



FACULTY
OF MATHEMATICS
AND PHYSICS
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Recent results from the NA62 experiment at CERN

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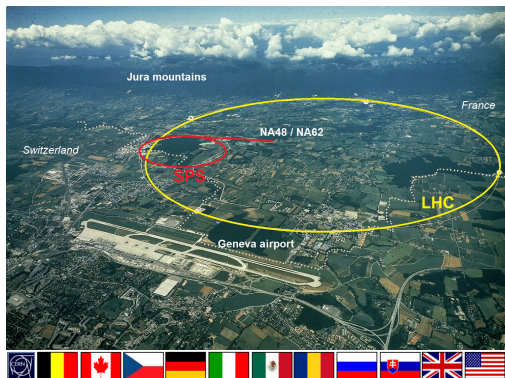
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Charles University in Prague

on behalf of the NA62 Collaboration

Les Rencontres de Physique de la Vallée d'Aoste
La Thuile, March 4, 2026

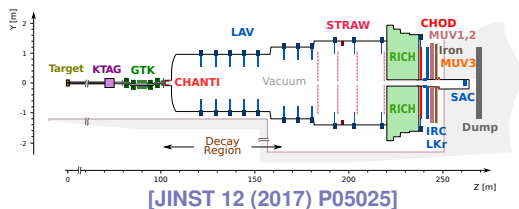
Kaon Experiments at CERN



NA62: ~ 250 participants, ~ 35 institutes

- **NA31**: 1980s, beam: K_L/K_S
 - First evidence of direct CPV
- **NA48**: 1997–2001, beam: K_L/K_S
 - Discovery of direct CPV
- **NA48/1**: 2002, beam: K_S /hyperons
 - Rare decay studies
- **NA48/2**: 2003–2004, beam: K^+/K^-
 - Precision measurements
- **NA62- R_K** : 2007–2008, beam: K^+/K^-
 - $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu2})$
- **NA62**: since 2015, beam: K^+
 - 2015: commissioning run
 - 2016–2018: NA62 Physics Run 1
 - 2021–2026: NA62 Physics Run 2

NA62: Beam and Detector



Beam parameters in K^+ mode:

- **Beam momentum:** 75 GeV/c ($\pm 1\%$)
- **Beam rate:** 450 – 600 MHz
- **Positive beam:** $\sim 6\% K^+$

Main subdetectors:

- **Beam tracker:** **GTK** ($\sigma_p = 0.15$ GeV/c)
- **Kaon tagger:** **KTAG** ($\sigma_t = 70$ ps)
- **Downstream tracker:** **Straw**
 $\sigma_p/p = 0.3\% \oplus 0.005\% \cdot p[\text{GeV}/c]$
- **Photon veto detectors:** **LAV**, **IRC**, **SAC**
- **Cherenkov counter:** **RICH** ($\sigma_t = 70$ ps)
- **Trigger and timing:** **CHOD** ($\sigma_t = 1$ ns), **NA48-CHOD** ($\sigma_t = 0.2$ ns)
- **Electromagnetic calorimeter:** **LKr**
 $\sigma_E/E = 4.8\%/\sqrt{E} \oplus 11\%/E \oplus 0.9\%$, $[E] = \text{GeV}$
- **Hadronic calorimeters:** **MUV1,2**
- **Muon detector:** **MUV3** ($\sigma_t = 500$ ps)

- Measurement of the branching fraction of very rare ($\mathcal{B}_{\pi\nu\nu} \approx 10^{-10}$) decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
 - Main goal of the experiment with the first observation published in [\[JHEP 02 \(2025\) 191\]](#)
 - See Renato's talk from this morning for the most recent measurement
- **Precision measurements:**
 - Up to $\mathcal{O}(0.1\%)$ level tests of ChPT and SM
 - Precision measurements of ChPT parameters

Decay	Dataset	Status	Reference
$K^+ \rightarrow \pi^+ \pi^+ \pi^- \gamma$ ($K_{3\pi\gamma}$)	NA62 Run 1 (2017–2018)	Preliminary	[KAON25]
$K^+ \rightarrow \mu^+ \nu \mu^+ \mu^-$ ($K_{\mu\nu\mu\mu}$)	NA62 Run 1+2 (2017–2024)	Preliminary	[KAON25]
$K^+ \rightarrow e^+ \nu_e \gamma$ ($K_{e2\gamma}$)	NA62 Run 1 (2017–2018)	Preliminary	[KAON25]

