V_{us} and V_{ud} from K and π decays

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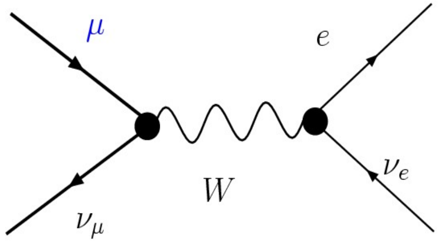
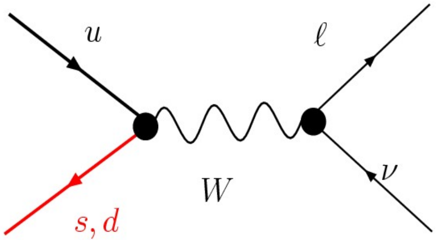
1st raw unitarity: G_F universality

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

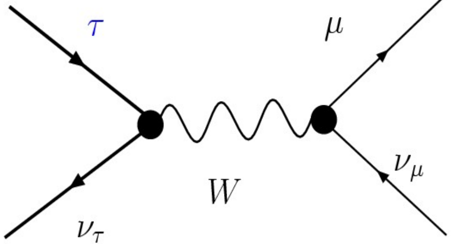
Universality of Weak coupling- $G_F=(g_W/M_W)^2$

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





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



$G_F = 1.166371(6)\times10^{-5}\ \text{GeV}^{-2}$

$G_{CKM} = 1.16xx(4)\times10^{-5}\ \text{GeV}^{-2}$

$G_{e.w.} = 1.1655(12)\times10^{-5}\ \text{GeV}^{-2}$

$G_\tau = 1.1678(26)\times10^{-5}\ \text{GeV}^{-2}$

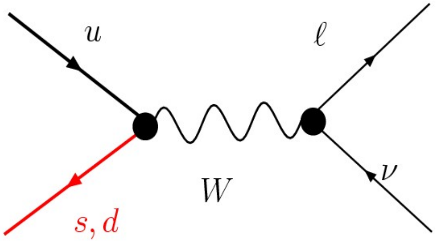
[Marciano]

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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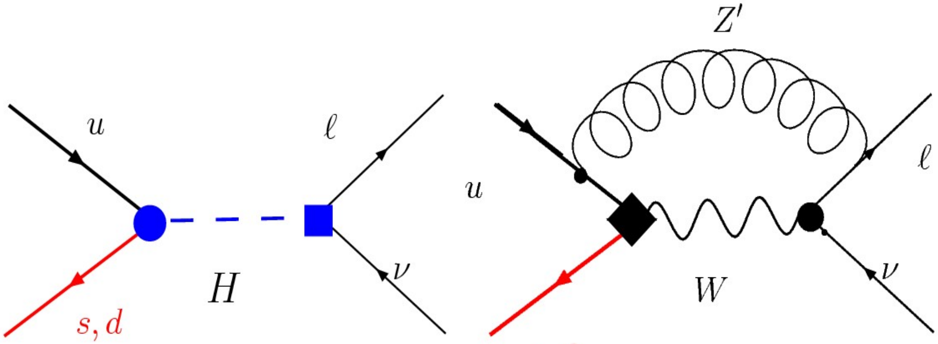
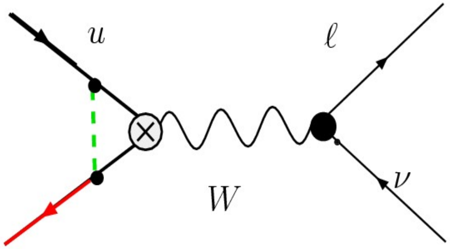




Sensitivity to new physics :

naively

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

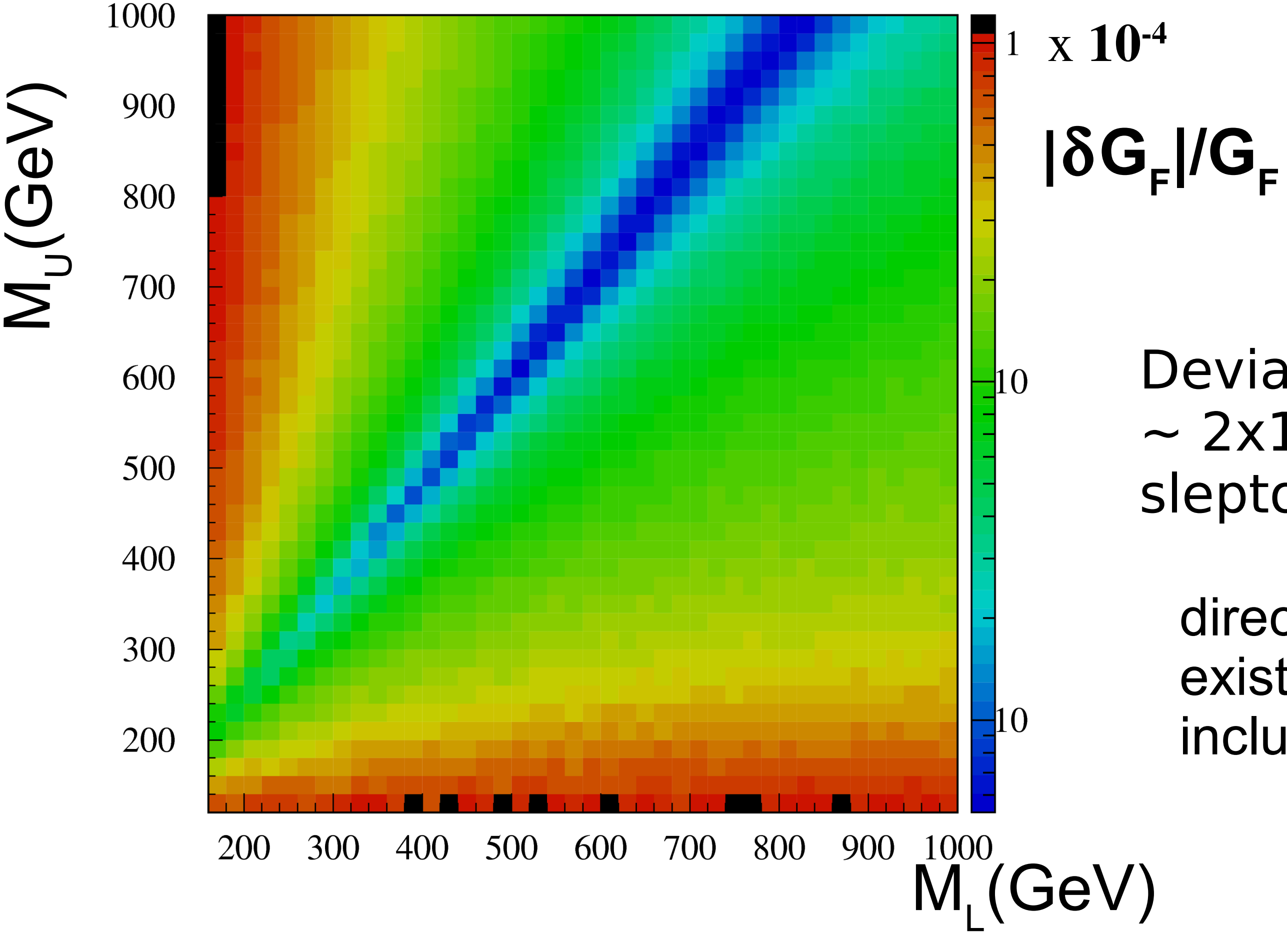
Tree level **$a \sim 1$** **$M_M \sim 10$ TeV**

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

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 ~ $2\text{x}10^{-4}$ for small slepton mass

direct and indirect existing limits included

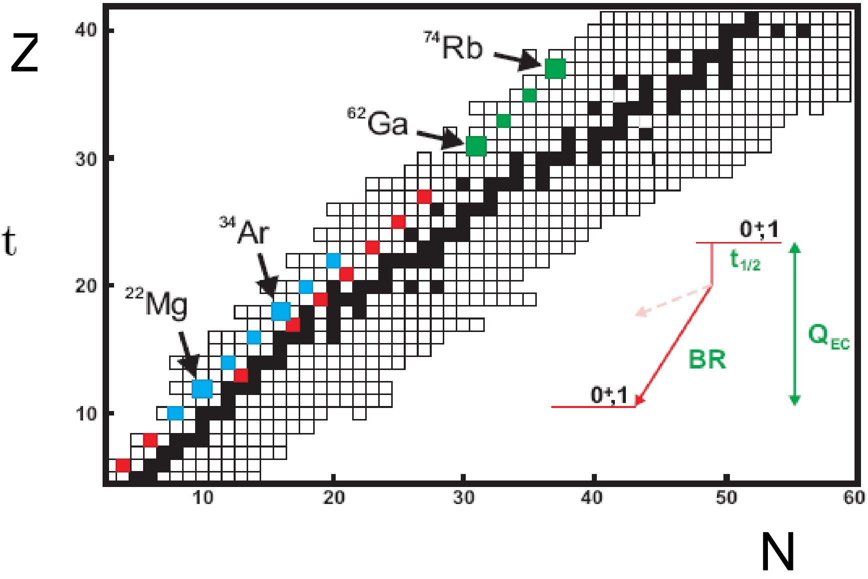
[© Mescia, Paradisi]

V_{ud} determination

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:

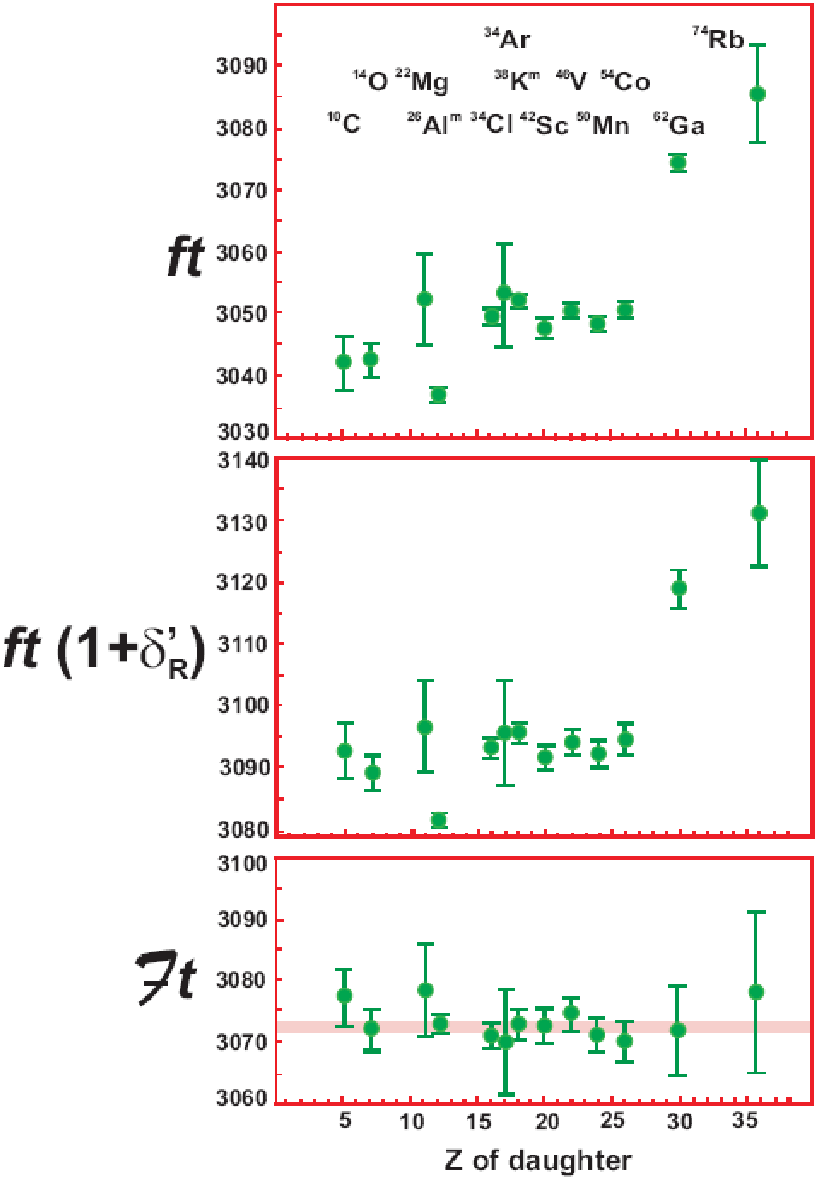
Δ_R=2.361(38)% Nucleus-independent [Marciano Sirlin]

