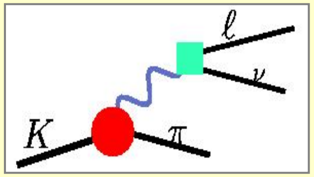
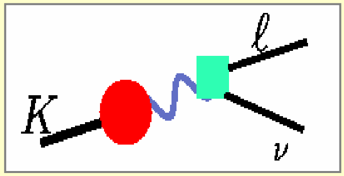
$K_{\ell 3}$ and $K_{\ell 2}$ decays: V_{us}





Federico Mescia

Laboratori Nazionali di Frascati

on behalf of the
FlaviaNet Kaon Working Group

V_{us} and the CKM Unitarity:

- Quark/Lepton Universality $\Rightarrow$ $|V_{us}|^2 + |V_{ud}|^2 + |V_{ub}|^2 - 1 = 0.9990(8)$
- Lepton Universality $\Rightarrow$ K_{e2}

Results from the FlaviaNet KWG

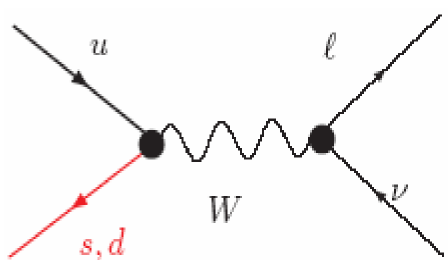
EPS-HEP 2007, July 19-25, 2007 - Manchester

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

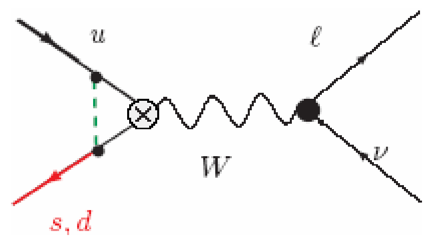
Universality of Weak coupling - $G_F = (g_w/M_w)^2$

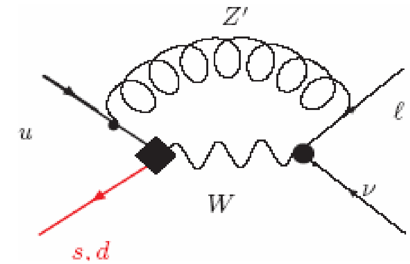
Standard Model

Susy, Little Higgs, Extra Dimesion

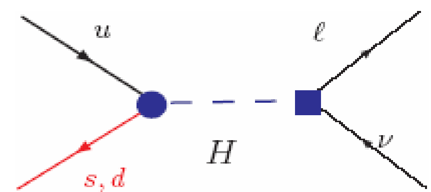


+





$\varepsilon \sim 10^{-3}$



$\varepsilon \sim 10^{-2}$

$\propto G_F^2 |V_{uq}|^2$

$\propto G_F^2 \varepsilon^{CKM}$

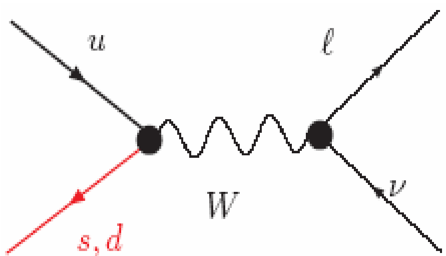
$$|V_{ud}|^2 + |V_{us}|^2 \neq 1$$

CKM Unitarity breaking

$$\left|V_{ud}\right|^2 + \left|V_{us}\right|^2 + \cancel{\left|V_{ub}\right|}^2 = 1$$

Universality of Weak coupling - $G_F = (g_w/M_w)^2$

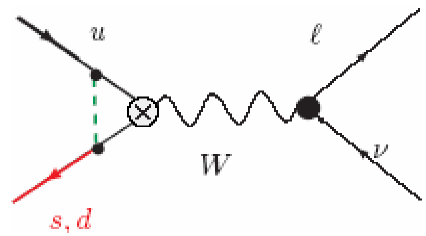
<u>*Standard Model*</u>

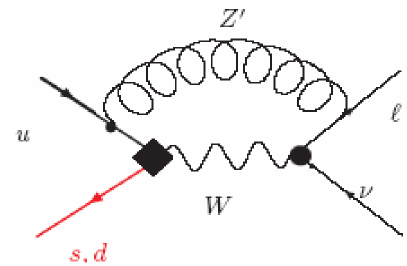


$\propto G_F^2 \left|V_{uq}\right|^2$

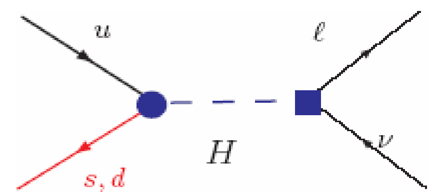
+

<u>*Susy, Little Higgs, Extra Dimesion*</u>





$\varepsilon \sim 10^{-3}$



$\varepsilon \sim 10^{-2}$

$\propto G_F^2 \varepsilon^{CKM}$

$$G_F^2 \times \left(\left|V_{ud}\right|^2 + \left|V_{us}\right|^2 \right) \neq 1 \times G_F^2$$

