
NA48 results on K_L semileptonic decays and extraction of $|V_{us}|$

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on behalf of the NA48 collaboration

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- K_{e3}^0 form factors

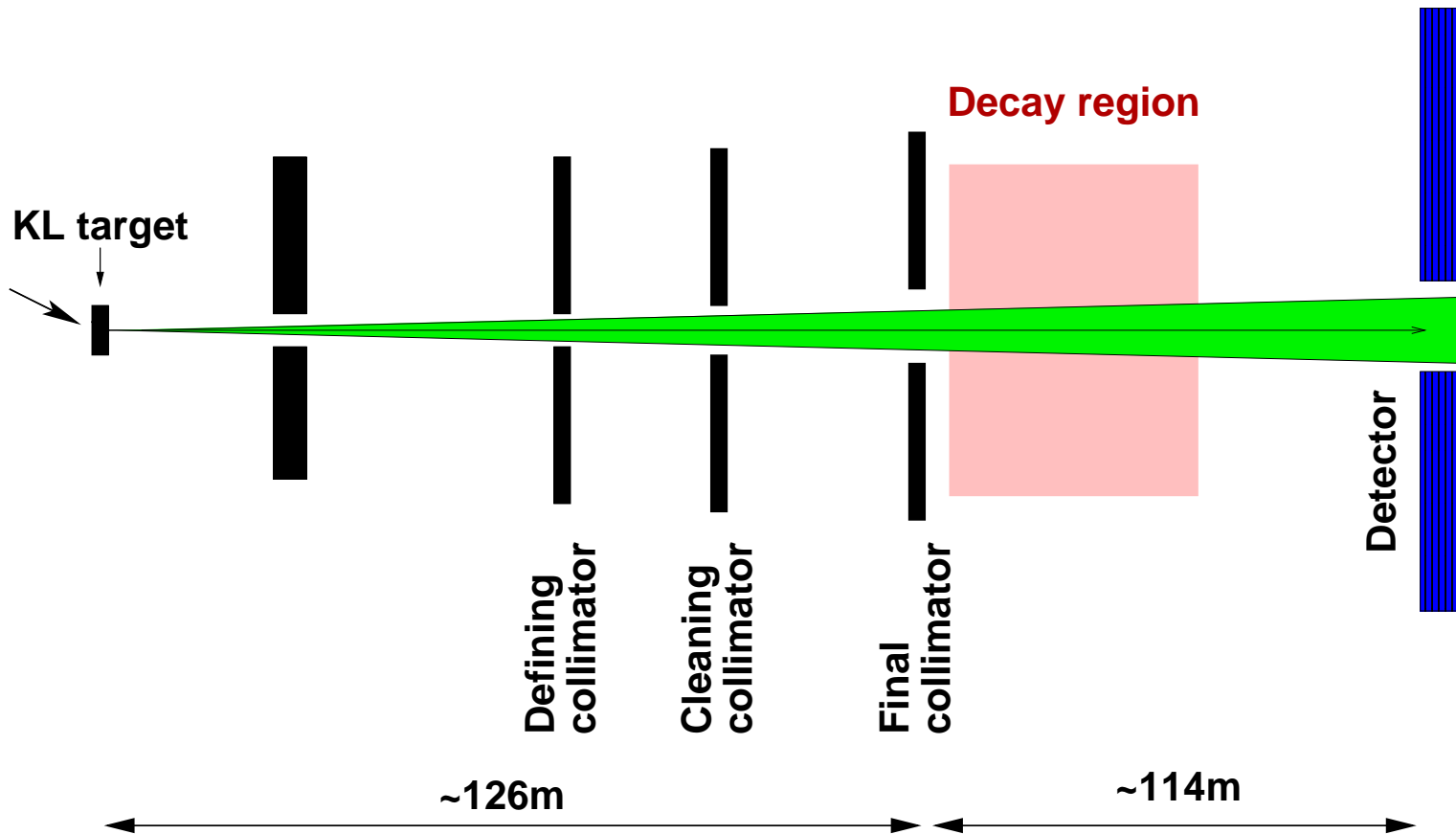
$$K_L \rightarrow \pi^\pm \mu^\mp \nu_e \quad (K_{\mu3}^0)$$

- $K_{\mu3}^0$ form factors

⇒ All four analyses are based on the same data sample,
taken in 1999 during a 2 days K_L run!

