New NA48 results on CPV

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EPS Conference - Aachen
July 2003

On behalf of the NA48 Experiment :
Cambridge, Chicago, CERN, Dubna, Edinburgh
Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay,
Siegen, Torino, Warsaw, Wien

Overview

- NA48 beam and detector

1997-1998-1999: $K_L + K_S$ beam, $\mathrm{Re}(\varepsilon'/\varepsilon)$ run
short high-intensity K_S run

Angular asymmetry in $K_{L,S} \to \pi^+\pi^-e^+e^-$

2001: $K_L + K_S$ beam, $\mathrm{Re}(\varepsilon'/\varepsilon)$ run

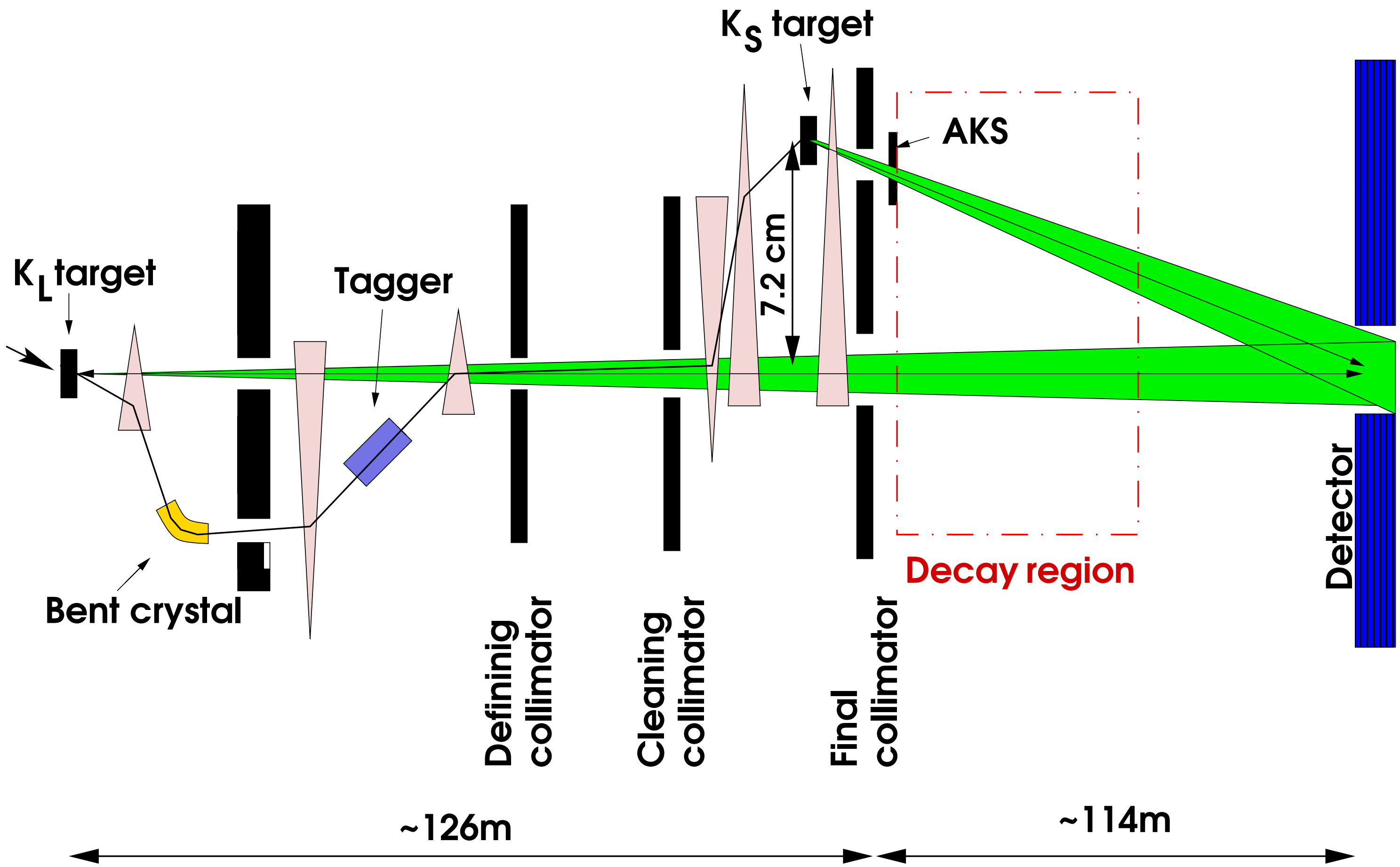
Charge asymmetry in $K_L \to e^{\pm}\pi^{\mp}\nu_e$

