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The large-angle photon veto detector system for the NA62 experiment at CERN

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ABSTRACT

The goal of the NA62 experiment is to collect about 80 $K^+\rightarrow\pi^+\nu\overline{\nu}$ events with a S/B ratio of $\sim 10:1$. The branching ratio (BR) for this decay is $\sim 10^{-10}$ and can be predicted in the Standard Model with minimal theoretical uncertainties, making it a sensitive probe for new physics. Measurement of this BR is challenging because of the background from dominant channels. To reduce background from $K^+\rightarrow\pi^+\pi^0$ decays (BR=21%) to an acceptable level, the π^0 must be detected with an inefficiency of less than 10^{-8}. NA62 will make use of the existing NA48 beam-line and liquid-krypton calorimeter. A new photon veto system consisting of 12 rings placed along the vacuum volume is needed to detect large-angle photons (7–50 mrad) with an inefficiency below 10^{-4} over the energy interval from a few hundred MeV to 35 GeV. A comprehensive R&D program was carried out in 2007–2008 to compare different detector technologies, including the re-use of lead-glass blocks from the OPAL barrel calorimeter, ultimately demonstrating the feasibility of this approach. In 2009, a complete prototype of one veto ring was constructed, complete with front-end electronics to measure energies through time-over-threshold with a dynamic range of 1000, and an in situ calibration and monitoring system. The prototype was successfully tested with electron and muon beams at the CERN SPS in fall 2009. The status of the project and present preliminary results from the recent tests will be reviewed.

1. Introduction

The CERN NA62 experiment [1] aims at collecting about 80 $K^+\rightarrow\pi^+\nu\overline{\nu}$ events in two years of data-taking, keeping the background by at least a factor of 10 below the signal. For this purpose, a very intense hadron beam of 75 GeV/c momentum, with 6% of Kaons, will be produced by 400 GeV/c protons slowly extracted from the SPS. The 10 MHz of kaon decays along the 120 m fiducial volume (in vacuum) will be detected by a series of detectors. The design of the experiment has been optimized for providing kinematical rejection of the backgrounds and particle identification.

In particular, in order to keep the $K^+\rightarrow\pi^+\pi^0$ background (BR = 21%) at the level of 10^{-12}, only a factor of $\sim 10^{-4}$ is achieved by kinematical cuts on the parent K^+ and the daughter π^+ tracks, so that the π^0 must be detected with an inefficiency below a few 10^{-8}. The two γ's from the π^0 decay will be detected by the NA48-legacy quasi-homogenous liquid-Krypton (LKr) calorimeter in the intermediate angular range and by a set of 12 veto stations placed all along the decay region for large angle γ's (large angle vetoes, LAV), as shown in the schematic layout in Fig. 1. Hermeticity will be ensured for photons inside the LKr hole by additional photon detectors after the primary beam-sweeping magnet.

In order to match the requirements, the LAV stations should detect photons above 200 MeV and up to several tens of GeV, in the $8.5\leq\theta\leq 50$ mrad range, with an inefficiency below 10^{-4}, providing a time-stamp with a resolution of ~ 1 ns and a measurement of the deposited energy of about 10%. In order to make use of beam-halo muons for calibration and efficiency studies, the detector should be sensitive to minimum ionizing particles (MIP). Finally, in order to be integrated in the decay region tank, the detectors should be capable of operation in vacuum (10^{-6} mbar in the region of the spectrometer).

2. LAV design and assembly

For the 12 LAV stations, three possible options were tested by the collaboration: lead/scintillating fibers, annular-shaped detectors, inspired by the KLOE calorimeter; rings of lead/scintillating tiles modules, read out radially by wave-length shifting fibers; rings of crystals from the OPAL experiment calorimeters, re-arranged in radial arrays. After extensive tests, all three choices

