The branching ratio (BR) for the decay $K^+ \to \pi^+ \nu \bar{\nu}$ can be related to the value of the CKM matrix element $V_{td}$ with minimal theoretical uncertainty, providing a sensitive probe of the flavor sector of the Standard Model. The goal of the NA62 experiment at the CERN SPS is to detect $\sim 100 K^+ \to \pi^+ \nu \bar{\nu}$ decays with a S/B ratio of 10:1. The experimental layout is illustrated in Fig. 1.

The experiment will make use of a 75 GeV unseparated positive secondary beam. The total beam rate is 800 MHz, providing $\sim 50$ MHz of $K^+$’s. The decay volume begins 102 m downstream of the production target. 5 MHz of kaon decays are observed in the 65-m long fiducial vacuum decay region. Ring-shaped large-angle photon vetoes (LAVs) are placed at 12 stations along the decay region and provide full coverage for decay photons with $8.5 \text{ mrad} < \theta < 50 \text{ mrad}$. The last 35 m of the decay region hosts a dipole spectrometer with four straw-tracker stations operated in vacuum. The NA48 liquid krypton calorimeter is used to veto high-energy photons at small angle. Additional detectors further downstream extend the coverage of the photon veto system (e.g. for particles traveling in the beam pipe).

In 2013, the main responsibilities of the LNF NA62 group were the following:

- Construction and installation of the LAV stations.
- Construction and installation of the front-end electronics (FEE) for the LAV stations. The LAV FEE boards use the time-over-threshold technique to obtain both hit times and energies.

![Figure 1: The NA62 experimental layout.](image-url)
from time measurements alone. This FEE board was developed at LNF and has been adapted for use with various other NA62 detectors.

- Development of level-zero trigger firmware for the LAV system.
- Construction and installation of the small-angle vetoes (IRC and SAC) and development of the associated readout systems.
- Commissioning of the above detector systems.
- Development of software and analysis tools for the above detector systems.
- Assistance with the development of a small, dedicated calorimeter system to veto charged pions leaving the acceptance through the beam pipe (HAC)
- Coordination of the NA62 Photon Veto working group.

The principal involvement of the LNF NA62 group is in the design and construction of the LAV system.

NA62 running will commence in mid-October 2014. In view of the approaching run, 2013 was a critical year for the Frascati NA62 group.

2 Large-Angle Photon Vetoes

Development and commissioning of the LAV system was the most important commitment of the group in 2013. The group’s activity on the LAV detectors can be divided into the following areas: construction and installation; electronics; commissioning and testing.

2.1 Construction and installation

In 2013, LAV stations A9 and A10 were constructed at Frascati and transported to CERN, bringing the total number of completed stations to 11, of 12 total. Stations A9 and A10 will be operated in the vicinity of the NA62 spectrometer magnet. They were assembled at a later time than stations A1–A8 and A11, since the vacuum vessels in which they are housed must be constructed from high-quality, non-magnetic stainless steel.

Also in 2013, LAV station A9 was installed into the NA62 vacuum tank, bringing the total number of installed stations to 9, of 12 total. Sections of the vacuum tank needed for the installation of stations A10 and A11 do not yet exist. The NA62 photon veto group has assumed responsibility for supplying these missing sections. With the coordination of the Frascati group and the SPAS, a contract for the missing sections was awarded to Fantini SpA (the manufacturer of the LAV vessels) and the sections are currently under construction.

The design of the A12 station is different from that of the other 11 stations in many important respects: it is operated in air rather than in vacuum, it is modular rather than monolithic because of its large size, and its installation into the closed space at the downstream end of the beamline will require a delicate insertion procedure. By the end of 2012, the basic design of the A12 station had been defined. In 2013, the construction drawings were finalized and offers were received for the external fabrication of the large mechanical components. Fabrication of the smaller components was organized at the Frascati central machine shop and at INFN Pisa. The lead-glass blocks for A12 were prepared for installation. Construction of A12 is now underway.
2.2 Readout, trigger, and detector control systems

The first NA62 technical run was carried out in November 2012. The goal of this run was to test the full readout chain and data acquisition system. During the technical run, three complete LAV stations were powered up with the definitive HV systems and data were acquired with the final acquisition chain with muon and kaon beams. The entire readout chain was tested, with data recorded in the L1 PC farm. The data collected during the technical run were comprehensively analyzed by group members in 2013.

One problem to emerge from the 2012 run was noise on some channels of the FEE boards designed at Frascati for use with the LAV detectors. This noise was traced to the crates in which these boards are housed. The NA62 group carried out extensive measurements of the noise as a function of applied threshold. In collaboration with CERN and Wiener (the manufacturer of the crates), members of the group and the LNF Electronics Service identified a technical solution (installation of line filters in the crates).

Additionally, data from the 2012 run showed that the amplification factor at the input stage of the FEE boards was too small to allow the effective discrimination thresholds to be set as low as required for the experiment. In collaboration with the LNF Electronics Service, the Frascati group tested boards with input gain increased from 3 (as in the previous version) to 5, 6, and 11. These tests were conducted in the laboratory and, with cosmic rays, on detectors already in the NA62 experimental area at CERN, with two different readout schemes. A gain of 6 was chosen and all boards from early production with gains of 3 were modified. As a result, the minimum set value of the effective threshold was decreased from 10 mV to 6 mV for all channels.