2002: high-intensity K_S and Hyperon beam

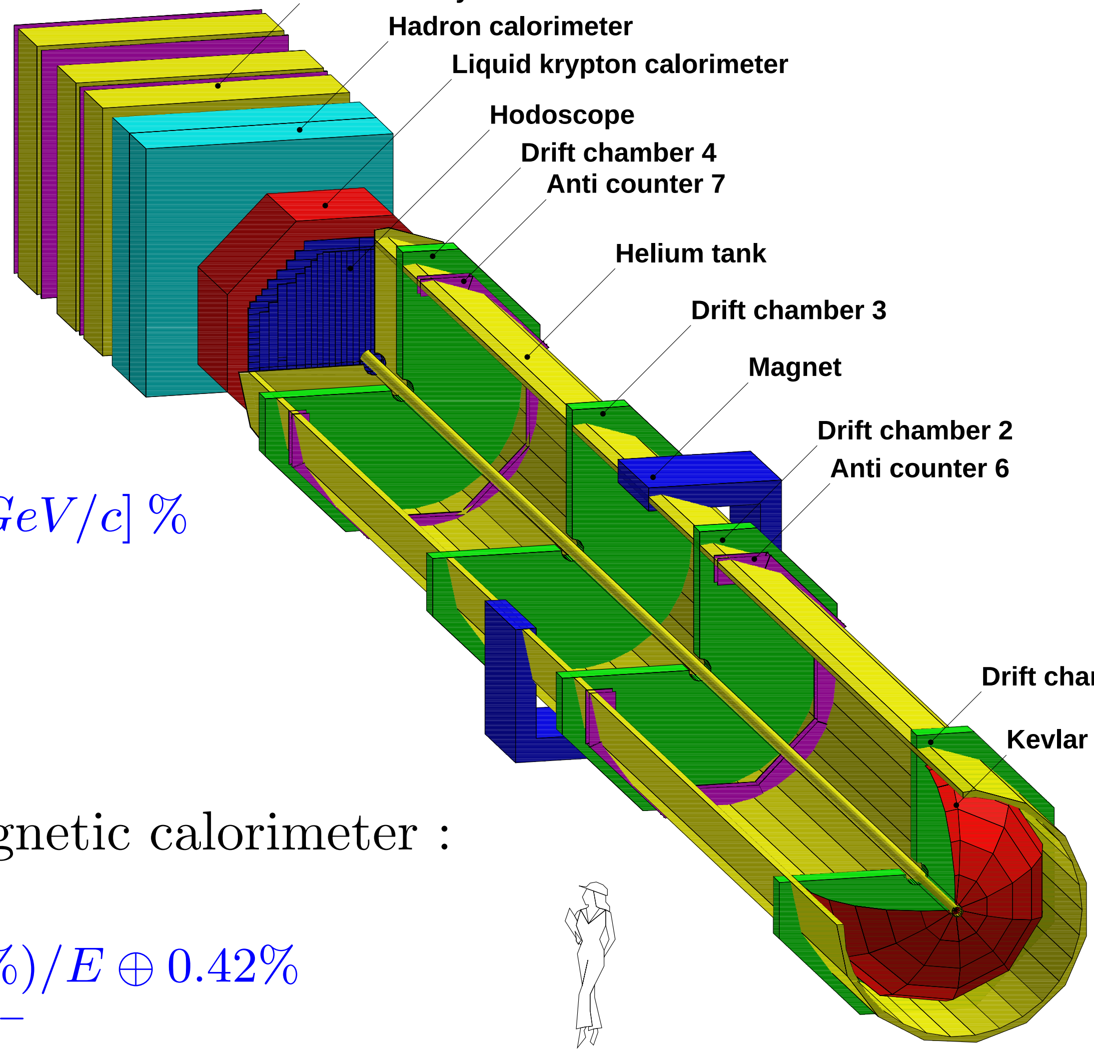
First observation of $K_S \to \pi^0 e^+e^-$

- Conclusions

The NA48 simultaneous K_S and K_L beams



NA48 Detector



- Magnetic spectrometer :
  charged particles
  $\sigma(p)/p \simeq 0.5\,\% \oplus 0.009\; p[GeV/c]\,\%$
  $(\mathrm{P}_{\perp}{}^{kick} \sim 265\mathrm{MeV}/c)$

- Liquid Krypton electromagnetic calorimeter :
  photons and electrons
  $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus (9\%)/E \oplus 0.42\%$
  $\sigma(t) \simeq 265ps$ for 50 GeV e^{-}

K_{e3} *charge asymmetry*

If CPT is conserved:

