FCNC Processes waiting for the Next Decade

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Warsaw, Nov 6th, 2009

Overture

Frontiers of Elementary Particle Physics → **Search for Physics Laws at very short distance scales**

Heisenberg Principle : **To test 10^{-18} m we need $E \cong 200$ GeV**

Frontiers of Elementary Particle Physics → Search for Physics Laws at very short distance scales

Heisenberg Principle : To test 10^{-18} m we need E ≅ 200 GeV

LHC E ≈ 4 TeV → Tests at $5 \cdot 10^{-20}$ m possible

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Unlikely that we can do better before 2046 through high energy collider experiments.

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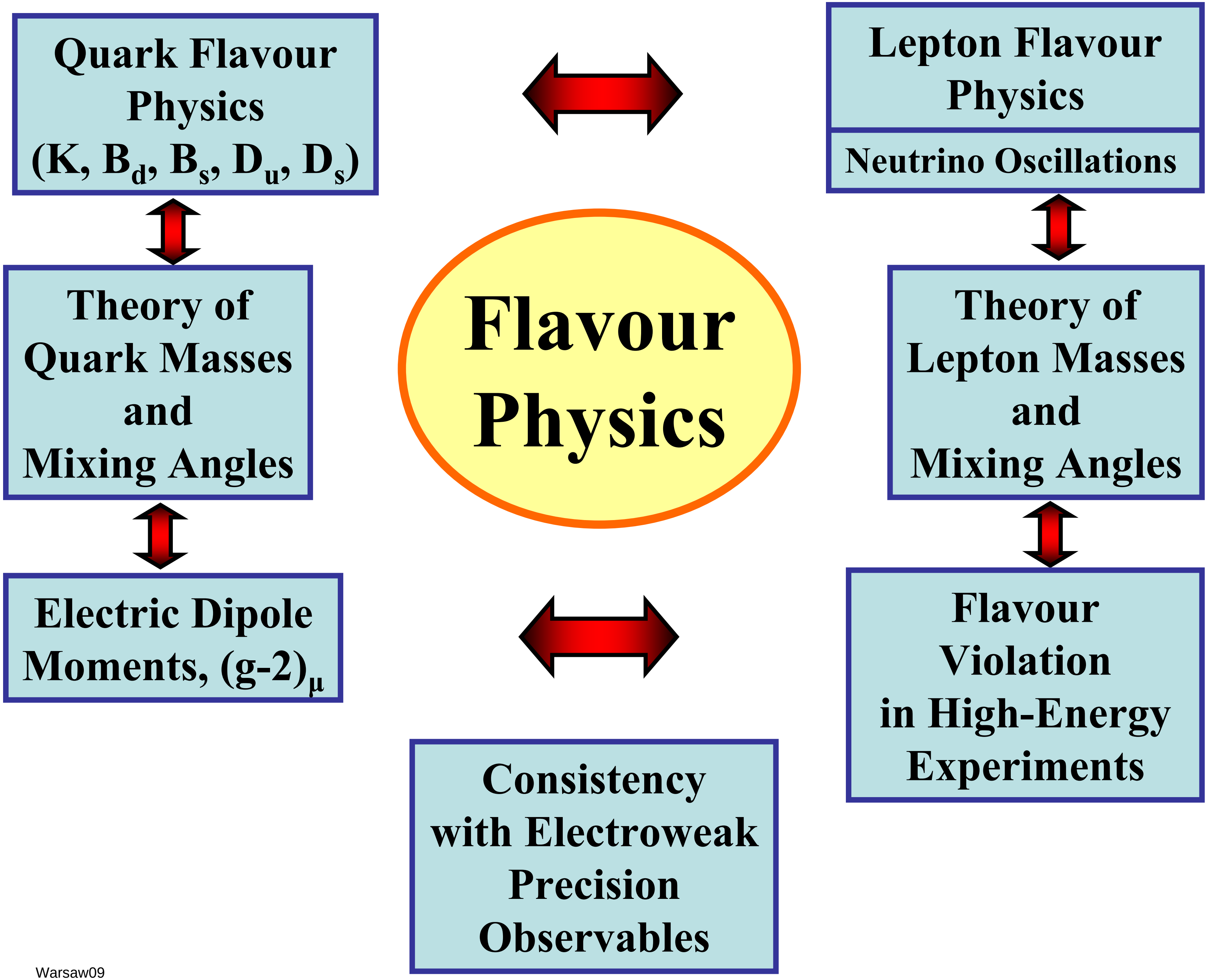
Flavour Physics governed by Quantum Fluctuations is sensitive to $E \approx 200$ TeV and even higher energy scales → **Tests at 10^{-21} m and shorter scales possible** → **Frontiers in testing very very short distance scales belong to Flavour Physics**

but **Very high precision required !!**

Main Message of this Talk

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


Quark Flavour Physics
(K, B_d, B_s, D_u, D_s)
Lepton Flavour Physics
Neutrino Oscillations
Theory of Quark Masses and Mixing Angles
Flavour Physics
Theory of Lepton Masses and Mixing Angles
Electric Dipole Moments, $(g-2)_\mu$
Flavour Violation in High-Energy Experiments
Consistency with Electroweak Precision Observables

Yet

Impressive Success of the CKM Picture of Flavour Changing Interactions

(GIM)

1. **Several tensions between the flavour data and the SM exist.**

2. **Hierarchies in Fermion Masses and Mixing Angles have to be understood with the help of some New Physics (NP).**

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.**

Are 1. - 3. somehow related ?
Will we see any footprints of this NP in the 2010´s ?

Strategy for the Next 50 Min

1. Theoretical Framework (~ 15 min)

2. 20 Goals in Flavour Physics for the Next Decade (~ 8 min)

3. Waiting for Signals of New Physics in FCNC Processes (~ 25 min)

4. Final Messages (~ 2 min)

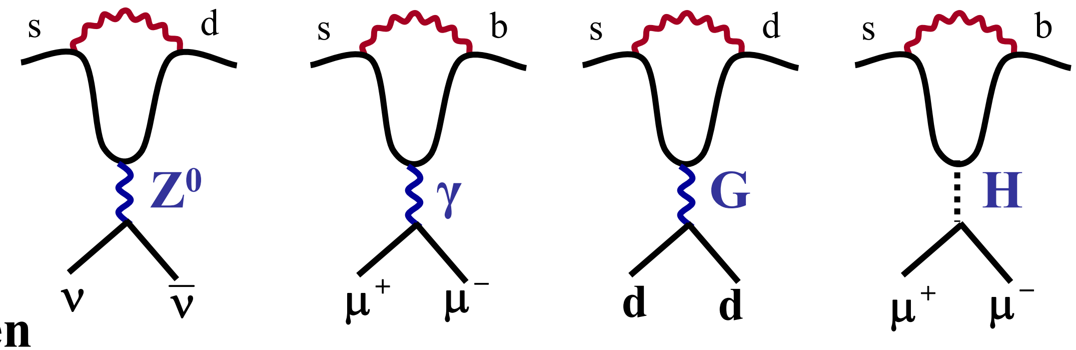
(hep-ph/0910.1032): "Flavour Theory : 2009"

1.

Theoretical Framework

Basic Diagrams in FCNC Processes

Penguin Family :

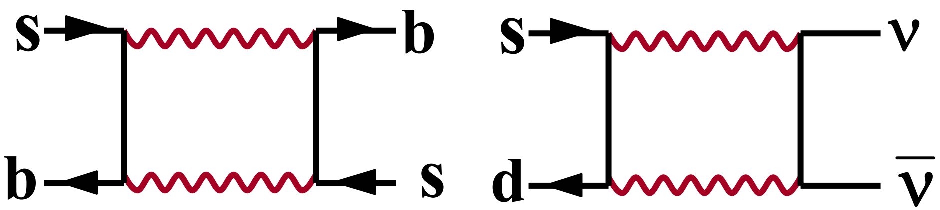


← **New Physics enters here**

Similar diagrams in LFV and EDM´s

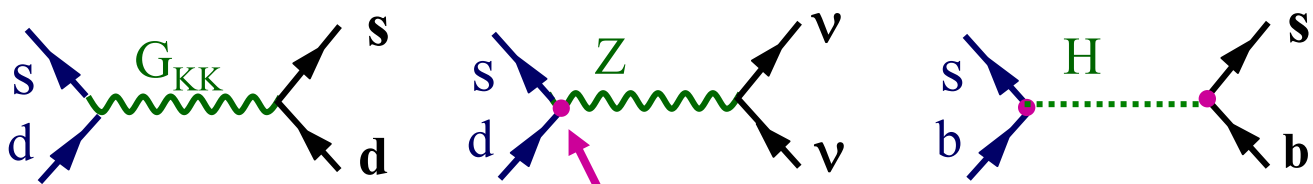
(GIM broken at one loop)

Box Diagrams

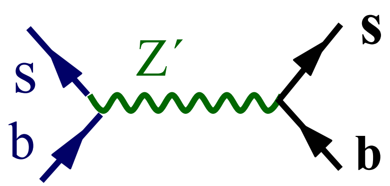


+ **other box diagrams**

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)

MFV (NMFV) (GMFV)

LHT

(Littlest Higgs with T-parity)

SUSY

(flavour models)

Z′

(Langacker…)

RS

(Randall-Sundrum)
(Warped Extra Dimensions)

4th G

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

Vector-Like Quarks

(Branco…, del Aguila)

Non-Decoupling

↓

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

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)

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

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)

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

~~CP~~
SM-like

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)

Spurion Technology

Nir et al.
AGIS
Feldmann, Mannel ← also beyond MFV

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

Battle in the Bulk to save RS with $M_{KK} \sim$ 2-3 TeV

"Warped Flavour"

Some fine tuning required

Blanke et al

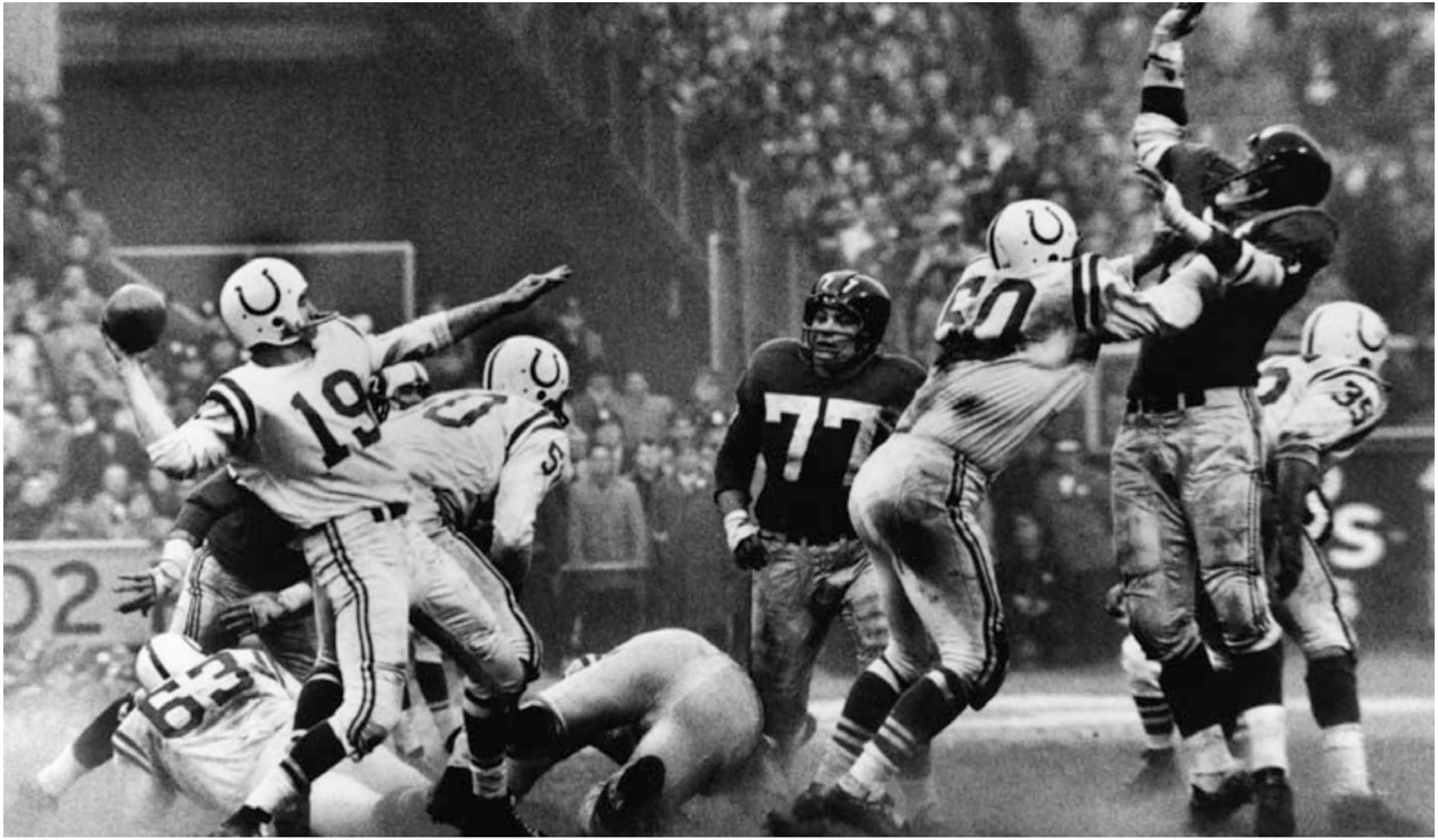
Custodial Symmetries, Flavour Symmetries, etc.

(some related to EWPT, some related to FCNC´s)

Ghergetta, Pomarol; Huber, Shafi (03)
Agashe, Delgado, May, Sundrum (03)
Csaki, Grojean, Pilo, Terning (03)
Agashe, Contino, Da Rold, Pomarol (06)
Agashe, Perez, Soni (06)
Cacciapaglia, Csaki, Weiler et al. (07)
Csaki, Falkowski, Weiler (08) ←
Fitzpatrick, Perez, Randall (07)
Santiago (08)
Casagrande, Goertz, Haisch, Neubert (08)
Blanke, AJB, Duling, Gori, Weiler (08) ←
Albrecht, Blanke, AJB, Duling, Gemmler (09)
AJB, Duling, Gori (09)
Csaki, Grossman, Perez, Surujon, Weiler (09)

Agashe, Azatov, Zhu (08)
Azatov, Toharia, Zhu (09)
Agashe, Contino (09)
Gedalia, Isidori, Perez (09)
Csaki, Curtin (09)

Q_{LR} and dipole operators most problematic
ε_K, $B \to X_s\gamma$, $\mu \to e\gamma$, d_n
ε'/ε



Quark flavor in RS: Overtime

Ulrich Haisch

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 $(\delta_{ij})_{AB}\neq 0$ RS, Other Z´models, LR Models, NMFV

2.

20 Goals in Flavour Physics for the Next Decade

1.

Determination of $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$ and γ from Tree Level Decays

2.

Improved Lattice Calculations of $F_{B_{s,d}}$, B_i -parameters

3.

Is ε_K (1964) consistent with $S_{\psi K_S} = \sin 2\beta$ (2001) within the SM?

4.

Is $S_{\psi\varphi}$ much larger than $\left(S_{\psi\varphi}\right)_{SM} \approx 0.035$?

($\not{C}\not{P}$ in $B_s \to \psi\varphi$) $\left(A^s_{SL}\right)$

5.

Clarification of few puzzles in Non-Leptonic Decays $\left(S_{\varphi K_S},\ S_{\pi^0 K_S},\ \pi K,\ \ldots\right)$

(Fleischer,..Buchalla, Gronau, London, …)

6.

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

7.

Improved TH+EXP

$B \to X_{s,d}\gamma$

$B \to K^*(\rho)\gamma$

$A_{CP}^{dir}(B \to X_s\gamma)$

(Misiak,…)

8.

$B \to X_s l^+ l^-$

$B \to K^* l^+ l^-$

in particular various angular observables (sensitive to NP)

(Hurth; Straub)

9.

$B^+ \to \tau^+\nu$

$B^+ \to D^0\tau^+\nu$

$H^\pm$ effects in Tree Level Decays

(Hou…,Recksiegel,..
Isidori, …Westhoff,…)

10.

Rare K Decays

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

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

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

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

(TH very clean,
sensitive to NP)

11.

