

New Physics bounds from CKM-unitarity



Rencontres de Moriond EW 2010

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Instituto de Física Corpuscular (CSIC – UV)



Introduction

$$V_{ud} = 0.97425(22)$$

$$V_{us} = 0.2252(9)$$

$$V_{ub} \sim 10^{-3}$$

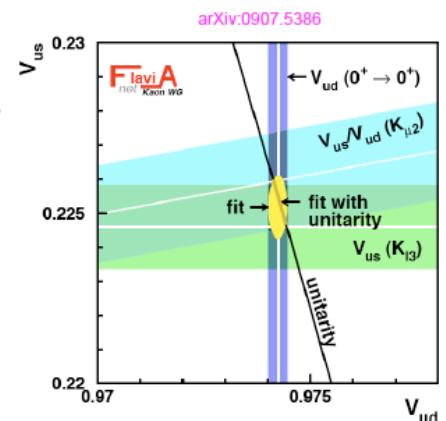
(Hardy & Towner, 2008)

From $0^+ \rightarrow 0^+$ nuclear beta decays

(Antonelli et al., 2009)

From KI3 and KI2

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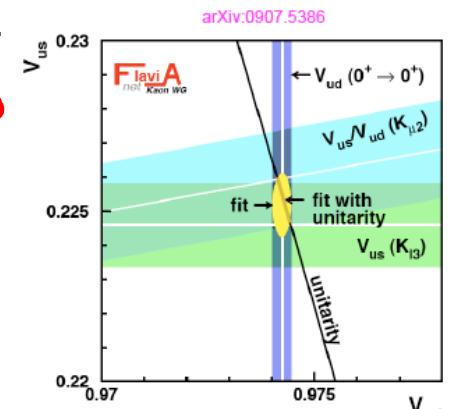
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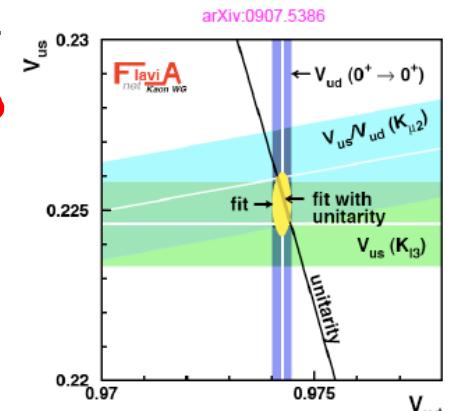
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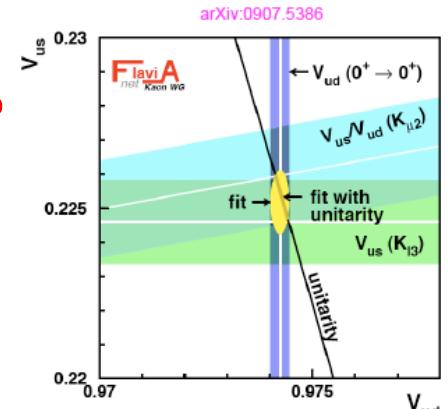
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- More model-independent approach...

V. Cirigliano, M. G.-A. & J. Jenkins
Nuc. Phys. B830: 95-115, 2010

YES!

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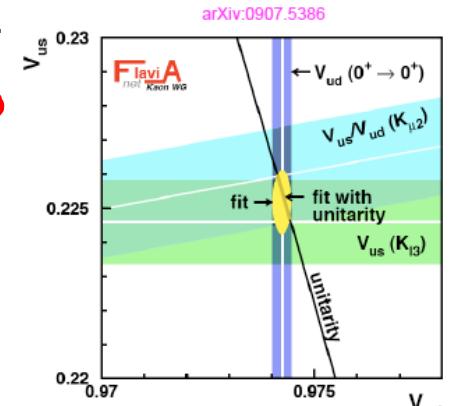
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Eff. Lagrangian = Particles + Symmetries

