

Semileptonic K_L Decays at NA48

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On behalf of the NA48 Collaboration:

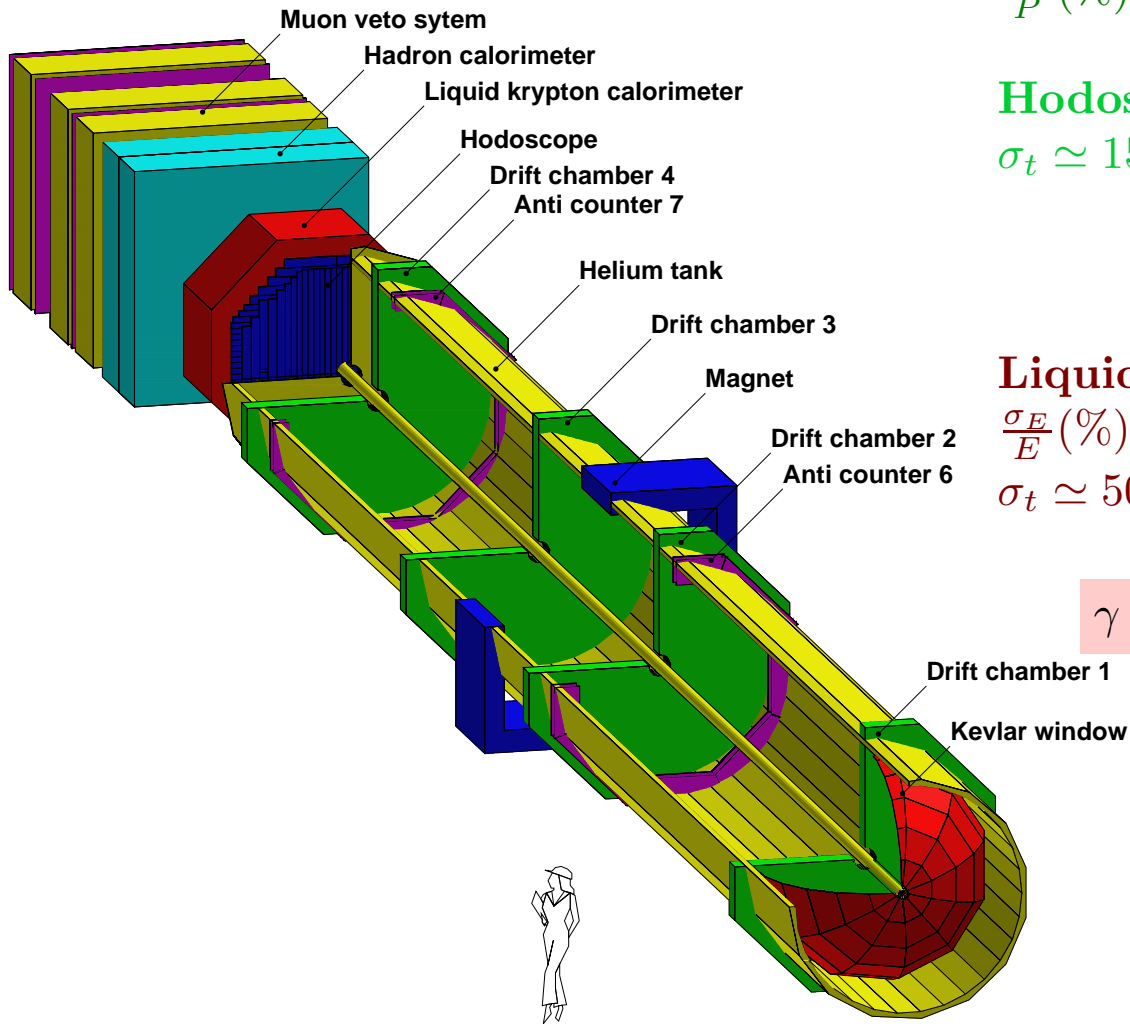


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Siegen Torino Warsaw Wien*

Outline

- The NA48 detector
- $K_L \rightarrow \pi^\pm e^\mp \nu_e$ (K_{e3}^0) Branching Ratio
- K_{e3}^0 Form Factors
- $K_L \rightarrow \pi^\pm e^\mp \nu_e \gamma$ ($K_{e3\gamma}^0$) Branching Ratio
- Summary

