

New NA48 results on CPV

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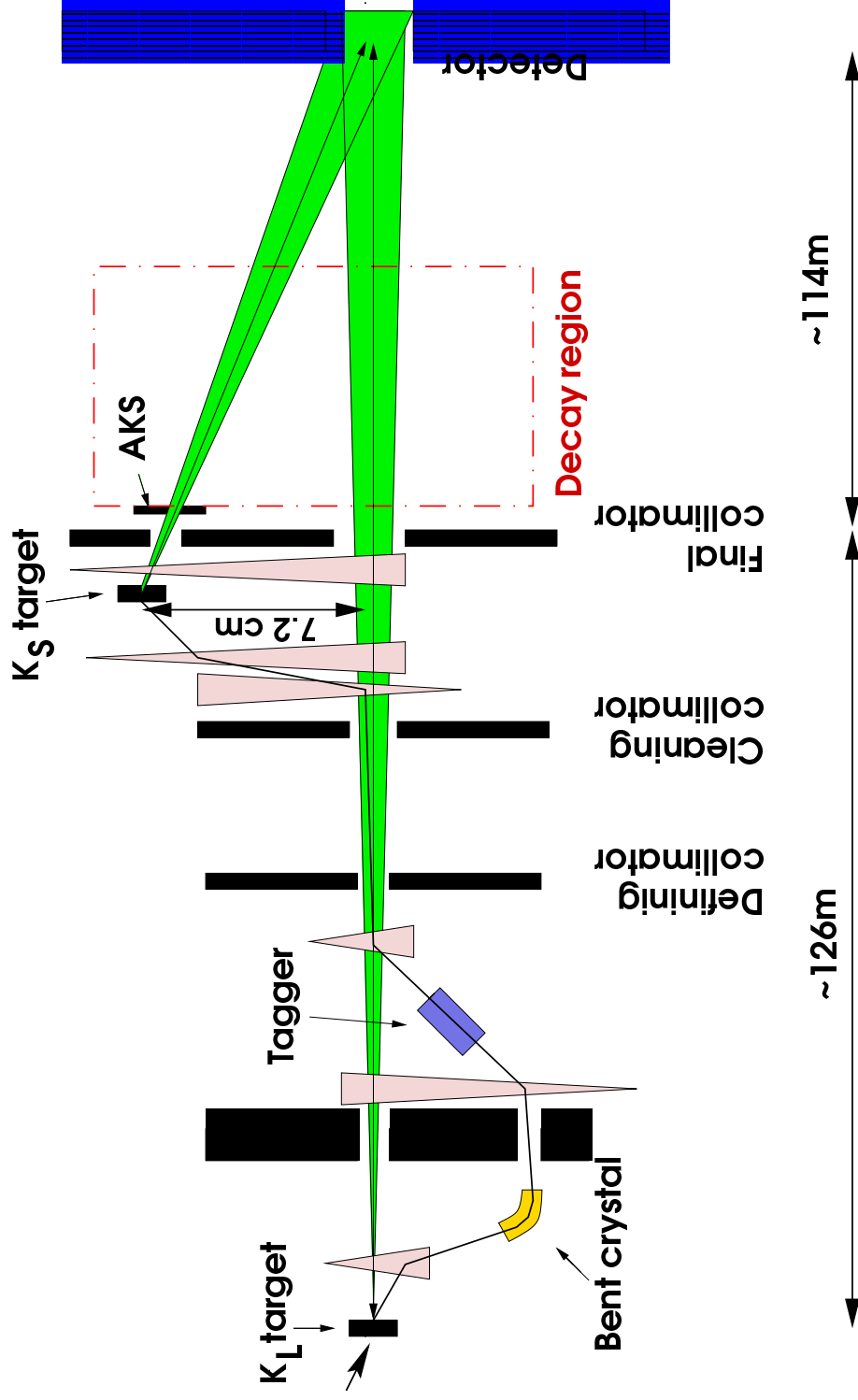
On behalf of the NA48 Experiment :

Cambridge, Chicago, CERN, Dubna, Edinburgh
Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay,
Siegen, Torino, Warsaw, Wien

