Did one observe couplings of right handed quarks to W ?

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V. Bernard, M. Oertel, E. Passemar, J. Stern : Phys.Lett. B638 (2006) 480

J. Hirn et J. Stern : Phys.Rev. D73 (2006) + in preparation

Couplings of right handed quarks to W :

i) Are they CONCEIVABLE ?

• Compatible with spontaneously broken $SU(2)_W \times U(1)_Y$ gauge symmetry.

• New way of probing EW symmetry breaking.

ii) Are they PLAUSIBLE ?

• Predicted at NLO of a general class of EW Effective Theories

• Predicted in a class of renormalizable models with extended Left - Right symmetric structure

iii) Are they COMPATIBLE with known experimental facts?

• Most of existing tests of $V - A$ structure of couplings to W concern LEPTONS

• Precise tests of $V - A$ couplings of QUARKS are difficult due to interference with QCD effects.

Framework :

ELECTROWEAK LOW ENERGY EFFECTIVE THEORY

Not quite decoupling LEET alternative - the bottom up approach

At $E > \Lambda_W$:

- New gauge particles beyond the SM

- New local symmetries $S_{nat} \supset S_{ew} = SU(2)_W \times U(1)_Y$

apriori unknown

At Low energy $E < \Lambda_W$

Heavy gauge particles decouple $\rightarrow$ leaving observed particles of the SM

BUT

The symmetry S_{nat} survives at low energies

S_{nat}/Sew "non linearly realized"

- Does not show up in the low-energy spectrum (W , Z , γ , leptons , quarks)

- Constrains effective interaction vertices

- Objects carrying local charges $\in S_{nat}/Sew$ do not propagate:
They are scalar **SPURIONS**

LEET provides a classification of effects beyond the SM

Non standard interaction vertices are **ordered** according to their

- importance in the low-energy limit :

  $\mathcal{L}_{eff} = \sum_{d\geq 2} \mathcal{L}_d \qquad \mathcal{L}_d = \mathcal{O}([\frac{p}{\Lambda_W}]^d)$

  counting powers of momenta $(\Lambda_W \sim 3TeV)$

- symmetry properties under S_{nat}

  counting powers of spurions

The Symmetry S_{nat} can be deduced from known SM vertices

- $\mathcal{L}_2$ contains **unsupressed** $SU(2)_W \times U(1)_Y$ invariant vertices absent in the SM . Since they are not observed, they have to be suppressed by the symmetry S_{nat}.
- There is a unique minimal choice of $S_{nat} \supset SU(2)_W \times U(1)_Y$ which guarantees that the leading order $\mathcal{O}(p^2)$ of the low-energy expansion coincides with the SM

THE MINIMAL LEET (Hirn, Stern, 2004

$S_{nat} = [SU(2)_L \times SU(2)_R]^2 \times U(1)_{B-L}$

$S_{nat}/S_{ew} = 3SU(2)$ SPURIONS : $\mathcal{X} \sim \xi, \mathcal{Y} \sim \eta, \mathcal{Z} \sim \zeta$

fermion masses: $\xi\eta \sim m_t/\Lambda_W = \mathcal{O}(p)$

Spurion $\mathcal{Z}$ breaks $B - L \rightarrow$ Majorana masses of neutrinos (ζ)

- **LO** $\mathcal{O}(p^2)$: Standard Model

  Higgs Sector : Just three GBs $\Sigma \in SU(2)$.
- **NLO** $\mathcal{O}(p^3)$: Only **two operators**

  $\bar{\Psi}_L \mathcal{X}^\dagger \gamma^\mu \Sigma D_\mu \Sigma^\dagger \mathcal{X} \Psi_L$

  $\bar{\Psi}_R \mathcal{Y}^\dagger \gamma^\mu \Sigma^\dagger D_\mu \Sigma \mathcal{Y} \Psi_R$

Universal non standard couplings of quarks to W and Z supressed by spurionic parameters ξ^2 (left) and η^2 (right). Loops, oblique corrections, FCNC, start at NNLO.

NLO Couplings of fermions to W.

$$\mathcal{L}_{cc} = \frac{1}{\sqrt{2}} g(1-\xi^2\rho_L)(J_\mu^{\bar{U}D} + J_\mu^{\bar{N}L})W^\mu + h.c$$

$$U = \begin{pmatrix} u \\ c \\ t \end{pmatrix}, D = \begin{pmatrix} d \\ s \\ b \end{pmatrix}, N = \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}, L = \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix}$$

$$J_\mu^{\bar{U}D} = (1+\delta)\overline{U_L} V_L \gamma_\mu D_L + \varepsilon \overline{U_R} V_R \gamma_\mu D_R$$

$$J_\mu^{\bar{N}L} = \overline{N_L} V_{MNS} \gamma_\mu L_L$$

- **V_L, V_R** : 2 unitary matrices coming from the diagonalization of the U and D quark mass matrices.
- 3 parameters arising from spurions:

$$(1-\xi^2\rho_L) \qquad (1+\delta) \qquad \varepsilon$$

Effective vector and axial vector EW couplings.

- Experimentally, we have access to vector and axial currents.