NA48 beam line for pure K_L beam

- Special run 1999: pure K_L beam at low intensity
- Simple trigger condition: minimum bias trigger to select only events with two charged tracks (~ 80 million events)



K_{e3}^0 BR and extraction of $|V_{us}|$

General idea:

- Normalize K_{e3} signal to as many other channels as possible
⇒ all K_L decays with two charged particles in final state
- The branching fraction for all K_L decays with two tracks is
$$\text{BR}(2\text{-track}) = 1 - \text{BR}(3\pi^0) \pm \text{small corrections} (\approx 80\%)$$

Measured quantity:

$$R = \frac{\Gamma(K_L \rightarrow \pi e \nu)}{\Gamma(K_L \rightarrow \text{all 2-track events})} = \frac{N_e / a_e}{N_{2T} / a_{2T}}$$

N_e = selected K_{e3} events, a_e = acceptance for K_{e3} events

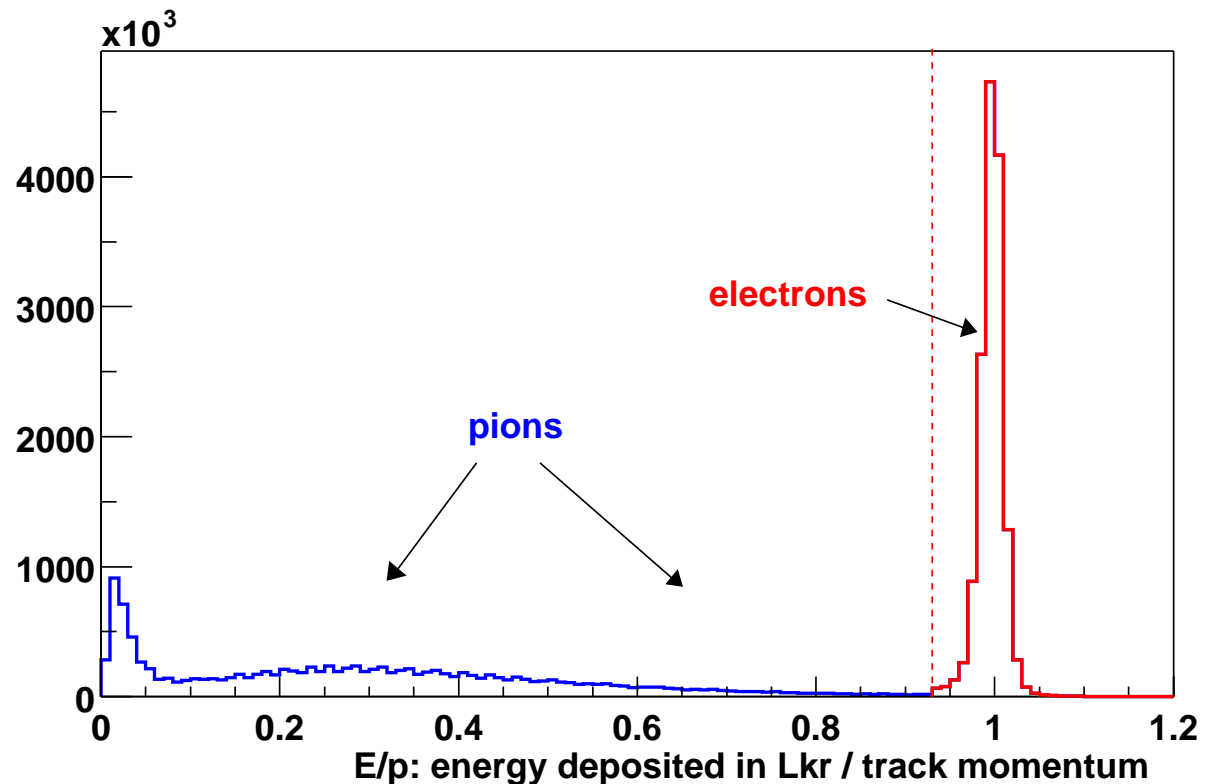
N_{2T} = selected 2-track events, a_{2T} = acceptance for 2-track events

$$\text{BR}(K_{e3}) = R \cdot \text{BR}(2\text{-track})$$

Event selection

- Apply set of cuts to **select good 2-track events** (12.6 million)
- From this data sample **extract the K_{e3} signal** (the only 2-track channel with an electron)
⇒ **Require $E/p > 0.93$ for at least one of the tracks**

~ 6.7 million
 K_{e3} decays



Result for BR (K_{e3}^0)

- $R = \frac{\Gamma(K_L \rightarrow \pi e \nu)}{\Gamma(K_L \rightarrow \text{all 2-track events})} = (49.78 \pm 0.35) \%$

(Uncertainty dominated by momentum spectrum, stat. error negligible)

- $\text{BR}(2\text{-track}) = (80.56 \pm 0.70) \%$

(Uncertainty coming from $\text{BR}(K_L \rightarrow 3\pi^0) = (19.92 \pm 0.70) \%$, averaged between PDG and the latest KTeV result)

$$\begin{aligned} \mathbf{BR(K_{e3}^0)} &= R \cdot \text{BR}(2\text{-track}) \\ &= (40.10 \pm 0.28 \text{ (exp.)} \pm 0.35 \text{ (norm.)}) \% \\ &= \mathbf{(40.10 \pm 0.45) \%} \end{aligned}$$

- Value for BR (K_{e3}) exceeds the 2004 world average by 3.4 % !

