Latest results on rare decays with NA62

R.Piandani

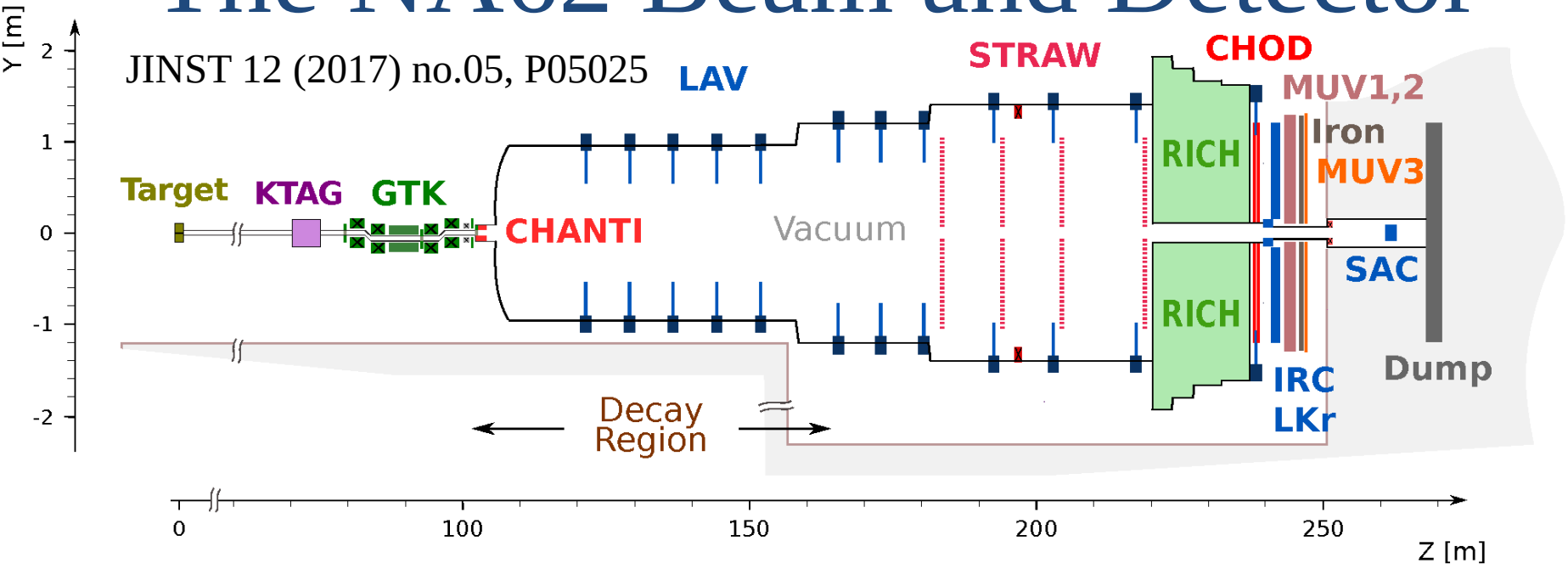
Univ. Autonoma de San Luis Potosi Mexico

on behalf of the NA62 Collaboration

Outline

- ✓ The NA62 Experiment at CERN
- ✓ Theoretical introduction to Heavy Neutral Leptons
- ✓ Search for $K^+ \to \mu^+\nu\nu\nu$ and $K^+ \to \mu^+\nu X$
- ✓ Theoretical introduction to Lepton Flavor and Lepton Number Violation
- ✓ Search for LFV and LNV in K^+ decays

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 and protons).
1% momentum bite, ~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: ~ 120 days, 100% nominal intensity
- 2022: ~ 200 days, 100% nominal intensity

HNLs

Heavy neutral leptons and νMSM

Possibility of a set of sterile neutrino mass states

- The νMSM: the most economical theory accounting for ν masses and oscillations, baryogenesis and dark matter
  [Asaka, Blanchet, Shaposhnikov PLB 631 (2005) 151]

