# Recent Progress in Kaon Physics

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*INFN-Frascati and University of Rome, "Roma Tre"*

*many thanks to the organizers*

IFAE, Catania March 30 – April 2

# A REMARKABLE HISTORY

**1947** Rochester and Butler
Observation of $K^0$ and $K^+$ particles

**1964** Cronin *et al.*, $K \to \pi\pi$ *CP VIOLATION*

**1963** Cabibbo – $V_{us}$
Universality of Weak Interactions

**1970** Glashow, Iliopoulos, Maiani – GIM
Suppression of $K \to \mu^+\mu^-$, $K \to \pi\, l^+ l^-$

**1972** Kobayashi, Maskawa – CKM Matrix

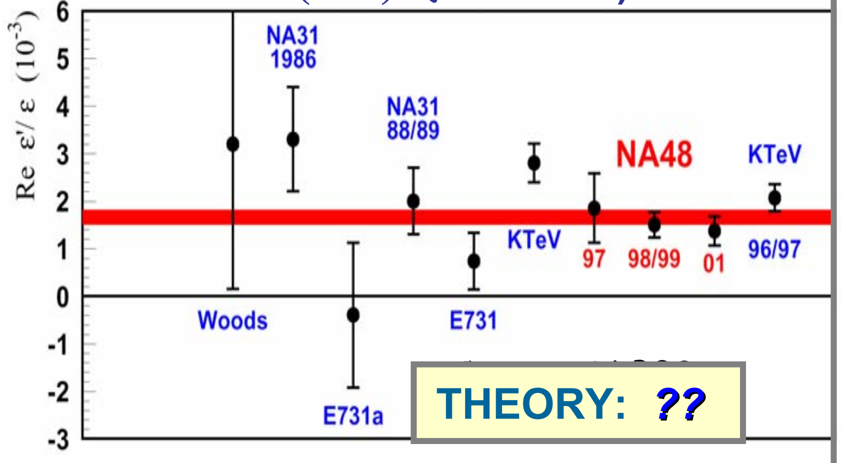
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

For the Future, Kaon physics will help looking for <u>inconsistencies</u> in SM using independent observables affected by small theoretical uncertainties and different sensitivity to new physics.

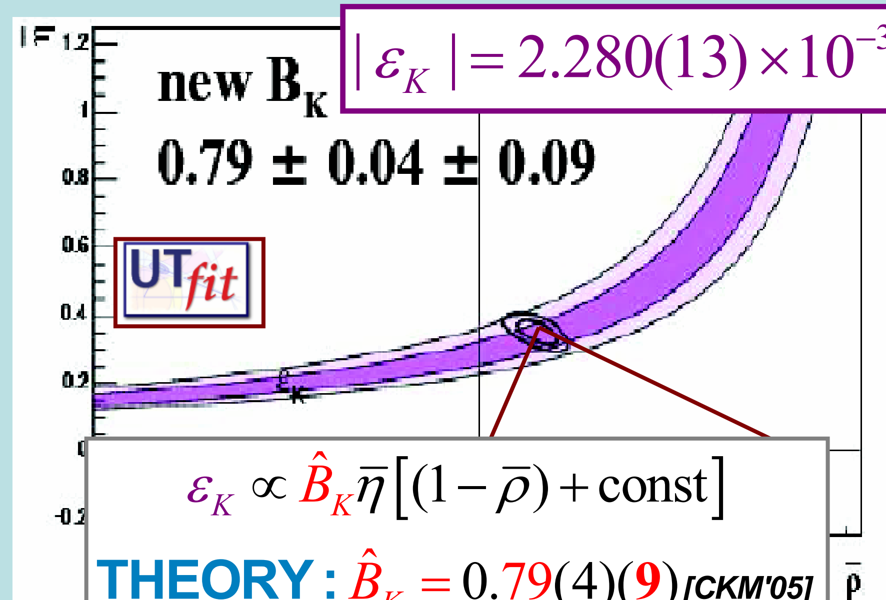
## Recently

**KTeV-NA48**

$Re(\varepsilon'/\varepsilon)=(16.6\pm1.6)\times10^{-4}$




THEORY: ***??***




$|\varepsilon_K| = 2.280(13)\times10^{-3}$

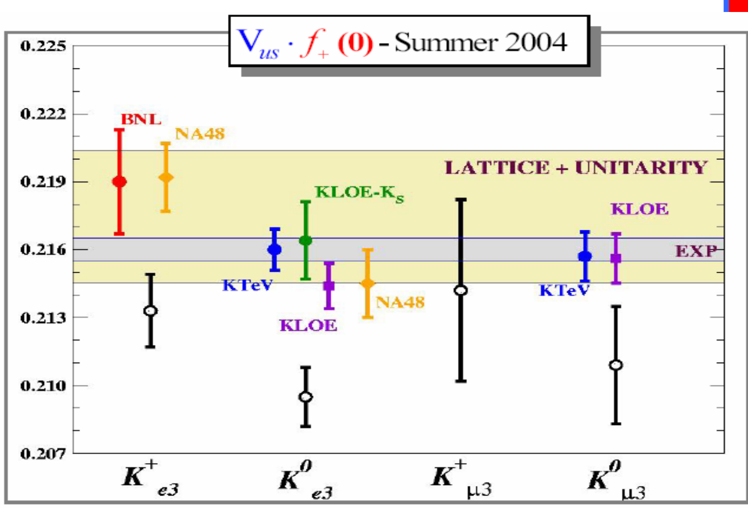
$\varepsilon_K \propto \hat{B}_K \bar{\eta}\left[(1-\bar{\rho})+\text{const}\right]$

**THEORY:** $\hat{B}_K = 0.79(4)(9)$ ***[CKM'05]***

## 2004

**BNL-KTeV-NA48-KLOE**

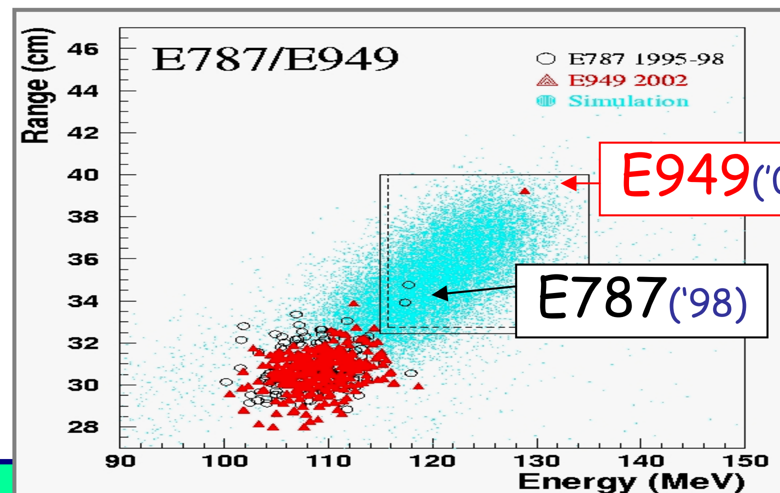
$|V_{us}|^2 + |V_{ud}|^2 + |V_{ub}|^2 = 0.999(1)$




THEORY: ***Becirevic et al, Nucl.Phys.B705:339,2005***

## a look to THE FUTURE

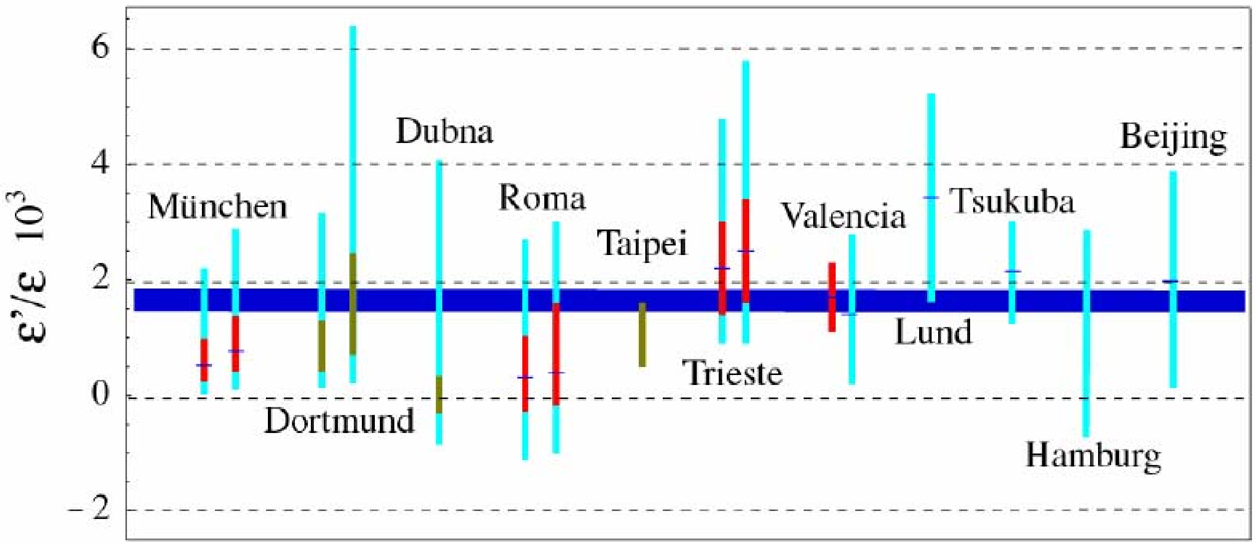
$K^+ \to \pi^+ \nu\nu$: the signal (?)




