Combined Analysis of Flavour Physics Effects in New Physics Models

Stefan Recksiegel (TUM) Portorož, April 14th, 2011

Minimal Flavour Violation ↔ Non-MFV

Buras et al. 01, D'Ambrosio et al. 02

Models are **MFV** if there are **no new sources** of Flavour Violation (i.e. only SM-Yukawa).

Examples of **MFV**:

- **Universal extra dimensions** (UED) (**A**ppelquist, **C**heng, **D**obrescu)
- **SUSY** with universal soft-scalar masses and trilinear soft terms proportional to Yukawa couplings (squark, quark masses aligned)
- **Little Higgs** without T-parity (no *mirror quarks*)

Examples of **non-MFV**:

- **General SUSY** (squark mass matrices not aligned with quarks)
- **Littlest Higgs with T-parity** (*mirror quarks*, new mix. matrix)
- **SM with a 4th generation** (*extended CKM matrix*)

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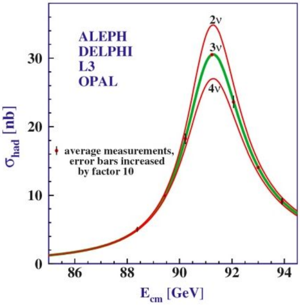
Two models of new physics:
I. The SM with a 4th generation

Why not four generations ?



Only **three** light neutrinos.

We do not really understand neutrino masses anyway, so $m_{\nu 4} \gg m_{\nu 1,2,3}$ **not a problem.**

Also: Potential problems with non-decoupling radiative corrections to **EWPO**, T parameter and $Zb\bar{b}$ vertex corrections are modified.

Upper bound on s_{34}: $|\sin\theta_{34}| \leq \frac{M_W}{m_{t'}}$ Chanowitz '09

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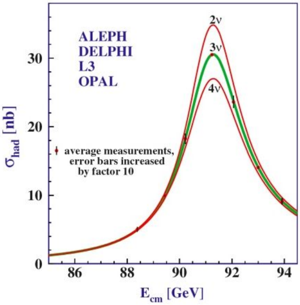

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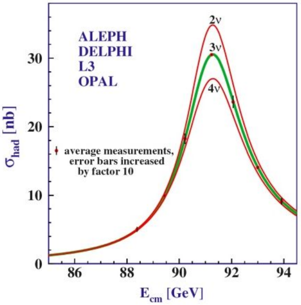

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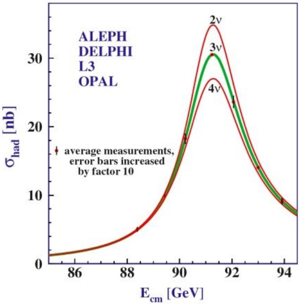

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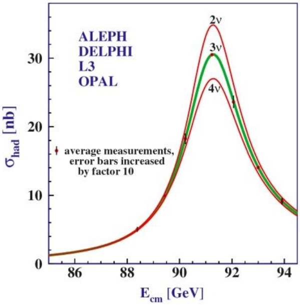

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- The most **obvious extension** to the SM
- Avoid necessity for **light Higgs**
  See above: Modification of EWPO, "blue band plot" changes
- SU(5) **gauge coupling unification** possible without SUSY
- **Electroweak baryogenesis** might be viable
- Relieve tension in **SM3 fits**
- **Interesting phenomenology**

Burdman, Chanowitz, Frampton, Holdom, Hou, Hung, King, Košnik, Lenz, Melić, Soni, ...

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The CKM Matrix for 4 generations

Five additional parameters: θ_{14}, θ_{24}, θ_{34}, δ_{14} and δ_{24}. (+masses, +leptons)

V_{CKM4} can be written as the product of a **new matrix** and V_{CKM3}:

$(c_{14} = \cos\theta_{14}, \ldots)$

$$V_{\mathrm{CKM4}} = \begin{pmatrix} c_{14} & 0 & 0 & e^{-i\delta_{14}} s_{14} \\ -e^{i(\delta_{14}-\delta_{24})} s_{14} s_{24} & c_{24} & 0 & e^{-i\delta_{24}} c_{14} s_{24} \\ -e^{i\delta_{14}} c_{24} s_{14} s_{34} & -e^{i\delta_{24}} s_{24} s_{34} & c_{34} & c_{14} c_{24} s_{34} \\ -e^{i\delta_{14}} c_{24} c_{34} s_{14} & -e^{i\delta_{24}} c_{34} s_{24} & -s_{34} & c_{14} c_{24} c_{34} \end{pmatrix}$$

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New mixing, **new** phases $\Rightarrow$ SM4 goes **beyond MFV** !

