Patterns of Flavour Violation in a RS Model with Custodial Protection and Littlest Higgs Model with T-Parity

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Kaon09, KEK, June 12th, 2009

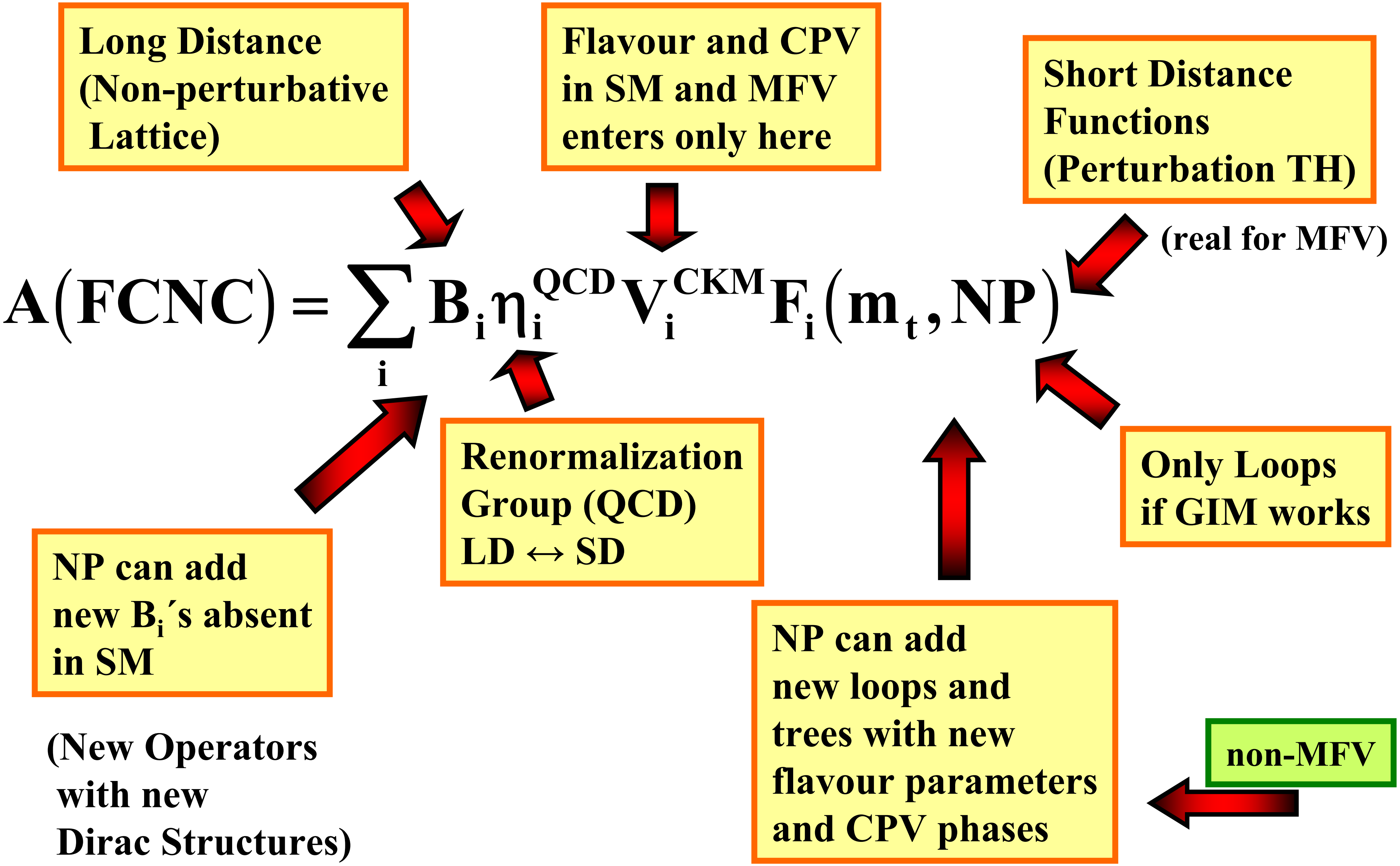
Strategy for the next 26 Minutes

1. Going beyond MFV
2. RS Framework
3. A RS-Model with Custodial Protection
4. Patterns of Flavour Violation in RS
5. News on LHT
6. Selected Numerical Results in RS and LHT
7. Final Messages

1.

Going beyond MFV

Basic Structure of FCNC Amplitudes



Long Distance
(Non-perturbative
Lattice)

Flavour and CPV
in SM and MFV
enters only here

Short Distance
Functions
(Perturbation TH)

(real for MFV)

$$A(FCNC) = \sum_i B_i \eta_i^{QCD} V_i^{CKM} F_i(m_t, NP)$$

Renormalization
Group (QCD)
LD ↔ SD

Only Loops
if GIM works

NP can add
new B_i´s absent
in SM

(New Operators
with new
Dirac Structures)

NP can add
new loops and
trees with new
flavour parameters
and CPV phases

non-MFV

Possible Dirac Structures in $K^0-\bar{K}^0$ and $B^0_{d,s}-\bar{B}^0_{d,s}$

SM:

$$\gamma_\mu(1-\gamma_5)\otimes\gamma^\mu(1-\gamma_5)$$

LHT

Beyond SM:

$$\gamma_\mu(1-\gamma_5)\otimes\gamma^\mu(1+\gamma_5)$$

★ $(1-\gamma_5)\otimes(1+\gamma_5)$

$$(1-\gamma_5)\otimes(1-\gamma_5)$$

$$\sigma_{\mu\nu}(1-\gamma_5)\otimes\sigma^{\mu\nu}(1-\gamma_5)$$

RS

SUSY

Strong enhancements

MSSM with large tanβ
General Supersymmetric Models
Models with complicated Higgs System; RS Models

NLO $\left[\eta^i_{QCD}\right]^{New}$: Ciuchini, Franco, Lubicz, Martinelli, Scimemi, Silvestrini

AJB, Misiak, Urban, Jäger

Enhancements of Q_{LR} versus Q_{LL} in $\Delta F=2$ Transitions

$$\mu \cong 3\mathrm{TeV} \xrightarrow{RG} \begin{matrix} \mu_B \approx 5\mathrm{GeV} \\ \mu_K \approx 2\mathrm{GeV} \end{matrix}$$

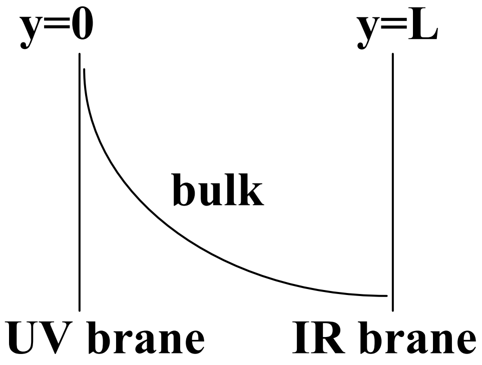
	Wilson Coefficient (RG Enhancement)	Hadronic Matrix Element (Chiral Enhancement)	Total
$K^0 - \overline{K}^0$	~ 7	20	140
$B^o_{d,s} - \overline{B}^0_{d,s}$	~ 4.3	1.5	6.5

2.

Randall-Sundrum Framework (Express Summary)

5D spacetime with warped metric:

$$\boxed{ds^2 = e^{-2ky}\eta_{\mu\nu}dx^{\mu} - dy^2 \qquad 0 \leq y \leq L}$$



- fermions and gauge bosons live in the bulk
- Higgs localised on IR brane

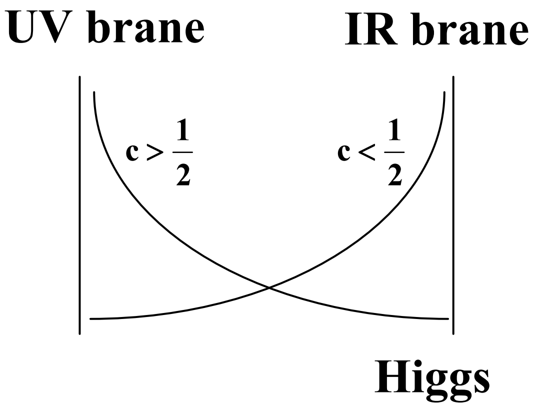
(Chang, Okada et al.
Grossman, Neubert
Gherghetta, Pomarol)

- energy scales suppressed by warp factor e^{-ky}
  natural solution to the gauge hierarchy problem.
- Kaluza-Klein (KK) excitations of both SM fermions and gauge bosons live close to the IR brane.

Fermion Localisation and Yukawa Couplings

SM fermion (zero mode) shape function depends strongly on bulk mass parameter characteristic for a given fermion:

$$f^{(0)}(y,c) \propto e^{\left(\frac{1}{2}-c\right)y}$$



$c > \frac{1}{2}$ **: localisation near UV brane**

$c < \frac{1}{2}$ **: localisation near IR brane**

effective 4D Yukawa couplings: $\left(Y_{u,d}\right)_{ij} = \left(\lambda_{u,d}\right)_{ij} f_i^Q f_j^{u,d}$

- $\lambda_{u,d} \sim 0(1)$ **anarchic complex 3 x 3 matrices** $\equiv Y_{5D}$
- **hierachical structure of quark masses and CKM parameters can be naturally generated by exponential suppression of** $f^{Q,u,d}$ **at IR brane.**

Bulk Profiles of SM Gauge Bosons

- Gluons and Photon : **flat** (protection by Gauge symmetry)
- $W^{\pm}$, Z : **flat** before EWSB

  but

  distorted near the IR brane after EWSB $0\left(\frac{v^2}{M_{KK}^2}\right)$

  Equivalently : Mixing of KK gauge bosons with $W^{\pm}$, Z in the process of EWSB modifies the couplings of mass eigenstates $W^{\pm}$, Z

- Recall : All KK gauge bosons live close to the IR brane

  All KK fermions live close to the IR brane

First Implications for Phenomenology

1.

Gauge-Fermion Interactions: Overlaps of shape functions

→

Non-universalities in Gauge Couplings

(in flavour)

of { KK-gauge bosons, $W^{\pm}$, Z }

to {SM fermions}

2.

Impact on Electroweak Precision Observables

$SU(2)_L \otimes U(1)_Y$

S parameter : $M_{KK} \geq (2\text{-}3)$ TeV

T parameter: $M_{KK} \gtrsim 10$ TeV

Agashe, Delgado, May, Sundrum (2003)

Csaki, Grojean, Pilo, Terning (2003)

Also problems with $Zb_L\bar{b}_L$

3.

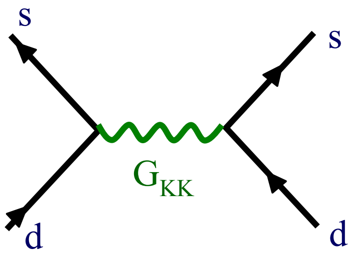
Tree Level FCNC mediated by KK gauge bosons and Z (breakdown of standard GIM mechanism)

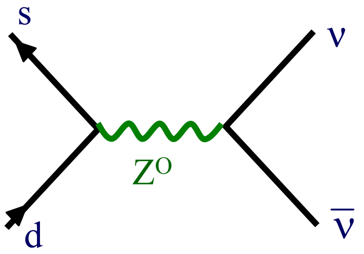
$$d \equiv \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\bar{d} D_L^{+} \begin{pmatrix} a & & \\ & b & \\ & & c \end{pmatrix} D_L \gamma_\mu Z^\mu d \neq \bar{d} \gamma_\mu Z^\mu d$$

(non-universality)

$$0\left(\frac{v^2}{M_{KK}^2}\right)$$





$$0\left(\frac{v^2}{M_{KK}^2}\right)$$

But RS-GIM helps in avoiding disaster.

Gherghetta, Pomarol
Huber, Shafi
Agashe, Soni, Perez

4.

Mixing of KK fermions with SM fermions and mixing of KK gauge bosons with SM gauge bosons

→ **Breakdown of Unitarity of the CKM matrix**

5.

Tree level exchanges of G_{KK} and Z → **Contributions of new operators. In particular Q_{LR} operators in addition to Q_{LL}, Q_{RR}**

6.

The presence of three 3 x 3 hermitian bulk matrices c^q, c^u, c^d in addition to usual Yukawa couplings → **New flavour and CP violating parameters:**

$3 * 6 = 18$ real
$3 * 3 = 9$ phases

Non-MFV

3.

A RS Model with Custodial Protection

$$SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_X \otimes P_{LR}$$

Gauge Group in the Bulk

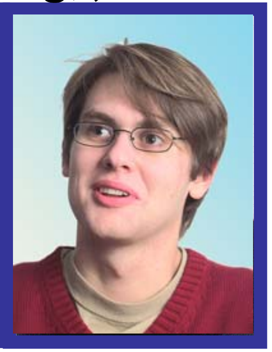
$$P_{LR} : SU(2)_L \leftrightarrow SU(2)_R$$

P_{LR} symmetric fermion representations

Mixing, $\not{CP}$ in RS model [hep-ph/0809.1073]


M. Blanke


AJB


B. Duling


S. Gori


A. Weiler

(50)

Rare K and B Decays in RS model [hep-ph/0812.3803]


M. Blanke


AJB


B. Duling


K. Gemmler


S. Gori

(49)

TUM
RS
Team

Electroweak and Flavour Structure [hep-ph/0903.2415]


M. Albrecht


M. Blanke


AJB


B. Duling


K. Gemmler

(72)

Impact of KK Fermions on SM fermion couplings [hep-ph/0905.2318]


AJB


B. Duling


S. Gori

(40)

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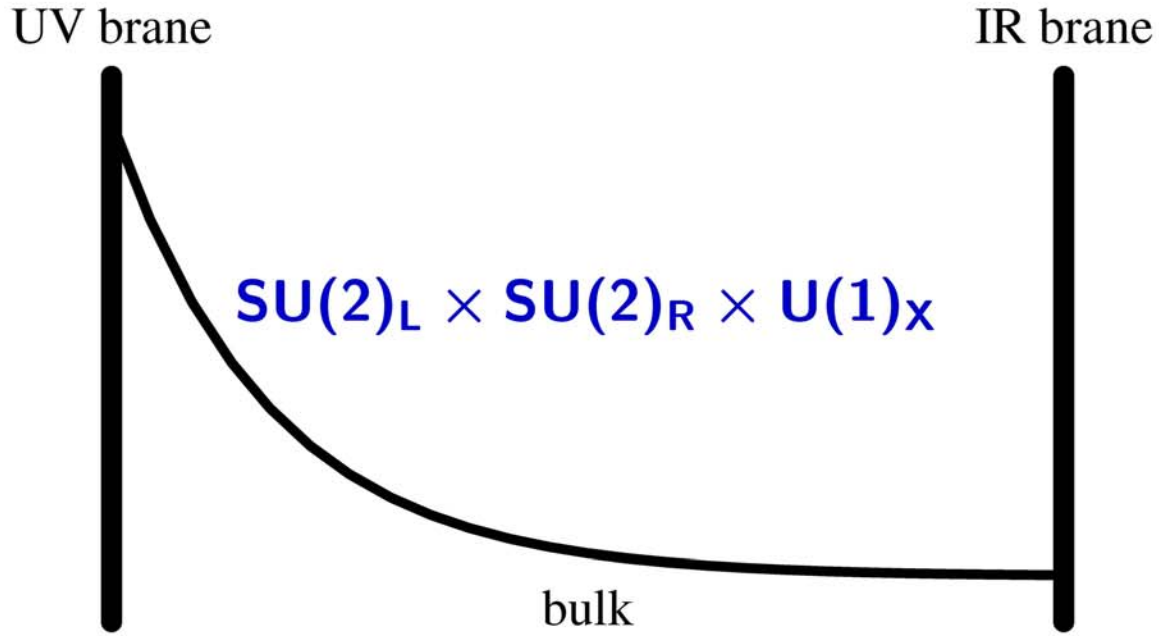
A Realistic Model in the Reach of the LHC



$SU(2)_L \times SU(2)_R \times U(1)_X$

$SU(2)_R \times U(1)_X \to U(1)_Y$
by boundary conditions

$SU(2)_L \times SU(2)_R \to SU(2)_V$
by Higgs VEV

$+$ $(L \leftrightarrow R)$-symmetric fermion representations

low energy theory: $SU(2)_L \times U(1)_Y \to U(1)_{em}$

What is protected in this Model?

