DIS 2012 – University of Bonn – Bonn (Germany), 26-30 March 2012

Recent results from NA48 and NA62 experiments at CERN

M. Piccini

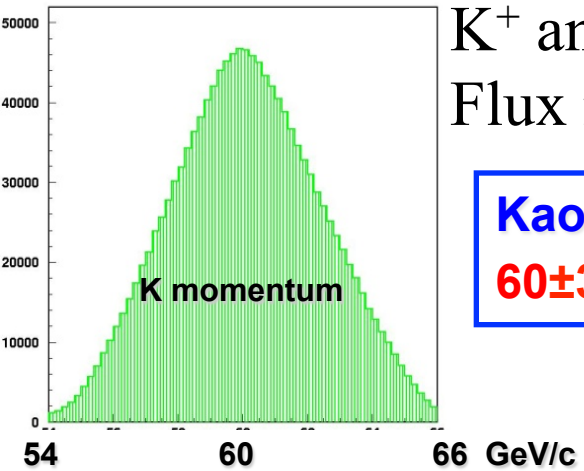
INFN - sezione di Perugia

on behalf of the NA48 and NA62 collaborations

Outline:

- The NA48 experiment
  - The beam and the detector, data taking periods
  - Recent results on Kμ3 and Ke3 Form Factors
- The NA62 experiment
  - First phase: R_K measurement from 2007 data
- Summary and outlook

The NA48 experiment

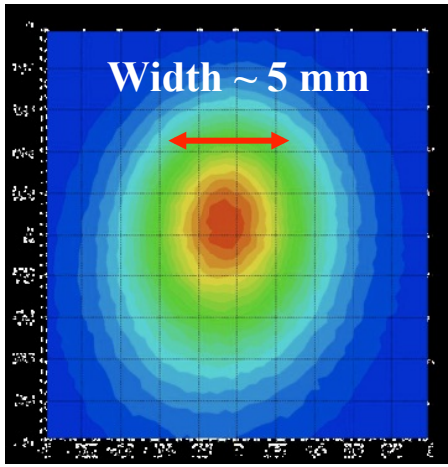


K^+ and K^- superimposed in space

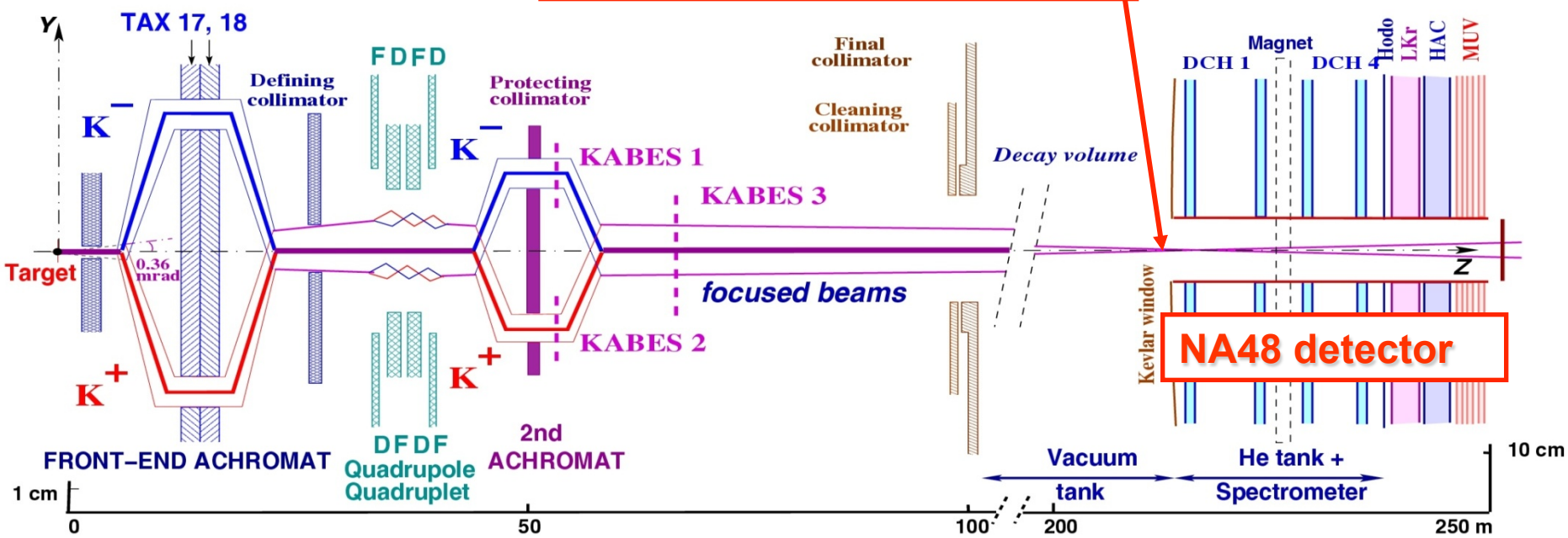
Flux ratio: $K^+/K^- \sim 1.8$

Kaon momentum:
60±3 GeV/c

Data taking:
2003 – 50 days
2004 – 60 days



Beams **coincide within 1 mm**



The NA48 Detector

Magnetic spectrometer (4 DCHs):

4 views: redundancy ⇒ efficiency

$\sigma(p)/p = 1.0\% + 0.044\%\ p$ [GeV/c]

Charged hodoscope (scintillators):

Fast trigger and precise time measurement (~200 ps on single track)

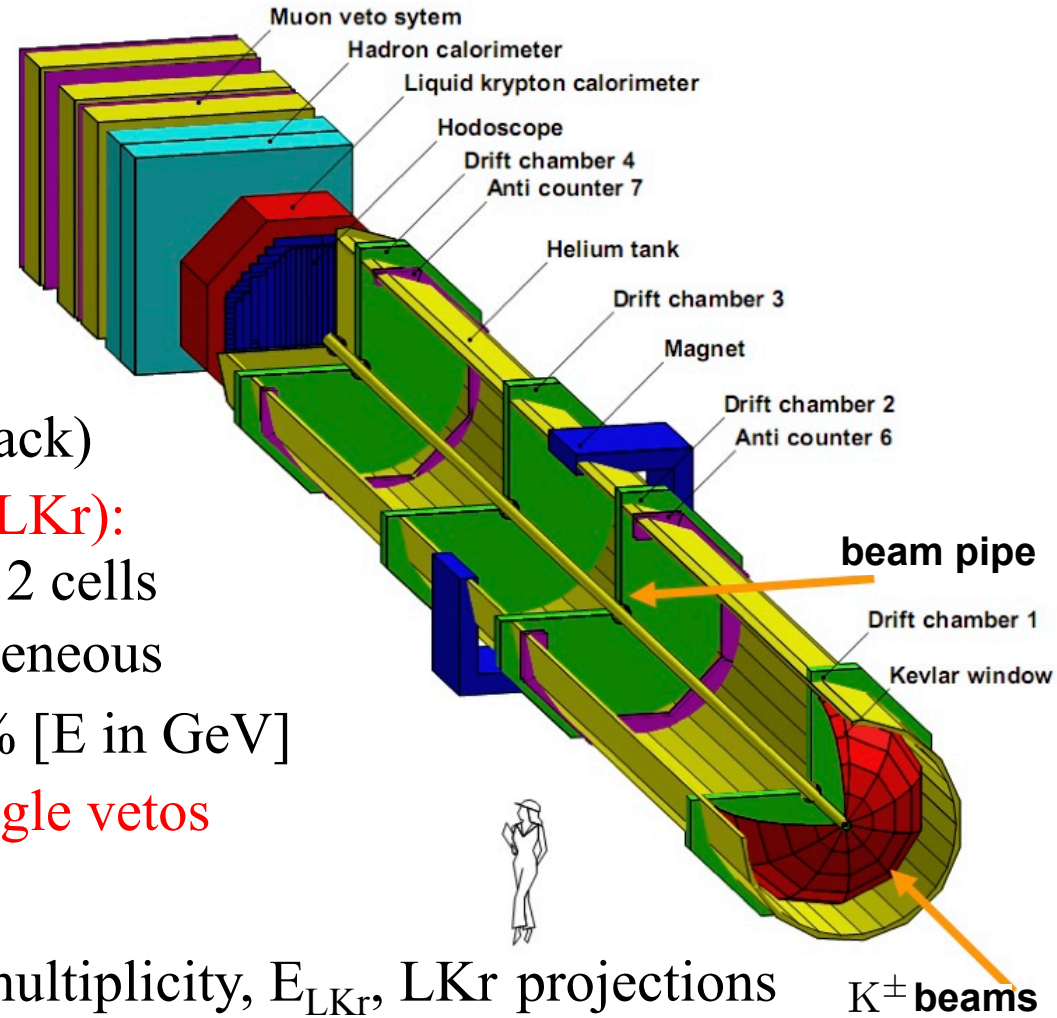
Liquid Krypton E.M. Calorimeter (LKr):

