Searches for LFV and LNV with NA62

Paolo Massarotti (massarotti@na.infn.it)

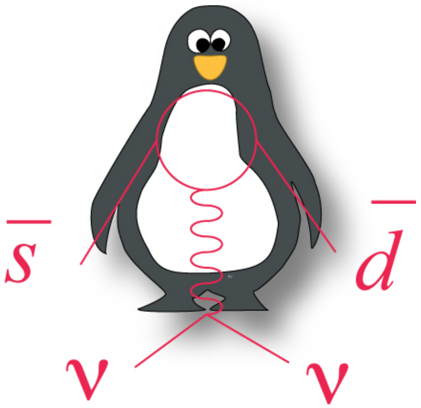
Università degli studi di Napoli Federico II and INFN Napoli

on behalf of the NA62 collaboration

PHENO 2020 , 4th-6th May 2020 Pittsburgh

Outline

- The NA62 experiment
- Experimental setup
- LNV/LFV
- R_K and LFU
- Conclusions



NA62 experiment at CERN

NA62 is located in the North Area at CERN:

- ✓ Main goal: **BR($K^+ \rightarrow \pi^+ \nu\nu$bar)** with **10% precision**
- ✓ Primary beam: **400 GeV/c protons** from SPS
- ✓ Secondary baem: **75 GeV/c** positive charged particle **(6% K^+)**

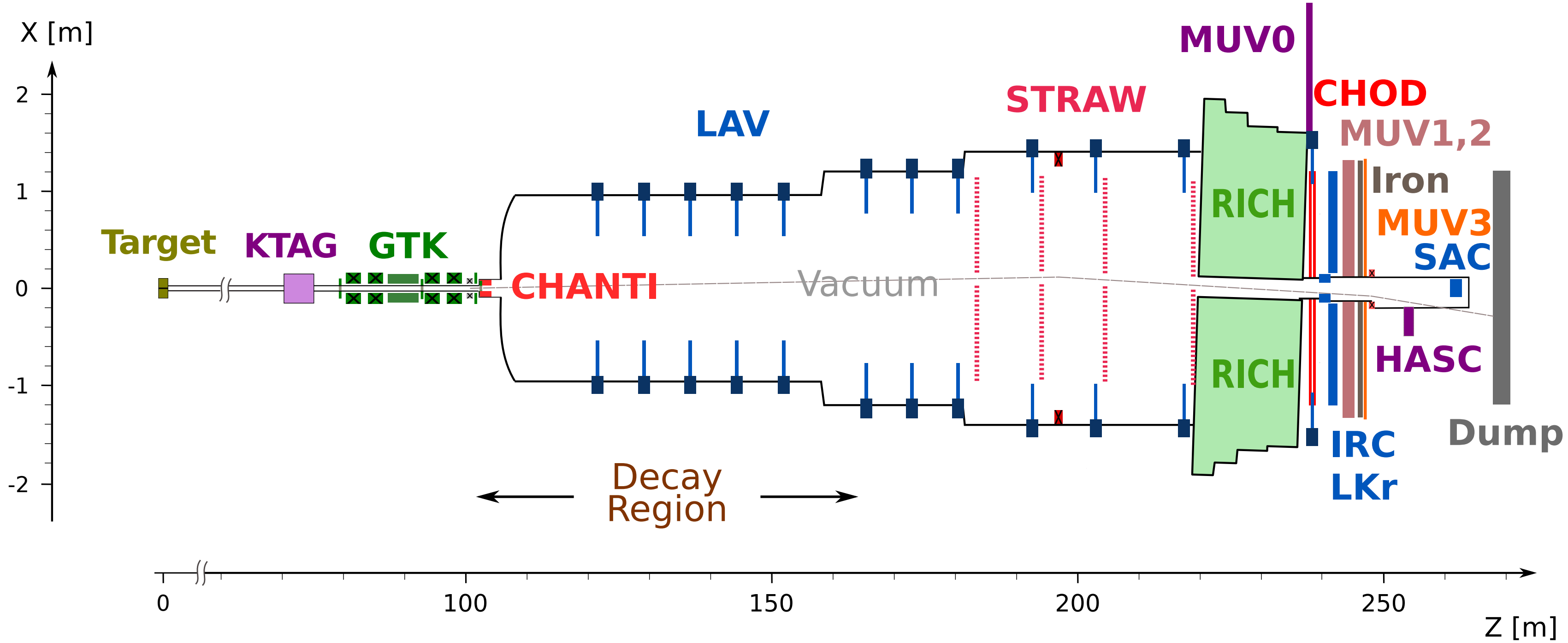
NA62 collaboration: ~ 200 participants from ~ 30 institution:

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, GMU-Fairfax, Ferrara, Firenze, Frascati, Glasgow, Lancaster, Liverpool, Louvain, Mainz, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Sofia, Torino, TRIUMF, Vancouver UBC

Timeline

2009 – 2014	2014 – 2015	2016 – 2018	2021 – 2023
Construction and installation	Technical runs	Physics runs	Physics runs

NA62 beam and detector



SPS Beam

400 GeV/c protons

3.5s spill

Secondary positive beam

75 GeV/c momentum, 1% bite

100 μrad divergence (RMS)

60x30 mm^2 transverse size

$K^+(6\%)/\pi^+(70\%)/p(24\%)$

33×10^{11} ppp on T10 (750 MHz at GTK3)