CKM Unitarity breaking

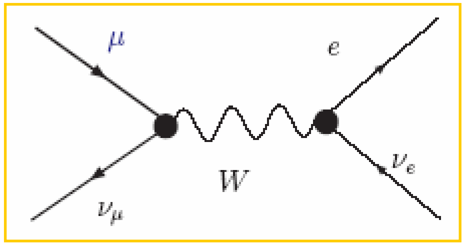
Gauge Universality Breaking

- **significantly different from the Unitarity Triangle Test**

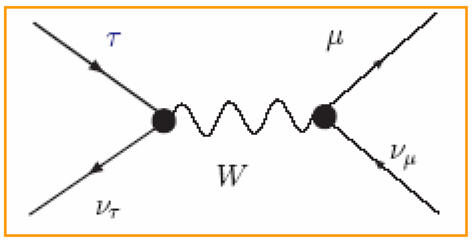
(overal normalisation arbitrary)

G_F – Universality

$$G_{CKM}^2 \equiv G_F^2 \times \left(|V_{ud}|^2 + |V_{us}|^2 \right) \neq G_F^2$$



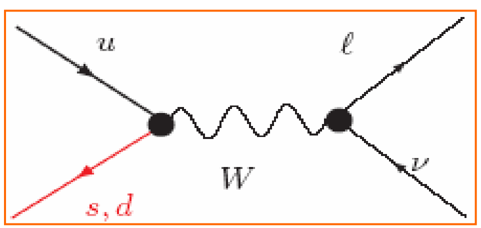
$G_F = 1.166371(6)\times 10^{-5}\ \mathrm{GeV}^{-2}$



$G_\tau = 1.1678(26)\times 10^{-5}\ \mathrm{GeV}^{-2}$

$\alpha + M_W + s_W$
[e.w. precision tests]

$G_{e.w.} = 1.1655(12)\times 10^{-5}\ \mathrm{GeV}^{-2}$



$G_{CKM} = 1.1658(04)\times 10^{-5}\ \mathrm{GeV}^{-2}$

V_{us} at 0.5%

- **V_{us} below 1% makes CKM unitarity competitive to Electro-Weak Precision Test**

• V_{us} below 1% makes the CKM unitarity test competetive to Electro-Weak Precision Test

• *In the spirit of the HFAG for B physics*, *a joint experimental and theory working group has been set up for Kaon physics*:

Working Group on Precise SM Tests in K Decays

Kaon WG home
FlaviaNet home

Master Formulae
Branching Ratios
Lifetimes
Form Factors

Radiative Corrections
SU(3) Breaking Form Factors

Contacts

ISTRA+:
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KLOE:
Matthew Moulson (Frascati) web contact
Patrizia De Simone (Frascati)

KTeV:
Sasha Glazov (DESY)

NA48:
Rainer Wanke (Uni. Mainz)
Michele Veltri (Uni. Urbino)
Mauro Piccini (CERN)

Theory:
Johan Bijnens (Lund)
Vincenzo Cirigliano (Los Alamos)
Juerg Gasser (Bern)
Claudio Gatti (Frascati)
Richard Hill (FNAL)
Federico Mescia (Frascati) web contact
Jan Stern (Orsay)

FlaviA net Kaon WG

http://www.lnf.infn.it/wg/vus/

News
Talks
Acknowledgements

Honorary chair: Paolo Franzini (LNF) Coordinators: Mario Antonelli (LNF) and Gino Isidori (LNF)

• *Measurements* (BR's + Lifetime's + Form Factors) and *Theory inputs* have not trivial correlations, which is crucial to take into account!!!

V_{us} determination and the CKM Unitarity

FlaviA net Kaon WG

Averages **from the FlaviaNet KWG**

- *Vector* **Weak Universality** $\Rightarrow$

$$V_{us} f_+(0) = 0.21668(45) \Rightarrow V_{us}^{Kl3} = 0.2254(13) \Rightarrow |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9990(8)$$

- *Vector* **Lepton Universality** $\Rightarrow$

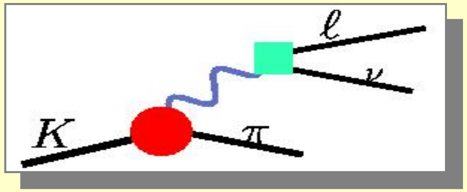
$$G_F^{\mu} / G_F^{e} = 1.0042(50) \quad [\Rightarrow 0.5\%]$$

talk by Spadaro

Mind

- **Theory:** QCD uncertainties need much better control!!
- **Experiment:** poor agreement on Form Factors measurements

suggestion for the new generation of *Lattice* and *P326* experiments



V_{us} from $K_{\ell 3}$ decays

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

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

Inputs from experiment:

$\Gamma(K_{l3(\gamma)})$ **Branching ratios** with well determined treatment of radiative decays; **lifetimes**

$I_{Kl}(\lambda)$ Phase space integral: λs parameterize form factor dependence on t :

