The NA62 RICH Detector

G. Anzivino, F. Bucci, A. Cassese, P. Cenci, R. Ciaranfi, V. Duk*, E. Iacopini, S. Lami, M. Lenti, M. Pepe, R. Piandani, M. Piccini

***Abstract*—The main goal of the NA62 experiment at SPS CERN is to measure the branching fraction of the ultra-rare kaon decay $K^+ \to \pi^+ \nu\bar{\nu}$ with ∼10% precision. RICH is a crucial detector for background suppression and particle indentification. RICH will provide muon/pion separation at the ∼0.5% level in the momentum range between 15 and 35 GeV/c, unique time resolution (∼100 ps) and a fast signal for the trigger system. This paper describes the main features of the RICH detector, results of the test beam and the construction status.**

I. NA62 Experiment

Rare decays provide a unique opportunity to search for the new physics (NP) beyond the Standard Model (SM). Study of rare decays is complementary to the direct searches of NP at colliders. The contribution to these decays from the SM is suppressed and in some cases can be calculated theoretically with good precision. For example, the SM calculation of the branching ratio of the decay $K^+ \to \pi^+ \nu\bar{\nu}$ is $BR_{SM} = (0.781 \pm 0.075 \pm 0.029) \cdot 10^{-10}$ [1]. The contribution from NP is predicted by many models and can reach 10-20% (see [2], [3] for more detail). The only experimental result has a very large (more than 50%) uncertainty: $BR = (1.73^{+1.15}_{-1.05}) \cdot 10^{-10}$ [4].

The main goal of the NA62 experiment [5] at CERN is to measure the branching ratio of the $K^+ \to \pi^+ \nu\bar{\nu}$ with ∼10% precision. To achieve this goal, about 100 events of the decay will be collected in two years of data taking.

The experiment will take place at the CERN SPS accelerator. The protons from SPS hit a Be target and produce hadron beam with ∼6% of K^+. The beam momentum is 75 GeV/c with the average rate 800 MHz. These parameters will provide the necessary amount of kaon decays (∼4.8 $\cdot$ 10^{12} kaon decays per year, assuming the signal acceptance ∼10%) in the fiducial volume of the detector (NA62 exploits the decay-in-flight technique).

The basic principles of the experiment are (i) the kinematic reconstruction of kaon decays; (ii) precise timing to associate the primary K^+ with the secondary π^+; (iii) system of efficient veto-detectors to suppress backgrounds; (iv) particle identification (i.e. to identify K^+ in the hadron beam and to distinguish π^+ from μ^+ and e$^+$ among the decay products).

* speaker and corresponding author; Viacheslav.Duk@cern.ch

G. Anzivino, P. Cenci, V. Duk, M. Pepe, R. Piandani, M. Piccini are from INFN Perugia, Via A. Pascoli 06123 Perugia Italy.

G. Anzivino and R. Piandani are also from Physics Department of the University of Perugia, Via A. Pascoli 06123 Perugia Italy.

R. Piandani is currecntly from INFN Pisa, Largo Pontecorvo 3, 56127 Pisa Italy.

F. Bucci, A. Cassese, R. Ciaranfi, E. Iacopini, S. Lami, M. Lenti are from INFN Florence, Via G. Sansone 1, 50019 Sesto Fiorentino (Florence), Italy.

E. Iacopini is also from Physics Department of the University of Florence, Via G. Sansone 1, 50019 Sesto Fiorentino (Florence), Italy.

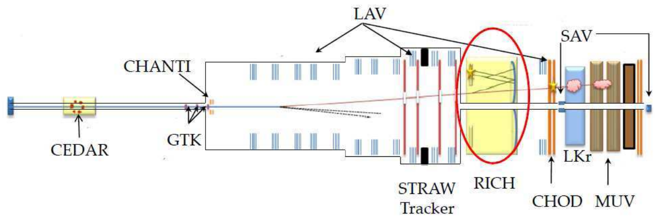

Fig. 1. NA62 experimental setup.

The NA62 setup is shown in Fig. 1 and decsribed elsewhere [6]. The detector is under construction. First runs are scheduled to 2014, physics runs are expected in 2015–2016.