Decay Region and Detectors

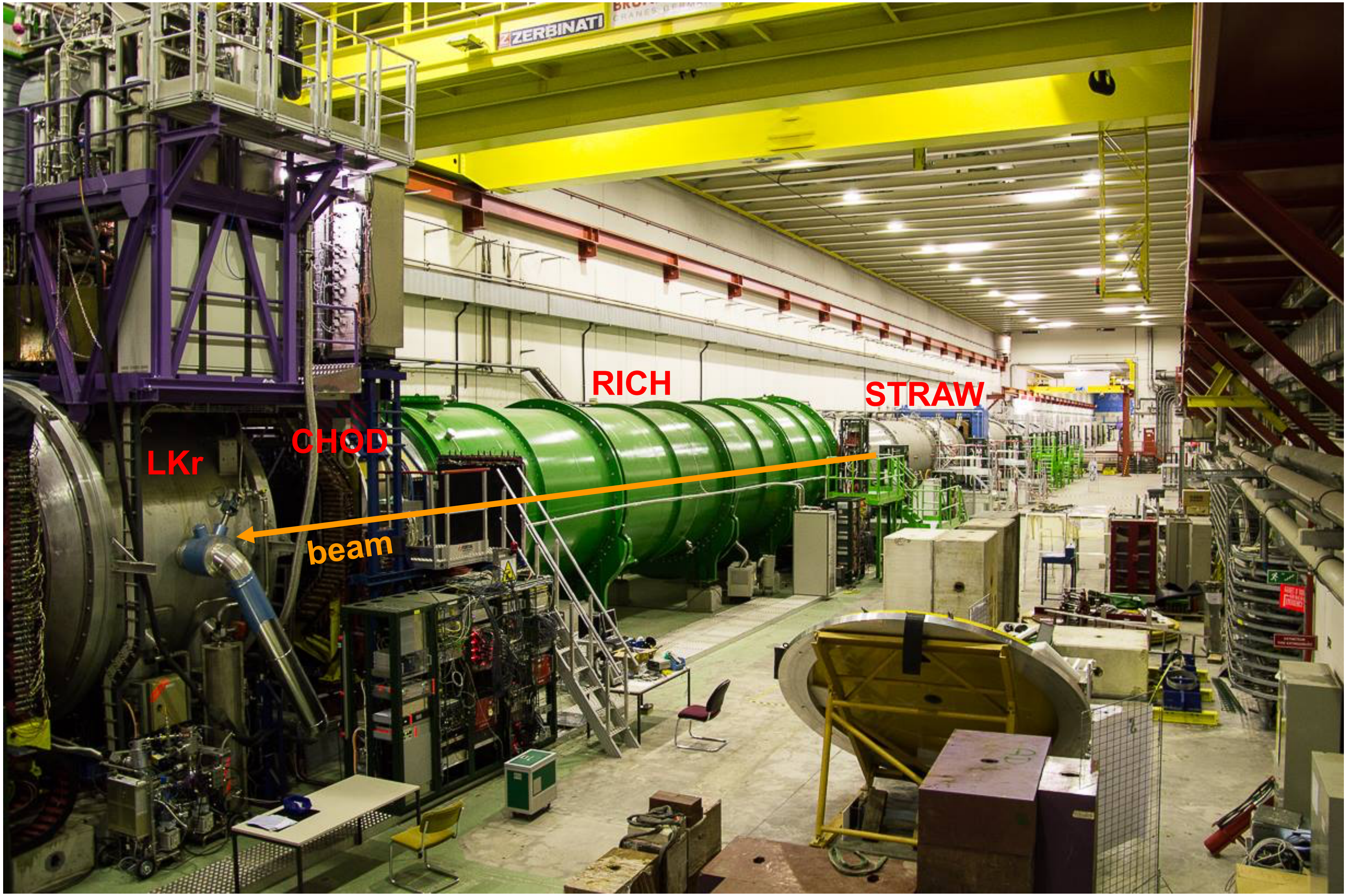
Fiducial region	60 m
K^+ decay rate	~ 5 MHz
Vacuum	$\mathcal{O}$ 10^{-6} mbar

Si pixel beam tracker + Straw tracker

LKr Calorimeter from NA48

Cerenkov counter for K id RICH for π/μ id

NA62 Detector

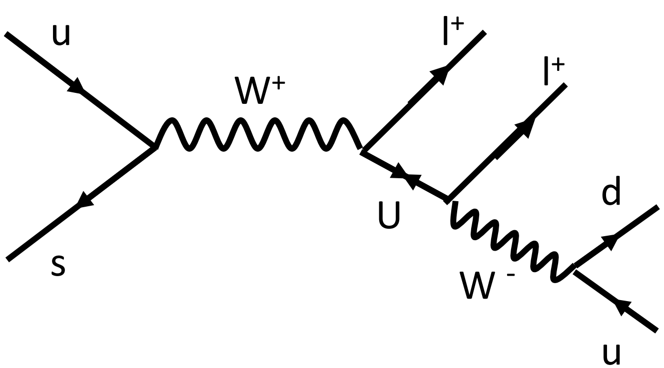


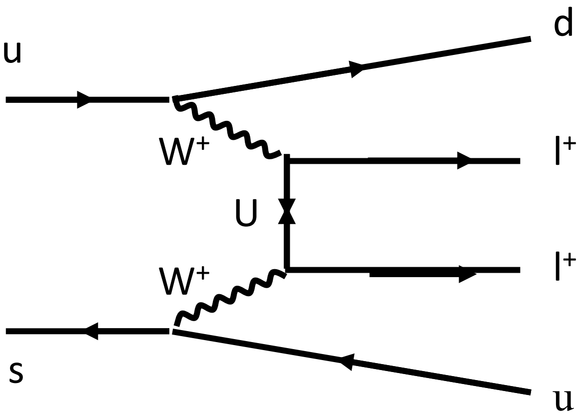
Search for LNV & LFV

- Neutrino oscillation experiments proved that individual lepton numbers are not conserved but don't necessarily imply the total LNV.
- BSM via Majorana neutrinos (U) for instance in $K^+ \to \pi^- l^+ l^+$ ($l = e, \mu$)

  LNV & LFV in $\Delta L = 2$: $\Delta L_e = 2$ or $\Delta L_\mu = 2$.

