NA48: Results on Rare Decays and Future Prospects

Cagliari-Cambridge-CERN-Dubna-Edinburgh-Ferrara-Firenze-Mainz-Orsay-Perugia-Pisa-Saclay-Siegen-Torino-Vienna-Warsaw Collaboration

Edoardo Mazzucato
CEA, DSM/DAPNIA
CE-Saclay, 91191 Gif-sur-Yvette Cedex, France

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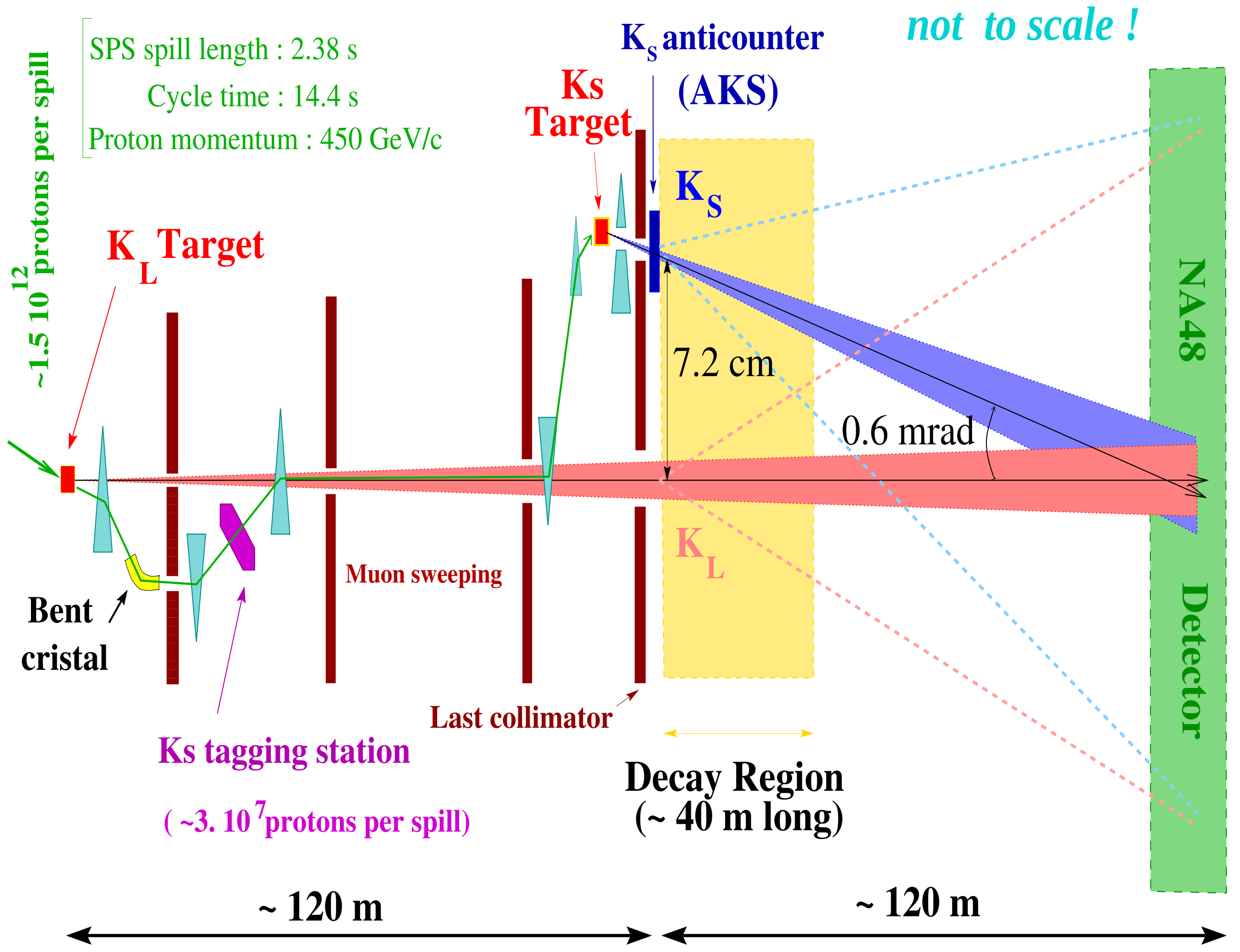
- **Rare Decays in NA48**
- **Recent Results with $K_L + K_S$ beams**
- **Recent Results with a High Intensity K_S beam**
- **Run 2000**
- **Future Prospects**

The NA48 simultaneous K_L and K_S beams



Rare decays in NA48

- 1997 - 1999 Re(ε'/ε) era:

  ◇ 450 GeV/c protons (SPS spill is 2.4 s every 14.4 s)

  ◇ Proton intensities:
  1.2 - 1.4 $\times 10^{12}$ / spill on K_L target
  3 $\times 10^7$ / spill on K_S target

  ◇ K_L flux: $\sim 2 \times 10^7$ / spill K_S flux: $\sim 3 \times 10^2$ / spill

  ◇ In the 70 - 170 GeV/c range:

  3.2×10^{10} K_L decays / year $\Rightarrow$ SES: $\sim 3 \times 10^{-10}$
  6.5×10^7 K_S decays / year $\Rightarrow$ SES: $\sim 1.5 \times 10^{-7}$
  (assuming 10% acceptance)

- 1999 High Intensity K_S Beam:

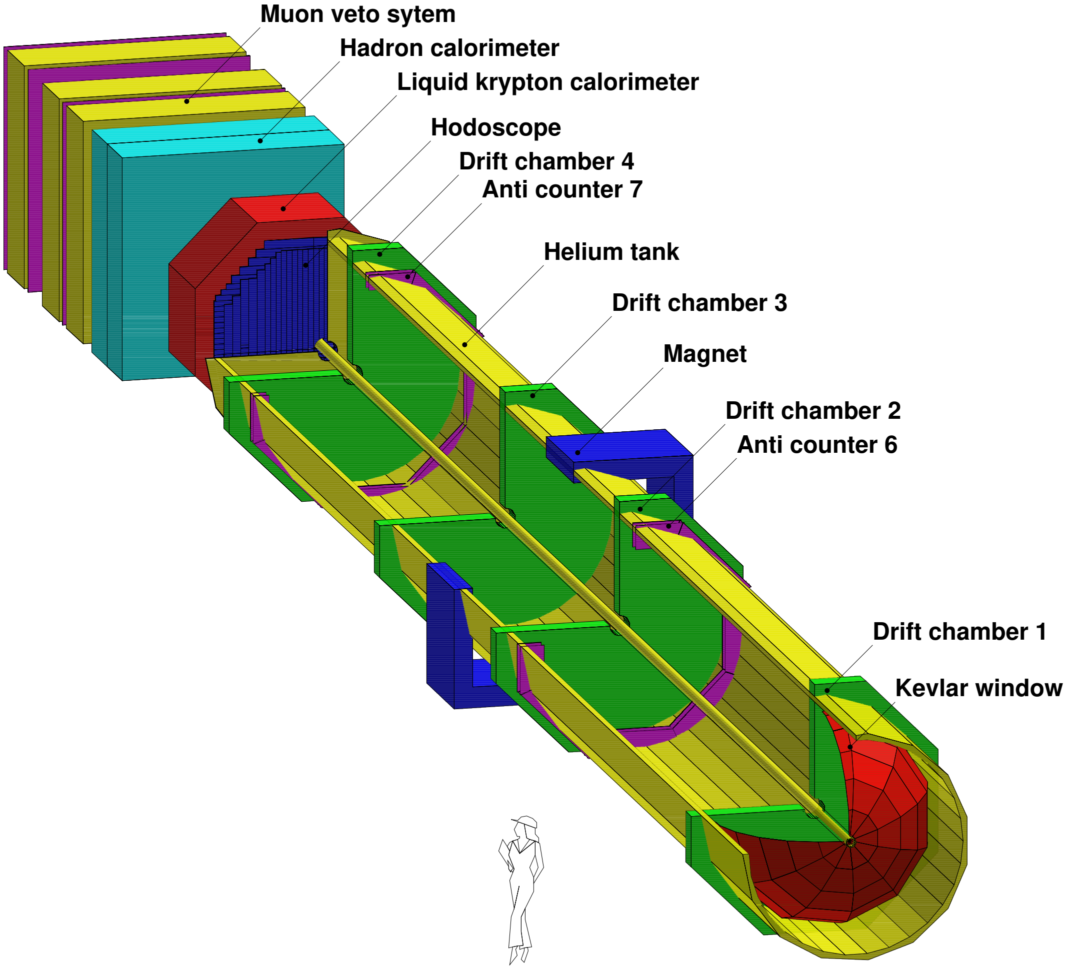
  ◇ No K_L beam

  ◇ Proton beam intensity on K_S target increased by a factor of ~ 200: $I_p \sim 6 \times 10^9$ / spill

  ◇ 2 day run $\approx$ 3-4 years of operation in Re(ε'/ε) mode!

