B and K Physics in the scenario of one extra Fermion family

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Plan of talk

- CP violation and New Physics
- B and K Physics : SM and BSM
- Analysis and Results : SM4
- Conclusions

CP violation and NP

- CP violation is crucial for the fact that we are here ... that matter dominates over antimatter in our universe
- New sources of CP violation must exists in nature $\Rightarrow$ Strong CP problem, History of matter and antimatter , Hierarchy problem...
- New measurement of CP asymmetries in meson decays are sensitive to new sources of CP violation that come from physics at the few Tev

CP violation provides an excellent probe for NP

CP violation and K Physics

Direct $\longrightarrow$ CP phase appear in decay, Indirect $\longrightarrow$ CP phase appear in mixing

- Indirect CP violation in $K \rightarrow \pi\pi$ and $K \rightarrow \pi l \nu$ is given by

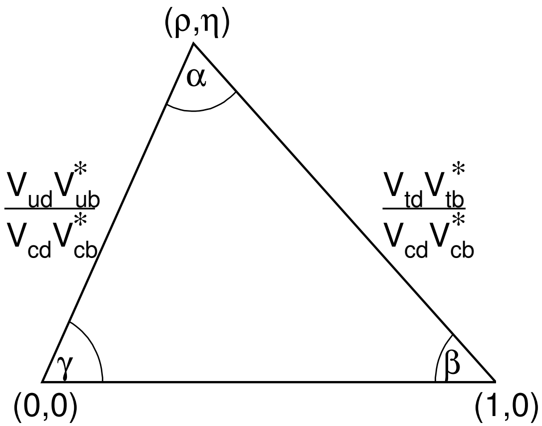
$$|\epsilon_k| = (2.32 \pm 0.007) \times 10^{-3}$$

- Direct CP violation in $K \rightarrow \pi\pi$ decays is given by

$$\epsilon'/\epsilon = (1.65 \pm 0.26) \times 10^{-3}$$

- $K_L \rightarrow \pi^0 \nu \bar{\nu}$ appears to be the best decay to measure $Im(\lambda_t)$

An important Goal of B Physics



The area of each triangle = $|J|/2$, $J \approx \lambda^6 A\eta$

- $|V_{ub}|^2 \propto \rho^2 + \eta^2 \rightarrow$ Charmless semileptonic decay rates
- $S_{\psi K_s} = \sin 2\beta$, *CP* asymmetry in $B \rightarrow \psi K_s$,
  $e^{i\beta} = 1 - \rho + i\eta$
- $e^{i\gamma} = \rho + i\eta$, γ is sensitive to various $B \rightarrow DK$ decay rates
- α is sensitive to $B \rightarrow \pi\pi, \rho\pi, \rho\rho$

Motivation: B - *CP* anomalies

- CP violation in Gold plated decay mode $B \to \psi K_s \Rightarrow$ $S_{\psi K_s} = 0.672 \pm 0.024$
  - SM predictions: $\sin 2\beta_{no\, V_{ub}}$ = 0.87 ± 0.09
  - $\sin 2\beta_{full\, fit}$ = 0.75 ± 0.04
    $\Rightarrow$ 1.7 to 2.1 σ deviation.. Lunghi and Soni, 2008
- $\sin 2\beta$ extracted from $B_d \to \phi K_s \Rightarrow 0.39 \pm 0.17$
- $\Delta A_{CP} \equiv A_{CP}(B^- \to K^-\pi^0) - A_{CP}(\bar{B}^0 \to K^-\pi^+)$ = $(14.4 \pm 2.9)\%$, $QCDF$ prediction $\to$ $(2.5 \pm 1.5)\%$.
- CP asymmetry in gold plated decay mode $B_s \to \psi\phi$, $S_{\psi\phi}$ = $\sin \phi_s \Rightarrow [-0.90,\ -0.17]$, 2σ range... CDF and D0 , 2008, $\phi_s = arg[-\frac{M_{12}}{\Gamma_{12}}] \to$ *CP* violating weak phase.. $\Rightarrow S^{SM}_{\psi\phi} \approx 0$

Table of Inputs

A. Soni, A. K. Alok, A. Giri, R. Mohanta and SN, arxiv:0807.1971 [hep-ph]

$B_K = 0.72 \pm 0.05$, Antonio *et al.*, 2008	$\|\epsilon_k\| \times 10^3 = 2.32 \pm 0.007$
$f_{bs}\sqrt{B_{bs}} = 0.281 \pm 0.021$ GeV	$\mathcal{BR}(K^+ \to \pi^+\nu\nu) = (0.147^{+0.130}_{-0.089}) \times 10^{-9}$
$\Delta M_s = (17.77 \pm 0.12) ps^{-1}$	$\mathcal{BR}(B \to X_s\gamma) = (3.55 \pm 0.25) \times 10^{-4}$
$\Delta M_d = (0.507 \pm 0.005) ps^{-1}$	$\mathcal{BR}(B \to X_s\ell^+\ell^-) = (0.44 \pm 0.12) \times 10^{-6}$
$\xi_s = 1.2 \pm 0.06$, Gamiz *et al.*, 2007	$\gamma = (75.0 \pm 22.0)^\circ$
$R_{bb} = 0.216 \pm 0.001$	$\|V_{ub}\| = (37.2 \pm 2.7) \times 10^{-4}$
$\|V_{cb}\| = (40.8 \pm 0.6) \times 10^{-3}$	$T_4 = 0.11 \pm 0.14$