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

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

$$\left|\mathcal{V}_{eff}^{ij}\right|^2 = \left|V_L^{ij}\right|^2\left\{1 + 2\delta + 2\varepsilon\,\mathrm{Re}\left(\frac{V_R^{ij}}{V_L^{ij}}\right)\right\}$$

$$\left|A_{eff}^{ij}\right|^2 = \left|V_L^{ij}\right|^2\left\{1 + 2\cdot\delta - 2\varepsilon\cdot\mathrm{Re}\left(\frac{V_R^{ij}}{V_L^{ij}}\right)\right\}$$

- In the light quark sector, 4 independant parameters :

$$\mathcal{V}_{eff}^{ud} \equiv \cos\hat{\theta}$$ $$\delta$$ $$\varepsilon_{NS} = \varepsilon\cdot\mathrm{Re}\left(\frac{V_R^{ud}}{V_L^{ud}}\right)$$ $$\varepsilon_S = \varepsilon\cdot\mathrm{Re}\left(\frac{V_R^{us}}{V_L^{us}}\right)$$

Order of magnitude of the parameters

- $\delta, \varepsilon \leq 1\%$ (top quark mass)

$$\varepsilon_{NS} = \varepsilon \, \mathrm{Re}\left(\frac{V_R^{ud}}{V_L^{ud}}\right) \qquad \varepsilon_S = \varepsilon \, \mathrm{Re}\left(\frac{V_R^{us}}{V_L^{us}}\right)$$

- V_L close to V_{CKM} ⇨ experimental measurements $\begin{cases} |V_L^{ud}| \sim 0.97 \\ |V_L^{us}| \sim 0.23 \end{cases}$

- Unitarity of V_R ⇨ $\begin{cases} |V_R^{ud}| \leq 1 \\ |V_R^{us}| \leq 1 \end{cases}$

⇨ $|\varepsilon_{NS}| \leq \varepsilon \sim 1\%$ et $|\varepsilon_S| \leq 4.5 \; \varepsilon$

- Possible enhancement of ε_S
- We are looking for effects of at most few percents.

Test of NLO effects

Experimental processes	Parameters extracted	Low Energy/QCD inputs
Nuclear β decays **$0^+ \rightarrow 0^+$**	$\left\lvert \mathcal{V}^{ud}_{eff} \right\rvert \equiv \cos\hat{\theta}$	**CVC + nuclear corrections** [Marciano & Sirlin ’05]
Hadronic τ decays **R_V,R_A, R_S,** **Moments** ALEPH, OPAL	ε_{NS}, $\delta+\varepsilon_{NS}$	**OPE** [Braaten et al ’92, Lediberder & Pich ’92….] **$\alpha_S(m_\tau)$, m_q, condensates**
Γ_W LEP, TEVATRON	δ	**Perturbative QCD** $\alpha_S(m_W)$
DIS $\nu(\bar{\nu})$ on protons	δ	**Normalized pdf**
Kl3 decay rates	$\left\lvert \mathcal{V}^{us}_{eff} \right\rvert^2 = \sin^2\hat{\theta}\left(1+2\frac{\delta+\varepsilon_{NS}}{\sin^2\hat{\theta}}\right)\left(1+2\left(\varepsilon_S-\varepsilon_{NS}\right)\right)$	**$f_+(0)$**
$K^L_{\mu 3}$ decay	$\varepsilon_S - \varepsilon_{NS}$	**$K\pi$ scattering phases** [Buettiker, Descotes, Moussallam’ 02] **and Δ_{CT}: χPT**

$K_{\mu 3}^{L}$ decays: Callan-Treiman Low Energy Theorem (cf. Talk E.Passemar)

$$C = f(\Delta_{K\pi}) = \frac{F_{K^+}}{F_\pi f_+^{K^0}(0)} + \Delta_{CT}$$

$$\Delta_{K\pi} = m_K^2 - m_\pi^2$$

$$\Delta_{CT}^{NLO} \sim -3.5.10^{-3}$$

[Gasser & Leutwyler]

- Experimental measurements :

→ $\left(\frac{F_K}{F_\pi} \left| \frac{\mathcal{A}_{eff}^{us}}{\mathcal{A}_{eff}^{ud}} \right| \right) = 0.27618(48)$

[updated using recent KLOE measurement of $K_{\mu 2}$]

→ $f_+^{K_0}(0) \left| \mathcal{V}_{eff}^{us} \right| = 0.21619(55)$

Average of most recent measurements of NA48, KTeV, KLOE.

→ $\left| \mathcal{V}^{ud} \right| = 0.97377(26)$

[Towner & Hardy] (0^+ → 0^+) updated by **[Marciano & Sirlin '05]**

$$C = f(\Delta_{K\pi}) = \underbrace{\frac{F_K \left|\mathcal{A}^{us}_{eff}\right|}{F_\pi \left|\mathcal{A}^{ud}_{eff}\right|} \frac{1}{f_+(0)\left|\mathcal{V}^{us}_{eff}\right|}\left|\mathcal{V}^{ud}_{eff}\right|}_{B_{exp}} \frac{\left|\mathcal{A}^{ud}_{eff}\right|}{\left|\mathcal{V}^{ud}_{eff}\right|}\frac{\left|\mathcal{V}^{us}_{eff}\right|}{\left|\mathcal{A}^{us}_{eff}\right|} + \Delta_{CT}$$

- Standard Model case : $\mathcal{V}_{eff} = -\mathcal{A}_{eff} = V_{CKM}$ ⇨ $\frac{\left|\mathcal{A}^{ud}_{eff}\right|}{\left|\mathcal{V}^{ud}_{eff}\right|}\frac{\left|\mathcal{V}^{us}_{eff}\right|}{\left|\mathcal{A}^{us}_{eff}\right|} = 1$

