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The NA62 RICH detector

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Summary. — The NA62 experiment is designed to measure the very rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$ at the CERN SPS with a 10% accuracy. The Standard Model prediction for the branching ratio is $(8.5\pm0.7)\times10^{-11}$. One of the challenging aspects of the experiment is the suppression of the $K^+ \to \mu^+\nu_\mu$ background at the 10^{-12} level. To satisfy this requirement a Ring Imaging Cherenkov Detector (RICH), able to separate $\pi^\pm$ from $\mu^\pm$ in the momentum range between 15 and 35 GeV/c, with a μ misidentification probability better than 10^{-2}, is needed. The RICH must also have a time resolution of about 100 ps to disentangle accidental time associations of beam particles with pions. The RICH will have a very long focal length (17 m) and will be filled with Ne gas at atmospheric pressure. Two tests beam were held at CERN in 2007 and 2009 with a RICH prototype. The results of the two tests beam will be presented: the μ misidentification probability is found to be about 0.7% and the time resolution better than 100 ps in the whole momentum range.

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1. – Introduction

The NA62 experiment [1,2], at present under construction, is a new generation, fixed-target, experiment which will study the kaon physics starting from an extracted beam of 400 GeV protons from the SPS (Super Proton Synchrotron).

The main goal of the experiment is the measurement of the Branching Ratio (BR) of the decay $K^+ \to \pi^+\nu\bar{\nu}$ ($\approx 10^{-10}$). This particular channel was chosen because it is theoretically very clean, due to the fact that the hadronic part of the decay can be related, by an isospin rotation, with the very well measured BR ($K^+ \to \pi^0 e^+\nu$). Moreover this decay is sensitive to physics beyond the Standard Model.

Given the very small value of the BR, the main problem is to suppress the background in such a way that the ratio between signal and background is more than 10:1. The two main channels of background are the decays $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu_\mu$, with a BR of about 21% and 63%, respectively. To reach the background suppression request a kinematical cut and a good PID (Particle IDentification) are needed together. In particular the kinematical cut is on the missing mass variable, defined as $m^2_{\rm miss} = (P_K - P_\pi)^2$, where P_K is the kaon momentum and P_π the pion one.

For what concerns the $K^+ \to \mu^+\nu_\mu$ rejection, in addition to the kinematical cut, a system of muon veto is used. These two requests, however, are not sufficient to suppress the background under the 10% level, so a RICH detector with a μ misidentification probability better than 10^{-2} is needed. Moreover, for the kinematical cut, it is very important to associate the charged track after the decay region with the right K^+ and so a time resolution better than 100 ps for the RICH is also required.

2. – The NA62 RICH detector

The NA62 RICH detector is made by a vessel, 17 m long and with a diameter of about 4 m, filled with gas neon at atmospheric pressure and room temperature. A mirror mosaic is located at the downstream side of the vessel to reflect the Cherenkov light backward in two regions (to avoid the beam pipe shadow) equipped with about 1000 PMs each.

The mirror mosaic is composed by 18 mirrors with a hexagonal shape and two with a semihexagonal shape and a hole for the beam pipe. The mirrors are spherical, with a nominal radius of curvature of 34 m (17 m of focal length), made by a glass substrate, 2.5 cm thick, aluminized and coated with a thin dielectric film. In the wavelength range between 195 and 650 nm the average reflectivity is better than 90% and the optical goodness parameter D_0, defined as the diameter of the smallest image of a point source placed in the center of curvature which contains the 95% of the light, is less than 4 mm. For the mirrors alignment piezo actuators will be used.

To collect the Cherenkov light reflected by the mirrors Hamamatsu R7400 U03 Photomultipliers (PMs) are used. Such PMs have an UV glass entrance window, with a diameter of 16 mm (8 mm is the diameter of the active area) and the sensitivity range of wavelength is from 185 to 650 nm, with a peak sensitivity at 420 nm. The PMs will operate at 900 V where the gain is of $\sim 1.5 \times 10^6$. To increase the active area Winston Cones (18 mm wide) covered with aluminized Mylar foils will be used in front of the PMs. A 1 mm thick quartz window will separate the area filled with neon from the PMs.

The output of the PMs has a roughly triangular shape with a rise time of 0.78 ns on average and a fall time about twice this. The signal is amplified by a custom made preamplifier and discriminated by the NINO ASIC [3] fast Time-over-Threshold discriminator (intrinsic resolution of 50 ps). The LVDS output is sent to a TDC board developed by INFN Pisa (TEL62) and exploiting the CERN HPTDC.

3. – Tests beam

In order to better understand the characteristics of the RICH, two tests beam were held at CERN in 2007 [4] and 2009 [5] with two different prototypes.

The 2007 test beam was performed, in the first place, to measure the time resolution and the average number of hit PMs per event. The prototype was made by a stainless-steel vessel 17 m long and with a diameter of 60 cm filled with neon at atmospheric pressure. At the downstream side of the vessel a circular spherical mirror was placed, while at the upstream one a flange with 96 PMs was located.

The results of this test beam are in agreement with what was expected from the Monte Carlo simulations. In particular, the time resolution, $\Delta t \approx 70$ ps, fullfills the experiment requirements and a resolution on the Cherenkov angle, $\Delta\theta_C \approx 50\,\mu$rad, is also found.

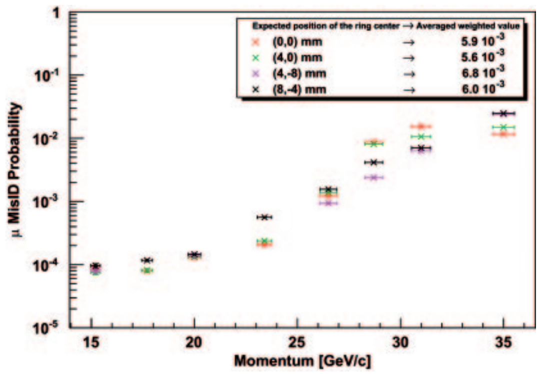

Fig. 1. – The μ suppression factor.

In the 2009 an improved version of the prototype was built: 414 PMs were placed in the flange to cover completely the acceptance region for the Cherenkov light. A cooling system, for the PMs region, and a new readout were also developed. The main purpose of this test beam was to measure the rejection factor for μ. The results show a good agreement with the Monte Carlo expectations: the average number of hit PMs, for a single ring, as a function of the momentum is $N_{\text{PM}} \approx 8$ for pions at 15 GeV$/c$, $N_{\text{PM}} \approx 17$ for pions at 35 GeV$/c$ and $N_{\text{PM}} \approx 20$ for particles at $\beta = 1$; the time and the Cherenkov angular resolutions results, for all the momentum region, fulfill the requirement for the NA62 RICH detector and are compatible with those of the 2007 test beam.

Finally in fig. 1 the probability to identify a muon as a pion, for 4 different alignment positions of the mirrors is depicted: we obtained a μ misidentification probability equal or better than 10^{-2} depending from pion momentum.

4. – Conclusion

A very demanding RICH is needed for the NA62 experiment. The result obtained on time and Cherenkov angle resolution and on π-μ separation from the test beams of the protoypes performed on 2007 and 2009 fulfill the design requirements.

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