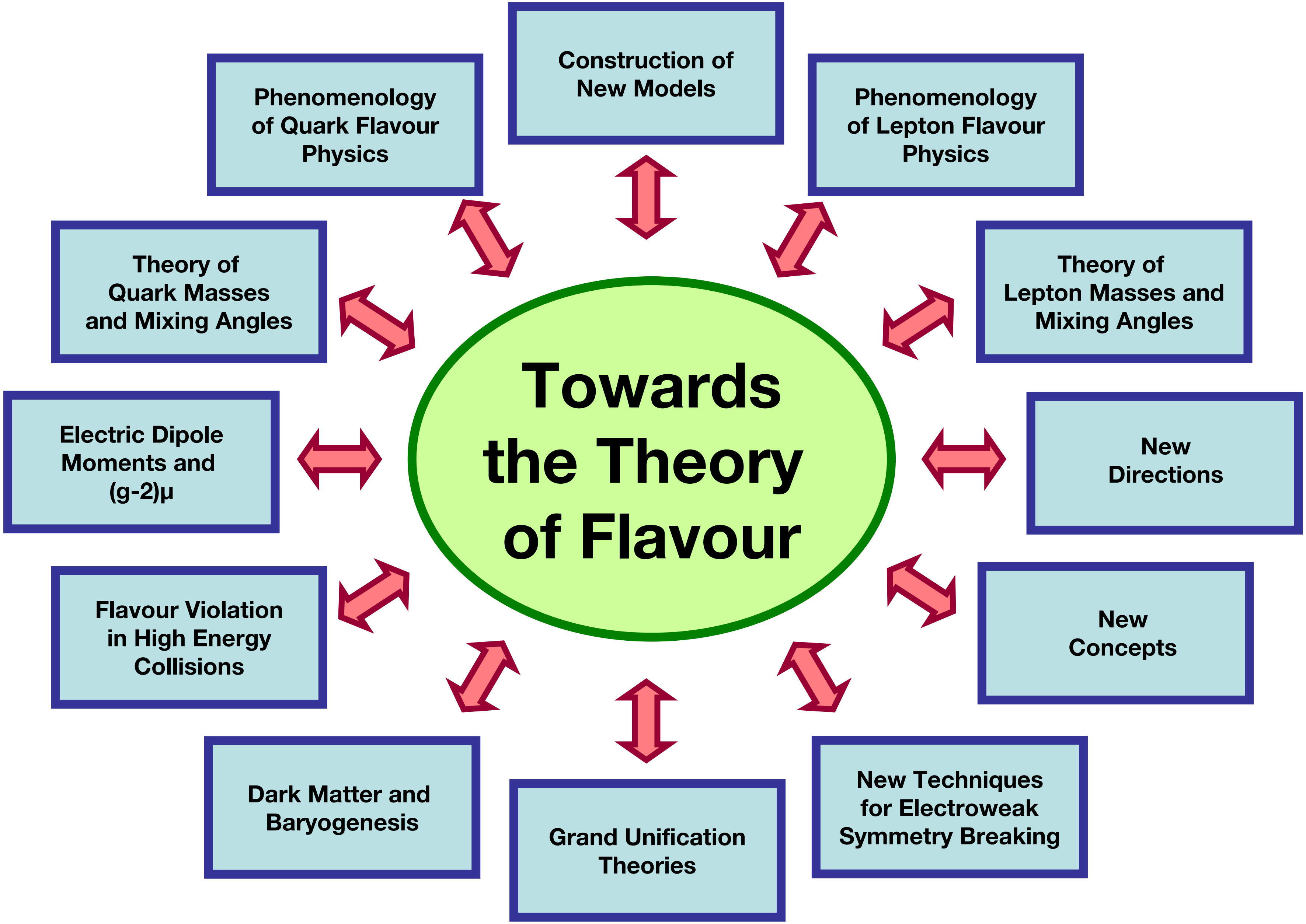
Flavour Theory and the LHC Era

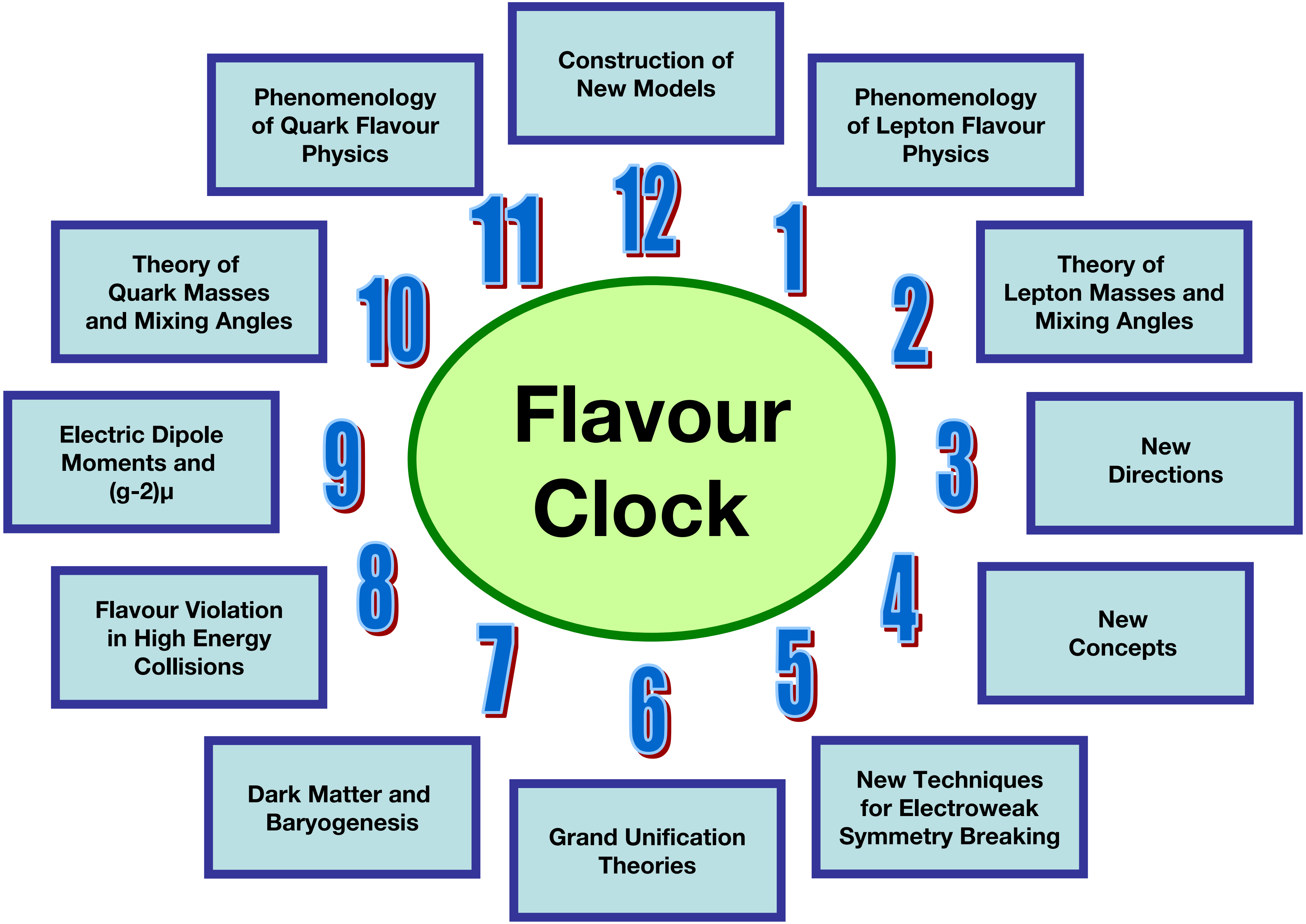
Andrzej J. Buras
(Technical University Munich, TUM-IAS)

DESY, Jun 11th, 2010
Physics at LHC 2010

Main Message of this Talk

In our search for a fundamental theory we need to improve our understanding of Flavour


Towards the Theory of Flavour
Construction of New Models
Phenomenology of Quark Flavour Physics
Phenomenology of Lepton Flavour Physics
Theory of Quark Masses and Mixing Angles
Theory of Lepton Masses and Mixing Angles
Electric Dipole Moments and (g-2)μ
New Directions
Flavour Violation in High Energy Collisions
New Concepts
Dark Matter and Baryogenesis
Grand Unification Theories
New Techniques for Electroweak Symmetry Breaking


Flavour Clock
Construction of New Models
12
Phenomenology of Lepton Flavour Physics
1
Theory of Lepton Masses and Mixing Angles
2
New Directions
3
New Concepts
4
New Techniques for Electroweak Symmetry Breaking
5
Grand Unification Theories
6
Dark Matter and Baryogenesis
7
Flavour Violation in High Energy Collisions
8
Electric Dipole Moments and (g-2)µ
9
Theory of Quark Masses and Mixing Angles
10
Phenomenology of Quark Flavour Physics
11

Basic Questions in Flavour Physics

New Flavour violating CPV phases?

Flavour Conserving CPV phases?

Non-MFV Interactions?

Right-Handed Charged Currents?

Scalars H^0, $H^\pm$ and related FCNC´s?

New Fermions? New Gauge Bosons?

★ How to explain dynamically 22 free Parameters in the Flavour Sector ?

CKM Parameters from Tree-Level Decays
(subject to very small NP Pollution)

$$|V_{us}| = s_{12} = 0.2254 \pm 0.0008$$

$$|V_{ub}| = s_{13} = (3.9 \pm 0.4) \cdot 10^{-3}$$

$$|V_{cb}| = s_{23} = (41.2 \pm 1.1) \cdot 10^{-3}$$

$$\delta_{CKM} = \gamma_{UT} = (75 \pm 15)^o$$

(-phase of V_{ub})

$$(\sin 2\beta)_{\psi K_s} = 0.672 \pm 0.023$$

(-phase of V_{td})

⇒ $\beta = (21.1 \pm 0.9)^o$

but could be subject to NP pollution

Phase of V_{ts}: $\approx -(1.2 \pm 0.1)^o$

Hierarchical Structure of the CKM Matrix

$$\begin{pmatrix} 0.97 & s_{12} & s_{13}e^{-i\gamma} \\ -s_{12} & 0.97 & s_{23} \\ s_{12}s_{23}-s_{13}e^{i\gamma} & -s_{23} & 1 \end{pmatrix}$$

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

$(4\cdot 10^{-3})$ $(4\cdot 10^{-2})$ (0.2)

GIM Structure of FCNC´s

Large $\not{C}\not{P}$ effects in B_d
Small $\not{C}\not{P}$ effects in B_s
Tiny $\not{C}\not{P}$ effects in K_L

$A_{CP}(B_d \to \psi K_s) \approx 0(1)$ $\quad S_{\psi K_s} \approx \frac{2}{3}$

$A_{CP}(B_s \to \psi \varphi) \approx 0(10^{-2})$ $\quad S_{\psi\varphi} \approx \frac{1}{25}$

$\varepsilon \approx 0(10^{-3}) \qquad \varepsilon' \approx 0(10^{-6})$

$Br(K_L \to \pi^0 \nu\bar{\nu}) \approx 0(10^{-11})$

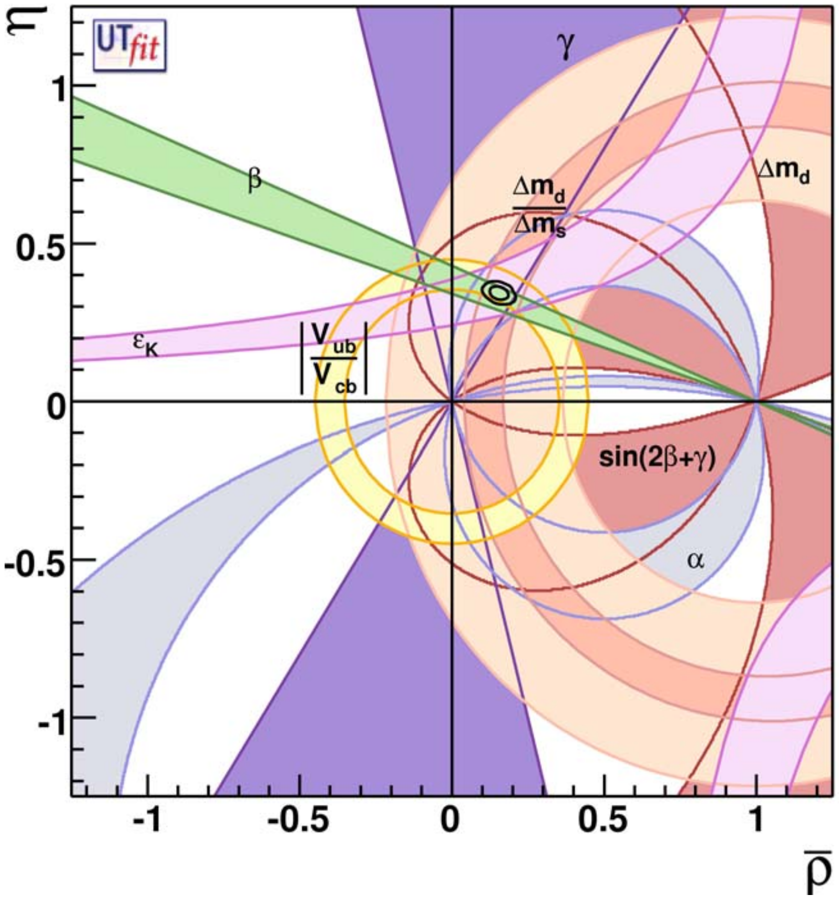
PMNS: Negligible LFV

(tiny ν masses)

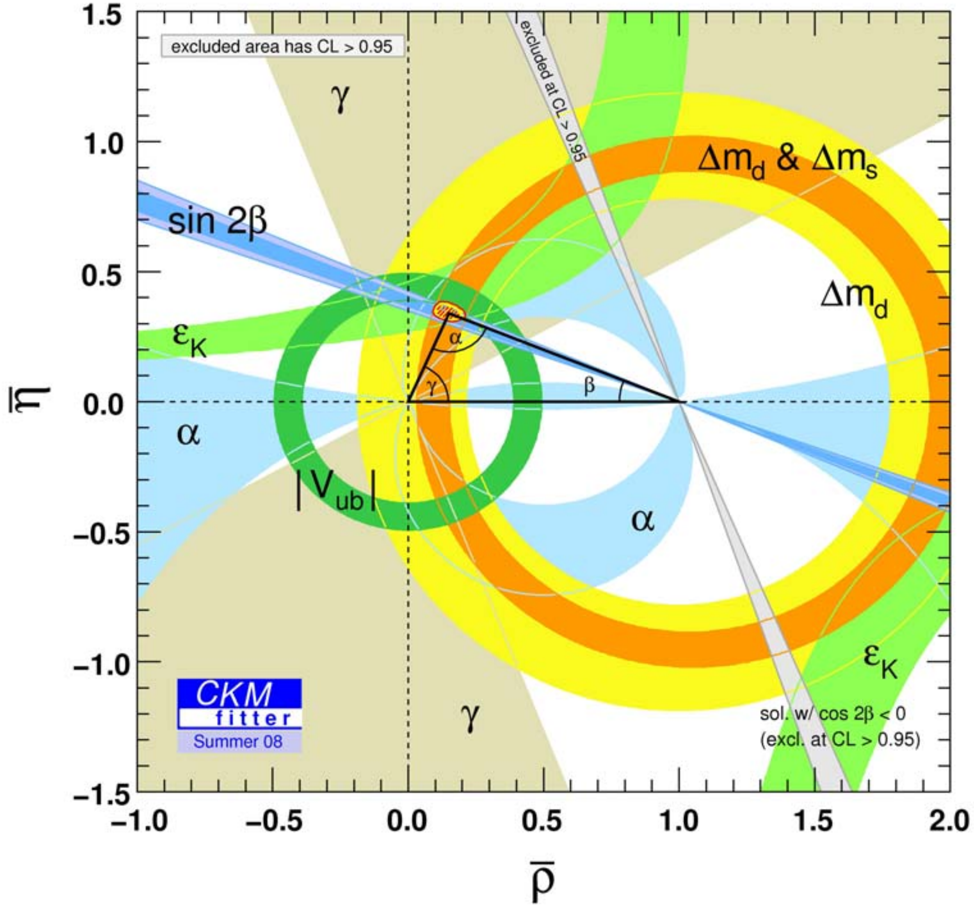
Unitarity Triangle Fits

(Icons of Flavour Physics)

UT fitter



CKM fitter



Yet

Impressive Success of the CKM Picture of Flavour Changing Interactions

(GIM)

1. EW-Symmetry Breaking has to be better understood.

2. Hierarchies in Fermion Masses and Mixing Angles have to be understood with the help of some New Physics (NP). This NP could have impact on Low Energies.

3. There is still a lot of room for NP contributions, in particular in rare decays of mesons and leptons, in ~~CP~~ flavour violating transitions and EDM´s.

4. Matter-Antimatter Asymmetry → New CPV Phases needed.

5. Several tensions between the flavour data and the SM exist.

Superstars of 2010 – 2015 (Flavour Physics)

$S_{\psi\varphi}$

$(B_s \to \varphi\varphi)$

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

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

$(B^+ \to \tau^+\nu_\tau)$

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

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

$(B_d \to K^*\mu^+\mu^-)$

γ from Tree Level Decays

$\mu \to e\gamma$

$\tau \to \mu\gamma$

$\tau \to e\gamma$

$\mu \to 3e$

$\tau \to 3$ leptons

ε'/ε *)

(Lattice)

EDM´s

$(g\text{-}2)_\mu$

*) see Sachrajda at Lattice 2010

Strategy for the Next 29 Min

1. Beyond the SM (~ 5 min)

2. Waiting for Signals of New Physics in FCNC Processes (~ 22 min)

3. Final Messages (~ 2 min)

(hep-ph/0910.1032): "Flavour Theory : 2009"

1.

Beyond the SM

Most popular BSM Directions

CMFV

(constrained MFV)

MFV

(NMFV)
(GMFV)

2HDM

LHT

(Littlest Higgs
with T-parity)

SUSY

(flavour models)

Z′

(Langacker…)

RS

(Randall-Sundrum)
(Warped Extra Dimensions)

4th G

(Hou.., Soni.., Lenz.., Melic)
Munich

Vector-Like Quarks

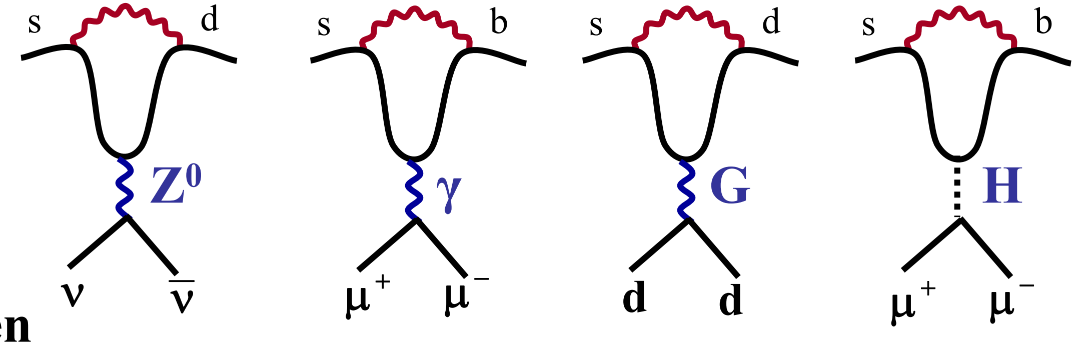
(Branco…,
del Aguila)

Non-Decoupling

New gauge bosons, fermions, scalars in loops and even trees with often non-CKM interactions.