⇨ $C_{SM} = 1.2440 \pm 0.0039 + \Delta_{CT}$

$$\ln C_{SM} = 0.2183 \pm 0.0031 + \frac{\Delta_{CT}}{B_{exp}}$$

- LEET case : $\frac{\left|\mathcal{A}^{ud}_{eff}\right|}{\left|\mathcal{V}^{ud}_{eff}\right|}\frac{\left|\mathcal{V}^{us}_{eff}\right|}{\left|\mathcal{A}^{us}_{eff}\right|} = 1 + 2(\varepsilon_S - \varepsilon_{NS})$

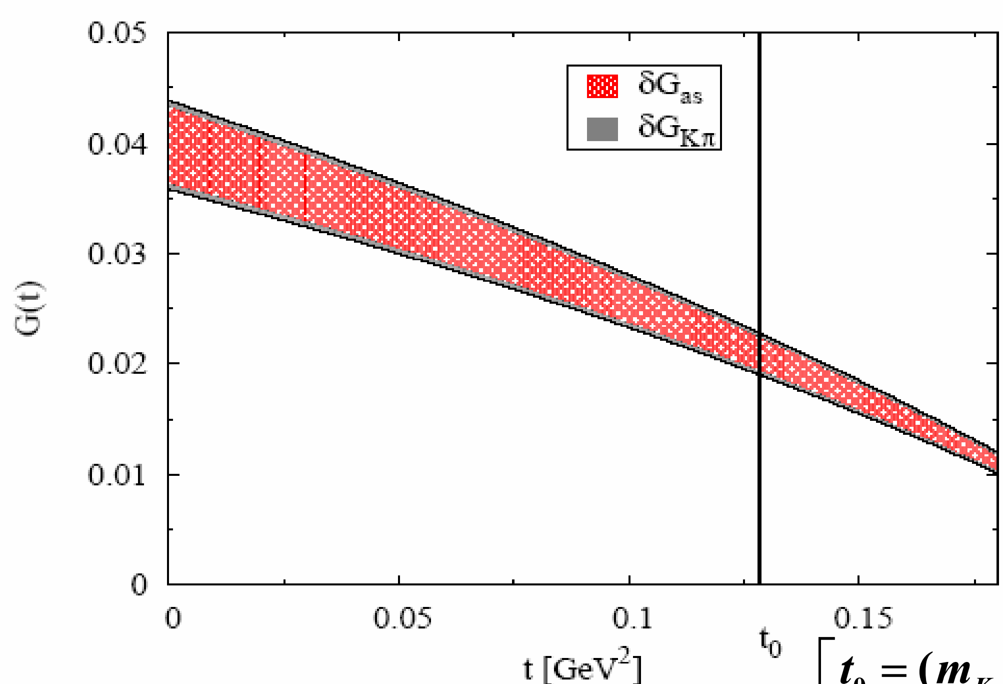
⇨ $\ln C = \underbrace{0.2183 \pm 0.0031}_{\text{Experimental uncertainties}} + \Delta\varepsilon$ with $\Delta\varepsilon = \underbrace{\tilde{\Delta}_{CT}}_{} + 2(\varepsilon_S - \varepsilon_{NS})$

Experimental uncertainties

$$\left[\tilde{\Delta}_{CT} = \frac{\Delta_{CT}}{B_{exp}}\right]$$

A dispersive representation of the Kπ scalar form factor.

$$f(t) = \exp\left[\frac{t}{\Delta_{K\pi}}(\ln C - G(t))\right]$$ with $$G(t) = \frac{\Delta_{K\pi}(\Delta_{K\pi} - t)}{\pi}\int_{t_{\pi K}}^{\infty}\frac{ds}{s}\frac{\phi(s)}{(s-\Delta_{K\pi})(s-t)}$$



$$\left[t_0 = (m_K - m_\pi)^2\right]$$

G(t) with the uncertainties added in quadrature

$$G(0) = 0.0398 \pm 0.0040$$

G(t) does not exceed 20% of the expected value of lnC

lnC~0.20

- Similar representation for the vector form factor in terms of its slope.

