BEACH04

Rare Kaon Decays in NA48/1

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On behalf of the NA48/1 Collaboration:

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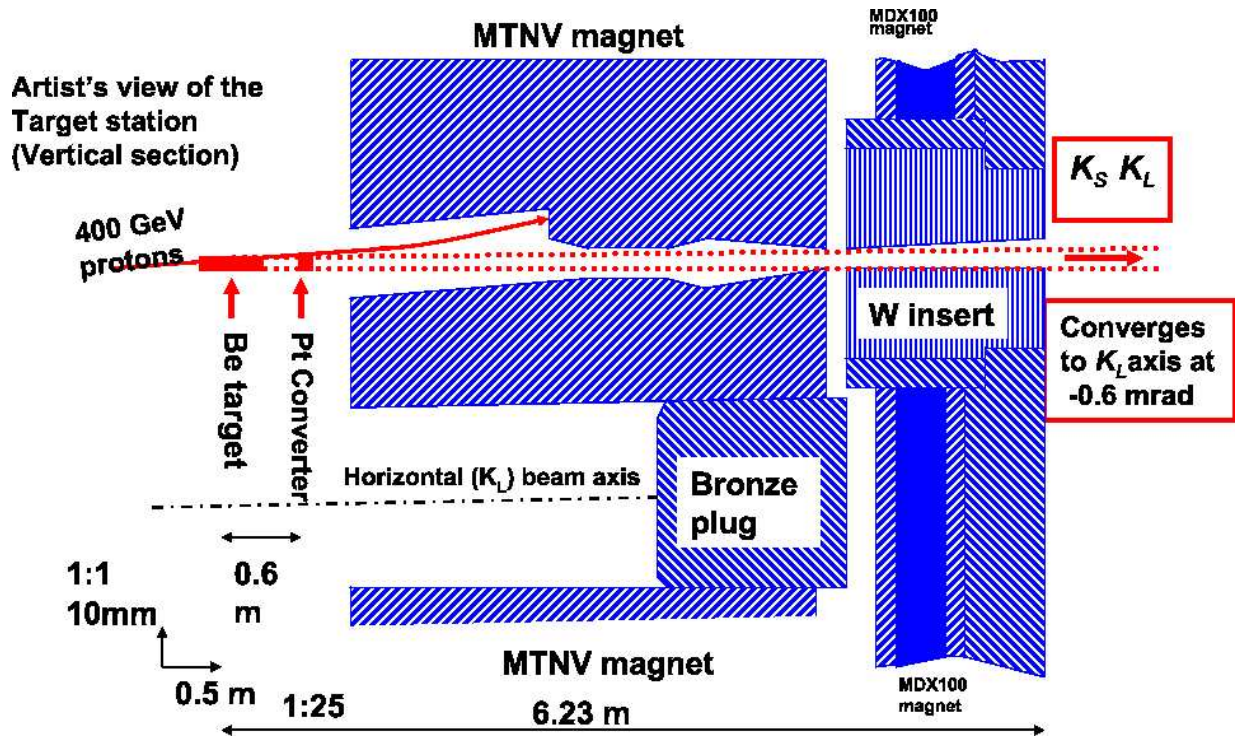
Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Warsaw, Wien

Overview

- NA48/1 beamline and detector
- Phyisics motivation for $K_S \to \pi^0 l^+ l^-$ searches
- First observation of $K_S \to \pi^0 e^+ e^-$
- First observation of $K_S \to \pi^0 \mu^+ \mu^-$
- Interpretation of $K_S \to \pi^0 l^+ l^-$ results
- Conclusions

