Results from the NA48 Experiment on Rare Neutral Kaon Decays

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EPS Budapest 12-18 July 2001

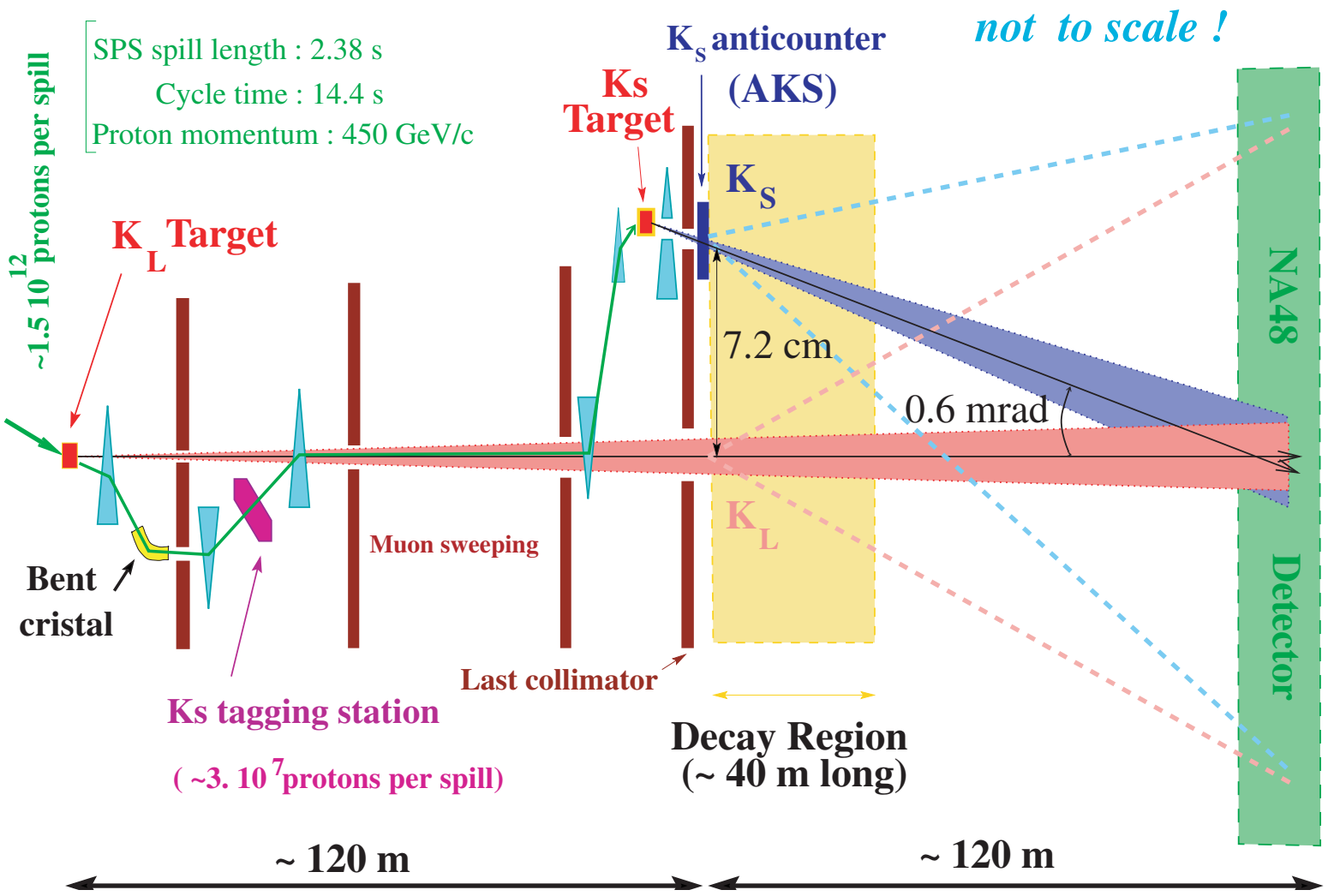
