Summary of WG 1:
Precise Determination of Vud and Vus

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Convenors:
- Mario Antonelli
- Vincenzo Cirigliano
- Andreas Jüttner
+ help from Gino Isidori

Thanks also to all speakers, the organisers and the IT-team

The four WG1 sessions

Vud and Vus

V_ud from nucelar decays by Ian TOWNER

Status of V_ud from neutron beta-decay by Brad PLASTER

Kl2/3 radiative corrections by Helmut NEUFELD

Kl3 experimentally NA48 by Rainer WANKE

Measurements of V_us from kaon decays at KLOE

by Alexej SIBIDANOV

MISCELLANEA

SU(2) kaon ChiPT and RBC-UKQCD lattice results by Jonathan FLYNN

CKM unitarity and "New Physics" constraints by William MARCIANO

Kl2 review by Tommaso SPADARO

V_us determination from tau-decays by Antonio PICH

Vus from tau by Richard KASS

RARE DECAYS

FLAVIANet by Barbara SCIASCIA

Rare K decays in the Standard Model by Joachim BROD

Rare K decays beyond SM by Christopher SMITH

"The well tempered Kaon" (searching for very rare kaon decays) by Marco SOZZI

Final results on K^+->pi^+ nu barnu from BNL E949 by David JAFFE

THEORY

Dispersive approaches by Emilie PASSEMAR

Determinations of V_us from unquenched lattice QCD simulations by Silvano SIMULA

WG1-mission / outline

first row unitarity

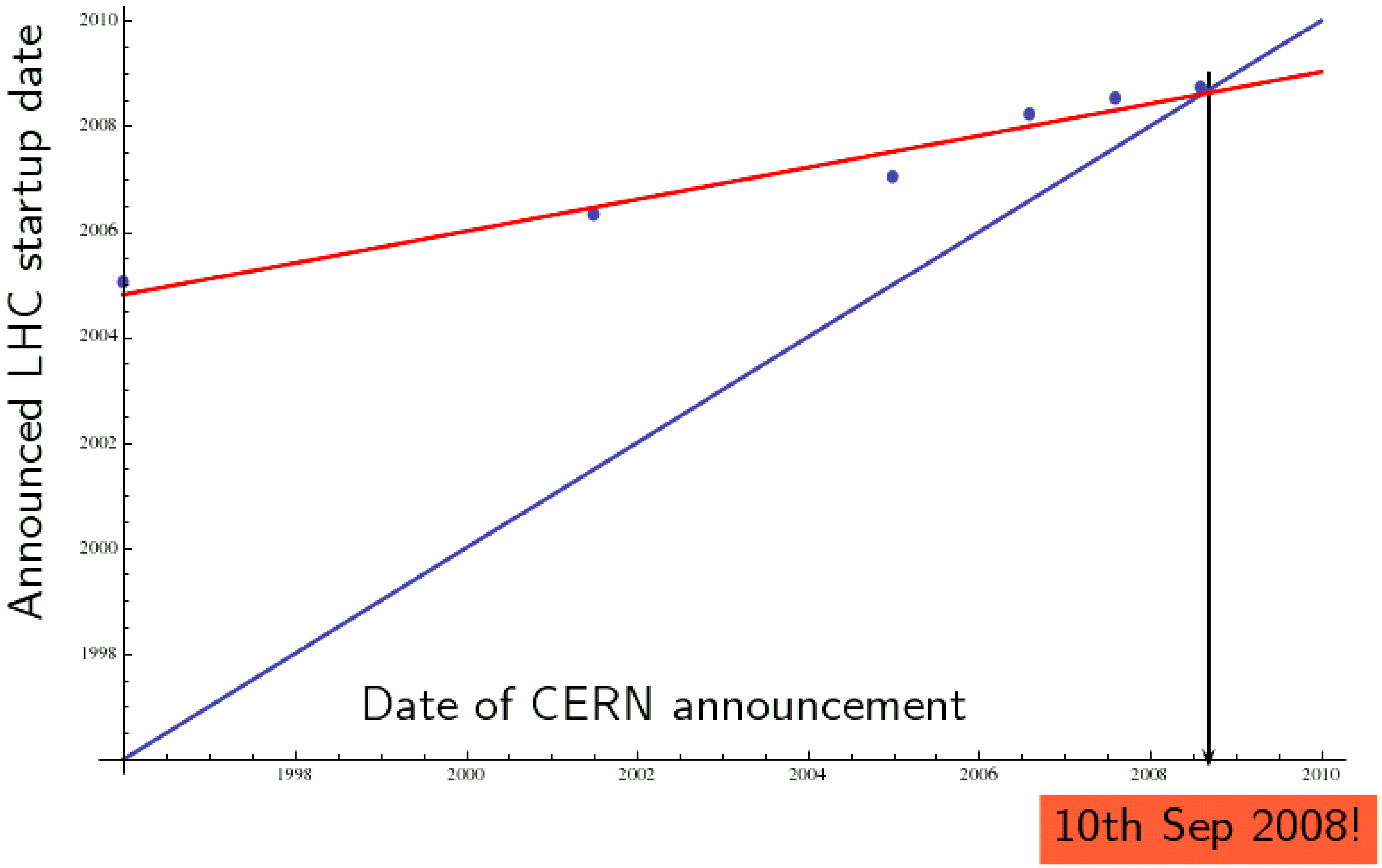
$$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2\overset{?}{=}1$$

signs of BSM in Kaon decays

- V_{ud} - theory and experiment
- V_{us} from K-decays
  - radiative corrections
  - parametrisations
  - experimental results
  - Callan-Treiman
  - lattice
    chiral PT
    results
- V_{us} from tau
  experiment and theory
- constraints from unitarity
- New physics searches with Kl2

Apologies – I could not cover all the nice and interesting results!

LHC-startup - post-diction



(J. Brod)

$$\left|V_{ud}\right|$$

NUCLEAR BETA-DECAY (talks by I. Towner)

$$ft = \frac{K}{G_V^2 \langle \tau_+ \rangle^2}$$

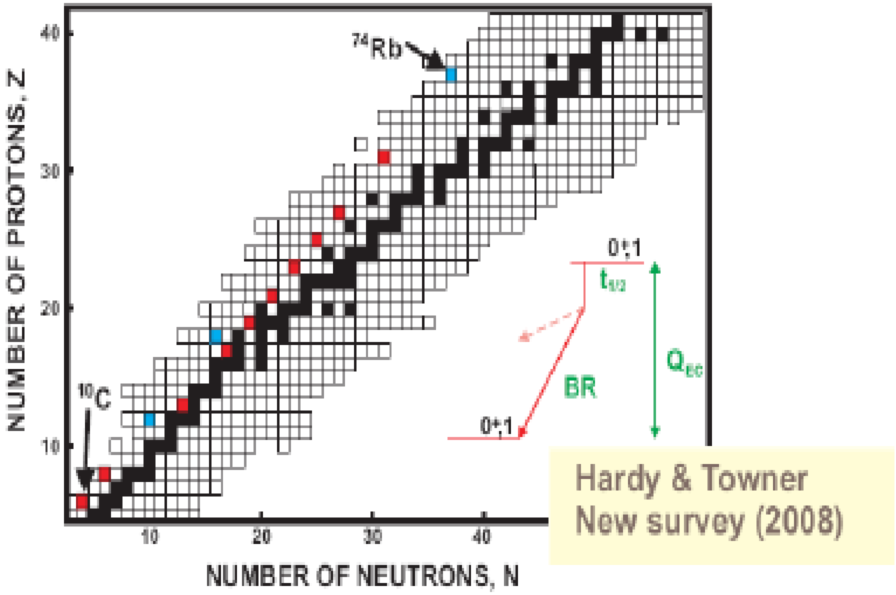
Isospin corr.

nucl. str

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

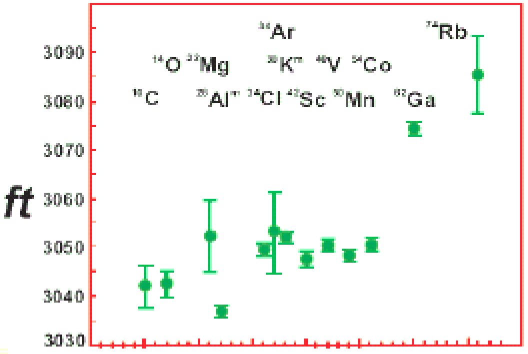
rad. corr

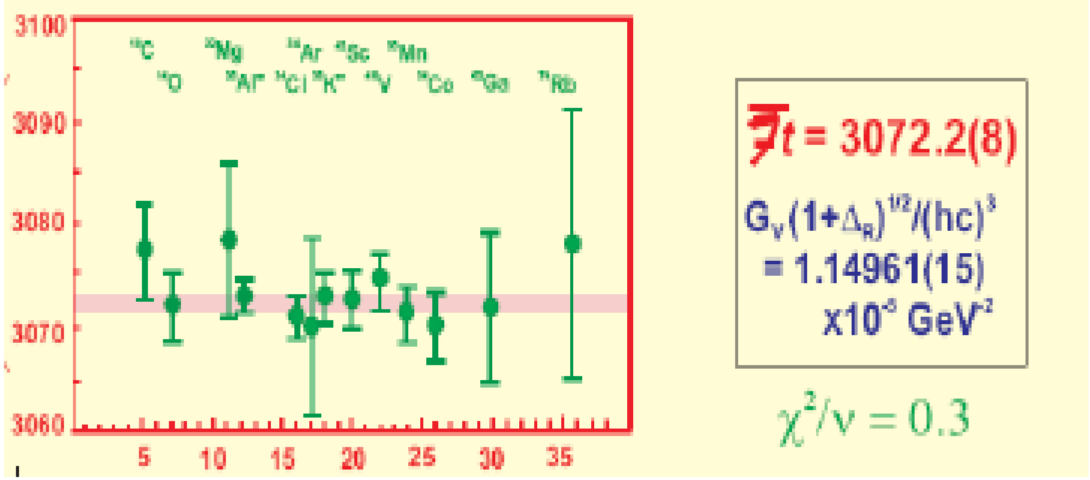
$$V_{ud}^2 = \frac{K}{2G_F^2 \mathcal{F}t(1+\Delta_R)} \qquad \frac{K}{(\hbar c)^6} = \frac{2\pi^3 \hbar \ln 2}{(m_e c^2)^5}$$



Hardy & Towner
New survey (2008)

Need input for RC
and SU(2)-breaking





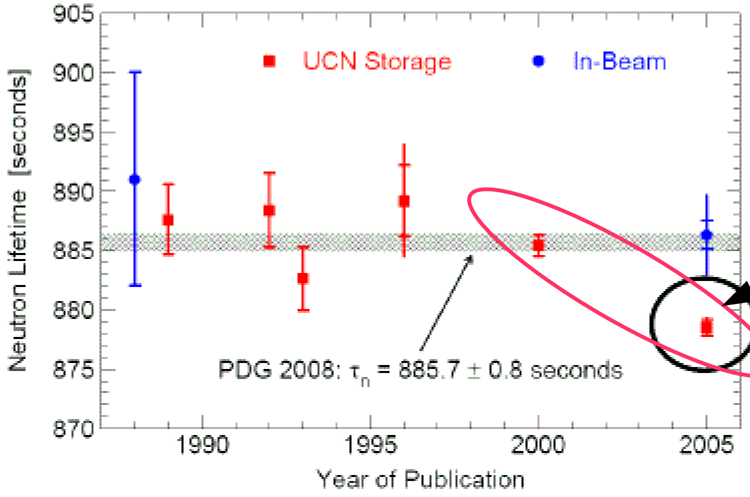
NEUTRON BETA-DECAY (talks by B. Plaster)

Master formula:

$$\frac{1}{\tau_n} \propto G_F^2 \, |V_{ud}|^2 \, (1 + 3\lambda^2)\,(1 + RC)$$

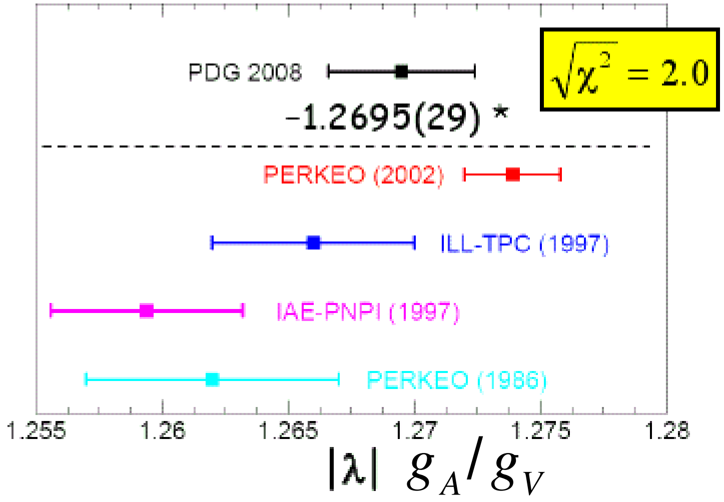
like for nuclear beta decay

Input
- neutron life-time
- beta-asymmetry g_A/g_V
  measurement in experiments with cold and ultra-cold neutrons



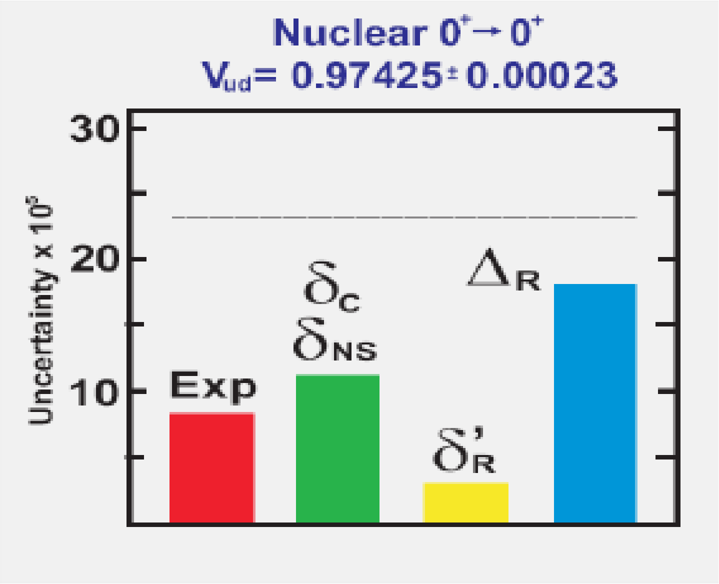
Serebrov 2005

huge difference



Error budget for nuclear and neutron beta decay

Nucleon beta decay



$V_{ud} = 0.97380(40)$ Review '05 :

$V_{ud} = 0.97425(23)$ Sept '08 :

error reduction mainly due to Marciano-Sirlin reevaluation of radiative correction.

