4th International Workshop on
CKM
Unitarity Triangle
2006 Nagoya

Quark and Lepton Flavour Physics in the Littlest Higgs Model with T-Parity (LHT)

1. **Introduction to Little Higgs Models**

2. **Flavour Analysis in LHT:**
- Mixing, ~~CP~~, B -> $X_s\ \gamma$
- K and B rare decays
- Lepton flavour violating decays

Andrzej J. Buras & Cecilia Tarantino

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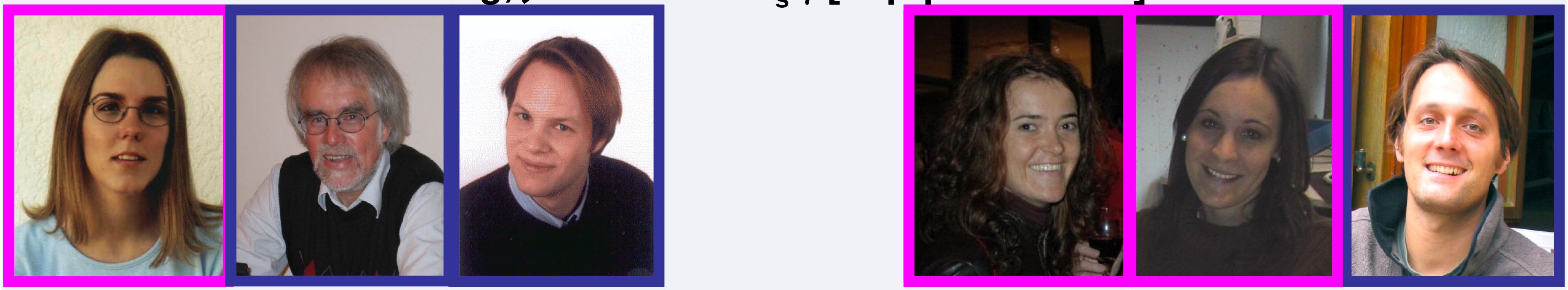
Mixing, $\not{CP}$ and $B \to X_s \gamma$ [hep-ph/0605214]



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K and B rare decays [hep-ph/0610298]

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Lepton flavour violating decays [coming soon!]

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A brief theoretical introduction…

The Little Hierarchy Problem of the Standard Model

``New Physics (NP) at 1 TeV is expected but its effects are not observed´´

From the instability of the (fundamental scalar) Higgs mass:

$$\delta m_H^2 \propto \Lambda^2 , \qquad m_H = O(v) \approx 10^2\,\mathrm{GeV}$$

⇒ $\Lambda \approx 1\,\mathrm{TeV}$ is the natural value for the NP scale

WHILE

Parameterizing NP by higher-dimensional operators suppressed by Λ:

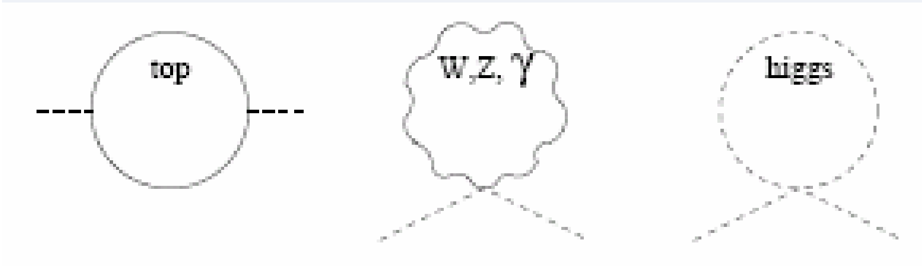
$(h^\dagger D_\mu h)^2/\Lambda^2$, $(D^2 h^\dagger D^2 h)/\Lambda^2$),…

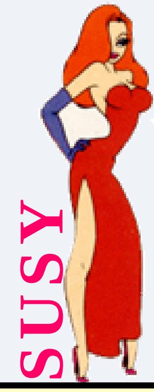
Ew precision tests yield $\Lambda \geq 5\text{-}10\,\mathrm{TeV}$

Is it possible to stabilize the Higgs mass without violating the above bound?

SUSY vs Little Higgs

Problematic quadratic divergences in m_H^2





	SUSY	Little Higgs
Quadratic divergences canceled by:	(different statistics) super-partners	(same statistics) heavy partners
Coupling relationships due to:	boson-fermion symmetry	global symmetry

- SUSY has a lot of virtues (required at M_{Pl}, computable up to M_{Pl}, helps GUT) but also …a lot of parameters (~120 in MSSM)
- Lack of SUSY signals at LEP constrains the MSSM parameters to be ~fine-tuned

- Little Higgs models are low-energy effective theories computable up to Λ~10 TeV
- Little Higgs can have less parameters(~20 in LH with T-parity) but some UV-sensitivity
- T-parity makes LH well compatible with ew precision tests, without fine-tuning

The General Mechanism of Little Higgs Models

The "little Higgs" is a pseudo-Nambu-Goldstone boson of a spontaneously broken symmetry. This symmetry is also explicitly broken but only "collectively", i.e. the symmetry is broken when two or more couplings in the Lagrangian are non-vanishing. Setting any one of these couplings to zero restores the symmetry and therefore the masslessness of the "little Higgs".

[N. Arkani-Hamed, A.G. Cohen, H. Georgi (2001)]

1. **The light Higgs is interpreted as a Goldstone boson of a spontaneously broken global symmetry (G)**

2. **Gauge and Yukawa couplings of the Higgs are introduced by gauging a subgroup of G**

3. **\`\`Dangerous´´ quadratic corrections are avoided at one-loop through Collective Symmetry Breaking**
   (the Higgs becomes massive only when two couplings are non-vanishing)

- **The Higgs dynamics is described (similarly to ChPT) by a non-linear sigma model up to Λ ~10TeV**
- **The UV completion is unknown (another LH?,SUSY?,ED?)**

The most economical in matter content: Littlest Higgs (LH)

[N. Arkani-Hamed, A.G. Cohen, E. Katz, A.E. Nelson (2002)]

Global Spontaneous SB: $SU(5) \xrightarrow{f \approx O(1\,TeV)} SO(5)$

Gauging: $[SU(2) \otimes U(1)]_1 \otimes [SU(2) \otimes U(1)]_2 \xrightarrow{f} SU(2)_L \otimes U(1)_Y$

(g_1) (g'_1) (g_2) (g'_2)

Collective SB: $\delta m_H^2 \propto g_1^{(\prime)2} g_2^{(\prime)2}$

Gauge Bosons: $W^{\pm}_H$, Z^0_H, A^0_H

Fermions: T

Scalars: Φ(triplet)

(with O(f) masses)

UV-cutoff $\Lambda = (4\pi f)$

LH(without T-parity) vs LHT(with T-parity)

Tree-level heavy gauge boson contributions and the triplet Φ vev make ew precision tests highly constraining
[Han, Logan, McElrath, Wang]
[Csaki, Hubisz, Kribs, Meade, Terning]

→ **f ≥ 2-3 TeV**

- The little hierarchy problem is back
- Only small effects in Flavour Physics

Buras, Poschenrieder, Uhlig, hep-ph/0410309//0501230
Buras, Poschenrieder, Uhlig, Bardeen, hep-ph/0607189
Choudhury, Gaur, Goyal, Mahajan, hep-ph/0407050
Lee, hep-ph/0408362
Fajfer, Prelovsek, hep-ph/0511048
Huo, Zhu, hep-ph/0306029
Choudhury, Gaur, Joshi, McKellar, hep-ph/0408125

These unwanted contributions are eliminated by a discrete symmetry:

T-parity

- SM particles are T-even,
- new particles are T-odd

(similarly to R-parity in SUSY)

smaller f allowed by ew tests
[Hubisz,Meade,Noble,Perelstein]

↓

f ≥ 500 GeV

- The little hierarchy problem is solved
- Large effects are possible in Flavour Physics

T-Parity

[H.C. Cheng, I. Low (2003)]

Symmetry under $[SU(2) \otimes U(1)]_1 \longleftrightarrow [SU(2) \otimes U(1)]_2$

$\Longleftrightarrow$ $g_1 = g_2$ $g'_1 = g'_2$

T-even Sector:

SM Particles + T_+

T-odd Sector:

Gauge Bosons: $W^{\pm}_H$, Z^0_H, A^0_H

Fermions: T_-, Mirror Fermions (f_H)

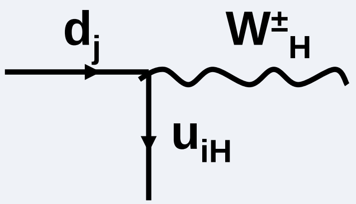
Scalars: Φ

with NEW flavour interactions

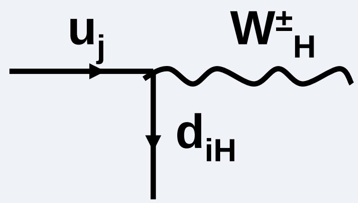
LHT goes beyond Minimal Flavour Violation (MFV)

(without introducing new operators and non-perturbative uncertainties)

``visible effects in flavour physics are possible´´



$\sim\ (V_{Hd})_{ij}\,\gamma_\mu\,(1-\gamma_5)$



$\sim\ (V_{Hu})_{ij}\,\gamma_\mu\,(1-\gamma_5)$

$V^\dagger_{Hu}\, V_{Hd} = V_{CKM}$

[Low], [Hubisz,Lee,Paz]

$$V_{Hd} = \begin{pmatrix} c_{12}^d c_{13}^d & s_{12}^d c_{13}^d e^{-i\delta_{12}^d} & s_{13}^d e^{-i\delta_{13}^d} \\ -s_{12}^d c_{23}^d e^{i\delta_{12}^d} - c_{12}^d s_{23}^d s_{13}^d e^{i(\delta_{13}^d - \delta_{23}^d)} & c_{12}^d c_{23}^d - s_{12}^d s_{23}^d s_{13}^d e^{i(\delta_{13}^d - \delta_{12}^d - \delta_{23}^d)} & s_{23}^d c_{13}^d e^{-i\delta_{23}^d} \\ s_{12}^d s_{23}^d e^{i(\delta_{12}^d + \delta_{23}^d)} - c_{12}^d c_{23}^d s_{13}^d e^{i\delta_{13}^d} & -c_{12}^d s_{23}^d e^{i\delta_{23}^d} - s_{12}^d c_{23}^d s_{13}^d e^{i(\delta_{13}^d - \delta_{12}^d)} & c_{23}^d c_{13}^d \end{pmatrix}$$

V_{Hd} parameterization similar to CKM, but with 2 additional phases

(the phases of SM quarks are no more free to be rotated)

[Blanke,AJB,Poschenrieder,Recksiegel,CT,Uhlig,Weiler]

[Similar new interactions and mixing matrices appear in the lepton sector]

LHT Flavour Analysis in the quark sector

M.Blanke AJB A.Poschenrieder S.Recksiegel CT S.Uhlig A.Weiler

Blanke,AJB,Poschenrieder,CT,Uhlig,Weiler,[hep-ph/0605214]

Mixing, ~~CP~~, B -> $X_s \gamma$

Blanke,AJB,Poschenrieder,Recksiegel,CT,Uhlig,Weiler,[hep-ph/0610298]

K and B rare decays

Mixing,
CP-Violation,
$B \rightarrow X_s \gamma$

Mixing, ~~CP~~, B $\to X_s\,\gamma$
``The Strategy´´

- Impose constraints on: ΔM_K, ε_K, $\Delta M_{d,s}$, $\Delta\Gamma^{d,s}$, $S_{\psi K_S}$, $B \to X_s\,\gamma$
- Explore LHT effects in: $A^{d,s}_{SL}$, $S_{\psi\Phi}$
- Special attention to: $S_{\psi K_S}$, ΔM_s

BaBar+Belle

$$\sin(2\beta)_{\psi K_S} = 0.675 \pm 0.026$$

tree-level decays only, free from NP

$$\sin(2\beta)_{UTA} = 0.794 \pm 0.045$$

recent CDF measurement

$$\Delta M_s = (17.77 \pm 0.10 \pm 0.07)/\mathrm{ps}$$

The UTA predicts a slightly larger value:

(18.4 ± 2.4)/ps [UTfit]

$(21.7\,^{+5.9}_{-4.2})$/ps [CKMfitter]

Can the LHT prediction approach the CDF measurement???

