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Search for exotic processes with the NA62 experiment

R. Lollini(1)(2) on behalf of the NA62 Collaboration

(1) *Dipartimento di Fisica e Geologia, Università degli Studi di Perugia - Perugia, Italy*
(2) *INFN, Sezione di Perugia - Perugia, Italy*

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Summary. — NA62 is a fixed target experiment at the CERN SPS which aims at measuring the branching fraction of the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$ with an unprecedented precision. With its high-energy beam and a hermetic detector coverage, NA62 has also the opportunity to directly search for a plethora of long-lived exotic particles, such as heavy neutral leptons, axion-like particles and dark photons. We will review the status of such searches and give prospects for future data taking at NA62.

1. – The NA62 experiment

NA62 is a fixed target experiment located at CERN which aims at measuring the branching ratio of the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$ with an unprecedented precision. NA62 makes use of a 75 GeV/c charged hadron beam ($\sim$6%K^+) which is produced by a 400 GeV/c proton beam extracted from the SPS interacting with a beryllium target. The theoretical prediction for the branching fraction of the aforementioned process is $BR_{th}(K^+ \to \pi^+\nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$ [1].

A number of theories beyond the Standard Model [2-7] predict a significantly different value for this branching ratio: since the SM prediction has a very small uncertainty, a precise experimental value will be an important test for the unitarity of the CKM matrix. The branching ratio was already measured by the experiments E787 and E949 at BNL and it is consistent with the Standard Model, although the associated uncertainties are very large: $BR_{exp}(K^+ \to \pi^+\nu\bar{\nu}) = 17.3^{+11.5}_{-10.5} \times 10^{-11}$ [8].

In addition to this, NA62 has the potential to explore several new physics models which include the search for heavy neutral leptons (HNL), axion-like particles (ALP) and invisible vector bosons. The results and prospects for this searches are described in the following sections.

2. – Heavy neutral lepton

The νMSM is an extention of the Standard Model that is consistent with the existence of dark matter, baryon asymmetry and non-zero neutrino masses. The model predicts three heavy sterile neutrinos N_i, weakly coupled to classical neutrinos [9].

In the NA62 detector, HNL can be produced in meson decays like $K^+ \to l^+ N$, where $l^+ = (e^+, \mu^+)$. The branching ratio for these processes is given by $BR(K^+ \to l^+ N) = BR(K^+ \to l^+ \nu) \cdot \rho_l(m_N) \cdot |U_{l4}|^2$, where $\rho_l(m_N)$ is a kinematic factor and $|U_{l4}|^2$ is the mixing to SM neutrinos.

NA62 collected $\sim 3 \times 10^8 K^+ \to e^+ \nu$ and $\sim 1 \times 10^8 K^+ \to \mu^+ \nu$ decays during the 2015 data taking. The results are shown in fig. 1. No signal events were observed and NA62 put upper limits on the couplings of HNL in the mass range $[170, 448]\,\mathrm{MeV}/c^2$ for $|U_{e4}|^2$ and $[250, 373]\,\mathrm{MeV}/c^2$ for $|U_{\mu 4}|^2$ [10]. The analysis of 2016–2018 data is ongoing and it could further improve the limits on the HNL masses and couplings.

3. – Axion-like particle

In order to perform hidden sector searches, NA62 can be run in dump mode: two copper collimators (the so-called TAXes) can be closed and hence act as a beam dump. The NA62 detector is particularly suitable for ALP searches: in the beam dump ALP would be produced via Primakoff production, which is both the cleanest and the dominant production mode, and they would decay into a pair of γ's that can be detected by the hermetic photon veto of NA62 [11]. Unfortunately the beam dump operation mode is incompatible with the $K^+ \to \pi^+ \nu \bar{\nu}$ measurement. On the other hand, as shown in fig. 1, a single day of data taking in dump mode would make NA62 competitive with other experiments looking for ALP [11].

