NA48 Rare Kaon Decays

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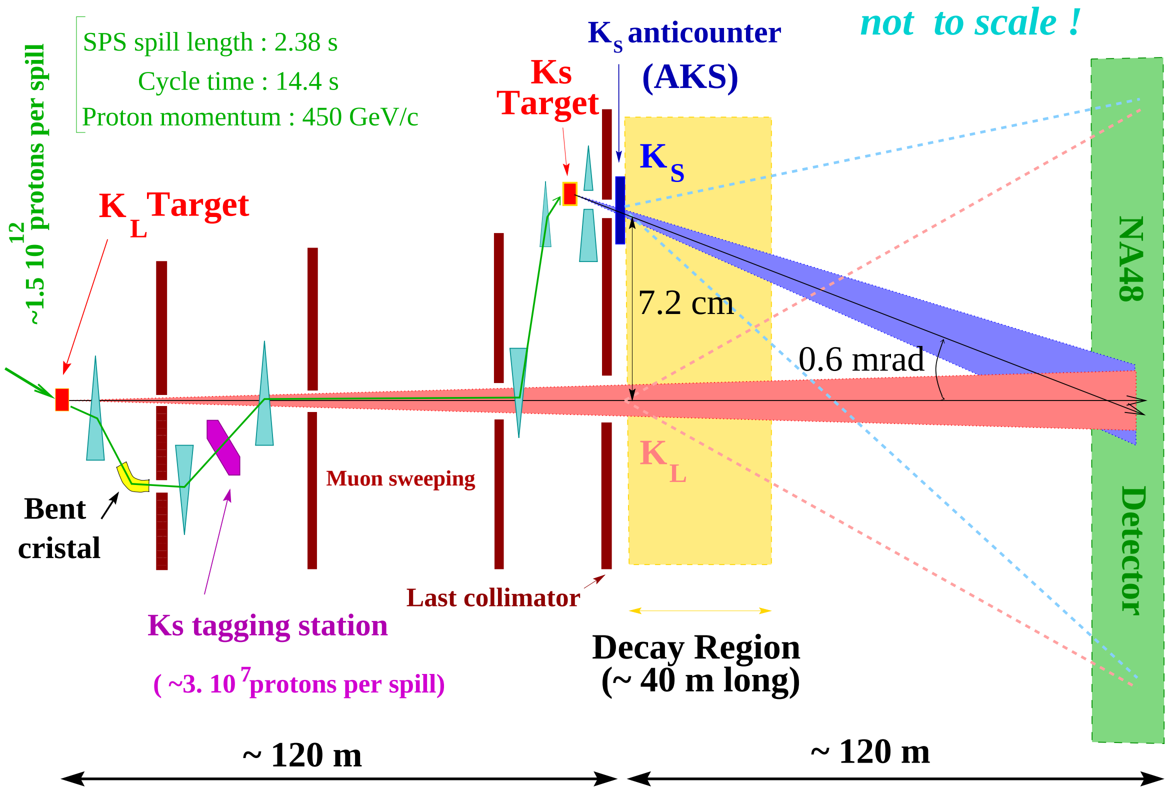
on behalf of the **NA48 COLLABORATION**
Cagliari-Cambridge-CERN-Dubna-Edinburgh-Ferrara-Firenze-Mainz-Orsay-Perugia-Pisa-Saclay-Siegen-Torino-Vienna-Warsaw

Outline

- Preliminary Results on Rare Kaon decays
  - $\mathrm{K_S} \rightarrow \gamma\gamma$ NEW!
  - $\mathrm{K_S} \rightarrow \pi^0 e^+ e^-$ NEW!
  - $\mathrm{K_L} \rightarrow e^+ e^- e^+ e^-$ NEW!
  - $\mathrm{K_S} \rightarrow \pi^+ \pi^- e^+ e^-$
- Summary
- Outlook

