Possible hints of *New* Physics in *Flavor* Physics

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CKM 2008 - Roma

Mostly based on: E.L. and A. Soni, arXiv:0707.0212
arXiv:0803.4340
in preparation

Outline

- A critical review of the UT fit:
  - New formula for ε_K [Andriyash,Ovanesyan,Vysotsky] [Buras,Guadagnoli]
  - The role of V_{cb} and V_{ub}
  - Updated inputs
- The UT fit and what it suggests about new physics:
  - NP in *B_d mixing* and in *$b \to s$ amplitudes* [EL,Soni]
  - NP in *K mixing* and in *$b \to s$ amplitudes* [Buras,Guadagnoli] [EL,Soni]
- Correlation with NP signals in Bs mixing and in $B \to K\pi$
- Conclusions

K mixing

$$\varepsilon_K = \frac{A(K_L \to (\pi\pi)_{I=0})}{A(K_S \to (\pi\pi)_{I=0})}$$
$$= e^{i\phi_\varepsilon} \sin\phi_\varepsilon \left(\frac{\mathrm{Im} M_{12}^K}{\Delta M_K} + \frac{\mathrm{Im} A_0}{\mathrm{Re} A_0} \right)$$
$$= e^{i\phi_\varepsilon} \kappa_\varepsilon C_\varepsilon \hat{B}_K |V_{cb}|^2 \lambda^2 \eta \Big(|V_{cb}|^2 (1-\bar{\rho}) + \eta_{tt} S_0(x_t) + \eta_{ct} S_0(x_c, x_t) - \eta_{cc} x_c \Big)$$

- Experimentally one has: $\phi_\varepsilon = (43.51 \pm 0.05)^o$ [PDG]
- $\mathrm{Im}A_0/\mathrm{Re}A_0$ can be extracted from experimental data on ε'/ε and theoretical calculation of isospin breaking corrections
- The final result is: $\kappa_\varepsilon = 0.92 \pm 0.02$ [Andryiash,Ovanesyan,Vysotsky; Nierste; Buras,Jamin; Bardeen,Buras,Gerard; Buras,Guadagnoli]

K mixing

$$|\varepsilon_K| = \kappa_\varepsilon C_\varepsilon \hat{B}_K |V_{cb}|^2 \lambda^2 \eta \left(|V_{cb}|^2 (1-\bar{\rho}) + \eta_{tt} S_0(x_t) + \eta_{ct} S_0(x_c, x_t) - \eta_{cc} x_c \right)$$

- Note the quartic dependence on V_{cb}: $|V_{cb}|^4 \sim A^4 \lambda^8$
- Critical input from lattice QCD:

$$\langle K^0 | \mathcal{O}_{VV+AA}(\mu) | \bar{K}^0 \rangle = \frac{8}{3} f_K^2 M_K^2 B_K(\mu)$$

Using *2+1 flavor domain wall fermions*, the RBC and UKQCD collaborations find [PRL'08, saw in Enno Scholz talk]:

$$\begin{aligned} B_K^{\overline{MS}}(2\text{GeV}) &= Z_{B_K}^{\overline{MS}} B_K = [0.928(05)_{\text{stat}}(23)_{\text{disc}}] \times \\ &\times [0.565(10)_{\text{stat}}(06)_{\text{FVE}}(11)_{\text{Ch}}(06)_{m_s}(23)_{\text{scale}}] \end{aligned}$$

Adding the systematic errors in quadrature they quote:

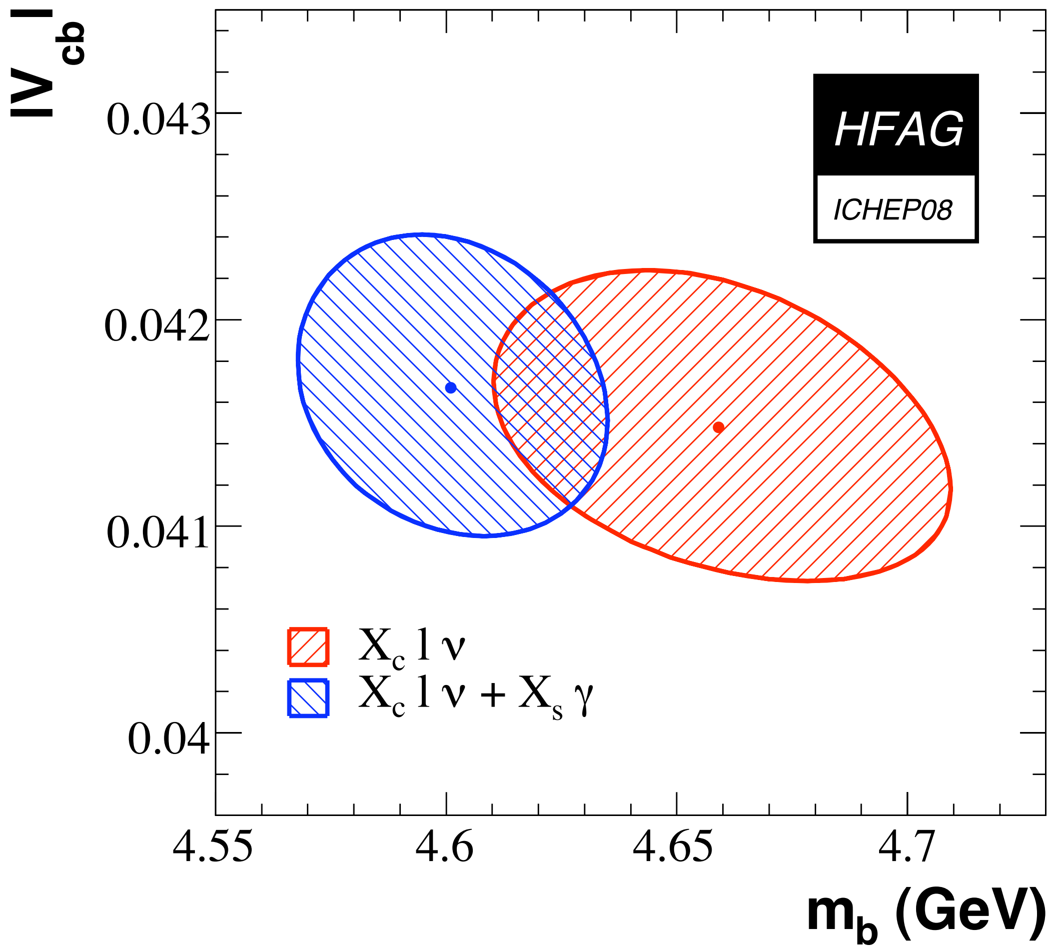
$$\hat{B}_K = 0.720 \pm 0.013_{\text{stat}} \pm 0.037_{\text{syst}}$$

V_{cb}

- Exclusive from $B \to D^* l\nu$. Using form factor from lattice QCD (2+1 dynamical staggered fermions) one finds:

$$|V_{cb}| = (38.7 \pm 0.7_{\rm stat} \pm 0.9_{\rm syst})\, 10^{-3}$$ [Laiho]

- Inclusive from global fit of $B \to X_c l\nu$ moments. [Büchmuller,Flächer]



- Inclusion of $b \to s\gamma$ has strong impact on quark masses but not on V_{cb}
- NNLO in α_s and $O(1/m_b^4)$ known
- Calculation of $O(\alpha_s/m_b^2)$ under way
- Issue of m_b is relevant for V_{ub}

$$|V_{cb}| = (41.67 \pm 0.43 \pm 0.08 \pm 0.58)\, 10^{-3}$$

2.2σ discrepancy between inclusive and exclusive

V_{ub}

- Exclusive from $B \to \pi l\nu$. Using form factor from lattice QCD (2+1 dynamical staggered fermions) one finds:

$$|V_{ub}| = (3.55 \pm 0.25_{\rm stat} \pm 0.5_{\rm syst})\, 10^{-3}$$ [HPQCD]

not independent

$$|V_{ub}| = (3.78 \pm 0.3_{\rm stat} \pm 0.34_{\rm syst} \pm 2.5_{\rm exp})\, 10^{-4}$$ [Fermilab,Milc]

