Summary of WG I

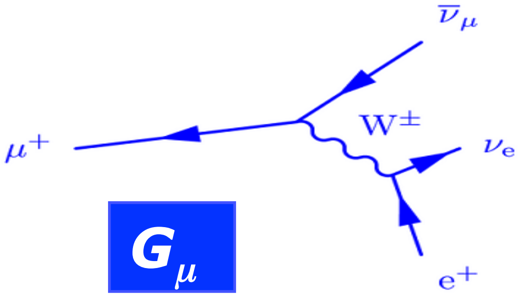
Tommaso Spadaro LNF INFN

Prepared together with **Albert Young and Federico Mescia**

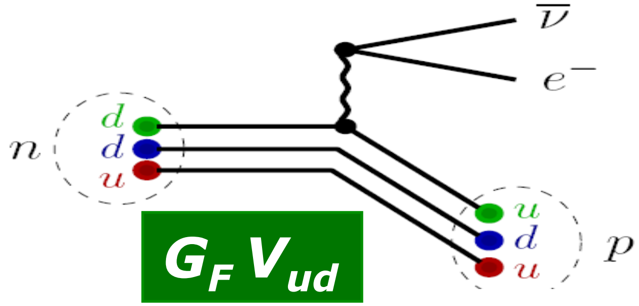
Thanks to all the speakers and the organizers

CKM 2010, September 6th-10th, Warwick, UK

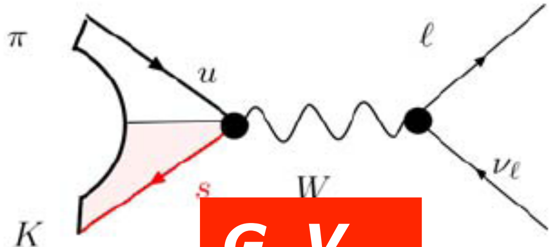
1) Tree-level mediated decays -> *CKM unitarity => High Precision SM tests*



G_μ



$G_F V_{ud}$



$G_F V_{us}$

+

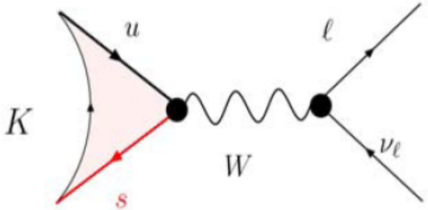
P. Debevic

D. Melconian, I. Towner, B. Maerkerich, A. Juttner, W. Marciano

A.Juttner, A. Ramos, R. Escribano, K. Maltman, M. Veltri, E. De Lucia, B. Sciascia

2) Lepton Universality test --> *sensitivity to the Higgs sector*

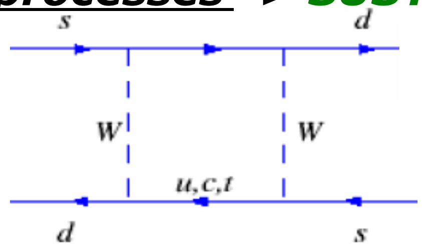
$K \to e\nu / K \to \mu\nu$



C. Lazzeroni

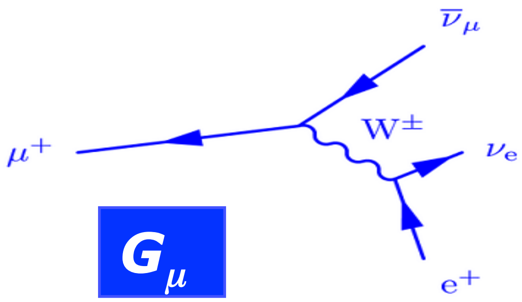
3) *FCNC processes* -> *SUSY, Little Higgs ....*

$+\varepsilon_K$



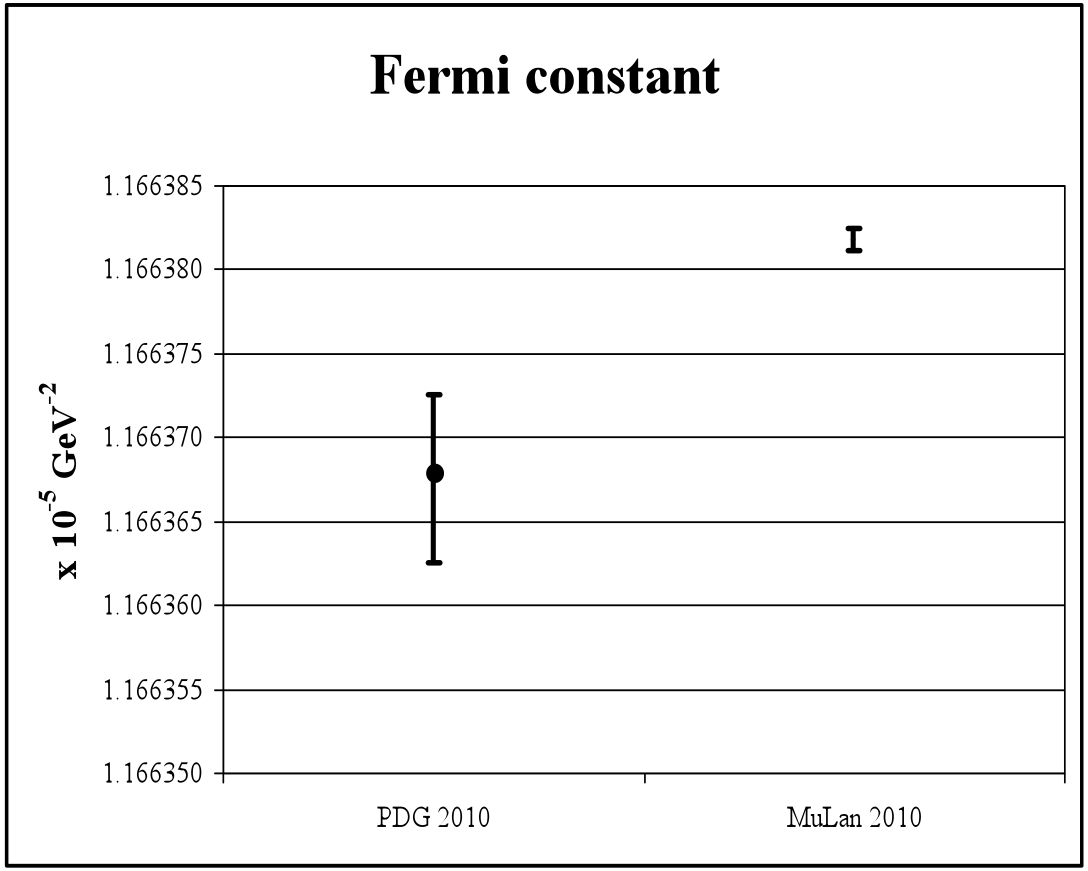
D. Guadagnoli, P. Dimopoulos

New and final MuLan result for μ lifetime



Final result after analysis of 2006-7 data sets

Impact on G_μ: the normalization of the Flavor couplings

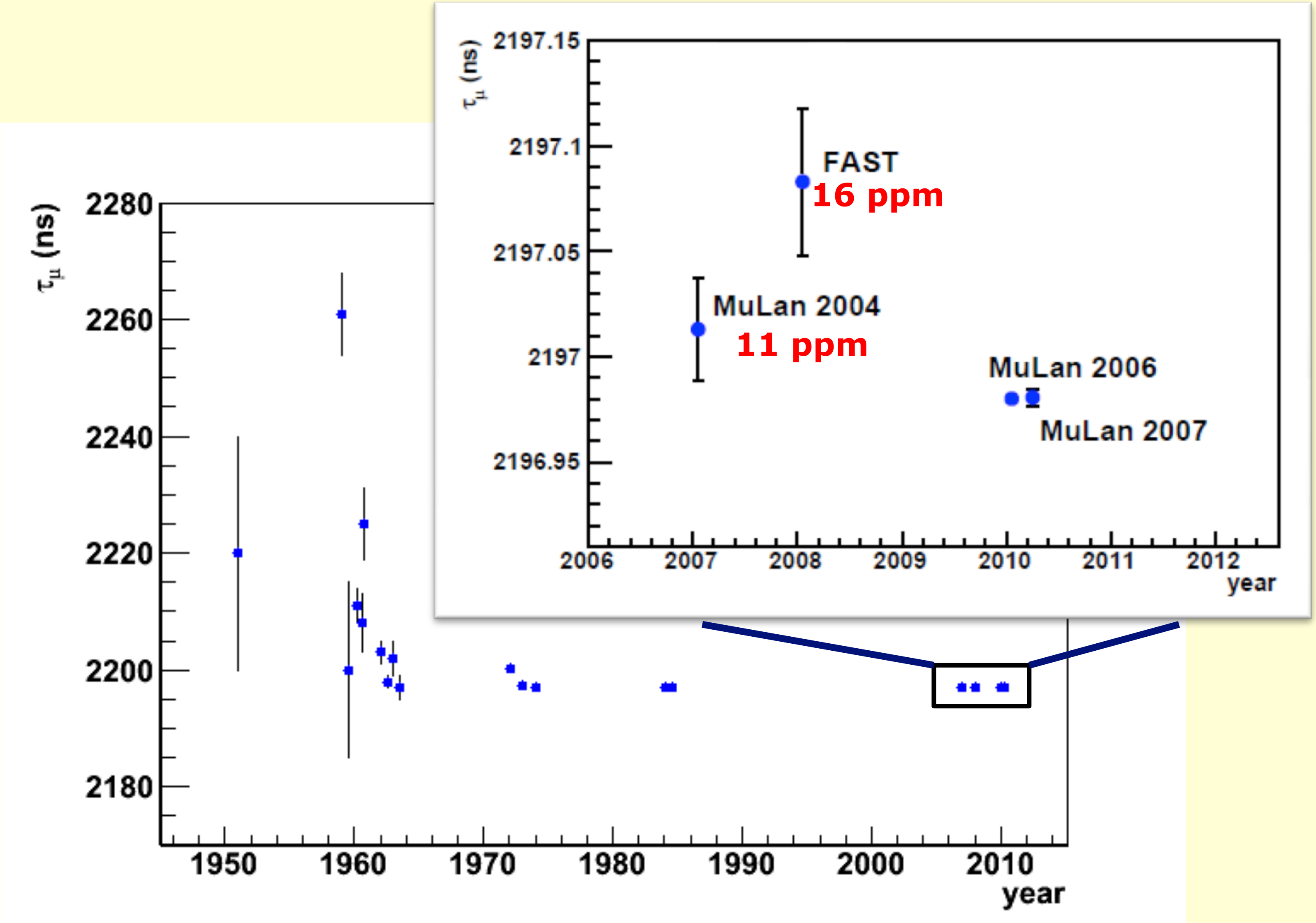


avg: τ_μ = 2196980.3 ± 2.2 ps (1.0 ppm)

G_F = 1.1663818(7) x 10^{-5} GeV^{-2} (0.6 ppm)

See talk by P. Debevic: MuLAN collaboration

μ lifetime measurements, 60 years of history

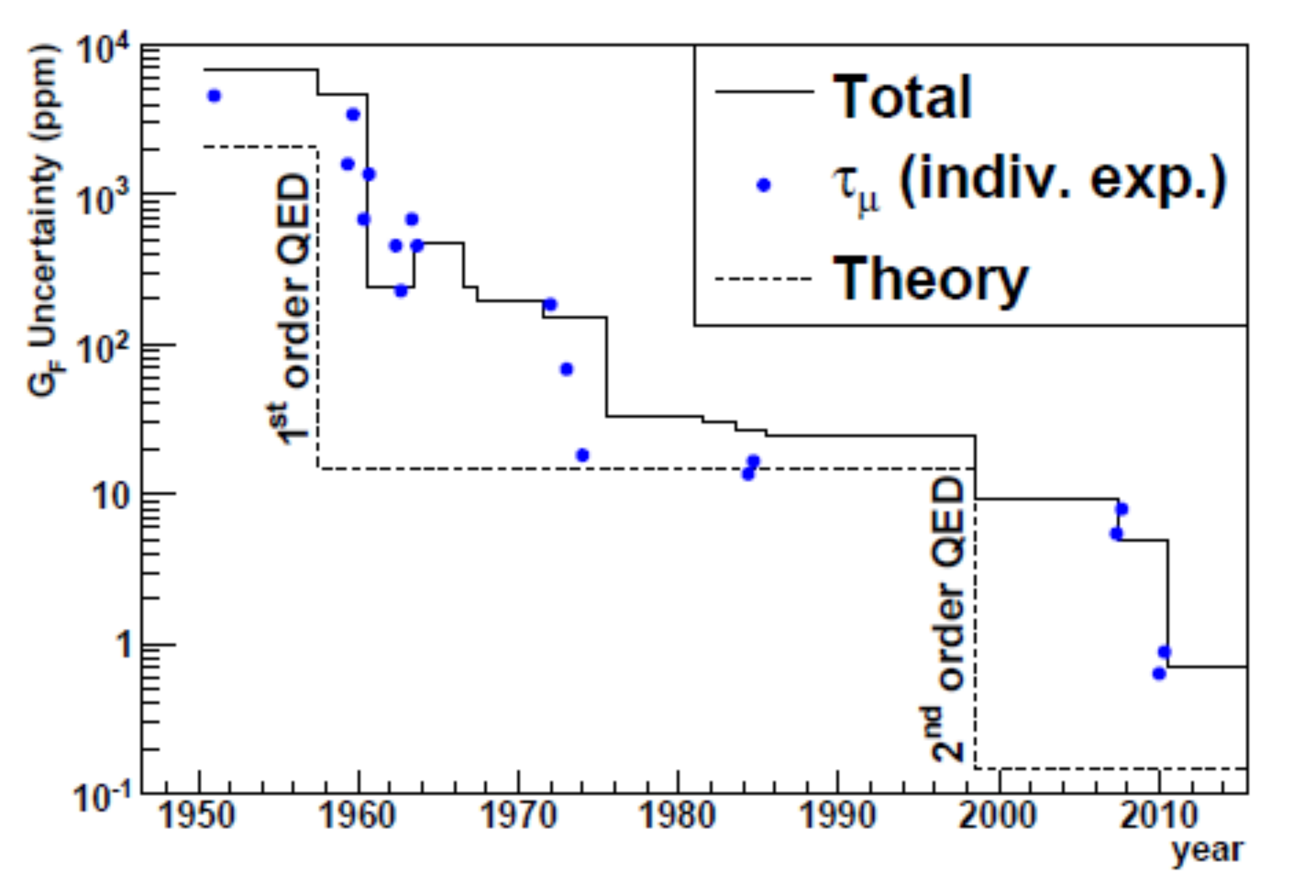


τ_μ: experiment and theory facing each other

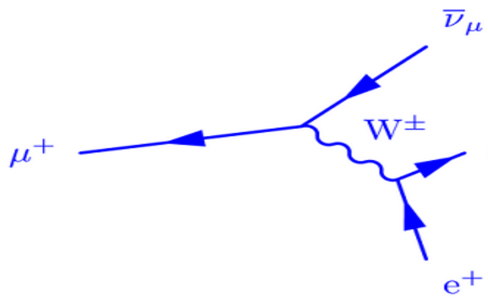
$$\frac{1}{\tau_\mu} = \frac{G_F^{\,2} m_\mu^{\,5}}{192\pi^3}\left(1+\Delta q\right)$$

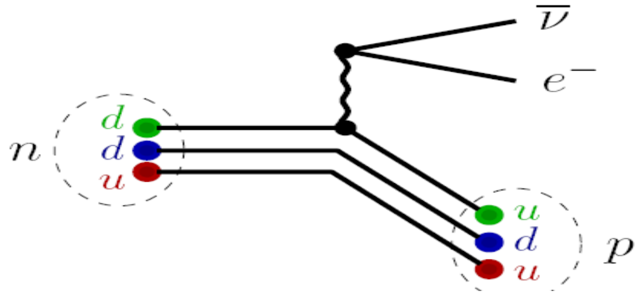
Δq, QED radiative corrections, van Ritbergen & Stuart, Nucl. Phys. B564 (2000) 343

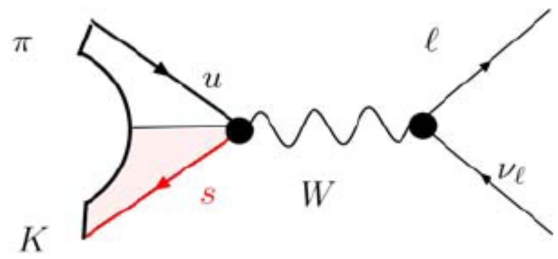
$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8M_W^{\,2}}\left(1+\Delta r\right)$$



Δr, weak interaction loop corrections







G_μ

$G_F V_{ud}$

$G_F V_{us}$

P. Debevic:
MuLAN

D. Melconian, I. Towner, B. Maerkerich, A. Juttner, W. Marciano

A.Juttner, A. Ramos, R. Escribano, K. Maltman, M. Veltri, E. De Lucia, B. Sciascia

2010: The Status of Lepton/Quark Universality

$\delta V_{ud} / V_{ud} \sim 0.02\%$

$\delta V_{us} / V_{us} \sim 0.5\%$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999(6)$$

Error budget: $0.0004_{Vud} + 0.0004_{Vus}$

V_{ud}

Nuclear β decay: $0^+ \rightarrow 0^+$ $T=1$

Golden modes,

- only vector current (CVC) $\langle p_f; 0^+ | \bar{u}\gamma_\mu d | p_i; 0^+ \rangle = \sqrt{2}(p_i + p_f)_\mu$
- small SU(2) corrections

