Search for Lepton Number and Lepton Flavour Violation at NA62

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Outline

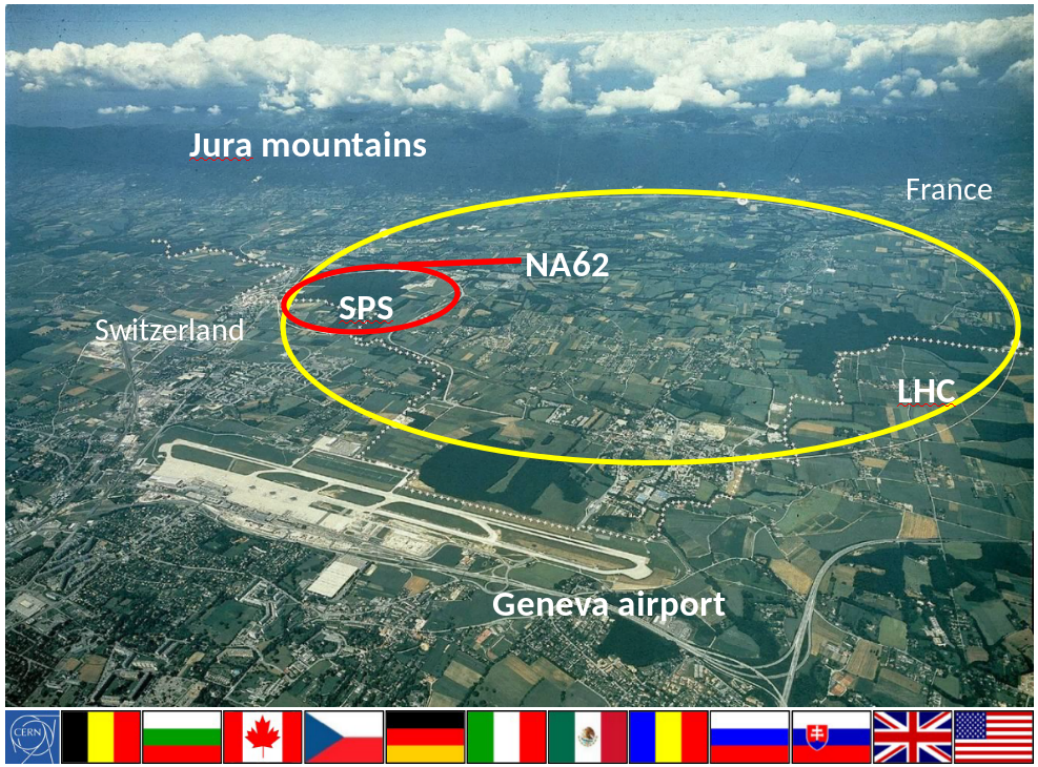
1. The NA62 experiment and detector
2. Lepton Number Violation
   Latest results
3. Future prospects on Lepton Number/Flavour Violation
4. Conclusions

