KAON'07
Laboratori Nazionali di Frascati dell'INFN
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Conference Summary

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FlaviAnet

O. Preface (disclaimer)

Impossible to summarize in a reasonable way all the 70 (!) talks of this very interesting conference...

Many apologies for all the subjects/speakers I won't be able to cover in any detail

I. The semileptonic challenge

3rd edition
semileptonic cup

I. The semileptonic challenge

The apparent (healthy!) challenges...

vs.

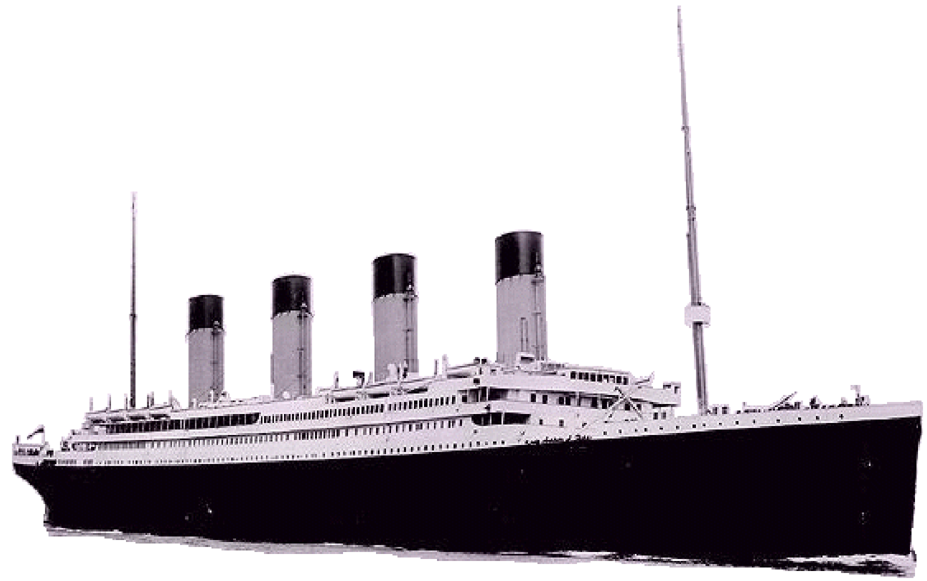
CHPT vs. Lattice-QCD

I. The semileptonic challenge

...the true challenge:

The flavour-physics community

vs.



The SM

3rd edition
semileptonic cup

What's behind the precise measurement of Vus
& more generally of K_{l2} & K_{l3} decay parameters ?

$$\mathcal{L}_{SM} = \underline{\mathcal{L}_{gauge}(A_i, \psi_i) + \mathcal{L}_{Higgs}(\phi_i, A_i, \psi_i)}$$

$$\downarrow$$

$$\mathcal{L}_{c.c.} = (g/\sqrt{2})\, W_\mu^+\, \bar{u}_L^{\,i}\, (V_{CKM})_{ij}\, \gamma^\mu\, d_L^{\,j} + \text{h.c.}$$

The universality of g & the unitarity of V_{CKM} holds also beyond the SM if the gauge symmetry is respected

What's behind the precise measurement of Vus & more generally of K_{l2} & K_{l3} decay parameters ?

$$\mathscr{L}_{\rm eff} = \mathscr{L}_{\rm gauge}(A_i, \psi_i) + \mathscr{L}_{\rm Higgs}(\phi_i, A_i, \psi_i) + \sum_{d\geq 5} \frac{c_n}{\Lambda^{d-4}} O_n^{\,d}(\phi_i, A_i, \psi_i)$$

$$\mathscr{L}_{\rm c.c.} = (g/\sqrt{2})\, W_\mu^{+}\ \bar{u}_L^{\,i}\, (V_{\rm CKM})_{ij}\, \gamma^\mu\, d_L^{\,j} + {\rm h.c.}$$

The universality of g & the unitarity of $V_{\rm CKM}$ holds also beyond the SM if the gauge symmetry is respected

However, thanks to the s.s.b. of the SU(2)×U(1) group, what we measure at low energy is *not necessarily* only the gauge coupling of the W boson:

$$\mathscr{L}_{\rm c.c.\text{-}eff.} = G_{\rm eff}\ (u^i\, \Gamma_A\, d^j)\, (l^k\, \Gamma_B\, \nu^l) + {\rm h.c.}$$

eff. <u>dimensional</u> coupling
potentially sensitive to NP

$$G_{\rm eff} \sim \frac{g^2 V_{ij}\, \delta^{kl}}{M_W^{\,2}} + \frac{c_n}{\Lambda^2}$$

Comparison of G_μ with other measurements unveils "New Physics"

[Marciano]

$\mu \to e$ Decay $G_\mu = 1.166371(6) \times 10^{-5} \text{GeV}^{-2}$

$\tau \to \mu$ Decay $G_F = 1.1678(26) \times 10^{-5} \text{GeV}^{-2}$

$\tau \to e$ Decay $G_F = 1.1675(26) \times 10^{-5} \text{GeV}^{-2}$

Other Precision Measurements:

$\alpha^{-1} = 137.036$, $m_W = 80.398(25) \text{GeV}$ (High)

$\sin^2\theta_W(m_Z)_{MS} = 0.23122(17)$

$\to G_F = 1.1655(12) \times 10^{-5} \text{GeV}^{-2}$

CKM Unitarity: $G_F^{CKM} = 1.1658(4) \times 10^{-5} \text{GeV}^{-2}$

$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9990(5)_{Vud}(2)_{Kl3}(5)_{f+}$

E.g.: Z' Bosons→WZ' Box Diagrams

[Marciano]

Different For Muon and Beta Decay

$G_\mu = G_F^{CKM}[1-0.007 Q_{eL}(Q_{\mu L}-Q_{dL}) \ln x_i/(x_i-1)]$

$x_i = (m_{Zi}/m_W)^2$

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

$m_{Z\chi} \geq 1\,\text{TeV}$ (95%CL-One Sided)

Main message:

Vus @ 0.5% more interesting than e.w. precision tests !

If the NP above the e.w. scale is strongly coupled, and the s.s.b breaking is realised in a non-linear way (no fundamental Higgs), we can even expect *non-negligible right-handed currents* :

[Stern]

$$J_\mu^{\overline{U}D} = \frac{1}{2}\left[\overline{U}\mathcal{V}_{eff}\gamma_\mu D + \overline{U}\mathcal{A}_{eff}\gamma_\mu\gamma_5 D\right]$$

$$\mathcal{V}_{eff}^{ij} = (1+\delta)\,V_L^{ij} + \varepsilon\, V_R^{ij} + \mathrm{NNLO}$$ and $$\mathcal{A}_{eff}^{ij} = -(1+\delta)\,V_L^{ij} + \varepsilon\, V_R^{ij} + \mathrm{NNLO}$$

testable in $K_{\mu 3}$ decays via precise measurements of the scalar f.f.

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

$$\ln C_{SM} + \Delta\varepsilon$$

Fixed with good accuracy by the Callan-Trieman rel.

possible sizable deviations from the SM prediction $\lambda_0 = 0.016 \pm 0.003$

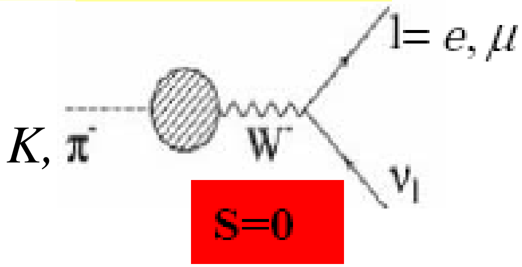
known term (πK scattering)

[Passemar]

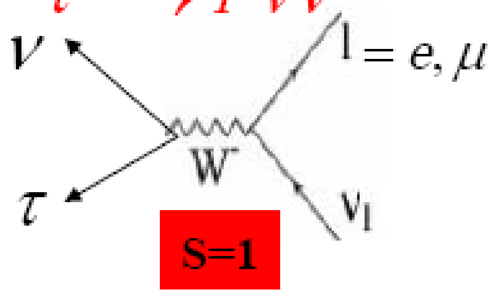
...but the most realistic/exciting NP scenario is the possibility of LFV effects modifying the μ/e ratio in K_{l2} decays (and similarly in π_{l2})

[Bryman, Paradisi]

$K, \pi^+ \to e^+\nu$



$\tau^+ \to l^+\nu\bar{\nu}$

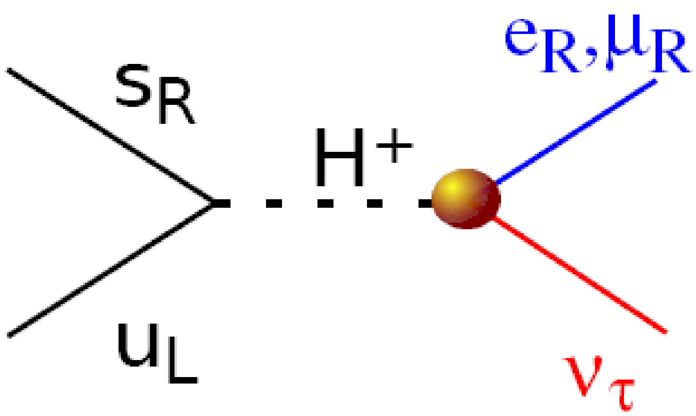


probe of the
s.s.b. sector of the SM

...but the most realistic/exciting NP scenario is the possibility of LFV effects modifying the μ/e ratio in K_{l2} decays (and similarly in π_{l2})

$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}\ , \quad i = e, \mu, \tau$$

[Paradisi]



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

$$\Delta_R^{31} \sim \frac{\alpha_2}{4\pi} \delta_{RR}^{31}$$

$$\Delta_R^{31} \sim 5\cdot 10^{-4} \quad t_\beta = 40 \quad M_{H^\pm} = 500\text{GeV}$$

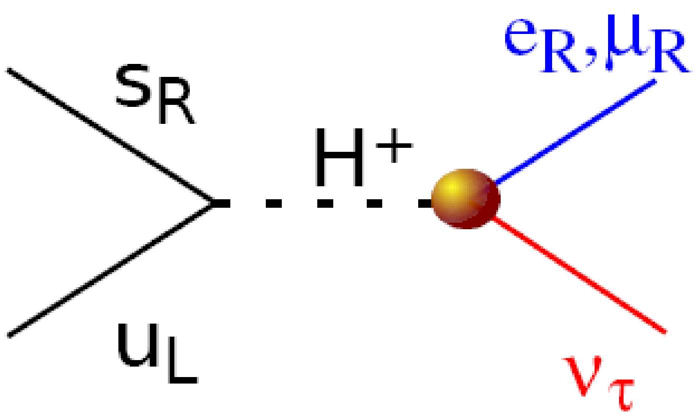
$$\Downarrow$$

$$\Delta r_{K\ SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right) |\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

...but the most realistic/exciting NP scenario is the possibility of LFV effects modifying the μ/e ratio in K_{l2} decays (and similarly in π_{l2})

$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}\ , \quad i = e, \mu, \tau$$

[Paradisi]



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

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key ingredeints for visible effects:

- Large $\tan\beta$, $M_H < 1TeV$
- Large LFV slepton minxings, $\delta_{3j} \sim \mathcal{O}(1)$, ($m_{SUSY} \geq 1\text{TeV}$)

Common question:

How these TeV-scale NP effects in the tree-level dominated K_{l2} & K_{l3} compare with the strong bounds on NP from FCNCs in K & B physics ?

From ε_K:

$\Lambda > 2\ 10^5$ TeV (tree-level) [Silvestrini]

$\Lambda > 7\ 10^3$ TeV (weak loop)

$$A(s \to d)_{\rm FCNC} \sim c_{\rm SM} \frac{y_t^2 V_{ts}^* V_{td}}{16\pi^2 M_W^2} + c_{\rm NP} \frac{1}{16\pi^2 \Lambda_{NP}^2}$$

Common question:

How these TeV-scale NP effects in the tree-level dominated K_{l2} & K_{l3} compare with the strong bounds on NP from FCNCs in K & B physics ?

From ε_K:

$\Lambda > 2\ 10^5$ TeV (tree-level)

$\Lambda > 7\ 10^3$ TeV (weak loop)

$\Lambda > 5.5$ TeV (tree-level)

$\Lambda > 185$ GeV (weak loop)

if $\delta_{21}^{\rm quark} \sim y_t^2 V_{ts}^* V_{td}$ (~ MFV)

$$A(s \to d)_{\rm FCNC} \sim c_{\rm SM} \frac{y_t^2 V_{ts}^* V_{td}}{16\pi^2 M_W^2} + c_{\rm NP} \frac{\delta_{21}^{\rm quark}}{16\pi^2 \Lambda_{NP}^2}$$

Answer:

In (*the most*) reasonable NP models, O(1%) effects in R_K & O(0.1%) effects in K_{l3} are perfectly allowed (complementary window on TeV scale NP)

Last but not least, precise measurements of K_{l3} decay parameters provide a useful information about low-energy QCD (convergence of CHPT & quark mass ratios):

[Cirigliano]

$K \to \pi \ell \nu$ master formula

$$K = \{K^+, K^0\} \quad \ell = \{e, \mu\}$$

$$\Gamma_{K_{\ell 3[\gamma]}} = C_K^2 \frac{G_\mu^2 S_{ew} M_K^5}{192\pi^3} \cdot |V_{us}|^2 \, |f_+^{K^0\pi^-}(0)|^2 \cdot I^{K\ell}(\lambda_i) \cdot [1 + 2\,\Delta_{SU(2)}^K + 2\,\Delta_{EM}^{K\ell}]$$

$$\Delta_{SU(2)}^K = (1.84 \pm 0.18(R) + 0.52 \pm 0.13(\Delta_M))\% = (2.36 \pm 0.22)\%$$

$$R = \frac{m_s - \hat{m}}{m_d - m_u} \qquad \frac{M_K^2}{M_\pi^2} = \frac{m_s + \hat{m}}{m_u + m_d}\left(1 + \Delta_M + O(m_q^2)\right)$$

K_{l3}: progress on the exp. side

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 I_{Kl}(\lambda) (1+2\Delta_K^{SU(2)} + 2\Delta_{Kl}^{EM})$$

with $K = K^+, K^0;\ l = e, \mu$ and C_K^2 = 1/2 for K^+, 1 for K^0

Inputs from theory:

S_{EW} Universal short distance EW correction (1.0232)

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

$\Delta_K^{SU(2)}$ Form factor correction for strong SU(2) breaking

Δ_{Kl}^{EM} Long distance EM effects

Inputs from experiment:

$\Gamma(K_{l3(\gamma)})$ **Branching ratios** with well determined treatment of radiative decays; **lifetimes**

$I_{Kl}(\lambda)$ Phase space integral: λs parameterize form factor dependence on t :

K_{e3} : only λ_+ (or λ_+' λ_+'')

$K_{\mu3}$: need λ_+ and λ_0

[Palutan]

New results on $K^{\pm}_{l3}$ BRs

1) **NA48** measures BR($K^{\pm}_{l3}$)/BR($\pi^{\pm}\pi^{0}$) using $K^{+} K^{-}$ simultaneous beams: 30k K^{-}_{l3}, 50k K^{+}_{l3}, statistics dominated

NA48/2
EPJC 50 (2007)

BR($K^{\pm}_{e3}$)/BR($\pi^{\pm}\pi^{0}$) = 0.2470(9)(4)

BR($K^{\pm}_{\mu3}$)/BR($\pi^{\pm}\pi^{0}$) = 0.1637(6)(3)

updated this conference

[Dabrowski]

2) **ISTRA+** measures BR(K^{-}_{e3})/BR($\pi^{-}\pi^{0}$): 2.2×10^{6} K^{-}_{e3}, systematics dominated

ISTRA+
arXiv: 0704.2052

BR(K^{-}_{e3})/BR($\pi^{-}\pi^{0}$) = 0.2449(4)(14)

[Duk]

3) **KLOE** measures absolute BR($K^{\pm}_{e3}$) and BR($K^{\pm}_{\mu3}$), tagging with $K^{\pm}\to\mu^{\pm}\nu$ and $K^{\pm}\to\pi^{\pm}\pi^{0}$: 8 measurements in total, each with 10^{5}

KLOE
updated
preliminary

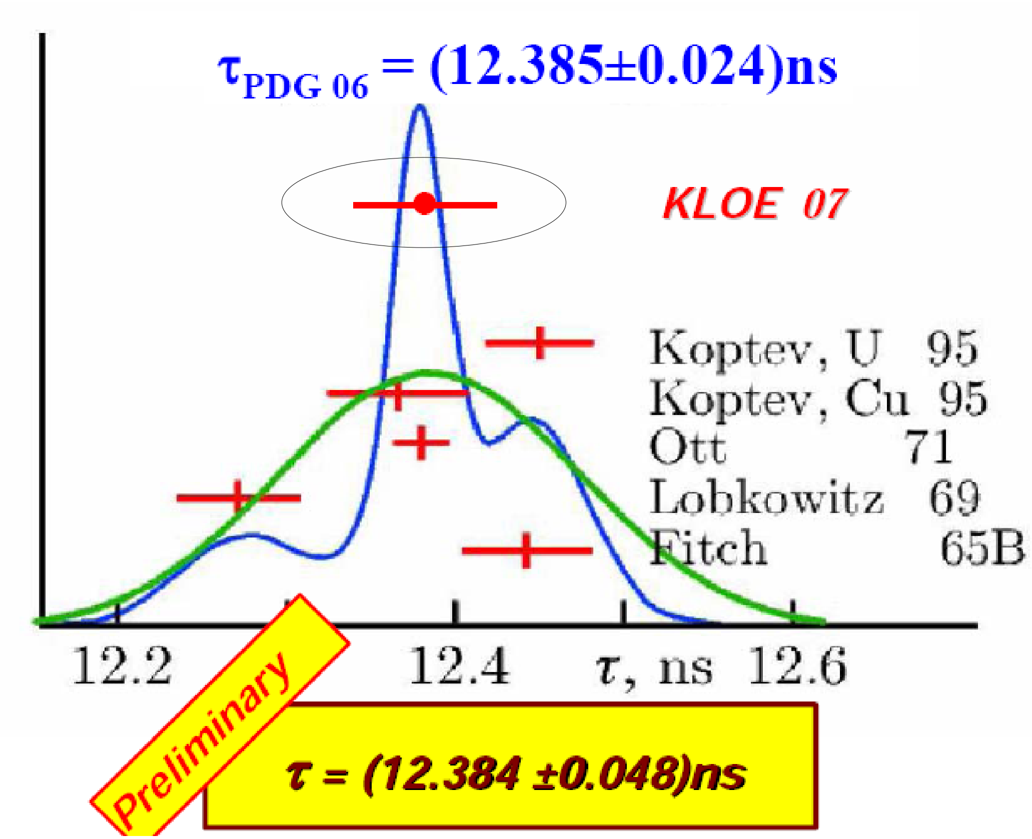
BR$^{(0)}$ ($K^{\pm}_{e3}$) = 4.965(52)%

