Review on Kaon decays

Durham 14 years later

Giancarlo D'Ambrosio

INFN-Sezione di Napoli

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Outline

- Beautiful decays: Kl3 and related
- Interplay Long -Short : $K_L \to \pi^0$ e e
- Chiral Perturbation theory tests

Many thanks to B. Sciascia, M. Moulson and Flavianet people

$K \to \pi l \nu$ and CKM unitarity

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

- Superallowed transitions $\Longrightarrow |V_{ud}| = 0.9738 \pm 0.0003 \overset{\text{Unit.}}{\Longrightarrow}$

$$|V_{us}|^{\text{Unit.}} = 0.2275 \pm 0.0012$$

$$|V_{us}|^{\text{PDG04}} = 0.2196 \pm 0.0026$$ Leutwyler,Roos

$$|V_{us}|^{\text{PDG06}} = 0.2257 \pm 0.0021$$

$$|V_{us}|^{\text{Flavianet}} = 0.22461 \pm 0.00048$$

All K's

$$\Gamma(K_{l3}^i) = \mathcal{N}_i |V_{us}|^2 |f_+(0)|^2 (1 + \delta_{rad}^l) I(\lambda_+, \lambda_0)$$

- Kaon revolution in 2004-2005: BNL E865, ISTRA,KTeV, NA48,KLOE $\Gamma(K_{l3}^i)$ all increased by 6% All Major KL BRs Changed! ϵ_K changed by 3.7σ

- After 06 NA48, KLOE improvements in semileptonic BRs

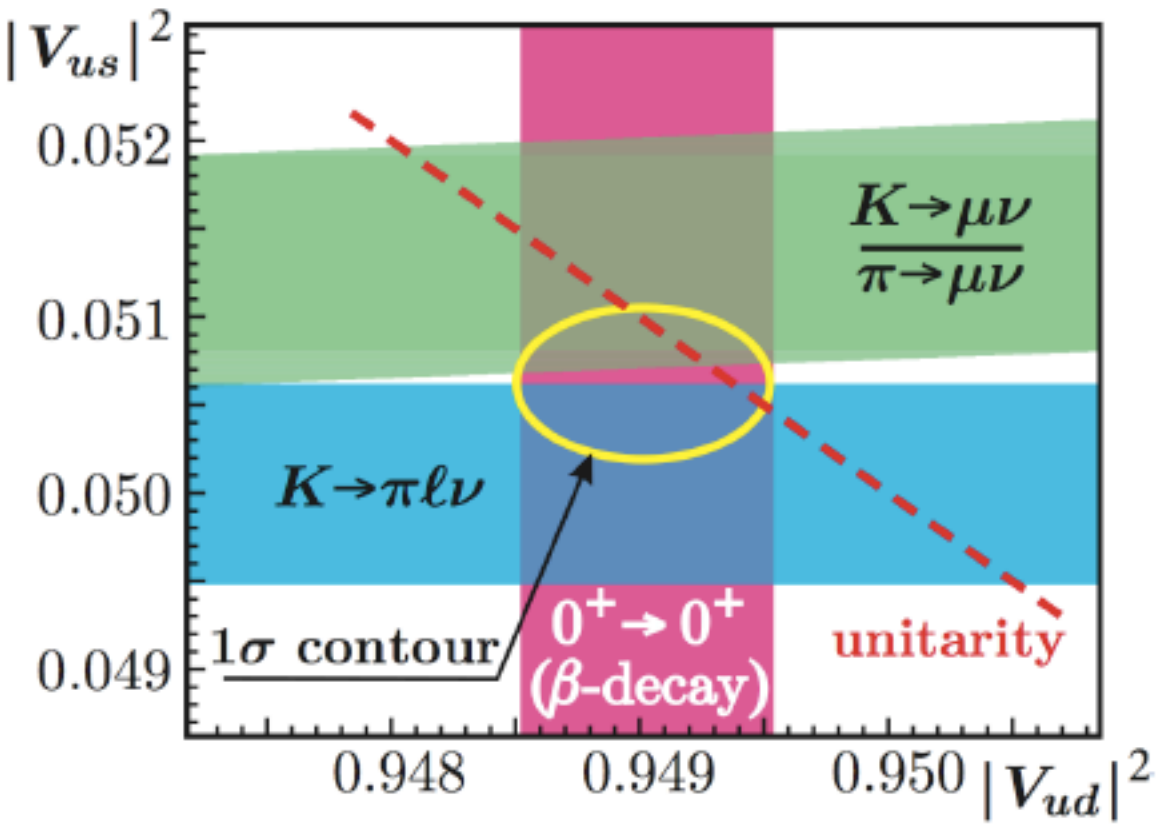
- NA48, KLOE $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$

- Better understanding theoretically of the form factor $f_{+,0}(t) = f_+(0)(1+ \lambda_{+,0} t/m_\pi^2)$ (see Passemar)

- Lattice $f_+(0) = 0.9644(49)$ RBC-UKQCD DW Lattice (see Juettner,Colangelo)

- TH radiat./isospin breaking corr. δ^l_{rad} known accurately BUT Chiral Pert Th. + Large N $\longrightarrow f_+(0) = 0.984(12)$ (see Neufeld)

CKM unitarity



V_{us}	K_{l3}
V_{us}/V_{ud}	$K_{\mu 2}/\pi_{\mu 2}$
V_{ud}	$0^+ \to 0^+$ β decay (HardyTowner07)

New value available

$|V_{us}| = 0.2249 \pm 0.0010$
$|V_{ud}| = 0.97418 \pm 0.00026$

$1 - |V_{us}|^2 - |V_{ud}|^2 = 0.0004 \pm 0.0007$

Was 0.0031 ± 0.0015 in PDG04

KLOE-Sibidanov-CKM

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Experimental evaluation of $f_+(0)$ and f_K/f_π

Matthew Moulson and Barbara Sciascia
LNF-INFN
for the FlaviaNet Working Group on Kaon decays

prepared for the FlaviaNet meeting,
Durham, 22-26 September 2008

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Summary

- Use $K\mu2/\pi\mu2$ ratio to evaluate f_K/f_π / $f_+(0)$ by fitting with experimental inputs

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

- use RBC-UKQCD07 **$f_+(0) = 0.9644(49)$** as reference th. value;
- use HPQCD-UKQCD07 **$f_K/f_\pi = 1.189(7)$** as reference th. value.
- Details of the experimental inputs:
  - $|V_{us} \times f_+(0)|$: FlaviaNet average;
  - Theoretical corrections entering $|V_{us} \times f_+(0)|$ value;
  - $|V_{ud}|$ from nuclear β–decays;
  - Theoretical corrections entering V_{ud} value;
  - Kinematical factor and its theoretical corrections.

- Definition of fit constraints.
- Outputs for different fit configurations.

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Definition of the experimental inputs

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

C: constant, including corrections.

$$\frac{\Gamma(K_{\mu2(\gamma)})}{\Gamma(\pi_{\mu2(\gamma)})} = \frac{|V_{us} f_+(0)|^2}{|V_{ud}|^2} \times \frac{1}{f_+(0)^2} \frac{f_K^2}{f_\pi^2} \times C$$

From decay rates

From Kl3

From nucl. β-decay

- $|V_{us} f_+(0)| = 0.2167(5)$
- $|V_{ud}| = 0.97425(23)$
- $\Gamma(K_{\mu2}) / \Gamma(\pi_{\mu2})/C = 0.076197(322)$

Details on $|V_{us}|\times f_+(0)$

Use FlaviaNet@CKM08 value:

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

Only experimental inputs (BRs, lifetimes, form factors) with the exception of **theoretical estimations** of:

- ***em* corrections** from ChPT $O(e^2p^2)$ with detailed error matrix (Cirigliano, Giannotti, and Neufeld, 0807.4507[hep-ph])
- **SU(2) breaking corrections**.

	$\delta^K_{SU(2)}$(%)	$\delta^{K\ell}_{em}$(%)
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 $|V_{us}|f_+(0)$

Details on $|V_{ud}|$

V_{ud} from nuclear β–decay: V_{ud} = 0.97425(23) presented by Towner at CKM08;
- total fractional error at **0.2 per mil**;
- new review paper in preparation [Hardy and Towner]

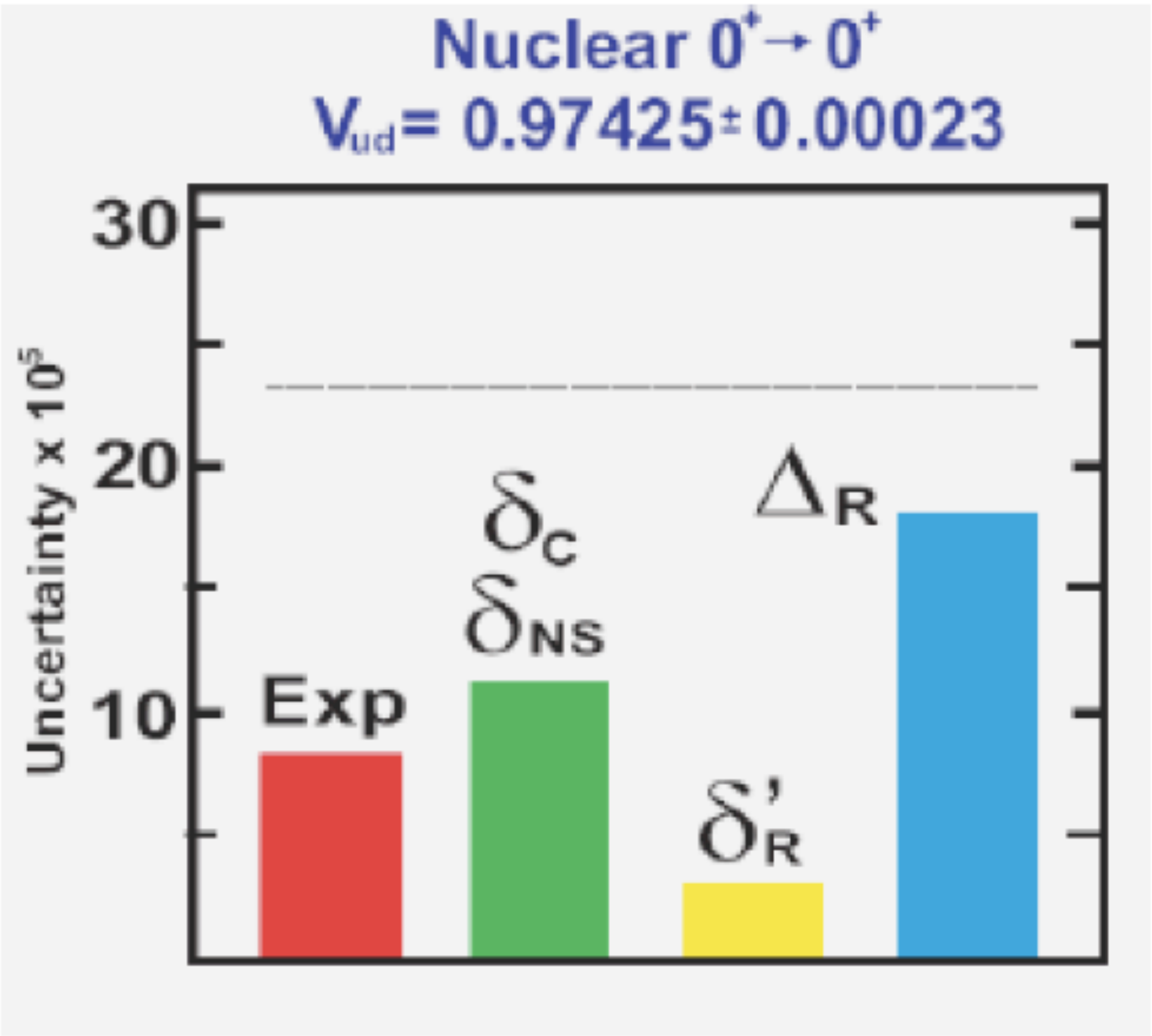
- **Theoretical contributions** to the V_{ud} determination:

δ_C: SU(2) breaking corrections

δ_{NS}: "small" nuclear-structure dependent component

δ'_R: "trivially" nucleus-dependent component

Δ_R: nucleus-independent component



Details on kinematic factor

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

C: constant, including corrections.

$\Gamma(K_{\mu 2})/\Gamma(\pi_{\mu 2})/C = 0.076197(322)$

- K lifetime and BR($K\mu 2$) from FlaviaNet
- π lifetime and BR($\pi\mu 2$) from PDG08
- masses from PDG08.

Theoretical contributions: radiative corrections [Marciano, hep-ph/0402299]

- C_K and C_π include short–distance EW effects and long–distance radiative corrections.
- use the difference: $C_K - C_\pi = 3.0 \pm 1.5$ [e.g. Finkemeier, hep-ph/9412267]
- conservative estimate of the error;
- dominant error contribution from hadronic structure dependent radiative corrections.

$f_+(0)$ and f_K/f_π: straight calculation

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$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us} f_+(0)|^2}{|V_{ud}|^2} \times \frac{1}{f_+(0)^2} \frac{f_K^2}{f_\pi^2} \times C$$

From decay rates — From Kl3 — From nucl. β-decay

Straight calculation from Kμ2/πμ2 relation and assuming SM:

- $f_K/f_\pi / f_+(0) = 1.2409(46)$

- **using** $f_+(0) = 0.9644(49)$ [RBC-UKQCD07] **obtain** $f_K/f_\pi = 1.1967(75)$
- **using** $f_K/f_\pi = 1.189(7)$ [HPQCD-UKQCD07] **obtain** $f+(0) = 0.9582(67)$

Experimental and theoretical evaluations agree to within ~1σ.

