The NA62 Experiment at CERN - Mesuring the very rare $K^+ \to \pi^+\nu\overline{\nu}$ decay at the SPS

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A Probe for Physics Beyond the Standard Model

The $K^+ \to \pi^+\nu\overline{\nu}$ decay is strongly suppressed in the Standard Model (SM). The decay branching ratio ($\mathcal{B}$) can be computed with remarkable accuracy in the SM: $\mathcal{B}_{\text{SM}} = (8.4 \pm 1.0) \times 10^{-11}$ [1]. It is a prime candidate for searches of beyond the SM signals in flavor sector.

Previously, the E787 and E949 experiments at Brookhaven National Laboratory reported the combined $\mathcal{B}_{\text{BNL}} = \left(17.3^{+11.5}_{-10.5}\right) \times 10^{-11}$, a value compatible with the SM prediction [14]. NA62 at the CERN SPS aims to bring the experimental uncertainties at the 10 % level using a novel decay-in-flight approach. Over the 2016–2018 period, it observed 20 signal candidates with an expected background of 7 ± 1 events. The corresponding branching ratio $\mathcal{B}_{\text{NA62}} = \left(10.6^{+4.0}_{-3.4}\big|_{\text{stat.}} \pm 0.9_{\text{syst.}}\right) \times 10^{-11}$ is compatible with the SM expectation. Data taking will resume in 2021 for an additional period of three years.

RICH (green, bottom left) and STRAW (gray, top right) detectors. ©CERN

Measurement Principle

Kaons in the 75 GeV/c secondary hadron beam are tagged and their momentum measured before they enter the evacuated fiducial region (FV). Kaon decay products are analyzed by a set of detectors installed downstream of the FV. Additional photon veto detectors ensure that the defined geometrical acceptance is hermetic to photons.

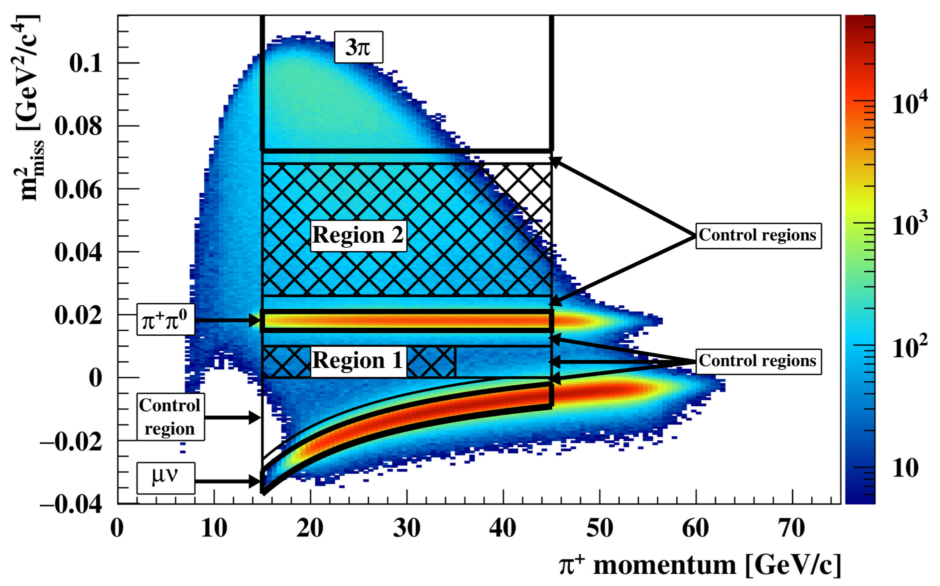

Fig. 1: Minimum-bias events plotted in the $(m^2_{\text{miss}}, p_{\pi^+})$ plane.

The $K^+ \to \pi^+\nu\overline{\nu}$ signature is a charged kaon in the initial state matched to a charged pion and missing energy in the final state. The square missing mass $m^2_{\text{miss}} = (P_K - P_\pi)^2$ defines two the signal regions.

Event Selection and Background Evaluation

The main background contributions (2018 S2 period) are listed in the Table below:

Process	Expected events
$K^+ \to \pi^+\pi^0$	0.52 ± 0.05
$K^+ \to \mu^+\nu_\mu$	0.45 ± 0.06
$K^+ \to \pi^+\pi^-e^+\nu_e$	0.41 ± 0.10
$K^+ \to \pi^+\pi^+\pi^-$	0.17 ± 0.08
Upstream	$2.76^{+0.90}_{-0.70}$
$K^+ \to \pi^+\nu\overline{\nu}$	$6.02 \pm 0.39 \pm 0.72_{\text{ext.}}$

