Measurements of K_{e4} and $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$ decays

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On behalf of the NA48/2 collaboration

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

Outline

1. Introduction
2. $K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$
   - Form factors and $\pi\pi$ scattering lengths
3. $K^{\pm} \to \pi^0\pi^0 e^{\pm}\nu_e$
   - Branching ratio and form factors
4. $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$
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   - Form factors and $\pi\pi$ scattering lengths
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$\pi\pi$ scattering lengths: why and how measure them?

WHY?

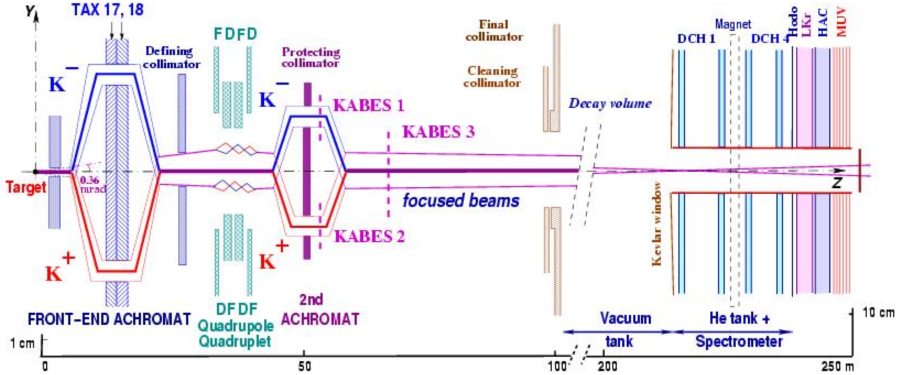
- Very precise theoretical predictions from χPT (2%) and generalised χPT, depending only on one free parameter: **the quark condensate $\langle 0 |\bar{q}q| 0\rangle$**
- $\langle 0 |\bar{q}q| 0\rangle$ must be determined experimentally
- The size of $\langle 0 |\bar{q}q| 0\rangle$ determines the order at which mass terms appear in the perturbative expansion

HOW?

- $\boldsymbol{K_{e4}}$ ($K \to \pi\pi e\nu$): no other hadrons, pions close to threshold
  No theoretical uncertainty on the form factors, only on $a_0^2 = f(a_0^0)$
- $\boldsymbol{K^\pm \to \pi^0\pi^0\pi^\pm}$: "cusp" at $M_{00}^2 = 4m_{\pi^+}^2$ due to rescattering
  Theoretical uncertainty of the Cabibbo-Isidori model: 5%

The NA48/2 beamline

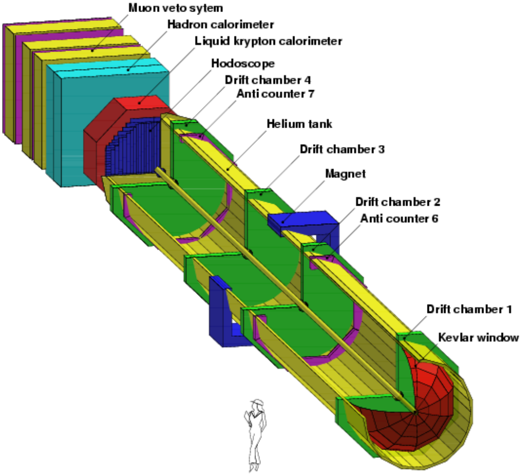
Simultaneous K^+ and K^- beams with $p_K = (60 \pm 3)$ GeV/c
to measure charge asymmetry in $K \to 3\pi$ decays



The NA48/2 detector

- **Magnetic spectrometer:**
  4 drift chambers
  + 1 dipole magnet
  $\boldsymbol{\sigma(p)/p \simeq 0.9\%}$ @ 20 GeV/
  ($p_{\perp}^{kick} \simeq$ 120 MeV/c)

