Vus from kaon decays

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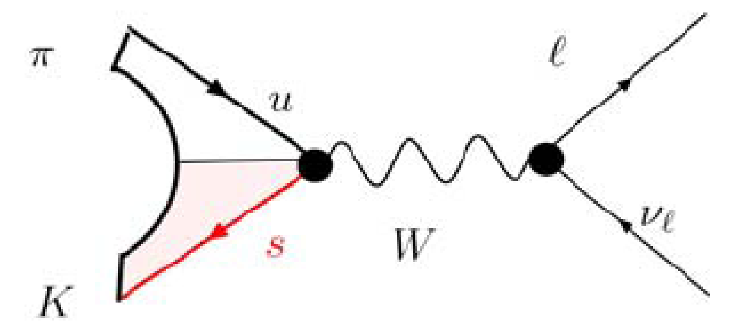
Frascati, October 11, 2010

Outline

- Experimental inputs to Vus
- Present accuracy on Vus
- SM tests
- Conclusions

CKM unitarity and lepton universality



Universality of the couplings of quark and leptons through CKM unitarity

$$G_{ij} = G_\mu V_{ij}$$

where $\sum_j |V_{ij}|^2 = 1$

Universality of the lepton coupling: G_{ij} independent from lepton flavor

New physics contributions through precision measurements of Vus

Test of Cabibbo's hypothesis of lepto-quark universality

New physics encoded by shifts of both G_μ and G_{semil}

$$G_{CKM} = G_\mu (|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2)^{1/2} = G_\mu (1 + \Delta_{semil} - \Delta_\mu)$$

leading to a unitarity-violating term Δ_{CKM}

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 + \Delta_{CKM}$$

Accuracy on G_{CKM} at the level of electroweak precision tests

$|V_{ud}|$ from $0^+ \rightarrow 0^+$ superallowed β-decays at $2 \cdot 10^{-4}$ precision level

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

Review on Vus,Vud by E.Blucher, W.Marciano
PDG(2010) J. Phys. *G* **37**, 075021

$|V_{ub}|$ does not contribute at this level

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

Vus determined from kaon, hyperon, and τ decays
The most precise measurement from K_{l3} decays

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

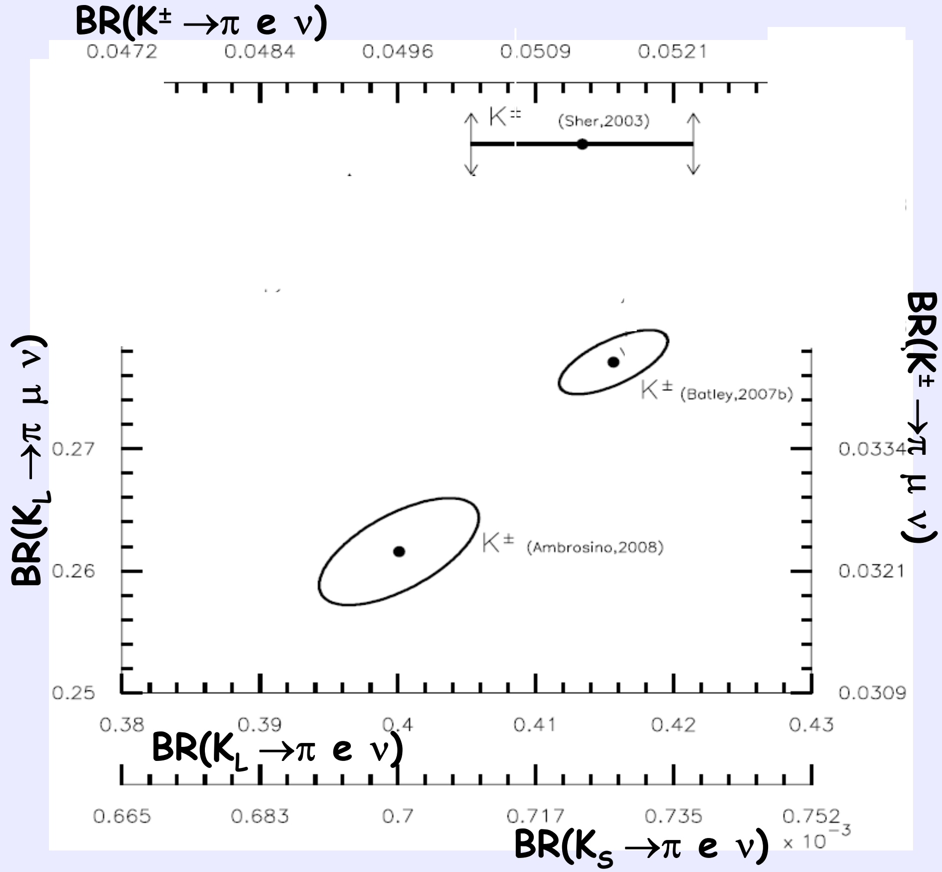
Branching fractions, lifetimes
Dalitz plot analysis to obtain $I_{K,l}(\lambda)$