Outline

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

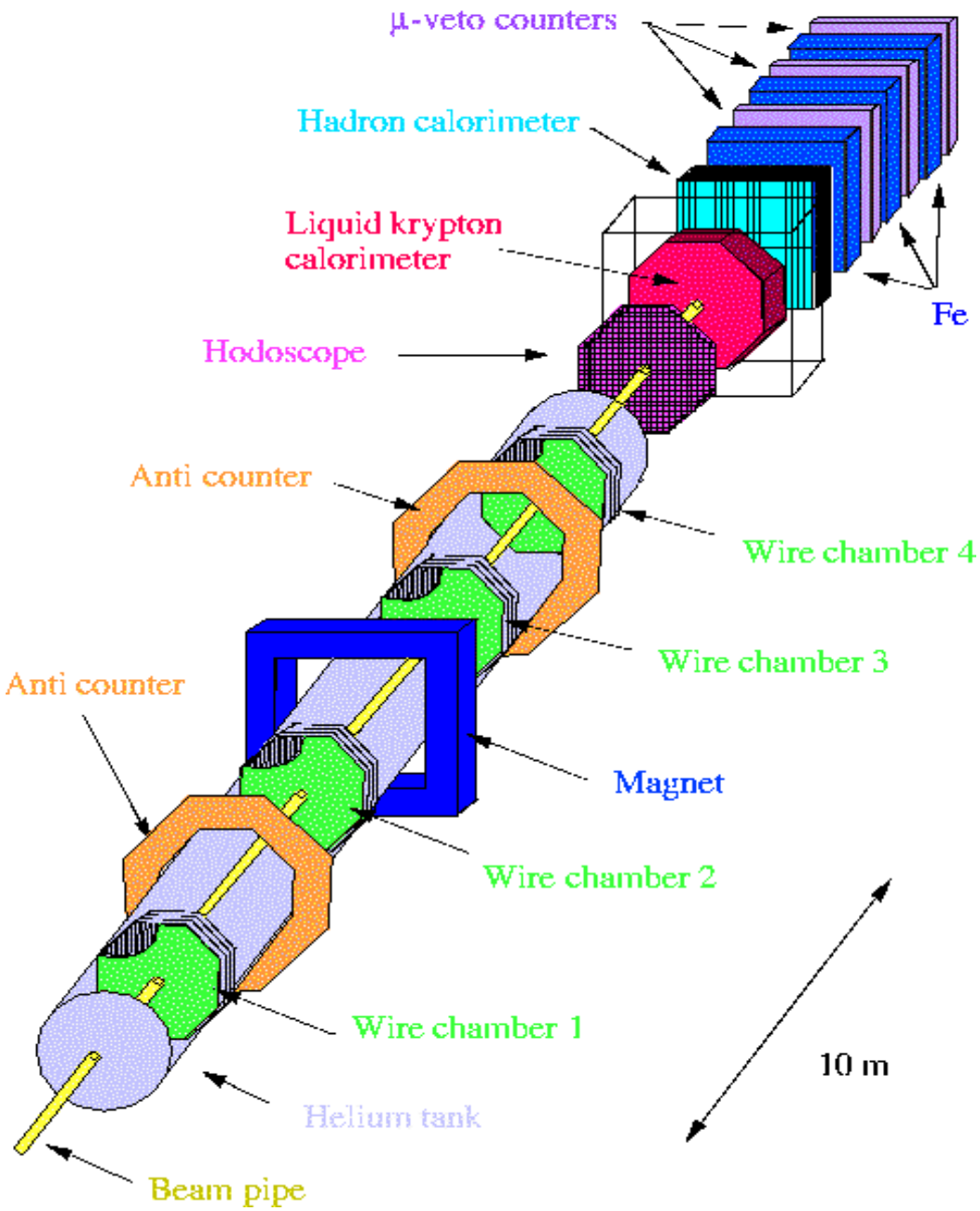
The NA48 Experiment (1)

- 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)



