Measurement of $\frac{\Gamma(K^+ \to \pi^0 \mu^+ \nu)}{\Gamma(K^+ \to \pi^0 e^+ \nu)}$ using stopped positive kaons

K. Horie (Osaka Univ.)
and
KEK-E246 Collaboration

$\frac{\Gamma(K_{\mu3})}{\Gamma(K_{e3})}$: the ratio of $K^+ \to \pi^0 \mu^+ \nu$ ($K_{\mu3}$) and $K^+ \to \pi^0 e^+ \nu$ (K_{e3}) decay width

λ_0 : form factor of $K_{\mu3}$ and K_{e3} decay

Introduction

- K_{e3} and $K_{\mu 3}$ form factors

$$f_+(q^2) = f_+(0)[1 + \lambda_+ (q/m_\pi)^2],$$
$$f_0(q^2) = f_0(0)[1 + \lambda_0 (q/m_\pi)^2].$$

$q^2 = (P_K - P_\pi)^2$

- Γ/Γ - $\lambda_+ \lambda_0$ relation

$$\Gamma(K_{\mu 3})/\Gamma(K_{e3}) = 0.6457 - 0.19\lambda_+ + 1.42\lambda_0 + O(\lambda_+^2 + \lambda_+\lambda_0 + \lambda_0^2)$$

↑ obtained (λ_+)

[H.W. Fearing et al. Phys. Rev. D2 54

We presented a measurement of $\Gamma(K_{\mu 3})/\Gamma(K_{e3})$ and λ_0 parameter

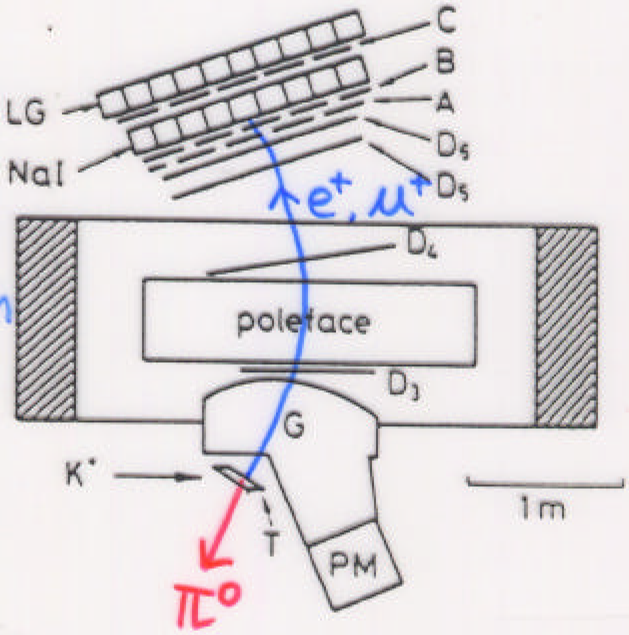
- Physics
  1. μ-e universality
     - λ_0^{BR} determined by Γ/Γ ass
     - λ_0^{DP} determined by $K_{\mu 3}$ Dalitz distribution NOT ass
  2. Chiral Perturbation Theory
     - λ_0 was predicted

Previous precise Γ'/Γ experiment

J. Heintz et al. Phys. Lett. B70 482 (1977)

- No π^0 detection
- Large background contamination

$K^+ \to \mu^+ \nu \gamma$
$K^+ \to \pi^+ \pi^- \pi^+$
$K^+ \to \pi^+ \pi^0 \pi^0$
$K^+ \to \pi^+ \pi^0$



Systematic error > 2× statistical error

$\lambda_0^{BR} = 0.019 \pm 0.010$

world record λ_0^{BR} was determined by the measureme

New measurement with π^0 detection had been needed.

