Status and Prospects of Rare $K^{\pm}$ and K_L Decays from NA48

Rainer Wanke

Institut für Physik, Universität Mainz

Kaon Mini Workshop

CERN, May 5, 2004

Introduction

1997	ε'/ε run	$K_L + K_S$
1998	ε'/ε run	$K_L + K_S$
1999	ε'/ε run $K_L + K_S$	K_S Hi. Int.
2000	K_L only	K_S High Intensity
	NO Spectrometer	
2001	ε'/ε run $K_L + K_S$	K_S High Int.
2002	K_S High Intensity	
2003	$K^\pm$ High Intensity	
2004	$K^\pm$ High Intensity	

$K^\pm$ Decays: A Look into the Future

- **NA48/2** Data taking 2003 (+ 2004):
  World largest multi-purpose sample of $K^\pm$ decays.

K_L Decays: Wrapping up the Past

- **NA48** Data taking up to 2001:
  Huge K_L sample, several publications, still some left-overs.

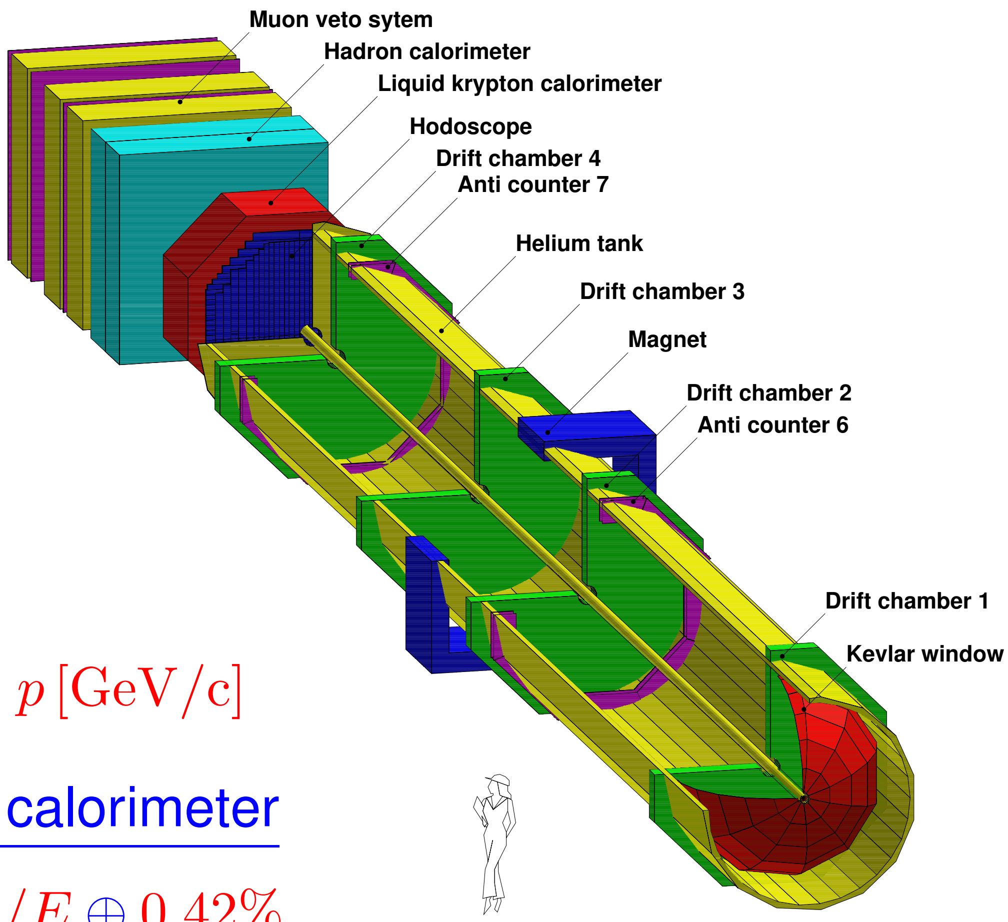
Aim of this talk:

- Introduce analyses which are expected to be finished soon.
- Estimates of sample sizes, backgrounds, and expected uncertainties.
- *But:* Mostly no results yet.

Overview

- $K^{\pm}$ **Decays:**
  - $K^{\pm} \to \pi^{\pm}\pi^{\mp}e^{\pm}\nu(\bar{\nu})$ (K_{e4}^{+}) branching ratio and form factors
  - $K^{\pm} \to \pi^{\pm}e^{+}e^{-}$ and $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ decays
  - First look into $K^{\pm} \to \pi^{\pm}\gamma\gamma$
- K_{L} **Decays:**
  - $K_{\mathrm{L}} \to \pi^{\pm}\pi^{0}e^{\mp}\nu_{e}$ (K_{e4}^{0}) branching ratio and form factors
  - Form factor in $K_{\mathrm{L}} \to e^{+}e^{-}\gamma$
  - Measurement of $K_{\mathrm{L}} \to e^{+}e^{-}e^{+}e^{-}$
- **Not covered here:**
  - CP violation in $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$ $\Longrightarrow$ Spasimir Balev
  - K_{S} and neutral hyperon decays $\Longrightarrow$ Cristina Lazzeroni
  - Semileptonic decays K_{l3}, $K_{l3\gamma}$ $\Longrightarrow$ Mayda Velasco

NA48 Detector



Main detector components:

- Magnetic spectrometer:

  $\Delta p/p \simeq 0.5\% \oplus 0.009\% \times p\,[\mathrm{GeV/c}]$

- Liquid-krypton el.-magn. calorimeter

  $\Delta E/E \simeq 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$

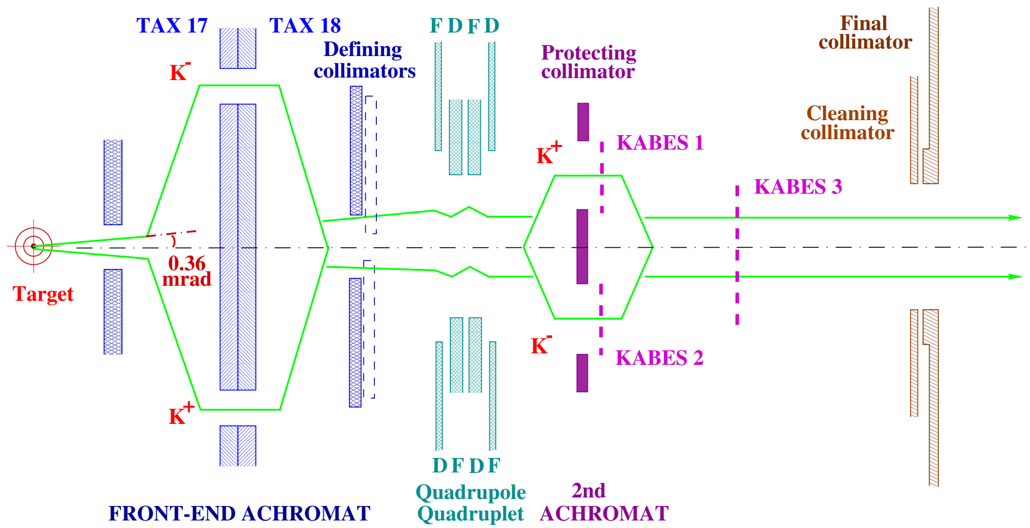
- Hadron calorimeter, photon veto, μ veto counters

Rare $K^{\pm}$ Decays

NA48/2 $K^{\pm}$ Data Taking in 2003

NA48/2 experiment in 2003:

- High intensity data taking with simultaneous K^+ and K^- beams.
- New beam spectrometer (Micromesh gas chambers)
  $\Longrightarrow$ $K^{\pm}$ momentum resolution $\sim 1\%$
- $\sim$ 50 days of data taking: $\sim 10^{11}$ $K^{\pm}$ decays in decay volume.



Trigger:

- All 3-track events
  ($\sim 98\%$ efficient)
- 1-track events
  with μ-veto and
  $$(p_K - p_\pi)^2 \gg m_{\pi^0}^2$$
  to reject $K^{\pm} \to \pi^{\pm}\pi^0$.

NA48/2 $K^{\pm}$ Data Taking in 2003

- Total data taking period 2003: $\sim$ 50 days.
- Data presented here: Last month of data taking (so-called Super Samples 1,2,3).

  $\Longrightarrow$ Stable running conditions during this period.
- All 2003 data almost twice as much.

  $\Longrightarrow$ Still useful for Rare Decay analyses.

Measurement of $K^+ \to \pi^+\pi^- e^+\nu$ (K_{e4}^+)

- **Physics interest:**
  - Low energy $\pi\pi$ scattering unambiguously predicted from Chiral Perturbation Theory first principles.
  - s-wave isospin zero $\pi\pi$ scattering length a_0^0 can be determined from form factors in K_{e4}^+ decays.

    $\Longrightarrow$ Predicted to $a_0^0 = 0.220 \pm 0.005$ in ChPT.
    (Colangelo, Gasser, Leutwyler, 2001)

    $\Longrightarrow$ Direct and firm test of Chiral Perturbation Theory.

- **Previous measurements:**
  - Geneva-Saclay (1977): $30\,000$ events
  - Brookhaven E865 (2001): $400\,000$ events

$$\Longrightarrow \quad a_0^0 = 0.216 \pm 0.013.$$

Measurement of $K^+ \to \pi^+\pi^- e^+\nu$ ***(***K^+_{e4}***)***

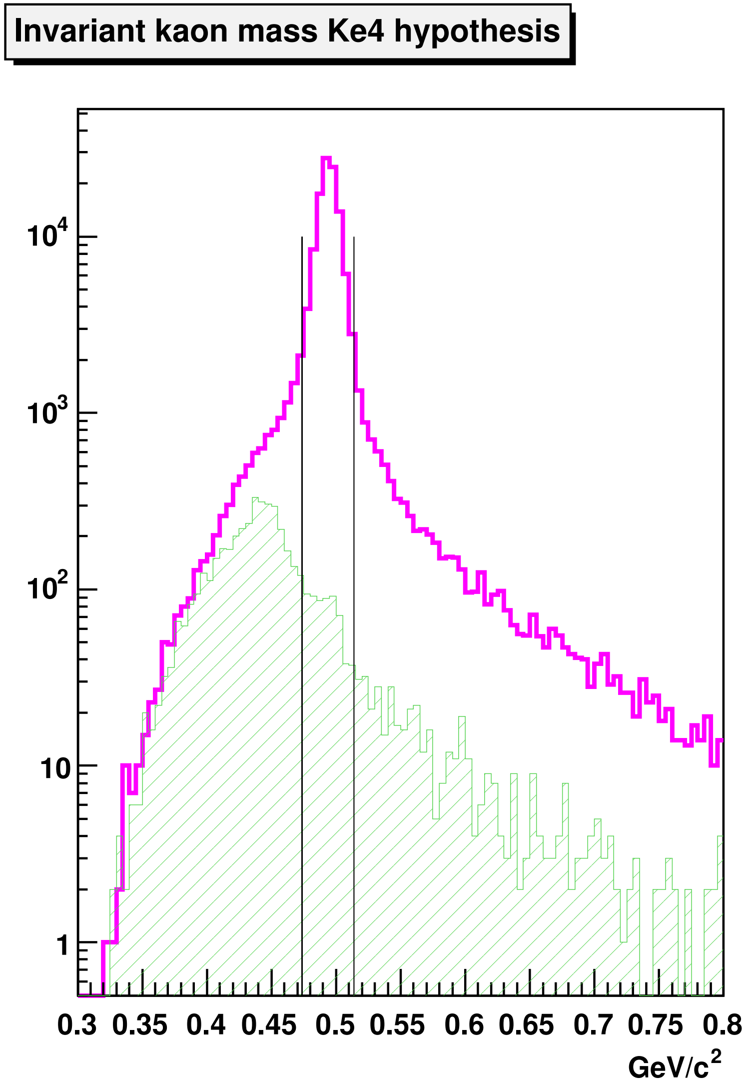
- Events fully reconstructed by using known kaon momenta.
  $\Longrightarrow$ More than $300\,000$ events in SS 1–3.

- **Background** mainly from $K^+ \to \pi^+\pi^+\pi^-$ and $K^+ \to \pi^+\pi^0_{\text{Dalitz}}$ with $\pi \leftrightarrow e$ mis-identification.

  $\Longrightarrow$ Use of neural network for e/π separation.

