New results on KL/KS rare decays by NA48

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On behalf of the NA48 Collaboration:
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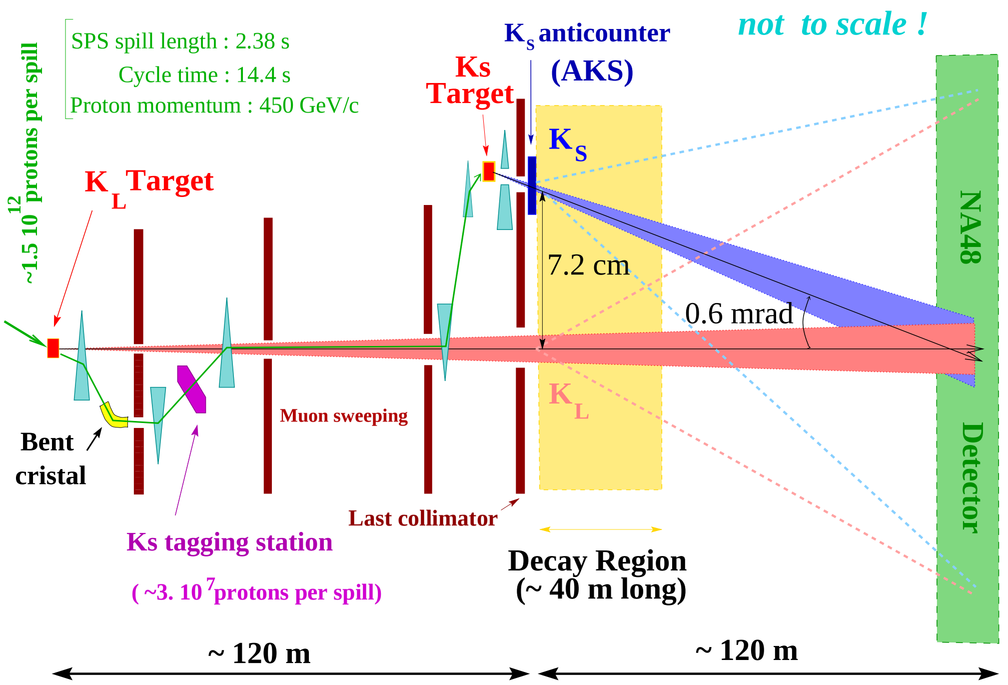
Plan of the presentation

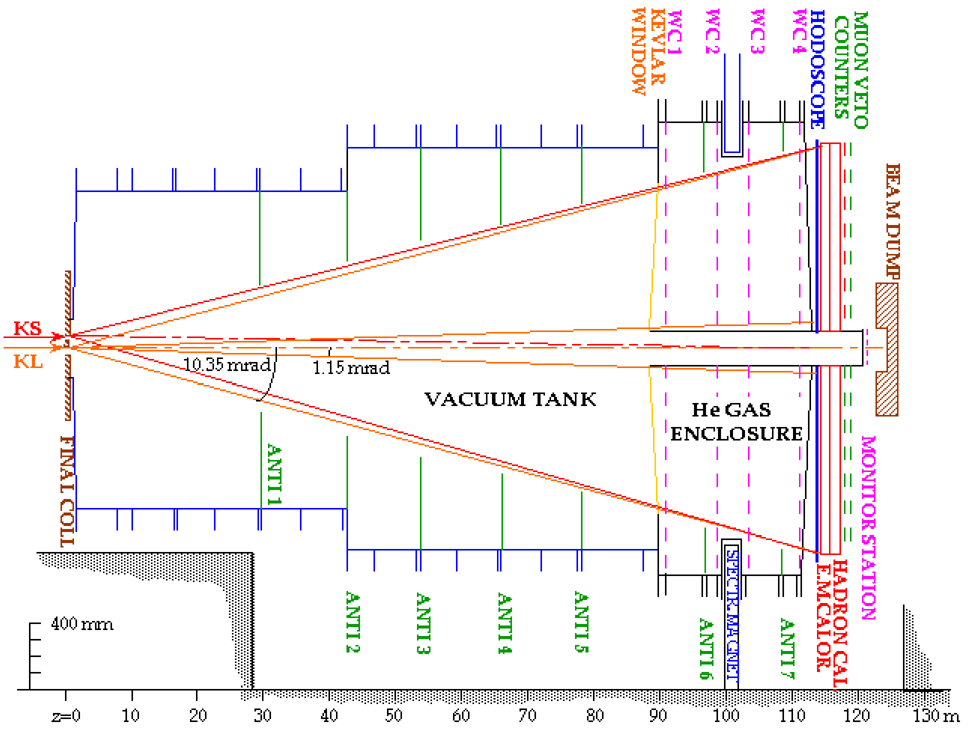
- NA48 is devoted to the measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$ via the double ratio (cf. Harald Fox, this conference)
- K_{L} rare decays are collected during the $\mathrm{Re}(\varepsilon'/\varepsilon)$ runs
- Today:
  - $K_{\mathrm{L}} \rightarrow e^+e^-e^+e^-$ (1999 data)
  - $K_{\mathrm{L}} \rightarrow e^+e^-\mu^+\mu^-$ (1999 data)
  - $K_{\mathrm{L}} \rightarrow \pi^0\gamma\gamma$ (1999 + part of 1998 data)
- K_{S} rare decays presented today are derived from a two day dedicated run (September 1999):
  - $K_{\mathrm{S}} \rightarrow \gamma\gamma$
  - $K_{\mathrm{S}} \rightarrow \pi^0e^+e^-$
- Future prospects

Results are Preliminary!

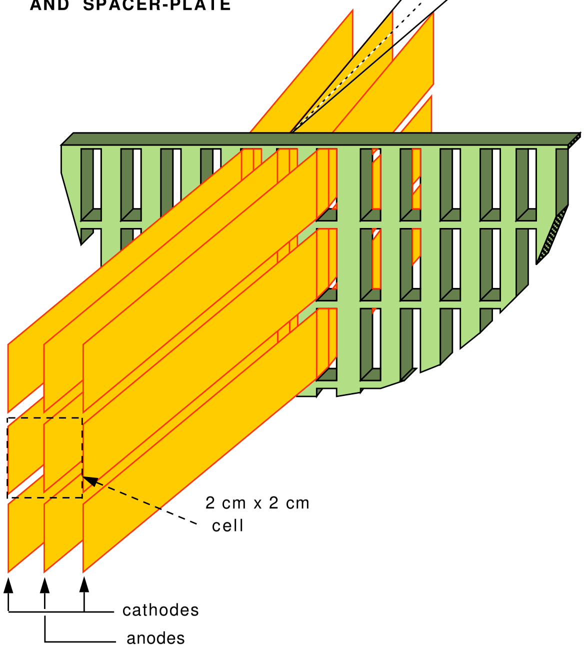
NA48 beams and detectors



- $\mathrm{Re}(\varepsilon'/\varepsilon)$ mode: K_S are tagged
- High Intensity K_S mode: the K_L target is removed and the protons bypass the tagger

