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A detector for the measurement of the ultrarare decay $K^+ \to \pi^+ \nu \bar{\nu}$: NA62 at the CERN SPS

Paolo Valente[*†]
INFN - Sezione di Roma, Piazzale Aldo Moro 2, 00185 Rome, Italy
E-mail: paolo.valente@roma1.infn.it

The NA62 experiment at CERN aims at the very challenging task of measuring with 10% relative error the Branching Ratio of the ultra-rare decay of the K^+ into $\pi^+ \nu \bar{\nu}$, which is expected to occur only in about 8 out of 10^{11} Kaon decays. This will be achieved by means of an intense hadron beam, an accurate kinematical reconstruction and a redundant veto system for identifying and suppressing all spurious events. The good resolution on the missing mass in the decay is achieved using a high-resolution beam tracker to measure the kaon momentum and with a spectrometer equipped with straw tubes operating in vacuum. Hermetic veto (up to 50 mrad) of the photon from π^0 decays is achieved with a combination of large angle veto (with a creative reuse of the old OPAL lead glass blocks), the NA48 LKr calorimeter and two small angle calorimeters to cover the angle down to zero. The identification of the muons and the consequent veto is performed by a fast hodoscope plane (used in the first level of the trigger to reduce the rate) and by a 17-meter, neon-filled RICH counter which is able to separate pions and muons in the momentum interval between 15 and 35 GeV. Particle identification in the beam (K/π separation) is achieved with an H_2 differential Cherenkov counter. The trigger for the experiment is based on a multilevel structure with a first level implemented in the readout boards and with the subsequent level done in software. The aim is to reduce the 10 MHz L0 rate to few KHz sent to the CERN computing center. Studies are underway to use GPU boards in some key point of the trigger system to improve the performance.

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*Speaker.
†on behalf of the NA62 Collaboration.

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1. Introduction

Among the many flavour-changing neutral current rare K and B decays, the decays $K \to \pi\nu\bar{\nu}$ play a key role in the search for new physics. The Standard Model (SM) branching ratio can be computed to an exceptionally high degree of precision: The error comes mainly from the uncertainty on the CKM matrix elements, while the irreducible theoretical uncertainty amounts to less than 2% [1].

Presently, the only existing measurement of $K^+ \to \pi^+\nu\bar{\nu}$ is based on seven signal events collected by BNL-AGS-E787(E949), that estimated a branching ratio of $(1.73^{+1.15}_{1.05}) \times 10^{10}$ [2]. However only a measurement of the branching ratio with at least 10% accuracy can be a significant test of new physics.

2. The NA62 detector description

The requirement of 100 events leads to $\sim$10% signal acceptance and at least to 10^{13} K^+ decays. The required signal to background ratio demands a background suppression factor of at least 10^{13}. The principle of the experiment is a decay-in-flight technique: the signal is composed by an incoming mother particle (the K^+) and an outgoing daughter particle (the π^+) and nothing else, all the other K^+ decay channels being background. The experiment will be housed in the CERN North Area High Intensity Facility (NAHIF) where the NA48 [8] was located, and it will use the same SPS extraction line and target of NA48 to produce a 75 GeV/c ($\pm$1%) positive hadron beam [3].

Two- and three-body decay modes will be reduced by a factor of 10^4 by cutting on the missing mass of reconstructed candidates. For this purpose, a fast up-stream tracker of every particle in the beam is used to measure incoming K momentum. This beam spectrometer (called Gigatracker [4]), consists of 3 Silicon pixel stations matching the beam size. The 18,000, 300μm$\times$300μm, pixels are formed by a 200 μm thick sensor, bump-bonded on 100 μm thick readout chips, thus keeping the total thickness below 0.5% X_0. In order to provide the timing of the mother kaon and keep the pile-up at the 10% level in a 800 MHz hadron beam, a 200 ps time resolution is required.

