V_{us} from kaon decays: Experimental status

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FlaviaNet Mini-Workshop on Kaon Decays

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Determination of V_{us} using K_{l3} rates

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 \, G_F^2 \, M_K^5}{192\pi^3} S_{EW} \, |V_{us}|^2 \, |f_+^{K^0\pi^-}(0)|^2 \times$$
$$I_{Kl}(\{\lambda\}_{Kl}) \, (1 + 2\Delta_K^{SU(2)} + 2\Delta_{Kl}^{EM})$$

with $K \in \{K^+, K^0\}$; $l \in \{e, \mu\}$, and:

C_K^2 1/2 for K^+, 1 for K^0

S_{EW} Universal SD EW correction (1.0232)

Inputs from theory:

$f_+^{K^0\pi^-}(0)$ Hadronic matrix element (form factor) at zero momentum transfer ($t = 0$)

$\Delta^K_{SU(2)}$ Form-factor correction for $SU(2)$ breaking

Δ^{Kl}_{EM} Form-factor correction for long-distance EM effects

Inputs from experiment:

$\Gamma(K_{l3(\gamma)})$ Rates with well-determined treatment of radiative decays:
- Branching ratios
- Kaon lifetimes

$I^{Kl}(\{\lambda\}_{Kl})$ Integral of form-factor over phase space: λs parameterize evolution in t
- K_{e3}: Only λ_+ (or λ_+', λ_+'')
- $K_{\mu3}$: Need λ_+ and λ_0

What's new since CKM '06 (Nagoya)

NA48 **Preliminary results published**
- **BR($K_L \to \pi^+\pi^-$): no changes**
- **BR($K^+ l3$)/BR($\pi\pi^0$): no changes**
- **$K_L\mu3$ form-factor slopes: final values slightly changed**

ISTRA+ **BR(K^+e3)/BR($\pi\pi^0$) submitted for publication**

KLOE **New preliminary $K_L e3$-$K_L\mu3$ form-factor slopes**

Most recent documentation: CKM '06 proceedings (hep-ex/0703013)
- Small changes in treatment of errors, corrections, etc.
- Final form-factor slopes from NA48 included
- New KLOE preliminary for λ_0 not yet included → **today**

Expect many new results at KAON '07!
- Calculations will be updated again to support speakers
- Wait until dust settles to finish memo

K_L branching ratios

KTeV
PRD 70 (2004)

5 ratios of main BRs from independent samples of 10^5-10^6 events collected with a single trigger

2-track ratios

BR($K_{\mu3}/K_{e3}$) = 0.6640(26)

BR($\pi^+\pi^-\pi^0/K_{e3}$) = 0.3078(18)

BR($\pi^+\pi^-/K_{e3}$) = 0.004856(28)

Neutral ratio

BR($2\pi^0/3\pi^0$) = 0.004446(25)

Mixed ratio

BR($3\pi^0/K_{e3}$) = 0.4782(55)

6 decays = 99.93% of K_L width
KTeV combines ratios to extract BRs

Our fit uses these BR ratios
Correlations available

NA48
PLB 602 (2004)

K_L beam only, 2-track sample, 80M events (6M signal)

$$\frac{\mathrm{BR}(K_{e3})}{\mathrm{BR}(2\ \mathrm{track})} = 0.4978(35) \approx \frac{\mathrm{BR}(K_{e3})}{1 - \mathrm{BR}(3\pi^0)}$$

NA48
preliminary

From BR($K_L \to 3\pi^0$)/BR($K_S \to 2\pi^0$)

$$\mathrm{BR}(3\pi^0)/\tau_L = 3.795(58)\ \mathrm{MHz}$$

K_L branching ratios and lifetime

KLOE
PLB 632 (2006)

Absolute BRs: K_L decays tagged by $K_S \to \pi^+\pi^-$
Errors on absolute BRs dominated by error on τ_L
Dependence on τ_L of geometrical efficiency known

For KLOE results: Set Σ_x BR($K_L \to x$) = 1 and solve for τ_L
For our fit: Use unconstrained BRs with dependence on τ_L

BR$^{(0)}$($Ke3$) = 0.4049(21)
BR$^{(0)}$($K\mu3$) = 0.2726(16)
BR$^{(0)}$($3\pi^0$) = 0.2018(24)
BR$^{(0)}$($\pi^+\pi^-\pi^0$) = 0.1276(15)

at $\tau_L^{(0)}$ = 51.54 ns, with
d BR/BR = 0.67$d\tau_L/\tau_L$

Correlations available

KLOE
PLB 626 (2005)

Lifetime: Direct measurement with $K_L \to 3\pi^0$ events
High, uniform reconstruction efficiency over 0.4λ_L
Independent of BR measurement

τ_L = 50.92(30) ns

cf. Vosburgh ’72: τ_L = 51.54(44) ns

$K_L \to \pi^+\pi^-$

New measurements of $K_L \to \pi^+\pi^-(\gamma)$ also useful in global fit

KTeV
PRD 70 (2004)

BR($\pi^+\pi^-/Ke3$) = 4.856(29) × 10⁻³
1 of 5 ratios in K_L BR analysis
Contribution from direct emission (DE) negligible

KLOE
PLB 638 (2006)

BR($\pi^+\pi^-/K\mu3$) = 7.275(68) × 10⁻³
Fully inclusive of DE component

NA48
PLB 645 (2007)

BR($\pi^+\pi^-/Ke3$) = 4.826(27) × 10⁻³
Residual DE contribution of 0.19% subtracted

For consistency and to better satisfy Σ BR = 1 in global fit,
DE contribution of **1.52(7)%*** added to **KTeV** and **NA48** results

* From E731 '93, KTeV '01 and KTeV '06 $K_L \to \pi^+\pi^-\gamma$ results

Fit to K_L BR and lifetime measurements

Availability of **comprehensive new K_L data set** with proper radiative corrections has **radically changed the PDG fit**

- **2004 fit used 50 measurements** - all but a handful pre-1990
- **2006 fit uses 17 measurements** - all but 2 post-2003

Compared to PDG 2006, our fit:

- Uses the KTeV BR ratios and KLOE BRs quoted before application of constraints

  In each case, PDG uses the constrained results and removes the $3\pi^0$ measurement from the fit
- Uses the NA48 preliminary $\Gamma(3\pi^0)$ and new BR($\pi^+\pi^-$) measurements
- Implements consistent treatment of DE for $K_L \to \pi^+\pi^-$

Results of fit to K_L BRs, τ

18 input measurements:

- **5 KTeV** ratios
- **NA48** BR($Ke3$/2 track)
- **NA48** $\Gamma(3\pi^0)$ [prelim.]
- **4 KLOE** BRs
  with dependence on τ_L
- **KLOE**, **NA48** BR($\pi^+\pi^-/Kl3$)
- **KLOE**, **NA48** BR($\gamma\gamma/3\pi^0$)
- **PDG** ETAFIT BR($2\pi^0/\pi^+\pi^-$)
- **KLOE** τ_L from $3\pi^0$
- **Vosburgh '72** τ_L

1 constraint: Σ BR = 1

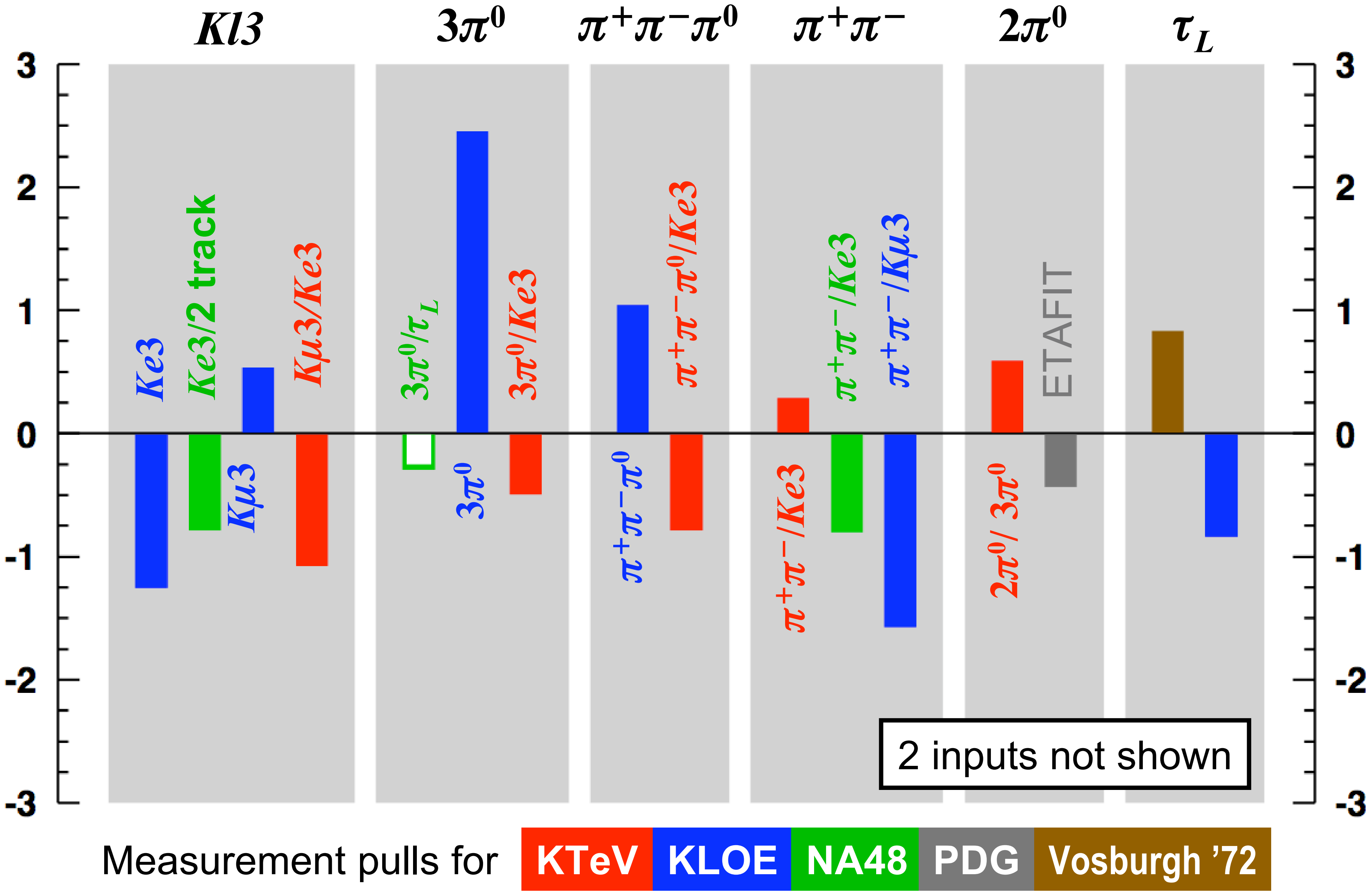
Parameter	Value	S
BR($Ke3$)	0.40563(74)	1.1
BR($K\mu3$)	0.27047(71)	1.1
BR($3\pi^0$)	0.19507(86)	1.2
BR($\pi^+\pi^-\pi^0$)	0.12542(57)	1.1
BR($\pi^+\pi^-$)	$1.9966(67)\times10^{-3}$	1.1
BR($2\pi^0$)	$8.644(42)\times10^{-4}$	1.3
BR($\gamma\gamma$)	$5.470(40)\times10^{-4}$	1.1
τ_L	51.173(200) ns	1.1