The NA48 Detector



Magnetic Spectrometer

$$\frac{\sigma_P}{P} (\%) = 0.48 \oplus 0.009 P \text{ (GeV/c)}$$

Hodoscope

$$\sigma_t \simeq 150 \text{ ps}$$

Charged particles

Liquid Krypton EM calorimeter

$$\frac{\sigma_E}{E} (\%) = \frac{3.2}{\sqrt{E}} \oplus \frac{9.0}{E} \oplus 0.42 \text{ (GeV)}$$

$$\sigma_t \simeq 500 \text{ ps in the range 3–100 GeV}$$

γ energy e/π separation

Muon veto

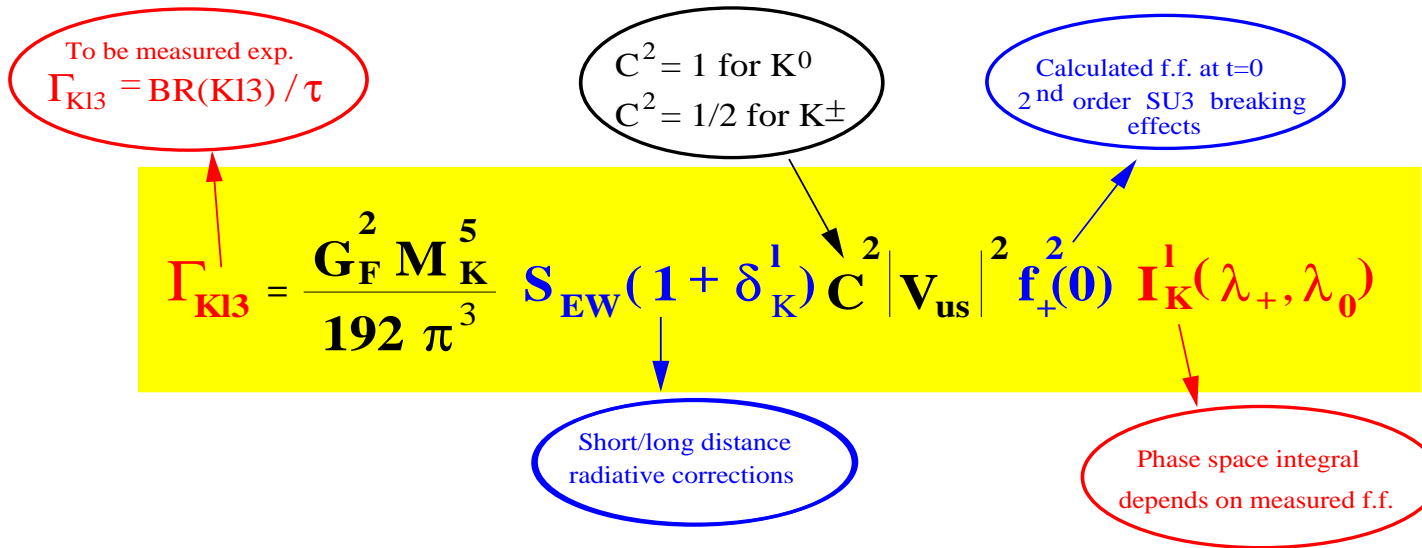
25cm × 25cm cells

$$\sigma_t \simeq 350 \text{ ps}$$

μ identification

$K_{\ell 3}$ Decays – Physics Motivations

$K_{\ell 3}$ decays \Rightarrow the most accurate and theoretically cleanest way to extract $|V_{us}|$



The unitarity test with the first row of CKM indicates a 2.2σ deviation from unity:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = 0.0033 \pm 0.0015 \quad (\text{PDG04})$$

Hint of new physics ?

Recent results from KTeV support K^+ value from E865 and “restore” unitarity

However their BR are not in agreement with PDG averages...

Additional exp/theo inputs are needed

K_{e3}^0 Branching Ratio – Analysis Strategy

- The determination of $BR(K_{e3})$ proceeds through the measurement of $BR(K_{e3})$ relative to all charged K_L decays $\Rightarrow \pi e \nu, \pi \mu \nu, \pi^+ \pi^- \pi^0, \pi^0 \pi^0 e e \gamma$
- Since the BR of all charged modes is known through the BR of neutral decays:

$$BR(2T) = \frac{\Gamma(K_L \rightarrow \text{all charged})}{\Gamma(K_L \rightarrow \text{all})} = 1 - \frac{\Gamma(K_L \rightarrow \text{all neutral})}{\Gamma(K_L \rightarrow \text{all})}$$

$$BR(2T) = 1 - BR(3\pi^0) - BR(2\pi^0) - BR(\gamma\gamma) + BR(3\pi_D^0) = 1.0061 - BR(3\pi^0)$$

- $BR(K_{e3}^0)$ can be evaluated using $BR(2T)$

$$BR(K_{e3}) = \frac{\Gamma(K_{e3})}{\Gamma(K_L \rightarrow \text{all})} = \frac{\Gamma(K_{e3})}{\Gamma(K_L \rightarrow \text{all charged})} \times BR(2T)$$