- Three Heavy Neutral Leptons (HNLs)

- See-saw mechanism: one with m_1~10KeV/c^2, two with $m_{2,3}$ ~1 GeV/c^2, these last ones observable via production and decay

NA62: $K^+ \rightarrow \ell^+ N$ (ℓ =e,μ)

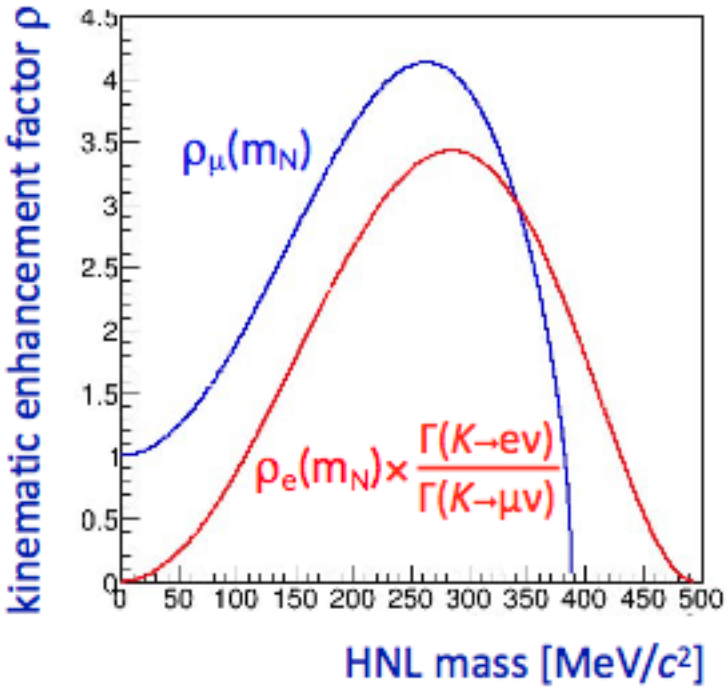
HNL production in K decays

$$BR(K^+ \to \ell^+ N) = BR(K^+ \to \ell^+ \nu) \cdot \rho_\ell(m_N) \cdot |U_{\ell 4}|^2$$

Strength of mixing with SM neutrinos.

Parameter of interest

Kinematic enhancement factor



- HNL production is enhanced wrt to SM decays
- A very strong enhancement in the $K^+ \to e^+ N$ case, because the helicity suppression is relaxed