χ^2/ndf = 20.2/11 (Prob = 4.3%)

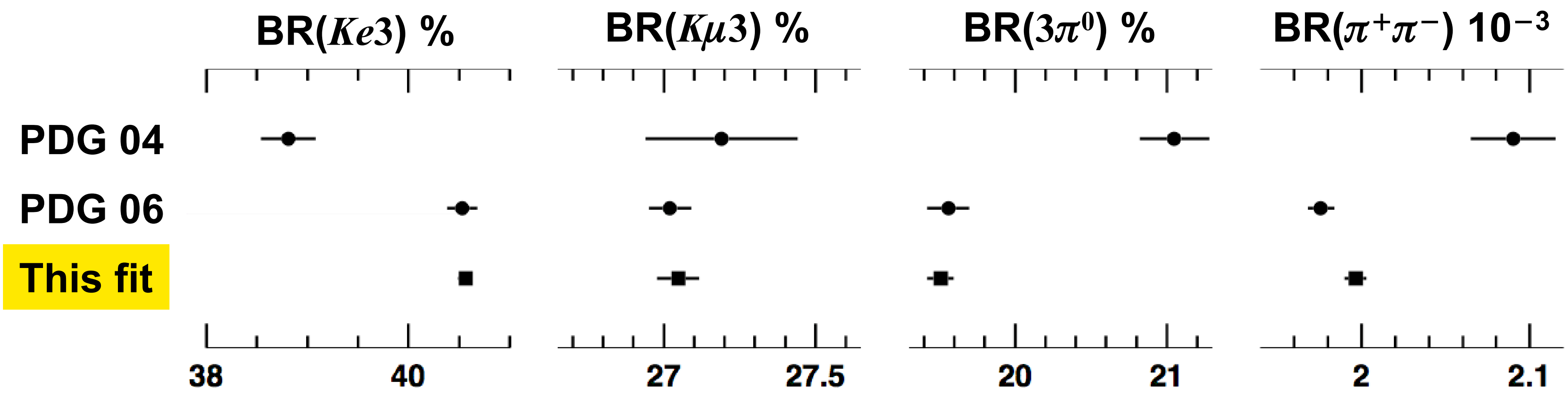
compare PDG '06: 14.8/10 (14%)

- Fit quality poorer than PDG '06 but scale factors more uniform
- PDG omits $3\pi^0$ results → large pulls for $Ke3$ and $3\pi^0$ measurements
- Even with scale factors, our fit reduces errors on $Ke3$ and $3\pi^0$

Comparison: K_L BR fit vs. data



Evolution of K_L BRs



PDG '04 → PDG '06:

- Consistent use of proper radiative corrections important for $Ke3$
- Exclusion of NA31 measurements significantly reduces BR($3\pi^0$)

Differences between our fit and PDG '06 are minor

From K_L BRs:	**PDG '04**	**This fit**	
$R_{\mu e} = \Gamma(K\mu3/\ Ke3)$	**0.701(9)**	**0.6668(24)**	Better agreement with lepton universality
$\mathrm{Re}\ \varepsilon'/\varepsilon \times 10^4$ using current K_S BRs	**-9 ± 12**	**15 ± 9**	Average of direct measurements: 16.7 ± 2.3

BR($K_S \to \pi e \nu$) and K_S lifetime

KLOE
PLB 636 (2006)

Using tagged K_S beam

BR($K_S \to \pi e \nu$)/BR($K_S \to \pi^+\pi^-$) = 10.19(13) × 10^{-4}

KLOE
EPJC 48 (2006)

410 pb^{-1}, averaged with KLOE ’02 result (17 pb^{-1})

BR($K_S \to \pi^+\pi^-$)/BR($K_S \to \pi^0\pi^0$) = 2.2549(54)

These two measurements completely determine main K_S BRs

BR($K_S \to \pi e \nu$) = 7.046(91) × 10^{-4}

PDG

τ_S = 0.08958(5) ns

From fit to CP parameters, does not assume CPT

Dominated by **NA48 ’02** and **KTeV ’03** τ_S values

Recent results on $K^{\pm}_{l3}$ BRs

NA48/2
EPJC 50 (2007)

Final results on BR($K^{\pm}e3/\pi\pi^0$) and BR($K^{\pm}\mu3/\pi\pi^0$)

BR($K^{\pm}e3$)/BR($\pi\pi^0$) = 0.2496(9)(4)
BR($K^{\pm}\mu3$)/BR($\pi\pi^0$) = 0.1637(6)(3)

Largest systematic from acceptance/PID corrections
Correlation provided

ISTRA+
arXiv:0704.2052

Final value for BR($K^{-}e3/\pi\pi^0$) submitted for publication

BR($K^{-}e3$)/BR($\pi\pi^0$) = 0.2449(4)(14)

Systematics studied by subdivision of large sample

KLOE
preliminary

Absolute BR($K^{\pm}e3$) and BR($K^{\pm}\mu3$) measurements

Separate measurements for each charge
Tagged by $K \to \mu\nu$ and $K \to \pi\pi^0$: 8 measurements total

BR$^{(0)}$($K^{\pm}e3$) = 5.047(92)%
BR$^{(0)}$($K^{\pm}\mu3$) = 3.310(81)%

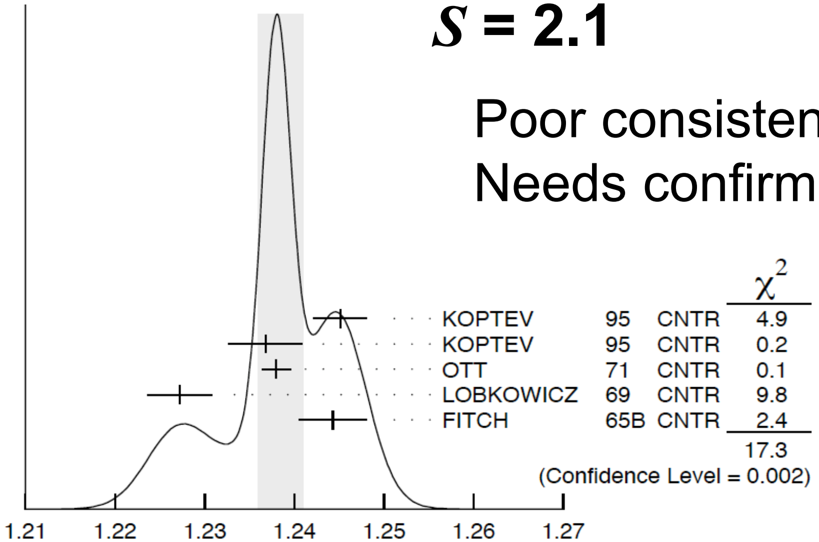
at $\tau_{\pm}^{(0)}$ = 12.36 ns, with d BR/BR = −0.50 $d\tau_{\pm}/\tau_{\pm}$

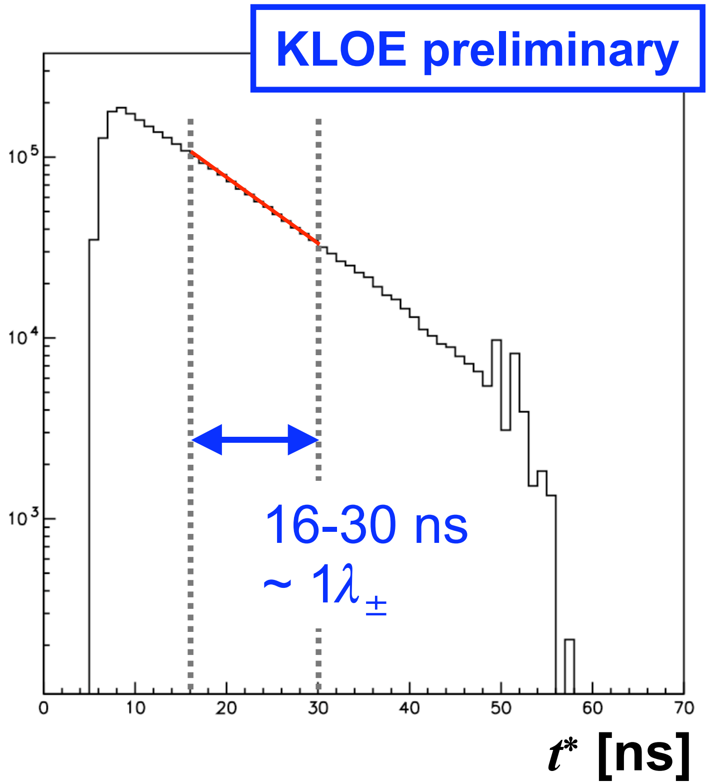
$K^{\pm}$ lifetime

PDG
average

12.385(25) ns
***S* = 2.1**

Poor consistency
Needs confirmation





KLOE
preliminary

Fit to t^* distribution from decay length
Use all $K \rightarrow \mu\nu$-tagged vertices in drift chamber

