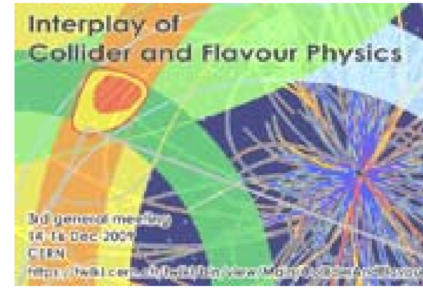
New Physics bounds from CKM-unitarity



Interplay of colliders & flavour physics

**CERN,
14-16 December'09**

Martín González-Alonso

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Instituto de Física Corpuscular (CSIC – UV)

Introduction

In the New Physics search...

Can flavor exp. compete with colliders exp.?

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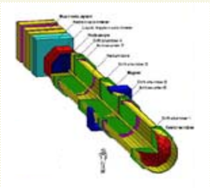

≈ 200 people

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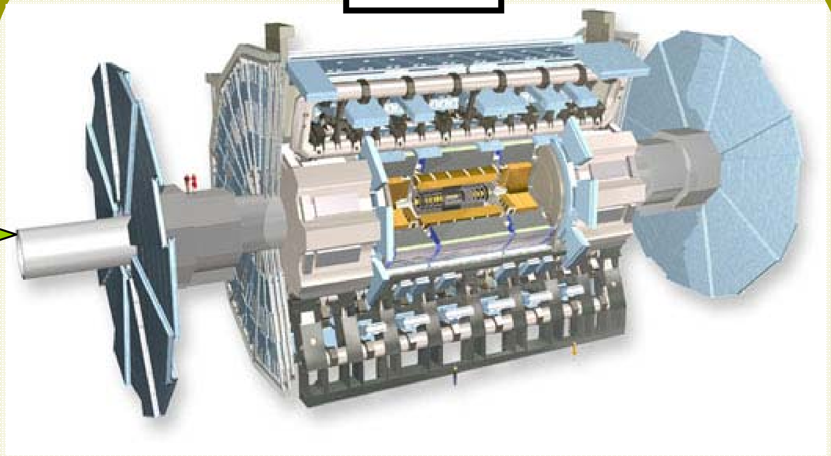

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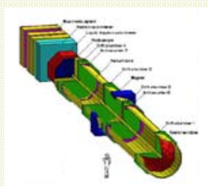

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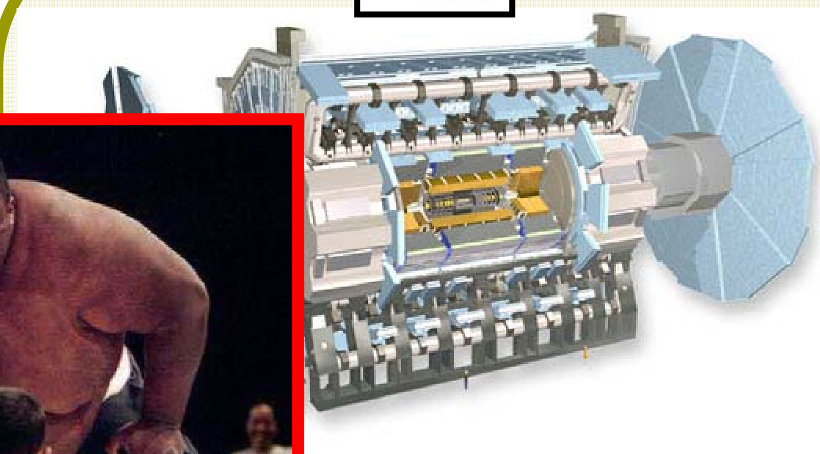

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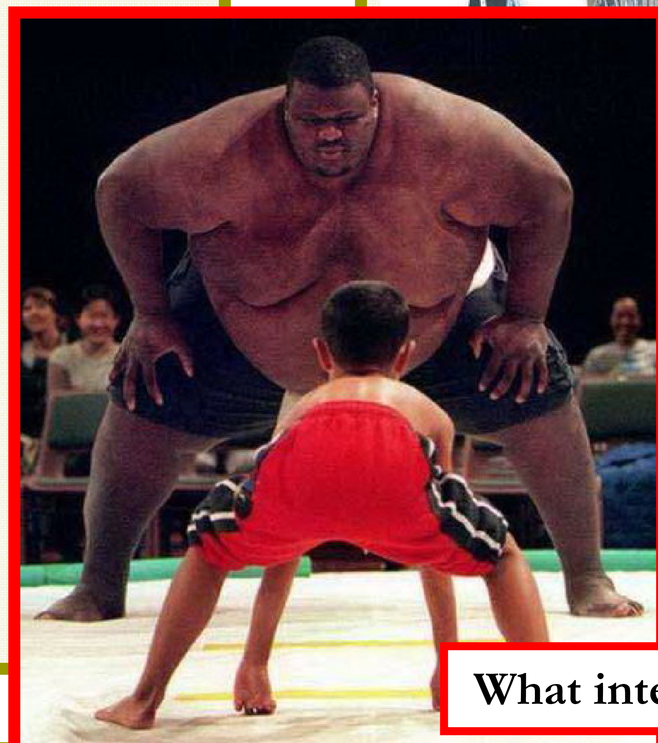

What interplay?

Colliders & flavour

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In the New Physics search…

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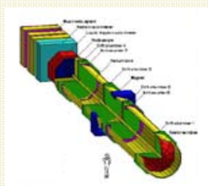

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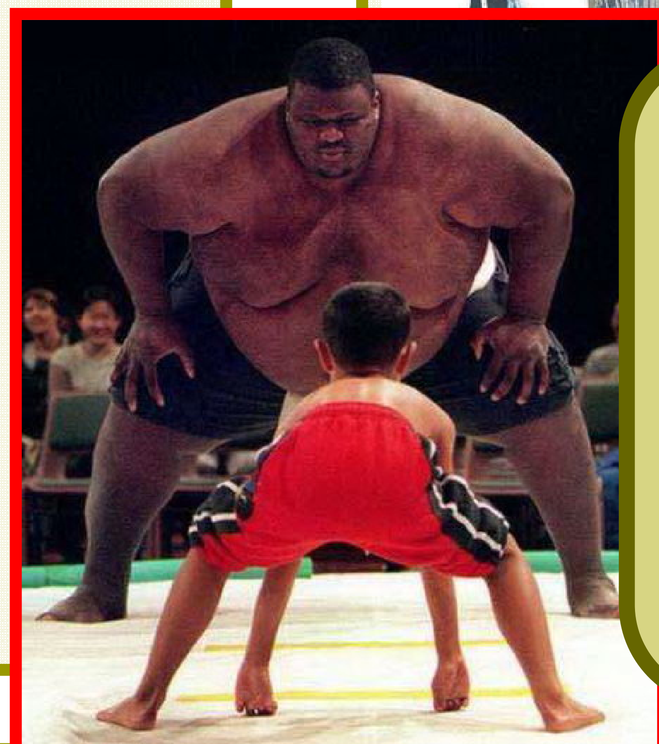

But we know this is not that simple…

Kaon processes:

- Theoretically clean! (errors < 1% in SM det.);
- Precise experimental data available and forthcoming ;

Introduction: Phenomenology of V_{ud} & V_{us}

$$\Delta_{CKM} \equiv |V_{ud}|^2 + |V_{us}|^2 + \cancel{|V_{ub}|^2} - 1$$

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

Colliders & flavour

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1) Beta decay ➔ determination of $G_F V_{ij}$:

$\left(d^j \to u^i l \bar{\nu}_l\right)$

$\langle f | \bar{u}^i \gamma^\mu d^j | i \rangle$ $\quad$ $\langle f | \bar{u}^i \gamma^\mu \gamma_5 d^j | i \rangle$

	Vector	Axial-Vector	Both
V_{ud}	$0^+ \to 0^+$ decays $\pi^+ \to \pi^0 e^+ \nu$	$\pi^+ \to e^+ \nu$	Neutron decay
V_{us}	$K \to \pi e \nu$	$K^+ \to e^+ \nu$	Hyperon decay Tau decay

$\left(\mu \to e \bar{\nu}_e \nu_\mu\right)$

2) Muon decay ➔ determination of G_F;

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V_{ij}

$(\mu \to e \bar{\nu}_e \nu_\mu)$

2) Muon decay ➔ determination of G_F;

How do the NP-terms affect this?

Colliders & flavour

Introduction: Phenomenology of V_{ud} & V_{us}

$$V_{ud} = 0.97425(22)$$
$$V_{us} = 0.2252(9)$$
$$V_{ub} \sim 10^{-3}$$

0.02% precision!

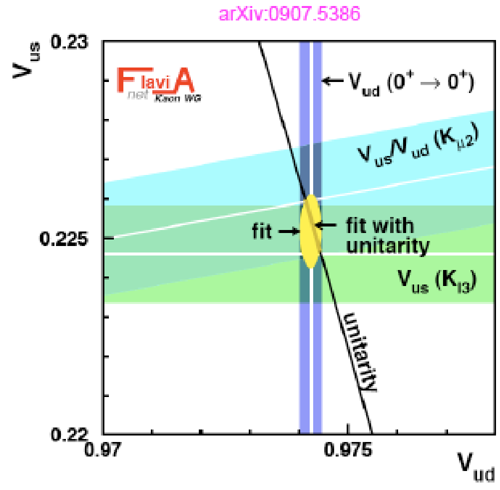
0.4% precision!

(Hardy & Towner, 2008)

From 0+→0+ nuclear beta decays

(Antonelli et al., 2009)

From Kl3 and Kl2



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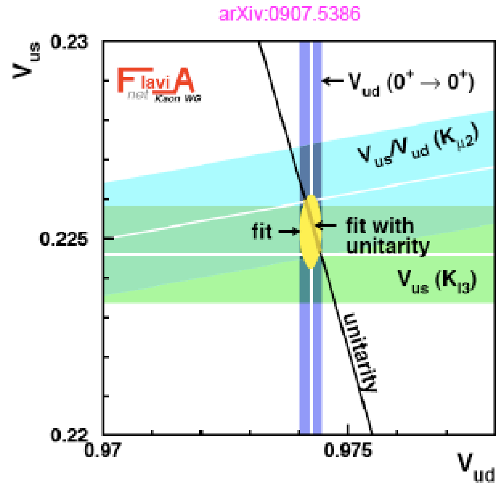

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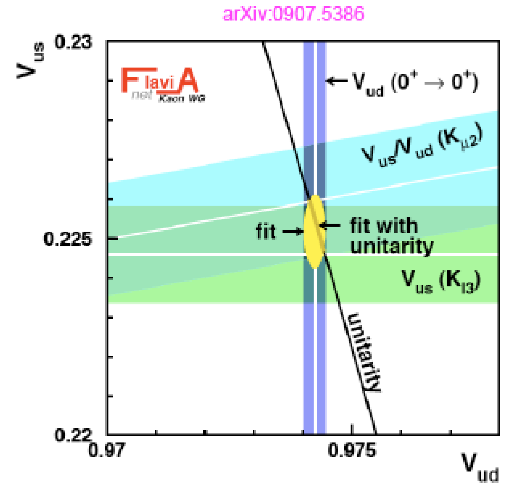

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$$NP \sim \frac{M_W^2}{\Lambda^2} \Rightarrow \Lambda \sim \mathrm{TeV}$$

- Confirms large EW rad. corr. ($2\,\alpha/\pi \log(M_Z/M_p)$=+3.6%) Marciano-Sirlin
- It would naively fit M_Z = (90 ± 7) GeV !! Marciano, CKM 2008

Introduction

$$\Delta_{CKM} \equiv |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = -(1 \pm 6) \cdot 10^{-4}$$

The precise question is:

Is this constraint telling us something about NP that we do not know from Collider experiments?

