$|V_{ud}|$ & $|V_{us}|$ determination from kaon decays

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INFN Naple -Naples University "Federico II",

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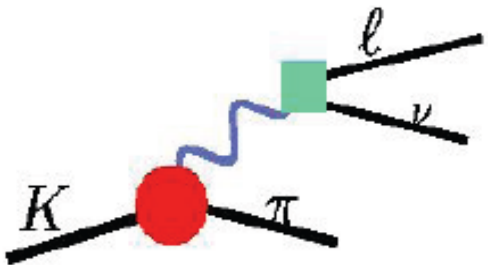

CKM most precise unitarity test

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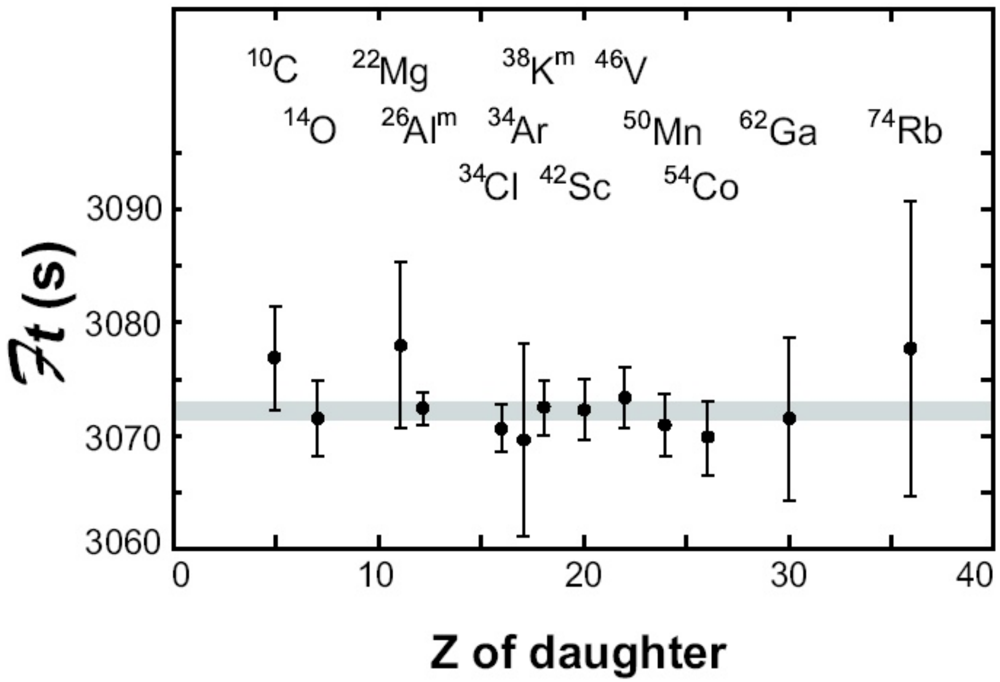
Need a precise determination of |Vus|

Vud determination

- Best result: from superallowed $0^+ \rightarrow 0^+$ nuclear transitions.
  (comprehensive review [Towner & Hardy Rep. Prog. Phys. 73 (2010) 046301])
- Master formula

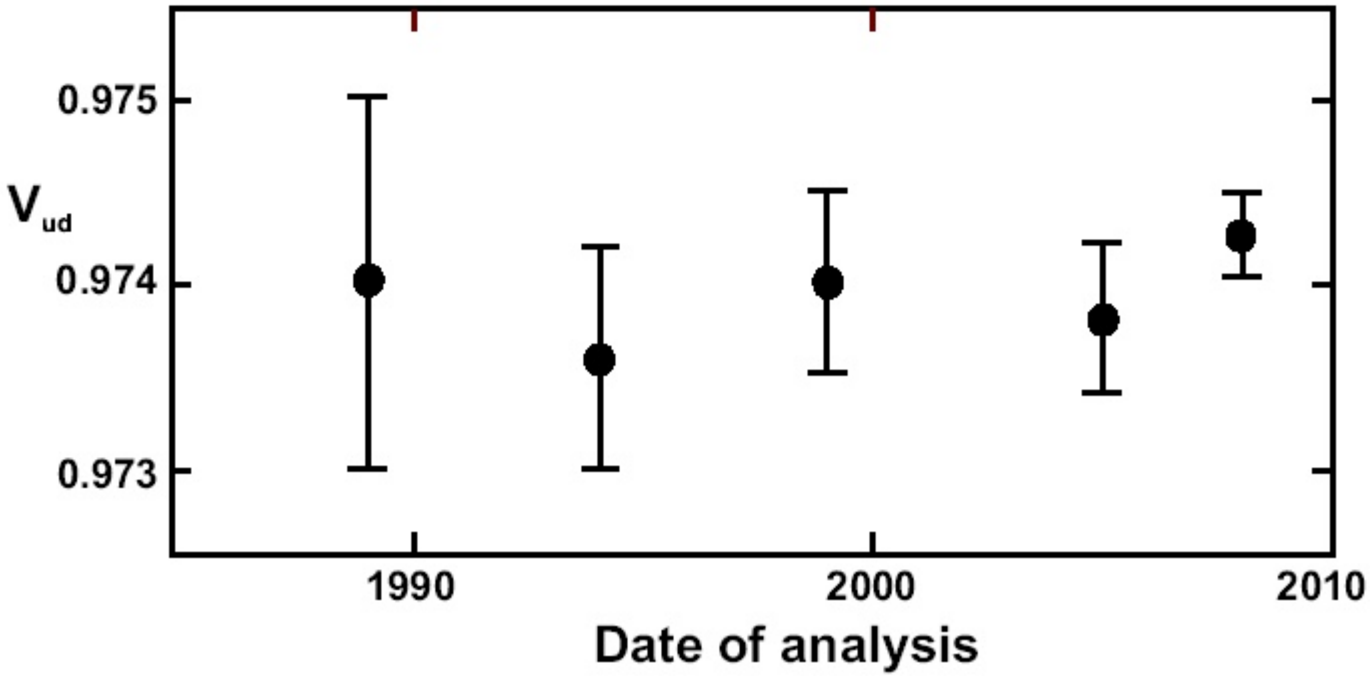
$$\mathcal{F}t = \frac{K}{2G^2_F\,|V_{ud}|^2\,(1+\Delta_R)}$$

- Constancy of $G_V = G_F|Vud|$ checked at 1.3×10^{-4} level
- Scalar current consistent with zero ($10^{-3} G_V$)
- <u>Assuming universal coupling</u> ($G_F = G_\mu$) can extract Vud



Vud determination

$$|V_{ud}| = 0.97425(22)$$



From most recent neutron β decay result: 0.9758(13)

From pion β decay (PDG08):0.9742(26)

The FlaviaNet Kaon working group

- **The most precise measurement of |Vus| is obtained from the charged and neutral kaon channel**

- **FlaviaNet Kaon WG (www.lnf.infn.it/wg/vus/)**. Recent kaon physics results come from many experimental (BNL-E869, KLOE, KTeV, ISTRA+, NA48) and theoretical (Lattice, χ_{PT},) improvements. The main purpose of this working group is to perform precision tests of the Standard Model and to determine with high accuracy fundamental couplings (such as V_{us}) using only published data on kaon decays, taking correlations into account.

Vus determination

Physics results:

- $|V_{us}| \times f_+(0)$

$$\Gamma_{K_{\ell 3}} = \frac{G_F^2 m_K^5}{192\pi^3} C_K^2 S_{\text{EW}} \left(|V_{us}| f_+^{K^0\pi^-}(0)\right)^2 I_{K\ell}\left(1 + \delta_{\text{EM}}^{K\ell} + \delta_{\text{SU}(2)}^{K\pi}\right)^2$$

- $|V_{us}|/|V_{ud}| \times f_K/f_\pi$.

$$\frac{\Gamma_{K_{\ell 2}}}{\Gamma_{\pi_{\ell 2}}} = \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{f_K^2}{f_\pi^2} \frac{m_K(1 - m_\ell^2/m_K^2)^2}{m_\pi(1 - m_\ell^2/m_\pi^2)^2} (1 + \delta_{\text{EM}})$$

Global fits and averages:

- K_L, K_S, and $K^\pm$, dominant BRs and lifetime.
- Parameterization of the $K \rightarrow \pi$ interaction (form factor)

Vus determination

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- Parameterization of the $K \rightarrow \pi$ interaction (form factor)

K_L leading branching ratios and τ_L

21 input measurements:

- **5+3 KTeV** ratios
- **NA48** K_{e3} /2tr and $\Gamma(3\pi^0)$
- **4 KLOE** BRs
- **KLOE**, **NA48** $\pi^+\pi^-/K_{l3}$
- **KLOE**, **NA48** $\gamma\gamma/3\pi^0$
- **PDG** ETAFIT for $\pi^+\pi^-/\pi^0\pi^0$
- **KLOE** τ_L from $3\pi^0$
- **Vosburgh** '72 τ_L