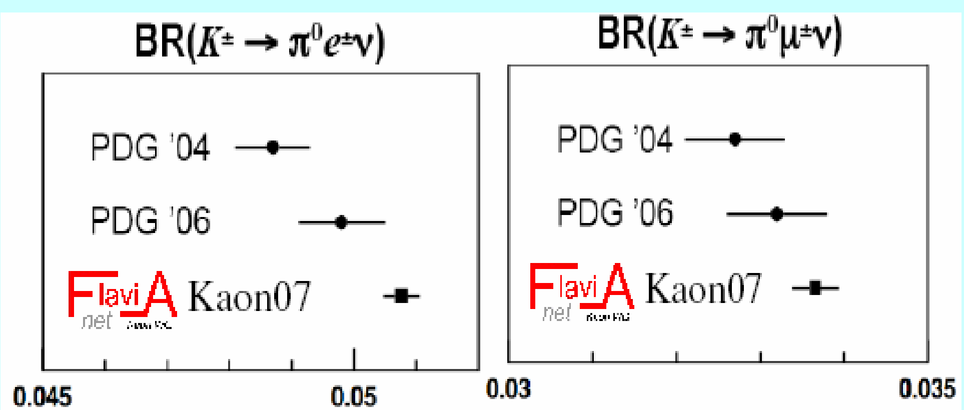
K_{e3} : only λ_+ (or λ_+' λ_+'')

$K_{\mu 3}$: need λ_+ and λ_0

Several new results in the last 2 years

KTeV | KLOE | NA48 | ISTRA+ | E865

Evolution of $K^\pm$ BRs



talk by De Lucia & Goudzovski

V_{us} from $K_{\ell 3}$ decays

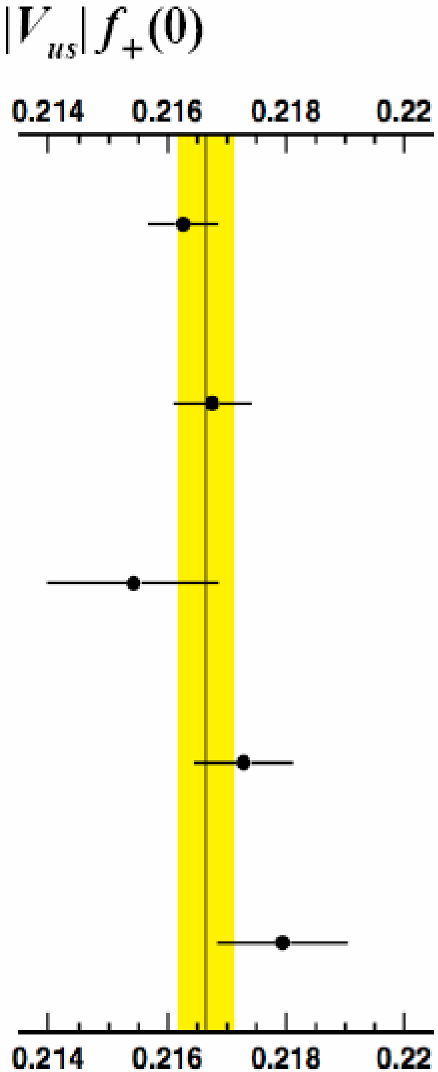
$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 I_{Kl}(\lambda) (1+2\Delta_K^{SU(2)} + 2\Delta_{Kl}^{EM})$$

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

Inputs from theory:

S_{EW}	Universal short distance EW correction (1.0232)	Marciano & Sirlin
$f_+^{K^0\pi^-}(0)$	Hadronic matrix element at zero momentum transfer (t=0)	Lattice (+CHPT) — Delicate Point
$\Delta_K^{SU(2)}$	Form factor correction for strong SU(2) breaking	News! CHPT
Δ_{Kl}^{EM}	Long distance EM effects	CHPT

CHPT
Knecht et al. '00
Cirigliano et al. '02-'04
Andre '04; Gatti '05
Moussalam et al. '06
Neufeld prelim. '07



FlaviA net Kaon WG

		% err	Approx. contrib. to % err from: BR	τ	Δ	Int
$K_L e3$	0.21625(60)	0.28	0.09	0.19	0.15	0.09
$K_L \mu 3$	0.21675(66)	0.31	0.10	0.18	0.15	0.15
$K_S e3$	0.21542(144)	0.67	0.65	0.03	0.15	0.09
$K^{\pm} e3$	0.21728(84)	0.39	0.26	0.09	0.26	0.09
$K^{\pm} \mu 3$	0.21794(111)	0.51	0.40	0.09	0.26	0.15

Average: $|V_{us}| f_+(0)$ = 0.21664(48) **χ^2/ndf = 2.88/4 (58%)**

News!

FlaviA net Kaon WG

$\Delta^{SU(2)}_{exp}$ = 2.86(39)% → success of CHPT calculations $[\Delta^{SU(2)}_{th}$ = 2.31(22)%]