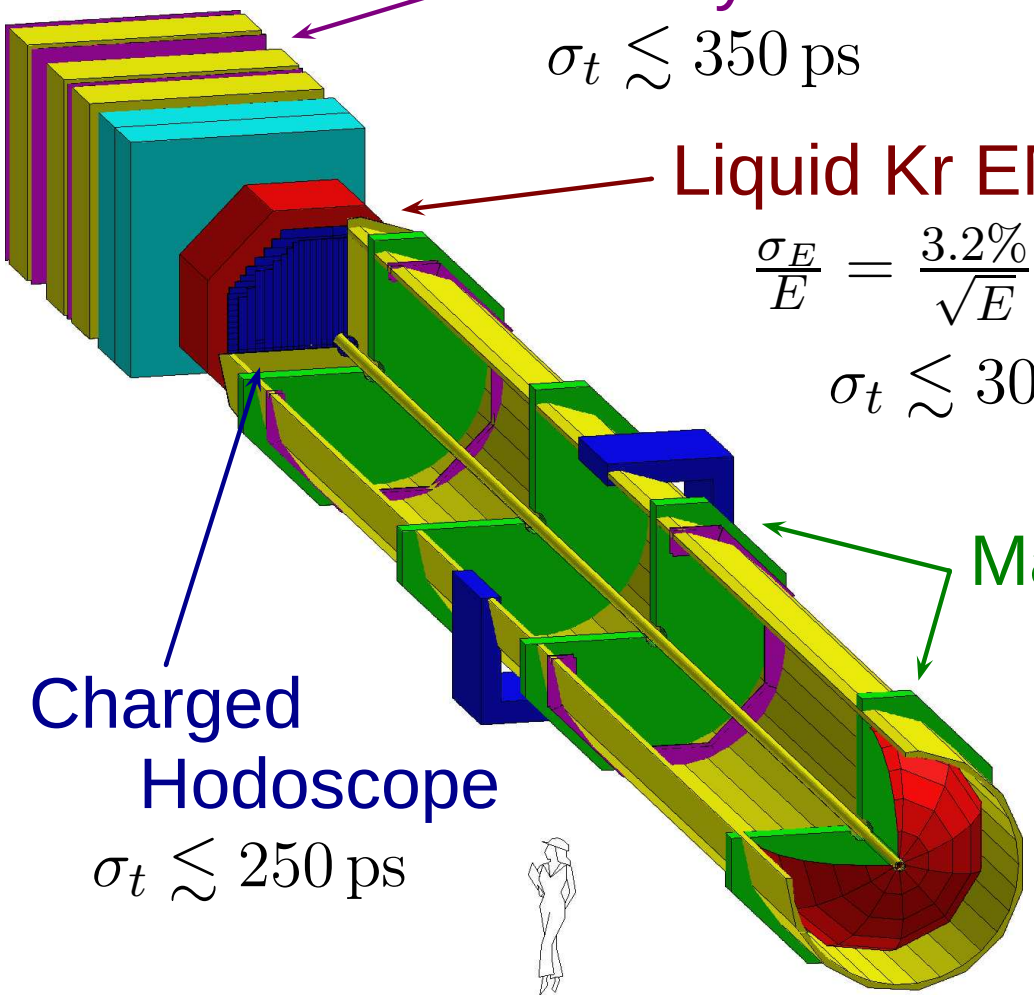
NA48

Beamline



- Primary Protons momentum
  $400\,\mathrm{GeV/c}$
- Protons per Pulse on Target
  $\sim 5 \times 10^{10}$
- Duty Cycle
  $4.8\,\mathrm{s}/16.8\,\mathrm{s}$
- Production Angle
  $-4.2\,\mathrm{mrad}$

Detector



Muon System

$\sigma_t \lesssim 350\,\mathrm{ps}$

Liquid Kr EM Calorimeter

$\frac{\sigma_E}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{0.1}{E} \oplus 0.5\%$

(E in GeV)

$\sigma_t \lesssim 300\,\mathrm{ps}$

Magnetic Spectrometer

$\sigma_p/p = 0.48\% \oplus 0.009\% \times p$

(p in GeV/c)