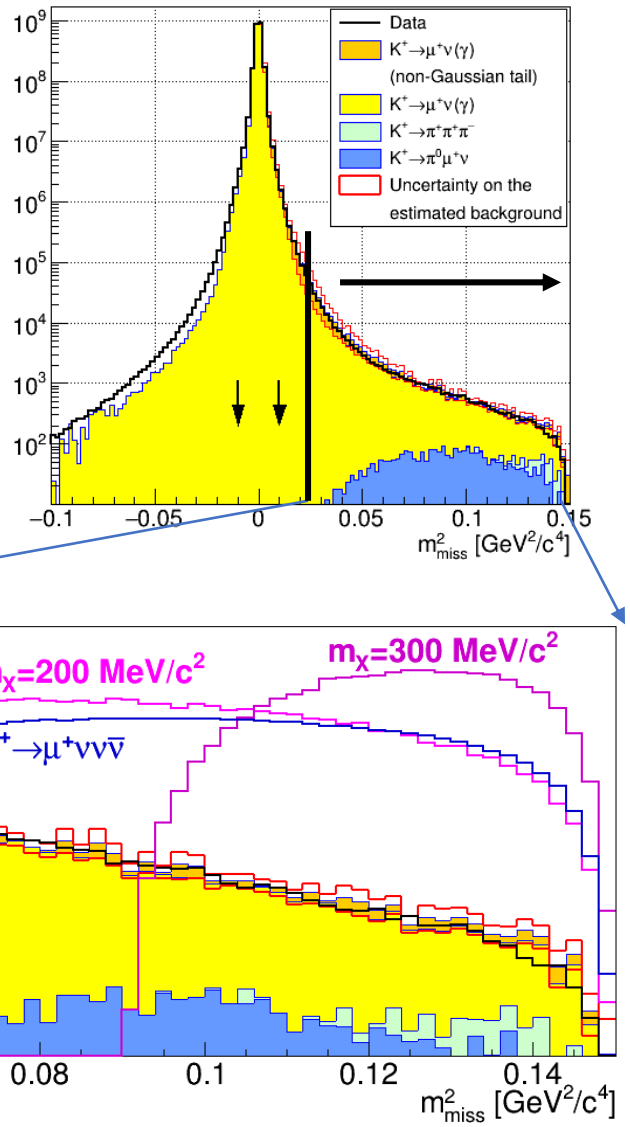
$R_K \sim 2.5 \times 10^{-5}$

Search for $K^+ \to \mu^+ \nu\nu\nu$ and $K^+ \to \mu^+ \nu X$

- **$K^+ \to \mu^+ \nu\nu\nu$:**
  - Very rare process
  - SM: Br ≈ 1.6 x 10^{-16}
    [Gorbunov,Mitofanov, JHEP 10 (2016) 039]
  - Current limit: Br < 2.4 x 10^{-6}
    [E949, PRD 94 (2016) 032012]

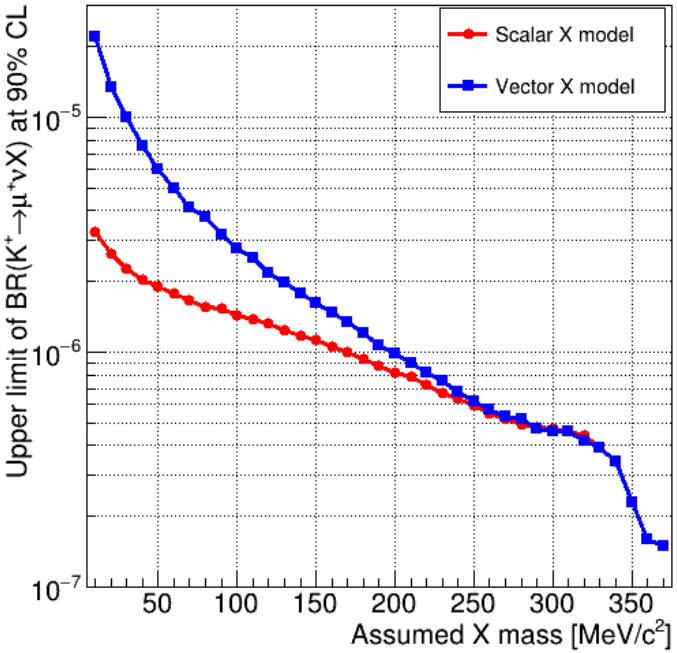
- **$K^+ \to \mu^+ \nu X$:**
  - X can be a scalar o vector particle
    [Krnjaic et al., PRD 124 (2020) 041802]