At this point … using inputs from Br, I_K and δ the quantity

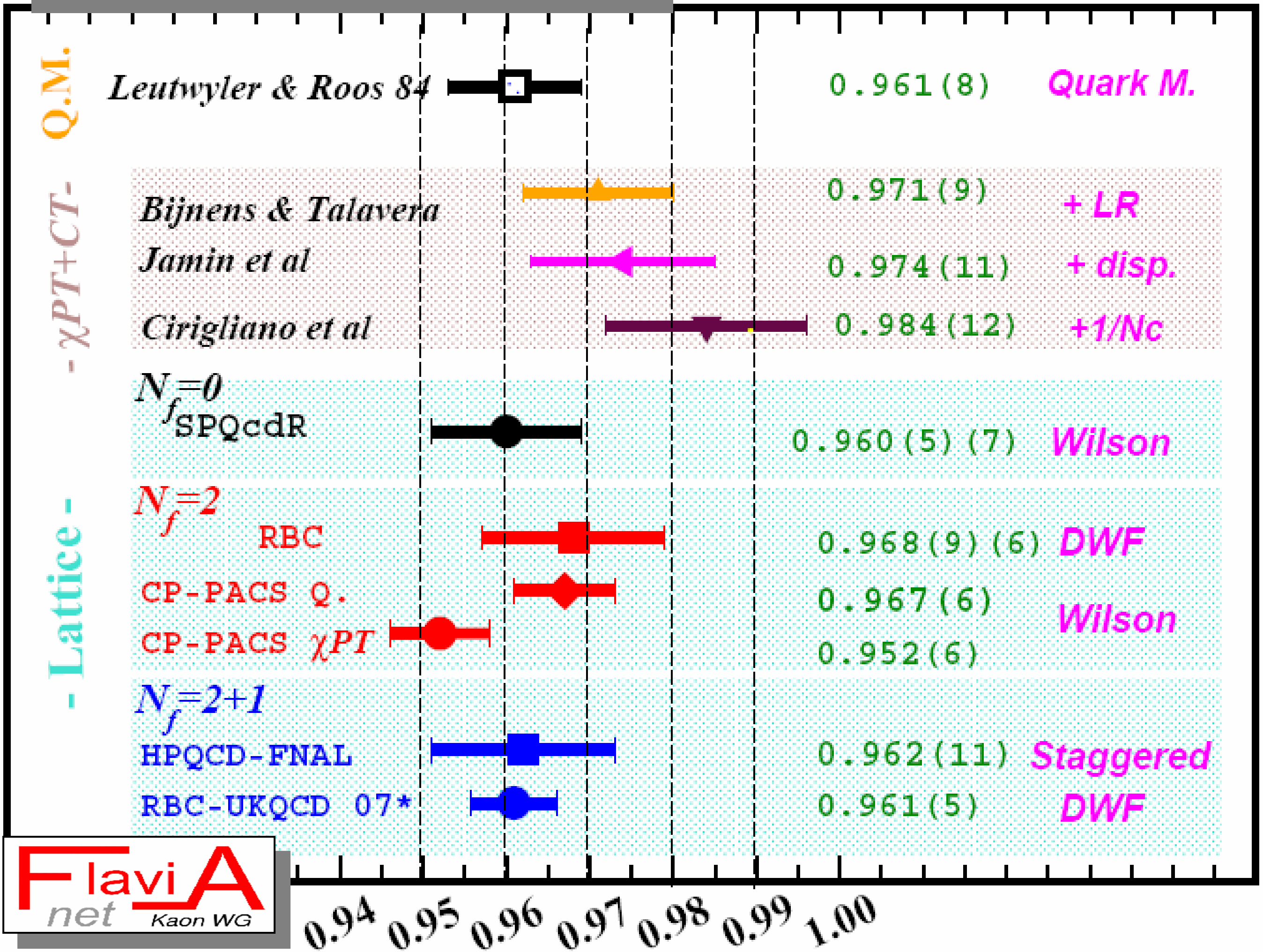
$\left(V_{us}\cdot f_+^{K^0\pi^-}(0)\right)$ is measured with small th. and exp. uncertainties.

$$\left(V_{us}\cdot f_+^{K^0\pi^-}\right)_{\text{FlaviaNet}}^{\text{Exp-Average}} = 0.21668(45) \Rightarrow\Rightarrow \sigma_{rel} \sim 0.21\%$$

Now to estimate V_{us} we need $f_+(0) \equiv f_+^{K^0\pi^-}(0)$

Experimental information diluted by the large theoretical error of $f_+(0)$ => $\sigma_{\text{rel}}\sim 1\%$

$f_+^{K^0\pi^-}(0)$ - Evaluations



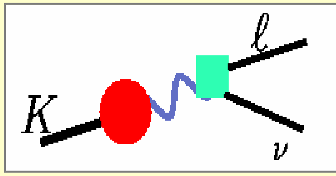
Many Theoretical Approaches

- First estimate by LR in 1984 => $f_+(0)$=0.961(8)
- Present values agree with each other at 1-2% [$f_+(0)$~0.96-0.98]
- **Next progress rely on Lattice approach**
- Many lattice estimates already available, typically at **$m_\pi \geq 500$ MeV** <=> large chiral uncertainties
- Lattice systematically smaller than χPT- inspired values

- **Encouraging result from UKQCD-RBC: N_F=2+1, DWF, $m_\pi \geq 300$ MeV**

$f_+(0)$=0.961(5) ==> σ ~0.5%

V_{us} from $K_{\ell 2}$ decays



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

$[1 + \delta_{\text{e.m.}}]$

KLOE
PLB 636 (2006)

BR($K^+ \to \mu^+ \nu(\gamma)$) = 0.6366(17)

