Study of the $K^+ \rightarrow \ell^+ \nu_\ell e^+ e^-$ decay with the NA62 Experiment

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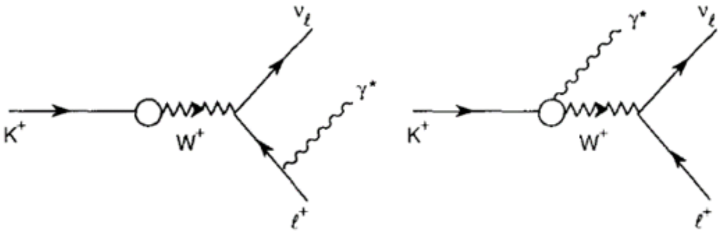
The $K_{\ell 2ee}$ decay in the ChPT

- In the ChPT program radiative kaon decays can serve both as an important test and as a source of input parameters for the theory



- The $K^+ \to \ell^+ \nu_\ell e^+ e^-$ processes are assumed to proceed via exchange of a W^+ boson ($\ell^+ \nu$) and photon ($e^+ e^-$)

Theoretical state of the art of the $K_{\mu 2ee}$

- The theoretical values of the Br for the $K_{\mu 2ee}$ process are well predicted in the ChPT framework

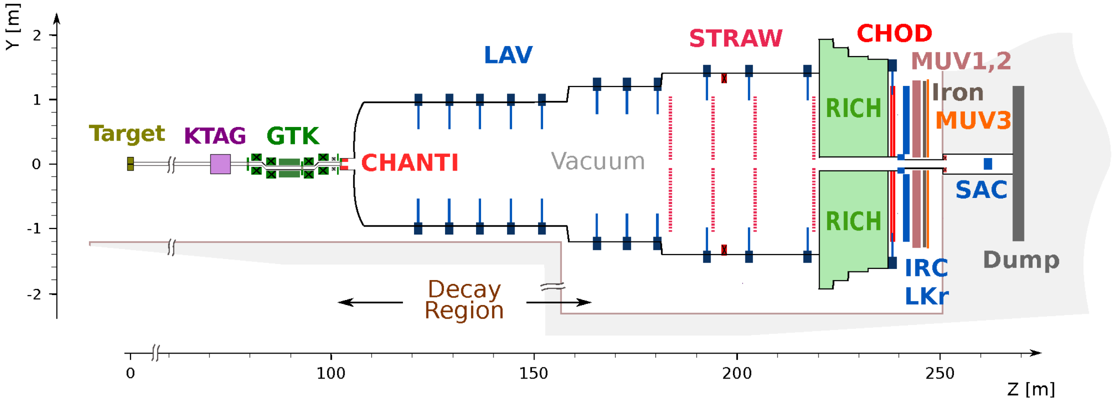
Cuts on $m_{e^+e^-}$	Tree level	Higher order correction by ChPT
Full phase space	2.49×10^{-5}	2.49×10^{-5}
$\sqrt{0.001} \cdot M_{K^+}$	4.12×10^{-6}	4.20×10^{-6}
$20\ MeV/c^2$	3.15×10^{-6}	3.23×10^{-6}
$140\ MeV/c^2$	4.98×10^{-6}	8.51×10^{-8}

Experimental state of the art of the $K_{\mu 2ee}$

- The earlier experimental measurements of the $K_{\mu 2ee}$ Br have been performed by the Experiment 865 at the Brookhaven National Laboratory in 2002
- 2679 $K^+ \to \mu^+ \nu_\nu e^+ e^-$ events collected including a 19% background contamination

$$Br(K_{\mu 2ee} | m_{e^+e^-} > 140\ MeV/c^2) = (793 \pm 18|_{stat} \pm 28|_{syst} \pm 0.5|_{model}) \cdot 10^{-10}$$
$$Br(K_{\mu 2ee} | m_{e^+e^-} > 145\ MeV/c^2) = (706 \pm 16|_{stat} \pm 26|_{syst} \pm 0.4|_{model}) \cdot 10^{-10}$$
$$Br(K_{\mu 2ee} | m_{e^+e^-} > 150\ MeV/c^2) = (635 \pm 15|_{stat} \pm 23|_{sist} \pm 0.3|_{model}) \cdot 10^{-10}$$

The NA62 setup



Experimental strategy

$$Br_{K_{\mu 2ee}} = \frac{N_{sign}}{N_{norm}} \frac{Acc_{norm}}{Acc_{sign}} \frac{\mathcal{E}_{norm}^{Trigger}}{\mathcal{E}_{sign}^{Trigger}} Br_{norm}$$

- Selection of a $K_{\mu 2ee}$ event
- Acceptance of the signal selection from Monte Carlo
- Trigger efficiency
- Background estimation