BR$^{(0)}$ ($K^{\pm}_{\mu3}$) = 3.233(39)%

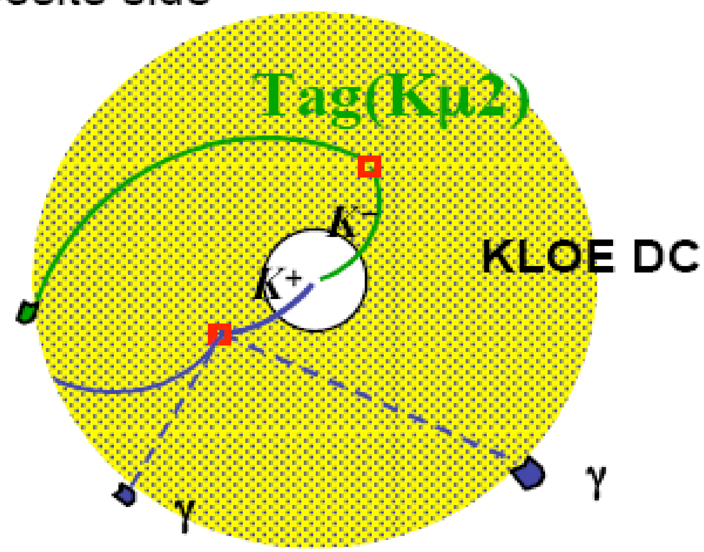
at $\tau_{\pm}^{(0)}$ = 12 .385 ns, with dBR/BR = $-0.5 d\tau_{\pm}/\tau_{\pm}$

[Sciascia]

$K^{\pm}$ lifetime from KLOE



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



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

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

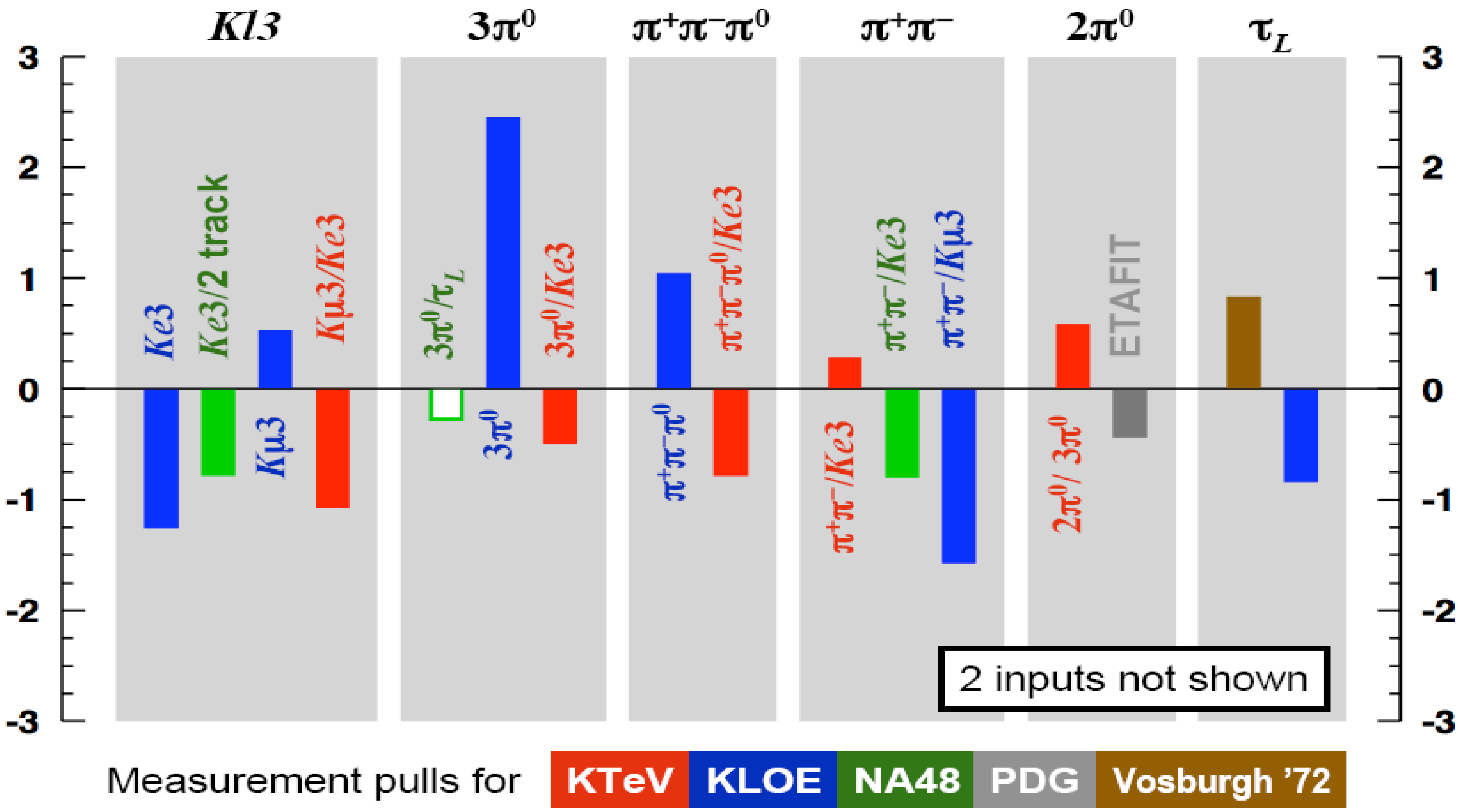
$\tau_{\pm}$ from the K decay time, using γ from $K^{\pm} \to \pi^{\pm}\pi^0$ decays

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

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

[Massarotti]

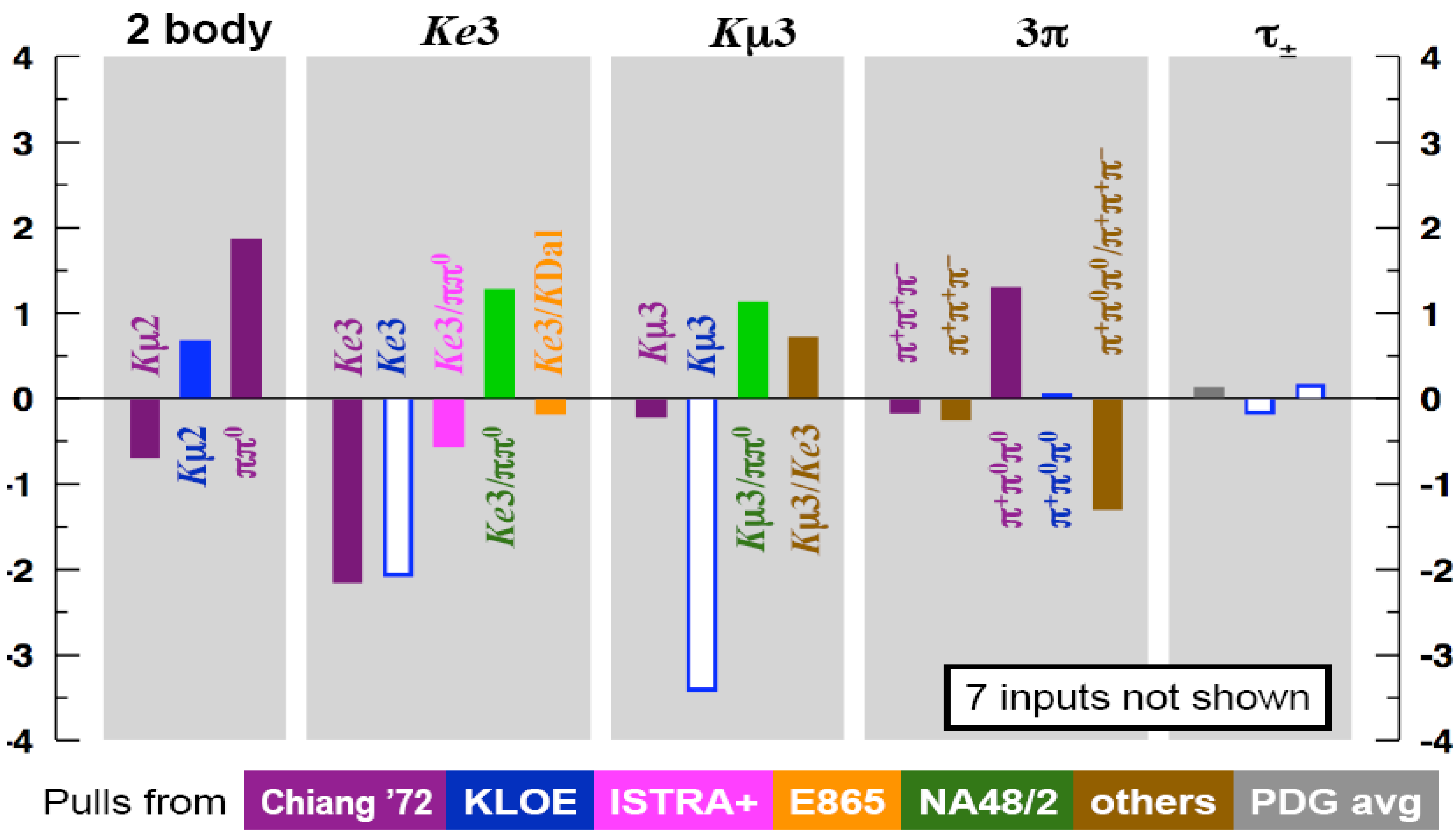
K_L BR fit vs. data



Nice overall agreement
(only recent measurements)

χ^2/ ndf = 20.2/11 (Prob = 4.3%)

$K^{\pm}$ BR fit vs. data



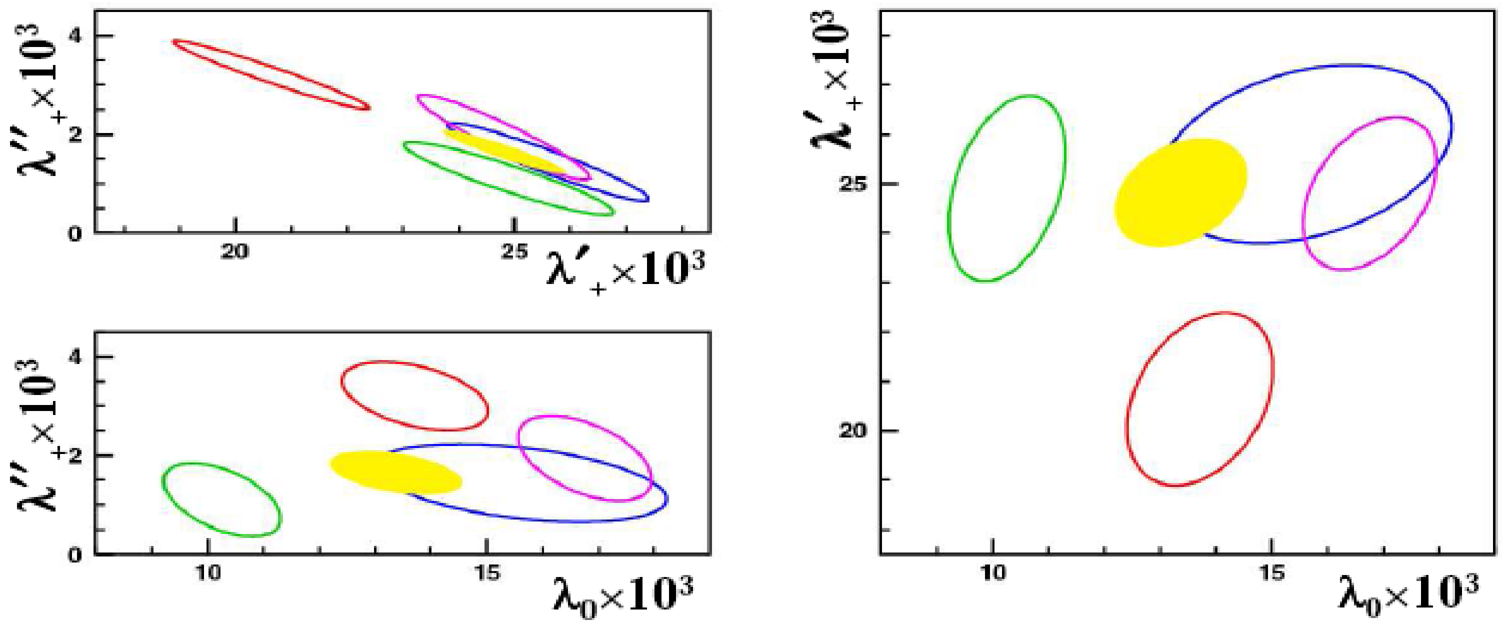
χ^2/ ndf = 52/25 (Prob = 0.11%) → **Improves to χ^2/ ndf = 35/21** (2.7%) with no changes to central values or errors, if 5 older $\tau_{\pm}$ measurements replaced by PDG avg (with S=2.1)

The situation of the slopes is not as good...

Comparison of experimental results (Ke3 and Kμ3)

KTeV KLOE NA48 ISTRA+

Each ellipse is from the average of Ke3 and Kμ3



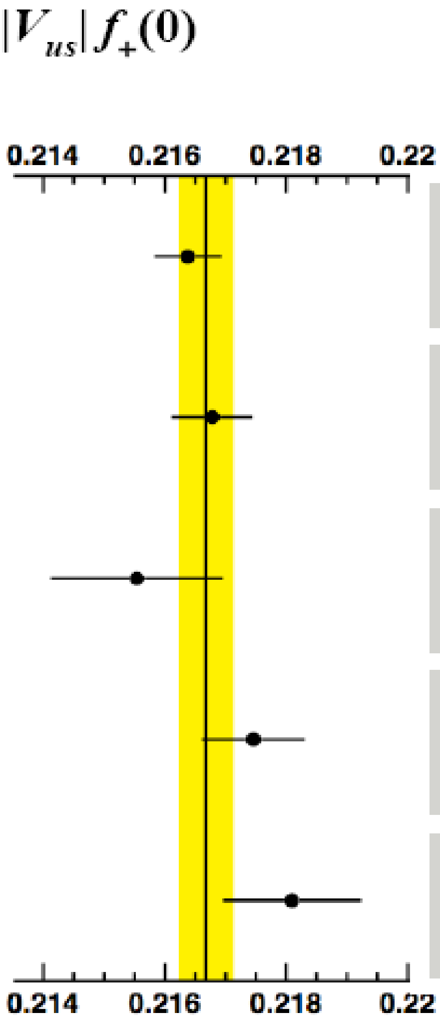
$\lambda'_+=(24.8\pm1.1)\times10^{-3}$ $\lambda''_+=(1.64\pm0.44)\times10^{-3}$ $\lambda_0=(13.4\pm1.2)\times10^{-3}$

$P(\chi^2)\sim10^{-6}$ S=1.4, 1.3, 1.9

C.Gatti KAON'07-Frascati 21/5/2007

...and any excitement about r.h. currents is definitely unjustified (at least now)

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



		% err	Approx. contrib. to % err from: BR	τ	Δ	Int
K_Le3	0.21638(55)	0.25	0.09	0.19	0.10	0.10
$K_L\mu3$	0.21678(67)	0.31	0.10	0.18	0.15	0.15
K_Se3	0.21554(142)	0.66	0.65	0.03	0.10	0.10
$K^\pm e3$	0.21746(85)	0.39	0.29	0.09	0.24	0.09
$K^\pm\mu3$	0.21810(114)	0.52	0.42	0.09	0.26	0.15

[Palutan]

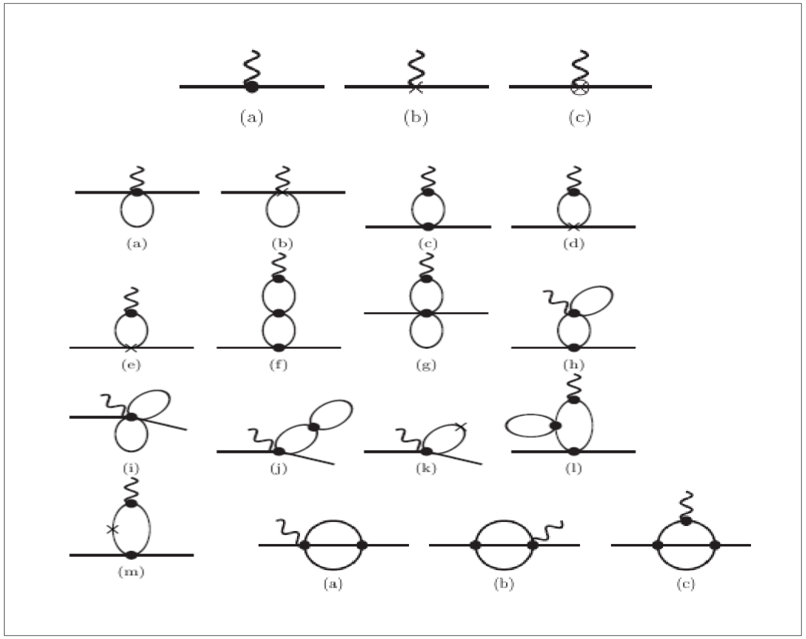
Average: $|V_{us}|\,f_+(0)$ = 0.21668(45) χ^2/ndf = 2.74/4 (60%)

$\Delta^{SU(2)}_{exp}$ = 2.86(38)% → great success of the th. calculations of isospin-breaking effects in CHPT !

K_{l3}: th. progress on $f(0)$

$$f_0(t) = 1 - \frac{8}{F_\pi^4}(C_{12}^r + C_{34}^r)\left(m_K^2 - m_\pi^2\right)^2 + 8\frac{t}{F_\pi^4}(2C_{12}^r + C_{34}^r)\left(m_K^2 + m_\pi^2\right) + \frac{t}{m_K^2 - m_\pi^2}(F_K/F_\pi - 1 - \frac{8}{F_\pi^4}t^2 C_{12}^r + \overline{\Delta}(t) + \Delta(0) .$$

Result of the heroic NNLO calculation in CHPT



[Bijnens]

K_{l3}: th. progress on $f(0)$

$$
\begin{aligned}
f_0(t) \;=\; & 1 - \frac{8}{F_\pi^4}(C_{12}^r + C_{34}^r)\left(m_K^2 - m_\pi^2\right)^2 \\
& + 8\frac{t}{F_\pi^4}(2C_{12}^r + C_{34}^r)\left(m_K^2 + m_\pi^2\right) + \frac{t}{m_K^2 - m_\pi^2}\left(F_K/F_\pi - 1\right. \\
& - \frac{8}{F_\pi^4} t^2 C_{12}^r + \overline{\Delta}(t) + \Delta(0)\,.
\end{aligned}
$$

$\overline{\Delta}(t)$ and $\Delta(0)$ contain NO C_i^r and only depend on the L_i^r at order p^6
$\Longrightarrow$
All needed parameters can be determined experimentally

$$\Delta(0) = -0.0080 \pm 0.0057[\text{loops}] \pm 0.0028[L_i^r]\,.$$

[Bijnens]

K_{l3}: th. progress on $f(0)$

It will never be possible to experimentally determine λ_0'' as an independent parameter. The error matrix, for N events is:

$$\begin{array}{cccc} \lambda_0' & \lambda_0'' & \lambda' & \lambda'' \end{array}$$

$$\mathbf{G} = \frac{1}{N}\begin{pmatrix} 63.9^2 & -1200 & -923 & 197 \\ -1200 & 18.8^2 & 272 & -59 \\ -923 & 272 & 14.8^2 & -49 \\ 197 & -59 & -48 & 3.4^2 \end{pmatrix}$$

[Franzini]

$\overline{\Delta}(t)$ and $\Delta(0)$ contain NO C_i^r and only depend on the L_i^r at order p^6

$\Longrightarrow$ Unfortunately -in real life- not all

~~All needed~~ parameters can be determined experimentally

In particular, for 1 million events, $\delta\lambda_0' = 0.064$, $\delta\lambda_0'' = 0.019$ and the correlation between λ_0' and λ_0'' is $\rho = -99.96\%$.