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- **Model-dependent approaches…**

YES!

W. Marciano, *KAON'07*

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- ***More* model-independent approach…**

  V. Cirigliano, M. G.-A. & J. Jenkins

  arXiv: 0908.1754 [hep-ph]

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- ***More* model-independent approach…**

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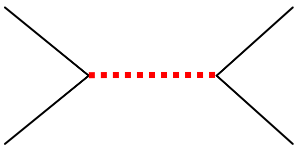
EFF. LAGRANGIAN
||
Particles + Symmetries

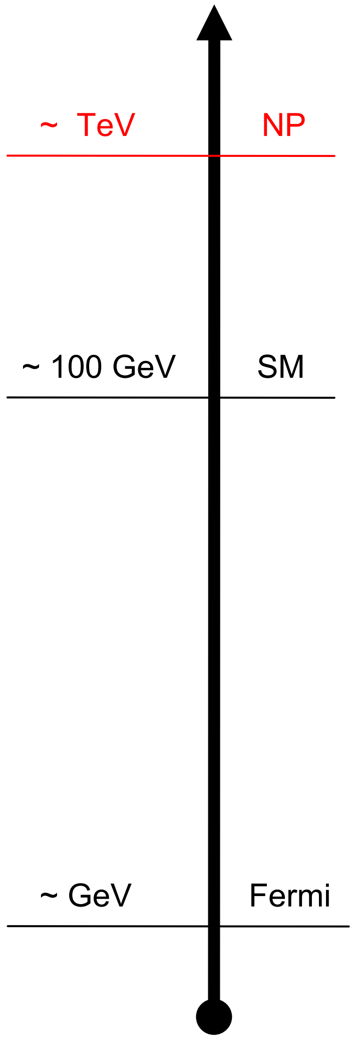
- SM-Higgs;
- THDM;
- No Higgs;
- With ν_R;
- …

+

- L, B cons.;
- CPV;
- Custodial sym.;
- Flavor sym.;
- …

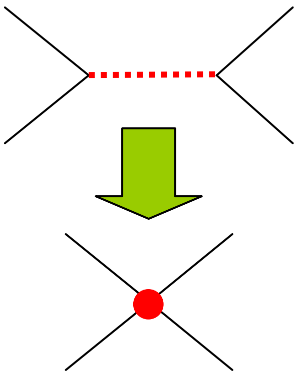
The eff. Lagrangian for E~100 GeV

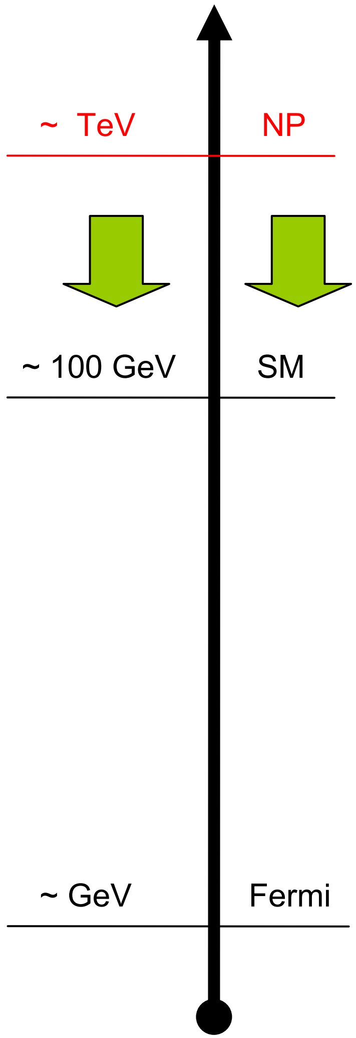




$$\mathcal{L}^{TeV}(x) = \mathcal{L}(\text{SM-fields, bSM-fields})$$

The eff. Lagrangian for E~100 GeV





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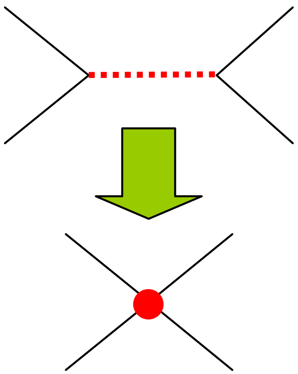
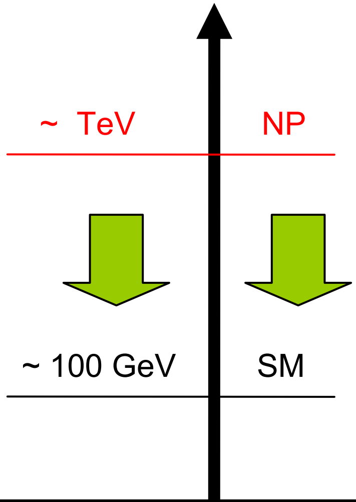
Buchmüller-Wyler'1986, Leung et al.'1986

$$\mathcal{L}^{\text{eff.}}(x) = \mathcal{L}_{SM}(x) + \frac{1}{\Lambda}\mathcal{L}_5(x) + \frac{1}{\Lambda^2}\mathcal{L}_6(x) + \dots$$

$$\left(\mathcal{L}_n(x) = \sum_i \alpha_i^{(n)} O_i^{(n)}(x) \right)$$

The eff. Lagrangian for E~100 GeV





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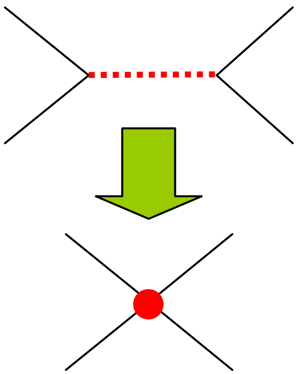
ASSUMPTIONS:

- Gap SM-NP;
- SM Higgs doublet;
- NP weakly coupled at the EW scale;
- Lepton and baryon number conservation;
- No new sources of CPV beyond CKM;
- Flavor symmetries?

The eff. Lagrangian for E~100 GeV



~ TeV | NP

~ 100 GeV | SM

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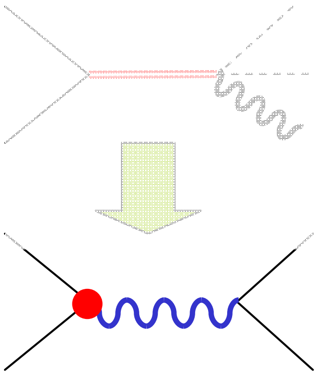
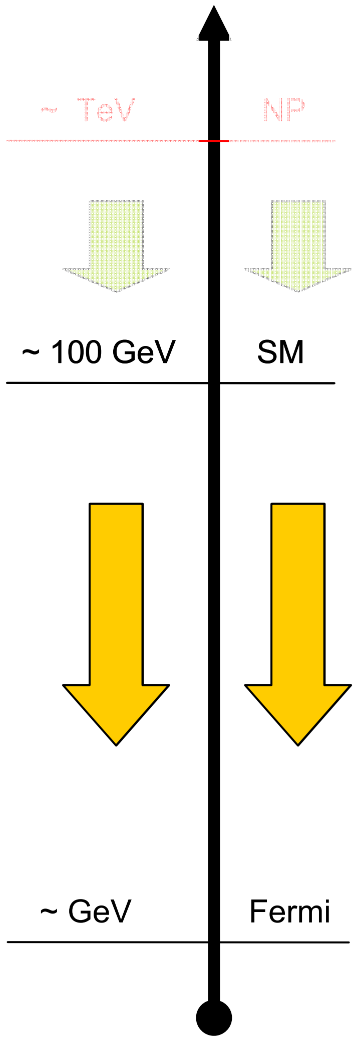
BW list: **77 operators;**

"Only" 25 contribute to…

- EW precision obs.;
- Muon & Beta decays;

The eff. Lagrangian for E~1 GeV





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Cirigliano, M. G-A., Jenkins'2009

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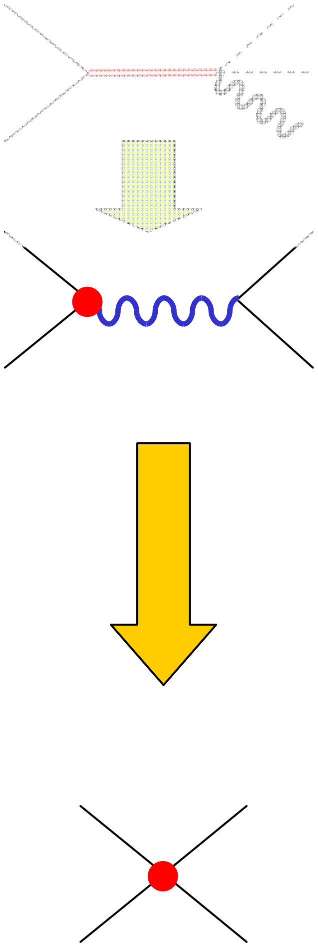

~ TeV	NP
~ 100 GeV	SM
~ GeV	Fermi

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$v \approx 174\ GeV$

$$\mathcal{L}^{eff}_{\mu\to e\nu\bar{\nu}}(x) = \mathcal{L}^{eff,\,SM}_{\mu\to e\nu\bar{\nu}}(x) + \frac{v^2}{\Lambda^2}\mathcal{L}^{eff,\,bSM}_{\mu\to e\nu\bar{\nu}}(x)$$

$$\mathcal{L}^{eff}_{d^j\to u^i l\bar{\nu}}(x) = \mathcal{L}^{eff,\,SM}_{d^j\to u^i l\bar{\nu}}(x) + \frac{v^2}{\Lambda^2}\mathcal{L}^{eff,\,bSM}_{d^j\to u^i l\bar{\nu}\nu}(x)$$