2.3 σ difference!

Is it the effect of a NP phase in

$$S_{\psi K_S} = \sin(2\beta + 2\varphi_{Bd})\text{???}$$

Benchmark Scenarios in LHT

Parameters:

- f
- x_L (top-sector)

} allowed ranges from ew precision tests

Mirror fermion masses: m_{H1}, m_{H2}, m_{H3}

V_{Hd} parameters: $\theta^d_{12}, \theta^d_{13}, \theta^d_{23}, \delta^d_{12}, \delta^d_{13}, \delta^d_{23}$

- The ΔM_K and ε_K constraints require almost degenerate $m_{H1} \approx m_{H2}$
- Large effects in K or B physics are possible with a peculiar V_{Hd} hierarchy

B_s Scenario:
large effects in B_s system

$s^d_{23} \ll s^d_{13} < s^d_{12}$
($4\cdot 10^{-4}$) ($8\cdot 10^{-2}$) (0.90)

K Scenario:
large effects in K system

$c^d_{12} = s^d_{12} = \frac{1}{\sqrt{2}}$

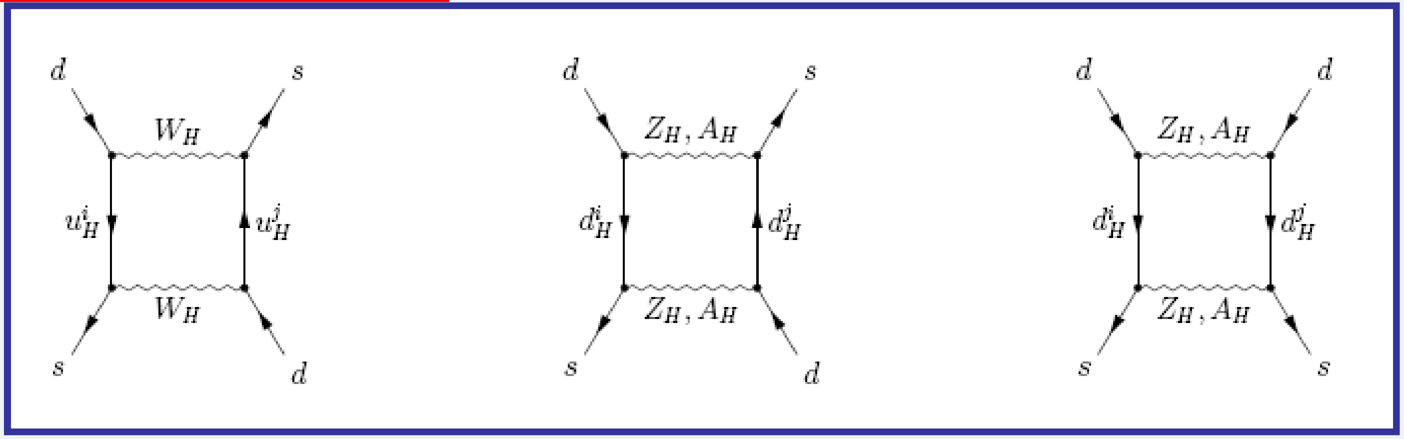
$s^d_{23} \approx s^d_{13} \leq 0.1$

{ $m_{H1} \approx m_{H2} \approx 500\,\text{GeV}$
$m_{H3} \approx 1000\,\text{GeV}$
$\delta^d_{12} = \delta^d_{23} = 0$
(minor impact) } (applies to both scenarios)

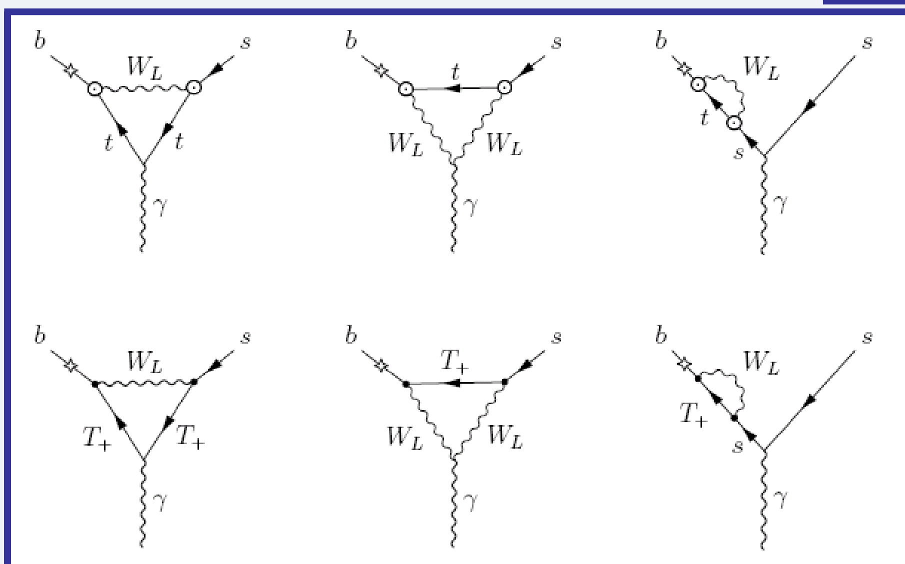
General scan over parameters:
large effects in both B and K systems

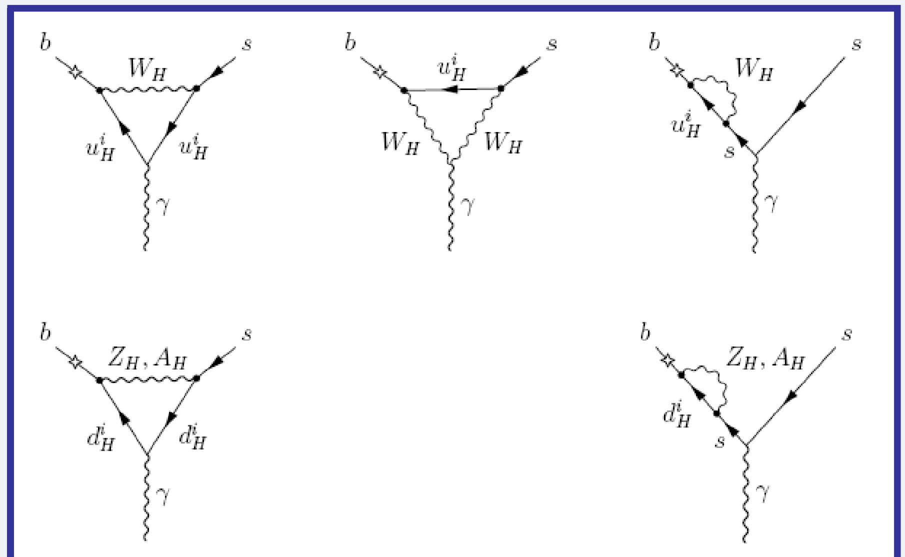
A quick look at **Feynman Diagrams**

Particle-Antiparticle Mixing



$B \to X_s\ \gamma$





T-even contribution

T-odd contribution

sin2β

The sin2β difference can be explained in terms of a new phase

$$\varphi_{Bd} \approx -5°$$

ΔM$_s$

$$C_{Bq} = \frac{(\Delta M_q)_{LHT}}{(\Delta M_q)_{SM}}$$

$$0.93 \leq C_{Bs} \leq 1.25$$

$$(\Delta M_s)_{LHT} < (\Delta M_s)_{SM}$$

is possible,

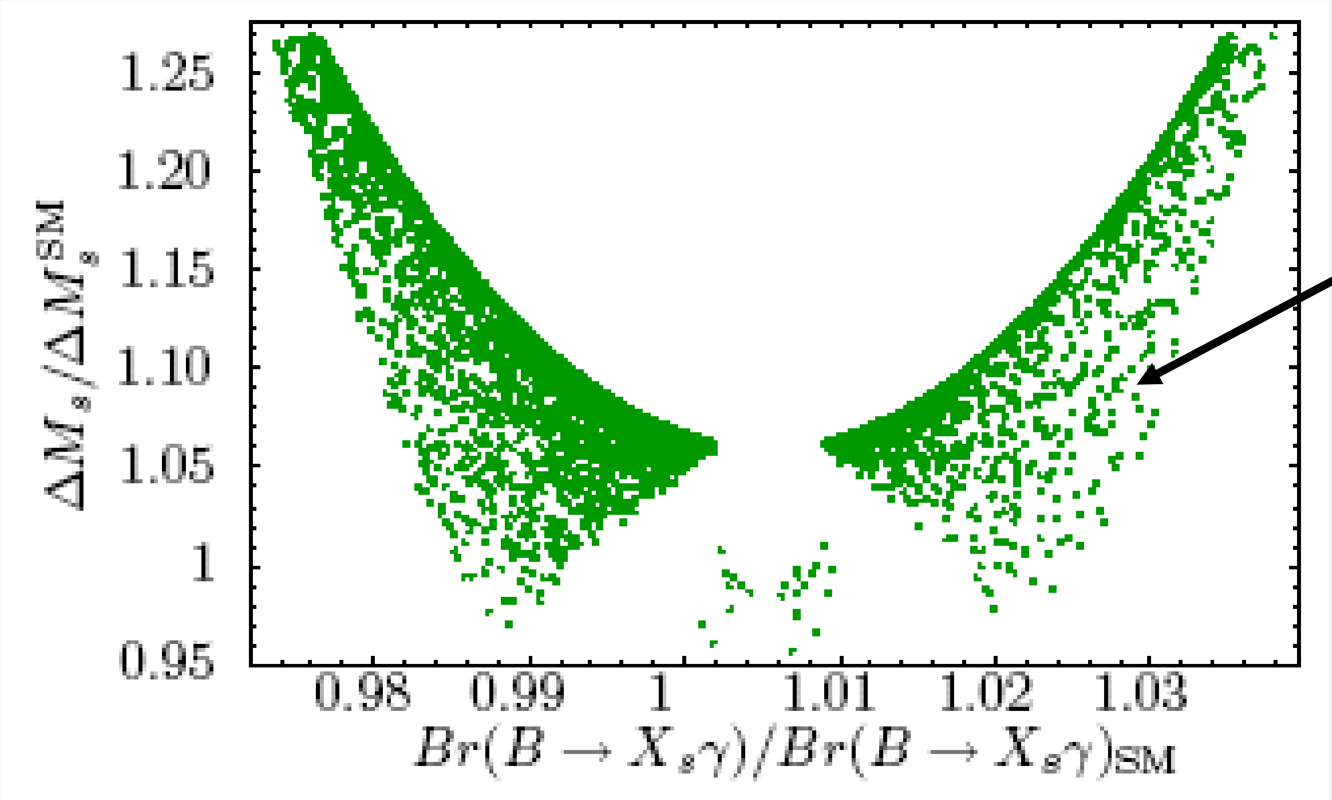
approaching the CDF measurement

$Br(B\text{->}X_s\,\gamma)$

At most ±4% effects in the LHT Model

Good agreement with data

Small effects also in $A_{CP}(B\text{->}X_s\,\gamma)$



Favored by the recent NNLO SM prediction [Misiak et al.]