K_{l3}: th. progress on $f(0)$

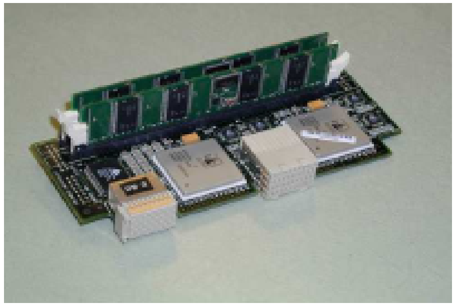
It will never be possible to experimentally determine λ''_0 as an independent parameter. The error matrix, for N events is:

$$G = \frac{1}{N}\begin{pmatrix} 63.9^2 & -1200 & -923 & 197 \\ -1200 & 18.8^2 & 272 & -59 \\ -923 & 272 & 14.8^2 & -49 \\ 197 & -59 & -48 & 3.4^2 \end{pmatrix}$$

(columns: λ'_0, λ''_0, λ', λ'')

[Franzini]

↓



The ultimate answer on $f(0)$ can only come from the Lattice

first study in quenched QCD:

Bećirević et al., 2005

- demonstrate that calculation with 1% accruracy is feasible
  1. calculate $f_0(q^2_{\rm max})$ accurately
  2. study q^2 of dependence and interpolate to q^2
  3. carry out chiral extrapolation of $f_+(0) = f_0(0)$
- $f_+(0) = 0.960(5)(6)$

unquenched calculations:

follow strategy proposed in the quenched calculation

	N_f	action	a[fm]	L[fm]	$M_{\rm PS}$[MeV]
JLQCD (2005)	2	clover	0.09	1.8	$\gtrsim 550$
RBC (2006)	2	domain-wall	0.12	1.9	$\gtrsim 490$
MILC (2005)	3	KS (d=clover)	0.12	2.5	$\gtrsim 500$
RBC+UKQCD (2007)	3	domain-wall	0.12	1.9, 2.9	$\gtrsim 300$

[Kaneko]

first study in quenched QCD:

Bećirević et al., 2005

- demonstrate that calculation with 1% accruracy is feasible
  1. calculate $f_0(q^2_{max})$ accurately — Done !
  2. study q^2 of dependence and interpolate to q^2
  3. carry out chiral extrapolation of $f_+(0) = f_0(0)$
- $f_+(0) = 0.960(5)(6)$

Substantial prog. thanks to twisted boundary cond. [Juttner]

Most delicate point...

unquenched calculations:

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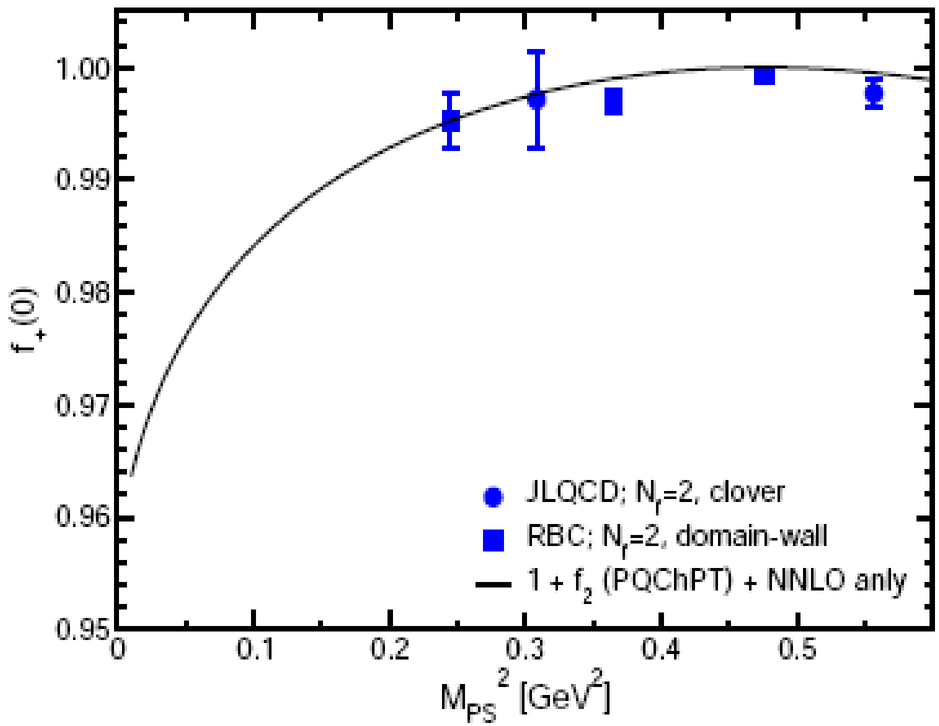
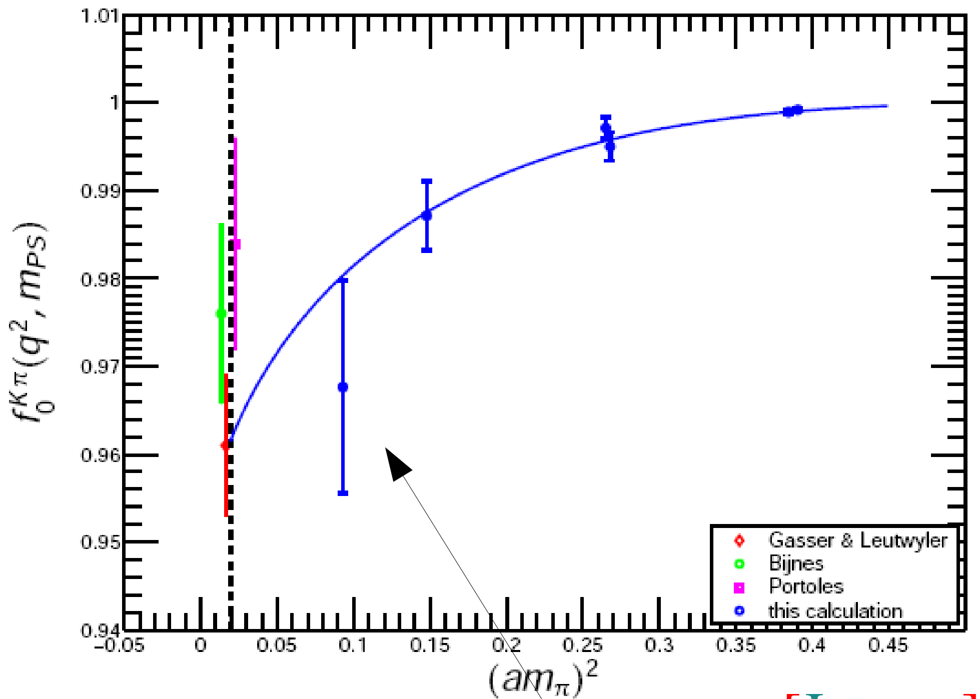
[Kaneko]

m_{ud} dependence of $f_+(0)$





[Juttner]

new point with m_π ~ 300 MeV not included yet in the fit

- JLQCD ($N_f = 2$), RBC ($N_f = 2$): $m_{\rm sea} > m_s/2$
- RBC+UKQCD ($N_f = 3$)

  rapid change toward $m_{ud} = 0$ $\rightarrow$ consistent w/ ChPT log ?

  larger error as $m_{ud} \rightarrow 0$

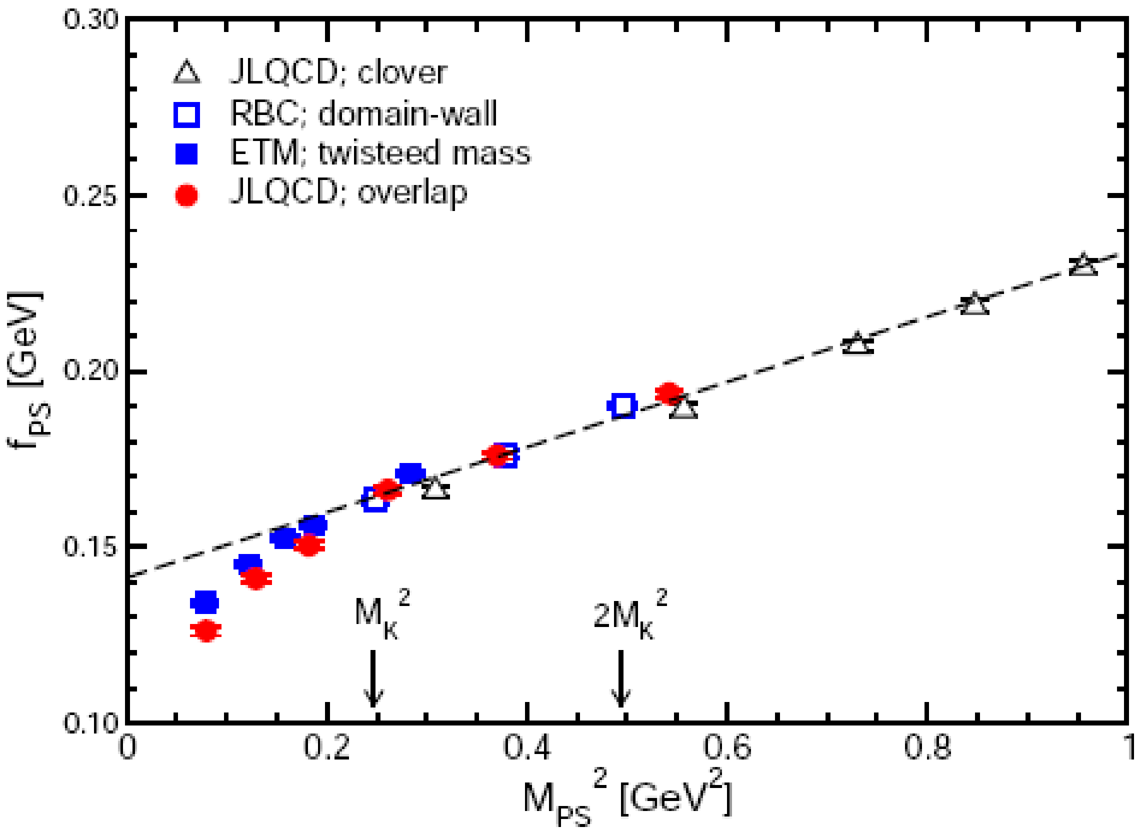
Good reasons to be quite optimistic for the near future:

$f_{\rm PS}$ vs $M^2_{\rm PS}$

$N_f = 2$ data, NP Z_A, a from r_0

$m_{\rm sea} \gtrsim m_s/2$: JLQCD(clover), RBC(domain-wall)

$m_{\rm sea} \lesssim m_s/2$: ETM(twisted mass), JLQCD(overlap)



- curvature at $m_{ud,\rm sim} \lesssim m_{s,\rm phys}$
  $\Rightarrow$ chiral log ?

- ETM: simultaneous NLO ChPT fit to $M^2_{\rm PS}$, $F_{\rm PS}$
  (FSEs corrected, stat. err. only)

  $F = 121.3(7)$, $\bar{l}_4 = 4.52(6)$

  $\Leftrightarrow$ $F = 122.5(3.1)$ *(MILC, 2006)*
  $F = 121.6(1.0)$ *(JLQCD, 2006, prelim.)*
  $\bar{l}_4 = 4.4(2)$ *(Colangelo et al., 2001)*

  $\Downarrow$

  exploring quark masses small enough to make contact with NLO ChPT!

[Kaneko]

V_{us} from K_{l3} data and CKM unitarity

K_{l3} average: $|V_{us}|\, f_+(0)$ = 0.21668(45)

-0.1% respect to CKM06 and PDG06

Leutwyler & Roos '84
$f_+(0)$ = **0.961(8)**

Conventional choice for value of $f_+(0)$ until a definitive evaluation becomes available

K_{l3} average: $|V_{us}|$ = 0.2255(19)

Marciano & Sirlin '06
$|V_{ud}|$ = **0.97377(27)**

Average from $0^+ \rightarrow 0^+$ β decays with recent evaluation of EW radiative corrections

$$V_{ud}^2 + V_{us}^2 - 1 = -0.0009(10)$$

Compatibility with unitarity –0.9σ

-1σ if V_{ud} updated to 0.97372

As usual the SM is in great shape...

...but when the error on $f(0)$ will reach few x 0.1% it will be fun !!

K_{e2}: progress on the exp. side

Two new preliminary results:

- **NA48/2 (2004 data), presented at KAON07:**
  - About 4000 signal events from special minimum bias trigger.
  - Small systematics, except background.
    (measured from data → large statistical uncertainty in syst. error.)
  - Completely uncorrelated with 2003 measurement.

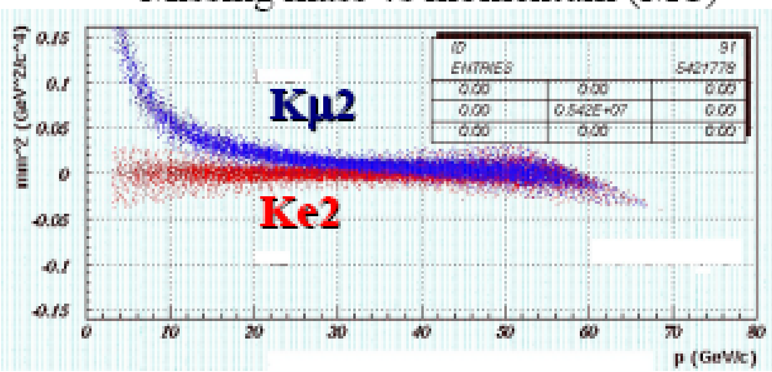
$$\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.455 \pm 0.045 \pm 0.041) \times 10^{-5}$$

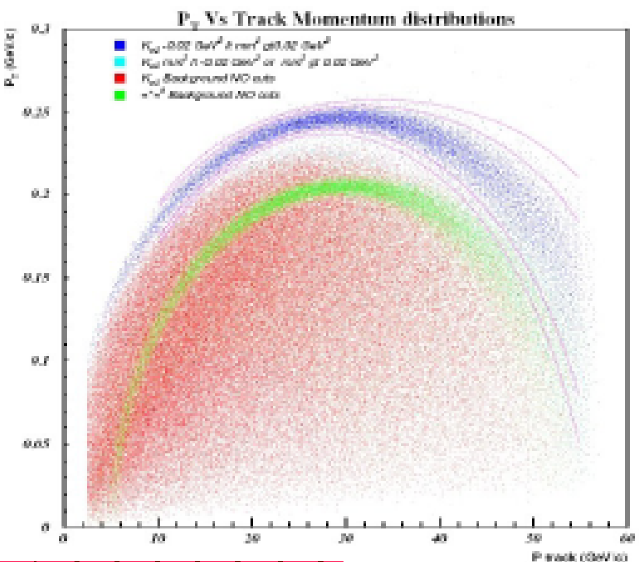
- **KLOE, presented at KAON07:**
  - About 8000 signal events from 1.7 fb^{-1}.
  - Statistics dominated by MC, conservative systematics estimation.

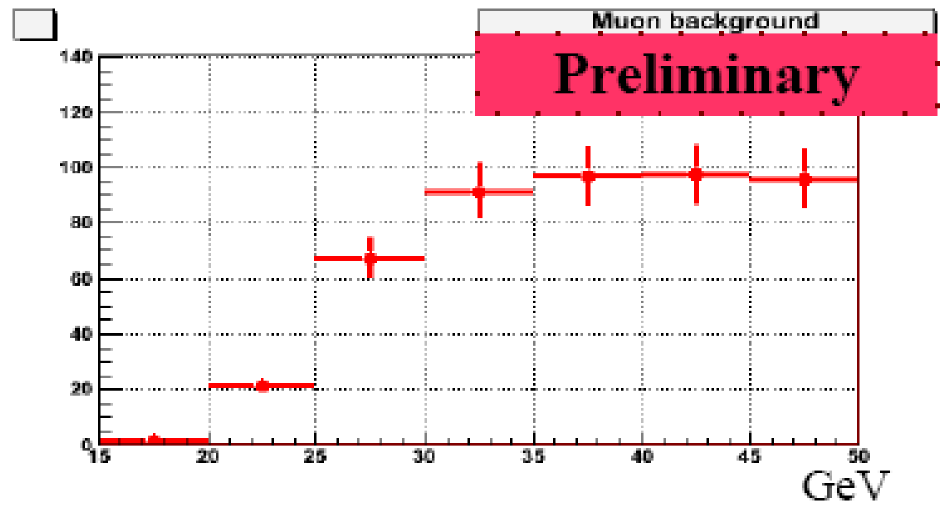
$$\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.55 \pm 0.05 \pm 0.05) \times 10^{-5}$$

It's definitely a difficult measurement...