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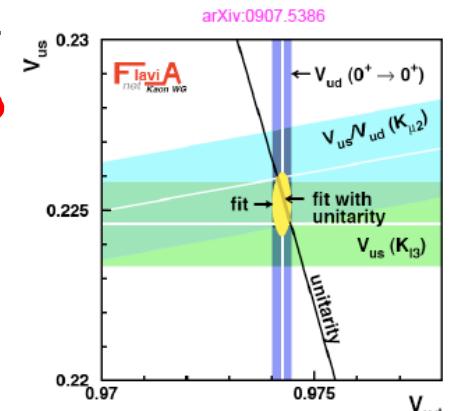
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Extraction of V_{ij} :

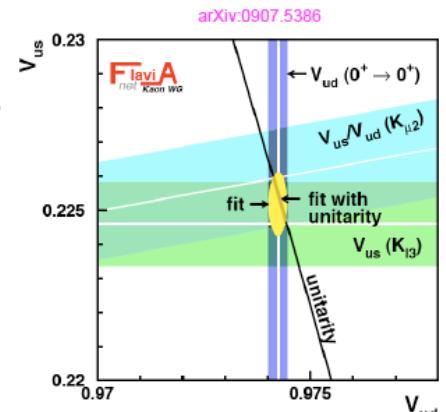
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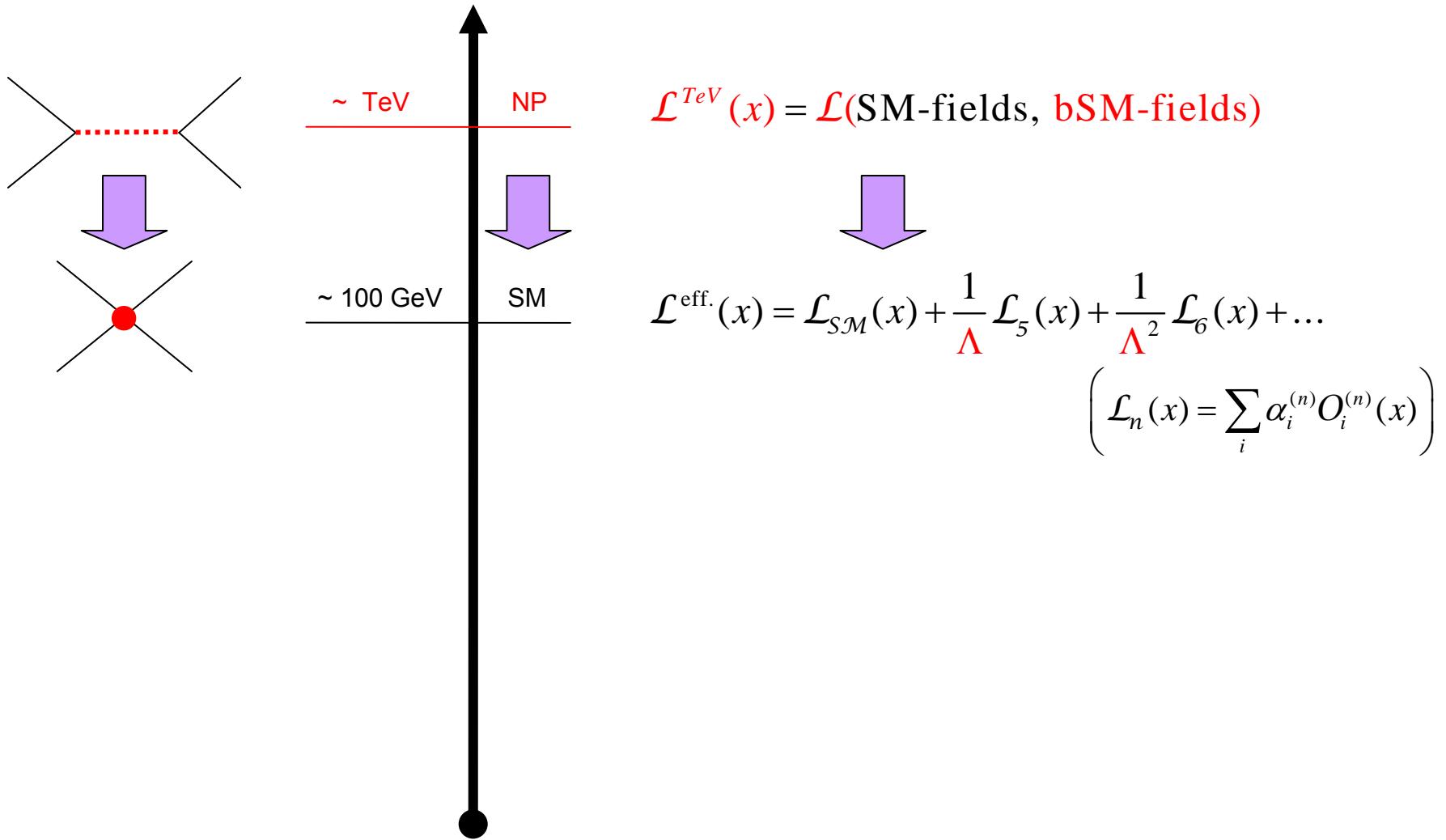


