Workshop
Effective Field Theories for Collider Physics, Flavor Phenomena and Electroweak Symmetry Breaking

Eltville, September 2016

Flavour Observables: Anomalies and correlations

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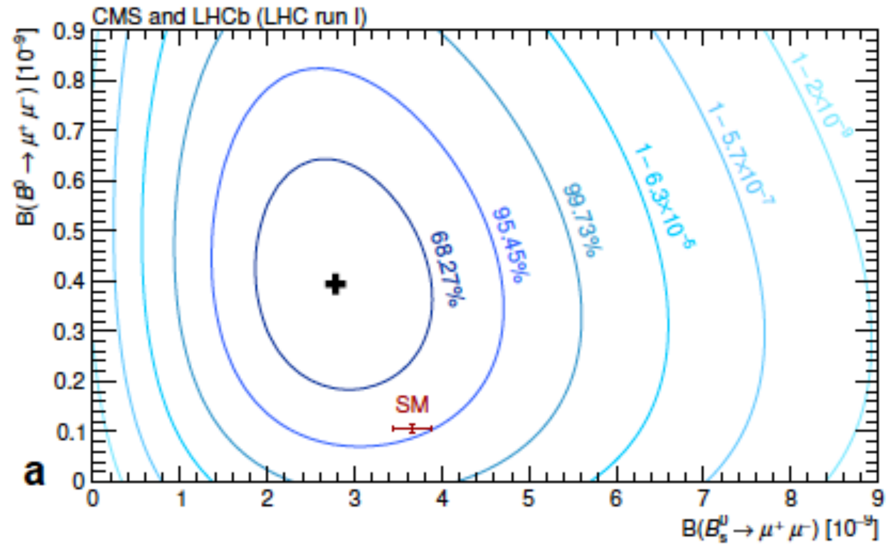
- Tensions between SM & (some) exp results
- 331 Models
- Focus on ε'/ε and correlations with other observables

Based on
A.J. Buras, J. Girrbach, FDF, JHEP 1402 (2014) 112
A.J. Buras, J. Girrbach-Noe, FDF JHEP 1408 (2014) 039
A.J. Buras, FDF JHEP 1603 (2016) 010
A.J. Buras, FDF JHEP 1608 (2016) 115

Results for flavour observables deviating from SM predictions

$BR(B_s \to \mu^+ \mu^-)$ & $BR(B_d \to \mu^+ \mu^-)$

CMS & LHCb
Nature 522 (2015) 68



Comparing to SM
Bobeth et al. PRL 112 (2014) 101801:

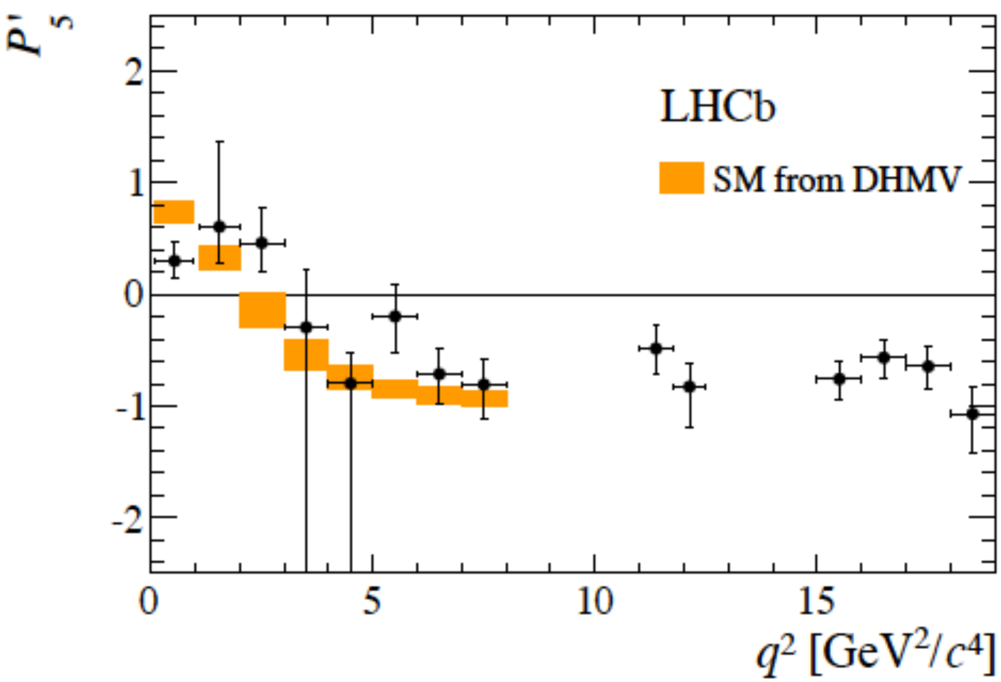
	CMS + LHCb	SM
$B(B_s \to \mu^+\mu^-)$	$(2.8\pm^{0.7}_{0.6}) \times 10^{-9}$	$(3.66 \pm 0.23) \times 10^{-9}$
$B(B_d \to \mu^+\mu^-)$	$(3.9\pm^{1.6}_{1.4}) \times 10^{-10}$	$(1.06 \pm 0.09) \times 10^{-10}$

Recent ATLAS result: $B(B_s \to \mu^+\mu^-) = (0.9\pm^{1.1}_{0.9}) \times 10^{-9}$

Models suppressing $B(B_s \to \mu^+ \mu^-)$ are favoured

Observables in $B \to K^* \mu^+ \mu^-$: LHCb results

LHCb JHEP 1602 (2016) 104



Theory indications: NP contributions to C_9 should be large

ε'/ε

World Ave NA48 + KTeV

$$(\varepsilon'/\varepsilon)_{\text{exp}} = (16.6 \pm 2.3) \times 10^{-4}$$

Recent SM result
using RBC-UKQCD lattice results
for B parameters

$$\varepsilon'/\varepsilon = (1.9 \pm 4.5) \times 10^{-4}$$

A.J. Buras, M. Gorbahn, S. Jager, M. Jamin
JHEP 11 (2015) 202

Using large – N results

A.J. Buras, J.-M. Gerard
JHEP 12 (2015) 008

$$(\varepsilon'/\varepsilon)_{\text{SM}} = (8.6 \pm 3.2) \times 10^{-4}$$

The main uncertainty in SM comes from the cancellation between QCD and EW penguin contribution

Aim of this talk:

Explore correlations between ε'/ε and these "*problematic*" observables in a well defined NP model

In the case of ε'/ε consider only the shift wrt SM

331 Models: general features

P. Frampton, PRL 69 (92) 2889
F. Pisano & V. Pleitez, PRD 46 (92) 410

Gauge group:	$SU(3)_C \times SU(3)_L \times U(1)_X$
Spontaneously broken to	$SU(3)_C \times SU(2)_L \times U(1)_X$
Spontaneously broken to	$SU(3)_C \times U(1)_Q$

Nice features:

- requirement of anomaly cancelation + asympotic freedom of QCD implies number of generations= number of colors
- two quark generations transform as triplets under $SU(3)_L$, one as an antitriplet this may allow to understand why top mass is so large

Fundamental relation:

$$Q = T_3 + \beta T_8 + X$$

Key parameter: defines the variant of the model

$\beta = \pm 1/\sqrt{3}, \pm 2/\sqrt{3}$

- lead to interesting phenomenology
- for $\beta = \pm 1/\sqrt{3}$ the new gauge bosons have integer charge

331 Model: new particle content

New Gauge Bosons

A new heavy Z' mediates
tree level FCNC in the quark sector

New heavy fermions

D,S ,T new heavy quarks

E_l new heavy neutrinos (both L & R)

Extended Higgs sector

Three $SU(3)_L$ triplets, one sextet

↓

ρ, η, ξ

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Extended Higgs sector

Three $SU(3)_L$ triplets, one sextet

ρ, η, ξ

give mass to up and down-type quarks with

$$a = \frac{1-\tan^2\bar{\beta}}{1+\tan^2\bar{\beta}}, \qquad \tan\bar{\beta} = \frac{v_\rho}{v_\eta}.$$

331 Models: gauge sector

SU(3)$_L$ Gauge Bosons:
W^a a=1,…8

$$W_\mu = W_\mu^a T^a = \frac{1}{2}\begin{pmatrix} W_\mu^3 + \frac{1}{\sqrt{3}}W_\mu^8 & \sqrt{2}W_\mu^+ & \sqrt{2}Y_\mu^{Q_Y} \\ \sqrt{2}W_\mu^- & -W_\mu^3 + \frac{1}{\sqrt{3}}W_\mu^8 & \sqrt{2}V_\mu^{Q_V} \\ \sqrt{2}Y_\mu^{-Q_Y} & \sqrt{2}V_\mu^{-Q_V} & -\frac{2}{\sqrt{3}}W_\mu^8 \end{pmatrix}$$

Charged ones:

$$W_\mu^\pm = \frac{1}{\sqrt{2}}(W_\mu^1 \mp i\, W_\mu^2),$$

SM ones

$$Y_\mu^{\pm Q_Y} = \frac{1}{\sqrt{2}}(W_\mu^4 \mp i\, W_\mu^5),$$

$$V_\mu^{\pm Q_V} = \frac{1}{\sqrt{2}}(W_\mu^6 \mp i\, W_\mu^7).$$

New Gauge Bosons,
with charges depending on β

Neutral ones:

W^3 and W^8

U(1)$_X$ Gauge Boson: **X**

331 Models: gauge sector

Mixing pattern among the neutral gauge bosons

$$X_\mu\,,W_\mu^8\,,W_\mu^3 \xrightarrow{\theta_{331}} Z'_\mu\,,B_\mu\,,W_\mu^3 \xrightarrow{\theta_W} Z'_\mu\,,Z_\mu\,,A_\mu\,.$$

$$\sin\theta_{331} = \frac{g}{\sqrt{g^2 + \frac{g_X^2\beta^2}{6}}}.$$

$$\sin\theta_W = \frac{g_Y}{\sqrt{g^2 + g_Y^2}}\,.$$

g $\rightarrow$ SU(3)$_L$ gauge coupling constant

g$_X$ $\rightarrow$ U(1)$_X$ gauge coupling constant

$$\frac{1}{g_Y^2} = \frac{6}{g_X^2} + \frac{\beta^2}{g^2}$$

It turns out that

$$\frac{M_W^2}{M_Z^2} = \cos\theta_W$$

θ_W is the Weinberg angle

331 Models: gauge sector

Mixing between Z and Z'

$$Z^1_\mu = \cos\xi Z_\mu + \sin\xi Z'_\mu, \qquad Z^2_\mu = -\sin\xi Z_\mu + \cos\xi Z'_\mu$$

$\sin\xi \cong O(10^{-3})$ $\Rightarrow$ $\boxed{Z^1_\mu = Z_\mu}$ $\boxed{Z^2_\mu = Z'_\mu}$

$$\sin\xi = \frac{c_W^2}{3}\sqrt{f(\beta)}\left(3\beta\frac{s_W^2}{c_W^2} + \sqrt{3}a\right)\left[\frac{M_Z^2}{M_{Z'}^2}\right] \equiv B(\beta, a)\left[\frac{M_Z^2}{M_{Z'}^2}\right]$$

$$f(\beta) = \frac{1}{1-(1+\beta^2)s_W^2} > 0$$

331 Models: gauge sector

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$$f(\beta) = \frac{1}{1-(1+\beta^2)s_W^2} > 0$$

Consequences of mixing:

- flavour violating couplings of Z to quarks are generated

$$\Delta_L^{ij}(Z) = \sin\xi\,\Delta_L^{ij}(Z') \qquad (i \neq j)$$

- flavour diagonal couplings to SM fermions differ from SM Z couplings

331 Models: Fermions

Left-handed quarks

SM quarks

$$\begin{pmatrix} u \\ d \\ D \end{pmatrix}_L \quad \begin{pmatrix} c \\ s \\ S \end{pmatrix}_L \quad \begin{pmatrix} b \\ -t \\ T \end{pmatrix}_L$$

SU(3)$_L$ triplets

antitriplet

Corresponding right-handed quarks are singlets

Left-handed leptons

$$\begin{pmatrix} e \\ -\nu_e \\ E_e \end{pmatrix}_L \quad \begin{pmatrix} \mu \\ -\nu_\mu \\ E_\mu \end{pmatrix}_L \quad \begin{pmatrix} \tau \\ -\nu_\tau \\ E_\tau \end{pmatrix}_L$$

The choice of the third component depends on the variant of the model

antitriplets

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F1 representation

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$SU(3)_L$ antitriplets

triplet

Corresponding right-handed quarks are singlets

Left-handed leptons

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331 Models: Fermions

Left-handed quarks

SM quarks

$$\begin{pmatrix} u \\ d \\ D \end{pmatrix}_L \quad \begin{pmatrix} c \\ s \\ S \end{pmatrix}_L \quad \begin{pmatrix} b \\ -t \\ T \end{pmatrix}_L$$

SU(3)$_L$ antitriplets

triplet

Corresponding right-handed quarks are singlets

F2 representation

Left-handed leptons

$$\begin{pmatrix} e \\ -\nu_e \\ E_e \end{pmatrix}_L \quad \begin{pmatrix} \mu \\ -\nu_\mu \\ E_\mu \end{pmatrix}_L \quad \begin{pmatrix} \tau \\ -\nu_\tau \\ E_\tau \end{pmatrix}_L$$