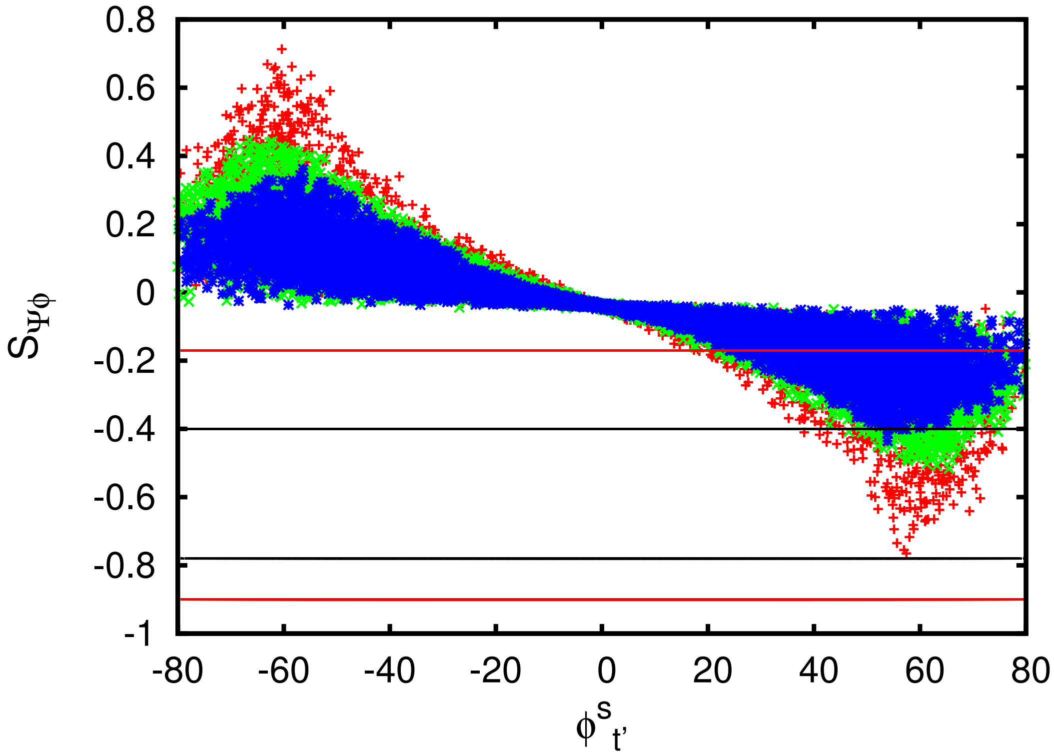
Constrain used $\Rightarrow$ *CKM* unitarity + Oblique corrections + $Br(B \to X_s\gamma)$ + ϵ_k + ΔM_d + $\frac{\Delta M_d}{\Delta M_s}$ + $Br(B \to X_s\ell^+\ell^-)$ + $\mathcal{BR}(K^+ \to \pi^+\nu\nu)$

Allowed ranges for the parameters, $\lambda^{\mathbf{s}}_{\mathbf{t'}} = \mathbf{V_{t'b}V^*_{t's}}$, phase of $\mathbf{V_{t's}} = \phi^{\mathbf{s}}_{\mathbf{t'}}$ and upper limit for $\lambda^{\mathbf{d}}_{\mathbf{t'}} = \mathbf{V_{t'b}V^*_{t'd}}$

$m_{t'}\ (GeV)$	400	600
$\lambda^s_{t'} \times 10^2$	(0.08 - 1.4)	(0.05 - 0.6)
$\phi^s_{t'}$	-80 $\longrightarrow$ 80	-80 $\longrightarrow$ 80
$\lambda^d_{t'} \times 10^3$	$<$ 2.0	$<$ 1.6