Section 1

The NA62 experiment and detector

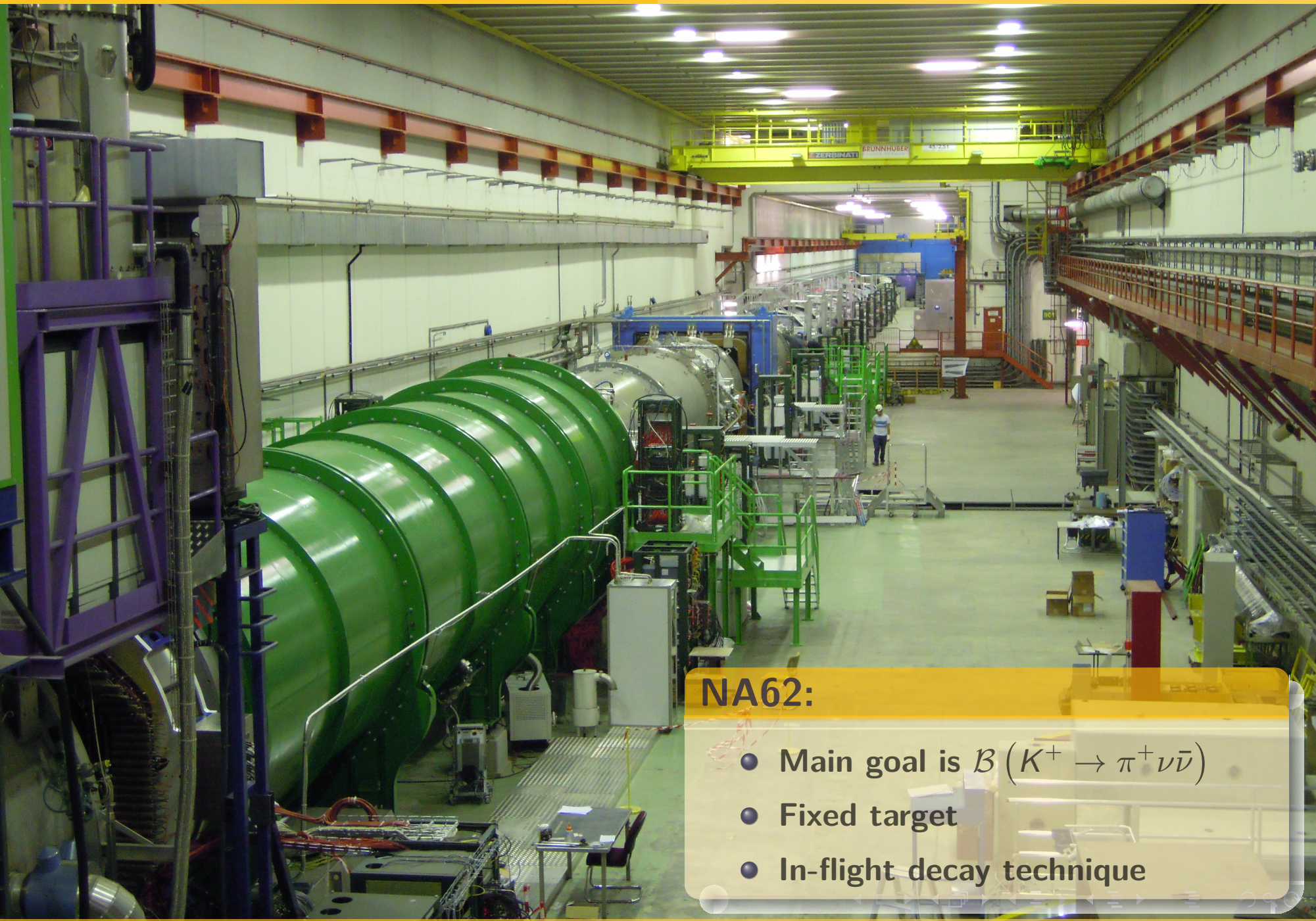
The NA62 Experiment

Fixed target kaon experiment at CERN SPS



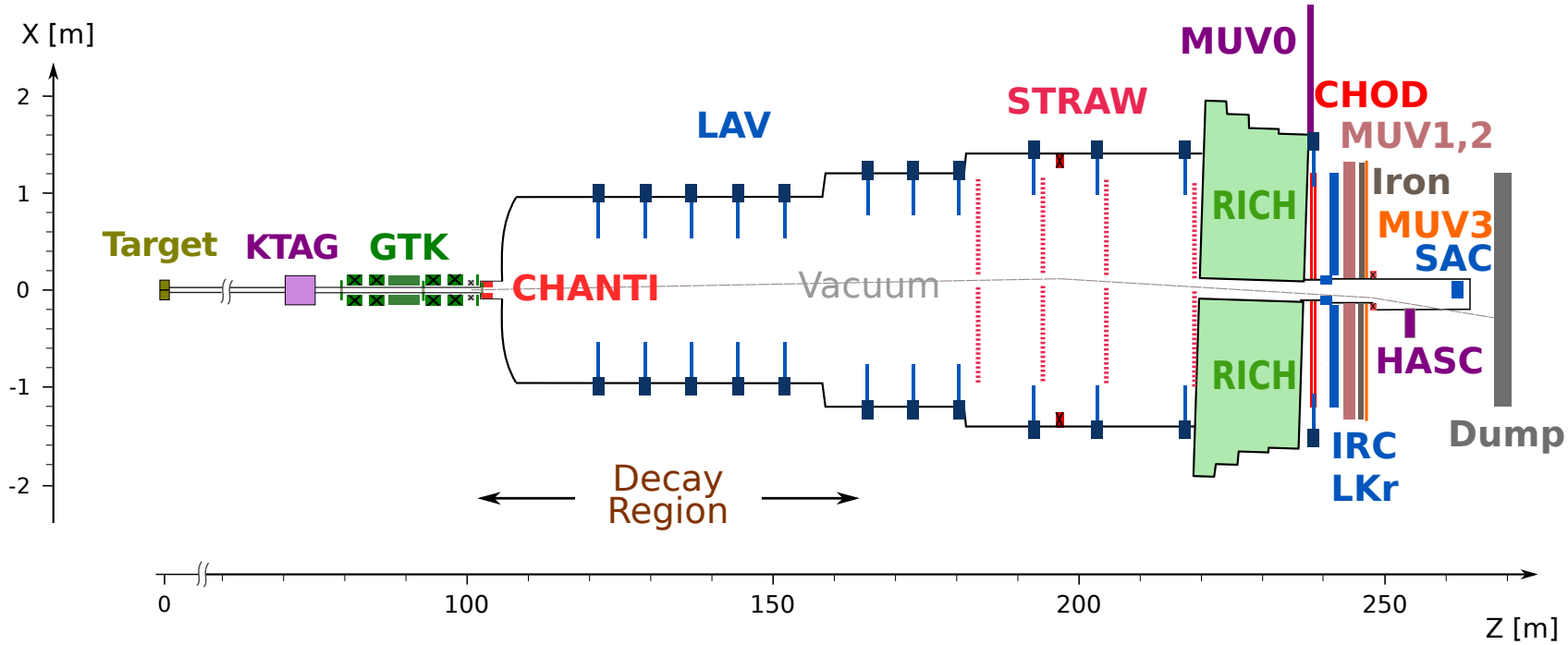
200 participants: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, GMU-Fairfax, Ferrara, Firenze, Frascati, Glasgow, Lancaster, Liverpool, Louvain-La-Neuve, Mainz, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Sofia, Torino, TRIUMF, Vancouver UBC