Neutron β decay: $n \rightarrow p\, l\, \nu$

- Both V and A contribute $\langle p(p_f) | \bar{u}\gamma_\mu d - \bar{u}\gamma_\mu\gamma_5 d | n(p_i) \rangle$
- A extracted by the β-asymmetry measurements (angular correlations)

Nuclear β decay: mirror decays

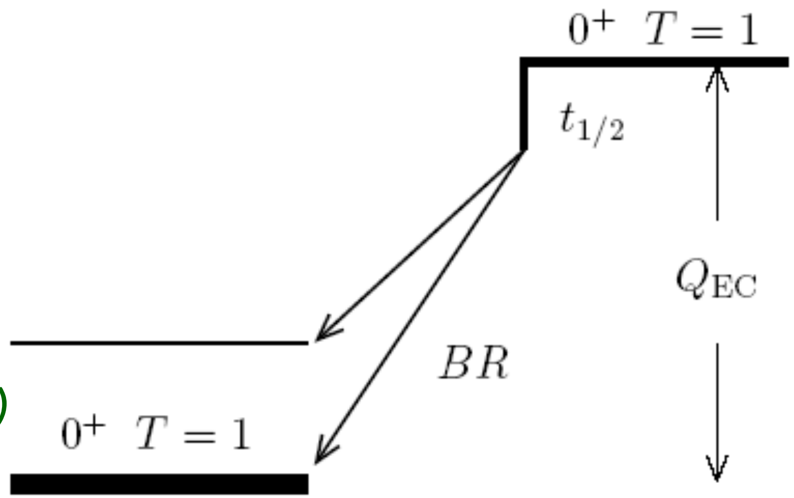
- Like n decay – V & A contribute, need angular correlations
- Recent analysis provides quantitative extraction of V_{ud}

Pion β decay: $\pi^+ \rightarrow \pi^0\, l\, \nu$ $0^-,1 \longrightarrow 0^-,1$

- ✓ only vector current (CVC)
- ✓ but small Br (10^{-8}), experimental error still large and dominating

Nuclear β decay, $0^+ \to 0^+$ transitions with *T=1*

Vud determination involves 3 measurements:



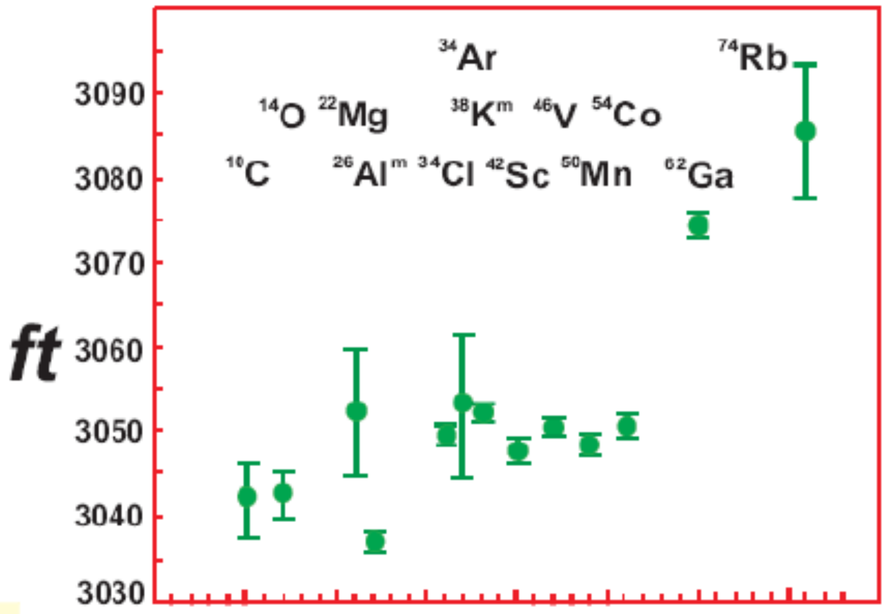
1, the energy gap $Q_{EC} \Rightarrow f$ *(Phase space)*

2, the half life $t_{1/2}$

3, the branching ratio BR

$t_{1/2},\ BR \Rightarrow t$

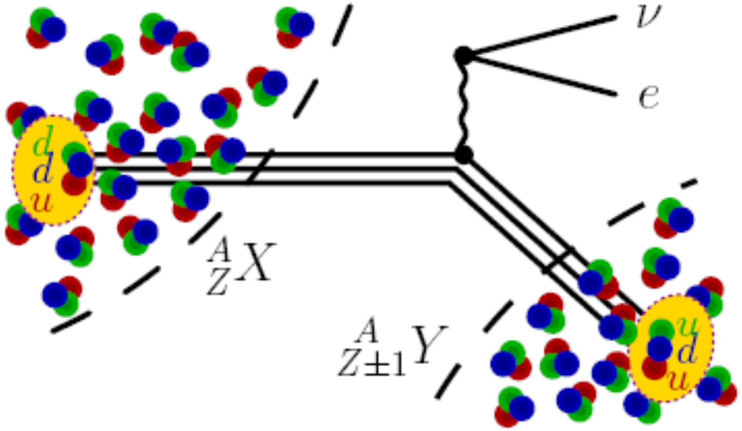
$$ft = \frac{K}{2G_F^2|V_{ud}|^2}$$ should be **constant**



I. I. Towner
II. D. Melconian

Corrected Ft value

We must account for the fact that **the decay occurs within the nuclear medium**



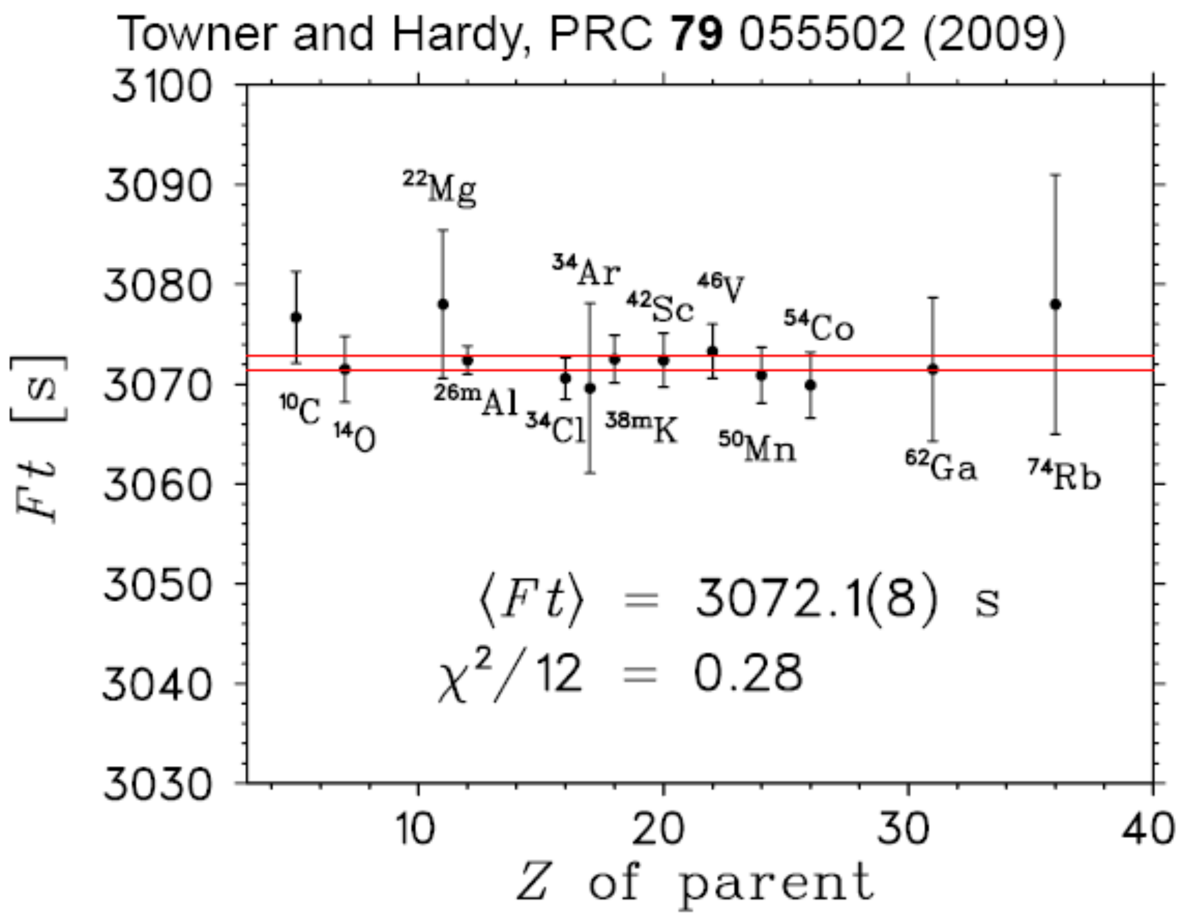
$$\mathcal{F}t \equiv ft\left(1+\delta'_R\right)\left(1+(\delta_{NS}-\delta_C)\right) = \frac{K}{G_F^2|V_{ud}|^2|M_F|^2\left(1+\Delta_R^V\right)}$$

(*really* should be constant)

- δ'_R = $E_e^{\max}$ and Z dependent radiative correction — **~1.5%**
- δ_{NS} = nuclear structure depenedent radiative correction — **0.3-0.7%** (together with δ_C)
- δ_C = isospin symmetry-breaking correction
- Δ_R^V = transition independent radiative correction — **~2.4%**

See talk by D. Melconian

Ft values for $0^+ \rightarrow 0^+$ transitions



corrected $\mathcal{F}t$ values constant to better than **3 parts in 10^4!**

hooray for the conserved vector current hypothesis!

See talk by D. Melconian

Neutron β decay: n-> p l v

$$|V_{ud}|^2 = \frac{(4908.7 \pm 1.9)s}{\tau(1+3\lambda^2)}$$

Marciano , Sirlin PRL 96 (2006)

- Neutron lifetime τ

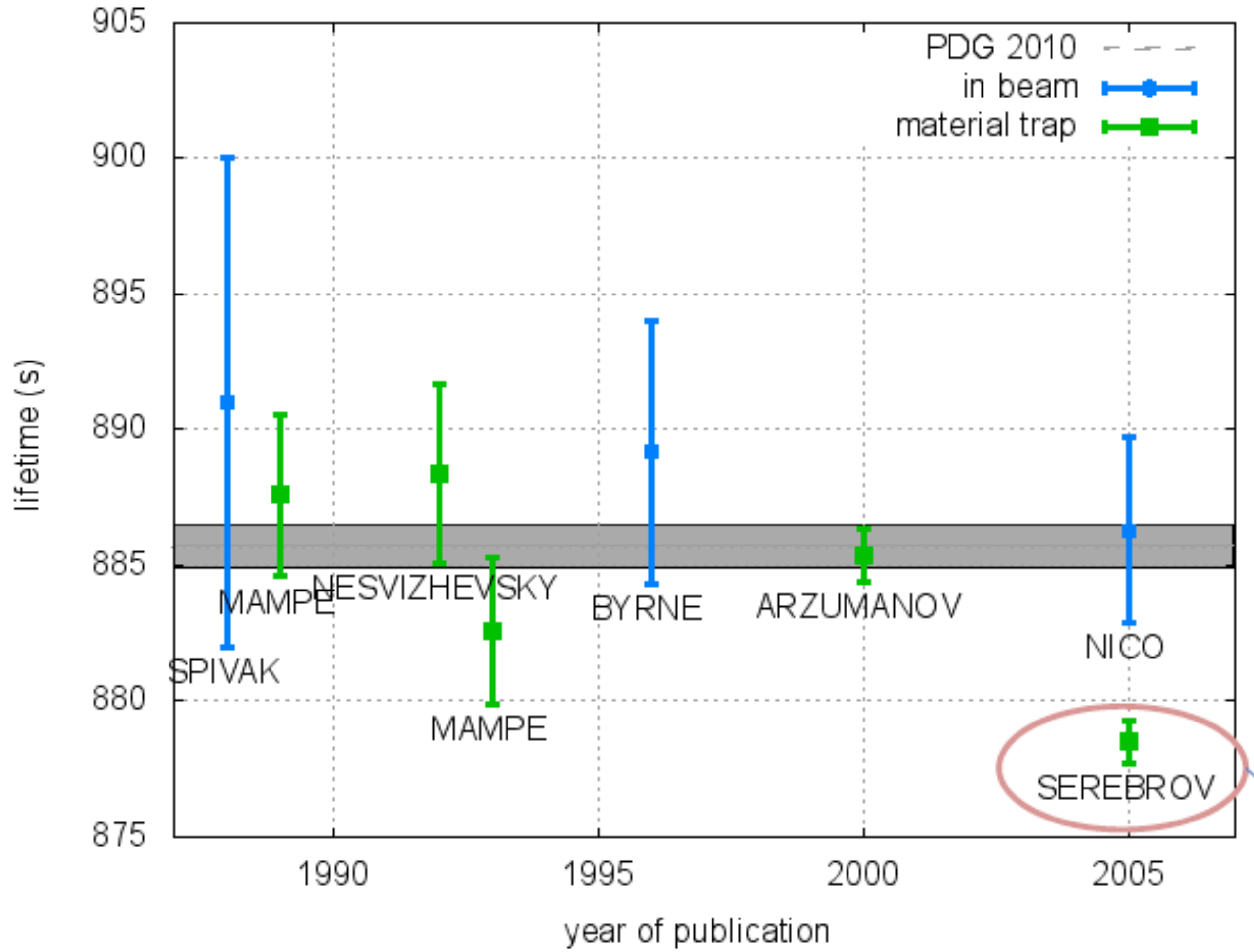
- Ratio of coupling constants

$$\lambda = g_A / g_V$$

from angular correlations

2 experimental inputs

Experimental status of n lifetime (PDG2010)



$$\tau_{PDG} = 885.7\ (8)\mathrm{s}$$

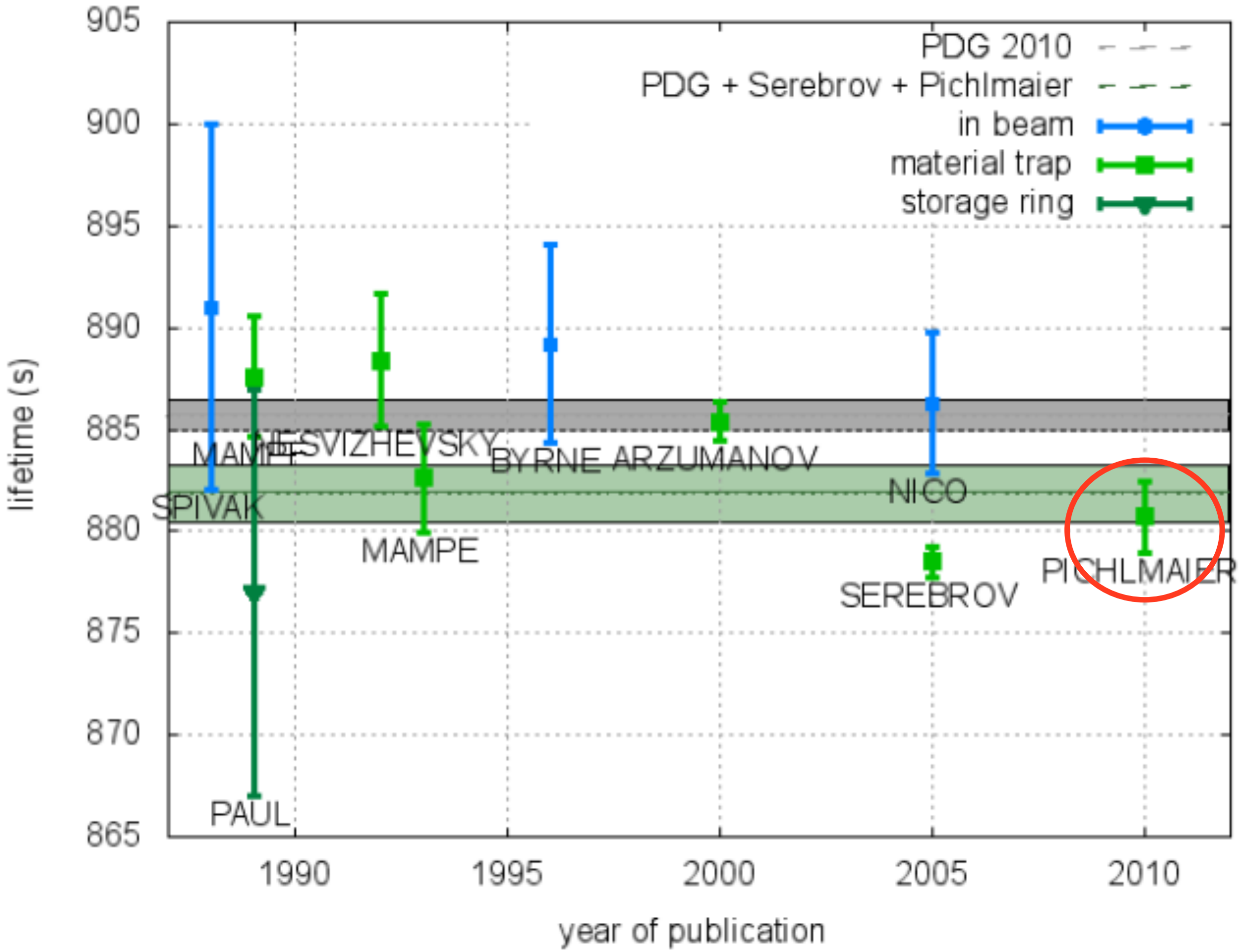
Not considered in average due to 6.5σ deviation from previous average

"Until this major disagreement is understood our present average of 885.7 ± 0.8 s must be suspect." PDG 2010

See talk by B. Märkisch

Status after new result from MAMBO II exp.

