

Results from the NA48 Experiment on Rare Neutral Kaon Decays

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for the NA48 Collaboration

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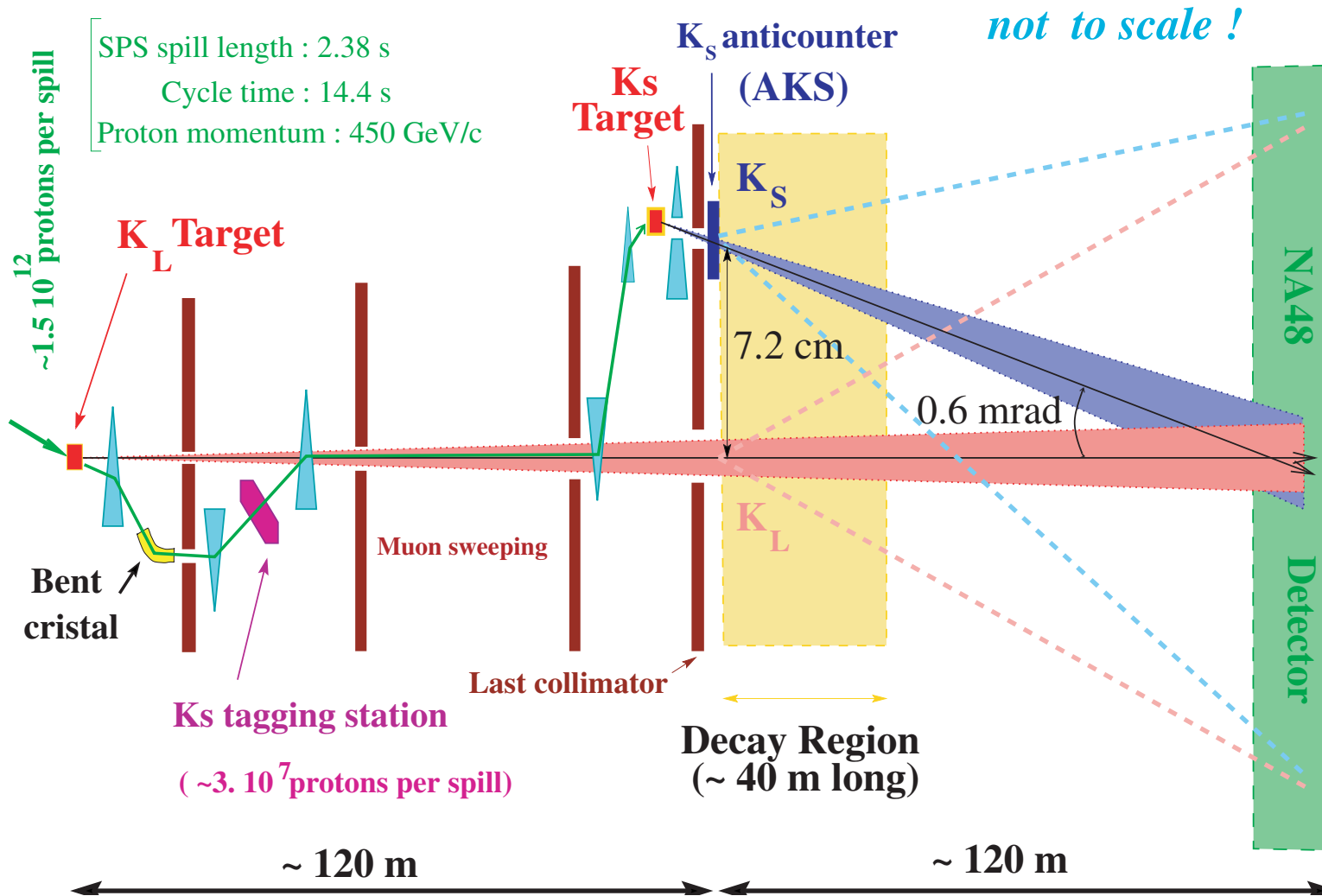
Outline

