Overview of recent physics results from the NA62 experiment

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University of Birmingham Particle Physics Seminar

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Kaon experiments at CERN's ECN3

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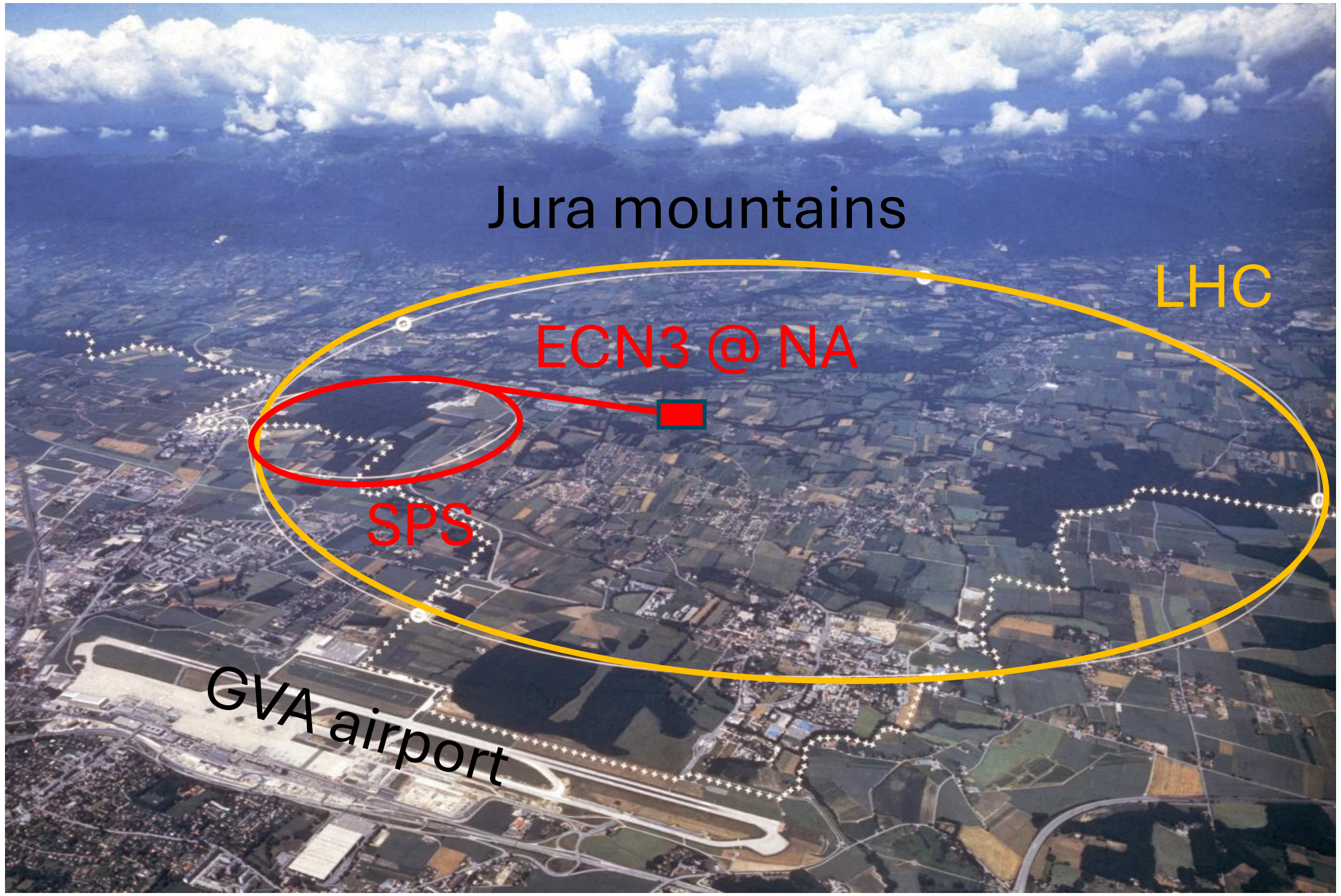
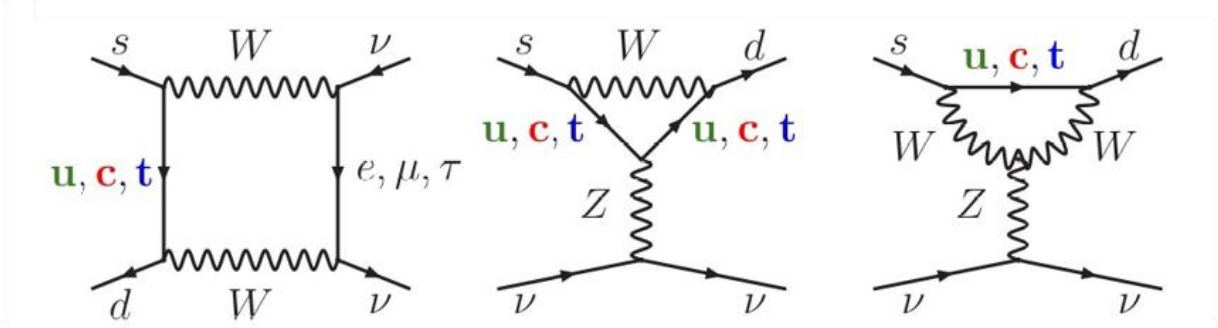


1980s	NA31 evidence for dCPV in $K_L - K_s$
1997-2001	NA48: discovery of dCPV in $K_L - K_s$
2002	NA48/1 K_s/hyperon decays (rare)
2003-2004	NA48/2 $K^{\pm}$ decays (precision)
2007-2008	NA62-R_K $\Gamma(K^{\pm} \to e^{\pm}\nu)/\Gamma(K^{\pm} \to \mu^{\pm}\nu)$
2015-2018	NA62 Run1: $K^+ \to \pi^+\nu\bar{\nu}$ & much more
2021-2026	NA62 Run2: $K^+ \to \pi^+\nu\bar{\nu}$ & much more

The NA62 goal - $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$ measurement



- Highly suppresed in the SM (GIM+CKM)
- Theoretically clean, with precise predicitons

$$\mathcal{B}_{SM1}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.60 \pm 0.42) \cdot 10^{-11}$$ EPJC 82 (2022) 7, 615

$$\mathcal{B}_{SM2}(K^+ \to \pi^+ \nu\bar{\nu}) = (7.86 \pm 0.61) \cdot 10^{-11}$$ JHEP 09 (2022) 148

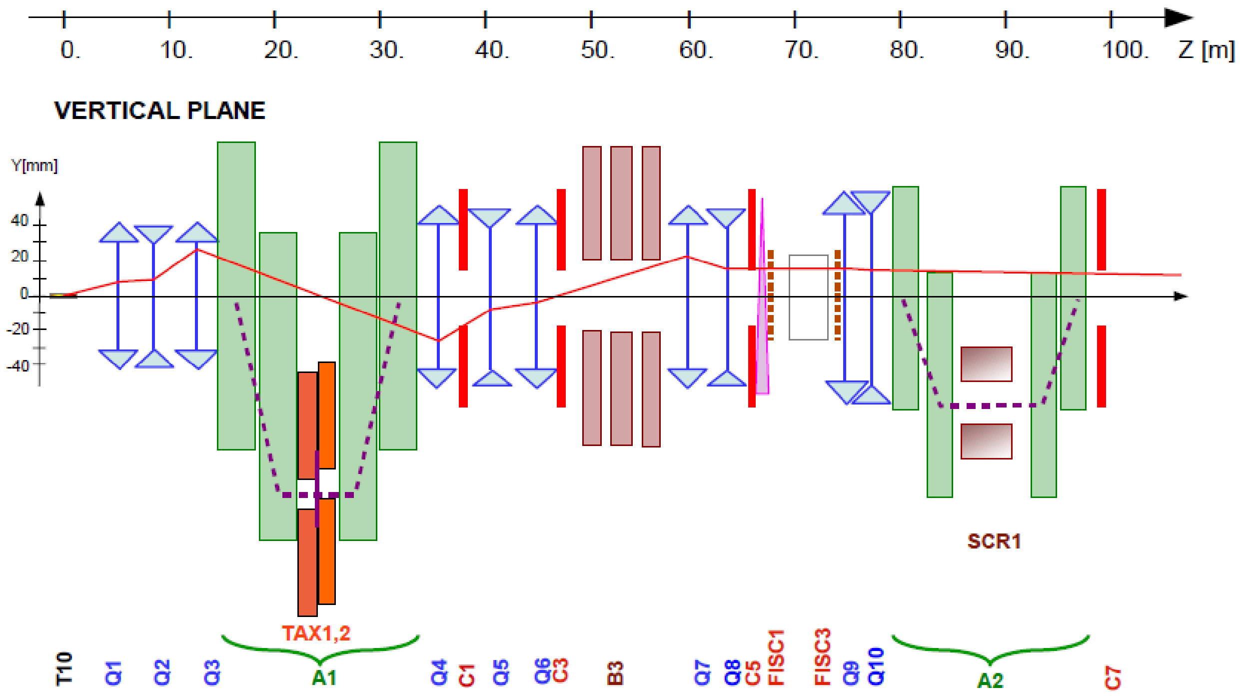
- Theory uncertainty driven by external contribution from V_{CKM}
- Sensitivity to new physics up to $O(100\ \mathrm{TeV})$

The backgrounds:

Decay	Branching ratio	Rejection method
$K^+ \to \mu^+ \nu$	$(63.56 \pm 0.11)\%$	PID and kinematics
$K^+ \to \pi^+ \pi^0$	$(20.67 \pm 0.08)\%$	Photon veto and kinematis
$K^+ \to \pi^+ \pi^+ \pi^-$	$(5.583 \pm 0.024)\%$	Kinematics and hermetic detector
$K^+ \to \pi^+ \pi^- e^+ \nu$	$(4.247 \pm 0.024) \cdot 10^{-5}$	PID and hermetic detector

The NA62 experiemnt - beam

- Decay-in-flight technique
- High intensity necessary to observe a (very) rare process
- 400 GeV/c proton beam delivered from the SPS on T10 target
- An unseparated hadron beam is produced:
  70% π^+, 24% p and 6% K^+
- The 75 GeV/c momentum component (kaon maximum, $\pm$1% RMS) is selected using a pair of achromats
- Mean intensity of 600-750 MHz
- Scraped magnet used to reject muon component
- A 50 mm tungsten plate in the path of the beam used to reject positrons by inducing heavy bremsstrahlung



The NA62 experiment - detector

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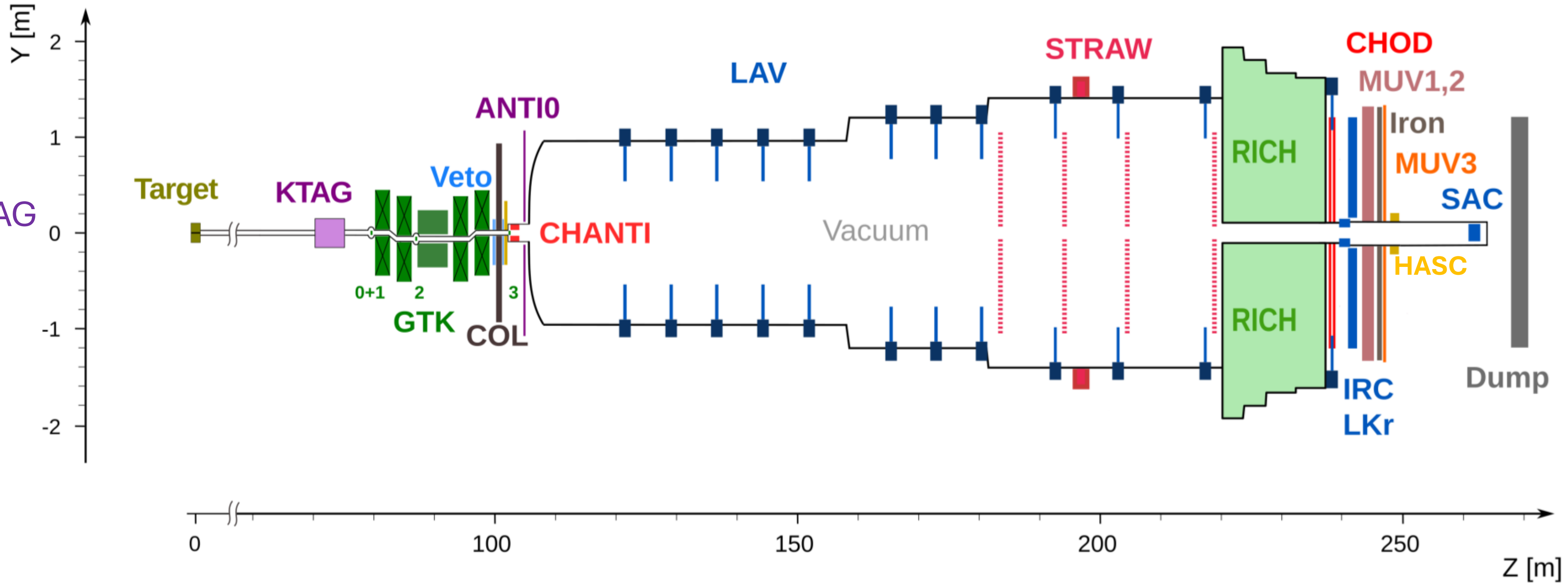
Incoming K^+:

