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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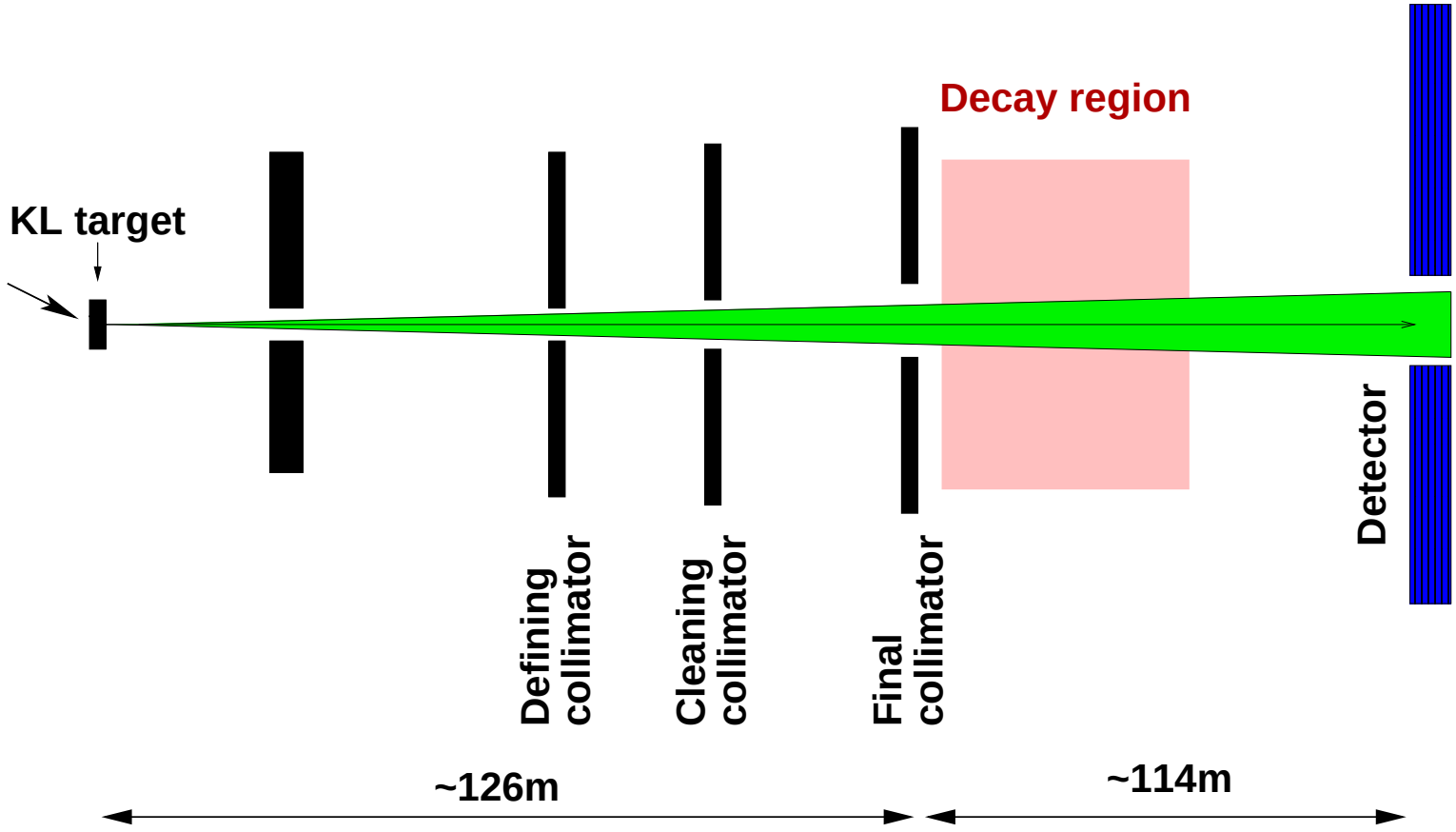
$K_L \to \pi^{\pm} \mu^{\mp} \nu_e \quad (K^0_{\mu 3})$

- $K^0_{\mu 3}$ form factors

$\Rightarrow$ 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 ($\sim$ 80 million events)



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

General idea:

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

Measured quantity:

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

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

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

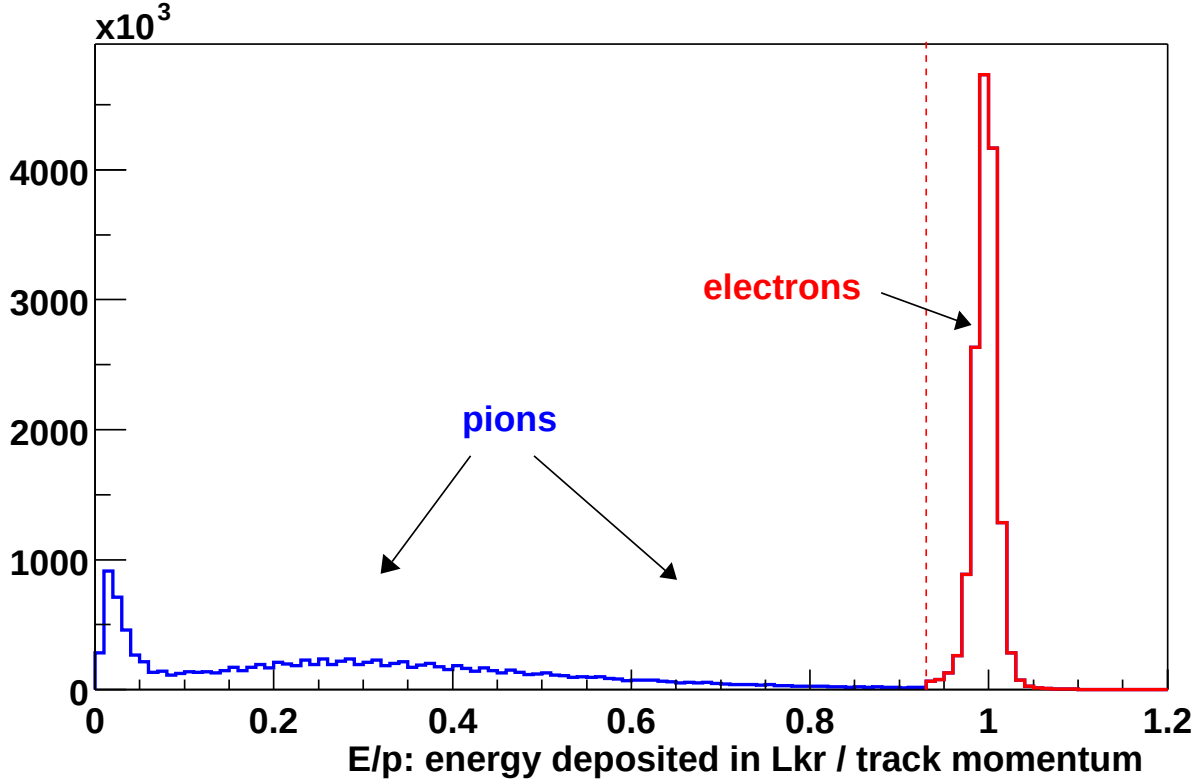
$$\mathbf{BR(K_{e3}) = R \cdot BR(2\text{-track})}$$

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)

  $\Rightarrow$ Require E/p > 0.93 for at least one of the tracks

$\sim$ 6.7 million K_{e3} decays



Result for $\mathrm{BR}(\mathrm{K}^0_{e3})$

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

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

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

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

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

- Value for $\mathrm{BR}\,(\mathrm{K_{e3}})$ exceeds the 2004 world average by $3.4\,\%$!
- In agreement with new results from KTeV + KLOE

Result for $|V_{us}|$

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

- 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)

$$\mathbf{|V_{us}|\,(K^0_{e3})} = 0.2187 \pm 0.0016\,\text{(exp.)} \pm 0.0023\,\text{(theo.)}$$

$$= \mathbf{0.2187 \pm 0.0028}$$

- 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^0_{e3} BR ($K^0_{e3\gamma}$)

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 $K_L \to \pi^{\pm} e^{\mp} \nu\gamma / K_L \to \pi^{\pm} e^{\mp} \nu$
- For K^0_{e3} events require in addition one hard γ in the LKr

