Recent results from the NA62 Experiment

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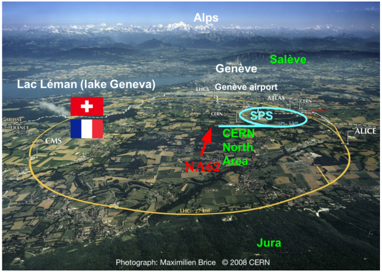
Outline

- The NA62 experiment
- New measurement of $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$ (2023–2024 dataset)
- Prague group work at NA62
- Conclusions

The NA62 Experiment



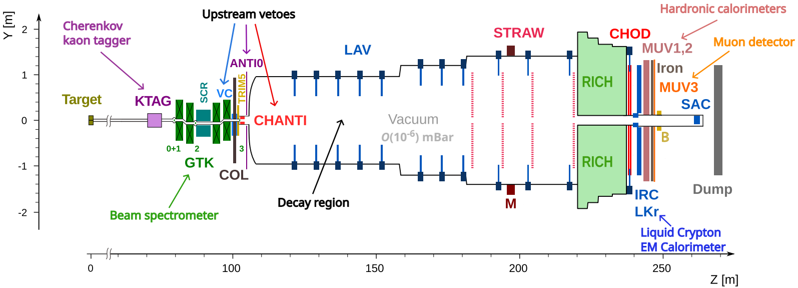
- $\sim$250 collaborators from $\sim$35 institutes
- Primary goal: $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$ measurement
- New technique: K^+ decay-in-flight
- Broad physics program:
  - Rare K^+ decays
  - LNV/LFV decays
  - Exotics

Data taking:

2016	2017	2018	2021	2022	**2023**	**2024**	2025	2026
45 days	160 days	217 days	85 days	215 days	**140 days**	**185 days**	210 days	145 days

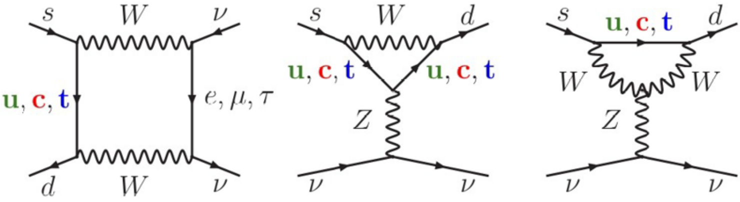
NA62 Beamline and Detector

- Primary 400 GeV/c beam: SPS protons
- Secondary 75 GeV/c beam: 70% π^+, 23% p, 6% K^+



- Particle tracking: GTK (beam particles), STRAW (downstream tracks)
- PID: K^+ – KTAG, π^+ – RICH, Calorimeters (LKr, MUV1, MUV2), MUV3 (μ-veto)
- Veto systems: CHANTI (beam interactions), LAV, LKr, IRC, SAC (γ-veto)

$K^+ \to \pi^+\nu\bar{\nu}$ – Motivation

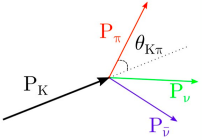


- Ultra rare decay in SM:
  $\boldsymbol{\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (8.6 \pm 0.4) \times 10^{-11}}$ [Buras et al. EPJC 82 (2022) 7, 615]
- FCNC process (loop level only)
- Theoretically very clean: 5% overall uncertainty
  - Dominated by uncertainty of CKM parameters
- **High sensitivity to New Physics up to $\mathcal{O}(100)$ TeV**

$K^+ \to \pi^+\nu\bar{\nu}$ – Analysis Strategy

Signal:

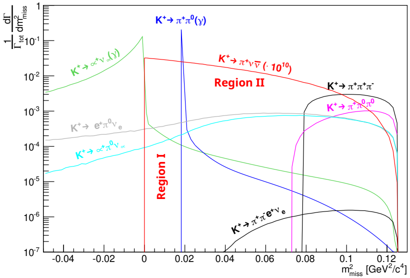
- Kaon decays in flight
- Time and space $K^+ - \pi^+$ matching
- Two signal regions defined by m^2_{miss} are kept blind



$$m^2_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2$$

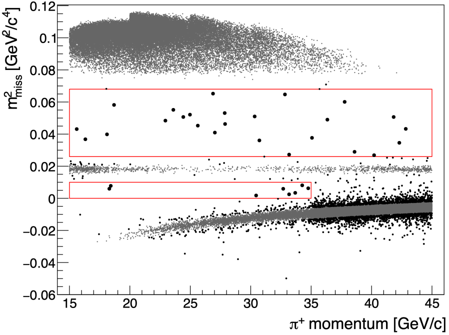
Main K^+ decay modes:

Decay mode	BR	Rejection tools
$K^+ \to \mu^+\nu_\mu$	64%	μ-ID + kinematics
$K^+ \to \pi^+\pi^0$	21%	γ-veto + kinematics
$K^+ \to \pi^+\pi^+\pi^-$	6%	multiplicity + kinematic
$K^+ \to \pi^0 e^+\nu_e$	5%	e-ID + γ-veto
$K^+ \to \pi^0\mu^+\nu_\mu$	3%	μ-ID + γ-veto
$K^+ \to \pi^+\pi^0\pi^0$	2%	γ-veto + kinematics



2023–2024 Dataset

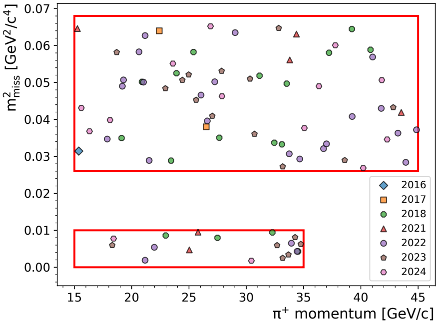
- Expected SM signal: 22.9 ± 1.1
- Estimated background: $12.0^{+2.9}_{-2.3}$
- Observed: $\boldsymbol{N_{\mathrm{obs}} = 33}$



$$\boldsymbol{\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})^{\mathrm{NA62}}_{2023-2024} = (7.2^{+2.2}_{-1.9}|_{\mathrm{stat}} \pm 0.9|_{\mathrm{syst}}) \times 10^{-11} = (7.2^{+2.3}_{-2.1}) \times 10^{-11}}$$

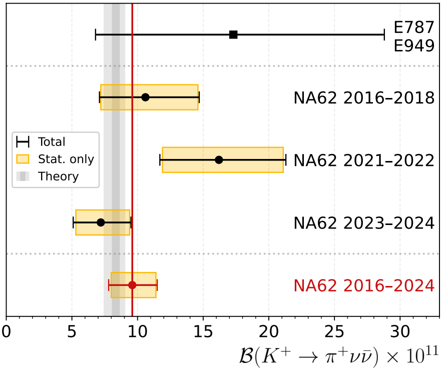
Combine: 2016–2024 Dataset

- Expected SM signal: 43 ± 1
- Estimated background: 30^{+4}_{-3}
- Observed: $\boldsymbol{N_{\mathrm{obs}} = 84}$



$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})^{\mathrm{NA62}}_{2016-2024} = (9.6^{+1.8}_{-1.6}|_{\mathrm{stat}}\ {}^{+0.8}_{-0.6}|_{\mathrm{syst}}) \times 10^{-11} = (9.6^{+1.9}_{-1.8}) \times 10^{-11}$$

The Global Picture

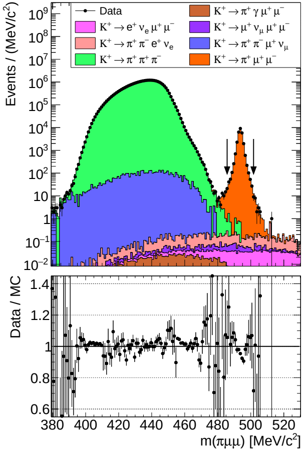


- Precision of $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$ better than 20%
- Result compatible with Standard Model
- Result significance $> 6\sigma$
- 2025–2026 dataset incoming