THEORY: ***Isidori, F.M., Smith hep-ph/0503107***

# Direct CP-Violation - Re(ε'/ε)

## Calculations of Re(ε'/ε)

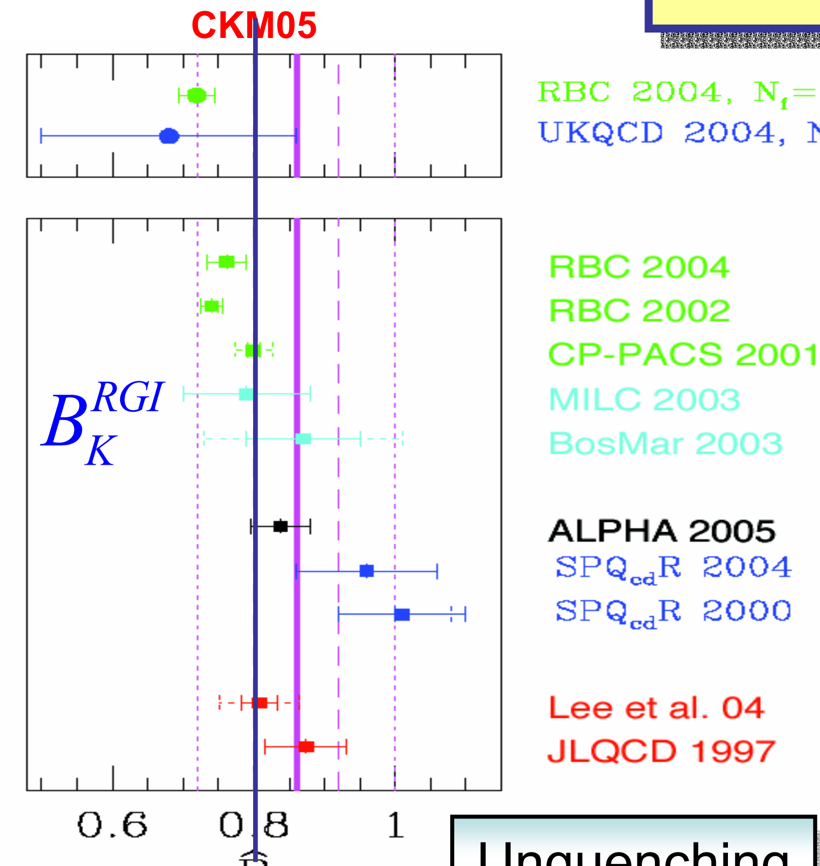



Bertolini, Sozzi

Re(ε'/ε) ∝ η, but large hadronic uncertainties currently make it impossible to convert measurement of Re(ε'/ε) into a meaningful CKM constraint (except that η≠0).

**Rare Kaon Decays will fill the miss**

# Current Lattice results for $B_K$




## Quenched Simulations

- ✓ High level of accuracy:
- ✓ Newer values by chirally-improved fermions lower than reference JLQCD 97 value of **0.86(6)**
- ✓ **Estimate of quenching error by $N_F$=2**

$$B_K^{RGI}(CKM03) = 0.87 \pm 0.06 \pm 0.14$$

$$B_K^{RGI}(CKM05) = 0.79 \pm 0.04 \pm 0.09$$

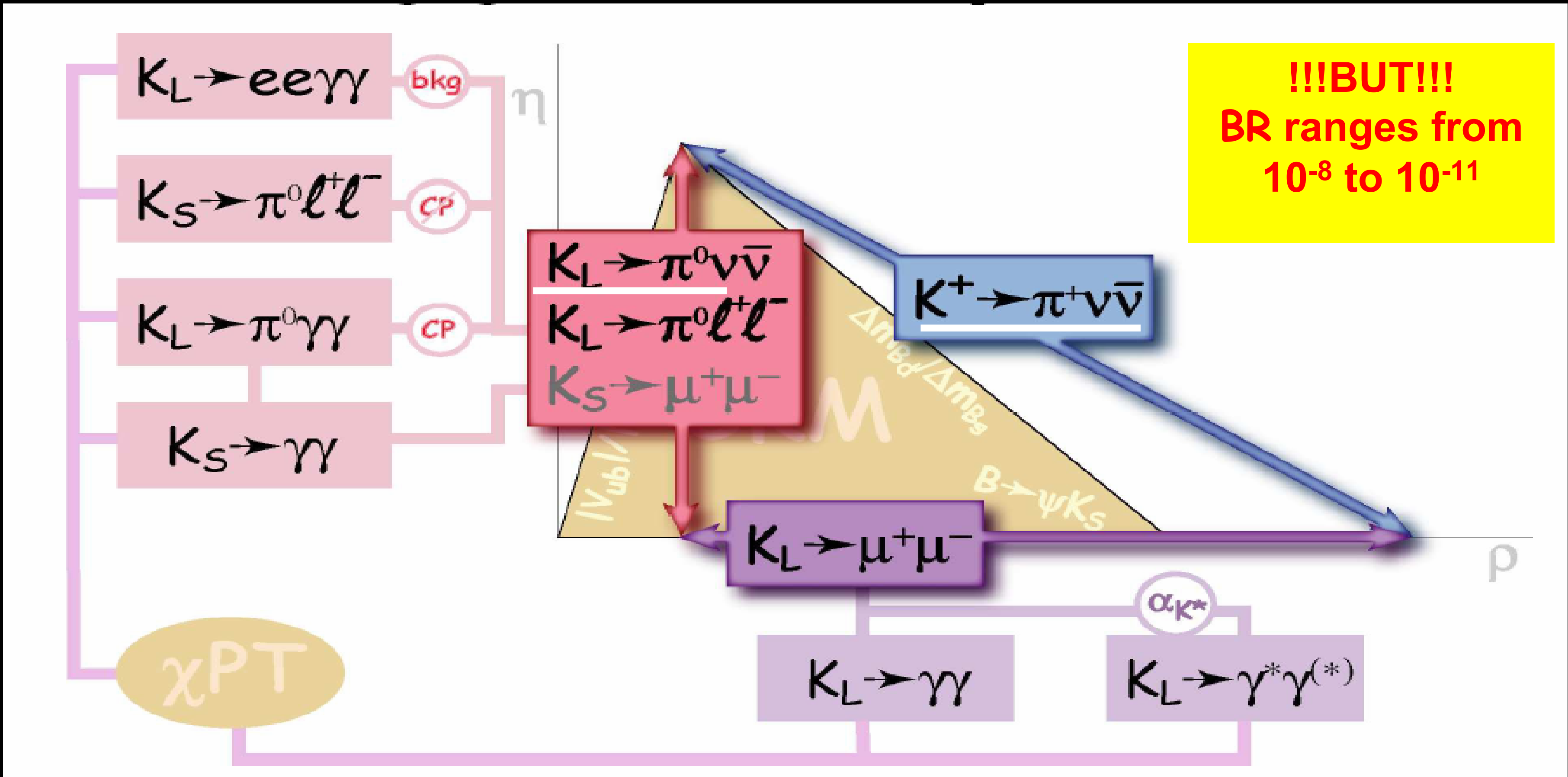
**[ CKM 2005]**

**Quenching**
**The largest uncertainty**

## Unquenching

- ✓ A few weak attempts (<'99): limited parameter space and no sea quark dependence was possible to observe.
- ✓ **Recently, first results: W. Fermions [Flynn, F.M.,Tariq UKQCD04] and D.W. Fermions [Dawson et *al* RBC04]:** a mild sea quark dependence seen.
- ✓ **In conclusion, still much to do.**

# Rare K Decays and the Unitarity Triangle




**!!!BUT!!!**
**BR ranges from**
**$10^{-8}$ to $10^{-11}$**

**by Komatsubara FPCP04**

**Rare Kaon decays provide quantitative tests of SM independent from B mesons**:
they are theoretically clean and highly sensitive to NP.