Including **all** results with $\delta\tau < 10\text{s}$



$$\tau_{\text{beam}} = 887.6 \pm 2.7\text{s}$$

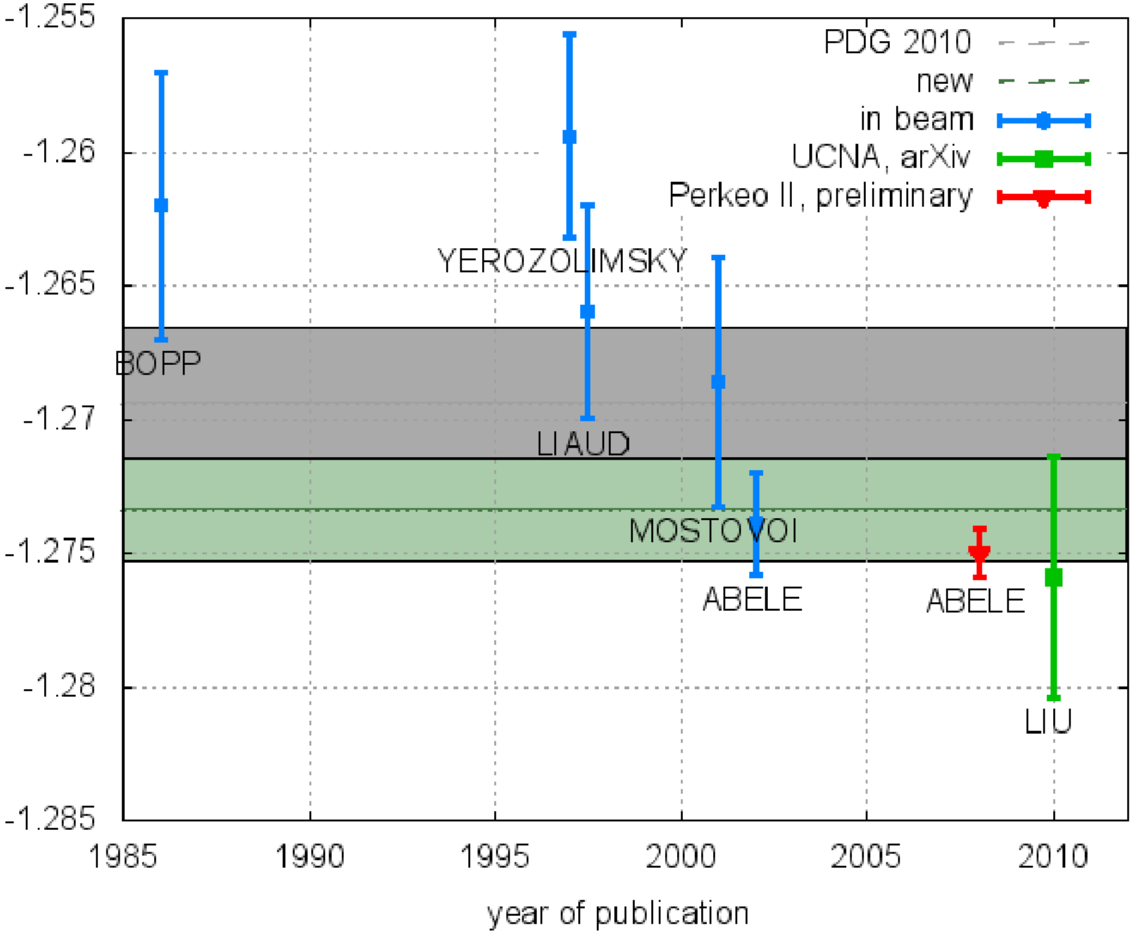
$$\tau_{\text{PDG}} = 885.7 \pm 0.8\text{s}$$

$$\tau_{\text{all}} = 881.8 \pm 1.4\text{s}$$

"Our MAMBO II result makes the PDG2008 present average of the neutron lifetime value even more 'suspect'. To resolve this issue new and improved

See talk by B. Märkisch

Experimental status of $\lambda = g_A/g_V$ after Perkeo II



PDG average:
-1.2694(28), S=2.0

including new data:
-1.2734(19), S=2.3

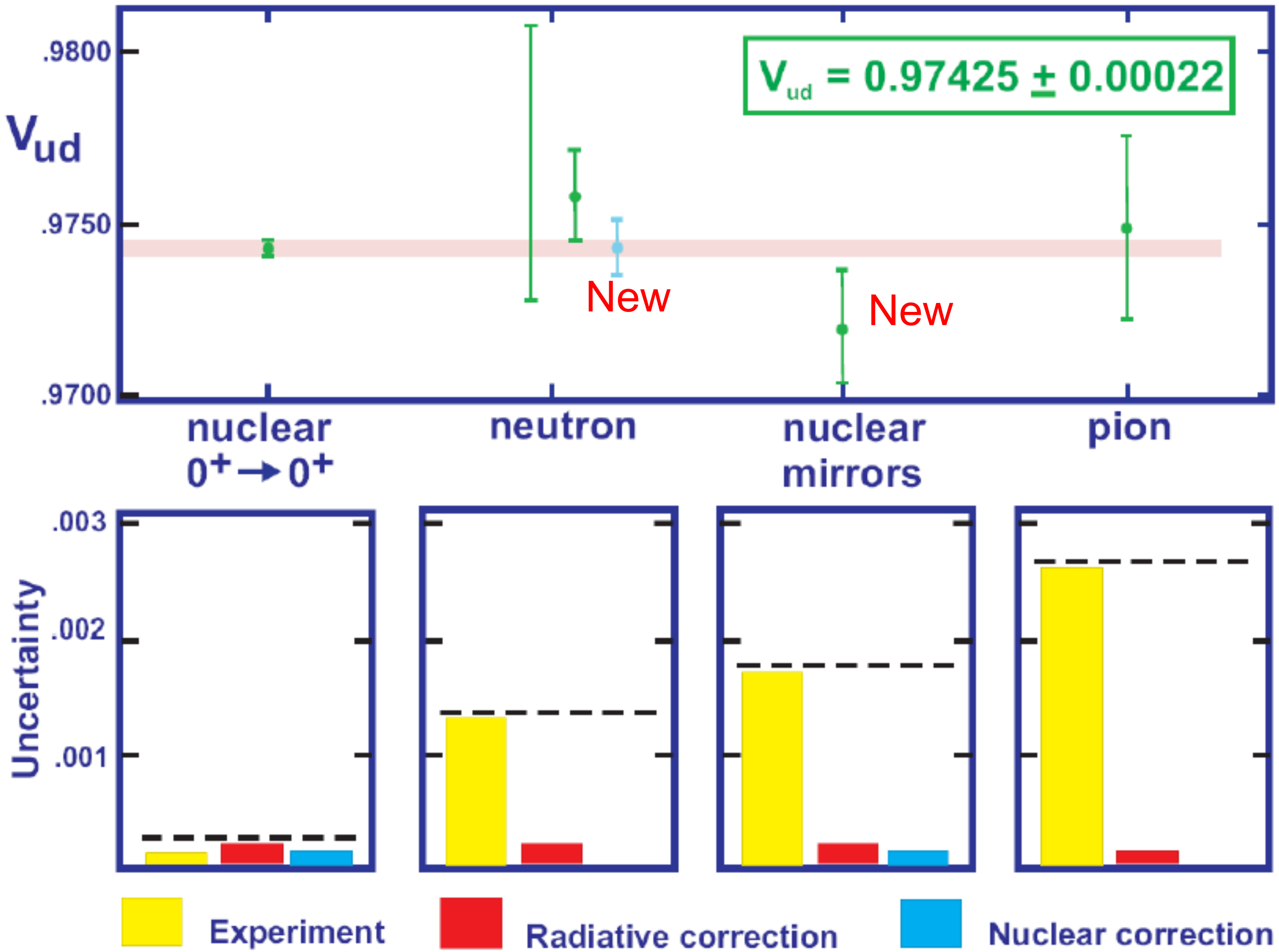
λ_{UCNA} = -1.2759(+41)(-45)

λ_{Perkeo} = -1.2750(9)

New measurements have much smaller **systematic corrections** on A of O(1%) (Perkeo II, UCNA)

See talk by B. Märkisch

Current status of V_{ud}



See talk by I. S. Towner

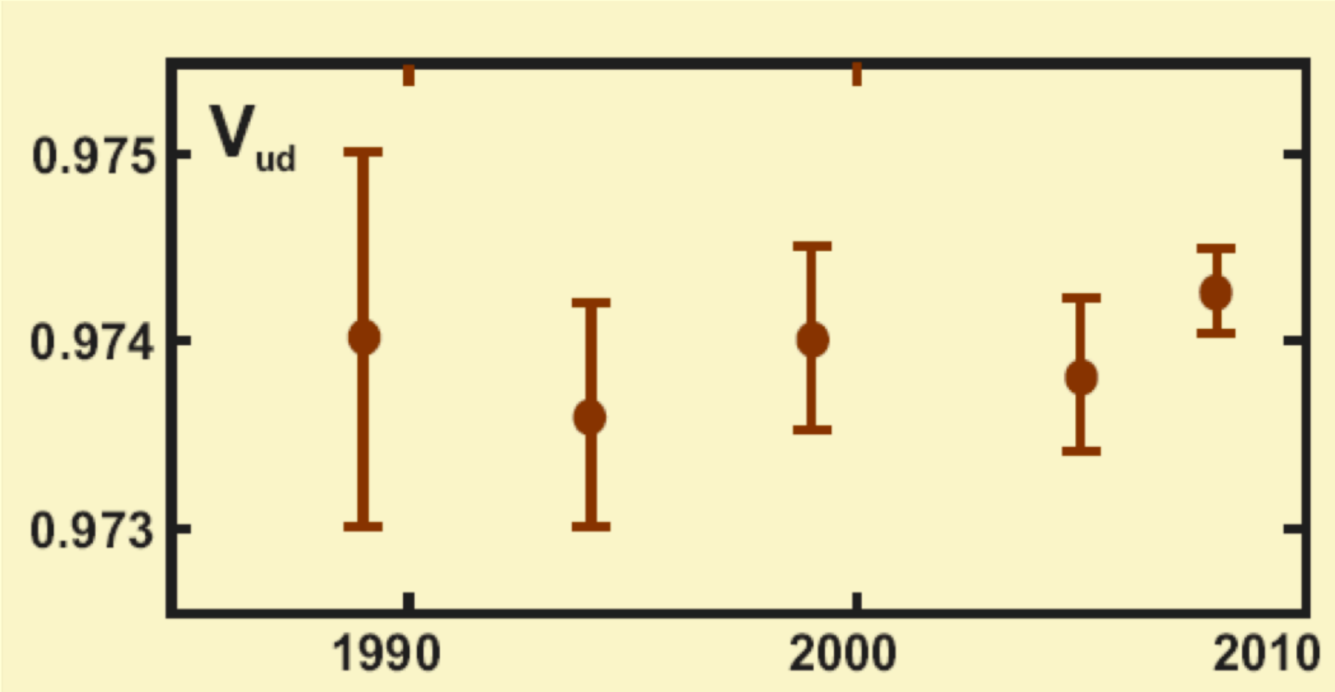
Current status of V_{ud}

Superallowed β decay currently yields most precise value of V_{ud}, limited by theory uncertainties: V_{ud} = 0.97425(22)

V_{ud} measurement very robust and stable along the years

T = ½ mirror nuclei, neutron, and pion decay consistent but with larger errors

Still a particularly vibrant and lively field: stay tuned



See talk by I. S. Towner

V_{us}

$K \to \pi \mu\nu$ & $K \to \pi e \nu$

✓ Only vector current (CVC): $f_+(0) = 1 + (m_s - m_u)^2$

$\langle \pi | \bar{s}\gamma^\mu u | K \rangle \Leftrightarrow f_{+,0}(q^2)$

✓ Small SU(2) br. corrections

$f_+(0)$, λ_{+0}, c_{+0} ?

$K \to \mu\nu$ ($\pi \to \mu\nu$)

✓ Only Axial current: no symmetry constraint

$f_K/f_\pi \sim 1 + (m_s - m_u)$

$\langle 0 | \bar{s}\gamma^\mu \gamma_5 u | K \rangle = p^\mu f_K$

$\tau \to h_s \, l\nu$ **(inclusive modes)**

❖ Both V and A but hard scale (m_τ) + inclusiveness -> OPE

$$R_{\tau,S} \sim |V_{us}|^2 \, L^{\mu\nu} \cdot \sum_{h_s} \langle 0 | J_\mu | h_s \rangle \langle h_s | J_\nu^\dagger | 0 \rangle$$

Vus extraction from Kl3

$K_{\ell 3}$ **decays** $\Rightarrow$ **most accurate and theoretically clean way to access** $|V_{us}|$

The master formula for $K_{\ell 3}$ decay rates:

$$\Gamma_{K\ell 3(\gamma)} = \frac{C_K^2 G_F^2 m_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+(0)|^2 I_K^\ell(\lambda_{+0}) (1 + \delta_{SU(2)}^\ell + \delta_{EM}^\ell)^2$$

$K = K^0, K^\pm;$ $\quad C_{K^0}^2 = 1$ $\quad C_{K^\pm}^2 = 1/2$

Experimental Inputs

$\Gamma(K_{\ell 3(\gamma)})$	Branching Ratios Kaon lifetimes
$I_K^\ell\,[f_{+,0}(t)]$	Phase space integral Depends on ff

Theory Inputs

S_{EW}	Universal short distance EW correction (1.0232±0.0003)
$f_+(0)$	Calculated ff at t=0 2^{nd} order SU(3)
$\delta_{SU(2)}^K$	Form factor correction for isospin breaking ($K^\pm$ only) $f_+^{K^\pm\pi^0}(0)/f_+^{K^0\pi^-}(0) - 1 = 0.029 \pm 0.0004$
$\delta_{EM}^{K_\ell}$	Long distance EM effects $\delta_{EM}^{K_\ell} \approx 0$ for $K^\pm$

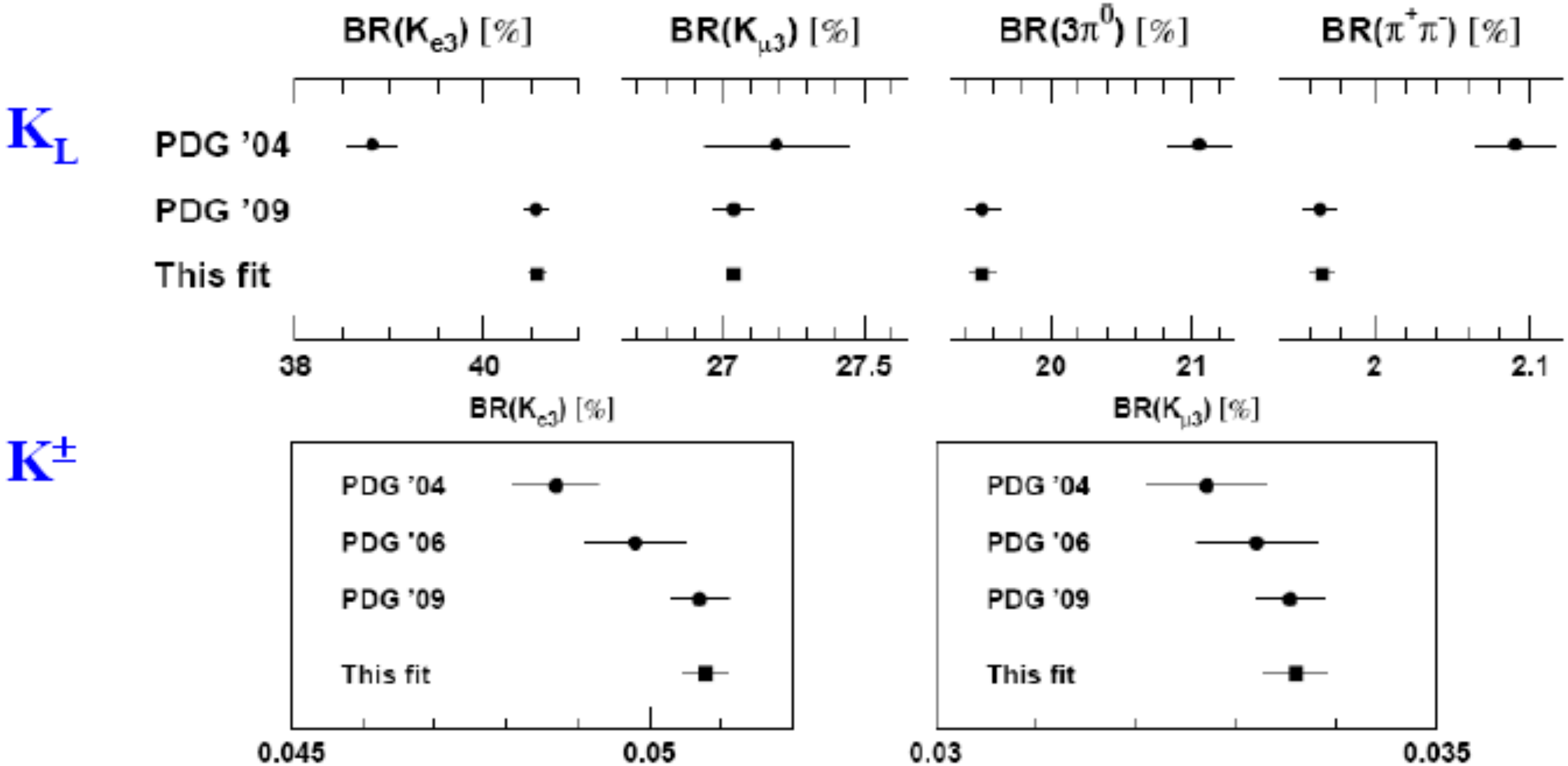
The experimental players in a per-mil game