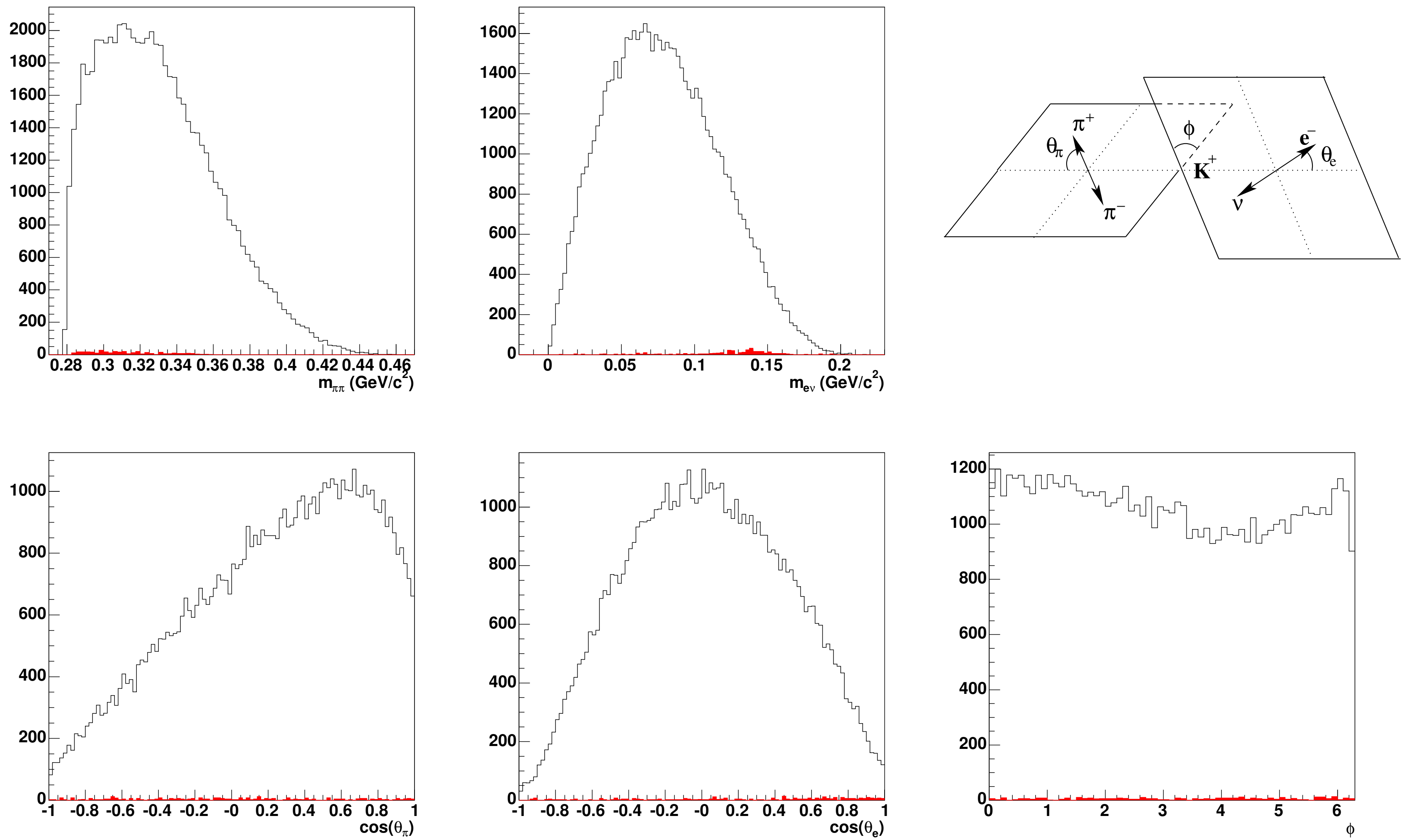
- Total background: $\mathbf{0.6\%}$

  Determined from wrong-sign $\pi^+\pi^+e^-$ data events.



Measurement of $K^+ \to \pi^+\pi^- e^+\nu$ (K^+_{e4})

Cabibbo-Maksymowicz variables: (Background in red)



Measurement of $K^+ \to \pi^+\pi^- e^+\nu$ ***(***K^+_{e4}***)***

Status and Prospects for K^+_{e4}**:**

- Expect more than half a million events in total 2003 data.
- Backgrounds are tiny, systematics should not be dominating.
- Analysis underway, but a lot of work.

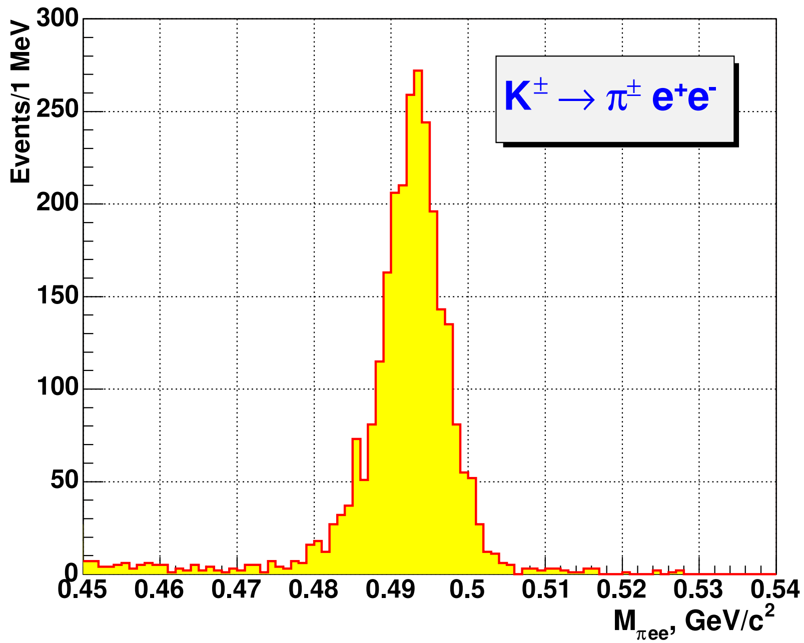
  $\Longrightarrow$ May have to wait til the end of the year.

