High precision measurement of the form factors of the semileptonic decays $K^{\pm} \rightarrow \pi^{0} l^{\pm} \nu$ (Kl3)

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on behalf of the **NA48/2** Collaboration:

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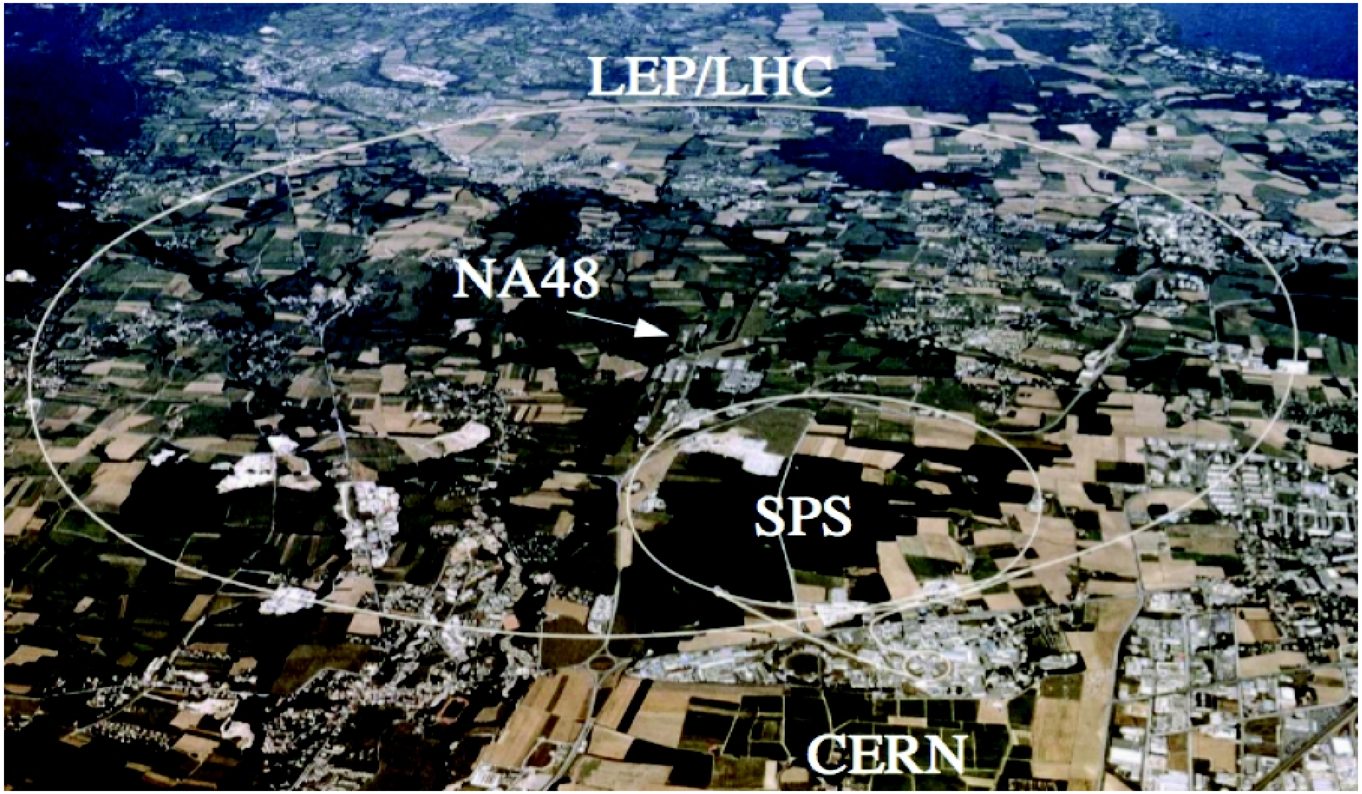
Outline

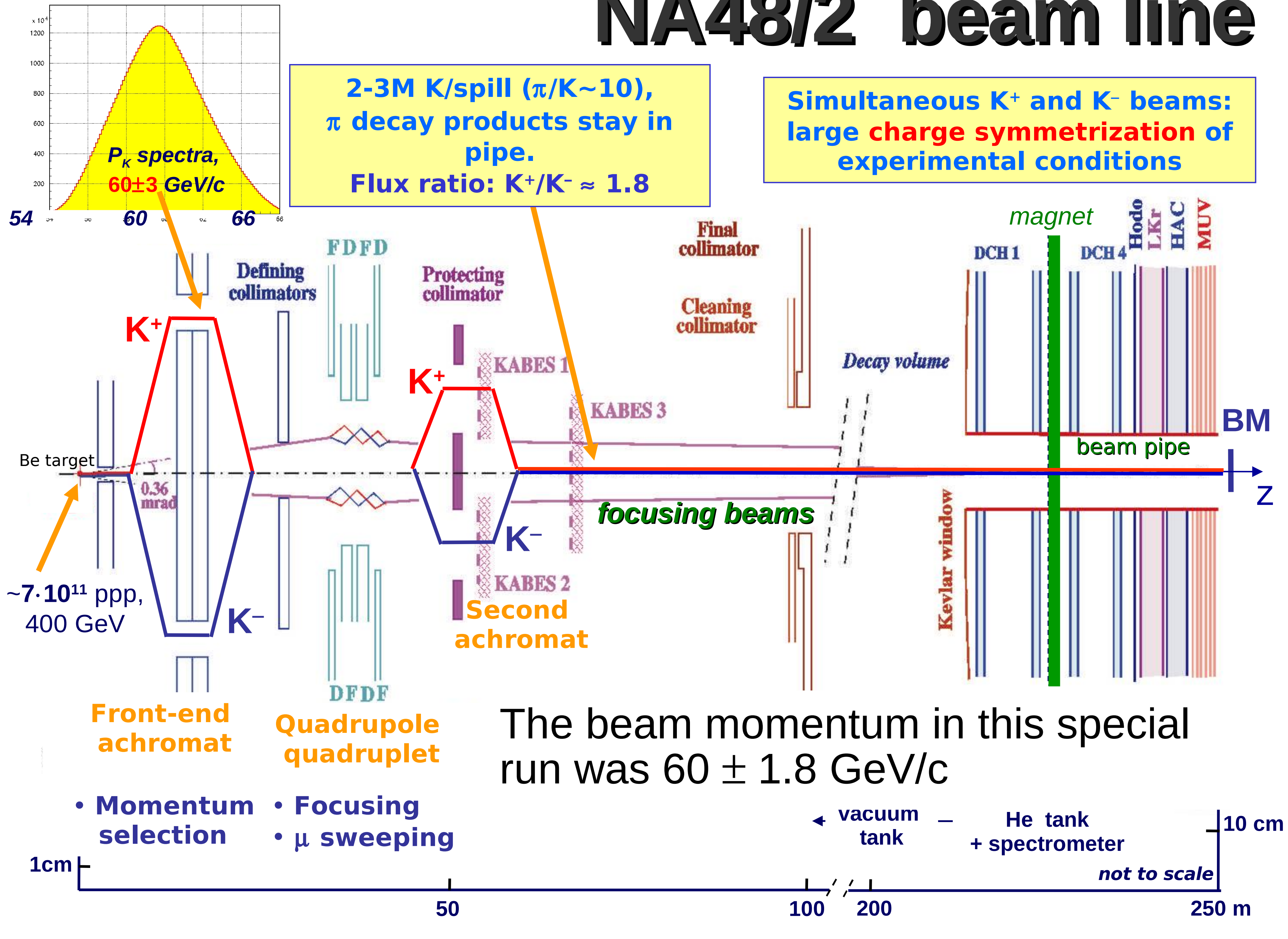
- Introduction to NA48/2 experiment
- Motivation
- $K^{\pm}_{l3}$ Form Factors
- NA48/2 analysis of $K^{\pm}_{l3}$
- Preliminary results and Summary