(up to small symmetry breaking due to UV boundry conditions)

A. T-Parameter

Agashe, Delgado, May, Sundrum (0308036)
Csaki, Grojean, Pilo, Terning (0308038)

B. $Z\bar{b}_L b_L$

Agashe, Contino, Rold, Pomarol (0605341)

C. $Z\bar{d}^i_L d^j_L$

Blanke, AJB, Duling, Gori, Weiler (0809.1073)
Blanke, AJB, Duling, Gemmler, Gori (0812.3803)

D. $Z\bar{u}^i_R u^j_R$

AJB, Duling, Gori (0905.2318)

But: $Z\bar{d}^i_R d^j_R, \quad Z\bar{u}^i_L u^j_L, \quad W^+\bar{u}^i_L d^j_L$ **not protected**

Particle Content of the Model

Albrecht, Blanke, AJB, Duling, Gemmler (0903.2415)

Gauge sector

$W^{\pm}$, $W_H^{\pm}$, $W'^{\pm}$

Z^0, Z_H, Z'

KK

A, $A^{(\prime)}$

G^a, $G^{a(\prime)}$

KK

Quark sector

(i=1,2,3)

$SU(2)_L \otimes SU(2)_R$

$$(2,2) = \begin{pmatrix} \chi^{u_i}(-+)_{5/3} & q^{u_i}(++)_{2/3} \\ \chi^{d_i}(-+)_{2/3} & q^{d_i}(++)_{-1/3} \end{pmatrix}_L \qquad (1,1) = u_R^i(++)_{2/3}$$

$$(3,1) = \begin{pmatrix} \psi'^i(-+)_{5/3} \\ U'^i(-+)_{2/3} \\ D'^i(-+)_{-1/3} \end{pmatrix}_R \oplus \begin{pmatrix} \psi''^i(-+)_{5/3} \\ U''^i(-+)_{2/3} \\ D^i(++)_{-1/3} \end{pmatrix}_R = (1,3)$$

+
states of
opposite
chirality

Q=5/3
Fermions!

(Feynman rules worked out for SM and n=1 KK modes)

4.

Patterns of Flavour Violation in RS (3 Steps)

First look at $\Delta F = 2$: Burdman; Agashe, Perez, Soni

First more sophisticated analysis : Csaki, Falkowski, Weiler (0804.1954)

Application of model-independent results of Utfit group to RS-type models.

Hierarchy of fermion masses and weak mixings solely due to geometry Y_{5D} anarchic and 0(1)

KK-Gluon

→

Contribution to ε_k

$$M_{KK} \gtrsim 21\ \text{TeV}$$

Step 1 : ($\Delta F = 2$ Processes)

(Blanke, AJB, Duling, Gori, Weiler (0809.1073))

A. **Full RG analysis at the NLO level: (using AJB, Misiak, Urban; Jäger) (2000)**

$$Q_1^{\mathrm{VLL}} = \left(\bar{s}\gamma_\mu P_L d\right)\left(\bar{s}\gamma^\mu P_L d\right) \qquad Q_1^{\mathrm{LR}} = \left(\bar{s}\gamma_\mu P_L d\right)\left(\bar{s}\gamma^\mu P_R d\right)$$

$$Q_1^{\mathrm{VRR}} = \left(\bar{s}\gamma_\mu P_R d\right)\left(\bar{s}\gamma^\mu P_R d\right) \qquad Q_2^{\mathrm{LR}} = \left(\bar{s}P_L d\right)\left(\bar{s}P_R d\right)$$

(For $K^0 - \bar{K}^0$, $B_d^0 - \bar{B}_d^0$ and $B_s^0 - \bar{B}_s^0$ systems)

B. **Inclusion of the contributions of all gauge bosons:**
(G_{KK}, A_{KK}, Z, Z_H, Z') (Protection of Z and Z' pointed out)

$$Z\bar{d}^i_d d^j_L$$

$$Z'\,\bar{d}^i_L d^j_L$$

C. **Phenomenology of ε_K, ΔM_K, ΔM_S, ΔM_d, $S_{\psi K_S}$, $S_{\psi\varphi}$, A_{SL}^q, $\Delta\Gamma_q$**

D. **Relation of RS flavour model to Froggatt-Nielsen (analytic formulae for masses and mixings)**

E. **Calculation of fine tuning (Barbieri + Giudice) of Yukawa couplings $\Delta_{BG}(\varepsilon_K)$ necessary to satisfy ε_K with $M_{KK} \sim$ 2-3 TeV**

Main Results of Step 1

A. **Confirmation of CFW analysis for anarchic 5D Yukawa's.**

B. **Identifications of regions in parameter space with only modest fine-tuning of Y_{5D} which satisfy all $\Delta F = 2$ constraints, agree with quark masses and mixings and electroweak constraints for $M_{KK} \sim$ 2-3 TeV.**

C. **Pattern of NP contributions**

: ε_K, ΔM_K : dominated by Q_2^{LR} and G_{KK}

$\Delta M_d, \Delta M_s, S_{\psi K_s} S_{\psi\varphi}$: Competition between Q_1^{VLL} and Q_2^{LR} (Z_H and G_{KK} dominate)

D. **$S_{\psi\varphi}$ asymmetry can be by order of magnitude larger than $\left(S_{\psi\varphi}\right)_{SM}$.**

Step 2 : (Rare K and B Decays) ($\Delta F=1$)

(Blanke, AJB, Duling, Gemmler, Gori (0812.3803))

A. Calculation of $K^+ \to \pi^+ \nu\bar{\nu}$, $K_L \to \pi^0 \nu\bar{\nu}$, $K_L \to \pi^0 l^+ l^-$, $K_L \to \mu^+\mu^-$, $B_{s,d} \to \mu^+\mu^-$, $B \to K\nu\bar{\nu}$, $B \to K^*\nu\bar{\nu}$, $B \to X_{s,d}\nu\bar{\nu}$

For all allowed regions of parameters from Step 1 with $\Delta_{BG}(\varepsilon_K) \le 20$

B. Dominance of tree level Z-exchanges but through its right-handed couplings.

C. Study of correlations between various $\Delta F=1$ branching ratios and of $(\Delta F=1) \leftrightarrow (\Delta F=2)$ correlations.

Main Results of Step 2

A. **Enhancements of** $\left.\begin{array}{l}\mathbf{Br}\left(K_L \to \pi^0 \nu\bar{\nu}\right) \text{ by a factor 5} \\ \mathbf{Br}\left(K^+ \to \pi^+ \nu\bar{\nu}\right) \text{ by a factor 2} \\ \mathbf{Br}\left(K_L \to \pi^0 l^+ l^-\right) \text{ by a factor 1.5}\end{array}\right\}$ **possible (even simultaneously)**

B. **Large Enhancements of** $\mathbf{Br}\left(K_L \to \mu^+\mu^-\right)$ **but not simultaneously with** $K^+ \to \pi^+ \nu\bar{\nu}$ **.**

C. **SM-like** $\left.\begin{array}{l}\mathbf{Br}\left(B_{s,d} \to \mu^+\mu^-\right),\ \mathbf{Br}\left(B \to K\nu\bar{\nu}\right) \\ \mathbf{Br}\left(B \to K^*\nu\bar{\nu}\right),\ \mathbf{Br}\left(B \to X_{s,d}\nu\bar{\nu}\right)\end{array}\right\}$ **(10-20% effects)**

D. **Simultaneous large effects in** $S_{\psi\varphi}$ **and** $K \to \pi\nu\bar{\nu}$ **not possible.**

E. **Non-Universality of NP effects and consequently "golden relations" of MFV can be strongly broken.**

Step 3 : Impact of KK fermions (Effective Lagrangian approach)

(AJB, Duling, Gori (0905.2318))

1. General formulae for corrections to SM fermion ↔ ($W^{\pm}$, Z, H) couplings from mixing with KK fermions.
2. Explicit demonstration that the custodial protection of $Z d_L^i \overline{d}_L^j$ and $Z u_R^i \overline{u}_R^j$ couplings remains valid in the presence of mixing with KK fermions (guaranteed by P_{LR} symmetric fermion representations)
3. Calculations of KK corrections to unprotected $Z d_R^i \overline{d}_R^j$ and $Z u_L^i \overline{u}_L^j$
4. Study of the violation of the unitarity of the CKM due to KK mixing

\+

Comparison with brute force numerical diagonalization of 18 x 18 and 12 x 12 matices

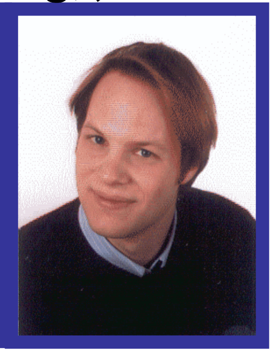
5.

News on LHT

Mixing, $\cancel{CP}$ and $B \to X_s \gamma$ [hep-ph/0605214]


M. Blanke


AJB


A. Poschenrieder


C. Tarantino

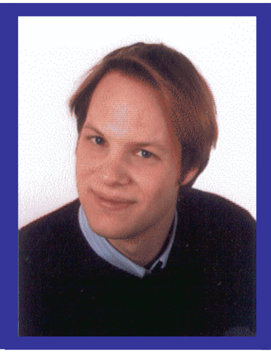

S. Uhlig


A. Weiler

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


M. Blanke


AJB


A. Poschenrieder


S. Recksiegel


C. Tarantino


S. Uhlig


A. Weiler

Lepton flavour violating decays [hep-ph/0702136]


M. Blanke


AJB


A. Poschenrieder


B. Duling


C. Tarantino

TUM
Little Higgs
Team

Littlest Higgs Models without and with T-Parity

New particles: (with O(f) masses)

LH

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

Fermions: T

Scalars: $\Phi^{\pm}$,…

LHT

T-even Sector

SM Particles + T_+

T-odd Sector

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

Fermions: T_-, Mirror Fermions

Scalars: $\Phi^{\pm}$,…

The World of Mirror Fermions

[I. Low, hep-ph/0409025]

Required to cut-off large 4-fermion operators constrained by LEP

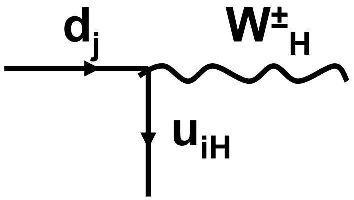
$$\begin{pmatrix} u_{1H} \\ d_{1H} \end{pmatrix} \quad \begin{pmatrix} u_{2H} \\ d_{2H} \end{pmatrix} \quad \begin{pmatrix} u_{3H} \\ d_{3H} \end{pmatrix}$$

Similarly for Leptons

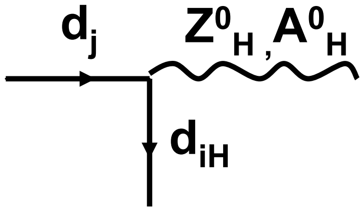
$m^u_{Hi} = m^d_{Hi}$ $i=1,2,3$
to first order in v/f

Vectorial couplings under $SU(2)_L$

New Flavour Interactions involving SM fermions, Mirror Fermions and $W^\pm_H$, Z^0_H, A^0_H



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



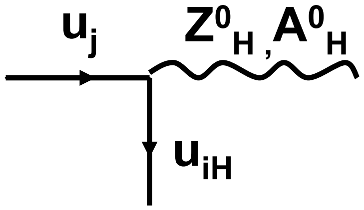
$\sim (V_{Hd})_{ij}\, \gamma_\mu\, (1-\gamma_5)$

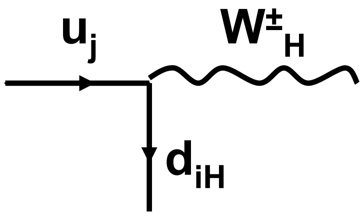
$V^\dagger_{Hu}\, V_{Hd} = V_{CKM}$

[I. Low, hep-ph/0409025]

[J. Hubisz, S.J. Lee, G. Paz]

$(V_{Hu})_{ij}$ for:





News on the Logarithmic UV cutoff Dependence

Recall: UV divergences in Z-penguin

2006 LH: AJB, Poschenrieder, Uhlig, Bardeen

LHT: Blanke, AJB, Poschenrieder, Recksiegel, Uhlig, Tarantino, Weiler

2008 LHT: divergence removed by Goto, Okada, Yamamoto; $(K \to \pi\nu\bar{\nu})$

del Aguila, Illana, Jenkins; (LFV)

(new contribution cancels the 2006 divergence)

★ LHT update: Blanke, AJB, Duling, Recksiegel, Tarantino (2009)(June)

- $\Delta F = 2$ Processes, $B \to X_s\gamma$, $\mu \to e\gamma$, $\tau \to e\gamma$, $\tau \to \mu\gamma$ (unchanged)
- Effects in $K \to \pi\nu\bar{\nu}$, $K_L \to \pi^0 l^+ l^-$, $\mu \to 3e$, $\tau \to 3\mu$ etc smaller but still sizeable.
- Distinction from SUSY in LFV still very clear.

2009 LHT Teams


M. Blanke


AJB


B. Duling


S. Recksiegel


C. Tarantino


I.Bigi


M. Blanke


AJB


S. Recksiegel

$\not{CP}$ in

$D^0 - \overline{D}^0$

News on LHT and Charm Physics

CP Violation in $D^0 - \overline{D}^0$ Oscillations can be very large !

