

Testing non-standard electroweak couplings of quarks at NLO of the Higgsless effective theory.

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Paper: In preparation

Outline

1. Framework: the Low Energy Effective Theory.
2. Tests of couplings to Z at NLO.
3. Tests of couplings to W at NLO.
4. Consistency of the analysis.
5. Conclusion and outlook.

1. Framework: Low Energy Effective Theory

1.1 The LEET, a not (quite) decoupling alternative.

- Heavy states present at $E > \Lambda$ decouple at low energy.
- **BUT** higher (local) symmetry $S_{nat} \supset SU(2)_W \otimes U(1)_Y$ survives at low energy and becomes non linearly realised.
- $S_{nat} / SU(2)_W \otimes U(1)_Y$:
 - not manifest in the low energy spectrum (the gauge fields associated to this symmetry do not all appear in the spectrum).
 - but constrains the interaction vertices (cf. Custodial Symmetry).

$$S_{nat} = [SU(2) \otimes SU(2)]^2 \otimes U(1)_{B-L} \otimes Z_{2\nu_R}$$
 [Hirn & Stern '05]
- Systematic Low Energy expansion in momenta : $p \ll \Lambda \sim 3 \text{ TeV}$
$$\mathcal{L}_{eff} = \sum_{d \geq 2} \mathcal{L}_d, \mathcal{L}_d = \mathcal{O}(p^d), \text{ as } p \rightarrow 0$$
 renormalized and unitarized order by order in powers of momenta (cf. $d \neq D$).

Covariant Low Energy reduction of S_{nat} via spurions : $S_{nat} \rightarrow SU(2)_W \otimes U(1)_Y$

- $SU(2)_W \otimes U(1)_Y$ linearly realised via SM gauge fields.
- $S_{nat} / SU(2)_W \otimes U(1)_Y \equiv [SU(2)]^3$ populated by spurions :
 - 3 non propagating $SU(2)$ valued scalar fields X transforming as a bifundamental representation of S_{nat} : $X \rightarrow U X V^{-1}$
 - Gauge invariant constraints: $D_\mu(\text{spurions}) = 0$.
 - It exists a gauge in which the X become constants K :
→ 3 small expansion parameters describing the hierarchical breaking of S_{nat} (~ mass of quarks in χ PT).

Counting scheme.

- Terms explicitly involving spurions \rightarrow fermion masses and genuine effects beyond the SM.
- The operators are ordered by power of momenta and of spurions with the counting rule :

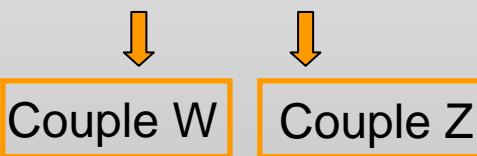
$$\frac{m_t}{\Lambda} \sim \kappa^2 = \mathcal{O}(p)$$

- Double expansion in momenta and explicit symmetry breaking parameters κ (preserved by loops) :

$$\mathcal{L}_{eff} = \underbrace{\mathcal{L}(p^2 \kappa^0)}_{LO : \mathcal{O}(p^2)} + \underbrace{\mathcal{L}(p^1 \kappa^2)}_{NLO : \mathcal{O}(p^3)} + \underbrace{\mathcal{L}(p^2 \kappa^2)}_{NNLO : \mathcal{O}(p^4)} + \mathcal{L}(p^4) + \dots$$

1.2 First effects beyond the SM

- At Leading Order (LO) $\mathcal{O}(p^2 \kappa^0)$ and $\mathcal{O}(p^1 \kappa^2)$: Standard Model without a Higgs.
- At Next to Leading Order (NLO) $\mathcal{O}(p^2 \kappa^2)$ new physics (contains spurions) arising before loops, oblique corrections..... only 2 operators :  new couplings of fermions to W and Z.

$$\mathcal{L}_{NLO} \equiv \mathcal{L}_{cc} + \mathcal{L}_{NC}$$


↓ ↓

Couple W

Couple Z

- NLO : potentially the most important effects of physics beyond the SM.

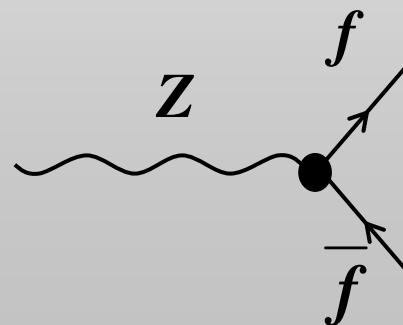
2. Tests of couplings to Z at NLO.

2.1 Neutral current interactions.

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

Normalized factor
absorbed in G_F

- $\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_w^2} (1 - \xi^2 \rho_L)^2 \quad N = \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}, L = \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix}, U = \begin{pmatrix} u \\ c \\ t \end{pmatrix}, D = \begin{pmatrix} d \\ s \\ b \end{pmatrix}$
- $g = \frac{e}{\sin\theta_w}$
- $\sin\theta_w^2 = 1 - \frac{m_w^2}{m_Z^2}$



2.1 Neutral current interactions.

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

Normalized factor
absorbed in G_F

- New couplings at NLO appearing in g_V^f and g_A^f :

$$\begin{cases} g_V^N = \frac{1}{2} \\ g_V^N = \frac{1}{2} + \frac{\varepsilon^\nu}{2} \\ \\ g_V^U = \frac{1+\delta}{2} - \frac{4}{3} s^2 + \frac{\varepsilon^u}{2} \\ g_A^U = \frac{1+\delta}{2} - \frac{\varepsilon^u}{2} \end{cases}$$

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

- At NLO 6 parameters:
 - modification of the left couplings: δ
 - modification of the right couplings :
 - For the neutrinos and electrons : ε^{ν} , ε^e
 - For the quarks: ε^u , ε^d
 - Normalisation factor: $1 - \xi^2 \rho_L \rightarrow \frac{s^2}{1 - \xi^2 \rho_L}$
- Expectation: percent level. $\left(\frac{m_t}{\Lambda} \sim \kappa^2 \right)$
- Universality of the couplings is assumed.

2.2 FIT to Z pole observables

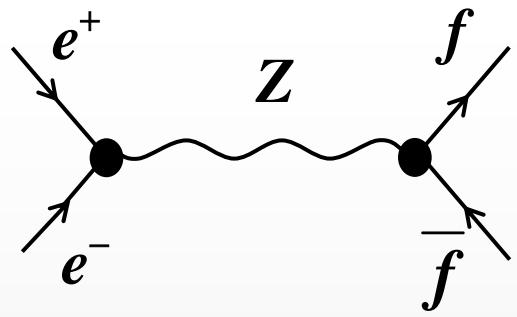
- How to constrain these parameters ?
 - ➡ Data from LEP and SLD.
- Definition of « pseudo-observables » : Γ_Z , Γ_{had} , Γ_{ff} , σ_f , A_{FB} , A_f ...
- Take the less correlated and the independant one for a FIT of the couplings: Γ_Z , σ_{had} , R_e , R_b , $A_{\text{FB}}^{e,b,c}$

$$\Gamma_f = N_c^f \frac{G_F}{6\sqrt{2}\pi} m_Z^3 \left[\left(g_V^f \right)^2 R_V^f + \left(g_A^f \right)^2 R_A^f \right]$$

↓ ↓
Corrections QCD+QED

Observables of the FIT :

- Total decay width of Z : $\Gamma_Z = \sum_f \Gamma_f$



- Hadronic pole cross section : $\sigma_{had} = \frac{12\pi}{m_Z^2} \frac{\Gamma_e \Gamma_{had}}{\Gamma_Z^2}$

- Ratio R_b : $R_b = \frac{\Gamma_b}{\Gamma_{had}}$ (3R_b+2R_c=1)

