Recent results from NA62 experiment at CERN

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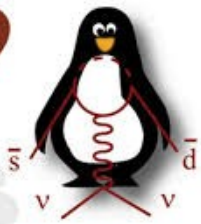
on behalf of the NA62 Collaboration



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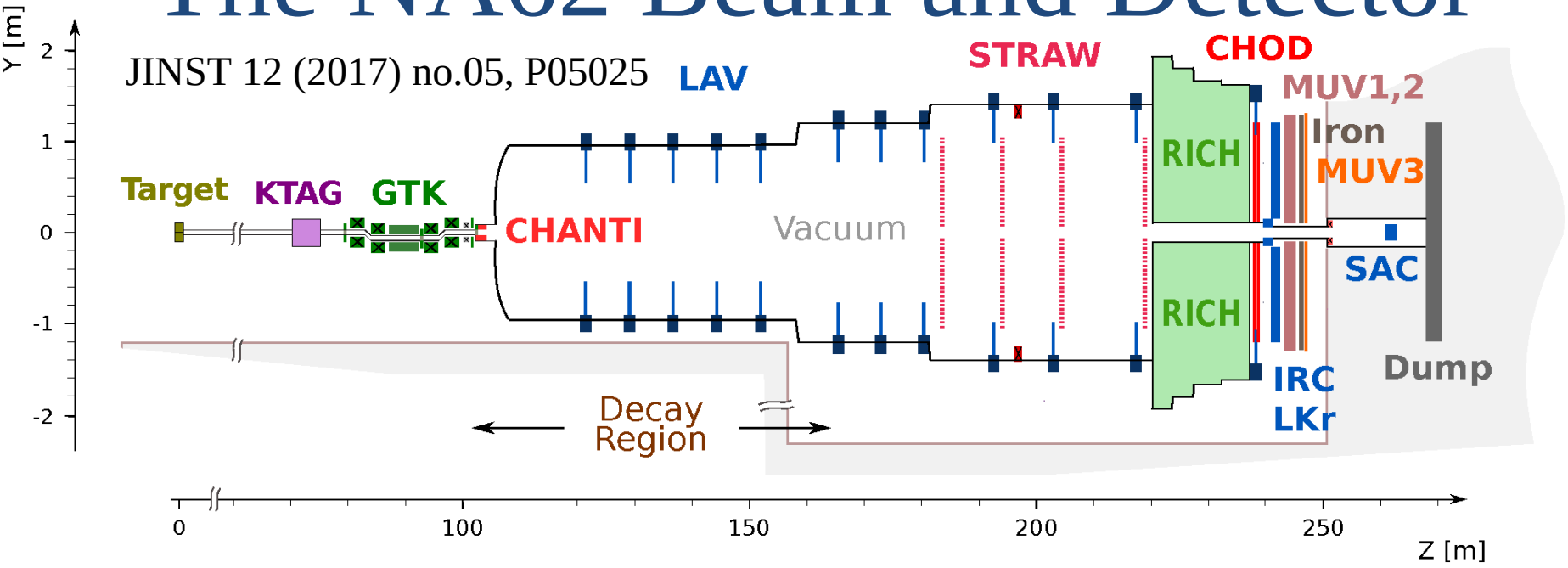
Outline

- ✓ The NA62 Experiment at CERN
- ✓ Recent NA62 results in the search for LFV and LNV in K^+ decays
- ✓ Hidden sector search in NA62 with K^+ decay

The NA62 Beam and Detector



400 GeV/c protons from the SPS on a beryllium target produce secondary charged beam:
6% are 75 GeV/c K^+ mixed with π^+ (70%) and protons (23%).
1% momentum spread (rms), ~100 μrad divergence

~10 MHz of raw input data to the L0 trigger (FPGA) from detectors
~1 MHz of events passing the first trigger level
L1 and L2 trigger (software) guarantee a maximum of $\mathcal{O}(10)$ kHz of acquisition rate.