The NA48 Experiment

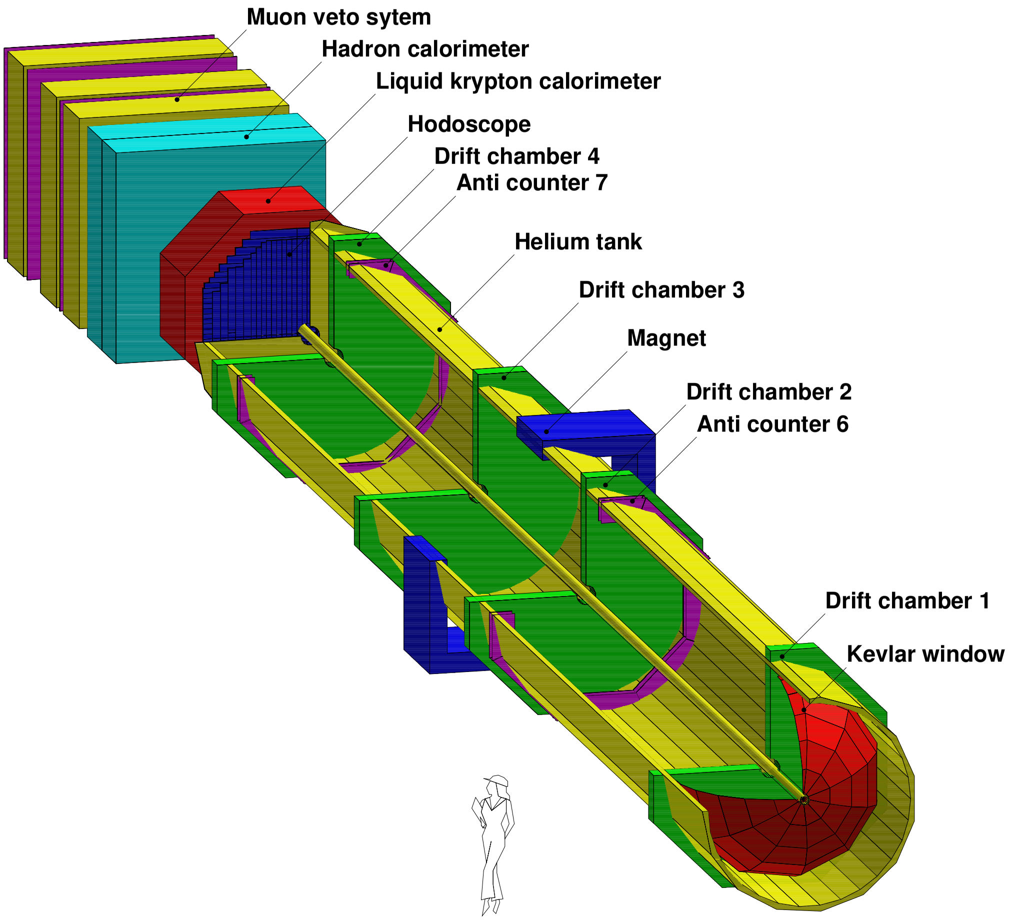


Two simultaneous and almost collinear neutral beams converge towards the NA48 calorimeters with an angle of 0.6 mrad.

KL beam is produced from a 450 GeV, 1.5×10^{12} ppp, SPS proton beam.

KS beam is produced splitting off a small fraction of the primary proton beam using a bent crystal. Protons impinging on the KS target are individually tagged.

The NA48 Detector



charged decays $\Rightarrow$ magnetic spectrometer

- $\sigma(p)/p \simeq 0.5\,\% \oplus 0.009\; p[GeV/c]\,\%$
- $\sigma_{X,Y} \;=\; 100\;\mu m$

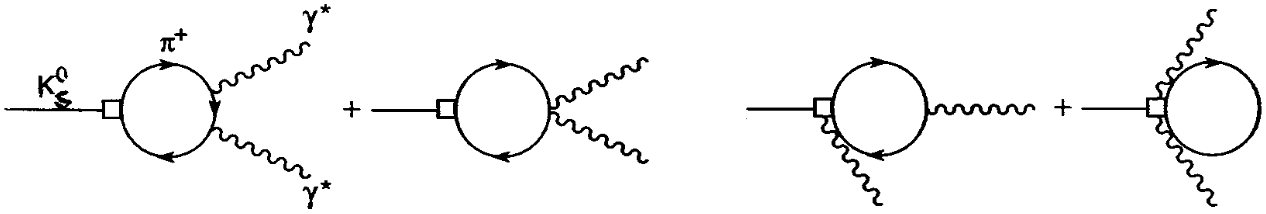
neutral decays $\Rightarrow$ quasi-homogeneous Liquid Kripton e.m. calorimeter

- high granularity (13212 $\;2 \times 2\,cm^2$ cells)
- $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus (100\,MeV)/E \oplus 0.5\%$
- $\sigma(t) \simeq 265\,ps$ for 50 $GeV\,e^-$
- $\sigma_{X,Y} \;=\; 1\,mm$

Physics Motivation

The decay $K_S \to \gamma\gamma$ is interesting to understand the low energy hadronic dynamics of Chiral Perturbation Theory (χPT)

The main diagrams contributing are loops of charged pions:



Importance of this decay is due to :

- No short distance contribution
- Finite and unambiguous prediction of BR($K_S \to \gamma\gamma$)

$\Rightarrow$ Good test of χPT

Thoretical prediction	$BR(K_S \to \gamma\gamma) = (2.3 \pm 0.2) \times 10^{-6}$
NA31 Result	$BR(K_S \to \gamma\gamma) = (2.4 \pm 0.9) \times 10^{-6}$

Data and Event Selection

Result based on High Intensity $\mathrm{K_S}$ run taken in 1999 with $7 \times 10^9\, ppp$ ($\sim 2\, days$)

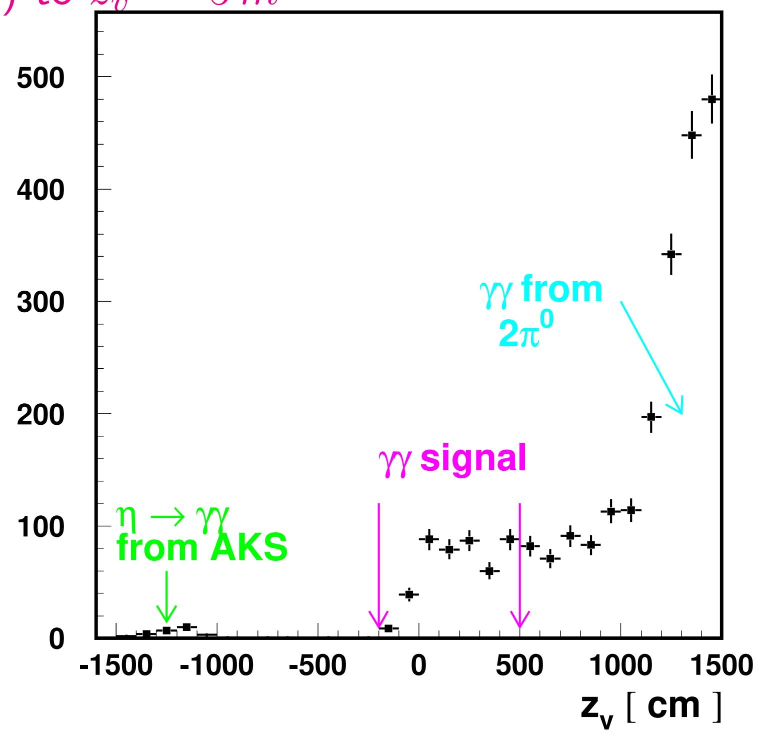
Main cuts applied on clusters:

- $3\, GeV < E_{cl} < 100\, GeV$
- distance between two clusters, $d > 10\, cm$
- No extra clusters with $E_{cl} > 1\, GeV$ within $\pm 3\, ns$
- $\mid t_{cl} - t_{event} \mid < 5\, ns$
- center of gravity of two clusters, $cog < 7$
- $60\, GeV < E_K < 170\, GeV$

Main background $\mathrm{K_S} \to \pi^0\pi^0$, with two photons lost

Maximum invariant $m_{\gamma\gamma}$ originating from $\mathrm{K_S} \to \pi^0\pi^0$ cannot produce a vertex position less than $9\, m$

$\Rightarrow$ Decay region defined from the end of the $\mathrm{K_S}$ collimator ($z_v = 0$) to $z_v = 5\, m$



$K_S \to \gamma\gamma$

Background events in the signal

After subtracting $N(K_S \to \pi^0\pi^0)$ background there remain $N = 450$ events in the signal originating from $K \to \gamma\gamma$ decays

Additional background:

- $K_L \to \gamma\gamma$

  Knowing the flux at the target from $2\pi^0$ events, the number of $\gamma\gamma$ events originating from K_L can be computed and subtracted from the signal $K \to \gamma\gamma$

  $N \sim 294$ events

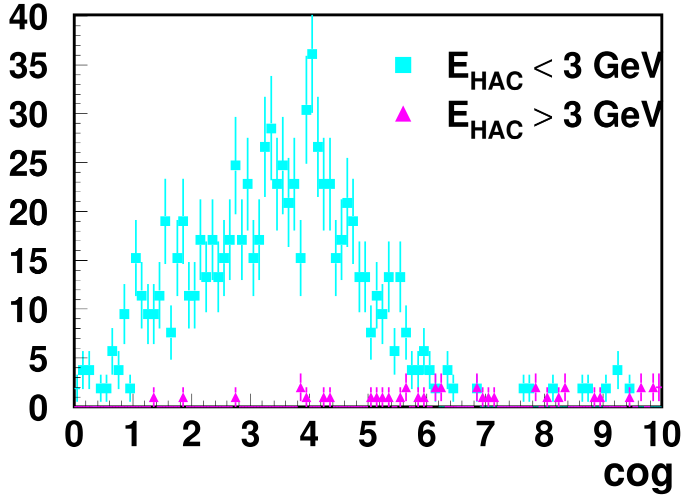
- $\Lambda \to n\pi^0$

  cuts applied on cluster variables:

  – cluster width

  – in time cluster in HAC, cog

  $N \sim 14$ events



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

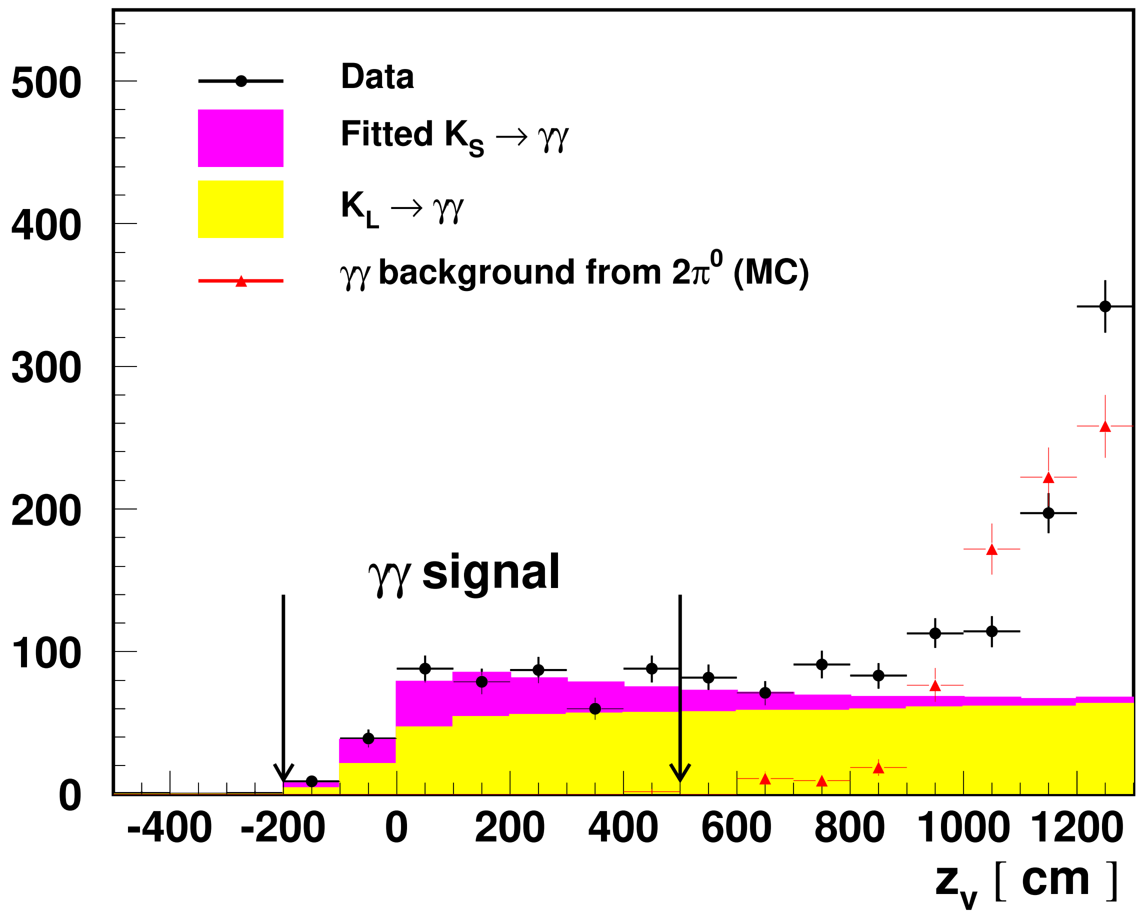
  Possible background events at $z_v < 5\,m$ studied with MC $\Rightarrow$ only overlapped clusters can be reconstructed as $\gamma\gamma$ events