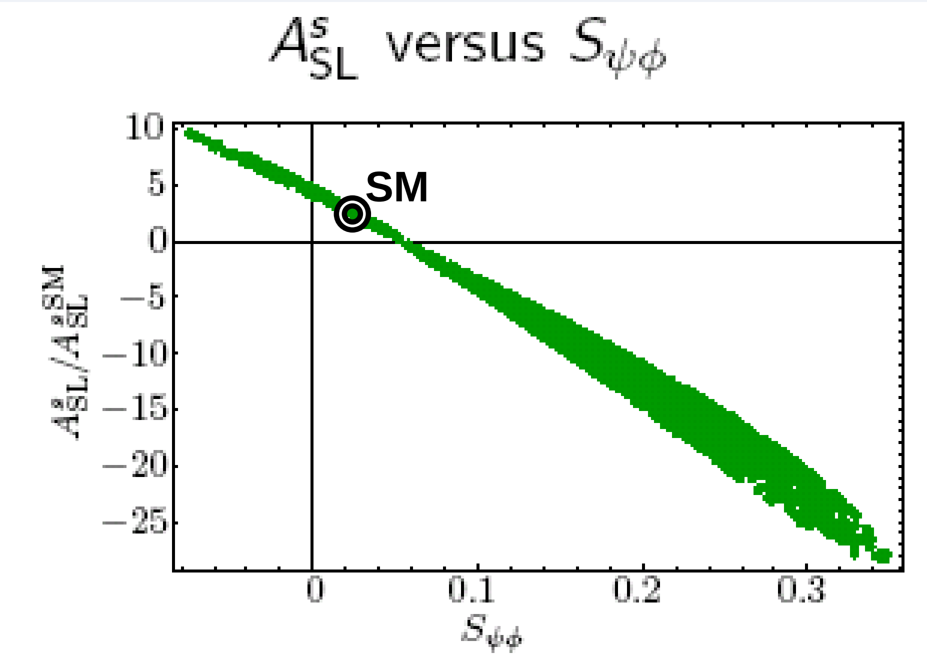
$Br(B\to X_s\gamma)_{SM} < Br(B\to X_s\gamma)_{exp}$

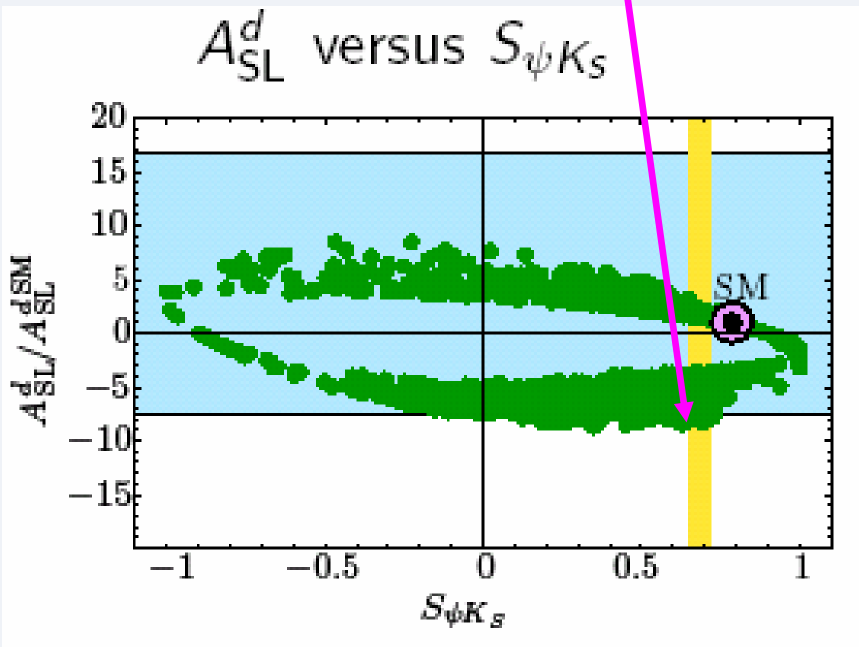
Semileptonic and t-dependent CP-asymmetries

$$A_{SL}^{q} = \frac{\Gamma(\overline{B}_s^0 \to l^+ X) - \Gamma(B_s^0 \to l^- X)}{\Gamma(\overline{B}_s^0 \to l^+ X) + \Gamma(B_s^0 \to l^- X)}$$

$$S_{\psi K_s} = \sin(2\beta + 2\varphi_{B_d}),$$
$$S_{\psi\phi} = \sin(2|\beta_s| - 2\varphi_{B_s})$$

φ_{Bd} =+43° disfavored also by $(A^d_{SL})_{exp}$





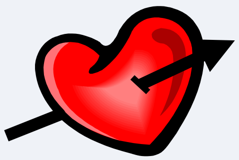
- A^s_{SL} enhanced by 10-20, A^d_{SL} by ~3
- $S_{\psi\Phi}$ can be as high as +0.3

Further results from AJB…

Rare K and B Decays in the LHT Model

The Magnificent Six

$K^+ \to \pi^+ \nu\bar{\nu}$



$K_L \to \pi^0 \nu\bar{\nu}$

$K_L \to \pi^0 e^+ e^-$

$K_L \to \pi^0 \mu^+ \mu^-$

$B_s \to \mu^+ \mu^-$

$B_d \to \mu^+ \mu^-$

General Structure of New Physics Contributions

SM : $\lambda_t^{(K)} = V_{ts}^* V_{td}$ $\lambda_t^{(d)} = V_{tb}^* V_{td}$ $\lambda_t^{(s)} = V_{tb}^* V_{ts}$

Amplitudes : $\lambda_t^{(i)} X_{SM}(m_t)$ $\lambda_t^{(i)} Y_{SM}(m_t)$

$\nu\bar{\nu}$ in the final state $\mu^+\mu^-$ in the final state

Universality of short distance functions

$i = K, B_d, B_s$

LHT :

$$X_i = \underbrace{X_{SM}(m_t) + \bar{X}_{even}}_{\text{real}} + \underbrace{\frac{1}{\lambda_t^{(i)}} \xi_i \bar{X}_{odd}}_{\text{complex}} \equiv |X_i| e^{i\theta_X^i}$$

$\xi_i \uparrow$ **V_{Hd}**

Breakdown of Universality

$$Y_i = \overbrace{Y_{SM}(m_t) + \bar{Y}_{even}} + \overbrace{\frac{1}{\lambda_t^{(i)}} \xi_i \bar{Y}_{odd}} \equiv |Y_i| e^{i\theta_Y^i}$$

(mirror fermions)

Natural Expectations

$$X_i = X_{SM}(m_t) + \overline{X}_{even} + \frac{1}{\lambda_t^{(i)}} \xi_i \overline{X}_{odd} \equiv |X_i| e^{i\theta_X^i}$$

$i = K, B_d, B_s$

(similarly for Y_i)

ξ_i ← V_{Hd}

$$\frac{1}{\lambda_t^{(K)}} \approx 2 \cdot 10^3$$

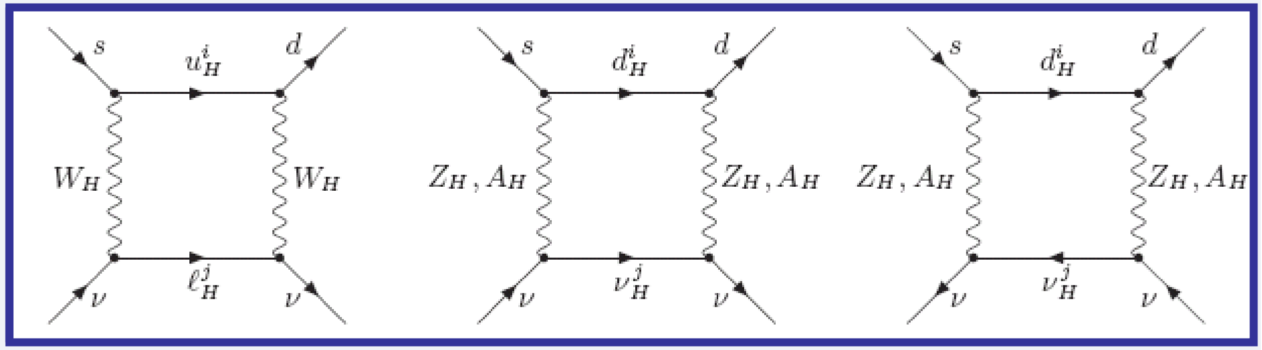
$$\frac{1}{\lambda_t^{(d)}} \approx 100$$

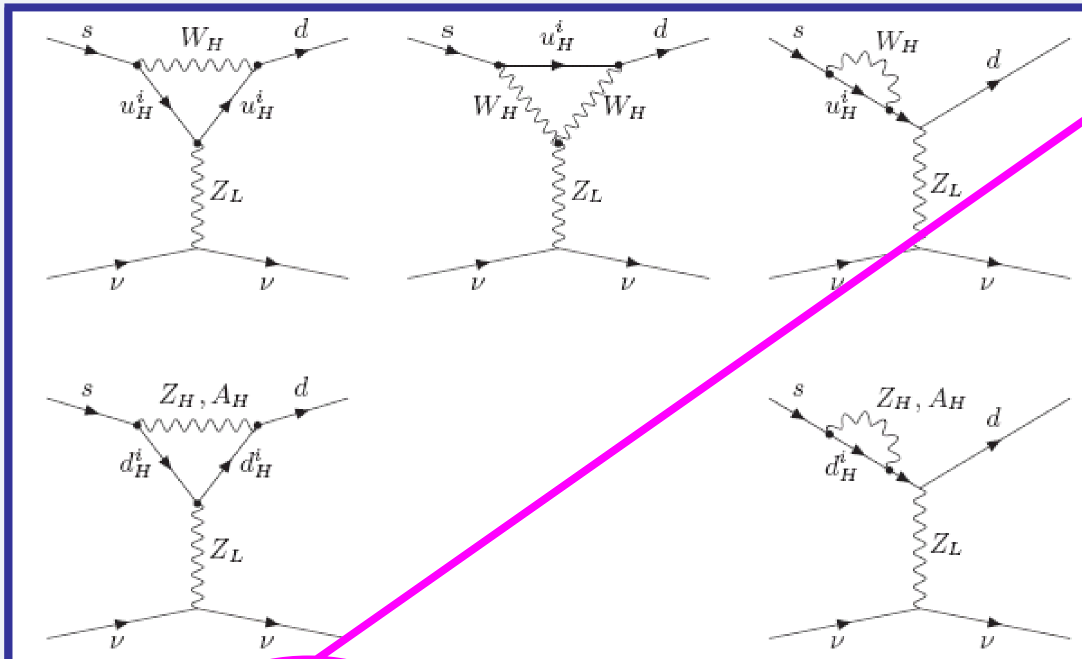
$$\frac{1}{\lambda_t^{(s)}} \approx 25$$

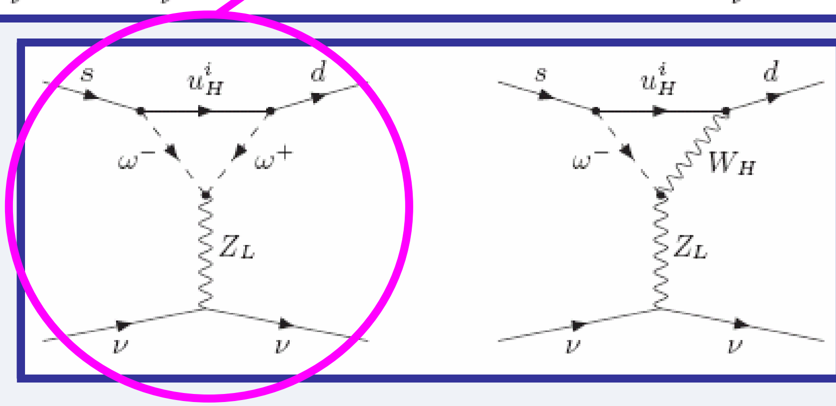
{ Natural size of NP contributions } : **$K \gg B_d > B_s$**

But can be reversed for special structures of V_{Hd}

A quick look at Feynman Diagrams







(gauge-independent)
divergence remains!!!