NA48/2 is a fixed target experiment in the North Area of the CERN SPS.

- 2003 (50 days) and 2004 (60 days) runs: the main goal was the search for direct CP violation in 3π decays of charged kaons.
- For the K_{l3} form factor measurement a dedicated 3-days run with a minimum bias trigger and low intensity was used.

NA48/2 beam line

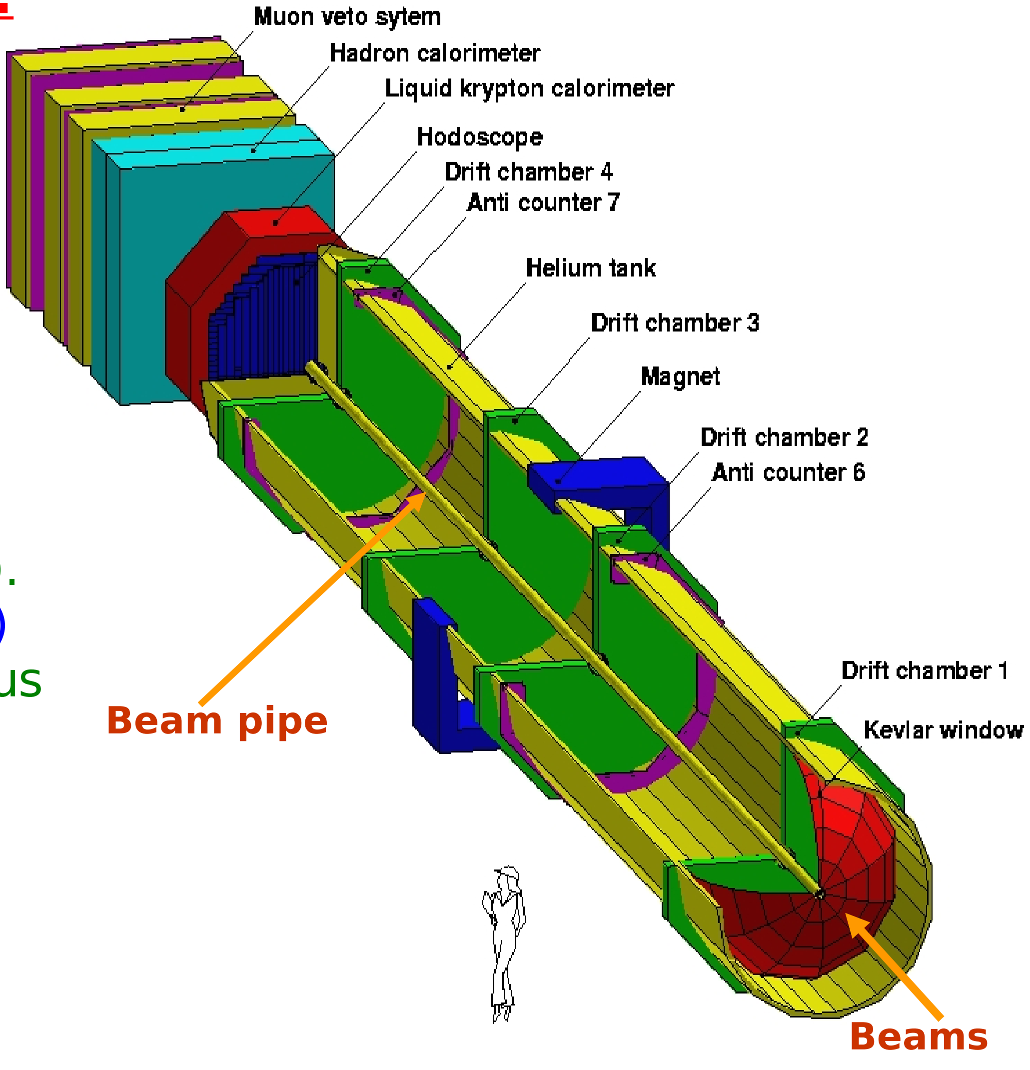


The beam momentum in this special run was 60 ± 1.8 GeV/c

The NA48 detector

Main detector components:

- Magnetic spectrometer (4 DCHs):
  4 views/DCH:
  redundancy ⇒efficiency;
  used in trigger logic;
  $\Delta p/p = 1.0\% + 0.044\%*p$
  [p in GeV/c].
- Hodoscope
  fast trigger;
  precise time measurement (150ps).
- Liquid Krypton EM calorimeter (LKr)
  High granularity, quasi-homogenious
  $\sigma_E/E = 3.2\%/E^{1/2} + 9\%/E + 0.42\%$
  $\sigma_x=\sigma_y=0.42/E^{1/2} + 0.06cm$
  [E in GeV].
  (0.15cm@10GeV).
- Hadron calorimeter, muon veto counters, photon vetoes.