Bigi, Blanke, AJB, Recksiegel (0904.1545)

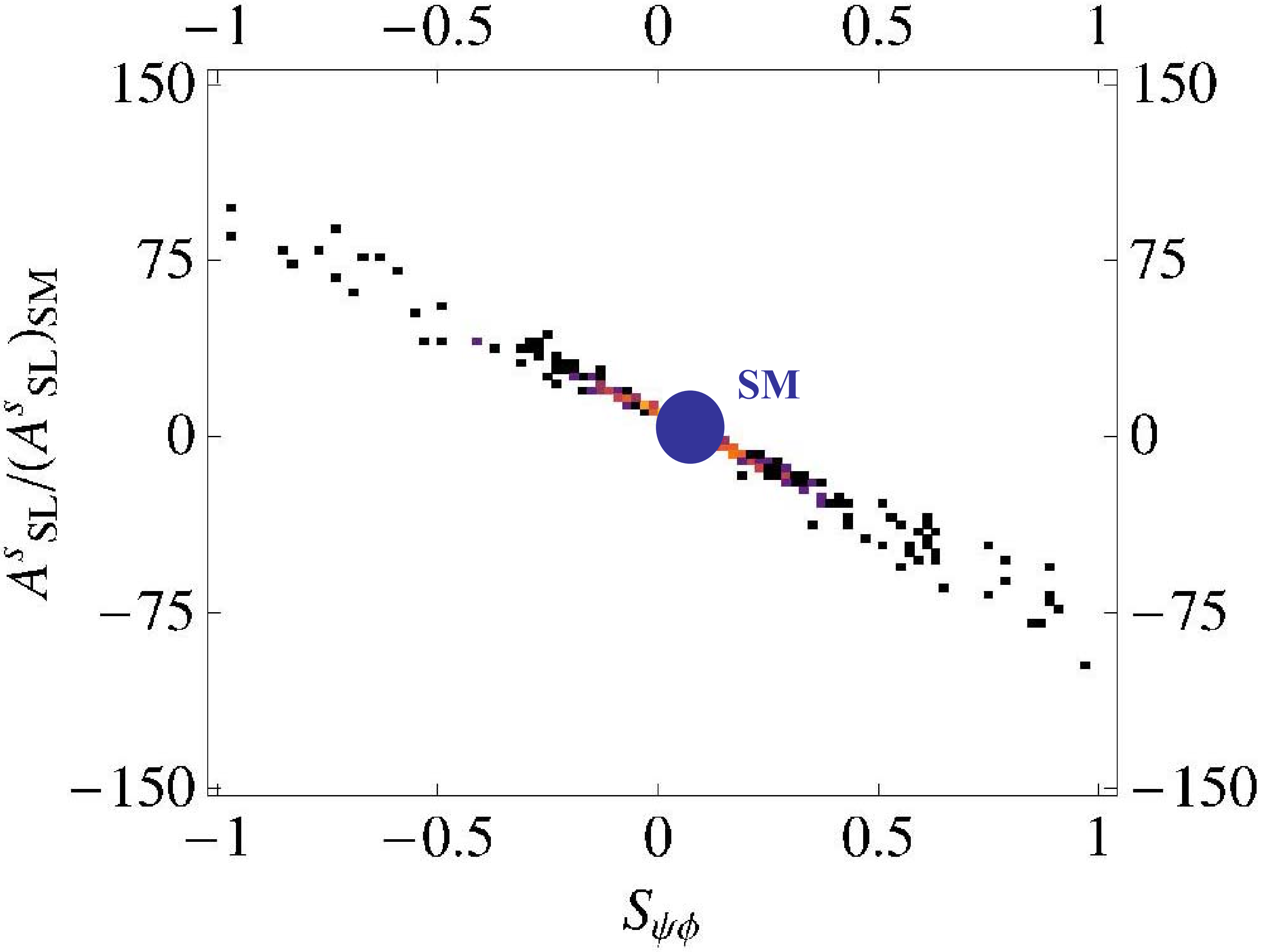
- ★ **General Considerations beyond LHT**
- ★ **Correlation between** $\boxed{\begin{array}{l} a_{SL}\left(D^0\right) \\ S_{D\to K_s\varphi} \end{array}}$

(analogous to A^S_{SL} and $S_{\psi\varphi}$ in B_s decays)

6.

Selected Numerical Results in RS and LHT

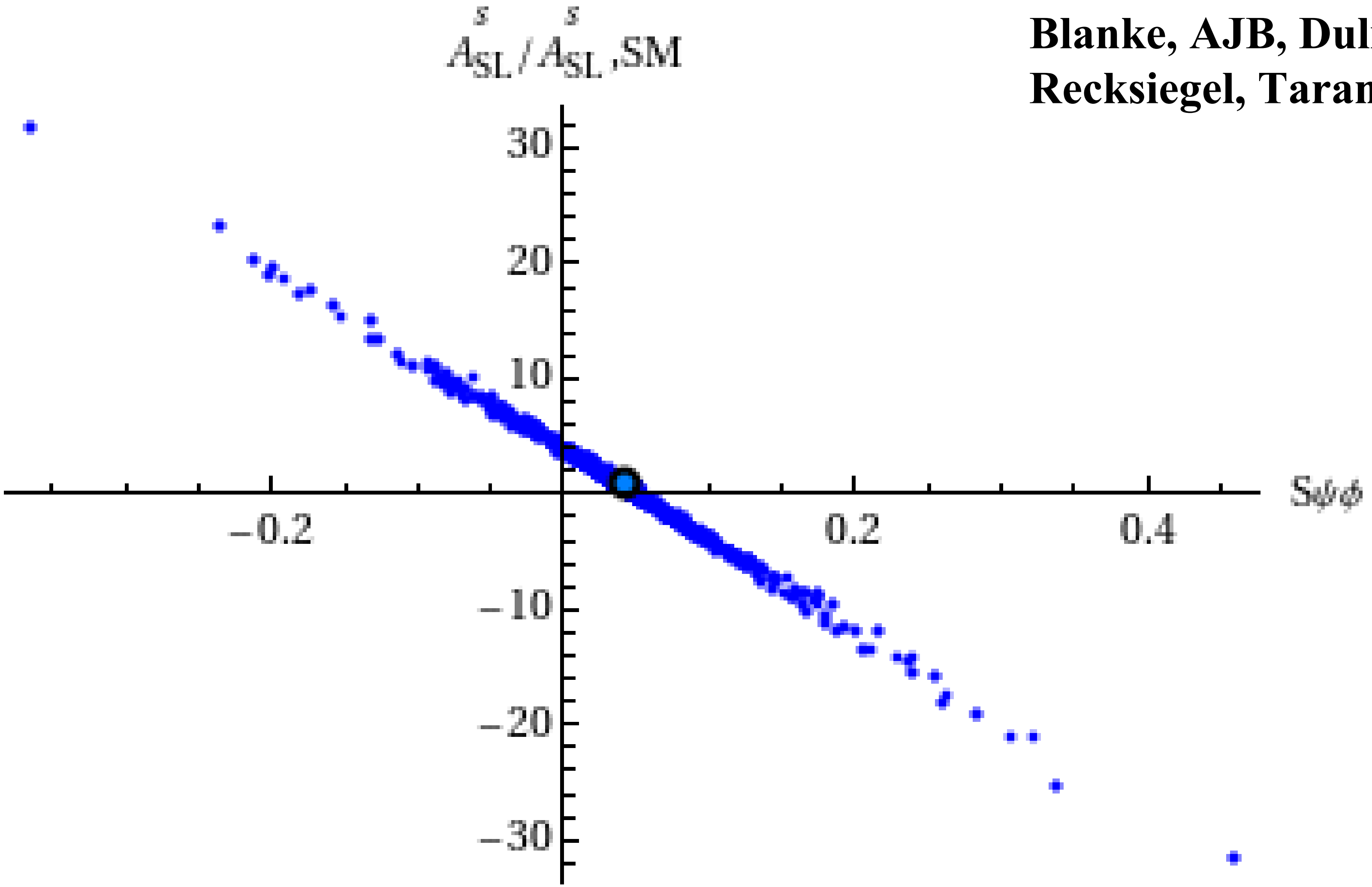
Correlation in Warped Extra Dimensions (RS)



M.Blanke, AJB, B.Duling, S.Gori, A.Weiler (2008)

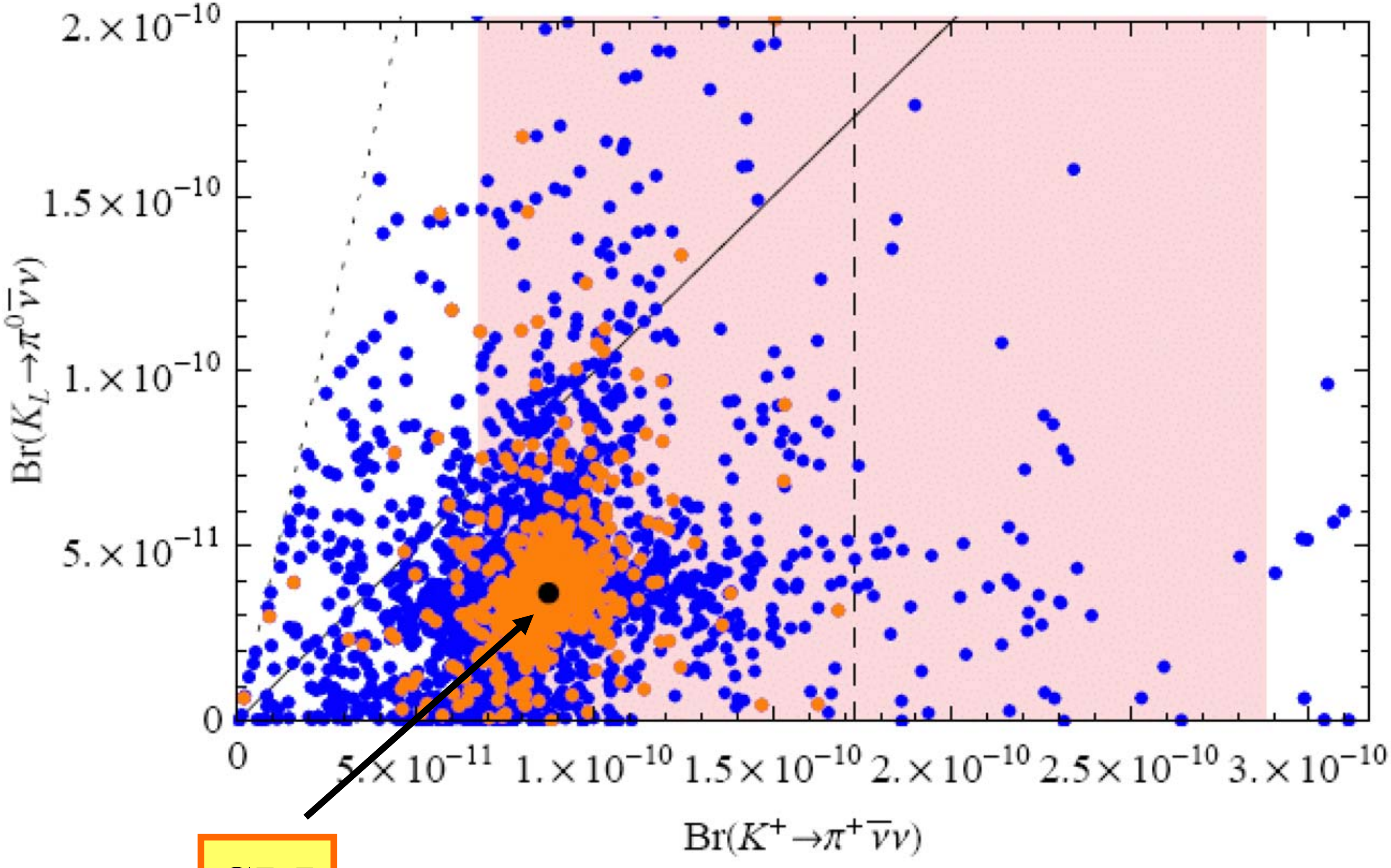
Correlation in LHT

Blanke, AJB, Duling, Recksiegel, Tarantino



$K_L \to \pi^0 \nu\bar{\nu}$ vs. $K^+ \to \pi^+ \nu\bar{\nu}$ (RS)

(Up to Factor 3 and 2 Enhancements)

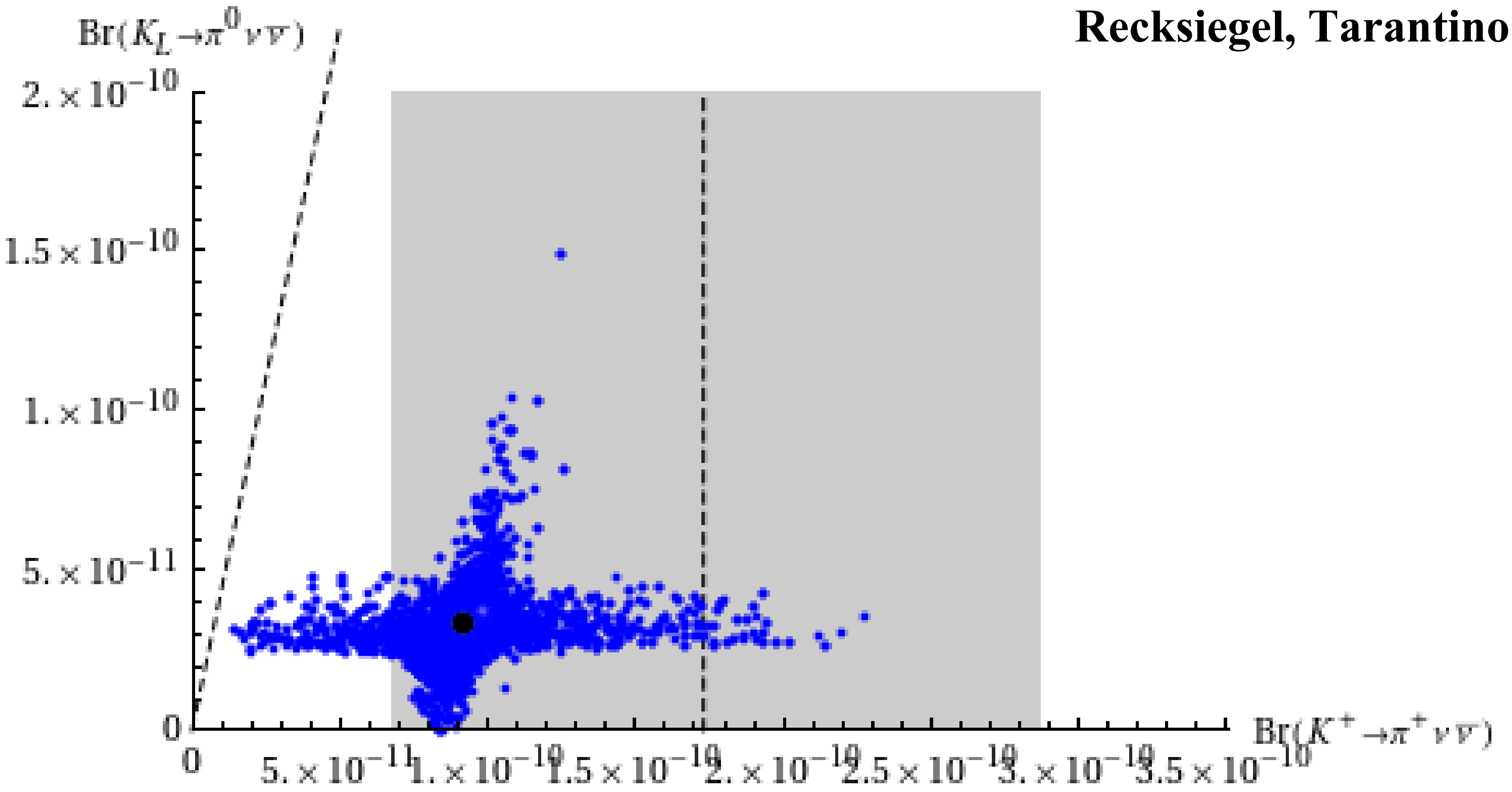


SM

$K_L \to \pi^0 \nu\bar{\nu}$ vs. $K^+ \to \pi^+ \nu\bar{\nu}$ (LHT)

