Semileptonic K_L Decays at NA48

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On behalf of the NA48 Collaboration:

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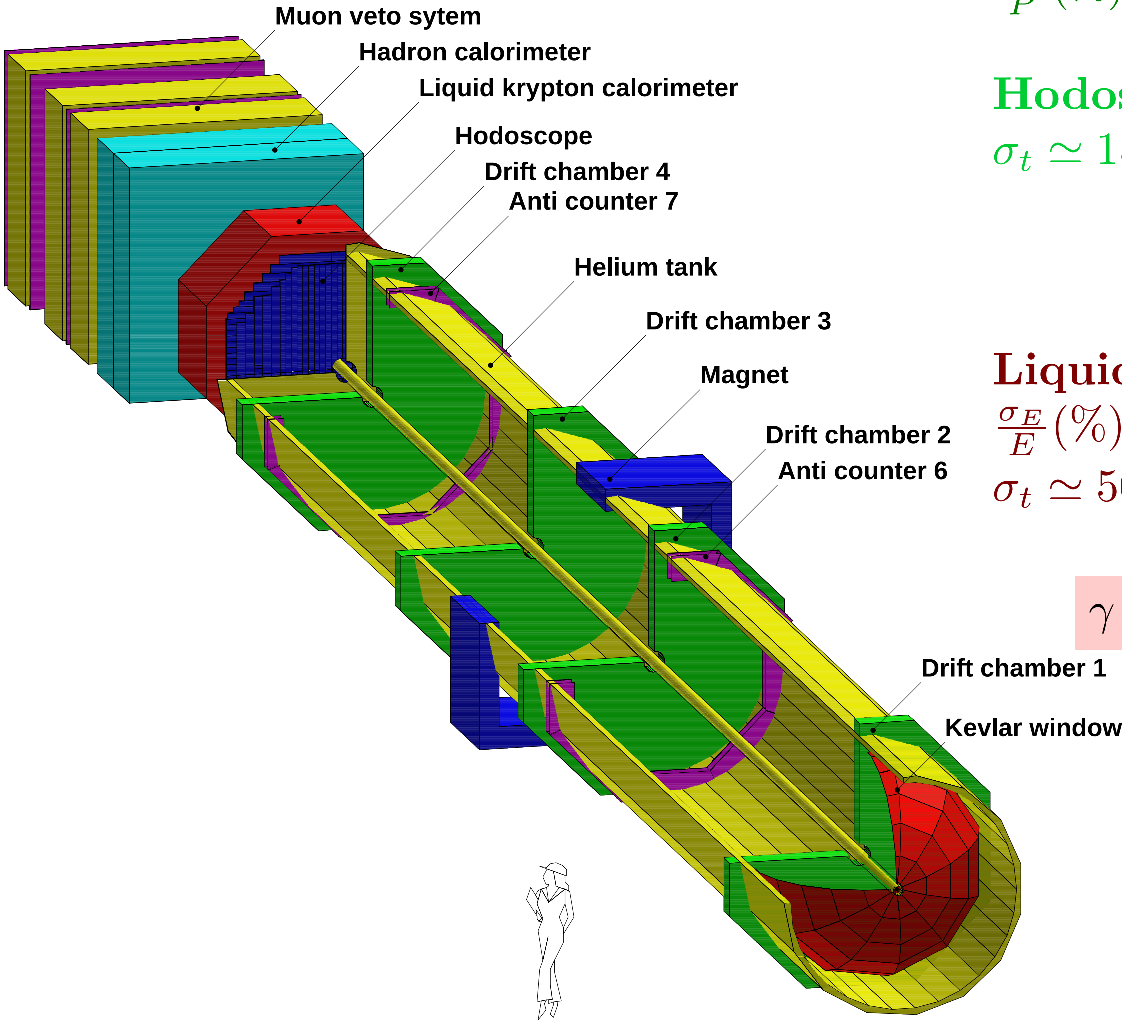
Outline