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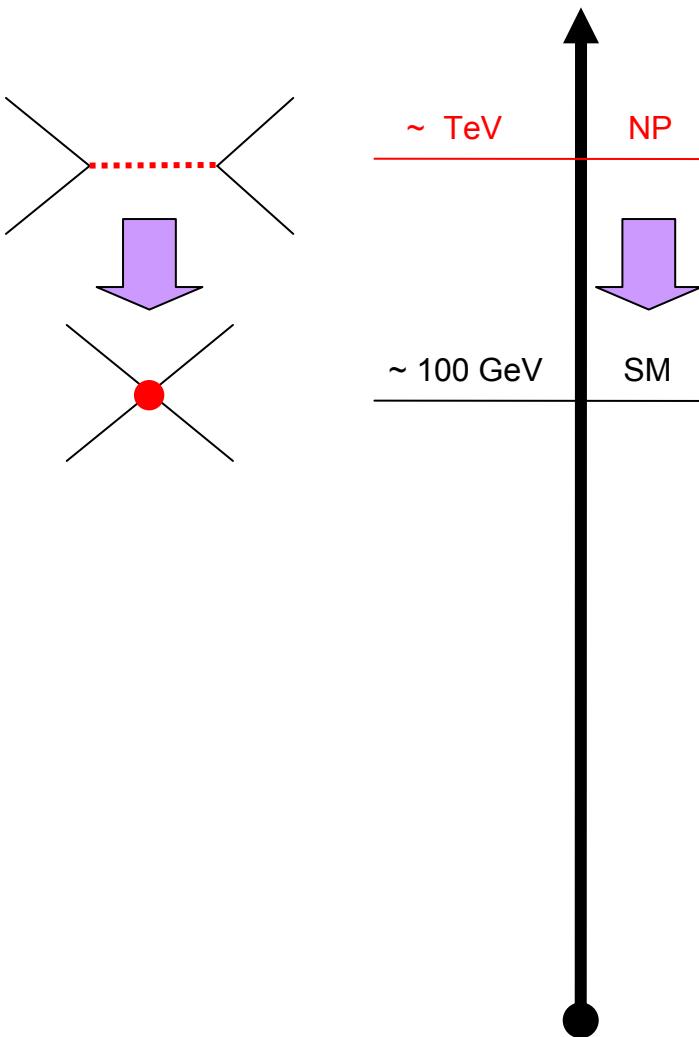
Extraction of V_{ij} :

- Beta decay \rightarrow determination of $G_F V_{ij}$
 $(d^j \rightarrow u^i l \bar{\nu}_l)$
- Muon decay \rightarrow determination of G_F
 $(\mu \rightarrow e \bar{\nu}_e \nu_\mu)$