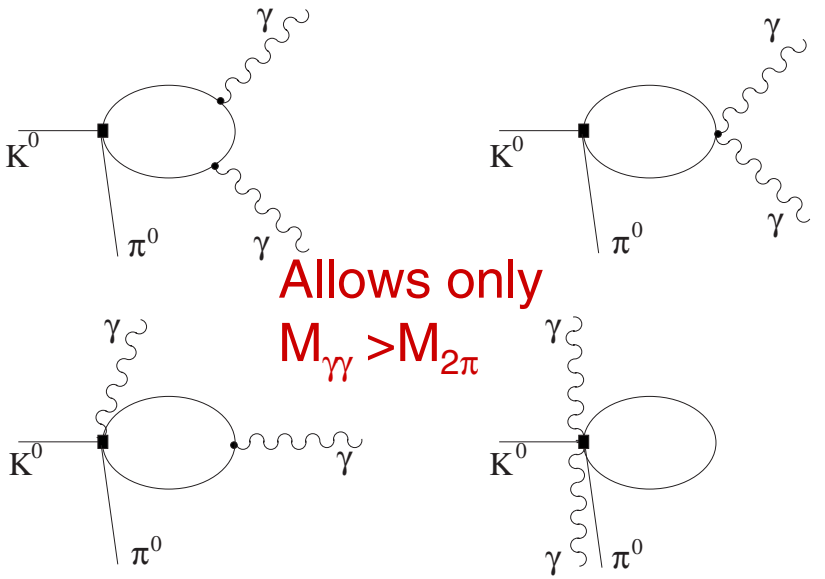
The NA48 Detector



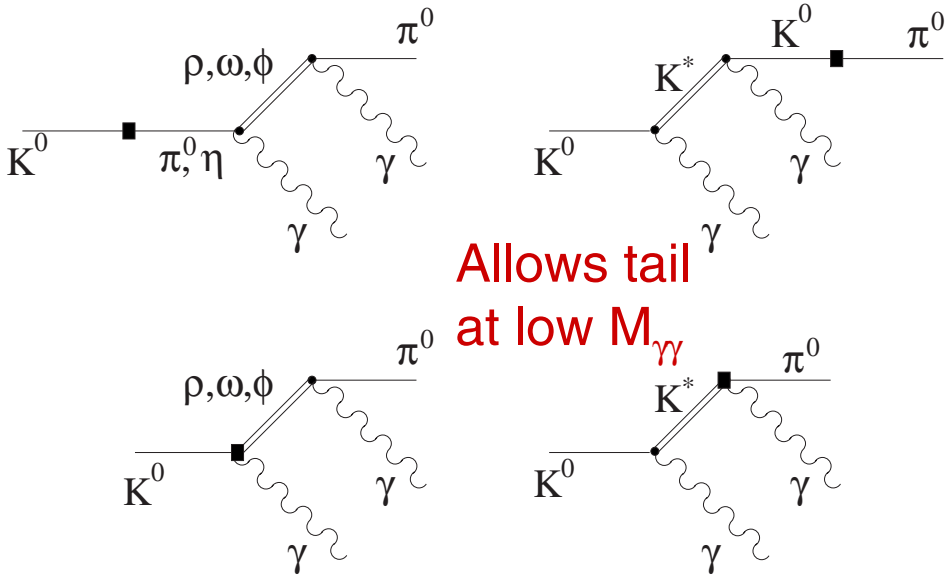
$K_L \rightarrow \pi^0\gamma\gamma$ (1)

Motivation:

- At one loop χPT (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)

