Future NA48 Programs - CP Violation and Rare Decay Measurements in K_S and $K^{\pm}$ Decays

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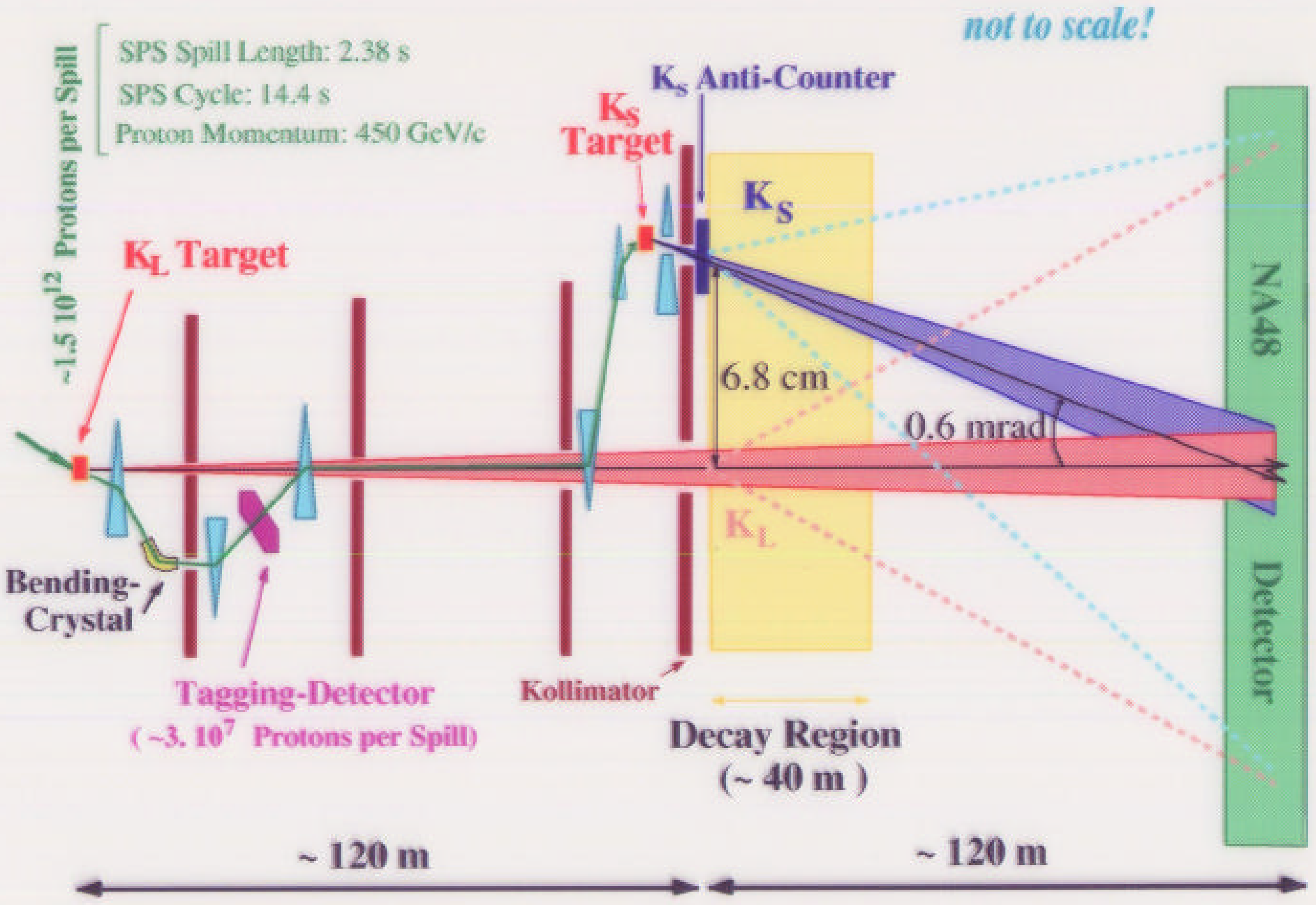
NA48 - A short Introduction

NA48 originally designed to measure the parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ with an accuracy $\sim 2 \times 10^{-4}$