II. NA62 RICH Detector

The main background process is $K^+ \to \mu^+ \nu$ decay (BR=63.5%). It should be suppressed by a factor of $4 \cdot 10^{-13}$. The kinematic selection and muon veto detectors give $8 \cdot 10^{-6}$ and 10^{-5} respectively. Additional factor $5 \cdot 10^{-3}$ is provided by the Ring Imaging Cherenkov detector (RICH). RICH will distinguish muons and pions from kaon decays in the momentum range 15–35 GeV/c. The detector must have time resolution better than 100 ps to provide a proper time matching between the primary kaon and the secondary pion. Also RICH will give a fast signal for the trigger system.

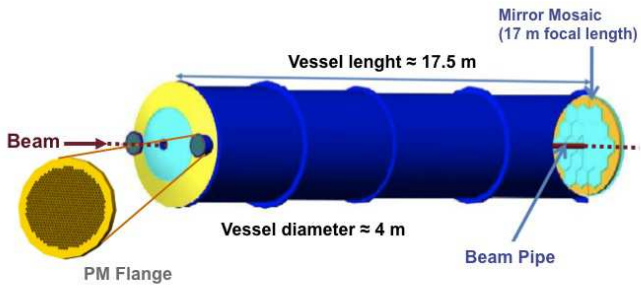

Fig. 2. RICH detector of the NA62 experiment.

A. Vessel

The scheme of the RICH detector is shown in Fig. 2. The main part of the RICH is the cylindrical steel vessel filled with Ne gas at atmospheric pressure. The length of the vessel is 17.5 m, the width varies from 4 to 3.4 m (there are four longitudinal sections with decreasing diameter). The volume is vacuum proof. No gas recirculation or purification are foreseen.

The optimal lower momentum limit (i.e. 15 GeV/c) defines the value of the refractive index $(n-1) \sim 64 \cdot 10^{-6}$. Ne was chosen as a radiator because it has a suitable value of n at the atmospheric pressure. Although the emission rate per unit length is not high, it is compensated by the large longitudinal size of the detector.

B. Mirrors

The mosaic of 20 mirrors (18 hexagonal and 2 half hexagonal segments, 35 cm side) is divided into two groups, one of them oriented to the left from the beam pipe and another one to the right. This is done in order to avoid the shadow of the beam pipe. Mirrors are made of 2.5 cm thick glass substrate coated with a dielectric film to protect the surface and improve reflectivity.

Each mirror is hung to a dowel inserted in the mirror support panel (aluminium honeycomb) and has two ribbons for an independent two-axis alignment. Ribbons are pulled by high precision piezo motors. Mirror positions can be monitored and corrected based on the processed data.

C. Photon Detectors

Two focal regions are equipped with ∼1000 photomultipliers (PMs) each. These regions are out of the detector acceptance. After numerous tests the Hamamatsu R7400-U03 PMs with UV glass window were chosen to readout light. They are very compact (cylindrical shape, 16 mm wide and 11.5 mm long, the diameter of the active area is 8 mm), provide high quantum efficiency (∼23% at 420 nm) and good time resolution (∼250 ns per PM).

The PMs are separated from Neon by 1 mm thick quartz windows. To enhance the ratio between instrumented and sensitive areas, Winston cones [7] are carved in the PM flanges and covered with aluminized mylar.

To power PMs, CAEN5 SY1527 main frames equipped with A1733N and A1535S boards are used. For the optimization of the time resolution the voltage is tuned by custom-made voltage dividers.

D. Readout

Signals from PMs (the amplitude is ∼ 10 mV) are discriminated in the custom-made ASIC NINO boards [8]. The readout system is based on TEL62 [9] board eqiupped with TDCBs [10]. TEL62 is the development of TELL1 [11] used in LHCb experiment, the TDCB readout is based on the embedded CERN HPTDCs [12]. Processors in TEL62 store the data (leading and trailing times) and produce trigger primitives.

E. Construction Status

The vessel is supposed to be delivered to CERN in September 2013. After the delivery the installation will start and continue in 2014. Mirrors are already shipped to CERN and will be aluminized soon. The mirror mechanics will be ready in 2014. The PMs have been tested as well as the HV system for them. The PM flanges with Winston cones are ready. The readout electronics is to be assembled and tested in 2013.

III. Results of the Beam Tests

A RICH prototype was tested at CERN in 2007 [13] and 2009 [14]. An 18 m steel cylindrical vessel (d = 60 cm) was built and filled with Ne. One spherical mirror was put inside the vessel (2.5 cm thick, 50 cm diameter, 17 m focal length). In 2007 100 PMs were used for the readout, whereas in 2009 this number was increased to 414.

