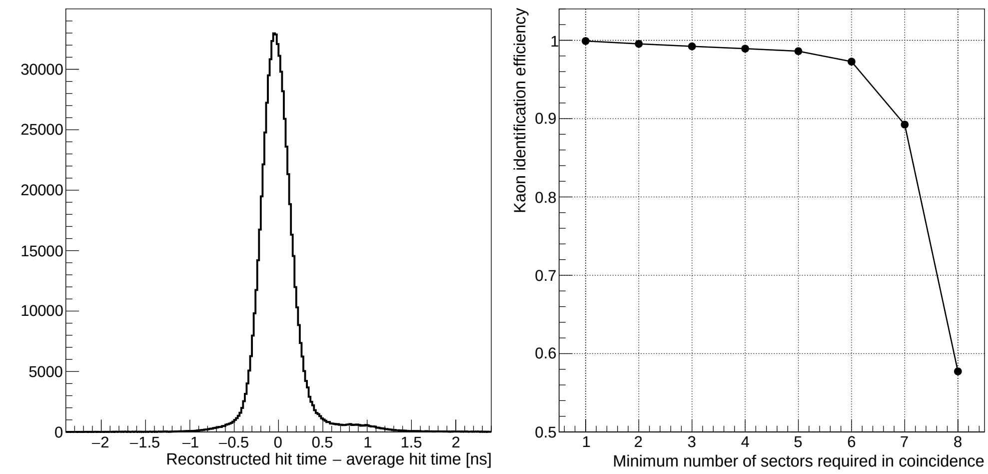

Figure 3. KTAG performance: (Left) Time resolution of a single PMT. (Right) Kaon tagging efficiency as a function of the number of sectors in coincidence.

evaluation uses $K^+ \to \pi^+\pi^0$ decays reconstructed from kinematic properties only. The time resolution of a single PMT signal is 280 ps(Figure 3-left), achieving a time resolution of about 70 ps when collecting 20 photons per kaon, which is significantly better than the design expectations. The K^+ is identified requiring at least 5 (of the 8) sectors in coincidence to remove background from π^+, as shown in Figure 3-right. The efficiency is approximately 99 % while the probability of misidentifying a pion as a kaon while operating at the kaon pressure is estimated to be of $\mathcal{O}(10^{-4})$.

In conclusion, the performance of the KTAG kaon tagger has been estimated and meets the requirements of the NA62 experiment.

References

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