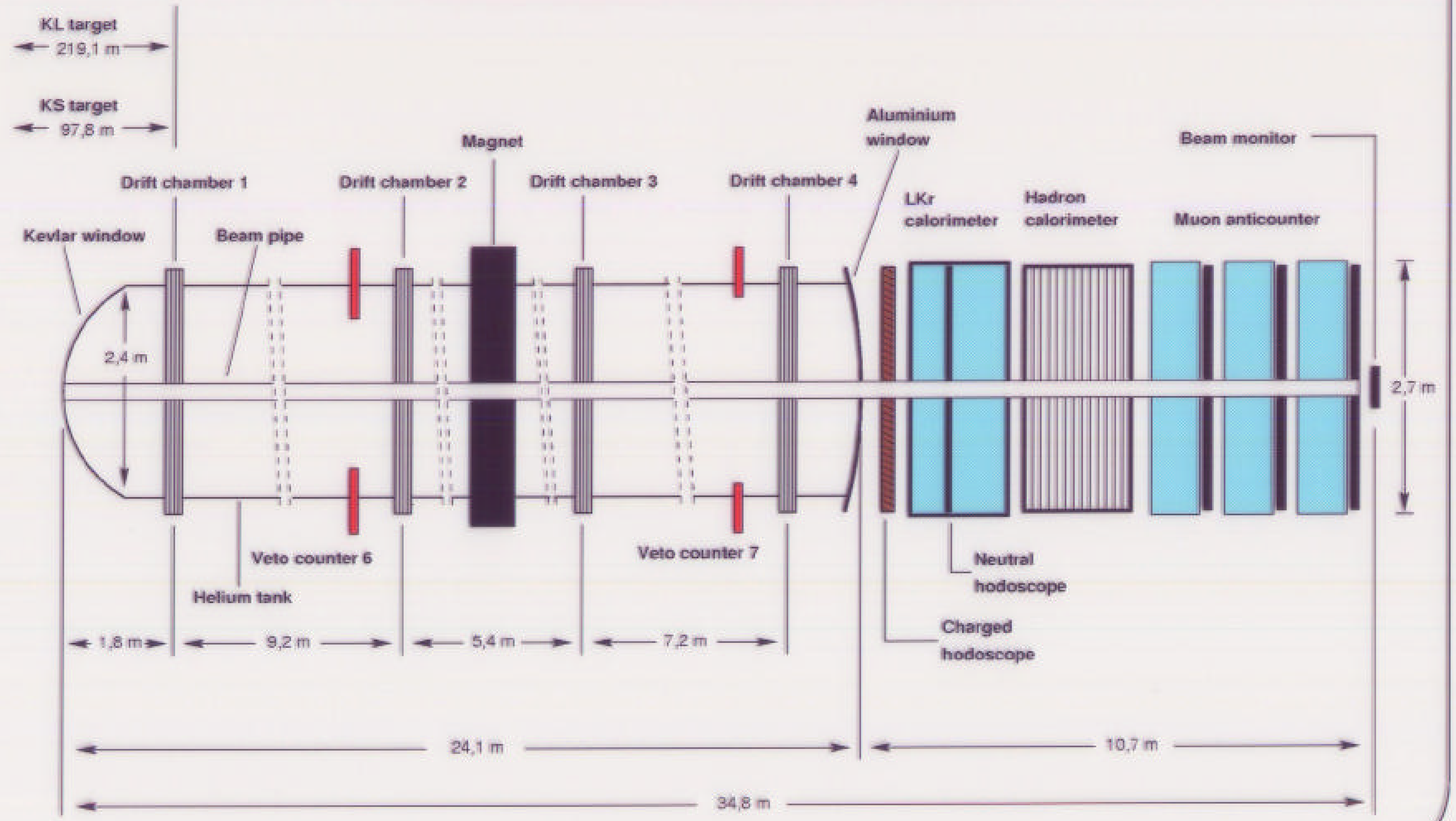
- 2 neutral almost collinear kaon beams with 1.5×10^{12} protons / spill to the K_L-target and 3×10^{7} protons / spill to the K_S-target to measure K_S and K_L decays simultaneously.
- magnet spectrometer with very good momentum and space resolution
- Liquid Krypton calorimeter with excellent energy, space and time resolution

$\rightsquigarrow$ device also very useful to measure rare kaon (and other) decays.