Charged Hodoscope

$\sigma_t \lesssim 250\,\mathrm{ps}$

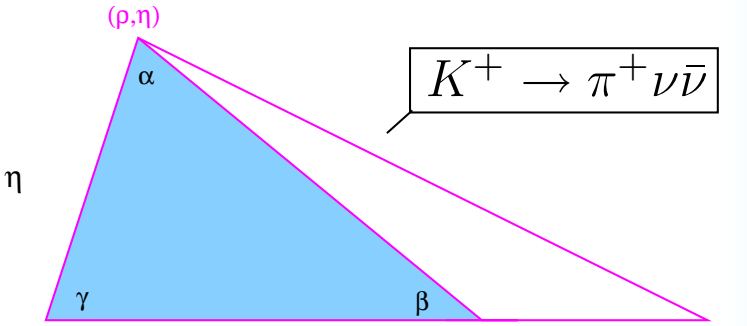
$$K_S \longrightarrow \pi^0 l^+ l^-$$

Physics Motivations for $K_S \to \pi^0 l^+ l^-$

Rare Kaon decays provide information on the parameters of the unitarity triangle

$K_L \to \pi^0 \nu\bar{\nu}$

$K_L \to \pi^0 l^+ l^-$ { $K_S \to \pi^0 l^+ l^-$, $K_L \to \pi^0 \gamma\gamma$, $K_L \to l^+ l^- \gamma\gamma$ } — η



$K_L \to \mu^+ \mu^-$ { $K_L \to \gamma\gamma$, $K_L \to e^+ e^- \gamma$; $K_L \to e^+ e^- e^+ e^-$, $e^+ e^- \mu^+ \mu^-$ }

$K_L \to \pi^0 l^+ l^-$ contains:

- a CP conserving part → $\mathrm{BR}(K_L \to \pi^0 \gamma\gamma)$
- a direct CP violating part → determines η
- an indirect CP violating part → $\mathrm{BR}(K_S \to \pi^0 l^+ l^-)$

Strategy of the Analysis

Predictions for the BRs $\sim 10^{-9}$

$\Downarrow$

only few events expected

Blind Analysis: signal and control regions masked

$\Downarrow$

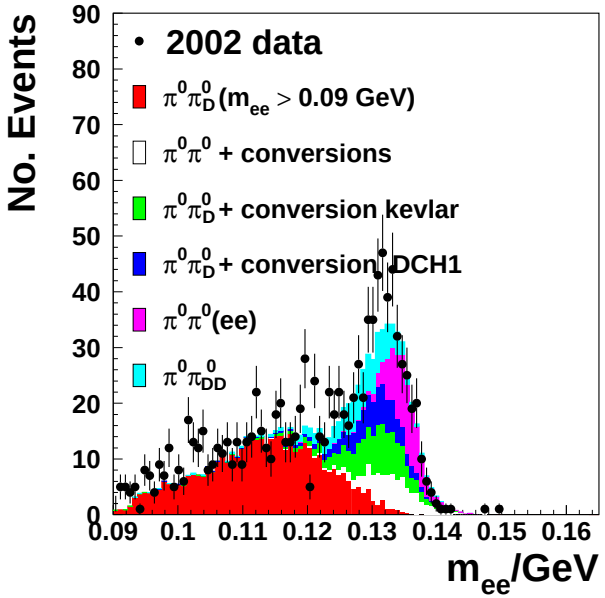
Signal Region	Control Region
$2.5\sigma_{M_K} \times 2.5\sigma_{M_{\pi^0}}$	$6.0\sigma_{M_K} \times 6.0\sigma_{M_{\pi^0}}$