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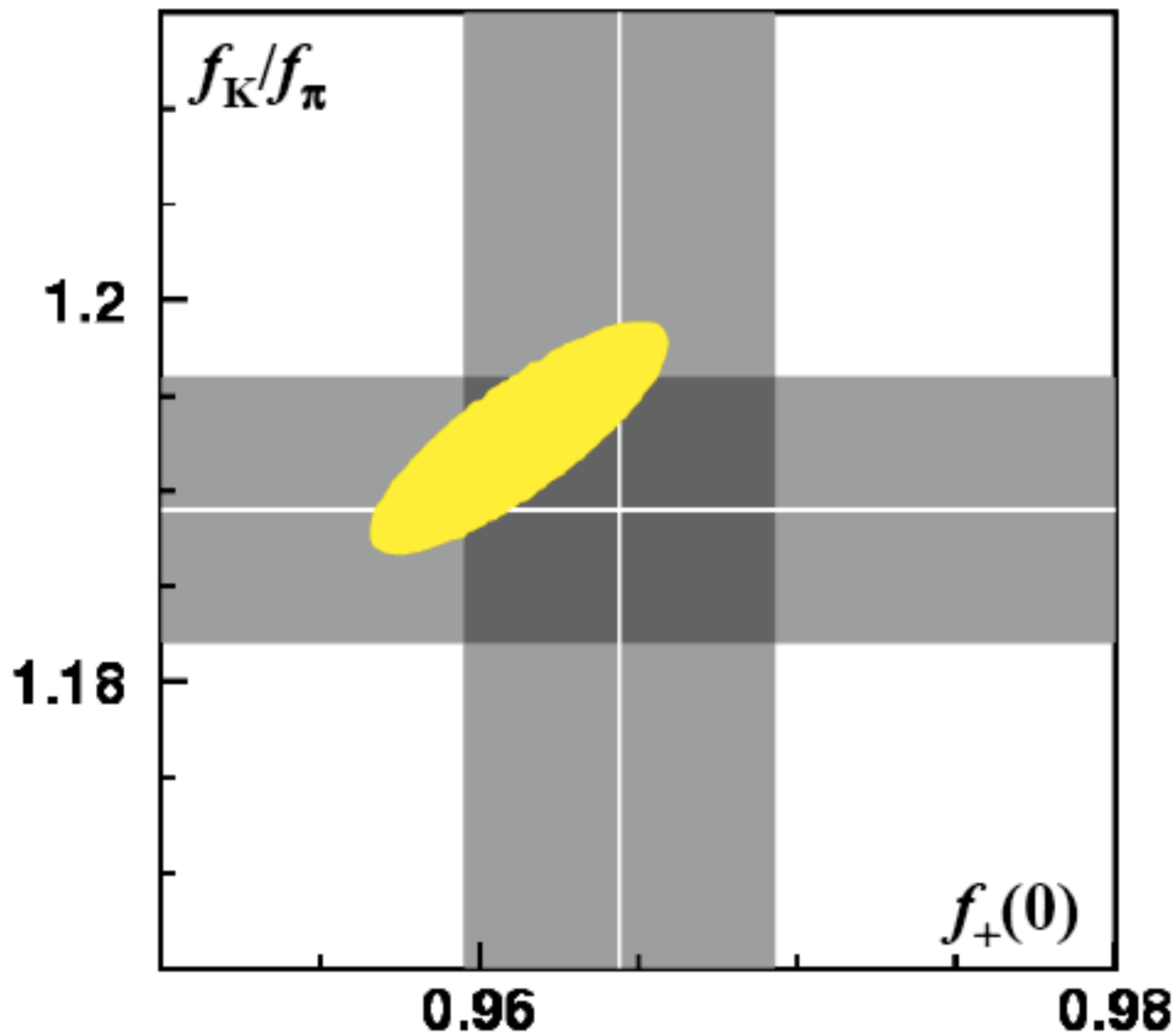
$f_+(0)$ and f_K/f_π: 0C fit

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us} f_+(0)|^2}{|V_{ud}|^2} \times \frac{1}{f_+(0)^2} \frac{f_K^2}{f_\pi^2} \times C$$

Assuming SM

From decay rates — From Kl3 — From nucl. β-decay

- Obtain f_K/f_π and $1/f_+(0)$ values from a fit.
- 5 parameters: V_{ud}, $V_{us} f_+(0)$, $\Gamma(K_{\mu 2}/\pi_{\mu 2})/C$, f_K/f_π, and $f_+(0)$.
  - 3 inputs: V_{ud}, $V_{us} f_+(0)$, $\Gamma(K_{\mu 2}/\pi_{\mu 2})/C$
  - 2 constraints:
    $\Gamma(K\mu 2)/\Gamma(\pi\mu 2)$ relation and Unitarity
- Obtain:
  $f_K/f_\pi = 1.1928(61)$ and $f_+(0) = 0.9612(47)$
  with a correlation of 0.82 (complete correlation matrix available)



- Very good agreement with th. estimations:
  $f_K/f_\pi = 1.189(7)$ and $f_+(0) = 0.9644(49)$.

$f_+(0)$ and f_K/f_π: 1C fit

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us} f_+(0)|^2}{|V_{ud}|^2} \times \frac{1}{f_+(0)^2} \frac{f_K^2}{f_\pi^2} \times C$$

Assuming SM

From decay rates — From Kl3 — From nucl. β-decay

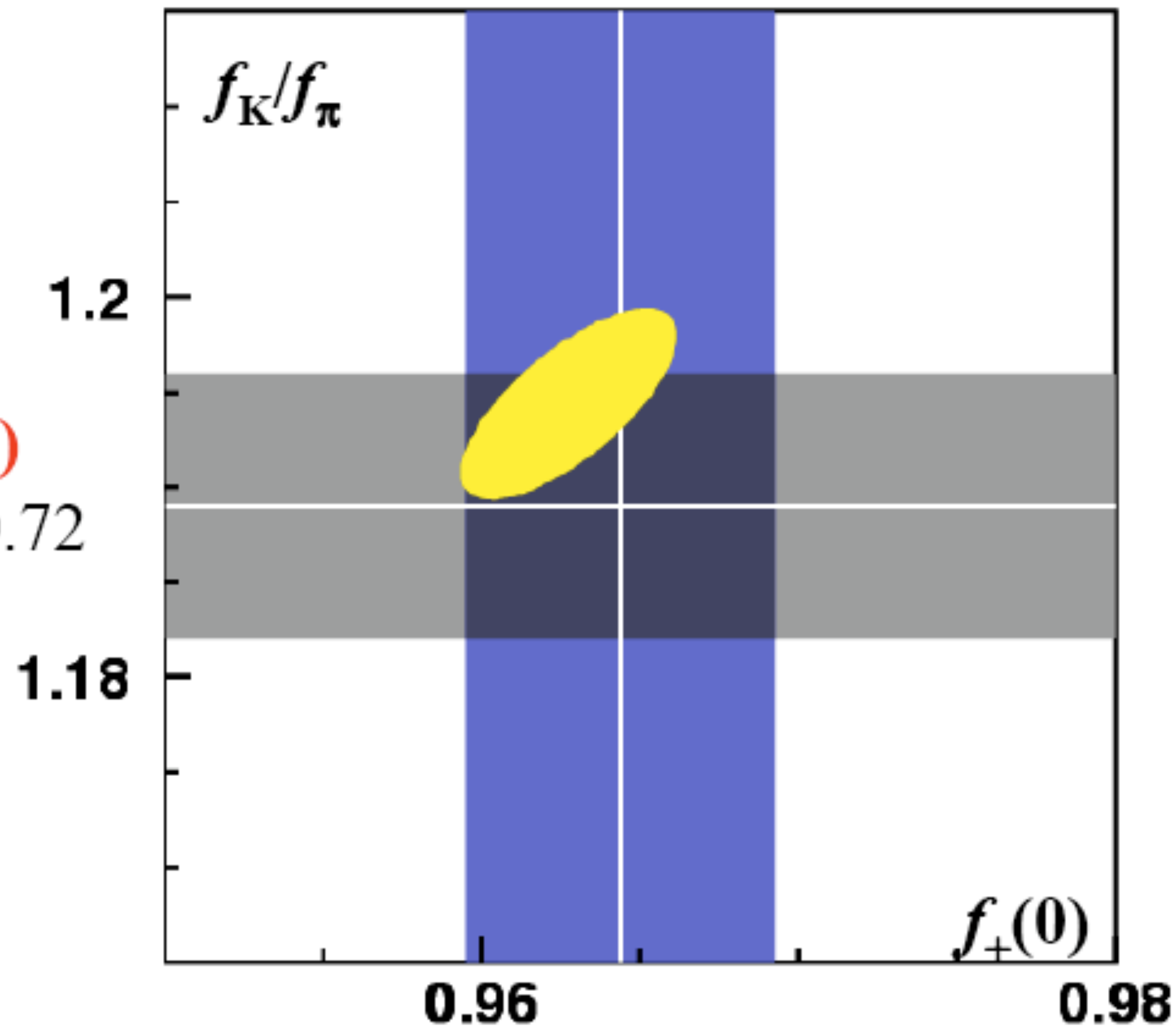
- Obtain f_K/f_π and $f_+(0)$ values from a fit:
  - one more input: $f_+(0) = 0.9644(49)$
  - 2 constraints:

    Γ(Kμ2)/Γ(πμ2) relation and Unitarity.
- Obtain:

  f_K/f_π = 1.1944(50) and **$f_+(0)$ = 0.9628(34)**

  with χ^2=0.22/1 (64%) and a correlation of 0.72 (complete correlation matrix available)

- Again very good agreement with th. estimations: f_K/f_π = 1.189(7) and $f_+(0)$ = 0.9644(49) (used as fit input).



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Conclusions

0C FIT

[no theory input for f_K/f_π or $f_+(0)$]

$f_K/f_\pi = 1.1928(61)$

$f_+(0) = 0.9612(47)$

1C FIT

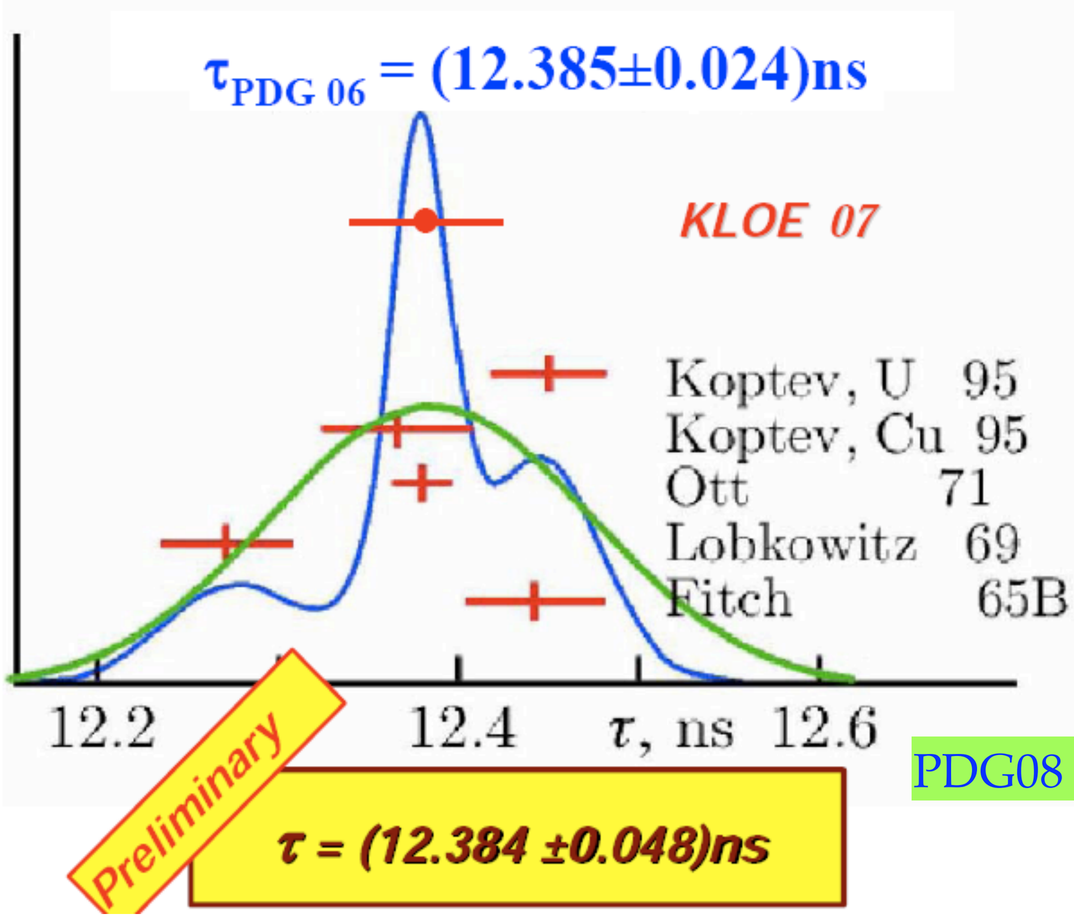
[$f_+(0) = 0.9644(49)$ used as input]

$f_K/f_\pi = 1.1944(50)$

$f_+(0) = 0.9628(34)$

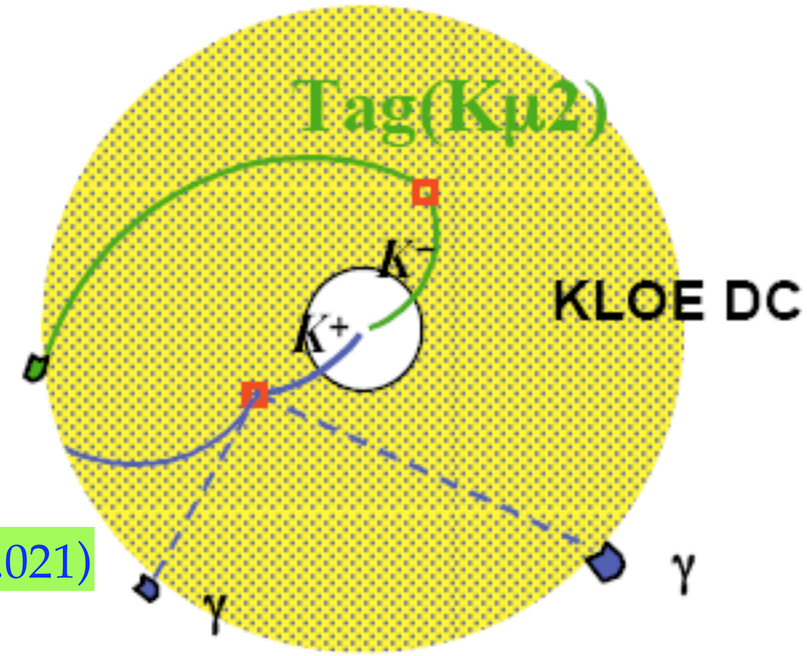
Good agreement of current world results on $|V_{ud}|$ and $|V_{us}|$ with first-row unitarity constraint translates into expected values for f_K/f_π and $f_+(0)$ in agreement with recent lattice estimates.