Prague group work at NA62

$K^+ \to \pi^+\mu^+\mu^-$ Analysis

2016-2018 result JHEP11 (2022) 011

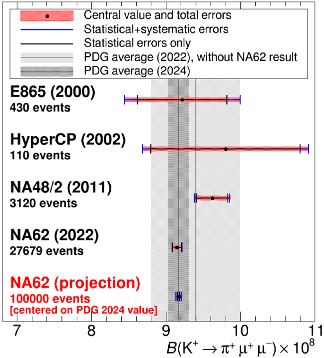


- 27k $K^+ \to \pi^+\mu^+\mu^-$ candidates
- Negligible background
- 0.3% systematic uncertainty

Work in progress (2016–2026 NA62 dataset)

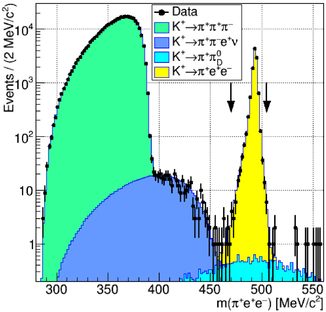
- Improve $\mathcal{B}(K^+ \to \pi^+\mu^+\mu^-)$ precision
- Measure form factor of $K^\pm \to \pi^\pm\gamma^*$ transition
- Lepton Universality test

Full dataset (2016–2026) projection



$K^+ \to \pi^+ e^+ e^-$ Analysis

2016–2018 NA62 dataset

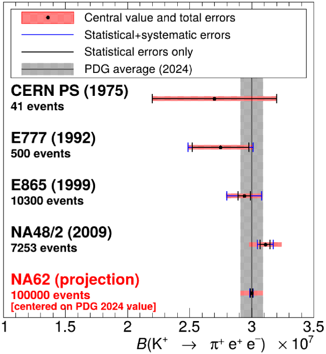


- 10k $K^+ \to \pi^+ e^+ e^-$ candidates
- Negligible background

Work in progress (2016–2026 NA62 dataset)

- Precision measurement of $\mathcal{B}(K^+ \to \pi^+ e^+ e^-)$
- Measure form factor of $K^\pm \to \pi^\pm \gamma^*$ transition
- Lepton Universality test

Full dataset (2016–2026) projection



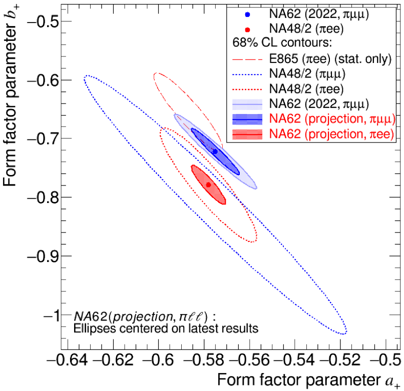
$K^+ \to \pi^+ l^+ l^-$: Lepton Universality Test

- $K^+ \to \pi^+ l^+ l^-$: FCNC, Long-distance (LD) dominated, mediated by $K^+ \to \pi^+ \gamma^*$

- $d\Gamma/dz \sim G_F M_K^2 (a + bz) + W^{\pi\pi}(z)$
  - $z = m^2(l^+ l^-)/M_K^2$
  - a, b are form factors
- Lepton Universality: $(a^\mu, b^\mu) = (a^e, b^e)$

Work in progress (2016–2026 NA62 dataset)

- Total (a, b) uncertainties expected to improve with respect to current results by:
  - $\sim 1.5\times$ for $K_{\pi\mu\mu}$
  - $\sim 3\times$ for $K_{\pi ee}$



