

The NA62 experiment at CERN: status and perspectives

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The future program of the NA62 experiment at CERN SPS is currently in advanced stage of development. The main goal of the experiment is to measure the branching ratio of the ultra-rare decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, by detecting approximately 80 events with a background on the order of 10%. In the present paper, the motivation behind this measurement and the overall design strategy of the experiment are briefly outlined. The experiment's construction status is discussed and perspectives are given for the first runs with the new detector.

PRESENTED AT

CKM workshop
Warwick, UK, September 6–10, 2010

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1 The physics case

In the search for new physics (NP) effects beyond the Standard Model (SM), flavor-changing neutral-current processes are particularly relevant. These processes are dominated by penguin and box diagrams and can sensitively test various NP scenarios. Kaons rare and ultra-rare decays, such as $K_L \rightarrow \pi^0 l^+ l^-$ and $K \rightarrow \pi \nu \bar{\nu}$, are particularly clean in that no long-distance contributions from processes with intermediate photons are involved and hadronic matrix elements can be obtained from branching ratios (BR) of leading K decays, such as $K \rightarrow \pi e \nu$, via isospin rotation [1, 2, 3, 4]. In the SM, the theoretical expectation for the charged mode [5], $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (8.5 \pm 0.7) \times 10^{-11}$, has a 7% non-parametric error. In contrast, possible NP contributions could change the BR by up to a factor of three in many scenarios [6]. Evidence of new physics may be seen in $K \rightarrow \pi \nu \bar{\nu}$ decays even in absence of significant signals from B decays [7]. Moreover, simultaneous BR measurements for $K_L \rightarrow \pi^0 \nu \bar{\nu}$ and $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ give information on CKM matrix elements in a complementary and independent manner with respect to the inputs from B physics. At present, seven $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events have been identified by the BNL E949/E787 stopped-kaon decay experiments [8]. The measured BR is compatible with the SM prediction, although with a large uncertainty: $BR = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$. There is still plenty of room for possible NP effects, see Fig. 1 from Ref. [9].

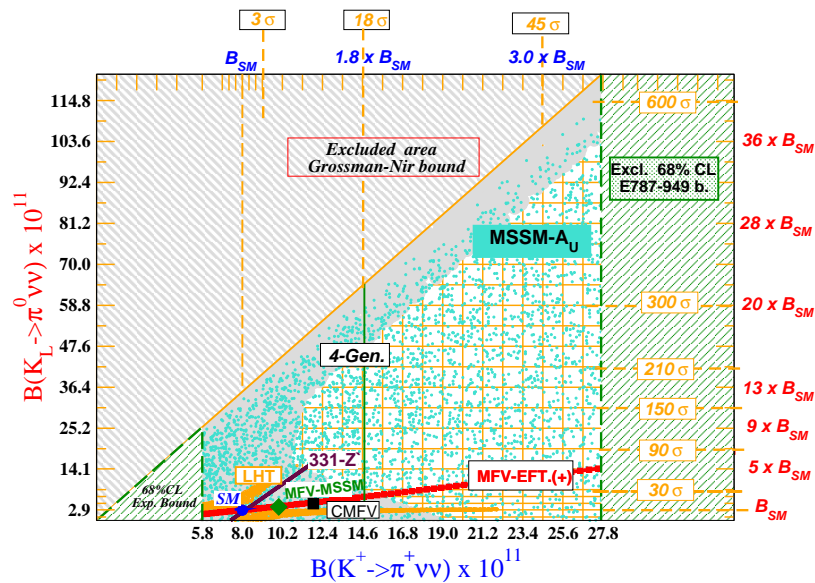


Figure 1: Expected BR for $K \rightarrow \pi \nu \bar{\nu}$ modes in various new physics scenarios, from the FlaviaNet Kaon working group [9].

2 The NA62 experimental technique

The aim of the NA62 experiment [10] is to detect about 80 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events with a $\mathcal{O}(\sim 10\%)$ signal acceptance and a background on the order of 10 % in two years of data-taking. The design is inspired by years of experience with the NA48 apparatus and infrastructure. For NA62, the K12 beamline at the CERN SPS will be upgraded to increase the intensity by a factor of 50. In the final setup, a 400-GeV SPS primary proton beam interacts into a beryllium target and produces an unseparated 75-GeV, 800-MHz beam with $\sim 6\%$ K^+ , corresponding to ~ 5 MHz kaon decays in a 60-m long fiducial volume. A transverse schematic view of the NA62 detector is shown in Fig. 2.