Parameter	Value	S
$\mathrm{BR}(K_{e3})$	0.4056(9)	1.3
$\mathrm{BR}(K_{\mu3})$	0.2704(10)	1.5
$\mathrm{BR}(3\pi^0)$	0.1952(9)	1.2
$\mathrm{BR}(\pi^+\pi^-\pi^0)$	0.1254(6)	1.3
$\mathrm{BR}(\pi^+\pi^-)$	$1.967(7)\times10^{-3}$	1.1
$\mathrm{BR}(\pi^+\pi^-\gamma)$	$4.15(9)\times10^{-5}$	1.6
$\mathrm{BR}(\pi^+\pi^-\gamma_{\mathrm{DE}})$	$2.84(8)\times10^{-5}$	1.3
$\mathrm{BR}(2\pi^0)$	$8.65(4)\times10^{-4}$	1.4
$\mathrm{BR}(\gamma\gamma)$	$5.47(4)\times10^{-4}$	1.1
τ_{K_L}	51.16(21) ns	1.1

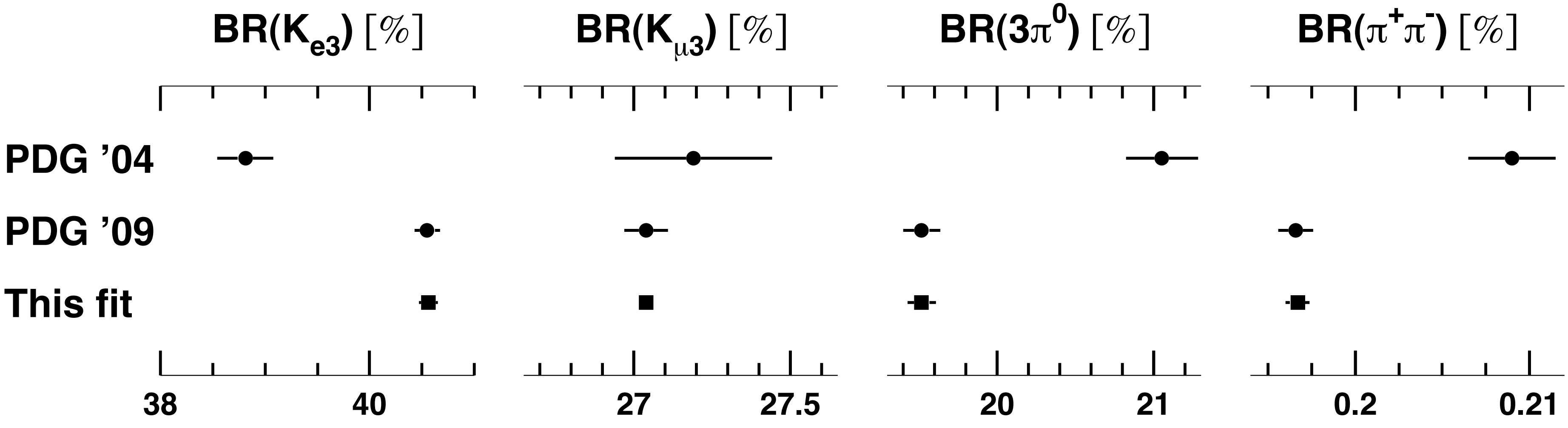
10 free parameters, 1 constraint: ΣBR=1

All $\pi^+\pi^-/K_{l3}$ measurements are fully inclusive of inner bremsstrahlung
KLOE measurement is fully inclusive of DE, negligible in KTeV one

Evolution of the average BR values

This fit χ^2/ndf = 19.8/12 (7.1%)
Minor differences wrt PDG04:
- elimination of numerous old measurements

BR's shifted by 6σ, -6σ, -5σ



K_S leading branching ratios and τ_S

6 input measurements:

KLOE $BR(Ke3)/BR(\pi^+\pi^-)$
KLOE $BR(\pi^+\pi^-)/BR(\pi^0\pi^0)$
Universal lepton coupling
NA48 $BR(K_S e3)/BR(K_L e3)$
τ_S: non CPT-constrained fit value,
2002 NA48 and 2003 KTeV measurements

Parameter	Value
$BR(\pi^+\pi^-)$	$0.6920(5)$
$BR(\pi^0\pi^0)$	$0.3069(5)$
$BR(K_{e3})$	$7.05(8) \times 10^{-4}$
$BR(K_{\mu 3})$	$4.69(6) \times 10^{-4}$
τ_{K_S}	$89.59(6)$ ps

5 free parameters: $K_S\pi\pi$, $K_S\pi^0\pi^0$, $K_S e3$, $K_S\mu 3$, τ_S,
1 constraint: $\Sigma BR=1$

KLOE meas. completely determine the leading BR values.

This fit $\chi^2/ndf = 0.015/1$ (90%) $S\approx 1$ for any of the output values.

K± leading branching ratios and τ±

17 input measurements:

KLOE + 3 old τ

KLOE BR(μν)

KLOE *Ke3*, *K*μ*3*, and *K*π*2* BRs

NA48/2 $K_{e3}/\pi\pi^0$, $K_{\mu3}/\pi\pi^0$

E865 K_{e3}/Kdal

3 old ππ⁰/μν

KEK-E246 *K*μ*3/Ke3*

1 old + 1 KLOE results on 3π

Parameter	Value	S
$\mathrm{BR}(K_{\mu2})$	63.47(18)%	1.3
$\mathrm{BR}(\pi\pi^0)$	20.61(8)%	1.1
$\mathrm{BR}(\pi\pi\pi)$	5.73(16)%	1.2
$\mathrm{BR}(K_{e3})$	5.078(31)%	1.3
$\mathrm{BR}(K_{\mu3})$	3.359(32)%	1.9
$\mathrm{BR}(\pi\pi^0\pi^0)$	1.757(24)%	1.0
$\tau_{K^\pm}$	12.384(15) ns	1.2

7 free parameters,
1 constraint: ΣBR=1

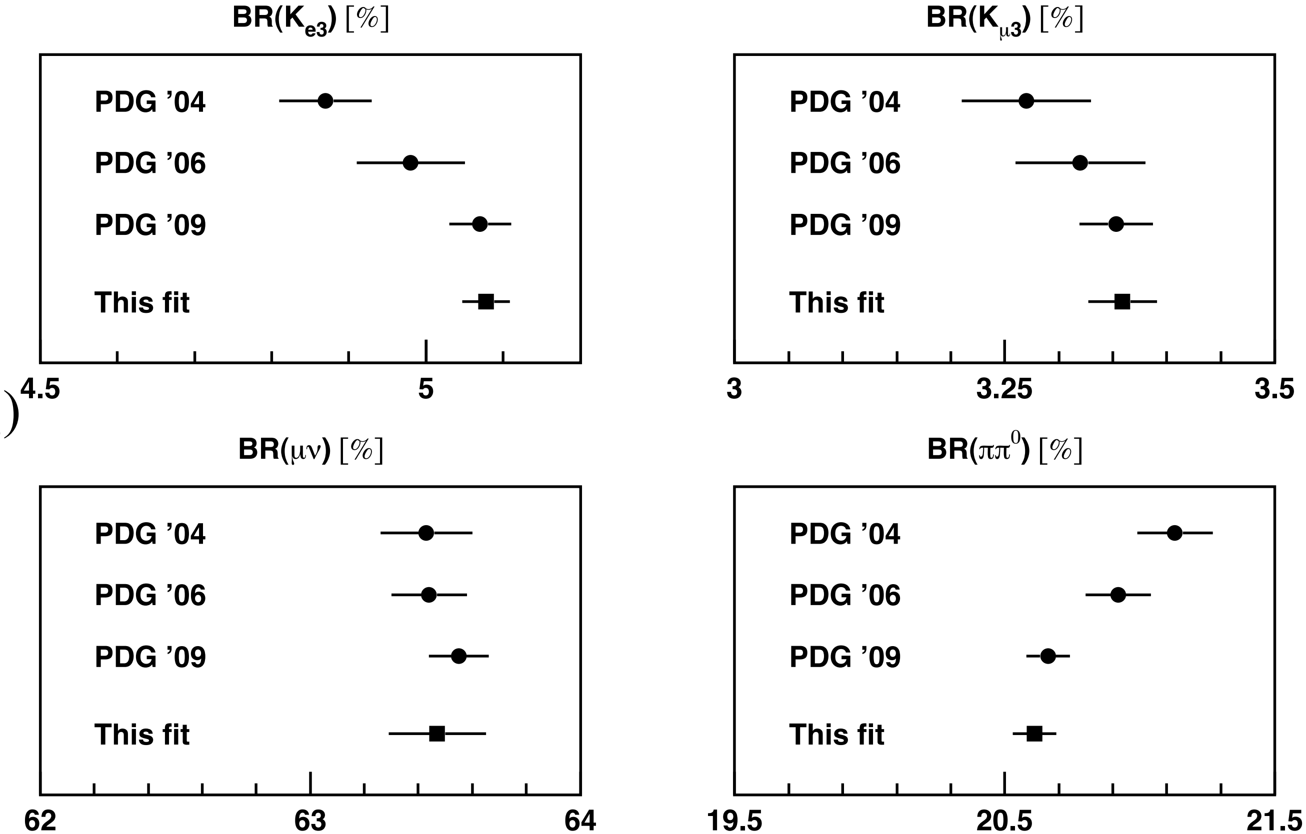
Don't use the result from Lobkowicz (τ), don't use the BRs from Chiang:

- 6 BRs constrained to sum to unit.
- the correlation matrix not available

Evolution of the average BR values

- This fit χ^2**/ndf = 25.8/11 (0.69%)**; PDG09 fit: χ^2/ndf = 52/25 (0.13%)
- **some conflict among newer meas. involving BR(Ke3)**: the pulls are +0.6 and -2.1 for NA48 and KLOE respectively
- **some conflict among newer meas. involving BR(Kμ3)**: the pulls are +1.0 and -3.2 for NA48 and KLOE respectively

Evolution of the BR($K_{\ell 3}$) and of the important normalization channels.