- Ratio R_l : $R_l = \frac{\Gamma_{had}}{\Gamma_l}$

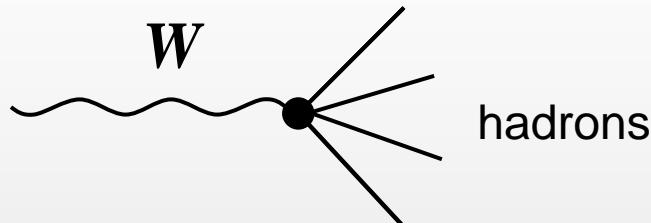
- The forward backward asymmetries:

$$A_{FB}^f = \frac{n_F(\theta_f < 90^\circ) - n_B(\theta_f > 90^\circ)}{n_F(\theta_f < 90^\circ) + n_B(\theta_f > 90^\circ)} \quad \text{for } f=e,b,c$$

$$A_{FB}^f = 3 \frac{g_V^e g_A^e}{\left[(g_V^e)^2 + (g_A^e)^2\right]} \frac{g_V^f g_A^f}{\left[(g_V^f)^2 + (g_A^f)^2\right]}$$

W leptonic Branching Ratios

- Interface charged/neutral currents: $\rightarrow \delta$



$$\Gamma(W^\pm \rightarrow h^\pm) \propto \langle \mathbf{0} | J^\mu | h \rangle \langle h | J^{\nu\dagger} | \mathbf{0} \rangle$$

$$\langle \mathbf{0} | J^\mu | h \rangle = \left\langle \mathbf{0} \left| \sum_{ij} (1 + \delta) V_L^{ij} \bar{u}_L^i \gamma_\mu d_L^j + \epsilon V_R^{ij} \bar{u}_R^i \gamma_\mu d_R^j \right| h \right\rangle$$

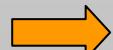
$$\Gamma(W^\pm \rightarrow h^\pm) = (1 + 2\delta) \cdot \Gamma_{SM}(W^\pm \rightarrow h^\pm)$$

- Theoretical calculation: perturbative QCD

$$\Gamma_{Wtot} = \frac{G_F M_W^3}{6\sqrt{2}\pi} \left[3 + 6 \cdot (1 + 2\delta) \cdot \left[1 + \frac{\alpha_s(M_W)}{\pi} + 1.409 \left(\frac{\alpha_s(M_W)}{\pi} \right)^2 - 12.77 \left(\frac{\alpha_s(M_W)}{\pi} \right)^3 \right] \right]$$

- Take the leptonic branching ratio:

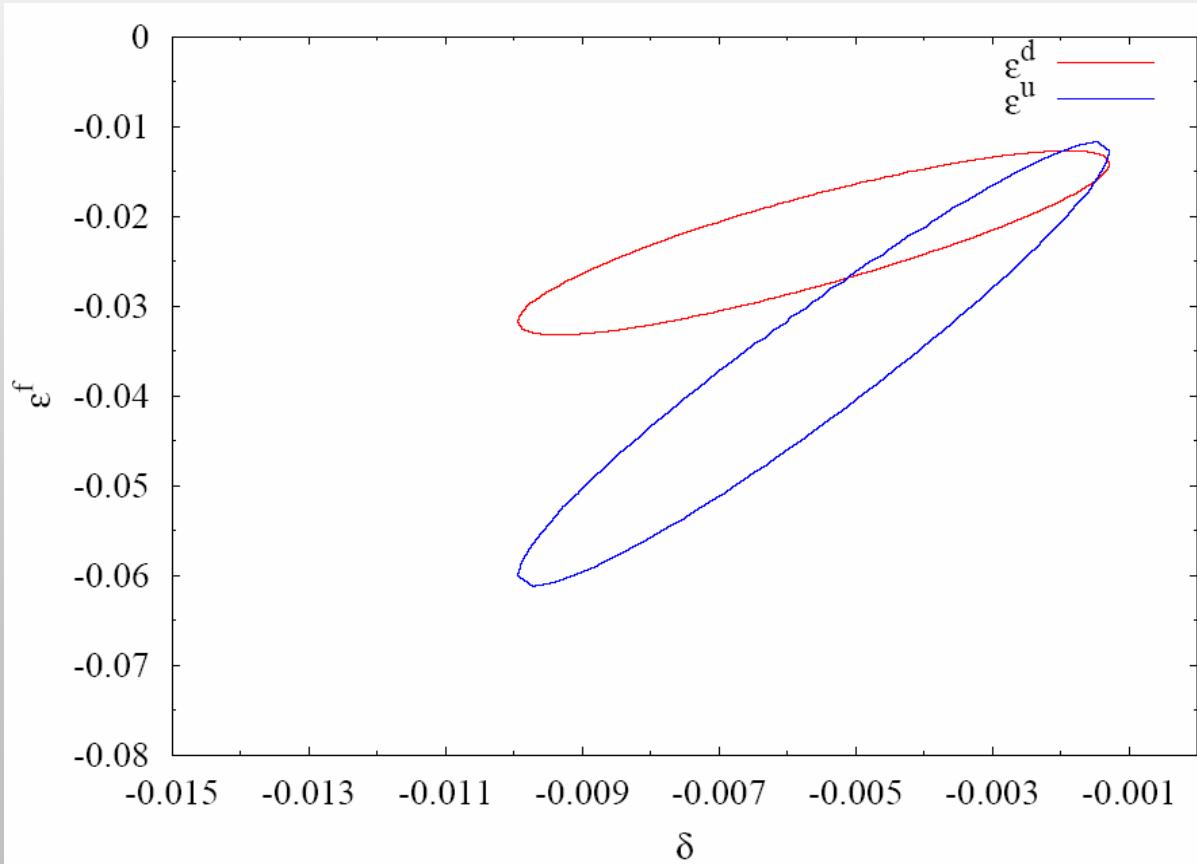
$$\text{Br}(W \rightarrow l\nu) = \frac{\Gamma_{W \rightarrow l\nu}}{\Gamma_{Wtot}}$$



very accurate measurement from LEP : $\text{Br}(W \rightarrow l\nu) = 0.1084(9)$.
Very sensitive to δ .

Results

- Fit to first order in ε (NLO) $\rightarrow \varepsilon^v$ not present in the fit
- $\delta = -0.0054(44)$, $\tilde{s}^2 = 0.2308(4)$, $\varepsilon^e = -0.0024(5)$,
 $\varepsilon^u = -0.0223(104)$, $\varepsilon^d = -0.0355(257)$, $\chi^2/\text{dof} = 3.09/3$.