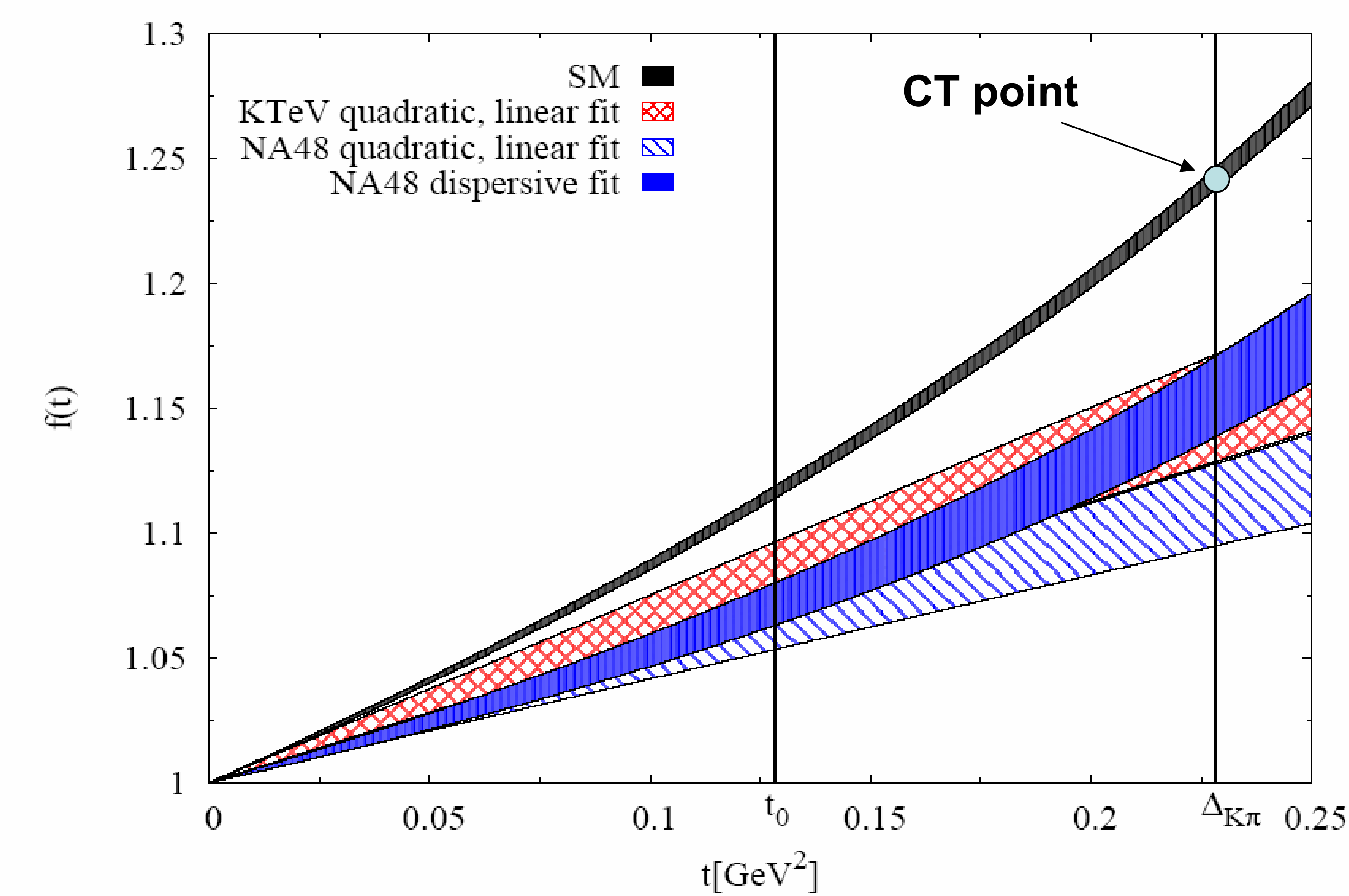
- Accurate dispersive parametrization of the $K_{\mu 3}$ Dalitz distribution $\left(E_{\mu}^{*}, E_{\pi}^{*}\right) \leftrightarrow$ 2 parameters $\Lambda_{+} = m_{\pi}^{2} \hat{f}_{+}^{'}(0), \ \ln C.$

- NA48 : First dedicated high statistics (2.6 M of events) analysis of $K_{L\mu 3}$ Dalitz plot to directly extract lnC :

$$\begin{cases} \ln C_{\exp} = 0.1438 \pm 0.014 \\ \Lambda_{+} = 0.0233 \pm 0.0009 \end{cases} \quad \text{with} \quad \rho(\ln C, \Lambda_{+}) = -0.44$$

[NA48, hep-ex/0703002, Accepted by Phys. Lett. B]

- NB: Extracting the slope λ0 using the linear parametrization does not help us to determine lnC.



- With $\Delta_{CT}^{NLO} = -3.5.10^{-3}$ $\quad \ln C_{SM} = 0.2183 \pm 0.0031 + \frac{\Delta_{CT}}{B_{\exp}}$

NA48 Dalitz plot analysis : $\ln C_{\exp} = 0.1438 \pm 0.014$

5 σ !

Interpretation in terms of RHCs :

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

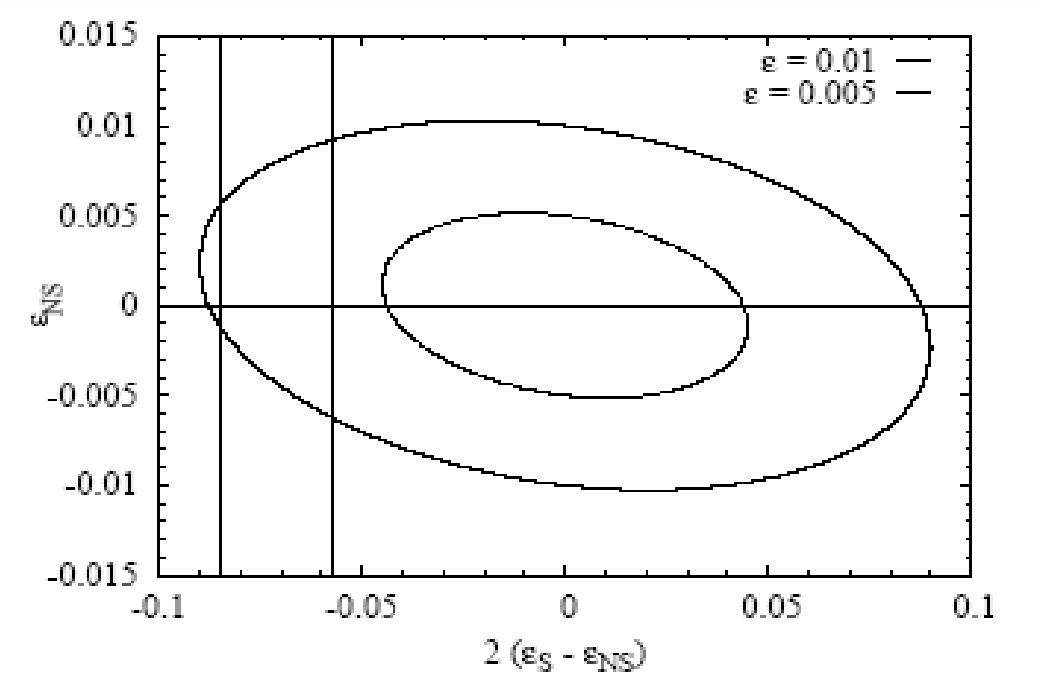
$$\Delta\varepsilon = \frac{\Delta_{CT}}{B_{\exp}} + 2(\varepsilon_S - \varepsilon_{NS})$$