10 m^3 (~22 t), 1.25 m (27 X_0), 13212 cells

granularity: 2x2 cm^2, quasi-homogeneous

$\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [E in GeV]

Then hadronic calorimeter, large angle vetos and muon counter (scintillators)



Trigger: ***L1:*** Hodoscope, DCH multiplicity, E_{LKr}, LKr projections

L2: ON-line processing of DCH information

Min Bias Trigger: Coincidence of two Hodoscope hits$\times E_{LKr} > 10$ GeV

3 days in 2004

The K^+ semileptonic decays

- $K \to \pi l \nu (K_{l3})$ decays provide the **most accurate** and **theoretically cleanest** way to access |Vus| :

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 m_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+(0)|^2 I_K^l(\lambda_{+0})(1 + \delta_{SU(2)}^l + \delta_{EM}^l)^2$$

Experimental Inputs:

- $\Gamma(K_{l3(\gamma)})$ Branching ratios and kaon lifetimes
- $I^l_K(\lambda_{+0})$ Phase space integral depends on the form factors

Theory Inputs:

- S_{EW} Universal short distance EW corrections(1.0232±0.0003)
- $f_+(0)$ Form factor at zero momentum transfer
- $\delta^l_{SU(2)}$ Form factor correction for isospin breaking (ch. mode only)
- δ^l_{EM} Long distance EM effects

Physics motivation

K_{l3} decays are described by **two form factors** $f_{\pm}(t)$, and the **matrix element** can be written as:

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

$t = q^2$ is the square of the four-momentum transfer to the lepton neutrino system

$f_-(t)$ can only be measured in $K_{\mu 3}$ decays because of $m_e << m_K$

$f_+(t)$ is the **vector form factor** and $f_0(t)$ the **scalar form factor** with:

$$f_0(t) = f_+(t) + \frac{t}{(m_K^2 - m_\pi^2)} f_-(t)$$

$f_+(0)$ cannot be measured directly, therefore the form factors are normalised to $f_+(0)$:

$$\bar{f}_+(t) = \frac{f_+(t)}{f_+(0)} \qquad \bar{f}_0(t) = \frac{f_0(t)}{f_+(0)}$$

Form Factor Parametrizations

Parametrizations using **physical quantities** are called **class 1** parametrizations. They depend on free parameters with a physical meaning.

Pole parametrization:

Assumes the exchange of vector and scalar resonances K* with spin-parity $1^-/0^+$ and masses m_V/m_S, $f_+(t)$ can be described by K*(892), for $f_0(t)$ no obvious dominance is seen:

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

Parametrizations without a **physical meaning** are called **class 2** parametrizations. They require more free parameters and are expansions in the momentum transfer.

Linear and quadratic parametrization:

$$\bar{f}_{+,0}(t) = \left[1 + \lambda_{+,0}\frac{t}{m_\pi^2}\right] \quad \textbf{Linear}$$

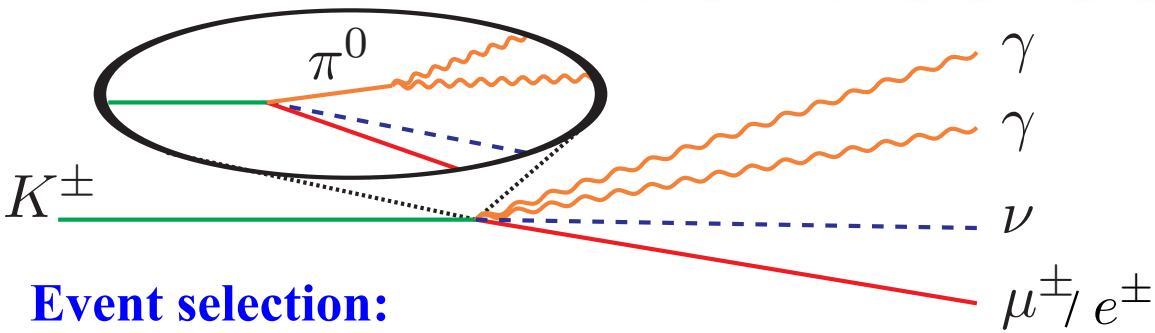
$$\bar{f}_{+,0}(t) = \left[1 + \lambda'_{+,0}\frac{t}{m_\pi^2} + \frac{1}{2}\lambda''_{+,0}\left(\frac{t}{m_\pi^2}\right)^2\right] \quad \textbf{Quadratic}$$

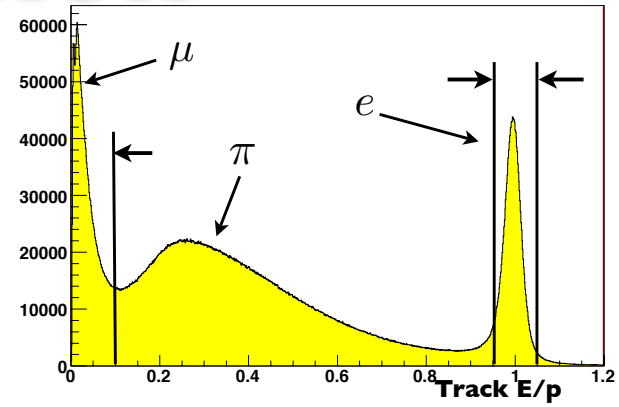
Correlations!