It reflects a **sensitivity** of the non-linear sigma model to the **UV completion**
(behavior known in ChPT and previously found in LH without T-parity
[Buras,Poschenrieder,Uhlig,Bardeen])

The **logarithmically enhanced** term can be estimated:

$$\frac{1}{\varepsilon} + \log\frac{\mu^2}{M_{W_H}^2} \rightarrow \log\frac{\Lambda^2}{M_{W_H}^2}$$

[dim.reg. $\rightarrow$ cut-off reg.]

Comments on the ``Divergence´´

1. Gauge Independent.
   Present only in a single diagram contributing to Z^0-penguin.

2. Follows entirely from the interactions of the Goldstone bosons ($\omega^\pm$) of the dynamically broken global SU(5) with light fermions (mediated by $W_H^\pm$).

3. Estimated through ($\Lambda = 4\pi f \approx 10$TeV)

$$\delta_{div} = \frac{1}{\varepsilon} + \log\frac{\mu^2}{M^2_{W_H}} \rightarrow \log\frac{\Lambda^2}{M^2_{W_H}}$$

   Logarithmically enhanced physics contributions from $M_{W_H} \leq \mu \leq \Lambda$

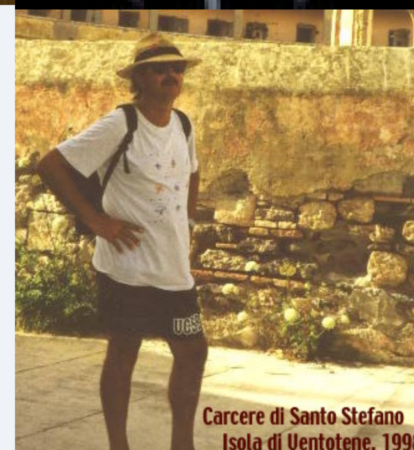
4. δ_{div} is universal with respect to light flavours
   $\longrightarrow$ can be traded for one observable and fit to the data.

5. If the UV-completion was known, matching to the full theory would replace δ_{div} by a Λ_{UV} independent contribution.

Message to the 3 Roman ``Musketeers´´

Luca Silvestrini

Gino Isidori



Guido Martinelli

…and to ChPT Purists

We are aware of the fact that the Gasser-Leutwyler analysis with counterterms could be performed here.

But, we think it would be an OVERKILL at present!

Classification of Decays

Class A

Decays with some sensitivity to Λ_{UV}

$K^+ \to \pi^+ \nu\bar{\nu},\ K_L \to \pi^0 \nu\bar{\nu},\ K_L \to \pi^0 l^+ l^-$

$B_{s,d} \to \mu^+\mu^-,\ B \to X_{s,d}\nu\bar{\nu}, B \to X_{s,d} l^+ l^-$

$$\tau^- \to \mu^- \pi, \mu^- \to e^- e^+ e^-, \tau^- \to \mu^- \mu^+ \mu^-, \tau^- \to e^- e^+ e^-,$$
$$\tau^- \to \mu^- e^+ e^-, \tau^- \to e^- \mu^+ \mu^-$$

Class B

Decays not exhibiting any logarithmic sensitivity to Λ_{UV}

$\Delta M_K,\ \varepsilon_K,\ \Delta M_{d,s},\ S_{\psi K_S},\ B \to X_s \gamma,\ \Delta\Gamma_{d,s},\ A^{d,s}_{SL},\ S_{\psi\Phi}$

$$K_L \to \mu e, B_{d,s} \to \mu e, B_{d,s} \to \tau e, B_{d,s} \to \tau\mu$$

$$\mu \to e\gamma, \tau \to \mu\gamma, \tau \to e\gamma, \tau^- \to e^- \mu^+ e^-, \tau^- \to \mu^- e^+ \mu^-, (g-2)_\mu$$

Golden Relations of CMFV:

AJB (03)

$$\frac{Br(B_s \to \mu^+\mu^-)}{Br(B_d \to \mu^+\mu^-)} = \frac{\hat{B}_{B_d}}{\hat{B}_{B_s}} \frac{\tau(B_s)}{\tau(B_d)} \frac{\Delta M_s}{\Delta M_d} r$$

(CMFV)

r = 1

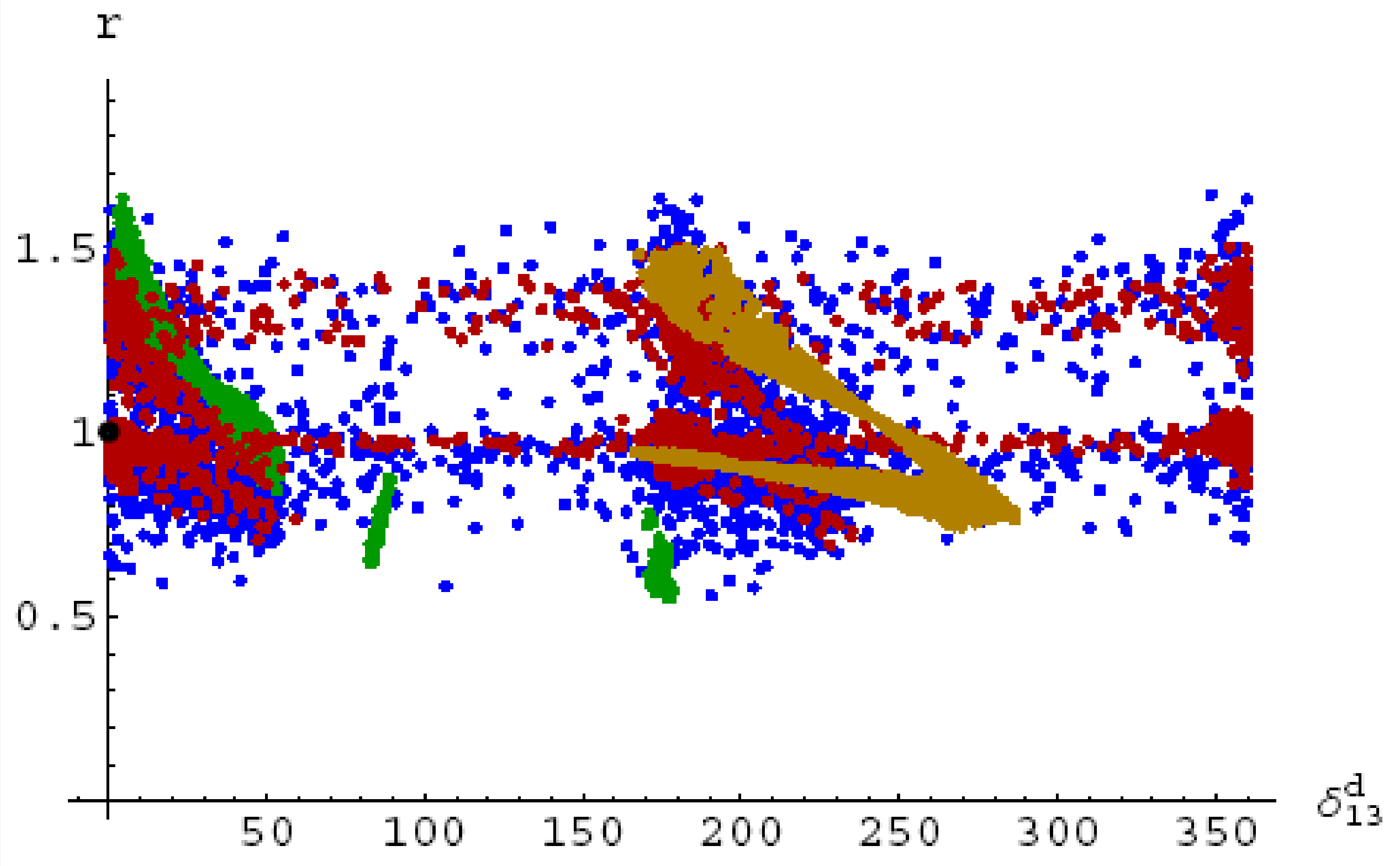
Buchalla
AJB (94)

$$(\sin 2\beta)_{B\to\psi K_S} = (\sin 2\beta)_{K\to\pi\nu\bar{\nu}}$$

(MFV)

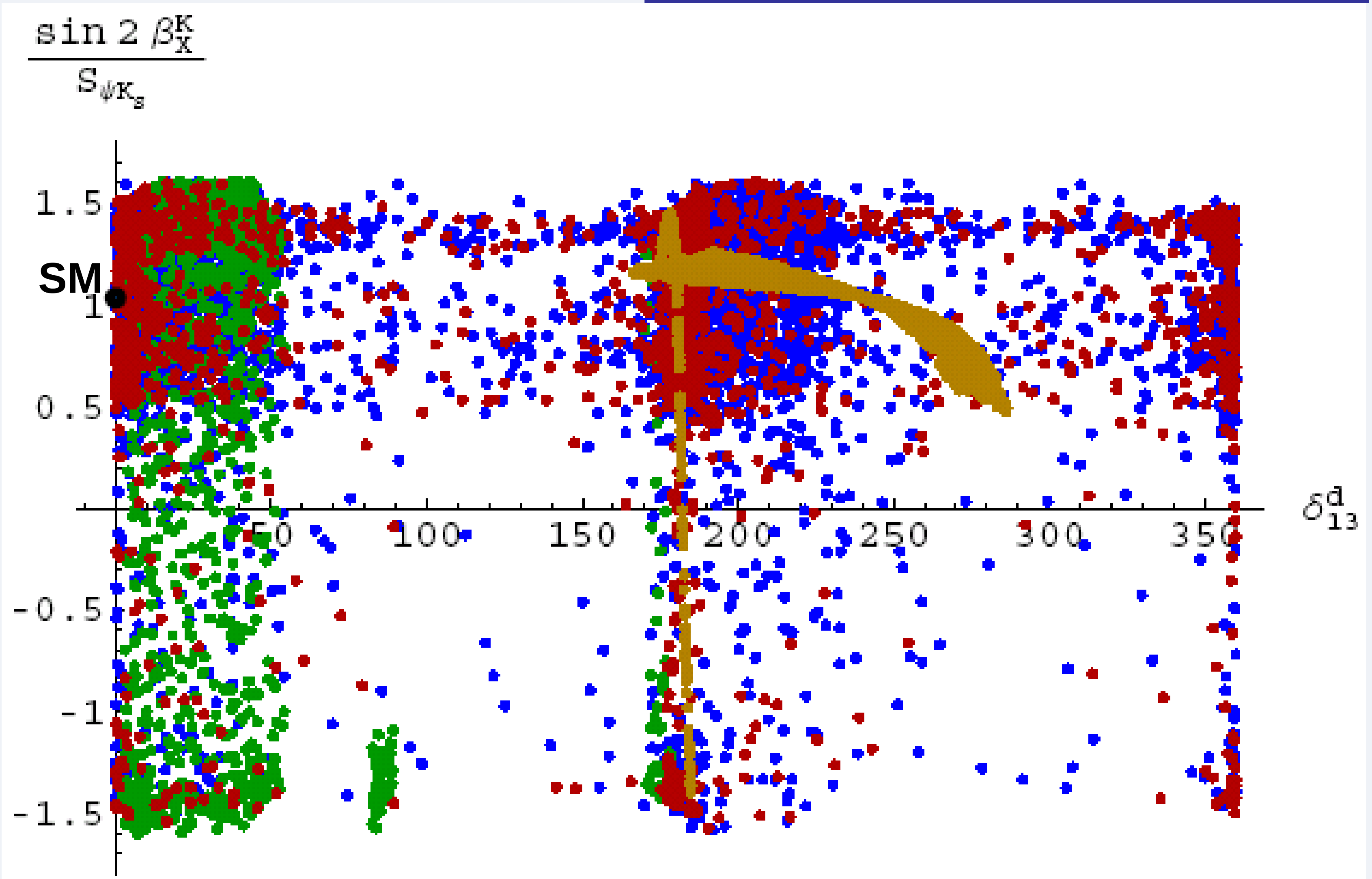
The violation of these model independent MFV (CMFV) relations would signal new flavour and CP-violating interactions (and/or new operators)

