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Workshop on the original of P, CP and T Violation

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New Dipole Penguin & CP-Violating Ratio e'/e

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New Dipole Penguin
&
CP-Violating Ratio ε'/ε

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The contents:

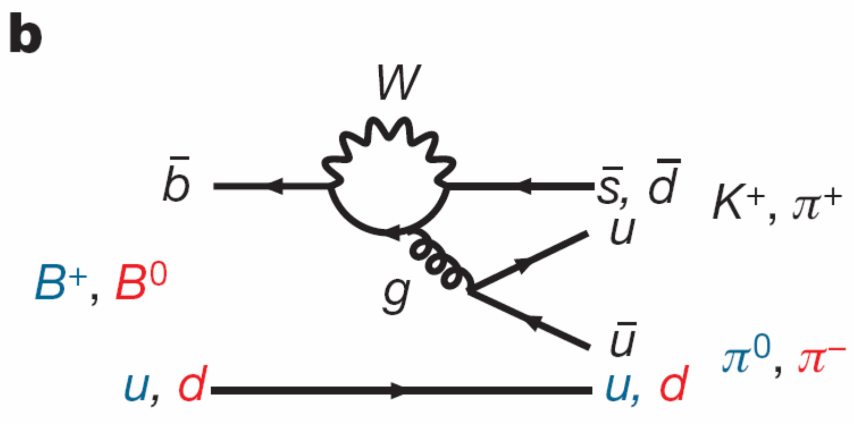
1. On the Direct CPV
   - Old & New

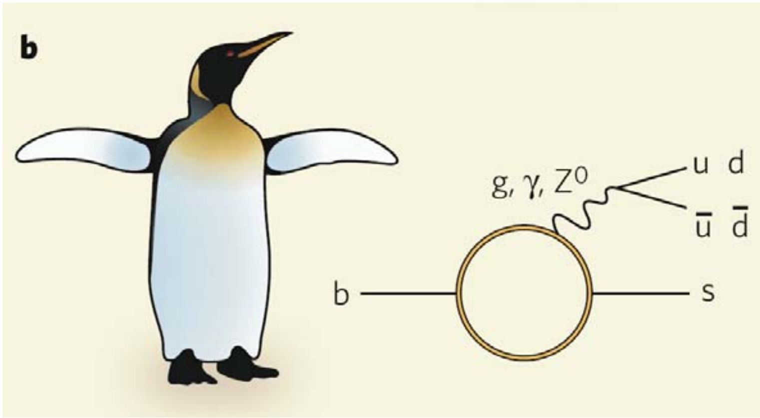
2. On Penguin Operators
   - Old & New

3. On CP-Violating Ratio ε'/ε
   - Old & New

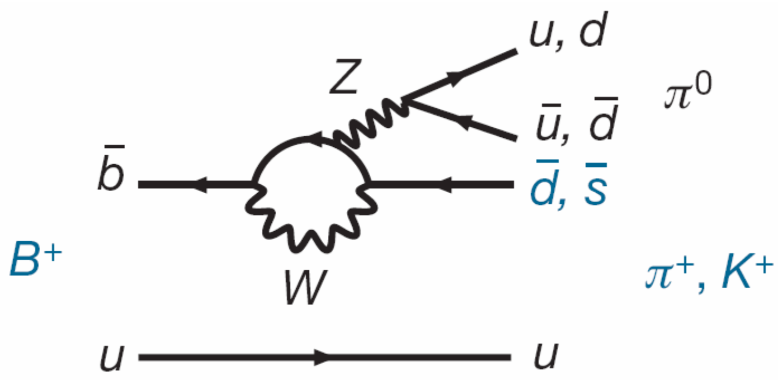
2nd Coming of Direct CPV

- "Song" of Penguins in B decays[Nature'08]





- The Electroweak Penguin can make the Difference



Difference in direct charge-parity violation (CPV) between charged and neutral B meson decays

[The Belle Collab.] Nature 452 (2008) 332

$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01,$$

$$\mathcal{A}_{\pi^\pm\pi^0} = +0.07 \pm 0.06 \pm 0.01.$$

$$\mathcal{A}_{K^\pm\pi^\mp} \equiv \frac{N(\bar{B}^0 \to K^-\pi^+) - N(B^0 - K^+\pi^-)}{N(\bar{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.094 \pm 0.018 \pm 0.008$$

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037$$

established at the 4.4σ level;

1st Direct (amplitude) CPV in K->ππ (NA48 & KTeV 1999)