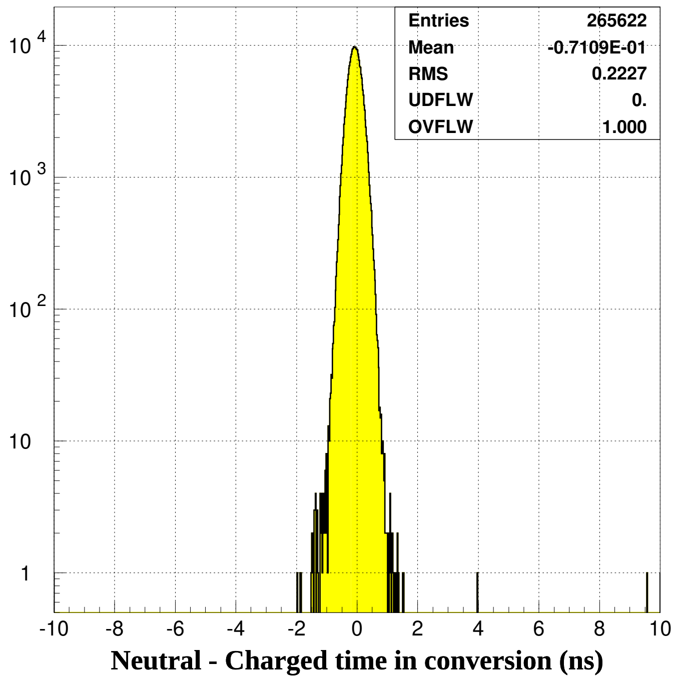


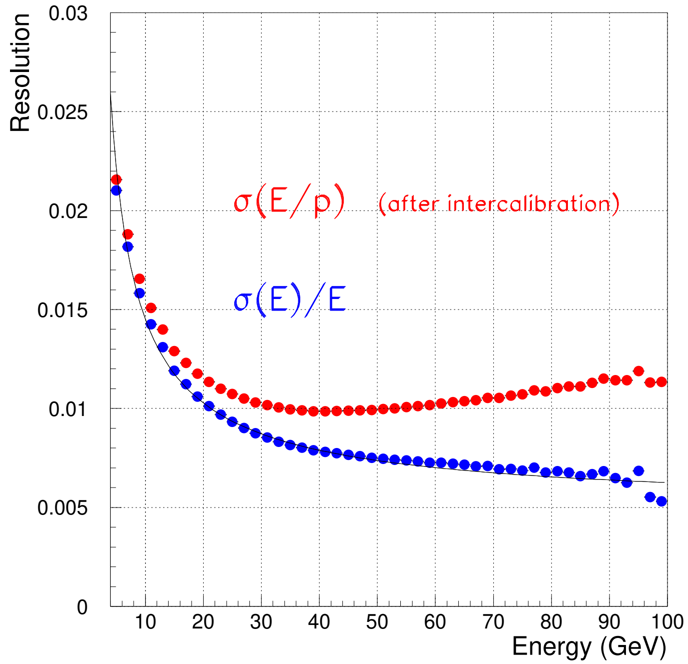
CERN-NA48 Liquid Krypton



- Made of $\approx 9m^3$ LKr
- Cu-Be electrodes
- bias HV: +3 KV/cm
- 2cm×2cm×127cm
- Five Spacer plates
- Electrodes: ± 48mrad zig-zag in each spacer
- Geometry controlled to ≈0.2mm/1m

NA48 time, energy and momentum resolution





- LKr e.m. calorimeter

$$\sigma(t) = 222 \text{ ps} \qquad \frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{0.1}{E} \oplus 0.5\%$$

- magnetic spectrometer

$$\sigma(p)/p \simeq 0.5\ \% \oplus 0.009\ p[\mathrm{GeV/c}]\ \%$$

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

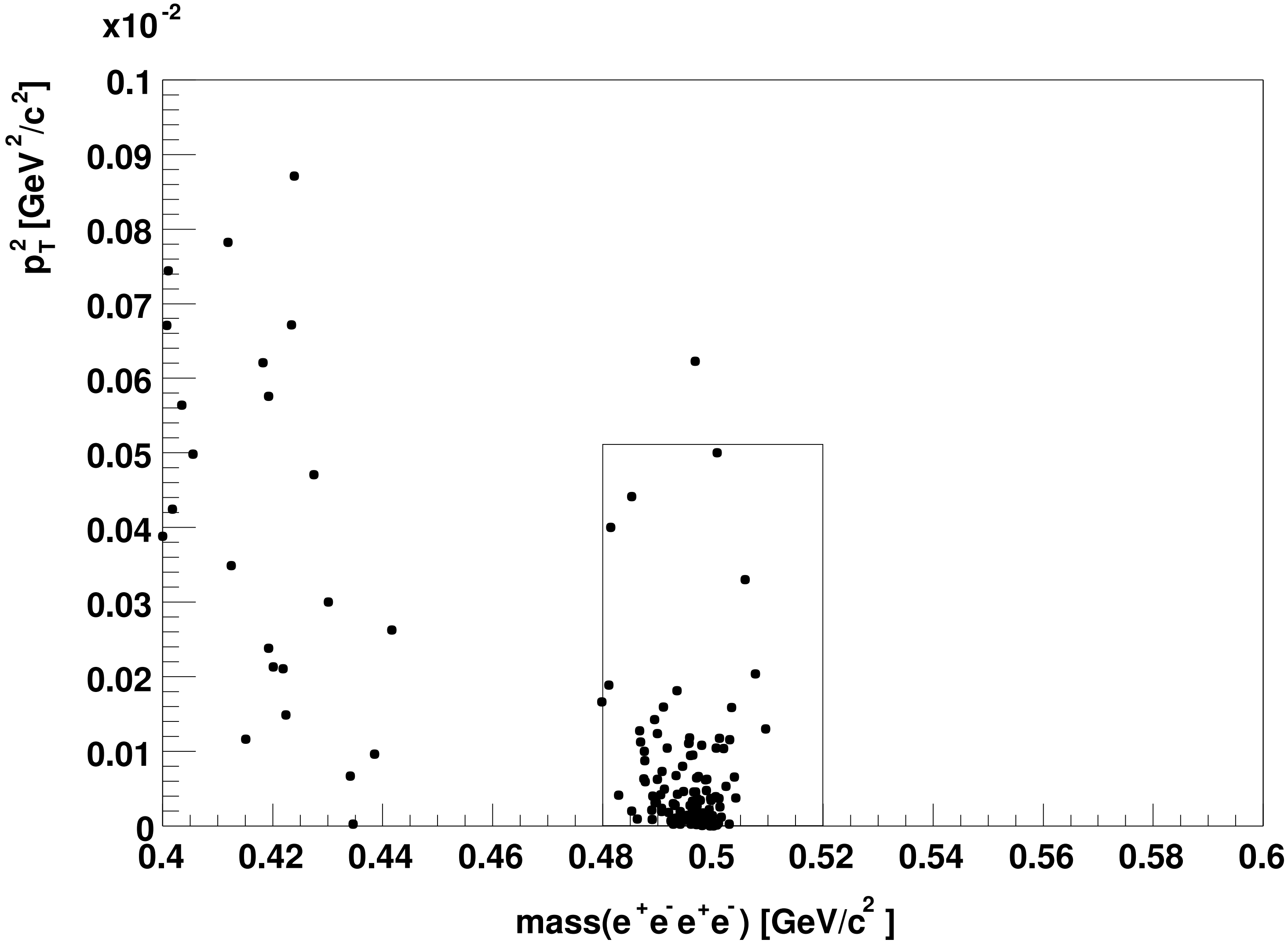
- Physics Motivation
  $K_L \to e^+e^-e^+e^-$ proceeds mainly via the double internal photon conversion probing the $K - \gamma^*\gamma^*$ vertex
- Theoretical Prediction (Zhang and Goity, PR D57 7031)

