Semileptonic Decays of Neutral Kaons at NA48

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on behalf of the NA48 collaboration

Cagliari, Cambridge, CERN, Dubna, Edinburgh, Ferrara, Firenze,

Mainz, Oray, Perugia, Pisa, Saclay, Siegen, Torino, Warsaw, Vienna
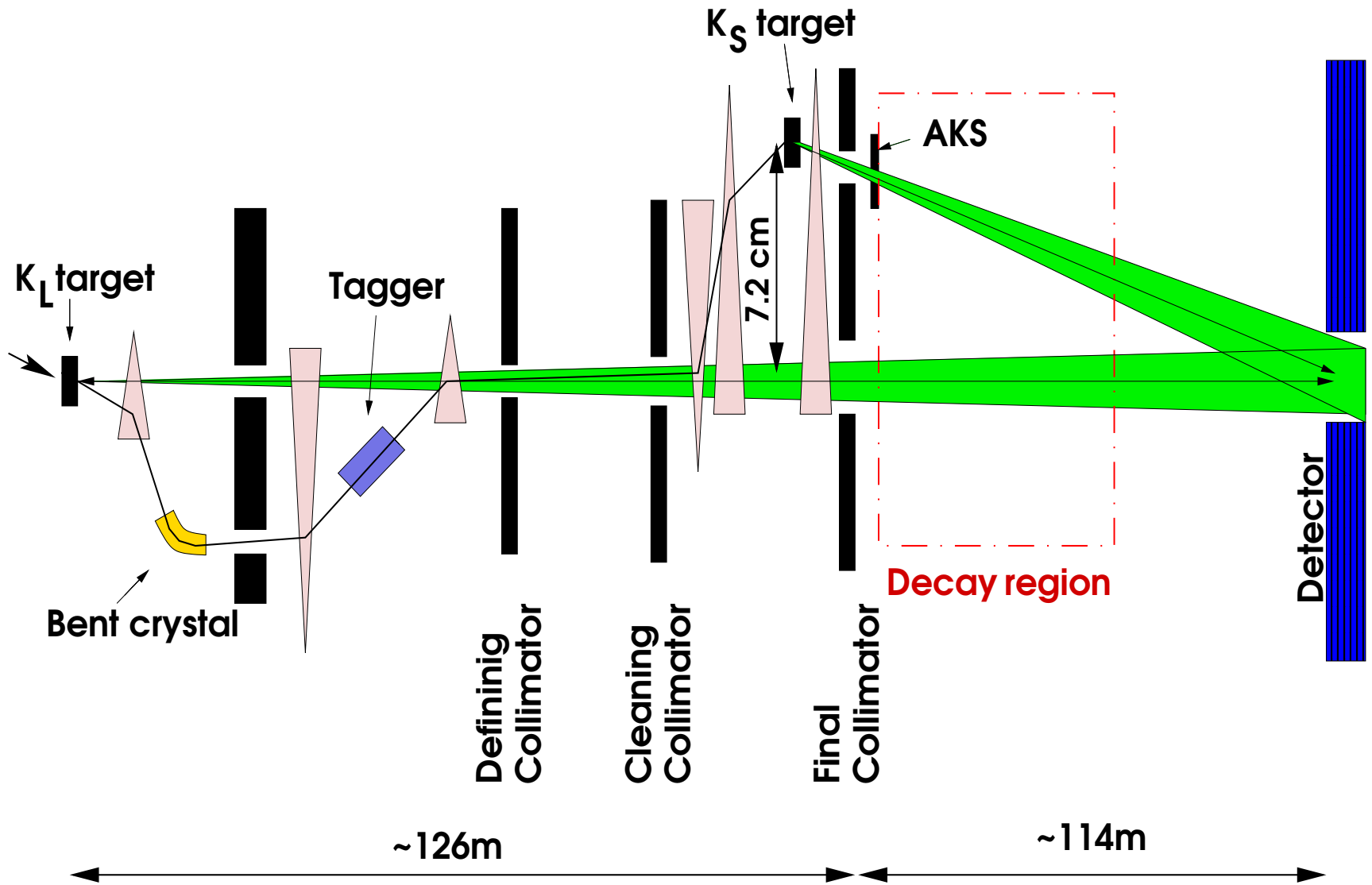
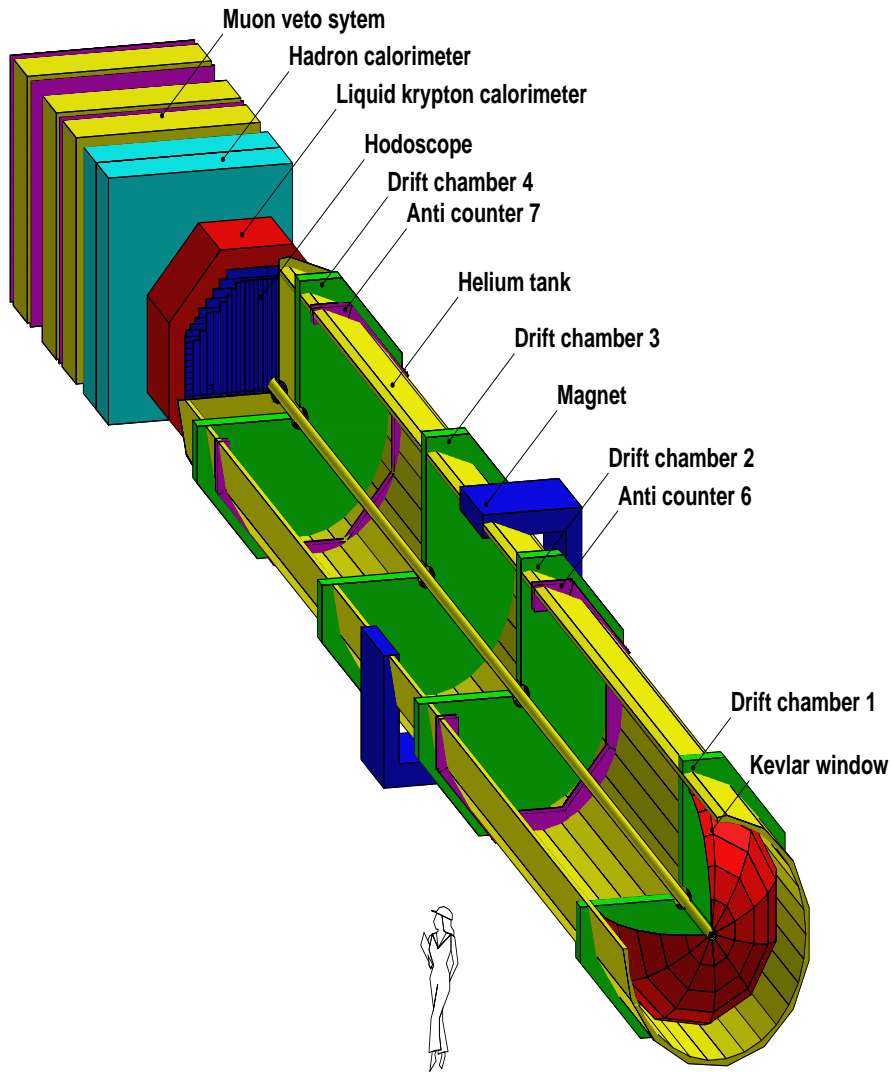`ulrich.moosbrugger@uni-mainz.de`

