



New Measurement of the $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ Decay at NA62

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on behalf of the NA62 Collaboration

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Kaon Experiments at CERN

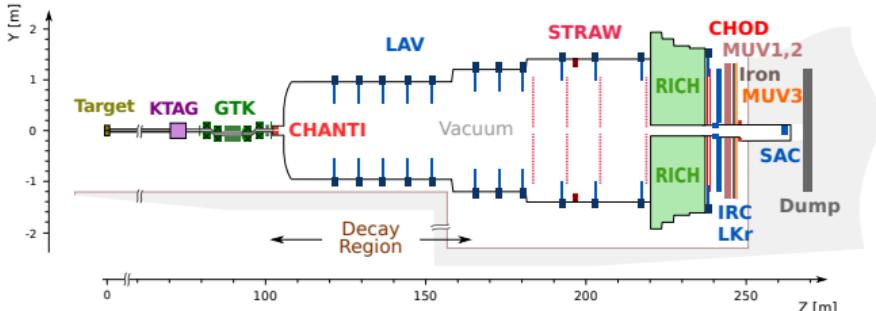


NA62: ~ 200 participants, 31 institutes



- **NA31:** 1980s, beam: K_L/K_S
 - First evidence of direct CPV
- **NA48:** 1997–2001, beam: K_L/K_S
 - Discovery of direct CPV
- **NA48/1:** 2002, beam: $K_S/\text{hyperons}$
 - Rare decay studies
- **NA48/2:** 2003–2004, beam: K^+/K^-
 - Precision measurements
- **NA62-R_K:** 2007–2008, beam: K^+/K^-
 - $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$
- **NA62:** since 2015, beam: K^+
 - 2015: commissioning run
 - 2016-2018: physics runs:
 - Main goal: $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$
 - Searches for LNV or LFV decays, HNL, axions, dark γ ,...
 - Precision measurements (e.g. $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ – **this talk**)

NA62: Beam and Detector



[JINST 12 (2017) P05025]

Beam parameters:

- Beam momentum: 75 GeV/c ($\pm 1\%$)
- Nominal rate: 750 MHz
- Positive beam: $\sim 6\% K^+$

Main subdetectors:

- Beam tracker: GTK
- Kaon tagger: KTAG ($\sigma_t \sim 70$ ps)
- Downstream tracker: ($\pi/\mu/e$): Straw
 $\sigma_p/p = 0.3\% \oplus 0.005\% \cdot p[\text{GeV}/c]$
- Photon veto detectors: LAV, IRC, SAC
- Cherenkov counter: RICH
- Trigger and timing: CHOD ($\sigma_t \sim 1$ ns), NA48-CHOD ($\sigma_t \sim 200$ ps)
- Electromagnetic calorimeter: LKr
 $\sigma_E/E = 4.8\%/\sqrt{E} \oplus 11\%/E \oplus 0.9\%$, $[E] = \text{GeV}$
- Hadronic calorimeters: MUV1,2
- Muon detector: MUV3 ($\sigma_t \sim 500$ ps)

$K^+ \rightarrow \pi^+ \mu^+ \mu^-$ ($K_{\pi\mu\mu}$) Decay – Theory Overview

- FCNC decay described in the scope of ChPT, mediated by one photon exchange $K^+ \rightarrow \pi^+ \gamma^*$
[\[Nucl. Phys. B291 \(1987\) 692–719\]](#), [\[Phys. Part. Nucl. Lett. 5 \(2008\) 76–84\]](#)
- Together with $K_{\pi ee}$ allows for tests of LFU
[\[J. Phys. Conf. Ser. 800 \(2017\) 1, 012014\]](#)
- Two Dalitz variables x and z :

$$x = m(\pi^+ \mu^+)^2 / M_K^2, \quad z = m(\mu^+ \mu^-)^2 / M_K^2$$

- Full differential decay width:

$$\frac{d^2\Gamma(x, z)}{dx dz} = \frac{d^2\Gamma_0(x, z)}{dx dz} \times (1 + \delta(x, z))$$