- Identified and timestamped by a differential Cherenkov counter, KTAG
- Momentum measured by a silicon beam spectrometer, GTK



Downstream detectors:

- Magnetic spectrometer, STRAW
- Ring-Imaging Cherenkov (RICH) detector for $\pi - \mu$ separation above 15 GeV/c momentum
- Electromagnetic (LKr) and hadronic (MUV1,2) calorimeters
- Muon veto (ID) hodoscope MUV3
- Photon veto outside the LKr coverage: SAC, IRC, LAV
- Timing hodoscopes CHODs
- Additional upstream vetoes: CHANTI, ANTI0, Veto
- Additional downstream vetoes: MUV0 (not shown), HASC

Modifications of the setup in 2021:

- ANTI0, Veto added
- Additional stations for HASC, GTK

$\mathcal{B}(K^+ \rightarrow \pi^+ \nu\bar{\nu})$ results (so far)

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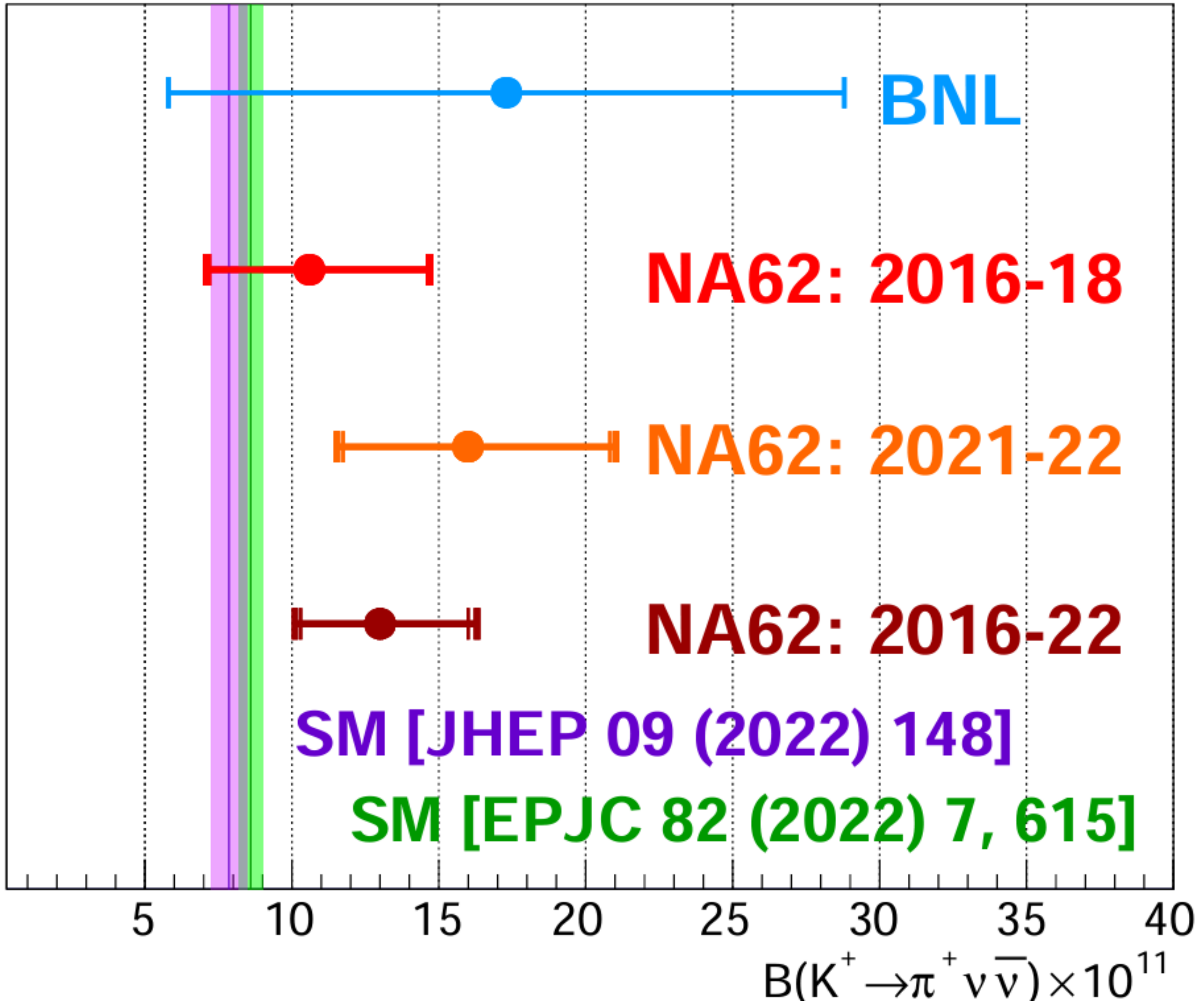
- Run1 (2016-2018) analysis [JHEP 06 (2021) 093]:
  - Expected SM signal, $N_{exp}^{SM} = 10.01 \pm 0.42$
  - Expected background, $N_B = 7.03^{+1.05}_{-0.82}$
  - Observed events, $N_{obs} = 20$
- 2021-2022 analysis [JHEP 02 (2025) 191]:
  - Expected SM signal, $N_{exp}^{SM} = 10.00 \pm 0.34$
  - Expected background, $N_B = 11.0^{+2.1}_{-01.9}$
  - Observed events, $N_{obs} = 31$
- $\mathcal{B}(K^+ \rightarrow \pi^+ \nu\bar{\nu})$ computed through a likelihood fit, with data split into categories by pion momentum and/or data-taking period
- Analysis of 2023-2024 data ongoing
- Data collection planned up to 2026 inclusive

$$\mathcal{B}_{NA62}^{16-22}\,(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = 13.0^{+3.3}_{-2.9} \cdot 10^{-11}$$



NA62 Physics Programme (in addition to $K^+ \to \pi^+ \nu\bar{\nu}$)

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Precision measurements of K^+ decays

- A study of the $K^+ \to \pi^0 e^+ \nu\gamma$ decay [JHEP 2309 (2023) 040] ***
- Measurement of the $K^+ \to \pi^+ \gamma\gamma$ decay [PLB 850 (2024) 138513] ***
- Measurement of $\mathcal{B}(K^+ \to \pi^+\pi^+\pi^-\gamma)$ [preliminary, KAON25]
- Measurement of $\mathcal{B}(K^+ \to e^+\nu\gamma(SD+))$ [preliminary, KAON25]

Rare and forbidden K^+ decays

- An extensive program for LNV/LFV K^+ decays ***
- First observation of the $K^+ \to \mu^+\nu\mu^+\mu^-$ decay [preliminary, KAON25] ***

Exotics searches

- Search for leptonic decays of dark photons at NA62 [PRL 133 (2024) 111802] BD
- Search for hadronic decays of feebly-interacting particles at NA62 [EPJC 85 (2025) 571] BD
- Search for heavy neutral leptons in π^+ decays to positrons [submitted to PLB, arXiv: 2507.07345]

Note: a selection of the most recent results ***Covered today BD: data collected in deam-dump mode

Precision measurements of K^+ decays

$K^+ \to \pi^0 e^+ \nu \gamma$: Introduction

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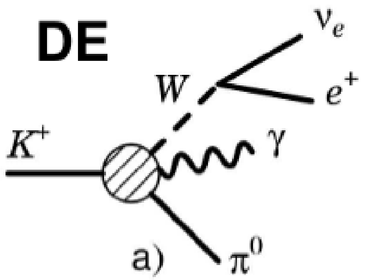
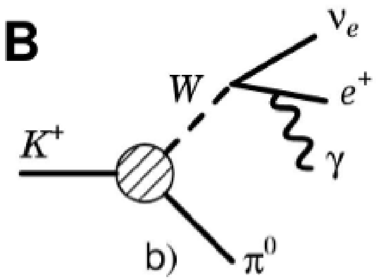
DE



IB



Inner Bremsstrahlung (IB) decay amplitude:
$\rightarrow$ divergent for $E_\gamma \rightarrow 0$ and $\theta_{e,\gamma} \rightarrow 0$

Theoretical predictions and experimental measurements for **3 sets** of cuts: minimal E_γ and $\theta_{e,\gamma}$ (in K^+ rest frame)

$$R_j = \frac{\mathcal{B}(Ke3\gamma^j)}{\mathcal{B}(Ke3)} = \frac{\mathcal{B}(K^+ \rightarrow \pi^0 e^+ \nu\gamma \mid E_\gamma^j,\ \theta_{e,\gamma}^j)}{\mathcal{B}(K^+ \rightarrow \pi^0 e^+ \nu(\gamma))}$$

	E_γ cut	$\theta_{e,\gamma}$ cut	$O(p^6)$ *ChPT* [EPJ C 50, 557]	ISTRA+	OKA
R_1 $(\times 10^2)$	$E_\gamma > 10$ *MeV*	$\theta_{e,\gamma} > 10°$	1.804 ± 0.021	$1.81 \pm 0.03 \pm 0.07$	$1.990 \pm 0.017 \pm 0.021$
R_2 $(\times 10^2)$	$E_\gamma > 30$ *MeV*	$\theta_{e,\gamma} > 20°$	0.640 ± 0.008	$0.63 \pm 0.02 \pm 0.03$	$0.587 \pm 0.010 \pm 0.015$
R_3 $(\times 10^2)$	$E_\gamma > 10$ *MeV*	$0.6 < \cos\theta_{e,\gamma} < 0.9$	0.559 ± 0.006	$0.47 \pm 0.02 \pm 0.03$	$0.532 \pm 0.010 \pm 0.012$

T-odd observable ξ (K^+ rest frame): $\xi = \dfrac{\vec{p_\gamma} \cdot (\vec{p_e} \times \vec{p_\pi})}{m_K^3}$; Asymmetry: $A_\xi = \dfrac{N_+ - N_-}{N_+ + N_-}$

$K^+ \to \pi^0 e^+ \nu\gamma$: Analysis

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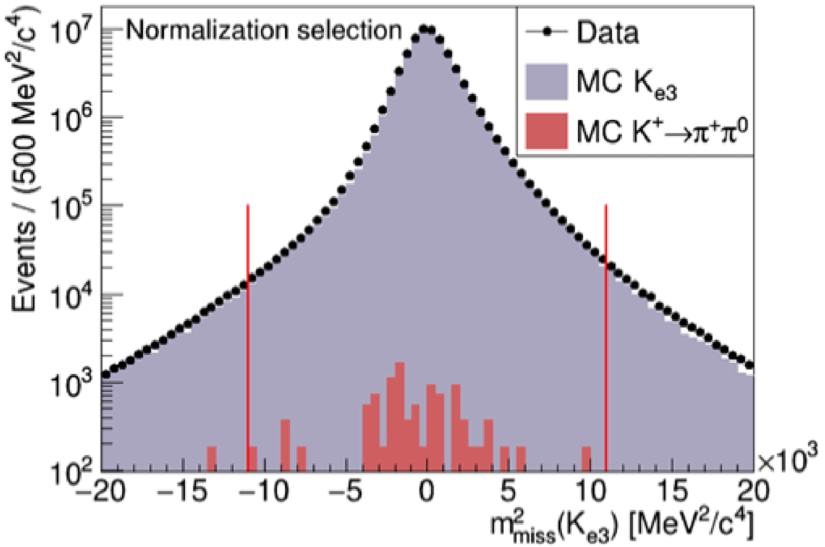
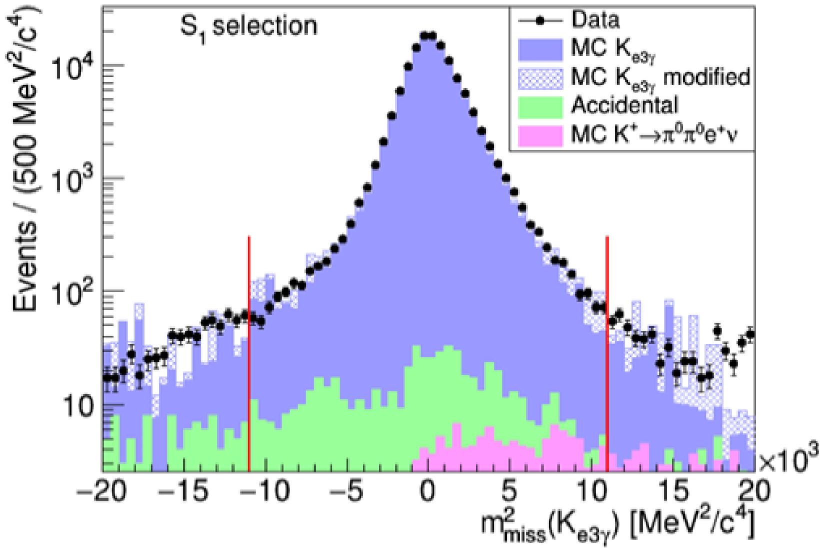
- Data sample collected by NA62 in 2017–18
- Normalization: $K^+ \to \pi^0 e^+ \nu$
  $N(\text{events}) \approx 6.6 \times 10^7$, 10^{-4} background
- $K^+ \to \pi^0 e^+ \nu\gamma$ signal samples, 3 regions S_i:
  - → $N(\text{events}) \approx 1 \times 10^5$
  - → Background: $< 1\%$
  - → Main source of bkg.: accidental activity
- Evaluation of R_j:

$$R_j = \frac{\mathcal{B}(K_{e3\gamma^j})}{\mathcal{B}(K_{e3})} = \frac{N^{\text{obs}}_{Ke3\gamma^j} - N^{\text{bkg}}_{Ke3\gamma^j}}{N^{\text{obs}}_{Ke3} - N^{\text{bkg}}_{Ke3}} \cdot \frac{A_{Ke3}}{A_{Ke3\gamma^j}} \cdot \frac{\epsilon^{\text{trig}}_{Ke3}}{\epsilon^{\text{trig}}_{Ke3\gamma^j}}.$$