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Contents

- The NA48 experiment

- $K_L \to \pi^+ \pi^0 e^- \nu$ $\qquad (K_{e4})$

- $K_L \to \pi^\pm e^\mp \nu \gamma$ $\qquad (K_{e3\gamma})$

- $K_L \to \pi^\pm e^\mp \nu$ $\qquad (K_{e3})$

- Prospects for further semileptonic neutral Kaon decays

- Summary/Conclusions

Beam Line - NA48

K_S target

K_L target

Tagger

AKS

Bent crystal

7.2 cm

Defininig Collimator

Cleaning Collimator

Final Collimator

Decay region

Detector

~126m

~114m

The NA48 Detector System

Muon veto sytem

Hadron calorimeter

Liquid krypton calorimeter

Hodoscope

Drift chamber 4

Anti counter 7

Helium tank

Drift chamber 3

Magnet

Drift chamber 2

Anti counter 6

Drift chamber 1

Kevlar window

- Magnetic spectrometer: charged particles

  - $\dfrac{\sigma(p)}{p} \approx 0.5\% \oplus 0.009\%\, p$

- Liquid Krypton em calorimeter photons and particle id

  - $\dfrac{\sigma(E)}{E} \approx \dfrac{3.2\%}{\sqrt{E}} \oplus \dfrac{9\%}{E} \oplus 0.42\%$

  - $\sigma(t) < 300\text{ps for } 50\text{GeV } e^-$

  - $\sigma(r) < \dfrac{5.4mm}{\sqrt{E/\mathrm{GeV}}}$

- Muon System: muon id

  - $\sigma(t) \approx 350\text{ps}$

  - $25\text{cm} \times 25\text{cm cells}$
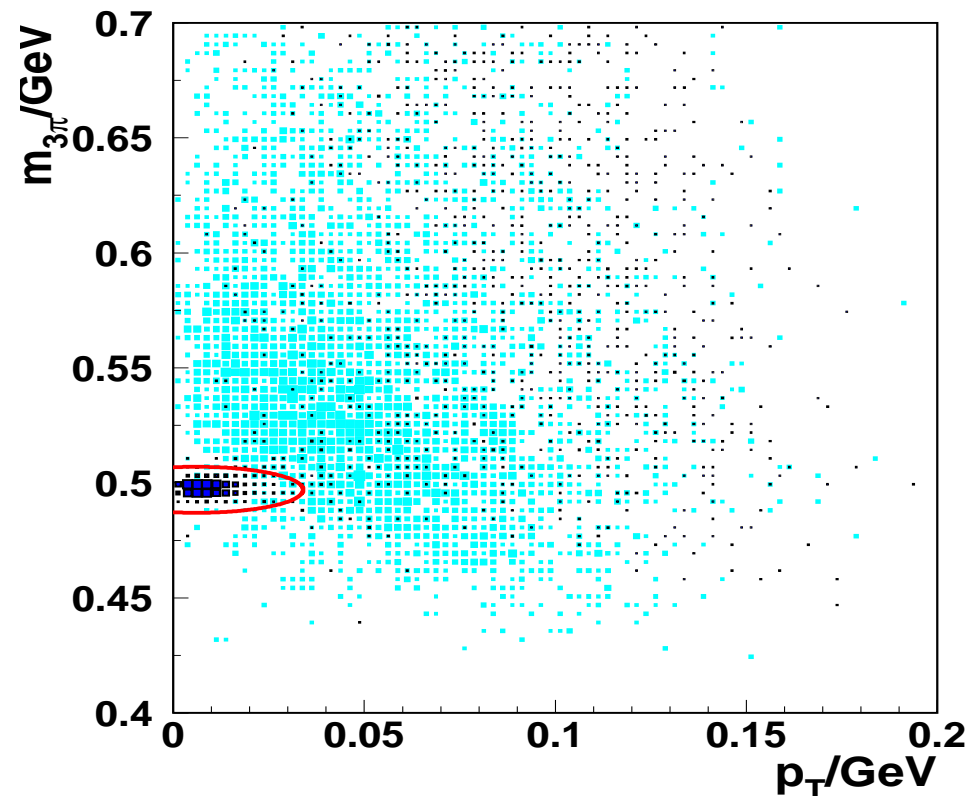
$K_L \to \pi^{\pm}\pi^0 e^{\mp}\nu_e$

Branching ratio and Form Factors of $K_L \to \pi^{\pm}\pi^0 e^{\mp}\nu_e$

- good testground for *ChPT* predictions for long distance meson interactions

- form factor measurement allows to deduce parameters of *ChPT*

Main Background

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

  with mis-identified e

  $\Rightarrow$ cut on $\chi^2_{3\pi} > 16$ with

  $\chi^2_{3\pi} = \left(\frac{M_{3\pi} - M_K}{\sigma_M}\right)^2 + \left(\frac{p_t - p_{t_0}}{\sigma_p}\right)^2$