Vus determination

Physics results:

- $|V_{us}| \times f_+(0)$

$$\Gamma_{K_{\ell 3}} = \frac{G_F^2 m_K^5}{192\pi^3} C_K^2 S_{\rm EW} \left(|V_{us}| f_+^{K^0\pi^-}(0) \right)^2 I_{K\ell} \left(1 + \delta_{\rm EM}^{K\ell} + \delta_{\rm SU(2)}^{K\pi} \right)^2$$

- $|V_{us}|/|V_{ud}| \times f_K/f_\pi$.

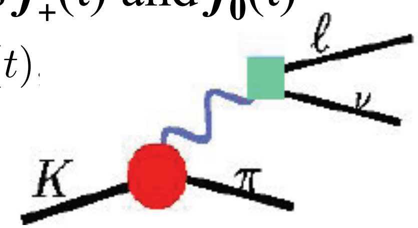
$$\frac{\Gamma_{K_{\ell 2}}}{\Gamma_{\pi_{\ell 2}}} = \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{f_K^2}{f_\pi^2} \frac{m_K (1 - m_\ell^2/m_K^2)^2}{m_\pi (1 - m_\ell^2/m_\pi^2)^2} (1 + \delta_{\rm EM})$$

Global fits and averages:

- K_L, K_S, and $K^\pm$, dominant BRs and lifetime.
- Parameterization of the $K \to \pi$ interaction (form factor)

Parameterization of $K_{\ell 3}$ form factors

- Hadronic K→π matrix element is described by two form factors $f_+(t)$ and $f_0(t)$ defined by: $\langle \pi(p_\pi)|\bar{s}\gamma_\mu u|K(p_K)\rangle = (p_\pi + p_K)_\mu f_+^{K\pi}(t) + (p_K - p_\pi)_\mu f_-^{K\pi}(t)$



$$f_0(t) = f_+(t) + \frac{t}{m_K^2 - m_\pi^2} f_-(t)$$

- Experimental or theoretical inputs to define ***t***-dependence of $f_{+,0}(t)$.
- $f_-(t)$ term negligible for K_{e3}.

➢ Taylor expansion: $\bar{f}_{+,0}^{\text{Taylor}}(t) = 1 + \lambda'_{+,0}\frac{t}{m_{\pi^\pm}^2} + \frac{1}{2}\lambda''_{+,0}\left(\frac{t}{m_{\pi^\pm}^2}\right)^2$

λ′ and λ″ are **strongly correlated: –95% for $f_+(t)$, and –99.96% for $f_0(t)$**.

One parameter parameterizations:

➢ Pole parameterization

$$\tilde{f}_{+,0}(t) = \frac{M_{V,S}^2}{M_{V,S}^2 - t}$$

➢ Dispersive approach plus Kπ scattering data for both $f_+(t)$ and $f_0(t)$

$$\bar{f}_+^{\text{disp}}(t) = \exp\left[\frac{t}{m_\pi^2}\left(\Lambda_+ + H(t)\right)\right] \qquad \bar{f}_0^{\text{disp}}(t) = \exp\left[\frac{t}{\Delta_{K\pi}}\left(\ln C - G(t)\right)\right]$$

Vector form factor from K_{e3}

Quadratic expansion:

- Measurements from ISTRA+, KLOE, KTeV, NA48 with K_Le3 and K^-e3 decays.
- **Good fit quality: χ^2/ndf=5.3/6(51%) for all data**; χ^2/ndf=4.7/4(32%) for K_L only
- The significance of the quadratic term is 4.2σ from all data and 3.5σ from K_L only.
- Using all data or K_L only changes the space phase integrals I^0_{e3} and $I^{\pm}_{e3}$ by 0.06% .
- Errors on I_{e3} are significantly smaller when K^- data are included.

A **pole parameterization** is in good agreement with present data:

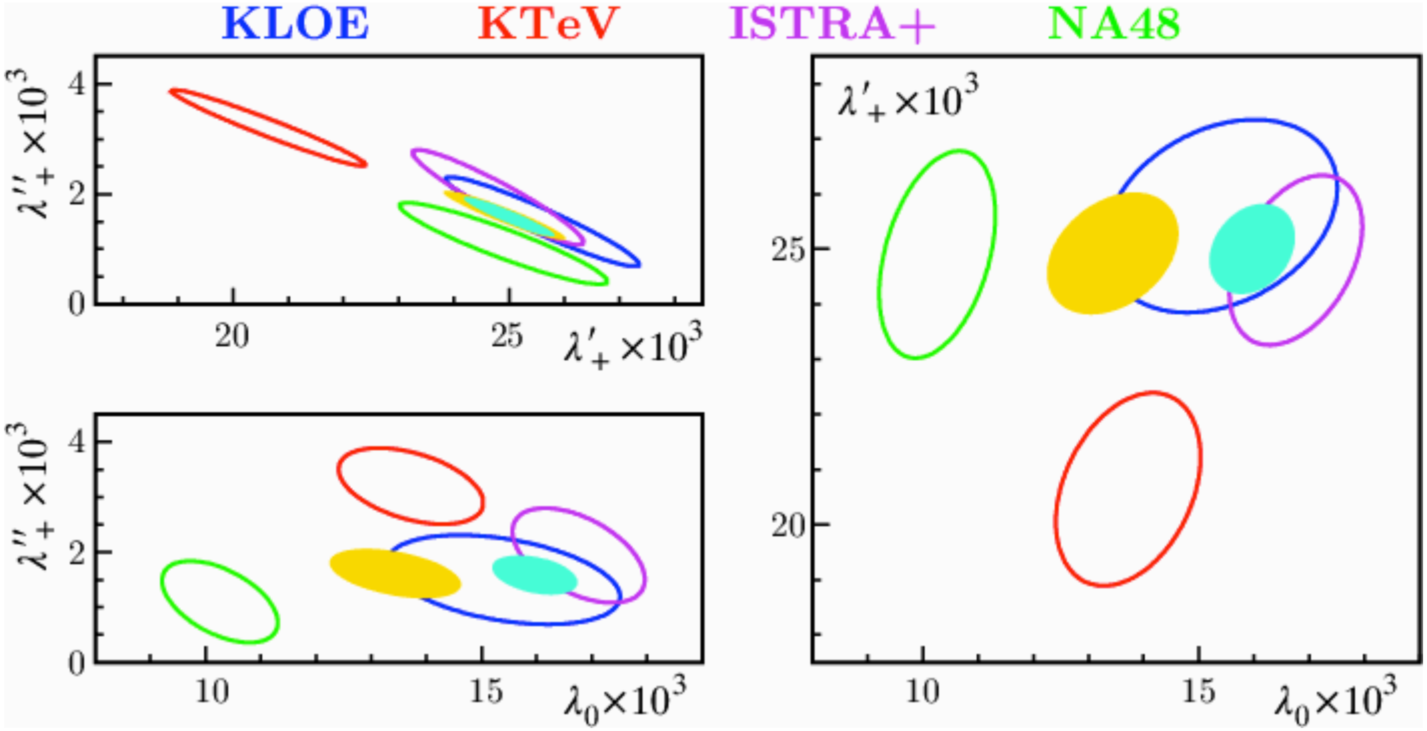
$$\tilde{f}_+(t) = M_V^2/(M_V^2 - t), \text{ with } M_V \sim 892 \text{ MeV} \qquad \lambda' = (m_{\pi^+}/M_V)^2;\ \lambda'' = 2\lambda'^2$$

- All four experiments quote value for M_V for pole fit to Ke3 data.
  The average value is Mv =871±5 MeV (χ^2/ndf=3.8/3)
- The values for λ_+' and λ_+'' from pole expansion are in agreement with quadratic fit results.
- Using quadratic averages or pole fit results changes I^0_{e3} by 0.11% .