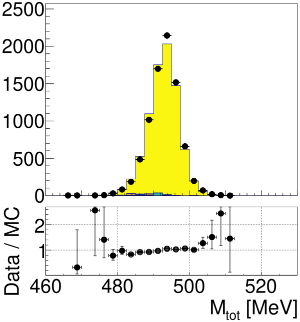
$K^+ \to \pi^+\pi^0 e^+ e^-$ Analysis

- NA48/2 result: $\mathcal{B}_{\mathrm{NA48}}(K_{\pi\pi^0 ee}) = (4.24 \pm 0.14) \times 10^{-6}$ (**precision 3.3%**)
  - Observed $\sim$ **5k events**, estimated background $\sim$ **5%** [PLB 788 (2019) 552-561]

Work in progress (2016–2026 NA62 dataset)

- Expected $\sim$ **10k signal events** with $\sim$ **2%** of background

2022–2025 NA62 dataset



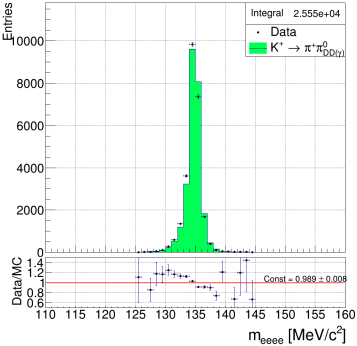
$\pi^0 \to e^+e^-e^+e^-$ (π^0_{DD}) Analysis

- KTeV result: $\mathcal{B}_{\text{KTeV}}(\pi^0_{DD}) = (3.26 \pm 0.18) \times 10^{-5}$ **(precision 5.5%)**
  - Used $K^0_L \to \pi^0\pi^0\pi^0_{DD}$ as a signal, observed $\sim$ **30k events** [PRL 100 (2008) 182001]

Work in progress (2016–2026 NA62 dataset)

- Used $K^+ \to \pi^+\pi^0_{DD}$ as a signal, expected $\sim$ **30k events**
- Expected precision $\sim$ **2%**

2016–2025 NA62 dataset



Conclusions

$K^+ \to \pi^+ \nu\bar{\nu}$ analysis

- $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})^{\text{NA62}}_{2016-2024} = (9.6^{+1.9}_{-1.8}) \times 10^{-11}$
- Result compatible with SM, precision $< 20\%$
- Result significance $> 6\sigma$

Prague group work at NA62

- $K^+ \to \pi^+ \mu^+ \mu^-$
- $K^+ \to \pi^+ e^+ e^-$
- $K^+ \to \pi^+ \pi^0 e^+ e^-$
- $\pi^0 \to e^+ e^- e^+ e^-$

Spares

$K^+ \to \pi^+\nu\bar{\nu}$ – Analysis Strategy

Main K^+ decay modes:

Decay mode	BR [PDG]	Rejection tools
$K^+ \to \mu^+\nu_\mu$	64%	μ-ID + kinematics
$K^+ \to \pi^+\pi^0$	21%	γ-veto + kinematics
$K^+ \to \pi^+\pi^+\pi^-$	6%	multiplicity + kinematics
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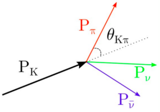
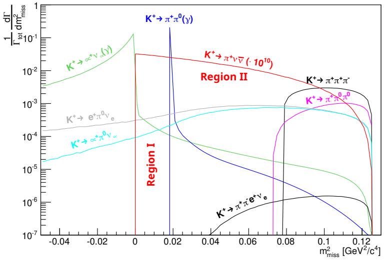


$$m^2_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2$$

NA62 Performance Keystones

- $\mathcal{O}(100)$ ps timing between detectors
- $\mathcal{O}(10^4)$ background suppression from kinematics
- $> 10^7$ muon rejection
- $> 10^7$ π^0 rejection



Signal Sensitivity

Normalization trigger downscale = 400

Trigger efficiency ratio

$$N^{\text{exp}}_{\pi\nu\nu} = N_{\pi\pi} D \frac{\mathcal{B}(\pi\nu\nu)_{\text{SM}}}{\mathcal{B}(\pi\pi)} \frac{A_{\pi\nu\nu}}{A_{\pi\pi}} \varepsilon_{\text{trigger}} \varepsilon_{\text{RV}}$$