The eff. Lagrangian for E~100 GeV



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

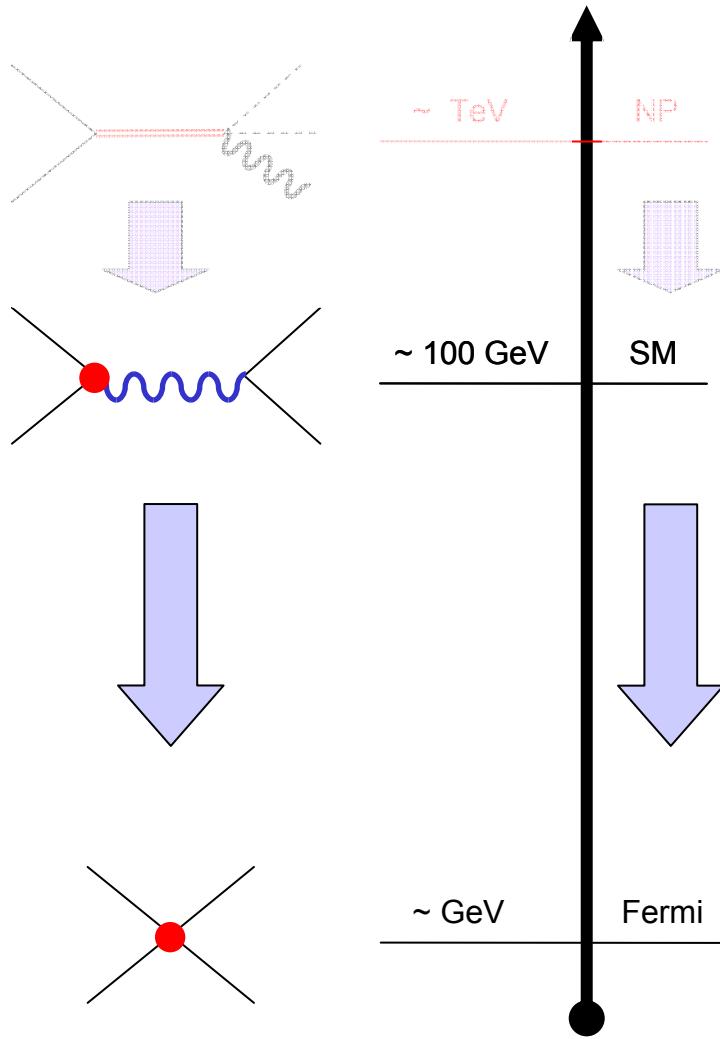
Buchmüller-Wyler'1986,
Leung et al.'1986

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

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

77 operators;

The eff. Lagrangian for $E \sim 1$ GeV



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$$\left(\mathcal{L}_6(x) = \sum_i^7 \alpha_i O_i(x) \right)$$

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

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

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

FB case: Phenomenology

- NP Flavor structure? Simplest case: Flavor Blind limit...

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

U(3)⁵ inv.

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

(Or nearly flavor blind, like MFV)
(*D'Ambrosio, Giudice, Isidori, Strumia, 2002*)

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

$$\mathcal{L}_{\mu \rightarrow e \nu \bar{\nu}}^{eff}(x) = \frac{-g^2}{2m_W^2} [(1 + 4\hat{\alpha}_{\phi l}^{(3)} - 2\hat{\alpha}_{ll}^{(3)}) (\bar{e}_L \gamma_\mu \nu_{eL})(\bar{\nu}_{\mu L} \gamma_\mu \mu_L)] + h.c.$$

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

$$\mathcal{L}_{d^j \rightarrow u^i l \bar{\nu}_l}^{eff}(x) = \frac{-g^2}{2m_W^2} V_{ij} [(1 + 2\hat{\alpha}_{\phi l}^{(3)} + 2\hat{\alpha}_{\phi q}^{(3)} - 2\hat{\alpha}_{lq}^{(3)}) (\bar{u}_L^i \gamma^\mu d_R^j)(\bar{l}_L \gamma_\mu \nu_{lL})] + h.c.$$