- In agreement with new results from KTeV + KLOE

Result for $|V_{us}|$

$$|V_{us}| = \sqrt{\frac{128\pi^3\Gamma(K_{e3}^0)}{G_F^2 M_{K^0}^5 S_{EW} I_{K^0}}} \cdot \frac{1}{f_+^{K^0\pi^-}}$$

- Different theoretical calculations for $f_+^{K^0\pi^-}$
(values between 0.961 and 0.981)
- We take $f_+^{K^0\pi^-} = 0.981 \pm 0.010$ from chiral model
(Cirigliano, Neufeld, Pichl, 2004)

$$\begin{aligned} |V_{us}| (K_{e3}^0) &= 0.2187 \pm 0.0016 \text{ (exp.)} \pm 0.0023 \text{ (theo.)} \\ &= \mathbf{0.2187 \pm 0.0028} \end{aligned}$$

- Result on $|V_{us}|$ is still too low to fulfill unitarity of the CKM matrix
(SM prediction: 0.2274 ± 0.0021)
- Insufficient knowledge of $f_+^{K^0\pi^-}$ dominates the uncertainty

Radiative K_{e3}^0 BR ($K_{e3\gamma}^0$)

Radiative semileptonic decays

- give information about the structure of the decaying particle
- allow to test models describing hadron interactions at small momentum transfer (*ChPT*)

Analysis:

- Measure relative BR of $K_L \rightarrow \pi^\pm e^\mp \nu \gamma / K_L \rightarrow \pi^\pm e^\mp \nu$
- For K_{e3}^0 events require in addition one hard γ in the LKr

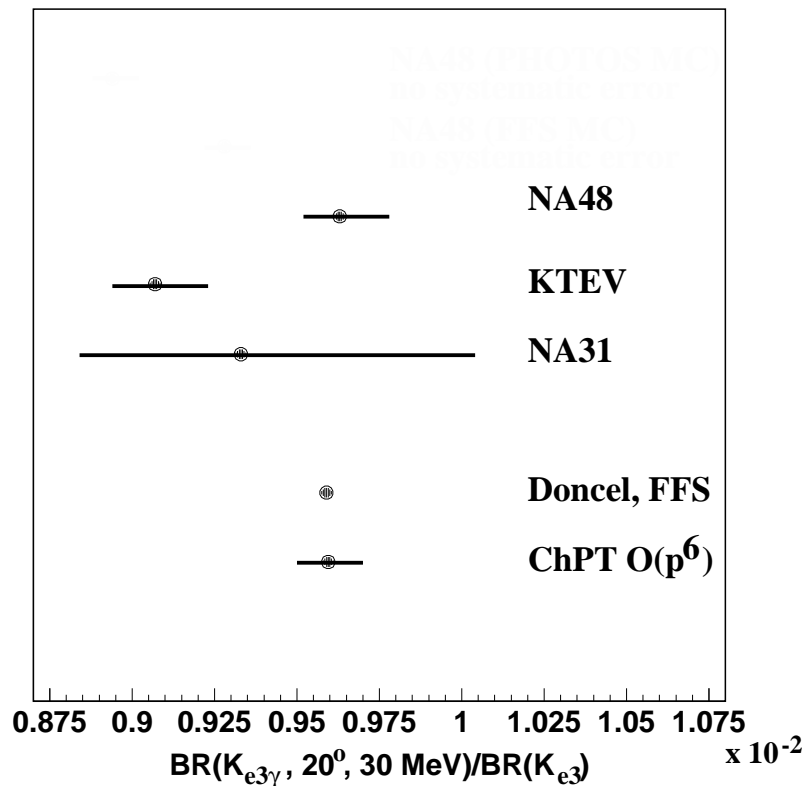
$$R = \frac{\Gamma(K_L \rightarrow \pi e \nu \gamma, E_\gamma^* > 30 \text{ MeV}, \Theta_{e\gamma}^* > 20^\circ)}{\Gamma(K_L \rightarrow \pi e \nu)}$$

- Radiative corrections in MC: Events generated with PHOTOS package (describes inner bremsstrahlung) modified to account for virtual effects (weight $\Theta_{e\gamma}^*$ to fit the data)

Result for radiative K_{e3}^0 BR

- Number of reconstructed $K_{e3\gamma}$ decays: 18977
- Number of reconstructed K_{e3} decays: 5.994 million
- Radiative K_{e3}^0 branching ratio:

$$R = (0.964 \pm 0.008_{-0.009}^{+0.011}) \% = (0.964_{-0.012}^{+0.014}) \%$$



In good agreement
with theory !