δ'_R, δ_{NS} Nucleus-dependent

δ_C Nucleus-dependent isospin breaking

* Z dependence account for e wave function

V_{ud} from Fermi transitions

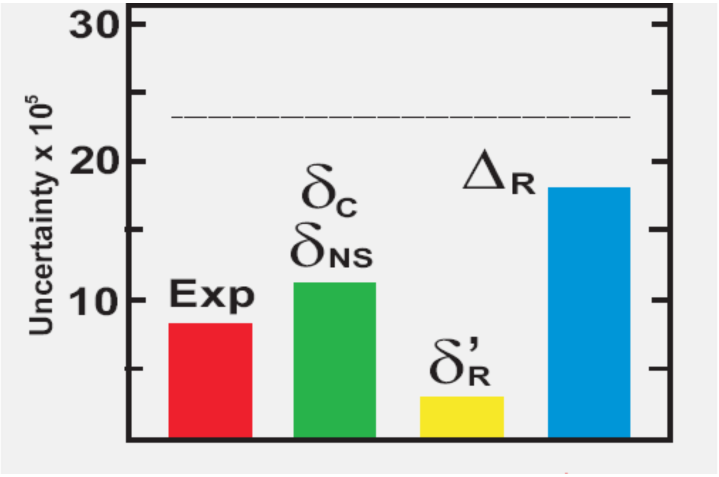


[Towner, Hardy 2008]

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

$$V_{ud} = 0.97425(23)$$

Error budget:



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

$K_{\ell 3}$ decays

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

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

with $K \in \{K^+, K^0\}$; $\ell \in \{e, \mu\}$, 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
$\Delta_{K\ell}^{EM}$	Form-factor correction for long-distance EM effects

Inputs from experiment:

$\Gamma(K_{\ell 3(\gamma)})$	Rates with well-determined treatment of radiative decays: • Branching ratios • Kaon lifetimes
$I_{K\ell}(\{\lambda\}_{K\ell})$	Integral of dalitz density (includes ff) over phase space: • K_{e3}: Only λ_+ (or λ_+', λ_+'') • $K_{\mu 3}$: Need λ_+ and λ_0

$P_{\ell 2}$ decays

$$\Gamma(P_{\ell 2(\gamma)}) = \frac{G_F^2 \, |V_{uq}|^2}{8\pi} \; f_P^2 \; m_\ell M_P (1 - m_\ell^2/M_P^2)^2 \; (1 + C_{P\ell})$$

Inputs from theory:

f_P	decay constants
$C_{P\ell}$	Radiative inclusive electroweak corrections

Inputs from experiment:

$\Gamma(P_{\ell 2(\gamma)})$ 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 → determine** V_{us}/V_{ud}

[Mariciano]

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

[Cirigliano, Rosell]

Results for K_L BRs, τ

18 input measurements

- **5 KTeV** ratios
- **NA48** BR($Ke3$/2 track)
- **NA48** $\Gamma(3\pi^0)$ [prelim.]
- **4 KLOE** Brs
- **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**

BR($Ke3$)	**0.4056(7)**	**1.1**
BR($K\mu3$)	**0.2705(7)**	**1.1**
BR($3\pi^0$)	**0.1951(9)**	**1.2**
BR($\pi^+\pi^-\pi^0$)	**0.1254(6)**	**1.1**
BR($\pi^+\pi^-$)	**$1.997(7)\times10^{-3}$**	**1.1**
BR($2\pi^0$)	**$8.64(4)\times10^{-4}$**	**1.3**
BR($\gamma\gamma$)	**$5.47(4)\times10^{-4}$**	**1.1**
τ_L	**51.17(20) ns**	**1.1**

χ^2/ndf = 20.2/11 (4.3%)

	PDG '04	**This fit**	
$\lvert\eta_{+-}\rvert$x10^3	**2.284(14)**	**2.223(6)**	~3.6 sigma change

Results for $K^\pm$ BRs, τ

25 input measurements:

- **5 older τ values in PDG**
- **KLOE τ**
- **KLOE BR $\mu\nu$, $\pi\pi^0$**
- **KLOE *Ke*3, *K*μ3 BRs**
  - with dependence on τ
- **ISTRA+ BR *Ke*3/$\pi\pi^0$**
- **NA48/2 BR *Ke*3/$\pi\pi^0$, *K*μ3/$\pi\pi^0$**
- **E865 BR *Ke*3/*K*Dal**
- **3 old BR $\pi\pi^0/\mu\nu$**
- **2 old BR *Ke*3/2 body**
- **3 *K*μ3/*Ke*3 (2 old)**
- **2 old + 1 KLOE results on 3π**

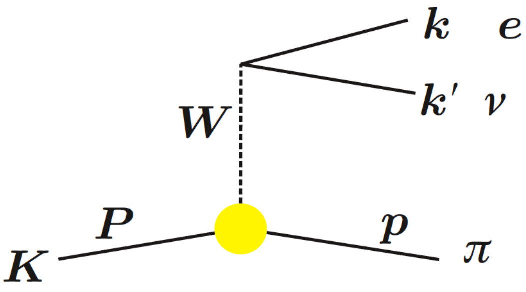
1 constraint: Σ BR = 1

BR($\mu\nu$)	**63.57(10)%**	**1.1**
BR($\pi\pi^0$)	**20.64(7)%**	**1.1**
BR($\pi\pi\pi$)	**5.593(32)%**	**1.1**
BR(*Ke*3)	**5.078(25)%**	**1.2**
BR(*K*μ3)	**3.365(26)%**	**1.7**
BR($\pi\pi^0\pi^0$)	**1.750(26)%**	**1.1**
$\tau_\pm$	**12.379(21) ns**	**1.7**

χ^2/ndf = 42.6/19 (0.15%)

Improves to χ^2/ndf = 24.8/15 (5.3%) with no changes to central values **(but τ)** or errors, if 5 older $\tau_\pm$ measurements replaced by PDG avg (with *S* = 2.1)

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

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

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

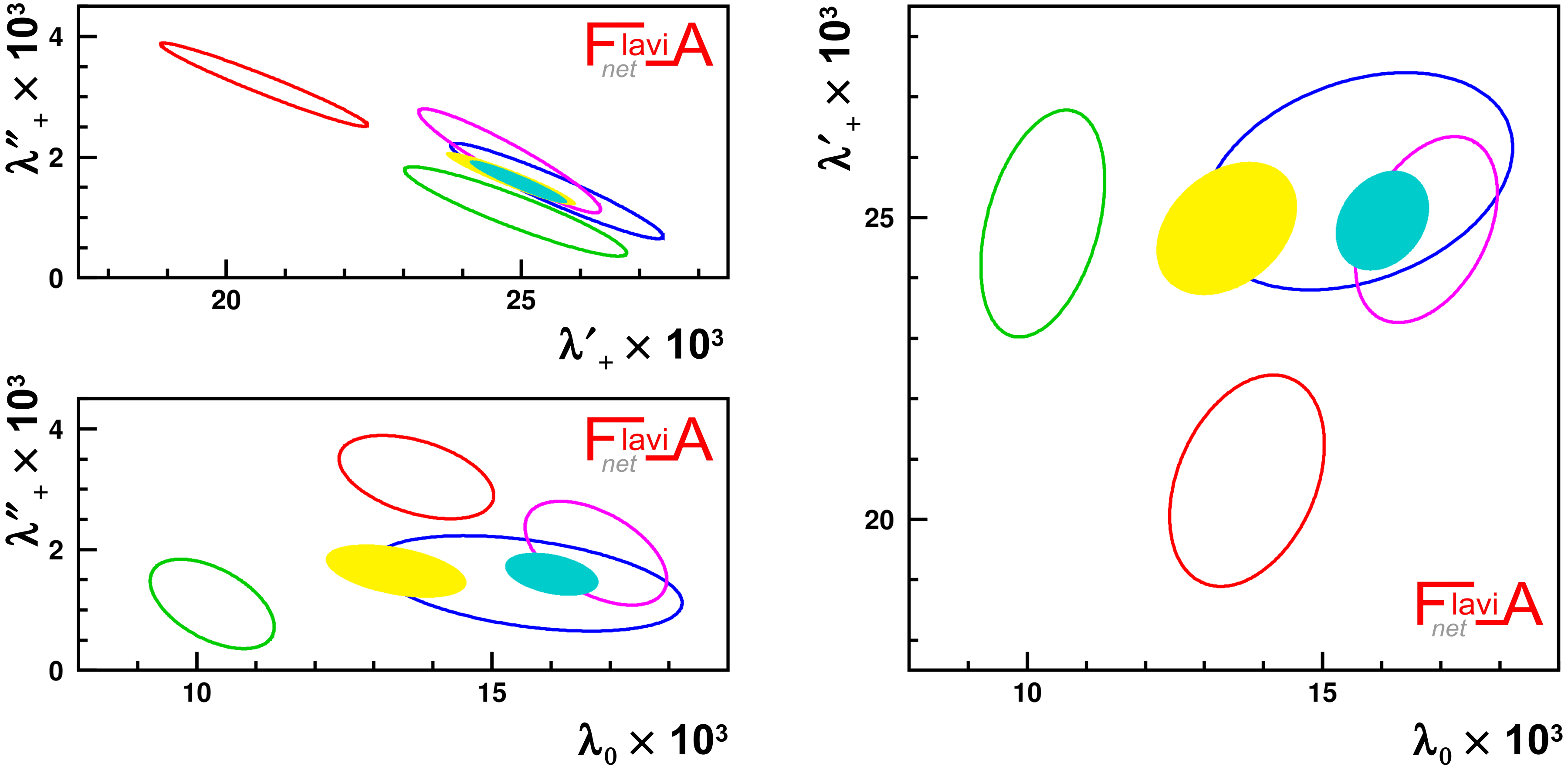
$$\lambda' = (m_{\pi+}/M)^2$$

$$\boldsymbol{\lambda'' = 2\lambda'^2}$$

poor sensitivity to quadratic terms

Fit to K_{l3} form-factor slopes

*e*3-μ3 averages from **KLOE** **KTeV** **ISTRA+** **NA48**

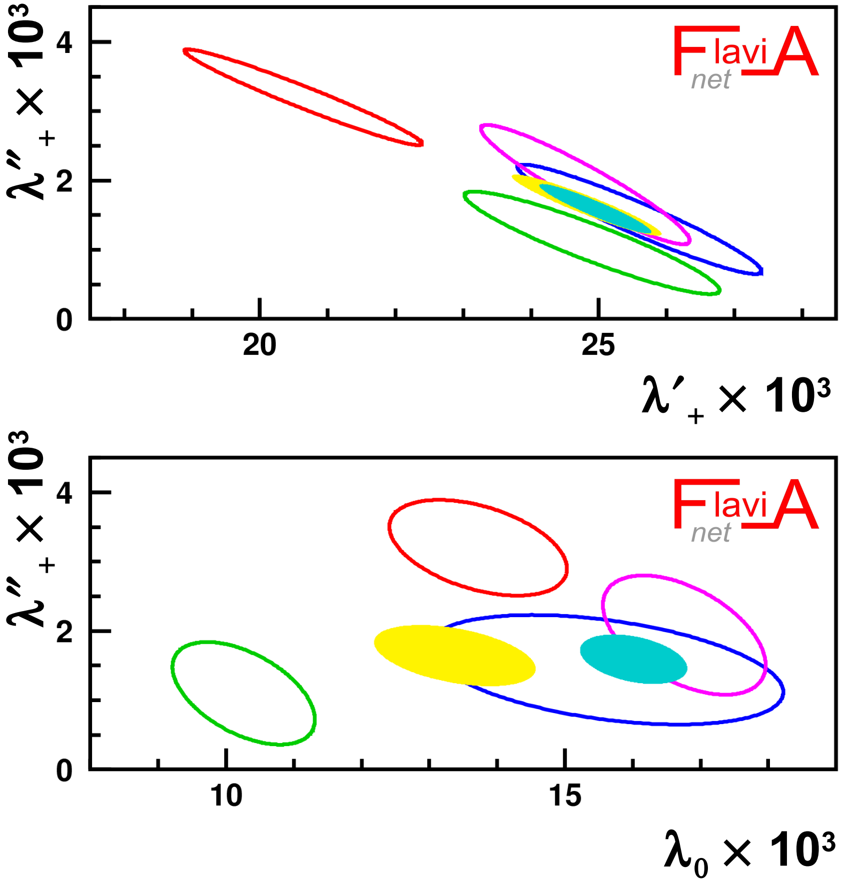


*Kl*3 fit, no NA48 *K*μ3: χ^2=12.6/10 (24.9%)

*Kl*3 fit, all data, χ^2=54/13 (10^{-6})

Fit to K_{l3} form-factor slopes

*e*3-μ3 averages from **KLOE** **KTeV** **ISTRA+** **NA48**



Measurements	16
χ^2/ndf	$54/13\ (7 \times 10^{-7})$
$\lambda'_+ \times 10^3$	$24.9 \pm 1.1\ (S = 1.4)$
$\lambda''_+ \times 10^3$	$1.6 \pm 0.5\ (S = 1.3)$
$\lambda_0 \times 10^3$	$13.4 \pm 1.2\ (S = 1.9)$
$\rho(\lambda'_+, \lambda''_+)$	-0.94
$\rho(\lambda'_+, \lambda_0)$	$+0.33$
$\rho(\lambda''_+, \lambda_0)$	-0.44
$I(K^0_{e3})$	$0.15457(29)$
$I(K^\pm_{e3})$	$0.15892(30)$
$I(K^0_{\mu3})$	$0.10212(31)$
$I(K^\pm_{\mu3})$	$0.10507(32)$
$\rho(I_{e3}, I_{\mu3})$	$+0.63$

*Kl*3 fit, no NA48 *K*μ3: χ^2=12.6/10 (24.9%)

