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The RICH detector of NA62

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Summary. — NA62 is a high-energy physics experiment located at the CERN SPS. NA62 aims at measuring the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$ with a 10% precision. The $K^+ \to \mu^+\nu$ decay is the main background which needs to be suppressed by a factor 2×10^{12}. This goal can be achieved by kinematical cuts, different stopping power of μ^+/π^+ and a RICH detector able to measure particles velocity in a momentum range between 15 and 35 GeV/c. Moreover, the RICH detector measures the pion crossing time with a resolution of 100 ps and produces the L0 trigger for a charged track. In this paper the NA62 RICH will be described, and the preliminar results regarding pion/muon separation in the 2015 data taking will be presented.

1. – The NA62 experiment

The NA62 experiment is intended to measure the branching ratio of the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$ with a 10% accuracy, collecting ~ 40 events/year [1]. The branching ratio can be evaluated with great precision and the currently predicted value is $BR_{\mathrm{th}}(K^+ \to \pi^+\nu\bar{\nu}) = (9.11 \pm 0.72) \times 10^{-11}$ [2]. Any significant deviation is a hint of new physics beyond the Standard Model. This branching ratio has been previously measured by the experiments E787 and E949 at the Brookhaven National Laboratory which collected 7 events and provided the value $BR_{\mathrm{exp}}(K^+ \to \pi^+\nu\bar{\nu}) = 1.73^{+1.15}_{-1.05} \times 10^{-10}$ [3]. To achieve a much better level of precision, NA62 uses a 75 GeV/c positively charged hadron beam at high intensity produced by 400 GeV/c SPS protons colliding with a beryllium target. The NA62 beam contains a 6% fraction of K^+.

The measurement of the aforementioned branching ratio is difficult not only because this decay has a very low probability, but also because its experimental signature consists of a charged track and nothing else, since the two neutrinos cannot be detected by the apparatus. As a consequence, the main source of background comes from the decay $K^+ \to \mu^+\nu_\mu$ (also known as $K_{\mu 2}$) whose branching ratio is (63.56 ± 0.11)%, about 10 orders of magnitude higher than the signal branching ratio. The background rejection relies on kinematic cuts, high-resolution timing, hermetic vetoing of photons and muons and particle identification (PID) of kaons, pions, muons, photons and electrons. In

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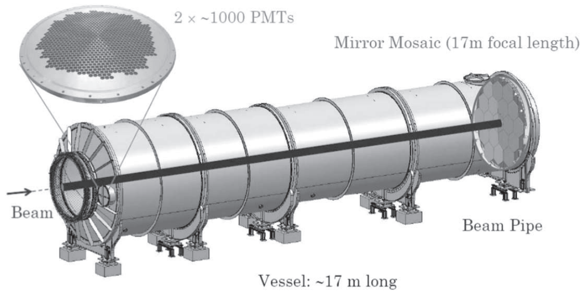


Fig. 1. – The NA62 RICH detector.

particular, a $K_{\mu 2}$ suppression factor of 10^5 can be reached from kinematic cuts. A muon veto system (MUV) provides an additional suppression factor of 10^5. A further 10^2 suppression is provided by the RICH detector [4].

2. – RICH detectors

RICH detectors are Cherenkov detectors widely used in High Energy Physics that determine the velocity of a charged particle by measuring the Cherenkov angle. In a RICH detector, a charged particle of velocity βc larger than the speed of light in the medium emits Cherenkov photons at an angle θ_c and a spherical mirror images the light onto a ring on its focal plane. The ring radius r is related to the Cherenkov angle by the equation $\tan\theta_c = r/f$, where f is the focal length. As far as the momentum p of the particle is known, a RICH detector allows to determine the mass m of the particle

$$mc = p\sqrt{n^2 \cos{\theta_c}^2 - 1}, \tag{1}$$

where n is the refractive index of the medium.

3. – The NA62 RICH detector

As stated above, NA62 needs a RICH detector to separate π^+ from μ^+ between 15 and 35 GeV/c, providing a misidentification probability lower than 10^{-2}. Moreover the RICH is needed to measure the π^+ crossing time with a resolution better than ~ 100 ps and to produce the L0 trigger for a charged track. A project is currently under way to use GPUs for recostructing Cherenkov rings in the L0 trigger [5].

Full efficiency for 15 GeV/c pions is achieved if the Cherenkov threshold momentum is about 20% smaller (12.5 GeV/c), so the refractive index n must be such that $(n-1) \simeq 62 \times 10^{-6}$. This leads to the choice of neon at about atmospheric pressure as radiating medium. In addition, neon has a good transparency in the visible and near UV, low chromatic dispersion, low atomic weight (to minimize the radiation length) and it is non-flammable. On the other hand, a small $(n-1)$ leads to a small number of emitted Cherenkov photons per unit length: for this reason a long radiator is required.

