

The RICH Detector of the NA62 experiment at CERN

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The RICH Detector of the NA62 experiment at CERN

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Abstract. The Ring Imaging Cherenkov (RICH) detector of the NA62 experiment at CERN is a key element for particle identification. This paper describes the detector design and some measurements of its performance obtained from the analysis of the data collected so far by NA62. The results fully match the detector requirements.

1. Introduction

The NA62 experiment [1] is the latest generation kaon experiment at the CERN SPS, exploiting an intense beam of charged kaons. It aims to measure the Branching Ratio (BR) of the golden $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ ultra-rare decay with a 10% precision. This process is highly suppressed in the Standard Model (SM): the BR prediction is of the order of 10^{-10} with minimal theoretical uncertainty [2]. Only one measurement is available so far, compatible with the SM within a large uncertainty [3]. As a result, the precision measurement of the BR will be a remarkable achievement for the SM flavour sector.

The most challenging aspect of the NA62 experiment is the suppression of decay channels with BR up to 10 orders of magnitude higher than the signal and similar experimental signature, such as the main background mode $K^+ \rightarrow \pi^+ \nu$, with BR = 63.55%. To this purpose a high kinematic rejection power, an effective π and γ reduction and very good particle identification (PID) are required. The Ring Imaging Cherenkov detector (RICH) is a key element of PID in NA62. Its purposes are: to identify pions from muons in the momentum range 15 to 35 GeV/c with a muon suppression factor better than 10^2 ; to provide precise measurements of the Cherenkov angle and of the pion crossing time, below 100 ps, to minimize wrong matching with the parent particle; to provide a fast signal to the trigger system. The NA62 detector³ was commissioned in 2014 and 2015. The experiment has been taking data since 2015 and will run until the year 2018. The RICH performance has been studied in detail and some results will be described in this paper.

2. The NA62 RICH detector design

The NA62 RICH consists of a steel vacuum-tight cylindrical vessel around 17.5 m long, constructed from 4 longitudinal sections with decreasing diameter (4 to 3.4 m) enclosing a central beam pipe. The vessel is filled with about 200 m³ of Neon gas slightly above atmospheric pressure, suitable as radiator medium thanks to appropriate refractive index, good light transmission and minimal chromatic

² On behalf of the RICH Working Group of the NA62 experiment: Anzivino G, Aisa D, Barbanera M, Bizzarri M, Bizzeti A, Bucci F, Campeggi C, Cenci P, Checucci B, Ciaranfi R, Duk V, Iacopini E, Imbergamo E, Latino G, Lenti M, Lollini R, Pepe M, Piccini M, Piluso A, Volpe R.

³ The NA62 detector details can be found in <http://na62.web.cern.ch/NA62/Documents/TechnicalDesign.html>.



dispersion. Gas recirculation is not required. Due to the low emission rate of Cherenkov photons per unit length in Neon, the RICH exploits the maximum space available along the NA62 beam line. Hamamatsu R7400-U03 PM have been chosen to collect the Cherenkov light due to their compactness and excellent timing properties. Figure 1 shows the RICH vessel with the two aluminium flanges that each hold ~ 1000 photomultipliers (PM) and are outside the detector acceptance, and the mirror layout.

The mirror system consists of a mosaic made of 18 spherical mirror segments with a 35 cm side hexagonal shape and two semi-hexagonal mirrors at the RICH center to fit the beam pipe. The mosaic covers a surface of about 3 m in diameter. Each mirror segment consists of a 2.5 cm thick glass with 17 m focal length, coated with aluminium that is protected with a thin dielectric film to provide the suitable optical quality. The mirror support panel consists of two halves of aluminium honeycomb. Each mirror segment is suspended with a dowel inserted in the back and oriented to point toward the two PM flanges in order to avoid the beam pipe shadow on the reflected Cherenkov photons. High precision piezo-motors, out of the detector acceptance, pull two thin aluminum ribbons installed at ± 45 degree with respect to the vertical direction, providing an independent two-axis alignment for each mirror. A third ribbon prevents on-axis rotations. A laser system is used for the initial mirror alignment, performed with the vessel open. Individual mirror positions are monitored during the data taking and corrected via software or adjusted remotely with piezo-motors. Thin entrance and exit beam windows, made of an aluminium alloy, minimize the material thickness in the decay volume. The mirror installation, with details of the movement system, is illustrated in figure 1 (right).

The PM signals feed custom-made current amplifiers with differential output. Customized front-end boards use the NINO ASIC chip [4] as discriminator operating in time-over-threshold mode, with LVDS output and about 50 ps intrinsic time resolution. The RICH exploits an integrated trigger and data acquisition system developed to read-out most of the NA62 detector subsystems. The key element is the FPGA-based TEL62 board [5] which houses four custom-made TDC boards (TDCB), with 512 channels in total. The TDCB sends the signal leading and trailing times to the TEL62 processors, which buffer data, produce trigger primitives in parallel with the read-out and send them to the Level 0 (L0) trigger processor. A three-level trigger system reduces the detector rate in the decay region from order of 10 MHz to few kHz. The RICH signals are well suited to be used as reference time and to select charged particles in the NA62 trigger system. A fast selection based on PM hit multiplicity is exploited by the L0 trigger processor. A selection based on multi-ring reconstruction can be implemented at higher trigger levels to increase the NA62 background rejection power.