*Kl*3 fit, all data, χ^2=54/13 (10^{-6})

SU(2) and *em* corrections

New values for $\delta^{K\ell}_{em}$ from ChPT O(e^2p^2)

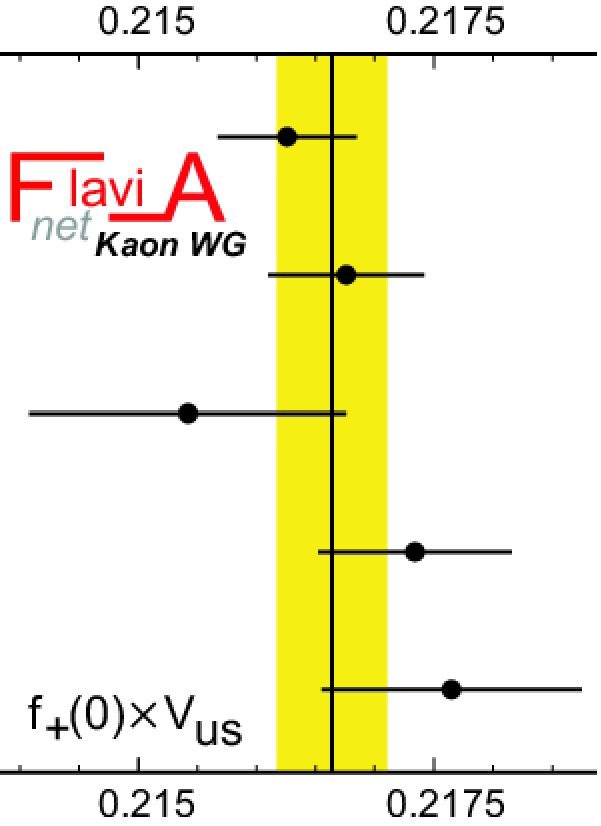
[Cirigliano, Giannotti, and Neufeld, 0807.4507]

error matrix available

	$\delta^{K}_{SU(2)}(\%)$	$\delta^{K\ell}_{em}(\%)$
K^0e3	0	+0.50(11)
$K^0\mu3$	0	+0.70(11)
K^+e3	+2.36(22)	+0.05(13)
$K^+\mu3$	+2.36(22)	+0.01(12)

	K^0e3	$K^0\mu3$	K^+e3	$K^+\mu3$
K^0e3	1	0.69	0.08	–0.15
$K^0\mu3$		1	–0.15	0.08
K^+e3			1	0.76
$K^+\mu3$				1

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



		% err	Approx. contr. to % err from:			
			BR	τ	δ	$I_{K\ell}$
$K_L e3$	**0.2164(6)**	**0.26**	0.09	**0.19**	0.11	0.09
$K_L \mu 3$	**0.2170(6)**	**0.29**	0.10	**0.18**	0.11	0.15
$K_S e3$	**0.2156(13)**	**0.62**	**0.60**	0.03	0.11	0.09
$K^\pm e3$	**0.2174(8)**	**0.38**	**0.26**	0.13	**0.25**	0.09
$K^\pm \mu 3$	**0.2177(11)**	**0.51**	**0.40**	0.13	**0.25**	0.15

Average: $|V_{us}|\ f_+(0) = 0.2167(5)$ χ^2/ndf = 2.83/4 (59%)

SU(2) breaking correction comparing values from K_L and $K^\pm$: **2.81(38)%**.

χ_{PT} prediction **2.36(22)%** (Kastner and Neufeld: **2.9(4)%**).

$K_{\ell 2}$ decays

[Mariciano]

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

Reduced uncertainty from e.m. Structure Dependence corrections

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K^{\,2}}{f_\pi^{\,2}} \times \frac{M_K(1-m_\mu^{\,2}/M_K^{\,2})^2}{m_\pi(1-m_\mu^{\,2}/m_\pi^{\,2})^2} \times 0.9930(35)$$

WA dominated by KLOE

$$\mathbf{BR(K^+ \rightarrow \mu^+\nu(\gamma)) = 0.6366(17)}$$

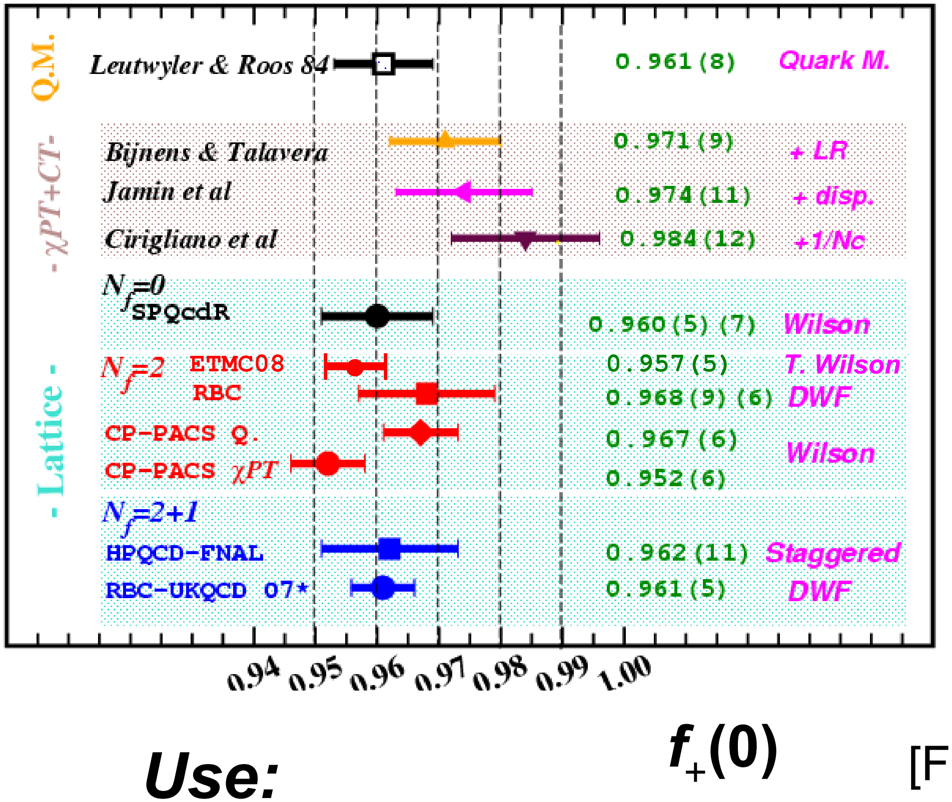
$$|V_{us}|/|V_{ud}|\ f_K/f_\pi = 0.2760(6)$$

$$f_K/f_\pi = 1.1890(7)$$ HPQCD-UKQCD

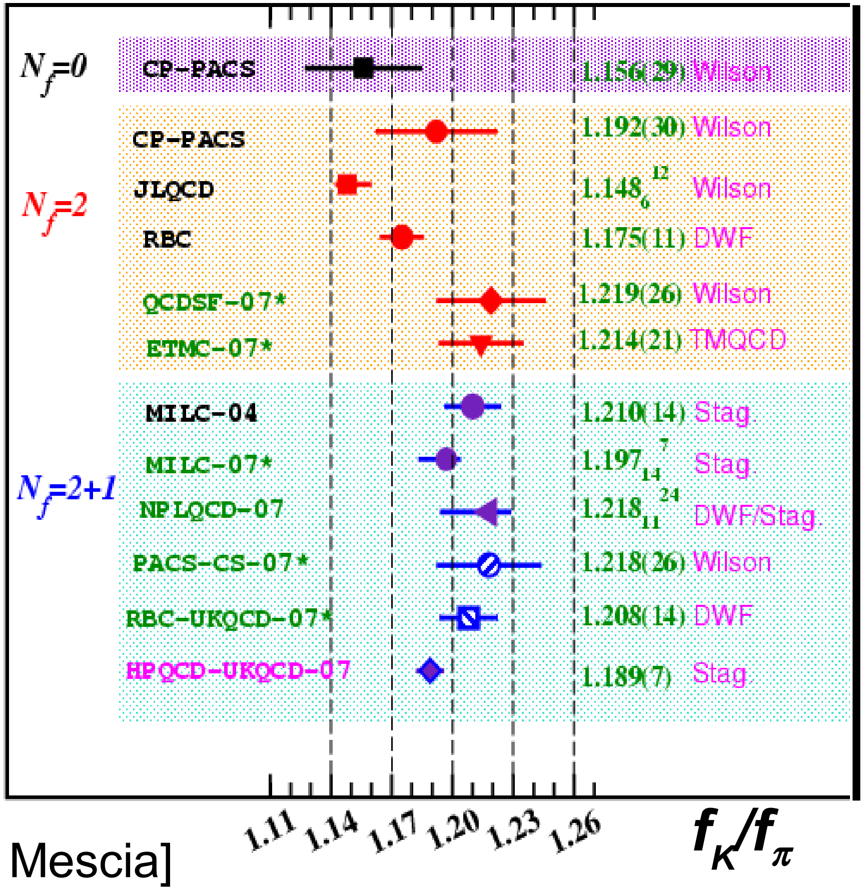
$$V_{us}/V_{ud} = 0.2322(15)$$

Evaluations of $f_+(0)$ and f_K/f_π

Lattice continuously improving



[F. Mescia]

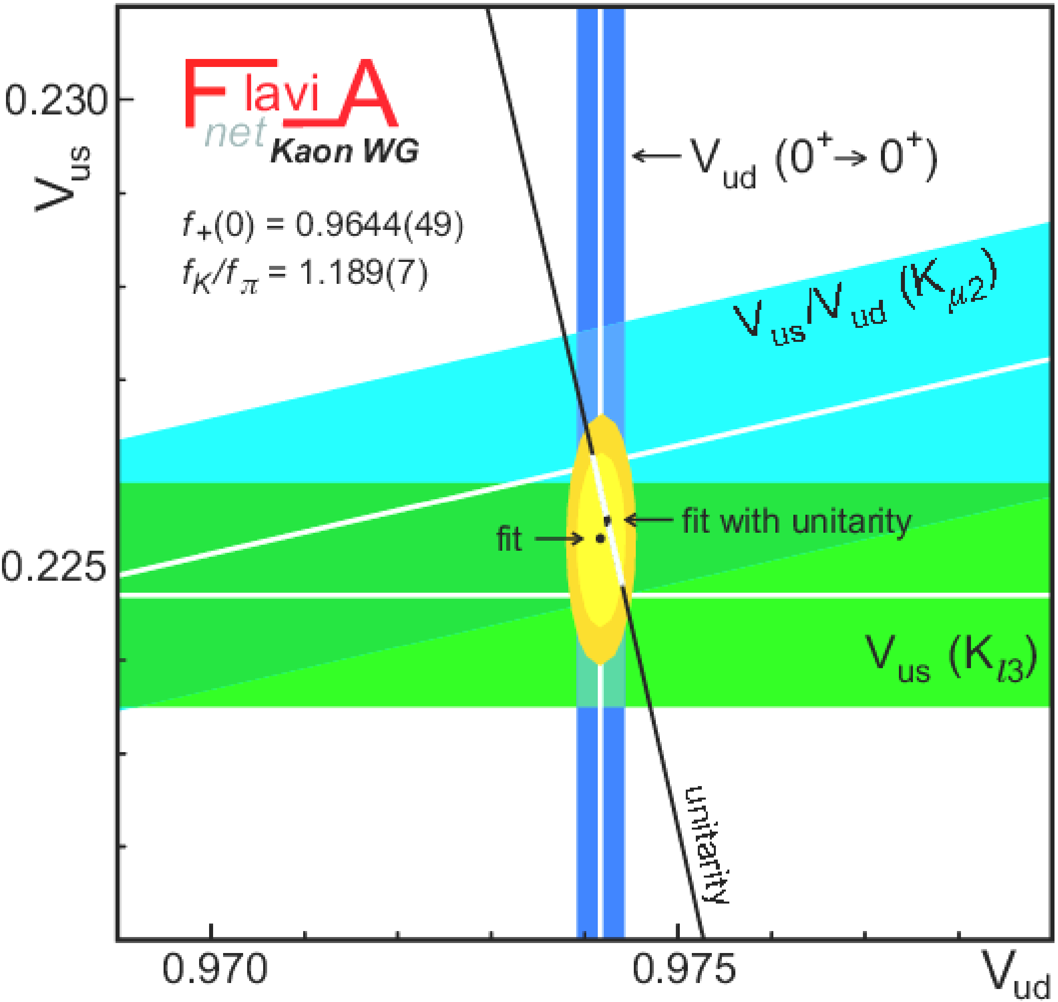


Use:

$f_+(0)$ = 0.964(5) RBC-UKQCD

f_K/f_π = 1.1890(7) HPQCD-UKQCD

CKM unitarity



Fit results, no constraint:

$$\boldsymbol{V_{ud} = 0.97425(23)}$$

$$\boldsymbol{V_{us} = 0.2254(9)}$$

χ^2/ndf = 0.6/1 (44%)

$1\text{-}V_{us}^2\text{-}V_{us}^2 = 0.00003(60)$

G_{CKM}=1.1662(4) x10^{-5} GeV^{-2}

Fit results, unitarity constraint:

$$\boldsymbol{V_{us} = \sin\theta_c = \lambda = 0.2254(7)}$$

$$\boldsymbol{\chi^2/\text{ndf} = 0.6/2\ (74\%)}$$

0.3 % accuracy!