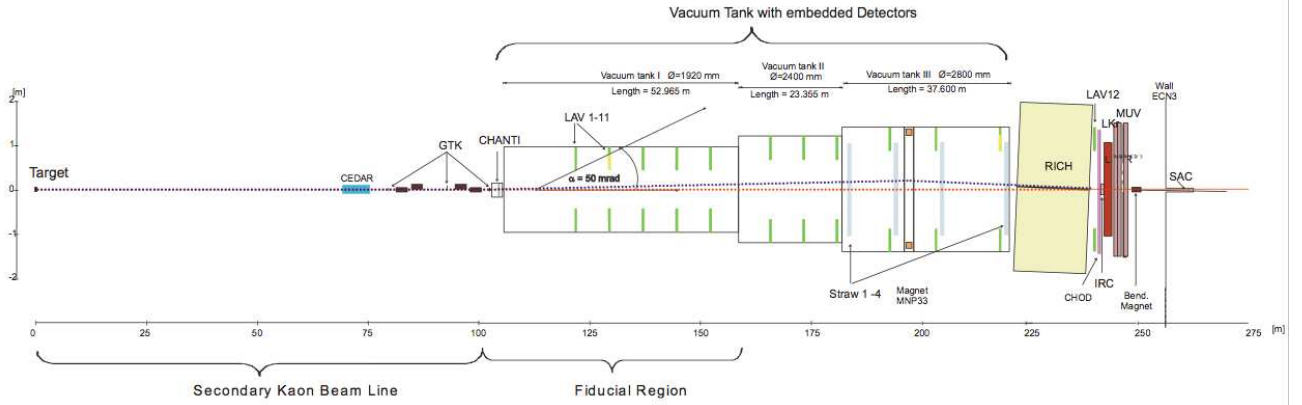


Figure 2: Schematic view of the NA62 detector.

The guiding principles in the experiment design follow from the need to sustain a high-rate environment while guaranteeing high-resolution timing. The goal is to identify a signal BR of $\sim 10^{-10}$ with a total background rejection of the order of 10^{12} against the leading K^+ decay modes.

Two- and three-body decay modes will be reduced by a factor of $\sim 10^4$ by cutting on the missing mass of reconstructed candidates. For this purpose, a fast up-stream tracker of every particle in the beam, the so-called Gigatracker (see Sec. 2.1), is used to measure incoming K momentum. 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.

Further rejection of $K_{\mu 2,3,4}$ and $K_{e 2,3,4}$ background will be obtained with a ring-imaging Cerenkov counter (see Sec. 2.2), used to efficiently and non-destructively identify daughter pions from muons and electrons. The π/μ separation is critical to achieve sufficient rejection for $K_{\mu 2}$ decays. For this purpose, additional information

will be provided by a sampling calorimeter, the so-called muon veto, placed after the 27 X_0 's of the existing LKr NA48 electromagnetic calorimeter.

Rejection of background from nuclear interactions of charged beam particles other than K^+ will be guaranteed by a differential Cerenkov counter, the so-called CEDAR, placed before K^+ 's enter the decay region.

Rejection of modes with π^0 's and/or (possibly radiative) photons will be provided by a hermetic, high-efficiency photon-veto system, covering from 0-50 mrad γ emission angles. This has to provide a rejection factor of 10^8 against $K^+ \rightarrow \pi^+\pi^0$.

2.1 Fast Tracking

The Gigatracker [11] will measure time of individual beam particles. It will also provide a momentum measurement for single particles with precision much better than that given by the momentum bite of the beam. This system is placed upstream, just before the decay volume, and must sustain rates of up to 800 MHz. Three silicon micro-pixel stations with a total thickness of less than 0.5% X_0 each will provide position measurement while particles traverse a magnetic achromat. A total of 18 000, $300 \times 300 \mu\text{m}^2$ pixels for a sensitive area of $60 \times 27 \text{mm}^2$ will provide spatial hit resolution of $\sim 100 \mu\text{m}$. Momentum will be measured with a fractional error of $\sim 0.2\%$, corresponding to 150 MeV resolution, while direction will be determined with 12 μrad angular resolution. In order not to cause station-by-station hit mismatch in more than 1% of the cases, a hit time resolution better than 200 ps is required. The read out has to sustain rates of up to 150 KHz. The R&D is almost completed, with two read out prototypes developed and compared, both with FE circuits in 130-nm IBM CMOS technology.