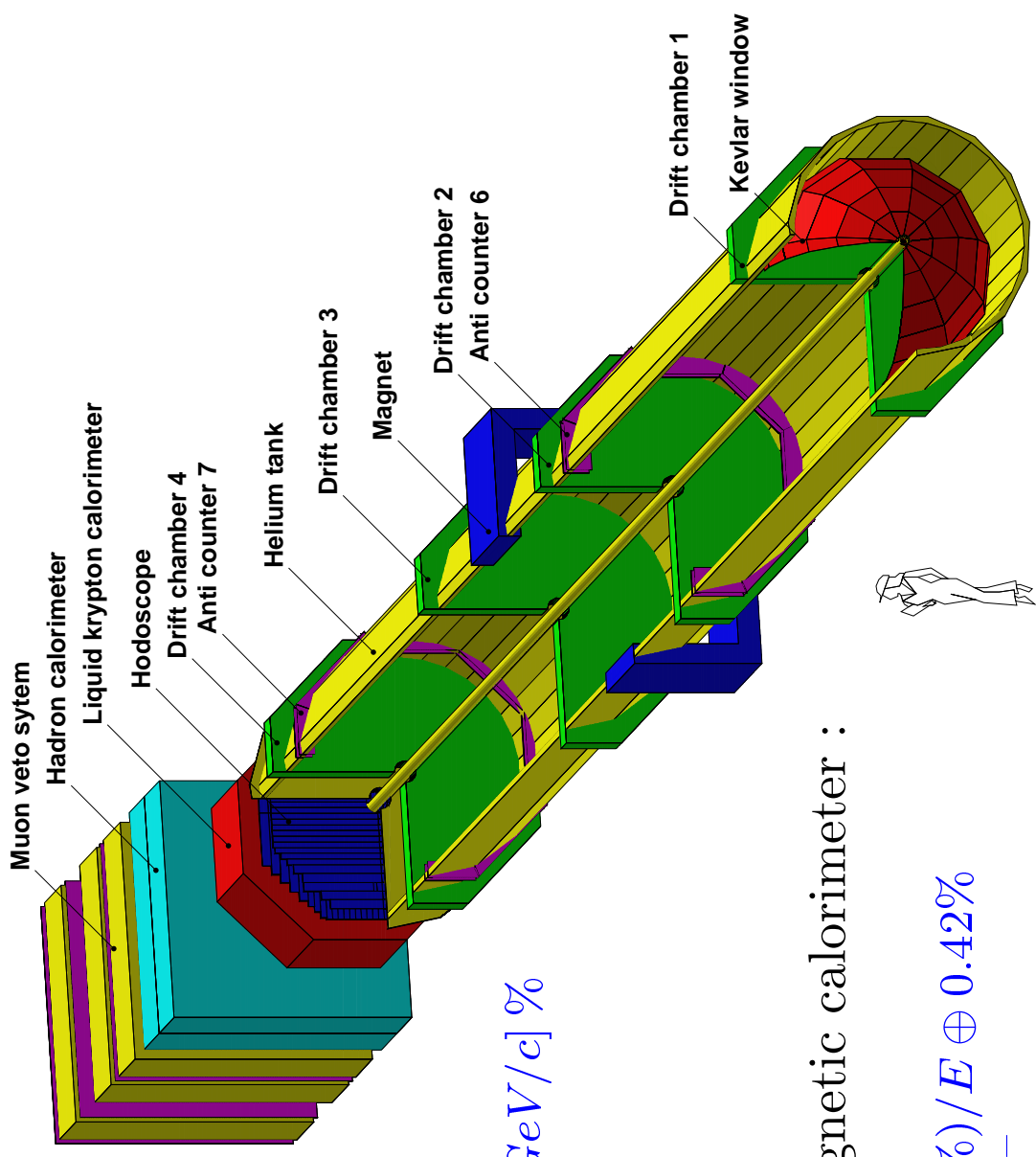
Overview

- NA48 beam and detector
- 1997-1998-1999: $K_L + K_S$ beam, $\text{Re}(\varepsilon'/\varepsilon)$ run
short high-intensity K_S run
Angular asymmetry in $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$
- 2001: $K_L + K_S$ beam, $\text{Re}(\varepsilon'/\varepsilon)$ run
Charge asymmetry in $K_L \rightarrow e^\pm \pi^\mp \nu_e$
- 2002: high-intensity K_S and Hyperon beam
First observation of $K_S \rightarrow \pi^0 e^+ e^-$
- Conclusions

The NA48 simultaneous K_S and K_L beams



NA48 Detector



- Magnetic spectrometer :
charged particles

$$\sigma(p)/p \simeq 0.5 \% \oplus 0.009 p[\text{GeV}/c] \%$$
$$(P_{\perp}^{kick} \sim 265\text{MeV}/c)$$

- Liquid Krypton electromagnetic calorimeter :
photons and electrons

$$\sigma(E)/E = 3.2\%/\sqrt{E} \oplus (9\%)/E \oplus 0.42\%$$
$$\sigma(t) \simeq 265\text{ps for } 50 \text{ GeV } e^{-}$$

