



BEACH04

Rare Kaon Decays in NA48/1

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On behalf of the NA48/1 Collaboration:

*Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz
Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Warsaw, Wien*



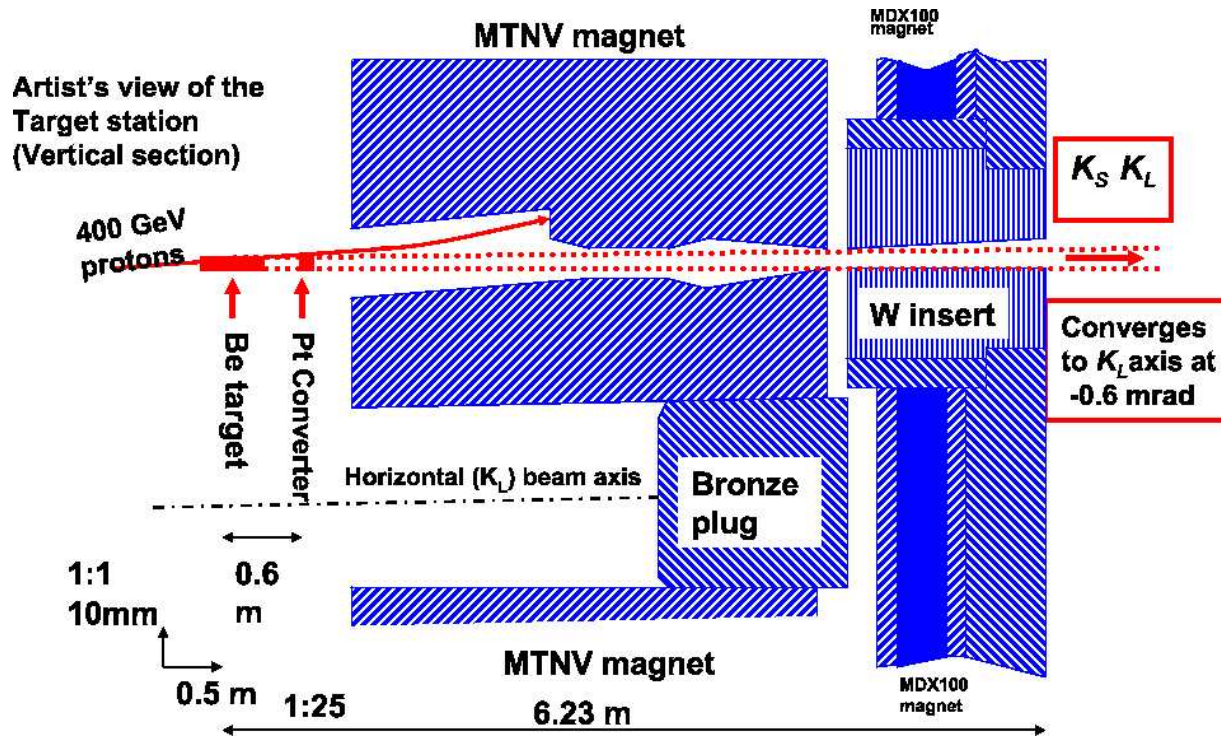
Overview

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



NA48

Beamline



▶ Primary Protons momentum

400 GeV/c