Physical motivation for $K^{\pm} \to \pi^0 l^{\pm} \nu$ (K_{l3})

$$\Gamma(K_{l3}(\gamma)) = \tfrac{1}{2}\, G_F^2\, m_K^5/(192\,\pi^3)\, S_{EW}\, |V_{us}|^2 |f_+(0)|^2\, I^l_K(\lambda_{+0})(1+2\delta^l_{SU(2)}+2\delta^l_{EM})$$

Theoretically clean and precise way to measure $|V_{us}|$

Experiment:

$\Gamma(K_{l3}(\gamma))$ — decay width (Br & lifetime)
$I^l_K(\lambda_{+0})$ —Phase space integral (depends on formfactors)

Theory:

S_{EW} —Universal short distance EW correction (1.0232 ± 0.0003)
$f_+(0)$ —Formfactor at zero momentum transfer
$\delta^l_{SU(2)}$ —Isospin breaking correction (only for charged kaon)
δ^l_{EM} —EM long distance correction

Matrix element depends on two form factors $f_+(t)$ and $f_-(t)$:

$$M = \tfrac{1}{2} G_F V_{us} \left(f_+(t)(P_K+P_\pi)^\mu \bar{u}_l \gamma_\mu (1+\gamma_5) u_\nu + f_-(t) m_l \bar{u}_l (1+\gamma_5) u_\nu\right)$$

$t = q^2$ — *square of momentum transfer to the lepton system*

in K_{e3} decays one can measure only $f_+(t)$ (small m_e)

Usually form factors are re-formulated in terms of the vector and scalar exchange contributions:

1) $f_+(t)$: vector form factor

2) $f_0(t) = f_+(t) + f_-(t)\, t/(m_K^2 - m_\pi^2)$: scalar form factor

All these formfactors are usually normalized to $f_+(0)$

Form Factor parameterizations

Pole parameterization (Class 1), that assumes an exchange by vector and scalar resonances with spin-parity: 1^- (may be K*(892)) and 0^+ (no obvious dominance).

$$\bar{f}_{+,0}(t) = m^2_{V,S} / (m^2_{V,S} - t)$$

Parameterizations without a physical meaning are called Class 2 ones.

Quadratic parameterization:

$$\bar{f}_{+,0}(t) = 1 + \lambda'_{+,0}\, t/m^2_{\pi} + \tfrac{1}{2}\lambda''_{+,0}\, (t/m^2_{\pi})^2$$

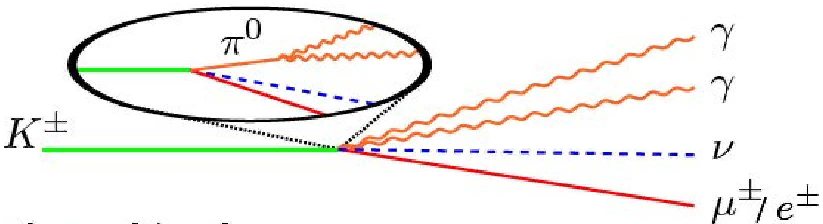
More parameters => correlations.
No sensitivity to measure λ''_0 , so $\bar{f}_0(t)$ is linear.

Other parameterizations also exist, but not used here

K_{l3} analysis of NA48/2 data

Min. Bias Trigger: 2 hodoscope hits (1 track) and E_{LKR} > 10 GeV: 3 days in 2004

Event selection



- **1 good track.**
  - Muon identification using muon veto and E/P
  - Electron identification using E/P

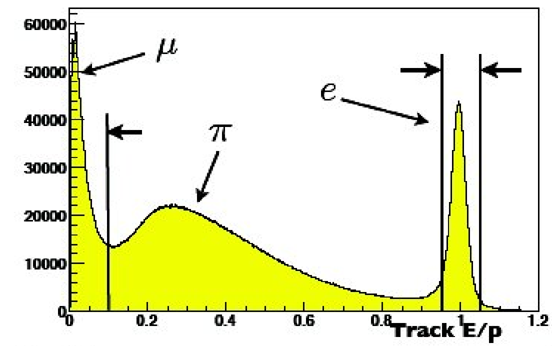
  P_μ > 10 GeV/c ; P_e > 5 GeV/c
- **1 good $\pi^0 \to \gamma\gamma$.**
  - Pion mass cut: $|m_{\gamma\gamma} - m_{\pi^0}^{PDG}| < 10\ \mathrm{MeV}$/c^2
- **Event reconstruction**
  - LKr clusters and muon track consistent in time
  - Missing mass cut using calculation with $K_{l3}^\pm$ hypothesis

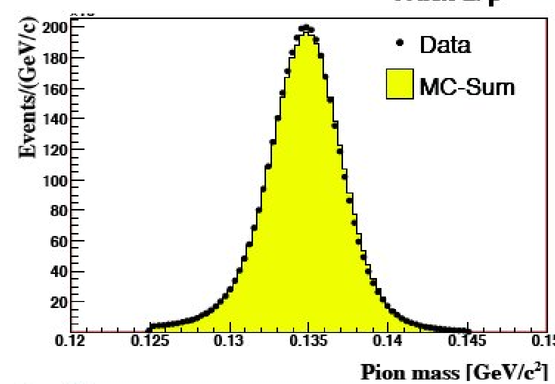
    $$MM_{K_{l3}}^2 = (P_K - P_l - P_{\pi^0})^2 < 10\ \mathrm{MeV}^2/c^4$$
  - Kaon energy reconstruction under the assumption of a missing undetected neutrino within the range of:

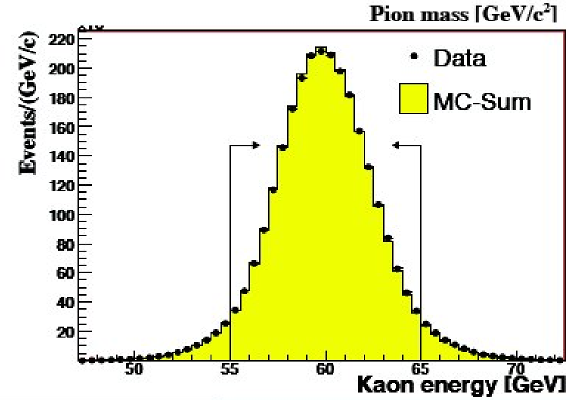
    55 GeV/c^2 < E_K < 65 GeV/c^2

2.5×10^6 $K_{\mu3}^\pm$ events selected

4.0×10^6 $K_{e3}^\pm$ events selected

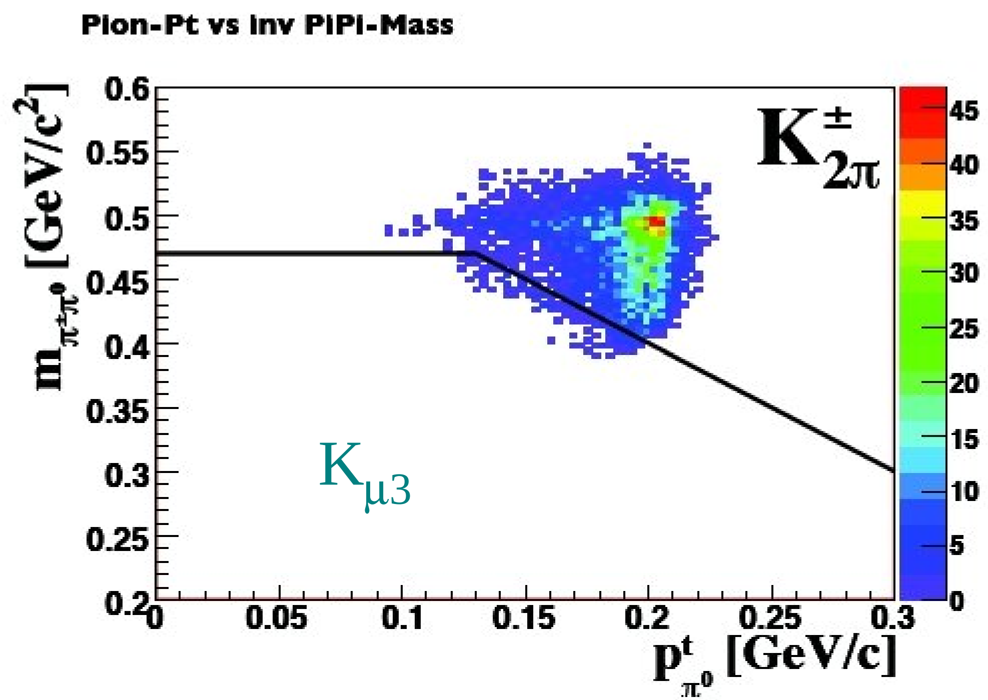






$K_{\mu3}$ channel: background from $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$

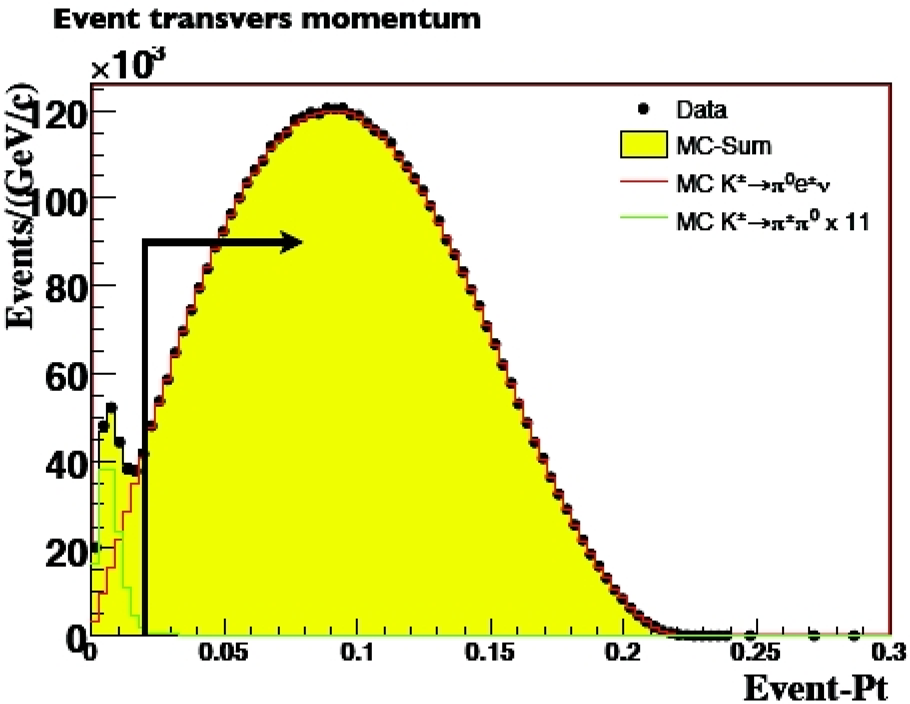
- $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ with $\pi^{\pm} \rightarrow \mu^{\pm}\bar{\nu}$ can fake $K_{\mu3}$ signature (20% of signal).
- Cut on the invariant $\pi^{\pm}\pi^{0}$ mass and the transverse pion momentum:
  - Loss of 24% of $K_{\mu3}$ signal
  - $\pi^{\pm}\pi^{0}$ background contamination reduced to 0.5%



K_{e3} channel: background from $K^{\pm} \to \pi^{\pm}\pi^{0}$

- $K^{\pm} \to \pi^{\pm}\pi^{0}$ with $\pi^{\pm}$ misidentified as *e* can fake K_{e3} signature (if E/P > 0.95).
- Cut on the transverse **event** momentum: $P_t > 0.02$ GeV/c

  - Loss of 3% of K_{e3} signal
  - $\pi^{\pm}\pi^{0}$ background contamination reduced to 0.1%



$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ background

- $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ with $\pi^{\pm} \rightarrow \mu^{\pm}\overline{\nu}$ and two lost photons from π^{0} can fake $K_{\mu 3}$ signature. Small, but introduces slope in Dalitz plot. No dedicated cut, background correction is applied (shifts results by ~ 0.5 σ_{stat})