$K^+ \to \pi^+\pi^+\pi^-$ **normalization channel** $\longrightarrow$

$$Br_{K_{3\pi}} = (5.583 \pm 0.024)\%$$

✓ low external error

✓ high branching ratio

General selection criteria I

- only **one 3-track vertex** ($T_{vertex}(CHOD) - T_{trigger} < 6$ ns)
- tracks in **geometric acceptance** with the STRAW, RICH, NewCHOD, CHOD, LKr and MUV3
- timing between the **track** and the **trigger time**
- **minimum separation** between tracks: 15 mm in the STRAW and 200 mm in the LKr
- $\chi^2_{\text{vertex}} < 30$

General selection criteria II

- $105\ \text{m} < Z_{\text{vertex}} < 180\ \text{m}$
- $8\ \text{GeV}/c < p < 50\ \text{GeV}/c$
- $P_{3T} > 85\ \text{GeV}/c$
- **conservation of the charge** at the vertex
- good matching between the **downstream tracks** and **upstream reconstructed vertex**
- photons veto in the **LAV** stations and in the **LKr**

Signal selection criteria I

PID

RICH

$\mathbf{e}^+$positron as most likely hypotesis

$\boldsymbol{\mu}^+$muon as most likely hypotesis

LKr

E/p for $\mu^+ < 0.2$

E/p for $e^+ > 0.9$

E/p for $e^- > 0.9$

$E_{LKr} > 23$ GeV

MUV3

$\boldsymbol{\mu}^+$ in time association ($\pm$ 5 ns)

Signal selection criteria II

Kinematic cuts

P_t (MeV/c) > 30

$M^2_{miss}(K_{2\pi})$ (GeV^2/c^4) < 0.008 or > 0.026

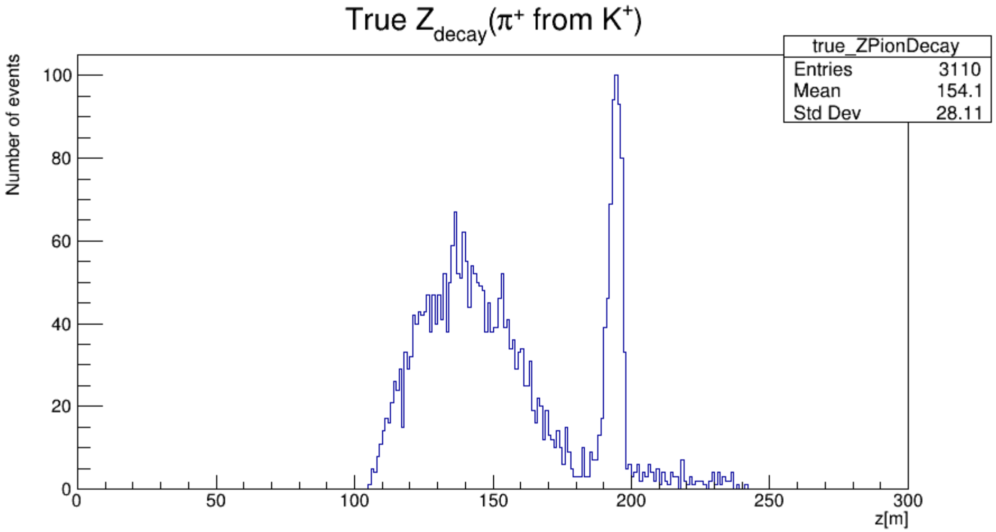
$M^2_{miss}(K_{e4})$(GeV^2/c^4) $<$ -0.003

$M_{\mu\nu}$ (MeV/c) > 150

$-\ 0.03 < M^2_{miss}(K_{\mu 2ee})$ (GeV^2/c^4) < 0.03

$m_{e^+e^-}$ (MeV/c) $> 140, 145, 150$

$\pi^+ \to \mu^+ \nu_\mu$ contamination



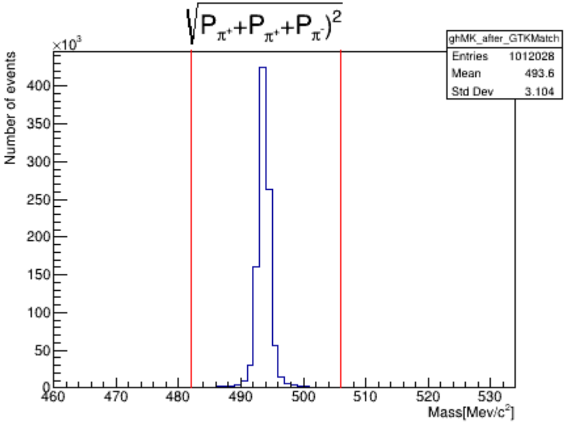
Normalization selection criteria

PID

e^- $E/p < 0.9$ (orthogonal sample w.r.t. signal)