Rare B Decays

$B \to X_s\nu\bar{\nu}$

$B \to K^*\nu\bar{\nu}$

$B \to K\nu\bar{\nu}$

(Straub) (sensitive to
right-handed currents)

12.

Lattice Calculations of Penguin hadronic matrix elements for ε'/ε (NA31, NA48, KTeV)

(Very sensitive to
NP in the EW-Penguins)

13.

$\not{CP}$ in Charm Decays and

$D^+ \to l^+\nu,\ D_s^+ \to l^+\nu$

$D^0 \to \mu^+\mu^-$

(Bigi; Grossman,..Golowich.. Kronfeld)

14.

Search for $\not{CP}$ in the Lepton Sector and θ_{13}

(Feruglio,…Antusch,… Branco,…Hagedorn)

15.

Tests of μ-e, μ-τ universalities in $K^+ \to l^+\nu$, $B^+ \to l^+\nu$

(Isidori,…Paradisi, …)

16.

Lepton Flavour Violation

$\mu\to e\gamma$, $\tau\to\mu\gamma$, $\tau\to e\gamma$

$\mu\to 3e$, $\tau\to 3e$

$\tau\to 3\mu$

(Hisano,…Raidal,…)

17.

Electric Dipole Moments of neutron, leptons (d_n, d_e)

(Nagai, …Paradisi,…)

18.

Clarification of $(g-2)_\mu$ Anomaly

(Passera,…Jegerlehner, Czarnecki,…de Rafael)

19.

Tests of Flavour Violation in High Energy Processes

(Hiller, Nir, Melic, Trampetic,…)

19.

Tests of Flavour Violation in High Energy Processes

(Hiller, Nir, Melic, Trampetic,…)

20.

Construction of a New SM

19.

Tests of Flavour Violation in High Energy Processes

(Hiller, Nir, Melic, Trampetic,…)

20.

Construction of a New SM

21.

22.

23.

24.

Searching for the Higgs

Near the Czarny Staw Gasiennicowy (10. September 2009)

3.

Waiting for Signals of New Physics in FCNC Processes

Models investigated by TUM-Teams

(This 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)
SUSY with SU(3) Flavour (Ross et al) (RVV2)	SUSY with SU(2) Flavour (LH-currents)	Flavour Blind MSSM

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

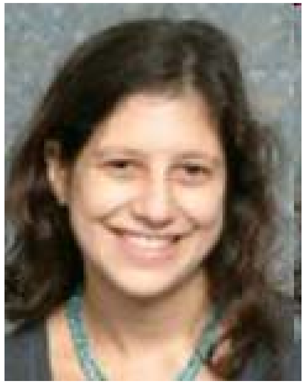
S. Gori

A. Weiler

The ABBBSW Collaboration

W. Altmannshofer

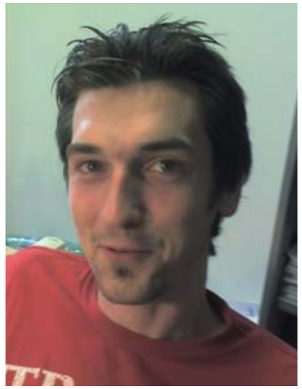
P. Ball



A. Bharucha

AJB

D. Straub



M. Wick

The BBBR Collaboration

I.Bigi

M. Blanke

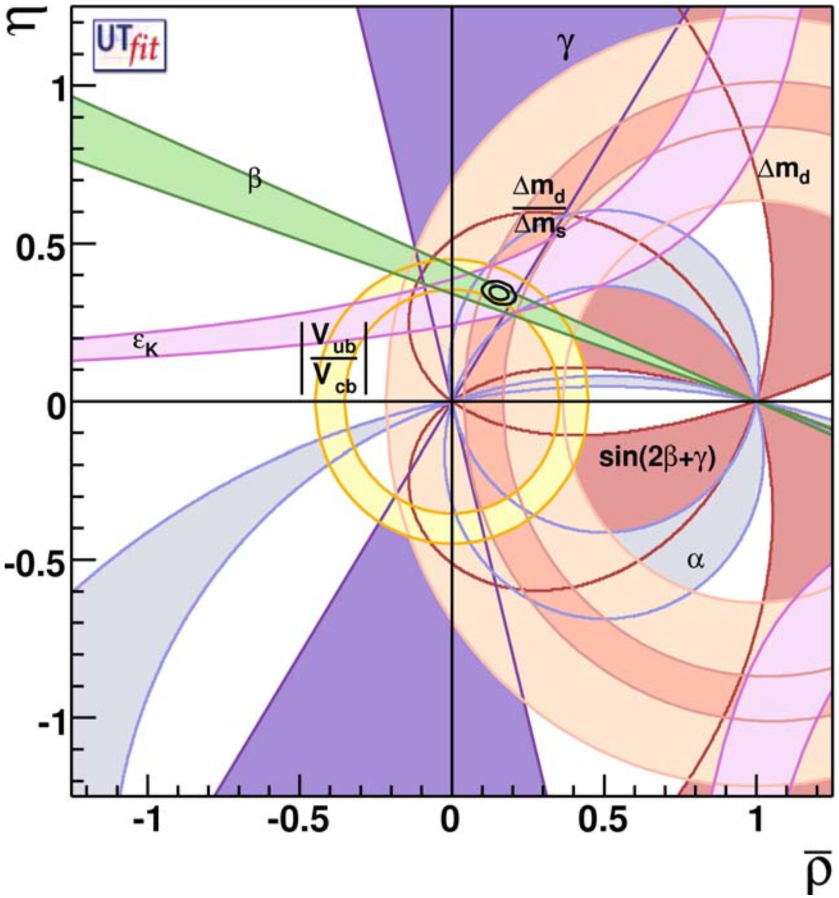
AJB

S. Recksiegel

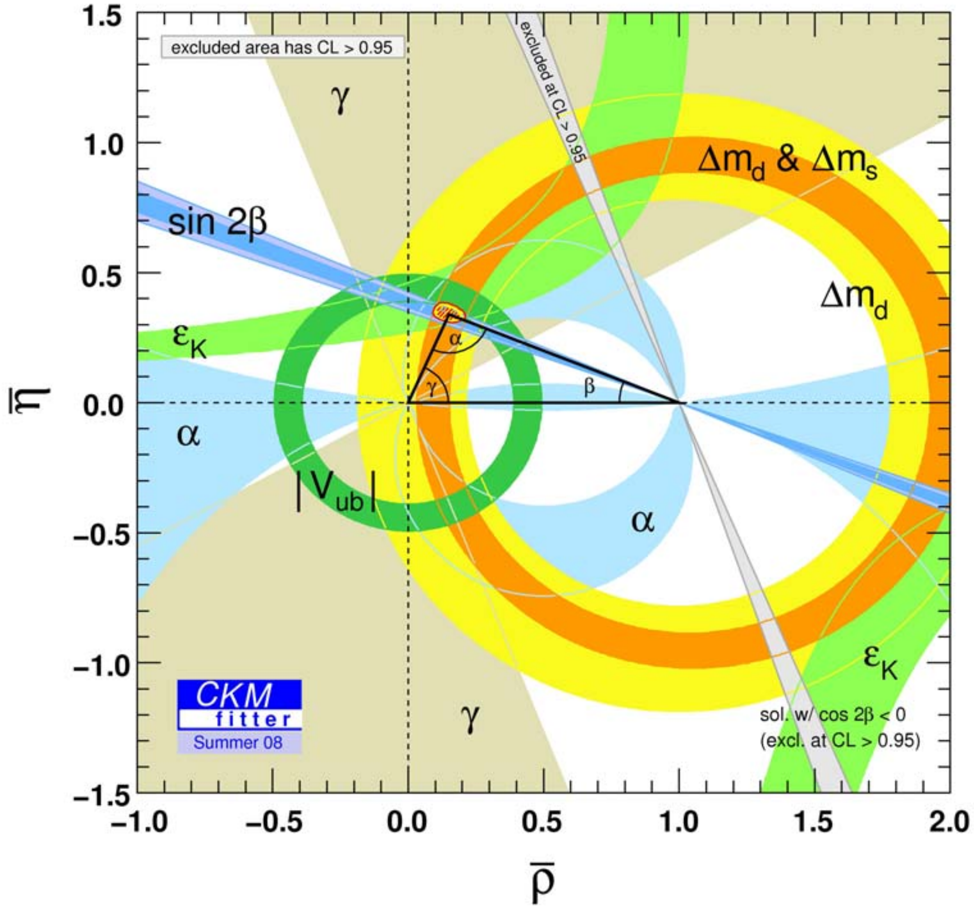
Unitarity Triangle Fits

(Icons of Flavour Physics)

UT fit



CKM fitter



Unitarity Triangle

(R_b, γ)
Reference UT
(Goto et al)

(coming decade)

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

(this decade)

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

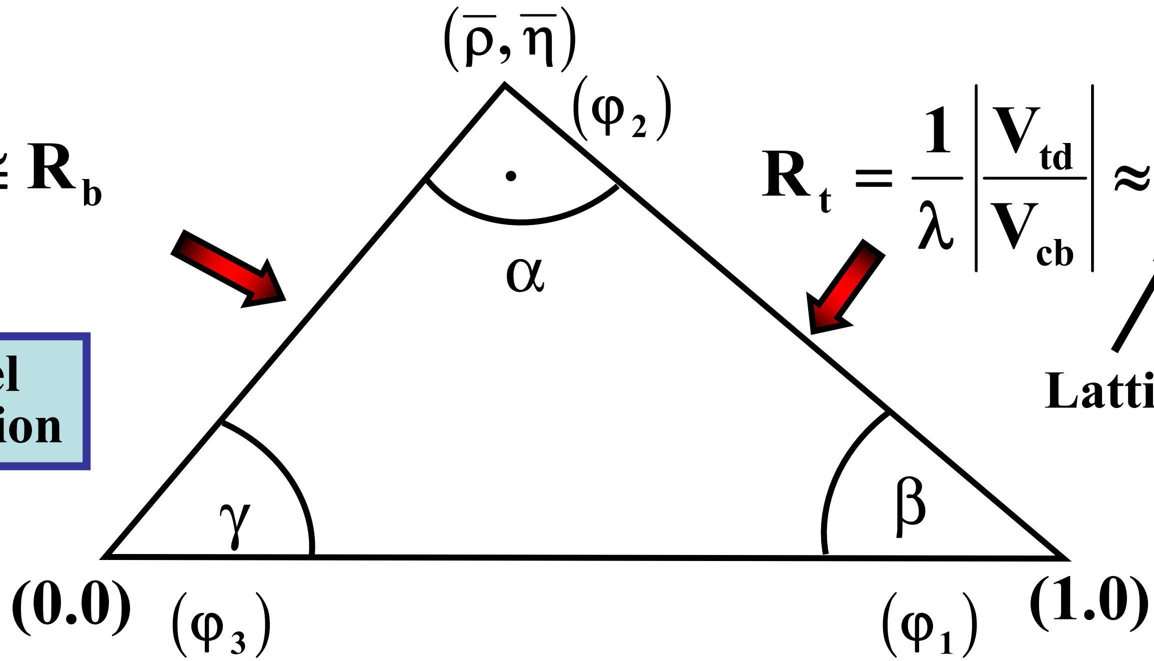
$(\varphi_{NP}=0,\ r_{NP}=1)$

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

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

$\xi = 1.21 \pm 0.04$

Lattice



Tree Level Determination
(NP free)

Loop Determination
(Not NP free)

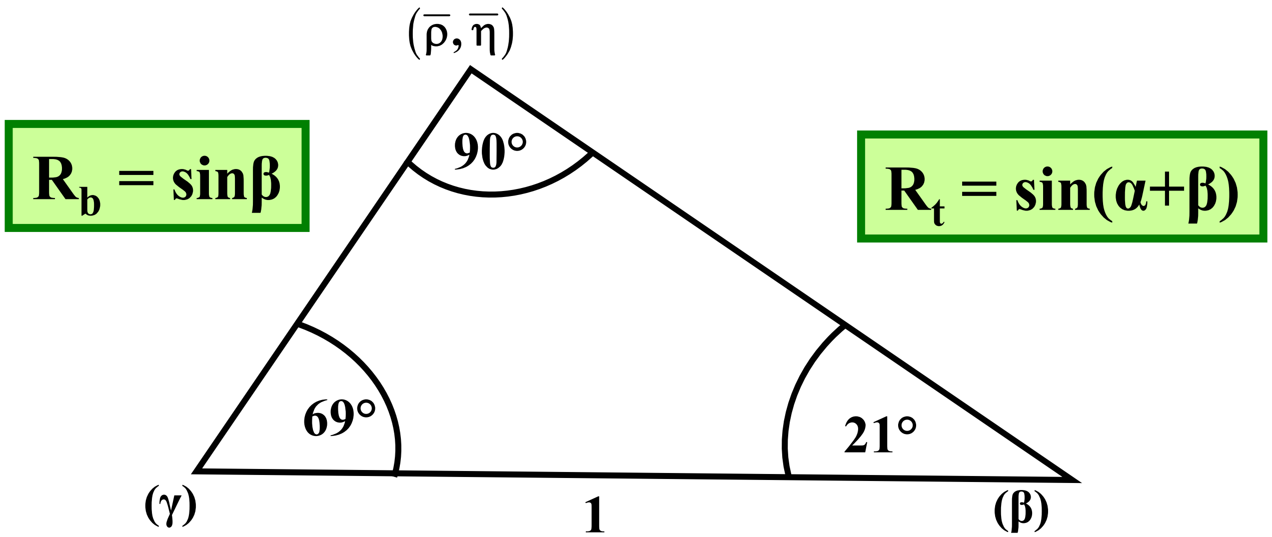
Flavour Matrix

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

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

Unitarity Triangle in LO Approximation

$\alpha = 90°$ $\sin 2\beta = 2/3$

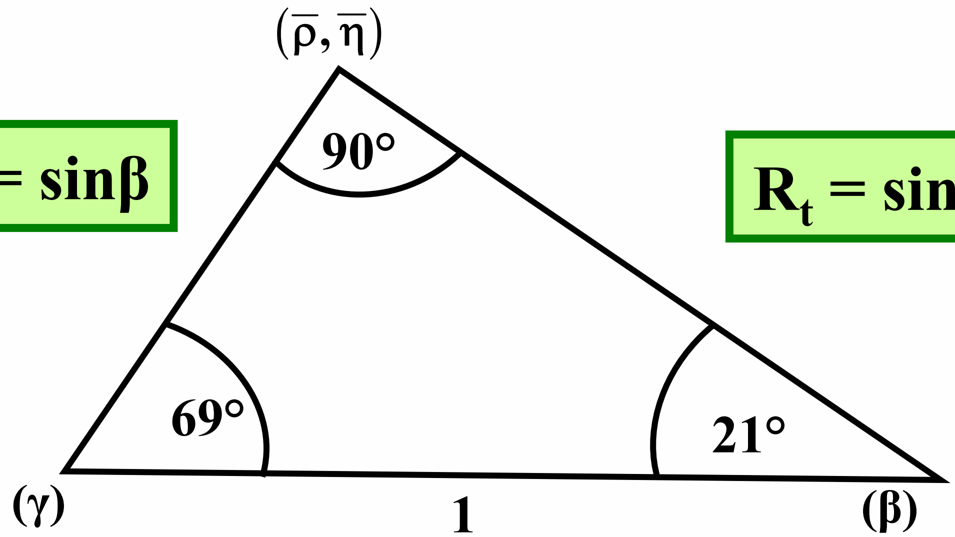


$\bar{\rho} = \sin\beta\cos\gamma$ $\bar{\eta} = \sin\beta\sin\gamma$

Unitarity Triangle in LO Approximation

$\alpha = 90°$ $\sin 2\beta = 2/3$

$R_b = \sin\beta$



$R_t = \sin(\alpha + \beta)$

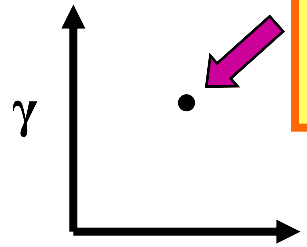
$\bar{\rho} = \sin\beta \cos\gamma$ $\bar{\eta} = \sin\beta \sin\gamma$

Search for New Physics in 2010´s

★ To study transparently possible tensions between ε_K, $\sin 2\beta$, V_{ub}, γ, $\Delta M_d / \Delta M_s$