Measurement

- Experimental Setup
  - K_{e3} form factors were simultaneously measured.
  - ToF : particle identification between e^+ and μ^+
  - π^0 was detected by CsI(Tl)
- Principle

accepted = decayed K^+ × acceptance × decay width

$$N(K_{e3}) = N_{K^+} \times [\Omega_{e^+}\Omega_{\pi^0}]_{K_{e3}} \times \Gamma(K_{e3})$$

$$N(K_{\mu3}) = N_{K^+} \times [\Omega_{\mu^+}\Omega_{\pi^0}]_{K_{\mu3}} \times \Gamma(K_{\mu3})$$

$$\frac{\Gamma(K_{\mu3})}{\Gamma(K_{e3})} = \boxed{\frac{N(K_{\mu3})}{N(K_{e3})}} \times \boxed{\frac{[\Omega_{e^+}\Omega_{\pi^0}]_{K_{e3}}}{[\Omega_{\mu^+}\Omega_{\pi^0}]_{K_{\mu3}}}}$$

↑ experiment ↑ simulation

Point

N : Background evaluation

Ω : Reproducibility of experimental conditi

Merit : Reduction of systematic error

- method

  similarity of the K_{e3} and $K_{\mu3}$ kinematic

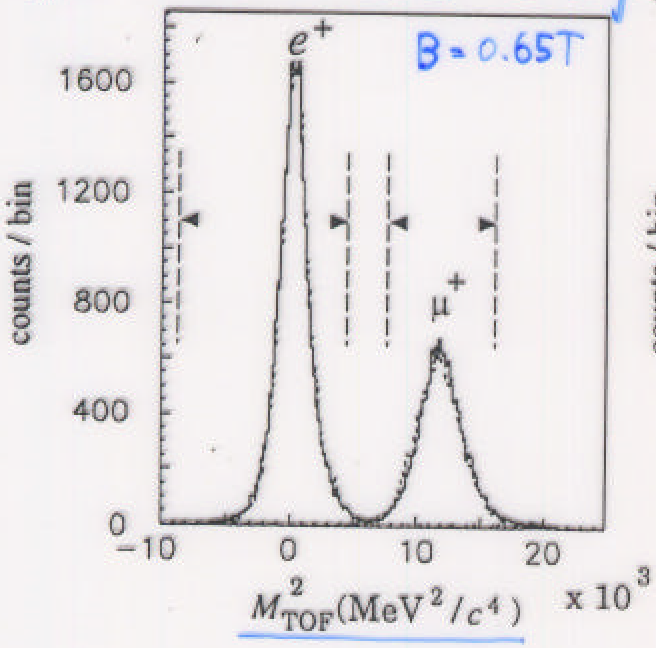
- experimental setup

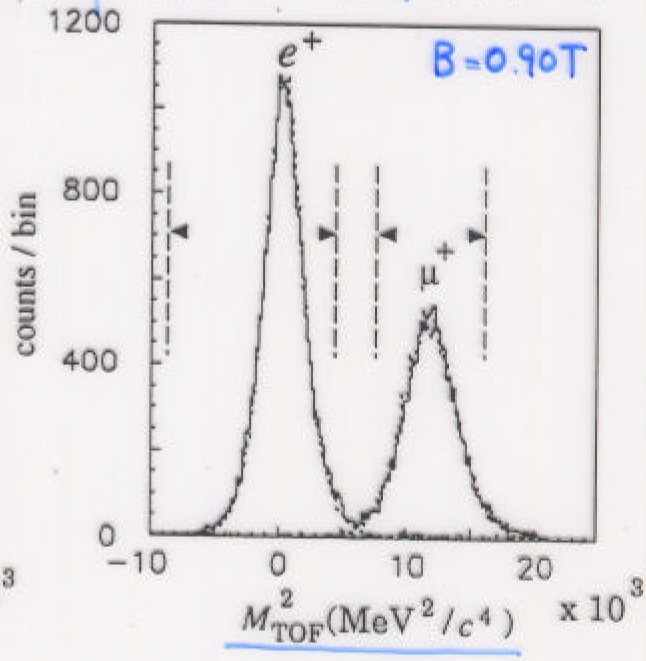
  complete kinematic reconstruction

Accepted number for Ke3, Kμ3

$$\frac{\Gamma(K_{\mu3})}{\Gamma(K_{e3})} = \boxed{\frac{N(K_{\mu3})}{N(K_{e3})}} \times \frac{\Omega_e \Omega_{\pi^0}}{\Omega_\mu \Omega_{\pi^0}}$$