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

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$$\Delta_{CKM} \equiv |V_{ud}^{\text{pheno}}|^2 + |V_{us}^{\text{pheno}}|^2 + |V_{ub}^{\text{pheno}}|^2 - 1 = 4 \left(-\hat{\alpha}_{\varphi l}^{(3)} + \hat{\alpha}_{\varphi q}^{(3)} - \hat{\alpha}_{lq}^{(3)} + \hat{\alpha}_{ll}^{(3)} \right)$$

Δ_{CKM} vs. EWPT

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

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

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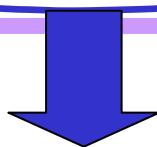
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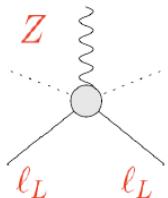
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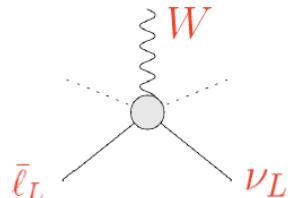


G_F -extraction
from mu-decay

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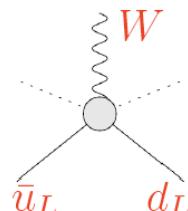
Gauge invariance



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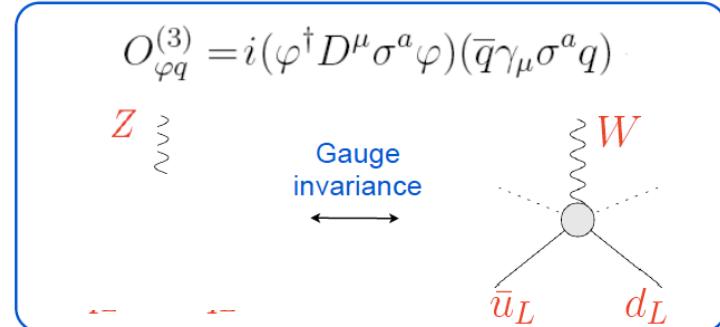
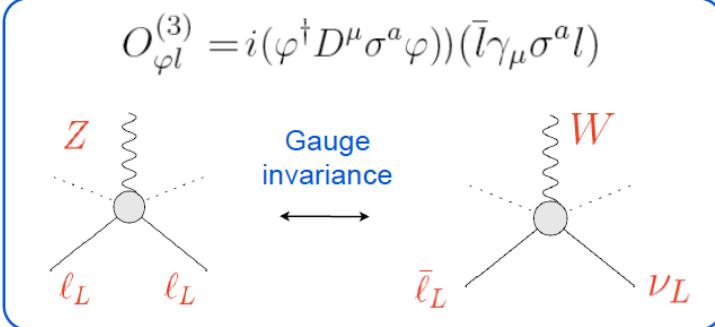
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LEPII: $e^+e^- \rightarrow q\bar{q}$

G_F-extraction
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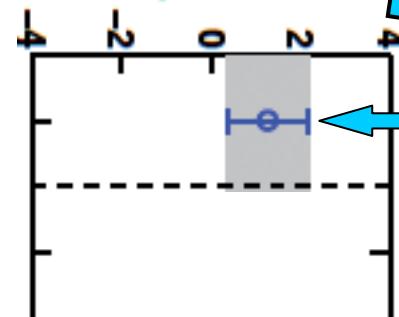
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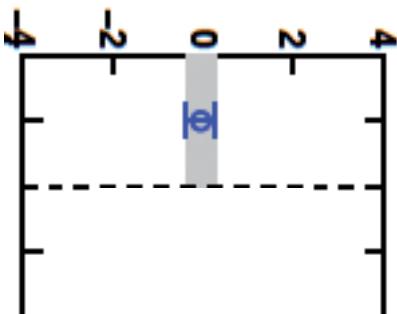
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$$\alpha_{lq}^{(3)} (\times 10^3)$$

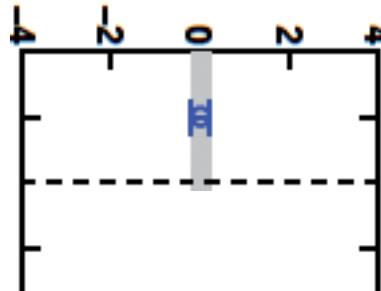
Han & Skiba,
PRD71, 2005.