- Evaluation of asymmetry:

$$A^{\text{NA62}}_{\xi} = A^{\text{Data}}_{\xi} - A^{\text{MC}}_{\xi}$$





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$K^+ \to \pi^0 e^+ \nu\gamma$: Results

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Ratio measurement:

	$O(p^6)$ ChPT	ISTRA+	OKA	**NA62**
R_1 ($\times 10^2$)	1.804 ± 0.021	$1.81 \pm 0.03 \pm 0.07$	$1.990 \pm 0.017 \pm 0.021$	$\mathbf{1.715 \pm 0.005 \pm 0.010}$
R_2 ($\times 10^2$)	0.640 ± 0.008	$0.63 \pm 0.02 \pm 0.03$	$0.587 \pm 0.010 \pm 0.015$	$\mathbf{0.609 \pm 0.003 \pm 0.006}$
R_3 ($\times 10^2$)	0.559 ± 0.006	$0.47 \pm 0.02 \pm 0.03$	$0.532 \pm 0.010 \pm 0.012$	$\mathbf{0.533 \pm 0.003 \pm 0.004}$

- Precision improved by a factor > 2
- About 5% smaller value than ChPT prediction

Asymmetry measurement:

	ISTRA+	OKA	**NA62**
$A_\xi(S_1)$ ($\times 10^3$)		$-0.1 \pm 3.9 \pm 1.7$	$\mathbf{-1.2 \pm 2.8 \pm 1.9}$
$A_\xi(S_2)$ ($\times 10^3$)		$-4.4 \pm 7.9 \pm 1.9$	$\mathbf{-3.4 \pm 4.3 \pm 3.0}$
$A_\xi(S_3)$ ($\times 10^3$)	15 ± 21	$7.0 \pm 8.1 \pm 1.5$	$\mathbf{-9.1 \pm 5.1 \pm 3.5}$

- Compatible with no asymmetry
- Uncertainties still larger than theory expectations

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$K^+ \to \pi^+\gamma\gamma$: Outline

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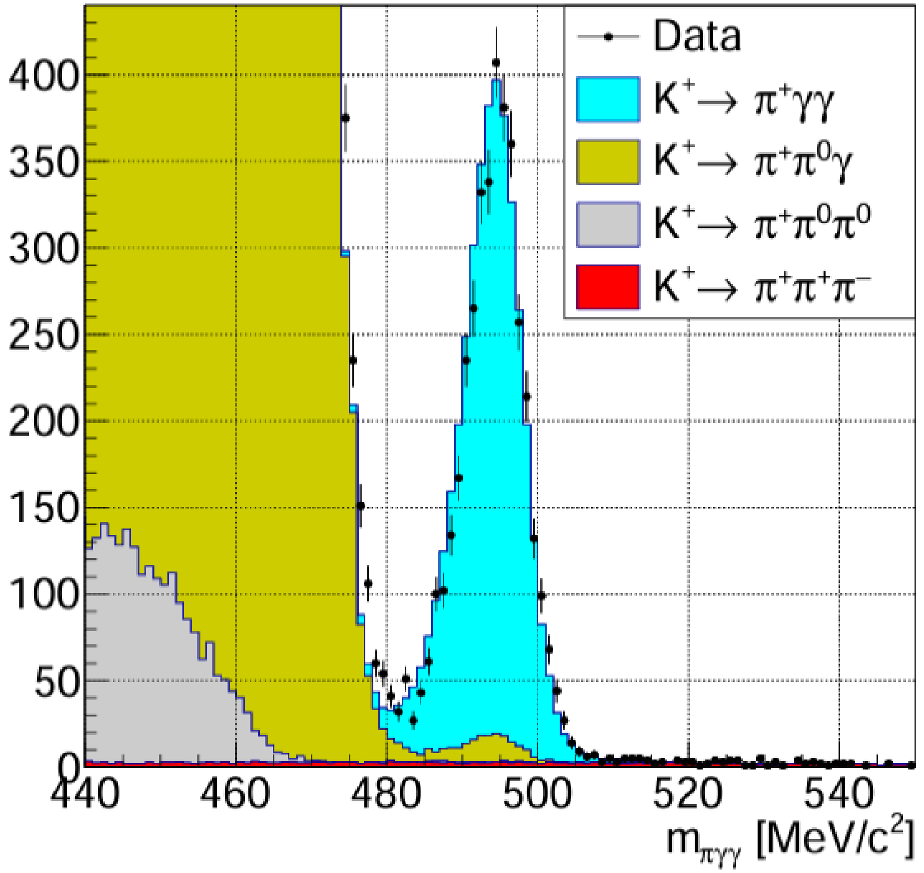
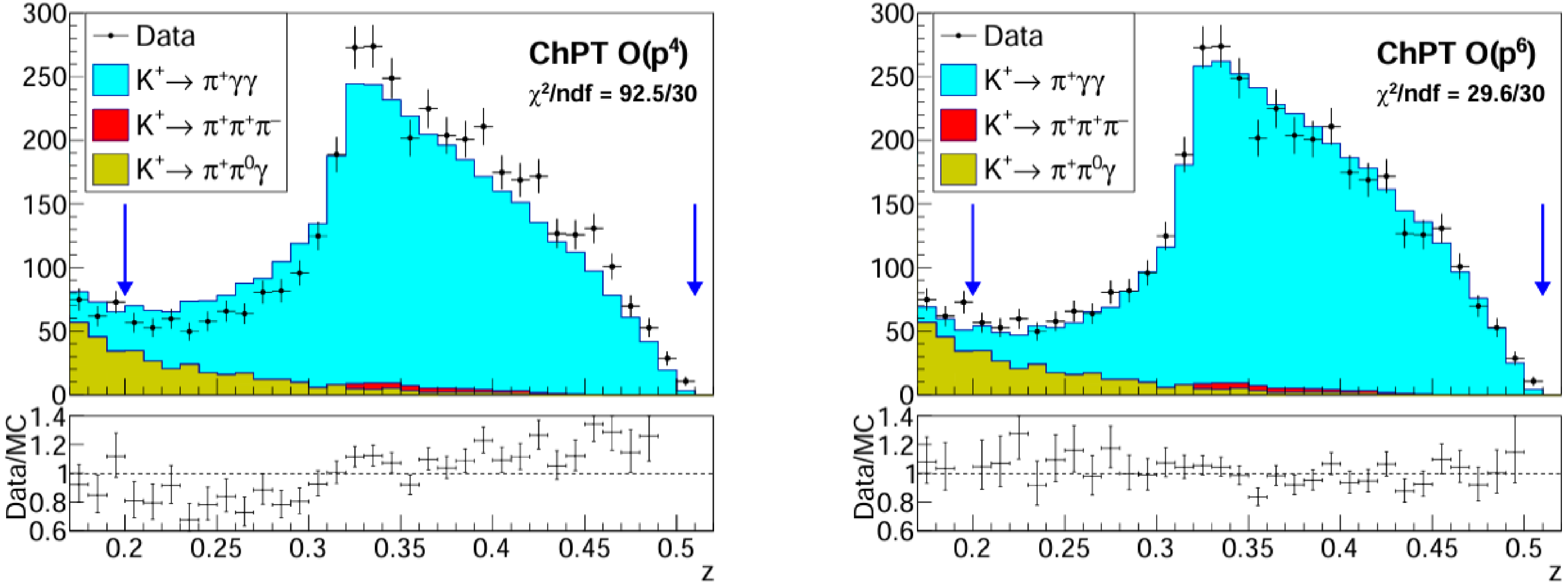
- Crucial test of ChPT
- Main kinematic variable :
  $z = (q_1 + q_2)^2 / M_K^2 = m_{\gamma\gamma}^2 / M_K^2$
- $\mathcal{B}(K^+ \to \pi^+\gamma\gamma)$ parameterized in ChPT by an unknown real parameter $\hat{c}$
- Signal selection
  - Single positive track identified as π^+ matched with a K^+ track
  - Two γ clusters in LKr
  - Kinematic constraints on $m_{\pi\gamma\gamma}$, $p_{\pi\gamma\gamma}$
  - $z \in (0.20, 0.51)$
- Normalization: $K^+ \to \pi^+\pi^0, \pi^0 \to \gamma\gamma$ with $z \in (0.04, 0.12)$
- Main background:
  $K^+ \to \pi^+\pi^0\gamma, \pi^0 \to \gamma\gamma$ decay;
  cluster merging in calorimeter



$K^+ \to \pi^+\gamma\gamma$: Results



- Data sample collected by NA62 in 2017 and 2018
- 3984 observed events; 291 $\pm$ 14 events - expected background
- $\hat{c}$ parameter measured in ChPT $\mathcal{O}(p^4)$ and $\mathcal{O}(p^6)$ using χ^2 minimization
- ChPT $\mathcal{O}(p^4)$ p-value: $2.7 \cdot 10^{-8}$: not sufficient to describe the z spectrum
- ChPT $\mathcal{O}(p^6)$ p-value: 0.49

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$K^+ \to \pi^+\gamma\gamma$: Results

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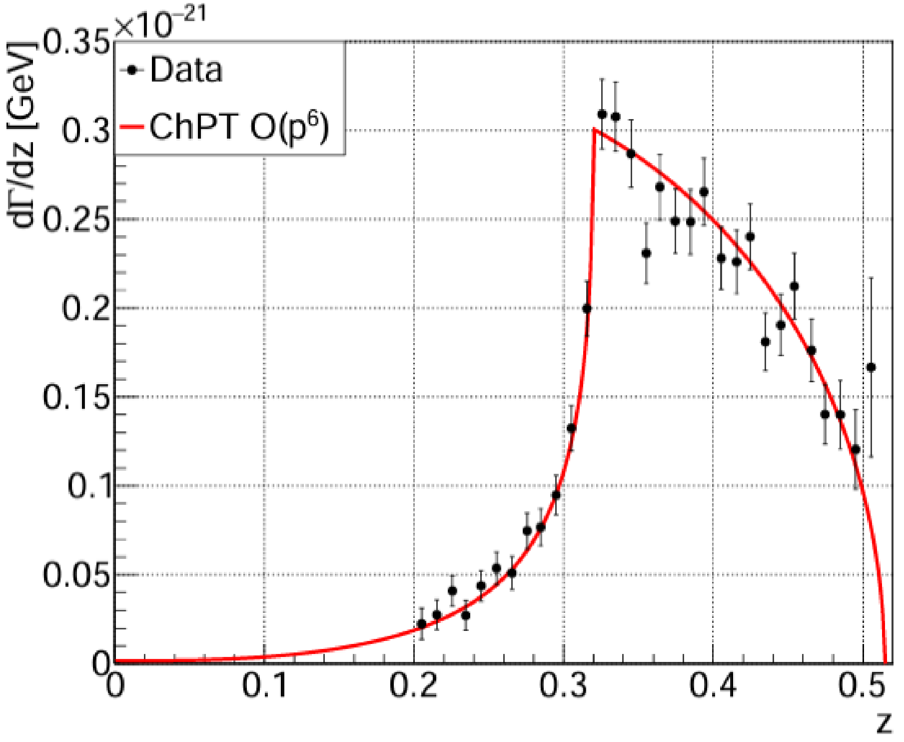