A schematic layout of the detector is shown in fig. 1. A cylindrical vessel, 17 m long and divided into four sections with decreasing diameter (4–3.4 m), is filled with 200 m^3 of neon slightly above the external atmospheric pressure.

A mosaic of 20 spherical mirrors (18 hexagonal mirrors and 2 semi-hexagonal ones, fig. 2) at the downstream end of the vessel images the Cherenkov cone into a ring on its

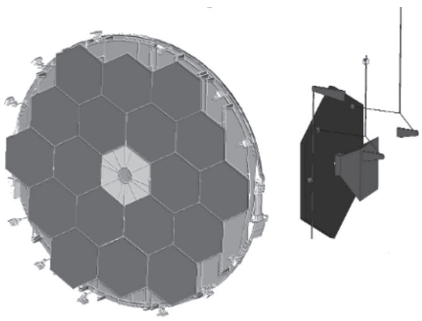
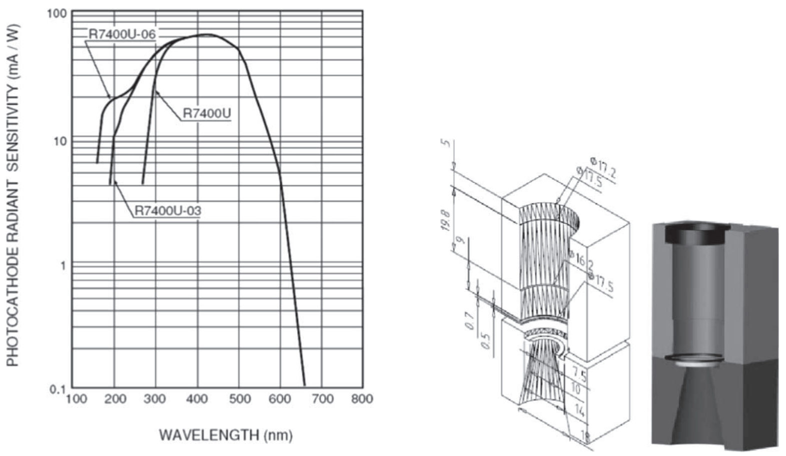


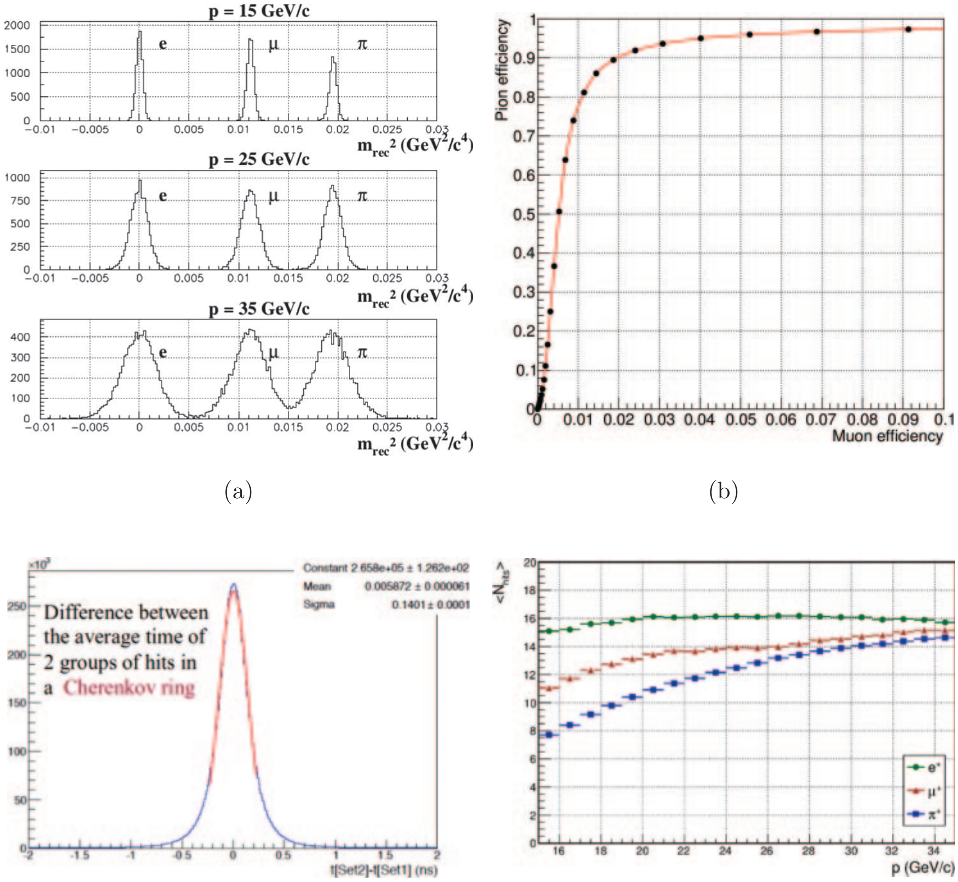
Fig. 2. – The mosaic of mirrors layout. The detail of the support for one mirror is shown.