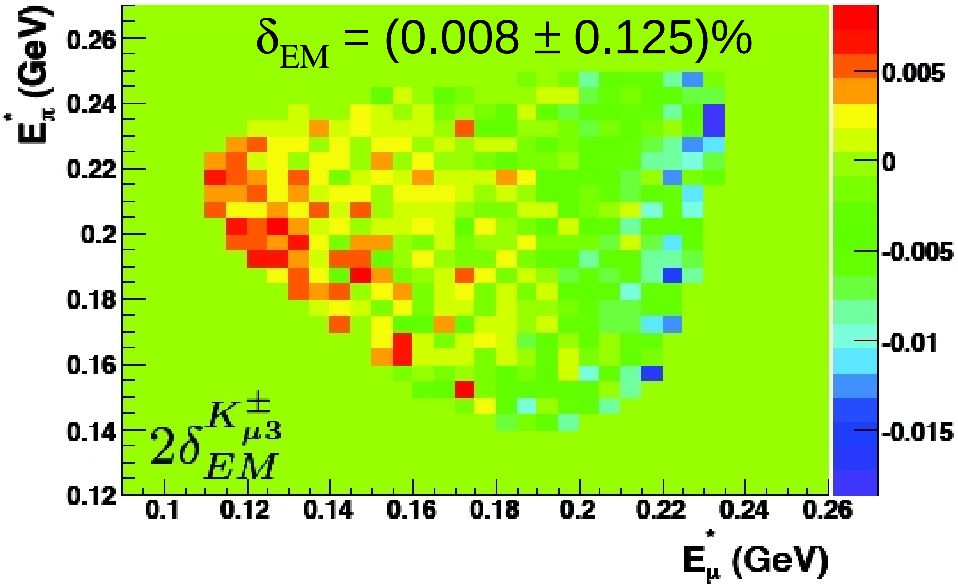
- For K_{e3} this $K_{3\pi}$ source of background is negligible.

Radiative corrections

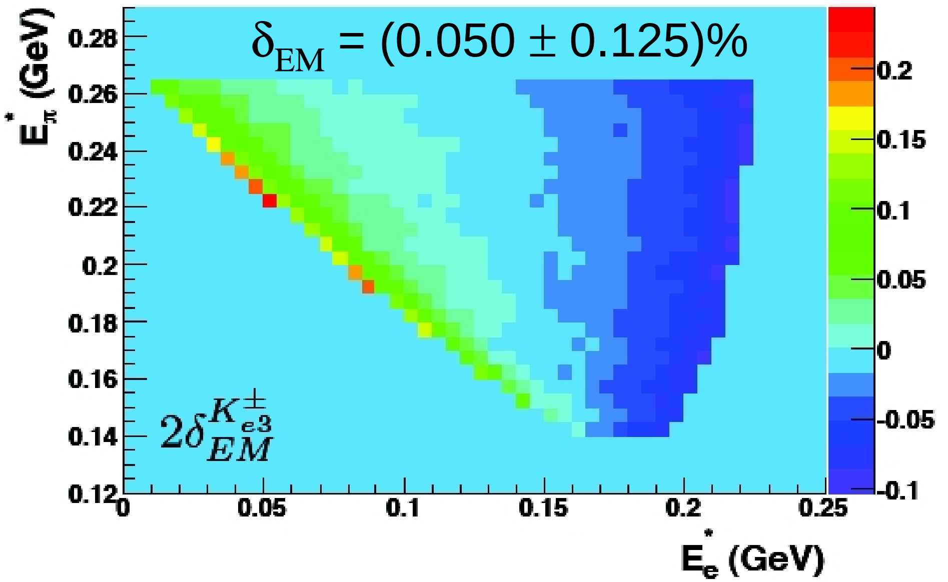
Simulation code for the first order correction is provided by KLOE.
[G.Gatti, EPJ C45 (2006) 417], [JHEP 11 (2008) 006].