K_{e3} charge asymmetry

If CPT is conserved:

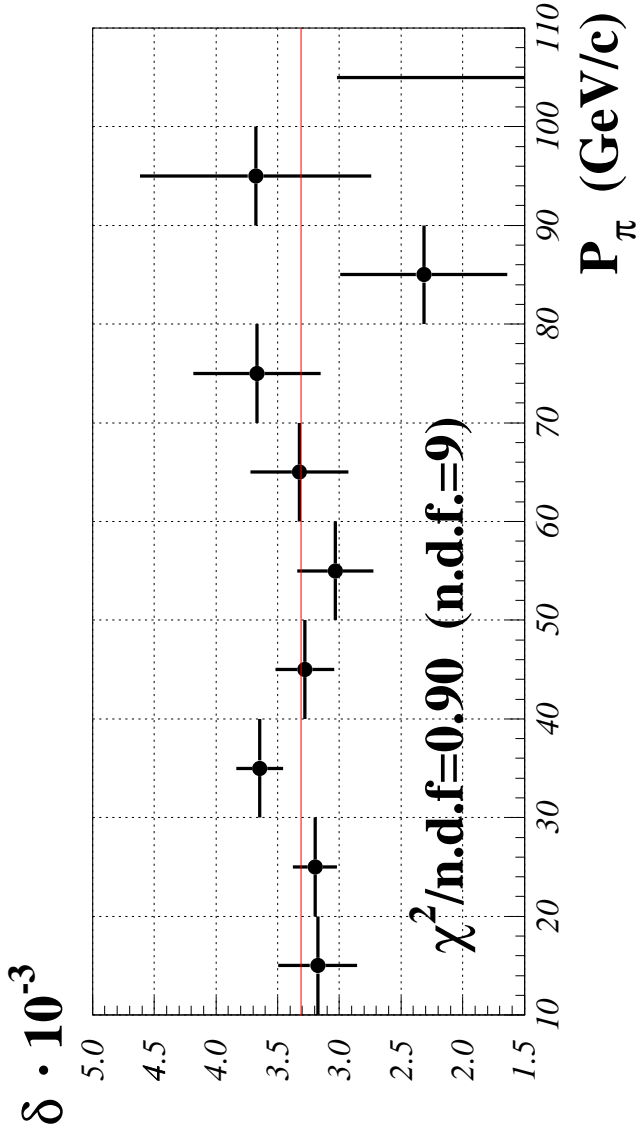
$$\delta_L(e) = \frac{\Gamma(K_L \rightarrow \pi^- e^+ \nu) - \Gamma(K_L \rightarrow \pi^+ e^- \nu)}{\Gamma(K_L \rightarrow \pi^- e^+ \nu) + \Gamma(K_L \rightarrow \pi^+ e^- \nu)} = 2 \times \text{Re}(\epsilon)$$

- 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 $\sim 7 \times 10^{-5}$

$K_L \rightarrow e^\pm \pi^\mp \nu_e$ 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