- The NA48 Setup
- $K_L \rightarrow \pi^0 \gamma \gamma$ (χ PT)
- $K_S \rightarrow \pi^0 e^+ e^-$ (CP Violation, χ PT)
- $K_S \rightarrow \gamma \gamma$ (χ PT)
- Other results
- Conclusions and Outlook

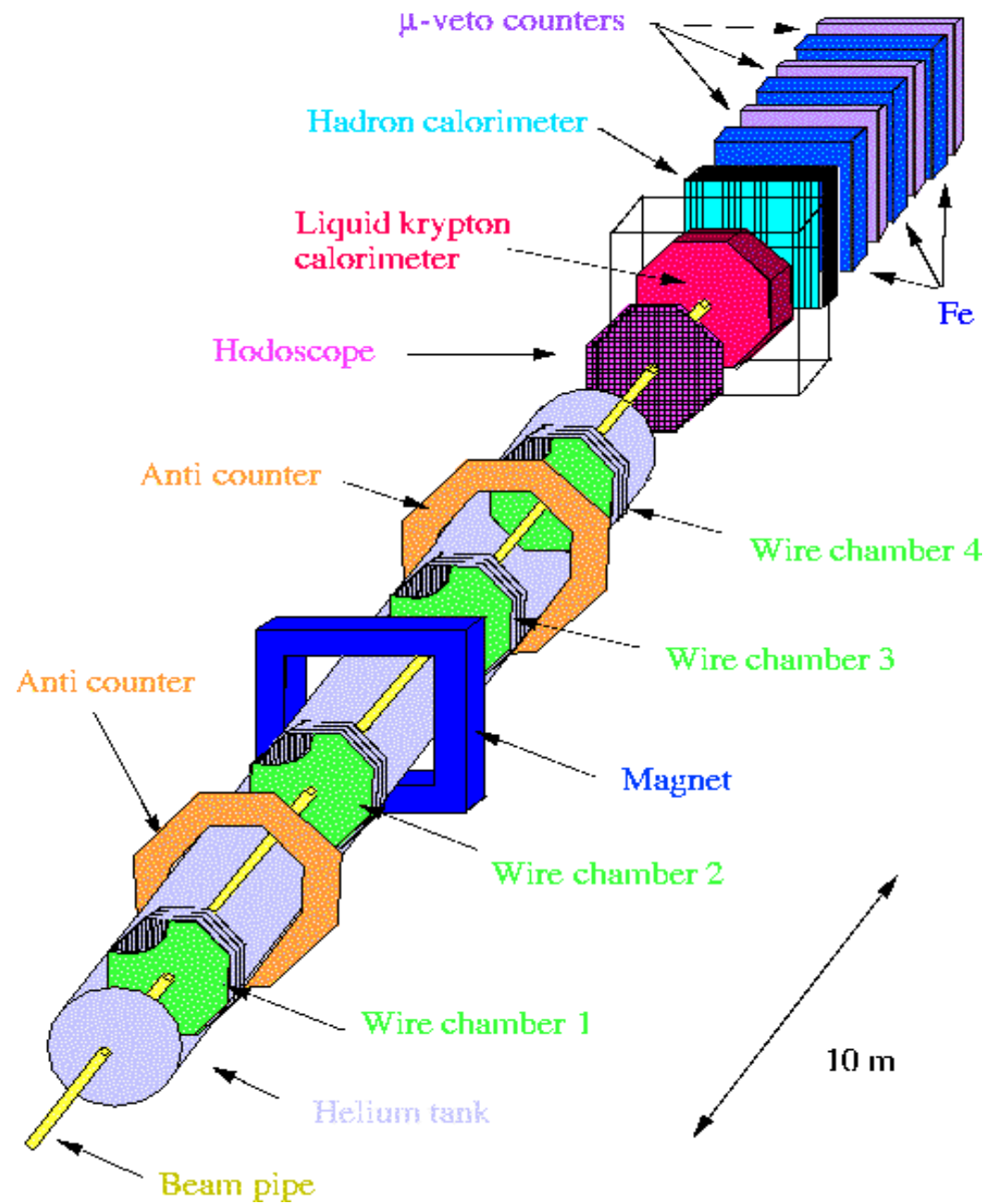
The NA48 Experiment (1)