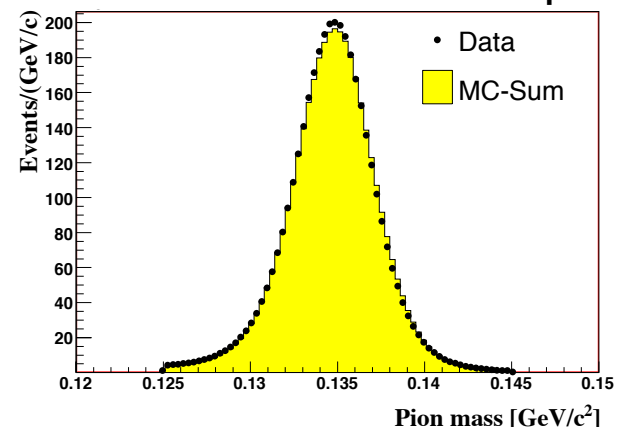
No sensitivity to λ''_0

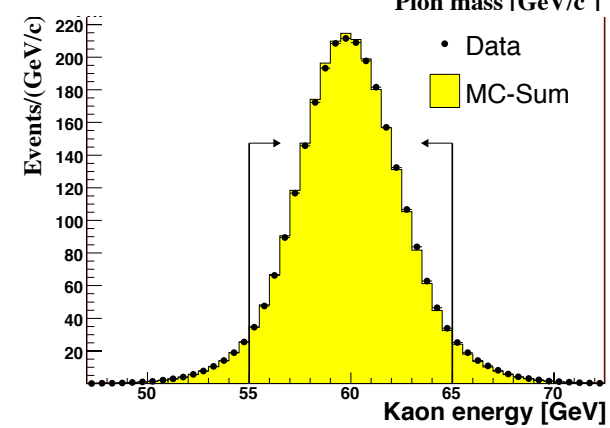
$\bar{f}_0(t)$ linear

Event selection









Event selection:

- **1 good track**
  - Muon identified by muon veto and E/p
  - Electron identified by E/p
- **1 good $\pi^0 \rightarrow \gamma\gamma$**
  - Pion mass cut: $|m_{\gamma\gamma} - m^{PDG}(\pi^0)| > 10$ MeV

Event reconstruction:

- LKr clusters and muon track consistent in time
- Missing mass cut using $K^\pm$ hypothesis

$$M^2_{K_{l3}} = (P_K - P_l - P_{\pi^0})^2 < 10 \text{ MeV}^2$$

- Kaon energy reconstructed under the assumption of a missing undetected neutrino within the range of:

$$55\text{GeV} < E \pm < 65\text{GeV}$$

2.5×10^6 $K^\pm_{\mu 3}$ events selected
4.0×10^6 $K^\pm_{e3}$ events selected

$\pi^+\pi^0$ background

To $K^{\pm}_{\mu 3}$:

$K^{\pm} \rightarrow \pi^{\pm}\pi^0$ with $\pi \rightarrow \mu$ can fake the signal

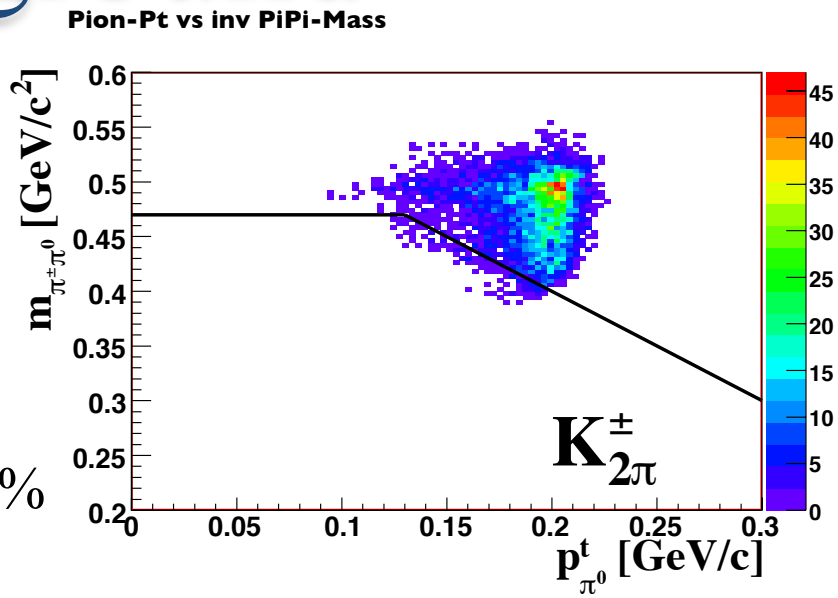
Without suppression, $K^{\pm} \rightarrow \pi^{\pm}\pi^0$ background at the level of 20%

Cut in the invariant $\pi^{\pm}\pi^0$ mass and the transverse momentum of the pion:

→ Background contamination reduced to 0.5%

→ about 24% of $K^{\pm}_{\mu 3}$ events are lost

Background is well localized in the Dalitz plot



To $K^{\pm}_{e3}$:

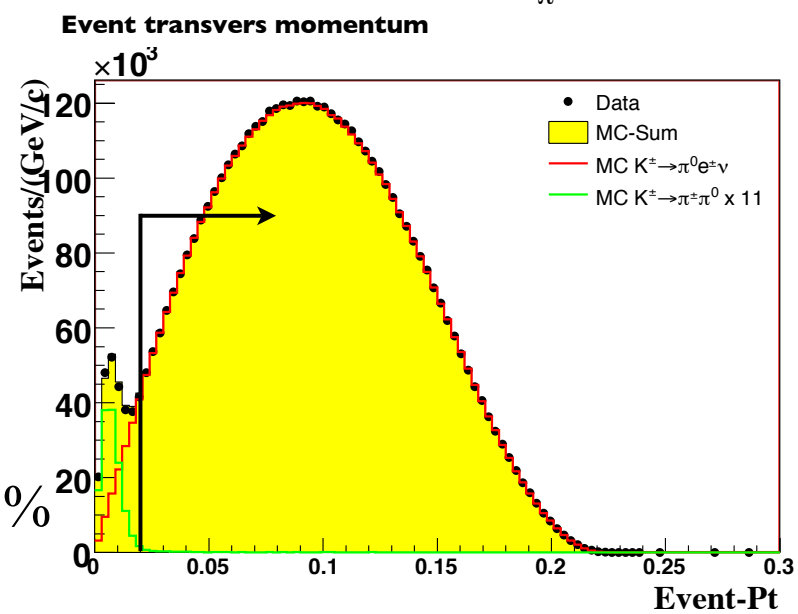
Pion with E/P > 0.95 can fake a $K^{\pm}_{e3}$ decay

Cut in the transverse momentum of the event:

$$p^T_{event} > 0.02 \text{ GeV/c}$$

→ Background contamination reduced to < 0.1%

→ about 3% of $K^{\pm}_{e3}$ events are lost



Radiative corrections

The K_{l3} decay rate including first order radiative corrections can be written as:

$$\Gamma_{K_{l3}} = \Gamma^0_{K_{l3}} + \Gamma^1_{K_{l3}} = \Gamma^0_{K_{l3}}(1 + 2\delta^{Kl}_{EM})$$