Violation of the Golden Relation

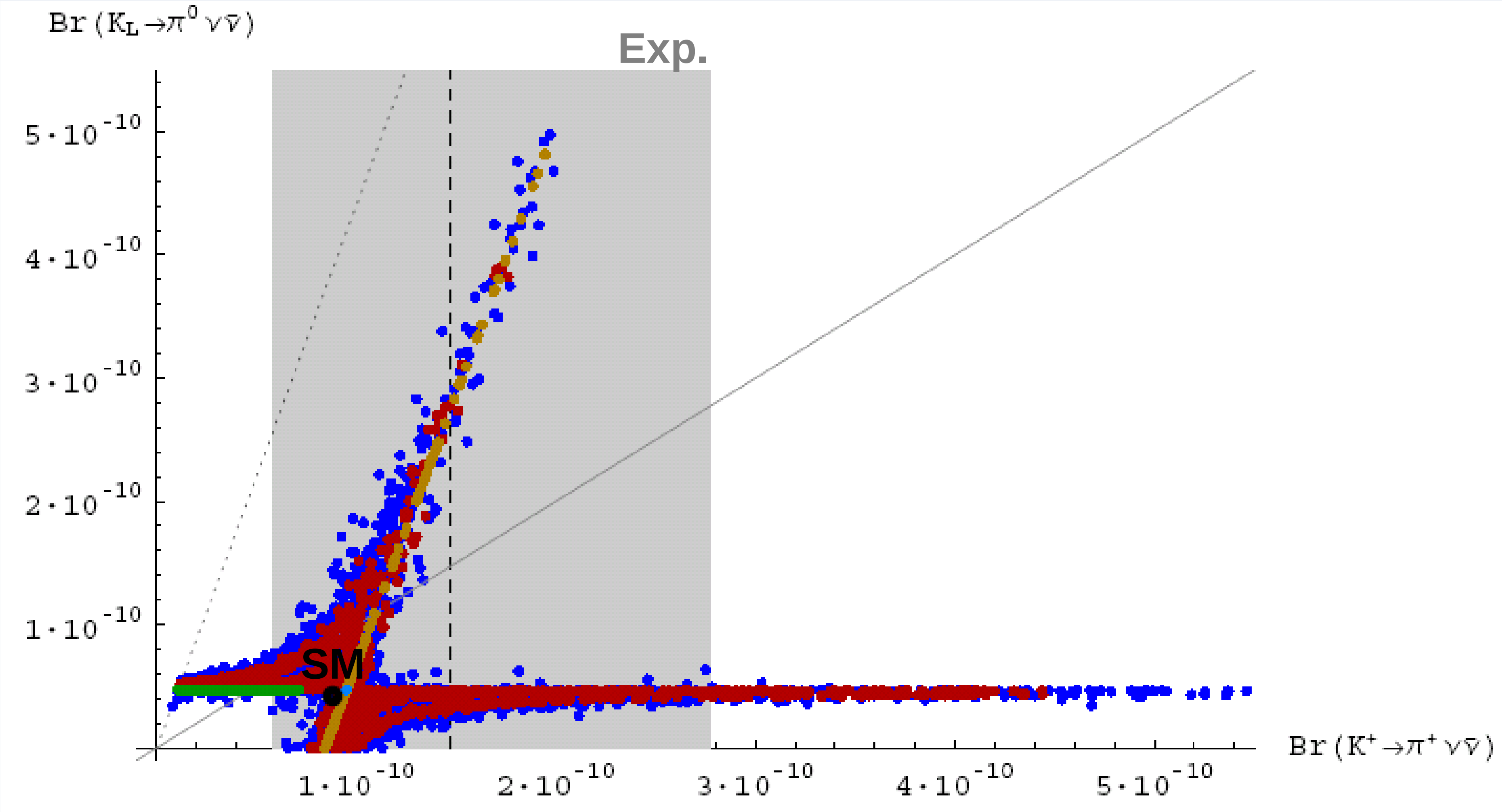


An evident Consequence of Universality Breakdown

The MFV identity between β from $B \to \psi K_S$ and $K_L \to \pi^0 \nu \bar{\nu}$ can be strongly violated



K-system: $K_L \to \pi^0 \nu\bar{\nu}$ vs $K^+ \to \pi^+ \nu\bar{\nu}$

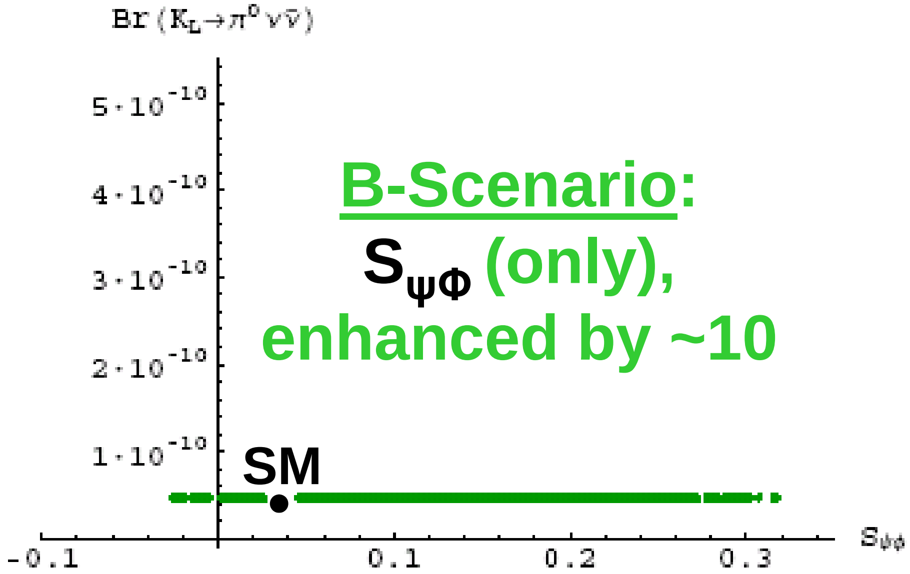


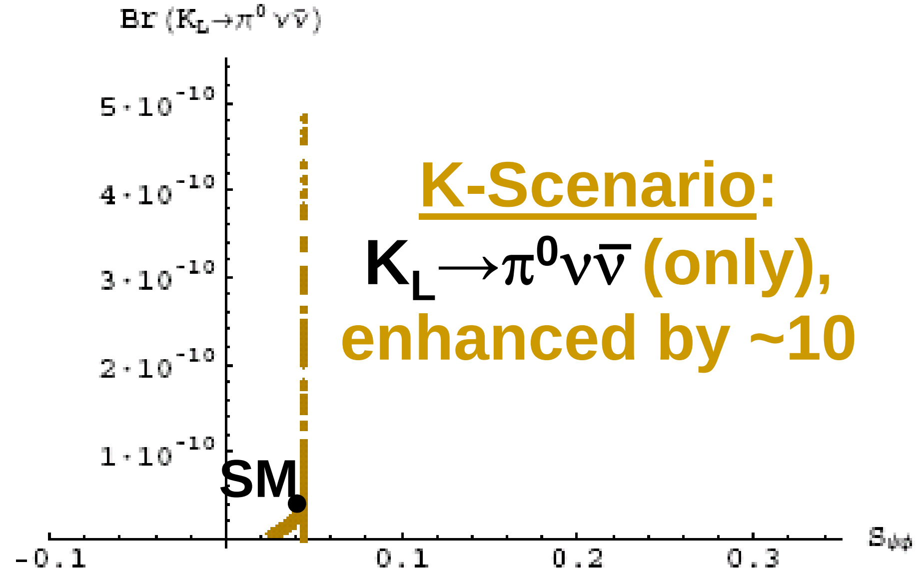
Two distinguished branches appear!

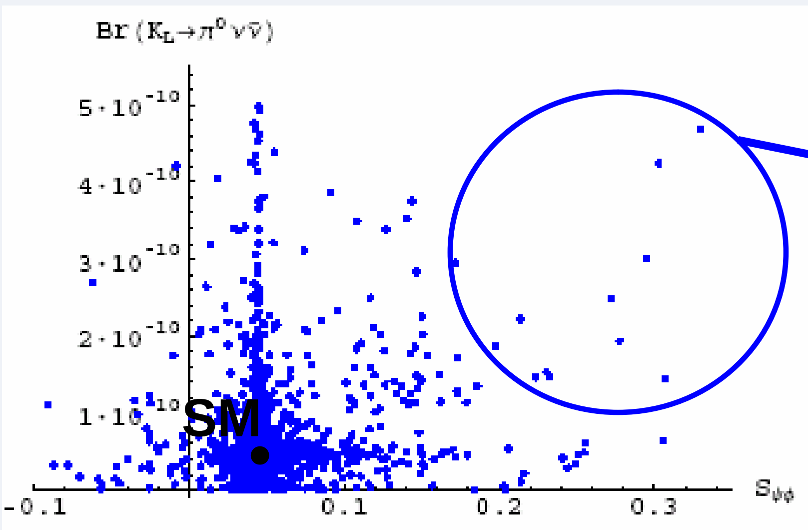
~10 times enhancement in $K_L \to \pi^0 \nu\bar{\nu}$