Leave ($\bar{\rho}, \bar{\eta}$) plane

Go to



Tree level (NP free) Determination possible

$R_b \sim \left|\frac{V_{ub}}{V_{cb}}\right|$

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

Go to

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

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

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

BJW (90) HN (94)

2009 News

Large N
$\hat{B}_K = 0.75$
BBG (87)

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

RBC-UKQCD
Aubin et al.
ETMC

★ $\kappa_\varepsilon \cong 0.92 \pm 0.02$ (correction neglected in the past)

AJB + Guadagnoli (08)
(Nierste; Vysotsky)

★ NNLO QCD calculation of η_{cc}, η_{ct} Brod + Gorbahn (09)

(BG) $|\varepsilon_K^{SM}| = (1.80 \pm 0.22) \cdot 10^{-3}$ $|\varepsilon_{exp}| = (2.223 \pm 0.012) \cdot 10^{-3}$

(BaBar Belle) using $(\sin 2\beta)_{\psi K_s} = 0.672 \pm 0.023$ (NA48, KLOE, KTeV)

Diego Guadagnoli

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)

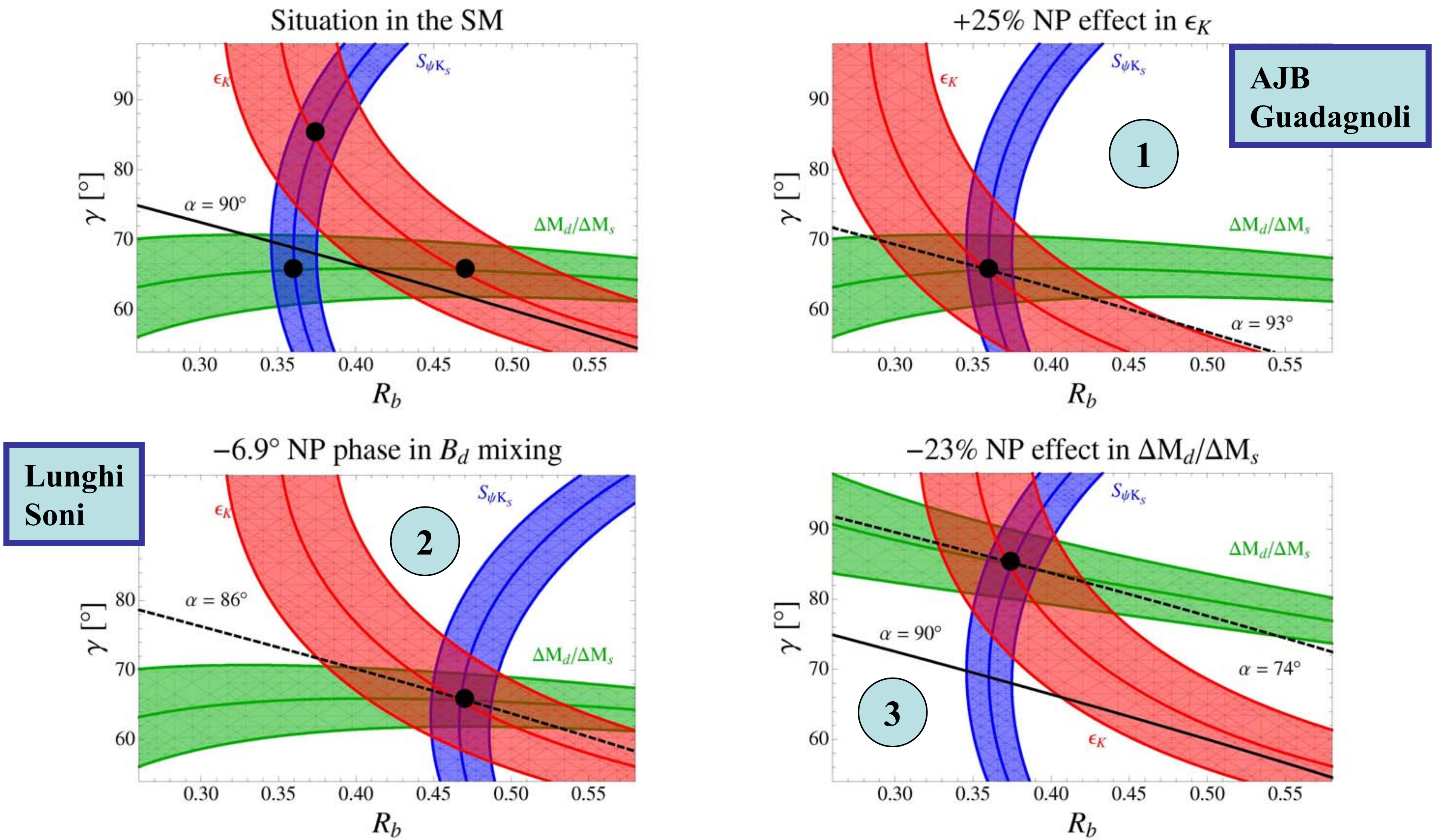
3. Increase R_t ⇒ $\gamma = \delta_{CKM} \approx 67^o \Rightarrow 82^o$ ⟺ LHC

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

AJB, Parodi, Stocchi (2002)
Altmannshofer, AJB, Guadagnoli (2007)

The R_b-γ Plane

Altmannshofer, AJB, Gori, Paradisi, Straub (2009)



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

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = \left(17 \begin{matrix} +11 \\ -10 \end{matrix}\right) \cdot 10^{-11}$$

(E787, E949 Brookhaven)

$$Br(K_L \to \pi^0 \nu\bar{\nu}) \leq 6.8 \cdot 10^{-8}$$

(E391a, KEK)

Future :

NA62
Project X (FNAL)

J-PARC KOTO

Both very sensitive to New Physics

CP-conserving
TH uncertainty 2-3%

CP-Violation in Decay
TH uncertainty 1-2%

Maximal Enhancements of $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$

Model independent bound

$$Br\left(K_L \to \pi^0 \nu\bar{\nu}\right) \le 4.4\ Br\left(K^+ \to \pi^+ \nu\bar{\nu}\right)$$

Grossman Nir

Model	$Br\left(K^+ \to \pi^+ \nu\bar{\nu}\right)$	$Br\left(K_L \to \pi^0 \nu\bar{\nu}\right)$
CMFV	20%	20%
MFV	30%	30%
LHT	150%	200%
RS	60%	150%
GMSSM	300%	500%
AC	2%	2%
RVV	10%	10%

(Bobeth et al Haisch, Weiler Isidori et al)

(Blanke et al)

(Duling et al)

(ABGPS)

SUSY with flavour symmetries

(abelian)

(non-abelian)

Large RH Currents

RS = RS with custodial protections

AC = Agashe, Carone

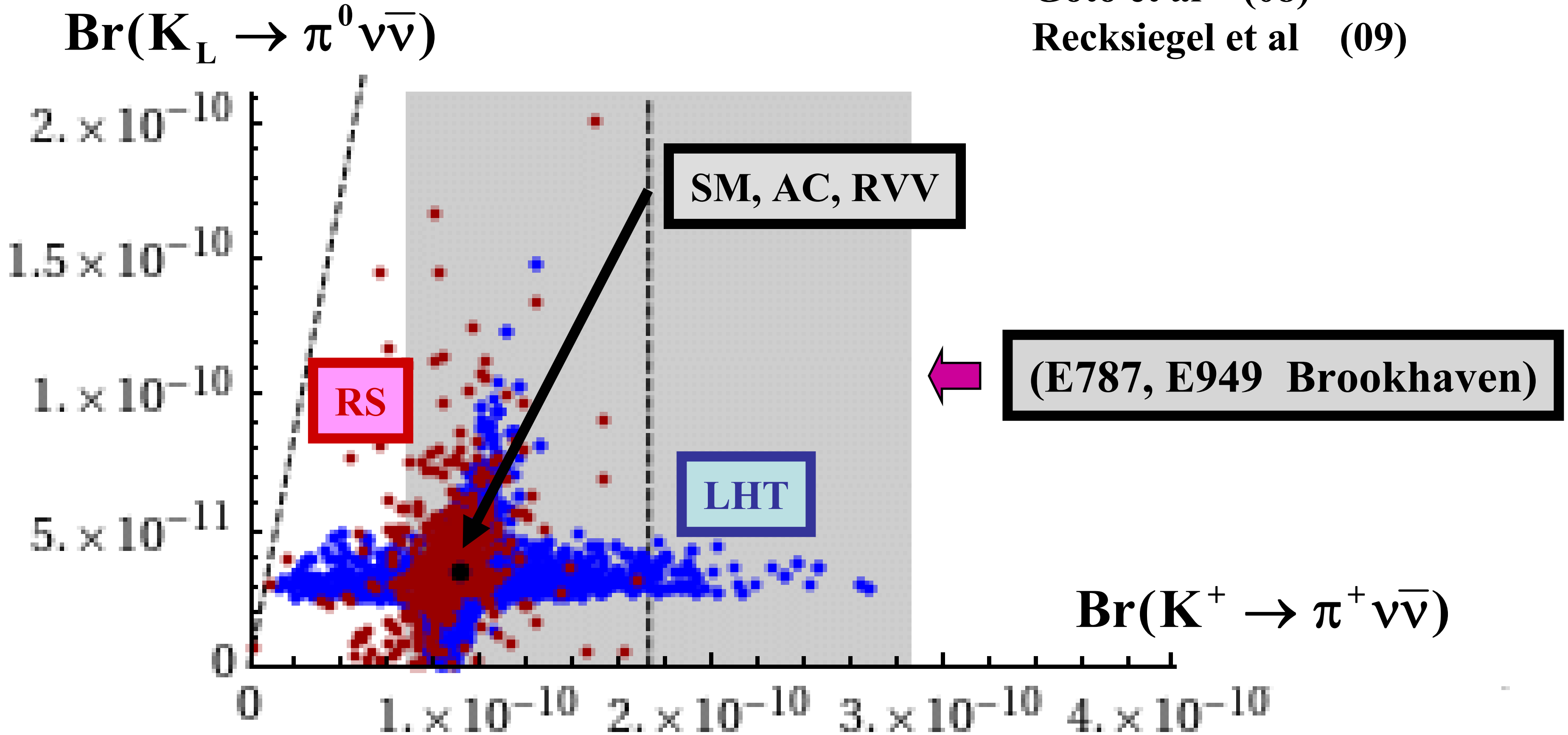
RVV = Ross, Velaso-Sevilla, Vives (04)

$U(1)_F$

$SU(3)_F$

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

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



★

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

Z-Penguin (SM
+ Boxes CMV)

SM

$$Br(B_s \to \mu^+\mu^-) = (3.6 \pm 0.4) \cdot 10^{-9}$$

$$Br(B_d \to \mu^+\mu^-) = (1.1 \pm 0.1) \cdot 10^{-10}$$

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

AJB (03)

CMFV "Golden Relation"

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

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

(1.00±0.03) Lattice

Valid in all CMFV models

Can be strongly violated in SUSY, LHT, RS

95% CL

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

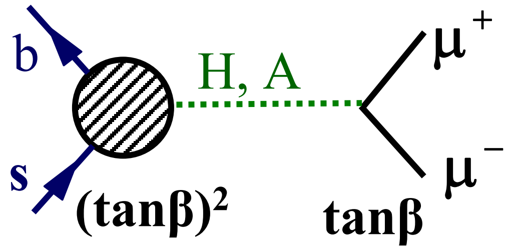
$$Br(B_d \to \mu^+\mu^-) \le 1 \cdot 10^{-8} \text{ (CDF)}$$

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

$B_{s,d} \to \mu^+\mu^-$ in SUSY and Higgs Penguins

(Helicity suppression lifted)

Babu, Kolda (99),…+100



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

Can reach CDF and DØ bounds

Very important for the distinction of SUSY from LHT and RS !!!

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

(Z-penguin)
(Blanke et al) (09)

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

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

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

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

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

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

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

$0.81^{+0.12}_{-0.32}$

★ CDF
D0

$$0.20 \le \left(S_{\psi\varphi}\right)_{exp} \le 0.98$$

90% C.L. (HFAG)

If confirmed, clear signal of NP with non-MFV interactions and new sources of ~~CP~~

Model Expectations

$$S_{\psi\varphi} \le \begin{cases} 0.75 \ \ (\text{AC}) \ \ (\text{abelian flavour, SUSY}) \ (\text{Higgs penguin}) \\ 0.50 \ \ (\text{RVV}) \ \ (\text{non-abelian flavour, SUSY}) \ (\text{Higgs penguin}) \\ 0.75 \ \ (\text{RS}) \ \ \ (\text{Heavy KK Gauge Bosons}) \ \ (\text{Duling et al (08)}) \\ 0.30 \ \ (\text{LHT}) \ \ (\text{Mirror Fermions at work}) \ \ (\text{Tarantino et al (09)}) \end{cases}$$

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

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

(without taking correlation between them)

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

Correlations between $K^+ \to \pi^+ \nu\bar{\nu}$, $K_L \to \pi^0 \nu\bar{\nu}$, $S_{\psi\varphi}$, $B_s \to \mu^+\mu^-$

★ **Impact of a future $S_{\psi\varphi} \approx 0.3$**

LHT
RS
}

Sizable Enhancements in $K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L \to \pi^0 \nu\bar{\nu}$ excluded in RS and unlikely in LHT

$B_{s,d} \to \mu^+\mu^-$ SM - like

(Blanke et al)

(abelian)
AC
RVV
(non-abelian)
}

$Br(B_s \to \mu^+\mu^-)$ forced to be $3 \cdot Br(B_s \to \mu^+\mu^-)_{SM} \sim 10^{-8}$

SUSY Flavour Models

Altmannshofer, AJB, Gori, Paradisi, Straub (09)

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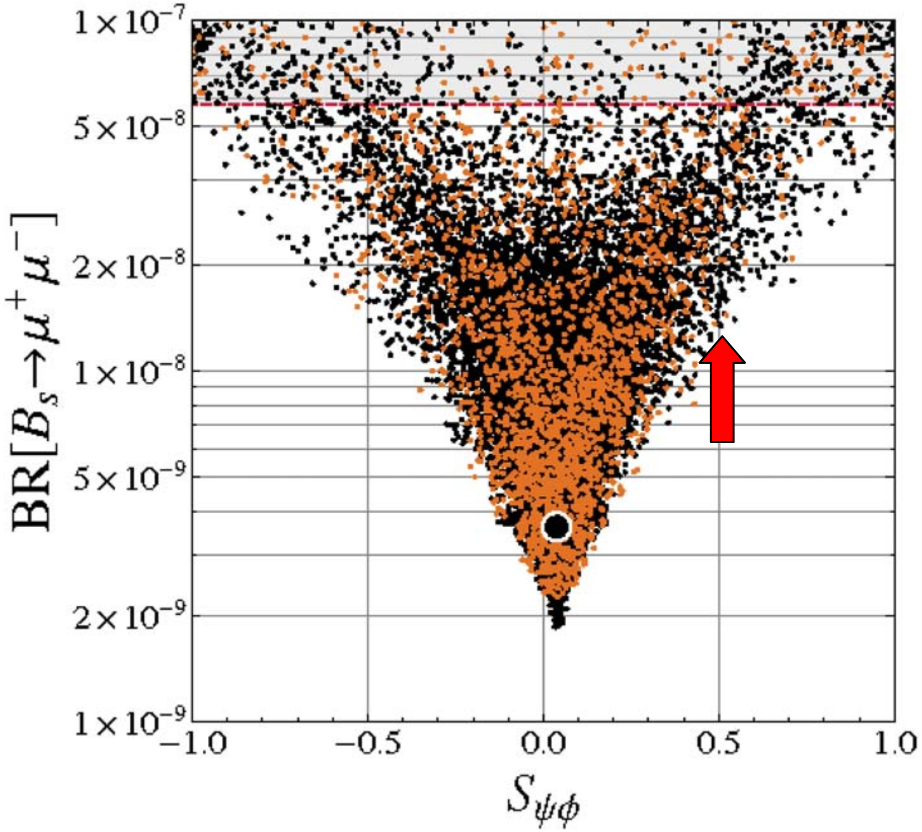
CDF, D0
LHCb