$$\Rightarrow \Delta\varepsilon = -0.071 \pm 0.014\big|_{NA48} \pm 0.002\big|_{th} \pm 0.005\big|_{exp}$$

- $\Delta\varepsilon = \frac{\Delta_{CT}}{B_{\exp}}$ requires $|\Delta_{CT}| \geq 20\ |\Delta_{CT}^{NLO}|$! with $\Delta_{CT}^{NLO} \sim -3.5.10^{-3}$
- If it is not the case :

  ε_S is enhanced !

  $|V_R^{ud}| < |V_R^{us}|$
- $|\varepsilon| \geq 0.0066$



Neutral current interactions.

$$\mathcal{L}_Z = \frac{e}{2\cos\theta_w \sin\theta_w}(1-\xi^2\rho_L)\Big[\bar{N}\gamma_\mu(g_V^N - g_A^N\gamma_5)N + \bar{L}\gamma_\mu(g_V^L - g_A^L\gamma_5)L$$
$$+ \bar{U}\gamma_\mu(g_V^U - g_A^U\gamma_5)U + \bar{D}\gamma_\mu(g_V^D - g_A^D\gamma_5)D\Big]Z_\mu$$

Normalized factor absorbed in G_F

- New couplings at NLO appearing in g^f_V and g^f_A :

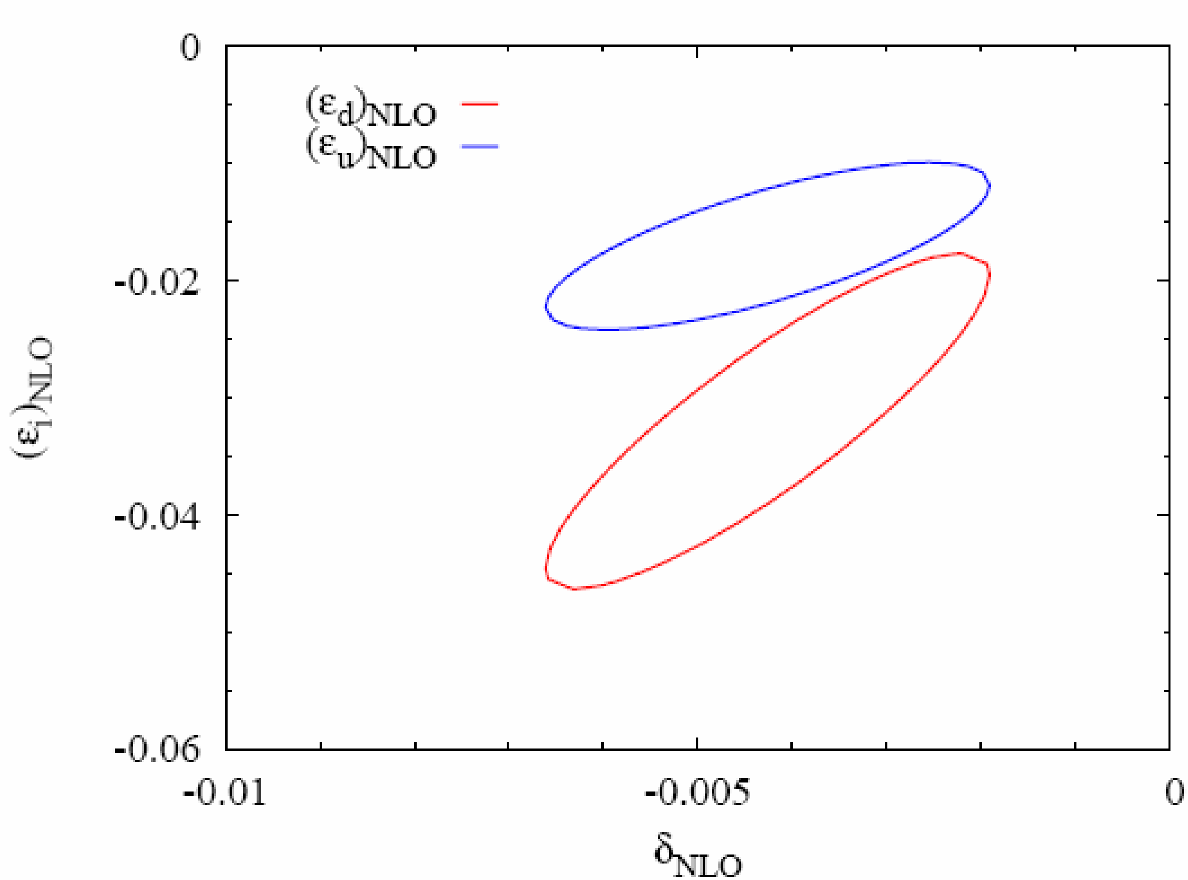
$$\begin{cases} g_V^N = \frac{1}{2} + \frac{\varepsilon^\nu}{2} \\ g_A^N = \frac{1}{2} - \frac{\varepsilon^\nu}{2} \end{cases} \qquad \begin{cases} g_V^L = -\frac{1}{2} + 2\tilde{s}^2 - \frac{\varepsilon^e}{2} \\ g_A^L = -\frac{1}{2} + \frac{\varepsilon^e}{2} \end{cases}$$