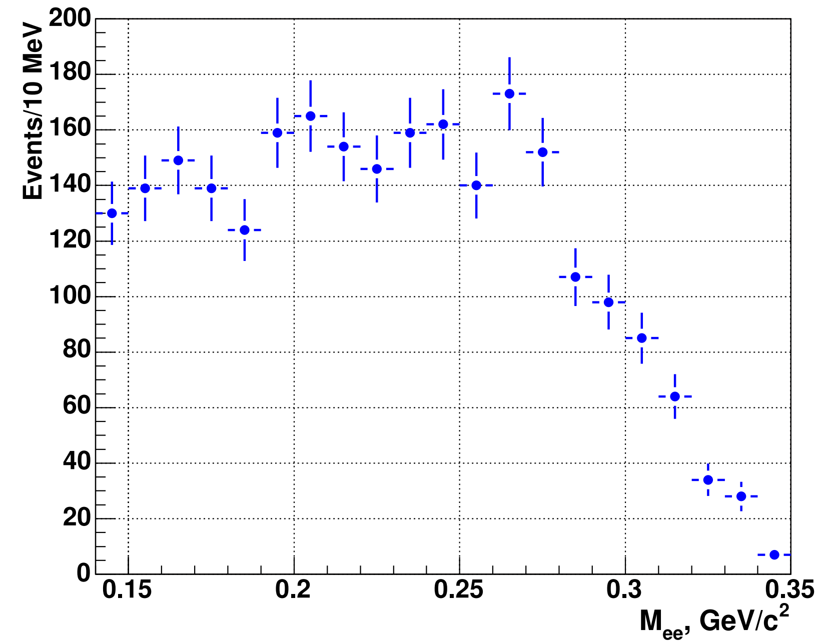
Measurement of $K^\pm \to \pi^\pm e^+ e^-$ and $K^\pm \to \pi^\pm \mu^+ \mu^-$

- **Physics interest:**
  - FCNC, suppressed by GIM mechanism.
  - Amplitude dominated by long-distance contributions (one-photon “bremsstrahlung” diagrams).
    $\Longrightarrow$ Can be extracted from form factor measurements!
  - Potentially interesting channels for CP violation between $\Gamma(K^+_{\pi ll})$ and $\Gamma(K^-_{\pi ll})$.

- **Previous measurements:**
  - $K^\pm \to \pi^\pm e^+ e^-$: BNL E865 found 10500 events
    $\Longrightarrow$ $\mathrm{Br} = (2.94 \pm 0.05 \pm 0.14) \times 10^{-7}$
    (Also form factor measurement.)
  - $K^\pm \to \pi^\pm \mu^+ \mu^-$: Several experiments, in total 800 events.
    $\Longrightarrow$ $\mathrm{Br} = (0.81 \pm 0.14) \times 10^{-7}$

Measurement of $K^{\pm} \to \pi^{\pm} e^{+} e^{-}$

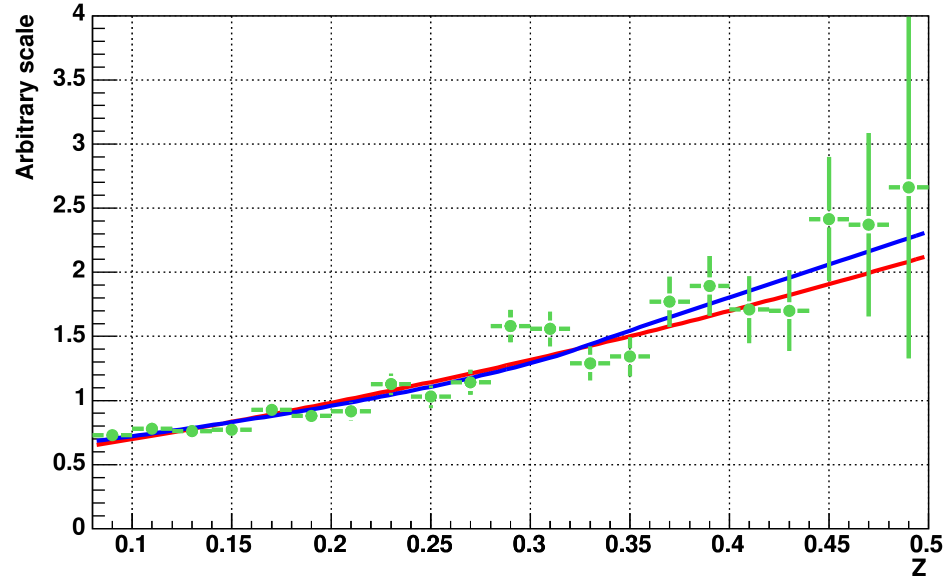




- About 2600 candidates for $m_{ee} > 140$ MeV/c^2 in one month of data taking.
- Background very small ($\sim 1 - 2\,\%$).

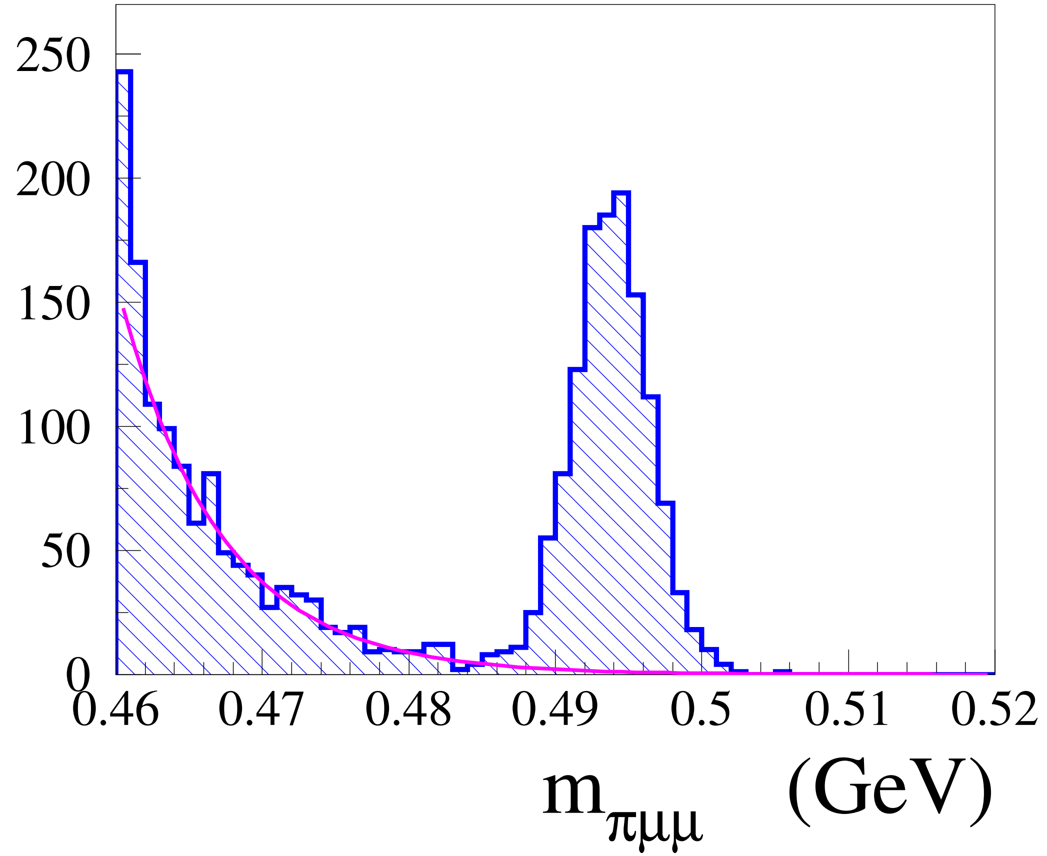
Measurement of $K^{\pm} \to \pi^{\pm} e^{+} e^{-}$