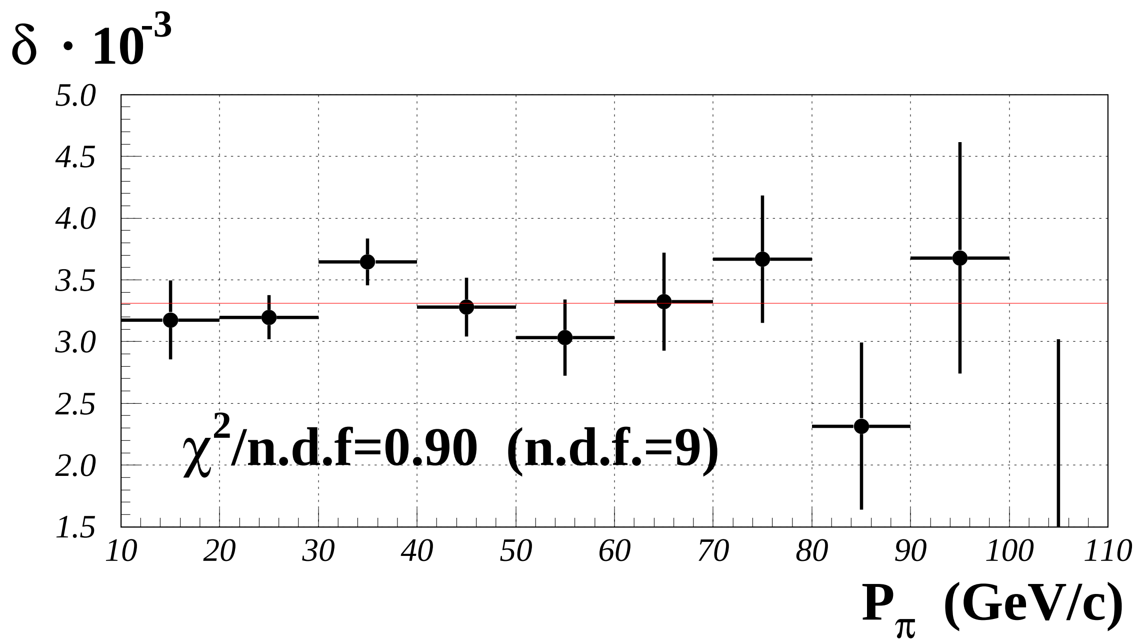
$$\delta_L(e) = \frac{\Gamma(K_L \to \pi^- e^+ \nu) - \Gamma(K_L \to \pi^+ e^- \nu)}{\Gamma(K_L \to \pi^- e^+ \nu) + \Gamma(K_L \to \pi^+ e^- \nu)} = 2 \times Re(\epsilon)$$

- 2001 data
- Count $\delta_L(e) = \frac{N(\pi^- e^+) - N(\pi^+ e^-)}{N(\pi^- e^+) + N(\pi^+ e^-)}$
- $e - \pi$ identification by E/p
- Events selected $\sim 2.1 \times 10^8$ (10^8 for each B field orientation)
- Statistical uncertainty $\sim 7 \times 10^{-5}$

$K_L \to e^{\pm}\pi^{\mp}\nu_e$ *systematics: preliminary*

- Fake asymmetry from different particle interactions
- Data control samples: $\pi^+\pi^-\pi^0$, $\pi^+\pi^-$
- Corrections in bins of track momentum
- Average over magnetic field orientations

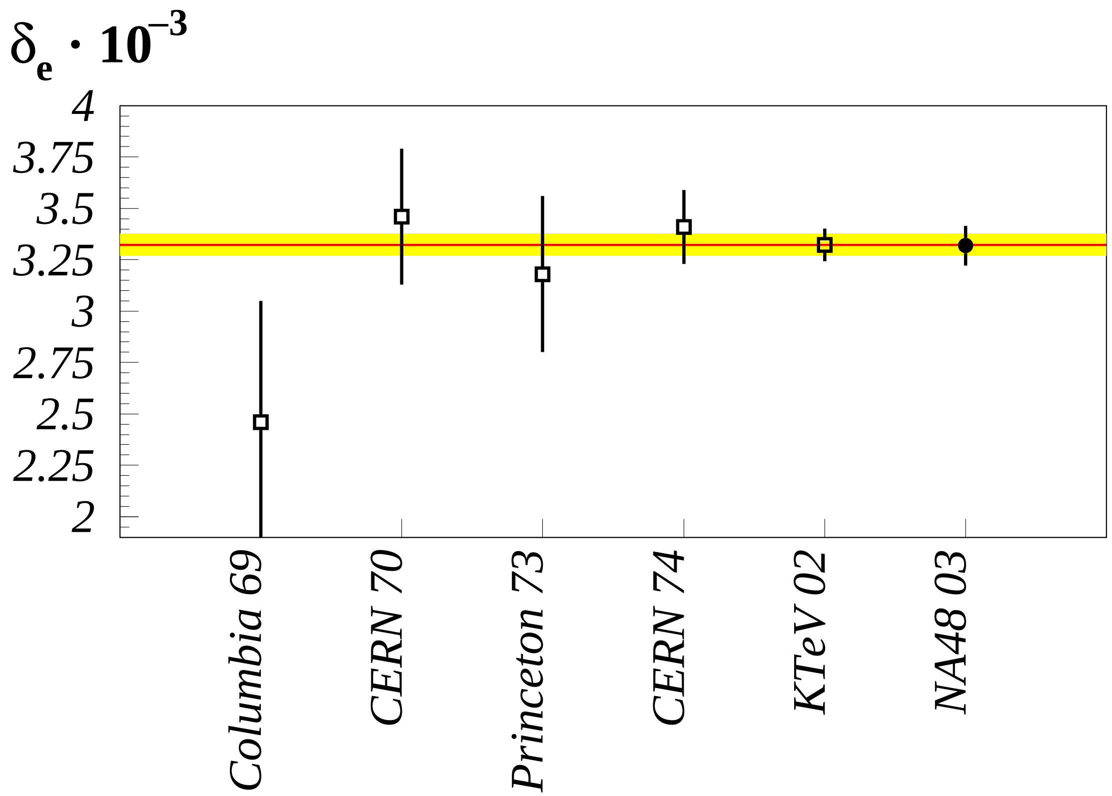
Source	10^{-5}
Trigger	$+26.2 \pm 6.0$
Punch through	-1.4 ± 3.5
Pion ID	-17.1 ± 2.4
Acceptance	± 0.5
Background	± 0.5
Total	$+7.7 \pm 7.2$