After one π^0 and charged particle selection





13K events — 11 K Kμ3 event

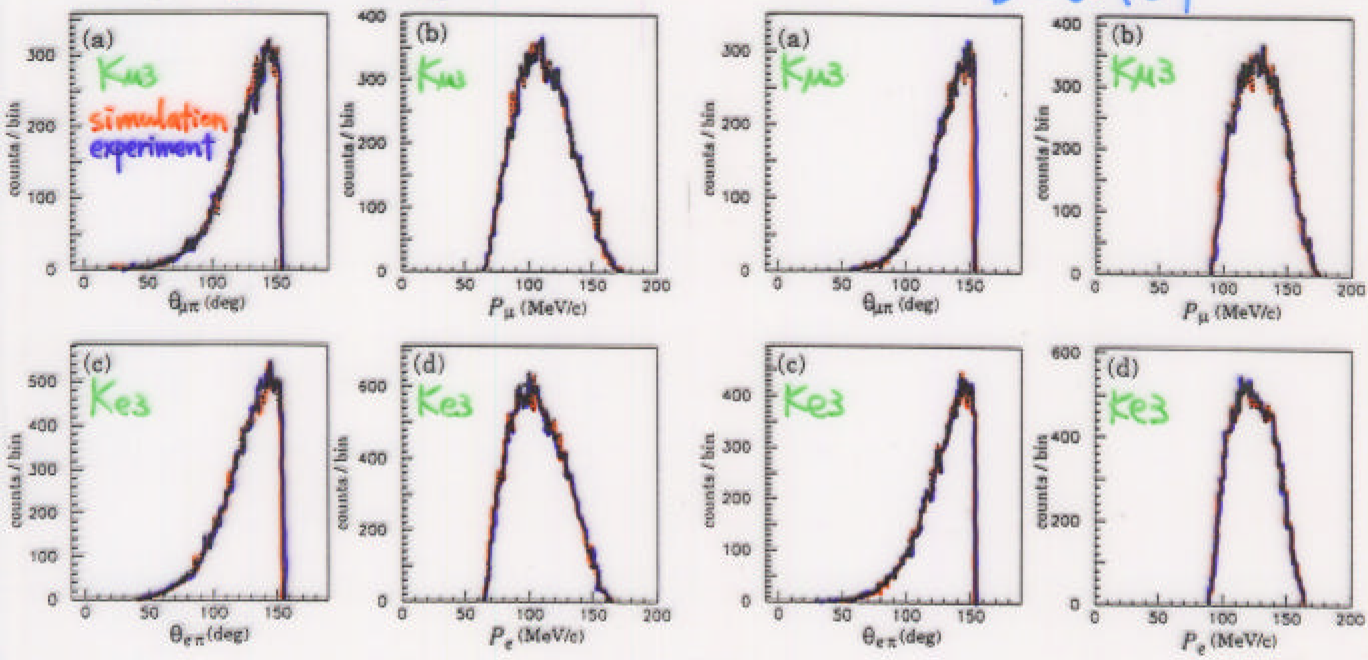
23K events — 17 K Ke3 event

were extracted

Acceptance determination

$$\frac{\Gamma(K_{\mu3})}{\Gamma(K_{e3})} = \frac{N(K_{\mu3})}{N(K_{e3})} \cdot \frac{[\Omega_e \Omega_{\pi^0}]_{K_{e3}}}{[\Omega_\mu \Omega_{\pi^0}]_{K_{\mu3}}}$$