- NA48 aims to measure the **direct CP violation** parameter ε'/ε .
- NA48 also carries out studies of **rare decays of neutral kaons**
- It uses **2 simultaneous** and almost collinear K_L and K_S beams
- In 1999 data from a 2 days **high intensity** (200x nominal) **K_S only** beam was taken.

The NA48 Experiment (2)



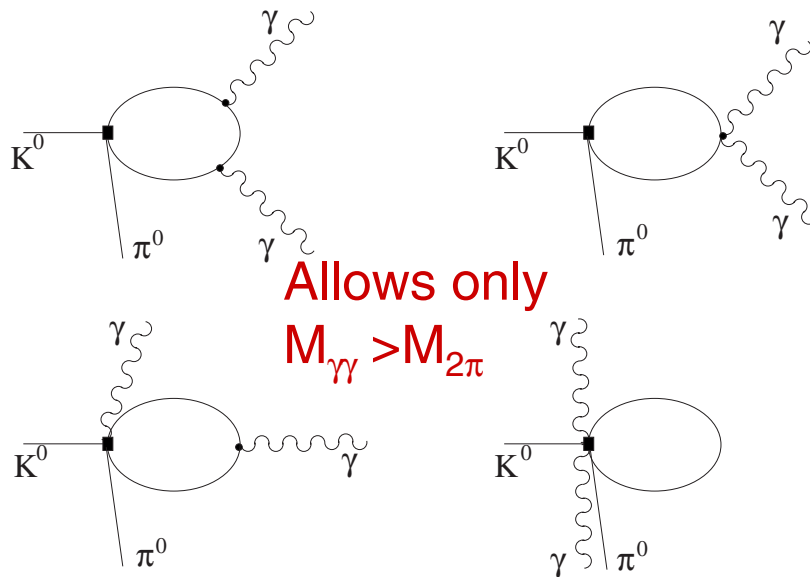
The NA48 Detector



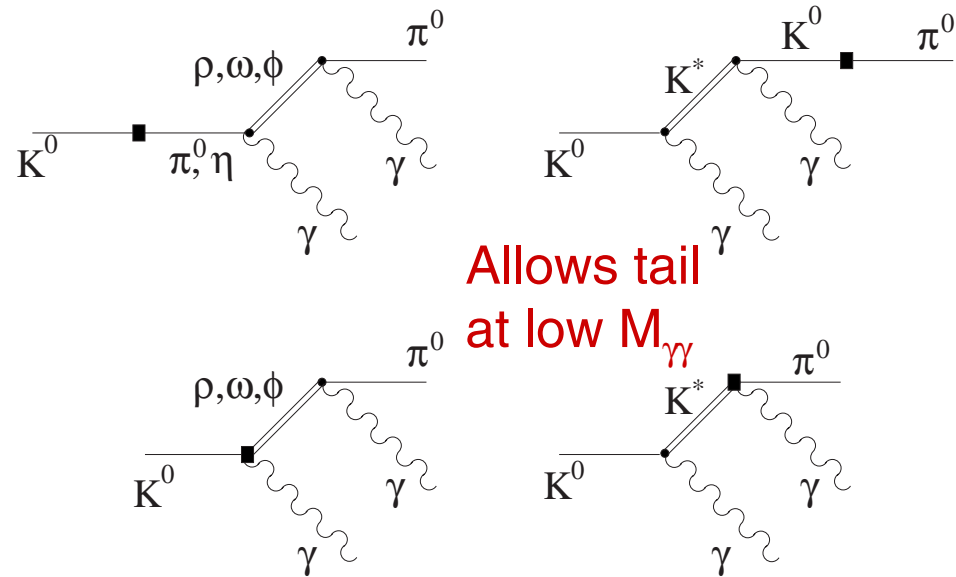
$K_L \rightarrow \pi^0 \gamma \gamma$ (1)

Motivation:

- At one loop χ PT ($O(p^4)$) the decay rate is finite, but only gives 1/3 of the measured rate.
- Calculations of $O(p^6)$ including vector meson exchange (VMD) reproduce the measured rate and allows a tail at low $M_{\gamma\gamma}$.
- The VMD contribution is parameterised by a_v , which has to be determined experimentally.