- **Searches for exotic particles: dark photon, exotic scalars, axions, HNLs,...**

Decay	Dataset	Status	Reference
$\pi^+ \rightarrow e^+ N$ (π_{eN})	NA62 Run 1+2 (2017–2024)	Published	[Phys.Lett.B 872 (2026) 140119]
$K^+ \rightarrow \pi^+ X$ ($K_{\pi X}$)	NA62 Run 1+2 (2016–2022)	Published	[JHEP 11 (2025) 143]

- Searches for rare and forbidden (e.g. LNV or LFV) K^+ decays

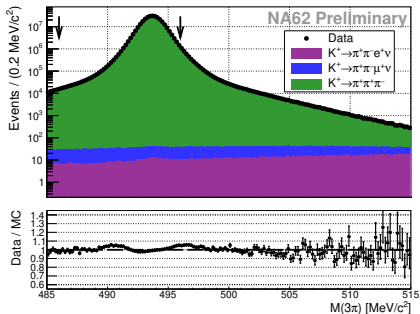
$K^+ \rightarrow \pi^+ \pi^+ \pi^- \gamma$: Selections

Common features:

- Data from 2017–2018
- Multi-track trigger line used

Normalisation ($K_{3\pi}$) selection:

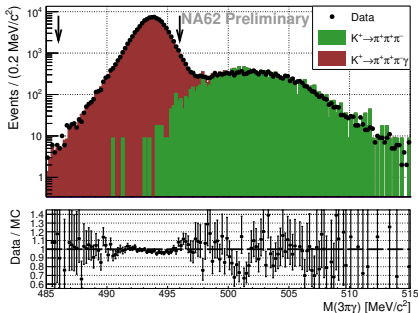
- $N_K = (7.400 \pm 0.001_{\text{stat}} \pm 0.032_{\text{ext}}) \times 10^{10}$



- Require 3-track ($\pi\pi\pi$)-compatible vertex
- Associate GTK track to 3π vertex

Signal selection:

- Reconstruct γ in the LKR
- Kinematic cuts against $K_{3\pi}$ background



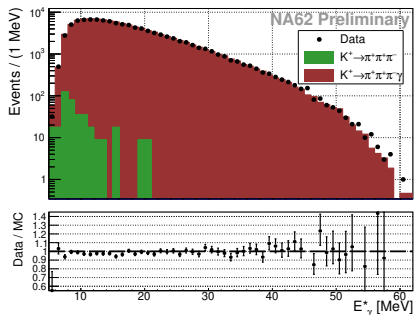
- Kinematic fit and unfolding techniques performed on selected events

$K^+ \rightarrow \pi^+\pi^+\pi^-\gamma$: Branching Fraction vs E_γ^*

- $K_{3\pi\gamma}$ branching fraction measured with respect to E_γ^* (photon energy in kaon rest frame):

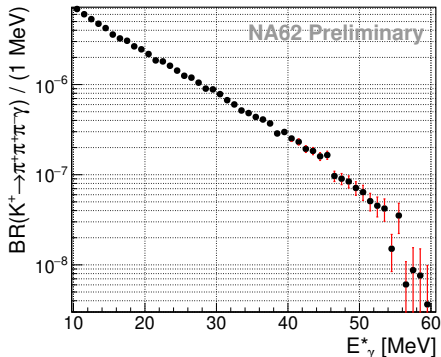
Final E_γ^* spectrum:

- Contamination for $E_\gamma^* > 10$ MeV is $< 0.2\%$



Branching fraction vs E_γ^* :