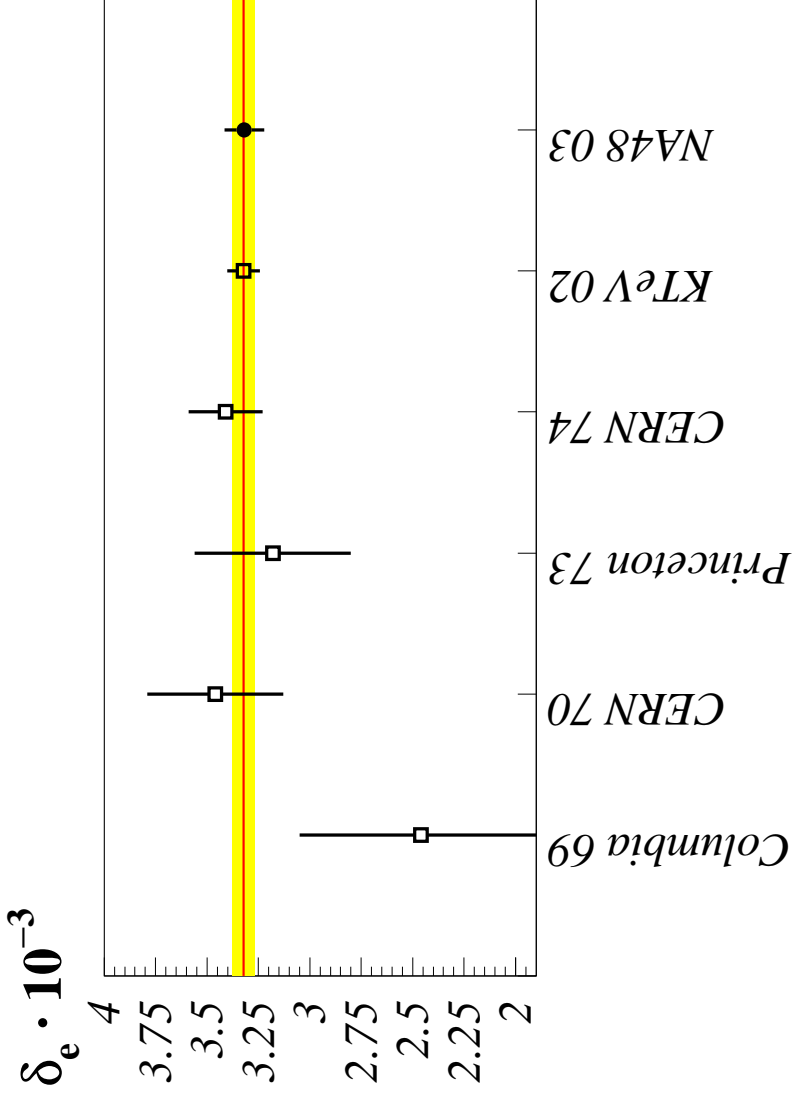
Source	10^{-5}
Trigger	$+26.2 \pm 6.0$
Punch through	-1.4 ± 3.5
Pion ID	-17.1 ± 2.4
Acceptance	± 0.5
Background	± 0.5
Total	$+7.7 \pm 7.2$



$K_L \rightarrow e^\pm \pi^\mp \nu_e$ result: *preliminary*

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

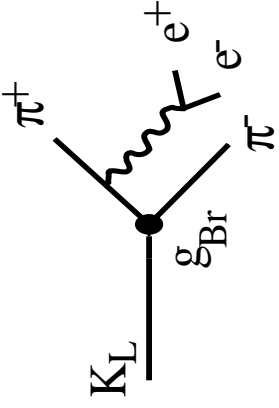
Consistent with KTeV and World average measurements:



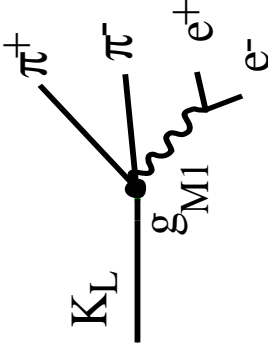
World average: $\delta_L(e) = (0.3322 \pm 0.0055)\%$