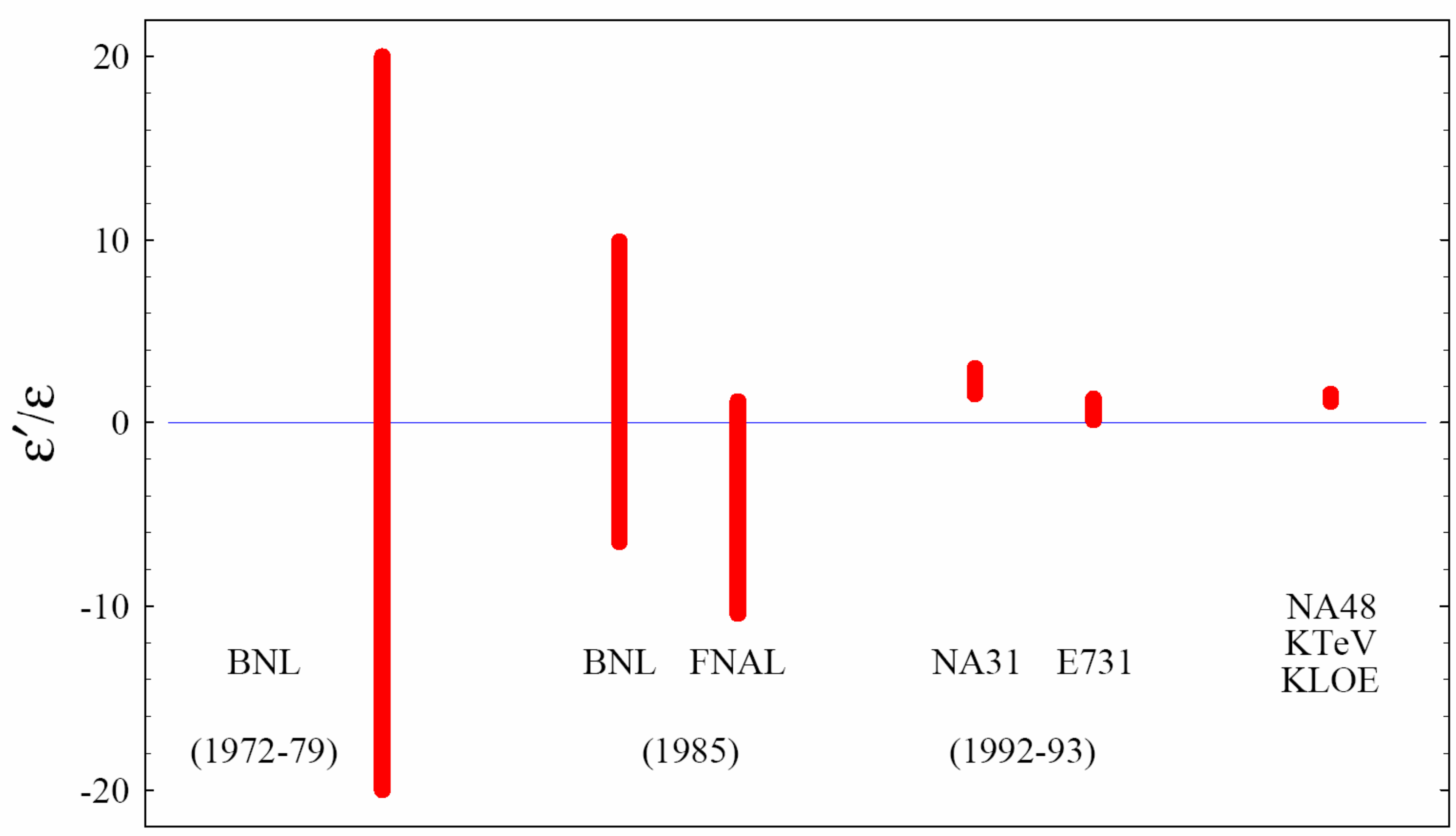
$$\mathrm{Re}\,(\varepsilon'/\varepsilon) = (16.7 \pm 1.6) \cdot 10^{-4}$$

$$\frac{\varepsilon'}{\varepsilon} = e^{i\Phi} \frac{\omega}{\sqrt{2}\,|\varepsilon|} \left[\frac{\mathrm{Im}A_2}{\mathrm{Re}A_2} - \frac{\mathrm{Im}A_0}{\mathrm{Re}A_0} \right]$$

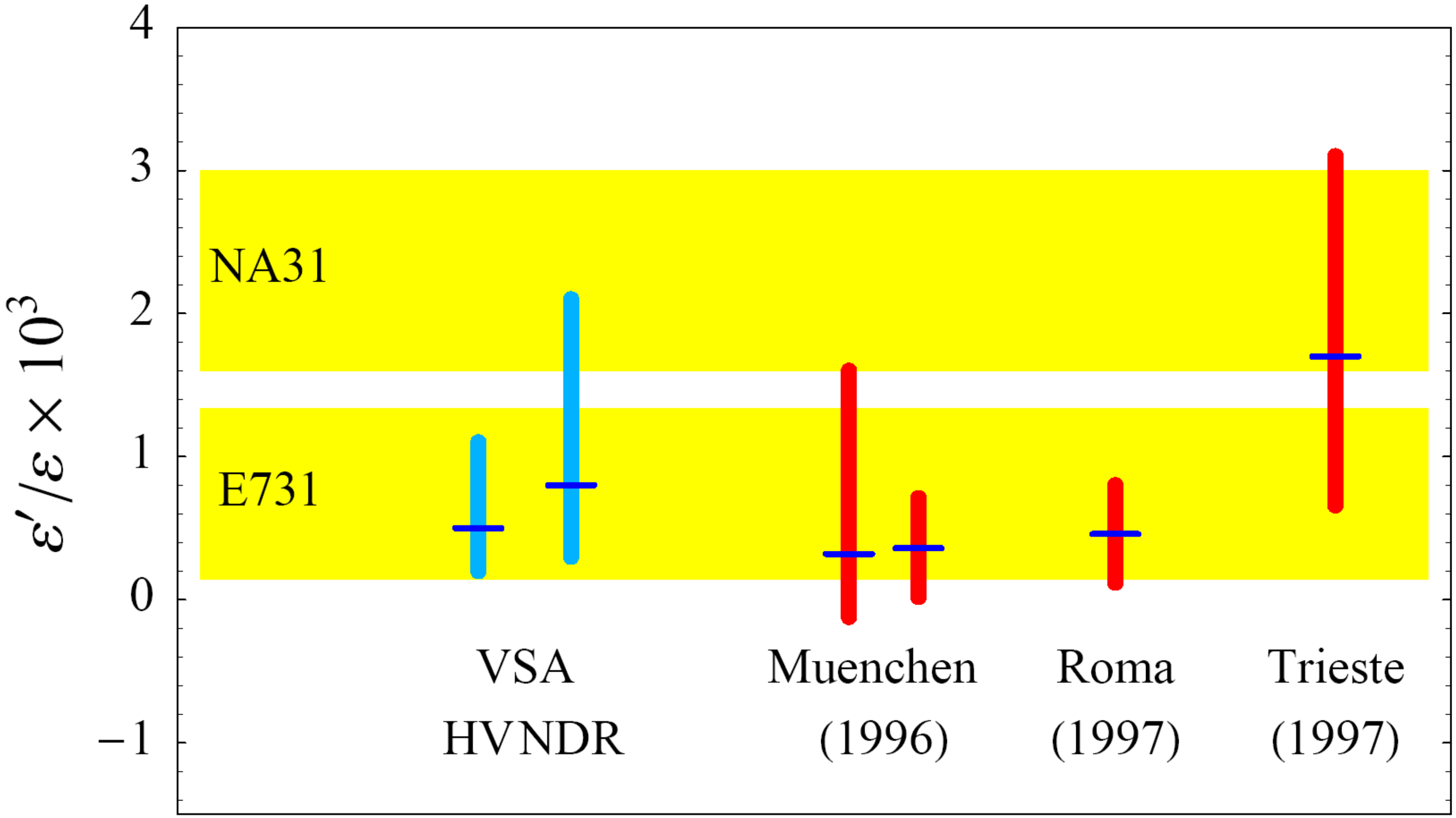
$$\omega = \mathrm{Re}A_2/\mathrm{Re}A_0 \approx 1/22$$