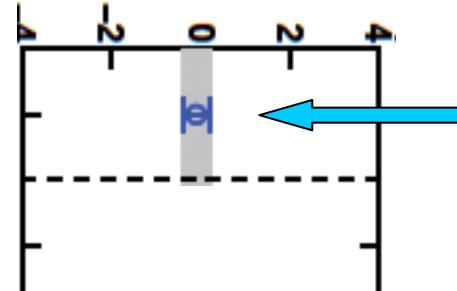
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EWPT

Δ_{CKM} vs. EWPT

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

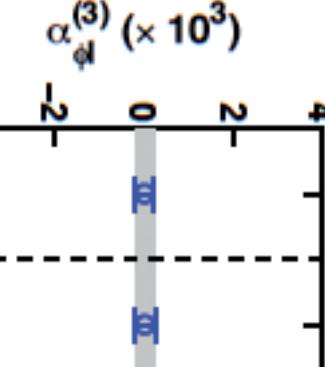
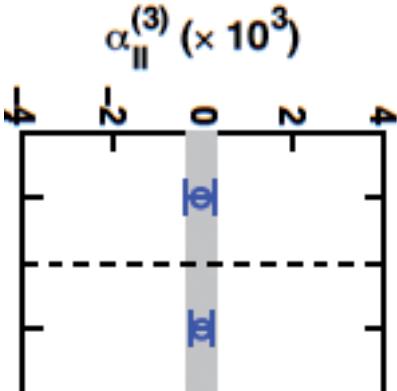
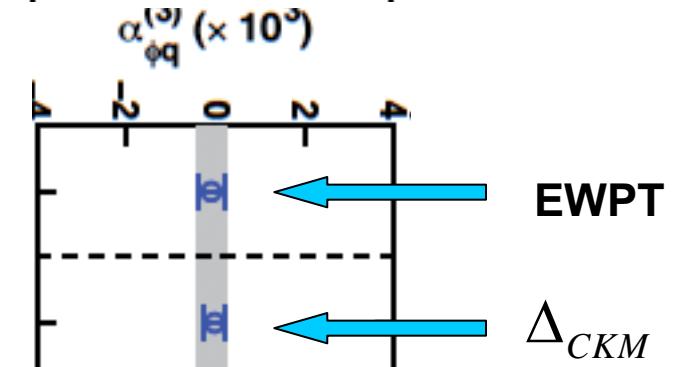
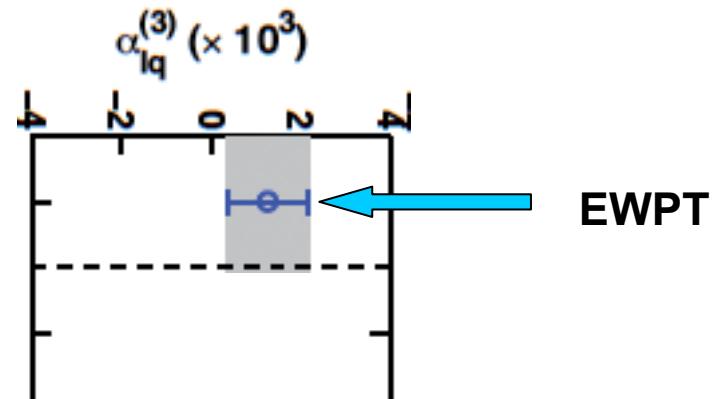
$$O_{ll}^{(3)} = \frac{1}{2}(\bar{l}\gamma^\mu\sigma^a l)(\bar{l}\gamma_\mu\sigma^a l)$$

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

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

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

What did we know about them from EWPT?