Improvements: **dispersive parameterization** for $f_+(t)$, with good analytical and unitarity properties and a correct threshold behavior,
(e.g. Bernard, Oertel, Passemar, Stern Phys. Rev. Lett. D80 (2009) 034034)

Vector and scalar form factor from $K_{\mu3}$

- λ_+', λ_+'' and λ_0 measured for Kμ3 from ISTRA+, KLOE, KTeV, and NA48.
- **NA48 results are difficult to accomodate in the [λ_+', λ_+'', λ_0] space**.
- Fit probability varies from 3×10^{-7} (with NA48) to 14.5% (without NA48).



1σ contour for all the experimental results.

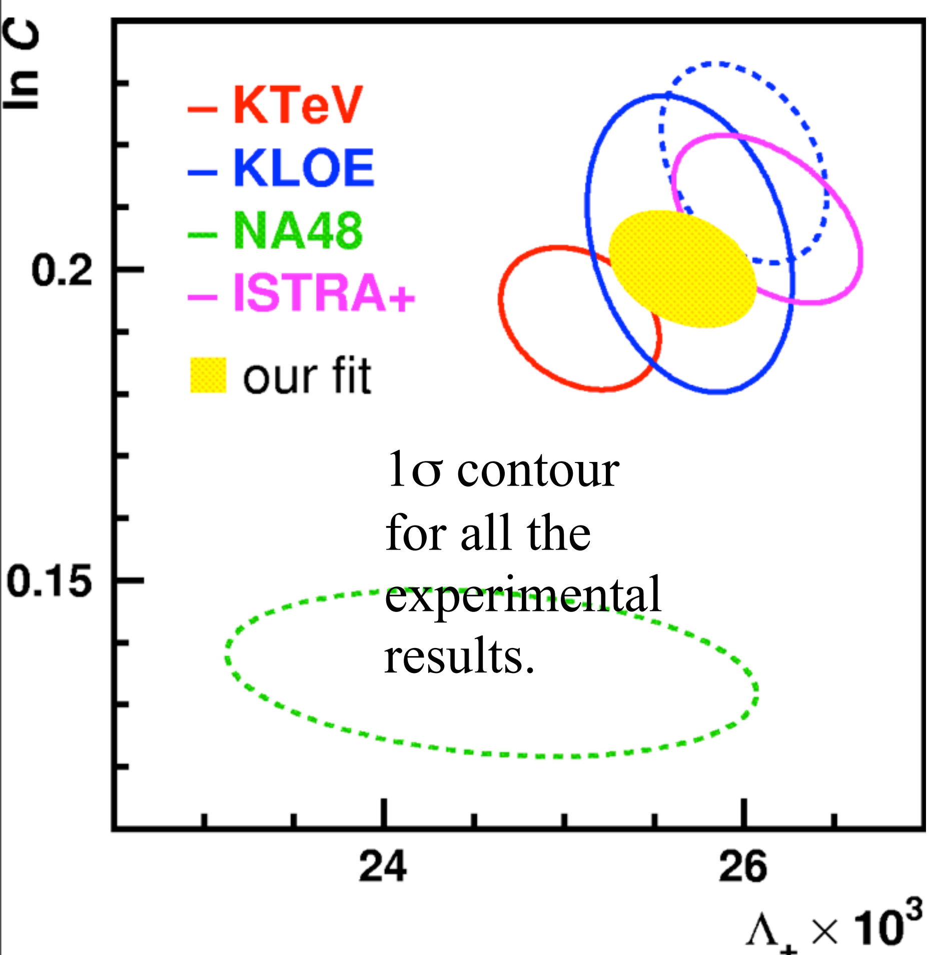
Fit with NA48

Fit without NA48

- Because of correlation, is not possible measure λ_0'' at any plausible level of stat.
- Neglecting a quadratic term in the param. of scalar FF implies: $\lambda_0' \rightarrow \lambda_0' + \mathbf{3.5}\lambda_0''$

Vector and scalar form factor from $K_{\mu3}$

The dispersive form factor parameterization clearly illustrate the contrast between $K_{\mu3}$ result from NA48 and those from the other experiment



1σ contour for all the experimental results.

Fit without NA48

Fit probability varies from 0.026% **(χ^2/ndf=25.7/6)** with NA48 to 34.4% without NA48 **χ^2/ndf=5.6/5**.

The blue dashed ellipse is a new preliminary result from KLOE, not included in the fit.

Vector and scalar form factor from $K_{\ell 3}$

•Comparison of phase-space integrals evaluated from our averages of results of quadratic-linear and dispersive fits

Integral	$\lambda'_+, \lambda''_+, \lambda_0$	$\Lambda_+, \ln C$	Rel. diff.
$I(K^0_{e3})$	$0.15457(20)$	$0.15476(18)$	$+0.12\%$
$I(K^\pm_{e3})$	$0.15894(21)$	$0.15922(18)$	$+0.18\%$
$I(K^0_{\mu 3})$	$0.10266(20)$	$0.10253(16)$	-0.13%
$I(K^\pm_{\mu 3})$	$0.10564(20)$	$0.10559(17)$	-0.05%
$\rho(K_{e3}, K_{\mu 3})$	$+0.56$	$+0.38$	

The intergals, when evaluated from the dispersive fit results, tend to be slightly greater (no more than 0.2%) than from the the quadratic fit results.

Global fits and averages:

- K_L, K_S, and $K^{\pm}$, dominant BRs and lifetime.
- Parameterization of the $K \rightarrow \pi$ interaction (form factor)

Physics results:

- $|V_{us}| \times f_+(0)$
- $|V_{us}|/|V_{ud}| \times f_K/f_\pi$.
- Theoretical estimations of $f_+(0)$ and f_K/f_π.
- V_{us} and V_{ud} determinations.
- Bounds on helicity suppressed amplitudes.

Determination of $|V_{us}| \times f_+(0)$

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 I_{K\ell}(\lambda_{+,0}) (1+\delta^K_{SU(2)}+\delta^{K\ell}_{em})^2$$

with $K = K^+, K^0$; $\ell = e, \mu$ and $C_K^2 = 1/2$ for K^+, 1 for K^0

Inputs from theory:

S_{EW} Universal short distance EW correction (1.0232)

$\delta^K_{SU(2)}$ Form factor correction for strong SU(2) breaking

$\delta^{K\ell}_{em}$ Long distance EM effects

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

Inputs from experiment:

$\Gamma(K_{l3(\gamma)})$ **Branching ratios** properly inclusive of radiative effects; **lifetimes**

$I_{K\ell}(\lambda)$ Phase space integral: λ's parameterize form factor dependence on t :

K_{e3}: only λ_+

$K_{\mu3}$: need λ_+ and λ_0

Callan-Treiman

SU(2) and *em* corrections

	$\delta^{K}_{SU(2)}(\%)$	$\delta^{K\ell}_{em}(\%)$
K^0e3	0	+0.495(110)
$K^0\mu3$	0	+0.700(110)
K^+e3	+2.9(4)	+0.050(125)
$K^+\mu3$	+2.9(4)	+0.008(125)

$$\begin{pmatrix} +1.000 & +0.081 & +0.685 & -0.147 \\ & +1.000 & -0.147 & +0.764 \\ & & +1.000 & +0.081 \\ & & & +1.000 \end{pmatrix}$$

(values used to extract $|V_{us}|f_+(0)$)

- δ_{em} for full phase space: all measurements assumed fully inclusive.
- **Different estimates of δ_{em} agree within the quoted errors**.
- Available correlation matrix between different corrections for δ_{em}.

Determination of $|V_{us}|\times f_+(0)$

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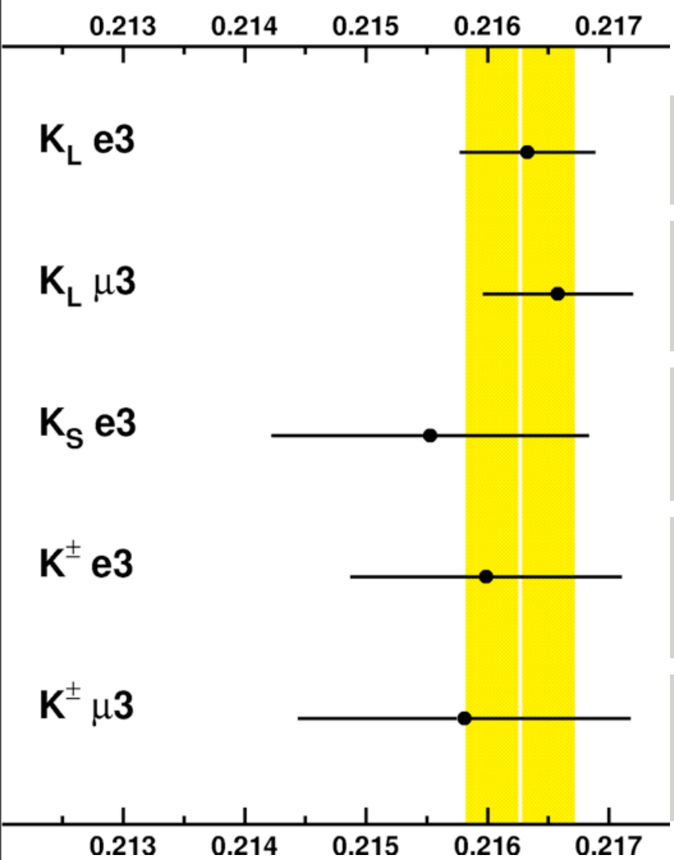