$$\Gamma_{Kl3} = \Gamma^0_{Kl3}(1+2\delta_{EM})$$

$K_{\mu 3}$



K_{e3}

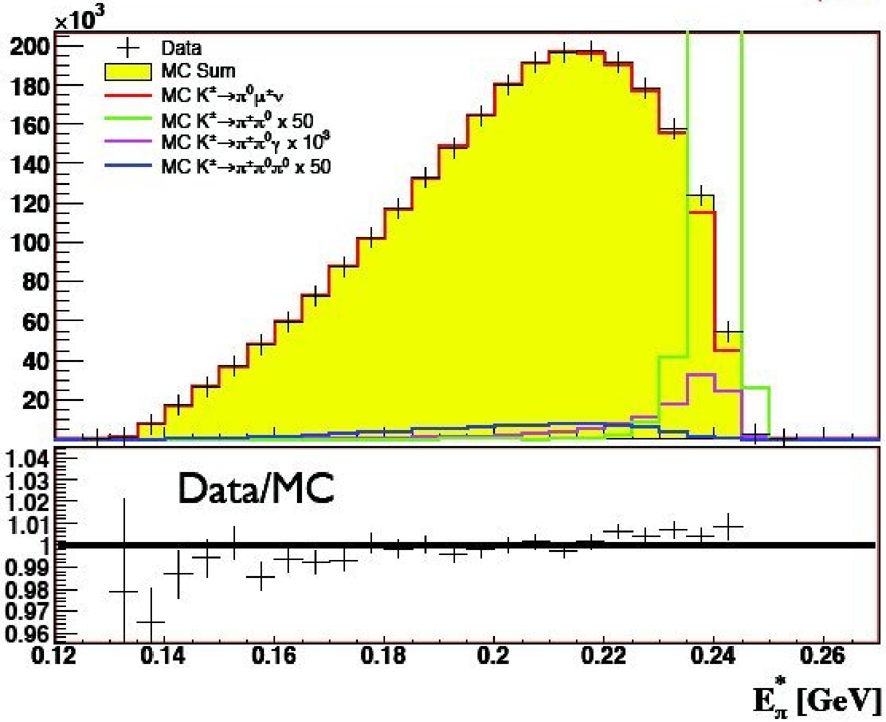


~1% effect on Dalitz slope

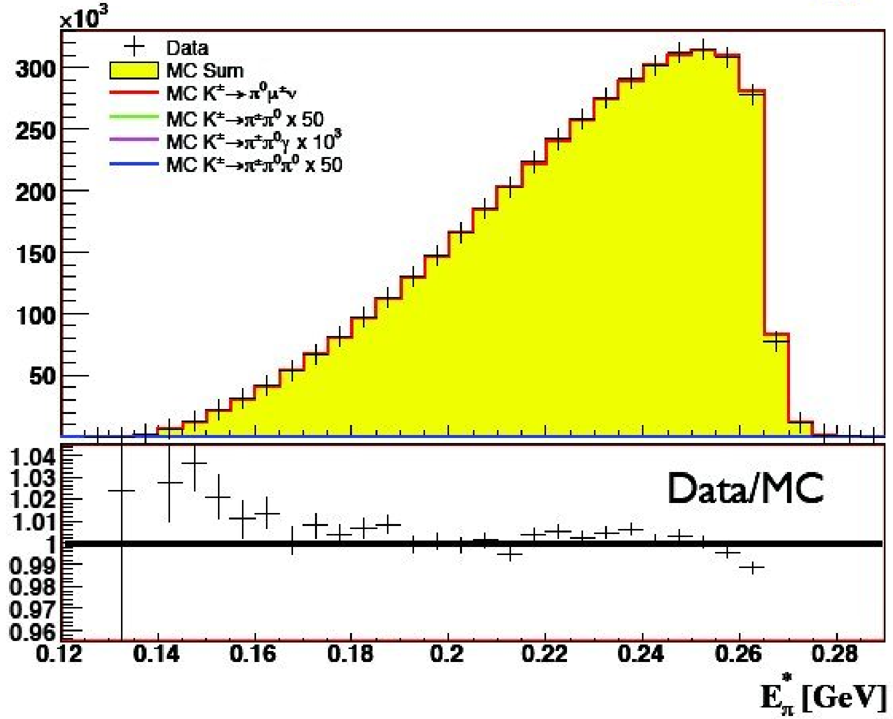
~10% effect on Dalitz slope

$K^{\pm}_{l3}$ Data-MC Comparison

- Pion energy in the kaon rest frame: $K^{\pm}_{\mu 3}$



- Pion energy in the kaon rest frame: $K^{\pm}_{e3}$

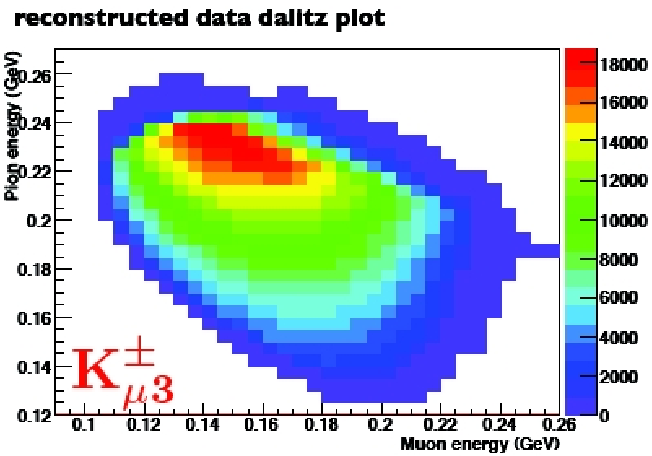


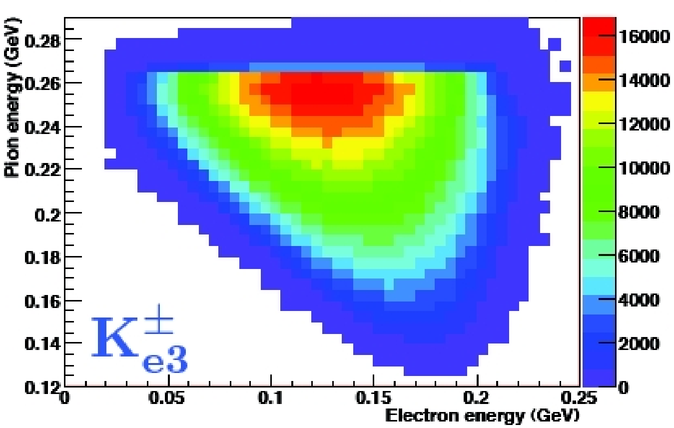
Form Factor Fitting Procedure

To extract the form factors, a fit to the Dalitz plot density is performed.

$$\rho(E_l^*, E_\pi^*) = \frac{d^2N(E_l^*, E_\pi^*)}{dE_\mu^* dE_\pi^*} \propto A f_+^2(t) + B f_+(t)(f_0 - f_+)\frac{m_K^2 - m_\pi^2}{t} + C\left[(f_0 - f_+)\frac{m_K^2 - m_\pi^2}{t})\right]^2$$

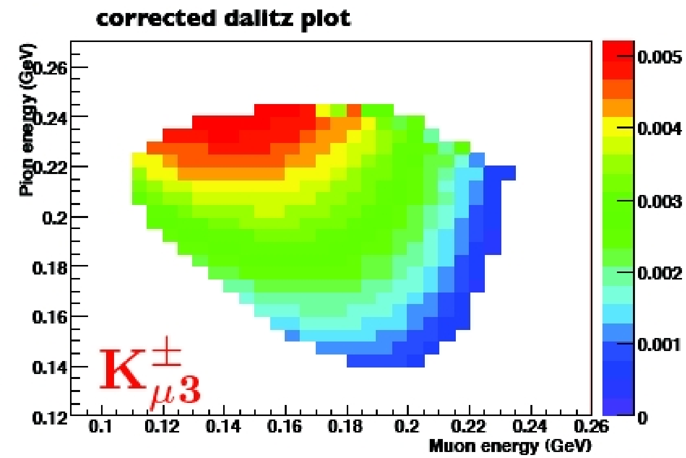
- E_l^* and E_π^* are the energy of the lepton and the pion in the kaon rest frame.
- *A*, *B* and *C* are kinematical terms.
- The fit is performed in cells of $5 \times 5\ \mathrm{MeV}^2$
- Cells which are outside or crossing the border of the physical region of the Dalitz plot are not used in the fit.