Missing mass vs momentum (MC)







- The dominant background is Kμ2
  - **Measured from the data in momentum bins**
- Ke3 contribution obtained from MC

Preliminary

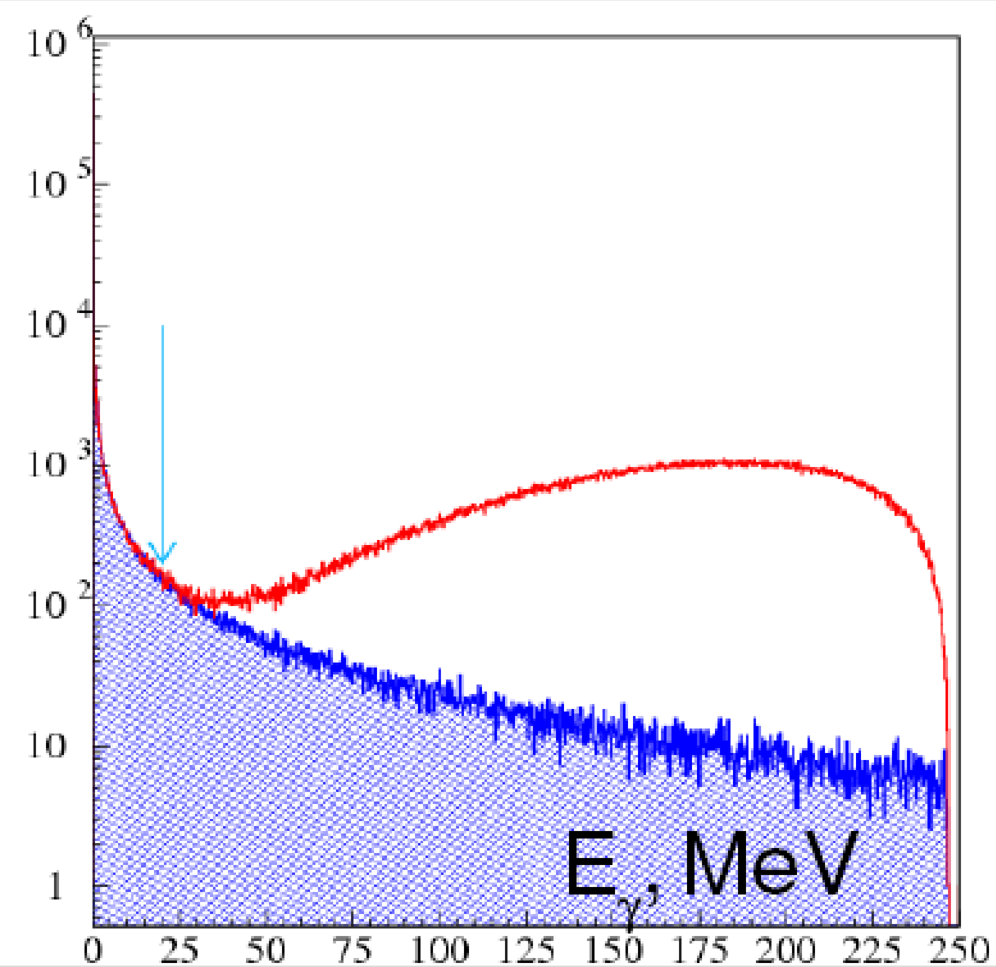
Total Ke2 events: ($3407 \pm 63_{stat} \pm 54_{syst}$)

[Kozhuharov]

It's definitely a difficult measurement...

Signal definition

- Radiative corrections: IB + DE terms in MC generator
- Signal: $K \to e\nu(\gamma)$, $E_\gamma < 20$ MeV
- DE is negligible in this range
- SM prediction made in terms of IB process only (unobservable)
  - After counting, correct for $\varepsilon_{IB} = 0.9528(5)$ to compare with SM



[Sibidanov]

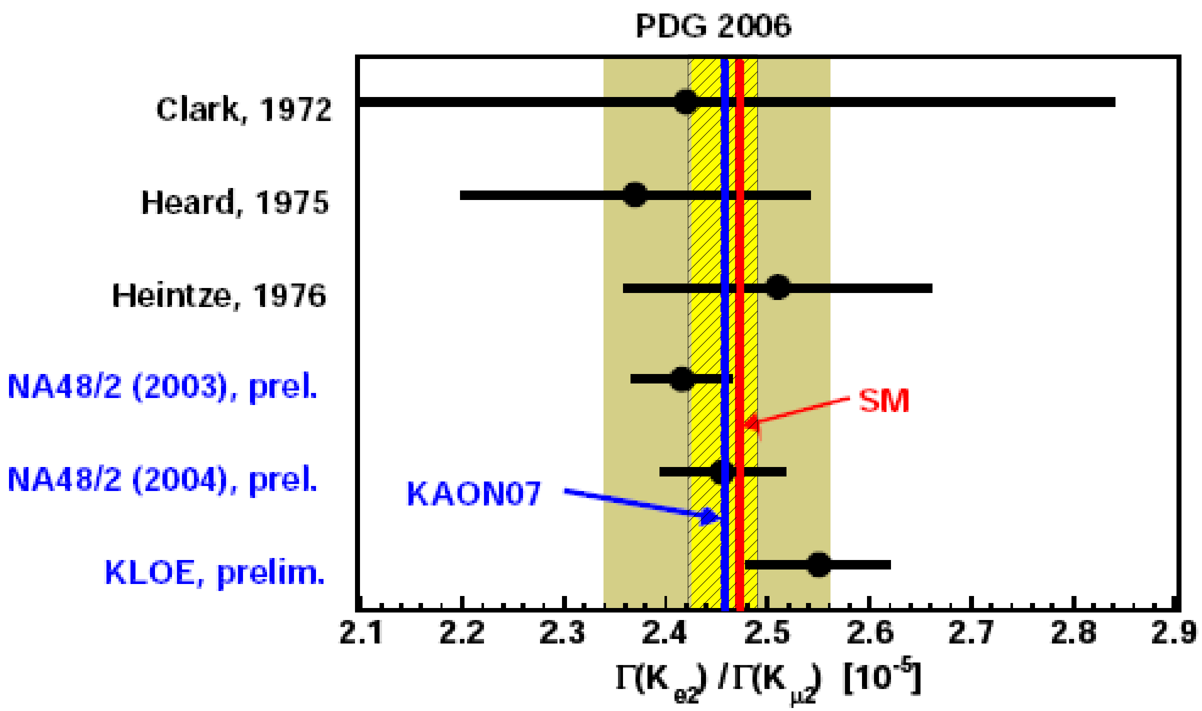
...but it already provides interesting constraints on NP:

$K_{e2}/K_{\mu 2}$ — *Measurements*

Combine all preliminary results and PDG2006:

$$\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.457 \pm 0.032) \times 10^{-5}$$ $(\chi^2/n_{\text{dof}} = 2.44/3)$

- Huge improvement w.r.t PDG 2006, $\sigma_{\text{rel.}} = 1.3\%$ now!
- Perfect agreement with SM expectation.



[Wanke]

...but it already provides interesting constraints on NP:

Limit on LFV in $H^{\pm}$ coupling:

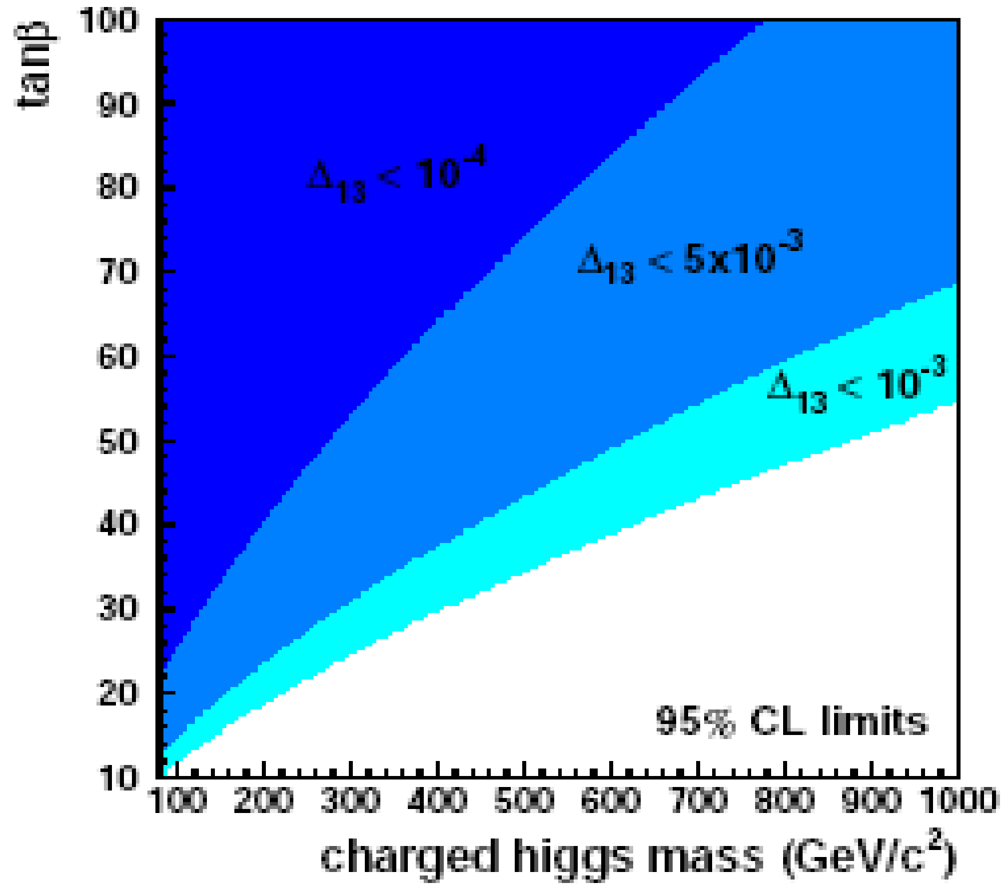
(Masiero, Paradisi, Petronzio, PRD 74, 2006)

LFV Yukawa coupling:

$$l H^{\pm} \nu_\tau \rightarrow \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_{13} \tan^2 \beta$$

$$\Delta_{3j} \sim \frac{\alpha_2}{4\pi} \delta_{3j}$$

slepton flavour-mixing angle



[Wanke + NA48 &KLOE]

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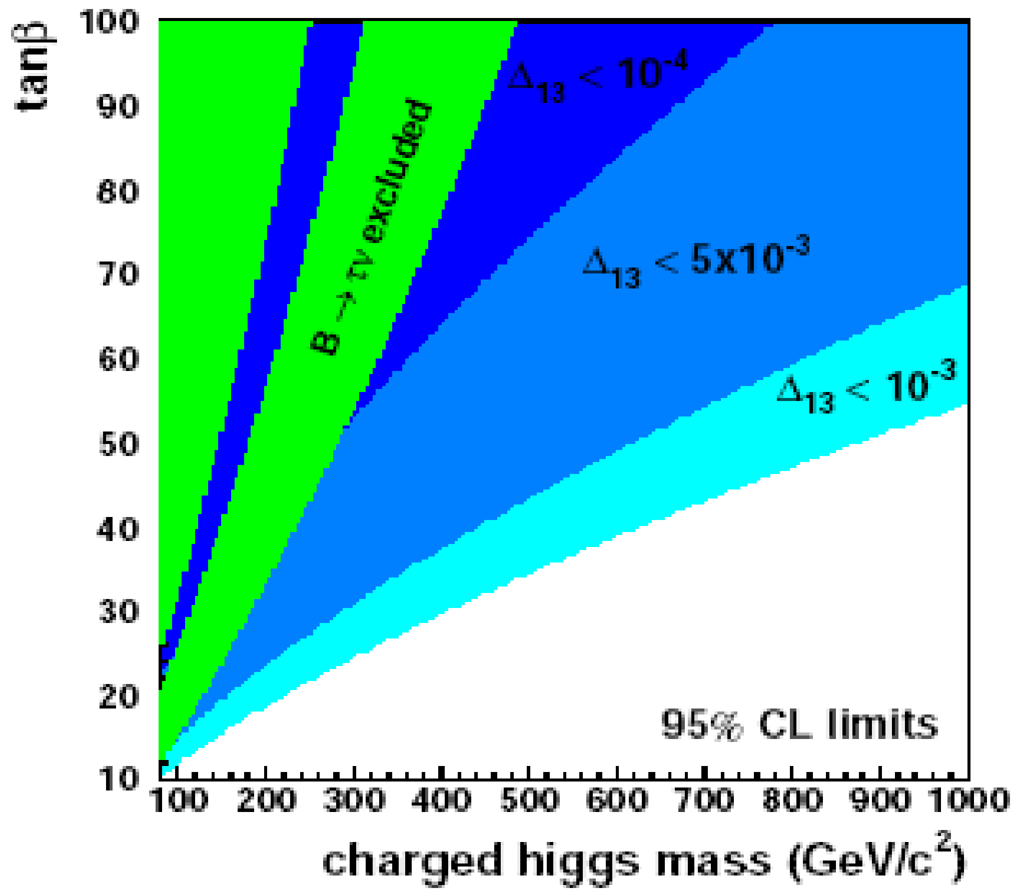


Sensitivity to $H^\pm$ in $K_{e2}/K_{\mu2}$ better than in $B \rightarrow \tau\nu_\tau$!

[Wanke + NA48 &KLOE]

The $K_{e2}/K_{\mu 2}$ — *Near Future* is bright !

KLOE:

- Has $\sim 20\%$ more data on tape.
- Another ~ 3000 events with other reconstruction method.
- Improve MC statistics & systematics

$\Longrightarrow$ Should arrive at $\sigma_{\text{rel}}(\mathbf{R_K}) \sim \pm 1\%$.

P-326: (also known as NA48/3)

- Similar setup as for NA48/2 (2004) prel. measurement, use of most parts of existing NA48 apparatus.
- Plan: 4 months (June-October 2007) run period

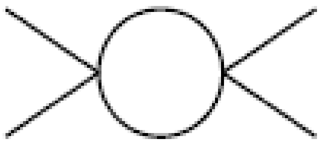
  $\Longrightarrow$ Collect $\sim 150\,000\ K_{e2}$ decays.

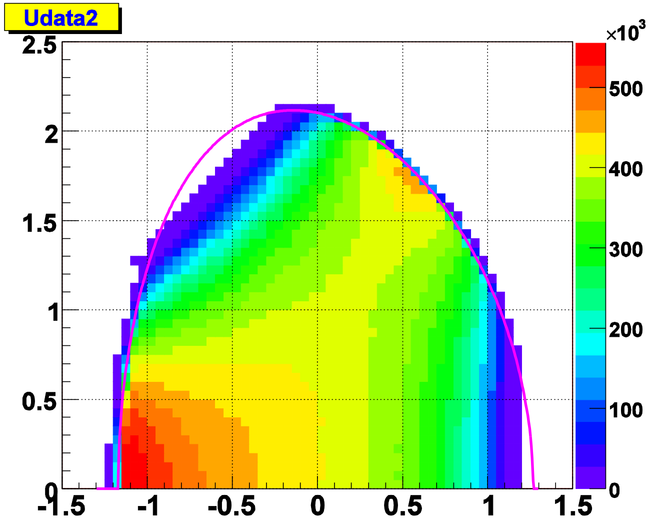
$\Longrightarrow$ Goal to reach $\sigma_{\text{rel}}(\mathbf{R_K}) \sim \pm 0.3\%$.

II. The *mystic world* of ππ scattering

???

Paradise ⟺ Real world





"Entia non sunt multiplicanda praeter necessitatem"

Why is $\pi\pi$ scattering interesting

- the pions are the quasi-Goldstone bosons of spontaneous chiral symmetry breaking of QCD
- their interaction vanishes in the limit of zero momenta and quark masses
- a precision study of the departure from this limit thoroughly tests our understanding of strong interactions in the nonperturbative regime (structure of the QCD vacuum)

CHPT below threshold + Roy

$$\begin{aligned} a_0^0 &= 0.197 \to 0.2195 \to 0.220 \\ 10 \cdot a_0^2 &= -0.402 \to -0.446 \to -0.444 \end{aligned}$$

$$\begin{aligned} a_0^0 &= 0.220 \pm 0.005 \\ 10 \cdot a_0^2 &= -0.444 \pm 0.01 \\ a_0^0 - a_0^2 &= 0.265 \pm 0.004 \end{aligned}$$

[Colangelo]

These marvelous predictions are obtained in an ideal world with no (or negligible) isospin breaking (*the paradise*)...

Experiments where scattering lengths can be measured:

$K \to 3\pi$	cusp	CERN/SPS NA48
$K \to \pi\pi e \nu_e$	phase	CERN/PS Geneva-Saclay
		BNL E865, CERN/SPS NA48
Pionium	lifetime	CERN/PS DIRAC
etc		

These experiments are performed in the real world, where

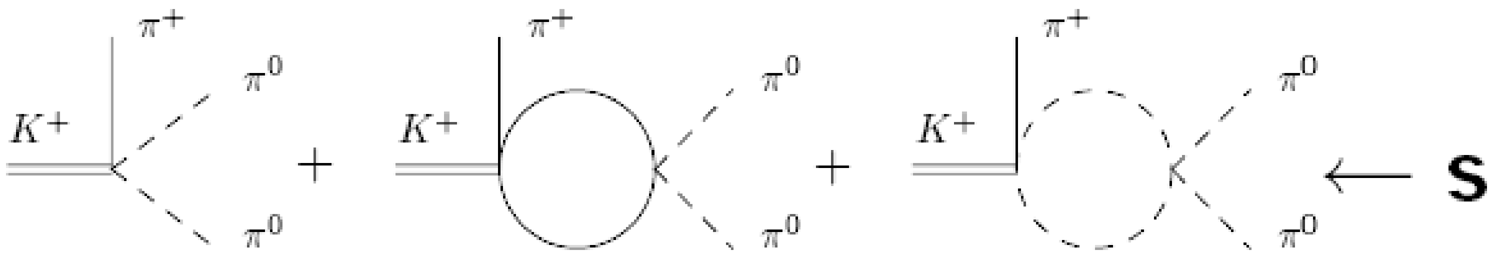
$$e \neq 0\,;\; G_F \neq 0\,;\; M_{\pi^+} \neq M_{\pi^0}\,;\; m_u \neq m_d\,.$$

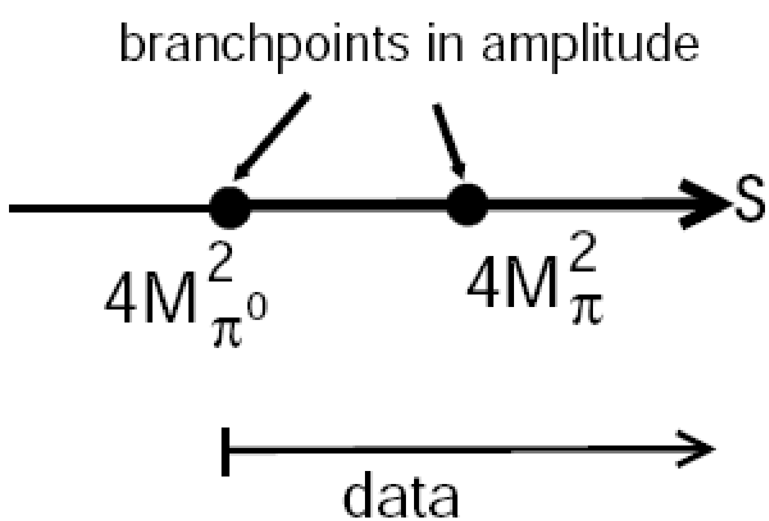
$$\text{Paradise} \overset{???}{\Longleftrightarrow} \text{Real world}$$

[Gasser]