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

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

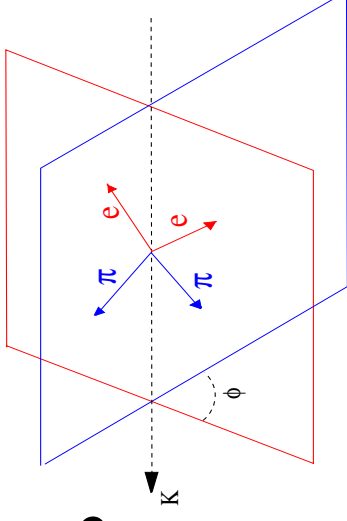


CP-violating
bremsstrahlung



CP-conserving
M1 γ emission

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



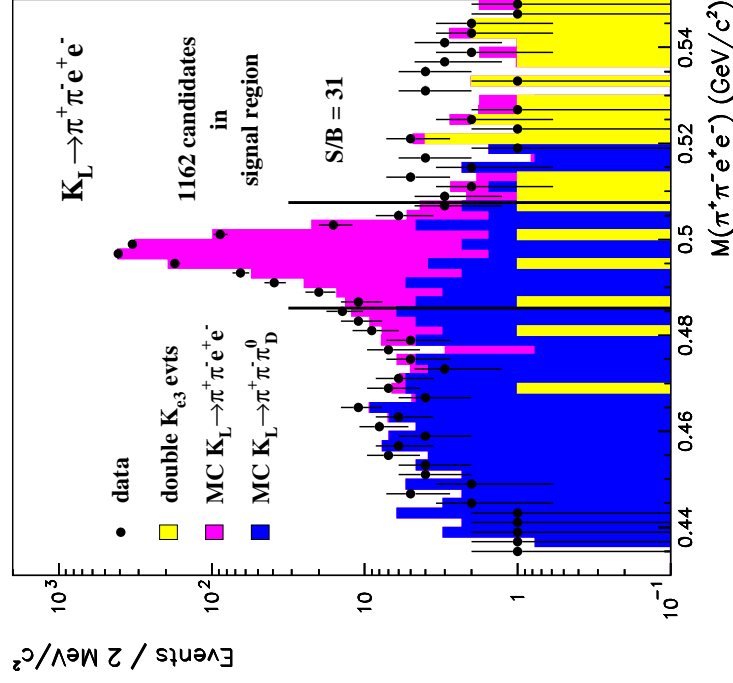
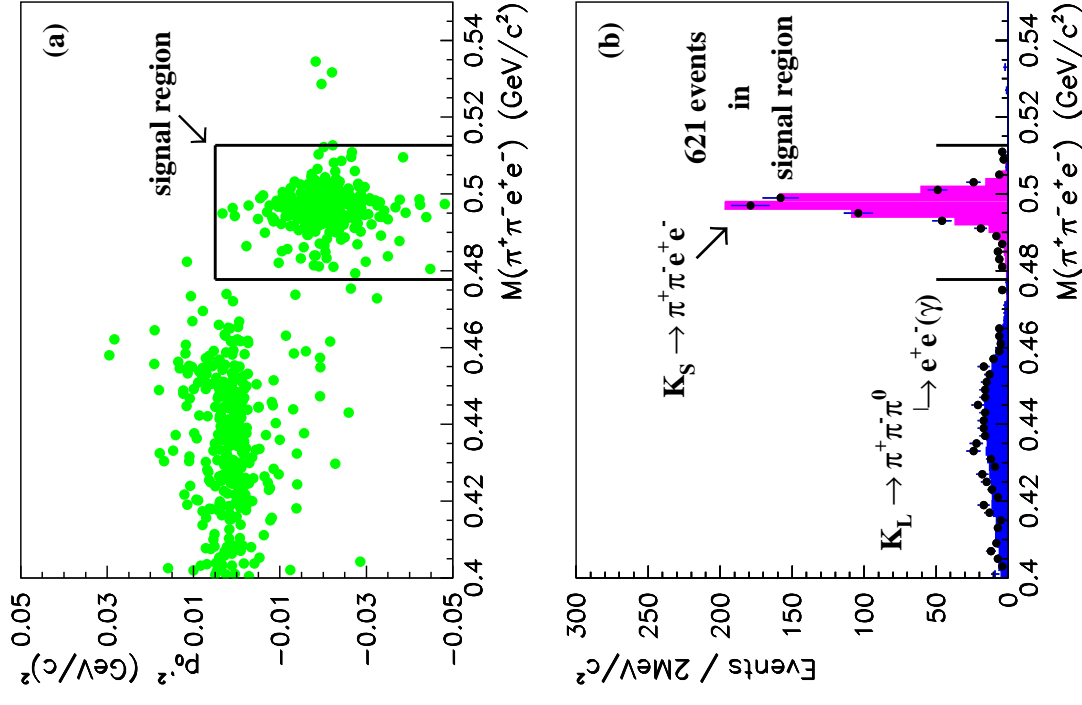
The effect is visible as an asymmetry in the decay rate