▶ Duty Cycle

4.8 s/16.8 s

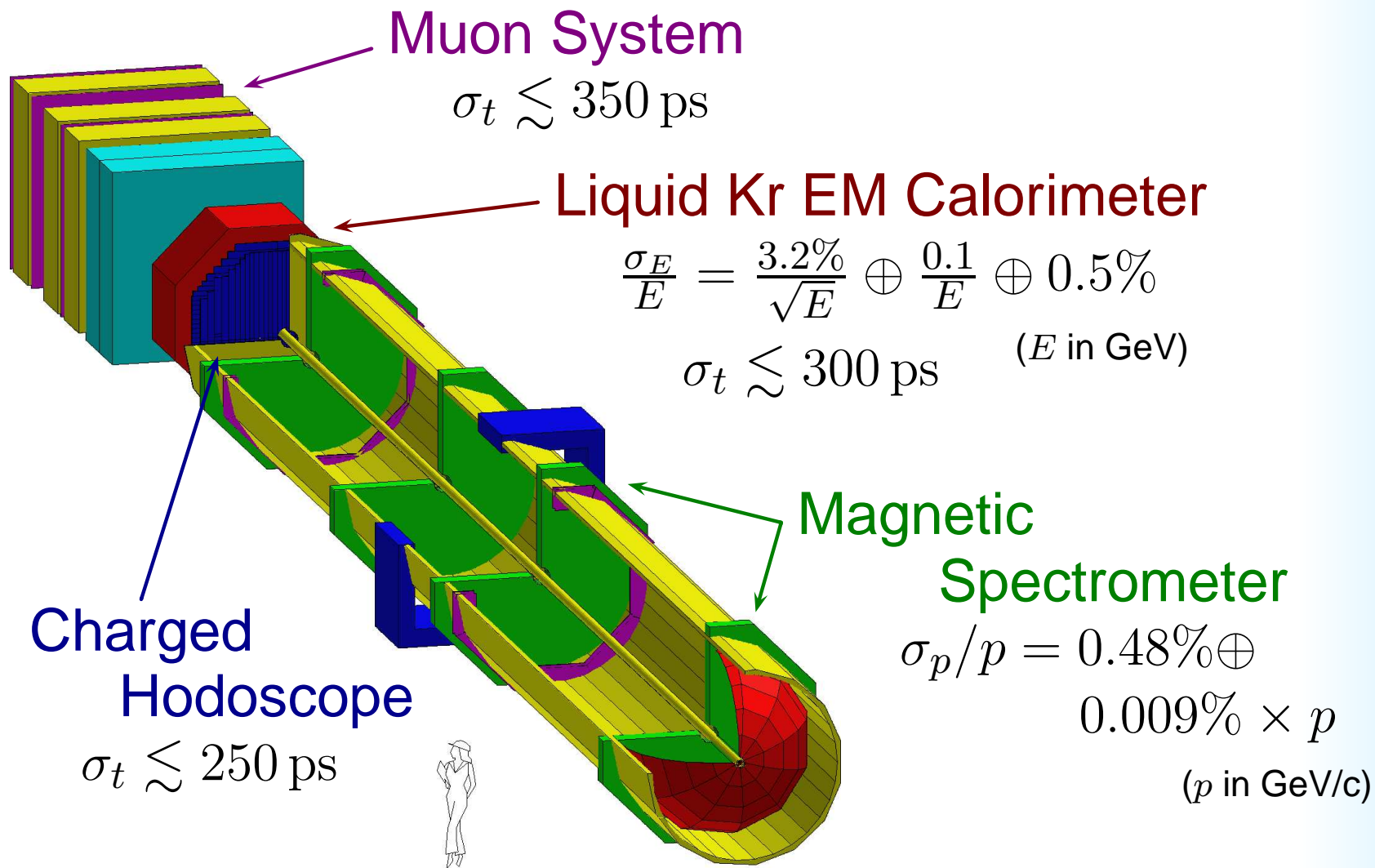
▶ Protons per Pulse on Target

$\sim 5 \times 10^{10}$

▶ Production Angle

-4.2 mrad

Detector

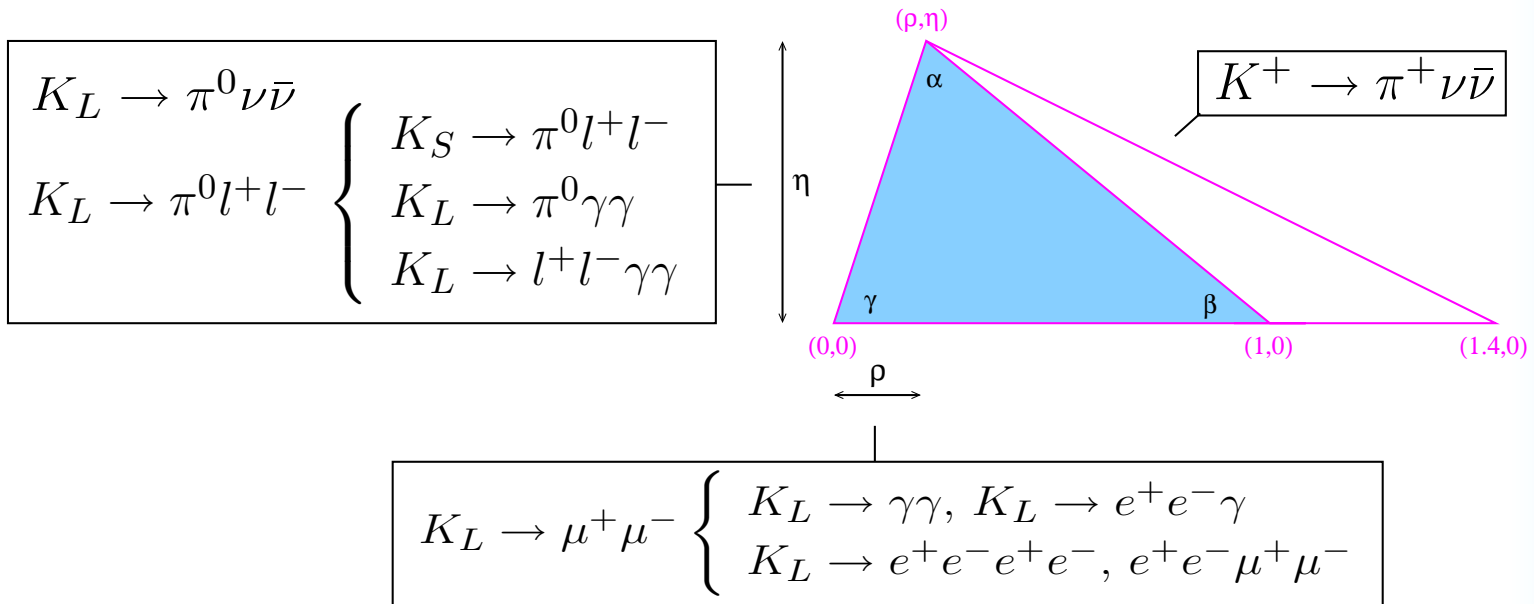




$$K_S \rightarrow \pi^0 l^+ l^-$$

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

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



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