NA62 Data taking

- 2014: Pilot Run
- 2015: Commissioning Run
- 2016: 30 days, 40% nominal intensity, 2×10^{11} useful kaon decays
- 2017: 161 days, 60% nominal intensity, 2×10^{12} useful kaon decays
- 2018: 217 days, 60% nominal intensity, 4×10^{12} useful kaon decays
- 2019 – 2020: LS2, no beam
- 2021: $\sim$ 120 days, 100% nominal intensity
- 2022: $\sim$ 200 days, 100% nominal intensity
- 2023: $\sim$ 140 days, 70%-100% nominal intensity

LFV and LNV

Lepton Number/Flavor violation

- Lepton number (L) and lepton flavor (L_e, L_μ, L_τ) in the SM are conserved quantities
- If violation of these quantities is observed this is a clear indication of Physics Beyond the SM

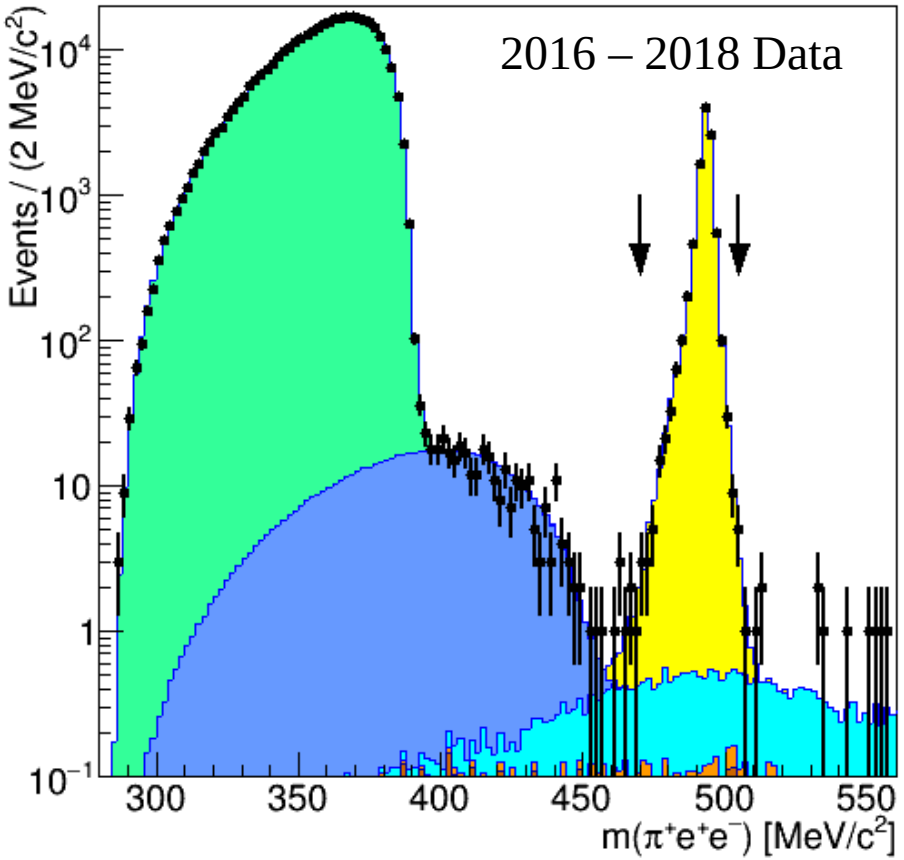
See saw mechanism provides a source of LNV ($\Delta L = 2$) through the exchange of Majorana neutrinos as in $0\nu2\beta$ decay [JHEP 0905 (2009) 030]

LFV ($\Delta le = 1$, $\Delta L\mu = 1$) processes can occur via the exchange of leptoquarks, of a Z' boson, or in SM extensions with light pseudoscalar bosons [JHEP 10 (2018) 148, Rev. Mod. Phys. 81, 1199 (2009), JHEP 01 (2020)158]