Basic Diagrams in FCNC Processes

Penguin Family :

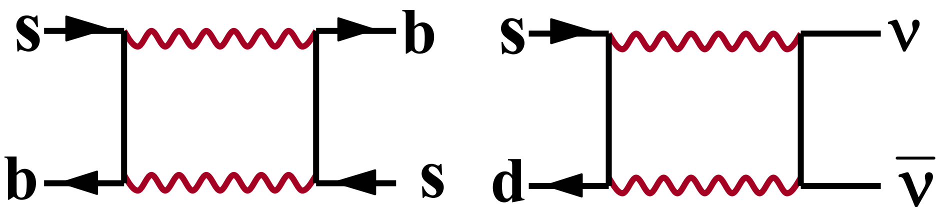


← **New Physics enters here**

Similar diagrams in LFV and EDM´s

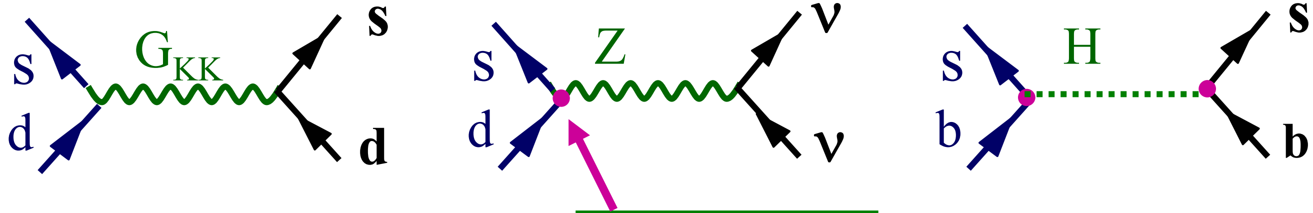
(GIM broken at one loop)

Box Diagrams

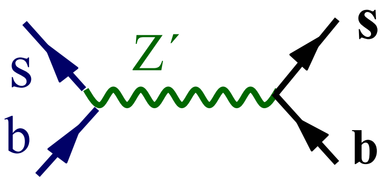


+ **other box diagrams**

Tree Diagrams



(GIM broken at tree level)



RS

Generated through mixing with New Gauge Bosons

Double Higgs Penguin in SUSY

Master Formula for 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)

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

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)

Q_{LR}
(right-handed
currents, S, P)

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

non-MFV

Most popular BSM Directions

CMFV
(constrained MFV)

NEW **MFV** (NMFV) (GMFV)

NEW **2HDM**

LHT
(Littlest Higgs with T-parity)

SUSY
(flavour models)

Z′
(Langacker…)

RS
(Randall-Sundrum)
(Warped Extra Dimensions)

NEW **4th G**
(Hou.., Soni.., Lenz.., Melic)
Munich

Vector-Like Quarks
(Branco…, del Aguila)

Non-Decoupling

New gauge bosons, fermions, scalars in loops and even trees with often non-CKM interactions.

4G Model

The CKM4 matrix : New: s_{14}, s_{24}, s_{34}, δ_{14}, δ_{24}, $m_{t'}$, $m_{b'}$, 300-600 GeV

$c_{12}c_{13}c_{14}$	$c_{13}c_{14}s_{12}$	$c_{14}s_{13}e^{-i\delta_{13}}$	$s_{14}e^{-i\delta_{14}}$
$-c_{23}c_{24}s_{12} - c_{12}c_{24}s_{13}s_{23}e^{i\delta_{13}}$ $-c_{12}c_{13}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})}$	$c_{12}c_{23}c_{24} - c_{24}s_{12}s_{13}s_{23}e^{i\delta_{13}}$ $-c_{13}s_{12}s_{14}s_{24}e^{i(\delta_{14}-\delta_{24})}$	$c_{13}c_{24}s_{23}$ $-s_{13}s_{14}s_{24}e^{-i(\delta_{13}+\delta_{24}-\delta_{14})}$	$c_{14}s_{24}e^{-i\delta_{24}}$
$-c_{12}c_{23}c_{34}s_{13}e^{i\delta_{13}} + c_{34}s_{12}s_{23}$ $-c_{12}c_{13}c_{24}s_{14}s_{34}e^{i\delta_{14}}$ $+c_{23}s_{12}s_{24}s_{34}e^{i\delta_{24}}$ $+c_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})}$	$-c_{12}c_{34}s_{23} - c_{23}c_{34}s_{12}s_{13}e^{i\delta_{13}}$ $-c_{12}c_{23}s_{24}s_{34}e^{i\delta_{24}}$ $-c_{13}c_{24}s_{12}s_{14}s_{34}e^{i\delta_{14}}$ $+s_{12}s_{13}s_{23}s_{24}s_{34}e^{i(\delta_{13}+\delta_{24})}$	$c_{13}c_{23}c_{34}$ $-c_{13}s_{23}s_{24}s_{34}e^{i\delta_{24}}$ $-c_{24}s_{13}s_{14}s_{34}e^{i(\delta_{14}-\delta_{13})}$	$c_{14}c_{24}s_{34}$
$-c_{12}c_{13}c_{24}c_{34}s_{14}e^{i\delta_{14}}$ $+c_{12}c_{23}s_{13}s_{34}e^{i\delta_{13}}$ $+c_{23}c_{34}s_{12}s_{24}e^{i\delta_{24}} - s_{12}s_{23}s_{34}$ $+c_{12}c_{34}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})}$	$-c_{12}c_{23}c_{34}s_{24}e^{i\delta_{24}} + c_{12}s_{23}s_{34}$ $-c_{13}c_{24}c_{34}s_{12}s_{14}e^{i\delta_{14}}$ $+c_{23}s_{12}s_{13}s_{34}e^{i\delta_{13}}$ $+c_{34}s_{12}s_{13}s_{23}s_{24}e^{i(\delta_{13}+\delta_{24})}$	$-c_{13}c_{23}s_{34}$ $-c_{13}c_{34}s_{23}s_{24}e^{i\delta_{24}}$ $-c_{24}c_{34}s_{13}s_{14}e^{i(\delta_{14}-\delta_{13})}$	$c_{14}c_{24}c_{34}$

Extensive New Interest in 4G

Very many papers: Hou; Hung; Chanowitz; Novikov et al. Kribs et al. + ...

FCNC´s :

Hou, Nagashima, Soddu
Soni, Alok, Giri, Mohanta, Nandi
Herrera, Benovides, Ponce
Bobrowski, Lenz, Riedl, Rohrwild
Eilam, Melic, Trampetic
AJB, Duling, Feldmann, Heidsieck, Promberger, Recksiegel
Lacker, Menzel

New Interest in Higgs-mediated FCNC´s

Guidice, Lebedev (08); Agashe, Contino (09), Azatov, Toharia, Zhu (09), AJB, Gori, Duling (09); Duling (09)

Recent: **Botella, Branco, Rebelo (09); Joshipura, Kodrani (08, 10)**
Pich, Tuzon (09)
Gupta, Wells (10)

May – June 2010

	Dobrescu, Fox, Martin (1005.4238)	
(28 May)	AJB, Carlucci, Gori, Isidori (1005.5310)	Neutral Higgs
(29 May)	Aranda, Montano, Ramirez-Zavaleta, Toscano, Tututi (1005.5452)	
(31 May)	Braeuninger, Ibarra, Simonetto	
(2 June)	Ligeti, Papucci, Perez, Zupan	
(2 June)	Jung, Pich, Tuzón	Charged Higgs

Few Messages on Higgs-mediated FCNC´s

	SUSY	2HDM	
ΔM_s	$(\tan\beta)^4$	$(\tan\beta)^2$	$\cdot 1/M_H^2$
$B_{s,d} \to \mu^+\mu^-$	$(\tan\beta)^6$	$(\tan\beta)^4$	$\cdot 1/M_H^4$

Glashow
Weinberg

1977

MFV more powerful than Natural Flavour Conservation (BCGI)

General 2HDM with MFV and flavour blind phases (AJB, Carlucci, Gori, Isidori) → **Aligned 2HDM (Pich,Tuzón) + flavour blind phases**

Flavour-Blind phases can be included in MFV

Mercoli, Smith (09)
Kagan, Perez, Volansky, Zupan (09) ⟵ (could help to generate large CP-phase in B_s-mixing)
Paradisi, Straub (09)

Little Hierarchy Problem

Electroweak Precision Tests

+

Agreement of the CKM Picture of Flavour and CP Violation with existing Data (FCNC)

$\Lambda_{NP} \approx 1000$ TeV (generic)

(generic) **$\Lambda_{NP} \approx 5$ TeV**

Very strong Constraints on Physics beyond SM with scales O (1 TeV)

Necessary to solve the hierarchy problem

$(M_{PLANCK} >> \Lambda_{EW})$

Message 1 : **New Physics at TeV-Scale must have a non-Generic Flavour Structure**

Message 2 : **Protection Mechanisms to suppress FCNCs generated by TeV-Scale New Physics required**

Ciuchini et al
Isidori et al
Agashe et al
+50

★

MFV | **GIM** | **RS-GIM** | **T-Parity** | **R-Parity**

Alignment | **Degeneracy** | **Flavour Symmetries**

(abelian, non-abelian)

Custodial Symmetries

(continuous, discrete)

2.

Waiting for Signals of New Physics in FCNC Processes

Three Strategies in Waiting for NP

1. **Precision Calculations** within the SM

Background to NP $\left(B \to X_s\gamma,\ K^+ \to \pi^+\nu\bar{\nu},\ B \to X_s l^+ l^-\right)$

2. **Bottom-Top Approach** Powerful in Electroweak Precision Physics

Personal View

In Flavour Physics less useful due to the presence of many operators (Buchmüller, Wyler: 1990)
Exception: Minimal Flavour Violation Hypothesis

3. **Top-Bottom Approach**

Study of patterns of flavour violation in concrete NP models. **Correlations between observables !**

Models investigated by TUM-Teams

(Last decade)

SM	MFV	MSSM+MFV	Z´-Models
General MSSM	Universal Extra Dimensions	RS with custodial protection	
Littlest Higgs	Littlest Higgs with T-Parity	SUSY+Flavour Abelian Symmetry (Agashe+Carone)	2 Higgs Doublet Models
SUSY with SU(3) Flavour (Ross et al) (RVV2)	SUSY with SU(2) Flavour (LH-currents)	Flavour Blind MSSM	4G

Search for New Physics in 2010´s through Flavour Physics

★ To search for NP in rare K, B_d, B_s, D decays, $\not{CP}$ in B_s, D decays, Lepton Flavour Violations

→

Specific Plots (Correlations)

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

$Br(B_s \to \mu^+\mu^-)$ vs $S_{\psi\varphi}$ ★

$Br(B_s \to \mu^+\mu^-)$ vs $Br(B_d \to \mu^+\mu^-)$

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

d_n vs $S_{\varphi K_s}$

$A_{CP}(B \to X_S\gamma)$ vs $S_{\varphi K_s}$

$Br(\tau \to \mu\gamma)$ vs $\Delta(g-2)_\mu$

$Br(\tau \to \mu\mu\mu)$ vs $Br(\tau \to \mu\gamma)$

$Br(\mu \to 3e)$ vs $Br(\mu \to e\gamma)$

★ Correlations will be crucial to distinguish various NP scenarios

↓

Patterns of Flavour Violations in specific NP Models

Minimal Flavour Violation (MFV)

MFV

SM Yukawa Couplings are the only breaking sources of the $SU(3)^5$ flavour symmetry of the low-energy effective theory

(Y_t, Y_b)

D´Ambrosio, Guidice, Isidori, Strumia (02) Chivukula, Georgi (87)

CKM the only source of Flavour Violation but for $Y_t \approx Y_b$ new operators could enter

CMFV

Operator structure of SM remains

↔

VERY STRONG RELATIONS BETWEEN K and B Physics and generally $\Delta F=2$ and $\Delta F=1$ FCNC Processes

AJB, Gambino, Gorbahn, Jäger, Silvestrini (00)
Ali, London

Related Studies :
- Ratz et al (08)
- Smith et al (08)
- Zupan et al (09)
- Kagan et al (09)

Spurion Technology

Nir et al.
AGIS
Feldmann, Mannel

← also beyond MFV

Can SM describe simultaneously ~~CP~~ in K and B_d Systems?

$R_t^2 \approx \xi \frac{\Delta M_d}{\Delta M_s}$

Can SM describe simultaneously $\not{CP}$ in K and B_d Systems?

$$|\varepsilon_K|^{SM} \sim \kappa_\varepsilon \hat{B}_K |V_{cb}|^2 \left(\frac{1}{2} |V_{cb}|^2 R_t^2 \sin 2\beta \underbrace{\eta_{tt}^{QCD}}_{\text{BJW (90)}} S_0(x_t) + F(\underbrace{\eta_{ct}^{QCD}, \eta_{cc}^{QCD}}_{\text{HN (94)}}, m_c, ..) \right)$$

(NLO) (NLO)

2009
2010
News

★ $\hat{B}_K \cong 0.72 \pm 0.03$ (precise and lower by ~ 10% vs 2007)

RBC-UKQCD
Aubin et al.
ETMC

(Nierste; Vysotsky)

★ $\kappa_\varepsilon \cong 0.94 \pm 0.02$ (LD Effects) AJB + Guadagnoli (08) + Isidori (10)

Large N
$\hat{B}_K \approx 0.70$

BBG (87)

★ NNLO QCD calculation of $\eta_{cc}^{QCD}, \eta_{ct}^{QCD}$ Brod + Gorbahn (10)

(BG) $|\varepsilon_K^{SM}| = (1.85 \pm 0.22) \cdot 10^{-3}$

$|\varepsilon_{exp}| = (2.229 \pm 0.012) \cdot 10^{-3}$ (NA48, KLOE, KTeV)

(BaBar Belle) using $(\sin 2\beta)_{\psi K_s} = 0.672 \pm 0.023$

Possible Solutions to ε_K - Anomaly

$$|\varepsilon_K|^{SM} \sim \kappa_\varepsilon \hat{B}_K |V_{cb}|^2 \left(\frac{1}{2} |V_{cb}|^2 R_t^2 \sin 2\beta \eta_{tt}^{QCD} S_0(x_t) + F(\eta_{ct}^{QCD}, \eta_{cc}^{QCD}, m_c, ..) \right)$$

1. Add New Physics to ε_K

CMFV $S_0(x_t) \to S_0(x_t) + \Delta S_0^{NP}$ or simply $\Delta\varepsilon_k$ (Non-MFV)

AJB Guadagnoli

2. Increase $\sin 2\beta \cong 0.67 \Rightarrow 0.85$

$\varphi_{NP} \cong -8.1^o$ ⇓ Large $|V_{ub}|$ ⟺ Super-B

Lunghi Soni

$$S_{\psi K_s} = \sin(2\beta + 2\varphi_{NP})$$

(Utfit; BBGT; Ball, Fleischer; Branco et al)

3. Increase R_t ⇒ $\gamma = \delta_{CKM} \approx 67^o \Rightarrow 82^o$ ⟺ LHC ★

4. Increase $|V_{cb}| \approx (41.2 \cdot 10^{-3}) \Rightarrow (43.5 \cdot 10^{-3})$ ⟺ Super-B

Superstars of 2010 – 2015 (Flavour Physics)

$S_{\psi\varphi}$

$(B_s \to \varphi\varphi)$

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

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

$(B^+ \to \tau^+\nu_\tau)$

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

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

$(B_d \to K^*\mu^+\mu^-)$

γ from Tree Level Decays

$\mu \to e\gamma$

$\tau \to \mu\gamma$

$\tau \to e\gamma$

$\mu \to 3e$

$\tau \to 3$ leptons

ε'/ε

(Lattice)

EDM´s

$(g\text{-}2)_\mu$

Superstars enter the Scene

in the context of

SUSY **LHT** **RS** **4G** **2HDM**

(flavour models)

Prima Donna of 2010 – Flavour Physics

Mixing Induced CP Asymmetry in $B_s \to \psi\varphi$ $\left(S_{\psi\varphi}\right)$ (A^S_{SL})

(TH very clean*); Analog of $S_{\psi K_s}$)

$$S_{\psi\varphi} = \sin\left(2|\beta_s| - 2\varphi_s^{new}\right) \overset{SM}{\cong} 0.035$$

$$V_{ts} = -|V_{ts}|e^{-\beta_s}$$
$$\left(\beta_s = -1^\circ\right)$$

New Phase in $B_s^0 - \overline{B}_s^0$ mixing

CDF : Hints for a much larger
D0 value

*) See however Faller, Fleischer, Mannel (08)

Prima Donna of 2010 – Flavour Physics

Mixing Induced CP Asymmetry in $B_s \to \psi\varphi$ $\left(S_{\psi\varphi}\right)$ (A^s_{SL})

(TH very clean*); Analog of $S_{\psi K_s}$)

$$S_{\psi\varphi} = \sin\left(2|\beta_s| - 2\varphi_s^{new}\right) \overset{SM}{\cong} 0.035$$

$$V_{ts} = -|V_{ts}|e^{-\beta_s}$$
$$(\beta_s = -1°)$$

New Phase in $B_s^0 - \bar{B}_s^0$ mixing

CDF : Hints for a much larger
D0 value

Preliminary result from Lenz, Nierste + CKM fitters

(soon!)

$$S_{\psi\varphi} = 0.78\,{}^{+0.12}_{-0.17}$$

3σ range : $[0.07,\ 1]$

(Without latest CDF result !) (0.8 σ)

Louise Oakes´s talk in Torino

But CDF cannot exclude values above 0.5 !

*) See however Faller, Fleischer, Mannel (08)

Patterns of Deviations from CPV – SM Predictions

$K^0 - \overline{K}^0$ $\quad (\varepsilon_K)$ $\quad \dfrac{|\varepsilon_K|_{SM}}{|\varepsilon_K|_{exp}} \approx 0.83 \pm 0.10$

$B_d^0 - \overline{B}_d^0$ $\quad (S_{\psi K_s})$ $\quad (S_{\psi K_s}) \cong \begin{array}{ll} 0.74 \pm 0.04 & \text{(SM)} \quad \text{(UTfit)} \\ 0.672 \pm 0.022 & \text{(exp)} \end{array}$

$B_s^0 - \overline{B}_s^0$ $\quad (S_{\psi\varphi})$ $\quad \dfrac{(S_{\psi\varphi})_{exp}}{(S_{\psi\varphi})_{SM}} \approx 10 - 20$

Do these deviations signal non-MFV interactions at work ?