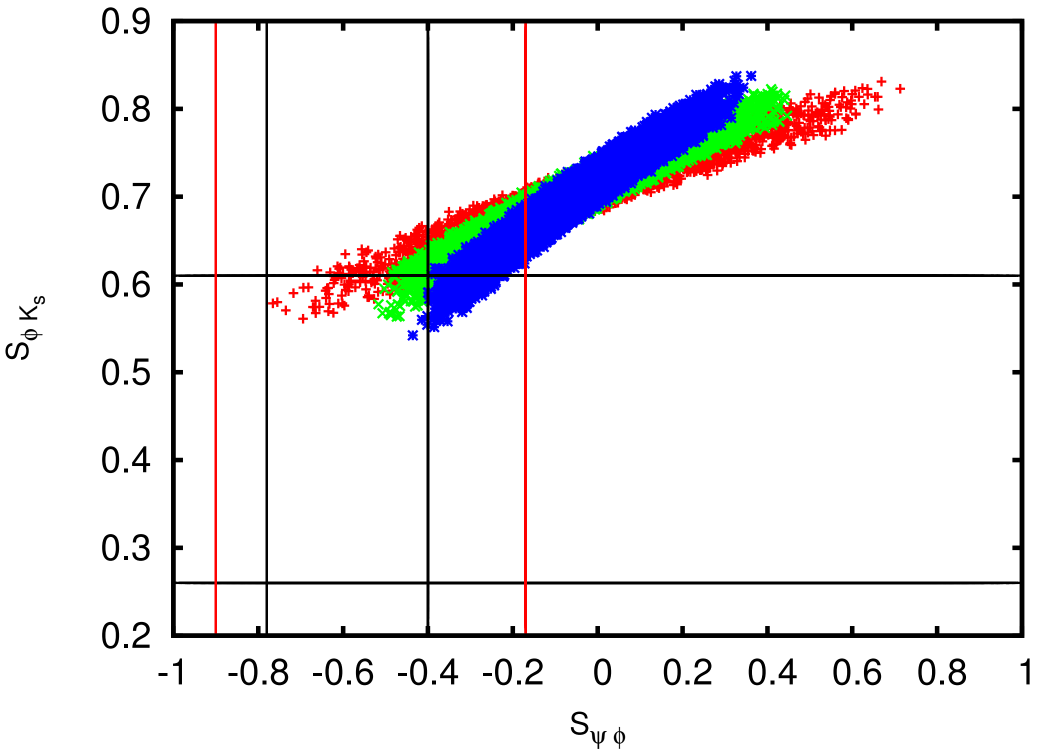
Upper bound on the SM4 coupling reducing with the mass of fourth family...

Variation of $\mathbf{S}_{\psi\phi}$ with the new phase $\phi^{s}_{t'}$



Present experimental bound on $\mathbf{S}_{\psi\phi}$ allows positive range for $\phi^{\mathbf{s}}_{\mathbf{t}'}$

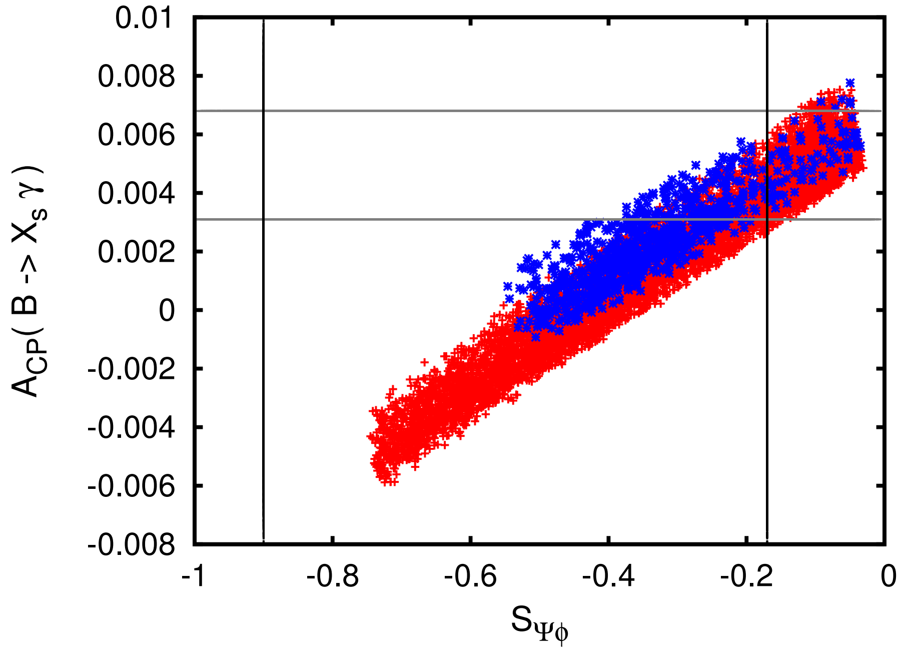
Correlation between $\mathbf{S}_{\psi\phi}$ with $\mathbf{S}_{\psi \mathbf{K_s}}$



correlation suggests that $m_{t'} \approx (400 - 600)\ GeV$ is more favoured

Correlation between $\mathbf{S}_{\psi\phi}$ and CP asymmetry in $\mathbf{B} \to \mathbf{X_s}\gamma$