Simulation code provided by KLOE author C. Gatti, *EPJ C45 (2006) 417*

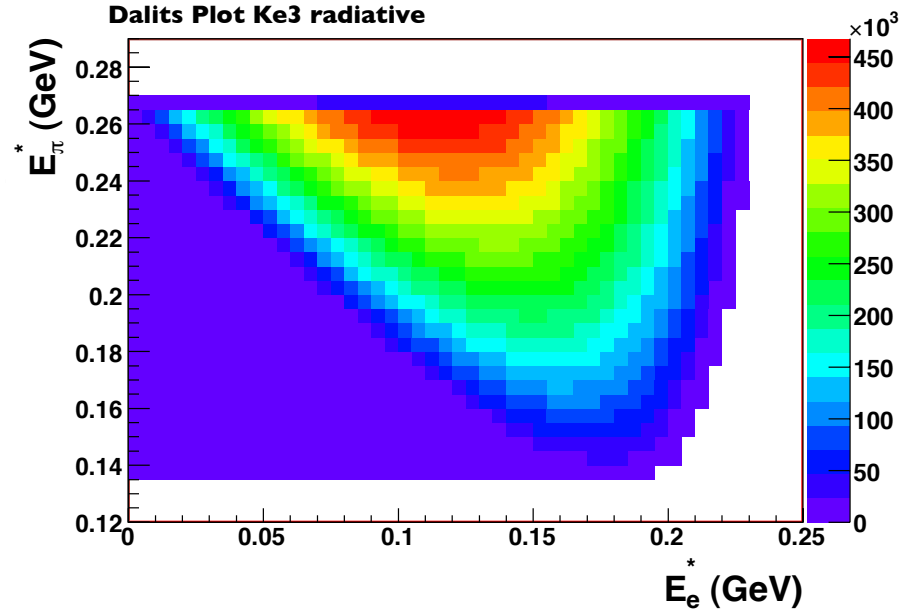
Parameters used for the normalization:

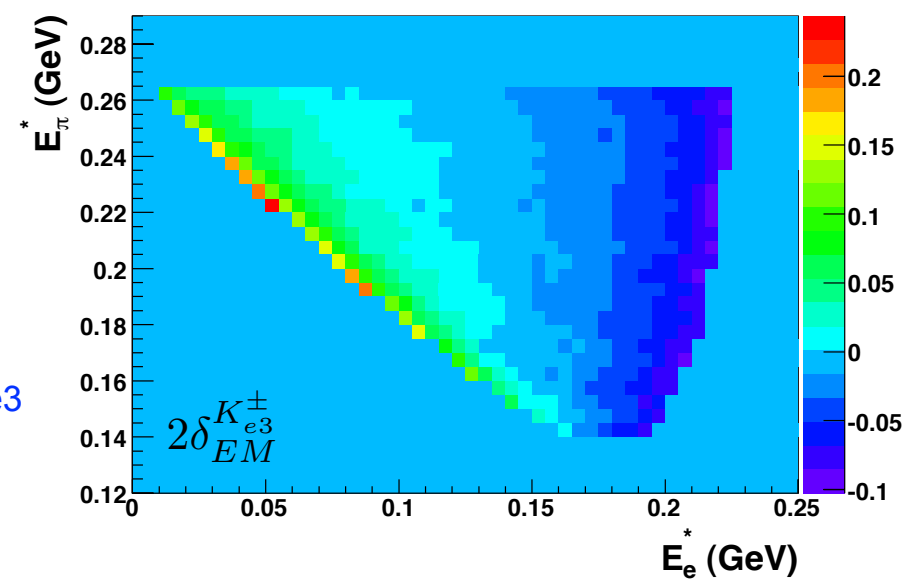
(JHEP 11 (2008) 006)

Mode	$\delta^{Kl3}_{EM}(\%)$
$K^{\pm}_{\mu 3}$	0.008 ± 0.125
$K^{\pm}_{e3}$	0.050 ± 0.125

For $K^{\pm}_{e3}$ the effects on the acceptance are bigger with respect to $K^{\pm}_{\mu 3}$

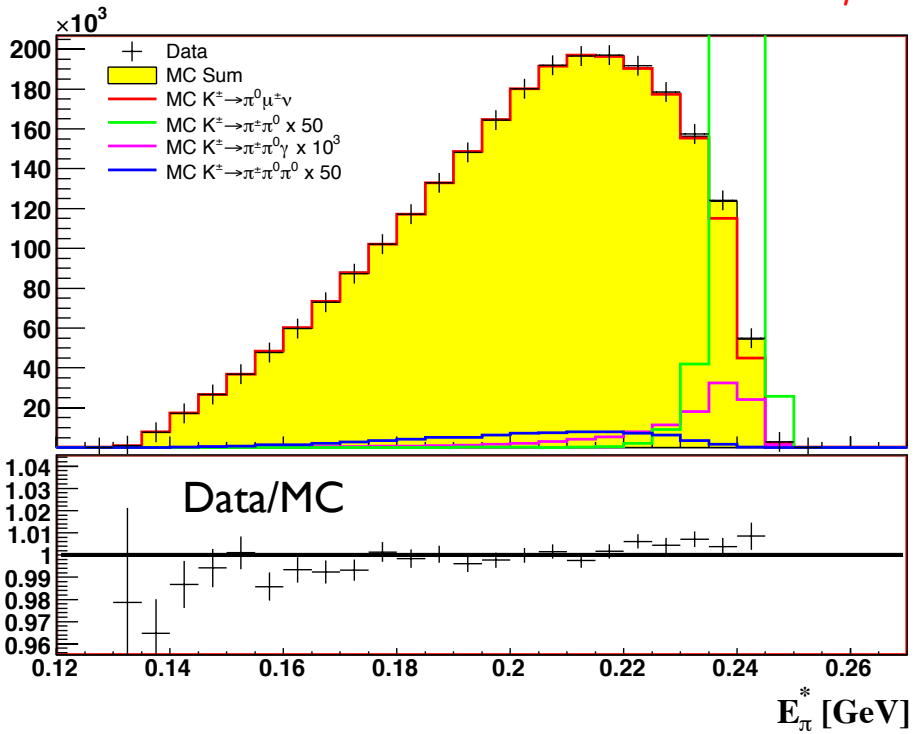
- ~10% effect on the Dalitz plot slope for $K^{\pm}_{e3}$
- Percent effect on slope for $K^{\pm}_{\mu 3}$