- employ neural network to improve e/π distinction

  (trained with well identified e and $\pi^{\pm}$

  from $K_{\pi 3}$ and K_{e3})

$K_L \to \pi^{\pm}\pi^0 e^{\mp}\nu_e$

- *Previous measurement:*

  - E731 (Fermilab) : 729 events

- Used data sample (run in 2001):

  - protons with $E_{\mathrm{beam}} = 400\mathrm{GeV/c}^2$ on beryllium target
  - 2 different triggers: special K_{e4} and minimum bias trigger

    (downscaled by a factor of 50 and 30 respectively)

- Total number of selected K_{e4} events (*NA48*)
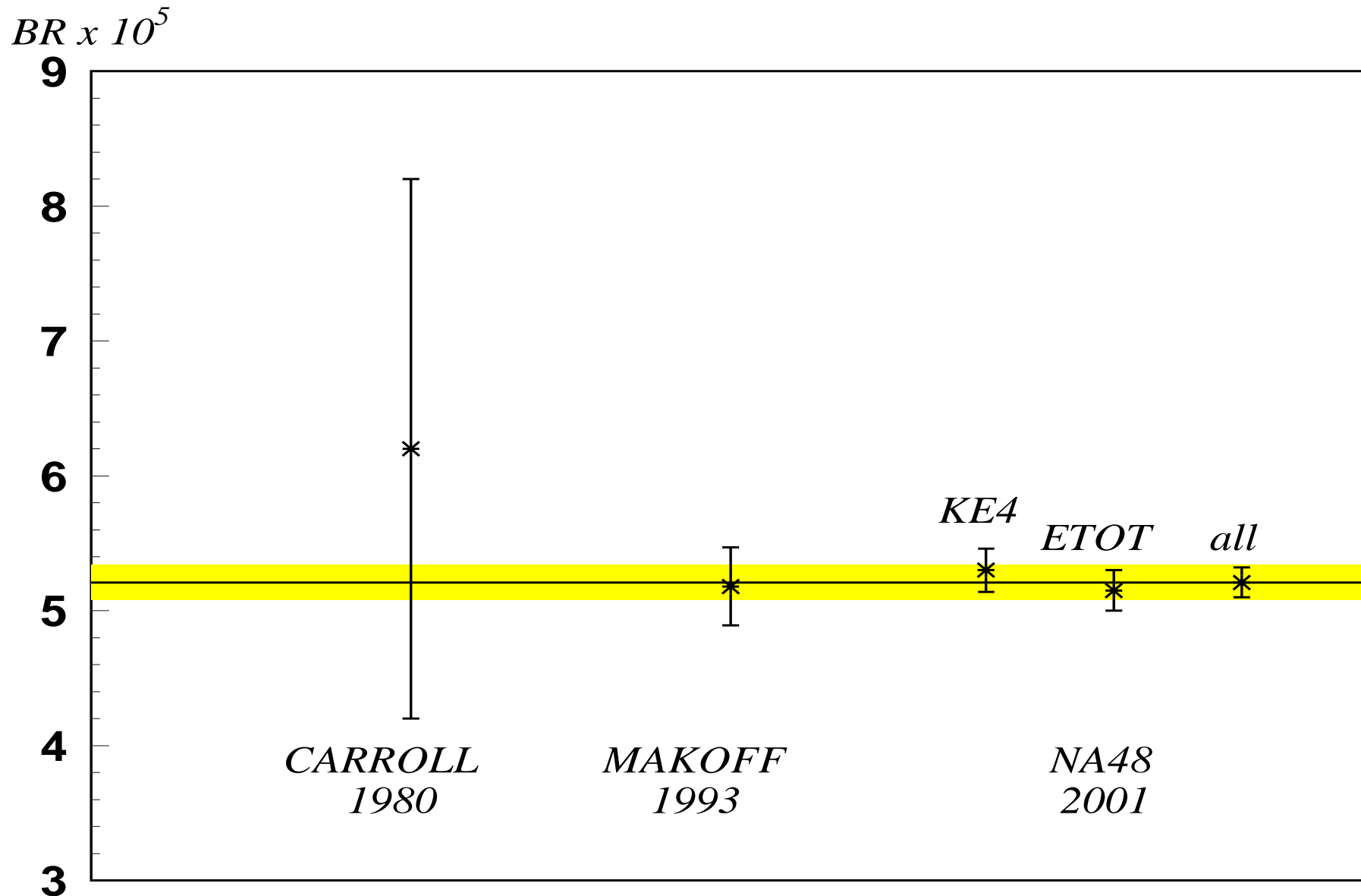
  $\Rightarrow 5464$ with 62 estimated background events

- Branching ratio

  $$\Rightarrow \mathrm{BR}(K_{e4}) = (5.21 \pm 0.07_{\mathrm{stat}} \pm 0.09_{\mathrm{syst}}) \times 10^{-5}$$