~5 times enhancement in $K^+ \to \pi^+ \nu\bar{\nu}$

K-system vs B_s-system: $K_L \to \pi^0 \nu \bar{\nu}$ vs $S_{\psi\Phi}$



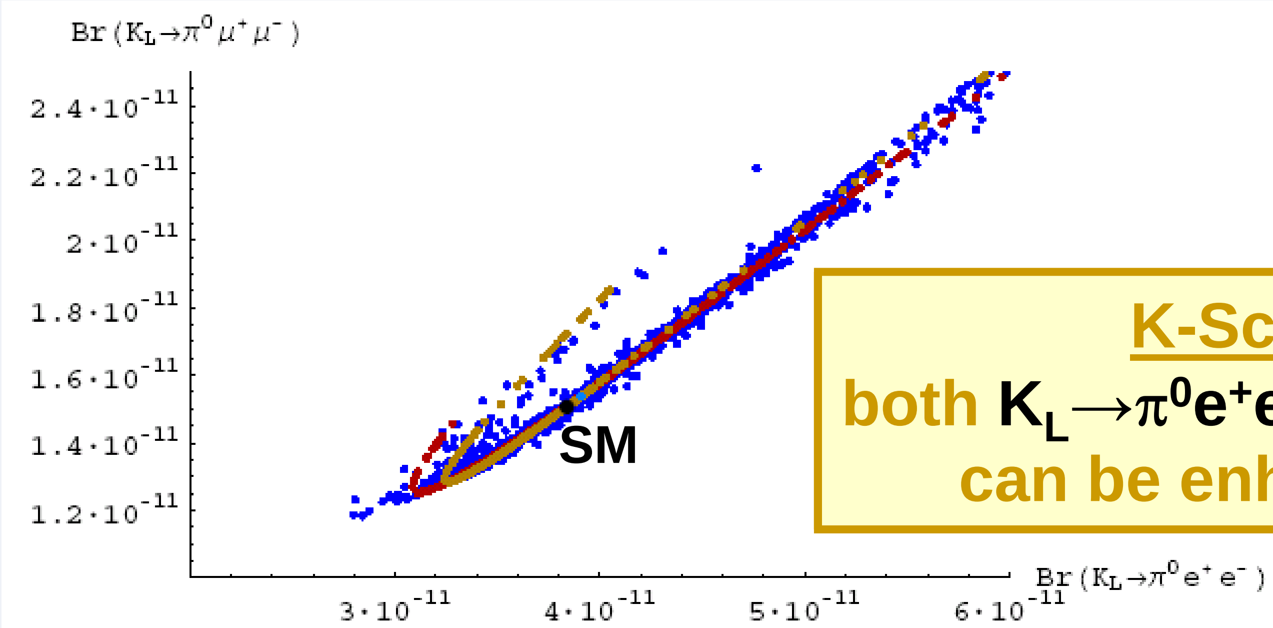




General Scan: simultaneous enhancements!

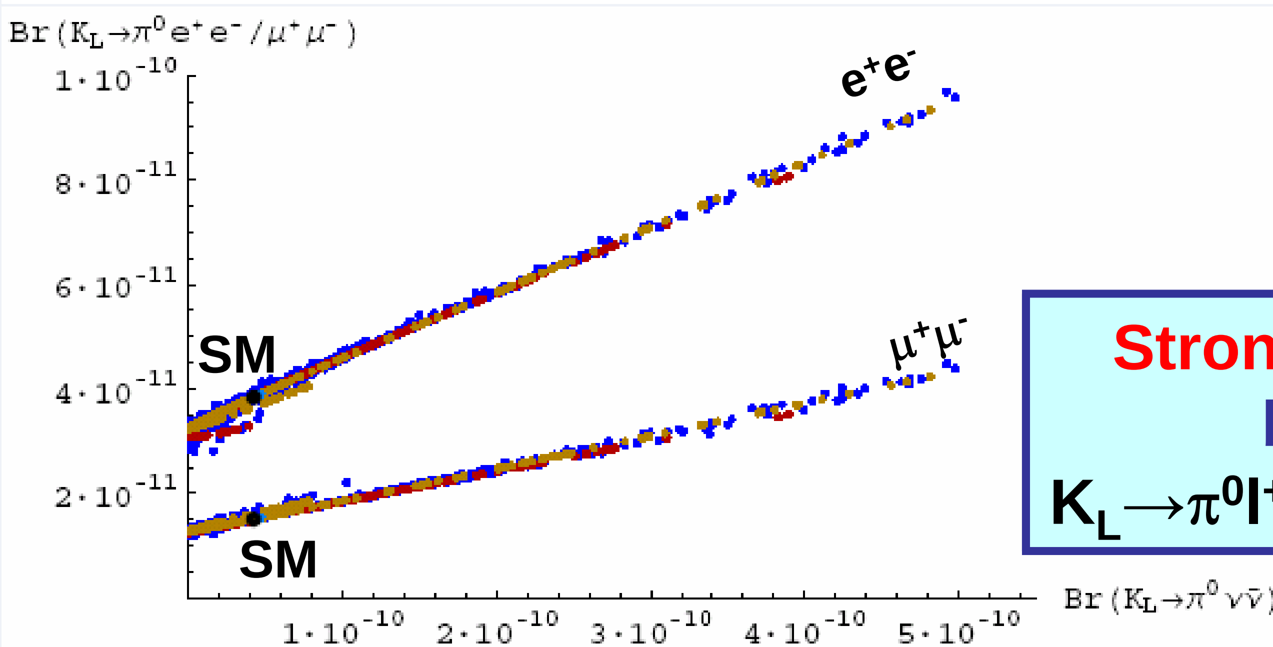
(with some fine-tuning between masses and V_{Hd})

K-system: $K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \mu^+ \mu^-$



Friot, Greynat, de Rafael (04)
General correlation:
Isidori, Smith, Unterdorfer (04)
Mescia, Smith, Trine (06)

K-Scenario:
both $K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \mu^+ \mu^-$
can be enhanced by ~2



BBPRTUW (06)

Strong correlation between $K_L \to \pi^0 l^+ l^-$ and $K_L \to \pi^0 \nu\bar{\nu}$

Lepton Flavour Violating Decays

[hep-ph/0701XXX]

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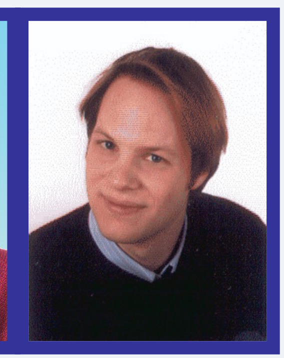


A.Poschenrieder

CT

Decays calculated by BBDPT

$\mu \to e\gamma$ ★
$\tau \to \mu\gamma$
$\tau \to e\gamma$

$\mu^- \to e^- e^+ e^-$
$\tau^- \to \mu^- \mu^+ \mu^-$
$\tau^- \to e^- e^+ e^-$

$K_L \to \mu e$
$B_{d,s} \to \mu e$
$B_{d,s} \to \tau e$
$B_{d,s} \to \tau\mu$
$K_L \to \pi^0 \mu e$

ΔL=1
ΔS=1
(ΔB=1)

$\tau^- \to e^- \mu^+ e^-$
$\tau^- \to \mu^- e^+ \mu^-$

ΔL=2

$\tau^- \to \mu^- e^+ e^-$
$\tau^- \to e^- \mu^+ \mu^-$

(ΔL=1, ΔL=2)

$\tau^- \to \mu^- \pi$ ★

$(g-2)_\mu$ ★

(well below exp. error)

★ **Previously calculated by A.Goyal [hep-ph/0609095]**

$\mu \rightarrow e\gamma$: State of the Art

- **SM (+right-handed neutrinos):**

  very much suppressed due to the smallnes of m_ν

$$Br(\mu \rightarrow e\gamma)_{SM} \approx 10^{-40}$$

- **Experimental bound:**

[MEGA Collaboration]

$$Br(\mu \rightarrow e\gamma)_{\text{exp}} < 1.2 \cdot 10^{-11} \quad (90\% C.L.)$$

It will be improved to $\sim 10^{-13}$ by MEG in 2007

- **SUSY could explain such high values.**

What about LHT?

General Picture

- **T-even Sector**

  LFV very strongly suppressed
  e.g. Br $(\mu \to e\gamma) \sim 10^{-40}$

- **Mirror Leptons can enhance LFV by 25-30 orders of magnitude**
  e.g. Br $(\mu \to e\gamma)_{LHT} \sim 10^{-(12\pm2)}$
  ⇒ could be tested by MEG(2007)

Other interesting Processes

- $\mu^- \to e^- e^+ e^-$: even more constrained than $\mu \to e\gamma$

$$Br(\mu^- \to e^- e^+ e^-)_{\exp} < 1.0 \cdot 10^{-12}$$

[SINDRUM Collaboration]

- $\tau \to \mu\gamma$ and $\tau \to e\gamma$: similar to $\mu \to e\gamma$

$$Br(\tau \to \mu\gamma)_{\exp} < 4.5 \cdot 10^{-8}$$

[Belle Collaboration]

$$Br(\tau \to e\gamma)_{\exp} < 1.2 \cdot 10^{-7}$$

[BaBar Collaboration]

- $\tau \to \mu\pi$: semileptonic decay

$$Br(\tau \to \mu\pi)_{\exp} < 4.1 \cdot 10^{-7}$$

[Belle Collaboration]

Bounds on τ-decays will be improved by SuperB

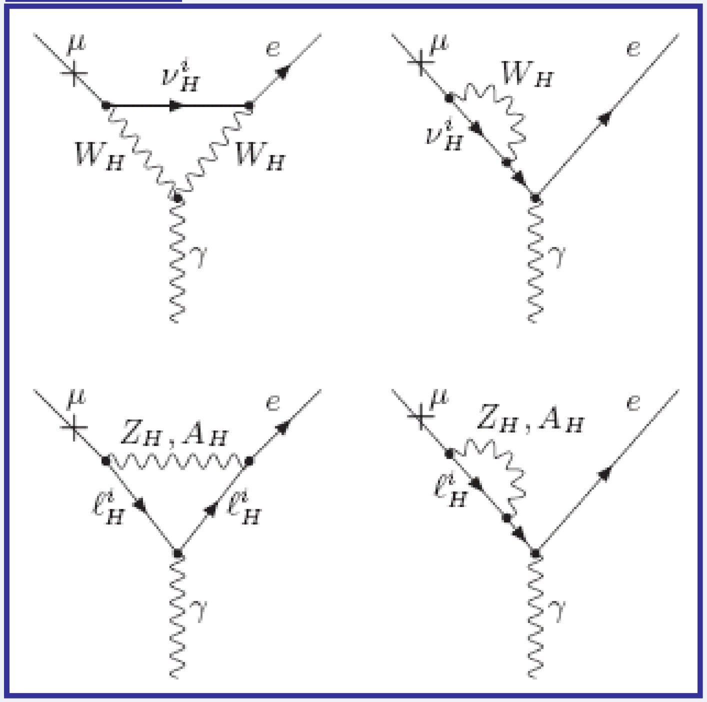
- $K_L \to \mu e$: flavour violating in both quark and lepton sectors