- Only statistical errors are shown



$K^+ \rightarrow \pi^+ \pi^+ \pi^- \gamma$: Branching Fractions

E_γ^* [MeV]	$\mathcal{B}_{\text{NA62}}(E_\gamma^*)$ Preliminary	$\mathcal{B}_{\text{Theory}}(E_\gamma^*)$ [ZPhysC 76 (1997) 301]	$\mathcal{B}_{\text{OKA}}(E_\gamma^*)$ [EPJC 79 (2019) 1]
10–20	$(4.22 \pm 0.05) \cdot 10^{-5}$	$(4.36 \pm 0.04) \cdot 10^{-5}$	
20–30	$(1.42 \pm 0.02) \cdot 10^{-5}$	$(1.43 \pm 0.01) \cdot 10^{-5}$	
30–40	$(4.86 \pm 0.09) \cdot 10^{-6}$	$(4.93 \pm 0.05) \cdot 10^{-6}$	$(5.17 \pm 0.34) \cdot 10^{-6}$
40–50	$(1.53 \pm 0.05) \cdot 10^{-6}$	$(1.44 \pm 0.01) \cdot 10^{-6}$	$(1.55 \pm 0.12) \cdot 10^{-6}$
50–60	$(2.80 \pm 0.31) \cdot 10^{-7}$	$(2.69 \pm 0.03) \cdot 10^{-7}$	$(3.5 \pm 0.5) \cdot 10^{-7}$
60–70		$(1.36 \pm 0.02) \cdot 10^{-8}$	$(1.1 \pm 0.6) \cdot 10^{-8}$
10–60	$(6.30 \pm 0.06) \cdot 10^{-5}$	$(6.45 \pm 0.06) \cdot 10^{-5}$	
30–60	$(6.66 \pm 0.10) \cdot 10^{-6}$	$(6.64 \pm 0.05) \cdot 10^{-6}$	
30–70		$(6.65 \pm 0.05) \cdot 10^{-6}$	$(7.1 \pm 0.4_{\text{stat}} \pm 0.3_{\text{syst}}) \cdot 10^{-6}$

Good agreement with theoretical predictions and measurements by the OKA experiment

$K^+ \rightarrow \mu^+ \nu \mu^+ \mu^-$: Selections and Branching Fraction

Common features:

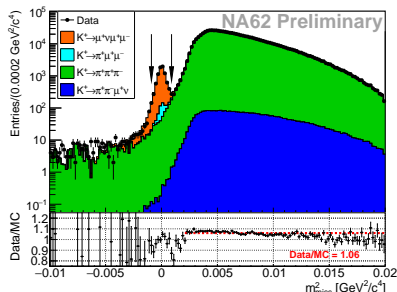
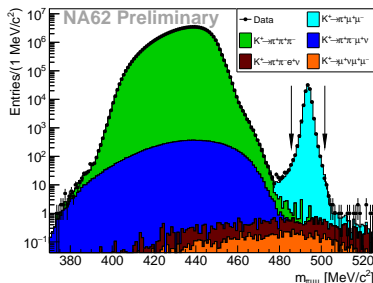
- Full available statistics (2017–2024)
- 2μ multi-track (2μ MT) trigger line

Normalisation ($K_{\pi\mu\mu}$) selection:

- Require 3-track ($\pi\mu\mu$)-compatible vertex
- Kinematic cuts against $K_{3\pi}$ background
- Observed 94112 $K_{\pi\mu\mu}$ candidates
- $N_K = (1.475 \pm 0.005_{\text{stat}}) \times 10^{13}$

Signal selection:

- Require 3-track ($\mu\mu\mu$)-compatible vertex
- Kinematic cuts against $K_{3\pi}$ background
- Observed 8227 $K_{\mu\nu\mu\mu}$ candidates
- Expected bckg.: $892 \pm 11_{\text{stat}} \pm 54_{\text{syst}}$



$$\mathcal{B}(K^+ \rightarrow \mu^+ \nu \mu^+ \mu^-) = (1.301 \pm 0.017_{\text{stat}} \pm 0.012_{\text{syst}} \pm 0.012_{\text{ext}}) \times 10^{-8}$$

First observation of the $K_{\mu\nu\mu\mu}$ decay

$K^+ \rightarrow e^+ \nu_e \gamma$: Selections and Branching Fraction

Common features:

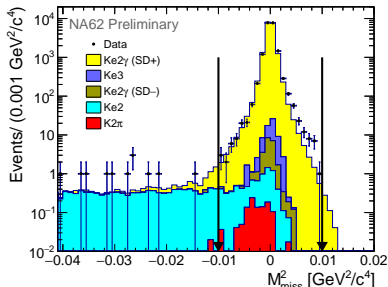
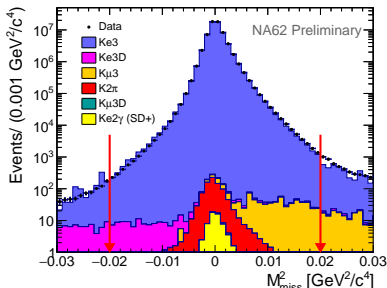
- Data from 2017–2018
- Non-muon trigger used
- Require single good e^+ track
- Match a GTK kaon to the e^+ track