The choice of the third component depends on the variant of the model

triplets

331 Models: quark mixing

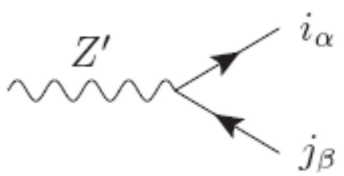
Quark mass eigenstates defined upon rotation through two unitary matrices $\mathbf{U_L}$ & $\mathbf{V_L}$

$$V_{\rm CKM} = U_L^\dagger V_L$$

In contrast to SM only one of them can be traded for VCKM, the other one enters in Z' couplings to quarks

$$V_L = \begin{pmatrix} \tilde{c}_{12}\tilde{c}_{13} & \tilde{s}_{12}\tilde{c}_{23}e^{i\delta_3} - \tilde{c}_{12}\tilde{s}_{13}\tilde{s}_{23}e^{i(\delta_1-\delta_2)} & \tilde{c}_{12}\tilde{c}_{23}\tilde{s}_{13}e^{i\delta_1} + \tilde{s}_{12}\tilde{s}_{23}e^{i(\delta_2+\delta_3)} \\ -\tilde{c}_{13}\tilde{s}_{12}e^{-i\delta_3} & \tilde{c}_{12}\tilde{c}_{23} + \tilde{s}_{12}\tilde{\tilde{s}}_{13}\tilde{s}_{23}e^{i(\delta_1-\delta_2-\delta_3)} & -\tilde{s}_{12}\tilde{s}_{13}\tilde{c}_{23}e^{i(\delta_1-\delta_3)} - \tilde{c}_{12}\tilde{s}_{23}e^{i\delta_2} \\ -\tilde{s}_{13}e^{-i\delta_1} & -\tilde{c}_{13}\tilde{s}_{23}e^{-i\delta_2} & \tilde{c}_{13}\tilde{c}_{23} \end{pmatrix}$$

331 Models: Z' couplings to quarks
The case of B_d,B_s,K systems



$$i\mathcal{L}_L(Z') = i\left[\Delta_L^{sd}(Z')(\bar{s}\gamma^\mu P_L d) + \Delta_L^{bd}(Z')(\bar{b}\gamma^\mu P_L d) + \Delta_L^{bs}(Z')(\bar{b}\gamma^\mu P_L s)\right] Z'_\mu$$

FCNC involve only left-handed quarks

depend only on four new parameters:

$$\tilde{s}_{13}, \quad \tilde{s}_{23}, \quad \delta_1, \quad \delta_2$$

B_d system → only on s_{13} and δ_1

B_s system → only on s_{23} and δ_2

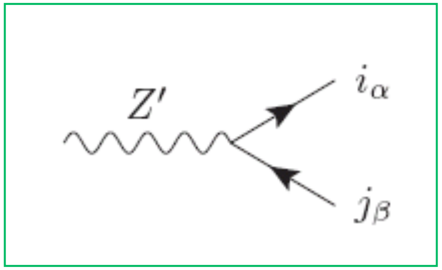
K system → on s_{13} , s_{23} and δ_2 - δ_1

Specific feature of this model
Not true in general!

stringent correlations between observables expected

$M_{Z'}$ fixed to 3 TeV

331 Models: Z' couplings to quarks
The case of B_d, B_s, K systems



$$i\mathcal{L}_L(Z') = i\left[\Delta_L^{sd}(Z')(\bar{s}\gamma^\mu P_L d) + \Delta_L^{bd}(Z')(\bar{b}\gamma^\mu P_L d) + \Delta_L^{bs}(Z')(\bar{b}\gamma^\mu P_L s)\right] Z'_\mu$$

FCNC involve only left-handed quarks

$$\Delta_L^{sd}(Z') = \frac{g_2(M_{Z'})}{\sqrt{3}} c_W \sqrt{f(\beta)}\, \tilde{s}_{13}\tilde{s}_{23} e^{i(\delta_2-\delta_1)}$$

Summary of the variants of 331 Models

- value of β: $\beta=\pm 1/\sqrt{3}, \pm 2/\sqrt{3}$
- fermion representation: F1 or F2
- Z-Z' mixing parameter: $\tan\bar{\beta}=0.2$, $\tan\bar{\beta}=1$, $\tan\bar{\beta}=5.0$

24 possibilities to be explored!

MI	scen.	β	$\tan\bar{\beta}$	MI	scen.	β	$\tan\bar{\beta}$	MI	scen.	β	$\tan\bar{\beta}$
M1	F_1	$-2/\sqrt{3}$	1	M9	F_2	$-2/\sqrt{3}$	1	M17	F_1	$-2/\sqrt{3}$	0.2
M2	F_1	$-2/\sqrt{3}$	5	M10	F_2	$-2/\sqrt{3}$	5	M18	F_2	$-2/\sqrt{3}$	0.2
M3	F_1	$-1/\sqrt{3}$	1	M11	F_2	$-1/\sqrt{3}$	1	M19	F_1	$-1/\sqrt{3}$	0.2
M4	F_1	$-1/\sqrt{3}$	5	M12	F_2	$-1/\sqrt{3}$	5	M20	F_2	$-1/\sqrt{3}$	0.2
M5	F_1	$1/\sqrt{3}$	1	M13	F_2	$1/\sqrt{3}$	1	M21	F_1	$1/\sqrt{3}$	0.2
M6	F_1	$1/\sqrt{3}$	5	M14	F_2	$1/\sqrt{3}$	5	M22	F_2	$1/\sqrt{3}$	0.2
M7	F_1	$2/\sqrt{3}$	1	M15	F_2	$2/\sqrt{3}$	1	M23	F_1	$2/\sqrt{3}$	0.2
M8	F_1	$2/\sqrt{3}$	5	M16	F_2	$2/\sqrt{3}$	5	M24	F_2	$2/\sqrt{3}$	0.2

Preliminary selection among the variants of 331 Models: constraints from EWPO

Quantity	Input Data	SMfit	Pull
Γ_Z	2.4952(23)	2.4954(14)	0.09
σ_h [nbarn]	41.540(37)	41.479(14)	-1.65
R_ℓ	20.767(25)	20.740(17)	-1.08
$\mathcal{A}^\ell_{\rm FB}$	0.0171(10)	0.01627(2)	-0.83
$\mathcal{A}_\ell$(LEP)	$-0.1465(33)$	$-0.1472(7)$	-0.2
$\mathcal{A}_\ell$(SLD)	$-0.1513(21)$	$-0.1472(7)$	1.95
$\mathcal{A}_\ell$	$-0.1499(18)$	$-0.1472(7)$	1.50
$\sin^2\theta^l_{\rm eff}$	0.2324(12)	0.23148(10)	-0.7
$\mathcal{A}_c$	$-0.670(27)$	$-0.6679(3)$	0.07
$\mathcal{A}_b$	$-0.923(20)$	$-0.93464(5)$	-0.58
$\mathcal{A}^c_{\rm FB}$	0.0707(35)	0.0738(4)	0.88
$\mathcal{A}^b_{\rm FB}$	0.0992(16)	0.1032(5)	2.5
R_c	0.1721(30)	0.17223(6)	0.04
R_b	0.21629(66)	0.21548(5)	-1.23

