L’avventura dei Next-to-Leading (NLO)

Pomeriggio in ricordo di Enrico

Guido Martinelli
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DIPARTIMENTO DI FISICA

SAPIENZA
UNIVERSITÀ DI ROMA

Tribute to Gauss & Kandinsky by G Martinelli

Roma May 23th 2023

UTfit

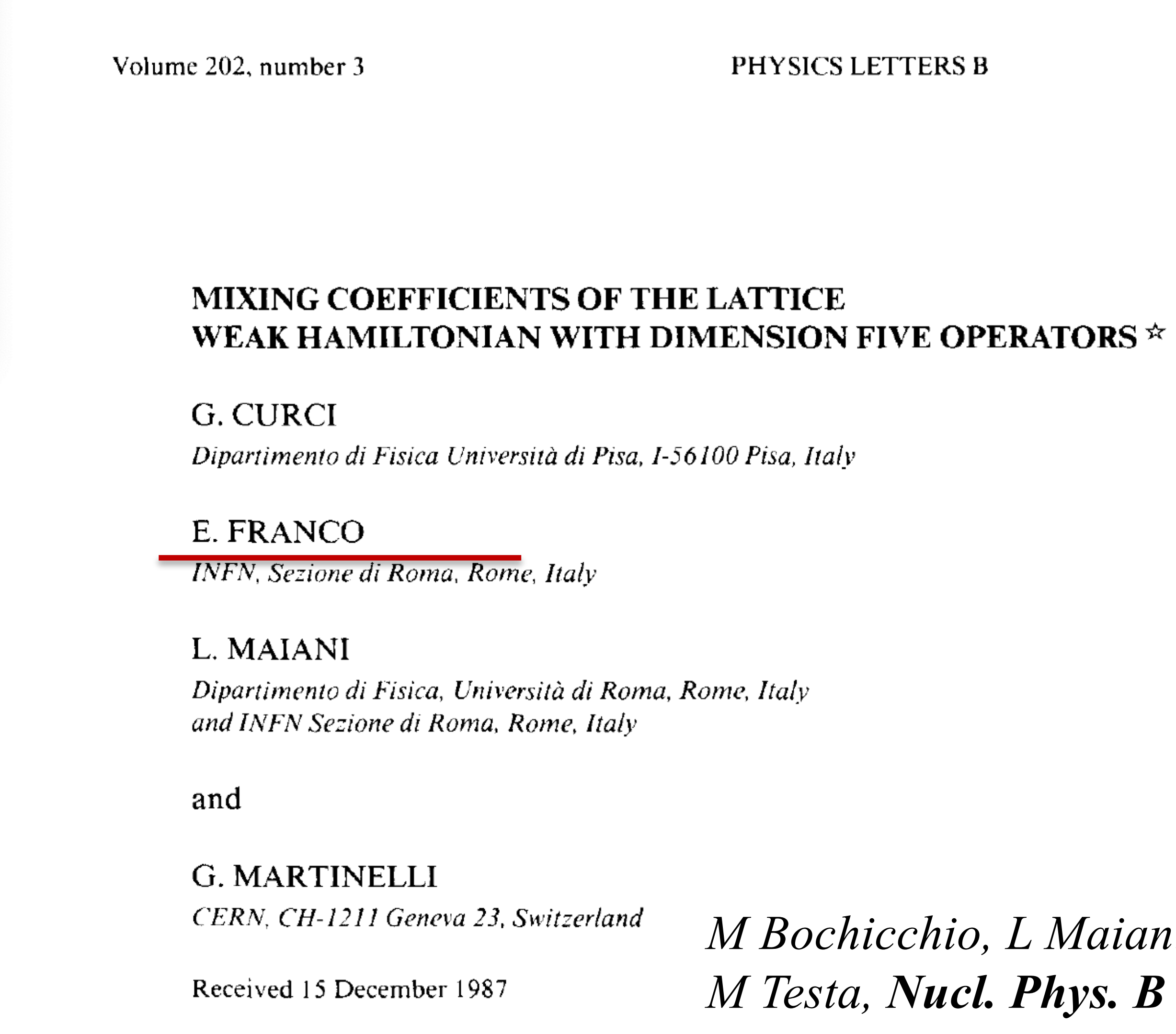
Extended Twisted Mass Collaboration

PRACE

INFN
Istituto Nazionale
di Fisica Nucleare

Enrico & Guido

*Varenna School 1984 Enrico was a Student (Barbara Mele, Giovanni Ridolfi, …), **Guido Scientific Secretary, Cabibbo Director***



Volume 202, number 3 PHYSICS LETTERS B 10 March 1988

MIXING COEFFICIENTS OF THE LATTICE WEAK HAMILTONIAN WITH DIMENSION FIVE OPERATORS ☆

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Received 15 December 1987

First paper together:
It is already a NLO calculation namely the finite term of the coefficient of the chromomagnetic operator

M Bochicchio, L Maiani, G Martinelli, GC Rossi, M Testa, ***Nucl. Phys. B 262 (1985), 331***

Enrico & Guido

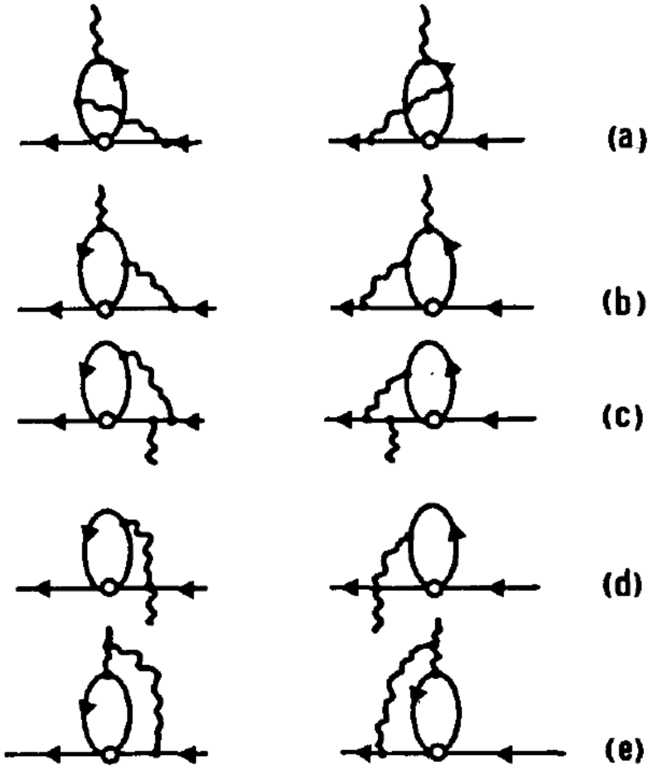
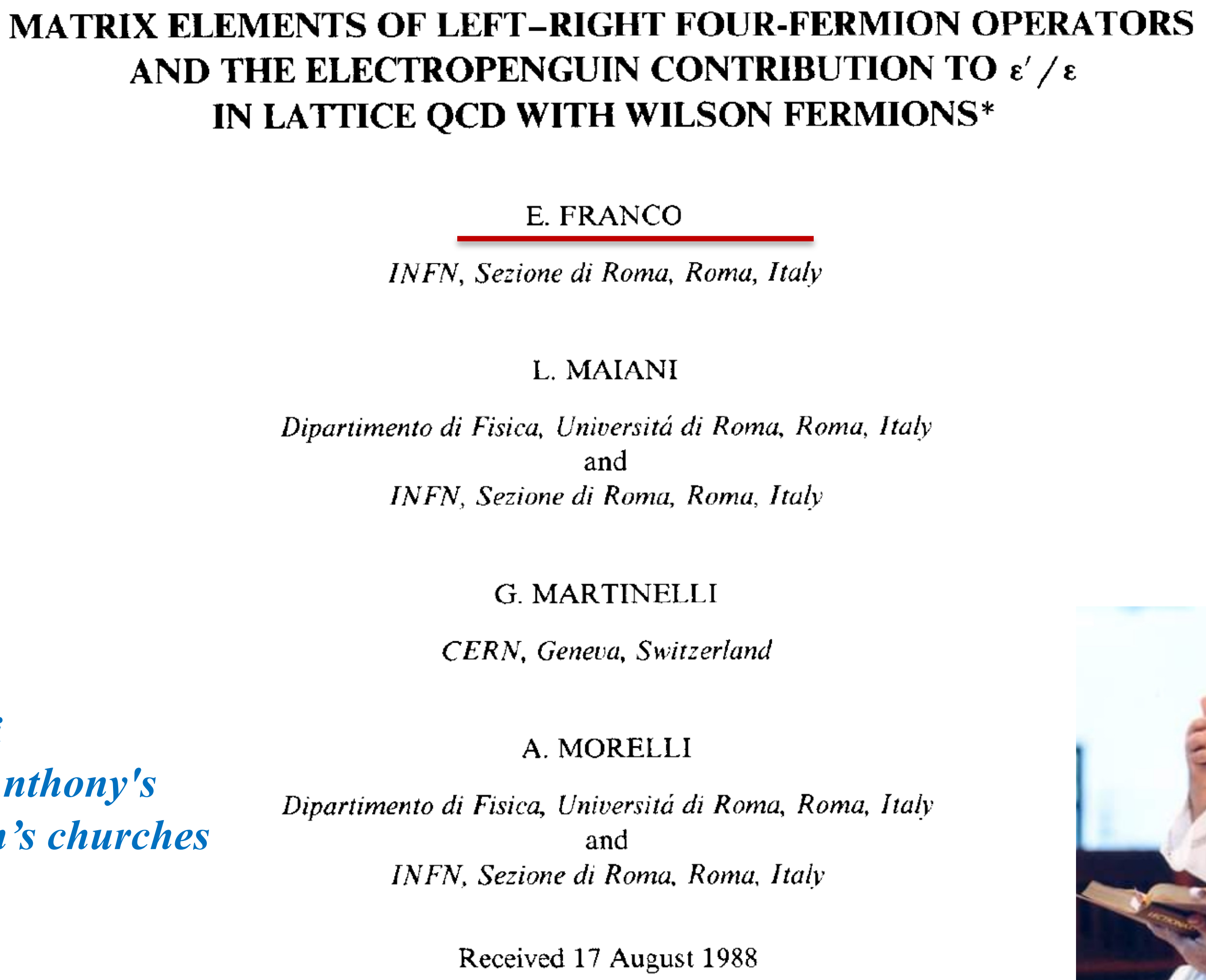


Fig. 3. Two loop diagrams for the calculation of $A^{(\pm)}$.

First paper together:
our common scientific journey started with a two loop calculation !

