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New measurement of the $K^+ \to \pi^+\mu^+\mu^-$ decay at NA62

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on behalf of the NA62 Collaboration

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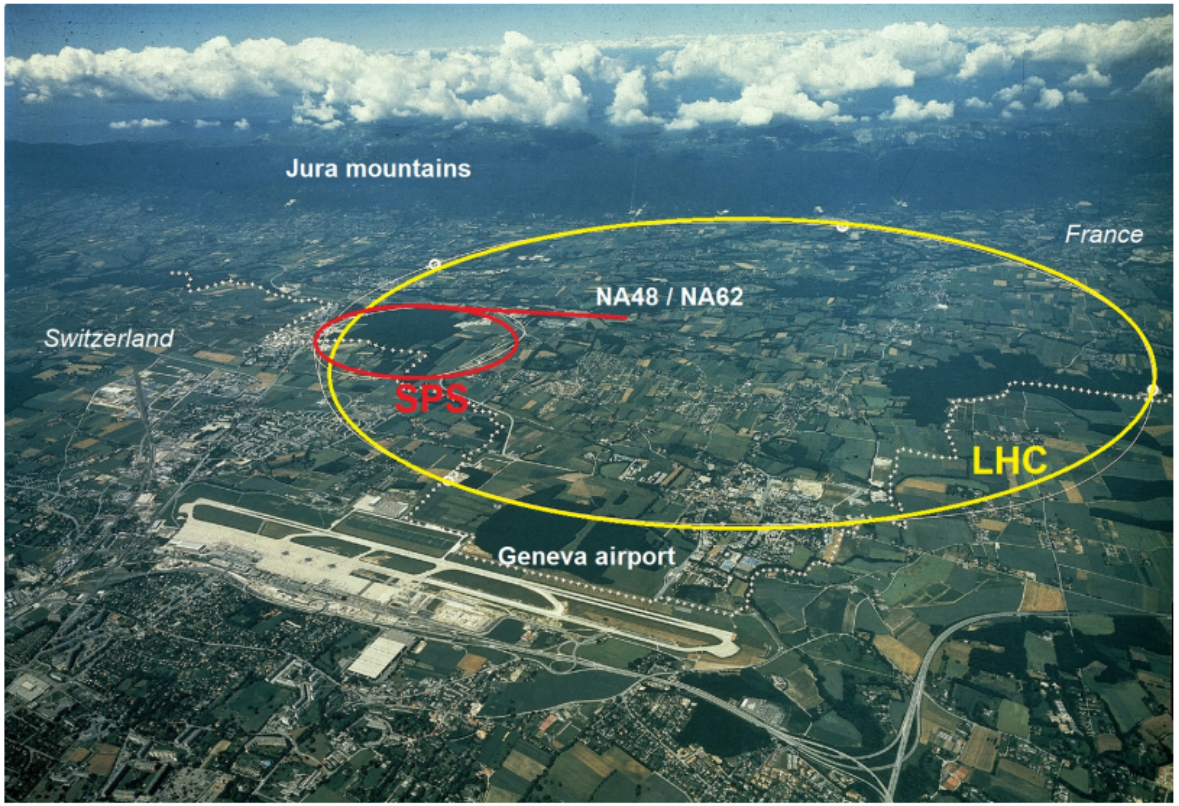
NA62 site