E865@BNL: rare K^+ decays in flight; π^0 Dalitz decay in final states.
KLOE@DaΦne: pure K beams, lifetimes, absolute BR
NA48@CERN: intense K^0, K^+ beams from SPS proton beam, ratio of BR's
KTeV@FermiLab: intense K_L beam from Tevatron proton beam, ratio of BR's
ISTRA+@IHEP (Protvino): ratio of K^+l3 BR's

See talk by B. Sciascia (FlaviaNet Kaon WG), M. Veltri (Naxx), E. De Lucia

A critical re-analysis of literature data: BR's, τ's

Careful reading of the original papers → definition of different data set and/or parameters wrt to PDG



Wrt to PDG09: minor differences on the fit results

See talk by B. Sciascia (FlaviaNet Kaon WG)

Form Factor parameterization

$|V_{us} f_+(0)|$ extraction needs calculation of the phase space integrals:

$$I_K^\ell = \int_{m_\ell^2}^{t_0} dt \, \frac{1}{m_K^8} \, \lambda^{3/2} \left(1 + \frac{m_\ell^2}{2t}\right) \left(1 - \frac{m_\ell^2}{2t}\right)^2 \left(\bar{f}_+^2(t) + \frac{3 m_\ell^2 \Delta_{K\pi}^2}{(2t + m_\ell^2)\lambda} \bar{f}_0^2(t)\right)$$

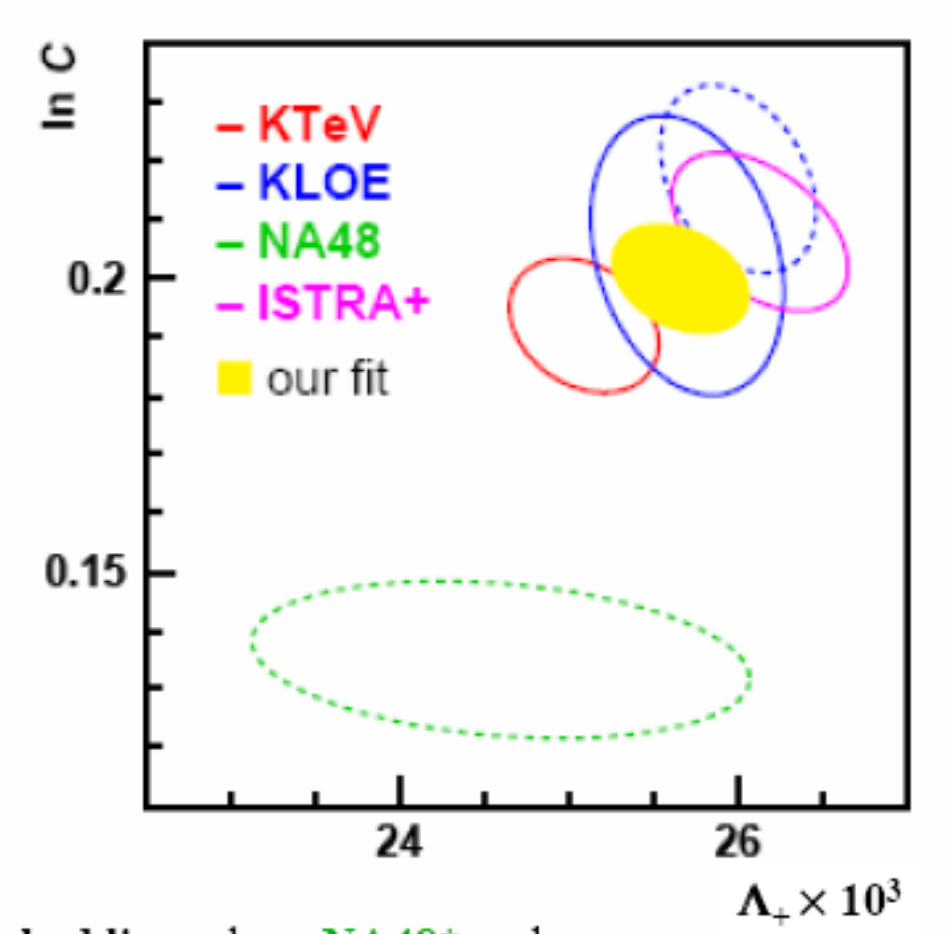
- **Class II**: based on a systematic mathematical expansion (e.g. Taylor, "z-par.")
  - freedom to determine high-order terms from data
  - strong par. correlation → no sensitivity to high order terms (λ_0'') **[PoS 2008(KAON)002]**
  - accurate description in physical region needs at least 2nd Taylor exp. **[PLB638(2009)480]**
  - test of low-energy dynamics involving Callan-Treiman th. needs orders>2nd.

- **Class I**: to reduce the number of parameters, impose additional physical constraints
  - **pole**: dominance of single resonance $M_{V,S}$ (one free parameter)
    vector: K*(892) ok; scalar: no obvious dominance.
  - **dispersive**: ff analytic (except real $t > (m_K + m_\pi)^2$) functions in the complex t-plane.
    vector: numerically similar to pole (K*(892) dominance);
    scalar: necessary without dominant one-particle intermediate state.

See talk by B. Sciascia (FlaviaNet Kaon WG)

Form Factors: dispersive approach

Results from **KTeV** **KLOE** **ISTRA+** **NA48** **This fit**



$$\Lambda_+ \times 10^3 = 25.66 \pm 0.41$$
$$\ln C = 0.2004(91)$$
$$\rho(\Lambda_+, \ln C) = -0.33$$
$$\chi^2/\text{ndf} = 5.6/5\ (34\%)$$

Integrals

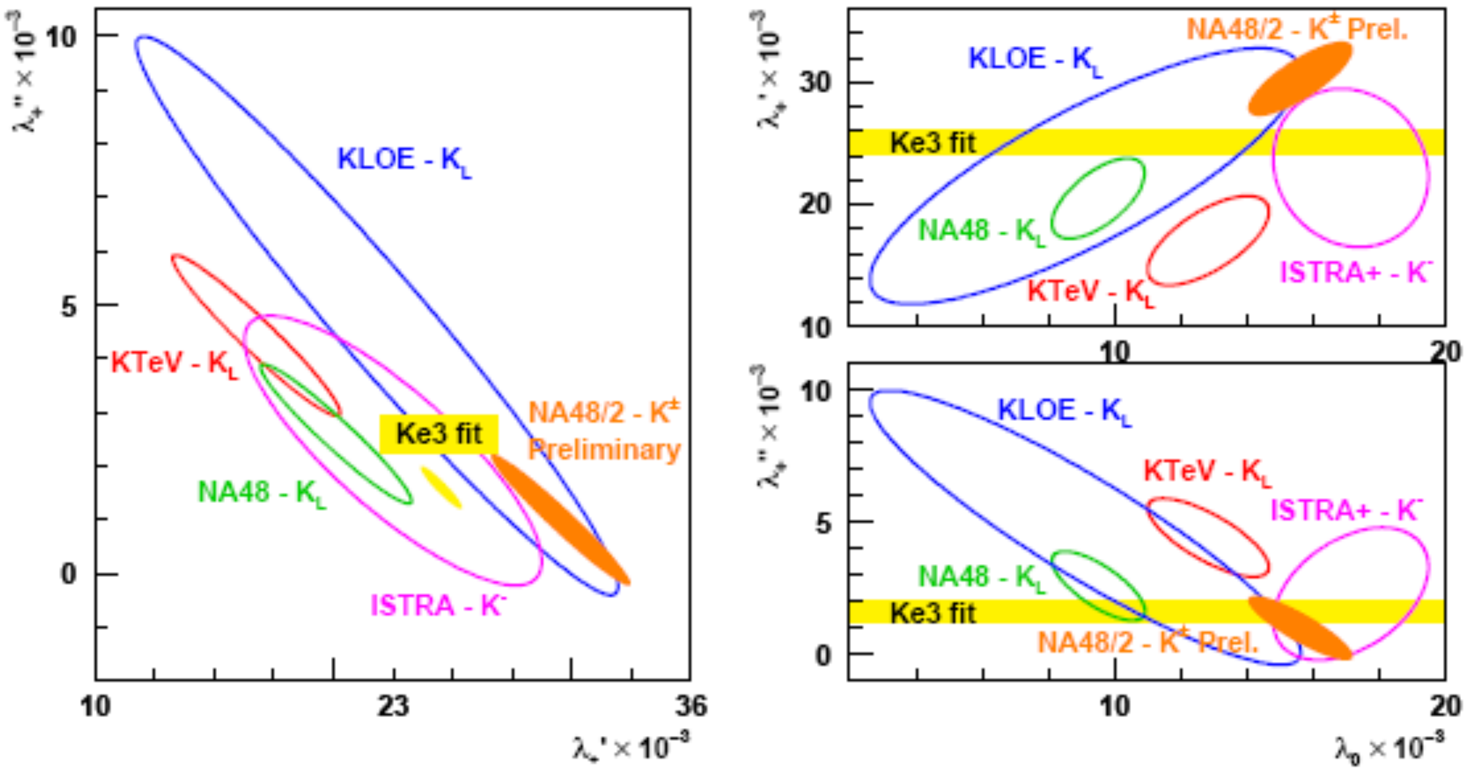
Mode	Quad-lin	Disp
K^0_{e3}	0.15457(20)	**0.15476(18)**
K^+_{e3}	0.15894(21)	**0.15922(18)**
$K^0_{\mu3}$	0.10266(20)	**0.10253(16)**
$K^+_{\mu3}$	0.10564(20)	**0.10559(17)**

Maximum change 0.2% if same data used as for quad-lin fits

Dashed lines show **NA48*** and **preliminary KLOE** data **not in fit**

See talk by B. Sciascia (FlaviaNet Kaon WG)

FF: new results coming, NA48/2



K_{e3} averages from FlaviA WG1

1 σ contours

- Experimental situation on quadratic fit for $K_{\mu 3}$ decay
- $K^0_{\mu 3}$ results from KLOE, KTeV and NA48, ISTRA measures $K^-_{\mu 3}$
- First measurement which uses also $K^+_{\mu 3}$
- High precision - Very competitive with other results
- Small quadratic term - Larger λ_0 with respect to NA48 case

See talk by M. Veltri (NA48/NA62)

New results will come in a near future, KLOE-2

$|V_{us}| f+(0)$: future perspectives with KLOE (2.5 fb^{-1}) & KLOE-2/step0 (5 fb^{-1})

- KLOE-2 can significantly improve the accuracy on the measurement of K_L , $K^{\pm}$ lifetimes and $K_S e3$ branching ratio with respect to present world average with data from the first year of data taking, at KLOE-2/step-0.
- The present 0.23% fractional uncertainty on |Vus| × f+(0) can be reduced to 0.14% using KLOE present data set together with the KLOE-2/step-0 statistics.
- Detector upgrades have not been considered in this evaluation

	$f_+(0) V_{us}$
KLOE today *(World Average)*	**0.28%** (0.23%)
KLOE + Step-0 + WA	**0.14%**

With $f_+(0)$ @ 0.5% the accuracy on the unitarity relation of the first row is

$$\sigma(1 - V_{ud}^2 - V_{us}^2) = 6 \times 10^{-4} \begin{cases} V_{us} \text{ @ } 0.4\% \text{ from fit} \\ V_{ud} \text{ @ } 0.026\% \end{cases}$$

See talk by E. De Lucia (KLOE/KLOE-2)

New results will come in a near future, NA62

NA62, during the 2007 run, collected data for a dedicated measurement of $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ and tests for the future $K^+ \to \pi^+ \nu \, \overline{\nu}$ experiment

- 4 months data taking with minimum bias trigger
  $\to$ 1 track+ 10 GeV deposition in EM calorimeter
- Simultaneous K^+ and K^- beams of P=(74 ± 1.6) GeV/c
- Better track momentum resolution ($\to p_T$ kick doubled)
- Collected $\sim$ 150000 K_{e2} events
- First results for 40% of stat presented at BEACH2010 and ICHEP2010
- Expected precision on the full data sample: $\sigma(R_K)/R_K \simeq \pm 0.4\%$

$K_{\ell 3}$ from NA62 2007 data

- Huge $K^+_{e3}/K^+_{\mu 3}$ statistics of $\approx 40/20 \times 10^6$
- Special K_L run (15 h) to measure electron ID efficiency
  K^0_{e3} and $K^0_{\mu 3}$ statistics $\approx 4 \times 10^6$

See talk by M. Veltri (NA48/NA62)

A new interesting idea to improve FF extraction

$K\pi$ vector form factor constrained by $\tau \to K\pi\nu_\tau$ and K_{l3} decays

to present a model for the $K\pi$ vector form factor using a dispersive representation and incorporating constraints from K_{l3} decays suited to describe both $\tau \to K\pi\nu_\tau$ and K_{l3} decays simultaneously

See talk by R. Escribano

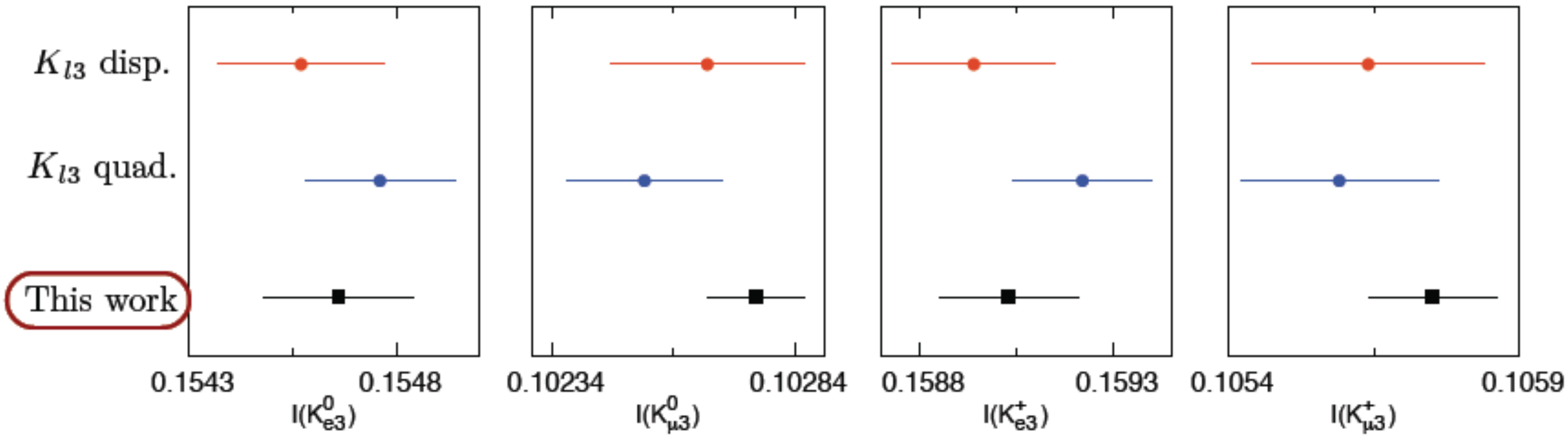
Promising: significant improvements for Kμ3

$$I_{K_{l_3}} = \frac{1}{m_K^2} \int_{m_l^2}^{(m_K-m_\pi)^2} \mathrm{d}t\, \lambda(t)^{3/2} \left(1+\frac{m_l^2}{2t}\right)\left(1-\frac{m_l^2}{t}\right)^2 \left(|\tilde{f}_+(t)|^2 + \frac{3\, m_l^2 (m_K^2 - m_\pi^2)^2}{(2t+m_l^2)\, m_K^4\, \lambda(t)} |\tilde{f}_0(t)|^2\right)$$

$$\lambda(t) = 1 + t^2/m_K^4 + r_\pi^4 - 2\, r_\pi^2 - 2\, r_\pi^2\, t/m_K^2 - 2\, t/m_K^2$$