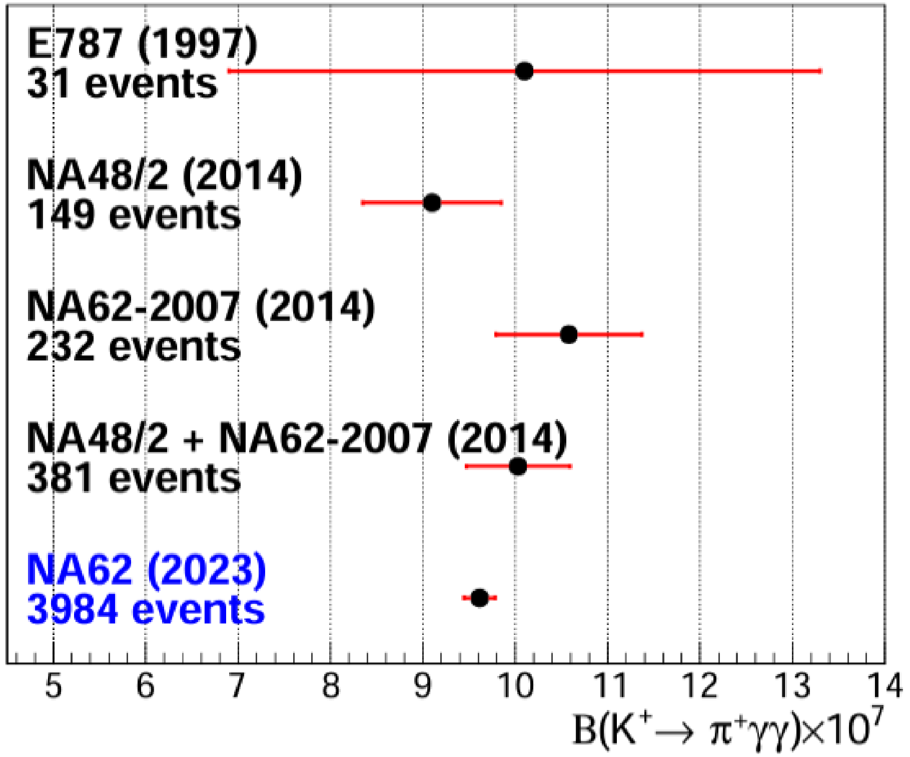

$$\hat{c}^6 = 1.144 \pm 0.069_{\text{stat.}} \pm 0.034_{\text{syst.}}$$

$$\mathcal{B}_{\text{ChPT}\mathcal{O}(p^6)}(K^+ \to \pi^+\gamma\gamma) = (9.61 \pm 0.15_{\text{stat.}} \pm 0.07_{\text{syst.}}) \cdot 10^{-7}$$

$$\mathcal{B}_{\text{MI}}(K^+ \to \pi^+\gamma\gamma | z > 0.20) = (9.46 \pm 0.19_{\text{stat.}} \pm 0.07_{\text{syst.}}) \cdot 10^{-7}$$

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First observation and branching ratio measurement of the $K^+ \to \mu^+\nu\mu^+\mu^-$ decay

$K^+ \rightarrow \mu^+\nu\mu^+\mu^-$: Introduction

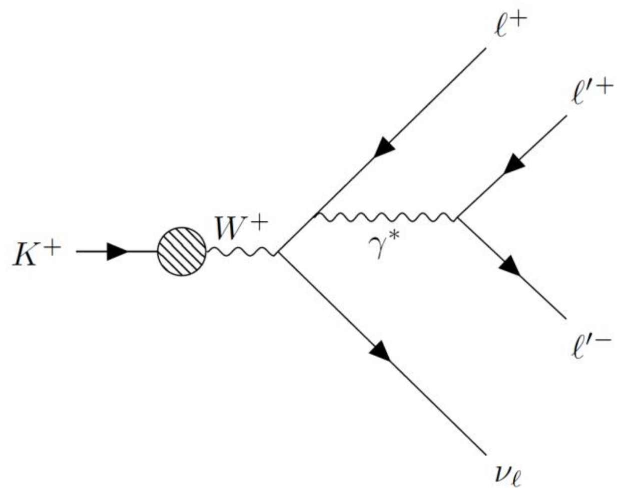
- The only unmeasured $K^+ \rightarrow l^+\nu l'^+l'^-$ decay

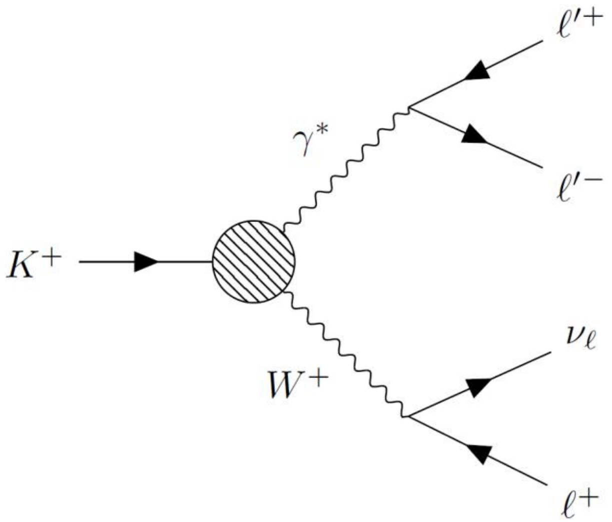
$$\mathcal{B}_{E787}(K^+ \rightarrow \mu^+\nu\mu^+\mu^-) < 7.1 \cdot 10^{-7}$$ [PRL 63 (1989) 2177]

- Three others studied by E865 experiment at BNL [PRL 89 (2002) 061803, PRD 73 (2006) 037101]
- The $K^+ \rightarrow \mu^+\nu\mu^+\mu^-$ decay width is dominated by the SD contribution, with a ~30 % IB component
- The challenge: $K^+ \rightarrow \pi^+\pi^+\pi^-$ background with $\mathcal{B} = (5.583 \pm 0.024)\%$
- Rate measurement with

$$\mathcal{B}(K^+ \rightarrow \mu^+\nu\mu^+\mu^-) = \frac{N_D - N_B}{A_S N_K}$$

- A_S estimated using a decay density $O(p^6)$ χPT prediction [NPB 396 (1993) 81-118]
- $K^+ \rightarrow \pi^+\mu^+\mu^-$ used as normalisation
  - $N_K = \frac{N_{\pi\mu\mu}}{A_N \mathcal{B}(K^+\rightarrow\pi^+\mu^+\mu^-)}$
  - Collected with the same trigger line, the Dimuon
  - Similar final state allows to minimise systematics
  - The NA62 Run1 analysis gave $BR_{NA62}\ (K^+ \rightarrow \pi^+\mu^+\mu^-) = (9.15 \pm 0.08) \cdot 10^{-8}$





$K^+ \to \mu^+ \nu \mu^+ \mu^-$: Datasets and event selections

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Period	Beam intensity	Dimuon trigger configuration	$\mathrm{D_{Dimuon}}$	GTK0
2017, 2018	Low	Run1	2	×
2022, 2023(2/3)	High	Run2	2	✓
2023(1/3), 2024	Low	Run2	1	✓

Common event selection

- A single good downstream three-track vertex consistent with the trigger time
- Kaon track consistent temporally (KTAG) and spatially (GTK) with the downstream vertex
- Rejection of vertices with tracks compatible with a beam $K^+ \to \mu^+ \nu$ decay

- Each of the three used datasets is modelled independently with simulated data produced and processed with relevant mean beam intensity (impacting pileup/overlays), detector and trigger configuration
- The A_S, A_N quantities are computed as size-based averages using the three datasets
- Background contamination, N_B, is computed for each dataset independently and summed

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Particle identification

- $\mu^\pm$: $E_{LKr}/p_{STRAW} < 0.2$ (MIP), MUV3 signal
- π^+ : $E_{LKr}/p_{STRAW} < 0.9$ (MIP or hadronic shower component), no MUV3 signal

$K^+ \to \mu^+ \nu \mu^+ \mu^-$: Normalisation channel

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- Common selection and $\pi^+\mu^+\mu^-$ PID
- Closed kinematics:

$$|p_K - p_{\pi\mu\mu}| < 2.5\ \text{GeV}/c$$
$$p_T < 30\ \text{MeV}/c$$

- Signal region: $|m_{\pi\mu\mu} - m_K| < 8\ \text{MeV}/c$
- Normalisation data candidates

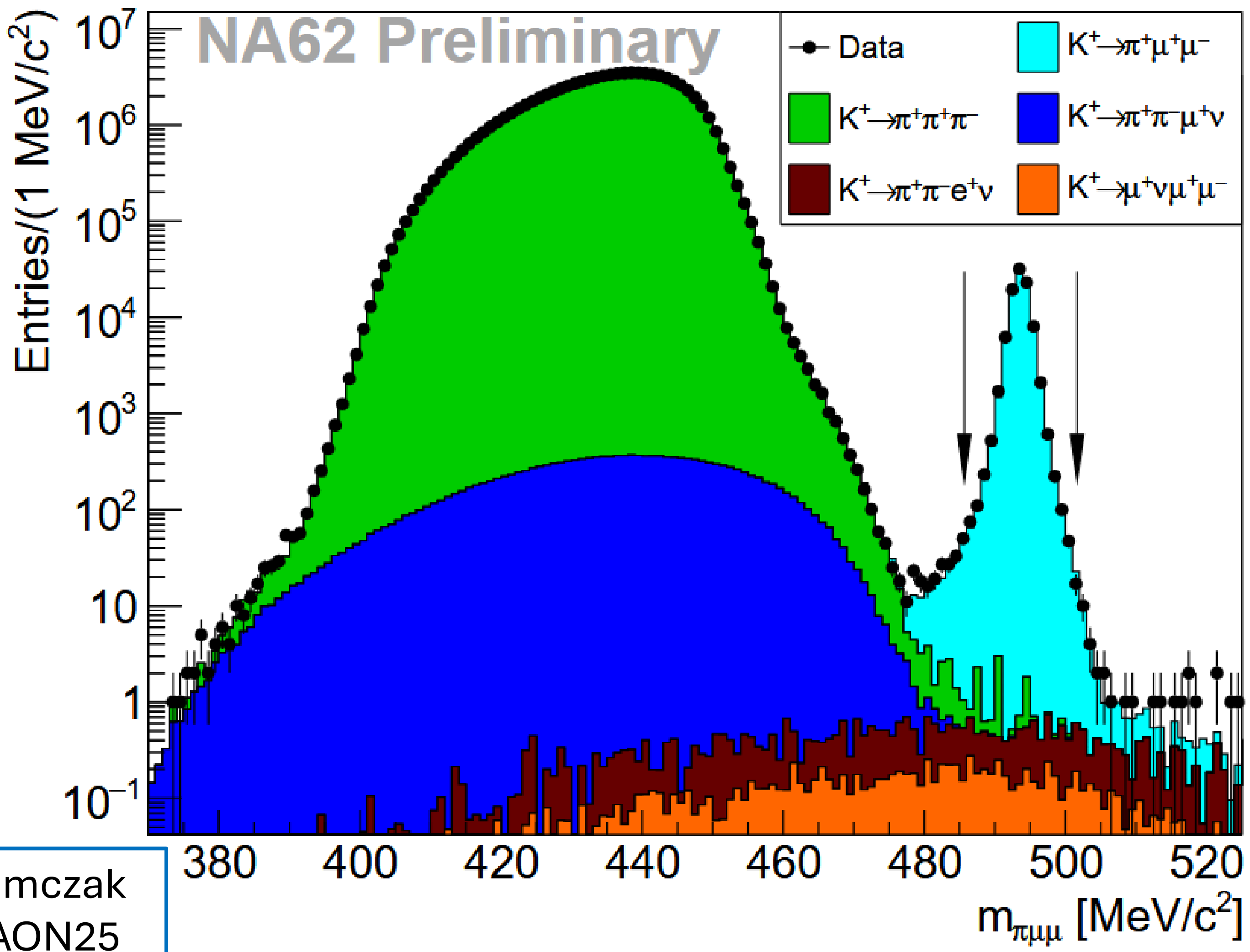
$$N_{\pi\mu\mu} = 94112$$

- Normalisation acceptance

$$A_N = (6.972 \pm 0.005_{\text{Stat}}) \times 10^{-2}$$

- Number of K^+ decays collected by the Dimuon trigger

$$N_K = (1.475 \pm 0.005_{\text{Stat}}) \times 10^{13}$$



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$K^+ \to \mu^+\nu\mu^+\mu^-$: Signal selection