- **2008** • NA62 Approval
- **2009-2014** • Detector R&D and Installation
- **2014** • Pilot Run
- **2015** • Commissioning run
- **2016-2018** • Physics runs
- **2021-2023** • Future runs



NA62:

- Main goal is $\mathcal{B}\left(K^+ \to \pi^+ \nu\bar{\nu}\right)$
- Fixed target
- In-flight decay technique



SPS Beam

- 400 GeV/c protons
- 2×10^{10} protons/spill
- 3.5 s spill

Secondary positive beam

- 75 GeV/c momentum, 1 % bite
- 100 µrad divergence (RMS)
- $60 \times 30\,\text{mm}^2$ transverse size
- $K^+(6\%)/\pi^+(70\%)/p(24\%)$
- 33×10^{11} ppp on T10 (750MHz at GTK3)

Decay region

- 60m long fiducial region
- decay rate
- varuum mbar

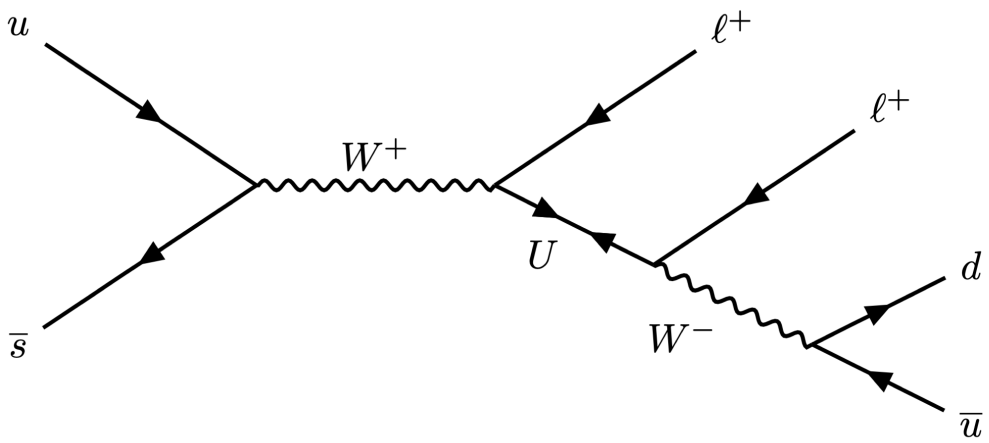
Section 2

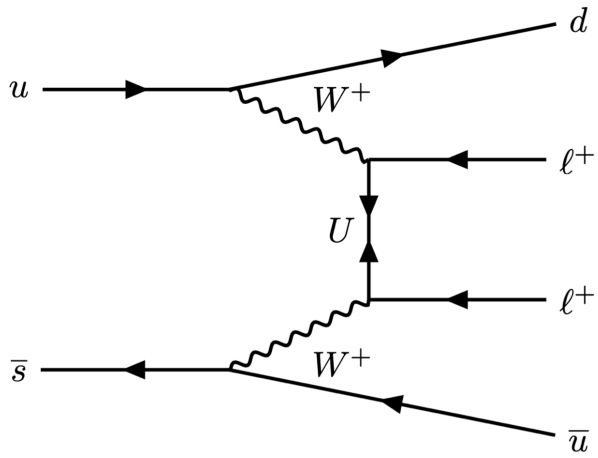
Lepton Number Violation
Latest results

LNV violating process $K^+ \to \pi^- \ell^+ \ell^+$

Violation of lepton number is predicted in some BSM models.
E.g: Majorana Neutrinos (U)

[JHEP 0905 (2009) 030], [Phys. Lett. B491 (2000) 285-290]





Previous result (90 % C.L.)

- BNL E865: $\mathcal{B}(K^+ \to \pi^- e^+ e^-) < 6.4 \times 10^{-10}$ [PRL 85 2877 (2000)]
- NA48/2: $\mathcal{B}(K^+ \to \pi^- \mu^+ \mu^-) < 8.6 \times 10^{-11}$ [Phys. Lett. B769 67 (2017)]

Search at NA62

- Subset of 2017 data: $\sim$3 months of data taking
- Blind analysis procedure
- Trigger lines dedicated to multi-track events, with $e^{\pm}$ or $\mu^{\pm}$

In all cases, normalization is done using the corresponding SM channel.