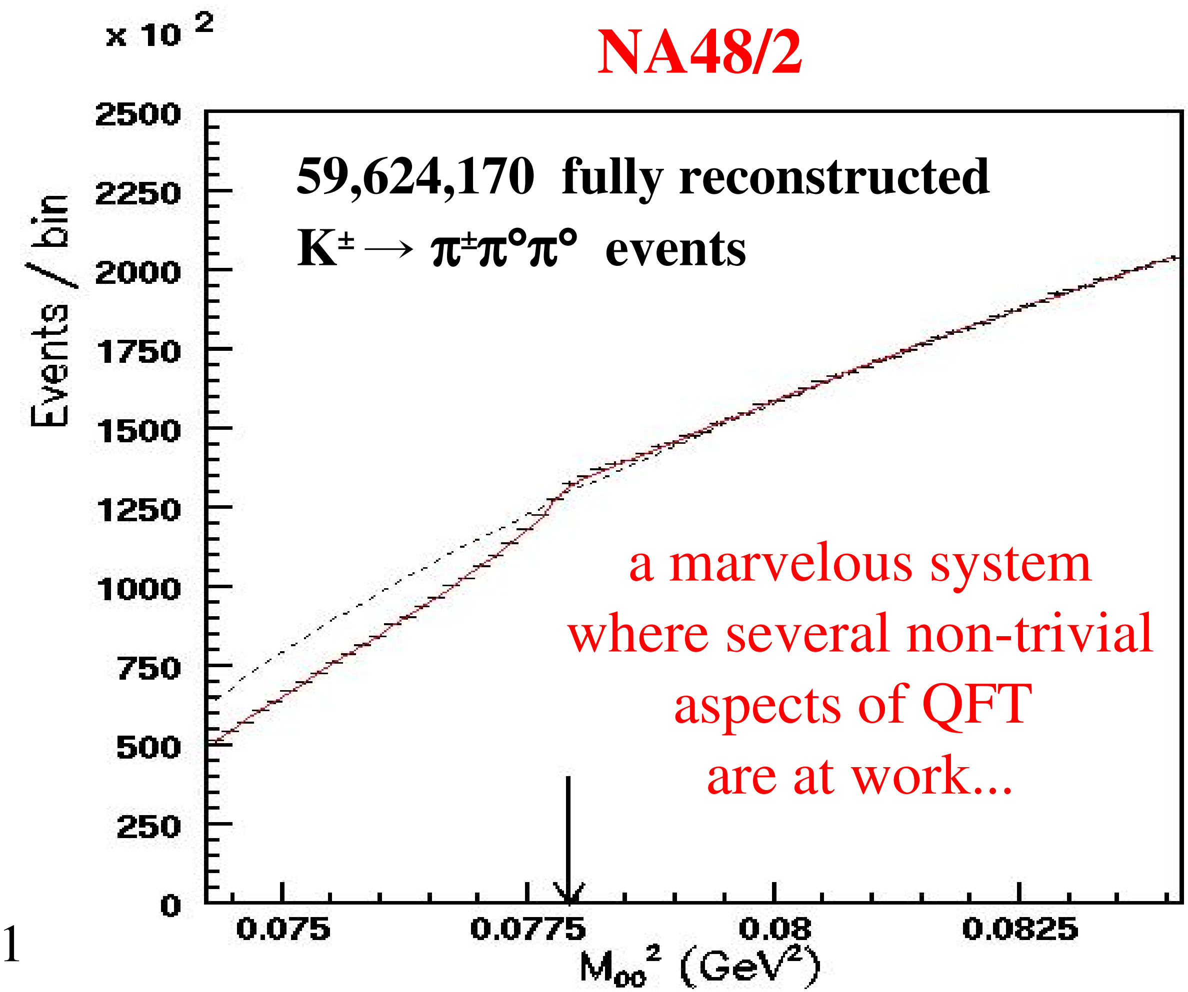
The $K_{3\pi}$ cusp

[Gasser, Di Lella]





NA48/2



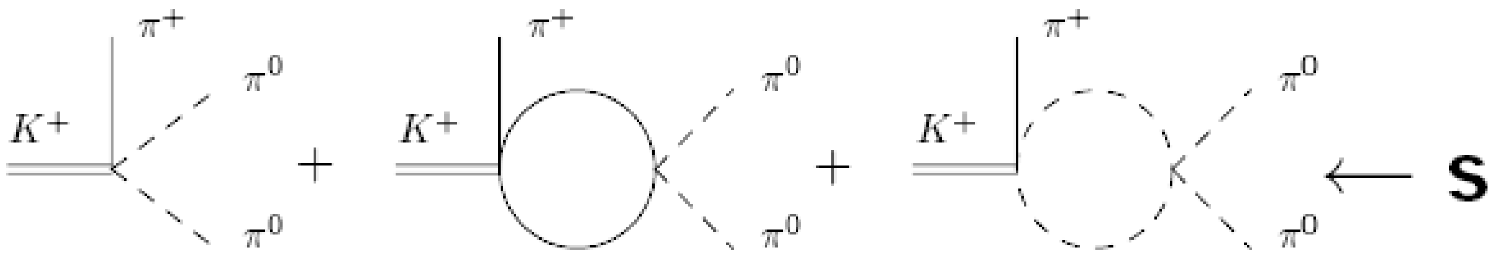
$\pi^+\pi^-$ charge exchange prop to $a_0 - a_2$

➡ new method to measure $a_0 - a_2$

N. Cabibbo, PRL 93 (2004) 12181

The $K_{3\pi}$ cusp

[Gasser]



Several approaches to cusp analysis

- Cabibbo, PRL 93:121801,2004

  Cabibbo, Isidori, JHEP 0503 (2005) 021

  analyticity + unitarity + expansion in $\pi\pi$ scattering lengths
- Gámiz, Prades, Scimemi, hep-ph/0602023

  ChPT + variation of Cabibbo/Isidori approach
- Colangelo, J.G., Kubis, Rusetsky, PLB 638 (2006) 187

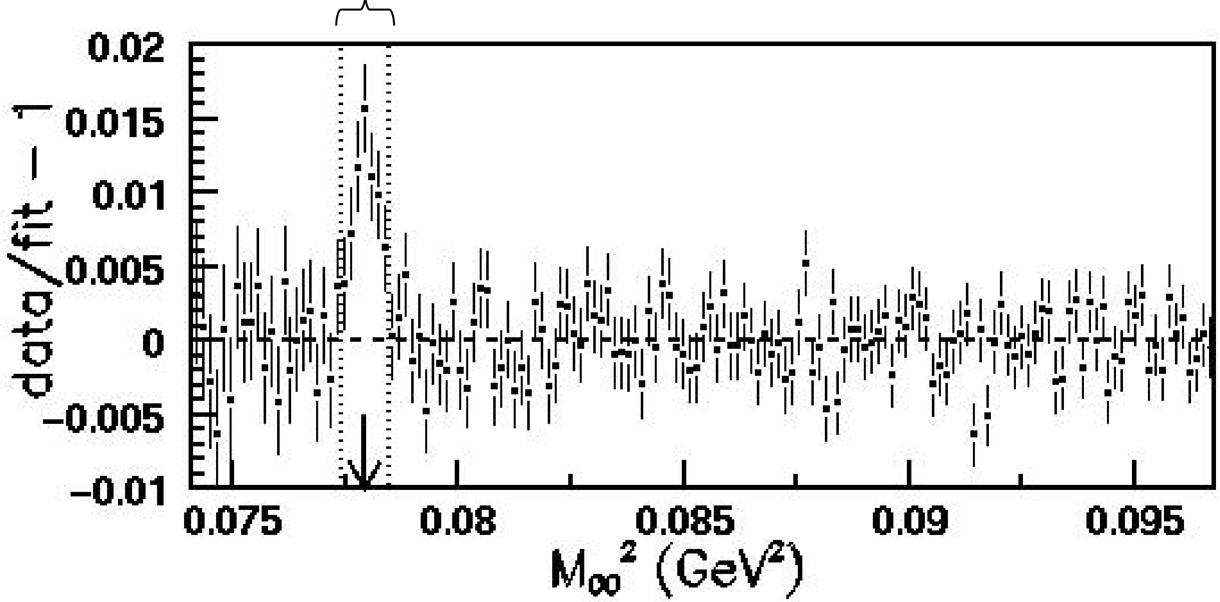
  Lagrangian framework: non-relativistic QFT. Advantage: Is a systematic procedure.

  November 2006: M. Bissegger, A. Fuhrer joined the group

promising approach to quanifty/reduce the error in the paradise/real-world transition

Fit quality

[Di Lella, Goudzovski]



Interestingly enough, if we exlude the 7 bins around the threshold, data are very close to the expecations of the (virtual) paradise...

$$(a_0 - a_2)m_+ = 0.261 \pm 0.006 \pm 0.003 \pm 0.0013 \pm 0.013$$

(stat.) (syst.) (ext.) (theor.)

$$a_2 m_+ = -0.037 \pm 0.013 \pm 0.009 \pm 0.002$$

Best fit to the Cabibbo – Isidori rescattering model (JHEP 0503 (2005) 21)

First attempt to perform a combined fit of $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^\circ\pi^\circ$ using the Bern – Bonn approach (PRELIMINARY – only statistical errors are shown):

$$\chi^2 = 757.1 / 757 \text{ d.f.}$$
$$(a_0 - a_2)m_+ = 0.266 \pm 0.003$$

The Roy/CHPT prediction:

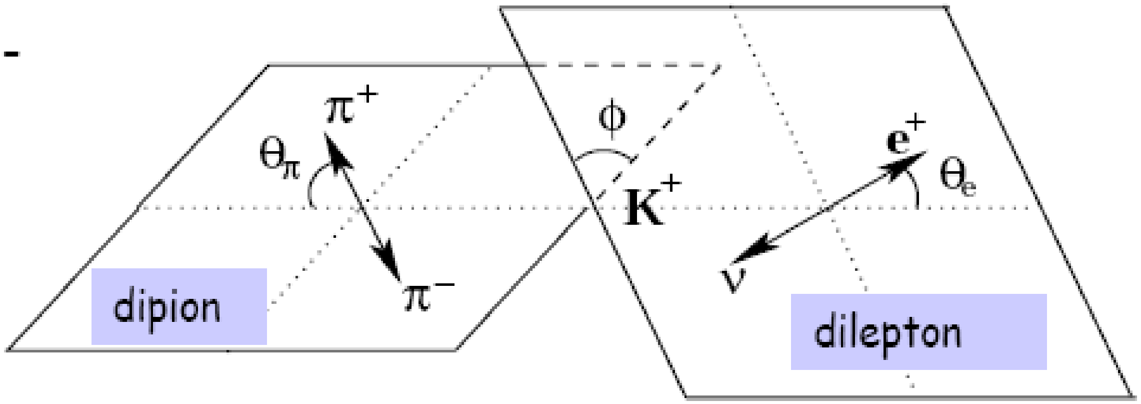
$$a_0^0 - a_0^2 = 0.265 \pm 0.004$$

Phase shifts from K_{l4}

Five kinematic variables (Cabibbo-Maksymowicz):

S_π ($M^2_{\pi\pi}$), S_e ($M^2_{e\nu}$),

$\cos\theta_\pi$, $\cos\theta_e$ and ϕ.



partial wave expansion of the amplitude:

F, G = Axial Form Factors

$F = F_s e^{i\delta s} + F_p e^{i\delta p} \cos\theta_\pi$ + d-wave term…

$G = G_p e^{i\delta g}$ + d-wave term…

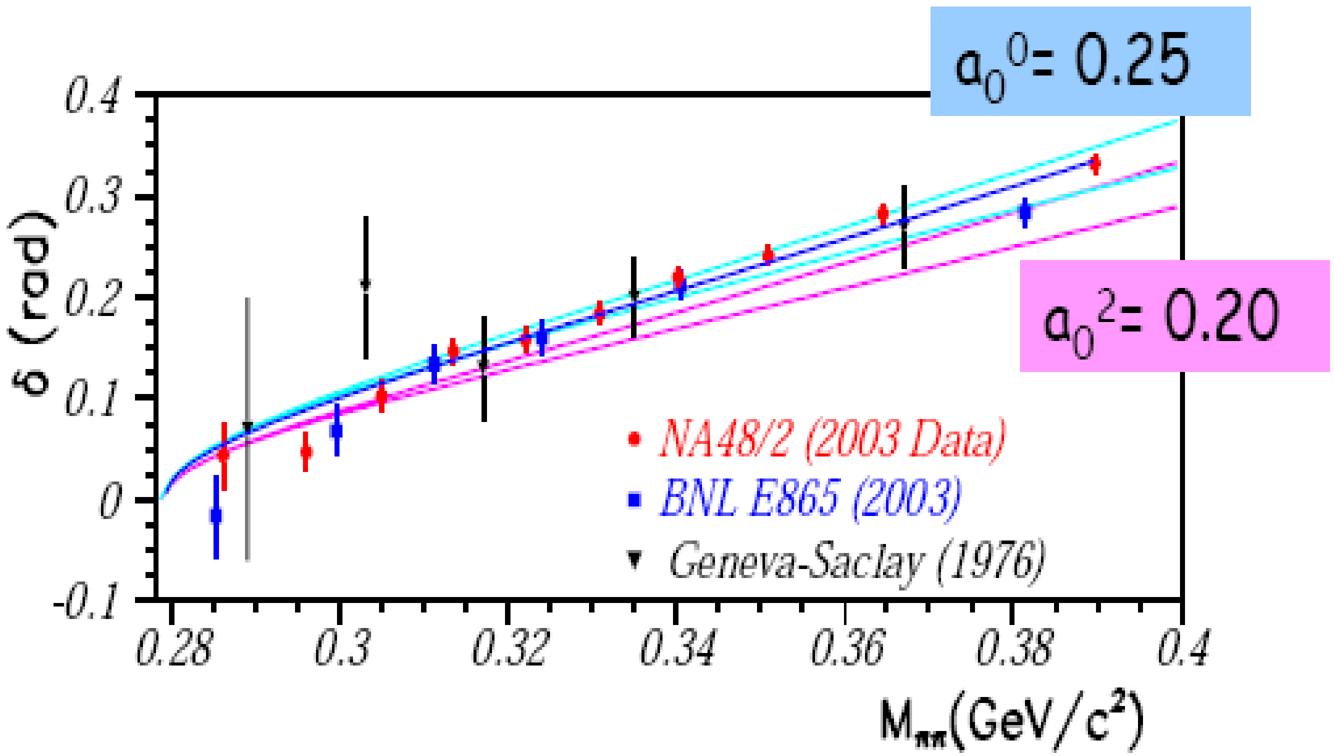
The fit parameters are : F_s F_p G_p H_p and $\delta = \delta_s - \delta_p$

[Bloch-Devaux]

Phase shifts from K_{l4}

Geneva – Saclay : ~ 30,000 events , p_{K^+} = 2.8 GeV/c
BNL E865 : 406,103 events (with ~ 4.4% background), p_{K^+} = 6 GeV/c
NA48/2 : 677,510 events (with ~0.5% background), $p_{K^\pm}$ = 6 GeV/c

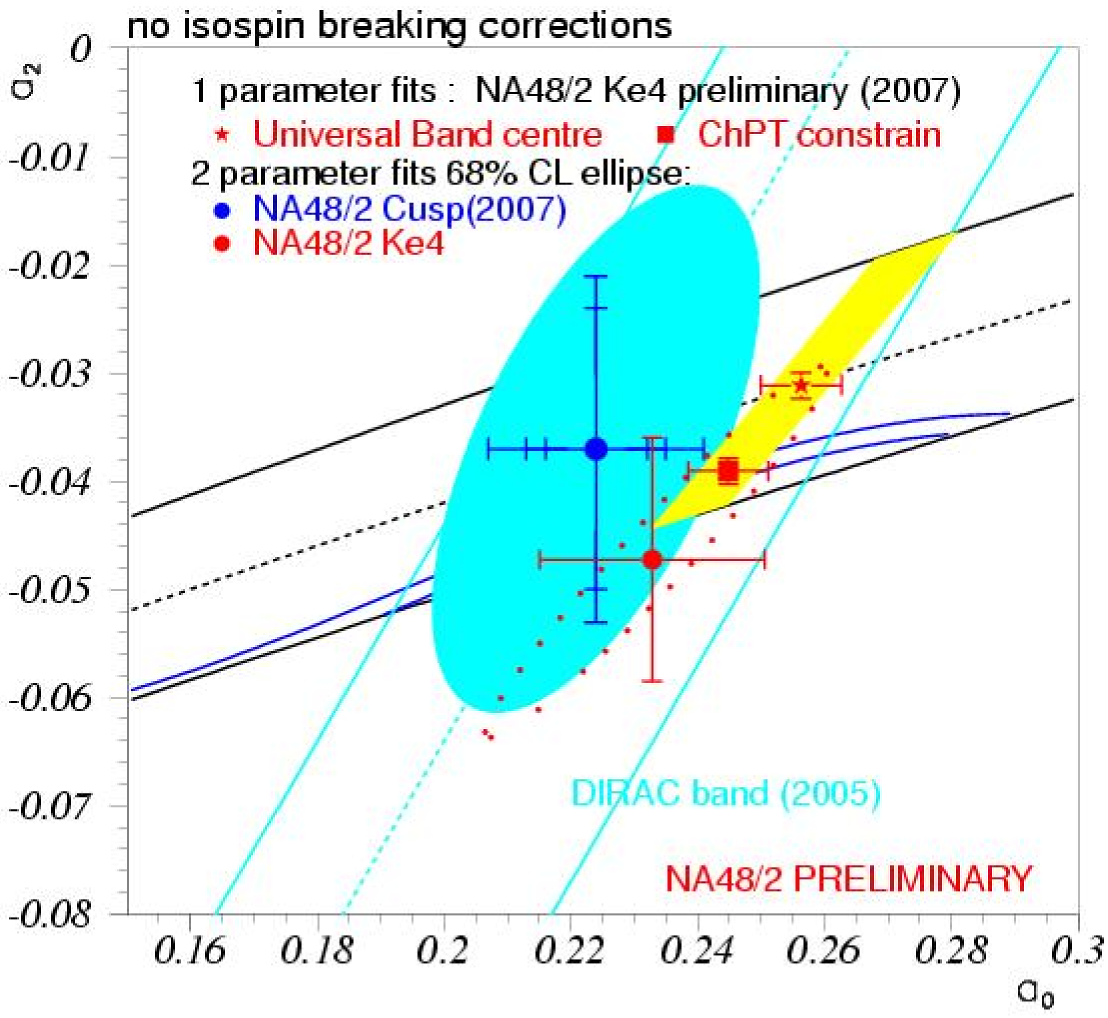
E865 quotes various values extracted from their Ke4 phase measurements, ranging from a_0^0 = 0.203 to a_0^0= 0.237
NA48/2 seems to prefer slightly higher values



Last point of E865 seems somewhat inconsistent with other points (Could that be a problem with the mass value quoted for the last bin ...?)