The eff. Lagrangian for E~1 GeV

- Muon decay: $\boxed{\mu^- \to e^- \nu_\mu \bar{\nu}_e}$

(V-A) • (V-A)

(S-P) • (S+P)

$$\mathcal{L}^{eff}_{\mu\to e\nu\bar{\nu}}(x) = \frac{-g^2}{2m_W^2}\left[(1+\tilde{v}_L)(\bar{e}_L\gamma_\mu\nu_{eL})(\bar{\nu}_{\mu L}\gamma_\mu\mu_L) + \tilde{s}_L(\bar{e}_R\nu_{eL})(\bar{\nu}_{\mu L}\mu_R)\right] + h.c..$$

where…

$$\tilde{v}_L = 2\,[\hat{\alpha}^{(3)}_{\varphi l}]_{11+22^*} - [\hat{\alpha}^{(1)}_{ll}]_{1221} - 2[\hat{\alpha}^{(3)}_{ll}]_{1122-\frac{1}{2}(1221)}$$

$$\tilde{s}_R = +2[\hat{\alpha}_{le}]_{2112}\ ,$$

$$\left(\hat{\alpha}_X \equiv \alpha_X \frac{v^2}{\Lambda^2}\right)$$

The eff. Lagrangian for E~1 GeV

- Beta decay: $\boxed{d^j \to u^i l \bar{\nu}_l}$

$$\mathcal{L}^{eff}_{d^j \to u^i l \bar{\nu}_l}(x) = \frac{-g^2}{2m_W^2} V_{ij} \left[\begin{array}{l} \overset{\text{(V-A)} \bullet \text{(V-A)}}{(1+v_L)(\bar{u}^i_L \gamma^\mu d^j_R)(\bar{l}_L \gamma_\mu \nu_{lL})} + \overset{\text{(V+A)} \bullet \text{(V-A)}}{v_R(\bar{u}^i_R \gamma^\mu d^j_R)(\bar{l}_L \gamma_\mu \nu_{lL})} \\ + \overset{\text{(S-P)} \bullet \text{(S+P)}}{s_L(\bar{u}^i_R d^j_L)(\bar{l}_R \nu_{lL})} + \overset{\text{(S+P)} \bullet \text{(S+P)}}{s_R(\bar{u}^i_L d^j_R)(\bar{l}_R \nu_{lL})} \\ + \overset{\text{(T-T')} \bullet \text{(T-T')}}{t_L(\bar{u}^i_R \sigma^{\mu\nu} d^j_L)(\bar{l}_R \sigma_{\mu\nu} \nu_{lL})} \end{array} \right] + h.c.$$

where…

$$\begin{aligned} V_{ij} \cdot [v_L]_{\ell\ell ij} &= 2\,V_{ij} \left[\hat{\alpha}^{(3)}_{\varphi l}\right]_{\ell\ell} + 2\,V_{im} \left[\hat{\alpha}^{(3)}_{\varphi q}\right]^*_{jm} - 2\,V_{im} \left[\hat{\alpha}^{(3)}_{lq}\right]_{\ell\ell mj} \\ V_{ij} \cdot [v_R]_{\ell\ell ij} &= -\left[\hat{\alpha}_{\varphi\varphi}\right]_{ij} \\ V_{ij} \cdot [s_L]_{\ell\ell ij} &= -\left[\hat{\alpha}_{lq}\right]^*_{\ell\ell ji} \\ V_{ij} \cdot [s_R]_{\ell\ell ij} &= -V_{im} \left[\hat{\alpha}_{qde}\right]^*_{\ell\ell jm} \\ V_{ij} \cdot [t_L]_{\ell\ell ij} &= -\left[\hat{\alpha}^t_{lq}\right]^*_{\ell\ell ji} \,. \end{aligned}$$

The eff. Lagrangian for E~1 GeV

- Muon decay: $\mathcal{L}^{eff}_{\mu \to e \nu \bar{\nu}}(x) = \ldots$
- Beta decay: $\mathcal{L}^{eff}_{d^j \to u^i l \bar{\nu}_l}(x) = \ldots$

(See FLAVIAnet Kaon Working Group'2008)

OBSERVABLES

$$\Gamma(K_{l3}),\ \frac{\Gamma(K_{l2})}{\Gamma(\pi_{l2})},\ \frac{\Gamma(P_{e2})}{\Gamma(P_{\mu 2})},\ \ldots = O_{SM}\left(1+\delta(\alpha_1,\alpha_2,\ldots)\right)$$

NP flavor structure

- Generic structure? FCNC!

$$O_{\varphi l}^{(3)} \equiv i(\varphi^\dagger D^\mu \sigma^a \varphi)(\bar{l}\gamma_\mu \sigma^a l) + h.c.$$

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$$\alpha_{\varphi l}^{(3)} O_{\varphi l}^{(3)} \equiv \sum_{\alpha,\beta=1}^{3} [\alpha_{\varphi l}^{(3)}]_{\alpha\beta} [O_{\varphi l}^{(3)}]_{\alpha\beta} + h.c.$$

$$= i(\varphi^\dagger D^\mu \sigma^a \varphi)\left(\begin{pmatrix} \bar{l}_e & \bar{l}_\mu & \bar{l}_\tau \end{pmatrix} \gamma_\mu \sigma^a \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} \begin{pmatrix} l_e \\ l_\mu \\ l_\tau \end{pmatrix} \right) + h.c.$$

Colliders & flavour

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Structure?

$$= i(\varphi^\dagger D^\mu \sigma^a \varphi)\left(\begin{pmatrix} \bar{l}_e & \bar{l}_\mu & \bar{l}_\tau \end{pmatrix} \gamma_\mu \sigma^a \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} \begin{pmatrix} l_e \\ l_\mu \\ l_\tau \end{pmatrix} \right) + h.c.$$

- It is convenient to organize the discussion in terms of perturbations around the FB limit…

NP flavor structure

$$i(\varphi^\dagger D^\mu \sigma^a \varphi)\left(\begin{pmatrix} \bar{l}_e \\ \bar{l}_\mu \\ \bar{l}_\tau \end{pmatrix} \gamma_\mu \sigma^a \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} \begin{pmatrix} l_e & l_\mu & l_\tau \end{pmatrix}\right)$$

- Case 1: FB…

$$\alpha_{\varphi l}^{(3)} = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} = \bar{\alpha}_{\varphi l}^{(3)} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Colliders & flavour

NP flavor structure

$$i(\varphi^\dagger D^\mu \sigma^a \varphi)\left(\begin{pmatrix} \bar{l}_e \\ \bar{l}_\mu \\ \bar{l}_\tau \end{pmatrix} \gamma_\mu \sigma^a \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} \begin{pmatrix} l_e & l_\mu & l_\tau \end{pmatrix}\right)$$

- Case 1: FB…

$$\alpha_{\varphi l}^{(3)} = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} = \bar{\alpha}_{\varphi l}^{(3)} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- Case 2: MFV… *(D'Ambrosio, Giudice, Isidori, Strumia, 2002)*

$$\alpha_{\varphi l}^{(3)} = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} = \bar{\alpha}_{\varphi l}^{(3)} \, \mathbb{I}_{3x3} + \bar{\beta}_{\varphi l}^{(3)} \, \Delta_{LL}^{(l)} + \ldots$$

$$= \bar{\alpha}_{\varphi l}^{(3)} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + \bar{\beta}_{\varphi l}^{(3)} \, 10^{-4} \begin{pmatrix} \sim 0.1 & \sim 0.1 & \sim 0.1 \\ \sim 0.1 & \sim 1 & \sim 1 \\ \sim 0.1 & \sim 1 & \sim 1 \end{pmatrix} + \ldots$$

$$\boxed{\begin{aligned} \Delta_{LL}^{(q)} &= V^\dagger \, \bar{\lambda}_u^2 \, V \\ \Delta_{LL}^{(\ell)} &= \frac{\Lambda_{\mathrm{LN}}^2}{v^4} \, U \, \bar{m}_\nu^2 \, U^\dagger \end{aligned}}$$

NP flavor structure

$$i(\varphi^\dagger D^\mu \sigma^a \varphi)\left(\begin{pmatrix}\bar{l}_e\\ \bar{l}_\mu \\ \bar{l}_\tau\end{pmatrix}\gamma_\mu\sigma^a\begin{pmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{pmatrix}\begin{pmatrix}l_e & l_\mu & l_\tau\end{pmatrix}\right)$$

- Case 1: FB…

$$\alpha_{\varphi l}^{(3)} = \begin{pmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{pmatrix} = \bar{\alpha}_{\varphi l}^{(3)}\begin{pmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{pmatrix}$$

- Case 2: MFV… *(D'Ambrosio, Giudice, Isidori, Strumia, 2002)*

$$\alpha_{\varphi l}^{(3)} = \begin{pmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{pmatrix} = \bar{\alpha}_{\varphi l}^{(3)}\ \mathbb{I}_{3x3} + \bar{\beta}_{\varphi l}^{(3)}\ \Delta_{LL}^{(l)} + \ldots$$

$$\begin{aligned}\Delta_{LL}^{(q)} &= V^\dagger\,\bar{\lambda}_u^2\,V\\ \Delta_{LL}^{(\ell)} &= \frac{\Lambda_{\rm LN}^2}{v^4}\,U\,\bar{m}_\nu^2\,U^\dagger\end{aligned}$$

$$= \bar{\alpha}_{\varphi l}^{(3)}\begin{pmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{pmatrix} + \bar{\beta}_{\varphi l}^{(3)}\ 10^{-4}\begin{pmatrix}\sim 0.1 & \sim 0.1 & \sim 0.1\\ \sim 0.1 & \sim 1 & \sim 1\\ \sim 0.1 & \sim 1 & \sim 1\end{pmatrix} + \ldots$$

- Case 3: More generic structure…

$$\alpha_{\varphi l}^{(3)} = \begin{pmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{pmatrix}$$

FB case: Phenomenology

$\mu^- \to e^- \nu_\mu \bar{\nu}_e$

$$\mathcal{L}^{eff}_{\mu\to e\nu\bar{\nu}}(x) = \frac{-g^2}{2m_W^2}\Big[(1+\tilde{v}_L)(\bar{e}_L\gamma_\mu \nu_{eL})(\bar{\nu}_{\mu L}\gamma_\mu \mu_L) + \tilde{s}_L(\bar{e}_R \nu_{eL})(\bar{\nu}_{\mu L}\mu_R)\Big] + h.c.$$