- Inclusive from global fit of $B \to X_u l\nu$ moments.

$$|V_{ub}| = \left(3.94 \pm 0.15_{\rm exp}{}^{+0.20}_{-0.23}{}_{\rm th}\right) 10^{-3}$$ [Gambino,Giordano,Ossola, Uraltsev (GGOU)]

$$|V_{ub}| = \left(4.48 \pm 0.16_{\rm exp}{}^{+0.25}_{-0.26}{}_{\rm th}\right) 10^{-3}$$ [Andersen,Gardi (DGE)]

$$|V_{ub}| = \left(3.99 \pm 0.14_{\rm exp}{}^{+0.32}_{-0.27}{}_{\rm th}\right) 10^{-3}$$ [Bosch,Lange,Neubert,Paz (BLNP)]

doesn't use $b \to s\gamma$

B_q mixing

- We consider the ratio of the B_s and B_d mass differences:

$$\frac{\Delta M_{B_s}}{\Delta M_{B_d}} = \frac{m_{B_s}}{m_{B_d}} \frac{\hat{B}_s f_{B_s}^2}{\hat{B}_d f_{B_d}^2} \left| \frac{V_{ts}}{V_{td}} \right|^2 = \frac{m_{B_s}}{m_{B_d}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

- No dependence on V_{cb}

- We use unquenched results for the ratio of decay constants:

$f_{B_s}/f_{B_d} = 1.20 \pm 0.02_{\rm stat} \pm 0.05_{\rm syst}$ [Fermilab-Milc,HPQCD]

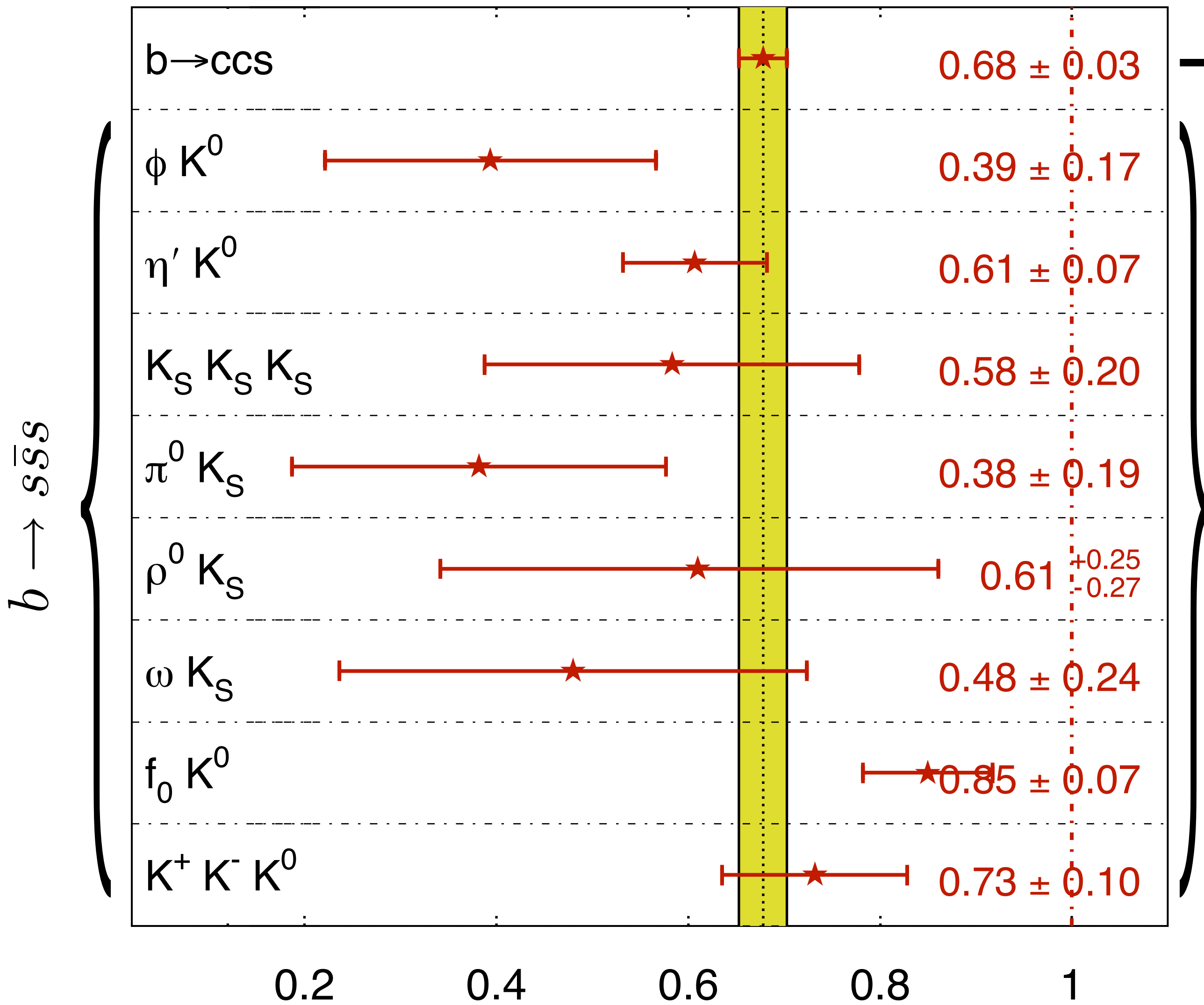
- Only quenched simulations for Bq are available:

$\hat{B}_s/\hat{B}_d = 1.00 \pm 0.02$ [Becirevic]

- Combining the two we obtain: $\xi = 1.20 \pm 0.06$

$\sin(2\beta)$

[HFAG 2008]



$$\rightarrow \quad a_{\psi K_s} = \sin(2\underset{\uparrow\ \arg(V_{td}^*)}{\beta}) + O(0.1\%)$$

In QCDF:

$$\Delta a_f \equiv a_f - \sin 2(\beta + \theta_d)$$

$$= 2 \underbrace{\left| \frac{V_{ub} V_{us}^*}{V_{cb} V_{cs}^*} \right|}_{0.025} \cos 2\beta \ \sin\gamma \ \mathrm{Re} \left(\frac{a_f^u}{a_f^c} \right)$$

$$\Delta a_\phi = 0.02 \pm 0.01$$

$$\Delta a_{\eta'} = 0.01 \pm 0.01$$

[Beneke, Neubert]

Other approaches find similar results
[Chen,Chua,Soni; Buchalla,Hiller,Nir,Raz]

- We will consider the asymmetries in the $J/\psi,\ \phi,\ \eta'$ modes
- A case can be made for the $K_s K_s K_s$ final state [Cheng,Chua,Soni]

Comments on systematic uncertainties

- We treat all systematic uncertainties as gaussian
- Most relevant systematic errors come from lattice QCD (B_K,ξ) and are obtained by adding in quadrature several different sources of uncertainty
- Gaussian treatment seems a fairly conservative choice