$$\Phi \approx \delta_2 - \delta_0 + \pi/4 \approx 0$$

1999 as a decisive year for direct CPV (35 years after the measurement of indirect CPV) – in units 10^-3



Predictions in pre-'99 era w.r.t.the VSA estimate in two renormalization schemes [S.Bertolini, hep-ph/0206095]



The Standard OPE approach

$$\mathcal{H}_{\Delta S=1} = \frac{G_{\rm F}}{\sqrt{2}} V_{ud}\, V^*_{us} \sum_i \Big[z_i(\mu) + \tau\ y_i(\mu) \Big] Q_i(\mu)$$

For $\mu < m_c$ $\qquad\qquad$ $\tau = -V_{td}V^*_{ts}/V_{ud}V^*_{us}$

$$\left.\begin{aligned} Q_1 &= (\overline{s}_\alpha u_\beta)_{\rm V-A}\, (\overline{u}_\beta d_\alpha)_{\rm V-A} \\ Q_2 &= (\overline{s} u)_{\rm V-A}\, (\overline{u} d)_{\rm V-A} \end{aligned}\right\} \quad \text{Current-Current}$$

$$\left.\begin{aligned} Q_{3,5} &= (\overline{s} d)_{\rm V-A} \textstyle\sum_q (\overline{q} q)_{\rm V\mp A} \\ Q_{4,6} &= (\overline{s}_\alpha d_\beta)_{\rm V-A} \textstyle\sum_q (\overline{q}_\beta q_\alpha)_{\rm V\mp A} \end{aligned}\right\} \quad \text{Gluon “penguins”}$$

$$\left.\begin{aligned} Q_{7,9} &= \tfrac{3}{2}\, (\overline{s} d)_{\rm V-A} \textstyle\sum_q \hat{e}_q\, (\overline{q} q)_{\rm V\pm A} \\ Q_{8,10} &= \tfrac{3}{2}\, (\overline{s}_\alpha d_\beta)_{\rm V-A} \textstyle\sum_q \hat{e}_q (\overline{q}_\beta q_\alpha)_{\rm V\pm A} \end{aligned}\right\} \quad \text{Electroweak “penguins”}$$

Munich-Rome

- [A.Pich, hep-ph/0410215]

$$\mathcal{L}_{\rm eff}^{\Delta S=1} = -\frac{G_F}{\sqrt{2}} V_{ud} V_{us}^* \sum_{i=1}^{10} C_i(\mu)\, Q_i(\mu)$$

$$\mathcal{L}_2^{\Delta S=1} = G_8\, \mathcal{L}_8 + G_{27}\, \mathcal{L}_{27} + G_{\rm ew}\, \mathcal{L}_{\rm ew}$$

Scale	Fields	Eff. Theory
M_W	W, Z, γ, g τ, μ, e, ν_i t, b, c, s, d, u	Standard Model
	$\downarrow$ OPE	
$\lesssim m_c$	$\gamma, g\,;\, \mu, e, \nu_i$ s, d, u	$\mathcal{L}_{\rm QCD}^{n_f=3}$, $\mathcal{L}_{\rm eff}^{\Delta S=1,2}$
	$\downarrow$ $N_C \to \infty$	
M_K	$\gamma\,;\, \mu, e, \nu_i$ π, K, η	χPT

