Status of V_{us} determination and perspectives

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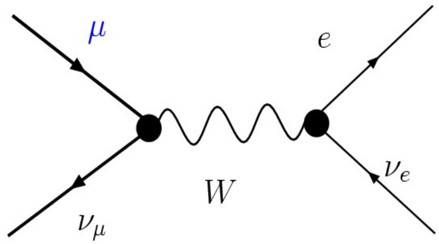
1^{st} raw unitarity: G_F universality

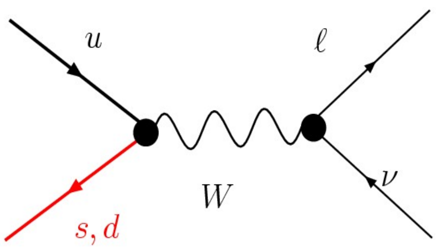
$$|V_{ud}|^2 + |V_{us}|^2 + |\cancel{V_{ub}}|^2 \equiv 1$$

Universality of Weak coupling- $G_F=(g_W/M_W)^2$

$$G_F^{\,2} \equiv G_{CKM}^{\;\;2} = (|V_{ud}|^2 + |V_{us}|^2)\, G_F^{\,2}$$



G_F = 1.166371(6)×10^{-5} GeV^{-2}



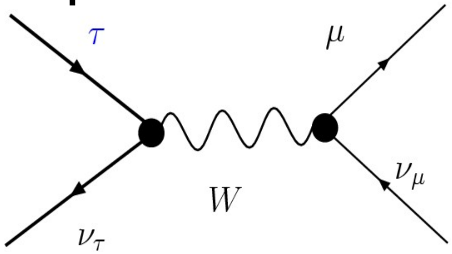
G_{CKM} = 1.16633(35)×10^{-5} GeV^{-}

2

$\alpha + M_W + s_W$

[e. w. precision tests]

G_{ew} = 1.1655(12)×10^{-5} GeV^{-2}



G_τ = 1.1678(26)×10^{-5} GeV^{-2}

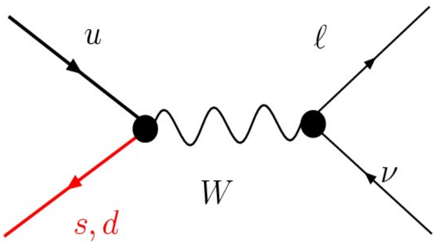
[Marciano]

G_F universality violation

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

Universality of Weak coupling- $G_F=(g_W/M_W)^2$

$$G_F^{\,2} \equiv G_{CKM}^{\;2} = (|V_{ud}|^2 + |V_{us}|^2)\, G_F^{\,2}$$



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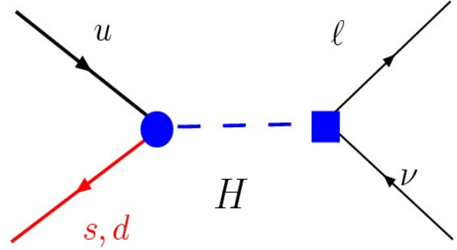
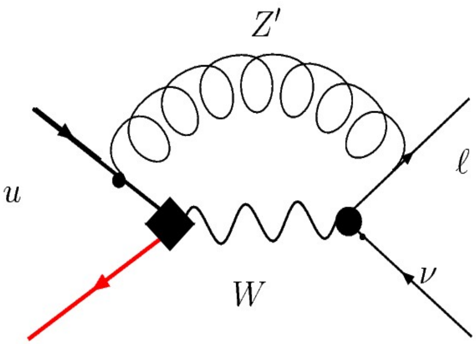
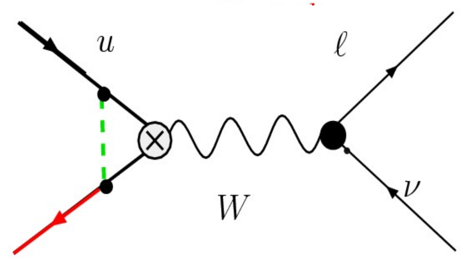






Sensitivity to new physics :
naively

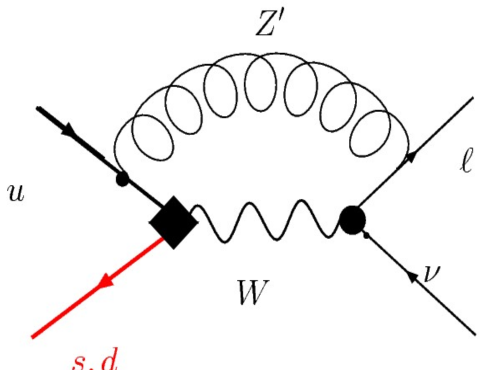
$$G_{CKM} = G_F\,[1+a(M_W/M_M)^2]$$

Tree level **a~1** **M_M~10 TeV**

loops **$a \sim g_W^{\,2}/(16\pi^2)$** **$M_M$~1 TeV**

sensitivity to NP: Z'oology

1)



$$G_F = G_{CKM}\left[1 - 0.007\, Q_{eL}\,(Q_{\mu L} - Q_{dL})\,\frac{2\ln(m_Z/m_W)}{(m_Z^2/m_W^2 - 1)}\right]$$

[Marciano]