  (normalized to the branching fraction of the reference channel $\mathrm{BR}(K_{\pi3}) = (12.58 \pm 0.19)\%$)
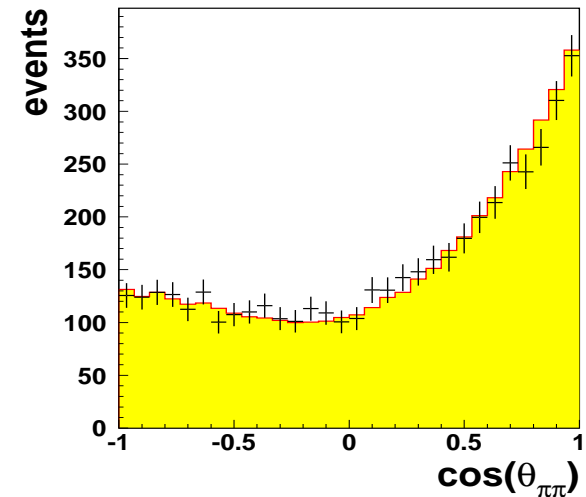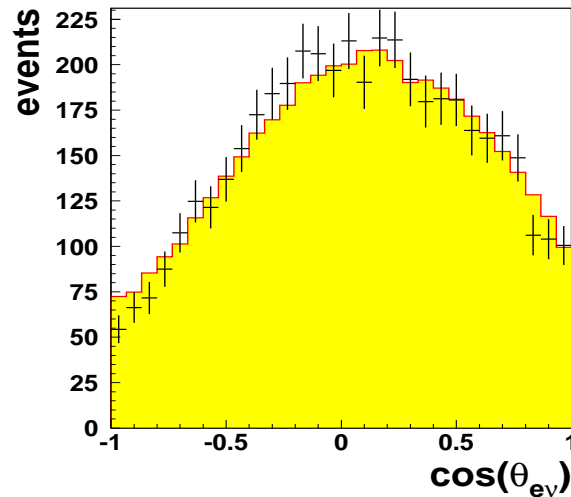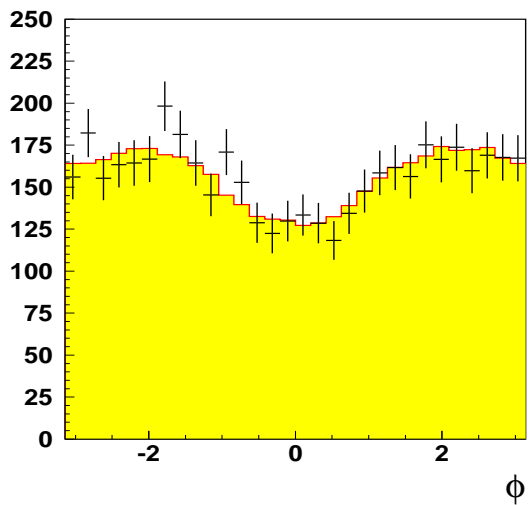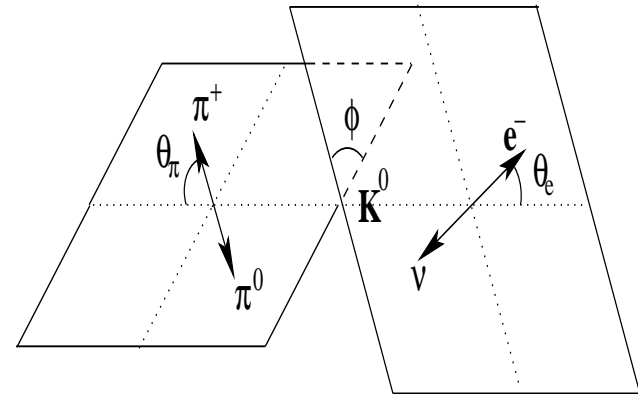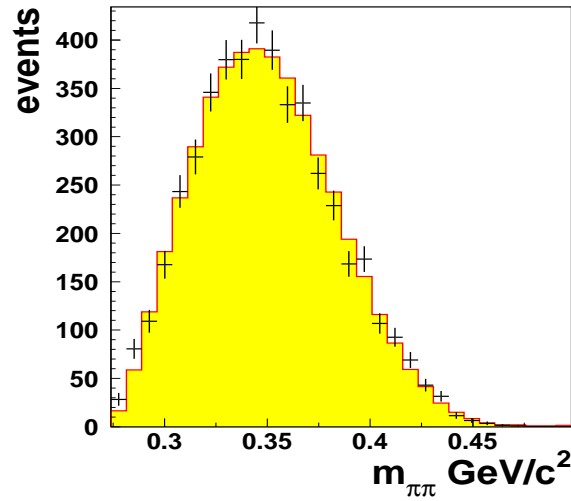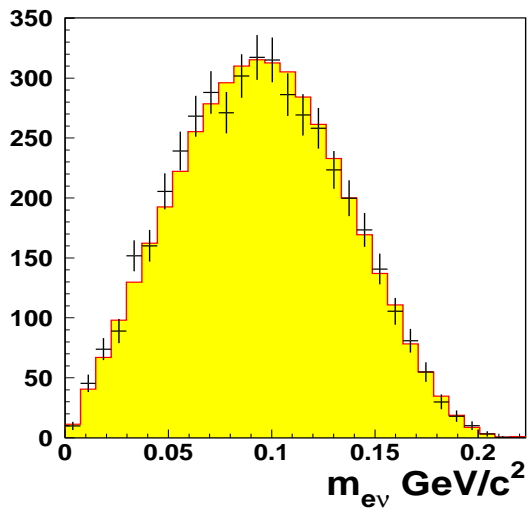
$\Rightarrow$ systematic uncertainty is dominated by the error of $\mathrm{BR}(K_{\pi3})$ ($\approx 0.08 \cdot 10^{-5}$)

$K_L \rightarrow \pi^{\pm}\pi^0 e^{\mp}\nu_e$

$K_L \rightarrow \pi^{\pm}\pi^0 e^{\mp}\nu_e$

Fit of the form factors in terms of *Cabibbo-Maksymowicz* variables:

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

Form Factor measurement:

- Hadronic part of the matrix element ($V - A$ structure) can be parametrized by the form factors

  - $\overline{f}_s, \overline{f}_p, \lambda_g$ (vector part)
  - $\overline{h}$ (axial part)

Result of simultaneous fit (C-M variables)

- $\overline{f}_s = 0.052 \pm 0.006_{\text{stat}} \pm 0.002_{\text{syst}}$

- $\overline{f}_p = -0.051 \pm 0.011_{\text{stat}} \pm 0.005_{\text{syst}}$

- $\lambda_g = 0.087 \pm 0.019_{\text{stat}} \pm 0.006_{\text{syst}}$

- $\overline{h} = -0.32 \pm 0.12_{\text{stat}} \pm 0.07_{\text{syst}}$

Determination of *ChPT parameter* L_3 (using the *BR*):

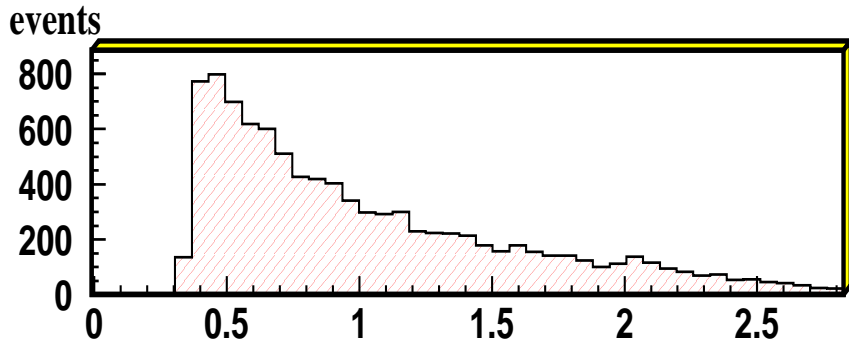$$\Rightarrow L_3 = (-4.1 \pm 0.2) \times 10^{-3}$$

