Searches for LF/LN violation and hidden sectors in Kaon decays at the NA62 experiment

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on behalf of the NA62 collaboration
DIS2024, Grenoble.

10/04/2024

Outline

- The NA62 experiment at CERN;
  - Ultra rare $K^+ \longrightarrow \pi^+ \nu \bar{\nu}$ decay.
- Lepton Flavour and Lepton Number violation searches at NA62;
  - Experimental search of $K^+ \to \mu^- \nu e^+ e^+$.
- Hidden sector particles searches at NA62;
  - Experimental search of $K^+ \to \pi^+ X(\to e^+e^-) X(\to e^+e^-)$.

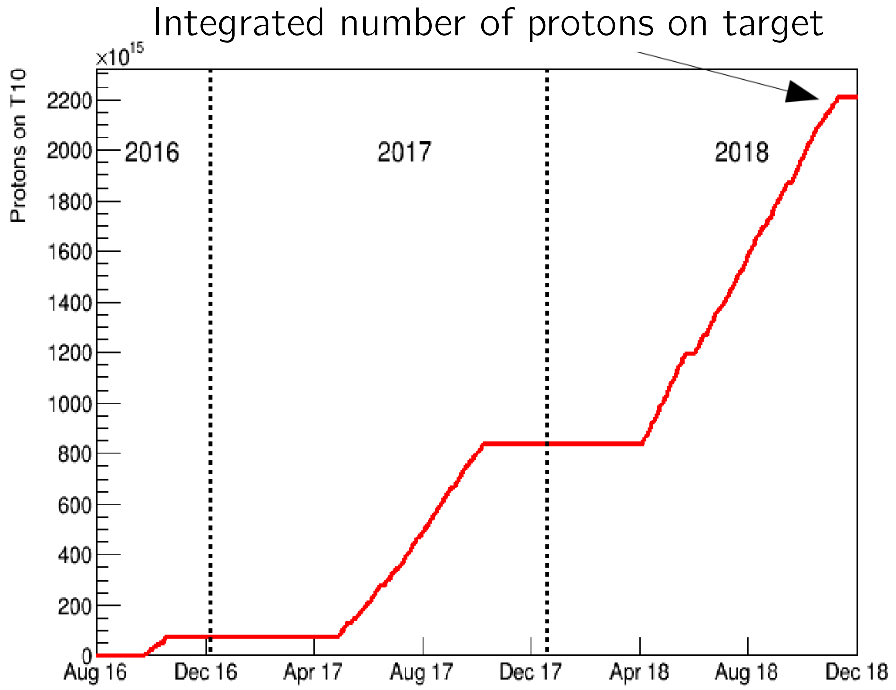
Other talks on NA62:
- Latest results from precision measurements at the NA62 experiment 10/04/24, 14:20.
- Latest results for searches of exotic decays with NA62 in beam-dump mode 10/04/24, 14:40.

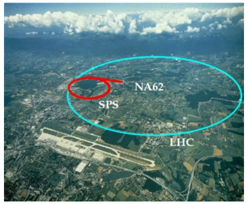
The NA62 experiment at CERN

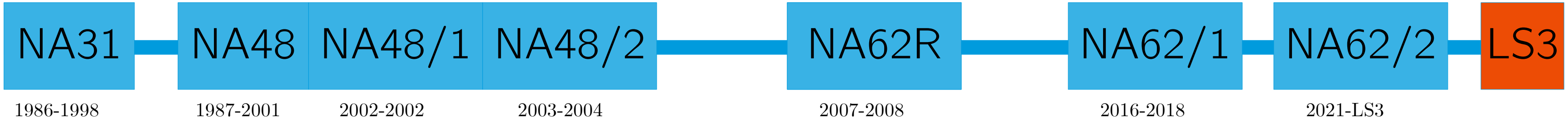
- **Successor of NA48**;
- Data taking **started in 2016**;
- Continuation until **beginning of LS3 (2025)**.

Data collected in 2 run periods:
- Run 1 (2016-2018), total $\mathcal{N}_{K^+} \sim 6 \times 10^{12}$;
- Run 2 (2021-ongoing).

Main configuration **Kaon beam mode**, also:
- **Beam dump** mode (see other NA62 talks);
- **Muon beam mode**, for detector set-up.







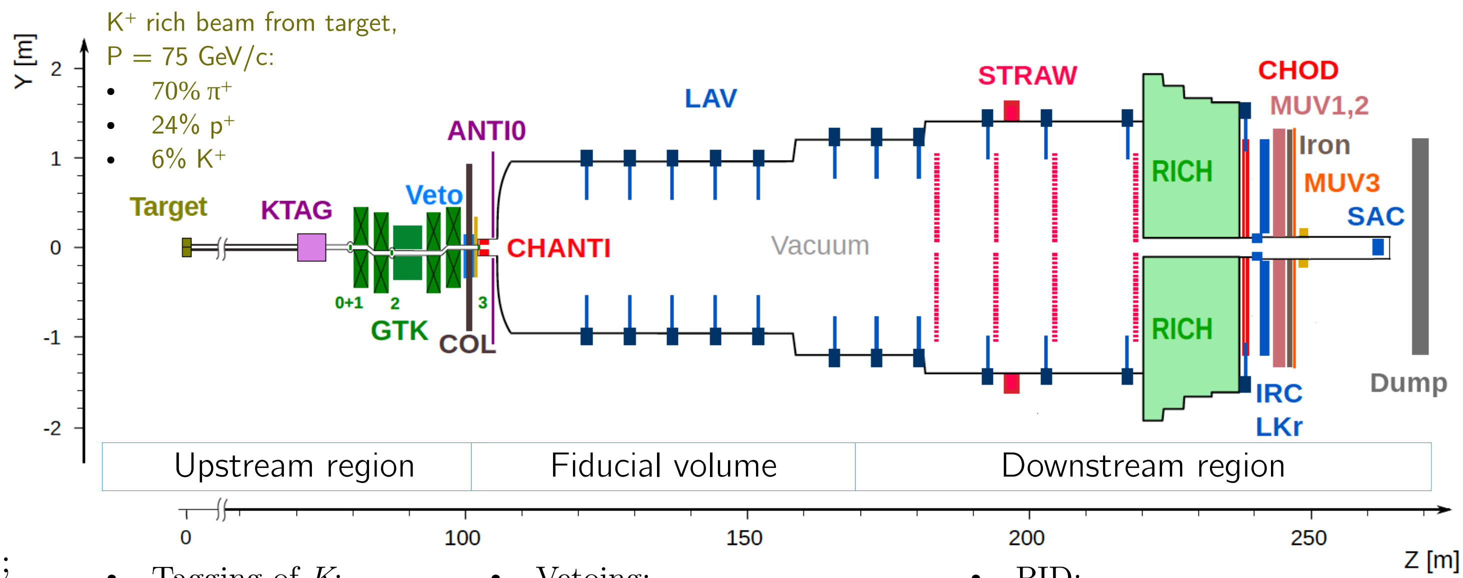
The NA62 experiment at CERN

NA62 is a **fixed target experiment**:

- **Designed** for $\pi\nu\bar{\nu}$ decay channel:

$$K^+ \longrightarrow \pi^+ \nu \bar{\nu}.$$

- K^+ **decay in-flight**;
- **High kaon rate.**
- 75 m long **decay volume**;
- **Reconstruction** of **initial** state K^+ and **final** state particles;
- **High timing resolution** $O(100 \text{ ps})$;
- **Excellent PID** system (K, π, μ, γ, e);
- **Hermetic γ and μ veto;**



- Tagging of K;
- Tracking;
- Vetoing.

- Vetoing;
- Free decay region.

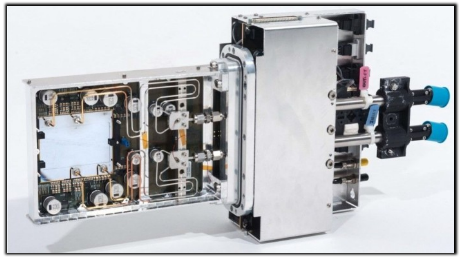
- PID;
- Downstream tracking;
- Calorimetry.

The NA62 experiment at CERN

NA62 experimental hall from downstream.
Green detector is the RICH.
Arrow indicates the beam direction.

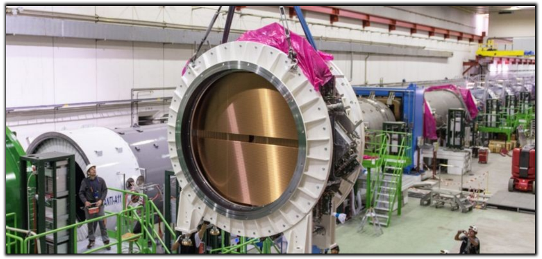
The upstream tagging Cherenkov detector (CEDAR)

$\sigma_t \approx 70$ ps.



Upstream tracker module (GTK)

$\sigma_t \approx 100 \text{ ps}, \sigma_\theta \approx 16\mu \text{ rad}, \Delta p/p \approx 0.2\%$



Downstream tracker-spectrometer (STRAW)

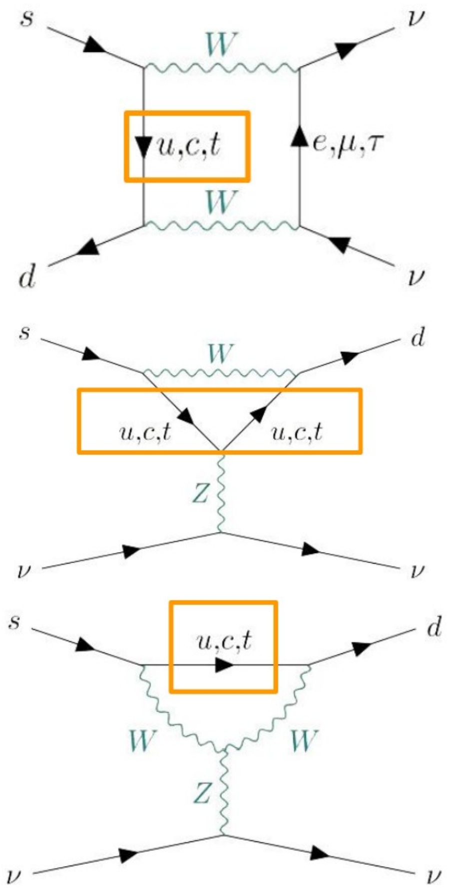
$\sigma_x \approx 130\mu \text{ m}, \Delta p/p \approx 0.3\% + 0.005\%p$

The $\pi\nu\bar{\nu}$ decay at NA62

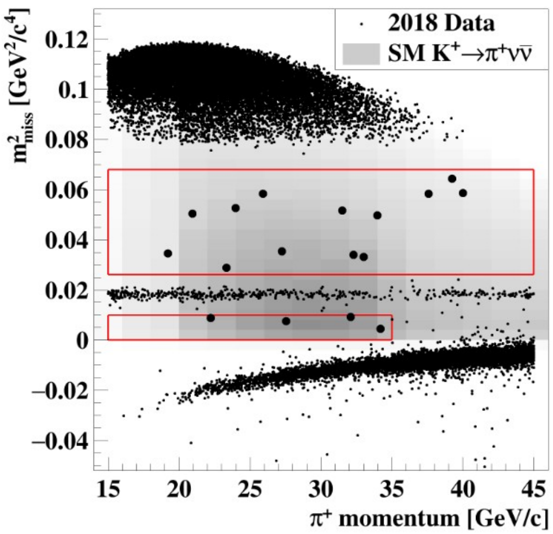
The $\pi\nu\bar{\nu}$ decay is a FCNC process:

- **Forbidden in SM at tree level** (penguin/box).
- **BR** measurement → **CKM matrix structure**;
- **Very clean SM prediction**.

Box (top) and penguin diagram processes.
Orange box *highlights sensitivity to CKM structure.*



Result from Run1 data:



$$\mathcal{N}^{\rm exp}_{\pi\nu\bar{\nu}} = 10.01 \pm 0.42|_{\rm syst} \pm 1.19|^{\rm exp}_{\rm SIG} + 7.03^{+1.05}_{-0.82}|^{\rm exp}_{\rm BG}$$

$$\mathcal{N}^{\rm obs}_{\pi\nu\bar{\nu}} = 20 \quad (17\,\text{in } 2018).$$

$$BR_{\pi\nu\bar{\nu}} = (10.6^{+4.0}_{-3.4}|_{\rm stat} \pm 0.9|_{\rm syst}) \times 10^{-11}.$$

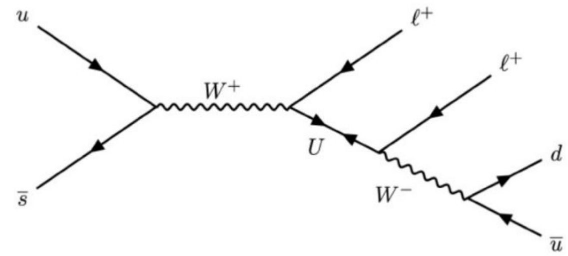
The most precise measurement available to date!