Allows only
 $M_{\gamma\gamma} > M_{2\pi}$



Allows tail
 at low $M_{\gamma\gamma}$

$K_L \rightarrow \pi^0 \gamma \gamma$ (2)

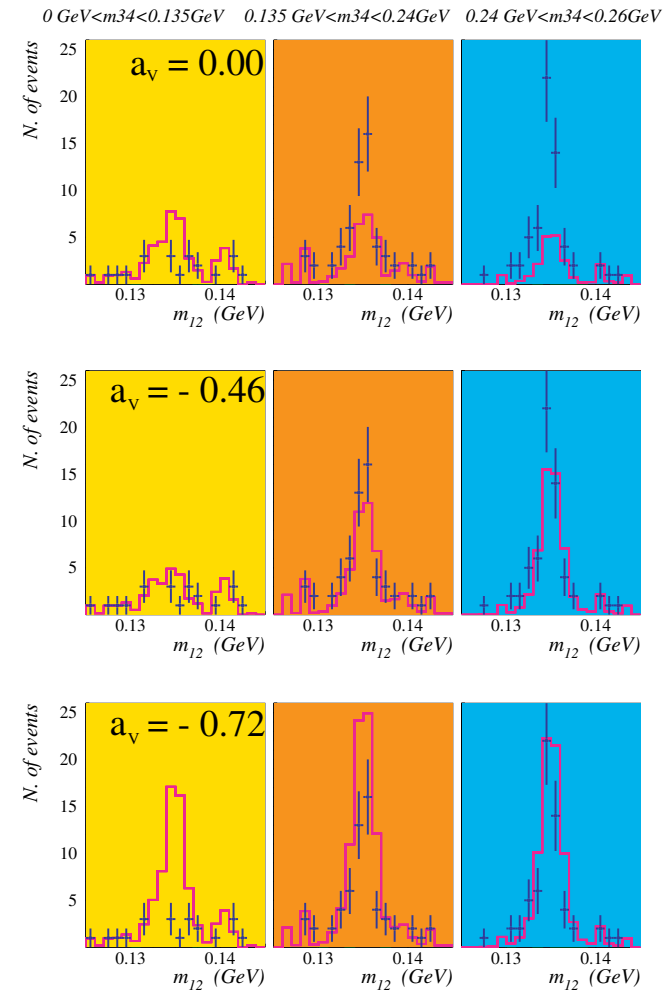
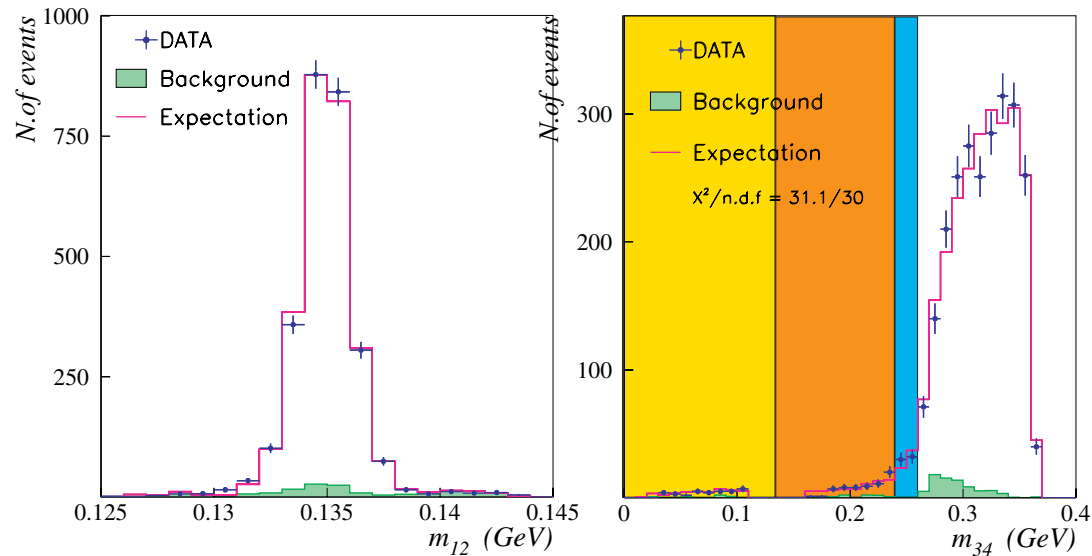
Data Selection:

- Events are similar in signature (4 γ) to $K_L \rightarrow \pi^0 \pi^0$ (norm. channel) \rightarrow most systematic uncertainties cancel.

Background: $2\pi^0$, $3\pi^0$

- The background from $2\pi^0$ is rejected with **invariant mass cuts**
- Background from $3\pi^0$ with missing or overlapping γ are rejected with **combinatorial cuts** \rightarrow Background results in wrong K vertex while giving a good π^0 vertex
- Additional cuts on the **shower width** of the cluster

$K_L \rightarrow \pi^0 \gamma \gamma$ (3)



Results:

- $\text{BR}(K_L \rightarrow \pi^0 \gamma \gamma) = (1.36 \pm 0.03_{\text{(stat)}} \pm 0.03_{\text{(syst)}} \pm 0.03_{\text{(norm)}}) \times 10^{-6}$
- $a_v = -0.46 \pm 0.03_{\text{(stat)}} \pm 0.03_{\text{(syst)}} \pm 0.02_{\text{(theo)}}$.

$K_s \rightarrow \pi^0 e^+ e^-$ (1)

Motivation:

- $K_s \rightarrow \pi^0 e^+ e^-$ is dominated by long-distance dynamics through one-photon exchange ($K \rightarrow \pi \gamma^*$)
- The decay measures the indirect CP violating components of $BR(K_L \rightarrow \pi^0 e^+ e^-) \times 10^{12} = 15.3 a_s^2 - 6.8 a_s \text{Im}(\lambda_t) \times 10^4 + 2.8 (\text{Im}(\lambda_t) \times 10^4)^2$, with $\text{Im}(\lambda_t) = V_{ts}^* V_{td}$ from the CKM elements.
- Theoretical expectation:
$$BR(K_s \rightarrow \pi^0 e^+ e^-) = 5.2 \times 10^{-9} a_s^2, \text{ with } a_s^2 \text{ of } O(1)$$
- $K_L \rightarrow \pi^0 e^+ e^-$ is interesting because it contains a direct CP violating component
- The current best value for $BR(K_s \rightarrow \pi^0 e^+ e^-) < 1.1 \times 10^{-6}$ (NA31)