$K^{\pm}$ lifetime from KLOE



PDG08 (12.380±0.021)

- Tag events with $K^{\pm} \to \mu\nu$ decay
- Identify a kaon decay on the opposite side



KLOE preliminary, 2 different methods:

$\tau_{\pm}$ from the K decay length, using tagged vertices in DC

$\tau_{\pm}$= 12.367(44)(65) ns

$\tau_{\pm}$ from the K decay time, using γ from $K^{\pm} \to \pi^{\pm}\pi^{0}$ decays

$\tau_{\pm}$= 12.391(49)(25) ns

Combined result (ρ = 0.34): $\tau_{\pm}$= 12.384(48) ns

The ratio R_K

R_K accurately predicted within the SM:

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu_e)}{\Gamma(K^\pm \to \mu^\pm \nu_\mu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \cdot 10^{-5}$$

[V. Cirigliano and I Rosell, JHEP 0710:005 (2007)]

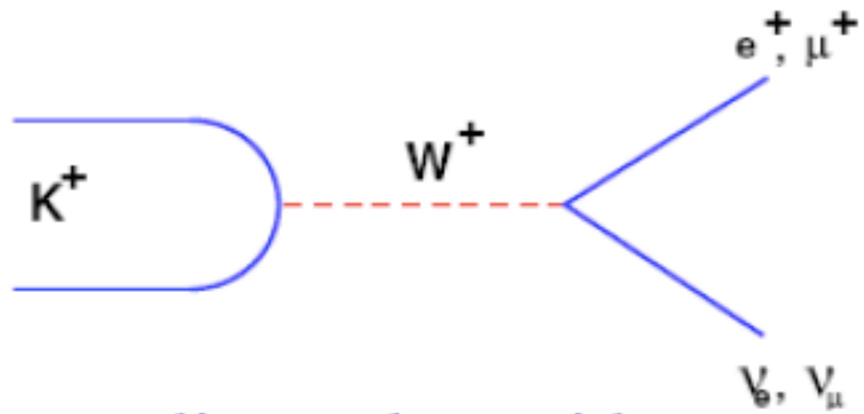
Helicity suppression

Radiative corrections

ChPT, $O(e^2p^4)$

Adronic contributions cancel in the ratio

→ R_K is sensitive to New Physics due to the helicity suppression



A precise measurement of R_K probes μ–e universality and provides a stringent test of the SM.

$\delta R_K = -3.8\%$ compared to $\Delta R_K / R_K \sim 0.04\%$

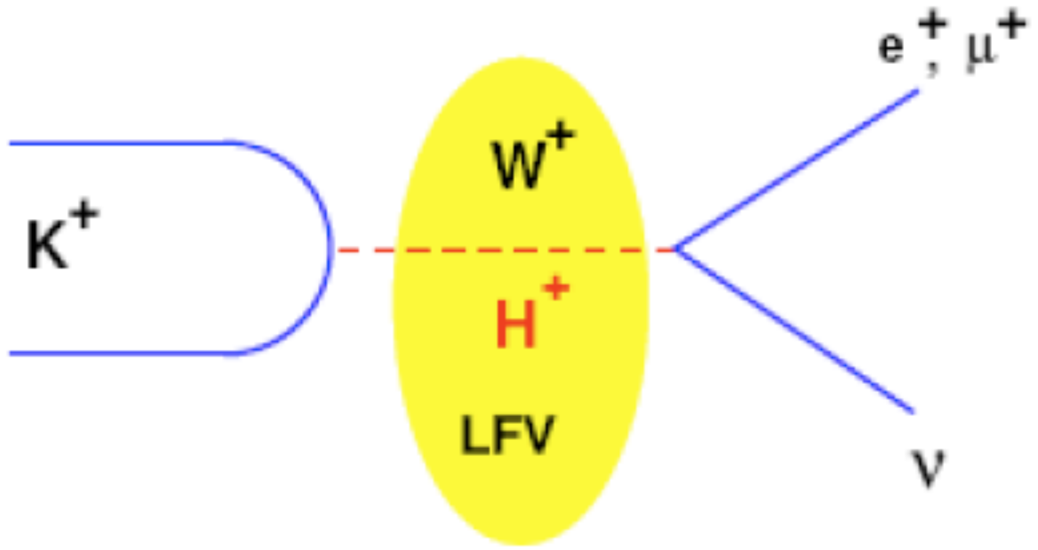
($K_{l2\gamma}$ and virtual photons)

R_K beyond the SM

SUSY effects (MSSM framework) can modify R_K wrt SM up to 3%

(Masiero, P. Paradisi, R. Petronzio hep-ph/0511289 PRD74 (2006))

R-parity is the source of new physics effect on R_K



Yukawa LFV effective couplings:

$$lH^{\pm}\nu_{\tau} \rightarrow \frac{g_2}{\sqrt{2}} \frac{m_{\tau}}{M_W} \Delta_R^{3l} \tan^2 \beta \qquad l = e, \mu$$

Δ^{31} is the LFV term connected to helicity suppression in Ke2

R_K in SUSY

The measurement of R_k produces limits to the value of $\Delta_{31}=\Delta_{31}(m_{H\pm},\tan\beta)$

$$R_K^{LFV} \approx R_K^{SM}\left[1+\left(\frac{m_K^4}{m_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_{31}|^2 \tan^6\beta\right]$$

- Loop diagrams mainly contribute
- LFC contributions $O((\tan\beta)^2)$ suppressed
- For large $\tan\beta$ values (still not experimentally excluded) LFV contributions $O(\tan\beta)^6$ dominate producing sizable effects on R_K
- Destructive interference between SM and SUSY LFC (arising from double LFV Mass Insertions) can give negative correction to R_K^{SM}

$\tan\beta=40$ e $M_H=500$ GeV/c^2

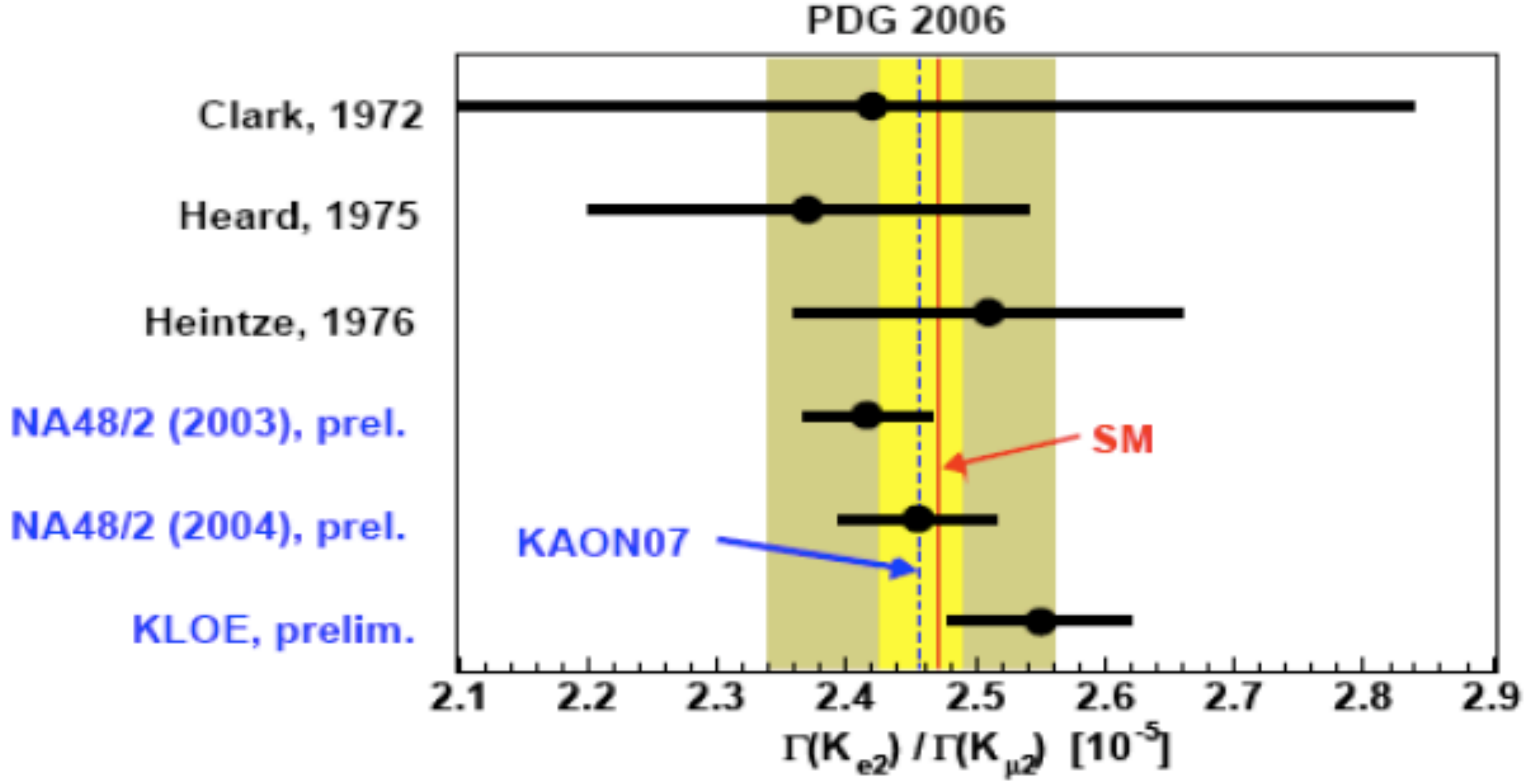
$$R_K^{LFV} = R_K^{SM}(1+0.013)$$

M Piccini

Flavianet fit to R_K

Before NA48/2 and Kloe results → $R_K^{PDG} = (2.45 \pm 0.11) \cdot 10^{-5}$ $\delta R_K / R_K = 4.5\%$

Flavianet fit to R_K combining PDG 2006, NA48/2 and KLOE results:



$$R_K = (2.457 \pm 0.032) \cdot 10^{-5} \qquad (\chi^2 / ndf = 2.44/3)$$

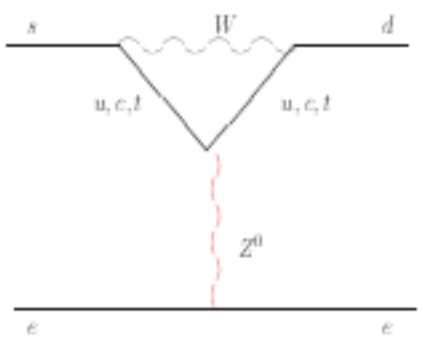
- ✓ Big improvement wrt PDG → now $\delta R_K/R_K \sim 1.3$ %
- ✓ Good agreement with SM prediction

Motivations

SM at short distance predicts the current⊗current structure for $K \to \pi e^+ e^-$

$$\mathcal{H} \sim \frac{G_F \alpha}{\sqrt{2} M_W^2} \quad \overline{s}_L \gamma_\mu d_L \quad \overline{e}_L \gamma^\mu e_L \quad \left[\sum_q V_{qs}^* V_{qd}\, m_q^2 \right] + h.c.$$

$$\left[A^2 \lambda^5 \,(1 - \rho - i\eta) m_t^2 + \lambda m_c^2 \right]$$



Gilman,Wise; Buchalla,Buras, Lautenbacher

$$K_L \to \pi^0 e^+ e^- \quad \begin{cases} \text{CP violating} \\ \text{sensitivity to new physics} \\ Im\lambda_t = \Im(V_{ts}^* V_{td}) \end{cases}$$

$K_L \to \pi^0 e^+ e^-$ vs. $K_L \to \pi^0 \nu\overline{\nu}$

- $K_L \to \pi^0\nu\overline{\nu}\ \overbrace{(2.76 \pm 0.40)}^{\text{SM}} \cdot 10^{-11}$ $\quad \overbrace{< 6.7 \cdot 10^{-8}}^{\text{E391a}}$ no e.m. bck.
-

$$K_L \to \pi^0 e^+ e^- : \overbrace{\sim 1 \cdot 10^{-11}}^{\text{SM}} \quad \text{But} \begin{cases} K_L \to \pi^0\gamma\gamma \to \pi^0 e^+ e^- \\ K_L = K_2 + \epsilon K_1 \to \pi^0 e^+ e^- \end{cases}$$

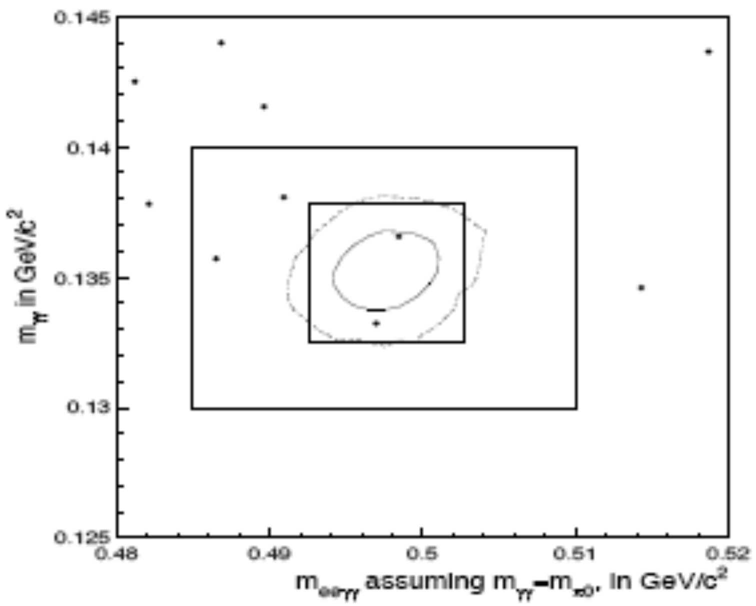
- – Greenlee bck.