[JHEP 0905 (2009) 030]
[Phys. Lett. B491 (2000) 285]





Experimental status @ 90% CL :

BR($K^+ \to \pi^- e^+ e^+$) < 6.4 10^{-10} [PRL 85 (2000) 2877]

BR($K^+ \to \pi^- \mu^+ \mu^+$) < 8.6 10^{-11} [PL B769 (2017) 67]

LNV & LFV in $K^+ \to \pi^- l^+ l^+$ @ NA62

- ✓ **Subset of 2017 data**, 3 months of data taking, but 3 times more data still to be analyzed.
- ✓ Collection of di-muon, di-electron and multi-track events simultaneously with $\pi^+\nu\bar{\nu}$ via dedicated and downscaled triggers

Trigger name	Requirements	Data Sample	Downscale factor
Di-Muon	3 tracks, 2 muon candidates	Signal/Norm	2
Multi-track e	3 track, $E_{LKr} > 20$ GeV	Signal/Norm	8
Multi-track	3 tracks, minimum bias	Control sample for bkg studies	100

- ✓ Normalization from corresponding SM channels

$BR(K^+ \to \pi^+ e^+ e^-) = (3.00 \pm 0.09)\ 10^{-7}$ **[PLB 677 (2009) 246]**

$BR(K^+ \to \pi^+ \mu^+ \mu^-) = (9.62 \pm 0.25)\ 10^{-8}$ **[PLB 697 (2011) 107]**

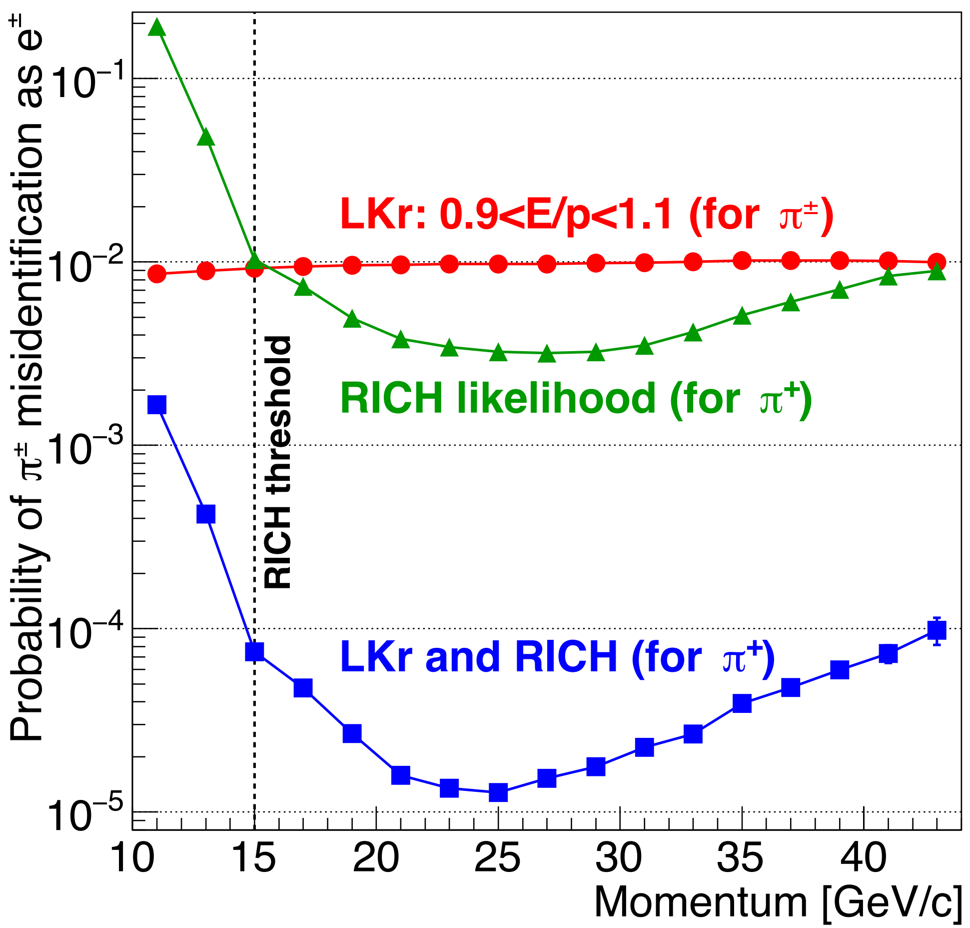
- ✓ Blind analysis in $M(\pi^- l^+ l^+)$: **Signal region $|M(\pi^- l^+ l^+) - M_K| < 3\ \sigma(M)$**
- ✓ Main systematic uncertainties cancel (trigger/ detector efficiency/pileup)