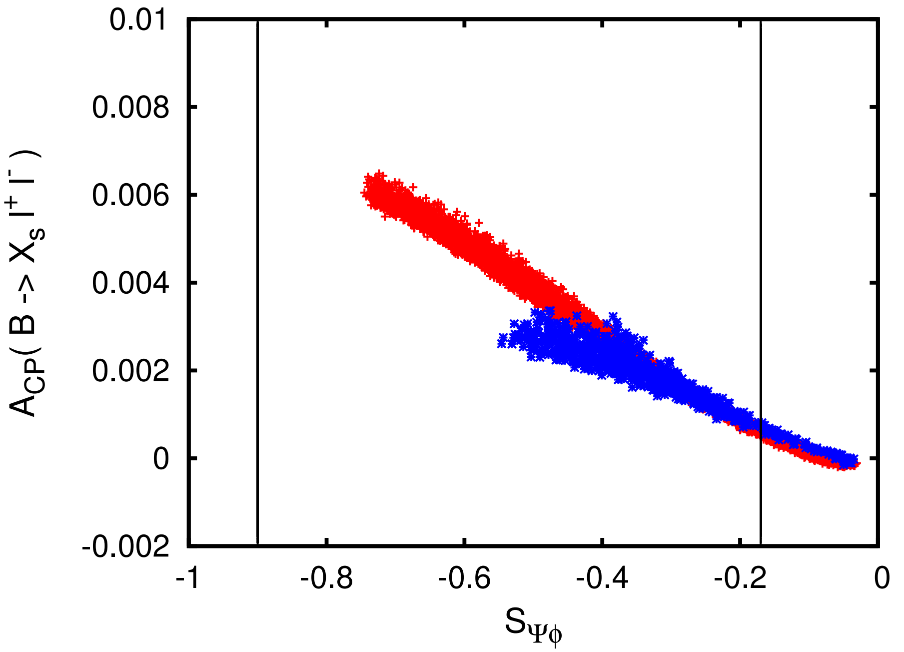
A. Soni, A. K. Alok, A. Giri, R. Mohanta and SN, in preparation



$$A_{CP}^{B\to X_s\gamma} \simeq \frac{10^{-2}}{|C_7^{\rm tot}(m_b)|^2}\Big\{ -1.82\,{\rm Im}\left[C_7^{\rm new}\right] + 1.72\,{\rm Im}\left[C_8^{\rm new}\right] - 4.46\,{\rm Im}\left[C_8^{\rm new} C_7^{\rm new*}\right] + 3.21\,{\rm Im}\left[\epsilon_s\left(1 - 2.18\,C_7^{\rm new*} - 0.26\,C_8^{\rm new*}\right)\right]\Big\}$$

A_{CP} is reducing with SM4 coupling......

Correlation between $\mathbf{S}_{\psi\phi}$ and CP asymmetry in $\mathbf{B} \rightarrow \mathbf{X_s}\ell^+\ell^-$

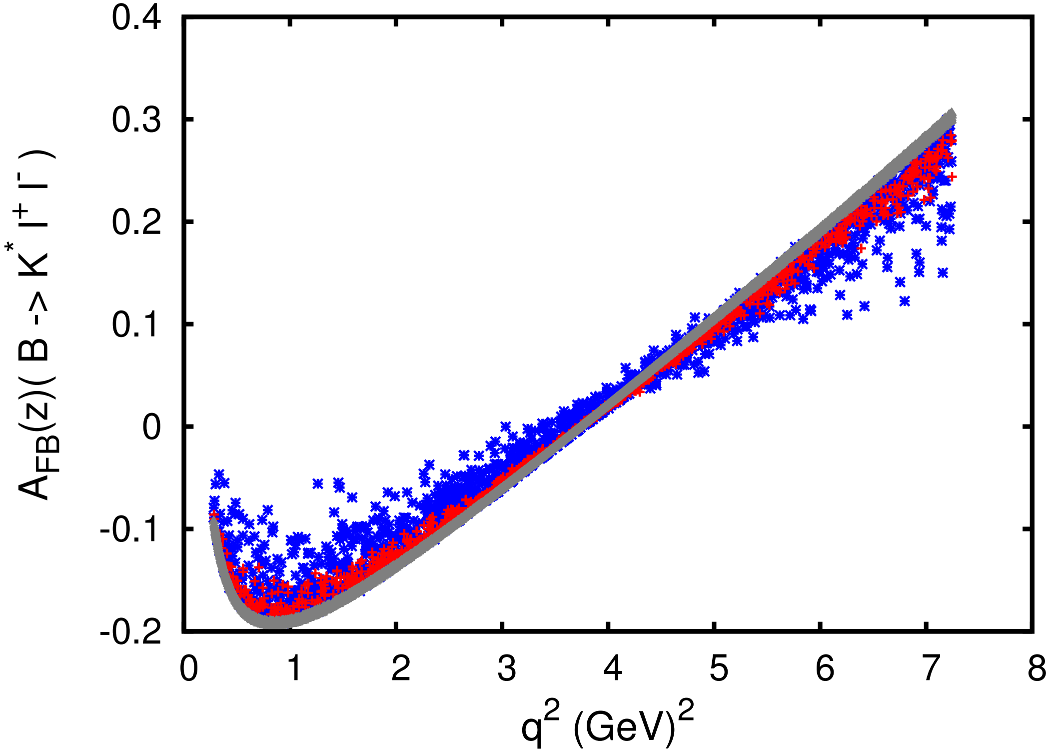


$$A_{CP} \propto \Big[\mathrm{Im}(\lambda_{tu}^s) \left\{ 2(1+2z)\mathrm{Im}(\xi_1 \xi_2^*) - 12 C_7 \mathrm{Im}(\xi_2) \right\} 2 \left(1 + \frac{2t^2}{z}\right) + X_{im} \left\{ (1+2z) C_9^{t'} + 6 C_7^{t'} \right\} \Big]$$