$$Br(K_L \to e^+e^-\gamma\gamma) \quad \begin{cases} (5.8 \pm 0.3) \cdot 10^{-7} & \text{No kin. cut} \\ 1 \cdot 10^{-10} & \text{kin. cut} \end{cases}$$

- $\frac{\text{signal}}{\text{bck.}} \sim 0.1$ But bck. can be known accurately (QED)$\Longrightarrow$ statistics

$Br(K_L \to \pi^0 e^+ e^-)$ KTeV

- '97('99) $2.6 \cdot 10^{11}\ K_L$
- expected bck. 1 evt. '97 ('99) 2 evt. (1)
- $Br < 5.1 \cdot 10^{-10}$ (3.5) combined $< 2.8 \cdot 10^{-10}$



KTeV

Foreseen statistics to measure the Direct- CP-violating part in the SM $\Im\lambda_t$ at 30% : 1.000 more K_L

Control over three contributions

- Direct CP violation in $K_L \to \pi^0 e^+ e^-$
- CP conserving $K_L \to \pi^0 e^+ e^-$
- $K_L = K_2 + \epsilon K_1 \to \pi^0 e^+ e^-$

Short distance contribution to $K_L \to \pi^0 e^+ e^-$

$K_2 \to \pi^0 (e^+ e^-)_{J=1}$ dominated by the s.d.

$$Q_{7V} = \overline{s}\gamma^\mu(1-\gamma_5)d\,\overline{\ell}\gamma_\mu\ell\ , \qquad Q_{7A} = \overline{s}\gamma^\mu(1-\gamma_5)d\,\overline{\ell}\gamma_\mu\gamma_5\ell$$

$$\begin{aligned} B(K_L \to \pi^0 e^+ e^-)_{\mathrm{CPV-dir}} &= \frac{\tau(K_L)}{\tau(K^+)} \frac{B(K^+_{e3})}{|V_{us}|^2} (y_{7A}^2 + y_{7V}^2) \left[\Im(V_{ts}^* V_{td})\right]^2 \ , \\ &= (2.45 \pm 0.22) \times 10^{-12} \left[\frac{\Im\lambda_t}{10^{-4}}\right]^2 \end{aligned}$$

where

$\Im\lambda_t = \Im(V_{ts}^* V_{td})$ from Buchalla et al,CKM

$K_L(p) \to \pi^0(p_3)\gamma(q_1)\gamma(q_2)$

Lorentz + gauge invariance $\Rightarrow$ $M \sim$ $A(y,z)$ $B(y,z)$

$y = p\cdot(q_1 - q_2)/m_K^2$, $z = (q_1+q_2)^2/m_K^2$, $r_\pi = m_\pi/m_K$

	$A(y,z)$	$B(y,z)$
	$\gamma\gamma$	$\gamma\gamma$
	$J=0$	D − wave too
	$F^{\mu\nu}F_{\mu\nu}$	$F^{\mu\nu}F_{\mu\lambda}\partial_\nu K_L \partial^\lambda \pi^0$

- $\frac{d^2\Gamma}{dydz} \sim z^2|A+B|^2 + \left(y^2 - \left(\frac{(1+r_\pi^2 - z)^2}{4} - r_\pi^2\right)\right)^2 |B|^2$ S, B
- Different gauge structure $\Rightarrow$ B≠0 at $z \to 0$ (collinear photons).

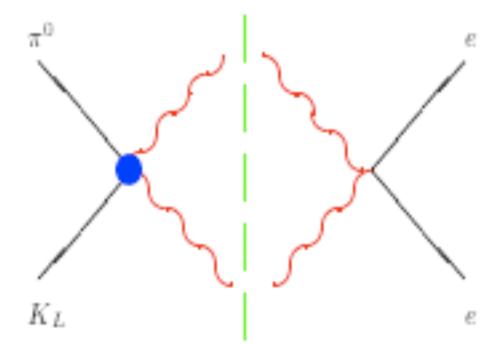
Crucial role in $K_L \to \pi^0 e^+ e^-$

A suppressed by m_e/m_K

B is not

Morozumi et al, Flynn Randall

Sehgal Heiliger, Ecker et al., Donoghue et al.

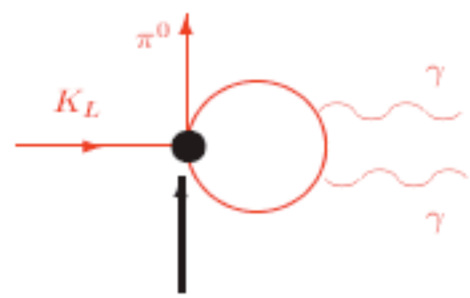


$K_L \to \pi^0\gamma\gamma$

- $O(p^4)$ Ecker, Pich, de Rafael; Cappiello,G.D

CT Loop

0

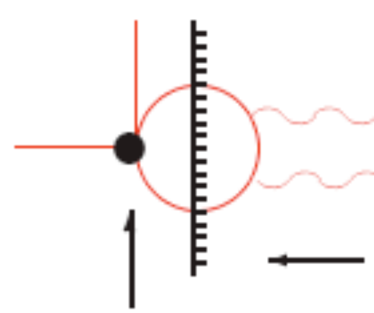


only A **But** $\frac{\Gamma(K_L\to\pi^0\gamma\gamma)_{p_4}}{\Gamma(K_L\to\pi^0\gamma\gamma)_{exp}} \sim \frac{1}{2.5}$

G_8 from $K_S \to 2\pi$

- $O(p^6)$ A, B from:

3 CT′s
$F_{\mu\nu}F^{\mu\alpha}\partial_\alpha K_L \partial^\nu \pi^0$
$F^2\ \partial K_L \partial \pi^0$
$F^2\ m_K^2 K_L \pi^0$



Cappiello, G.D., Miragliulo
Cohen, Ecker, Pich

Full description of unitarity cut

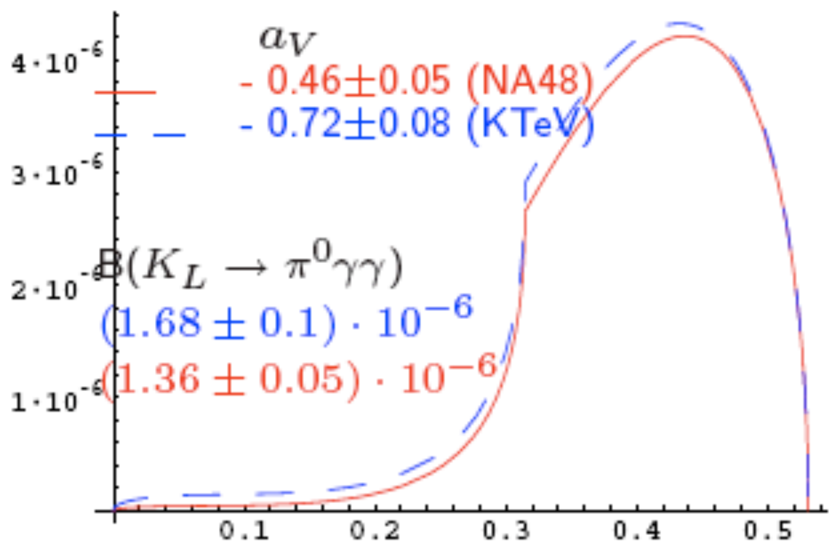
$A(K\to 3\pi) = a + b\ Y + c\ Y^2 + d\ X^2$

$$A_{\rm CT} = \alpha_1(z - r_\pi^2) + \alpha_2$$
$$B_{\rm CT} = \beta$$

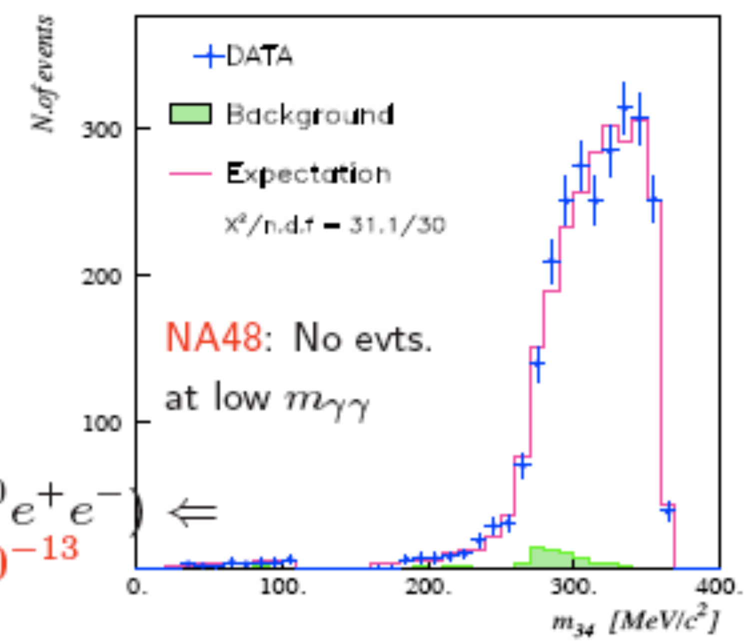
VMD $\Rightarrow$ 1 coupling a_V (~ -0.6 G.D., Portoles)
(Ecker, Pich, de Rafael;Sehgal et al.)

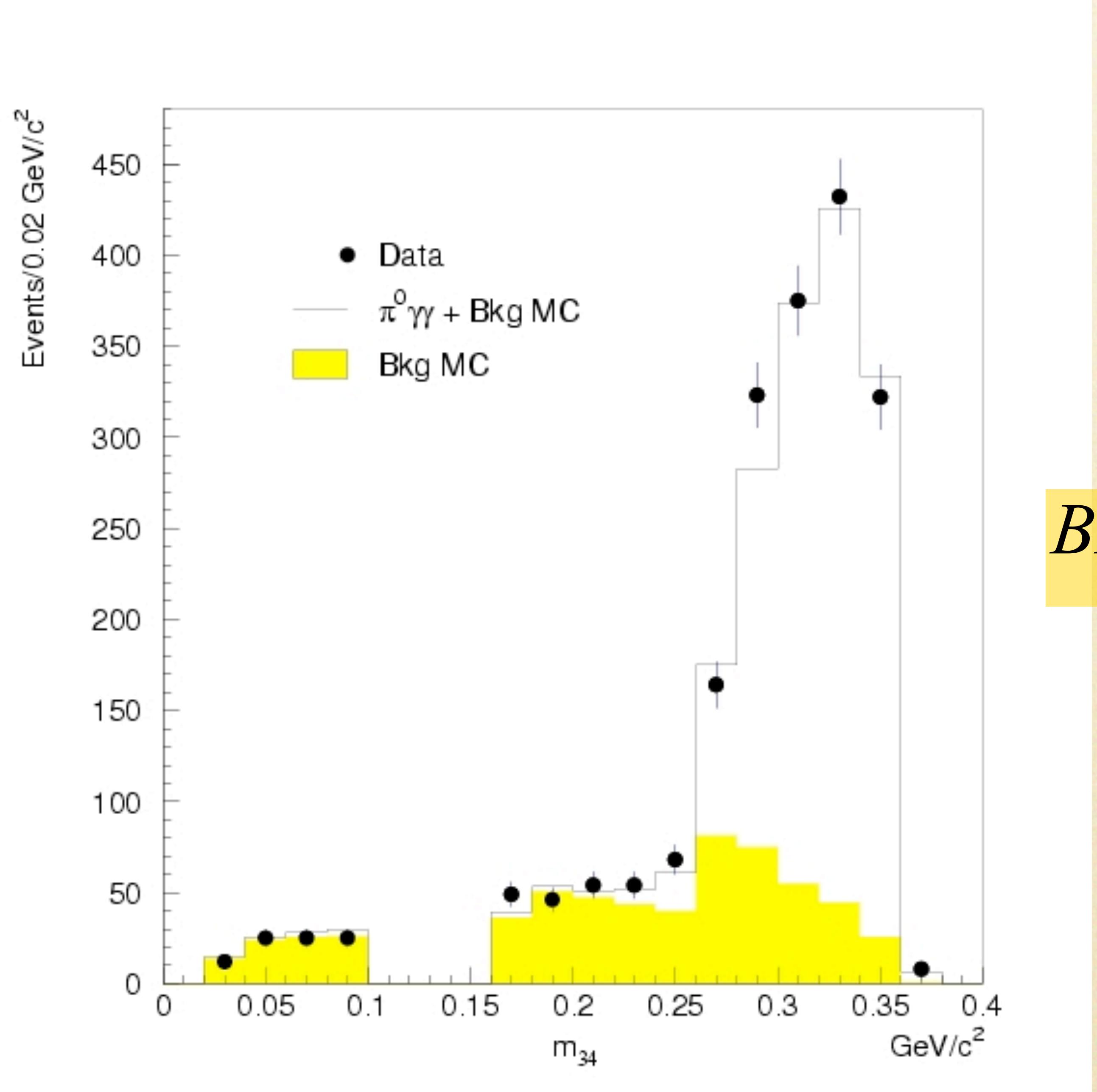
$$\alpha_1 = \frac{\beta}{2} = -\frac{\alpha_2}{3} = -4a_V \sim 2 \qquad \text{n.d.a.}\sim 0.2$$