- **Electromagnetic calorimeter:**
  Liquid krypton calorimeter
  $\boldsymbol{\sigma(E)/E \simeq 1\%}$ @ 20 GeV
  $\sigma(t) \simeq$ 265 ps for 50 GeV e^-



$K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$: Signal and background

K_{e4}^{+-} candidates (2003): $\sim$ 370,000 with 0.5% background

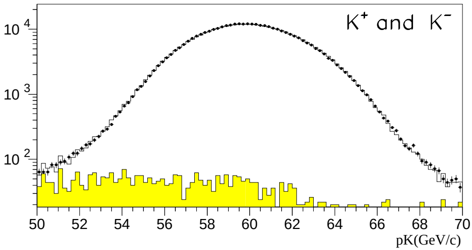
Background estimate from data:

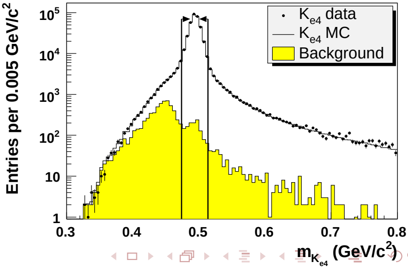
"Wrong sign" events ($\pi^{\pm}\pi^{\pm}e^{\mp}\nu_e$) can only be background($\Delta S = \Delta Q$ rule)

Main contributions from $K^{\pm} \to \pi^+\pi^-\pi^{\pm}$ with $\pi \to e\nu$ or π mis-ID

Factor 2 scaling applied to background from $K^{\pm} \to \pi^+\pi^-\pi^{\pm}$

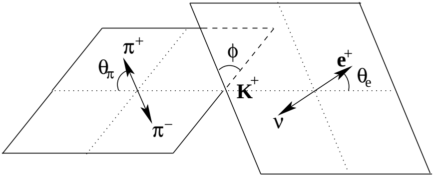
Agreement between estimates from data and from MC





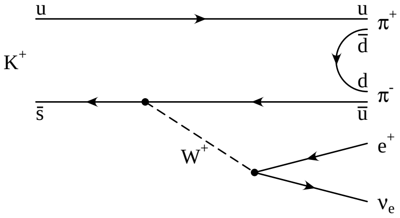
$K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$: Form factor parametrisation

Kinematic variables



- $M_{\pi\pi}$
- $M_{e\nu}$
- $\cos\theta_\pi$ (in the $\pi\pi$ cm system)
- $\cos\theta_e$ (in the $e\nu$ cm system)
- ϕ (angle between the $\pi\pi$ and $e\nu$ planes in the K cm system)

Matrix element



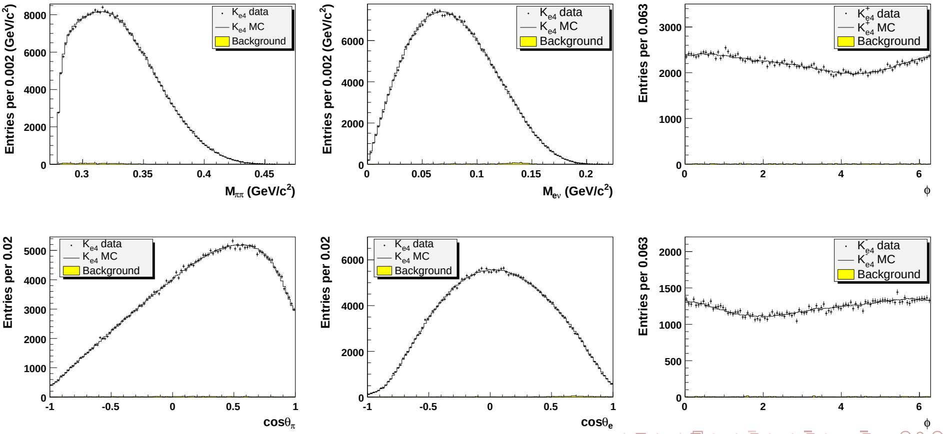
$$T = \frac{G_F}{\sqrt{2}} V_{us}^* \bar{u}(p_\nu)\gamma_\mu(1-\gamma_5)v(p_e)(V^\mu - A^\mu)$$