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



Strategy of the Analysis

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



only few events expected

Blind Analysis: signal and control regions masked



Signal Region

$$2.5\sigma_{M_K} \times 2.5\sigma_{M_{\pi^0}}$$

Backgrounds studied

using both

Data & MC simulation

Control Region

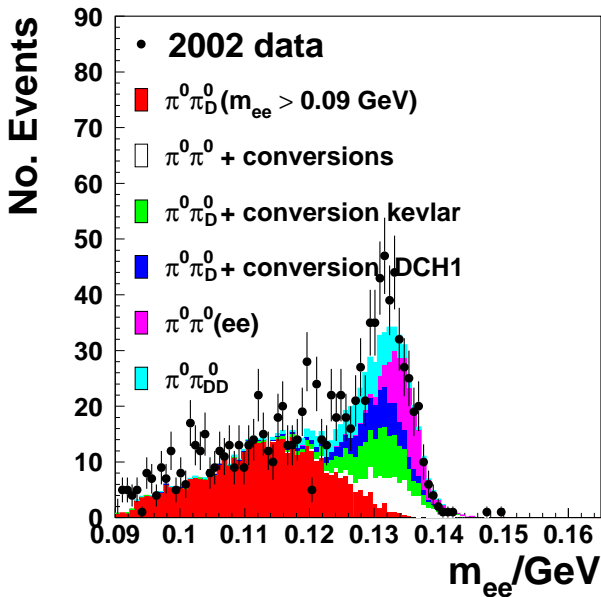
$$6.0\sigma_{M_K} \times 6.0\sigma_{M_{\pi^0}}$$