- Common selection (differs mostly by charge)
- Many systematic uncertainties cancel (trigger and detector efficiencies, pileup)
- $\mathcal{B}(K^+ \to \pi^+ e^+ e^-) = (3.00 \pm 0.09) \times 10^{-7}$
- $\mathcal{B}(K^+ \to \pi^+ \mu^+ \mu^-) = (9.4 \pm 0.6) \times 10^{-8}$

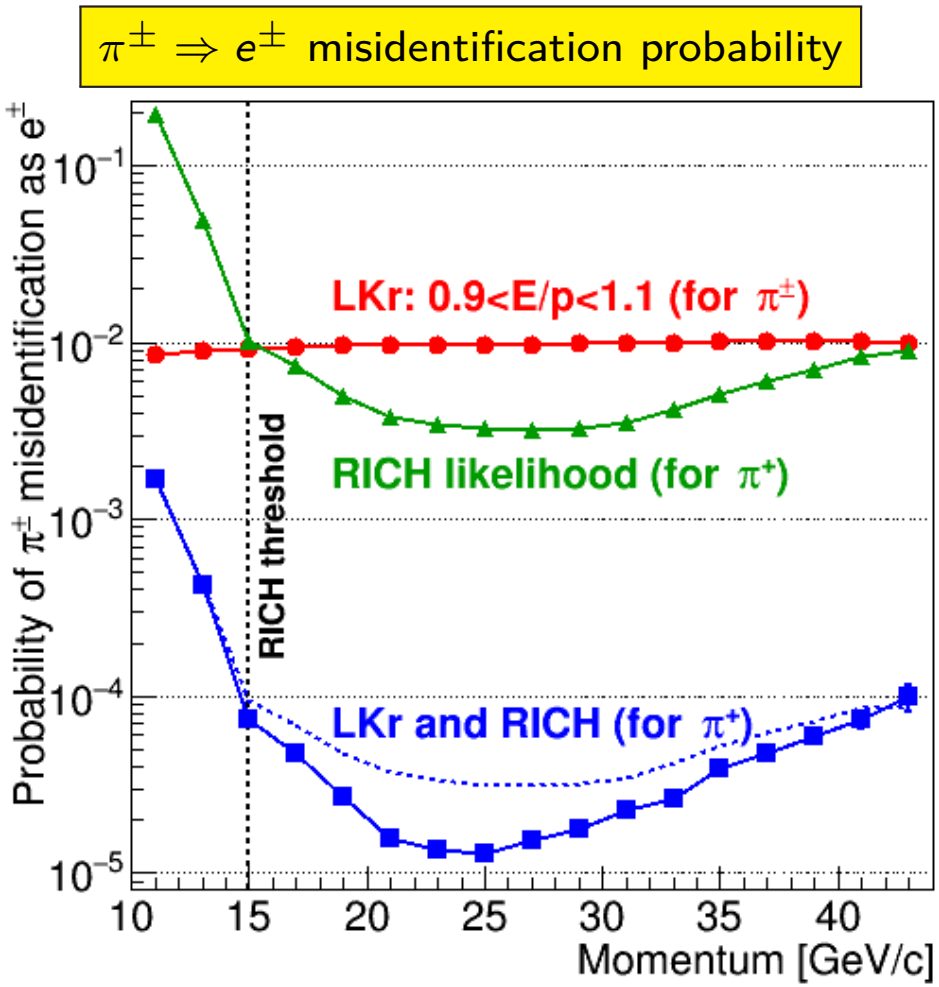
Background

The main source of background is $K^+ \to \pi^+\pi^+\pi^-$ $K_{3\pi}$ (largest $\mathcal{B}$ for 3-track)

- Single/double mis-identification: $\pi^\pm \Rightarrow e^\pm$, $\pi^\pm \Rightarrow \mu^\pm$
- Pion decay in flight (9 % probability): $\pi^\pm \to \mu^\pm\nu$ (99.9 %), $\pi^\pm \to e^\pm\nu$ (1.2×10^{-4})