$K^{\pm}$ semileptonic branching fractions

Measurements

BNL-E865	$BR(K_{e3})/BR(\pi\pi^0+K_{\mu3}+\pi\pi^0\pi^0)$	0.1962(36)
NA48/2	$BR(K_{e3})/BR(\pi\pi^0)$	0.2470(10)
NA48/2	$BR(K_{\mu3})/BR(\pi\pi^0)$	0.1637(7)
KLOE	$BR(K_{e3})$	0.04965(53)
KLOE	$BR(K_{\mu3})$	0.03233(39)

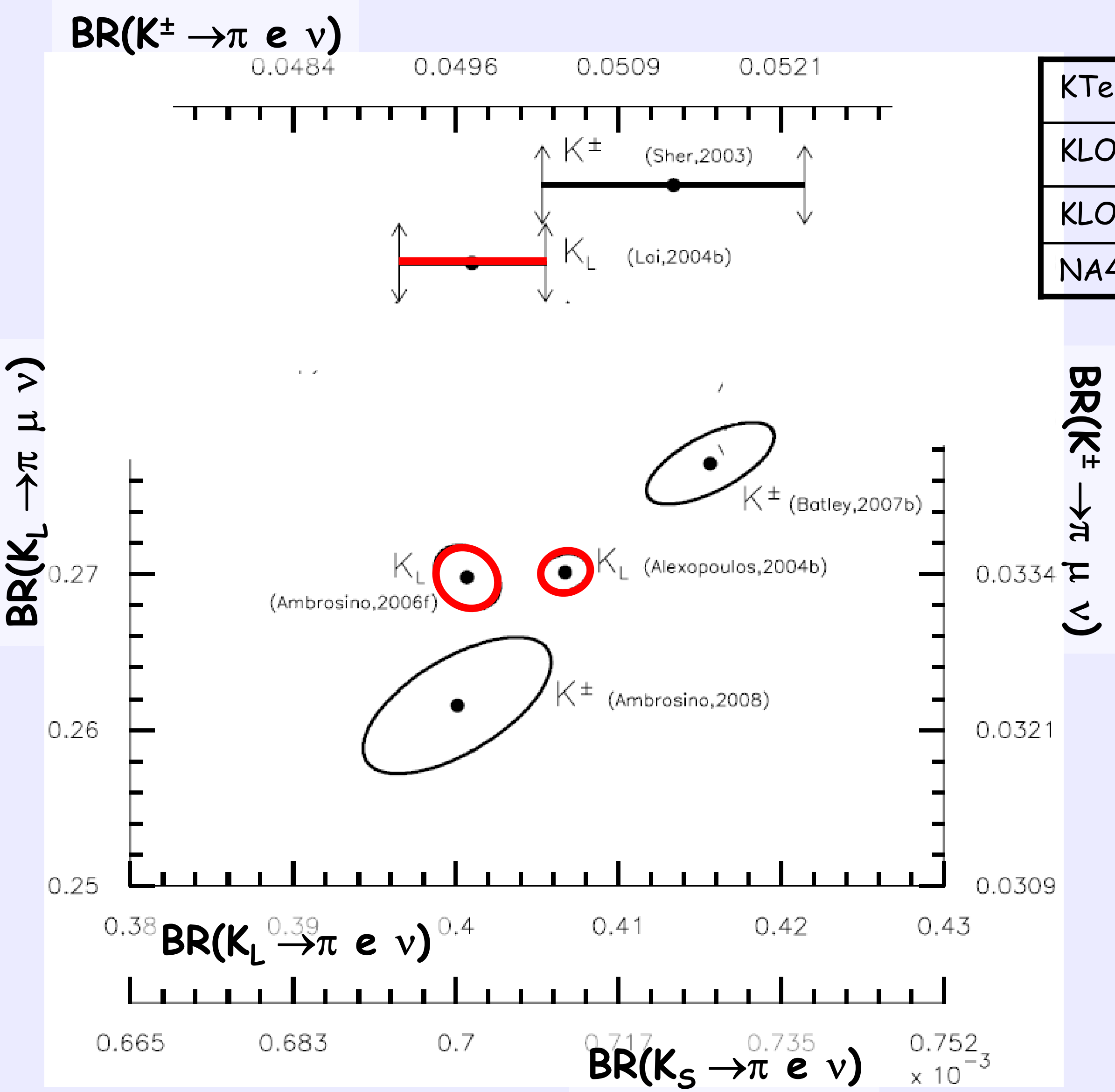
M.Antonelli et al. (FlaviANet Kaon WG), EPJC/s10052-010-1406-3, arXiv:1005.2323