Selection can be done comparing the performance of 331 models to that of SM through the pulls for a generic observable O_i :

$$P_i^{\rm SM} = \frac{{\rm SMfit}_i - ({\rm Input\ Data})_i}{\sigma^i_{\rm exp}}, \qquad P_i^{331} = \frac{{\rm SMfit}_i + \delta\mathcal{O}_i - ({\rm Input\ Data})_i}{\sigma^i_{\rm exp}}.$$

$$\Omega^{\rm SM} = \sum_i \left(P_i^{\rm SM}\right)^2 = 15.72 \qquad\qquad \Omega^{331} = \sum_i \left(P_i^{331}\right)^2$$

Models with smallest Ω^{331} are favoured

Preliminary selection among the variants of 331 Models: constraints from EWPO

MI	scen.	β	$\tan\bar{\beta}$	MI	scen.	β	$\tan\bar{\beta}$	MI	scen.	β	$\tan\bar{\beta}$
M1	F_1	$-2/\sqrt{3}$	1	M9	F_2	$-2/\sqrt{3}$	1	M17	F_1	$-2/\sqrt{3}$	0.2
M2	F_1	$-2/\sqrt{3}$	5	M10	F_2	$-2/\sqrt{3}$	5	M18	F_2	$-2/\sqrt{3}$	0.2
M3	F_1	$-1/\sqrt{3}$	1	M11	F_2	$-1/\sqrt{3}$	1	M19	F_1	$-1/\sqrt{3}$	0.2
M4	F_1	$-1/\sqrt{3}$	5	M12	F_2	$-1/\sqrt{3}$	5	M20	F_2	$-1/\sqrt{3}$	0.2
M5	F_1	$1/\sqrt{3}$	1	M13	F_2	$1/\sqrt{3}$	1	M21	F_1	$1/\sqrt{3}$	0.2
M6	F_1	$1/\sqrt{3}$	5	M14	F_2	$1/\sqrt{3}$	5	M22	F_2	$1/\sqrt{3}$	0.2
M7	F_1	$2/\sqrt{3}$	1	M15	F_2	$2/\sqrt{3}$	1	M23	F_1	$2/\sqrt{3}$	0.2
M8	F_1	$2/\sqrt{3}$	5	M16	F_2	$2/\sqrt{3}$	5	M24	F_2	$2/\sqrt{3}$	0.2

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M3	F_1	$-1/\sqrt{3}$	1	M11	F_2	$-1/\sqrt{3}$	1				
M6	F_1	$1/\sqrt{3}$	5	M14	F_2	$1/\sqrt{3}$	5				
M8	F_1	$2/\sqrt{3}$	5	M16	F_2	$2/\sqrt{3}$	5				

only 7 survive!

ε′/ε in 331 Models

$$\left(\frac{\varepsilon'}{\varepsilon}\right)_{331} = \left(\frac{\varepsilon'}{\varepsilon}\right)_{\rm SM} + \left(\frac{\varepsilon'}{\varepsilon}\right)_{Z'} + \left(\frac{\varepsilon'}{\varepsilon}\right)_{Z} \equiv \left(\frac{\varepsilon'}{\varepsilon}\right)_{\rm SM} + \Delta(\varepsilon'/\varepsilon)$$

for V=Z, Z’

$$\left(\frac{\varepsilon'}{\varepsilon}\right)_{V} = \frac{\omega}{|\varepsilon_K|\sqrt{2}}\frac{{\rm Im}A_2(V)}{{\rm Re}A_2}, \qquad \omega = \frac{{\rm Re}A_2}{{\rm Re}A_0} = (4.46)\times 10^{-2}$$

$$A_I \equiv \langle(\pi\pi)_I|\mathcal{H}_{\rm eff}|K\rangle$$

ε'/ε in 331 Models

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$$A_I \equiv \langle(\pi\pi)_I|\mathcal{H}_{\rm eff}|K\rangle$$

taken from exp

$${\rm Re}A_2 = 1.210(2)\times 10^{-8}\ {\rm GeV}, \qquad |\varepsilon_K| = 2.228(11)\times 10^{-3}$$

ε'/ε in 331 Models

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$$\boxed{A_I \equiv \langle(\pi\pi)_I|\mathcal{H}_{\rm eff}|K\rangle}$$

$$\boxed{A_2(V) = C_8(m_c, V)\langle Q_8(m_c)\rangle_2}$$

ε'/ε in 331 Models

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$$A_2(V) = C_8(m_c, V)\langle Q_8(m_c)\rangle_2$$

$$\langle Q_8(m_c)\rangle_2 = \sqrt{2}\left[\frac{m_{\rm K}^2}{m_s(m_c)+m_d(m_c)}\right]^2 F_\pi\, B_8^{(3/2)} = 0.862\, B_8^{(3/2)}\ {\rm GeV}^3$$

ε'/ε in 331 Models

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for V=Z, Z'

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accounts for deviation from vacuum insertion approximation

ε′/ε in 331 Models

$$C_8(m_c, Z') = 1.35 \left[\frac{g_2 s_W^2}{6 c_W}\right]_{M_{Z'}} \beta \sqrt{f(\beta)} \frac{\Delta_L^{sd}(Z')}{M_{Z'}^2}$$

$$\left(\frac{\varepsilon'}{\varepsilon}\right)_{Z'} = \pm 1.10 \, [\beta f(\beta)] \, \tilde{s}_{13} \tilde{s}_{23} \sin(\delta_2 - \delta_1) \left[\frac{B_8^{(3/2)}}{0.76}\right] \left[\frac{3\,\mathrm{TeV}}{M_{Z'}}\right]^2$$

$$C_8(m_c, Z) = -0.76 \left[\frac{g_2 s_W^2}{6 c_W}\right]_{M_Z} \frac{\Delta_L^{sd}(Z)}{M_Z^2}$$

due to Z-Z′ mixing

$$\left(\frac{\varepsilon'}{\varepsilon}\right)_Z = R_{\varepsilon'} \left(\frac{\varepsilon'}{\varepsilon}\right)_{Z'}$$

$$R_{\varepsilon'} = \frac{C_8(m_c, Z)}{C_8(m_c, Z')} = \mp \frac{0.53}{\beta} \frac{c_W^2}{3} \left[3\beta \frac{s_W^2}{c_W^2} + \sqrt{3} a\right]$$

$$\Delta(\varepsilon'/\varepsilon) = (1 + R_{\varepsilon'}) \left(\frac{\varepsilon'}{\varepsilon}\right)_{Z'}$$

depends on β, on Z-Z′ mixing,
on the fermion representation

ε'/ε in 331 Models: constraining the parameter space

$$16.9/\text{ps} \le \Delta M_s \le 18.7/\text{ps}, \qquad -0.055 \le S_{\psi\phi} \le 0.085,$$