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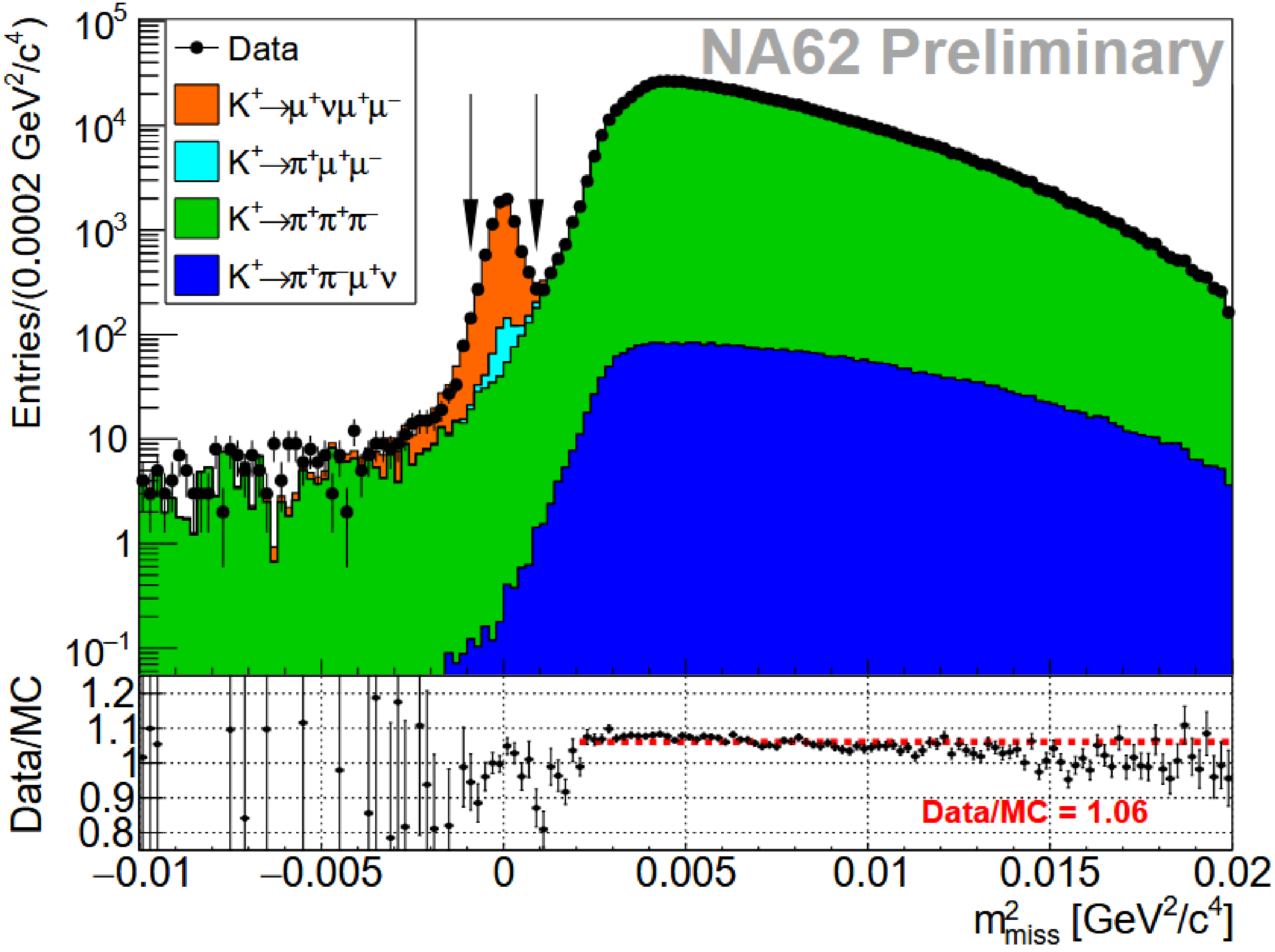
- Common selection and $\mu^+\mu^+\mu^-$ PID
- Open kinematics:

$$|p_K - p_{\mu\mu\mu}| \in [4, 40]\ \text{GeV}/c$$
$$p_T \in [0, 140]\ \text{MeV}/c$$

- Signal region: $|m^2_{miss}| < 900\ \text{MeV}^2/c^4$
- Signal data candidates

$$N_D = 8227$$

- Significant background contamination, dominated by $K^+ \to \pi^+\pi^+\pi^-$ decays
- Systematic uncertainty on N_B of 6 % motivated by the sideband Data/MC fit



$K^+ \to \mu^+\nu\mu^+\mu^-$: Background modelling

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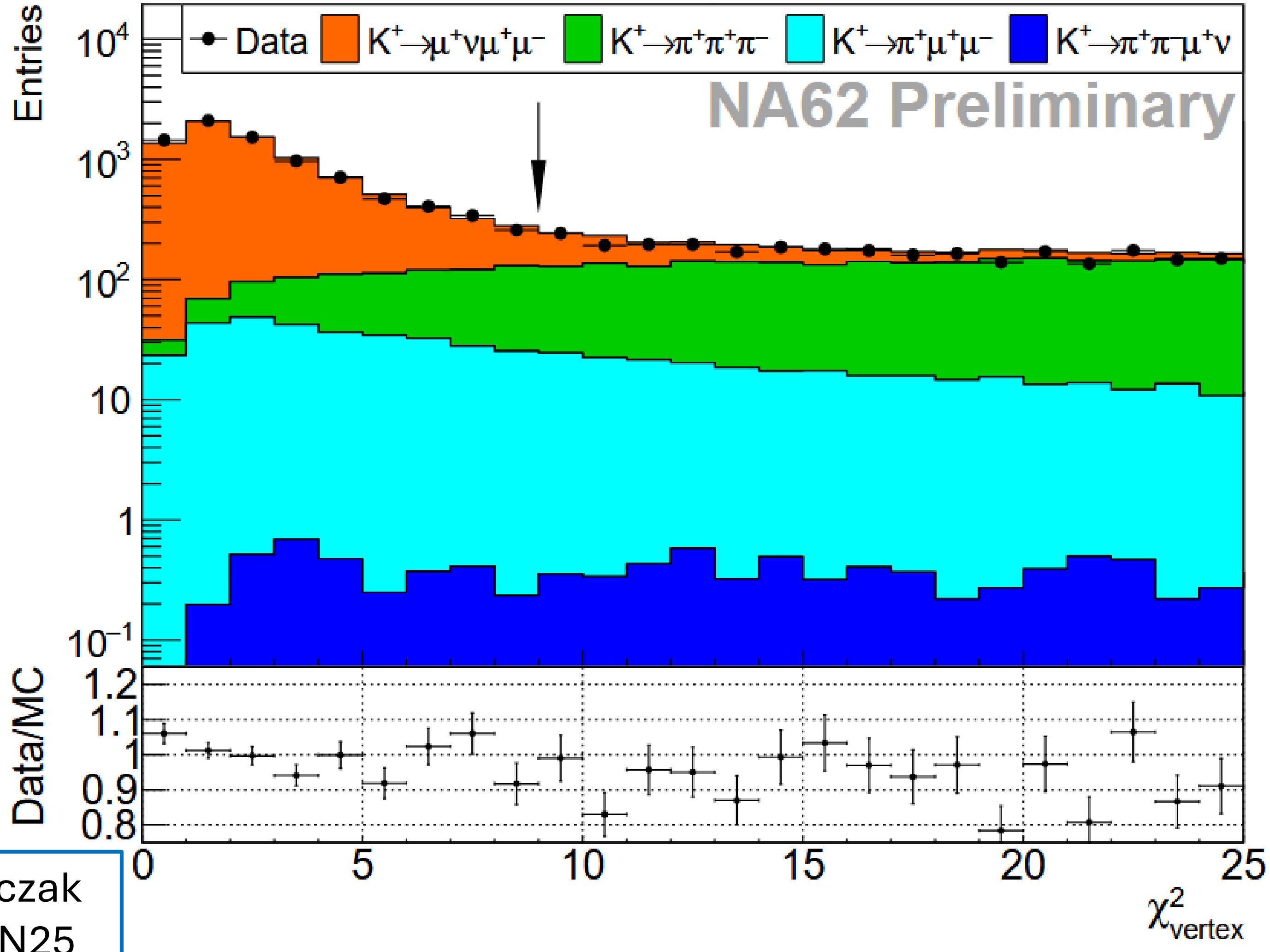
- Probability of in-flight decay for a 20 GeV/c pion before reaching the first PID detector (LKr) is (6–9) %
- The probability of $\pi^\pm \Rightarrow \mu^\pm$ misidentification is $\sim$1 %
- To supply necessary statistics, simulate $K^+ \to \pi^+\pi^+\pi^-$ events with 2 or 3 forced $\pi^\pm \to \mu^\pm\nu$ decays and $K^+ \to \pi^+\pi^-\mu^+\nu$ with 1 or 2 such decays
- Decays make the background level very sensitive to vertex geometry cut
- Cut value of $\chi^2_{\text{vertex}} < 9$, applied in common selection, was optimised for $S/\sqrt{S+B}$



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$K^+ \to \mu^+ \nu \mu^+ \mu^-$: Background composition

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Process	Contribution	$\mathfrak{B}$
$K^+ \to \pi^+ \mu^+ \mu^-$	311 ± 4	$(9.15 \pm 0.08) \times 10^{-8}$
$K^+ \to \pi^+ \pi^+ \pi^-$ $3 \times (\pi^\pm \to \mu^\pm \nu)$	506 ± 6	$(5.583 \pm 0.024) \times 10^{-2}$
$K^+ \to \pi^+ \pi^+ \pi^-$ $2 \times (\pi^\pm \to \mu^\pm \nu)$	70 ± 8	$(5.583 \pm 0.024) \times 10^{-2}$
$K^+ \to \pi^+ \pi^+ \pi^- \gamma$	2 ± 1	$(3.011 \pm 0.024) \times 10^{-4}$
$K^+ \to \pi^+ \pi^- \mu^+ \nu$	3 ± 1	$(4.5 \pm 0.2) \times 10^{-6}$

Background contributions.
Contribution uncertainties are statistical.

- Signal data candidates

$$N_D = 8227$$

- Background contamination

$$N_B = 892 \pm 11_{\mathrm{Stat}} \pm 54_{\mathrm{Syst}}$$

- Simulated data with forced $\pi^\pm \to \mu^\pm \nu$ decays allows to achieve comparable statistical uncertainty on all background sources
- Systematic uncertainty extracted from the Data/MC ratio in a m^2_{miss}-sideband

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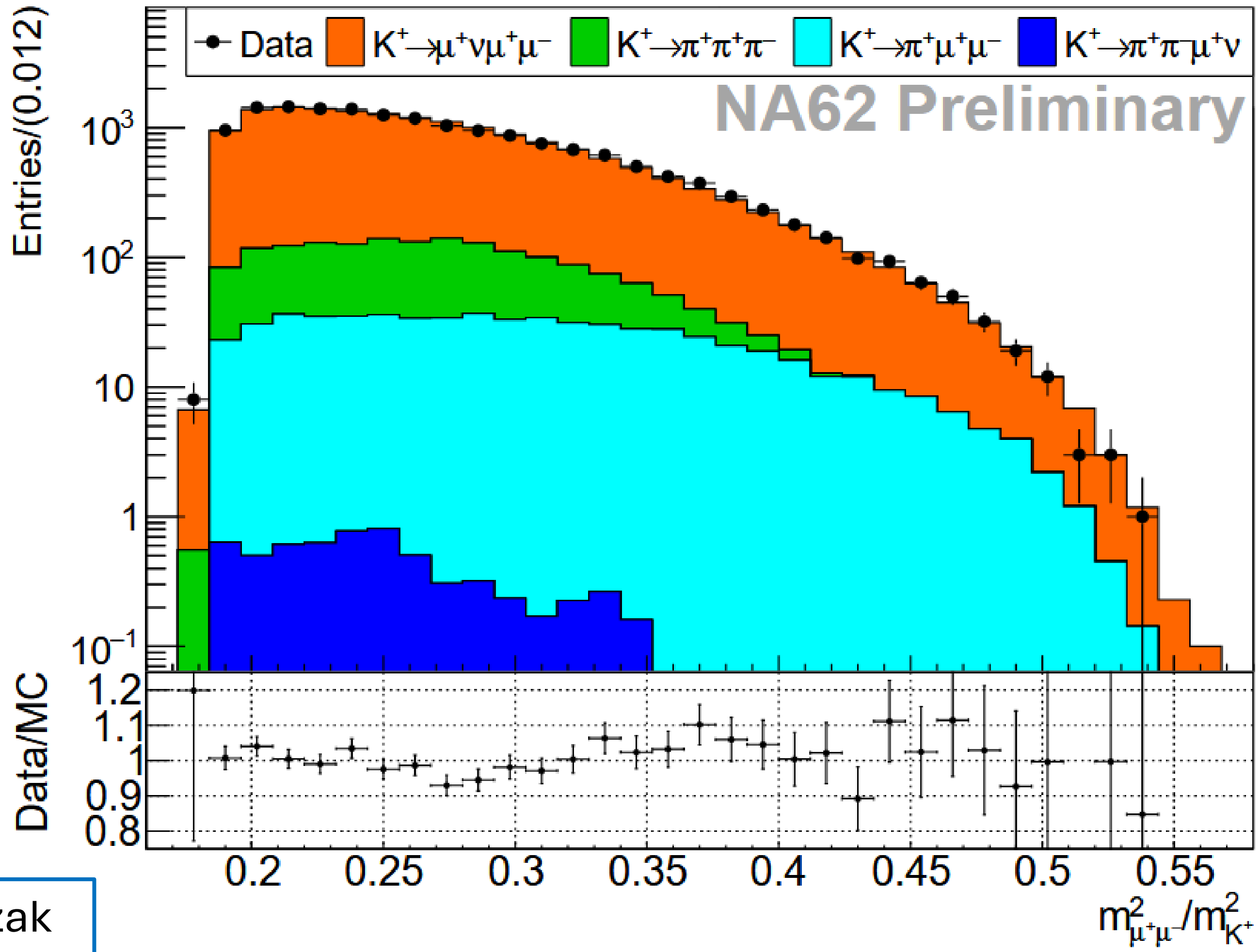
$K^+ \to \mu^+\nu\mu^+\mu^-$: Validation of the signal decay density model

- $m_{\mu^+\mu^-}$ spectrum has two entries per event due to the μ^+ ambiguity
- Data is modelled well by the $O(p^6)\ \chi PT$ prediction NPB 396 (1993) 81-118
- Signal acceptance, A_S, calculated assuming decay density from the $O(p^6)\ \chi PT$ prediction

$$A_S = (3.821 \pm 0.004_{\text{Stat}}) \times 10^{-2}$$

- Potential analysis extension: search for a promptly-decaying BSM vector/scalar particle X, with $K^+ \to \mu^+\nu X(X \to \mu^+\mu^-)$