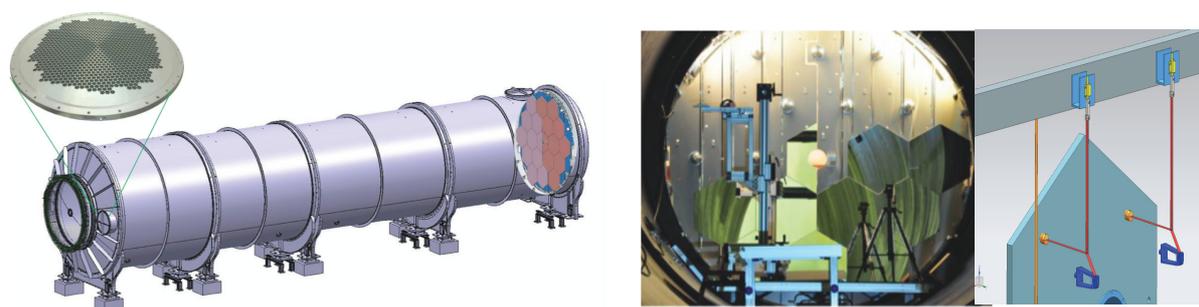


Figure 1. Left: Schematic drawing of the NA62 RICH detector showing vessel, PM assembly and mirror layout. Right: the installation of the mirror system and a detail of the mirror movement system.

3. The NA62 RICH Performance

A full-length RICH prototype was built and tested with hadron beams at CERN in 2007 and 2009 to demonstrate the performance of the proposed layout [6][7]. The construction was completed by mid-2014 and the detector, commissioned in 2014 and 2015, is successfully working since then.

The RICH time resolution has been first measured in 2014 with charged pion samples from the $K^+ \rightarrow \pi^+ \pi^0$ decay mode. The hits of a Cherenkov ring have been split into two halves to compute the

average time of each group. The RICH intrinsic time resolution is given by the difference of those average times. The distribution, shown in figure 2 (left), has a sigma width of 140 ps, resulting in an event time resolution of about 70 ps. This result has been confirmed with the 2015 and 2016 data.

In the 2016 run the complete mirror alignment has been accomplished for the first time after a special maintenance intervention operated during the winter shutdown. This maintenance aimed to restore the proper operation of the mirror movement system after repairing the small amount of damage suffered during the detector installation. All the mirrors were first individually aligned with a laser when the vessel was open. The alignment has been later fine-tuned with particle data by piezo-motor remote adjustment getting a mirror orientation within ± 60 μ rad with respect to the reference semi-hexagonal mirrors.

The PID performance of the RICH has been assessed with the physics data collected by NA62 in 2015. The Cherenkov ring radius has been reconstructed from the hit information and the center of the rings has been compared to the extrapolated track position measured with the spectrometer. In this way different particle types have been well identified, as clearly seen in figure 2 (center), illustrating the ring radius as a function of the particle momentum. Positrons, muons, pions and a kaon component coming from beam particles scattered in the upstream beam tracker can be clearly distinguished in different bands.

In order to separate charged pions from muons a cut on the reconstructed squared mass m^2 is used. The mass is defined using the track momentum p and some RICH information as $m^2 \approx p^2(\theta_{max}^2 - \theta_c^2)$, where θ_{max} is the maximum Cherenkov angle and θ_c the Cherenkov angle measured by the fitted ring radius divided by the mirror focal length. The pion identification efficiency as a function of the muon misidentification probability has been measured by selecting clean pion and muon samples and scanning over the cut on m^2 . The preliminary result obtained with the 2016 data is shown in figure 2 (right): a pion identification efficiency of 90% corresponds to some 0.8% muon misidentification probability. This result improves the previous measurement done in 2015 due to the better alignment of the mirror system achieved after the special maintenance intervention of the winter shutdown.

The performance of the RICH detector measured with the data collected so far by the NA62 experiment matches the expectations and meets the main detector requirements: time resolution better than 100 ps and a 90% pion identification efficiency for about 1% muon misidentification probability.

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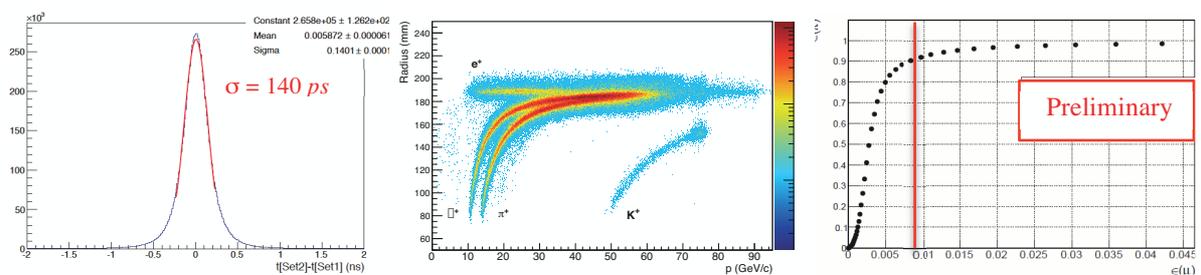


Figure 2. The RICH performance. Left: difference between the average times of the hits of two halves of a Cherenkov ring. Center: the Cherenkov ring radius as a function of the particle momentum. Different particle types are clearly identified. Right: Pion identification efficiency (a line is drawn at 90% value) versus muon misidentification probability (preliminary result, 2016 data).