# Rare K Decays: Present Status

| Golden Modes | Standard Model | Experiment | |
|---|---|---|---|
| $K_L \to \pi^0 \nu\bar{\nu}$ | $3.0^{+0.6}_{-0.6} \times 10^{-11}$ | $< 5.9 \times 10^{-7}$ | KTeV |
| $K_L \to \pi^0 e^+ e^-$ | $3.7^{+1.1}_{-0.9} \times 10^{-11}$ | $< 2.8 \times 10^{-10}$ | KTeV |
| $K_L \to \pi^0 \mu^+ \mu^-$ | $1.5^{+0.3}_{-0.3} \times 10^{-11}$ | $< 3.8 \times 10^{-10}$ | KTeV |
| $K^+ \to \pi^+ \nu\bar{\nu}$ | $7.8^{+1.2}_{-1.2} \times 10^{-11}$ | $14.7^{+13.0}_{-8.9} \times 10^{-11}$ | E787 E949 |

New generation of experiments needed
[KOPIO@ BNL]
[JPARC@ KEK]
[NA48-@CERN]
2008 …. 2010

**by C. Smith Moriond'05**

- $K^0_L \to \pi^0 \nu\nu$
  - –Expect results from data collected by E391a (proposed SES~3 $10^{-10}$)

**2004-Progress**

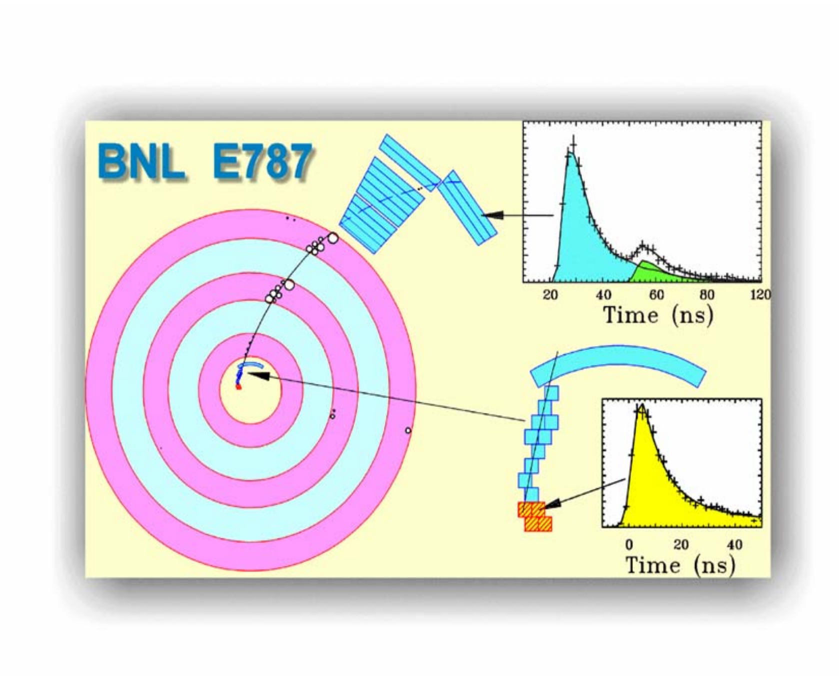
$K^0_L \to \pi^0 ee\ (\mu\mu)$

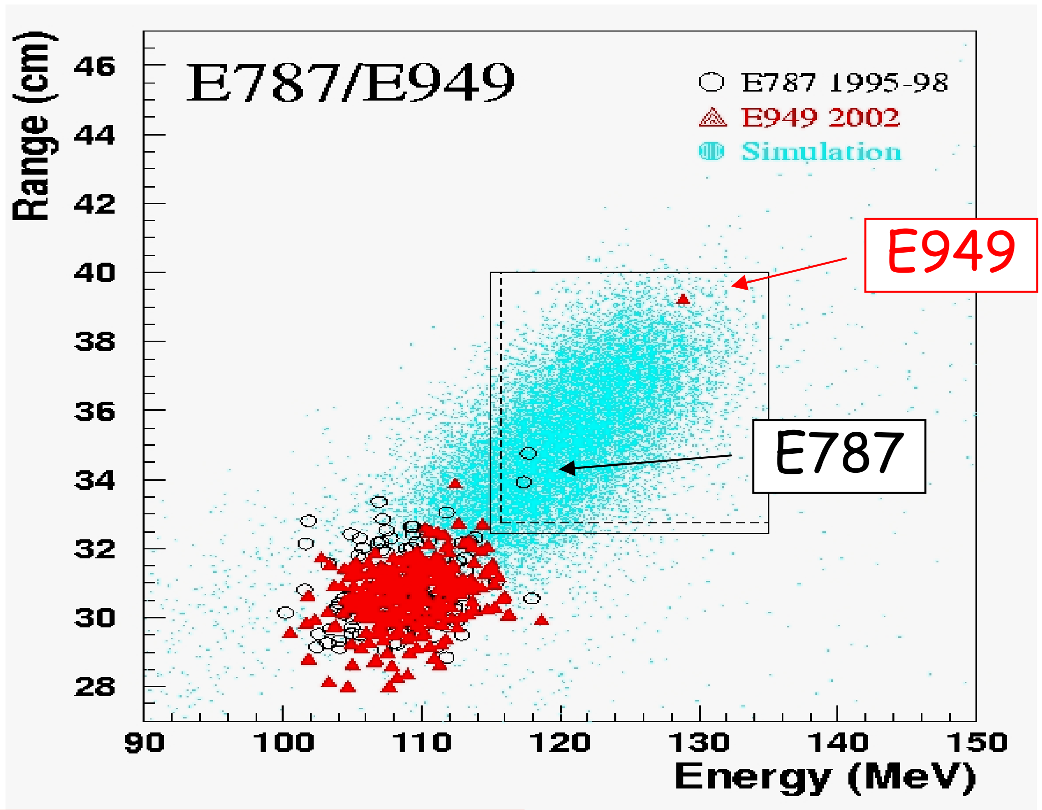
– Long distance contributions under control
[Buchalla, D'Ambrosio, Isidori,'03; Friot, Greynat, De Rafael '04: Isidori, Unterdorfer, Smith '04]

– **NA48** result of Br[$K^0_S \to \pi^0 ee$] and Br[$K^0_S \to \pi^0 \mu\mu$] has allowed SM prediction [D'Ambrosio,Ecker,Isidori,Portolés ('98)]

# $K^+ \rightarrow \pi^+ \nu\nu$: State of the Art

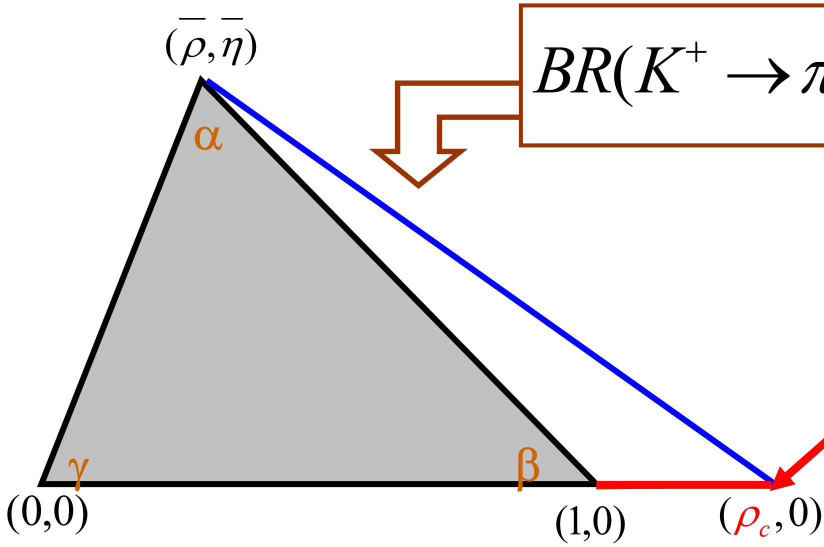
**hep-ex/0403036 PRL93 (2004)**




$$Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$$

Twice the SM but compatible within errors




$$BR(K^+\to\pi^+\nu\bar\nu)_{SM} = C\,|V_{cb}|^4\left[(\bar\rho-\rho_c)^2+(\sigma\bar\eta)^2\right]$$

$$\rho_c - 1 = \frac{\lambda^4}{|V_{cb}|^2}\frac{P_c(x_c)}{X(x_t)} = 0.37(7)$$

Charm Contribution *is RELEVANT*

**Precision Test:** $BR(K^+\to\pi^+\nu\bar\nu)_{SM} = (7.8 \pm \underline{0.82}_{Pc} \pm 0.91_{CKM,m_t})\times 10^{-11}$

- ⊙ Hadronic ME from $K_{l3}$ via isospin corrections (2%) (Marciano-Parsa 96):
- ⊙ The t-quark loops: $X(x_t) \overset{NLO}{=} 1.53 \pm 0.04$ *known to* ~ 3%
- ⊙ The c-quark loops: $P_c(x_c) \overset{NLO}{=} 0.39 \pm 0.07$ *known to* ~ 18% [8% @N$^2$LO Buras soon].

