Rapporto attività LNF 2021

NA62

A. Antonelli (Resp.),
V.Kozhuharov (associato), G. Lanfranchi, S. Martellotti,
M. Martini (associato), G. Tinti (a.r.), M. Moulson, T. Spadaro

in collaboration with
P. Ciambrone, A. Balla (Servizio di Elettronica)

The NA62 Experiment

The branching ratios (BRs) for the extremely rare decays $K \rightarrow \pi\nu\bar{\nu}$ are among the observables in the quark-flavor sector most sensitive to new physics. Because these decays are strongly suppressed and their BRs are calculated very precisely in the Standard Model (SM), they are excellent probes for new physics at mass scales of hundreds of TeV, surpassing the sensitivity of B-meson decays in many SM extensions. Observations of lepton-flavor-universality-violating phenomena are mounting in the B sector. Measurements of the $K \rightarrow \pi\nu\bar{\nu}$ BRs are critical to interpreting the data from rare B decays, and may demonstrate that these effects are a manifestation of new degrees of freedom, fundamentally disrupting the Standard Model. The SM predicts BR($K^+ \rightarrow \pi^+\nu\bar{\nu}$) = $(8.4 \pm 1.0) \times 10^{-11}$. The NA62 experiment at the CERN SPS took data from 2016 to 2018, collecting 20 candidate $K^+ \rightarrow \pi^+\nu\bar{\nu}$ events, allowing this BR to be determined to within about 40%. NA62 resumed data taking in 2021 and will collect about 100 candidate events for a measurement of BR($K^+ \rightarrow \pi^+\nu\bar{\nu}$) to O(10%) precision by the end of LHC Run 3.

The NA62 experiment (**Fig. 1**) makes use of a 75 GeV unseparated positive secondary beam. The total beam rate is 750 MHz, providing ~50 MHz of K^+ mesons. The decay volume begins 105 m downstream of the production target. 6 MHz of kaon decays are observed in the 65-m long fiducial vacuum decay region by means of tracking and particle-identification systems. 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 mrad < θ < 50 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 (LKr) is used to veto high-energy photons at small angle. Additional detectors further downstream extend the coverage of the photon veto system, including the Small-Angle Calorimeter (SAC), to intercept photons that would exit the experiment through the downstream beam pipe, and the Intermediate Ring Calorimeter (IRC), to provide veto coverage between the LKr and the SAC. The IRC and SAC are collectively referred to as the Small-Angle Vetoes (SAV).

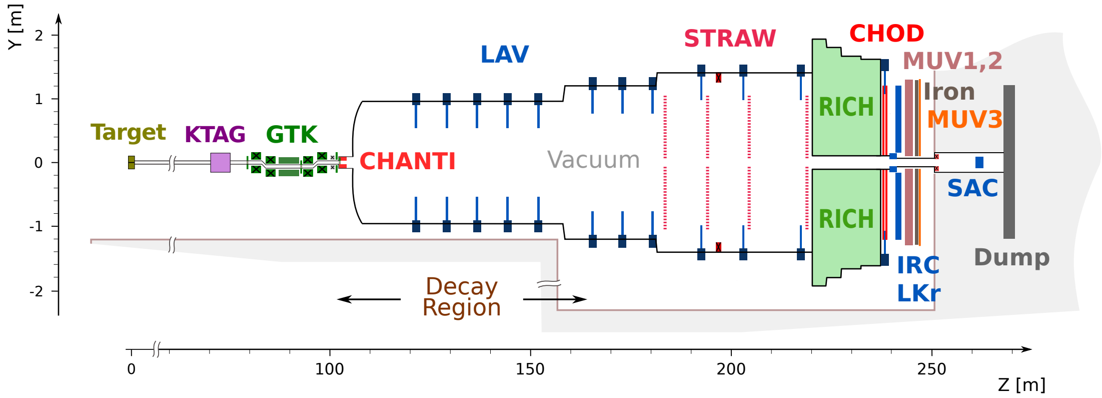

Fig. 1: Schematic view of the NA62 experiment, showing the kaon production target, KTAG Cerenkov K^{+} beam tagger, GTK beam tracker, CHANTI collar veto, LAV large-angle photon vetoes, STRAW straw-tube trackers, RICH ring-imaging Cerenkov detector, CHOD hodoscope, MUV1-3 hadron calorimeters and muon vetoes, LKr calorimeter, and IRC and SAC small-angle photon vetoes.

LNF group responsibilities

The principal responsibility of the NA62 LNF group is in the maintenance, operation, and analysis of data from two of the experiment's main photon detection systems, the Large-Angle Veto (LAV) system and the Small-Angle Veto (SAV) system, as well as providing general support to the experiment, assisting with run planning and coordination, and participating in data taking and data analysis. In 2021, the group also made significant contributions in the coordination of the exotic physics working group and in feasibility studies for the experimental program after the end of LHC Run 3.