The NA48 Beam Lines



The NA48 Detector



The Performance of the Detector

- Liquid Krypton Calorimeter (LKr)
  - $\frac{\sigma_E}{E} \simeq \frac{3.2\%}{\sqrt{E}} \oplus \frac{0.10}{E} \oplus 0.5\%$
  - $\sigma_t < 300ps$
  - $\sigma_{x,y} \simeq 1.3mm$
- Magnetic Spectrometer
  - $P(kick) \simeq 265MeV/c$
  - $\sigma_P/P \simeq 0.5\% \oplus 0.009\%(P(GeV/c)$
  - $\sigma_{x,y}^{vertex} \simeq 2mm$, $\sigma_z^{vertex} \simeq 50cm$, $\sigma_t^{trk} \simeq 200ps$

Timetable of the Na48 activities

- 1997 - 1999: Data taking for $\mathrm{Re}(\varepsilon'/\varepsilon)$
- 1999: High Intensity K_S test runs of 8h (August) and 40h (September)
- 1999: November: Beampipe in the spectrometer region exploded. Beampipe, 4 chambers and Kevlar window destroyed.
- 2000: Data taking for $\mathrm{Re}(\varepsilon'/\varepsilon)$ (systematic studies) and High Intensity K_S run for neutral decay modes.
- 2000: December - High Intensity K_S- and Charged Kaon program (Addendum 2 and Addendum 3) have been accepted
- 2001: Data taking for $\mathrm{Re}(\varepsilon'/\varepsilon)$
- 2002: Data taking with high intensity K_S beam.
- 2003-2004: Charged Kaon program

CP Violation in the $K_S \to 3\pi$ Decay Modes

- $K_S \to \pi^+\pi^-\pi^0$
  3 Pions $\rightsquigarrow$ internal angular momentum possible
  $CP(\pi^+\pi^-\pi^0) = (-1)^l(-1)^{3+l-l} = (-1)^{l+1}$ $\rightsquigarrow$ CP violating mode for l=0, CP conserving mode for l=1.
  CPLEAR(1998): $Br(K_S \to \pi^+\pi^-\pi^0) = (2.5^{+1.4}_{-1.2}) \times 10^{-7}$, but no CP violation established.

- $K_S \to \pi^0\pi^0\pi^0$
  $CP(\pi^0\pi^0\pi^0) = (-1)$ $\rightsquigarrow$ no CP conserving contribution
  $\rightsquigarrow$ $K_S \to \pi^0\pi^0\pi^0$ similar to $K_L \to \pi^0\pi^0$

CP Violation in the $K_S \to \pi^0\pi^0\pi^0$ Decay Mode

CP violation in $K_S \to 3\pi^0$ is parametrized by

$\eta_{000} = \frac{A(K_S \to 3\pi^0)}{A(K_L \to 3\pi^0} = \epsilon + i\frac{Im(a1)}{Re(a1)}$ with a1: $I = 1$ amplitude

Previous measurements:

- CPLEAR 1998: $Re(\eta_{000}) = -0.18 \pm 0.15$, $Im(\eta_{000}) = 0.15 \pm 0.2$, $BR(90\%CL) < 1.9 \times 10^{-5}$
- SND 1999: $BR(90\%CL) < 1.4 \times 10^{-5}$

CPT Test with η_{000}

η_{000} is also important input to CPT test - Possibility to measure CPT violation parameter $\mathrm{Im}(\delta)$ through Bell-Steinberger relation

(couples the CPT violating phase δ to a linear combination of the η parameters of several CP violating decays)

$$(1 + i\tan\phi_{SW})\,[\,\mathrm{Re}(\epsilon) - i\,\mathrm{Im}(\delta)\,] = \sum_f \alpha_f,$$

where ϕ_{SW} is the superweak phase with $\tan\phi_{SW} = 2\Delta m/(\Gamma_S - \Gamma_L)$ and $\alpha_f = A^*(K_S \to f)A(K_L \to f)/\Gamma_S$.

