Analysis of the rare $K^+ \to e^+\nu\mu^+\mu^-$ decay in the NA62 @ SPS-CERN

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Outline:

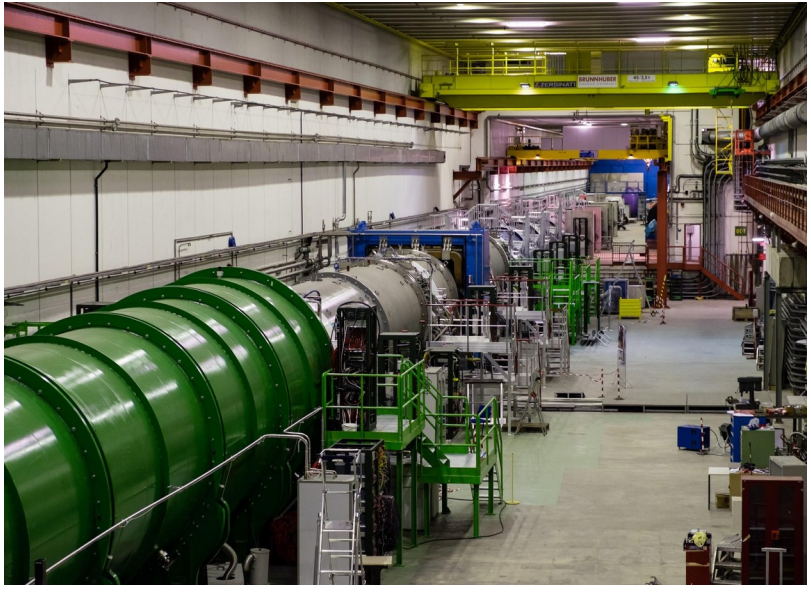
- The NA62 experiment
- Motivation & State of the art
- Analysis of the $K^+ \to e^+\nu\mu^+\mu^-$
- Summary

Kaon decays @CERN

Kaon decay in flight experiments.
NA62: ~300 participants, ~ 30 institutes

	Earlier: NA31	
NA48 discovery of direct CPV	1997: ε'/ε: K_L+K_S	
	1998: K_L+K_S	
	1999: K_L+K_S	K_S HI
	2000: K_L only	K_S HI
	2001: K_L+K_S	K_S HI
NA48/1	2002: K_S/hyperons	
	2003: K^+/K^-	
NA48/2	2004: K^+/K^-	
NA62 R_K phase	2007: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$	tests
	2008: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$	tests
NA62	2014: pilot run	
	2015: commissioning run	
	2016 –18 : $K^+ \to \pi^+ \nu\nu$ run	
	2021 – : $K^+ \to \pi^+ \nu\nu$ run	

The NA62 experiment at the CERN SPS



- **Data taking: 2016-2018, 2021-before LS3**
- **Fixed target experiment**
  (400 GeV/c proton from SPS onto a Beryllium target)
- **Unseparated secondary beam**
- **Kaon decay-in-flight technique**
  ~5 MHz K^+ decay rate within the fiducial volume

Main goal:

Measure $Br(K^+ \to \pi^+\nu\nu)$ **with O(10%) precision**

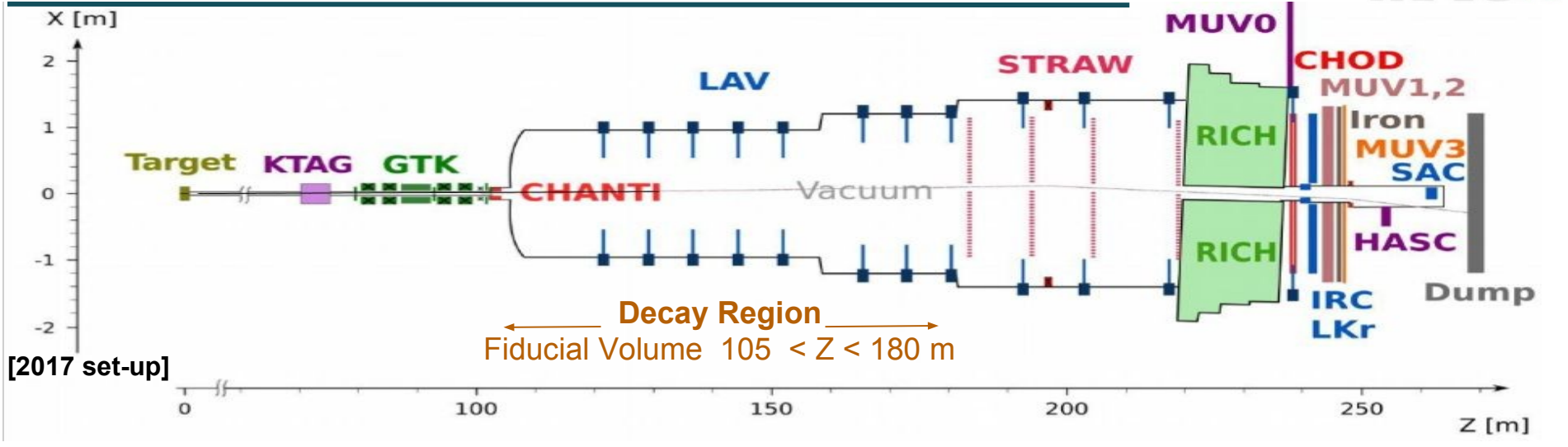
SM prediction :
$Br(K^+ \to \pi^+\nu\nu) = (8.4 \pm 1.0) * 10^{-11}$
[Buras et al. JHEP 1511(2015)33]

Previous experiment @BNL
$Br(K^+ \to \pi^+\nu\nu) = (17.3 \pm 11.5) * 10^{-11}$
[Phys. Rev. D77,052003 (2008), Phys. Rev. D79,092004 (2009)]

Broad physics program

- **Rare and forbidden decays:**
  K4l decays: **K→ eνμμ (this talk)**
  K→ μνμμ (Aigul Baeva)
  K→ eνee (Dmitry Emelyanov)
  K→ μνee (Sergei Shkarovsky)
- **Precision measurements of SM decays.**
- **Exotics searches:** dark photon, heavy neutral leptons, axion-like particles

The NA62 experiment



Tag K+: **KTAG** (Cherenkov detector), $\sigma_t \sim 70$ps

Reconstruct momentum and direction of 3 charged tracks: STRAW

- Total momentum consistent with the K+ beam momentum
- Reconstruct vertex in **FV**

PID:

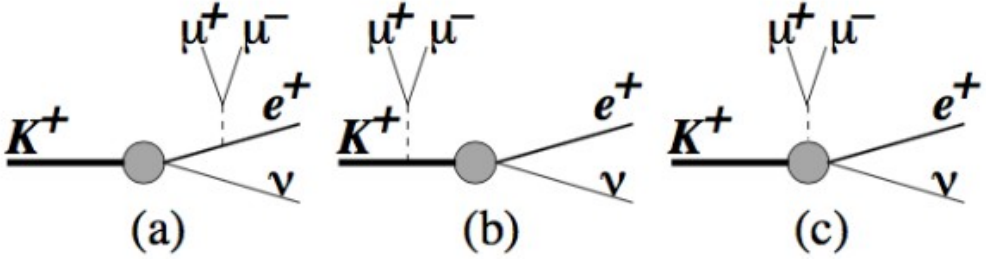
- **LKr:** E/P → E= energy deposited in calorimeter; P= reconstructed momentum
- **MUV3**: ID/veto muons
- **RICH:** ID positive charged particle: **$\pi/\mu/e$** separation

Photon vetos: hermetic (0-50) mrad: **12LAVs**, 2SAVs (**IRC+SAC**), **LKr**

Track Timing: CHOD $\sigma_t \sim 200$ps

[NA62 Collaboration 2017 JINST 12 P05025]

Motivation & State of the art



$K^+ \rightarrow e^+\nu\mu^+\mu^-$

Br(SM) = 1.12 x 10^{-8} ChPT prediction

[J. Bijnes, G. Ecker and J. Gasser, Nucl. Phys. B 396, (1993)]