$\tau_{\pm}$= 12.367(78) ns

Fit to $K^{\pm}$ BR and lifetime measurements

Not possible to fit to only new $K^{\pm}$ data (unlike for K_L)

Only $Kl3$ and $Kl3/\pi\pi^0$ have been measured recently

- $Kl3$ and $\pi\pi^0$ highly correlated in fit
- New measurement of $\pi\pi^0$ is crucial

For channels like $\pi\pi^0$ and $\pi^+\pi^+\pi^-$, fit rests heavily on Chiang '72

- No radiative corrections
- 6 BRs constrained by Σ BR = 1, correlations unavailable

Compared to PDG 2006, our fit:

- Uses new results from NA48/2, ISTRA+, and KLOE (preliminary)
- Does not use BR($\pi^0\pi^0 e\nu$) as a free parameter

Results of fit to $K^{\pm}$ BRs, τ

30 input measurements:

- **5 older τ values in PDG**
- **KLOE τ**
- **KLOE BR($\mu\nu$)**
- **KLOE $Ke3$, $K\mu3$ BRs**
  with dependence on τ
- **ISTRA+ BR($Ke3/\pi\pi^0$)**
- **NA48/2 $Ke3/\pi\pi^0$, $K\mu3/\pi\pi^0$**
- **E865 BR($Ke3/K$Dal)**
- **6 Chiang '72 BRs**
- **3 old BR($\pi\pi^0/\mu\nu$)**
- **2 old BR($Ke3$/2 body)**
- **3 $K\mu3/Ke3$ (2 old)**
- **2 old + 1 KLOE results on 3π**

1 constraint: Σ BR = 1

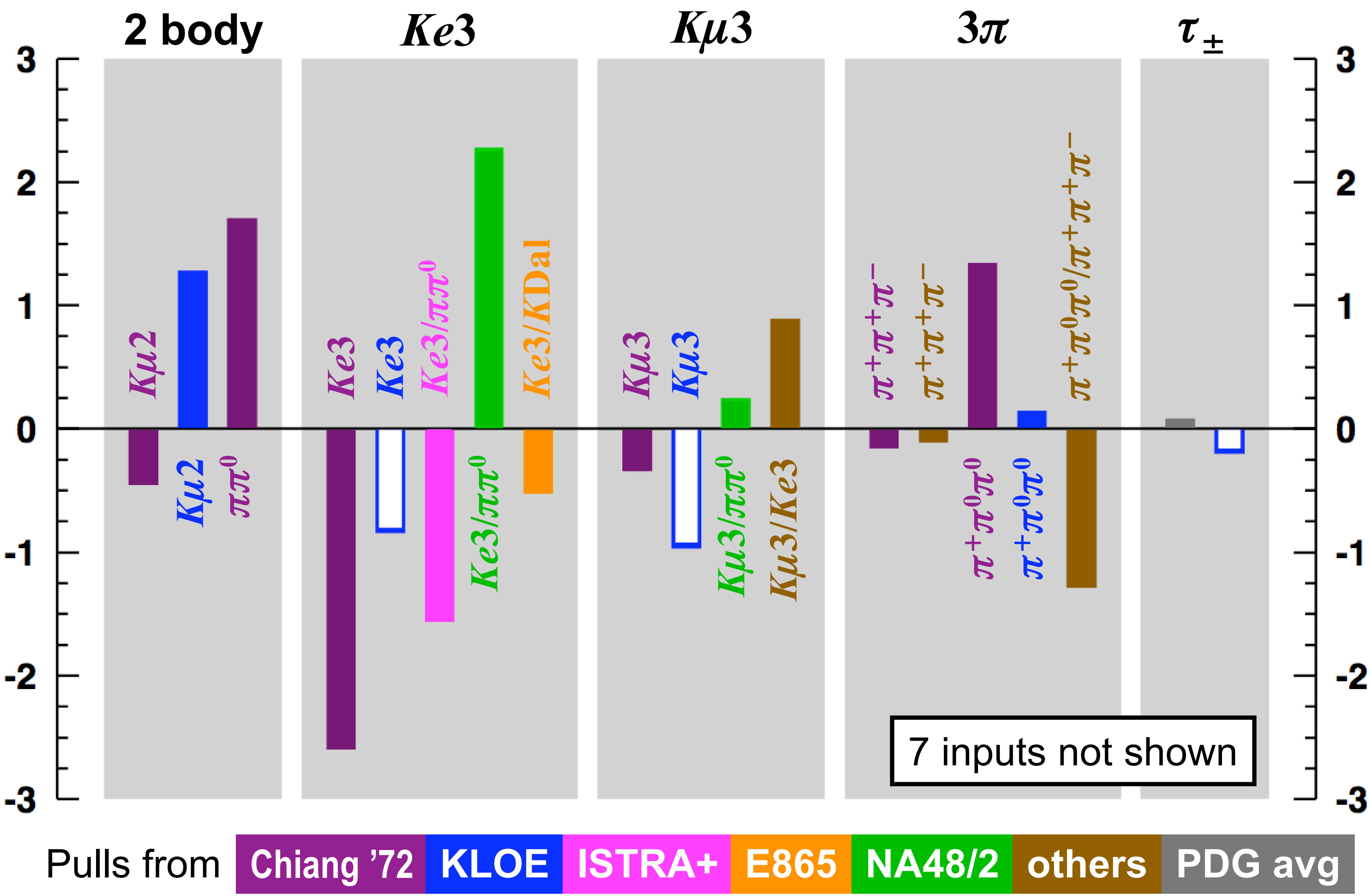
Parameter	Value	S
BR($\mu\nu$)	63.442(145)%	1.3
BR($\pi\pi^0$)	20.701(108)%	1.3
BR($\pi\pi\pi$)	5.5921(305)%	
BR($Ke3$)	5.121(38)%	1.6
BR($K\mu3$)	3.3855(203)%	1.2
BR($\pi\pi^0\pi^0$)	1.7592(234)%	1.1
$\tau_{\pm}$	12.3840(213) ns	1.8

χ^2/ndf = 49/24 (Prob = 0.21%)

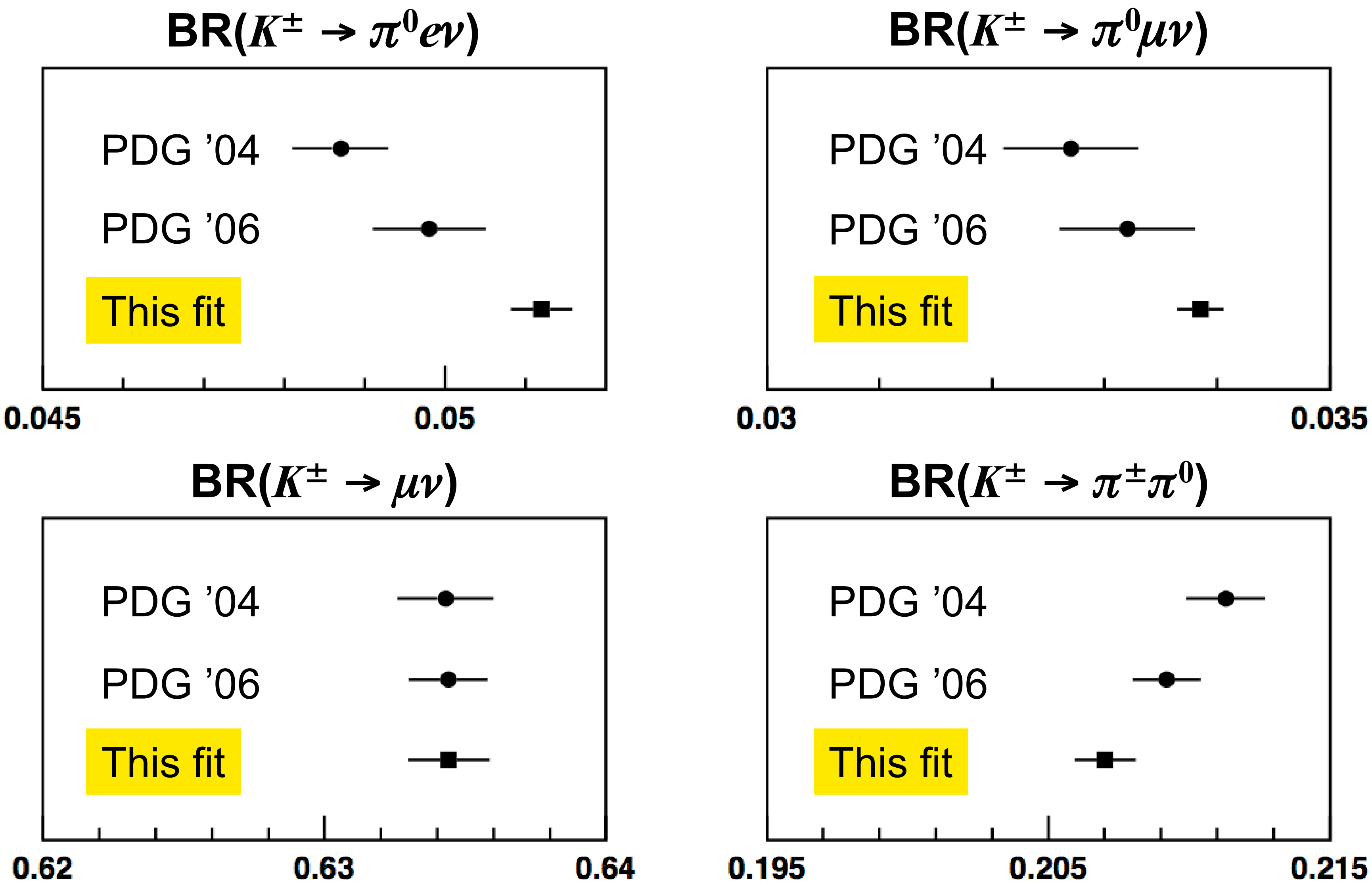
compare PDG '06: 30.0/19 (5.2%)

