THE NA62 EXPERIMENT AT CERN AND THE MEASUREMENT OF THE ULTRA-RARE DECAY K⁺ → π⁺νν̄

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Abstract. 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 π⁺νν̄ 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. 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 liquid Krypton 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⁺ 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 the software. The aim is to reduce the 10 MHz level zero rate to a few kHz sent to the CERN computing centre. Studies are underway to use GPU boards in some key point of the trigger system to improve the performance.

Keywords: NA62 kaon flavour.

1. Introduction

Among the many flavour-changing neutral current rare K and B decays, the decays K → πνν̄ 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 theoretical comes mainly from the uncertainty on the CKM matrix elements, while the irreducible theoretical uncertainty amounts to less than 2.5 % for the neutral mode and 3.7 % for the charged one, and the latter could be further reduced by lattice calculation [1].

Presently, the only existing measurement of K⁺ → π⁺νν̄ based on seven signal events collected by BNL-AGS-E787(E949), which estimated a branching ratio of $(1.73^{+1.15}_{-1.05}) \cdot 10^{10}$ [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

The requirement of 100 events leads to ~10 % signal acceptance and to at least 10^{13} K⁺ decays. The required signal to background ratio demands a background suppression factor of at least 10^{12}. 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 [3] was located, and it will use the same Super Proton Synchrotron (SPS) extraction line and target of NA48 to produce a 75 GeV/c (±1 %) positive hadron beam Two-body 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 the incoming K⁺ momentum. This beam spectrometer (called Gigatracker [4]), consists of 3 silicon pixel stations matching the beam size. The 18000, 300 μm × 300 μm, pixels are formed by a 200 μm thick sensor, bump-bonded on 100 μm thick readout chips, thus keeping the total thickness below $5 \cdot 10^{-3}$ radiation length. In order to provide the timing of the mother kaon and keep the pile-up at the 10 % level in an 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 (Fig. 1 left) is used to measure daughter particle momenta with high resolution [5]. Further rejection of $K_{\mu 2,3,4}$ and $K_{e 2,3,4}$ background will be obtained with a ring-imaging Cherenkov counter (RICH), used to efficiently and non-destructively identify daughter pions and disentangle them 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 a Cherenkov radiator. Mirrors at the downstream side of the volume will focus the rings of Cherenkov light into two separated regions on the upstream side. These region will be instrumented with 2000 18 mm photomultiplier tubes (PMTs). Dedicated beam-tests of a 400 PMT prototype demonstrated muon rejection better than 1 %, with an overall pion loss of a few per mille 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]).

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

Rejection of modes with neutral pions and/or (possibly radiative) photons will be provided by the LKr calorimeter, complemented by high-efficiency photon-veto detectors, covering $0 \div 50$ mrad emission angles. This has to provide a rejection factor of 10^8 against $K^+ \to \pi^+\pi^0$. Photons emitted at a 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 causes an inefficiency measured to be $< 10^{-5}$ for photons above 6 GeV. At a large angle, between 8 mrad and 50 mrad, a new system, called Large Angle Veto (LAV) will provide detection with inefficiency $< 10^{-4}$ above 100 MeV, as measured in test beams performed at the DAΦNE Beam Test facility in Frascati, using positrons [3].

The LAV system is constituted by 12 stations of increasing diameter (see Fig. 1 right), placed at different positions along the vacuum decay tube. Each station is composed of 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. Cherenkov light is readout by 2-inch PMT. With 32 to 48 crystals per layer, a total of 2496 blocks will be used. A double time-over-threshold (ToT) discriminator, with multiple adjustable thresholds [8], will be used in order to be able to reconstruct the charge of wide-dynamic-range signals coming from $0.02 \div 20$ GeV photons. A scheme of the NA62 experimental layout is drawn in Fig. 2.

The second LAV station (A2) was tested in the T9 area at the CERN PS, by means of a beam, it is composed of electrons, pions, and muons with energies
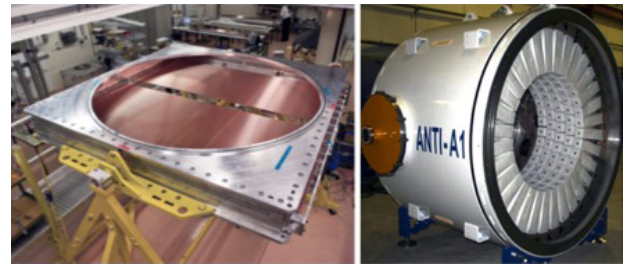

FIGURE 1. A picture of the straws (left) and of the A1 station of the LAV (right).

between 0.3 and 10 GeV. The timing performance was proven to be excellent [10], the resolution of the whole system is $\sim 200 \, \text{ps}/\sqrt{E[\text{GeV}]}$ for a single block. A measurement of the energy can be obtained by means of the two ToT values. The energy resolution obtained in this fashion is

$$\sigma(E)/E = 9.2\,\%/\sqrt{E[\text{GeV}]} + 5\,\%/E[\text{GeV}] + 2.5\,\%.$$

In order to extract a few interesting decays from a very intense flux a complex and performing three level trigger and data acquisition system (TDAQ [11]) 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 was 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 muon veto detector, 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 the 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 [12]. 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 various sub-detectors, and is now progressing in building and installing the experiment: the new beam-line, the muon-veto, and the magnetic straw-chamber spectrometer will be completed or close to completion by Fall 2012. As far as the LAV system is concerned 8 stations out of 12 are successfully installed and tested. A technical run is planned for 2013 before the SPS undergoes the shutdown for LHC injection chain improvement. The readout of the liquid Krypton calorimeter is being consolidated and the TDAQ and computing system development are currently under way. In fact a test
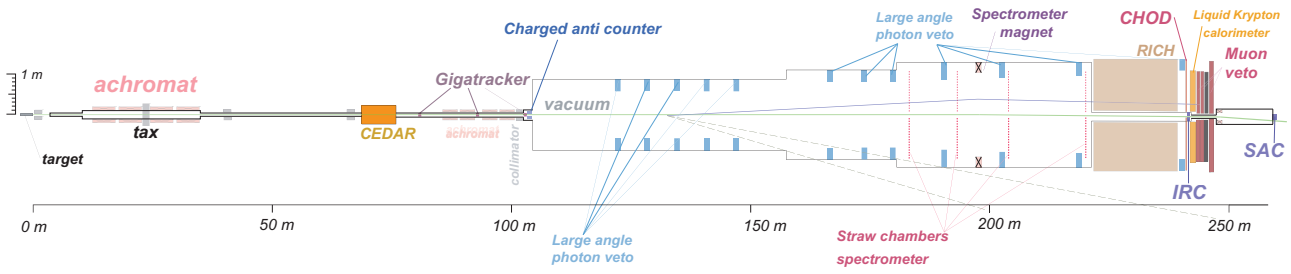
FIGURE 2. Scheme of the NA62 layout.

of the whole electronics has been performed in the experimental area. On the other hand, the RICH and the Gigatracker will be 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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