# The NA62 RICH detector

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The NA62 experiment at CERN aims at measuring the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$ with a 10% accuracy; the main background is $K^+ \to \mu^+\nu$ which is suppressed by means of kinematical cuts and by the different stopping power of $\mu^+$ and $\pi^+$. A further 0.5% $\mu^+$ suppression must be provided by a RICH detector in a momentum range between 15 and 35 GeV/c. In this paper a RICH filled with Neon at atmospheric pressure contained in a 17 m long, 3 m wide vessel and in which the Cherenkov light is readout by 2000 single-anode photomultipliers, will be described. The results of a test beam performed with a prototype will be presented.

## 1. INTRODUCTION

The CERN NA62 experiment [1] aims at measuring the branching ratio of the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$ with a 10% accuracy. The main background is $K^+ \to \mu^+\nu$ which must be suppressed by a factor $4\times10^{-13}$: this goal can be accomplished by a combination of kinematical cuts and by pion-muon separation. According to the MC simulation of the experiment, a kinematical suppression of $8 \times 10^{-6}$ can be reached. A muon rejection factor of $10^{-5}$ can be achieved exploiting the different penetration probability through matter of the two particles. A further $5 \times 10^{-3}$ suppression factor can be provided by a Ring Imaging CHerenkov (RICH) detector.

The momentum range over which pions and muons must be identified by the RICH is between 15 and 35 GeV/c; the best pion-muon separation is achieved when the lowest accepted momentum is close to the Cherenkov threshold. As full efficiency is achieved only at a momentum about 20% higher than the threshold, the latter has to be 12.5 GeV/c for a pion, i.e. the index of refraction $n$ must be such that $(n-1) \approx 60 \times 10^{-6}$. Neon gas at roughly atmospheric pressure fulfills this requirement and also guarantees a small dispersion [2]. On the other hand, the tiny $(n-1)$ implies a small number of emitted Cherenkov photons per unit length and therefore a long radiator is mandatory. A 10 m long Neon RICH was built and operated by the SELEX experiment [3] and a longer one was proposed by the CKM collaboration [4]. The available space for the RICH in the NA62 experiment setup is about 18 m: a detector of about this size is foreseen.

In a RICH detector [5] the Cherenkov light, emitted at an angle $\theta_c$ by a charged particle of velocity $\beta c$ larger than the speed of light in the crossed medium $(c/n)$, is imaged by means of a spherical mirror onto a ring on its focal plane. The ring radius $r$ is related to the Cherenkov angle as $\theta_c = r/f$ for small $n$ (as it is the case for gas radiators), where $f$ is the mirror focal length. The relation between Cherenkov angle and momentum $p$ of a charged particle of mass $m$ is given by:

$$\theta_c^2 = \theta_{c\,\mathrm{MAX}}^2 - m^2c^2/\left(m^2c^2 + p^2\right) \qquad (1)$$

where $\theta_{c\,\mathrm{MAX}} = \sqrt{2(n-1)}$ is the Cherenkov angle for $\beta = 1$. The $\theta_c$ resolution must be better than 80 $\mu$rad in order to achieve the requested pion-muon separation.

Besides pion-muon separation, the NA62 RICH detector must fulfill two other very important tasks: provide the time of pion crossing with 100 ps resolution (in order to suppress accidental coincidences with an upstream beam detector) and give the level-zero trigger for a charged particle. These further requirements led to the choice of fast single-anode photomultipliers with a small size in order to match both the Cherenkov angle and the time resolution constraints.

## 2. THE APPARATUS

### 2.1. The Vessel

The available space in the NA62 setup is about 18 m for the RICH. A cylindrical vessel (divided in at least 3 sections) about 17 m long and at least 3 m wide has been foreseen; the Neon will be at roughly atmospheric pressure so that the vessel should not be vacuum certified. The entrance and exit windows of the vessel should be relatively light and a thin aluminum flange is the main option. The undecayed particle beam will cross the vessel passing through a beam pipe recuperated from the old NA48 spectrometer; the pipe has a 158 mm external diameter.