Decay constants & f(0)

In the Standard Model f_P can be determined from the measurement of Γ $(\mathbf{P}_{\ell 2(\gamma)})$ and the value of the relevant CKM matrix element.

f_K = 156.1(8) MeV

f_π=130.4(2) MeV

$\mathbf{V_{us}}$ **= 0.2247(12)** from Kl3

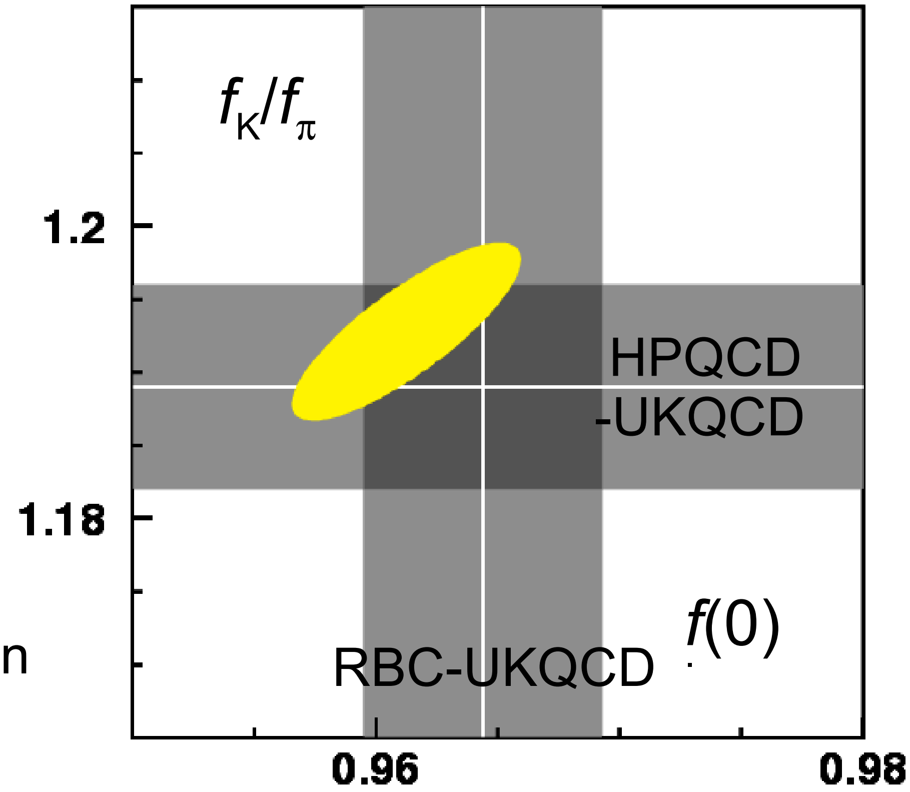
$\mathbf{V_{ud}}$**=0.97425(23)** from β decays

unitarity + V_{ud} , $f_0 V_{us}$,Γ $(\mathbf{P}_{\ell 2(\gamma)})$

f_K/f_π = 1.1928(61)

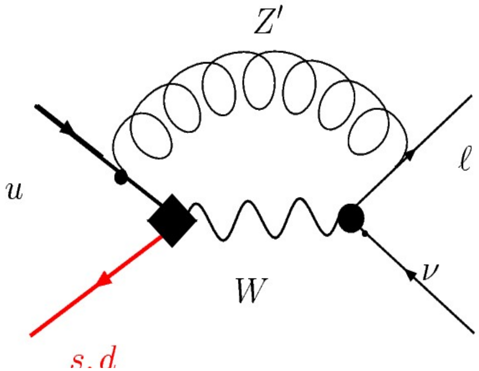
$f(0)$ = 0.9612(47)

0.8 correlation



sensitivity to NP: Z'oology

1)



$$G_F = G_{CKM}[1 - 0.007 Q_{eL}(Q_{\mu L} - Q_{dL}) \frac{2\ \ln(m_{Z'}/m_W)}{(m_{Z'}^2/m_W^2 - 1)}]$$

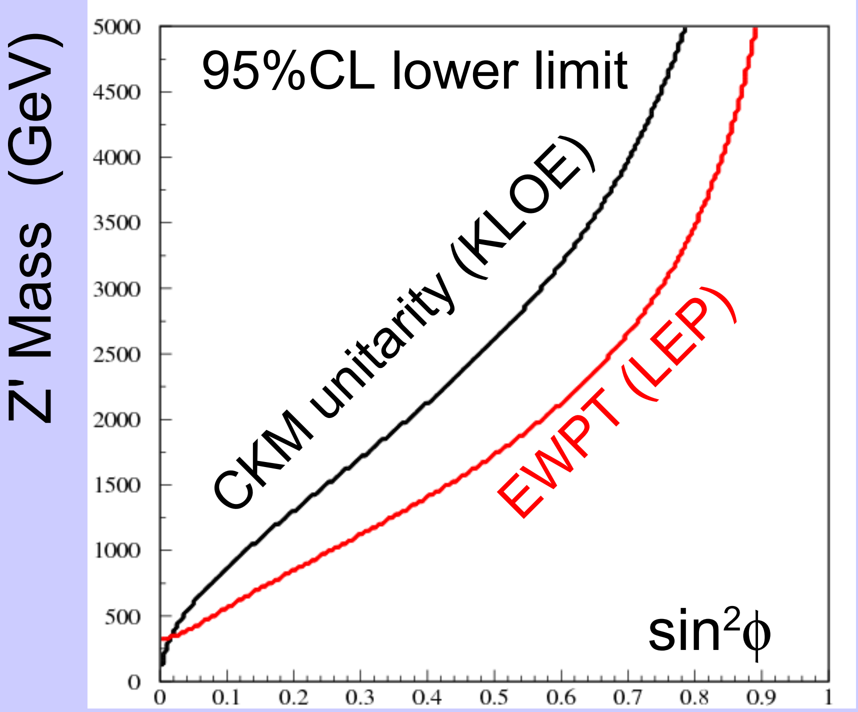
SO(10) Zχ Boson: $Q_{eL} = Q_{\mu L} = -3Q_{dL} = 1$ [Marciano]

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

2)

[K.Y. Lee]

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



sensitivity to NP: charged Higgs

JHEP 0804:059

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

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

for M = K, π

Hou, Isidori-Paradisi

The observable

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

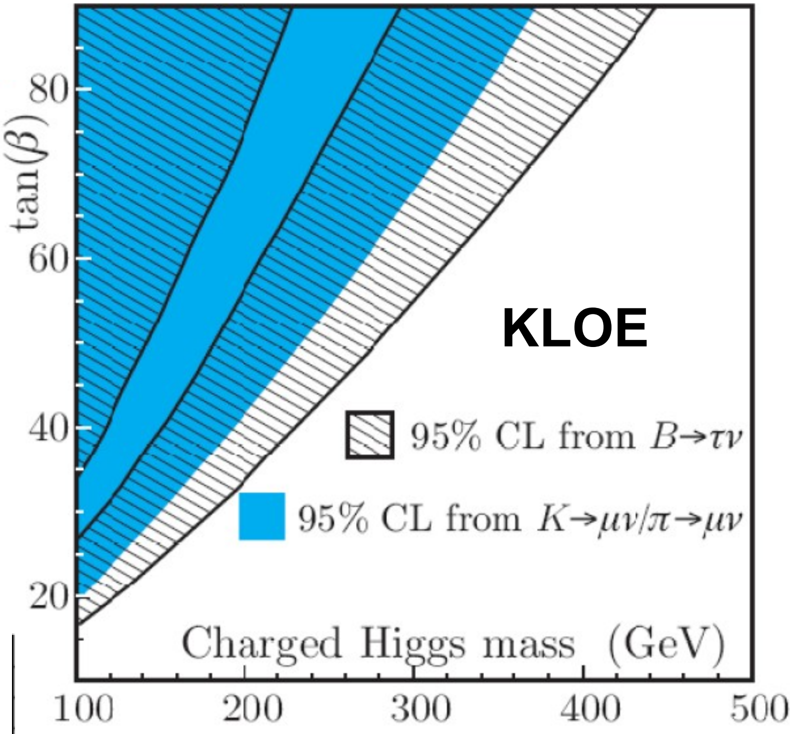
KLOE:

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

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

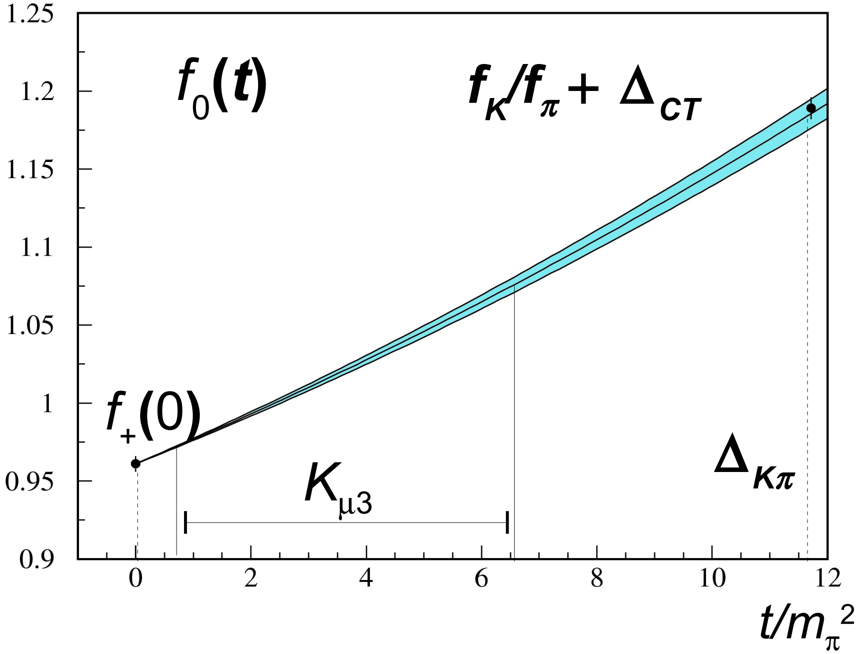
R_{l23} sensitivity to H± exchange

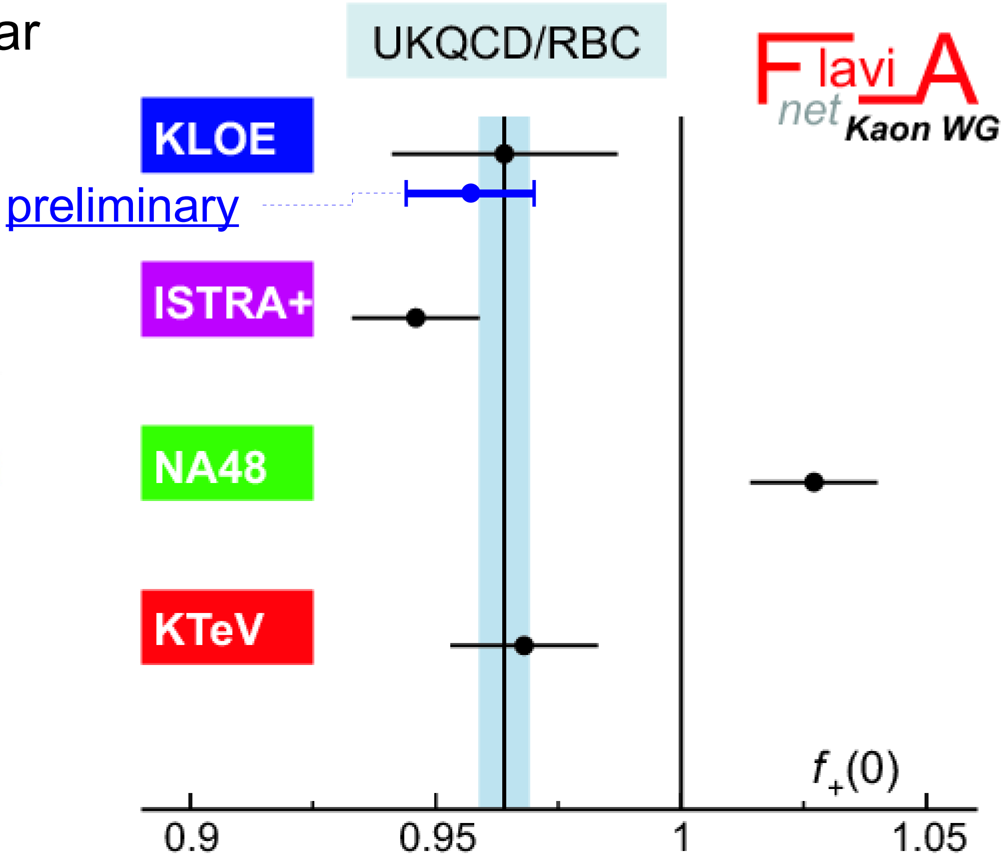
$$R_{\ell 23}=\left|1-\frac{m_{K^+}^2}{m_{H^+}^2}\left(1-\frac{m_{\pi^+}^2}{m_{K^+}^2}\right)\frac{\tan^2\beta}{1+\epsilon_0\,\tan\beta}\right|$$