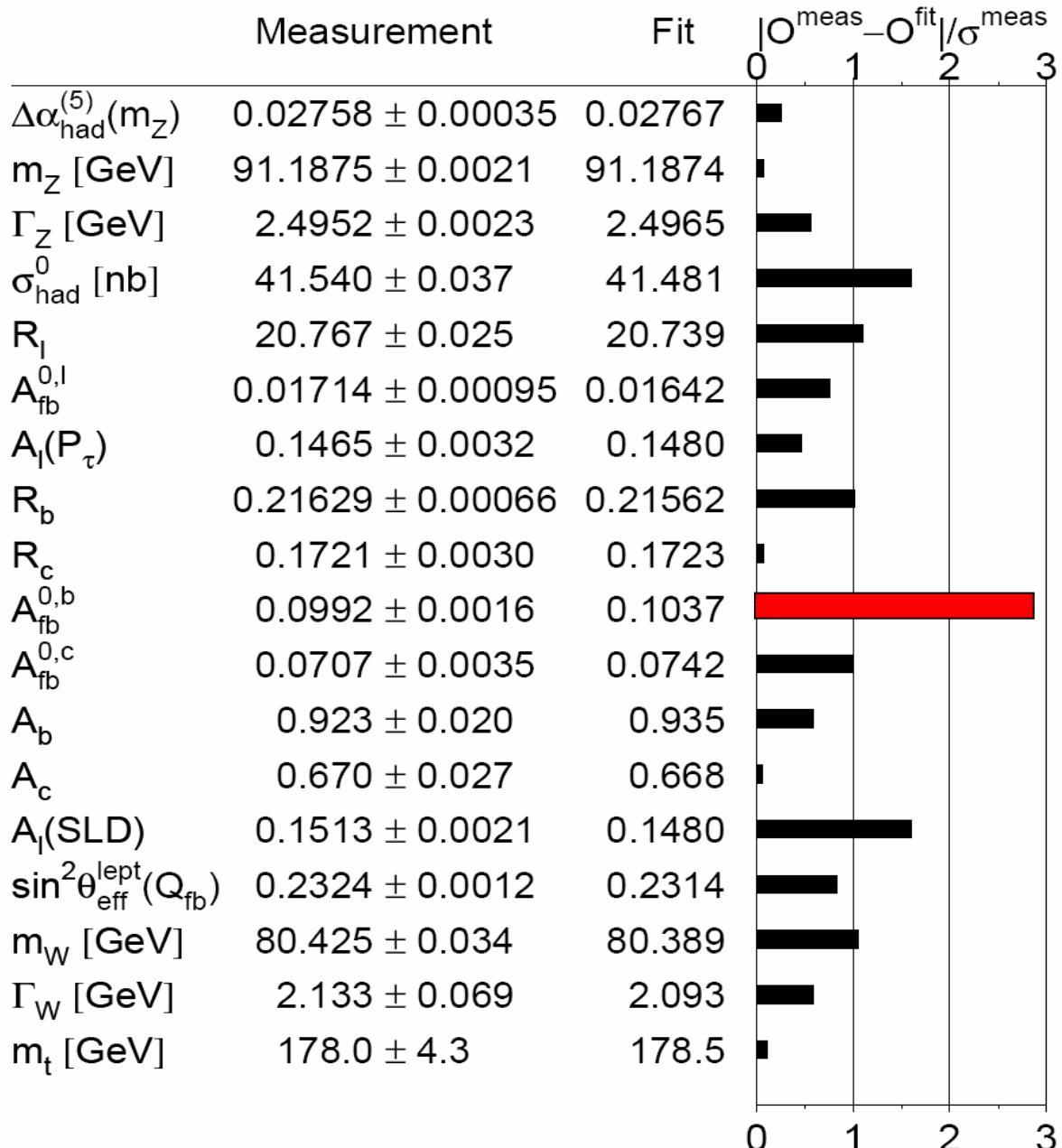


δ and ε^e very small
 \rightarrow left-handed
couplings not very
affected at NLO.

Results in
agreement with the
order of magnitude

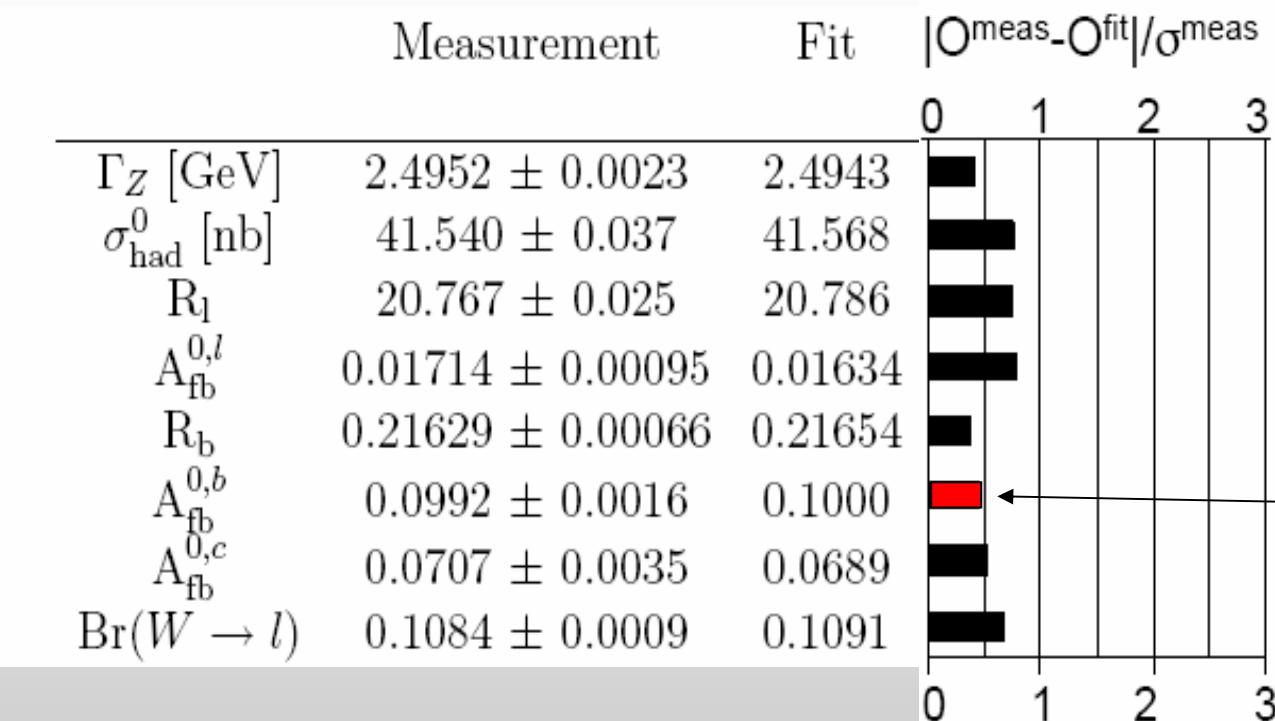
Uncertainties from
experiments only !

Results FIT SM (LEP'06)



← Anomaly A_{FB}^b !

From the NLO fit



Anomaly A_{FB}^b disappears !

- Remarkable agreement at NLO (less than 1 σ) , the anomaly A_{FB} for b quarks disappears without breaking the universality.

2.3 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).

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

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

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

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

Kinematic factor $(y = Q^2 / s)$

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

- Results :

Observable	Measurement	NLO prediction
$Q_W ({}^{133}\text{Cs})$	-72.62 ± 0.46	-70.73 ± 4.44
$Q_W ({}^{205}\text{Tl})$	-116.40 ± 3.64	-111.95 ± 7.47
Q_W^p	Qweak ?	0.060 ± 0.017
Q_W^e	0.041 ± 0.005	0.074 ± 0.02

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5 σ !

- Good agreements except for weak charge of electron

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

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

3. Tests of couplings to W at NLO.

3.1 Charged current interactions

→ Talk M.Oertel

$$\mathcal{L}_{\text{CC}} = \tilde{\mathbf{g}} \left[\mathbf{1}_\mu + \frac{1}{2} \bar{\mathbf{U}} (\mathcal{V}_{\text{eff}} \gamma_\mu + \mathcal{A}_{\text{eff}} \gamma_\mu \gamma_5) \mathbf{D} \right] \mathbf{W}^\mu + h.c., \quad \mathbf{U} = \begin{pmatrix} u \\ c \\ t \end{pmatrix}, \quad \mathbf{D} = \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- $\mathbf{1}_\mu$: standard V-A leptonic current (NB: There are no charged right-handed leptonic currents).
- $\mathcal{V}_{\text{eff}}, \mathcal{A}_{\text{eff}}$: 3x3 complex matrices of effective couplings.
- At LO (SM) : $\mathcal{V}_{\text{eff}} = -\mathcal{A}_{\text{eff}} = V_{CKM}$
- At NLO, right-handed quarks currents (RHCs) : $\mathcal{V}_{\text{eff}} \neq -\mathcal{A}_{\text{eff}}$

$$\mathcal{V}_{\text{eff}}^{ij} = (1 + \delta) \mathbf{V}_L^{ij} + \varepsilon \mathbf{V}_R^{ij} + \text{NNLO} \quad \text{and} \quad \mathcal{A}_{\text{eff}}^{ij} = -(1 + \delta) \mathbf{V}_L^{ij} + \varepsilon \mathbf{V}_R^{ij} + \text{NNLO}$$

- $\mathbf{V}_L, \mathbf{V}_R$: 2 unitary flavor mixing matrixes from the diagonalisation of the mass matrix of U and D quarks.
- δ, ε : S_{nat} breaking parameters arising from spurions ($\sim 1\%$).

