NA62 Kaon Physics Handbook
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Executive Summary

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The Scientific Program started with an introduction to the NA62 experiment. The fortunate combination of having a machine like the CERN SPS available to perform fixed target experiments while serving as an injector for the LHC was recalled. The current schedule of CERN foresees to run the LHC until at least 2035, with regular stops (Long Shutdowns) of about 18 - 24 months every three years of data taking.

It is assumed that if a compelling physics case can be made, this line of research could continue into the future with suitable detector improvements and possible changes to the beam configurations, for instance:

- charged kaons (positive and/or negative);
- neutral kaons;
- Beam Dump.

It should be stressed that while Kaons are emphasized, the science program could also include charged and neutral pion decays, and searches for hypothetical low mass, weakly coupled *dark sector* and axion-like particles.

What makes NA62 superior with respect to previous experiments is the large acceptance, its high rate capability, its full particle identification (including pion muon separation up to large momenta) and a very light tracking to minimize the interactions of particles with matter.

Innovative detector technologies have been developed to cope with the high rate. In particular, NA62 has developed the capability to track beam particles up to a rate of one GHz (Gigatracker) over a surface of a few cm^2. NA62 was built to minimize the resolution effects induced by multiple scattering thanks to the Straw spectrometer where each tube is an independent leak-tight detector operated in the vacuum decay tank. With respect to the predecessor experiment, this avoids:

- the presence of He in between the chambers;
- the presence of a heavy beam-pipe crossing the spectrometer;
- the presence of a window separating the decay volume from the tracking volume;

The above, coupled to a system of almost hermetic photon calorimeters form the essential ingredients for addressing the main goal of NA62 which is the measurement of the $K^+ \to \pi^+ \nu\bar{\nu}$ decay.

The sensitivity of the experiment was thoroughly assessed a using monte carlo simulation and a sample of data from the NA48 experiment. One expects a signal / background ratio of about five with the accumulation of ≈ 45 Standard Model events in a year of data

taking at full proton intensity on target and an overall acceptance×reconstruction×trigger efficiency of 10%.

The status of the experiment was recalled: after a commissioning run in 2014, a first sample of about 2×10^{10} kaons was accumulated in 2015, mostly at low beam intensity. Full proton intensity on target was achieved during the last days of the run. Data collected in 2015 should allow to verify the sensitivity of the experiment but are still insufficient to provide a significant physics result.

The experiment expects to collect of the order of 10^{13} kaon decays before the end of 2018 when the CERN accelerators will stop for the Long Shutdown 2 (LS2) that will last until the end of 2020.

The keynote talk *kaon Physics strikes back* was given by Andrzej Buras. Renewed interested in the calculation of CP-Violation in $K_L^0 \to \pi\pi$ and correlation between golden quantities in kaon physics were reviewed, in the spirit of recent appraisal of hadronic matrix elements (B6 and B8) in large N formulations. Effects of final state interactions on the amplitudes was one of the themes of the discussion which continued into the second week with the presentation by Toni Pich. Correlations between $B \to \mu\mu$ and $K^+ \to \pi^+\nu\bar{\nu}$ were emphasized.

A full day was devoted to the status of kaon physics on the lattice. Chris Sachrajda summarized the progress made through the past few years concerning the lattice computation of $K \to \pi\pi$ amplitudes, culminating in the calculation of the B6 operator and the suppression of the $\delta I = 3/2$ transition. Progress on rare decays has also appeared on the lattice. Chris emphasized the importance for the experiments to state precisely the analysis cuts for the electromagnetic radiation. Kaons are a lucky combination where both long distance and short distance aspects can be precisely treated so experiments should be careful in order to profit from the theoretical precision.

The talk of Guido Martinelli focused on EM and Isospin corrections on the lattice. *Ab initio* calculations of long distance effects are possible on the lattice for kaons because there are no nearby resonances (e.g. hyperfine splitting like in B mesons). A lot of attention on the inclusion of re-scattering on the lattice is to be addressed.