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

Normalization channel

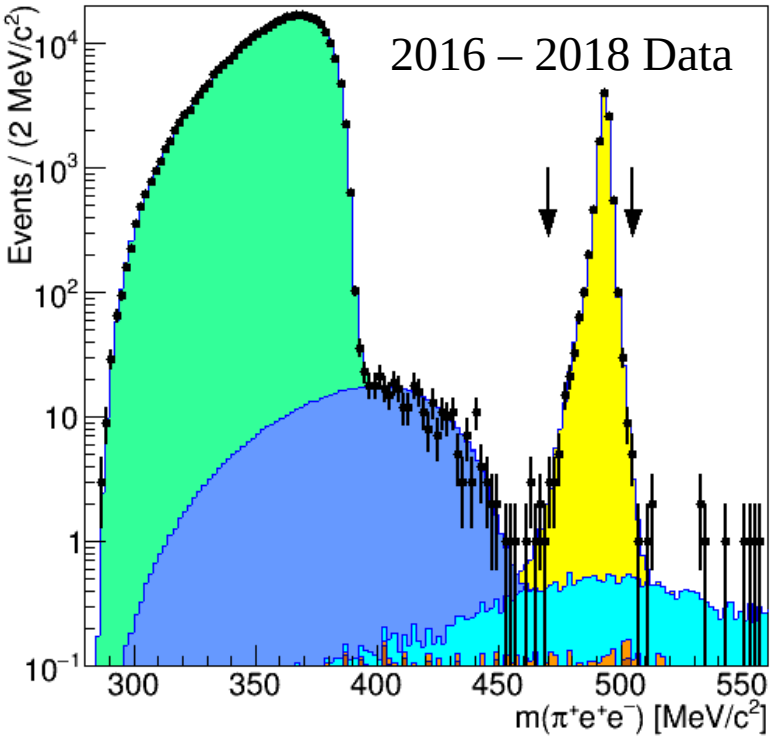
SM: $K^+ \to \pi^+ e^+e^-$



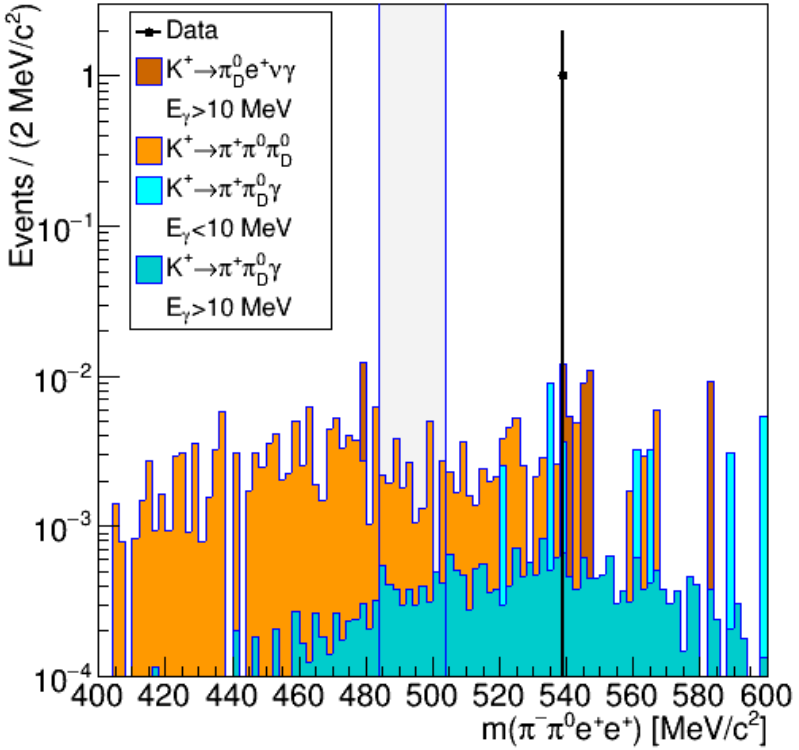
- $N(K^+ \to \pi^+ e^+e^-) = 11041$
- $N(K^+) = (1.015 \pm 0.010 \pm 0.030) \times 10^{12}$