SM3 $\Rightarrow Im(\xi_2) \propto Im\Big(g_(\hat{m}_u, z) - g_(\hat{m}_c, z)\Big) \approx$ zero

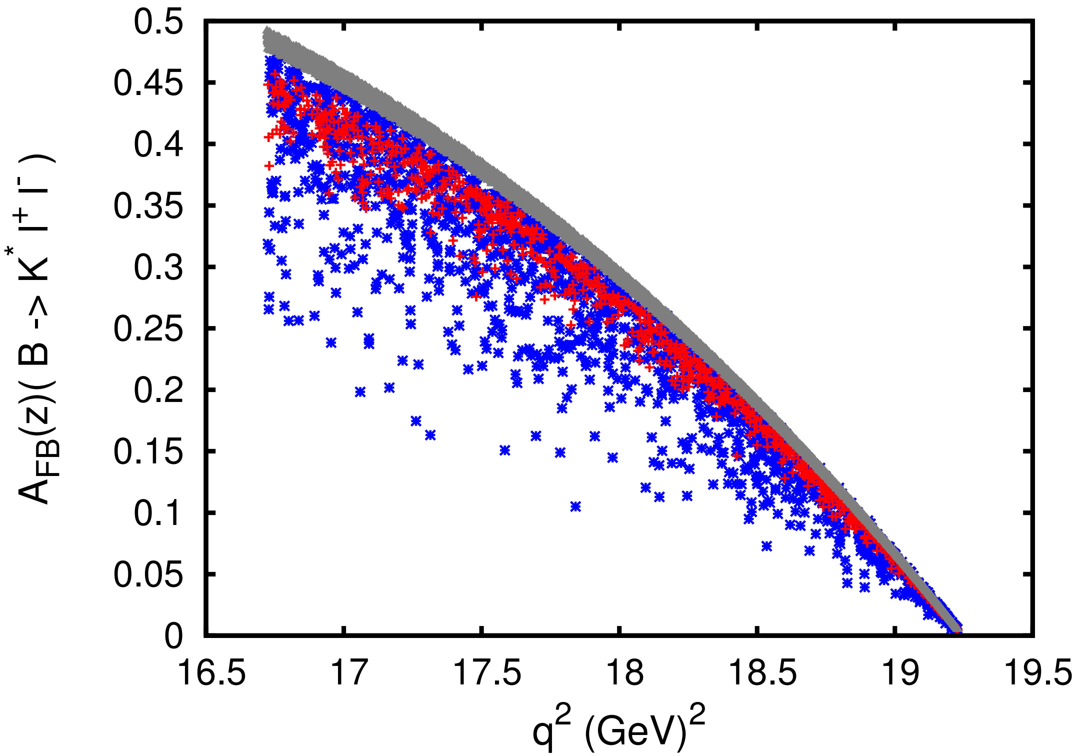
SM4 $\Rightarrow Im(\xi_2)$ unaffected but ξ_1 increases

Forward Backward asymmetry as a function of $\mathbf{q^2}$ (low $\mathbf{q^2}$ region), grey region corresponds to the SM prediction



Small deviation from SM3 can be observed for q^2 in between $0.6 \rightarrow 1.0$....more prominant for $m_{t'} = 600\ GeV$

Forward Backward asymmetry as a function of $\mathbf{q^2}$ (high $\mathbf{q^2}$ region)