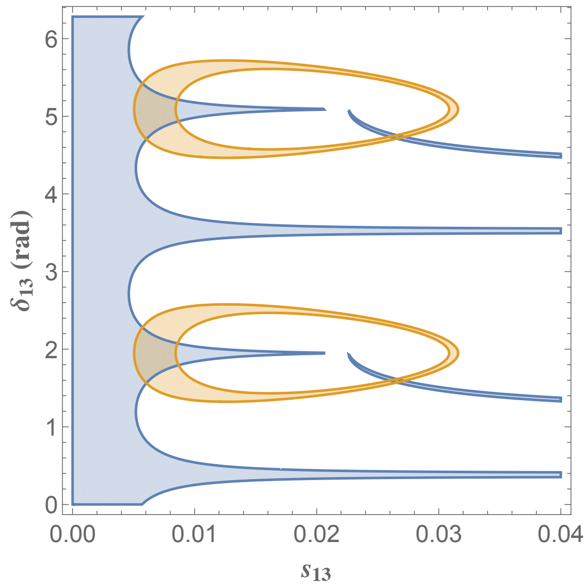
$$0.48/\text{ps} \le \Delta M_d \le 0.53/\text{ps}, \qquad 0.657 \le S_{\psi K_S} \le 0.725$$

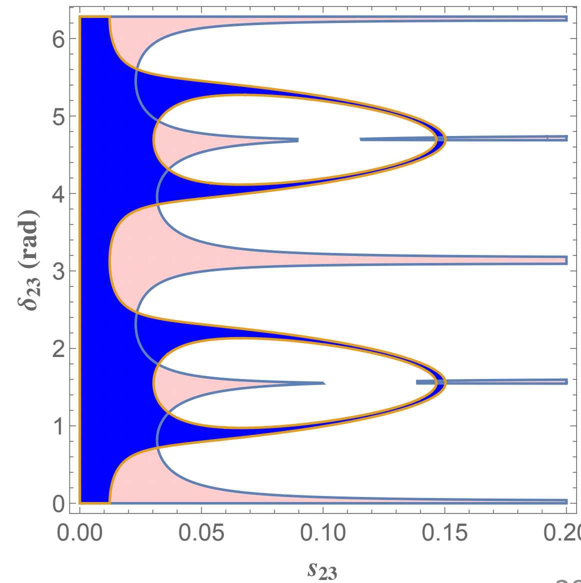
$$1.60 \times 10^{-3} < |\varepsilon_K| < 2.50 \times 10^{-3}, \qquad -0.30 \le \frac{(\Delta M_K)^{Z'}}{(\Delta M_K)_{\text{exp}}} \le 0.30.$$

selected ranges depend on β but invariant under F1 <-> F2

play a role only for large $M_{Z'}$

example: β=-1/√3





First study of ε'/ε in 331 Models: results

A.J. Buras, FDF JHEP 1603 (2016) 010

MI	scen.	β	$\tan\bar\beta$	MI	scen.	β	$\tan\bar\beta$	MI	scen.	β	$\tan\bar\beta$
				M9	F_2	$-2/\sqrt{3}$	1				
M3	F_1	$-1/\sqrt{3}$	1	M11	F_2	$-1/\sqrt{3}$	1				
M6	F_1	$1/\sqrt{3}$	5	M14	F_2	$1/\sqrt{3}$	5				
M8	F_1	$2/\sqrt{3}$	5	M16	F_2	$2/\sqrt{3}$	5				

First study of ε'/ε in 331 Models: results

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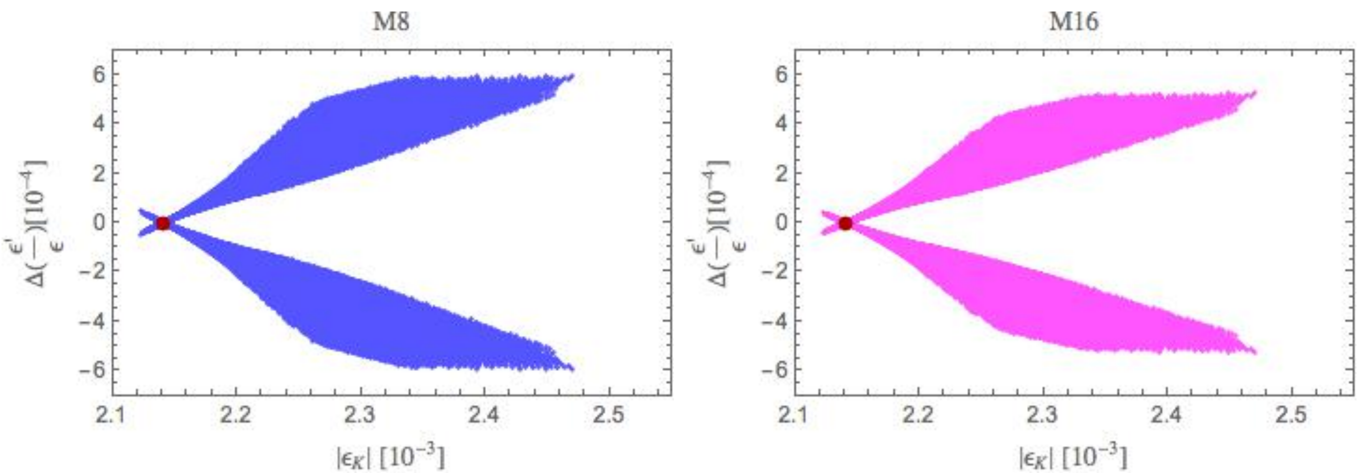
MI	scen.	β	$\tan\beta$	MI	scen.	β	$\tan\beta$	MI	scen.	β	$\tan\beta$
				M9	F_2	$-2/\sqrt{3}$	1				
M8	F_1	$2/\sqrt{3}$	5	M16	F_2	$2/\sqrt{3}$	5				

only 3 survive!

First study of ε'/ε in 331 Models: results

A.J. Buras, FDF JHEP 1608 (2016) 115

Reference set of parameters:
$M_{Z'}$=3 TeV
V_{cb}=0.042
V_{ub}=0.036



- Similar results for M8 & M9, differences in M16
- other correlations should be investigated