Neutron beta decay

- issue with neutron life-time tau
- new experiments for tau and also g_A/g_V which is source of dominant error (PERKEO III and UCNA)

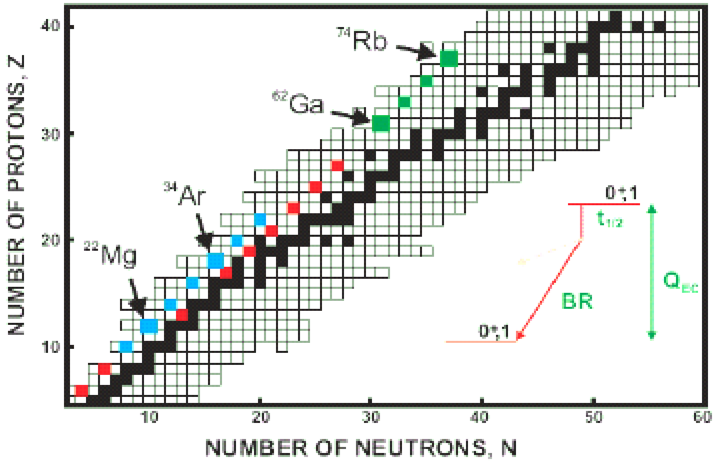
PDG 2008 Neutron Result

$V_{ud} = 0.9746\ (4)_\tau\ (18)_{gA}\ (2)_{RC}$

Dominant error

Future for nuclear beta decay (Towner):

- Increase measured precision on “traditional” nine *ft*-values
- measure new $0^+ \rightarrow 0^+$ decays with $18 \leq A \leq 42$ ($T_z = -1$)
- measure new $0^+ \rightarrow 0^+$ decays with $A \geq 62$ ($T_z = 0$)



Future perspectives for Neutron beta decay (B. Plaster)

	A	λ	Notes
Current PDG 2008	1.1% *4 results*	0.23% *4 results on A, 1 on A and B*	$\sqrt{\chi^2} = 2.3$ for A $\sqrt{\chi^2} = 2.0$ for λ
PERKEO III *Projected result*	0.3%	0.07%	Running now 2008
UCNA	1.0%	0.25%	Running now 2008
Projected results	< 0.7%	< 0.12%	Projected 2009

PERKEO III (ILL) and UCNA (LANL) experiments new precision data on λ to sub-0.1% level within next 2-3 years

Potentially reduce error contribution of λ to V_{ud} by factor of 3-4, *but need consistency among results !!*
Is current error on lifetime underestimated ?

$|V_{ud}|$

- nuclear beta decay most precise $\delta = 0.02\%$
- competitor neutron beta decay will still need some time $\delta = 0.2\%$
- but competition is healthy
- issue with nucleon life time needs clarification

$$|V_{us}|$$

$|V_{us}|$ from semi-leptonic K-decays

Possible with Kl3 and Kl2 but most news on Kl3

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

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
$f_+^{K^0\pi^-}(0)$	Hadronic matrix element at zero momentum transfer (t=0)

Talk by Neufeld

Talks by Flynn and Simula

CT

Inputs from experiment:

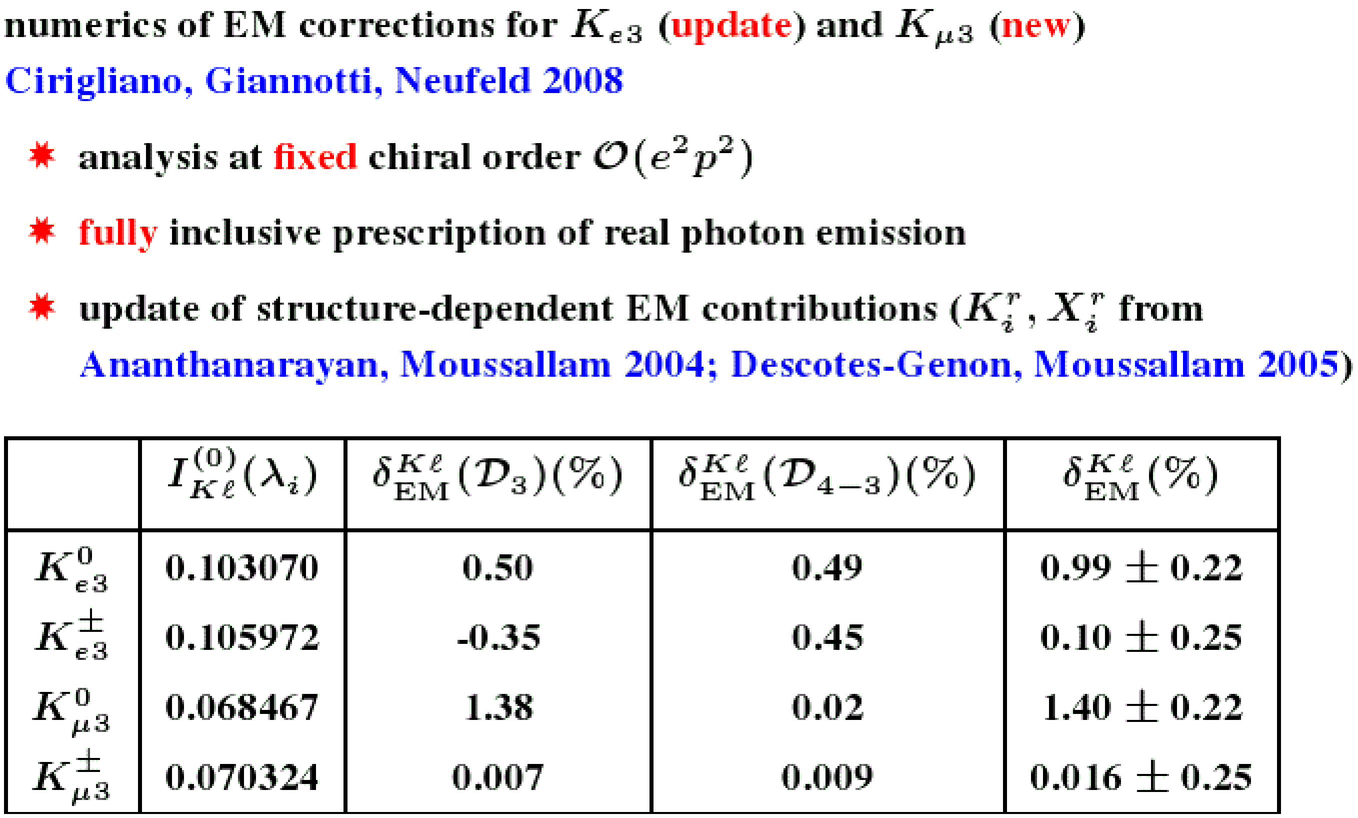
$\Gamma(K_{l3(\gamma)})$	**Branching ratios** with well determined treatment of radiative decays; **lifetimes**
$I_{K\ell}(\lambda)$	Phase space integral: λ's parameterize form factor dependence on t : K_{e3}: *only* λ_+ $K_{\mu3}$: *need* λ_+ *and* λ_0

Talks by Sciascia, Sibidanov, Wanke

Talk by Passemar

EM and SU(2) corrections (H. Neufeld)

δ^{Kl}_{EM}



numerics of EM corrections for K_{e3} (update) and $K_{\mu 3}$ (new)

Cirigliano, Giannotti, Neufeld 2008

- **analysis at fixed chiral order $\mathcal{O}(e^2p^2)$**
- **fully inclusive prescription of real photon emission**
- **update of structure-dependent EM contributions (K_i^r, X_i^r from Ananthanarayan, Moussallam 2004; Descotes-Genon, Moussallam 2005)**

	$I^{(0)}_{K\ell}(\lambda_i)$	$\delta^{K\ell}_{\rm EM}(\mathcal{D}_3)(\%)$	$\delta^{K\ell}_{\rm EM}(\mathcal{D}_{4-3})(\%)$	$\delta^{K\ell}_{\rm EM}(\%)$
K^0_{e3}	0.103070	0.50	0.49	0.99 ± 0.22
$K^\pm_{e3}$	0.105972	-0.35	0.45	0.10 ± 0.25
$K^0_{\mu 3}$	0.068467	1.38	0.02	1.40 ± 0.22
$K^\pm_{\mu 3}$	0.070324	0.007	0.009	0.016 ± 0.25

$\delta^{Kl}_{SU(2)}$ Updated value by Kastner and Neufeld 2008:

$$2^*\delta_{\rm SU(2)} = 0.058(8)$$

FlaviA net Kaon WG average (B. Sciascia)

18 input measurements:

5 KTeV ratios
NA48 K_{e3} /2t 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

K_L

Parameter	Value	S
BR(K_{e3})	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($\pi^+\pi^-$)	$1.997(7) \times 10^{-3}$	1.1
BR($2\pi^0$)	$8.64(4) \times 10^{-4}$	1.3
BR($\gamma\gamma$)	$5.47(4) \times 10^{-4}$	1.1
τ_L	51.17(20) ns	1.1

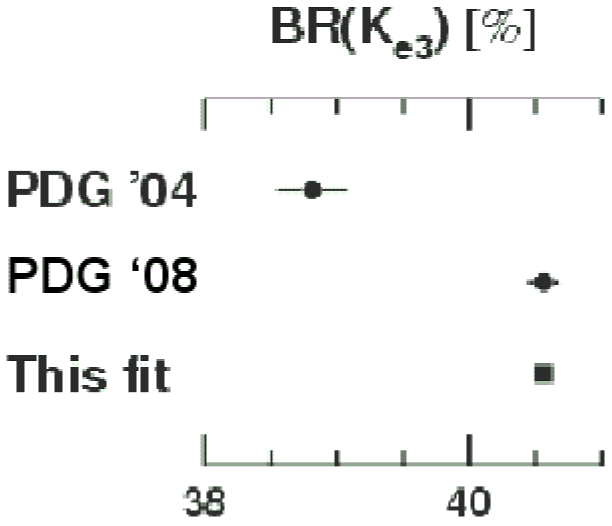
25 input measurements
(cf. B. Sciascia's talk)

$K^\pm$

Parameter	**Value**	**S**
BR(Kμ2)	**63.57(10)%**	**1.1**
BR(Kπ2)	**20.64(7)%**	**1.1**
BR(Kπππ)	**5.593(32)%**	**1.1**
BR(Ke3)	**5.078(25)%**	**1.2**
BR(Kμ3)	**3.365(26)%**	**1.7**
BR(Kππ⁰π⁰)	**1.750(26)%**	**1.1**
τ	**12.379(21) ns**	**1.9**

Summ

Time-evolution (B. Sciascia)



NA48 – most precise single measurement for charged Kaon decay (Rainer Wanke's talk)

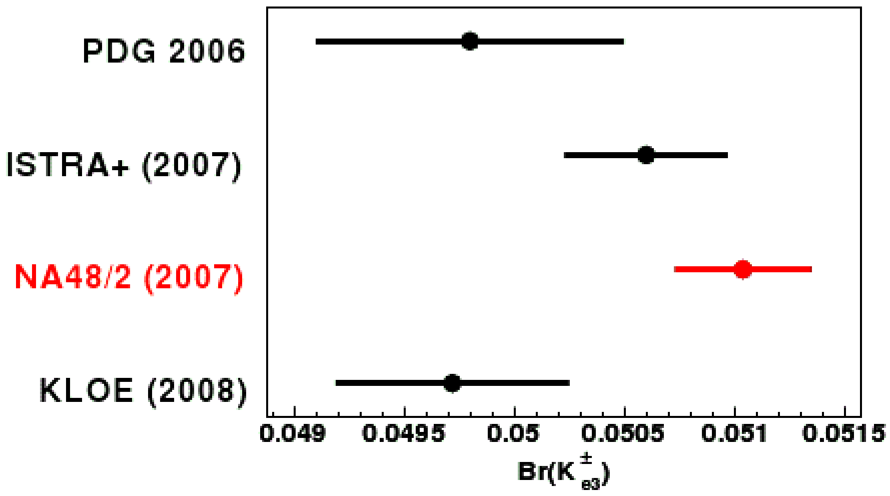
Absolute BR's: *(Update w.r.t. publication)*