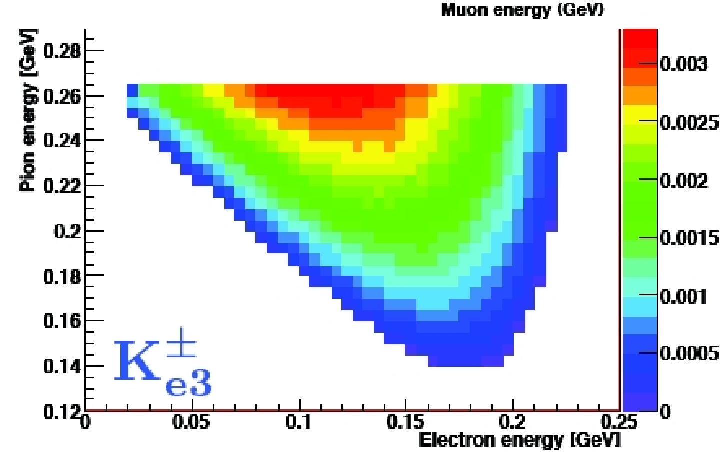




Applied corrections:

- Background subtraction.
- Acceptance.
- Radiative corrections.





Systematic checks

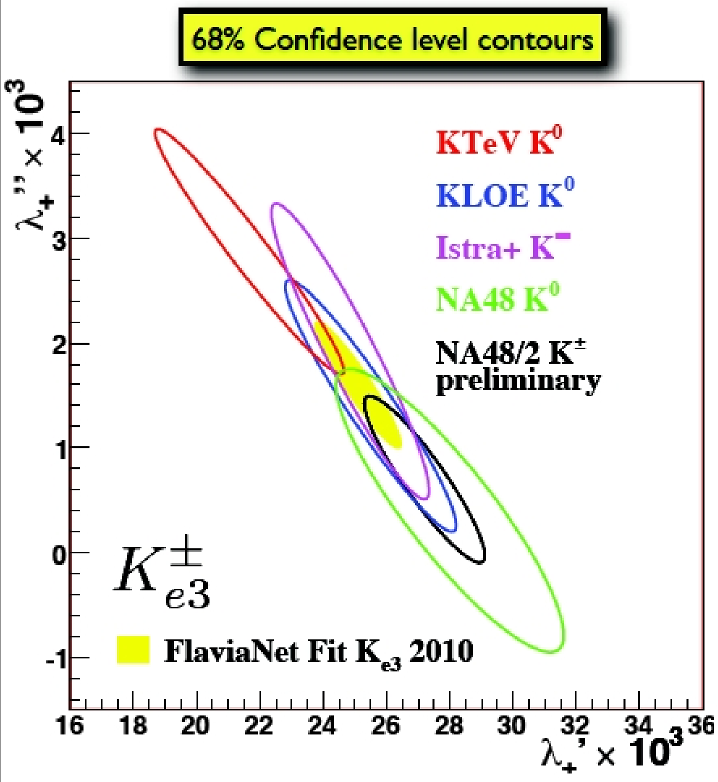
$K^{\pm}_{\mu3}$	$\Delta\lambda'_+$	$\Delta\lambda''_+$ $\times10^{-3}$	$\Delta\lambda_0$	Δm_V	Δm_S MeV/c^2
Kaon Energy	±0.1	±0.0	±0.3	±1	±8
Vertex	±1.0	±0.5	±0.1	±2	±7
Bin size	±0.8	±0.4	±0.7	±3	±10
Energy scale	±0.3	±0.1	±0.1	±0	±1
Acceptance	±0.2	±0.1	±0.3	±2	±5
$K_{2\pi}$ background	±1.7	±0.5	±0.6	±3	±0
2nd Analysis	±0.1	±0.1	±0.2	±2	±5
FF input	±0.3	±0.8	±0.1	±7	±3
Systematic	±2.2	±1.1	±1.0	±9	±16
Statistical	±3.0	±1.1	±1.4	±8	±31

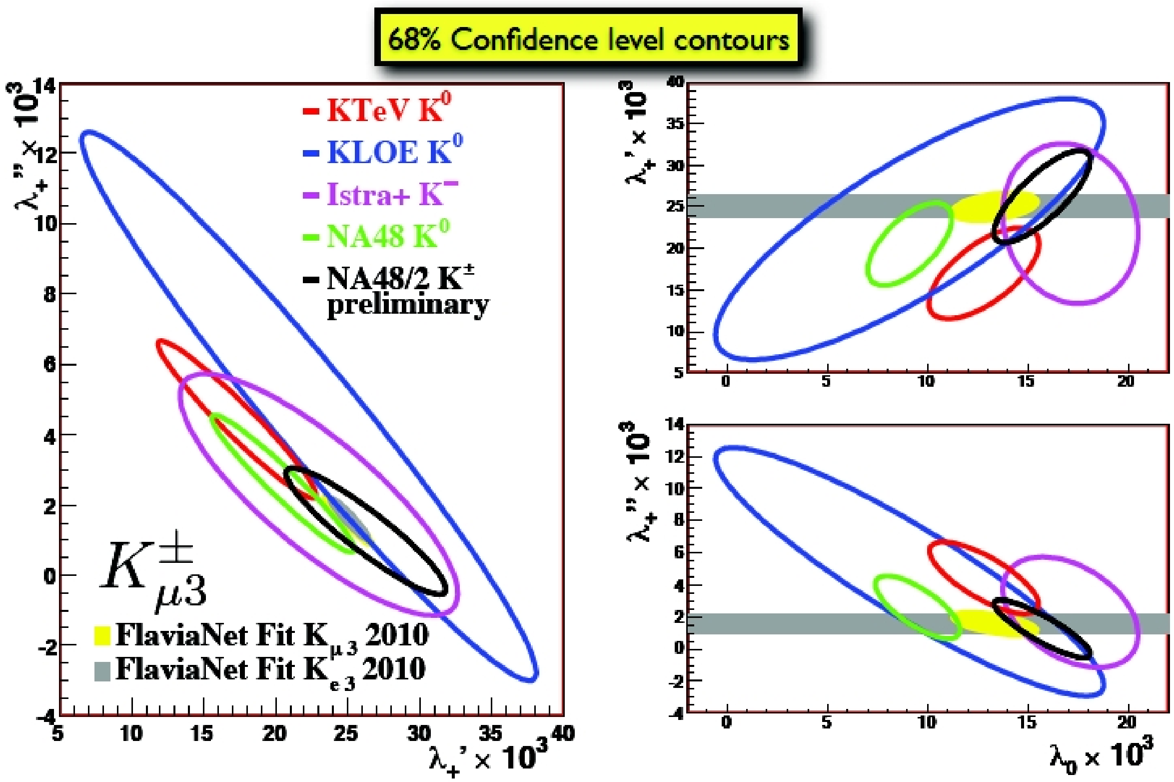
$K^{\pm}_{e3}$	$\Delta\lambda'_+$	$\Delta\lambda''_+$ $\times10^{-3}$	Δm_V MeV/c^2
Kaon Energy	±0.3	±0.1	±6
Vertex	±0.2	±0.1	±0
Bin size	±0.0	±0.1	±2
Energy scale	±0.1	±0.0	±0
Acceptance	±0.2	±0.0	±3
2nd Ana	±0.9	±0.4	±1
FF input	±0.4	±0.0	±1
Sytematic	±1.1	±0.4	±7
Statistical	±0.7	±0.3	±3

- $K^{\pm}_{\mu3}$ is dominated by statistics, $K^{\pm}_{e3}$ is dominated by the systematics.