- Practically NA48 measured the ratio of K_{e3}^0 events to events with two charged tracks, each corrected by its acceptance

$$R = \frac{N_{Ke3}}{N_{2T}} \cdot \frac{A_{2T}}{A_{Ke3}}$$

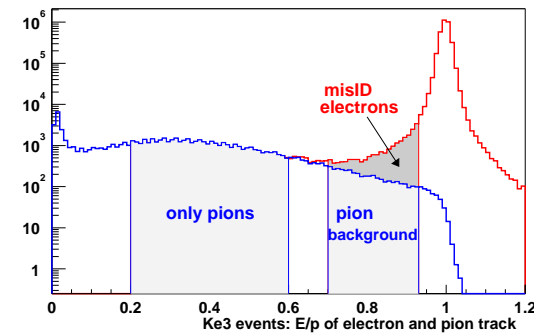
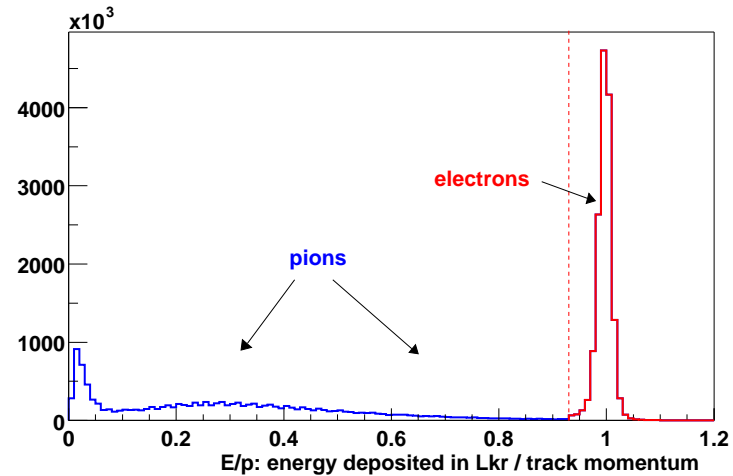
K_{e3}^0 Branching Ratio – Analysis

Sample of 5.6×10^6 reconstructed K_{e3}^0 events from a special run (no K_S) taken in 1999

- K_{e3}^0 selected by means of E/p
⇒ electrons: $E/P > 0.93$
- Measure background and inefficiencies using the data

Background from $K_{\mu 3}$ and $K_{3\pi}$
⇒ $W(\pi \rightarrow e) = (0.576 \pm 0.005)\%$

e ID inefficiency
⇒ $W(e \rightarrow \pi) = (0.487 \pm 0.004)\%$



- Use MC to determine the detector acceptances for the charged decay modes
- Determine A_{2T} from a weighted mean of A_i and BR_i
⇒ BR_i obtained by combining PDG02 and new KTeV results

$$R = 0.4981 \pm 0.0035$$

K_{e3}^0 Branching Ratio – Extraction of $|V_{us}|$

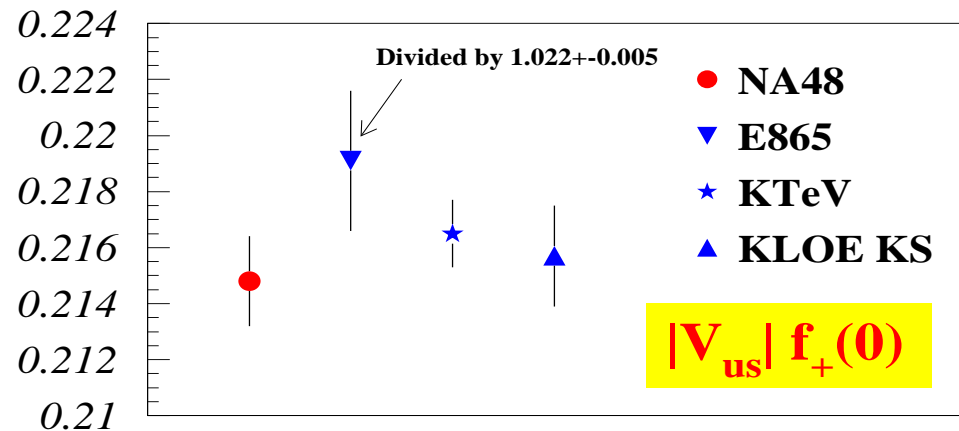
$$BR(K_{e3}^0) = R \times BR(2T) = 0.4019 \pm 0.0028_{NA48} \pm 0.0035_{ext}$$

Determine Γ_{Ke3} by using PDG value of τ_L and extract $|V_{us}| f_+(0)$

$$|V_{us}| f_+(0) = 0.2148 \pm 0.0016$$

Which $f_+(0)$ to use ?