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II. The Littlest Higgs Model with T parity

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Arkani-Hamed, Cohen, Katz, Nelson '02

Higgs boson is **pseudo-Goldstone boson** from **symmetry breaking** of a global $SU(5)$ to a global $SO(5)$ at scale $f \sim \mathcal{O}(\mathrm{TeV})$.

In the original Littlest Higgs, custodial $SU(2)$ is **broken already at tree level** $\rightarrow$ electroweak precision observables demand $f \gtrsim 2{-}3\,\mathrm{TeV}$
$\Rightarrow$ **Small** (10−20%) effects in **Flavour Physics.**

Littlest Higgs with T parity (LHT): Cheng, Low '03

Littlest Higgs with a discrete symmetry ("T parity"),
all **new** particles (except T_+) are **odd**, all **SM** particles are **even**.

No contributions by **T odd** particles at **tree level**.
(Cancellation of divergences still works: loop effect !)
$\Rightarrow f \sim 1\,\mathrm{TeV}$ (or even lower) **OK!**

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Particle content of the LHT model

	T-even sector	**T-odd sector**
gauge bosons	$W_L^\pm$, Z_L, A_L gluons	$W_H^\pm$, Z_H, A_H —
fermions	SM quarks top partner T_+ SM leptons	mirror quarks T_- mirror leptons
scalars	Higgs doublet H	scalar triplet Φ

New parameters in LHT:

- f: NP scale ($\to M_{W_H}, \ldots$), x_L: $t-T$ mixing
- mirror quark masses: m_{H1}, m_{H2}, m_{H2} (MFV if degenerate !)
- mirror quark mixing matrix: V_{Hd} $(V_{Hu}^\dagger V_{Hd} = V_{CKM})$
  $\to$ three angles and **three** phases

Details/citations in BBPRTUW, JHEP 0701:066,2007; 0706:082,2007; APP B41:657,2010.

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SM4/LHT go **beyond MFV**, but **operator structure** of the SM(3) effective Hamiltonian **remains intact** (unlike e.g. SUSY).

$\Rightarrow$ Introduce generalised complex **master functions**

$$S_i,\ X_i,\ Y_i,\ Z_i,\ D'_i,\ E'_i,\ E_i \quad (i = K, d, s)$$

Observables can be written in terms of these functions, e.g. **$B\bar{B}$ mixing**:

$$M_{12}^q = \frac{G_F^2}{12\pi^2} F_{B_q}^2 \hat{B}_{B_q} m_{B_q} M_W^2 \lambda_t^{(q)*2} \eta_B S_q^*$$

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where $S_0(x_t) = S_{\mathrm{SM}}$ and e.g. $\lambda_i^{(K)} = V_{is}^* V_{id}$.

For **LHT**

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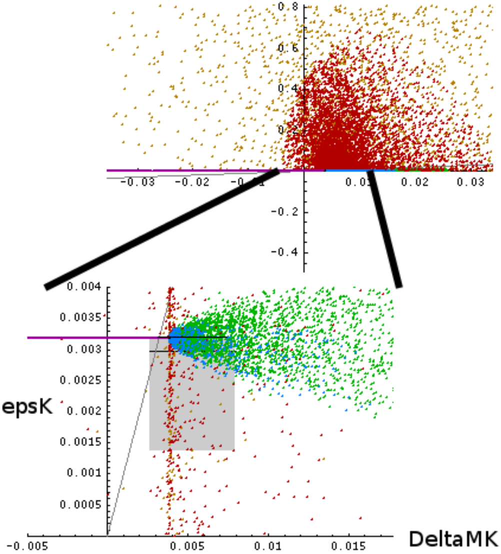
Possible Problems with New Physics analyses



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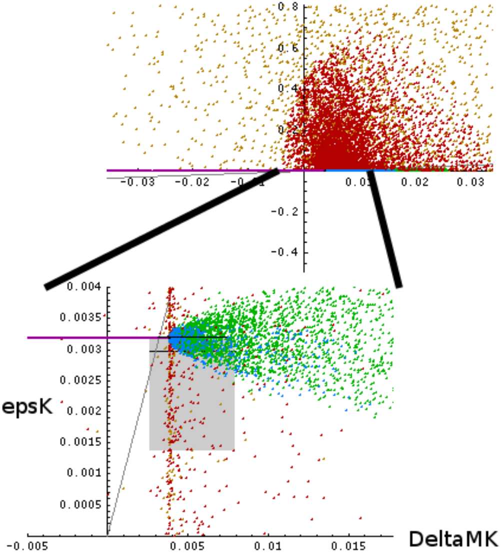

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Flavour Physics Observables

We require the **observables**

$$\varepsilon_K\,,\quad \Delta M_K\,,\quad \Delta M_q\,,\quad \Delta M_d/\Delta M_s\,,\quad S_{\psi K_s}$$

to lie inside their **experimental 1σ ranges**.