  ◇ $\sim 2.3 \times 10^8$ K_S decays in a 60 - 190 GeV/c range
  (SES: $\sim 4 \times 10^{-8}$ for 10% acceptance)

The NA48 Detector



- **Magnetic Spectrometer ($P_{\perp}^{kick} \simeq$ 265MeV/c)**
  - $\frac{\sigma_P}{P} \simeq 0.5\% \oplus 0.009\% \, P(\mathrm{GeV/c})$ $\qquad \epsilon_{plane} > 99\%$
  - $\sigma^{vtx}_{X,Y} \simeq 2\,mm$ $\qquad \sigma^{vtx}_{Z} \simeq 50\,cm$ $\qquad \sigma^{trk}_{t} \simeq 200\,ps$
- **Liquid Krypton Electromagnetic Calorimeter (LKr)**
  - $\frac{\sigma_E}{E} \simeq \frac{3.2\%}{\sqrt{E}} \oplus \frac{.10}{E} \oplus 0.5\%$ $\;(E\,\mathrm{in\,GeV})$ $\qquad \sigma_{m_{\pi^0}} \simeq 1\,\mathrm{MeV}$
  - $\sigma_{X,Y} < 1.3$ mm and $\sigma_t < 300$ ps above 20 GeV

Triggers

High DAQ capability and triggers versatility

Neutral Triggers :

- 40MHz pipelined system based on LKr information from 64 vertical and 64 horizontal projections.
- Select on number of X and Y number of peaks, total energy, centre-of-gravity (COG), and lifetime.

$$D \equiv Z_{LKr} - Z_{decay} = \frac{\sqrt{\sum_i \sum_{j>i} E_i E_j r_{ij}^2}}{M_K}$$

Used for : $\gamma\gamma$, $e^+e^-\gamma$, $e^+e^-\gamma\gamma$, $\pi^0\gamma\gamma$, $\pi^0e^+e^-$, $3\pi^0 \ldots$

Charged Triggers :

- Total energy, DCH1 track multiplicity and Charged Hodoscopes.
- Level 2 ϵ'/ϵ trigger used as 2 tracks or ≥ 3 tracks vertex finder.

Used for : $\mu^+\mu^-\gamma$, K_{e4}, $e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, $\pi^+\pi^-e^+e^-$

- Additionnal anti - $K_S \to \pi^+\pi^-$ mass and P^+/P^- cuts for **hyperons** during the High Intensity K_S run.

Rare decays in NA48

- K_L decays (concurrently with $\mathrm{Re}(\varepsilon'/\varepsilon)$ measurement)

$K_L \to \pi^0\gamma\gamma$

$K_L \to \pi^0\pi^0\gamma$

$K_L \to \gamma\gamma$

$K_L \to e^+e^-\gamma$

$K_L \to \mu^+\mu^-\gamma$

$K_L \to \pi^0\pi^\pm e^\mp\nu$

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

$K_L \to e^+e^-e^+e^-$

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

- K_S and Hyperon decays (mainly with High Intensity Beams from K_S target)

$K_S \to \gamma\gamma$

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

$K_S \to \pi^0\pi^0\pi^0$

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

$K_S \to \pi^0\gamma\gamma$

$K_S \to \pi^0\pi^0\gamma$

$K_S \to \pi^0\pi^0\gamma\gamma$

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

$\Xi^0 \to \Sigma^0\gamma$

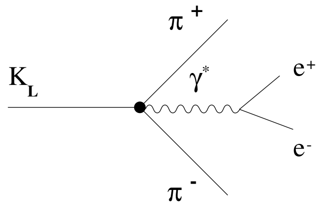
$\Xi^0 \to \Sigma^+e^-\overline{\nu}_e$

$\Xi^0 \to p\pi^-$

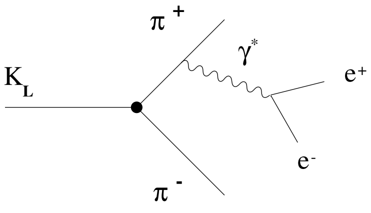
$K_L \to \pi^+\pi^-e^+e^-$

- Main contributions to the $K_L \to \pi^+\pi^-e^+e^-$ process:

(E1, M1)

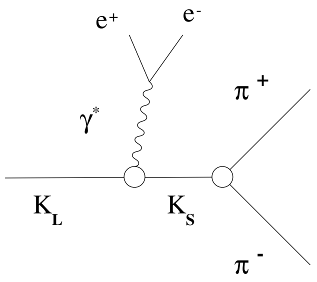


(a) Direct Emission



(b) Inner Bremsstrahlung

(IB)



(CR)

(c) K Charge Radius

- The interference between the dominant M1 (CP=-1) and IB (CP=+1) diagrams gives rise to a large CP-violating asymmetry in the ϕ distribution between the normals to the $\pi^+\pi^-$ and e^+e^- planes in the kaon c.m. system:

$$\frac{d\Gamma}{d\phi} = \Gamma_1 cos^2\phi + \Gamma_2 sin^2\phi + \Gamma_3 sin\phi cos\phi$$

$\Gamma_3 \neq 0 \Rightarrow$ *unambiguous signature of CP violation!*

$$|\mathcal{A}(\phi)| = 15\% sin(\phi_{+-} + \delta_0(M_K^2) - \overline{\delta_1}) \approx 14\%$$

(P. Heiliger and L.M. Sehgal, Phys. Rev. D48 (1993) 4146)

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

- Event selection from 4-track triggers.

- Identification of $K_L \rightarrow \pi^+\pi^-e^+e^-$ events using very good tracking performance of magnetic spectrometer + high resolution LKr calorimetry for e/π separation.

- Large background ($> \times 10^3$) from $K_L \rightarrow \pi^+\pi^-\pi^0_D$ decays can be suppressed using the well-known $P_0'^2$ kinematic variable:

$$P_0'^2 = \frac{(M_K^2 - M_{\pi^0}^2 - M_{\pi\pi}^2)^2 - 4M_{\pi^0}^2 M_{\pi\pi}^2 - 4(P_\perp^2)_{\pi\pi} M_K^2}{4(M_{\pi\pi}^2 + (P_\perp^2)_{\pi\pi})}$$

$P_0'^2 > 0$ for $K_L \rightarrow \pi^+\pi^-\pi^0_D$ but mostly negative for $K_L \rightarrow \pi^+\pi^-e^+e^-$

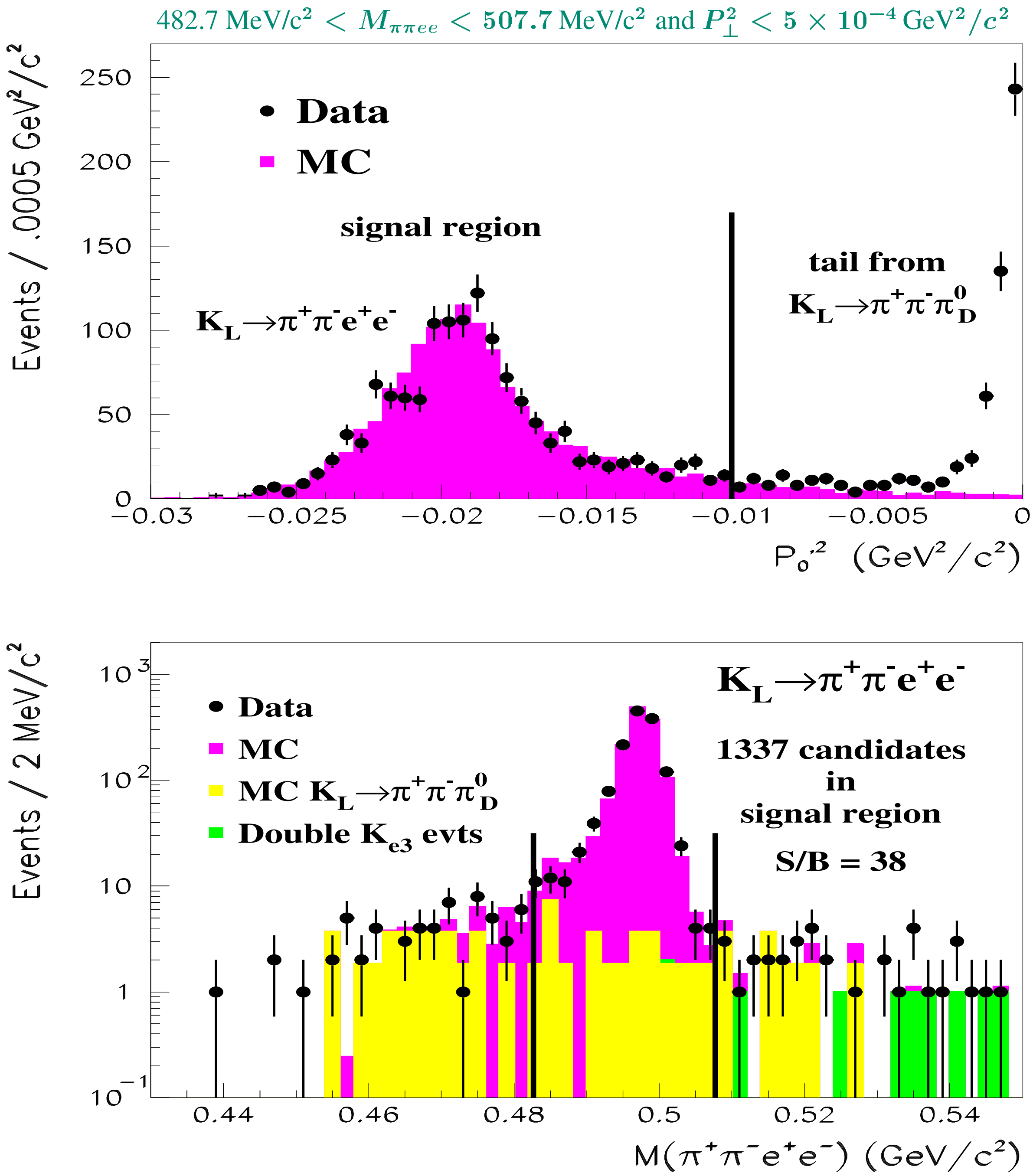
- γ conversions in kevlar window from $K_L \rightarrow \pi^+\pi^-\gamma$ decays removed by requiring 2 cm separation between electron tracks in DCH1.