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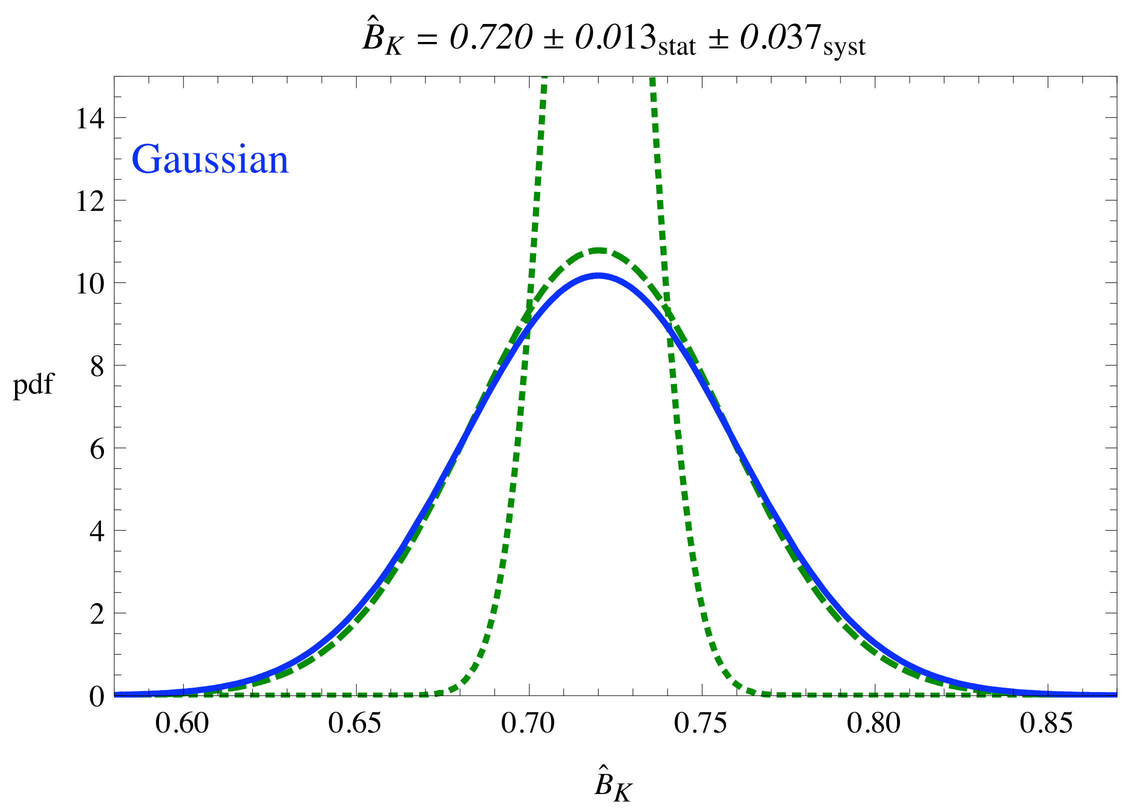

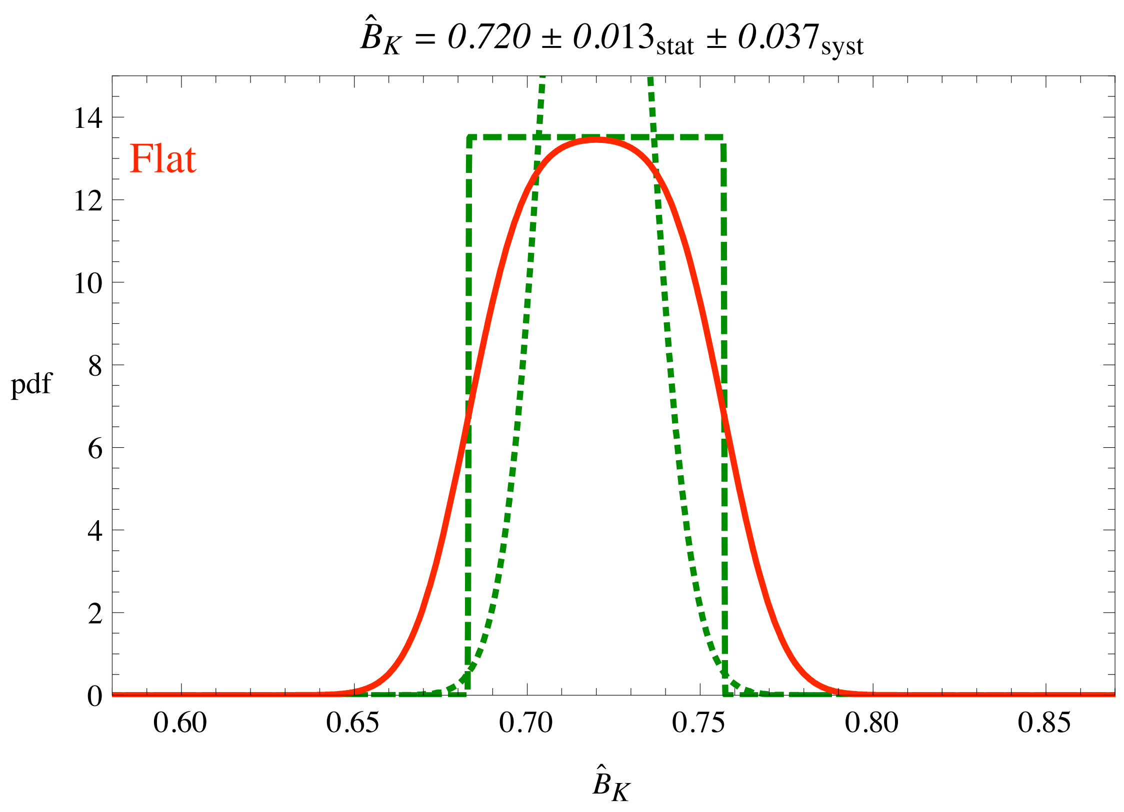

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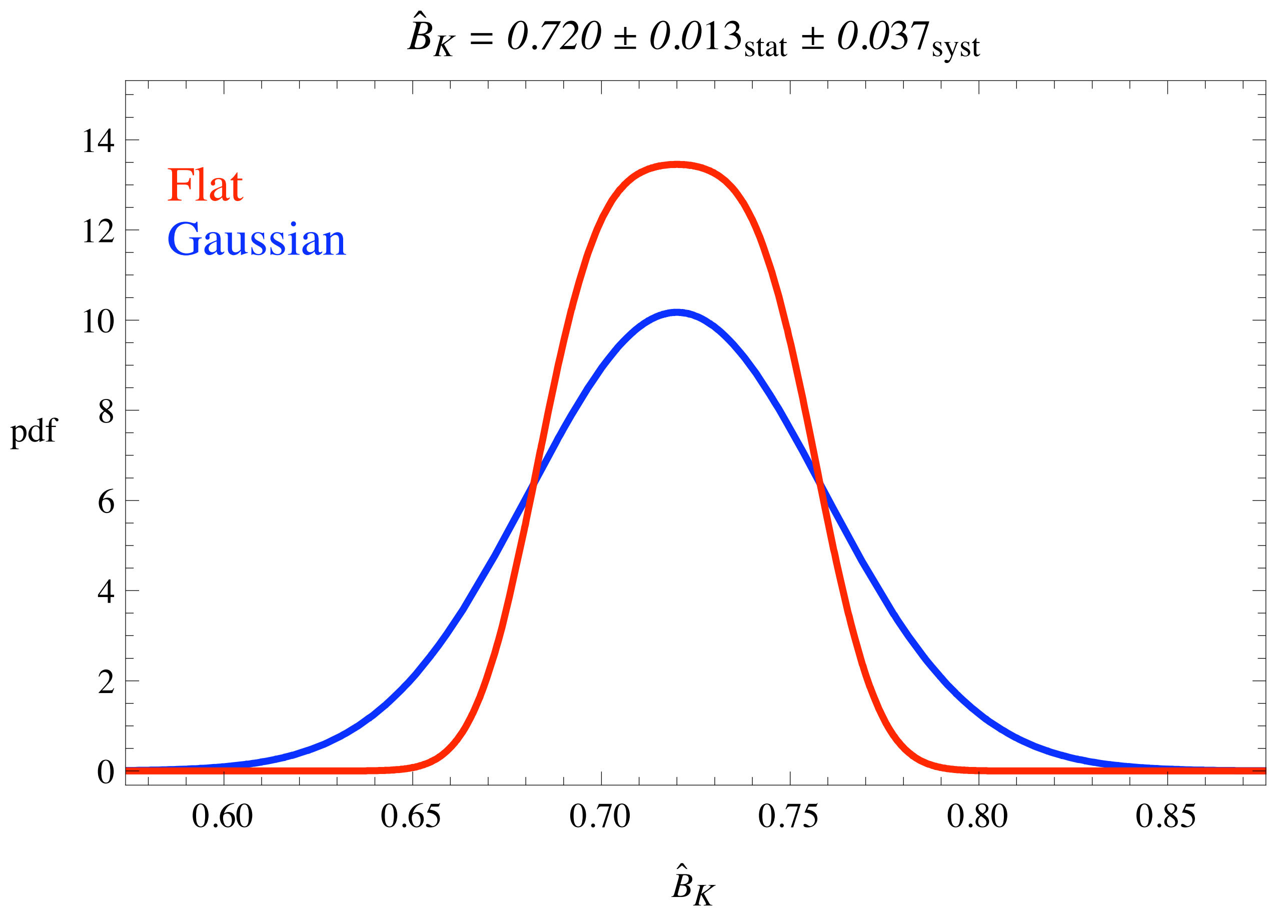