- No competition from non-Lattice approaches

no Ademollo-Gatto protection

$f_K/f_\pi = 1.208(2)(^{+7}_{-14})$

MILC '05

$\boxed{f_K/f_\pi = 1.189(7)}$

UKQCD+HPQCD '07

$N_f = (2+1)_{\text{stag}}$ [MILC]

reached rel. err. ~ 0.7 %

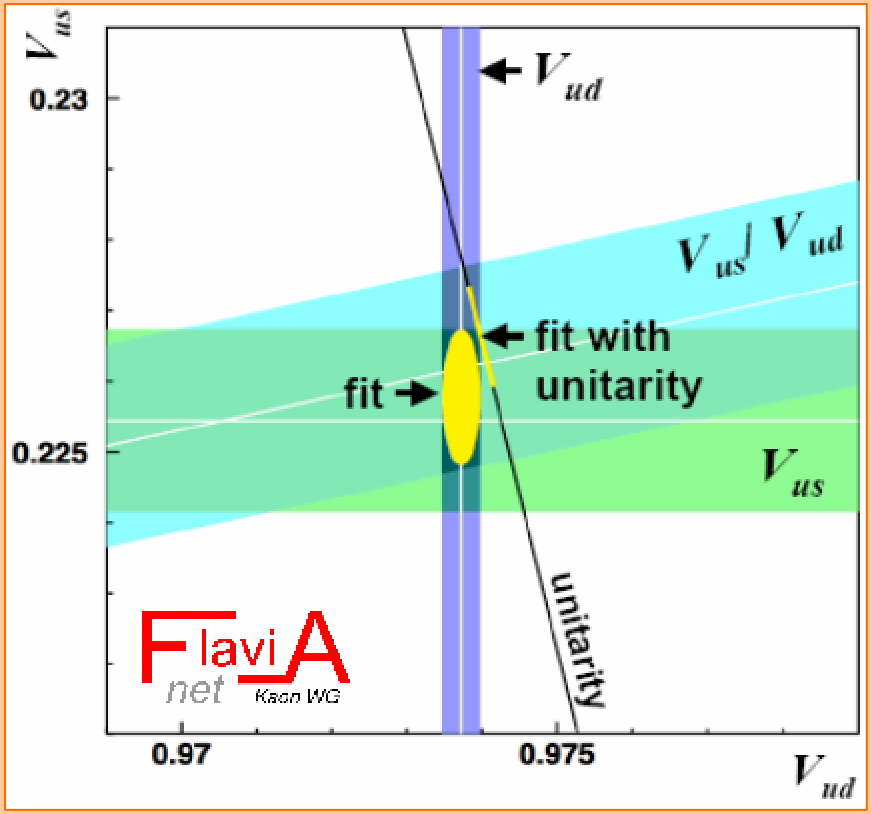
$V_{us}/V_{ud} = \mathbf{0.2323(15)}$

Reminder:
Recent unquenched Lattice results are still under scrutiny from other groups

V_{us} and CKM Unitarity at Summer 2007

$f_+(0)$=0.961(5) **from UKQCD / RBC'07**
$|V_{us}|$=0.2254(13) *from Kl3*

f_K/f_π=1.189(7) **from HPQCD'07**
$|V_{us}/V_{ud}|$=0.2323(15) *from Kl2*



Fit results, no constraint:

V_{ud} = 0.97372(26)
V_{us} = 0.2258(10)
χ^2/ndf = 0.142/1 (70%)

Fit results, unitarity constraint:

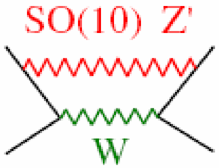
V_{ud} = 0.97398(17)
V_{us} = 0.2266(7)
χ^2/ndf = 1.92/2 (38%)

Agreement with unitarity 0.9σ

$$|V_{ud}|^2 + |V_{us}|^2 = 0.9990(8)$$

This is a highly non-trivial constraint for NP models...

E.g.:



$\rightarrow$ $M_{Z'} > 1.2$ TeV

V_{us} and CKM Unitarity at Summer 2007

FlaviA net Kaon WG

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$|V_{us}|$=0.2254(13) ***from Kl3***

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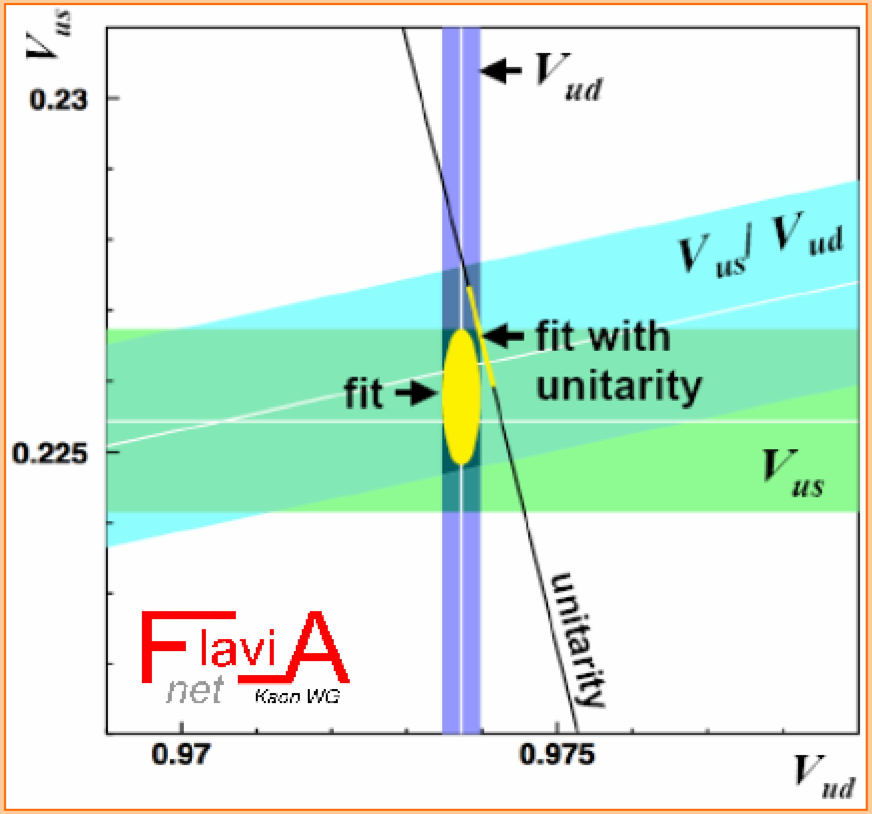
$|V_{us}/V_{ud}|$=0.2323(15) ***from Kl2***