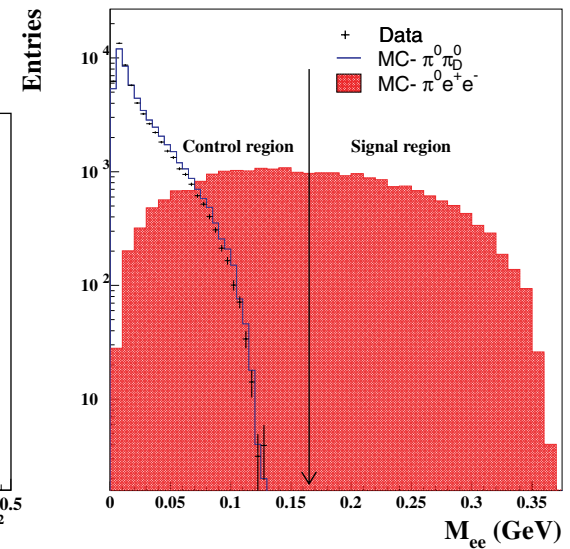
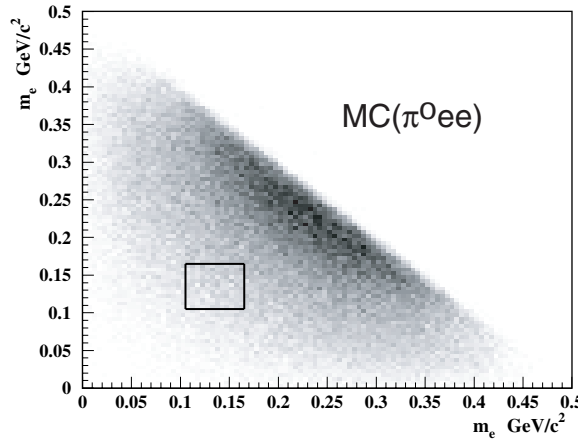
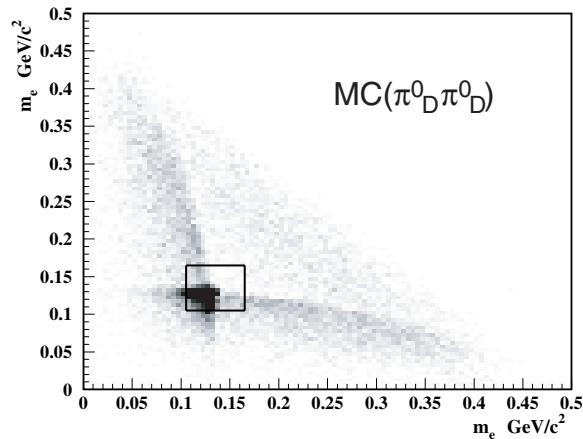
$K_s \rightarrow \pi^0 e^+ e^-$ (2)

Data Selection:

Select events with 2 tracks with $0.9 < E/p < 1.1$ and at least 4 good clusters in the calorimeter with a mass around the K^0 mass.

$M_{e\gamma} - M_{\pi^0} < 30 \text{ MeV}$ – removes $\pi^0\pi^0_D$ and $\pi^0_D\pi^0_D$

$M_{ee} > 165 \text{ MeV}/c^2$ – removes $\pi^0\pi^0_D$ background



$K_S \rightarrow \pi^0 e^+ e^-$ (3)

Results:

The final selection contains **no** event. Using $K_S \rightarrow \pi^0 \pi^0_D$ as normalization channel taken with the same trigger an upper limit is given:

$$\text{BR}(K_S \rightarrow \pi^0 e^+ e^-) < 1.4 \times 10^{-7} \text{ (90\% CL)}$$

This includes a **7% systematic error**. It improves the current best measurement by a **factor of 10**.

A **paper** has been submitted **Phys Lett B** (CERN Preprint **EP2001-042**)

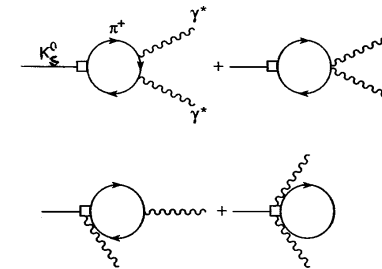
Outlook:

In 2002 a dedicated K_S and hyperon run is foreseen. We aim at collecting 6×10^{10} K_S thus - assuming an acceptance of 5% - reaching a SES of 3×10^{-10} .

$K_S \rightarrow \gamma\gamma$ (1)

Motivation:

- This decay is an important test for χ PT, because of its finite and **unambiguous** result.
- It has **no** short distance contributions.
- From theory: $\text{BR}(K_S \rightarrow \gamma\gamma) = (2.3 \pm 0.2) \times 10^{-6}$.