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

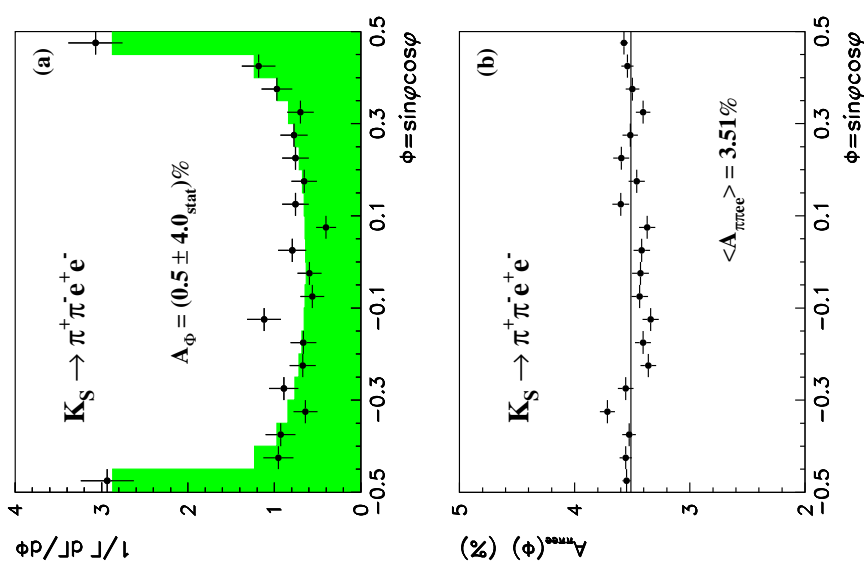
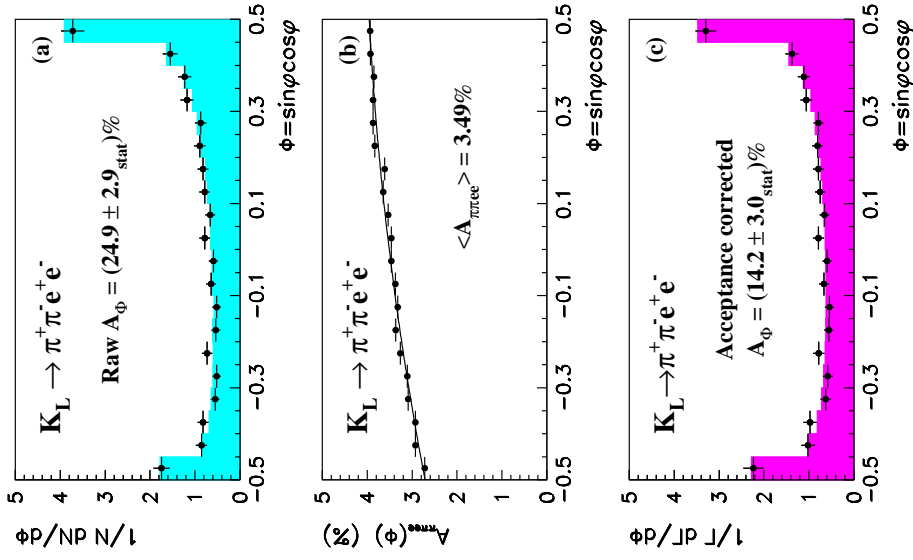
K_S : dominated by CP-conserving bremsstrahlung

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



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

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

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

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

- CP conserving

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

$$\rightarrow BR(K_L \rightarrow \pi^0 e^+ e^-)_{CP\ cons} = 0.47^{+0.22}_{-0.18} \times 10^{-12} \quad [\text{PL B536 229}]$$

- direct CP violating

Proportional to η or $\text{Im}(\lambda_t)$

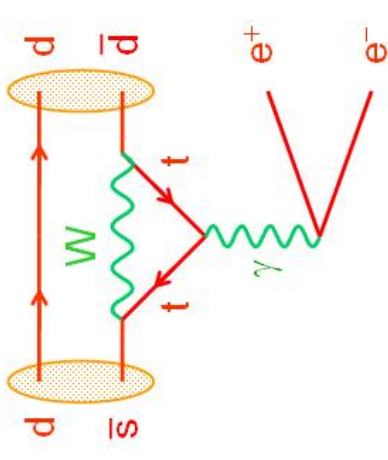
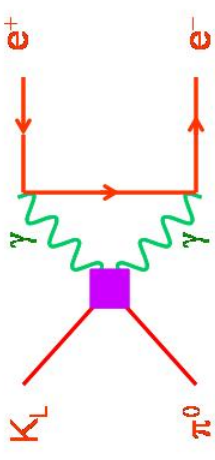
$$\text{Im}(\lambda_t) = \eta A^2 \lambda^5 \quad \lambda_t = V_{ts}^* V_{td}$$

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

- indirect CP violating

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

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



$$K_L \rightarrow \pi^0 e^+ e^- \text{ and } K_S \rightarrow \pi^0 e^+ e^-$$

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

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

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

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

Published limits:

$$BR(K_L \rightarrow \pi^0 e^+ e^-) < 5.1 \times 10^{-10} \text{ (KTeV, [PRL 86 397])}$$

2 events with background of 1.1 event

$$BR(K_S \rightarrow \pi^0 e^+ e^-) < 1.4 \times 10^{-7} \text{ (NA48, [PL B514 253])}$$