For ΔM_K we employ a larger range due to the large **hadronic uncertainty**, the SM(3) **short distance contribution** is only $\sim 70\%$ of the measured value.

Also, we impose (looser) **constraints** on $\mathrm{Br}(B \to X_s \ell^+\ell^-)$, $\mathrm{Br}(B \to X_s\gamma)$, $\mathrm{Br}(K^+ \to \pi^+\nu\bar{\nu})$ and $B_{s,d} \to \mu^+\mu^-$.

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Numerical results

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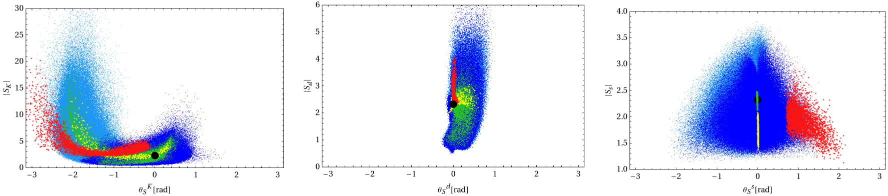
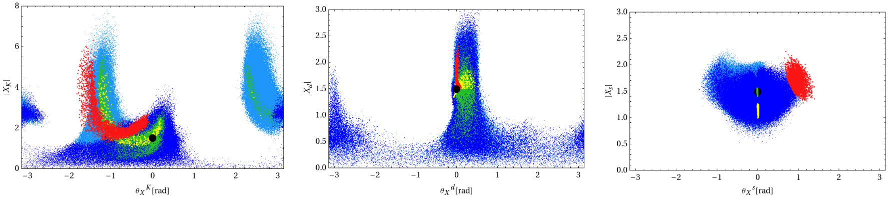


⇑ ArgS_i against $|S_i|$ ⇑ $i = K, d, s$ ⇓ ArgX_i against $|X_i|$ ⇓



In **SM3** (•), the functions are real and independent of the meson system !

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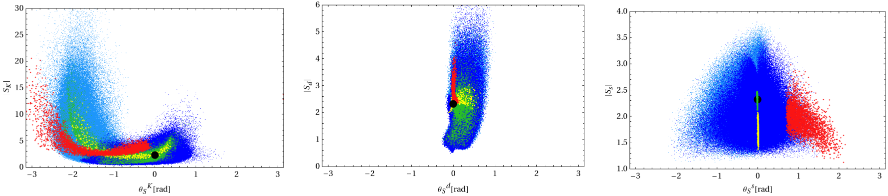
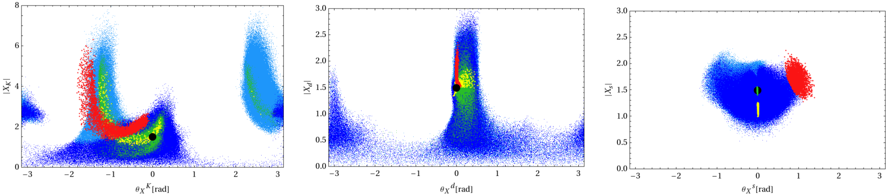
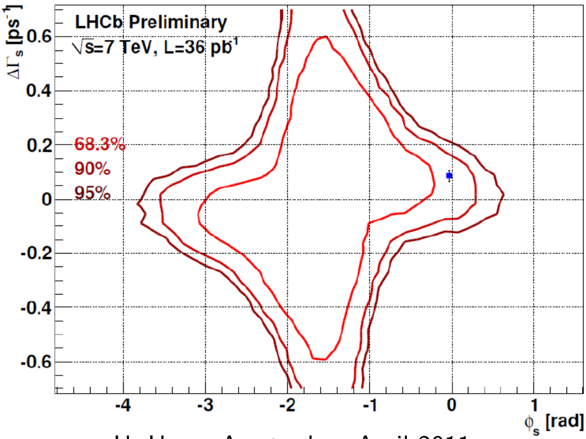


$\Uparrow$ ArgS_i against $|S_i|$ $\Uparrow$ $\quad$ $i = K, d, s$ $\quad$ $\Downarrow$ ArgX_i against $|X_i|$ $\Downarrow$



Effects **largest in K system** because $\lambda_{t'}^{(q)}/\lambda_t^{(q)}$ and $\lambda_t^{(K)} \ll \lambda_t^{(d)} < \lambda_t^{(s)}$