Improves to χ^2/ndf = 31.3/20 (5.1%) with no changes to central values or errors, if 5 older $\tau_{\pm}$ measurements replaced by PDG avg (with S = 2.1)

Comparison: $K^{\pm}$ BR fit vs. input data



Evolution of $K^\pm$ BRs

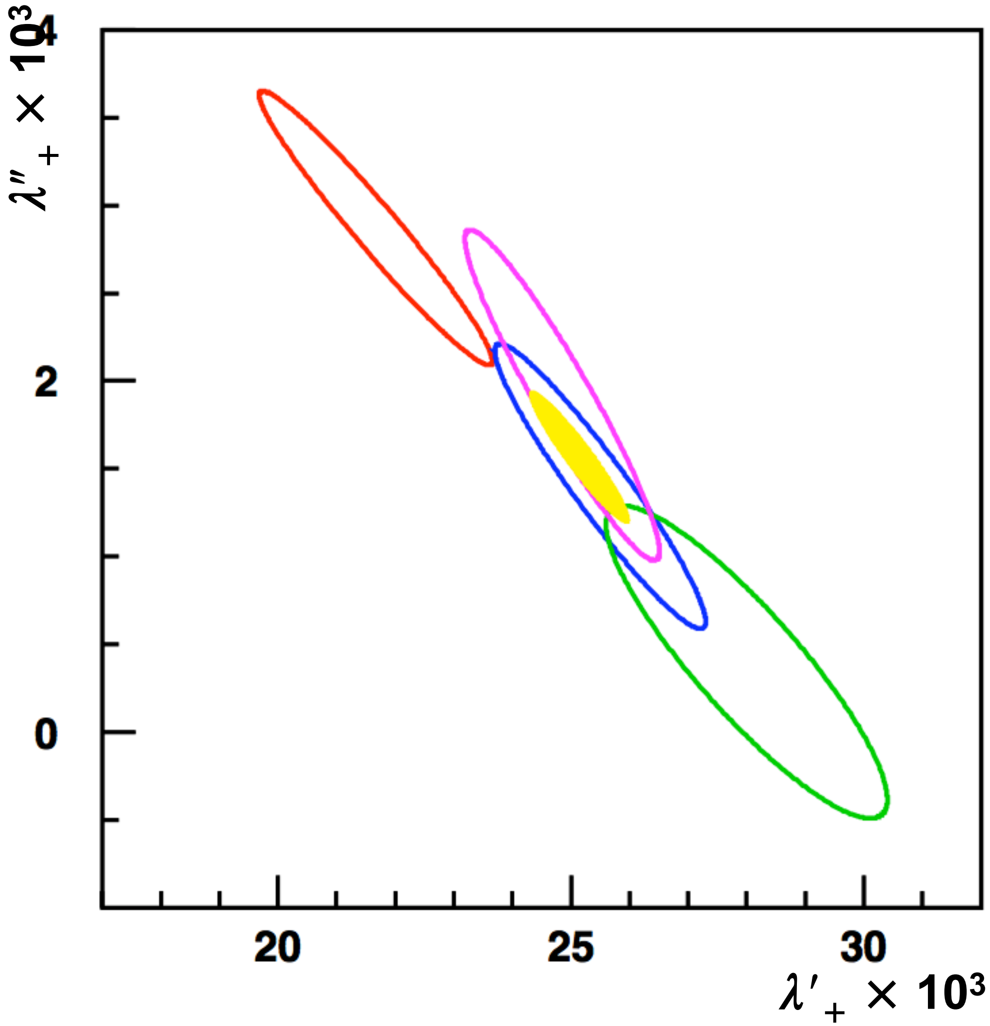


Current data on K_{e3} form-factor slopes

	Type	$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$	Analysis
KTeV PRD 70 (2004)	K_L	21.7 ± 2.0	2.9 ± 0.8	$t_\perp^\pi$
KLOE PLB 636 (2006)	K_L	25.5 ± 1.8	1.4 ± 0.8	t from K_S
NA48 PLB 604 (2004)	K_L	28.0 ± 2.4	0.4 ± 0.9	$(E_\nu^*, t_{\mathrm{low}}, t_{\mathrm{high}})$
ISTRA+ PLB 581 (2004)	K^-	24.9 ± 1.7	1.9 ± 0.9	(y, z) 2C fit

K_{e3} slopes: Quadratic fits

Slopes from KTeV KLOE ISTRA+ NA48 This fit



Slope parameters × 10³

$\lambda'_+ = 25.15 \pm 0.87$

$\lambda''_+ = 1.57 \pm 0.38$

$\rho(\lambda'_+, \lambda''_+) = -0.941$

$\chi^2/\text{ndf} = 5.3/6\ (51\%)$

Excellent compatibility
Significance of $\lambda''_+ > 4\sigma$

$I(K^0e3) = 0.15465(21)$

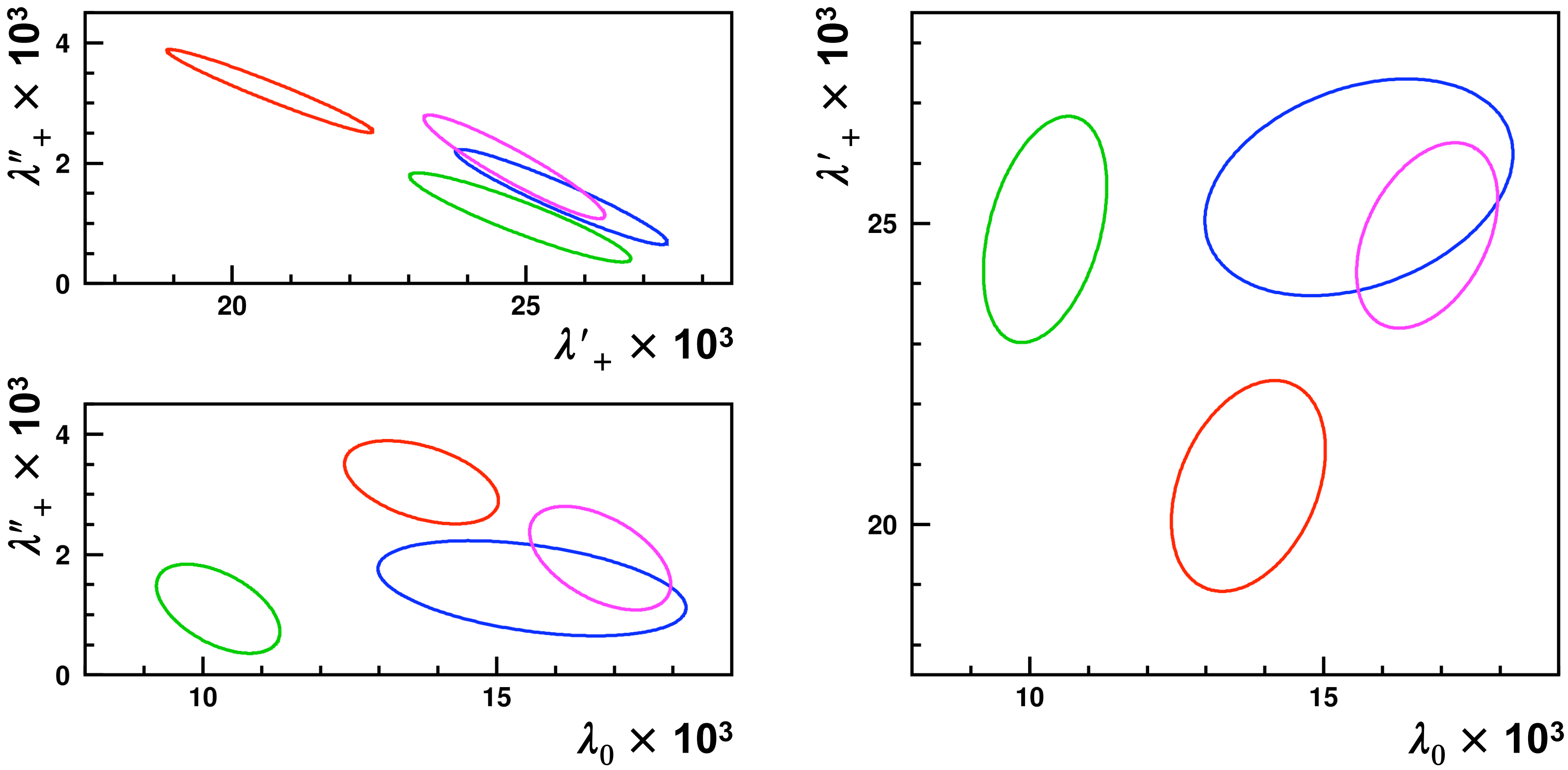
$I(K^+e3) = 0.15901(22)$

Current data on $K_{\mu 3}$ form-factor slopes

	$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$	$\lambda_0 \times 10^3$	Analysis
KTeV PRD 70 (2004)	17.0 ± 3.7	4.4 ± 1.5	12.8 ± 1.8	$(t_\perp^\mu, M_{\pi\mu})$
KLOE **preliminary**	25.6 ± 1.8	1.4 ± 0.8	15.6 ± 2.6	E_ν^* + $Ke3$ result
NA48 PLB 647 (2007)	20.5 ± 3.3	2.6 ± 1.3	9.5 ± 1.4	(y, z) low
ISTRA+ PLB 589 (2004)	23.0 ± 6.4	2.3 ± 2.3	17.1 ± 2.2	(y, z) 2C fit