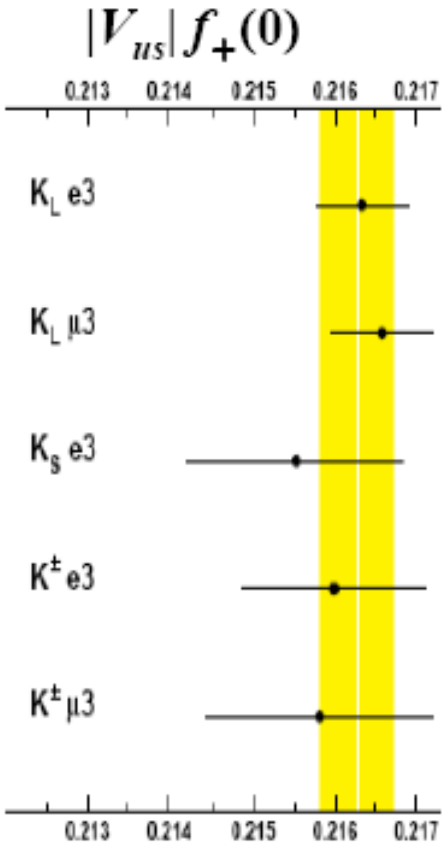
	This Work	K_{l_3} disp. [9]	K_{l_3} quad. [9]
$I_{K^0_{e3}}$	0.15466(17)	0.15476(18)	0.15457(20)
$I_{K^0_{\mu3}}$	0.10276(10)	0.10253(16)	0.10266(20)
$I_{K^+_{e3}}$	0.15903(17)	0.15922(18)	0.15894(21)
$I_{K^+_{\mu3}}$	0.10575(11)	0.10559(17)	0.10564(20)

[9] M. Antonelli *et. al.*, arXiv:1005.2323



See talk by R. Escribano

Present status of $V_{us}f+(0)$ from Kl3 data



			Approx. contrib. to % err from:			
		% err	BR	τ	Δ	Int
K_Le3	0.2163(6)	0.26	0.09	0.20	0.11	0.06
$K_L\mu3$	0.2166(6)	0.29	0.15	0.18	0.11	0.08
K_Se3	0.2155(13)	0.61	0.60	0.03	0.11	0.06
$K^\pm e3$	0.2160(11)	0.52	0.31	0.09	0.40	0.06
$K^\pm\mu3$	0.2158(14)	0.63	0.47	0.08	0.39	0.08

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

Theory still driving the error in the charged modes: SU(2) breaking corr.:

$\delta^{SU(2)}{}_{\text{theory}} = 2.9(4)\%$ vs $\delta^{SU(2)}{}_{\text{exp}} = 2.7(4)\%$

See talk by B. Sciascia (FlaviaNet Kaon WG)

Present status of f+(0) from Lattice

G. Colangelo, S. Dürr, A. J., L. Lellouch, H. Leutwyler, V. Lubicz, S. Necco,
C. Sachrajda, S. Simula, A. Vladikas, U. Wenger, H. Wittig

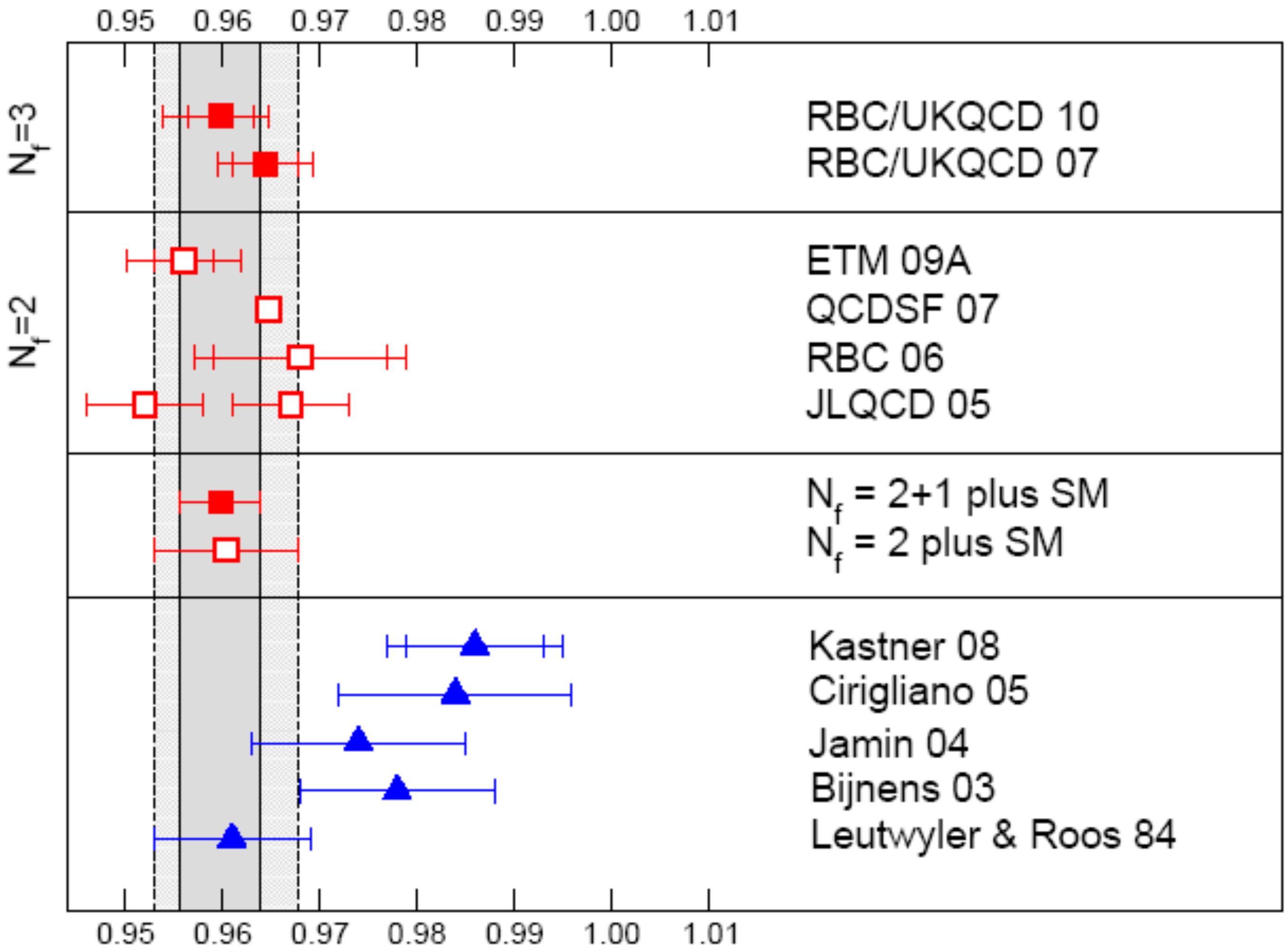
Results for $f_+^{K\pi}(0)$

Collaboration	N_f	publication status	chiral extrapolation	finite volume error	continuum extrapo	$f_+(0)$
RBC/UKQCD 10	2+1	A	●	★	■	$0.9599(34)(^{+31}_{-47})(14)$
RBC/UKQCD 07	2+1	A	●	★	■	0.9644(33)(34)(14)
ETM 09A	2	A	●	●	●	0.9560(57)(62)
QCDSF 07	2	C	■	★	■	$0.9647(15)_{stat}$
RBC 06	2	A	■	★	■	0.968(9)(6)
JLQCD 05	2	C	■	★	■	0.967(6) and 0.952(6)

A precision of ~ 0.5% is possible

See talk by A. Jüttner (FlaviaNet Lattice WG)

Present status of f+(0) from Lattice



Averages:

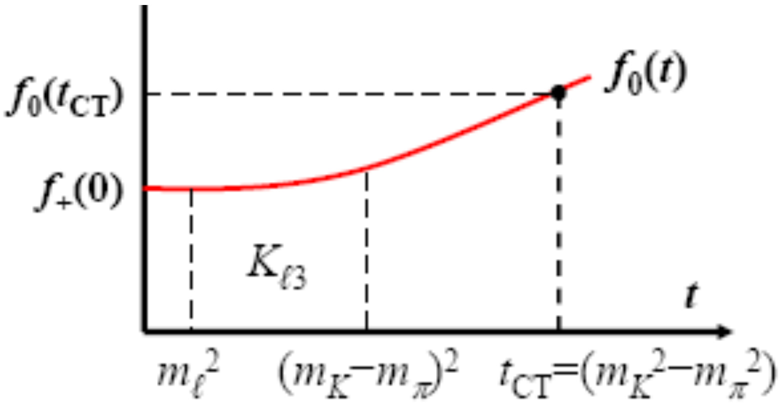
$$f_+(0) = 0.9599(34)(^{+31}_{-47})(14) \qquad (N_f = 2+1)$$
$$f_+(0) = 0.956(6)(6) \qquad (N_f = 2)$$

See talk by A. Jüttner (FlaviaNet Lattice WG)

Data can cross-check Lattice or vice-versa

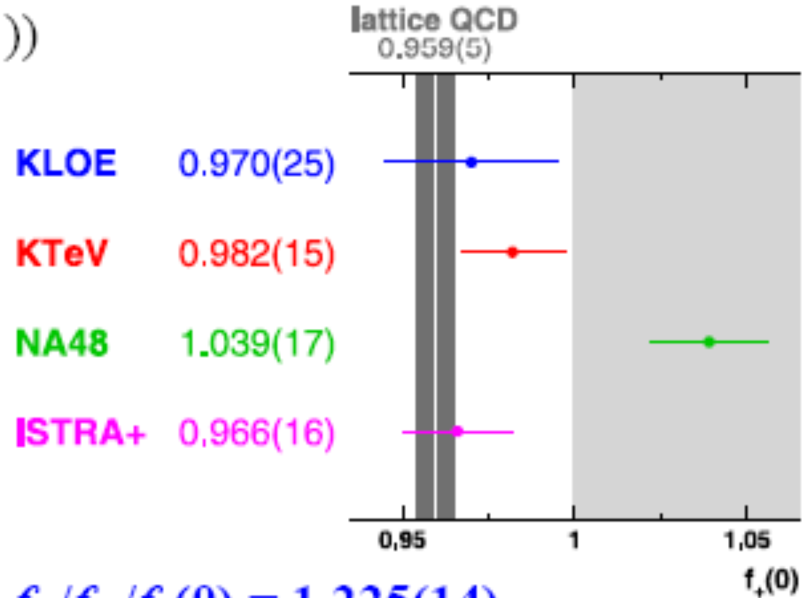
Dispersive parameterization for f_0(t) plus Callan-Treiman relation

$$C \equiv \tilde{f}_0(\Delta_{K\pi}) = \frac{f_K}{f_\pi}\frac{1}{f_+(0)} + \Delta_{CT}$$



- Assuming a f_K/f_π value, obtain a value for $f_+(0)$.
- Consistency test between scalar ff measurement and lattice calculations: WA for ln C (0.2004(91)) gives: $f_+(0) = 0.974(12)$

- NA48 value is inconsistent with theoretical expectations: $f_+(0)<1 \rightarrow$ exclude NA48 Kμ3 ff from averages used for V_{us}.



WA exp. data on ln C alone gives $f_K/f_\pi/f_+(0) = 1.225(14)$ completely independent of any information from lattice estimates

See talk by B. Sciascia (FlaviaNet Kaon WG)

Determination of V_{us} from Kl2 decays

FlaviA net Kaon WG

Within SM, the ratio of photon inclusive K_{l2} to π_{l2} decay rates is:

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

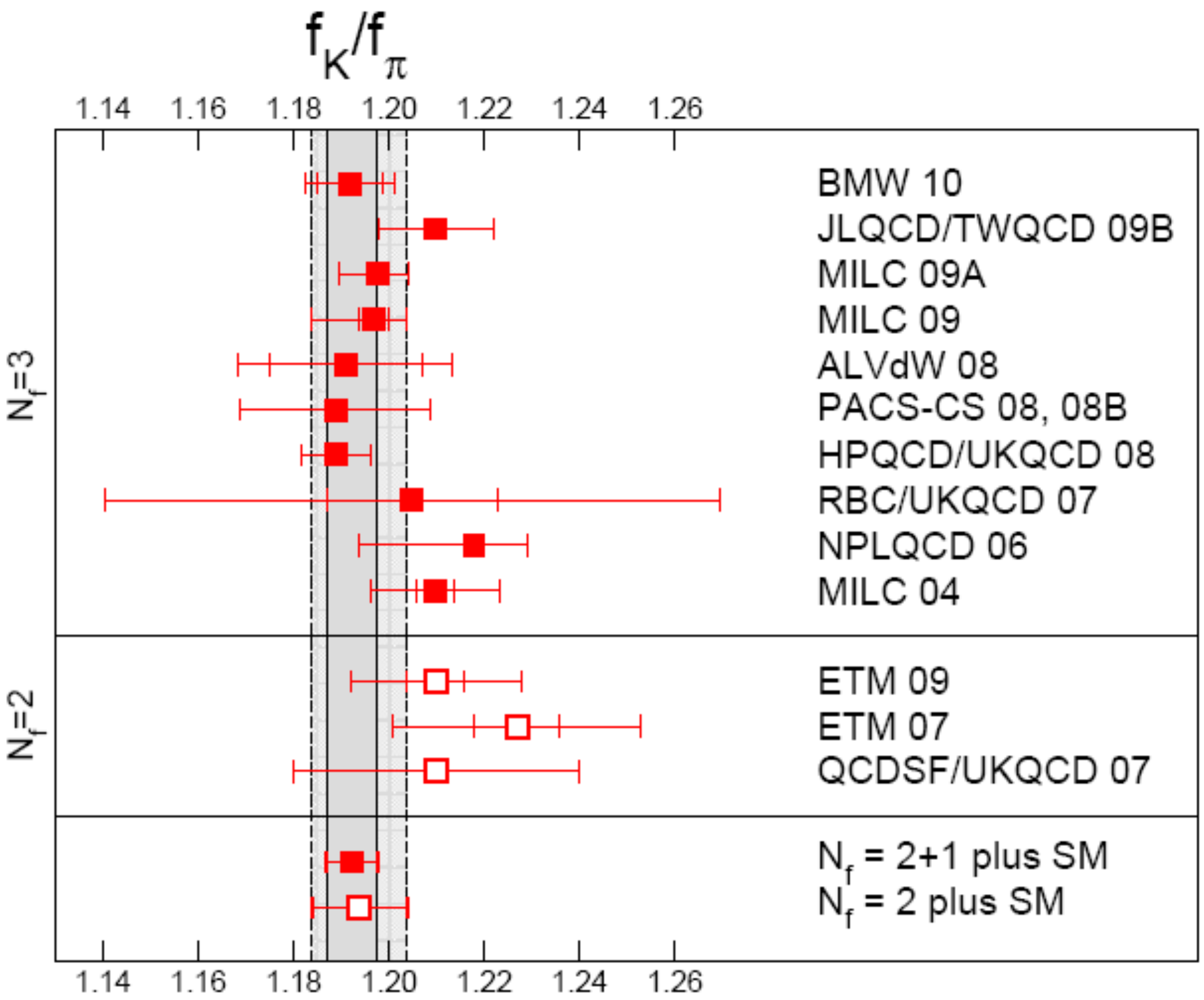
Obtain $|V_{us}|$ **from**:

- measurements of the inclusive K_{l2} and π_{l2} decay widths;
- $|V_{ud}|$**=0.97425(22)** from super-allowed $0^+ \to 0^+$ nuclear beta decays
  [Hardy and Towner, Phys. Rev. C79(2009) 055502]

Use precise evaluation of long-distance e.m. corrections $\delta_{em} = -0.0070(18)$.

f_K/f_π not protected by the Ademollo-Gatto theorem: only lattice.

(lattice calculation of f_K/f_π and radiative corrections benefit of cancellations).