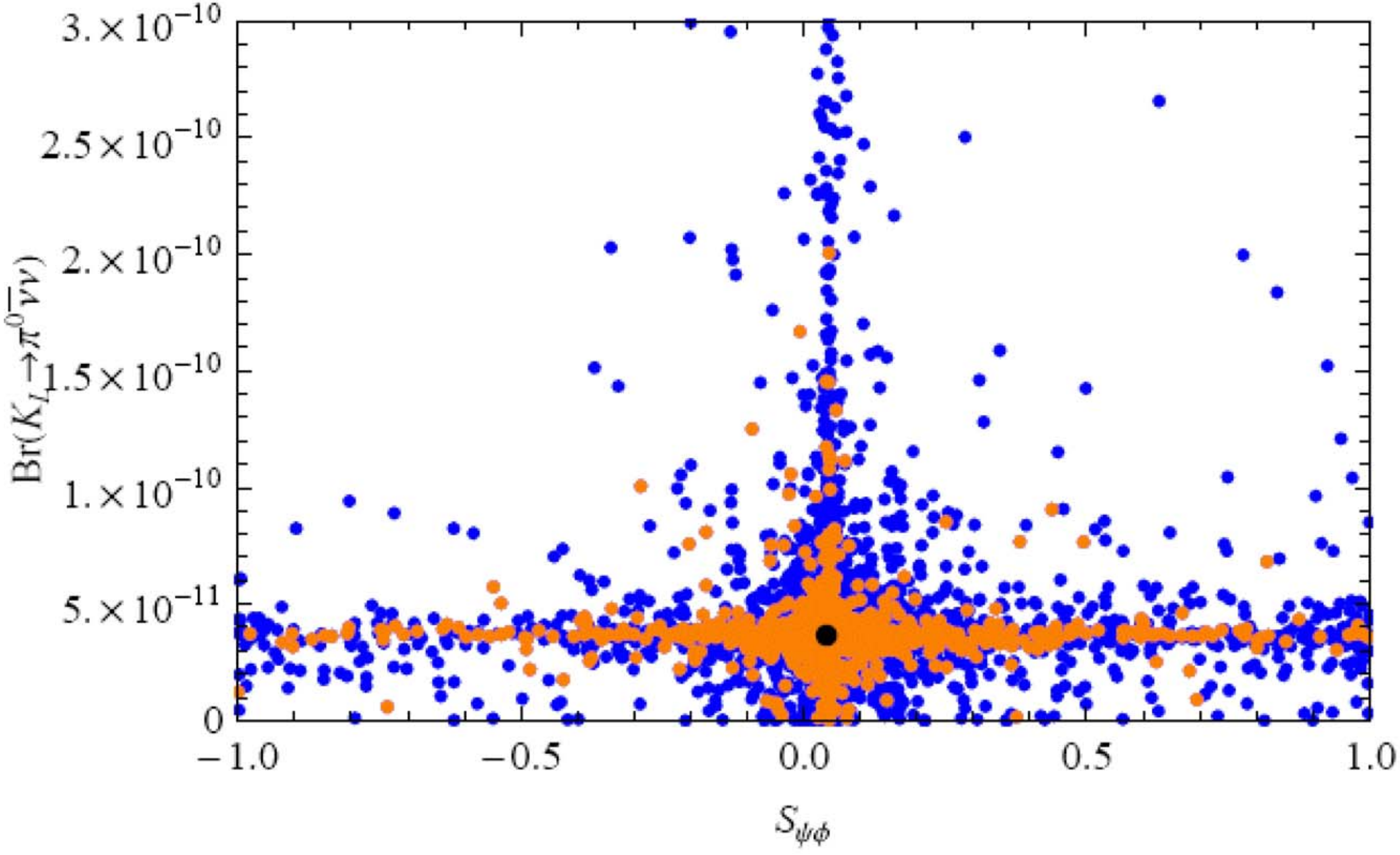
(Up to Factor 4 and 3 Enhancements)

Blanke, AJB, Duling,
Recksiegel, Tarantino



$K_L \to \pi^0 \nu\bar{\nu}$ vs. $S_{\psi\varphi}$ (RS)

(Simultaneous Large Enhancements unlikely)



$K_L \to \pi^0 \nu\bar{\nu}$ vs. $S_{\psi\varphi}$ (LHT)

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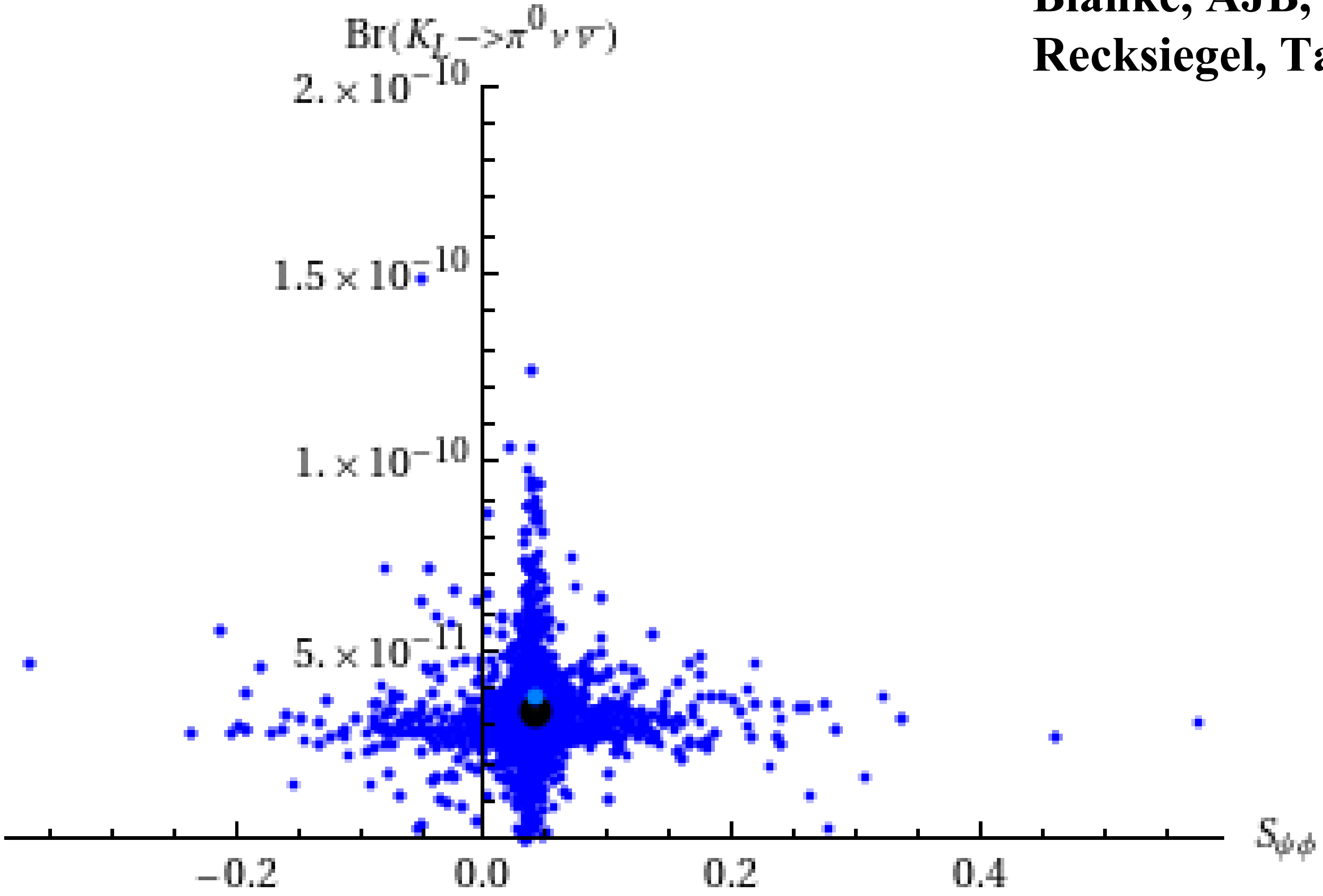
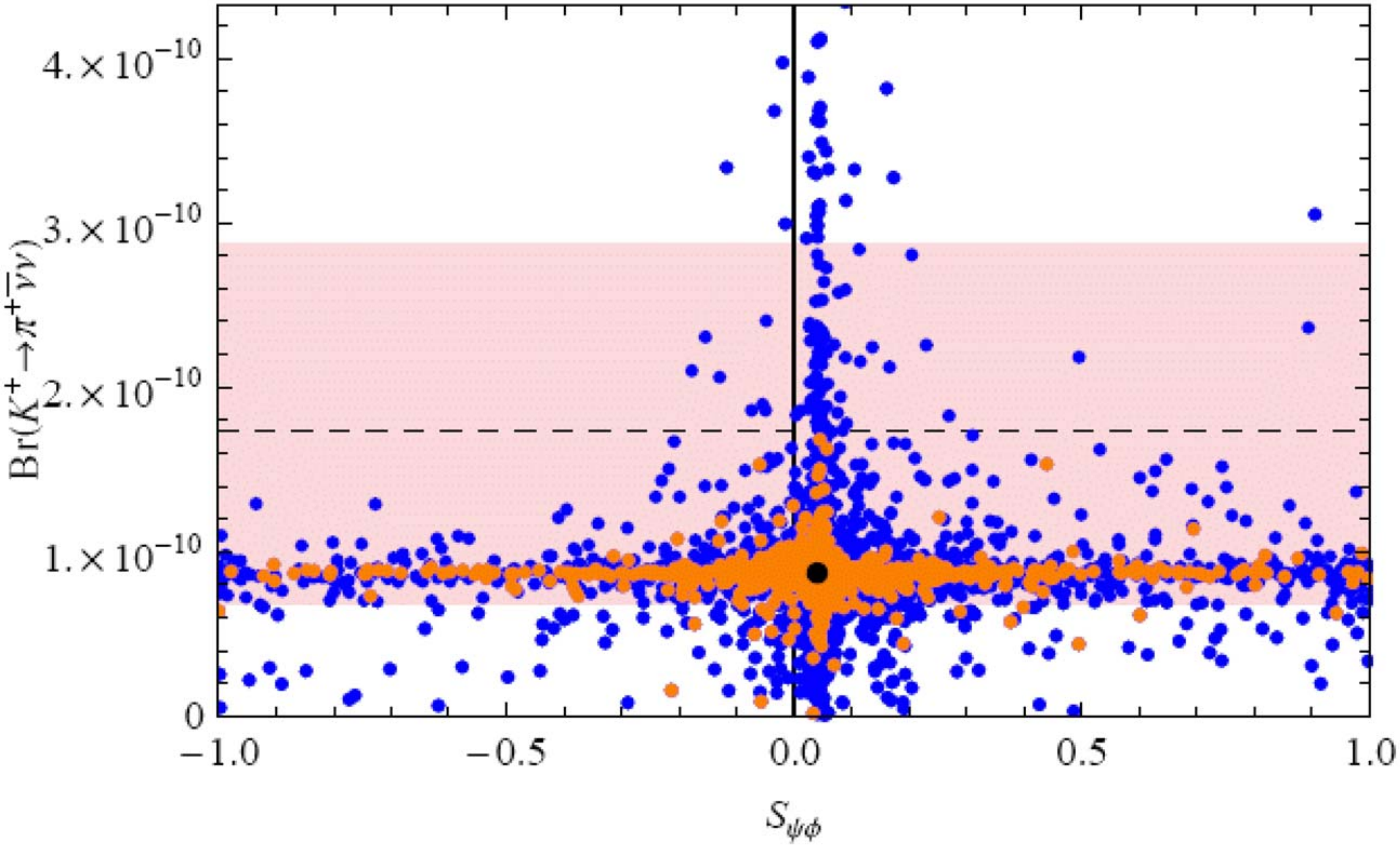
Blanke, AJB, Duling, Recksiegel, Tarantino



$K^+ \to \pi^+ \nu\bar{\nu}$ vs. $S_{\psi\varphi}$ (RS)

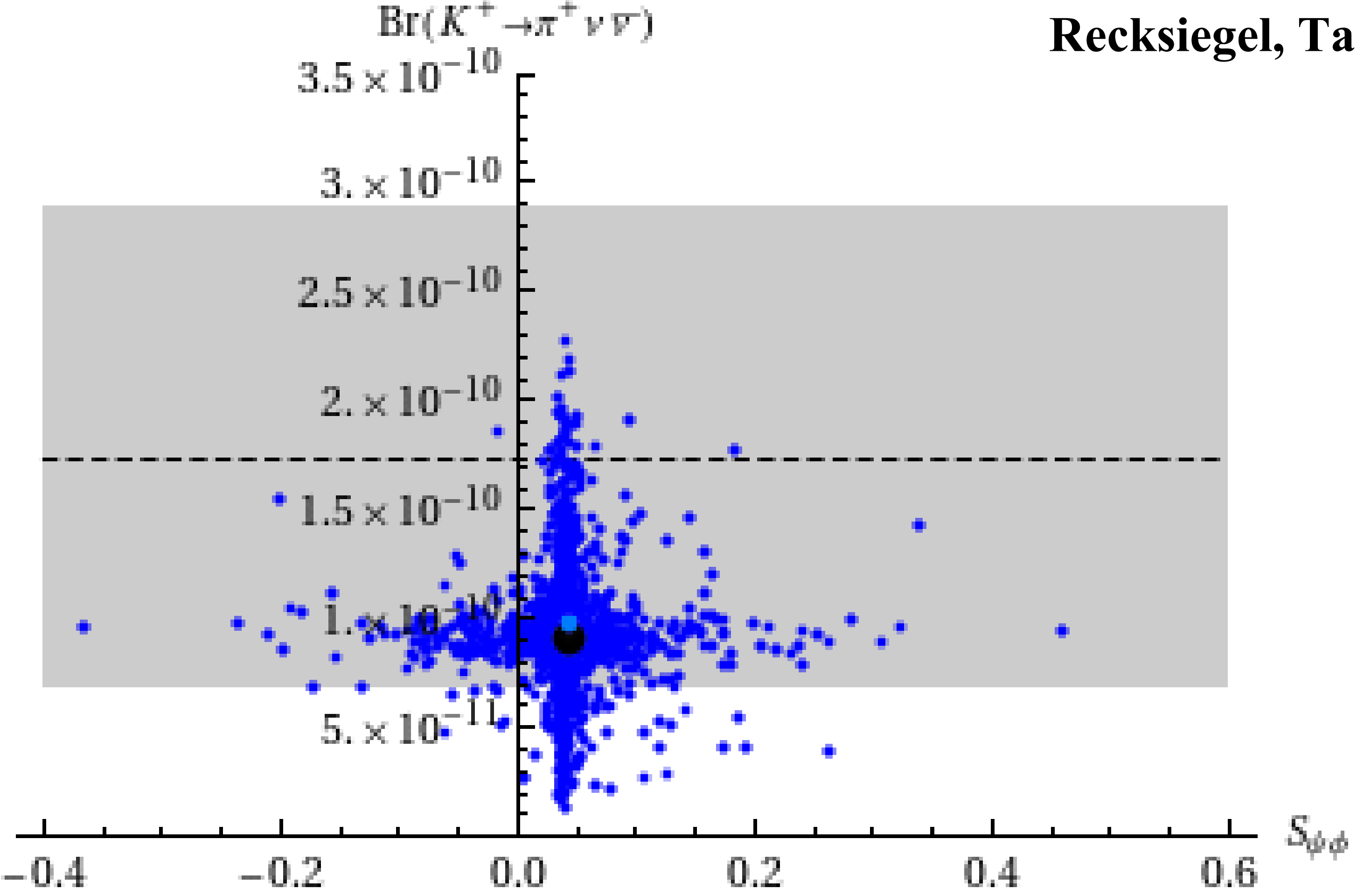
(Simultaneous Large Enhancements unlikely)