LF and LN violation searches at NA62

Lepton Flavor and Lepton Number are conserved quantities within the SM → Beyond SM physics via violation.
In K^+ decays, it is possible to probe several BSM theories up to $\underline{O(100\text{ TeV})}$ energy scale.

Lepton number violation

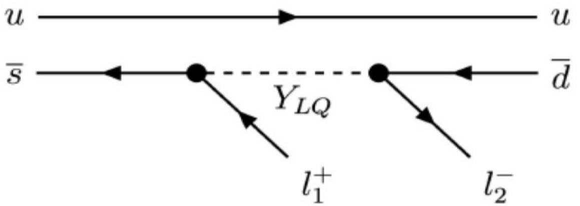
[JHEP 0905 (2009) 030]



$K^+ \to \pi^- l^+ l^+ \quad \Delta L = 2$

Lepton flavour violation

[JHEP 10 (2018) 148]
[Rev. Mod. Phys. 81, 1199 (2009)]
[JHEP 01 (2020)158]



$K^+ \to \pi^+ l_1^+ l_2^- \quad \Delta L_1 = 1, \Delta L_2 = 1$

NA62 is a leading experiment in Kaon physics:

- Full **kinematic characterization** of the products;
- Easy choice on normalization channels;
  (very rich SM phenomenology with similar final states)
- Data driven models for evaluating MC-data discrepancies;
- Hermetic photon veto;
- **Dedicated multi-track lepton trigger lines:**
  - **Multi-track** (100 downscale);
  - **Electron multi-track** (8 downscale);
  - **Muon multi-track** (8 downscale).

Search for the $K^+ \to \mu^- \nu e^+ e^+$ decay

The decay channel $K^+ \to \mu^- \nu e^+ e^+$ is forbidden in SM by LN+LF (for ν_e) or LF (for ν_μ).

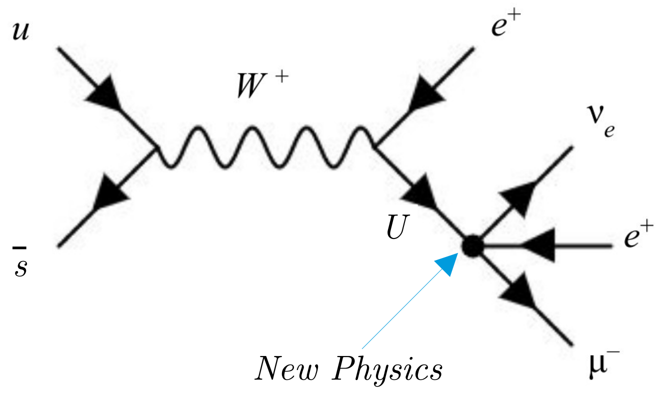
Observation of LN/LF decays such as this one may:

- Provide evidence of the neutrino being a **Majorana particle** (LN violation).
  [JHEP 02 (2018) 169] [Phy. Letters B 491 (2023) 285-290]
- Provide evidence for BSM models involving **Flavour violating ALPs**.
  [JHEP 01 (2020) 158] [Rep. Prog. Phys. 86 (2023) 016201]

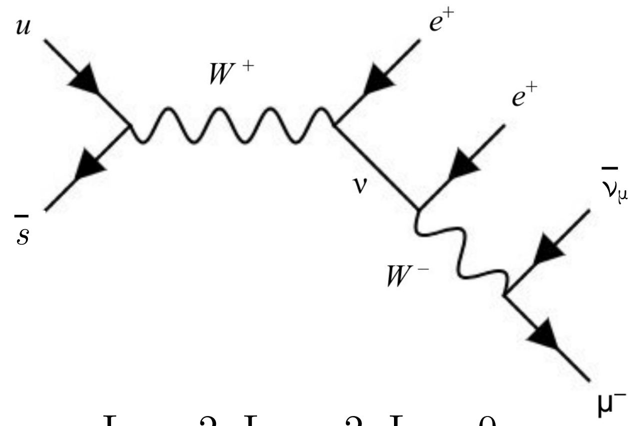
Current best upper limit is:

$BR(K^+ \to \mu^- \nu e^+ e^+) < 2.1 \times 10^{-8}$ @ 90% CL.

[PLB 62 (1976) 485]



L = 0, L_e = -1, L_μ = 1.



L = -2, L_e = -2, L_μ = 0.

Search for the $K^+ \to \mu^- \nu e^+ e^+$ decay

Trigger lines: multi-track (e/μ)

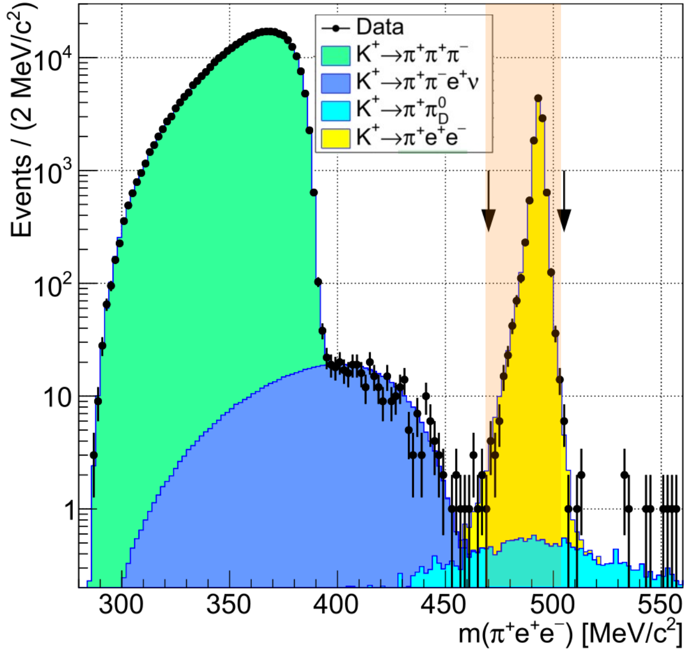
SM decay $K^+ \to \pi^+ e^+ e^-$ as normalization, undetectable final state ν.