Backgrounds studied using both Data & MC simulation

- Fix cuts
- Unmask control region
- Unmask signal region

$$K_S \to \pi^0 e^+ e^-$$

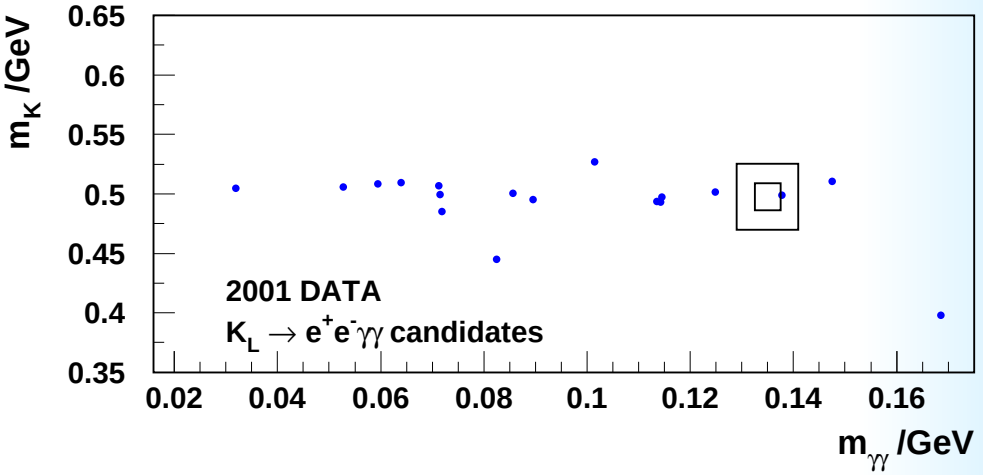
Backgrounds for $K_S \to \pi^0 e^+ e^-$



- Possible BG from Dalitz decays and conversions
- MC describes those BGs well
- Removed by asking $m_{ee} > 0.165\,\mathrm{GeV}$

- Irreducible BG from $K_L \to e^+ e^- \gamma\gamma$
- Estimated to be ~ 0.075 evts.

(2001 K_L data)



Backgrounds for $K_S \to \pi^0 e^+ e^-$ (cont.)

Ξ^0 decays contribute to the BG

- $\Xi^0 \to \Lambda(p\pi^-)\pi^0$
- $\Xi^0 \to \Lambda(pe\bar{\nu})\pi^0$
- $\Xi^0 \to \Sigma^+(p\pi^0)e\bar{\nu}$

$\Rightarrow$ removed by cutting on the *Momentum Asymmetry*

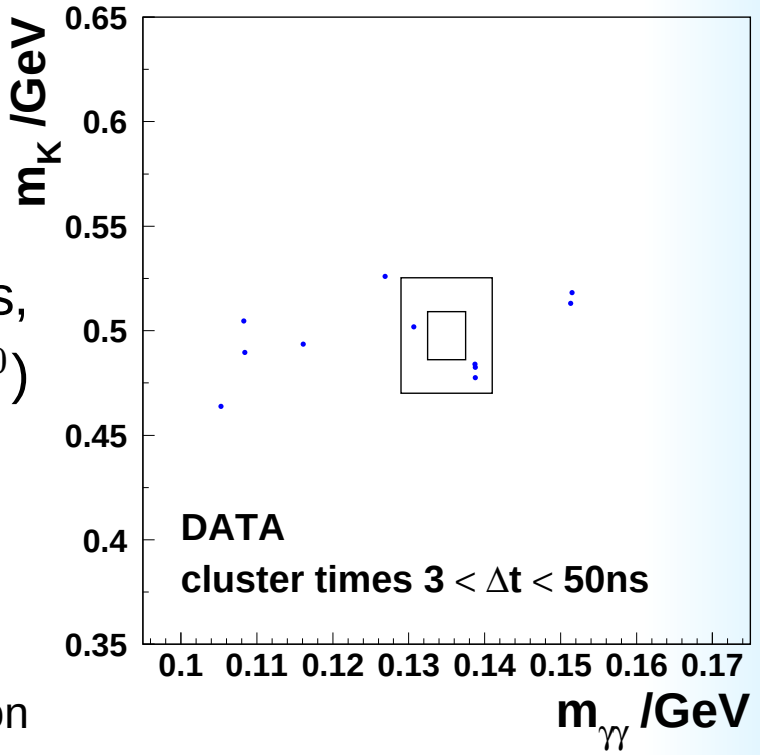
Accidental BG:

(overlapping fragments of decays, like $K_L \to \pi^\pm e^\mp \nu + K_S \to \pi^0\pi^0$)