NP bounds from CKM unitarity

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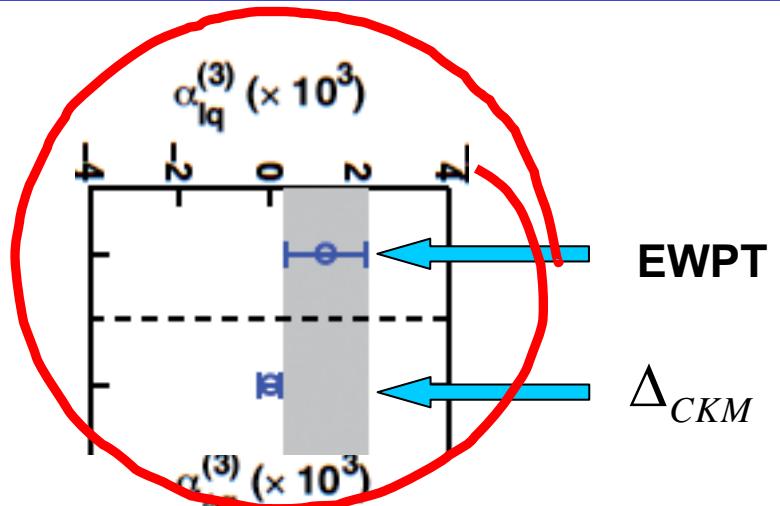
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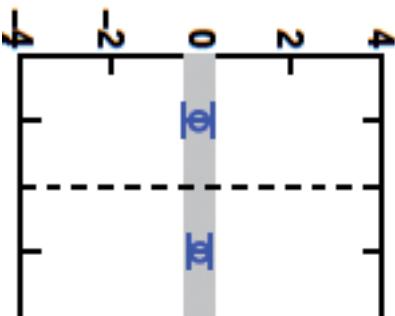
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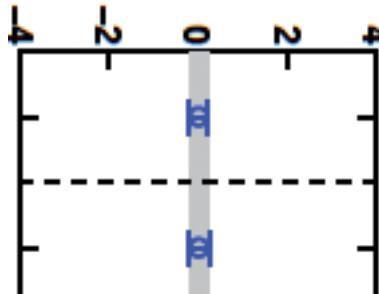
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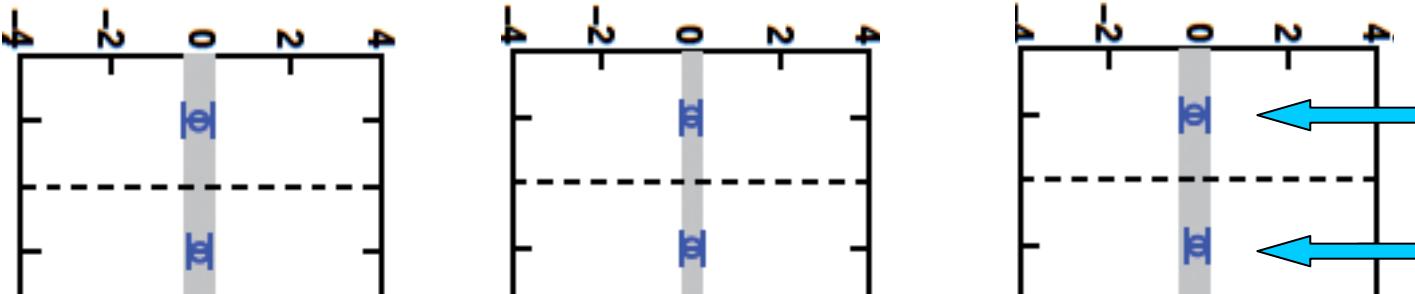
$\alpha_{ll}^{(3)} (\times 10^3)$



$\alpha_{\varphi l}^{(3)} (\times 10^3)$



$\alpha_{\varphi q}^{(3)} (\times 10^3)$



Conclusions

- In a model independent framework we have found the 4 short-distance operators that generate violations of CKM-unitarity

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

- The direct experimental limit puts strong constraints on all 4 operators, at the level of the colliders constraints or better.

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



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

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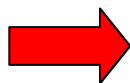
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Message for Model-Builders:

Take into account the CKM unitarity test! Especially if your model generates the contact term...

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

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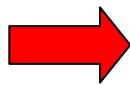
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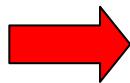
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Message for Experimentalists:

Measuring V_{ud} (V_{us}) you are really probing the TeV scale!