The $S_{\psi\phi}$ anomaly

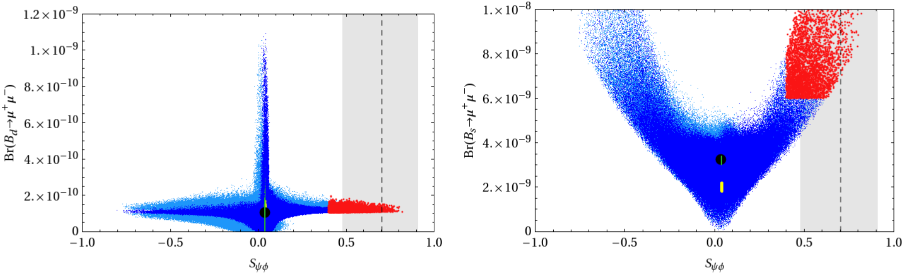


U. Uwer, Amsterdam April 2011

The $S_{\psi\phi}$ **anomaly** still holds, can we explain this with **4G**/**LHT**?

$S_{\psi\phi}$ and $\mathrm{Br}(B_{d/s} \to \mu^+\mu^-)$ (4G)

	Scenario1	Scenario2	Scenario3
$S_{\psi\phi}$	0.04 ± 0.01	0.04 ± 0.01	≥ 0.4
$\mathrm{Br}(B_s \to \mu^+\mu^-)$	$(2 \pm 0.2) \cdot 10^{-9}$	$(3.2 \pm 0.2) \cdot 10^{-9}$	$\geq 6 \cdot 10^{-9}$



$\mathrm{Br}(B_d \to \mu^+\mu^-)$ and $\mathrm{Br}(B_s \to \mu^+\mu^-)$ as a function of $S_{\psi\phi}$

Exp. bounds: $\mathrm{Br}(B_s \to \mu^+\mu^-) \leq 3.3\ (5.3) \cdot 10^{-8}$, $\mathrm{Br}(B_d \to \mu^+\mu^-) \leq 1 \cdot 10^{-8}$.

$\mathrm{Br}(B_s \to \mu^+\mu^-)$ is **correlated with $S_{\psi\phi}$** , $\mathrm{Br}(B_d \to \mu^+\mu^-)$ is not !

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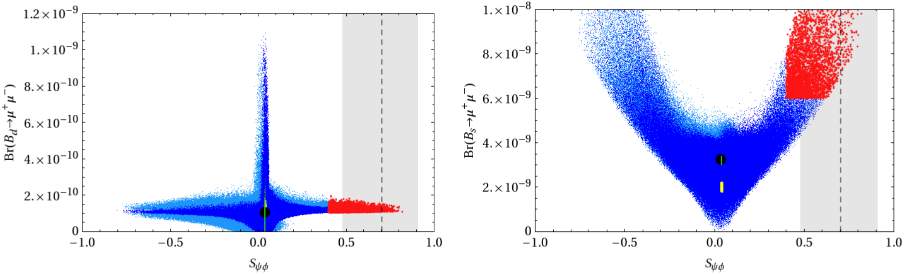

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$\mathbf{S}_{\psi\phi}$ can go up to the **high measured value**!

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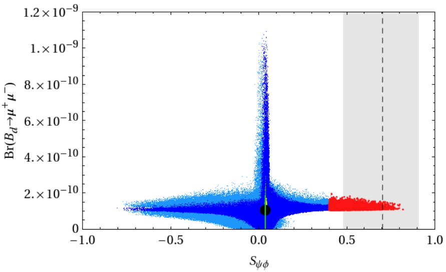

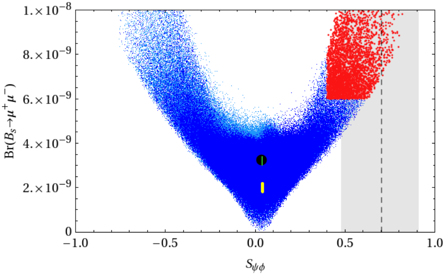

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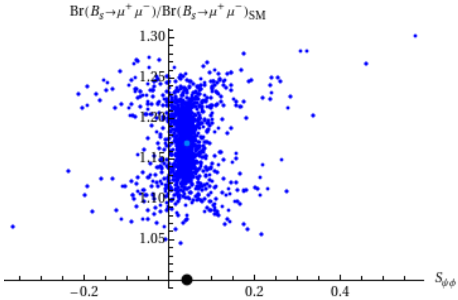
$\mathbf{Br(B_{s/d} \to \mu^+\mu^-)}$ can be **significantly enhanced**! (→LHCb)

$S_{\psi\phi}$ and $\mathrm{Br}(B_{d/s} \to \mu^+\mu^-)$ (LHT)



In **LHT**, simultaneous significant effects in $Br(B_s \to \mu^+\mu^-)$ and $S_{\psi\phi}$ are are rather **likely** but **not necessary**.