Downstream to a 60-m long fiducial region for K decays, a straw-chamber magnetic spectrometer is used to measure with high resolution daughter particle momenta [5]. Further rejection of $K_{\mu 2,3,4}$ and $K_{e2,3,4}$ background will be obtained with a ring-imaging Cerenkov counter (RICH), used to efficiently and non-destructively identify daughter pions from muons and electrons. The RICH should provide 3-sigma π/μ separation in the 15-35 GeV/c pion momentum range, and a time resolution better than 100 ps should be guaranteed, to efficiently match with Gigatracker information. This performance will be obtained by using a 17-m long, 3-m diameter volume, filled with 1 atm Neon gas acting as Cerenkov radiator. Mirrors at the downstream side of the volume will focus rings of Cerenkov light into two separated regions on the upstream side. These are instrumented with 2,000 18-mm photo-multiplier tubes (PMT's). Dedicated beam-tests of a 400 PMT prototype demonstrated a muon rejection better than 1%, with an overall pion loss of few per mil and a time resolution better than 100 ps [6]. Since it is critical to achieve sufficient rejection for $K_{\mu 2}$ decays, additional information will be provided by the muon veto, a sampling calorimeter placed after the existing 27 X_0 liquid Krypton electromagnetic calorimeter of the NA48 experiment (LKr [7]).

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Rejection of background from nuclear interactions of charged beam particles other than K^+ will be guaranteed by a differential Cerenkov counter (CEDAR) placed before kaons enter the decay region: Cerenkov photons radiated in a 6 m long vessel, filled with H_2 gas, are focussed by an optimized optical system on eight fast PMT's.

Rejection of modes with π^0's and/or (possibly radiative) photons will be provided by the LKr calorimeter, complemented by high-efficiency photon-veto detectors, covering 0-50 mrad γ emission angles. This has to provide a rejection factor of 10^8 against $K^+ \to \pi^+\pi^0$. Photons emitted at very small angle, < 2 mrad, will be detected by compact calorimeters in the forward direction, with a required inefficiency of $< 10^{-6}$ above 6 GeV. In the angular range between 1 mrad and 8 mrad, the LKr provides an inefficiency measured to be $< 10^{-5}$ for photons above 6 GeV. At large angle, between 8 mrad and 50 mrad, a new system (so-called LAV) will provide γ detection with an inefficiency $< 10^{-4}$ above 100 MeV, as measured in test beams performed at the Dafne Beam Test facility in Frascati, using positrons [8]. The LAV system is constituted by 12 stations of increasing diameter, placed at different positions along the vacuum decay tube. Each station is composed by four or five layers of SF57 lead-glass blocks, formerly used in the barrel of the OPAL electromagnetic calorimeter, arranged radially to form a ring-shaped sensitive area. Layers are staggered to guarantee that incident particles cross at least three blocks: total thickness ranges from 29 to 37 X_0. Cerenkov light is readout by 2-inches PMT. With 32 to 48 crystals per layer, a total of ~ 2500 blocks will be used. A time-over-threshold discriminator, with multiple adjustable thresholds, will be used in order to cope with the wide dynamic range: from 20 MeV to 20 GeV photons.

In order to extract a few interesting decays from a very intense flux a complex and performing three levels trigger and data acquisition system (TDAQ [9]) was designed. The TDAQ is a unified completely digital system: the readout data, stored in large buffers waiting for trigger decisions, is exactly the same as used to construct the trigger primitives. The Level 0 (L0) trigger algorithm is based on the presence of a charged particle in the RICH and veto conditions on LKr, LAV and MUV, and is performed by dedicated custom hardware modules, with a maximum output rate of 1 MHz and a maximum latency of 1 ms.

Level 1 and Level 2 software triggers are executed on a dedicated PC farm. The maximum Level 1 (Level 2) output rate is of the order of 100 (10) kHz. Due to large amount of data to be processed in a reasonable time, the number of PC cores at the L1 will be quite large. The use of a dedicated GPU-based farm is under evaluation [10]. After this level of selection the data from all the detectors will arrive at L2 through a network switch; the event will be fully reconstructed in order to apply a tighter selection based on the full kinematics.

3. Status and plans

The NA62 Collaboration has completed many of the intense R&D programs on different subdetectors, and is now progressing in building and installing the experiment: new beam-line, muon-veto, magnetic straw-chamber spectrometer, LAV system will be completed or close to completion by Fall 2012, thus enabling a technical run before the SPS will undergo the shutdown for LHC injection chain improvement, presently planned for 2013. The LKr readout is being consolidated and the TDAQ and computing system developement are currently under way. The RICH and

Gigatracker will be instead ready for the full physics run, right after the restart of the fixed-target program of CERN subsequent to the long SPS shutdown.

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