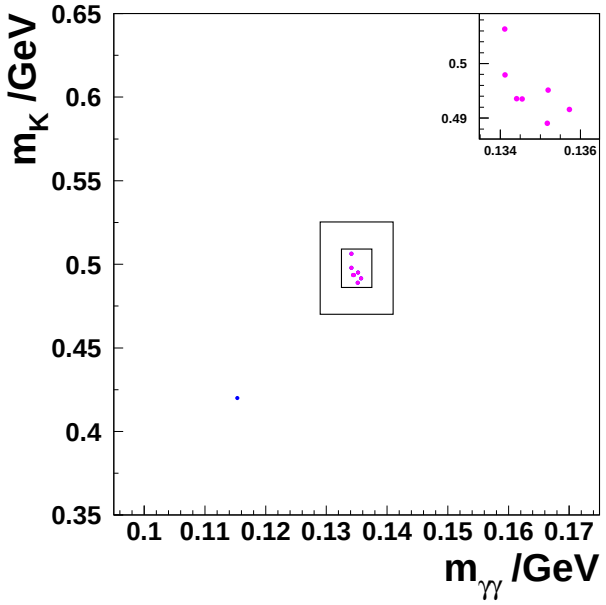
Estimated by using the time sidebands

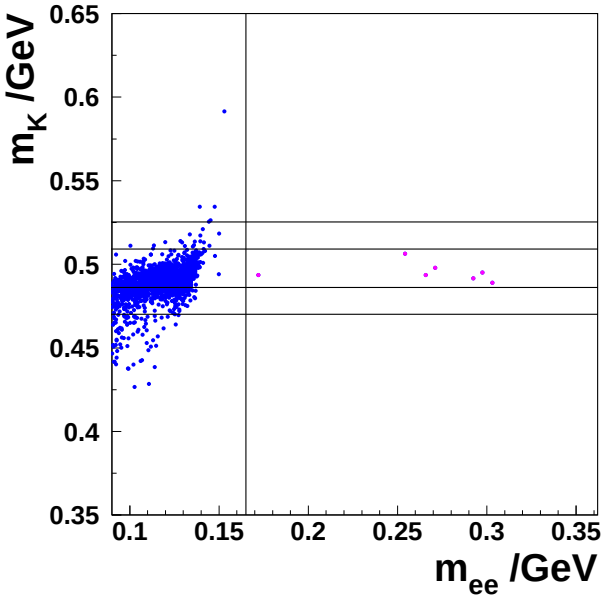
$\Rightarrow 0.069$ expected events

extrapolation from Control Region



BR of $K_S \to \pi^0 e^+ e^-$





7 events found with a BG of $0.15^{+0.05}_{-0.04}$

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) =$$

$$(5.8^{+2.8}_{-2.3}(\mathrm{stat}) \pm 0.3(\mathrm{syst}) \pm 0.8(\mathrm{theory})) \times 10^{-9}$$

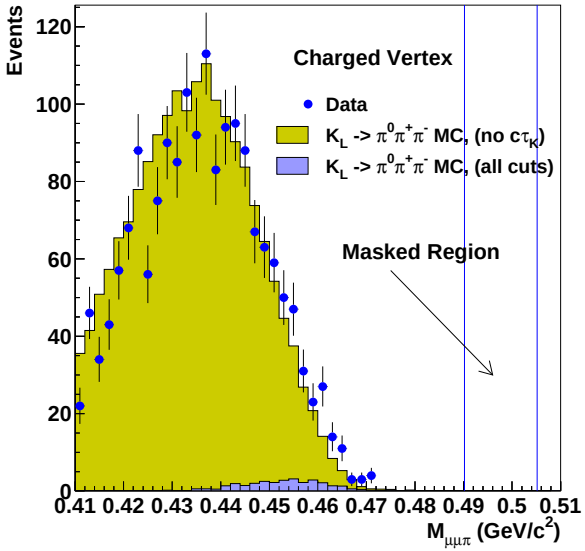
[PLB576 (2003)]