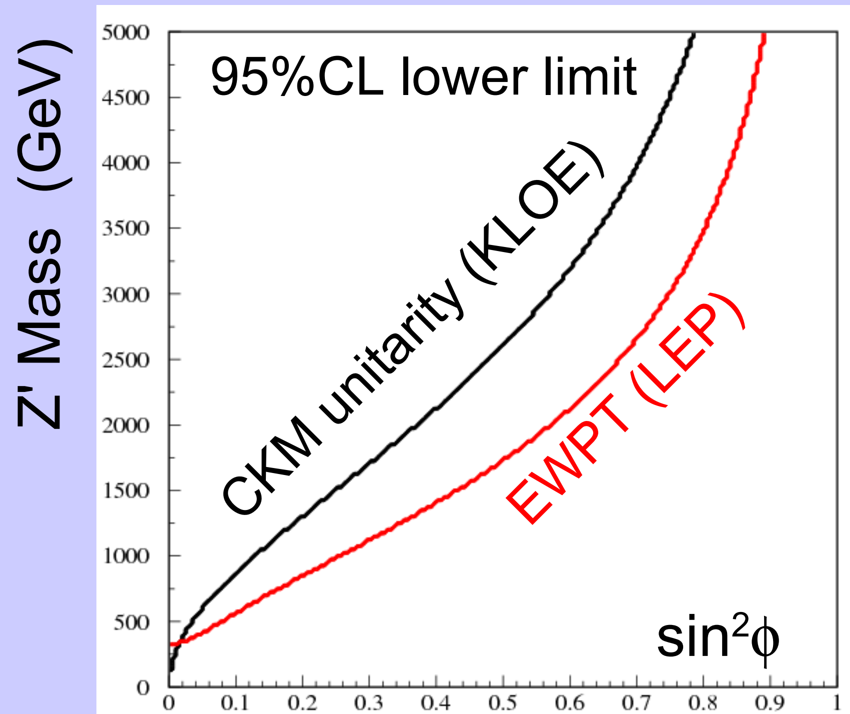
SO(10) $Z\chi$ Boson: $Q_{eL} = Q_{\mu L} = -3Q_{dL} = 1$

$m_{Z\chi}$ > 750 GeV 95%CL

2)

[K.Y. Lee]

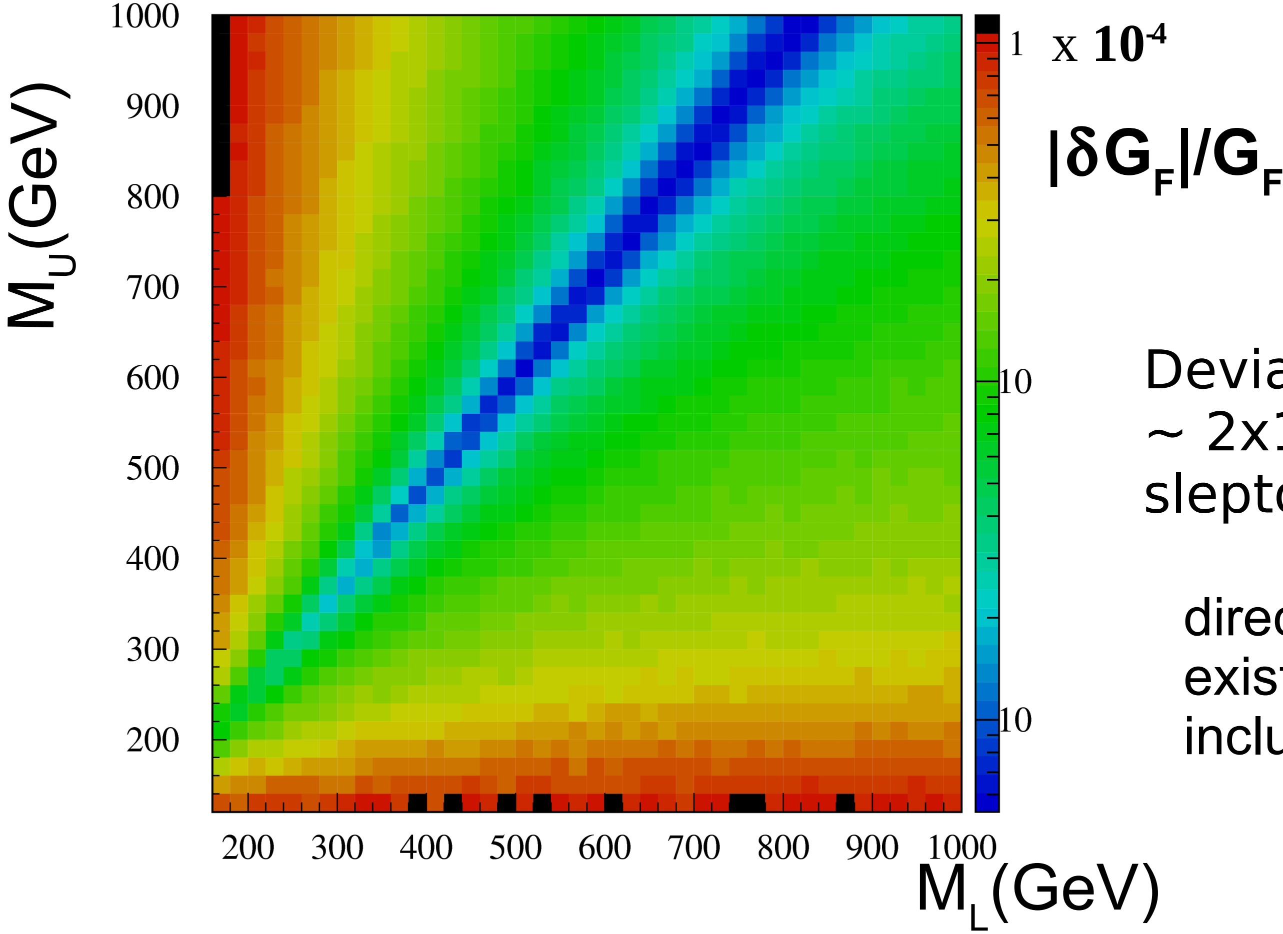
Tree level breaking of unitarity in models with non-universal gauge interaction



sensitivity to NP: MSSM

sensitive to squark-slepton mass difference

[R. Barbieri '85, K.Hagiwara et al '95, A. Kurylov et al '00]



Deviations up to ~ 2x10^{-4} for small slepton mass

direct and indirect existing limits included

[© Mescia, Paradisi]

sensitivity to NP: charged Higgs

Pseudoscalar currents, e.g. due to H±, affect the K width:

JHEP 0804:059

$$\frac{\Gamma(M \to \ell\nu)}{\Gamma_{SM}(M \to \ell\nu)} = \left[1 - \tan^2\beta \left(\frac{m_{s,d}}{m_u + m_{s,d}}\right) \frac{m_M^2}{m_H^2}\right]^2$$

for M = K, π

Hou, Isidori-Paradisi

The observable

$$R_{\ell 23} = \left| \frac{V_{us}(K_{\mu 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\mu 2})} \right|$$