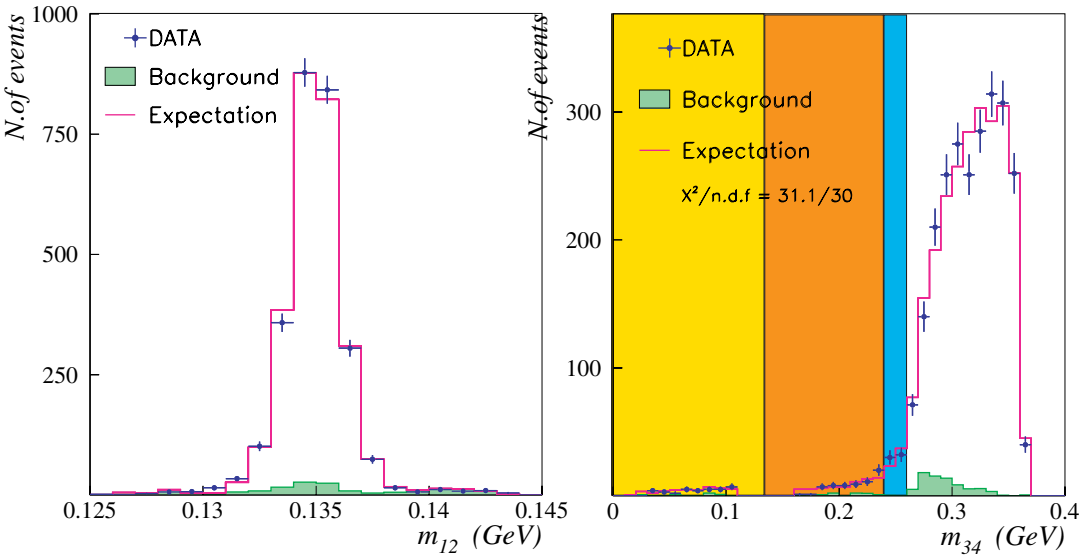
Data Selection:

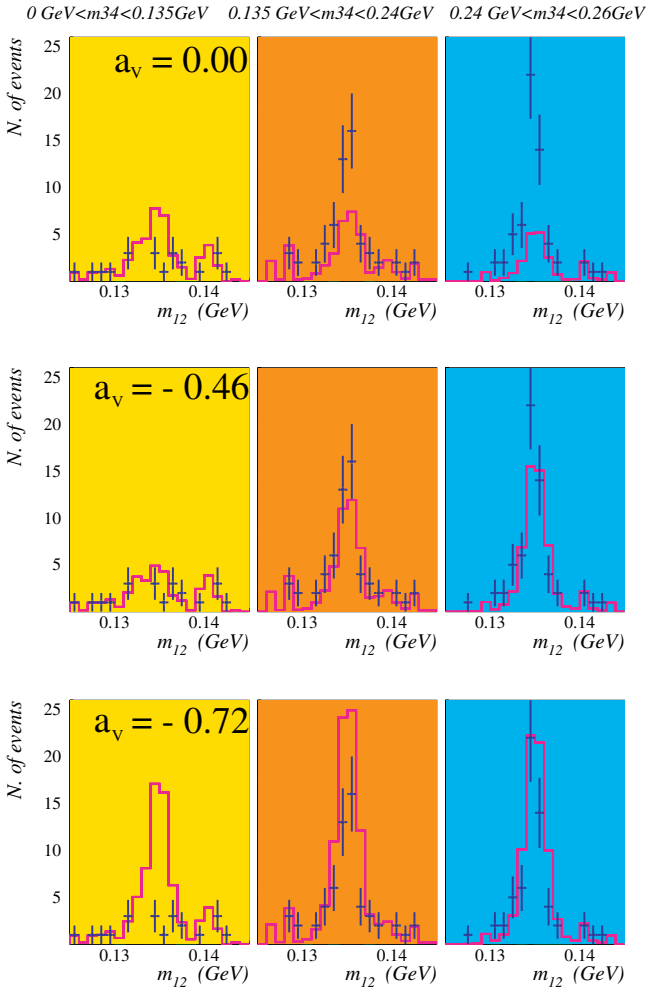
- Events are similar in signature (4 γ) to $K_L \rightarrow \pi^0\pi^0$ (norm. channel) –> most systematic uncertainties cancel.

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 –> 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:

- BR($K_L \rightarrow \pi^0\gamma\gamma$) = $(1.36 \pm 0.03_{(stat)} \pm 0.03_{(syst)} \pm 0.03_{(norm)})\times10^{-6}$
- $a_V = -0.46 \pm 0.03_{(stat)} \pm 0.03_{(syst)} \pm 0.02_{(theo)}$.