Normalisation (K_{e3}) selection:

- π^0 reconstructed from two γ clusters in LKR
- Kinematic $K^+ \rightarrow \pi^+ \pi^0$ suppression
- $N_K \sim 2.9 \times 10^{10}$

Signal selection:

- Reconstruct the radiative γ in the LKR
- Kinematic cuts against $K_{e2}, K_{e3}, K_{2\pi}$
- $N_{e2\gamma} = 18929$, background $\sim 0.4\%$



$$\mathcal{B}(K_{e2\gamma}, \text{SD}^+) = (0.466 \pm 0.003_{\text{stat}} \pm 0.003_{\text{syst}} \pm 0.004_{\text{ext}}) \times 10^{-5}$$

Most precise measurement of SD^+ amplitudes in kaon decays to date

$K^+ \rightarrow e^+ \nu_e \gamma$: Global Context

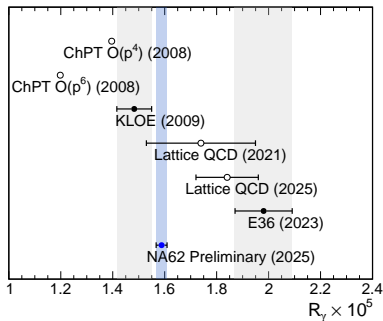
$$R_\gamma = \Gamma(K^+ \rightarrow e^+ \nu_e \gamma, SD^+)/\Gamma(K_{\mu 2}):$$

Comparison of R_γ with KLOE and E36:

Kinematic region: $P_e > 200 \text{ MeV}/c, E_\gamma > 10 \text{ MeV}$ in K^+ rest frame	$\Gamma(K_{e2\gamma} SD^+)/\Gamma(K_{\mu 2}) [10^{-5}]$
KLOE	$1.483 \pm 0.066 \pm 0.013$
E36	1.98 ± 0.11
NA62 Preliminary	1.59 ± 0.02

- All measurements and theoretical predictions are computed in KLOE kinematic region: $P_e > 200 \text{ MeV}/c$ and $E_\gamma > 10 \text{ MeV}$
- PDG 2024 average:
 $R_\gamma = (1.62 \pm 0.22) \times 10^{-5}$
(error includes scale factor of 3.9)

$$\text{NA62: } R_\gamma = (1.59 \pm 0.02) \times 10^{-5}$$

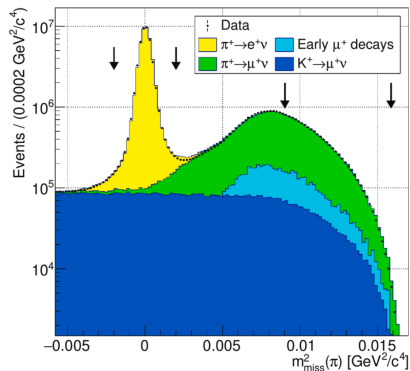


- ChPT: [PRD 77, 014004 (2008)]
- KLOE: [EPJC 64 627 (2009)]
- Lattice QCD: [PRD 103 053005 (2021)], [PRD 111 (2025) 11, 114523]
- E36: [PLB 843 138020 (2023)]

Search for HNLs in Pion Decays to Positrons

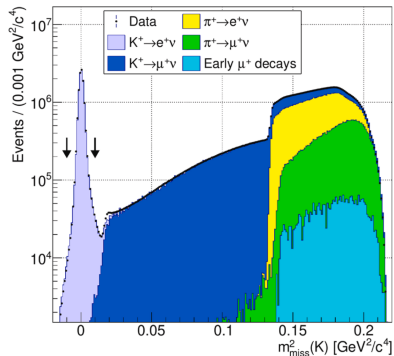
Pion-to-positron selections:

- 2017–2024 data, $K_{\pi\nu\nu}$ trigger used
- Straw track identified as e^+ (LKr, RICH) matched to a GTK track (π^+)
- Multi-body K^+ decays suppressed by γ veto and multiplicity requirements
- SM $\pi_{e\nu}$ used for HNL search normalisation ($N_\pi = 6.54(3) \times 10^{12}$)



K_{e2} normalisation selection:

- Used to obtain the number of kaon decays
- Required to scale the $K_{\mu 2}$ background component in $\pi^+ \rightarrow e^+ \nu_e$ sample (left)
- $N_K = (19.02 \pm 0.08) \times 10^{12}$