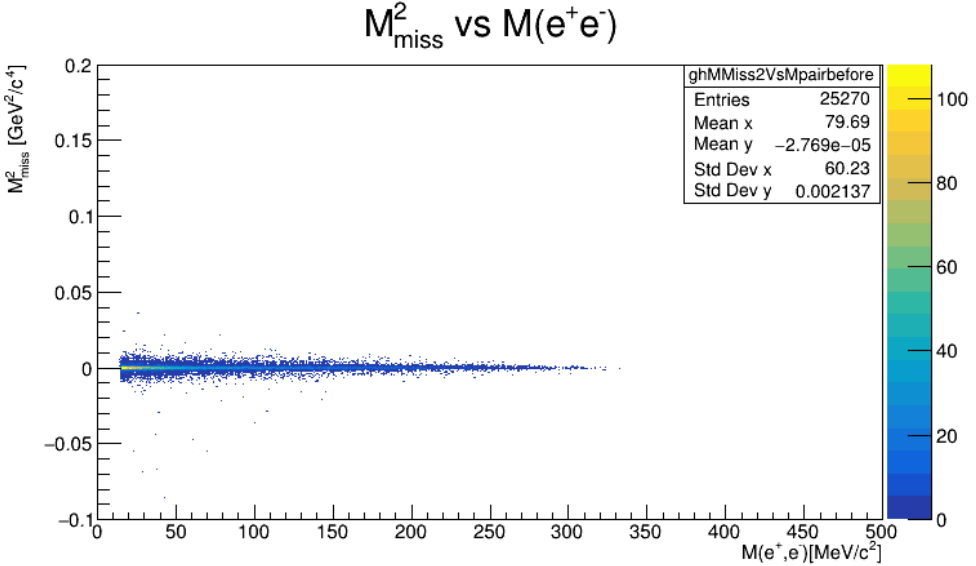
Kinematic cuts

$486\ \mathrm{MeV}/c^2 < M_K < 502\ \mathrm{MeV}/c^2$

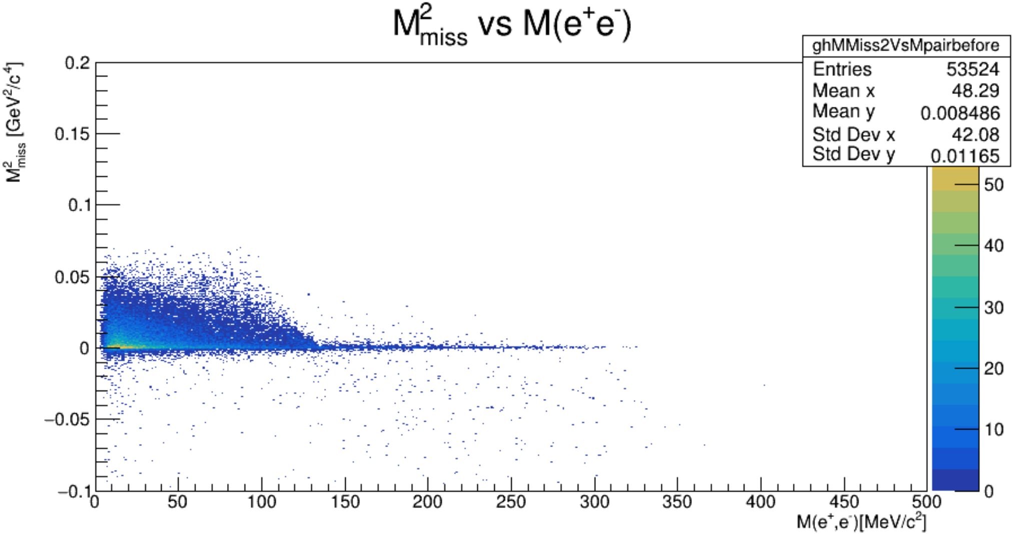


Normalization acceptance $\rightarrow (5.79 \pm 0.01)\%$

M^2_{miss} vs $m_{e^+e^-}$ from $K_{\mu 2ee}$ MC



M^2_{miss} vs $m_{e^+e^-}$ from 2017-2018 data

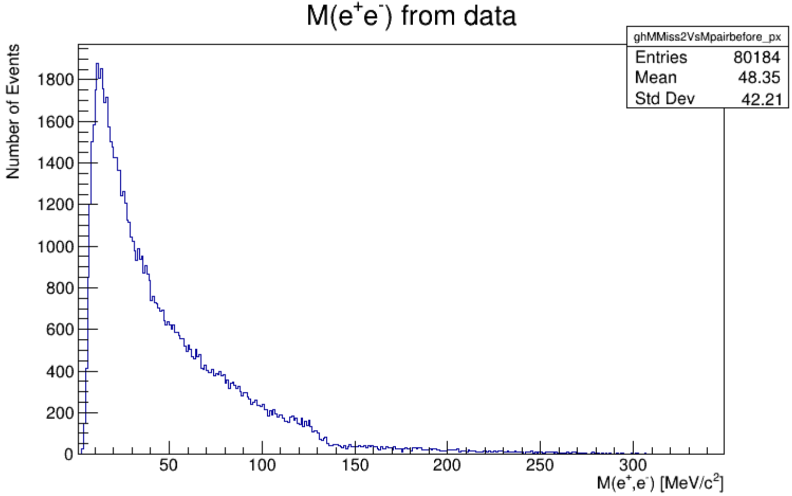


Conclusion and outlook

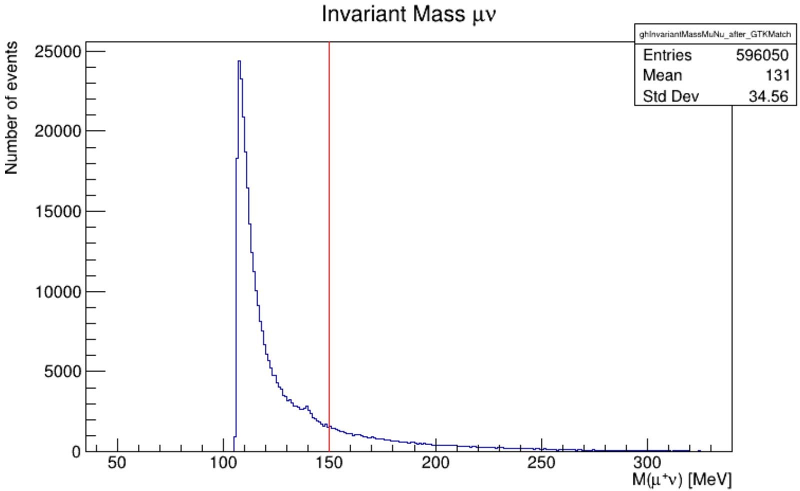
- The results presented in this talk show the possibility to investigate the $K_{\mu 2ee}$ decay in a competitive way w.r.t. the previous measurements
- Statistic uncertainty can be reduced including the 2021-ongoing data
- More investigations needed on the trigger efficiency, comparison between MC and Data and LKr20 systematic contribution
- Relaxation of $m_{e^+e^-}$ cut in order to explore a different portion of phase space w.r.t. the E865 measurements
- Common features between K_{e2ee} and $K_{\mu 2ee}$
- Form factors estimation

Backup slides

$m_{e^+e^-}$ from 2017-2018 data



$M_{\mu\nu}$ from $K_{\pi ee}$ MC



Acceptance of the signal selection