		% err ×10⁻²	BR×10⁻²	τ×10⁻²	Δ×10⁻²	$I_{K\ell}$×10⁻²
K_Le3	0.2163(6)	26	9	**20**	11	6
$K_L\mu3$	0.2166(6)	29	15	**18**	11	8
K_Se3	0.2155(13)	61	**60**	3	11	6
$K^\pm e3$	0.2160(11)	52	**31**	8	**40**	6
$K^\pm\mu3$	0.2158(14)	63	**47**	8	**39**	8

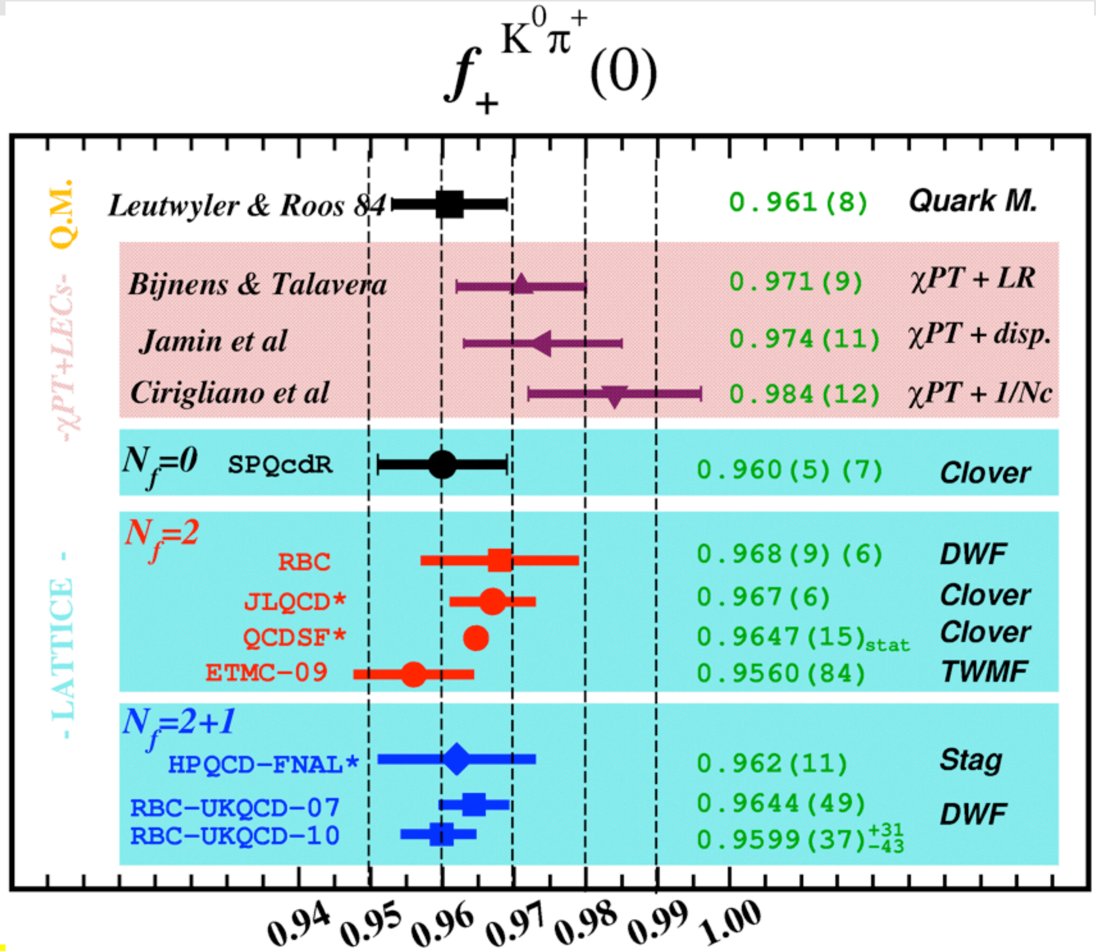
Average: $|V_{us}| f_+(0) = 0.2163(5)$ $\chi^2/\text{ndf} = 0.77/4\ (94\%)$

Theoretical estimate of $f_+(0)$

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2\, G_F^2 M_K^5}{192\pi^3}\, S_{EW}\, |V_{us}|^2\, |f_+^{K^0\pi^-}(0)|^2\, I_{K\ell}(\lambda_{+,0})\, (1+\delta^K_{SU(2)}+\delta^{K\ell}_{em})^2$$

Leutwyler & Roos estimate still widely used:
$f_+(0) = \mathbf{0.961(8)}$.

Lattice evaluations generally agree well with this value; use RBC-UKQCD10 value:
$f_+(0) = \mathbf{0.959(5)}$ (0.5% accuracy, total err.).



K13: $|V_{us}| f_+(0) = 0.2163(5)$ and $f_+(0) = 0.959(5)$, obtain $|V_{us}| = \mathbf{0.2254(13)}$

V_{us}/V_{ud} determination from BR($K_{\mu2}$)

$$\frac{\Gamma(K_{\mu2(\gamma)})}{\Gamma(\pi_{\mu2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K}{f_\pi} \times \frac{M_K(1-m_\mu^2/M_K^2)^2}{m_\pi(1-m_\mu^2/m_\pi^2)^2} \times (1+\alpha(C_K-C_\pi))$$

Inputs from experiment:

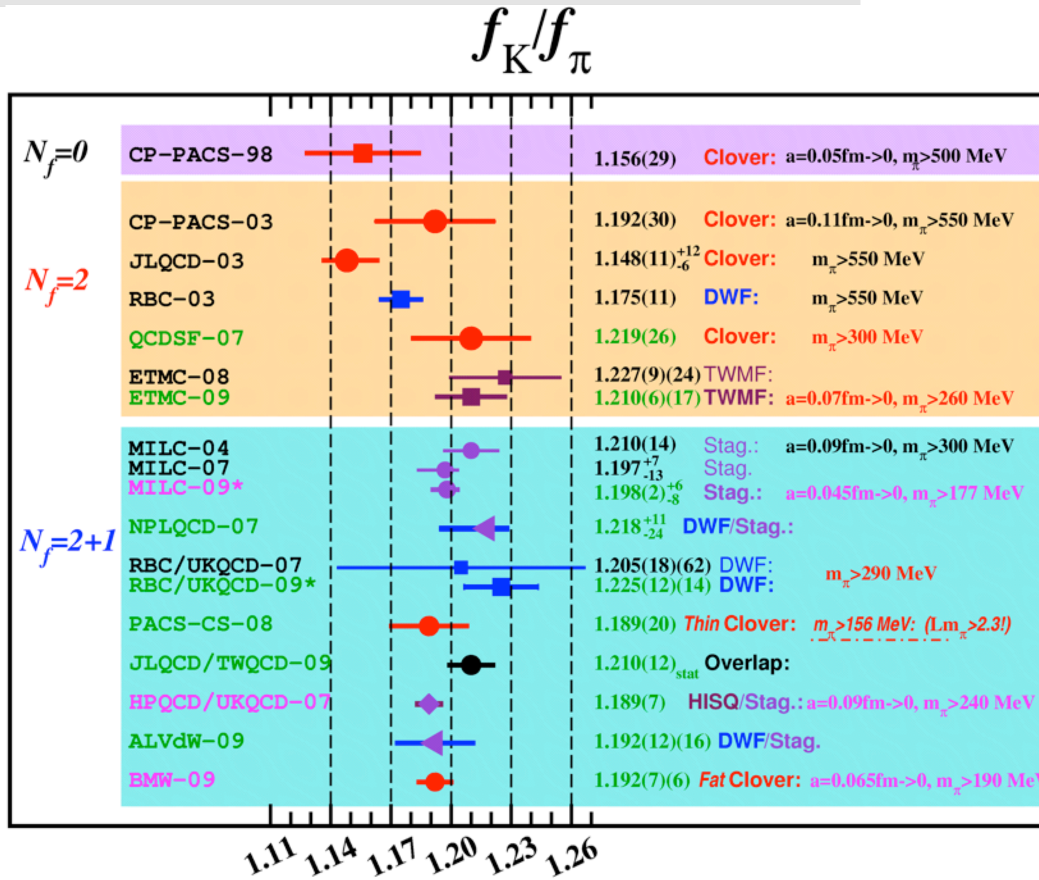
$\Gamma(\pi,K_{l2(\gamma)})$ BR properly inclusive of radiative effects; **lifetimes**

Inputs from theory:

$C_{K,\pi}$ Rad. inclusive EW corr.

f_K/f_π Not protected by the Ademollo-Gatto theorem: only lattice.