Search for $K^+ \to \pi^-\pi^0 e^+e^+$

SM: $K^+ \to \pi^+ e^+e^-$



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



- A_{cc}(sig) = 0.271%
- SES = 3.68×10^{-10}

After unblinding N_{SR} ($K^+ \to \pi^-\pi^0 e^+e^+$) = 0

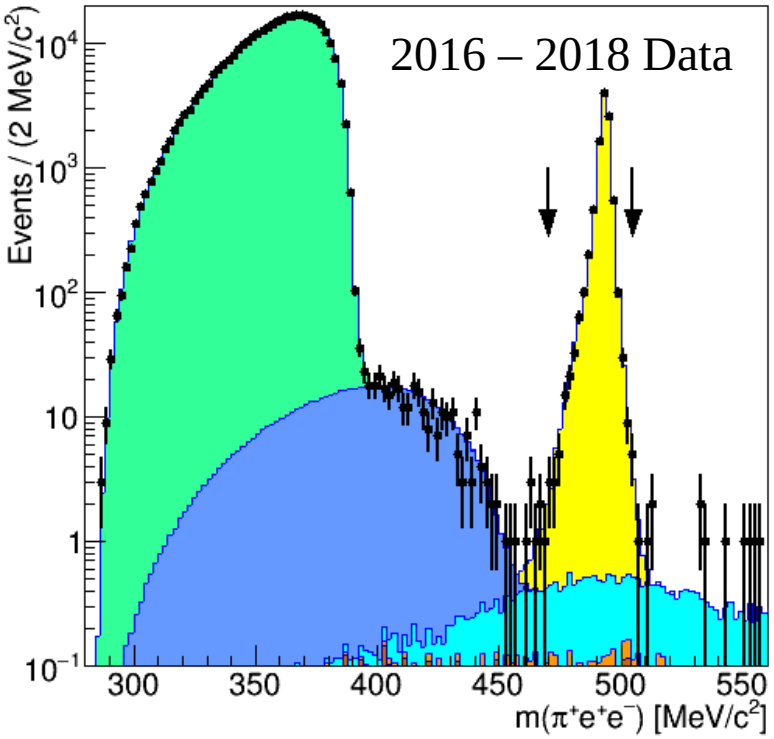
N_{exp}(bkg) = 0.044 ± 0.020

$Br(K^+ \to \pi^- \pi^0 e^+e^+) < 8.5 \times 10^{-10}$ @ 90%CL [PLB 830 (2022) 137172**]**

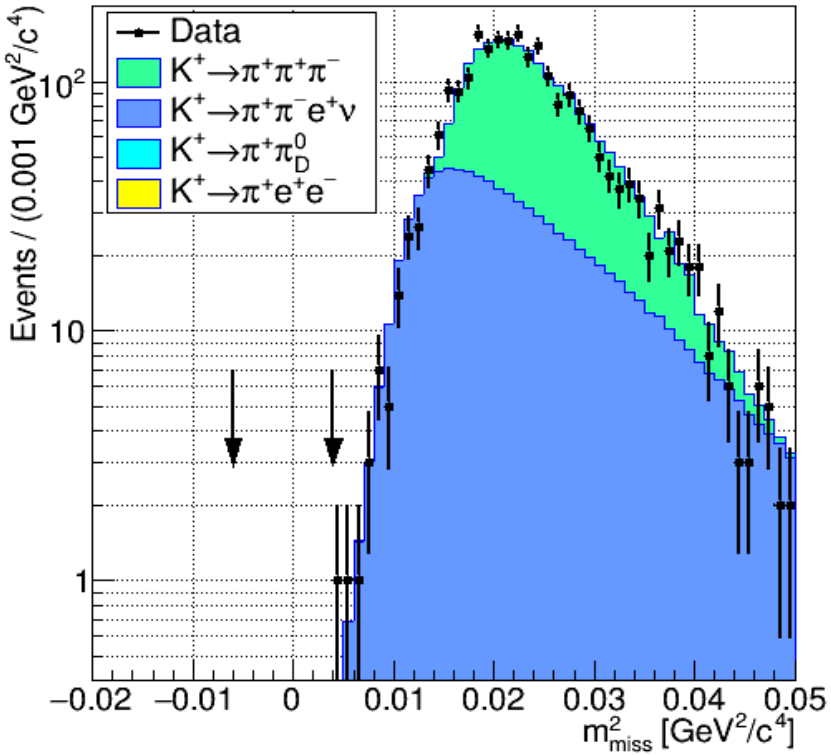
First search of this decay mode

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

SM: $K^+ \to \pi^+ e^+ e^-$



$K^+ \to \mu^- \nu e^+ e^+$



- A_{cc}(sig) = 1.44%
- SES = 3.53×10^{-11}

After unblinding N_{SR} ($K^+ \to \mu^- \nu e^+ e^+$) = 0

N_{exp}(bkg) = 0.26 ± 0.04

$Br(K^+ \to \mu^- \nu e^+ e^+) < 8.1 \times 10^{-11}$ @ 90%CL [PLB 838 (2023) 137679]