- KTeV and NA48: 1 parameter fit (a_V) with all the unitarity corrections



$B(K_L \to \pi^0 e^+ e^-) \Leftarrow$
$< 5 \cdot 10^{-13}$





KTeV

New KTeV result on full dataset
1982 events
Normalization to $K_L \rightarrow \pi^0\pi^0$
30% background ($K_L \rightarrow 3\pi^0$)

$$BR = (1.29 \pm 0.03 \pm 0.05) \times 10^{-6}$$

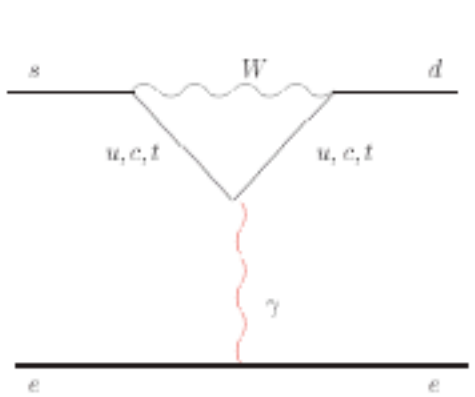
Supersedes previous KTeV result (half dataset) $BR=(1.55\pm0.07\pm0.08)\cdot10^{-6}$

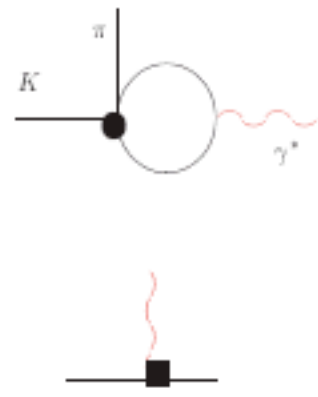
Agrees with NA48 2002 result: $BR=(1.27\pm0.04\pm0.01)\cdot10^{-6}$

$K^{\pm}(K_S) \to \pi^{\pm}(\pi^0)\ell^+\ell^-$

- short distance << long distance

LD described by form factor W





$$W^i = G_F m_K^2 (a_i + b_i z) + W^i_{\pi\pi}(z)$$

$$i = \pm, S$$

$$a_i, b_i \sim O(1), \qquad z = \frac{q^2}{m_K^2}$$

- Observables $\Gamma(K^+ \to \pi^+ e^+ e^-)$, $\Gamma(K^+ \to \pi^+ \mu\overline{\mu})$, slopes
- $a_i \quad O(p^4)$ — Ecker, Pich, de Rafael
- $b_i \quad O(p^6)$ — G.D., Ecker, Isidori, Portoles
- $a_+,\ b_+$ in general not related to $a_S,\ b_S$

- Expt. E865
  $K^+ \to \pi^+ e^+ e^- : \quad a_+ = -0.586 \pm 0.010 \quad b_+ = -0.655 \pm 0.044$

  confirmed by NA48/2 (1.4 σ's away) also in $K^+ \to \pi^+ \mu\overline{\mu}$

- HyperCP has confirmed E865 (02) ($K^+ \to \pi^+ \mu\overline{\mu}$) and put a bound on the CP asymmetry (≤ 0.1)

Problems:	a_i	b_i	same phenomenological size
	p^4	p^6	different theoretical order

Probably explained by large VMD. Then we can just parameterize

$$\mathrm{Br}(K_S \to \pi^0 e^+ e^-) = 4.6 \times 10^{-9} a_S^2$$

not predicted but dynamically interesting: $a_S \sim \mathcal{O}(1)$: NA48 Great expt!

$K_S \to \pi^0 e^+ e^-$ at NA48/1 Collaboration at CERN

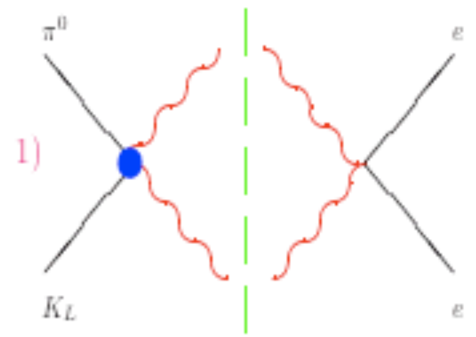
- 7 events observed (with 0.15 expected background events)

$$B(K_S \to \pi^0 e^+ e^-)_{m_{ee}>165 \text{ MeV}} = \left(3.0^{+1.5}_{-1.2} \pm 0.2\right) \times 10^{-9}$$

$$|a_S| = 1.08^{+0.26}_{-0.21}$$

$K_L \to \pi^0 e^+ e^-$: summary

$\mathrm{Br}(K_L \to \pi^0 e^+ e^-) \leq 5 \cdot 10^{-10}$ KTeV

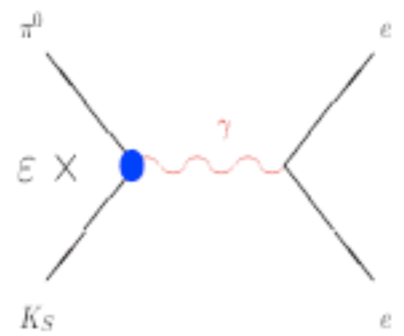


CP conserving NA48

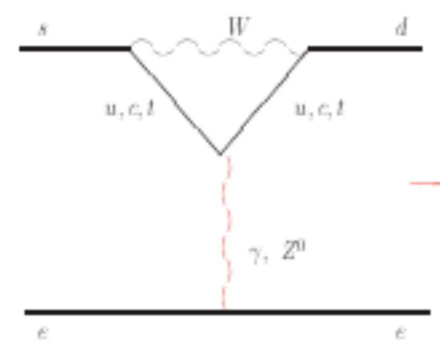
$\mathrm{Br}(K_L \to \pi^0 e^+ e^-) < 3 \cdot 10^{-12}$

V-A$\otimes$ V-A $\Rightarrow \langle \pi^0 e^+ e^- | (\bar{s}d)_{V-A} (\bar{e}e)_{V-A} | K_L \rangle$ violates CP

2) $\varepsilon \times$



$+$ 3)



$\longrightarrow \text{Im}\,\lambda_t$

$\lambda_t = V_{td} V_{ts}^*$

$\uparrow$ $\mathrm{B}(K_S \to \pi^0 e^+ e^-) = 4.6 a_S^2 \times 10^{-9}$

Possible large interference: $a_S < -0.5$ or $a_S > 1$; short distance probe even for a_S large

$$|2) + 3)|^2 = \left[15.3\ a_S^2 - 6.8 \frac{Im\lambda_t}{10^{-4}}\ a_S + 2.8 \left(\frac{Im\lambda_t}{10^{-4}} \right)^2 \right] \cdot 10^{-12}$$

$$[17.7 \pm \quad 9.5 + \quad 4.7] \quad \cdot 10^{-12}$$

- The large slope for $K^+ \to \pi^+ e^+ e^-$ calls for large VMD
- $K^+ \to \pi^+ e^+ e^-$ receives substantial $\pi\pi$-loop, contrary to $K_S \to \pi^0 e^+ e^-$ (~ 0),
- if we split

$$\left(\frac{a_i^{\rm VMD}}{1 - z m_K^2 / m_V^2} + a_i^{\rm nVMD} \right) \approx \left[\left(a_i^{\rm VMD} + a_i^{\rm nVMD} \right) + a_i^{\rm VMD} \frac{m_K^2}{m_V^2} z \right]$$

Then we can determine both terms from expt.

$$a_+^{\rm VMD} = \frac{m_V^2}{m_K^2} b_+^{\rm exp} = -1.6 \pm 0.1 \; , \qquad a_+^{\rm nVMD} = a_+^{\rm exp} - a_+^{\rm VMD} = 1.0 \pm 0.1$$

- Also we can hope $a_i^{\rm VMD}$ obey a short distance relation since i) VMD is a larger scale and ii) NOT affected by $\pi\pi$-loop
- The only operator at short distances is $Q_7 = \overline{s}\gamma^\mu(1-\gamma_5)d\,\overline{\ell}\gamma_\mu\ell$,

$$\mathcal{H}_{eff}^{|\Delta S|=1} = \frac{G_F}{\sqrt{2}} V_{us}^* V_{ud} \Big[\sum_{i=1}^{6,7V} (z_i(\mu) + \tau y_i(\mu)) Q_i(\mu) \ + \ \tau y_{7A}(M_W) Q_{7A}(M_W) \Big]$$

$\tau = -V_{ts}^* V_{td}/V_{us}^* V_{ud}$. The Wilson coefficients $z_7(\mu)$ and $\tau y_7(\mu)$ determine the CPC CPV amplitudes and their relative sign. The isospin structure of Q_{7V} leads

$$(a_S)_{\langle Q_{7V}\rangle} = -(a_+)_{\langle Q_{7V}\rangle}$$

- If this relation is obeyed by the full VMD amplitude

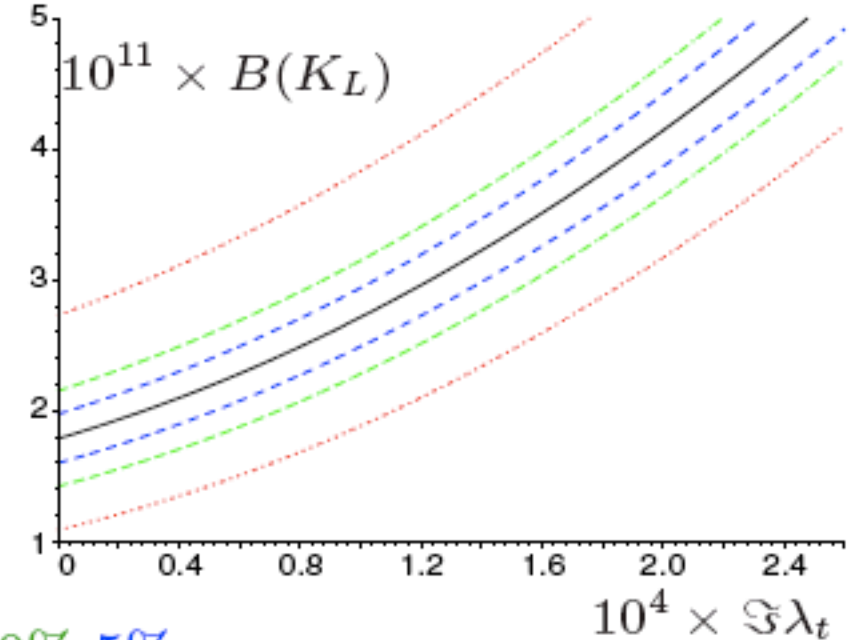
$$(a_S^{\rm VMD})_{\langle Q_{7V}\rangle} = -a_+^{\rm VMD} = 1.6 \pm 0.1$$

in good agreement with NA48 $(|a_S| = 1.08^{+0.26}_{-0.21})$

- Having i) separated the contribution better suited to comparison with s.d. (VMD) and ii) realized that this dominates Theoret. and Phenom.(NA48) a_S

- we believe the positive interference of s.d.

$$B(K_L \to \pi^0 e^+ e^-)_{\rm SM} = (3.1^{+1.2}_{-0.9}) \times 10^{-11} \quad a_S$$



$$\text{KTeV} \quad B(K_L \to \pi^0 e^+ e^-)$$

$$< 2.8 \times 10^{-10} \quad \text{at} \quad 90\,\%\text{C.L.}$$

Present error on $a_S = 1.08$, 10% 5%, no error

K-physics bound: $-1.2 \times 10^{-3} < \Im\lambda_t < 1.0 \times 10^{-3}$ at $90\,\%$C.L.

see Mescia et al. for updated CKM

Chiral Perturbation Theory

χPT effective field theory based on the two assumptions

- π's are the Goldstone boson of $SU(3)_L \otimes SU(3)_R \to SU(3)_V$
- *(chiral) power counting* i.e. the theory has a small expansion parameter: $p^2/\ \Lambda^2_{\chi SB}$: $\Lambda_{\chi SB} \sim 4\pi F_\pi \sim 1.2$ GeV

$$\mathcal{L}_{\Delta S=0} = \mathcal{L}^2_{\Delta S=0} + \mathcal{L}^4_{\Delta S=0} + \cdots = \frac{F_\pi{}^2}{4} \overbrace{\langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + U \chi^\dagger \rangle}^{\pi\to l\nu,\ \pi\pi\to\pi\pi,\ K\to\pi..} + \overbrace{\sum_i L_i O_i}^{K\to\pi..} + \cdots$$

Fantastic chiral prediction $A_{\pi\pi} \sim (s - m_\pi^2)/F_\pi{}^2$ Weinberg, Colangelo *et al*

$$\mathcal{L}_{\Delta S=1} = \mathcal{L}^2_{\Delta S=1} + \mathcal{L}^4_{\Delta S=1} + \cdots = G_8 F^4 \underbrace{\langle \lambda_6 D_\mu U^\dagger D^\mu U \rangle}_{K\to 2\pi/3\pi} + \underbrace{G_8 F^2 \sum_i N_i W_i}_{K^+\to\pi^+\gamma\gamma,\, K\to\pi l^+ l^-} + \cdots$$

Vector Meson Dominance in the strong sector

Ecker,Gasser,de Rafael,Pich

i	$L_i^r(M_\rho)$	V	A	Total	Total[c)]
1	0.4 ± 0.3	0.6	0	0.6	0.9
2	1.4 ± 0.3	1.2	0	1.2	1.8
3	-3.5 ± 1.1	-3.6	0	-3.0	-4.9
4	-0.3 ± 0.5	0	0	0.0	0.0
5	1.4 ± 0.5	0	0	1.4	1.4
6	-0.2 ± 0.3	0	0	0.0	0.0
7	-0.4 ± 0.2	0	0	-0.3	-0.3
8	0.9 ± 0.3	0	0	0.9	0.9
9	6.9 ± 0.7	6.9[a)]	0	6.9	7.3
10	-5.5 ± 0.7	-10.0	4.0	-6.0	-5.5

[c)] uses QCD "inspired" relations

$$F_V = 2G_V = \sqrt{2} f_\pi,$$
$$F_A = f_\pi$$
$$M_A = \sqrt{2} M_V$$

$$L_1^V = \frac{L_2^V}{2} = -\frac{L_3^V}{6} = \frac{G_V^2}{8M_V^2}, \qquad L_9^V = \frac{F_V G_V}{2M_V^2}, \qquad L_{10}^{V+A} = -\frac{F_V^2}{4M_V^2} + \frac{F_A^2}{4M_A^2}$$