The performance of the prototype was measured (time resolution, angle resolution, number of fired PMs per event, muon-pion separation) and found to be in agreement with Monte Carlo simulations and experiment requirements. The performance has been checked by changing several parameters of the experimental setup (e.g. beam momentum, beam intensity, mirror orientation, Ne impurity by adding air and CO_2 [15]).

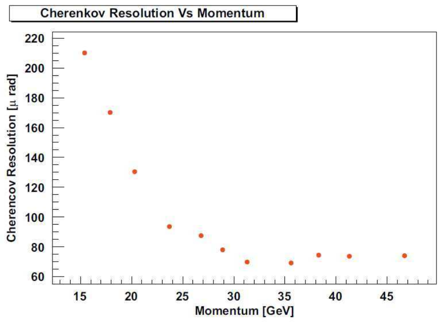

Fig. 3. Angular resolution of the RICH prototype for the 2009 beam test.

The measured angular resolution was 70 μrad for particles with β=1 (Fig. 3). The muon-pion separation was measured for different momenta in the range 15–35 GeV/c. The results are shown in Fig. 4. For the separation two variables were used – ring radius and reconstructed mass. The average value of muon-pion separation was found to be ∼0.7% which is close to the required 0.5% and can be achieved by applying more strict event selection cuts.

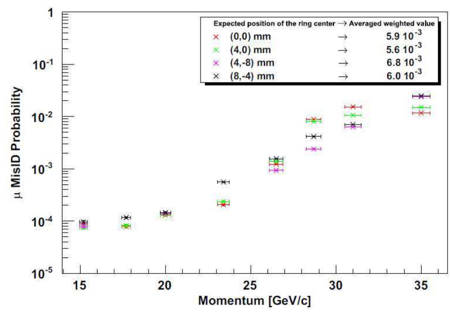

Fig. 4. Muon-pion separation for the 2009 beam test of the RICH prototype.

In 2012 the HV and readout system of the RICH were tested during the Technical Run. The HV system was used to power PMs of the CHOD detector of the NA62 setup. The TEL62+TDCB readout system was used to handle the CHOD data.

IV. RICH IN THE TRIGGER

Fig. 5 illustrates the NA62 integrated TDAQ system. The rate in the RICH region is 10 MHz. Most of this rate comes from kaon decays, the contribution from the muon halo is ∼1 MHz and from pion decays it is lower than 1 MHz. The multi-level trigger system reduces the total rate to few KHz.

The trigger primitives are formed in TEL62 and then sent to Level 0 trigger processor (L0TP). L0TP takes the trigger decision and sends the information back to the TEL62. If the decision is positive, the data is read from TEL62 by L1 processors. The filtered data are sent to L2 processors and then finally transferred to the Central Data Recording (CDR) system.

The information from RICH will be used both at the L0 (fast trigger signal with a simple selection on PM hit multiplicity) and the L1 triggers (ring reconstruction, related to the direction and the velocity of charged particles).

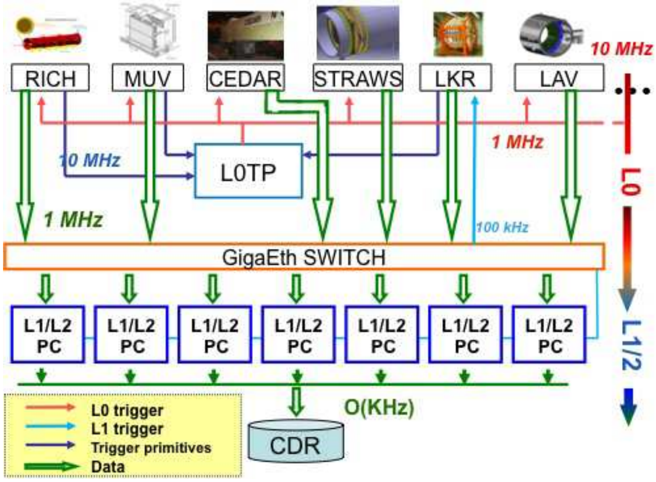

Fig. 5. TDAQ system of the NA62 experiment.

V. CONCLUSIONS

RICH detector is a very important part of the NA62 experimental setup. It is used both for particle identification and trigger formation. The construction of the detector is in progress and will be completed in 2014. Several beam tests were performed. Reasonable results were obtained for the time and angular resolution, muon-pion separation. The HV and readout systems were also tested.

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