- In the light quarks sector : only 3 parameters :
 - modification of the left couplings: δ
 - Right-Handed quark Currents (RHCs):
 - In the non-strange sector: $\epsilon_{\text{NS}} = \epsilon \text{ Re} \left(\frac{\mathbf{V}_R^{\text{ud}}}{\mathbf{V}_L^{\text{ud}}} \right)$
 - In the strange sector: $\epsilon_s = \epsilon \text{ Re} \left(\frac{\mathbf{V}_R^{\text{us}}}{\mathbf{V}_L^{\text{us}}} \right)$
- Order of magnitude: $\delta, \epsilon \sim 1\%$

Tests in Charged sector

Experimental processes	Parameters extracted	Low Energy/QCD inputs
Nuclear β decays $0^+ \rightarrow 0^+$	$ \mathcal{V}_{eff}^{ud} $	CVC + nuclear corrections [Marciano & Sirlin '05]
Hadronic τ decays R_V, R_A, R_S , Moments ALEPH, OPAL	$\varepsilon_{NS}, \delta + \varepsilon_{NS}$	OPE [Braaten et al '92, Leibinger & 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
$K^L_{\mu 3}$ decay KTeV, NA48, KLOE	$\varepsilon_S - \varepsilon_{NS}$	$K\pi$ scattering phases [Buettiker, Descotes, Moussallam' 02] and Δ_{CT} : χ PT

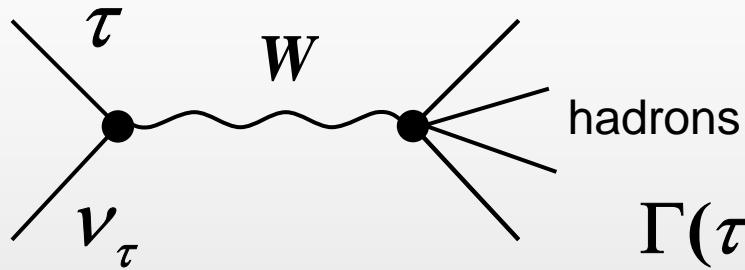
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DIS $\nu(\bar{\nu})$ on protons	δ	Normalized pdf
$K^L_{\mu 3}$ decay KTeV, NA48, KLOE	$2(\varepsilon_S - \varepsilon_{NS}) + \Delta_{CT}/B_{exp} =$ -0.074(14) → Talk M.oertel	$K\pi$ scattering phases [Buettiker, Descotes, Moussallam' 02] and Δ_{CT} : χ PT

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3.2 Inclusive Hadronic Tau decays: A test of physics at NLO ?



$$\Gamma(\tau^- \rightarrow \nu_\tau h^-(\gamma)) \propto \text{Im}(\Pi^{\mu\nu}(q))$$

$$\Pi^{\mu\nu}(q) = i \int d^4x \cdot e^{iqx} \langle \mathbf{0} | T \{ J^\mu(x) J^{\nu\dagger}(0) \} | \mathbf{0} \rangle$$

Lorentz decomposition:

$$\Pi^{\mu\nu}(q) = (-g_{\mu\nu} q^2 + q^\mu q^\nu) \Pi^1(q^2) + q^\mu q^\nu \Pi^0(q^2)$$

$$\Pi^{(J)}(s) = \left| \mathcal{V}_{ud}^{eff} \right|^2 \Pi_{ud,V}^{(J)}(s) + \left| \mathcal{A}_{ud}^{eff} \right|^2 \Pi_{ud,A}^{(J)}(s) + \left| \mathcal{V}_{us}^{eff} \right|^2 \Pi_{us,V}^{(J)}(s) + \left| \mathcal{A}_{us}^{eff} \right|^2 \Pi_{us,A}^{(J)}(s)$$

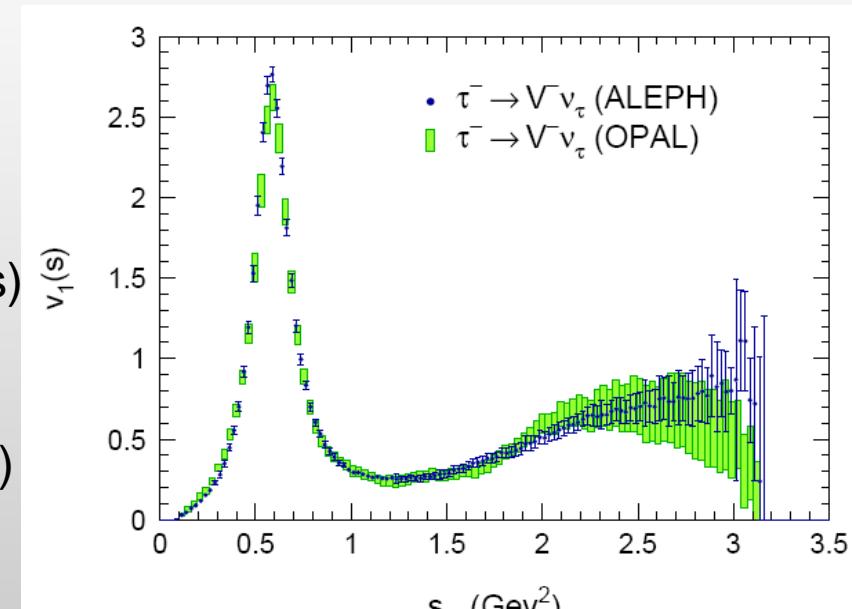
- We define : $R_\tau = \frac{\Gamma(\tau^- \rightarrow \nu_\tau \cdot h^- \cdot (\gamma))}{\Gamma(\tau^- \rightarrow \nu_\tau \cdot e^- \cdot \bar{\nu}_e(\gamma))}$
- Decomposition according to the final states observed and experimentally extracted :

$$R_\tau = R_{\tau,V} + R_{\tau,A} + R_{\tau,S}$$

$R_{\tau,V} \rightarrow \tau^- \rightarrow \nu_\tau + h_{V,s=0}$
(Ex: even number of pions)

$R_{\tau,A} \rightarrow \tau^- \rightarrow \nu_\tau + h_{A,s=0}$
(Ex: odd number of pions)

$R_{\tau,S} \rightarrow \tau^- \rightarrow \nu_\tau + h_{V+A,s=1}$



[Davier et al '05]

- Additional informations from the shape of the spectral functions
→ Different moments

$$R_{\tau,V/A}^{kl} = \int_0^{m_\tau^2} ds \left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \frac{dR_{\tau,V/A}}{ds}$$

3.3 Non-strange sector $\rightarrow \varepsilon_{\text{NS}}$

- Total rate:

$$R_{\tau,V+A} = 3 S_{EW} |\mathcal{V}_{eff}^{ud}|^2 (1 - 2\varepsilon_{ns}) (1 + \delta^{(0)}) \left(1 + \frac{\sum_{D=2,4..} (\delta_{ud,V}^{(D)} + \delta_{ud,A}^{(D)})}{1 + \delta^{(0)}} \right)$$

$$\frac{R_{\tau,A}}{R_{\tau,V}} = (1 - 4\varepsilon_{ns}) \cdot \frac{\left(1 + \delta^{(0)} + \sum_{D=2,4..} \delta_{ud,A}^{(D)} \right)}{\left(1 + \delta^{(0)} + \sum_{D=2,4..} \delta_{ud,V}^{(D)} \right)} \simeq (1 - 4\varepsilon_{ns}) \cdot \left(1 - \frac{\sum_{D=2,4..} (\delta_{ud,V}^{(D)} - \delta_{ud,A}^{(D)})}{1 + \delta^{(0)}} \right)$$

- Data from ALEPH and OPAL for $R_{V+A}^{k,l}$ and $R_{V/A}^{k,l}$
- Possible extraction of ε_{NS} , strongly correlated with $\alpha_s(m_\tau)$ (D=0)
 $|\mathcal{V}_{eff}^{ud}|$ is known from $0^+ \rightarrow 0^+$ superallowed β decays.
- What about the hadronic part ? \rightarrow Description using OPE
[Braaten et al '92, LeDiberder & Pich '92....]
- Inputs for the OPE : $\alpha_s(m_\tau), m_q(m_\tau), \left\langle \frac{\alpha_s}{\pi} GG \right\rangle, \langle \bar{q}_i q_i \rangle, \langle \bar{q}_i \Gamma_1 q_j \bar{q}_j \Gamma_2 q_i \rangle, \dots$

Theoretical framework: using OPE

[Braaten et al '92, LeDiberder & Pich '92....]

$$R_{\tau,V+A} = 3 S_{EW} \left| \mathcal{V}_{eff}^{ud} \right|^2 (1 - 2 \varepsilon_{ns}) (1 + \delta^{(0)}) \left(1 + \frac{\sum_{D=2,4..} (\delta_{ud,V}^{(D)} + \delta_{ud,A}^{(D)})}{1 + \delta^{(0)}} \right)$$

$$\delta^D = \frac{1}{(-s)^{D/2}} \sum_{\dim O=D} C^{(J)}(s, \mu) \cdot \langle O(\mu) \rangle$$

Wilson coefficients

Operators

with μ the separation scale between long and short distances.