Necessary to get rid of infrared and ultraviolet singularities appearing in the intermediate steps, technically very complex, contribution by Enrico fundamental



MATRIX ELEMENTS OF LEFT–RIGHT FOUR-FERMION OPERATORS AND THE ELECTROPENGUIN CONTRIBUTION TO ε'/ε IN LATTICE QCD WITH WILSON FERMIONS*

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Attilio Morelli
Pastor at St. Anthony's
and St. Joseph's churches
Bermuda
670 followers

Chromomagnetic operator, Penguin Operators, What is all this about?

the Standard Model and beyond

Vacuum Energy

Hierarchy

Vacuum Stability

$$\mathcal{L} = \Lambda^4 + \Lambda^2 H^2 + \lambda H^4 +$$

$$(D_\mu H)^2 + \bar{\psi} \not{D} \psi + F_{\mu\nu}^2 + F_{\mu\nu} \tilde{F}_{\mu\nu}$$

Strong $\not{C}\not{P}$

$$Y H \bar{\psi} \psi + \frac{1}{\Lambda} (\bar{L} H)^2 + \frac{1}{\Lambda^2} \sum_i C_i O_i + \ldots$$

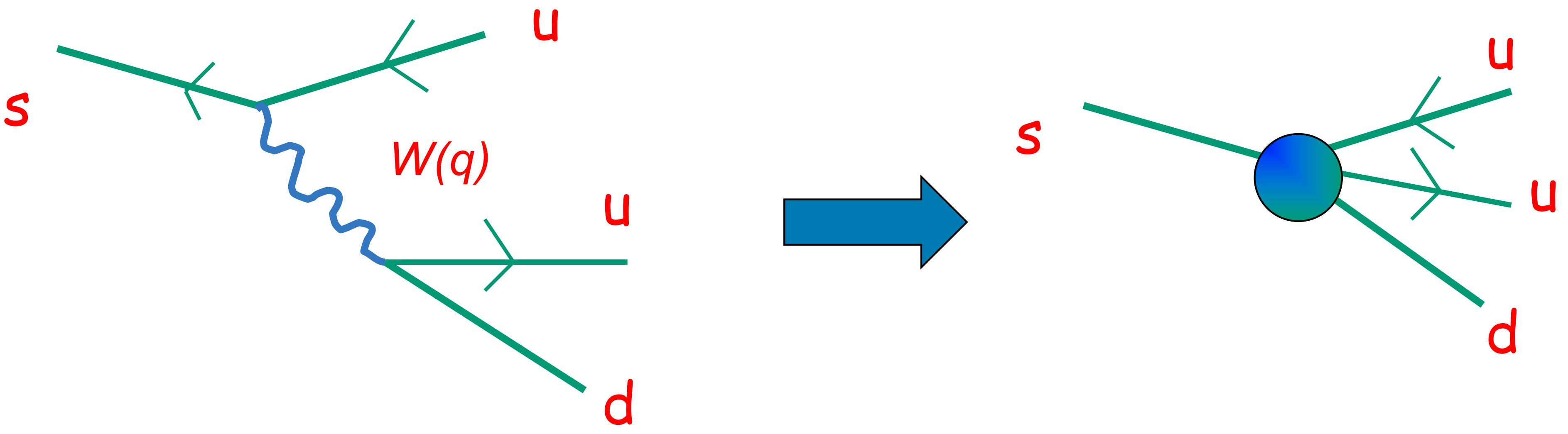
Flavor puzzle

Neutrino Masses

New Physics

Possible breaking of accidental symmetries

The Effective Hamiltonian



$$q \sim m_K \ll M_W$$

$$\mathcal{H}_{eff} = -\frac{G_F}{\sqrt{2}} V_{ud} V_{us}^* \ (\bar{s}\gamma_\mu(1-\gamma_5)u)\,(\bar{u}\gamma^\mu(1-\gamma_5)d)$$

GENERAL FRAMEWORK: THE OPE

$$A_{\mathbf{FI}}(2\pi^4)\delta^4(p_F - p_I) = \int d^4x\, d^4y\, D_{\mu\nu}(x, M_W) \langle F | T[J_\mu(y+x/2) J^\dagger_\nu(y-x/2)] | I \rangle$$

$$\Downarrow$$

$$\langle F | H^{\Delta S=1} | I \rangle = G_F/\sqrt{2}\, V_{ud}\, V_{us} \quad \Sigma_i\, C_i(\mu) \frac{\langle F | Q_i(\mu) | I \rangle}{(M_W)^{di-6}}$$

di= dimension of the operator $Q_i(\mu)$

$C_i(\mu)$ Wilson coefficient: it depends on M_W/μ and $\alpha_W(\mu)$

$Q_i(\mu)$ local operator renormalized at the scale μ

New local four-fermion operators are generated

$Q_1 = (\bar{s}_L{}^A \gamma_\mu u_L{}^B)(\bar{u}_L{}^B \gamma_\mu d_L{}^A)$ Current-Current

$Q_2 = (\bar{s}_L{}^A \gamma_\mu u_L{}^A)(\bar{u}_L{}^B \gamma_\mu d_L{}^B)$

$Q_{3,5} = (\bar{s}_R{}^A \gamma_\mu d_L{}^A)\sum_q (\bar{q}_{L,R}{}^B \gamma_\mu q_{L,R}{}^B)$ Gluon

$Q_{4,6} = (\bar{s}_R{}^A \gamma_\mu d_L{}^B)\sum_q (\bar{q}_{L,R}{}^B \gamma_\mu q_{L,R}{}^A)$ Penguins

$Q_{7,9} = 3/2(\bar{s}_R{}^A \gamma_\mu d_L{}^A)\sum_q e_q (\bar{q}_{R,L}{}^B \gamma_\mu q_{R,L}{}^B)$ Electroweak

$Q_{8,10} = 3/2(\bar{s}_R{}^A \gamma_\mu d_L{}^B)\sum_q e_q (\bar{q}_{R,L}{}^B \gamma_\mu q_{R,L}{}^A)$ Penguins

+ Chromomagnetic end electromagnetic operators

$$\mathcal{A}(K \to \pi\pi) = \sum_i C_W^i(\mu)\langle \pi\pi | O_i(\mu) | K \rangle$$

GENERAL FRAMEWORK

$$H^{\Delta S=1} = G_F/\sqrt{2}\, V_{ud}\, V_{us}^{*} \Big[\, (1-\tau)\, \Sigma_{i=1,2}\, z_i\, (Q_i - Q^c_i) +$$

$$\tau\, \Sigma_{i=1,10} \,(\, z_i + y_i\,)\, Q_i \quad \Big]$$

Where y_i and z_i are short distance coefficients, which are known in perturbation theory at the NLO (Buras et al.
+ Marco Ciuchini, Enrico Franco, Guido Martinelli, Laura Reina)

$$\tau = -V_{ts}^{*} V_{td} / V_{us}^{*} V_{ud}$$

We have to compute $A^{I=0,2}_i = \langle\, (\pi\, \pi)_{I=0,2}\, |\, Q_i\, |\, K\, \rangle$
with a non perturbative technique (lattice,
QCD sum rules, 1/N expansion etc.)

$$A_0 = \sum_i C_i(\mu) \ \langle (\pi\, \pi) | Q_i (\mu) | \ K \rangle_{I=0} \ (1 - \Omega_{IB})$$

μ = renormalization scale
μ-dependence cancels if operator matrix elements are consistently computed

ISOSPIN BREAKING

$$A_2 = \sum_i C_i(\mu) \ \langle (\pi\, \pi) | Q_i (\mu) | K \rangle_{I=2}$$

Ω_{IB} = 0.25± 0.08 (Munich from Buras & Gerard)
0.25± 0.15 (Rome Group) 0.16± 0.03 (Ecker et al.)
0.10± 0.20 Gardner & Valencia, Maltman & Wolf, Cirigliano & al.

$$A_0 = \sum_i C_i(\mu) \, \langle (\pi\,\pi) | Q_i(\mu) | K \rangle_{I=0}$$

$$A_2 = \sum_i C_i(\mu) \, \langle (\pi\,\pi) | Q_i(\mu) | K \rangle_{I=2}$$

μ = renormalization scale
μ-dependence cancels if operator matrix elements are consistently computed

NLO & Lattice Calculations of the Matrix Elements essential for a quantitative prediction of the physical amplitude

NNLO even better

Enrico was a pillar of all the progresses we made

$$A^{I=0,2}_{i}(\mu) = \langle (\pi\,\pi)_{I=0,2}\,|Q_{i}(\mu)\,|\,K\rangle$$
$$= Z_{ik}(\mu\, a)\,\langle (\pi\,\pi)_{I=0,2}\,|\,Q_{k}(a)\,|\,K\rangle$$

Where $Q_{i}(a)$ is the bare lattice operator
And *a* the lattice spacing.

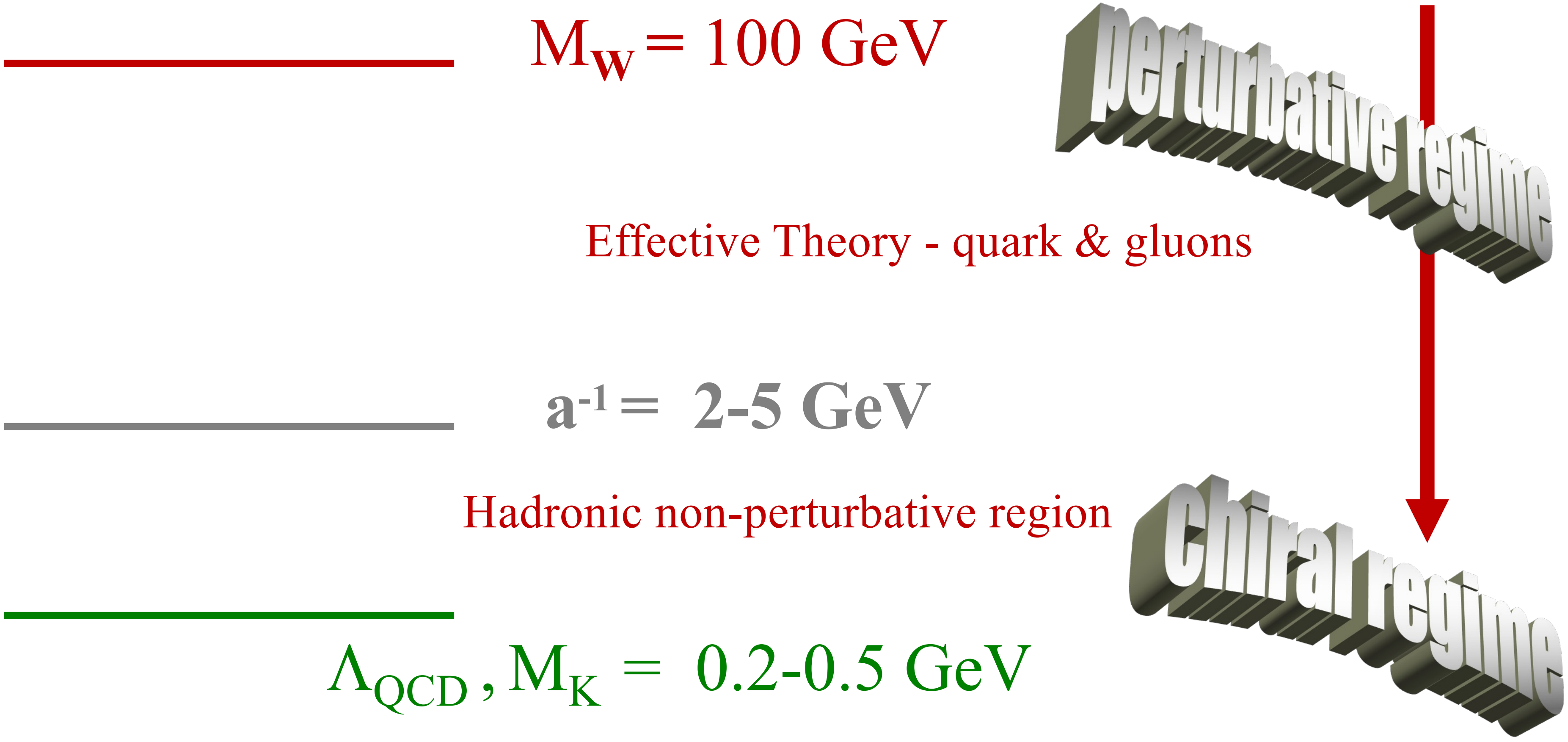
The effective Hamiltonian can then be read as:

$$\langle F\,|\,H^{\Delta S=1}\,|\,I\rangle = G_F/\sqrt{2}V_{ud}V_{us}{}^{*}\Sigma_i\, C_i\,(1/a)\,\langle F\,|\,Q_i\,(a)\,|\,I\rangle$$