$d^j \to u^i l \bar{\nu}_l$

$$\mathcal{L}^{eff}_{d^j\to u^i l\bar{\nu}_l}(x) = \frac{-g^2}{2m_W^2}V_{ij}\begin{bmatrix}(1+v_L)(\bar{u}^i_L\gamma^\mu d^j_R)(\bar{l}_L\gamma_\mu \nu_{lL}) + v_R(\bar{u}^i_R\gamma^\mu d^j_R)(\bar{l}_L\gamma_\mu \nu_{lL}) \\ +s_L(\bar{u}^i_R d^j_L)(\bar{l}_R \nu_{lL}) + s_R(\bar{u}^i_L d^j_R)(\bar{l}_R \nu_{lL}) \\ +t_L(\bar{u}^i_R\sigma^{\mu\nu} d^j_L)(\bar{l}_R\sigma_{\mu\nu}\nu_{lL})\end{bmatrix} + h.c.$$

Colliders & flavour

FB case: Phenomenology

$\mu^- \to e^- \nu_\mu \bar{\nu}_e$

$$\mathcal{L}^{eff}_{\mu\to e\nu\bar{\nu}}(x) = \frac{-g^2}{2m_W^2}\left[(1+\tilde{v}_L)(\bar{e}_L\gamma_\mu \nu_{eL})(\bar{\nu}_{\mu L}\gamma_\mu \mu_L) + \cancel{\tilde{s}_L(\bar{e}_R \nu_{eL})(\bar{\nu}_{\mu L}\mu_R)}\right] + h.c.$$

where… $\tilde{v}_L = 4\bar{\alpha}^{(3)}_{\varphi l} - 2\bar{\alpha}^{(3)}_{ll}$

$$G_F^{pheno(\mu)} = G_F^{(0)}(1+\tilde{v}_L)$$

$d^j \to u^i l \bar{\nu}_l$

$$\mathcal{L}^{eff}_{d^j\to u^i l\bar{\nu}_l}(x) = \frac{-g^2}{2m_W^2} V_{ij} \left[\begin{array}{l} (1+v_L)(\bar{u}^i_L\gamma^\mu d^j_R)(\bar{l}_L\gamma_\mu \nu_{lL}) + \cancel{v_R(\bar{u}^i_R\gamma^\mu d^j_R)(\bar{l}_L\gamma_\mu \nu_{lL})} \\ \cancel{+s_L(\bar{u}^i_R d^j_L)(\bar{l}_R \nu_{lL})} + \cancel{s_R(\bar{u}^i_L d^j_R)(\bar{l}_R \nu_{lL})} \\ +t_L \cancel{(\bar{u}^i_R \sigma^{\mu\nu} d^j_L)(\bar{l}_R \sigma_{\mu\nu} \nu_{lL})} \end{array}\right] + h.c.$$

$$G_F^{pheno(SL)} = G_F^{(0)}(1+v_L)$$

where… $[v_L]_{llij} = 2\bar{\alpha}^{(3)}_{\varphi l} + 2\bar{\alpha}^{(3)}_{\varphi q} - 2\bar{\alpha}^{(3)}_{lq}$

FB case: Phenomenology

- Therefore, all the NP are:

$$G_F^{pheno(\mu)} = G_F^{(0)}(1+\tilde{v}_L)$$
$$G_F^{pheno(SL)} = G_F^{(0)}(1+v_L)$$

where…
$$\tilde{v}_L = 4\overline{\alpha}_{\varphi l}^{(3)} - 2\overline{\alpha}_{ll}^{(3)}$$
$$v_L = 2\overline{\alpha}_{\varphi l}^{(3)} + 2\overline{\alpha}_{\varphi q}^{(3)} - 2\overline{\alpha}_{lq}^{(3)}$$

- Just shifts of GF and Vij!!! (no channel-dependence)

➔ Only one place where we are sensitive to this…

$$\Delta_{CKM} \equiv |V_{ud}^{pheno}|^2 + |V_{us}^{pheno}|^2 + |V_{ub}^{pheno}|^2 - 1$$

Colliders & flavour

FB case: Phenomenology

- Therefore, all the NP are:

$$\boxed{\begin{aligned} G_F^{pheno(\mu)} &= G_F^{(0)}(1+\tilde{v}_L) \\ G_F^{pheno(SL)} &= G_F^{(0)}(1+v_L) \end{aligned}}$$

where…

$$\begin{aligned} \tilde{v}_L &= 4\overline{\alpha}_{\varphi l}^{(3)} - 2\overline{\alpha}_{ll}^{(3)} \\ v_L &= 2\overline{\alpha}_{\varphi l}^{(3)} + 2\overline{\alpha}_{\varphi q}^{(3)} - 2\overline{\alpha}_{lq}^{(3)} \end{aligned}$$

- Just shifts of GF and Vij!!! (no channel-dependence)

➔ Only one place where we are sensitive to this…

$$\Delta_{CKM} \equiv |V_{ud}^{pheno}|^2 + |V_{us}^{pheno}|^2 + |V_{ub}^{pheno}|^2 - 1$$

$$V_{ij}^{pheno} = \frac{G_F^{pheno(SL)} V_{ij}}{G_F^{pheno(\mu)}} = (1 + v_L - \tilde{v}_L)\, V_{ij}$$

$$\boxed{\Delta_{CKM} = 4\left(-\overline{\alpha}_{\varphi l}^{(3)} + \overline{\alpha}_{\varphi q}^{(3)} - \overline{\alpha}_{lq}^{(3)} + \overline{\alpha}_{ll}^{(3)}\right)} \quad \ldots - \left|V_{uD}\right|^2$$

Colliders & flavour

FB case: Phenomenology

$$\Delta_{CKM} = 4\left(-\bar{\alpha}_{\varphi l}^{(3)} + \bar{\alpha}_{\varphi q}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}\right) = -(1 \pm 6)\cdot 10^{-4}$$

$$\begin{aligned}
O_{ll}^{(3)} &= \frac{1}{2}(\bar{l}\gamma^{\mu}\sigma^{a}l)(\bar{l}\gamma_{\mu}\sigma^{a}l) \\
O_{lq}^{(3)} &= (\bar{l}\gamma^{\mu}\sigma^{a}l)(\bar{q}\gamma_{\mu}\sigma^{a}q) \\
O_{\varphi l}^{(3)} &= i(h^{\dagger}D^{\mu}\sigma^{a}\varphi)(\bar{l}\gamma_{\mu}\sigma^{a}l) + \text{h.c.}, \\
O_{\varphi q}^{(3)} &= i(\varphi^{\dagger}D^{\mu}\sigma^{a}\varphi)(\bar{q}\gamma_{\mu}\sigma^{a}q) + \text{h.c.}
\end{aligned}$$

FB case: Phenomenology

$$\Delta_{CKM} = 4\left(-\bar{\alpha}_{\varphi l}^{(3)} + \bar{\alpha}_{\varphi q}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}\right) = -(1 \pm 6)\cdot 10^{-4}$$

What did we know about them from colliders?

$$O_{ll}^{(3)} = \frac{1}{2}(\bar{l}\gamma^{\mu}\sigma^{a}l)(\bar{l}\gamma_{\mu}\sigma^{a}l)$$

$$O_{lq}^{(3)} = (\bar{l}\gamma^{\mu}\sigma^{a}l)(\bar{q}\gamma_{\mu}\sigma^{a}q)$$

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G_F-extraction from mu-decay

FB case: Phenomenology

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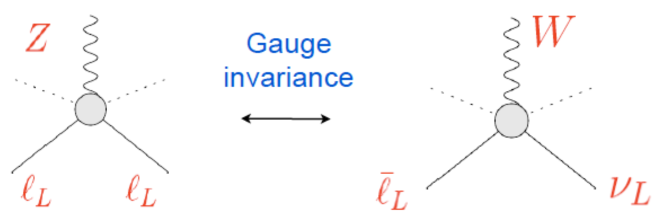
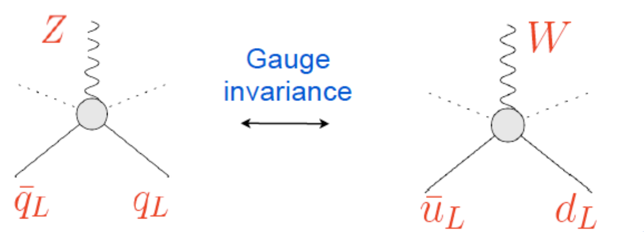
G_F-extraction from mu-decay

$$O_{\varphi l}^{(3)} = i(\varphi^\dagger D^\mu\sigma^a\varphi))(\bar{l}\gamma_\mu\sigma^a l)$$



$$O_{\varphi q}^{(3)} = i(\varphi^\dagger D^\mu\sigma^a\varphi)(\bar{q}\gamma_\mu\sigma^a q)$$



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G_F-extraction from mu-decay

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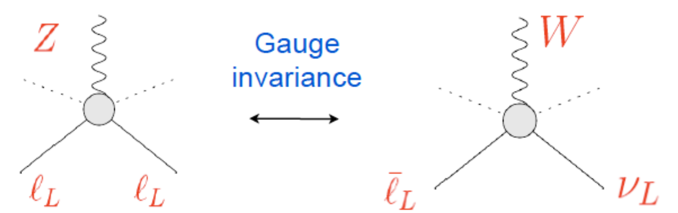
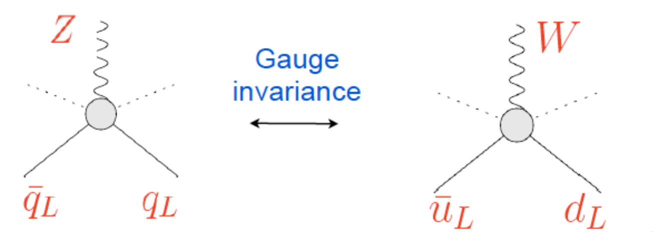


LEPII: $e^{+}e^{-} \rightarrow q\bar{q}$

$$O_{\varphi q}^{(3)} = i(\varphi^{\dagger}D^{\mu}\sigma^{a}\varphi)(\bar{q}\gamma_{\mu}\sigma^{a}q)$$



FB case: Phenomenology

$$\Delta_{CKM} = 4\left(-\bar{\alpha}_{\varphi l}^{(3)} + \bar{\alpha}_{\varphi q}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}\right) = -(1\pm 6)\cdot 10^{-4}$$

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$$O_{\varphi l}^{(3)} = i(h^\dagger D^\mu\sigma^a\varphi)(\bar{l}\gamma_\mu\sigma^a l) + \text{h.c.},$$

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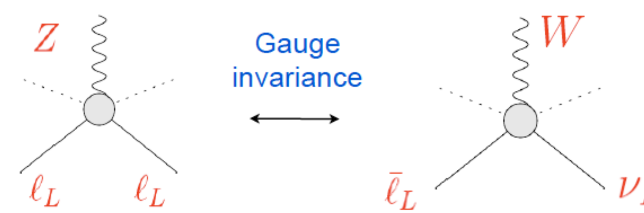
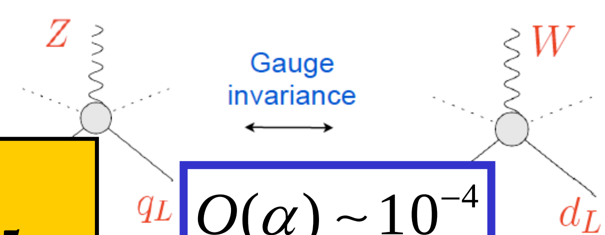
G_F-extraction from mu-decay

$$O_{\varphi l}^{(3)} = i(\varphi^\dagger D^\mu\sigma^a\varphi))(\bar{l}\gamma_\mu\sigma^a l)$$



$$O_{\varphi q}^{(3)} = i(\varphi^\dagger D^\mu\sigma^a\varphi)(\bar{q}\gamma_\mu\sigma^a q)$$



LEPII: $e^+e^- \to q\bar{q}$

$$\boxed{O(\alpha)\sim 10^{-3}}$$

$$\boxed{O(\alpha)\sim 10^{-4}}$$

Han & Skiba, PRD71:075009, 2005.