- D=0: perturbative contributions
- D=2: quark masses corrections.
- D=4: non perturbative operators: $\left\langle \frac{\alpha_s}{\pi} GG \right\rangle, \left\langle m_j \bar{q}_i q_i \right\rangle$
- D=6: 4 quarks operators: $\left\langle \bar{q}_i \Gamma_1 q_j \bar{q}_j \Gamma_2 q_i \right\rangle$
- D≥8: Terms theoretically small and unknown → in a FIT !

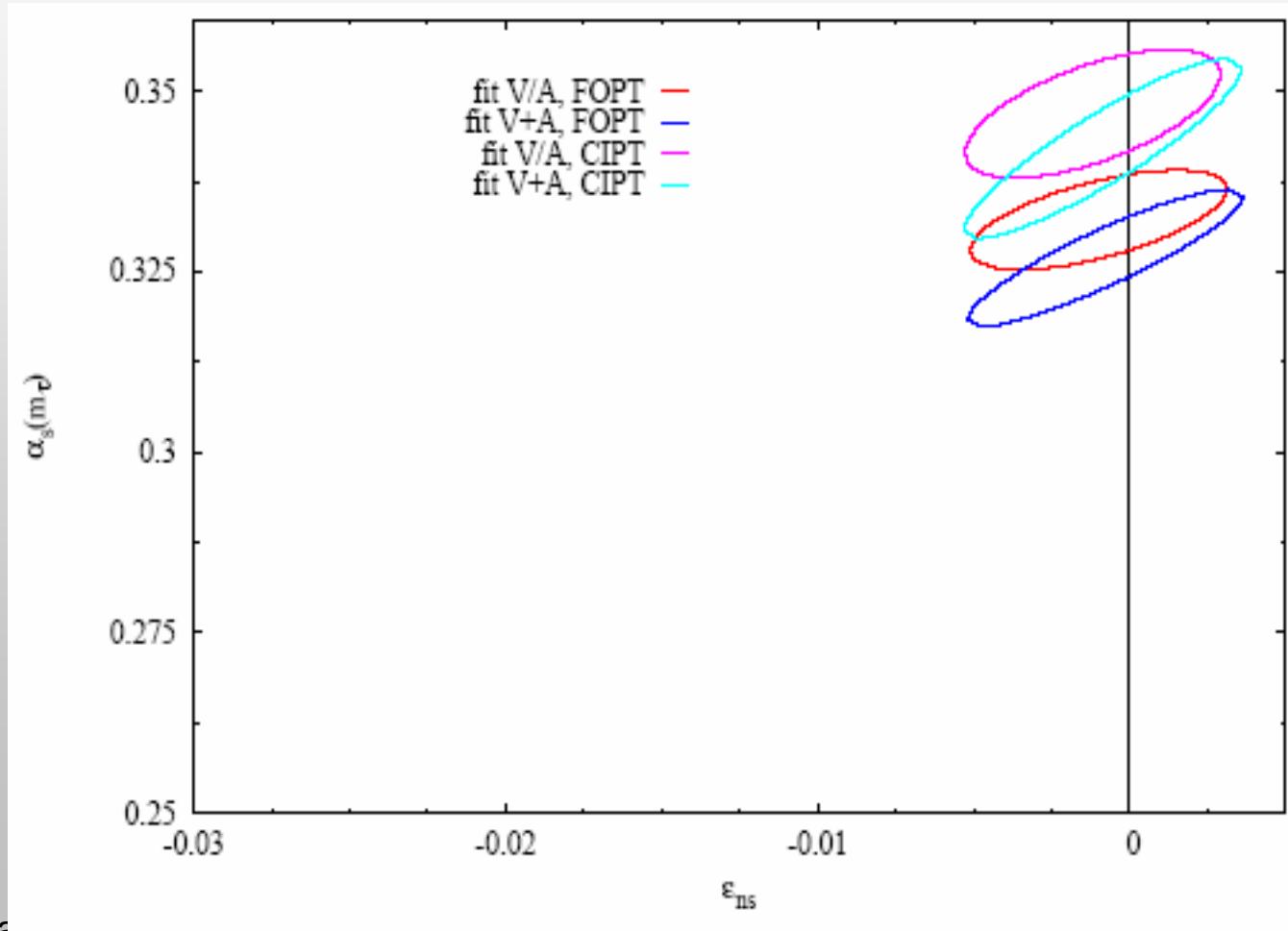
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Results of a FIT V+A and V and A with the OPAL data.

- Inputs : $R_{\tau,V/A}$ and $R_{\tau,V+A}$ and different moments : $R_{\tau,V/A, V+A}^{k,l}$ $[(k,l)=(1,0),(1,1),(1,2)...]$
- Parameters : $\alpha_s(m_\tau)$, $\left\langle \frac{\alpha_s}{\pi} GG \right\rangle$, ε_{NS} , condensates D=6 V-A, 8 and 10.
- Strong dependance in $\left\langle \frac{\alpha_s}{\pi} GG \right\rangle$ a priori unknown \rightarrow Put it outside the FIT.

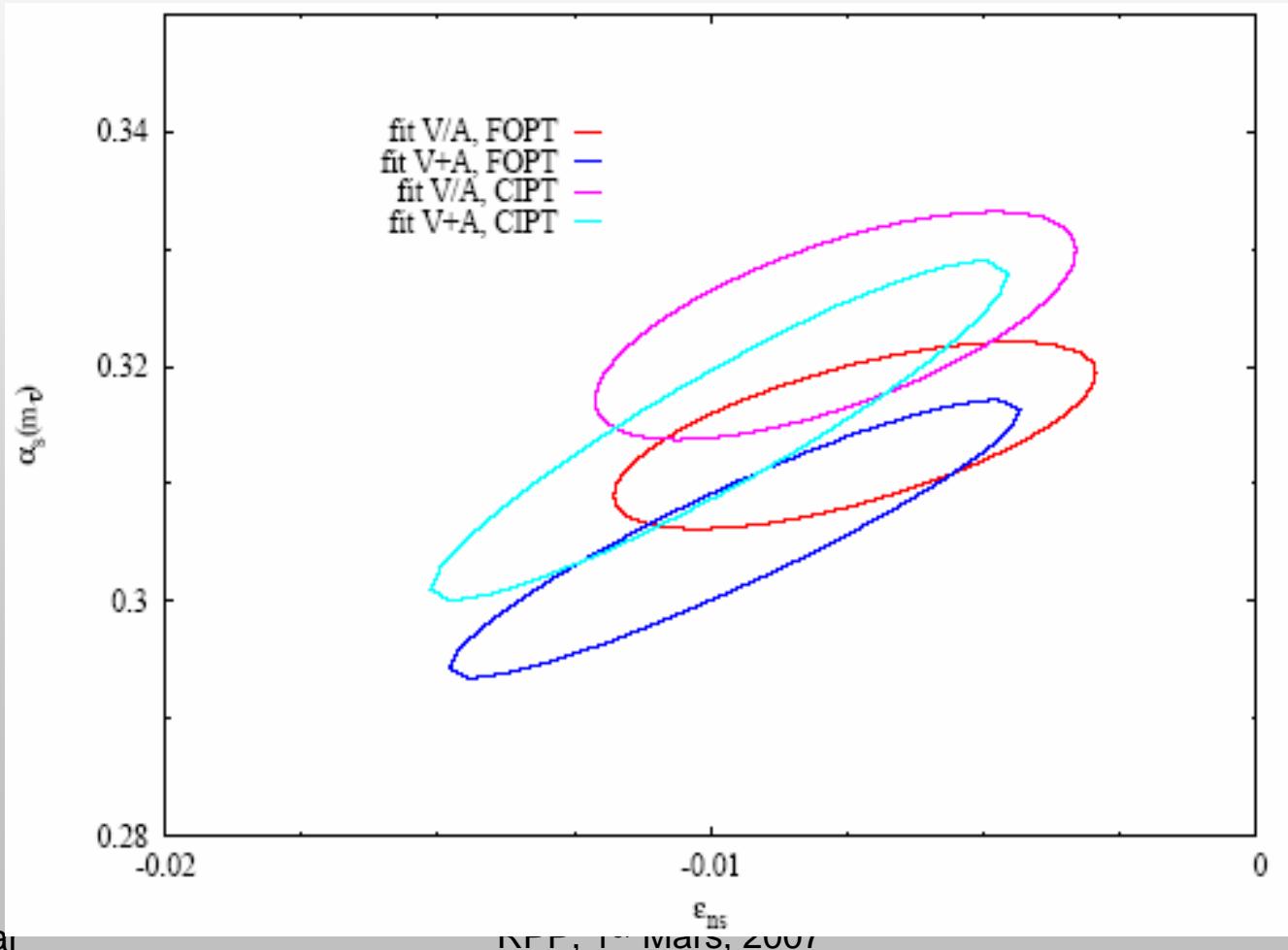
Results of a FIT V+A and V and A with the OPAL data.