$K_L \to e^{\pm}\pi^{\mp}\nu_e$ *result: preliminary*

$\delta_L(e) = (0.3317 \pm 0.0070_{stat} \pm 0.0072_{syst})\%$

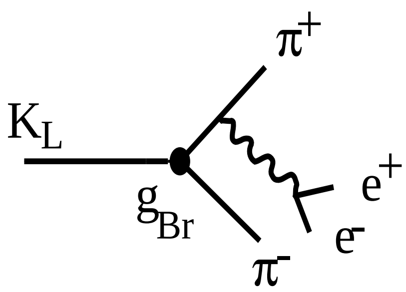
Consistent with KTeV and World average measurements:



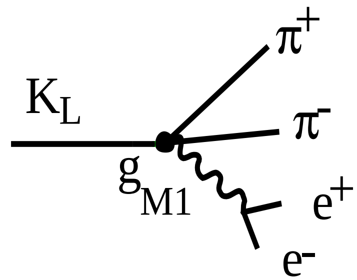
World average: $\delta_L(e) = (0.3322 \pm 0.0055)\%$

(Old world average: $\delta_L(e) = (0.3307 \pm 0.0063)\%$)

$K_{L,S} \to \pi^+\pi^-e^+e^-$

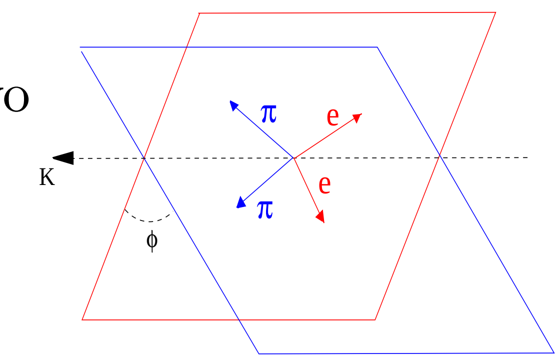


CP-violating
bremsstrahlung



CP-conserving
M1 γ emission

The interference between the two terms results in a CP-violating circular polarization of the γ^*



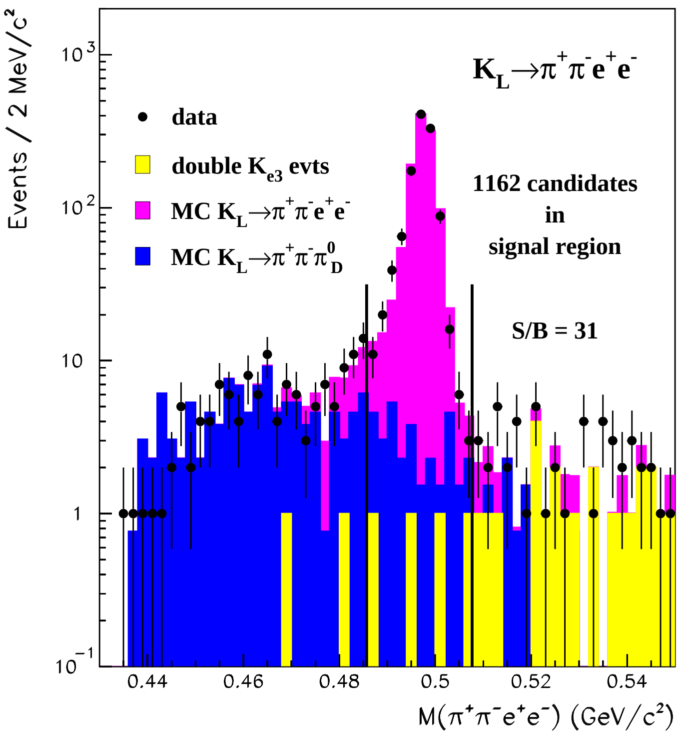
The effect is visible as an asymmetry in the decay rate

