The Ring Imaging Cherenkov Detector of the NA62 Experiment

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The NA62 experiment is designed to measure the branching ratio of the decay $K^+ \to \pi^+ \nu \overline{\nu}$ with a 10% accuracy at the CERN SPS. To suppress the main background coming from the $K^+ \to \mu^+ \nu$ decay, a Ring Imaging Cherenkov detector (RICH), able to separate π and μ in the momentum range between 15 and 35 GeV/c with a muon contamination in a pion sample $< 10^{-2}$ is needed. The RICH must also have an unprecedented time resolution (100 ps) to disentangle accidental time associations of beam particles with pions. The last updates of the detector layout are presented along with the results of the beam tests of the RICH prototype: the muon misidentification probability was found to be 0.7% and the time resolution $<$ 100 ps in all the momentum range.

Keywords: PID; RICH; timing; kaon rare decays

1. The NA62 experiment

NA62 is a fixed target experiment which aims at measuring the branching ratio of the $K^+ \to \pi^+ \nu \overline{\nu}$ decay with a precision of 10% by collecting $\mathcal{O}(100)$ signal events with a signal to background ratio $S/B \approx 10$ in two years of data taking.[1] The contributions to this process due to the Standard Model are extremely suppressed and can be calculated with excellent precision ($BR_{SM} = (7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$) .[2] This makes the decay a favoured place to look for possible new physics. The measurement is experimentally challenging and its present value, $(1.73^{+1.15}_{-1.05}) \times 10^{-10}$, has an uncertainty of more than 50%.[3]

A 75 GeV/c momentum beam derived from a flux of 400 GeV/c protons hitting a Be target is employed. 6% of particles are kaons, the rest are pions and protons. The NA62 detector (Fig. 1) is described elsewhere.[4] An incoming kaon and an outgoing pion in time with the incoming kaon are the signal signature. To match the downstream track to the correct

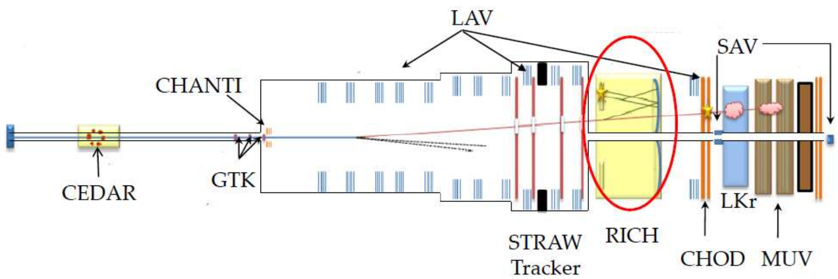


Fig. 1. The NA62 layout

kaon the time of both the upstream and downstream tracks need to be measured at 100 ps level. The main background, due to the $K^+ \to \mu^+\nu$ decay where the muon is misidentified as a pion, requires a 10^{12} rejection factor. According to MC simulation, with a kinematical cut and a muon veto system a total 10^{10} suppression factor can be achieved. Thereby, a Ring Imaging Cherenkov detector (RICH) must provide a further rejection of at least 10^2.

2. RICH

The RICH (Fig. 2) is composed of a 18 m long cylindrical vessel filled with neon at atmospheric pressure. Two semispherical mirrors are placed at the downstream end of the vessel. The Cherenkov photons are reflected on two focal regions equipped with $\sim$ 1000 photomultiplier tubes (PMTs) each. Since the area to be covered by each mirror is very large, a mosaic of smaller segments is used.

2.1. *Vessel and radiator*

The vessel is a vacuum proof segmented tube with a diameter varying from 4 to 3.4 m. No gas recirculation and purification system is foreseen. Since the momentum range over which π and μ must be identified goes from 15 to 35 GeV/c, neon gas at roughly atmospheric pressure is chosen as radiator ($(n-1) = 63.7 \times 10^{-6}$ at $\lambda = 300$ nm and 20° C; $p_{th} = 12.3$ GeV/c for π).

2.2. *Mirrors*

A mosaic of 20 mirrors with a focal length of 17 m is used, 18 hexagonal and 2 semi-hexagonal. The mirrors are made of a 2.5 cm thick glass substrate

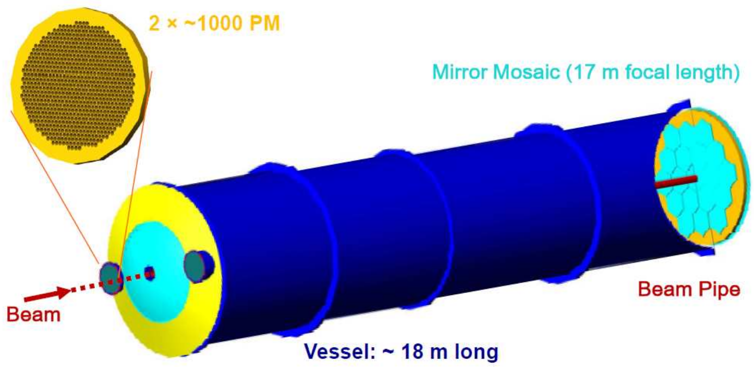


Fig. 2. The RICH detector

coated with aluminium. Each mirror must be supported and adjustable for alignment. A dowel with a spherical head is inserted in the hole drilled on the not-reflecting surface and used to sustain the mirror. Two actuating ribbons give the horizontal and vertical alignment. Piezo motors, located out of the acceptance, are used to pull the ribbons. An aluminium honeycomb structure, 5 mm thick, has been chosen as mirror support structure to minimize the material in front of the electromagnetic calorimeter.