Data sample:

- 1999 **high intensity K_S run** with dedicated trigger ($\epsilon_{\text{trigger}} > 99\%$)
- Since K_S and K_L are both produced at the target it is important to subtract the $K_L \rightarrow \gamma\gamma$ events.
- The **flux** of the K_S is measured via $K_S \rightarrow \pi^0\pi^0$ (also normalisation channel)
- The **K_L flux** is measured also via $K_L \rightarrow 3\pi^0$.

$K_S \rightarrow \gamma\gamma$ (2)

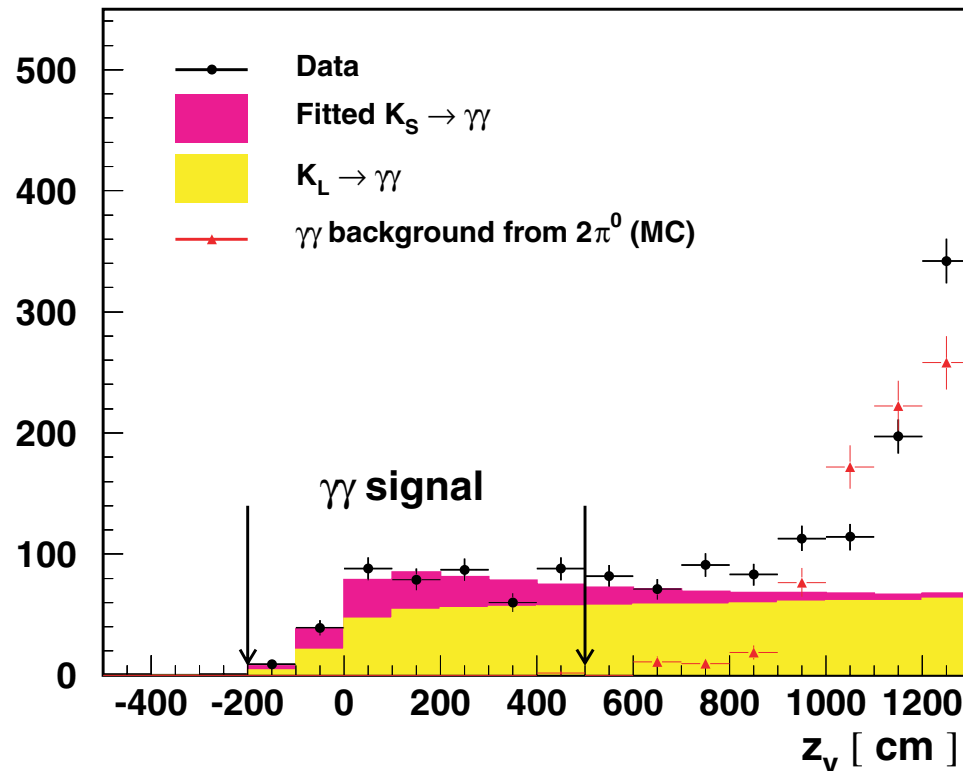
Event Selection:

- Search for 2 clusters in the calorimeter

Background rejection:

- The **background** $\Lambda \rightarrow n\pi^0$ is estimated from COG tails and is suppressed by **cutting** on the **energy** of the hadron calorimeter
- $K_L \rightarrow \gamma\gamma$ is estimated from the K_L flux
- The **background** from $K_S \rightarrow \pi^0\pi^0$ with 2 missing photons is shifted by at least 9 m \rightarrow a virtually **background free** region of about **5m**

$K_S \rightarrow \gamma\gamma$ (3)



Results:

149 ± 21 $K_S \rightarrow \gamma\gamma$ candidates

$$\text{BR}(K_S \rightarrow \gamma\gamma) = 2.58 \pm 0.36_{(\text{stat})} \pm 0.22_{(\text{syst})} \times 10^{-6}$$

$$R = \Gamma(K_S \rightarrow \gamma\gamma) / \Gamma(K_L \rightarrow \gamma\gamma) = 2.53 \pm 0.35_{(\text{stat})} \pm 0.22_{(\text{syst})}$$