Br(exp) = (1.72 ± 0.45) x 10^{-8}

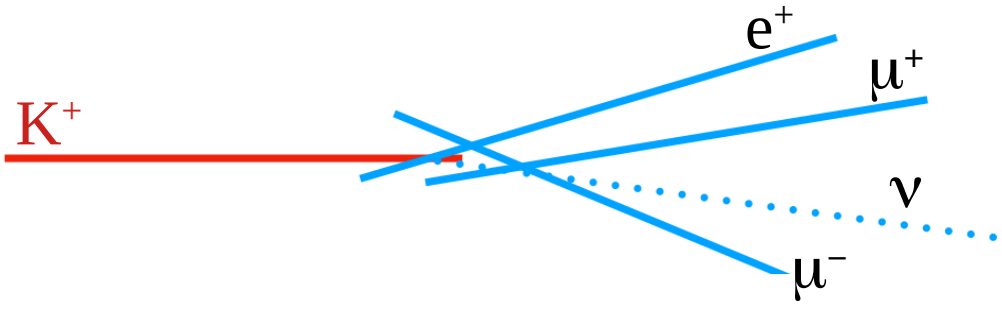
~26% uncertainty* E865 experiment @BNL

[H. Ma et al., Phys. Rev. D 73, (2006)]

*We need to have small uncertainties

- The internally converted, radiative *Kl2γ* decays, *K4l*, are an important source of information on the kaon.
- Within the framework of **Chiral Perturbation Theory (ChPT)** radiative kaon decays can serve both as an important test and a source of input parameters for the theory.
- **Inner Bremsstrahlung (IB)** helicity-suppressed for Ke2γ. IB dominates Kμ2γ (K→ μνμμ: 30% of IB; for K→ eνμμ: 0.03%).
- **If IB suppressed: more interesting for the form factor measurement.**

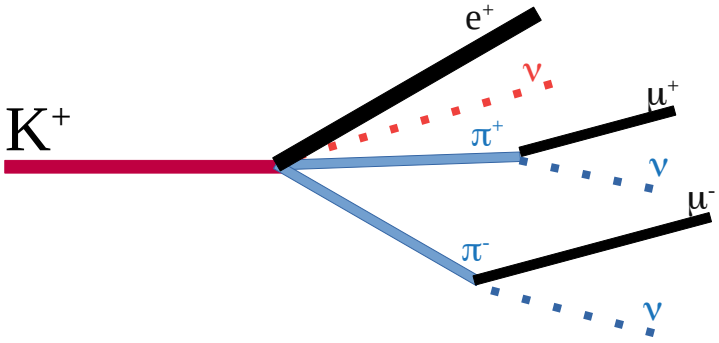
My selection:



- Each track in acceptance with Straw1-4, RICH, LKr, MUV3;
- $\chi^2_{STRAW} \leq 20$;
- $5\ GeV/c^2 \leq P_{STRAW} track \leq 65\ GeV/c^2$;
- $q_{3tr\_vtx} = +1$;
- $105\ m \leq Z_{vtx} \leq 180\ m$ (only FV region);
- $P_{3tr\_vtx} \leq 71.5\ GeV/c^2$ (to reduce $Br(K^+ \rightarrow \pi^+\pi^+\pi^-) = 5.583\%$);
- Neutrino momentum:
  $(P_K - P_e - P_\mu - P_\mu) > 5\ GeV/c^2$ - to reduce the background

Main background: Br($K^+ \to e^+\nu\pi^+\pi^-$) = 4.247*10^{-5} [PDG]