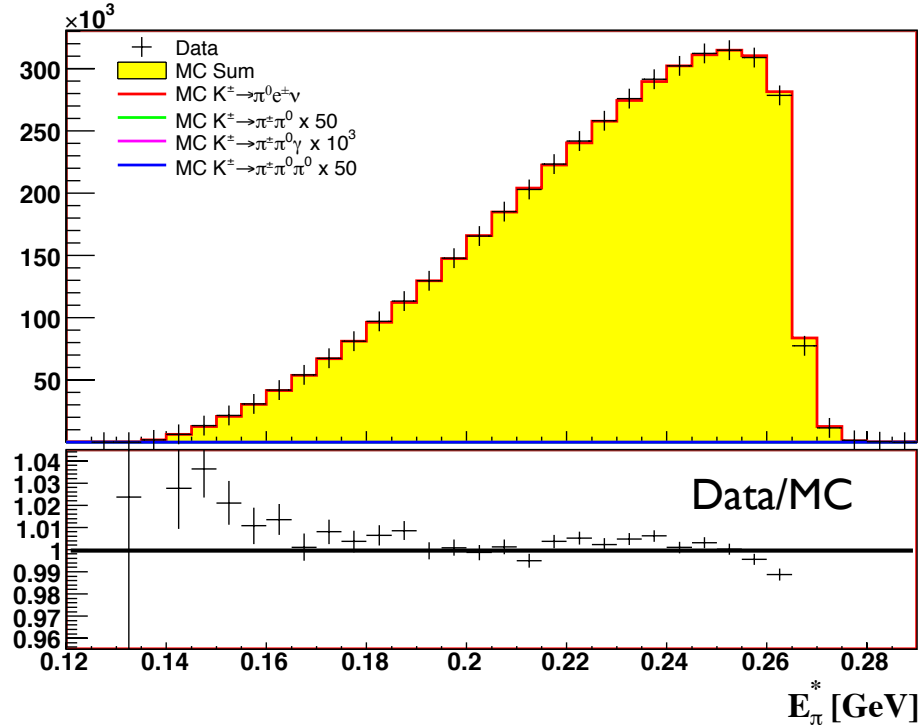


Data – MC comparison

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



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



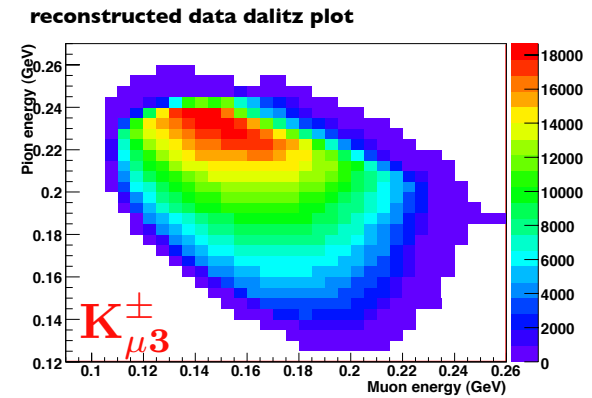
Form factors fitting procedure

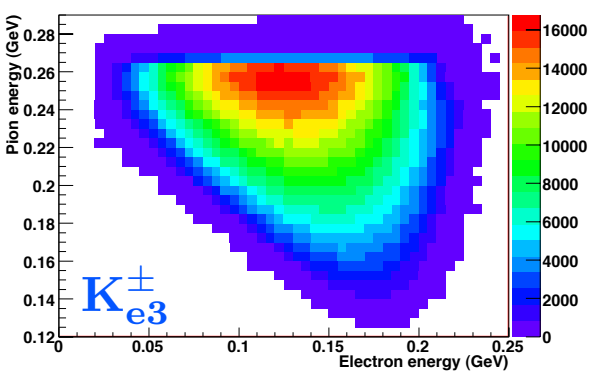
To extract the form factors a fit to the Dalitz plot density is performed:

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

- E_l^* and E_π^* are the energy of the lepton and of the pion in the kaon rest frame
- A, B and C are kinamatical terms

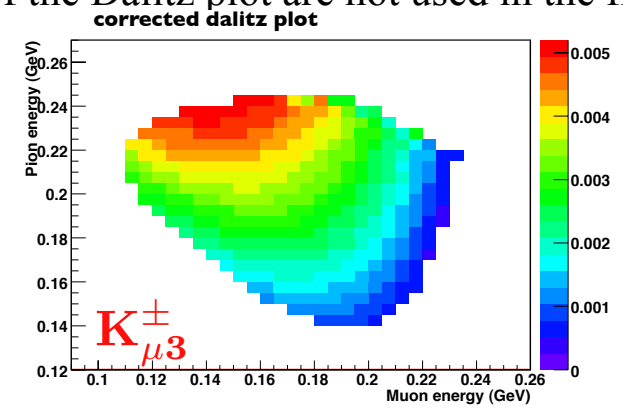
- The fit is performed in cells of 5x5 MeV^2
- Cells which are outside or crossing the border of the physical region of the Dalitz plot are not used in the fit.

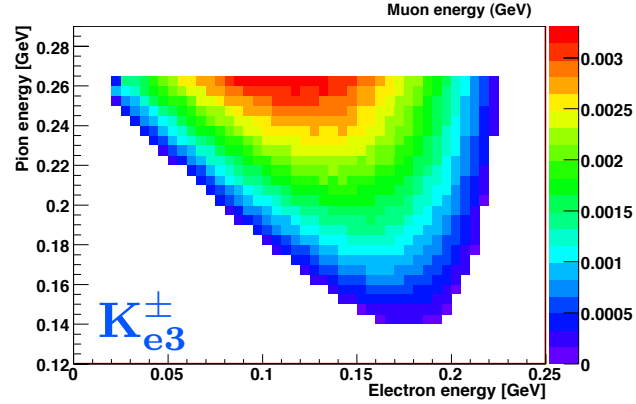




Applied corrections:

- Background subtraction
- Acceptance
- Radiative corrections





Systematic checks

$K^{\pm}_{\mu 3}$	$\Delta\lambda'_+$	$\Delta\lambda''_+$	$\Delta\lambda_0$	Δm_V	Δm_S
	$\times 10^{-3}$			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

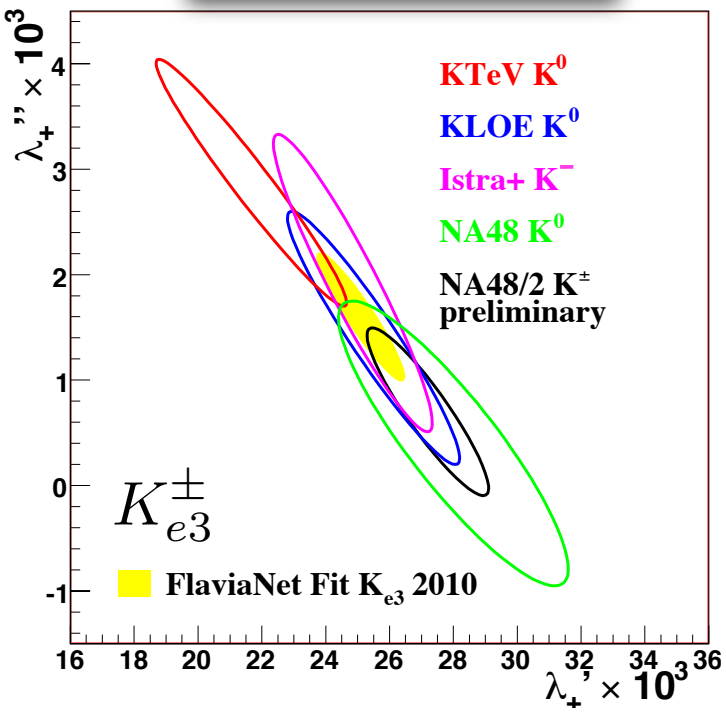
$K^{\pm}_{e3}$	$\Delta\lambda'_+$	$\Delta\lambda''_+$	Δm_V
	$\times 10^{-3}$		MeV/c^2
Kaon Energy	± 0.3	± 0.1	± 6
Vertex	± 0.2	± 0.1	± 0
Bin size	± 0.0	± 0.1	± 2
Energy scale	± 0.1	± 0.0	± 0
Acceptance	± 0.2	± 0.0	± 3
2nd Ana	± 0.9	± 0.4	± 1
FF input	± 0.4	± 0.0	± 1
Sytematic	± 1.1	± 0.4	± 7
Statistical	± 0.7	± 0.3	± 3

$K^{\pm}_{\mu 3}$ is dominated by statistics, $K^{\pm}_{e3}$ is dominated by the systematics