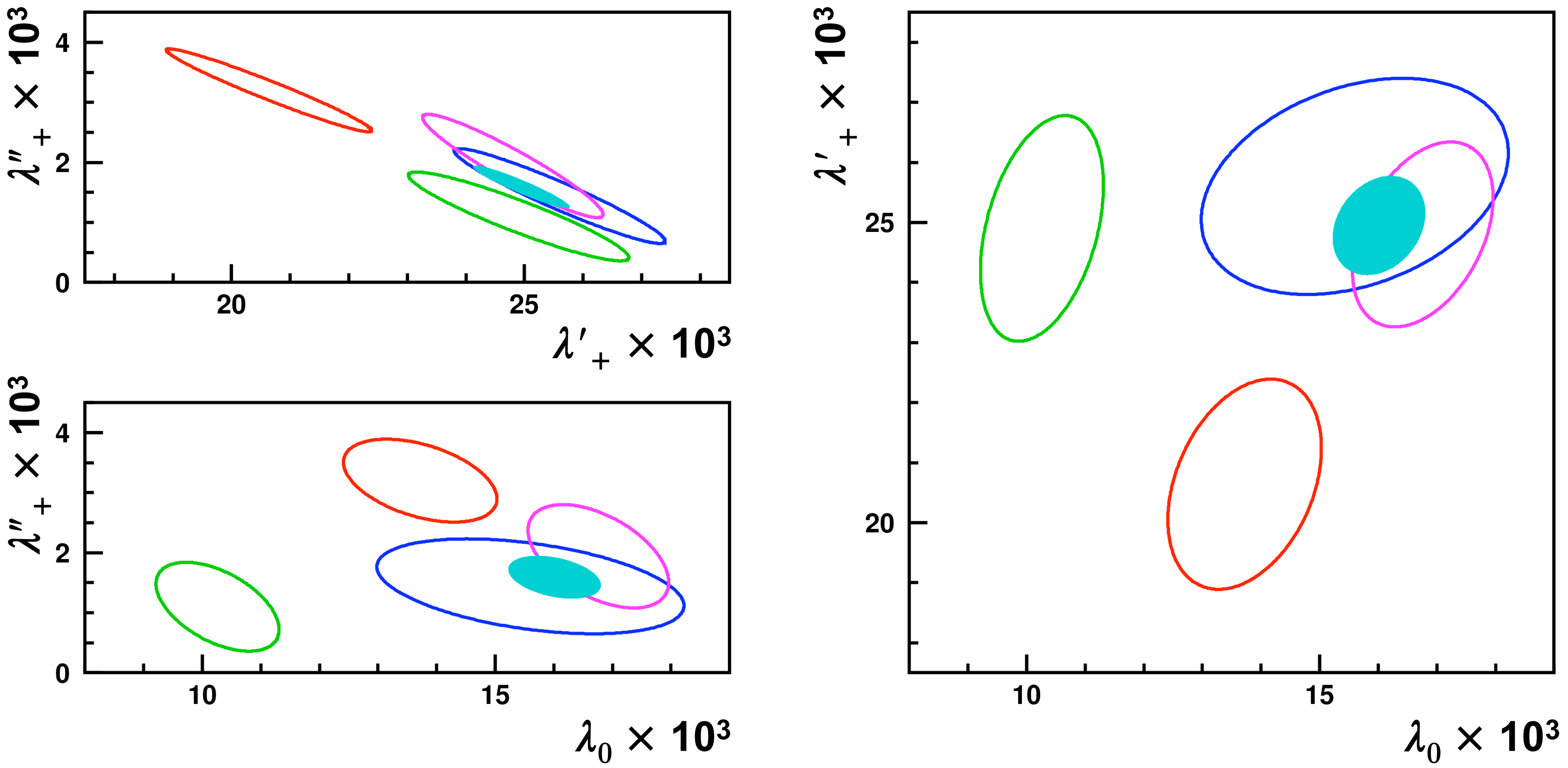
Fit to K_{l3} form-factor slopes

$e3$-$\mu3$ averages from **KLOE** **KTeV** **ISTRA+** **NA48**



Fit to K_{l3} form-factor slopes

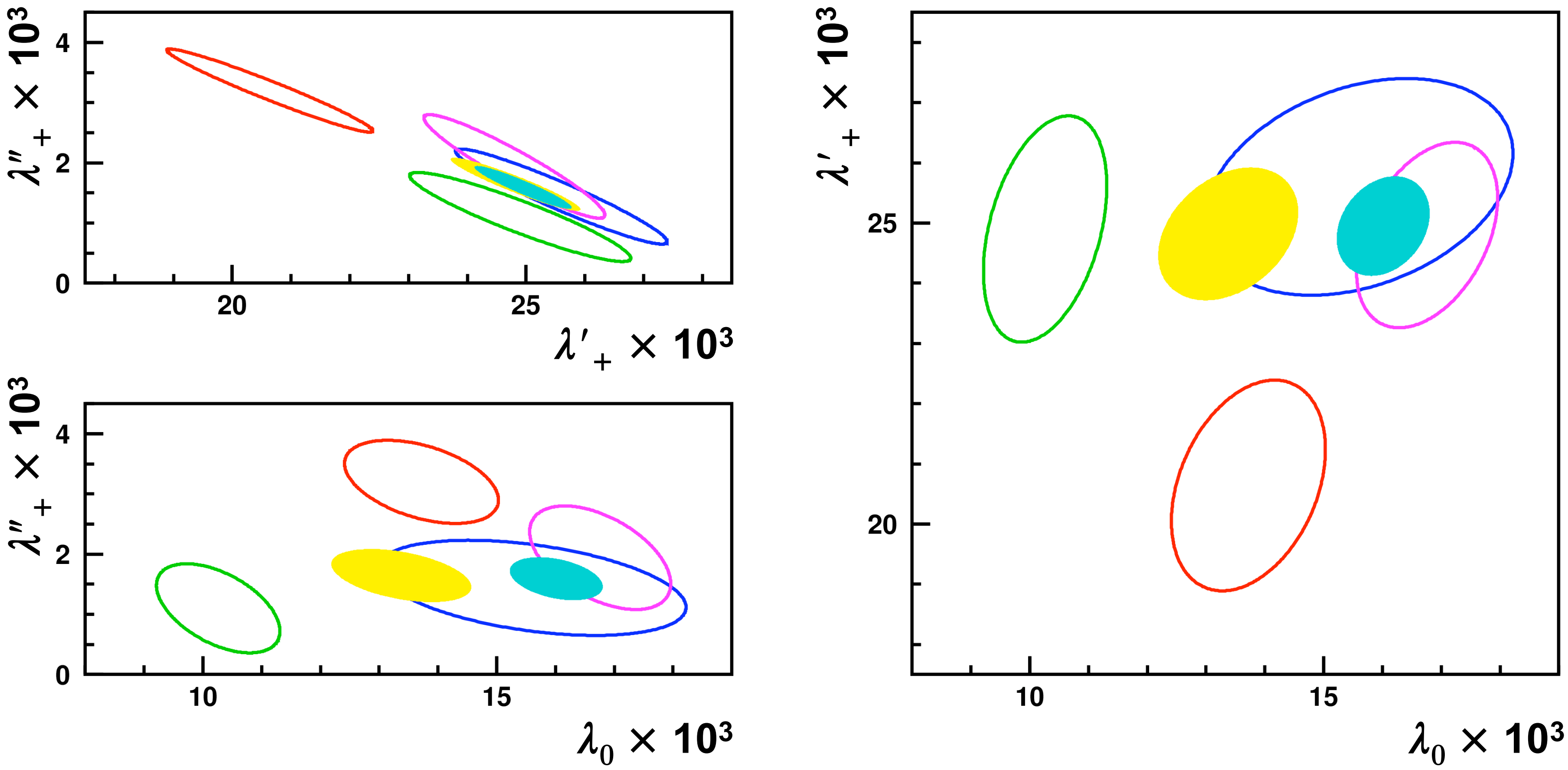
$e3$-$\mu3$ averages from **KLOE** **KTeV** **ISTRA+** **NA48**



$Kl3$ fit, no NA48 $K\mu3$: χ^2=12.2/10 (27.1%)

Fit to K_{l3} form-factor slopes

$e3$-$\mu3$ averages from **KLOE** **KTeV** **ISTRA+** **NA48**



$Kl3$ fit, no NA48 $K\mu3$: χ^2=12.2/10 (27.1%) | $Kl3$ fit, all data, χ^2=53/13 (10^{-6})

K_{l3} form-factor slopes: Fit results

Although compatibility poor, no *a priori* reason to exclude NA48 $K\mu 3$ data
Inconsistency parameterized by scale factors for fit results

Slope parameters × 10³:

$\lambda'_+ = 24.82 \pm 1.10 \quad S = 1.4$

$\lambda''_+ = 1.64 \pm 0.44 \quad S = 1.3$

$\lambda_0 = 13.38 \pm 1.19 \quad S = 1.9$

χ^2/ndf = 53/13 (10^{-6})

Correlation coefficients:

	λ'_+	λ_0
λ'_+		+0.32
λ''_+	−0.95	−0.43

Integrals	
$I(K^0e3)$	0.15454(29)
$I(K^+e3)$	0.15889(30)
$I(K^0\mu 3)$	0.10209(31)
$I(K^+\mu 3)$	0.10504(32)

These results used to evaluate $|V_{us}|\, f_+(0)$ for all modes

$SU(2)$ and EM corrections

$$\Delta^{SU(2)} = \begin{cases} 0 & \text{for } K^0 l3 \\ +2.31(22)\% & \text{for } K^+ l3 \end{cases}$$

Cirigliano et al. '02
ChPT

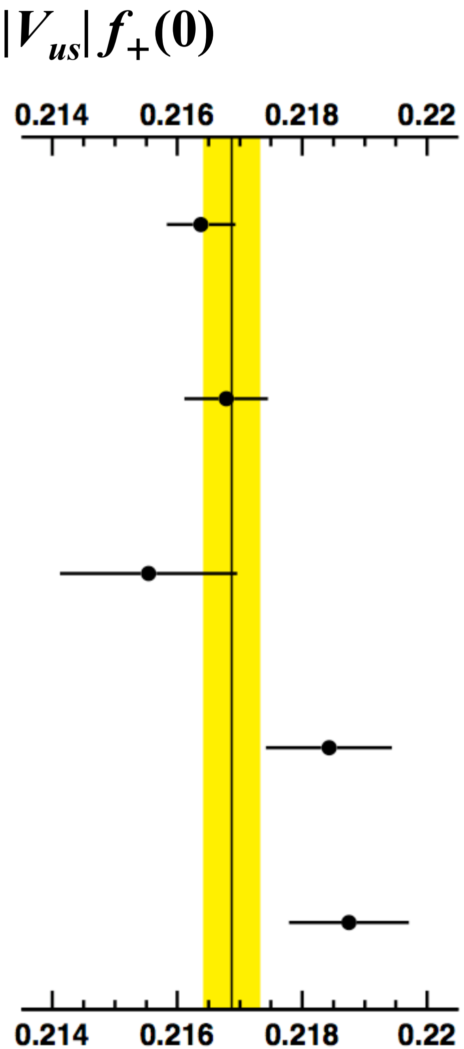
Δ^{EM} for full phase space - all measurements assumed fully inclusive