Callan-Treiman relation

Check from measurement of scalar ff slopes in Kμ3 and use of dispersive parametrization [Stern et al] [Pich et al] (further info from τ)





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

f_K/f_π= 1.189(7) from HPQCD-UKQCD

V_{us} from τ

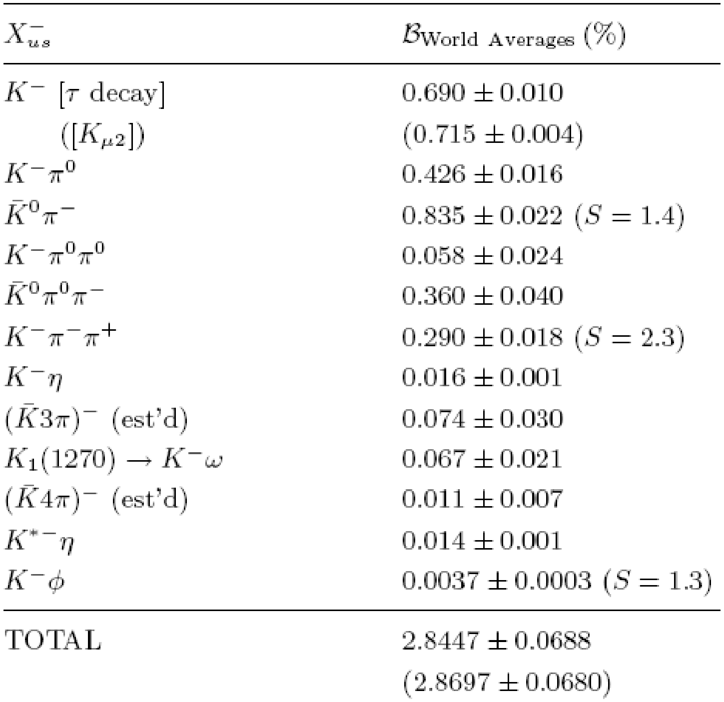
V_{us} from inclusive $\tau \to \nu X_{us}$ involves PQCD

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

Gámiz-Jamin-Pich-Prades-Schwab

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

S. Banerjee arXiv:0811.1429



X^-_{us}	$\mathcal{B}_{\text{World Averages}}$ (%)
K^- [τ decay]	0.690 ± 0.010
([$K_{\mu 2}$])	(0.715 ± 0.004)
$K^-\pi^0$	0.426 ± 0.016
$\bar{K}^0\pi^-$	0.835 ± 0.022 ($S = 1.4$)
$K^-\pi^0\pi^0$	0.058 ± 0.024
$\bar{K}^0\pi^0\pi^-$	0.360 ± 0.040
$K^-\pi^-\pi^+$	0.290 ± 0.018 ($S = 2.3$)
$K^-\eta$	0.016 ± 0.001
$(\bar{K}3\pi)^-$ (est'd)	0.074 ± 0.030
$K_1(1270) \to K^-\omega$	0.067 ± 0.021
$(\bar{K}4\pi)^-$ (est'd)	0.011 ± 0.007
$K^{*-}\eta$	0.014 ± 0.001
$K^-\phi$	0.0037 ± 0.0003 ($S = 1.3$)
TOTAL	2.8447 ± 0.0688
	(2.8697 ± 0.0680)

~3 σ lower wrt kaons (same fitting m_s, V_{us})

Theory? Exp.?

check with kaons on exclusive modes(~70% of R_S):

(24% of R_S) BR($K\nu$) = 0.69(1) vs 0.715(4) from $K\mu 2$

but BR($K\nu$)/BR($\pi\nu$) ok

V_{us} from τ

check with kaons on exclusive modes(~70% of R_S):

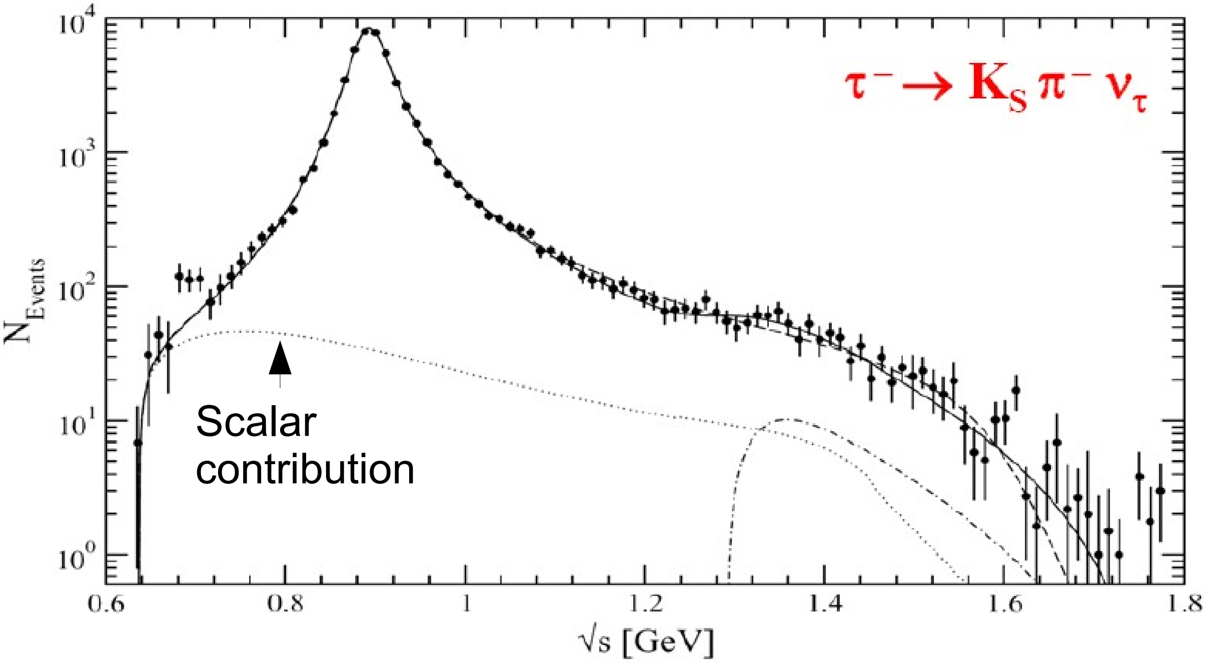
(46% of R_S) BR($K\pi\nu$) need precise form factor parameters

Prediction (no exp. Syst. included):

BR($K_S\pi^-\nu$) = 0.427(11)(21_{model})

In agreement with measured values but still limited accuracy (modeling)

Jamin-Pich-Portolés 08 fit to **BELLE** data



Many new results from Belle-BaBar expected

lepton universality

For each state of kaon charge, we evaluate:

$$r_{\mu e} = \frac{(R_{\mu e})_{\mathrm{obs}}}{(R_{\mu e})_{\mathrm{SM}}} = \frac{\Gamma_{\mu 3}}{\Gamma_{e3}} \cdot \frac{I_{e3}\,(1+\delta_{e3})}{I_{\mu 3}\,(1+\delta_{\mu 3})} = \frac{g_\mu^2}{g_e^2}$$

$r_{\mu e}$ = 1.0050(44) from Kl3

$\tau \rightarrow l\nu\nu$ decays:

$(r_{\mu e})_\tau$ = 1.0005(41) [PDG08]

$(r_{\mu e})_{\pi l2}$ = 1.0030(32) Bryman @ Seattle '08

$r_{\mu e}$ = 1.0028(22) K, τ, π average

$$R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$$

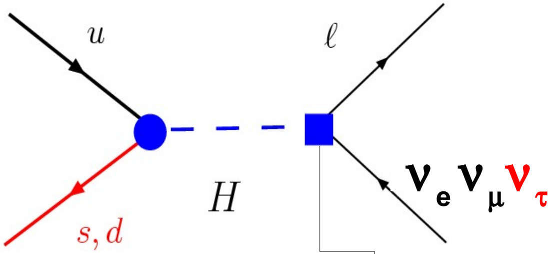
The special role of $\Gamma(K_{e2})/\Gamma(K_{\mu 2})$

SM: very well known no hadronic uncertainties (no f_K)

In MSSM, LFV can give up to % deviations [Masiero, Paradisi, Petronzio]

NP dominated by contribution of $e\nu_\tau$ final state:

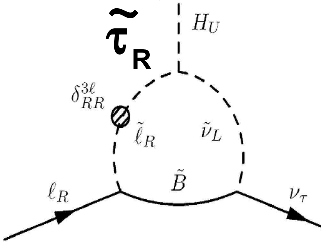
$$R_K \approx \frac{\Gamma(K\rightarrow e\nu_e) + \Gamma(K\rightarrow e\nu_\tau)}{\Gamma(K\rightarrow \mu\nu_\mu)}$$



$$R_K \approx R_K^{SM}\left[\,1+ \frac{m_K^4}{m_H^4}\,\frac{m_\tau^2}{m_e^2}\,|\Delta_R^{31}|^2 \tan^6\beta\right]$$

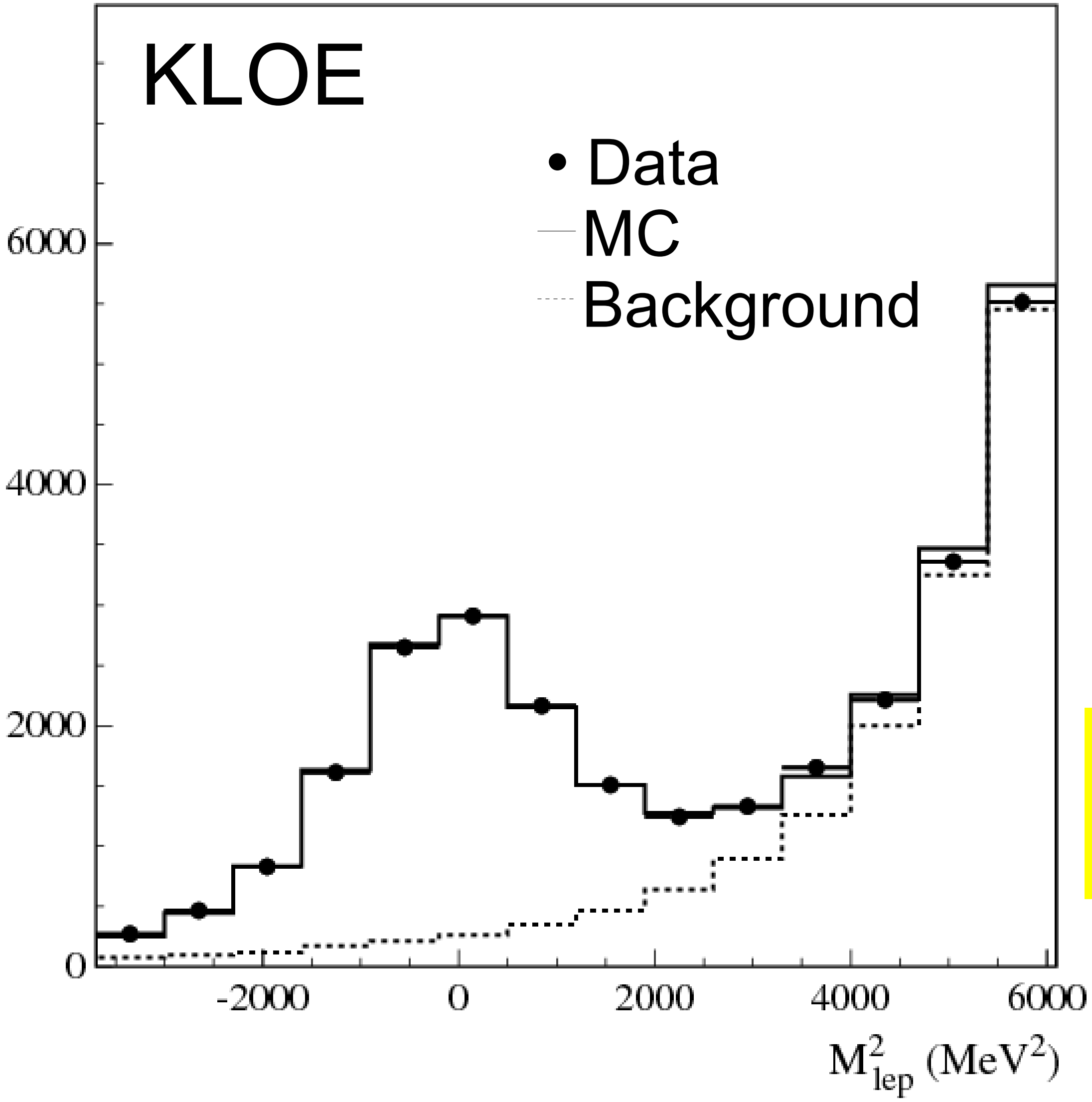
$$eH^{\pm}\nu_\tau \rightarrow \frac{g_2}{\sqrt{2}}\frac{m_\tau}{M_W}\Delta_R^{31}\tan^2\beta$$