  $N \sim 2$ events

$K_S \to \gamma\gamma$

Preliminary Result on Branching Ratio

The number of $K_S \to \gamma\gamma$ events in the $K \to \gamma\gamma$ sample, N_S, and the branching ratio $BR(K_S \to \gamma\gamma)$ are estimated using binned maximum log likelihood method $\Rightarrow N_S = 148$



PRELIMINARY

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

$\mathrm{K_S} \rightarrow \pi^0 \mathrm{e^+e^-}$

Physics Motivation

Interest:

measure the $\mathrm{K_S} \rightarrow \pi^0 \mathrm{e^+e^-}$ branching ratio

$\Rightarrow$ put bounds on the indirect CP-violating term in the $\mathrm{K_L} \rightarrow \pi^0 \mathrm{e^+e^-}$ decay

Thoretical prediction	$BR(\mathrm{K_S} \rightarrow \pi^0 \mathrm{e^+e^-}) < 5.2 \times 10^{-9}$
NA31 Result	$BR(\mathrm{K_S} \rightarrow \pi^0 \mathrm{e^+e^-}) < 1.1 \times 10^{-6}$ $(90\,\%\,CL)$

Event Selection

- 2 tracks, 2 clusters (e^+e^-) + 2 clusters (π^0)
- $0.9 < E/p < 1.1$
- π^0 mass, K mass $(3\,\sigma)$
- data sample: HI $\mathrm{K_S}$ run
- normalization channel: $\mathrm{K_S} \rightarrow \pi^0 \pi^0_{\mathrm{D}}$

Background Rejection

- $\mathrm{K_S} \rightarrow \pi^0 \pi^0_{\mathrm{D}}$ with $\pi^0_D \rightarrow e^+e^-\gamma$
  $\Rightarrow < 0.3$ events
- $\mathrm{K_S} \rightarrow \pi^0_{\mathrm{D}} \pi^0_{\mathrm{D}}$ with two $\pi^0_D \rightarrow e^+e^-\gamma$
  $\Rightarrow < 0.03$ events
- $\mathrm{K_{L,S}} \rightarrow \mathrm{e^+e^-}\gamma\gamma$
  $\Rightarrow$ negligible

$\mathrm{K_S} \to \pi^0 e^+ e^-$

Preliminary Result

After applying all the selection cuts, the signal region is defined for $M_{ee} > 165\,MeV$

$\Rightarrow$ NO EVENTS FOUND

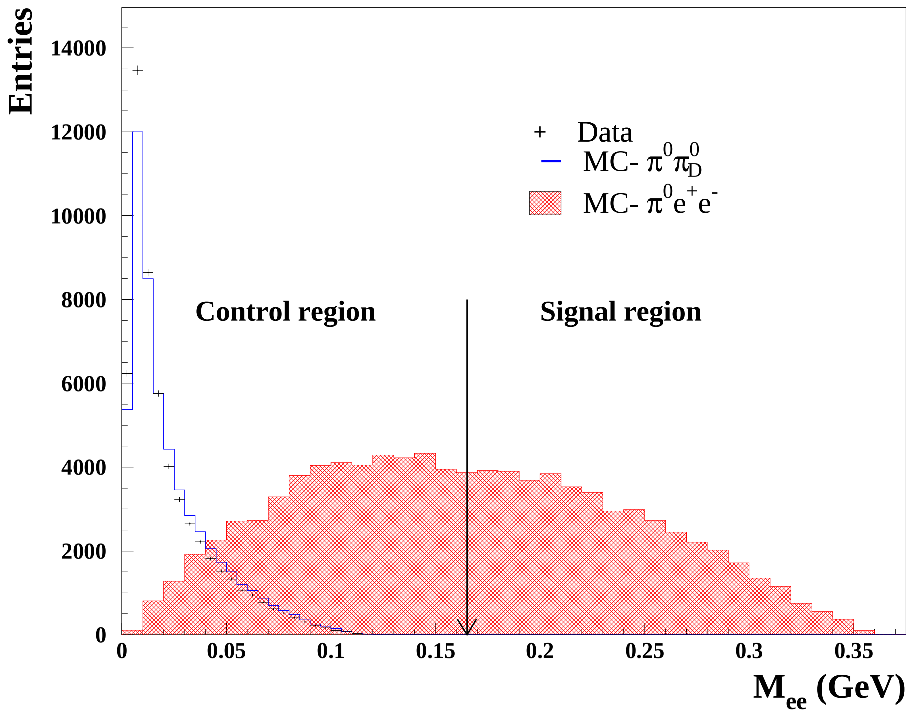
This corresponds to an upper limit:

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

assuming matrix elements from

G. D'Ambrosio et al. (hep-ph/9808289) and

G. Ecker et al.Nucl.Phys. B303 (1998) 665-702



A model independent calculation gives:

$$\boxed{\mathrm{BR}(\mathrm{K_S} \to \pi^0 e^+ e^-, M_{ee} > 165\,MeV) < 8.3 \times 10^{-8} \quad (90\,\%\,CL)}$$

$\mathrm{K_L} \to \mathrm{e^+e^-e^+e^-}$

Physics Motivation

The $\mathrm{K_L} \to \mathrm{e^+e^-e^+e^-}$ is expected to proceed mainly via the double internal photon conversion of $\mathrm{K_L} \to \gamma^*\gamma^*$ in e^+e^-

$\Rightarrow$ Probe the structure of $\mathrm{K_L} \to \gamma^*\gamma^*$ vertex

Event Selection

- Online selection
  - First level: adjacent hits in the hodoscope in coincidence with a total energy condition ($E_{tot} > 30\,GeV$)
  - Second level: DCH hits to reconstruct tracks and invariant masses
- Offline selection
  - 4 clusters in LKR, 4 tracks in DCH
  - cuts on distance between tracks and clusters
  - $500\,cm < z_{vertex} < 9000\,cm$
  - $0.475\,GeV < mass_K < 0.525\,GeV$
  - $50\,GeV < E_K < 200\,GeV$
- Background rejection
  - $\mathrm{K_L} \to \pi e \nu$
    two decays in time and pions misidentified as electrons
    $\Rightarrow$ requiry good vertex quality ($cda < 5\,cm$; clusters in time within $3\,ns$)
  - $\mathrm{K_L} \to \pi^0\pi^0\pi^0$
    Dalitz decay of π^0's and photon conversion
    $\Rightarrow$ use invariant mass
  - $\mathrm{K_L} \to \gamma\gamma$ and $\mathrm{K_L} \to \mathrm{e^+e^-}\gamma$
    photon conversion
    $\Rightarrow$ invariant mass and separation of each pair of oppositely charged tracks $> 2\,cm$