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

  $BR(\mathbf{K_L \rightarrow \pi^0 e^+ e^-}) \times 10^{12} = 15.3 a_s^2 - 6.8 a_s \, \mathrm{Im}(\lambda_t) \times 10^4 + 2.8 (\mathrm{Im}(\lambda_t) \times 10^4)^2$,

  with $\mathrm{Im}(\lambda_t) = V^*_{ts} V_{td}$ from the CKM elements.
- Theoretical expectation:

  $$BR(\mathbf{K_s \rightarrow \pi^0 e^+ e^-}) = 5.2 \times 10^{-9} \, a_s^2, \text{ with } a_s^2 \text{ of O(1)}$$
- KL $\rightarrow \pi^0 e^+ e^-$ is interesting because it contains a direct CP violating component
- The current best value for $BR(\mathbf{K_s \rightarrow \pi^0 e^+ e^-}) < 1.1 \times 10^{-6}$ (NA31)

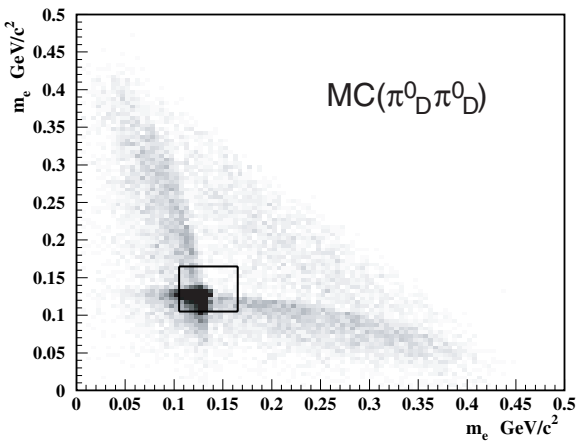
$K_s \rightarrow \pi^0 e^+ e^-$ (2)

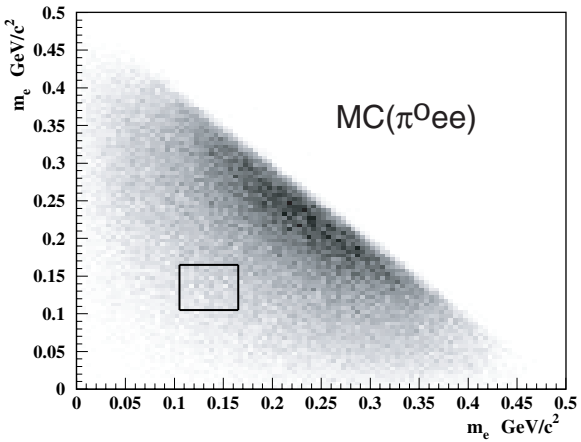
Data Selection:

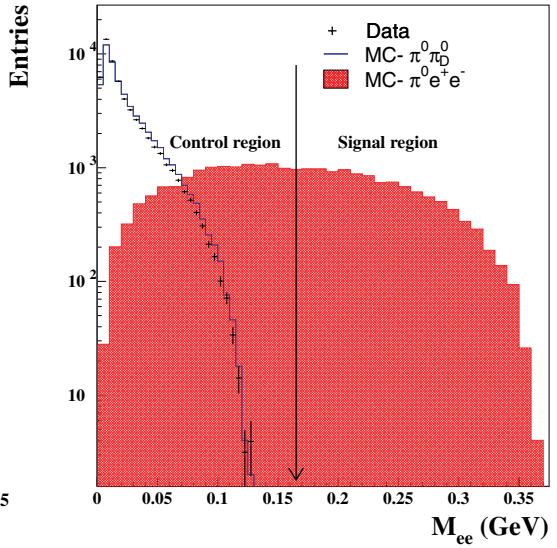
Select events with 2 tracks with $0.9<E/p<1.1$ and at least 4 good clusters in the calorimeter with a mass around the K^0 mass.

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

$M_{ee} > 165$ 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:

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

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)

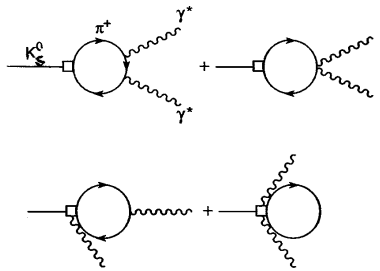
Outlook:

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 χPT, because of its finite and unambiguous result.
- It has no short distance contributions.
- From theory: BR($K_S \rightarrow \gamma\gamma$) = (2.3±0.2) $\times 10^{-6}$.