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

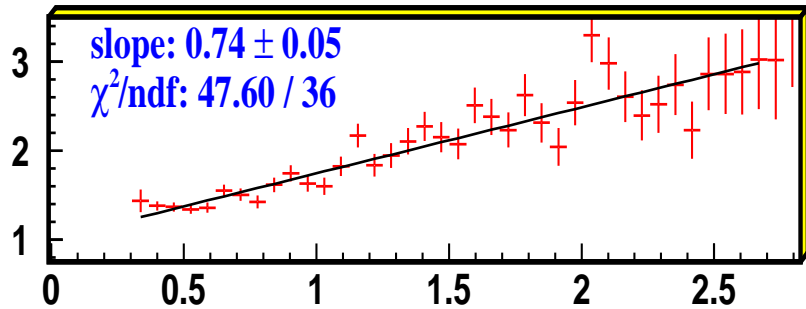## Relative Branching Ratio of $K_L \to \pi^\pm e^\mp \nu\gamma / K_L \to \pi^\pm e^\mp \nu$

- Most precise measurement so far by *KTeV*

  - $\mathrm{Br}^{\mathrm{exp}}(K_L \to \pi^\pm e^\mp \nu\gamma / K_L \to \pi^\pm e^\mp \nu) = 0.908 \pm 0.008^{+0.013}_{-0.012}\%$

  - in disagreement with theoretical predictions:
    $\mathrm{Br}^{\mathrm{theo}}(K_L \to \pi^\pm e^\mp \nu\gamma / K_L \to \pi^\pm e^\mp \nu) = (0.95 - 0.99)\%$

- New NA48 measurement on 1999 data
  (*special 2 days run, minimum bias trigger*)

  - analysis highly dependent on model for radiative corrections
    - MC simulation uses the *PHOTOS* package

      $\Rightarrow$ not very good agreement with data!
    - weight $\theta^*_{e\gamma}$ to fit the data (Model independent analysis)

      $\Rightarrow$ MC and data show very good agreement for all variables!
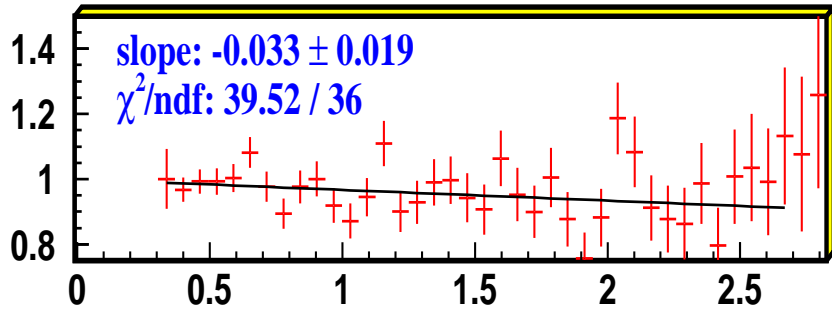
$K_L \rightarrow \pi^{\pm} e^{\mp} \nu \gamma$
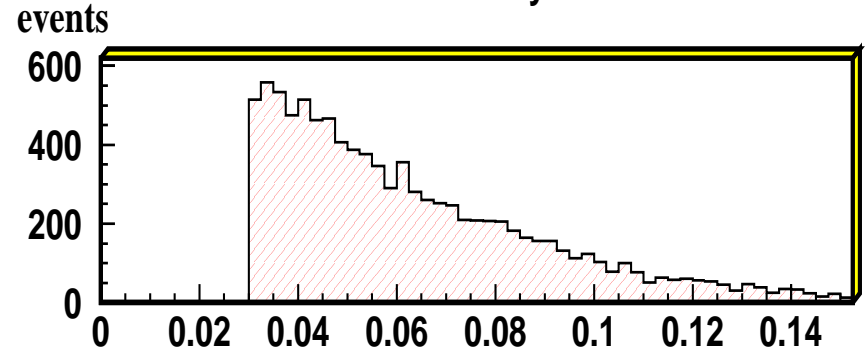
Data distribution and linearly fitted ratio Data/MC

Data distribution and linearly fitted ratio Data/MC

PHOTOS

slope: 0.74 ± 0.05
$\chi^2/\text{ndf}: 47.60 / 36$

PHOTOS

slope: 1.39 ± 0.46 / GeV
$\chi^2/\text{ndf}: 62.34 / 46$

MI

slope: -0.033 ± 0.019
$\chi^2/\text{ndf}: 39.52 / 36$

MI

slope: 0.34 ± 0.43 / GeV
$\chi^2/\text{ndf}: 54.90 / 46$
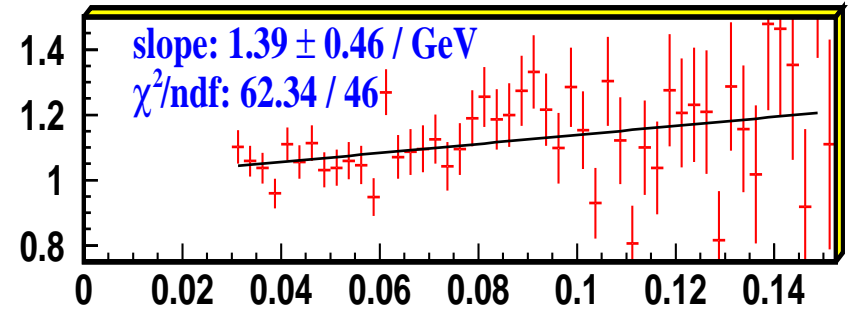
$\theta_{e\gamma}^*$ - first solution, rad
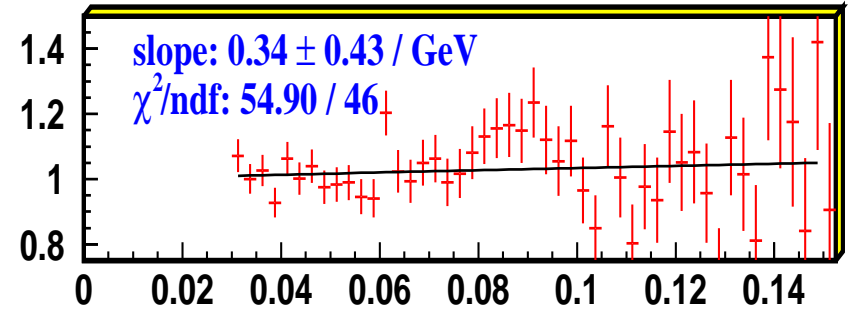
E_{γ}^* - first solution, GeV