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

The NA48 Detector



Magnetic Spectrometer

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

Hodoscope

$\sigma_t \simeq 150$ ps

Charged particles

Liquid Krypton EM calorimeter

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

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

γ energy e/π separation

Muon veto

25cm×25cm cells

$\sigma_t \simeq 350$ ps

μ identification

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

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

To be measured exp.
$\Gamma_{Kl3} = BR(Kl3)/\tau$

$C^2 = 1$ for K^0
$C^2 = 1/2$ for $K^{\pm}$

Calculated f.f. at t=0
2 nd order SU3 breaking effects

$$\Gamma_{Kl3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW}(1+\delta_K^l)\, C^2 \left|V_{us}\right|^2 f_+^2(0)\, I_K^l(\lambda_+,\lambda_0)$$

Short/long distance radiative corrections

Phase space integral
depends on measured f.f.

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

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

Hint of new physiscs ?

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^0_{e3} 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 $\Rightarrow$ $\pi e\nu$, $\pi\mu\nu$, $\pi^+\pi^-\pi^0$, $\pi^0\pi^0 ee\gamma$

- Since the BR of all charged modes is known through the BR of neutral decays:

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

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

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

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

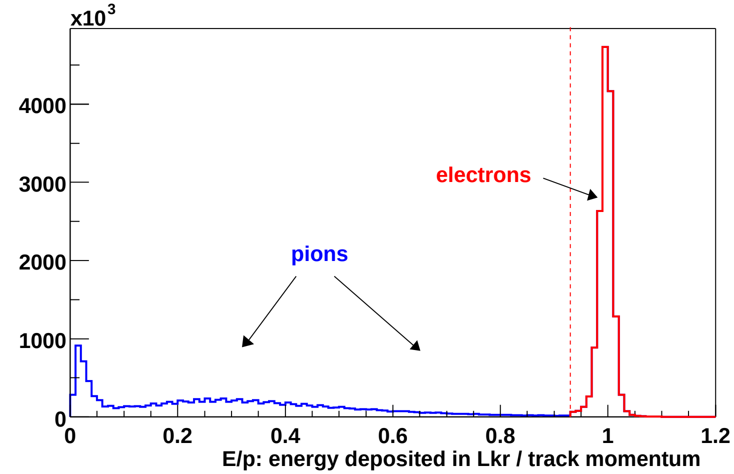
- Practically NA48 measured the ratio of K^0_{e3} events to events with two charged tracks, each corrected by its acceptance

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

K^0_{e3} Branching Ratio – Analysis

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

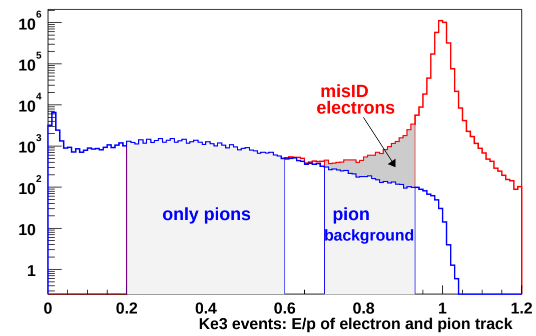
- K^0_{e3} selected by means of E/p
  $\Rightarrow$ electrons: $E/P > 0.93$



- Measure background and inef–ficiencies using the data

Background from $K_{\mu3}$ and $K_{3\pi}$
$\Rightarrow$ $W(\pi \to e) = (0.576 \pm 0.005)\%$