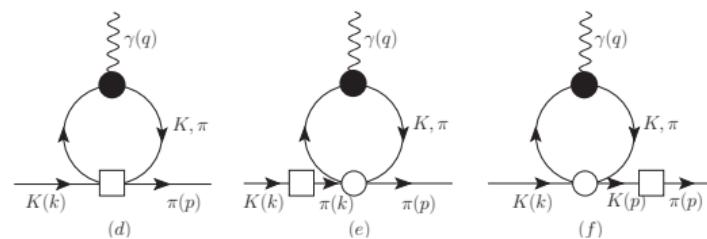
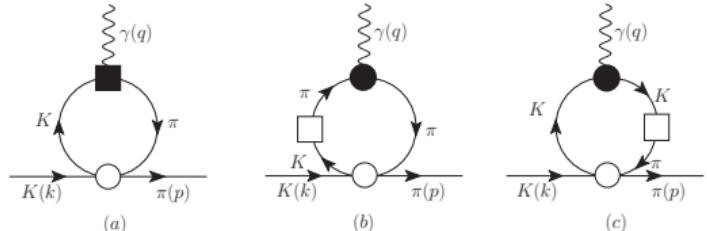
- Radiative corrections $\delta(x, z)$
[\[Eur. Phys. J. C70 \(2010\) 219–231\]](#)
- Without radiative corrections ($r_i = m_i / M_K$):

$$\frac{d^2\Gamma_0(x, z)}{dx dz} = \frac{\alpha^2 M_K}{8\pi(4\pi)^4} [(2x + z - 2 - 2r_\mu^2)(-2x - z + 2r_\pi^2 + 2r_\mu^2) + z(z - 2 - 2r_\pi^2)] |W(z)|^2$$

- Parametrization of form factor (FF) $W(z)$ in NLO ChPT [\[JHEP 08 \(1998\) 004\]](#):

$$W(z) = G_F M_K^2 (a + bz) + W^{\pi\pi}(z)$$

a, b : $K_{\pi\mu\mu}$ FF parameters, $W^{\pi\pi}(z)$: $K_{3\pi}$ pion loop term



Analysis Overview

- Measurement of FF parameters a and b and model-dependent $\mathcal{B}(K_{\pi\mu\mu})$
- Natural choice of normalization decay channel: $K^+ \rightarrow \pi^+\pi^+\pi^-$ ($K_{3\pi}$):
 - Abundant: $\mathcal{B}(K_{3\pi}) = 5.583(24)\%$ [**Phys. Rev. D, 98, p. 030001**]
 - Kinematically similar to $K_{\pi\mu\mu}$
→ minimal differences in event selections ⇒ reduced complexity and systematic effects

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- Two physics trigger streams used to collect $K_{3\pi}$ and $K_{\pi\mu\mu}$ events in parallel:
 - $K_{3\pi}$ collected using “Multi-track” trigger:
 - **L0**: RICH, CHOD; downscaling factor $D_{L0\ MT} \sim 100$
 - **L1**: KTAG, Straw; no downscaling
 - $K_{\pi\mu\mu}$ collected using “Di-muon multi-track” \simeq (“Multi-track” + 2 muons in MUV3) trigger:
 - **L0**: RICH, CHOD, MUV3; downscaling factor $D_{L0\ 2\mu\ MT} \sim 2$
 - **L1**: Straw; no downscaling
 - Total trigger efficiencies of both trigger streams are $\sim 90\%$

$K_{3\pi}$ Normalization Sample

2017+2018 Data Sample:

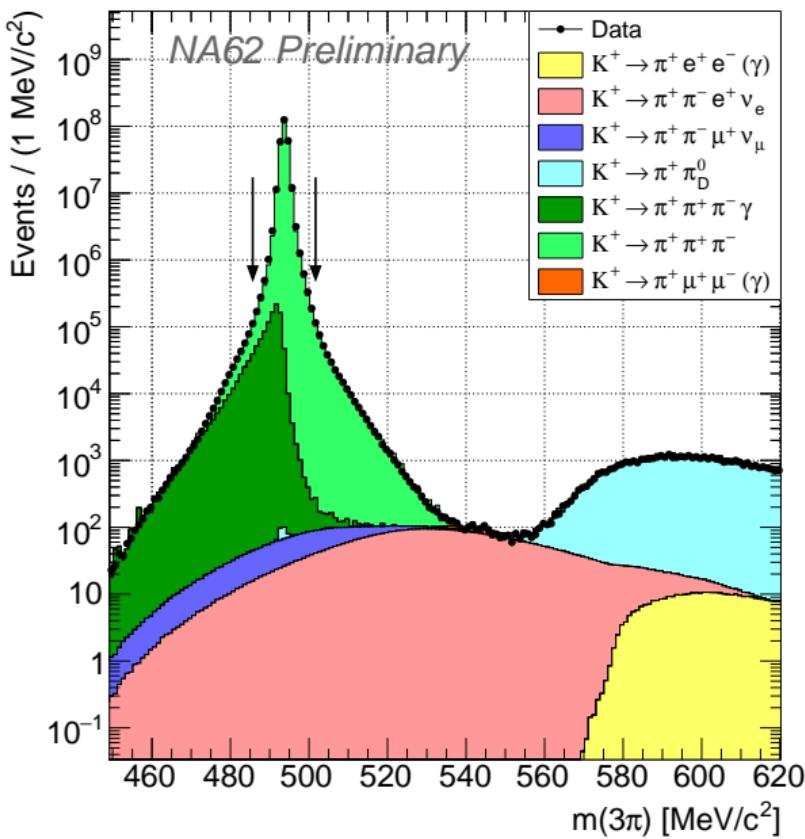
- $N_K \simeq 6.76 \times 10^{12}$
kaon decays in the decay region
(corrected for downscaling)

Generic 3-track event selection:

- Three track vertex topology
→ Straw tracker
- Timing cuts
→ CHOD, NA48-CHOD, KTAG, RICH
- Suppression of e^\pm background
→ Straw tracker and LKr ($E/p < 0.9c$)

$K_{3\pi}$ normalization sample:

- $|m(3\pi) - M_K| < 8 \text{ MeV}/c^2$
- **Data:** $N(3\pi) \simeq 2.78 \times 10^8$,
 $\sim 0.3\% K^+ \rightarrow \pi^+\pi^+\pi^- \gamma$ contamination
- **MC:** Acceptance $A(3\pi) \simeq 7.11\%$