$$\left\langle \frac{\alpha_s}{\pi} GG \right\rangle = -0.01 \text{ GeV}^4$$



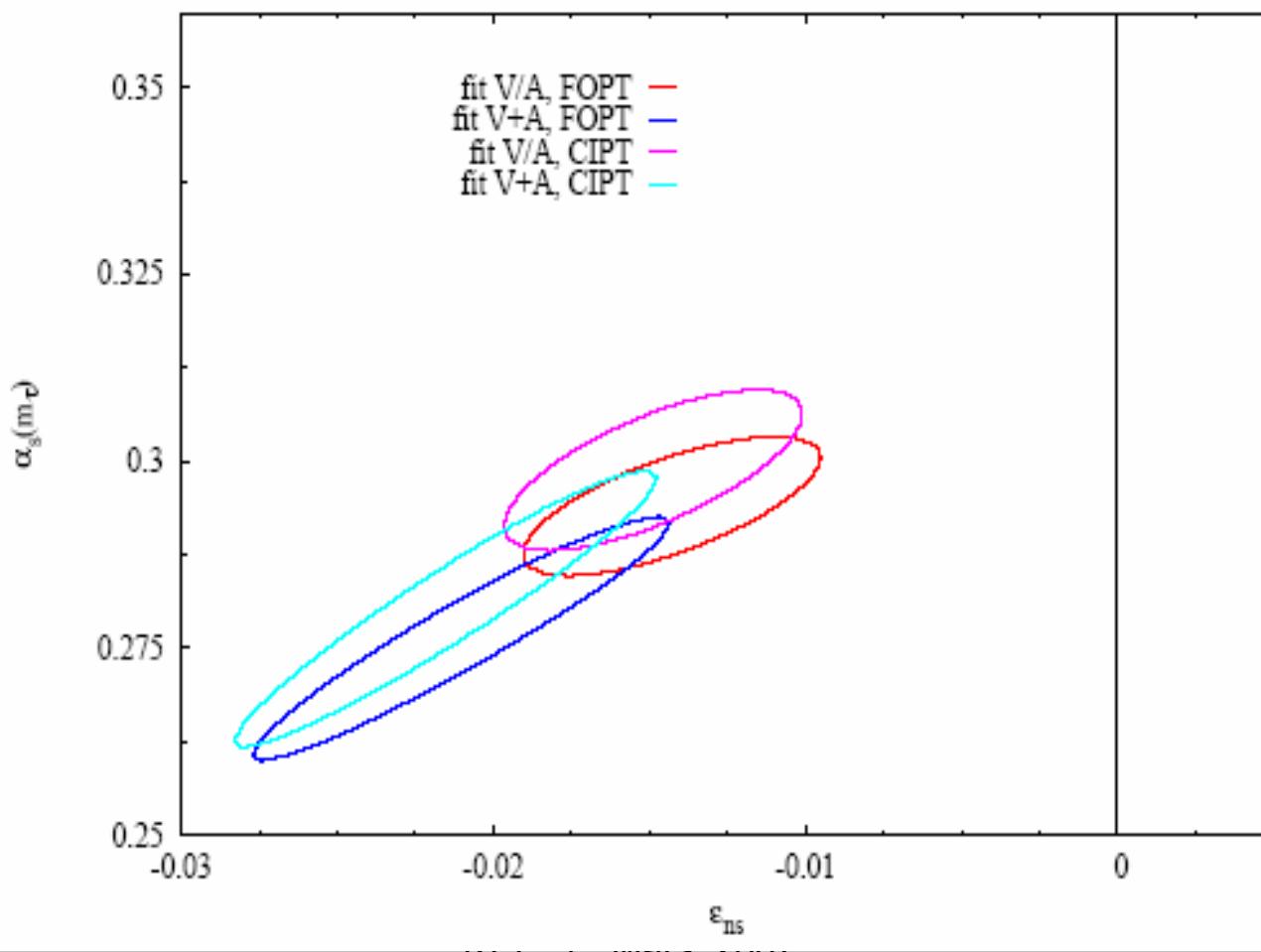
Results of a FIT V+A and V and A with the OPAL data.

$$\left\langle \frac{\alpha_s}{\pi} GG \right\rangle = 0 \text{ GeV}^4$$



Results of a FIT V+A and V and A with the OPAL data.

$$\left\langle \frac{\alpha_s}{\pi} GG \right\rangle = +0.01 \text{ GeV}^4$$



- Consistency between V+A and V/A data: same QCD parameters ($\alpha_s(m_\tau)$, condensates...),
- Theoretical uncertainties (knowledge of the gluonic condensate) limit the extraction of ε_{NS} . Fit not enough sensitive to all the unknown QCD parameters.
- $|\varepsilon_{\text{NS}}| \leq 0.01$, in agreement with the order of magnitude expected.
- We have to wait for more precise data (Babar, Belle...) and correlations between V and A from ALEPH.
- Theoretical improvements ?

3.3 Strange Sector: $\delta + \varepsilon_{\text{NS}}$

- In the Standard model : Many studies in the strange sector
[Gamiz et al. '04, ...]

$$\delta R_\tau = \frac{R_{\tau,V+A}}{|V^{ud}|^2} - \frac{R_{\tau,S}}{|V^{us}|^2}$$

SU(3) symmetry breaking quantity:
Theoretical uncertainty reduced.

- In the LEET, quantity impossible to use. Look instead at :

$$\frac{R_s}{R_{\text{NS}}} \simeq \frac{\sin^2 \hat{\theta}}{\cos^2 \hat{\theta}} \left(1 + \frac{2(\varepsilon_{\text{NS}} + \delta)}{\sin^2 \hat{\theta}} \right) \left(1 + \frac{\sum_{D=2,4..} (\delta_{us,V}^{(D)} + \delta_{us,A}^{(D)})}{2(1 + \delta^{(0)})} - \frac{\sum_{D=2,4..} (\delta_{ud,V}^{(D)} + \delta_{ud,A}^{(D)})}{2(1 + \delta^{(0)})} \right)$$

- Sensitive to $\delta + \varepsilon_{\text{NS}}$ ($1/\sin^2 \theta \sim 20$).