e ID inefficiency
$\Rightarrow$ $W(e \to \pi) = (0.487 \pm 0.004)\%$



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

$$R = 0.4981 \pm 0.0035$$

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

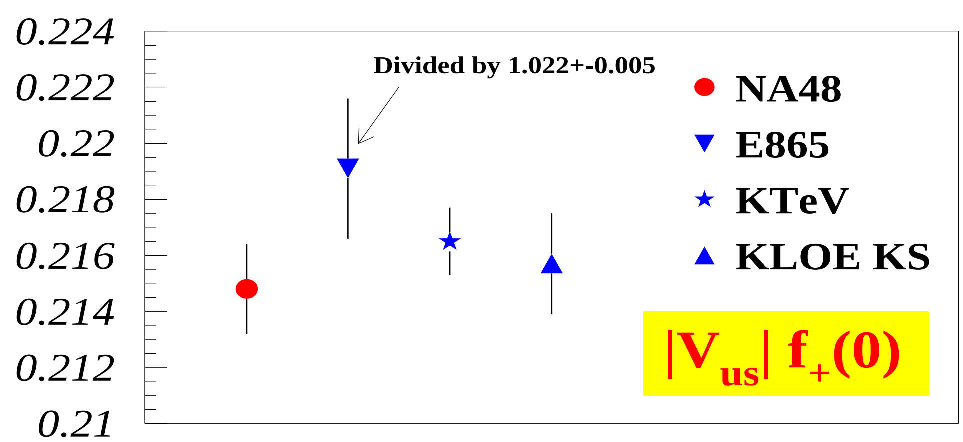
$$BR(K^0_{e3}) \;=\; R \times BR(2T) \;=\; 0.4019 \pm 0.0028_{NA48} \pm 0.0035_{ext}$$

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	*Cirigliano et al. 04*
0.976 ± 0.010	*Bijnens et al. 03*
0.974 ± 0.011	*Jamin et al. 04*
0.961 ± 0.008	*Leutwyler and Roos 84*



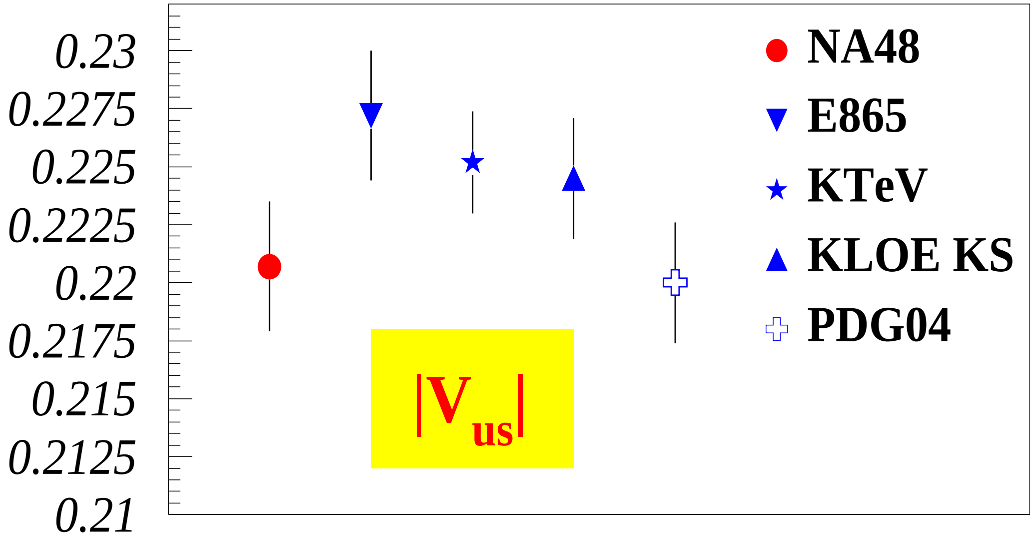
Take the average of chiral calculations: $f_+(0) = 0.973 \pm 0.010$

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

K^0_{e3} 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 1.9 σ 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^0_{e3} 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 $f_\pm(t)$:

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

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

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

The form factor can be extracted from the K^0_{e3} 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