Fit results

PDG-2010	$BR(K_{e3})$	0.05070(40)
FLAVIANET	$BR(K_{e3})$	0.05078(31)
PDG-2010	$BR(K_{\mu3})$	0.03353(34)
FLAVIANET	$BR(K_{\mu3})$	0.03359(32)

K_L semileptonic branching fractions



Measurements

KTeV	$BR(K_{\mu3})/ BR(K_{e3})$	0.6640(26)
KLOE	$BR(K_{e3})$	0.4049(21)
KLOE	$BR(K_{\mu3})$	0.2726(16)
NA48	$BR(K_{e3})$)/ $BR(K\to 2tracks)$	0.4978(35)

Fit results

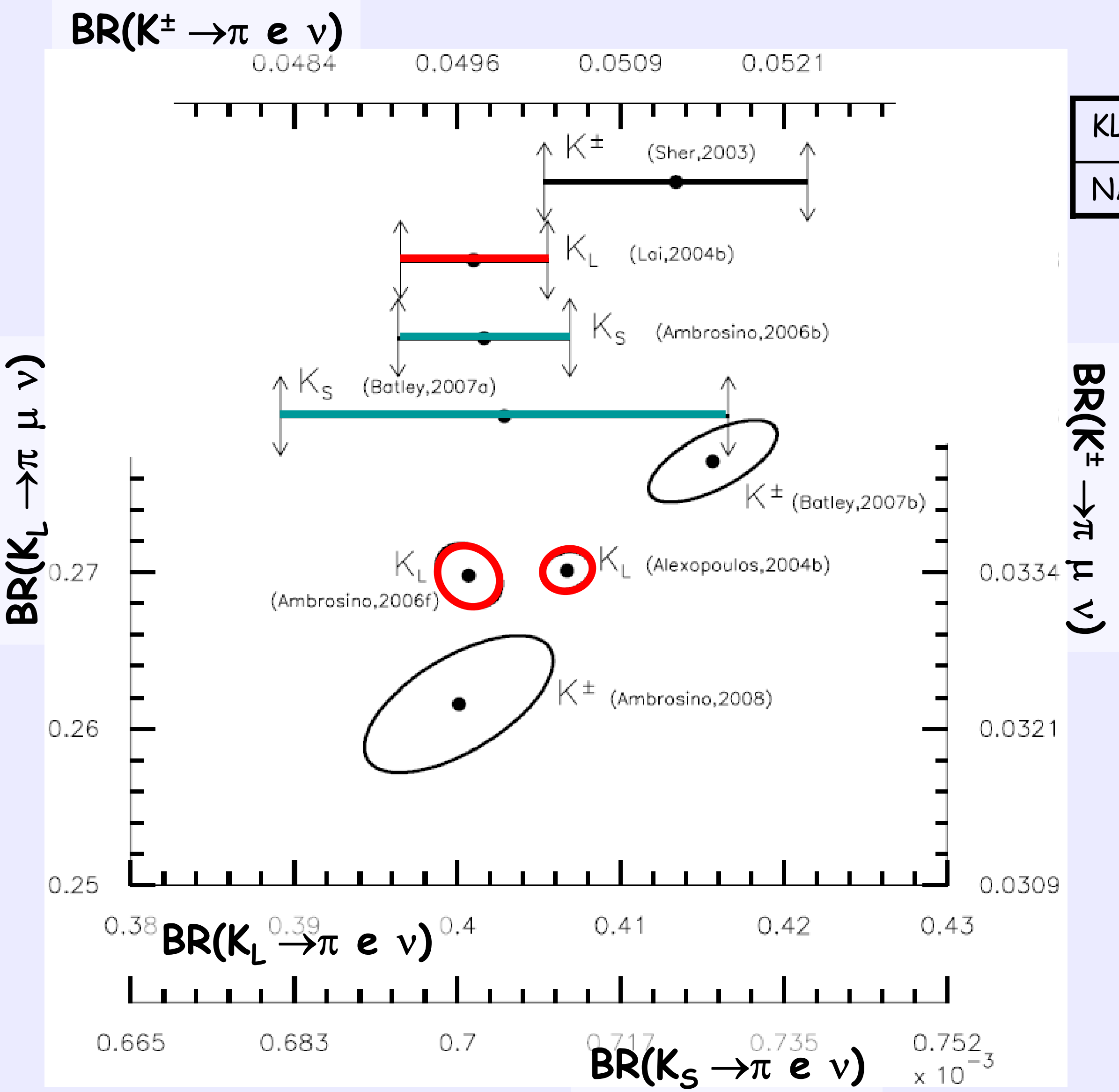
FlaviA net Kaon WG

PDG-2010	$BR(K_{e3})$	0.4055(12)
FLAVIANET	$BR(K_{e3})$	0.4056(9)
PDG-2010	$BR(K_{\mu3})$	0.2704(7)
FLAVIANET	$BR(K_{\mu3})$	0.2704(10)

Pulls

KTeV	$BR(K_{\mu3})/ BR(K_{e3})$	-1.1
KLOE	$BR(K_{e3})$	-1.3
KLOE	$BR(K_{\mu3})$	+0.5
NA48	$BR(K_{e3})$)/ $BR(K\to 2tracks)$	-0.8

K_S semileptonic branching fractions



Measurements

KLOE	$BR(K_{e3})$	$7.03(9)\ 10^{-4}$
NA48	$\Gamma(K_{e3})\ )/\ \Gamma\ (K_{Le3})$	0.993(34)

Fit results

PDG-2010	$BR(K_{e3})$	$7.04(8)\ 10^{-4}$
FLAVIANET	$BR(K_{e3})$	$7.05(8)\ 10^{-4}$
PDG-2010	$BR(K_{\mu3})$	$4.69(5)\ 10^{-4}$
FLAVIANET	$BR(K_{\mu3})$	$4.69(6)\ 10^{-4}$