### 2.2. The Mirrors

The Cherenkov light emitted by a charged particle entering the RICH vessel will be reflected by a mosaic of mirrors placed at the downstream end of the detector. The mirrors will have a 17 m focal length and they will be made by 2.5 cm thick glass; the mirrors transverse dimension will depend on the quality guaranteed by the manufacturer: present options are 1 m wide mirrors (8 in total) or 70 cm wide (20 in total). The mirrors will be shaped as regular hexagons but the two central ones which will have a half-hexagonal shape with a hole for the beam pipe passage. All the mirrors will be aluminized to improve the light reflectivity and coated with one or more thin dielectric layers to avoid oxidation. The requested optical quality is very high with a $D_0$ (the diameter of the smallest spot image of a point source, placed in the mirror curvature center, where 95% of the light is collected) smaller than 4 mm. The Cherenkov light reflected by the mirrors will be imaged upstream in the focal plane: in order to avoid the beam pipe shadow, half of the mirrors will point to the left of the pipe and half to the right. The alignment of the mirrors will be achieved by means of remotely controlled piezo-actuators.

### 2.3. The light collection

The Cherenkov light reflected by the mirrors will be collected by means of Winston cones [6] covered with a thin mylar foil; the truncated cones will be 18 mm wide on the largest base and 7.5 mm wide on the smallest one, 22 mm high; a 1 mm thick quartz window placed on the small base will isolate the vessel filled with Neon from the photomultipliers placed in air. The Winston cones will be drilled on a stainless steel flange in a honeycomb geometry of 18 mm side.

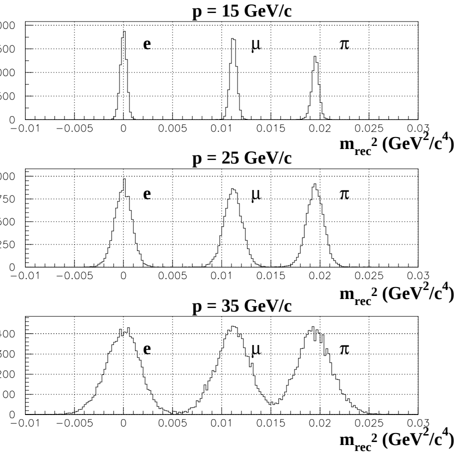


Figure 1. The NA62 RICH simulation. Reconstructed squared mass for three different momenta, with the particle velocity measured by the RICH and the momentum measured by other detectors. The different particle species are indicated

### 2.4. The Photomultipliers

About 2000 Photomultipliers, placed in two spots to avoid the beam pipe shadow, are necessary. The Hamamatsu [7] R7400U-03 metal-package PM has been chosen for its fastness (280 ps FWHM transit time jitter), small dimension (16 mm wide with an active diameter of 8 mm) and relative cheapness; thanks to the UV-glass window and bialkali cathode the PM has good response up to the near ultraviolet with a peak quantum efficiency of about 20% at 420 nm. The PM will be operated at about 900 V negative voltage.

### 2.5. The Readout

A fast readout is needed to profit of the PM characteristics. The PM output signal will be amplified and then sent to the NINO ASIC [8] working in Time-over-Threshold mode providing a fast LVDS signal sent to a HPTDC mounted on a TELL1 multipurpose board.

## 3. THE SIMULATION

A fast simulation was developed taking into account the proper generation of Cherenkov photons, the geometry of the mirror and the photomultiplier performances. The fast simulation has been cross-checked by a full GEANT4 Montecarlo [9]. The main results of the simulation are the expected number of fired PM per event (about 23 for $\beta = 1$ particle), the Cherenkov angle resolution (about 65 $\mu$rad for a pion at 35 GeV/c momentum) and a total muon suppression in the pion sample of $1.3 \times 10^{-3}$ (integrated between 15 and 35 GeV/c momentum).

In fig. 1 some results of the simulation are shown: the particle reconstructed mass, calculated by the measured Cherenkov angle and using the momentum information from the magnetic spectrometer of the experiment, is shown for three different particle momenta: the good separation between electrons, muons and pions is shown; at 35 GeV/c momentum the pion-muon separation is still quite good.