Preliminary results

Quadratic ($\times 10^{-3}$)	λ'_+	λ''_+	λ_0
$K^\pm_{\mu 3}$	$26.3 \pm 3.0_{stat} \pm 2.2_{syst}$	$1.2 \pm 1.1_{stat} \pm 1.1_{syst}$	$15.7 \pm 1.4_{stat} \pm 1.0_{syst}$
$K^\pm_{e3}$	$27.2 \pm 0.7_{stat} \pm 1.1_{syst}$	$0.7 \pm 0.3_{stat} \pm 0.4_{syst}$	
Pole (MeV/c^2)	m_V		m_S
$K^\pm_{\mu 3}$	$873 \pm 8_{stat} \pm 9_{syst}$		$1183 \pm 31_{stat} \pm 16_{syst}$
$K^\pm_{e3}$	$879 \pm 3_{stat} \pm 7_{syst}$		





NA48/2 preliminary combined results

Quadratic ($\times 10^{-3}$)	λ'_+	λ''_+	λ_0
$K^\pm_{\mu3} K^\pm_{e3}$ combined	26.98 ± 1.11	0.81 ± 0.46	16.23 ± 0.95
Pole (MeV/c^2)	m_V		m_S
$K^\pm_{\mu3} K^\pm_{e3}$ combined	877 ± 6		1176 ± 31

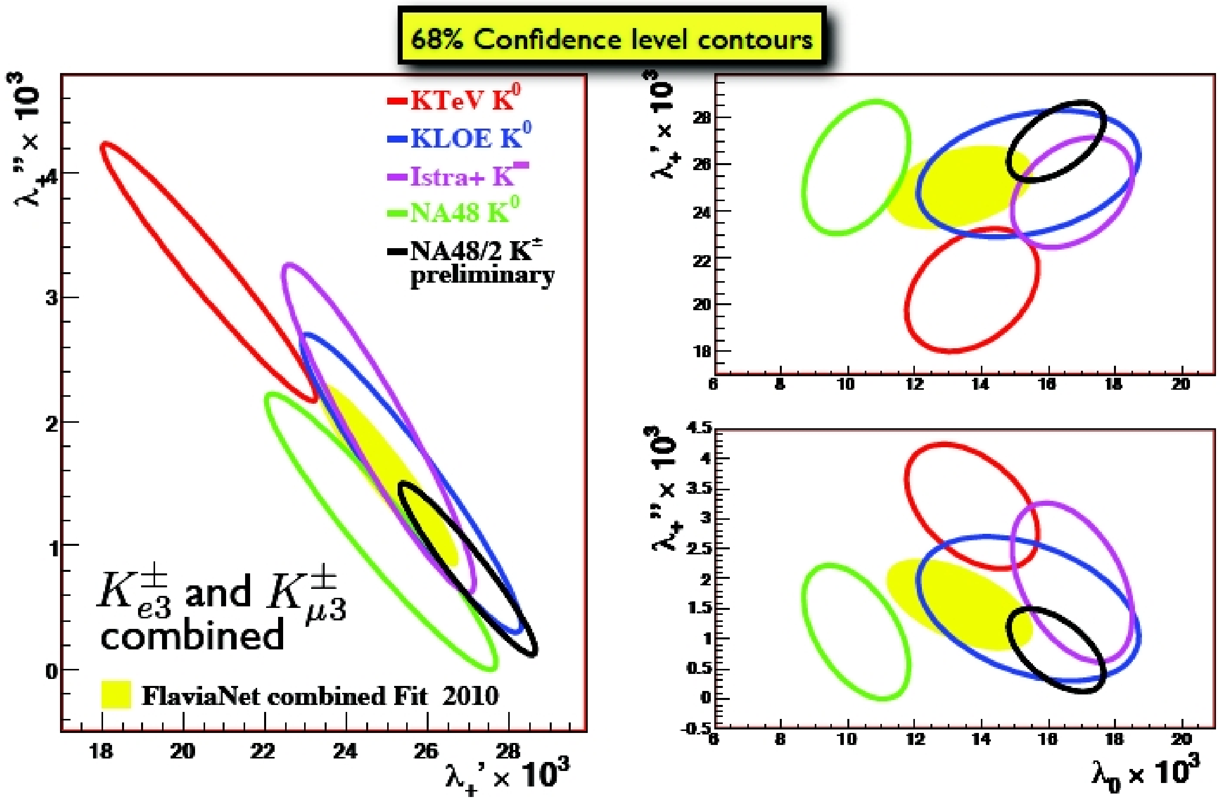
- statistical and systematical uncertainties combined.

Experimental situation:

• K_{l3}^0 results from **KLOE**, **KTeV**, and **NA48**, K_{l3}^- from **ISTRA+**.

• **NA48/2** is the first measurement which uses both $K_{\mu3}^\pm$ and $K_{e3}^\pm$. The results for these modes are in good agreement.

• **NA48/2 preliminary result** with high precision is very competitive with the other results. Offers the combined result with the smallest error.



Summary

- NA48/2 provides new preliminary results for K_{l3} formfactors based on few millions events.
- For the first time both K^+ and K^- $K_{e3}^{\pm}$ decays were studied together.
- Preliminary results for the quadratic and pole parametrizations, competitive for $K_{e3}^{\pm}$ and most precise for $K_{\mu3}^{\pm}$. The combined results are the most precise measurements so far.
- NA62 data from run 2007 are available with a larger statistics $O(10^7)$ for charged kaon K_{l3} and with a neutral kaon K_{l3} statistics of the order of 10^6 events.