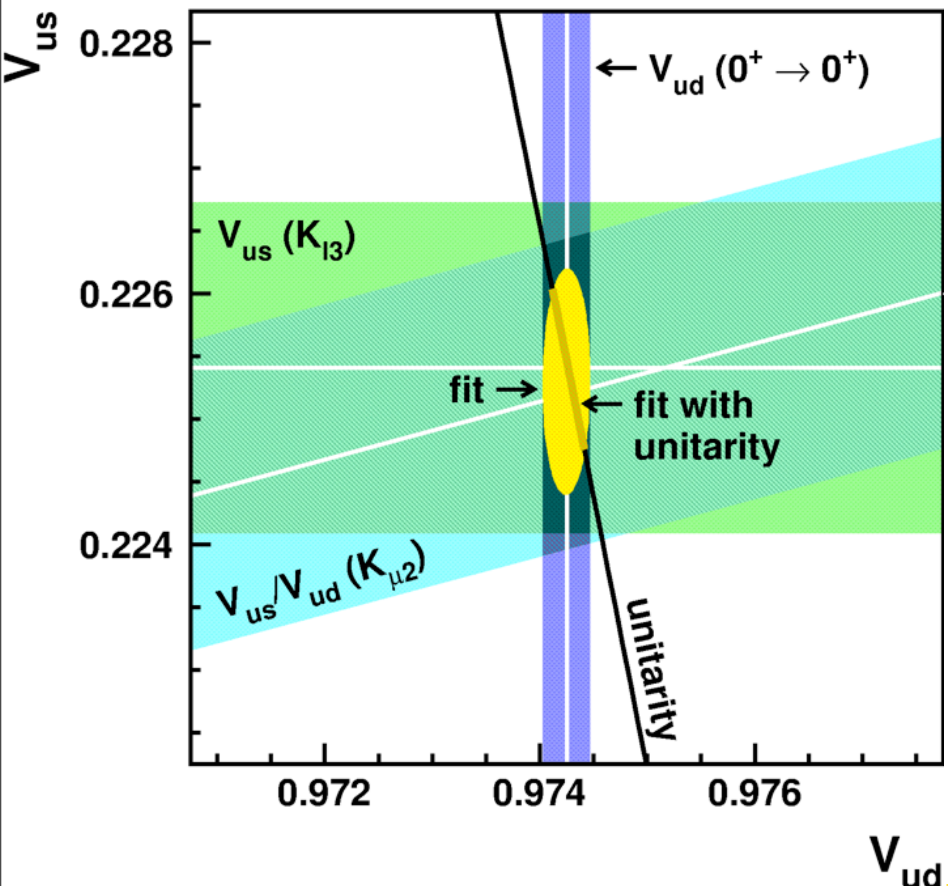
- Lattice calculation of f_K/f_π and radiative corrections benefit of cancellations.
- Use average of HPQCD-UKQCD07, BMW, and MILC'09: f_K/f_π = **1.193(6)**.



K12: $|V_{us}|/|V_{ud}|\, f_K/f_\pi$ = 0.2758(5) and f_K/f_π = 1.193(6), obtain $|V_{us}|/|V_{ud}|$=0.2312(13)

V_{ud}, V_{us} and V_{us}/V_{ud}

$|V_{us}| = 0.2254(13)$, $|V_{us}|/|V_{ud}| = 0.2312(13)$ $V_{ud} = 0.97425(22)$



Fit (no CKM unitarity constraint):

$V_{ud} = 0.97425(22)$; $V_{us} = 0.2253(9)$

$\chi^2/\text{ndf} = 0.014/1$ (91%)

- **$|V_{ud}|^2 - |V_{us}|^2 - |V_{ub}|^2 - 1 = -0.0001(6)$**

- The test on the unitarity of CKM can be also interpreted as a **test of the universality of lepton and quark gauge coupling**:

$$G_{\text{CKM}} \equiv G_\mu \left[|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2\right]^{1/2} :$$

$$1.16633(35) \times 10^{-5}\ \text{GeV}^{-2}$$

$$G_\mu = 1.166371(6) \times 10^{-5}\ \text{GeV}^{-2}$$

Fit (with CKM unitarity constraint): V_{us} = **0.2254(6)** $\chi^2/\text{ndf} = 0.024/2$ (99%)

$K_{\mu 2}$: sensitivity to NP

Comparison of V_{us} from $K_{\ell 2}$ (helicity suppressed) and from $K_{\ell 3}$ (helicity allowed)
To reduce theoretical uncertainties study the quantity:

$$R_{l23} = \left| \frac{V_{us}(K_{\ell 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\ell 2})} \right|$$

Within SM $R_{\ell 23} = 1$; NP effects can show as scalar currents due to a charged Higgs:

$$R_{\mu 23} \approx \left| 1 \; - \; \frac{m_{K^+}^2}{m_{H^+}^2} \frac{\tan^2 \beta}{1 + \epsilon_0 \tan \beta} \right|$$

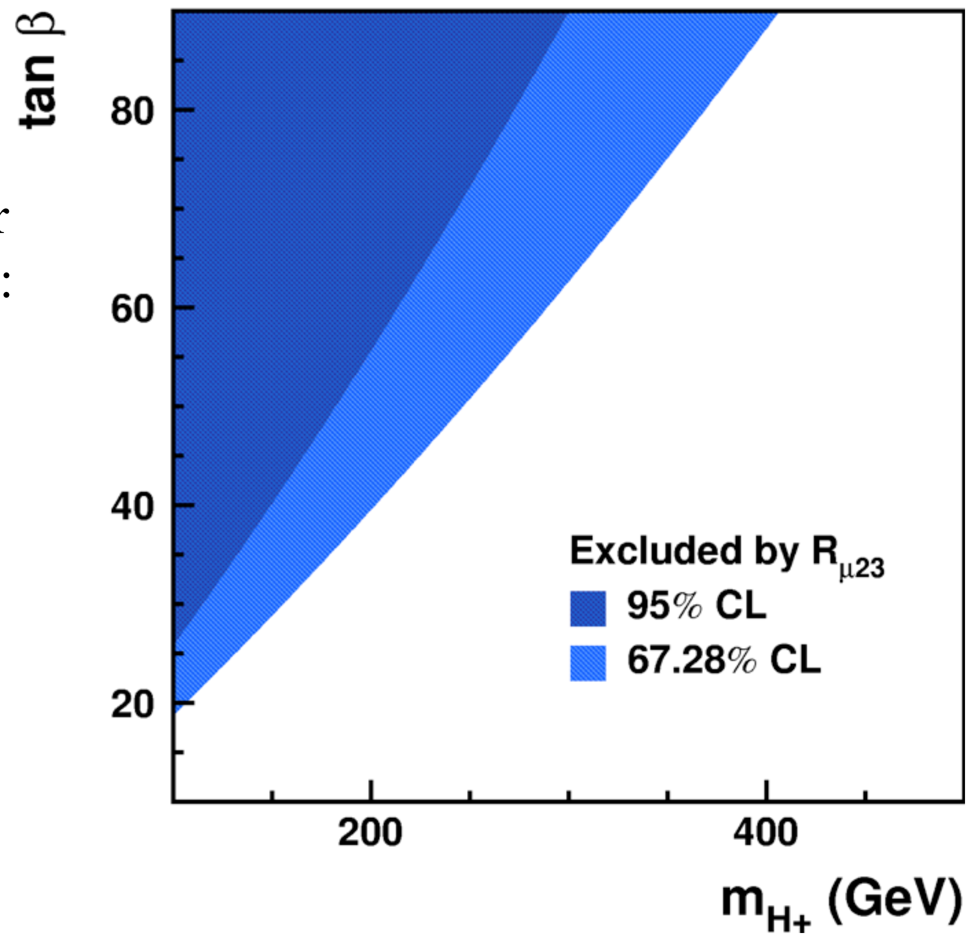
$K_{\mu 2}$: sensitivity to NP!

$R_{\ell 23}$ is accessible via $BR(K_{\mu 2})/BR(\pi_{\mu 2})$, $V_{us}f_+(0)$, and V_{ud}, and $f_K/f_\pi/f_+(0)$ determinations.

- Using K± fit results, assuming unitarity for Vus($K_{\ell 3}$) and using $f_K/f_\pi/f_+(0)$ from lattice:

  $R_{\ell 23} = 0.999(7)$

- Uncertainty dominated by $f_K/f_\pi/f_+(0)$.
- 95% CL excluded region (with $\varepsilon_0 \sim 0.01$).
- In tanβ-$M_{H\pm}$ plane, $R_{\mu 23}$ **fully cover the region uncovered by BR(B→τν)**.