$f_+(0)$	
0.981 ± 0.010	<i>Cirigliano et al. 04</i>
0.976 ± 0.010	<i>Bijnens et al. 03</i>
0.974 ± 0.011	<i>Jamin et al. 04</i>
0.961 ± 0.008	<i>Leutwyler and Roos 84</i>



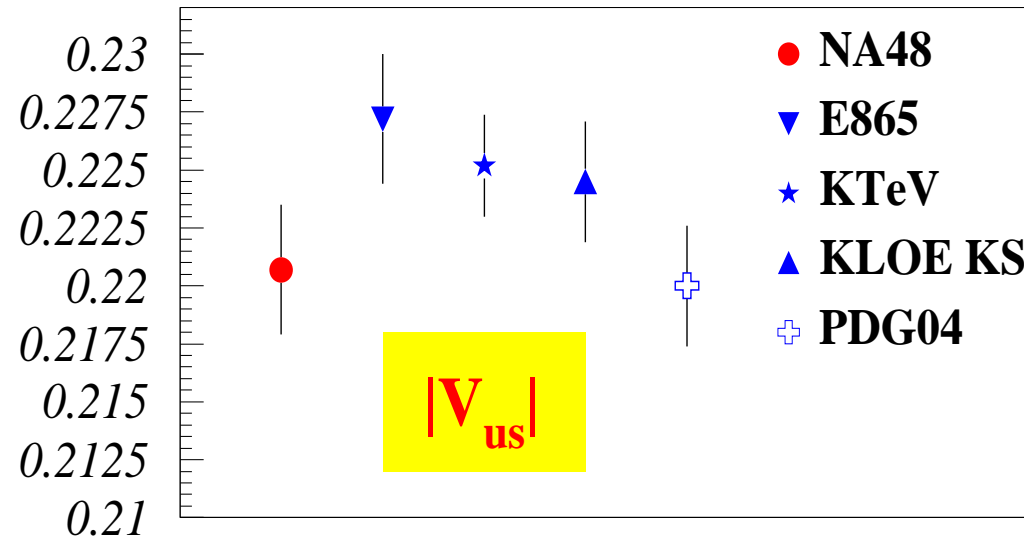
Take the average of chiral calculations: $f_+(0) = 0.973 \pm 0.010$

$S_{EW}, I_{K^0}^e$ and δ^e from Cirigliano et al. 04

K_{e3}^0 Branching Ratio – Extraction of $|V_{us}|$

$$|V_{us}| = 0.2207 \pm 0.0028$$

Preliminary



Using the NA48 value of $|V_{us}|$ the deviation from unitarity is at the 1.9σ level

A crucial point is the choice of $f_+(0)$ which is the dominant source of uncertainty

Furthermore this results depends on $BR(3\pi^0)$ which is at present only poorly known.....

K_{e3}^0 Form Factors – Physics Motivations

Assuming that only the vector coupling contributes to the $K_{\ell 3}(\ell = e, \mu)$ decay the matrix element can be written in terms of two dimensionless form factors $f_{\pm}(t)$:

$$\mathfrak{M} = G/\sqrt{2} V_{us} [f_+(t) (P_K + P_\pi)^\mu \bar{u}_\ell \gamma_\mu (1 + \gamma_5) u_\nu + f_-(t) m_\ell \bar{u}_\ell (1 + \gamma_5) u_\nu]$$

$$t = (P_K - P_\pi)^2 = m_K^2 + m_\pi^2 - 2m_K E_\pi^*$$

$f_-(t) \Rightarrow m_e^2/M_K^2 \sim 10^{-6}$ and in K_{e3}^0 decays can be neglected

The form factor can be extracted from the K_{e3}^0 Dalitz plot density:

$$\rho(E_e^*, E_\pi^*) = \frac{dN^2(E_e^*, E_\pi^*)}{dE_e^* dE_\pi^*} \propto f_+^2(t) A$$

A is a kinematical term and $f_+(t)$ is usually assumed to be linearly dependent on t

$$f_+ = f_+(0) \left(1 + \lambda_+ t/m_\pi^2 \right)$$

Exotic couplings can also be tested: f_S, f_T

\Rightarrow Evidence for nonzero contributions was reported in the past for K_{e3}^+ mode