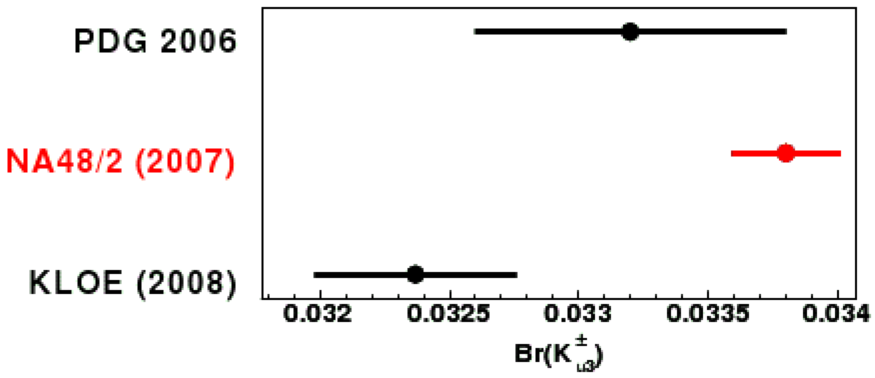
Use new KLOE measurement of Br$(K_{2\pi(\gamma)}) = 0.2065(5)(8)$,
shifted $(+0.06\%)$ to $\tau_{K^\pm} = 12.370(19)$ ns (average PDG'06 & KLOE'08):

$$\mathrm{Br}(\mathbf{K}^\pm_{\mathbf{e3}}) = 0.05104 \pm 0.00019_{\mathrm{stat}} \pm 0.00008_{\mathrm{sys}} \pm 0.00023_{\mathrm{norm}}$$

$$\mathrm{Br}(\mathbf{K}^\pm_{\mu\mathbf{3}}) = 0.03380 \pm 0.00013_{\mathrm{stat}} \pm 0.00006_{\mathrm{sys}} \pm 0.00015_{\mathrm{norm}}$$

Most precise single measurements!





How to parametrise the $K \to \pi$ form factors?:

scalar form factor

- polynomial, z-parametrisation (R. Hill)
- dispersion relation with subtraction at
  input: $q^2 = 0, \Delta_{CT}$

determine from fit

input

→ $\bar{f}_0(0) = 1$

→ $\bar{f}_0(\Delta_{K\pi}) = C$, Callan-Treiman point

→ $K\pi$ scattering phase

→ Asymptotic behaviour of the form factor : $\bar{f}_0(s) \overset{s\to-\infty}{=} \mathcal{O}(1/s)$

(E. Passemar)

$$\bar{f}_0(t) = \exp\left[\frac{t}{\Delta_{K\pi}}\left(\ln C - G(t)\right)\right]$$

with

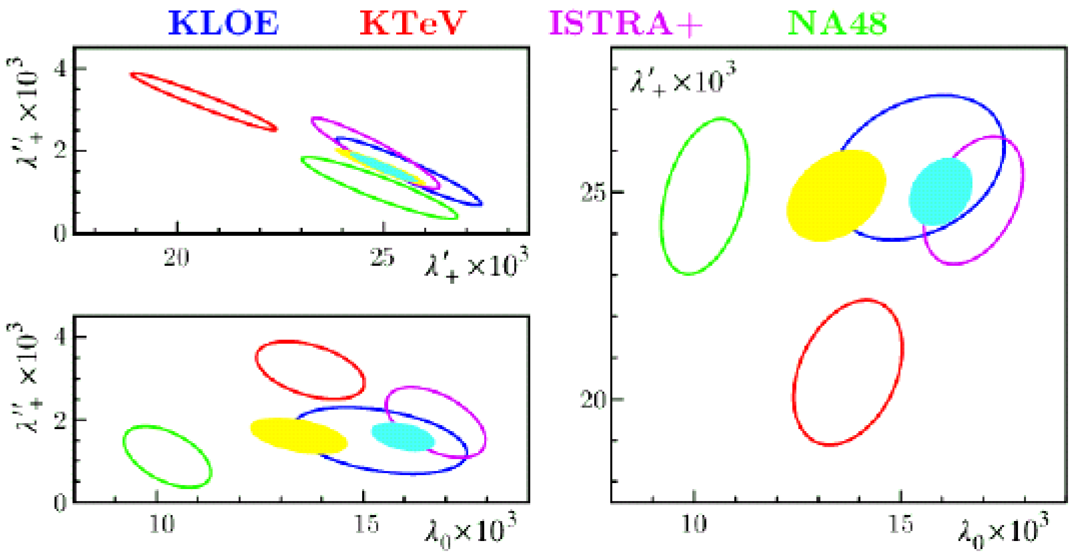
$$G(t) = \frac{\Delta_{K\pi}(\Delta_{K\pi} - t)}{\pi}\int_{t_{K\pi}}^{\infty}\frac{ds}{s}\frac{\phi(s)}{(s - \Delta_{K\pi})(s - t)}$$

→ $\phi(t)$ phase of the form factor : $\bar{f}_0(t) = \left|\bar{f}_0(t)\right| e^{i\phi(t)}$

also dispersive approach for vector form factor

Results for form factor params - correlations (B. Sciascia)

- Gives combined results from independent experiments (KLOE, ISTRA, NA48, KteV, http://www.lnf.infn.it/wg/vus/)
- Consider K_L, K_S, and $K^{\pm}$.



1σ contour for all the experimental results.

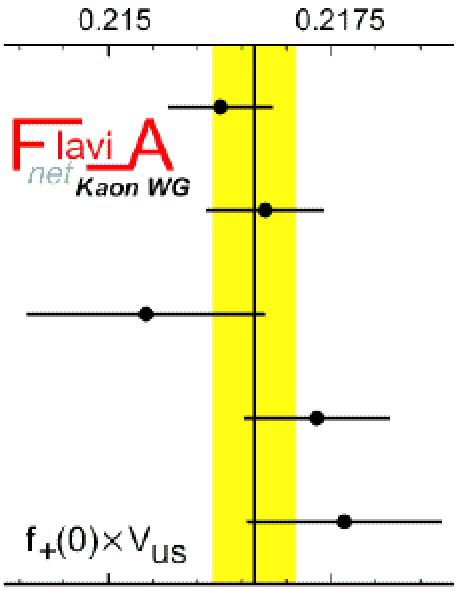
EM corrections by Cirigliano, Gianotti, Neufeld 2008 and SU(2) corrections by Kastner and Neufeld 2008 (B. Sciascia)

	$\delta^{K}_{SU(2)}$(%)	$\delta^{K\ell}_{em}$(%)
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

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

Available correlation matrix between different δ_{em} corrections.



		% err	Approx. contr. to % err from: BR	τ	δ	$I_{K\ell}$
K_Le3	0.2164(6)	0.26	0.09	0.19	0.11	0.09
$K_L\mu3$	0.2170(6)	0.29	0.10	0.18	0.11	0.15
K_Se3	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
$K^{\pm}\mu3$	0.2177(11)	0.51	0.40	0.13	0.25	0.15

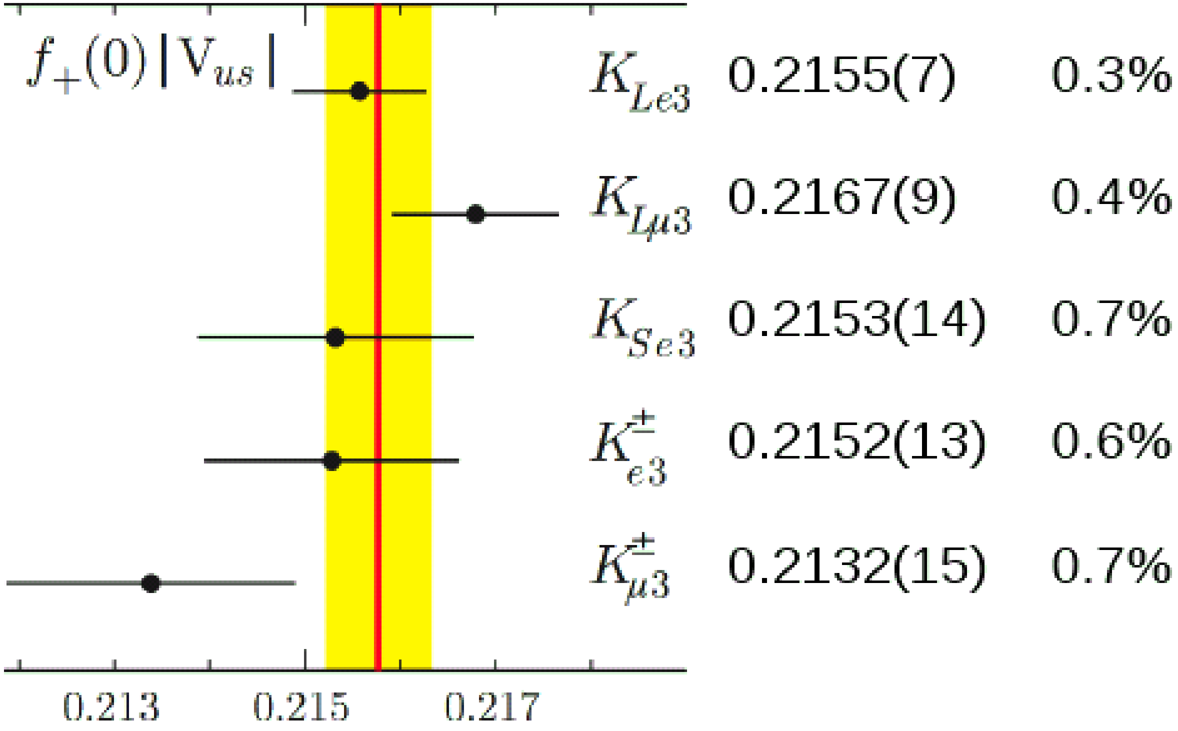
by charge:

$K_{L,S} = 0.2165(5)$,

$K^{\pm} = 0.2174(8)$

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

KLOE has variety of channels for Kl3 (A. Sibidanov's talk)



K_{Le3}	0.2155(7)	0.3%
$K_{L\mu3}$	0.2167(9)	0.4%
K_{Se3}	0.2153(14)	0.7%
$K^{\pm}_{e3}$	0.2152(13)	0.6%
$K^{\pm}_{\mu3}$	0.2132(15)	0.7%

Lattice QCD results relevant for V_{us} from Kl2 and Kl3 (S. Simula)

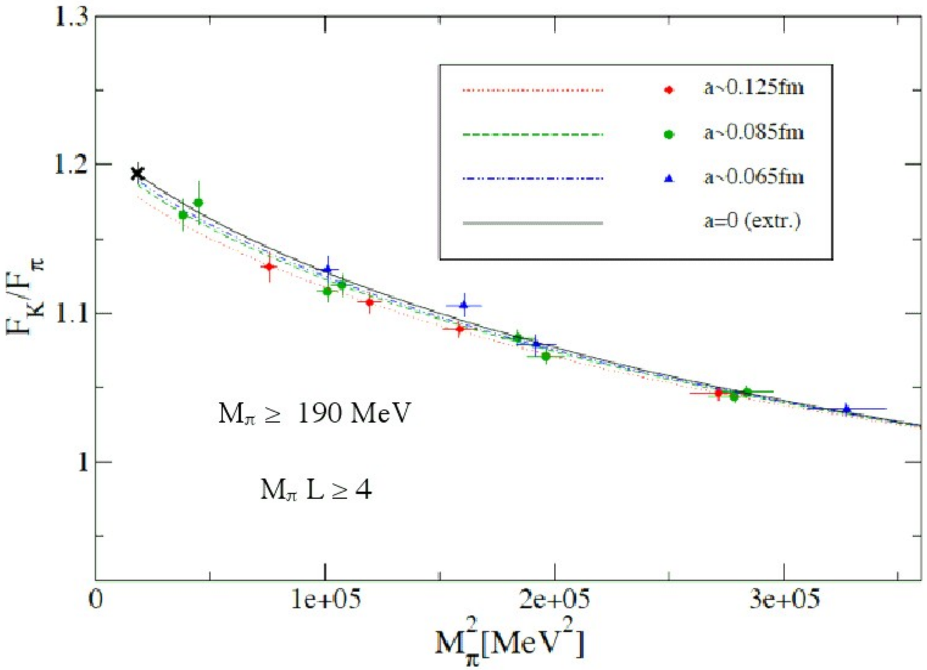
$$C_{A_0P}(t) \equiv \int d\vec{x}\, \langle A_0(x)\,P(0)\rangle_{\mathrm{QCD}} \xrightarrow{t\to\infty} \frac{1}{2M_{PS}} \langle 0|\bar{q}\gamma_0\gamma_5 q'|PS\rangle \langle PS|\bar{q}'\gamma_5 q|0\rangle e^{-M_{PS}t}$$

$$\longrightarrow \sqrt{2}M_{PS}f_{PS}$$

dominant systematic errors here

- discretisation errors
  finite lattice spacing = cut-off
  continuum limit
- finite volume
  analytical estimates or scaling study
- quark mass
  physical quark mass currently not feasible
  simulate “heavy pions” and use
  ChiPT to extrapolate to the physical point

BMW: Dürr @ Lattice '08



Conceptual question: (J. Flynn, RBC/UKQCD)

Chiral extrapolations are used for decay constants, PS masses and form factors, ...
Does SU(3)xSU(3) ChiPT at NLO fit the data?