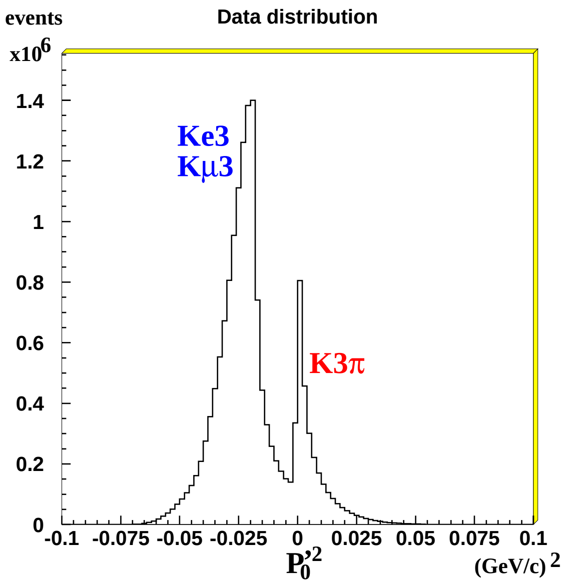
K^0_{e3} Form Factors – Analysis

The data sample is the same used for the BR(K^0_{e3}) analysis

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

Kinematical ambiguity arising from the unknown K/ν energies
$\Rightarrow$ 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^0_{e3} Form Factors – Results

Vector, scalar and tensor fit:

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

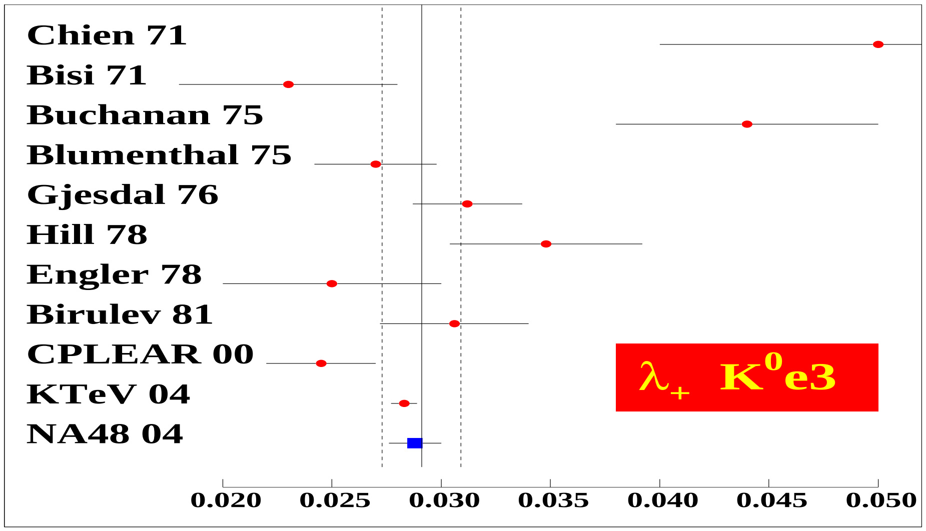
Preliminary

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 cuplings

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

Radiative Corrections → Virtual, Real

⇒ Experimentally accessible states with a real γ

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

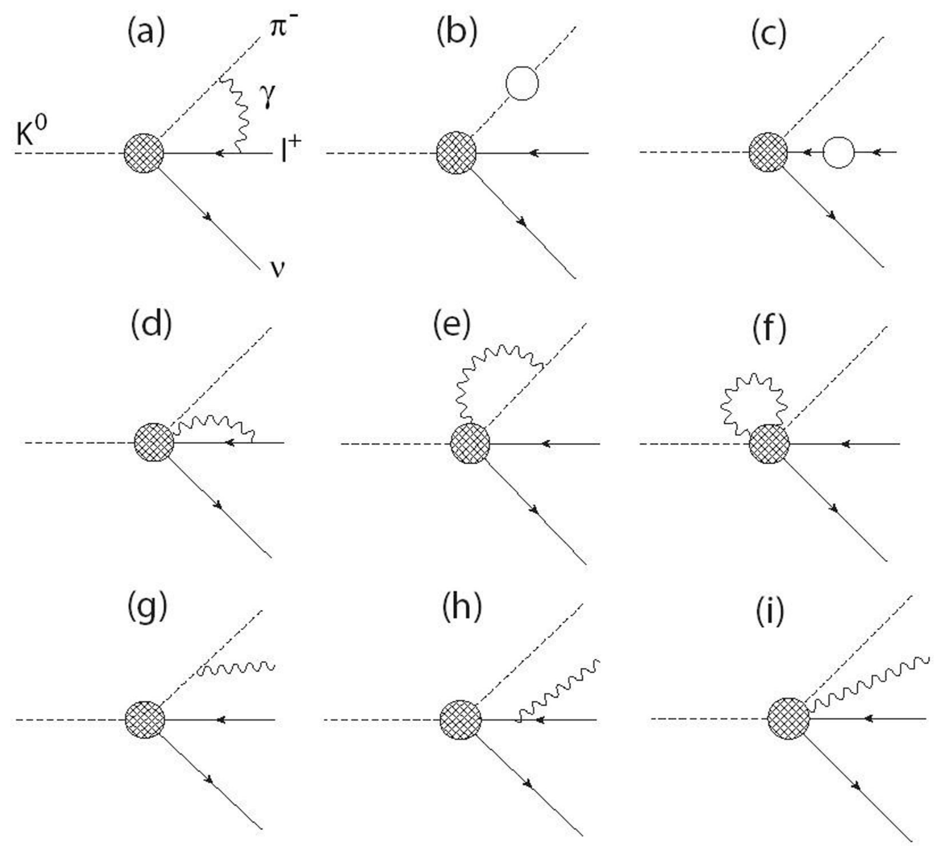
- Described by QED
- Infrared divergencies cancel out with virtual terms