$$\begin{cases} g_V^U = \frac{1+\delta}{2} - \frac{4}{3}\tilde{s}^2 + \frac{\varepsilon^u}{2} \\ g_A^U = \frac{1+\delta}{2} - \frac{\varepsilon^u}{2} \end{cases} \qquad \begin{cases} g_V^D = -\frac{1+\delta}{2} + \frac{2}{3}\tilde{s}^2 - \frac{\varepsilon^d}{2} \\ g_A^D = -\frac{1+\delta}{2} + \frac{\varepsilon^d}{2} \end{cases}$$

Results

- Fit to first order in ε (NLO) ⇨ ε^ν not present in the fit
- δ =-0.004(2), $\tilde{s}^2$ = 0.2307(2), ε^e= -0.0024(5) ,

  ε^u= -0.02(1) , ε^d= -0.03(1) , χ^2/dof=8.5/8.



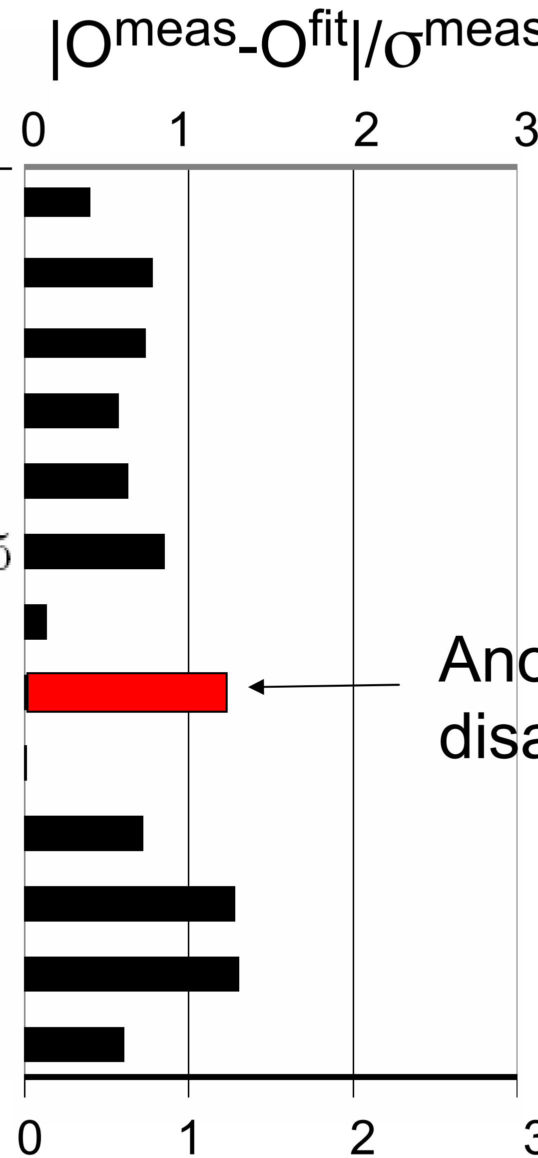
δ and ε^e very small ⇨ left-handed couplings not very affected at NLO.

Results in agreement with the order of magnitude

Uncertainties from experiments only !

Result of the NLO FIT

	Measurement	Fit
Γ_Z [GeV]	2.4952 ± 0.0023	2.4943
σ^0_{had} [nb]	41.540 ± 0.037	41.569
R_l	20.767 ± 0.025	20.785
$A^{0,l}_{fb}$	0.0171 ± 0.0010	0.0165
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1485
R_b	0.21629 ± 0.00066	0.21685
R_c	0.1721 ± 0.0030	0.1725
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1012
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0707
A_b	0.923 ± 0.020	0.910
A_c	0.670 ± 0.027	0.636
A_l(SLD)	0.1513 ± 0.0021	0.1485
$Br(W \to l)$	0.1084 ± 0.0009	0.1089



Anomaly A^b_{FB} disappears !

Values of low energy QCD observables extracted from semileptonic weak transitions

$$\mathcal{V}_{eff}^{ud} = 0.97377(26) \equiv \cos\hat{\theta} \quad (0^+ \to 0^+,\ CVC)$$

$$\Gamma\left[\pi^+ \to \mu^+\nu(\gamma)\right] \sim \left|F_\pi \mathcal{A}_{eff}^{ud}\right| \Longrightarrow F_\pi = \widehat{F}_\pi\left(1+2\varepsilon_{NS}\right)$$