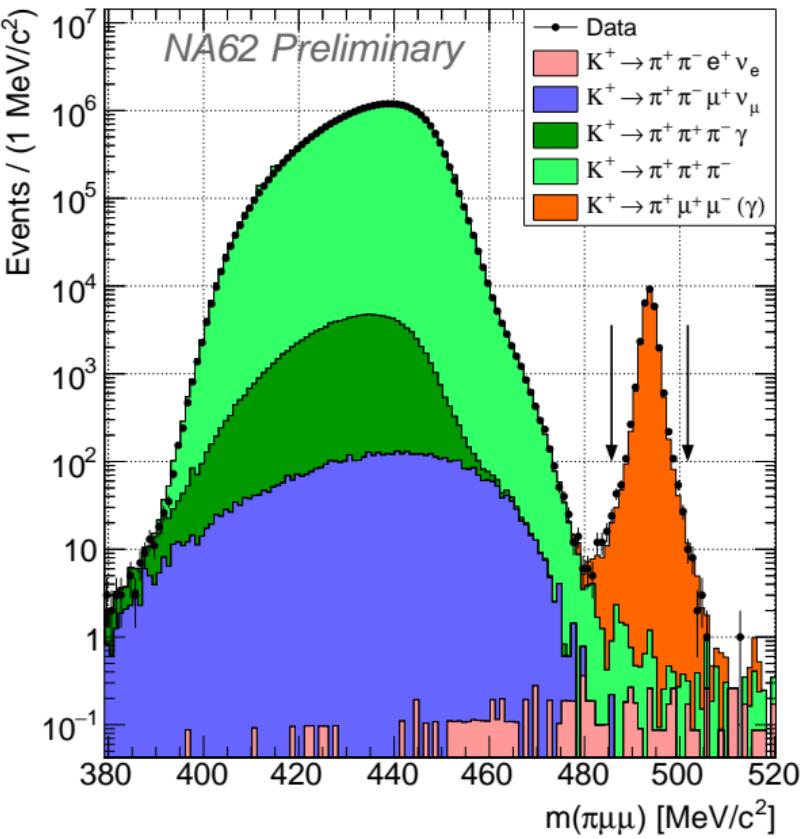
$K_{\pi\mu\mu}$ Signal Sample

Specific $K_{\pi\mu\mu}$ event selection:

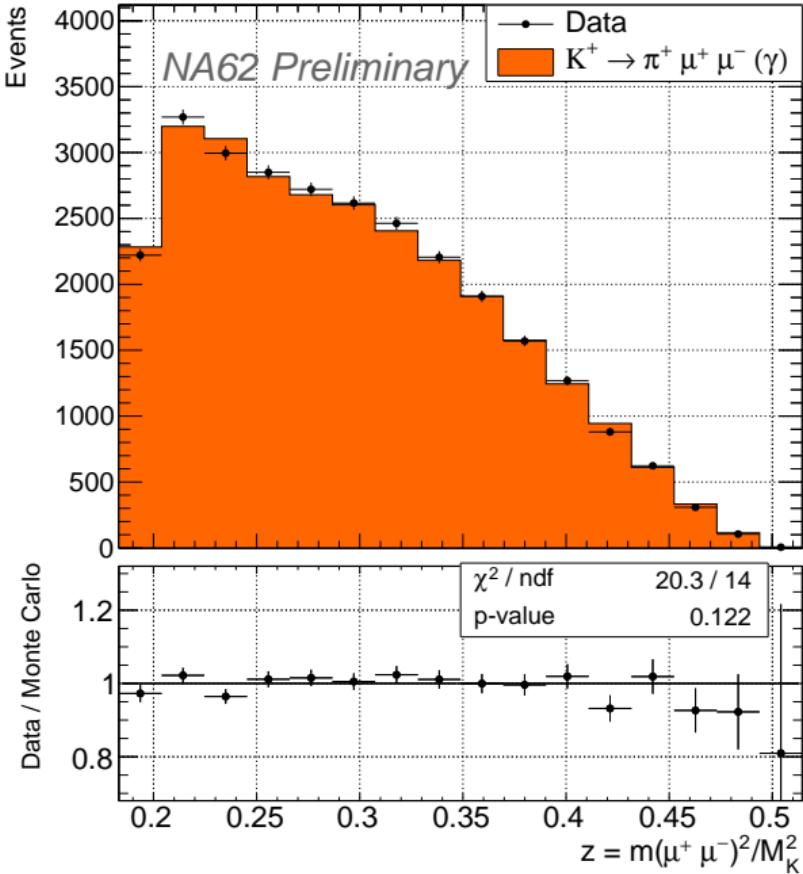
- Generic 3-track selection cuts applied
- MUV3 and LKr-based PID:
 - μ^\pm : in-time MUV3 response, $E/p < 0.2c$
 - π^+ : no in-time MUV3 response, $E/p < 0.9c$
- Additional kinematic cuts applied to suppress $K_{3\pi}$ background

$K_{\pi\mu\mu}$ signal sample:

- $|m(\pi\mu\mu) - M_K| < 8 \text{ MeV}/c^2$
- **Data:** $N(\pi\mu\mu) = 28011$
 - $\sim 9 \times$ more than NA48/2
 - [Phys. Lett. B 697 (2011) 107-115]
 - Expected background
 - $N(\text{bckg.}) = 12.5 \pm 1.7_{\text{stat}} \pm 12.5_{\text{syst}}$
- **MC:** Acceptance $A(\pi\mu\mu) \simeq 9.40\%$



Fit of the Form Factor Parameters



Fitting procedure:

- z spectrum of $K_{\pi\mu\mu}$ MC reweighted to best fit the data (minimizing $\chi^2(a, b)$)

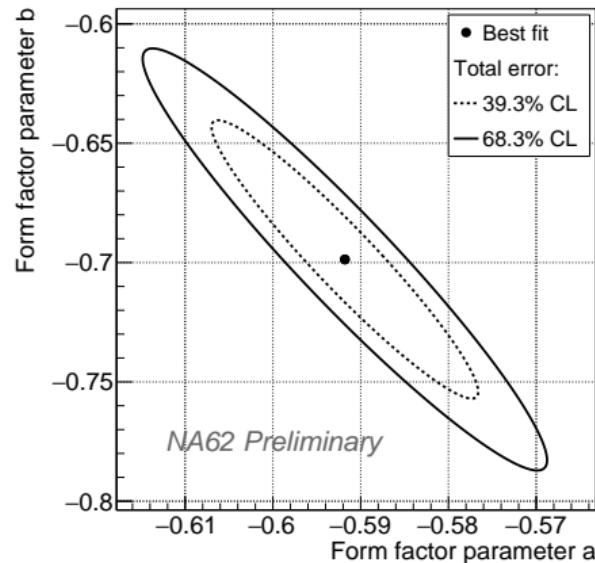
Best fit of FF parameters:

- $a = -0.592 \pm 0.013_{\text{stat}}$
- $b = -0.699 \pm 0.046_{\text{stat}}$
- Goodness of fit:
 $\chi^2/\text{ndf} = 20.3/14$, $p\text{-value} = 0.122$
- Correlation coefficient:
 $\rho_{\text{stat}}(a, b) = -0.973$
- Model-dependent $\mathcal{B}(K_{\pi\mu\mu})$:
 $\mathcal{B}(K_{\pi\mu\mu}) \times 10^8 = 9.27 \pm 0.07_{\text{stat}}$

-
- Second local minimum of $\chi^2(a, b)$:
 $a = 0.368 \pm 0.013_{\text{stat}}$
 $b = 2.045 \pm 0.046_{\text{stat}}$
 - Goodness of fit:
 $\chi^2/\text{ndf} = 30.7/14$, $p\text{-value} = 0.006$