- Use fully reconstructed $K_L \rightarrow \pi^+\pi^-\pi^0_D \rightarrow \pi^+\pi^-e^+e^-\gamma$ decays as normalization channel.

  $\Rightarrow$ Trigger + reconstruction inefficiencies cancel to first order

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

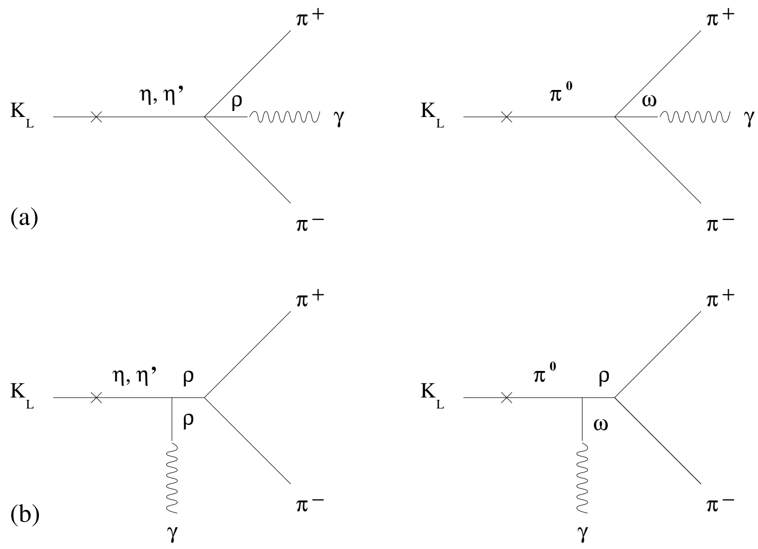
1998 + 1999 data



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

- The branching ratio and asymmetry determination for the $K_L \to \pi^+\pi^-e^+e^-$ process is based on the model of Heiliger and Sehgal (1993) + the inclusion of a form factor (F) in the M1 direct emission term:

$$F = \tilde{g}_{M1}\left[1 + \frac{a_1/a_2}{(M_\rho^2 - M_K^2) + 2M_K E_\gamma^*}\right]$$



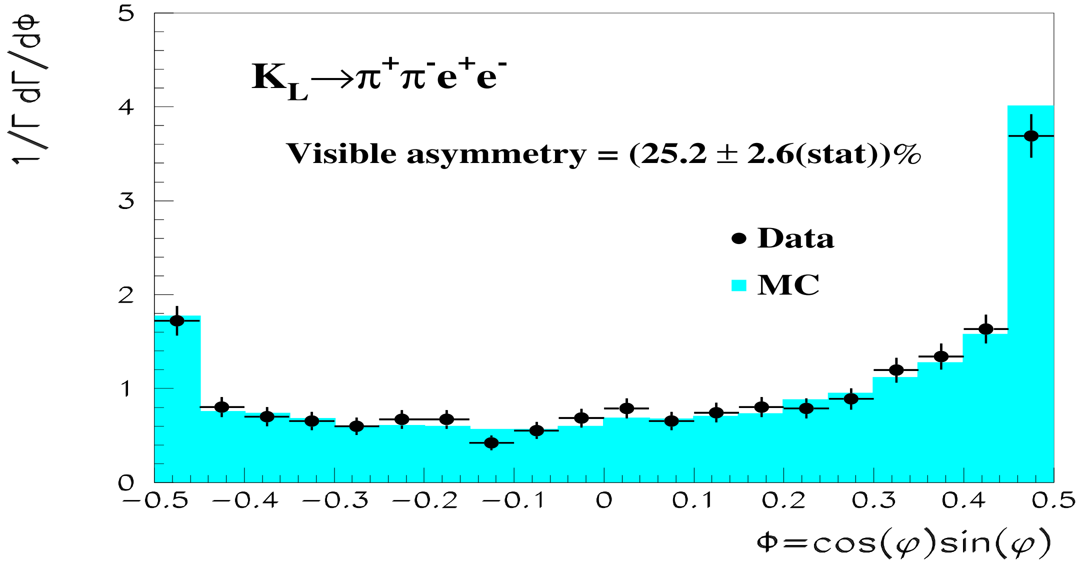
- Using $\tilde{g}_{M1} = 1.35^{+0.20}_{-0.17}$ and $a_1/a_2 = -0.720 \pm 0.029\ \mathrm{GeV}^2/c^2$ as measured by KTeV (Phys. Rev. Lett. 84 (2000) 408) we obtain the preliminary result:

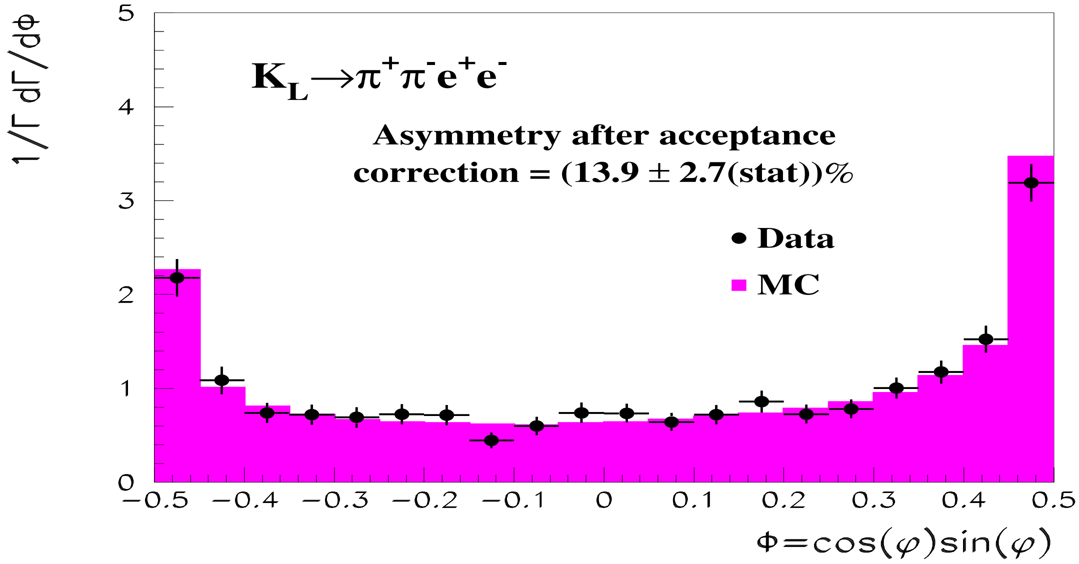
$$\mathrm{BR}(K_L \to \pi^+\pi^-e^+e^-) = (3.1 \pm 0.1_{stat} \pm 0.2_{syst}) \times 10^{-7}$$

KTeV (preliminary): $(3.63 \pm 0.11 \pm 0.14) \times 10^{-7}$

- Extraction of the $\tilde{g}_{M1}$ and a_1/a_2 parameters from the NA48 1998 + 1999 data in progress.

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





Preliminary result in agreement with theoretical expectations:

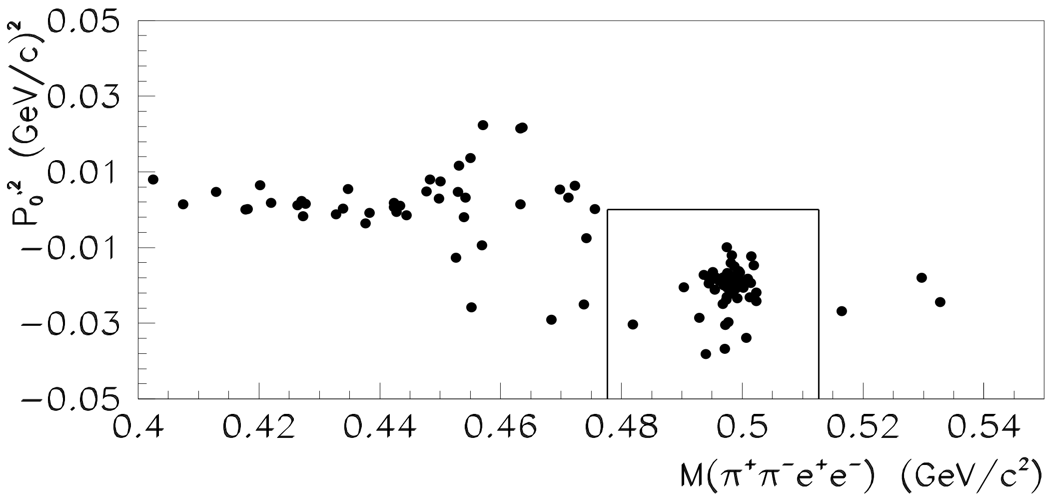
$$\mathcal{A}^L_{\pi\pi ee} = (13.9 \pm 2.7_{stat} \pm 2.0_{syst})\%$$ ('98 + '99 data)