Data sample:

- 1999 high intensity K_S run with dedicated trigger ($\varepsilon_{trigger}$ >99%)
- Since K_S and K_L are both produced at the target is 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)

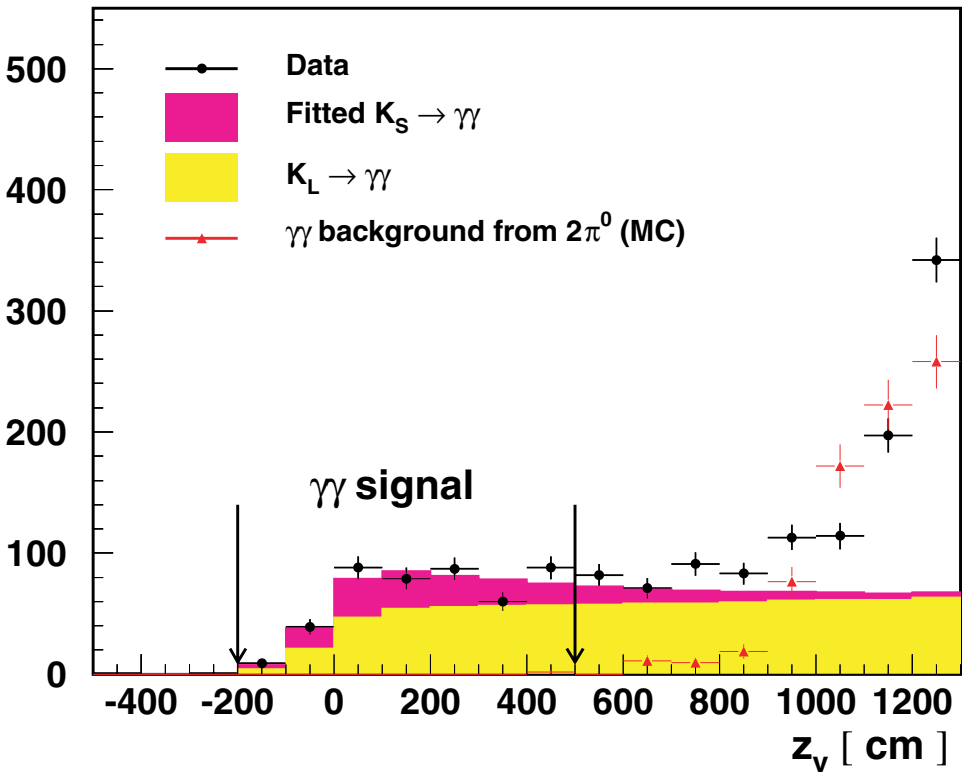
Event Selection:

- 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 –> a virtually background free region of about 5m

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



Results:

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

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

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

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:

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

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

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

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

- 56 events found in 1998 data.

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

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

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

- `and a preliminary measurement of the asymmetry

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

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 $K_L \rightarrow \pi^0\gamma\gamma$:

$BR(K_L \rightarrow \pi^0\gamma\gamma) = (1.36\pm0.5)\times10^{-6}$

$a_V = -0.46\pm 0.05.$

- NA48 has improved the limit for the BR of KS $\rightarrow\pi^0e^+e^-$ by a factor 10:

$BR(K_S \rightarrow \pi^0e^+e^-) < 1.4 \times 10^{-7}$ (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 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 –> $\pi^0\gamma\gamma$ (4)

Upper limit for the B amplitude

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

$$z = \frac{m_{\gamma\gamma}^2}{m_K^2} \qquad y = \frac{E_1 - E_2}{m_K}$$

In the region of 30 MeV/c^2 < $m_{\gamma\gamma}$< 110 MeV/c^2 and 0 < |y| < 0.2
- An amplitude gives a negligible contribution
- The acceptance is almost flat

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

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

Other Results(2)

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

139 events found in 1999 data

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

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

19 events found in the 1999 data