In practice the renormalization scale (or 1/*a*) are the scales which separate short and long distance dynamics

GENERAL FRAMEWORK

$$\langle\, H^{\Delta S=1} \,\rangle = G_F/\sqrt{2}\; V_{ud}\, V_{us}^{\,*} \ldots \Sigma_i\, C_i\,(a)\, \langle\, Q_i(a)\, \rangle$$



$M_W = 100$ GeV

perturbative regime

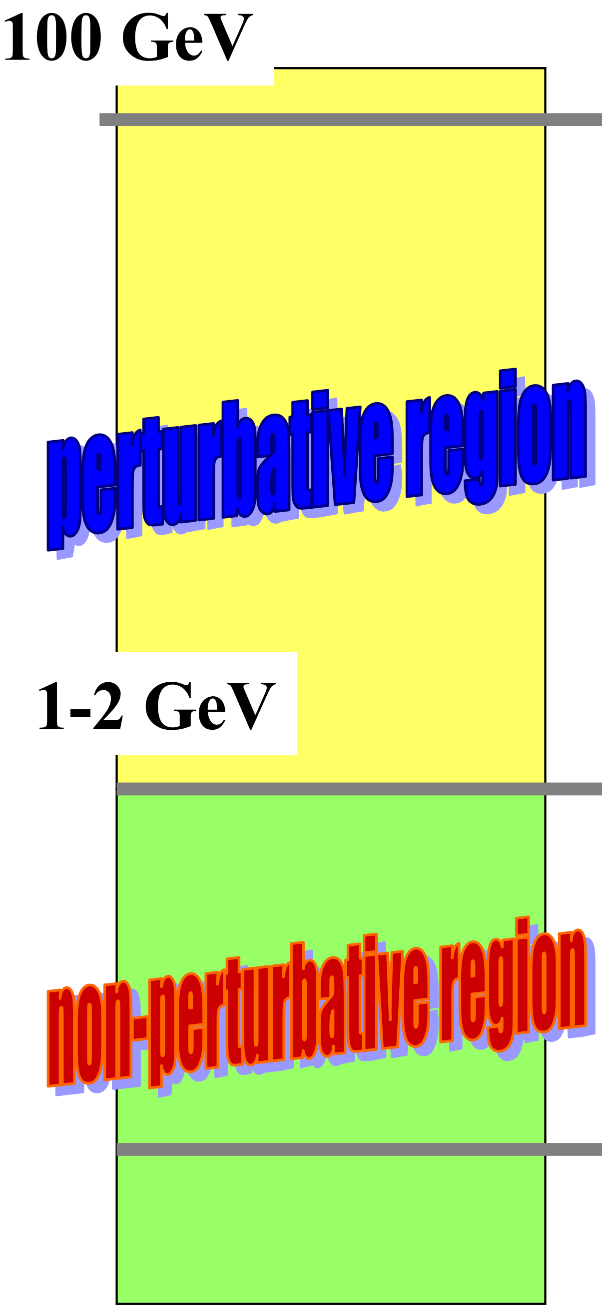
Effective Theory - quark & gluons

$a^{-1} =$ 2-5 GeV

Hadronic non-perturbative region

Chiral regime

Λ_{QCD} , M_K = 0.2-0.5 GeV



Large mass scale: heavy degrees of freedom (m_t , $M_{W,}$ M_s) are removed and their effect included in the Wilson coefficients

renormalizazion scale μ (inverse lattice spacing 1/a); this is the scale where the quark theory is matched to the effective hadronic theory

Scale of the low energy process
$\Lambda \sim M_W$

THE SCALE PROBLEM: Effective theories prefer low scales,
Perturbation Theory prefers large scales

if the scale μ is too low
problems from higher dimensional operators

(Cirigliano, Donoghue, Golowich)

- it is illusory to think that the problem is solved by using dimensional regularization

on the lattice this problem is called
DISCRETIZATION ERRORS

(reduced by using improved actions and/or scales μ > 2-4 GeV

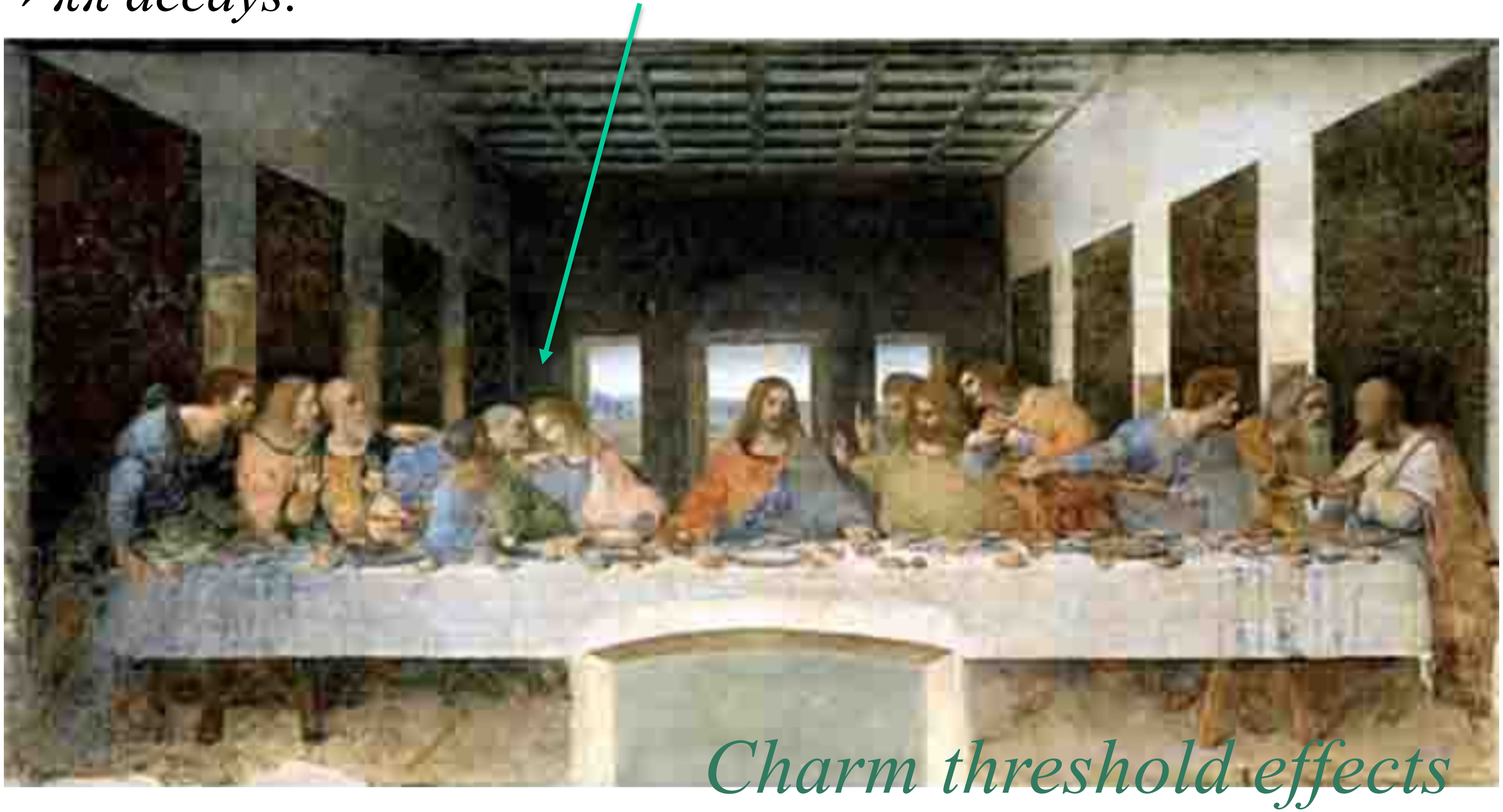
The True Story of NLO Calculations in Weak Decays

1) G. Altarelli, G. Curci, G. Martinelli and S. Petrarca, "Weak Nonleptonic Decays Beyond Leading Logarithms In QCD," Phys. Lett. B 99 (1981) 141;
2) G. Altarelli, G. Curci, G. Martinelli and S. Petrarca, "QCD Nonleading Corrections To Weak Decays As An Application of Regularization By Dimensional Reduction" Nucl.Phys. B 187 (1981) 461.

Improvement for neutral meson mixing,
DI=3/2 transitions and charm decays
No penguin diagrams, however,
which were considered fundamental for
DI=1/2 decays

The story according to Andrzej Buras (with my comments)

During the last supper of the Ringberg workshop Guido Martinelli and me realized that it would be important to calculate NLO QCD corrections to the Wilson coefficients of penguin operators relevant for $K \rightarrow \pi\pi$ decays.



Charm threshold effects

This calculation done in collaboration with Guido Altarelli, Curci and Petrarca has been unfortunately performed in the dimensional reduction scheme (DRED) that was not familiar to most phenomenologists (so what?)and its complicated structure discussed in detail by these authors most probably scared many from checking their results.

Moreover it was known that the treatment of $\gamma5$ in the DRED scheme, similarly to the dimensional regularization scheme with anticommunicating $\gamma5$ (known presently as the NDR scheme), may lead to mathematically inconsistent results. Consequently it was not clear in 1988 whether the result of Altarelli et al. was really correct. To us it was clear that it was correct

Indeed Andrzej and Peter Weisz repeated the calculation for K^0 - $\overline{K}^0$ mixing in NDR and HV And found perfect agreement with Altarelli et al.

At this last supper of the Ringberg 1988 workshop Guido told me that he will put some of his PhD students to look into NLO QCD corrections to Wilson coefficients of QCD penguin operators relevant for $K \to \pi\pi$ decays

Laura Reina

Altarelli et al.