Best determination so far: CPLEAR $Im(\delta) = (2.4 \pm 5.0) \times 10^{-5}$

Uncertainty dominated by error on η_{000}

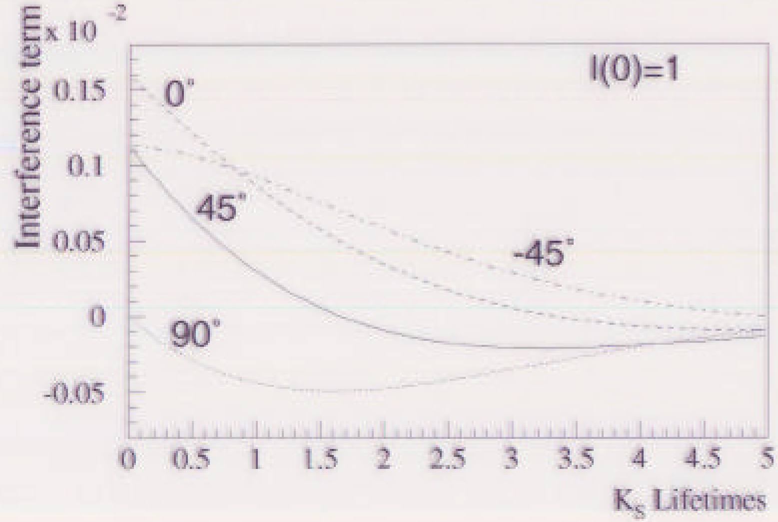
$\rightsquigarrow$ Improvement of CPT test by better limit on η_{000}

How to Measure η_{000}

Sensitivity to η_{000} comes from $K_S - K_L$ interference term (superimposed on a very large, flat $K_L \to \pi^0\pi^0\pi^0$ component).

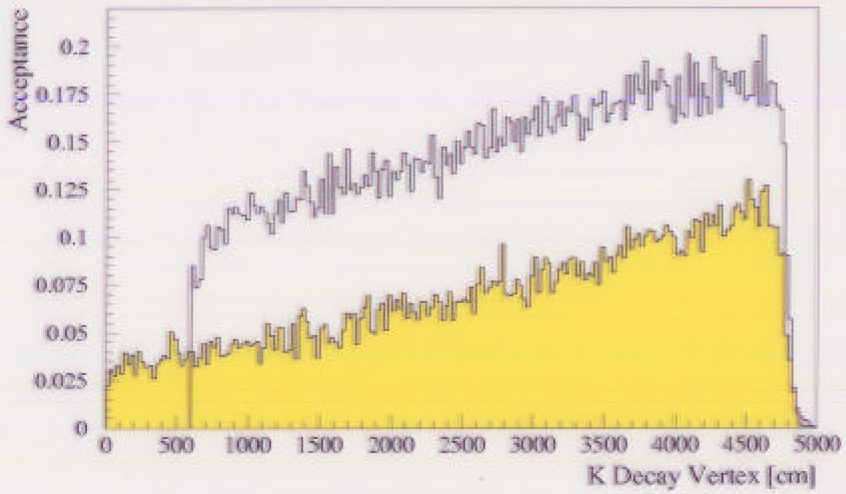
$$I_{3\pi^0}(t) \propto$$
$$e^{-t/\tau_L} + |\eta_{000}|^2 e^{-t/\tau_S} + 2D|\eta_{000}|e^{-t/2(1/\tau_L+1/\tau_S)} \cos(\Delta m t + \phi_{000}),$$

where $D = (N_{K^0} - N_{\bar{K}^0})/(N_{K^0} + N_{\bar{K}^0}) \approx 0.3$ (for NA48)



- High $K^0 \to 3\pi^0$ statics required to improve present limits
- excellent knowledge of detector acceptance necessary

Sensitivity to η_{000} from samples of $3\pi^0$ from a K_S -only high intensity run and a Monte Carlo simulation.



$\rightsquigarrow$ Effect mainly contained within a few K_S lifetimes from the target.
NA48: First lifetime is lost due to the presence of collimator
This effect is partly compensated due to possible higher flux and wider cuts against background compared to situation without

Including the data from 2000 and 2002 it should be possible to set a limit on η_{000} in the order of 1%.