Δ^{EM}	**Cirigliano** ChPT	**Neufeld** ChPT	**Andre** Had. model
K^0e3	**+0.52(10)%**	+0.57(15)%	+0.65(15)%
K^+e3	**+0.03(10)%**	+0.08(15)%	
$K^0\mu3$		**+0.80(15)%**	+0.95(15)%
$K^+\mu3$		**−0.12(15)%**	

For this evaluation, use new ChPT estimates (Neufeld) for Km3 channels

Need common set of definitive values for Δ^{EM} *with correlation matrix*

$|V_{us}|\,f_+(0)$ from K_{l3} data



Approx. contrib. to % err from:

		% err	BR	τ	Δ	Int
$K_L e3$	**0.21638(55)**	**0.25**	0.09	0.19	0.10	0.10
$K_L \mu 3$	**0.21678(67)**	**0.31**	0.10	0.18	0.15	0.15
$K_S e3$	**0.21554(142)**	**0.66**	0.65	0.03	0.10	0.10
$K^{\pm} e3$	**0.21843(101)**	**0.46**	0.38	0.11	0.24	0.09
$K^{\pm} \mu 3$	**0.21875(96)**	**0.44**	0.31	0.10	0.26	0.15

Average: $|V_{us}|\,f_+(0)$ = 0.21687(46) **χ^2/ndf = 6.0/4 (20.2%)**

$|V_{us}|\, f_+(0)$: $K^\pm$ vs. $K_{L,S}$

Fit 5 modes with separate values of $|V_{us}|\, f_+(0)$ for $K^\pm$ and $K_{L,S}$ modes

- Using results of overall fit to form-factor slopes
- With $SU(2)$ corrections for $K^\pm$ modes [$\Delta^{SU(2)}{}_{\text{th}}$ = 2.31(22)%]

$K^\pm$ modes
$|V_{us}|\, f_+(0)$ = 0.21856(88)

↔

$K_{L,S}$ modes
$|V_{us}|\, f_+(0)$ = 0.21641(50)

2.25σ difference

χ^2/ndf = 0.90/3 (83%) ρ = 0.12

When fit performed without $SU(2)$ corrections for $K^\pm$ modes,
obtain an experimental value for $\Delta^{SU(2)}$

$K^\pm$ modes, no $SU(2)$
$|V_{us}|\, f_+(0)$ = 0.22362(76)

$\Delta^{SU(2)}{}_{\text{exp}}$ = 3.33(39)%

K_{l3} data and lepton universality

For each state of kaon charge, we evaluate:

$$r_{\mu e} = \frac{(R_{\mu e})_{\text{obs}}}{(R_{\mu e})_{\text{SM}}} = \frac{\Gamma_{\mu 3}}{\Gamma_{e3}} \cdot \frac{I_{e3}\,(1+\delta_{e3})}{I_{\mu 3}\,(1+\delta_{\mu 3})} = \frac{[|V_{us}|\,f_+(0)]^2_{\mu 3,\,\text{obs}}}{[|V_{us}|\,f_+(0)]^2_{e3,\,\text{obs}}} = \frac{(G_F^\mu)^2}{(G_F^e)^2}$$

$K^\pm$ modes

$r_{\mu e}$ = 1.0029(80)

Using 2004 BRs*

$r_{\mu e}$ = 1.019(13)

$K_{L,S}$ modes

$r_{\mu e}$ = 1.0039(56)

Using 2004 BRs*

$r_{\mu e}$ = 1.054(15)

Average

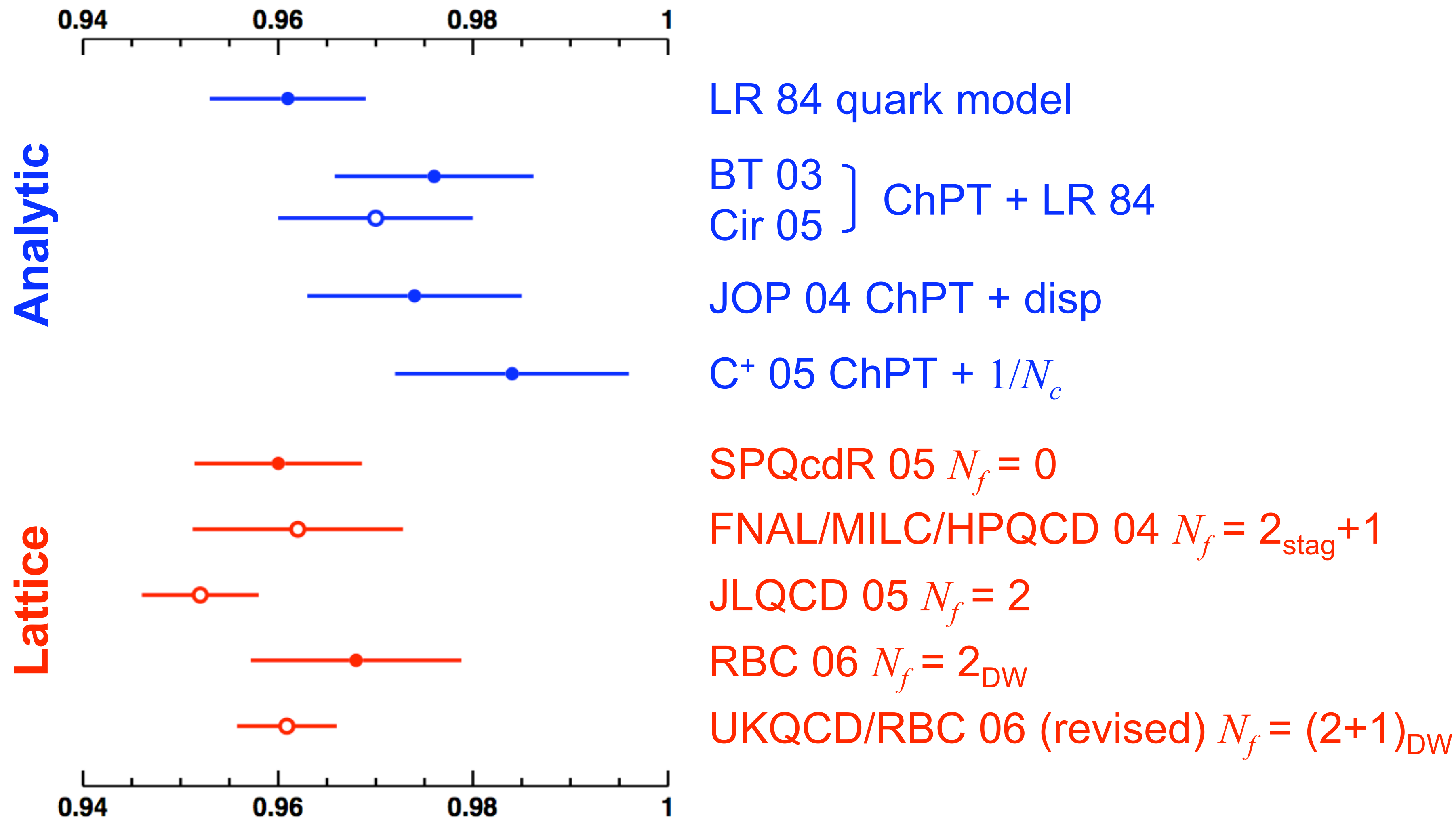
(incl. ρ = 0.13)

$r_{\mu e}$ = 1.0036(49)

Compare sensitivity from $\pi \to l\nu$ decays: **$(r_{e\mu})_{\pi l2}$ = 0.9966(30)**
see Erler, Ramsey-Musolf '06

*Assuming current values for form-factor slopes and Δ^{EM}

Evaluations of $f_+(0)$



Leutwyler & Roos estimate (LR 84) still widely used: $f_+(0)$ **= 0.961(8)**

Lattice evaluations generally agree well with this value

$|V_{us}|$ from K_{l3} data and CKM unitarity

K_{l3} average: $|V_{us}| f_+(0)$ = 0.21687(46)

Leutwyler & Roos '84
$f_+(0)$ = **0.961(8)**

Conventional choice for value of $f_+(0)$ until a definitive evaluation becomes available

K_{l3} average: $|V_{us}|$ = 0.2257(19)

Marciano & Sirlin '06
$|V_{ud}|$ = **0.97377(27)**

Average from $0^+ \rightarrow 0^+$ β decays with recent evaluation of EW radiative corrections

$V_{ud}^2 + V_{us}^2 - 1 = -0.0008(10)$
Compatibility with unitarity -0.8σ

V_{ud}, V_{us} & BR($K^{\pm} \to \mu^{\pm}\nu$)

Marciano '04

$$\frac{\Gamma(K^{\pm} \to \mu^{\pm}\nu(\gamma))}{\Gamma(\pi^{\pm} \to \mu^{\pm}\nu(\gamma))} = \frac{|V_{us}|^2 f_K^2 \, m_K \, (1 - m_\mu^2/m_K^2)^2}{|V_{ud}|^2 f_\pi^2 \, m_\pi \, (1 - m_\mu^2/m_\pi^2)^2} \times 0.9930(35)$$

Uncertainty from SD virtual corrections

MILC '06 preliminary

f_K/f_π **= 1.208(2)($^{+7}_{-14}$)**
N_f = $(2+1)_{\text{stag}}$
Cancellation of lattice-scale uncertainties

KLOE
PLB 636 (2006)

