Particle identification with the NA62 RICH detector

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Abstract

NA62 is a new generation kaon experiment at the CERN SPS aiming at studying rare and forbidden decays. One of main challenges of the experiment is the suppression of background decay channels with branching ratios up to 10 orders of magnitude higher than the signal and with similar experimental signatures. To provide such suppression, a powerful particle identification (PID) is needed.

A key element of PID in NA62 is the Ring Imaging Cherenkov (RICH) detector. The RICH has successfully operated during the 2016–2018 data taking periods, being essential in the measurement of the branching ratio of the $K^+ \to \pi^+ \nu \bar{\nu}$ decay. The detector was also used for searches for lepton number violation in 3-track kaon decays. The results on the π/μ and π/e separation directly measured with the data for the aforementioned decays are presented.

Keywords: kaon decays, lepton flavor violation, RICH detector, detector performance, particle identification

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1. Introduction

The NA62 experiment is currently running at the CERN SPS and its main goal is the 10% precision measurement of the branching ratio (BR) of a rare decay $K^+ \to \pi^+ \nu \bar{\nu}$. Fig. 1 represents the experimental setup described in detail in [1].

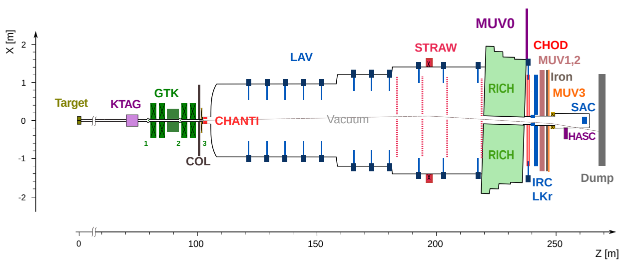

Figure 1: NA62 experimental setup. The beam goes in the positive Z direction. The positive direction of the Y axis is vertical.

The Ring Imaging CHerenkov detector (RICH) detector is crucial for identifying positively charged particles from kaon and pion decays. It also provides the reference time for the trigger system. The detailed description of the detector can be found in [2], the basic performance is measured using the data collected in 2016 [3]. The detector layout is shown in Fig. 2.

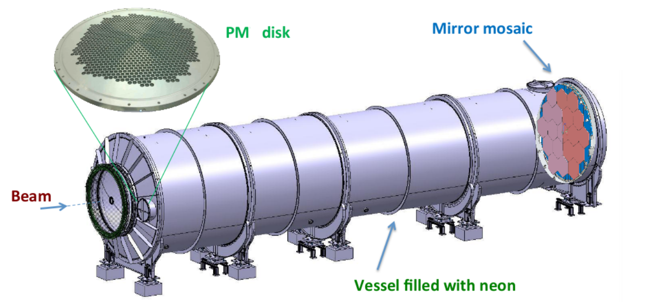

Figure 2: RICH detector. One of two photomultiplier disks is zoomed. The mirror group shown in dark pink reflects light towards the zoomed disk, while the other half shown in light pink is oriented towards the second disk.

The RICH mirror system is comprised of 20 mirrors with the focal length of 17 m: 18 hexagonal (350 mm side) and two semi-hexagonal in the central part. Mirrors are oriented by means of two stabilizing aluminium ribbons connected to the mirror at one end and to a piezo motor at the other end. To prevent the rotation around the longitudinal axis, a third anti-rotating ribbon is implemented. To avoid light loss due to interactions with the beam pipe, mirrors are divided in two groups each one having the same centre of curvature to the left and to the right of the beam pipe.

The Cherenkov light is focused on the focal plane where two photomultiplier (PM) disks are installed, 976 PMs per disk. Each PM is complemented by a Winston cone [4] to improve light collection. The PM disk location and size are optimized

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for rings from positively charged tracks.

2. Particle identification with the RICH

There are two methods for particle identification (PID) used for the data analysis. The first one is based on the ring radius measurement from the standalone ring fit complemented by the momentum measurement. Fig. 3 illustrates the separation between different particle types.