Result based on 9572 $K_{e3\gamma}$ and 2722118 K_{e3} reconstructed events:

- $\mathrm{Br}^{\mathrm{exp}}_{\mathrm{NA48}}(K_L \to \pi^\pm e^\mp \nu \gamma / K_L \to \pi^\pm e^\mp \nu) = 0.960 \pm 0.07^{+0.012}_{-0.011}\%$

Plot legend:
- NA48 (PHOTOS MC) no systematic error
- NA48 (FFS MC) no systematic error
- NA48 (MI MC)
- KTEV
- NA31
- FFS
- Donsel
- ChPT O(p^4)

x-axis: 0.875 0.9 0.925 0.95 0.975 1 1.025 1.05 1.075

$\mathrm{BR}(K_{e3\gamma}, 20^\circ, 30\ \mathrm{MeV})/\mathrm{BR}(K_{e3})$
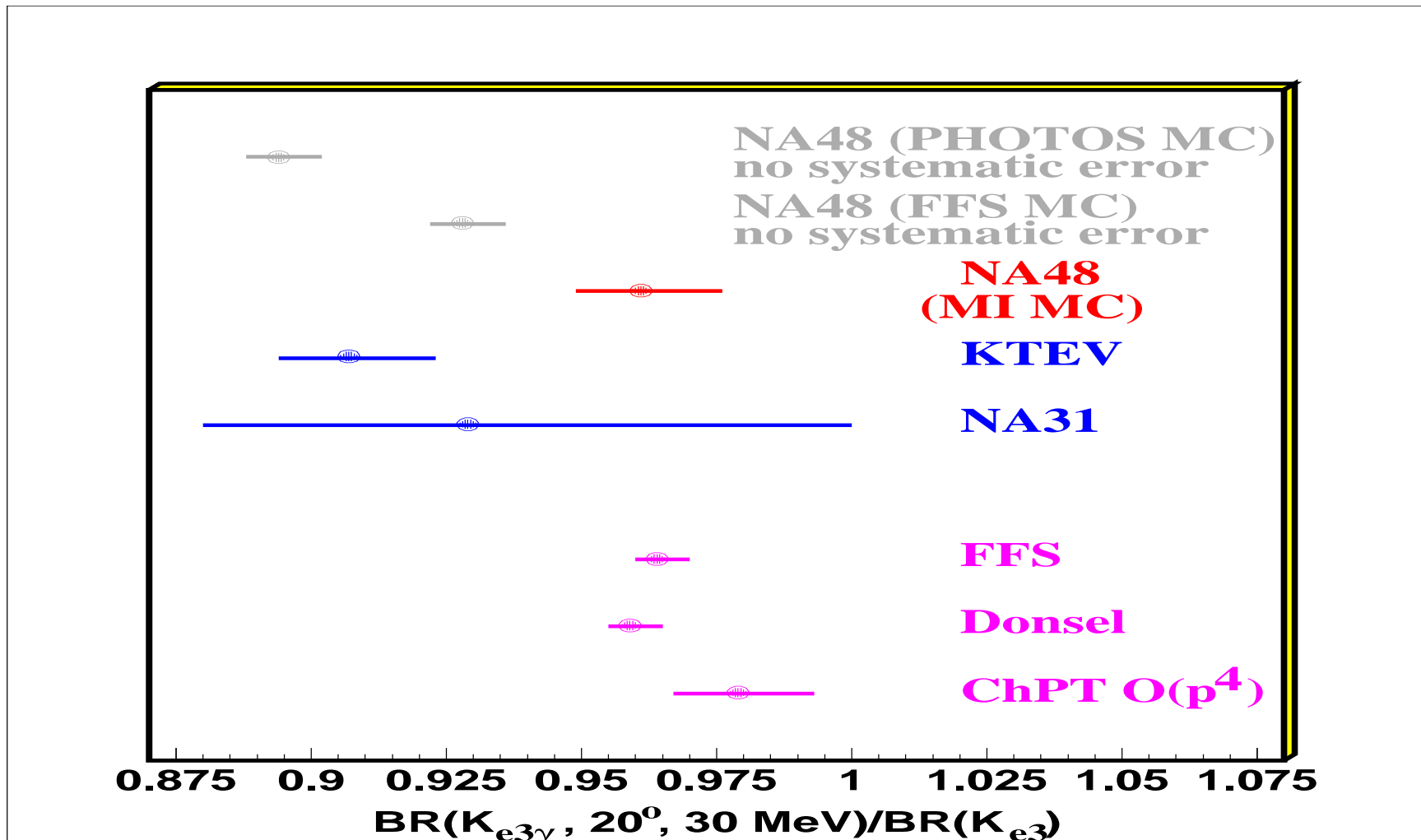
$K_L \to \pi^{\pm} e^{\mp} \nu$

Measurement of Form Factors in $K_L \to \pi^{\pm} e^{\mp} \nu$

- Sample from 1999 of $5.6 \cdot 10^6$ fully reconstructed K_{e3} events

- Measurement of the Dalitz plot density admitting all possible Lorentz-covariant couplings: measure form factors for
  - vector interaction ($f_+(q^2) = f_+(0)(1 + \lambda_+ q^2/m_\pi^2)$)
  - scalar interaction (f_S)
  - tensor interaction (f_T)