- Chiral perturbation theory (ChPT) is used for the extrapolation $m_l \longrightarrow m_{ud}$
  - How reliable?
  - What are the values of the Low Energy Constants (LECs)?
  - $\mathrm{SU}(3)_\mathrm{L} \times \mathrm{SU}(3)_\mathrm{R}$ or $\mathrm{SU}(2)_\mathrm{L} \times \mathrm{SU}(2)_\mathrm{R}$?

$$f_\pi = f_0 \left\{ 1 + \frac{24}{f_0{}^2} L_4 \bar{\chi} + \frac{8}{f_0{}^2} L_5 \chi_{ud} - \frac{1}{16\pi^2 f_0{}^2} \left(2\chi_{ud} \log \frac{\chi_{ud}}{\Lambda_\chi^2} + \frac{\chi_{ud}+\chi_s}{2} \log \frac{\chi_{ud}+\chi_s}{2\Lambda_\chi^2} \right) \right\}$$

where $\chi_i = 2B_0 m_i$ for $i = ud, s$, $\chi_\eta = (\chi_{ud} + 2\chi_s)/3$ and $\bar{\chi} = (2\chi_{ud} + \chi_s)/3$

- Do such formulae represent our data?

Same questions recently addressed by RBC/UKQCD, ETMC and PACS-CS

Chiral extrapolations of decay constants, PS masses and form factors
does SU(3)xSU(3) ChiPT at NLO fit the data? (J. Flynn)

for pion:

- NLO SU(3) fits to PS masses and decay constants works well for mpi<400 MeV
  NLO contrib 50%
- NLO SU(2) smaller contribs.

for kaon: strange seems to heavy -> KChitPT
(first by Roessel, now Flynn, Sachrajda)

- only u&d transform, strange as matter field
- fits work well

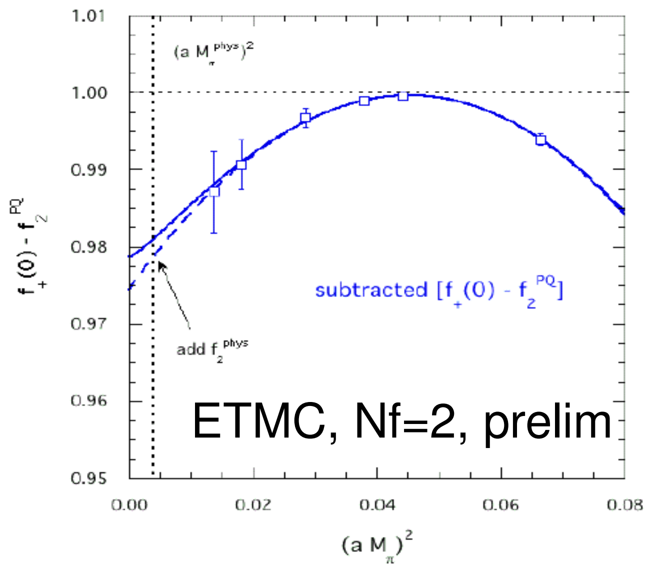
Lattice results: Kl3 form factor (S. Simula)

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

$$\langle \pi(p_\pi)|\hat{V}_\mu|K(p_K)\rangle = f_+(q^2)(p_K+p_\pi)_\mu + f_-(q^2)(p_\pi - p_K)_\mu$$

In ChiPT: $f_+(0) = 1 + f_2 + f_4 + \ldots$

compute this on the lattice
- for various light quark masses to be extrapolated
- for various lattice Fourier momenta to be interpolated
  (or use “partially twisted boundary conditions” which
  allows to remove systematic due to the interpolation)



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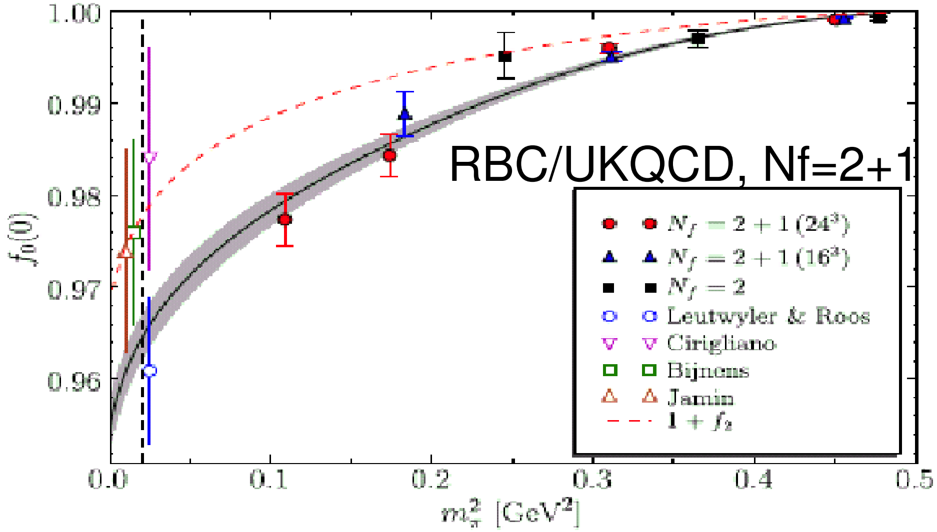
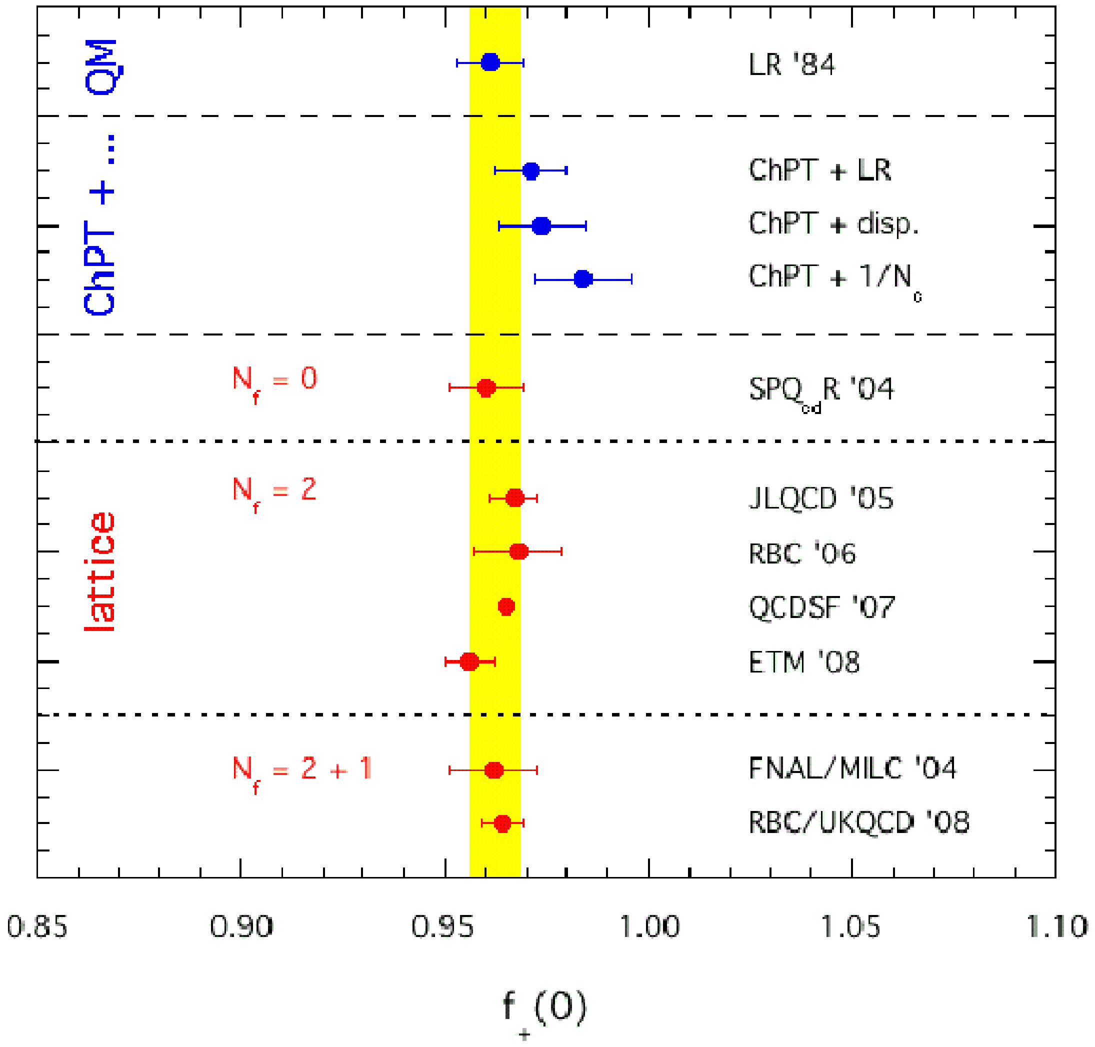
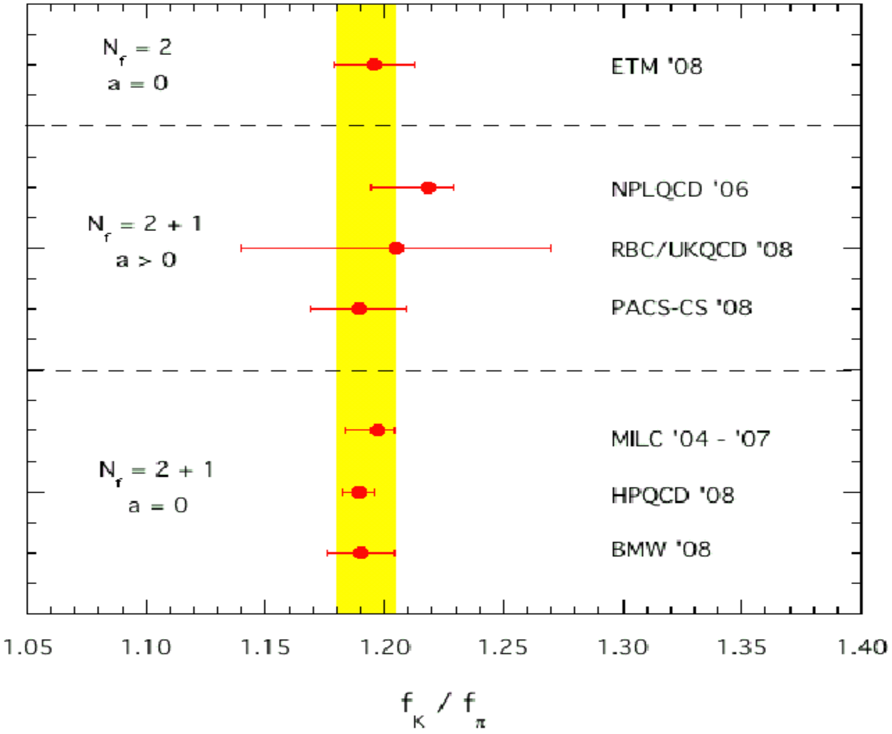


K->pi scalar form factor – summary of lattice results (S. Simula)



fK/fpi from the lattice – summary of results (S. Simula)

$$\frac{\Gamma(K^{\pm}_{\ell 2(\gamma)})}{\Gamma(\pi^{\pm}_{\ell 2(\gamma)})} = \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{f_K^2 m_K}{f_\pi^2 m_\pi} \left(\frac{1 - m_\ell^2/m_K^2}{1 - m_\ell^2/m_\pi^2}\right)^2 \times (1 + \delta_{\rm em})$$ (Marciano)



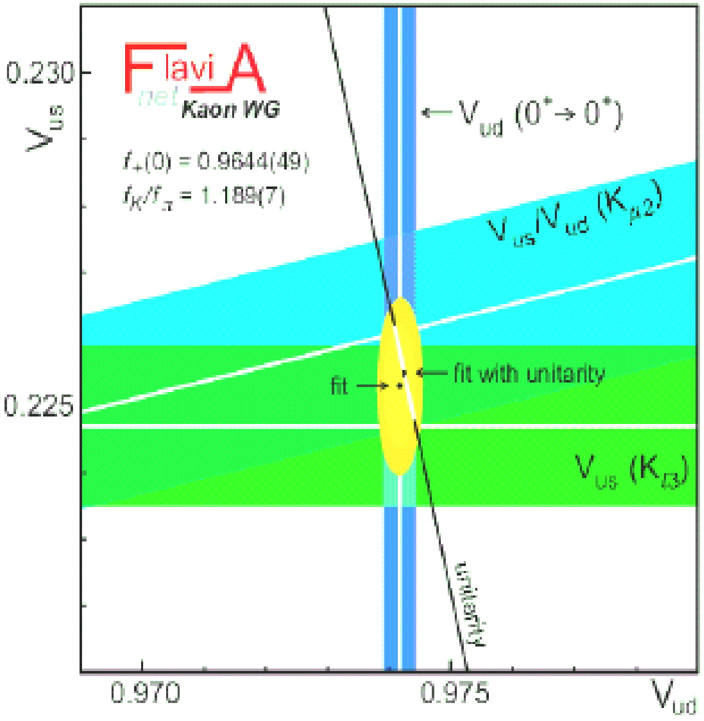
Summary of WG1

Experiment + Lattice -> FLAVIANet summary (B. Sciascia)