⇒ **Different signatures** for different NP models.

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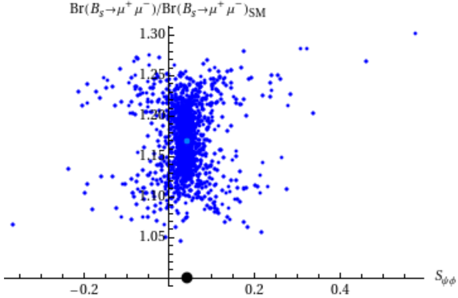

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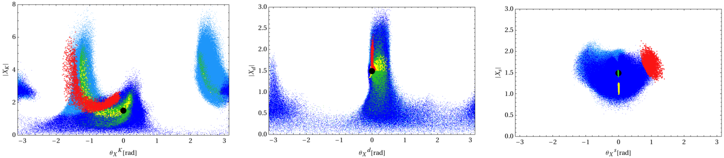
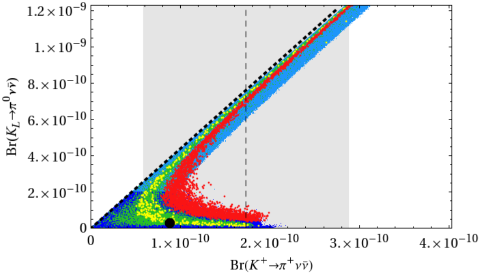
$\Rightarrow$ **Different signatures** for different NP models.

$K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L \to \pi^0 \nu\bar{\nu}$ (4G)

Reminder: Scenarios restrict B_s , but **large effects** in K system possible !





$\mathrm{Br}(K_L \to \pi^0 \nu\bar{\nu})$ against $\mathrm{Br}(K^+ \to \pi^+ \nu\bar{\nu})$

$\mathrm{Br}(K_L \to \pi^0 \nu\bar{\nu})$ can be **large**, close to the Grossman-Nir-bound !

Interesting: Large $K^+ \to \pi^+ \nu\bar{\nu}$ only for large $K_L \to \pi^0 \nu\bar{\nu}$.

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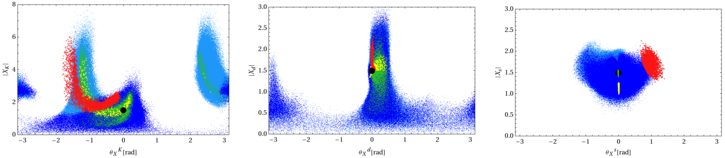

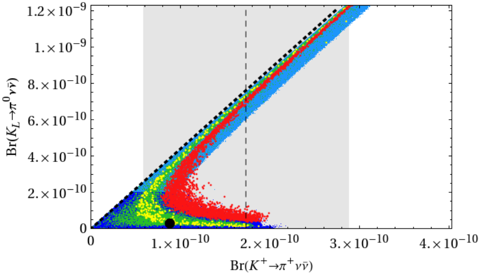

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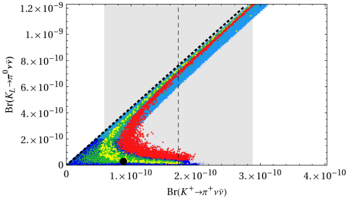
Comparison of NP models

How can we distinguish between **different models of New Physics** ?



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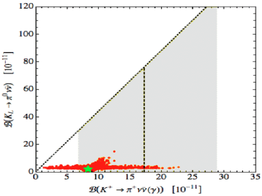
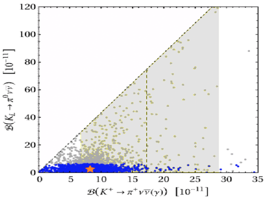


LHT



RS

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(Thanks to U. Haisch for RS plot)

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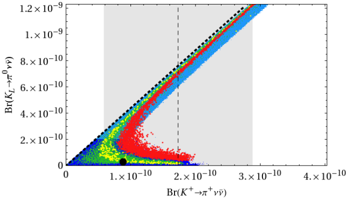

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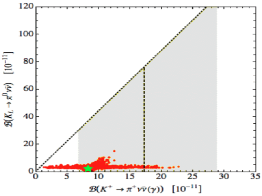

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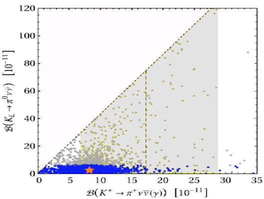

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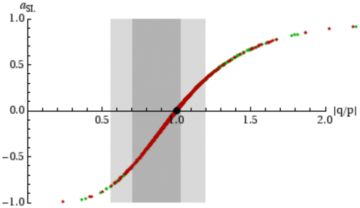
New Physics effects in the $D\bar{D}$ system (LHT)

Processes in the $D\bar{D}$ **system** are often dominated by **SM long-distance dynamics**.