Factor 250 of improvement with respect the previous limit

NA62 LNV and LFV summary

Decay	Previous limit @90% CL	NA62 limit @90% CL	Data taking	Improved by a factor	Paper
$K^+ \to \pi^- \mu^+\mu^+$	8.6×10^{-11}	4.2×10^{-11}	2017	2	PLB 797 (2019) 134794
$K^+ \to \pi^- e^+e^+$	6.4×10^{-10}	5.3×10^{-11}	Run1	12	PLB 830 (2022) 137172
$K^+ \to \pi^- \pi^0e^+e^+$	no limit	8.5×10^{-10}	Run1		
$K^+ \to \pi^- \mu^+e^+$	5.0×10^{-10}	4.2×10^{-11}	2017+2018	12	PRL 127 131802 (2021)
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}	6.6×10^{-11}	2017+2018	8	
$\pi^0 \to \mu^-e^+$	3.4×10^{-9}	3.2×10^{-10}	2017+2018	10	
$K^+ \to \mu^+\nu e^+e^+$	2.1×10^{-8}	8.1×10^{-11}	Run1	250	PLB 838 (2023) 137679
$K^+ \to e^+\nu\mu^+\mu^+$	no limit	An. in progress			

Using the data sample coming from NA62 Run2 data taking at least a a factor 2 Improvement is expected

Hidden sector searches with NA62

$K^+ \to \pi^+XX$, $X \to e^+e^-$

- $K^+ \to \pi^+e^+e^-e^+e^-$ is heavily suppressed in the SM: Br(non resonant) = $(7.2 \pm 0.7) \times 10^{-11}$ [Phys. Rev. D106 (2022) L071301]

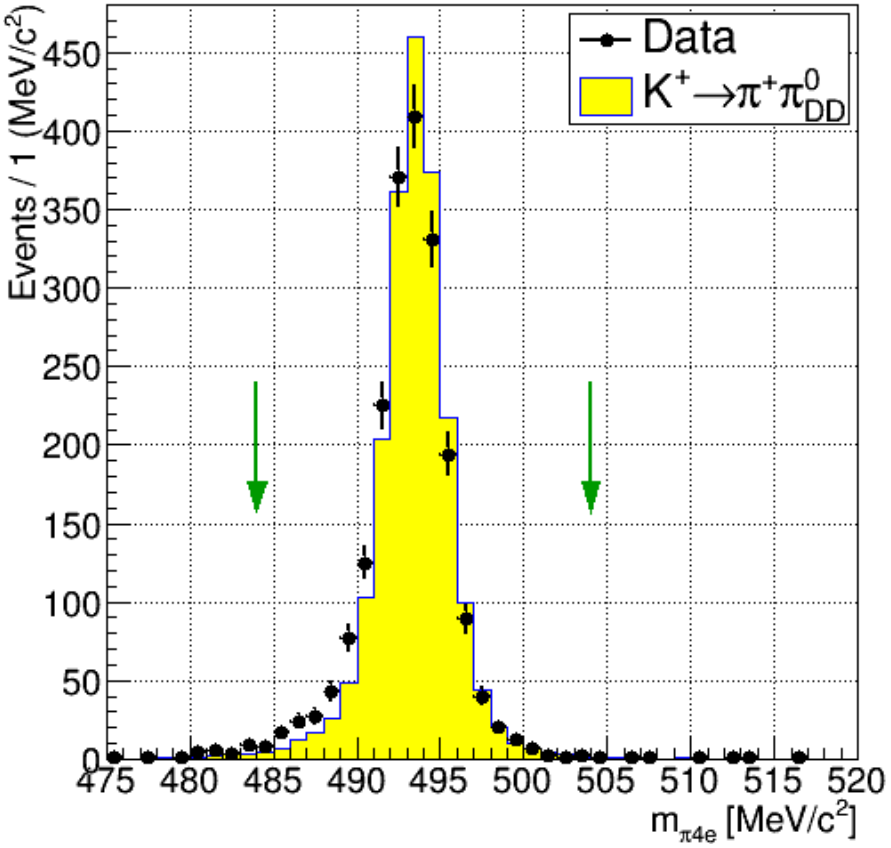
- Short-lived QCD Axion: $K^+ \to \pi^+aa$ with following $a \to e^+e^-$
  - Br($K^+ \to \pi^+aa$)$> 2 \times 10^{-8}$ if m_a=17 MeV/c^2 [Phys.Rev.D105 (2022)015017]
  - The presence of this QCD axion can explain the “17 MeV” Be anomaly [Phys.Rev.D103 (2021)055018, Eur.Phys.J. C83 (2023)230]