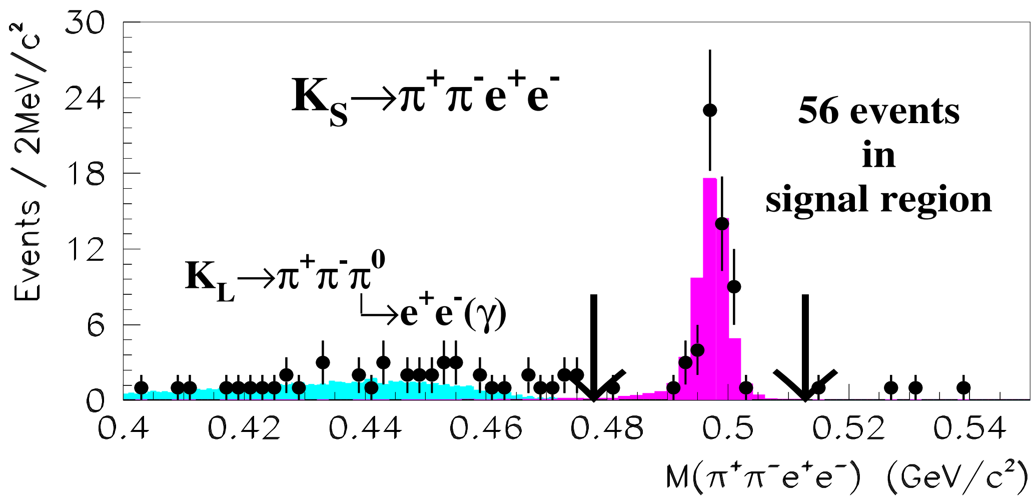
KTeV: $\mathcal{A}^L_{\pi\pi ee} = (13.6 \pm 2.5_{stat} \pm 1.2_{syst})\%$
(Phys. Rev. Lett. 84 (2000) 408)

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

- Rely on very good vertex resolution for K_S/K_L separation
- Tagger detector provides extra $\times 20$ in background suppression from K_L beam.
- $K_L \to \pi^+\pi^-\pi^0_D$ decays produced at K_S target used as normalization channel.

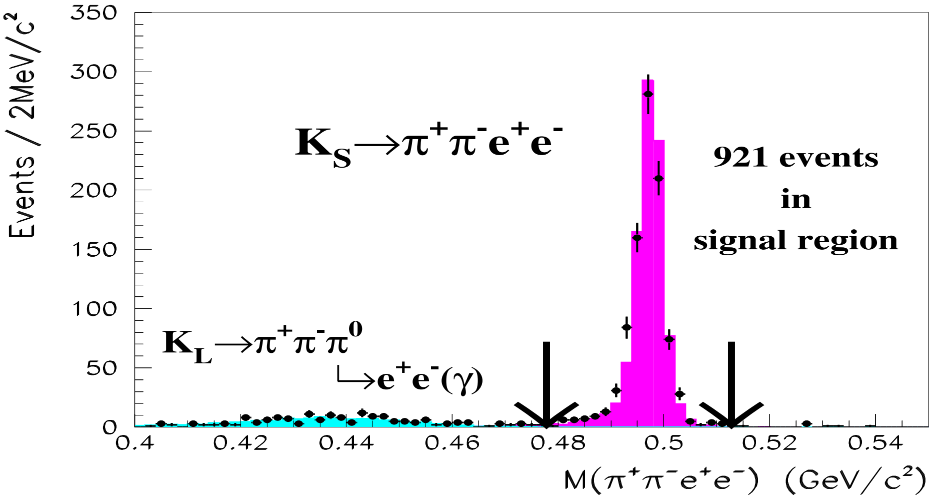
First observation of $K_S \to \pi^+\pi^-e^+e^-$ with 1998 data!

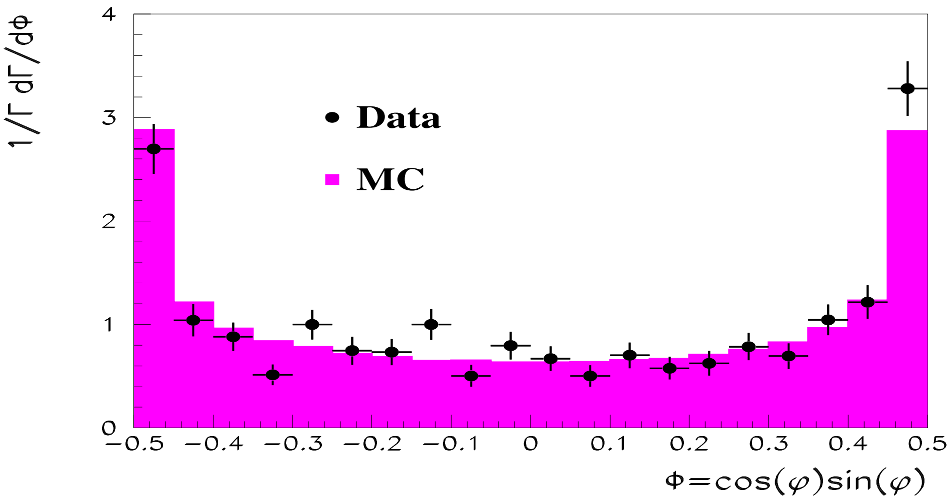




$K_S \to \pi^+\pi^-e^+e^-$

1998 + 1999 data .... (with 2 days of High Intensity K_S beam in 1999)





Preliminary results:

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

$$\Rightarrow \mathrm{BR}(K_L^{IB} \to \pi^+\pi^-e^+e^-) = (1.3 \pm 0.1) \times 10^{-7}$$

No asymmetry observed:

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

Rare K_L decays

Preliminary results!

Channel	Year	Events	S/B
$K_L \to \pi^+\pi^- e^+e^-$	1998 + 1999	1337	38
	BR = $(3.1 \pm 0.1_{stat} \pm 0.2_{syst}) \times 10^{-7}$ $\mathcal{A}^L_{\pi\pi ee} = (13.9 \pm 2.7_{stat} \pm 2.0_{syst})\%$		
$K_L \to e^+e^-e^+e^-$	1999	132	40
	BR = $(3.67 \pm 0.32_{stat} \pm 0.23_{syst} \pm 0.08_{norm}) \times 10^{-8}$		
$K_L \to e^+e^-\mu^+\mu^-$	1999	19	
$K_L \to e^+e^-\gamma\gamma$	1997 + 1998	492	20
	BR = $(6.32 \pm 0.31_{stat} \pm 0.20_{syst} \pm 0.29_{norm}) \times 10^{-7}$ $(E_{\gamma^*} > 5$ MeV)		
$K_L \to \pi^0\gamma\gamma$	part of 1998 + 1999	1397	47
	BR = $(1.51 \pm 0.05_{stat} \pm 0.20_{syst}) \times 10^{-6}$ $(a_v = -0.45)$		

$K_S \to \gamma\gamma$

- **Theoretical Motivation:**

  - Short distance contributions are negligible.
  - Within the framework of chiral lagrangians, the one-loop contribution to $K_S \to \gamma\gamma$ is finite and gives an unambiguous prediction of the branching ratio.
  - A precise determination of BR$(K_S \to \gamma\gamma)$ would provide a valuable test of χPT and shed light on contributions from higher-order loop corrections.

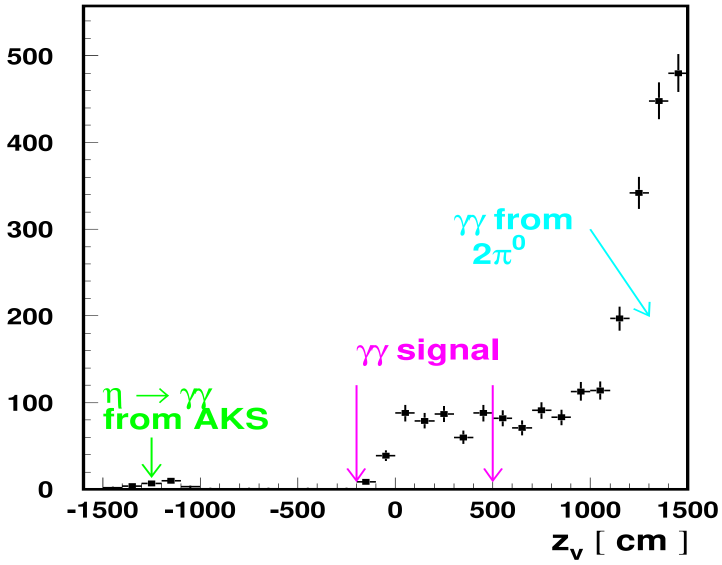
  NA31 (1995): BR$(K_S \to \gamma\gamma) = (2.4 \pm 0.9) \times 10^{-6}$
  Theory: BR$(K_S \to \gamma\gamma) = 2.25 \times 10^{-6}$ $(\pm 10\%)$

- **NA48 Experimental Features:**

  - The study of $K_S \to \gamma\gamma$ can only be carried out in a very restricted decay region, close to the end of the beam collimators, due to the large background from $K_S \to \pi^0\pi^0$ decays.
  - Maximum $M_{\gamma\gamma}$ from $K_S \to \pi^0\pi^0$decays $<$ 458 MeV/c^2
    - $\Rightarrow$ apparent neutral vertex shift of $\sim$ 9 m
    - $\Rightarrow$ mainly $K_{L,S} \to \gamma\gamma$ in that region
  - Selective neutral trigger obtained with $COG < 15$ cm cut, $E > 50$ GeV and $n_{peaks} < 3$ in both x and y LKr calorimeter projections.
  - Normalize $\gamma\gamma$ data with abundant $K_S \to \pi^0\pi^0$ decays with a downscaled minimum bias trigger.