- **Form Factor:**



- **Status and Prospects:**
  - Statistical error on branching fraction $\Delta\mathrm{Br} \leq \pm 0.06 \times 10^{-7}$.
    (Total PDG error now is $\pm 0.13 \times 10^{-7}$)
  - Systematics expected to be small.
  - Analysis far advanced.
    $\Longrightarrow$ Expect result within the next months.

Measurement of $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$



- Event sample of $> 10^3\ K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ candidates (SS 1–3).
  (Current world sample: 800 events)
- Again: Very small background.

Measurement of $K^{\pm} \to \pi^{\pm}\gamma\gamma$

- $\underline{K^{\pm} \to \pi^{\pm}\gamma\gamma}$:

  Similar situation as for $K_{\mathsf{L}} \to \pi^0\gamma\gamma$:

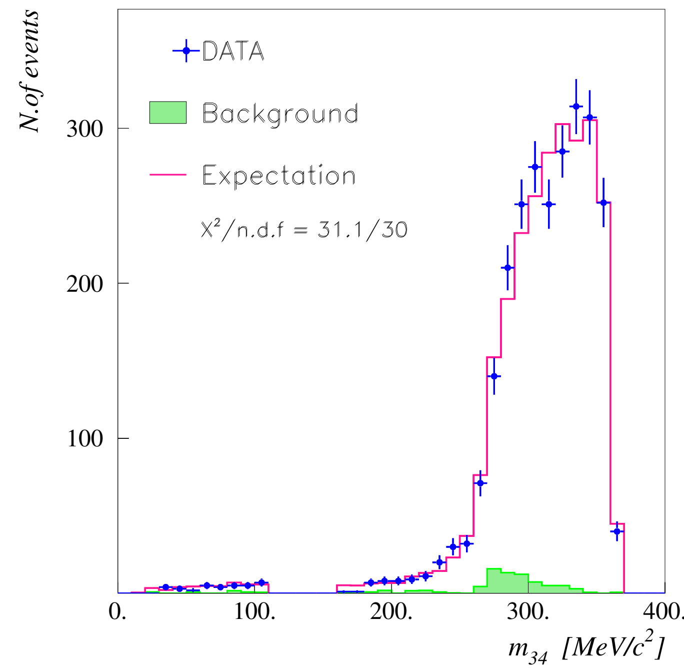
  - $\mathcal{O}(p^2)$ ChPT amplitude vanishes.
  - $\mathcal{O}(p^4)$ computed

    (but not exactly known for $K^{\pm} \to \pi^{\pm}\gamma\gamma$!)

    $\Longrightarrow$ Signal mainly has $m_{\gamma\gamma} > 2m_{\pi}$
  - Fit to $m_{\gamma\gamma}$ distribution:

    $\Longrightarrow$ Information on $\mathcal{O}(p^6)$

$K_{\mathsf{L}} \to \pi^0\gamma\gamma$:



- **Experimental problem:**

  Suppression of $K^{\pm} \to \pi^{\pm}\pi^0$ at trigger level.

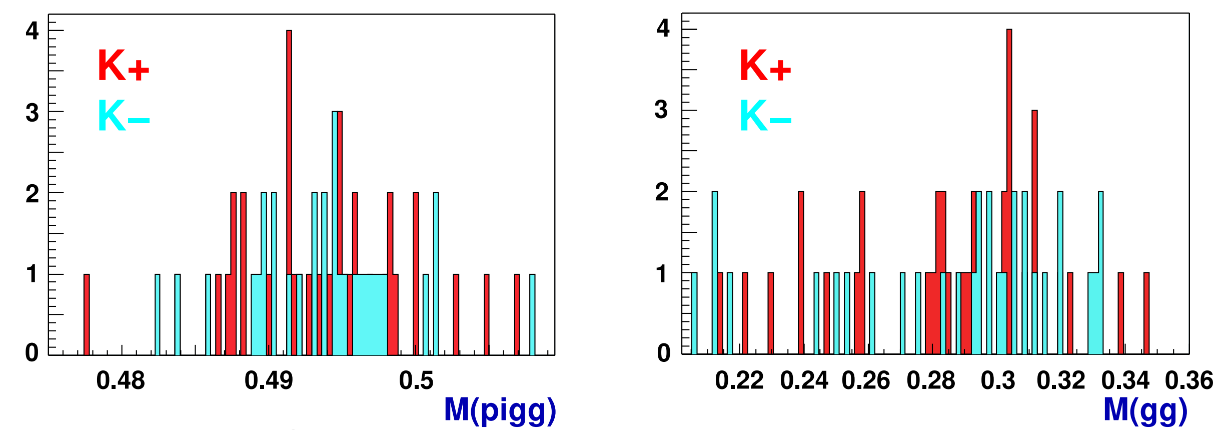
  $\Longrightarrow$ Two trigger conditions for $K^{\pm} \to \pi^{\pm}\gamma\gamma$ events:

  - Normal neutral trigger $\to$ down-scaled by 80.
  - "High-$m_{\gamma\gamma}$" trigger $\to$ no down-scaling, but no low-$m_{\gamma\gamma}$

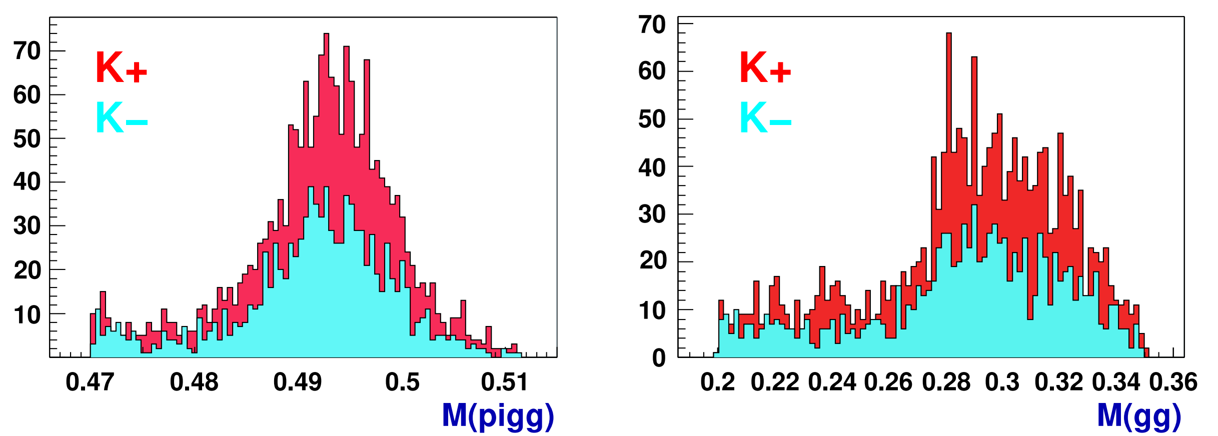
Measurement of $K^{\pm} \to \pi^{\pm}\gamma\gamma$

First look into the data: (Compare with 31 events of E787!)

Neutral trigger (DS=80):



High−M(gg) trigger (DS=1):



$\Longrightarrow$ Promising — but still a lot of work to do!

Rare K_L Decays

Rare K_L Decays from NA48

- Main goal of **NA48/0:**

  Measurement of $\mathrm{Re}(\epsilon'/\epsilon) = (14.7 \pm 2.2) \times 10^{-4}$.

  $\Longrightarrow$ Data taking finished in 2001, published in 2002.

- Meanwhile: Several rare decay analyses published.

  (E.g. $K_\mathsf{L} \to \pi^0\gamma\gamma$, $K_\mathsf{L,S} \to \pi^+\pi^-e^+e^-$, rare K_S decays, . . .)

- Still some left-overs due to complicated analyses and available man-power.

  $\Longrightarrow$ Now being finished!

  - $K_\mathsf{L} \to \pi^\pm\pi^0 e^\mp \nu_e$ (K^0_{e4})
  - $K_\mathsf{L} \to e^+e^-\gamma$
  - $K_\mathsf{L} \to e^+e^-e^+e^-$
  - K_{e3}, $K_{\mu3}$ $\Longrightarrow$ Mayda Velasco

Measurement of $K_L \to \pi^\pm \pi^0 e^\mp \nu_e$ *(*K^0_{e4}*)*

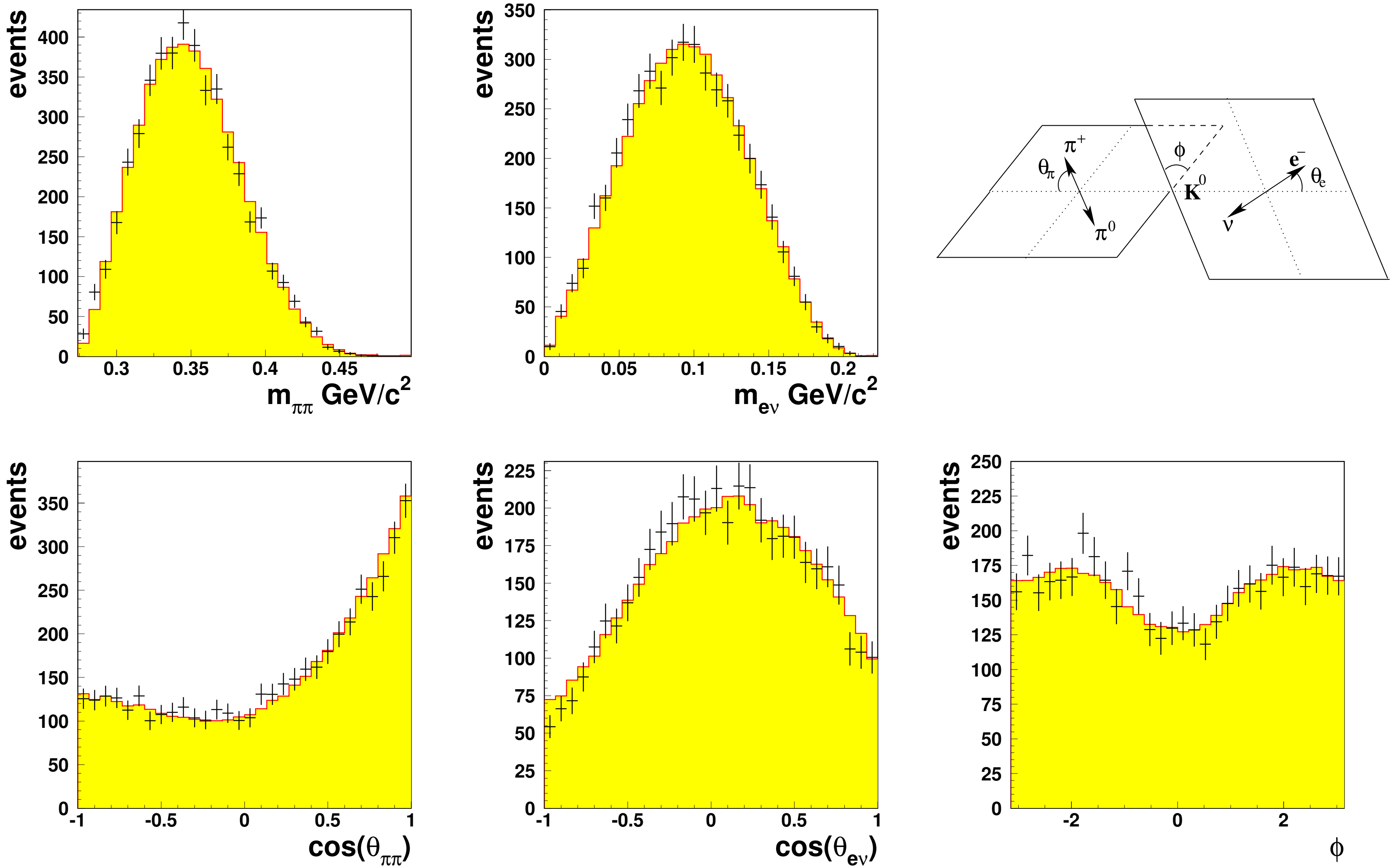
- **Physics interest:** Similar, but not identical, to K^+_{e4}.
  - Measurement of branching fraction and form factors allow determination of ChPT parameters as e.g. the coefficient L_3.
- **Previous measurements:**
  - E731 (Fermilab, 1993): 729 events