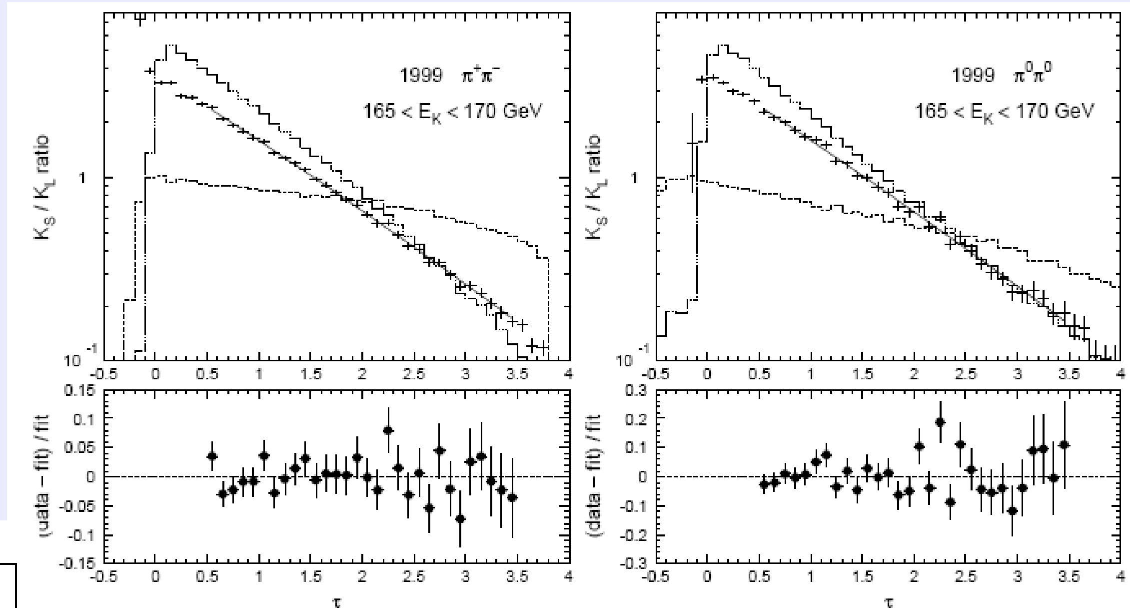
FlaviA net Kaon WG

Kaon lifetimes

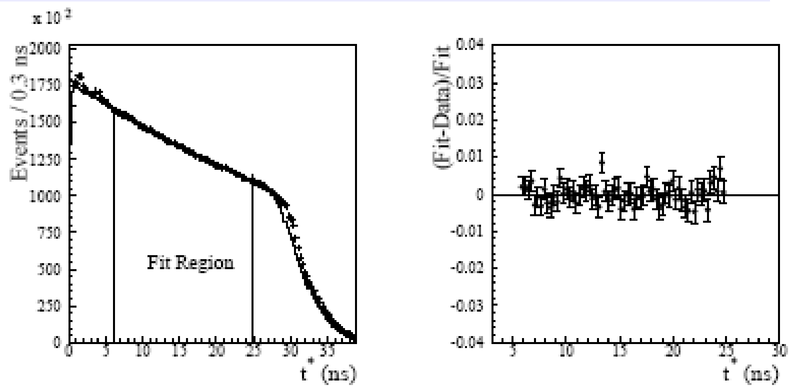
Measurements

NA48	τ_S	0.08960(7) ns
KTeV	τ_S	0.08958(13) ns
KLOE	τ_L	50.92(30) ns
KLOE	$\tau_\pm$	12.347(30) ns

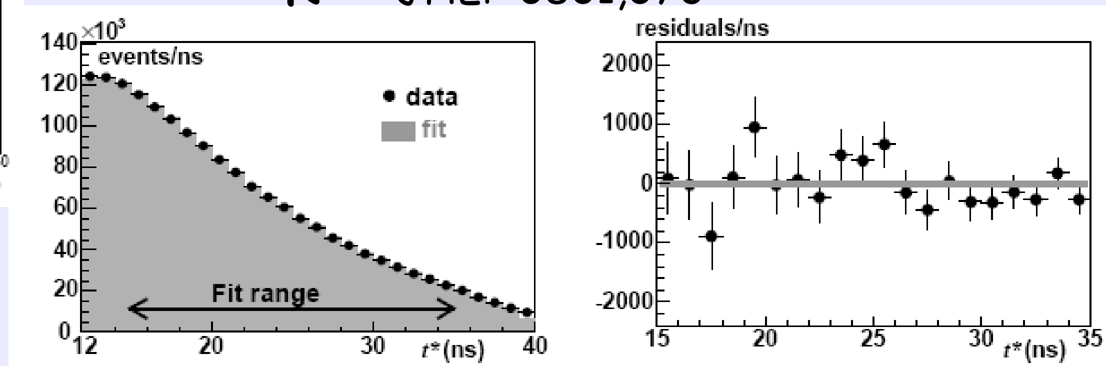
K_S PLB537(2002)28



K_L PLB626(2005)15



$K^\pm$ JHEP 0801,073



Form factor slopes

Analysis of the Dalitz plot of semileptonic decays needed to obtain the dependence from momentum transfer for the phase-space integral $I_{K,l}$ (λ)

Ke3 decays : sensitive to vector ff dependence

Kμ3 decays : sensitive to both, vector and scalar ff slopes

Parametrization of the t-dependence:

vector ff : quadratic Taylor expansion

scalar ff : linear approximation

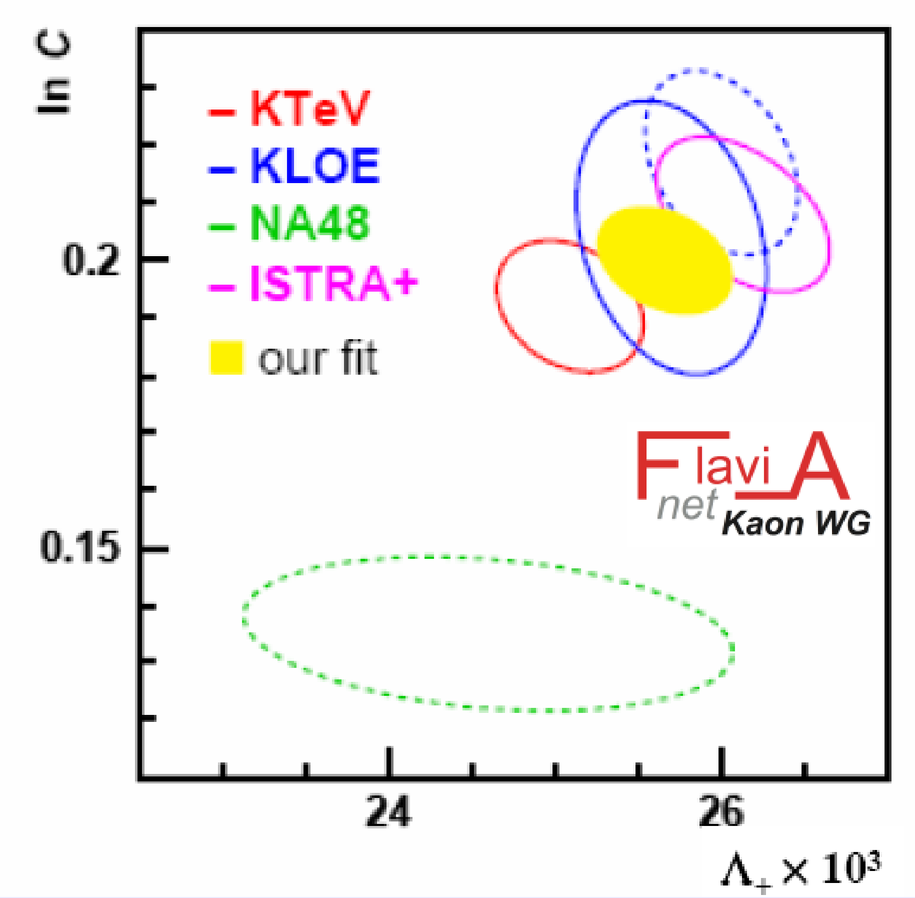
Single-parameter function introduced using dispersive relations

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

Form factor slopes

Integrals		
Mode	Quad-lin	Disp
K^0_{e3}	0.15457(20)	**0.15476(18)**
K^+_{e3}	0.15894(21)	**0.15922(18)**
$K^0_{\mu3}$	0.10266(20)	**0.10253(16)**
$K^+_{\mu3}$	0.10564(20)	**0.10559(17)**

FlaviA net Kaon WG



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

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

S_{EW}	1.0232(3)
$\Delta_{K\pm}^{SU(2)}$	0.029(4)
$\Delta_{K0,e}^{EM}$	0.0050(11)
$\Delta_{K0,\mu}^{EM}$	0.0005(12)
$\Delta_{K\pm,e}^{EM}$	0.0070(11)
$\Delta_{K\pm\mu}^{EM}$	0.0001(12)

$r_{\mu,e} = 1.002(5)$

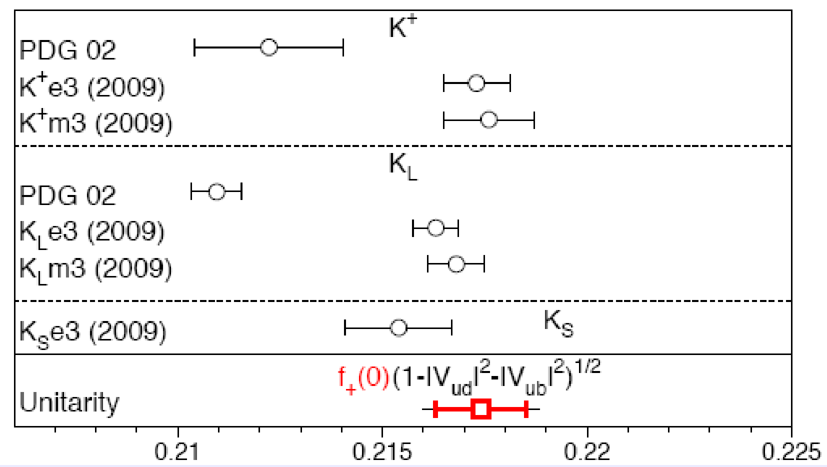
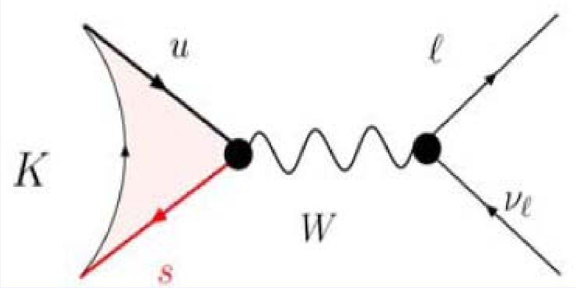


Table 1: $|V_{us}|f_+(0)$ from $K_{\ell 3}$.