K13: $|V_{us}| f_+(0) = 0.2167(5)$ and $f_+(0) = 0.964(5)$, obtain $|\mathbf{V_{us}}| = \mathbf{0.2247(12)}$

K12: $|V_{us}|/|V_{ud}| f_K/f_\pi = 0.2760(6)$ and $f_K/f_\pi = 1.189(7)$, obtain $|\mathbf{V_{us}}|/|\mathbf{V_{ud}}| = \mathbf{0.2322(15)}$

V_{ud} from nuclear β decay: $\mathbf{V_{ud}} = \mathbf{0.97425(23)}$ [Towner, CKM08]



Fit (no CKM unitarity constraint):

$\mathbf{V_{ud} = 0.97425(23); V_{us} = 0.2254(9)}$

$\chi^2/\text{ndf} = 0.60/1$ (44%)

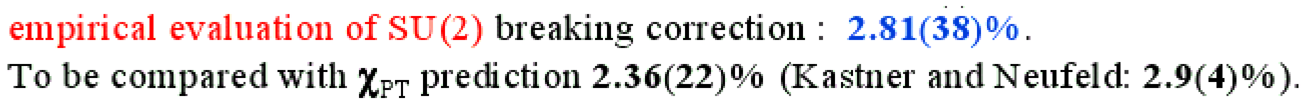
- Unitarity: $\mathbf{1 - V_{ud}^2 - V_{us}^2 = 0.00003(60)}$
- The test on the unitarity of CKM can be also interpreted as a **test of the universality of lepton and quark gauge coupling**:

$$G_{\rm CKM} \equiv G_\mu \left[|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2\right]^{1/2}$$
$$= (1.1662 \pm 0.0004) \times 10^{-5}\ \text{GeV}^{-2}$$
$$G_\mu = (1.166371 \pm 0.000007) \times 10^{-5}\ \text{GeV}^{-2}$$

Fit (with CKM unitarity constraint): $\mathbf{V_{us} = 0.2254(7)}$ $\chi^2/\text{ndf} = 0.60/2$ (74%)

Watch out for FLAVIANet summary of lattice results
(including summary of systematic errors)

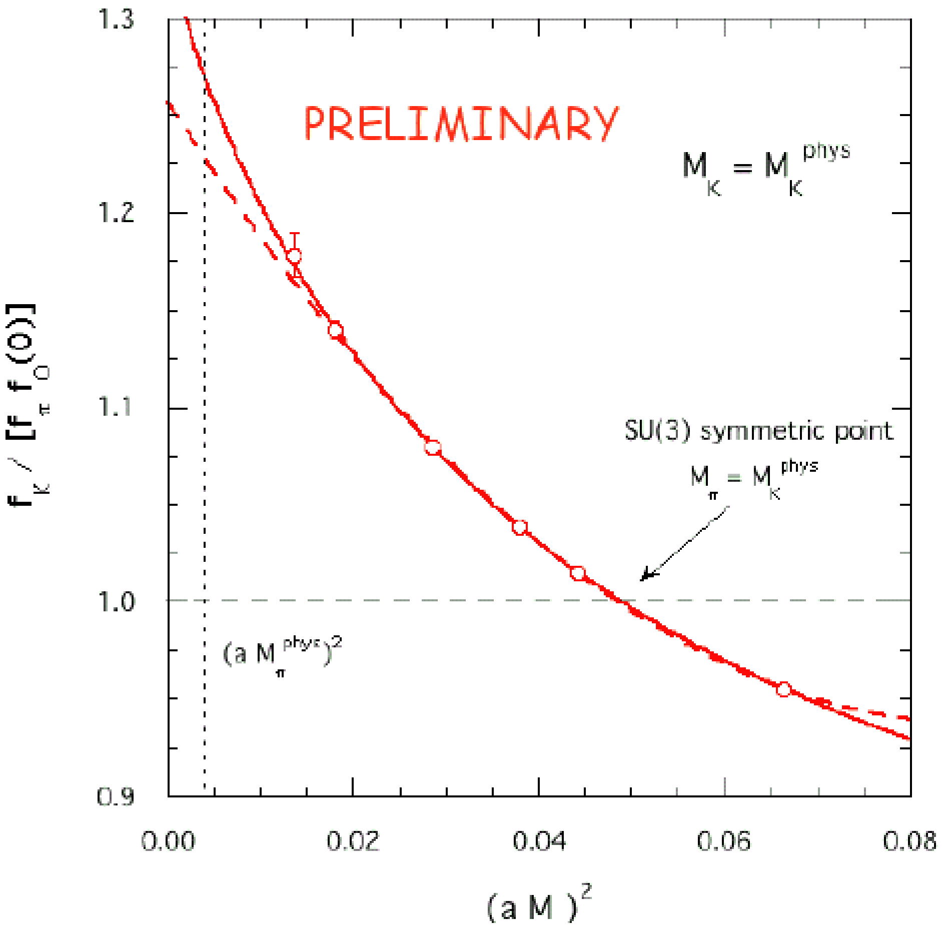
Playing around with the data (B. Sciascia):
Use experiment to compute EM corrections to Kl3:



empirical evaluation of SU(2) breaking correction : **2.81(38)%**.

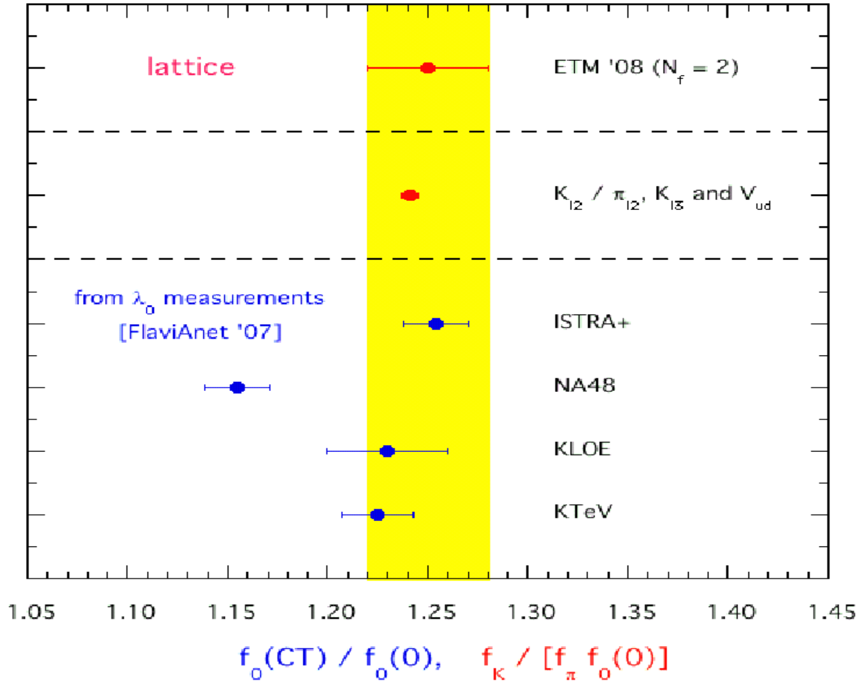
To be compared with χ_{PT} prediction **2.36(22)%** (Kastner and Neufeld: **2.9(4)%**).

Callan-Treiman on the lattice – results by ETMC '08 (S. Simula)



$$\frac{f_0\left(q^2 = M_K^2 - M_\pi^2\right)}{f_0(0)} = \frac{f_K}{f_\pi\, f_0(0)} + O(m_\ell)$$

1.25 ± 0.03



Yet another way to determine it: Vus from hadronic tau decays (A. Pich)

$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \mathrm{had})}{\Gamma(\tau^- \to \nu_\tau e^- \overline{\nu}_e)} = 12\pi \int_0^1 dx\,(1-x)^2 \left[(1+2x)\,\mathrm{Im}\,\Pi^{(1)}(x m_\tau^2) + \mathrm{Im}\,\Pi^{(0)}(x m_\tau^2)\right]$$

$$R_\tau^{kl}(s_0) \equiv \int_0^{s_0} ds \left(1 - \frac{s}{s_0}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \frac{dR_\tau}{ds}$$

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

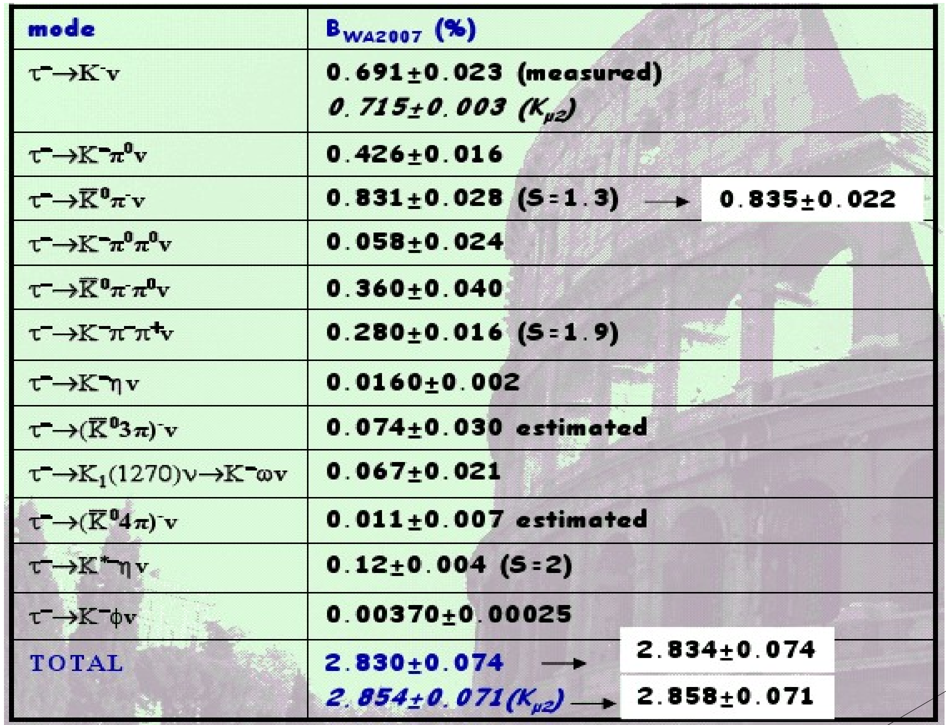
From experiment (Belle, BaBar)

OPE

Taking as input (from non τ sources) $m_s(m_\tau) = 100 \pm 10 \ \mathrm{MeV}$:

$$\delta R^{00}_{\tau,\mathrm{th}} = 0.216\ (16) \quad \Rightarrow \quad \boxed{\left|V_{us}\right| = 0.2212 \pm 0.0031_{\mathrm{exp}} \pm 0.0005_{\mathrm{th}}}$$

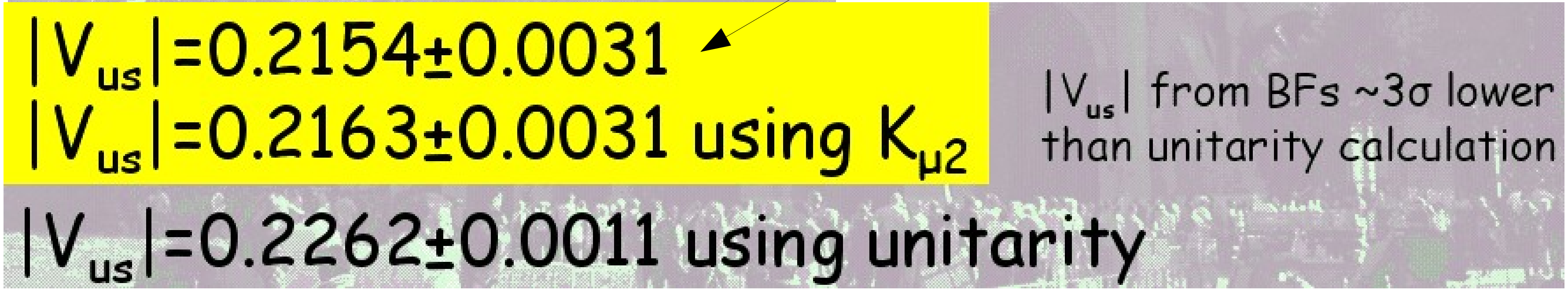
hadronic tau decays (R. Kass)
newer results



mode	B_{WA2007} (%)
$\tau^- \to K^- \nu$	0.691±0.023 (measured) *0.715±0.003 ($K_{\mu 2}$)*
$\tau^- \to K^- \pi^0 \nu$	0.426±0.016
$\tau^- \to \bar{K}^0 \pi^- \nu$	0.831±0.028 (S=1.3) → 0.835±0.022
$\tau^- \to K^- \pi^0 \pi^0 \nu$	0.058±0.024
$\tau^- \to \bar{K}^0 \pi^- \pi^0 \nu$	0.360±0.040
$\tau^- \to K^- \pi^- \pi^+ \nu$	0.280±0.016 (S=1.9)
$\tau^- \to K^- \eta \nu$	0.0160±0.002
$\tau^- \to (\bar{K}^0 3\pi)^- \nu$	0.074±0.030 estimated
$\tau^- \to K_1(1270)\nu \to K^- \omega \nu$	0.067±0.021
$\tau^- \to (\bar{K}^0 4\pi)^- \nu$	0.011±0.007 estimated
$\tau^- \to K^{*-} \eta \nu$	0.12±0.004 (S=2)
$\tau^- \to K^- \phi \nu$	0.00370±0.00025
TOTAL	2.830±0.074 → 2.834±0.074 *2.854±0.071($K_{\mu 2}$)* → 2.858±0.071