NP contributions can be much larger than the **SM short-distance** contributions, sometimes they can even compete with **SM LD**.
Especially in **asymmetries** they can have a large impact.



Semileptonic **CP asymmetry** $a_{SL}^{D^0}$ is closely related to q/p, $|q/p|_{\rm exp} = 0.86^{+0.17}_{-0.15}$.
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Bigi/Blanke/Buras/SR JHEP 0907:097,2009

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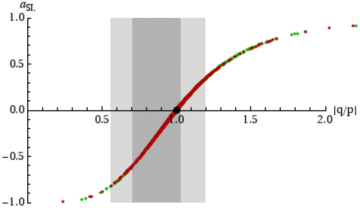

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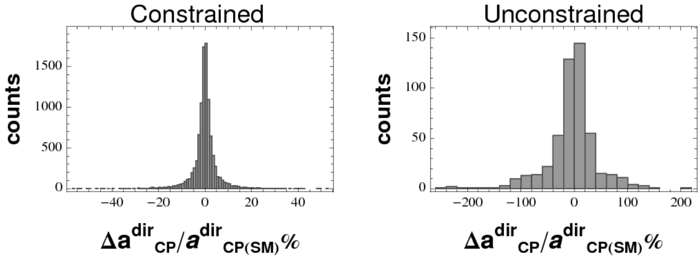

Possibly NP could be seen in **special observables** like the **CP asymmetry of the forward-backward asymmetry** $A^{\rm CP}_{\rm fb}$.

Bigi/Paul/SR Phys.Rev.D82:094006,2010; arXiv:1101.6053; arXiv:1103.5785

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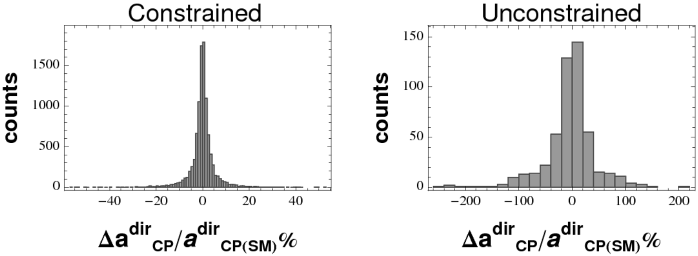

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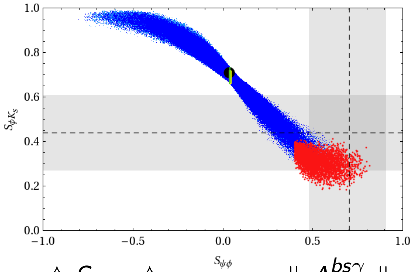
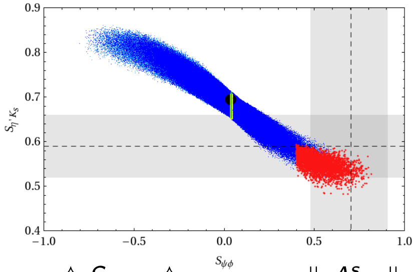
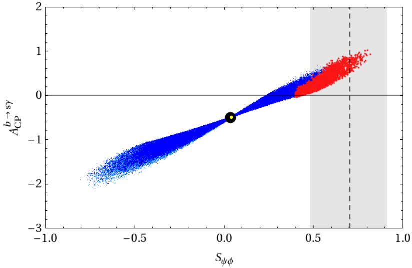
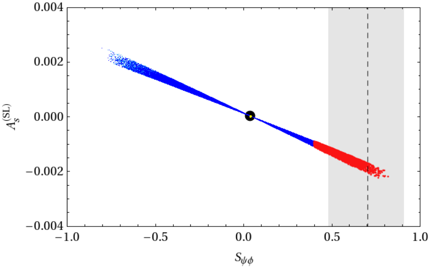
CP asymmetries as a function of $S_{\psi\phi}$ in 4G