Decay Mode	$\vert V_{us}\vert f_+(0)$
$K^{\pm}e3$	0.2173 ± 0.0008
$K^{\pm}\mu 3$	0.2176 ± 0.0011
$K_L e3$	0.2163 ± 0.0006
$K_L \mu 3$	0.2168 ± 0.0007
$K_S e3$	0.2154 ± 0.0013
Average	0.2166 ± 0.0005

Vus from $K_{\mu 2}$ decays



Vus has also been obtained from $\Gamma(\pi \to \mu\nu)$ (2‰ precision) and the BR($K_{\mu 2}$) measured by KLOE at 3‰ , BR($K_{\mu 2}$) =0.6366(17)

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

electromagnetic correction -0.0070(18)

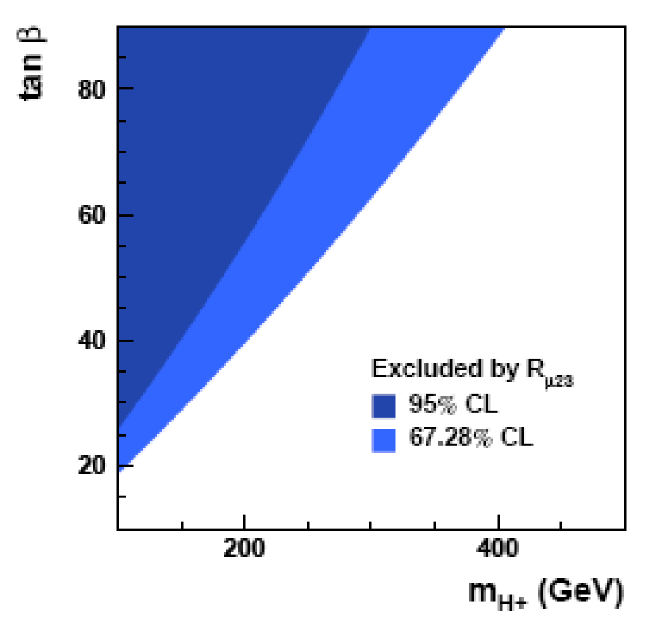
$$\frac{|V_{us}|}{|V_{ud}|} \times \frac{f_K}{f_\pi} = 0.2758(5)$$

$R_{\mu 23}$

New-physics could affect helicity-suppressed kaon decays only, so that

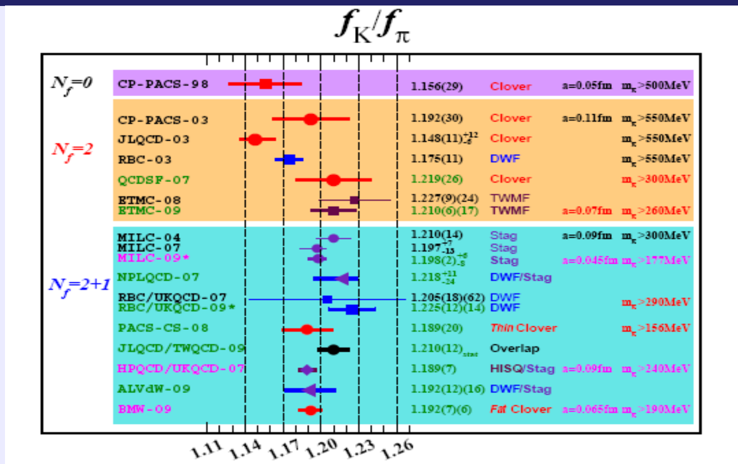
- Vus from semileptonic decays as expected in the SM
- Vus from leptonic decays smaller than expected

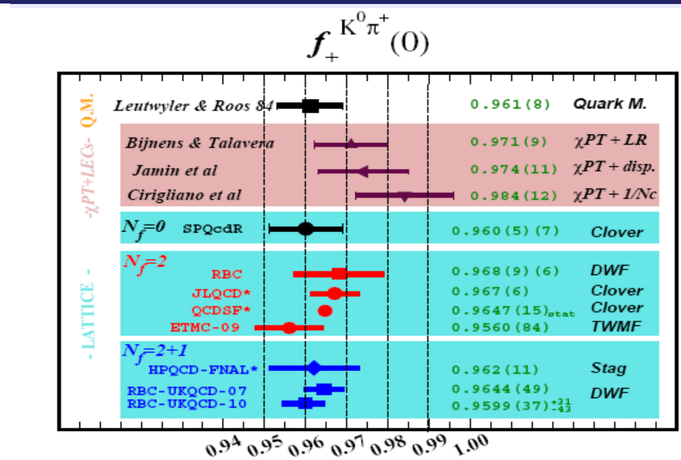
$R_{\mu 23}$ used to constrain Higgs-mediated scalar currents