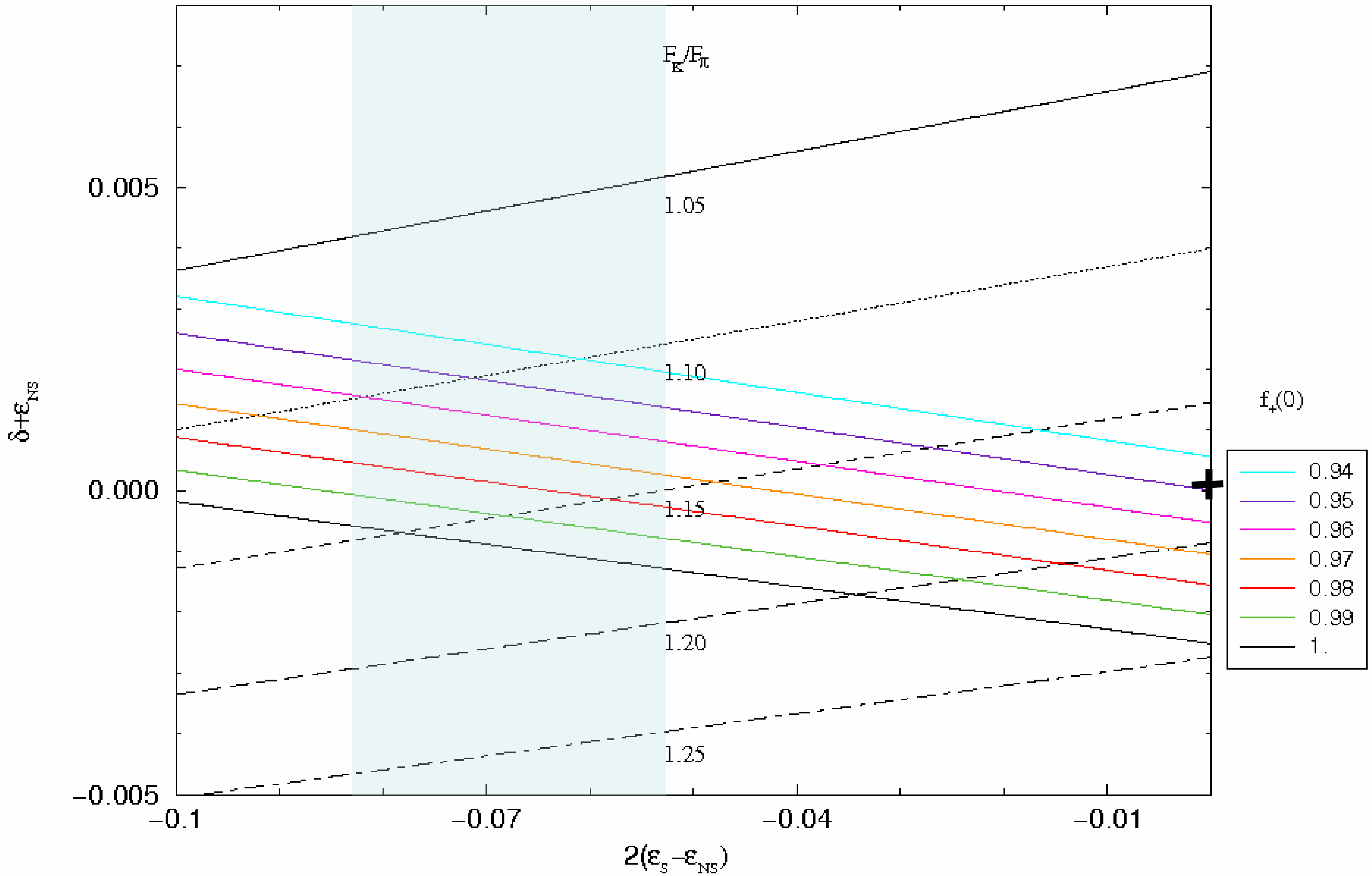
$$\widehat{F}_\pi = \left(92.4 \pm 0.2\right) MeV$$

$$Br\frac{\left[K^+ \to \mu^+\nu(\gamma)\right]}{\left[\pi^+ \to \mu^+\nu(\gamma)\right]} \sim \frac{\left|F_K \mathcal{A}_{eff}^{us}\right|^2}{\left|F_\pi \mathcal{A}_{eff}^{ud}\right|^2} \Longrightarrow \left(\frac{F_K}{F_\pi}\right)^2 = \left(\frac{\widehat{F}_K}{\widehat{F}_\pi}\right)^2 \frac{1+2\left(\varepsilon_S - \varepsilon_{NS}\right)}{1+\frac{2}{\sin^2\hat{\theta}}\left(\delta+\varepsilon_{NS}\right)}$$

$$\frac{\widehat{F}_K}{\widehat{F}_\pi} = 1.182 \pm 0.007$$

$$\Gamma\left[K^0 \to \pi^+ e^- \nu(\gamma)\right] \sim \left|f_+^{K^0}(0)\mathcal{V}_{eff}^{us}\right|^2 \Longrightarrow \left[f_+^{K^0\pi^-}(0)\right]^2 = \left[\widehat{f}_+^{K^0\pi^-}(0)\right]^2 \frac{1-2\left(\varepsilon_S - \varepsilon_{NS}\right)}{1+\frac{2}{\sin^2\hat{\theta}}\left(\delta+\varepsilon_{NS}\right)}$$

$$\widehat{f}_+^{K^0\pi^-}(0) = 0.951 \pm 0.005$$



$$\left|\mathcal{V}_{eff}^{ud}\right|^2+\left|\mathcal{V}_{eff}^{us}\right|^2 = 1+\underbrace{2(\varepsilon_S-\varepsilon_{NS})\sin^2\hat{\theta}}+2(\delta+\varepsilon_{NS})$$

NA48 : -0.0035(7)

SUMMARY AND COMMENTS

1. General class of electroweak LEET based on **infrared power counting and extended EW symmetries** predicts at NLO non standard universal couplings of right handed quarks to W and Z.
2. **In the CC sector**
   - Compare effective flavor mixing in the vector and axial vector currents. $\mathcal{V}_{eff} \neq -\mathcal{A}_{eff} \Rightarrow$ RHCs.
   - SM $\longrightarrow$ accurate prediction of $C = f(\Delta_{K\pi})$ based on QCD Callan-Treiman theorem.