Δ_{CKM} vs. EW precision measurements

FB case

Han & Skiba (2005)

- $U(3)^5$ limit;
- 237 measurements;
- 21 parameters (α's);

Classification	Standard Notation	Measurement
Atomic parity violation (Q_W)	$Q_W(Cs)$	Weak charge in Cs
	$Q_W(Tl)$	Weak charge in Tl
DIS	g_L^2, g_R^2	ν_μ-nucleon scattering from NuTeV
	R^ν	ν_μ-nucleon scattering from CDHS and CHARM
	κ	ν_μ-nucleon scattering from CCFR
	$g_V^{\nu e}, g_A^{\nu e}$	ν-e scattering from CHARM II
Zline (lepton and light quark)	Γ_Z	Total Z width
	σ_0	e^+e^- hadronic cross section at Z pole
	$R_f^0(f=e,\mu,\tau)$	Ratios of lepton decay rates
	$A_{FB}^{0,f}(f=e,\mu,\tau)$	Forward-backward lepton asymmetries
pol	$A_f(f=e,\mu,\tau)$	Polarized lepton asymmetries
bc (heavy quark)	$R_f^0(f=b,c)$	Ratios of hadronic decay rates
	$A_{FB}^{0,f}(f=b,c)$	Forward-backward hadronic asymmetries
	$A_f(f=b,c)$	Polarized hadronic asymmetries
LEPII Fermion production	$\sigma_f(f=q,\mu,\tau)$	Total cross sections for $e^+e^- \to f\bar{f}$
	$A_{FB}^f(f=\mu,\tau)$	Forward-backward asymmetries for $e^+e^- \to f\bar{f}$
eOPAL	$d\sigma_e/d\cos\theta$	Differential cross section for $e^+e^- \to e^+e^-$
WL3	$d\sigma_W/d\cos\theta$	Differential cross section for $e^+e^- \to W^+W^-$
MW	M_W	W mass
Q_{FB}	$\sin^2\theta_{eff}^{lept}$	Hadronic charge asymmetry

Δ_{CKM} vs. EW precision measurements

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$$\chi^2(\hat{\alpha}_k) = \sum_{i,j} \left(X^i_{\text{th}}(\hat{\alpha}_k) - X^i_{\text{exp}}\right) \left(\sigma^2\right)^{-1}_{ij} \left(X^j_{\text{th}}(\hat{\alpha}_k) - X^j_{\text{exp}}\right)$$

Classification	Standard Notation	Measurement
Atomic parity	$Q_W(Cs)$	Weak charge in Cs
	$g_V^{\nu e}, g_A^{\nu e}$	ν-e scattering from CHARM II
Zline	Γ_Z	Total Z width
(lepton and	σ_0	e^+e^- hadronic cross section at Z pole
light quark)	$R_f^0(f=e,\mu,\tau)$	Ratios of lepton decay rates
	$A_{FB}^{0,f}(f=e,\mu,\tau)$	Forward-backward lepton asymmetries
pol	$A_f(f=e,\mu,\tau)$	Polarized lepton asymmetries
bc	$R_f^0(f=b,c)$	Ratios of hadronic decay rates
(heavy quark)	$A_{FB}^{0,f}(f=b,c)$	Forward-backward hadronic asymmetries
	$A_f(f=b,c)$	Polarized hadronic asymmetries
LEPII Fermion	$\sigma_f(f=q,\mu,\tau)$	Total cross sections for $e^+e^- \to f\bar{f}$
production	$A_{FB}^f(f=\mu,\tau)$	Forward-backward asymmetries for $e^+e^- \to f\bar{f}$
eOPAL	$d\sigma_e/d\cos\theta$	Differential cross section for $e^+e^- \to e^+e^-$
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Classification	Standard Notation	Measurement
Atomic parity	$Q_W(Cs)$	Weak charge in Cs
	$g_V^{\nu e}, g_A^{\nu e}$	-e scattering from CHARM II
Zline	Γ_Z	Total Z width
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$$\chi^2(\hat{\alpha}_k) = \sum_{i,j} \left(X^i_{\rm th}(\hat{\alpha}_k) - X^i_{\rm exp}\right) \left(\sigma^2\right)^{-1}_{ij} \left(X^j_{\rm th}(\hat{\alpha}_k) - X^j_{\rm exp}\right)$$

$$\Delta_{CKM}^{HEP-fit} = 4\left(-\bar{\alpha}^{(3)}_{\varphi l} + \bar{\alpha}^{(3)}_{\varphi q} - \bar{\alpha}^{(3)}_{lq} + \bar{\alpha}^{(3)}_{ll}\right) = -(4.7 \pm 2.9)\cdot 10^{-3}$$

Colliders & flavour

Δ_{CKM} vs. EW precision measurements

FB case

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Classification	Standard Notation	Measurement
Atomic parity	$Q_W(Cs)$	Weak charge in Cs
	$g_V^{\nu e}, g_A^{\nu e}$	[illegible]
Zline	Γ_Z	
(lepton and	σ_0	e^+e^- hadronic cross section at Z pole
(heavy quark)	$A_{FB}^{0,f}(f=b,c)$	Forward-backward hadronic asymmetries
	$A_f(f=b,c)$	Polarized hadronic asymmetries
LEPII Fermion	$\sigma_f(f=q,\mu,\tau)$	Total cross sections for $e^+e^- \to f\bar{f}$
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This leaves ample room for a sizeable violation of CKM-unitarity

$$\Delta_{CKM}^{HEP-fit} = 4\left(-\bar{\alpha}^{(3)}_{\varphi l} + \bar{\alpha}^{(3)}_{\varphi q} - \bar{\alpha}^{(3)}_{lq} + \bar{\alpha}^{(3)}_{ll}\right) = -(4.7 \pm 2.9)\cdot 10^{-3}$$

$$\Delta_{CKM}^{\rm exp.} = -(0.1 \pm 0.6)\cdot 10^{-3}$$

5 times more precise!

Δ_{CKM} vs. EW precision measurements

FB case

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$$\chi^2(\hat{\alpha}_k) = \sum_{i,j} \left(X^i_{\rm th}(\hat{\alpha}_k) - X^i_{\rm exp}\right) \left(\sigma^2\right)^{-1}_{ij} \left(X^j_{\rm th}(\hat{\alpha}_k) - X^j_{\rm exp}\right)$$

$$\Delta_{CKM}^{HEP-fit} = 4\left(-\bar{\alpha}^{(3)}_{\varphi l} + \bar{\alpha}^{(3)}_{\varphi q} - \bar{\alpha}^{(3)}_{lq} + \bar{\alpha}^{(3)}_{ll}\right) = -(4.7 \pm 2.9)\cdot 10^{-3}$$

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$$\Delta_{CKM}^{\rm exp.} = -(0.1 \pm 0.6)\cdot 10^{-3}$$

5 times more precise!

Then, let's do it in the other way around!

Adding Δ_{CKM} to the fit will improve the NP bounds.

Global analysis → Weaker bounds on NP (cancellations);

Single-operator analysis → Stronger bounds and correlations;