$$R_{\mu 23} = \frac{f_+(0)}{f_k / f_\pi} \left(\frac{|V_{us}|}{|V_{ud}|} \frac{f_k}{f_\pi} \right)_{\mu 2} \frac{|V_{ud}|_{0^+ \to 0^+}}{\left(|V_{us}| f_+(0) \right)_{l3}} \approx \left| 1 - \frac{m_k^2}{m_{H^+}^2} \frac{\tan^2 \beta}{1 + \varepsilon_0 \tan \beta} \right|$$

LQCD calculations



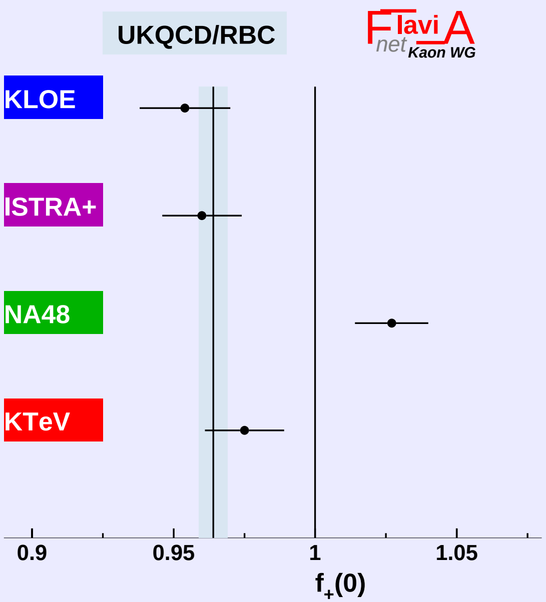


Recent progress in LQCD calculations

From the dispersion parametrization of the ff dependence from the momentum transfer,

based on analyticity constraints and the CT theorem, the experimental measurement of the ratio

$f_K/f_\pi/f_+(0) = 1.225(14)$ was obtained



CKM unitarity

Combining the results from semileptonic and leptonic kaon decays,

$$\frac{|V_{us}|}{|V_{ud}|} \times \frac{f_K}{f_\pi} = 0.2758(5) \qquad |V_{us}| \times f_+(0) = 0.2166(5)$$

and using the LQCD calculations

$$\frac{f_K}{f_\pi} = 1.193(6) \qquad f_+(0) = 0.959(5)$$

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

$\rightarrow$ $|V_{us}| = 0.2252(9)$ and $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999(4)(4)$

Improving on |Vus| $\times f_+(0)$

KLOE-2 can improve the experimental accuracy by a factor of 2 with one year of data taking at DAFNE (5 fb^{-1} of integrated luminosity)

KLOE-2 measurements : semileptonic BR's and lifetimes

	%err	BR	τ	δ	I_{Kl}	%err	BR	τ	δ	I_{Kl}
$K_L e3$ 0.2163(6)	**0.28**	0.09	0.19	0.15	0.09	**0.24**	0.09	0.13	0.15	0.09
$K_L \mu 3$ 0.2168(7)	**0.30**	0.10	0.18	0.15	0.15	**0.27**	0.10	0.13	0.15	0.15
$K_S e3$ 0.2154(13)	**0.67**	0.65	0.03	0.15	0.09	**0.35**	0.30	0.03	0.15	0.09
$K^{\pm} e3$ 0.2173(8)	**0.39**	0.26	0.09	0.26	0.09	**0.38**	0.25	0.05	0.26	0.09
$K^{\pm} \mu 3$ 0.2176(11)	**0.51**	0.40	0.09	0.26	0.15	**0.41**	0.27	0.05	0.26	0.15
Aver 0.2166(5)	**0.23**					**0.14**				

EPJC68(2010)619

Conclusions

A consistent set of precision measurements in the kaon sector together with LQCD calculations lead to

the Cabibbo's angle measurement Vus = 0.2252(9)

This and the precision results on Vud allow the test of CKM

unitarity to $6 \cdot 10^{-4}$ precision level

With the present accuracy we are probing NP at the 10-TeV scale

Sensitivity improvement is feasible in the light of recent big progress on lattice calculations and

new data at the ϕ-factory to improve the experimental accuracy on

$|V_{us}| \times f_+(0)$ to 0.14%.