Conclusions

- Dominant K_S, K_L, and $K^\pm$ BRs, and lifetime known with very good accuracy.
- Dispersive approach for form factors.
- Constant improvements from lattice calculations of $f_+(0)$ and f_K/f_π:

- $|V_{us}| f_+(0)$ at 0.2% level.
- $|V_{us}|$ measured with 0.6% accuracy (with $f_+(0)$= 0.959(5))

  Dominant contribution to uncertainty on $|V_{us}|$ still from $f_+(0)$.

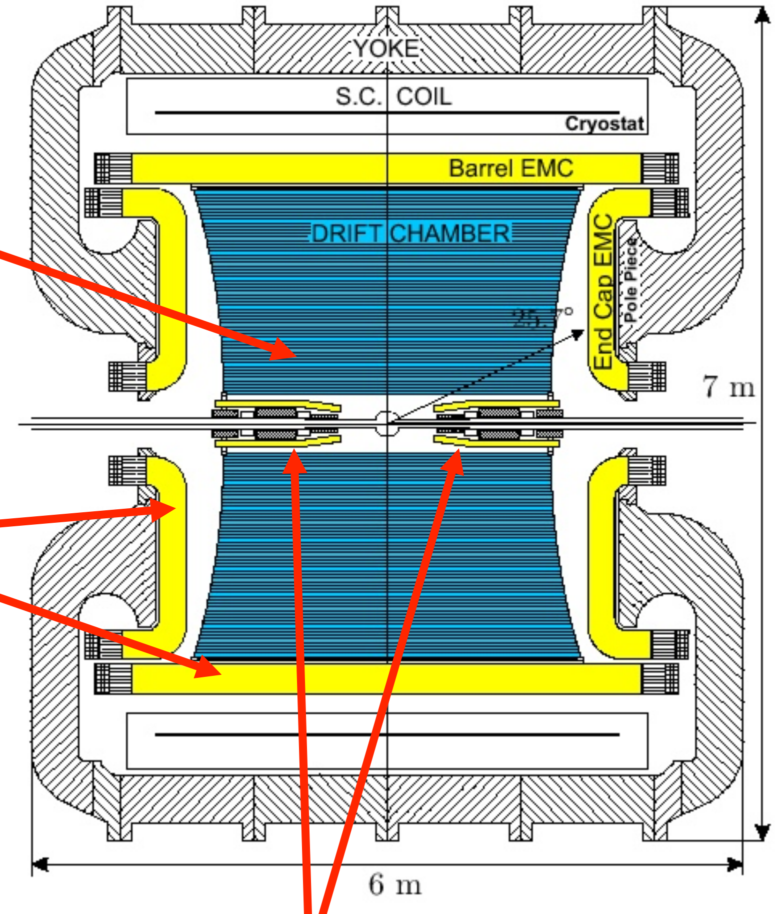
  CKM unitarity test satisfied at 0.17σ level

- Comparing $|V_{us}|$ values from Kμ2 and Kl3, exclude large region in the (m_{H+-},tanβ) plane, complementary to results from B→τν decays.

KLOE-2 experiment

Drift chamber:
- gas: 90% He-10% iC_4H_{10}
- $\delta p_T/p_T = 0.4\%$
- $\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm
- $\sigma_{vertex} \approx 1$ mm

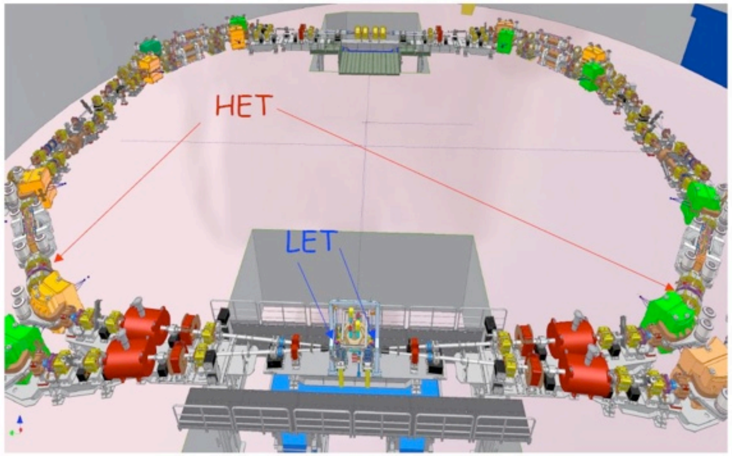
Calorimeter (Pb-Sci.Fi.):
- $\sigma_E/E = 5.7\% / \sqrt{(E(GeV))}$
- $\sigma_t = 55\ ps/\sqrt{(E(GeV))} \oplus 100$ ps
- 98% of 4π



Magnetic field: 0.52 T

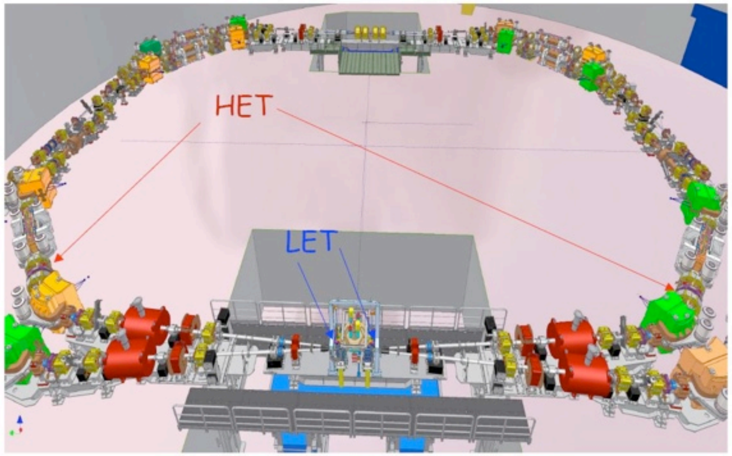
QCAL vetos: (Pb-scintillator)

KLOE-2 experiment



$$e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- \mathbf{X}$$

KLOE-2 experiment

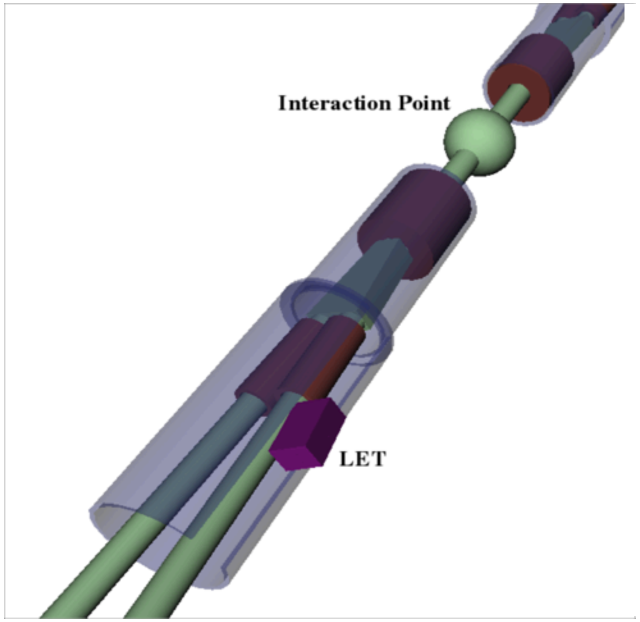


Minimal detector upgrade

- **Tagger for γγ physics: to detect off-momentum $e^{\pm}$ from**

$$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\mathbf{X}$$

- **Low Energy Tagger (130-230 MeV)**
  calorimeters, LYSO + SiPM
- **High Energy Tagger (E > 400 MeV)**
  position sensitive detectors
  (strong energy-position correlation
  ⇒ use the DAΦNE magnets as $e^{\pm}$ spectrometer)



- **No QCAL on quadrupoles (Pb shields)**

- **Luminosity goal: 5 fb^{-1} @ $\sqrt{s} \approx M_{\phi}$**

Roll-in (Dec 2009) and alignment (Jan 2010)
Commisioning Mid June 2010

Determination of $|V_{us}|\times f_+(0)$: improvements

		% err $\times 10^{-2}$	BR$\times 10^{-2}$	$\tau\times 10^{-2}$	$\Delta\times 10^{-2}$	$I_{K\ell}\times 10^{-2}$
K_Le3	**0.2163(6)**	**26**	9	**20**	11	6
$K_L\mu3$	**0.2166(6)**	**29**	15	**18**	11	8
K_Se3	**0.2155(13)**	**61**	**60**	3	11	6
$K^\pm e3$	**0.2160(11)**	**52**	**31**	9	**40**	6
$K^\pm\mu3$	**0.2158(14)**	**63**	**47**	8	**39**	8