K_{e3}^0 Form Factors – Analysis

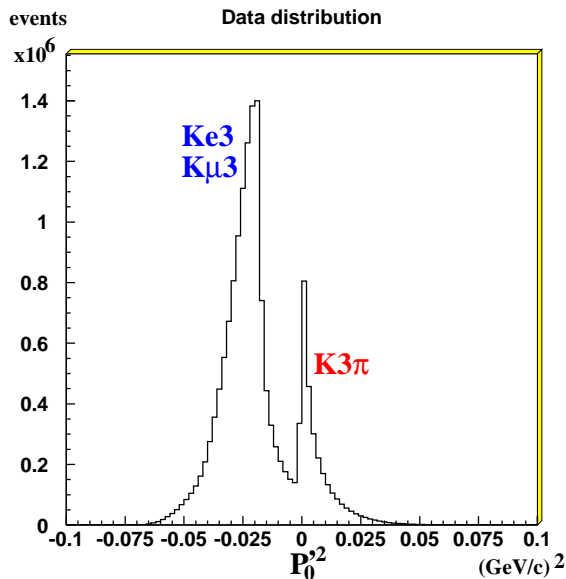
The data sample is the same used for the $\text{BR}(K_{e3}^0)$ analysis

Analysis strategy: 3–dim fit to EXP and MC distributions of: $N(E_\nu^*, t_1/m_\pi^2, t_2/m_\pi^2)$

Kinematical ambiguity arising from the unknown K/ν energies

⇒ For every event there are two solutions corresponding to the two possible orientation of P_ν^*

In this case BOTH solutions are used



e, π identified by means of E/p

Main background from:

- $K_L \rightarrow \pi^+ \pi^- \pi^0 \Rightarrow$ suppressed by $P_0'^2$ cut
- $K_{\mu 3} \Rightarrow$ suppressed by muon veto signal

Main systematics:

- Kaon beam spectrum

K_{e3}^0 Form Factors – Results

Vector, scalar and tensor fit:

$$\lambda_+ = 0.0284 \pm 0.0007_{stat} \pm 0.0013_{syst}$$

$$\left| \frac{f_S}{f_+(0)} \right| = 0.015^{+0.007}_{-0.010}{}_{stat} \pm 0.012_{syst}$$

$$\left| \frac{f_T}{f_+(0)} \right| = 0.05^{+0.03}_{-0.04}{}_{stat} \pm 0.03_{syst}$$

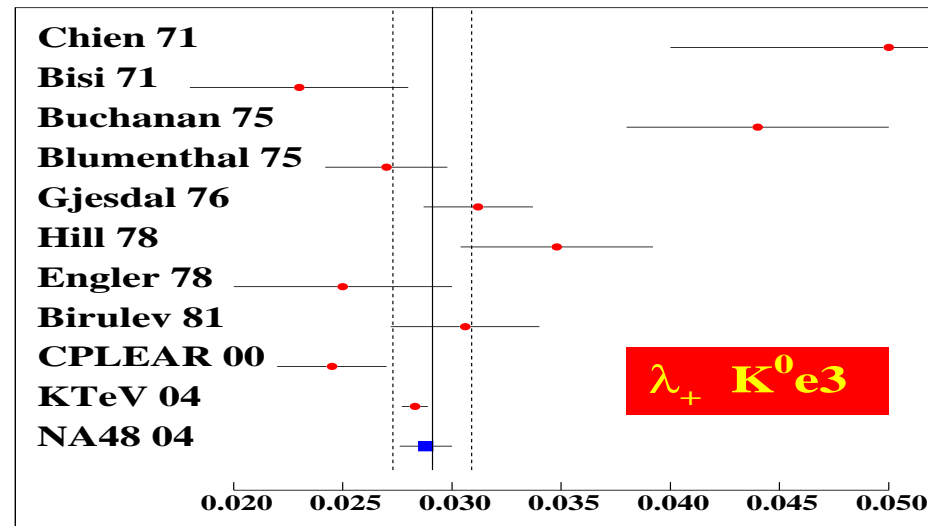
Preliminary

Pure vector interaction:

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

Preliminary

Extraction of the quadratic term in progress



No indication for scalar or tensor couplings

$K_L \rightarrow \pi^\pm e^\mp \nu_e \gamma$ Branching Ratio

Radiative Corrections $\begin{cases} \text{Virtual} \\ \text{Real} \end{cases}$

\Rightarrow Experimentally accessible states with a real γ

IB dominant component for $K_{e3\gamma}^0$

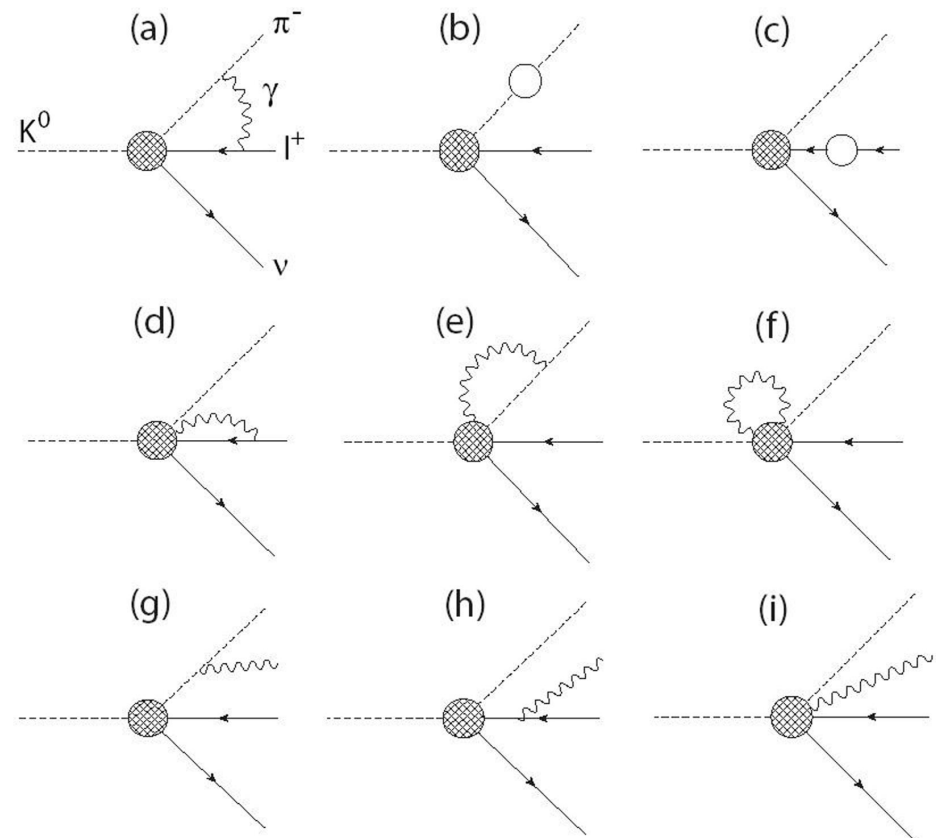
- Described by QED
- Infrared divergencies cancel out with virtual terms

$\Rightarrow E_\gamma^* > 30 \text{ MeV}; \theta_{e\gamma}^* > 20^\circ$

DE structure dependent

- Expected 0.1 \div 1% of IB

Good testing ground for χ PT



First order radiative corrections

$K_{e3\gamma}^0$ Branching Ratio – Analysis

K_{e3}^0 is the normalization channel: $R = \Gamma(K_{e3\gamma}^0, E_\gamma^* > 30 \text{ MeV}, \theta_{e\gamma}^* > 20^\circ) / \Gamma(K_{e3}^0)$

Most precise measurement so far by KTeV:

$$R = (0.908 \pm 0.008_{stat} +0.013_{syst} -0.012_{syst})\%$$

”significantly lower than all published theoretical predictions” PRD 64.112004

$$R^{theo} = (0.95 \div 0.99)\%$$

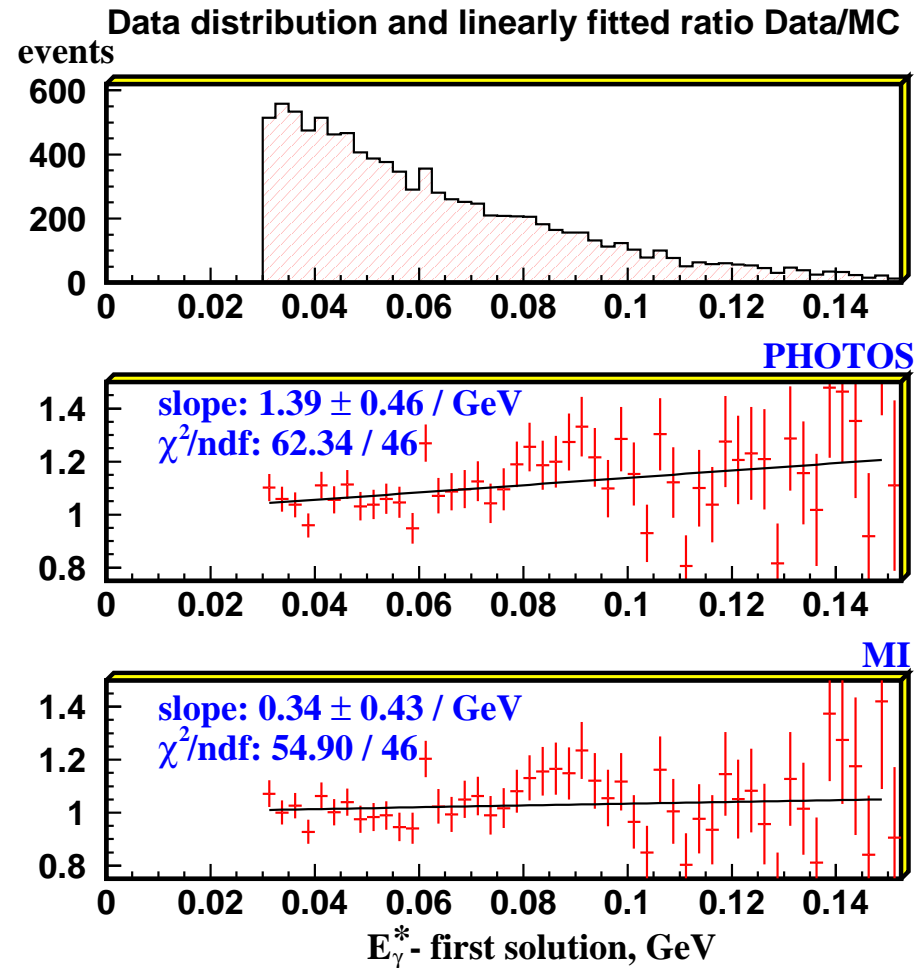
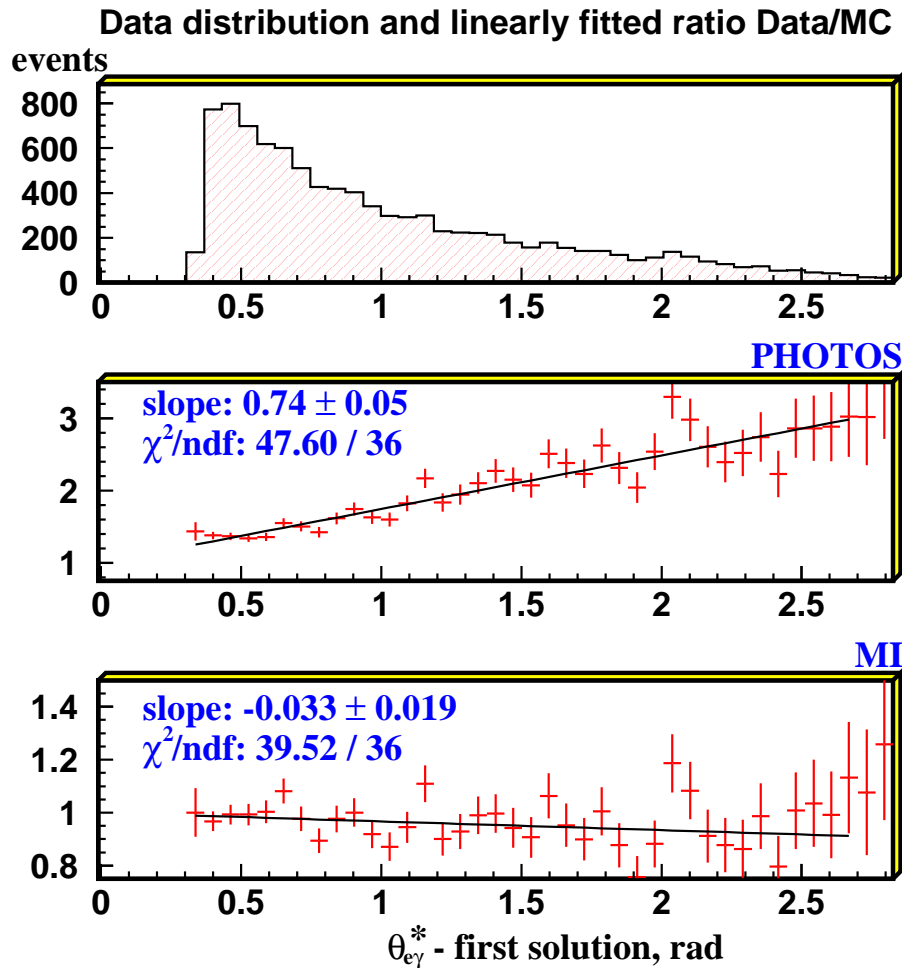
NA48 measurement:

- Similar selection as the K_{e3}^0 sample used for the BR and f.f. analysis
- $K_{e3\gamma}^0$ ask for exactly one γ candidate cluster in the LKr