**Br : 15% of uncertainty**

**10% comes from CHARM Dim=6 Contributions @NLO:**

***to be reduced to below 4% by the NNLO calculation*** **(Buras)**

## *Aiming to get a few % th. accurancy on $K^+ \to \pi^+ \nu\nu$, subleading terms $\propto (1/m_c)^2$ have to be considered:*

1) Subleading *c-quark loops*: Dimension-eight operators

Possible correction to $P_c(x_c)$ of the order of $m_K^2 / m_c^2 \approx 15\%$

Lu and Wise (1994)

2) Residual *u-quark loops*: Genuine ΔS=1 Long-distance effects

Possible correction to $P_c(x_c)$ of the order of $\Lambda_{QCD}^2 / m_c^2 \approx 10\%$

Falk, Lewandowski, Petrov (2000)

**Theoretical Progress (2005)**

**Isidori, F.M., Smith hep-ph/0503107**

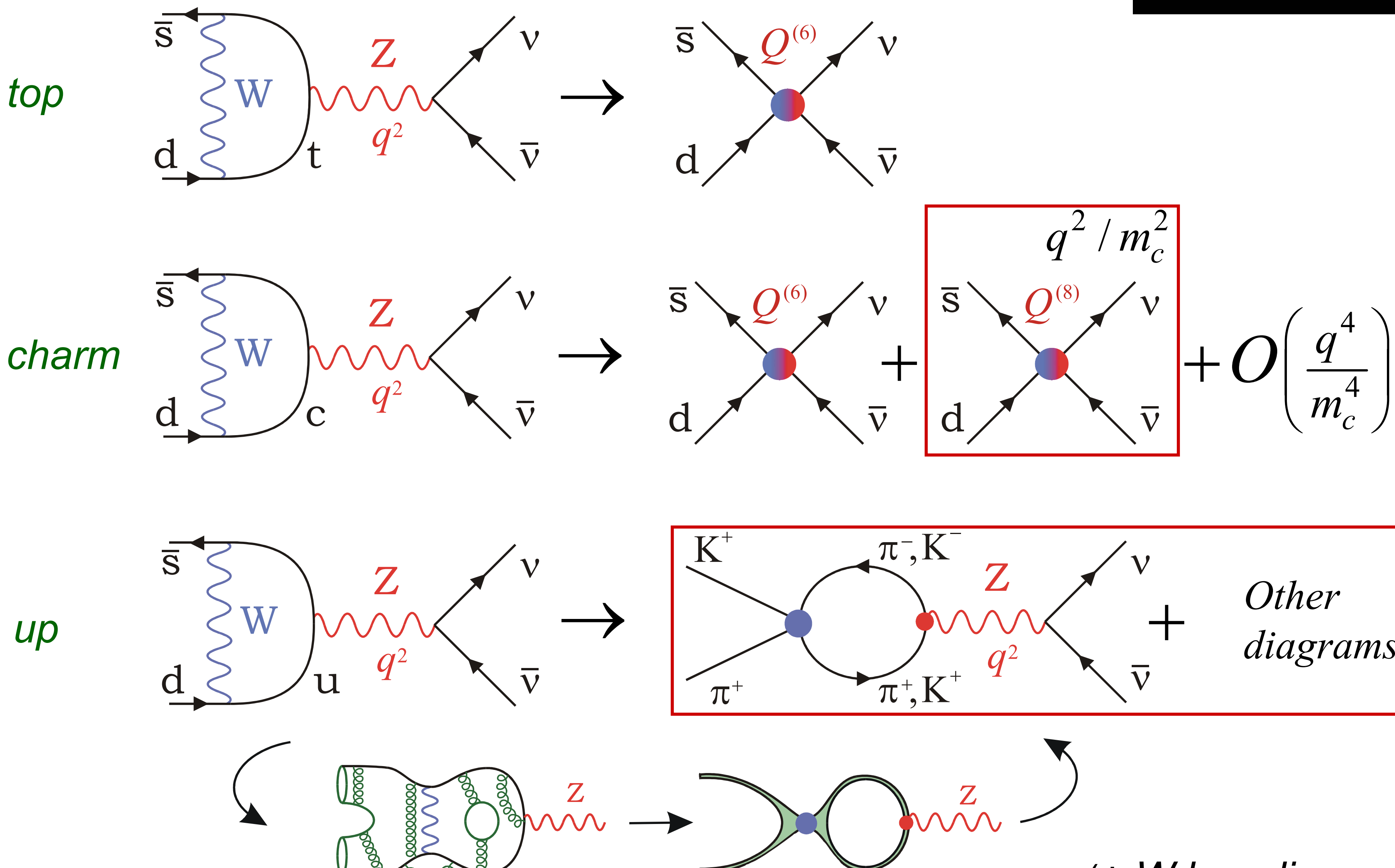
**The right estimate is**

$$\delta P_c / P(x_c) \simeq 10\% \;\rightarrow BR(K^+ \rightarrow \pi^+ \nu\bar{\nu})_{SM} \text{ increases by } 6\%$$

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

Isidori, F.M., Smith **'05**

- Identification of Subleading Corrections




(+ *W box diagram*)

***by C. Smith Moriond'05***

## $O(G_F^2 \Lambda_{QCD}^2) - Matching$

Isidori, F.M., Smith '05

Dim. 6 Dim. 8

$$A_{SD}^Z\left(q^2 \to 0\right) \propto (\bar{s}d)_{V-A} \frac{\lambda_t}{M_W^2}\left[ X(x_t) + x_t \frac{q^2}{m_t^2}(\log x_t + \ldots) \right](\bar{\nu}\nu)_{V-A}$$

OPE

at $O(q^2/m_c^2)$

$$+(\bar{s}d)_{V-A} \frac{\lambda_c}{M_W^2}\left[ P_c(x_c) + \frac{q^2}{M_W^2}\left(\log \frac{m_c^2}{M_W^2} + \ldots\right)\right](\bar{\nu}\nu)_{V-A}$$

$$-(\bar{s}d)_{V-A} \frac{\lambda_c}{M_W^2}\left[ + \frac{q^2}{M_W^2}\left(\log \frac{\mu_{IR}^2}{M_W^2} + \ldots\right)\right](\bar{\nu}\nu)_{V-A}$$

- *Identification* of short-distance dimension-eight operators like $Q_c^{(8)} = (\bar{s}d)_{V-A}\partial^2(\bar{\nu}\nu)_{V-A}$ by an OPE at the charm scale. (Falk, Lewandowski, Petrov ('00))

- *Compute* the one-loop amplitude in ChPT for the long-distance u-quark effects.

-*Match* ChPT UV divergence to SD IR one to get $A^Z(K^+ \to \pi^+ \nu\bar{\nu})$ at $O(G_F^2 \Lambda_{QCD}^2)$

$$\lambda_c \frac{q^2}{M_W^2}\left(\log \frac{m_c^2}{\mu_{IR}^2} - \log \frac{m_\pi^2}{\mu_{UV}^2}\right) \to \lambda_c \frac{q^2}{M_W^2} \log \frac{m_c^2}{m_\pi^2}$$

$$\mu_{IR} = \mu_{UV} \approx m_c$$

$$\mu - independent$$

Isidori, F.M., Smith '05

- ## Z Penguin in ChPT

Lu and Wise (1994) is wrong

A new operator must be introduced in ChPT to enforce GIM mechanism:

$$L^{(2)}_{|\Delta S|=1+GIM} = F_\pi^4 G_8 \left\{ \langle \lambda_6 L_\mu L^\mu \rangle - \frac{2ig}{\cos\theta_W} \langle \lambda_6 L_\mu T_3 \rangle Z^\mu \right\}$$

at $O(G_F^2 p^2)$


$= 0$

With this new piece:
1/ No sensitivity to the singlet part of the $Z$ current.
2/ At loop level, a structure matching SD arises.

- ## Conclusion

The result of the analysis is that instead of $m_K^2/m_c^2 \approx O(15\%)$ for $\langle \pi | Q_c^{(8)} | K \rangle$ and $\Lambda_{QCD}^2/m_c^2 \approx O(10\%)$ for *u-quark*, both of them scale as

$$(\pi F_\pi / m_c)^2 \approx O(5\%)$$

$$P_c(x_c) + \delta P_c : \begin{cases} P_c(x_c) = 0.39 \pm 0.07 \\ \delta P_c = 0.04 \pm 0.02 \end{cases}$$

# BSM Scenarios

**Compiled by S. Kettel**

| | $BR(K^+ \to \pi^+ \nu\bar{\nu}) \times 10^{11}$ | $BR(K_L^0 \to \pi^0 \nu\bar{\nu}) \times 10^{11}$ |
|---|---|---|
| **SM** | **8.0 ± 1.1** | **3.0 ± 0.6** |
| **MFV**<br>hep-ph/0310208 | $\leq$ **19.1** | $\leq$ **9.9** |
| **EEWP**<br>NP B697 133 | **7.5 ± 2.1** | **31 ± 10** |
| **EDSQ**<br>hep-ph/0407021 | $\leq$ **15** | $\leq$ **10** |
| **MSSM**<br>hep-ph/0408142 | $\leq$**40** | $\leq$ **50** |

- **Complementary programme to the high energy frontier:**
  - **When new physics will appear at the Tevatron/LHC, K rare decays may help to understand the nature of it**

# The most accurate test of CKM unitarity

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

***CKM05***

$$|V_{ud}| = 0.9739(3) \Rightarrow |V_{us}^{UNI}| = \sqrt{|V_{ud}|^2 + \cancel{|V_{ub}|^2} - 1} = 0.2269(13)$$

***PDG04*** $|V_{us}| = 0.2200(26)$

**~2.4 σ discrepancy**

**$|V_{us}|$** → ***possibly responsible!!***

*Relies on old experimental and theoretical results of* $K_{l3}$

# $V_{us}$ from $K_{\ell 3}$ decays

$$\Gamma(K \to \pi l \nu(\gamma)) = \frac{G_F^2 M_K^5}{192\pi^3} C_K^2 |V_{us}|^2 \cdot |f_+^{K^0\pi^-}(0)|^2 I_K S_{ew} (1 + \delta_{SU(2)}^K + \delta_{em}^{Kl})^2$$