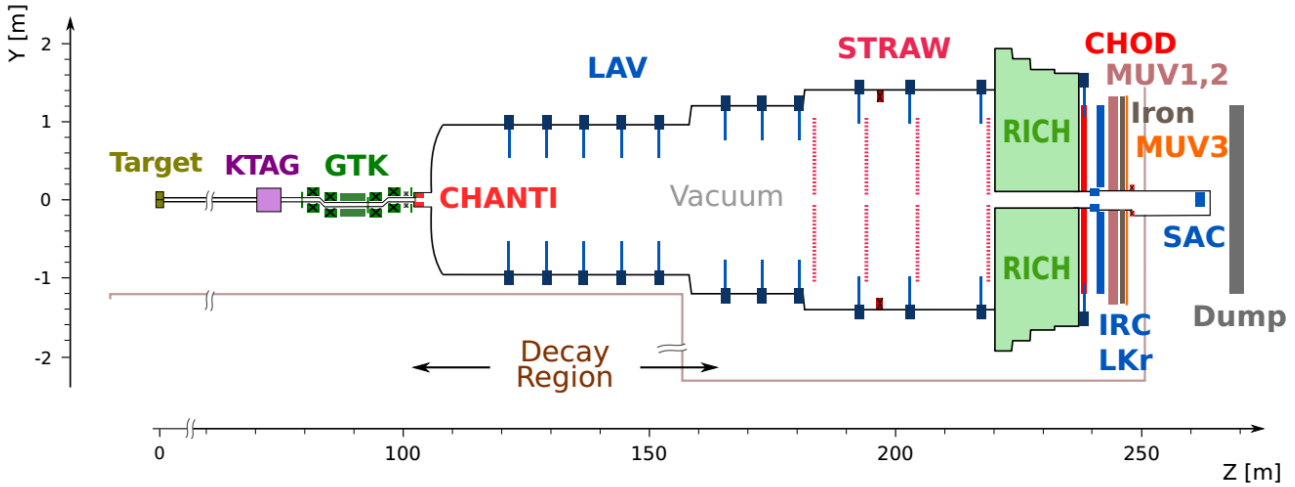


NA62: ~ 200 participants, 31 institutes

Genesis

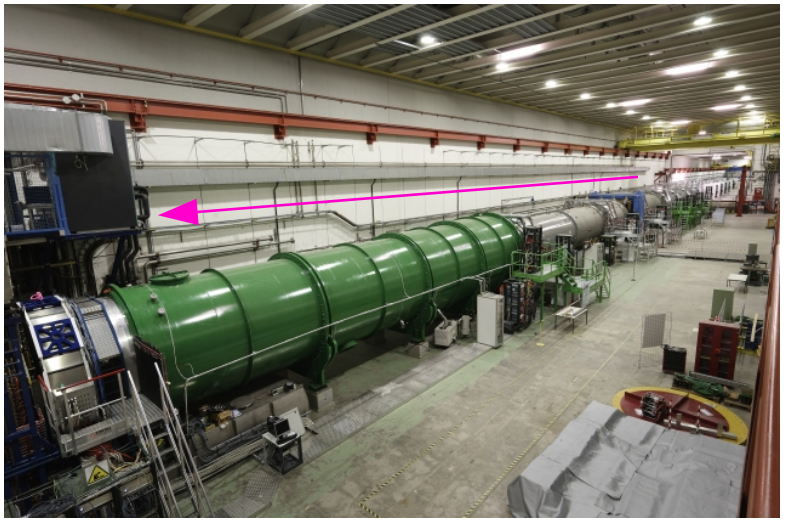
- **NA31**: 1980s, *beam:* K_L/K_S
  - *First evidence of direct CPV*
- **NA48**: 1997–2001, *beam:* K_L/K_S
  - *Discovery of direct CPV*
- **NA48/1**: 2002, *beam:* K_S/hyperons
  - *Rare decay studies*
- **NA48/2**: 2003–2004, *beam:* K^+/K^-
  - *Precision measurements*
- **NA62-R_K**: 2007–2008, *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: $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$
  - Searches for LNV or LFV decays, HNL, axions, dark γ,...
  - Precision measurements (e.g. $K^+ \to \pi^+\mu^+\mu^-$ – **this talk**)

NA62 beam & detector



[JINST 12 (2017) P05025]

Beam momentum 75 GeV/c ±1%
Nominal rate 750 MHz
Positively charged beam, ~ 6% K^+

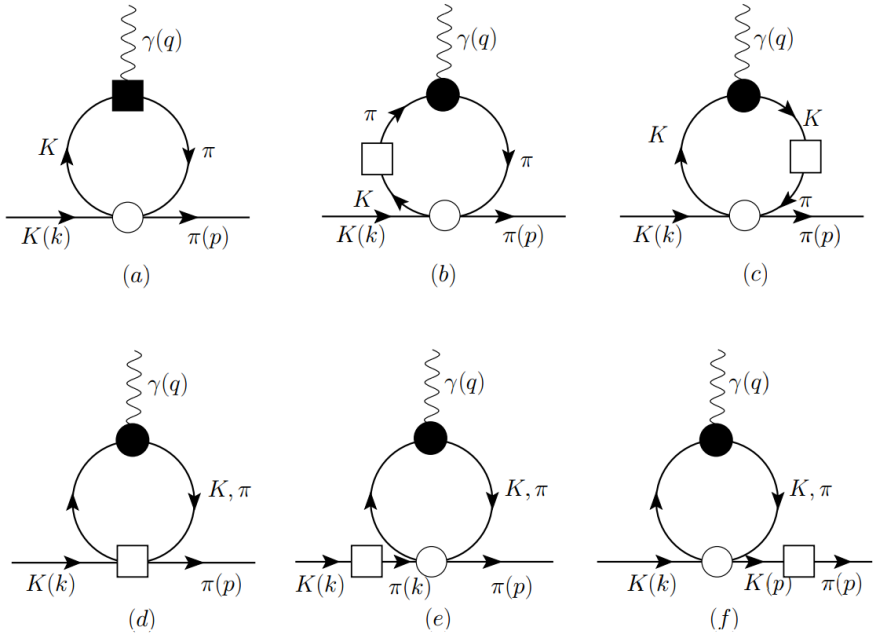


- Beam tracker: GTK
- Kaon tagger: KTAG (σ_t ~ 70 ps)
- Decay π,μ,e tracker: STRAW Spectrometer

  $\frac{\sigma(p)}{p} = 0.3\% \oplus (0.005\% \times p)$, where *p* in GeV/c.
- Decay π,μ,e Cherenkov rings id : RICH
- Photon veto detectors: LAV,IRC,SAC
- Trigger and timing:
  CHOD (σ_t ~ 1ns); NA48-CHOD (σ_t ~ 200 ps)
- Electromagnetic calorimeter: LKr

  $\frac{\sigma(E)}{E} = \frac{4.8\%}{\sqrt{E}} \oplus \frac{11\%}{E} \oplus 0.9\%$, *E* in GeV.
- Hadron calorimeters MUV1,2
- Muon detector MUV3 (σ_t ~ 500 ps)