First study of ε'/ε in 331 Models: results

A.J. Buras, FDF JHEP 1608 (2016) 115

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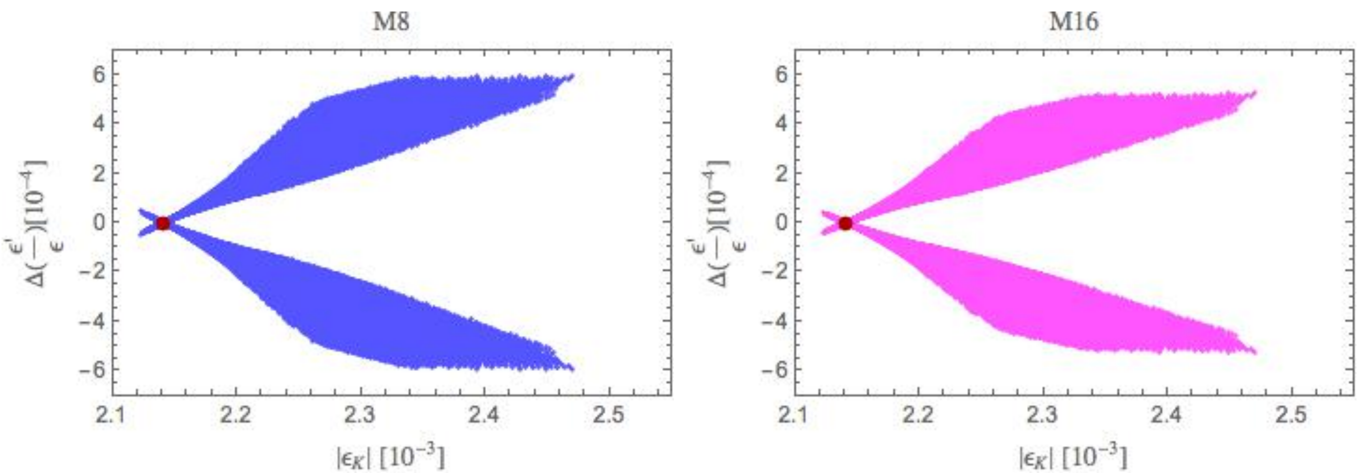
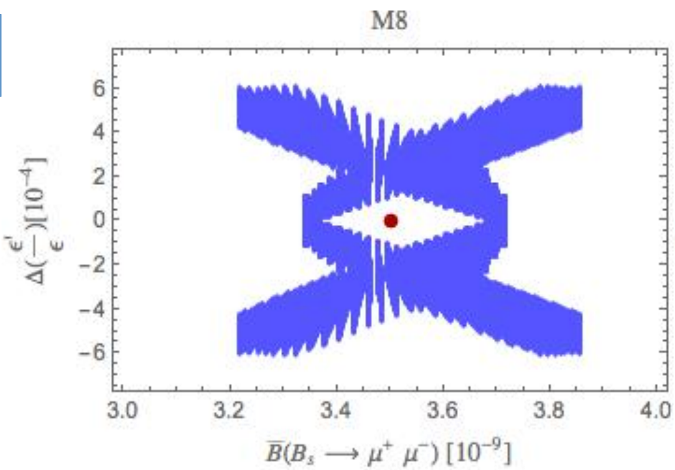


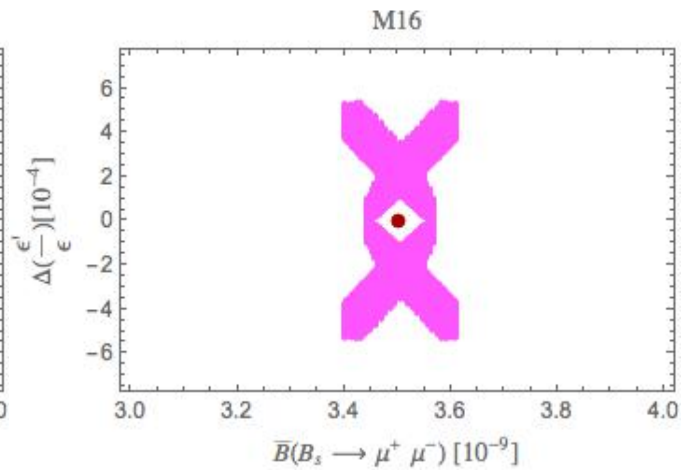
- Similar results for M8 & M9, differences in M16
- other correlations should be investigated

the shift in ε'/ε is larger when ε_K is enhanced in all the 3 cases

correlations with B physics observables

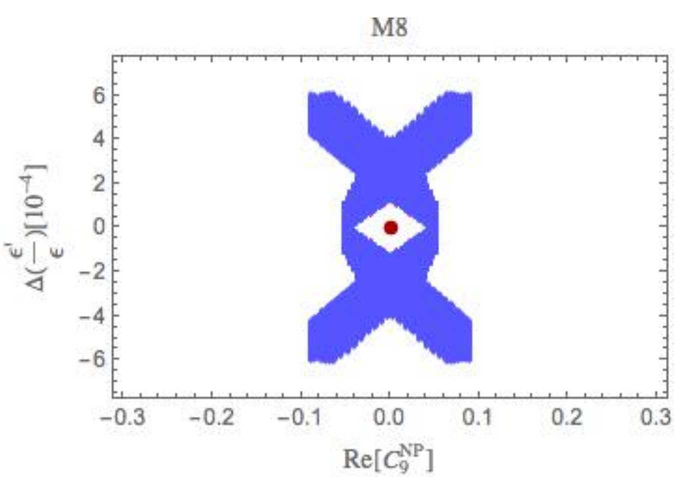
ε'/ε vs $B(B_s \to \mu^+ \mu^-)$

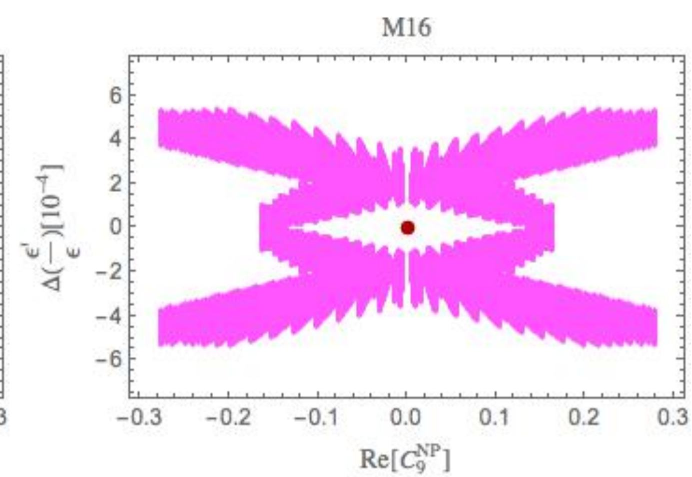




The strongest suppression can be achieved in M8 & M9

ε'/ε vs $\mathrm{Re}(C_9^{NP})$





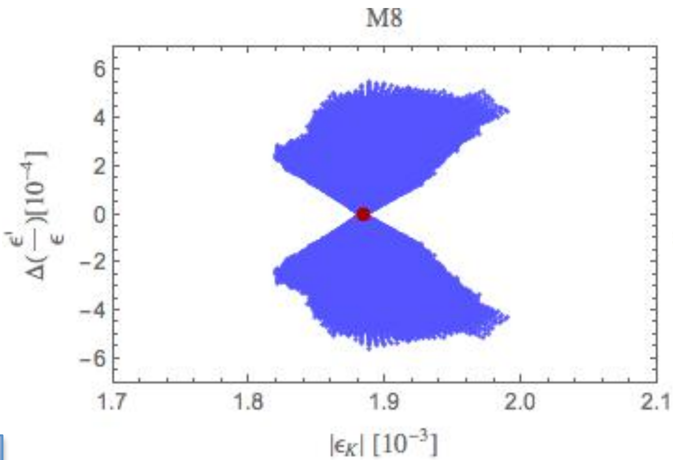
M16 produces the largest new contribution to C_9 -> can help softening the angular anomaly