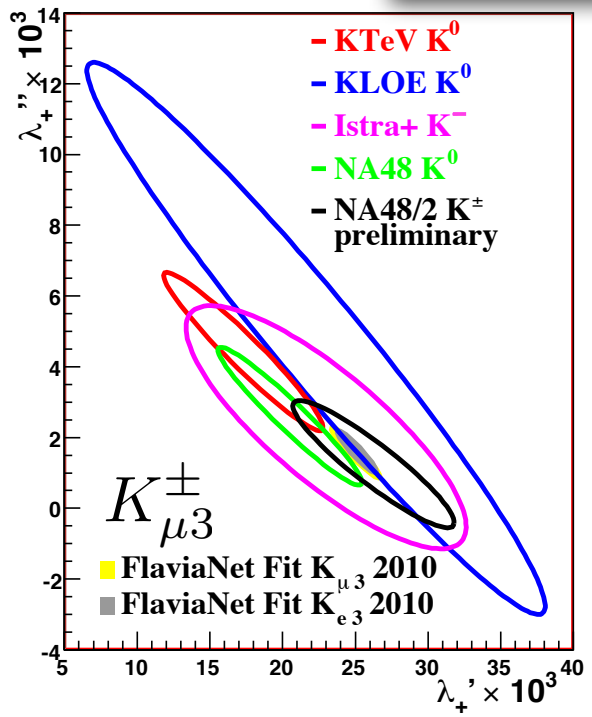
Preliminary results

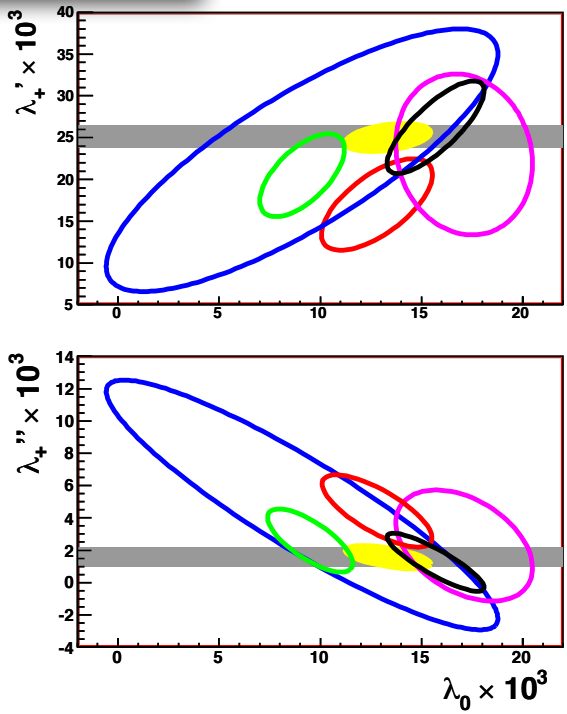
Quadratic $(\times 10^{-3})$	λ'_+	λ''_+	λ_0
$K^{\pm}_{\mu 3}$	$26.3 \pm 3.0_{\rm stat} \pm 2.2_{\rm syst}$	$1.2 \pm 1.1_{\rm stat} \pm 1.1_{\rm syst}$	$15.7 \pm 1.4_{\rm stat} \pm 1.0_{\rm syst}$
$K^{\pm}_{e3}$	$27.2 \pm 0.7_{\rm stat} \pm 1.1_{\rm syst}$	$0.7 \pm 0.3_{\rm stat} \pm 0.4_{\rm syst}$	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

68% Confidence level contours



68% Confidence level contours

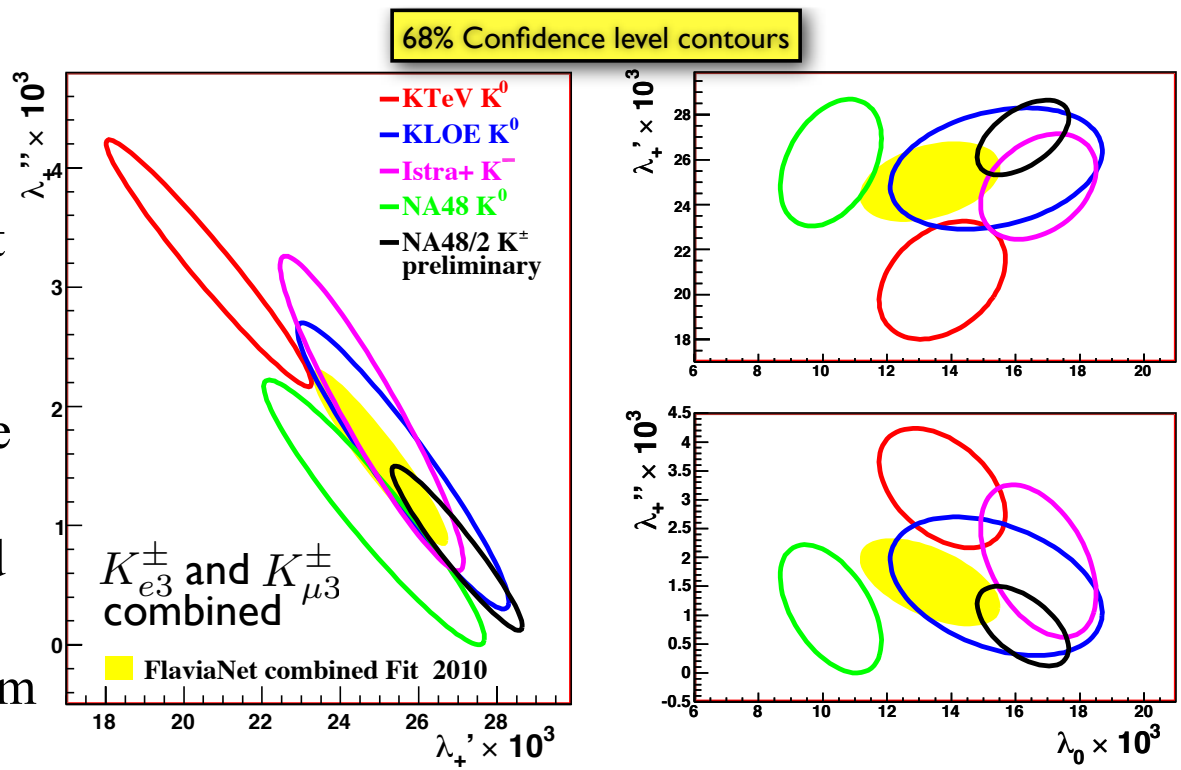




Preliminary results: combined

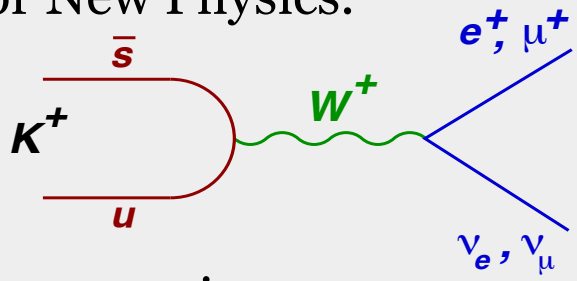
Quadratic ($\times 10^{-3}$)	λ'_+	λ''_+	λ_0
$K^{\pm}_{\mu 3} K^{\pm}_{e3}$ combined	26.98 ± 1.11	0.81 ± 0.46	16.23 ± 0.95
Pole (MeV/c^2)	m_V		m_S
$K^{\pm}_{\mu 3} K^{\pm}_{e3}$ combined	877 ± 6		1176 ± 31

- Experimental situation: K^0_{l3} results from KLOE, KTeV and NA48, K^-_{l3} from ISTRA+
- NA48/2 is the first measurement with both $K^{\pm}_{e3}$ and $K^{\pm}_{\mu 3}$
- NA48/2 preliminary result with high precision - very competitive with the other results. Offers the smallest error with the combined result.
- The results for Ke3 and Kμ3 from NA48/2 are in good agreement



R_K measurement in NA62

A precise measurement of the ratio R_K of $K^{\pm}\to l^{\pm}\nu_l$ (K_{l2}) leptonic decays provides a stringent test of SM and indirect search for New Physics.