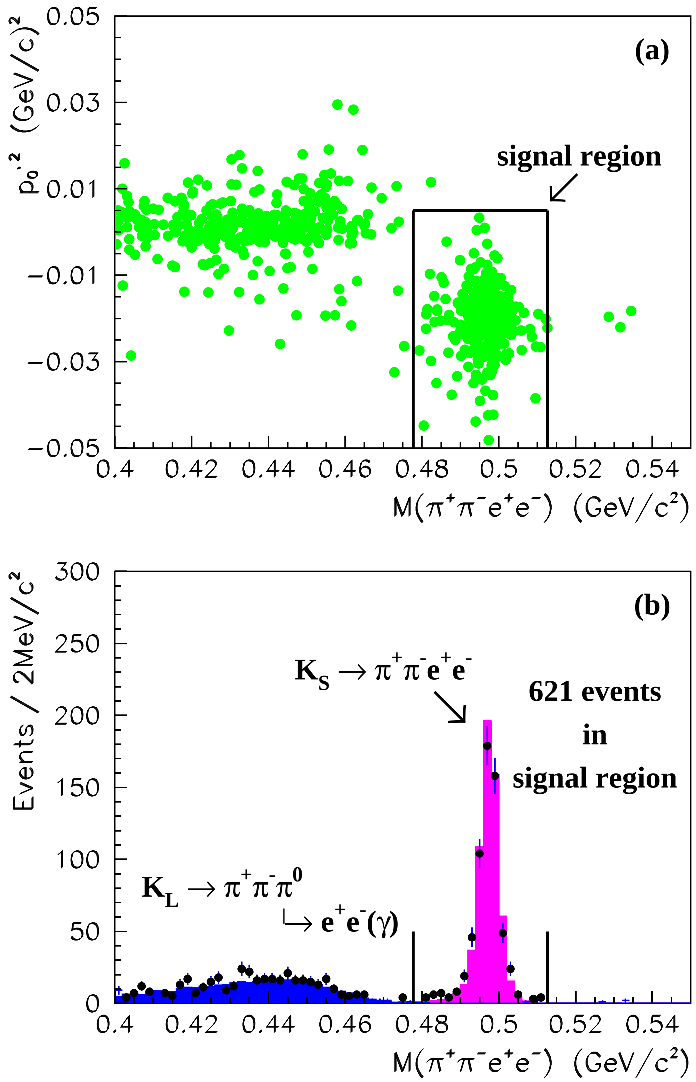
$$\frac{N_{\cos\phi\sin\phi>0} - N_{\cos\phi\sin\phi<0}}{N_{\cos\phi\sin\phi>0} + N_{\cos\phi\sin\phi<0}} \approx 14\%(theo)$$

K_S: dominated by CP-conserving bremsstrahlung

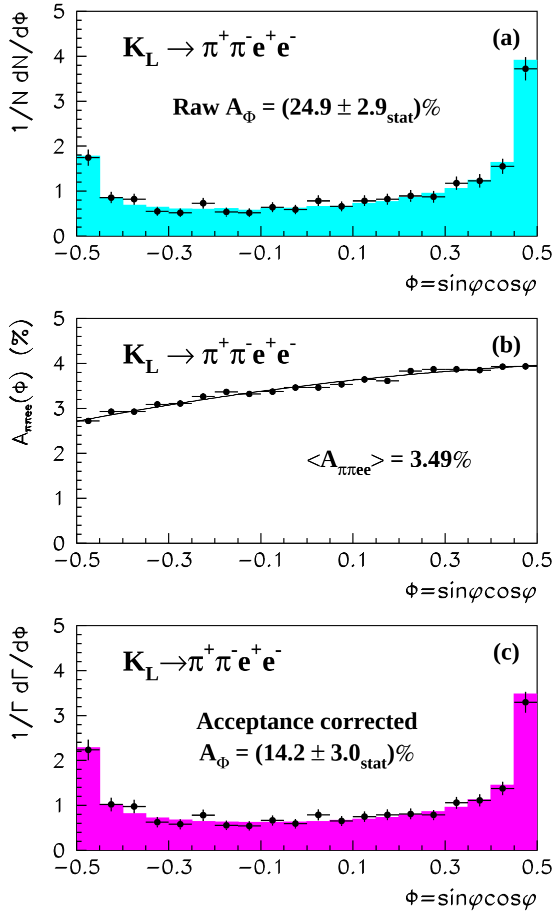
$K_{L,S} \to \pi^+\pi^-e^+e^-$ *signals*

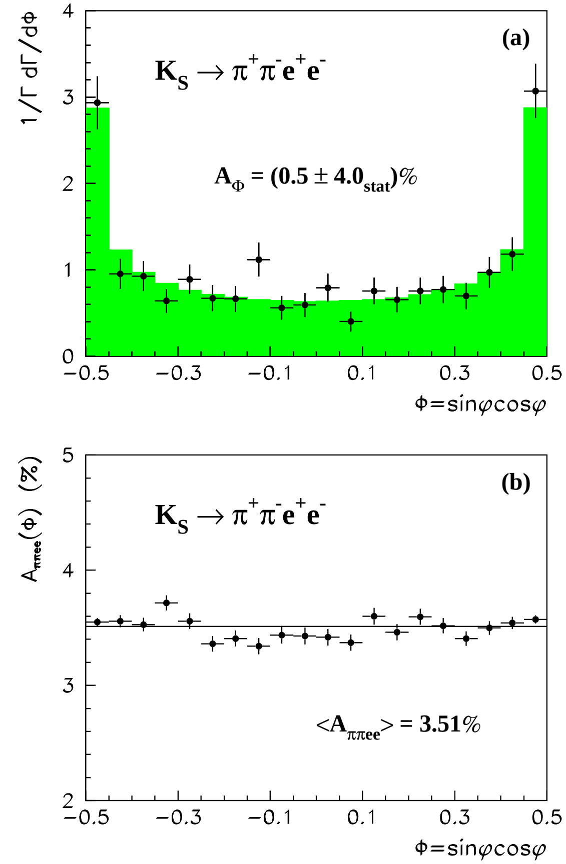
- 1998-1999 data
- Events: 1162 K_L; 621 K_S
- Background: $(3.2 \pm 0.5)\%$ K_L; $(0.1 \pm 0.2)\%$ K_S