    (Measured both Br and form factors.)
- **NA48 2001:**
  - Two different triggers:
    - Neutral minimum-bias (downscaled by 30)
    - Special K_{e4} trigger (downscaled by 50)
  - Total K_{e4} sample: 5464 events (bkg contamination only 1.1%)

$\Longrightarrow$ One order of magnitude more precise than previous measurement!

Measurement of $K_L \rightarrow \pi^{\pm}\pi^{0}e^{\mp}\nu_e$ (K^0_{e4})

Fit of Cabibbo-Maksymowicz variables:



Measurement of $K_L \rightarrow \pi^{\pm}\pi^{0}e^{\mp}\nu_e$ (K^0_{e4})

Results on K^0_{e4}: (submitted to PLB)

- Branching fraction:

$$\mathrm{Br}(\mathrm{K}^0_{\mathrm{e}4}) = (5.21 \pm 0.07_{\text{stat.}} \pm 0.09_{\text{syst.}}) \times 10^{-5}$$

- Form factors:

$$\begin{aligned}
\overline{f_s} &= 0.052 \pm 0.006_{\text{stat.}} \pm 0.002_{\text{syst.}} \\
\overline{f_p} &= -0.051 \pm 0.011_{\text{stat.}} \pm 0.005_{\text{syst.}} \\
\lambda_g &= 0.087 \pm 0.019_{\text{stat.}} \pm 0.006_{\text{syst.}} \\
\overline{h} &= -0.32 \pm 0.12_{\text{stat.}} \pm 0.05_{\text{syst.}}
\end{aligned}$$

in good agreement with ChPT predictions.

- Determination of ChPT coefficient L_3 (from branching ratio):

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

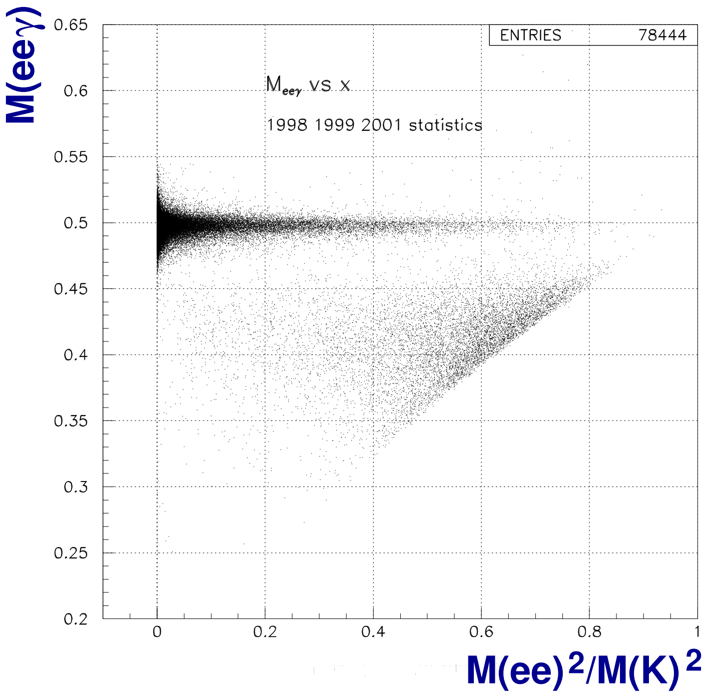
Form Factor in $K_L \to e^+e^-\gamma$

- NA48 publication (2000) on 97 data:
  BMS form factor: $\alpha_{K^*} = 0.36 \pm 0.06$.

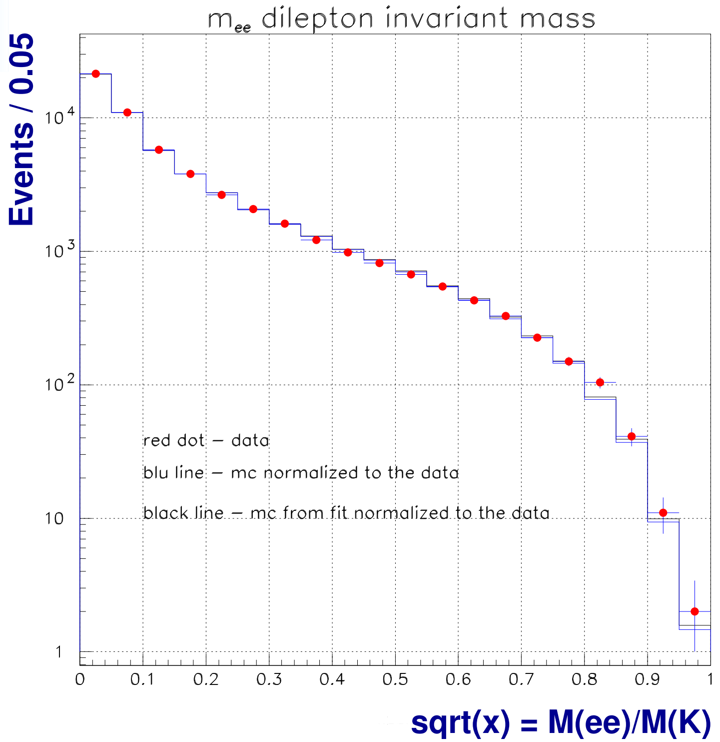
- Result in slight contradiction with KTeV measurements
  on $K_L \to e^+e^-\gamma$ and $K_L \to \mu^+\mu^-\gamma$
  on a much larger data sample.