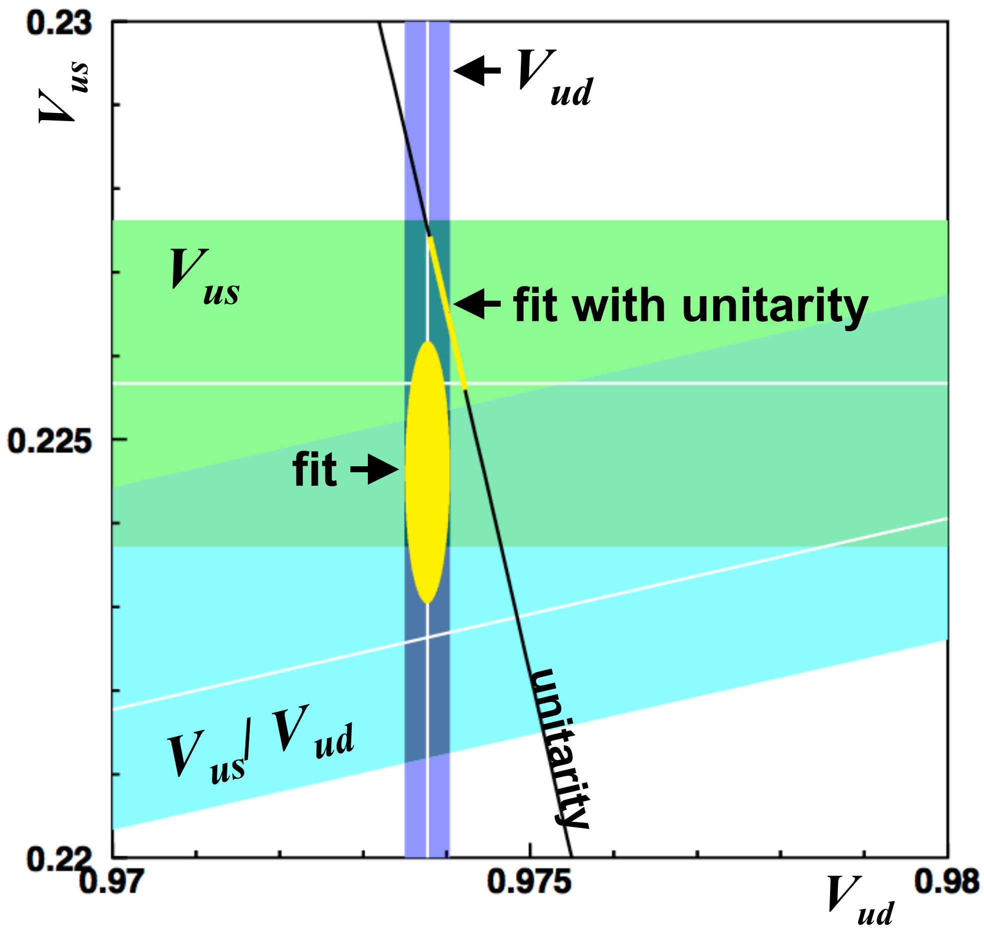
BR($K^+ \to \mu^+\nu(\gamma)$) = 0.6366(17)
Uses $K^- \to \mu^-\nu$ to tag 2-body K decays
Counts $K^+ \to \mu^+\nu$ from decay-momentum spectrum

Use KLOE BR($K^+ \to \mu^+\nu(\gamma)$) instead of value from BR/lifetime fit:
Error slightly larger, but radiative contribution under better control

$$V_{us}/V_{ud} = 0.2286(^{+27}_{-15})$$

V_{ud}, V_{us} & BR($K^{\pm} \rightarrow \mu^{\pm}\nu$)

$f_+(0)$ from LR 84
$|V_{us}|$ = 0.2257(19) from $Kl3$



Fit results, no constraint:

V_{ud} = 0.97377(27)
V_{us} = 0.2246(16)
χ^2/ndf = 0.85/1 (36%)

Fit results, unitarity constraint:

V_{ud} = 0.97401(22)
V_{us} = 0.2265(9)
χ^2/ndf = 3.04/2 (22%)

Agreement with unitarity at 1.2σ

Summary and outlook

$Kl3$ average: $|V_{us}|\,f_+(0)$ = 0.21687(46)

Prob(χ^2) for fits:

$|V_{us}|\,f_+(0)$ 5-mode avg: 20% (good!)

K_L BR/τ fit:	**4.3%** (acceptable)
$K^\pm$ BR/τ fit:	**0.21% → 5.3%** (marginal)
Form-factor slopes:	**10^{-6}** (terrible!)

- New $K^\pm$ rate measurements being finalized/published
- Accuracy of $\Delta^{SU(2)}$ a significant issue for charged modes
  Some evidence that $\Delta^{SU(2)}$ may be underestimated
- Experimental uncertainty on $|V_{us}|\,f_+(0)$ at 0.2% level
- Dominant contribution to uncertainty on $|V_{us}|$ still from $f_+(0)$
- With $f_+(0)$ = 0.961(8), first-row unitarity test satisfied at ~1σ level

KAON '07: What to expect

KAON'07 — Laboratori Nazionali di Frascati dell'INFN — May 21 - 25, 2007

Home | Program | Bulletin | Speakers | Registration | Travel | Lodging | Participants | LOC | IAC | Events | Important date

Session I Vus (14:30->19:10) — **Location:** High Energy Building - Aula Bruno Touschek

	14:30	Precision tests of the SM via Kl3 decays (30')	Vincenzo Cirigliano (*Los Alamos*)
	15:00	Theoretical progress on Vus extraction from tau decays (30')	Antonio Pich (*Valencia University, IFIC*)
	15:30	Tau hadronic decays and measurement of Vus (20')	Swagato Banerjee (*University of Victoria*)
	15:50	K to pi semileptonic form factor with 2+1 flavor Domain Wall Fermions on the lattice (20')	Andreas Juettner (*Univ. of Southampton*)
NA48/2	16:10	NA48/2 Final results on charged semileptonic kaon decays and Vus (30')	Anne Dabrowski (*Department of Physics and Astronomy, Northwestern University*)
	16:40	Coffee break	
	17:00	Dispersive representation and shape of K_{l3} form factors. (20')	Emilie Passemar (*IPN Orsay*)
	17:20	Did one observe couplings of right - handed quarks to W? (30')	Jan Stern (*IPN Orsay*)
KLOE	17:50	KLOE measurement of the charged kaon absolute semileptonic BR's (20')	Barbara Sciascia (*LNF - INFN, Frascati*)
ISTRA+	18:10	Measurement of Ke3 branching ratio and study of K to mu nu gamma decay at ISTRA+ setup (20')	Viacheslav Duk (*INR RAS*)
KLOE	18:30	KLOE measurement of the scalar Form-Factor slope for $K_L \rightarrow \pi \mu \nu$ decay. (20')	Claudio Gatti (*LNF - INFN, Frascati*)
KLOE	18:50	KLOE measurements of the charged Kaon lifetime and BR(K+ into pi+ pi0) (20')	Paolo Massarotti (*Naples University & INFN*)

Additional information

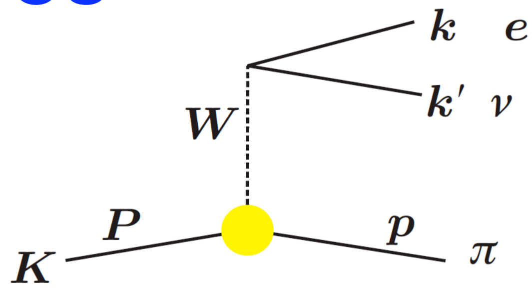
Fit to K_L BRs, τ: Comparison to PDG

Parameter	This fit Value	This fit S	PDG 2006 Value	PDG 2006 S
$Ke3$	0.40563(74)	1.1	0.4053(15)	2.1
$K\mu3$	0.27047(71)	1.1	0.2702(7)	
$3\pi^0$	0.19507(86)	1.2	0.1956(14)	1.9
$\pi^+\pi^-\pi^0$	0.12542(57)	1.1	0.1256(5)	
$\pi^+\pi^-$	$1.9966(67) \times 10^{-3}$	1.1	$1.976(8) \times 10^{-3}$	
$2\pi^0$	$8.644(42) \times 10^{-4}$	1.3	$8.69(4) \times 10^{-4}$	1.1
$\gamma\gamma$	$5.470(40) \times 10^{-4}$	1.1	$5.48(5) \times 10^{-4}$	1.2
τ	51.173(200) ns	1.1	51.14(21) ns	
	18 measurements χ^2/ndf = 20.2/11 (4.3%)		17 measurements χ^2/ndf = 14.8/10 (14.0%)	

Fit to $K^{\pm}$ BRs, τ: Comparison to PDG

Parameter	This fit Value	S	PDG 2006 Value	S
$\mu\nu$	63.442(145)%	1.3	63.44(14)%	1.2
$\pi\pi^0$	20.701(108)%	1.3	20.92(12)%	1.1
$\pi\pi\pi$	5.5921(305)%		5.590(31)%	1.1
$Ke3$	5.121(38)%	1.6	4.98(7)%	1.3
$K\mu3$	3.3855(203)%	1.2	3.32(6)%	1.2
$\pi\pi^0\pi^0$	1.7592(234)%	1.1	1.757(24)%	1.1
$\pi^0\pi^0e\nu$	Not in fit		$2.2(4) \times 10^{-5}$	
τ	12.3840(213) ns	1.8	12.385(24) ns	2.1
	30 measurements		26 measurements	
	χ^2/ndf = 49/24 (0.21%)		χ^2/ndf = 30.0/19 (5.2%)	

K_{l3} form-factor slopes



Hadronic matrix element:

$$\langle\pi|\, J_\alpha \,|K\rangle = f(0) \times [\tilde{f}_+(t)(P+p)_\alpha + \tilde{f}_-(t)(P-p)_\alpha]$$

$f_-(t)$ term only important for $K_{\mu3}$.
For $K_{\mu3}$, use $f_+(t)$ and $f_0(t) = f_+(t) + \dfrac{t}{m_K^2 - m_{\pi+}^2} f_-(t)$

For V_{us}, need integral over phase space of squared matrix element

Expand form factor:

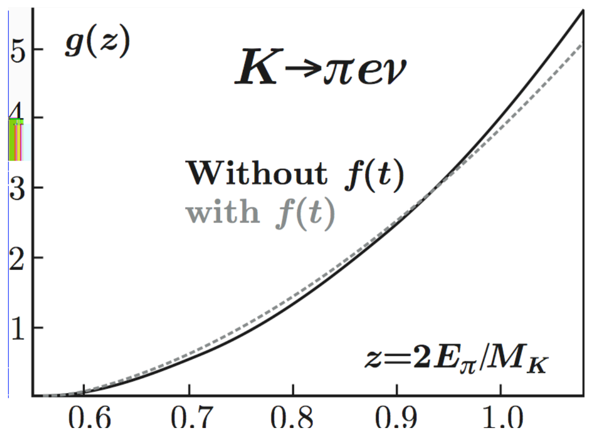
Linear: $\tilde{f}_{+,0}(t) = 1 + \lambda_{+,0}\,[t/m_{\pi+}^2]$

Quadratic: $\tilde{f}_{+,0}(t) = 1 + \lambda'_{+,0}\,[t/m_{\pi+}^2] + 1/2\,\lambda''_{+,0}\,[t/m_{\pi+}^2]^2$

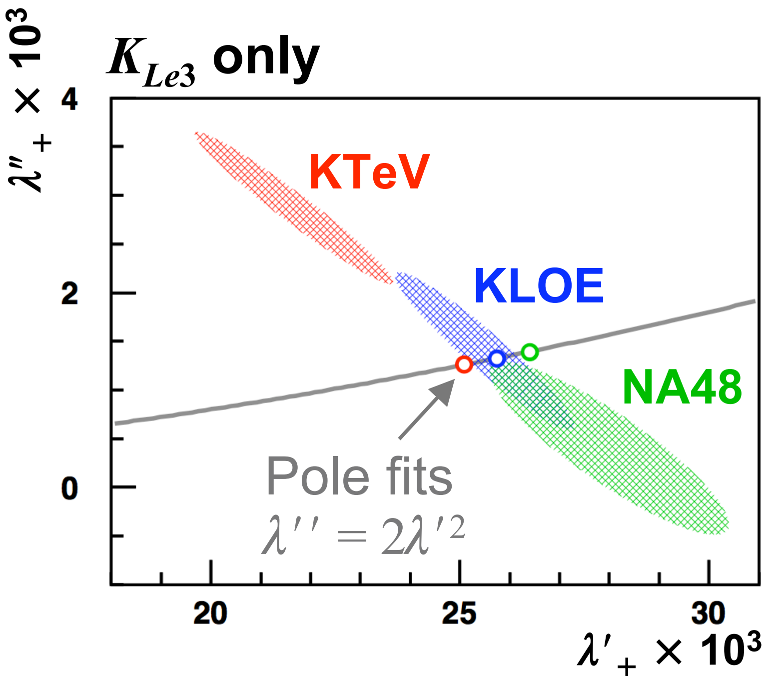
Fits to t-distribution give poor sensitivity to quadratic terms

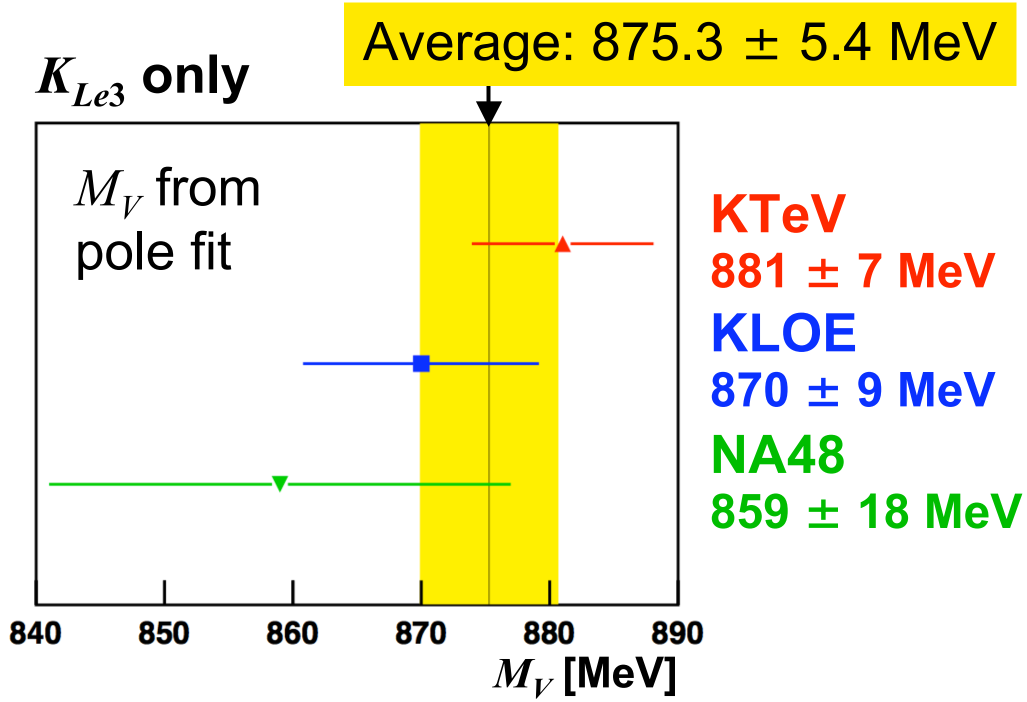
Polar fit:

$$\tilde{f}_{+,0}(t) = \frac{M_{V,S}^2}{M_{V,S}^2 - t} \qquad \lambda' = (m_{\pi+}/M)^2 \qquad \lambda'' = 2\lambda'^2$$



K_{e3} slopes: Quadratic vs. pole fits





K_{Le3} data	$P(\chi^2)$ fit Quad	K_{Le3} integral Quad	$P(\chi^2)$ fit Pole	K_{Le3} integral Pole	Difference
KTeV	54%	0.15378(51)	43%	0.15449(25)	**+0.46%**
KLOE	92%	0.15472(42)	92%	0.15489(33)	**+0.11%**
K_{Le3} avg		0.15456(29)		0.15469(19)	**+0.09%**

Beyond quadratic and pole fits

Hill, PRD 74 (2006):

Power series expansion based on analyticity of form factors

Constraints from crossing symmetry, e.g., bounds on $f_+(t)$ from $\tau \to K\pi\nu$ data

Rigorous estimate of error from truncation of series expansion

KTeV
PRD 74 (2006)

Refit $Ke3$ data using Hill parameterization

$I(K^0e3)$ **= 0.15392(48)$_{\text{exp}}$(6)$_{\text{th}}$**

Bernard et al., PLB 638 (2006):

Dispersion relation for ln $f_0(t)$ subtracted at t = 0 and $t = m_K{}^2 - m_\pi{}^2$, giving:

$$f_0(t) = \exp\left[\frac{t}{m_K^2 - m_\pi^2}\left(\ln C - G(t)\right)\right]$$

$G(t)$ evaluated using $K\pi$ scattering data and given as a polynomial

1 fit parameter: ln C = ln $f_0(m_K{}^2 - m_\pi{}^2)$

Value of ln C a test for right-handed quark currents

NA48
PLB 647 (2007)

From new analysis of $K\mu3$ form-factor slopes

ln C = 0.1438(138)

$|V_{us}|\,f_+(0)$: $K_{L,S}$ vs. $K^\pm$

Using separate fit results for form-factor slopes:

$K^\pm$ only, $e3$ and $\mu3$:

ISTRA+ $e3$, $\mu3$

λ'_+	=	24.80 ± 1.54
λ''_+	=	1.94 ± 0.86
λ_0	=	16.76 ± 1.20
χ^2/ndf	=	0.100/2 (95%)
$I(Ke3)$	=	0.15910(32)
$I(K\mu3)$	=	0.10595(30)

K_L only, $e3$ and $\mu3$:

KTeV avg, KLOE avg, NA48 $e3$, $\mu3$

λ'_+	=	23.73 ± 1.74 (S=1.7)
λ''_+	=	2.07 ± 0.65 (S=1.6)
λ_0	=	11.49 ± 1.41 (S=1.8)
χ^2/ndf	=	30.4/8 (0.02%)
$I(Ke3)$	=	0.15428(48)
$I(K\mu3)$	=	0.10156(43)

With $SU(2)$ corrections for $K^\pm$ modes:

$|V_{us}|\,f_+(0)$ = **0.21800(87)**
χ^2/ndf = 0.298/1 (59%)

$|V_{us}|\,f_+(0)$ = **0.21670(57)**
χ^2/ndf = 2.01/2 (37%)

With NO $SU(2)$ corrections for $K^\pm$ modes:

$|V_{us}|\,f_+(0)$ = **0.22304(76)**

$\Delta^{SU(2)}_{\text{exp}}$ = **2.93(43)%**

Results without NA48 $K\mu 3$ slopes

Slope parameters × 10^3	
λ'_+	= **24.95 ± 0.83**
λ''_+	= **1.59 ± 0.36**
λ_0	= **16.01 ± 0.79**
χ^2/ndf	= 12.2/10 (27.1%)

Integrals	
$I(K^0e3)$	0.15457(21)
$I(K^+e3)$	0.15892(21)
$I(K^0\mu 3)$	0.10268(20)
$I(K^+\mu 3)$	0.10565(21)

$\lvert V_{us}\rvert f_+(0)$	
K_Le3	**0.21636(53)**
$K_L\mu 3$	**0.21616(61)**
K_Se3	**0.21552(142)**
K^+e3	**0.21841(100)**
$K^-\mu 3$	**0.21812(92)**

$Kl3$ average
$\lvert V_{us}\rvert f_+(0)$ = 0.21666(42)
χ^2/ndf = 5.0/4 (28.5%)

$K^+ - K^0$ diff.: 2.1σ
$\Delta^{SU(2)}_{\text{exp}}$ = 3.27(39)%

$r_{\mu e}$ = 0.9981(45)

$\lvert V_{us}\rvert$ = 0.2255(19)
Unitarity test: -0.9σ