- Not sensitive to ε_s : Part

$$\frac{\sum_{D=2,4..} (\delta_{us,V}^{(D)} - \delta_{us,A}^{(D)})}{1 + \delta^{(0)}} \varepsilon_s \sim 10^{-4}$$

negligible.

$$\frac{R_S}{R_{NS}} \simeq \frac{\sin^2 \hat{\theta}}{\cos^2 \hat{\theta}} \left(1 + \frac{2(\varepsilon_{NS} + \delta)}{\sin^2 \hat{\theta}} \right) \left(1 + \frac{\sum_{D=2,4..} (\delta_{us,V}^{(D)} + \delta_{us,A}^{(D)})}{2(1 + \delta^{(0)})} - \frac{\sum_{D=2,4..} (\delta_{ud,V}^{(D)} + \delta_{ud,A}^{(D)})}{2(1 + \delta^{(0)})} \right)$$

- QCD part: same SU(3) symmetry breaking quantity, dominant term:

$$\frac{m_s^2(m_\tau^2)}{m_\tau^2}$$

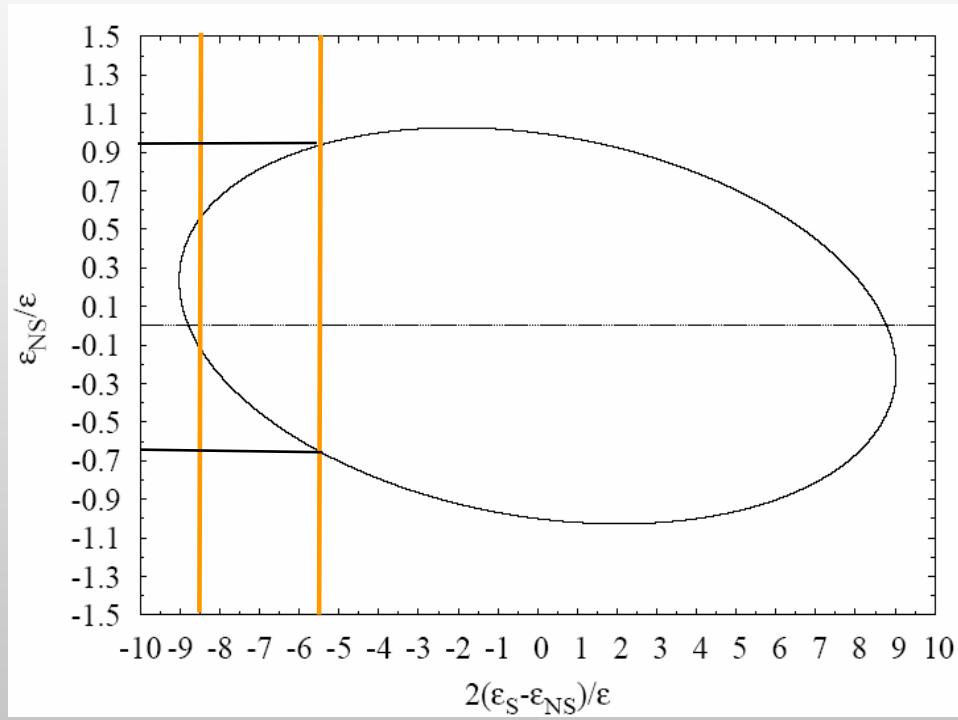


Convergence of the D=2 Wilson coefficient ? Knowledge of m_s ?

- Try phenomenological models to improve the convergence with different values of m_s .
 $\delta + \varepsilon_{NS}$ small per mile level.

4. Consistency of the analysis ?

- From the talk of M.Oertel, unitarity of V_R and $V_L + \text{NA48}$ measurement :



→ ϵ_{NS} small

Consistent with the Tau analysis.

$$2(\epsilon_s - \epsilon_{ns}) + \frac{\Delta_{CT}}{B_{\text{exp}}} = -0.074 \pm 0.014$$

$$\Delta_{CT}^{NLO} \sim -3.5 \cdot 10^{-3}$$

4. Consistency of the analysis ?

- Discussion: Unitarity of \mathcal{V}_{eff} ?

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

From nuclear
superallowed β
decays

From Ke3

$$2(\varepsilon_s - \varepsilon_{NS}) + \frac{\Delta_{CT}}{B_{exp}} = -0.074 \pm 0.014$$

$$\Delta_{CT}^{NLO} \sim -3.5 \cdot 10^{-3}$$

No reasons a priori for \mathcal{V}_{eff} unitary !

- Since $|\mathcal{V}_{eff}^{ud}|^2 + |\mathcal{V}_{eff}^{us}|^2 \sim 1 \rightarrow \delta + \varepsilon_{NS} \sim -(\varepsilon_s - \varepsilon_{NS}) \sin^2 \hat{\theta}$

$$\left. \begin{array}{l} \sin \hat{\theta} = 0.22 \\ \varepsilon_s - \varepsilon_{NS} \sim -0.035(7) \end{array} \right\} \delta + \varepsilon_{NS} \sim 0.002 \quad \begin{array}{l} \text{Z pole FIT:} \\ \delta = -0.0054(44) \end{array}$$

➡ Consistent !

Tau: ε_{NS} small

Conclusion :

- The LEET: a non decoupling scenario to look for physics beyond the standard model
- Analysis at NLO :
- Couplings to Z: 6 parameters to determine \rightarrow remarkable agreement with the data_{K_L} at Z pole.
- Couplings to W in the light quark sector: 3 parameters to determine δ and 2 ε .
 - $K_{\mu 3}^L$ decay constrains $(\varepsilon_s - \varepsilon_{NS})$ (Cf Talk M.Oertel)
 - No other experiments where we can detect a possible enhancement of ε_S
 - Hadronic τ decays : $\rightarrow \varepsilon_{NS}$ and $\delta + \varepsilon_{NS}$ but uncertainties on the hadronic parameters: order of magnitude in agreement with the prediction of the LEET.
 - Γ_W , neutrinos $\rightarrow \delta$
- Consistency !

Outlook :

- Heavy quarks, neutral currents, loop effects (CP violation, FCNC....).

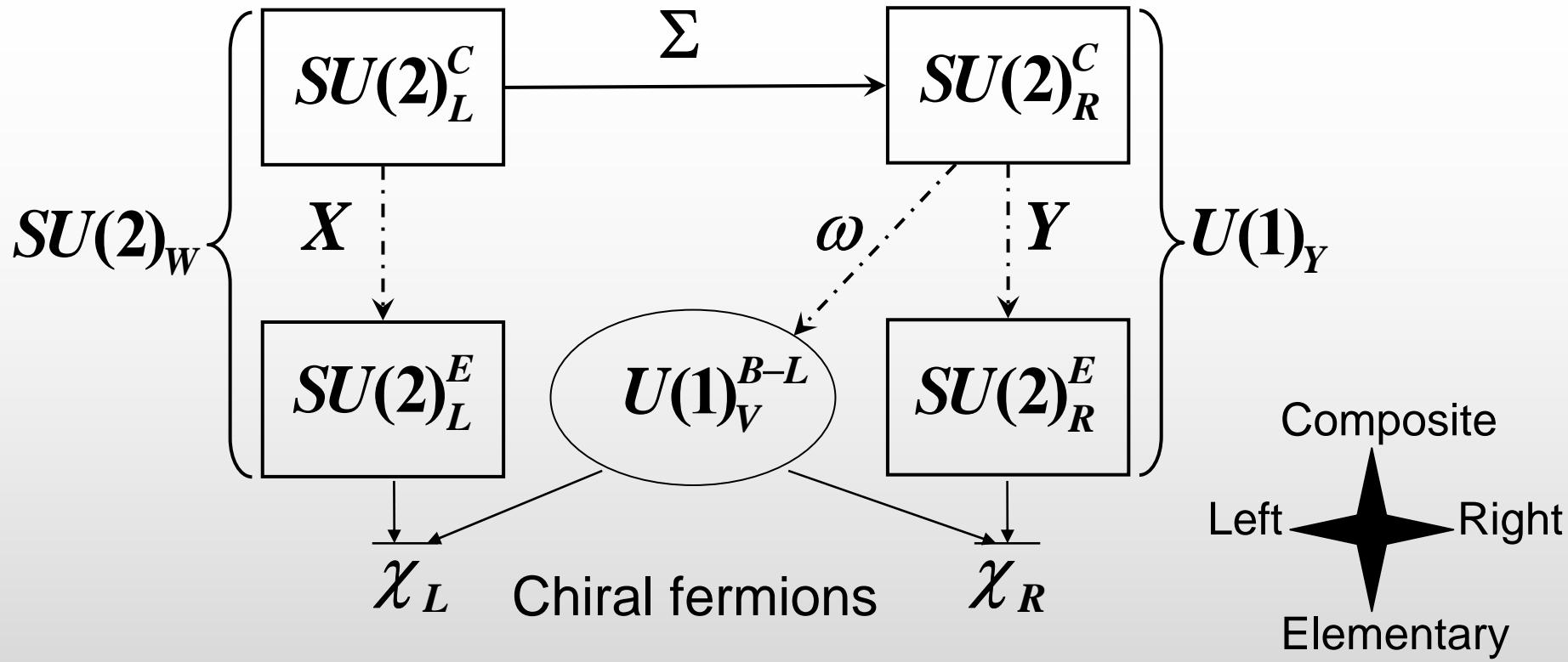
Additionnal slides

The LEET :