B = 0.65 T B = 0.90 T



$\Omega(K_{\mu3}) = (1.79 \pm 0.01) \times 10^{-3}$

$(K_{e3}) = (2.16 \pm 0.01) \times 10^{-3}$

$\Omega(K_{\mu3}) = (1.67 \pm 0.01) \times ($

$(K_{e3}) = (1.76 \pm 0.01) \times ($

- Background evaluation

	background item	background fraction B=0.65 T	background fraction B=0.90 T	
$K_{\mu3}$	$K_{\pi2}$	0.6%	0.9%	← dominant
	K_{e3}	0.1%	0.1%	negligible
	$K_{\mu3\gamma}$	< 0.1%	< 0.1%	
K_{e3}	$K_{\pi2}$	0.4%	0.3%	←
	$K_{\mu3}$	< 0.1%	< 0.1%	}
	$K_{e3\gamma}$	< 0.1%	< 0.1%	

• Results

	$\Gamma(K_{\mu3})/\Gamma(K_{e3})$	λ_0
B = 0.65T	0.673± 0.010	0.023± 0.007
B = 0.90T	0.668± 0.011	0.020± 0.008
combined	0.671± 0.007	0.022± 0.005

• Systematic error

	$\Delta\Gamma(K_{\mu3})/\Gamma(K_{e3})$	$\Delta\lambda_0$
[Background contamination]		
decay-in-flight from $K_{\pi2}$ decay	0.004	0.003
TOF response	0.004	0.003
[Detector acceptance]		
instrumental misalignment	<0.001	<0.001
energy loss in the target	<0.001	<0.001
experimental error of the λ_+ parameter	0.001	0.001
ambiguity choice of the $K_{\mu3}\lambda_+$ parameter	0.005	–
total	0.008	0.004

} → domina

Similar in size to the statistical error

• Combined results

$\Gamma(K_{\mu3})/\Gamma(K_{e3}) = 0.671 \pm 0.007\,(stat.) \pm 0.008\,(sy$

$\lambda_0 = 0.022 \pm 0.005\,(stat.) \pm 0.004\,(sy$

λ_0 determination

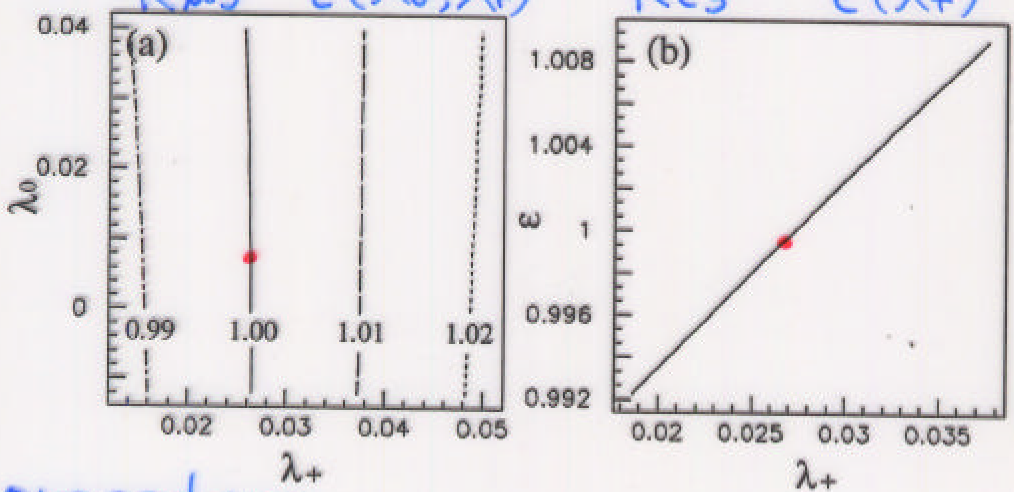
- principle determination

$$\Gamma(K_{\mu3})/\Gamma(K_{e3}) = 0.6457 - 0.19\lambda_+ + 1.42\boxed{\lambda_0} + O(\lambda$$

$$= \frac{N(K_{\mu3})}{N(K_{e3})} \cdot \frac{\Omega(K_{e3})}{\Omega(K_{\mu3})}$$