focal plane. The mirrors have a (17 ± 0.1) m focal length and they are made of 2.5 cm thick glass coated with aluminium to improve the reflectivity. A thin dielectric layer is added to avoid oxidation. The mirrors have a hexagonal shape (35 cm side), except for the 2 central mirrors which have a semi-hexagonal shape with a hole for the beam pipe. The average reflectivity is $> 90\%$ in the wavelenght range between 195 and 650 nm. Each mirror has a 10 mm wide hole on the non-reflecting surface and an aluminium dowel is inserted in the hole to support the mirror. The dowel is connected to a support panel with an aluminium cone. Furthermore, the mirrors can be remotely oriented by means of piezoelectric actuators. The RICH detector is equipped with 1952 single anode R7400U-03 Hamamatsu photomultipliers, the best compromise among good quantum efficiency, fast response, small dimensions and cost. Figure 3(a) shows the spectral sensitivity of the PMT. An UV-glass entrance window and a bialkali cathode allow the PMT to be sensitive up to the near ultraviolet. The quantum efficiency has a peak of $\sim 20\%$ at



(a) (b)

Fig. 3. – (a) Spectral sensitivity as a function of incident light wavelength for different Hamamatsu R7400 photomultipliers. (b) Photomultiplier support structure. The upper flange holds the PMT, the bottom flange is located inside the radiator volume holding the Winston cone. A thin quartz window connects the flanges.



(a) (b)

(c) (d)

Fig. 4. – NA62 preliminary. (a) Squared reconstructed mass for three different momenta (Monte Carlo). The peaks corresponding to electrons, muons and pions are clearly visible. (b) Pion selection efficiency as a function of muon misidentification probability for charged track of momenta between 15 and 35 GeV/c in the 2015 data set. (c) Difference between the average time of two groups of hits in a Cherenkov ring. (d) Number of hits in the PMTs as a function of momentum for electrons, muons and pions.

420 nm. Each PMT is 16 mm wide, with an active diameter of 8 mm. They have 8 dynodes and they will be operated at $\sim$ 900 V negative voltage. The photomultipliers are distributed over two different disks ($\sim$ 1000 PMTs for each disk) on the focal plane of the mirrors: in fact, the mirror system is split in two halves, pointing to the PMT disks. This is needed to avoid the shadow of the beam pipe. The PMT are packed in a honeycomb structure with a minimum distance of 18 mm and their assembly consists of two flanges (fig. 3(b)): an aluminium flange holding the PMT outside the radiator volume and a flange facing the radiator volume with a Winston cone [6] which tunnels the light through a quartz window between the two flanges, separating the neon from the air.

The RICH detector collected data during 2014 and 2015 runs. In the next section, some preliminary results based on 2015 data are presented.

4. – RICH performances

As stated above, the main background is given by the $K_{\mu 2}$ decay and a suppression factor of 10^2 is provided by the RICH detector which should be able to separate pions from muons with a probability of misidentification smaller than 1%. In fact, as shown in fig. 4(a), π/μ identification is non-trivial at high momenta: the curves are partially overlapping, making it necessary to choose reconstructed mass selection cuts. Therefore it is necessary to determine the pion selection efficiency as a function of misidentification probability for different mass cuts. The results of this analysis are shown in fig. 4(b): in order to have a 1% misidentification probability, the pion selection efficiency must be about $\sim 77\%$. The pion efficiency is relatively lower than expected. This happens because some mirrors were not properly aligned and some piezoelectric actuators were malfunctioning during the 2015 run.

In addition to this analysis, other relevant variables of the RICH were determined. As is shown in fig. 4(c), the time resolution of detector is $0.5 \cdot \sigma = 70\,\text{ps}$, as good as expected. In fig. 4(d) the number of hits (*i.e.* fired PMT) per track as a function of momentum for different particles is shown.

5. – Conclusions

In the 2015 data taking the RICH behaved as expected. Time resolution and number of hits met the requirements. The pions selection efficiency is a bit low when the misidentification probability is in the order of 1%. However there is certainly room for improvement: after the 2015 data taking the RICH vessel was opened, the mirrors were re-aligned and the malfunctioning actuators were repaired, so it is expected to reach at least an 85%–90% efficiency during the 2016 run.

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