1% effect (Δ^R_{31} ~5x10^{-4}, tanβ~40, m_H~500GeV) not unnatural



Present accuracy on R_K @ 6% Need for precise measurements

New KLOE measurement



About 14K events selected

~17% background

error dominated by statistics

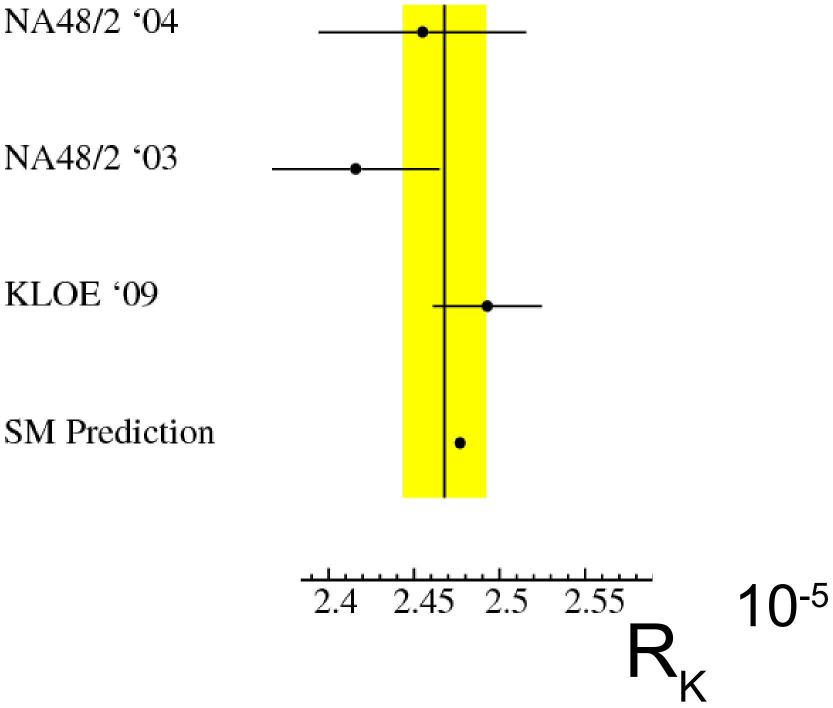
(Ke2 + C.S.)

R_K= 2.493(25)(19) x10^{-5}

R_K world average

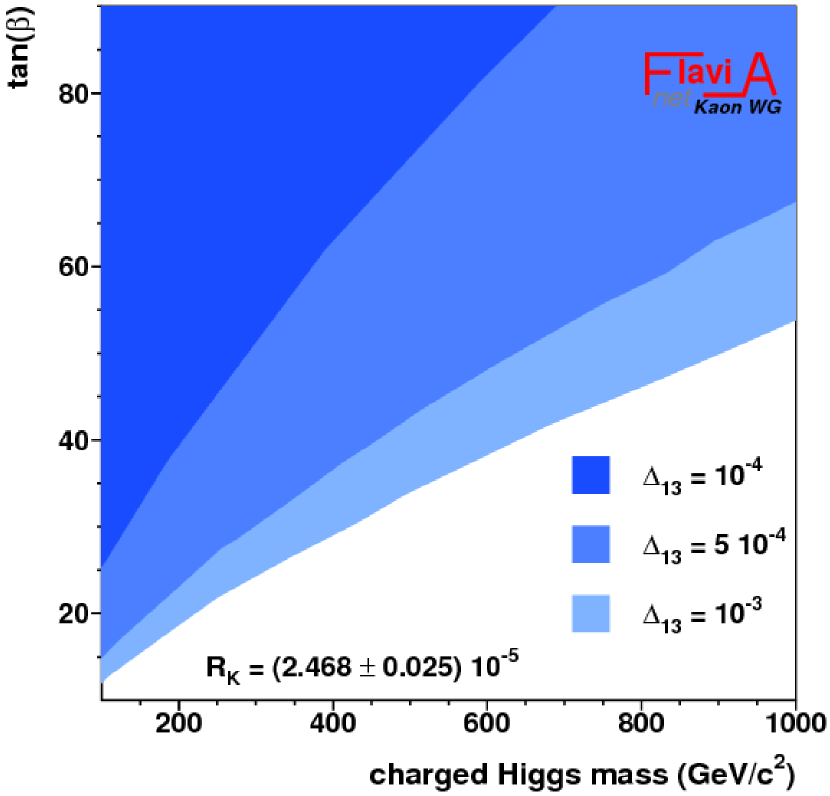
Uncertainty @ 1%

$R_K=(2.468\pm0.025)\times 10^{-5}$



95%-CL excluded regions in the tanβ - M_H plane, for

$\Delta_{13} = 10^{-3}$, 0.5×10^{-3}, 10^{-4}



CONCLUSION

V_{ud} = 0.97425(23)

V_{us} = 0.2247(12)

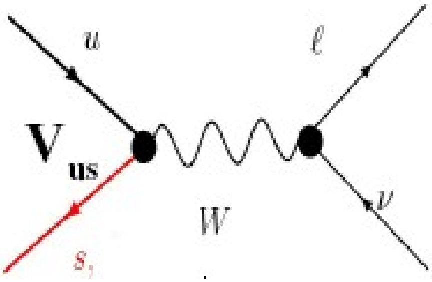
V_{us}/V_{ud} = 0.2322(15)

agreement with unitarity:

$$1-V_{ud}^{2}-V_{us}^{2} = 4(6)\times 10^{-4}$$

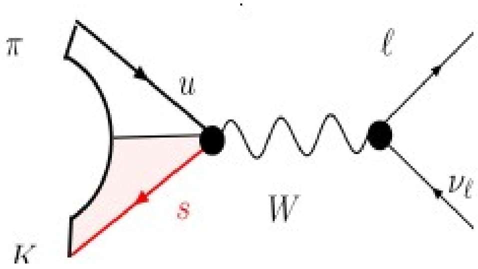
Important constraints for physics BSM

Kaon high precision observables



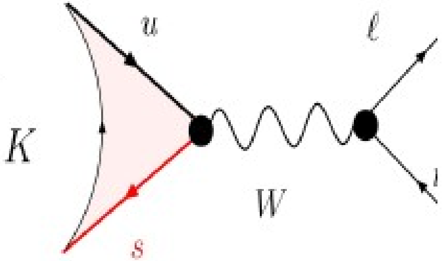
Short distance physics

$\mathbf{K_{\ell 3}}$: $K \to \pi \, \ell \, \nu$



Experimental processes

$\mathbf{K_{\ell 2}}$: $K \to \ell \, \nu$



Vector transition protected against SU(3) corrections

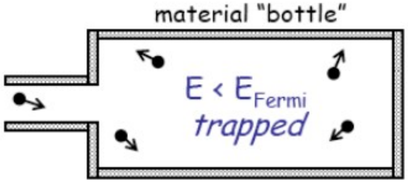
Small uncertainties in f_K/f_π from lattice

Other V_{ud} determinations

neutron β decay *not pure vector, needs g_A/g_V but no nuclear structure. δV_{ud}~0.002, will be improved through asymmetry measuremnts at PERKEO, Heidelberg and UCNA, LANL. 2005 measurement of n lifetime (6σ away) serious problem!*

$$V_{ud} = 0.9746(4)_{\tau_n}(18)_{g_A}(2)_{\rm RC}$$

Ultracold neutrons



Long interaction times in apparatus

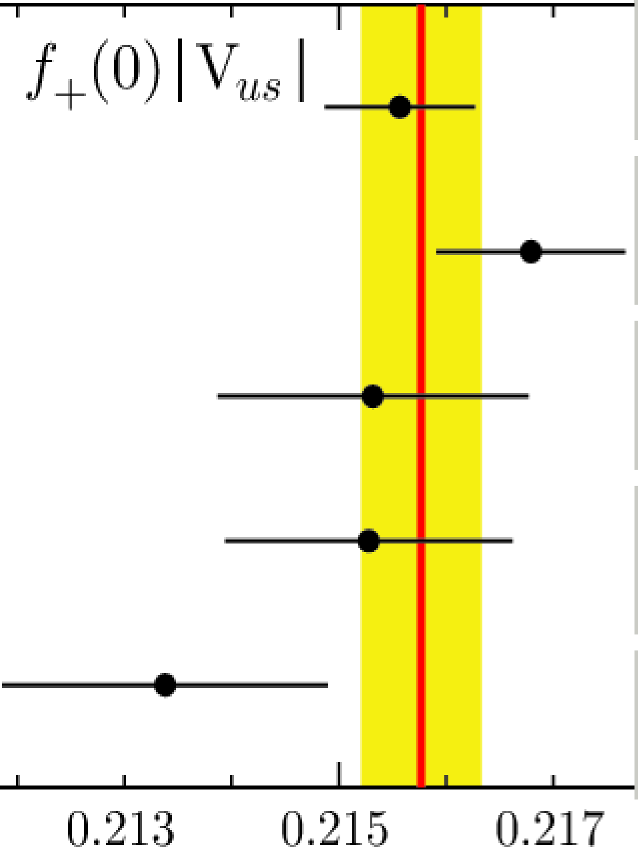
↓

Need relatively small number of neutrons

π^+ decay to $\pi^0 e\nu$ *th cleanest, promising in long term but BR~10^{-8} PIBETA at PSI has δV_{ud}~0.003*

$$V_{ud} = 0.9749(26)\left[\frac{BR(\pi^+ \to e^+\nu_e(\gamma))}{1.2352 \times 10^{-4}}\right]^{\frac{1}{2}}$$

V_{us} from KLOE K_{l3} data



		% err
K_Le3	0.2155(7)	0.3
$K_L\mu3$	0.2167(9)	0.4
K_Se3	0.2152(14)	0.7
$K^{\pm}e3$	0.2152(13)	0.6
$K^{\pm}\mu3$	0.2132(15)	0.7

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

KLOE Avg:
0.2157(6)
χ^2/ndf = 7/4 (13%)

World Avg:
0.2166(5)

$f_+(0)$=0.964(5)

V_{ud} = 0.97418(26)

RBC/UKQCD

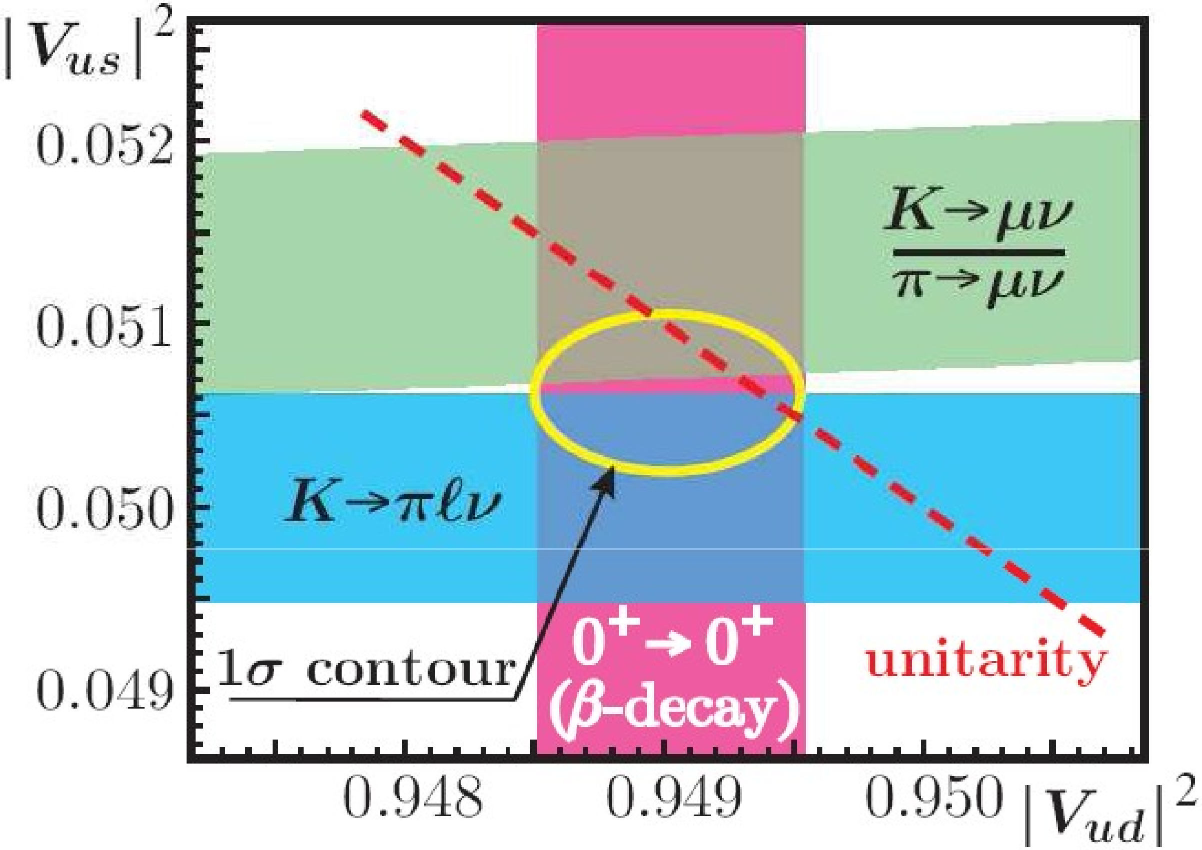
arXiv:0710.3181

$\Rightarrow V_{us} = 0.2237(13)$

$\Rightarrow 1-V_{ud}^2-V_{us}^2 = 9(8)\times 10^{-4}$

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

JHEP 0804:059



no constraint:

$V_{ud}^2 = 0.9490(5)$

$V_{us}^2 = 0.0506(4)$

$\chi^2/\mathrm{ndf} = 2.3/1$ (13%)

agreement with unitarity:

$1-V_{ud}^2-V_{us}^2 = 4(7)\times 10^{-4}$

@ 0.6 σ

$|V_{ud}| = 0.97418(26)$ [Towner & Hardy arXiv:0710.3181]

$f_+(0) = 0.964(5)$ UKQCD/RBC NF=2+1, DWF

$f_K/f_\pi = 1.189(7)$ HPQCD-UKQCD(MILC) NF=2+1, Stag

RESULTS FROM $0^+ \rightarrow 0^+$ DECAY IN 2008

1) G_V constant $\boxed{\mathcal{F}t = \frac{K}{2G_V^2\,(1+\Delta_R)}}$ ✓ verified to ± 0.013%

2) Scalar current zero ✓ limit, $C_S/C_V = 0.0011\,(14)$

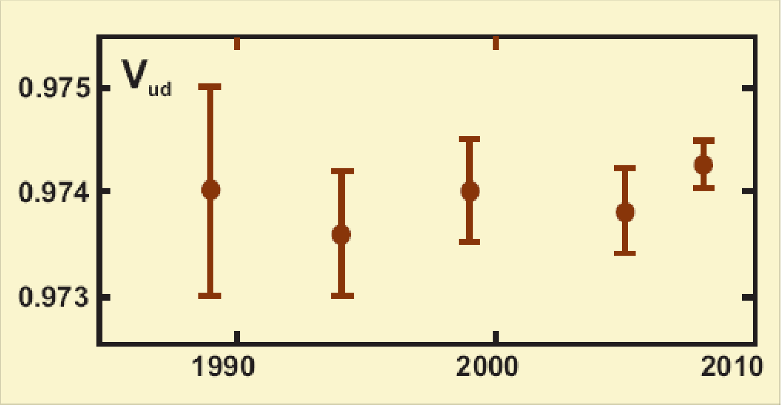
3) Precise value determined for V_{ud} $\boxed{V_{ud} = G_V/G_\mu}$

$$\boxed{V_{ud} = 0.97425 \pm 0.00023}$$

Compare:

neutron $V_{ud} = 0.9746 \pm 0.0019$

pion $V_{ud} = 0.9749 \pm 0.0026$



I. S. Towner
@ CKM08

Dominant K_L branching ratios

Absolute BR mmts to 0.5-1% using K_L beam tagged by $K_S \to \pi^+\pi^-$

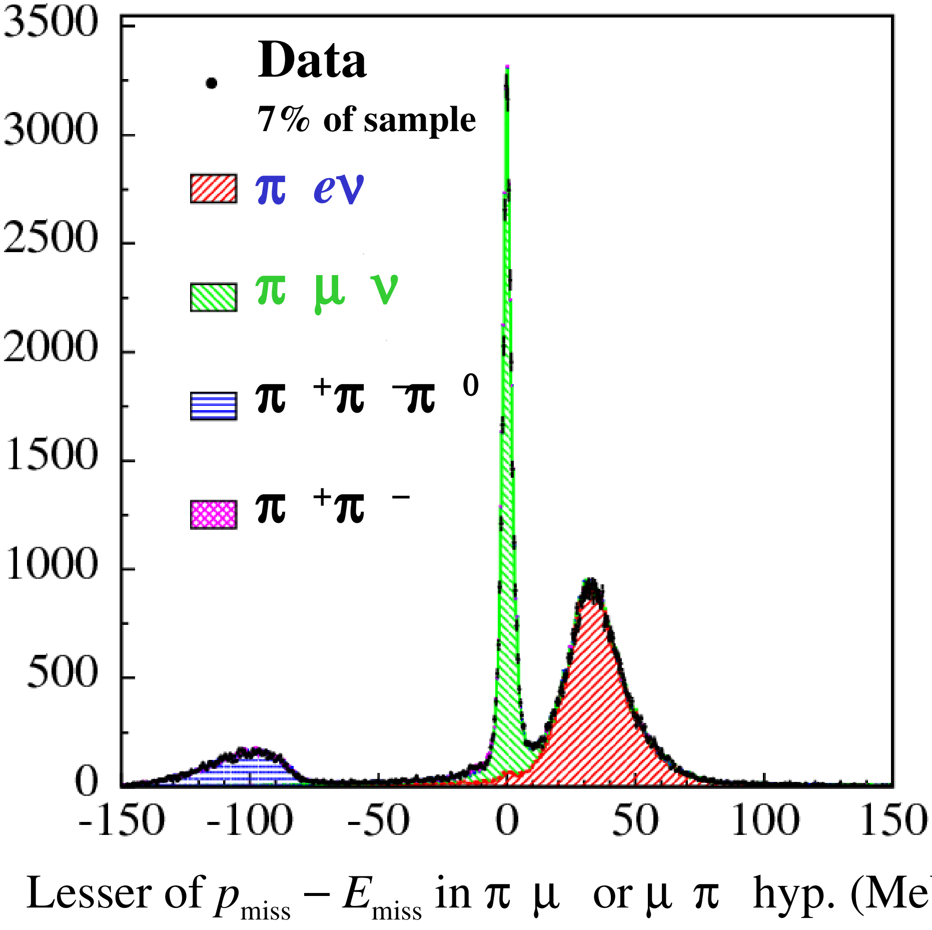
328 pb^{-1} '01 + '02 data

13×10^6 K_L's for counting (25%)

75% used to evaluate efficiencies

BR's to $\pi e\nu$, $\pi\mu\nu$, and $\pi^+\pi^-\pi^0$:

- K_L vertex reconstructed in DC
- PID using decay kinematics
- Fit with MC spectra including radiative processes and optimized EmC response to $\mu/\pi/K_L$



BR to $\pi^0\pi^0\pi^0$:

- vertex by EmC TOF (≥ 3 clusters)
- ε_{rec} = 99%, background < 1%

$K_{e2}/K_{\mu 2}$: SM prediction

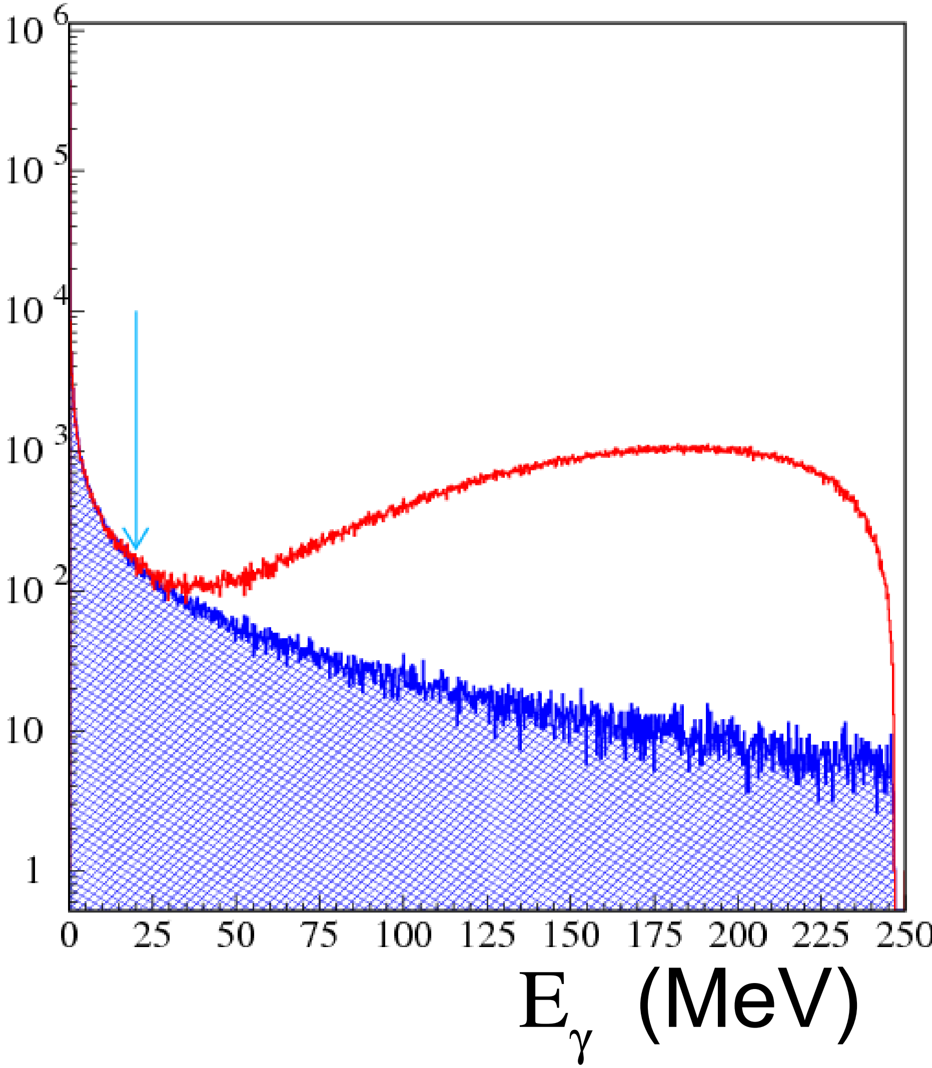
SM prediction made in terms of IB process only (unobservable)

$R_K = 2.477(1) \times 10^{-5}$ [Cirigliano, Rosell]