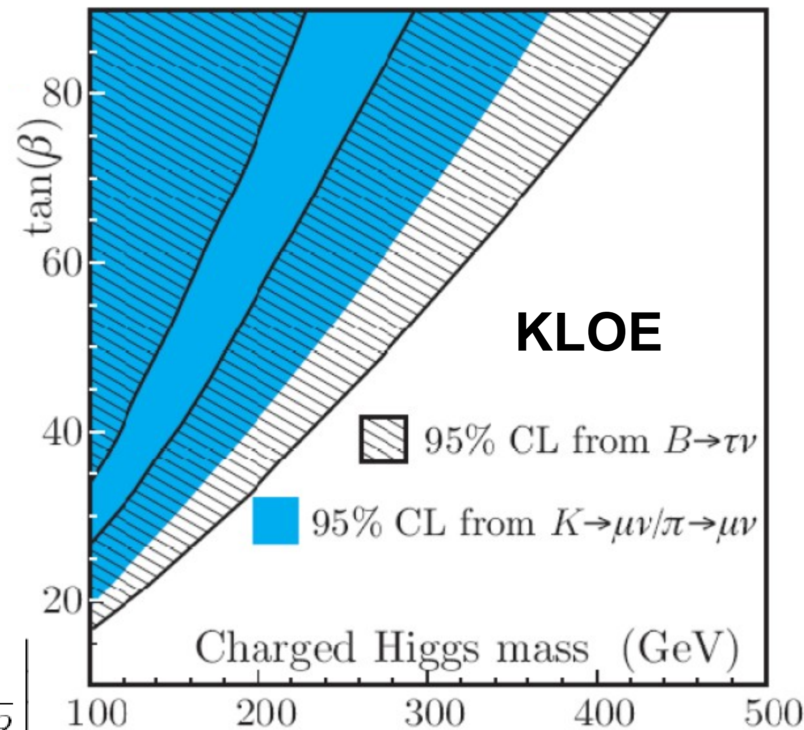
KLOE:

- **R_{l23} = 1.008(8)**

(unitarity for K_{l3} and β-decays is used)

R_{l23} sensitivity to H± exchange

$$R_{\ell 23} = \left| 1 - \frac{m_{K^+}^2}{m_{H^+}^2} \left(1 - \frac{m_{\pi^+}^2}{m_{K^+}^2}\right) \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta} \right|$$



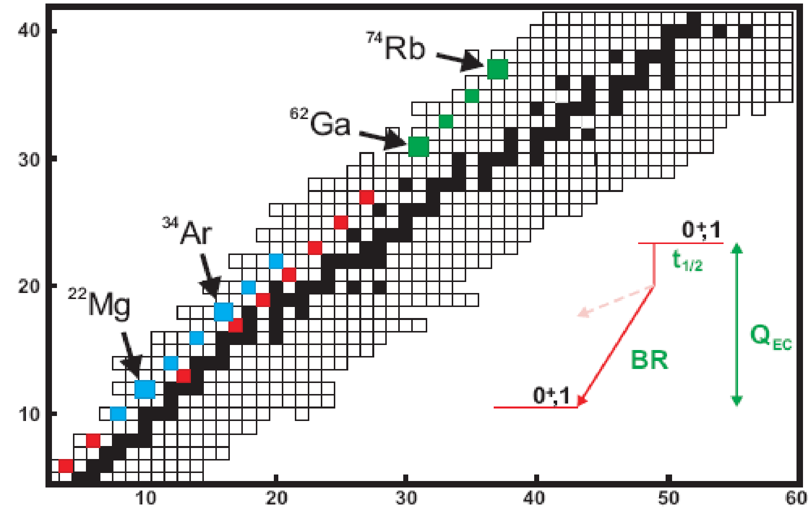
Status of V_{ud} determination

(superallowed β-decays only)

V_{ud} from Fermi transitions

$$V_{ud}^2 = \frac{K}{2G_F^2\overline{\mathcal{F}t}(1+\Delta_R)}$$

$$\mathcal{F}t = ft(1+\delta'_R)(1-(\delta_C-\delta_{NS})) = \text{constant}$$



Measured on 13 Nuclei:

$t = t_{1/2}$ /BR = partial half life

f = statistical rate function $f(Z,Q_{ec})$*

Radiative and isospin breaking corrections:

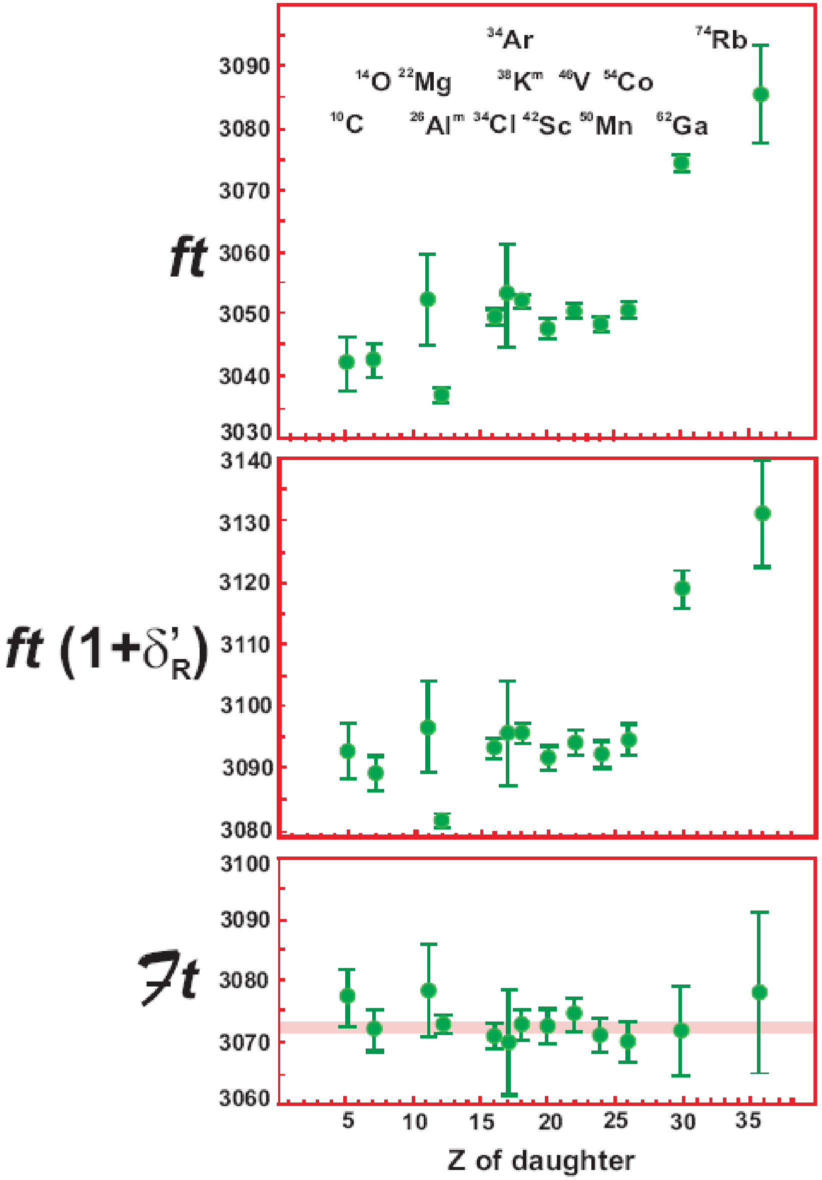
Δ_R=2.361(38)% Nucleus-independent [Marciano Sirlin]