LNF group activities: LAV and SAV systems

In 2021, the LNF group prepared the LAV and SAV systems for the restart of NA62 data taking. In particular, the group made the following contributions:

- Thorough diagnostics and repair of the LAV and SAV systems in preparation for data taking in 2021 after three years of shutdown.
- Operation of the LAV and SAV detectors during the 2021 (June-November) run, providing continuous expert support throughout the entire period.
- Improvement and optimization of the simulation and reconstruction code for the LAV and SAV systems.
- Management of data quality, with emphasis on the LAV and SAV detectors.
- Analysis of data acquired in 2016-2018 and measurement of system performance.

The LAV system consists of 12 detector stations arranged at intervals of 6 to 10 m along the vacuum tank along its entire length. Each station consists of four or five rings of lead glass blocks, with the blocks staggered in azimuth in successive rings. The total depth of a five-layer station is 27 radiation lengths. This structure guarantees high efficiency, hermeticity, and uniformity of response. The readout chain for the LAV stations consists of two different types of boards, a dedicated front-end board (LAV-FEE) developed for the LAV detector, and a common digital readout board (TEL62) used by many of the NA62 detectors. The LAV detectors and the front-end electronics were designed and constructed at LNF between 2008 and 2014.

The small-angle veto detectors, SAC and IRC, are shashlyk-type electromagnetic calorimeters that provide veto coverage for photons with polar angles down to zero degrees. They are exposed to a very high rate of photons from kaon decays and, for the IRC, muons from pion and kaon decays. The IRC was assembled at LNF in 2014. The SAC and IRC signals are read out with the LAV-FEE and TEL62 boards described above.

LNF group activity: $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ data taking and analysis

The NA62 experiment collected its first data sample successfully in 2016-2018 for a total of about $4{\times}10^{12}$ kaon decays in fiducial volume. The NA62 in-flight technique for the measurement of $\mathrm{BR}(K^+ \rightarrow \pi^+ \nu\bar{\nu})$ has been established and proven to work. The first physics result on $K^+ \rightarrow \pi^+ \nu\bar{\nu}$, based on the 2016 data set, was obtained in 2018 and published in early 2019 [6]; the results of the analyses of the 2017 and 2018 data sets, were published in 2020 and 2021, respectively [7, 4].

For the analysis, a blind procedure was adopted, with the signal and control regions kept masked until the evaluation of expected signal and background was completed. Control samples of $K^+ \rightarrow \pi^+\pi^0(\gamma)$, $K^+ \rightarrow \pi^+\nu(\gamma)$ and $K^+ \rightarrow \pi^+\pi^+\pi^-$ decays are employed for background studies. The analysis is mostly based on kinematic cuts and particle identification. The invariant $m^2_{miss} = (p_{K+} - p_{\pi+})^2$ is used to discriminate between the signal and background kinematics, where p_{K+} and $p_{\pi+}$ are the K^+ and π^+ 4-momenta, respectively. **Fig. 2** shows the distribution of the selected K^+ decays in the (m^2_{miss}, $P_{\pi+}$) plane, with $P_{\pi+}$ the magnitude of the π^+ 3-momentum. Regions populated mostly by $K^+ \rightarrow \pi^+\pi^0(\gamma)$, $K^+ \rightarrow \pi^+\nu(\gamma)$ and $K^+ \rightarrow \pi^+\pi^+\pi^-$ are visible. Two signal regions are defined: the region at lower (higher) m^2_{miss} is referred as region 1 (2). The m^2_{miss} resolution is on the order of 10^{-3} GeV^2/c^4 for the $K^+ \rightarrow \pi^+\pi^0(\gamma)$, and this drives the choice of the boundaries of these regions. For the analysis of the 2016 and 2017 data, the momentum range was restricted to $15 < P_{\pi+} < 35$ GeV/c, ensuring at least 40 GeV/c of missing energy, thus improving significantly the efficiency for π^0 detection. For the 2018 data, a broader momentum range was used to define region 2, $15 < P_{\pi+} < 45$ GeV/c, since the $K^+ \rightarrow \pi^+\pi^0(\gamma)$ background was seen to be under control and the $K^+ \rightarrow \mu^+\nu(\gamma)$ background is much lower than in region 1. The momentum cut costs roughly half of the signal acceptance. The calorimeters and RICH provide π^+ identification and the photon veto system ensures rejection of photons with angles from 0 up to 50 mrad with respect to the beam axis.

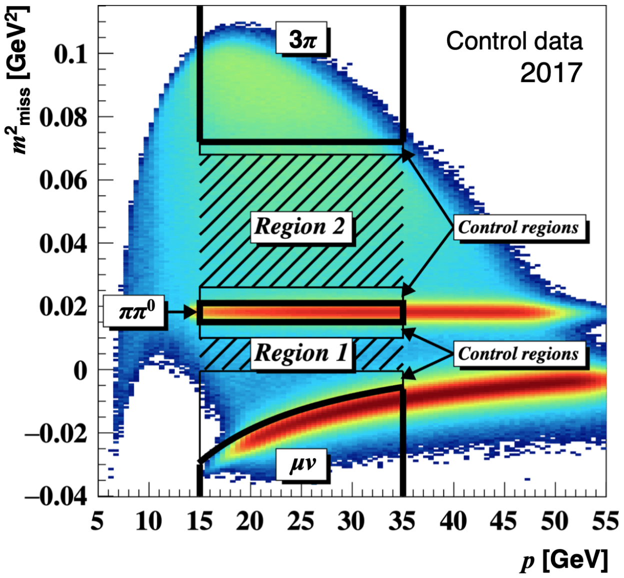

Fig. 2: Left: m^2_{miss} as a function of $P_{\pi+}$ for control data after K^+ decay selection. Signal and background control regions are illustrated, as are regions for the selection of control samples of background events.