- Ω dependence on λ_0 λ_+

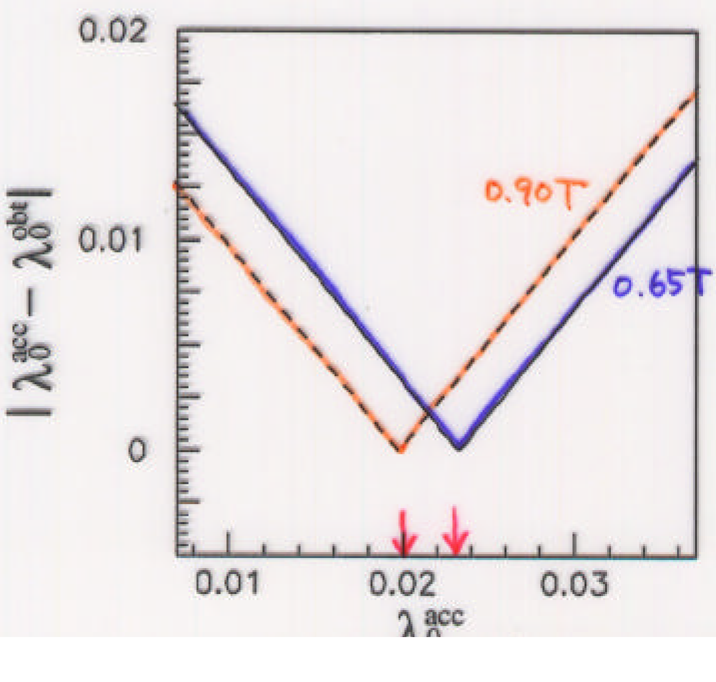
$K_{\mu3}$ $\varepsilon(\lambda_0, \lambda_+)$ K_{e3} $\varepsilon(\lambda_+)$



$$\varepsilon(\lambda_0, \lambda_+) = \frac{\Omega(\lambda_0, \lambda_+)}{\Omega(\lambda_0^\bullet, \lambda_+^\bullet)}$$

$$\left[\begin{array}{l}\lambda_0^\bullet = 0.006 \\ \lambda_+^\bullet = 0.0278\end{array}\right]$$

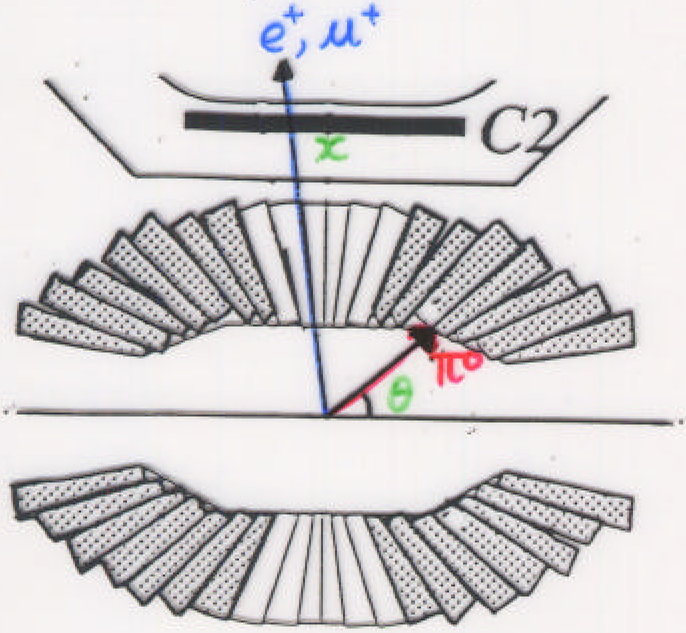
- procedure
  - Ω was determined by λ_0^{acc}
  - λ_0^{obt} was obtained
  - minimize $|\lambda_0^{acc} - \lambda_0^{obt}|$