## 4. THE RICH PROTOTYPE

A RICH prototype was built and tested at CERN in October 2007. A stainless steel vessel, 17 m long and 60 cm wide (divided in 5 sections) and vacuum resistant, was placed in the NA62 cavern. A 50 cm wide, 2.5 cm thick mirror, with a focal length of 17 m, built by Marcon [10], was used; this mirror was of high optical quality with a $D_0$ of 0.4 mm. The vessel was evacuated, then filled with nitrogen for cleaning, again evacuated and finally filled with Neon at 980 mbar. The mirror was placed at the downstream end of the vessel, mounted on a support structure which could be oriented in two axis by means of two remotely controlled step motors and closed with

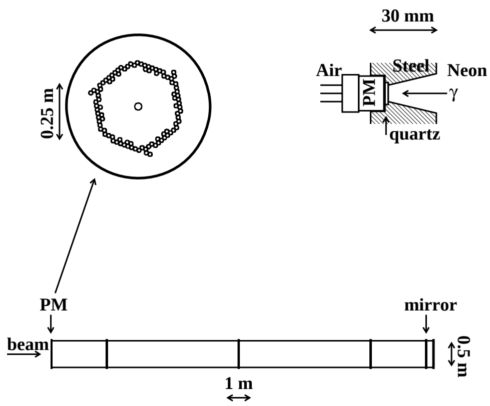


Figure 2. The RICH prototype setup. At the bottom a side view of the prototype is shown; a front view of the upstream endcap is shown on the top left; a detail of the upstream endcap cut, together with a photomultiplier, is shown on the top right. The scales are different in each picture, as indicated; in the bottom plot the horizontal and vertical scales are also different.

a stainless steel flange 30 mm thick. At the upstream end a stainless steel flange, again 30 mm thick, was placed and properly drilled to accomodate 96 PM of Hamamatsu R7400 U03 and U06 type (see fig. 2).

Each PM was separated from the Neon by a 1 mm thick quartz window; a Winston cone, covered with a thin mylar foil, was used to convey the light to each PM, as it is foreseen for the final detector. The PMs were placed where the Cherenkov ring of a 200 GeV/c pion beam was expected, at an interdistance of 18 mm.

In a test performed in the 2006 fall, using a CEDAR detector, Hamamatsu PM R7400 of type U03, U04 and U06 were tested and U04 type turned out to be too inefficient for the experiment needs; the 2007 test beam pointed to the choice of U03 because U06 has a larger cost, worse time resolution and didn't provide a sensible higher num-

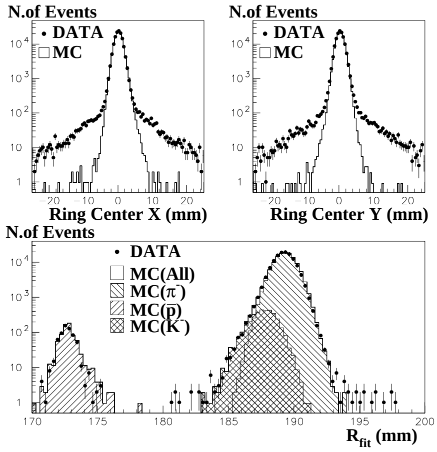


Figure 3. Top left: fitted ring center (x coordinate); top right: fitted ring center (y coordinate); bottom: fitted ring radius (a 3 mm cut on the ring center, both in x and y, was applied). Data and Montecarlo are shown.

ber of photoelectrons.

The RICH prototype was exposed to a 200 GeV/c momentum negative beam, composed mainly of pions, between the end of October 2007 and the first two weeks of November 2007. The data analysis was completed and confirmed the expectations: an event time resolution better than 100 ps, a Cherenkov ring resolution better than 60 $\mu$rad and an average number of 17 fired PM per event. A paper on the prototype construction and results has been published [11]. A comparison of the agreement between data and Montecarlo is shown in fig. 3

In 2009 a further test beam with the same prototype is foreseen, adapting the upstream flange to accomodate 414 PM; a beam of various momenta will be used to check the separation of various particles species as a function of momentum.

## CONCLUSIONS

The NA62 experiment needs a very demanding RICH detector for pion-muon separation and for precise time measurement. A valuable project has been developed, matching the experiment requirements. A full longitudinal scale prototype, equipped with 96 PM was built and tested, confirming the expectations; an improved version, with 414 PM is expected to be tested in 2009.

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