Radiative corrections: IB + DE amplitudes in MC generator

Signal: $K \rightarrow e\nu(\gamma)$, $E_\gamma < 20$ MeV

DE is negligible in this range



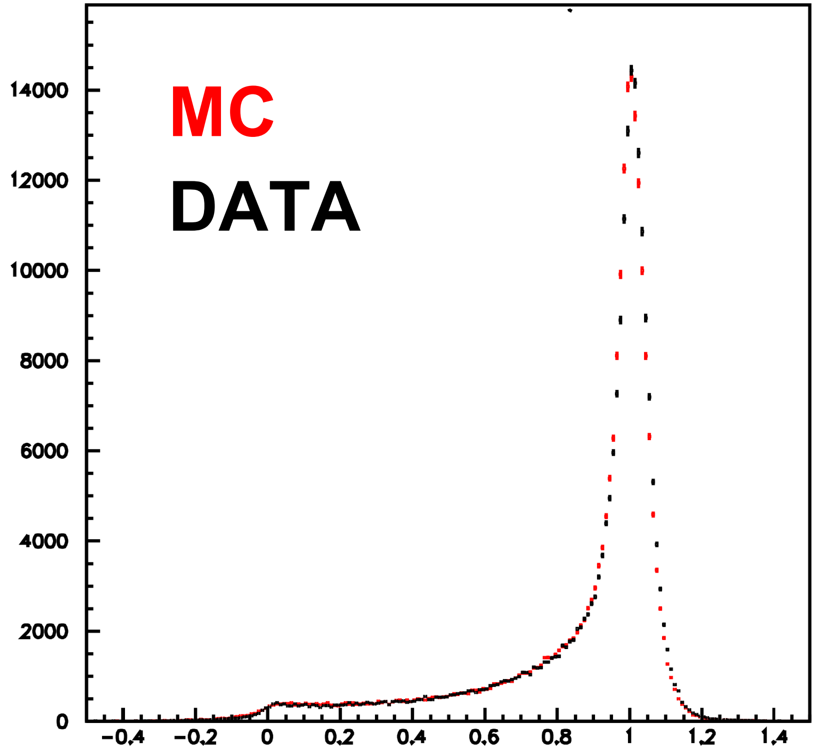
Particle Identification

particle ID exploits EmC granularity: energy deposits into 5 layers in depth

Combine infos with a neural network

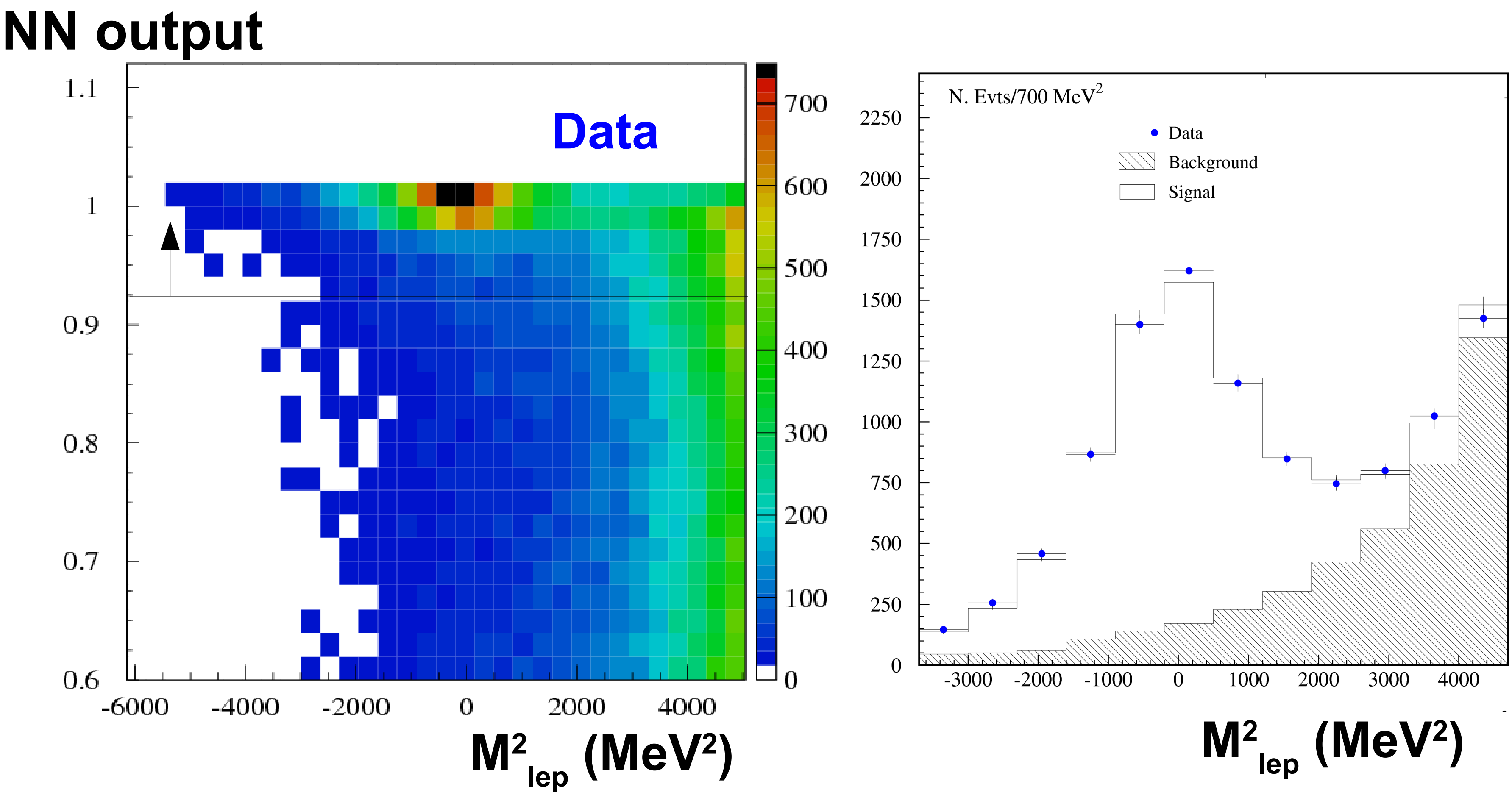
use pure sample of K_Le3 to correct cell response in MC and for NN training

K_Le3 control sample



NN output

Counting K_{e2} events

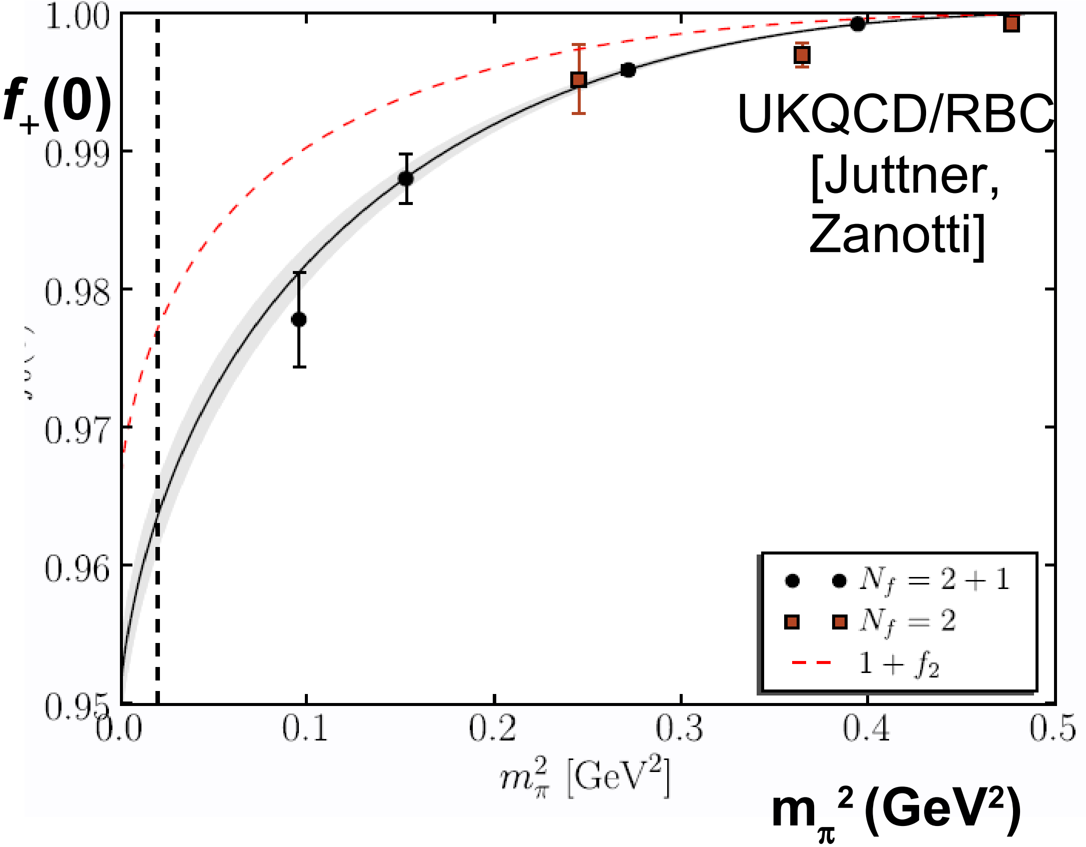


Two-dimensional binned likelihood fit in the plane

NN output - M^2_{lep} count 7060 + 6750 Ke2 events

Evaluations of $f_+(0)$

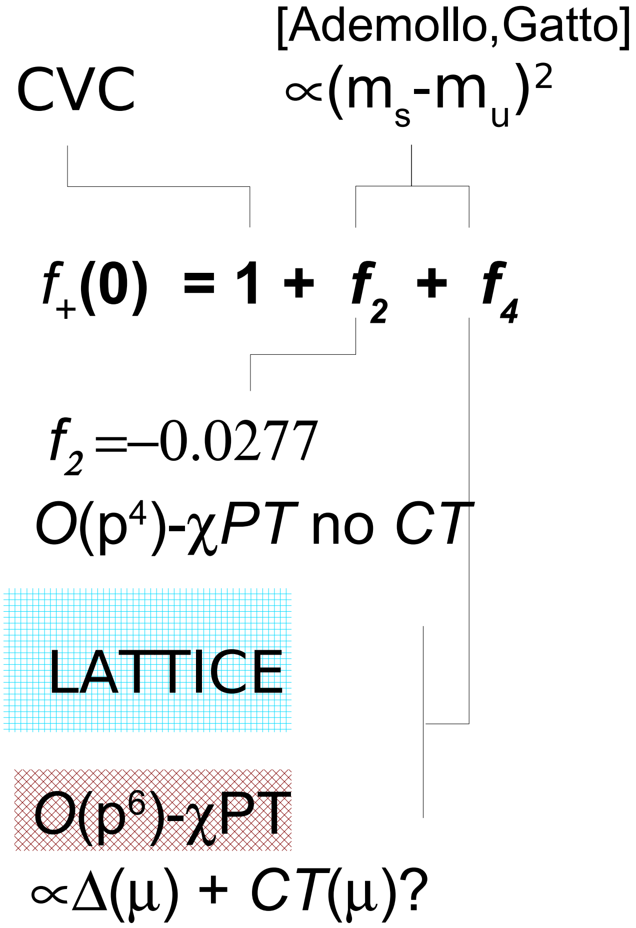
Chiral extrapolation seen for the first time



$f_+(0)$

UKQCD/RBC [Juttner, Zanotti]

m_π^2 **(GeV²)**



CVC

[Ademollo,Gatto] $\propto(m_s\text{-}m_u)^2$

$$f_+(0) = 1 + f_2 + f_4$$

$f_2 = -0.0277$

$O(p^4)$-χPT no *CT*

LATTICE

$O(p^6)$-χPT

$\propto\Delta(\mu) + CT(\mu)$?

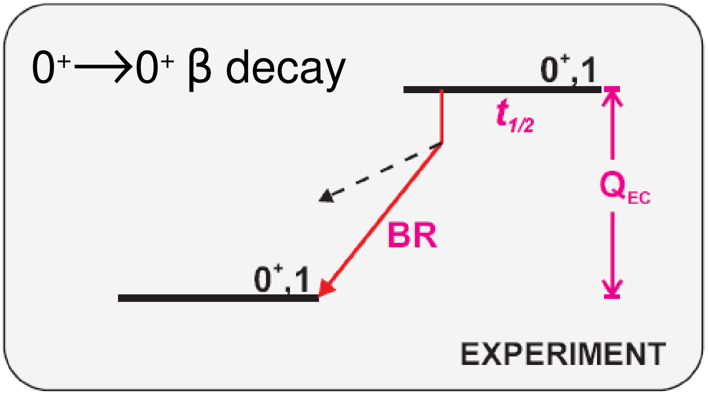
encouraging results from UKQCD/RBC NF=2+1, DWF, m_π>=300MeV:

$f_+(0) = 0.964(5)$

Vud from Fermi transitions

$$G_F^2|V_{ud}|^2 = \frac{K}{M_K(1-m_\mu^2/M_K^2)^2}$$

CVC



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

[Marciano Sirlin]

$K_{\mu3}$ form-factor slopes

- Knowledge of $\tilde{f}_0(t)$ important to test QCD parameters: $f_0(\Delta_{K\pi}=m_K^2-m_\pi^2) = f_K/f_\pi$

[Callan-Treiman]

- Linear parametrization not a good physics approximation: hints for λ''_0 ?
- Fractional partial width difference by varying slopes values :

$\Delta(1/\Gamma\, d\Gamma/dt)$ **[λ''_0=0.4, 0]**

$\Delta(1/\Gamma\, d\Gamma/dt)$ **[λ'_0=14.7, 16]**

λx10^3

- Almost exact cancellation

$\Delta(1/\Gamma\, d\Gamma/dt)$ **[λ'_0=14.7, 16: λ''_0=0.4, 0]**

- Correlation matrix from Ideal t-spectrum experiment:

λ'_0	1	-0.9996	-0.97	0.9
λ''_0		1	0.98	-0.92
λ'_+			1	-0.98
λ''_+				1

[Franzini]

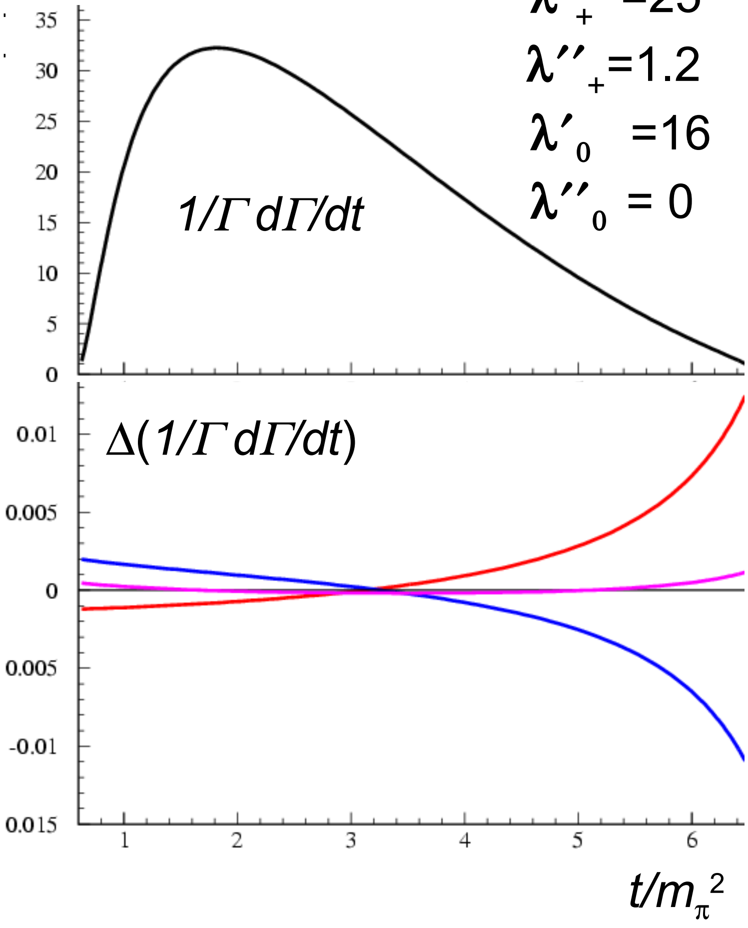
λx10^3

λ'_+ =25

λ''_+=1.2

λ'_0 =16

λ''_0 = 0



Simultaneous λ'_0, λ''_0 measurement not possible