BR (no form factor)	BR form factor
3.7×10^{-8}	3.85×10^{-8}

- Trigger selection
  - Level I
    - Hits in opposite quadrants of the hodoscope
    - $E_{\mathrm{LKr+HAC}} > 30$ GeV
  - Level II
    at least two vertices within 6 m
- Event Selection
  - c.d.a. < 15 cm
  - $0.9 < \frac{E}{P} < 1.2$
  - 700 cm $< z_{\mathrm{vertex}} <$ 9000 cm
  - $p_T^2 < 0.0005\ (\mathrm{GeV/c})^2$
  - $0.475\ \mathrm{GeV/c^2} < m_{4e} < 0.525\ \mathrm{GeV/c^2}$
- Normalisation channels
  - $K_L \to \pi^0\pi^0_D\pi^0_D$
  - $K_L \to \pi^+\pi^-\pi^0_D$
    $\pi^0_D \equiv \pi^0 \to \gamma\, e^+e^-$

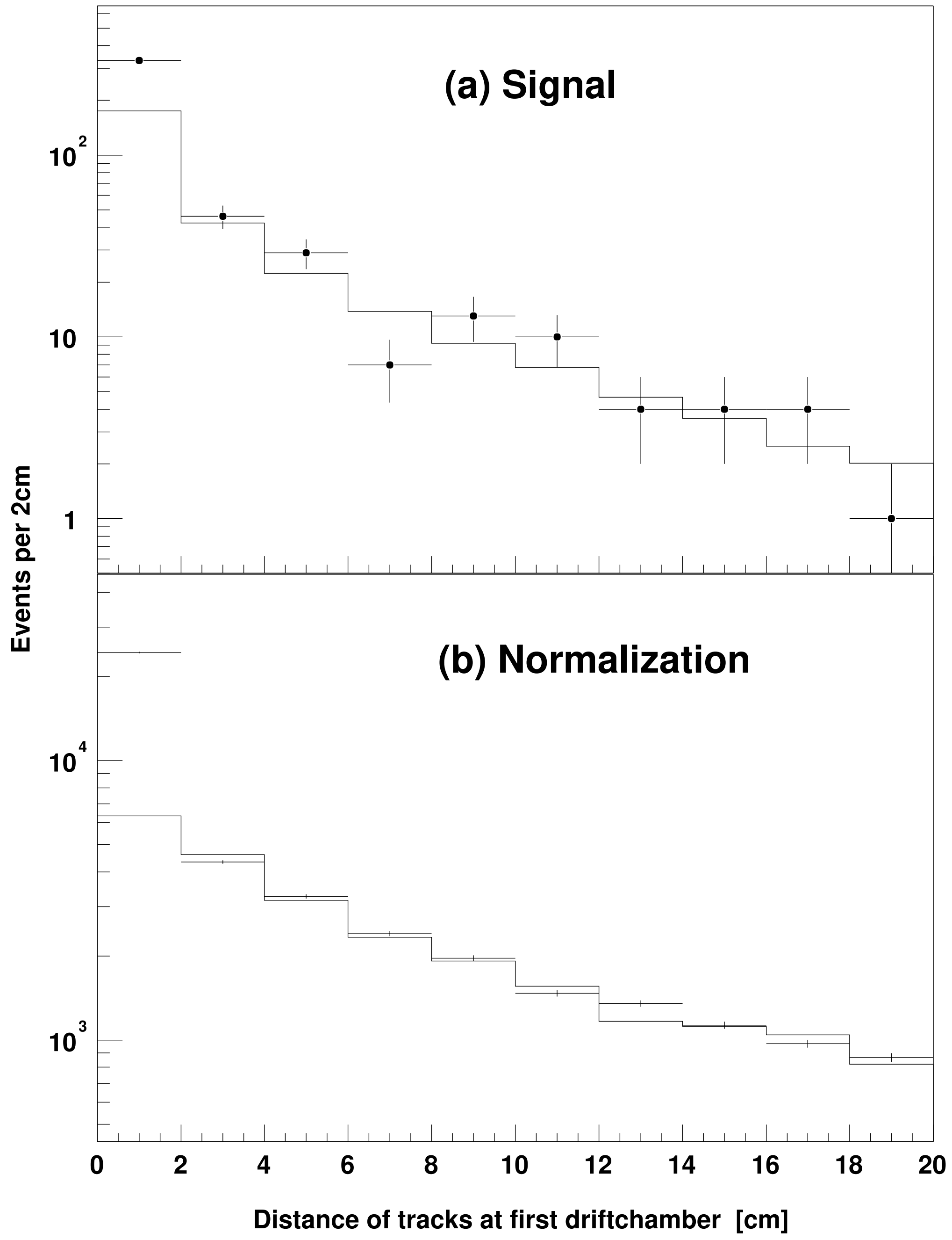
$K_L \to e^+e^-e^+e^-$

Background from $K_L \to 3\pi^0$ with π^0_D decays and/or γ conversions and lost photons peaks at values smaller than the K mass



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

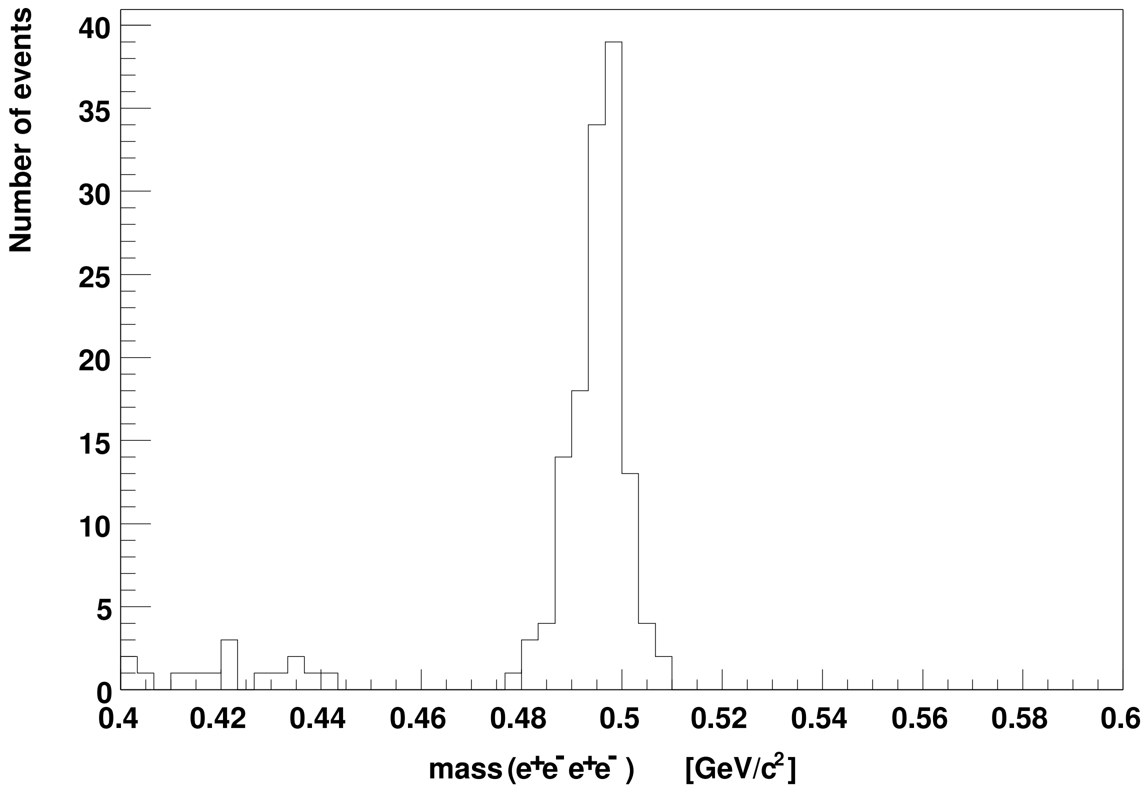
Background from $K_L \to \gamma e^+ e^-$ ($K_L \to \gamma\gamma$) with one (two) photon converted is rejected requiring a minimum distance between two tracks of opposite charge of at least 2 cm at chamber 1