Backgrounds and PID

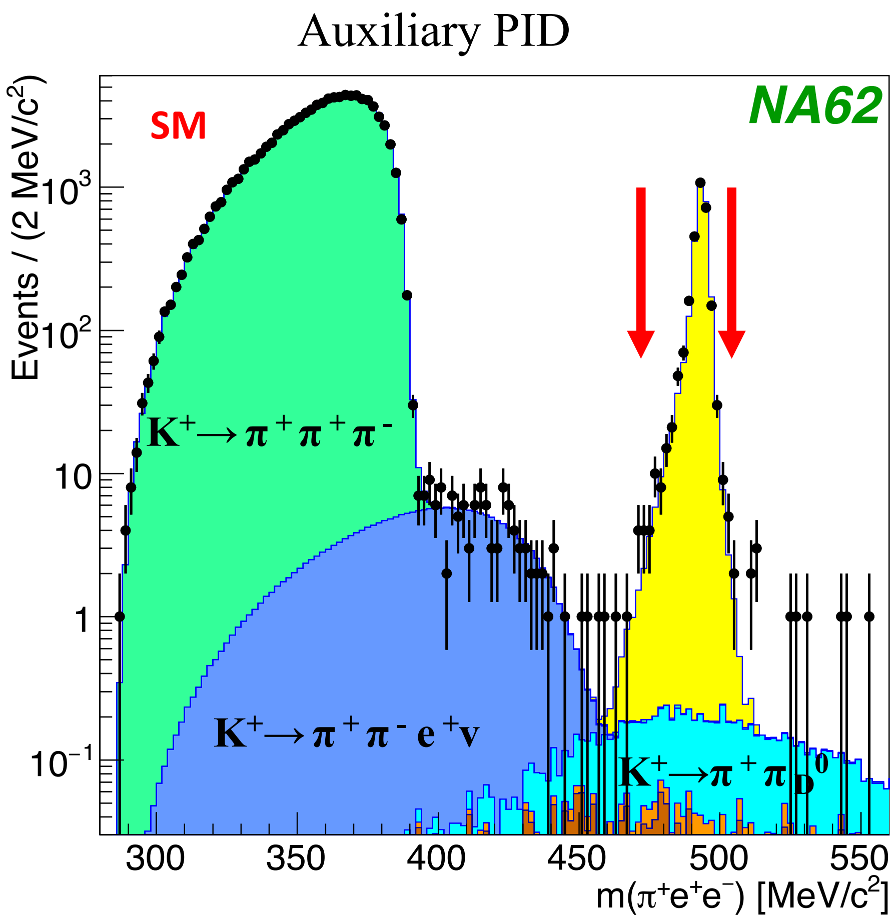
- ✓ Major background for 3-track decays: BR($K^+ \rightarrow \pi^+ \pi^+ \pi^-$) = **5.6%**

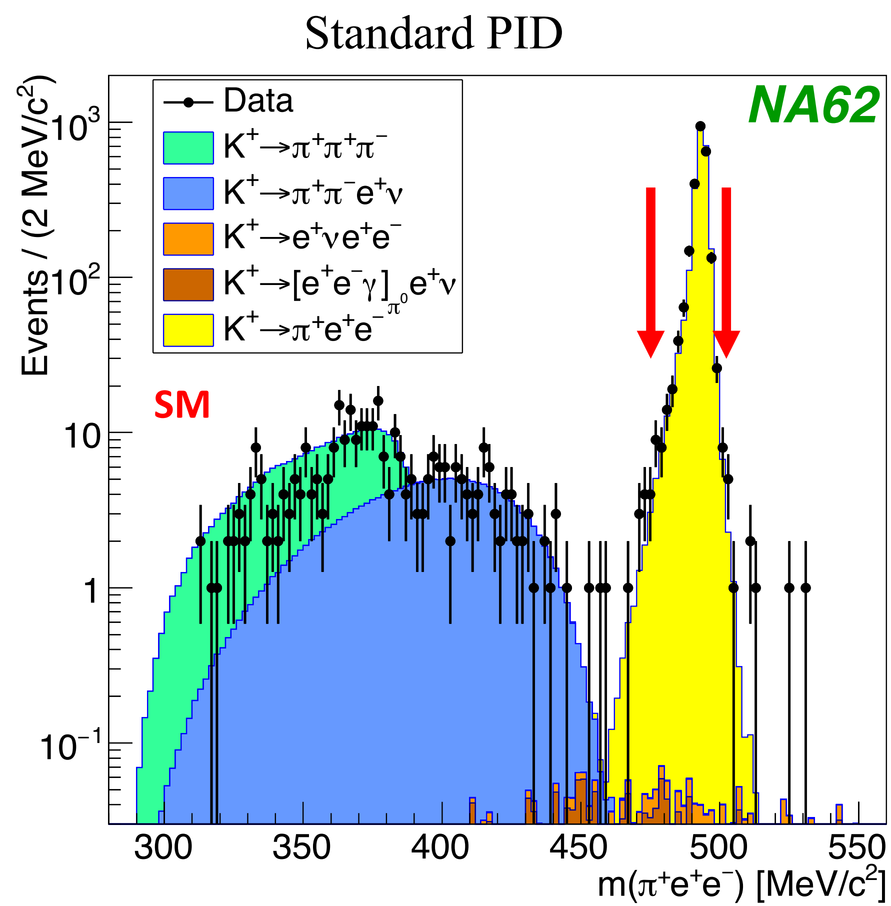
Background mechanisms:

- ✓ Single/double misidentification: $\pi^\pm \rightarrow e^\pm$, $\pi^\pm \rightarrow \mu^\pm$
- ✓ Pion decay in flight (9% probability): $\pi^\pm \rightarrow \mu^\pm$(99.9%), $\pi^\pm \rightarrow e^\pm$ (1.2×10^{-4})
- ✓ Studied with data-driven methods and dedicated simulations
- ✓ Pion/electron identification:
  1) E_{LKr} vs P_{straw} (**E/p**);
  2) RICH signal