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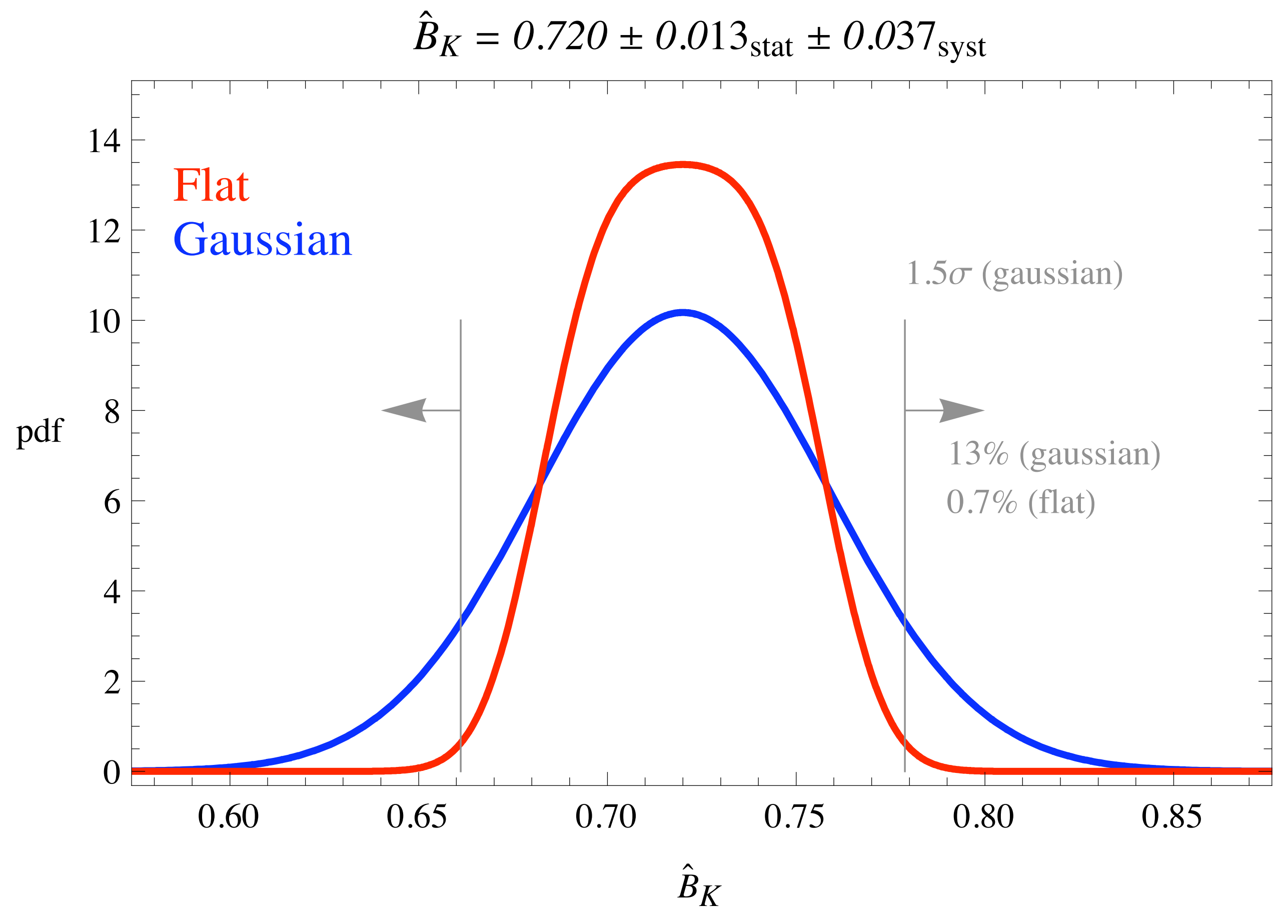