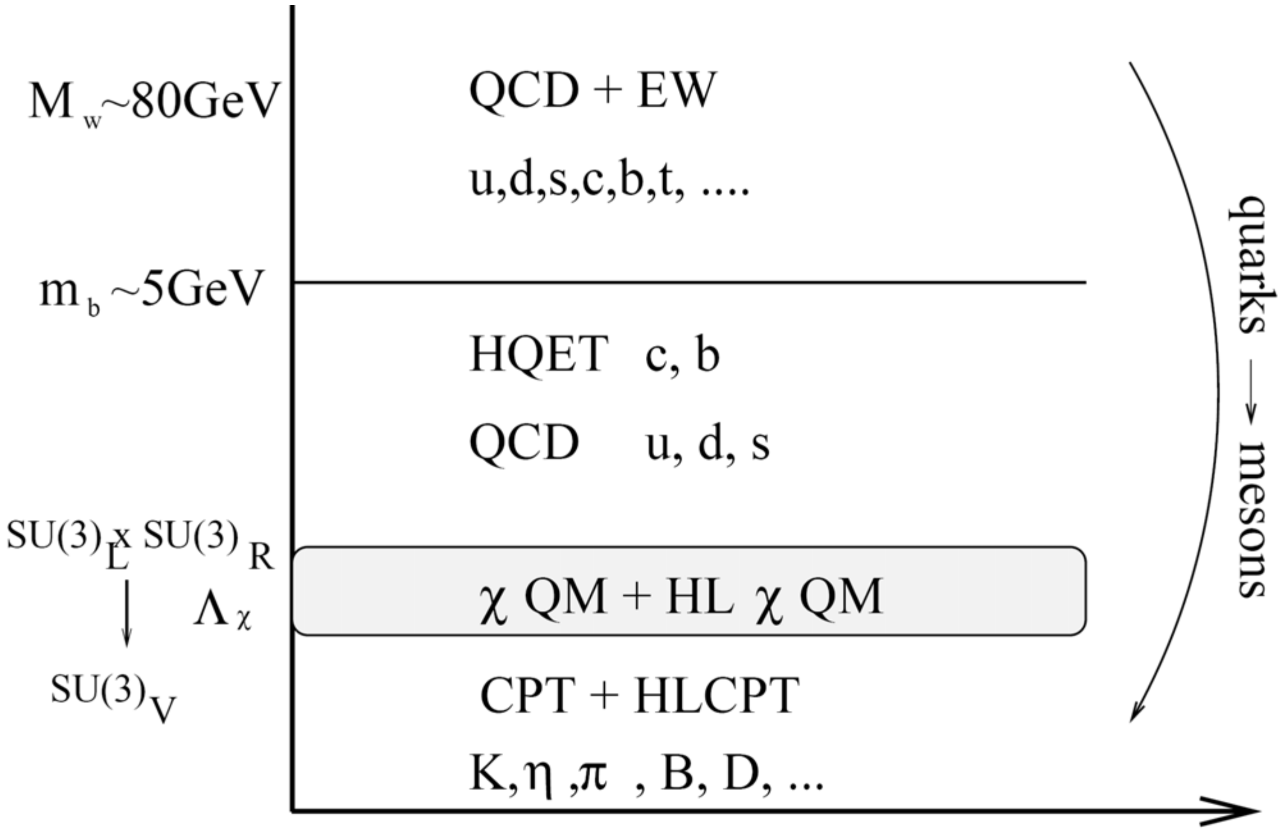
- By employing **Chiral Perturbation Theory,** pion loops enhance the A_0 amplitude
- **Updated** SM prediction by Munich and Rome

$$\mathrm{Re}\,(\varepsilon'/\varepsilon) = \left(19 \pm 2\,{}^{+9}_{-6} \pm 6\right) \cdot 10^{-4}$$

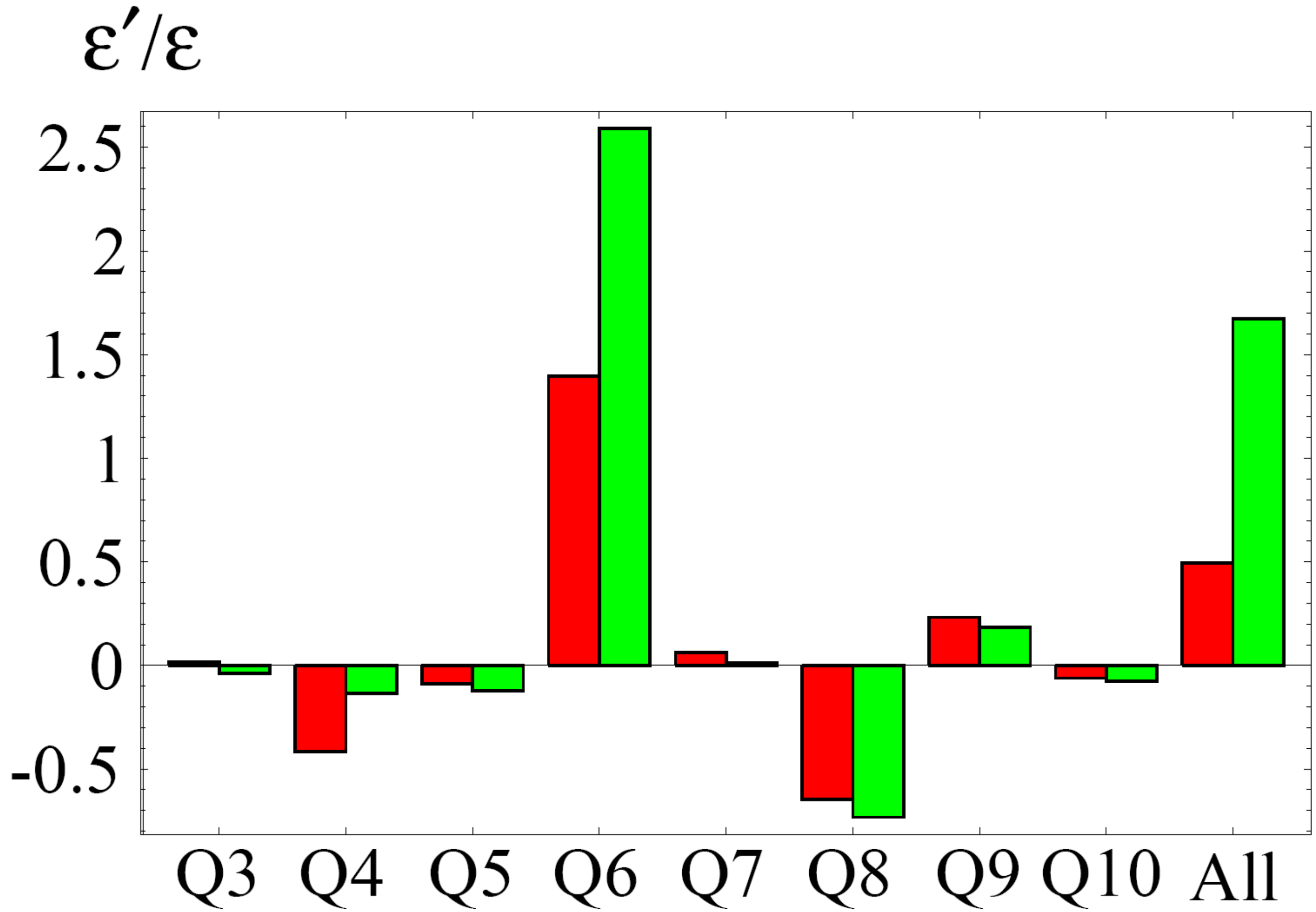
Trieste-Oslo (before '99)