M. Ciuchini et al. / $\Delta S = 1$ effective hamiltonian

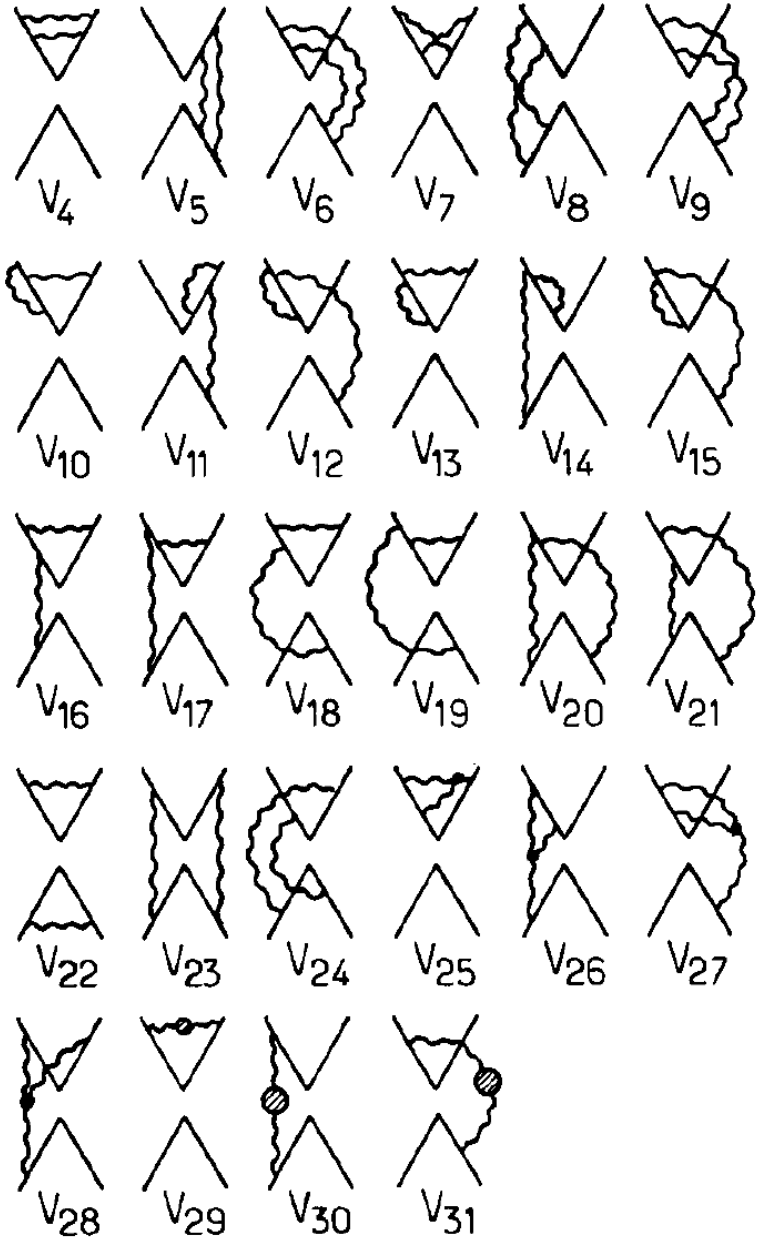


Fig. 10. Current–current diagrams at two loops.

M. Ciuchini et al. / $\Delta S = 1$ effective hamiltonian

Franco et al.

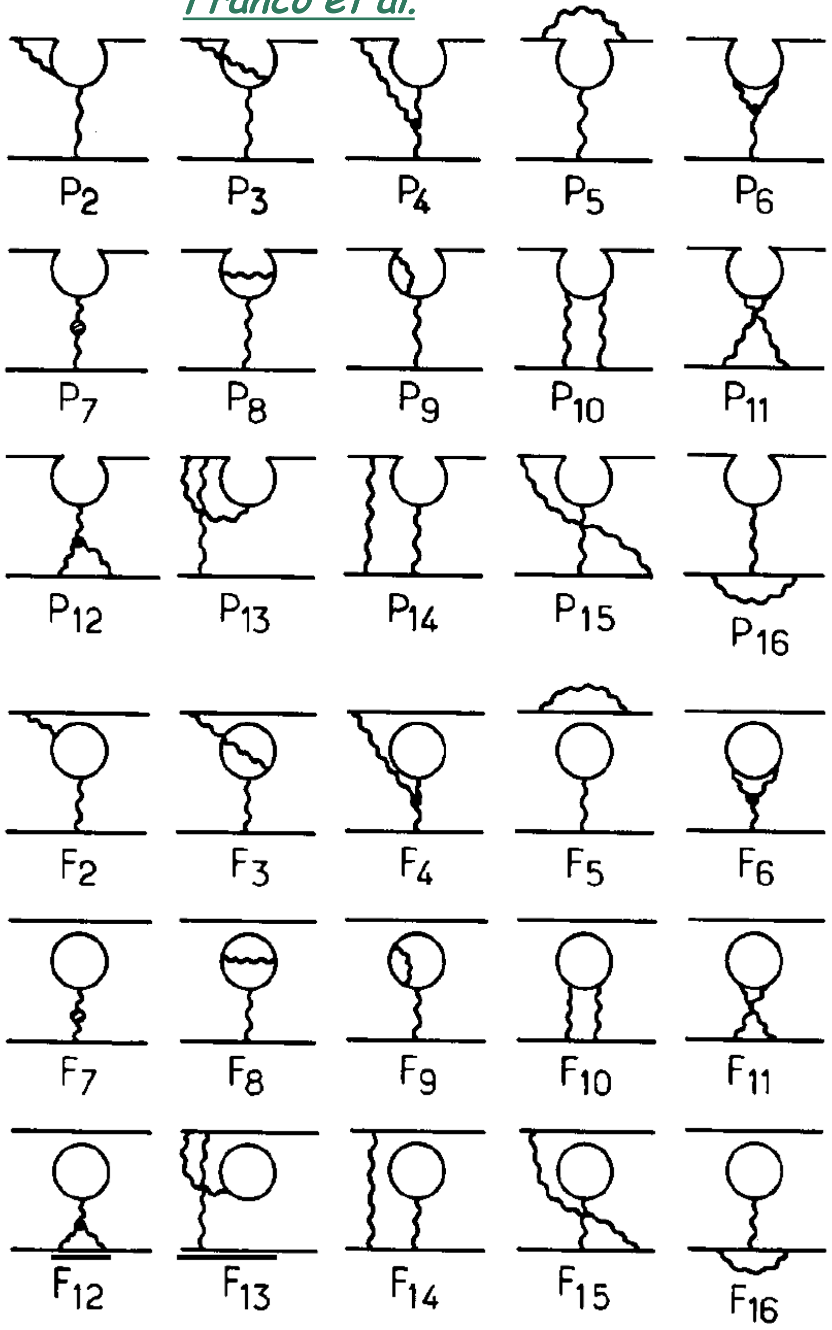


Fig. 11. Penguin diagrams at two loops.

Anomalous Dimension Matrix

(only strong interactions)

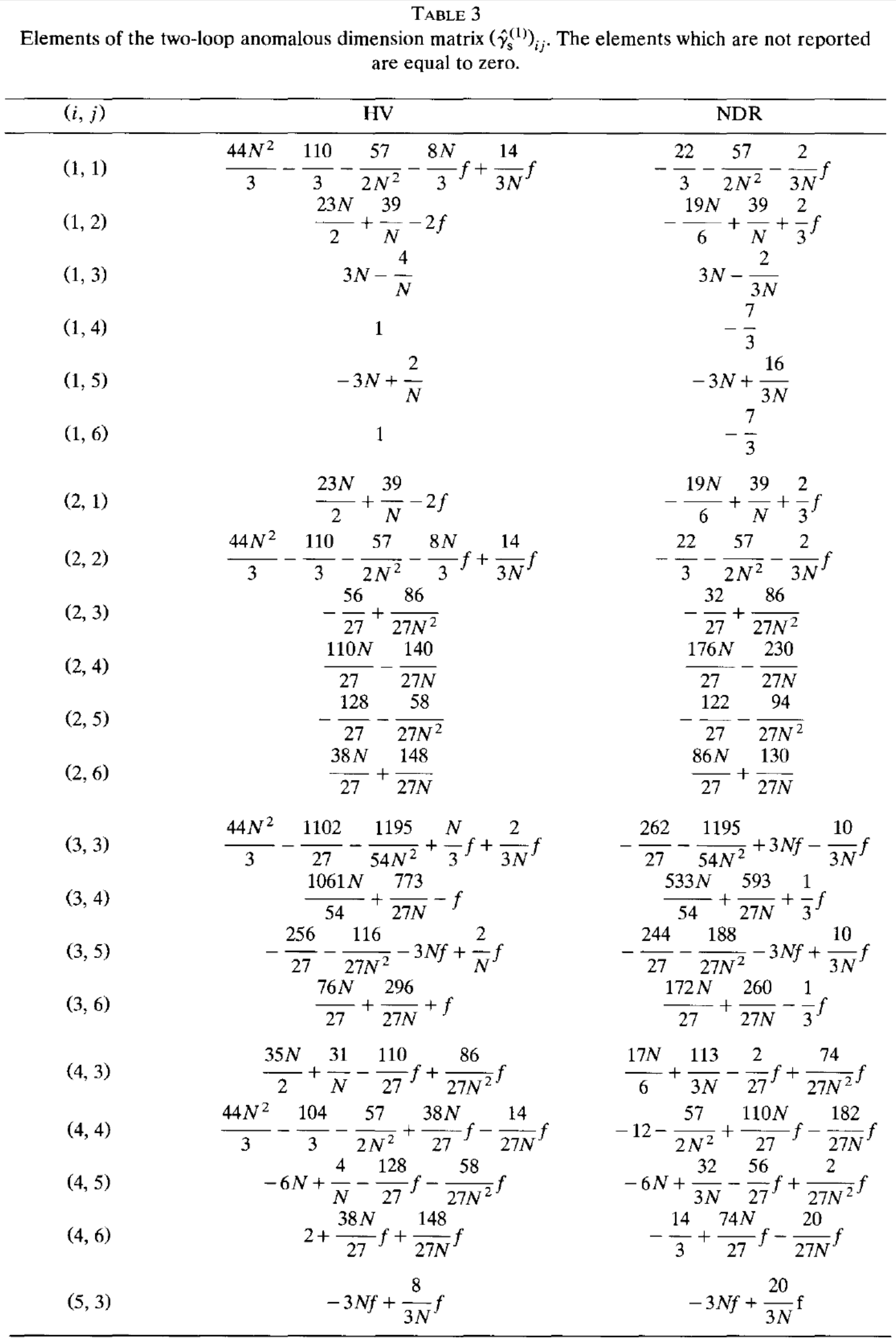
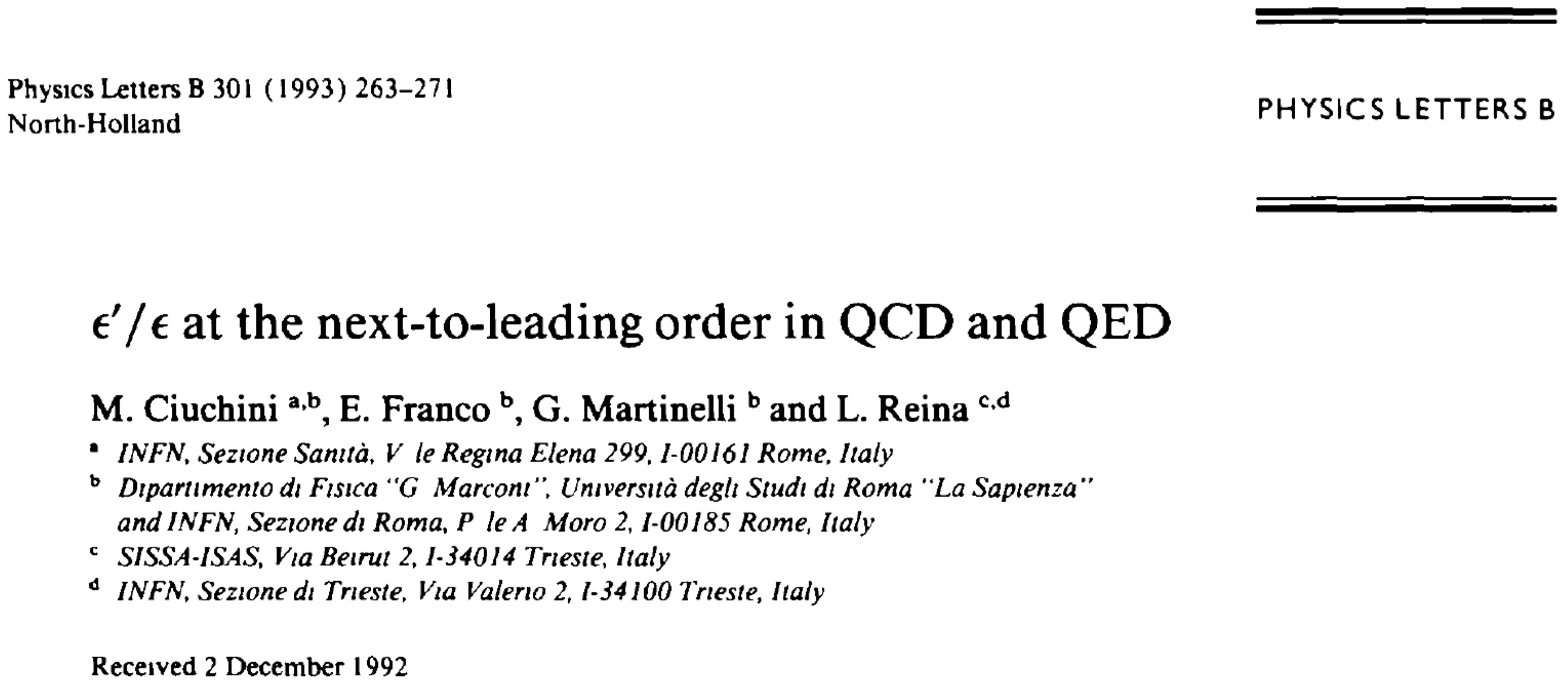