$S_{ew} = 1.0230(3)$

(Sirlin 82')

| | $\delta^K_{SU(2)}$ (%) | 3-body ← $\delta^{K\ell}_{em}$ (%) → Full | |
|---|---|---|---|
| $K^+_{e3}$ | $2.31 \pm 0.22$ | $-0.35 \pm 0.16$ | $-0.10 \pm 0.16$ |
| $K^0_{e3}$ | 0 | $+0.30 \pm 0.10$ | $+0.55 \pm 0.10$ |
| $K^+_{\mu 3}$ | $2.31 \pm 0.22$ | $-0.05 \pm 0.20$ | $+0.20 \pm 0.20$ |
| $K^0_{\mu 3}$ | 0 | $+0.55 \pm 0.20$ | $+0.80 \pm 0.20$ |

$f_+^{K^+\pi^0}(0) = 1.023 f_+^{K^0\pi^-}(0)$

(Andre 04', Cirigliano 04'-02')

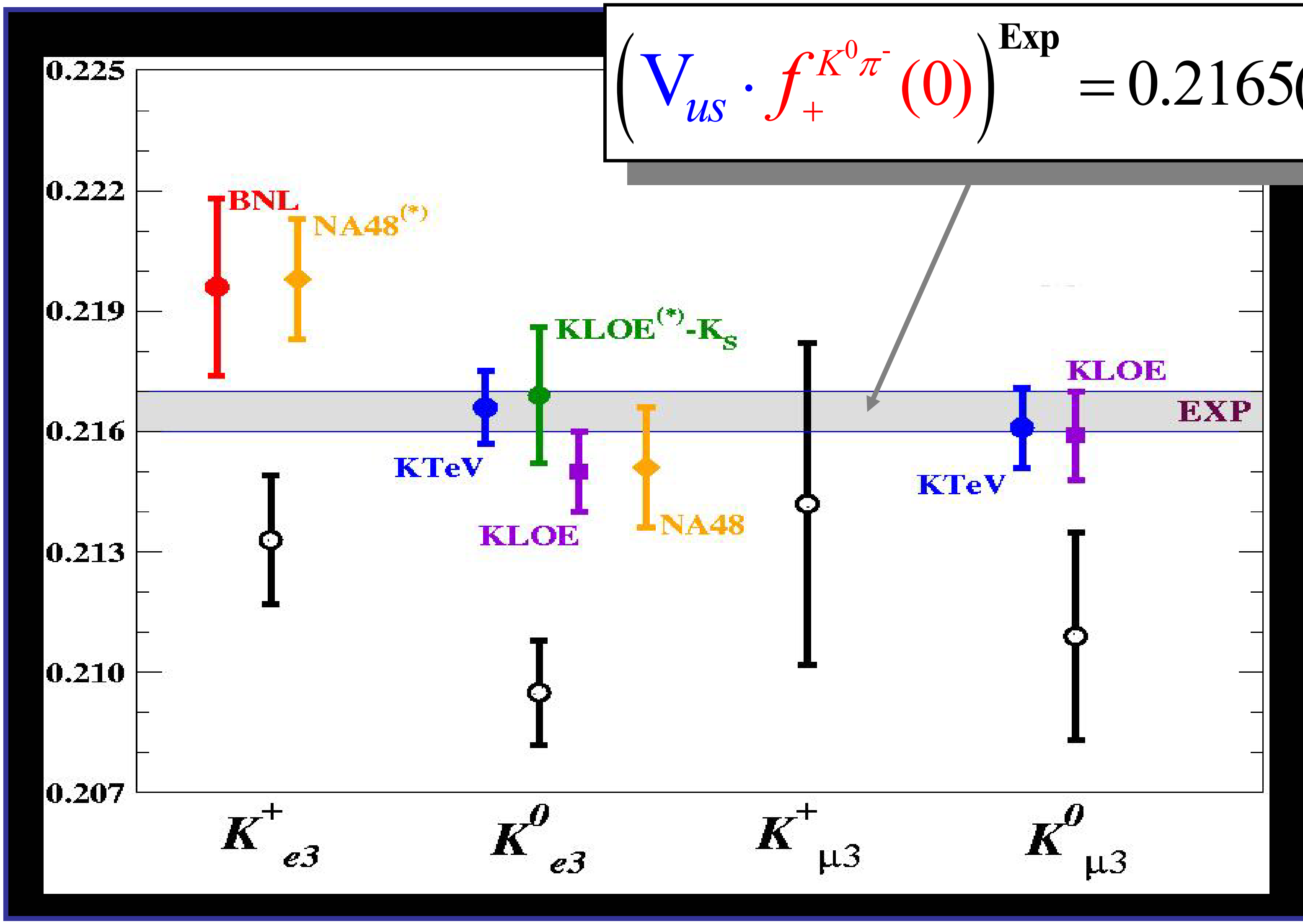
Accurately known

$$\frac{\Delta |V_{us}|}{|V_{us}|} \cong 0.2\%$$

$I_K(\lambda_+, \lambda_0)$ Accurately measured (ISTRA+,KTeV, NA48) $\Delta|V_{us}|/|V_{us}| \cong 0.3\%$

*Then … just using inputs from Br, $I_K$ and $\delta$ the quantity*

$\left(V_{us} \cdot f_+^{K^0\pi^-}(0)\right)$ can be measured with small th. and exp. uncertainties.




$$\left(V_{us}\cdot f_+^{K^0\pi^-}(0)\right)^{Exp} = 0.2165(5)$$

Now to estimate $V_{us}$ we need $f_+(0) \equiv f_+^{K^0\pi^-}(0)$

$$\Delta|V_{us}|/|V_{us}| \cong 1\%$$

# $f_+(0)$ and The Ademollo-Gatto Theorem

χpT

$$f_+(0) = 1 + f_2 + f_4 + O(p^8)$$

**Vector Current Conservation**
**$m_s = m_u$**

**-0.023 (NO UNCERTAINTY!)**

**$O(m_s - m_u)^2$ – AG Theorem**

**Independent of $L_i$ and $\mu$**

**DOMINANT UNCERTAINTY !**

**$O(m_s - m_u)^2$ – AG Theorem**

**$\mu$–Independent**

# MODEL ESTIMATES OF $f_4$

**The PDG-quoted estimate**

Leutwyler-Roos (1984), (QUARK MODEL) $f_4 = -0.016 \pm 0.008$

**The most recent estimates**

Bijnens et al (2003), ( $\Delta_{loops}^{O(p^6)-\chi pT}$ + LR) $f_4 = -0.001 \pm 0.010$

Jamin et al (2004), ( $\Delta_{loops}^{O(p^6)-\chi pT}$ + D. Analysis) $f_4 = -0.003 \pm 0.010$

Ambiguity: $\mu$ = ??? $\Delta_{loops}(1\mathrm{GeV}) = 0.004$, $\Delta_{loops}(M_\rho) = 0.015$, $\Delta_{loops}(0.5\mathrm{GeV}) = 0.035$

From O($p^6$) $\chi$PT : Post-Schilcher ('01), Bijnens-Talavera ('03):

$$f_4 = \Delta_{loops}(\mu) - \frac{8}{F_\pi^4}\,[C_{12}(\mu) + C_{34}(\mu)]\,(M_K^2 - M_\pi^2)^2$$

***A lattice estimate of $f_4$ is clearly needed!***

***!!No Scale Ambiguity!!***

# $f_4$-Lattice QCD Challenge: Our Strategy

**D.Becirevic, G.Isidori, V.Lubicz, G.Martinelli, F.Mescia, S.Simula, C.Tarantino, G.Villadoro.**

**[NPB 705 (2005) 339, hep-ph/0403217; hep-lat/0411016]**

**VERY CHALLENGING:**

**A PRECISION OF O(1%) MUST BE REACHED ON THE LATTICE !!**

<u>1</u>. Evaluation of $f_0[q^2 = (M_K - M_\pi)^2]$ **with very high precision** (<1%).