Search for HNLs in Pion Decays to Positrons

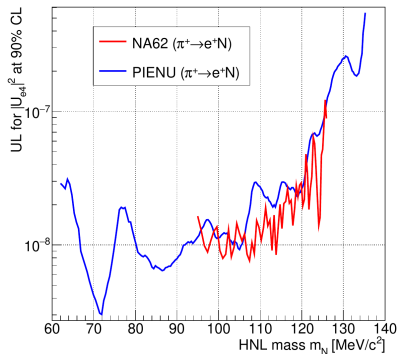
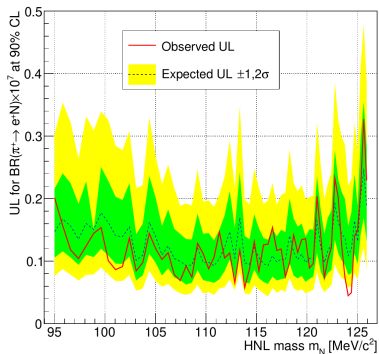
Decay rate and mixing matrix element:

- $\mathcal{B}(\pi_{eN}) = \mathcal{B}(\pi_{e\nu}) \cdot \rho(m_N) \cdot |U_{e4}|^2$
- $\rho(m_N) = \frac{x+y-(x-y)^2}{x(1-x)^2} \lambda^{1/2}(1, x, y)$
- $\lambda(1, x, y) = (1 + x^2 + y^2) - 2(x + y + xy)$
- $x = (m_e/m_\pi)^2, y = (m_N/m_\pi)^2$

- Peak search performed with various HNL mass hypotheses

- ULs on $\mathcal{B}(\pi_{eN})$ and $|U_{e4}|^2$ obtained:

- $\mathcal{B}(\pi_{eN}) = \frac{N_S}{N_\pi \cdot A_N}$
 - A_N : signal acceptance from simulation
- $|U_{e4}|^2 = \mathcal{B}(\pi_{eN}) \cdot \frac{1}{\mathcal{B}(\pi_{e\nu})\rho(m_N)}$



Searches for $K^+ \rightarrow \pi^+ X$

Various scenarios considered:

Benchmark	BSM particle (X)	Type	Coupling to SM	Search
BC1	dark photon (A')	vector	ε	$\mu^+\mu^-$
BC2	dark photon (A')	vector	ε	invisible
BC4	dark scalar (S)	scalar	θ	invisible, $\mu^+\mu^-$
BC4-inv	dark scalar (S)	scalar	θ	invisible
BC10	axion-like particle (a)	pseudoscalar	C_{ff} (to fermions)	invisible, $\mu^+\mu^-$
BC10-inv	axion-like particle (a)	pseudoscalar	C_{ff} (to fermions)	invisible
BC11	axion-like particle (a)	pseudoscalar	C_{GG} (to gluons)	invisible, $\gamma\gamma$

Coupling of BSM particles to SM:

- **BC1&2:** a new $U(1)$ symmetry gauge boson A' (dark photon):

$$\mathcal{L}_{\text{portal}} = -(\varepsilon/(2 \cos \theta_W)) F'_{\mu\nu} B^{\mu\nu}$$

- **BC4:** a new scalar singlet S (dark scalar):

$$\mathcal{L}_{\text{portal}} = -\mu S H^\dagger H \text{ (below EW breaking, } \theta \simeq \mu v / (m_h^2 - m_S^2))$$

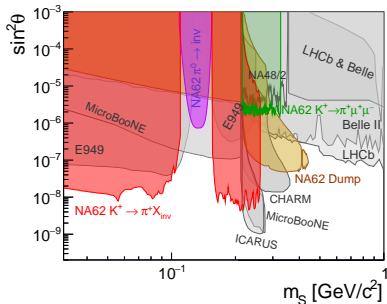
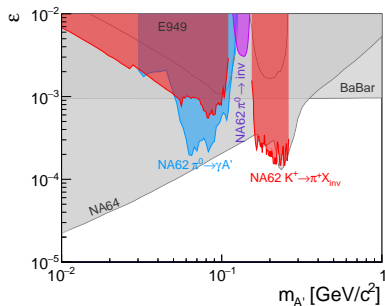
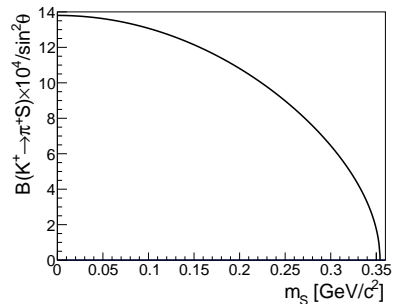
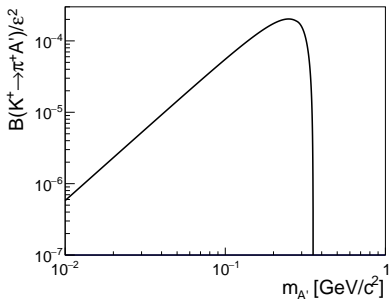
- **BC10&11:** a new axion-like particle a :