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

There are 132 events in the signal region with negligible background

($\times 5$ the statistics of previous best measurement)

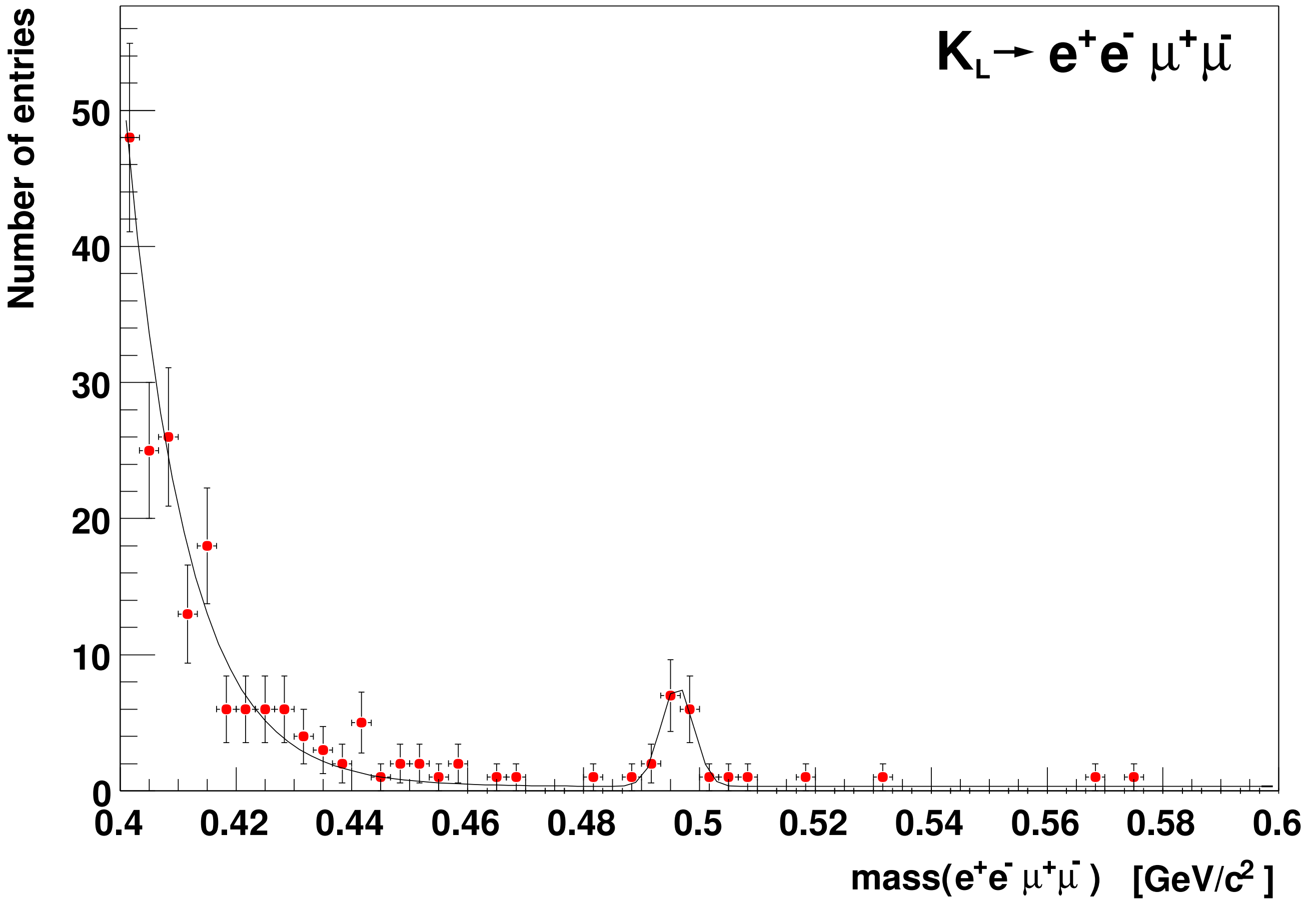


NA48 Preliminary (matrix element from Miyazaki and Taksugi, PR D8 2051):

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

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

- This decay mode is more sensitive to a non-trivial form factor.
- One event published by E799:
  $BR(K_L \to e + e^-\mu^+\mu^-) = (2.9^{+6.7}_{-2.4}) \times 10^{-9}$
- NA48 sees a clean signal peak with 21 events (background ~ 2)