$K_{L,S} \rightarrow \pi^+\pi^-e^+e^-$ *asymmetry*





$A_\phi(K_L) = (14.2 \pm 3.0_{stat} \pm 1.9_{sys})\%$: indirect CPV established

$A_\phi(K_S) = (0.5 \pm 4.0_{stat} \pm 1.6_{sys})\%$: no asymmetry expected

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

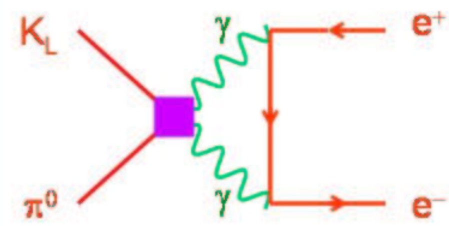
The decay $K_L \to \pi^0 e^+ e^-$ has three components :

- CP conserving

  NA48 measurement $BR(K_L \to \pi^0 \gamma\gamma)$:

  $\to BR(K_L \to \pi^0 e^+ e^-)_{CP\,cons} = 0.47^{+0.22}_{-0.18} \times 10^{-12}$

  [PL B536 229]

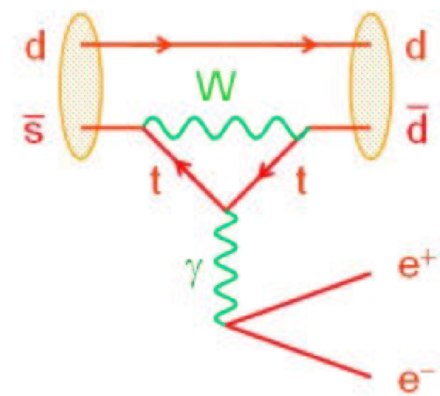


- direct CP violating

  Proportional to η or $\mathcal{I}m(\lambda_t)$

  $\mathcal{I}m(\lambda_t) = \eta A^2 \lambda^5 \qquad \lambda_t = V_{ts}^* V_{td}$

  $\to BR(K_L \to \pi^0 e^+ e^-)_{dir} \sim few \times 10^{-12}$



- indirect CP violating

  $\to BR(K_L \to \pi^0 e^+ e^-)_{ind} = |\epsilon|^2 (\frac{\tau_L}{\tau_S}) BR(K_S \to \pi^0 e^+ e^-)$

$BR(K_S \to \pi^0 e^+ e^-)$ and $BR(K_L \to \pi^0 \gamma\gamma)$ determine whether it will be possible to extract η from a measurement of $BR(K_L \to \pi^0 e^+ e^-)$

$K_L \to \pi^0 e^+ e^-$ *and* $K_S \to \pi^0 e^+ e^-$

Theory $BR(K_S \to \pi^0 e^+ e^-) = 5 - 50 \times 10^{-10}$

Direct/indirect CP violating components of $K_L \to \pi^0 e^+ e^-$ interfere :

$$BR(K_L \to \pi^0 e^+ e^-)_{CPV} = 1 \times 10^{-12} \left(15.3 a_s^2 \pm 6.8 \frac{\mathcal{I}m(\lambda_t)}{10^{-4}} |a_s| + 2.8 \left(\frac{\mathcal{I}m(\lambda_t)}{10^{-4}} \right)^2 \right)$$

$$BR(K_S \to \pi^0 e^+ e^-) \qquad = 5 \times 10^{-9} |a_s|^2 \qquad \Rightarrow \text{determines } |a_s|$$

Published limits:

$BR(K_L \to \pi^0 e^+ e^-) < 5.1 \times 10^{-10}$ (KTeV, [PRL 86 397])
2 events with background of 1.1 event

$BR(K_S \to \pi^0 e^+ e^-) < 1.4 \times 10^{-7}$ (NA48, [PL B514 253])
2-days test run in 1999