Theory of the $K^+ \to \pi^+\mu^+\mu^-$ ($K_{\pi\mu\mu}$) decay



- FCNC decay via $K^+ \to \pi^+\gamma^*$, ChPT [Nucl.Phys. B291(1987)692-719]
- LFU test with $K_{\pi ee}$

Two Dalitz variables:

$$x = \frac{m^2(\pi^+\mu^+)}{M_K^2} \qquad z = \frac{m^2(\mu^+\mu^-)}{M_K^2}$$

Decay width:

$$\frac{d^2\Gamma}{dx\,dz} = \frac{\alpha^2 M_K}{8\pi(4\pi)^4}\left[(2x+z-2-2r_\mu^2)(-2x-z+2r_\pi^2+2r_\mu^2)+z(z-2-2r_\pi^2)\right]|W(z)|^2(1+\delta(x,z)),$$

where $r_i = \frac{m_i}{M_K}$, $\delta(x,z)$ is the radiative correction [EPJ C70(2010) 219-231] and

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

where

- *a,b* are the form factor parameters in NLO ChPT [JHEP 08(1998) 004];
- $W^{\pi\pi}(z)$ is the $K_{3\pi}$ pion loop term coming from $K^+ \to \pi^+\pi^+\pi^-$ with $\pi^+\pi^- \to \gamma^*$.

Analysis overview

- We measure form factor parameters **a, b** and the branching ratio **Br($K_{\pi\mu\mu}$)**.
- Natural choice of normalization channel is $K^+ \to \pi^+\pi^+\pi^-$ ($K_{3\pi}$),
  Br = 5.583(24)% (PDG), kinematically similar to the signal channel $K_{\pi\mu\mu}$.
- Two trigger streams used to collect the decay channels in parallel:
  - $K_{3\pi}$ collected with “Multi-track” trigger:
    - L0: RICH and CHOD , downscaling D_{MT} ~ 100;
    - L1: KTAG and STRAW.
  - $K_{\pi\mu\mu}$ collected with “Dimuon multi-track” trigger (“Multi-track + 2 muons in MUV3”):
    - L0: RICH and CHOD and MUV3 , downscaling $D_{2\mu MT}$ ~ 2;
    - L1: STRAW.
- Total trigger efficiency for the both trigger streams is about 90% .

Generic 3-track event selection

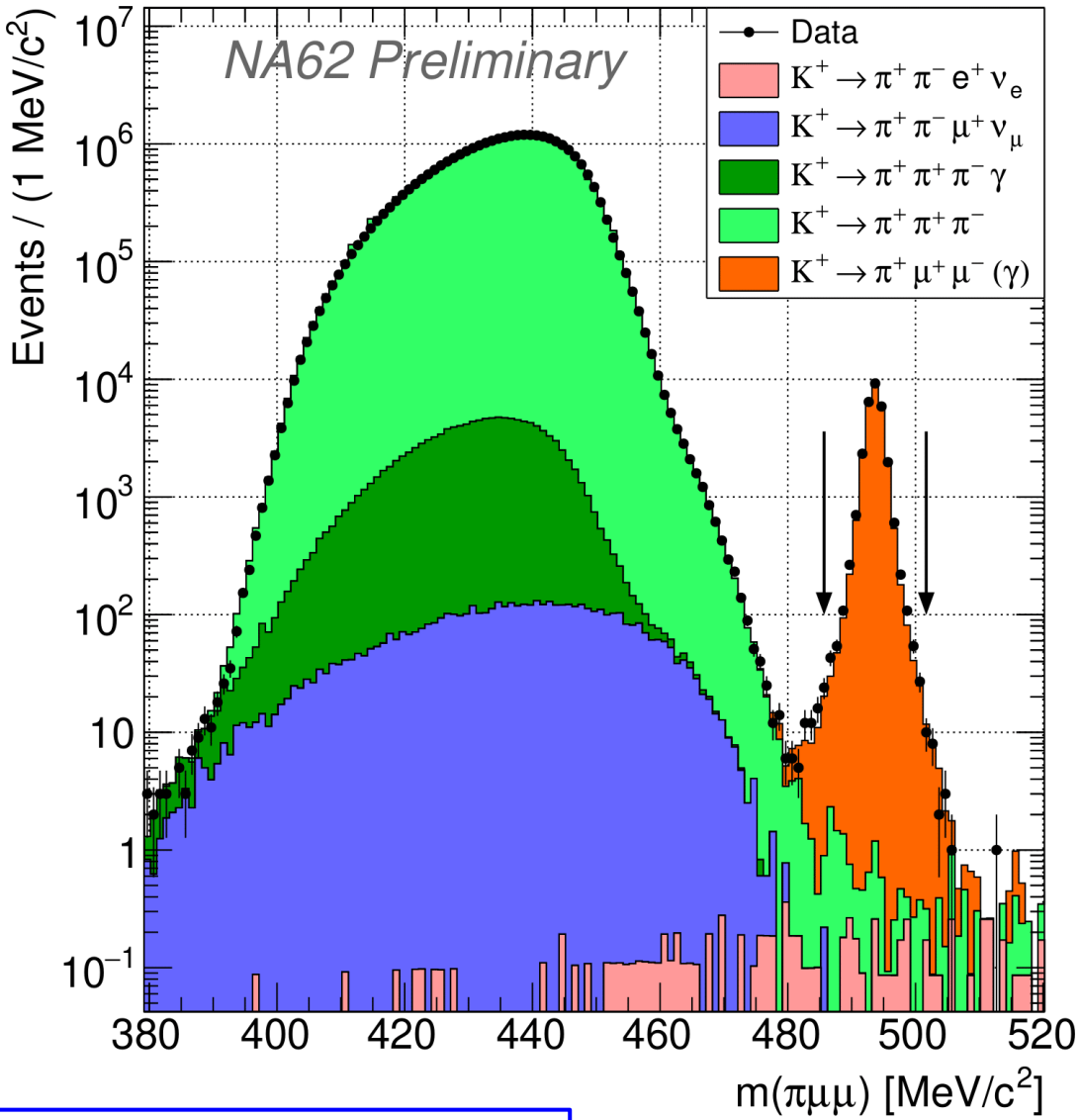
- 2017 + 2018 data sample
- $N_K \sim 6.76 \cdot 10^{12}$
- One 3-track positively charged vertex from Spectrometer in 5 cm around the nominal beam axis;
- $|p_{vtx} - p_{beam}| < 2.5$ GeV/c;
- $p_T < 30$ MeV;
- All 3 tracks in acceptance of STRAW 1-4, CHOD, NA48-CHOD, LKr, MUV3, !LAV12 ;
- Timing cuts using CHOD,NA48-CHOD,KTAG,RICH ;
- Track momentum p > 10 GeV/c ;
- Angle between the track and the nominal beam < 9 mrad ;
- Distance between the tracks at first Spectrometer chamber > 1.5 cm ;
- Distance between the tracks at LKr > 20 cm ;
- Background from $e^{\pm}$ is suppressed by the requirement