- Existence of a Dark Scalar (S) and a Dark Photon (A’)
  - $K^+ \to \pi^+S$, $S \to A'A'$ and $A' \to e^+e^-$ possible if $m_S > 2m_{A'}$ [Phys.Rev.D105 (2022)015017]

Normalization channel

SM: $K^+ \to \pi^+\pi^0$ with $\pi^0 \to e^+e^-\, e^+e^-$ (Double Dalitz π^0 decay)

2017 – 2018 Data

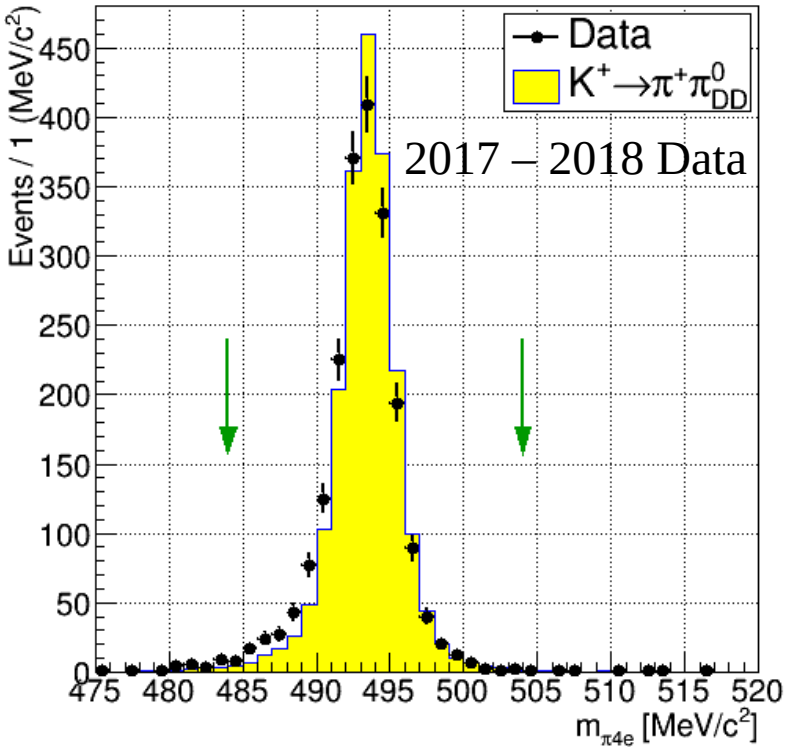


$N(K2\pi_{DD}) = 2023$

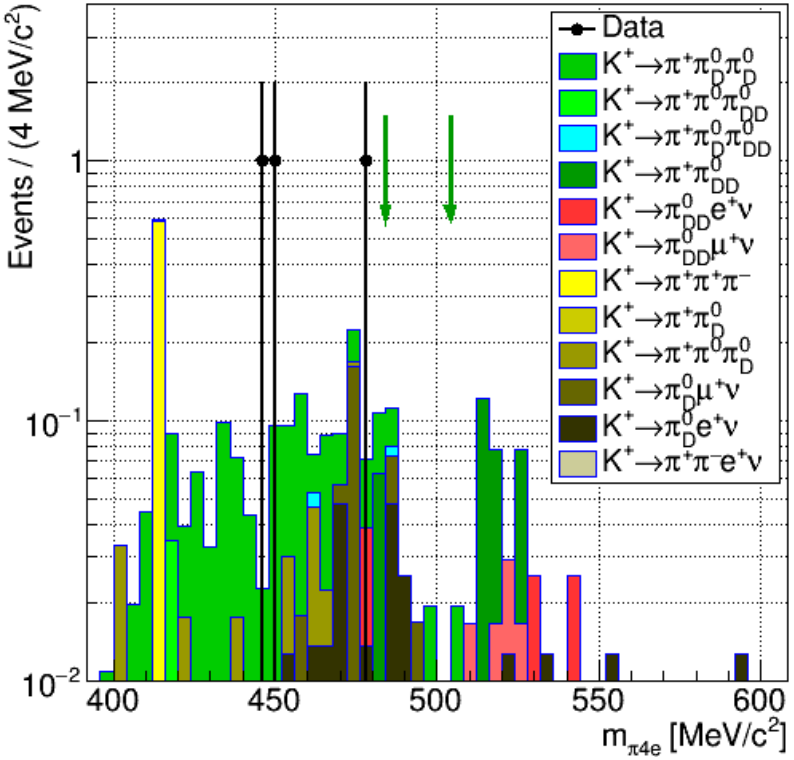
$N(K^+) = (8.58 \pm 0.19 \pm 0.07 \pm 0.41\ ) \times 10^{11}$

Search for $K^+ \to \pi^+e^+e^-e^+e^-$ (1)