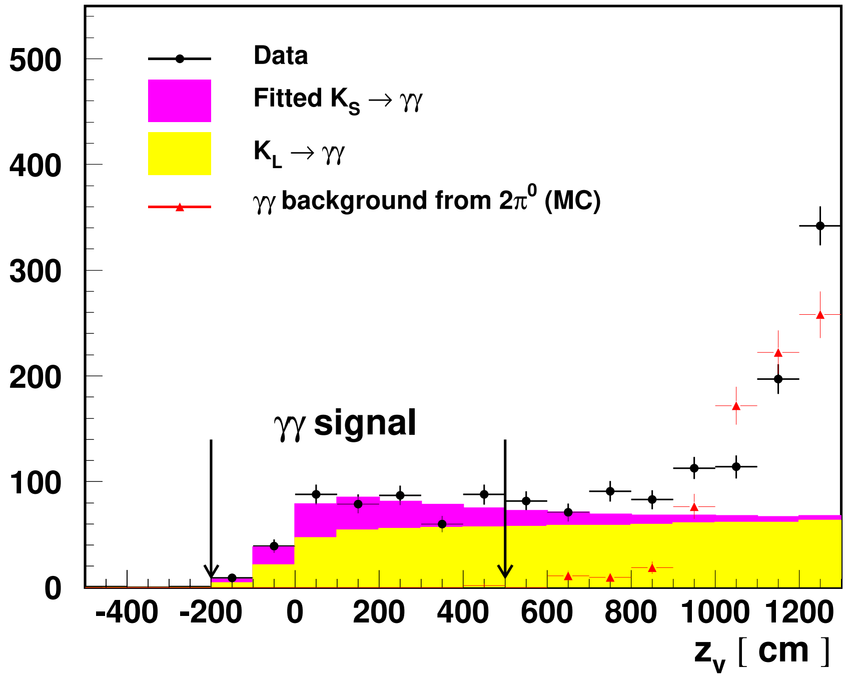
$K_S \rightarrow \gamma\gamma$

1999 data collected in 2 days with a High Intensity K_S beam



$60 < E < 170\,\mathrm{GeV}$

$COG < 7\,\mathrm{cm}$



$-2\,\mathrm{m} < Z_V < 5\,\mathrm{m}$

450 $K \rightarrow \gamma\gamma$ candidates

From binned ML method:

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

Bkg:

2 ± 2 $K_S \rightarrow \pi^0\pi^0$

11 ± 8 $\Lambda \rightarrow n\pi^0$

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

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

(Submitted to Phys. Lett. B)

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

Motivations:

- $K_S \to \pi^0 e^+ e^-$ is dominated by long-distance dynamics through one-photon exchange. Theoretical expectation:

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) \simeq 5.2 a_S^2 \times 10^{-9} \quad \text{with } a_S \sim \mathcal{O}(1)$$

G. D'Ambrosio, G. Ecker, G. Isidori and J. Portolés, JHEP 08 (1998) 004

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

- A more precise measurement of $\mathrm{BR}(K_S \to \pi^0 e^+ e^-)$ is clearly important to improve the limit on the indirect CP violating term in $K_L \to \pi^0 e^+ e^-$

  - $\mathrm{BR}(K_L \to \pi^0 e^+ e^-)_{CPC} \lesssim$ few $\times 10^{-12}$
    dominated by the two-photon process $K_L \to \pi^0 \gamma^* \gamma^*$

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

$$\left[15.3 a_S^2 - 6.8 \frac{Im(\lambda_t)}{10^{-4}} a_S + 2.8 \left(\frac{Im(\lambda_t)}{10^{-4}}\right)^2\right] \times 10^{-12}$$

$\lambda_t = V_{td} V_{ts}^*$ describes the short distance CP violation.

$$Im(\lambda_t) \sim \mathcal{O}(10^{-4})$$

With $a_S \lesssim$ -0.5 or $a_S \gtrsim$ 1.0, the rate of $K_L \to \pi^0 e^+ e^-$ would be mainly due to CP violating effects and the determination of $\mathrm{BR}(K_S \to \pi^0 e^+ e^-)$ could become accessible to experiment.

In a 2 day long run with a High Intensity K_S beam, NA48 has improved the limit on $\mathrm{BR}(K_S \to \pi^0 e^+ e^-)$ by almost a factor 10 !

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

1999 High Intensity K_S run

- "Dalitz" Trigger: $\sim$4k / SPS cycle $\epsilon^{trigger} > 99\%$

E >50 GeV COG <15 cm τ/τ_S <5

$n^x_{peaks} + n^y_{peaks} \geq 8$ $E_{had} < 10$ GeV n^{DCH1}_{trks} >0

- Main background from $K_S \to \pi^0\pi^0_D \to \pi^0 e^+ e^- (\gamma)$

Kinematical limit is $M_{ee} < M_{\pi^0} \simeq 135$ MeV/c^2 ... can be spoiled by resolution effects or interactions in detector material!

- Event selection:

4 clusters in LKr and 2 tracks with $0.9 < E/P < 1.1$

60 GeV< E_K < 190 GeV 600 cm< Z_{vtx} < 4500 cm

$d^{DCH1}_{ee} > 2$ cm $E_{had} < 6$ GeV $COG < 10$ cm

$|M_{\gamma\gamma} - M_{\pi^0}| < 3$ MeV/c^2 $|M_{ee\gamma\gamma} - M_K| < 6$ MeV/c^2

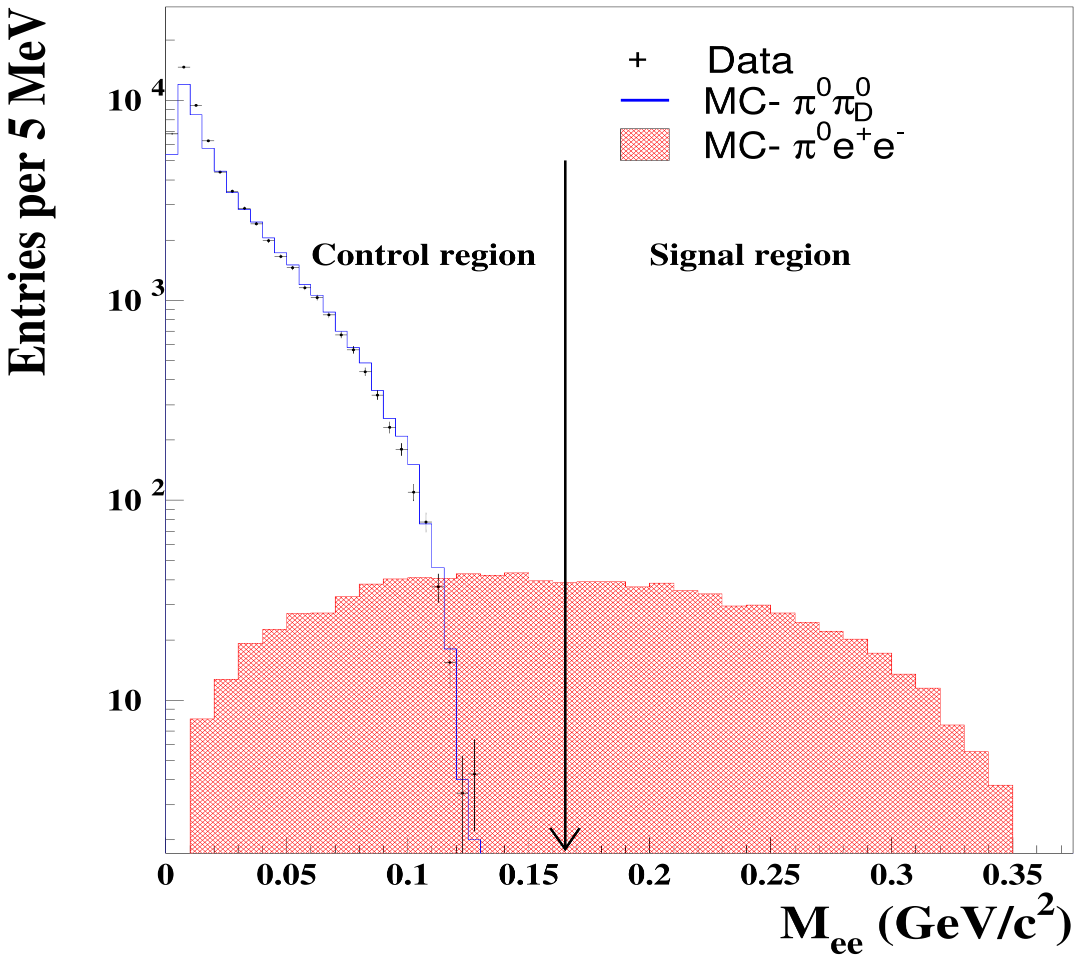
- $K_S \to \pi^0\pi^0_D$ and $K_S \to \pi^0_D\pi^0_D$ background rejection:

$M_{ee} > 165$ MeV/c^2 $|M_{e\gamma} - M_{\pi^0}| > 30$ MeV/c^2

- Normalization: $K_S \to \pi^0\pi^0_D \to \pi^0 e^+ e^- \gamma$

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

No $K_S \to \pi^0 e^+ e^-$ candidate found with M_{ee} >165 MeV/c²



MC simulation of $K_S \to \pi^0 e^+ e^-$ based on model of G. D'Ambrosio et al., (1998).