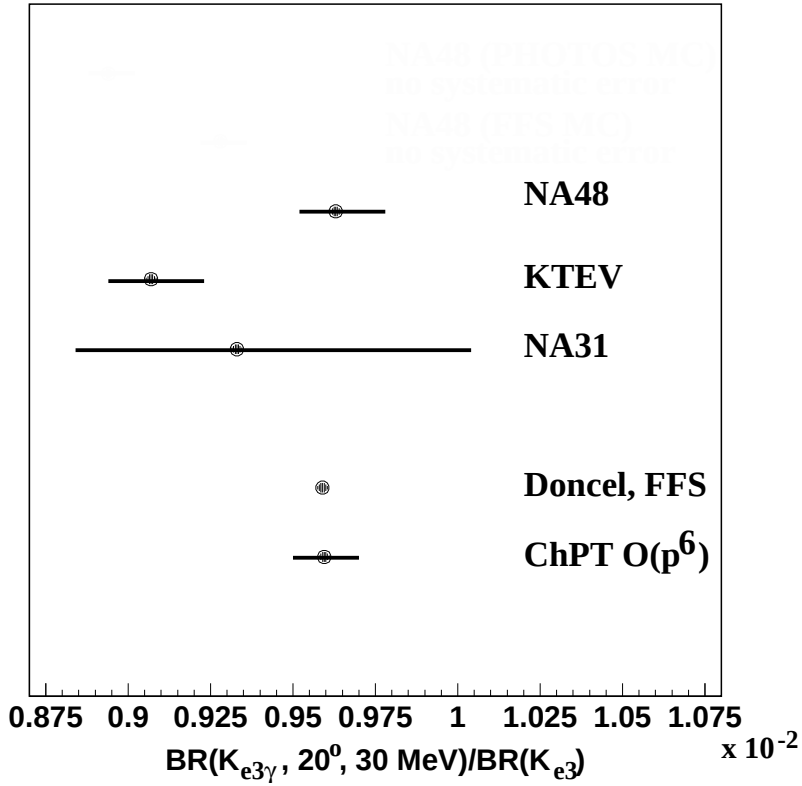
$$\mathbf{R = \frac{\Gamma(K_L \to \pi e \nu \gamma,\ E^*_\gamma > 30\ \text{MeV},\ \Theta^*_{e\gamma} > 20^\circ)}{\Gamma(K_L \to \pi e \nu)}}$$

- 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^0_{e3} BR

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

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



In good agreement with theory!

Form factors in K^0_{e3}

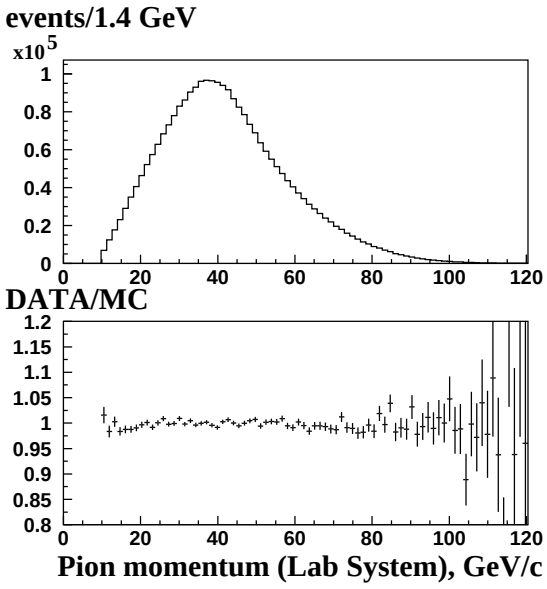
- Measurement of the **Dalitz plot density** admitting all possible Lorentz-covariant couplings: measure form factors for
  - vector coupling ($f_+(q^2) = f_+(0)\,(1 + \lambda_+\, q^2/m_\pi^2)$)
  - scalar coupling (f_S)
  - tensor coupling (f_T)
- f_S and f_T are $= 0$ according to the SM !
- The applied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

Form factors in K^0_{e3}

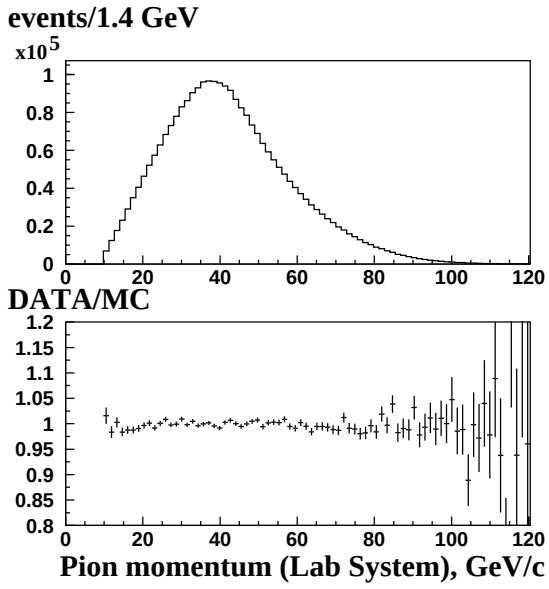
Data sample: 5.6 million fully reconstructed K^0_{e3} decays, with both solutions for kaon energy between 60 GeV and 180 GeV

Some comparisons between DATA and MC...