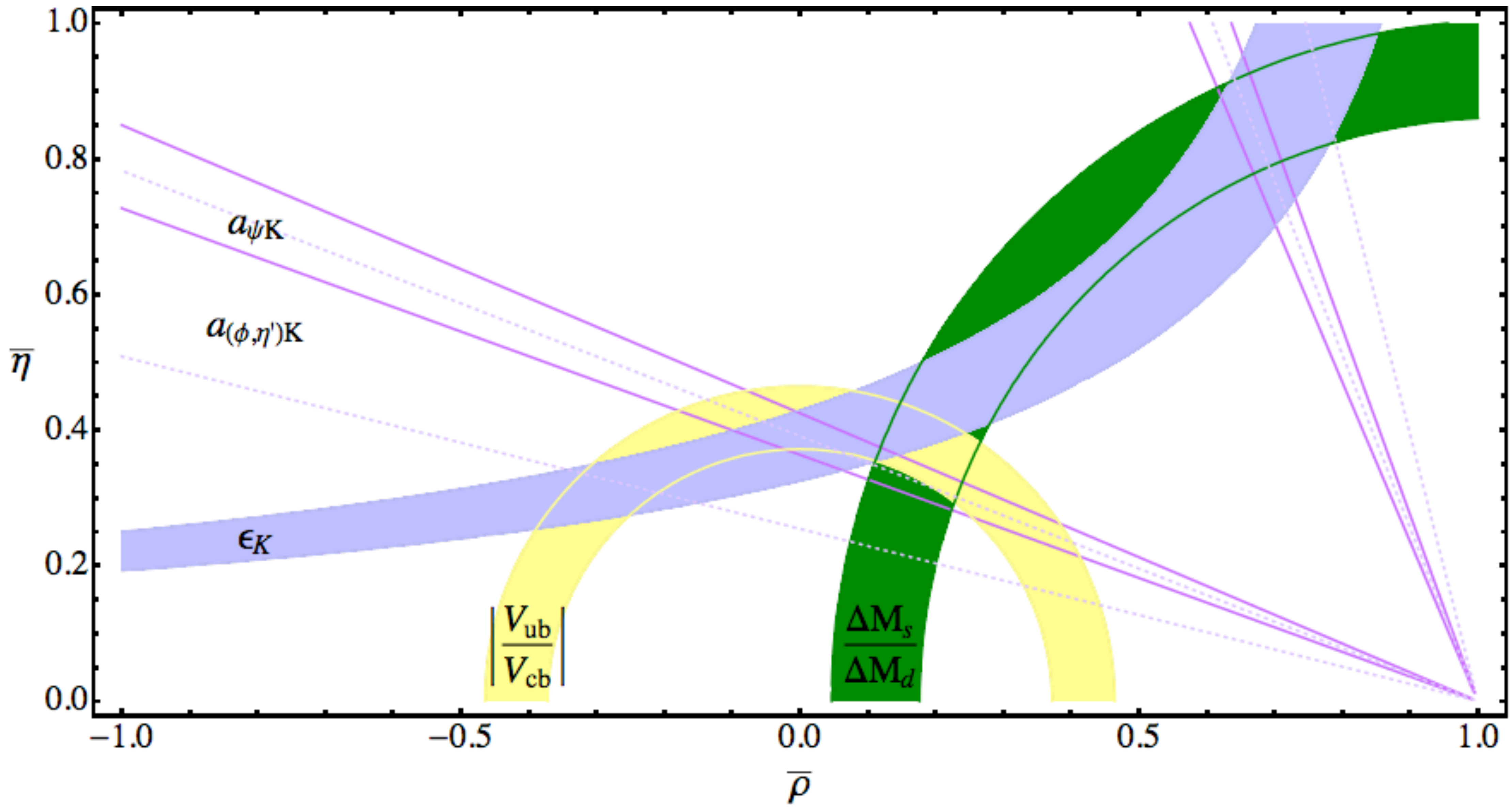
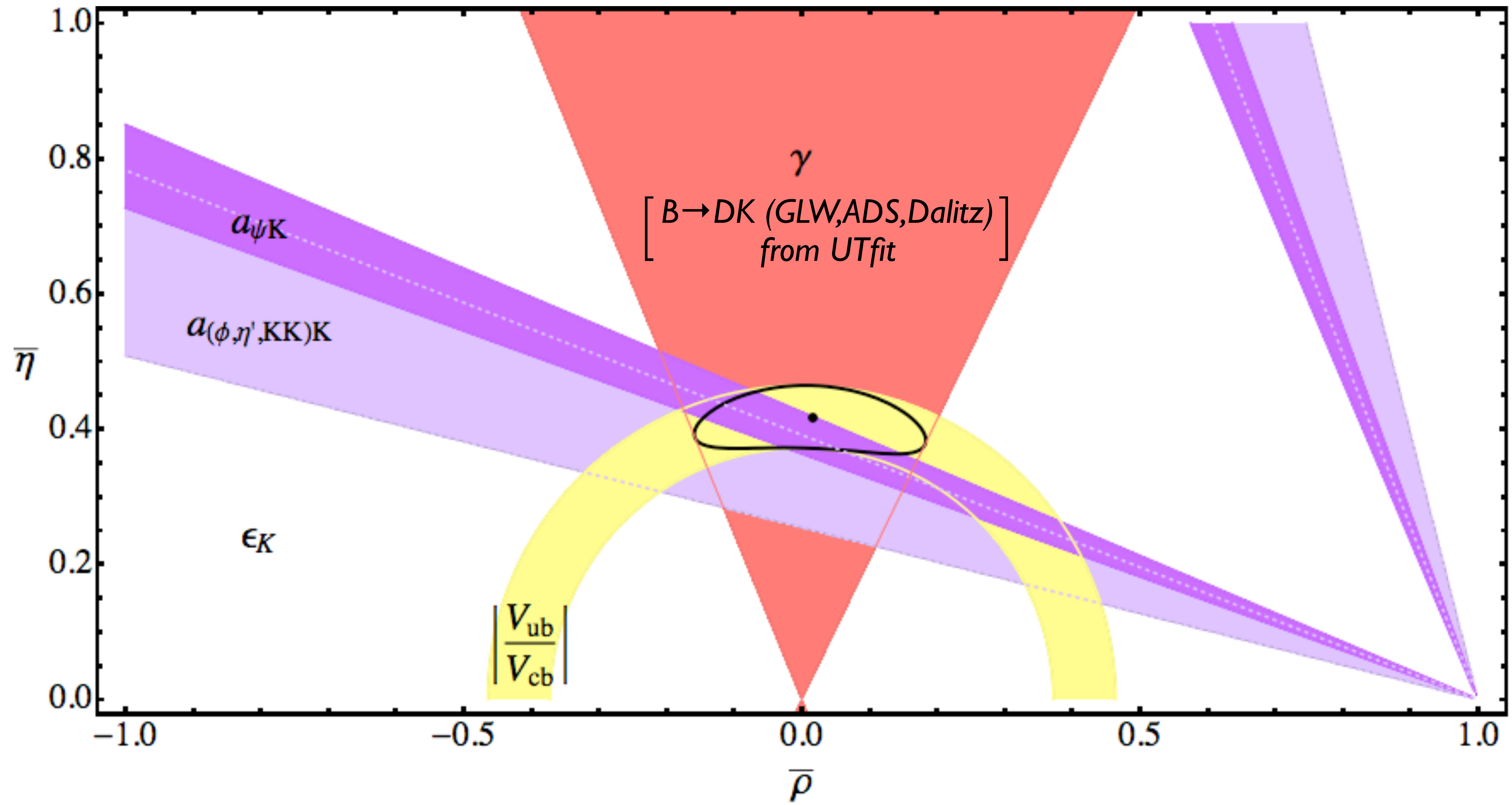