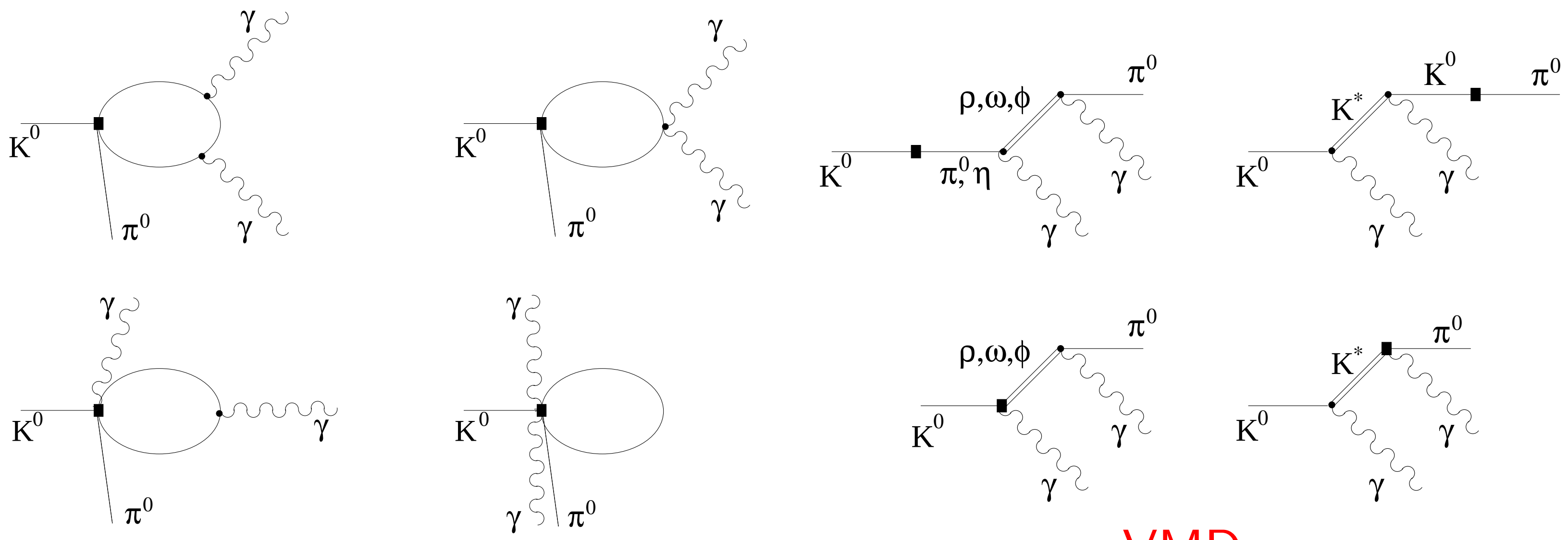
$K_{\rm L} \to \pi^0\gamma\gamma$

Physics Motivation

- The decay rate is finite at one loop Chiral Perturbation Theory (χ PT)
- The χPT calculation at $O(p^4)$ predicts only 1/3 of the measured rate
- $O(p^6)$ calculations including a VMD contribution parameterised by $a_{\rm V}$ can reproduce the rate and predicts a tail at low $m_{\gamma\gamma}$
- The difference *y* between the energy of the two non-π^0 photons in the kaon rest frame is also sensitive to $a_{\rm V}$
- The $a_{\rm V}$ contribution leads to a CP conserving component to $K_{\rm L} \to \pi^0 e^+ e^-$, e.g.:
  $BR(K_{\rm L} \to \pi^0 e^+ e^-)_{\rm CPC} = 1.24 \times 10^{-12}$ for $a_{\rm V} = -0.7$[a]
- KTEV has recently published:
  $BR(K_{\rm L} \to \pi^0\gamma\gamma) = (1.68 \pm 0.07 \pm 0.08) \times 10^{-6}$
  $a_{\rm V} = -0.72 \pm 0.05 \pm 0.06$

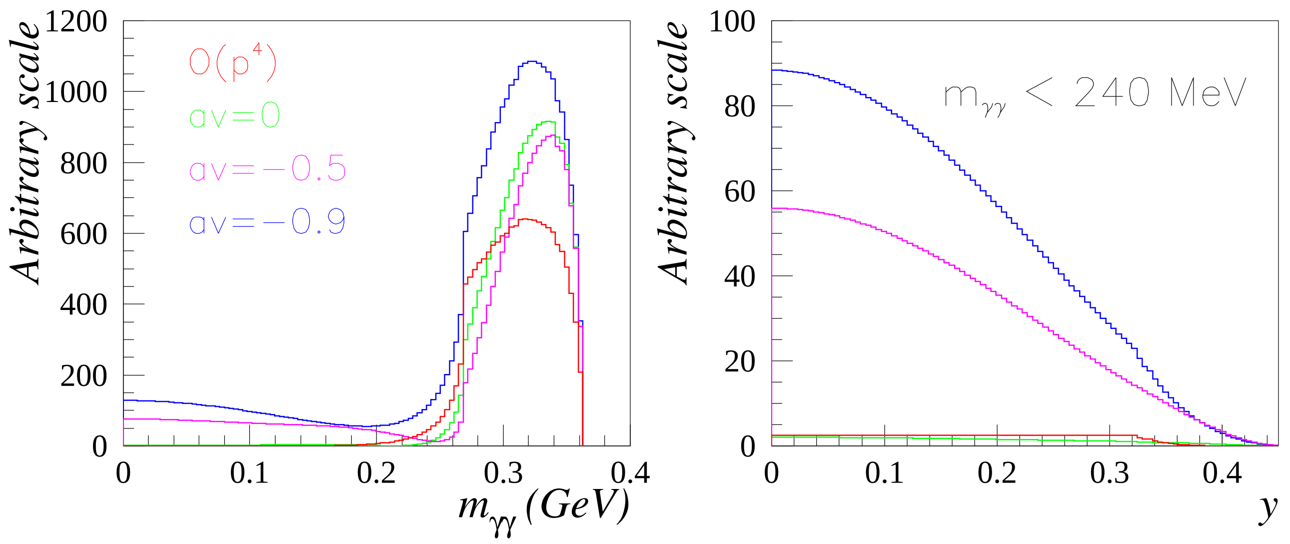
[a] G. D'Ambrosio, J. Portolés, NP B492 417