2.2 PID of decay products

A ring-imaging Cerenkov counter, the RICH [12], will provide rejection for muons with less than 0.5% mis-ID probability for events not identified by the muon veto. More than three standard deviations of π/μ separation should be achieved in the $K \rightarrow \pi\nu\bar{\nu}$ pion momentum range, $15 < p_\pi < 35 \text{ GeV}$. Time determination with a 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 Ne 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 2000 photomultiplier tubes (PMT's), each 18-mm wide. In a dedicated test beam for a prototype with ~ 400 PMT's a muon rejection better than 1% has been measured, with an overall pion loss of few per mil (see fig 3) and a time resolution better than 100 ps, these figures holding across the momentum range of interest.

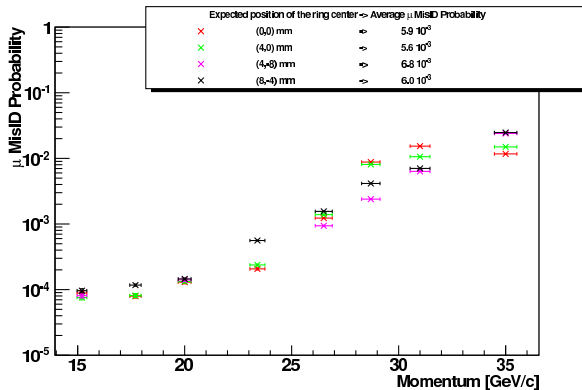


Figure 3: Result from a RICH prototype beam test: muon mis-identification probability as a pion as a function of particle momentum. To estimate the effect induced by the use of a fixed ring position in the prototype, measurements were repeated comparing four alignment positions of the mirror, corresponding to different colors in the plot.

2.3 Efficient photon vetoing

A system of different detectors will veto photons and will provide a rejection of 10^8 for photons from K^+ decay in a 60 m-long fiducial volume, allowing the background from $K^+ \rightarrow \pi^+\pi^0$ decays to be reduced to less than one part in 10^{12} . Photons emitted at very small angle, $< \sim 2$ 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 existing NA48 LKr calorimeter will be re-used, profiting of a measured inefficiency $< 10^{-5}$ 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 $< \sim 10^{-4}$ above 100 MeV.

2.3.1 The LAV system

After an intense R&D activity, the re-use of SF57 lead glass blocks from the dismantled OPAL barrel electromagnetic calorimeter, already instrumented with R-2238 Hamamatsu phototubes, has been validated. The inefficiency measured with dedicated test beams satisfies the requirements and is comparable with other alternatives, including lead/scintillating-fiber or lead/scintillating-tile sampling calorimeters (see Fig. 4, left).

The LAV will be made of 12 stations of increasing diameter to cover hermetically the angular range from 7 to 50 mrad. Each station will be composed of four or five layers, for a total depth of 29 to 37 X_0 's. Layers are staggered to guarantee that incident particles must encounter at least three blocks, corresponding to more than

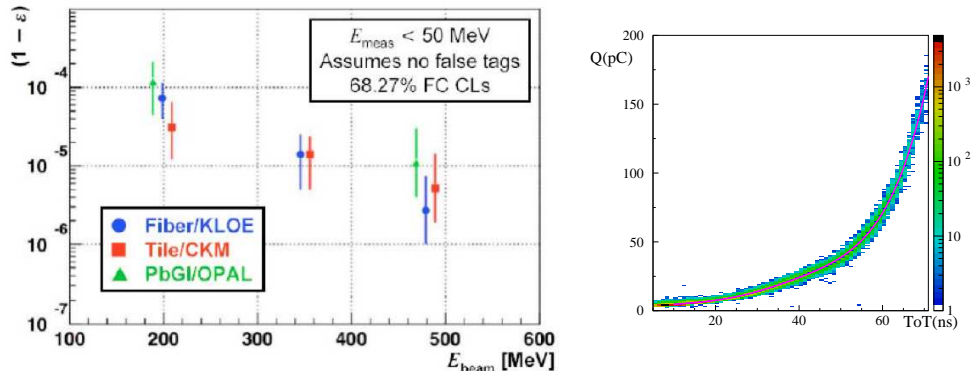


Figure 4: Left: results from large-angle photon veto prototype beam tests. Inefficiency for electron detection as a function of particle momentum is compared for a fiber calorimeter “à-la KLOE” (circles), for a structure alternating scintillator and lead tiles, “à-la CKM” (squares), and for a structure made of OPAL lead-glass blocks (triangles). Right: data from test with electron beam. Charge integrated by a QDC with 0.1 pC LSB versus time over a 30 mV threshold, measured with a prototype of the LAV front-end electronics and a TDC with 0.25 ps LSB.