δ'_R, δ_{NS} Nucleus-dependent

δ_C Nucleus-dependent isospin breaking

* Z dependence account for e wave function

V_{ud} from Fermi transitions

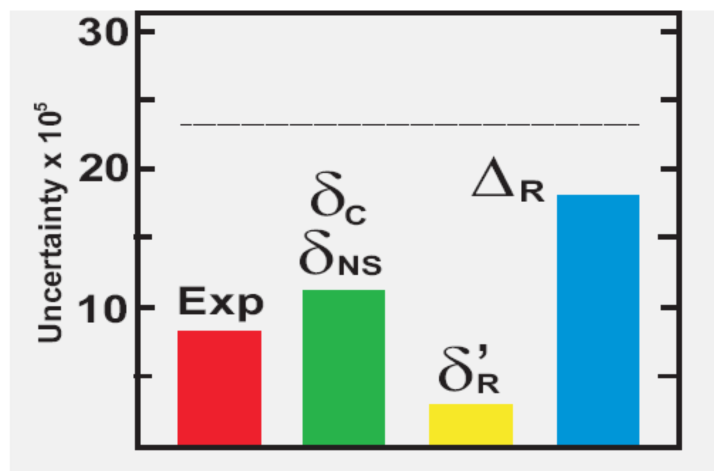


[Towner, Hardy 2008]

$$V_{ud}^2 = \frac{K}{2G_F^2 \overline{\mathcal{F}t}(1+\Delta_R)}$$

V_{ud} = 0.97425(23)

Error budget:



Status of V_{us} and V_{us}/V_{ud} determination

$\tau \to K\pi\nu$, $K_{\ell 3}$ decays

Vector transition protected against $\cancel{SU}(3)$ corrections: [Ademollo Gatto]

$$\Gamma \propto M^{5(3)} S_{EW} \mathbf{G_F^2 |V_{us}|^2} \, | f_+^{K^0\pi^-}(0)|^2 \, I_K \left(1 + 2\Delta_K^{SU(2)} + 2\Delta_{K\ell}^{EM}\right)$$

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

$\Delta_{K\ell}^{EM}$ Form-factor correction for long-distance EM effects

Inputs from experiment:

Γ Rates with well-determined treatment of radiative decays:

- Branching ratios
- lifetimes

I_K Integral of dalitz density (includes ff) over phase space:

- $\tau \to K\pi\nu$, $K_{\ell 3}$

$\tau \to P\nu$, $P_{\ell 2}$ decays ($P=K,\pi$)

$$\Gamma \propto G_F^2\,|V_{uq}|^2\, f_P^2\, (1+C_{P\ell})$$

Inputs from theory:

f_P decay constants

$C_{P\ell}$ Radiative inclusive electroweak corrections

Inputs from experiment:

Γ Rates with well-determined treatment of radiative decays:

- Branching ratios
- lifetimes

Used to determine pseudoscalar decay constants

Small uncertainties for ratios:

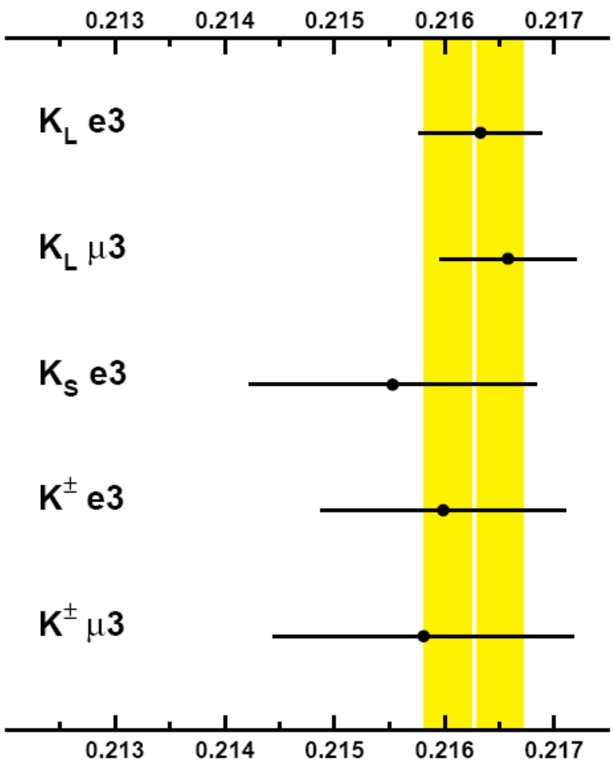
$\Gamma(K_{\mu 2(\gamma)})/\Gamma(\pi_{\mu 2(\gamma)})$ **f_K/f_π from lattice $\to$ determine V_{us}/V_{ud}**

[Marciano]

$R_P=\Gamma(P_{e2(\gamma)})/\Gamma(P_{\mu 2(\gamma)})$ **no $f_P \to$ test lepton universality**

[Cirigliano, Rosell]