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$K^+ \to \mu^+ \nu \mu^+ \mu^-$: Branching ratio result

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$$\mathfrak{B}(K^+ \to \mu^+ \nu \mu^+ \mu^-) = (1.301 \pm 0.017_{\text{Stat}} \pm 0.012_{\text{Syst}} \pm 0.012_{\text{Ext}}) \times 10^{-8} = (1.301 \pm 0.024) \times 10^{-8}$$

- Number of K^+ decays collected with the Dimuon trigger

$$N_K = (1.475 \pm 0.005_{\text{Stat}}) \times 10^{13}$$

- Signal data candidates

$$N_D = 8227$$

- Signal acceptance from $O(p^6)$ χPT

NPB 396 (1993) 81-118

$$A_S = (3.821 \pm 0.004_{\text{Stat}}) \times 10^{-2}$$

- Background contamination

$$N_B = 892 \pm 11_{\text{Stat}} \pm 54_{\text{Syst}}$$

Source	$\delta\mathfrak{B}$ $[10^{-8}]$	$\delta\mathfrak{B}/\mathfrak{B}$ [%]
Data statistical (signal)	0.016	1.23
Data statistical (normalisation)	0.005	0.38
Total statistical	**0.017**	**1.31**
Trigger efficiency	0.005	0.38
Reconstruction and PID	0.004	0.31
Beam intensity modelling	0.001	0.08
Background modelling	0.010	0.76
Limited MC sample size	0.002	0.15
Total systematic	**0.012**	**0.92**
Error on $\mathfrak{B}(K^+ \to \pi^+ \mu^+ \mu^-)$	0.012	0.92
Total external	**0.012**	**0.92**
TOTAL	**0.024**	**1.84**

A. Tomczak @ KAON25

$K^+ \to \mu^+\nu\mu^+\mu^-$: Comparison with theory and outlook

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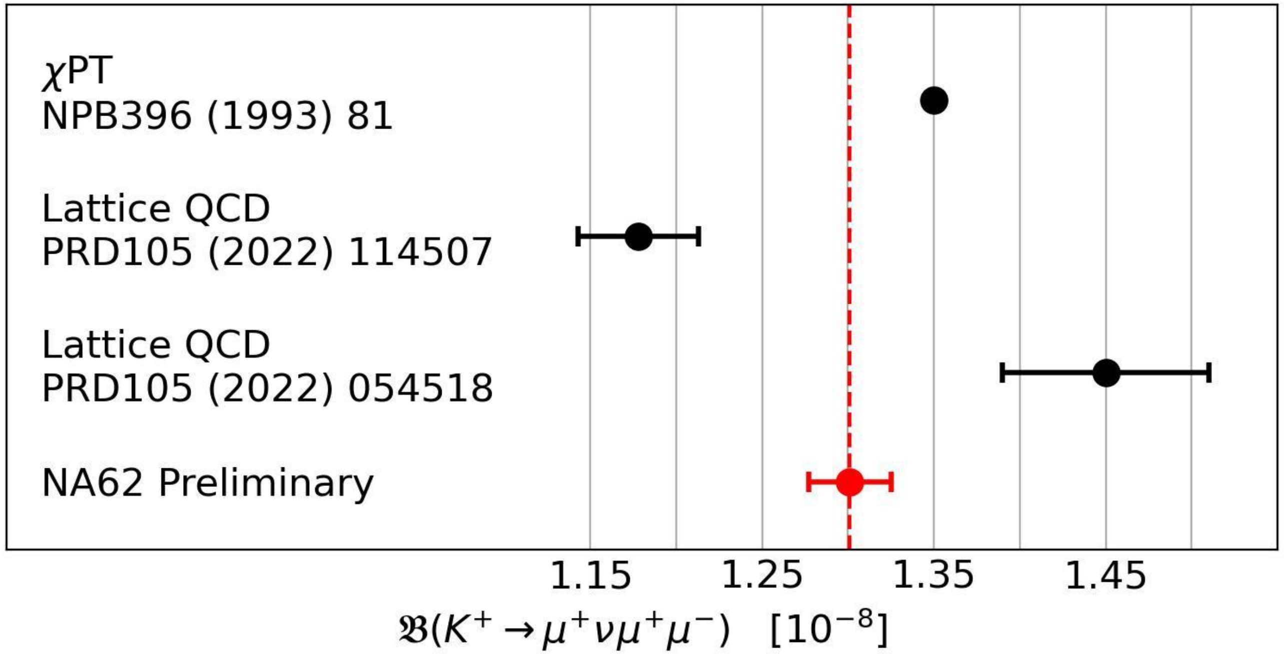
$$\mathfrak{B}_{\mathrm{NA62}}(K^+ \to \mu^+\nu\mu^+\mu^-) = (1.301 \pm 0.017_{\mathrm{Stat}} \pm 0.012_{\mathrm{Syst}} \pm 0.012_{\mathrm{Ext}}) \times 10^{-8} = (1.301 \pm 0.024) \times 10^{-8}$$



- No uncertainty on the χPT prediction
- The lattice QCD calculations "are affected by systematic uncertainties due to the missing chiral, continuum and infinite-volume extrapolations"
  PRD105 (2022) 114507
- Updates on the lattice QCD predictions are expected in the near future

- Even with the inclusion of data (to be) collected by NA62 in 2025 and 2026, the fractional statistical uncertainty to will remain >1 %
- Sensitivity to potential form-factor measurement reduced by two μ^+ in the final state

A. Tomczak
@ KAON25

Searches for LNV/LFV in K^+ decays

LNV/LFV in K^+ decays : Introduction

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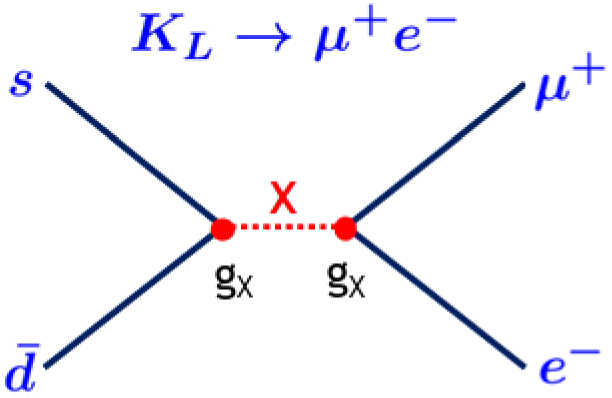
E. Goudzovski @ KAON25

- Observation of an **LNV** process (including a kaon decay): strong evidence for the Majorana nature of the neutrino.
- **LFV** kaon decays are expected e.g. in models involving ALPs or **Z'**.

Kaons are competitive in searches for LFV phenomena:

- copious production: high statistics;
- simple decay topologies: clean experimental signatures;
- tagged π^0 via $K^+ \to \pi^+\pi^0$, $K_L \to 3\pi^0$: precision π^0 decay physics.

High NP mass scales are accessible, for example:



$$\frac{\Gamma_X}{\Gamma_{SM}} \sim \left(\frac{g_X}{g_W} \cdot \frac{M_W}{M_X} \right)^4$$

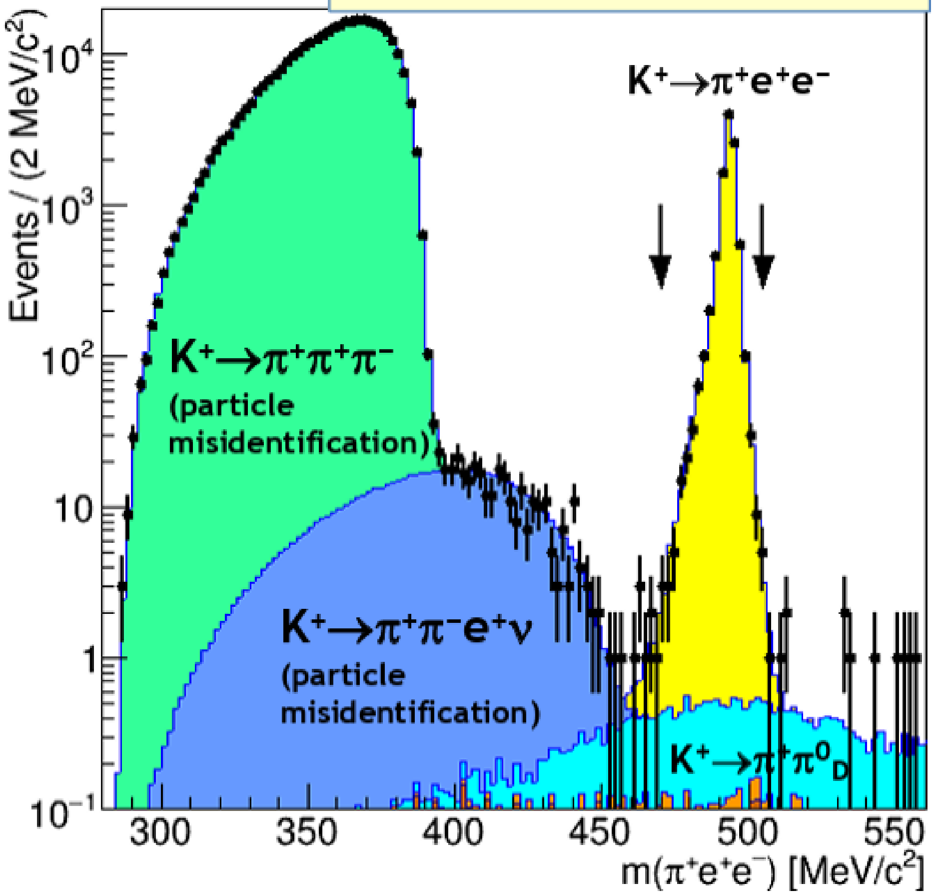
For $g_X \approx g_W$ and $\mathcal{B} \sim 10^{-12}$,

$$M_X \sim 100\ \text{TeV}$$

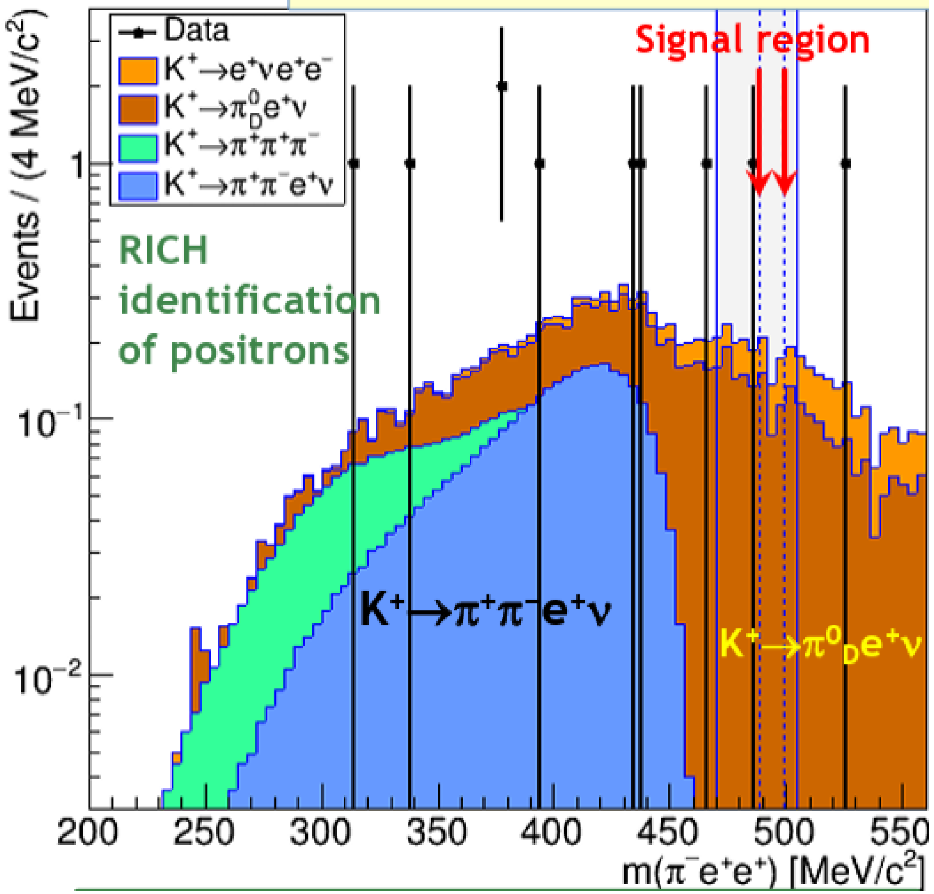
- Current studies use the Run1 (2017-18) dataset
- Changes to trigger configuration allowed to significantly reduce the dowscaling for the Multi-Track lines from 2023 onwards

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

SM selection: m(π⁺e⁺e⁻)



LNV selection: m(π⁻e⁺e⁺)



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[PLB 830 (2022) 137172]

- NA62 has collected world's largest $K^+ \to \pi^+ e^+ e^-$ sample
- The SM analysis is in progress