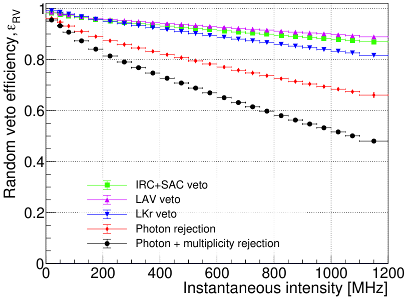
Expected signal events

External inputs

Selection acceptances

Normalization $K^+ \to \pi^+\pi^0$ events

Random veto efficiency



	2021–2022 JHEP 02 (2025) 191	**2023–2024** arXiv:2607.16413
$N_{\pi\pi}$	1.95×10^8	3.93×10^8
$A_{\pi\pi}$	$(13.410 \pm 0.005)\%$	$(12.971 \pm 0.009)\%$
$A_{\pi\nu\nu}$	$(7.62 \pm 0.22)\%$	$(7.36 \pm 0.33)\%$
$\varepsilon_{\text{trigger}}$	$(85.9 \pm 1.4)\%$	$(86.4 \pm 1.2)\%$
ε_{RV}	$(63.2 \pm 0.6)\%$	$(72.3 \pm 0.7)\%$
$N^{\text{exp}}_{\pi\nu\nu}$	9.9 ± 0.3	22.9 ± 1.1

Improvements over 21–22 dataset:

- 2x normalization statistics
- 1.14x random veto efficiency
- 2.3x signal statistics expected

Background Summary

	2021–2022 JHEP 02 (2025) 191	2023–2024 arXiv:2607.16413
$K^+ \to \pi^+\pi^0(\gamma)$	0.83 ± 0.05	1.19 ± 0.10
$K^+ \to \mu^+\nu(\gamma)$	1.70 ± 0.47	1.39 ± 0.29
$K^+ \to \pi^+\pi^+\pi^-$	0.11 ± 0.03	0.25 ± 0.05
$K^+ \to \pi^+\pi^- e^+\nu$	$0.89^{+0.33}_{-0.27}$	$1.59^{+0.51}_{-0.43}$
Upstream	$7.4^{+2.1}_{-1.8}$	$7.5^{+2.8}_{-2.2}$
Total	$\mathbf{11.0^{+2.1}_{-1.9}}$	$\mathbf{12.0^{+2.9}_{-2.3}}$
$N^{\text{exp}}_{\pi\nu\nu}$	9.9 ± 0.3	22.9 ± 1.1

- Better π^0 rejection
- Better μ^+ mis-ID
- Improved upstream background rejection
- Combining with previous datasets: $\boldsymbol{N_{\text{bkg}} = 30^{+4}_{-3}}$, $\boldsymbol{N^{\text{exp}}_{\pi\nu\nu} = 43 \pm 1}$

Broad NA62 Physics Program

Precision measurements & rare decays

- $K^+ \to \pi^+\mu^+\mu^-$ [JHEP 11 (2022) 011]
- $K^+ \to \pi^+e^+e^+e^-e^-$ [PLB 846 (2023) 138193]
- $\pi^0 \to e^+e^-$ [Moriond2024]
- $K^+ \to \mu^+\nu\mu^+\mu^-$ [Kaon25]
- $K^+ \to e^+\nu\gamma$ [Kaon25]
- $K^+ \to \pi^+\pi^+\pi^-\gamma$ [Kaon25]

Forbidden decays

- $K^+ \to \pi^-l^+l^+$ [PLB 797 (2019) 134794]
- $K^+ \to \mu^-\nu e^+e^+$ [PLB 838 (2023) 137679]
- $K^+ \to \pi^0\pi\mu e$ [PLB 859 (2024) 139122]

Invisible particles

- $K^+ \to e^+N$ [PLB 807 (2020) 135599]
- $K^+ \to \pi^+ + \text{inv.}$ [JHEP 11 (2025) 143]
- $\pi^+ \to e^+N$ [PLB 872 (2026) 140119]