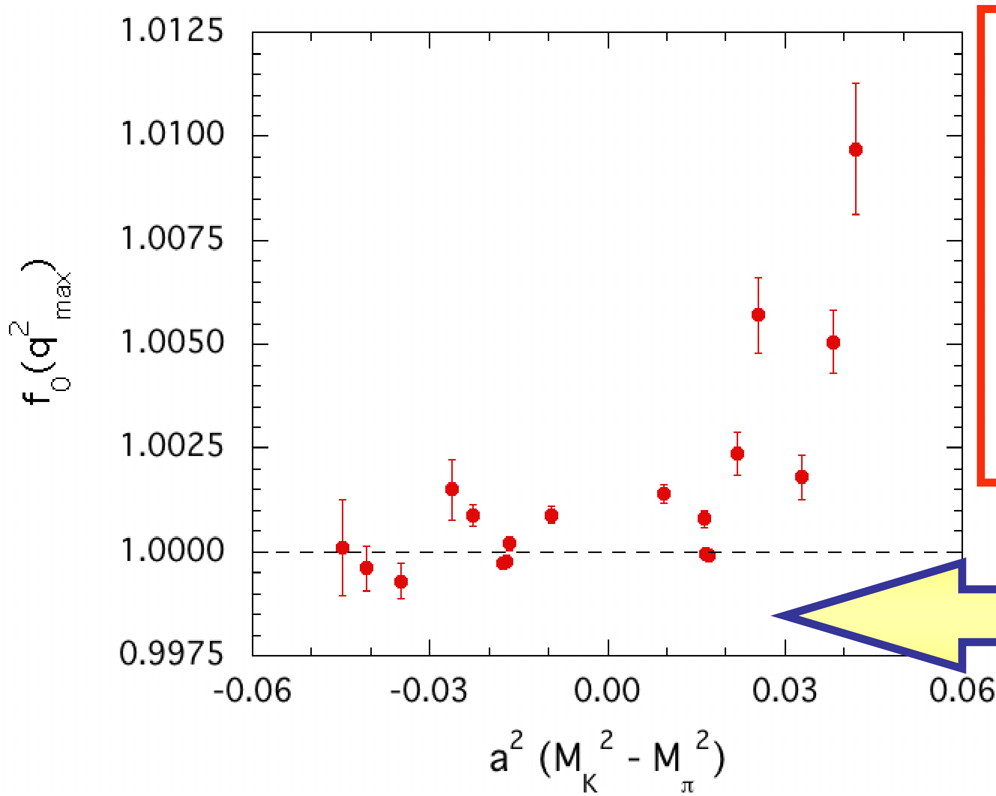
<u>2.</u> Extrapolation of $f_0(q^2_{max})$ **to** $f_0(0)=f_+(0)$ estimating the **slope** $\lambda_0$

<u>3</u>. We consider $\Delta f \equiv f_+(0)-1-f_2^Q$ (subtraction of the **unphysical** chiral logs) and <u>extrapolate</u> **($m_s/2 \le m_q \le m_s$)** <u>to the physical meson masses:</u>

Finally, **$\Delta f$ will be our estimate of $f_4$.**

# 1) $f_0(q^2_{max})$- High precision measure (FNAL)

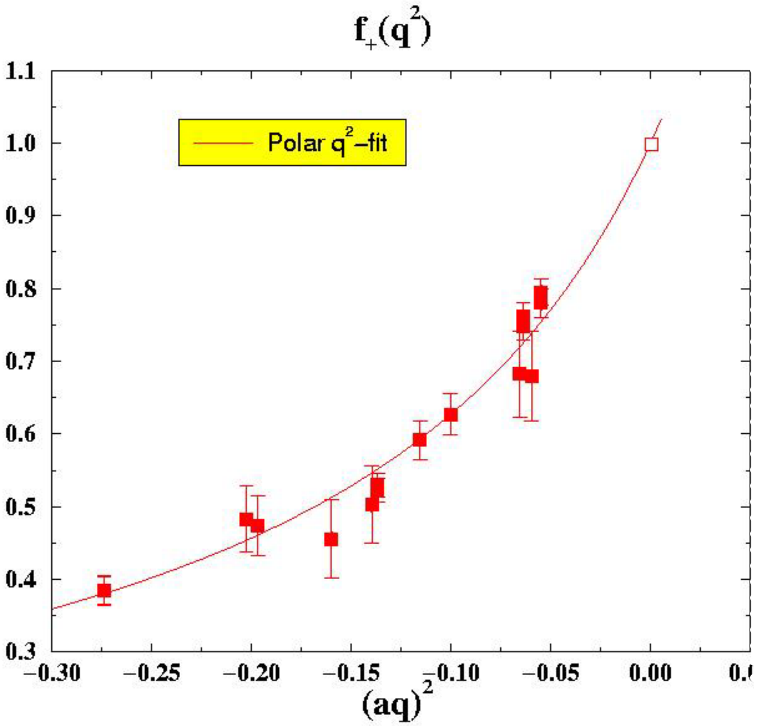
$$R \to \frac{\langle \pi | \bar{s}\gamma^0 u | K\rangle \cdot \langle K | \bar{u}\gamma^0 s | \pi\rangle}{\langle K | \bar{s}\gamma^0 s | K\rangle \cdot \langle \pi | \bar{u}\gamma^0 u | \pi\rangle} = f_0^2(q^2_{max}) \frac{(M_K + M_\pi)^2}{4 M_K M_\pi}$$

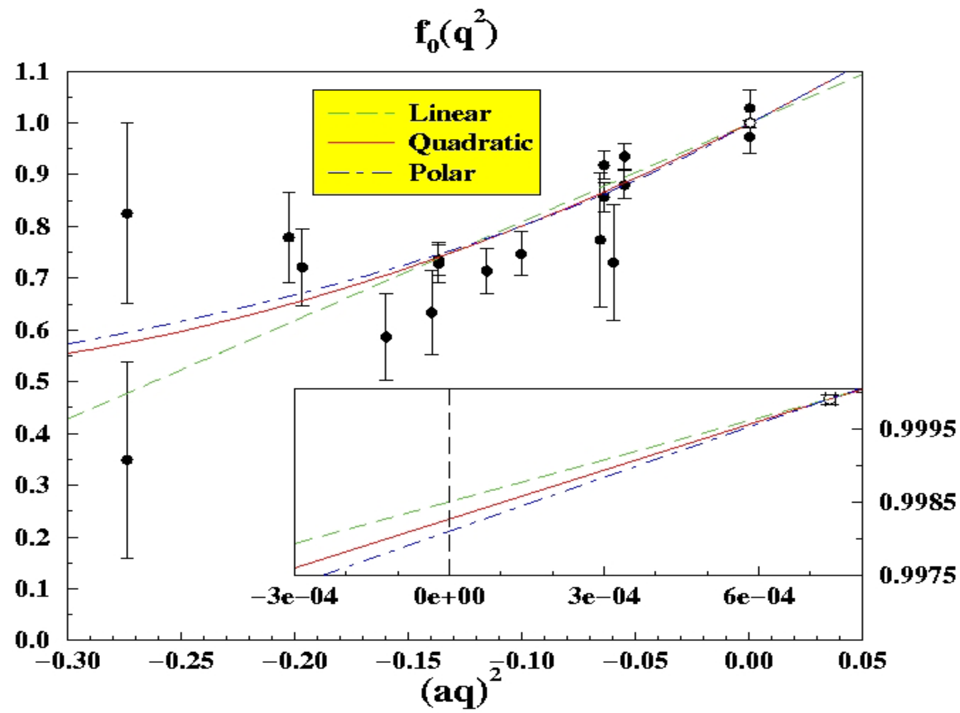



- For $M_K \to M_\pi$, $R \to 1 + \mathbf{O(M^2_K - M^2_\pi)^2}$
- Stat. and Syst. errors scale as $\mathbf{(M^2_K - M^2_\pi)^2}$, like the physical SU(3) breaking effects.
- Independent of $Z_V$ and $b_V$

*Stat. errors well below 1%*

# 2) Extrapolation of $f_0(q_{MAX})$ to $f_+(0)$




$$f_+(q^2) = \frac{f_+(0)}{1-\lambda_+ q^2}$$

(Vector Meson Dominace)

$$f_0^{(lin)}(q^2) = f_+(0)\cdot(1+\lambda_0^{(lin)}\cdot q^2)$$

$$f_0^{(quad)}(q^2) = f_+(0)\cdot(1+\lambda_0^{(quad)}\cdot q^2 + c_0\cdot q^2)$$

$$f_0^{(pol)}(q^2) = \frac{f_+(0)}{1-\lambda_0^{(pol)} q^2}$$

**Systematic uncertainty for the determination of $f_+(0)$**

# Check of the theory: form factor vs experiment

The theoretical estimate of $f_+(0)$ can be checked comparing $f_+(q^2)$ vs experiment (Bijnens-Talavera ('03)):

REAL PREDICTION

| Polar fit: | Our (March'04) | KTeV (June'04) |
|---|---|---|
| | $\lambda_+ = 0.025(2)$ | $\lambda_+ = 0.0250(4)$ |
| | $\lambda_0 = 0.012(2)$ | $\lambda_0 = 0.0141(10)$ |

good agreement between data and theory

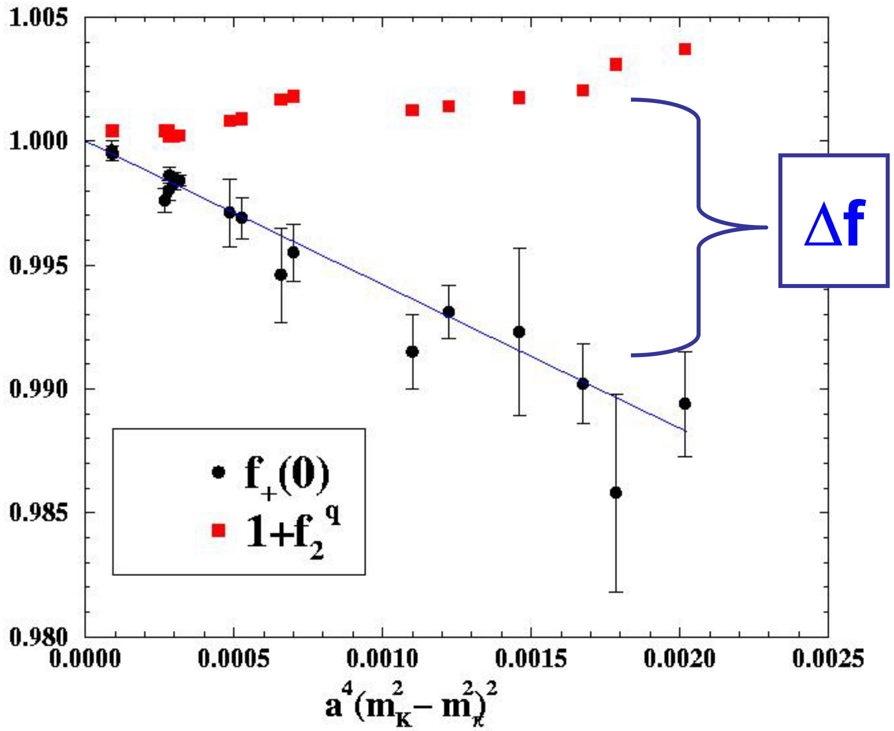
**Chiral-QCD** also predicts similar values.