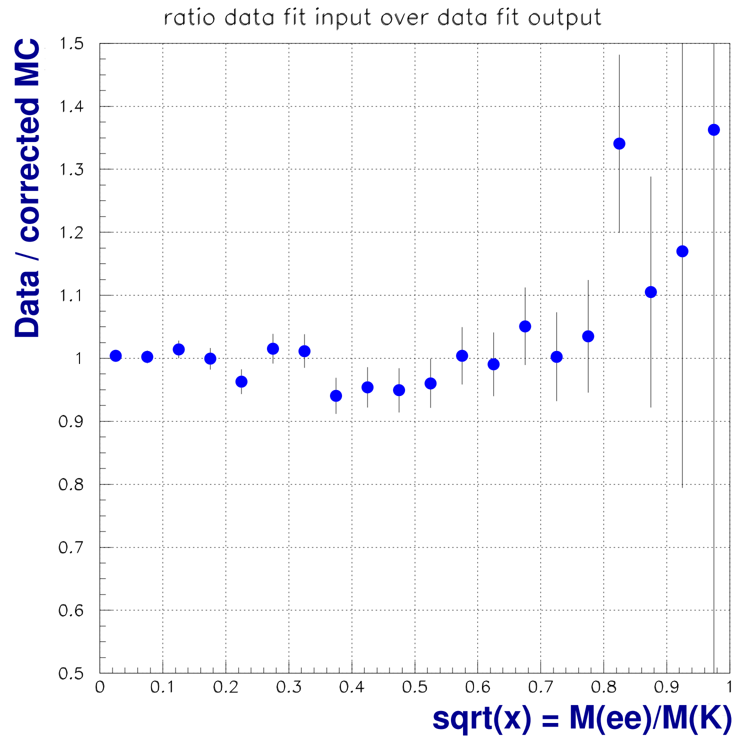
- **Now:** Using total NA48 data set
  (97,98,99,2001)

  $\Longrightarrow$ About a factor of 9
  statistical improvement
  w.r.t. 97 publication.



Form Factor in $K_L \to e^+e^-\gamma$



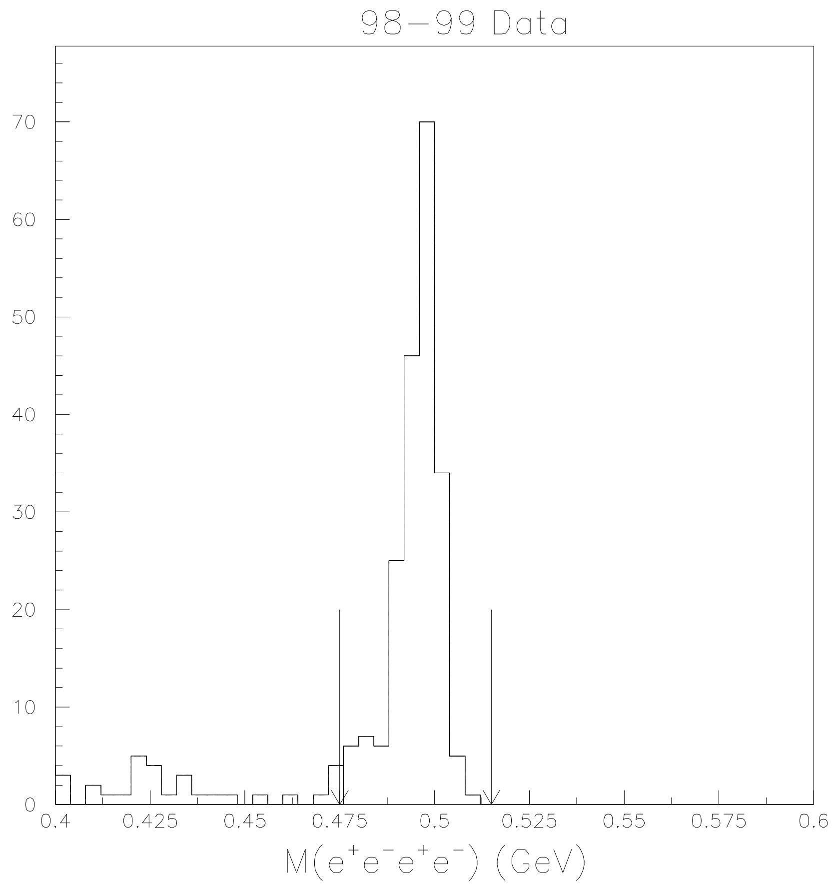


- $\approx$ 60 000 events in total NA48 data (Background $\sim 1\%$)

  $\Longrightarrow$ Statistical error: $\Delta\alpha_{K^*} \approx 0.02$
- Huge amount of work was done on radiative corrections.
- Expect result for BMS and DIP models within the next months.

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

- $K_L \to e^+e^-e^+e^-$ measurement soon to be finished.
- 200 events found with expected background of 1%.



Conclusions

- **Rare $K^{\pm}$ decays:**

  All measurements with large statistics and low systematics.

  Lots of on-going work:

  - High precision measurement of K^{+}_{e4}.
  - Branching fraction and form factors of $K^{\pm} \to \pi^{\pm} e^{+} e^{-}$ and $K^{\pm} \to \pi^{\pm} \mu^{+} \mu^{-}$.
  - Work on $K^{+} \to \pi^{+} \gamma\gamma$.
  - Many more analyses not shown here:

    $K_{\mu 4}$, $K^{\pm} \to \pi^{\pm} \pi^{0} \gamma$, $K^{\pm} \to \pi^{\pm} \gamma e^{+} e^{-}$, $K^{\pm} \to l^{\pm} l^{+} l^{-} \nu$, $\ldots$

- **K_{L} decays:**

  - Precision measurement on K^{0}_{e4} finished.
  - Measurements of $K_{\mathrm{L}} \to e^{+} e^{-} \gamma$ and $K_{\mathrm{L}} \to e^{+} e^{-} e^{+} e^{-}$ on whole data set expected to be published in summer.