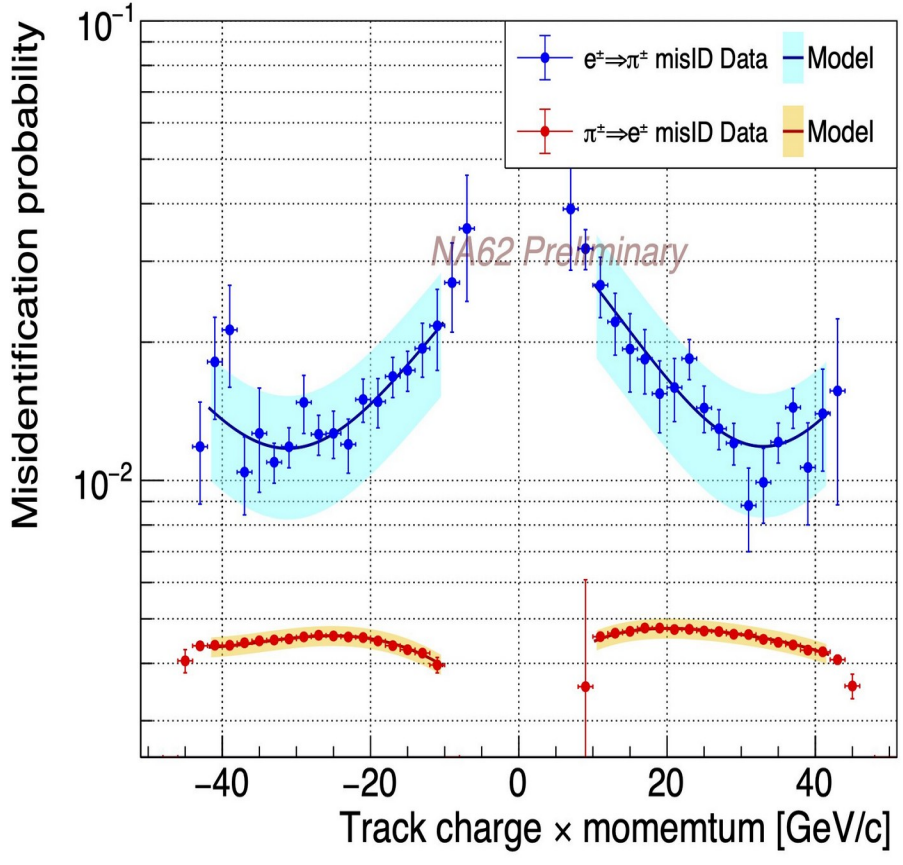
Ke4 events passing *K4l* selection



1. Mis-identification (mis-ID)

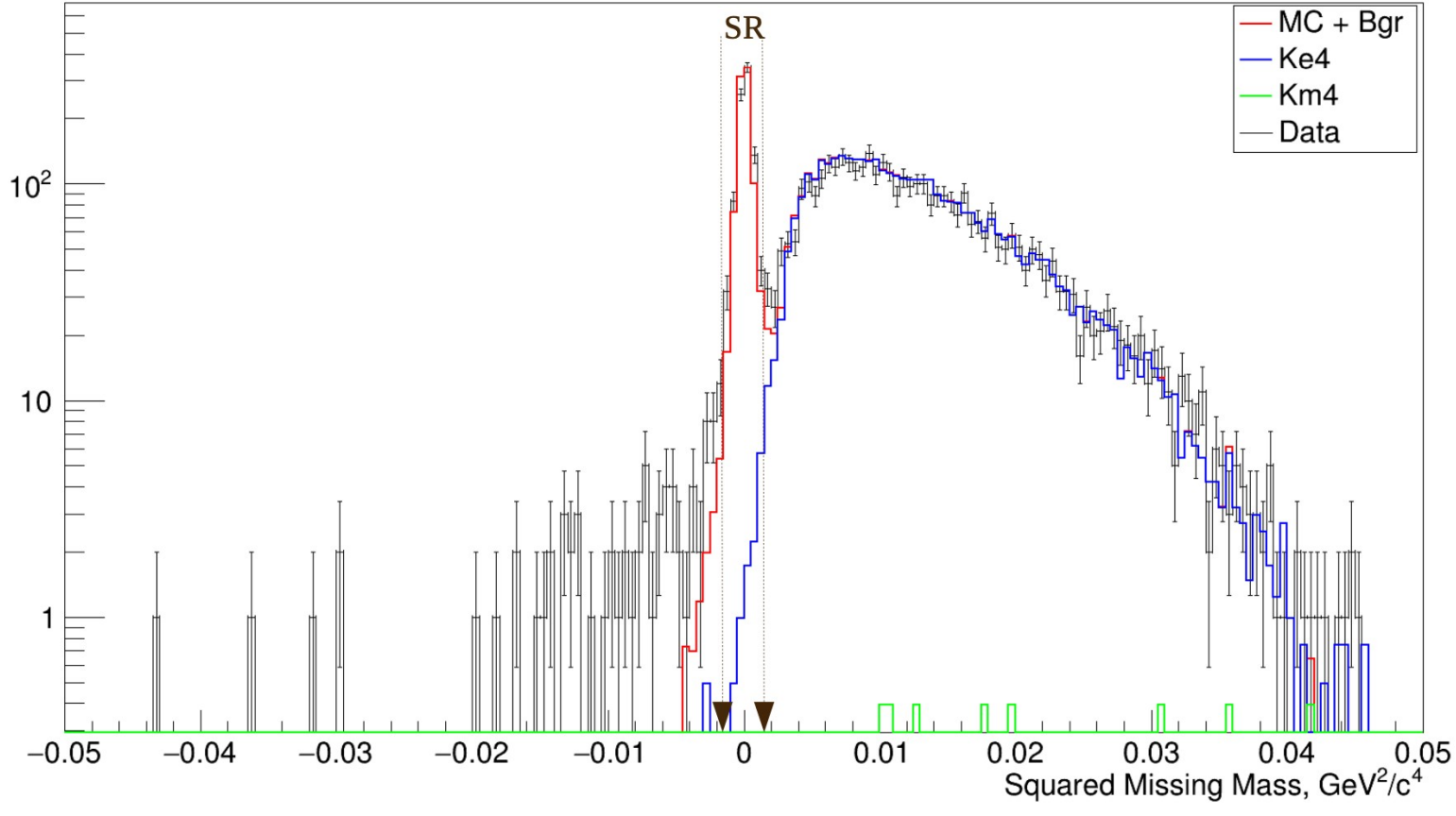
Measure the mis-ID probability from data
($\pi \to e$) from pure sample of $K^+ \to \pi^+\pi^+\pi^-$
($\pi \to \mu$) from pure sample of $K+ \to \pi^+\pi^0$, $\pi^0 \to e^+e^-\gamma$