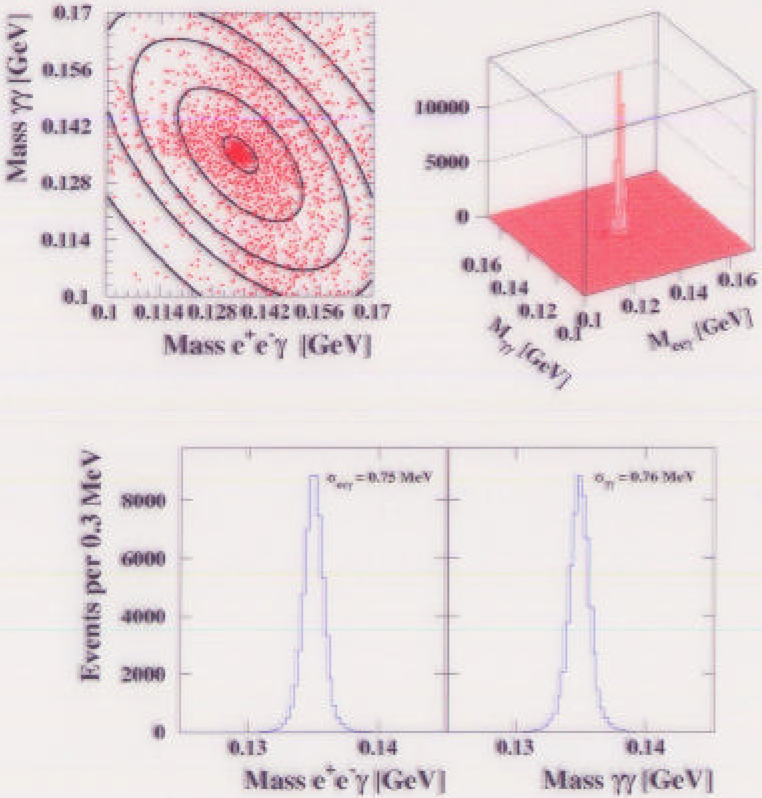
The $K_S \to \pi^0 e^+ e^-$ Decay Mode

Motivation:

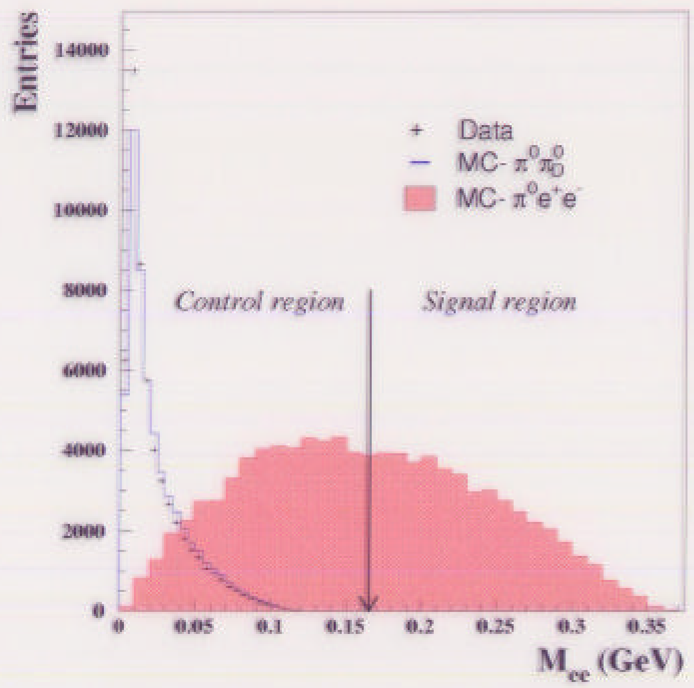
- $K_S \to \pi^0 e^+ e^-$ Theoretical expectation (Ambrosio, Ecker, Isidori and Portolés): $BR(K_S \to \pi^0 e^+ e^-) \simeq 5.2 a_s^2 \times 10^{-9}$ with $a_s^2 \sim O(1)$ (dominated by long-distance dynamics (one photon exchange))
- Constrains the indirect CP violating term in $K_L \to \pi^0 e^+ e^-$

Previous measurement: $BR(K_S \to \pi^0 e^+ e^-) < 1.1 \times 10^{-6} (90\% CL)$ (NA31, 1993)

Normalization: $K_S \to \pi^0\pi^0_D$



- 83960 reconstructed $K_S \to \pi^0\pi^0_D$ events
- Acceptance $A = 4.81\%$
- Background channel $K_S \to \pi^0\pi^0_D \to K_S \to \pi^0 e^+e^-$: 0.3 events



- 1999 High-Intensity-KS data: 0 events with $M_{ee} > 165 MeV/c^2$
- Acceptance: $A = 7.68\%$

⇝ Upper limit of

$Br(K_S \to \pi^0 e^+ e^-, M_{ee} > 165 MeV/c^2) < 8.3 \cdot 10^{-8} (90\% CL)$ (Preliminary)

($\sim$ 10 times better than previous measurement)

(MC of $K_S \to \pi^0 e^+ e^-$ based on model from D'Ambrosio et al)