[Bloch-Devaux]

NA48/2 Cusp – Ke4 comparison



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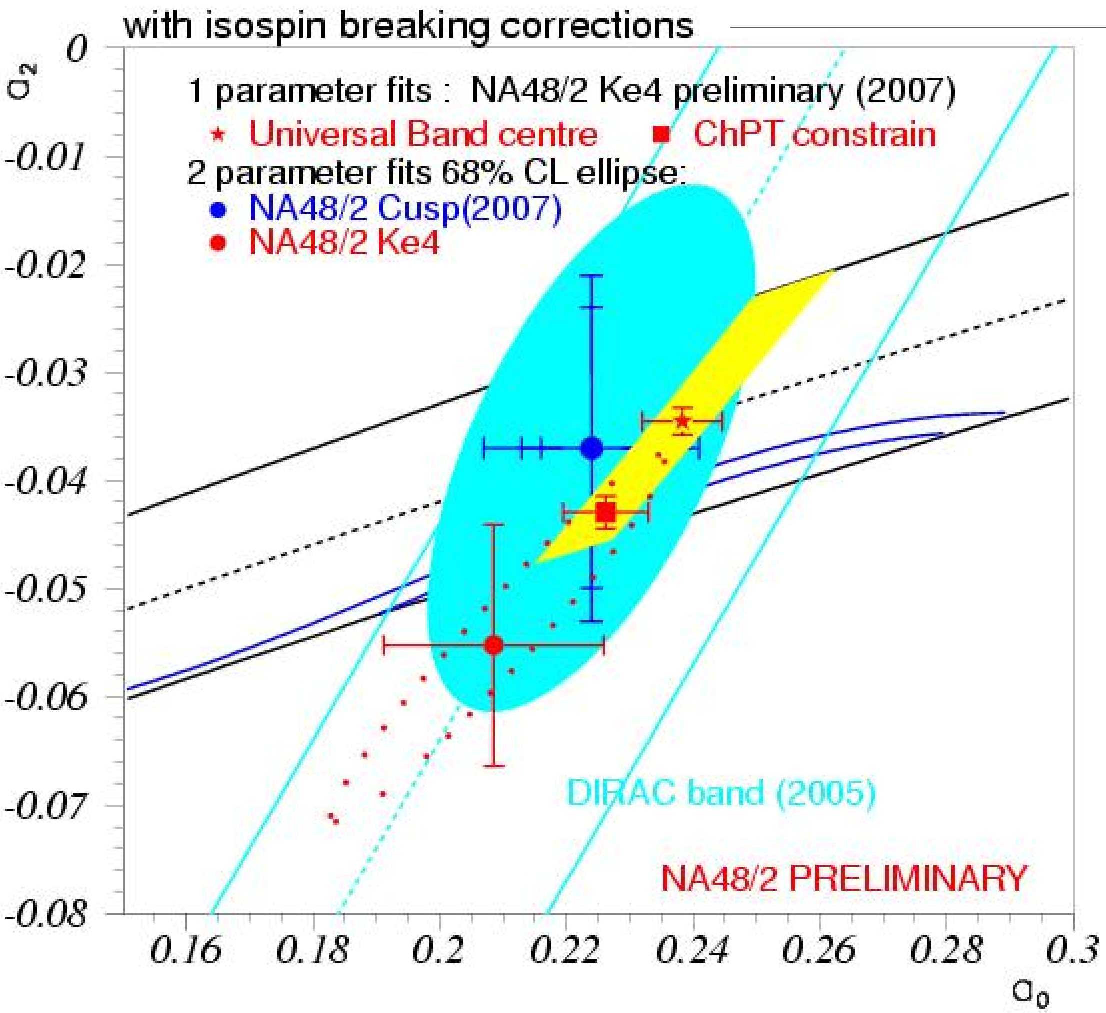


→ Colangelo, Gasser, Rusetsky, work in prog.

Occam's razor at work

III. The *chaotic world* of non-leptonic & radiative decays

ε'/ε knows much more than G_F

but....

Progress on direct CPV

Final results for 2003 + 2004 (NA48/2)

Charged mode (3.11×10^9 selected $K^\pm \to \pi^\pm\pi^+\pi^-$)

$$A_g = (-1.5 \pm 1.5_{stat.} \pm 0.9_{trig.} \pm 1.1_{syst.}) \times 10^{-4} = (-1.5 \pm 2.1) \times 10^{-4}$$

Neutral mode (9.13×10^7 selected $K^\pm \to \pi^\pm\pi^0\pi^0$)

$$A_g = (1.8 \pm 1.7_{stat.} \pm 0.9_{syst.}) \times 10^{-4} = (1.8 \pm 1.9) \times 10^{-4}$$

$$A_g = \frac{g^+ - g^-}{g^+ + g^-}$$

[Winhart]

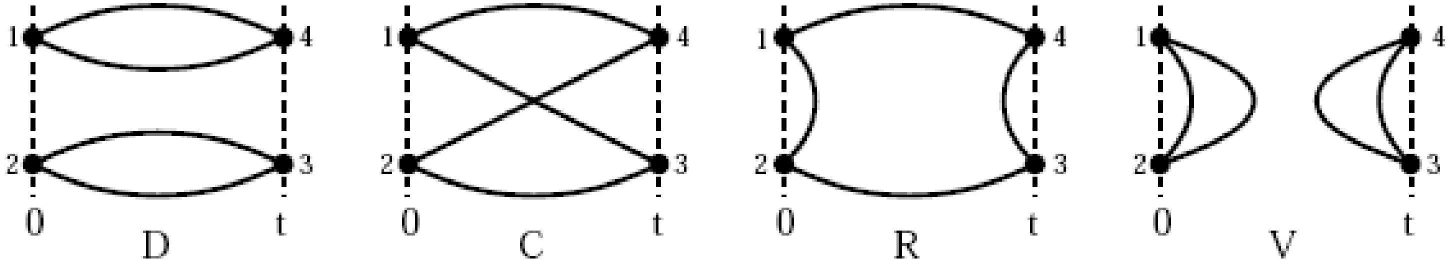
Consistent with zero,
and also with the CHPT + large N prediction:

$$\Delta g_C = -(2.4 \pm 1.2) \times 10^{-5}$$

[Prades]

Can we hope, one day, to translate the precise infos on direct CPV in kaon physics into a quantitative SM test ?

- There has been a considerable amount of theoretical progress in formulating $K \to \pi\pi$ decays in a form suitable for lattice simulations.
- There is the opportunity of achieving significant numerical results for $K \to \pi\pi$ decay amplitudes.
  - For $I = 2$ final states, there is now no barrier to calculating the matrix elements precisely.
  - For $I = 0$ $\pi\pi$ states we need to learn how to calculate the disconnected diagrams with sufficient precision.



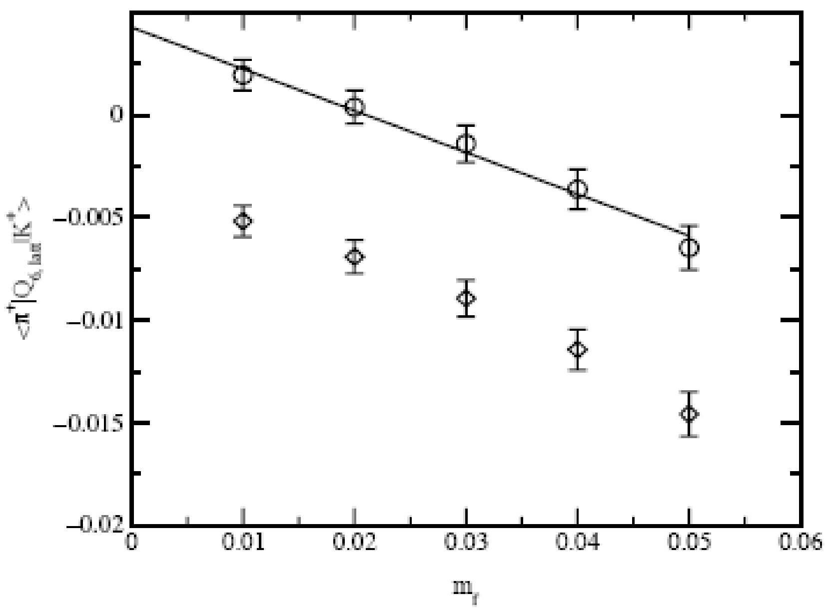
[Sachrajda]

It's not hopeless... (but also not around the corner)

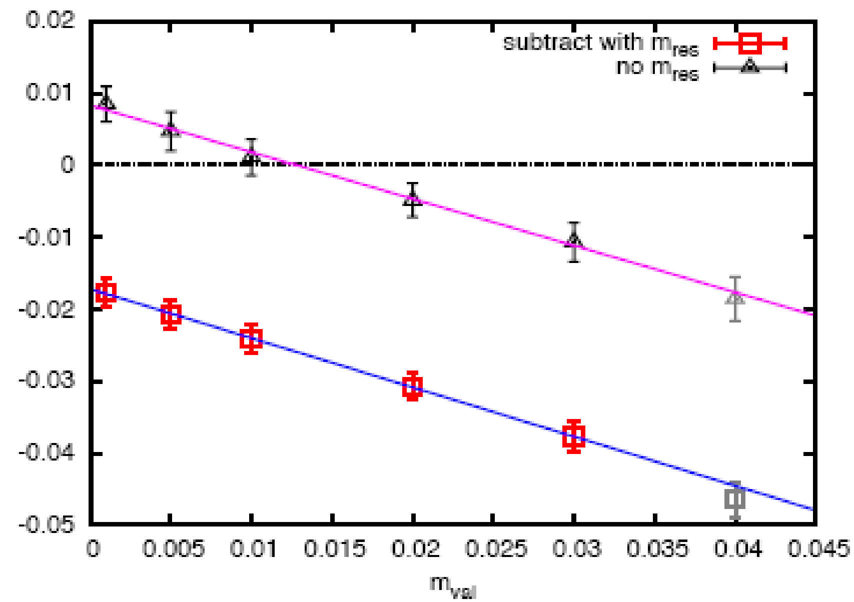
Can we hope, one day, to translate the precise infos on direct CPV in kaon physics into a quantitative SM test ?

$$\langle \pi^+ | Q_{i,\mathrm{lat}}^{(1/2)} | K^+ \rangle + \eta_{1,i}(m_s + m_d) \langle \pi^+ | (\bar{s}d)_{\mathrm{lat}} | K^+ \rangle$$

Previous Quenched



New 2+1 Flavor



RBC-UKQCD calculation of NLO coefficients from K -> π and K -> vacuum

[Mawhinney]

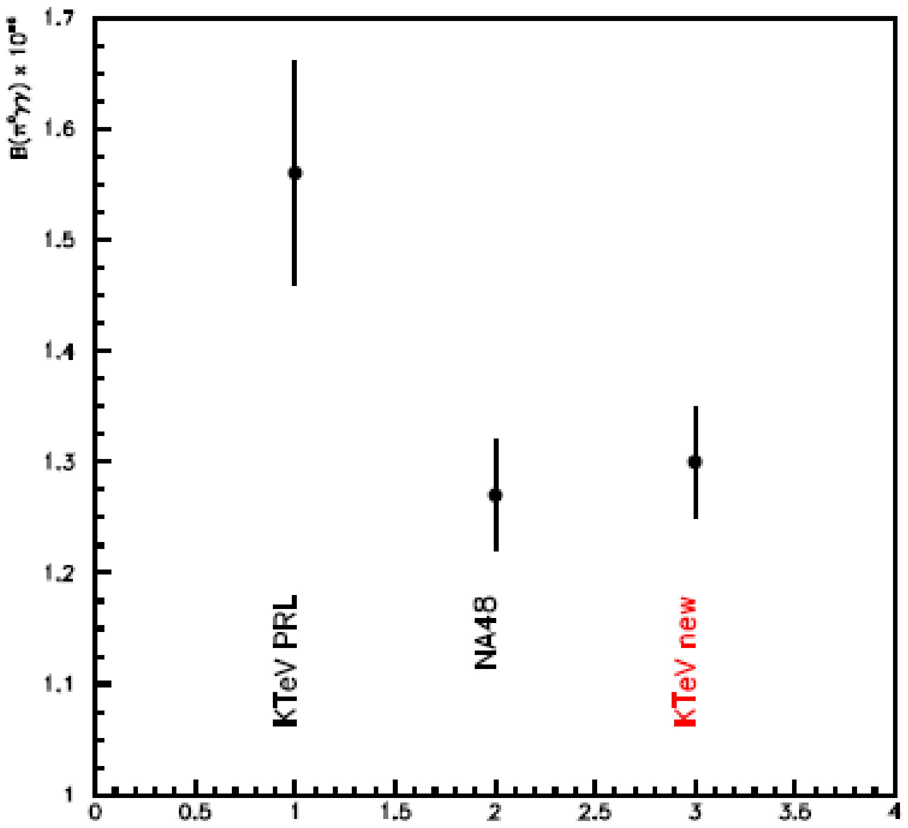
Progress on radiative decays

I) the solution of a long-standing disagreement...

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

[*and a good news for* $K_L \to \pi^0 ee$]

- Underestimate of background led to higher value in previous KTeV result.
  - New results consistent with published NA48 result.
- Result supercedes previous KTeV result.
- All BR adjusted to new $K_L \to \pi^0\pi^0$ BR.



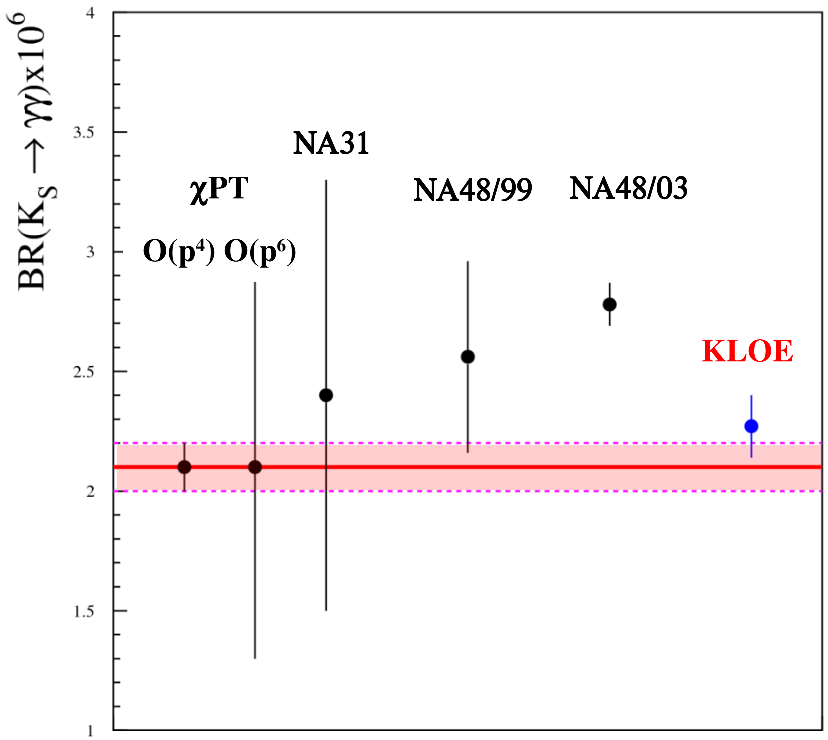
[Cheu]

Progress on radiative decays

II) ... and the announcement of a new one

$B(K_s \to \gamma\gamma) = (2.27 \pm 0.13_{stat}\ {}^{+0.03}_{-0.04})\ 10^{-6}$ @

-The NA48 measurement implied the existence of a sizeable $O(p^6)$ CT
Our number makes this contribution practically negligible

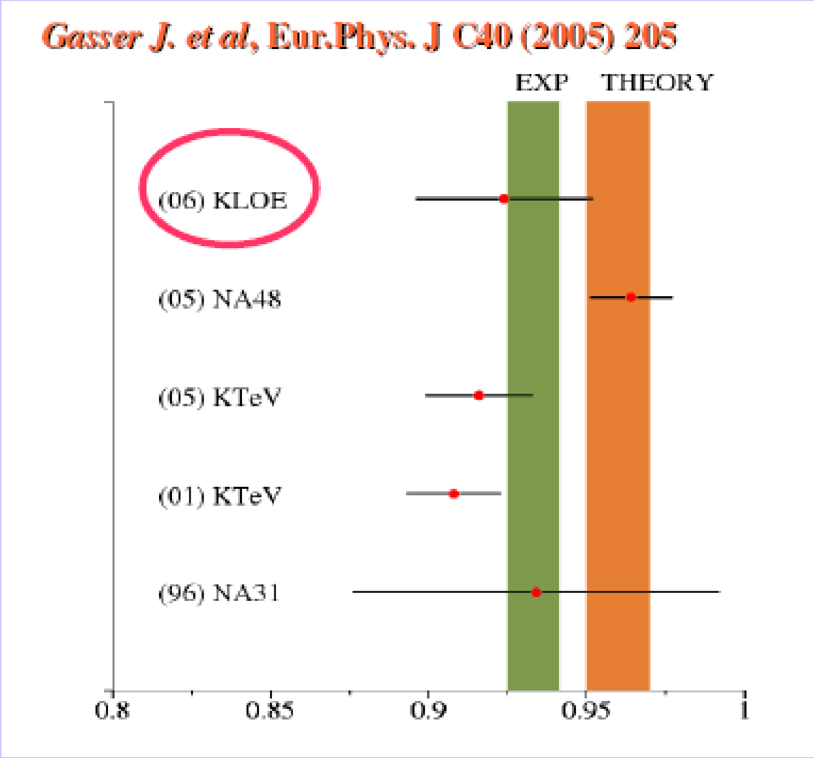


[Martini]

Progress on radiative decays

III) new entries in good agreement with CHPT...

$$R = \mathbf{BR}(Ke3\gamma\,;\, E^*_\gamma > 30\ \mathrm{MeV},\ \theta^*_{lep\text{-}\gamma} > 20^o)\ /\ \mathbf{BR}(\ Ke3(\gamma))$$



$$R = (\ 924 \pm 23_{stat} \pm 16_{syst}\ ) \times 10^{-5}$$

[Dreucci]

Progress on radiative decays

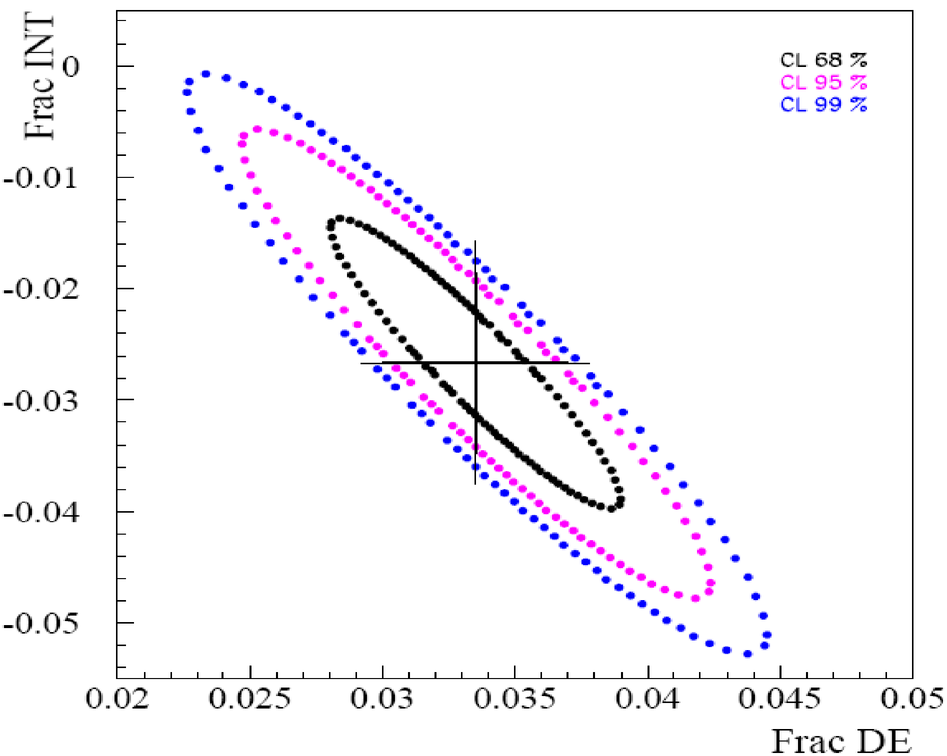
IV) ...and new challeges for our understanding of CHPT in non-lept. modes

$K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ @ NA48

- fit the W data spectrum using MC shapes with the weights to be extracted:

$$W_{dat} = (1-\alpha-\beta)W_{IB} + \alpha W_{DE} + \beta W_{INT}$$

- systematic dominated by Trigger efficiency.
- parameters are highly correlated r=-0.92



First evidence of non zero INT term!