- Theory prediction $\lambda_+ = 0.028$

- *Akimenko et al. (1991), Steiner et al.(1971)* reported evidence for nonzero scalar and tensor form factors for K_{e3}^+

- *recent measurements* of *charged and neutral kaon decays* show no deviation from vector type interaction
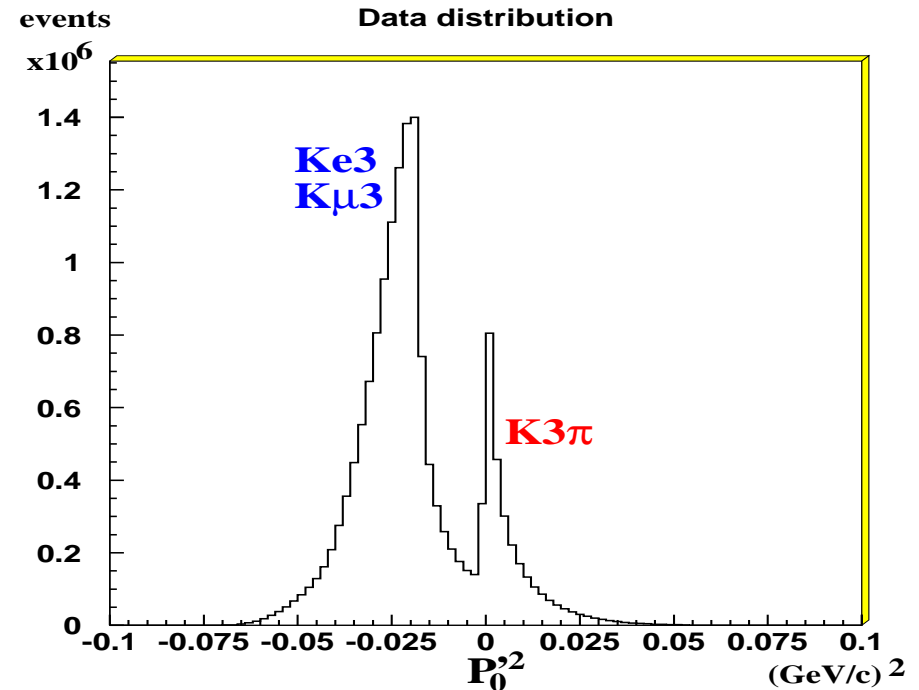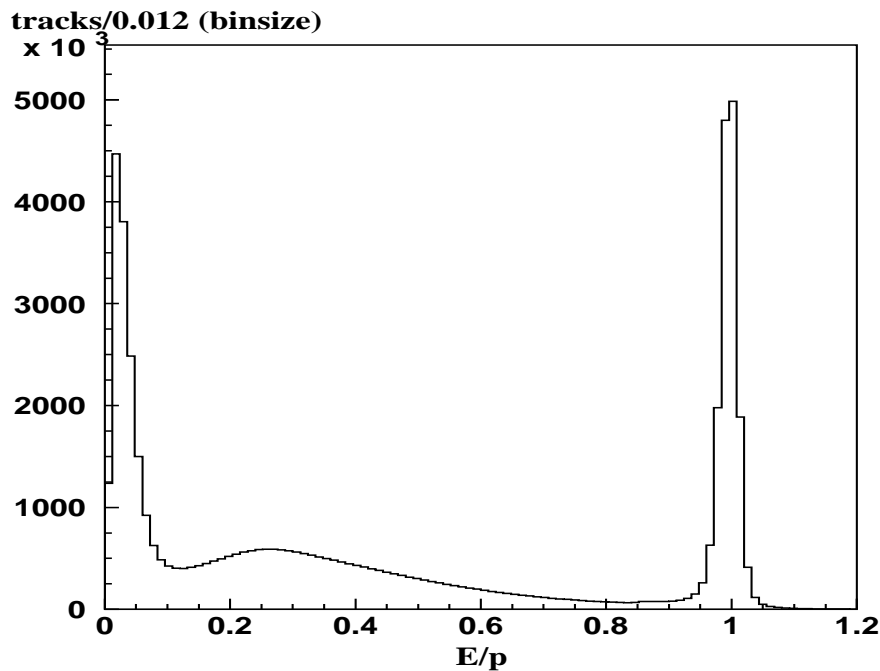
$K_L \to \pi^\pm e^\mp \nu$

- Main backgrounds from $K_L \to \pi^\pm \mu^\mp \nu$ and $K_L \to \pi^+ \pi^- \pi^0$