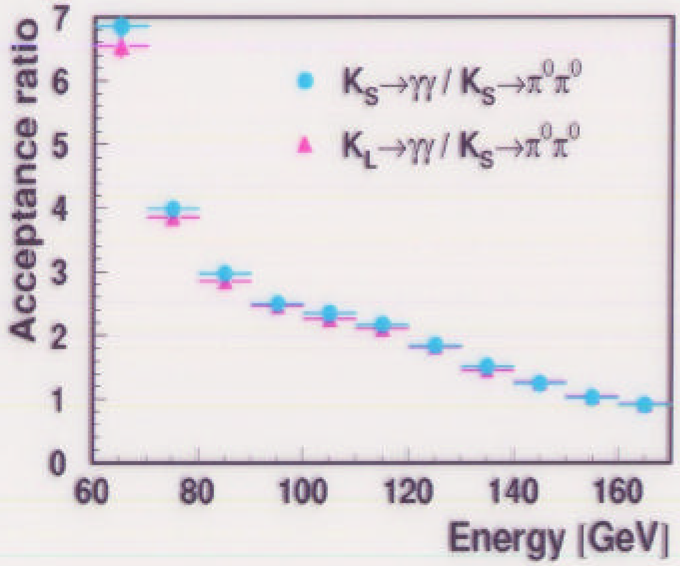
The $\mathrm{K_S} \to \gamma\gamma$ Decay Mode

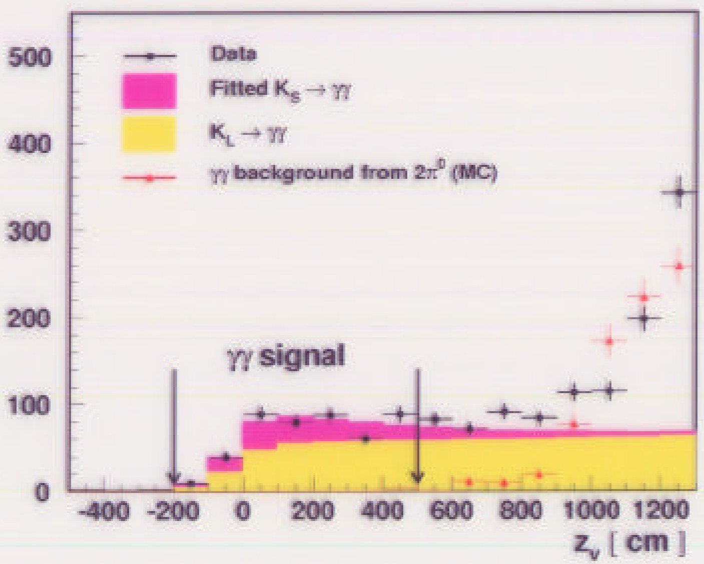
Motivation:

- Negligible short distance contributions
- Unambiguous prediction for the branching ratio from ChPTh: $BR(K_S \to \gamma\gamma) = 2.25 \times 10^{-6} (\pm 10\%)$
- precise measurement of the provides test of ChPTh and gives more information about higher order contributions.

Previous Results: NA31: $BR(K_S \to \gamma\gamma) = (2.4 \pm 0.9) \times 10^{-6}$

1999 High-Intensity-K_S data: 148 $K_S \to \gamma\gamma$ candidates
Background: $\sim 294 K_L \to \gamma\gamma$, $\sim 14 \Lambda \to n\pi^0$, and $\sim 2 K_S \to \pi^0\pi^0$ events. Normalization with $K_S \to \pi^0\pi^0$