Mass production of the FEE boards was started and completed in 2013. Each FEE board ready to be installed was individually tested and characterized. A new, more accurate test procedure was developed to calibrate the effective threshold setting as a function of the nominal setting for each board. In addition, the firmware for the FEE boards was extensively tested and a new version, with increased stability and reliability, was released. The FEE boards were successfully integrated into the NA62 detector control system.

During the July 2013, the group participated in an exercise at CERN to test the integration with the experiment’s trigger and data-acquisition systems. Using LAV stations A1 and A2, which were fully cabled, we performed intensive tests of the firmware developed at Pisa for the collaboration’s standard TEL62 digital readout board. We identified some substantial limitations, in particular in the DDR memory manager, which led to a rewrite of some of the code sections.

3 Forward vetoes: IRC and SAC

The Small-Angle Calorimeter (SAC) and Intermediate-Ring Calorimeter (IRC) complete the coverage of the NA62 photon veto system for particles that would otherwise escape down the beam pipe. Both detectors are of the shashlyk type, with alternating layers of lead and scintillator traversed perpendicularly by a dense matrix of wavelength-shifting (WLS) fibers, which are read out by photomultiplier tubes (PMTs). The development of these detector systems is currently the responsibility of the Frascati group. During 2013, the following milestones were reached.

3.1 Detector construction

In data from the 2012 technical run, the signals from the SAC were measured to be more than 30 ns FWHM in duration. Moreover, the photoelectron yield obtained with the FEU-85 PMTs used for the SAC prototype and during the technical run was found to be too low at the nominal operating voltage of the tubes. The PMTs were therefore changed with Hamamatsu R6427 tubes,
which have a rise time of $\sim 1.7$ ns. Changes to the mechanics of the PMT assembly were also required.

The scintillator geometry for the IRC was finalized and a supplier for the plastic scintillator was selected. An order for 300 square tiles 1.5-mm thick, of area $150 \times 150$ mm$^2$, was placed and the material was delivered to CERN, as were the WLS fibers. The scintillator was painted with a reflective white paint to provide better light collection, and then sent to IHEP Protvino for drilling and cutting. A series of measurements were undertaken to confirm that it was possible to match the holes in the lead with the holes in the original matrix and to produce a precise map of the 570 holes. After the scintillator is cut and drilled, final assembly will take place at Frascati.

3.2 SAC tests at the Frascati Beam-Test Facility (BTF)

After replacement of the PMTs, the SAC was tested at the BTF. A single-electron beam with an energy of 600 MeV was used for the test. The SAC was read out using two different types of waveform digitizer. Clear peaks in the distribution of deposited energy were observed for electron multiplicities from 1 to up to 8 electrons. The linearity and the energy resolution were measured, as well as the inefficiency of the detector for 600 MeV electrons, which was found to be lower than $5 \times 10^{-3}$. After the BTF test run the SAC was transported back to CERN and is ready for reinstallation.

3.3 Detector readout

In 2013, the data chain and readout model for the IRC and SAC was defined. These detectors are very near the beam. Because of the high expected rate and the need to be able to distinguish between beam halo muons (which occur randomly) and low energy electrons and positrons from photon conversions (which are in time with the event), a continuous waveform digitizer must be used.

After investigating various commercial solutions, we decided to use the GANDALF framework, which provides 8 channels of 500 MS/s and an optical interface board able to sustain transfer rates of 3.1 GB/s. A readout system similar to that intended for use was obtained on loan in June and was tested with the SAC both at the BTF test run and at the NA62 dry run. With new firmware, the readout was able to sustain a rate up to about 1 MHz of NA62 triggers.

4 Conference talks by NA62 LNF members


- M. Raggi: 2013 Kaon Physics International Conference (KAON13). Ann Arbor MI, USA, 29 April–1 May 2013. Talk: “High precision measurement of the form factors of the semileptonic decays $K^\pm \rightarrow \pi^0 \ell^\pm \nu$ ($K_{\ell 3}$) at NA48/2”.

- M. Moulson: Meeting of the American Physical Society Division of Particles and Fields (DPF13).
Santa Cruz CA, USA, 13–17 August 2013.
Talk: “Searches for rare and forbidden decays with the NA62 experiment at CERN”.

• V. Kozhuharov: International Workshop on $e^+e^-$ collisions from Phi to Psi (PHIPSI13).
  Rome, Italy, 9–12 September 2013.
  Talk: “Measurement of the ratio of charged kaon leptonic decay rates at NA62”.

• M. Raggi: International Workshop on $e^+e^-$ collisions from Phi to Psi (PHIPSI13).
  Rome, Italy, 9–12 September 2013.
  Talk: “Study of the rare decay $K^\pm \to \pi^\pm \gamma\gamma$ and high precision measurement of the form factors of the semileptonic decays $K \to \pi^0\ell\nu$.”
  Poster: “Tests of chiral perturbation theory with $K^\pm_{c4}$ and $K^0_{c4}$ decays at the CERN NA48/2 experiment”.

  Taipei, Taiwan, 20–26 November 2013.
  Talk: “Searches for rare and forbidden decays with the NA62 experiment at CERN”.