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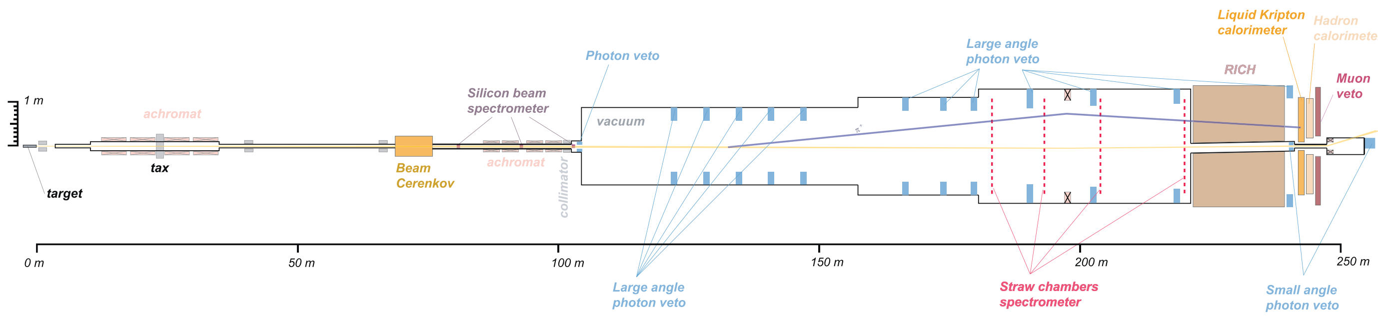

Fig. 1. Schematic layout of the NA62 experiment. The 12 LAV stations all along the decay vacuum tube are shown.

Fig. 2. LAV station assembly phases (from top-left): cabling of PMT, wrapping of crystals, mounting of four-crystals brackets, fixing of brackets inside the steel cylinder, routing of cables to vacuum flange ports.

were found to match the 10^{-4} inefficiency requirement and the OPAL-crystals solution has been selected. Details on prototypes studies can be found in Refs. [2,3].

Counters will be mounted in each ring with a radial orientation. As the inner radius of curvature of the blocks is not matched to the radius of the rings, several layers of blocks will be used. As an example, the first five rings, with an inner radius of 53 cm, will be composed of five layers, 32 blocks each. Each layer is shifted by a fifth of the angle between two blocks in order to have complete hermeticity: at least three blocks ($20X_0$) are crossed by each impinging particle.

The crystals are fixed to aluminum support structures in groups of four, forming azimuth segments which are then fixed to the inner surface of a stainless-steel cylinder to form the five layers of crystals, protruding towards the center of the cylinder. The steel cylinders will be inserted into the main tank of NA62 to form the 120 m long vacuum decay volume.

Every crystal has its own photomultiplier, Hamamatsu R2238, which has to operate in vacuum, and an optical connector for the connection of a LED light source, for calibration and monitoring purposes. The analog signals from the photomultipliers are connected to vacuum feed-throughs housed on flanges (ISO K200) on the cylindrical vessel through coaxial cables.

In Fig. 2 all the steps of the assembly of one veto ring are shown: each lead-glass crystal is wrapped using 0.2 mm thick DuPont Tyvek pre-cut sheets, in order to increase light collection; then crystals are mounted in groups of four in the support brackets; after having routed HV and signal cabling to the PMTs, the support brackets are placed and fixed to the inner surface of the ring vessel (with the cylinder held in vertical position) and the cables are routed to the portholes of flanges. Once the mounting of crystals is completed, the vessel is rotated by 90° and vacuum and electrical tests are performed.

3. LAV electronics

This wide photon energy range, together with the necessity of detecting muon signals, requires operating the R2238 PMT at a gain of order 10^6. The average photoelectron yield of the crystals is 0.3 p.e./MeV. This translates in a 4.5 pC charge for a MIP, corresponding to a signal amplitude of $20\,\text{mV}/50\,\Omega$. On the upper part of the range, signals from 20 GeV showers can reach an amplitude of $10\,\text{V}/\Omega$. Such a signal range would be outside the possibilities of commonly used ADC chips, whose dynamic range is at most 50. On the other hand, the range of a typical amplifier–shaper–discriminator chain is of order 10.

In selecting the readout scheme, the cost and data through-put must also be considered. Moreover, since we should build a veto system, a simple and robust solution is desirable. Since the requirement of signals as high as a few volts rules out most commonly used ASICs produced for HEP applications, our idea is to use commercial amplifier and comparator circuits to produce a digital output signal with time duration equal to that of the analog input (time-over-threshold), exploiting the advantage of