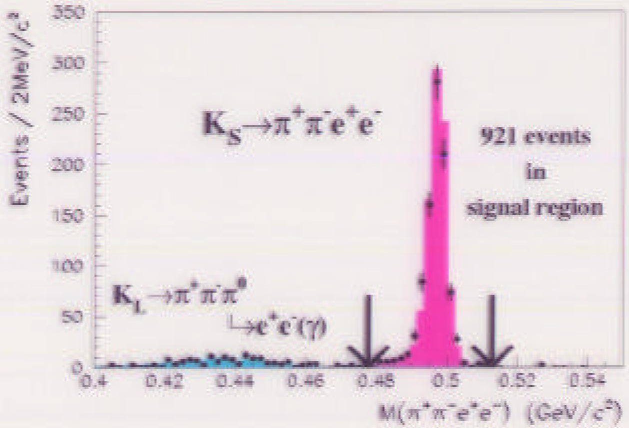


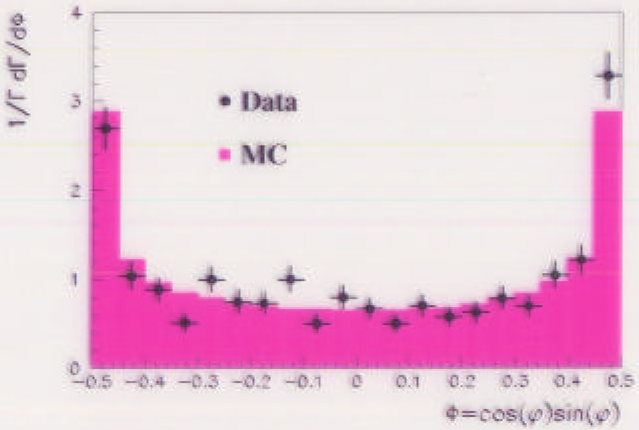


$\rightsquigarrow Br(K_S \to \gamma\gamma) = (2.6 \pm 0.4(stat) \pm 0.2(syst)) \times 10^{-6}$

Recently published in [Phys. Lett. B493 (2000) 29]

The $K_S \to \pi^+\pi^-e^+e^-$ Decay Mode





Unlike $K_L \to \pi^+\pi^-e^+e^-$, no CP asymmetry in the distribution of the angle between the planes of decay of the $\pi^+\pi^-$ and e^+e^- pairs is expected for $K_S \to \pi^+\pi^-e^+e^-$. ⇝ ⇝ Possibility to measure final state interactions on the large asymmetry for the $K_L \to \pi^+\pi^-e^+e^-$ decay

From 1998 and 1999 data we find:

$BR(K_S \to \pi^+\pi^-e^+e^-) = (4.3 \pm 0.2(stat) \pm 0.3(syst)) \times 10^{-3}$

$A^S_{\pi\pi ee} = (-0.2 \pm 3.4(stat) \pm 1.4(syst))\%$

(Preliminary)

Non-leptonic K_S decays

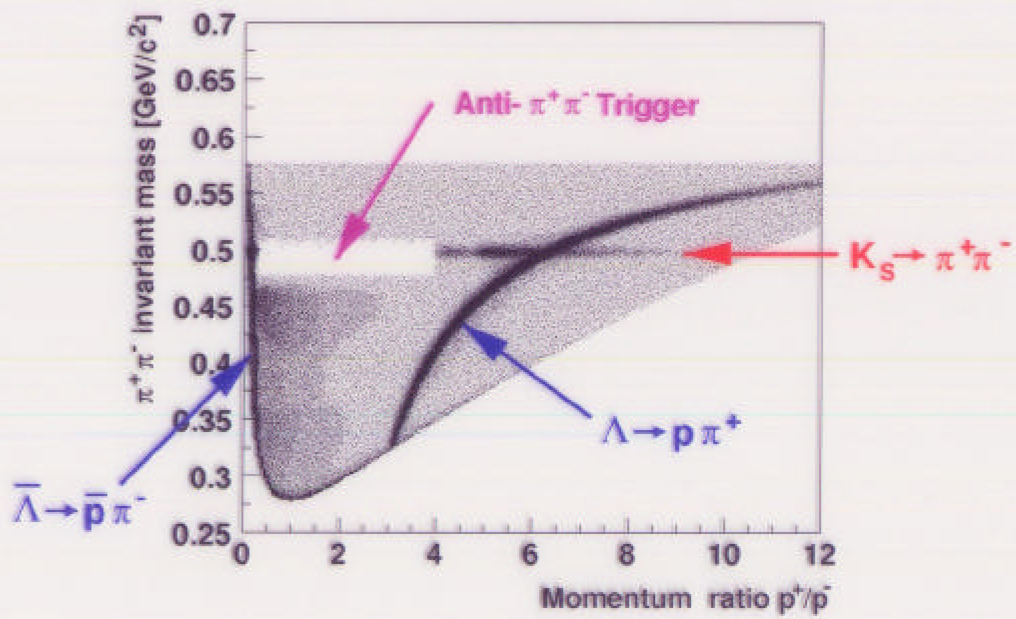
Non-leptonic $K_{S,L}$ decays important for the low energy hadron dynamics of Chiral Perturbation Theory (χPT), since they are sensitive to higher order loop effects.