Candidates observed: 11041

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

K^+ decays in FV: $(1.015 \pm 0.032) \times 10^{12}$

Expected background: 0.43 ± 0.09 evt

Candidates observed: 0

BR($K^+ \to \pi^- e^+ e^+$) $< 5.3 \times 10^{-11}$ at 90% CL

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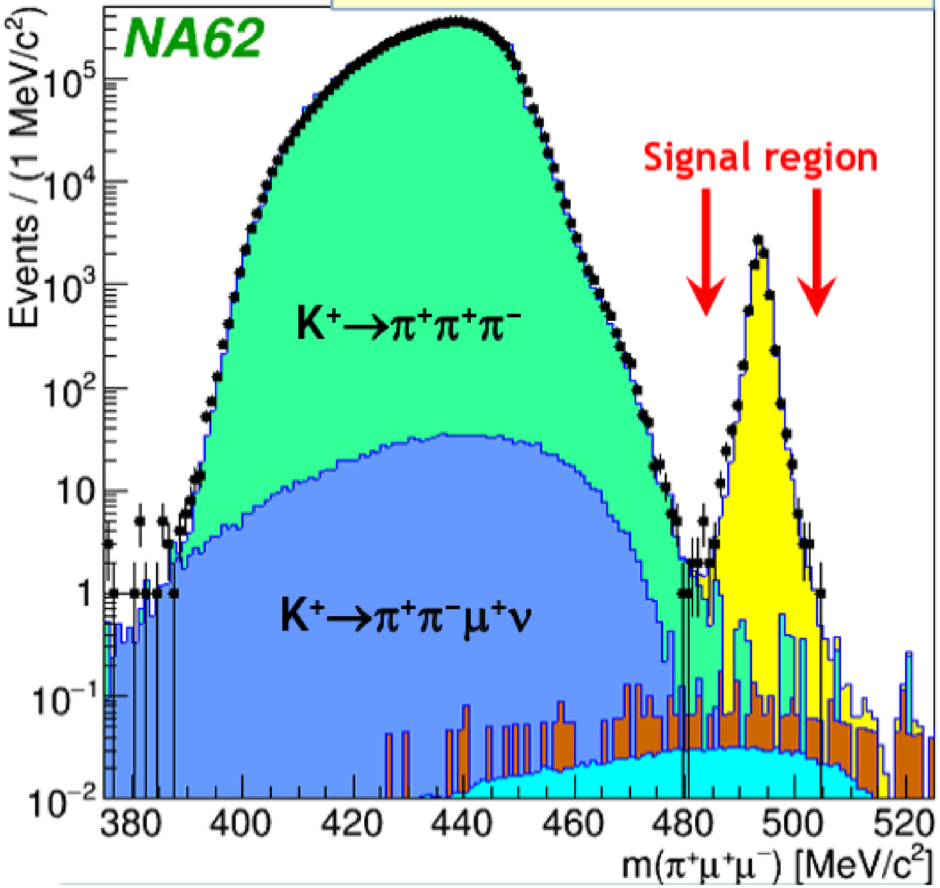
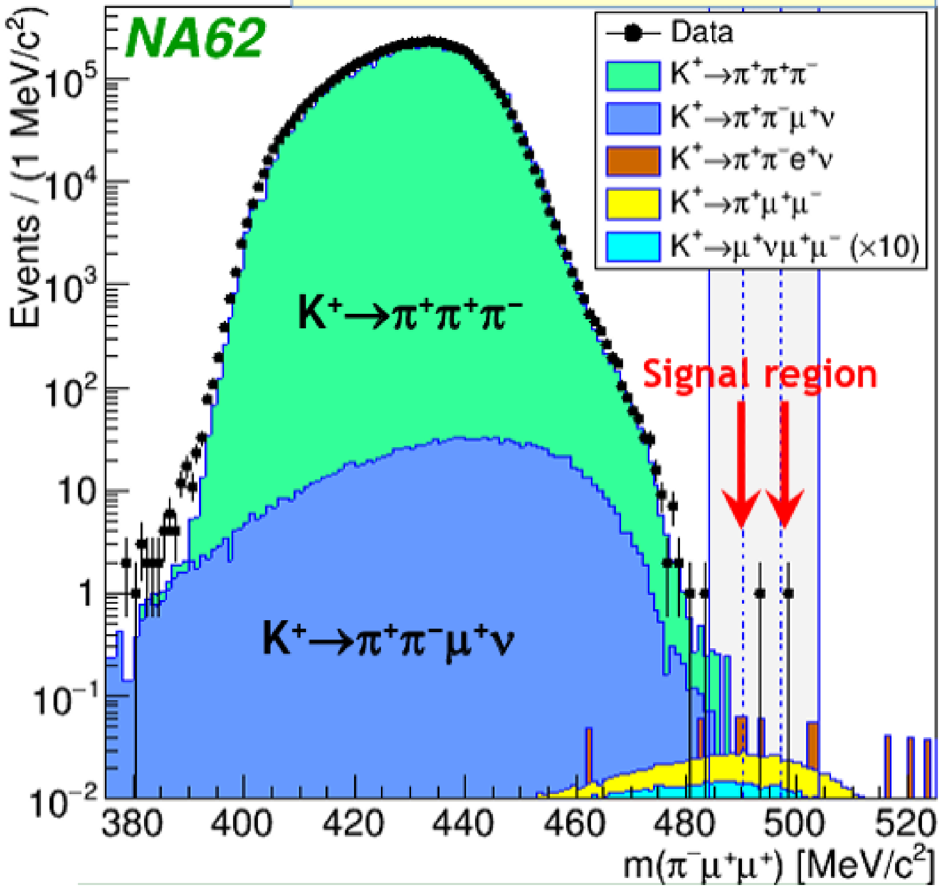
$K^+ \to \pi^- \mu^+ \mu^+$

SM selection: $m(\pi^+\mu^+\mu^-)$



Candidates (25% of Run 1 data): **8357**
Background: **0.07%**
$BR(K^+\to\pi^+\mu^+\mu^-) = (0.962\pm0.025)\times10^{-7}$
K^+ decays in FV: $(7.94\pm0.23)\times10^{11}$

LNV selection: $m(\pi^-\mu^+\mu^+)$



Expected background: **0.91±0.41** evt
Candidates observed: **1**
$BR(K^+\to\pi^-\mu^+\mu^+)<4.2\times10^{-11}$ at 90% CL

[PLB 797 (2019) 134794]

- Normalised using a pre-NA62 $BR(K^+\to\pi^+\mu^+\mu^-)$
- The SM NA62 Run1 analysis gave

$BR_{NA62}\,(K^+\to\pi^+\mu^+\mu^-) = (9.15\ \pm 0.08)\cdot 10^{-8}$

- Run2 SM analysis in progress

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

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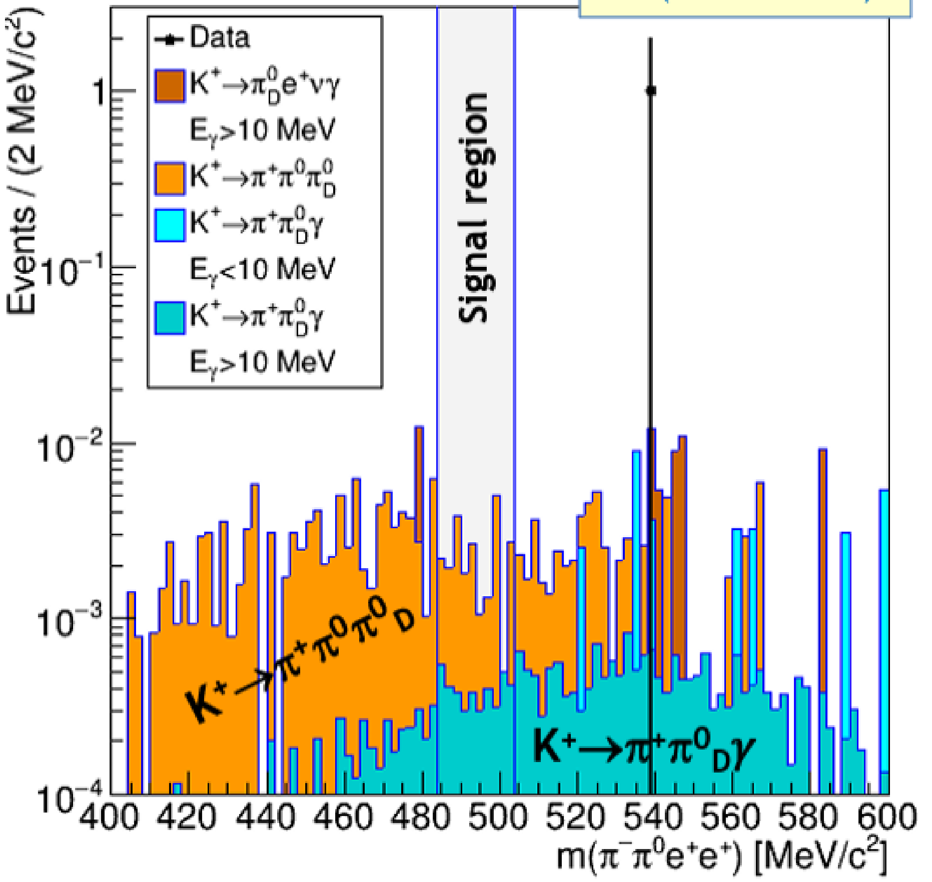
$m(\pi^- \pi^0 e^+ e^+)$

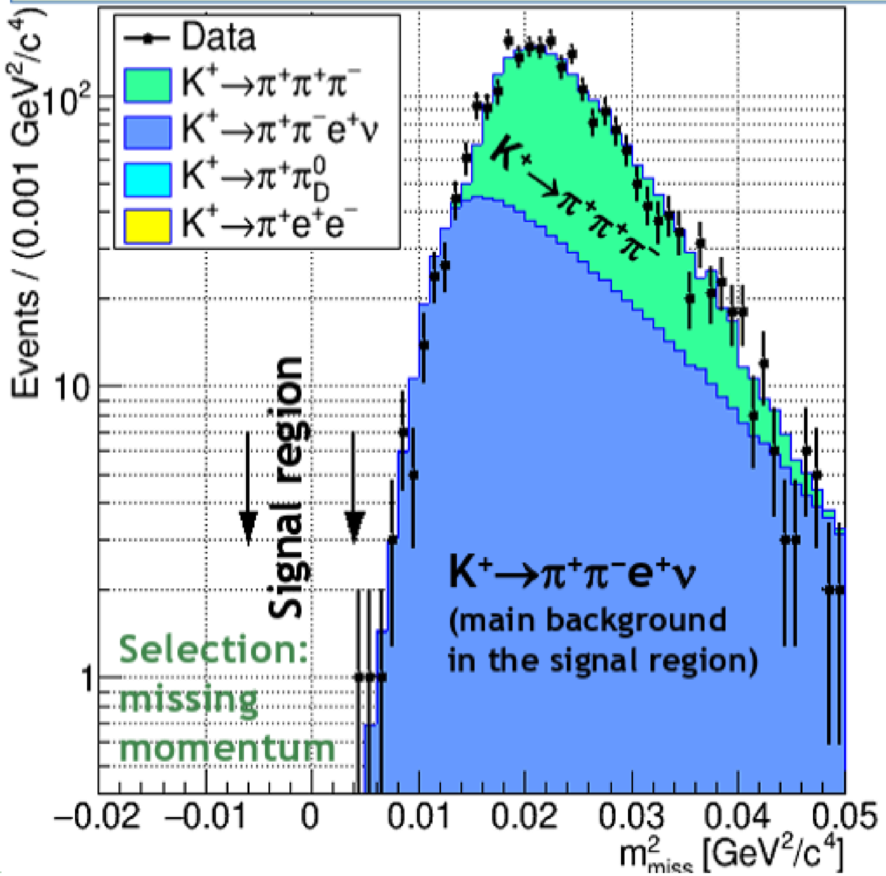


Expected background: **0.044±0.020** evt

Candidates observed: **0**

$BR(K^+ \to \pi^- \pi^0 e^+ e^+) < 8.5 \times 10^{-10}$ at 90% CL

Squared missing mass, $(P_K - P_\mu - P_{e1} - P_{e2})^2$



Expected background: **0.26±0.04** evt

Candidates observed: **0**

$BR(K^+ \to \mu^- \nu e^+ e^+) < 8.1 \times 10^{-11}$ at 90% CL

[PLB 830 (2022) 137172]

[PLB 838 (2023) 137679]

