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Kaon identification in the NA62 experiment at CERN

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Summary. — The NA62 experiment at the CERN SPS aims to collect about 100 events of the rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$, with a signal-to-background ratio of 10/1. The main purpose is the measurement of the branching ratio of the decay with a 10% accuracy. NA62 will use a high-energy unseparated charged beam, with a kaon decay-in-flight technique. For the kaon identification a hydrogen gas-filled differential Cherenkov counter (CEDAR) is placed in the incoming beam. The CEDAR detector is required to achieve a kaon identification efficiency of at least 95% with a time resolution of about 100 ps.

PACS 13.25.Es – Decays of K mesons.
PACS 29.40.Ka – Cherenkov detectors.
PACS 29.40.Cs – Gas-filled counters: ionization chambers, proportional, and avalanche counters.
PACS 41.60.Bq – Cherenkov radiation.

1. – The NA62 experiment at CERN SPS

The NA62 (North Area 62) experiment [1] at the CERN SPS is designed to use rare kaon decays to probe physics Beyond the Standard Model in a manner complementary to the programme of direct searches for the Higgs boson and other potential new particles at the LHC. The main goal of NA62 is the measurement of the Branching Ratio (BR) of the decay $K^+ \to \pi^+\nu\bar{\nu}$ with a 10% accuracy. The branching ratio can be computed with minimal theoretical uncertainty and is related to the CKM matrix element V_{td}. The Standard Model prediction is $BR(K^+ \to \pi^+\nu\bar{\nu}) = (0.85 \pm 0.07) \times 10^{-10}$ [2]. The measured value is based on 7 events from the E787/949 experiments at BNL [3]: $1.73^{+1.15}_{-1.05} \times 10^{-10}$. To provide a significative test of new physics scenarios, as well as an estimation of V_{td}, the NA62 experiment aims to collect about 100 events of the rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$, keeping the background contamination lower than 10%, in two years of data taking starting after LHC shutdown in 2013.

2. – The kaon identification detector

NA62 will use 400 GeV/c protons from the SPS to produce a 75 GeV/c secondary kaon beam. A challenge arising from kaons produced in this way is that pions and protons cannot be separated efficiently from kaons at the beam level: upstream detectors, which tag the kaons and measure their momentum and direction, are then exposed to a particle flux about 17 times larger than the useful (kaon) one. A critical aspect is to make a positive identification of the $\sim 6\%$ of kaons in the high-rate beam environment before they decay. This will be achieved by placing a *ChErenkov Differential counter with Achromatic Ring focus* (CEDAR) in the incoming beam; the CEDAR is insensitive to pions and protons with minimal accidental mistagging. The counter was built in the 70s to be used with the SPS secondary beams [4]. An upgraded version has been proposed to positively tag incident kaons with an average rate of 50 MHz. It uses hydrogen instead of helium as radiator to reduce the beam scattering in the gas and it is equipped with new photon detectors (PMTs) and readout electronics. The CEDAR detector is required to achieve a kaon identification efficiency of at least 95%. In addition, a time resolution of ~ 100 ps, in conjuction with timing information from other detectors, is necessary to reconstruct the $K^+ \to \pi^+ \nu\bar{\nu}$ decay and ensure the rejection of the background due to the accidental overlap of events in the NA62 detector.

The Cherenkov light produced in the gas is reflected by a Mangin mirror via a chromatic corrector lens through a diaphragm, and via condenser lenses onto eight optical ports (light spots) where the PMTs are located. The high rate of kaons (~ 50 MHz) results in an illumination of $\sim 10^9$ Cherenkov photons per second at each light spot. Moreover, photons are not uniformly distributed resulting in more critical high photon density regions. The upgraded CEDAR version being considered has eight additional mirrors used to reflect photons from the light spots on eight PMT planes. The achieved enlarged and uniform photon distributions are collected by tiling several PMTs together. This configuration allows to reduce the photon flux at the single device and to keep the PMT anode current within a safe limit. The technology under discussion consists of metal package photomultipliers of the HAMAMATSU [5] R7400 series, U-03 (UV glass window) type, which were chosen for their compactness, speed and relative cheapness. PMTs are rated at a maximum anode current in the region of $100\,\mu$A and a gain in the region of 10^6. Because they have a relatively small active area, a very careful design of optics and light collection cones is required to reduce the effect of dead areas.

The photon rate on single PMT (~ 5 MHZ) implies several limitations on the performances of the photon detection involving event pile-up, electronics dead time and smearing effects on the readout system. Several inefficiencies can thus decrease the number of detected Cherenkov photons per kaon. A Monte Carlo simulation has been developed to study all these effects and to evaluate the final number of hit light spots and detected photons per kaon. The simulation results show that a number of ~ 250 PMTs is necessary to optimize the CEDAR photon detector performances and to get the required kaon identification efficiency ($\geq 95\%$) and time resolution (~ 100 ps).

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