A. Juttner

- very good agreement
- no (sea-)strange-quark effects visible at the current precision of data
- FLAG averages:

$N_f = 2+1$	$f_K/f_\pi = 1.193(6)$	BMW 10, MILC 09A, HPQCD/UKQCD 08
$N_f = 2$	$f_K/f_\pi = 1.210(18)$	ETM 09

f_K/f_π @ the lattice state-of-the-art

2 results with NF=2+1

Similar accuracy, both published:

$f_K/f_\pi = 1.192(7)(6)$	***BMW 2010****	***Wilson***
$f_K/f_\pi = 1.189(2)(7)$	***HPQDC 2007***	***Staggered***
$f_K/f_\pi = 1.198(1)(^{+6}_{-8})$	***MILC 2009***	***Staggered***

Share advisable features of good lattice calculations

Continuum limit, finite volume effects, small pion mass

**** See talk by A. Ramos***

f_K/f_π a systematic approach for error definition

Thorough analysis of main source of errors:

Continuum limit, a → 0

Finite volume effects, L = Na wrt 1/mπ

Small m_π, corrections as exp(-Lm), Lm required > 4

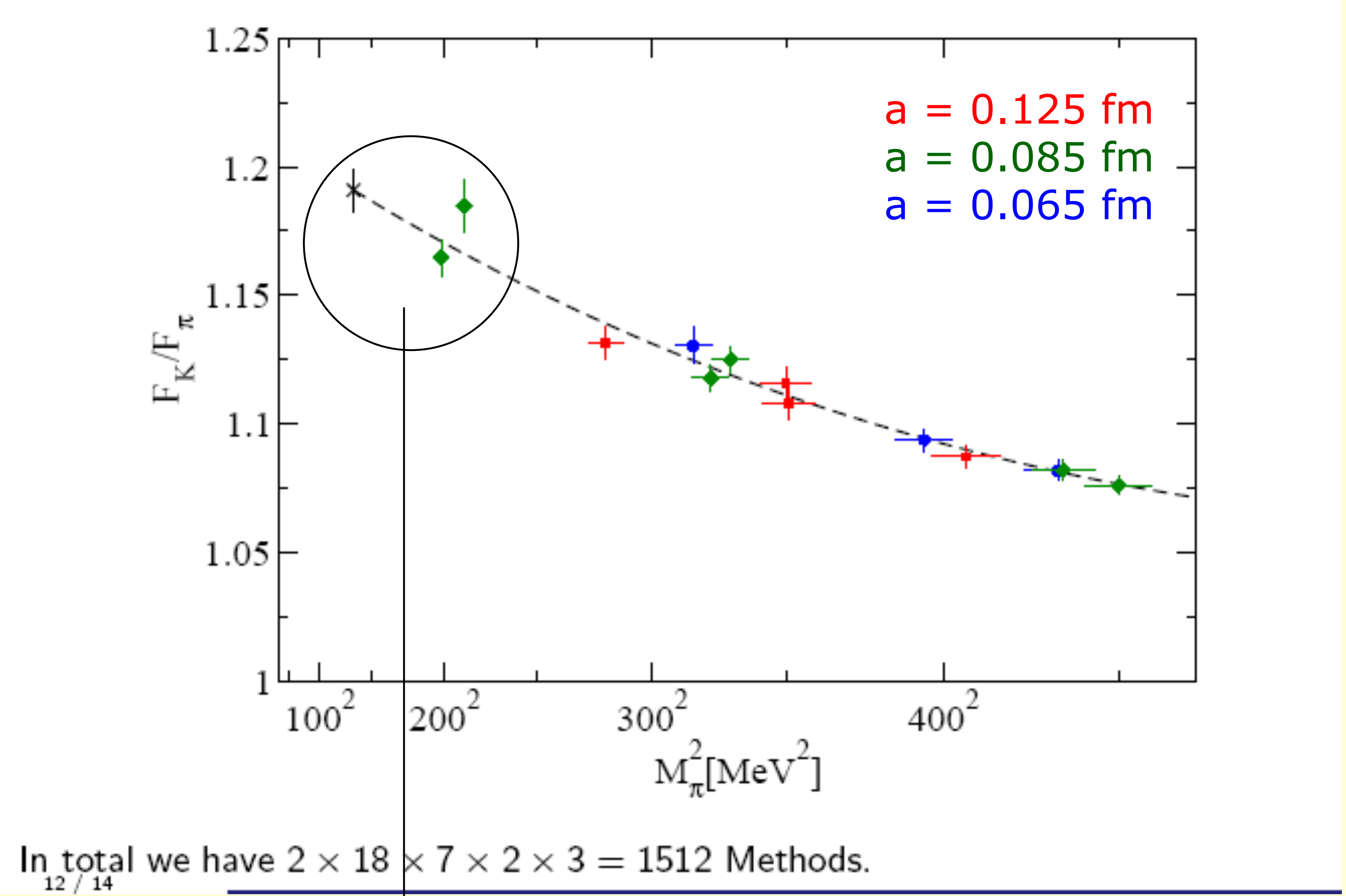
For each source, fit for different assumptions

Simultaneous fit for all the systematic sources

Error from the spread of the results

**** See talk by A. Ramos***

f_K/f_π BMW 2010: one of the 1500 fits



Close to the physical point!
Simulated data close to the final value

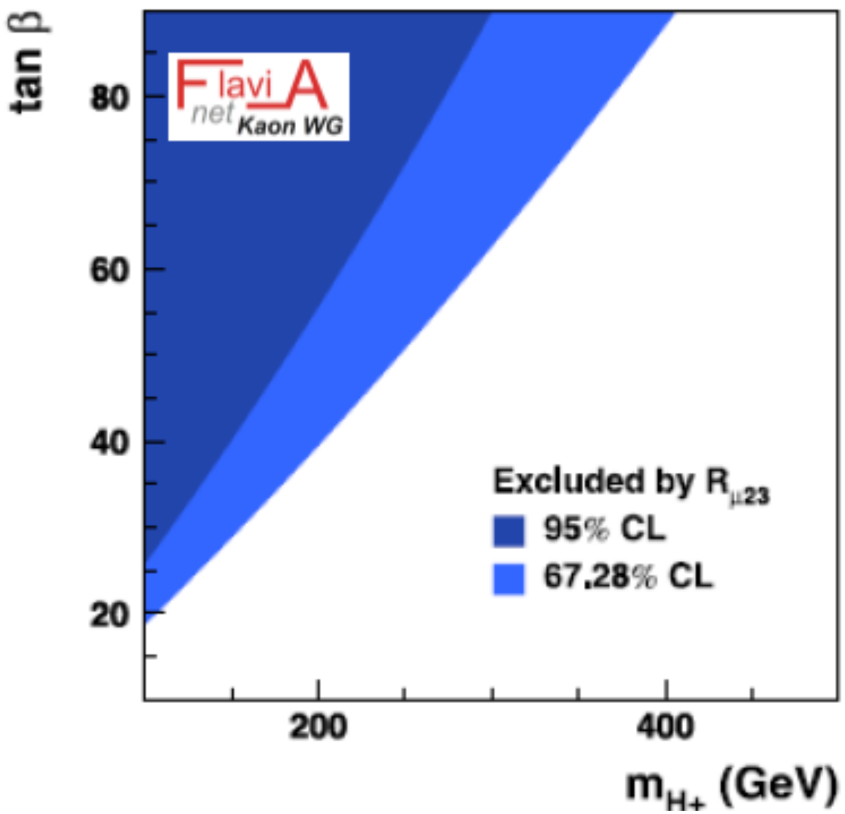
See talk by A. Ramos

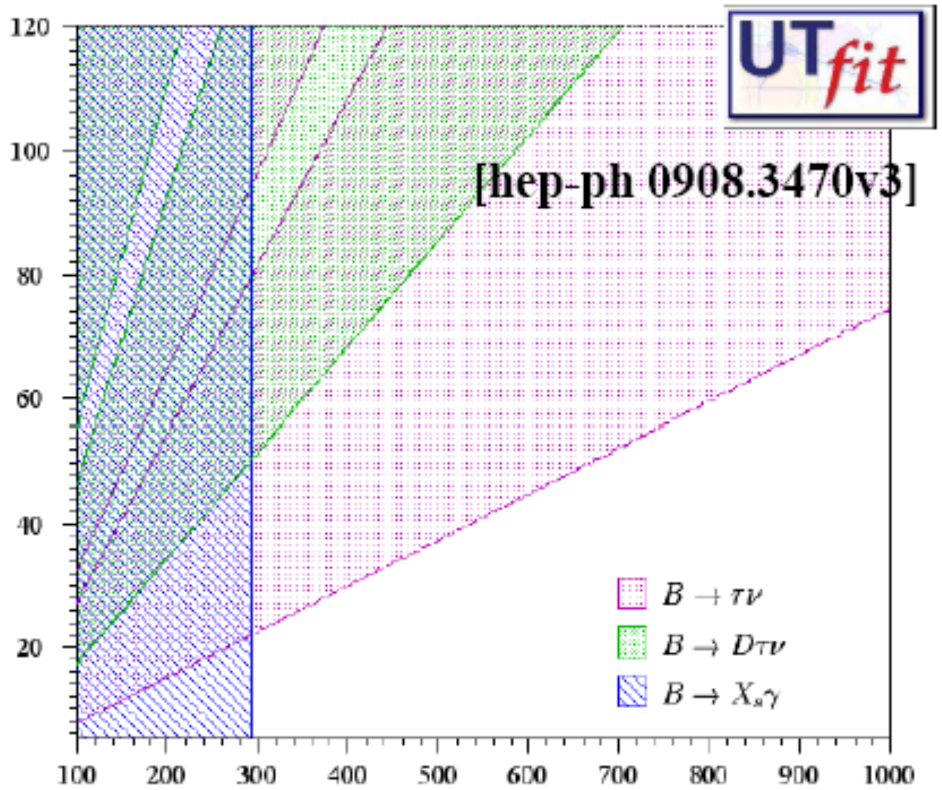
NP test: bounds on scalar component (H^+)

With a 3-parameter fit (V_{us} from Kl3, V_{us}/V_{ud} from Kμ2, V_{ud}) with 1 constraint: $[V_{us}(K_{l3})]^2+[V_{ud}(0^+\to0^+)]^2+[V_{ub}]^2 = 1$, obtains ($\chi^2$/ndf=0.0003/1 P=99%, **ρ=** –0.55):

$$|V_{us}| = 0.2254(8) \quad [K_{\ell 3}, 0^+ \to 0^+, \text{unitarity}],$$
$$R_{\mu 23} = 0.999(7) \quad [K_{\mu 2}].$$

this excludes the region at low m_{H+} and large tg β





See talk by B. Sciascia (FlaviaNet Kaon WG)

CURRENT STATUS of CKM Unitarity

B. Marciano

$$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9999(4)_{Vud}(4)_{Vus}$$

$$=0.9999(6)$$

Outstanding Agreement With Unitarity

Confirms CVC & SM Radiative Corrections:

$2\alpha\ln(m_Z/m_p)/\pi+\ldots \approx +3.6\%$ at 60 sigma level!

Naively Fits m_Z=90(7)GeV vs 91.1875GeV (Direct)

Comparison of G_μ with other measurements (normalization) constrains or unveils **"New Physics"**

New Physics Constraints-Implications:

Exotic Muon Decays, W*bosons, SUSY, Technicolor,
Z' Bosons, $H^\pm$, Heavy Quark/Lepton Mixing…

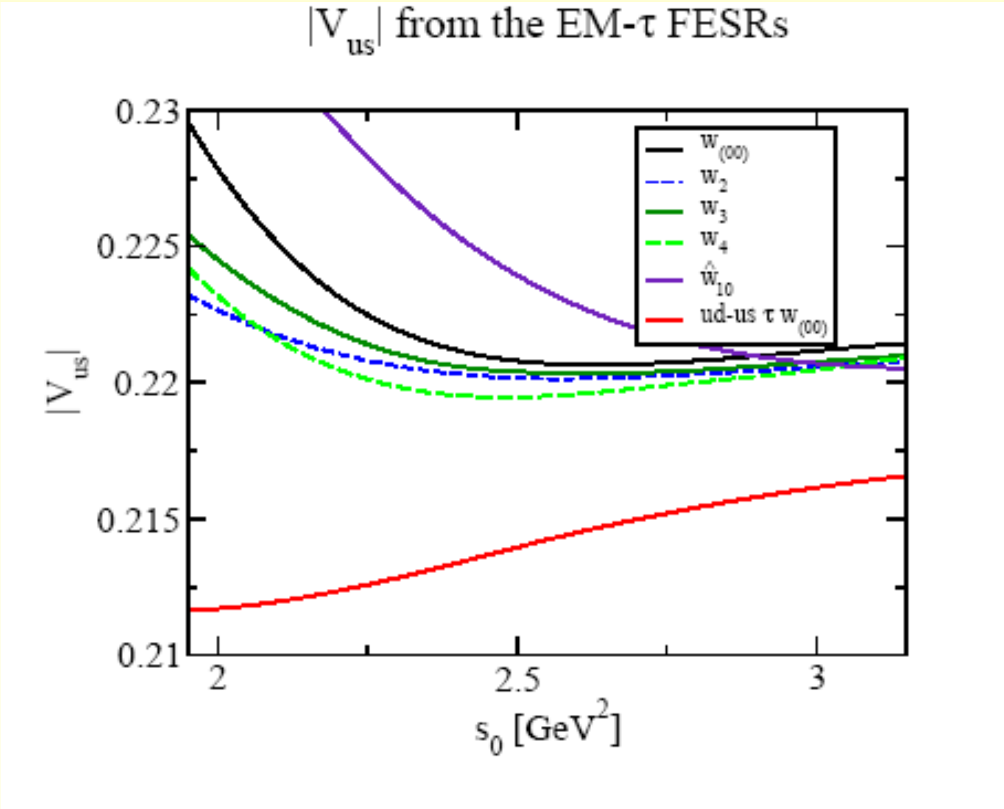
- **δVus=0.5%** combined with **δVud=0.02%** (nuclear beta decays) allow to probe NP effective scales of the **order of 10 TeV**.

An independent approach: Vus from τ decays

Comparison between lattice and other determinations

	$\|V_{us}\|$
$N_f = 2+1$	0.2253(10)
$N_f = 2$	0.2251(18)
β-dec.[1]	0.22544(95)
τ-dec.[2]	0.2165(26)
τ-dec.[3]	0.2214(36)

[1] Hardy & Towner
[2] Gamiz et al.
[3] Maltman



Missing τ->K4pi, K3pi.. Adding these modes Vus will raise

See talk by K. Maltman

Intro 2: what is ϵ_K (experimentally)

However, the actual physical admixtures are (slightly) different:

$$|K_S\rangle \;\propto\; |K\rangle_{\rm even} + \overline{\epsilon}\,|K\rangle_{\rm odd}$$

$$|K_L\rangle \;\propto\; |K\rangle_{\rm odd} + \overline{\epsilon}\,|K\rangle_{\rm even}$$

small parameter

Reflecting the experimental fact that mixing (slightly) violates CP

The magnitude of this *CP* violation is accessed experimentally by measuring the amplitude ratios:

$$\eta_{+-} \;=\; \frac{\langle\pi^+\pi^-|K_L\rangle}{\langle\pi^+\pi^-|K_S\rangle} \qquad \eta_{00} \;=\; \frac{\langle\pi^0\pi^0|K_L\rangle}{\langle\pi^0\pi^0|K_S\rangle}$$

Note: K_L can decay to $\pi\pi$ either directly or indirectly, namely via mixing into K_S

It turns out that the corresponding types of CP violation can be disentangled by the following quantities:

$$\epsilon_K \;=\; \frac{1}{3}\left(\eta_{00} + 2\eta_{+-}\right) \qquad \epsilon' \;=\; \frac{1}{3}\left(\eta_{+-} - \eta_{00}\right)$$

"Indirect" CP violation (through mixing)

"Direct" CP violation (directly in the decay)

See talk by D. Guadagnoli

Evaluation of CKM constraint from ε_K up to 2007

$$\epsilon_K = e^{i\phi_\epsilon} \sin\phi_\epsilon \left(\frac{\mathrm{Im}(M_{12}^K)}{\Delta M_K} + \xi \right)$$

$M_{12}^K = F(\rho,\eta)\, B_K\, 8/3\, F^2_K\, M^2_K$

B_K from Lattice, known at 10%

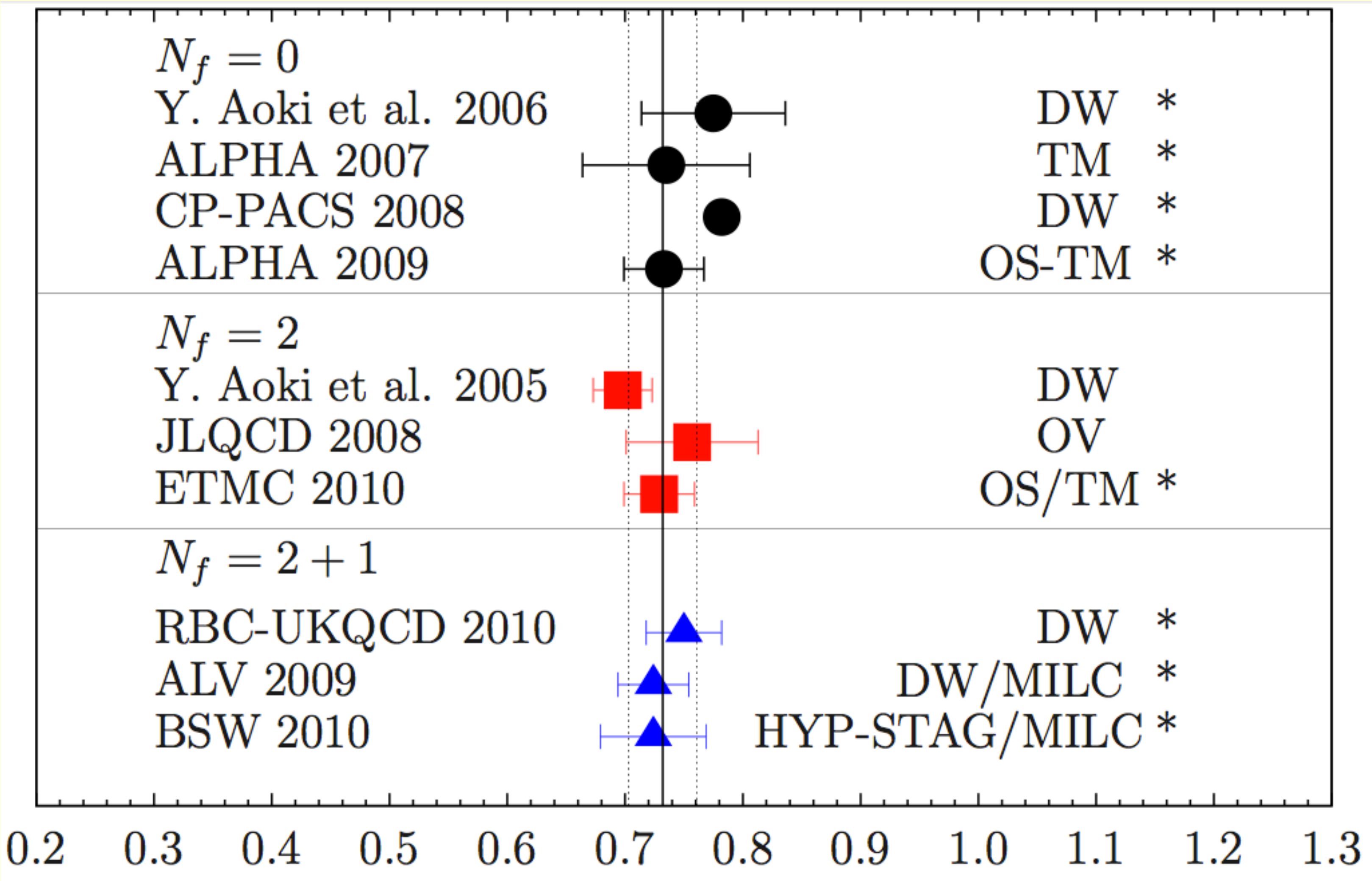
$$\xi \equiv \frac{\mathrm{Im} A_0}{\mathrm{Re} A_0}$$

with A_0 the amplitude for the decay $K^0 \to \pi\pi$ (0-isospin)