Determination of $|V_{us}|\times f_+(0)$: improvements

		% err $\times 10^{-2}$	BR$\times 10^{-2}$	$\tau\times 10^{-2}$	$\Delta\times 10^{-2}$	$I_{K\ell}\times 10^{-2}$
$K_L e3$	**0.2163(6)**	**26**	9	**13**	11	6
$K_L \mu 3$	**0.2166(6)**	**29**	10	**13**	11	8
$K_S e3$	**0.2155(13)**	**61**	**30**	3	11	6
$K^\pm e3$	**0.2160(11)**	**52**	**25**	5	**25**	6
$K^\pm \mu 3$	**0.2158(14)**	**63**	**23**	8	**25**	8

arXiv: 1003.3868v2 [hep-ex] 29 Mar 2010: Approved by EPJ

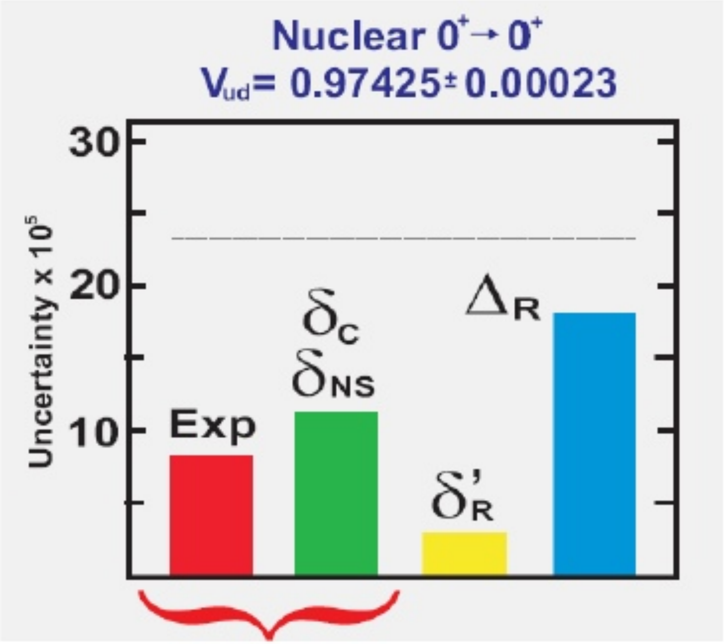
Additional information

Vud: error budget

OPPORTUNITIES FOR IMPROVEMENT

- Goal remains to tighten the window for new physics by reducing the uncertainty on V_{ud}.
- Uncertainty on calculated radiative correction Δ_R is the dominant contribution to the error budget.
- Nuclear-structure-dependent corrections, δ_C and δ_{NS}, can be tested by experiment; this has already led to improvements, but more are still possible.

Data on "well known" transitions can be made more precise, and new cases can be measured.



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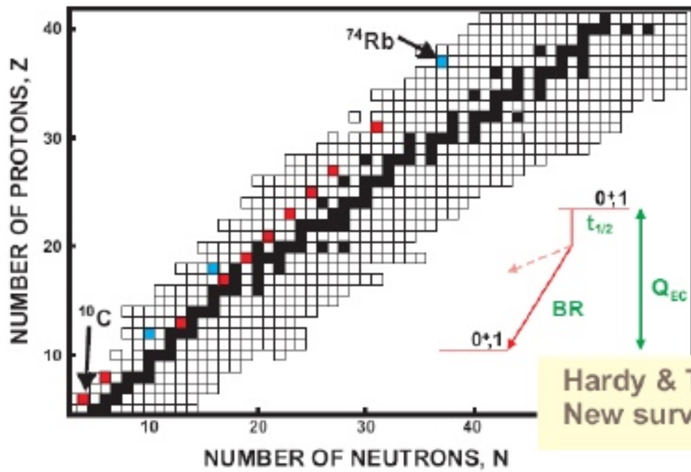
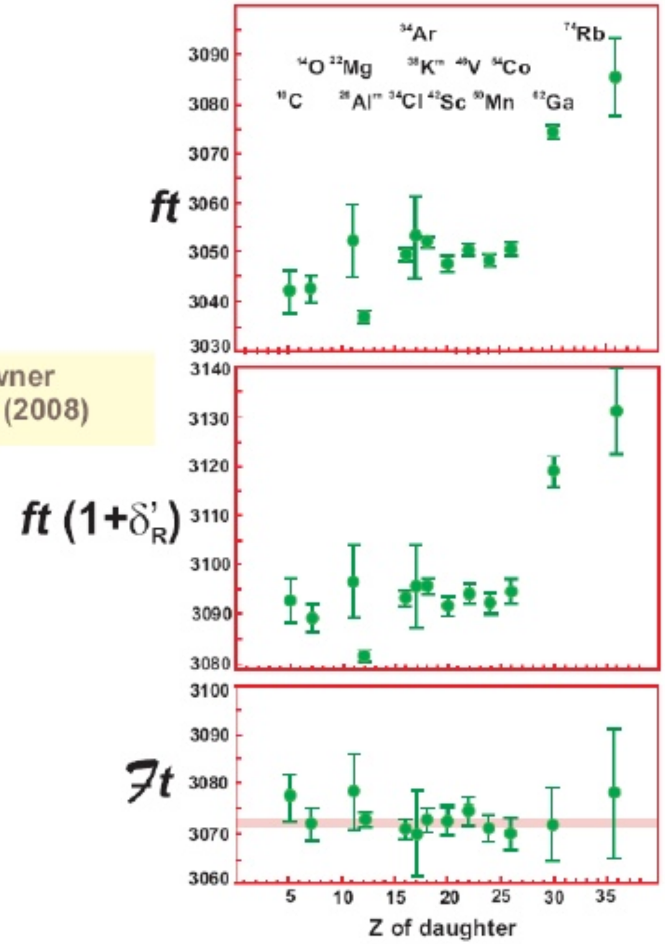
Vud : data

WORLD DATA FOR $0^+ \rightarrow 0^+$ DECAY, 2008



Hardy & Towner
New survey (2008)



- 10 cases with *ft*-values measured to ~0.1% precision; 3 more cases with <0.3% precision.
- ~150 individual measurements with compatible precision

$$\mathcal{F}t = ft\,(1+\delta'_R)\left[1-(\delta_C-\delta_{NS})\right] = \frac{K}{2G_V^2\,(1+\Delta_R)}$$

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Dispersive parameterization: a test of lattice calculations

Scalar form factor $f_0(t) = \tilde{f}_0(t)\, f_+(0)$ extrapolation at **Callan-Treiman** point:

$$\bar{f}_0(\Delta_{K\pi}) = \frac{f_K}{f_\pi}\frac{1}{f_+(0)} + \Delta_{CT} \qquad \Delta_{CT} = (-3.5 \pm 8) \times 10^{-3}$$

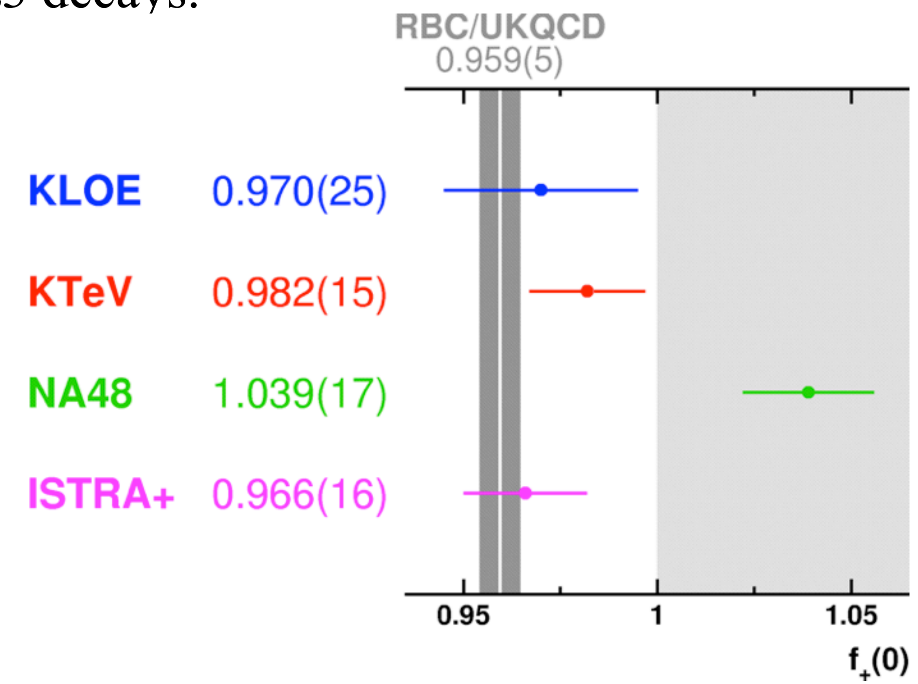
- links $f_+(0)$ and f_K/f_π with λ_0 measured in Kμ3 decays.

$\tilde{f}_0(\Delta_{K\pi})$ is evaluated fitting $K_L\mu3$ with a dispersive parameterization

$$\tilde{f}_0(t) = \exp\left(\frac{t}{\Delta_{K\pi}}\log(C - G(t))\right)$$

G(t) from Kπ scattering data.

To fit we use a 3rd order expansion



From CT, using f_K/f_π=1.193(6) obtain: $f_+(0)$=0.974(12) in agreement with RBC/UKQCD10 value: $f_+(0)$ = 0.959(5).