Theoretical motivations of success of VMD

- VMD improves the matching with QCD Ecker,Gasser,Leutwyler,Pich,de Rafael

$$F_V^{\pi^\pm}(t) \approx \frac{M_\rho^2}{M_\rho^2 - t},$$

$$L_1^V = L_2^V/2 = -L_3^V/6 = L_9^V/8 = -L_{10}^{V+A}/6 = f_\pi^2/(16M_V^2)\,.$$

- Picture consolidated by in the chiral quark model $\chi\mathrm{QM}$ Georgi-Manohar;Espriu,de Rafael,Taron
This is a dynamical interpretation (in CHPT) of the success of the non-relativstic quark model. In this model

$$L_i^{\chi\mathrm{QM}} \sim L_i^{VMD}$$

- Also Large N

- Strong consolidated picture: Must work also in the WEAK sector in some way: **WHICH WAY?**

- Many CT's (37) Ecker,Kambor, Wyler; G.D. Portoles

$$\mathcal{L}^{(4)}_{|\Delta S|=1} = G_8\, F^2 \sum_{i=1}^{37} N_i\, W_i$$

- There are **tests**
- $K^+ \to \pi^+\pi^0\gamma$ and $K_S \to \pi^+\pi^-\gamma$ same CT combination
- $K \to \pi l^+ l^-$, $K^+ \to \pi^+\pi^0\gamma$, $K^+ \to \pi^+\gamma\gamma$ (observed or close to observation) and others probe the the same CT's $\Longrightarrow$ **CHPT tests**
- We need desperately some dynamical info and also some theory prejudice
- VMD must work and it is easy testable: form factor

Weak interactions in CHPT and VMD

- We know is tough: see $\Delta I = 1/2$-rule
- Actually even in the strong sector: $V^{\mu\nu}$ better than V^{μ}
- $\mathcal{L}^{(4)}_{\Delta S=1}$: $V^{\mu\nu}$ and V^{μ} similar results (+) but important differences

Is there any chance that VMD works in CHPT weak?

- Evidence that VMD form factor describes better the photon energy distribution in $K_L \to \pi^+\pi^-\gamma$
- size and sign of a_V in $K_L \to \pi^0\gamma\gamma$ were postdicted in VMD
- the large slope in $K^+ \to \pi^+ l^+ l^-$ maybe explained by the large size of VMD
- It is not a lot ...We need more infos

i	W_i	Vectors	Axials
14	$i\langle\Delta\{f_+^{\mu\nu}, u_\mu u_\nu\}\rangle$	$\frac{1}{2}f_V^2\eta_V$	
15	$i\langle\Delta u_\mu f_+^{\mu\nu} u_\nu\rangle$	$f_V^2\eta_V$	
16	$i\langle\Delta\{f_-^{\mu\nu}, u_\mu u_\nu\}\rangle$		$\frac{1}{2}f_A^2\eta_A$
17	$i\langle\Delta u_\mu f_-^{\mu\nu} u_\nu\rangle$		$f_A^2\eta_A$
18	$\langle\Delta(f_{+\,\mu\nu}^2 - f_{-\,\mu\nu}^2)\rangle$	$-\frac{1}{4}f_V^2\eta_V$	$\frac{3}{4}f_A^2\eta_A$

η_V **Weak Vector coupling**

η_A **Weak Axial coupling**

we have used $f_V = 2\ g_V$
This approx. too drastic
(when V-contributions cancel)

$K^+ \to \pi^+\pi^0\gamma$
$N_{14} - N_{15} - N_{16} - N_{17}$

$K^+ \to \pi^+\gamma\gamma$
$N_{14} - N_{15} - 2N_{18}$
size and sign from Axials
$f_V \stackrel{?}{=} 2\ g_V$

Counterterm combination	Processes	VMD weak coupling
$N_{14}^r - N_{15}^r$	$K^+ \to \pi^+\gamma^*$ $K^+ \to \pi^+\pi^0\gamma^*$	$-0.020\,\eta_V + 0.004\,\eta_A$
$2N_{14}^r + N_{15}^r$	$K_S \to \pi^0\gamma^*$	$0.08\,\eta_V$
$N_{14} - N_{15} - 2N_{18}$	$K^+ \to \pi^+\gamma\gamma$ $K^+ \to \pi^+\pi^0\gamma\gamma$	$-0.01\,\eta_A$
$N_{14} - N_{15} - N_{16} - N_{17}$	$K^+ \to \pi^+\pi^0\gamma$ $K_S \to \pi^+\pi^-\gamma$	$-0.010\,\eta_A$
$N_{14}^r - N_{15}^r - 3(N_{16}^r - N_{17})$	$K_L \to \pi^+\pi^-\gamma^*$	$-0.004\,\eta_V + 0.018\,\eta_A$
$N_{14}^r - N_{15}^r - 3(N_{16}^r + N_{17})$	$K_S \to \pi^+\pi^-\gamma^*$	$0.05\,\eta_V - 0.04\,\eta_A$
$N_{14}^r + 2N_{15}^r - 3(N_{16}^r - N_{17})$	$K^+ \to \pi^+\pi^0\gamma^*$	$0.12\,\eta_V + 0.01\,\eta_A$
$N_{29} + N_{31}$	$K_L \to \pi^+\pi^-\gamma$	$0.005\,\eta_V + 0.003\,\eta_A$
$3N_{29} - N_{30}$	$K^+ \to \pi^+\pi^0\gamma$	$-0.005\,\eta_V - 0.003\,\eta_A$

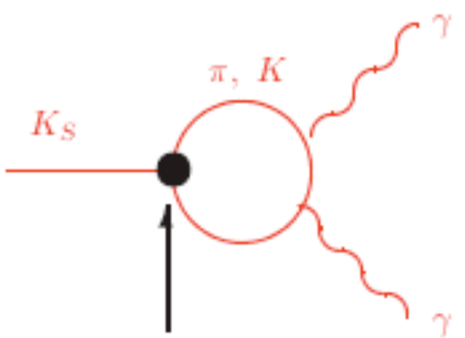
Observation hidden by other effects: different analysis maybe useful (Kaon charge radius)
NA48 has a good chance

$K_S \to \gamma\gamma$

- No short distance contributions, No $O(p^2)$
- Neutral particles $(K_S) \Rightarrow$ No $O(p^4)$ CT : $F_{\mu\nu}F^{\mu\nu}\langle\lambda_6 QU^+QU\rangle$
- Loop contribution finite scale independent and unambigous χPT prediction

$\mathrm{Br}_{\chi\mathrm{PT}}(K_S \to \gamma\gamma)$=2.1$\cdot 10^{-6}$

(G.D. and Espriu 86, Goity 87)



G_8 from $K_S \to \pi\pi$

$(2.78 \pm 0.072) \cdot 10^{-6}$ (NA48 '02)

$(2.26 \pm 0.12 \pm 0.06) \cdot 10^{-6}$ (KLOE08)

- $O(p^6)_{\rm CT}$ $\qquad$ $F^{\mu\nu}F_{\mu\nu}\langle\lambda_6 Q^2 \mu M U^+\rangle$

  No VMD $\qquad$ $\Rightarrow \dfrac{A^{(6)}}{A^{(4)}} \sim \dfrac{m_K^2}{(4\pi F_\pi)^2} \sim 0.2$

  (No terms $\sim \dfrac{m_K^2}{m_\rho^2} \sim 0.4$)

- NA48 $\Rightarrow \dfrac{A^{(6)}}{A^{(4)}} \sim 15\%$

  $\Downarrow$

- The error in the amplitude, is smaller than the naive expectation, 20-30%

$K^+ \to \pi^+\gamma\gamma$

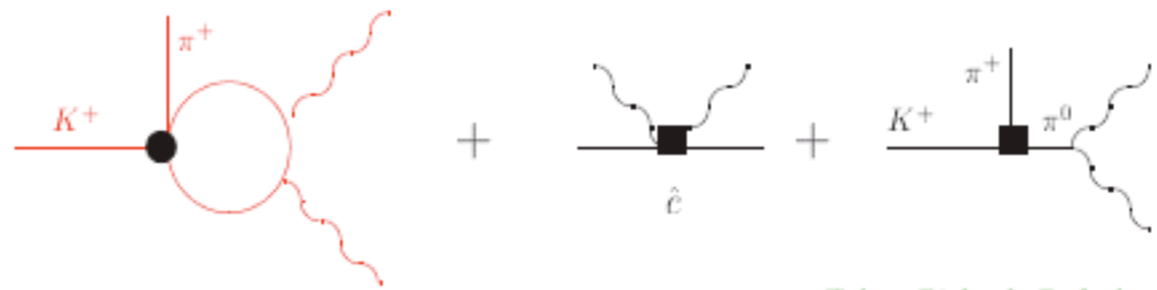
$$\gamma\gamma \quad \text{in} \quad \overbrace{\begin{matrix} F_{\mu\nu}F^{\mu\nu} & F\tilde{F} \\ P=+1 & P=-1 \\ A & C \end{matrix}}^{J=0} \qquad \begin{matrix} J=2 \\ \\ \\ B \end{matrix} \quad + \ \dots$$

Lorentz + gauge invariance

$$\frac{d^2\Gamma}{dydz} \sim \left[z^2(|A+B|^2+|C|^2) + \left(y^2 - \left(\frac{(1+r_\pi^2-z)^2}{4} - r_\pi^2\right)\right)^2 |B|^2\right]$$

$K^+ \to \pi^+\gamma\gamma$

- $O(p^4)$



Ecker, Pich, de Rafael

In factorization $\hat{c} = 2.3(1 - 2k_f)$

spin-1 contributions (axials)

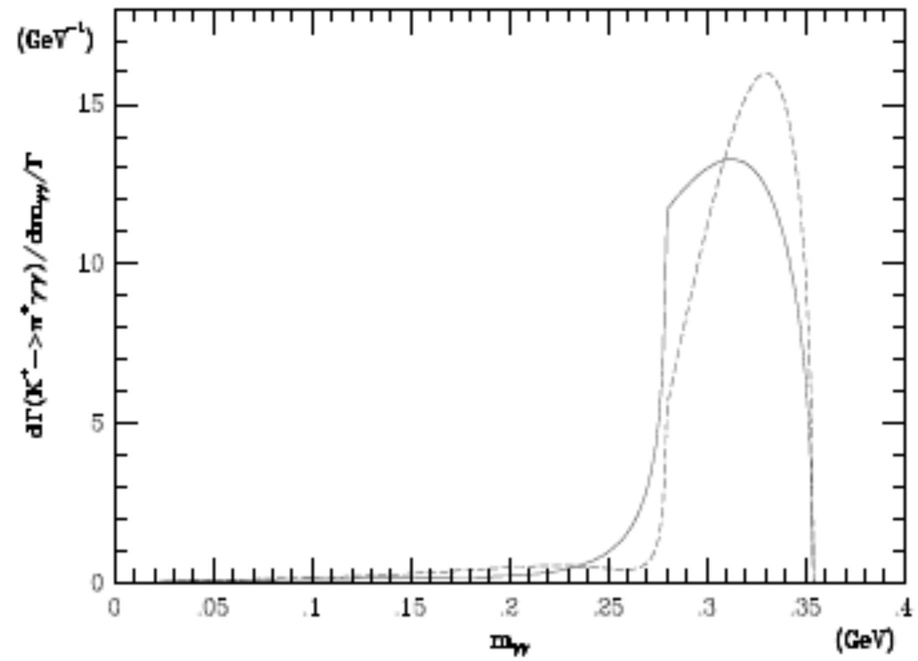
to $\hat{c}$

- $O(p^6)$ G.D., Portoles 96

Unitarity corrections: 30%-40%

a_{V^+} negligible

$K^+ \to \pi^+\gamma\gamma$



	$\hat{c}$
———	0
– – –	−2.3

NA48 preliminary
B=(1.07±0.04±0.08)*10^{-6}
assuming c=2

BNL 787 (96) got 31 events:
i) confirm $O(p^6)$
ii) Br$\sim$ $(6 \pm 1.6) \cdot 10^{-7}$
iii) $\hat{c} = 1.8 \pm 0.6$

NA48 publ. $K^+ \to \pi^+\gamma e^+e^-$
first observation O(10^{-8})
c=0.90 ±0.45

E949 no events at low $m_{\gamma\gamma}$, work for NA48/2, see Smith

$$K(p_K) \to \pi(p_1)\pi(p_2)\gamma(q)$$

- Lorentz + gauge invariance $\Rightarrow$ Electric (E) and Magnetic(M) amplitude

$$A(K \to \pi\pi\gamma) = F^{\mu\nu}\left[E\partial_\mu K\partial_\nu\pi + M\varepsilon_{\mu\nu\rho\sigma}\partial^\rho K\partial^\sigma\pi\right]$$

- Unpolarizated photons

$$\frac{d^2\Gamma}{dz_1 dz_2} \sim |E|^2 + |M|^2$$

$$|E^2| = |E_{IB}|^2 + 2Re(E_{IB}^* E_D) + |E_D|^2$$

$$\downarrow$$

Low Theorem $\Rightarrow E_{IB} \sim \frac{1}{E_\gamma^*} + \text{c}$ $\qquad$ E_D, M chiral tests

We need FIGHT DE/IB$\sim 10^{-3}$

	IB	DE_{exp}	
$K_S \to \pi^+\pi^-\gamma$	10^{-3}	$< 9 \cdot 10^{-5}$	$E1$
$K^+ \to \pi^+\pi^0\gamma$	10^{-4} $(\Delta I = \frac{3}{2})$	$(0.44 \pm 0.07)10^{-5}$ PDG	$M1$,$E1$
$K_L \to \pi^+\pi^-\gamma$	10^{-5} (CPV)	$(2.92 \pm 0.07)10^{-5}$ KTeV new	$M1$, VMD

CPV is only from IB K_L (also measured in $K_L \to \pi^+\pi^-e^+e^-$)

BUT IB suppressed in K^+ and K_L.