Form factors

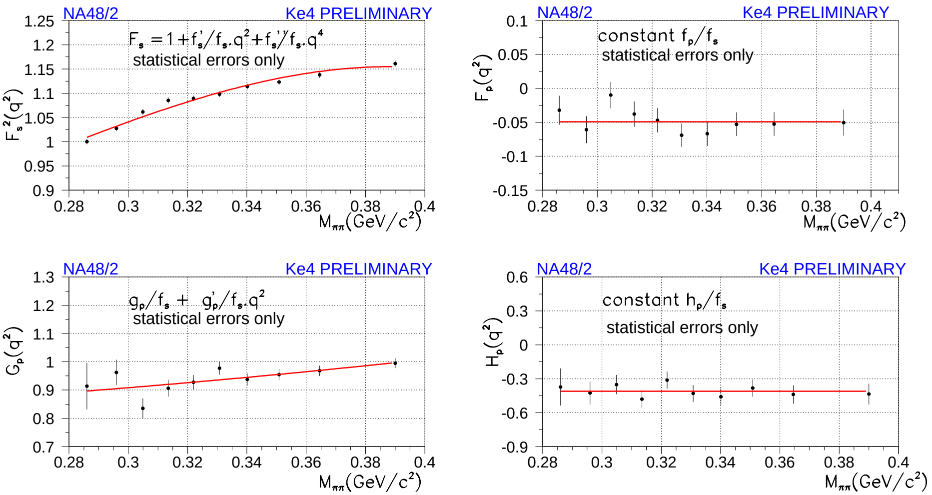
$$\begin{aligned} F &= F_s e^{i\delta_0^0} + F_p e^{i\delta_1^1}\cos\theta_\pi \\ G &= G_p e^{i\delta_1^1} \\ H &= H_p e^{i\delta_1^1} \end{aligned}$$

10 independent 5 parameter fits for each bin in $M_{\pi\pi}$.

For each fit 1500 equal population bins in the 4-dimensional space of the kinematic variables



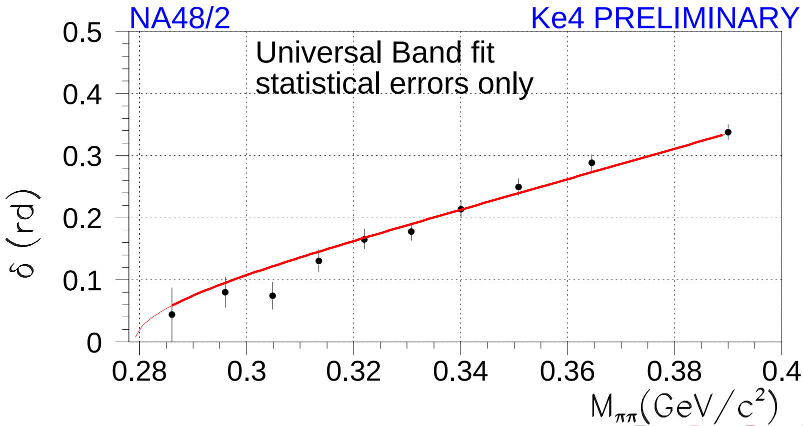
$K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$: F, G and H