General 2HDM with MFV and Flavour Blind CPV Phases

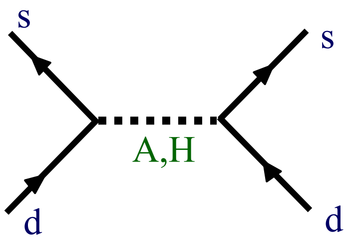
(non-SUSY)

(1005.5310)

(AJB, Carlucci, Gori, Isidori)

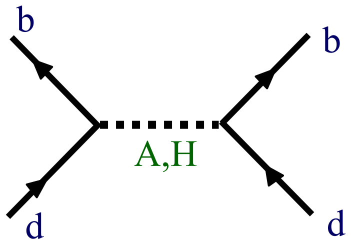
Provides correct pattern

ε_K :



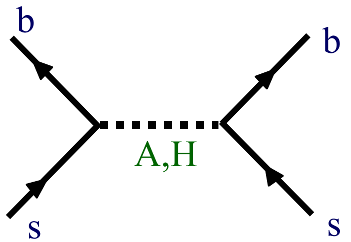
$$\approx \left[\frac{m_d m_s}{M_H^2}\right] m_t^4 (\tan\beta)^2 \left(V_{ts}^* V_{td}\right)^2$$ (tiny)

$S_{\psi K_s}$:



$$\approx \left[\frac{m_b m_d}{M_H^2}\right] m_t^4 (\tan\beta)^2 \left(V_{tb}^* V_{td}\right)^2 e^{i\varphi_{new}}$$

$S_{\psi\varphi}$:



$$\approx \left[\frac{m_b m_s}{M_H^2}\right] m_t^4 (\tan\beta)^2 \left(V_{tb}^* V_{ts}\right)^2 e^{i\varphi_{new}}$$

$$S_{\psi K_s} = \sin\left(2\beta - \theta_d^H\right) \qquad S_{\psi\varphi} \cong \sin\left(\theta_s^H\right)$$

$$\sin 2\beta > S_{\psi K_s}$$

$$\left(\left|\varepsilon_K\right| \text{ enhanced}\right)$$

$$\frac{\theta_d^H}{\theta_s^H} \approx \frac{m_d}{m_s} \approx \frac{1}{17}$$

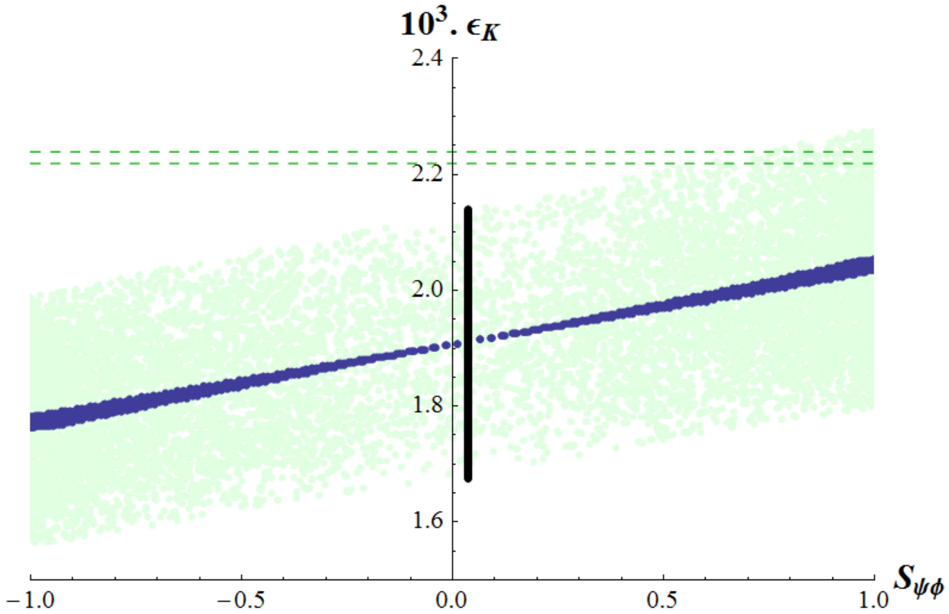
$$\frac{\tan\beta \approx 10 - 20}{M_H \approx 250\,\text{GeV}}$$

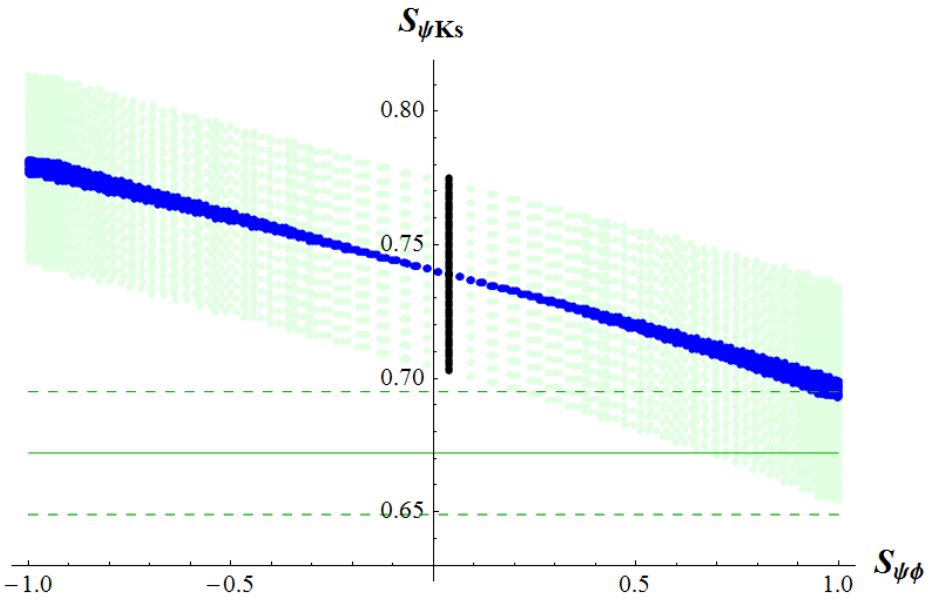
Large RG QCD effects Q_{LR}

$S_{\psi K_s}$ vs $S_{\psi\varphi}$ and $|\varepsilon_K|$ vs $S_{\psi\varphi}$ in a General 2HDM with MFV and Flavour Blind CPV

(AJB, Carlucci, Gori, Isidori)

Correct pattern of NP effecs





Models with non-MFV Interactions facing Large $S_{\psi\varphi}$

<u>Model Expectations</u>

$$S_{\psi\varphi} \le \begin{cases} 0.80 \;\; \text{(4G) (Fourth Generation) (t') (Soni, Hou, Munich, Lenz)} \\ 0.75 \;\; \text{(AC) (abelian flavour, SUSY) (Higgs penguin)} \\ 0.50 \;\; \text{(RVV) (non-abelian flavour, SUSY) (Higgs penguin)} \\ 0.75 \;\; \text{(RS) (Heavy KK Gauge Bosons) (Duling et al (08))} \\ 0.30 \;\; \text{(LHT) (Mirror Fermions at work) (Tarantino et al (09))} \end{cases}$$

ABGPS

★

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

Z-Penguin + Boxes (SM CMFV)

SM

$$Br(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \cdot 10^{-9}$$
$$Br(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \cdot 10^{-10}$$

Error dominated by $\hat{B}_{d,s}$

AJB (03)

CMFV "Golden Relation"

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

$(\Delta B = 1)$ $(\Delta B = 2)$

(0.95±0.03) Lattice

Valid in all CMFV models

Can be strongly violated in SUSY, LHT, RS, 4G

95% CL

$$Br(B_s \to \mu^+\mu^-) \le \begin{cases} 3.3 \cdot 10^{-8} & \text{(CDF)} \\ 5.3 \cdot 10^{-8} & \text{(D0)} \end{cases}$$

$$Br(B_d \to \mu^+\mu^-) \le 1 \cdot 10^{-8} \quad \text{(CDF)}$$

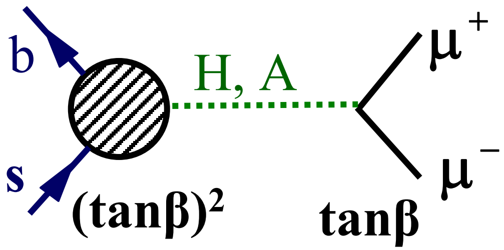
Fleischer et al

LHC should be able to discover $B_s \to \mu^+\mu^-$ even at the SM level

$B_{s,d} \to \mu^+\mu^-$ in Various Models

Babu, Kolda (99),…+100

SUSY :



$$Br\left(B_{s,d} \to \mu^+\mu^-\right) \sim \frac{(\tan\beta)^6}{M_A^4}$$

Can reach CDF and DØ bounds

$$\frac{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{4G}}{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{SM}} \leq 4$$

$$\frac{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{SUSY}}{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{SM}} \leq 20$$

$$\frac{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{LHT}}{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{SM}} \leq 1.3$$

$$\frac{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{RS}}{Br\left(B_{s,d} \to \mu^+\mu^-\right)_{SM}} \leq 1.1$$

(Z-penguin)
(Blanke et al) (09)
Larger effects without
custodial protection (Haisch et al.)

(Z-penguin + Z-tree with
r.h. couplings)
(Custodial protection at work)
(Gori et al) (08)

CDF, D0
LHCb

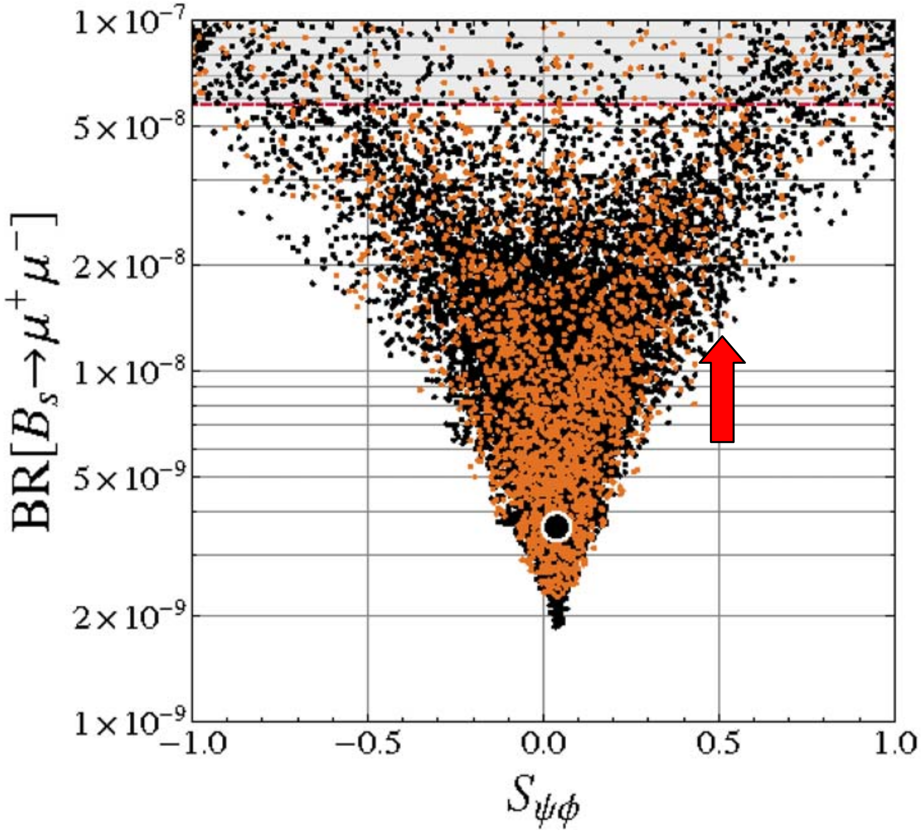
$Br(B_s \to \mu^+\mu^-)$ vs $S_{\psi\varphi}$

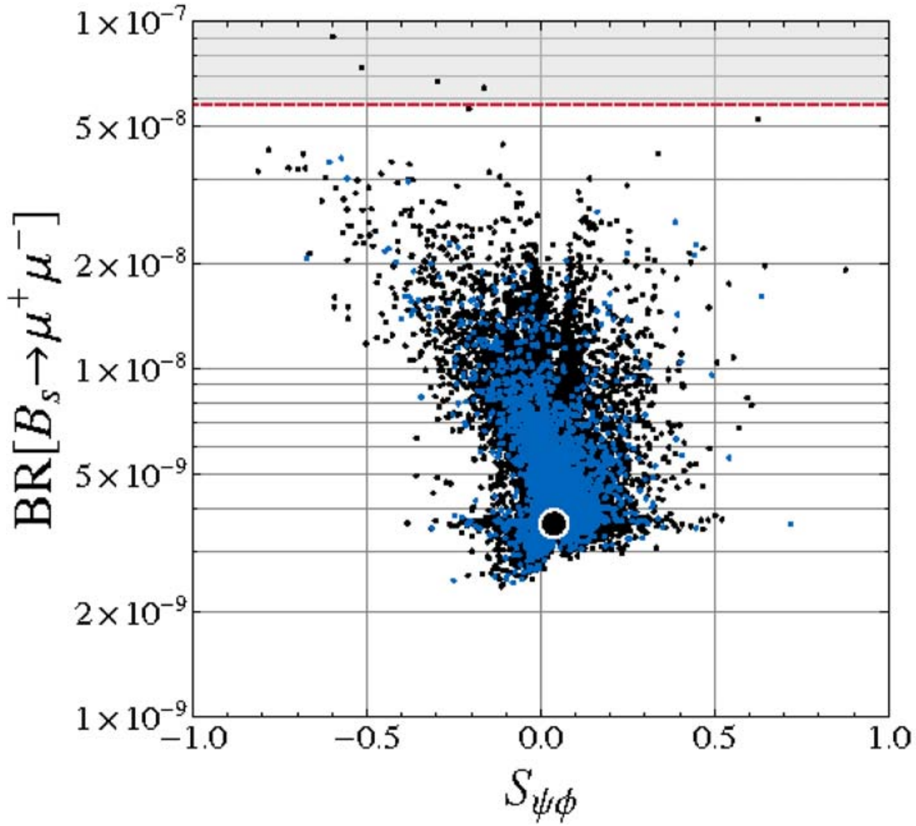
SUSY

ABGPS
(0909.1333)

Solution 3 to ε_K-Anomaly
Abelian (AC)

Solution 1 to ε_K-Anomaly
Non-Abelian (RVV)





(Large Effects in D^0-$\bar{D}^0$)

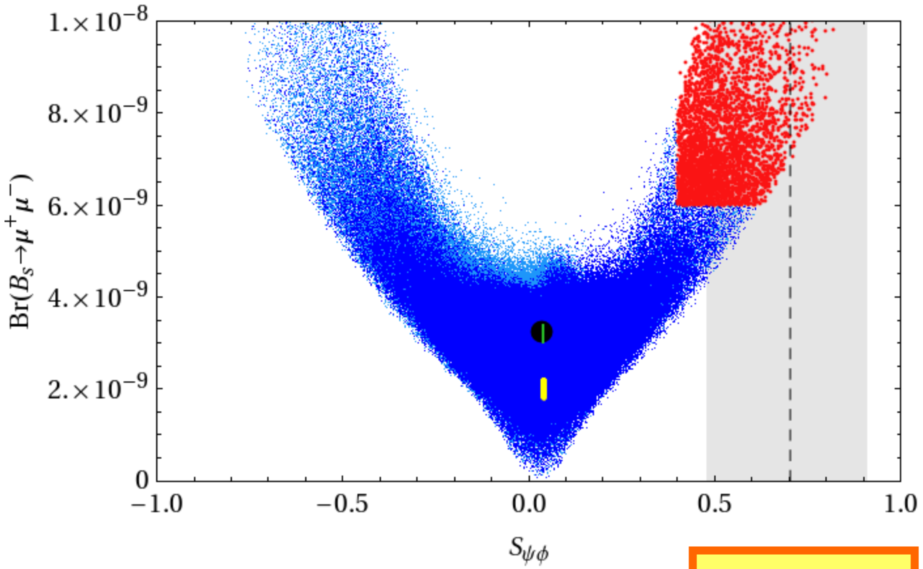
(Small Effects in D^0-$\bar{D}^0$)

Similar Result by Soni et al.

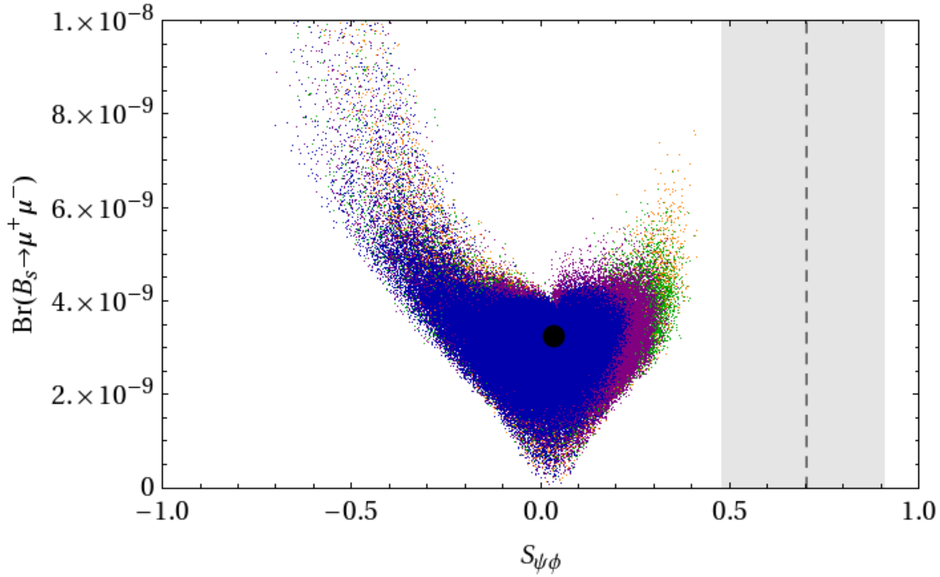
$Br(B_s \to \mu^+\mu^-)$ vs $S_{\psi\varphi}$

4G

BDFHPR (1002.2126)



CDF D0



Adding ε'/ε Constraint

4G has hard time to describe simultaneously ε'/ε and $S_{\psi\varphi} > 0.2$ if $B_{6,8}$ within 20% from large N values