SM: $K^+ \to \pi^+\pi^0$ with $\pi^0 \to e^+e^-\,e^+e^-$



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



- A_{cc}(Kπ4e non resonant.) = 0.0185%
- Assuming SM prediction

N_{SR} ($K^+ \to \pi^+e^+e^-\,e^+e^-$) = 0

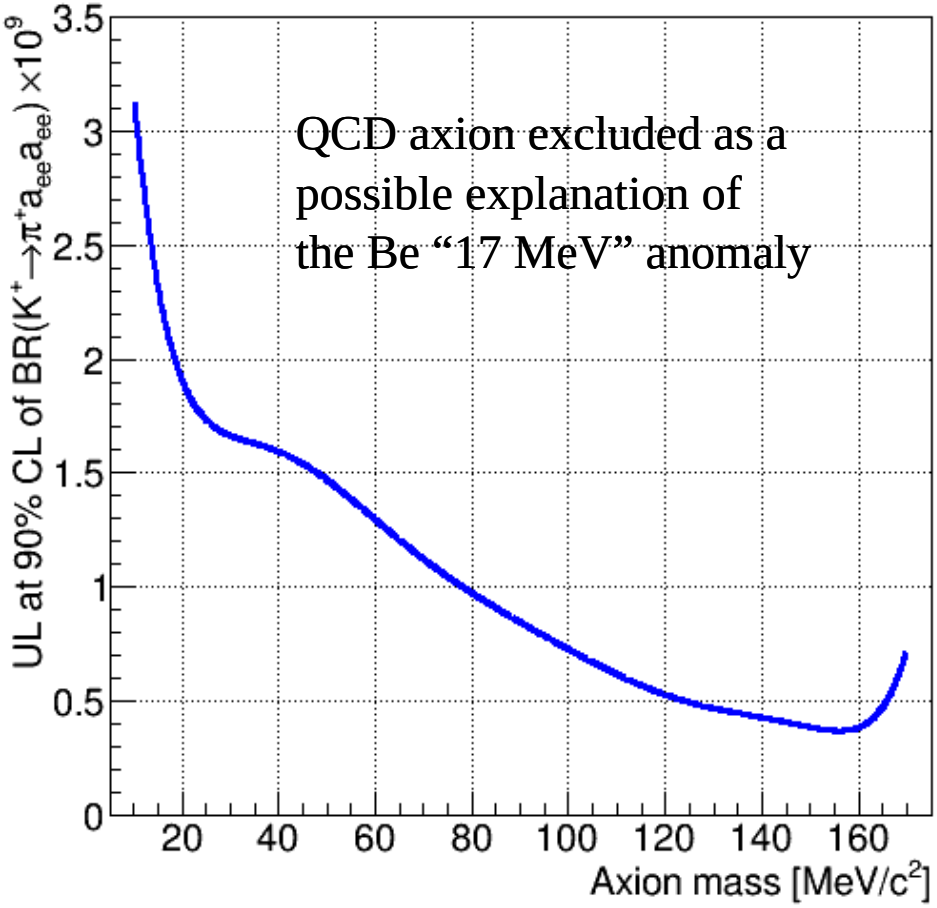
N_{exp}(bkg) = 0.18 ± 0.14

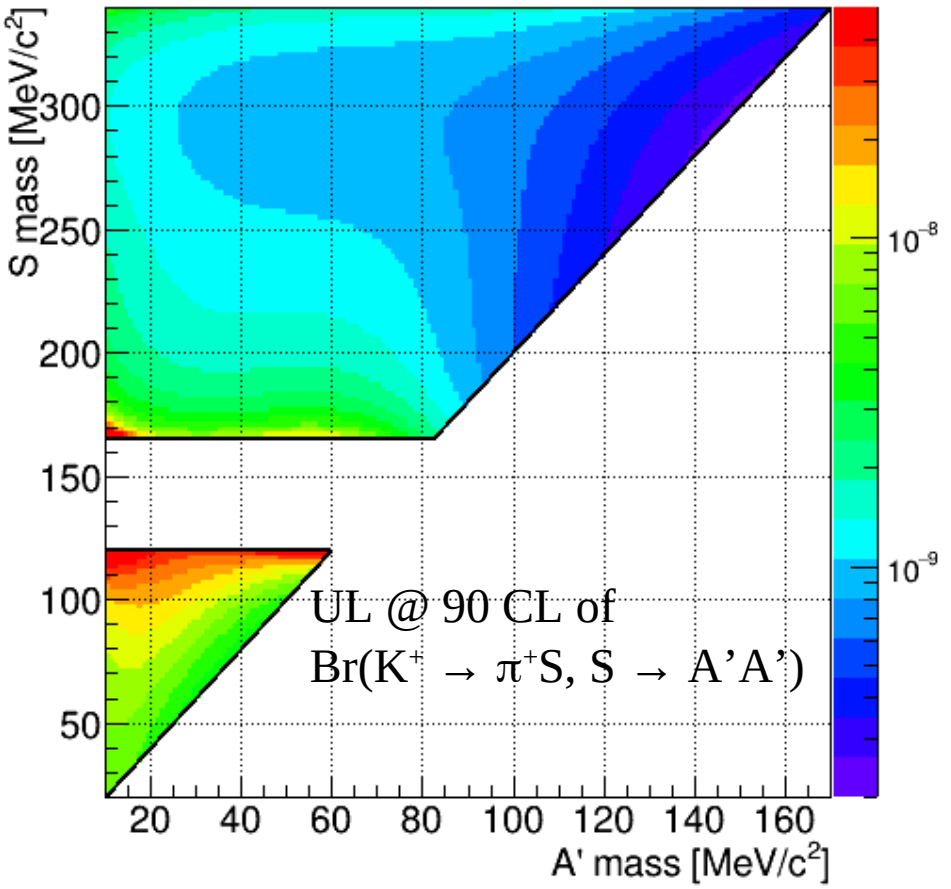
Br($K^+ \to \pi^+e^+e^-e^+e^-$ non res.) <1.4 x 10^{-8} @ 90%CL [PLB 846(2023)138193]

Factor 200 higher than the SM prediction

Search for $K^+ \to \pi^+ e^+ e^- e^+ e^-$ (2)

PLB 846(2023)138193





Uniform phase space assumed for K^+ decays, isotropic decays of dark states

Conclusion

- First search of $K^+ \to \pi^- \pi^0 e^+ e^+$
- Factor 250 improvement in the UL of Br($K^+ \to \mu^- \nu e^+ e^+$)
- Using NA62 Run2 data taking at least a factor 2 of improvement for the various LFV/LNV channels

- UL of Br($K^+ \to \pi^+ e^+ e^- e^+ e^-$ non res.) a factor 200 higher than the SM
- UL @ 90% CL derived for $K^+ \to \pi^+ aa$, $a \to e^+ e^-$ and $K^+ \to \pi^+ S$, $S \to A'A'$, $A' \to e^+ e^-$
- QCD Axion excluded as explanation of the Be “17 MeV” anomaly

Spares