Form factors in K_{e3}^0

- Measurement of the **Dalitz plot density** admitting all possible Lorentz-covariant couplings: measure form factors for
 - vector coupling ($f_+(q^2) = f_+(0) (1 + \lambda_+ q^2/m_\pi^2)$)
 - scalar coupling (f_S)
 - tensor coupling (f_T)
- f_S and f_T are = 0 according to the SM!
- The applied fitting method allows to extract parameters from multi-dimensional data distributions (based on Loglikelihood technique)
- Test form factor q^2 -**dependence**
(linear, quadratic, pole-dominance)

Form factors in K_{e3}^0

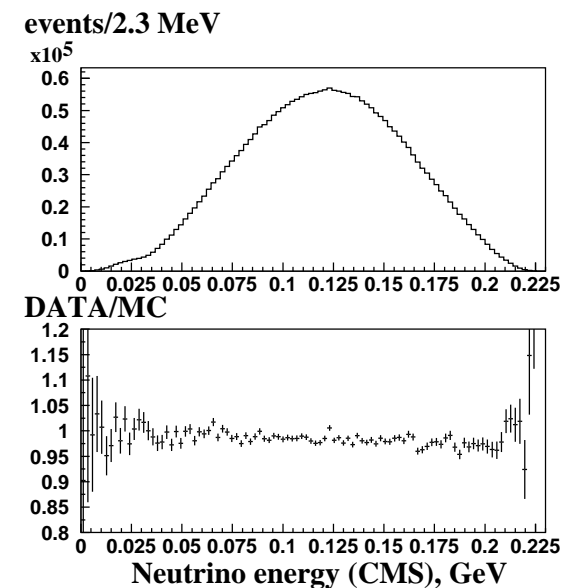
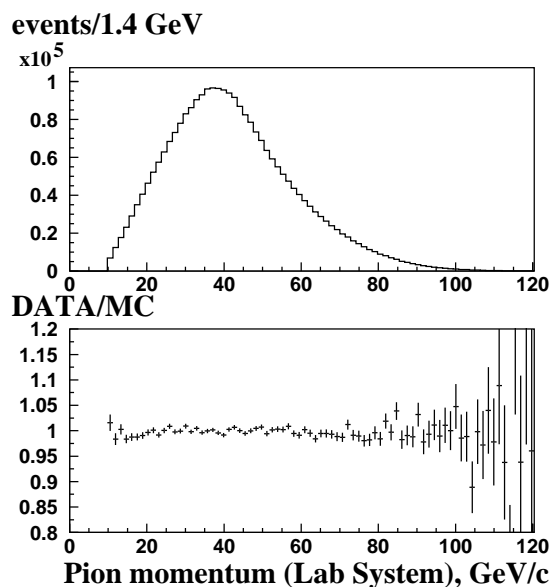
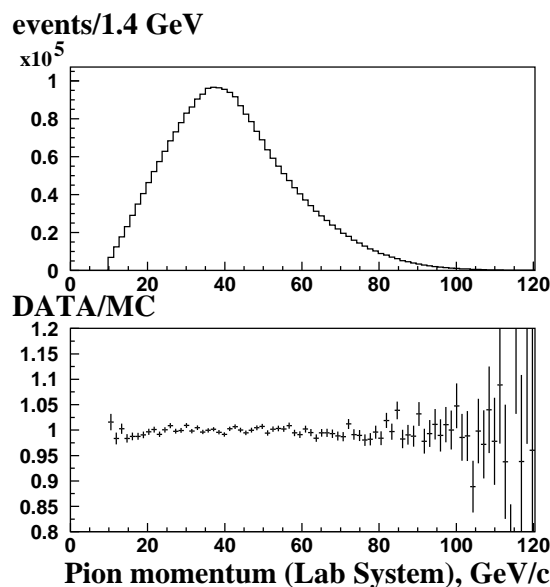
Data sample: 5.6 million fully reconstructed K_{e3}^0 decays, with both solutions for kaon energy between 60 GeV and 180 GeV

Some comparisons between DATA and MC...