20 X_0 's. With 32 to 48 crystals per layer, a total of ~ 2500 blocks will be used. Since high sensitivity to photons in the range from 20 MeV to 20 GeV is required, the front end electronics must guarantee a wide dynamic range. Since the typical yield is ~ 0.3 photo-electrons per MeV and the typical PMT gain is 10^6 , signals from 20 mV up to 10 V on a 50 Ω load must be treated. A simple and cost-effective solution, easy to scale and to integrate with a common NA62 trigger and data acquisition infrastructure has been adopted: a time-over-threshold discriminator, with multiple adjustable thresholds. Signals will be clamped, split into two, amplified, and discriminated with two thresholds to allow slewing corrections. The digital output in LVDS standard will allow accurate leading and trailing edge time determinations. From the time-over-threshold, a 10% resolution measurement of the charge will be made (see Fig. 4, right), allowing the LAV system to operate as a calorimeter as well as a veto. Test beam results show that a fractional energy resolution $\sim 10\%E(\text{GeV})^{-1/2}$ and a time resolution $\sim 300 \text{ ps}E(\text{GeV})^{-1/2}$ are achieved.

2.4 Experiment status

In September 2005, the experiment was presented to the CERN SPS Committee and in December 2005 the R&D was endorsed by the CERN Research Board. In December 2008, the experiment was approved by the CERN Research Board. At present, the collaboration has 191 participants from 25 institutes. Beam tests have

been performed for advanced prototypes or parts of single sub-detectors, as discussed above. Construction and commissioning will last until 2010, and the first physics run is expected to take place in 2013.

The experiment aims to collect ~ 80 signal events in two years of data taking, with a $\mathcal{O}(\sim 10\%)$ signal acceptance and a total background of less than 10%.

References

- [1] A. J. Buras, M. Gorbahn, U. Haisch, and U. Nierste, Phys. Rev. Lett. **95**, 261805 (2005); J. High Energy Phys. **11** 002 (2006).
- [2] G. Isidori, F. Mescia, and C. Smith, Nucl. Phys. **B718**, 319 (2005).
- [3] G. Buchalla, G. D'Ambrosio, and G. Isidori, Nucl. Phys. **B672**, 387 (2003); G. Isidori, C. Smith, and R. Unterdorfer, Eur. Phys. J. **C 36**, 57 (2004).
- [4] F. Mescia and C. Smith, arXiv:0705.2025 [hep-ph], update for Phys. Rev. **D76**, 034017 (2007).
- [5] J. Brod, M. Gorbahn, and E. Stamou, arXiv:1009.0947 [hep-ph], and references therein.
- [6] G. Isidori, F. Mescia, P. Paradisi, C. Smith, S. Trine, JHEP **0608**, 064 (2006) [hep-ph/0604074].
- [7] Nucl. Phys. **B 763** 35 (2007) [hep-ph/0608123]. M. Blanke, A. J. Buras, A. Poschenrieder, S. Recksiegel, C. Tarantino, S. Uhlig and A. Weiler, JHEP **0701** 066 (2007) [arXiv:hep-ph/0610298]; D. Bryman, A. J. Buras, G. Isidori and L. Littenberg, Int. J. Mod. Phys. **A 21** 487 (2006) [arXiv:hep-ph/0505171].
- [8] A. V. Artamonov *et al.* [BNL-E949 Collaboration], Phys. Rev. **D79**, 092004 (2009) [arXiv:0903.0030 [hep-ex]]; S. Adler *et al.*, Phys. Rev. **D77**, 052003 (2008), arXiv:0709.1000; S. Adler *et al.*, Phys. Rev. **D70**, 037102 (2004), hep-ex/0403034; S. Adler *et al.*, Phys. Lett. **B537**, 211 (2002), hep-ex/0201037.
- [9] From the FlaviaNet Kaon working group, http://www.lnf.infn.it/wg/vus/content/Krare_BSM_new.eps
- [10] NA62 Collaboration, CERN NA62 note, NA62-10-07, <http://na62.web.cern.ch/NA62/Documents/NotesDoc/na62-07-10.pdf>.
- [11] G. Mazza, A. Ceccucci, E. Cortina *et al.*, Nucl. Instrum. Meth. **A617**, 558-559 (2010).

- [12] F. Bucci, G. Collazuol, A. Sergi, Nucl. Instrum. Meth. **A623**, 327-329 (2010).
- [13] A. Antonelli *et al.*, J. Phys. Conf. Ser. **160**, 012020 (2009) [Nucl. Phys. Proc. Suppl. **197**, 224 (2009)].