- ▶ Fix cuts
- ▶ Unmask control region
- ▶ Unmask signal region



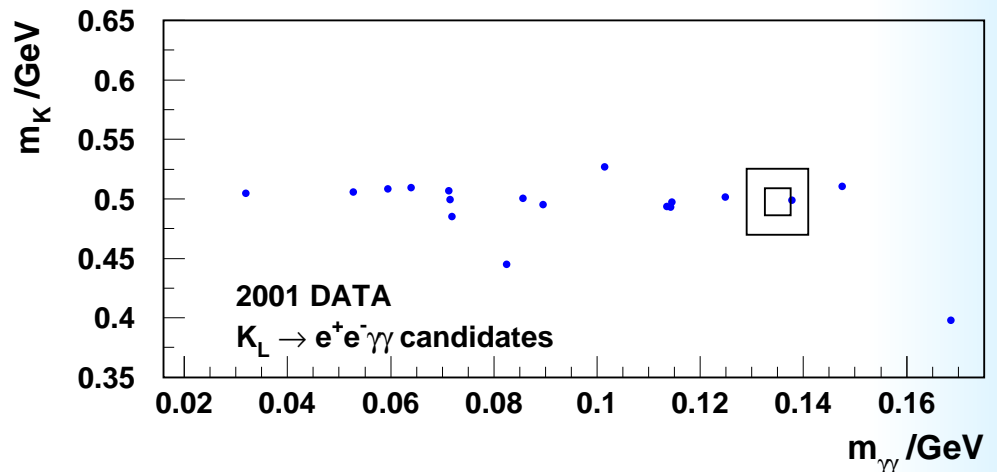
$$K_S \rightarrow \pi^0 e^+ e^-$$

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



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

- Irreducible BG from $K_L \rightarrow e^+ e^- \gamma \gamma$
- Estimated to be $\sim 0.075 \text{ evts.}$
(2001 K_L data)



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

Ξ^0 decays contribute to the BG

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

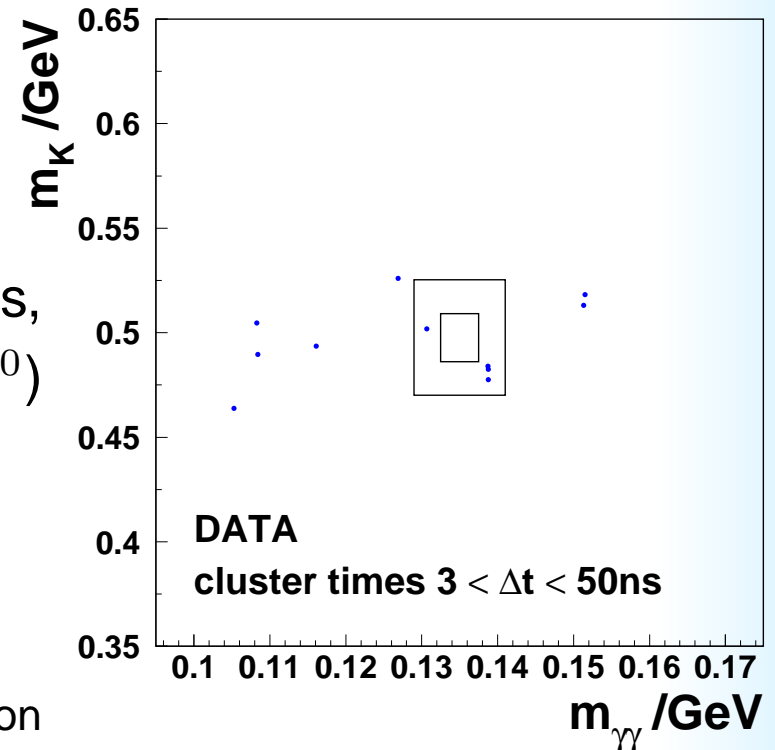
\Rightarrow removed by cutting on the *Momentum Asymmetry*

Accidental BG:

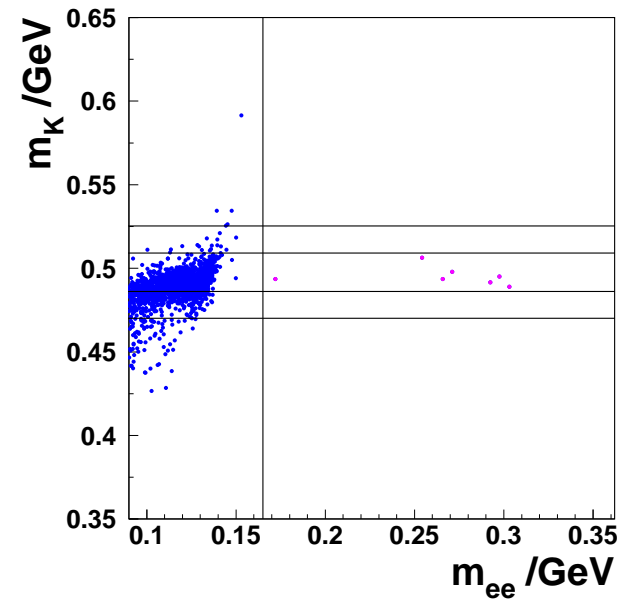
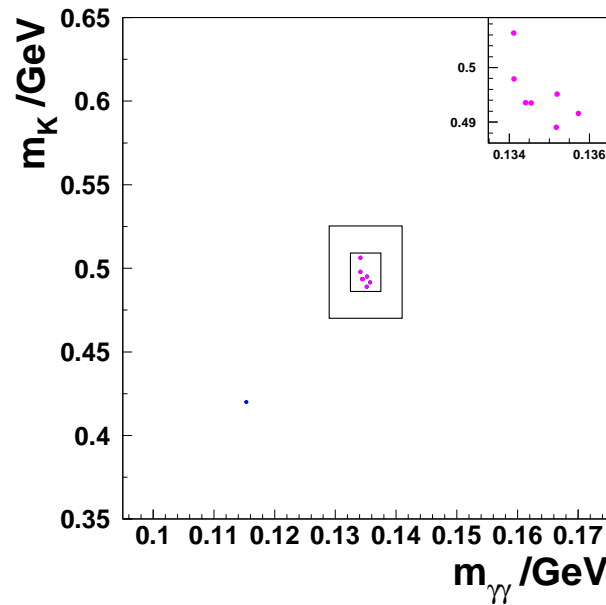
(overlapping fragments of decays,
like $K_L \rightarrow \pi^\pm e^\mp \nu + K_S \rightarrow \pi^0 \pi^0$)

Estimated by using the time
sidebands

\Rightarrow 0.069 expected events
extrapolation from Control Region



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



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

$$\text{BR}(K_S \rightarrow \pi^0 e^+ e^-) =$$

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

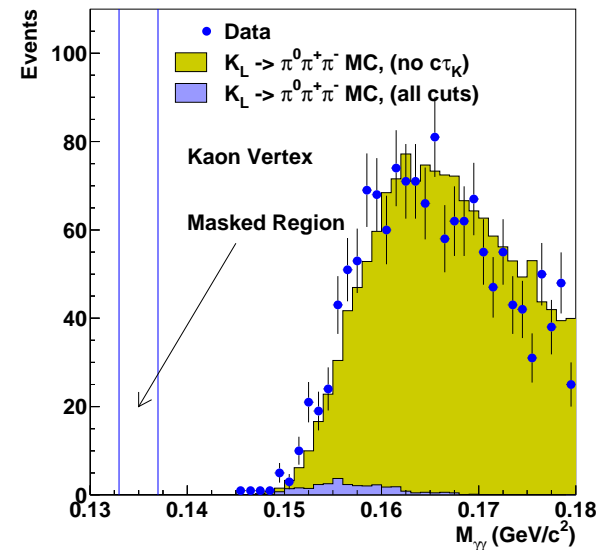
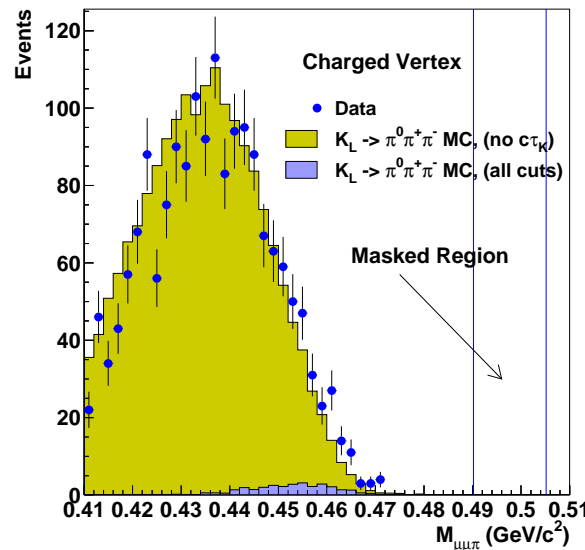
[PLB576 (2003)]