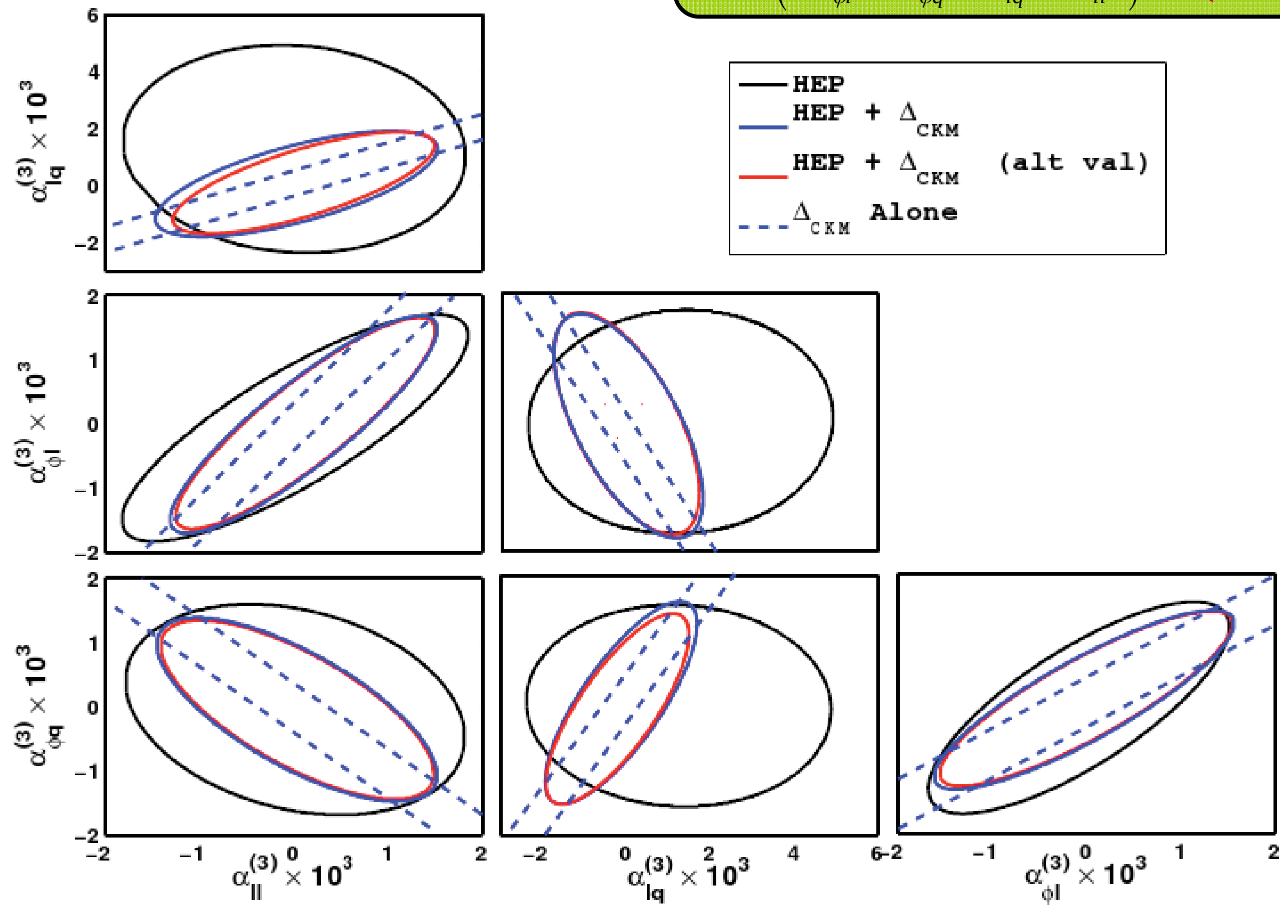
Δ_{CKM} vs. EW precision measurements

FB case

- Global analysis

$$4\left(-\bar{\alpha}^{(3)}_{\varphi l}+\bar{\alpha}^{(3)}_{\varphi q}-\bar{\alpha}^{(3)}_{lq}+\bar{\alpha}^{(3)}_{ll}\right)=-(0.1\pm0.6)\cdot10^{-3}$$

$$4\left(-\bar{\alpha}^{(3)}_{\varphi l}+\bar{\alpha}^{(3)}_{\varphi q}-\bar{\alpha}^{(3)}_{lq}+\bar{\alpha}^{(3)}_{ll}\right)=-(2.5\pm0.6)\cdot10^{-3}$$



Δ_{CKM} vs. EW precision measurements

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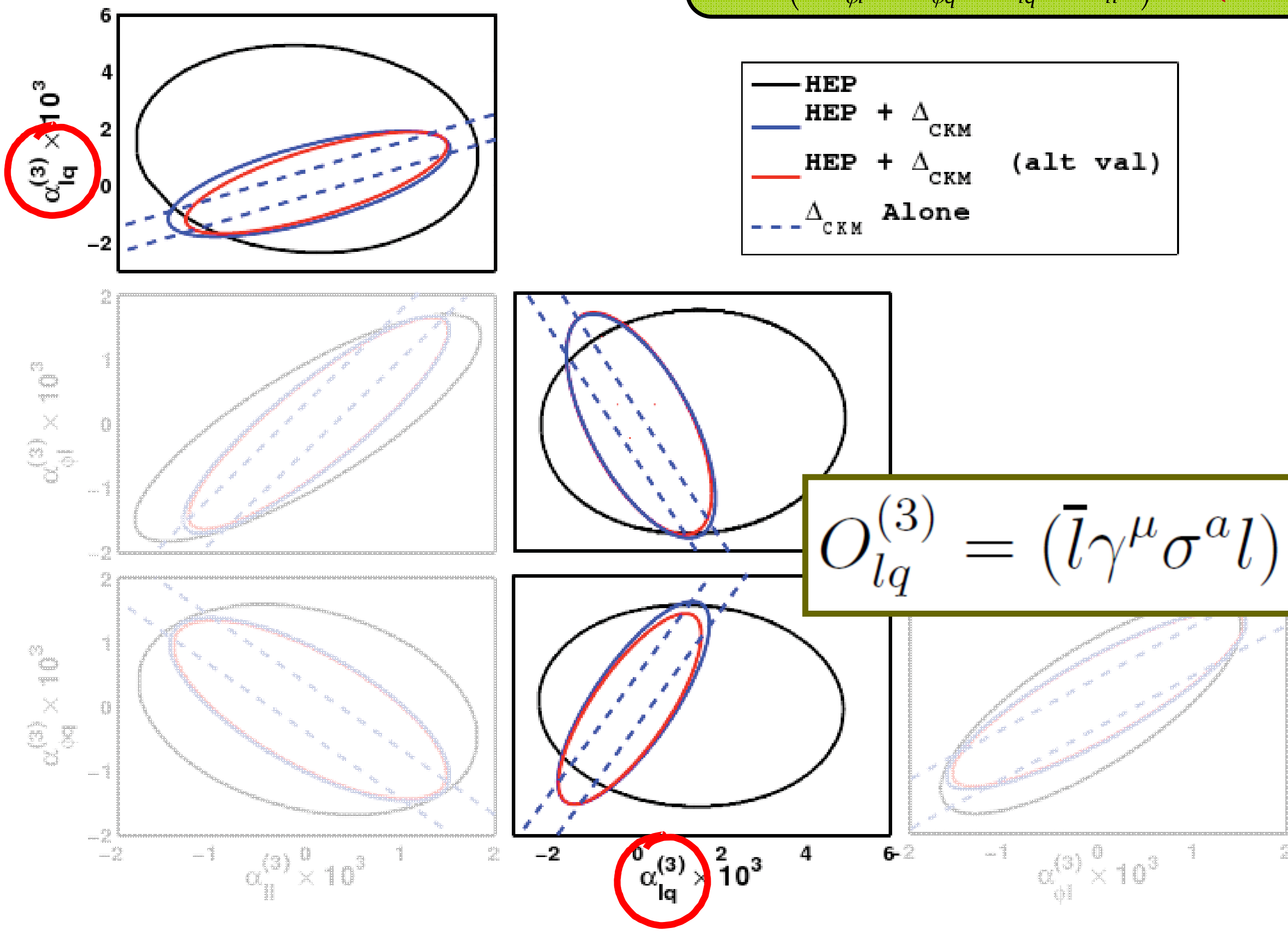

$$O^{(3)}_{lq}=(\bar{l}\gamma^\mu\sigma^a l)(\bar{q}\gamma_\mu\sigma^a q)$$

FB case

Δ_{CKM} vs. EW precision measurements

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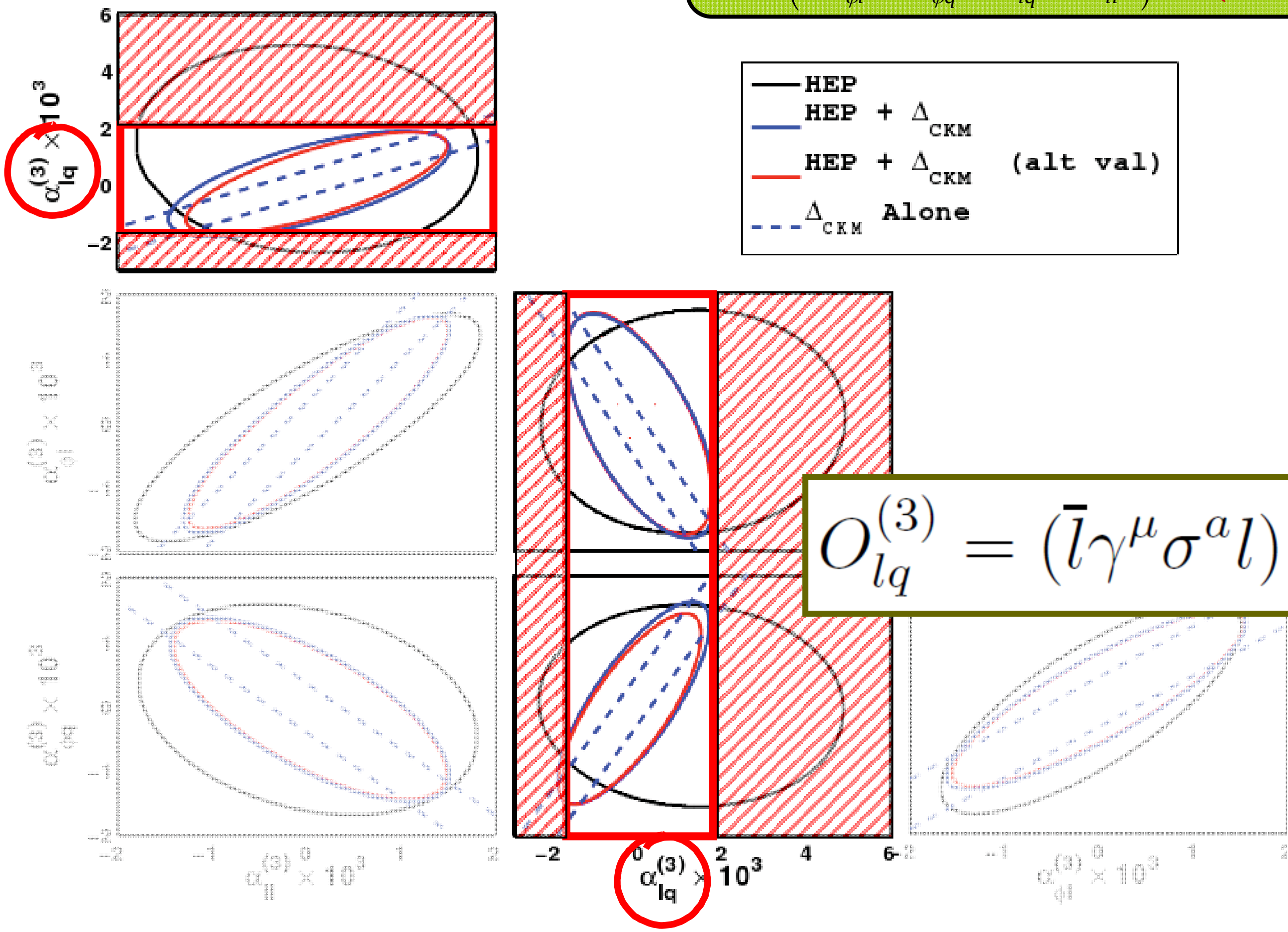
- Global analysis