- Normalised using $K^+ \to \pi^+ e^+ e^-$
- See $K^+ \to \pi^- e^+ e^+$ slide

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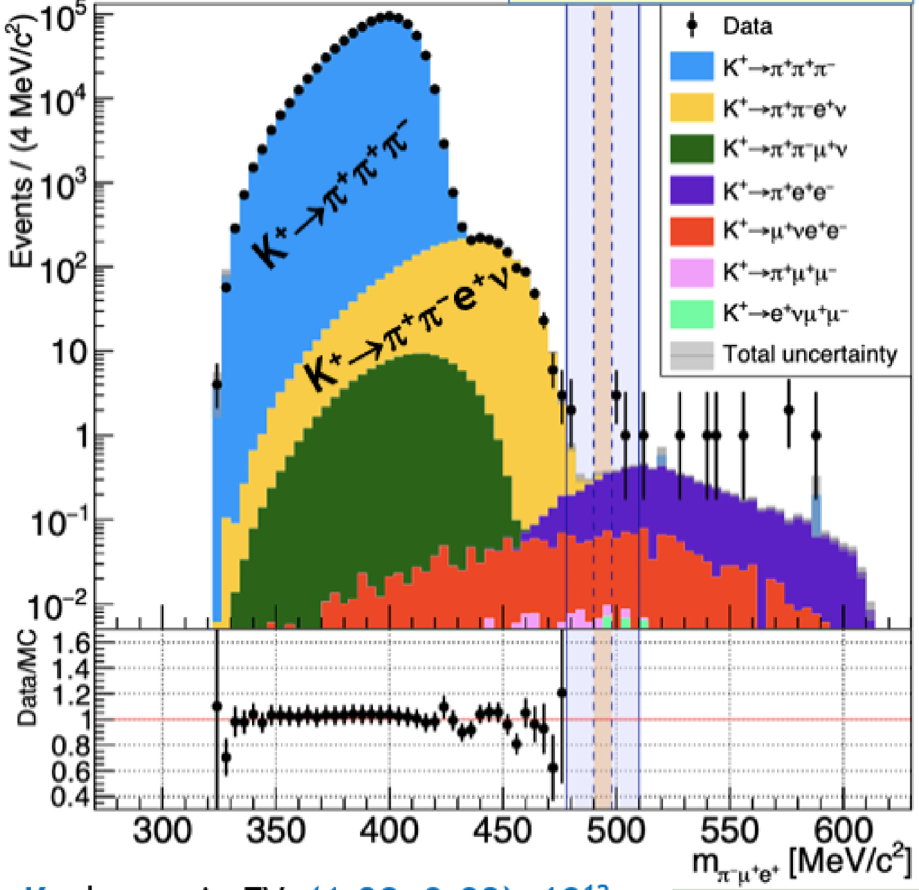
$K^+ \to \pi\mu e$

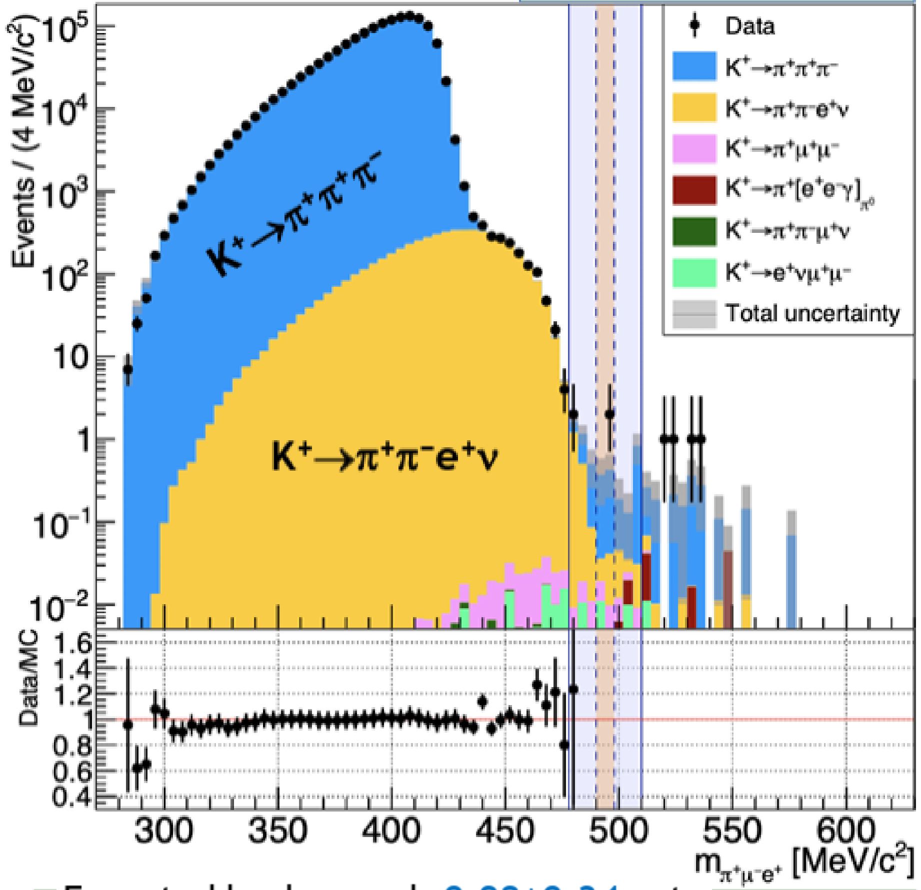
[PRL 127 (2021) 131802]

LNV: m($\pi^-\mu^+e^+$)



K⁺ decays in FV: (1.33±0.02)×10¹²
Expected background: 1.07±0.20 evt
Candidates observed: 0
BR($K^+ \to \pi^-\mu^+e^+$)<4.2×10^{-11} at 90% CL

LFV: m($\pi^+\mu^-e^+$)



Expected background: 0.92±0.34 evt
Candidates observed: 2
BR($K^+ \to \pi^+\mu^-e^+$)<6.6×10^{-11} at 90% CL
BR($\pi^0 \to \mu^-e^+$)<3.2×10^{-10} at 90% CL

- Normalised using $K^+ \to \pi^+\pi^+\pi^-$
- $K^+ \to \pi^+\mu^+e^-$ not competitive with E865 @ BNL

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

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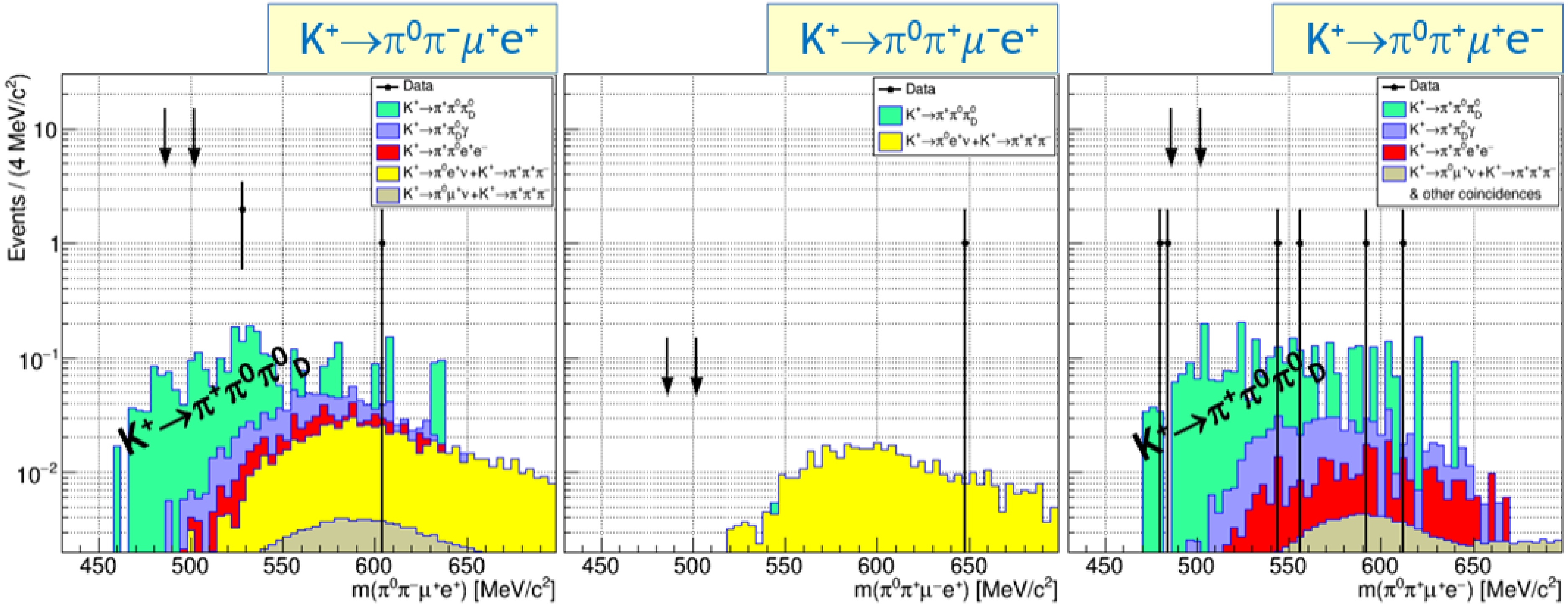

[PLB 859 (2024) 139122]

- Normalised using $K^+ \to \pi^+ e^+ e^-$
- See $K^+ \to \pi^- e^+ e^+$ slide

Mode	Expected background	Candidates observed	Upper limit of BR at 90% CL
$K^+ \to \pi^0 \pi^- \mu^+ e^+$	0.33±0.07	0	2.9×10^{-10}
$K^+ \to \pi^0 \pi^+ \mu^- e^+$	0.004±0.003	0	3.1×10^{-10}
$K^+ \to \pi^0 \pi^+ \mu^+ e^-$	0.29±0.07	0	5.0×10^{-10}

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Searches for LNV/LFV in K^+ decays: summary

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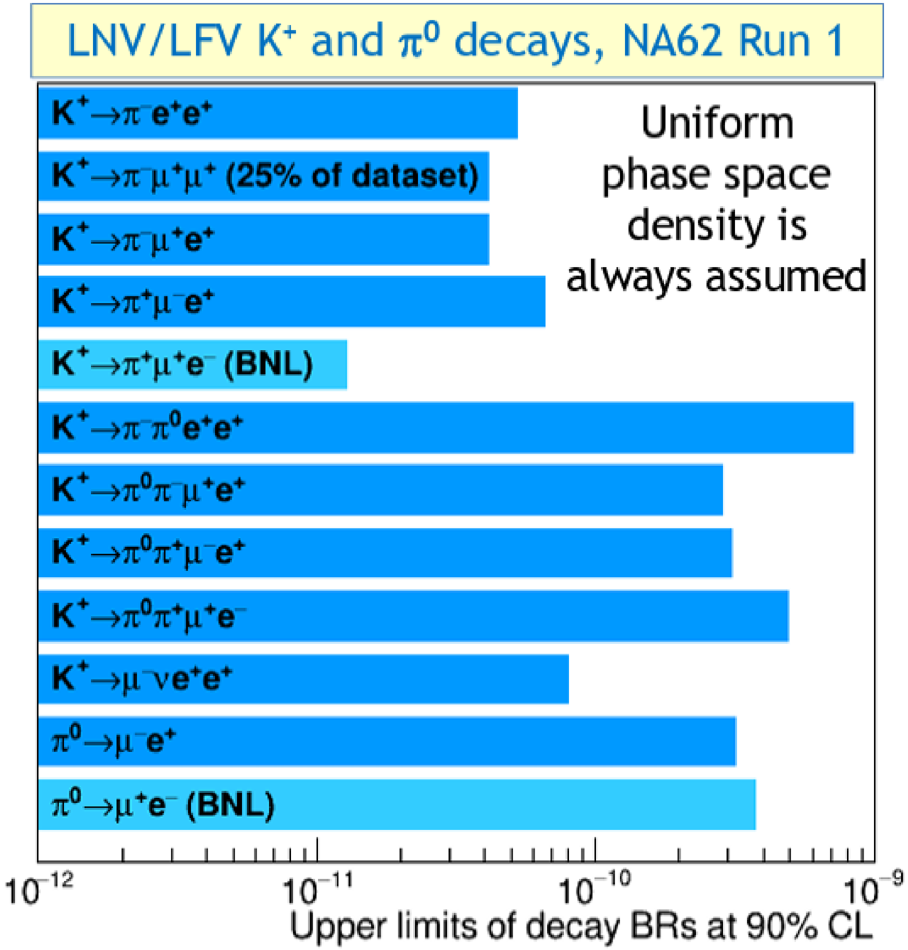
Run 1 results summary:

- LFV/LNV programme completed; best limits set for 10 decay modes.
- Sensitivity is not limited by backgrounds.

Prospects with Run 2 dataset:

- Di-lepton trigger upgrades including LKr clustering at L0, improved L1-STRAW reconstruction.
- Di-lepton trigger downscaling factors set to D=1 in late 2023.
- Di-lepton datasets equivalent to $O(10^{13})$ kaon decays are collected.
- Expect an order of magnitude improvement in sensitivity.
- Further decay modes to be added.



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Summary

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- The NA62 experiment has a broad physics programme including K^+ and π^0 decays and dump-mode operation
- The recent physics results (based on the Run1 dataset) include the studies of $K^+ \to \pi^0 e^+ \nu\gamma$ and $K^+ \to \pi^+ \gamma\gamma$ processes and a comprehensive programme of searches for LNV/LFV decays
- The $K^+ \to \mu^+ \nu \mu^+ \mu^-$ decay was observed for the first time with 2017-2024 NA62 data
- NA62 continues collecting data until LS3
- The complete NA62 dataset (Run1+Run2) promises unprecendented precission for measurements in the K^+ sector, see K.Massri's talk @ KAON25

Thank you for listening!