2-days test run in 1999

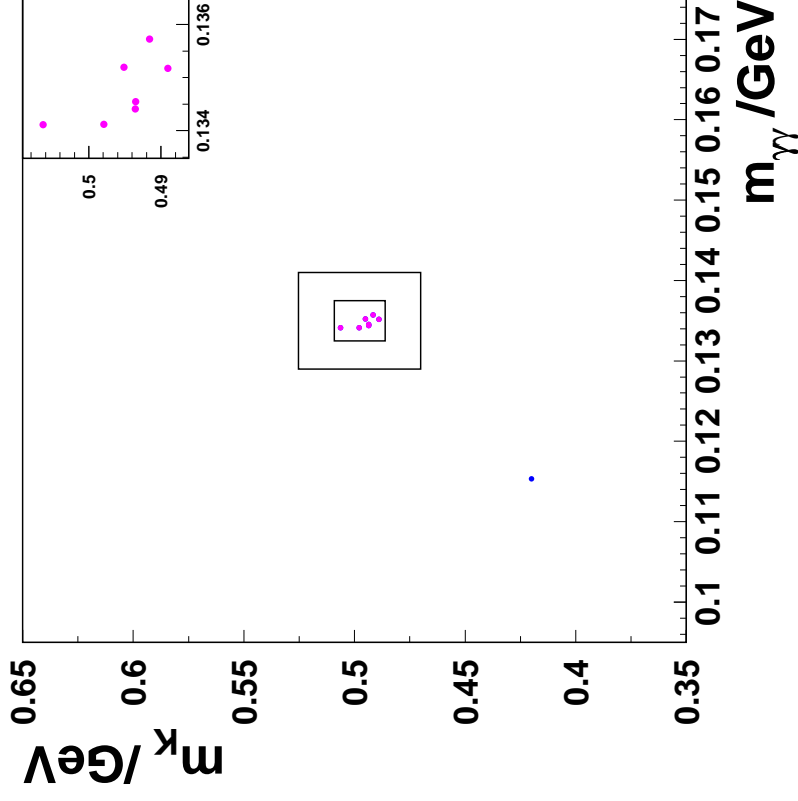
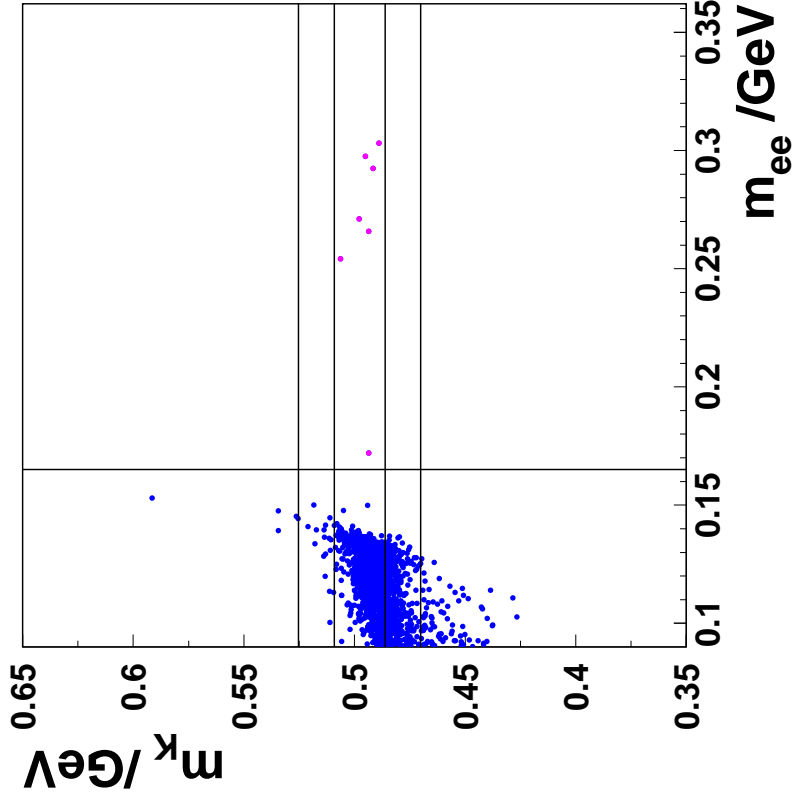
$K_S \rightarrow \pi^0 e^+ e^-$: *analysis strategy*

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

- “Blind analysis procedure” \rightarrow signal and control regions masked :
Signal region : $2.5\sigma_{m_K} \times 2.5\sigma_{m_\pi}$
Control region : $6.0\sigma_{m_K} \times 6.0\sigma_{m_\pi}$
($\sigma_{m_K} = 4.7$ MeV, $\sigma_{m_\pi} = 1.0$ 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
$K_S \rightarrow \pi_D^0 \pi^0$	0.03	0.007
$K_L \rightarrow ee\gamma\gamma$	0.11	0.075
$(\pi^\pm e^\mp \nu) + (\pi^0 \pi^0 (\pi^0))$	0.19	0.069
Total background	$0.33^{+0.18}_{-0.11}$	$0.15^{+0.05}_{-0.04}$