TABLE 3

Elements of the two-loop anomalous dimension matrix $(\hat{\gamma}_s^{(1)})_{ij}$. The elements which are not reported are equal to zero.

(i, j)	HV	NDR
(1, 1)	$\frac{44N^2}{3} - \frac{110}{3} - \frac{57}{2N^2} - \frac{8N}{3}f + \frac{14}{3N}f$	$-\frac{22}{3} - \frac{57}{2N^2} - \frac{2}{3N}f$
(1, 2)	$\frac{23N}{2} + \frac{39}{N} - 2f$	$-\frac{19N}{6} + \frac{39}{N} + \frac{2}{3}f$
(1, 3)	$3N - \frac{4}{N}$	$3N - \frac{2}{3N}$
(1, 4)	1	$-\frac{7}{3}$
(1, 5)	$-3N + \frac{2}{N}$	$-3N + \frac{16}{3N}$
(1, 6)	1	$-\frac{7}{3}$
(2, 1)	$\frac{23N}{2} + \frac{39}{N} - 2f$	$-\frac{19N}{6} + \frac{39}{N} + \frac{2}{3}f$
(2, 2)	$\frac{44N^2}{3} - \frac{110}{3} - \frac{57}{2N^2} - \frac{8N}{3}f + \frac{14}{3N}f$	$-\frac{22}{3} - \frac{57}{2N^2} - \frac{2}{3N}f$
(2, 3)	$-\frac{56}{27} + \frac{86}{27N^2}$	$-\frac{32}{27} + \frac{86}{27N^2}$
(2, 4)	$\frac{110N}{27} - \frac{140}{27N}$	$\frac{176N}{27} - \frac{230}{27N}$
(2, 5)	$-\frac{128}{27} - \frac{58}{27N^2}$	$-\frac{122}{27} - \frac{94}{27N^2}$
(2, 6)	$\frac{38N}{27} + \frac{148}{27N}$	$\frac{86N}{27} + \frac{130}{27N}$
(3, 3)	$\frac{44N^2}{3} - \frac{1102}{27} - \frac{1195}{54N^2} + \frac{N}{3}f + \frac{2}{3N}f$	$-\frac{262}{27} - \frac{1195}{54N^2} + 3Nf - \frac{10}{3N}f$
(3, 4)	$\frac{1061N}{54} + \frac{773}{27N} - f$	$\frac{533N}{54} + \frac{593}{27N} + \frac{1}{3}f$
(3, 5)	$-\frac{256}{27} - \frac{116}{27N^2} - 3Nf + \frac{2}{N}f$	$-\frac{244}{27} - \frac{188}{27N^2} - 3Nf + \frac{10}{3N}f$
(3, 6)	$\frac{76N}{27} + \frac{296}{27N} + f$	$\frac{172N}{27} + \frac{260}{27N} - \frac{1}{3}f$
(4, 3)	$\frac{35N}{2} + \frac{31}{N} - \frac{110}{27}f + \frac{86}{27N^2}f$	$\frac{17N}{6} + \frac{113}{3N} - \frac{2}{27}f + \frac{74}{27N^2}f$
(4, 4)	$\frac{44N^2}{3} - \frac{104}{3} - \frac{57}{2N^2} + \frac{38N}{27}f - \frac{14}{27N}f$	$-12 - \frac{57}{2N^2} + \frac{110N}{27}f - \frac{182}{27N}f$
(4, 5)	$-6N + \frac{4}{N} - \frac{128}{27}f - \frac{58}{27N^2}f$	$-6N + \frac{32}{3N} - \frac{56}{27}f + \frac{2}{27N^2}f$
(4, 6)	$2 + \frac{38N}{27}f + \frac{148}{27N}f$	$-\frac{14}{3} + \frac{74N}{27}f - \frac{20}{27N}f$
(5, 3)	$-3Nf + \frac{8}{3N}f$	$-3Nf + \frac{20}{3N}\mathrm{f}$



Physics Letters B 301 (1993) 263–271
North-Holland

PHYSICS LETTERS B

ϵ'/ϵ at the next-to-leading order in QCD and QED

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Received 2 December 1992

Enrico gave extraordinary contributions to all the NLO calculations of the Rome group

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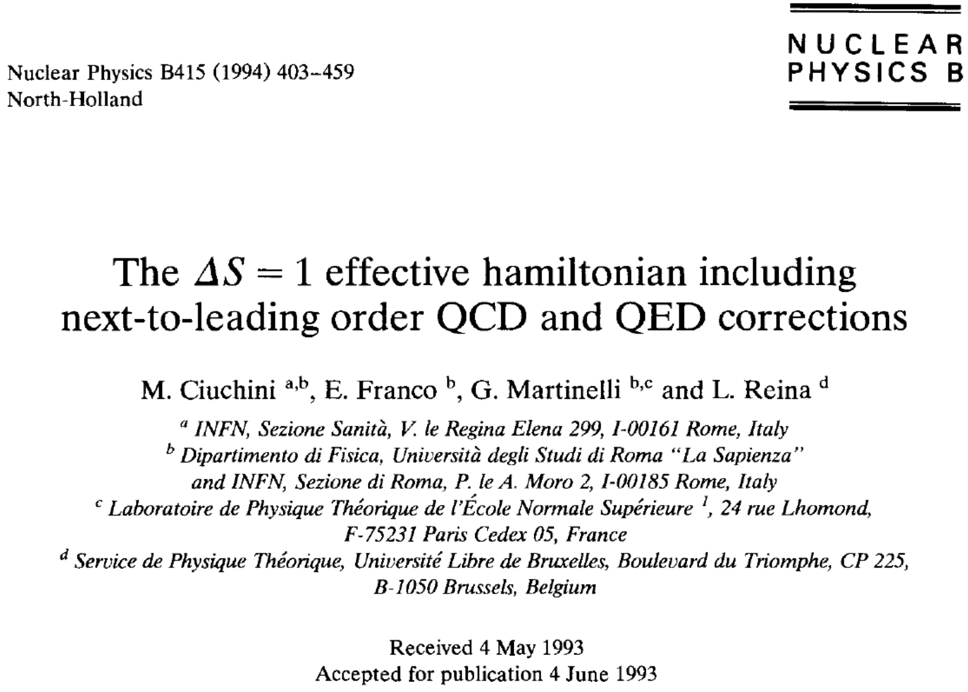

Nuclear Physics B415 (1994) 403–459
North-Holland

NUCLEAR
PHYSICS B

The $\Delta S = 1$ effective hamiltonian including next-to-leading order QCD and QED corrections

M. Ciuchini [a,b], E. Franco [b], G. Martinelli [b,c] and L. Reina [d]

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The story according to some gossips

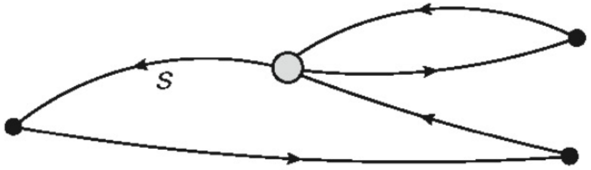
The equations of motions in NDR and HV

Lattice from K-π

Pioneering LQCD attempts to compute the matrix elements by Gavela, Maiani, Martinelli, Pene, Petrarca - Bernard and Soni - Gupta, Kilcup, Sharpe

B -> $\pi\pi$,$K\pi$, etc. No !