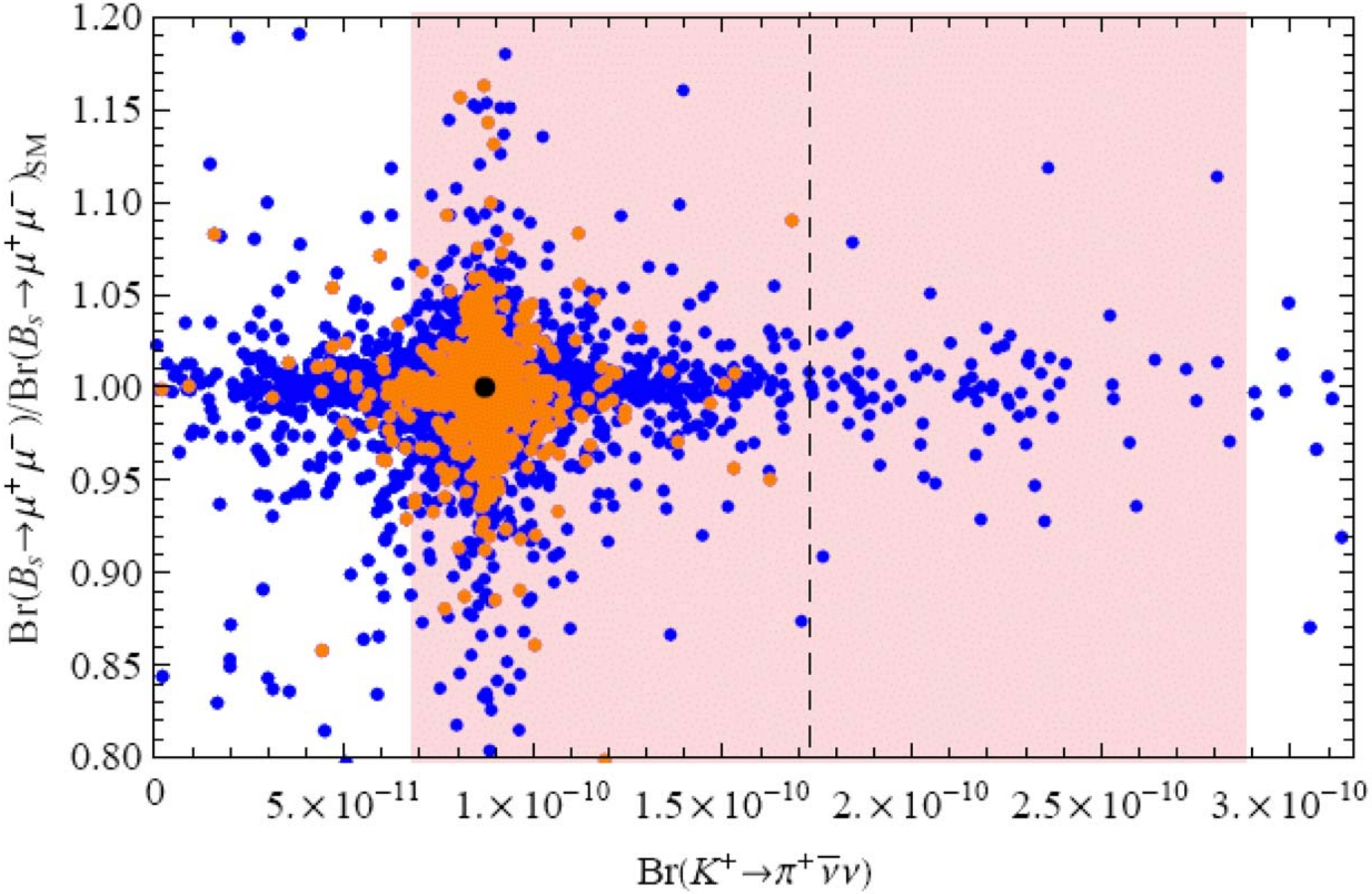
$K^+ \to \pi^+ \nu\bar{\nu}$ vs. $S_{\psi\varphi}$ (LHT)

(Simultaneous Large Enhancements unlikely)

Blanke, AJB, Duling, Recksiegel, Tarantino



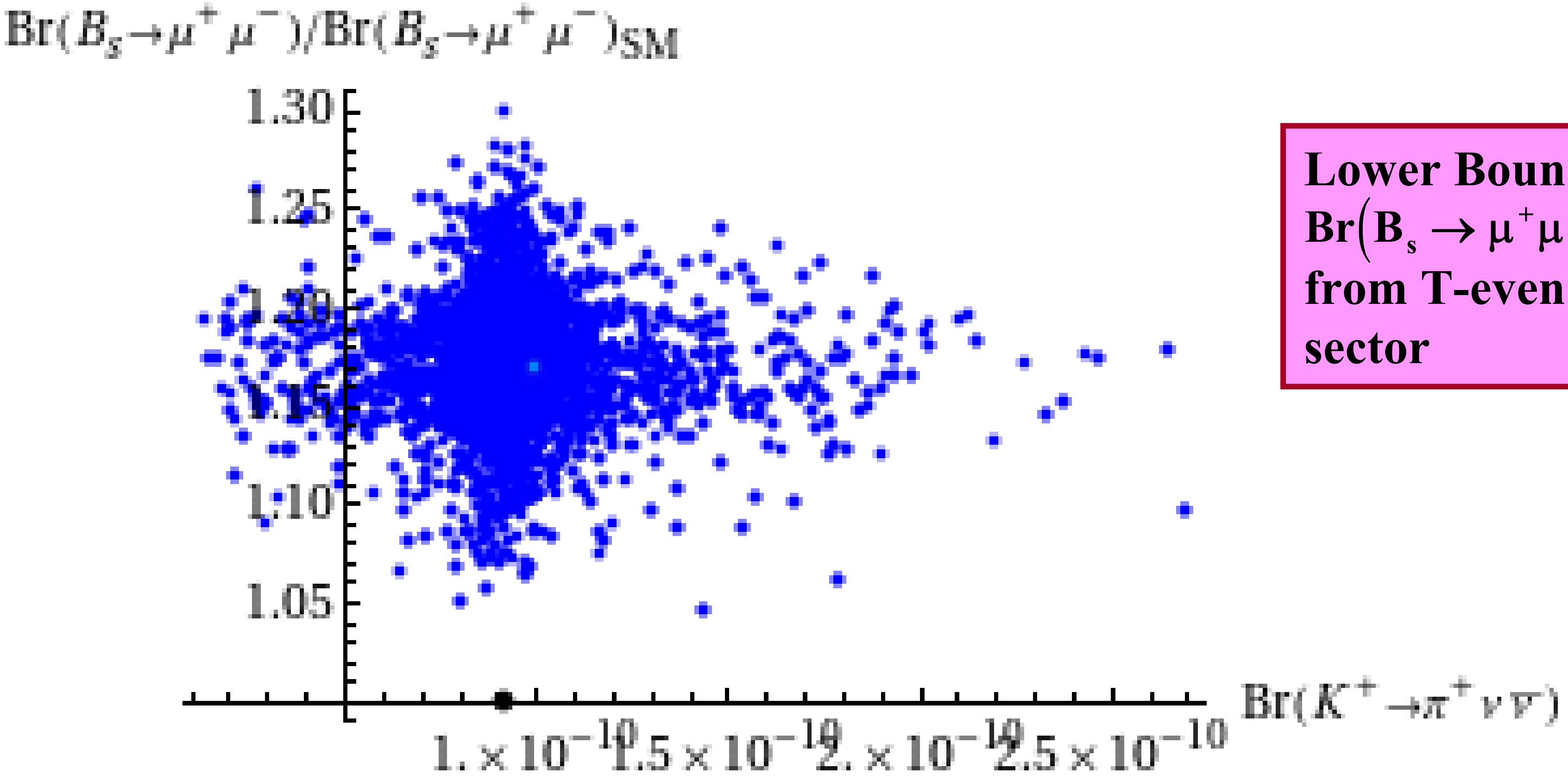
Very strong Protection for $B_s \to \mu^+\mu^-$ (RS)



$B_s \to \mu^+\mu^-$ vs. $K^+ \to \pi^+\nu\bar{\nu}$

(LHT)

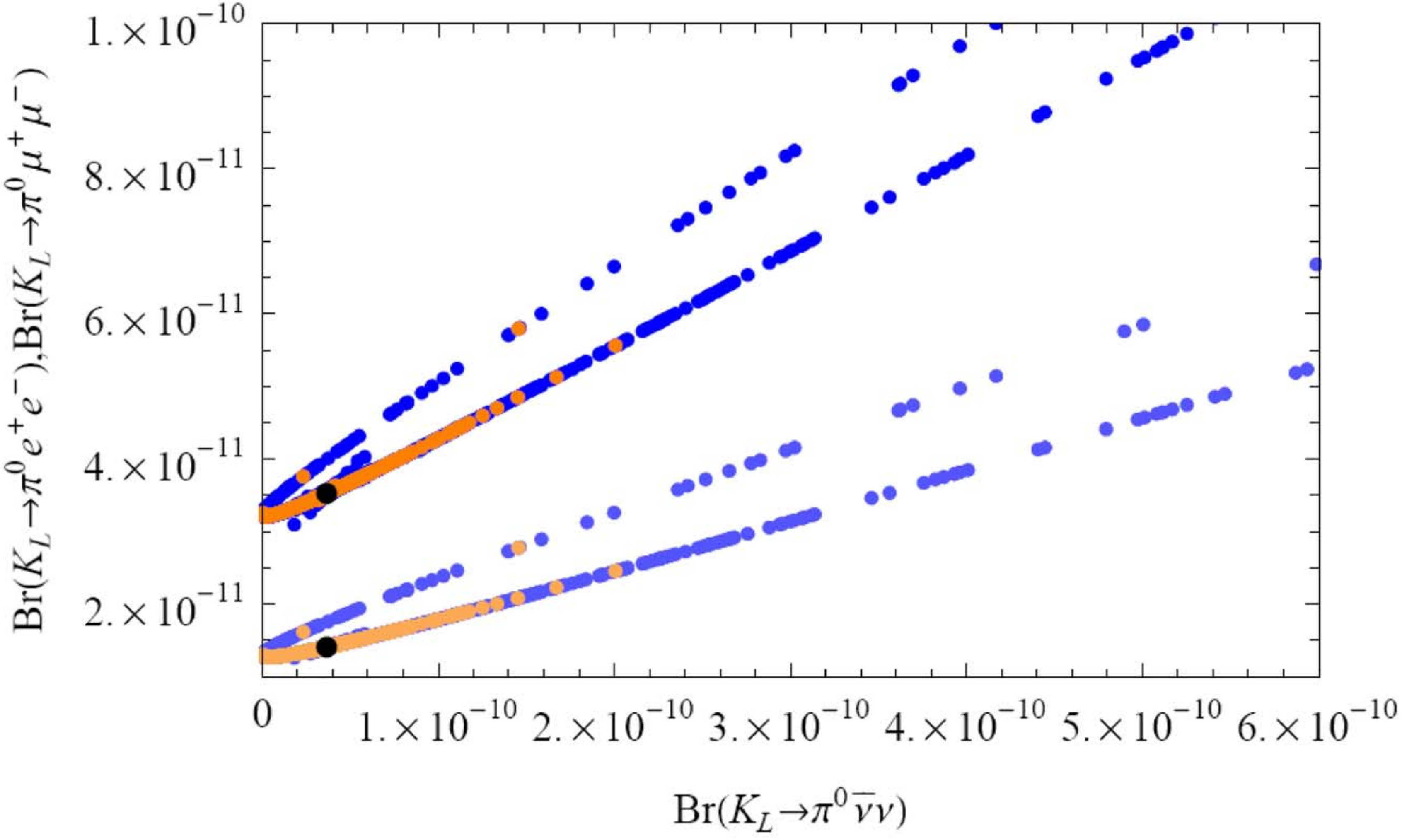
Blanke, AJB, Duling,
Recksiegel, Tarantino



Lower Bound on
$Br(B_s \to \mu^+\mu^-)$
from T-even
sector

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

(RS)