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





2484 SM $K^+ \to \pi^+ e^+ e^-$ observed candidates

BR ($K^+ \to \pi^+ e^+ e^-$) = $(3.00 \pm 0.09) \times 10^{-7}$

K^+ decays in FV: $\mathbf{N_K = (2.14 \pm 0.07) \times 10^{11}}$

Search for LNV @ NA62: $K^+ \to \pi^- e^+ e^+$

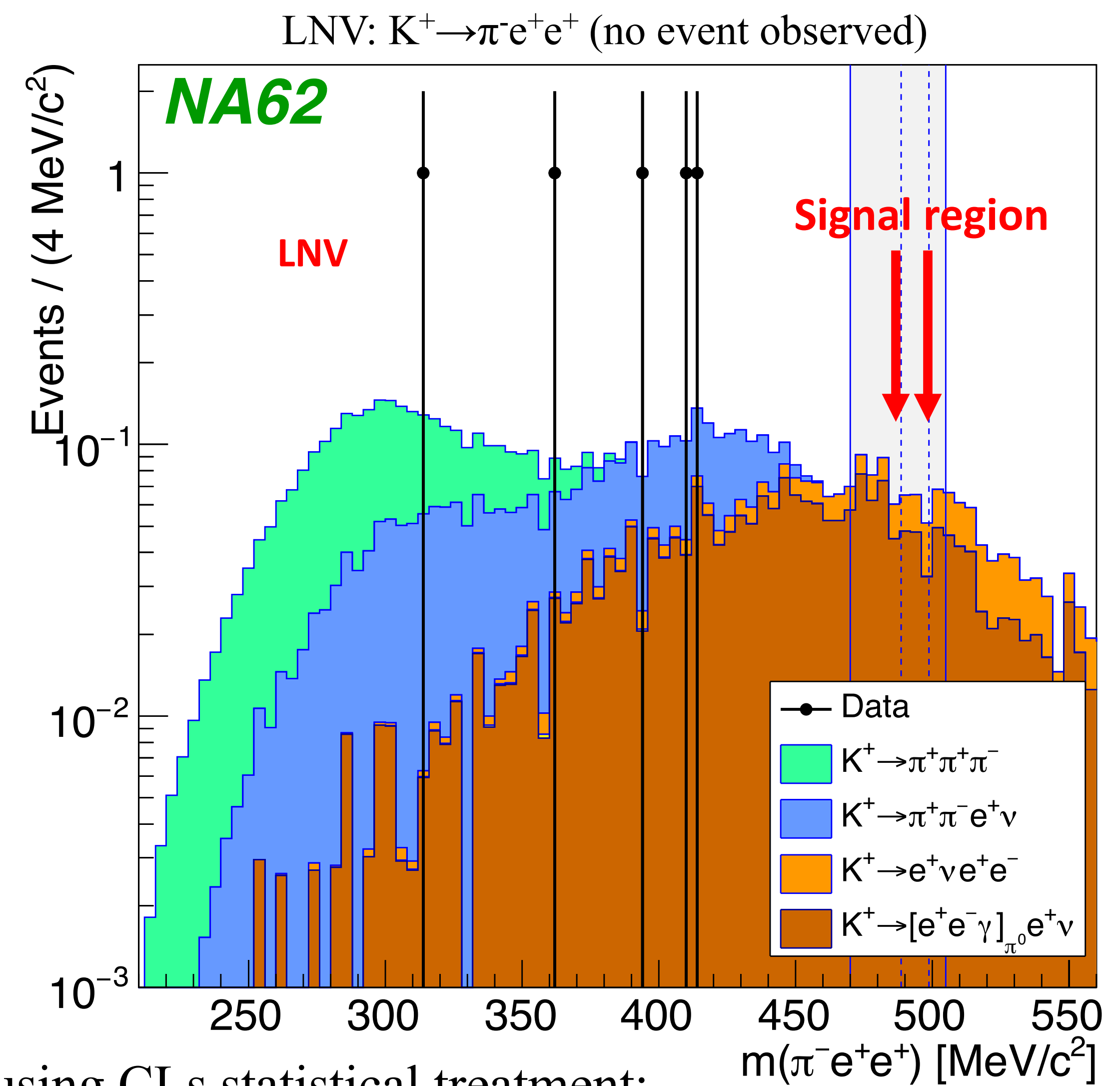
$N_K = (2.14 \pm 0.07) \times 10^{11}$

Signal Acceptance **A = 4.98%**