**Neutrino momentum
in the CMS**

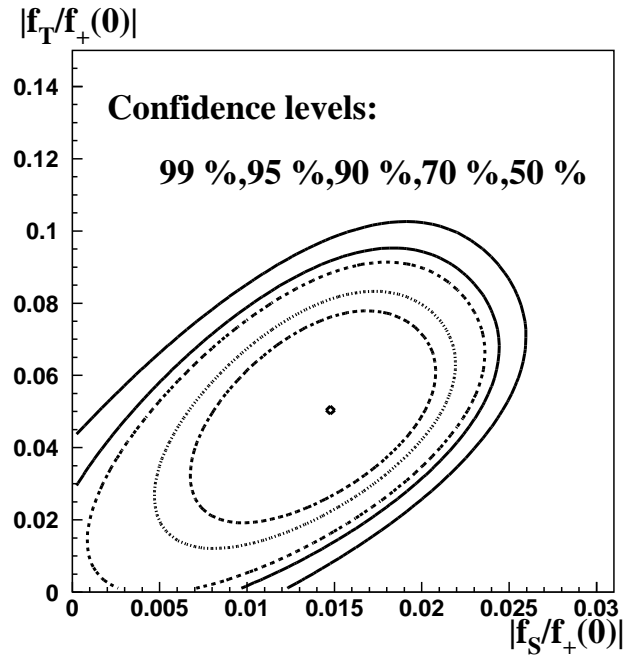
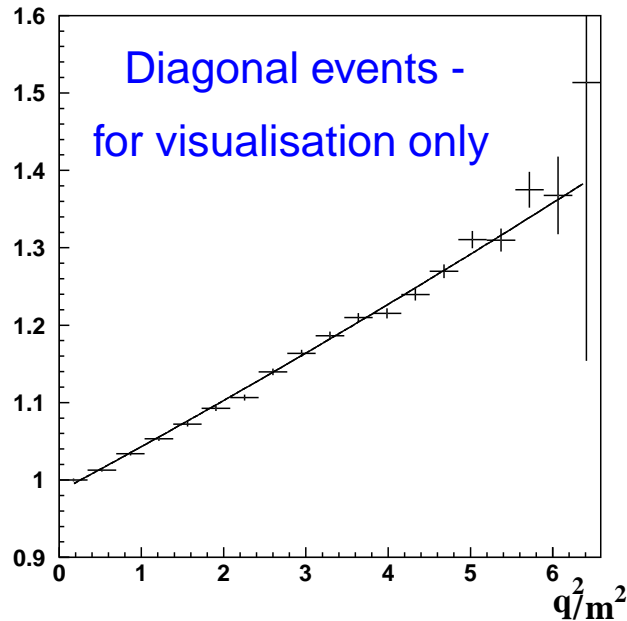
Electron momentum

Pion momentum



Form factors in K_{e3}^0 - Results

DATA/MC



Results for 3 form factor fit

- $\lambda_+ = 0.0284 \pm 0.0007_{stat.} \pm 0.0013_{syst.}$
- $\left| \frac{f_S}{f_+(0)} \right| = 0.015_{-0.010}^{+0.007} \pm 0.012_{syst.}$
- $\left| \frac{f_T}{f_+(0)} \right| = 0.05_{-0.04}^{+0.03} \pm 0.03_{syst.}$

Result for pure vector coupling

$$\lambda_+ = 0.0288 \pm 0.0005_{stat.} \pm 0.0011_{syst.}$$

⇒ no evidence for scalar or tensor couplings!

q^2 -dependence

- **linear** (with slope parameter λ_+)!
- no evidence for quadratic term
- dipole form factor in agreement with data with a pole mass of 859 ± 18 MeV (consistent with the $K^*(892)$ mass)

Form factors in $K_{\mu 3}^0$

- Due to the much higher lepton mass a second (scalar) form factor comes into play (with **slope parameter** λ_0)
- Test form factor q^2 -**dependence**
(linear, quadratic, pole-dominance)
- **Dalitz plot analysis:** determine FF by fitting the corrected data to a Dalitz plot density parametrisation
- Radiative effects properly simulated in MC
(real and virtual diagrams)

Form factors in $K_{\mu 3}^0$ - Results

Preliminary result (based on 2.64 million reconstructed $K_{\mu 3}^0$ decays in data):

● $\lambda_+ = 0.026 \pm 0.007_{stat.} \pm 0.010_{syst.}$

● $\lambda_0 = 0.012 \pm 0.008_{stat.} \pm 0.015_{syst.}$