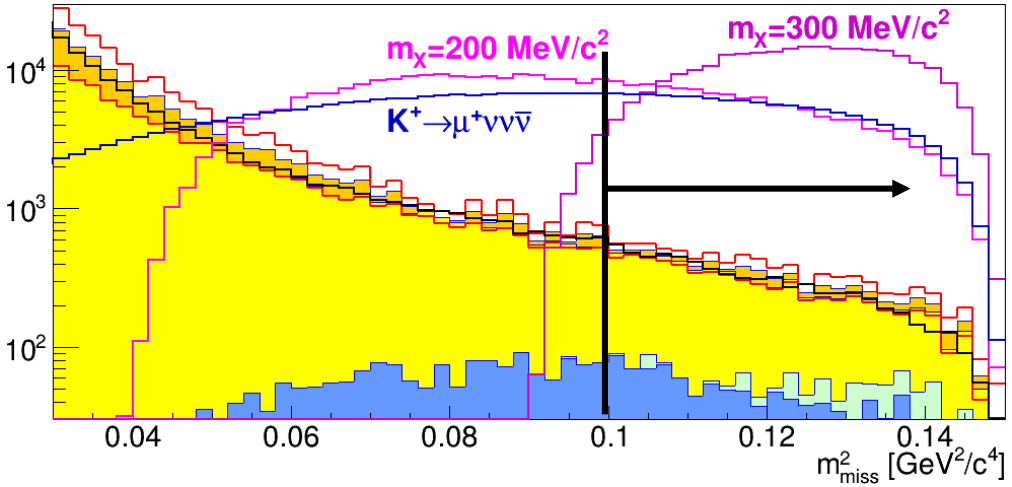
$(P_K - P_\mu)^2$



Search for $K^+ \to \mu^+\nu\nu\nu$ and $K^+ \to \mu^+\nu X$

- **$K^+ \to \mu^+\nu\nu\nu$** :
  - Search region: $m^2_{miss} > 0.1$ GeV$^2/c^4$
    (optimized to extract strongest limit)
  - Observed events: 6894
    MC expectation: 7549 ± 92
    Br($K^+ \to \mu^+\nu\nu\nu$) < 1.0 x 10^{-6} @ 90% CL
- **$K^+ \to \mu^+\nu X$** :
  - Limit extraction in the mass range 10 -137 MeV/c^2
  - No signal observed
    UL of $\mathcal{O}(10^{-7} – 10^{-5})$





LFV and LNV

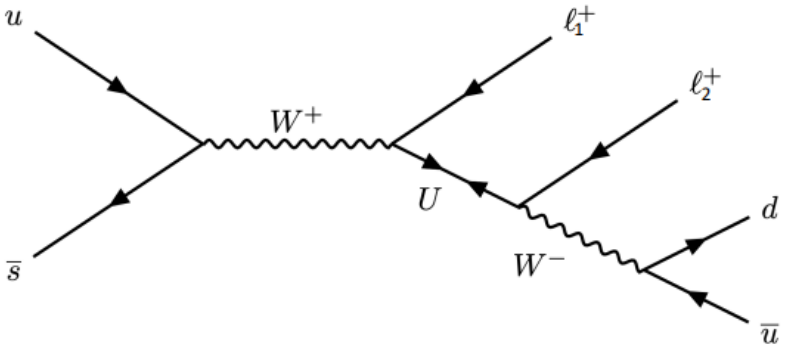
Lepton Number/Flavor violation

- 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

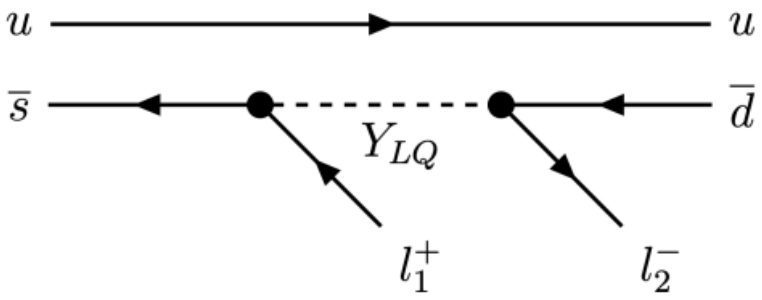
See saw mechanism provides a source of LNV ($\Delta L = 2$) through the exchange of Majorana neutrinos as in $0\nu2\beta$ decay [JHEP 0905 (2009) 030]

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]