Non-leptonic
but only below the inelastic threshold
(may be also 3 body decays)



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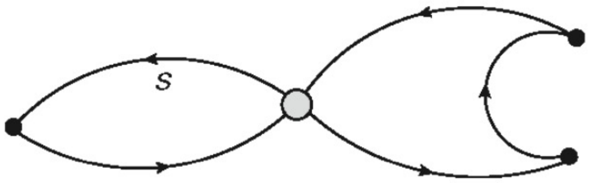
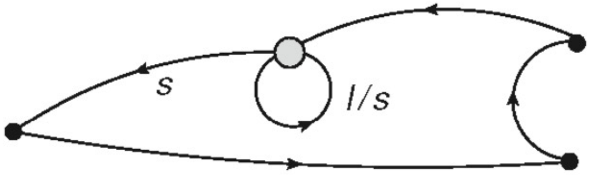
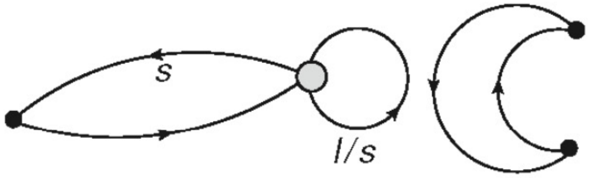


type2



type3

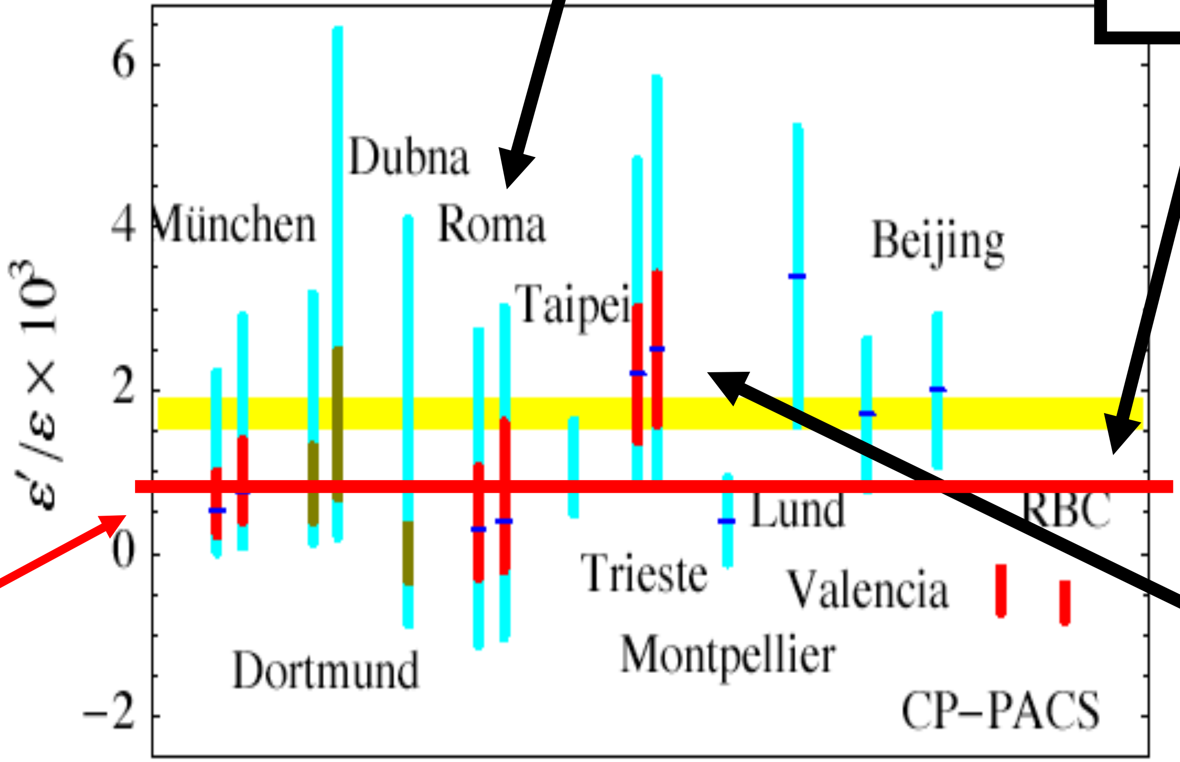


type4

From
S. Bertolini

Lattice $B_6 = 1$

Lattice from K-π



χQM
Trieste

Typical
Prediction
5-8 10^{-4}

Figure 3: Recent theoretical calculations of ε'/ε are compared with the combined 1-σ average of the NA31, E731, KTeV and NA48 results ($\varepsilon'/\varepsilon = 17.2 \pm 1.8 \times 10^{-4}$), depicted by the g horizontal band.

RBC-UK QCD

NEW PHYSICS IN KAON DECAYS?

Soni et al.
-110 10^{-4}!

$$\varepsilon'/\varepsilon = (1.4 \pm 7.0) \cdot 10^{-4}$$

$$\left(\frac{\mathrm{Re}\,A_0}{\mathrm{Re}\,A_2}\right) = 31.0 \pm 6.6$$

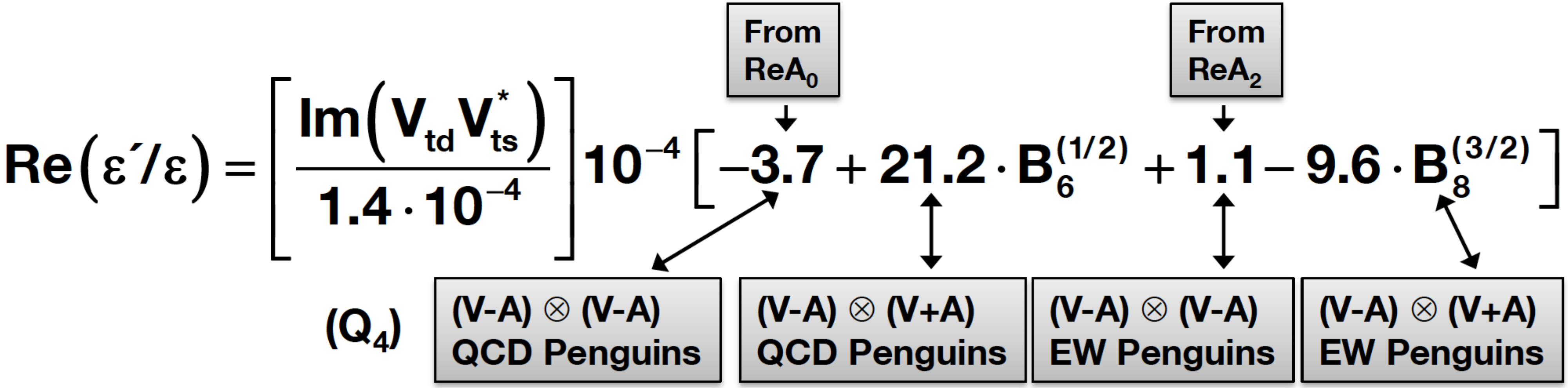
$$(\varepsilon'/\varepsilon)_{\mathrm{exp}} = (16.6 \pm 2.3) \cdot 10^{-4}$$

$$\left(\frac{\mathrm{Re}\,A_0}{\mathrm{Re}\,A_2}\right)_{\mathrm{exp}} = 22.4$$

Courtesy by A. Buras 2015

Four dominant contributions to ε´/ε in the SM

AJB, Jamin, Lautenbacher (1993); AJB, Gorbahn, Jäger, Jamin (2015)



From ReA$_0$

From ReA$_2$

$$\mathrm{Re}\left(\varepsilon'/\varepsilon\right)=\left[\frac{\mathrm{Im}\left(V_{td}V_{ts}^{*}\right)}{1.4\cdot10^{-4}}\right]10^{-4}\left[-3.7+21.2\cdot B_6^{(1/2)}+1.1-9.6\cdot B_8^{(3/2)}\right]$$

(Q$_4$)

(V-A) ⊗ (V-A)
QCD Penguins

(V-A) ⊗ (V+A)
QCD Penguins

(V-A) ⊗ (V-A)
EW Penguins

(V-A) ⊗ (V+A)
EW Penguins

Assumes that ReA$_0$ and ReA$_2$ (ΔI=1/2 Rule) fully described by SM (includes isospin breaking corrections)

ε´/ε from RBC-UKQCD

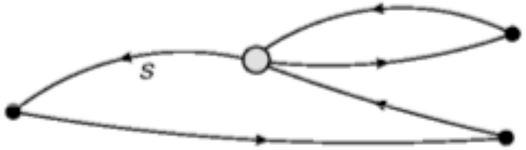
Calculate all contributions directly (no isospin breaking corrections)

$$\left[-\left(6.5\pm3.2\right)+25.3\cdot B_6^{(1/2)}+\left(1.2\pm0.8\right)-10.2\cdot B_8^{(3/2)}\right]$$

$\Delta I = 1/2$ $K \rightarrow \pi\,\pi$

(**Qi Liu**)

- Code 50 different contractions
- For each of 400 configurations invert with source at each of 32 times.
- Use Ran Zhou's deflation code



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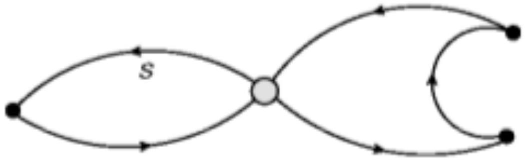
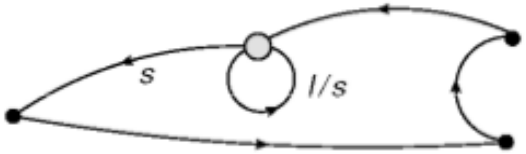


type2



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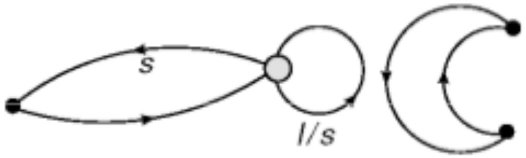
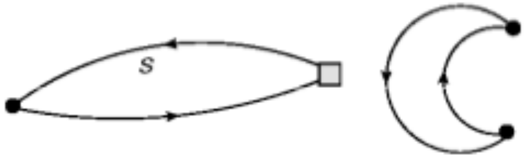


type4

mix3



mix4

Anatomy of ε'/ε – A new flavour anomaly?

AJB, Gorbahn, Jäger, Jamin,, 1507.xxxx

RBC-UKQCD

$$\boxed{\varepsilon'/\varepsilon = (1.4 \pm 7.0) \cdot 10^{-4}}$$

(3.2σ) $\varepsilon'/\varepsilon = (2.2 \pm 3.8) \cdot 10^{-4}$

RBC-QCD values

$B_6^{(1/2)} = 0.57 \pm 0.15$

$B_8^{(3/2)} = 0.76 \pm 0.05$

$\varepsilon'/\varepsilon = (6.3 \pm 2.5) \cdot 10^{-4}$

large N bounds (AJB, Gérard)

$B_6^{(1/2)} = B_8^{(3/2)} = 0.76$

$\varepsilon'/\varepsilon = (9.1 \pm 3.3) \cdot 10^{-4}$

large N bounds (AJB, Gérard)

$B_6^{(1/2)} = B_8^{(3/2)} = 1.0$

exp: $\varepsilon'/\varepsilon = (16.6 \pm 3.3) \cdot 10^{-4}$

Final result for ε’

- Combining our new result for Im(A_0) and our 2015 result for Im(A_2), and again using expt. for the real parts, we find

$$\mathrm{Re}\left(\frac{\varepsilon'}{\varepsilon}\right) = \mathrm{Re}\left\{\frac{i\omega e^{i(\delta_2-\delta_0)}}{\sqrt{2}\varepsilon}\left[\frac{\mathrm{Im}A_2}{\mathrm{Re}A_2} - \frac{\mathrm{Im}A_0}{\mathrm{Re}A_0}\right]\right\}$$

$$= 0.00217(26)(62)(50)$$

IB + EM

stat

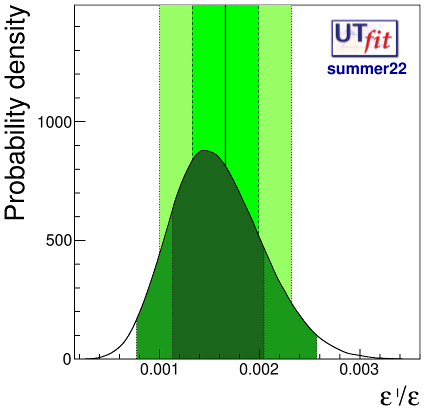
sys

Consistent with experimental result:

$$\mathrm{Re}(\epsilon'/\epsilon)_{\mathrm{expt}} = 0.00166(23)$$

e’/e from RBC (16.7 $x10^{-4}$)

now in Utfit: e’/ e= 15.2(4.7) $x10^{-4}$



A second group should do this calculation!!