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

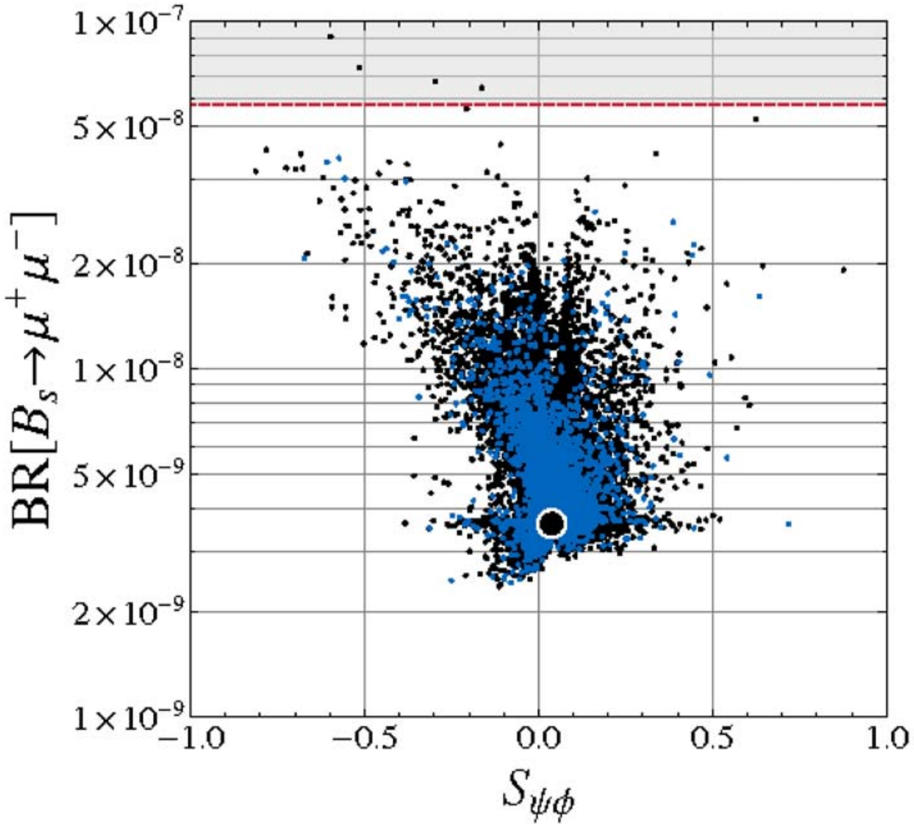
ABGPS

Solution 3 to ε_K-Anomaly
Abelian (AC)



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

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



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

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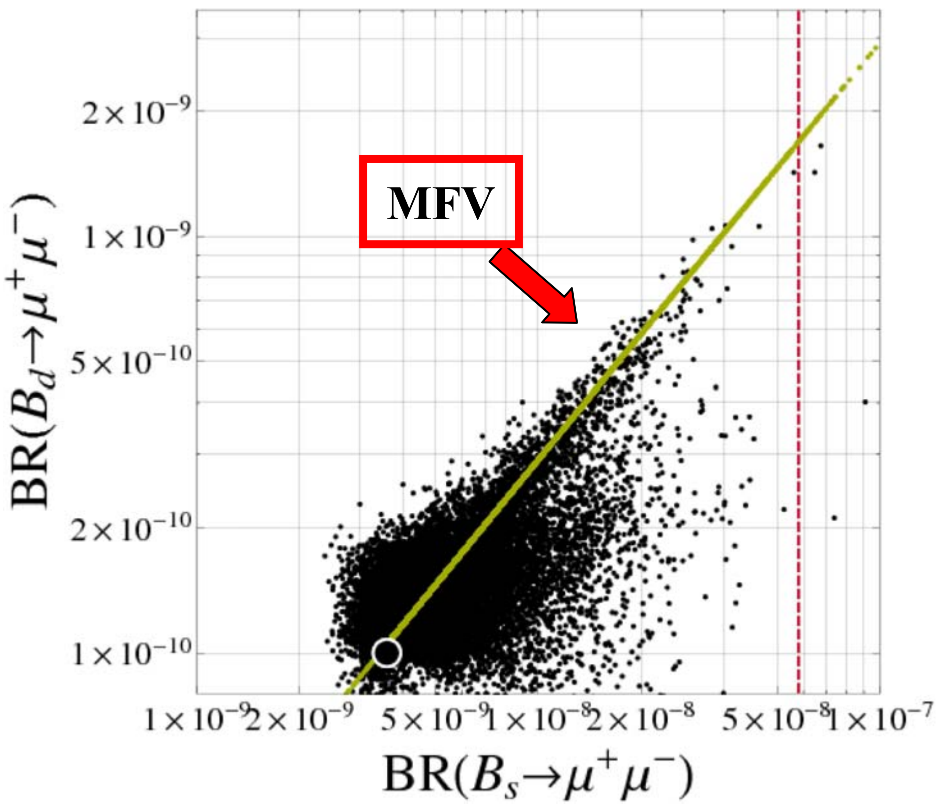
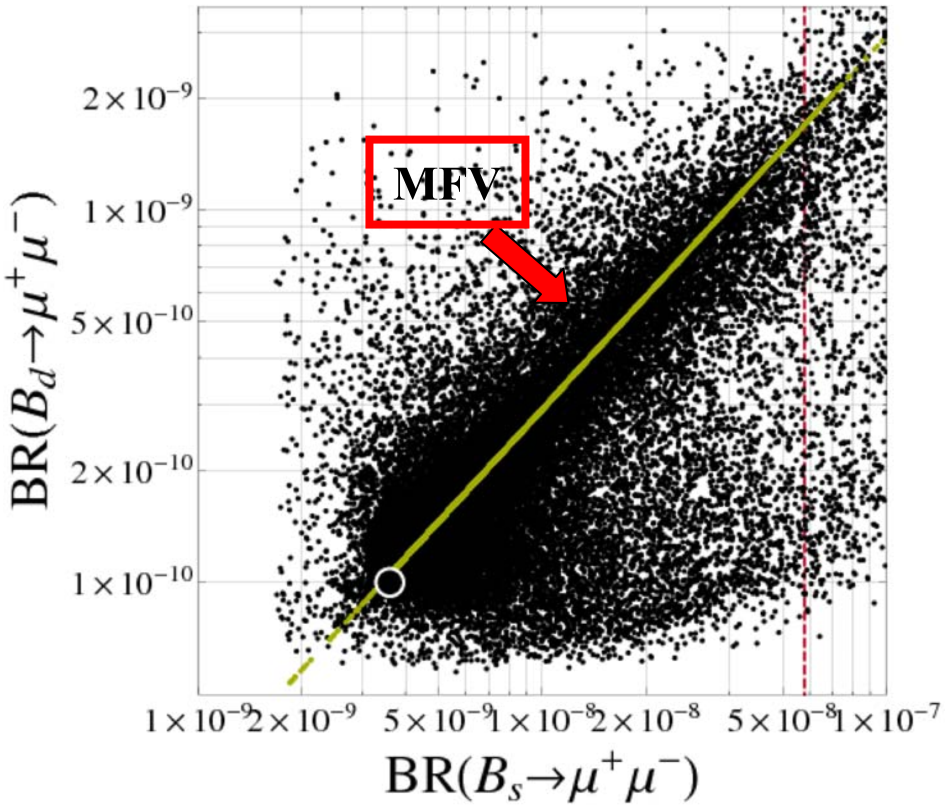
$Br(B_d \to \mu^+\mu^-)$ vs $Br(B_s \to \mu^+\mu^-)$

MFV **AJB; Hurth, Isidori, Kamenik Mescia**





RVV2 **(RH currents)**

LH currents

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

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

(Beneke)

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

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

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

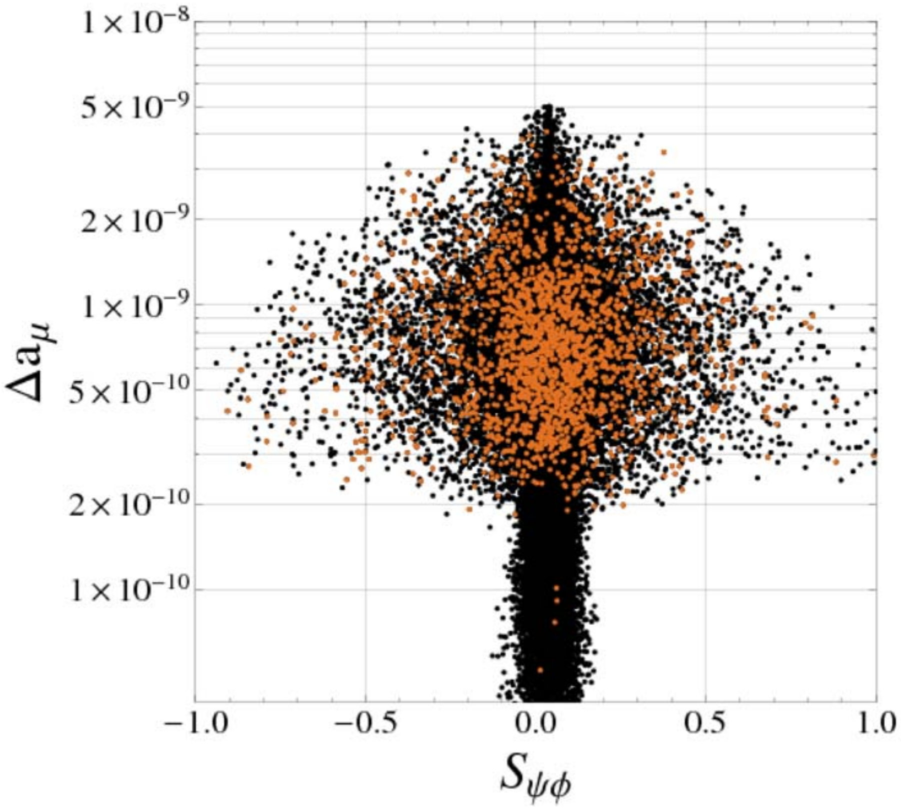
(Regan et al) $d_e < 1.6 \cdot 10^{-27}$ ➡ 10^{-31} $(d_e)_{SM} \approx 10^{-38}$

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

[e cm]

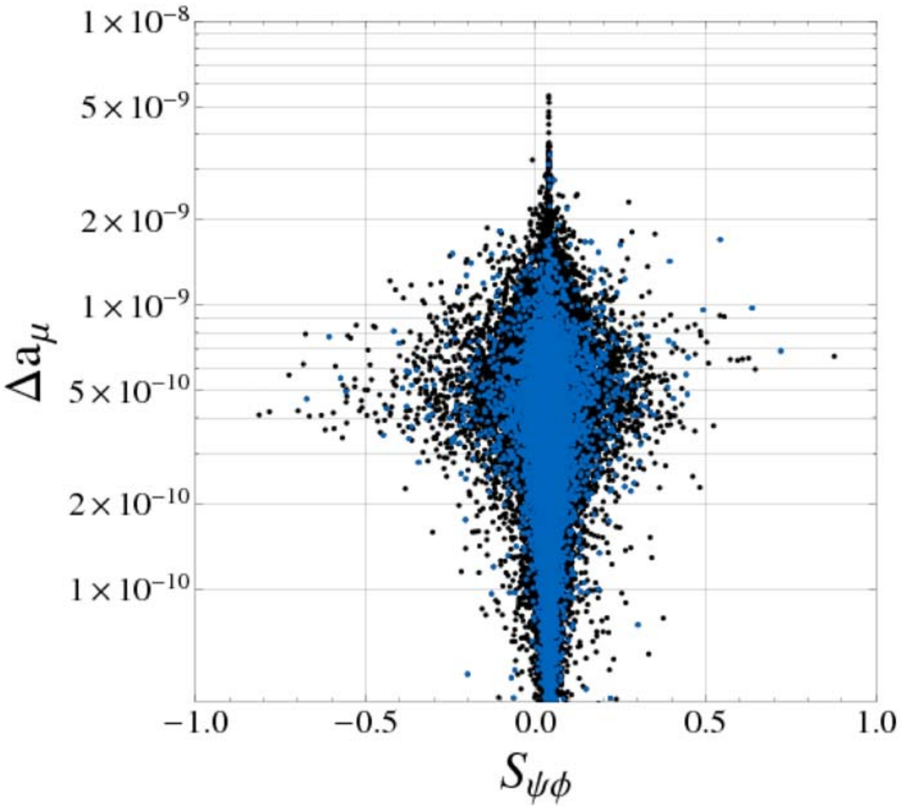
Simultaneous Solution to Δa_μ and $S_{\psi\varphi}$ Anomalies

Solution 3 to ε_K-Anomaly
Abelian (AC)



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

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

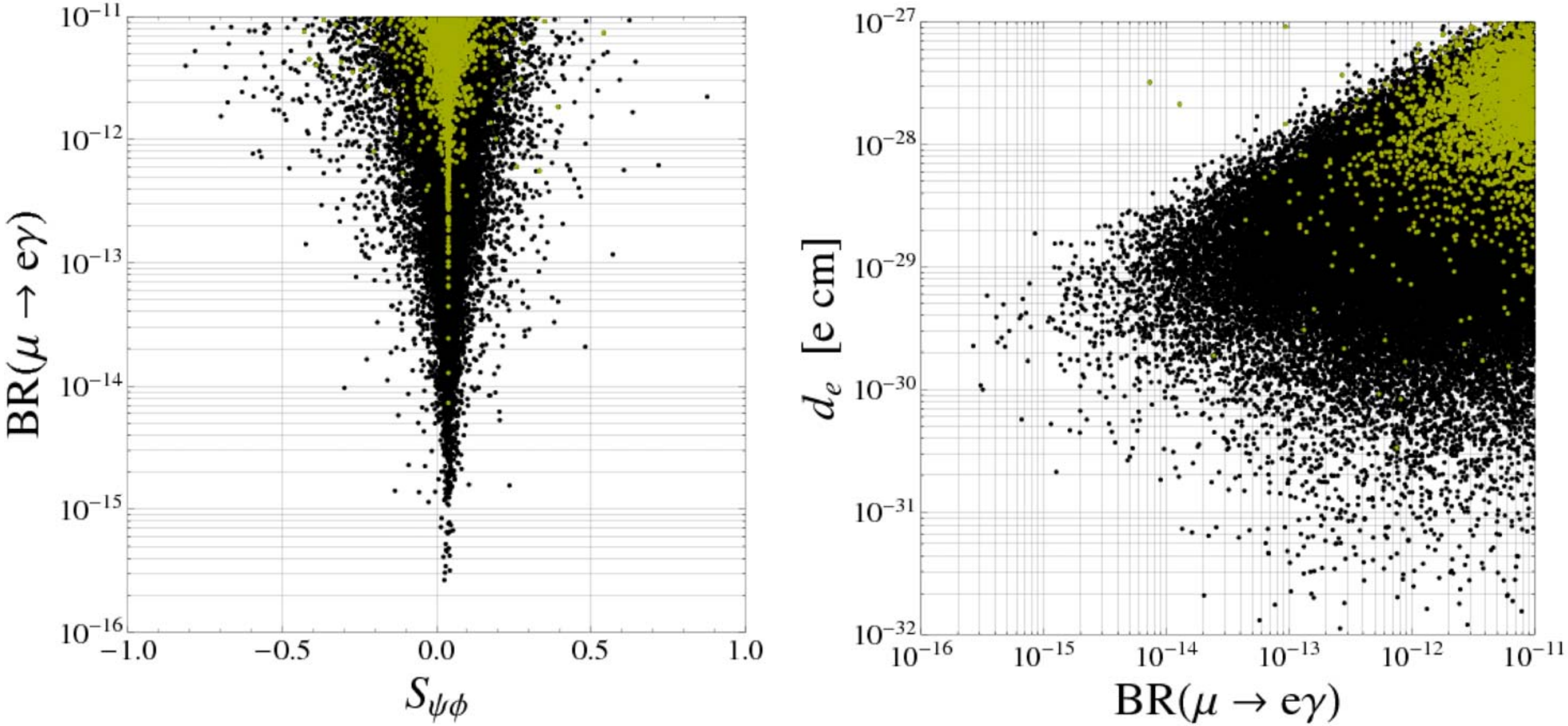


(Small Effects in D^0-$\bar{D}^0$)