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

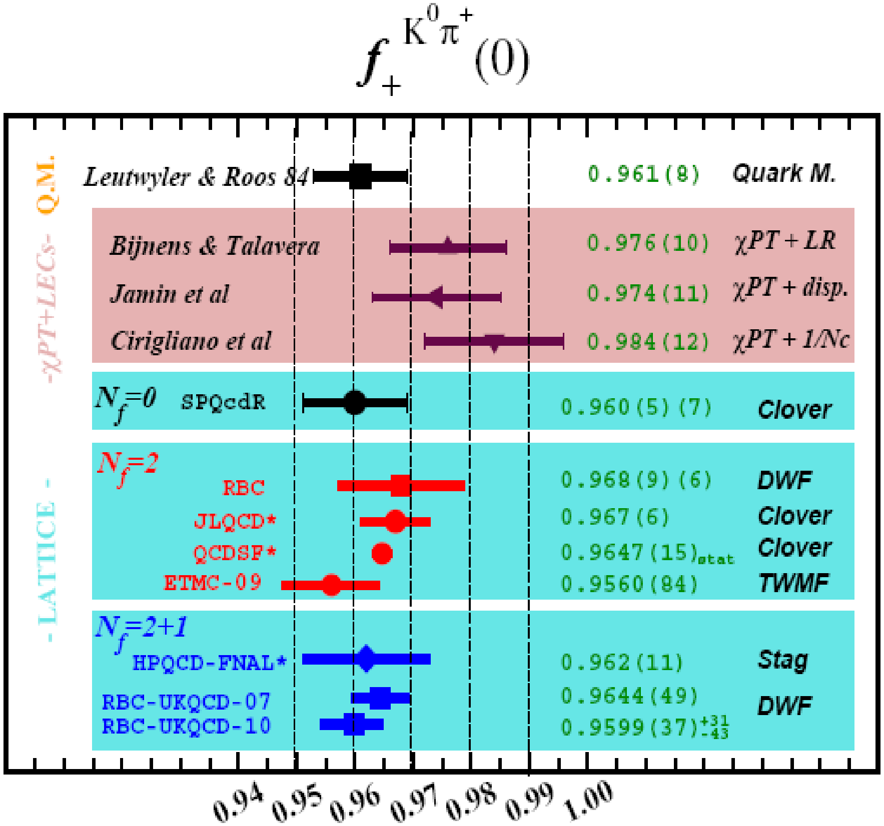


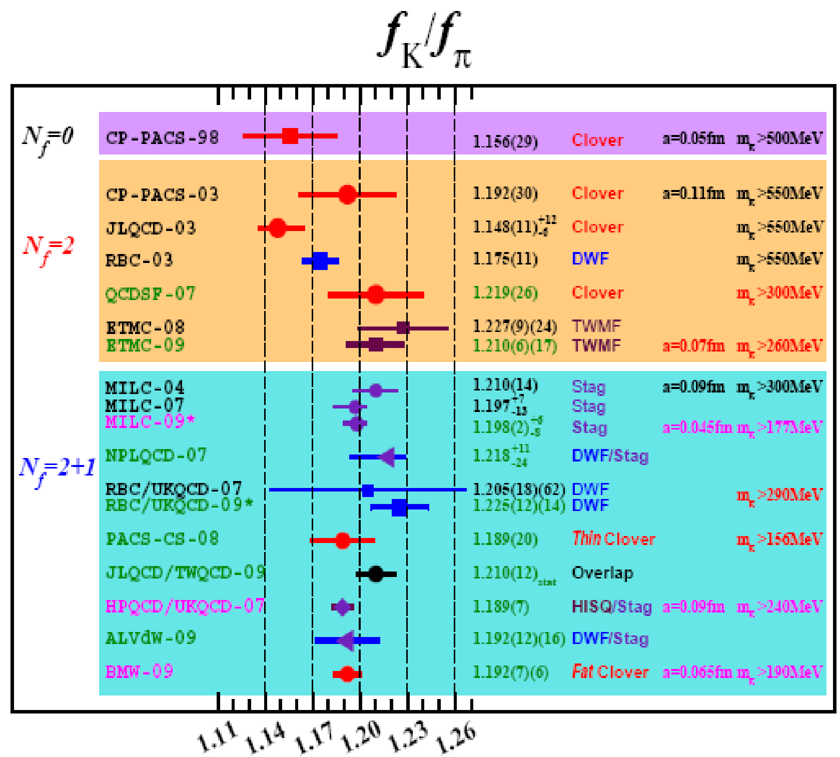
$\lvert V_{us}\rvert f_+(0)$	% err	BR	τ	Δ	Int
0.2163(6)	0.26	0.09	0.20	0.11	0.06
0.2166(6)	0.29	0.15	0.18	0.11	0.08
0.2155(13)	0.61	0.60	0.03	0.11	0.06
0.2160(11)	0.52	0.31	0.09	0.40	0.06
0.2158(14)	0.63	0.47	0.08	0.39	0.08
0.2163(5)					

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

Evaluations of $f_+(0)$ and f_K/f_π

Lattice continuously improving





Use:

$f_+(0)$ = 0.964(5) RBC-UKQCD [FLAG 0.956(8)] [F. Mescia]

f_K/f_π = 1.193(6) Kaon WG and FLAG average

$\tau \to P\nu$, $K_{\ell 2}$ decays

[Marciano]

Small uncertainties in f_K/f_π from lattice → determine V_{us}/V_{ud}

Reduced uncertainty from e.m. Structure Dependence corrections

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

$|V_{us}|/|V_{ud}|\, f_K/f_\pi = 0.2760(6)$

$$\frac{\Gamma(\tau\to K\nu)}{\Gamma(\tau\to\pi\nu)} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K^{\,2}}{f_\pi^{\,2}} \times \frac{(1-m_K^{\,2}/m_\tau^{\,2})^2}{(1-m_\pi^{\,2}/m_\tau^{\,2})^2} \times 1.0003(44)$$

$|V_{us}|/|V_{ud}|\, f_K/f_\pi = 0.273(2)$

$f_K/f_\pi = 1.193(6)$ [Kaon WG FLAG WG]

$V_{us}/V_{ud} = \mathbf{0.2312(13)}$ [Kaon WG]

Inclusive V_{us} determination *(more on D. Boito talk)*

V_{us} from inclusive $\tau \to \nu X_{us}$ involves PQCD

$$|V_{us}|^2 = \frac{R^{00}_{\tau,S}}{\frac{R^{00}_{\tau,V+A}}{|V_{ud}|^2} - \delta R^{00}_{\tau,\mathrm{th}}}$$