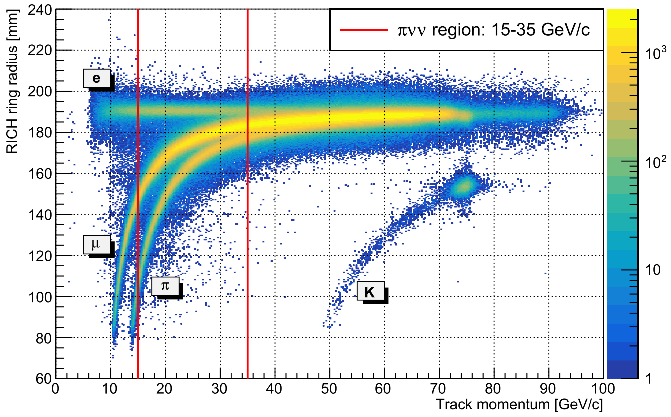

Figure 3: Ring radius as a function of the track momentum for the one track selection. Structures corresponding to positron, muon, pion and kaon are visible.

The following variable is used to discriminate between different particle types: $m^2_{RICH} = p^2 \times (\frac{F^2 n^2}{F^2+R^2} - 1)$. Here the ring radius R is measured by the RICH, the momentum p is provided by the spectrometer, $F = 17020$ mm is the focal length of RICH mirrors, n is the neon refractive index. The method can be used for single track final states.

The second method is based on likelihood calculation for several mass hypotheses (e, μ, π, K, background) and can be applied for any final state. The track slope measured by the spectrometer allows to predict the ring center coordinates and the expected radius is calculated from a mass hypothesis and the momentum. The identification can be done using the most likely hypothesis or by applying a cut on the likelihood ratio.

The general approach to the PID is data driven: the identification probabilities are measured as a function of momentum using control data samples and then applied as event weight to the Monte Carlo samples.

3. PID in the analysis of the $K^+ \to \pi^+ \nu\bar{\nu}$ decay

The $K^+ \to \pi^+ \nu\bar{\nu}$ decay was studied using 2016–2018 data [5]. Twenty candidates were observed in the signal region resulting in the 3.4σ significance evidence of the decay and the BR measurement: BR($K^+ \to \pi^+ \nu\bar{\nu}$) = $(10.6\ ^{+4.0}_{-3.4}|_{stat} \pm 0.9_{syst}) \times 10^{-11}$. One of the most important background processes is the $K^+ \to \mu^+ \nu_\mu$ decay with a muon misidentified as a pion. Given its high BR (63%), the suppression of the order of 10^{12} should be achieved. The kinematic selection and the calorimeter PID allow for the 10^9 rejection, the remaining factor of 10^3 is provided by the RICH using both methods described above.

The distributions of m_{RICH} for pions and muons obtained from dedicated control samples within the $K^+ \to \pi^+ \nu\bar{\nu}$ search and the cut value are shown in Fig. 4.

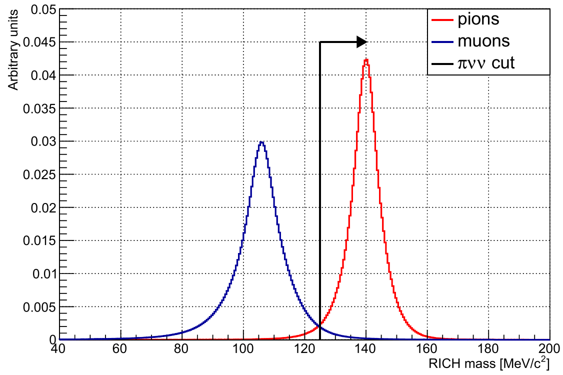

Figure 4: Distribution of m_{RICH} for muons (blue) and pions (red) for the one-track selection, the cut value is optimized for the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis.

Within the likelihood approach, all likelihoods are normalised to the most probably one and the cut is applied on the likelihood of the most probable non-pion hypothesis, see Fig. 5.

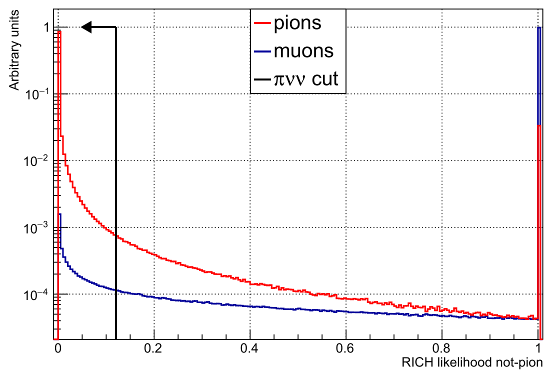

Figure 5: Distribution of the non-pion likelihood for muons (blue) and pions (red) for the one-track selection, the cut value is optimized for the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis.