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

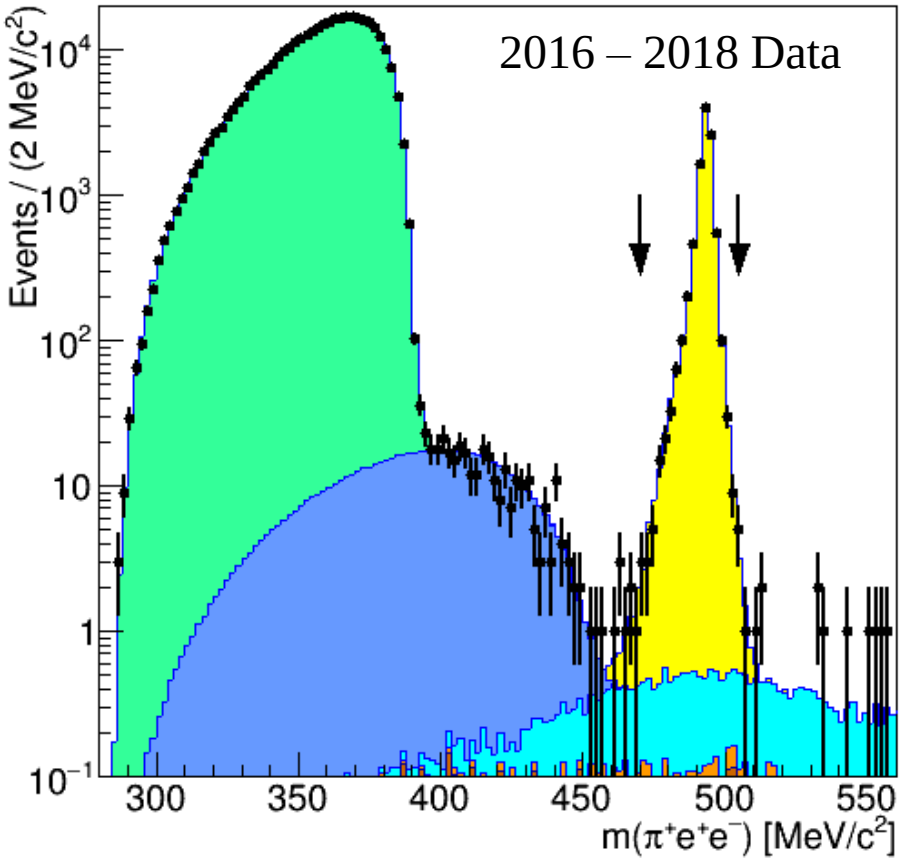


$K^+ \to \pi^+ l_1^+ l_2^-$



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