Martin Gorbahn detailed the steps of the Standard Model calculations for the $K \to \pi\nu\bar{\nu}$ rare decays, ϵ_K and ϵ'/ϵ. Questions related to how well can perturbation theory work down to the charm mass were discussed. Soon a NNLO calculation for ϵ_k will become available.

Gilberto Colangelo explained the success of dispersion relation techniques to extract the $\pi\pi$ scattering length. It was pointed out that lattice prediction gives a significantly lower result. The application of dispersion relations to K_{e4} decays was described by Peter Stoffer. He showed implications for NA62 and interesting analogies between between K_{e4} and $\pi\pi\pi$ decays were pointed out.

Three presentations were devoted to radiative corrections and radiative decays. Mark Knecht reviewed radiative corrections for $\pi\pi$ and K_{e4} decays. He also expressed interest in possibly improving the pion beta decay measurement. The determination from the super-allowed $0^+ - 0^+$ nuclear transitions is very precise but it is difficult to understand how the radiative corrections are applied. The determination from the neutron beta decay is not a pure vector transition and requires the knowledge of the decay asymmetry. Pion beta decay is ideal from a theoretical point of view, and one is limited by the experimental statistics (PIBETA) because of the extremely small phase space available. Could NA62, with suitably adjusted beam parameters, be competitive? The systematics would certainly be different from the PIBETA measurement which is done at rest.

Ramon Stucki reviewed radiative decays of the kaons in the framework of dispersion relations. In particular he underlined the interest to study better the $K \to \ell^+\ell^-$ transitions, while the phenomenology of $K \to \pi\ell^+\ell^-$ decays was described by David Greynat the day after.

Of course we could not avoid discussing the implication of the $\gamma\gamma$ hints presented in December by the ATLAS and CMS collaborations, a presentation on the topic was given by Sebastian Jäger. Puzzles in B rare decays have re-ignited the interest in looking for lepton flavour violation in rare decays as witnessed by the talks by Diego Guadagnoli and Lewis Tunstall.

To place kaon physics in the broader context, Antonio Masiero addressed the question: *Where are we going in Particle Physics?* emphasizing the relation between the standard models of cosmology and particle physics. He invited the audience to look through the crystal ball into the relations between particle accelerators, dark matter searches, neutrino mysteries, gravitational waves and multi-messenger astronomy.

Going beyond the SM, Sebastian Jäger reviewed supersymmetric models and kaon physics, while non-supersymmetric extensions of the Sm were covered by Monika Blanke on the last day of the programme.

The ϵ'/ϵ discussion continued with the presentation by Toni Pich which stressed the importance of re-scattering effects and final state interactions. A photo was taken to put on record Andrzej and Toni SM predictions for ϵ'/ϵ: 5 vs. 19 $\times 10^{-4}$. It was stressed that the cancellations of the B6 and B8 operators that appear in the SM and make the prediction difficult don't appear beyond the SM. The impact of kaon observables on the CKM unitarity triangle fits was reviewed by Sébastien Descotes-Genon.

A detailed update on the semileptonic decays was given by Johan Bijnens, and the phenomenological implications for experiments were carefully addressed by Emily Passemar. Kaon and hyperon semileptonic decays in a effective theory framework were addressed by Jorge Camelich. Giancarlo D'Ambrosio reviewed the structure of weak counterterms and the Vector Meson Dominance hypothesis in several experimentally accessible decays.

One session was devoted to the physics of π^0: Karol Kampf thoroughly reviewed the status and Pere Masjuan spoke about searches for new physics in π^0 rare decays.

Model independent, effective theory approaches were discussed by Ulrich Haisch and considerations about Flavour as portal to Dark Matter were given by Andreas Crivellin.

Plenty of time was reserved for spontaneous discussion, a lot of coffee, pretzels and cakes fueled the discussions. We hope to receive written up contributions in draft form within a couple of months in order to proceed to a plausible NA62 Physics Handbook by the end of 2016.

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