That's quite low;
Pich's update agrees:

$$|V_{us}|_{\mathrm{NEW}} = 0.2165 \pm 0.0026_{\mathrm{exp}} \pm 0.0005_{\mathrm{th}}$$



$|V_{us}|=0.2154±0.0031$

$|V_{us}|=0.2163±0.0031$ using $K_{\mu 2}$

$|V_{us}|$ from BFs ~3σ lower than unitarity calculation

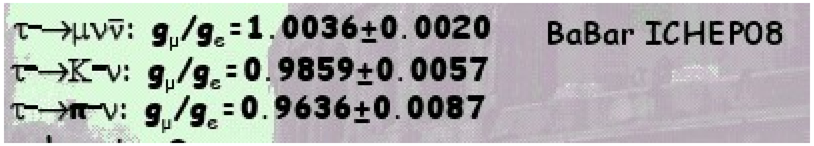
$|V_{us}|=0.2262±0.0011$ using unitarity

$$\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)} = \frac{f_K^2}{f_\pi^2}\frac{|V_{us}|^2}{|V_{ud}|^2}\frac{(1-m_K^2/m_\tau^2)^2}{(1-m_\pi^2/m_\tau^2)^2}$$

$|V_{us}|=0.2255±0.0023$

leptonic tau decay

but: individual rates not compatible with universality:



$\tau^- \to \mu \nu \bar{\nu}$: $g_\mu/g_e=1.0036±0.0020$

$\tau^- \to K^- \nu$: $g_\mu/g_e=0.9859±0.0057$

$\tau^- \to \pi^- \nu$: $g_\mu/g_e=0.9636±0.0087$

BaBar ICHEP08

OK, we don't see a unitarity violation (excluding for now tau decays),
but what can we learn from this?
Constraints from the first row

Marciano: one can constrain

Heavy New Quark or Lepton Mixing, W_R, W*(extra dim.), Leptoquarks, Z', Supersymmetry, Scalars, Exotic Muon Decays….

e.g. Scalar coupling:

$$\left|\frac{V_{us}(K_{\ell 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\ell 2})}\right| \overset{?}{=} \left|1 - \frac{m_{K^+}^2}{M_{H^+}^2}\left(1 - \frac{m_d}{m_s}\right)\frac{\tan^2\beta}{1+\epsilon_0 \tan\beta}\right|$$

Constraints from the first row – is the Fermi constant universal? (W. Marciano)

assuming CKM-unitarity

CKM Unitarity: $G_F^{CKM}=1.166079(409)\times 10^{-5}\,\text{GeV}^{-2}$

Various Fermi Constants

$G_F \times 10^5\,\text{GeV}^2$	Input
1.166371(6)	Muon Lifetime
1.166079(409)	CKM Unitarity
1.165600(1100)	α, m_W, $\sin^2\theta_W(m_Z)_{MS}$ → S=0.08(11)
1.166202(1400)	$\Gamma(Z\to l^+l^-)$, $\sin^2\theta_W(m_Z)_{MS}$ → T=-0.02(15)
1.167071(2600)	$\Gamma(\tau\to e\nu\nu)$
1.166954(2700)	$\Gamma(\tau\to \mu\nu\nu)$
etc.	

No Deviation

No Sign of "New Physics"

Current precision of unitarity test allows for constraints,

- e.g. exotic muon decay BR=0.0005(7) allowed <u>$\leq$0.0015</u> (90%CL)
- heavy quark mixing $V_{uD} \leq 0.04$

If A.J. screwed up with $f_+(0)$ ...

What If $V_{us} \approx 0.218(2)$ (tau decays, $f_+(0)$ of χ Pert. Th.)?
$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9963(11)$ 3.4sigma deviation

More Interesting-Potential Future 4-5 sigma!

With improvements in $f_+(0)$, f_k/f_π, <u>tau exp</u>.

<u>Then pick your favorite “New Physics”</u>

Further tests with Kaon decays

Further tests with Kaon decays (T. Spadaro)

$R_{e\mu} = \Gamma(K_{e3})/\Gamma(K_{\mu3}) \to G_F^{e}/G_F^{\mu}$,

Test of lepton universality for weak vector currents

Result, $g_\mu^2/g_e^2 = 1.0043(52)$, comparable w $g_\mu^2/g_e^2(\tau)=0.9998(40)$

$R_{K\pi} = \Gamma(K \to \mu\nu)/\Gamma(\pi \to \mu\nu)$,

Test for H^+ exchange (scalar) or presence of right-handed currents

$R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$

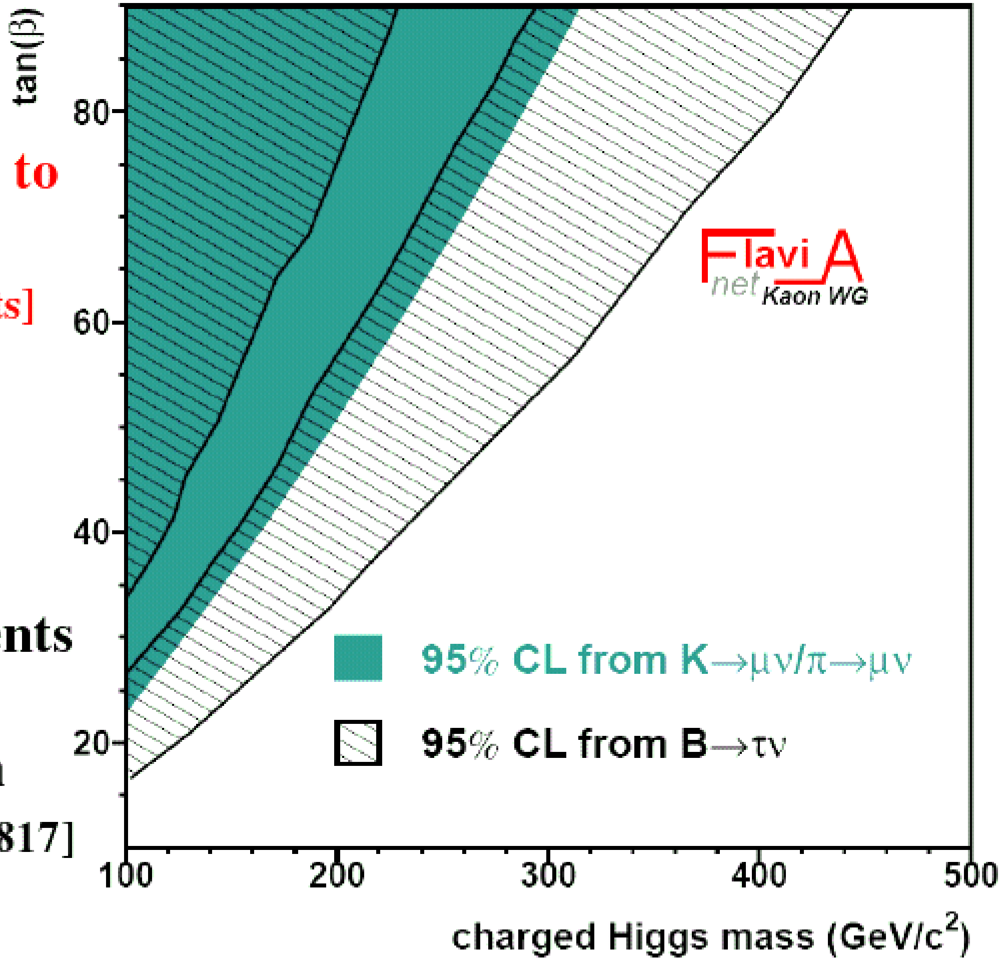
Test for LFV due to effective pseudoscalar weak currents

Scenario e.g. contribution from additional scalar current:

$$\left|\frac{V_{us}(K_{\ell2})}{V_{us}(K_{\ell3})}\times\frac{V_{ud}(0^+\to 0^+)}{V_{ud}(\pi_{\ell2})}\right| \overset{?}{=} \left|1-\frac{m_{K^+}^2}{M_{H^+}^2}\left(1-\frac{m_d}{m_s}\right)\frac{\tan^2\beta}{1+\epsilon_0\tan\beta}\right|$$

Further tests with Kaons (T. Spadaro)

Result is: $$\left|\frac{V_{us}(K_{\ell 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\ell 2})}\right| = 1.0028(74)$$



NP sensitivity from K→ μν comparable to that from BR(B → τν) = 1.42(44)×10^{-4}

[Babar-Belle avg, update expected from new results]

Error dominated by theoretical uncertainties in form factors

NP induced by weak right-handed currents can be also tested (there, complement lattice information with Callan-Treiman scalar ff constraint) [FlaviaNet arXiv:0801.1817]

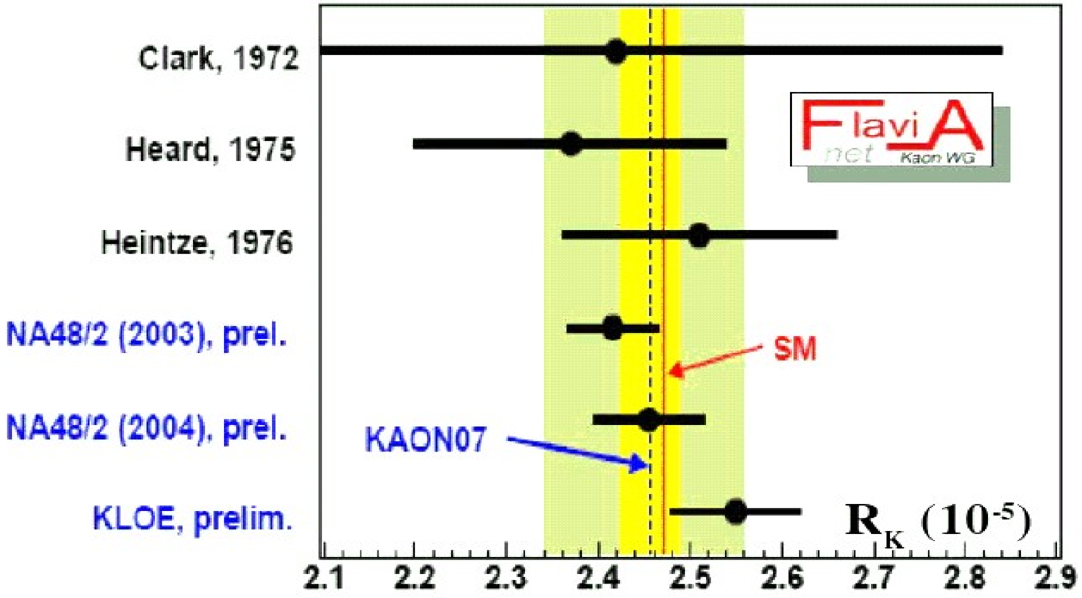
Also interesting, theory much better than experiment and currently agreement (T. Spadaro):

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

KLOE, NA48/2 and NA68 working hard to push uncertainty down to 1% level
SM: Cirigliano and Rossel: $2.477(1)x10^{-5}$

Recent (preliminary) results improved greatly with respect to 2006 PDG

World average, $R_K = 2.457(32)\times 10^{-5}$, agrees with SM

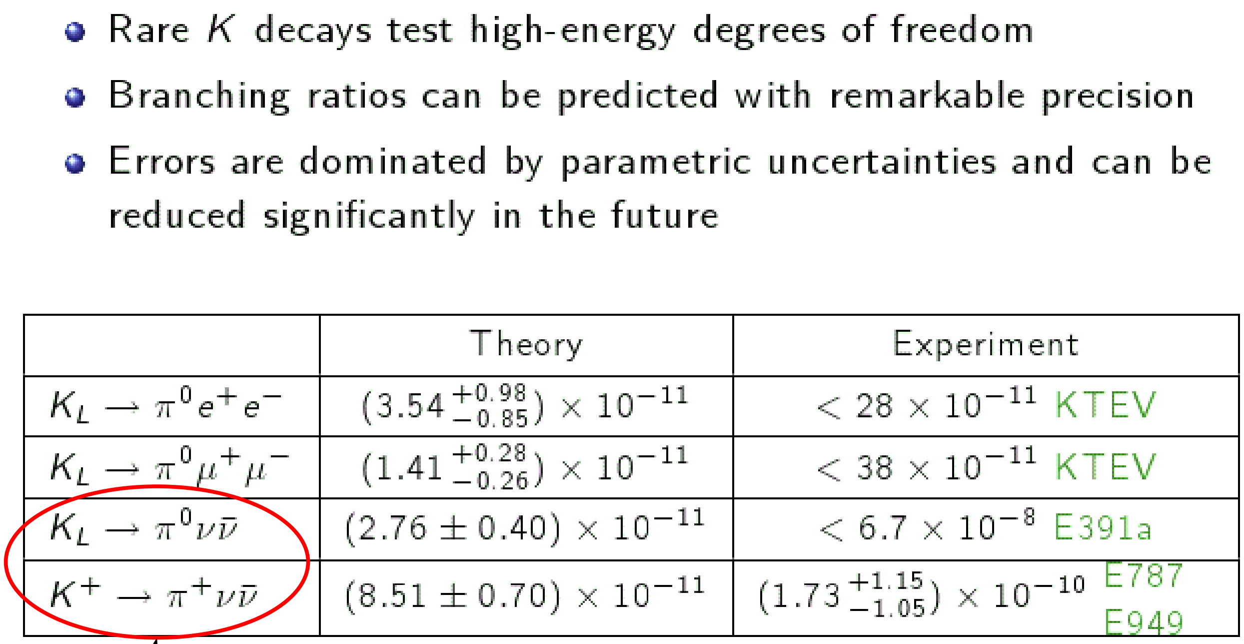


Huge effort to enter the precision realm for R_K:

- **KLOE expects to push error @ ~1.3%, after analysis completion**
- **NA62 dedicated 2007 run aims at reaching <0.5% error**

Rare decays of Kaons

Rare Kaon decays in the SM (J. Brod)



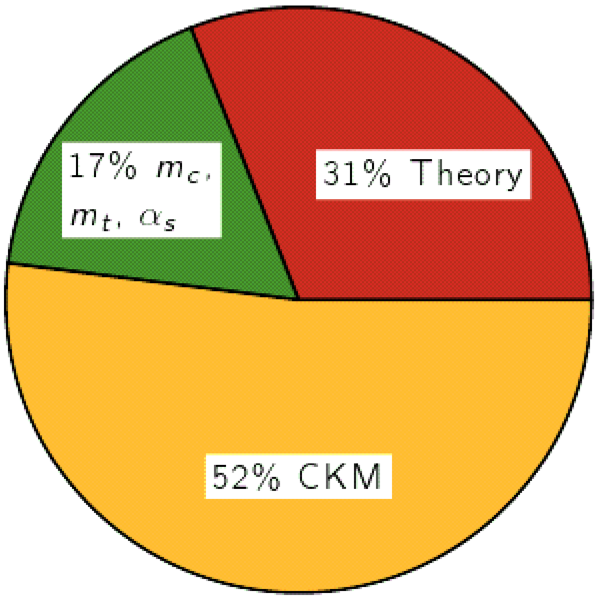
- Rare K decays test high-energy degrees of freedom
- Branching ratios can be predicted with remarkable precision
- Errors are dominated by parametric uncertainties and can be reduced significantly in the future

	Theory	Experiment
$K_L \to \pi^0 e^+ e^-$	$(3.54^{+0.98}_{-0.85}) \times 10^{-11}$	$< 28 \times 10^{-11}$ KTEV
$K_L \to \pi^0 \mu^+ \mu^-$	$(1.41^{+0.28}_{-0.26}) \times 10^{-11}$	$< 38 \times 10^{-11}$ KTEV
$K_L \to \pi^0 \nu\bar{\nu}$	$(2.76 \pm 0.40) \times 10^{-11}$	$< 6.7 \times 10^{-8}$ E391a
$K^+ \to \pi^+ \nu\bar{\nu}$	$(8.51 \pm 0.70) \times 10^{-11}$	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$ E787 E949

short distance dominated

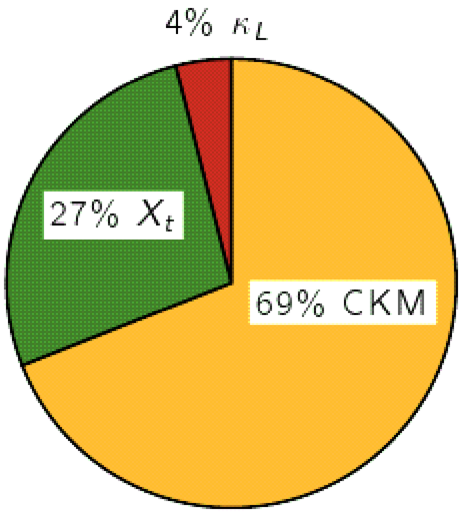
Sozzi: The holy grail - “Theoretical heaven and experimental hell”

SM error budget (J. Brod)



$K^+ \to \pi^+ \nu\bar{\nu}$

- Error dominated by CKM elements
- Theory error can still be reduced



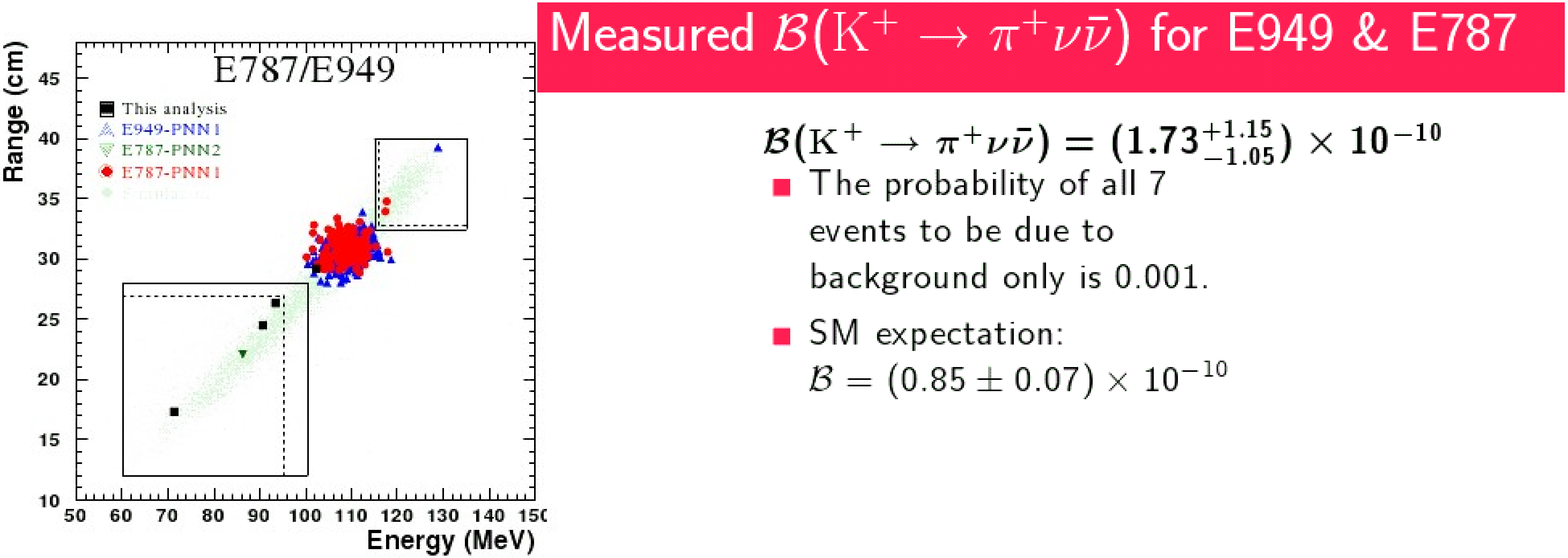
$K_L \to \pi^0 \nu\bar{\nu}$

- Mainly parametric uncertainties
- Electroweak corrections to X_t

$$B^{\text{theo}}\left(K_L \to \pi^0 \nu\bar{\nu}\right) = (2.76 \pm 0.40) \times 10^{-11}$$

$$B^{\text{exp}}\left(K_L \to \pi^0 \nu\bar{\nu}\right) < 6.7 \times 10^{-8}$$ [E391a '08]

Experimental results (D. Jaffe)

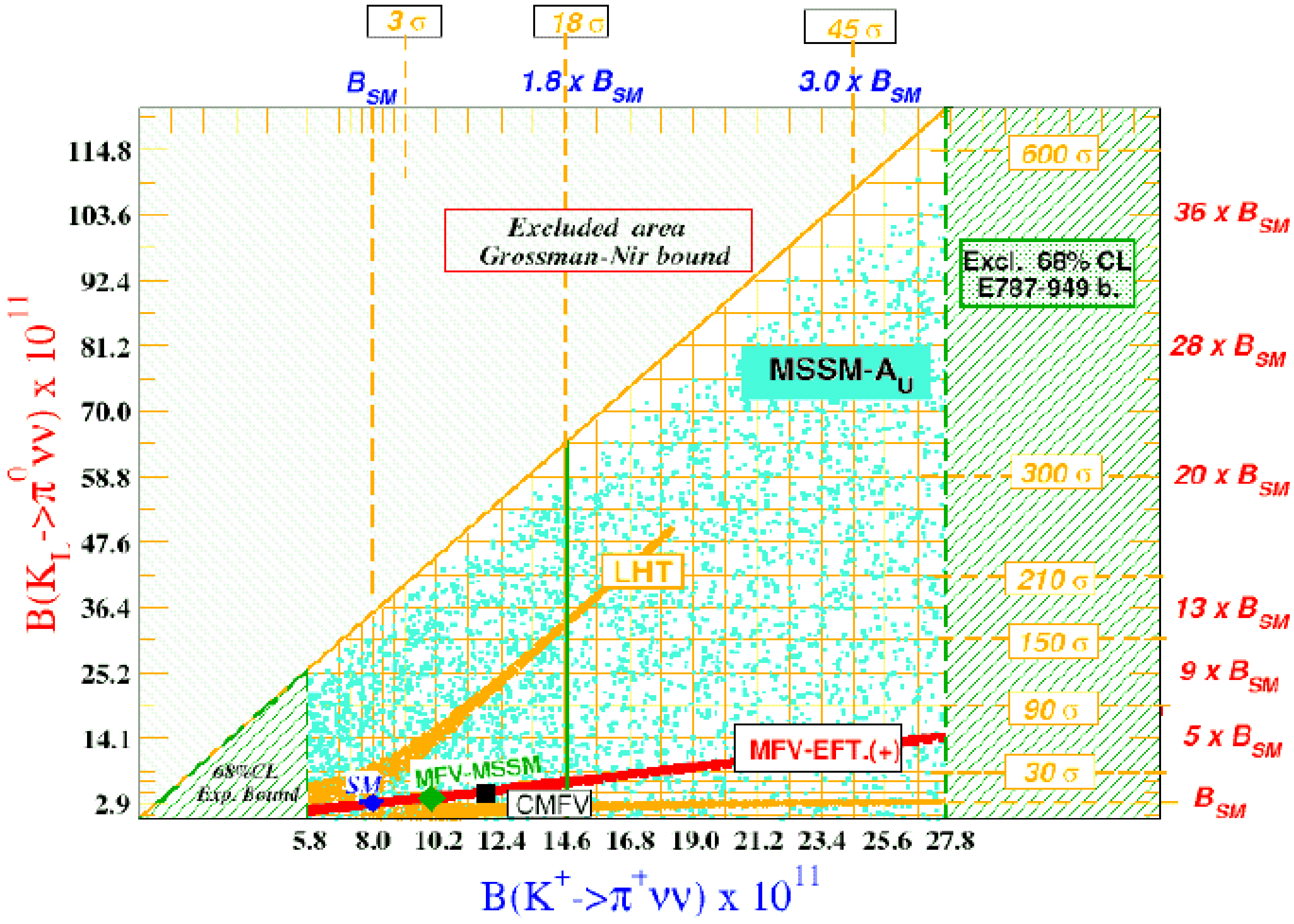


Measured $\mathcal{B}(\mathrm{K}^+ \to \pi^+\nu\bar{\nu})$ for E949 & E787

$$\mathcal{B}(\mathrm{K}^+ \to \pi^+\nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$

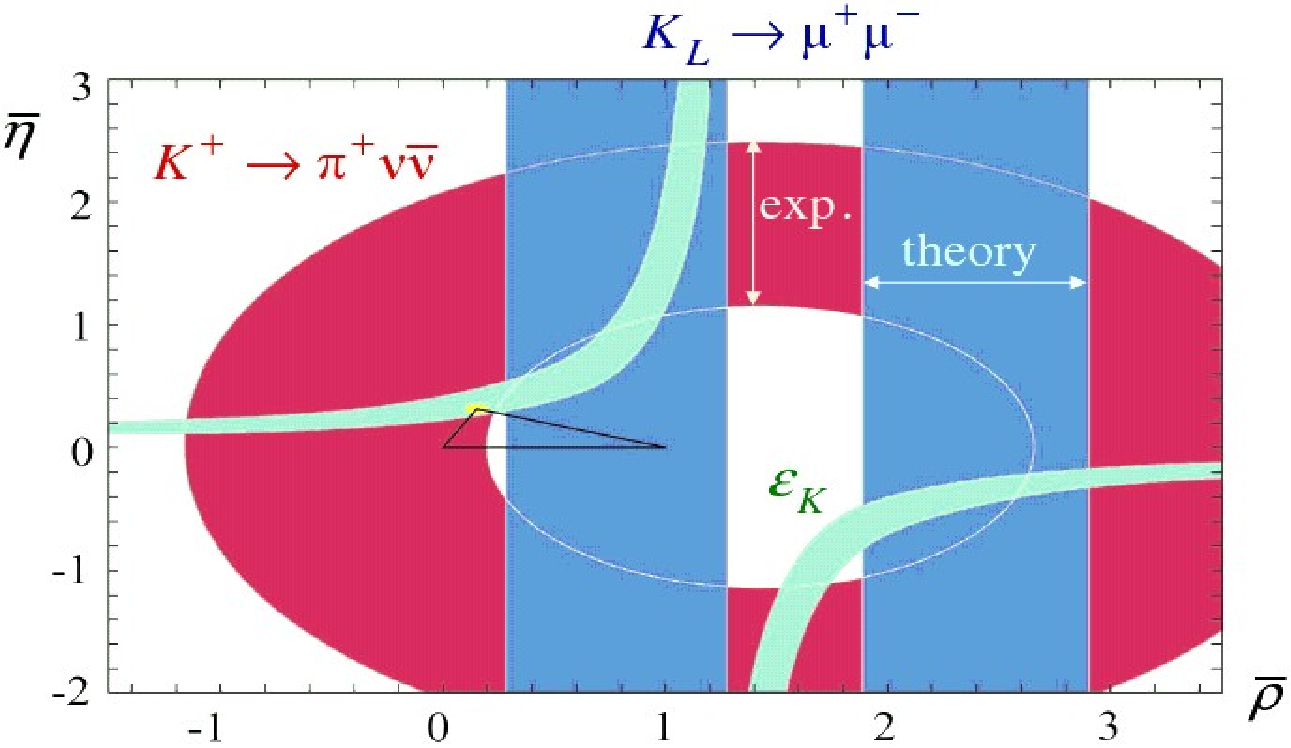
- The probability of all 7 events to be due to background only is 0.001.
- SM expectation: $\mathcal{B} = (0.85 \pm 0.07) \times 10^{-10}$