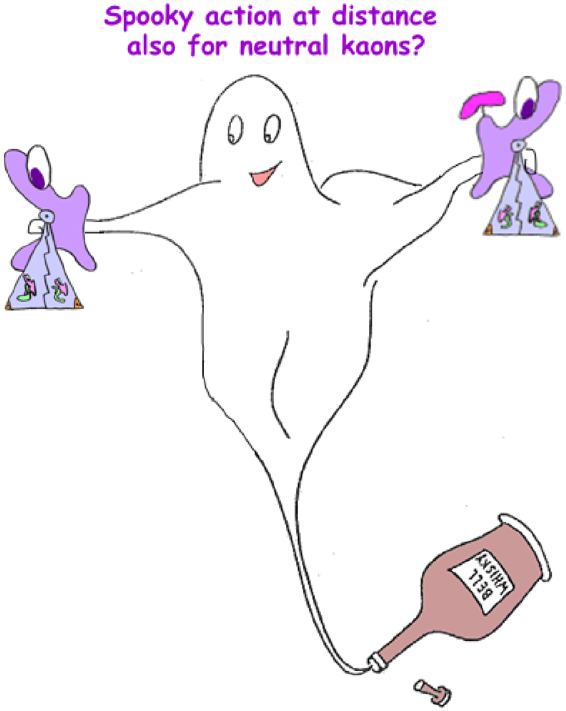
$$Frac(DE)_{0<T^*_{\pi}<80\,MeV} = (3.35 \pm 0.35 \pm 0.25)\%$$

$$Frac(INT)_{0<T^*_{\pi}<80\,MeV} = (-2.67 \pm 0.81 \pm 0.73)\%$$

2004 data set: x4 # events and lower systematic due to trigger

[Imbergamo]

IV. Challenging the basis: CPT & QM tests



Some Theory

[Mavromatos]

- **CPT SYMMETRY:**
  - (1) Lorentz Invariance, (2) Locality , (3) Unitarity
    - **Theorem proven for FLAT space times**

      (Jost, Luders, Pauli, Bell, Greenberg)
- **Why CPT Violation?**
  - Quantum Gravity (QG) Models violating Lorentz and/or Quantum Coherence:

    (I) Space-time foam: QG as "Environment"

    → **Decoherence, CPT Ill defined (Wald 1979)**

    (II) Standard Model Extension: Lorentz Violation in Hamiltonian H:

    → **CPT well defined but non-commuting with H**

    (III) Loop QG/space-time background independent; Non-linearly Deformed Special Relativities : Quantum version not fully understood…

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    (III) Loop QG/space-time background independent; Non-linearly Deformed Special Relativities : Quantum version not fully understood…

Remember CP lesson (not theoretically predicted)

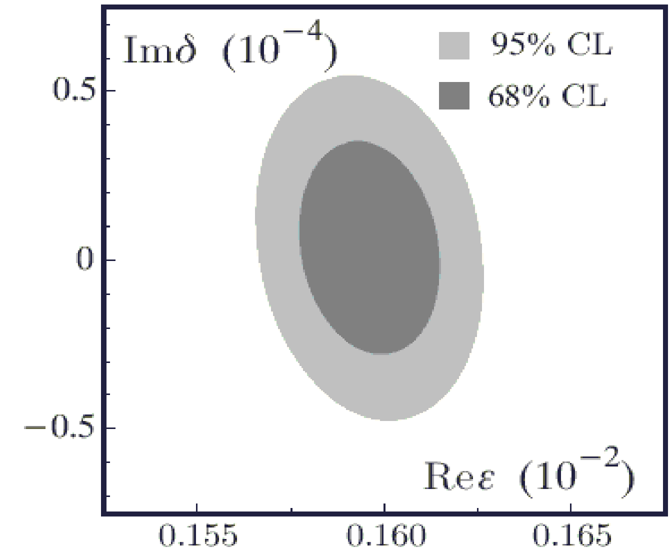
= never trust theoreticians...

[D'Ambrosio]

CPT test using the Bell-Steinberger relation at KLOE

KLOE result:

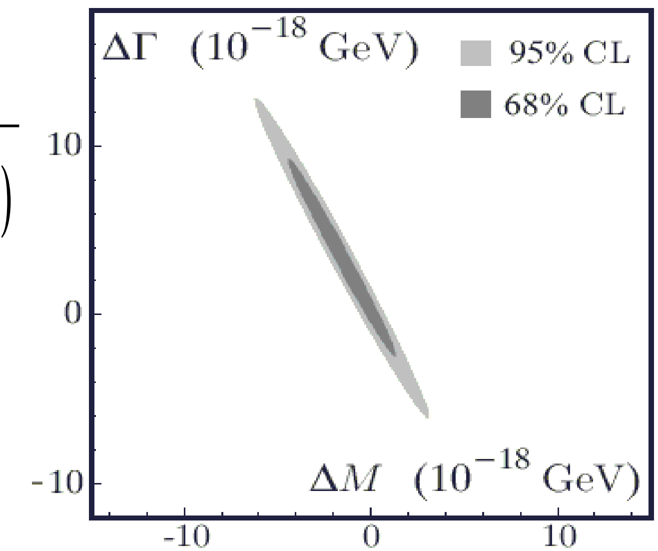
$\mathrm{Re}\,\varepsilon = (159.6 \pm 1.3) \times 10^{-5}$
$\mathrm{Im}\,\delta = (0.4 \pm 2.1) \times 10^{-5}$



CPLEAR:
$\mathrm{Re}\,\varepsilon = (164.9 \pm 2.5) \times 10^{-5}$
$\mathrm{Im}\,\delta = (2.4 \pm 5.0) \times 10^{-5}$

$$\Delta\Gamma = \Gamma(K^0) - \Gamma(\overline{K}^0)$$
$$\Delta M = M(K^0) - M(\overline{K}^0)$$

$$\delta = \frac{1}{2}\,\frac{\Delta M - \frac{i}{2}\Delta\Gamma}{(M_L - M_S) + \frac{i}{2}(\Gamma_S - \Gamma_L)}$$



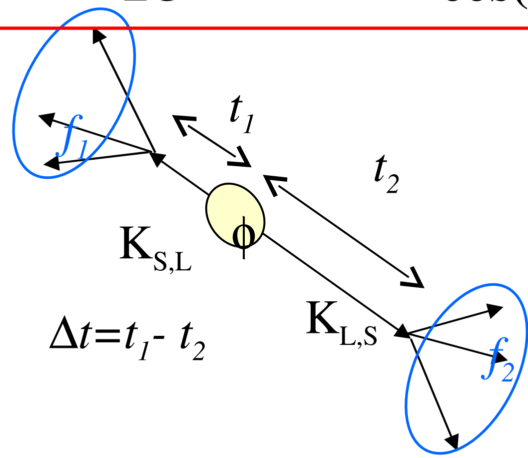
Assuming $\Delta\Gamma=0$, i.e. no ~~CPT~~ in decay:
-5.3×10^{-19} GeV < ΔM < 6.3×10^{-19} GeV at 95% C.L.

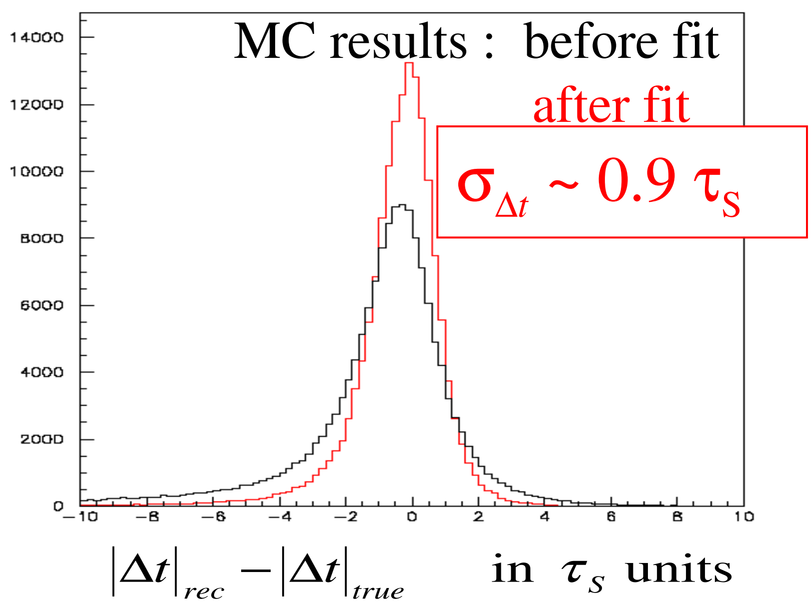
Main improvements:
K_S semileptonic asymmetry, UL $K_S \to \pi^0\pi^0\pi^0$
Im x_+ from a combined fit of KLOE + CPLEAR data
main uncertainty now comes from η_{+-} trough ϕ_{+-}

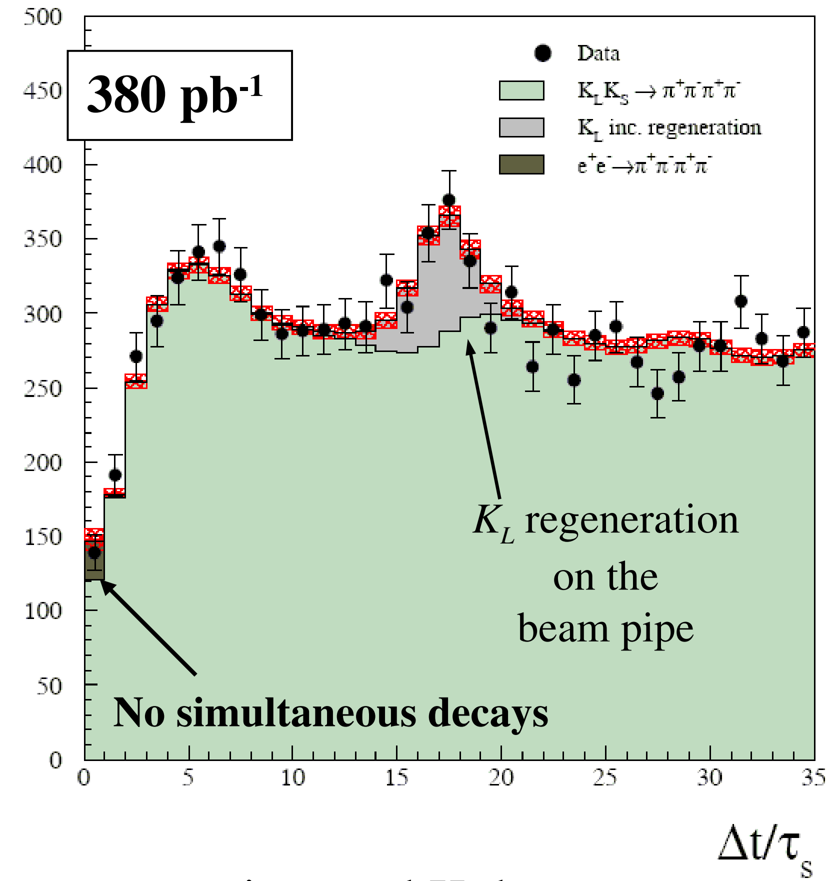
[Testa]

$\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$: test of QM at KLOE

$$I(\Delta t; \pi^+\pi^-\,\pi^+\pi^-) \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos(\Delta m\,\Delta t)$$







For interferometry a quite good K decay vertex reconstruction capability is required: $\delta(\Delta t) \le 1\,\tau_S$

[Testa]

Decoherence parameter: fit to KLOE data(II)

$$I(\pi^+\pi^-,\pi^+\pi^-;\Delta t) = \frac{N}{2}\Big[\left|\langle \pi^+\pi^-,\pi^+\pi^- | K^0\bar{K}^0(\Delta t)\rangle\right|^2 + \left|\langle \pi^+\pi^-,\pi^+\pi^- | \bar{K}^0 K^0(\Delta t)\rangle\right|^2$$

$$-(1-\zeta_{0\bar{0}})\, 2\Re\left(\langle \pi^+\pi^-,\pi^+\pi^- | K^0\bar{K}^0(\Delta t)\rangle \langle \pi^+\pi^-,\pi^+\pi^- | \bar{K}^0 K^0(\Delta t)\rangle^*\right)\Big]$$

- Fit including Δt resolution and efficiency effects + regeneration
- Γ_S, Γ_L Δm fixed from PDG
- continuum bkg from sideband

Decoherence parameter:

$\zeta_{0\bar{0}} = 0 \quad \rightarrow \quad$ QM

$\zeta_{0\bar{0}} = 1 \quad \rightarrow \quad$ total decoherence

KLOE result: PLB 642(2006) 315

$$\zeta_{0\bar{0}} = (1.0 \pm 2.1_{STAT} \pm 0.4_{SYST}) \times 10^{-6}$$

$$\zeta_{0\bar{0}} < 5 \times 10^{-6} \text{ at 95\% C.L.}$$

with 2.5 fb^{-1} $\pm 0.8 \times 10^{-6}$

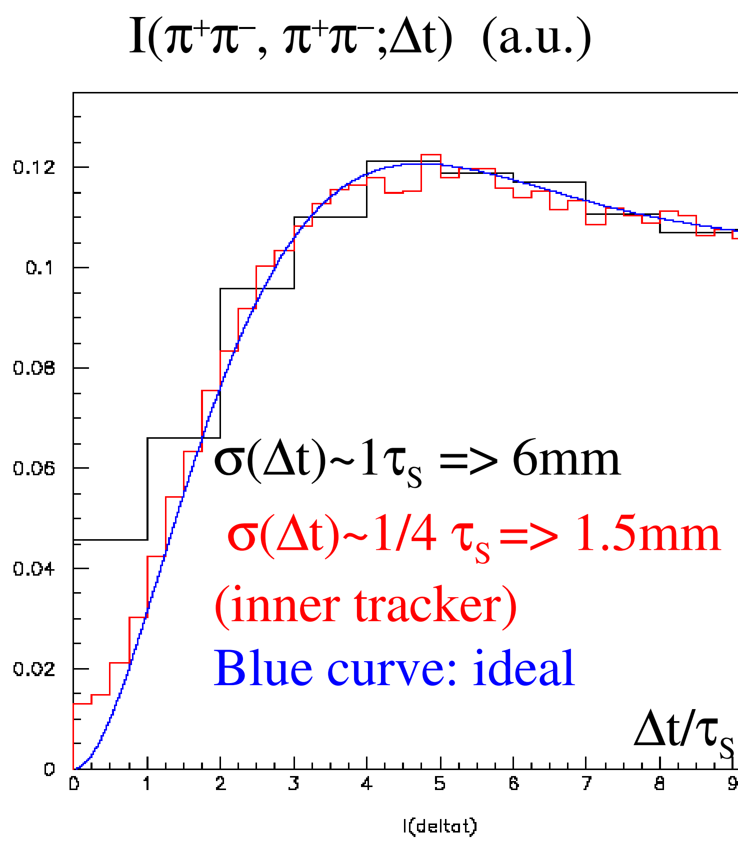
as CP viol. $O(|\eta_{+-}|^2) \sim 10^{-6}$ => high sensitivity to ζ

From CPLEAR data:

$$\zeta_{0\bar{0}} = 0.4 \pm 0.7$$

In the B-meson system, BELLE coll. (quant-ph/0702267) obtains: $\zeta^B_{0\bar{0}} = 0.029 \pm 0.057$

[Testa]



This physics program would of course benefit a lot from the higher statistics & better vertex resolution expected @ KLOE-2...