$$Br(K_L \to \mu e)_{\exp} < 4.7 \cdot 10^{-12}$$

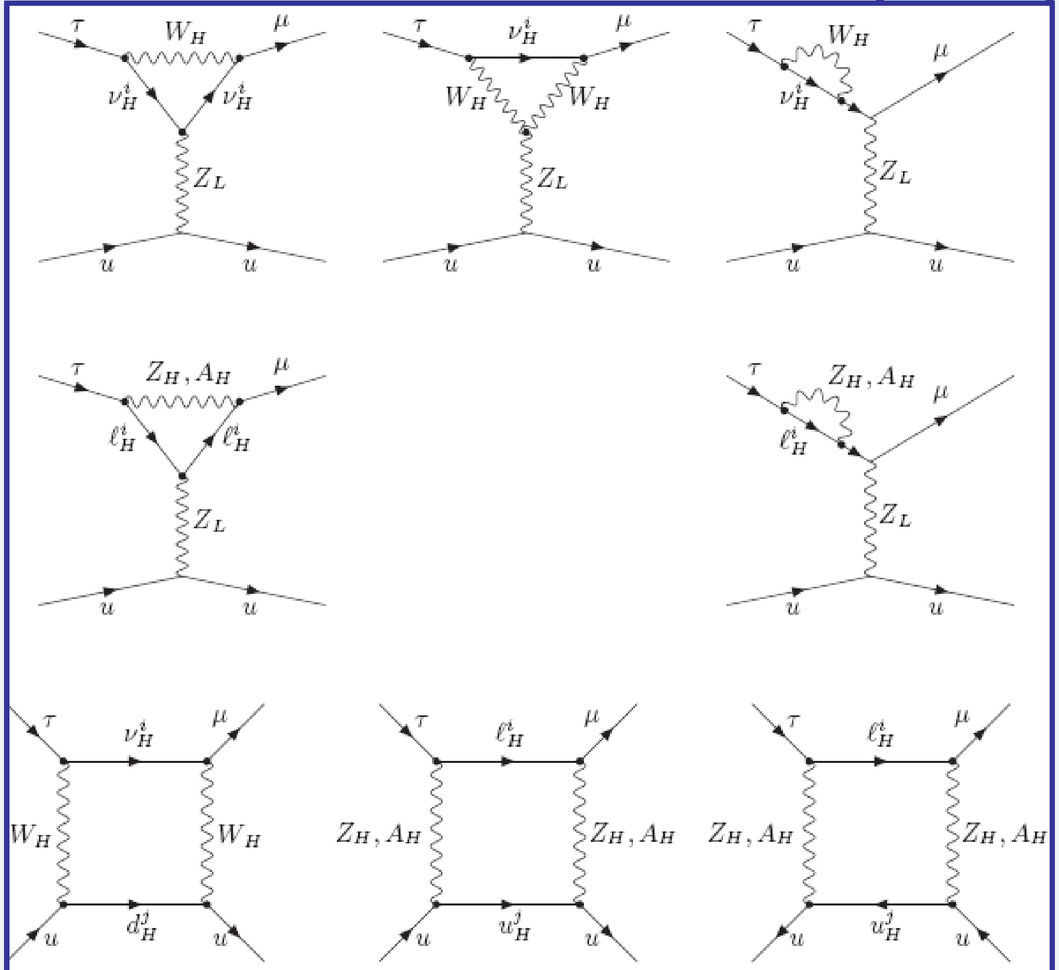
[BNL E871 Collaboration]

A quick look at Feynman Diagrams

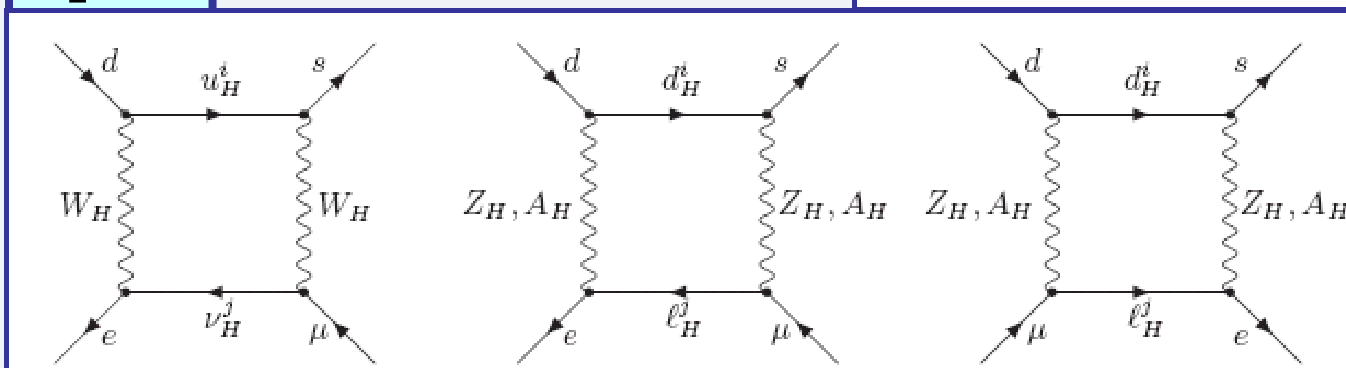
μ→eγ



τ→μπ

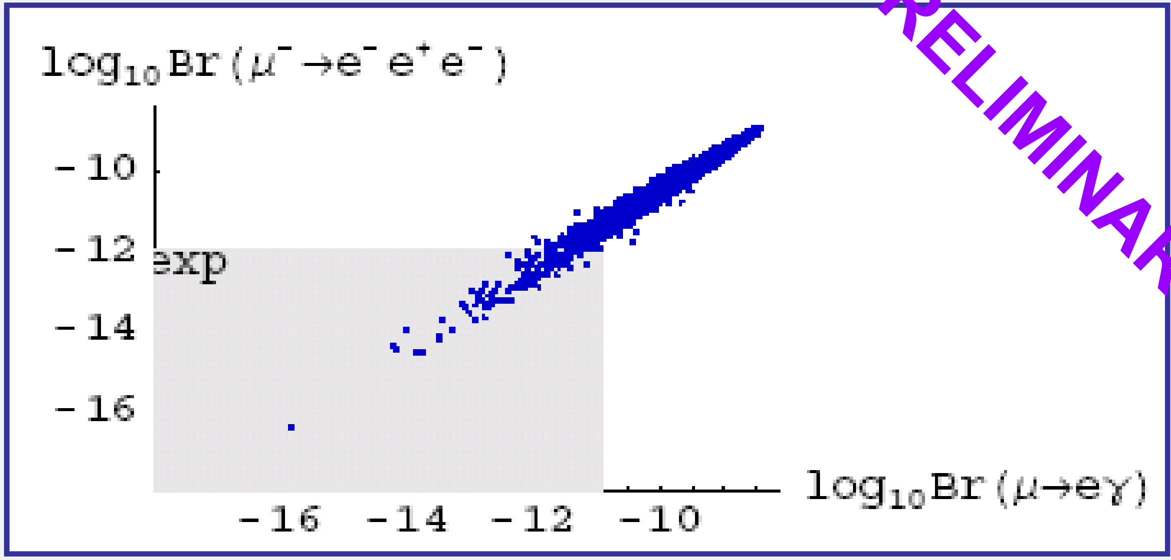


K_L→μe



$\mu \to e\gamma$ vs $\mu^- \to e^- e^+ e^-$

PRELIMINARY

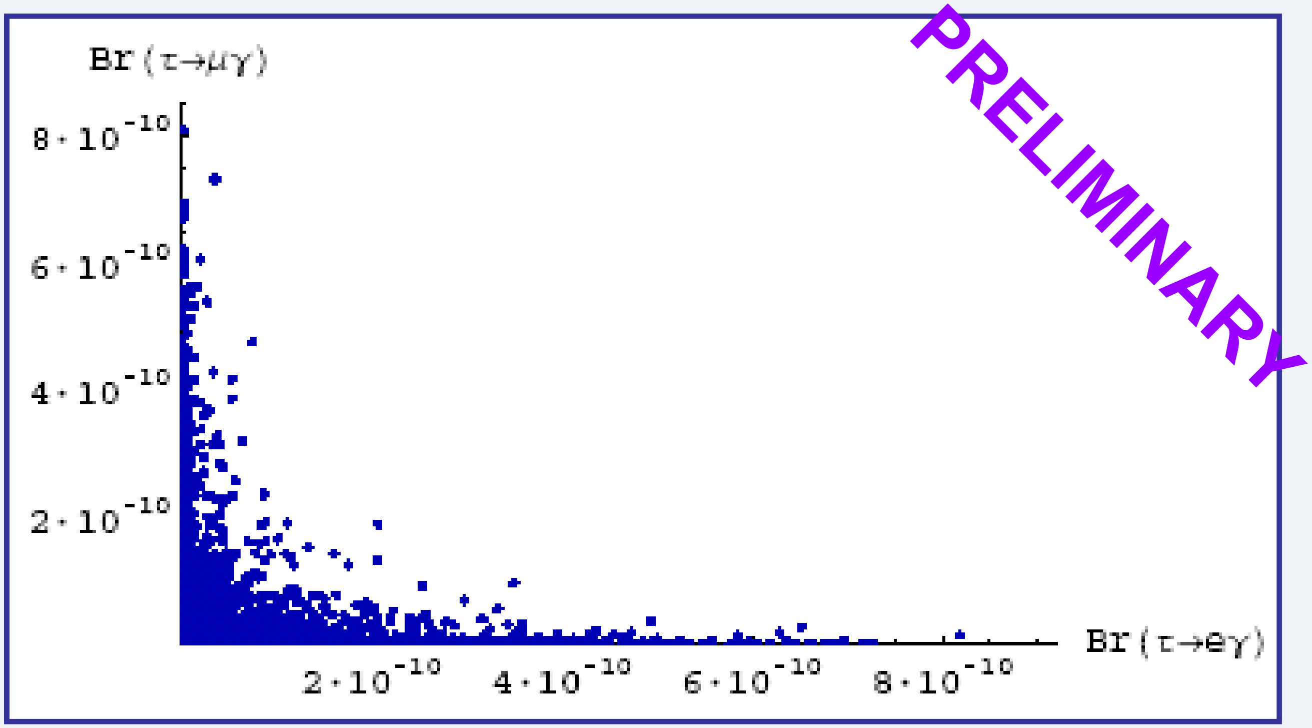


$V_{H\ell}$ is constrained to be hierarchical, but different from V_{CKM}

unless

the mirror lepton spectrum is quasi-degenerate

$\tau \to e\gamma$ vs $\tau \to \mu\gamma$

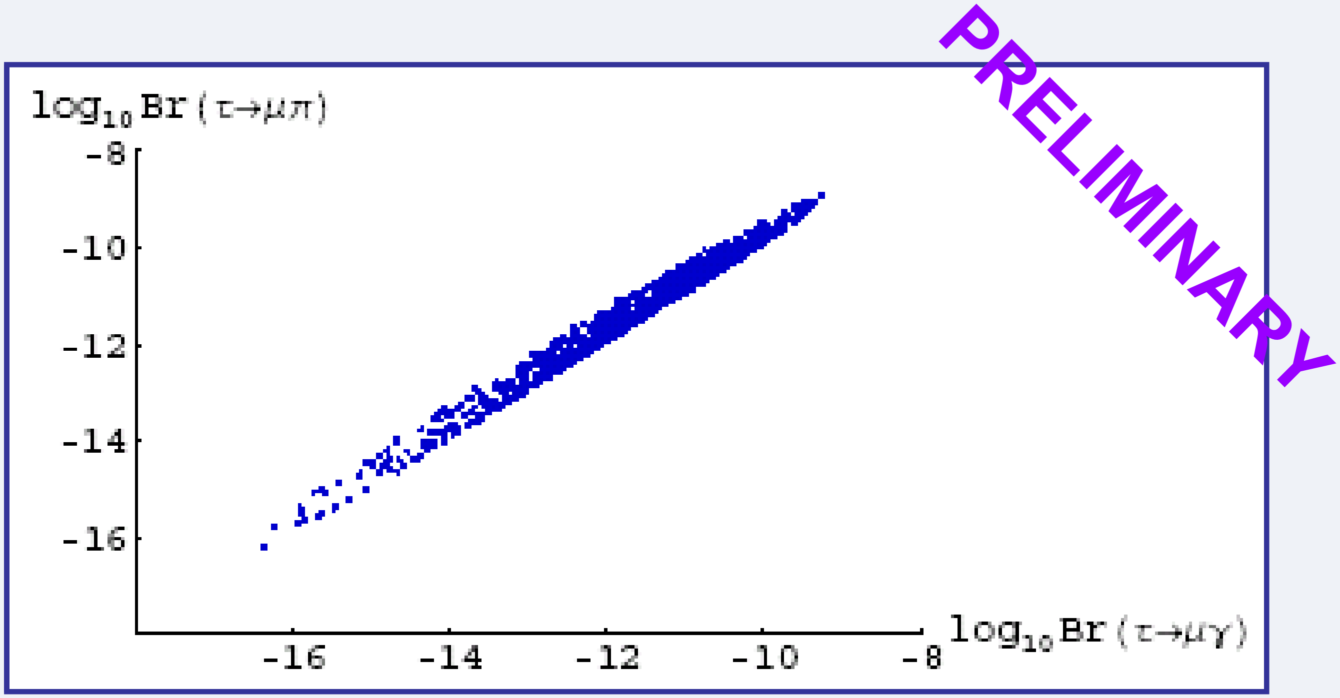


Imposing the constraints from $Br(\mu \to e\gamma)$ and $Br(\mu^- \to e^- e^+ e^-)$,