  $E/p = E_{LKr} / p_{Spectrometer} < 0.9$.

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

Signal specific selection

- Muon selection:
  - in-time MUV3 response;
  - E/p < 0.2
- Pion selection:
  - no in-time MUV3 response;
  - E/p < 0.9
  - |X| > 40 mm or |Y| > 25 mm @ last collimator
- $K_{3\pi}$ ($2\pi \to 2\mu$) background suppression:
  - p_μ < 45 GeV
  - $|p_{\mu 1} - p_{\mu 2}|$ < 35 GeV
- $|m(\pi\mu\mu) - M_K|$ < 8 MeV/c²



N(πμμ) = 28011 (~ 9 × NA48/2)

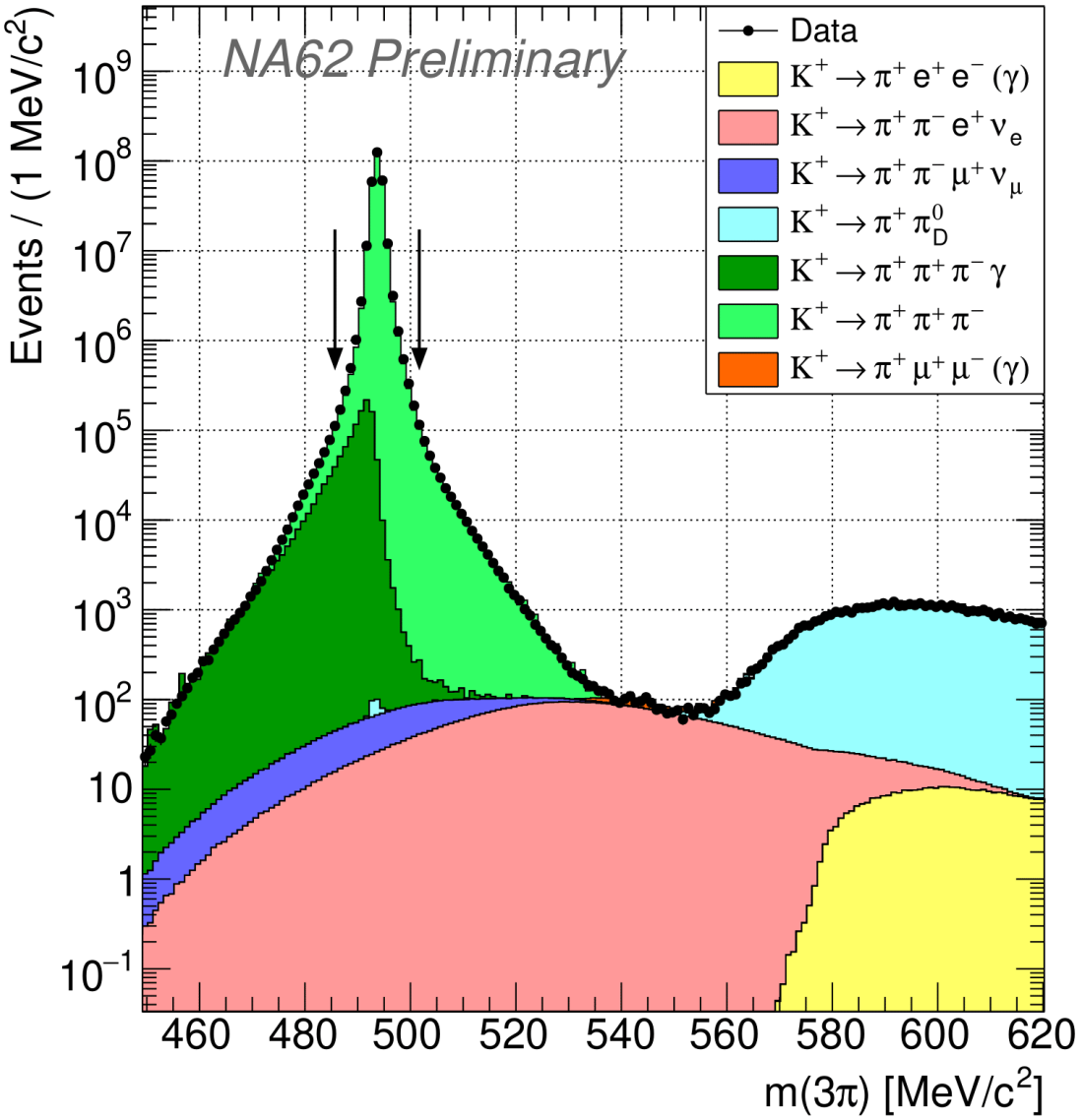
Expected background
$12.5 \pm 1.7_{stat} \pm 12.5_{syst}$ events