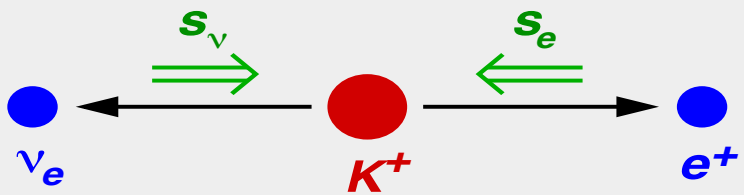
- Hadronic uncertainties cancel in the ratio $K_{e2}/K_{\mu2}$
- SM prediction: excellent sub-permille accuracy

R_K is sensitive to lepton flavour violation and its SM expectation:

$$R_K = \frac{\Gamma(K^{\pm}\to e^{\pm}\nu)}{\Gamma(K^{\pm}\to \mu^{\pm}\nu)} = \underbrace{\frac{m_e^2}{m_\mu^2}}_{\text{Helicity suppression: } f\sim 10^{-5}} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot \underbrace{(1+\delta R_K^{rad.corr.})}_{\text{Radiative correction}}$$

Radiative correction (few %) due to $K^+\to e^+\nu\gamma$ (IB) process, by definition included into R_K

[V.Cirigliano, I.Rosell JHEP 0710:005 (2007)]



Helicity suppression of R_K might enhance sensitivity to non-SM effects to an experimentally accessible level.

$$R_K^{SM} = (2.477\pm0.001)\times10^{-5}$$

Phys. Rev. Lett. 99 (2007) 231801

Measurement strategy

(1) $K_{e2}/K_{\mu 2}$ candidates are collected concurrently:

- analysis does not rely on kaon flux measurement;
- several systematic effects cancel in the ratio (at first order);

(2) MC simulations used to a limited extent:

- Geometrical part of the acceptance correction and bkg estimation;

(3) PID, trigger, readout efficiencies and beam halo bkg measured directly from data;

Counting experiment - analysis in 10 lepton momentum bins:

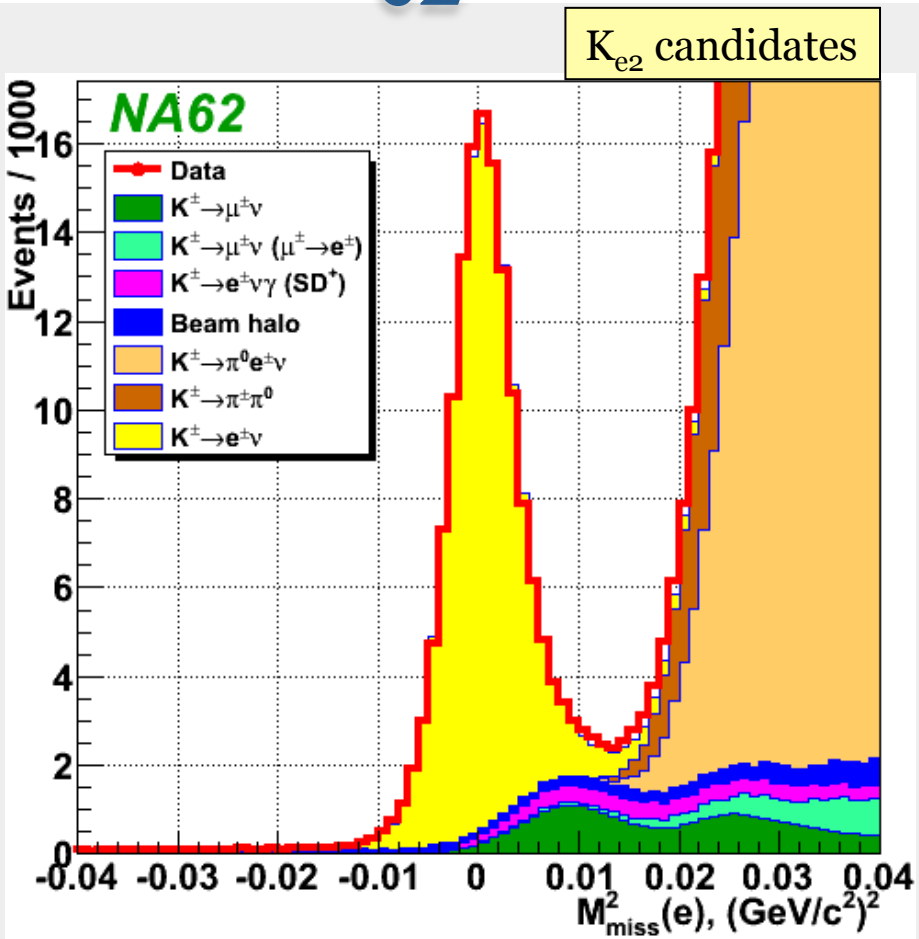
(due to strong momentum dependence of backgrounds and event topology)

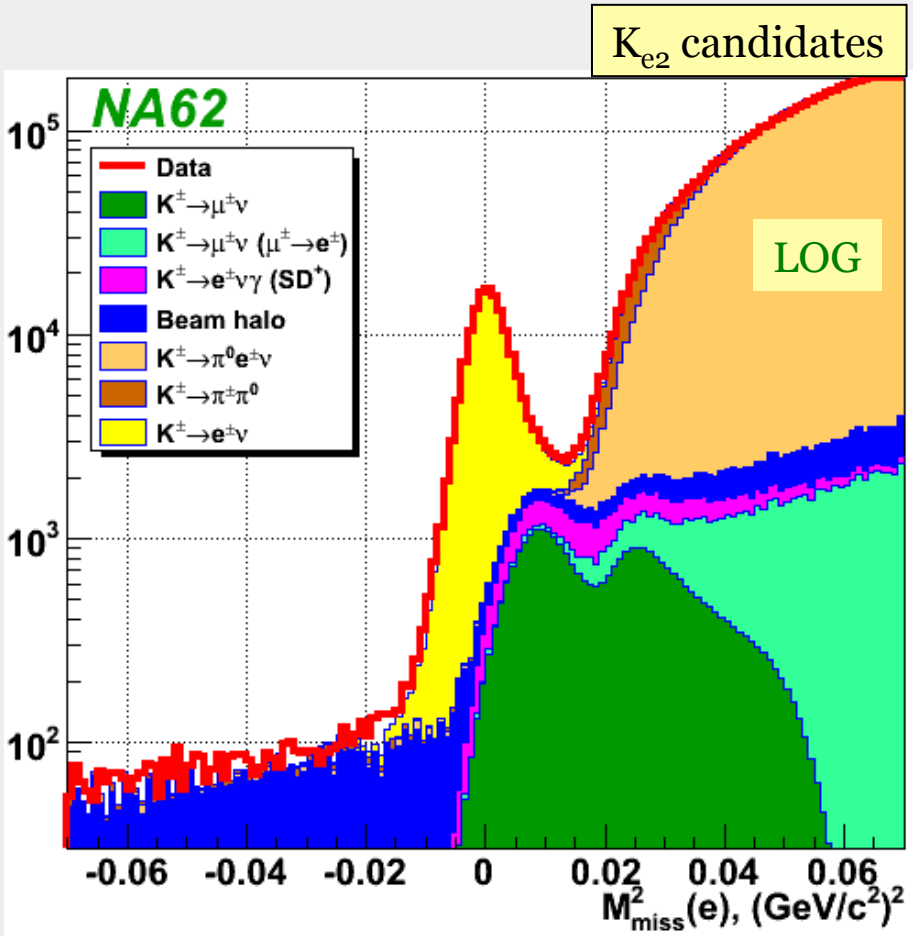
Signal events — *Particle ID eff* — *Trigger efficiency*