**High precision measurements**

**ISTRA+** (hep-ex/0404030-$K^+_{\ell 3}$): Polar fit not available but curvature visible for $f_+(q^2)$.
$\lambda_+$ and $\lambda_0$ from a linear fit consistent with KTeV.

**NA48** (hep-ex/0410065-$K^{L+}_{e3}$): $\lambda_+$ from a linear and a polar fit consistent with KTeV.

# 3) Δf and subtraction of the chiral logs




- <u>At the simulated masses</u>

$$\Delta f^q \equiv f_+(0) - 1 - f_2^q \neq 0$$

- $f_2^q$ =<u>quenched artefacts:</u>

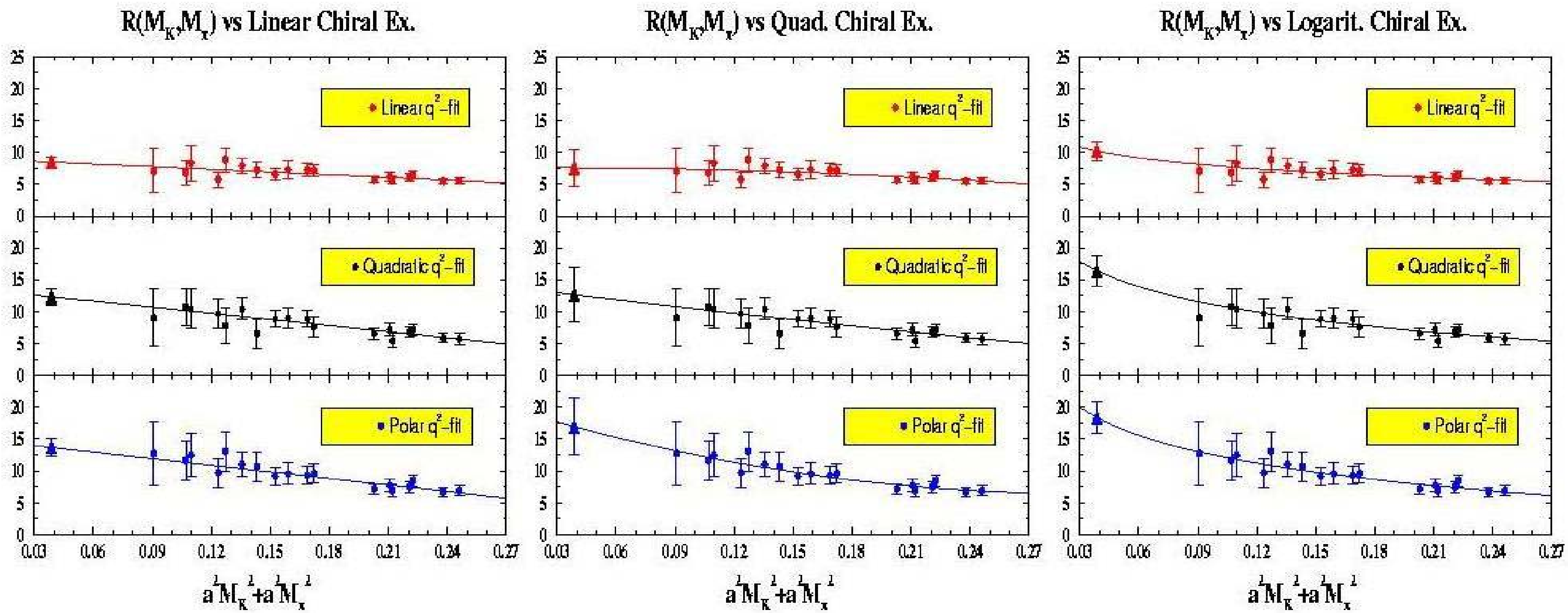
<u>well defined but non-trivial chiral behaviour</u>

$$\Delta f^q \propto B\left(M_K^2 - M_\pi^2\right)^2 \quad \text{(Ademollo-Gatto)}$$

- *<u>Scale independent and no leading quenched artefacts</u>*
- *<u>Hopefully suited for a smoth chiral behaviour</u>*

# 3) Chiral extrapolation

$$R(M_K, M_\pi) \equiv \frac{\Delta f^q}{(M_K^2 - M_K^2)^2} \equiv \frac{f_+(0) - 1 - f_2^{quenched}}{(M_K^2 - M_K^2)^2}$$




**Having subtracted the leading log. correction, several extrapolations are tried**

The **final result** is: $\Delta f = -0.017 \pm 0.005_{stat} \pm 0.007_{syst}$

[Leutwyler and Roos (PDG2002): $\Delta f^{LR} = -0.016 \pm 0.008$ ]

$f_+^{K^0\pi^-}(0) = 0.960 \pm 0.005_{stat} \pm 0.007_{syst}$

+ quenching error at $O(p^6)$ !

Systematic error: The dominant contributions come from the uncertainties on the $q^2$ and mass dependencies of the form factor

D.Becirevic, G.Isidori, V.Lubicz, G.Martinelli, F.Mescia, S.Simula, C.Tarantino, G.Villadoro. [NPB 705 (2005) 339]

Two preliminary unquenched estimates have been recently presented

$\Delta f = -0.015 \pm 0.006_{stat} \pm 0.009_{syst}$ MILC-[Dec-04] $N_F=2+1$

our strategy (good!) but staggered fermions (less good!!)

$\Delta f = -0.023 \pm 0.009_{syst}$ JLQCD-[Mach-05] $N_F=2$

$f_+^{K^0\pi^-}(0) = 0.960 \pm 0.005_{stat} \pm 0.007_{syst}$

$$\left(V_{us} \cdot f_+^{K^0\pi^-}\right)^{Exp} = 0.2165(5)$$

• **CKM-Unitarity recovered:**

$|V_{us}|^2 + |V_{ud}|^2 + |V_{ub}|^2 = 0.9993(11)$

• $|V_{ud}| = 0.9739(5)$

(Updated average: CKM 2005)

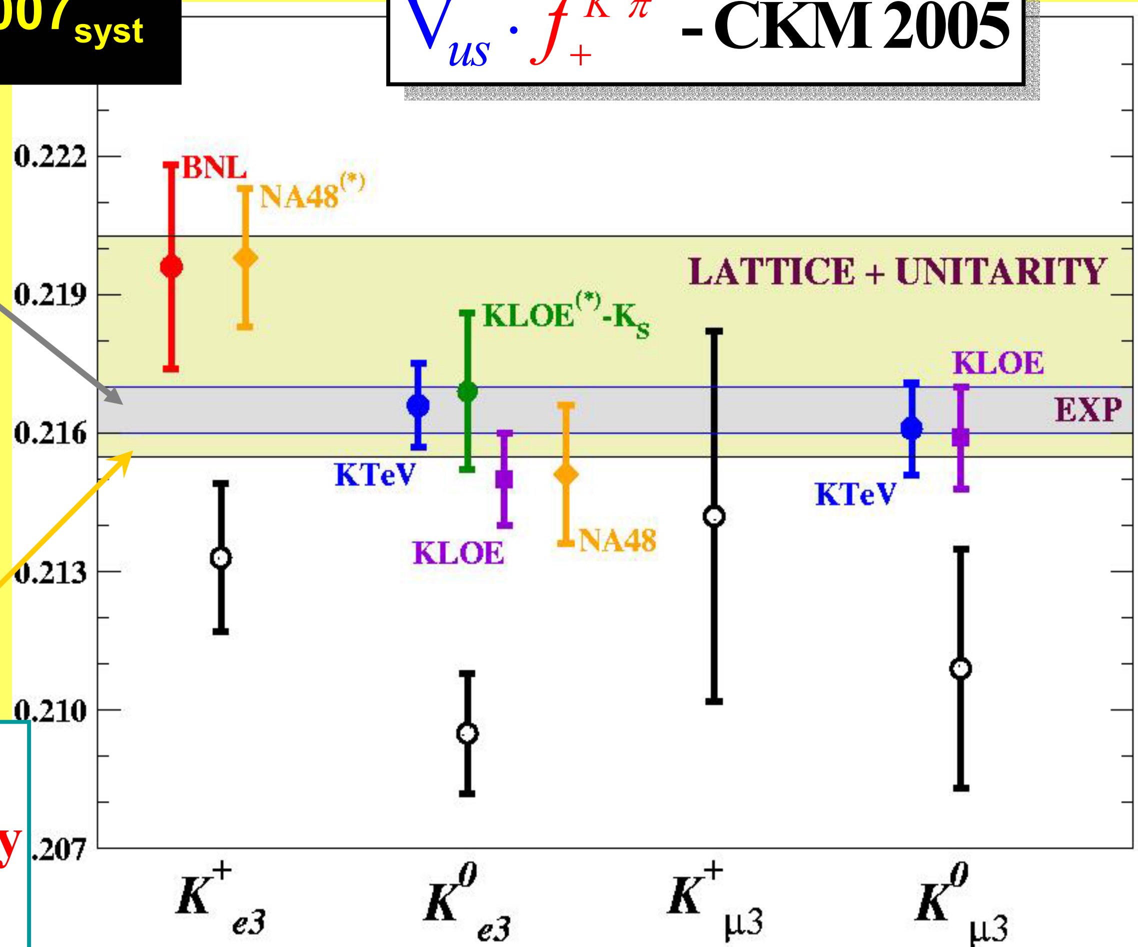
$$V_{us}^{uni} \cdot f_+^{our\text{-}LR} = 0.2179(24)$$