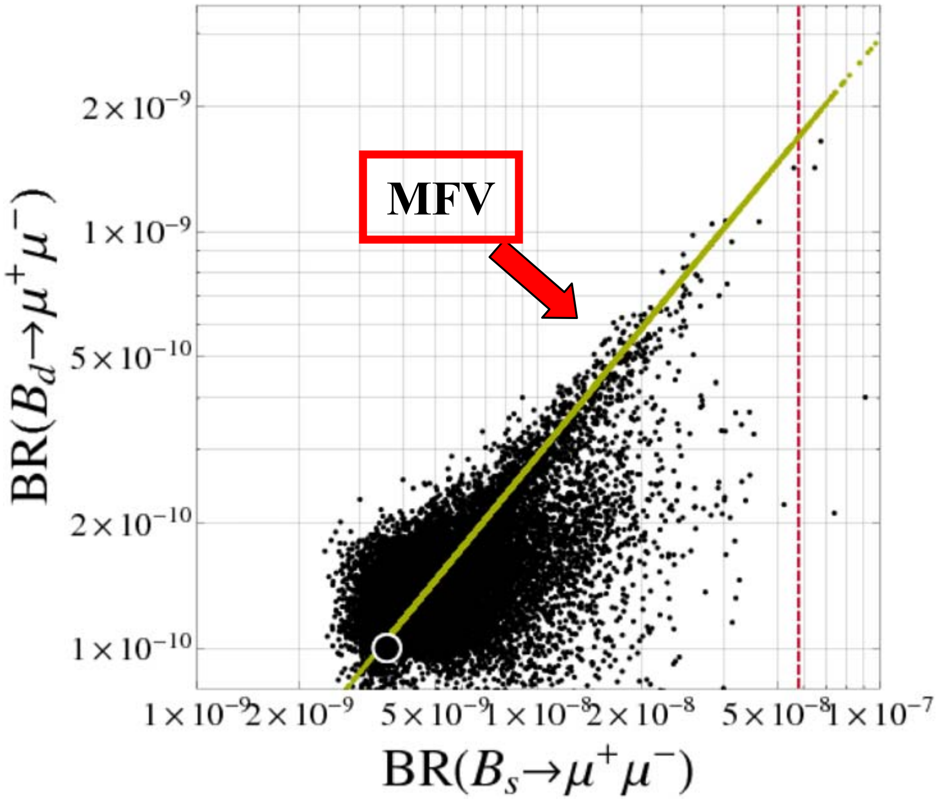
ABGPS

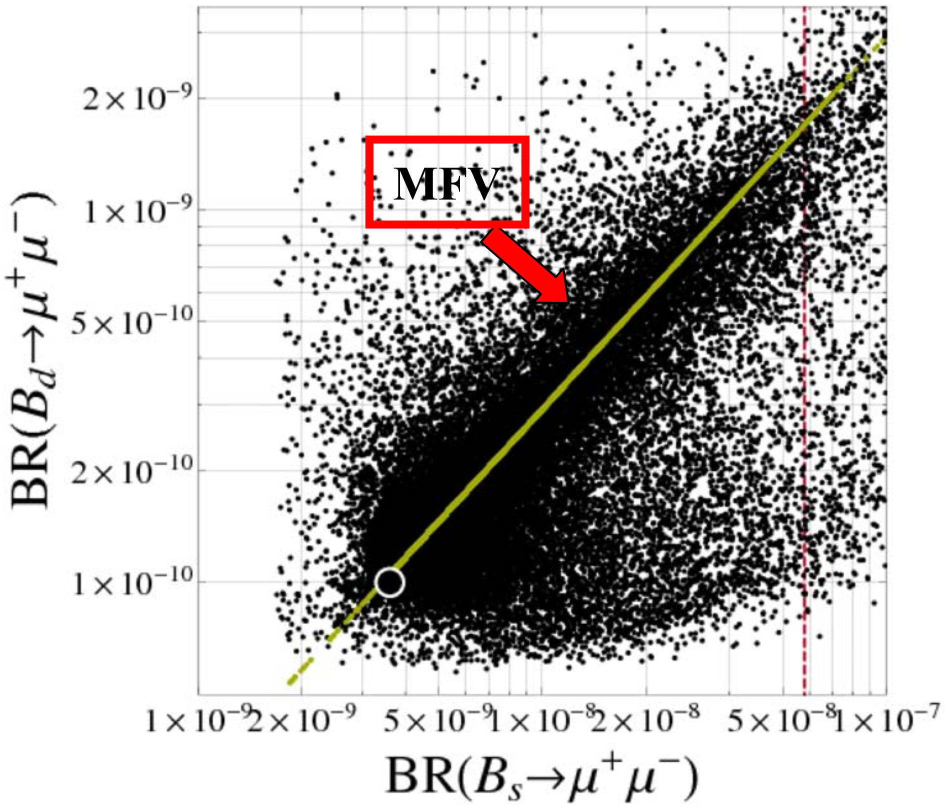
(0909.1333)

$Br(B_d \to \mu^+\mu^-)$ vs $Br(B_s \to \mu^+\mu^-)$

SUSY

MFV AJB; Hurth, Isidori, Kamenik, Mescia



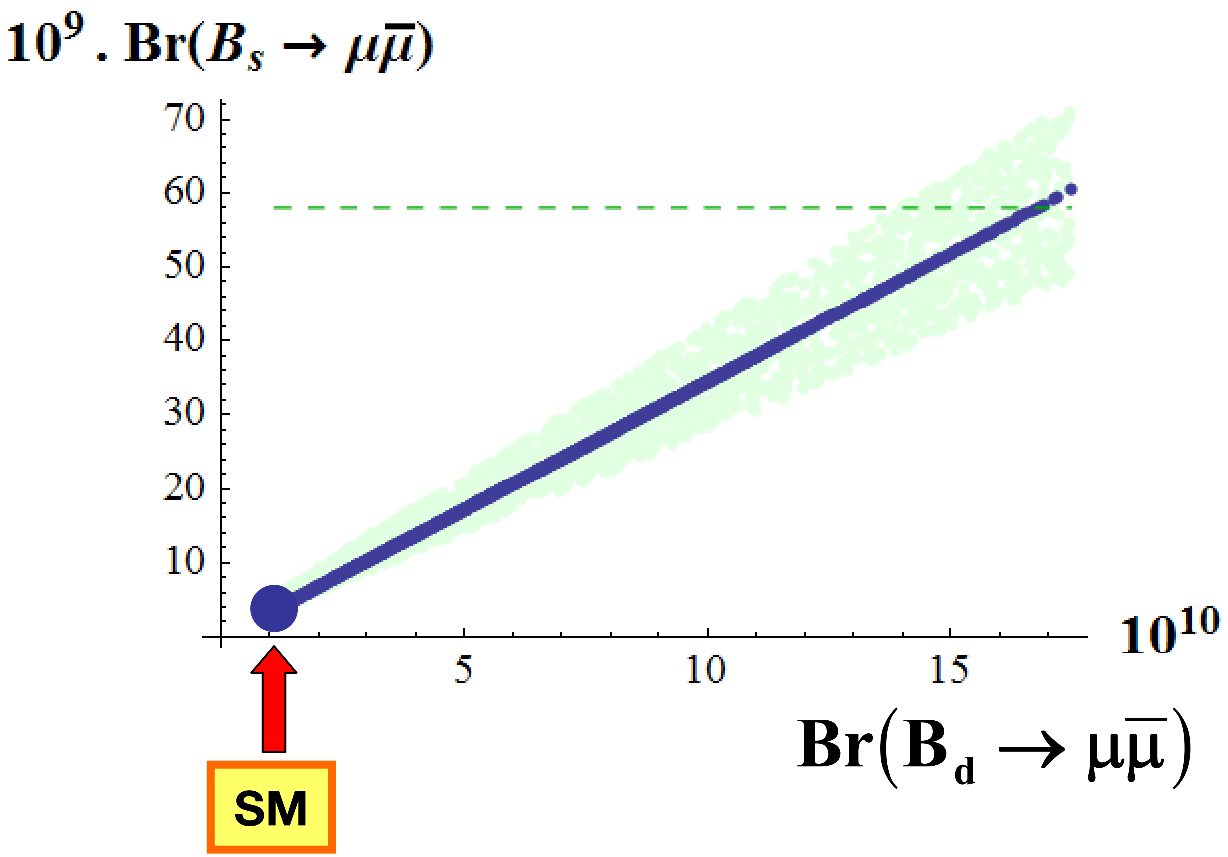


RVV2 (RH currents)

LH currents

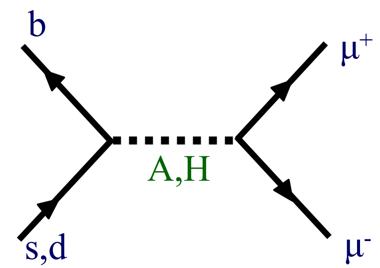
$B_{s,d} \to \mu^+\mu^-$ in 2HDM - MFV $\approx (\tan\beta)^4 / M_A^4$

(AJB, Carlucci, Gori, Isidori)



within few% determined by

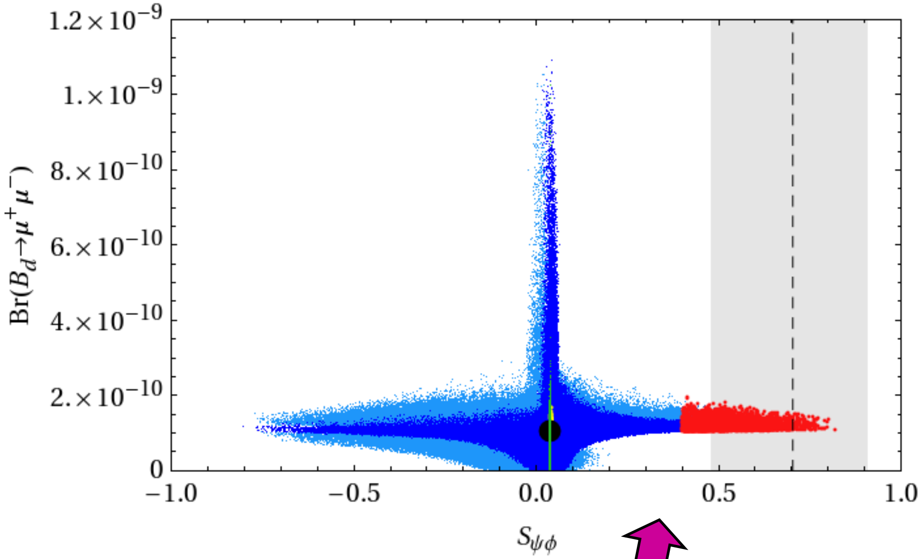
$$\frac{\Delta M_s}{\Delta M_d}$$

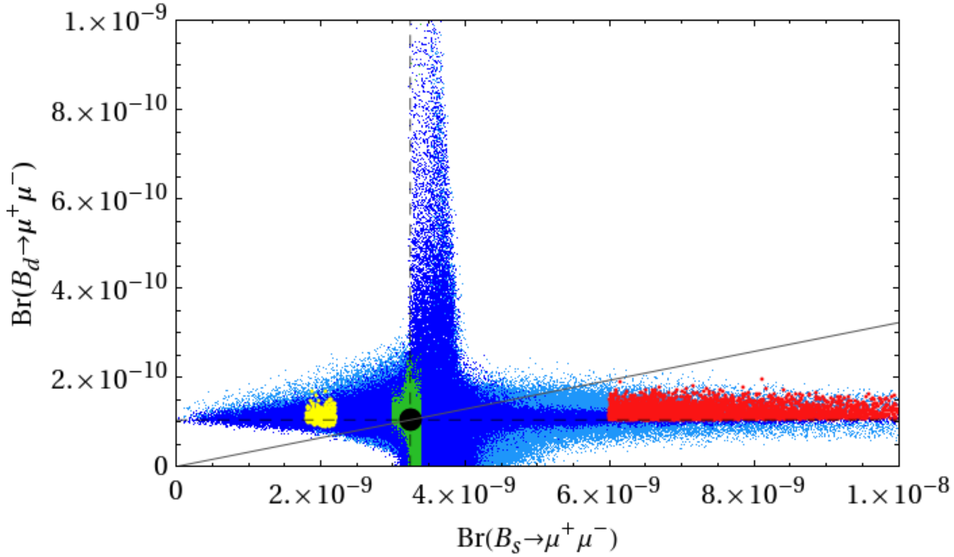


$Br(B_d \to \mu^+\mu^-)$ vs $Br(B_s \to \mu^+\mu^-)$

4G

BDFHPR





$Br(B_d \to \mu^+\mu^-)$ vs $S_{\psi\varphi}$

Very different patterns compared with SUSY, 2HDM, MFV

$K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L \to \pi^0 \nu\bar{\nu}$ (Z°-penguins)

(TH cleanest FCNC decays in Quark Sector)

Extensive TH efforts over 20 years :

- Buchalla, AJB; Misiak, Urban (NLO QCD)
- AJB, Gorbahn, Haisch, Nierste (NNLO QCD)
- Brod, Gorbahn (QED, EW two loop)
- Isidori, Mescia, Smith (several LD analyses)
- Buchalla, Isidori (LD in $K_L \to \pi^0 \nu\bar{\nu}$)

$$\frac{Br(K^+ \to \pi^+ \nu\bar{\nu})}{Br(K_L \to \pi^0 \nu\bar{\nu})} = 3.2 \pm 0.2$$

SM : $Br(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 0.7) \cdot 10^{-11}$ $Br(K_L \to \pi^0 \nu\bar{\nu}) = (2.6 \pm 0.4) \cdot 10^{-11}$

Exp : $Br(K^+ \to \pi^+ \nu\bar{\nu}) = \left(17 {}^{+11}_{-10}\right) \cdot 10^{-11}$ $Br(K_L \to \pi^0 \nu\bar{\nu}) \leq 6.8 \cdot 10^{-8}$

(E787, E949 Brookhaven) (E391a, KEK)

Future :

NA62
Project X (FNAL)

CP-conserving
TH uncertainty 2-3%

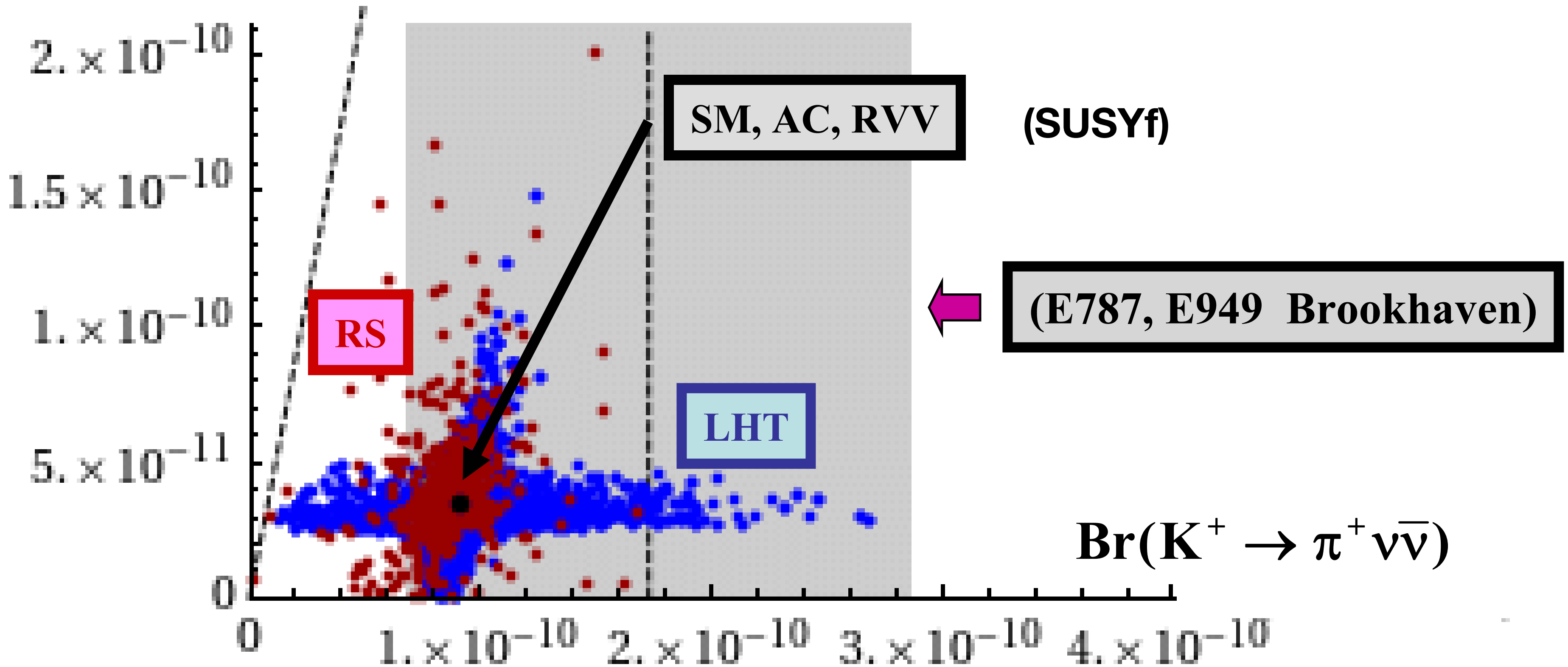
Both very sensitive to New Physics

J-PARC KOTO

CP-Violation in Decay
TH uncertainty 1-2%

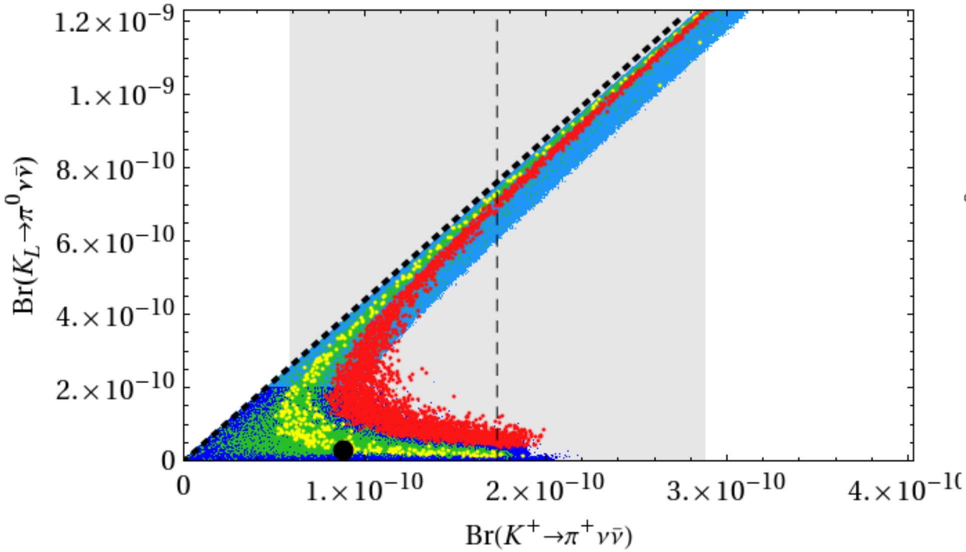
$K_L \to \pi^0 \nu\bar{\nu}$ vs. $K^+ \to \pi^+ \nu\bar{\nu}$

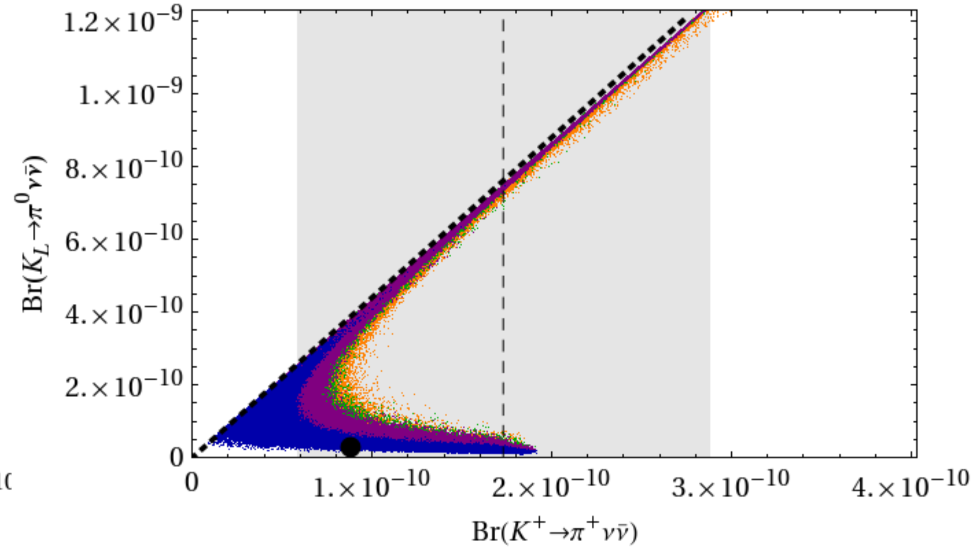
Blanke et al (08)
Goto et al (08)
Recksiegel et al (09)