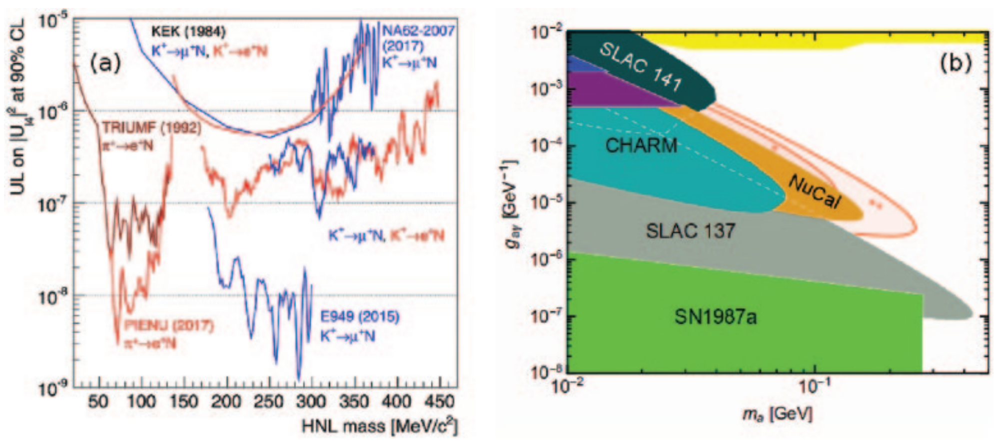

Fig. 1. – (a) UL at 90% CL on $|U_{l4}|^2$ obtained for each assumed HNL mass compared to the limits established by earlier HNL production searches. (b) Expected sensitivity of NA62 in the $(m_a, g_{a\gamma})$ plane for a number of protons on target roughly equivalent to one day (*) and one month (**) of data taking. m_a and $g_{a\gamma}$ are, respectively, the ALP mass and the ALP-γ coupling. The NA62 projected sensitivity is compared with the constraints from other experiments.

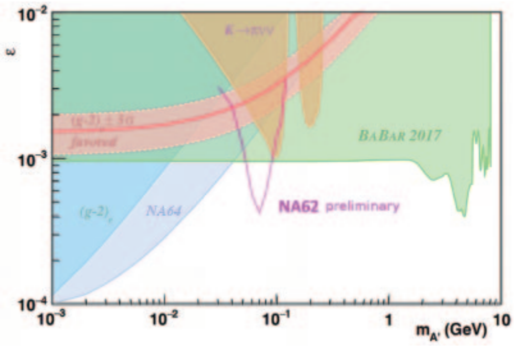

Fig. 2. – 90% CL exclusion plot in the $(\epsilon, M_{A'})$-plane for $\pi^0 \to \gamma A'$ events with an undetected A'. The limits from other experiments [12-14] are shown together with the NA62 preliminary result obtained with the 5% of 2016 data.

4. – Dark photon

In a number of hidden sectors models, an extra $U(1)$ gauge simmetry generates an invisible vector boson A', or *dark photon*, acting as a portal between the SM and the dark sector [15]. Since the dark photon is supposed to have a small coupling to the classical photon, if this exotic particle exists the following decay chain could be observed:

$$K^+ \to \pi^+\pi^0, \qquad \pi^0 \to \gamma A', \qquad A' \to \text{ invisible},$$

where A' is not detected. In the squared missing mass distribution, a peak is expected around the mass of the dark photon $M^2_{A'}$. The squared missing mass is defined as $M^2_{miss} = (P_K - P_\pi - P_\gamma)^2$, where P_K, P_π and P_γ are, respectively, the 4-momenta of the K^+, the π^+ and the γ. The main contribution to the background is given by the decay $\pi^0 \to \gamma\gamma$ when a photon is lost: in this case, M^2_{miss} peaks around zero.

The results of NA62 are shown in fig. 2 and they are obtained using 1.5×10^{10} K^+ decays, corresponding to about the 5% of data collected in 2016: no statistically significant excess was observed and upper limits were computed in the $(\epsilon, M_{A'})$-plane.

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