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

Branching Ratio

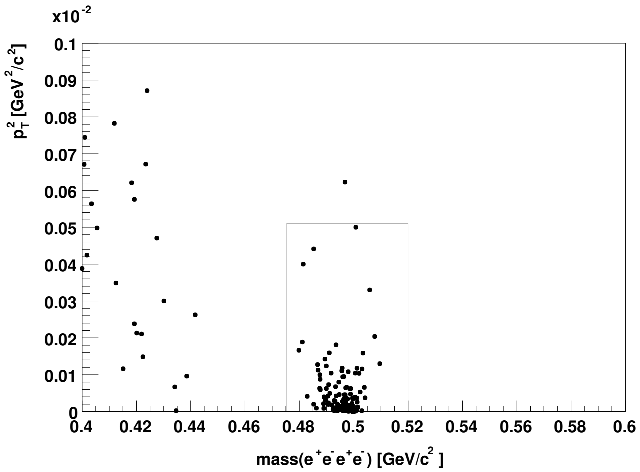
PRELIMINARY

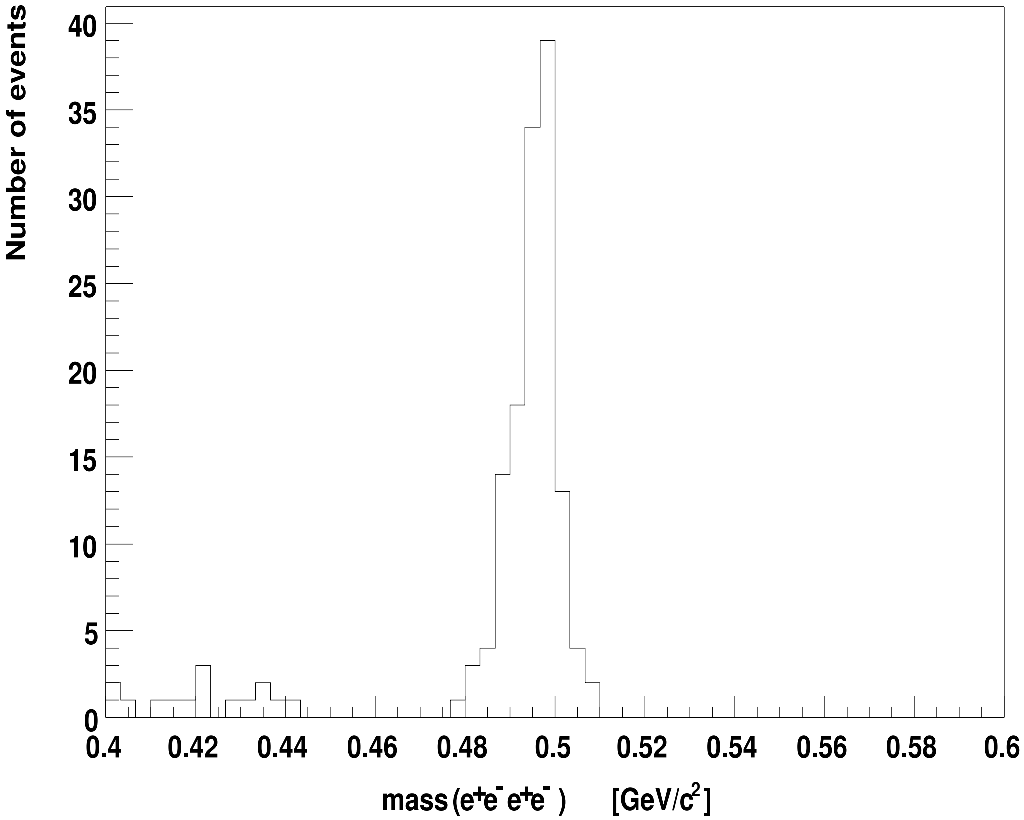
132 candidate events

Normalization channel:

$K_L \to \pi^+\pi^-\pi^0_D$

$(\pi^0_D \to e^+e^-)$



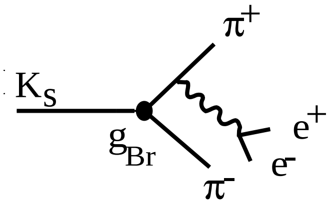


$$\mathrm{BR}(K_L \to e^+e^-e^+e^-) = (3.67 \pm 0.32\ (stat) \pm 0.23(syst) \pm 0.08(norm)) \times 10^{-8}$$

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

Physics Motivation

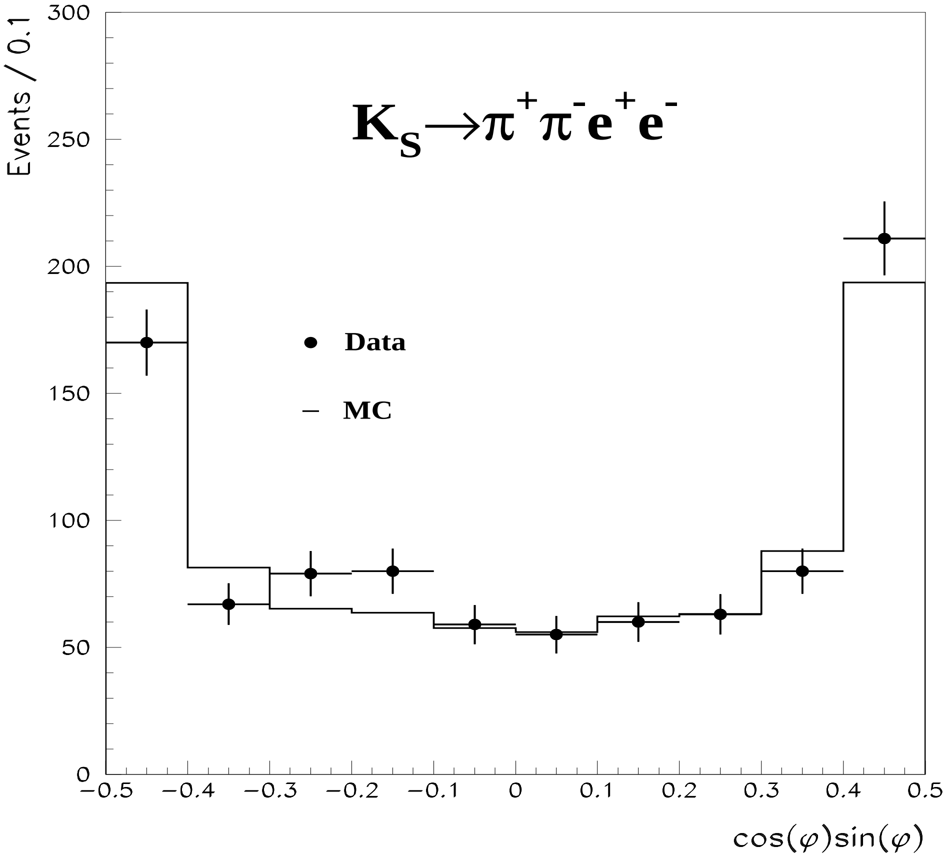
Main production process: CP conserving bremsstrahlung
No asymmetry expected!