$K_L \to \pi^0 \nu\bar{\nu}$ vs. $K^+ \to \pi^+ \nu\bar{\nu}$ in 4G

see also { BDFHPR (1002.2126)
Soni et al.
Hou et al. }



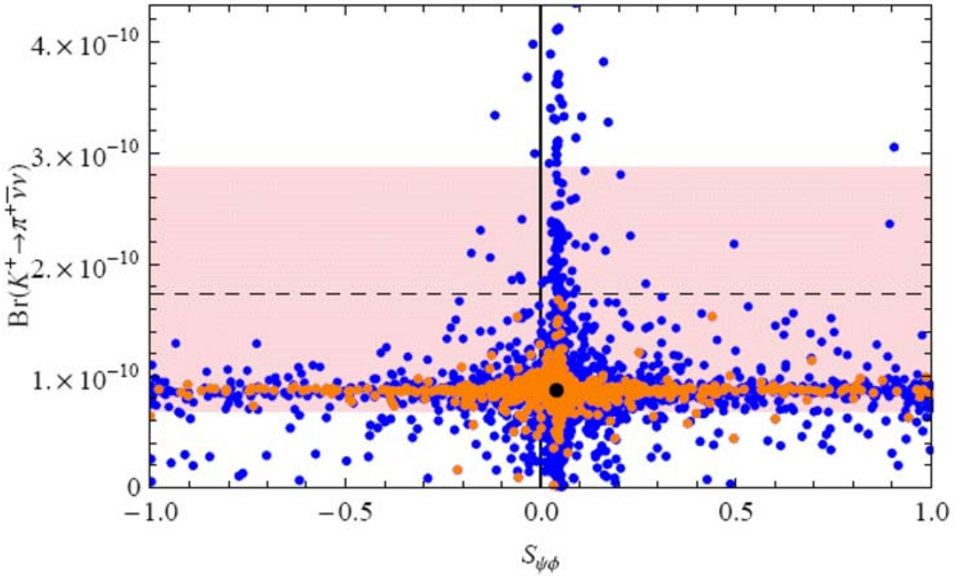


With ε'/ε Constraint

Much larger enhancements than in LHT, RS, SUSYf possible

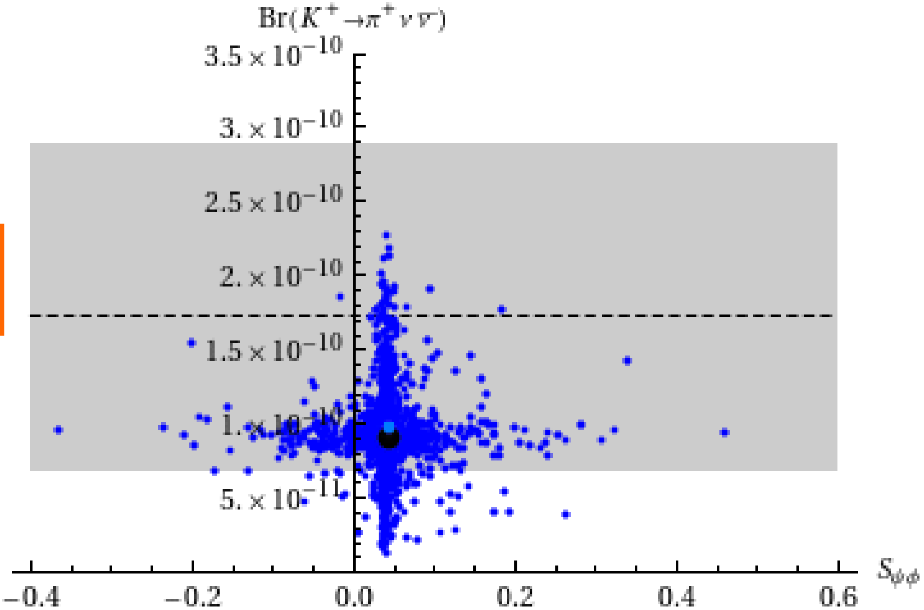
$K^+ \to \pi^+ \nu\bar{\nu}$ vs. $S_{\psi\varphi}$

(Simultaneous Large Enhancements unlikely)



RS

Blanke, AJB, Duling, Gori, Weiler



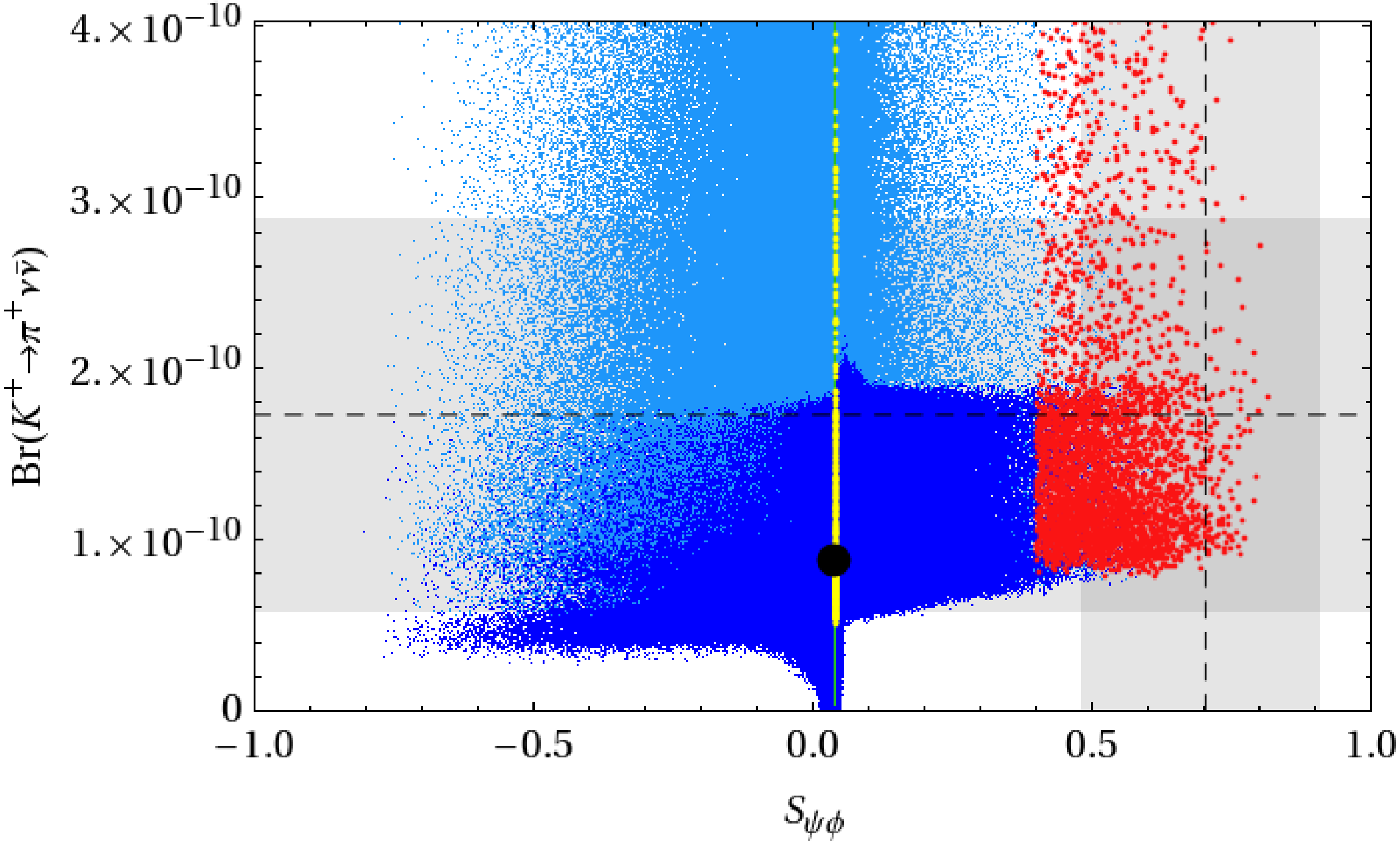
LHT

Blanke, AJB, Duling, Recksiegel, Tarantino

$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ vs $S_{\psi\varphi}$ (4G)

(Simultaneous Large Enhancements Possible)

BDFHPR



DNA Tests of Flavour Models

O_i : Observables ***M_i : Models beyond SM***

	M_1	M_2	M_3	M_4	M_5
O_1	★★★	★	★	★	★★
O_2	★	★★	★★★	★★	★
O_3	★★	★★★	★★	★	★
O_4	★★★	★★	★	★★★	★★
O_5	★	★★★	★	★★	★★★

★★★ **Very large New Physics effect**

★★ **Moderate New Physics effect**

★ **Very small New Physics effect**

ABGPS

DNA Tests of Flavour Models

0909.1333

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS	4G
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?	★★
ϵ_K	★	★★★	★★★	★	★	★★	★★★	★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?	★★
$A_{\rm CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?	★
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?	★★
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?	★★
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★	★★★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★	★
d_e	★★★	★★★	★★	★	★★★	★	★★★	★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?	★

2020 Vision

	NEW SM
$D^0 - \bar{D}^0$	★★
ϵ_K	★★
$S_{\psi\phi}$	★★★
$S_{\phi K_S}$	★★
$A_{\rm CP}\,(B \to X_s\gamma)$	★
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★★
$A_9(B \to K^*\mu^+\mu^-)$	★
$B \to K^{(*)}\nu\bar{\nu}$	★★★
$B_s \to \mu^+\mu^-$	★★★
$K^+ \to \pi^+\nu\bar{\nu}$	★★
$K_L \to \pi^0\nu\bar{\nu}$	★★★
$\mu \to e\gamma$	★★★
$\tau \to \mu\gamma$	★★★
$\mu + N \to e + N$	★★★
d_n	★★★
d_e	★★★
$(g-2)_\mu$	★★

3.

Final Messages

3.

Final Messages

World Cup begins today !

Many Thanks to my Collaborators

SUSY


W. Altmannshofer


S. Gori


P. Paradisi


D. Straub

LHT


M. Blanke


B. Duling


S. Recksiegel


C. Tarantino

RS


M. Albrecht


M. Blanke


B. Duling


K. Gemmler


S. Gori


A. Weiler

4 G

B. Duling

T. Heidsieck

C. Promberger

T. Feldmann

S. Recksiegel

2 HDM

M.V.Carlucci

S. Gori

G. Isidori

ε_K

D. Guadagnoli

I.Bigi

P. Ball

A. Bharucha

M. Wick

L. Calibbi

M. Nagai

Strong Indian 4G Team

A. Soni

S. Nandi

A.K. Alok

A. Giri

R. Mohanta

Superstars of 2010 – 2015
(Flavour Physics)

$S_{\psi\varphi}$

$(B_s \to \varphi\varphi)$

★

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

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

$(B^+ \to \tau^+\nu_\tau)$

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

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

$(B_d \to K^*\mu^+\mu^-)$

γ
from Tree Level Decays

$\mu \to e\gamma$

$\tau \to \mu\gamma$

$\tau \to e\gamma$

$\mu \to 3e$

$\tau \to 3$ leptons

ε'/ε

(Lattice)

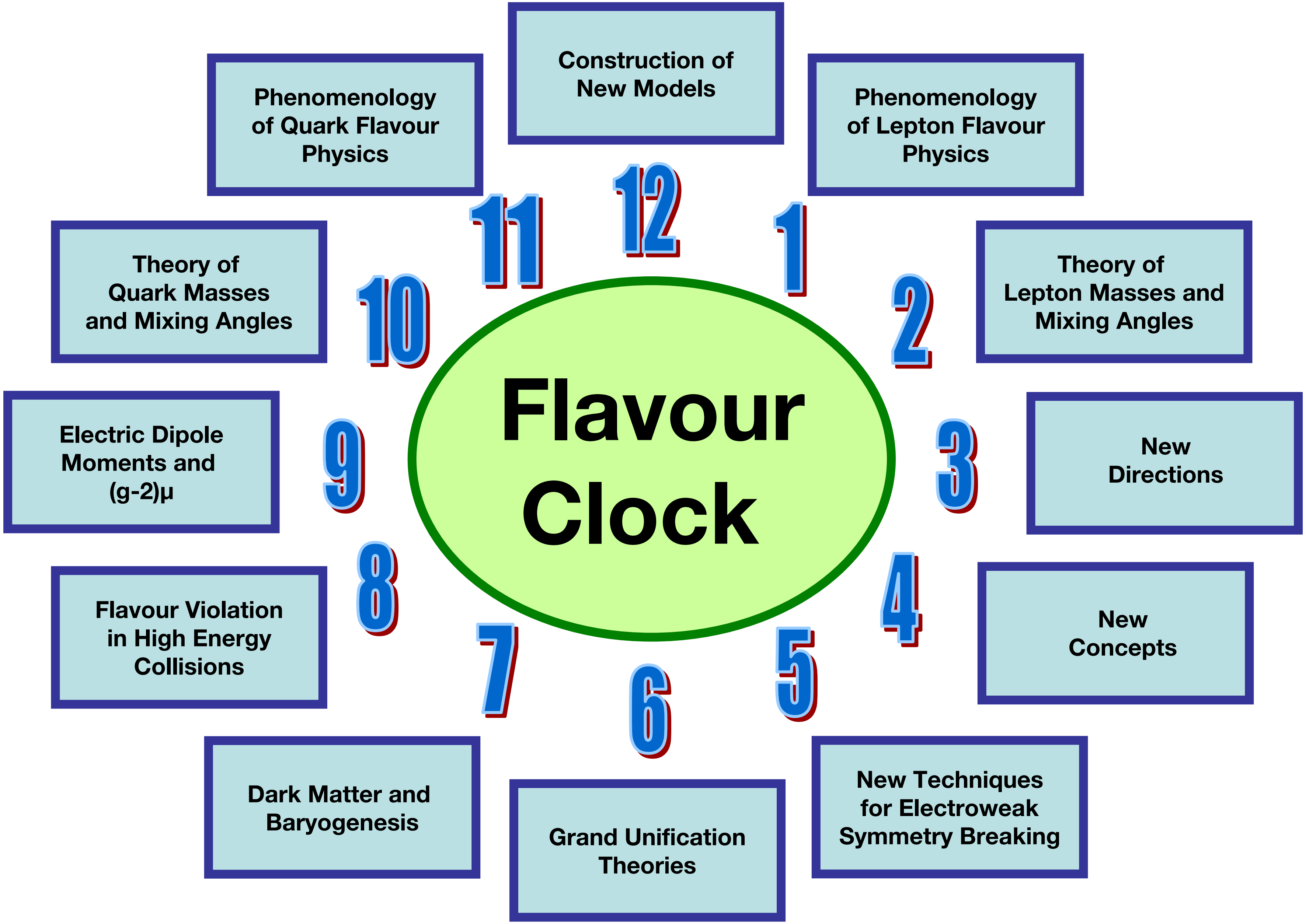
EDM´s

$(g\text{-}2)_\mu$

Flavour Theory and the Flavour Era

NN

June 2016


Construction of New Models
Phenomenology of Quark Flavour Physics
Phenomenology of Lepton Flavour Physics
Theory of Quark Masses and Mixing Angles
Theory of Lepton Masses and Mixing Angles
Electric Dipole Moments and (g-2)μ
New Directions
Flavour Violation in High Energy Collisions
New Concepts
Dark Matter and Baryogenesis
Grand Unification Theories
New Techniques for Electroweak Symmetry Breaking
Flavour Clock
12
1
2
3
4
5
6
7
8
9
10
11


Construction of New Models
Phenomenology of Lepton Flavour Physics
Theory of Lepton Masses and Mixing Angles
New Directions
New Concepts
New Techniques for Electroweak Symmetry Breaking
Grand Unification Theories
Dark Matter and Baryogenesis
Flavour Violation in High Energy Collisions
Electric Dipole Moments and (g-2)μ
Theory of Quark Masses and Mixing Angles
Phenomenology of Quark Flavour Physics
12
1
2
3
4
5
6
7
8
9
10
11
Thank You!