employing the Chiral Quark Model

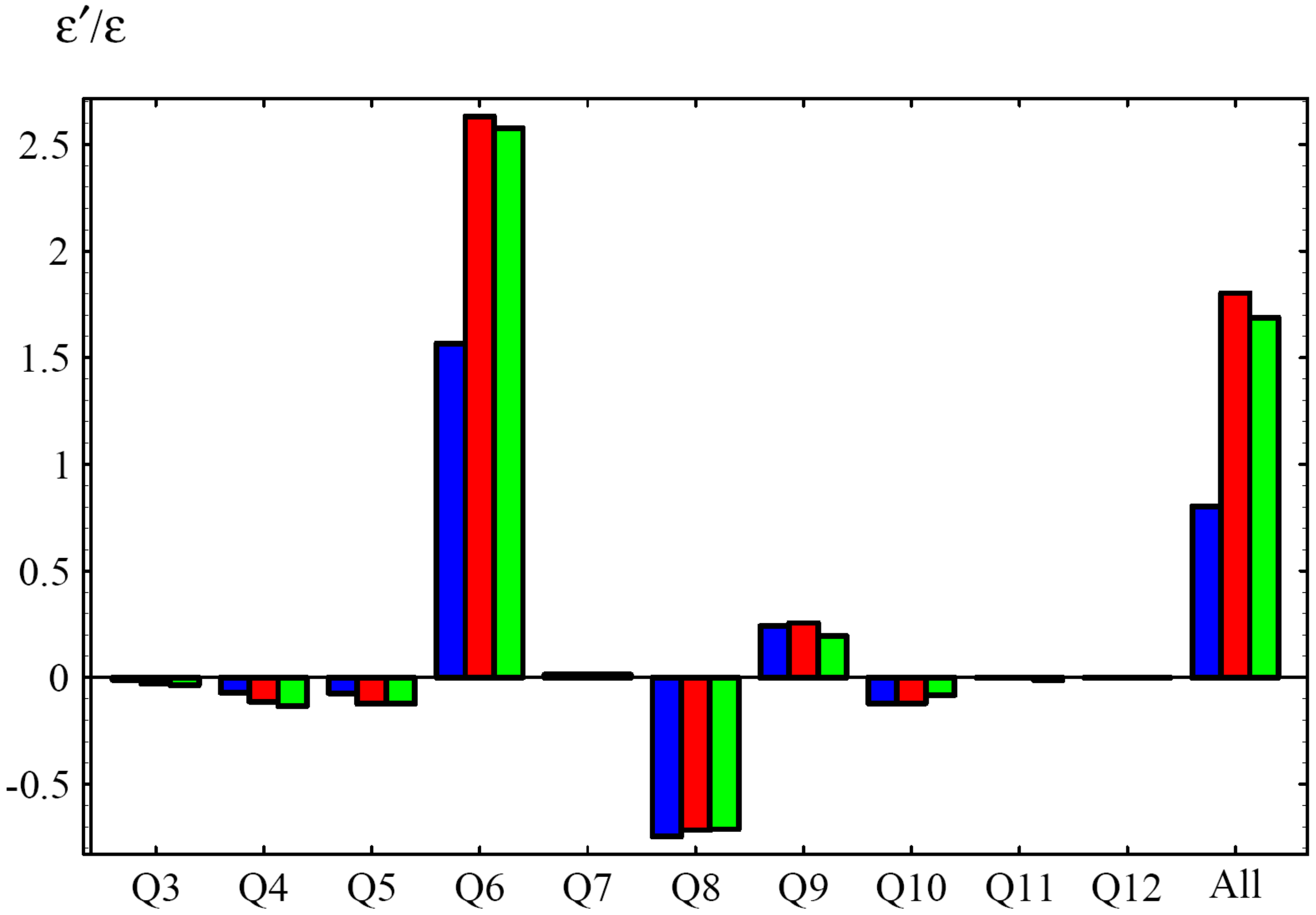
- ME for all OP's within a single framework
- Makes off-shellness calculable (Lamb-shift type eff. For QCD)