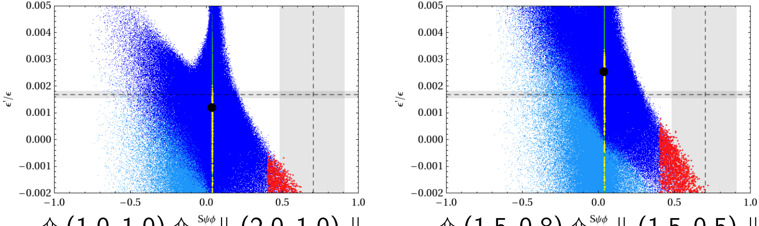
$\Uparrow S_{\phi K_S} \Uparrow$ $\Downarrow A_{\text{CP}}^{bs\gamma} \Downarrow$ $\Uparrow S_{\eta' K_S} \Uparrow$ $\Downarrow A^s_{SL} \Downarrow$



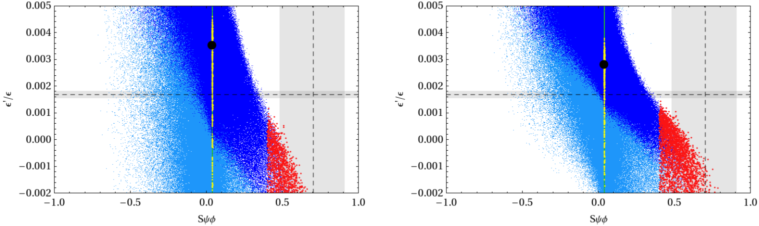


Direct $\not{CP}$ in the Kaon system: ε'/ε in 4G

ε'/ε depends strong on two **hadronic parameters**: R_6 and R_8



$\Uparrow$ (1.0, 1.0) $\Uparrow$ $\Downarrow$ (2.0, 1.0) $\Downarrow$ $\Uparrow$ (1.5, 0.8) $\Uparrow$ $\Downarrow$ (1.5, 0.5) $\Downarrow$



All values of the hadr. parameters are **consistent** with experiment in SM4.

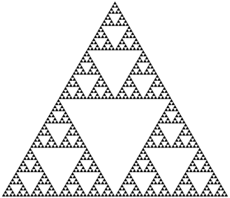
Dimensional Analysis

Fractal Dimensions

Haussdorff dimension

A geometric shape has **Haussdorff dimension** d if the relationship between its mass m and length L is $\mathbf{m \propto L^d}$

This coincides with the **“normal life” understanding** of dimensionality for **integer** d. For **Fractals**, d is not an integer.



E.g. **Sierpínski triangle**: mass triples when size doubles $\rightarrow d = log(3)/log(2) \approx 1.585$

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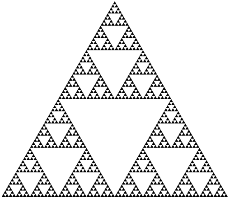

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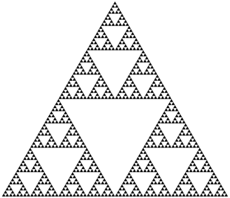

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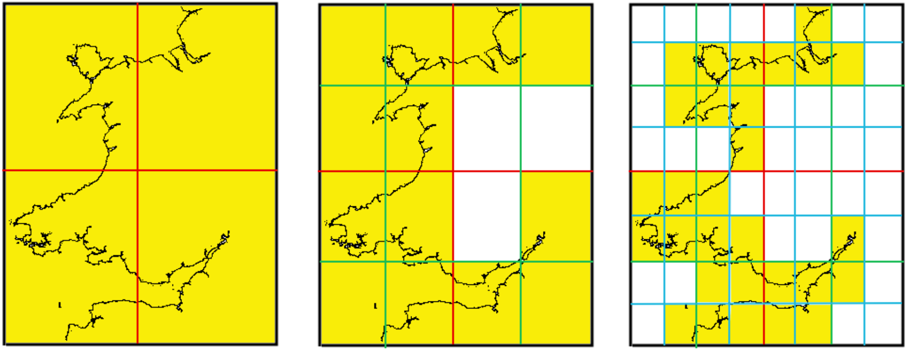
▸ Conclusions

The Box Counting algorithm



1/1 4/4 13/16 28/64

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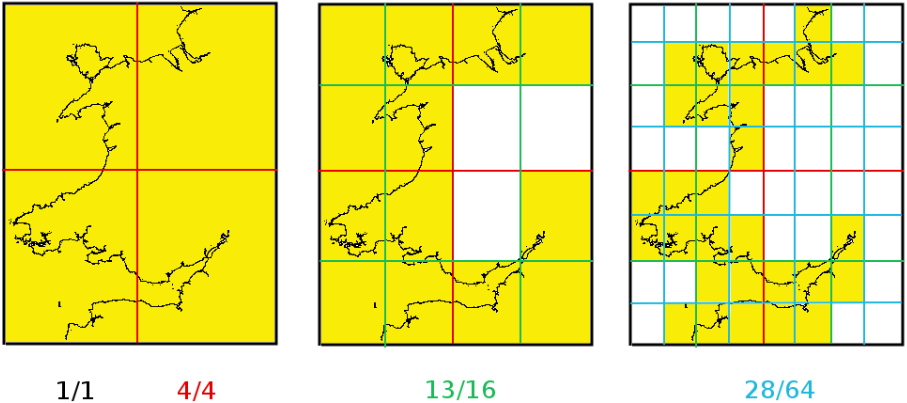