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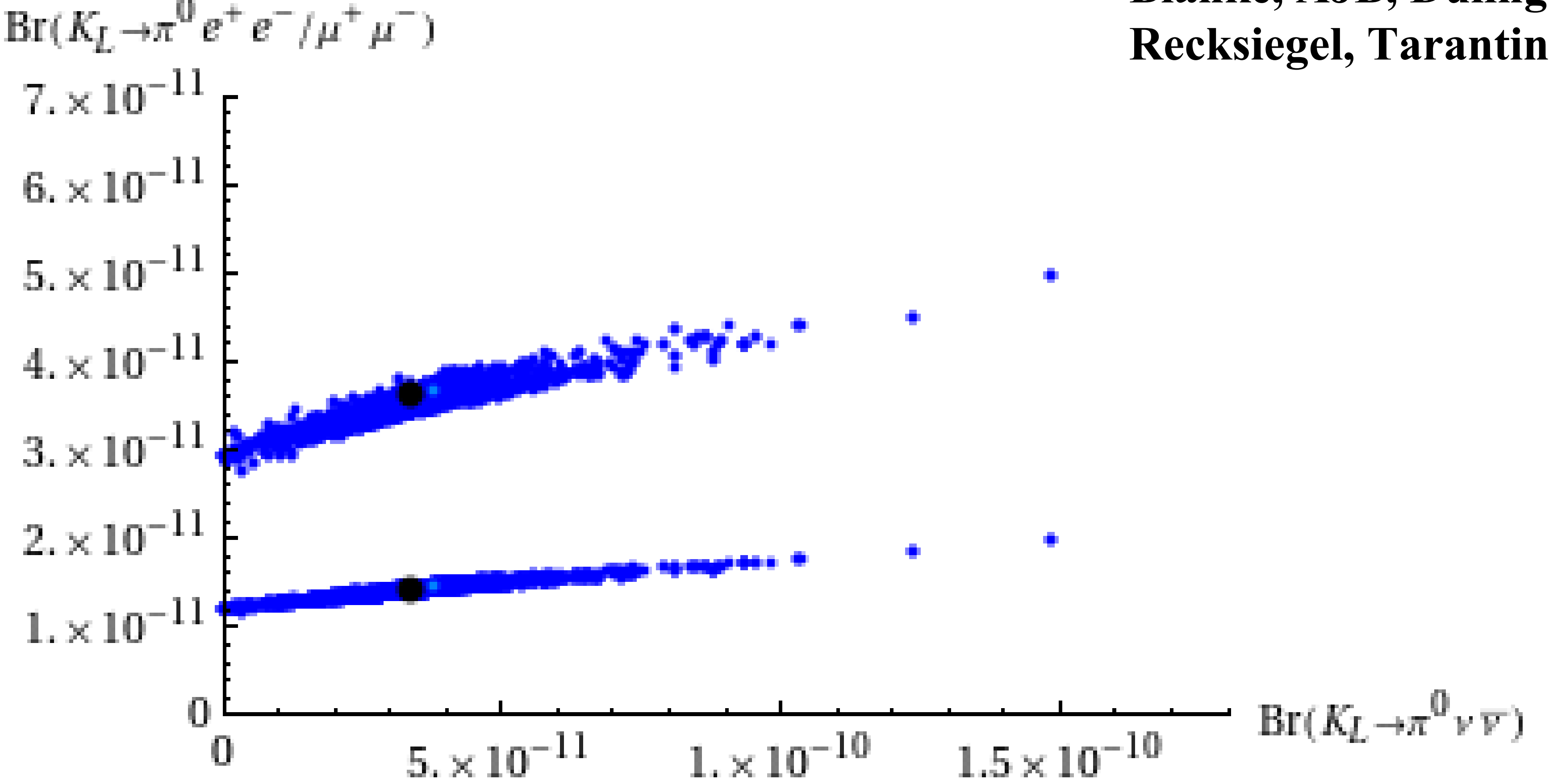
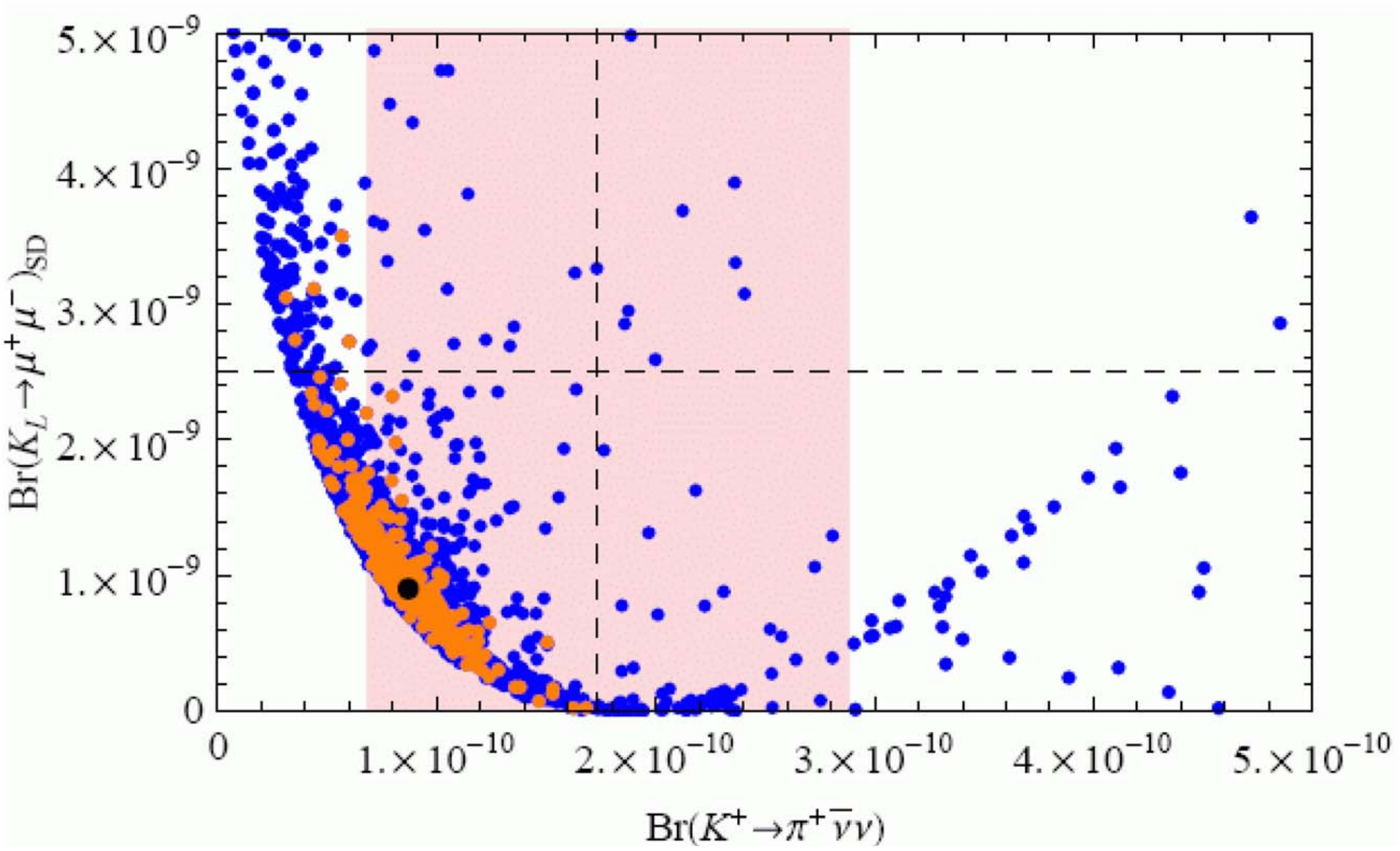
Blanke, AJB, Duling, Recksiegel, Tarantino



Correlation between $K_L \to \mu^+\mu^-$ and $K^+ \to \pi^+\nu\bar{\nu}$

(RS)

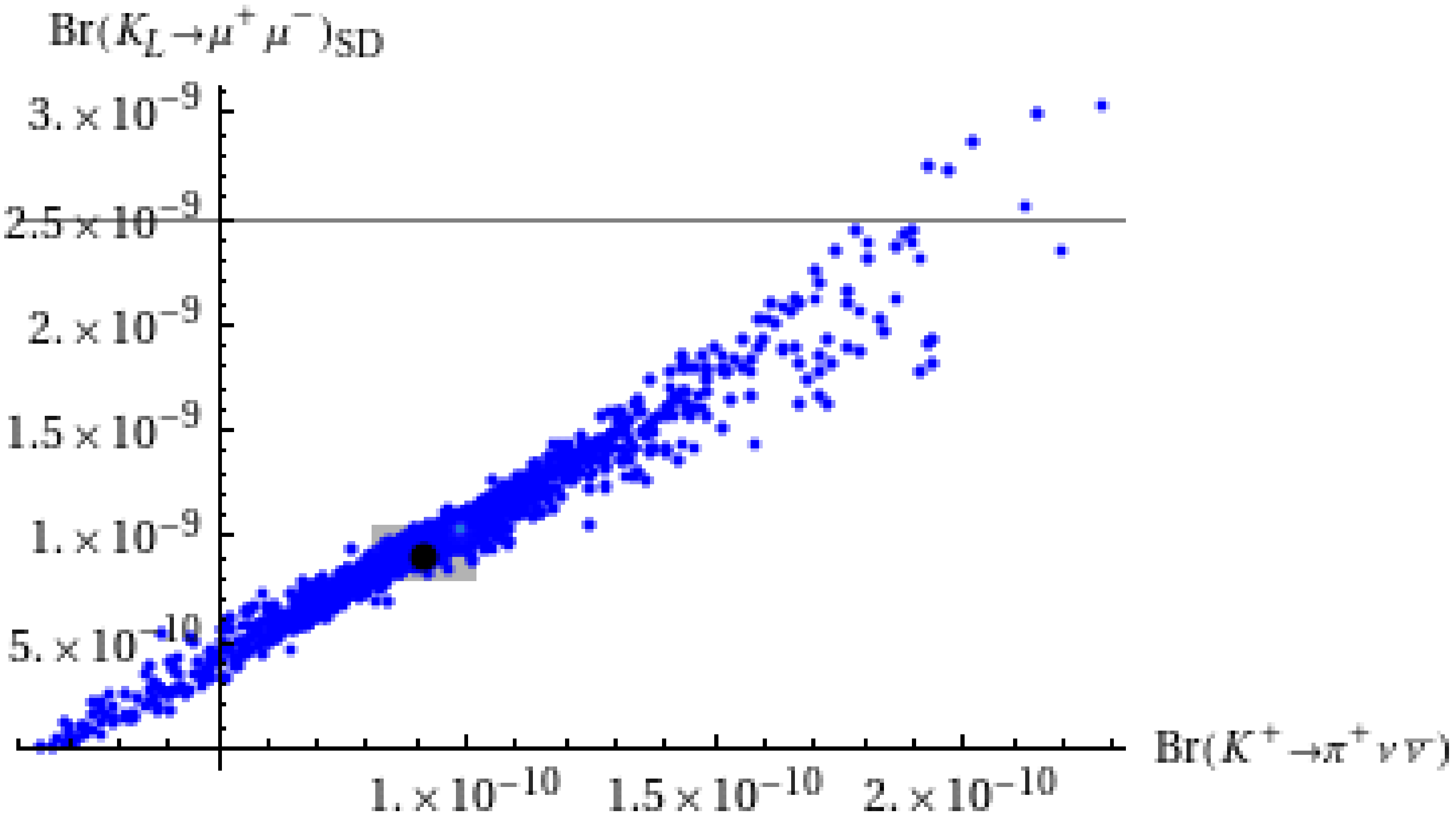


Correlation between

$K_L \to \mu^+\mu^-$ and $K^+ \to \pi^+\nu\bar{\nu}$

(LHT)

Blanke, AJB, Duling, Recksiegel, Tarantino



Comparison of RS and LHT Results

A. Both models can have $S_{\psi\varphi} >> (S_{\psi\varphi})_{SM}$ but $(S_{\psi\varphi})_{RS}$ generally larger than $(S_{\psi\varphi})_{LHT}$
(Q_{LR} present in RS but not in LHT)

B. Both models can have large enhancements of $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ but the effects are larger in LHT
(custodial protection in RS effective)

C. Strong correlation between $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ in LHT
No correlation in RS (see Blanke (2009) for explanation)

D. Simultaneous large enhancements in $S_{\psi\varphi}$ and $K \to \pi\nu\bar{\nu}$ rather unlikely in LHT and very unlikely in RS

E. Rare B-decays : small effects in both models but LHT > RS

Final Messages

1. The discovery of $S_{\psi\varphi} \approx 0.4$ will favour RS but will eliminate large effects in $K \to \pi\nu\bar{\nu}$ in both models.

2. The discovery of $Br(B_s \to \mu^+\mu^-) \approx (2-3) \cdot Br(B_s \to \mu^+\mu^-)_{SM}$ will eliminate both models but in RS removal of protection could help (then fine tuning in EWPT).

3. $(S_{\psi\varphi})_{exp} \leq 0.1$ will open the road to large effects in $K \to \pi\nu\bar{\nu}$, $K_L \to \pi^0 l^+ l^-$.

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Thank you !

Backup

Number of new Flavour Parameters

(Quark Sector) (physical)

	Real	$\not{CP}$ Phases	
SUSY	36	27	(R-parity)
LHT	7	3	some sensitivity to UV
RS	18	9	
SM	9	1	

Fine Tuning in $\Delta F=2$ Processes

(BBDGW)

$$\Delta_{BG}(Q) = \max_{i} \left| \frac{x_i}{Q} \frac{\partial Q}{\partial x_i} \right|$$

Barbieri + Giudice

$M_{KK} \approx 2.5\mathrm{TeV}$

◆ Generically: $\varepsilon_K \cong 10^2 \varepsilon_K^{exp}$

◆ $\Delta_{BG}(\varepsilon_K)$ decreases with increasing ε_K

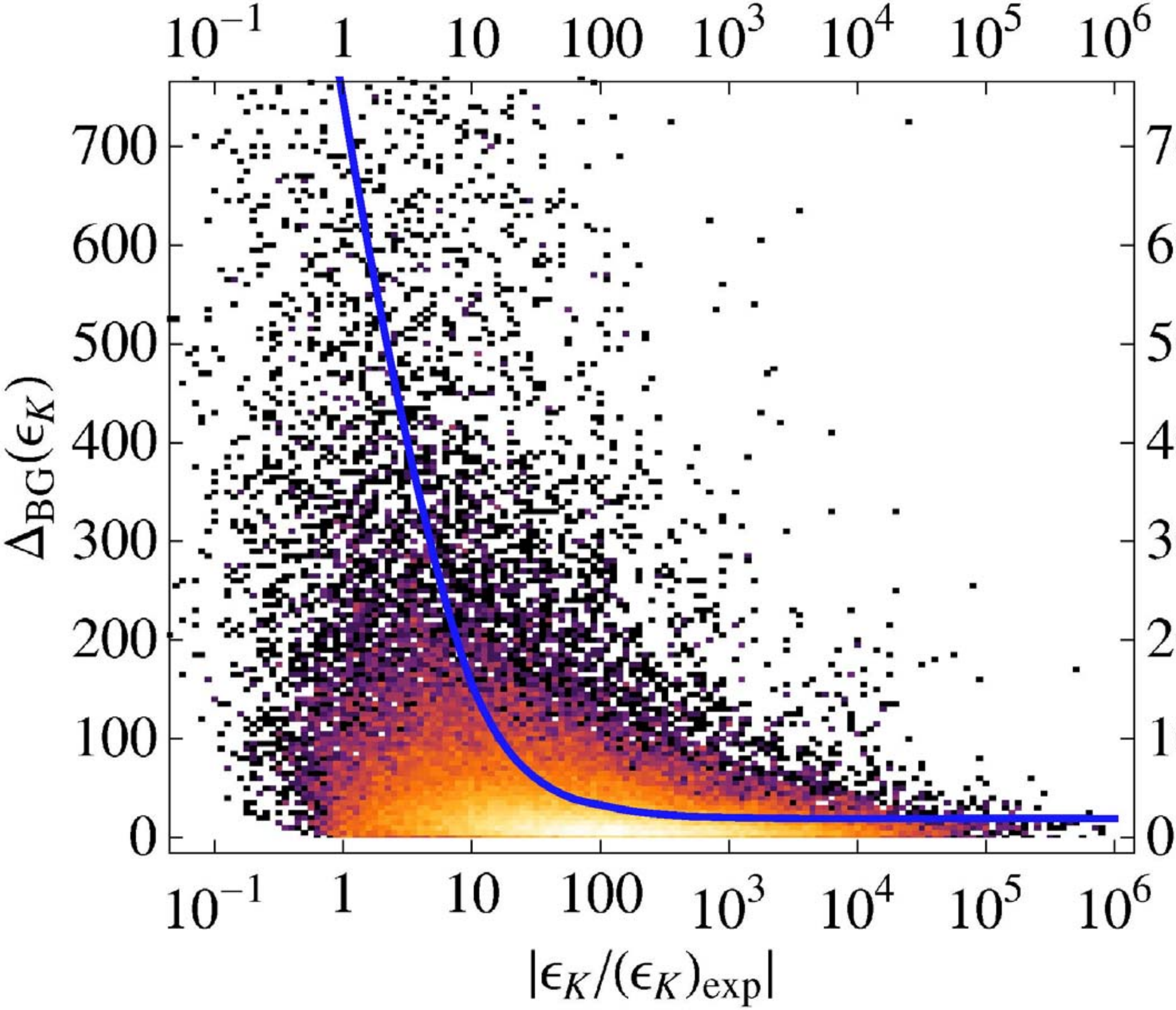
◆ Parameter sets with moderate $\Delta_{BG}(\varepsilon_K) \le 20$ and $\varepsilon_K \approx \varepsilon_K^{exp}$ exist.