Gámiz-Jamin-Pich-Prades-Schwab

$$V_{us} = 0.2159\ (30_{exp})(5_{th})$$

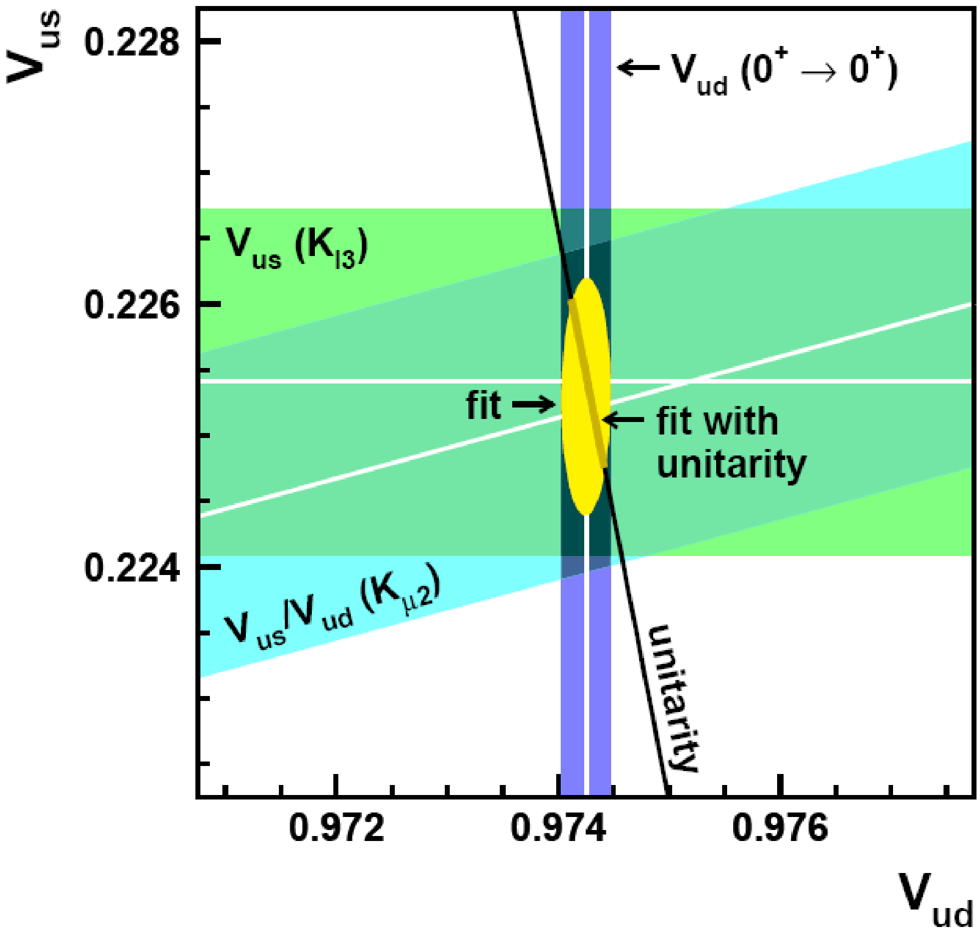
[HFAG]

Base modes from τ^- decay	No B-Factory Data	With B-Factory Data
$K^-\nu_\tau$	0.686 ± 0.022	0.697 ± 0.010
$K^-\pi^0\nu_\tau$	0.453 ± 0.027	0.431 ± 0.015
$K^-2\pi^0\nu_\tau$ (ex. K^0)	0.057 ± 0.023	0.060 ± 0.022
$K^-3\pi^0\nu_\tau$ (ex. K^0, η)	0.036 ± 0.022	0.039 ± 0.022
$\overline{K}^0\pi^-\nu_\tau$	0.888 ± 0.037	0.831 ± 0.018
$\overline{K}^0\pi^-\pi^0\nu_\tau$	0.358 ± 0.035	0.350 ± 0.015
$\overline{K}^0\pi^-2\pi^0\nu_\tau$	0.027 ± 0.023	0.035 ± 0.023
$\overline{K}^0h^-h^-h^+\nu_\tau$	0.023 ± 0.020	0.028 ± 0.020
$K^-\pi^-\pi^+\nu_\tau$ (ex. K^0, ω)	0.334 ± 0.023	0.293 ± 0.007
$K^-\pi^-\pi^+\pi^0\nu_\tau$ (ex. K^0, ω, η)	0.039 ± 0.014	0.041 ± 0.014
$K^-\phi\nu_\tau(\phi \to KK)$		0.004 ± 0.001
$K^-\eta\nu_\tau$	0.027 ± 0.006	0.016 ± 0.001
$K^-\pi^0\eta\nu_\tau$	0.018 ± 0.009	0.005 ± 0.001
$\overline{K}^0\pi^-\eta\nu_\tau$	0.022 ± 0.007	0.009 ± 0.001
$K^-\omega\nu_\tau$	0.041 ± 0.009	0.041 ± 0.009
Sum of strange modes	3.0091 ± 0.0722	2.8796 ± 0.0501
Sum of all modes	100.00	100.00

Different theoretical analysis give somewhat larger errors : ~ 1%
[Maltman et al]

[HFAG] $V_{us} = 0.2169\ (23)$

CKM unitarity



Fit results, no constraint:

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

$$1-V_{us}^{2}-V_{us}^{2} = 0.0001(6)$$

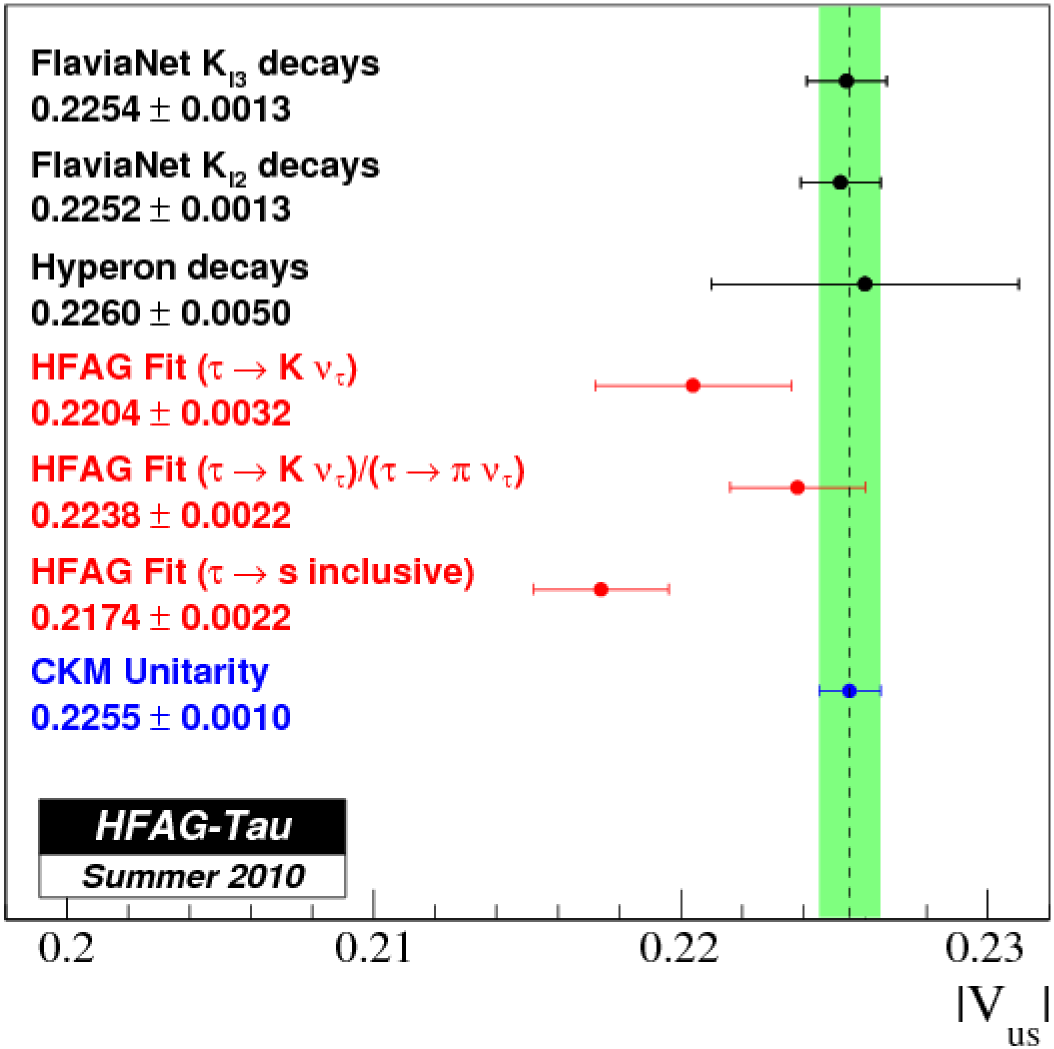
$$G_{CKM} = 1.16633(35) \times 10^{-5}\ \mathrm{GeV}^{-2}$$

Fit results, unitarity constraint:

$$V_{us} = \sin\theta_c = \lambda = 0.2254(6)$$

0.3 % accuracy!

τ and kaons summary



inclusive vs exclusive

inclusive

theory

Involve PQCD (~same method produced the best α_s determination)

Exp.

many sub-percent channels
New B-factory precision measurements not always In agreement with old measurements from LEP

exclusive

theory

non perturbative QCD regime

Lattice + low energy theorems current dominating uncertainy

Exp.

Very precise measurements form K, precise B($\tau \to K\nu$) from b-factory (2.6% below prediction form K) more complicated picture for $\tau \to K\pi\nu$