Whole NA62 Run 1 dataset used

$$\mathcal{N}_{\text{decays}} \approx 2 \times 10^{12}$$

Signature of final state:

- Exactly **3 well separated downstream track** events (STRAW);
- Correct **PID of the track candidates**.
- Tracks forming a vertex with $\mathbf{Q = +1}$ in the fiducial volume.
- **Photon veto** downstream of the vertex
  - Mitigation of Dalitz decays: $K^+ \to \pi^+ \pi^0_D$, $K^+ \to \pi^0_D e^+ \nu$; $(\pi^0_D \to \gamma e^+ e^-)$



Downstream mass in normalisation channel.

Signal region blinded during selection.

Search for the $K^+ \to \mu^- \nu e^+ e^+$ decay

K$\mu\nu$ee selection (signal)

- Track identified as μ, e^+, e^-
- **Momentum deficit of the vertex** (K3π suppression).
- Electromagnetic veto from calorimeter.

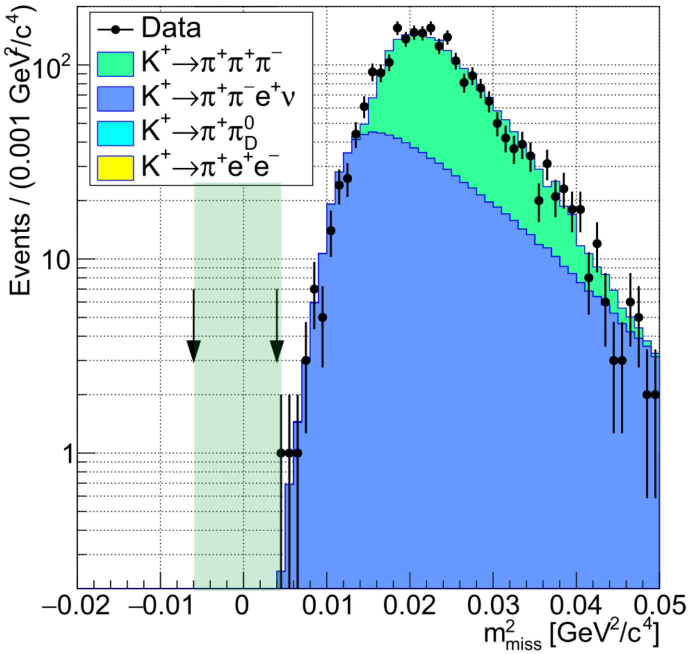
0 events observed in signal region:

$$\text{SES}(K^+ \to \mu^- \nu e^+ e^+) = (3.53 \pm 0.12) \times 10^{-11}.$$

$$\text{BR}(K^+ \to \mu^- \nu e^+ e^+) < 8.1 \times 10^{-11} \quad (@\,90\%\ \text{CL}).$$

- Improvement of approx. 250 w.r.t [PLB 62 (1976) 485].
- Achieved sensitivity not sufficient for exclusion of LF/LN modes.

Final state missing mass (ν)
Signal region highlighted.



$$m^2_{\text{miss}} = (P_K - P_\mu - P_{e1} - P_{e2})^2 = m^2_\nu$$

$$-6 \times 10^{-3}\ \text{GeV}^2/\text{c}^4 < m^2_{\text{miss}} < +4 \times 10^{-3}\ \text{GeV}^2/\text{c}^4$$

Summary of LN/LF violation analyses in NA62 Run 1

Type	Process	Prev. UL	NA62 UL	Improvement	Reference
LNV/LFV	$K^+ \to \mu^- \nu e^+ e^+$	$< 2.1 \times 10^{-8}$	$< 8.1 \times 10^{-11}$	$\mathcal{O}(10^2)$	Phys. Lett. B 838 (2023) 137679
LNV/LFV	$K^+ \to e^- \nu \mu^+ \mu^+$	—	$\sim 2 \times 10^{-11}$	—	
LNV	$K^+ \to \pi^- \mu^+ \mu^+$	$< 8.6 \times 10^{-11}$	$< 4.2 \times 10^{-11}$	2 (w/30% Run1)	Phys. Lett. B 797 (2019) 134794
LNV	$K^+ \to \pi^- e^+ e^+$	$< 6.4 \times 10^{-10}$	$< 5.3 \times 10^{-11}$	$\mathcal{O}(10)$	Phys. Lett. B 830 (2022) 137172
LNV	$K^+ \to \pi^- \pi^0 e^+ e^+$	—	$< 8.5 \times 10^{-10}$	**FIRST SEARCH!**	Phys. Lett. B 830 (2022) 137172
LNV	$K^+ \to \pi^- \pi^0 \mu^+ e^+$	—	—	—	
LNV	$K^+ \to \pi^- \mu^+ e^+$	$< 5.0 \times 10^{-10}$	$< 4.2 \times 10^{-11}$	$\mathcal{O}(10)$	Phys. Rev. Lett. 127,131802(2021)
LFV	$K^+ \to \pi^+ \mu^- e^+$	$< 5.2 \times 10^{-10}$	$< 6.6 \times 10^{-11}$	$\mathcal{O}(10)$	Phys. Rev. Lett. 127,131802(2021)
LFV	$\pi^0 \to \mu^- e^+$	$< 3.4 \times 10^{-9}$	$< 3.2 \times 10^{-10}$	$\mathcal{O}(10)$	Phys. Rev. Lett. 127,131802(2021)
LFV	$K^+ \to \pi^+ \pi^0 \mu^- e^+$	—	—	—	
LFV	$K^+ \to \pi^+ \mu^+ e^-$	$< 1.3 \times 10^{-11}$	—	—	
LFV	$\pi^0 \to e^- \mu^+$	$< 3.8 \times 10^{-10}$	—	—	

Hidden sector searches in $K^+ \to \pi^+ e^- e^+ e^- e^+$.

Searches for Dark Sector particles from K focused on single particle production… (**NA62 is involved in $K^+ \to \pi^+ X$**)

Proposed channel with **pair production** of dark mediators:
$K^+ \to \pi^+ X(\to e^+e^-) X(\to e^+e^-)$;

New search!

There are **SM channels with the same signature** → Normalization.