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

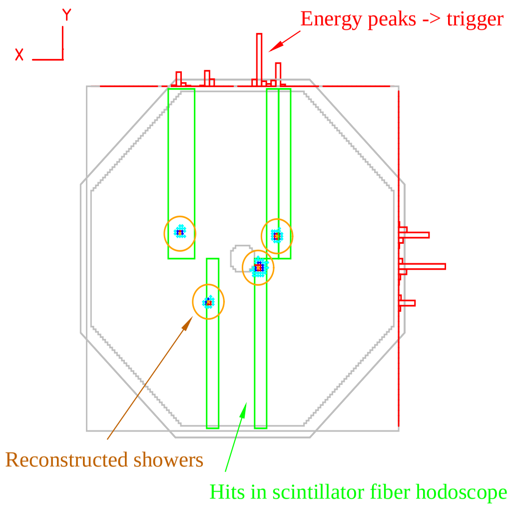


$O(p^4)$

VMD



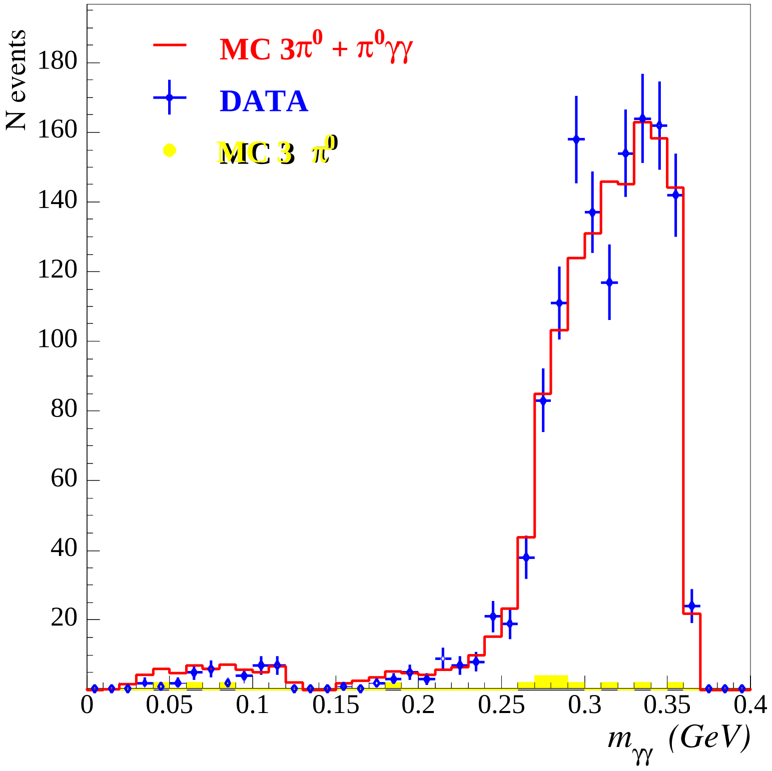
$K_L \to \pi^0\gamma\gamma$



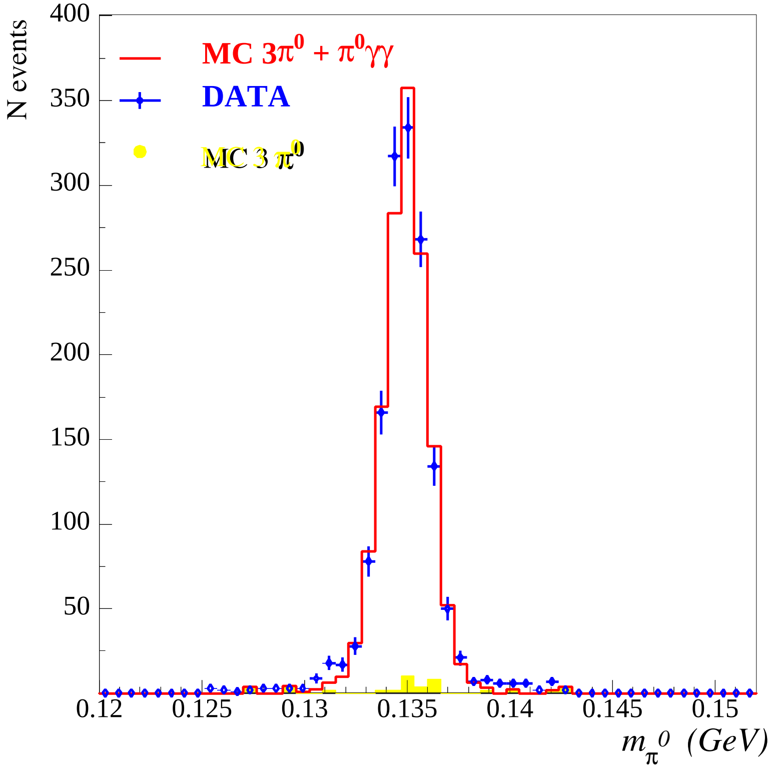
- Trigger Selection
  - $E_{LKr} > 50$ GeV
  - $COG <$ 15 cm
  - t $< 5.5\ c\tau_S$
  - $<$ 6 peaks in each LKr projection
- Event Selection
  - only four clusters in time and no in time hits in DCH and/or anti-rings
  - $R_{ell} \equiv$
    $$\left\{ \left(\frac{\frac{m_1+m_2}{2} - m_{\pi^0}}{\sigma_{\frac{m_1+m2}{2}}} \right)^2 + \left(\frac{\frac{m_1-m_2}{2}}{\sigma_{\frac{m_1-m2}{2}}} \right)^2 \right\} > 100$$
  - $70\ GeV < E_K < 170\ GeV$
- Background from $K_L \to 3\pi^0$
  - lost photons
    - ∗ Short decay region (20 m)
    - ∗ reject events if 2 γ reconstruct a π^0 more than 6 m upstream of the K decay vertex
  - overlapping photons
    - ∗ Cuts on the cluster width
    - ∗ reject events if 3 clusters reconstruct 2 π^0 more than 6 m upstream of the K decay vertex

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

- 1999 data + fraction of 1998
- 1397 candidates (background approx. 30)



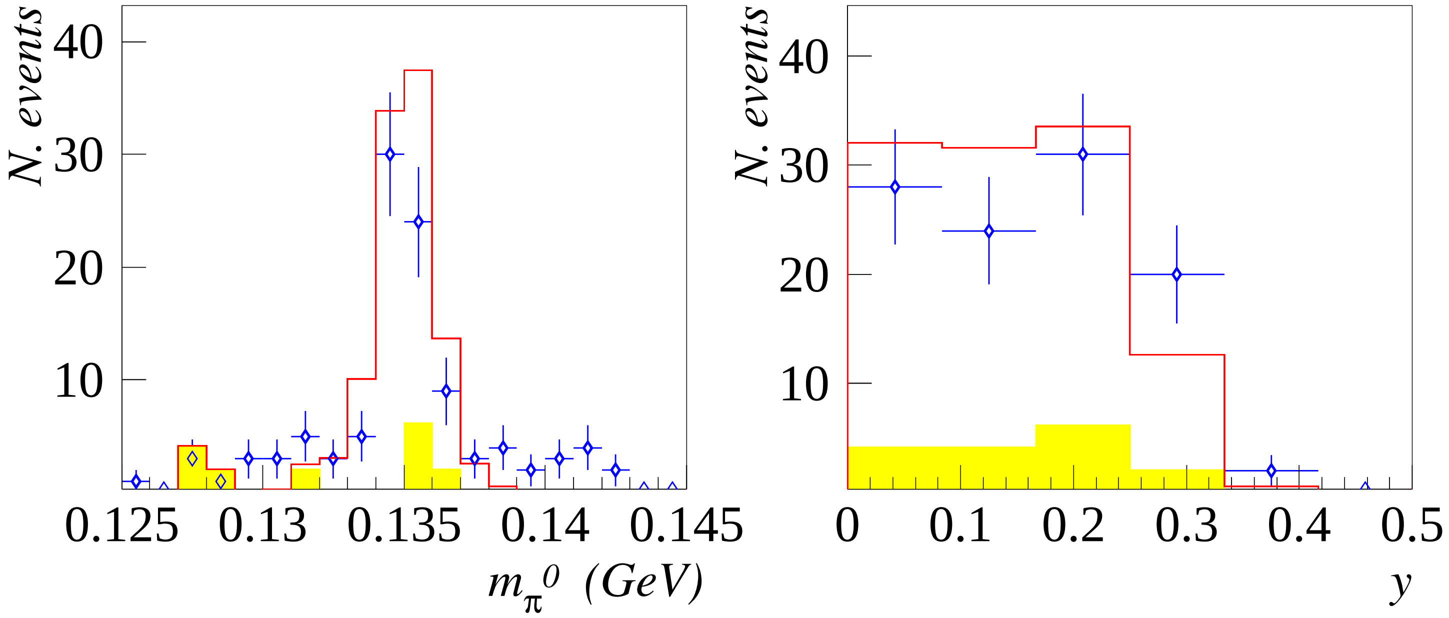
$m_{\gamma\gamma}$ for the two non-π^0 photons



$m_{\gamma\gamma}$ for the π^0 candidate

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

The NA48 signal at small $m_{\gamma\gamma}$ is very clean as demonstrated by the m_{π^0} and y distributions shown here for $m_{\gamma\gamma} < 240\ \mathrm{MeV/c^2}$



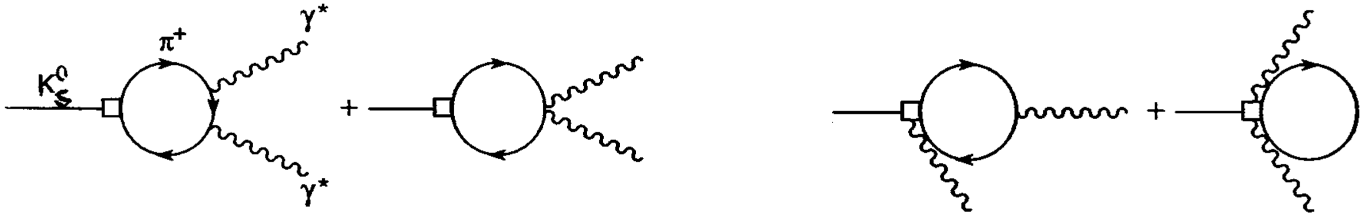
Branching Ratio (NA48 Preliminary):

$$BR(K_L \to \pi^0\gamma\gamma, a_V = -0.45) = (1.51 \pm 0.05(stat) \pm 0.20(syst)) \times 10^{-6}$$

$K_S \to \gamma\gamma$

Physics motivation

- This decay is interesting because it is calculable in χPT with no counter-terms and it is sensitive to loops



- Theory: $BR(K_S \to \gamma\gamma) \sim 2.1 \times 10^{-6}$ with small error
- NA31: $BR(K_S \to \gamma\gamma) = (2.4 \pm 0.9) \times 10^{-6}$