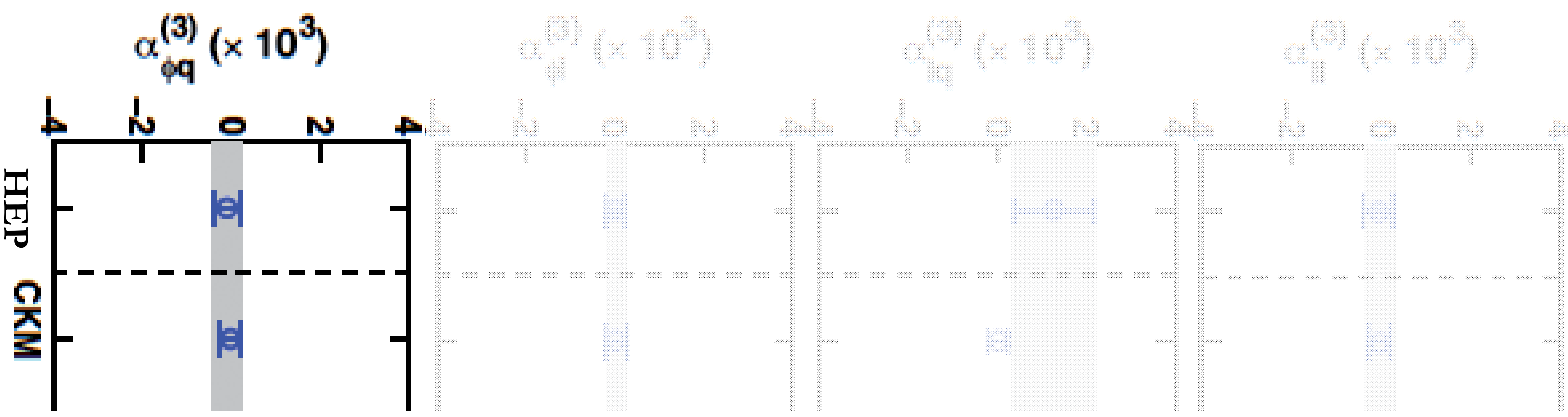
$$O_{lq}^{(3)} = (\bar{l}\gamma^\mu\sigma^a l)(\bar{q}\gamma_\mu\sigma^a q)$$

Δ_{CKM} vs. EW precision measurements

FB case

- Single operator analysis:

$$\Delta^{\mathrm{exp.}}_{CKM} = 4\left(-\cancel{\bar{\alpha}^{(3)}_{\varphi l}} + \bar{\alpha}^{(3)}_{\varphi q} - \cancel{\bar{\alpha}^{(3)}_{lq}} + \cancel{\bar{\alpha}^{(3)}_{ll}}\right) = -(0.1 \pm 0.6)\cdot 10^{-3}$$



Δ_{CKM} vs. EW precision measurements

FB case

- Single operator analysis:

$$\Lambda_{NP}^{eff} = \frac{\Lambda_{NP}}{\sqrt{\alpha}} > 11\,\mathrm{TeV}\ (90\%\ \mathrm{CL})$$

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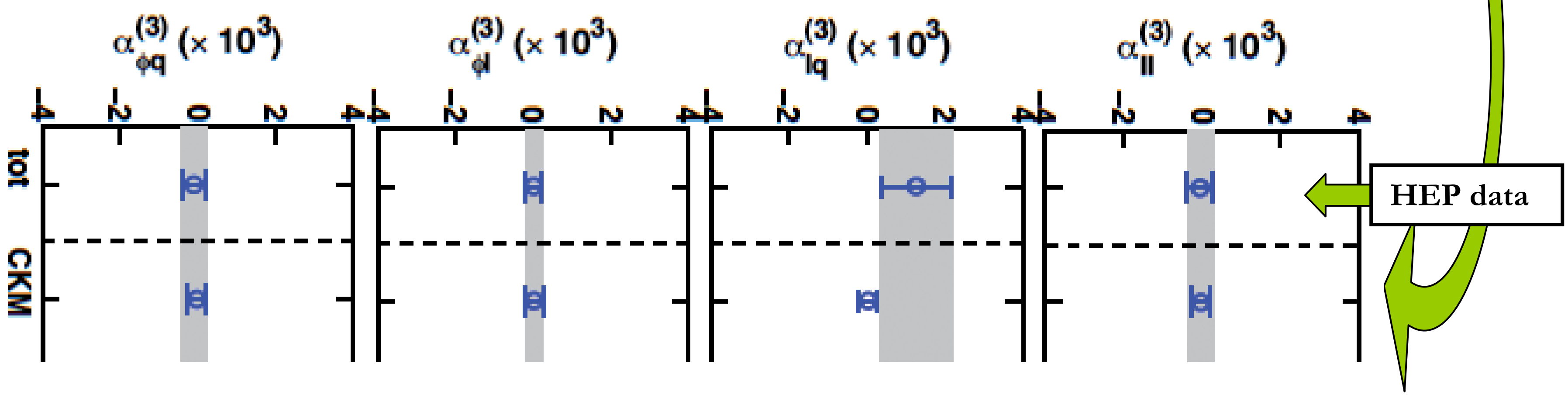
$$\pm 4\alpha_X = -(0.1 \pm 0.6)\cdot 10^{-3}$$



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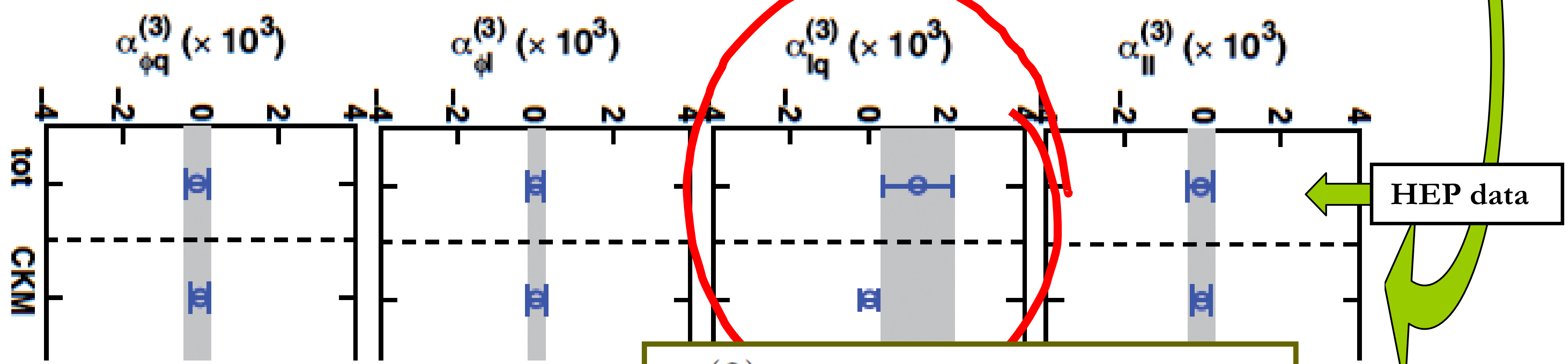

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Phenomenology beyond FB

- MFV case…

$$i(\varphi^\dagger D^\mu \sigma^a \varphi)\left(\begin{pmatrix}\bar{l}_e \\ \bar{l}_\mu \\ \bar{l}_\tau\end{pmatrix}\gamma_\mu \sigma^a \begin{pmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{pmatrix}\begin{pmatrix}l_e & l_\mu & l_\tau\end{pmatrix}\right)$$

$$\alpha_{\varphi l}^{(3)} = \begin{pmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{pmatrix} = \bar{\alpha}_{\varphi l}^{(3)} \, \mathbb{I}_{3x3} + \bar{\beta}_{\varphi l}^{(3)} \, \Delta_{LL}^{(l)} + \ldots$$

$$\Delta_{LL}^{(q)} = V^\dagger \, \bar{\lambda}_u^2 \, V$$

$$\Delta_{LL}^{(\ell)} = \frac{\Lambda_{\mathrm{LN}}^2}{v^4} \, U \, \bar{m}_\nu^2 \, U^\dagger$$

$$= \bar{\alpha}_{\varphi l}^{(3)} \begin{pmatrix}1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1\end{pmatrix} + \bar{\beta}_{\varphi l}^{(3)} \, 10^{-4} \begin{pmatrix}\sim 0.1 & \sim 0.1 & \sim 0.1 \\ \sim 0.1 & \sim 1 & \sim 1 \\ \sim 0.1 & \sim 1 & \sim 1\end{pmatrix} + \ldots$$

Phenomenology beyond FB

- **MFV case…**

$$i(\varphi^\dagger D^\mu \sigma^a \varphi)\left(\begin{pmatrix}\bar{l}_e \\ \bar{l}_\mu \\ \bar{l}_\tau\end{pmatrix}\gamma_\mu \sigma^a \begin{pmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{pmatrix}\begin{pmatrix}l_e & l_\mu & l_\tau\end{pmatrix}\right)$$

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- Essentially = FB case…

The main effect will be $\Delta_{CKM} \neq 0$ plus subdominant effects.

The V_{ij} receive a common dominant shift plus suppressed channel-dependent corrections.

$$\Delta_{CKM} \approx 4\left(-\bar{\alpha}_{\varphi l}^{(3)} + \bar{\alpha}_{\varphi q}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}\right)$$

Phenomenology beyond FB

- Beyond MFV…

$$\mathcal{L}^{eff}_{d^j \to u^i l \bar{\nu}_l}(x) = \frac{-g^2}{2m_W^2} V_{ij} \left[\begin{array}{l} (1+v_L)(V-A)(V-A) + v_R (V+A)(V-A) \\ + s_L (S-P)(S+P) + s_R (S+P)(S+P) + t_L (T-T')(T-T') \end{array} \right]$$

Phenomenology beyond FB

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- New Lorentz structures ➔ Very rich phenomenology…
  - **V_{ij} are channel-dependent;**
  - Possible sizable lepton universality violations; $\Gamma(P_{e2})/\Gamma(P_{\mu 2})$
  - Possible sizeble contributions to $\frac{\Gamma(K_{l2})}{\Gamma(\pi_{l2})}, \frac{\Gamma(K_{l2}) \cdot V_{ud}(0^+ \to 0^+)}{\Gamma(\pi_{l2}) \cdot \Gamma(K_{l3})}$
  - Effects on the kinematical distributions;

Phenomenology beyond FB

- **Beyond MFV…**

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Masiero et al'06, 08 (SUSY)

Hou, Isidori-Paradisi'06

Filipuzzi-Isidori'09 (MFV, MFV-GUT)

Colliders & flavour

Conclusions

- In a model independent framework we have built the low-E $\mathcal{L}^{\text{eff.}}$ for SL decays, identifying the 4(9) operators that are involved;

- In the simple ~FB limit, we have been able to compare within an effective field theory framework the CKM information with the EWPO and check the relevance of the ***interplay*** of them.

$$\Delta_{CKM} = 4\left(-\bar{\alpha}_{\varphi l}^{(3)} + \bar{\alpha}_{\varphi q}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}\right) = -(0.1 \pm 0.6)\cdot 10^{-3}$$

$$\Lambda_i^{eff} > 11\,\text{TeV (90\% CL)}$$

Colliders & flavour

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Message for Model-Builders:

Take into account the CKM unitarity test!