- Double Dalitz decay in a K2π event: $K^+ \to \pi^+ \pi^0_{DD}(\to e^+e^-e^+e^-)$; $\mathrm{BR} = (6.9 \pm 0.3) \times 10^{-6}$. [Prog. Theor. Exp. Phys. 2022 (2022) 083C01]
- Single and double γ exchange: $K^+ \to \pi^+ \gamma^*$, $K^+ \to \pi^+ \gamma^* \gamma^*$; $\mathrm{BR} = (7.2 \pm 0.7) \times 10^{-11}$. [Phys. Rev. D106 (2022) L071301]

BSM proposed phenomena:

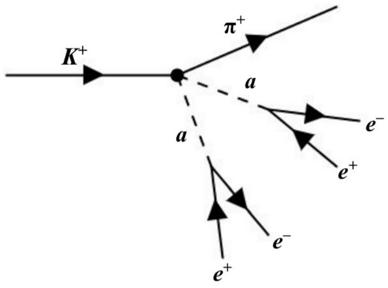
QCD Axion Like Particle (ALP):
- Explains the "17 MeV anomaly" for atomic nuclei de-excitation through dielectron emission
- The existence of this ALP with $m_a = 17$ MeV/c^2 puts a bound on the process!

Valid explanation only if Axion mass matches the anomaly

$$\mathrm{BR}(K^+ \to \pi^+ aa) > 2 \times 10^{-8}.$$

[Phys.Rev.D103(2021)055018, Eur.Phys.J.C83(2023)230]
[Phys.Rev.D105(2022)015017]

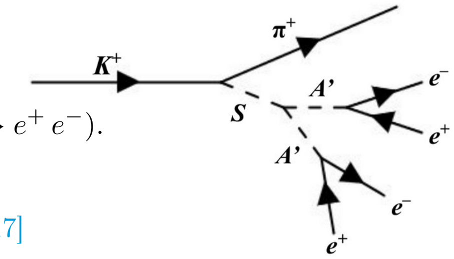
$$2m_e \leq m_a \leq (m_K - m_\pi)/2$$



Cascade process of several Dark sector particles:
- Dark Scalar S' decaying in Dark Photons A';
- A' decaying to di-electrons

$$K^+ \to \pi^+ S'(S' \to A' A'), (A' \to e^+ e^-).$$
$$m_{S'} > 2m_{A'}$$

[Phys. Rev. D105 (2022) 015017]



First experimental result for $K^+ \to \pi^+ e^- e^+ e^- e^+$.

Trigger lines: multi-track (e/μ).

Signal region blinded during selection.

Whole NA62 Run 1 dataset used

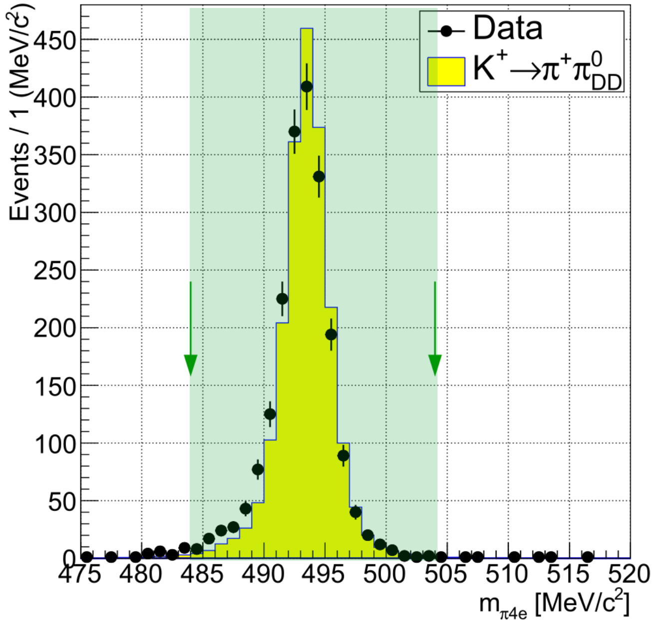
$\mathcal{N}_{\text{decays}} \approx 8.6 \times 10^{11}$

Signature of final state:

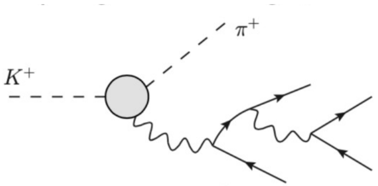
- **5** downstream tracks;
  - **STRAW** is used exclusively, no acceptance check;
  - Tracks forming a vertex with $\boldsymbol{Q} = +\mathbf{1}$, consistent with the beam momentum and direction;

- **Signal** events **→ subset** of **Kπ4e** selection;
- **Kπ⁰DD** decay channel as **normalisation**.

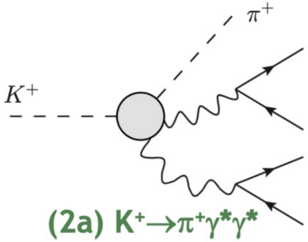
m_{4e} for data and MC after the Kπ⁰DD *selection. Normalisation region highlighted.*



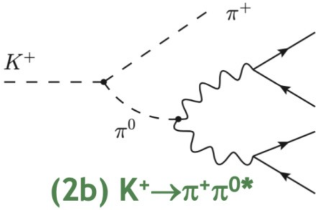
Kπ4e channel (non resonant)



(1) $K^+ \to \pi^+ \gamma^*$



(2a) $K^+ \to \pi^+ \gamma^* \gamma^*$



(2b) $K^+ \to \pi^+ \pi^{0*}$

First experimental result for $K^+ \to \pi^+ e^- e^+ e^- e^+$.

Result:

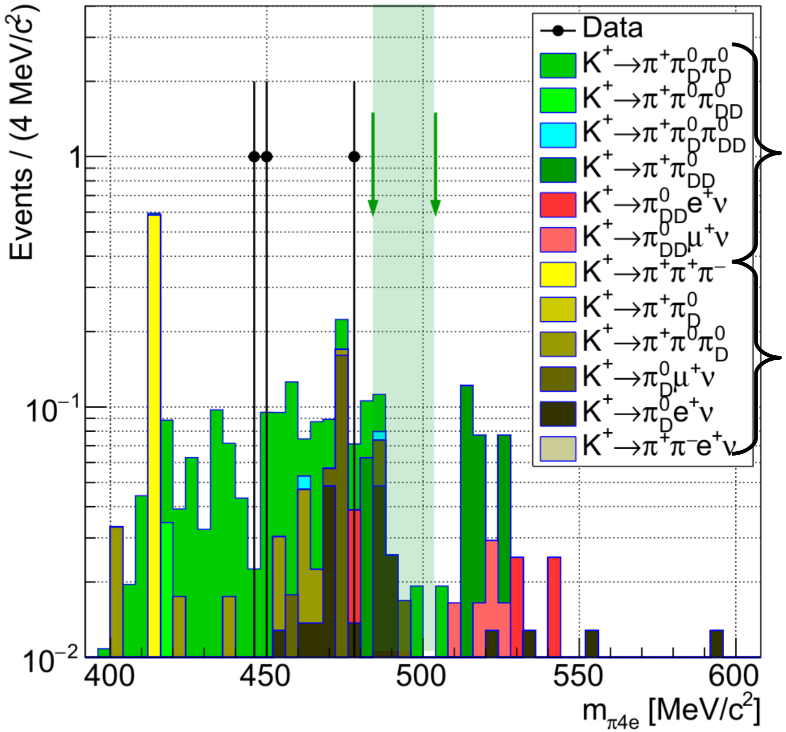
- **0 events observed in signal region;**
  - Expected background from MC in signal region:

$$\mathcal{N}_{\rm BG} = (0.18 \pm 0.14).$$

- **Branching ratio for non resonant case:**

$$\mathrm{BR}(K^+ \to \pi^+ 4e) < 1.4 \times 10^{-8} \quad (@\,90\%\ \mathrm{CL}).$$

(200 times greater than SM prediction)



5 tracks and 7 tracks backgrounds. (only shown BR > 10^{-8})

3 tracks backgrounds with K3π coincidence. (only shown BR > 10^{-6})

$m_{\pi 4e}$ after Kπ4e selection, with signal region highlighted.
Most relevant backgrounds for 3 track and 5+ track included.

Signal region blinded during selection.

First experimental result for $K^+ \to \pi^+ e^- e^+ e^- e^+$.

Signal-like events are subset of $K\pi 4e$; discrimination is based on:

1) Parent particle (X = ALP or A') of each e^+e^- couple is pair produced, so masses of couples should be consistent!

Discriminant: compatibility of couple masses, normalised over expected couple mass resolution (from MC).

$$\mathcal{D} = \frac{(m_{ee1} - m_{ee2})^2}{(4.9 \times 10^{-3} m_{ee})^2}.$$

2) The mass hypothesis for the parent particle should not be "too far" from the one of the couple.

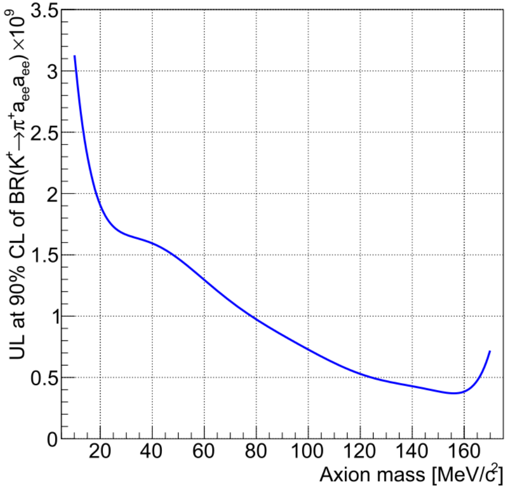
$$|m_{ee} - m_X| < 0.02 m_X.$$

Expected SM background in signal region:

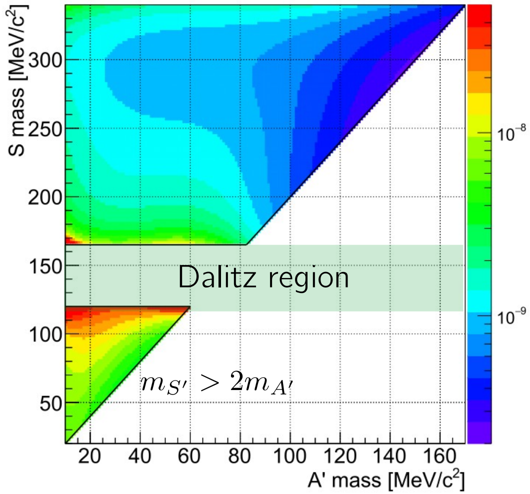
$$\mathcal{N}_{\text{BG}} = (4 \pm 4) \times 10^{-4}.$$

$$\mathcal{N}_{\text{obs}} = 0.$$

UL of $K^+ \to \pi^+ aa$ **(ALP case)**



UL of $K^+ \to \pi^+ S'$ ($S' \to A'$ ($A' \to e^+e^-$))
(DARK SCALAR case)



Exclusion of the light QCD ALP as source of "17MeV" anomaly!

$$\text{BR}_{\text{exp}}(K^+ \to \pi^+ aa)\text{BR}_{\text{exp}}(a \to e^+e^-)^2 < 2.1 \times 10^{-9} \,@\, m_a = 17\text{MeV/c}^2.$$

$$\text{BR}_{\text{theo}}(K^+ \to \pi^+ aa)\text{BR}_{\text{theo}}(a \to e^+e^-)^2 > 2 \times 10^{-8} \,@\, m_a = 17\text{MeV/c}^2.$$

Outlook and future

- The **NA62** experiment provided the **best available estimation** for the ultra-rare $\pi\nu\bar{\nu}$ decay.
  - NA62 Run 1 data published;
  - NA62 Run 2 data being analysed.
- Rich Rare and Exotics decay physics program ← powerful probe for BSM Physics;
- Improvement up to $O(10^2)$ on several LF/LN-violating decay channels involving K^+.
- First result for $K^+ \to \pi^+ X(\to e^+e^-) X(\to e^+e^-)$.
- All the measurements, including the $\pi\nu\bar{\nu}$, will provide better upper limits with Run 2 data.

END
Backup slides

Introduction to the $K^+ \longrightarrow \pi^+ \nu \bar{\nu}$ decay

The PNN decay is a FCNC process:

- **Forbidden in SM at tree level** (penguin/box).
- **BR** directly related to **CKM matrix structure**.
  - **Quadratic GIM Mechanism** → experimentally measurable short range operators.
- **Very clean SM prediction** through $Ke3$ decay channel.