- $K \to \pi\nu\bar{\nu}$: best probe, and their correlation tests various possible models



Mescia '06

Constrain CKM triangle with Kaon input only (C. Smith)

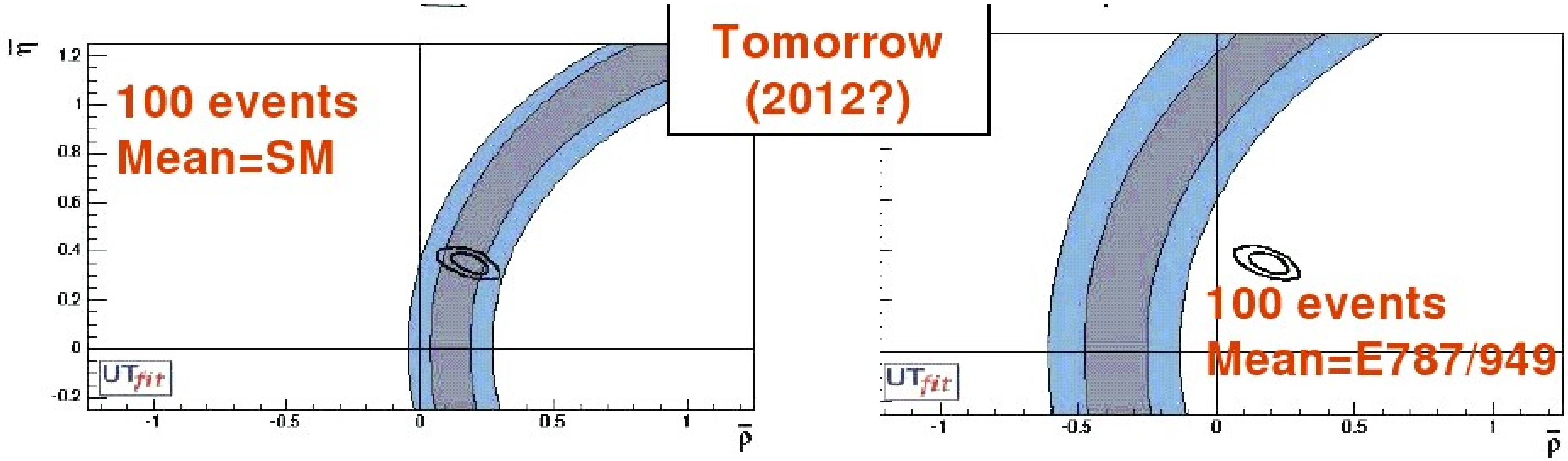


$K_L \to \pi^0 \nu\bar{\nu}$:
$\bar{\eta} < 17$

$K_L \to \pi^0 e^+ e^-$:
$\bar{\eta} < 3.3$

$K_L \to \pi^0 \mu^+ \mu^-$:
$\bar{\eta} < 5.4$

A (optimistic) look into the future – future experimental bound (M. Sozzi):



Ongoing and future experiments will tell us

C. Smith (slide) and M. Sozzi:

1- $K \to \pi\nu\bar{\nu}$ *and* $K_L \to \pi^0 \ell^+ \ell^-$ *decays are unique windows into the* $s \to d$ *sector.*

Essential to constrain (and discriminate among) New Physics models.

2- Still, *do not forget* $K_L \to \mu^+\mu^-$, the only mode measured with precision.

Further theoretical work would be much welcome on the two-photon contribution.

3- *Message to experimentalists*: Go for the $K \to \pi\nu\bar{\nu}$ modes, they are the cleanest,

But do not disregard other modes:

$K_L \to \pi^0 \ell^+ \ell^-$: Sensitive to a larger class of NP effects

$K_S \to \pi^0 \ell^+ \ell^-, K_L \to \pi^0 \gamma\gamma, K_{\ell 3}$: Theoretical control for rare K decays

$K_S \to \pi^0 \gamma\gamma, K^+ \to \pi^+ \gamma\gamma$: Theoretical control over $K_L \to \mu^+\mu^-$

$K \to (\pi) e\mu$: Probably too small, but one never knows...

Summary

- first row unitarity confirmed: $1-V_{ud}^2-V_{us}^2 = 0.00003(60)$

- best determination currently from
  - Vud – nuclear beta decay
  - Vus – Kl3 exp. lattice
    (though Kl2 on the lattice is catching up)
  - tau decay for Vus on the low side

- lattice QCD:
  - many collaborations are computing observables (Kl2 and Kl3, independent results)
  - close to physical point, so systematics better under control
  - tests of ChiPT

- precision in first row unitarity test allows for constraints on NP
  (but bear in mind destructive interference)

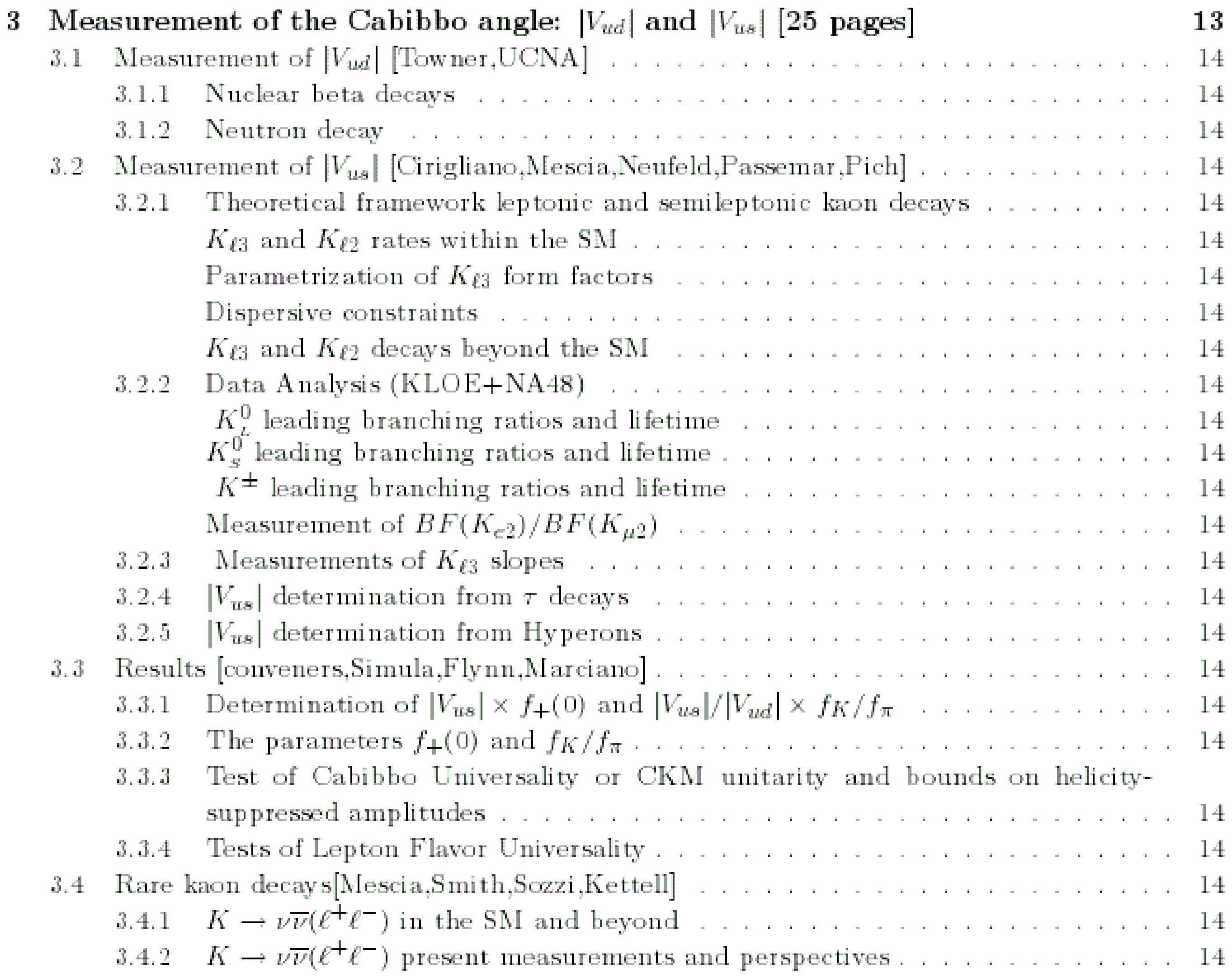
- tests of lepton flavour violation and scalar couplings from leptonic K-decays
  will soon become better (experiment)

- theory fine for discussed rare decays – have to wait experiments

Status of the book

THE BOOK – a prelim outline

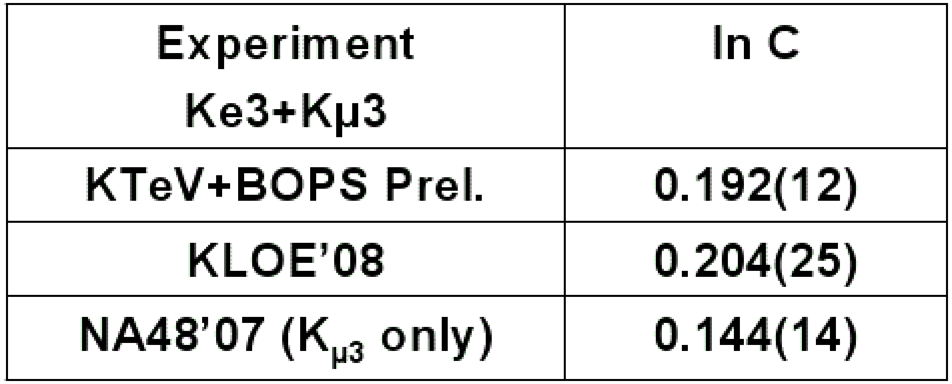
In the introductory part: primers on OPE, lattice, generic fromulas



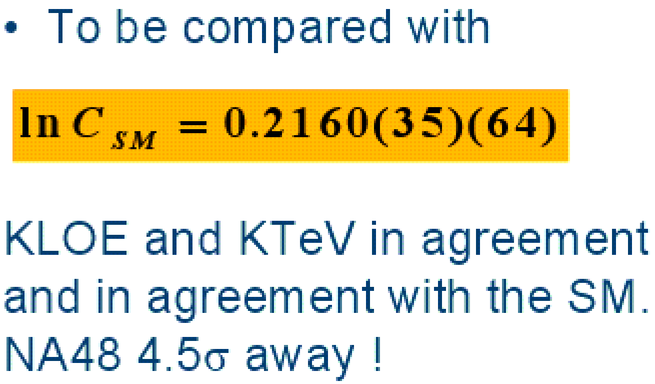
- introductory part
- lead authors determined
- ~4 pages per sub-topic

Thank you for your attention!

An aside: result of the dispersive fit (E. Passemar):



Experiment Ke3+Kμ3	ln C
KTeV+BOPS Prel.	0.192(12)
KLOE'08	0.204(25)
NA48'07 ($K_{\mu3}$ only)	0.144(14)



- To be compared with

$$\ln C_{SM} = 0.2160(35)(64)$$

KLOE and KTeV in agreement and in agreement with the SM. NA48 4.5σ away !

If discrepancy eventually manifest, interpretation as BSM

Callan-Treimann Theorem (E. Passemar)

Callan-Treiman Theorem: SU(2) x SU(2) theorem

$$\boxed{C = \overline{f_0}(\Delta_{K\pi}) = \frac{F_K}{F_\pi f_+^{K^0}(0)} + \Delta_{CT}}$$

$$\Delta_{K\pi} = m_K^2 - m_\pi^2$$

Test of SM:

$$C_{SM} = \overline{f}_0(\Delta_{K\pi}) = \underbrace{\frac{F_K |V_{us}|}{F_\pi |V_{ud}|} \frac{1}{f_+(0) |V_{us}|} |V_{ud}|}_{B_{exp}} + \Delta_{CT}$$

C is predicted in the Standard Model using the measured Br:

$Br(K_{l2}/\pi_{l2})$, $\Gamma(K_{e3})$ and $|V_{ud}|$. ($|V_{us}|$ not needed in this prediction.)

⇨ $\boxed{B_{exp} = 1.2446 \pm 0.0041}$ $\ln C_{SM} = 0.2188(35) + \Delta_{CT}$