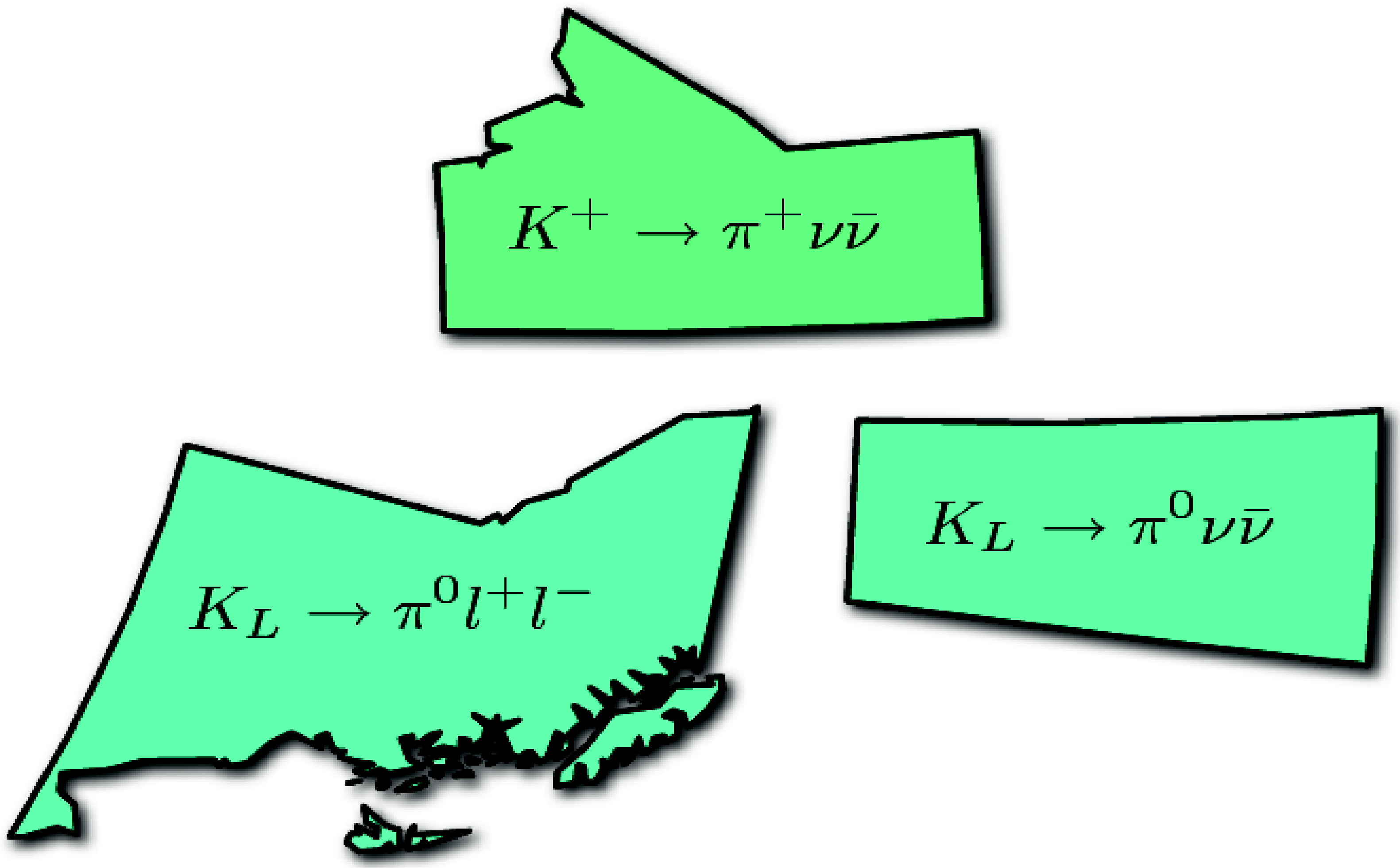
[Testa]

..and with a proper choice of regenerators, one could tests different aspects of QM

[Garbarino, Heismayer]

...but I should admit it's not clear to me what we would gain with respect to entangled photon systems...

V. The *holy grail* of Kaon physics

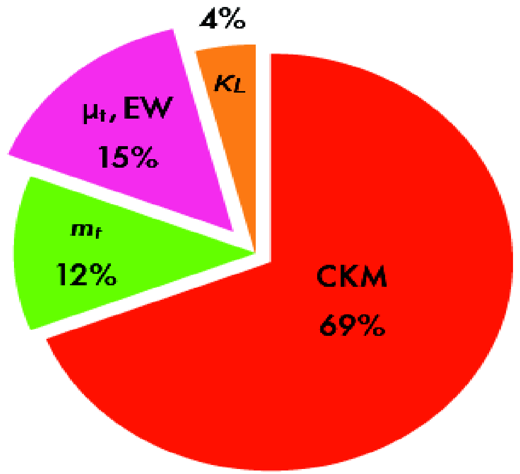


V. The *holy grail* of Kaon physics

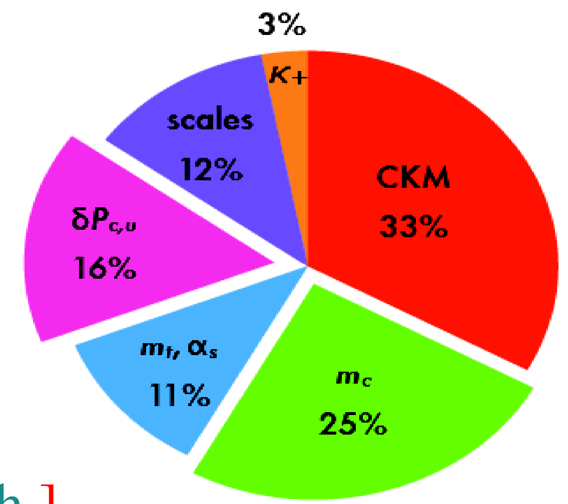
The fact the theoretical community really like such decays should be quite clear by the continuous th. progress (despite the long time with no exp. News)

Both on the SM side...

$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) = (2.54 \pm 0.35) \times 10^{-11}$$



$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)) = 7.90 \pm 0.67, \times 10^{-11}$$

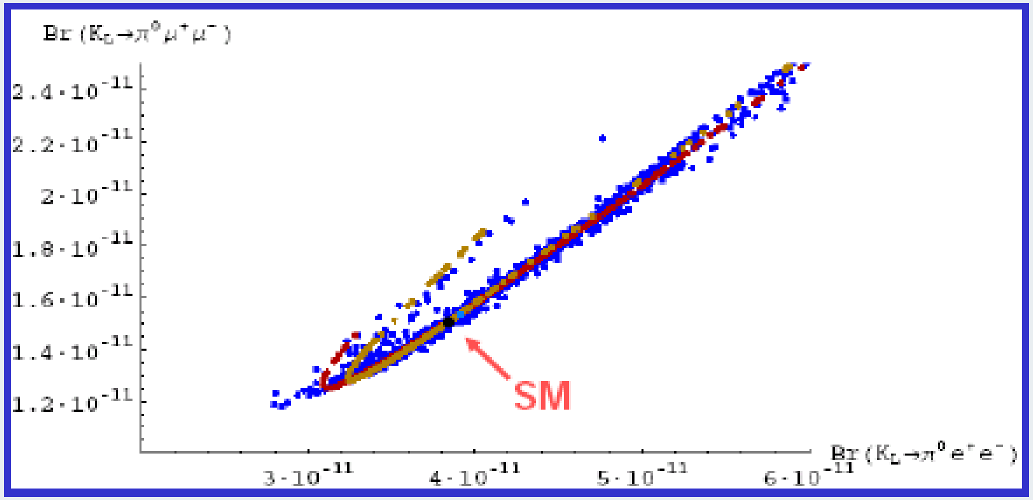


[Haisch]

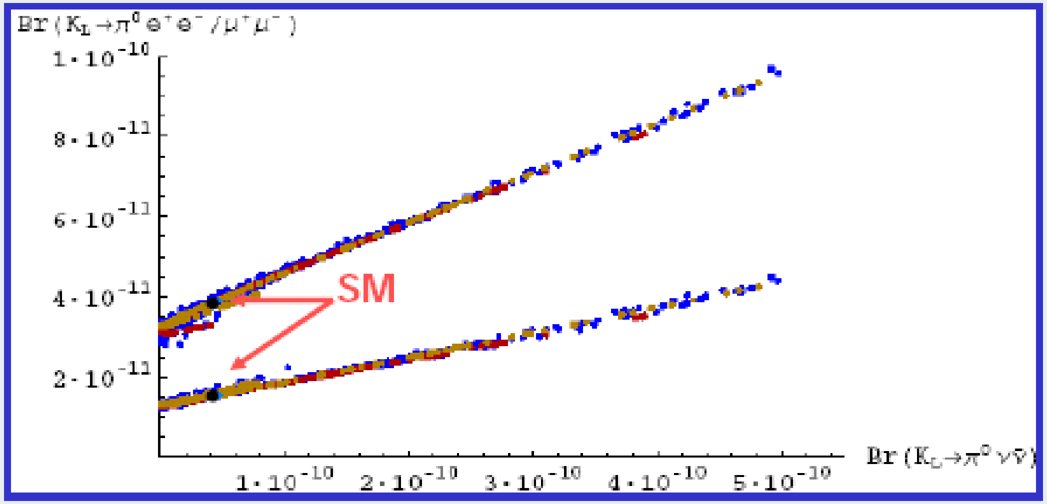
V. The *holy grail* of Kaon physics

... and beyond the SM:

$K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \mu^+ \mu^-$



Blanke,Buras,Poschenrieder,Recksiegel,C.T.,Uhlig,Weiler, hep-ph/0610298



Littlest Higgs Model with T-Parity (LHT)

[Tarantino]

- Strong correlations between muon and electron modes and with $K_L \to \pi^0 \nu \bar{\nu}$
- Enhancements up to a factor 2 w.r.t. the SM

V. The *holy grail* of Kaon physics

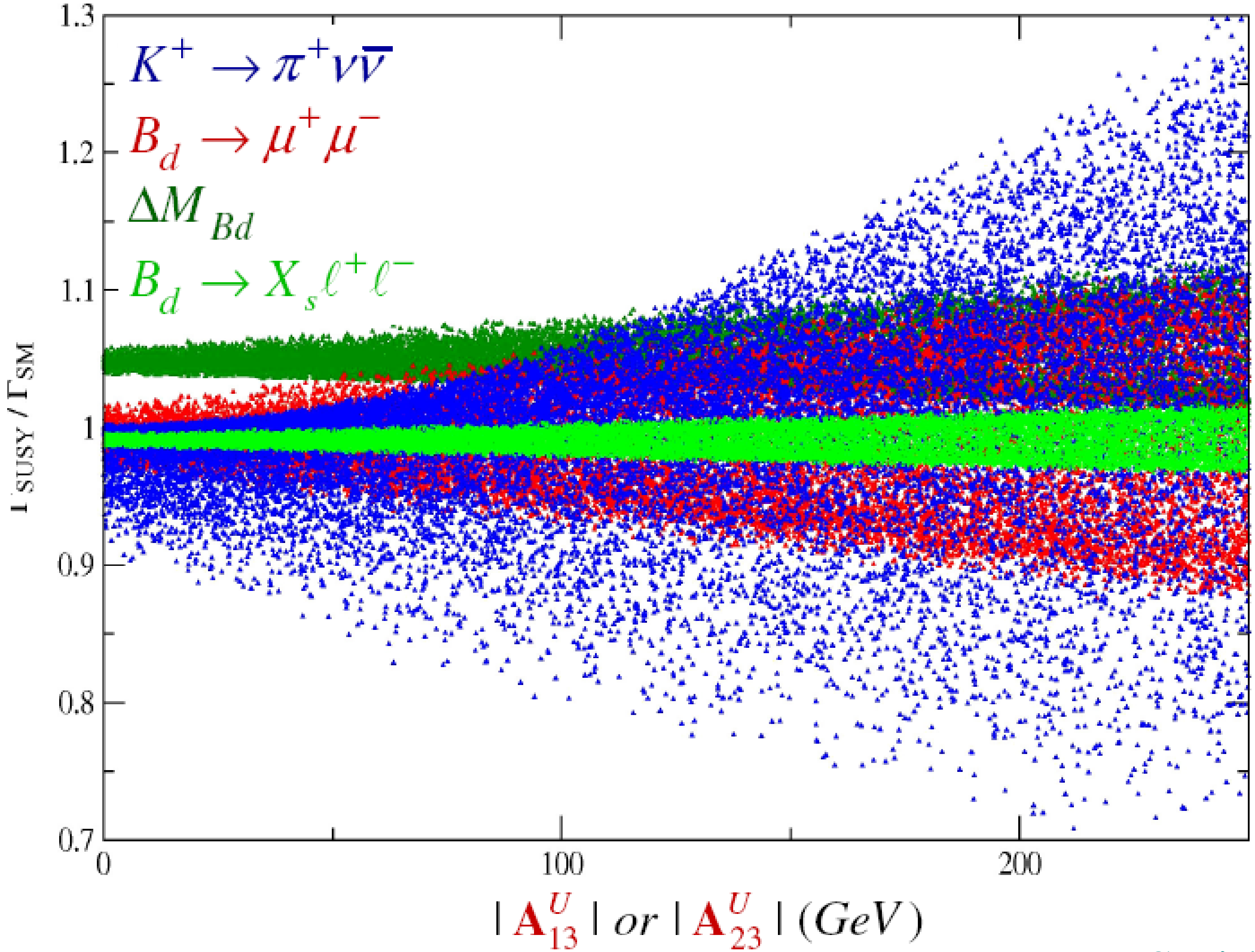
... and beyond the SM:

Scanning over trilinear terms:

$|\mathbf{A}_{13}^{U}|, |\mathbf{A}_{23}^{U}| \leq A_0 \lambda,$
$A_0 = 1 \text{ TeV}$
Phases left free.

Fixed sparticle masses:

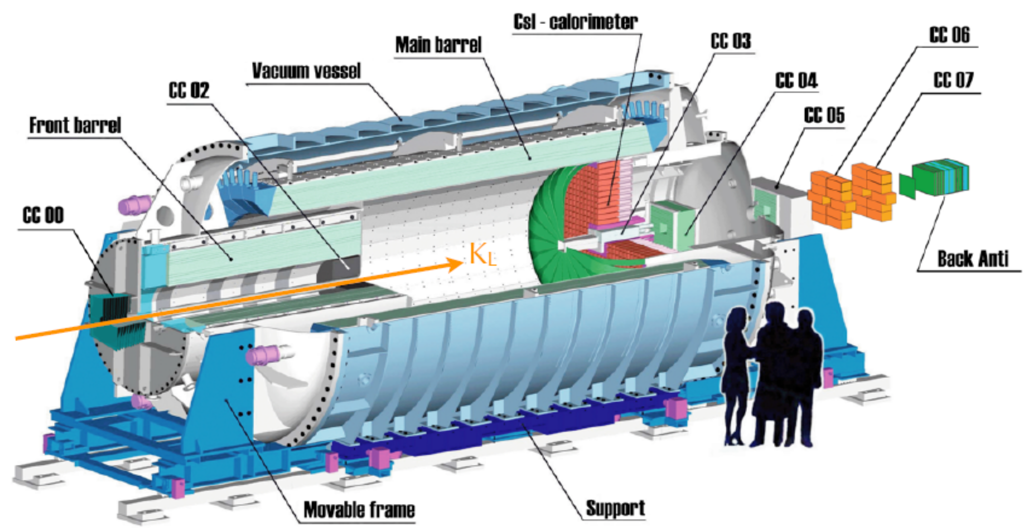
$\tan\beta = 2 - 4$
$\mu = 500 \pm 10 \text{ GeV}$
$M_2 = 300 \pm 10 \text{ GeV}$
$m_{u_R} = 600 \pm 20 \text{ GeV}$
$m_{q_L} = 800 \pm 20 \text{ GeV}$
$others: 2 \text{ TeV}$



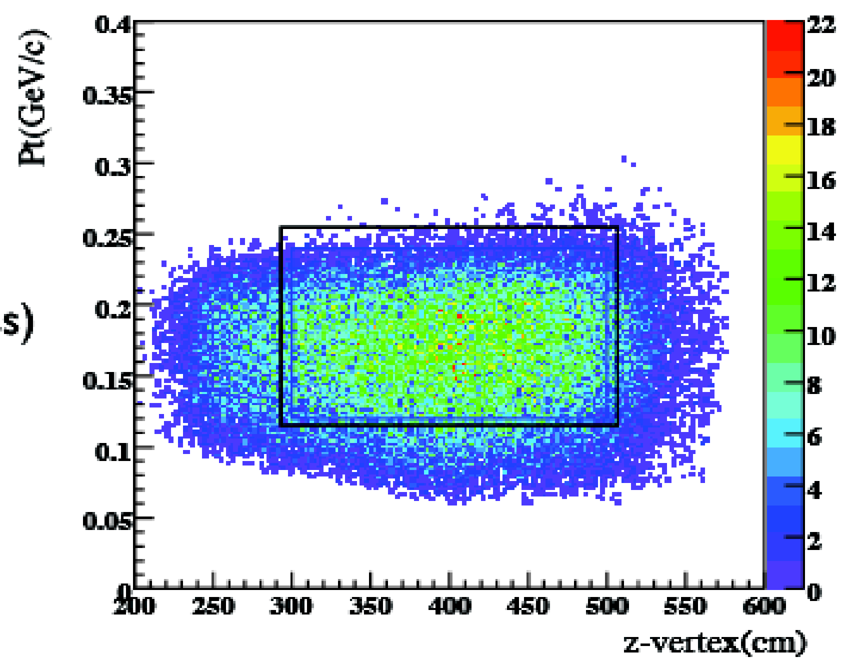
[Smith]

Unfortunately, on the experimental side we are still quite far from the interesting region...

The E391a Detector:



- pi0nn MC
  - 44080 events in fiducial / 1 x 10^8 KL
  - A = 44080 / 10^8
    / 0.0283 (decay prob.) * 0.8445 (acci. loss)
    = 1.32 x 10^{-2}
- NKL = (5.35±0.74) x 10^9
- SES = 1 / (1.32x10^{-2} * 5.35 x10^9)
  = 1.42 x 10^{-8}



[Perdue, Sumida]

Most interesting experimental result on very-rare K decays at this conf. is the remarkable improvement on LFV-FCNCs by KTeV:

PRELIMINARY result using Feldman-Cousins method

$BR(K_L \to \pi^0 \mu e) < 7.56 \times 10^{-11}$ (90% CL)

Corresponding to $M_{X^0} > 54$ TeV/c^2.

Previous results: $B(K_L \to \pi^0 \mu e) < 3.4 \times 10^{-10}$ (KTeV Preliminary)
$B(K_L \to \pi^0 \mu e) < 6.2 \times 10^{-9}$ (E799, PL **B320** 407 (94))

[Tschirhart]

Hopefully, the situation should substantially improve with the JPARC proposal on $K_L \to \pi^0 \nu\nu$ ...

- J-PARC E14 experiment aims at First Observation of $K_L \to \pi^0 \nu\nu$ decay.
  - Upgrade of KEK-E391a detector are planed.
- E14 submitted a proposal to PAC (program advisory committee).
  → 1st-stage scientific approval.
  → 2nd stage process is in progress.
- 2007:
  - All engineering design of beam-line will be completed.
  - KTeV CsI's will be started to move to J-PARC.
  - Many R&D's are in progress.
- 2008: beam-line construction will be scheduled.
  - Dec, 2008~: First commissioning of slow beam extraction is scheduled.
  - Beam survey : measuring the beam-line performances.
- 2008~2009: Assembling of Detector system.
- 2010~: First Engineering Run or/and Physics Run.

[Watanabe]

...and the CERN proposal on $K^+ \to \pi^+\nu\nu$:

P-326:

Events/year	Total	Region I	Region II
Signal (SM)	65	16	49
$K^+\to\pi^+\pi^0$	2.7±0.2	1.7±0.2	1.0±0.1
$K_{\mu 2}$	1.2±0.3	1.1±0.3	<0.1
K_{e4}	2±2	negligible	2±2
$K^+\to\pi^+\pi^+\pi^-$ and other 3-tracks bckg.	1±1	negligible	1±1
$K_{\pi 2}\gamma$	1.3±0.4	negligible	1.3±0.4
$K_{\mu 2}\gamma$	0.4±0.1	0.2±0.1	0.2±0.1
K_{e3}, $K_{\mu 3}$,others	negligible	–	–
Total bkg	9±3	3.0±0.2	6±3

- SPS used as LHC injector (so it will run in the future)
- No flagrant time overlap with CNGS
- P-326 fully compatible with the rest of CERN fixed target
- Conservative beam request based on decennial NA48 experience at SPS

[Ruggiero]

Conclusions

Many thanks to the organizers
and to all the speakers !