Testing ground for BSM flavour physics, such as:

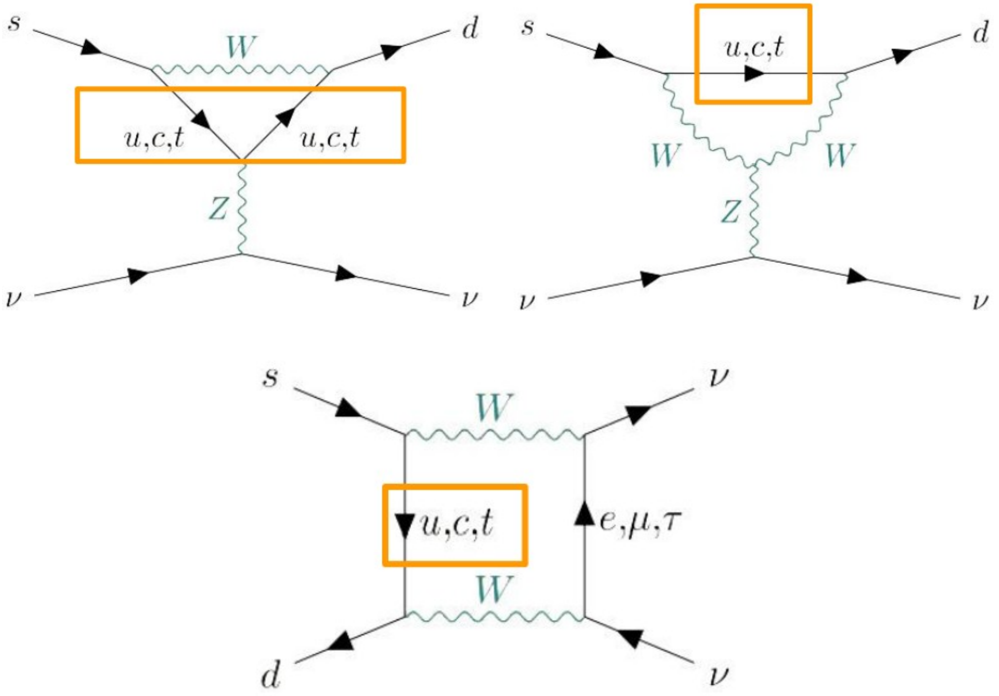
- Direct evidence of CP violation (together with $K_L \pi^0 \nu\nu$);
- Lepton flavour (non)universality;
- Provide constraint to Leptoquark models;
- Deviations from SM.

Strong SM branching ratio predictions:

$BR = (7.86 \pm 0.61) \times 10^{-11}$ JHEP 09 (2022) 148

$BR = (8.60 \pm 0.42) \times 10^{-11}$ arXiv:2109.11032

$BR = (7.73 \pm 0.61) \times 10^{-11}$ arXiv:2105.02868



Penguin (top) and Box diagram processes involved in the PNN decay.
Orange box highlights sensitivity to CKM structure.

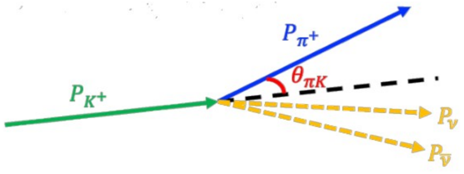
The PNN decay at NA62

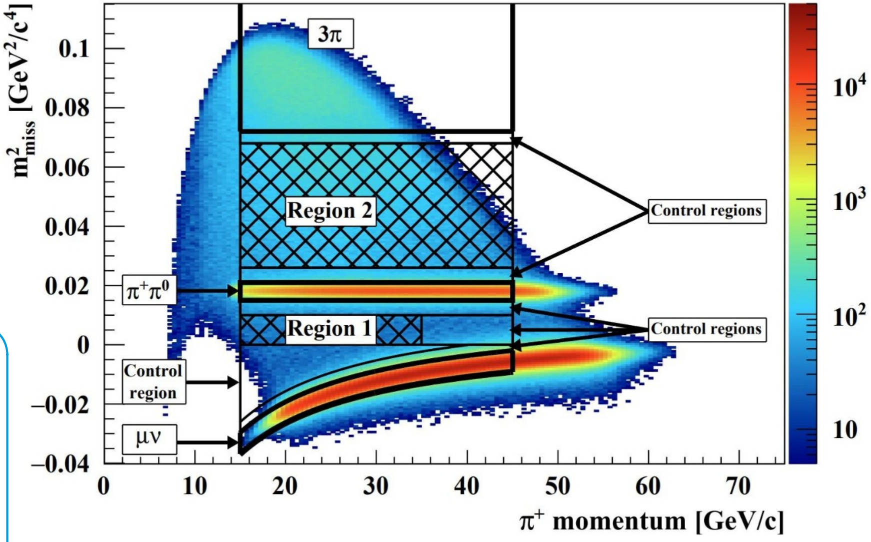
Signature of PNN:

- One downstream track identified as a π^+, matched with one good K^+ (upstream track);
- Well **characterised** charged **products energy**;
- Some **missing momentum in the final state**.

Selection based on

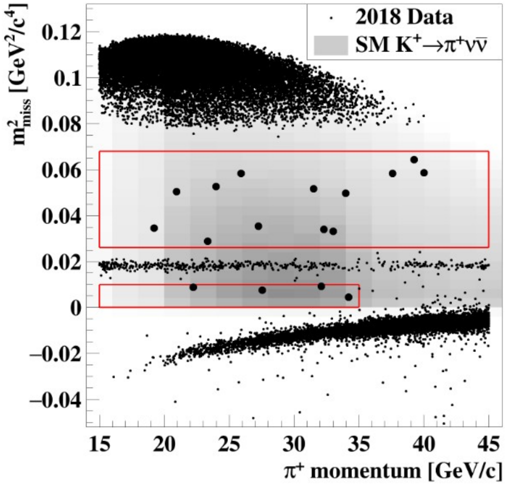
- Downstream track (π^+) momentum;
- Invariant missing mass $m^2_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2$





Plot of the phase space concerning the PNN search at NA62.
Events in the plot are Run1 data
Several control regions are defined close to the signal regions (hatch mark).
High count regions corresponding to known backgrounds are also highlighted.

Result from Run1 data [JHEP 06 (2021) 093]



$$\mathcal{N}^{\text{exp}}_{\text{PNN}} = 10.01 \pm 0.42|_{\text{syst}} \pm 1.19|^{\text{exp}}_{\text{SIG}} + 7.03^{+1.05}_{-0.82}|^{\text{exp}}_{\text{BG}}$$

$$\mathcal{N}^{\text{obs}}_{\text{PNN}} = 20 \quad (17 \text{ in } 2018).$$

$$BR_{\text{PNN}} = (10.6^{+4.0}_{-3.4}|_{\text{stat}} \pm 0.9|_{\text{syst}}) \times 10^{-11}.$$

The most precise measurement of PNN available to date!