The analysis is highly dependent on the modeling of the radiative corrections

- Start with PHOTOS in the MC
 - \Rightarrow not very good agreement with the DATA
- Weight $\theta_{e\gamma}^*$ in order to reproduce the DATA (model independent analysis)
 - \Rightarrow the agreement DATA/MC becomes very good for ALL the variables

$K_{e3\gamma}^0$ Branching Ratio – DATA/MC



$K_{e3\gamma}^0$ Branching Ratio – Result

Main background for $K_{e3\gamma}^0$:

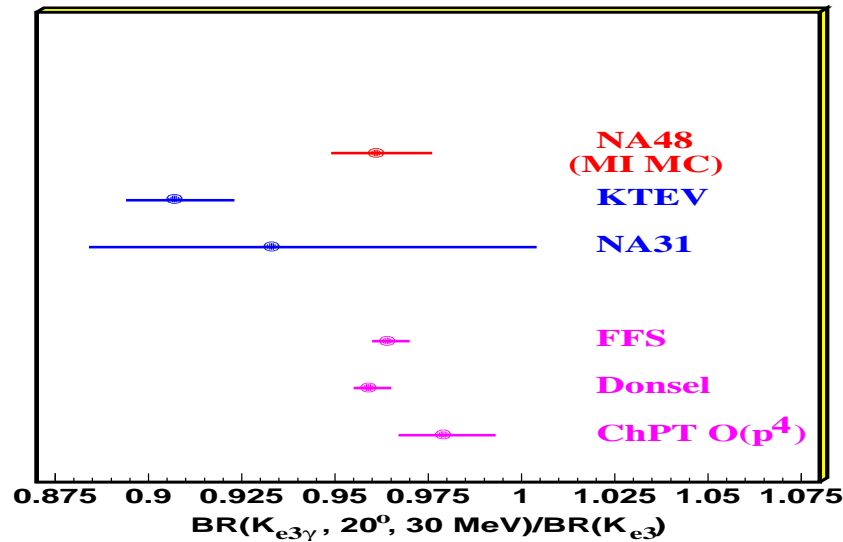
- $K_L \rightarrow \pi^+\pi^-\pi^0$
 \Rightarrow suppressed by P'_0 cut
- K_{e4}
 \Rightarrow determined with the MC

- $K_{e3}^0 + \text{fake } \gamma$ (π shower leakage)
 \Rightarrow apply distance cut
- $K_{e3}^0 + \text{accidental } \gamma$
 \Rightarrow time of γ candidate w.r.t. the other clusters

Main background for K_{e3}^0 : as in the BR/f.f. analysis

$$R = \frac{NK_{e3\gamma}^0}{NK_{e3}^0} \frac{AK_{e3}^0}{AK_{e3\gamma}^0} C_B C_A C_M$$

C_B	=	0.9946	Background corr.
C_A	=	0.9991	Accidental corr.
C_M	=	0.9995	Multiplicity corr.



$$R = (0.962 \pm 0.007_{stat} +0.012_{syst} -0.011_{syst})\%$$

Preliminary

Summary

Preliminary results on K_{e3}^0 decays:

$$BR(K_{e3}^0) = 0.4019 \pm 0.0028_{NA48} \pm 0.0035_{ext}$$

$$|V_{us}| f_+(0) = 0.2148 \pm 0.0016 \quad \Longrightarrow \quad |V_{us}| = 0.2207 \pm 0.0028$$

$$\text{Form Factors: } \lambda_+ = 0.0288 \pm 0.0005_{stat} \pm 0.0011_{syst}$$

No indication for scalar or tensor couplings

$$\Gamma(K_{e3}^0 \gamma, E_\gamma^* > 30 \text{ MeV}, \theta_{e\gamma}^* > 20^\circ) / \Gamma(K_{e3}^0) = (0.962 \pm 0.007_{stat} {}^{+0.012}_{-0.011}_{syst})\%$$

Other results on K_L :

$$BR(K_L \rightarrow \pi^\pm \pi^0 e^\mp \nu_e) = (5.21 \pm 0.07_{stat} \pm 0.09_{syst}) \times 10^{-5} \quad \text{PLB 595(2004) 75}$$

$$BR(K_L \rightarrow e^+ e^- e^+ e^-) = (3.30 \pm 0.24_{stat} \pm 0.14_{syst} \pm 0.10_{norm}) \times 10^{-8} \quad (\text{Preliminary})$$

Ongoing activities:

$K_{\mu 3}^0$ Form Factors

K_{e3} and $K_{\mu 3}$ BR and form factors with charged K at NA48/2