Backup

Unitarity Triangle

(R_b, γ) Reference UT (Goto et al)

(coming decade)

$$\alpha \overset{?}{=} 90^\circ$$

(this decade)

R_t, β Universal UT of CMFV (BGGJS, BBGT)

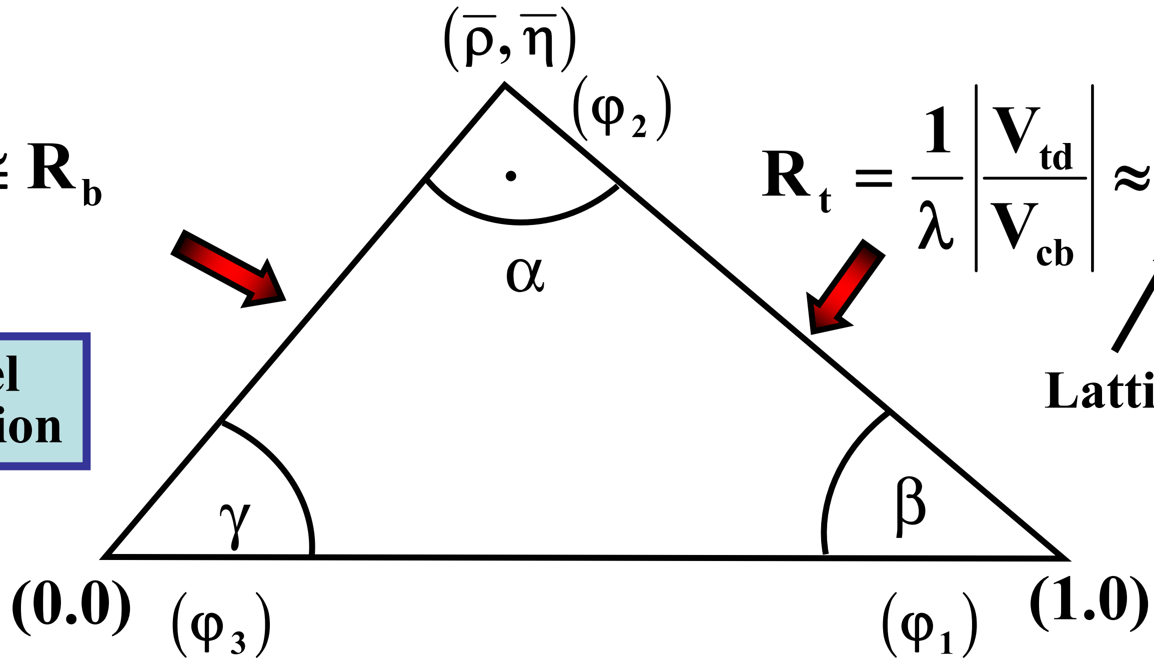
$(\varphi_{NP}=0,\ r_{NP}=1)$

$$\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right| \cong R_b$$

$$R_t = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right| \approx \xi \sqrt{\frac{\Delta M_d}{\Delta M_s}}\, r_{NP}$$

Lattice

$$\xi = 1.21 \pm 0.04$$



Tree Level Determination

(NP free)

Loop Determination

(Not NP free)

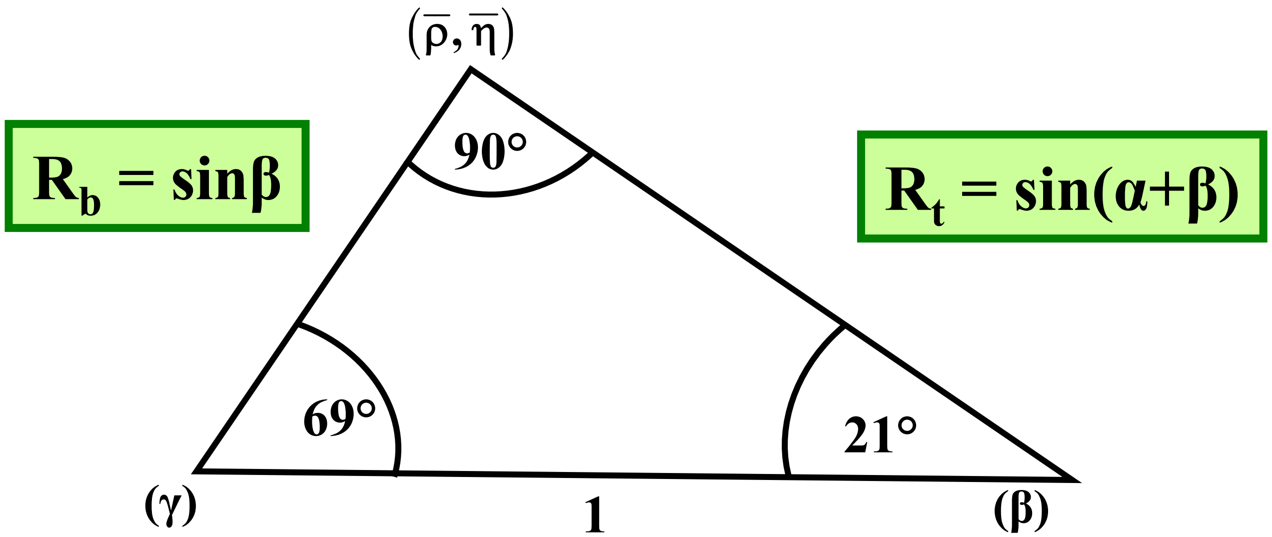
Flavour Matrix

$\varphi_{NP} = 0$, $r_{NP} = 1$	$\varphi_{NP} = 0$, $r_{NP} \neq 1$
$\varphi_{NP} \neq 0$, $r_{NP} \neq 1$	$\varphi_{NP} \neq 0$, $r_{NP} \neq 1$

$$S_{\psi K_s} = \sin(2\beta + 2\varphi_{NP})$$

Unitarity Triangle in LO Approximation

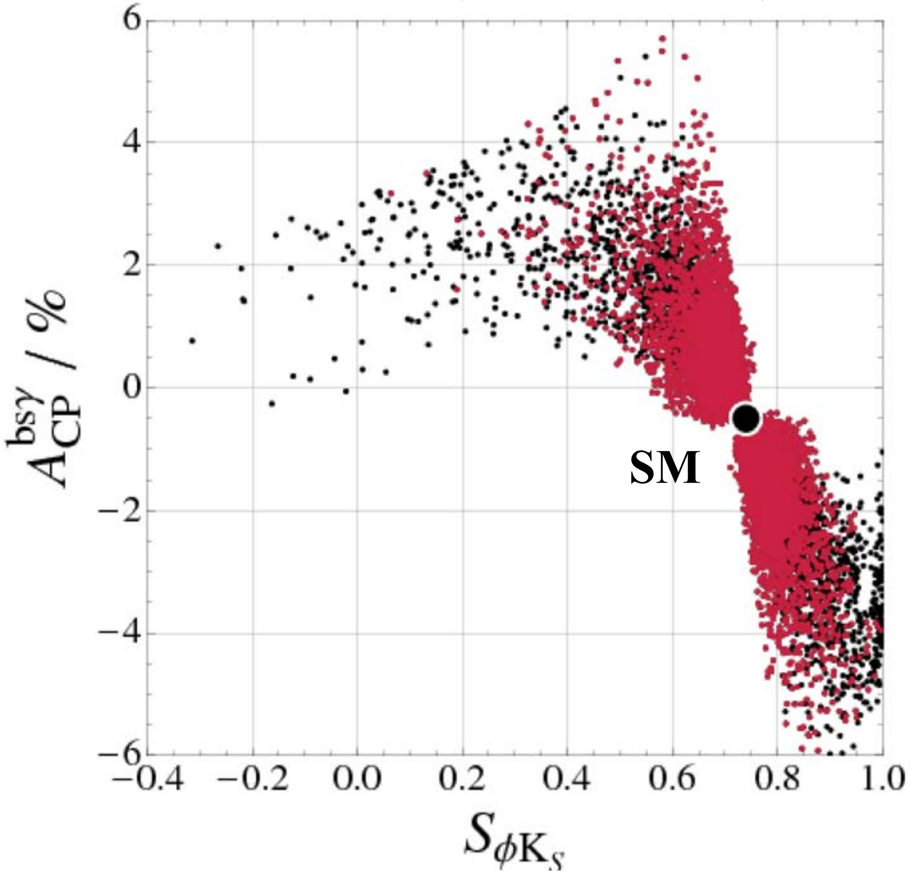
$\alpha = 90°$ $\sin 2\beta = 2/3$

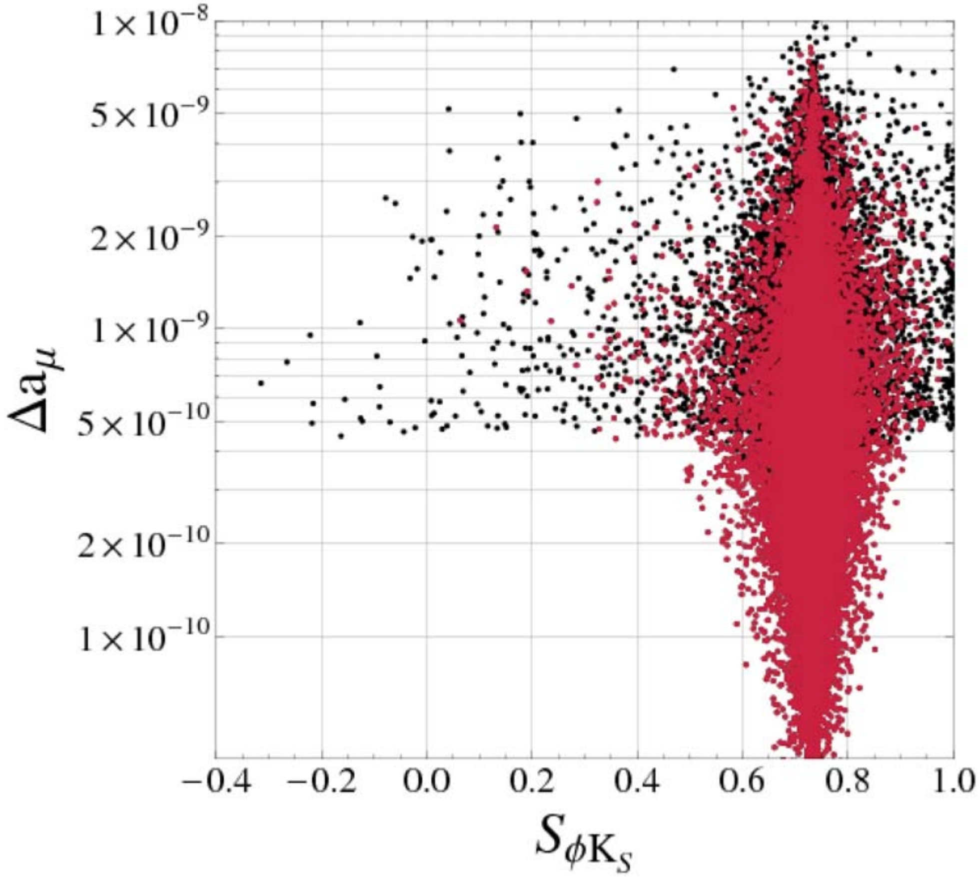


$\bar\rho = \sin\beta\cos\gamma$ $\bar\eta = \sin\beta\sin\gamma$

Correlations in a Flavour Model with LH Currents

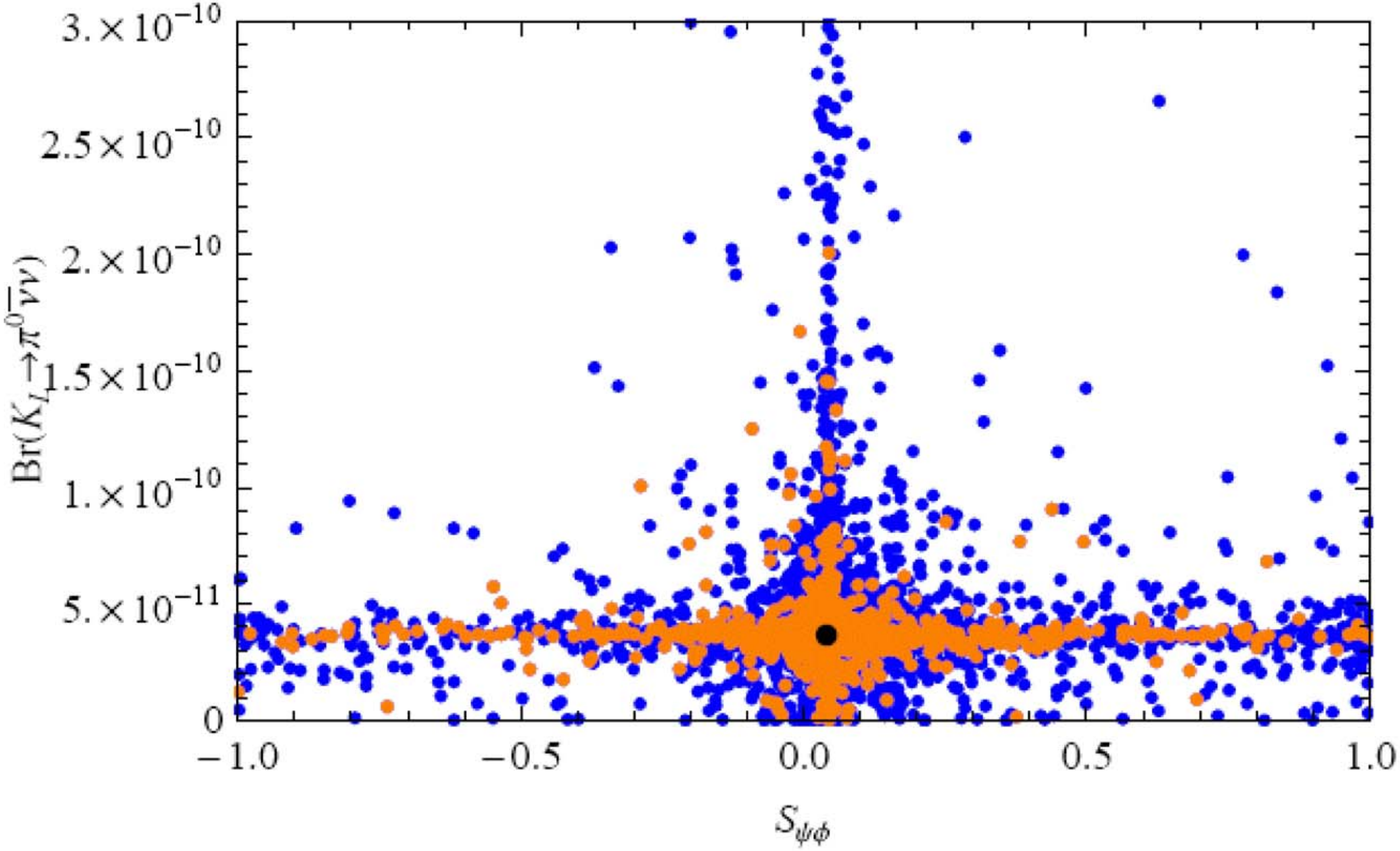
■ $Br(B_s \to \mu^+\mu^-) < 6 \cdot 10^{-9}$





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

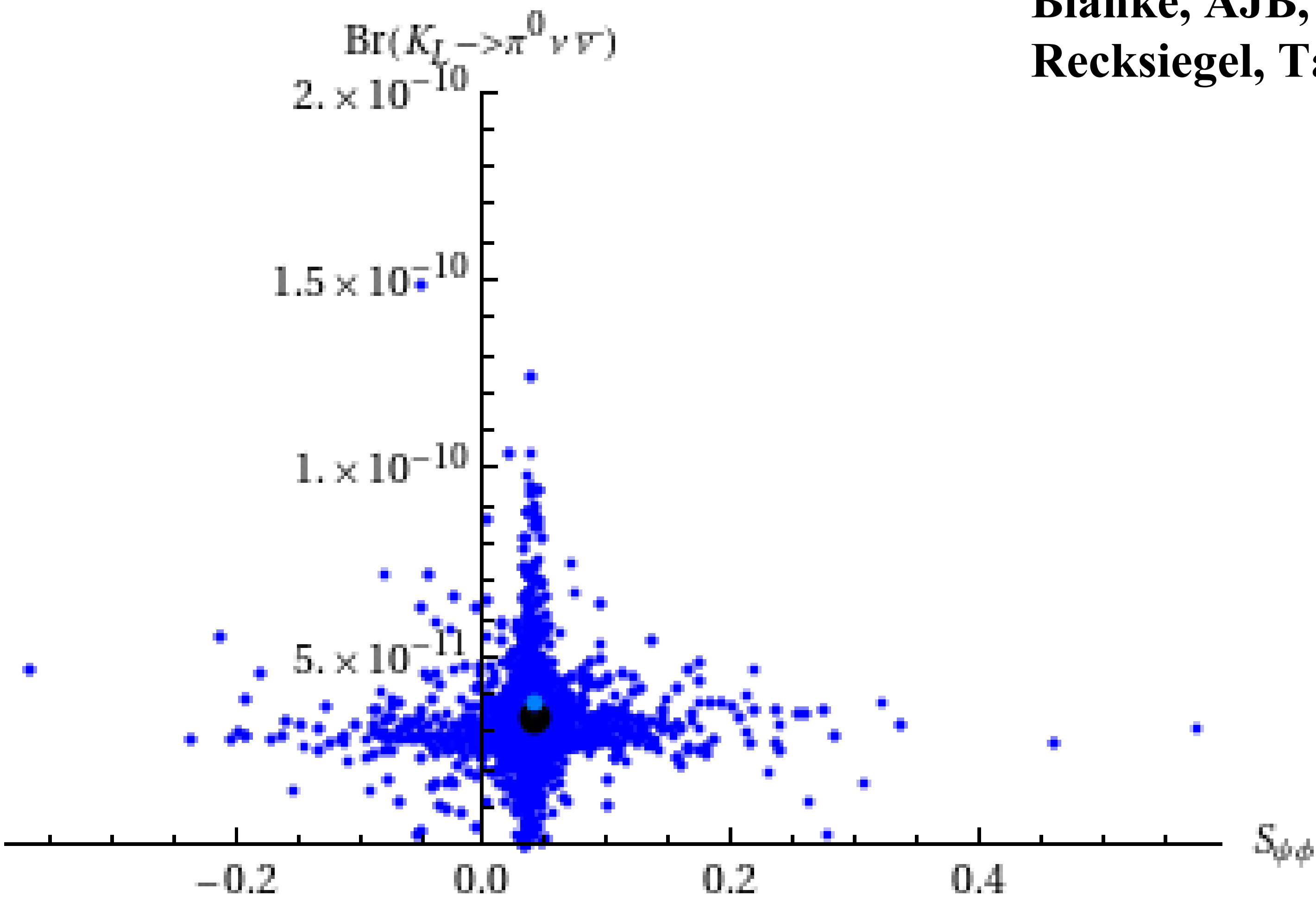
(Simultaneous Large Enhancements unlikely)



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

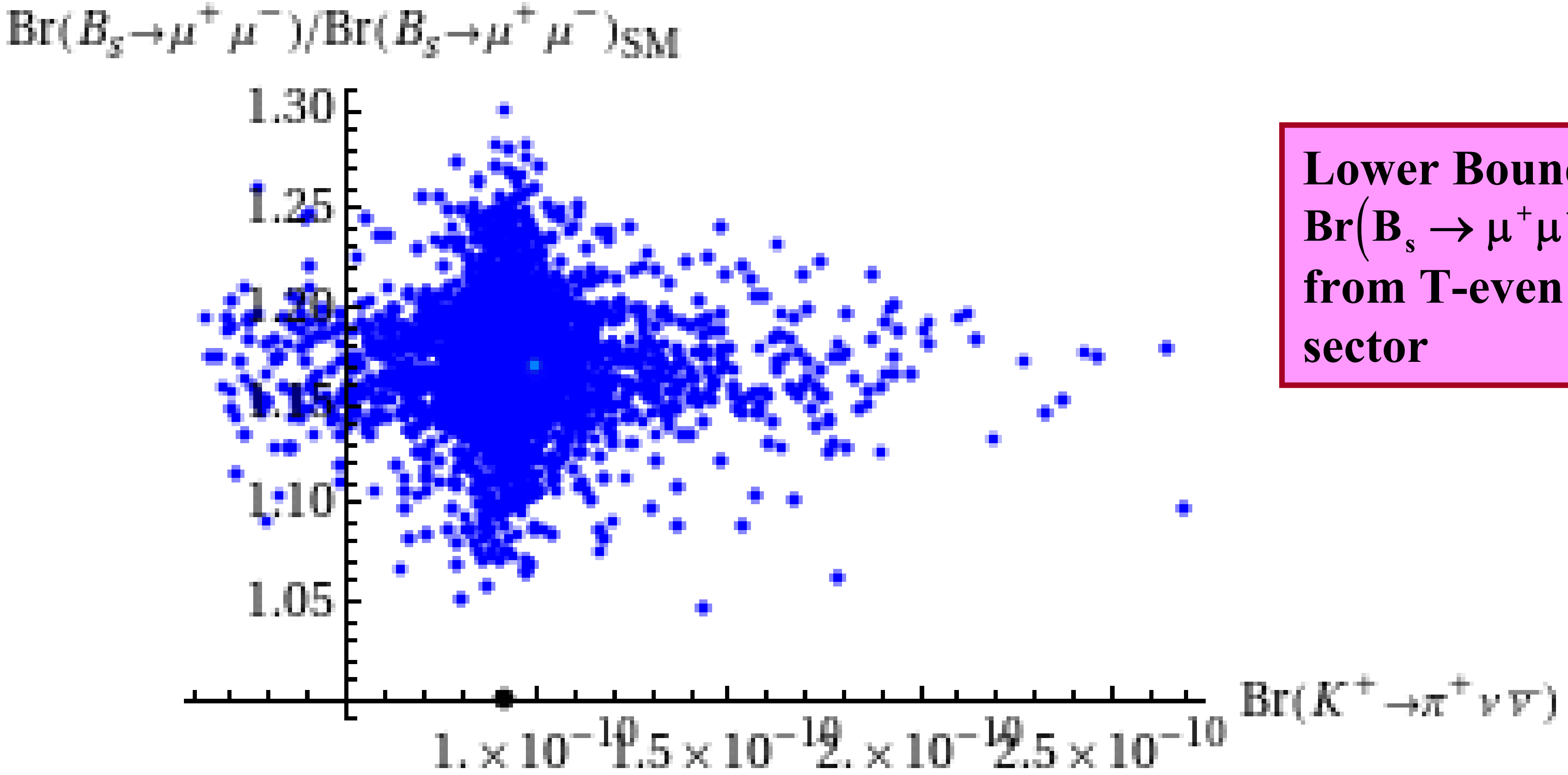
(Simultaneous Large Enhancements unlikely)