$\lambda_0 = 0.023 \pm 0.007$ (0

$= 0.020 \pm 0.008$ (0

Validity of our Γ/P

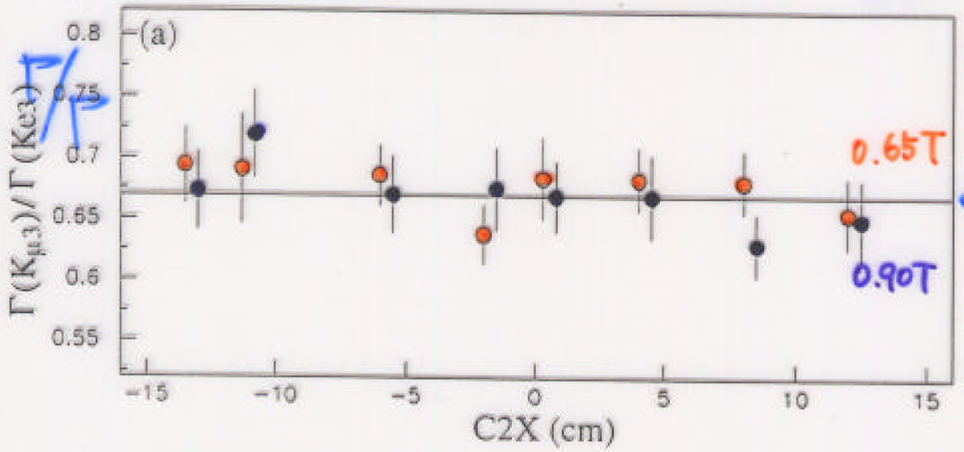


No reproducibility of detector acceptance

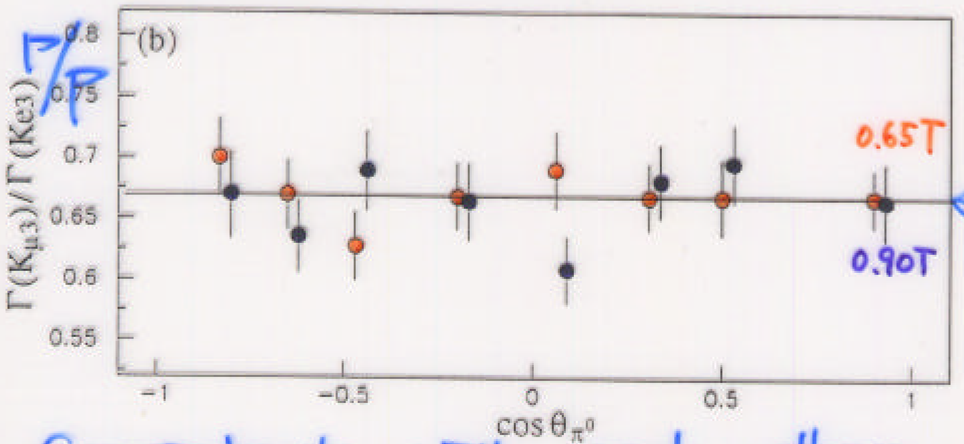
⇓

Γ/P should depend on x, θ

Dependence of Γ/P on π^0 and e^+, μ^+ direction



← combined Γ/P



← combined Γ/P

Consistent with each other

- Consistency check with regard to the different magnetic field

B= 0.65T Γ/P = 0.673 ± 0.010

Conclusion

$$\frac{\Gamma(K_{\mu 3})}{\Gamma(K_{e3})} = 0.671 \pm 0.007(\text{stat}) \pm 0.008(\text{syst.}$$

world average 0.680 ± 0.013

$$\lambda_0 = 0.022 \pm 0.005(\text{stat.}) \pm 0.004(\text{syst.}$$

world average 0.019 ± 0.010

Γ/Γ and λ_0 were precisely obtained

Discussion

1. μ-e universality

$$\lambda_0^{DP} = 0.029 \pm 0.011$$

[R. whitman et al. Phys. Rev. D21 652 (19

supports the validity of μ-e universali

2. Chiral Perturbation Theory (ChPT)

$$\lambda_0^{ChPT} = 0.017 \pm 0.004$$

[J. Gasser et al. Nucl. Phys. B250 517 (

support the validity of ChPT