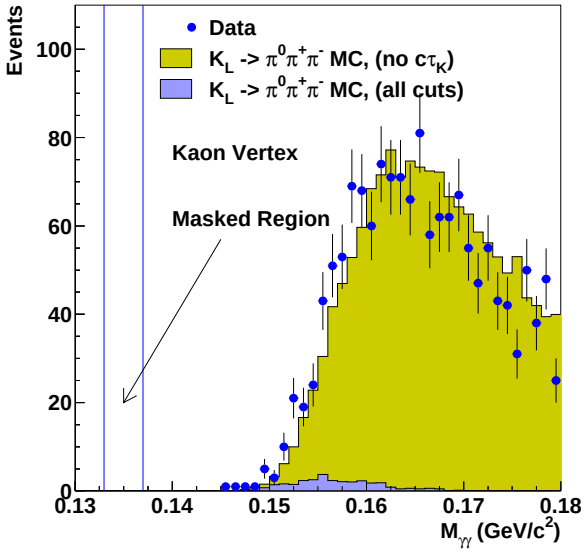
$$K_S \to \pi^0 \mu^+ \mu^-$$

Physical BGs for $K_S \to \pi^0\mu^+\mu^-$

MC simulation used to study BG from $K_L \to \pi^0\pi^+\pi^-$

with π^+ and π^- decaying in flight



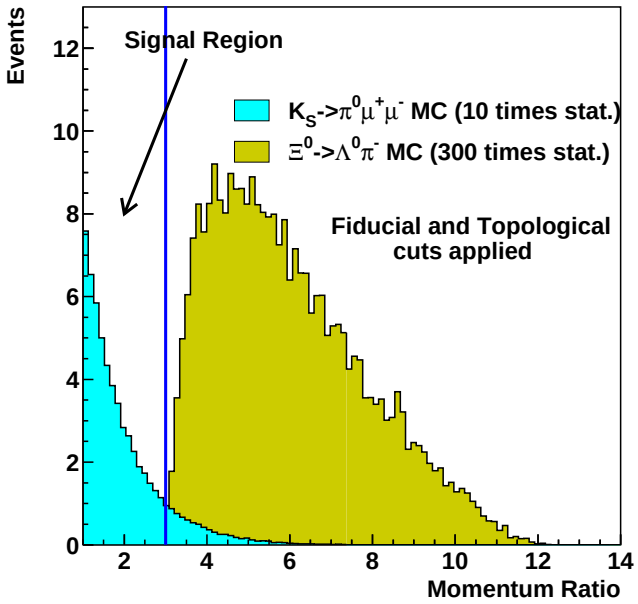


Nearly 24 times the 2002 stat. generated

- ≤ 0.019 events expected

  (no MC events in signal region)

Physical BGs for $K_S \to \pi^0\mu^+\mu^-$ (cont.)



Contribution from Ξ^0 decays, as for $K_S \to \pi^0 e^+ e^-$

Removed by a cut on the *Momentum Asymmetry*

Background from $K_L \to \mu^+\mu^-\gamma\gamma$ also studied (Greenlee)

From MC simulation 0.04 ± 0.04 events expected

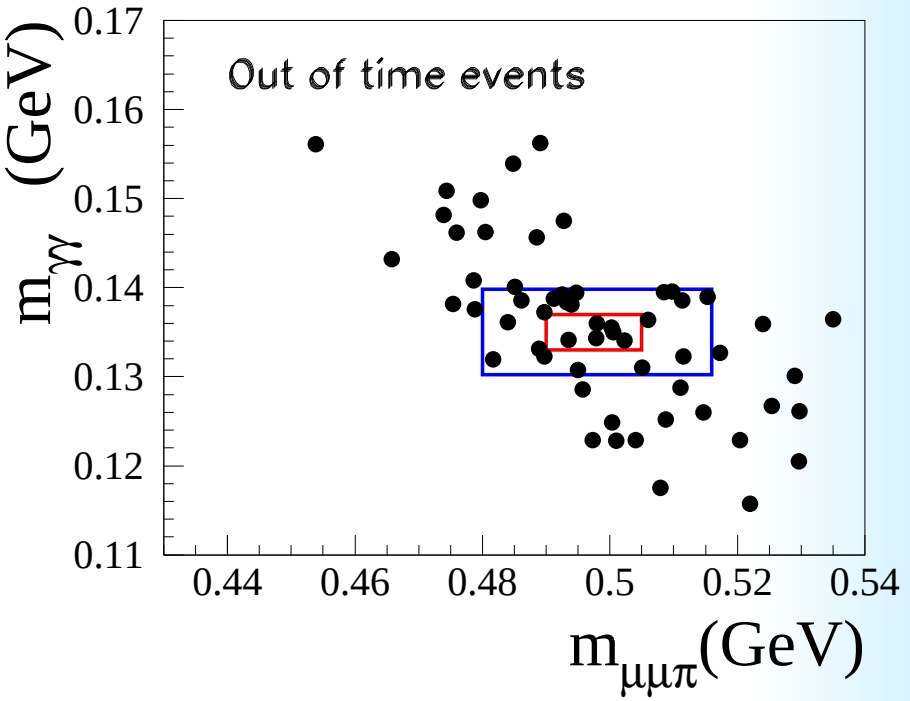
Accidental BGs for $K_S \to \pi^0\mu^+\mu^-$