$<$ 0.03 event expected in signal region from
$K_S \to \pi^0 \pi^0_D \to \pi^0 e^+ e^- (\gamma)$

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

$\sim 2.3 \times 10^8$ K_S **decays**

Channel	Nb of events	Acceptance (%)
$K_S \to \pi^0 e^+ e^-$ ($M_{ee} > 165\,\mathrm{MeV/c^2}$)	0	7.7
$K_S \to \pi^0 \pi^0_D$ *(normalization)*	84 k	4.8
$K_S \to \pi^0 \pi^0_D \to \pi^0 e^+ e^- (\gamma)$	< 0.03	
$K_S \to \pi^0_D \pi^0_D \to \pi^0 e^+ e^- (e^+ e^- \gamma\gamma)$	< 0.03	

Systematics: $\sim 10\%$

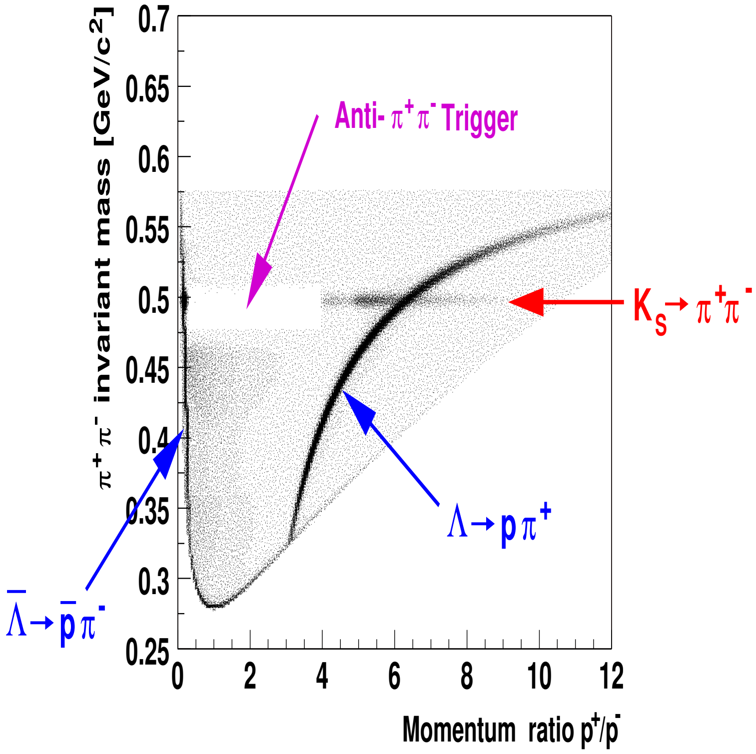
$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) < 1.6 \times 10^{-7} \quad (90\%\ \mathrm{CL})$$

$$\Rightarrow \quad \mathrm{BR}(K_L^{mixing} \to \pi^0 e^+ e^-) < 4.6 \times 10^{-10} \quad (90\%\ \mathrm{CL})$$

Preliminary!

Neutral Hyperon decays

- Hyperon Trigger: use combined cuts on invariant $\pi^+\pi^-$ mass and p^+/p^- momenta ratio.



41×10^6 2-track events

$17\times10^6\ \Lambda \to p\pi^-$

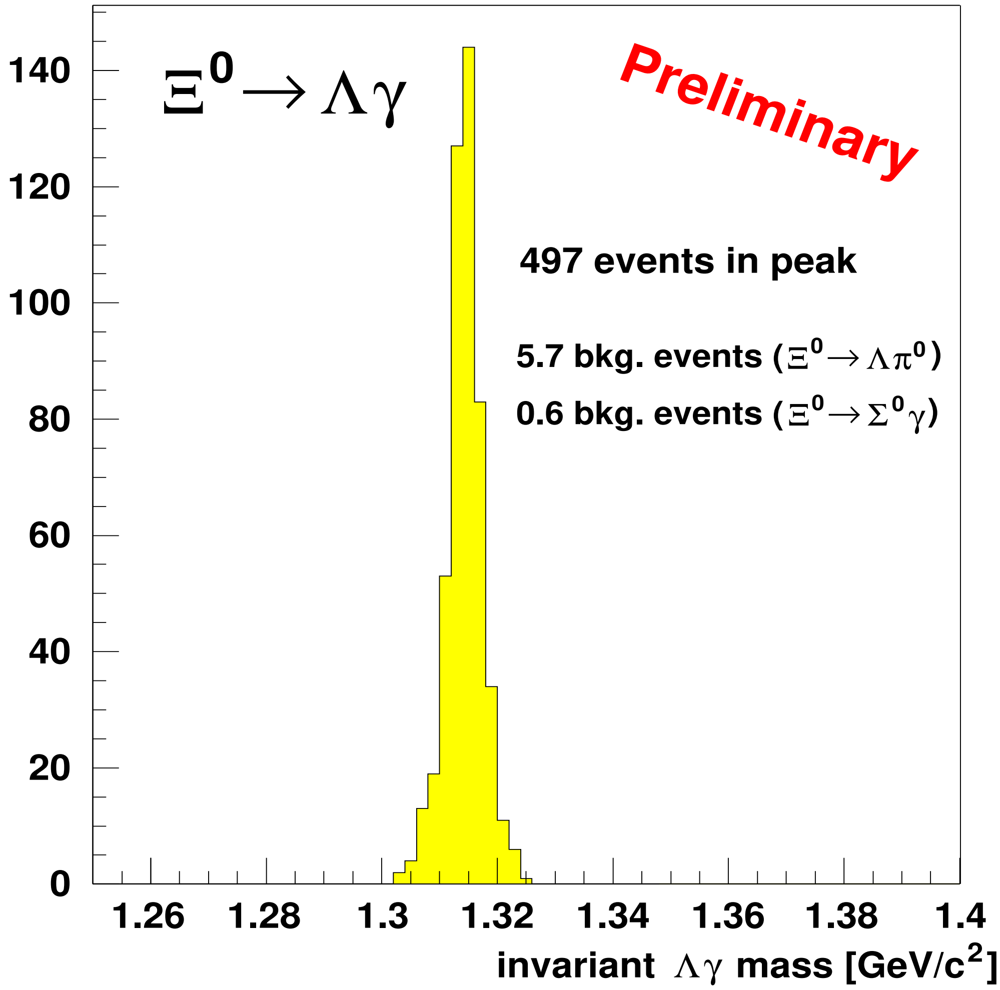
$2\times10^6\ \overline{\Lambda} \to \overline{p}\pi^+$

in 2 days of
High Intensity "K_S" beam

- Study of Ξ^0 decays:

  - $\Xi^0 \to \Sigma^0\gamma$ (see A. Zinchenko's talk)
  - $\Xi^0 \to \Lambda\gamma$ 497 events BR=$(1.9\pm0.1\pm0.2)\times10^{-3}$ *Preliminary*
  - $\Xi^0 \to \Sigma^+ e^- \overline{\nu}_e$ 60 events observed
  - $\Xi^0 \to p\pi^-$ no candidate ... should improve ΔS=2 limit by a factor of 10

$\Xi^0 \rightarrow \Lambda\gamma$



Preliminary result:

$$BR(\Xi^0 \rightarrow \Lambda\gamma) = (1.9 \pm 0.1_{stat} \pm 0.2_{syst}) \times 10^{-3}$$

Systematics dominated by Ξ^0 polarization and asymmetry.

High Intensity K_S Run in 2000

(July 17th - Sept 4th)

- Modified beam + detector layout:
  - ◇ No DCH during 2000 run.
    Implosion in Nov 1999 of carbon fibre beam pipe seriously damaged all four chambers. Drift chambers being repaired and spectrometer scheduled to be operational by June 2001.
  - ◇ Continuous vacuum up to scintillator hodoscope.
    (no kevlar window, no beam pipe).
  - ◇ AKS veto counter removed.
  - ◇ 1.5 m bronze absorber plug into K_L beam aperture.

- Beam characteristics:
  - ◇ 450 $\rightarrow$ 400 GeV/c protons.
  - ◇ 4.2 $\rightarrow$ 3 mrad production angle (compensates P_P decrease).
  - ◇ Duty cycle: 2.4 $\rightarrow$ 3.2 s SPS pulse every 14.4 s.
  - ◇ Proton intensity on K_S target: $\sim 9 \times 10^9$ per SPS pulse.
  - ◇ Total number of K_S decays in detector: $\sim 1 \times 10^{10}$ ($\sim$40 days).