2.3. *Photon Detection*

The best compromise between fast response, small dimensions and cost seems to be the PMT Hamamatsu R7400U-03. It has a good response up to the near ultraviolet (185 nm) with a peak quantum efficiency of $\sim 20\%$ at 420 nm. The PMT will be operating at 900 V with a gain of $\sim 1.5 \times 10^6$. The transit time jitter is 280 ps (FWHM). To convey the Cherenkov light to the active area of the PMT a Winston cone[5] covered with an aluminized mylar foil is used. The PMTs are separated from the neon by 1 mm thick quartz windows and are mounted on an external aluminium window. A cooling system is required to avoid a local heat source on the radiator due to the power dissipation of the PMT HV divider.

To exploit the fast PMT response, the NINO[6] ASIC was chosen as discriminator. To match the optimal NINO performance region, the PMT output is sent to a current amplifier with a differential output. The readout system relies on HPTDCs embedded in a TEL62 board, which is a development of the TELL1 board designed for the LHCb experiment.[7]

3. RICH prototype

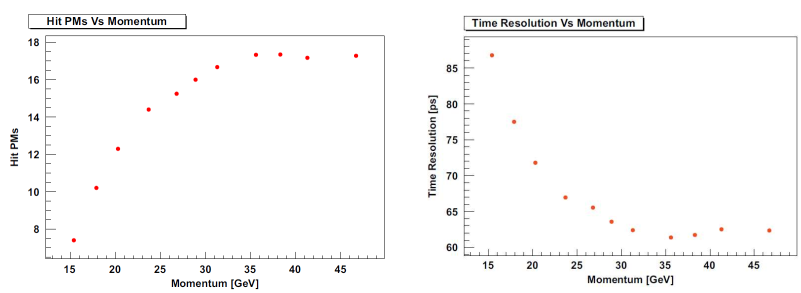
A RICH prototype was built and tested. A stainless steel vessel, vacuum resistant, 18 m long but with a diameter of 60 cm, has been placed along the K12 beam line in the SPS North Area and a single spherical mirror, 2.5 cm thick and with a focal length of 17 m, has been used.

3.1. *2007 test beam*

A first test was performed in October 2007 to measure the average number of hit PMTs and the event time resolution. The RICH prototype was exposed to a 200 GeV/c momentum negative beam composed mainly of pions. The detector was equipped with a limited number of PMTs (96) placed in the region where the Cherenkov ring of a 200 GeV/c pion was expected. The average number of hit PMTs per event was found to be 17 and the RMS of the average event time was measured to be ~ 70 ps.[8]

3.2. *2009 test beam*

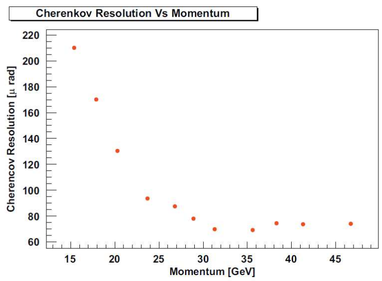
The RICH prototype was tested again in May-June 2009.[9] The improvements with respect to the previous test were: the larger number of PMTs (414), a new readout electronics based on the TELL1 board and a water cooling system. Positive hadron beams with different momenta in the 10 to 75 GeV/c range were used.



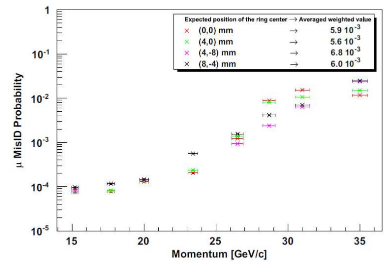
(a) Average number of hit PMTs for a single ring as a function of the momentum. (b) Time resolution as a function of the momentum.

Fig. 3.

The number of hit PMTs per ring as a function of the momentum is presented in Fig. 3(a). Figure 3(b) shows the event time resolution: a value



(a) Cherenkov angle resolution as a function of the momentum



(b) Muon misidentification probability measured for 4 alignment positions of the mirror as a function of the momentum.

Fig. 4.

below 100 ps has been measured over the momentum range of interest. The Cherenkov angle resolution (Fig. 4(a)) decreases to a constant value of about 70 μrad for $\beta = 1$ particles. The π/μ separation in the momentum range 15-35 GeV/c was also measured. Figure 4(b) shows the muon misidentification probability as a function of the particle momentum, measured for four different positions of the mirror with respect to the beam line. The overall integral of the measurements gives a muon misidentification probability of $< 0.7\%$.

4. Conclusions

The design parameters of the NA62 RICH have been validated by the results of the beam tests performed in 2007 and 2009. The project matches the requirements expected for the NA62 experiment. The final detector is under construction and the first physical run is foreseen in Spring 2014.

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