$$\mathbf{SES} = \frac{1}{A\,N_K} = (0.94 \pm 0.03)\ 10^{-10}$$

Expected Background **0.16 ± 0.03**

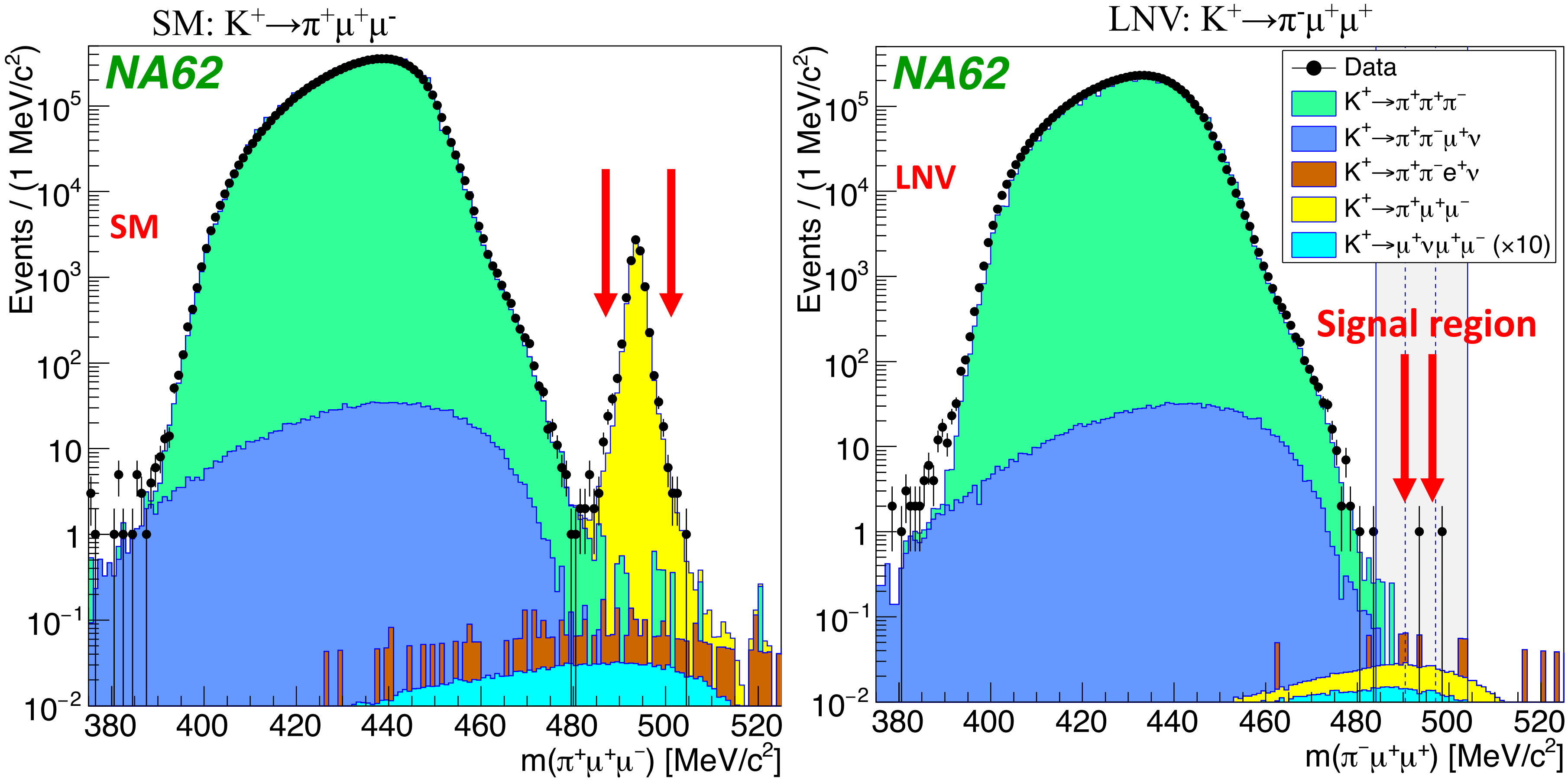
Event Observed **0**



Set upper limit on BR using CLs statistical treatment:

$BR(K^+ \to \pi^- e^+ e^+) < 2.2 \times 10^{-10}$ @90% CL

Search for LNV @ NA62: $K^+ \to \pi^- \mu^+ \mu^+$



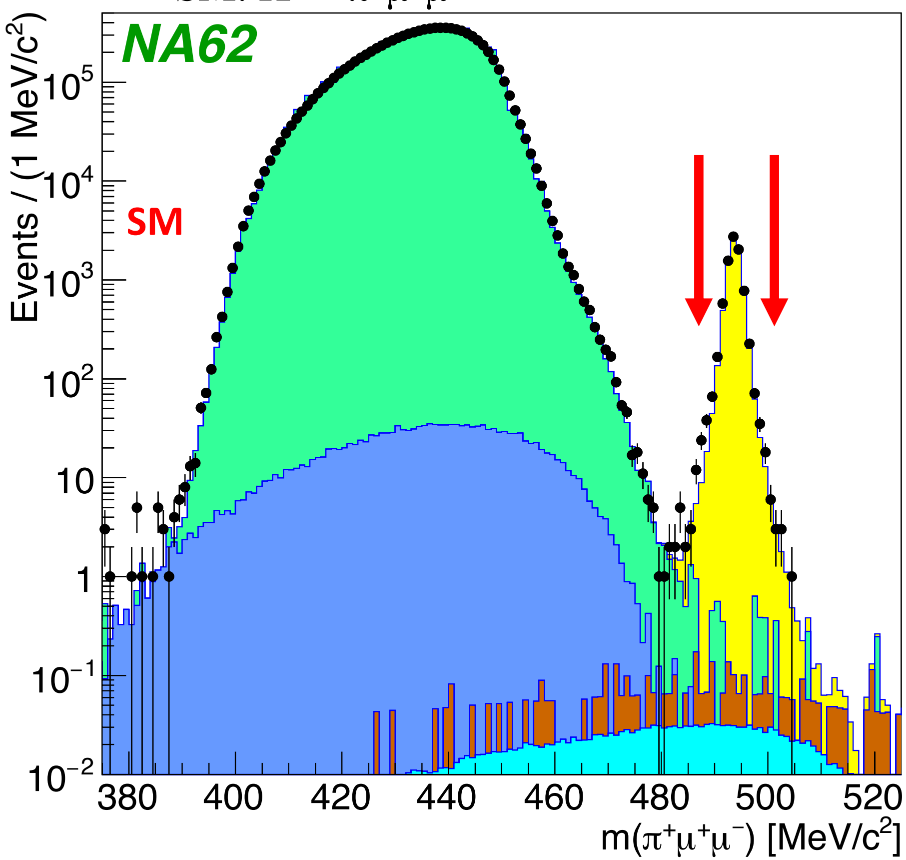
LKr+MUV3 used for pion/muon identification