The fraction of background events entering each signal region via the reconstructed tails of the corresponding m^2_{miss} peak is modeled with data control samples and corrected with MC simulation for biases induced by the selection criteria. An additional source of background is from decays or interactions of K^+ mesons occurring upstream of the final collimator, in which a daughter pion mimics a signal event by being accidentally matched to random beam particles that are nearby in time. The geometrical distribution of these upstream events is used to define the analysis cuts and estimate the background for the selected signal sample.

The single-event sensitivity is defined as $1/(N_K\ \varepsilon_{\pi+\nu\nu})$, where N_K is the number of K^+ decays in the fiducial volume and $\varepsilon_{\pi+\nu\nu}$ is the signal efficiency for the selection. Both are derived from the data using control samples and from simulation. The sensitivity obtained in each year of data taking, together with the estimated total background and number of candidate events observed, is summarized in **Tab. 1**. The distribution in the m^2_{miss} vs. $P_{\pi+}$ plane of the 17 selected events in 2018 data is shown in **Fig. 3**.

	2016	2017	2018
Days of running	45	160	217
Typical intensity, % of nominal	40	55	65
Kaon decays in FV	1.2×10^{11}	1.5×10^{12}	2.7×10^{12}
Sensitivity (10^{-10})	3.15 ± 0.24	0.389 ± 0.024	0.111 ± 0.007
Expected signal (SM)	0.267 ± 0.037	2.16 ± 0.28	7.6 ± 1.0
Expected background	$0.15^{+0.09}_{-0.04}$	1.46 ± 0.30	$5.4^{+1.0}_{-0.8}$
Candidates observed	1	2	17

Tab. 1: Run statistics, sensitivity, expected number of signal and background events, and number of candidates observed for each year of NA62 data taking, 2016-2018.

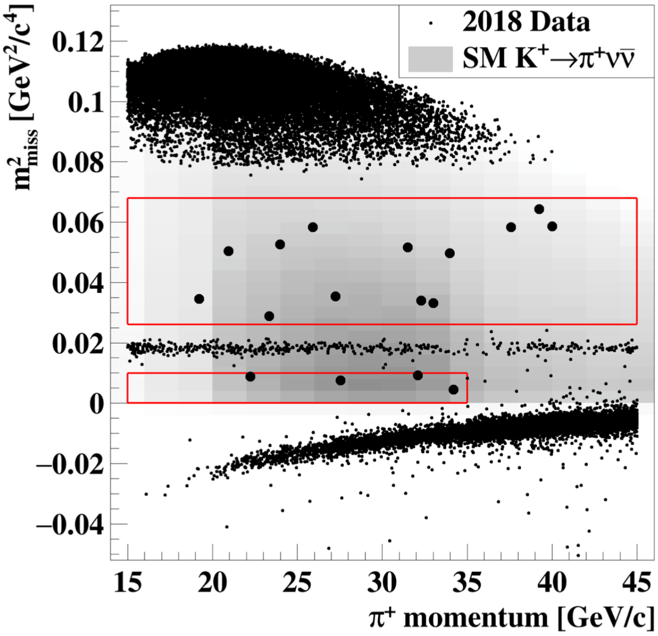

Fig. 3: m^2_{miss} vs. $P_{\pi+}$ distribution for 2018 data, showing 17 selected events.

The measurement of the branching ratio [4] is obtained by combining the data samples from 2016, 2017, and 2018,

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \left(10.6^{+4.0}_{-3.4}{}_{\mathrm{stat}} \pm 0.9_{\mathrm{syst}}\right) \times 10^{-11}$$

from which the $K^+ \to \pi^+ \nu\bar{\nu}$ decay is observed for the first time with 3.4σ significance. This is the most precise measurement so far. It is compatible with the SM expectation to within one standard deviation. The NA62 measurement, together with the preliminary KOTO limit for the analogous K_L branching ratio and theoretical predictions from a number of new-physics models, is illustrated in **Fig. 4**. Some of the models predict large deviations from the SM expectation and seem to be excluded. More precise measurements would help to clarify the situation.

During most of 2016-2018 data taking, the beam intensity was kept stable at about 50-70% of the nominal value (**Tab. 1**). This mode of operation was optimized for efficient data taking. For 2021, several modifications were made to the experiment to reduce background from upstream decays and interactions, including the rearrangement of beamline elements around GTK achromat, the addition of a fourth GTK beam tracker station, and the introduction of a new veto hodoscope upstream of the decay volume as well as additional veto counters around the downstream beam pipe. In 2021, the experiment took data at the nominal value of the beam intensity for practically the entire run.