$K^{\pm} \rightarrow \pi^{+}\pi^{-}e^{\pm}\nu_e$: a_0^0 and a_0^2

The $\delta = \delta_0^0 - \delta_1^1$ distribution was fitted with a **1 parameter (a_0^0) function** given by the numerical solution of the Roy equations in Phys. Rept. 353, 207

a_0^0 and a_0^2 were constrained to lie on the **centre of the universal band**



$K^\pm \to \pi^+\pi^- e^\pm \nu_e$: Systematics and preliminary result

Systematic checks

- Two independent analyses with different reconstruction methods, acceptance corrections, fit methods and MC parameters
- Stability of acceptance vs time (variation of the simulated beam conditions)
- Uncertainty on background estimate (checked with data and MC)
- Uncertainty on electron-ID efficiency (variation of LDA cut)
- Uncertainty on radiative corrections (fraction of total effect with or w/o PHOTOS)
- Bias from neglected s_e dependence (MC tests)

NA48/2 preliminary result (2003 data)

$$f'_s/f_s = 0.169 \pm 0.009_{stat} \pm 0.034_{syst}$$

$$f''_s/f_s = -0.091 \pm 0.009_{stat} \pm 0.031_{syst}$$

$$f_p/f_s = -0.047 \pm 0.006_{stat} \pm 0.008_{syst}$$

$$g_p/f_s = 0.891 \pm 0.019_{stat} \pm 0.020_{syst}$$

$$g'_p/f_s = 0.111 \pm 0.031_{stat} \pm 0.032_{syst}$$

$$h_p/f_s = -0.411 \pm 0.027_{stat} \pm 0.038_{syst}$$

$$a_0^0 = 0.256 \pm 0.008_{stat} \pm 0.007_{syst}$$

$$\pm 0.018_{theor}$$ (universal band)

χPT prediction: 0.220 ± 0.005

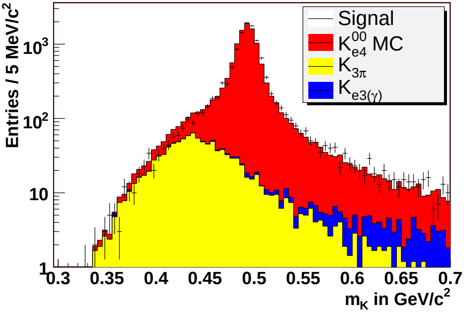
$K^{\pm} \to \pi^0\pi^0 e^{\pm}\nu_e$: Branching ratio

K_{e4}^{00} candidates (2003): $\sim$ 10,000
with 3% background

K_{e4}^{00} candidates (2004): $\sim$ 30,000
with 2% background

Background estimate from data,
reversing cuts

Main contribution from $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$
with π mis-ID



Systematic uncertainties

Acceptance, trigger efficiency and energy measurement of the calorimeter

NA48/2 preliminary result (2003 data)

$$BR(K_{e4}^{00}) = (2.587 \pm 0.026_{stat} \pm 0.019_{syst} \pm 0.029_{ext}) \times 10^{-5}$$

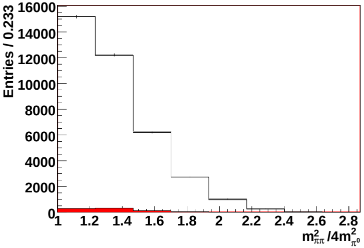
$K^{\pm} \to \pi^0\pi^0 e^{\pm}\nu_e$: Form factors

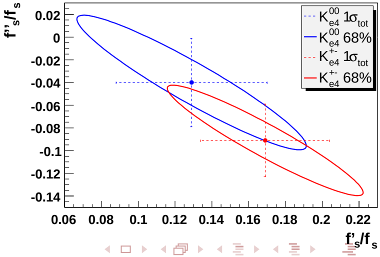
Same formalism as for K_{e4}^{+-}, but, for the symmetry of the $\pi^0\pi^0$ system, **no *P*-wave!**

Effect of cusp at $M_{00}^2 = 4m_{\pi^+}^2$ taken into account

NA48/2 preliminary result (2003+2004 data)

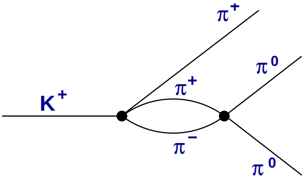
$$f'_s/f_s = 0.129 \pm 0.036_{stat} \pm 0.020_{syst}$$
$$f''_s/f_s = -0.040 \pm 0.034_{stat} \pm 0.020_{syst}$$