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Reminder:
Recent unquenched Lattice results are still under scrutiny from other groups

Future Perspectives

- **QCD Test of** $\frac{f_K}{f_\pi} / f_+(0)$ *by the Callan-Treiman theorem*

⇨ ***improved bound on right-handed current and scalar densities*** → Bernard, Oertel, Passemar & Stern

→ Hou - Isidori & Paradisi,

- **Lepton Universality Test** $\Rightarrow$

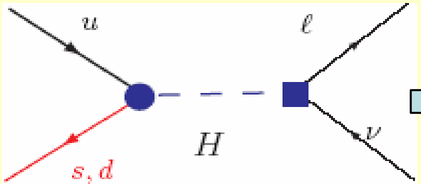
$$B(K \to e\nu) / B(K \to \mu\nu)$$

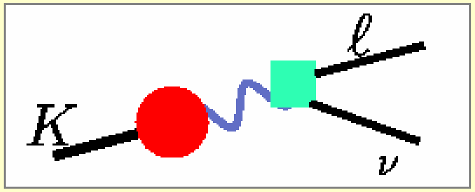
Masiero, Paradisi & Petronzio

*large tan*β & LFV

Key Point:

scalar operators enhanced by elicity suppression





- *Callan-Treiman soft-pion theorem* $\Rightarrow$

$$\left(\frac{f_K}{f_\pi}\frac{1}{f_+(0)}\right) = f_0\,(m_K^2 - m_\pi^2) + \delta_{SU(2)}^{CT} \rightarrow 1 + \lambda_0^{\exp}\,\frac{m_K^2 - m_\pi^2}{m_\pi^2} + \Delta$$

experimental input

disp. relation + th. input

Bernard, Oertel, Passemar & Stern

consistency test between experiments and Lattice QCD

- *Callan-Treiman soft-pion theorem* $\Rightarrow$

$$\left(\frac{f_K}{f_\pi}\frac{1}{f_+(0)}\right) = 1 + \lambda_0^{\text{exp}}\frac{m_K^2 - m_\pi^2}{m_\pi^2} + \Delta$$