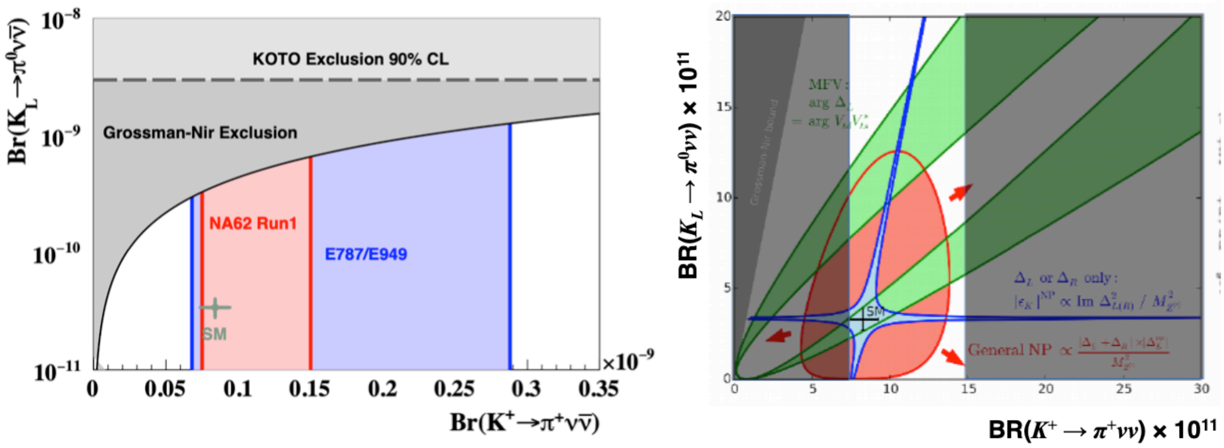

Fig. 4: Comparison between K_L and K^+ branching ratio measurements and different theoretical models. Left: Region allowed by NA62 2016-2018 measurement and model independent Grossman-Nir bound derived from NA62 result. Right: bands of correlation expected from new physics models involving minimal flavor violation (green), new physics deriving from couplings to quarks of definite chirality, e.g., models with modified Z couplings or a Z' coupling to left- or right-handed quarks only (blue), and in new-physics models without these characteristics (red).

Contributions to the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis and search for π^0 decays to invisible states

The LNF group has made significant contributions to essential aspects of the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis related to the photon vetoes, specifically, in developing and tuning the conditions applied to reject photon-induced activity in the LAVs, and precisely determining the photon detection efficiency and the NA62 veto capability against $\pi^+\pi^0$ background.

The use of information from the LAVs was tuned to optimize background rejection while reducing the loss of signal events to accidental coincidences. A matching window of ±3 ns between the event time and the LAV hit time was chosen, and for the 2018 analysis, events with in-time activity in LAV stations upstream of the K^+ decay vertex are kept, thus increasing the signal efficiency by 3% in absolute terms. We have demonstrated that the $\pi^+\pi^0$ background is basically unchanged after the LAV-based veto condition is loosened as described.

A data-driven multivariate analysis making use of the boosted decision tree (BDT) method is under development to further reduce losses from accidental coincidences on the LAVs. The whole 2018 data sample is being used to train and test the BDT and to evaluate the performance of the new LAV veto algorithm for the selection of $\pi^+\nu\bar{\nu}$ events. The aim of the multivariate analysis is to discriminate events that must be rejected (mainly containing activity from photons from $\pi^+\pi^0$ decays and charged pion related signals from $\pi^+\pi^+\pi^-$ final states) from muon-halo signals randomly in time with the event. Geometrical information and intrinsic characteristics of the hits in the LAV blocks are exploited. An enriched sample of physics background is obtained from $\pi^+\nu\bar{\nu}$-triggered data using the signal selection with photon vetoes applied in all calorimeters except the LAVs. The random-veto sample is obtained from a $K_{\mu2}$ event selection applied to control-triggered data in which the LAV veto in the L1 trigger is emulated. This sample is expected to contain only hits on the LAVs from events in accidental coincidence, and the emulation of the L1 trigger LAV veto logic guarantees that the random hits on the LAVs have the same characteristics expected in the $\pi^+\nu\bar{\nu}$-triggered events. Since the LAV veto is based on hits that are inside a time window of ±3 ns of the reconstructed track time, these hits are studied in the BDT. Two different BDT classifiers are under development to treat events with either one or two in-time hits. The small contribution from events with more than two in-time hits is rejected. This multivariate analysis is currently being optimized.