Blanke, AJB, Duling, Recksiegel, Tarantino

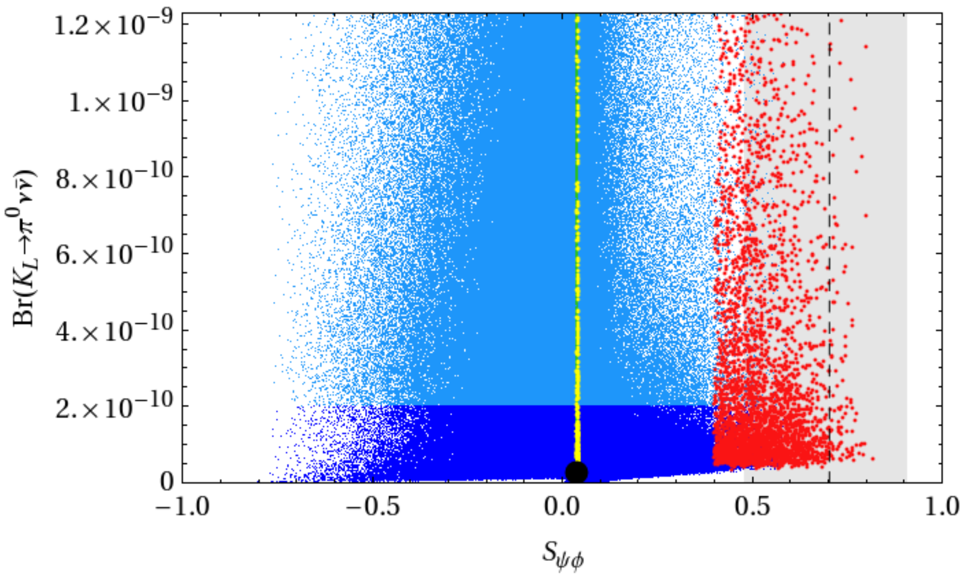


$B_s \to \mu^+\mu^-$ vs. $K^+ \to \pi^+\nu\bar{\nu}$ (LHT)

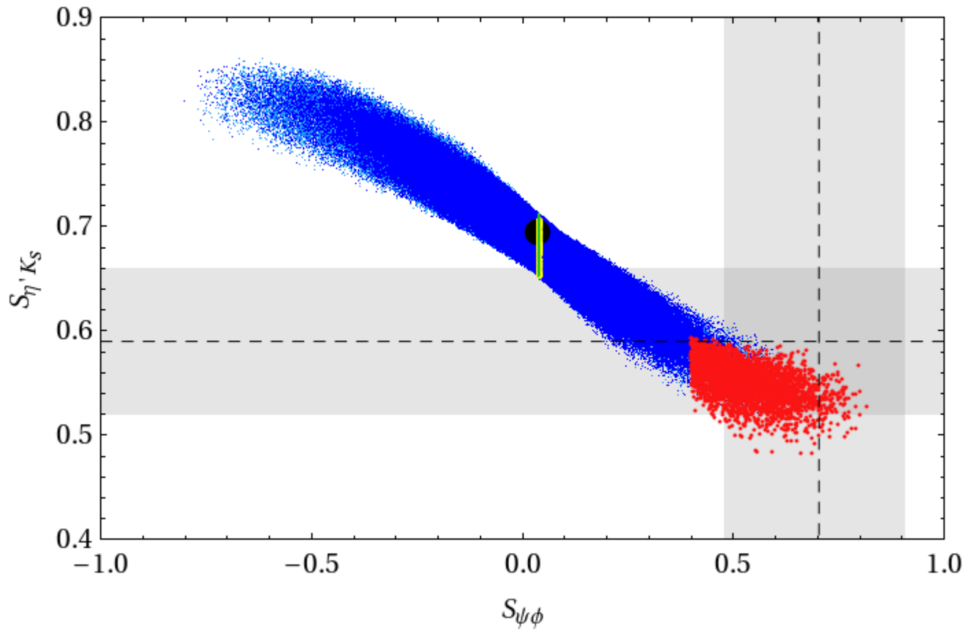
Blanke, AJB, Duling, Recksiegel, Tarantino



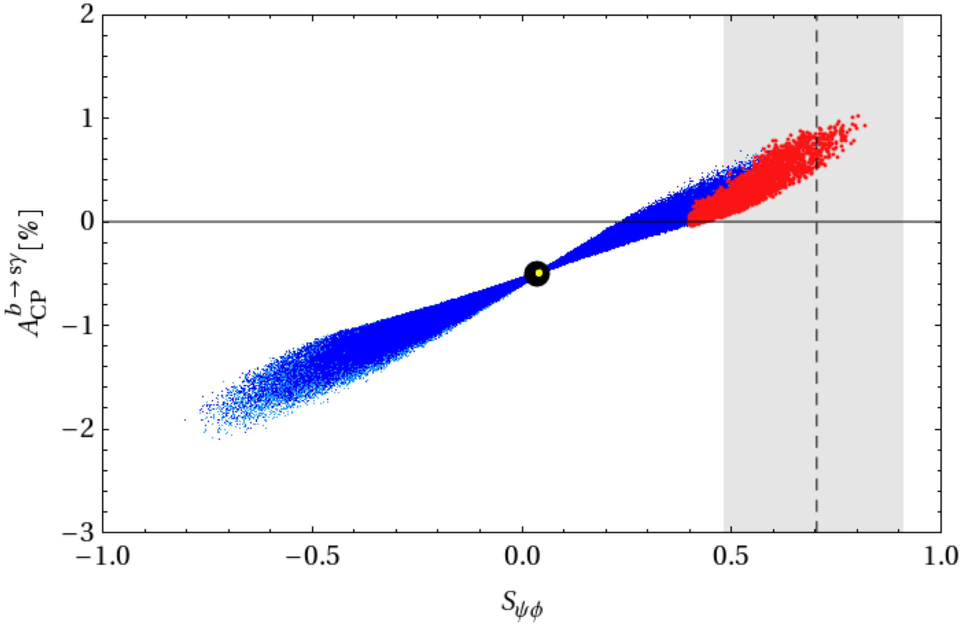
Lower Bound on $Br(B_s \to \mu^+\mu^-)$ from T-even sector



1.2×10^{-9}
$1.\times10^{-9}$
$8.\times10^{-10}$
$6.\times10^{-10}$
$4.\times10^{-10}$
$2.\times10^{-10}$
0
$Br(K_L\to\pi^0\nu\bar{\nu})$
−1.0
−0.5
0.0
0.5
1.0
$S_{\psi\phi}$



0.9
0.8
0.7
0.6
0.5
0.4
$S_{\eta' K_S}$
−1.0
−0.5
0.0
0.5
1.0
$S_{\psi\phi}$


2
1
0
−1
−2
−3
−1.0
−0.5
0.0
0.5
1.0
$A_{CP}^{b\to s\gamma}$ [%]
$S_{\psi\phi}$

Lepton Flavour Violation, $\Delta(g-2)_\mu$ and EDM's

$S_{\varphi K_s} = 0.44 \pm 0.17$ $\qquad$ $\left(S_{\varphi K_s}\right)_{SM} \approx \left(S_{\psi K_s}\right)_{SM} + 0.02 \approx 0.70$

(Beneke)

(MEGA) $\quad Br(\mu \to e\gamma) < 1.2 \cdot 10^{-11}$ ➡ 10^{-13}(MEG) $\quad$ SM:10^{-54}

$\left(a_\mu\right)_{SM} < \left(a_\mu\right)_{exp} \quad (3.1\sigma)$

$a_\mu = \frac{1}{2}(g-2)_\mu$

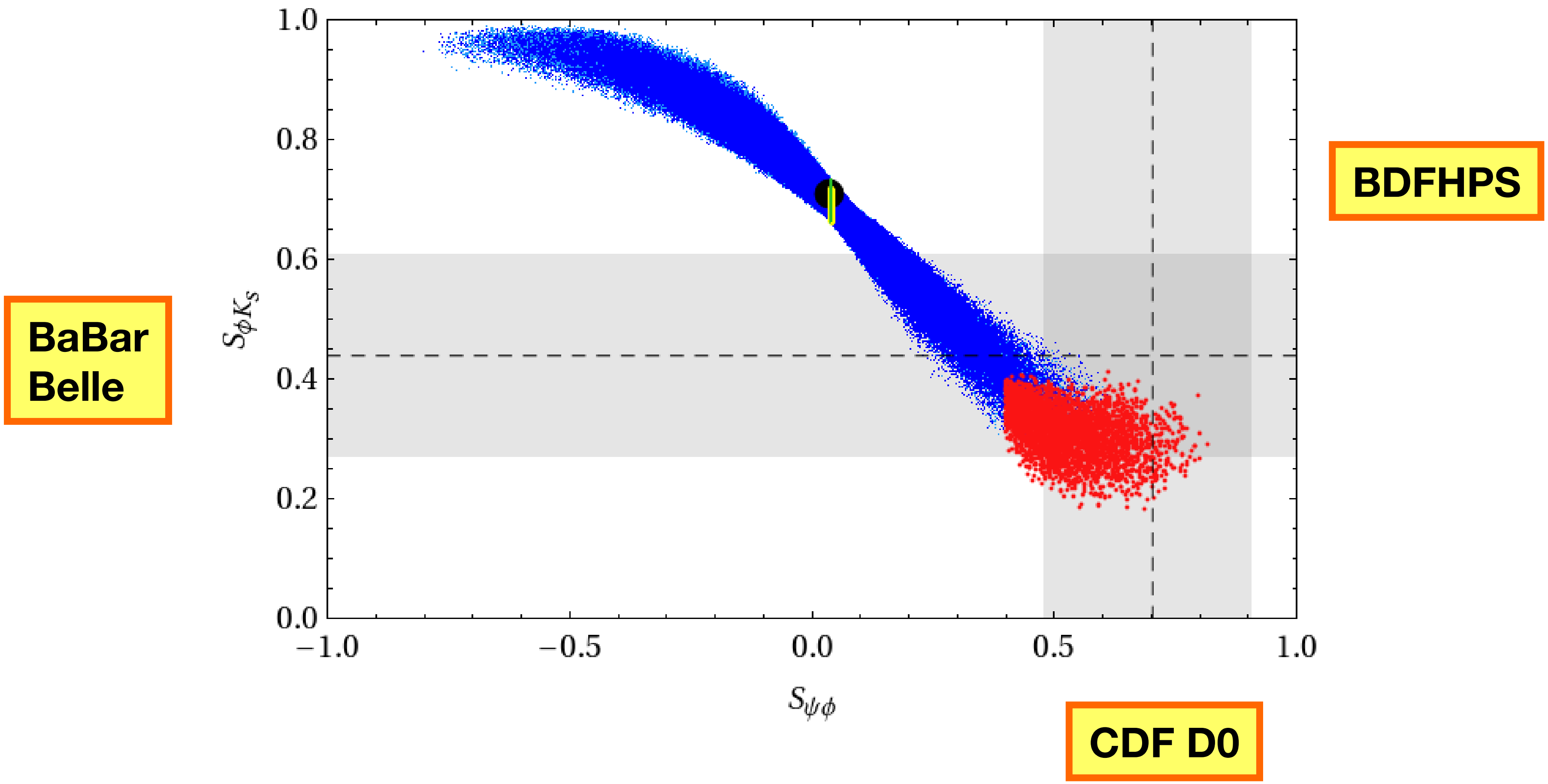
(Regan et al) $\quad d_e < 1.6 \cdot 10^{-27}$ ➡ 10^{-31} $\quad (d_e)_{SM} \approx 10^{-38}$

(Baker et al) $\quad d_n < 2.9 \cdot 10^{-26}$ ➡ 10^{-28} $\quad (d_n)_{SM} \approx 10^{-32}$

[e cm]

Simultaneous Solution to $S_{\varphi K_s}$ and $S_{\psi\varphi}$ Anomalies in 4G Model

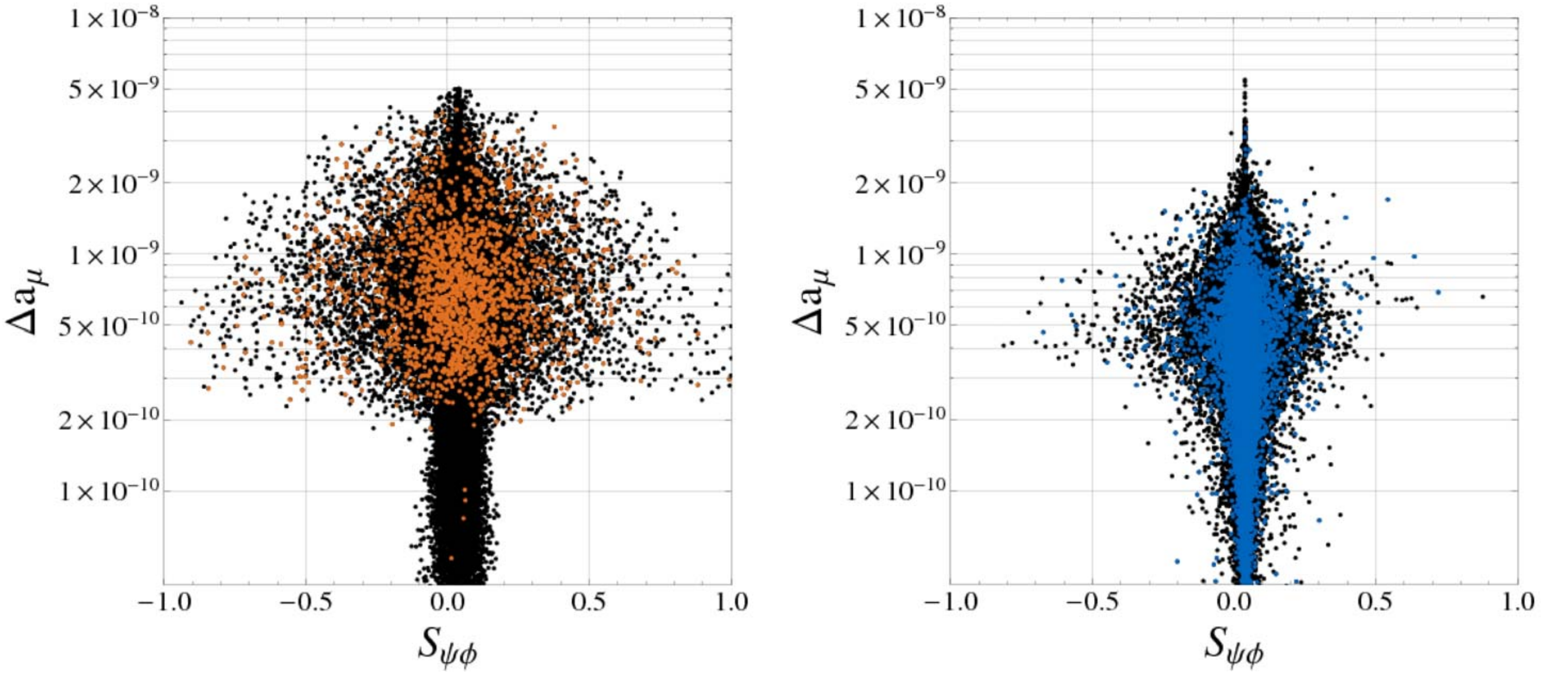
Soni et al.



Simultaneous Solution to Δa_μ and $S_{\psi\varphi}$ Anomalies

Solution 3 to ε_K-Anomaly
Abelian (AC)

Solution 1 to ε_K-Anomaly
Non-Abelian (RVV)



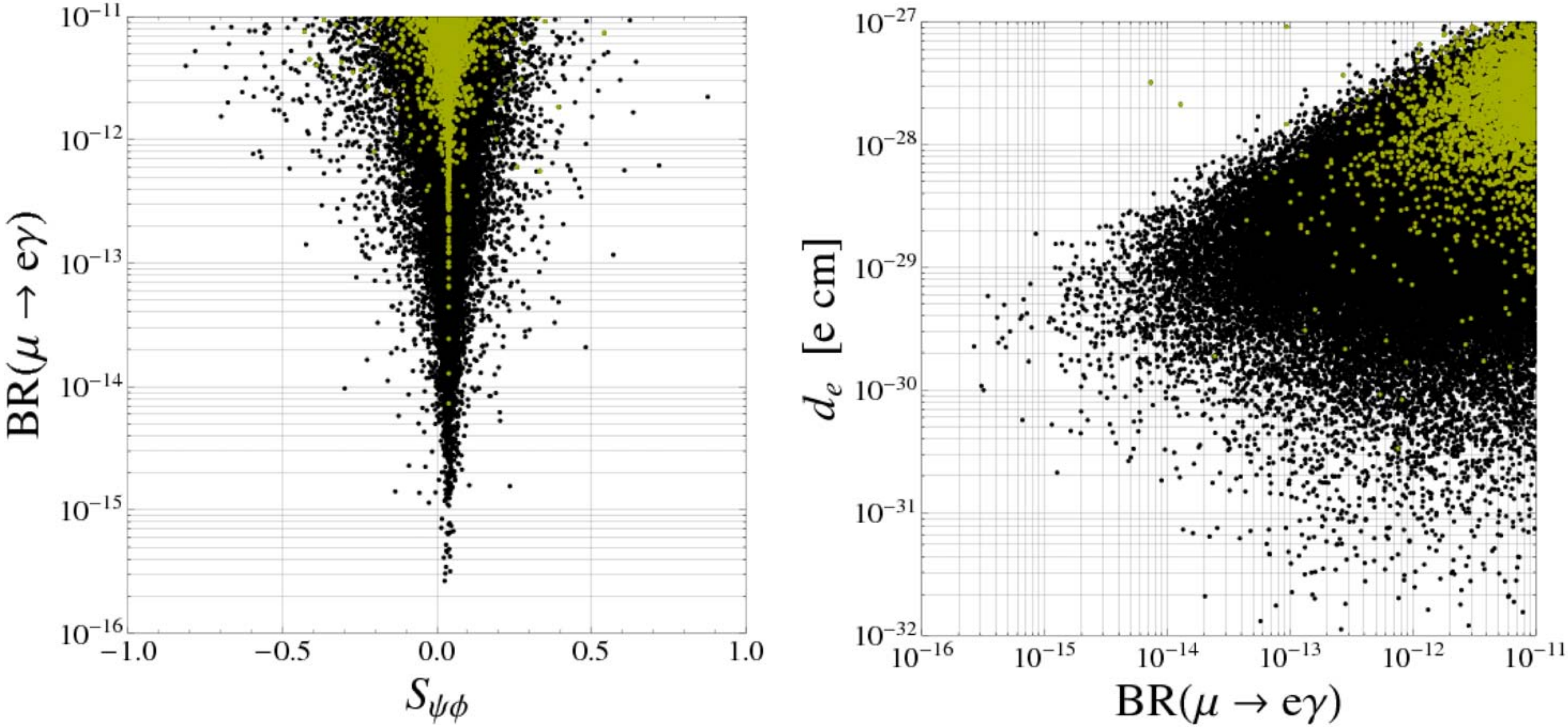
(Large Effects in D^0-$\bar{D}^0$)

(Small Effects in D^0-$\bar{D}^0$)

ABGPS

Correlations in the SU(3) Flavour Model (RVV2)

Solution to $(g\text{-}2)_\mu$ anomaly



Clear Distinction between MSSM and LHT

	MSSM	LHT
	$$\frac{Br(\mu^- \to e^- e^+ e^-)}{Br(\mu^- \to e^- \gamma)} \approx \frac{1}{161}$$	0.02 – 1
	$$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau^- \to \mu^- \gamma)} \approx \frac{1}{435}$$	0.04 – 0.4

Both can reach MEGA´s $\mu \to e\gamma$ bound

MSSM : (Ellis, Hisano, Raidal, Shimizu; Arganda, Herrero; Paradisi)
(Brignole, Rossi)

LHT : (Blanke, AJB, Duling, Poschenrieder, Tarantino) (2007)
del Aguila, Illana, Jenkins (2008), Goto, Okada, Yamamoto (2009)

Impressive Success of the CKM Picture of Flavour Changing Interactions

(GIM)
(NFC)

(Once quarked masses determined : only 4 parameters)

1. All leading decays of $K,\ D,\ B_s^0,\ B_d^0$ mesons correctly described

2. Suppressed transitions : $K^0 - \overline{K}^0,\ B_d^0 - \overline{B}_d^0,\ B_s^0 - \overline{B}_s^0$ mixings found at suppressed level

3. CP-violating Data (K, B_d) correctly described

4. $B \to X_s\gamma,\ \ B \to X_s l^+ l^-$ OK

$\not{CP}$ in B_s?