2. Decay-in-flight
Br($\pi \to \mu\nu$) = 99.98%
Br($\pi \to e\nu$) = (1.230 ± 0.004) * 10^{-4}
Dalitz decay : $\pi^0 \to e^+e^-\gamma$



Final plot for interim results

In the signal region (SR): ~ 900 events with small background from Ke4

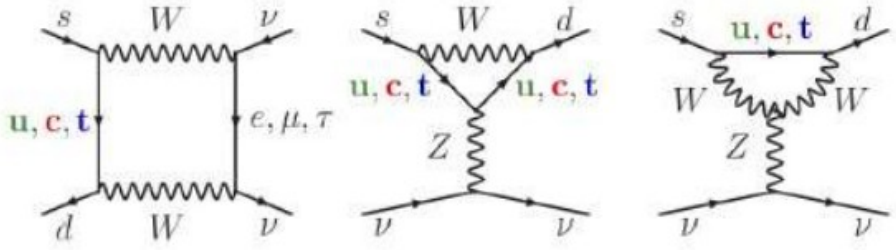


Summary

- NA62 experiment works very well (decay-in-flight technique);
- 2017-2018 DATA analyzed ~ 900 signal events in the SR;
- Good background events estimation;
- Continue work on systematic uncertainties (normalization mode);
- Continue data taking until 2025.


Thank you for your attention

Backup slides



FCNC loop processes:
s->d coupling
Highest CKM suppression

Very clean theoretically
No hadronic uncertainties
Hadronic matrix element related to the precisely measured BR ($K^+ \to \pi^0 e^+ \nu$)

SM predictions [Buras et al. JHEP 1511 (2015) 33]

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \cdot 10^{-11} \cdot \left(\frac{V_{cb}}{0.0407}\right)^{2.8} \cdot \left(\frac{\gamma}{73.2^0}\right)^{0.74} = (0.84 \pm 0.10) \cdot 10^{-10}$$

$$BR(K^0 \to \pi^0 \nu\bar{\nu}) = (3.36 \pm 0.05) \cdot 10^{-11} \cdot \left(\frac{V_{ub}}{0.00388}\right)^{2} \cdot \left(\frac{V_{cb}}{0.0407}\right)^{2} \cdot \left(\frac{\sin\gamma}{\sin 73.2^0}\right)^{0.74} = (0.34 \pm 0.06) \cdot 10^{-10}$$

$K \to \pi\nu\nu$ are the most sensitive probes to NP models among B and K decays

The combined measurement of K^+ and K_L modes could shed light on the flavour structure of NP ($\Delta S=2$ / $\Delta S=1$ correlation)