ABGPS

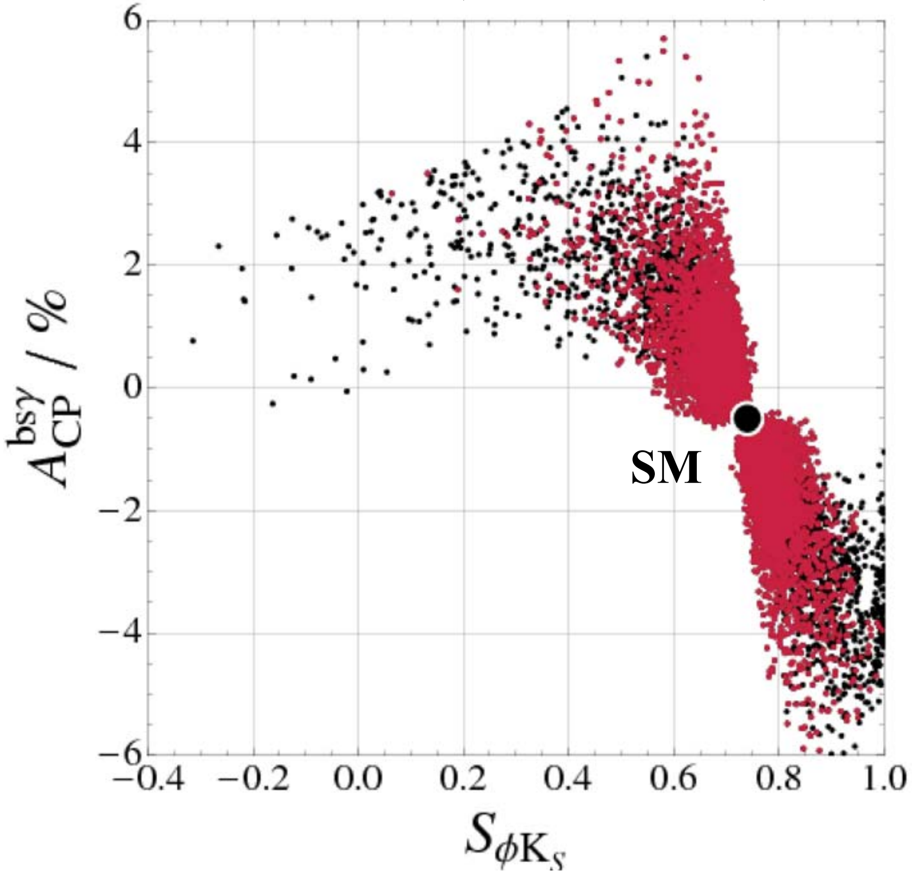
Correlations in the SU(3) Flavour Model (RVV2)

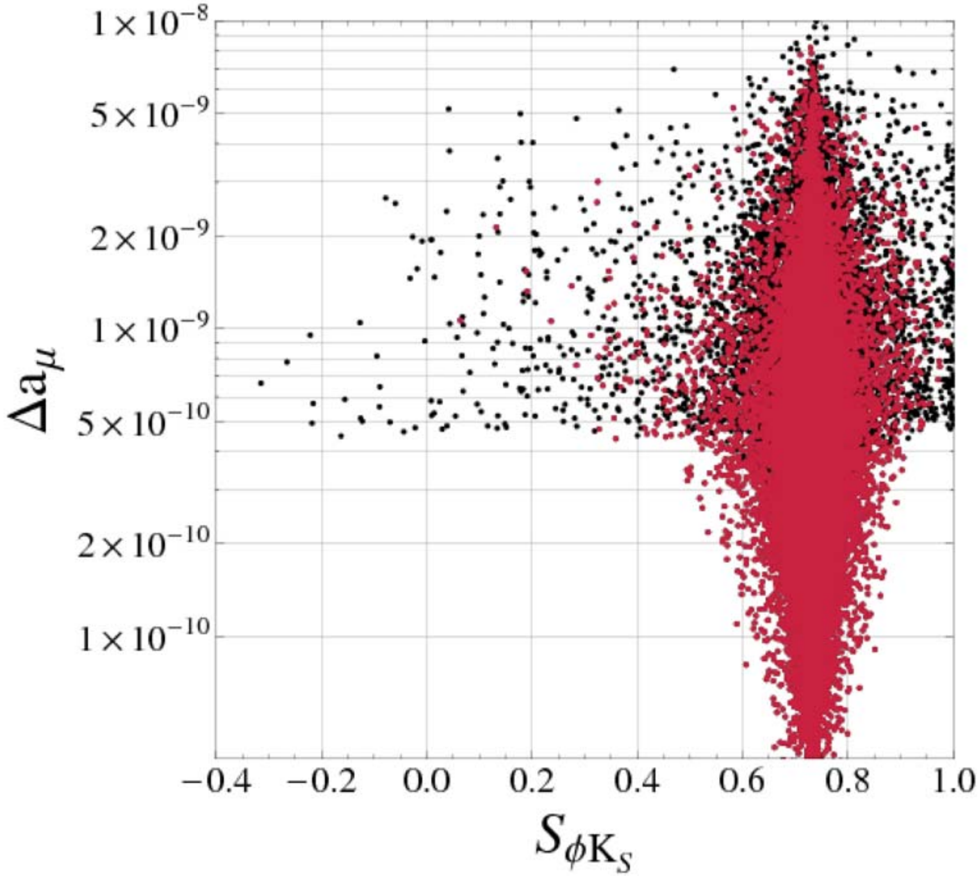
Solution to $(g\text{-}2)_\mu$ anomaly



Correlations in a Flavour Model with LH Currents

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





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)

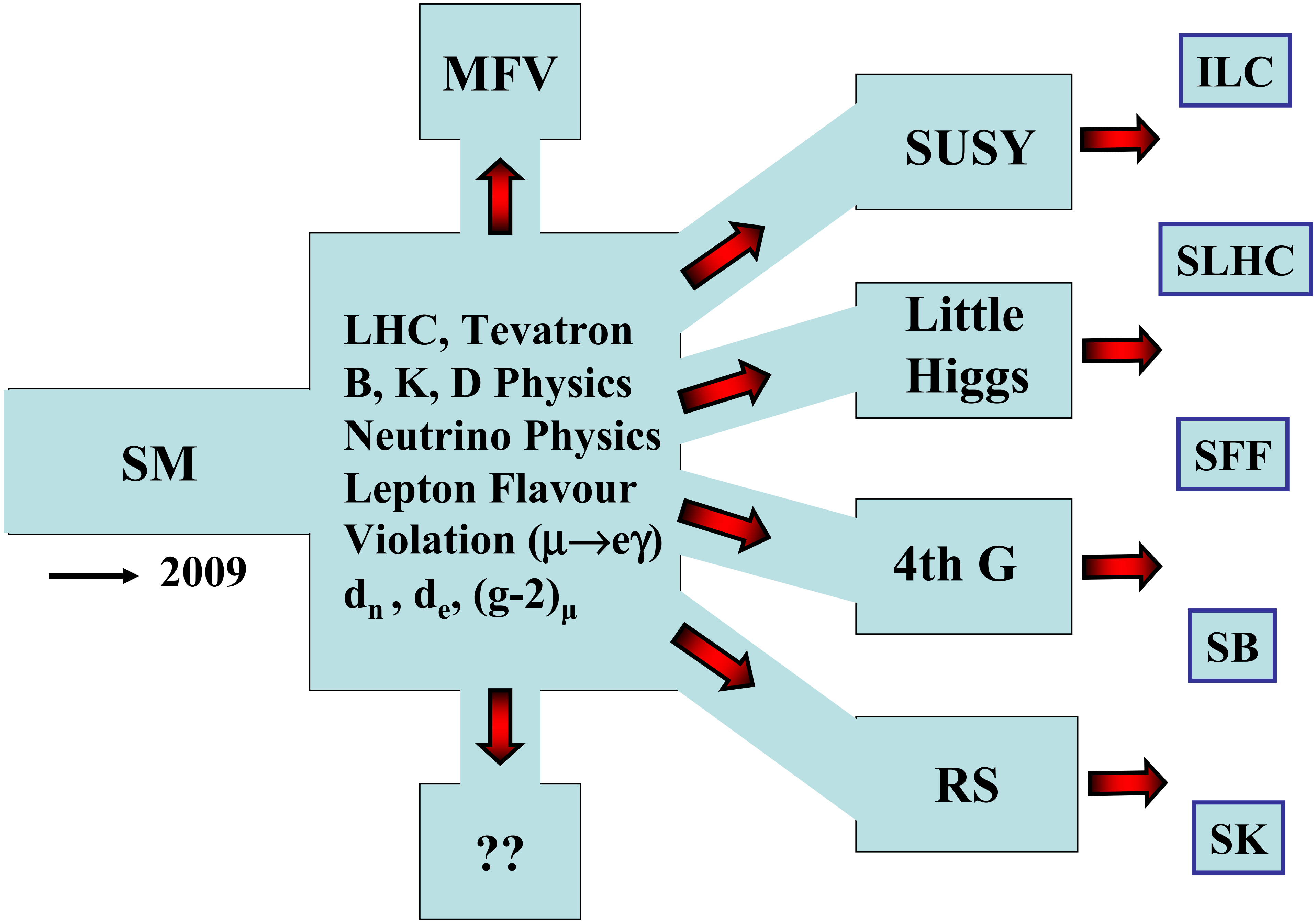
ABGPS

DNA Tests of Flavour Models

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

4.

Final Messages


MFV
SUSY
ILC
SLHC
Little Higgs
SFF
4th G
SB
RS
SK
SM
2009
LHC, Tevatron
B, K, D Physics
Neutrino Physics
Lepton Flavour
Violation ($\mu \to e\gamma$)
d_n , d_e, $(g-2)_\mu$
??

Final Messages of this Talk

Flavour Physics (Quarks and Leptons) :

Many observables (decays) not measured yet or measured poorly. Flavour Physics only now enters the precision era.

↓

Spectacular deviations from SM still possible ⟷ (Interplay) **Direct searches at Tevatron, LHC, ILC**

Final Messages of this Talk

Flavour Physics (Quarks and Leptons) :

Many observables (decays) not measured yet or measured poorly. Flavour Physics only now enters the precision era.

Spectacular deviations from SM still possible

Interplay

Direct searches at Tevatron, LHC, ILC

DNA Flavour Test of NP models

Correlations between various observables can distinguish NP scenarios easier than LHC !

Great discoveries are just ahead of us !

Final Messages of this Talk

Flavour Physics (Quarks and Leptons) :

Many observables (decays) not measured yet or measured poorly. Flavour Physics only now enters the precision era.

↓

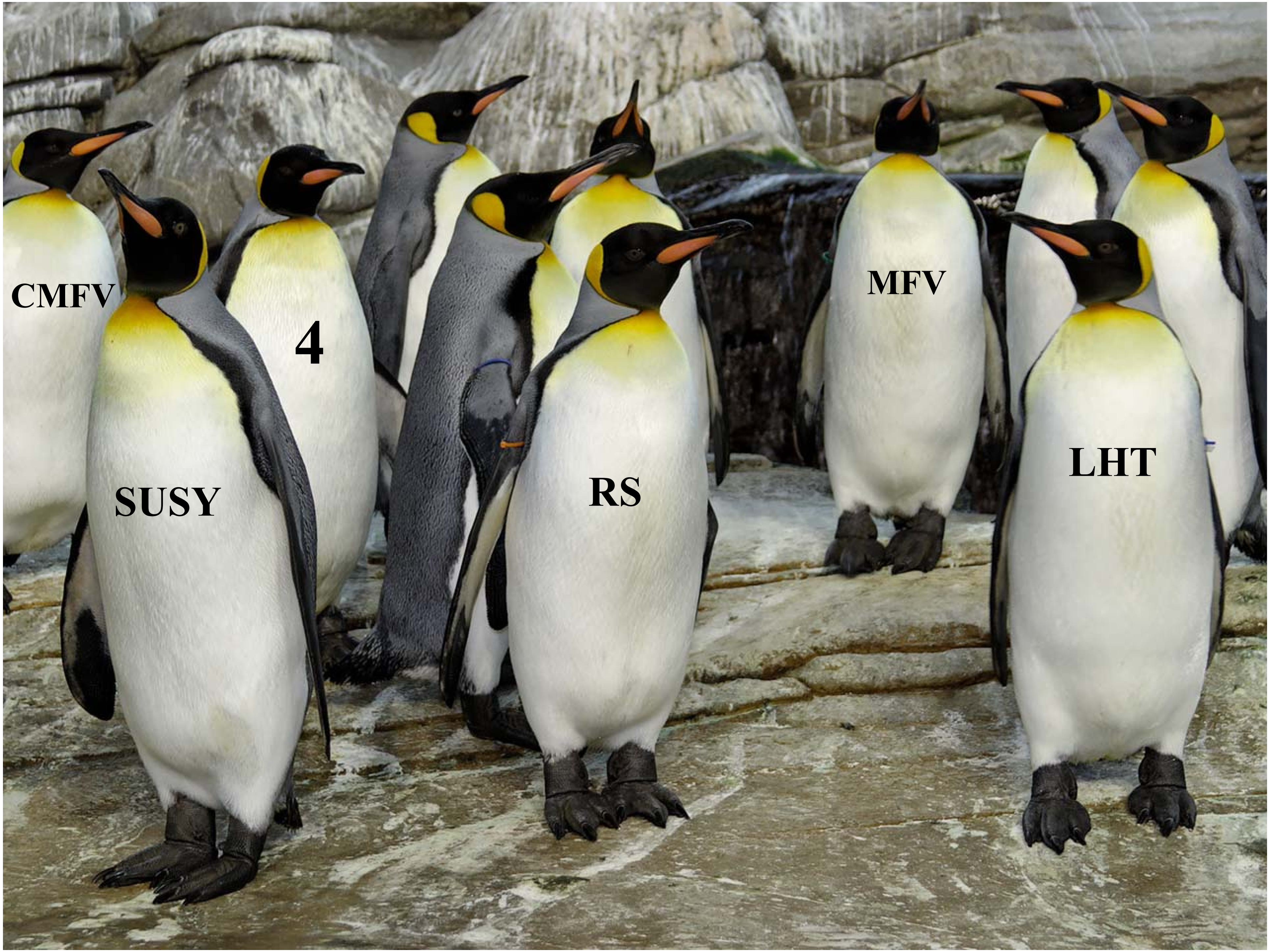
Spectacular deviations from SM still possible ⟷ Interplay ⟷ Direct searches at Tevatron, LHC, ILC