$(g\text{-}2)_\mu$?

5. Very very highly suppressed transitions in the SM consistent with experiment: (not seen)

Standard Model		Exp Upper Bound
$Br(B_s \to \mu^+\mu^-) \cong 3\cdot 10^{-9}$		$\sim 4\cdot 10^{-8}$
$Br(K_L \to \pi^0\nu\bar{\nu}) \cong 3\cdot 10^{-11}$		$\sim 6\cdot 10^{-8}$
$Br(K_L \to \mu e) \cong$	10^{-40}	$\sim 10^{-12}$
$Br(\mu \to e\gamma) \approx$	10^{-54}	$\sim 10^{-11}$
$d_n \approx$	10^{-32} ecm	$\sim 10^{-26}$ ecm

Number of new Flavour Parameters

(Quark Sector) (physical)

	Real	~~CP~~ Phases	
SUSY	36	27	(R-parity)
4G	5	2	
LHT	7	3	some sensitivity to UV
RS	18	9	
SM	9	1	

Standard Model Predictions for Superstars

$$S_{\psi\varphi} = 0.035 \pm 0.005$$

$$\left(S_{\psi\varphi}\right)_{exp} = 0.52 \pm 0.20$$

$$Br\left(B_s \to \mu^+\mu^-\right) = \left(3.2 \pm 0.2\right)\cdot 10^{-9}$$

$$Br\left(B_s \to \mu^+\mu^-\right)_{exp} \le 4.2 \cdot 10^{-8}$$

$$Br\left(B_d \to \mu^+\mu^-\right) = \left(1.0 \pm 0.1\right)\cdot 10^{-10}$$

$$Br\left(B_d \to \mu^+\mu^-\right)_{exp} \le 1.0 \cdot 10^{-8}$$

$$Br\left(K^+ \to \pi^+\nu\bar{\nu}\right) = \left(8.4 \pm 0.7\right)\cdot 10^{-11}$$

$$Br\left(K^+ \to \pi^+\nu\bar{\nu}\right)_{exp} = \left(17 \pm 11\right)\cdot 10^{-11}$$

$$\gamma = \left(64.2 \pm 3.1\right)^{o}$$

$$\gamma_{exp} = \left(75 \pm 15\right)^{o}$$

(tree)

$$Br\left(K_L \to \pi^0\nu\bar{\nu}\right) = \left(2.8 \pm 0.6\right)\cdot 10^{-11}$$

$$Br\left(K_L \to \pi^0\nu\bar{\nu}\right)_{exp} \le 6 \cdot 10^{-8}$$

Maximal Enhancements of $S_{\psi\varphi}$, $Br(B_s \to \mu^+\mu^-)$ and $K^+ \to \pi^+\nu\bar{\nu}$

(without taking correlation between them)

Model	Upper Bound on ($S_{\psi\varphi}$)	Enhancement of $Br(B_s \to \mu^+\mu^-)$	Enhancement of $Br(K^+ \to \pi^+\nu\bar{\nu})$
CMFV	0.04	20%	20%
MFV	0.04	1000%	30%
LHT	0.30	30%	150%
RS	0.75	10%	60%
4G	0.80	400%	300%
AC	0.75	1000%	2%
RVV	0.50	1000%	10%

Large RH Currents

RS = RS with custodial protections
AC = Agashe, Carone $U(1)_F$
RVV = Ross, Velaso-Sevilla, Vives (04) $SU(3)_F$

Dominant New Flavour and CP Violating Interactions at $0(\mu_{NP})$

SUSY:

GIM

a) Misalignment of quark- and squark mass matrices, similarly for lepton sector
b) Effects enhanced at large $\tan\beta$: δ_{ij}^{AB}

Typical scales(200-1000 GeV)

LHT:

New flavour and CP violating mixing matrices in the interactions of SM fermions with mirror fermions mediated by W_H, Z_H, A_H

Typical scales (500-1000 GeV)

RS:

RS-GIM

New Heavy Gauge Bosons (KK)
New Heavy Vector-like Fermions (KK)

Tree Level FCNC´s mediated by KK Gluon ($\Delta F=2$) and Z($\Delta F=1$)
(Typical scales $M_{KK} \approx 2\text{-}3$ TeV)

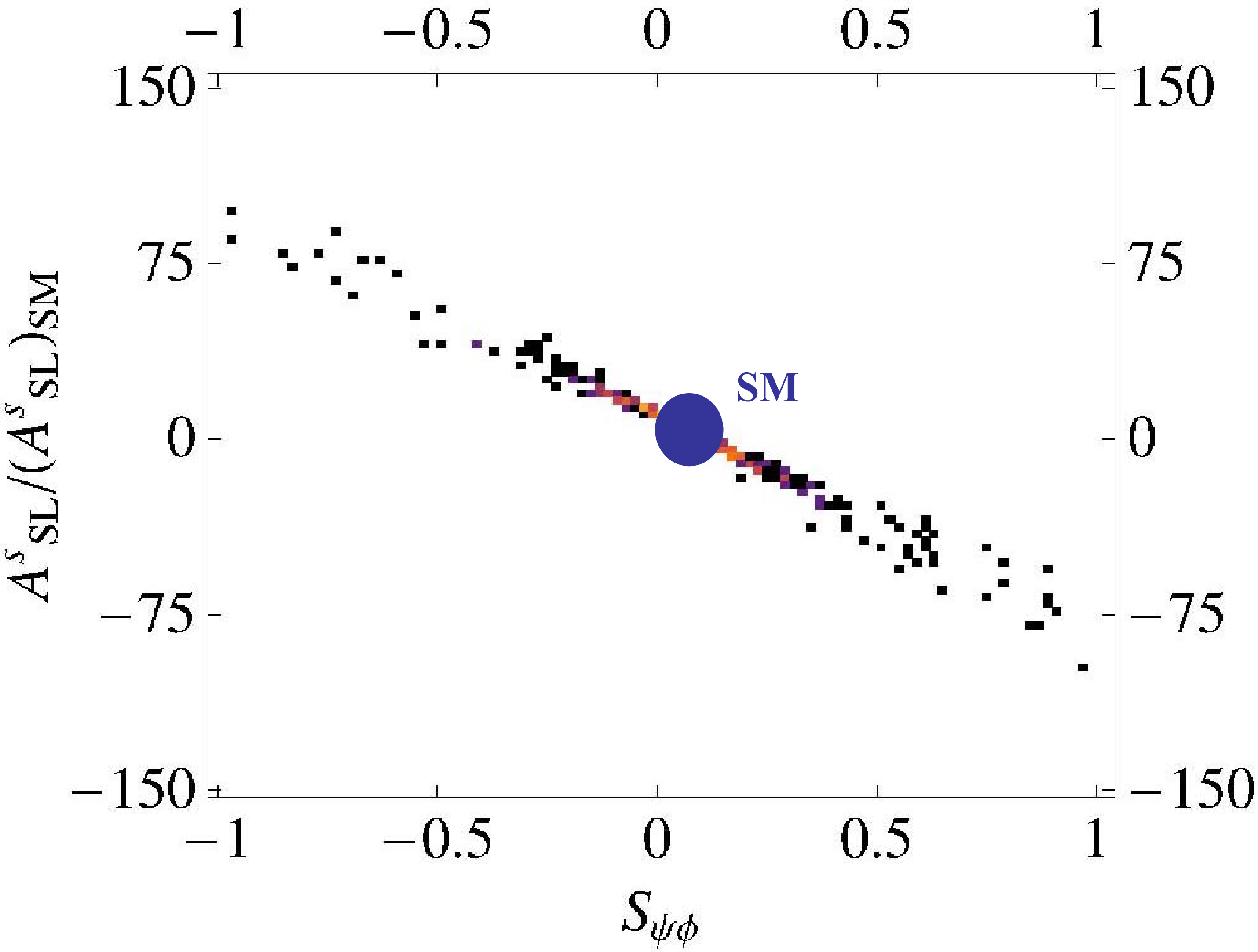
Related to the explanation of hierarchies in masses and mixings

2 x 2 Flavour Matrix of Basic NP Scenarios

(AJB, hep-ph/0101336, Erice)

	SM Operators	+ Additional Operators
CKM	**A** CMFV (Y_t) SM, 2 HDM at low tanβ LH without T-parity Universal flat ED	**B** MFV (Y_t,Y_b) MSSM with MFV 2 HDM at large tanβ
New Flavour (CP) Violating Interactions	**C** beyond CMFV LH with T-parity Some Z´-models 4^{th} generation	**D** beyond MFV MSSM with $(\delta_{ij})_{AB}\neq0$ RS, Other Z´models, LR Models, NMFV

Correlation in Warped Extra Dimensions (RS)



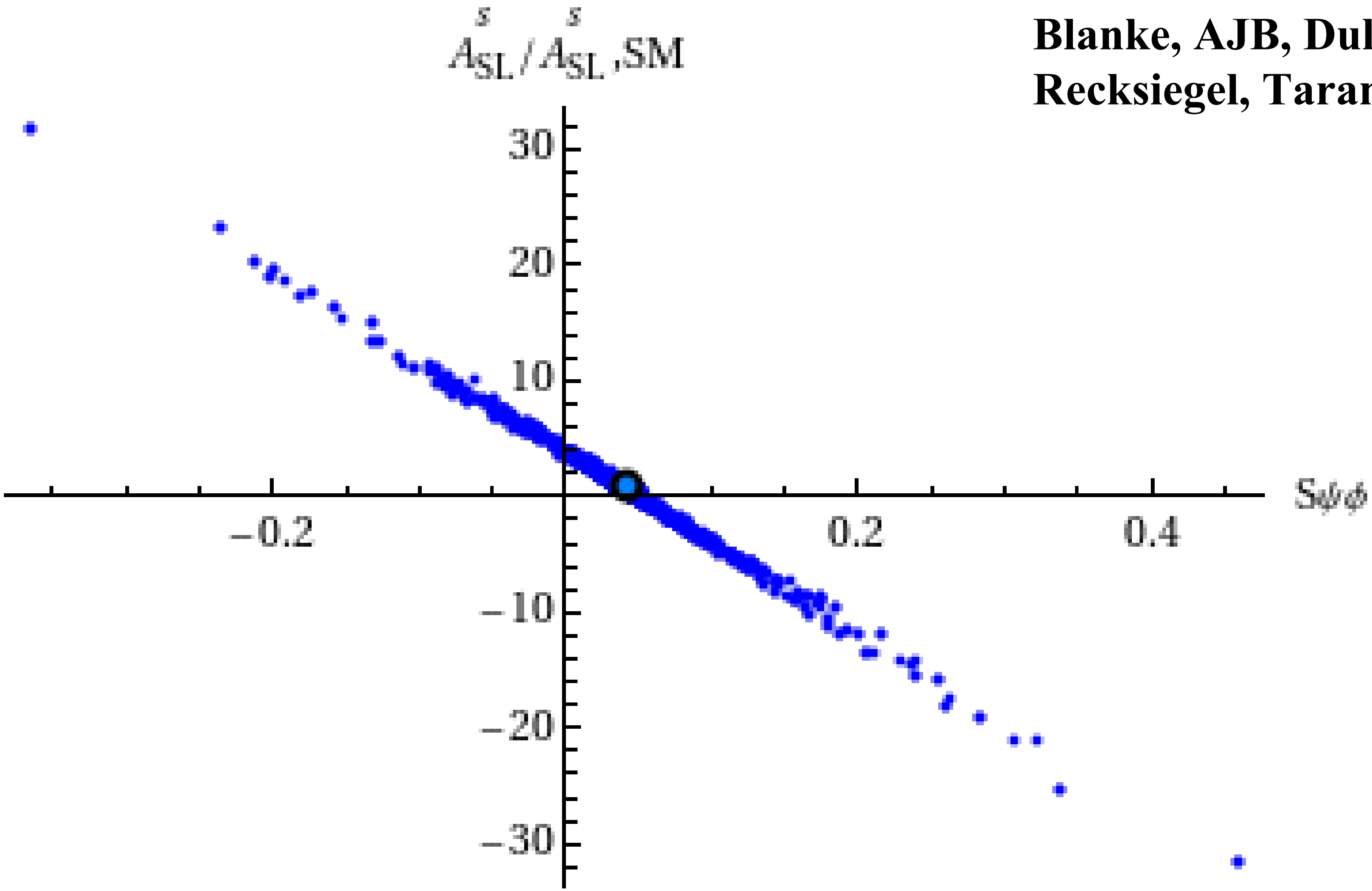
M.Blanke, AJB, B.Duling, S.Gori, A.Weiler (2008)

Model Independent Correlation

(Ligeti, Perez,…)

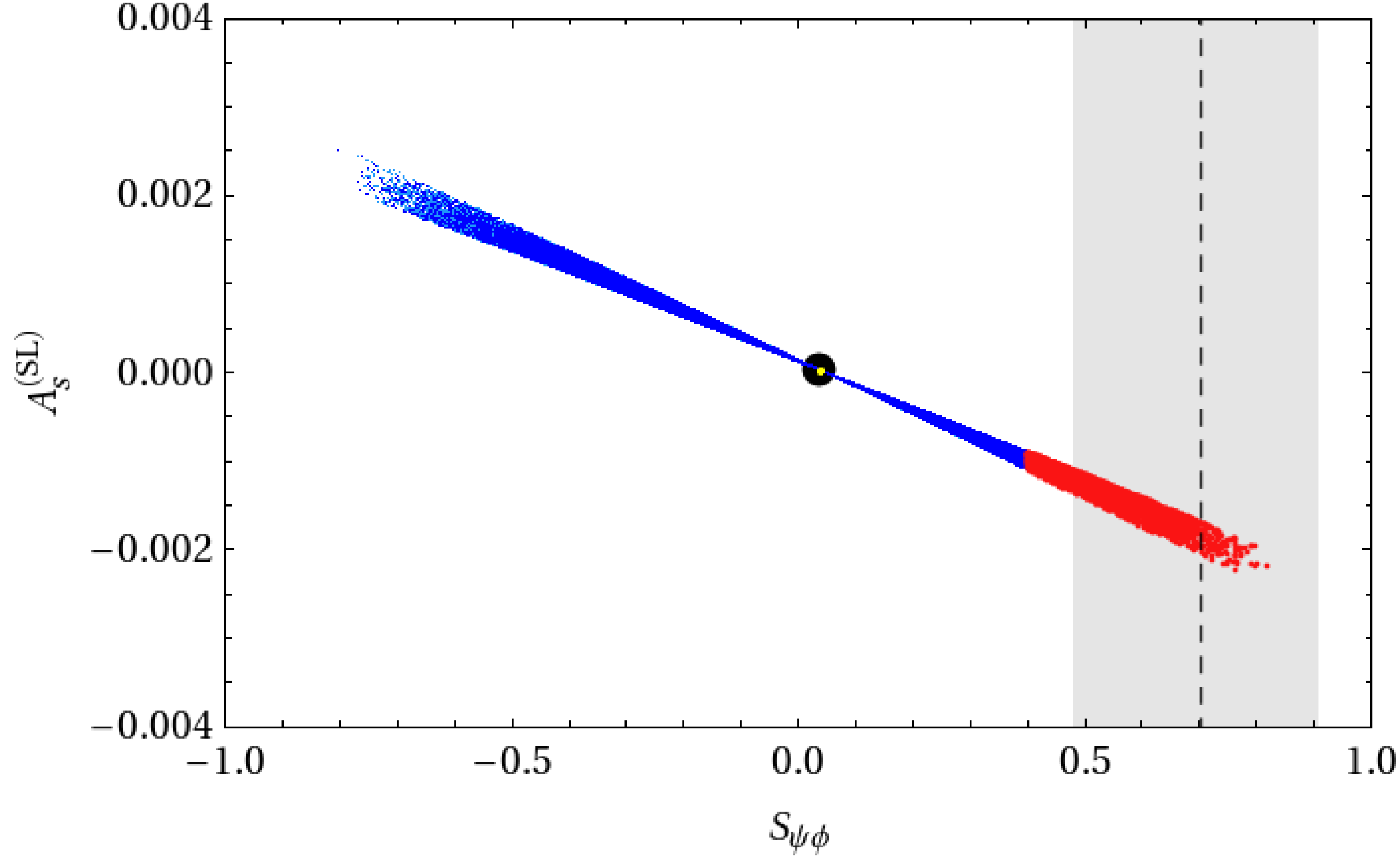
Correlation in LHT

Blanke, AJB, Duling, Recksiegel, Tarantino



Correlation in 4G Model

AJB, Duling, Feldmann, Heidsieck, Promberger, Recksiegel (BDFHPR)



Correlation in Flavour SUSY Models

ABGPS