$K_L \rightarrow \pi^+\pi^-\gamma$

M1 transtions clearly measured KTeV (00) with large slope

form factor measured

$$\mathcal{F} = 1 + \frac{\mathrm{a}}{1 - \frac{m_k^2}{m_\rho^2} + \frac{2 m_K E_\gamma^*}{m_\rho^2}}$$

E_γ^* photon energy

KTeV:

- a$= -1.243 \pm 0.057$
-

	linear slope	quadratic slope	$\mathcal{F}$
χ^2/DOF	$43.2/27$	$37.6/26$	$38.8/27$

$\Rightarrow$ Large VMD: $\rho-$pole

$$\text{Theory} \quad M1 \sim \quad \overbrace{a_2 + 2a_4}^{p^4} \quad +h.o.$$

$$\Downarrow$$

Large VMD in the a_i. Not automatic in all spin-1 formulations

[G.D. Portoles, G.D. Gao]

Consistent with M1 in $K^+ \to \pi^+\pi^0\gamma$ and predictive for spectrum (work for NA48/2)

$K^+ \to \pi^+\pi^0\gamma$

$$A(K \to \pi\pi\gamma) = F^{\mu\nu}\left[E\partial_\mu K\partial_\nu\pi + M\varepsilon_{\mu\nu\rho\sigma}\partial^\rho K\partial^\sigma\pi\right]$$

$E1$ and $M1$ are measured with Dalitz plot

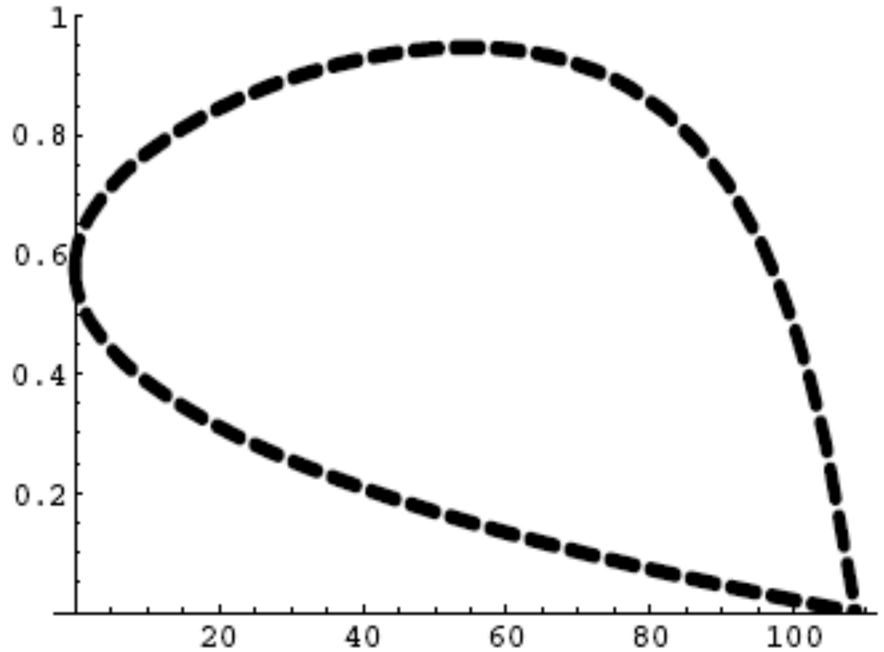
$$\frac{\partial^2\Gamma}{\partial T_c^*\partial W^2} = \frac{\partial^2\Gamma_{IB}}{\partial T_c^*\partial W^2}\left[1 + \frac{m_{\pi^+}^2}{m_K}2Re\left(\frac{E1}{eA}\right)W^2 + \frac{m_{\pi^+}^4}{m_K^2}\left(\left|\frac{E1}{eA}\right|^2 + \left|\frac{M1}{eA}\right|^2\right)W^4\right]$$

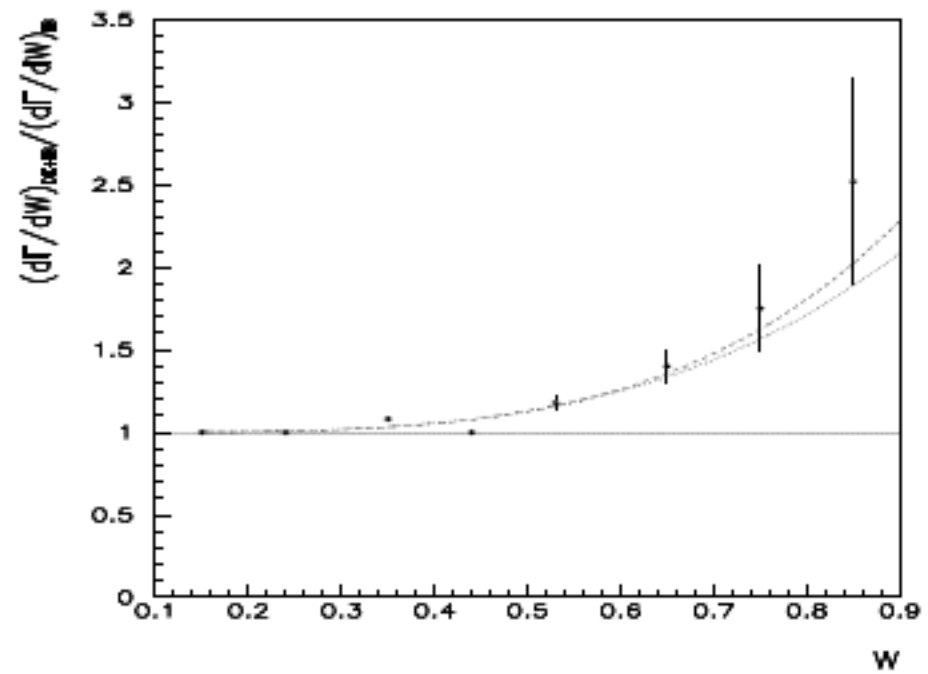
$$W^2 = (q\cdot p_K)(q\cdot p_+)/(m_\pi^2 m_K^2)$$

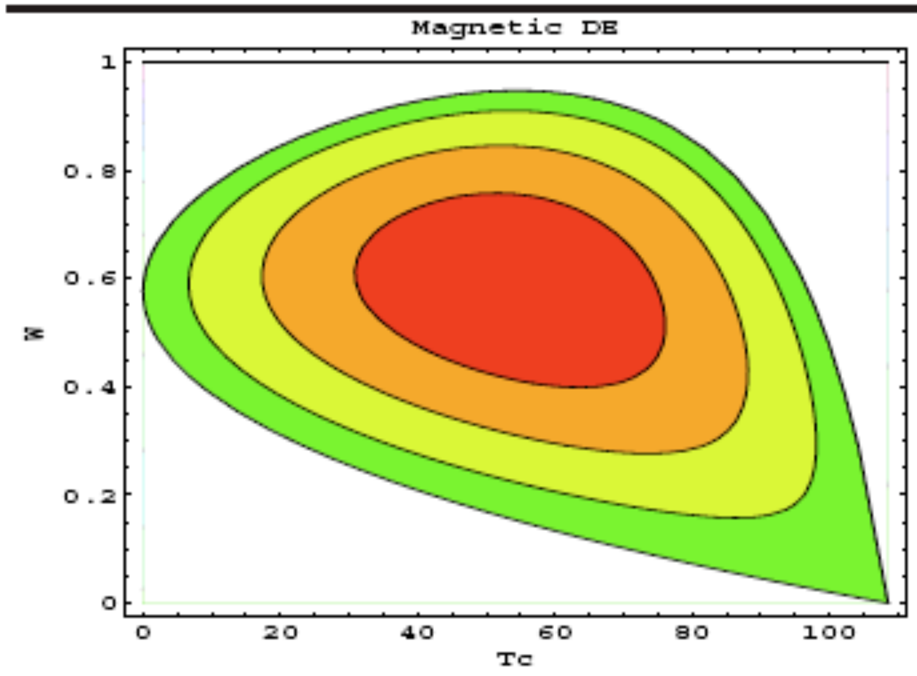
$$A = A(K^+ \to \pi^+\pi^0)$$

$K^+ \to \pi^+\pi^0\gamma \; W - T_c$ Dalitz plot

Integrating over T_c deviations from IB measured





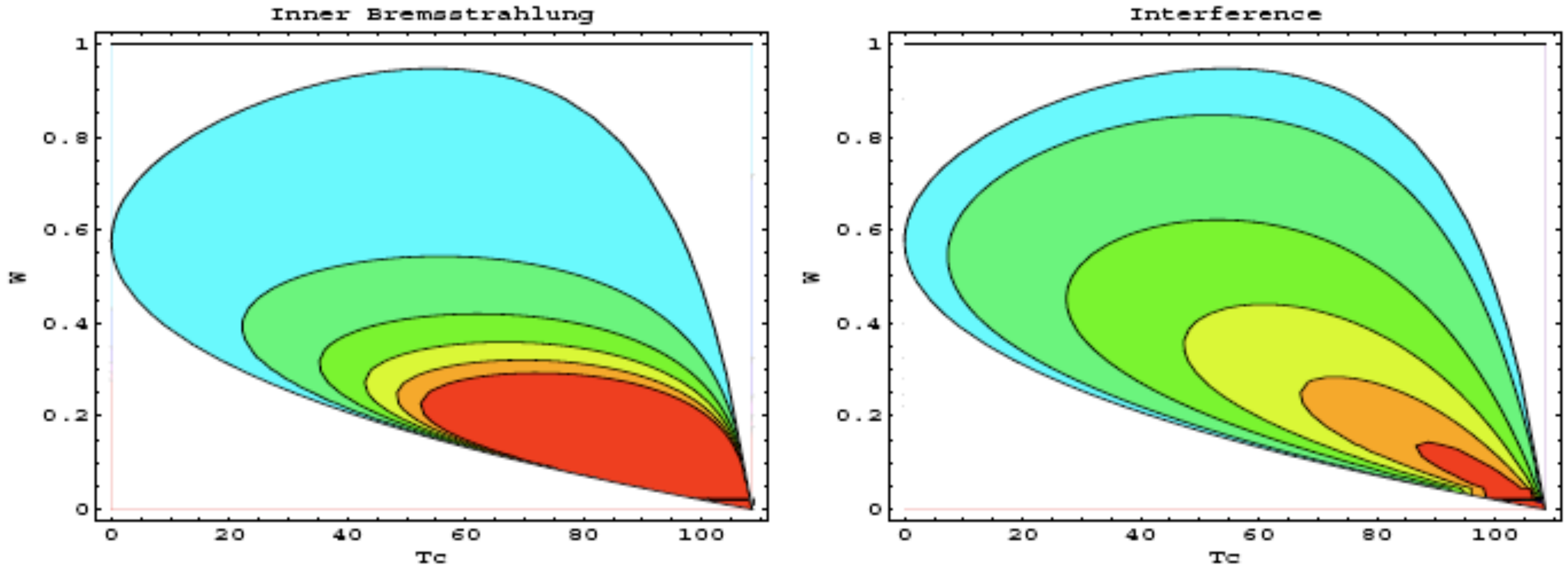


- M1 $\sim$ (-2 + $3a_2 - 6a_3$) -2.5

  ↑ Wess Zumino ↑ p^4 CT's (VMD) ⇓ a_i small?

Cheng
Bijnens, Ecker, Pich; G.D.,Gao

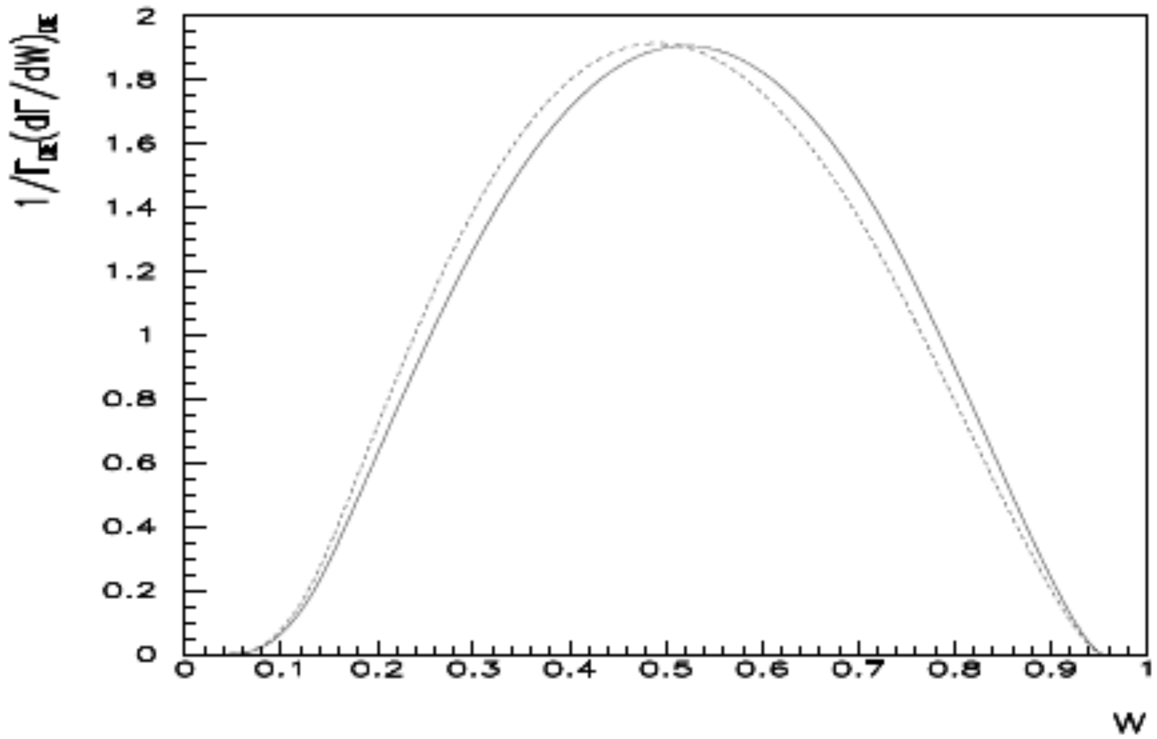
$K^+ \to \pi^+\pi^0\gamma$



- E787 has measured M1 and $\mathrm{Re}\left(\frac{E1}{E_{IB}}\right) \sim (-0.4 \pm 1.6)\%$

$$\downarrow$$

- E1 dominated by CT $\Rightarrow$ E787 constrains models ($k_f < 1$)