⇒ $E^*_{\gamma} > 30$ MeV; $\theta^*_{e\gamma} > 20°$

DE structure dependent

- Expected $0.1 \div 1\%$ of IB

Good testing ground for χPT



First order radiative corrections

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

K^0_{e3} is the normalization channel: $R = \Gamma(K^0_{e3\gamma},\ E^*_\gamma > 30\ \mathrm{MeV},\ \theta^*_{e\gamma} > 20°)/\Gamma(K^0_{e3})$

Most precise measurement so far by KTeV:

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

"significantly lower than all published theoretical predictions" *PRD 64.112004*

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

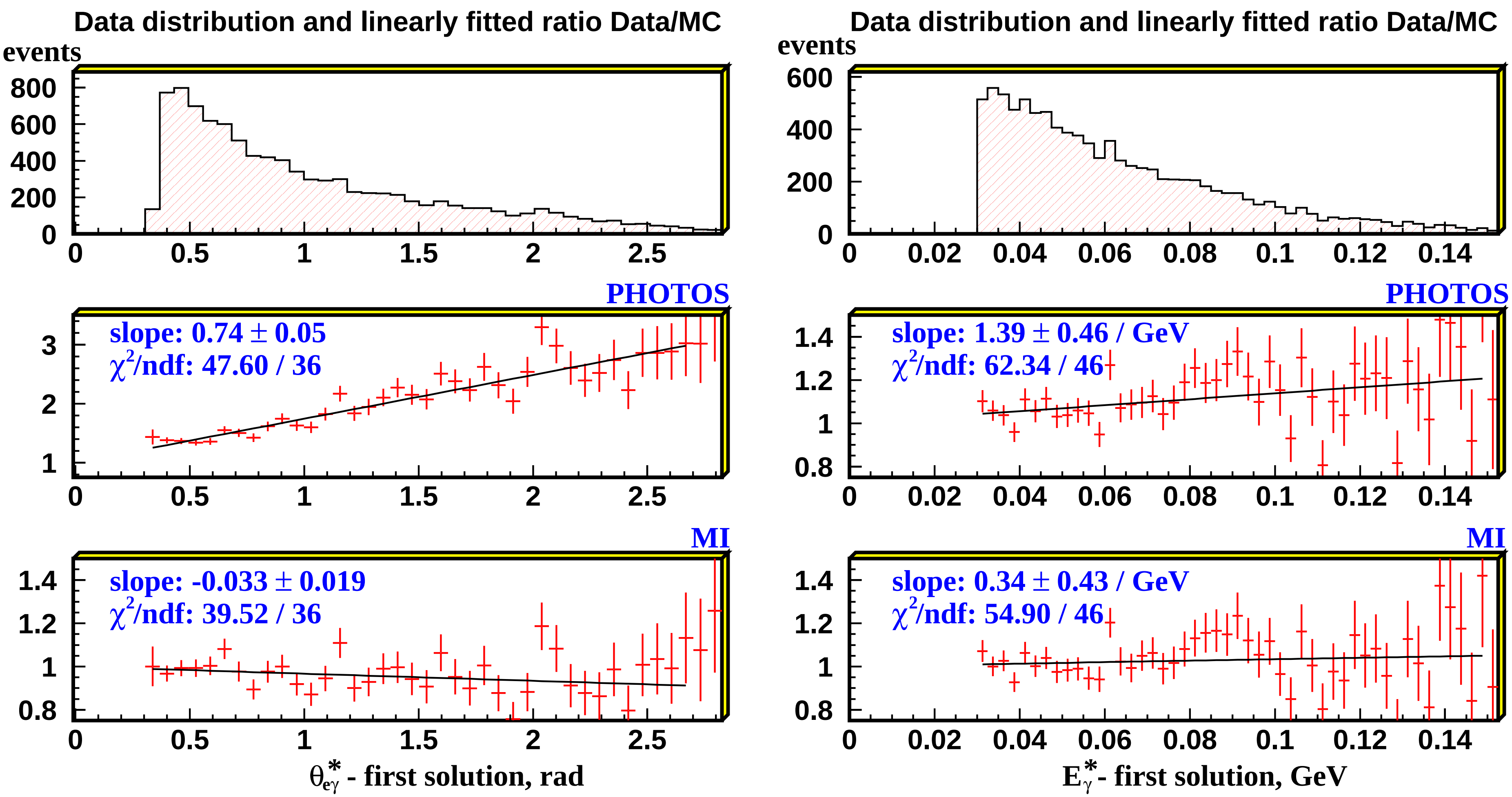
NA48 measurement:

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

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

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

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



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

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

- $K_L \rightarrow \pi^+\pi^-\pi^0$

$\Rightarrow$ suppressed by P_0' cut

- K_{e4}

$\Rightarrow$ determined with the MC

- K^0_{e3}+ fake γ (π shower leakage)

$\Rightarrow$ apply distance cut

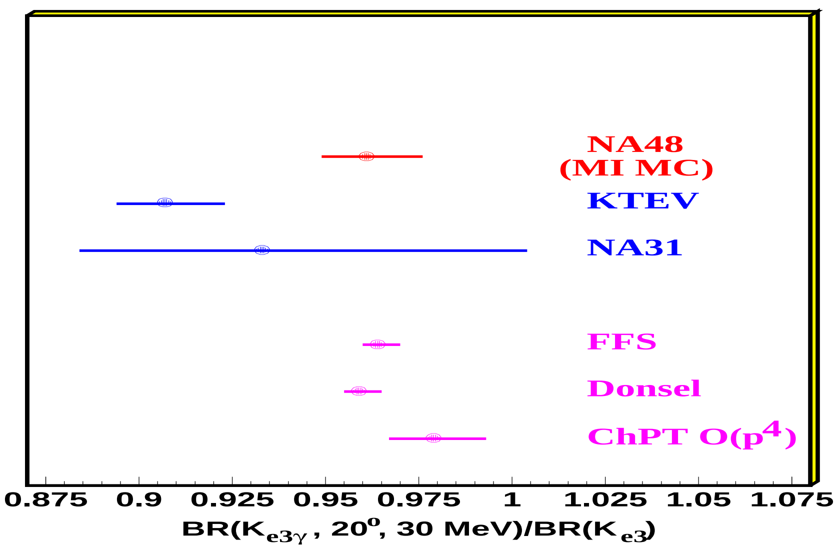
- K^0_{e3}+ accidental γ

$\Rightarrow$ time of γ candidate w.r.t. the other clusters

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

$$R = \frac{NK^0_{e3\gamma}}{NK^0_{e3}} \frac{AK^0_{e3}}{AK^0_{e3\gamma}} C_B\ C_A\ C_M$$

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



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

Preliminary

Summary

Preliminary results on K^0_{e3} decays:

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

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

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

No indication for scalar or tensor couplings

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

Other results on K_L:

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

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

Ongoing activities:

$K^0_{\mu3}$ Form Factors

K_{e3} and $K_{\mu3}$ BR and form factors with charged K at NA48/2