Standard approximation:
Since $\Delta\Gamma K \sim -2\Delta MK$, assume $\phi_\varepsilon = 45°$
Assume $\xi = 0$

See talk by D. Guadagnoli

Dramatic recent progress in B_K evaluation (see P. Dimopoulos talk)



* = @ the Continuum Limit

Averages: Lahio, Lunghi, Van de Water: $B_K = 0.725(26)$

Lubicz: $B_K = 0.731(36)$

Present accuracy calls for improvements in ε_K CKM contraint

Evaluation of CKM constraint at present (2010)

Evaluation of superweak phase, $\phi_\varepsilon = 43.5°$

$$\epsilon_K = e^{i\phi_\epsilon} \sin\phi_\epsilon \left(\frac{\mathrm{Im}(M_{12}^K)}{\Delta M_K} + \xi \right)$$

Buras, Guadagnoli (2008), Buras, Guadagnoli, Isidori (2010) re-esamine the $\xi = 0$ assumption and evaluate at NLO

$$\epsilon_K = k_\varepsilon \, e^{i\phi_{sw}}/\sqrt{2} \left(\frac{\mathrm{Im}(M_{12}^K)}{\Delta M_K} \right)$$

The net effect is $k_\varepsilon = 0.94(2)$, imposing a ~2σ tension, confirmed by UT fit and CKM fitter

$$\epsilon_K \propto \bar{\eta}\,(1-\bar{\rho}) = R_t^2 \sin\beta \cos\beta \propto R_t^2 \sin 2\beta$$

$$|\epsilon_K|^{SM} \propto \kappa_\epsilon \hat{B}_K |V_{cb}|^4 |V_{us}|^2 R_t^2 \sin 2\beta$$

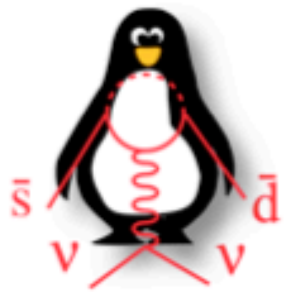
5% 11% 8%

$$\Rightarrow \frac{\delta|\epsilon_K|^{SM}}{|\epsilon_K|^{SM}} \approx \sqrt{\left(\frac{\delta \hat{B}_K}{\hat{B}_K}\right)^2 + \left(4\frac{\delta|V_{cb}|}{|V_{cb}|}\right)^2 + \left(2\frac{\delta R_t}{R_t}\right)^2} \approx 15\%$$

See D. Guadagnoli talk

Important step forward by experiment for NP tests

Lepton Universality tests with Leptonic Kaon decays



Cristina Lazzeroni

(Royal Society University Fellow, University of Birmingham)

for the NA62 collaboration

(Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, IHEP Protvino, INR Moscow, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, Saclay, San Luis Potosí, SLAC, Sofia, TRIUMF, Turin)

RK in the SM

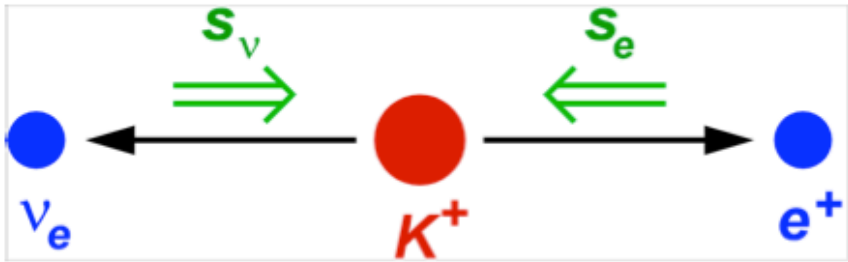
Observable sensitive to lepton flavour violation and its SM expectation:

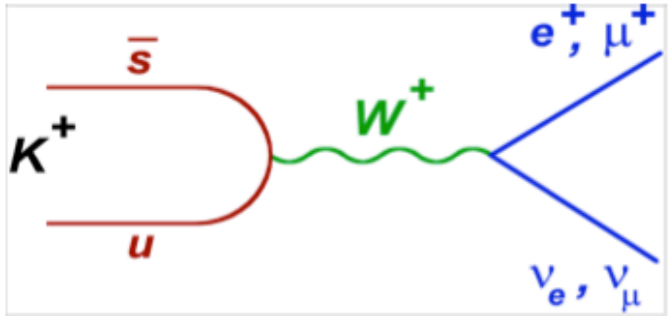
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{rad.corr.})$$

(similarly, R_π in the pion sector)

Helicity suppression: $f \sim 10^{-5}$

Radiative correction (few %) due to $K^+ \to e^+ \nu \gamma$ (IB) process, by definition included into R_K





- SM prediction: excellent sub-permille accuracy due to cancellation of hadronic uncertainties.
- Measurements of R_K and R_π have long been considered as tests of lepton universality.
- Recently understood: helicity suppression of R_K might enhance sensitivity to non-SM effects to an experimentally accessible level.

$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

$R_\pi^{SM} = (12.352 \pm 0.001) \times 10^{-5}$

Phys. Lett. 99 (2007) 231801

RK beyond the SM

2HDM – tree level (including SUSY)

K_{l2} can proceed via exchange of charged Higgs $H^{\pm}$ instead of $W^{\pm}$

→ Does not affect the ratio R_K

2HDM – one-loop level

Dominant contribution to ΔR_K: $H^{\pm}$ mediated LFV (rather than LFC) with emission of ν_τ

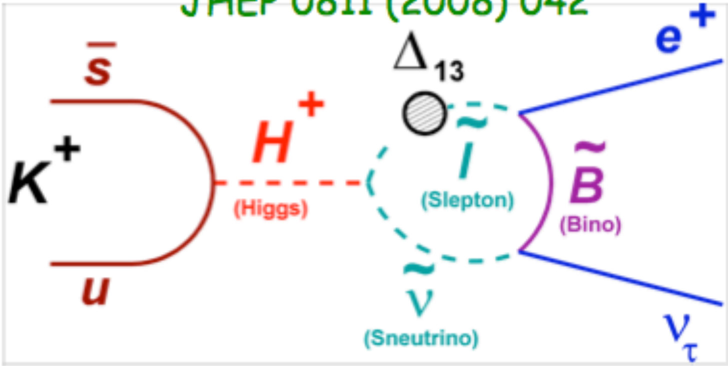
→ R_K enhancement can be experimentally accessible

$$R_K^{LFV} \approx R_K^{SM}\left[1+\left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right)|\Delta_{13}|^2\tan^6\beta\right]$$

Up to ~1% effect :

slepton mixing $\Delta_{13}=5\times10^{-4}$, $\tan\beta=40$, $M_H=500$ GeV/c^2 lead to $R_K^{MSSM} = R_K^{SM}(1+0.013)$

PRD 74 (2006) 011701, JHEP 0811 (2008) 042



Analogous SUSY effect in pion decay is suppressed by a factor $(M_\pi/M_K)^4 \approx 6\times10^{-3}$

(see also PRD76 (007) 095017)

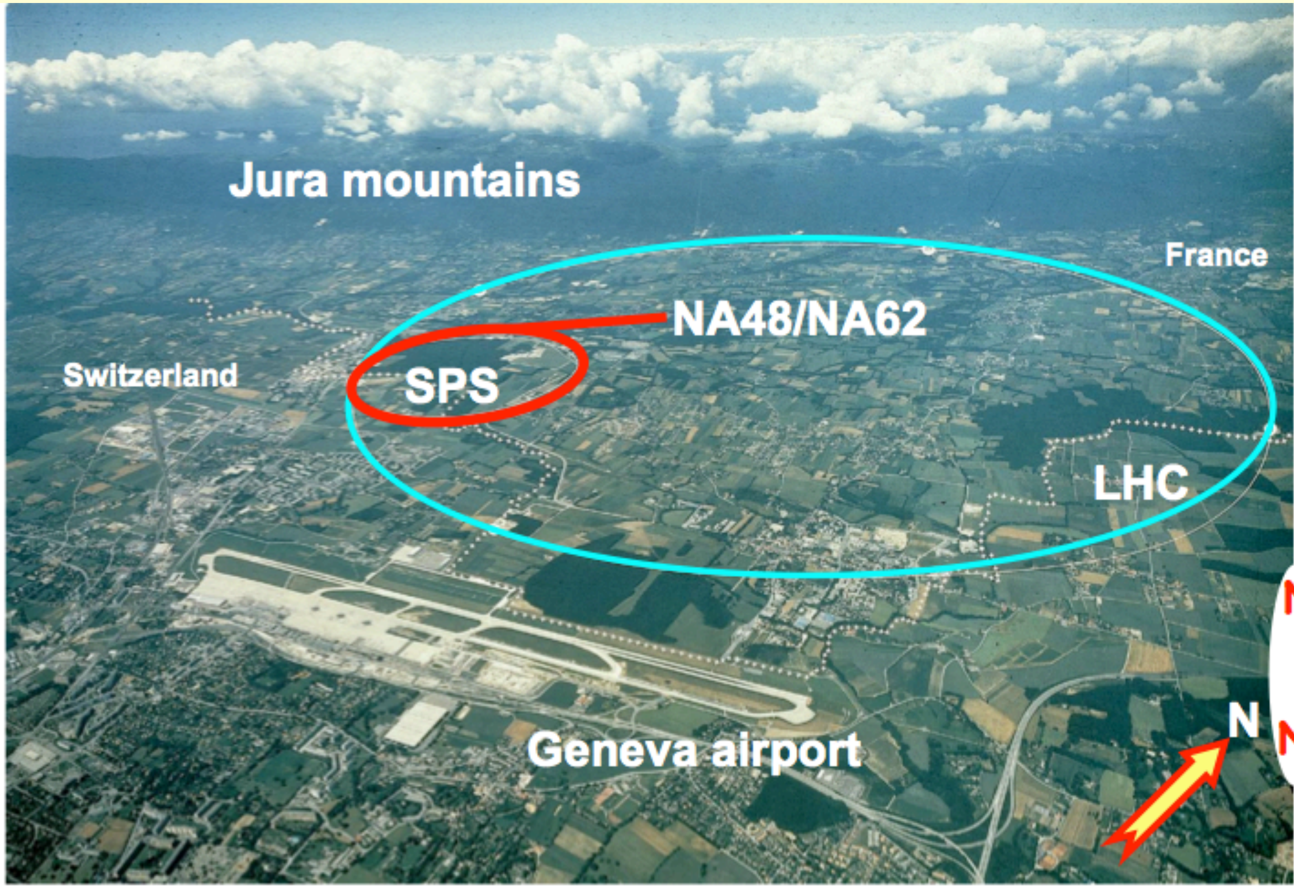
Large effects in B decays due to $(M_B/M_K)^4 \sim 10^4$:

$B_{\mu\nu}/B_{\tau\nu}$ → ~50% enhancement;

$B_{e\nu}/B_{\tau\nu}$ → enhanced by ~one order of magnitude.

Out of reach: $Br^{SM}(B_{e\nu}) \approx 10^{-11}$

The NA48/NA62 experiment



NA48 discovery of direct CPV
- 1997: ε'/ε: K_L+K_S
- 1998: K_L+K_S
- 1999: K_L+K_S | K_S HI
- 2000: K_L only | K_S HI
- 2001: K_L+K_S | K_S HI

NA48/1
- 2002: K_S/hyperons

NA48/2
- 2003: K^+/K^-
- 2004: K^+/K^-

NA62 (phase I)
- 2007: $K^\pm_{e2}/K^\pm_{\mu2}$
- 2008: $K^\pm_{e2}/K^\pm_{\mu2}$

NA62 (phase II)
- 2007–2011: design & construction
- 2012–2015: $K^+\to\pi^+\nu\bar{\nu}$ data taking

Primary SPS protons (400 GeV/c): 1.8×10^{12}/SPS spill
Unseparated secondary positive beam: p=(74.0±1.6) GeV/c
Composition: $K^+(\pi^+)$ = 5%(63%).
K^+ decaying in vacuum tank: 18%.

Measurement strategy: a counting experiment

Large common part (topological similarity)

- one reconstructed track;
- geometrical acceptance cuts;
- K decay vertex: closest approach of track & nominal kaon axis;
- veto extra LKr energy deposition clusters;
- track momentum: 13GeV/c<p<65GeV/c.

Kinematic separation

missing mass $M^2_{miss} = (P_K - P_l)^2$

P_K : average measured with $K_{3\pi}$ decays

→ Sufficient $K_{e2}/K_{\mu 2}$ separation at p_{track}<25GeV/c

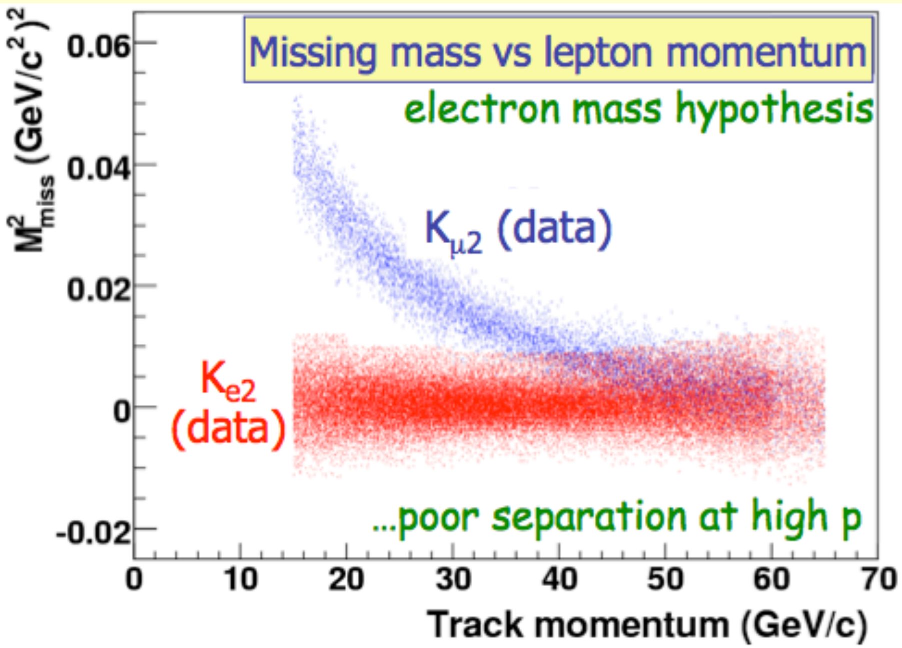
Separation by particle ID

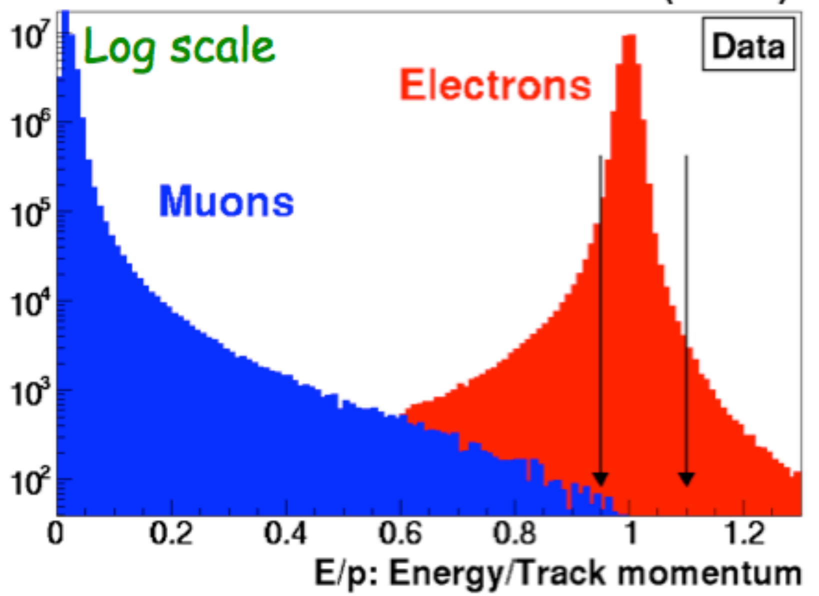
E/p = (LKr energy deposit/track momentum).