A tag-and-probe method exploiting a sub-sample of $K^+ \to \pi^+\pi^0$ events triggered by a minimum-bias condition has been used to thoroughly study the single-photon detection efficiency and the corresponding veto capability against $\pi^+\pi^0$ background. Events with one photon detected in the LKr calorimeter are used to determine the expected momentum and direction of the other photon from the $\pi^0 \to \gamma\gamma$ decay. The efficiency is evaluated as the fraction of events in which the second photon is matched. Various sources of method bias have been studied in detail. In particular, the bias deriving from resolution effects, photon conversions upstream of the LKr, and random-veto activity fulfilling the photon matching conditions have been evaluated and corrected. The photon detection inefficiencies (**Fig. 5**) have been evaluated separately for each of the detectors of the photon-veto system.

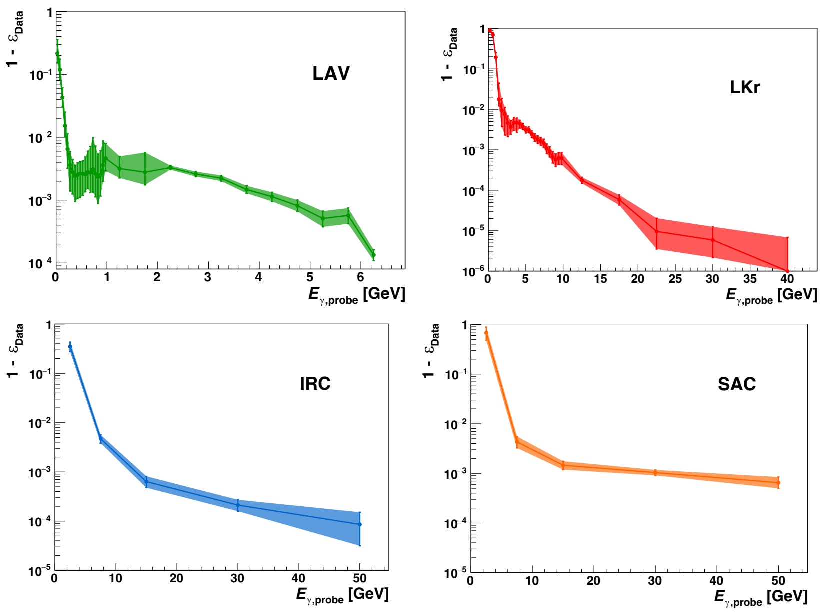

Fig. 5: Photon detection inefficiencies for the four detectors composing the NA62 photon-veto system. The error bands correspond to a 68%-CL coverage.

The inefficiencies have been used as weights for simulated $K^+ \to \pi^+\pi^0$ events to determine the expected veto inefficiency. In the π^+ momentum range 25-40 GeV/c, we expect to veto all but a fraction of approximately 3×10^{-9} of the $\pi^0 \to \gamma\gamma$ decays. This study confirms that the NA62 LAV efficiency meets design specifications and provides validation of the $K^+ \to \pi^+\pi^0$ background estimate for the $\pi^+\nu\bar{\nu}$ analysis. Additionally, this study makes possible a high-sensitivity search for π^0 decays to invisible particles. The result, published in 2021 [1], has a significant contribution from the LNF team and improves by a factor of 60 on the past literature. It can be interpreted as a search for the emission of an invisible particle X in the decay $K^+ \to \pi^+X$, where the X mass is around the π^0 mass. Models in which X is an axion-like particle or a dark scalar are constrained significantly with respect to previous results.

Analysis of exotic particle decays

Thanks to its high intensity beam and detector performance (redundant particle-identification capability, extremely efficient veto system and high-resolution measurements of momentum, time, and energy), NA62 can achieve sensitivities to long-lived light mediators in a variety of new-physics scenarios. Such feebly-interacting particles are expected to be produced after interaction of the proton beam with the most upstream collimator (TAX), approximately 23 m downstream of the NA62 target T10. The decay of these "exotic" mediators into SM particles are searched for in the NA62 decay volume, more than 100 m downstream of T10. Two schemes are in use. First, during standard data taking, 40% of the protons punch through T10 and interact in the TAX: dedicated triggers have been designed to collect signal candidates in parasitic mode. Second, a dedicated setup has been tested for short periods, in which the T10 target is lifted and the entire proton beam is dumped into the TAX collimator (beam-dump, or BD, mode). The corresponding analyses and activities are a responsibility of the LNF group.

In 2021, significant progress was made on the analysis of data taken with parasitic triggers and in the BD configuration. As an example, we discuss here the progress in modeling the background for the search for an axion-like-particle (ALP) decaying to two photons.

A data set with statistics equivalent to a few x 10^{16} protons on target (POT) has been collected in BD mode in 2016-2018 to make possible a first, comprehensive search of exotic particle decays. The search for ALP decays to two photons is particularly advanced and should make it possible to explore a new region of the parameter space [8]. Two main sources of background have been identified:

- Muon-halo showers initiated producing photons in the beam elements just upstream of the NA62 decay volume, which can pollute the sample for total LKr energies below 20 GeV;
- Tertiary production of neutral hadrons such as K_S or Λ decaying to neutral final states, which can mimic the ALP signal for LKr energies above 20 GeV.