Minimal Higgs-less LEET

[J.Hirn & J.Stern, Phys.Rev.D73 '06]

- What is S_{nat} ?
 - S_{nat} can be inferred from \mathcal{L}_{SM} asking :
 - At $\mathcal{O}(p^2)$, S_{nat} selects all the (Higgs-less) vertices of the SM and nothing else.
 - Minimality.
 - $S_{nat} = [SU(2) \otimes SU(2)]^2 \otimes U(1)_{B-L} \otimes Z_{2\nu_R}$
- $Z_{2\nu_R}$: $\nu_R \rightarrow -\nu_R$: forbids Dirac neutrino masses and charged leptonic right-handed currents.



- GB Σ : link $L \longleftrightarrow R$
- Spurions X, Y, ω : link $C \longleftrightarrow E$
- Covariant constraints reducing the symmetry and the physical dof to

$$SU(2) \otimes U(1)_Y \Leftrightarrow D_\mu X = D_\mu Y = D_\mu \omega = 0$$

- $X \sim \xi$ $Y \sim \eta$ $\omega \sim \zeta$ small expansion parameters :

RP $\xi \cdot \eta = \frac{m_{top}}{\Lambda_w} = O(p)$, $\zeta \ll \xi, \eta \dots LNV$

Theoretical prediction

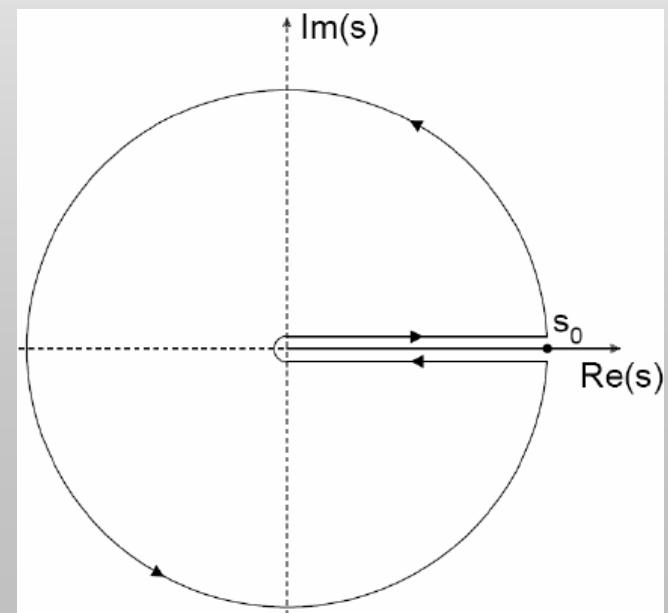
[Braaten et al '92, LeDiberder & Pich '92....]

$$R_\tau(m_\tau^2) = 6i\pi S_{EW} \oint_{|s|=m_\tau^2} \frac{ds}{m_\tau^2} \left(1 - \frac{s}{m_\tau^2}\right)^2 \left[\left(1 + 2\frac{s}{m_\tau^2}\right) \text{Im} \Pi^{(1)}(s) + \text{Im} \Pi^{(0)}(s) \right]$$

- Problem: $\text{Im} \Pi_{V/A}$ contains hadronic part that cannot be predicted in QCD.
- Use of the analytic properties of the correlator and the Cauchy Theorem:
 Π is analytic except on the real, positive x axis.

$$\frac{1}{\pi} \int_0^{s_0} ds \cdot g(s) \cdot \text{Im} \Pi(s) = -\frac{1}{2\pi i} \oint_{|s|=s_0} ds \cdot g(s) \cdot \Pi(s)$$

- We are now at High energy $s_0 = M_\tau^2 = 3 \text{ GeV}^2$
OPE is valid.
- Kinematical factor \rightarrow
small contribution near the real positive axis.



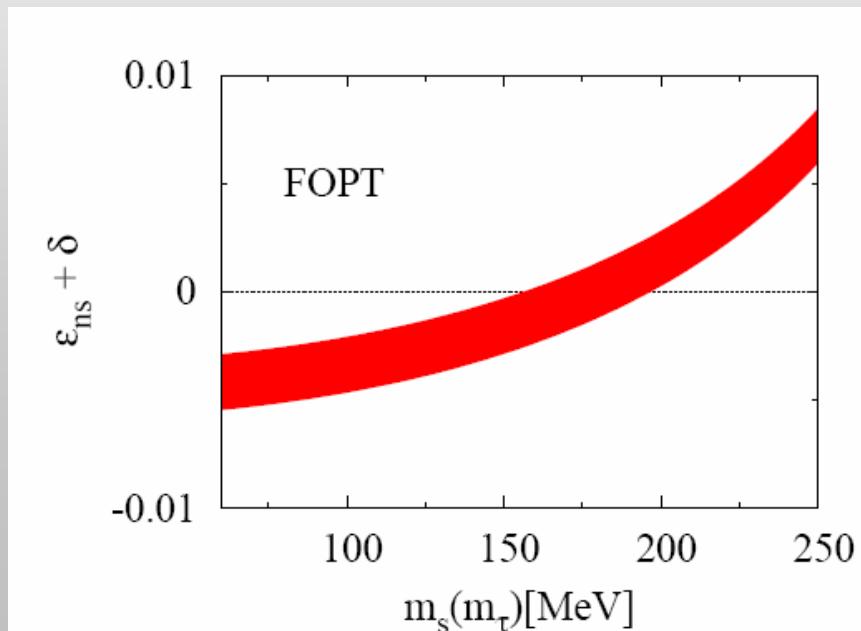
$$\frac{R_S}{R_{NS}} \simeq \frac{\sin^2 \hat{\theta}}{\cos^2 \hat{\theta}} \left(1 + \frac{2(\varepsilon_{NS} + \delta)}{\sin^2 \hat{\theta}} \right) \left(1 + \frac{\sum_{D=2,4..} (\delta_{us,V}^{(D)} + \delta_{us,A}^{(D)})}{2(1 + \delta^{(0)})} - \frac{\sum_{D=2,4..} (\delta_{ud,V}^{(D)} + \delta_{ud,A}^{(D)})}{2(1 + \delta^{(0)})} \right)$$

- QCD part: same SU(3) symmetry breaking quantity, dominant term:

$$\frac{m_s^2(m_\tau^2)}{m_\tau^2}$$



Convergence of the D=2 Wilson coefficient ? Knowledge of m_s ?



[ALEPH data]

1.1 Standard decoupling scenario

- Low Energy degrees of freedom:
 - all observed particles
 - gauge group $SU(2)_W \otimes U(1)_Y$

Standard Model
 - At Higher Energy, new symmetries and particles:
 - Heavy states beyond the SM.
 - Higher symmetries beyond $SU(2)_W \otimes U(1)_Y$
- Irrelevant at Low Energy $E \ll \Lambda$

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{D>4} \frac{1}{\Lambda^{D-4}} \mathcal{O}_D \quad \text{With D: mass dimension}$$

- At NLO, 80 independent D=6 $SU(2)_W \otimes U(1)_Y$ invariant operators.
- A finer classification of these new operators is needed !