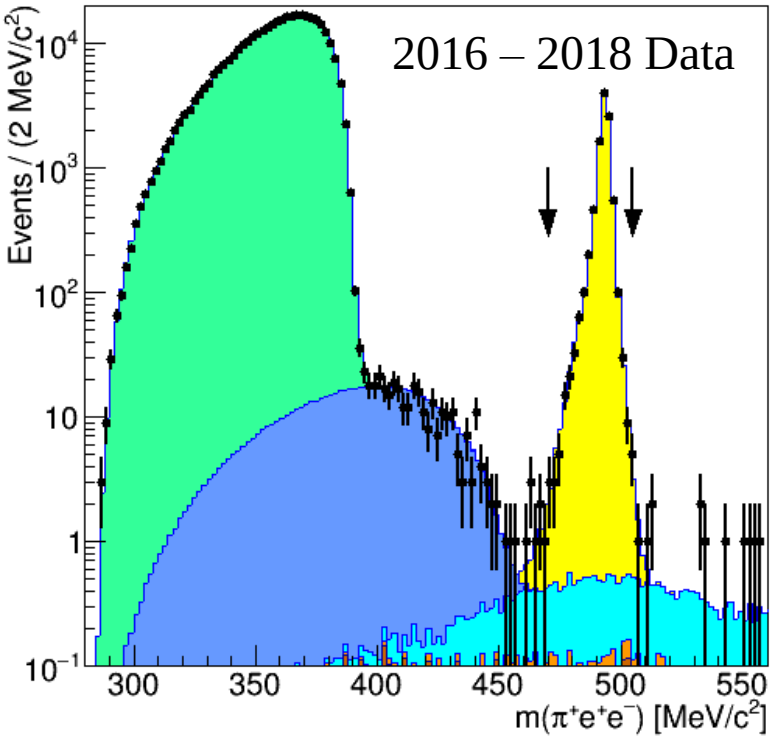
SM: $K^+ \to \pi^- e^+e^-$



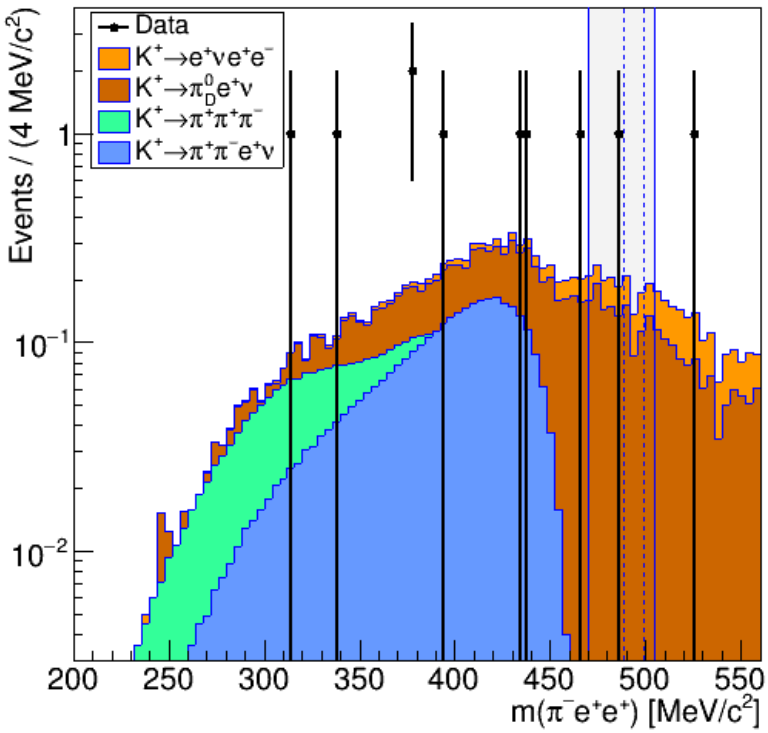
- $N(K^+ \to \pi^- e^+e^-) = 11041$
- $N(K^+) = (1.015 \pm 0.010 \pm 0.030) \times 10^{12}$