Backup

Main K decay channels

Decay channel		BR [%]
$K^+ \longrightarrow \mu^+ \nu$	$[K_{\mu 2}]$	63.55
$K^+ \longrightarrow \pi^+ \pi^0$	$[K_{2\pi}]$	20.66
$K^+ \longrightarrow 2\pi^+ \pi^-$	$[K_{3\pi}]$	5.59
$K^+ \longrightarrow \pi^0 e^+ \nu$	$[K_{e3}]$	5.07
$K^+ \longrightarrow \pi^0 \mu^+ \nu$	$[K_{\mu 3}]$	3.353
$K^+ \longrightarrow \pi^+ 2\pi^0$	$[K_{3\pi 0}]$	1.761
$\mathbf{K^+ \longrightarrow \pi^+ \nu \bar{\nu}}$	[PNN]	$\sim \mathbf{7.8 \times 10^{-9}}$

Decay BG of pieeee

Source	Branching ratio (or their product)
5 track, 7 track decays:	
$K_{2\pi \mathrm{DD}}$	6.9×10^{-6}
$K^+ \to \pi^+ \pi^0_{\mathrm{D}} \pi^0_{\mathrm{D}}$	2.4×10^{-6}
$K^+ \to \pi^0_{\mathrm{DD}} e^+ \nu$	1.7×10^{-6}
$K^+ \to \pi^+ \pi^0 \pi^0_{\mathrm{DD}}$	1.2×10^{-6}
$K^+ \to \pi^0_{\mathrm{DD}} \mu^+ \nu$	1.1×10^{-6}
$K^+ \to \pi^+ \pi^0_{\mathrm{D}} \pi^0_{\mathrm{DD}}$	1.4×10^{-8}
3 track decays with K3π coincidence:	
$K^+ \to \pi^0_{\mathrm{D}} e^+ \nu$	3.3×10^{-5}
$K^+ \to \pi^+ \pi^0 \pi^0_{\mathrm{D}}$	2.3×10^{-5}
$K^+ \to \pi^0_{\mathrm{D}} \mu^+ \nu$	2.2×10^{-5}

Kπ4e selection

Rejection of π^0, done with:

- Cut on m_{4e};
- Cut on $m^2_{\mathrm{miss}} = (P_{K^+} - P_{\pi^+})^2$.

m_{4e} incompatible with $m_{\pi 0}$

Missing mass does not hint π^0

Kπ⁰DD selection

selection of events with m^2_{miss} and m_{4e} compatible with π^0 in final state.

Backup

Table 1
Backgrounds to the $K_{\pi 4e}$ decay, their branching ratios (or products of branching ratios for coincidences of two decays), and estimated backgrounds with their statistical uncertainties in the control ($\Delta p < -2$ GeV/c) and signal ($|\Delta p| < 2$ GeV/c) momentum excess regions shown in Fig. 3 (left). Estimated backgrounds in the control region for a loose $K_{\pi 4e}$ selection, with the $p_\pi > 10$ GeV/c condition removed, are also shown. The $K^+ \to \pi^+\pi^0_D e^+e^-$ decay, as well as the $K^+ \to \pi^+\pi^-e^+\nu$ decay in coincidence with a $K^+ \to \pi^+\pi^+\pi^-$ decay, and coincidences of any of the two decays, $K^+ \to \pi^+\pi^+\pi^-$ and $K^+ \to \pi^+\pi^0_D$, lead to negligible backgrounds in the control and signal regions, and are not listed.

Source	Branching ratio (or their product)	Control region	Control region, loose selection	Signal region
Single five-track and seven-track decays				
$K_{2\pi DD}$	6.9×10^{-6}	0.06 ± 0.06	0.06 ± 0.06	–
$K^+ \to \pi^+\pi^0_D\pi^0_D$	2.4×10^{-6}	0.30 ± 0.06	2.47 ± 0.16	0.04 ± 0.02
$K^+ \to \pi^0_{DD}e^+\nu$	1.7×10^{-6}	0.10 ± 0.05	0.10 ± 0.05	–
$K^+ \to \pi^+\pi^0\pi^0_{DD}$	1.2×10^{-6}	0.03 ± 0.03	0.03 ± 0.03	–
$K^+ \to \pi^0_{DD}\mu^+\nu$	1.1×10^{-6}	0.02 ± 0.02	0.03 ± 0.02	–
$K^+ \to \pi^+\pi^0_D\pi^0_{DD}$	1.4×10^{-8}	0.05 ± 0.02	0.10 ± 0.02	0.01 ± 0.01
Coincidences of three-track decays with a $K^+ \to \pi^+\pi^+\pi^-$ decay				
$K^+ \to \pi^0_D e^+\nu$	3.3×10^{-5}	0.15 ± 0.07	0.15 ± 0.07	0.08 ± 0.05
$K^+ \to \pi^+\pi^0\pi^0_D$	2.3×10^{-5}	0.03 ± 0.03	0.08 ± 0.05	–
$K^+ \to \pi^0_D\mu^+\nu$	2.2×10^{-5}	0.03 ± 0.02	0.04 ± 0.02	0.05 ± 0.02
Total		0.77 ± 0.13	3.06 ± 0.21	0.18 ± 0.06
Data		1	4	0

Table 1
Background estimates in the lower, signal and upper $K_{\mu\nu ee}$ squared missing mass regions with their statistical uncertainties. The contributions from upstream $K^+ \to \pi^+\pi^+\pi^-$ and $K^+ \to \pi^+\pi^-e^+\nu$ decays are quoted separately. Upper limits at 90% CL are quoted when no simulated events satisfy the selection. The numbers of observed data events are also listed.

Mode / Region	Lower	Signal	Upper
$K^+ \to \pi^+\pi^+\pi^-$	< 0.07	< 0.07	1412 ± 11
$K^+ \to \pi^+\pi^-e^+\nu$	0.01 ± 0.01	0.16 ± 0.02	867 ± 1
$K^+ \to \pi^+\pi^+\pi^-$ (upstream)	< 0.03	0.06 ± 0.03	1.5 ± 0.3
$K^+ \to \pi^+\pi^-e^+\nu$ (upstream)	0.01 ± 0.01	0.01 ± 0.01	0.14 ± 0.03
$K^+ \to \pi^0_D e^+\nu$	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01
$K^+ \to e^+\nu\mu^+\mu^-$	< 0.01	< 0.01	0.05 ± 0.02
Total expected	0.04 ± 0.02	0.26 ± 0.04	2281 ± 11
Data	0	0	2271