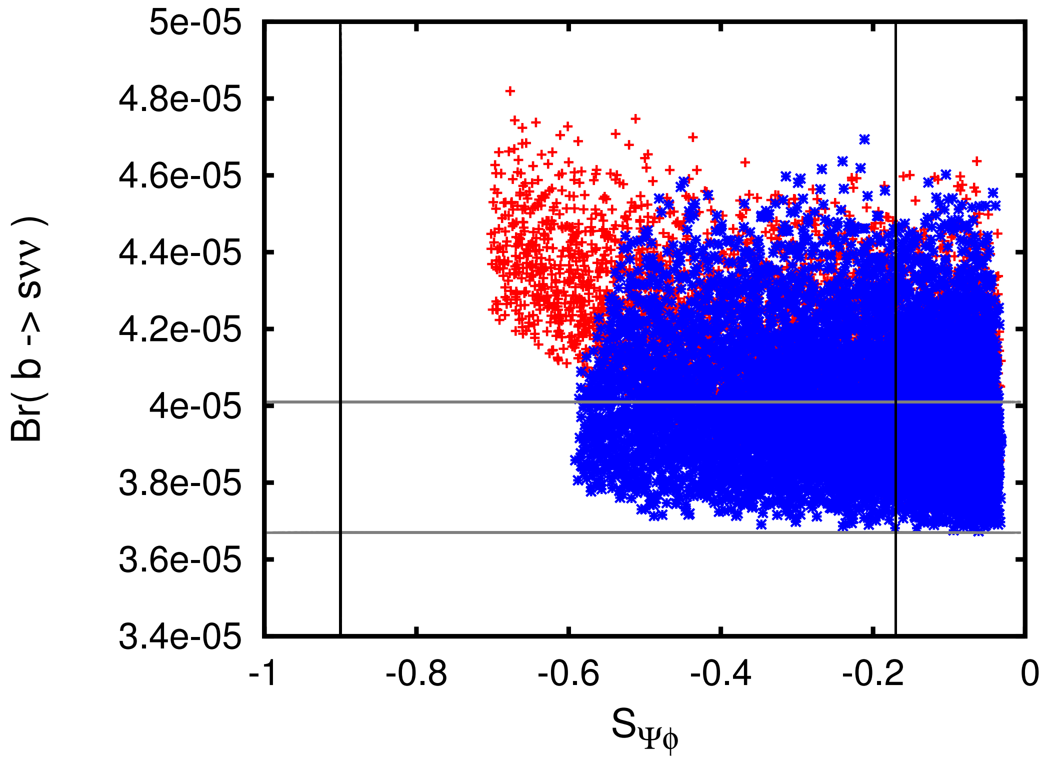


For $\mathbf{q^2}$ in between $\mathbf{16.0 \to 18.0}$, 10% to 30% deviation from SM3 prediction could be observed for $m_{t'} = 400$ and $600\,GeV$ respectively

$q^2(\mathrm{GeV}^2/c^2)$	A_{FB}			
	exp	SM	$m_t' = 400\,\mathrm{GeV}$	$m_t' = 600\,\mathrm{GeV}$
$0.6 - 1.0$	$0.47^{+0.26}_{-0.33}$	$-0.18 \to -0.19$	$-0.13 \to -0.19$	$-0.08 \to -0.19$
$1.0 - 6.0$	$0.26^{+0.28}_{-0.31}$	$-0.2 \to 0.2$	$-0.2 \to 0.2$	$-0.2 \to 0.2$
$6.0 - 8.0$	$0.45^{+0.21}_{-0.26}$	$0.19 \to 0.30$	$0.17 \to 0.28$	$0.11 \to 0.30$
$16.5 - 18.0$	$0.66^{+0.12}_{-0.16}$	$0.28 \to 0.49$	$0.25 \to 0.45$	$0.15 \to 0.47$
$18.0 - 19.5$	For $q^2 > 16$	$0.003 \to 0.30$	$0.003 \to 0.27$	$0.003 \to 0.28$

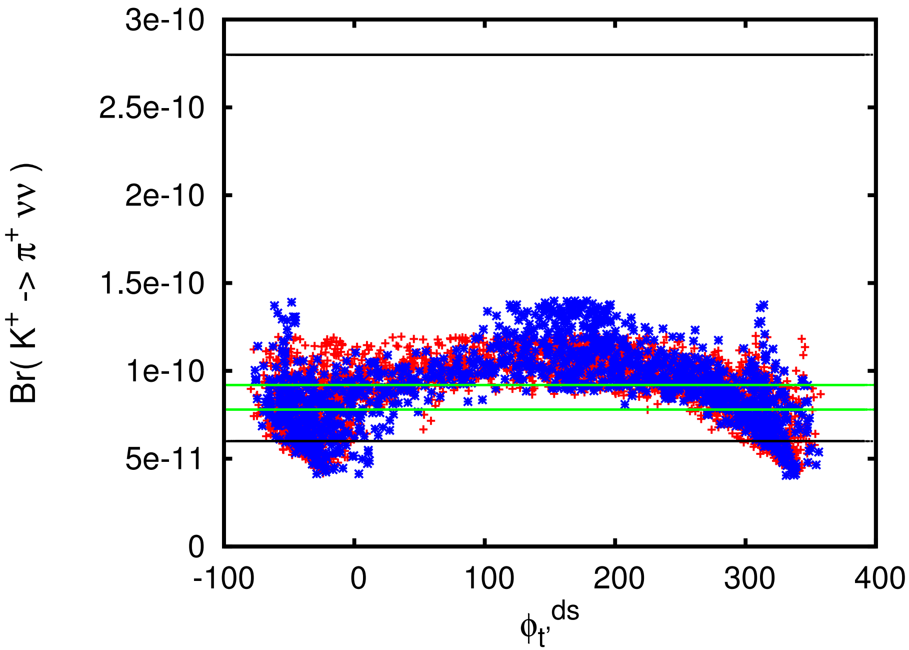
SM4 predicted ranges are consistent with the present experimental bound

Correlation between $\mathbf{S}_{\psi\phi}$ and $\mathbf{Br(b \to s\nu\bar{\nu})}$, grey horizontal lines represent the SM limit



$$Br\left(B \to X_s \nu\bar{\nu}\right) \propto \frac{\alpha^2}{2\pi^2 \sin^4\Theta_W}\left|V_{tb}^* V_{ts} X_0(x_t)\right|^2 \left|1 + \frac{V_{t'b}^* V_{t's}}{V_{tb}^* V_{ts}} \frac{X_0(x_{t'})}{X_0(x_t)}\right|^2$$