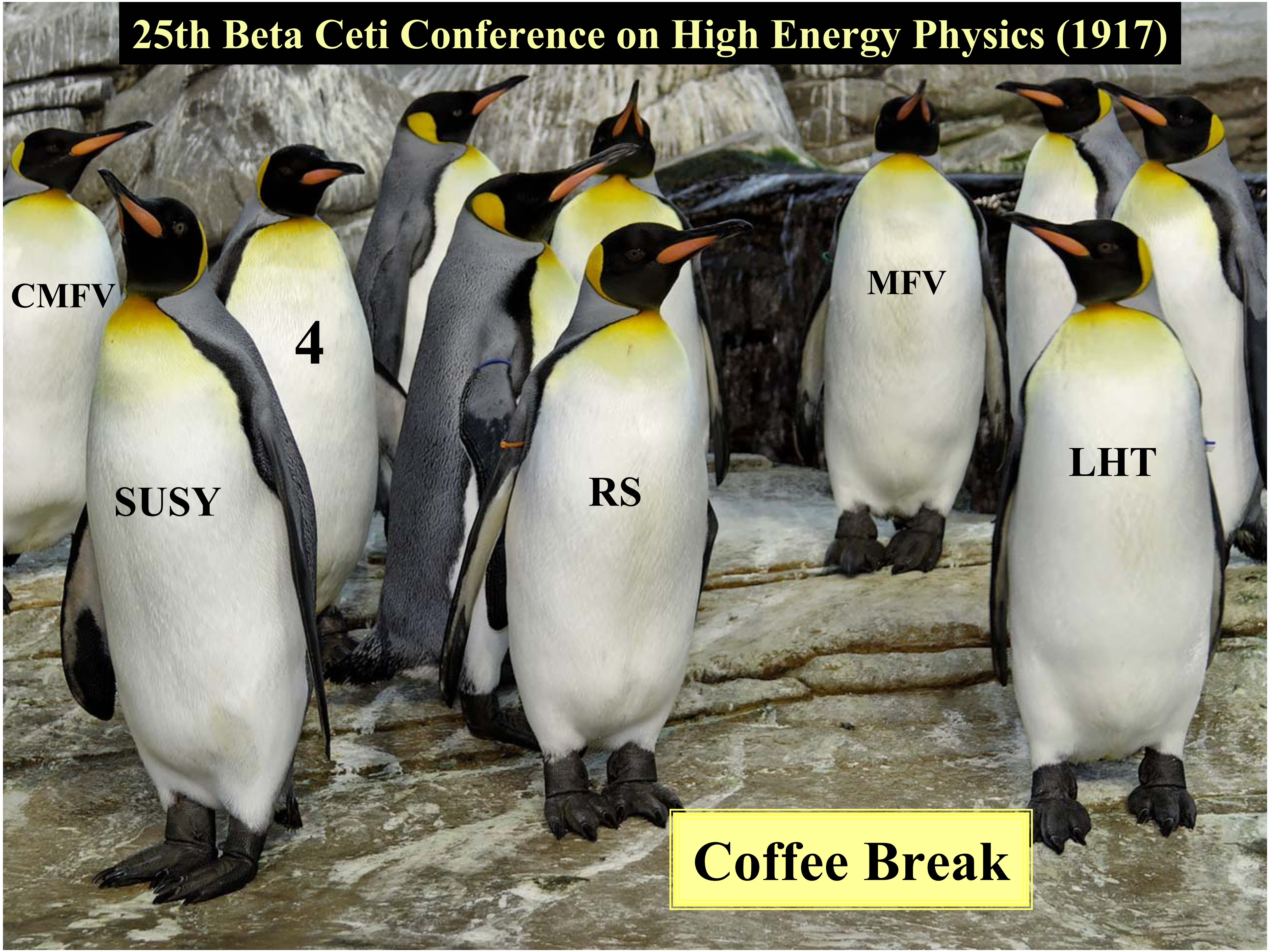
DNA Flavour Test of NP models

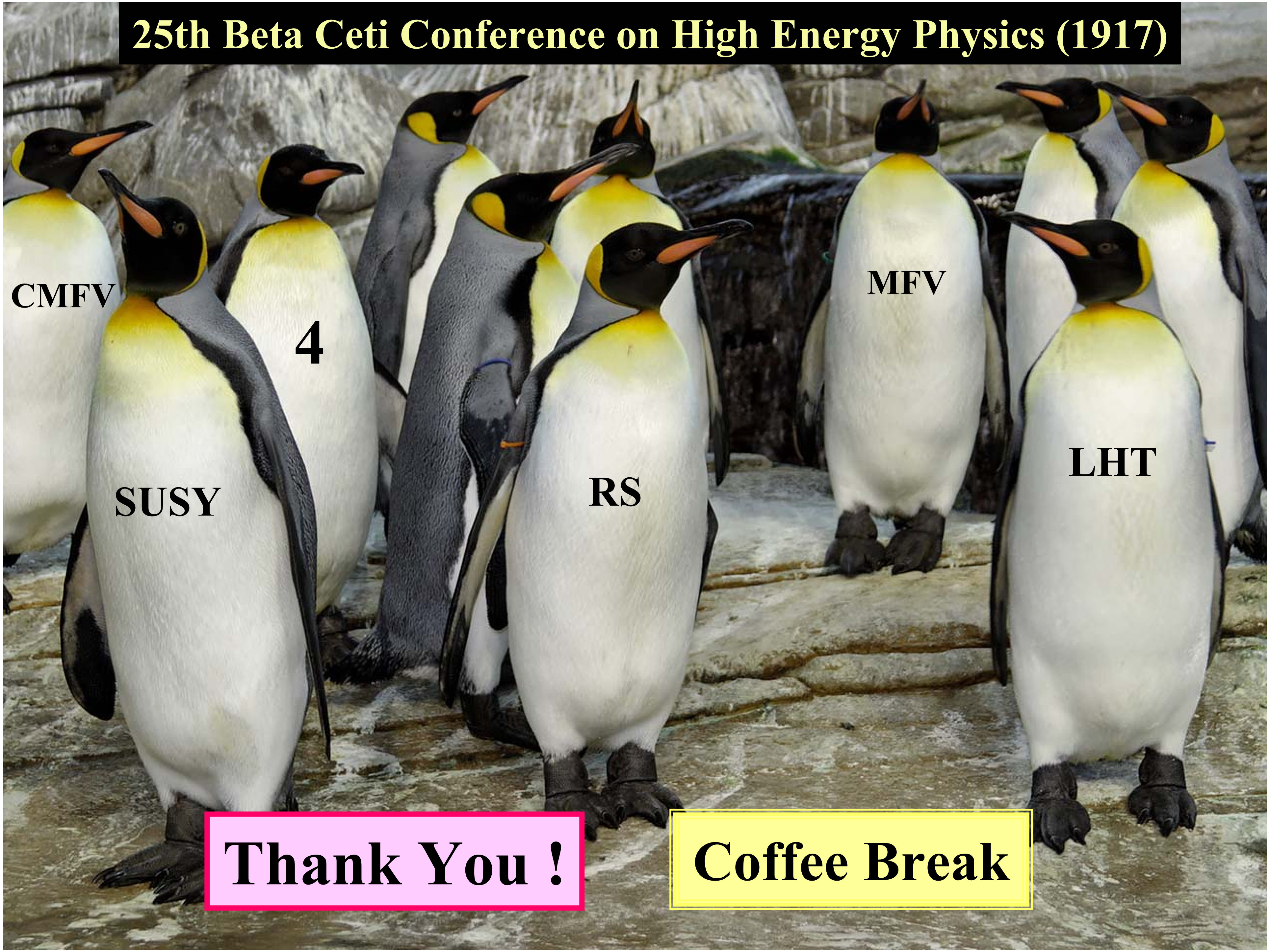
Correlations between various observables can distinguish NP scenarios easier than LHC !

★ **Thank You !**

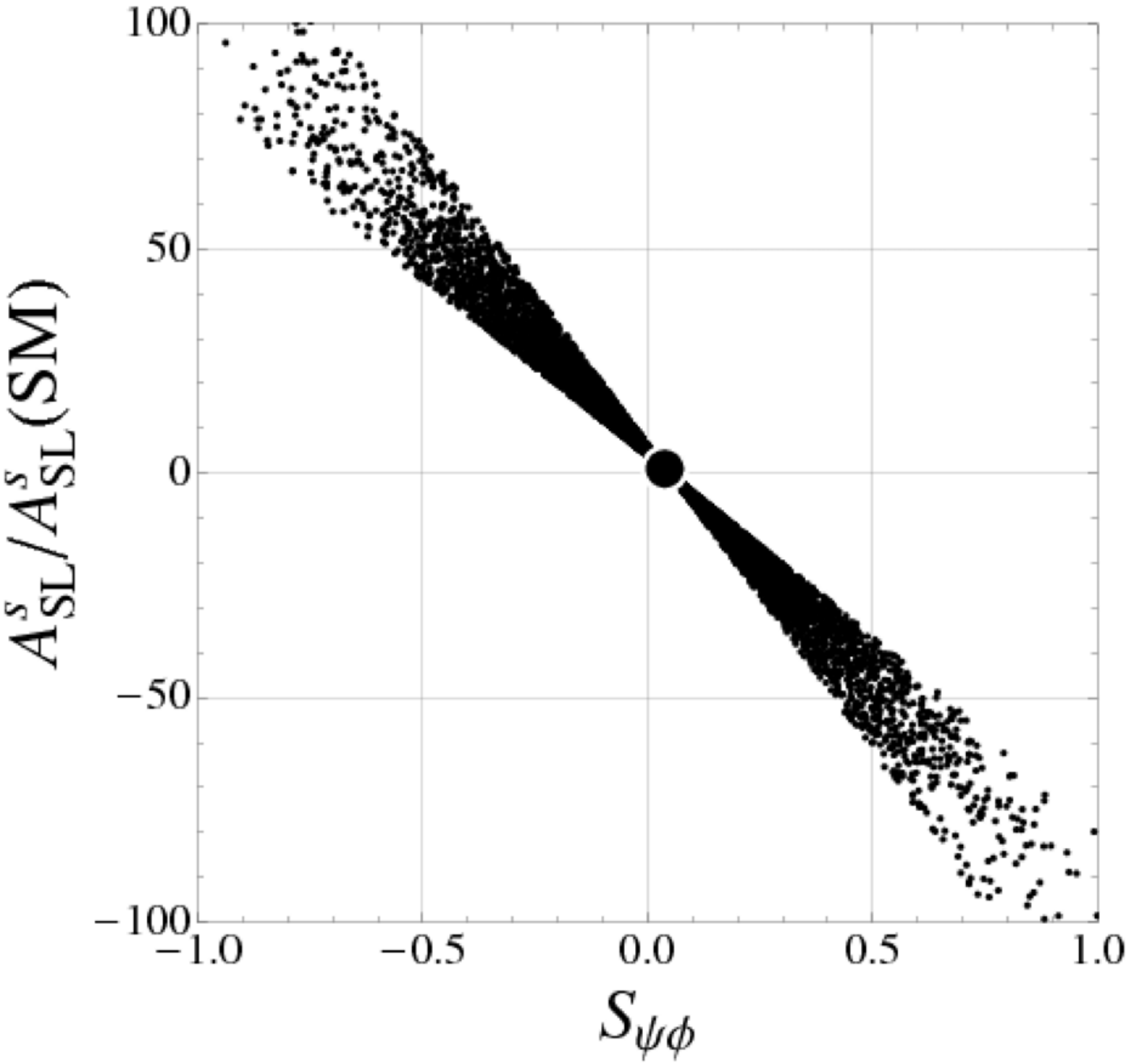
Great discoveries are just ahead of us !

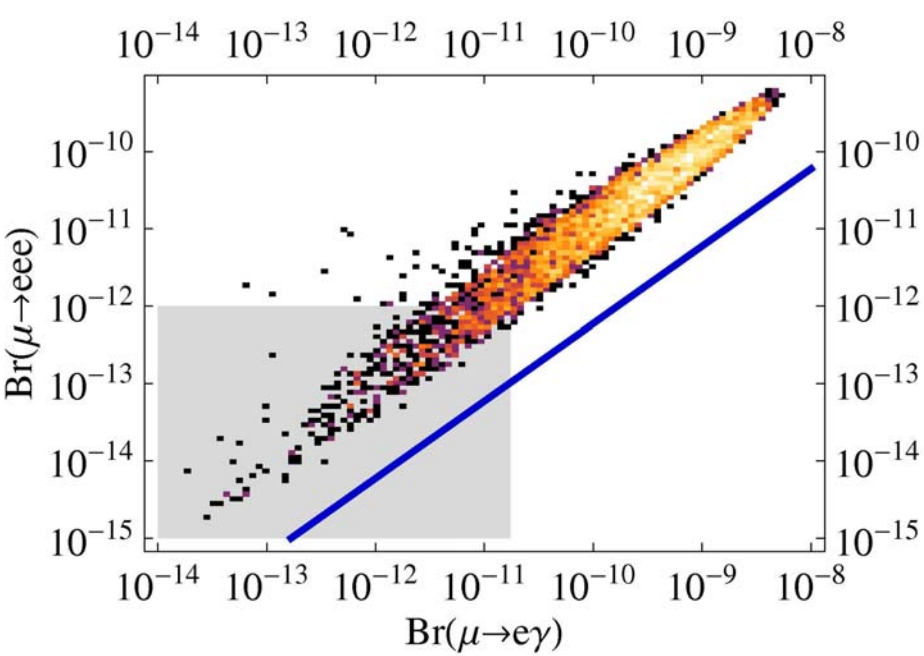

CMFV
4
MFV
LHT
RS
SUSY


25th Beta Ceti Conference on High Energy Physics (1917)
CMFV
4
SUSY
RS
MFV
LHT
Coffee Break

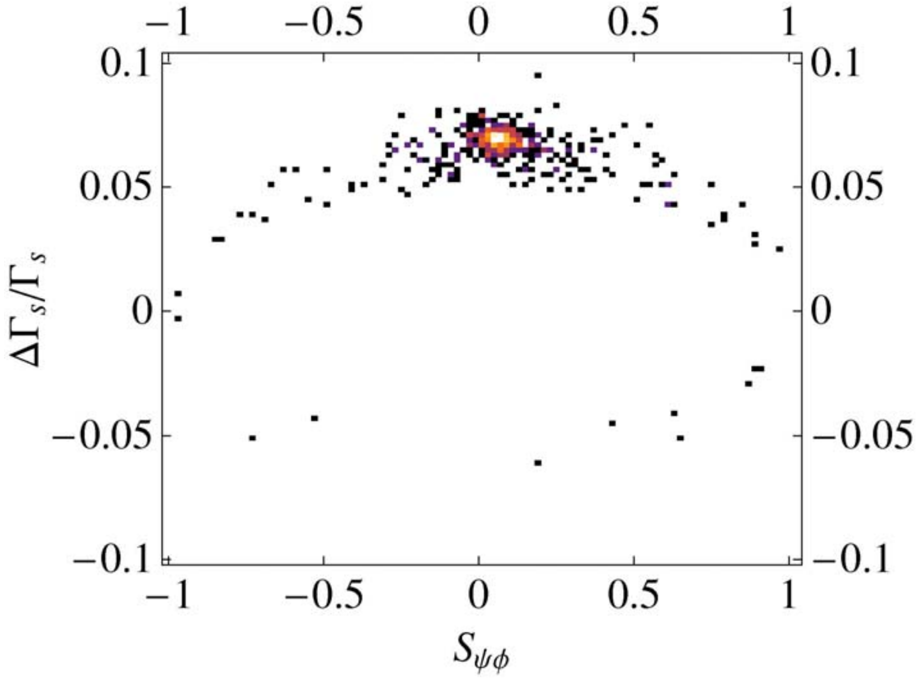

25th Beta Ceti Conference on High Energy Physics (1917)
CMFV
4
MFV
SUSY
RS
LHT
Thank You !
Coffee Break

Backup

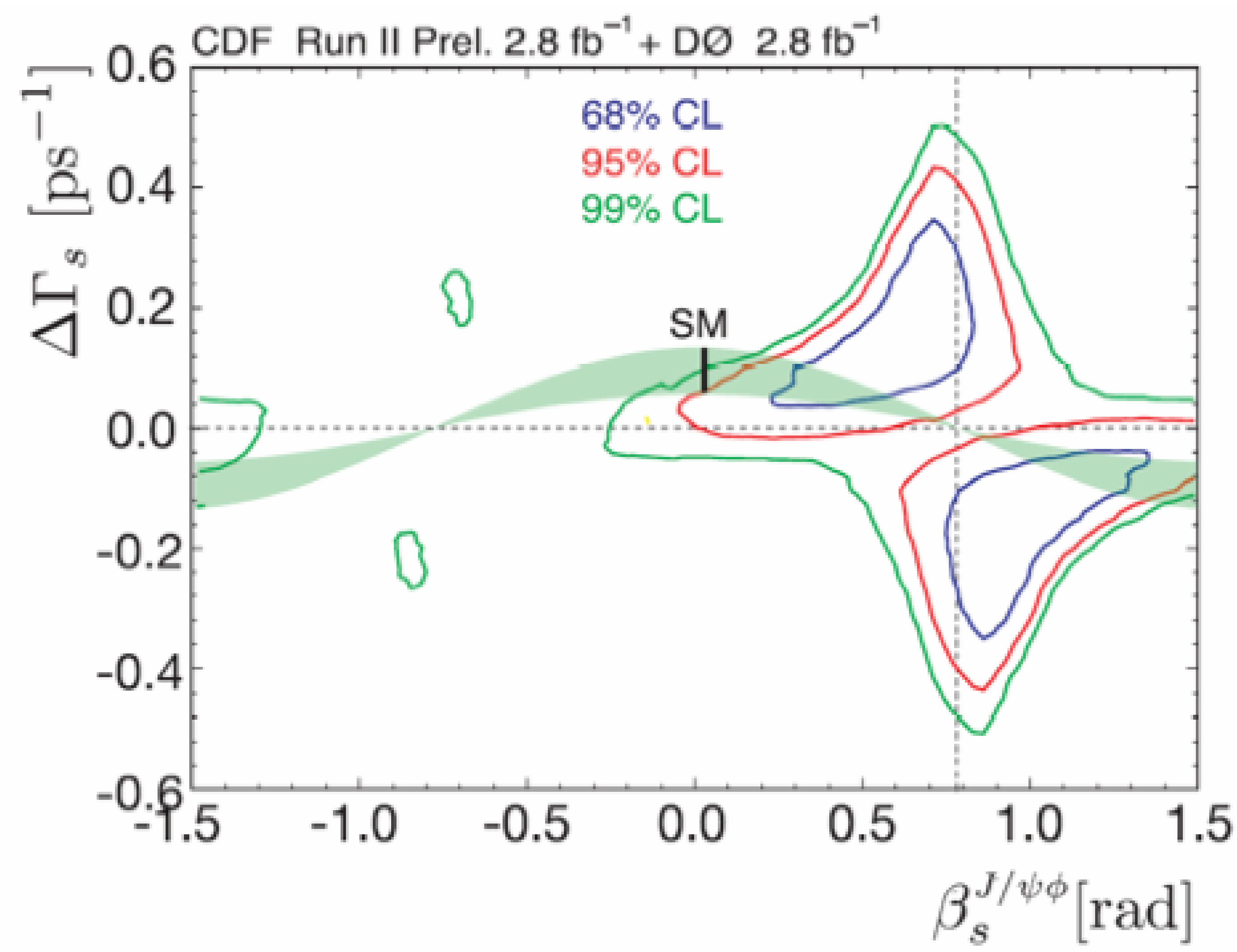

100
50
0
−50
−100
−1.0
−0.5
0.0
0.5
1.0
$A^s_{SL}/A^s_{SL}(SM)$
$S_{\psi\phi}$



Br(μ→eee)
Br(μ→eγ)