- $\frac{d\Gamma}{dW}$ may be crucial to study well the form factor $W^2 = (q \cdot p_K)(q \cdot p_+)/(m_\pi^2 m_K^2)$

- to establish VMD

CP asymmetry

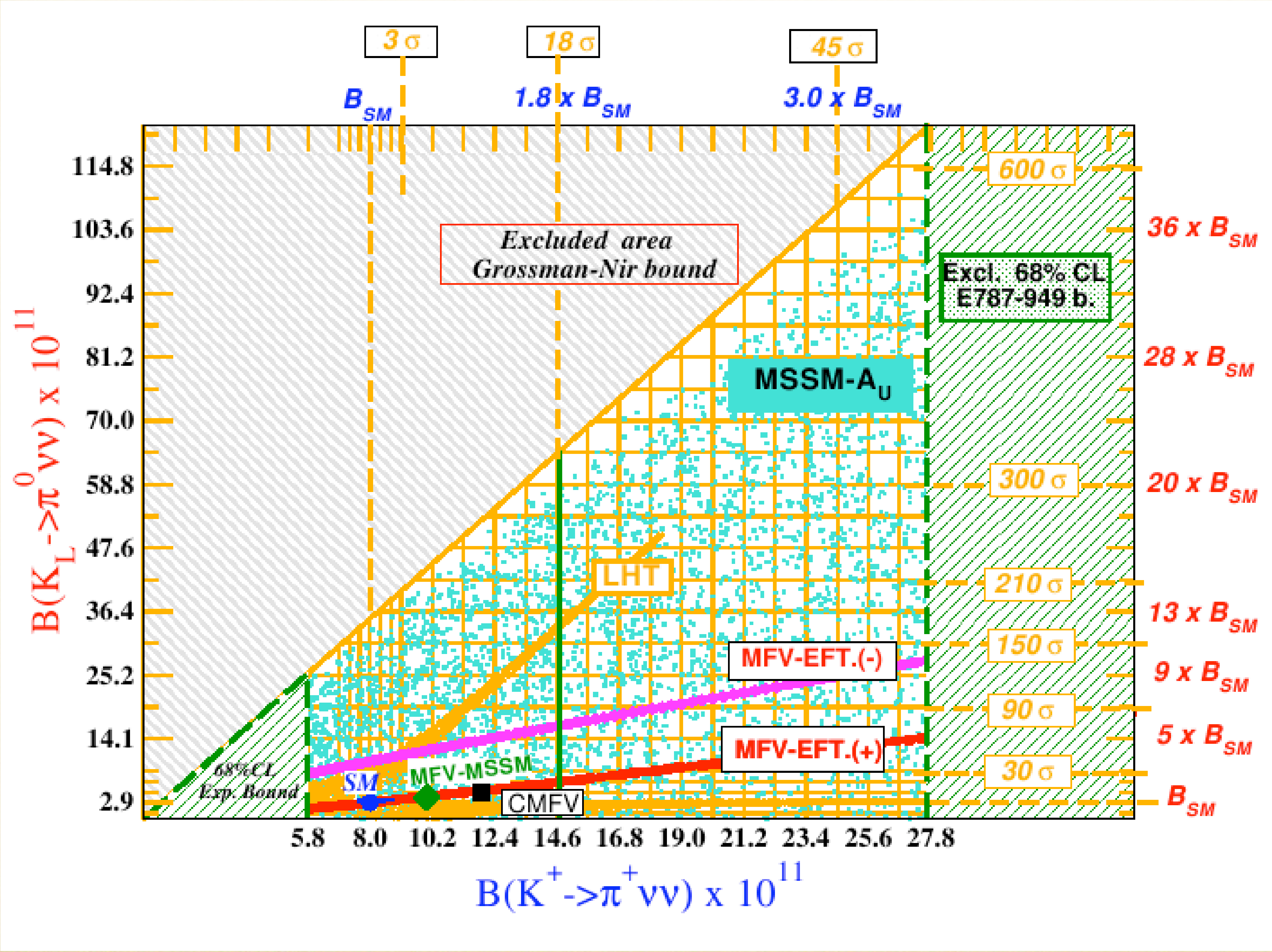
- In the asymmetry in the slope, $\frac{\partial^2\Gamma^\pm}{\partial T_c^* \partial W^2}$ select a favourable kin. region (large W^2)
- This asymm., Ω, in extensions of SM $\sim \mathcal{O}(10^{-4})$ Colangelo et al.
- SM $\leq \mathcal{O}(10^{-5})$ Paver et al.
- Assuming the expts. are almost seeing the CP conserving $E1$ Statistics seems tough but previous limit (Smith eta l. 76) weak
- Similar analysis for CPV in K_L: but time interf. required

G. D'Ambrosio, N. Paver, A. Pugliese, G. Pancheri and P. Gensini during the
Collaboration Meeting, in Durham, 10–15 December, 1994

Conclusions

- We have reached a precision in golden decays making worthy to check the less clean ones
- Many kaon decays still to explore
  i.e. $K_L \to \pi^+ \pi^- e\, e$ $\quad K^+ \to \pi^+ \pi^0 e\, e$
- Sorry not discussing the cusp and $K \to \pi \pi \pi$

NA62 Fantastic attack



Mescia

A. The New Physics flavor puzzle

- Most New Physics (NP) models have either *new flavored particles*, or *new flavor-breaking interactions* between quarks and leptons.

  → *New contributions to FCNC's*!

- At the same time, there is *no signal of NP in low-energy experiments.*

  → Experiments ~ SM predictions

  → $\begin{cases} b \to s: \\ |V_{tb}^* V_{ts}| \sim \lambda^2 \end{cases}$ $\begin{cases} b \to d: \\ |V_{tb}^* V_{td}| \sim \lambda^3 \end{cases}$ $\boxed{\begin{cases} s \to d: \\ |V_{ts}^* V_{td}| \sim \lambda^5 \end{cases}}$

  Most constraining!

- New Physics cannot be *both light and generic*:

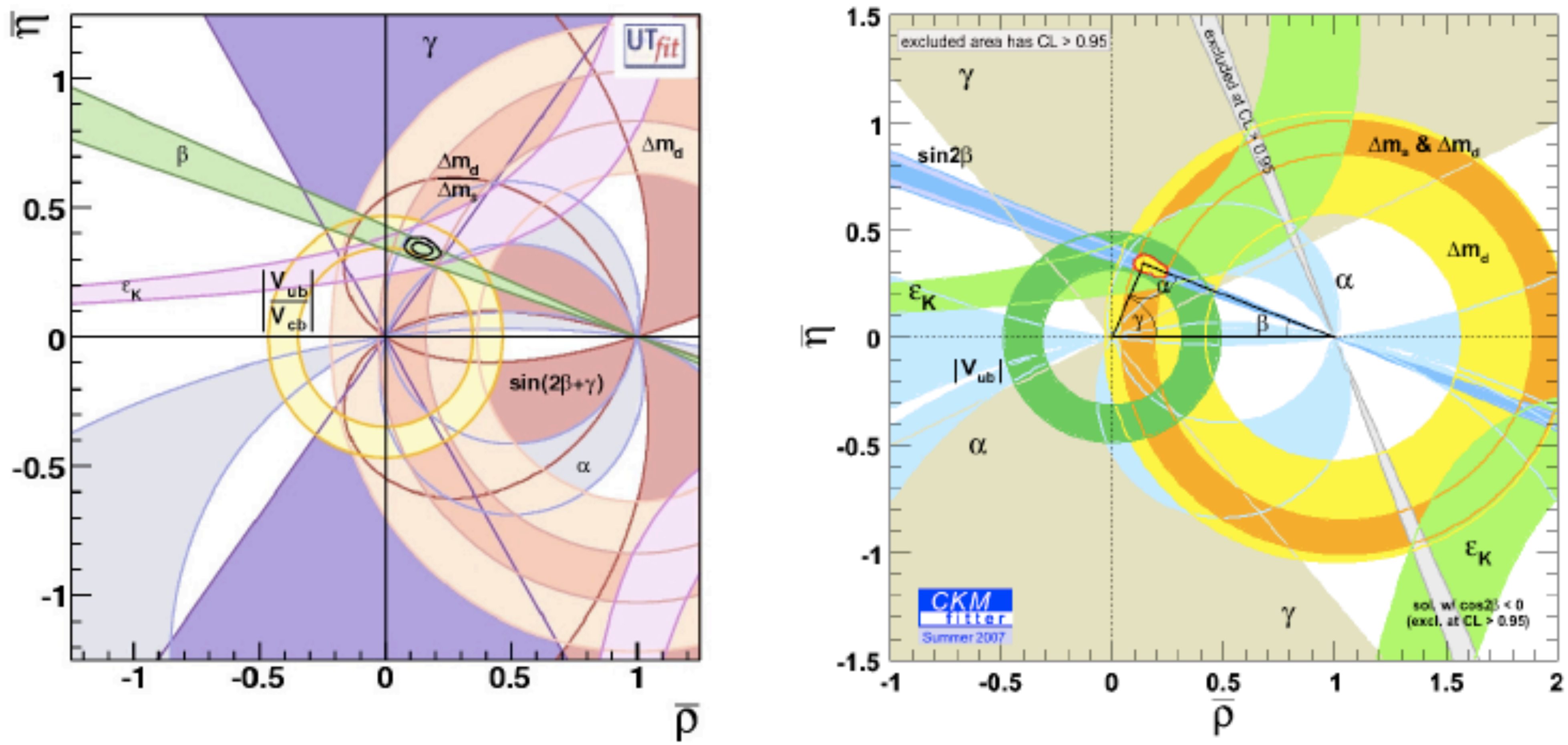
$$\mathcal{L}_{eff} = \frac{c_{bs}}{\Lambda^2}(\bar{b}\Gamma s)(\bar{\nu}\Gamma\nu) + \frac{c_{bd}}{\Lambda^2}(\bar{b}\Gamma d)(\bar{\nu}\Gamma\nu) + \boxed{\frac{c_{sd}}{\Lambda^2}(\bar{s}\Gamma d)(\bar{\nu}\Gamma\nu)} + \ldots$$

$c_{sd} \approx 1,\ \ \Lambda \gtrsim 75\,\mathrm{TeV}:$ NP very massive, beyond the reach of LHC,

$\Lambda \approx 1\,\mathrm{TeV},\ \ c_{sd} \lesssim V_{ts}^* V_{td}:$ NP flavor structures highly non-generic.

B. Global CKM fits and constraints on New Physics

Flavianet members contribute to CKMfitter and UTfit analyses:



Bayesian vs. frequentist? *Charles, Hocker, Lacker, Le Diberder, T'Jampens '06*

Hint of a large new physics phase in b → s transitions? *Bona et al. '08*

C. Bottom-up approach to the New Physics flavor puzzle

Minimal Flavor Violation: New Physics scale as in the SM.

$$\mathcal{L}_{eff} = \frac{c_{qq'}}{\Lambda^2}(\bar{q}\Gamma q')(\bar{\nu}\Gamma\nu) + \ldots \quad \text{with} \quad c_{qq'} \sim \left|V_{tq}^* V_{tq'}\right| \quad \Rightarrow \Lambda \leq 1\,\text{TeV}$$

"Constrained" MFV: No new phase, no new operator.

"Symmetric" MFV: Only the Yukawas can break the $SU(3)^5$ flavor-symmetry.

- MSSM at large $\tan\beta \equiv v_u / v_d$ — *Freitas,Gasser,Haisch '07; Isidori,Mescia,Paradisi,Temes '07*
- MSSM: UT fit in the B sector — *Altmannshofer,Buras,Guadagnoli '07; Altmannshofer,Buras,Guadagnoli,Wick '07*
- MSSM: running MFV — *Paradisi,Ratz,Schieren,Simonetto '07*
- MFV as an alternative to R-parity — *Nikolidakis,CS '07*
- Extra quarks: connection with LHC — *Grossman,Nir,Thaler,Volansky,Zupan '07*
- Generic: constraints from $Z \to b\bar{b}, \ldots$ — *Haisch,Weiler '07*
- Lepton sector & leptogenesis — *Cirigliano,De Simone,Isidori,Masina,Riotto '07*

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D. Top-down approach to the New Physics flavor puzzle

Specific New Physics models: identifying interesting scenarios, and studying their impact on flavor physics, including their correlation with LHC observables.

Supersymmetry:
- Generic MSSM
- with MFV
- with large $\tan\beta$
- with RPV

(see e.g. Refs. on the previous slide)

Supersymmetric *GUT scenarios*

Dorsner, Fileviez Perez, Rodrigo '06
Cuichini, Masiero, Paradisi, Silvestrini, Vempati, Vives '07
Albrecht, Altmannshofer, Buras, Guadagnoli, Straub '07
Altmannshofer, Guadagnoli, Raby, Straub '08

Alternatives:

- *Little Higgs* — *Blanke, Buras, Recksiegel, Tarantino, Uhlig '07*; *Blanke, Buras, Recksiegel, Tarantino '08*
- *Higgsless* — *Bernard, Oertel, Passemar, Stern '07*; *Barbieri, Isidori, Rychkov, Trincherini '08*
- *Extra-dimensions* — *Davidson, Isidori, Uhlig '07, Haisch, Weiler '07*; *Colangelo, De Fazio, Ferrandes, Pham '06*
- *Unparticles* — *Zwicky '07, Freitas, Wyler '07*

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