Acceptance from MC A(πμμ) ≅ 9.40%

$K_{3\pi}$ normalization sample

Normalization specific selection

- For symmetry with the signal selection, only one randomly chosen π^+ must pass the pion requirements:
  - no in-time MUV3 response;
  - E/p < 0.9
  - |X| > 40 mm or |Y| > 25 mm @ last collimator
- $|m(3\pi) - M_K| < 8$ MeV/c^2

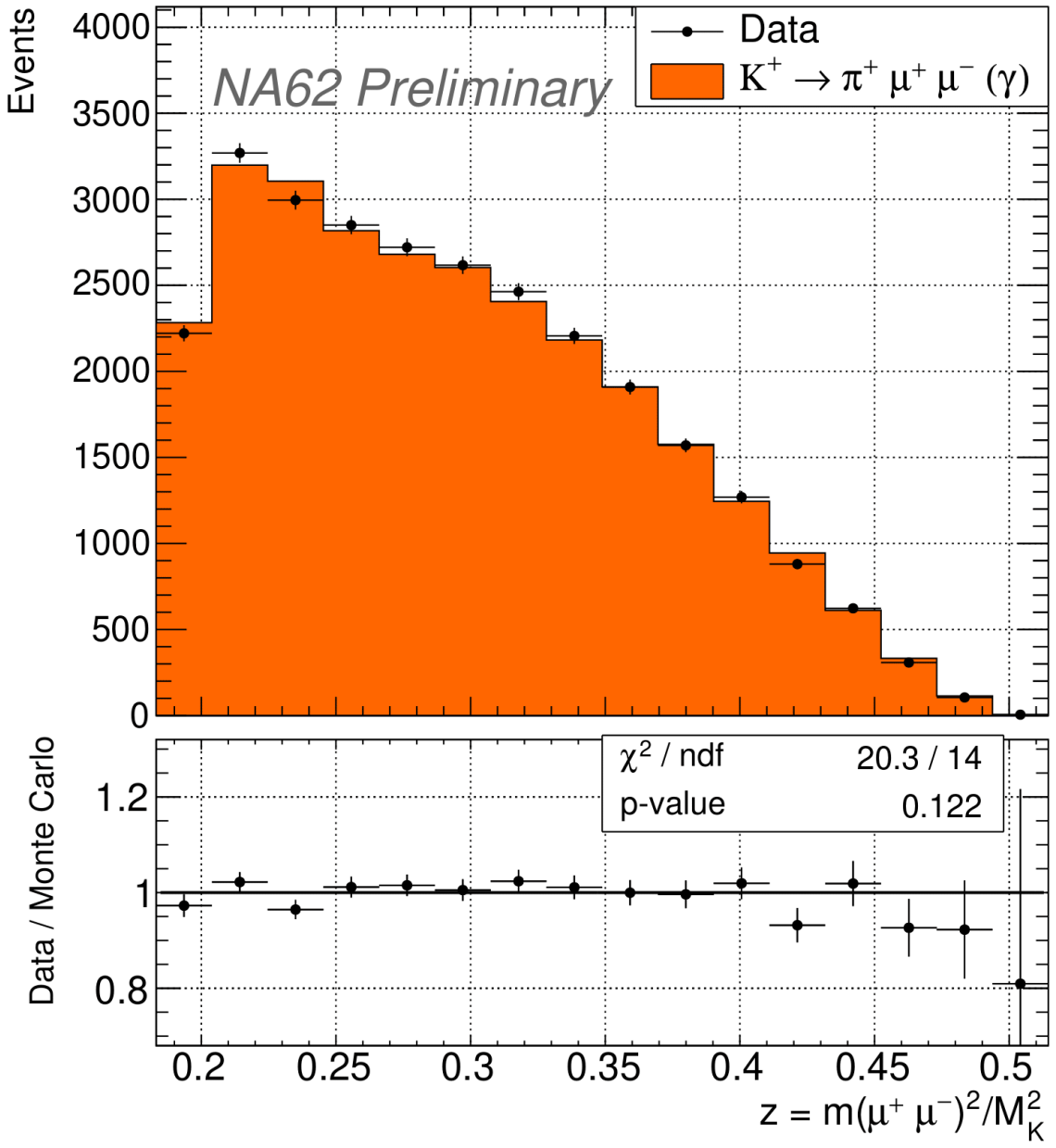


$K^+ \to \pi^+\pi^+\pi^-\gamma$ MC sample with E_γ > 1 MeV in the kaon rest frame has been simulated separately with a theoretically advanced generator to compose a complete γ-inclusive $K_{3\pi}$ model.

$N(3\pi) \cong 2.78 \cdot 10^8$