The pitfall of the equations of motions
Or
Again with Enrico at NLO
+ Marco, Laura and a newcomer

The pitfall of the equations of motions
Or
Again with Enrico
at NLO
+ Marco, Laura

and a newcomer

Luca Silvestrini

École Normale Supe


Physics Letters B 316 (1993) 127–136
North-Holland

PHYSICS LETTERS B

Scheme independence of the effective Hamiltonian for $b \to s\gamma$ and $b \to sg$ decays

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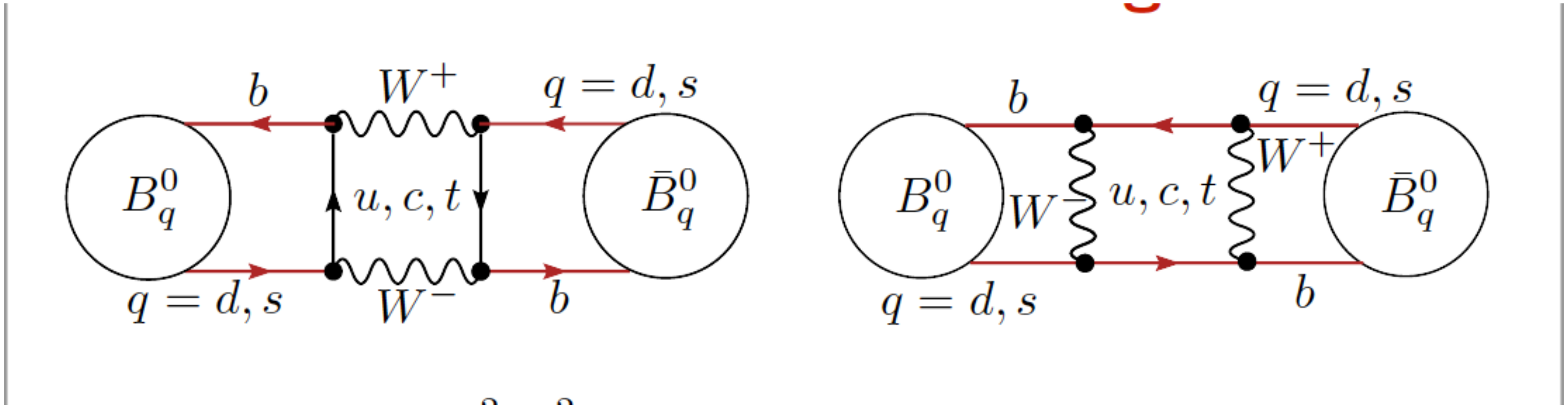
Editor: R. Gatto

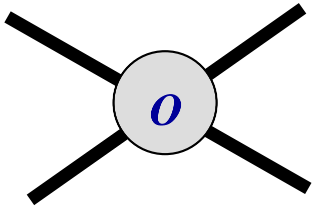
Different groups found different (two-loops) $O(\alpha_s)$ anomalous dimensions working with different regularisation/renormalisation schemes. *The thesis of Luca was to check these calculation and tell us which one was correct.*

The answer was in the scheme dependence of the one-loop $O(\alpha_s^0)$ coefficient functions which changed, insome cases, the equation of motion.

Neutral Meson Mixing $B^0 - \overline{B}^0$



$$H = \begin{pmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{pmatrix}$$



$$H_{eff}^{\Delta B=2} \propto \left(\overline{d}\, \gamma_\mu (1 - \gamma_5)\, b \right)^2$$

CKM

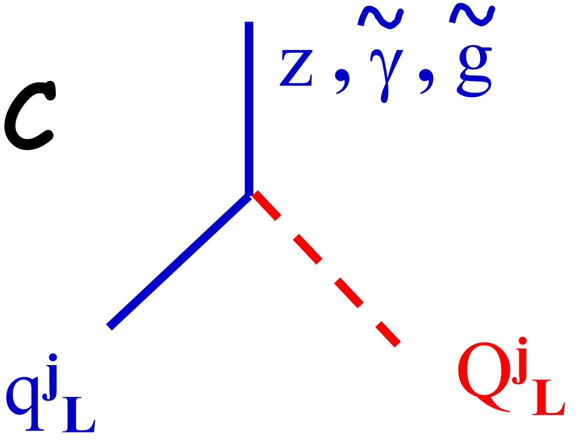
Hadronic matrix element

$$\Delta m_{d,s} = \frac{G_F^2 M_W^2}{16 \pi^2} \, A^2 \lambda^6 \, F_{tt}\left(\frac{m_t^2}{M_W^2}\right) \; < O >$$

In general the mixing mass matrix of the SQuarks (SMM) is not diagonal in flavour space analogously to the quark case We may either

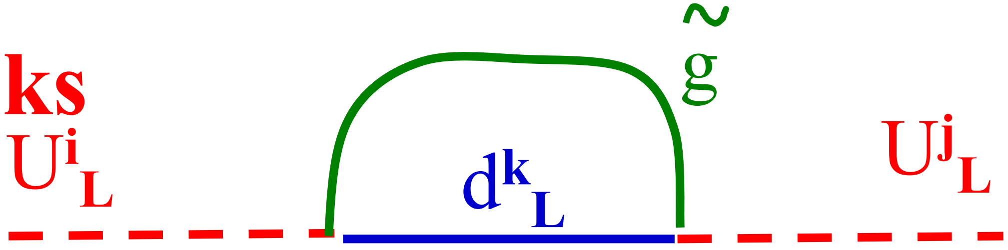
Diagonalize the SMM

FCNC

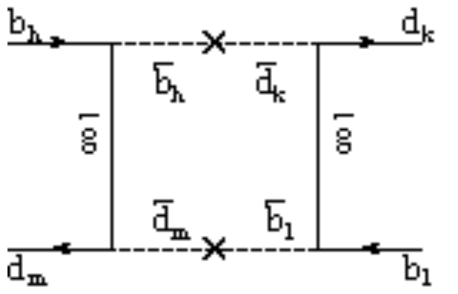


or Rotate by the same matrices the SUSY partners of the u- and d- like quarks

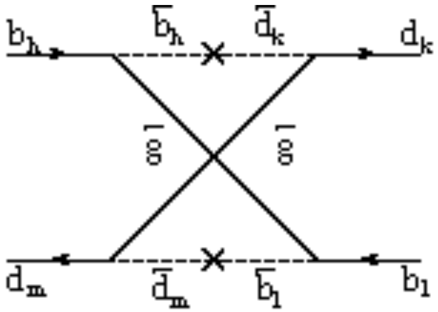
$$(Q^j_L)' = U^{ij}_L Q^j_L$$



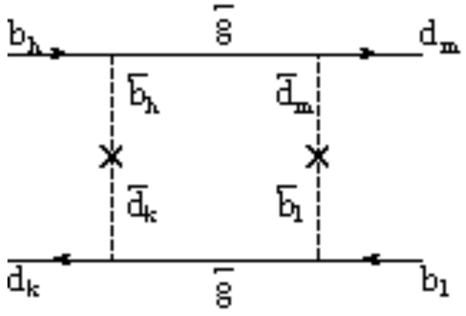
In the latter case the Squark Mass Matrix is not diagonal



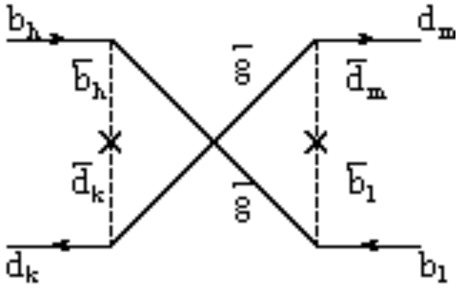
a)



c)



b)



d)

$$(m^2{}_Q)_{ij} = m^2{}_{average}\, 1_{ij} + \Delta m_{ij}{}^2 \qquad \delta_{ij} = \Delta m_{ij}{}^2 / m^2{}_{average}$$

TESTING THE NEW PHYSICS SCALE

Effective Theory Analysis ΔF=2

$$C_j(\Lambda) = \frac{LF_j}{\Lambda^2} \Rightarrow \Lambda = \sqrt{\frac{LF_j}{C_j(\Lambda)}}$$

Effective Hamiltonian in the mixing amplitudes

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \overline{q}^{\alpha}_{L} \gamma_{\mu} b^{\alpha}_{L} \, \overline{q}^{\beta}_{L} \gamma^{\mu} b^{\beta}_{L} \qquad \text{(SM/MFV)}$$

$$Q_2 = \overline{q}^{\alpha}_{R} b^{\alpha}_{L} \, \overline{q}^{\beta}_{R} b^{\beta}_{L} \qquad Q_3 = \overline{q}^{\alpha}_{R} b^{\beta}_{L} \, \overline{q}^{\beta}_{R} b^{\beta}_{L}$$

$$Q_4 = \overline{q}^{\alpha}_{R} b^{\alpha}_{L} \, \overline{q}^{\beta}_{L} b^{\beta}_{R} \qquad Q_5 = \overline{q}^{\alpha}_{R} b^{\beta}_{L} \, \overline{q}^{\beta}_{L} b^{\beta}_{R}$$

$$\tilde{Q}_1 = \overline{q}^{\alpha}_{R} \gamma_{\mu} b^{\alpha}_{R} \, \overline{q}^{\beta}_{R} \gamma^{\mu} b^{\beta}_{R}$$

$$\tilde{Q}_2 = \overline{q}^{\alpha}_{L} b^{\alpha}_{R} \, \overline{q}^{\beta}_{L} b^{\beta}_{R} \qquad \tilde{Q}_3 = \overline{q}^{\alpha}_{L} b^{\beta}_{R} \, \overline{q}^{\beta}_{L} b^{\beta}_{R}$$

C(Λ) coefficients are extracted from data

L is loop factor and should be :
L=1 tree/strong int. NP
L=α^2_s or α^2_W for strong/weak perturb. NP