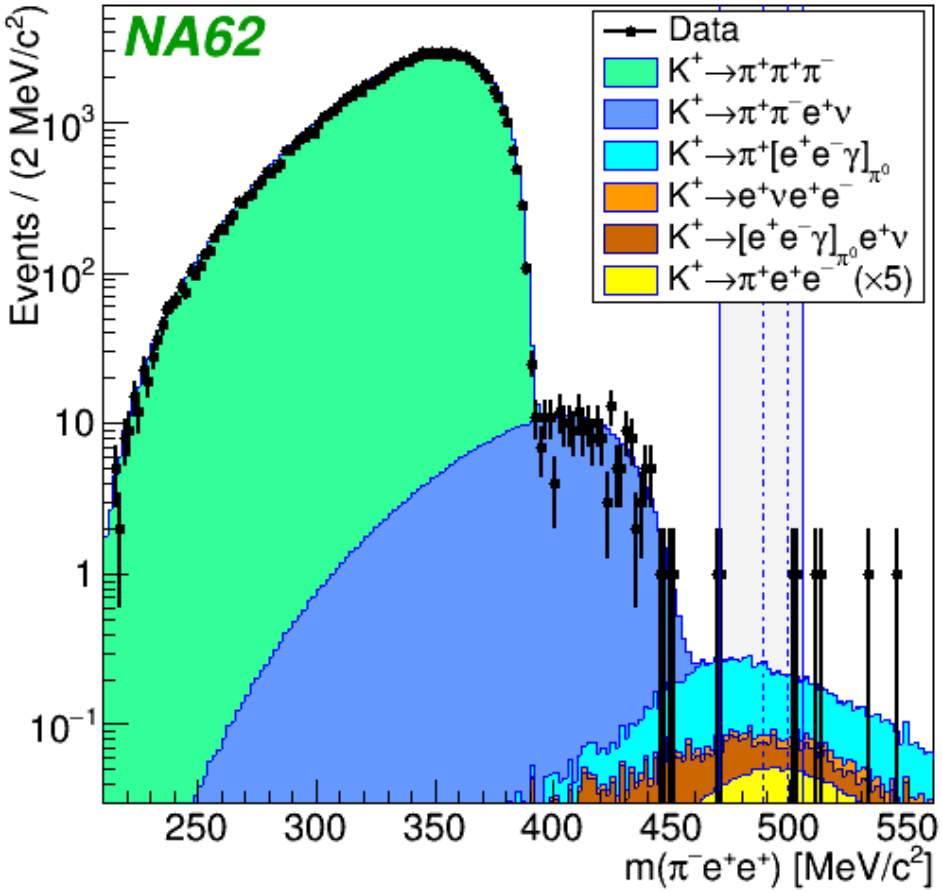
Techniques

- Force particle misidentification and assign weight $P(\pi^\pm \Rightarrow \ell^\pm)$
- Special $\pi^\pm$ decay enriched MC
- Data-driven studies: $K_{3\pi}$ control sample obtained by inverting PID criteria.

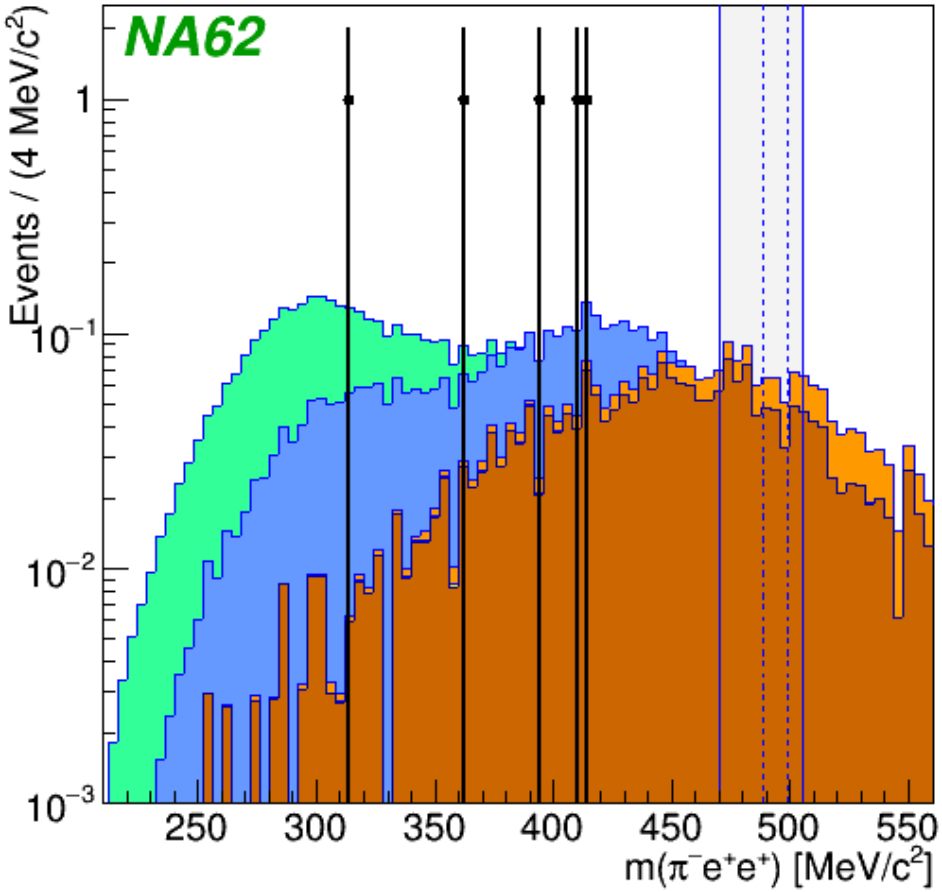


$K^+ \to \pi^- e^+ e^+$

$K^+ \to \pi^- e^+ e^+$ [PID: LKr]