  - suppress $K_{3\pi}$ by cut on $P_0'^2 < -0.004$ (GeV/c)^2

$$\left(P_0'^2 = \frac{(m_K^2 - m_{+-}^2 - m_{\pi^0}^2)^2 - 4(m_{+-}^2)m_{\pi^0}^2 + m_K^2 p_\perp^2}{4(p_\perp^2 + m_{+-}^2)} \right)$$
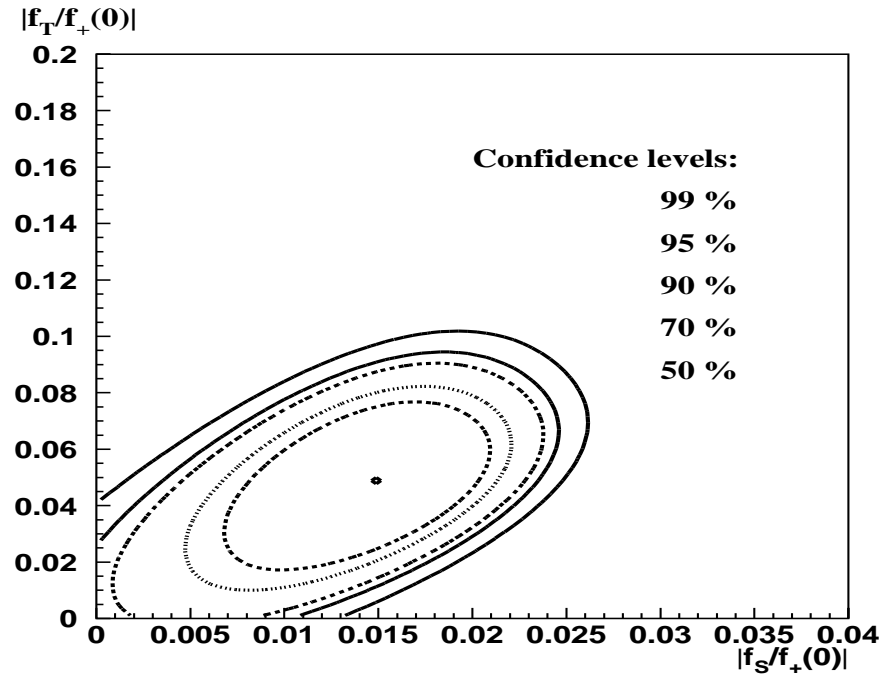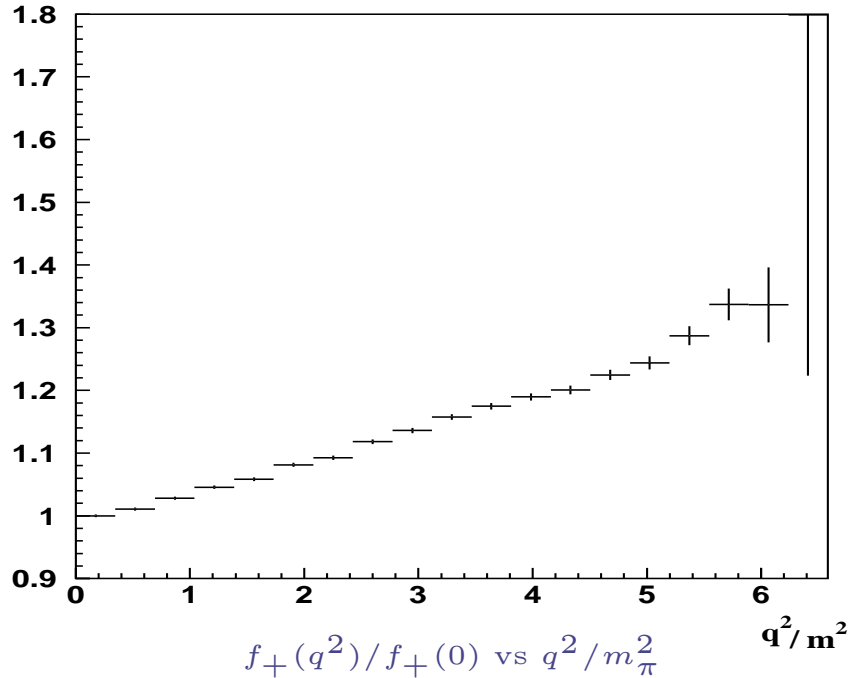
  $\Rightarrow$ remaining with **20 background events from this source**

  - suppress $K_{\mu 3}$ by **muon veto signal** and *E/p cut*

  $\Rightarrow$ remaining with 400 ± 100 **background events from this source**

tracks/0.012 (binsize)
x 10^3
E/p

events
x10^6
Data distribution
Ke3
Kμ3
K3π
$P_0'^2$
(GeV/c)^2

$K_L \to \pi^{\pm} e^{\mp} \nu$

$f_+(q^2)/f_+(0)$ vs q^2/m_π^2

Results 3 form factor fit:

- $\lambda_+ = 0.0284 \pm 0.0007_{\text{stat}} \pm 0.0013_{\text{syst}}$

- $\left|\frac{f_S}{f_+(0)}\right| = 0.015^{+0.007}_{-0.010} \pm 0.012_{\text{syst}}$

- $\left|\frac{f_T}{f_+(0)}\right| = 0.05^{+0.03}_{-0.04} \pm 0.03_{\text{syst}}$

→ No evidence for scalar or tensor couplings!

Result pure vector interaction:

- $\lambda_+ = 0.0288 \pm 0.0005_{\text{stat}} \pm 0.0011_{\text{s}}$

current PDG Limits:

- $f_s/f_+ < 0.04$ (CL 68%)

- $f_t/f_+ < 0.23$ (CL 68%)

Prospects...

- Measurement of Form Factors in $K_L \to \pi^\pm \mu^\mp \nu$

  - Sample from 1999 of $2.3 \cdot 10^6$ fully reconstructed $K_{\mu 3}$ events

  - Measurement of the Dalitz plot density (analog to K_{e3})

- Measurement of the BR($K_L \to \pi^\pm e^\mp \nu$)

  - Sample from dedicated minimum bias run (*2 days*) with $6.7 \cdot 10^6$ reconstructed K_{e3} events

  - Determination of V_{us}

  - Error is expected to be of the order of 1% (*limited by theoretical uncertainty*)

$\Rightarrow$ Results will be published soon..

Conclusions/Summary

Measured form factors and branching ratios
for semileptonic neutral Kaon decays:

- $\mathrm{BR}(K_{e4}) = (5.21 \pm 0.07_{\mathrm{stat}} \pm 0.09_{\mathrm{syst}}) \times 10^{-5}$

  - $\overline{f}_s = 0.052 \pm 0.006_{\mathrm{stat}} \pm 0.002_{\mathrm{syst}}$

  - $\overline{f}_p = -0.051 \pm 0.011_{\mathrm{stat}} \pm 0.005_{\mathrm{syst}}$

  - $\lambda_g = 0.087 \pm 0.019_{\mathrm{stat}} \pm 0.006_{\mathrm{syst}}$

  - $\overline{h} = -0.32 \pm 0.12_{\mathrm{stat}} \pm 0.07_{\mathrm{syst}}$

- $\mathrm{Br}^{\mathrm{exp}}_{\mathrm{NA48}}(K_L \to \pi^{\pm} e^{\mp} \nu \gamma / K_L \to \pi^{\pm} e^{\mp} \nu) = (0.960 \pm 0.07^{+0.012}_{-0.011})\%$

- $\lambda_+(K_{e3}) = 0.0288 \pm 0.0005_{\mathrm{stat}} \pm 0.0011_{\mathrm{syst}}$

  $\Rightarrow$ No hint of *scalar* or *tensor* couplings

Expect from 2003/2004 data (*NA48/2*)

new exciting results for semileptonic *charged* Kaon decays!