The challenging task of achieving an *a priori* background estimate has been tackled using biased simulation techniques, as well as by exploiting studies ongoing within the recently restarted PBC effort. The background estimate for muon-halo showers is being evaluated using control samples with in-time activity detected by the upstream LAV stations. For the neutral hadrons, secondary K^+ mesons produced in the TAX and surviving up to the last elements of the beam line upstream of the decay volume are simulated. These K^+ can produce K_S and Λ tertiaries in the so-called final collimator. Preliminary results show a good agreement between the distribution shapes for data and expected background when the decays $K_S \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi^-$ are reconstructed. The distributions of the K_S momentum and vertex z-coordinate are shown in **Fig. 7** for data and simulation.

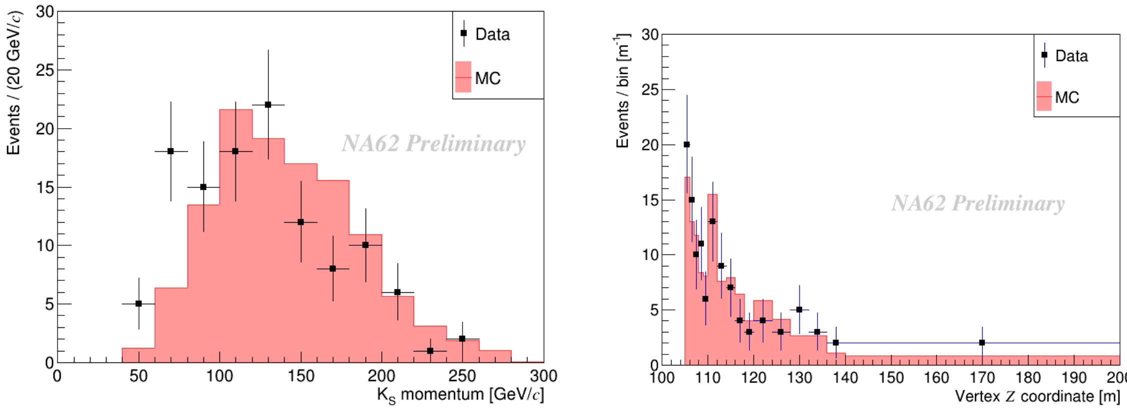

Fig. 7: Distributions from reconstructed $K_S \rightarrow \pi^+\pi^-$ decays: momentum (left panel) and z-coordinate of the decay vertex (right panel). Data corresponding to $1.6\text{x}10^{16}$ POT (117 events, black dots, error bars statistical only) are compared to the simulation obtained from a combination of G4BeamLine and NA62MC Monte Carlo techniques (red, normalized to the data integral).

A statistics equivalent to a few x 10^{17} protons on target (POT) in parasitic mode has been collected to allow searches of exotic particle decays to di-muon pairs. The analysis of these data has shown that the background from both accidental activity and in-time track pairs is well under control. The sensitivity achievable with a future data set corresponding to a few 10^{18} POT would considerably improve on that of the present data set. The improvement in background rejection obtained from the new anti-halo hodoscope in operation from 2021 onward is under evaluation.

The possibility of collecting around 10^{18} POT in upcoming data taking in beam-dump configuration should allow sensitivities well beyond the past experiments for a multitude of model dependent [10] and model-independent [11] physics cases. In preparation, a number of readiness studies have been carried out. Simple and easily reversible optimizations of the beam line have been defined, guaranteeing a reduction of the muon-halo background by a factor of 4 at the trigger level [9], and an improved trigger setup has been defined, guaranteeing acceptance to visible exotic-particle decays both to charged and neutral final states over a broader range in exotic-particle mass than before. The charged modes will be triggered requiring two or more in-time

NewCHOD tiles, thus allowing sensitivity starting from the start of the kinematic threshold. The neutral modes will be triggered requiring one or more LKr energy deposits, with a threshold low enough to allow collection of a muon control sample to be exploited for quick monitoring of the efficiency of the charged trigger. The trigger improvements in particular were tested during a 9-day acquisition in beam dump mode coordinated by the Frascati team and carried out during the 2021 NA62 run. During this run, an intensity of 150% of the NA62 nominal intensity was achieved. A total of about 1.5 x 10^{17} POT were collected, which will allow a thorough test of the trigger scheme as well as validation of the a priori background estimate and evaluation of the background mitigation strategy.

The LNF group and the future of NA62:

Since the start of data taking, the LNF group has had a leading role in planning the future of the rare-kaon decay program at CERN. For the past few years, this effort has focused mainly on design studies for KLEVER, an experiment to measure BR($K_L \to \pi^0 \nu\nu$) at the CERN SPS with a sensitivity of about 60 signal events at the SM BR and a signal-to-background ratio of about 1. KLEVER is intended as a follow up on NA62, reusing as much of the existing apparatus as possible, but until recently, the transition path from NA62 to KLEVER was not clearly defined. In particular, possibilities for high-statistics measurements of BR($K^+ \to \pi^+ \nu\bar{\nu}$) decays in a future generation of NA62 were unexplored.