For ΔM_K and $\Delta B=2$ observables fine tuning much smaller.
Generically: $(\Delta_{BG} \lesssim 20)$ $(\Delta_{BG} \le 5)$

RS-GIM
very
effective

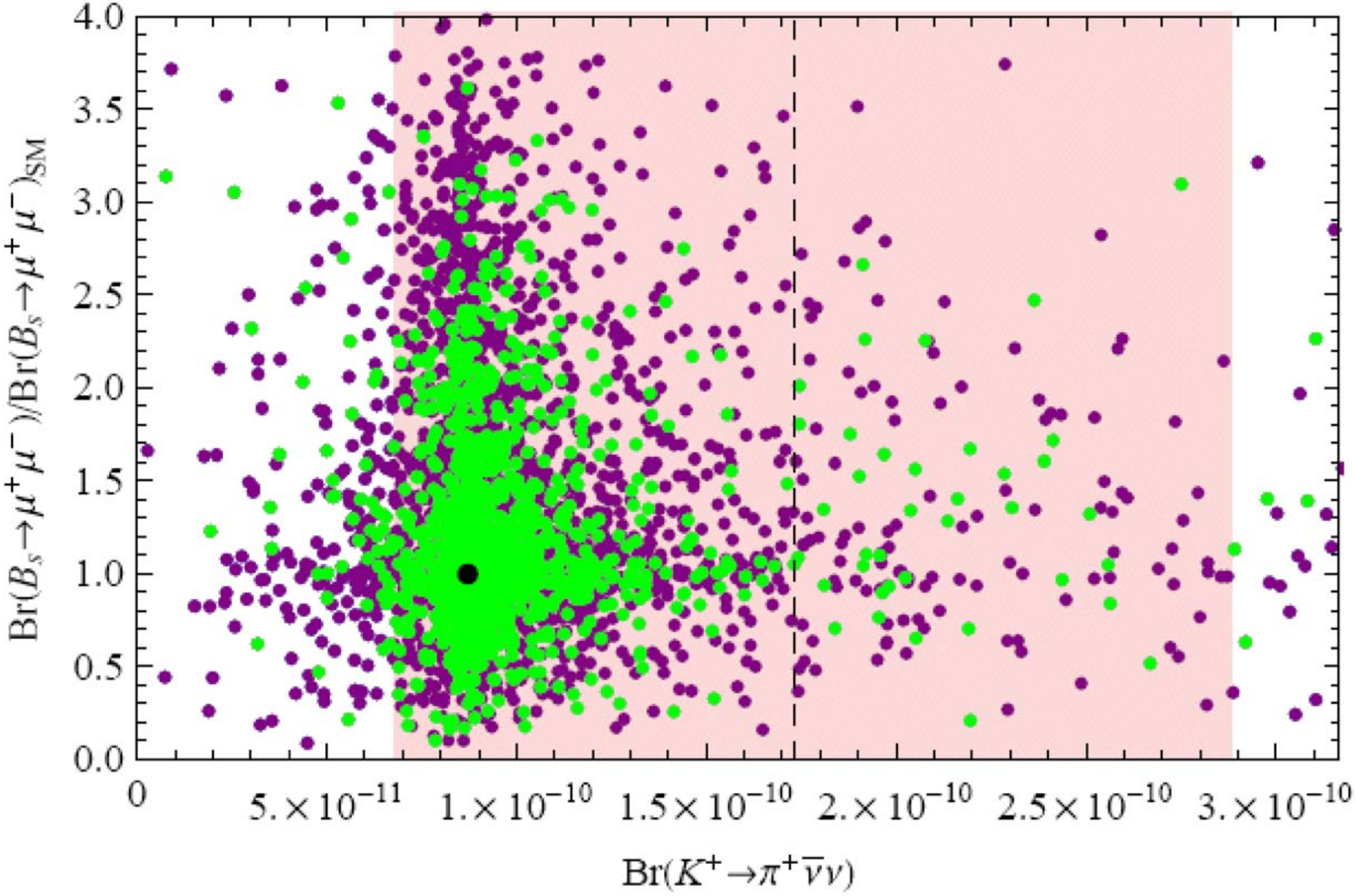
Fine Tuning in ε_K

Blanke
AJB
Duling
Gori
Weiler



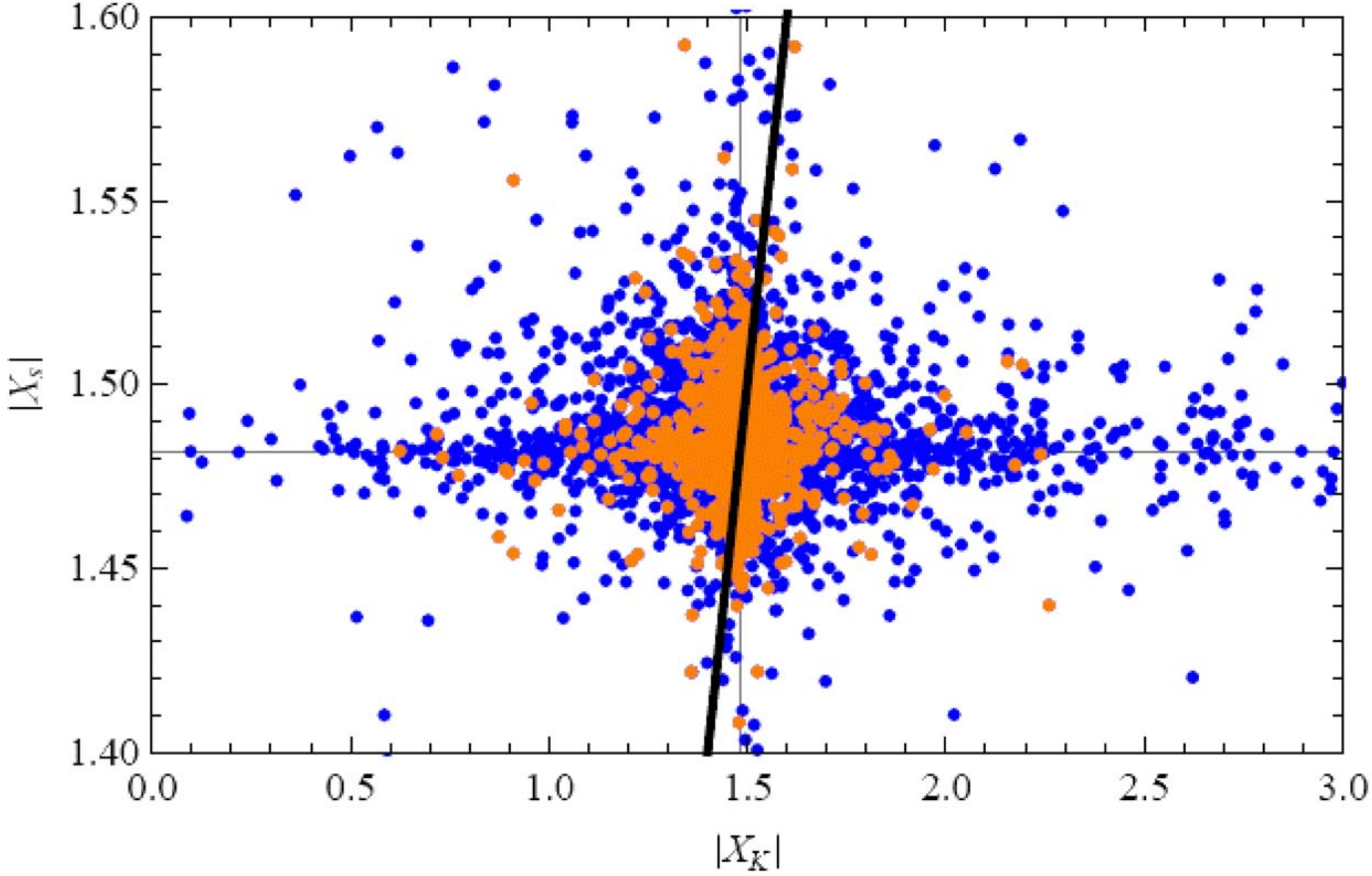
Removal of Protection

($\mathrm{Br}\left(B_s \to \mu^+\mu^-\right)$ enhanced up to 10^{-8})



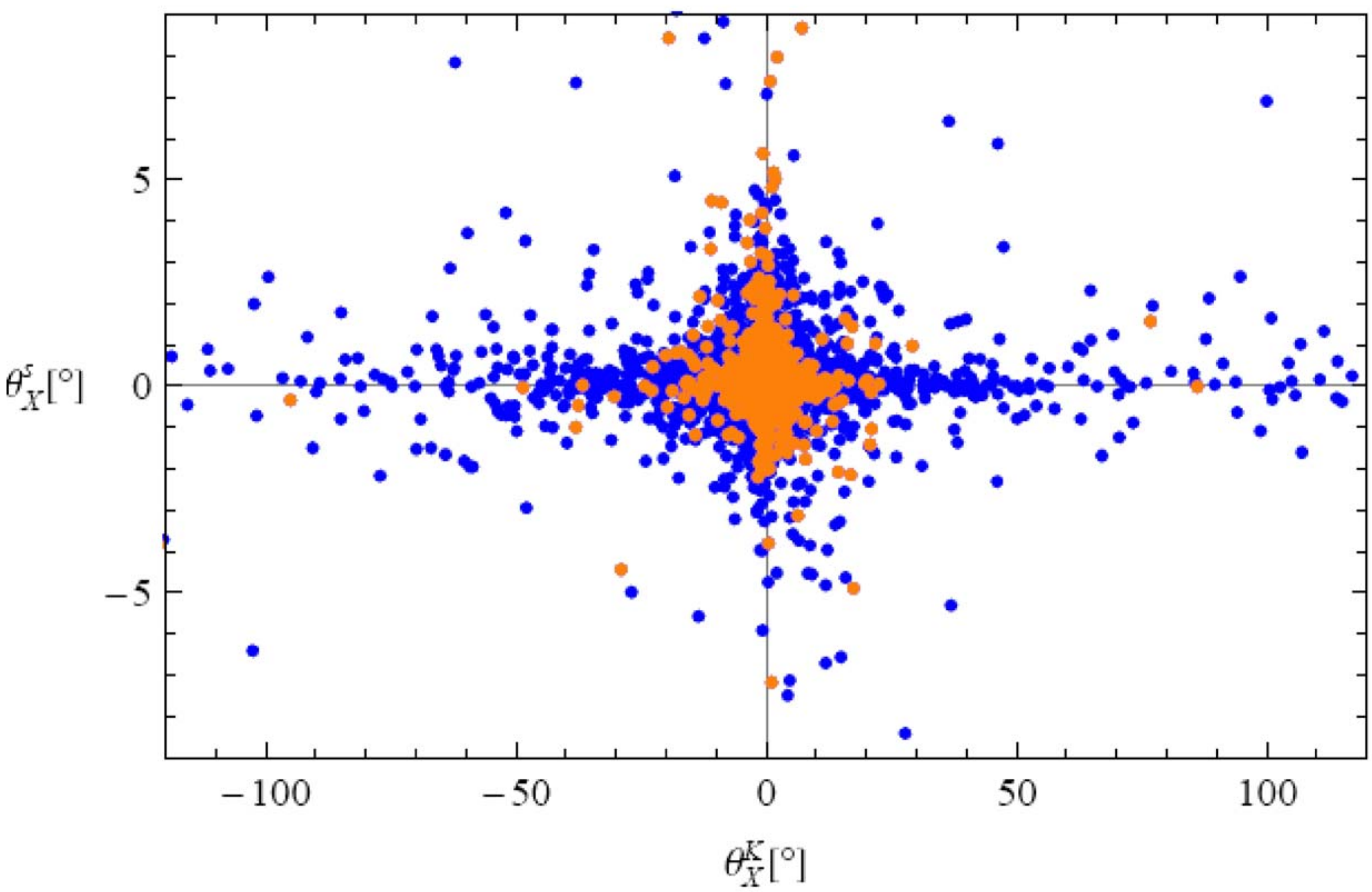
Breakdown of Universality in X (RS)

(NP effects much larger in K decays)



New CP-Violating Phases (RS)

(NP effects much larger in K decays)



Higgs and Mass Matrices

$$H = \begin{pmatrix} \pi^+/\sqrt{2} & -\left(h^0 - i\pi^0\right)/2 \\ \left(h^0 + i\pi^0\right)/2 & \pi^-/\sqrt{2} \end{pmatrix}$$

For SM and n=1 KK modes with flavour i=1,2,3

$M(5/3) = 9 \text{ x } 9$ $M(2/3) = 18 \text{ x } 18$ $M(-1/3) = 12 \text{ x } 12$

a) Numerical Diagonalization (BB D GW)

b) Analytic Reduction to 3 x 3 by means of effective Lagrangians (integrating out of KK modes) (AJB, Duling, Gori)

Comparison of Beyond-MFV Scenarios

Scenario	New Flavour and CP Violation	New Operators	FCNC at Tree Level
LHT	★		
SUSY	★	★	
RS	★	★	★

(non-universitalities in gauge couplings implied by the manner CKM and mass hierarchies are explained)

General Structure of New Physics Contributions

SM :

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

Amplitudes :

$$\boxed{\lambda_t^{(i)} X_{SM}(m_t)}$$

$\nu\bar{\nu}$ in the final state

$$\boxed{\lambda_t^{(i)} Y_{SM}(m_t)}$$

$\mu^+\mu^-$ in the final state

Universality of short distance functions

$i = K, B_d, B_s$

LHT

RS :

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

$$Y_i = \overbrace{Y_{MFV}} + \overbrace{\frac{1}{\lambda_t^{(i)}} \xi_i \bar{Y}} \equiv |Y_i| e^{i\theta_Y^i}$$

Breakdown of Universality

New Flavour and $\not{C}\not{P}$ in ξ_i

Non-MFV

Natural Expectations

$$X_i = X_{MFV} + \frac{1}{\lambda_t^{(i)}} \xi_i \overline{X} \equiv |X_i| e^{i\theta_X^i}$$

(similarly for Y_i)

Non-MFV

$i = K, B_d, B_s$

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

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

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

$\left\{ \begin{array}{c} \textbf{Natural} \\ \textbf{size} \\ \textbf{of NP} \\ \textbf{contributions} \end{array} \right\}$:

$K \gg B_d > B_s$

But can be modified for special structures of ξ_i

Golden Relations of CMFV:

AJB (03)