1998 + 1999 + HI K_S DATA
Preliminary

Not corrected for acceptance

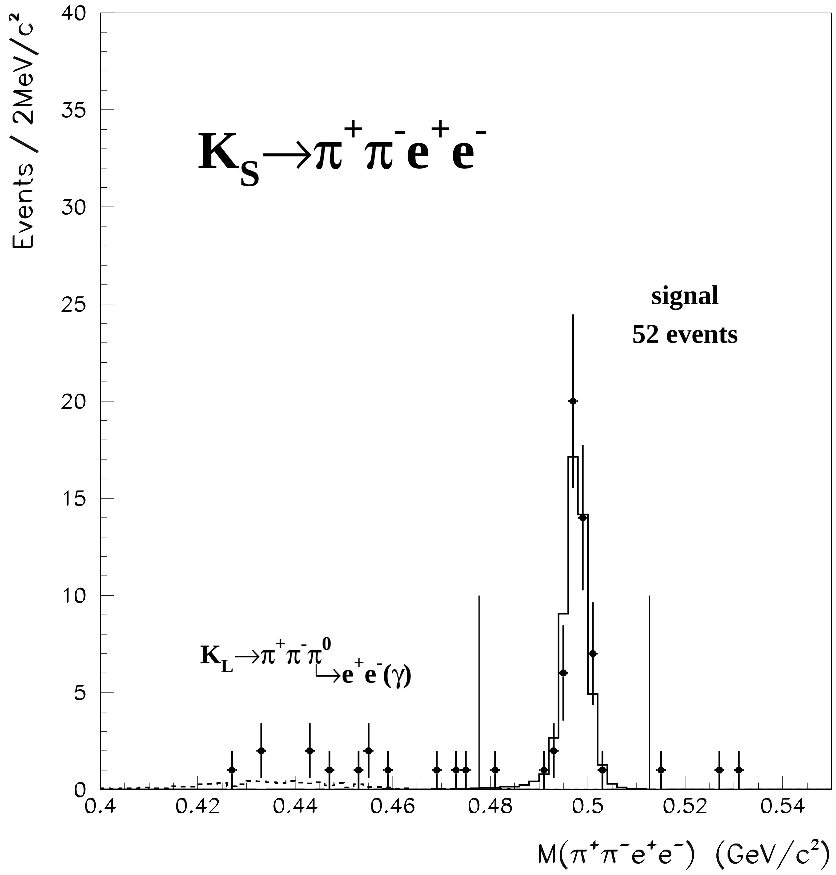
Asymmetry consistent with 0



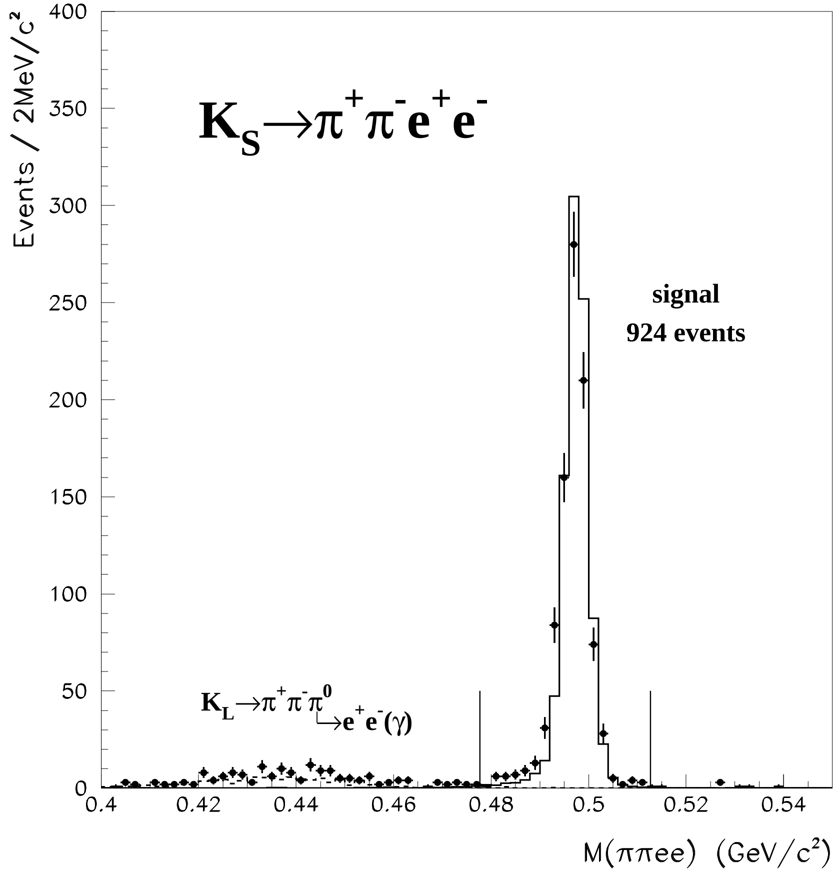
$K_S \to \pi^+\pi^-e^+e^-$

Preliminary Results

First observation 1998 data



'98 + '99 + HI K_S



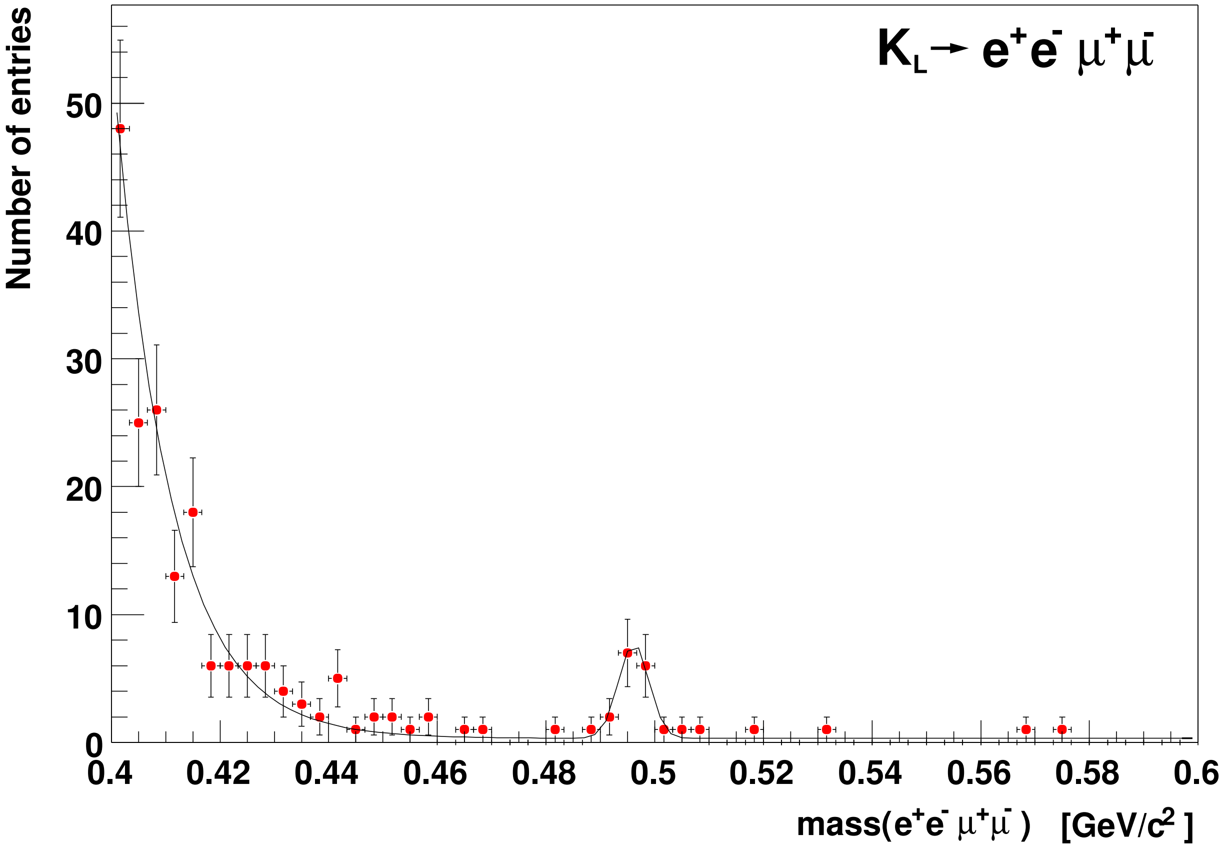
$$BR(K_S \to \pi^+\pi^-e^+e^-) = (5.1 \pm 0.9\ (stat) \pm 0.3(syst)) \times 10^{-5}$$

(1998 data)

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

1999 DATA

21 candidate events



Summary-1

The NA48 experiment has reported
NEW PRELIMINARY Branching Ratio results:

- $\boxed{\mathrm{K_S} \rightarrow \gamma\gamma}$ $\Rightarrow$ New result

  $\mathrm{BR(K_S} \rightarrow \gamma\gamma) = (2.6 \pm 0.4\ (stat) \pm 0.2(syst)) \times 10^{-6}$

- $\boxed{\mathrm{K_S} \rightarrow \pi^0 \mathrm{e^+e^-}}$ $\Rightarrow$ New result

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

- $\boxed{\mathrm{K_L} \rightarrow \mathrm{e^+e^-e^+e^-}}$ $\Rightarrow$ New result

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

Summary-2

Other Branching Ratio Results
PRELIMINARY

- $\boxed{\mathrm{K_L} \to \pi^0\gamma\gamma}$
  - $\mathrm{BR}(\mathrm{K_L} \to \pi^0\gamma\gamma) = (1.51 \pm 0.05\,(stat) \pm 0.20\,(syst)) \times 10^{-6}$