Variation of $\mathbf{Br(K^+ \to \pi^+ \nu\bar{\nu})}$ with $\phi_{\mathbf{t'}}^{\mathbf{ds}} = \phi_{\mathbf{t'}}^{\mathbf{d}} - \phi_{\mathbf{t'}}^{\mathbf{s}}$, green horizontal lines correspond to SM limit

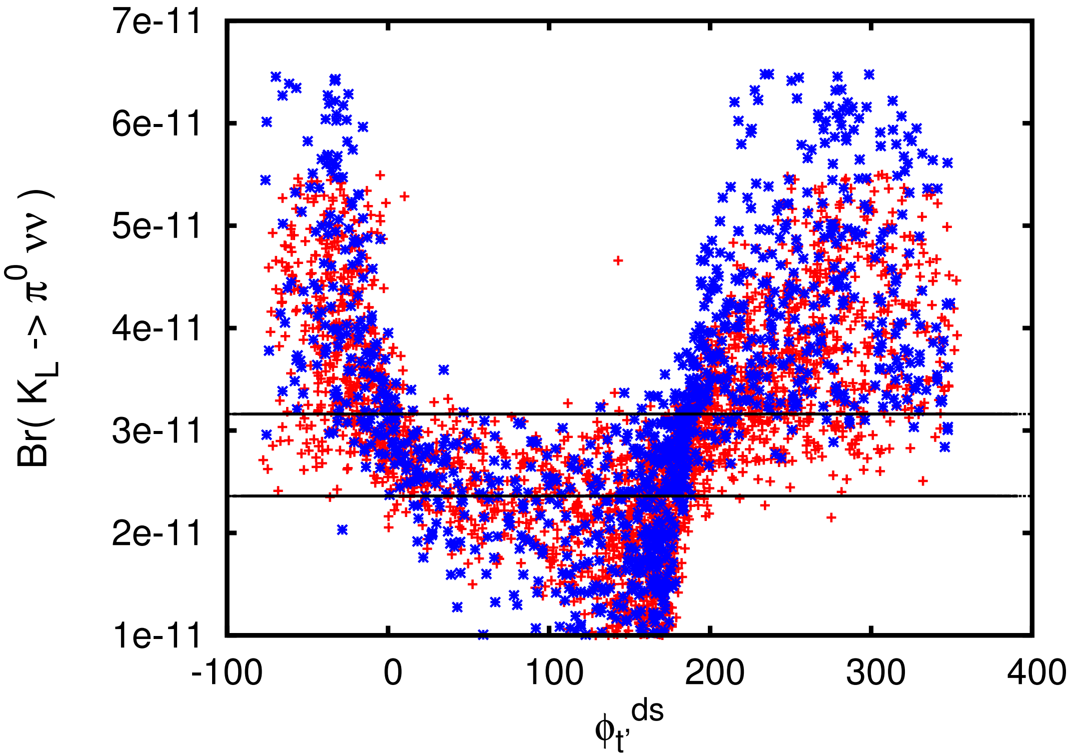


$Br(K^+ \to \pi^+ \nu\bar{\nu}) \propto$

$$\left[\left(\frac{\mathrm{Im}\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Im}\lambda_{t'}}{\lambda^5} X(x_{t'}) \right)^2 + \left(\frac{\mathrm{Re}\lambda_c}{\lambda} P_0(X) + \frac{\mathrm{Re}\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\lambda_{t'}}{\lambda^5} X(x_{t'}) \right)^2 \right]$$

$Br(K^+ \to \pi^+ \nu\bar{\nu}) = (4.0 \to 12.0) \times 10^{-11} \Rightarrow 1\,\sigma$ range in SM4

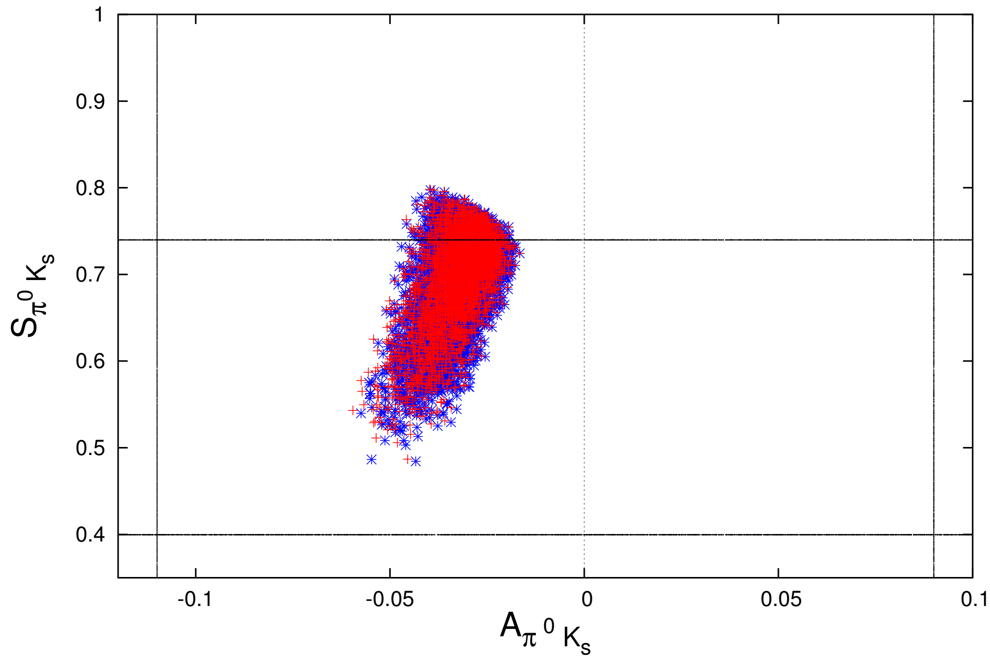
Variation of $\mathbf{Br(K_L \to \pi^0 \nu\bar{\nu})}$ with $\phi_{t'}^{ds} = \phi_{t'}^{d} - \phi_{t'}^{s}$, black horizontal lines correspond to SM limit