$K_S \rightarrow \pi^0 e^+ e^-$ events



7 events found in the signal region :

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

→ presence of signal well established

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

Measured branching ratio :

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

Extrapolating to all m_{ee} (*) :

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

$$\chi\text{PT prediction : } BR(K_S \rightarrow \pi^0 e^+ e^-) = 5 \times 10^{-9} |a_s|^2 \quad \rightarrow$$

Preliminary measurement of $|a_s|$:

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

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

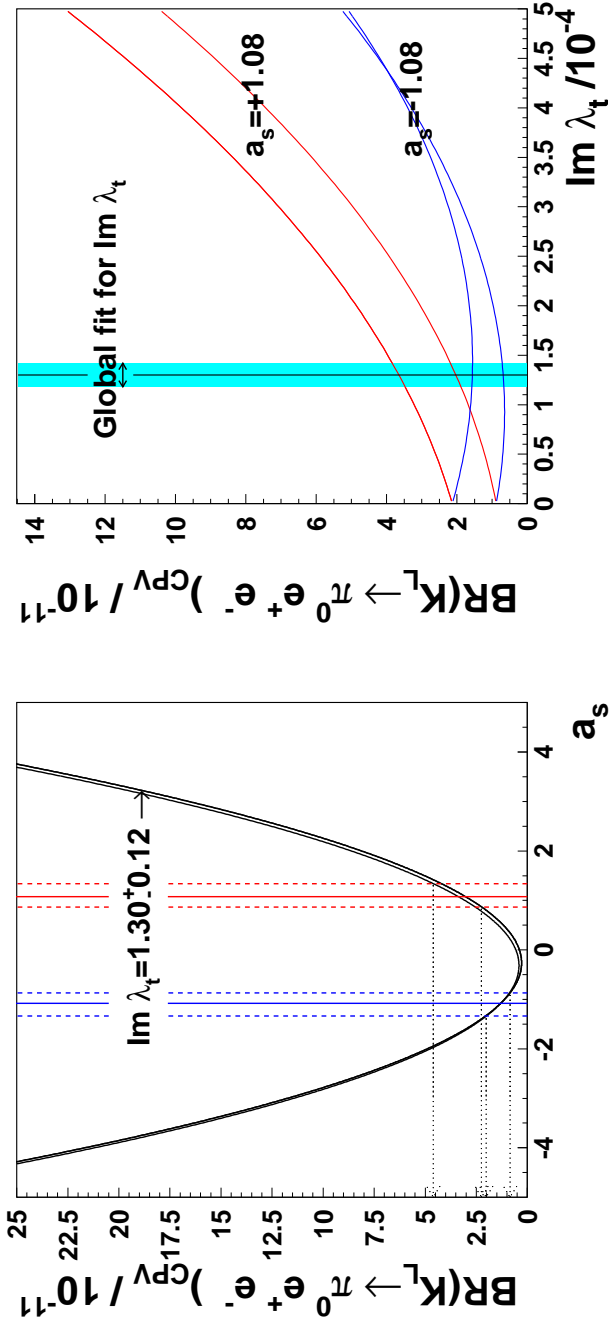
Implications for $K_L \rightarrow \pi^0 e^+ e^-$

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

$$\text{BR}(K_L \rightarrow \pi^0 e^+ e^-)_{CPV} = (\text{indirect } \text{interference } \text{direct}) \times 10^{-12}$$

$$= (17.7 \pm 9.5 + 4.7) \times 10^{-12}$$

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



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



- From χ PT, 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

- $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$: final
- $A_\phi(K_L) = (14.2 \pm 3.0(stat) \pm 1.9(sys))\%$: indirect CPV established
- $A_\phi(K_S) = (0.5 \pm 4.0(stat) \pm 1.6(sys))\%$
- $K_L \rightarrow e^\pm \pi^\mp \nu_e$: preliminary
- $\delta_L(e) = (0.3317 \pm 0.0070(stat) \pm 0.0072(sys))\%$
- $K_S \rightarrow \pi^0 e^+ e^-$: preliminary
- 7 $K_S \rightarrow \pi^0 e^+ e^-$ decays found in region $m_{ee} > 0.165$ GeV
- $BR(K_S \rightarrow \pi^0 e^+ e^-) = (5.8_{-2.3}^{+2.8}(stat) \pm 0.3(sys) \pm 0.8(theor)) \times 10^{-9}$
- $|a_s| = 1.08_{-0.21}^{+0.26}$
- $K_S \rightarrow \pi^0 \mu^+ \mu^-$ analysis ready soon