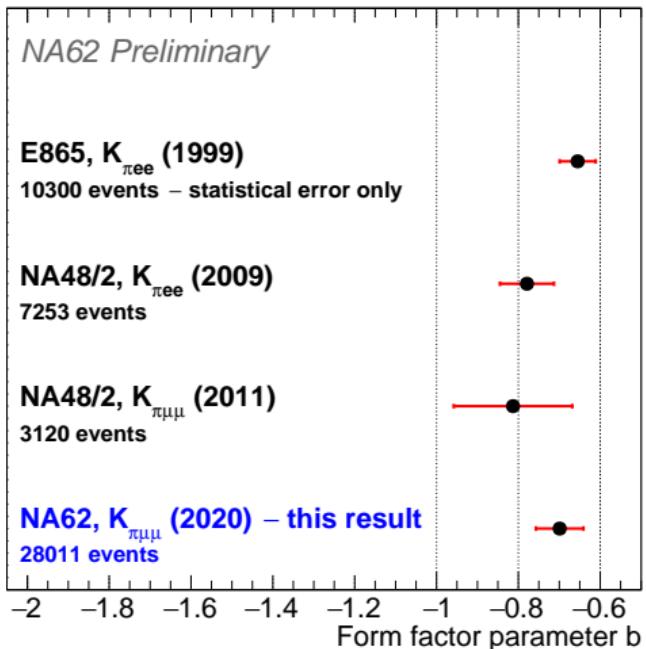
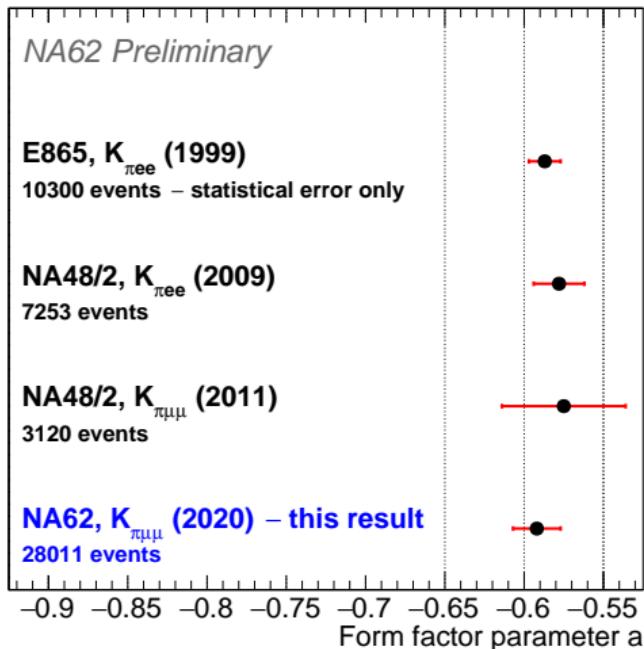
Error Budget

	a	b	$\mathcal{B}_{\pi\mu\mu} \times 10^8$
Best fit	-0.592	-0.699	9.27
Errors	δa	δb	$\delta \mathcal{B}_{\pi\mu\mu} \times 10^8$
Statistical	0.013	0.046	0.07
Systematic			
Reconstruction efficiency	0.005	0.026	0.06
Beam & pileup simulation	0.005	0.024	0.05
Trigger efficiency	0.001	0.005	0.04
Background	0.000	0.001	0.01
Total systematic	0.007	0.035	0.08
External			
PDG error on $\mathcal{B}(K_{3\pi})$	0.001	0.003	0.04
Total	0.015	0.058	0.11



Comparison with the World

- Preliminary $K_{\pi\mu\mu}$ result consistent with $K_{\pi ee}$ FF parameters → no tension in LFU observed



- E865, $K_{\pi ee}$: [Phys. Rev. Lett. 83 (1999) 4482-4485]
- NA48/2, $K_{\pi ee}$: [Phys. Lett. B 677 (2009) 246-254]
- NA48/2, $K_{\pi\mu\mu}$: [Phys. Lett. B 697 (2011) 107-115]

Summary

- NA62 experiment collected physics data between 2016 and 2018
- Presented analysis was performed on 2017 + 2018 dataset:
 - Number of kaon decays in the decay region $N_K \simeq 6.8 \times 10^{12}$
 - Observed very clean sample of 28011 $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ event candidates; $\sim 9\times$ more than NA48/2
 - Measured $K_{\pi\mu\mu}$ form factor parameters a and b , and model-dependent $\mathcal{B}(K_{\pi\mu\mu})$
- Preliminary result: $\chi^2/\text{ndf} = 20.3/14$, $p\text{-value} = 0.122$, $\rho_{\text{stat}}(a, b) = -0.973$

$a =$	-0.592	\pm	0.013 _{stat}	\pm	0.007 _{syst}	\pm	0.001 _{ext}	=	-0.592	\pm	0.015
$b =$	-0.699	\pm	0.046 _{stat}	\pm	0.035 _{syst}	\pm	0.003 _{ext}	=	-0.699	\pm	0.058
$\mathcal{B}_{\pi\mu\mu} \times 10^8 =$	9.27	\pm	0.07 _{stat}	\pm	0.08 _{syst}	\pm	0.04 _{ext}	=	9.27	\pm	0.11