ΔΓs/Γs
Sψφ


CDF Run II Prel. 2.8 fb^{-1} + DØ 2.8 fb^{-1}
68% CL
95% CL
99% CL
SM
$\Delta\Gamma_s$ [ps^{-1}]
$\beta_s^{J/\psi\phi}$[rad]
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5

DNA Flavour Test of New Physics Models

	GMSSM	AC	RVV	δ_{LL} only	FBMSSM
$D^0-\bar{D}^0$ mixing	★★★	★★★	★	★	★
ϵ_K	★★★	★	★★★	★	★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★
$S_{\phi K_S}$, $S_{\eta' K_S}$	★★★	★★★	★★	★★★	★★★
$A_{CP}^{bs\gamma}$	★★★	★	★	★★★	★★★
$\langle A_{7,8}\rangle(B\to K^*\mu^+\mu^-)$	★★★	★	★★	★★★	★★★
$\langle A_9\rangle(B\to K^*\mu^+\mu^-)$	★★★	★	★★	★	★
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★
$B\to K^{(*)}\nu\bar{\nu}$	★★	★	★	★	★
$K\to\pi\nu\bar{\nu}$	★★★	★	★★	★	★
d_e, d_n	★★★	★★★	★★	★★	★★★

★★★: large effects, ★★: medium effects, ★: small effects

Return of ε′/ε ?

Final Result (NA48, KTeV)

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (16.8 \pm 1.4)\cdot 10^{-4}$$

(2009)

$$\mathrm{Re}(\varepsilon'/\varepsilon)_{SM} \approx \left\{\begin{matrix}\text{QCD}\\ \text{Penguins}\end{matrix}\right\} - \left\{\begin{matrix}\text{Electroweak}\\ \text{Penguins}\end{matrix}\right\}$$

(B_6) (B_8)

Very sensitive to New Physics

Wilson Coefficients of Penguins known at NLO (1990´s)
Munich (92,93)
Rome (93)

Large N calculations of hadronic Matrix Elements

Bardeen, AJB, Gerard (85)
Pich et al
De Rafael et al.
Bijnens + Prades
} (1990´s)

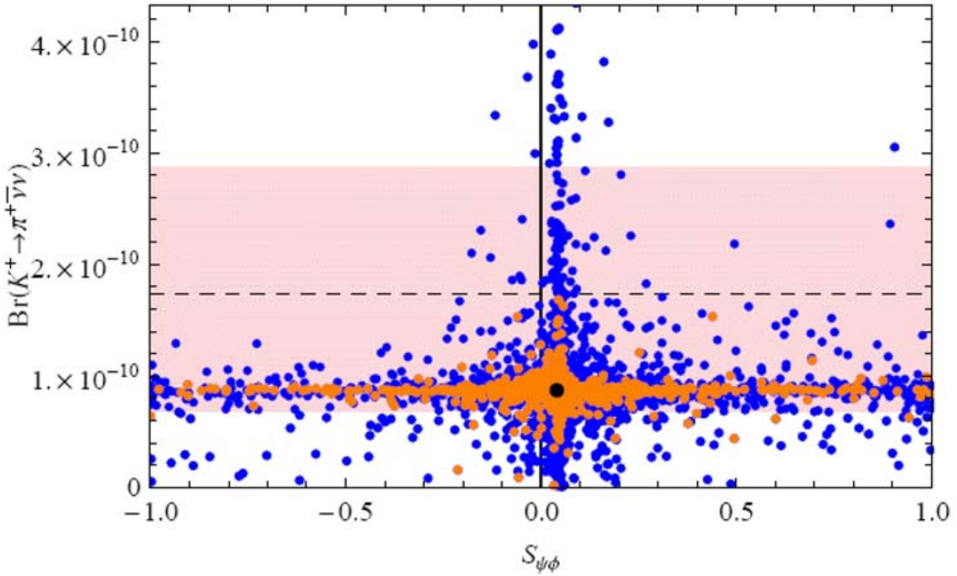
New Efforts on the Lattice

(Norman Christ et al.)

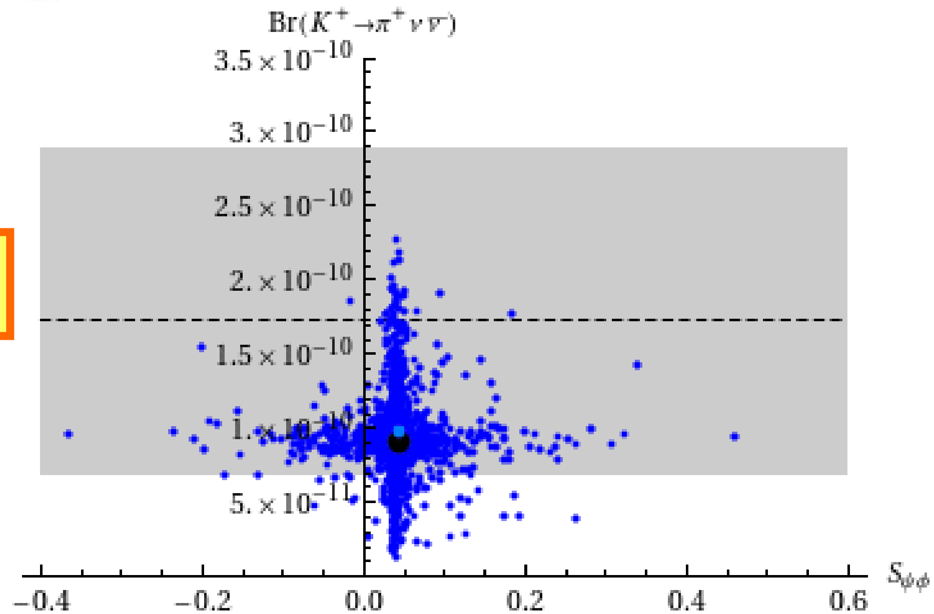
20015 ?

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

(Simultaneous Large Enhancements unlikely)



RS

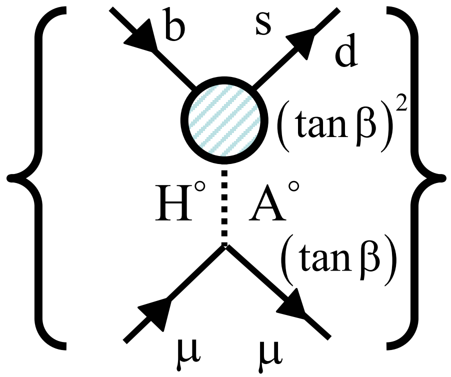


LHT

$B_{s,d} \to \mu^+\mu^-$ and MSSM with MFV at large tanβ

In MSSM at large tanβ
(CKM still the only source of Flavour and CP Violation)

Strong Enhancement



$$Br(B_{s,d} \to \mu\bar{\mu}) \sim (\tan\beta)^6$$

$10^{-6}\,(10^{-7})$ possible

SM ~ 10^{-9}

Babu, Kolda
Chankowski, Slawianowska
Bobeth, Ewerth, Krüger, Urban
Huang, Liao, Yan, Zhu
Isidori, Retico
Dedes, Dreiner, Nierste
Dedes, Pilaftis
Chankowski, Rosiek
Foster, Okumura, Roszkowski
Carena et al.
Isidori, Paradisi

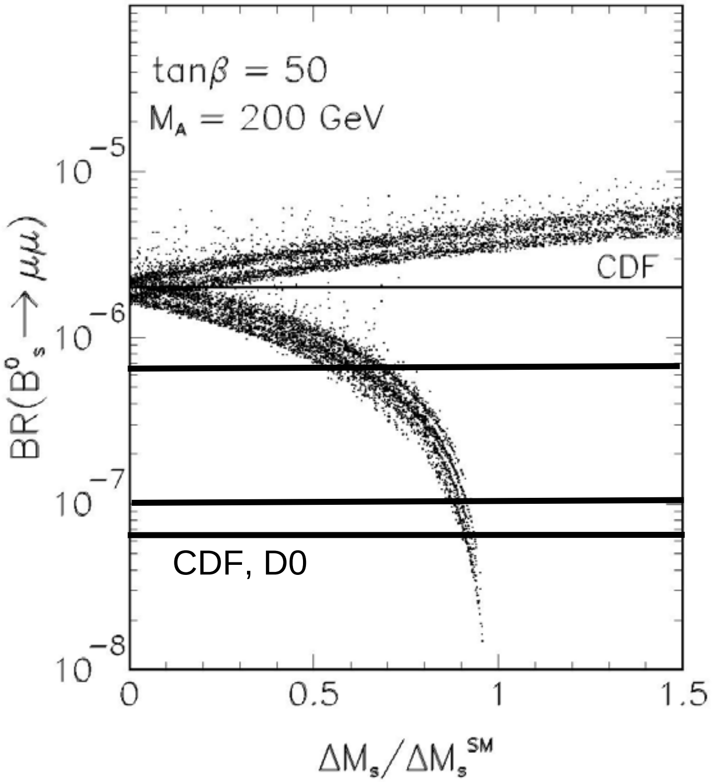
$\mathbf{Br(B_s \to \mu\bar{\mu}) < 6 \cdot 10^{-8}}$ 95% C.L (CDF, DØ)

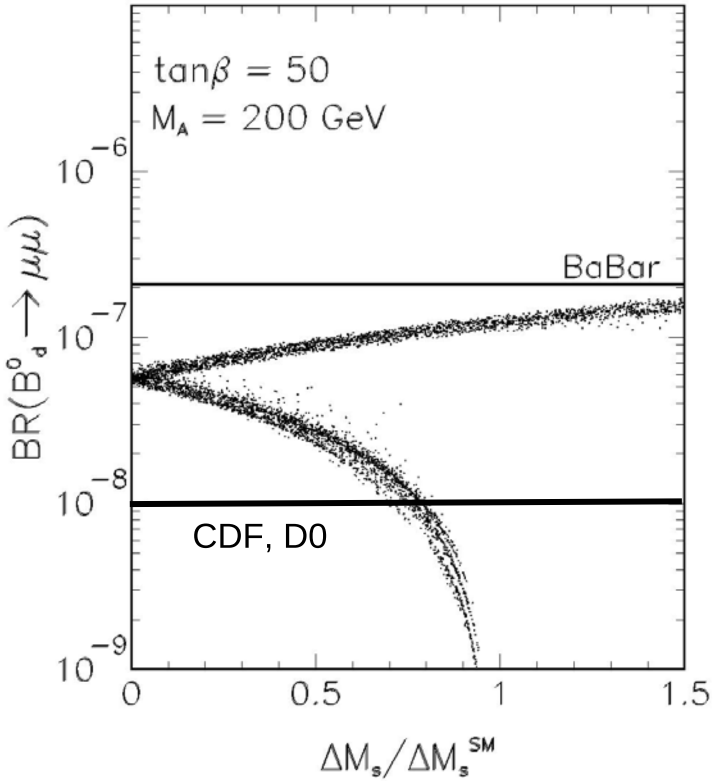
$\mathbf{Br(B_d \to \mu\bar{\mu}) < 2 \cdot 10^{-8}}$ 95% C.L.

$Br\left(B_{s,d} \to \mu^+\mu^-\right)$ vs $(\Delta M_s)^{exp} / (\Delta M_s)^{SM}$ in SUSY at Large $\tan\beta$

AJB, Chankowski, Rosiek, Slawianowska (2002)
Gorbahn, Jäger, Nierste, Trine (2008)
Could be modified by Non-MFV (Chankowski; Dedes, Pilaftsis)

2002
2004
2007
2008





2002
2008

$B^+ \to \tau^+ \nu$ $(\mu^+\nu)$

$$Br\left(B^+ \to \tau^+\nu\right)_{exp} = \left(1.73 \pm 0.35\right)\cdot 10^{-4}$$ (Belle, BaBar)

$$Br\left(B^+ \to \tau\nu\right)_{SM} \approx G_F^2 F_B^2 \left|V_{ub}\right|^2 = \left(1.1 \pm 0.5\right)\cdot 10^{-4}$$

$$\frac{Br\left(B^+ \to \tau\nu\right)_{MSSM}}{Br\left(B^+ \to \tau\nu\right)_{SM}} = \left[1 - \left(\frac{m_B}{m_{H^\pm}}\right)^2 \frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta}\right]^2$$

(Hou)
(Akeroyd, Recksiegel)
(Isidori, Paradisi)

Tree-Level
H^+ exchange

This decay could be problematic for MSSM-MFV with large $\tan\beta$

Altmannshofer, AJB, Guadagnoli, Wick (07)

$B^+ \to \tau^+\nu,\ K^+ \to l^+\nu$

(LFV effects in B and K Physics)

Sensitivity to NP

A.

$$\frac{Br\left(B^+ \to \mu^+\nu\right)}{Br\left(B^+ \to \tau^+\nu\right)}$$

(test of $\mu \leftrightarrow \tau$ universitality)

Isidori - Paradisi (2006)

B.

$$\frac{\Gamma\left(K^+ \to \mu^+\nu\right)}{\Gamma\left(K^+ \to e^+\nu\right)}$$

(test of $\mu \leftrightarrow e$ universitality)

Masiero, Paradisi, Petronzio (2005)

Very accurate precision test

Tested soon at CERN to 0.5%

TH: $\pm$ 0.1%

$(g-2)_\mu$ and EDM's

Flavour Conserving ★

A $(g-2)_\mu$: Flavour and CP conserving

Resolution of the $(g-2)_\mu$ problem

$$\left[(g-2)_\mu\right]_{SM} \neq \left[(g-2)_\mu\right]_{exp}$$

$$a_\mu^{exp} = 11659\,2080\ (63)\ 10^{-11}$$
$$a_\mu^{SM} = 11659\,1785\ (51)\ 10^{-11}$$

3.6 σ discrepancy

MSSM
~~LHT~~

But e^+e^- from BaBar $\rightarrow$ 0.9 σ

(?)

B EDM´s Flavour conserving but ~~CP~~

MSSM, ~~LHT~~, WED

Putting S0(10)-SUSY-GUT of Dermisek-Raby into difficulties

M. Albrecht, W. Altmannshofer, AJB, D. Guadagnoli, D. Straub

1. The Model gives a nice description of quark and lepton masses, PMNS and most of CKM elements.

Also SUSY Spectrum

2. But fails to describe simultaneously the data on

$$B_{s,d} \to \mu^+\mu^-,\ B \to X_s\gamma,\ B \to X_s l^+l^-,\ B_u \to \tau\nu$$

↑ Generally too low

3. Gives $\left|V_{ub}\right| \approx 3.2 \cdot 10^{-3}$

$$< \underbrace{(4.2 \pm 0.3) \cdot 10^{-3}}_{\text{Exp.}}$$

Some recent solutions: Altmannshofer et al.