Experimental technique

- $\sim 6 \times 10^9$ ppp on a Be target placed 6 m upstream of the decay region
- The same number of K_S and K_L is produced at the target. The $K_L \to \gamma\gamma$ events must be subtracted
- The maximum $m_{\gamma\gamma}$ from a $K_S \to \pi^0 \pi^0$ decay is 458 $\mathrm{MeV/c^2}$ $\Rightarrow$ the reconstructed vertex for $\pi^0\pi^0$ decay with two lost photons is shifted downstream by at least 9 m

$K_S \to \gamma\gamma$

- The flux is measured using $K_S \to 2\pi^0$ and $K_L \to 3\pi^0$ decays
- The converter of the K_S anti-counter was removed

Trigger Selection

- $E_{\mathrm{LKr}} > 50$ GeV
- $z < 18$ m
- ≤ 2 peaks in each LKr projection $(\epsilon > 99\%)$

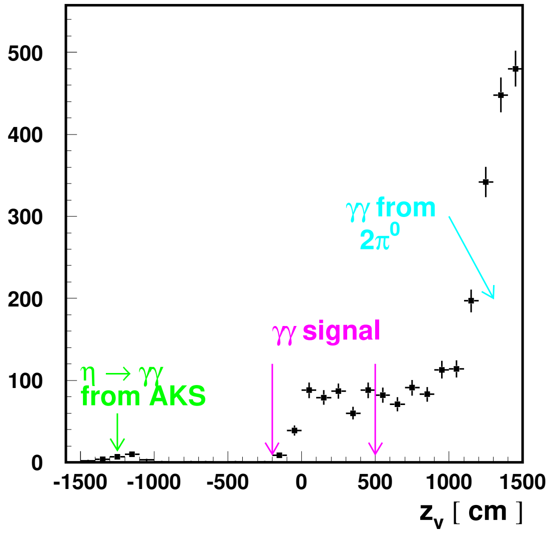
Event Selection

- $3 \text{ GeV} \leq E_\gamma \leq 100 \text{ GeV}$
- $60 \text{ GeV} \leq E_K \leq 170 \text{ GeV}$
- $COG = \sqrt{COG_x^2 + COG_y^2} < 7$ cm
- No extra photon $(E > 1.5$ GeV) within 3ns from the event
- No hits in the Drift Chambers and in the K_L anti-rings
- Energy in the hadronic calorimeter < 3 GeV

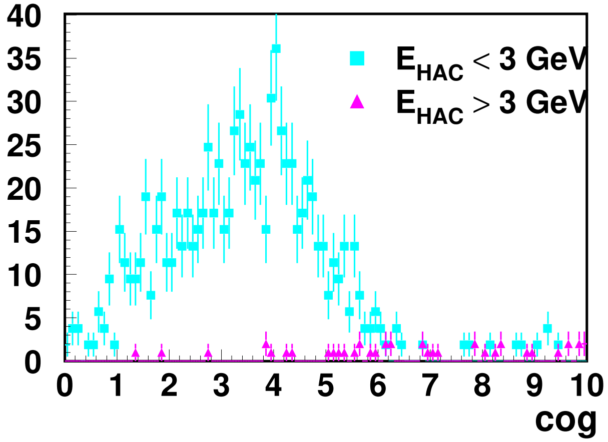
$K_S \rightarrow \gamma\gamma$

Background subtraction

- $K_S \rightarrow 2\pi^0$: 2 ± 2
  - 10^8 simulated $K_S \rightarrow 2\pi^0$
  - The overlap of showers reduces the background free region to about 5 m

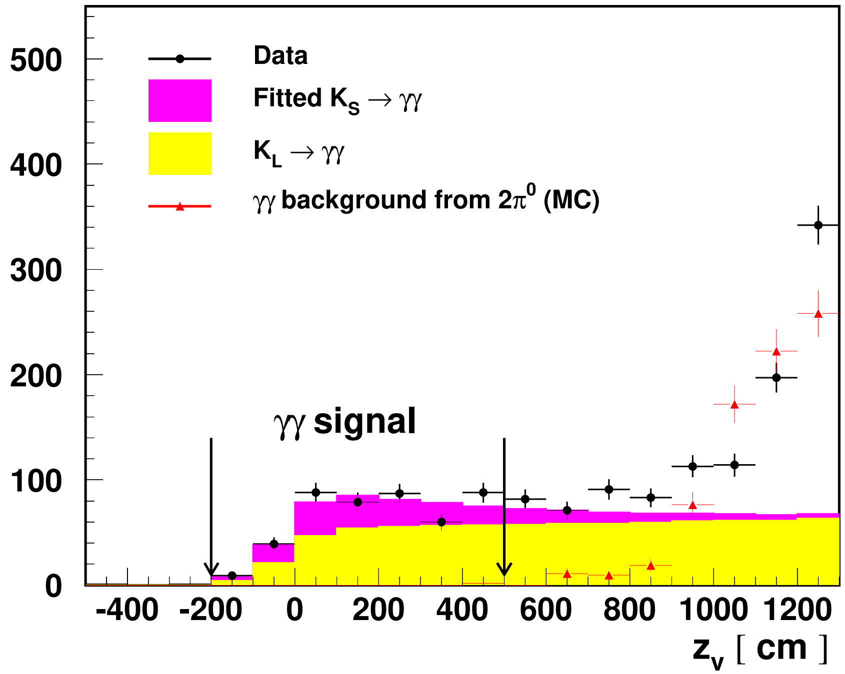


- Hadronic background: 12 ± 6
  - The excess of events for $COG > 7$ cm is 9 ± 3
  - The extrapolation to the signal region is done using a sample for which $E_{\mathrm{HAC}} > 3$ GeV



Result

- 450 $K \to \gamma\gamma$
- $7.5 \times 10^6\ 2\pi^0$(Down-scale 100)
- A likelihood function (11 kaon energies and 7 longitudinal vertex positions) is maximised to extract $BR(K_S \to \gamma\gamma)$
- 50 % of the systematic error comes from the uncertainty of $BR(K_L \to \gamma\gamma)$



NA48 Preliminary:

$$\boxed{BR(K_S \to \gamma\gamma) = (2.56 \pm 0.35(stat) \pm 0.20(syst)) \times 10^{-6}}$$

$$\boxed{R = \frac{\Gamma(K_S \to \gamma\gamma)}{\Gamma(K_L \to \gamma\gamma)} = 2.5 \pm 0.3(stat) \pm 0.2(syst)}$$

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

Physics Motivation

The main interest in $K_S \to \pi^0 e^+ e^-$ is to bound the indirect CP violation component of the $K_L \to \pi^0 e^+ e^-$ decay

- In the SM: $\mathrm{BR}(K_L \to \pi^0 e^+ e^-)_{\mathrm{CPVdir}} \sim 6.7 \times 10^{-11} \mathrm{A}^4 \eta^2$ where η is the CP violating phase in the CKM matrix
- The current upper limit[a] $BR(K_L \to \pi^0 e^+ e^-) < 5.64 \times 10^{-10}$ could be improved in the next few years by a factor of ≈ 2 by KTEV and more significantly by the KAMI (P804) proposal at FNAL

$\mathrm{BR}(K_L \to \pi^0 e^+ e^-)_{\mathrm{CPVind}} = |\epsilon|^2 \frac{\tau_L}{\tau_S} \times BR(K_S \to \pi^0 e^+ e^-) \sim 1/330 \times BR(K_S \to \pi^0 e^+ e^-)$

The $BR(K_S \to \pi^0 e^+ e^-)$ cannot be reliably predicted and is not well bound experimentally:

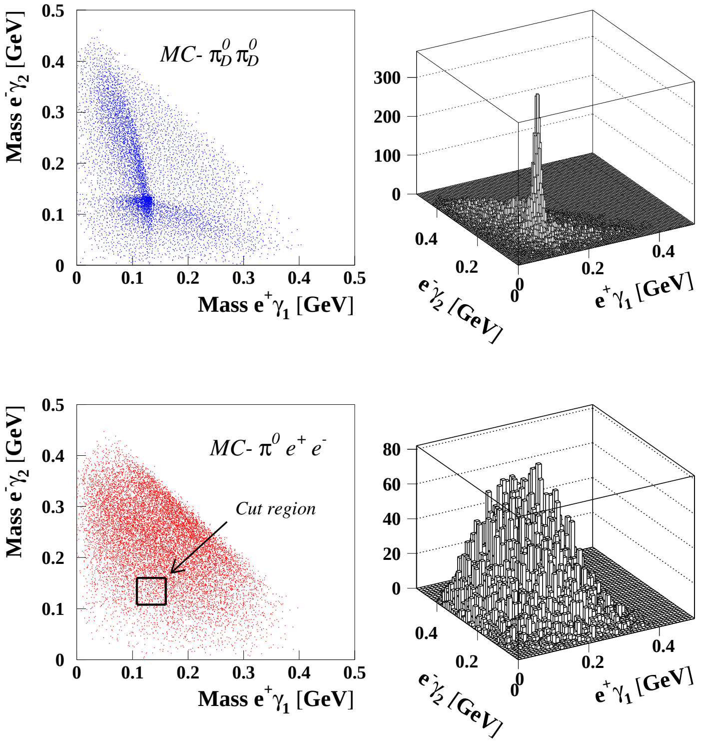
NA31: $BR(K_S \to \pi^0 e^+ e^-) < 1.1 \times 10^{-6}$

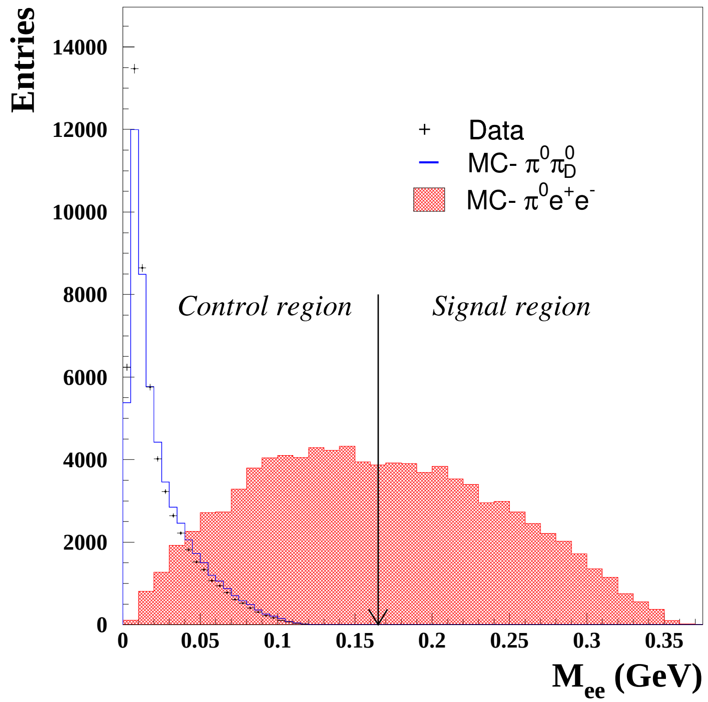
[a] J. Whitmore, KTEV, KAON-99 Conference, June 1999.

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

- **Trigger Selection**
  - $E_{LKr} > 50$ GeV
  - $t < 5\, c\tau_S$
  - $COG < 10$ cm
  - $E_{HAC} < 8$ GeV
  - 1 or 2 hits in DCH1
- **Event Selection**
  - 2 tracks, 4 clusters
  - $0.9 < E/P < 1.1$ for the 2 electron tracks
  - $|m_{\gamma\gamma} - m_{\pi^0}| < 3$ MeV/c^2
  - $|m_{ee\gamma\gamma} - m_K| < 10$ MeV/c^2
  - normalisation channel: $K_S \to \pi^0 \pi^0_D$
- **Background Rejection**
  - $K_S \to \pi^0_D \pi^0_D$
    $|m_{e\gamma} - m_{\pi^0}| < 0.03$ GeV/c^2
    $\Rightarrow$ < 0.03 events
  - $K_S \to \pi^0 \pi^0_D$
    $m_{ee} > 0.165$ GeV/c^2
    $\Rightarrow$ < 0.03 events (based on 10^8 simulated $\pi^0\pi^0_D$)
  - $K_S, K_L \to e^+ e^- \gamma\gamma$
    $\Rightarrow$ negligible

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





$\Rightarrow$ No events found:

$$\boxed{BR(K_S \to \pi^0 e^+ e^-, m_{e^+e^-} > 165 MeV/c^2) < 8.3 \times 10^{-8} \text{ 90 \% CL}}$$

Assuming matrix element from

G.D'Ambrosio et al., hep-ph/9808289, G. Ecker et al., NP B303 665

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

Summary

NA48 has presented the following preliminary results:

- $K_{\mathrm{L}} \rightarrow e^+e^-e^+e^-$
  $\mathrm{BR}(K_{\mathrm{L}} \rightarrow e^+e^-e^+e^-) =$
  $(3.67 \pm 0.32(stat) \pm 0.23(syst) \pm 0.08(norm)) \times 10^{-8}$
- $K_{\mathrm{L}} \rightarrow \pi^0\gamma\gamma$
  $BR(K_{\mathrm{S}} \rightarrow \gamma\gamma) = (2.56 \pm 0.35(stat) \pm 0.20(syst)) \times 10^{-6}$
- $K_{\mathrm{S}} \rightarrow \gamma\gamma$
  $BR(K_{\mathrm{S}} \rightarrow \gamma\gamma) = (2.56 \pm 0.35(stat) \pm 0.20(syst)) \times 10^{-6}$
- $K_{\mathrm{S}} \rightarrow \pi^0e^+e^-$
  $BR(K_{\mathrm{S}} \rightarrow \pi^0e^+e^-, m_{e^+e^-} > 165\ \mathrm{MeV/c^2}) < 8.3 \times 10^{-8}$ 90 % CL

Prospects

- The NA48 Drift Chambers were damaged by the beam pipe implosion in November 1999
- NA48 is currently collecting K_S decays into final states with π^0s and photons ($\sim 10^{10}$ K_S exposure in approx. 45 days)
- Three Drift Chambers should be repaired by April 2001 to complete $\mathrm{Re}(\varepsilon'/\varepsilon)$
- We plan a K_S rare decay search for the year 2002. This program is currently under consideration by the CERN committees (CERN-SPSC-P-253-ADD-2, Dec 1999). The program should allow, among other things:
  - Single Event Sensitivity of $\sim 3\ 10^{-10}$ for $K_S \to \pi^0 e^+ e^-$
  - Study of $\Xi^0 \to \Sigma^+ e^- \bar{\nu}$ with approx. 25000 events
- For the year 2003 a run with simultaneous K^+/K^- beams is proposed. The aim is to reach a sensitivity of 10^{-4} on direct CP violation in $K^\pm \to 3\pi$ decays (CERN-SPSC-P-253-ADD-3, Dec 1999)