Comparison of pre-99 predictions: Munich vs Trieste - in units 10^-3

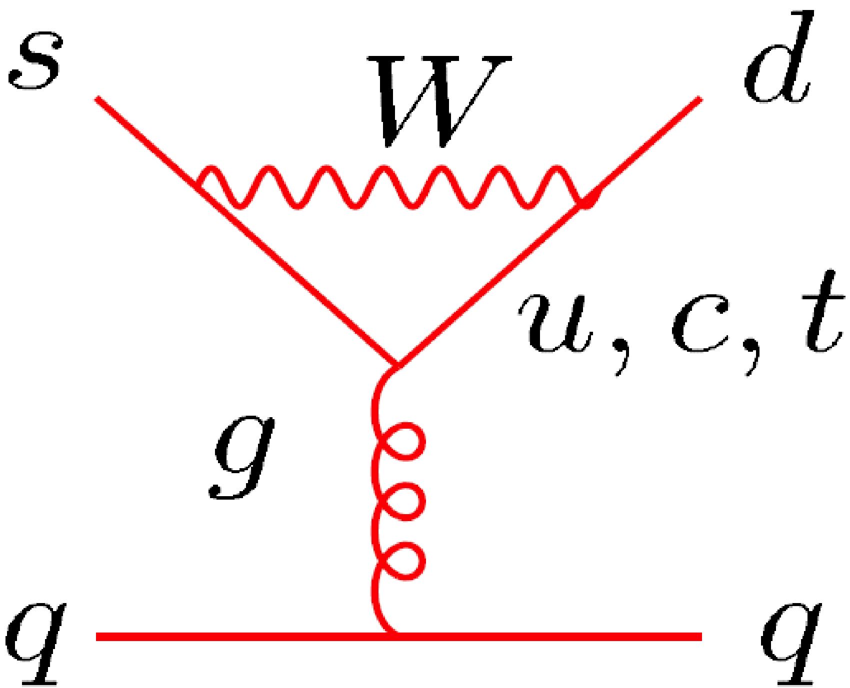


LO/chiral-loop corrected / full O(p^4) Trieste-Oslo – in units 10^-3



Decisive Q6 and Q8 Penguin Operators

QCD Penguin Operators



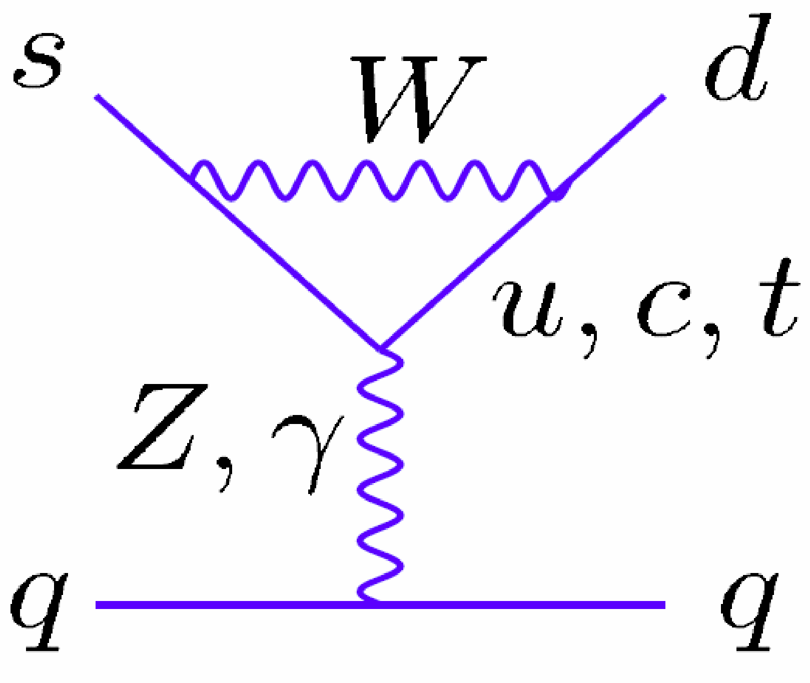
$$Q_3 = (\bar{s}_i d_i)_{V-A} \sum_q (\bar{q}_j q_j)_{V-A}$$

$$Q_4 = (\bar{s}_i d_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V-A}$$

$$Q_5 = (\bar{s}_i d_i)_{V-A} \sum_q (\bar{q}_j q_j)_{V+A}$$

$$Q_6 = (\bar{s}_i d_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V+A}$$

Electroweak Penguin Operators



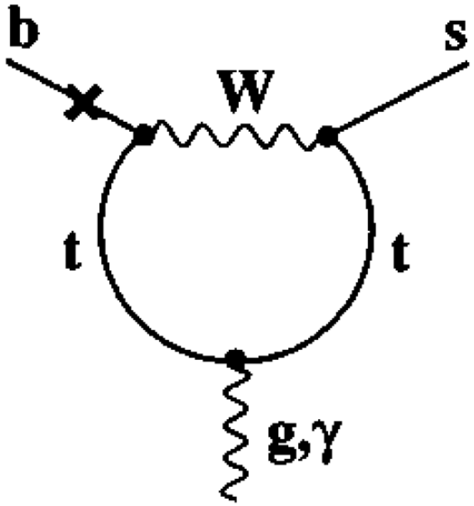
$$Q_7 = \frac{3}{2}(\bar{s}_i d_i)_{V-A} \sum_q e_q (\bar{q}_j q_j)_{V+A}$$

$$Q_8 = \frac{3}{2}(\bar{s}_i d_j)_{V-A} \sum_q e_q (\bar{q}_j q_i)_{V+A}$$

$$Q_9 = \frac{3}{2}(\bar{s}_i d_i)_{V-A} \sum_q e_q (\bar{q}_j q_j)_{V-A}$$

$$Q_{10} = \frac{3}{2}(\bar{s}_i d_j)_{V-A} \sum_q e_q (\bar{q}_j q_i)_{V-A}$$

Magnetic Penguin Operators



-from mass insertion on the external b-quark line

$$Q_{12} \equiv Q_{7\gamma} = \frac{e}{8\pi^2} m_b \bar{s}_i \sigma^{\mu\nu}(1+\gamma_5) b_i F_{\mu\nu},$$

$$Q_{11} \equiv Q_{8G} = \frac{g}{8\pi^2} m_b \bar{s}_i \sigma^{\mu\nu}(1+\gamma_5) T^a_{ij} b_j G^a_{\mu\nu}$$

New Dipole Penguin Operator Q_G (partner to Q_{11}) corresponding to off-shell external quarks

$$\mathcal{L}(s \to dG) \; = \; B\,\epsilon^{\mu\nu\lambda\rho}\, t^a\, G^a_{\mu\nu}\, (\bar{d}_L \; i \; \overleftrightarrow{D}_\lambda \; \gamma_\rho s_L)$$

$$\mathcal{L}(s \to dG) \; = \; \mathcal{L}_G + \mathcal{L}_\sigma$$

$$\mathcal{L}_G = C_G\, Q_G \quad ; \; \mathcal{L}_\sigma = C_{11}\, Q_{11}$$

$$Q_G \; = \; \frac{g_s}{8\pi^2}\bar{d}\left[(i\gamma\cdot D - m_d)\,\sigma\cdot GL \,+\, \sigma\cdot GR(i\gamma\cdot D - m_s)\right]s \,+\, h.c.$$

$$Q_{11} \; = \; \frac{g_s}{8\pi^2}\bar{d}\left[m_s\, R + m_d\, L\right]\,\sigma\cdot G\; s \,+\, h.c. \qquad \sigma\,\cdot\, G \;\equiv\; \sigma^{\mu\nu}\, G^a_{\mu\nu} t^a$$