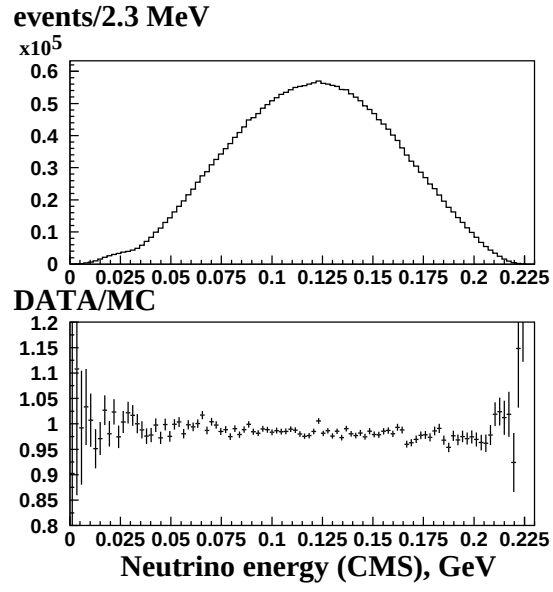
Electron momentum



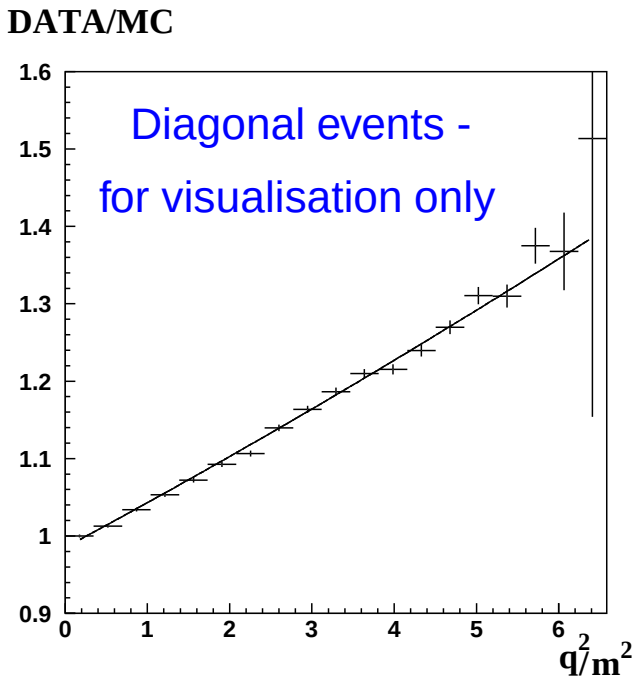
Pion momentum

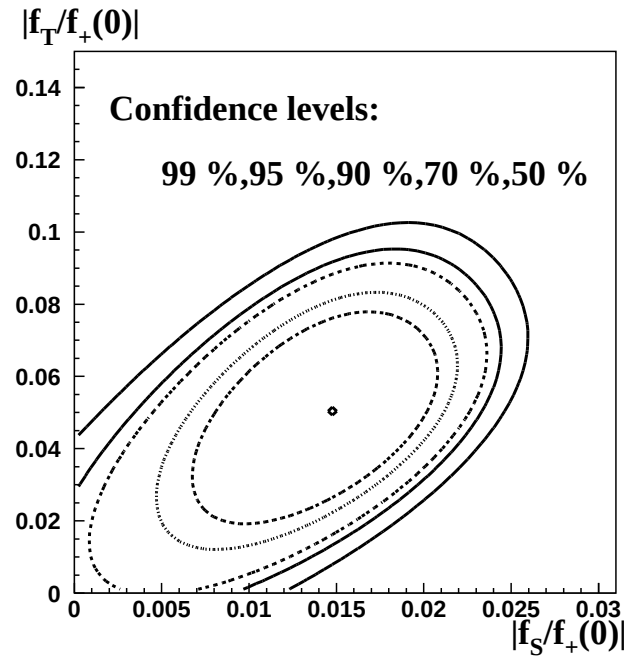


Neutrino momentum in the CMS



Form factors in K^0_{e3} - Results





Results for 3 form factor fit

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

Result for pure vector coupling

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

$\Rightarrow$ no evidence for scalar or tensor couplings!