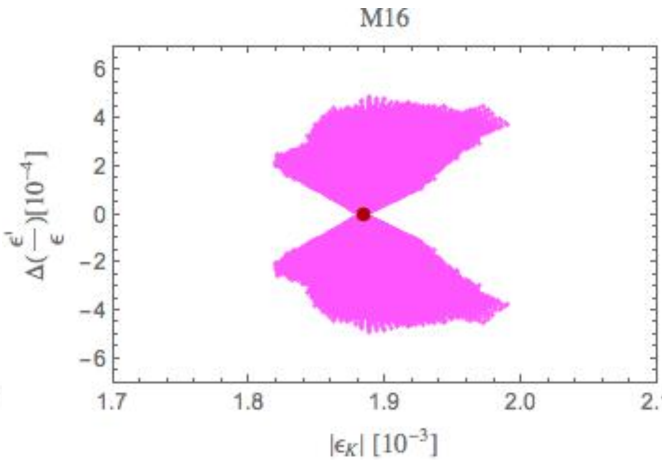
correlations with B physics observables:
in a few words…

- B Physics can distinguish between (M8,M9) and M16
- (M8,M9) perform better with suppression of *B*($B_s \to \mu^+ \mu^-$)
- M16 could help with the angular anomaly in $B \to K^* \mu^+ \mu^-$

Dependence on V_{cb}

Set of parameters:
$M_{Z'}$=3 TeV
V_{cb}=0.040
V_{ub}=0.0036

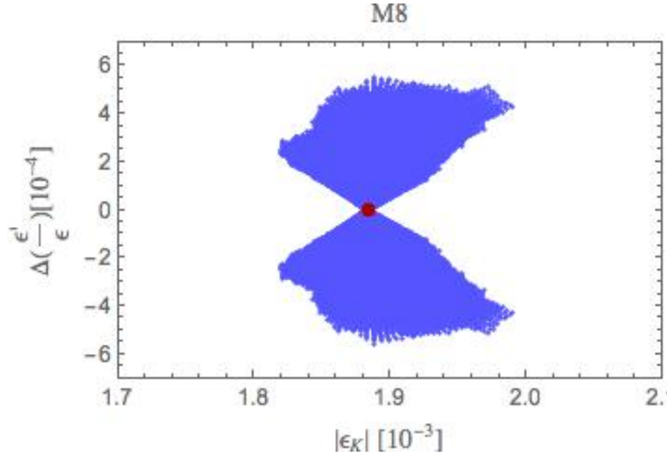


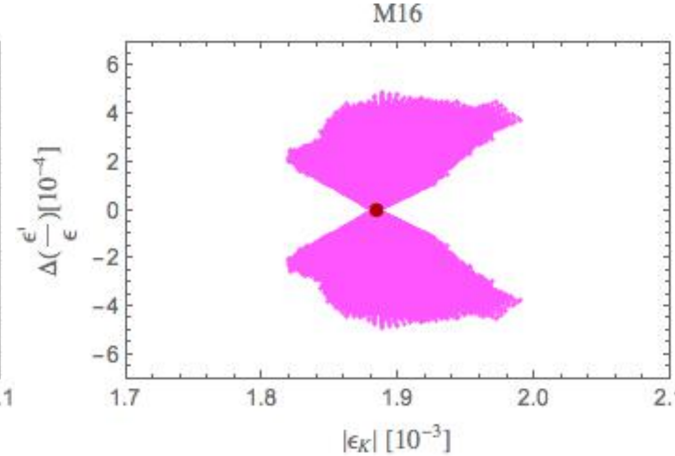


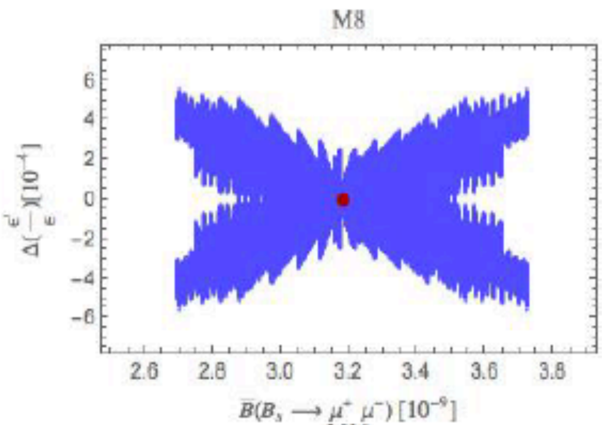
Still a shift of ε'/ε of (5-6) x 10^{-4} is possible

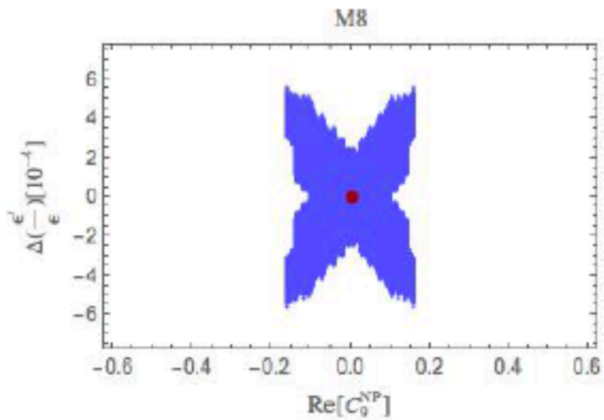
Dependence on V_{cb}

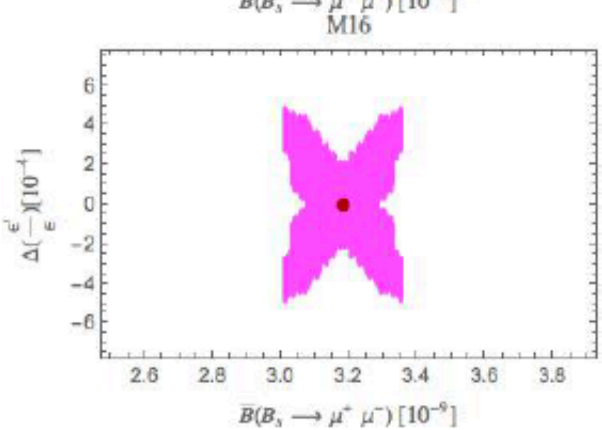
Set of parameters:
$M_{Z'}$=3 TeV
V_{cb}=0.040
V_{ub}=0.0036