In 2020, a long-term plan for a program at a high-intensity kaon facility was outlined, consisting of the following phases:

1. A high-statistics K^+ experiment to measure BR($K^+ \to \pi^+ \nu\bar{\nu}$) to 5% ("NA62x4")
2. A high-statistics K_L experiment to measure BR($K_L \to \pi^0 \nu\bar{\nu}$) to 20% (KLEVER)
3. A transitional experiment making use of a K_L beam for KLEVER and the downstream detector with tracking and PID for NA62x4 to investigate other rare K_L decays such as $K_L \to \pi^0 \ell^+ \ell^-$.
4. Additional running in beam-dump mode to attain the highest possible precision in searches for exotic physics, as discussed in the previous section, to the maximum extent compatible with the rare kaon decay program.

For the KLEVER phase, extension of the NA62 beamline by 150 m is required to mitigate background from $\Lambda \to n\pi^0$ decays. The NA62x4 phase therefore seems more likely to be ready by the end of LS4, currently foreseen at the start of 2028. The program outlined above was presented in a Letter of Intent [12] and White Paper [13] for Snowmass 2021, and is now the basis for NA62/KLEVER participation in Physics Beyond Colliders. A proposal to the CERN SPSC is in preparation.

For the experimental program outlined above, many of the same detectors would be used in all of the different phases. In particular, the calorimeter and photon veto systems conceptually designed for KLEVER would be used in NA62x4. R&D work on the two important detector systems for future experiments—the main electromagnetic calorimeter, to replace the NA48 LKr calorimeter, and the KLEVER small-angle calorimeter (SAC)—has been in progress at Frascati for the past few years, in part within the framework of the AIDAinnova research infrastructure. Participation of several KLEVER collaborators from INFN in AIDAinnova began in November after project approval, with M. Moulson serving as INFN task leader for 8.3.1 (innovative crystals for calorimetry). Together with I. Sarra and the LNF muon collider group, beam time at the BTF-2 beamline was scheduled for 2021 to test a small prototype PbF_2 segmented-crystal calorimeter (CRILIN) that is nearly identical in design to the KLEVER SAC. Data were collected in parasitic mode during BTF-2 commissioning from 28 Jun to 9 July, with the help of L. Foggetta and C. Di Giulio (**Fig. 8**). Two PbF_2 crystals (10 x 10 x 40 mm^3) were exposed to the 450-MeV single electron beam, each read out with four 4 mm^2 SiPMs (front-end electronics from the Mu2e experiment were used for test). This allowed debugging of the setup and preliminary measurements of the time resolution obtainable.

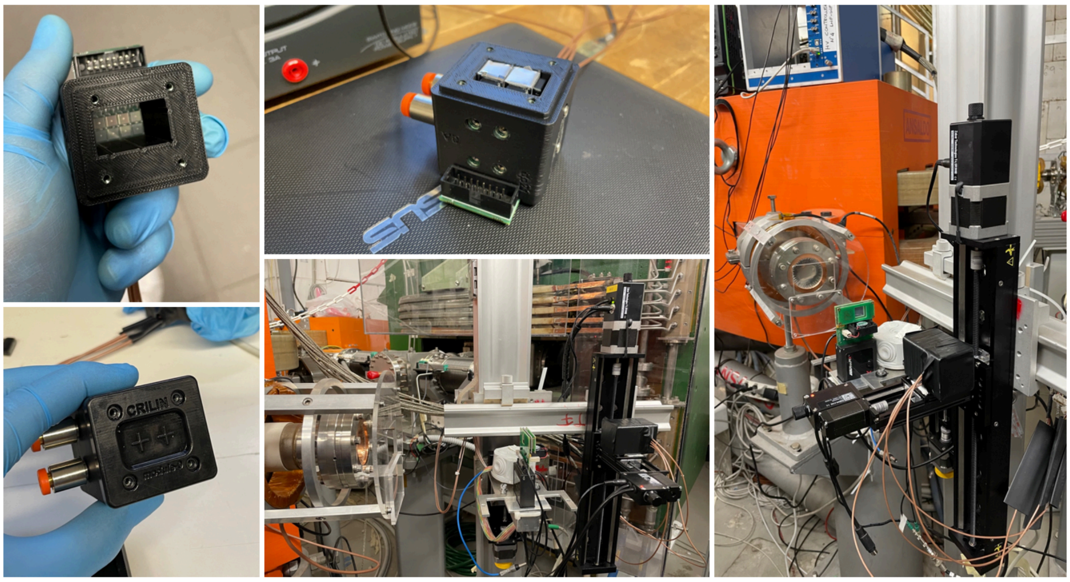

Fig. 8: CRILIN/KLEVER beam test at the BTF, July 2021. Clockwise from lower left: CRILIN module zero closed and open, showing SiPMs for light readout, CRILIN module zero with two PbF2 crystals mounted, CRILIN module zero on the BTF-1 straight beamline for data taking.