Signal acceptance for $m_{e^+e^-} > 140$ MeV $\longrightarrow$ 2.2 %
Signal acceptance for $m_{e^+e^-} > 145$ MeV $\longrightarrow$ 2.3 %
Signal acceptance for $m_{e^+e^-} > 150$ MeV $\longrightarrow$ 2.3 %

Selected events for $m_{e^+e^-} > 140$ MeV $\longrightarrow$ 2570
Selected events for $m_{e^+e^-} > 145$ MeV $\longrightarrow$ 2377
Selected events for $m_{e^+e^-} > 150$ MeV $\longrightarrow$ 2202

Background estimation

Channel	B/S	Background contamination
$K^+ \to \mu^+ \nu_\mu \pi^0_D$	2%	22±4
$K^+ \to \pi^+ \pi^- e^+ \nu_e$	2%	18±2
$K^+ \to \pi^+ e^+ e^-$ $(m_{e^+e^-} > 140\ MeV)$	3‰	2.9±0.3
other background	6‰	< 9 (C.L. 68%)

Trigger efficiency

Data

Normalization 96%

Signal Mask4/CTRL $\longrightarrow$ 1213/28

Monte Carlo

Normalization L0 NewCHOD and RICH emulator L1 KTAG and STRAW exotic

Signal NewCHOD, RICH, LKr20 emulator L1 KTAG and STRAW exotic

Normalization from MC $\mathcal{E}_{mask5} = (90.79 \pm 0.03)\%$

$$\frac{\mathcal{E}_{mask5}}{\mathcal{E}_{mask4}} = (101.3 \pm 0.5)\%$$

Signal from MC $\mathcal{E}_{mask4} = (89.7 \pm 0.5)\%$