A first look at the fit



- Strain between $|V_{ub}|/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ and $a_{(\psi,\phi,\eta')K_s}$

A first look at the fit



- $|V_{ub}/V_{cb}|$ + γ : $\sin(2\beta) = 0.71 \pm 0.07$

$a_{\psi K} = 0.681 \pm 0.025$ [consistent]

$a_{\phi K} = 0.39 \pm 0.17$ [1.8 σ]

$a_{\eta' K} = 0.61 \pm 0.07$ [consistent]

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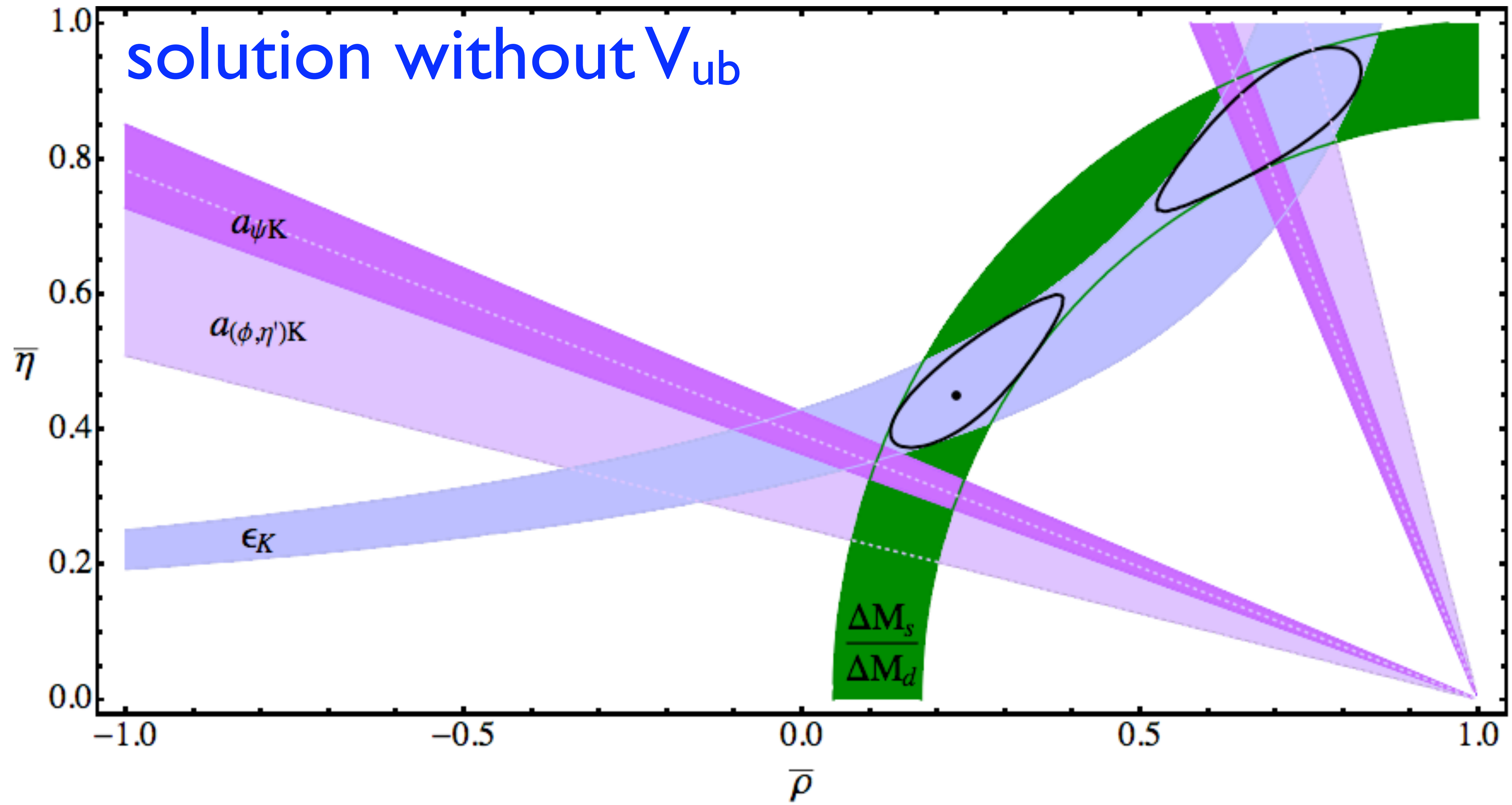
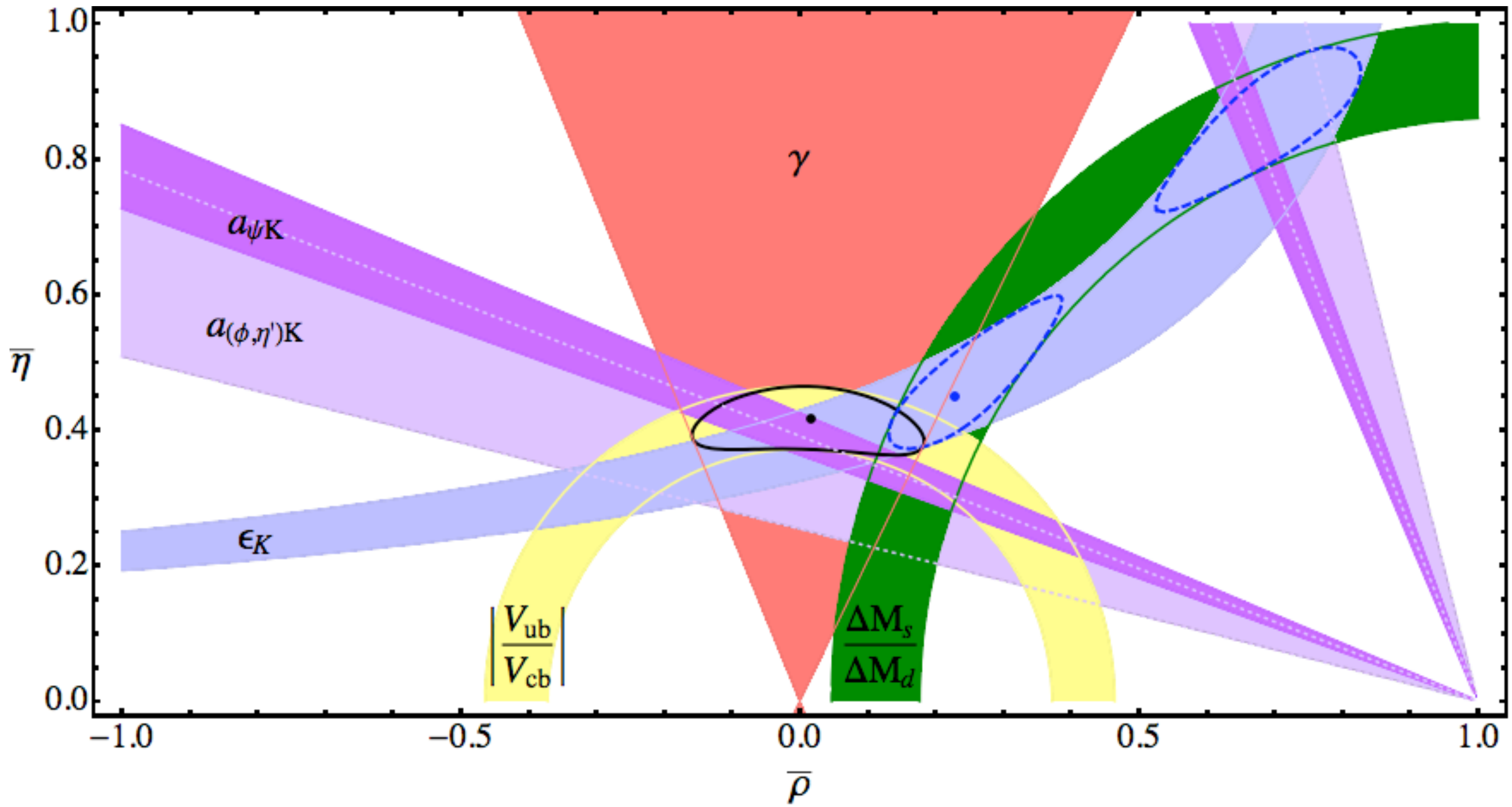


- $\varepsilon_K + \Delta M_{Bs}/\Delta M_{Bd} + V_{cb}$: $\sin(2\beta) = 0.87 \pm 0.09$

$$a_{\psi K} = 0.681 \pm 0.025 \quad [2\ \sigma]$$
$$a_{\phi K} = 0.39 \pm 0.17 \quad [2.5\ \sigma]$$
$$a_{\eta' K} = 0.61 \pm 0.07 \quad [2.3\ \sigma]$$

A first look at the fit



- $\varepsilon_K + \Delta M_{Bs}/\Delta M_{Bd} + V_{cb}$: $\sin(2\beta) = 0.87 \pm 0.09$ [1.4 σ]
- $|V_{ub}/V_{cb}| + \gamma$: $\sin(2\beta) = 0.71 \pm 0.07$

New physics in B mixing and $A(b \to s)$

- We can interpret (K mixing could also play a role) the strain in the UT fit as new physics in the *B_d mixing phase* and in *$b \to s$ amplitudes*:

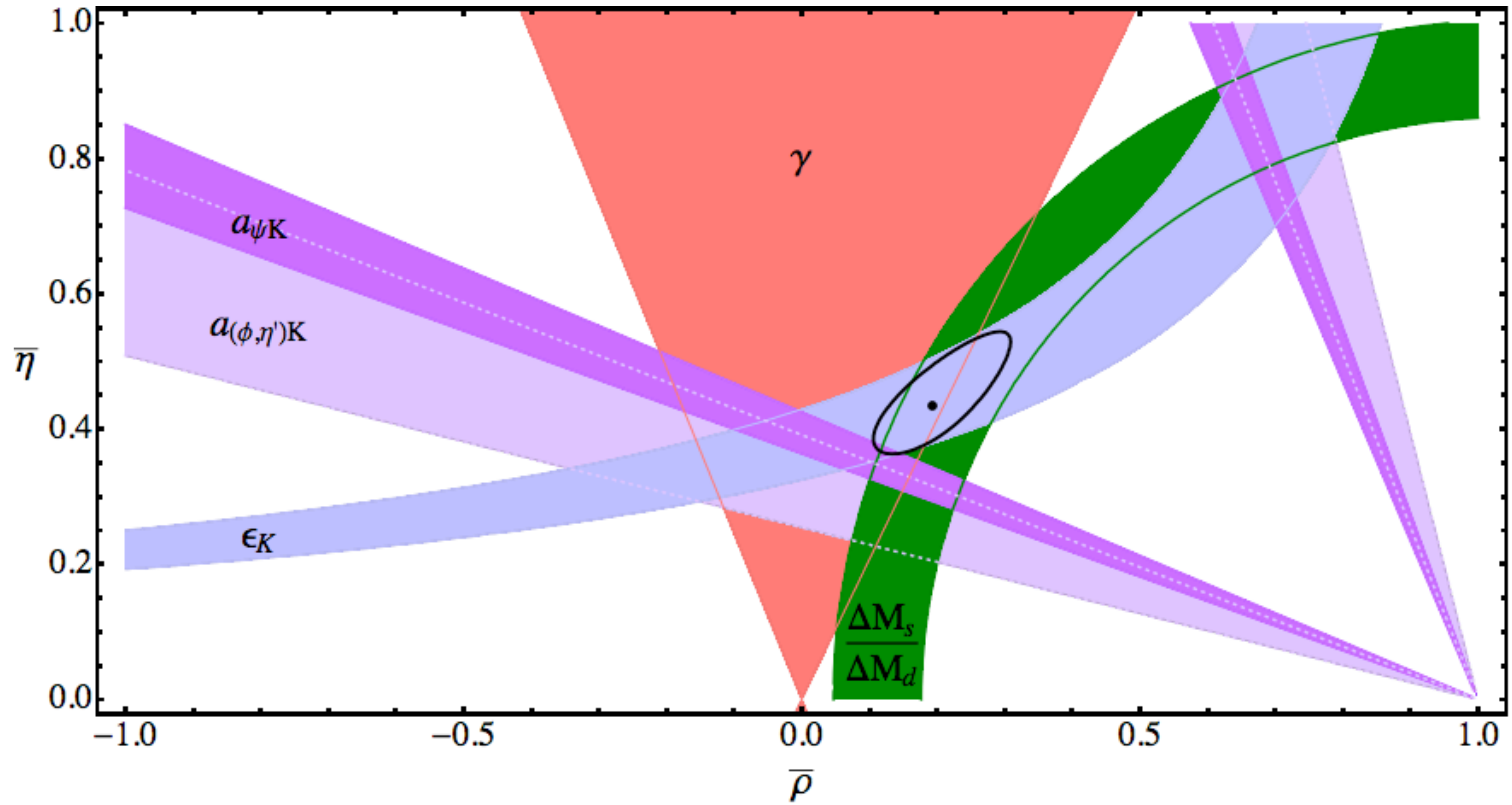
$$\begin{aligned} M_{12} &= M_{12}^{\rm SM}\, r^2 e^{2i\phi_d} \\ A(b \to s\bar{s}s) &= [A(b \to s\bar{s}s)]_{\rm SM}\, e^{i\theta_A} \end{aligned}$$

- This implies:

$$\begin{aligned} a_{\psi K_s} &= \sin 2(\beta + \phi_d) \\ a_{(\phi,\eta')K_s} &= \sin 2(\beta + \phi_d + \theta_A) \end{aligned}$$

- In general NP will affect in different ways the various $b \to s$ channels so this is only a first step

New physics in B mixing and $A(b \to s)$



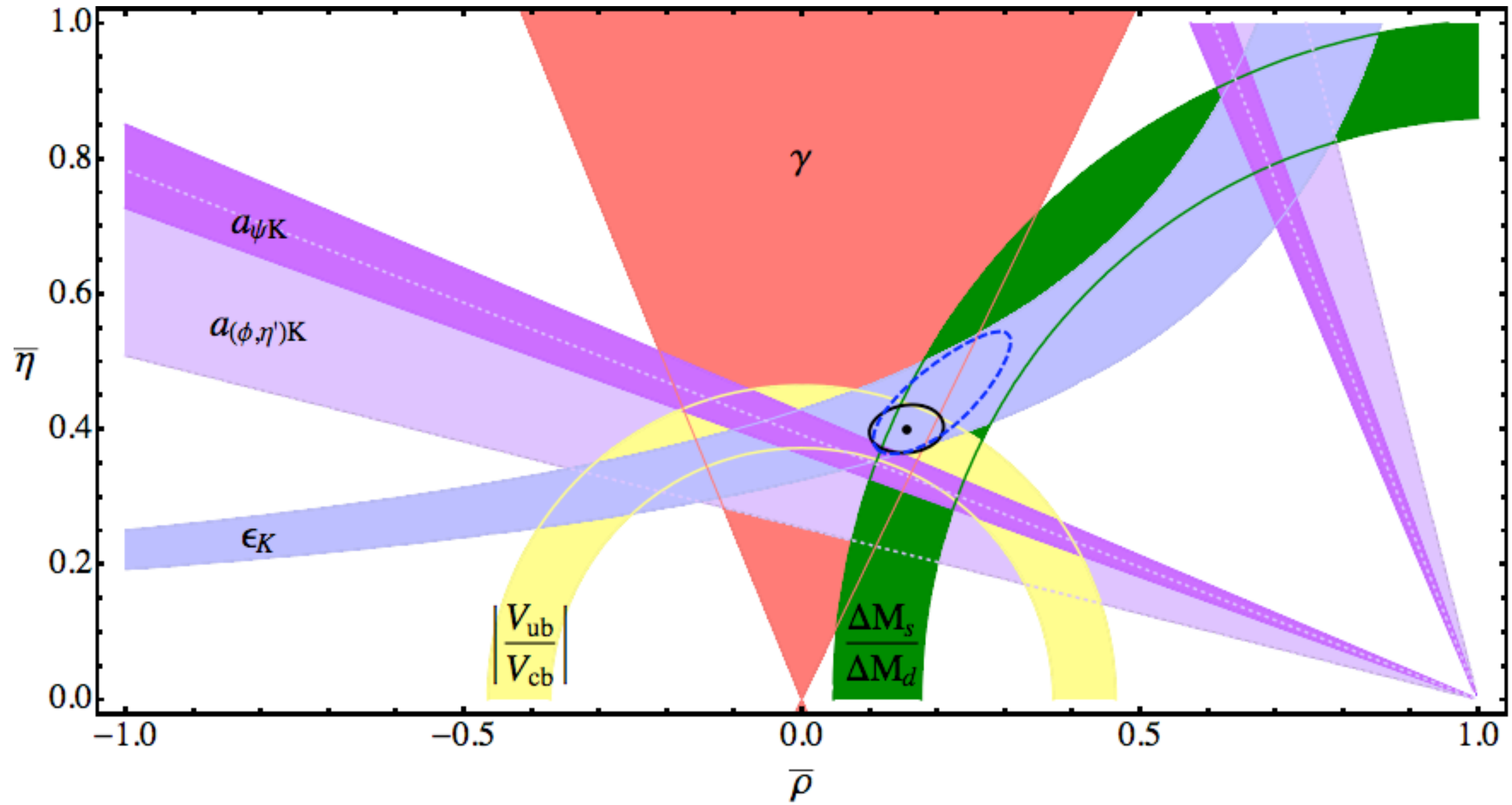
- $\varepsilon_K + \Delta M_{Bs}/\Delta M_{Bd} + V_{cb} + \gamma$: $\sin(2\beta) = 0.84 \pm 0.086$

$a_{\psi K} = 0.681 \pm 0.025$ [1.7 σ]

$a_{\phi K} = 0.39 \pm 0.17$ [2.3 σ]

$a_{\eta' K} = 0.61 \pm 0.07$ [2 σ]