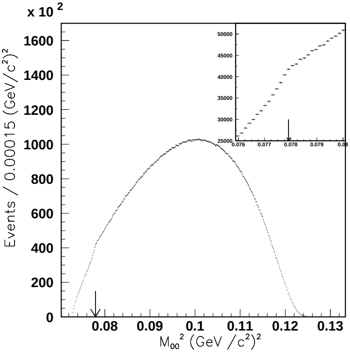


$K^\pm \to \pi^0\pi^0\pi^\pm$: Cusp in the M^2_{00} distribution

Selected events (2003): 23×10^6
M^2_{00} computed imposing the mean vertex of the π^0's (improved resolution close to threshold)



Evidence for a cusp at $M^2_{00} = 4m^2_{\pi^+}$ due to $\pi\pi$ rescattering



Fit to the Cabibbo-Isidori model (JHEP03 021):

$$M_0 = A_0\left(1 + \frac{1}{2} g_0 u + \frac{1}{2} h' u^2\right)$$

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$$g_0 = 0.645 \pm 0.004_{stat} \pm 0.009_{syst}$$
$$h' = -0.047 \pm 0.012_{stat} \pm 0.011_{syst}$$
$$a_2 = -0.041 \pm 0.022_{stat} \pm 0.014_{syst}$$
$$a_0 - a_2 = 0.268 \pm 0.010_{stat} \pm 0.004_{syst} \pm 0.013_{theor}$$

$K^\pm \to \pi^0\pi^0\pi^\pm$: $k'v^2$ term

Modified matrix element:

$$M_0 = A_0(1 + \frac{1}{2} g_0 u + \frac{1}{2} h' u^2 + \frac{1}{2} k' v^2)$$

Systematic checks:

Acceptance, trigger efficiency

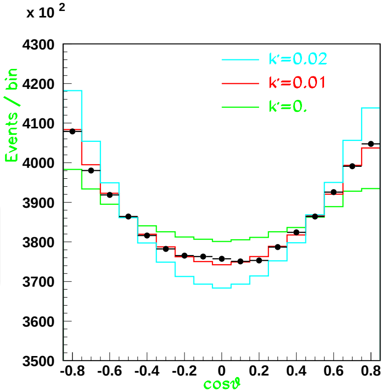
NA48/2 preliminary result (2003 data)

$$k' = 0.0097 \pm 0.0003_{stat} \pm 0.0008_{syst}$$

Meaning and value of g_0 and h' change with the new matrix element

No change in $a_0 - a_2$ and a_2

Note: h' and k' are not the same as the PDG parameters h and k



$\cos\theta$ = angle between $\pi^\pm$ and π^0 in $\pi^0\pi^0$ cms

Conclusions

- Form factor and $\pi\pi$ scattering length measurement from K_{e4}^{+-}

$$a_0^0 = 0.256 \pm 0.008_{stat} \pm 0.007_{syst} \pm 0.018_{theor}$$

Compatible with χPT prediction and previous results, higher sensitivity

- Branching ratio and form factor measurements from K_{e4}^{00}

$$BR(K_{e4}^{00}) = (2.587 \pm 0.026_{stat} \pm 0.019_{syst} \pm 0.029_{ext}) \times 10^{-5}$$

BR: factor 8 better than latest measurement
Form factors: compatible with charged channel

- $\pi\pi$ scattering length and slope measurements from $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$

$$a_0 - a_2 = 0.268 \pm 0.010_{stat} \pm 0.004_{syst} \pm 0.013_{theor}$$

- First evidence for a value of $k \neq 0$ in the $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$ Dalitz plot

$$k' = 0.0097 \pm 0.0003_{stat} \pm 0.0008_{syst}$$