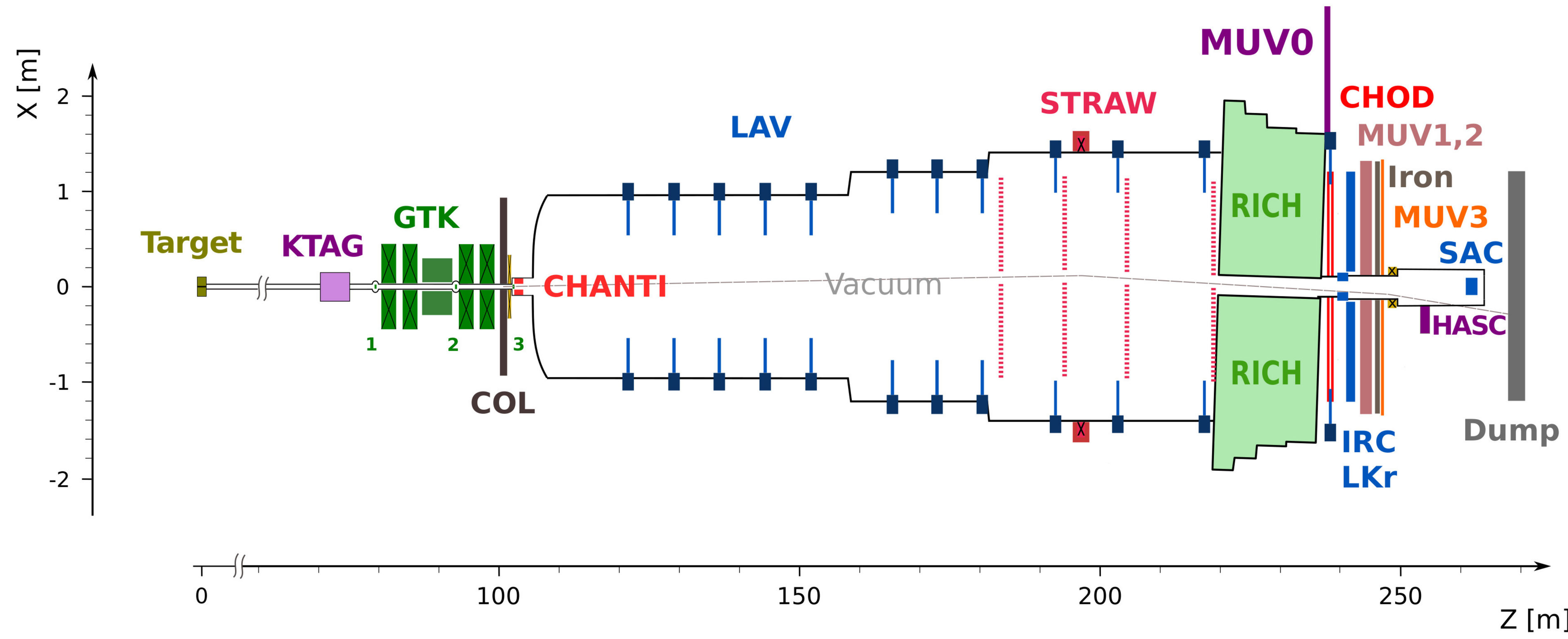

Fig. 2: Schema of the NA62 experimental setup viewed from the top. The beam travels in the positive Z-direction.

Kaon decay backgrounds are evaluated assuming that the photon rejection, particle identification and multitrack event rejection are independent of the m^2_{miss}. They are validated in six blinded control regions. The upstream processes are assessed separately using a data-driven approach.

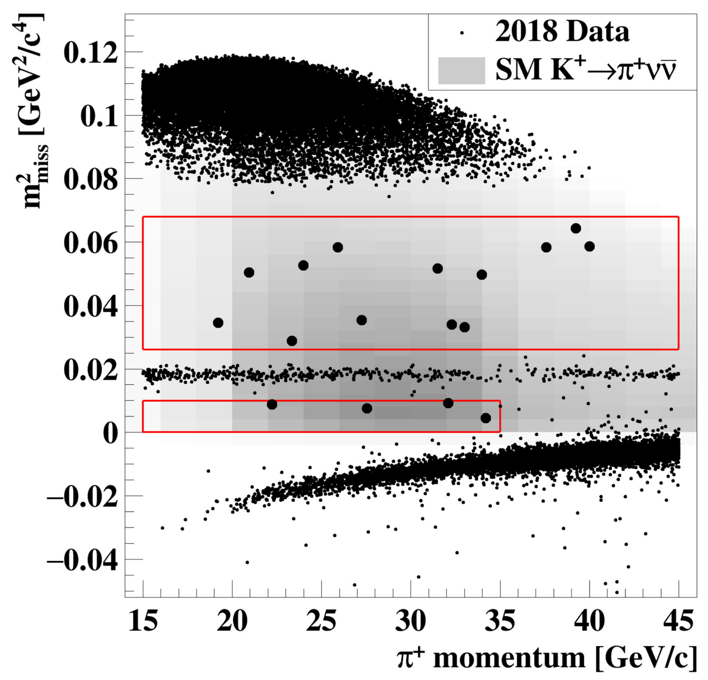

Fig. 3: Reconstructed m^2_{miss} as a function of the π^+ momentum for all events passing the $K^+ \to \pi^+\nu\overline{\nu}$ selection.

Results & Conclusion

Combining the 2016–2018 results $7.03^{+1.05}_{-0.82}$ background and $(10.01 \pm 0.42_{\text{syst.}} \pm 1.19_{\text{ext.}})$ SM signal events are expected in the combined signal regions. After unblinding, a total of 20 candidates were found, consistent with the expectations. The corresponding branching ratio is $\mathcal{B}_{\text{NA62}} = \left(10.6^{+4.0}_{-3.4}\big|_{\text{stat.}} \pm 0.9_{\text{syst.}}\right) \times 10^{-11}$ at 68 % CL, in agreement with the SM value.

The beam line was modified during the 2019–2020 stop to enhance the upstream background suppression.

Recently, the TRIUMF group made significant contributions to NA62, notably by improving the particle identification performance with machine learning algorithms and by developing a purity monitoring system for the liquid krypton calorimeter (LKr).

Discovery, accelerated