The CRILIN module zero prototype was also tested in the CERN SPS H2 beamline 18-25 August 2021, as part of a broader investigation into advanced crystal calorimetry for KLEVER, using electron beams of energy 20-120 GeV. The experimental setup (**Fig. 9**) also allowed for a tagged photon beam to be realized. The photon beam was created from the radiation of the electron beam from a copper target. After passing through the target, the beam electrons were swept into an array of lead-glass calorimeter blocks, to allow the photon energy to be determined event by event. High-energy shower initiation in several crystals was studied, including the PbF2 crystals tested at the BTF, a single, aligned PbF2 crystal fit into the CRILIN module, with the crystal axis parallel to the the incident electron beam, and a similarly sized sample of aligned lead tungstate (PWO). The CRILIN module was placed on a remote-controlled goniometer to allow studies of the electromagnetic shower development as a function of angle of incidence with respect to the crystal axis. Forward charged multiplicity and forward energy measurements were made with supplementary calorimeters downstream of the CRILIN module.

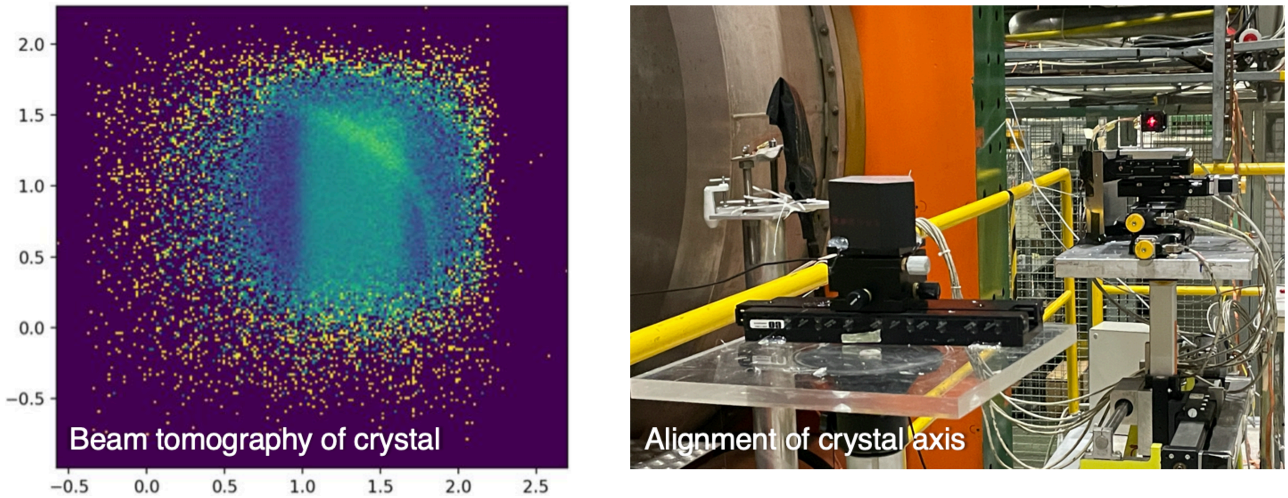

Fig. 9: CRILIN/KLEVER test beam at the CERN SPS H2 beamline in August 2021. Left: Tomography of crystals as seen with electron beam. Right: Setup for laser alignment of the crystal axis on the H2 beamline.

Significant progress was also made on analysis of data taken together with the AXIAL collaboration in the H2 beamline at the SPS in August 2018 with a similar setup, to study shower initiation by tagged photons in a 10-mm-thick tungsten crystal to be used in the KLEVER beamline to clean prompt photons from the neutral beam. In 2021, a paper on the results of this test was submitted for publication [14]. When the ⟨111⟩ crystal axis was aligned with the beam to within 2.5 mrad, the multiplicity of charged particles was found to be enhanced by a factor 1.6–2.3 for photon energies over the range of 30–100 GeV. Simulations validated by this result that suggest that a crystal of this type could be used to reduce the thickness of the photon converter by 15–20% at no cost in effectiveness. Such a solution appears to present little technical difficulty.

PUBLISHED PAPERS

1) Search for π^0 decays to invisible particles
E. Cortina Gil et al. (NA62 collaboration), J. High Energ. Phys. 2102 (2021) 201
doi.org/10.1007/JHEP02(2021)201

2) Search for a feebly interacting particle X in the decay $K^+ \to \pi^+ X$
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3) Search for K^+ decays to a muon and invisible particles
E. Cortina Gil et al. (NA62 collaboration), Phys. Lett. B 816 (2021) 136259
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CONFERENCE TALKS

A. Antonelli:

- Latest results from NA62, 10th International Workshop on Chiral Dynamics, Beijing, 15 November 2021

S. Martellotti:

- Recent kaon results at NA62, 19th Conference on Flavor Physics and CP Violation, Shanghai, China, 10 June 2021

M. Moulson:

- Next-generation kaon experiments (plenary), 19th Conference on Flavor Physics and CP Violation, Shanghai, China, 11 June 2021
- Next-generation kaon experiments (plenary), XV International Conference on Heavy Quarks and Leptons, Warwick, UK, 17 September 2021

G. Tinti:

- Latest results from the NA62 experiment at CERN, 32nd Rencontres de Blois on Particle Physics and Cosmology, Blois, France, 20 October 2021