Background in SM signal mass region ~ **0.07%**

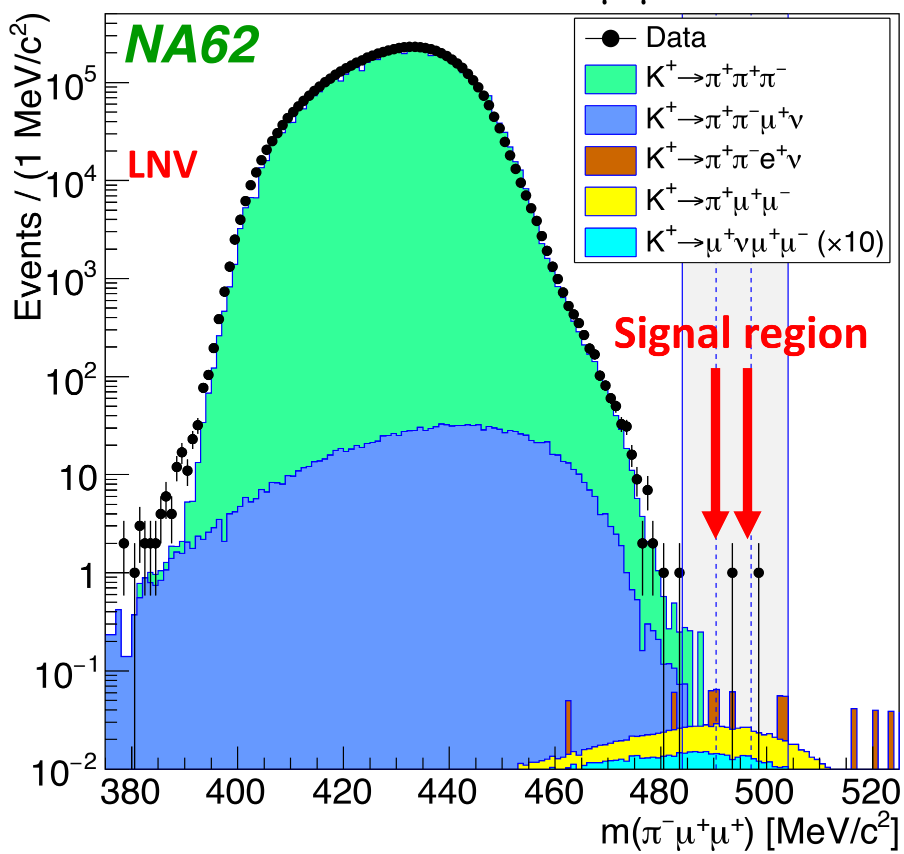
Background to LNV due to in **flight $\pi^\pm \to \mu^\pm$ decays and $\pi^\pm/\mu^\pm$ misidentification**

Normalizzation: $K^+ \to \pi^+ \mu^+ \mu^-$

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



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



8357 observed candidates

$BR(K^+ \to \pi^+\mu^+\mu^-) = \mathbf{(9.62 \pm 0.25)\ 10^{-8}}$

$\mathbf{N_K = (7.94 \pm 0.23)\ 10^{11}}$

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

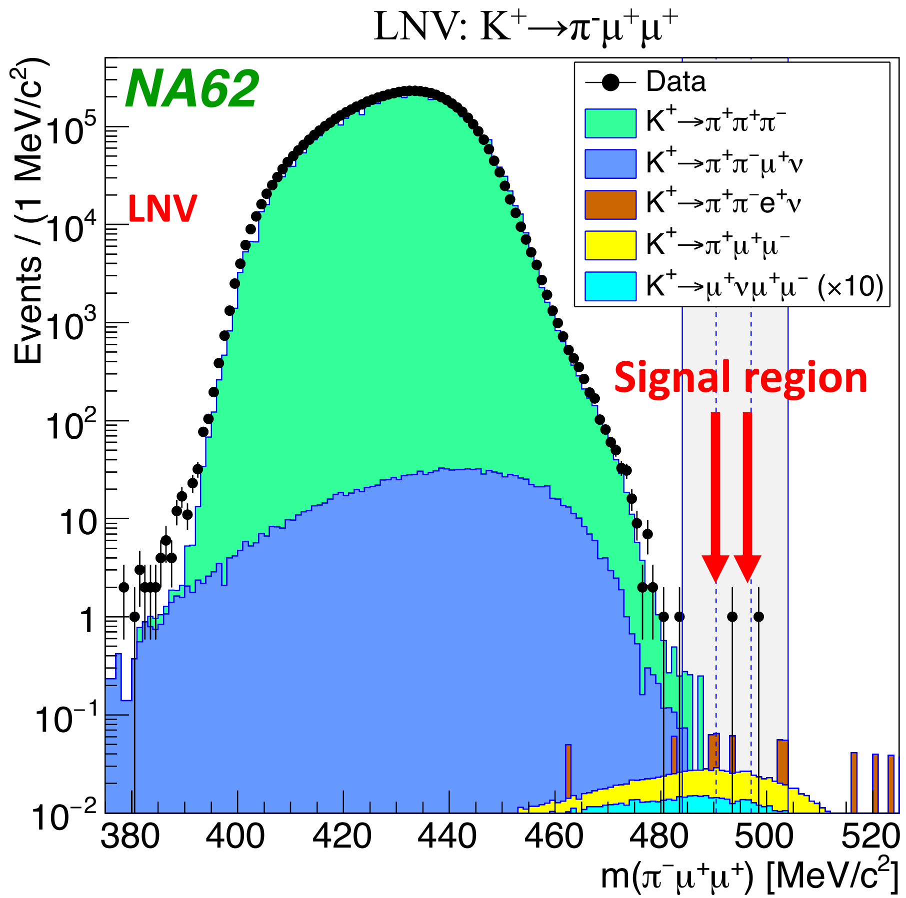
$N_K = (7.94 \pm 0.23)\ 10^{11}$

Signal Acceptance: **9.81%**

SES = (1.28 ± 0.04) 10^{-11}

Expected background: **0.91 ± 0.41 evt**

Candidates observed: **1**



Set upper limit on BR using CLs statistical treatment:

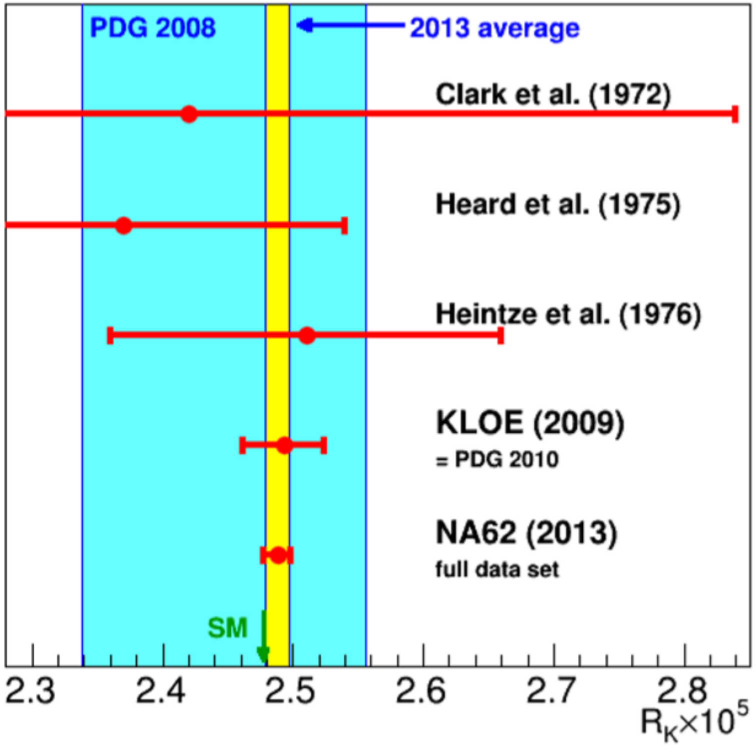
$BR(K^+ \to \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$@90% CL

LFU and R_K

$$R_K = \frac{\Gamma(K^+ \to e^+ \nu)}{\Gamma(K^+ \to \mu^+ \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot \left(1 + \delta R_K^{rad.corr.}\right)$$

- very sensitive to new physics
- hadronic uncertainties cancel in the ratio
- $R_K = (2.477 \pm 0.001)\ 10^{-5}$

Cirigliano and Rosell, Phys. Rev. Lett. 99, 231801

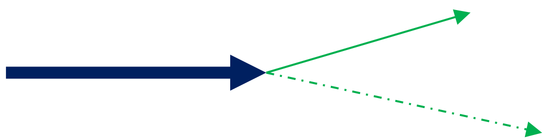


$$R_K = (2.488 \pm 0.009) \times 10^{-5} \text{ (PDG 2018)}$$

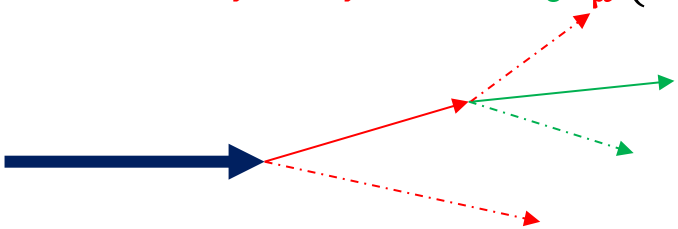
The goal is to improve the experimental status

New technique in order to use the same trigger and to apply almost the same selection:

$K^+ \rightarrow e^+\nu\ (K_{e2})$



$K^+ \rightarrow \mu^+\nu\ ,\ \mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu\ (K_{\mu e})$



The same signature for both channels (kaon in the initial state and only one positron in the final state) leads to have a common selection for K_{e2} and $K_{\mu e}$ samples

Analysis is on going

Conclusions

Set upper limits on BR using CLs statistical treatment:

$BR(K^+ \rightarrow \pi^- e^+ e^+) < 2.2\ 10^{-10}$ at 90% CL

$BR(K^+ \rightarrow \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$ at 90% CL

Phys. Lett. B 797 (2019) 134794

Factor 3-2 improvement over previous results [NA48/2 and BNL-E865]

Other analyses are in progress, none is limited by background

For $\mathbf{K^+ \rightarrow \pi^- \mu^+ e^+}$ [LNV] and $\mathbf{K^+ \rightarrow \pi^+ \mu^- e^+}$ [LFV]

SES ~ 5 $\times 10^{-11}$ (factor ~ 5 improvement on BNL-E865)

For $\mathbf{K^+ \rightarrow e^- \nu \mu^+ \mu^+}$ [LFV], SES ~ 5 x 10^{-11} (the first search for this mode);

For $\mathbf{K^+ \rightarrow \mu^- \nu e^+ e^+}$ [LFV], SES ~ 1 x 10^{-10} (factor 100 improvement on PDG).

R_K Analysis is in progress