$$\mathcal{L}_{\text{portal},f} = (C_{ff}/(2\Lambda)) \partial_\mu a \bar{f} \gamma^\mu \gamma^5 f, \text{ or } \mathcal{L}_{\text{portal},G} = g^2 (C_{VV}/\Lambda) a V_{\mu\nu} \tilde{V}^{\mu\nu} \text{ (} \Lambda \sim 1 \text{ TeV)}$$

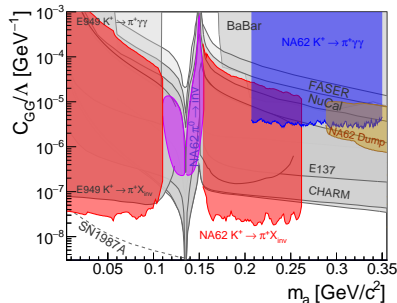
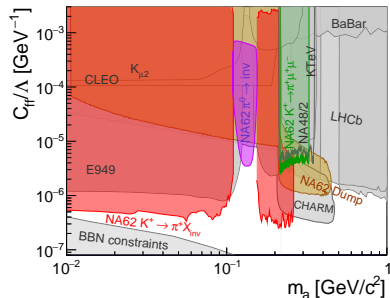
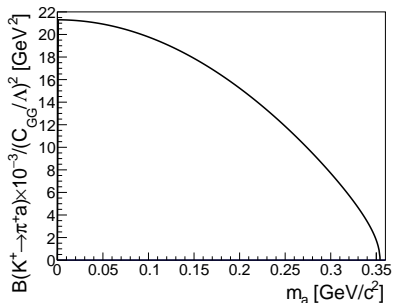
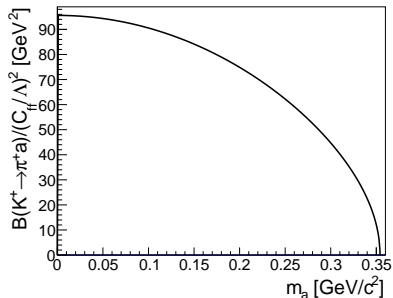
Processes exploited for the searches:

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$: 2016–2022 dataset ([JHEP 02 (2025) 191])
- $K^+ \rightarrow \pi^+ \mu^+ \mu^-$: 2017–2018 dataset ([JHEP 11 (2022) 011])
- $K^+ \rightarrow \pi^+ \gamma\gamma$: 2017–2018 dataset ([Phys.Lett.B 850 (2024) 138513])
- $\pi^0 \rightarrow \text{invisible}$: 2017 dataset ([JHEP 02 (2021) 201])
- $\pi^0 \rightarrow \gamma \text{ invisible}$: 2016 dataset ([JHEP 05 (2019) 182])
- $X \rightarrow hh, X \rightarrow \ell\ell$: 2021 dataset ([Eur.Phys.J.C 85 (2025) 5, 571])

Searches for $K^+ \rightarrow \pi^+ A'$ and $K^+ \rightarrow \pi^+ S$



Searches for $K^+ \rightarrow \pi^+ a$, with a Coupling to Fermions or Gluons



Precision measurements (preliminary results):

- $K^+ \rightarrow \pi^+ \pi^+ \pi^- \gamma$ decay branching fraction in bins of E_γ^*
- First observation and branching fraction measurement of $K^+ \rightarrow \mu^+ \nu \mu^+ \mu^-$ decay
- $K^+ \rightarrow e^+ \nu_e \gamma$ (SD^+) branching fraction, most precise kaon decay SD^+ amplitude measurement

Searches for BSM particles:

- Search for HNL in pion decays to positrons
- Searches for $K^+ \rightarrow \pi^+ X$ in various scenarios, $X \in \{A', S, a\}$

Stay tuned for more results from NA62!