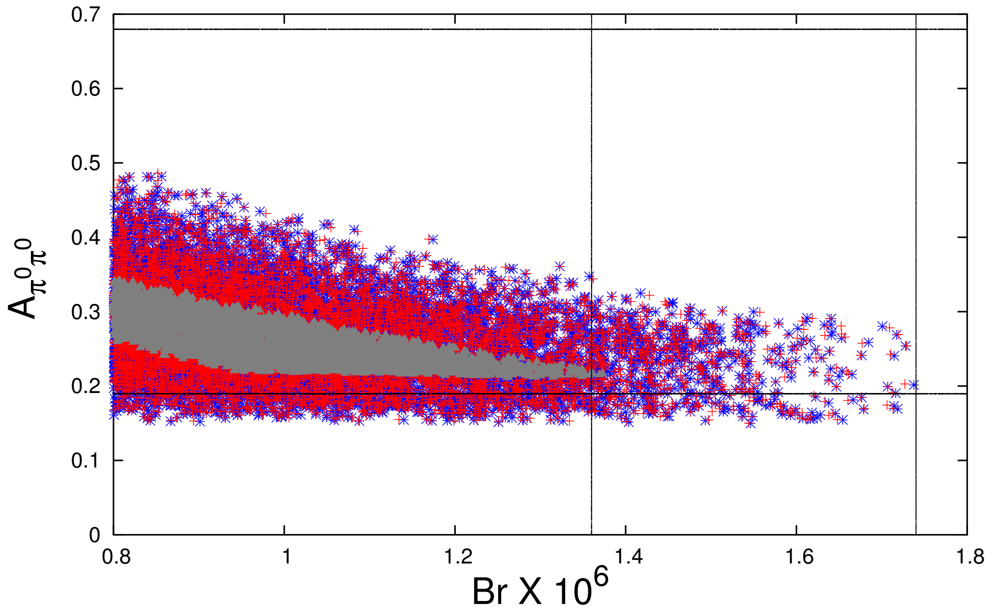
$$Br(K_L \to \pi^0 \nu\bar{\nu}) \propto \left[\left(\frac{Im\lambda_t}{\lambda^5} X(x_t) + \frac{Im\lambda_{t'}}{\lambda^5} X(x_{t'})\right)^2\right]$$

$Br(K_L \to \pi^0 \nu\bar{\nu}) = (1.0 \to 5.2) \times 10^{-11} \Rightarrow 1\,\sigma$ range in SM4

Correlation Plots between the mixing induced CP asymmetry $\mathbf{S_{\pi^0 K_s}}$ and the direct CP asymmetry $\mathbf{A_{\pi^0 K_s}}$



SM3 contribution $\Rightarrow$ $S_{\pi^0 K_s} \approx (0.7 \rightarrow 0.8)$ and $A_{\pi^0 K_s} \approx (0 \rightarrow -0.05)$ $\Rightarrow$ For $S_{\pi^0 K_s}$ SM4 prediction have few σ deviations from that of SM3 correlation plot between the direct CP **asymmetry** and the CP $-$ **averaged branching** ratio for the $\mathbf{B^0} \to \pi^0\pi^0$ process



Large deviations for $A_{\pi^0\pi^0}$....

Conclusions

- Shortly after the discovery of third generation, a fourth generation was an obvious extension $\Rightarrow$ Consistent with Electroweak precision test
- Heavier quarks with masses $(\mathbf{400-600})\ GeV$ can play a crucial role in dynamical electroweak-symmetry breaking...
- SM4 offers a simple explanation to many anomalies seen in B and B_s system..
- It is not clear whether we are able to reproduce the full size of the observed discrepancy in $\mathbf{\Delta A}_{CP}$ $\Rightarrow$ Could be a limitation of QCDF model..
- Several processes wherein SM4 causes large deviations from the expectations of SM3; for example $\mathbf{b} \to \mathbf{s}\nu\bar{\nu}$, $\mathbf{K_L} \to \pi^{\mathbf{0}}\nu\bar{\nu}$, $\mathbf{A}_{\pi^{\mathbf{0}}\pi^{\mathbf{0}}}$, $\mathbf{S}_{\psi\phi}$ *e.t.c* $\Rightarrow$ may provide further indirect evidence for an additional family of quark

Thank you !