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

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



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



- A_{cc}(sig) = 4.23%
- SES = 2.28 x 10^{-11}

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

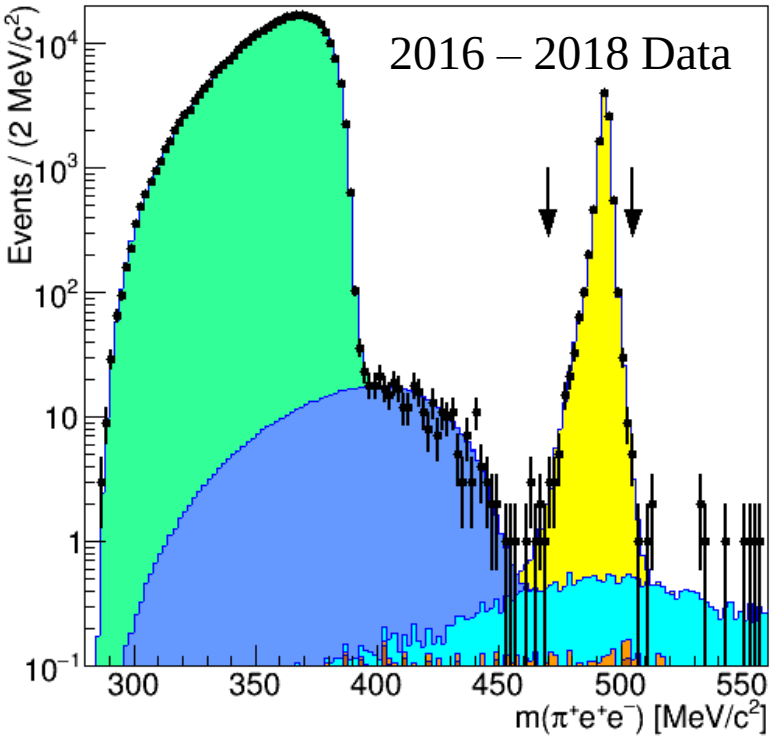
N_{exp}(bkg) = 0.43 ± 0.09

Br($K^+ \to \pi^- e^+ e^+$) < 5.3 x 10^{-11} @ 90%CL [PLB 830 (2022) 137172**]**

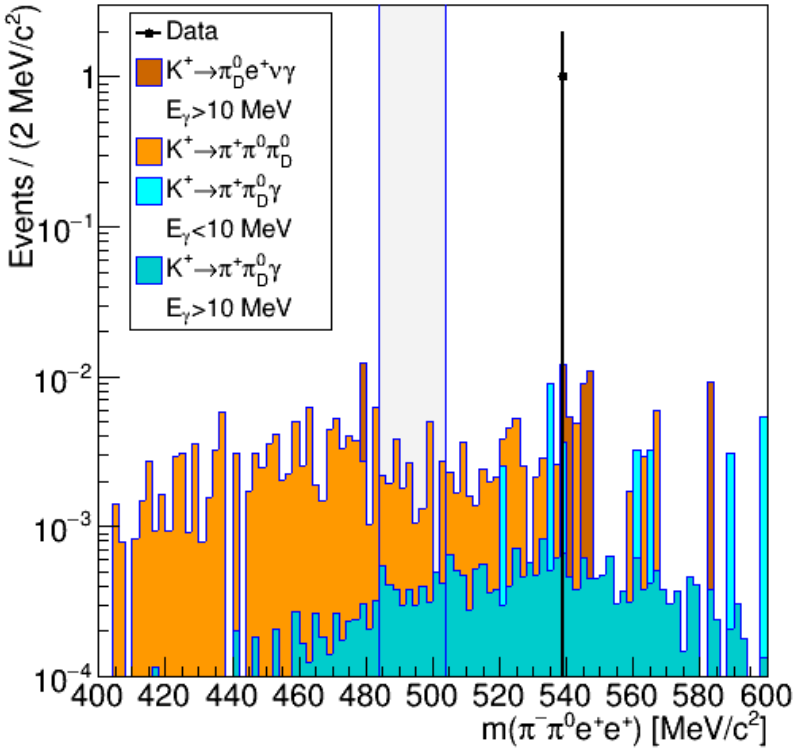
Br($K^+ \to \pi^- e^+ e^+$) < 6.4 x 10^{-10} @ 90%CL (Previous limit)

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

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



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



- A_{cc}(sig) = 0.271%
- SES = 3.68 x 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**]**

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	13	
$K^+ \to \mu^+\nu e^+e^+$	2.1×10^{-8}	An. in progress			
$K^+ \to e^+\nu\mu^+\mu^+$	no limit	An. in progress			

Conclusion

- World best upper limit on Br($K^+ \to \mu^+ \nu\nu\nu$)
- World best upper limits on LNV/LFV kaon decays have been set
- First search of $K^+ \to \pi^- \pi^0 e^+ e^+$
- NA62 Run 2 started in 2021 until the LS3

Spares

$K^+ \rightarrow l^+ N$ Upper Limitis