Additional contributions to ε'/ε – refer to more complete

$$\mathcal{L}_W = \mathcal{L}_{4q} + \mathcal{L}_\sigma + \mathcal{L}_G + \mathcal{L}_{sd}^R$$

$\mathcal{L}_\sigma$

- Chromomagnetic Penguin Q11 contribution considered by Bertolini et al. 1994

$\mathcal{L}_{sd}^R$

- Off-shell, off-diagonal self energy by Bergan & Eeg 1997

$\mathcal{L}_G$

- Off-shell Dipole Penguin QG by Eeg, Kumerički & Π /0803.2106

The Wilson cofficients for selected operators in

$$\mathcal{L}_W = \sum_i C_i(\mu)\, Q_i(\mu)$$

$$C_i(\mu) = -\frac{G_F}{\sqrt{2}}\left[\lambda_u\, z_i(\mu) - \lambda_t\, y_i(\mu)\right]$$

- **CPC(z) & CPV(y)-parts, Qn (n=6,11,G)**

	Q_6	Q_{11}	Q_G
$z(\mu = 1\,\mathrm{GeV})$	-0.009	-0.033	-0.035
$y(\mu = m_c)$	-0.083	-0.318	-0.407

Bosonization in Chiral Quark Model $\mathcal{L}_{QCD} \to \mathcal{L}_{QCD\chi} = \mathcal{L}_{QCD} + \mathcal{L}_{\chi}$

- Chiral-symmetry breaking by adding a nonperturbative term

$$\mathcal{L}_{\chi} = -m(\overline{q_L}\,\Sigma^{\dagger}\,q_R + \overline{q_R}\,\Sigma\,q_L)$$

$$\Sigma = exp(i\sum \lambda^a \pi^a / f_{\pi})$$

- in addition to fermionic QCD term

$$\mathcal{L}_f(q) = \bar{q}(i\gamma \cdot D - \mathcal{M}_q)q$$

$$\mathcal{M}_q = \mathrm{diag}\,(m_u, m_d, m_s)$$

Off-shell part transformed away by EOM/field redefinition

$$d' = d + B\sigma\cdot GLs - \frac{1}{2}A(i\gamma\cdot DR + M_R R + M_L L)(i\gamma\cdot D - m_s)s$$

$$s' = s + B^*\sigma\cdot GLd - \frac{1}{2}A^*(i\gamma\cdot DR + M_R L + M_L R)(i\gamma\cdot D - m_s)d$$

- \- absorbed into fermionic term

$$\mathcal{L}_f(q) + \mathcal{L}_G + \mathcal{L}_{ds}^R = \mathcal{L}_f(q')$$

- \- reappears in nonpert. term

$$\mathcal{L}_\chi(q) = \mathcal{L}_\chi(q') + \Delta\mathcal{L}_\chi(q') + O(G_F^2)$$

ΔL for the dipole operator QG

$$\Delta\mathcal{L}_\chi(q')_G = m\,\frac{C_G}{8\pi^2}\left(\overline{q'}_L\,\lambda_-\,\sigma\cdot G\,\Sigma\,q'_R + \overline{q'}_R\,\Sigma^\dagger\sigma\cdot G\,\lambda_-^\dagger\,q'_L\right)$$

$$\lambda_- = (\lambda_6 - i\,\lambda_7)/2$$

- Employing the flavour rotation

$$q_L \to \chi_L = \xi q_L \quad \text{and} \quad q_R \to \chi_R = \xi^\dagger q_R$$

$$\text{where } \xi\cdot\xi = \Sigma$$

- the term suitable for bosonization in terms of quark loops

$$\Delta\mathcal{L}_\chi(q')_G = m\,\frac{C_G}{8\pi^2}\,\overline{\chi'}\,F_{(-)}\sigma\cdot G\chi' + h.c.$$

$$F_{(-)} = \xi\,\lambda_-\xi^\dagger$$

The dipole operator Q11

in chiral SU(3) invariant form

$$Q_{11} \;=\; \frac{g_s}{8\pi^2}\left[\overline{q}_R\,\mathcal{M}_q\lambda_-\;\sigma\cdot G\,q_L\;+\;\overline{q}_L\;\;\sigma\cdot G\;\lambda_-\mathcal{M}_q^\dagger\,q_R\right]$$

- after flavour rotation

$$Q_{11} \;=\; \frac{g_s}{8\pi^2}\,\overline{\chi}\left[F^V_{(-)}\;+\;F^A_{(-)}\,\gamma_5\right]\sigma\cdot G\,\chi \qquad F^{V,A}_{(-)} = \left(F^R_{(-)} \pm F^L_{(-)}\right)/2$$