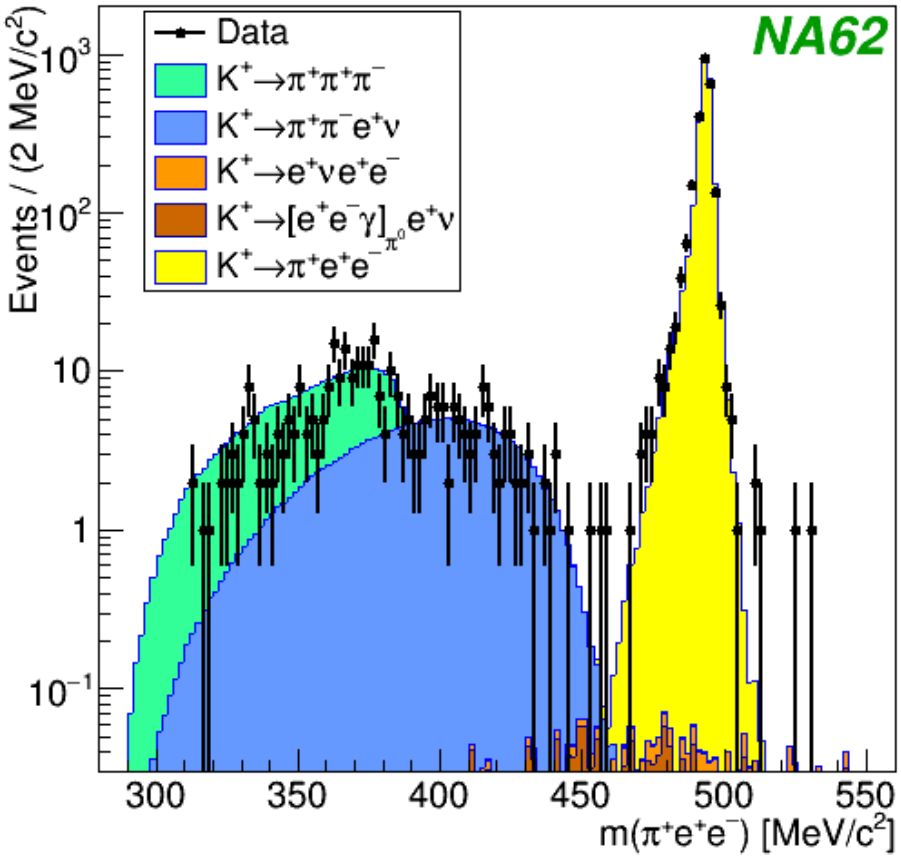
$K^+ \to \pi^- e^+ e^+$ [PID: LKr and RICH]



Sensitivity assessed using LKr only PID or LKr+RICH PID (acceptance drop of 14 % but higher background rejection)

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

$K^+ \to \pi^+ e^+ e^-$ [PID: LKr and RICH]