disp. relation + th. input

Bernard, Oertel, Passemar & Stern

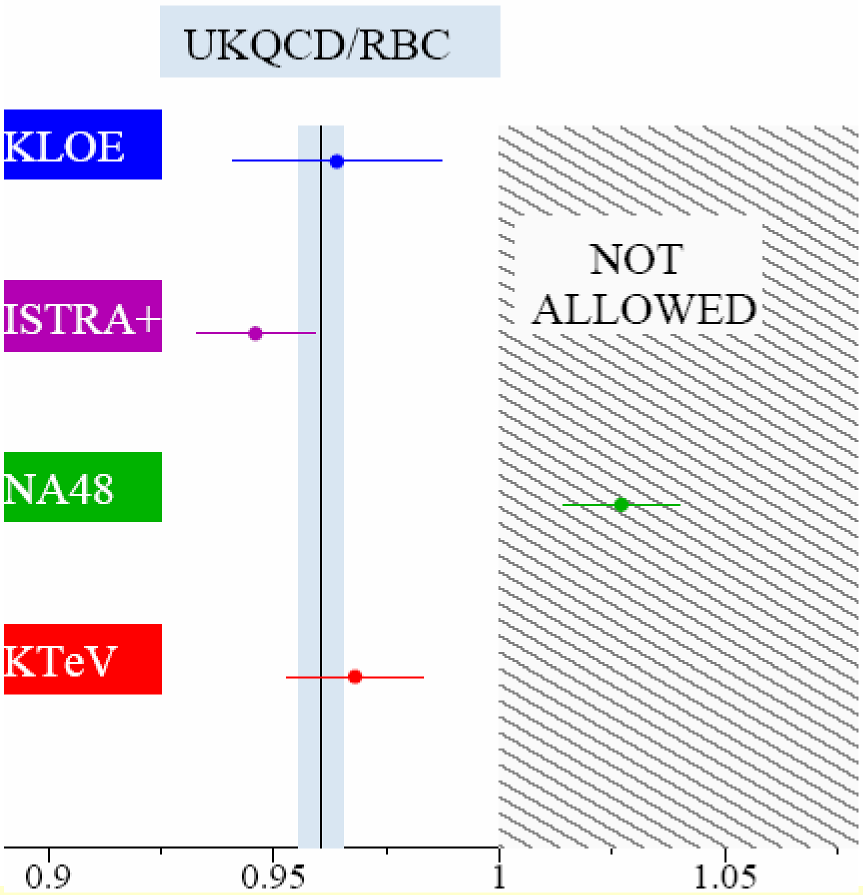
exp. input

$f_K/f_\pi = 1.189(7)$ **from HPQCD'07**

+

$$\boxed{f_+(0)^{\text{exp}}_{CT}}$$

consistency test between experiments and Lattice QCD



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disp. relation
+ th. input

Bernard, Oertel, Passemar & Stern

consistency test
between experiments
and Lattice QCD

promising in view of future lattice and exp. data

improved determination of hadronic parameters
useful to test/constraint NP models on

$$\frac{B(K \to l\nu)}{B(\pi \to l\nu)} \times \frac{B(n \to pl\nu)}{B(K \to \pi l\nu)} \propto \left(\frac{f_K}{f_\pi}\frac{1}{f_+(0)}\right)^2$$

1. *Higgs contributions on scalar operators* $\Rightarrow$

MFV @*large* tanβ
Isidori & Paradisi '06,

$$\frac{B(K\to l\nu)}{B(\pi\to l\nu)}\times\frac{B(n\to pl\nu)}{B(K\to\pi l\nu)}=\left(\frac{f_K}{f_\pi}\frac{1}{f_+(0)}\right)^2\times\left(1-\frac{m_K^2}{m_{H^+}^2}\frac{\tan\beta^2}{1+\varepsilon_0\tan\beta}\right)^2\frac{(\text{known f.s})}{I_{Kl}\left(\lambda_{+,0}\right)}$$

~ 0.3%

~ 0.2% @*large tan*β

competitive to Br(B->τν) at 30% uncertanties

2. *Right-Handed Current* $\Rightarrow$

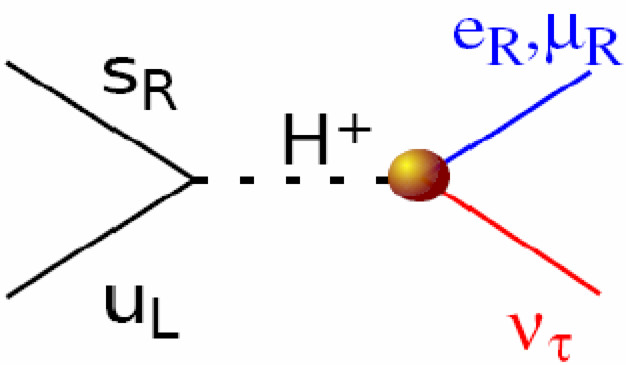
Bernard, Oertel, Passemar & Stern

talk by Oertel on ``BSM session"

Lepton Universality Test $\Rightarrow$ $B(K \to e\nu) / B(K \to \mu\nu)$

The most popular/exciting NP scenario which could affect c.c. semileptonic decays is the possibility of LFV effects modifying the μ/e ratio in K_{l2}

$$R_K = (1+\Delta r_K^{e-\mu}) = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}$$



$$eH^\pm\nu_\tau \to \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{31} \tan^2\beta$$

$$\Delta_R^{31} \sim \frac{\alpha_2}{4\pi} \delta_{RR}^{31}$$

$$\Delta_R^{31} \sim 5 \cdot 10^{-4} \quad t_\beta = 40 \quad M_{H^\pm} = 500\mathrm{GeV}$$

$$\Downarrow$$

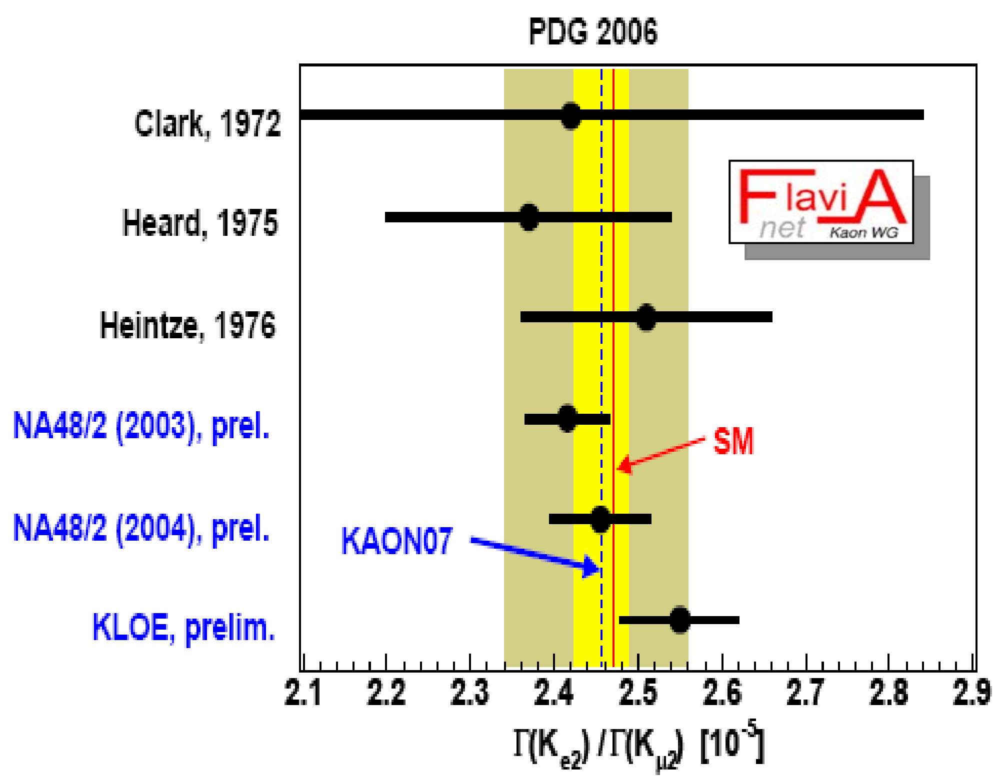
$$\Delta r_{K\,SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right) |\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