$$V_{us}^{uni} \cdot f_+^{Bijnens\text{-}Jamin} = 0.2215(26)$$

Theory

$\nwarrow 2\sigma - \text{higher} \nearrow$

$V_{us} \cdot f_+^{K^0\pi^-}$ - CKM 2005




$$\tau_{K^+}^{PDG} = 1.2384(24) \cdot 10^{-8} s, \tau_L^{PDG} = 5.15(4) \cdot 10^{-8} s, \tau_S^{PDG} = 8.935(8) \cdot 10^{-11} s$$

$|V_{us}|^{K_{l3}} = (0.2253 \pm 0.0020) \Rightarrow \delta|V_{us}| \sim 1\%$

*(dominated by the $f_+(0)$ theoretical uncertainty)*

# Comments on other routes to $V_{us}$

$|V_{us}|^{Uni}$ =(0.2269±0.0013) $|V_{us}|^{K_{l3}}$ =(0.2253±0.0020)

$$\frac{\Gamma(K \to \mu\bar{\nu}_\mu(\gamma))}{\Gamma(\pi \to \mu\bar{\nu}_\mu(\gamma))} = \frac{|V_{us}|^2 f_K^2 m_K \left(1 - \frac{m_\mu^2}{m_K^2}\right)^2}{|V_{ud}|^2 f_\pi^2 m_\pi \left(1 - \frac{m_\mu^2}{m_\pi^2}\right)^2} \, 0.9930(35)$$

[Rad.Corr.]

- $f_K/f_\pi - 1 = 0.210(4)(13)$ (MILC **hep-lat/0407028)** — Unquenched, **Staggered-Fermions** → $|V_{us}|$ =(0.2219±0.0026) (Marciano **hep-ph/0406324)**

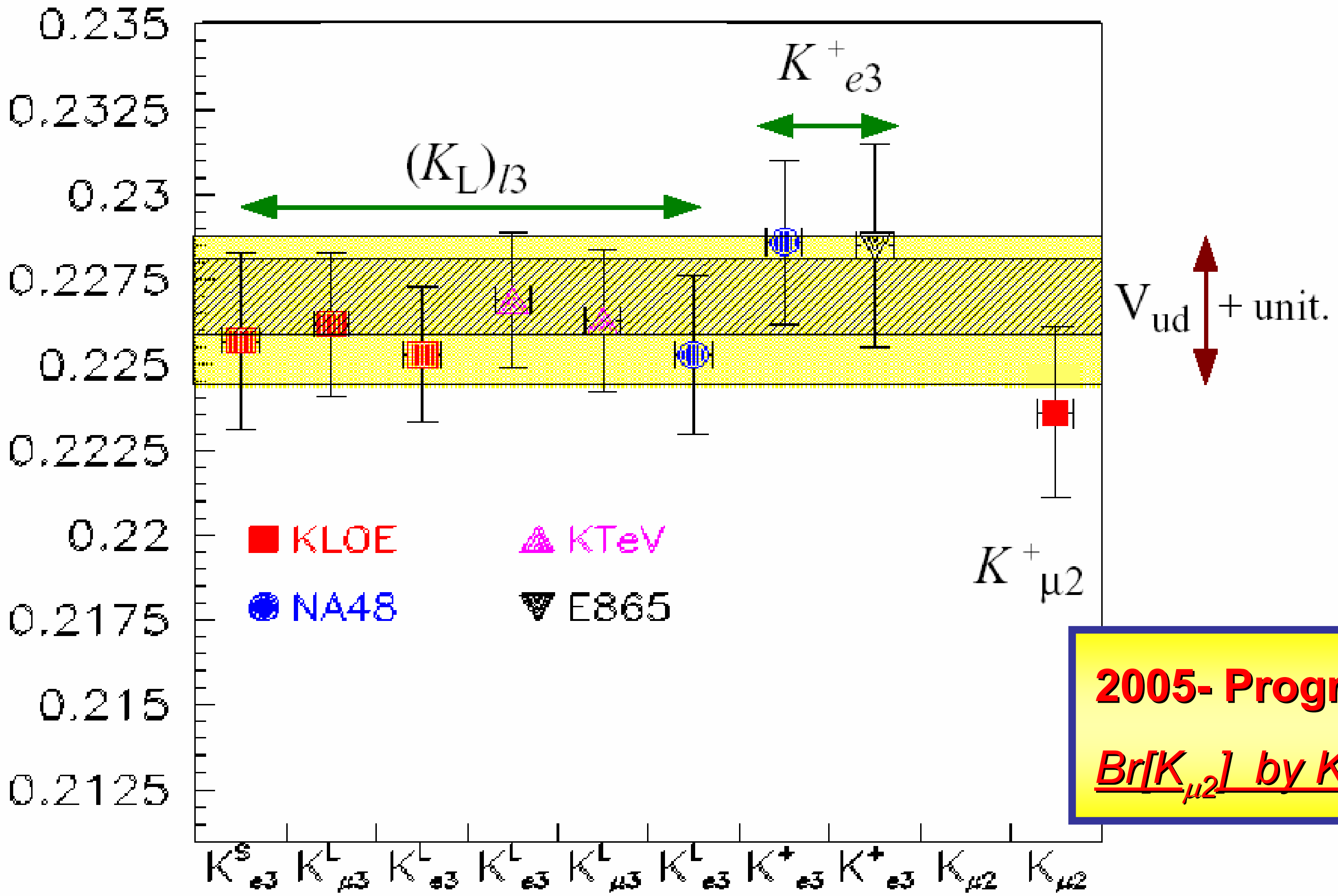
**Charming: Unquenched & 6.5% uncertainty**

**Disappointing: not better, $\delta|V_{us}|$ ~ 1.2%**

**The dominant source of systematic error comes from the lattice calculation. VERY DIFFICULT TO REDUCE !!**

Summary of $V_{us}$ from from *K* decays :

**3rd CKM Workshop**
[*March 2005, San Diego*]




**2005- Progress:**

***Br[$K_{\mu 2}$] by KLOE***

# $V_{us}$-CONCLUSIONS

- $K_{l3}$ decays offer a good opportunity to estimate $V_{us}$ and test the CKM relation, thanks to Ademollo-Gatto Theorem.
- Over the years, a great deal of activity has been devoted to reach higher precision and to reduce model-assumptions.
- We have presented a methodology to reach 1% accuracy for $f_+(0)$
- Our calculation of $f_+(0)$ is the first one obtained by using a non-perturbative method based only on QCD, albeit in the quenched approximation (which can be in principle removed)
- Our final result, $f_+(0) = 0.960 \pm 0.005_{stat} \pm 0.007_{syst}$ is in good agreement with the estimate made by Leutwyler and Roos (PDG)
- The most important step is to remove the quenched approximation
- Further steps: using lower masses(considering finite volume effects)

**KAON PHYSICS** HAS REPRESENTED SO FAR A HUGE SOURCE OF INFORMATION FOR PARTICLE PHYSICS. NEW IMPORTANT RESULTS ARE EXPECTED IN THE FUTURE.

**Grazie mille e Buon Lavoro**

# BACKUP

TH very clean : (With improved CKM parameters ~ 2008) ⇒

$\sigma\left(Br\left(K^+ \to \pi^+ \nu\bar{\nu}\right)\right) < 5\%$

$\sigma\left(Br\left(K_L \to \pi^0 \nu\bar{\nu}\right)\right) < 5\%$

Very clean determination of Unitarity Triangle

| | | | |
|---|---|---|---|
| $\sigma(Br) \cong 10\%$ | $\sigma(\sin 2\beta \cong 0.04)$ | $\sigma(\gamma) = 9^o$ | $\sigma(\lvert V_{td} \rvert) = 7\%$ |
| $\sigma(Br) \cong 5\%$ | $\sigma(\sin 2\beta \cong 0.025)$ | $\sigma(\gamma) = 5^o$ | $\sigma(\lvert V_{td} \rvert) = 4\%$ |

San Diego 27

**by Buras CKM05**