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

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

MC simulation used to study BG from $K_L \rightarrow \pi^0 \pi^+ \pi^-$
with π^+ and π^- decaying in flight

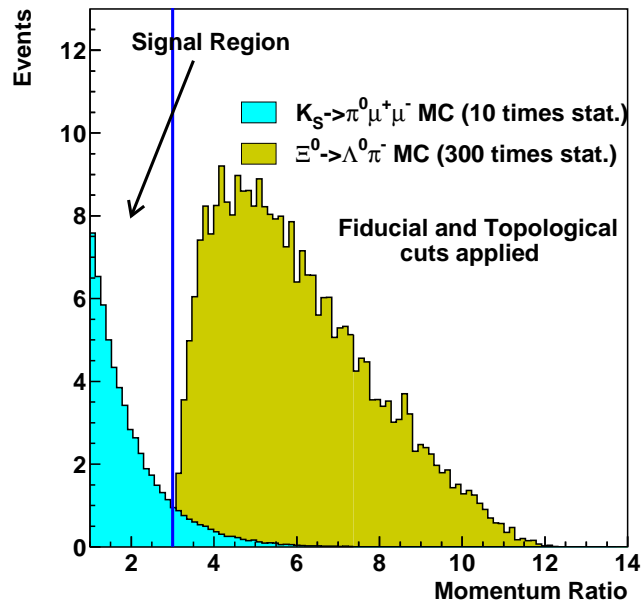


Nearly 24 times the 2002 stat. generated

▶ ≤ 0.019 events expected

(no MC events in signal region)

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



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

Removed by a cut on the *Momentum Asymmetry*

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

From MC simulation 0.04 ± 0.04 events expected

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

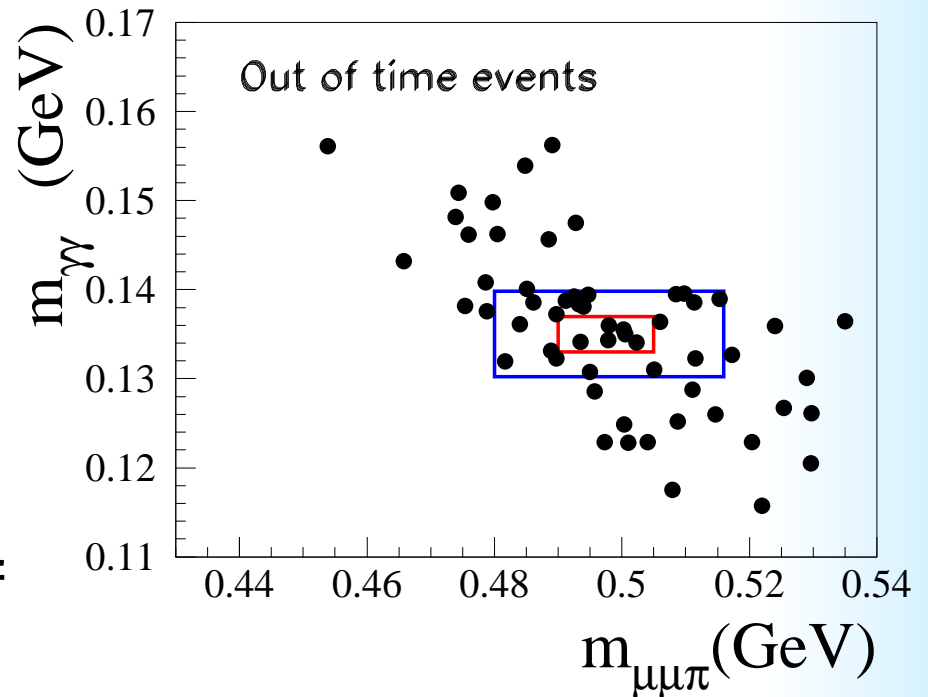
Main contributions from:

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

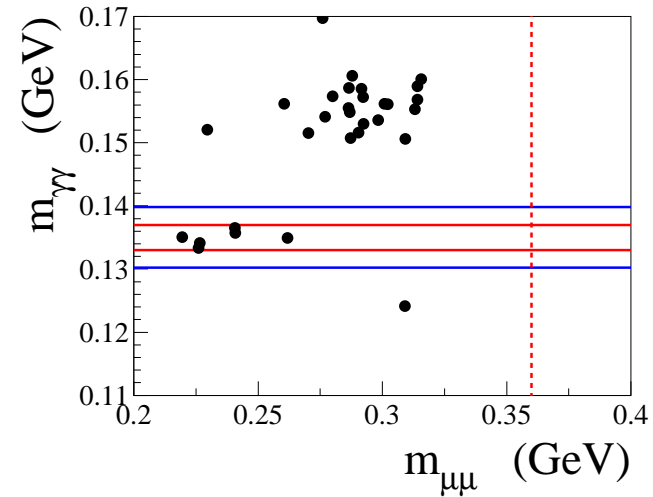
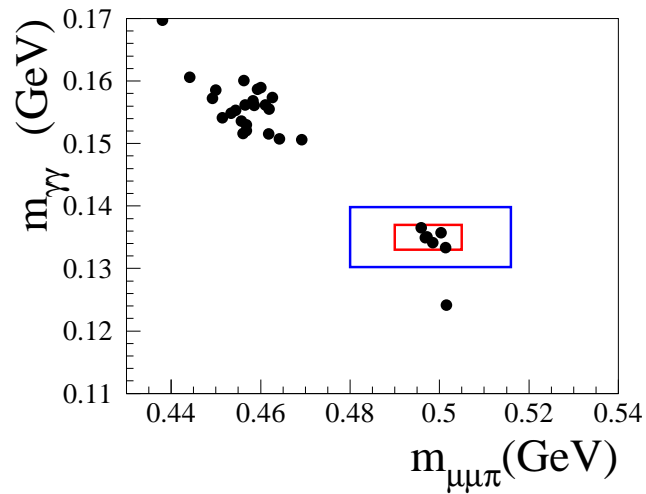
Time sidebands used:

- ▶ 6 events found out of time in Signal Region

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



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




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

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



Results Interpretation



$K_S \rightarrow \pi^0 l^+ l^-$ in χPT

Chiral Perturbation Theory (χPT) predicts:

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

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

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

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

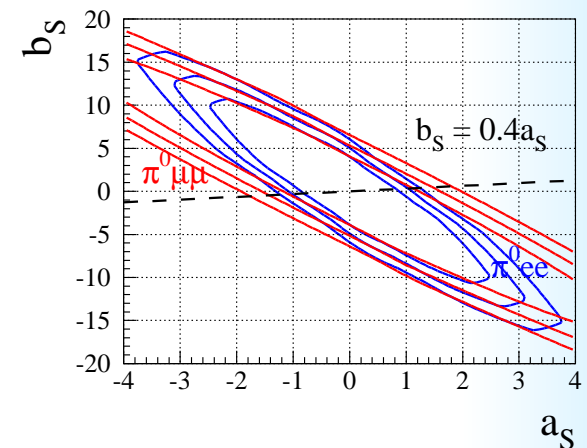
$$\Rightarrow |a_S|_{\pi^0 ee} = 1.06^{+0.26}_{-0.21} \pm 0.07$$

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

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

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

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



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

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

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

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

Where C_{DIR}

Direct CPV component

$$C_{IND} \propto \text{BR}(K_S \rightarrow \pi^0 l^+ l^-)$$

Indirect CPV component

$$C_{INT} \propto \sqrt{\text{BR}(K_S \rightarrow \pi^0 l^+ l^-)}$$

Interference term

$$\text{Im}(\lambda_t) = -A^2 \lambda^5 \eta$$

Measures CPV in Kaon system

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

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

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



Conclusions

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

$$\text{BR}(K_S \rightarrow \pi^0 e^+ e^-) =$$

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

$$\text{BR}(K_S \rightarrow \pi^0 \mu^+ \mu^-) =$$

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

- ▶ The results are compatible with each other in the framework of χ PT and VMD
- ▶ Estimate of the $\text{BR}(K_L \rightarrow \pi^0 l^+ l^-)$ has been given