$F_1=F_{SM}=(V_{tq}V_{tb}{}^*)^2$ **$F_{j=1}=0$**	**MFV**
$\lvert F_j \rvert = F_{SM}$ **arbitrary phases**	**NMFV**
$\lvert F_j \rvert = 1$ **arbitrary phases**	**Flavour generic**

Next-to-leading order QCD corrections to $\Delta F = 2$ effective hamiltonians

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Received 26 November 1997; accepted 5 February 1998

(2) *The B_s–$\bar{B}_s$ width difference $\Delta\Gamma_{B_s}$.*

At lowest order in $1/m_b$, by using the OPE, the width difference $\Delta\Gamma_{B_s}$ can be written in terms of two $\Delta B = 2$ operators [4]

$$\begin{aligned} Q &= \bar{b}\gamma_\mu(1-\gamma_5)s\ \bar{b}\gamma_\mu(1-\gamma_5)s\,,\\ Q_S &= \bar{b}(1-\gamma_5)s\ \bar{b}(1-\gamma_5)s\,. \end{aligned} \tag{3}$$

(3) *Heavy-hadrons lifetimes (τ_B, τ_{B_s}, τ_{Λ_b}).*

In this case, the $1/m_b^3$ corrections to the lifetime, due to Pauli interference and W-exchange, can be written in terms of four operators [5]

$$\begin{aligned} O^q_{V-A} &= \bar{b}\gamma_\mu(1-\gamma_5)q\ \bar{q}\gamma^\mu(1-\gamma_5)b\,,\\ O^q_{S-P} &= \bar{b}(1-\gamma_5)q\ \bar{q}(1+\gamma_5)b\,,\\ T^q_{V-A} &= \bar{b}t^A\gamma_\mu(1-\gamma_5)q\ \bar{q}t^A\gamma^\mu(1-\gamma_5)b\,,\\ T^q_{S-P} &= \bar{b}t^A(1-\gamma_5)q\ \bar{q}t^A(1+\gamma_5)b\,, \end{aligned} \tag{4}$$

ΔM_K and ε_K in SUSY at the Next-to-Leading order

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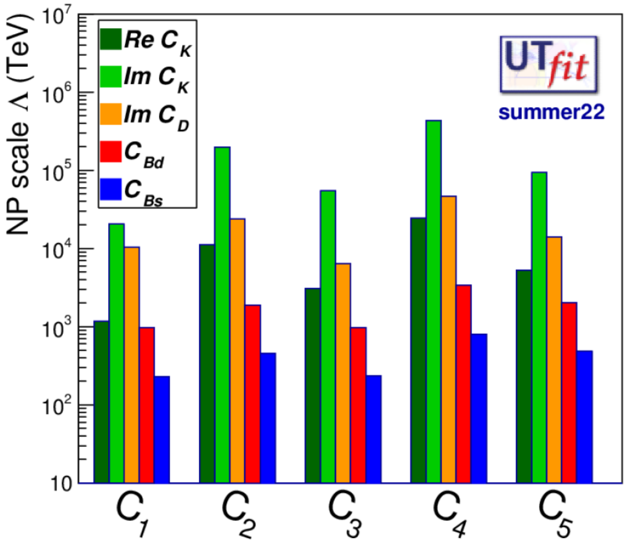
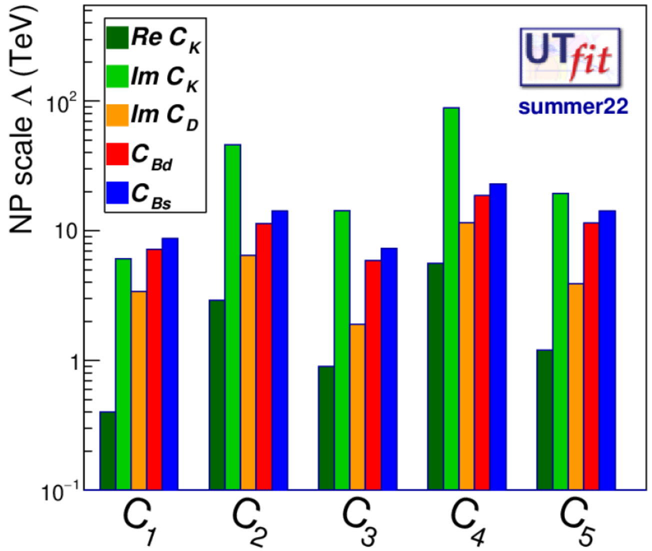
Beyond the SM

results from the Wilson coefficients

Generic: $C(\Lambda) = \alpha/\Lambda^2$,
F_i~1, arbitrary phase
α ~ 1 for strongly coupled NP

NMFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$,
F_i~$|F_{SM}|$, arbitrary phase





$\Lambda > 4.4\ 10^5$ TeV

Lower bounds on NP scale
(at 95% prob.)

$\Lambda > 95$ TeV

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

$\Lambda > 1.3\ 10^4$ TeV

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

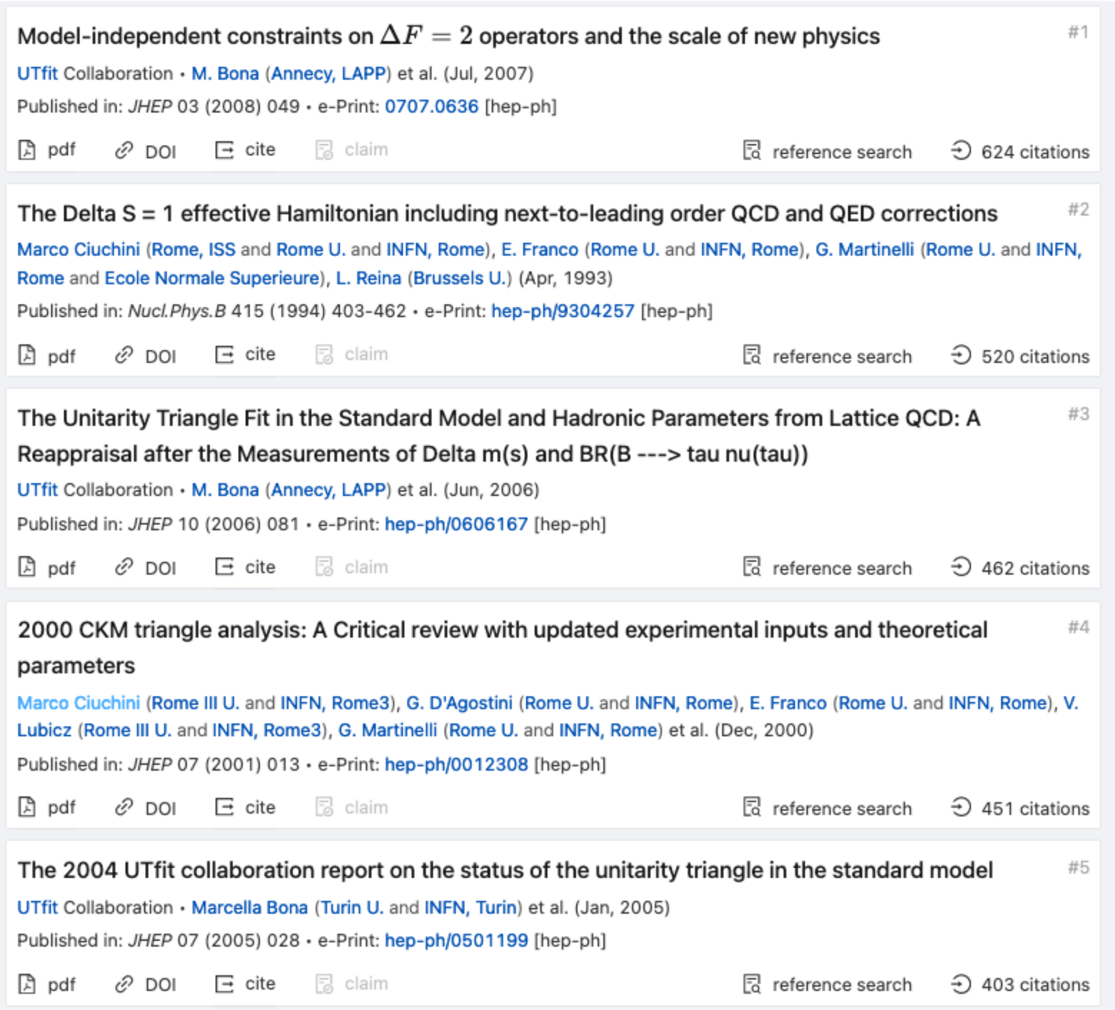
$\Lambda > 2.9$ TeV

for lower bound for loop-mediated contributions, simply multiply by α_s (~ 0.1) or by α_W (~ 0.03).

Enrico & Guido (questo lo leggete voi perché io mi commuovo troppo):

Caro Enrico il nostro è stato un lungo viaggio insieme

1) *Abbiamo collaborato per 35 anni*
2) *Scritto 71 pubblicazioni di cui 39 su riviste internazionali con referee*
3) *Ottenuto una media di 166,7 citazioni per pubblicazione*



Model-independent constraints on $\Delta F = 2$ operators and the scale of new physics #1
UTfit Collaboration • M. Bona (Annecy, LAPP) et al. (Jul, 2007)
Published in: *JHEP* 03 (2008) 049 • e-Print: 0707.0636 [hep-ph]
pdf DOI cite claim reference search 624 citations

The Delta S = 1 effective Hamiltonian including next-to-leading order QCD and QED corrections #2
Marco Ciuchini (Rome, ISS and Rome U. and INFN, Rome), E. Franco (Rome U. and INFN, Rome), G. Martinelli (Rome U. and INFN, Rome and Ecole Normale Superieure), L. Reina (Brussels U.) (Apr, 1993)
Published in: *Nucl.Phys.B* 415 (1994) 403-462 • e-Print: hep-ph/9304257 [hep-ph]
pdf DOI cite claim reference search 520 citations

The Unitarity Triangle Fit in the Standard Model and Hadronic Parameters from Lattice QCD: A Reappraisal after the Measurements of Delta m(s) and BR(B ---> tau nu(tau)) #3
UTfit Collaboration • M. Bona (Annecy, LAPP) et al. (Jun, 2006)
Published in: *JHEP* 10 (2006) 081 • e-Print: hep-ph/0606167 [hep-ph]
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2000 CKM triangle analysis: A Critical review with updated experimental inputs and theoretical parameters #4
Marco Ciuchini (Rome III U. and INFN, Rome3), G. D'Agostini (Rome U. and INFN, Rome), E. Franco (Rome U. and INFN, Rome), V. Lubicz (Rome III U. and INFN, Rome3), G. Martinelli (Rome U. and INFN, Rome) et al. (Dec, 2000)
Published in: *JHEP* 07 (2001) 013 • e-Print: hep-ph/0012308 [hep-ph]
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The 2004 UTfit collaboration report on the status of the unitarity triangle in the standard model #5
UTfit Collaboration • Marcella Bona (Turin U. and INFN, Turin) et al. (Jan, 2005)
Published in: *JHEP* 07 (2005) 028 • e-Print: hep-ph/0501199 [hep-ph]
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Grazie per tutto quanto ci hai dato
e che porteremo per sempre con noi