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

(CMFV)

r = 1

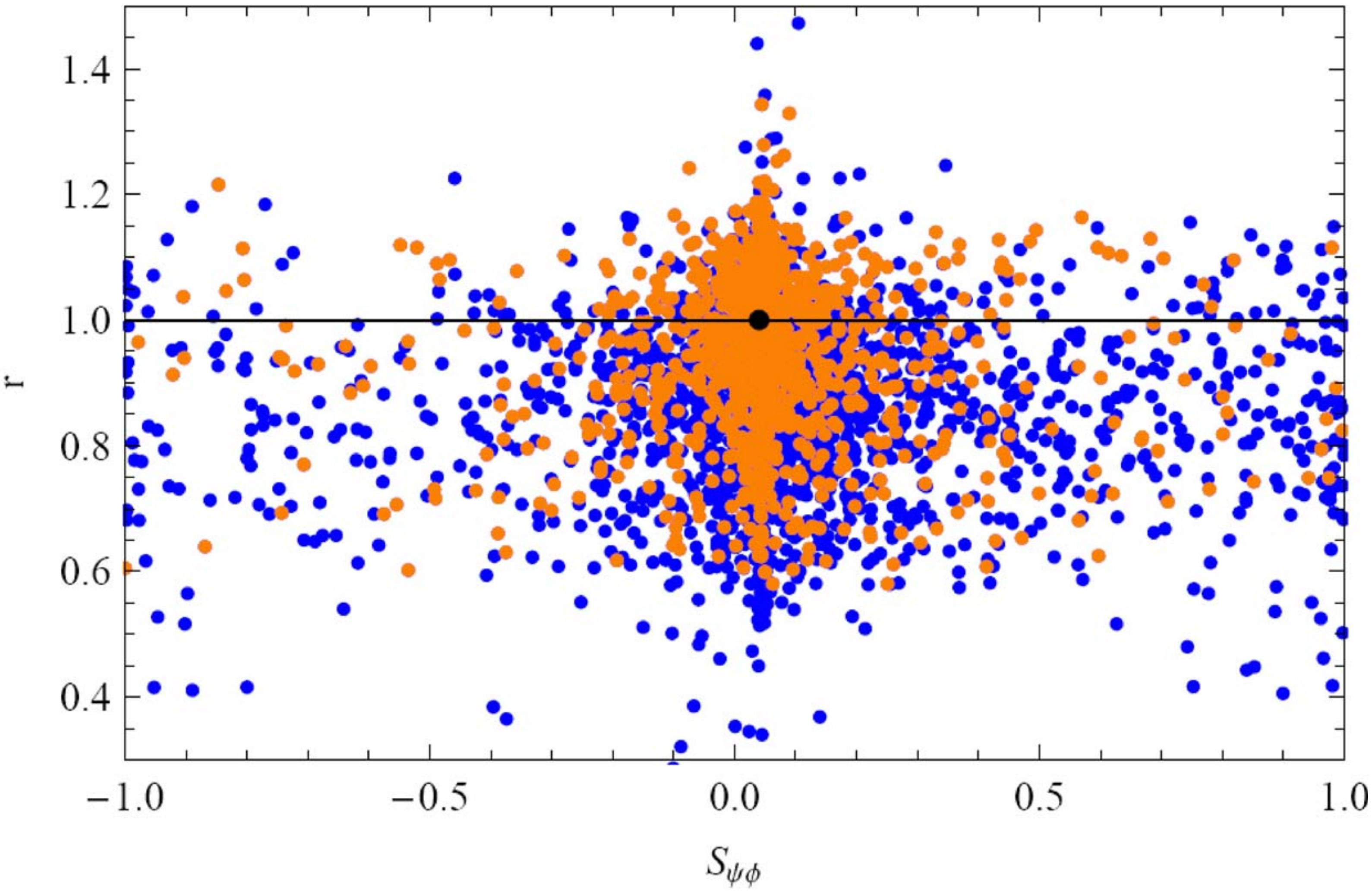
Buchalla, AJB (94)
AJB, Fleischer (01)

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

(MFV)

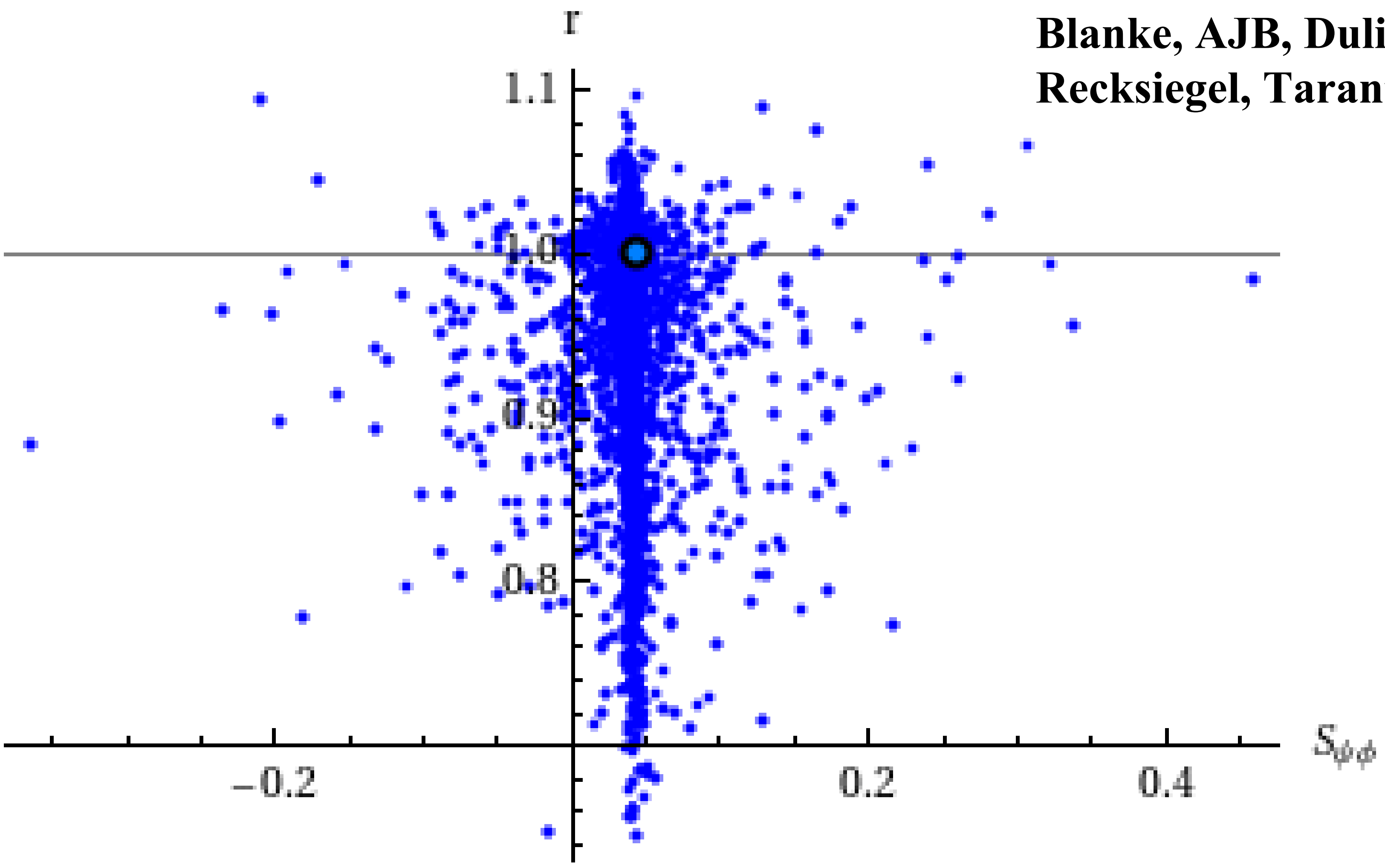
The violation of these model independent MFV (CMFV) relations would signal new flavour and CP-violating interactions (and/or new operators)

Violation of the Golden MFV Relation I (RS)



Violation of the Golden MFV Relation I

(LHT)



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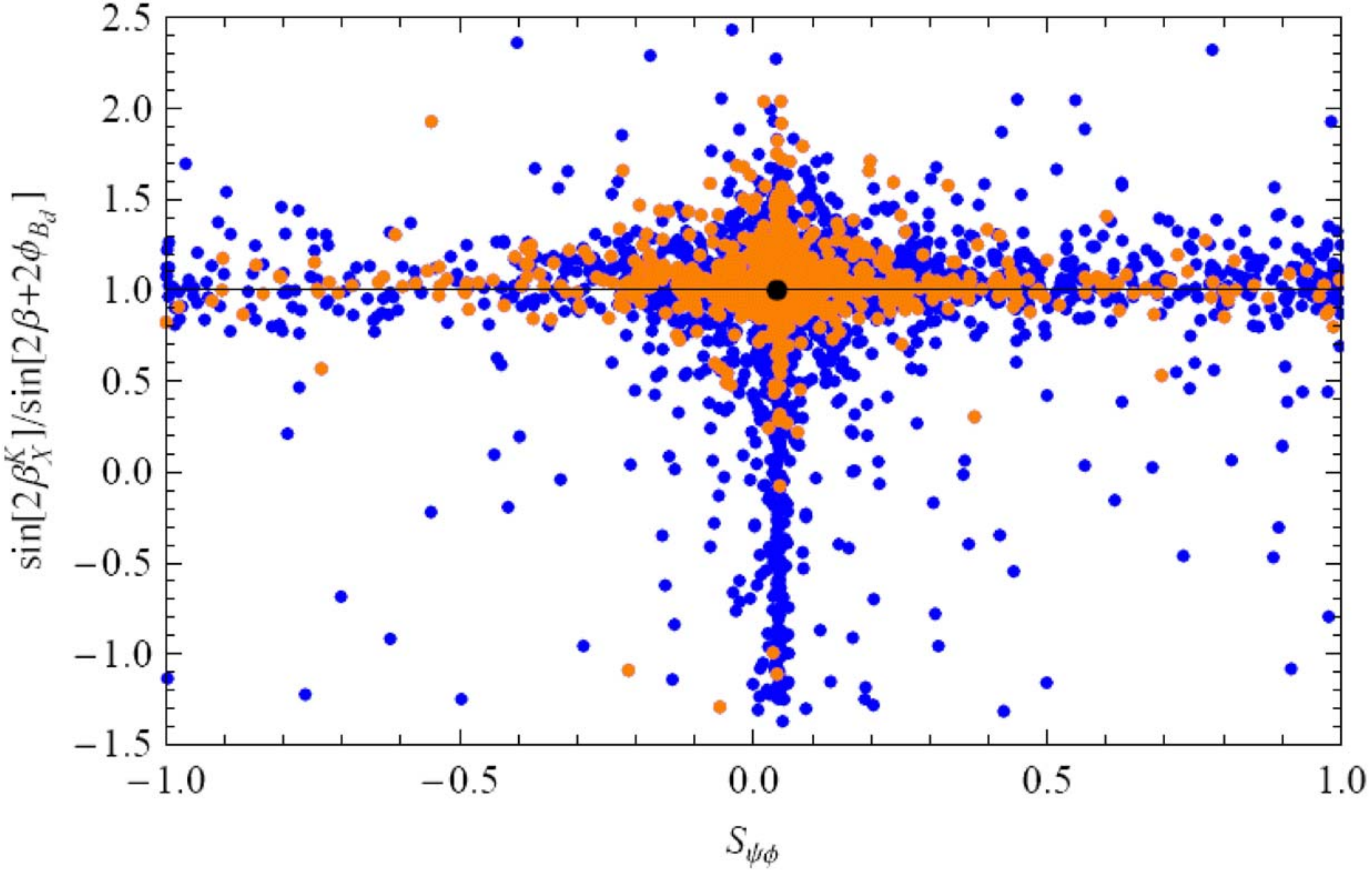
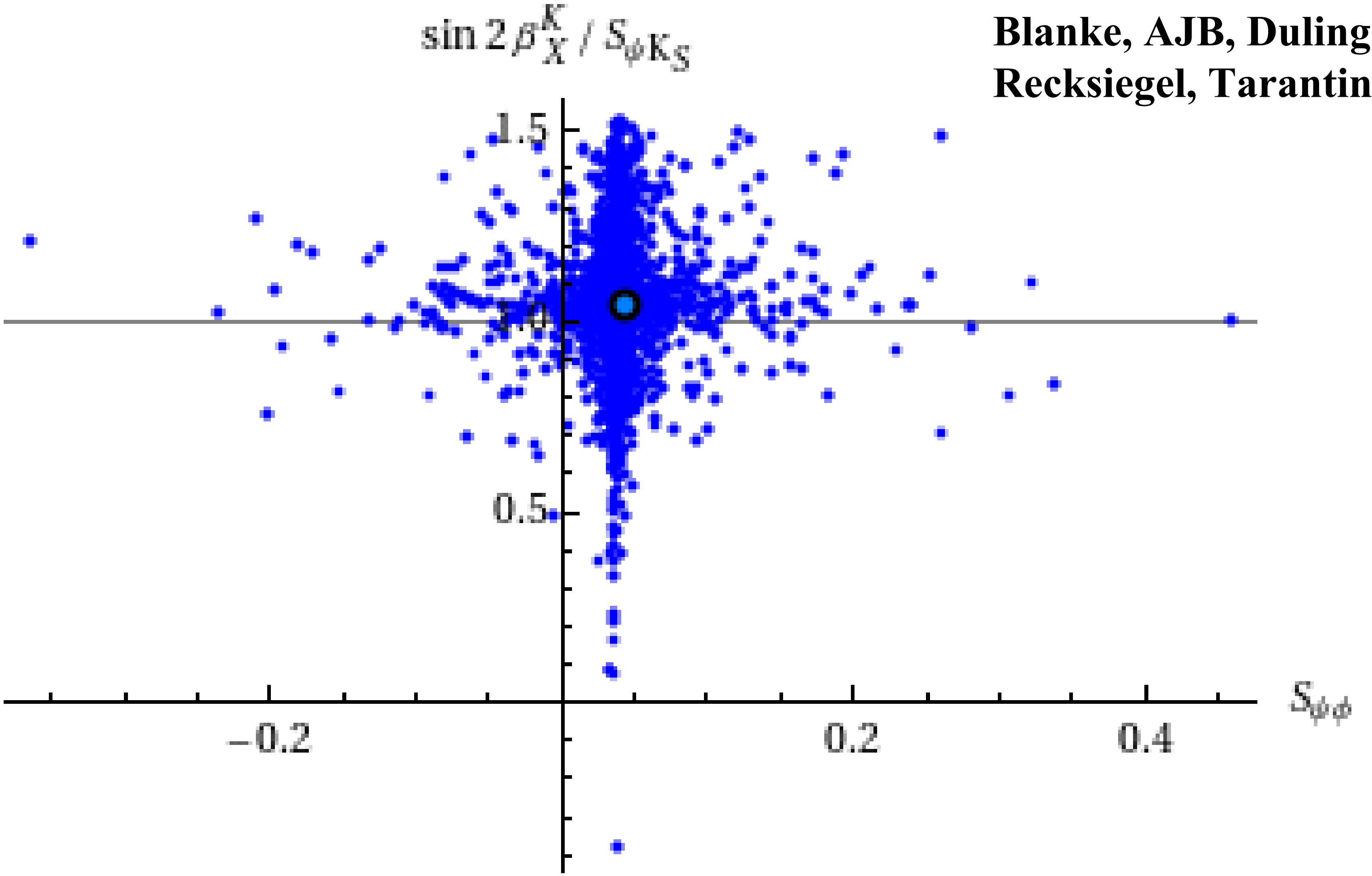
Violation of the Golden MFV Relation II (RS)



Violation of the Golden MFV Relation II (LHT)

Blanke, AJB, Duling, Recksiegel, Tarantino



Clear Pattern of Flavour Violation

(RS)

1. ε_K can be made consistent with data for $M_{KK} \cong 2-3\text{TeV}$ with only moderate tuning of Y_{5D}
2. $S_{\psi\varphi}$ can be much larger than $(S_{\psi\varphi})_{SM}$
3. $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ can be enhanced up to factors 5 and 2
4. Rare B-decays SM-like
5. Simultaneous enhancements of $S_{\psi\varphi}$ and $K \to \pi\nu\bar{\nu}$ very unlikely
6. Analysis of $B \to X_S\gamma$, $\mu \to e\gamma$, … in progress