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

Z^0 - Penguin dominated Decays

Decay	SM	Exp	TH
$K^+ \to \pi^+ \nu\bar{\nu}$	$(8.5\pm0.7)\cdot10^{-11}$	$(17.3^{+11.5}_{-10.5})\cdot10^{-11}$ (BNL)	±2-3%
$K_L \to \pi^0 \nu\bar{\nu}$	$(2.6\pm0.3)\cdot10^{-11}$	$< 6.7\cdot10^{-8}$ (KEK)	±1-2%
$K_L \to \pi^0 e^+ e^-$	$(3.5\pm1.0)\cdot10^{-11}$	$< 28\cdot10^{-11}$ (KTeV)	±15%
$K_L \to \pi^0 \mu^+ \mu^-$	$(1.4\pm0.3)\cdot10^{-11}$	$< 38\cdot10^{-11}$ (KTeV)	±15%
$B \to K^+ \nu\bar{\nu}$	$(4.5\pm0.7)\cdot10^{-6}$	$< 14\cdot10^{-6}$ (Belle)	±15%
$B \to K^* \nu\bar{\nu}$	$(6.8\pm1.1)\cdot10^{-6}$	$< 80\cdot10^{-6}$ (BABAR)	±15%
$B \to X_S \nu\bar{\nu}$	$(2.7\pm0.2)\cdot10^{-5}$	$< 64\cdot10^{-5}$ (ALEPH)	±3%

Very strong Constraints on New Physics

$$\mathrm{Br}(B \to X_S \gamma)_{exp} = (3.52 \pm 0.24) \cdot 10^{-4}$$

$$\mathrm{Br}(B \to X_S \gamma)_{SM} = \begin{cases} (3.15 \pm 0.23) \cdot 10^{-4} & \text{(Misiak et al)} \\ (2.98 \pm 0.26) \cdot 10^{-4} & \text{(Becher, Neubert)} \end{cases}$$

$$\mathrm{Br}(B \to X_S l^+ l^-)_{exp} = \begin{cases} (1.6 \pm 0.5) \cdot 10^{-6} & (\text{low } q^2) \\ (4.4 \pm 1.3) \cdot 10^{-7} & (\text{high } q^2) \end{cases}$$

$$\mathrm{Br}(B \to X_S l^+ l^-)_{SM} = \begin{cases} (1.6 \pm 0.1) \cdot 10^{-6} & (\text{low } q^2) \\ (2.3 \pm 0.8) \cdot 10^{-6} & (\text{high } q^2) \end{cases}$$

Isidori et al. (incl.)
Gorbahn et al. (incl.)
Feldmann et al. (excl.)

Zero in A_{FB}

$$\hat{s}_0 = (3.50 \pm 0.12)\mathrm{GeV}^2$$

★ TH very clean

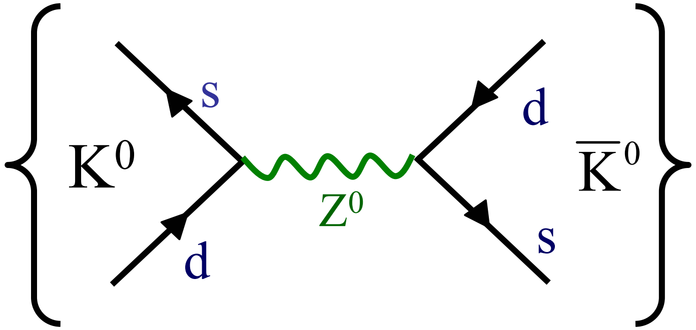
$$A_{CP}(B \to X_S \gamma)_{exp} = 0.004 \pm 0.036$$

$$A_{CP}(B \to X_S \gamma)_{SM} = 0.004 \pm 0.002$$

(Still factor 10 enhancement possible !)

All this can be improved at Super-B
Super-Belle

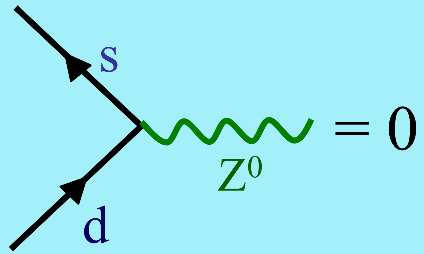
FCNCs at Tree Level and ΔM_K



$$\Delta M_K \cong 2\cdot 10^{-7}\,\mathrm{GeV}$$

(ε_K even worse)

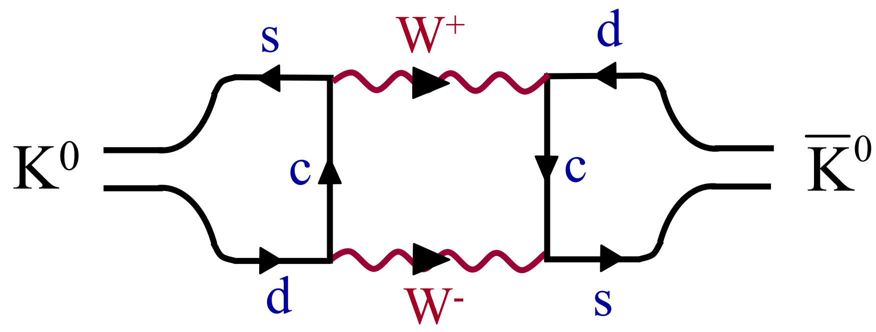
Disaster !!!
Missed by
8 orders of
magnitude !!!

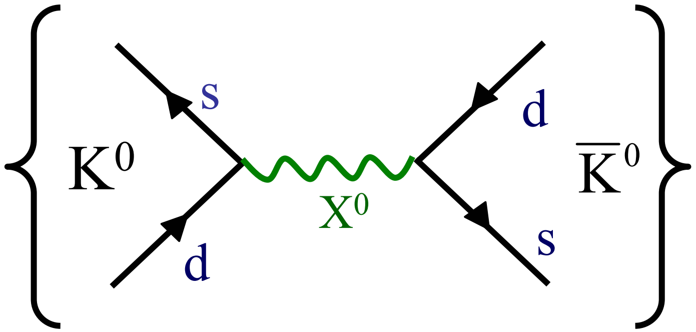


GIM Mechanism

(1971)

Gaillard + Lee (1974)





$$\Delta M_K \cong 2\cdot 10^{-7}\left[\frac{M_Z^2}{M_X^2}\right]\mathrm{GeV} = 3.5\cdot 10^{-15}\,\mathrm{GeV}$$

New very heavy neutral boson !

$$\{M_X \cong 10^6\,\mathrm{GeV}\}$$

Testing
10^{-22}m !

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

RS

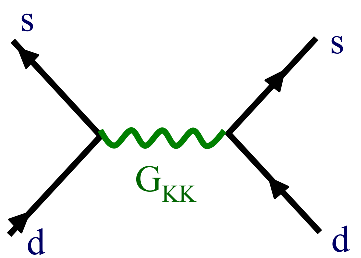
$$d \equiv \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

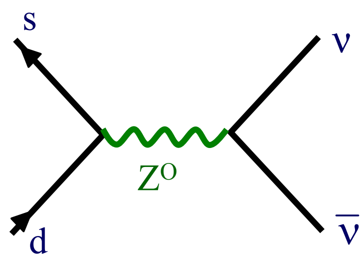
$$\bar{d} D_L^{+} \begin{pmatrix} a & & \\ & b & \\ & & c \end{pmatrix} D_L \gamma_\mu Z^\mu d \neq \bar{d} \gamma_\mu Z^\mu d$$

Related to the explanation of hierarchies in masses and mixings

(non-universality in gauge interactions)

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





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

But RS-GIM helps in avoiding disaster.

Gherghetta, Pomarol
Huber, Shafi
Agashe, Soni, Perez

Essential Ingredients in the Master Formula

1. Hadronic Matrix Elements $(\hat{B}_i)$

(Progress still has to be made) Recent progress: $\hat{B}_K$

2. QCD and QED RG-Effects for $\mu < m_t$ (η_i^{QCD})

1990´s - era of NLO calculations
2000´s - era of NNLO calculations

- ★ $B \to X_s l^+ l^-$ (Greub et al; Isidori et al, Beneke et al
- ★ $B \to X_s \gamma$ (Misiak et al) Bobeth et al)
- ★ $K^+ \to \pi^+ \nu\bar{\nu}$ (AJB, Gorbahn, Haisch, Nierste)
- ★ Non - Leptonic (Buchalla; Beneke, Jäger,…)
  + Semi - Leptonic (Gorbahn, Haisch)
  3 Loop $\hat{\gamma}_{anom}$

Selected Actors for the next 15 Minutes

$|V_{ub}|$, $|V_{cb}|$, γ from tree decays

ε_K

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

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

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

$S_{\psi\varphi}$, A^s_{SL}

$\mu \to e\gamma$, $\tau \to \mu\gamma$

d_n, d_e (EDM´s)

$S_{\varphi K_s}$, $\left(S_{\varphi\varphi}\right)$

$\Delta(g-2)_\mu$

$A_{CP}\left(b \to s\gamma\right)$

$B \to K^* l^+ l^-$

4th Generation

GIM at tree level
but strongly broken
at one loop
$m_{t'}, m_{b'}, > m_t >> m_c$

Still a possibility !!

New activities:

George Hou at al.

Soni, Alok, Giri, Mohanda, Nandi (08)
Bobrowski, Lenz, Riedl, Rohrwild (09)

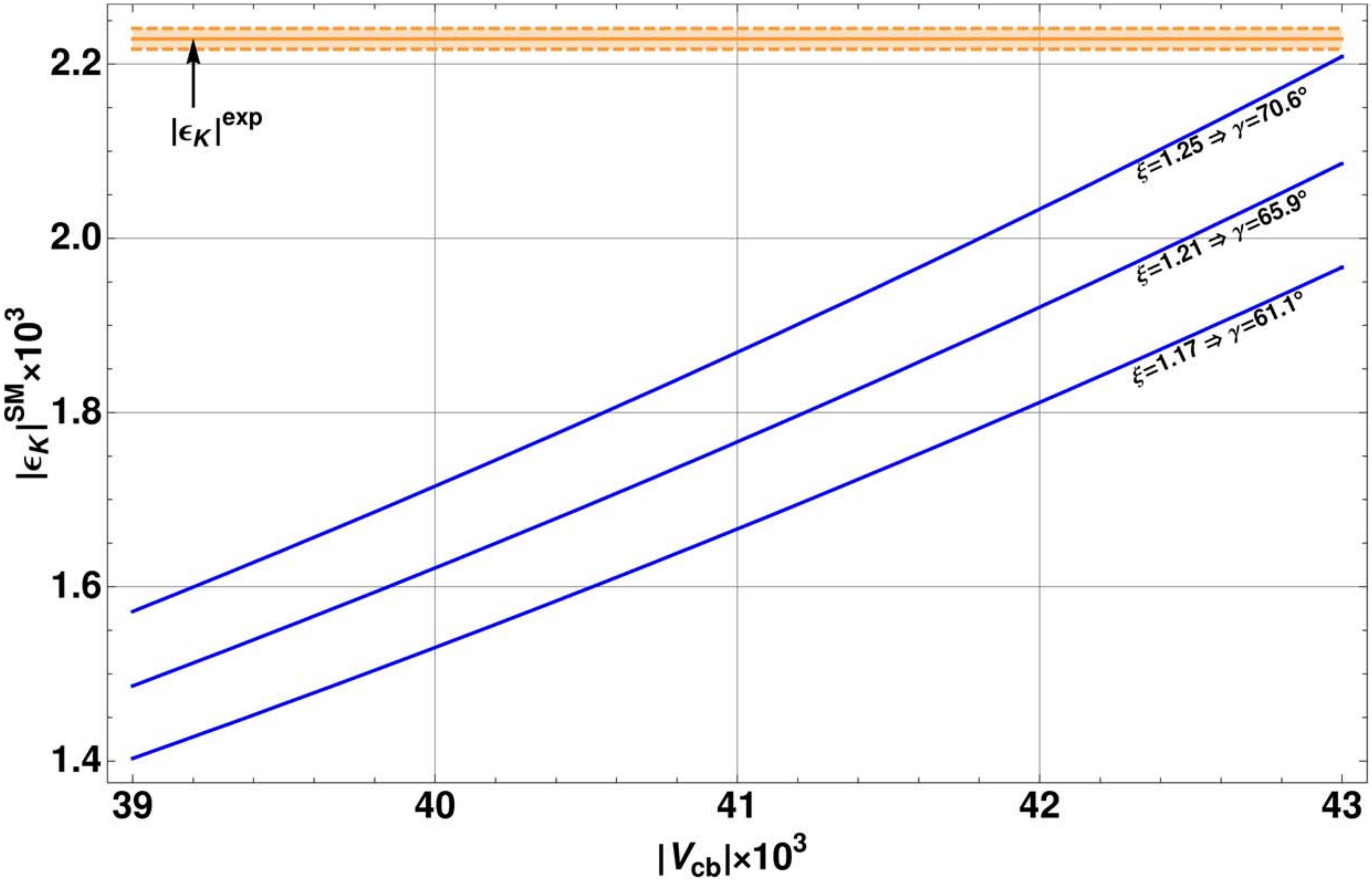
This NP Scenario is very different from SUSY, LHT, RS : **Non-Decoupling Effects of the 4th Generation Fermions in Low Energy Processes**

However : **It does not address the hierarchy problems**

ε_K needs precise value of $|V_{cb}|$

AJB
Guadagnoli
(2009)

$\varepsilon_K \sim |V_{cb}|^4$



Number of new Flavour Parameters

(Quark Sector) (physical)

	Real	~~CP~~ Phases	
SUSY	36	27	(R-parity)
FBMSSM	6	1	
LHT	7	3	
RS	18	9	
SM	9	1	

some sensitivity to UV

Where to Expect Large NP Effects

1. LFV $(\mu \to e\gamma,\ \mu \to 3e,\ \tau \to 3e)$; EDM´s

2. $K_L \to \pi^0 \nu\bar{\nu},\ K^+ \to \pi^+ \nu\bar{\nu},\ K_L \to \pi^0 l^+ l^-,\ (\varepsilon_K),\ \varepsilon'/\varepsilon$

3. CP-Violation in B_s-Decays, in $B \to X_d \gamma$

4. $B_{s,d} \to \mu^+\mu^-, \left(B_{s,d} \to \tau^+\nu\right)$

5. CP-Violation in D-Decays

6. $B \to X_s \nu\bar{\nu},\ B_{s,d} \to K^* l^+ l^-$

7. CP-Violation in B_d, $B^\pm$ Decays $\left(S_{\varphi K_s},\ S_{\pi^0 K_s}, \ldots\right)$

Other interesting Processes

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

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

[SINDRUM Collaboration]

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

$$Br(\tau \to \mu\gamma)_{exp} < 1.6 \cdot 10^{-8}$$

[Belle, BaBar]

$$Br(\tau \to e\gamma)_{exp} < 9.4 \cdot 10^{-8}$$

[BaBar, Belle]

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

$$Br(\tau \to \mu\pi)_{exp} < 5.8 \cdot 10^{-8}$$

[Belle, BaBar]

(Future: Super B)

- $\mu \to e$ conversion

$$R(\mu T_i \to e T_i) < 4.3 \cdot 10^{-12}$$

10^{-18} (J-Parc)

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

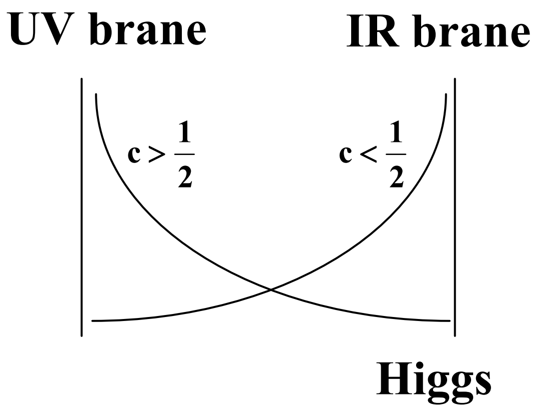
$$Br(K_L \to \mu e)_{\exp} < 4.7 \cdot 10^{-12}$$

[BNL E871 Collaboration]

Fermion Localisation and Yukawa Couplings

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

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



$c > \frac{1}{2}$ **: 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.**

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

$M_{KK} \gtrsim 21$ TeV