  - Evidence for low $m_{\gamma\gamma}$ with very low background (contribution beyond $O(p^4)$)

- $\boxed{\mathrm{K_S} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-}$
  - $\mathrm{BR}(\mathrm{K_S} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-) = (5.1 \pm 0.9\,(stat) \pm 0.3(syst)) \times 10^{-5}$ (Prel. '98 data)
  - Measured asymmetry consistent with 0

- $\boxed{\mathrm{K_L} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-}$
  - $\mathrm{BR}(\mathrm{K_S} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-) = (2.90 \pm 0.15\,(stat)) \times 10^{-7}$ (Prel.'98 data)
  - Measured asymmetry consistent with theory

Outlook

Future Plans
High Intensity $\mathrm{K_S}$

- very successfull test run in 1999
- 2 days $\Rightarrow$ good physics

$\Rightarrow$ 43 days run this year:

- taking data now at 200 times the standard proton flux (3×10^7)

$\Rightarrow$ Proposed $\mathrm{K_S}$ run 2002:

- 400 times the standard proton flux
- minor optimization of the beam $(400\, GeV/c)$ protons
- minor changes in NA48 detector

$\Rightarrow$ Physics reach (run 2002):

SES for a 120 day run at 50 % efficiency estimated
to be $\frac{1}{\alpha}(3 \times 10^{-11})$ (α being the total acceptance of the channel)

For $\mathrm{K_S} \rightarrow \pi^0 \mathrm{e^+e^-}$ ($\alpha =$ 0.05) $\Rightarrow SES \sim 6 \times 10^{-10}$