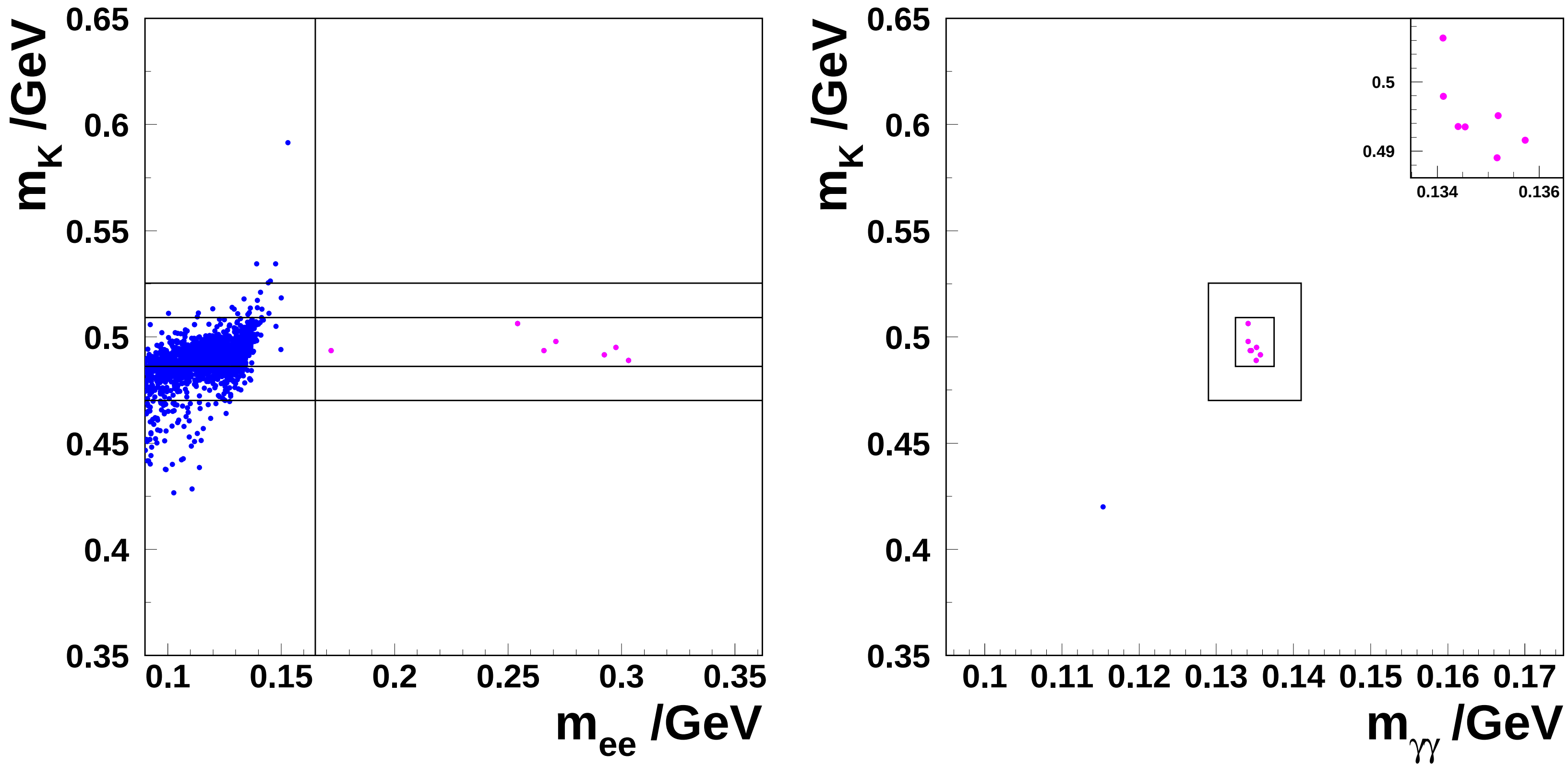
$K_S \to \pi^0 e^+ e^-$: *analysis strategy*

Rare decay analysis strategy $\Rightarrow$ understand and minimise all possible background processes, without cutting away the signal

- "Blind analysis procedure" $\longrightarrow$ signal and control regions masked :
  Signal region : $2.5\sigma_{m_K} \times 2.5\sigma_{m_{\pi^0}}$
  Control region : $6.0\sigma_{m_K} \times 6.0\sigma_{m_{\pi^0}}$
  ($\sigma_{m_K} = 4.7$ MeV, $\sigma_{m_{\pi^0}} = 1.0$ MeV)
- Study backgrounds using the data and a Monte Carlo simulation
- Unmask control region $\rightarrow$ final background estimate
- Unmask signal region $\rightarrow$ result

Source	control region	signal region
$K_S \to \pi^0_D \pi^0_D$	0.03	0.007
$K_L \to ee\gamma\gamma$	0.11	0.075
$(\pi^{\pm} e^{\mp} \nu) + (\pi^0 \pi^0 (\pi^0))$	0.19	0.069
Total background	$0.33^{+0.18}_{-0.11}$	$0.15^{+0.05}_{-0.04}$

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



7 events found in the signal region :

Negligible probability that all 7 events are consistent with background ($\sim 10^{-10}$)

$\rightarrow$ presence of signal well established

$K_S \to \pi^0 e^+ e^-$: *preliminary results*

Measured branching ratio :

$$BR(K_S \to \pi^0 e^+ e^-)_{(m_{ee}>0.165\ \mathrm{GeV})} = (3.0^{+1.5}_{-1.2}(stat) \pm 0.2(syst))\times 10^{-9}$$

Extrapolating to all m_{ee} (*) :

$$BR(K_S \to \pi^0 e^+ e^-) = (5.8^{+2.8}_{-2.3}(stat) \pm 0.3(syst) \pm 0.8(theor))\times 10^{-9}$$