     5σ discrepancy with the **direct measurement of C** through the NA48 $KL\mu3$ Dalitz plot analysis.
   - Either QCD/ChPT at NLO underestimates Δ_{CT} by a factor 20, or there exist couplings of RH quarks to W.
   - The observed size of the effect (7 percent) can be explained:

Inverted hierarchy in the RH CKM mixing matrix.

3. **In the NC sector** Perfect NLO fit to precision Z - pole observables and atomic PV. A^b_{FB} puzzle solved.
4. **Extraction of λ_0^{exp} based on linear parametrization** hard to exploit quantitatively: Discrepancy of NA48 value of lnC with the ISTRA and preliminary KLOE values of λ_0^{exp} ?
   $\lambda_0 = m_\pi^2 f'(0) < \lambda_0^{exp}$
5. Values of F_K/F_π extracted from $BR(Kl2/\pi l2)$ modified by RHCs. Change in the ChPT inputs.
   (Low values of λ_0 in a good agreement with NLO ChPT).
6. Hardly other sensitive NLO tests (tau decays).
7. **NNLO** new tests $(K_0 - \bar{K}_0, B - \bar{B}, FCNC)$ and new parameters : V_R^{ij} . New CP violating effects to be expected :
   e.g. in K_{e4} decays.

Additionnal slides

Low energy Experiments.

- Using the values of the parameters determined in the FIT
  ⇒ predictions at low energy.

- Atomic parity violation: test the couplings of electrons to the quarks inside the nucleus via neutral current.
  – Violating part amplitude: 2 contributions ($A_e V_q$) and ($V_e A_q$).
  – Limitate the uncertainties, take vector couplings for quarks (CVC).

$$\mathcal{L}_{NC}^{lq} = \frac{G_F}{\sqrt{2}} 4 g_A^e \bar{e}\gamma_\mu \gamma^5 e \left(g_V^u \bar{u}\gamma^\mu u + g_V^d \bar{d}\gamma^\mu d \right)$$

$$\Rightarrow \quad Q_W = 4 g_A^e \left[Z\left(2g_V^u + g_V^d\right) + N\left(g_V^u + 2g_V^d\right) \right]$$

- Parity violation in Polarized Moller Scattering
  Measurement of the parity violating asymmetry (E-158)

$$A_{PV} = \frac{\sigma_R(e_R) - \sigma_L(e_L)}{\sigma_R(e_R) + \sigma_L(e_L)} = -\mathcal{A}\left(Q^2, y\right) Q_W^e$$

Kinematic factor

$$\left(y = Q^2 / s \right)$$

$$Q_W^e = 4 g_A^e g_V^e$$

- Results :

Observable	Measurement	NLO prediction
$Q_W\,(^{133}Cs)$	-72.62 ± 0.46	-70.72 ± 4.19
$Q_W\,(^{205}Tl)$	-116.40 ± 3.64	-111.95 ± 7.47
Q_W^p	Qweak ?	0.062 ± 0.022
Q_W^e	0.041± 0.005	0.074 ± 0.01

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3 σ !

- Good agreements except for weak charge of electron

⇨ $$Q_W^e = 1 - 4\tilde{s}^2 (1 - \varepsilon^e)$$ Accidental cancelation at NLO !

$$\left(4\tilde{s}^2 (1 - \varepsilon^e) \sim 1 \right)$$

⇨ We have to go to NNLO !

Interdependence of Electroweak couplings and Low Energy QCD observables

- Example: Pion decay :

$$\Gamma\left[\pi^+ \to \mu^+ \nu(\gamma)\right] \to \mathcal{A}_{eff}^{ud} \langle 0 | \bar{u}\gamma_\mu \gamma_5 d | \pi \rangle \sim \left| F_\pi \mathcal{A}_{eff}^{ud} \right|$$

⇨ **We do not measure directly Fπ but a combination of Fπ and $\mathcal{A}_{eff}^{ud}$.**

$$F_\pi = F_\pi \left|\mathcal{A}_{eff}^{ud}\right| \left|\frac{1}{\mathcal{V}_{eff}^{ud}}\right| \left|\frac{\mathcal{V}_{eff}^{ud}}{\mathcal{A}_{eff}^{ud}}\right|$$

Exp. $\quad (0^+ \to 0^+) \quad 1 + 2\varepsilon_{NS}$

⇨ $$F_\pi = \widehat{F}_\pi \left(1 + 2\varepsilon_{NS}\right)$$

unknown (F_π) **in the PDG** ($\widehat{F}_\pi$)

F_π extracted in the SM ($\mathcal{V}_{eff}^{ud} = -\mathcal{A}_{eff}^{ud} = V_{CKM}^{ud}$) ⇨ $$\widehat{F}_\pi = \left(92.4 \pm 0.2\right) MeV$$