Acceptance from MC $A(3\pi) \cong 7.11\%$

Form Factor fit



- Procedure: z–dependent reweighting of each MC event minimizing χ^2 (a,b).
- Best fit form factor:

  $a = -0.592 \pm 0.013_{stat}$
  $b = -0.699 \pm 0.046_{stat}$

- **$\rho_{stat}(a,b) = -0.973$**
- **Fit quality:**
  χ^2 / ndf = 20.3/14; p-value = 0.122
- **Branching ratio:**

  $Br(K_{\pi\mu\mu}) = (9.27 \pm 0.07) \cdot 10^{-8}$

Second local minimum of χ^2 is well above the level of the main one-σ CL contour (20.3+1) :

χ^2 / ndf = 30.7/14; p-value = 0.006

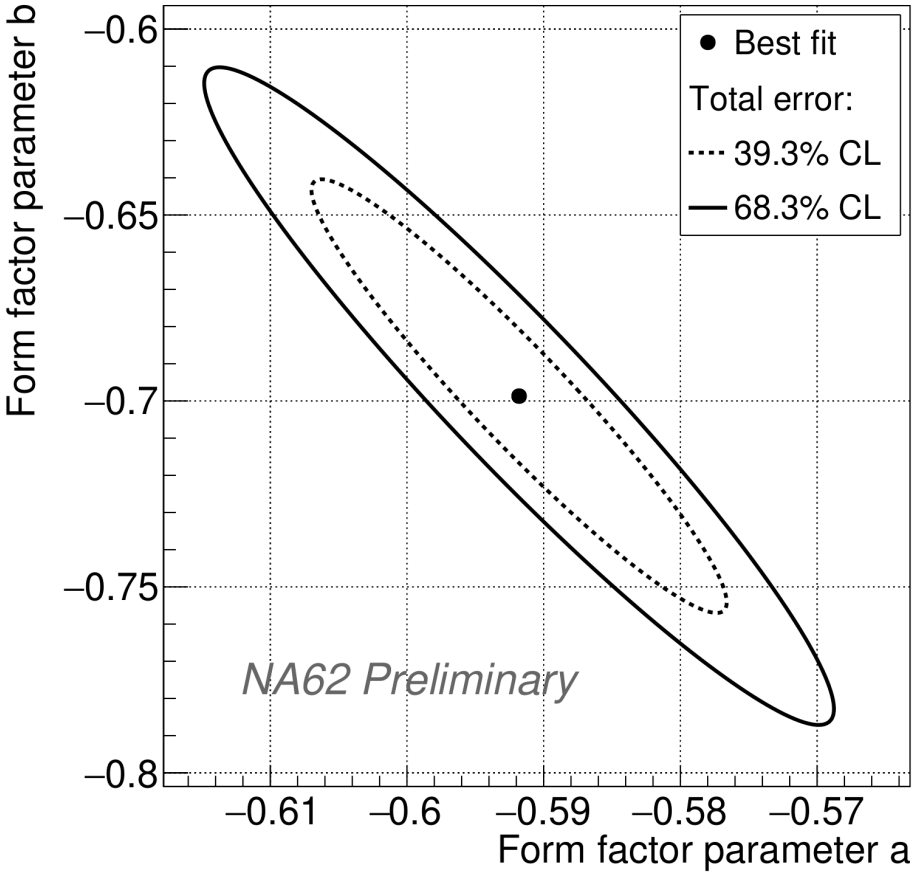
$a = 0.368 \pm 0.013_{stat}$
$b = 2.045 \pm 0.046_{stat}$