Especially if your model generates the contact term…

$$\boxed{O_{lq}^{(3)} = (\bar{l}\gamma^\mu \sigma^a l)(\bar{q}\gamma_\mu \sigma^a q)}$$

Thanks!

Backup slides

The eff. Lagrangian for E~100 GeV

Vectors and Scalars:

$$O_{WB} = (\varphi^\dagger \sigma^a \varphi) W^a_{\mu\nu} B^{\mu\nu} \qquad O_\varphi^{(3)} = |\varphi^\dagger D_\mu \varphi|^2 \qquad O_W = \epsilon^{abc} W_\mu^{a\nu} W_\nu^{b\lambda} W_\lambda^{c\mu}$$

4-Fermion operators:

$$O_{ll}^{(1)} = \frac{1}{2}(\bar{l}\gamma^\mu l)(\bar{l}\gamma_\mu l), \qquad O_{ll}^{(3)} = \frac{1}{2}(\bar{l}\gamma^\mu \sigma^a l)(\bar{l}\gamma_\mu \sigma^a l)$$

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$$O_{le} = (\bar{l}\gamma^\mu l)(\bar{e}\gamma_\mu e), \qquad O_{qe} = (\bar{q}\gamma^\mu q)(\bar{e}\gamma_\mu e),$$

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2-Fermions + V + S:

$$O_{\varphi l}^{(1)} = i(\varphi^\dagger D^\mu \varphi)(\bar{l}\gamma_\mu l) + \text{h.c.}, \quad O_{\varphi l}^{(3)} = i(h^\dagger D^\mu \sigma^a \varphi)(\bar{l}\gamma_\mu \sigma^a l) + \text{h.c.},$$

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21 $U(3)^5$ inv. operators

$$\begin{pmatrix} l_e \\ l_\mu \\ l_\tau \end{pmatrix}, \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix}, \begin{pmatrix} q_u \\ q_c \\ q_t \end{pmatrix}, \begin{pmatrix} u \\ c \\ t \end{pmatrix}, \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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4 non-U(3)^5 inv. ops

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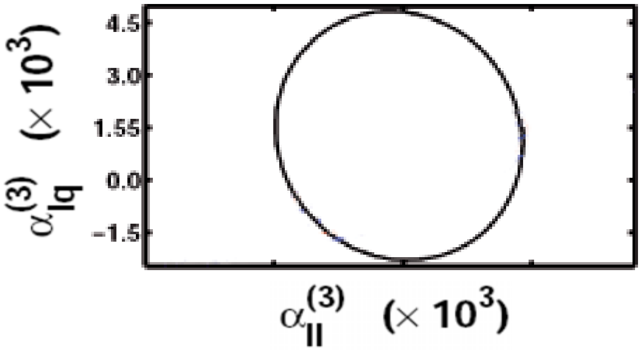
4 non-$U(3)^5$ inv. ops

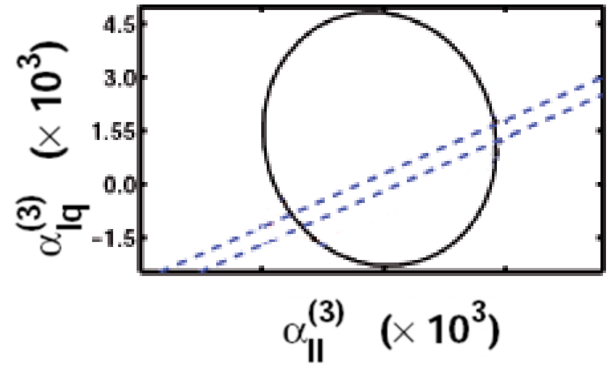
Δ_{CKM} vs. EW precision measurements

- Global analysis

HEP constraint



CKM constraint



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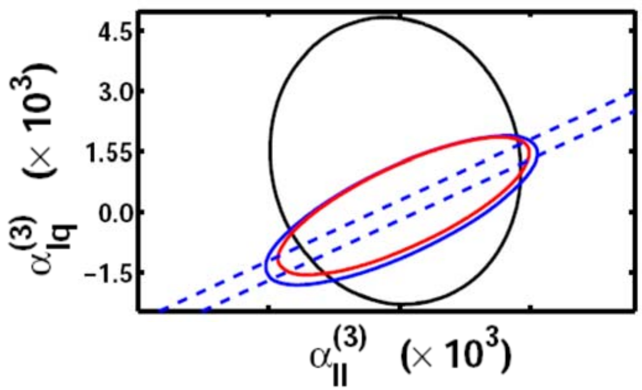


Combination

HEP + CKM

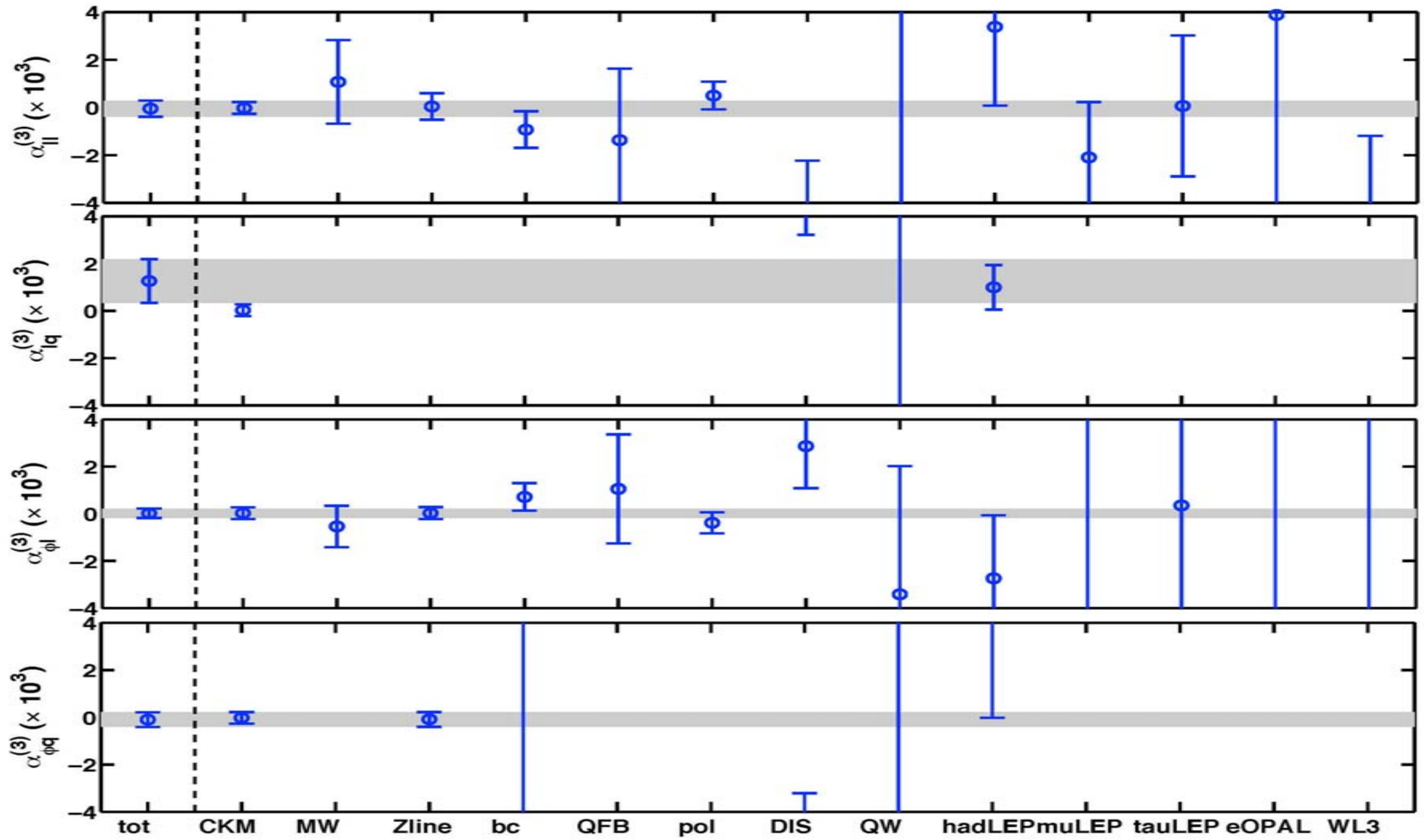
HEP + CKM (alt)

Δ_{CKM} vs. EW precision measurements

$\pm 4\alpha_X = -(0.1 \pm 0.6) \cdot 10^{-3}$

$\Lambda > 11\text{TeV}$ (90% CL)

- Single operator analysis:

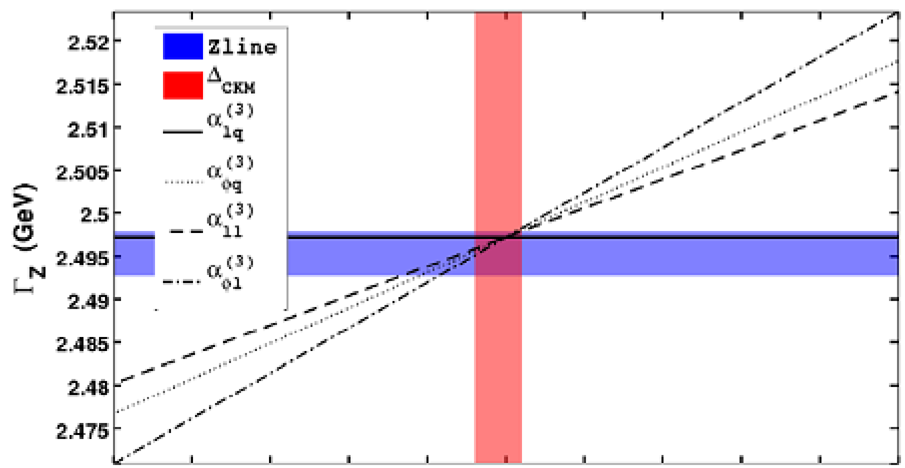


Δ_{CKM} vs. EW precision measurements

FB case

- Single operator analysis: Looking for **correlations**…

In case of $\Delta_{CKM} \neq 0$, we can immediately read off in which direction other precision measurement should move, and by how much.



Effective ν-nucleon coupling measured by NuTeV