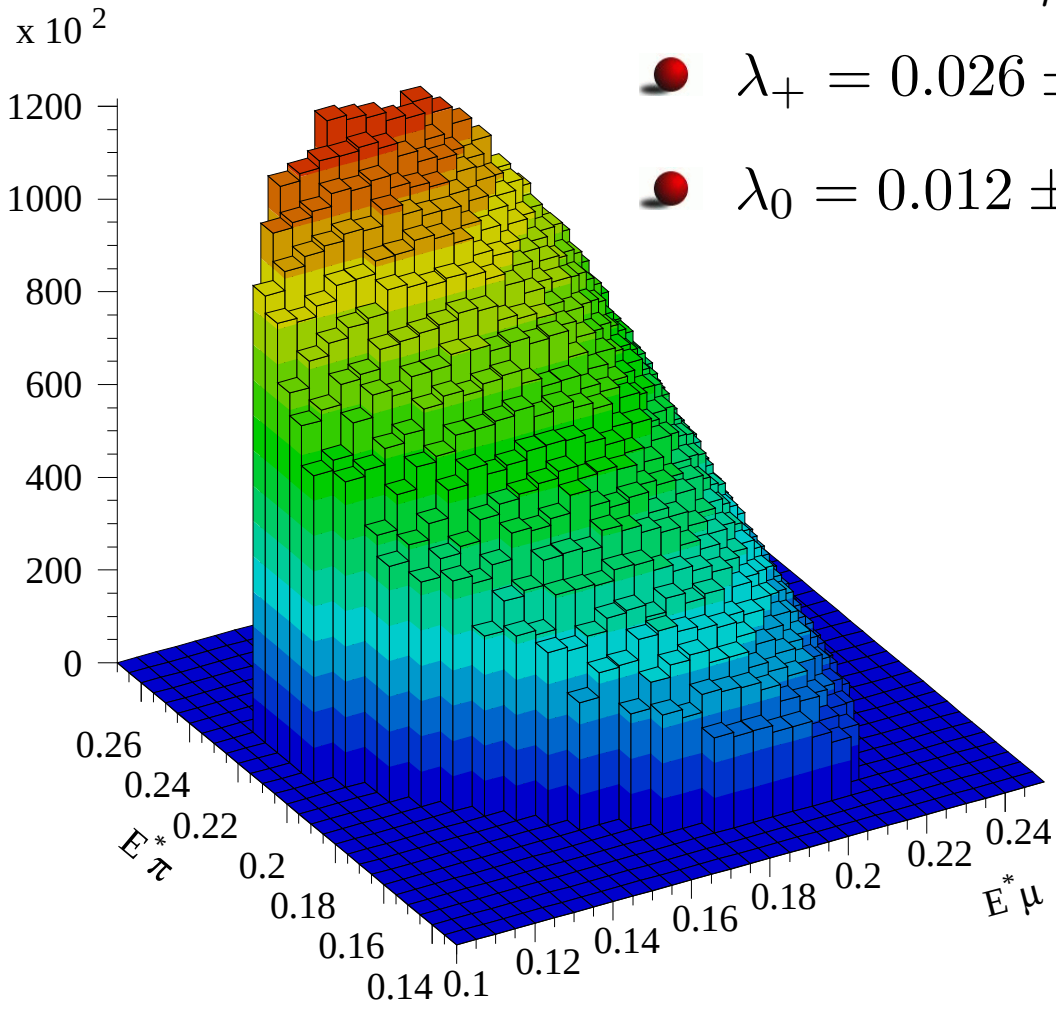
q^2-dependence

- 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 $K^0_{\mu 3}$

- Due to the much higher lepton mass a second (scalar) form factor comes into play (with slope parameter λ_0)
- Test form factor $\mathbf{q^2}$**-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 $K^0_{\mu 3}$ - Results



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

- $\lambda_+ = 0.026 \pm 0.007_{stat.} \pm 0.010_{syst.}$
- $\lambda_0 = 0.012 \pm 0.008_{stat.} \pm 0.015_{syst.}$