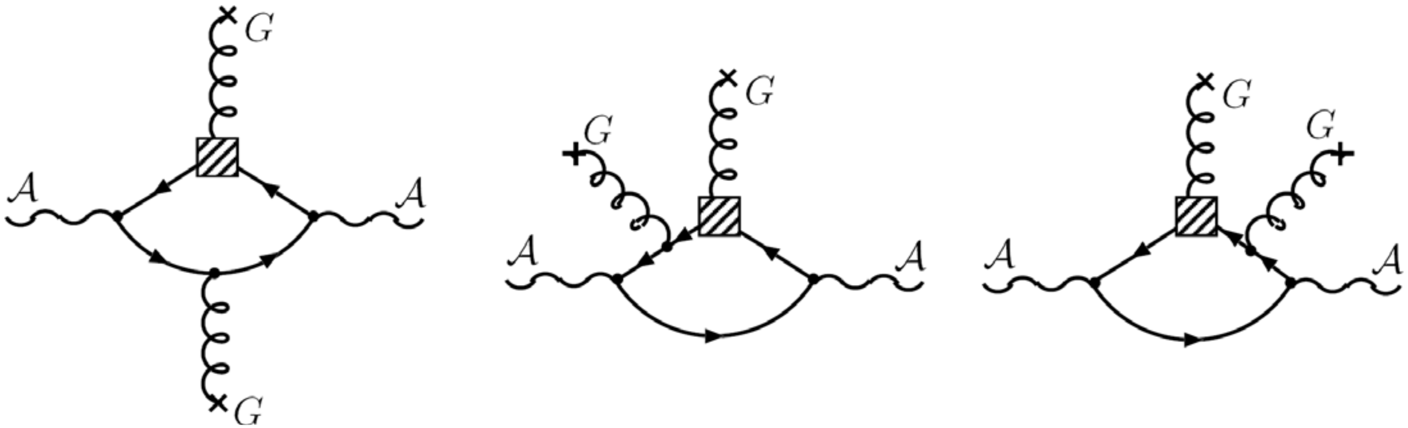
in terms of $\quad F^L_{(-)} \;=\; \xi^\dagger\,\mathcal{M}_q\lambda_-\xi^\dagger\,, \qquad$ and $\qquad F^R_{(-)} \;=\; \xi\,\lambda_-\mathcal{M}_q^\dagger\,\xi$

- understood in terms of a quark loop, corresponding to

$$\mathcal{L}^{(4)}(Q_{11}) \;\sim\; \mathrm{Tr}\;\left[F^V_{(-)}\mathcal{A}_\mu\,\mathcal{A}^\mu\right]$$

- **Using** $2i\,\mathcal{A}_\mu \;=\; -\,\xi^\dagger (D^\mu \Sigma)\xi^\dagger \;=\; \xi(D_\mu \Sigma^\dagger)\xi$

in



- **gives the final bosonized form**

$$\mathcal{L}^{(4)}(Q_{11}) = G^{(4)}_{\underline{8}}(Q_{11})\ \mathrm{Tr}\ \left[\left(\Sigma^\dagger \mathcal{M}_q \lambda_- + \lambda_- \mathcal{M}_q^\dagger \Sigma\right)\ D^\mu \Sigma^\dagger D_\mu \Sigma\right]$$

(the coeff. alculated by Bertolini et al.'95)

The coeff. calculated in terms of the 2-gluon condensate

Bertolini et al.'95

$$G_{\underline{8}}^{(4)}(Q_{11}) \sim \ \langle \frac{\alpha_s}{\pi} G^2 \rangle \, C_{11}/(8\pi^2)$$

- gives the **K->ππ** amplitude

$$\mathcal{A}(K^0 \to \pi^+\pi^-; Q_{11}) = \frac{\sqrt{2}}{f^3} (m_s - m_d) \, m_\pi^2 \ G_{\underline{8}}^{(4)}(Q_{11})$$

- suppressed kinematically, by **mπ**

Operator Q6 in rotated picture

$$Q_6 \;=\; -\,8\,(F_{(-)})_{\alpha\beta}\,(\overline{\chi}_L)_\alpha(\chi_R)_\delta(\overline{\chi}_R)_\delta(\chi_L)_\beta$$

- Like other octet operators

$$\mathcal{L}^{(2)}_{\Delta S=1} \;=\; G^{(2)}_{\underline{8}}(Q_6)\;\mathrm{Tr}\;\left(\lambda_- D^\mu \Sigma^\dagger D_\mu \Sigma\right)$$

Q6 gives unsuppressed amplitude

$$\mathcal{A}(K^0 \to \pi^+\pi^-;\,Q_6) \;=\; \frac{\sqrt{2}}{f^3}\left[m_K^2 - m_\pi^2\right]G^{(2)}_{\underline{8}}(Q_6)$$

$$G^{(2)}_{\underline{8}}(Q_6) \;\;=\;\; -16\,C_6\,\frac{L_5}{f_\pi^2}|\langle\bar{q}q\rangle|^2$$

$$\Delta\mathcal{L}_\chi(q')_G = m\,\frac{C_G}{8\pi^2}\,\overline{\chi'}\,F_{(-)}\sigma\cdot G\chi' + h.c.$$

inserted into loop diagram, gives the coefficient

$$G_{\underline{8}}(Q_G) \;=\; -\frac{C_D}{8\pi^2}\,\frac{1}{24}\,\langle\frac{\alpha_s}{\pi}G^2\rangle$$

New Dipole Penguin – in ratio to Q6 contribution

$$\rho \equiv \frac{\mathcal{A}(K^0 \to \pi^+\pi^-;\, Q_G)}{\mathcal{A}(K^0 \to \pi^+\pi^-;\, Q_6)} = \frac{C_G}{C_6}\, h$$

- where $$h = \frac{f_\pi^2\, \langle \frac{\alpha_s}{\pi} G^2 \rangle}{24 \cdot 8\pi^2 \cdot 16\, L_5\, |\langle \bar{q} q \rangle|^2}$$

- gives CPV and CPC parts, respectively

$$\rho_{\text{CP-violating}} = \frac{y_G}{y_6}\, h \simeq 0.05$$

$$\rho_{\text{CP-conserving}} = \frac{z_G}{z_6}\, h \simeq 0.04$$

Conclusions

- Penguins deserve a further study
- Off-shell effects (Lamb-shift like) deserve a further study [Brodsky&Shrock'08]
- Off-shell effects normalized to Q_6 contribution to ε'/ε, in total 20%:

  5% from New Dipole Penguin Q_G [EKP'08]

  15% of Self Penguin Q_{sd} [Bergan&Eeg'97]

  -within uncertainty of Trieste-Oslo
  -in favour of NEW KTeV value