Published in

Phys Lett B. 49 (2000) 29

Other Results(1)

$K_L \rightarrow \pi^+\pi^-e^+e^-$

- 1300 events found resulting in a preliminary result:

$$BR(K_L \rightarrow \pi^+\pi^-e^+e^-) = (3.1 \pm 0.1(\text{stat}) \pm 0.2(\text{syst})) \times 10^{-7}$$

- For the angular distribution of the $\sin\phi\cos\phi$ distribution:

$$A_L = (13.9 \pm 2.7(\text{stat}) \pm 2.0(\text{syst}))\%$$

$K_S \rightarrow \pi^+\pi^-e^+e^-$ – (Phys. Lett. B496 (2000) 137)

- 56 events found in 1998 data.

$$BR(K_S \rightarrow \pi^+\pi^-e^+e^-) = (4.5 \pm 0.7(\text{stat}) \pm 0.4(\text{syst})) \times 10^{-5}$$

- From the high intensity K_S run in 99 we have a **preliminary** update of the

$$BR(K_S \rightarrow \pi^+\pi^-e^+e^-) = (4.3 \pm 0.2(\text{stat}) \pm 0.3(\text{syst})) \times 10^{-5}$$

- and a **preliminary** measurement of the **asymmetry**

$$A_S = (-0.2 \pm 3.4(\text{stat}) \pm 1.4(\text{syst}))\%$$

Conclusions and Outlook

- NA48 provides interesting physics in the neutral sector of the kaon sector for chiral perturbation theory and CP violation
- NA48 has a new result on the decay $K_L \rightarrow \pi^0 \gamma \gamma$:
 $BR(K_L \rightarrow \pi^0 \gamma \gamma) = (1.36 \pm 0.5) \times 10^{-6}$
 $a_V = -0.46 \pm 0.05$.
- NA48 has improved the limit for the BR of $K_S \rightarrow \pi^0 e^+ e^-$ by a factor **10**:
 $BR(K_S \rightarrow \pi^0 e^+ e^-) < 1.4 \times 10^{-7}$ (90% CL)
- In 2001 the ε'/ε program will be completed and **additional rare decay data** will be taken.
- In 2002 a dedicated **high intensity K_S** run will aim at delivering competitive results in the domain of neutral Ks and hyperon physics.
- The K_S run will be followed by a dedicated charged kaon run (2003)

KL \rightarrow $\pi^0\gamma\gamma$ (4)

Upper limit for the B amplitude

$$\frac{\partial^2 \Gamma}{\partial x \partial y} = \frac{m_K}{2^9 \pi^3} \left[z^2 \cdot |A + B|^2 + (y^2 - y_{max}^2)^2 \cdot |B|^2 \right]$$

$$z = \frac{m_{\gamma\gamma}^2}{m_K^2}$$

$$y = \frac{E_1 - E_2}{m_K}$$



In the region of $30 \text{ MeV}/c^2 < m_{\gamma\gamma} < 110 \text{ MeV}/c^2$ and $0 < |y| < 0.2$

- An amplitude gives a negligible contribution
- The acceptance is almost flat

\rightarrow model independent upper limit for the KL $\rightarrow \pi^0\gamma\gamma$ decay rate

BR($\pi^0\gamma\gamma$)[$30 \text{ MeV}/c^2 < m_{\gamma\gamma} < 110 \text{ MeV}/c^2$, $0 < |y| < 0.2$] $< 0.6 \times 10^{-8}$
(preliminary)

Other Results(2)

$K_L \rightarrow e^+e^-e^+e^-$ – (hep-ph/0006040)

139 events found in 1999 data

$$\text{BR}(K_L \rightarrow e^+e^-e^+e^-) = (3.67 \pm 0.32(\text{stat}) \pm 0.23(\text{syst}) \pm 0.08(\text{norm})) \times 10^{-8}$$

$K_L \rightarrow \mu^+\mu^-e^+e^-$

19 events found in the 1999 data