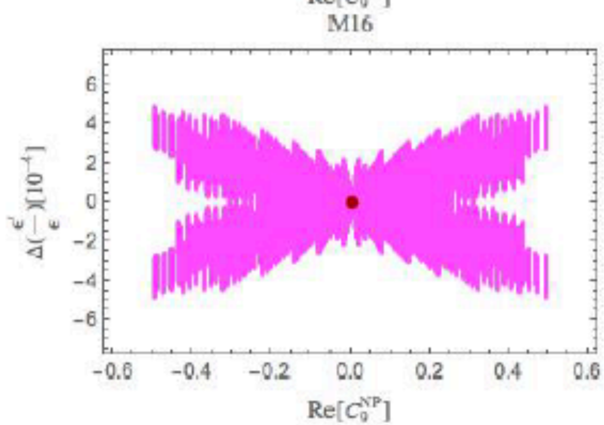








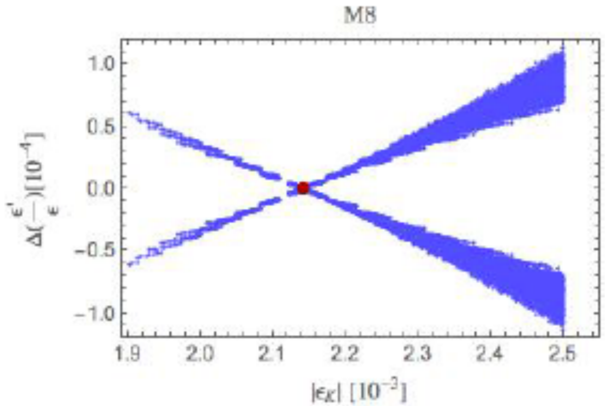


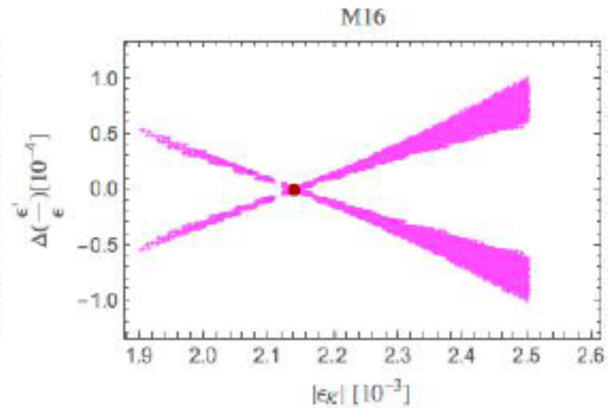


Larger effects!

Varying also $M_{Z'}$

Set of parameters:
$M_{Z'}$=10 TeV
V_{cb}=0.042
V_{ub}=0.0036





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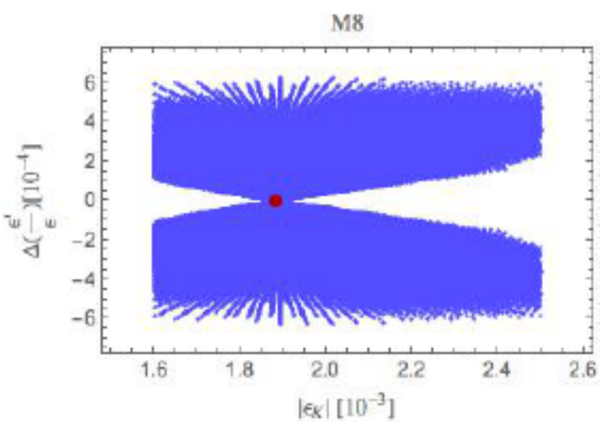
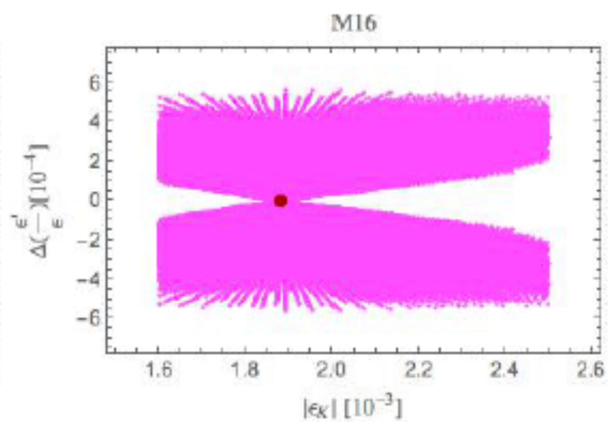
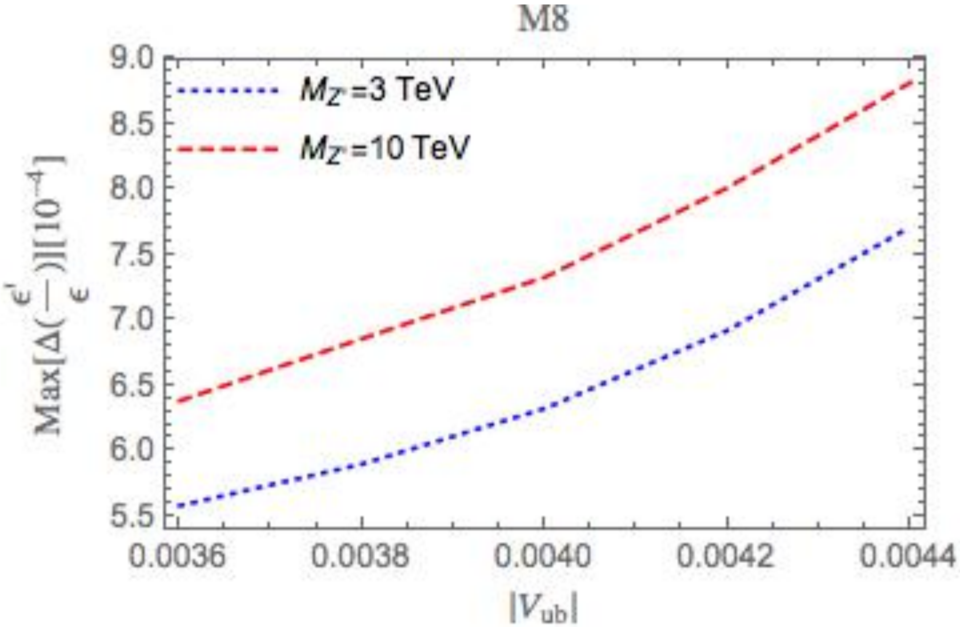




NP effects in $\mathcal{B}(B_s \to \mu^+ \mu^-)$ and in $\mathrm{Re}(C_9^{NP})$ decrease

Varying also V_{ub}



Summary

New SM results for ε'/ε are significantly below data

331 models:

- among 24 considered variants only 7 survive EPWO test
- only 3 can provide $\Delta(\varepsilon'/\varepsilon) > 4.0\ 10^{-4}$ (for $M_{Z'}$=3 TeV)
- M8 & M9 can also suppress $\mathcal{B}(B_s \to \mu^+ \mu^-)$ but cannot solve angular anomaly in $B \to K^* \mu^+ \mu^-$
- M16 performs the opposite
- For larger $M_{Z'}$ (but below 50 TeV) ε'/ε can still be accomodated but effects in B physics are negligible
- In 331 models V_{cb}=0.040 favoured over V_{cb}=0.042