Thanks!

Backup slides

The eff. Lagrangian for E~1 GeV

- Muon decay $\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$

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

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

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

where...

$$\tilde{\nu}_L = 2[\hat{\alpha}_{\phi l}^{(3)}]_{11+22*} - [\hat{\alpha}_{ll}^{(1)}]_{1221} - 2[\hat{\alpha}_{ll}^{(3)}]_{1122-(1221)/2}$$

...

NP flavor structure

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

- Case 1: FB...

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

U(3)⁵ inv.

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

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

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

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

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

- Case 3: More generic structure...

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

Δ_{CKM} vs. EW precision measurements

Han & Skiba (2005)

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

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

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

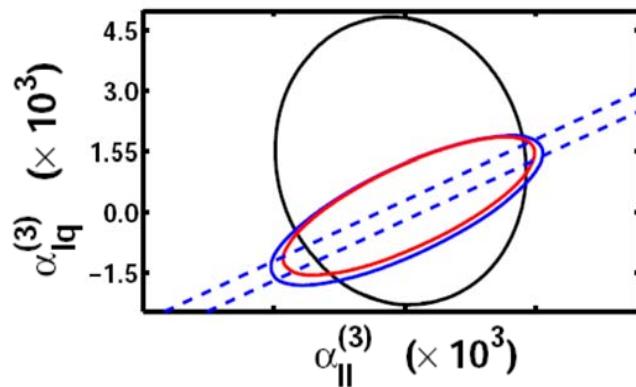
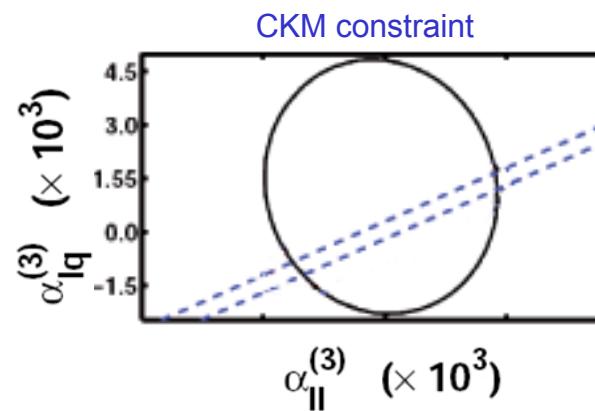
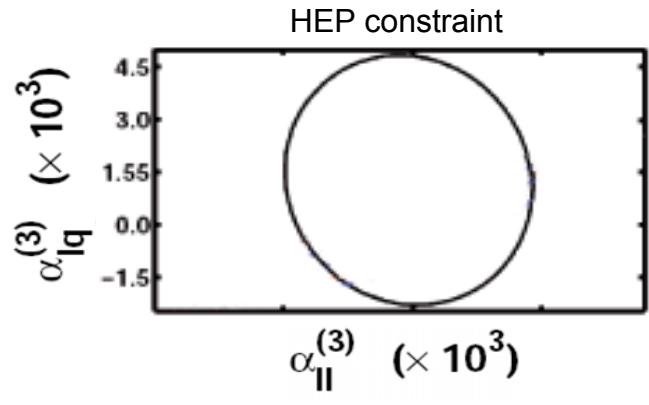
$$\Delta_{CKM}^{\text{exp.}} = -(0.1 \pm 0.6) \cdot 10^{-3}$$

5 times more
precise!

This leaves ample room
for a sizeable violation
of CKM-unitarity

Δ_{CKM} vs. EW precision measurements

□ Global analysis



$$4(-\bar{\alpha}_{ql}^{(3)} + \bar{\alpha}_{pq}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}) = -(0.1 \pm 0.6) \cdot 10^{-3}$$

$$4(-\bar{\alpha}_{ql}^{(3)} + \bar{\alpha}_{pq}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}) = -(2.5 \pm 0.6) \cdot 10^{-3}$$

Combination
HEP + CKM
HEP + CKM (alt)