Physics Goals for Run 2000

- Non-leptonic K_S decays (probes of chiral dynamics)

Channel	BR (experiment)	BR* (theory)	Events / $10^{10} K_S$
$K_S \to \gamma\gamma$	$(2.4 \pm 0.9) \times 10^{-6}$	2.1×10^{-6}	8000
$K_S \to \pi^0\gamma\gamma$	*not observed*	3.8×10^{-8}	38
$K_S \to \pi^0\pi^0\gamma\gamma$	*not observed*	5.6×10^{-9}	2
$K_S \to \pi^0\pi^0\gamma$	*not observed*	1.7×10^{-11}	0

(*) The Second DAΦNE Physics Handbook

- CP Violation in $K_S \to \pi^0\pi^0\pi^0$ (measurement of η_{000})

All the above neutral decay modes can be investigated by NA48 using "$2\pi^0$" and "$3\pi^0$" type triggers.

CP Violation in $K_S \to \pi^0\pi^0\pi^0$

- CP violation in $K_S \to \pi^0\pi^0\pi^0$ decays is parametrized by:

$$\eta_{000} = \frac{A(K_S \to \pi^0\pi^0\pi^0)}{A(K_L \to \pi^0\pi^0\pi^0)}$$

Experiment	Re(η_{000})	Im(η_{000})	BR (90% CL)
Barmin et al. (1983)	-0.08 $\pm$ 0.18	-0.05 $\pm$ 0.27	$< 3.7 \times 10^{-5}$
CPLEAR (1998)	0.18 $\pm$ 0.15	0.15 $\pm$ 0.20	$< 1.9 \times 10^{-5}$
SND (1999)			$< 1.4 \times 10^{-5}$

- η_{000} is also an important input to CPT tests.

If one assumes unitarity, one can measure the CPT violation parameter Im(δ) through the Bell-Steinberger relation which relates K_S and K_L decay amplitudes into all final states:

$$(1 + i \tan \phi_{SW})[\mathrm{Re}(\epsilon) - i\, \mathrm{Im}(\delta)] = \sum A_{fL} A^*_{fS} / \Gamma_S$$

ϵ describes CP violation with CPT conservation.

Best determinations of Im(δ) and Re(ϵ) come from CPLEAR (unitarity assumption only):

Re(ϵ)= $(164.9 \pm 2.5) \times 10^{-5}$ Im(δ)= $(2.4 \pm 5.0) \times 10^{-5}$

(A. Apostolakis et al., Phys. Lett. B456 (1999) 297)

Uncertainty on both parameters dominated by the error on η_{000}

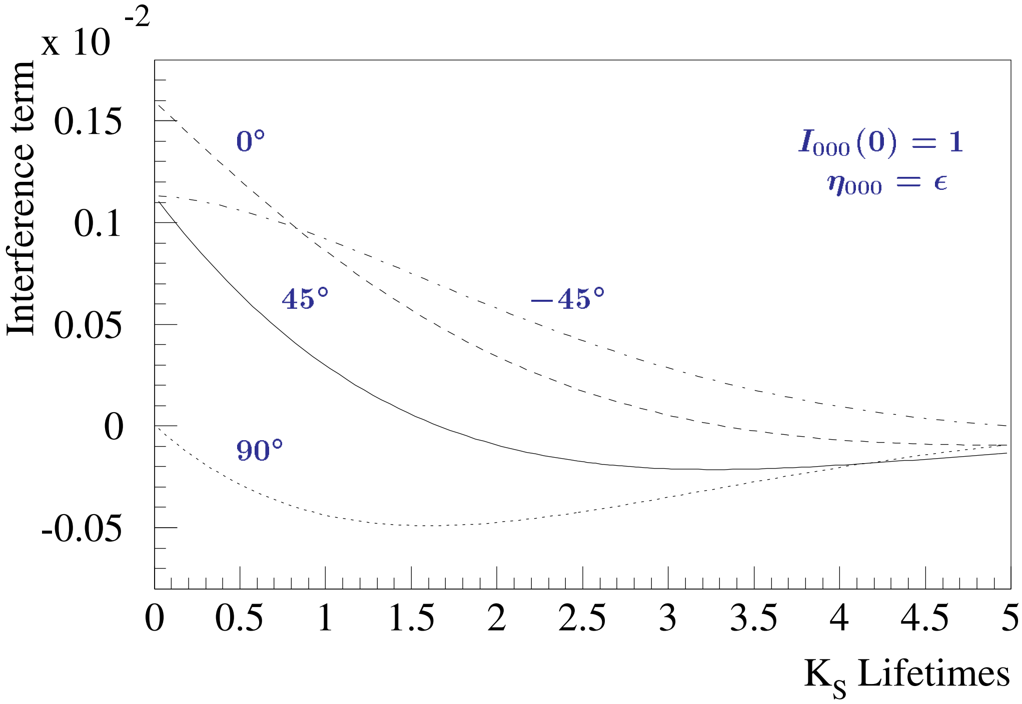
$\Rightarrow$ A better limit on η_{000} would improve the test of CPT

CP Violation in $K_S \rightarrow \pi^0\pi^0\pi^0$

- The NA48 method is based on the extraction of η_{000} from the $K_S - K_L$ interference term:

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

where D is the $K^0 - \overline{K^0}$ dilution factor ($\sim$ 0.3 for NA48)



- The effect is superimposed on the very large and flat $K_L \rightarrow 3\pi^0$ component and is mostly contained within a few K_S lifetimes from the target (collimator ends at $\sim 1.2\tau_S$).

- High $K^0 \rightarrow 3\pi^0$ statistics ($> 10^6$ in $\sim 5\tau_S$) required to improve significantly ($\times 3$) present limits on Re(η_{000}) and Im(η_{000}).

- Excellent knowledge of detector acceptance necessary to reach high sensitivity to η_{000} .

CP Violation in $K_S \rightarrow \pi^0\pi^0\pi^0$

$3\pi^0$ statistics in run 2000

◇ Expect $\sim 10^6/c\tau_S$ reconstructed $K^0 \rightarrow \pi^0\pi^0\pi^0$ decays in the 90 - 140 GeV range.

◇ Use the much larger sample of $K_L \rightarrow \pi^0\pi^0\pi^0$ collected during part of run 2000 that was dedicated to the ε'/ε systematic studies to cross-check Monte Carlo simulation for the acceptance correction.

◇ Can also limit systematics from uncertainties in the K^0 beam spectrum by performing an analysis in energy bins.

Hope to set a limit of $\sim 3\%$ on Re(η_{000}) and Im(η_{000}).

$\Rightarrow$ significant improvement on η_{000} measurement and CPT test

Prospects for 2002

A High Sensitivity Investigation of K_S and Neutral Hyperon Decays Using a Modified K_S Beam
(Addendum II to P253, CERN/SPSC 2000-002)

◇ The proposed physics program could start in 2002 after the completion of the Re$(\varepsilon'/\varepsilon)$ measurement in 2001.

◇ Use slightly modified K_S beam line compared to the standard Re$(\varepsilon'/\varepsilon)$ operation mode:

- P_P = 400 GeV/c and 2.5 mrad production angle
- Expect improved duty cycle of 5.2 s every 16.8 s.
- No AKS converter and first AKL Veto counter removed.
- We propose to use a sweeping magnet at the end of the K_S collimator ($\oint B \cdot dl \simeq 0.6$ Tm) to reject conversions and to operate the K_S sweeping magnet at the maximum 7.5 Tm strength.
- Absorber plug into K_L beam aperture.

Expect $\sim 3\times 10^{10}$ K_S decays / year
(1 year = 120 days at 50% efficiency)

Rates in detector elements expected to be $\sim$ 1.5 the ones in the Re$(\varepsilon'/\varepsilon)$ mode.

SES = 6×10^{-10} / year for $K_S \rightarrow \pi^0 e^+ e^-$ $\quad$ (Acc=5%)

Main Physics Topics for 2002

with 3×10^10 K_S decays in one year

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

  - Signal is ~7 events for BR of 5×10^{-9}
  - Main background due to $K_S \to \pi^0\pi^0_D$ expected to be <0.3 event from MC simulation of events generated with $M_{ee} > 90$ MeV/c^2.
  - Other backgrounds like $K_S \to \pi^0_D\pi^0_D$, $K_{L,S} \to e^+e^-\gamma\gamma$ should be negligible.

  More detailed MC simulations in progress

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

  - Its branching ratio is about 5 times smaller than the one of $K_S \to \pi^0 e^+ e^-$ and has different background sources.

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

  - The experiment sensitivity should allow to put a bound on η_{000} of ~1% and provide a further test of CPT.

- $K_S \to \gamma\gamma$

  - Expect ~24k events with similar $K_L \to \gamma\gamma$ background level per K_S lifetime.

- $K_S \to \pi^0\gamma\gamma,\ \pi^0\pi^0\gamma\gamma, e^+e^-\gamma, \mu^+\mu^-\gamma$

  - The sensitivity of the experiment should allow their observation.

- $K_S \to \pi^+\pi^-\gamma,\ \pi^+\pi^-e^+e^-$

  - Copious modes. Expect 5×10^6 and 5×10^4 events respectively.