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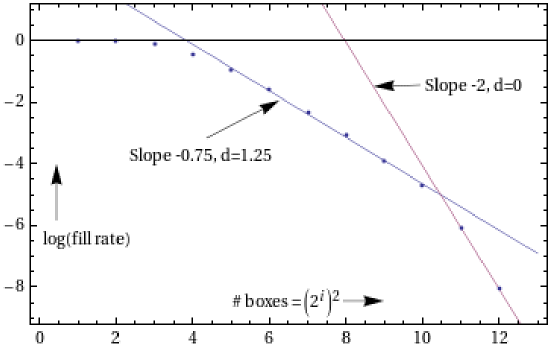

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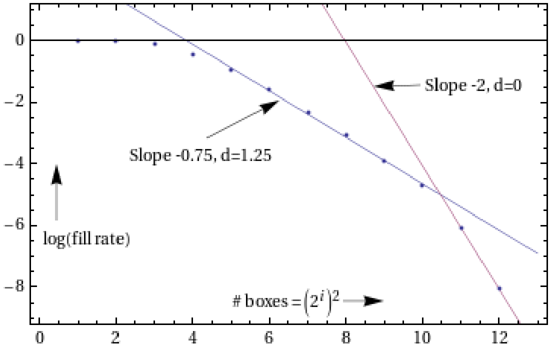

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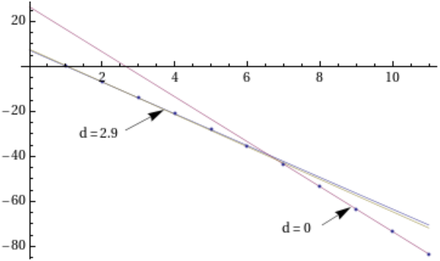
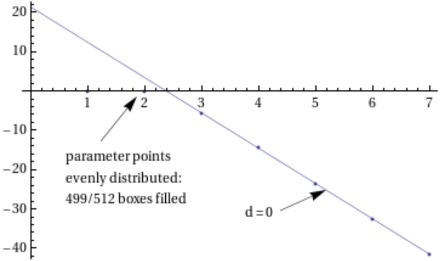
Effective dim. of the parameter space of SM4 and LHT

The parameter space in **SM4** ... ... and in **LHT**





In **SM4**, the valid points in parameter space lie on a complicated structure in 10-dim. space with an **effective dimension** of ~ 3.

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Feldmann/Promberger/SR arXiv:1009.5283

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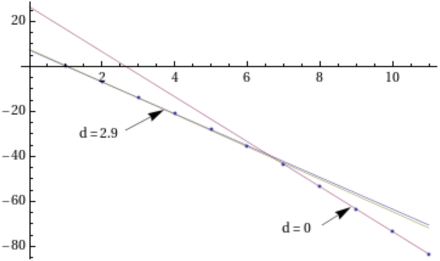

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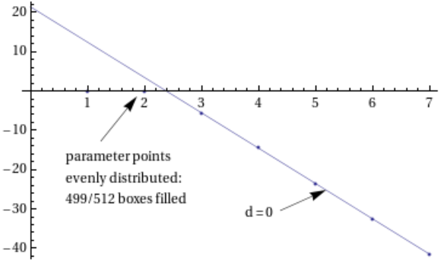

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  Contrary to popular belief, not excluded by LEP, EWPO, ...
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- Both models have rather **few parameters** (no new operators)
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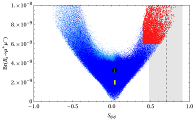

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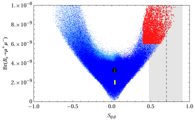

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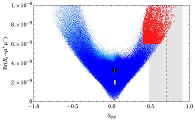

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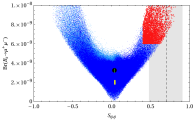

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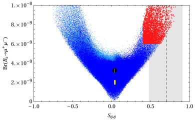

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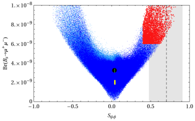

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