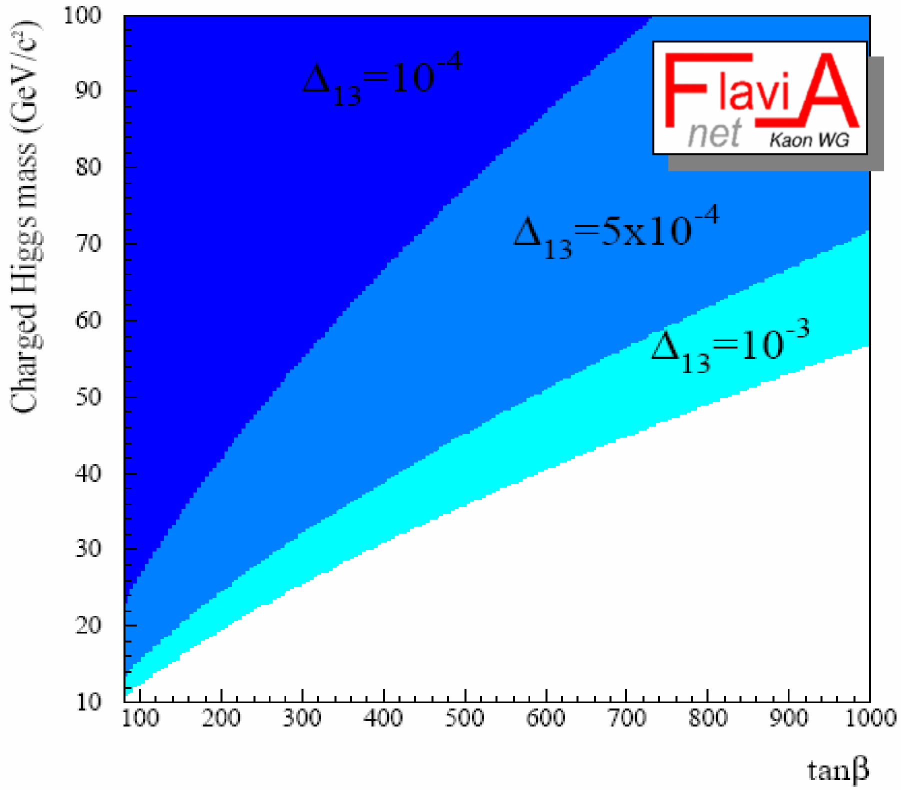
Masiero Paradisi Petronzio '06

key ingredeints for visible effects in SUSY:

- Large $\tan\beta$, $M_H < 1 TeV$
- Large LFV slepton minxings, $\delta_{3j} \sim \mathcal{O}(1)$, ($m_{SUSY} \geq 1\mathrm{TeV}$)

Limit on LFV in H^+ coupling $\Rightarrow$ $B(K \to e\nu)/B(K \to \mu\nu)$





	$\Gamma(K_{e2})/\Gamma(K_{\mu 2})$ $[10^{-5}]$
PDG 2006 [1]	2.45 ± 0.11
NA48/2 prel. ('03) [22]	$2.416 \pm 0.043 \pm 0.024$
★ NA48/2 prel. ('04) [23]	$2.455 \pm 0.045 \pm 0.041$
★ KLOE prel. [24]	$2.55 \pm 0.05 \pm 0.05$
SM prediction	2.472 ± 0.001

Recent Results at O(1-2%)

$\Rightarrow$ 0.3% from P326 in the fall of 2007

talk by Fantecchi on ``BSM session"

★@Kaon07

$$\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.457 \pm 0.032) \times 10^{-5}$$

Lessons from Kaon Physics

1. V_{us} at 0.1% precision not impossible

$\Rightarrow$ *significant SM test competitive with EWPT*

2. To reach this goal a collaboration between theorist and experimentalist is essential

$\Rightarrow$ *e.m corrections*

$\Rightarrow$ strong *SU(2) corrections*

$\Rightarrow$ chiral extrapolation of lattice results

$\Rightarrow$ correlated data analysis

FlaviAnet Kaon WG