70% of rs is made by

$\tau \to K\nu + \tau \to K\pi\nu$

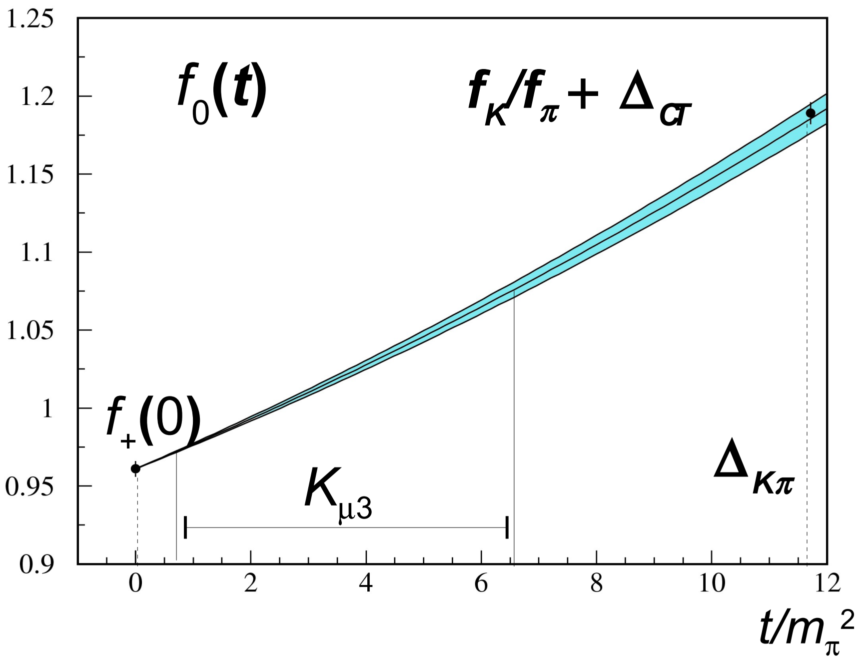
Predictions from K might help

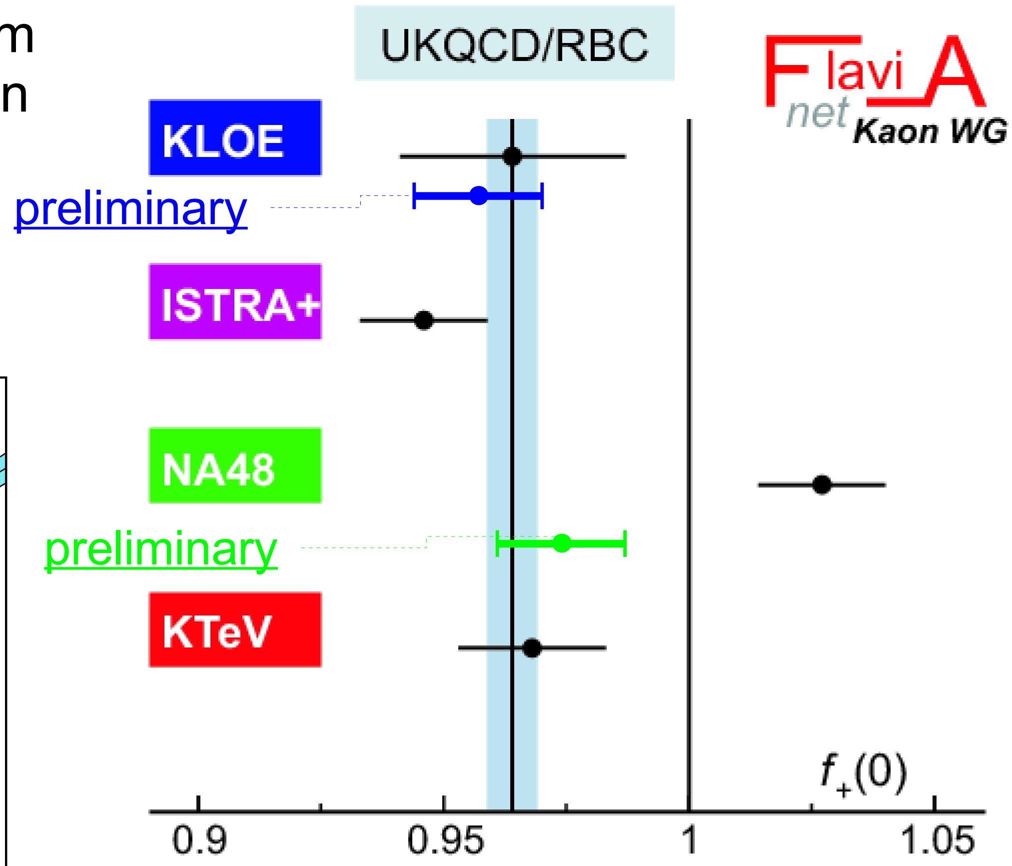
$\longleftrightarrow$

Must have a consistent picture between τ and K (no new physics in the game)

Callan-Treiman relation

Check/improve lattice results from measurement of scalar ff slopes in $K\mu3$ and use of dispersive parametrization
[Stern et al] [Pich et al]





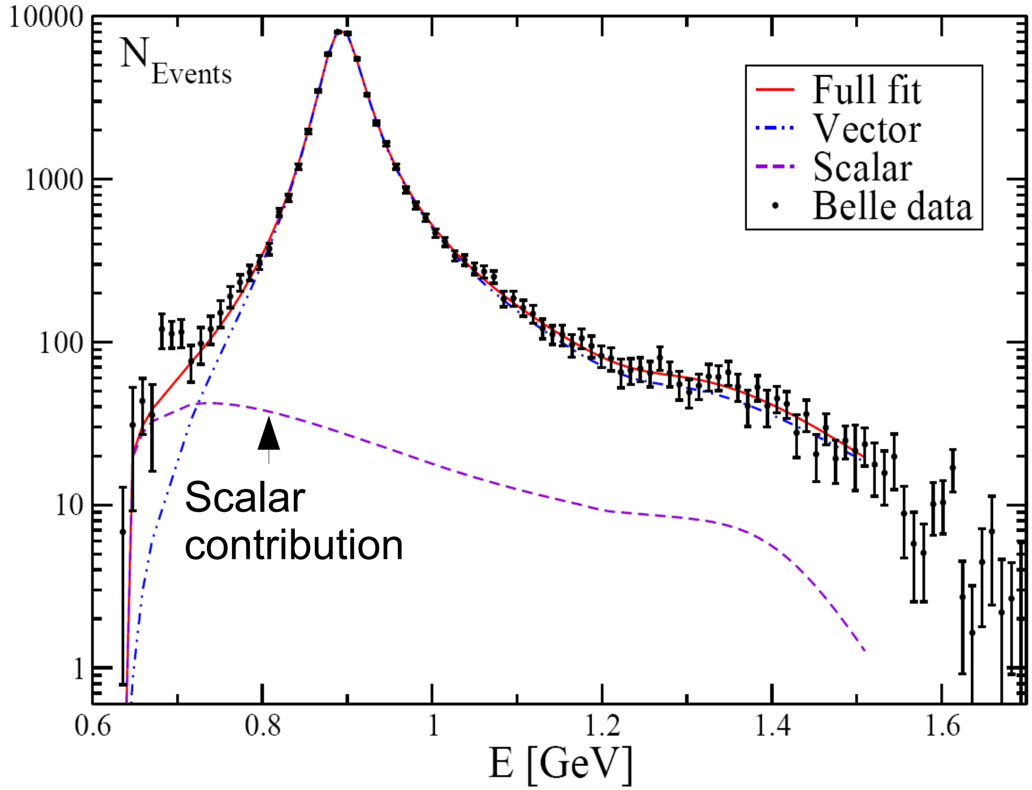
$f_+(0) = (f_K/f_\pi + \Delta_{CT})/C$

f_K/f_π= 1.189(7) from HPQCD-UKQCD

Relevance of $\tau \to K\pi\nu$ *(more on D. Boito talk)*

Present knowledge of the scalar ff parameter can be already improved by a factor ~ 2 with present B-factory data

Jamin-Pich-Portolés 08, D. Boito, E. Passemar V. Bernard11 fit to **BELLE** data



Prediction for $B(\tau \to K\pi\nu)$ from Kl3 and ff parameters important for Rs
Current accuracy still ~2%
Need 100 x data to match current exp. error on K BRs

[E. Passemar]

Polarization and angular analysis helps a lot

Conclusion

1^{st} raw unitarity status

G_{CKM} =1.16633(35) x10^{-5} GeV^{-2}

V_{ud} = 0.97425(22)

V_{us} = 0.2253(9)

0.03% accuracy on G_F from quarks

sinθ$_c$ = λ = 0.2254(6)

Cabibbo angle at 0.3 % accuracy!

Present accuracy allows to test NP at ~1 TeV

V_{us} determination can be improved combining K and τ:

PQCD vs LATTICE QCD

ff knowledge can be improved with τ

Precise K BR measurements to predict 70% of Rs

Cabibbo angle must be measured at the Cabibbo Lab