χPT prediction : $BR(K_S \to \pi^0 e^+ e^-) = 5 \times 10^{-9} |a_s|^2 \quad \to$
Preliminary measurement of $|a_s|$:

$$|a_s| = 1.08^{+0.26}_{-0.21}$$

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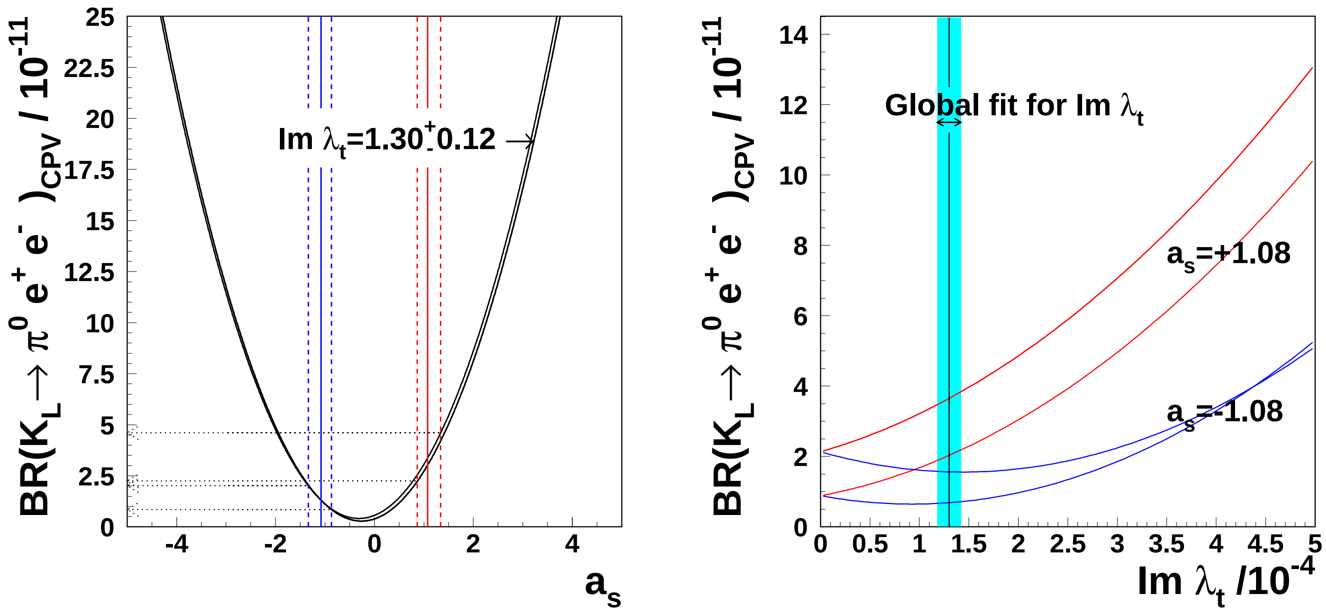
* Matrix element from [JHEP 08 (1998) 004] used with form factor $w(z) = 1$

Implications for $K_L \to \pi^0 e^+ e^-$

Measurement of $|a_s|$ allows BR($K_L \to \pi^0 e^+ e^-$) to be predicted as a function of $\mathcal{I}m(\lambda_t)$ to within a sign ambiguity :

$$BR(K_L \to \pi^0 e^+ e^-)_{CPV} = (\underbrace{17.7}_{\text{indirect}} \pm \underbrace{9.5}_{\text{interference}} + \underbrace{4.7}_{\text{direct}}) \times 10^{-12}$$

(Global fit $\Rightarrow \mathcal{I}m(\lambda_t) = (1.30 \pm 0.12) \times 10^{-4}$ [hep-ph/0212321])



$$\Rightarrow BR(K_L \to \pi^0 e^+ e^-) = 1 - 4 \times 10^{-11}$$

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

- From χPT, ratio of branching ratios well predicted:

$$BR(K_S \rightarrow \pi^0 \mu^+ \mu^-)/BR(K_S \rightarrow \pi^0 e^+ e^-) = 0.20 - 0.28$$

- Expect 2 - 4 events in the box
- Background from $K_L \rightarrow \pi^+ \pi^- \pi^0$ where pions decay in flight is minimised by kinematical constraints
- Dominant background from fragments of events
- Preliminary result ready soon

Conclusions

- $K_{L,S} \to \pi^+\pi^-e^+e^-$: final

  $A_\phi(K_L) = (14.2 \pm 3.0(stat) \pm 1.9(sys))\%$: indirect CPV established

  $A_\phi(K_S) = (0.5 \pm 4.0(stat) \pm 1.6(sys))\%$

- $K_L \to e^\pm\pi^\mp\nu_e$: preliminary

  $\delta_L(e) = (0.3317 \pm 0.0070(stat) \pm 0.0072(syst))\%$

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

  7 $K_S \to \pi^0e^+e^-$decays found in region $m_{ee} > 0.165$ GeV

  $BR(K_S \to \pi^0e^+e^-) =$
  $(5.8^{+2.8}_{-2.3}(stat) \pm 0.3(syst) \pm 0.8(theor)) \times 10^{-9}$

  $|a_s| = 1.08^{+0.26}_{-0.21}$

- $K_S \to \pi^0\mu^+\mu^-$ analysis ready soon