$Br(\tau \to \mu\gamma)$ and $Br(\tau \to e\gamma)$ can be:

- **as high as $8 \cdot 10^{-10}$, individually**
- **as high as $2 \cdot 10^{-10}$, simultaneously**

$\tau \to \mu\gamma$ VS $\tau \to \mu\pi$



<u>Messages to the Belle Collaboration</u>:

- **Br($\tau \to \mu\gamma$) and Br($\tau \to \mu\pi$) are strongly correlated**
- **Br($\tau \to \mu\pi$) can be as high as $2 \cdot 10^{-9}$**

Largest Values Consistent with Br(μ→eγ) and Br(μ⁻→e⁻e⁺e⁻)

PRELIMINARY

f = 1TeV (500GeV)

$$Br(\tau \to \mu\gamma) \approx 8\cdot 10^{-10}\left(2\cdot 10^{-8}\right)$$

[exp. < 4.5•10^-8]

$$Br(\tau^- \to \mu^-\mu^+\mu^-) \approx 2\cdot 10^{-10}\left(3\cdot 10^{-8}\right)$$

[exp. < 2•10^-7]

$$Br(\tau \to \mu\pi) \approx 2\cdot 10^{-9}\left(2\cdot 10^{-7}\right)$$

[exp. <4.1•10^-7]

$$Br(K_L \to \mu e) \approx 3\cdot 10^{-13}$$

[exp. <4.7•10^-12]

$$Br(B_d \to \mu e) \approx 6\cdot 10^{-16}$$

[exp. <1.7•10^-7]

$$Br(B_d \to \tau\mu) \approx 3\cdot 10^{-11}$$

[exp. <3.8•10^-5]

Main Messages on FCNC in LHT

- Rather small number of new parameters (~20)
- A useful playground for non-MFV effects (MFV relations can be sizably violated)
- Significant departures from SM possible

In the quark sector

Largest Effects :

$A_{SL}^{S}, \; S_{\psi\varphi}, \; K_L \to \pi^0 \nu\bar{\nu}$ (enhanced by ~10)

$K^+ \to \pi^+ \nu\bar{\nu}$ (enhanced by ~5), $K_L \to \pi^0 l^+ l^-$ (enhanced by ~2)

Interesting Correlations

Moderate Effects :

$B_{s,d} \to \mu^+ \mu^-$ (enhanced by 50%)

$B \to X_{s,d} \nu\bar{\nu}$ (enhanced by 35%)

sin2β-Problem can be solved and $(\Delta M_s)_{LHT} < (\Delta M_s)_{SM}$ possible

Small Effects :

$B \to X_{s,d}\gamma$ (5%), $B \to X_{s,d} l^+ l^-$ (15%), $B \to \pi K$ (10%)

Even if **Tevatron, LHC, Belle, Babar Super-B, ...**

would not see any significant new physics effects in $B_{s,d}$ decays

Large departures **in** $K_L \to \pi^0 \nu\bar{\nu}$, $K^+ \to \pi^+ \nu\bar{\nu}$

and $K_L \to \pi^0 l^+ l^-$ **from SM possible**

These decays have to be measured !!!

In the Lepton Sector

• $\mu \to e\gamma$ and $\mu^- \to e^- e^+ e^-$ can be seen soon

Measuring all channels considered would determine all parameters of the Lepton Sector : V_{Hl}, m^{l}_{Hi}

$(g-2)_\mu$ naturally small

Final Message on LHT

Mirror Quarks and Leptons at LHC

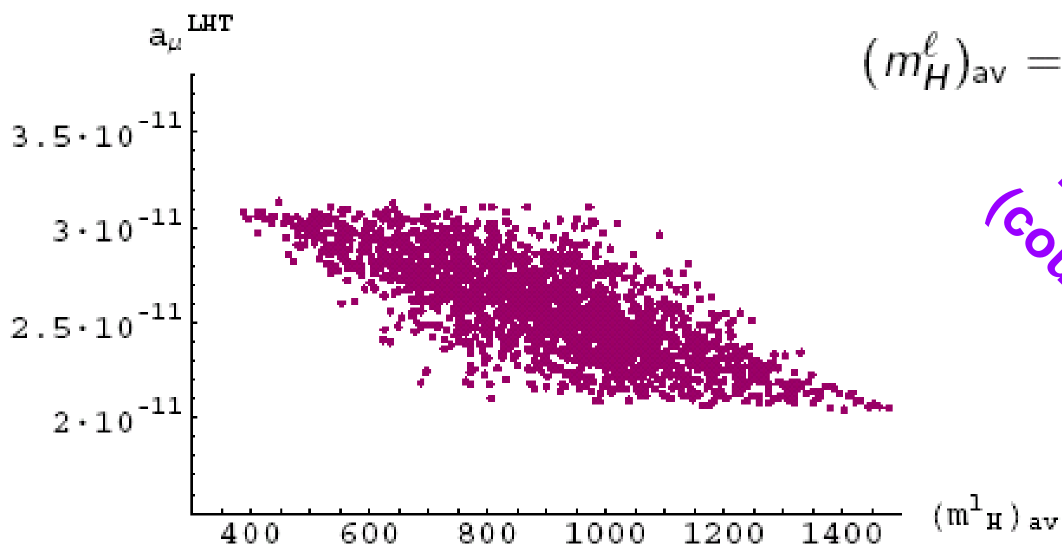
⇓

Dramatic Impact on FCNC processes in Quark and, in particular, Lepton Sectors naturally expected !

Backup

New contributions to $a_\mu = (g-2)_\mu/2$

$a_\mu^{\text{exp}} = 11659208(6) \cdot 10^{-10}$



$(m_H^\ell)_{\text{av}} = (\sum m_{Hi}^\ell)/3$

PRELIMINARY
(courtesy of M.Blanke)

- **LHT effects are far below experimental uncertainty**
- discrepancy between a_μ^{SM} and a_μ^{exp} cannot be resolved

B and K rare decays

``The Strategy´´

- Impose constraints on:
  ΔM_K, ε_K, $\Delta M_{d,s}$, $\Delta\Gamma^{d,s}$, $S_{\psi K_S}$, $B\to X_s\gamma$ and $B\to X_s l^+ l^-$
- Explore LHT effects in: $B_{s,d}\to\mu^+\mu^-$, $B\to X_{s,d}\nu\bar{\nu}$
  $K^+\to\pi^+\nu\bar{\nu}$, $K_L\to\pi^0\nu\bar{\nu}$, $K_L\to\pi^0 l^+ l^-$, $B\to\pi K$

	Exp.	SM	One-loop Functions
$B\to X_s\nu\bar{\nu}$	$<6.4\cdot10^{-4}$ [Aleph]	$3.2(4)\cdot10^{-5}$ [Buras]	X_s
$B_d\to\mu^+\mu^-$	$<3\cdot10^{-8}$ [CDF]	$1.0(1)\cdot10^{-10}$ [Buras]	Y_d
$B_s\to\mu^+\mu^-$	$<1\cdot10^{-7}$ [CDF]	$3.4(3)\cdot10^{-9}$ [Buras]	Y_s
$K_L\to\pi^0\nu\bar{\nu}$	$<2.1\cdot10^{-7}$ [E391a]	$2.9(4)\cdot10^{-11}$ [Buras,Gorbahn,Haisch,Nierste]	X_K
$K^+\to\pi^+\nu\bar{\nu}$	$1.5(11)\cdot10^{-10}$ [E787,E949]	$8.0(11)\cdot10^{-11}$ [Buras,Gorbahn,Haisch,Nierste]	X_K
$K_L\to\pi^0 e^+e^-$	$<2.8\cdot10^{-10}$ [KTeV]	$3.5(10)\cdot10^{-11}$ [Buchalla,D'Ambrosio,Isidori] [Isidori,Smith,Unterdorfer] [Mescia,Smith,Trine]	Y_K, Z_K
$K_L\to\pi^0\mu^+\mu^-$	$<3.8\cdot10^{-10}$ [KTeV]	$1.4(3)\cdot10^{-11}$ [Buchalla,D'Ambrosio,Isidori] [Isidori,Smith,Unterdorfer] [Mescia,Smith,Trine]	Y_K, Z_K

``B_s Scenario´´

V_{CKM}

V_{Hd} + Quasi-degeneracy of Mirror Fermions in the first two generations

$$\begin{pmatrix} c_{12} & s_{12} & s_{13}e^{-i\gamma} \\ -s_{12} & c_{12} & s_{23} \\ s_{12}s_{23}-s_{13}e^{i\gamma} & -s_{23} & 1 \end{pmatrix}$$

$$\begin{pmatrix} c^d_{12} & s^d_{12} & s^d_{13}e^{-i\delta^d_{13}} \\ -s^d_{12} & c^d_{12} & s^d_{23} \\ -c^d_{12}s^d_{13}e^{i\delta^d_{13}} & -s^d_{12}s^d_{13}e^{i\delta^d_{13}} & 1 \end{pmatrix}$$

Large $\not{CP}$ in $B^0_d - \bar{B}^0_d$
Small $\not{CP}$ in $B^0_s - \bar{B}^0_s$
Tiny $\not{CP}$ in K_L

Large $\not{CP}$ in $B^0_s - \bar{B}^0_s$
Small $\not{CP}$ in $B^0_d - \bar{B}^0_d$
Tiny $\not{CP}$ in K_L

$s_{13} << s_{23} << s_{12}$

($4\cdot10^{-3}$) ($4\cdot10^{-2}$) (0.2)

$s^d_{23} << s^d_{13} < s^d_{12}$

($4\cdot10^{-4}$) ($8\cdot10^{-2}$) (0.90)

``K Scenario´´

V_{CKM}

V_{Hd} + **Quasi-degeneracy of Mirror Fermions in the first two generations**

$$\begin{pmatrix} c_{12} & s_{12} & s_{13}e^{-i\gamma} \\ -s_{12} & c_{12} & s_{23} \\ s_{12}s_{23}-s_{13}e^{i\gamma} & -s_{23} & 1 \end{pmatrix}$$

$$\begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & s^d_{13}e^{-i\delta^d_{13}} \\ -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & s^d_{13} \\ \frac{s^d_{13}}{\sqrt{2}}(1-e^{i\delta^d_{13}}) & -\frac{s^d_{13}}{\sqrt{2}}(1+e^{i\delta^d_{13}}) & 1 \end{pmatrix}$$

Large $\not{CP}$ in $B^0_d - \bar{B}^0_d$
Small $\not{CP}$ in $B^0_s - \bar{B}^0_s$
Tiny $\not{CP}$ in K_L

$s_{13} << s_{23} << s_{12}$

$(4\cdot10^{-3})$ $(4\cdot10^{-2})$ (0.2)

Large $\not{CP}$ in K-Physics
Small $\not{CP}$ in B-Physics

$c^d_{12} = s^d_{12} = \frac{1}{\sqrt{2}}$

$s^d_{23} \approx s^d_{13} \leq 0.1$