The PID probabilities for the combination of both methods are shown in Fig. 6. The average pion efficiency for the $K^+ \to \pi^+ \nu\bar{\nu}$ selection is $\epsilon(\pi) \sim 85\%$ and the muon misID probability is $\epsilon(\mu) \sim 0.2\%$.

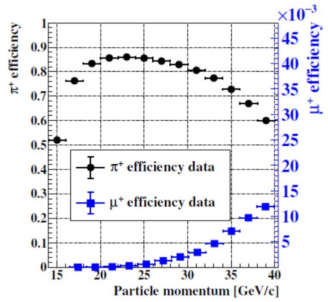

Figure 6: Pion efficiency and muon misidentification probability as a function of momentum for the one-track selection.

4. PID in the search for the $K^+ \to \pi^- e^+ e^+$ decay

A search for the $K^+ \to \pi^- e^+ e^+$ decay has recently been published by NA62 [6]. The 2016–2018 data are analysed and the decay $K^+ \to \pi^+ e^+ e^-$ is used for the normalization. No events have been observed in the signal region, with the 0.43(9) expected background. The following upper limit has been set: UL(BR)=5.3×10^{-11} @90% CL which improves the previous result by the factor of 12.

The RICH is crucial to reject background processes with π^+ misidentified as e^+. For the signal selection it is the decay chain $K^+ \to \pi^+\pi^0, \pi^0 \to e^+e^-\gamma$ (π^+ is misidentified as e^+, e^- is misidentified as π^-) and for the normalization it is the $K^+ \to \pi^+\pi^+\pi^-$ decay with two misidentified pions.

The PID probabilities are measured using a control sample with the $K^+ \to \pi^+\pi^+\pi^-$ selection. Results are shown in Figs. 7 and 8. The RICH-based e^+ identification provides an additional π^+ rejection factor of up to 10^3 (both for the signal and normalization selections) and the identification efficiency is momentum-dependent.

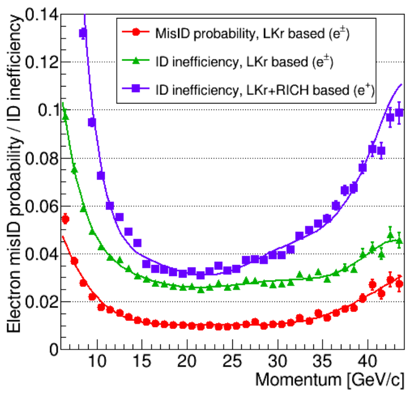

Figure 7: Electron misidentification probability $P_{e\pi}$ for the LKr-based π^+ PID, and e^+ identification inefficiency $1-\epsilon_e$ for the LKr-based and RICH-based PID.

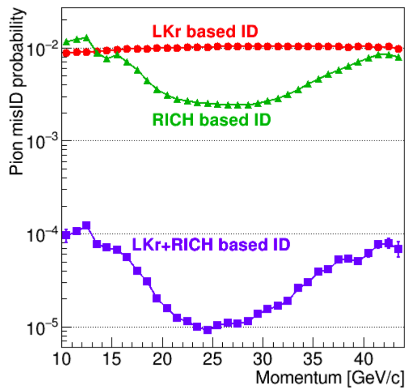

Figure 8: Pion misidentification probability $P_{\pi e}$ for the LKr-based and RICH-based PID.

5. Conclusion

The RICH PID is essential for the NA62 experiment. Due to the geometrical acceptance of the detector, it can be effectively used only for positively charged tracks. The PID probabilities as a function of momentum are measured in the control data samples. Within the $K^+ \to \pi^+\nu\bar{\nu}$ analysis, the RICH provides $O(10^3)$ additional suppression of the $K^+ \to \mu^+\nu_\mu$ decay. In the search for the lepton number violating decay $K^+ \to \pi^- e^+ e^+$ the detector allows to supress backgrounds with $\pi^+ \to e^+$ misidentification by the same order of magnitude.

6. Acknowledgments

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References

[1] The NA62 Collaboration, *JINST* **12** (2017) P05025.
[2] D. Aisa et al, *JINST* **12** (2017) P12017.
[3] G. Anzivino et al, *JINST* **13** (2018) P07012.
[4] H. Hinterberger and R. Winston, *Rev. Sci. Instrum.* **37** (1966) 1094.
[5] The NA62 Collaboration, *JHEP* **06** (2021) 93.
[6] The NA62 Collaboration, *Phys. Lett. B* **830** (2022) 137172.