Main contributions from:

- $K_L \to \pi^\pm\mu^\mp\nu +$
  $K_S \to \pi^0\pi^0$
- $K_S \to \pi^+\pi^- +$
  $K_S \to \pi^0\pi^0$

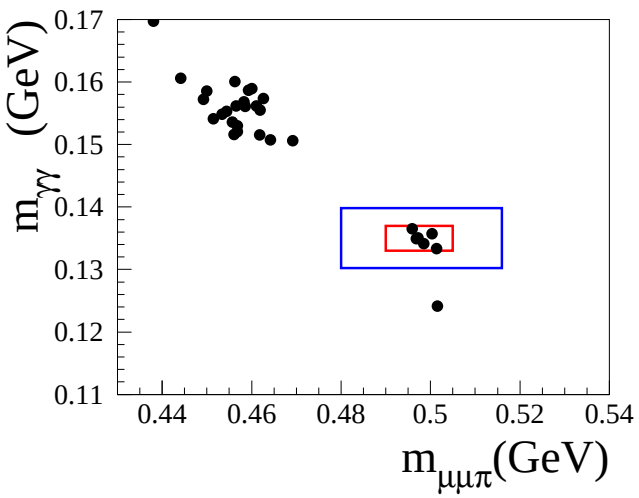
Time sidebands used:

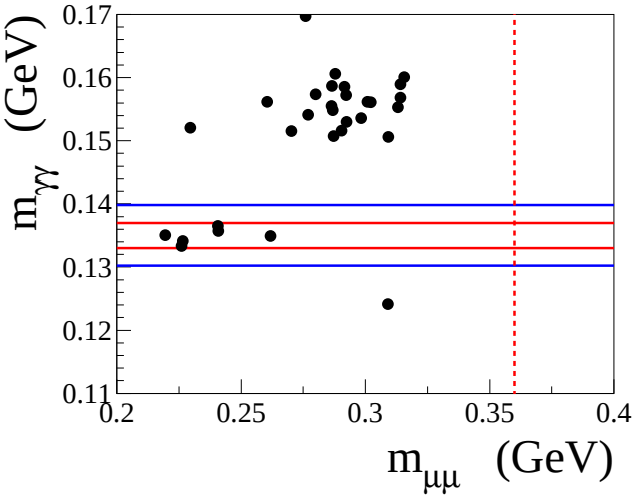
- 6 events found out of time in Signal Region



$0.18^{+0.18}_{-0.11}$ events expected

BR of $K_S \to \pi^0\mu^+\mu^-$





6 events found with a BG of $0.22^{+0.19}_{-0.12}$

$$\mathrm{BR}(K_S \to \pi^0\mu^+\mu^-) = (2.9^{+1.5}_{-1.2}(\mathrm{stat}) \pm 0.2(\mathrm{syst})) \times 10^{-9}$$

Results Interpretation

$K_S \to \pi^0 l^+ l^-$ *in* χ*PT*

Chiral Perturbation Theory (χPT) predicts:

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) = [0.01 - 0.76 a_S - 0.21 b_S + 46.5 a_S^2 + 12.9 a_S b_S + 1.44 b_S^2] \times 10^{-10}$$

$$\mathrm{BR}(K_S \to \pi^0 \mu^+ \mu^-) = [0.07 - 4.52 a_S - 1.50 b_S + 98.7 a_S^2 + 57.7 a_S b_S + 8.95 b_S^2] \times 10^{-11}$$

a_S and b_S being the coefficients of the form factor

$|a_S|$ extraction

The Vector Meson Dominance (VMD) Model gives $b_S/a_S = 0.4$, thus

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) \simeq 5.2 \times 10^{-9} a_S^2$$

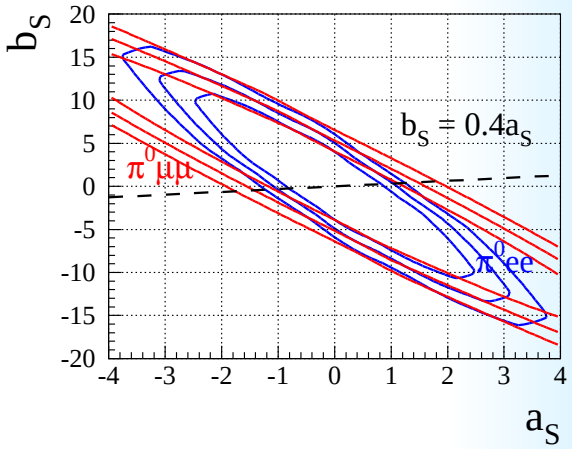
$$\Rightarrow |a_S|_{\pi^0 ee} = 1.06^{+0.26}_{-0.21} \pm 0.07$$

$$\mathrm{BR}(K_S \to \pi^0 \mu^+ \mu^-) \simeq 1.2 \times 10^{-9} a_S^2$$

$$\Rightarrow |a_S|_{\pi^0 \mu\mu} = 1.55^{+0.38}_{-0.32} \pm 0.05$$

Combining both $K_S \to \pi^0 l^+ l^-$ results in a log-likelihood fit:

- the 2 results are compatible with each other and with the VMD



Implications for $K_L \to \pi^0 l^+ l^-$

$|a_S|$ can be used to predict $\mathrm{BR}(K_L \to \pi^0 l^+ l^-)$:

$$\mathrm{BR}(K_L \to \pi^0 l^+ l^-)_{CPV} \times 10^{12} =$$

$$C_{IND} \pm C_{INT} \left(\frac{Im(\lambda_t)}{10^{-4}} \right) \pm C_{DIR} \left(\frac{Im(\lambda_t)}{10^{-4}} \right)^2$$

Where	C_{DIR}	Direct CPV component
	$C_{IND} \propto \mathrm{BR}(K_S \to \pi^0 l^+ l^-)$	Indirect CPV component
	$C_{INT} \propto \sqrt{\mathrm{BR}(K_S \to \pi^0 l^+ l^-)}$	Interference term
	$Im(\lambda_t) = -A^2 \lambda^5 \eta$	Measures CPV in Kaon system

From PDG World Average $Im(\lambda_t) = (1.36 \pm 0.12) \times 10^{-4}$

$$\mathrm{BR}(K_L \to \pi^0 e^+ e^-)_{CPV} \times 10^{12} \simeq 17_{IND} \pm 9_{INT} + 5_{DIR}$$

$$\mathrm{BR}(K_L \to \pi^0 \mu^+ \mu^-)_{CPV} \times 10^{12} \simeq 9_{IND} \pm 3_{INT} + 1_{DIR}$$

Conclusions

- First observation of the decays $K_S \to \pi^0 e^+ e^-$ and $K_S \to \pi^0 \mu^+ \mu^-$ has been made

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) =$$

$$(5.8^{+2.8}_{-2.3}(\mathrm{stat}) \pm 0.3(\mathrm{syst}) \pm 0.8(\mathrm{theory})) \times 10^{-9}$$

$$\mathrm{BR}(K_S \to \pi^0 \mu^+ \mu^-) =$$

$$(2.9^{+1.5}_{-1.2}(\mathrm{stat}) \pm 0.2(\mathrm{syst})) \times 10^{-9}$$

- The results are compatible with each other in the framework of χPT and VMD
- Estimate of the $\mathrm{BR}(K_L \to \pi^0 l^+ l^-)$ has been given