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Study for an experiment to measure the $K_L \to \pi^0 \nu \bar{\nu}$ decay at CERN

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Summary. — The $K \to \pi\nu\nu$ decays are *flavour-changing neutral current* (FCNC) processes, very suppressed in the Standard Model (SM). The latter, moreover, predicts their branching ratios (BR) with high precision, making them excellent probes of new physics. The NA62 experiment at the CERN Super Proton Synchrotron (SPS), currently taking data, is measuring the BR of the $K^+ \to \pi^+\nu\bar{\nu}$ decay. The KOTO experiment at JPARC, using a low-energy K_L beam, foresees to reach the SM sensitivity for $K_L \to \pi^0\nu\bar{\nu}$ by 2021. A complementary measurement of $K_L \to \pi^0\nu\bar{\nu}$ exploiting part of the NA62 existing apparatus could be possible at the SPS with a high-energy K_L beam. Ongoing studies indicate the possibility of observing 60 decay events in 5 years of data taking with a signal-to-background ratio of 1.

1. – The $K \to \pi\nu\nu$ processes in the SM and beyond

The $K \to \pi\nu\nu$ decays are FCNC processes [1]. They are therefore forbidden at *tree level* and can only occur through higher-order diagrams such as *penguin* and *W box* diagrams in the SM. By virtue of the two neutrinos in the final state, which can only be produced by weak interactions through the *hard GIM mechanism*, the SM also predicts their BRs with theoretical uncertainties of the order of only a few percent. The SM predictions for the charged and the neutral channels are $BR(K_L \to \pi^0\nu\bar{\nu}) = (3.4\pm0.6)\times10^{-11}$ and $BR(K^+ \to \pi^+\nu\bar{\nu}) = (8.4\pm1.0)\times10^{-11}$. Being ultra-rare processes with very precise theoretical predictions, these decays constitute excellent experimental probes. A combined measurement of the BR of the charged and the neutral channels constrains the *unitarity triangle* independently of B mesons decays. It, moreover, allows to discriminate between several scenarios of physics beyond the SM (fig. 1).

The fixed-target experiment NA62 at the CERN SPS, currently taking data, expects to make the most precise measurement of the BR of $K^+ \to \pi^+\nu\bar{\nu}$ [2]. At NA62, secondary beam kaons with 75 GeV/c average momentum decay *in flight*. Approximately 30 events are expected by the end of 2018. The KOTO experiment at JPARC, which employs a low-energy beam of K_L with 2.1 GeV/c average momentum, expects to reach the SM sensitivity for $K_L \to \pi^0\nu\bar{\nu}$ by 2021, with a possibility to collect up to 100 events at a later stage following substantial upgrades of the detector [3]. At the CERN SPS, a

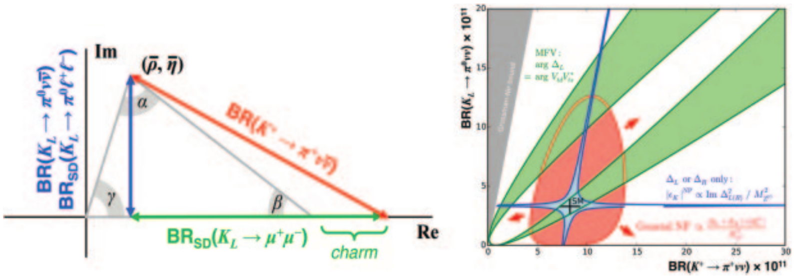

Fig. 1. – Unitarity triangle with constraints coming from kaon physics (left), combined predictions for $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ according to different new physics scenarios (right).

complementary measurement could be made by using a high-energy K_L beam with an average momentum of 97 GeV/c during a future SPS Run and reusing part of the NA62 infrastructure. A high-energy beam has the advantage of requiring a smaller angular coverage for the decay products thanks to their large forward momentum.

2. – A measurement of the $K_L \to \pi^0 \nu\bar{\nu}$ decay at the CERN SPS

The main experimental challenge lies in the impossibility to know precisely the momentum of neutral kaons in the beam. The experimental signature of the decay consists in a pair of photons with unbalanced transverse momentum and no other activity in the detector [4]. The main backgrounds come from K_L decays to two and three neutral pions, and the $K_L \to \pi e \nu(\gamma)$, $\Lambda \to \pi^0 n$, $n+$ gas $\to X\pi^0$ decays. They can be suppressed by using photons and charged particles vetoes, by cutting on the transverse momentum and by ensuring hard vacuum in the fiducial volume (FV). The kinematic constraint $m_{\gamma\gamma} = M_{\pi^0}$ is employed to reconstruct the decay vertex, also useful to suppress background.

The detector would consist, starting from the target, of veto sub-detectors to reject upstream decays of the K_L, 26 new large-angle photon veto stations (LAV), the NA62 liquid krypton electromagnetic calorimeter (LKr), small angle photon vetoes to reject high-energy photons escaping from the LKr beamhole, and charged particle veto against particles reconstructed as fake π^0 in the calorimeter. Ongoing studies are focused on optimizing the performance of the detector and possible alternatives to some of the subdetectors are being explored. In particular, replacing the NA62 LKr with a longitudinally segmented Shashlik would provide better time resolution while allowing reconstruction of the direction of incoming particles. Investigations include the possibility of adding a pre-shower detector in front of the LKr, changing the production angle to minimize the flux of Λ hyperons, and increasing photon detection through pair production in tungsten crystals (studies in collaboration with AXIAL). Finally, the physics scope may be widened by adding a charged particles spectrometer to the setup.

With the described setup for a CERN SPS experiment, about 60 events of $K_L \to \pi^0 \nu\bar{\nu}$ can be collected in 5 years of data taking with a signal-to-background ratio of about 1.

REFERENCES

[1] Buras A.J., Buttazzo D., Girrbach-Noe J. and Knegjens R., *JHEP*, **11** (2015) 33.
[2] Cortina Gil E. *et al.*, *JINST*, **12** (2017) P05025.
[3] KOTO Collaboration, *Prog. Theor. Exp. Phys.*, **2017** (2017) 021C01.
[4] Moulson M. *et al.*, *J. Phys.: Conf. Ser.*, **800** (2017) 012037.