Main Physics Topics for 2002 (cont^{d})

- Hyperon electromagnetic mass splitting

  - High resolution NA48 γ detector allows very precise measurement of Ξ^0 mass. Expect to reduce

$$\delta[M(\Xi^-) - M(\Xi^0)] \sim 0.1 MeV$$

- Hyperon radiative decays

  - Increase the $\Xi^0 \rightarrow \Lambda\gamma$ and $\Xi^0 \rightarrow \Sigma\gamma$ event samples by a factor of 100, reduce systematics by a factor of 2. Expect :

5% accuracy on BR's

- Hyperon β decays

  - detect $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}$ (and subsequent $\Sigma^+ \rightarrow p\pi^0$ decay) of $BR = 2.5 \times 10^{-4}$, for a new consistency check of SU(3) symmetry. Expect :

25,000 $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}$ events

- Search for $\Xi^0 \rightarrow p\pi^-$ $\Delta S = 2$ transition

  - Current limit $BR \leq 4 \times 10^{-4}$ (90% CL). Expect :

factor of 100 improvement on existing limit

NA48 and Beyond

Precision Measurement of Charged Kaon Decay Parameters
with an Extended NA48 Setup
(Addendum III to P253, CERN/SPSC 2000-003)

Direct CP Violation in $K^{\pm}$ decays

- Interesting to look for manifestation of CP violation in other decay modes, e.g. $K^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}$:

$$|M(u,v)|^2 \propto 1 + gu + hu^2 + kv^2$$

$$u{=}(s_3\text{-}s_0)/m_\pi^2 \quad v{=}(s_1\text{-}s_2)/m_\pi^2 \quad s_0{=}(s_1{+}s_2{+}s_3)/3$$

$$s_i = (P_K - P_i)^2 \quad \textit{(i=3 for the odd pion)}$$

- If CP conservation holds then coefficients g, h and k are the same for K^+ as for K^- decays.

- Measurement of Direct CP Violation through the asymmetry

$$A_g = (g^+ - g^-)/(g^+ + g^-)$$

- Theoretical predictions for A_g are in the $\mathcal{O}(10^{-6} - 10^{-4})$ range. Some super-symmetric models could give a value of $\sim 10^{-4}$
  (G. D'Ambrosio, G. Isidori, G. Martinelli, Phys. Lett. B480 (2000) 164)

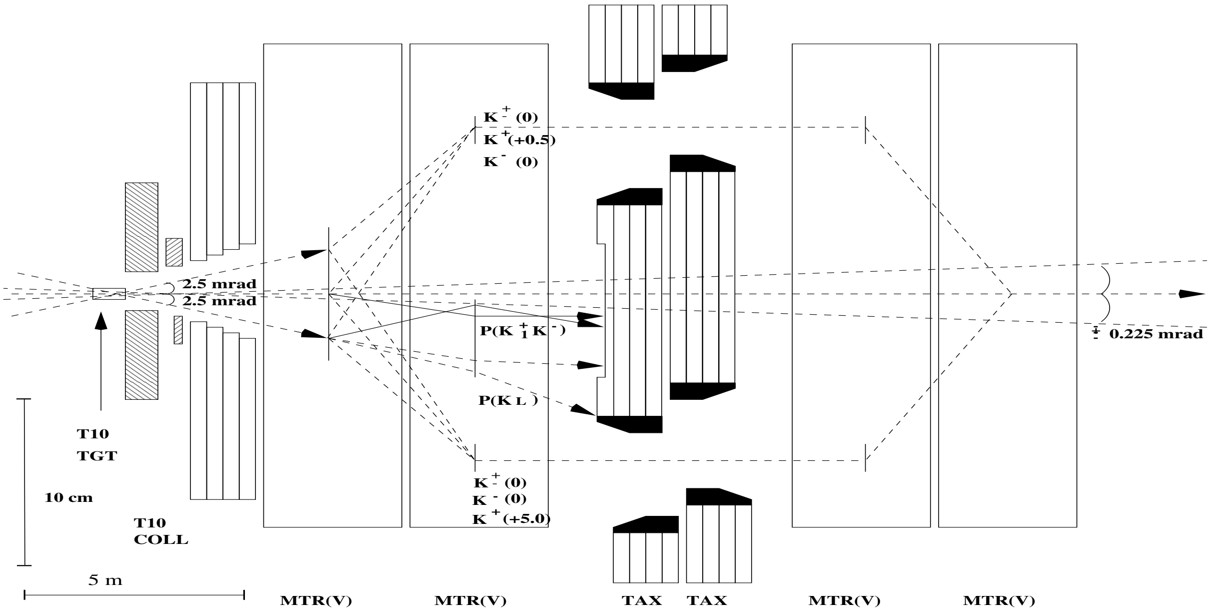
Expt: A_g = (-7 $\pm$ 5) $\times 10^{-3}$ Ford et al. (1970)

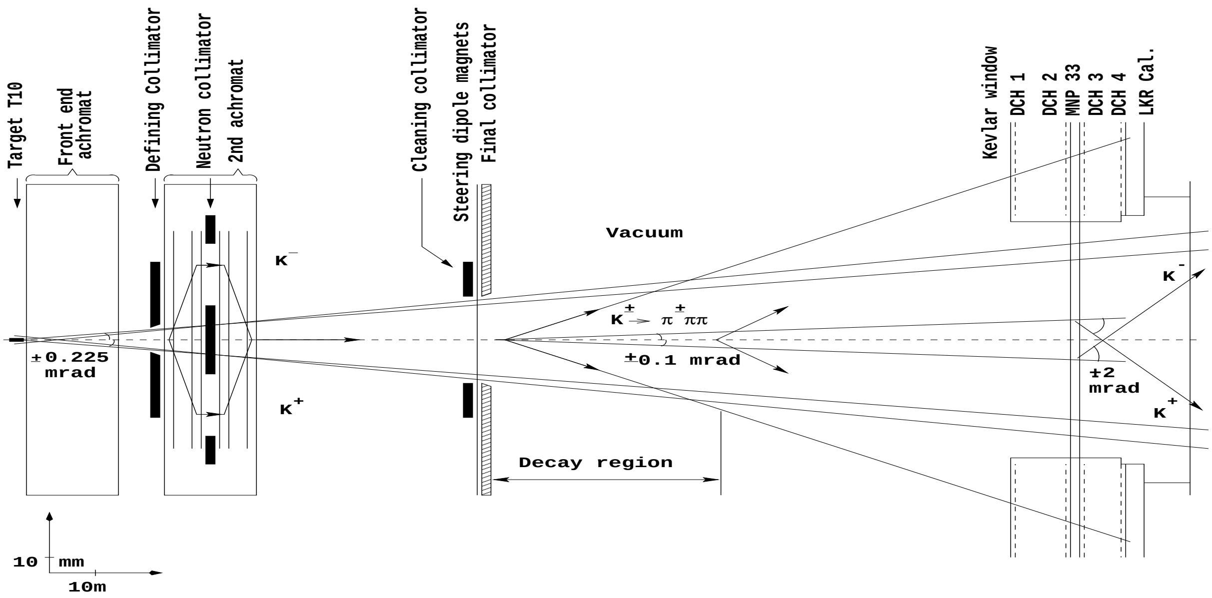
- With more than 2×10^9 $K^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}$ decays / year, NA48 could measure A_g with a precision of $< 2 \times 10^{-4}$

- CP violation can also be investigated in decays such as $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ or $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$

NA48 Simultaneous K^+ and K^- Beams

P_K=60 GeV/c $\quad \Delta P/P$=10-20%





2×10^6/cycle K^+ and 10^6/cycle K^- with $\Delta P/P$=10%

Other interesting topics (with 3 charged particles)

- $K^{\pm} \to \pi^+\pi^-e^{\pm}\nu(\overline{\nu})$ $(Ke4)$ BR = 3.9×10^{-5}

  - Study of $\pi^+\pi^-$ interaction at low energy in a clean way (no other hadron in the final state).
  - Size of single flavor condensate $\langle 0|q\overline{q}|0\rangle$ in the QCD vacuum can be extracted from the $\pi^+\pi^-$ elastic scattering lengths a_0^0 and a_0^2 near threshold.
  - Important to understand the mechanism of spontaneous chiral symmetry breaking. Precision needed: $\delta a_0^0 \leq 0.01$

    ◇ Rosselet et al. (from 30k events):
    $a_0^0 = 0.263 \pm 0.052$ (Phys. Rev. D15 (1977) 574)

    ◇ BNL E865 very preliminary result (from 400k events:)
    $a_0^0 = 0.235 \pm 0.013$ (S. Pislak, LNF seminar, 22/06/00)
    (no syst. error and radiative corrections)

  - NA48 features:

    ◇ Very good resolution on the 5 kinematic variables.
    ◇ Kaon momentum from a beam spectrometer.
    ◇ Very small $K^{\pm} \to \pi^+\pi^-\pi^{\pm}$ contamination ($\leq 2 \times 10^{-6}$) by using TRD of NOMAD

  Expect $\delta a_0^0 \simeq 0.007(stat)$ for 10^6 Ke4 events ($\sim$ 1 year)

- $K^{\pm} \to \pi^{\pm}e^+e^-$ BR = 2.7×10^{-7}

  - Test of χPT $\sim$ 10k events expected per year.

Conclusions

- The investigation of rare decays by NA48, concurrently with the measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$, is providing interesting physics results for the understanding of Chiral Dynamics and CP Violation in the neutral kaon sector.
- The high intensity K_S beam test performed last year together with the successful 2000 run have demonstrated clearly the capability of the NA48 experiment to investigate, in the near future, rare K_S and Neutral Hyperon decays with high sensitivities.
- Two proposals have been submitted recently to the SPSC for the continuation of the NA48 experiment with high intensity K_S and charged kaon beams. The proposed experimental programmes aim at exploring in a very competitive way a rich domain in kaon physics.