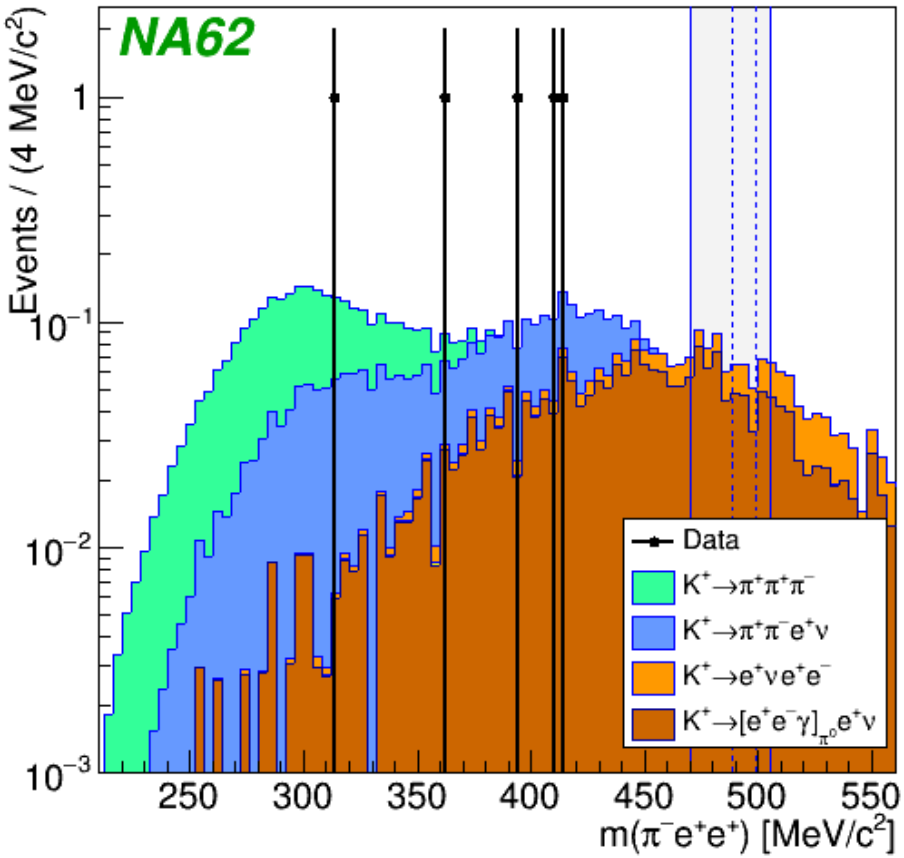


SM channel

- 2484 candidates ($m_{ee} > 140\,\mathrm{MeV}/c^2$)
- $\mathcal{B} = (3.00 \pm 0.09) \times 10^{-7}$
  $\Rightarrow N_K = (2.14 \pm 0.07) \times 10^{11}$

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

$K^+ \to \pi^+ e^+ e^-$ [PID: LKr and RICH]



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LNV channel

- Signal acceptance: 4.98 %
- $SES = (0.94 \pm 0.04) \times 10^{-10}$

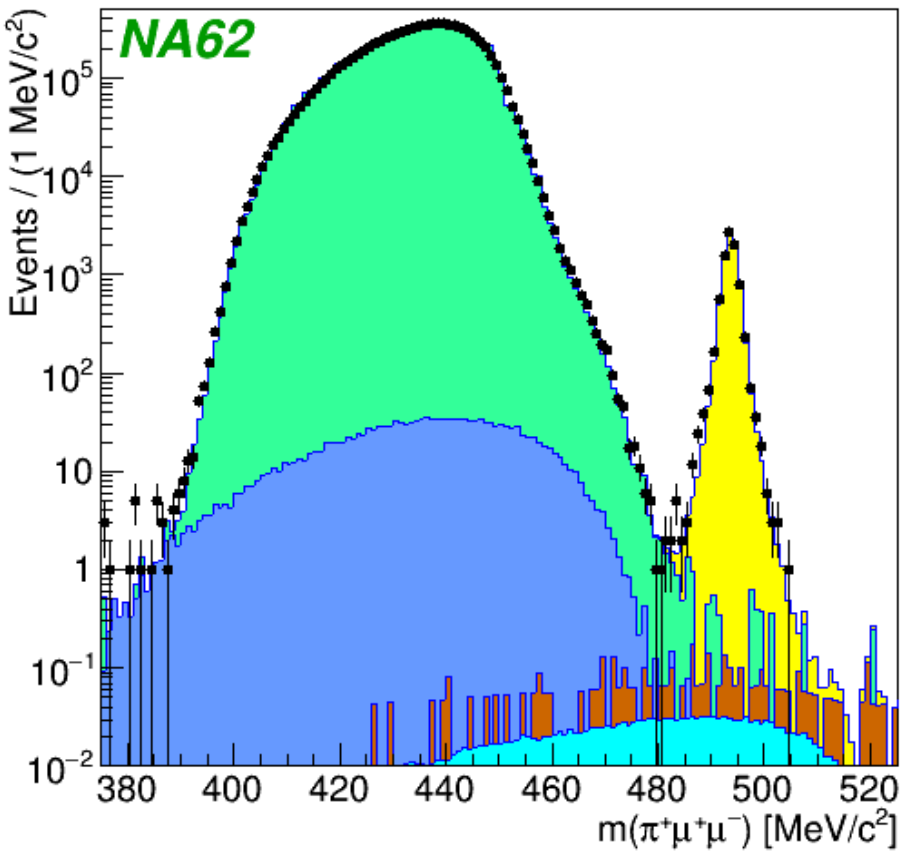
Process	Sig. Reg.
$K^+ \to e^+\nu e^+ e^-$	0.12 ± 0.02
$K^+ \to [e^+e^-\gamma]_{\pi^0}\, e^+\nu$	0.04
Total	0.16 ± 0.03

- Limit at 90%C.L.

$$\mathcal{B}(K^+ \to \pi^- e^+ e^+) < 2.2 \times 10^{-10}$$

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

$K^+ \to \pi^+ \mu^+ \mu^-$ [PID: LKr and RICH]