Uncertainties

Main contributions to the results uncertainty

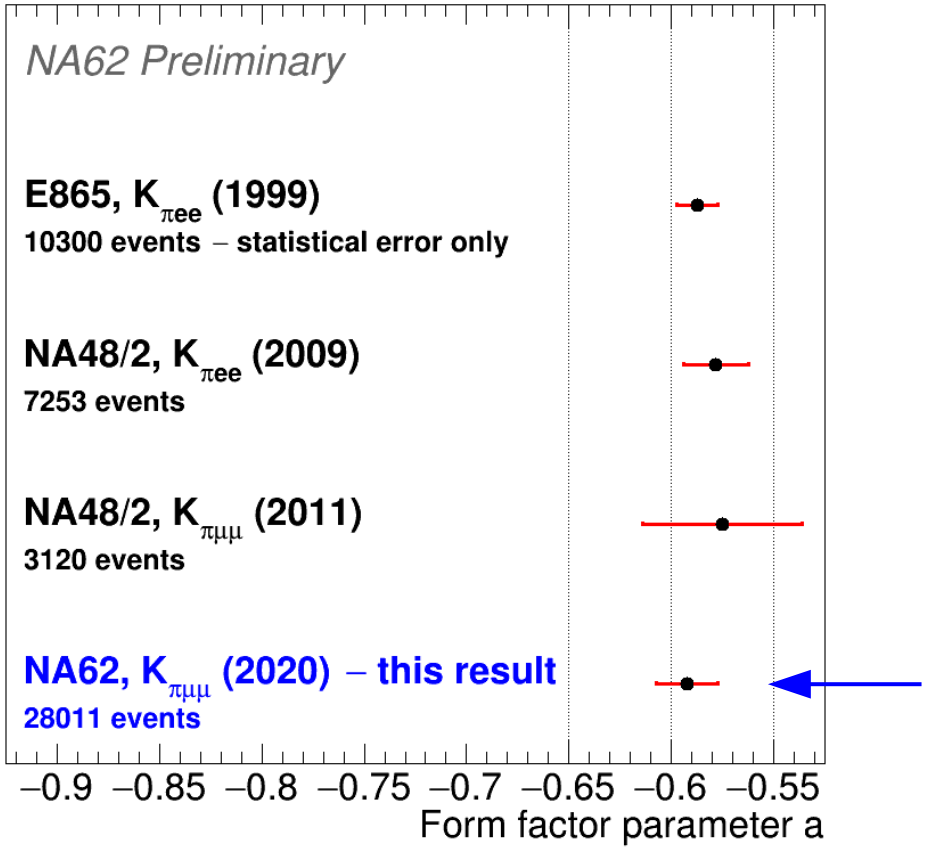
	a	b	$10^8 \cdot$ Br
Best fit point	*-0.592*	*-0.699*	*9.27*
Statistical	**0.013**	**0.046**	**0.07**
Reconstruction efficiency	0.005	0.026	0.06
Beam & pileup simulation	0.005	0.024	0.05
Trigger efficiency	0.001	0.005	0.04
Background	0.000	0.001	0.01
Systematic	**0.007**	**0.035**	**0.08**
External: Br ($K_{3\pi}$)	**0.001**	**0.003**	**0.04**
Total	**0.015**	**0.058**	**0.11**

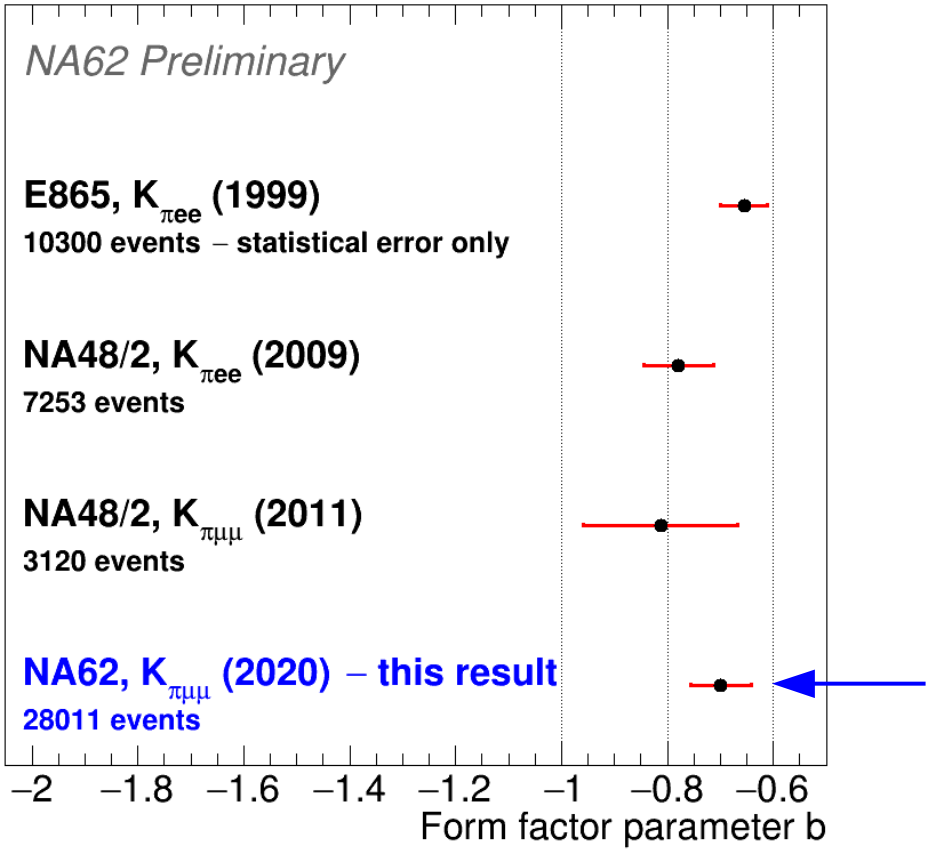
Confidence level ellipses



One σ corresponds to 39.3% CL in the case of two dimensions.