Decay mode	BR (exp)	BR (th)	Evts/year
$K_S \to \gamma\gamma$	$(2.4 \pm 0.9) \times 10^{-6}$	2.1×10^{-6}	24000
$K_S \to \pi^0\gamma\gamma$		3.8×10^{-8}	114
$K_S \to \pi^0\pi^0\gamma\gamma$		5.6×10^{-9}	7
$K_S \to \pi^0\pi^0\gamma$		1.7×10^{-11}	
$K_L \to \gamma\gamma$	$(5.92 \pm 0.15) \times 10^{-4}$	$\sim 5 \times 10^{-4}$	$25000/c\tau_S$
$K_L \to \pi^0\gamma\gamma$	$(1.70 \pm 0.15) \times 10^{-6}$	1.5×10^{-6}	$23/c\tau_S$
$K_L \to \pi^0\pi^0\gamma\gamma$		2.0×10^{-7}	$1/c\tau_S$
$K_L \to \pi^0\pi^0\gamma$		1×10^{-8}	

Neutral Hyperon Decays

Neutral hyperons as the Λ or the Ξ^0 have about the same lifetime as the K_S ($\sim 10^{-10}s$).

⇝ Decays can be observed by the detector.



1999 K_S Test (40h)

- 41,000,000 two track events recorded
- $\sim 15,000,000$ $\Lambda \to p\pi^-$ events
- $\sim 120,000$ $\Xi^0 \to \Lambda\pi^0$ events

Radiative Hyperon Decays

Hara Theorem (1964): The parity violating amplitude of the decay $\Sigma^+ \to p\gamma$ should vanish in the limit of SU(3) flavour symmetry.

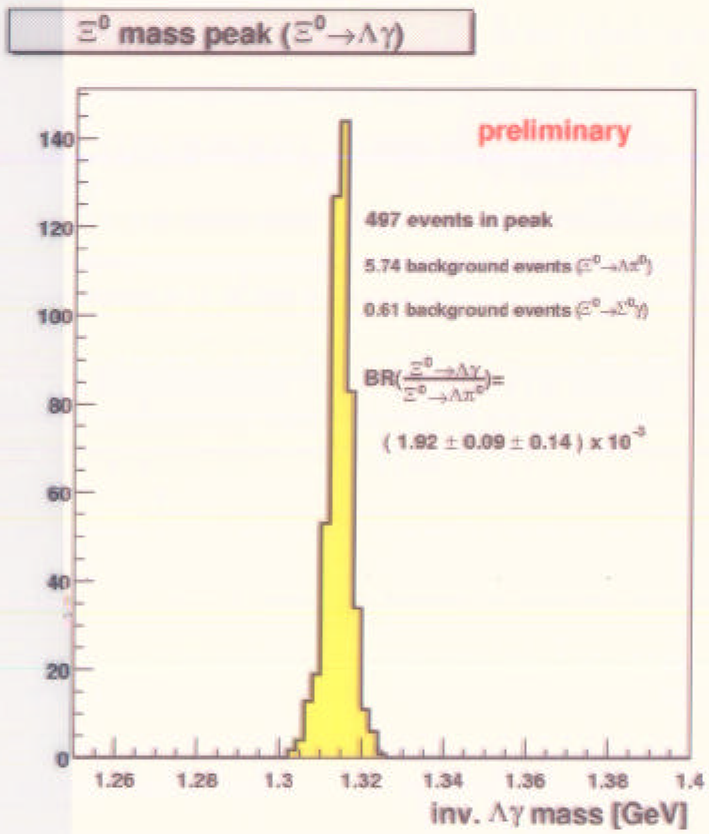
Symmetry is known to be weakly broken ⇝ expect a small asymmetry in that decay mode.

The experimental result differs from that expectation:
$\alpha(\Sigma^+ \to p\gamma) = -0.72 \pm 0.086 \pm 0.045$ (large and negative)

⇝ theoretical problem which becomes even more difficult when all experimental values of asymmetries of the related WRHDs ($\Lambda \to n\gamma$, $\Xi^0 \to \Sigma^0\gamma$, $\Xi^0 \to \Lambda\gamma$) are to be described as well.

⇝No theoretical framework so far to describe both branching ratio and asymmetry at the same time and measurements are not yet of high accuracy.

The Decay $\Xi^0 \to \Lambda\gamma$



- 497 candidates founds
- Background: 5.74 events from $\Xi^0 \to \Lambda\pi^0$, 0.6 events from $\Xi^0 \to \Sigma^0\gamma$
- $BR(\Xi^0 \to \Lambda\gamma) = (1.91 \pm 0.09(stat) \pm 0.14(syst)) \cdot 10^{-3}$
- Branching ratio dependent from decay asymmetry (acceptance)