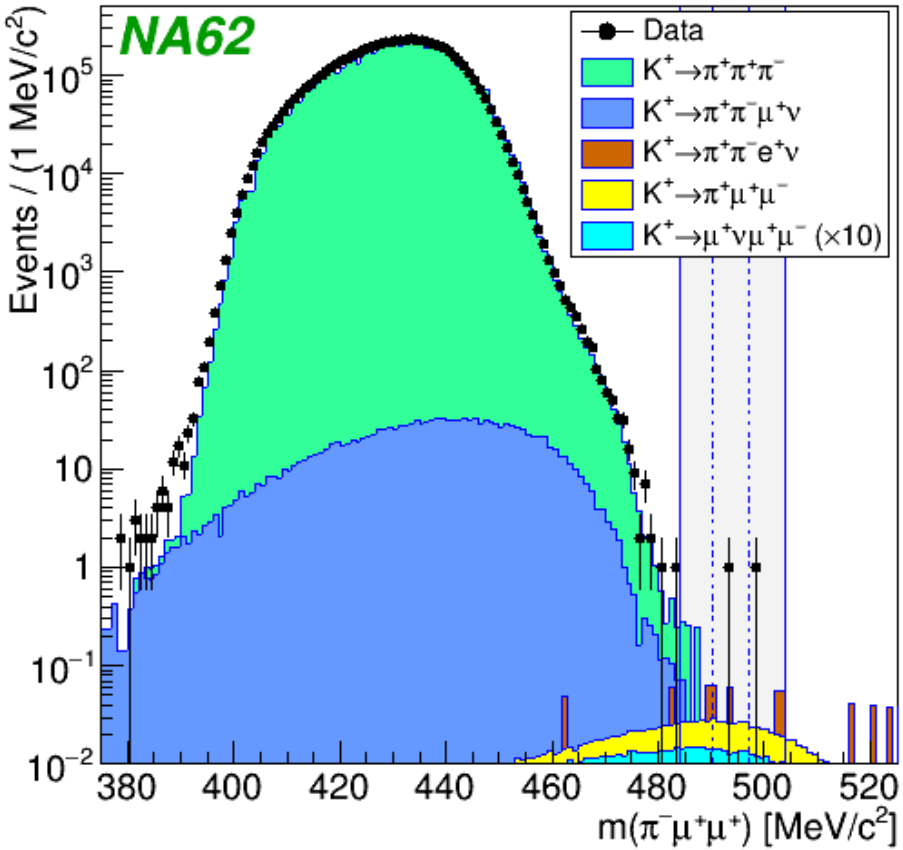


SM channel

- 8357 candidates
- $\mathcal{B} = (9.4 \pm 0.6) \times 10^{-8}$
  $\Rightarrow N_K = (7.94 \pm 0.23) \times 10^{11}$

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

$K^+ \to \pi^+\mu^+\mu^-$ [PID: LKr and RICH]



SM channel

- 8357 candidates
- $\mathcal{B} = (9.4 \pm 0.6) \times 10^{-8}$
  $\Rightarrow N_K = (7.94 \pm 0.23) \times 10^{11}$

LNV channel

- Signal acceptance: 9.81 %
- $SES = (1.23 \pm 0.03) \times 10^{-11}$

Process	Exp. in Signal Region
$K^+ \to \pi^+\pi^+\pi^-$	0.70 ± 0.40
$K^+ \to \pi^+\pi^-\ell^+\nu$	$0.06(7) \pm 0.05$ $\mu(e)$
$K^+ \to \pi^+\mu^+\mu^-$	0.08 ± 0.02
$K^+ \to \mu^+\nu\mu^+\mu^-$	0.01
Total	0.91 ± 0.41

- Limit at 90%C.L.

$$\mathcal{B}(K^+ \to \pi^-\mu^+\mu^+) < 4.2 \times 10^{-11}$$

Section 3

Future prospects on Lepton Number/Flavour Violation

Prospects

- Assuming background free searches

Process	PDG Limit	NA62 expected
$K^+ \to \pi^- \mu^+ e^+$	5×10^{-10}	$\mathcal{O}(10^{-10})$
$K^+ \to \pi^+ \mu^- e^+$	5.2×10^{-10}	$\mathcal{O}(10^{-10})$
$K^+ \to \pi^+ \mu^+ e^-$	1.3×10^{-11}	$\mathcal{O}(10^{-10})$
$K^+ \to e^- \nu \mu^+ \mu^+$	None	$\mathcal{O}(10^{-11})$
$K^+ \to \mu^- \nu e^+ e^+$	2.1×10^{-8}	$\mathcal{O}(10^{-8})$
$\pi^0 \to \mu^+ e^-$	3.8×10^{-10}	$\mathcal{O}(10^{-9})$
$\pi^0 \to \mu^- e^+$	3.4×10^{-9}	$\mathcal{O}(10^{-9})$

- Projecting after Run3 (2021-2022) with same conditions as 2018, expect another order of magnitude across all channels

Conclusions

Improved world limits on two LNV channels [arXiv:1905.07770]:

- Very low background (<1) searches in both cases
- $\mathcal{B}(K^+ \to \pi^- e^+ e^+) < 2.2 \times 10^{-10}$ 90% C.L.
- $\mathcal{B}(K^+ \to \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$ 90% C.L.

More analyses ongoing, improvements expected in several other LNV/LFV channels
More data to be analysed
Extrapolating after NA62 Run3 (same running conditions as in 2018), another order of magnitude.

Thank you!