(0.9 to 0.95)<E/p<1.10 for electrons,

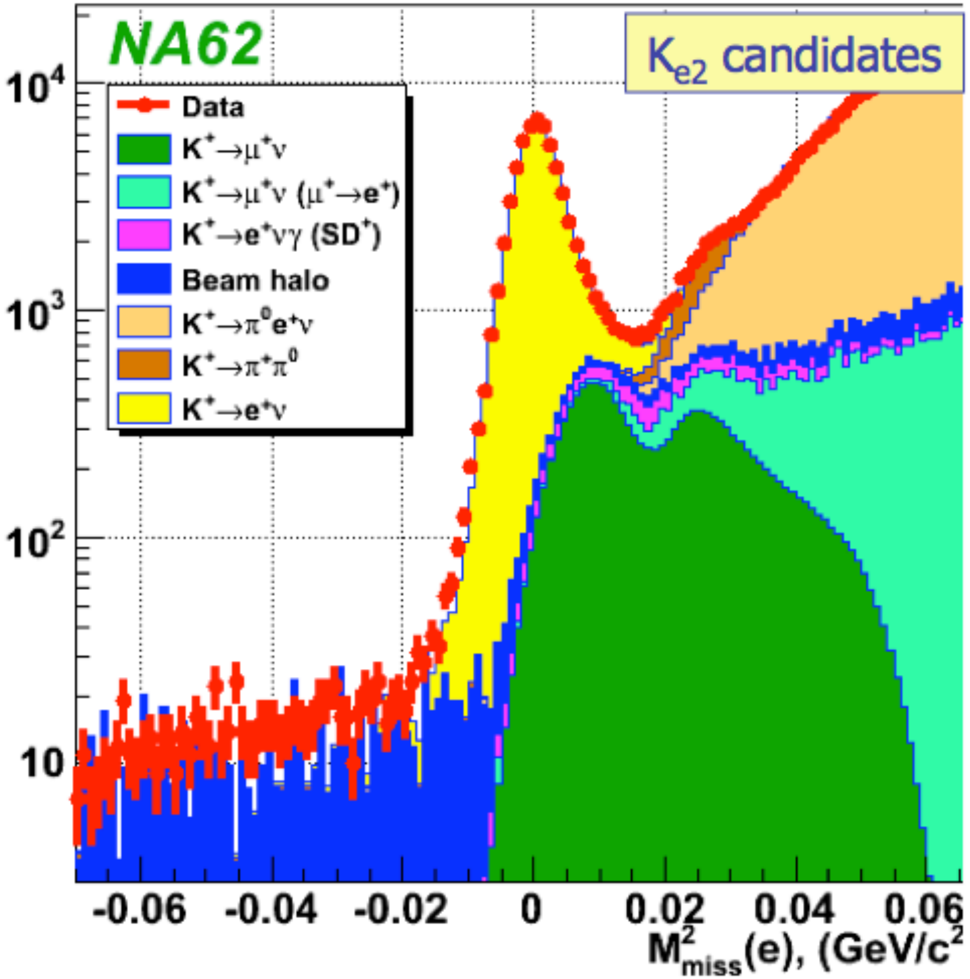
E/p<0.85 for muons.

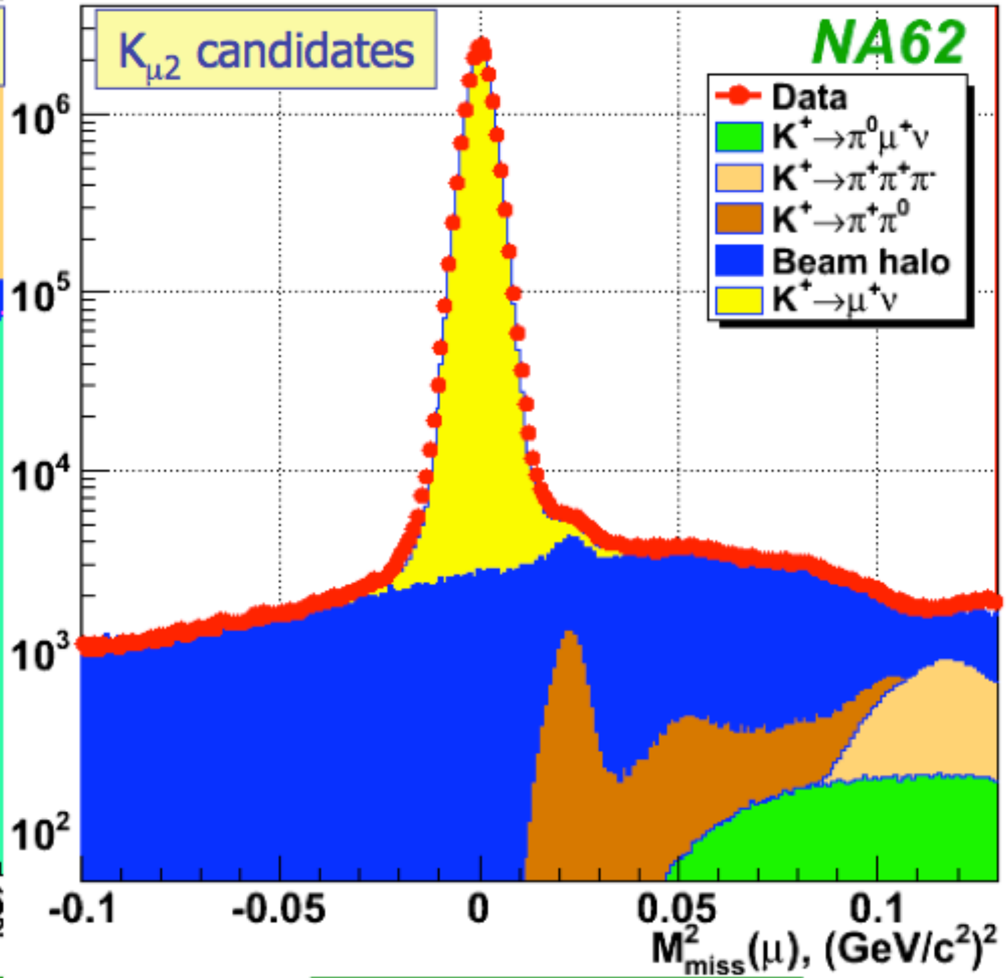
→ Powerful $\mu^\pm$ suppression in $e^\pm$ sample: ~10^6





Ke2 and Km2 Signal selection





59,963 $K^+ \to e^+\nu$ candidates.
Positron ID efficiency: (99.27±0.05)%.
B/(S+B) = (8.8±0.3)%.

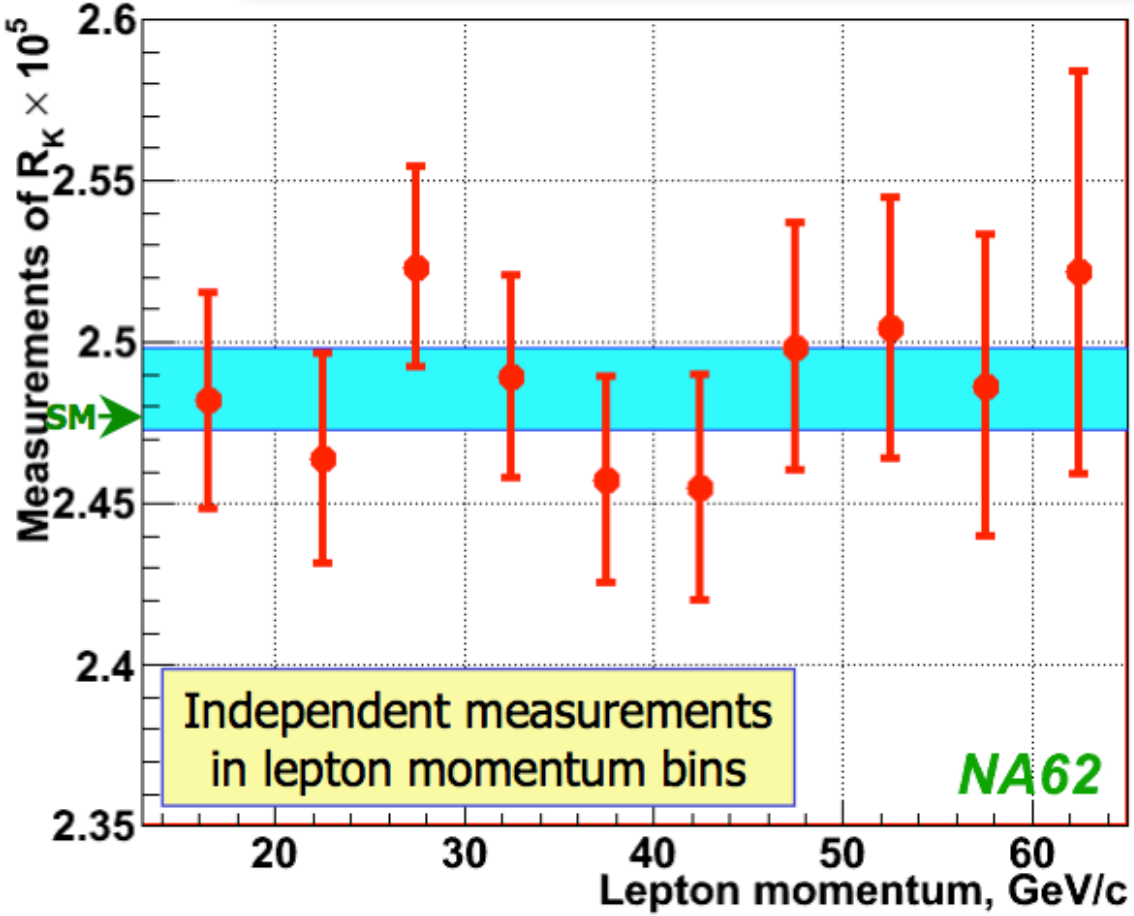
18.030 M candidates
with low background
B/(S+B) = 0.38%

NA62 estimated total K_{e2} sample:
~130K K^+ & ~20K K^- candidates

Result for RK

$R_K = (2.486 \pm 0.011_{stat} \pm 0.007_{syst}) \times 10^{-5}$
$= (2.486 \pm 0.013) \times 10^{-5}$

(new: June 2010)



(systematic errors included, partially correlated)

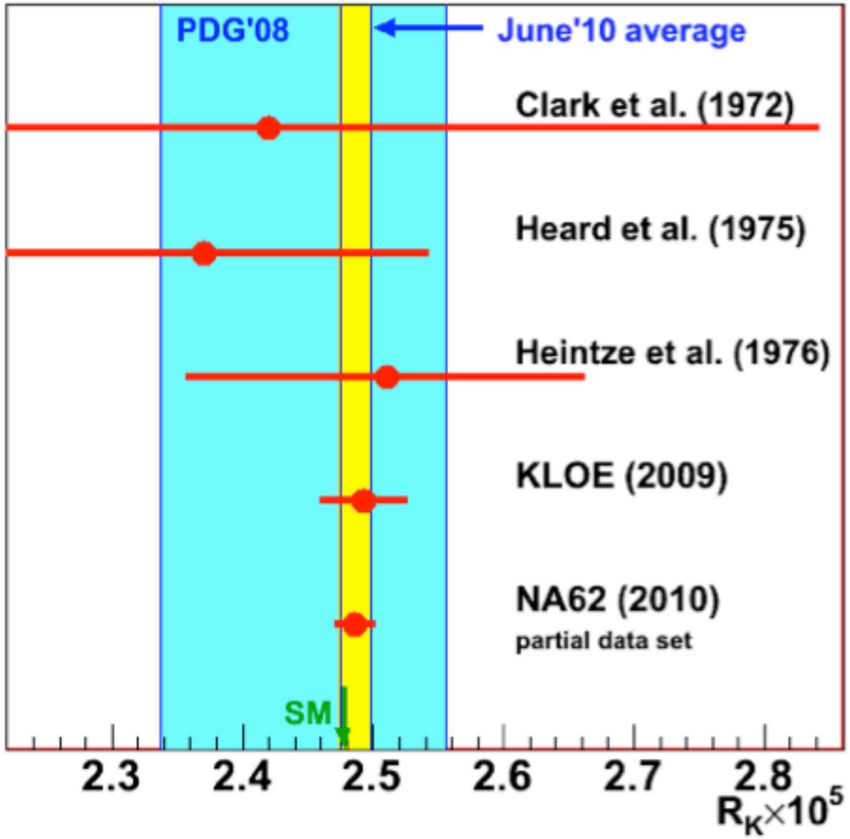
Uncertainties

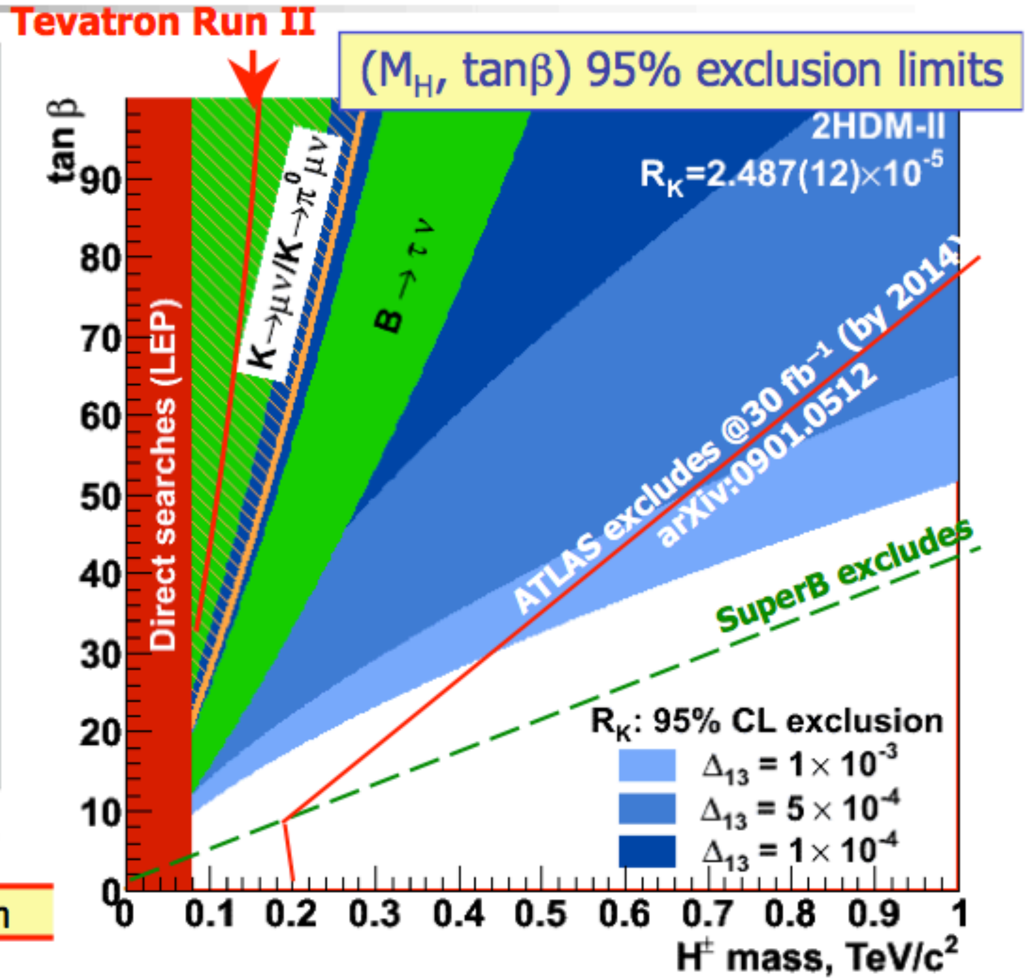
Source	$\delta R_K \times 10^5$
Statistical	0.011
$K_{\mu 2}$	0.005
$BR(K_{e2\gamma}\ SD^+)$	0.004
Beam halo	0.001
Acceptance	0.002
DCH alignment	0.001
Positron ID	0.001
1-track trigger	0.002
Total	0.013

(0.52% precision)

Preliminary result: $R_K=2.500(16)\times10^{-5}$. Shift due to multi-photon corrections to the $K_{e2\gamma}$ (IB) decay.

RK: world average and Higgs exclusion plot





World average	$\delta R_K \times 10^5$	Precision
March 2009	2.467±0.024	0.97%
June 2010	2.487±0.012	0.48%

R_K measurements are currently in agreement with the SM expectation at ~1σ.
Any significant enhancement with respect to the SM would be evidence of new physics.

For non-tiny values of the LFV slepton mixing Δ_{13}, sensitivity to $H^{\pm}$ in $R_K=K_{e2}/K_{\mu2}$ is better than in $B\to\tau\nu$

Summary of WG1 – The present status

A general consideration: in the LHC era, still a lively and vibrant field

The door to the flavor realm, G_μ:

New result by MuLan experiment @ PSI: G_μ now at the 1ppm level!
Difficult to even think to improve on that
Gm is like the fixed stars to which flavor physics has to confront

Vud determination:

An active community, many new experiments approved/running
New experimental techniques, leading to new determination
$0^+ \rightarrow 0^+$ transitions dominate, but might change in a mid-term future

Vus determination:

rock solid status of experimental data, @0.2% both from K_{l3} and K_{l2}
major and fundamental improvements by Lattice
News from K oscillation (ε_K) → 2σ tension on CKM UT fits

Summary of WGI – The future perspectives

Lattice reliability for Kaon observables gives confidence when going up to B (SuperB)

Continuous further improvements from both experiments and theory on Kl3 FF's are easily foreseen

new results by KLOE, NAxx

LFV NP test from Ke2/Km2

new measurement @0.5% presented for NA62
improvement on 1.3% mmt expected by KLOE

And waiting for ultra rare K decay experiments:

NA62, KOTO for NP in FCNC, $K \rightarrow \pi\nu\nu$ (see WG III)

CKM 1st row unitarity and gauge universality represent a tight constraint for any NP model