$$R_K = \frac{1}{D} \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \frac{f_\mu \cdot A(K_{\mu 2}) \cdot \varepsilon(K_{\mu 2})}{f_e \cdot A(K_{e2}) \cdot \varepsilon(K_{e2})} \frac{1}{f_{LKR}}$$

$K_{\mu 2}$ downscaling — *Background events* — *Geometrical acceptance* — *Global LKr readout eff*

K_{e2}: NA62 full data set





145,958 $K^{+}\to e^{+}\nu$ candidates.
Positron ID efficiency: (99.28±0.05)%.
B/(S+B) = (10.95±0.27)%.

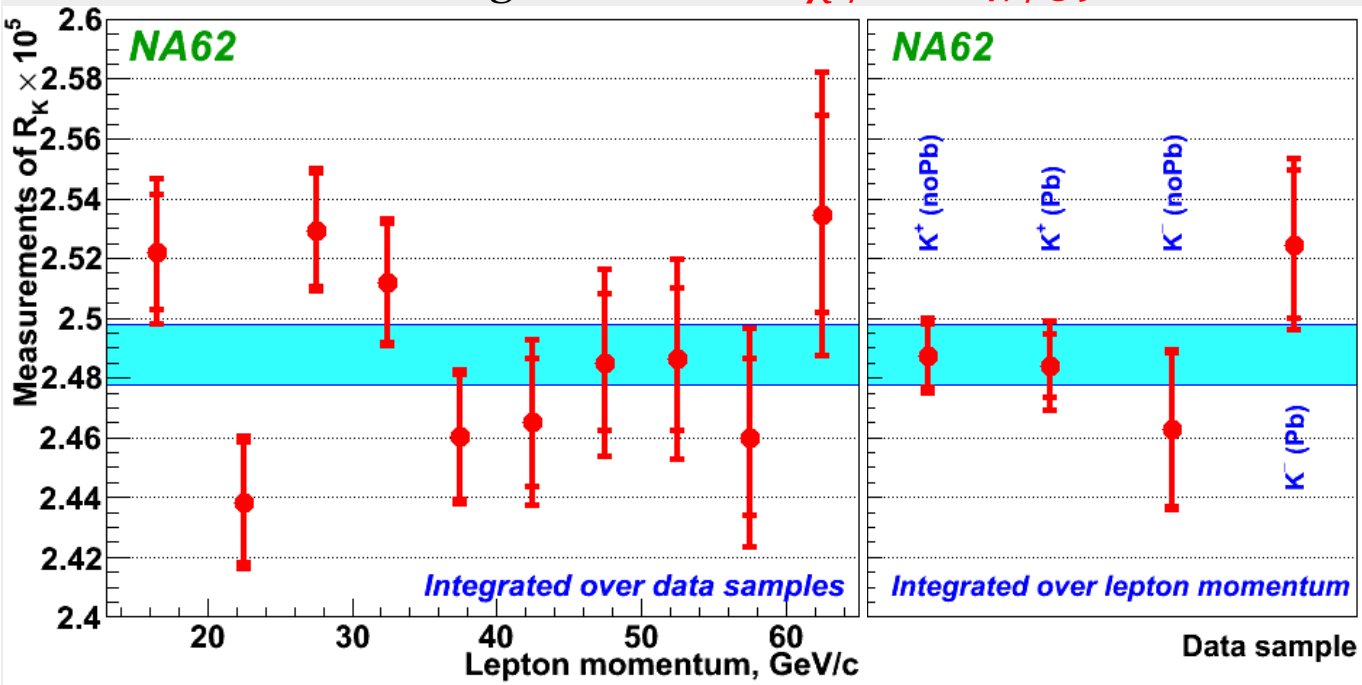
Proposal (CERN-SPSC-2006-033):
~ 150k candidates

cf. KLOE: 13.8K candidates (K^{+} and K^{-}), ~90% electron ID efficiency, 16% bkg

NA62 result

$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}$$
$$= (2.488 \pm 0.010) \times 10^{-5}$$

Fit over 40 measurements (4 data samples x 10 momentum bins) including correlations: $\chi^2/ndf=47/39$.



Independent measurements in lepton momentum bins

(systematic errors included, partially correlated)

Uncertainties
0.4% tot precision

Source	$\delta R_K \times 10^5$
Statistical	0.007
$K_{\mu 2}$	0.004
$BR(K_{e2\gamma}\ SD^+)$	0.002
Beam halo	0.002
$K^\pm \to \pi^0 e^\pm \nu$, $K^\pm \to \pi^\pm \pi^0$	0.003
Matter Composition	0.003
Acceptance	0.002
DCH alignment	0.001
Electron ID	0.001
LKr readout inef	0.001
1-track trigger	0.001
Total	**0.010**

NA62 result (40% data set): $R_K=(2.487\pm0.013)\times10^{-5}$ [PLB698 (2011) 105]

Summary and outlook

NA48/2 provides **new preliminary results** on the $K^{\pm}_{l3}$ form factors in the quadratic and Pole parametrization.

For the first time a result is presented studying both K^+ and K^- decays

- Very competitive with the other results in $K^{\pm}_{\mu 3}$ and smallest error in $K^{\pm}_{e3}$
- Offers the combined result with the smallest error.

In the year 2007 NA62 collected data for a dedicated measurement of $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$, the final result has been shown here.

4 months of data taking in 2007 with K^+ and K^- beams (mostly K^+) with a beam momentum of $P_K = (74 \pm 1.6)$ GeV/c, trigger very similar to the 2004 special run.
Transverse momentum kick of the magnetic spectrometer was doubled wrt 2003/2004
→ improvement in the track momentum resolution.
Huge statistics in $K^{\pm}_{\mu 3}$ and $K^{\pm}_{e3}$ of $O(10^7)$ events, also a special (15 h) K^0_L run collected

So K_{l3} Form Factors can be studied on NA62 2007 run with different/larger data sets

Moreover the construction of the new NA62 detector is on-going. Foreseen to start the data taking for the second phase in 2014 to measure the Branching Ratio of the very rare decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$