Preliminary result for $K_{\pi\mu\mu}$ form factor is consistent with $K_{\pi ee}$ experiments, so μ-e lepton flavor universality is not in danger.



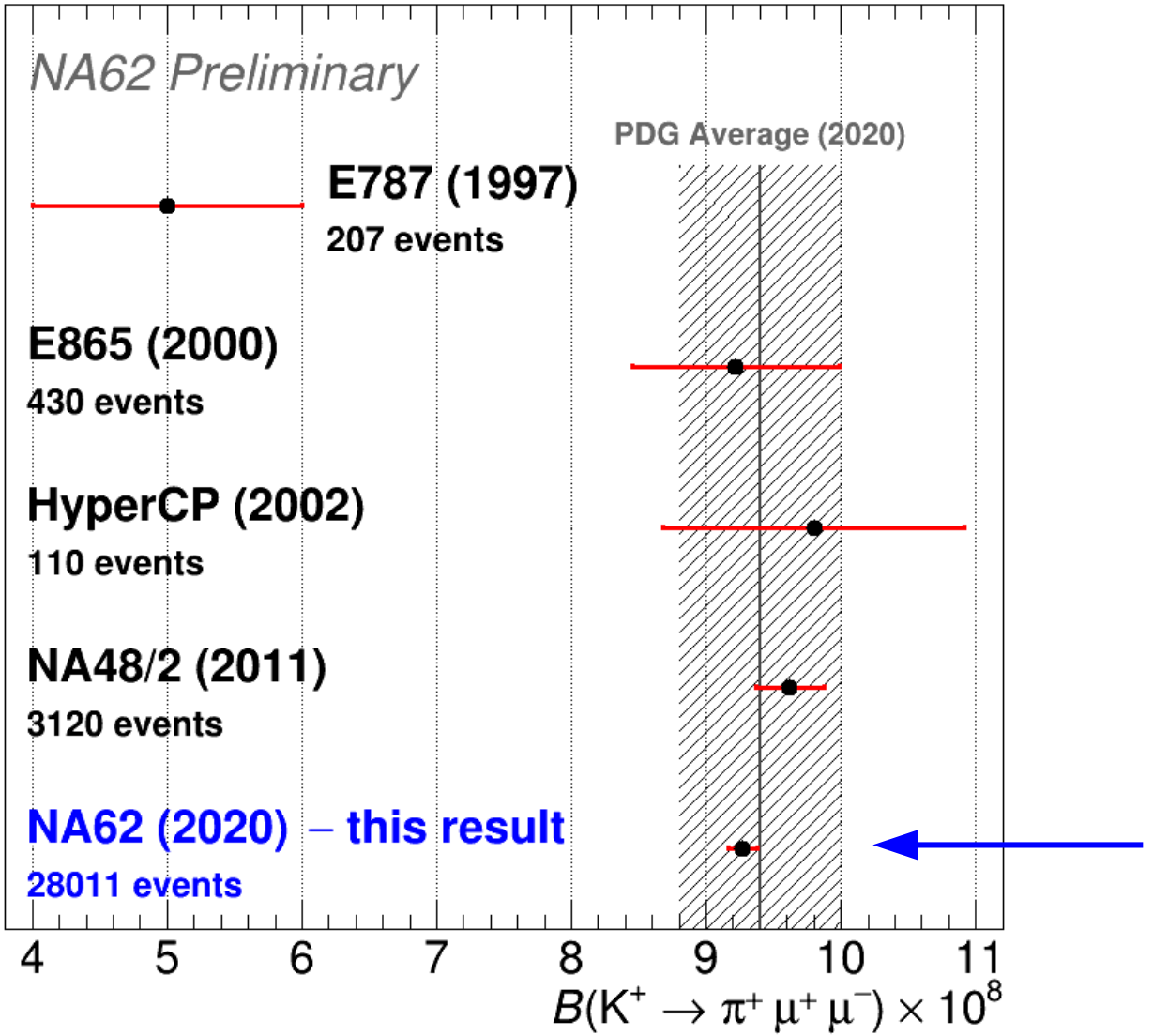


E865 ($K_{\pi ee}$) [Phys. Rev. Lett. 83 (1999) 4482-4485]

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]

Preliminary $K_{\pi\mu\mu}$ branching ratio



Summary

- NA62 data were collected in 2016-2018
- 2017-2018 data are used for $K_{\pi\mu\mu}$
- Very clean sample of 28011 candidates is selected (~ 9 × NA48/2).
- Preliminary:

$$a = -0.592 \pm 0.013_{stat} \pm 0.007_{syst} \pm 0.001_{ext} = -0.592 \pm 0.015$$

$$b = -0.699 \pm 0.046_{stat} \pm 0.035_{syst} \pm 0.003_{ext} = -0.699 \pm 0.058$$

$$\rho_{stat}(a,b) = -0.973$$

$$Br(K_{\pi\mu\mu}) = (9.27 \pm 0.07_{stat} \pm 0.08_{syst} \pm 0.04_{ext}) \cdot 10^{-8} = (9.27 \pm 0.11) \cdot 10^{-8}$$