New physics in B mixing and $A(b \to s)$



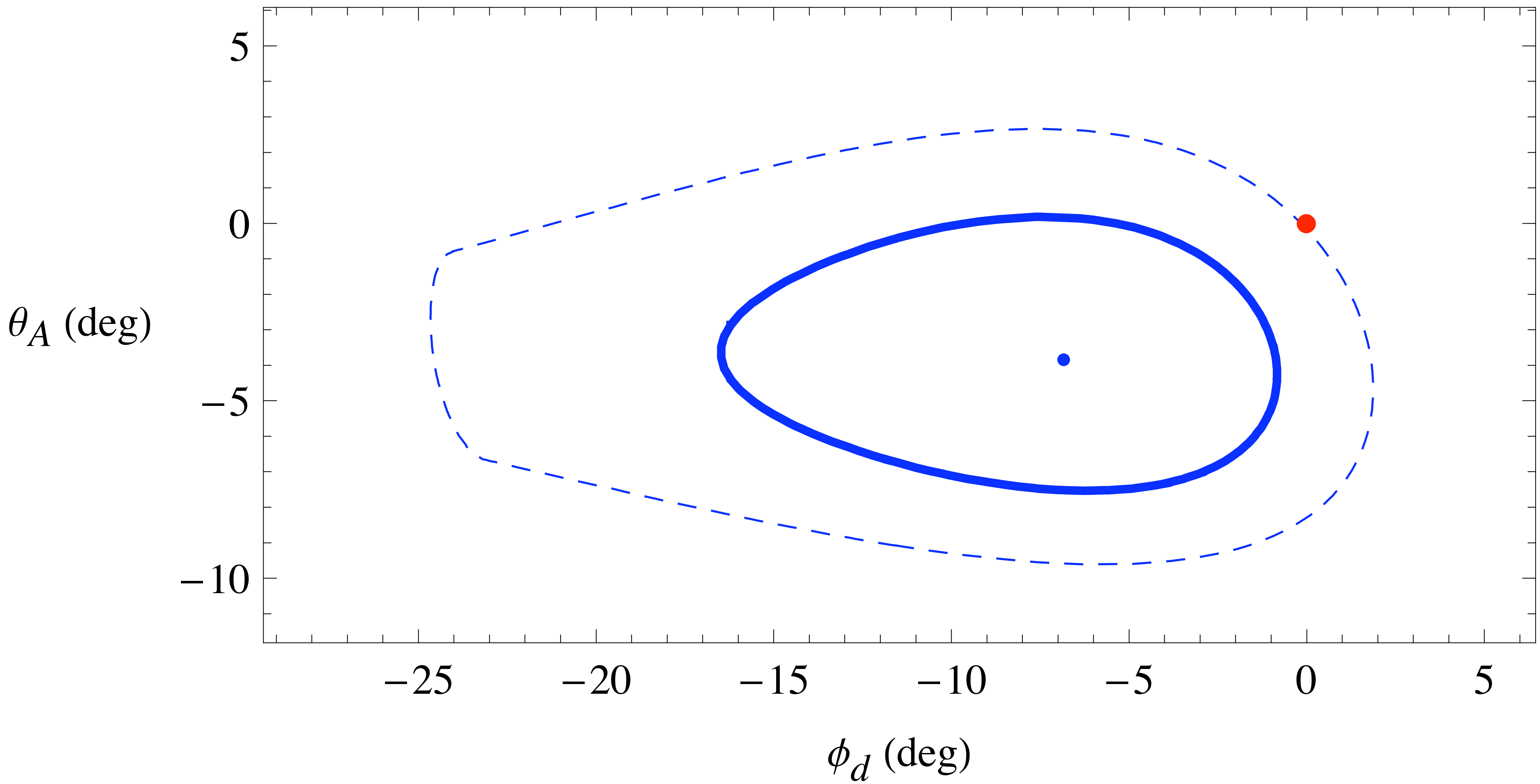
- $\varepsilon_K + \Delta M_{Bs}/\Delta M_{Bd} + V_{cb} + \gamma + V_{ub}$: $\sin(2\beta) = 0.77 \pm 0.037$

$a_{\psi K} = 0.681 \pm 0.025$ [2.1 σ]

$a_{\phi K} = 0.39 \pm 0.17$ [2.2 σ]

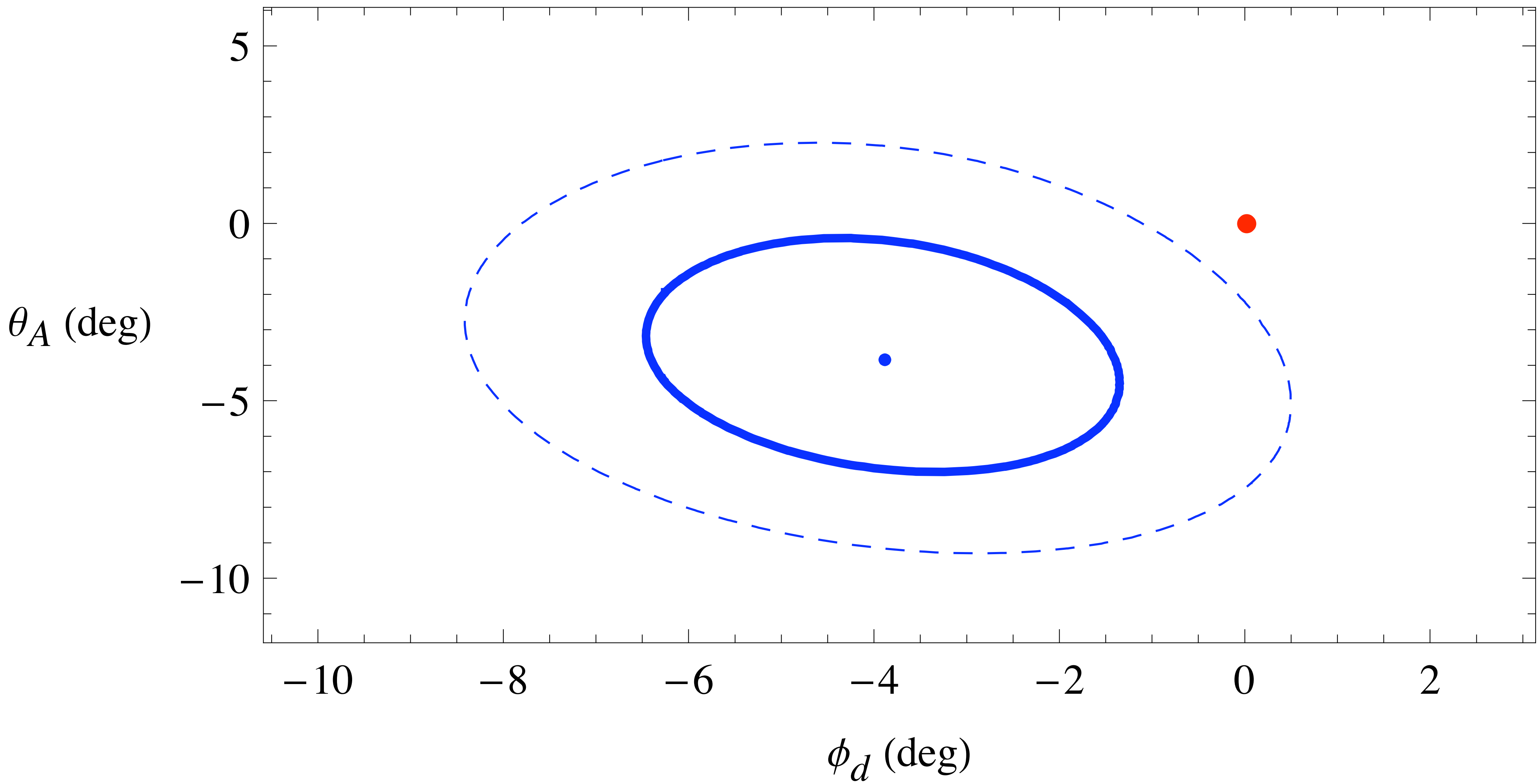
$a_{\eta' K} = 0.61 \pm 0.07$ [2.1 σ]

Model Independent Analysis



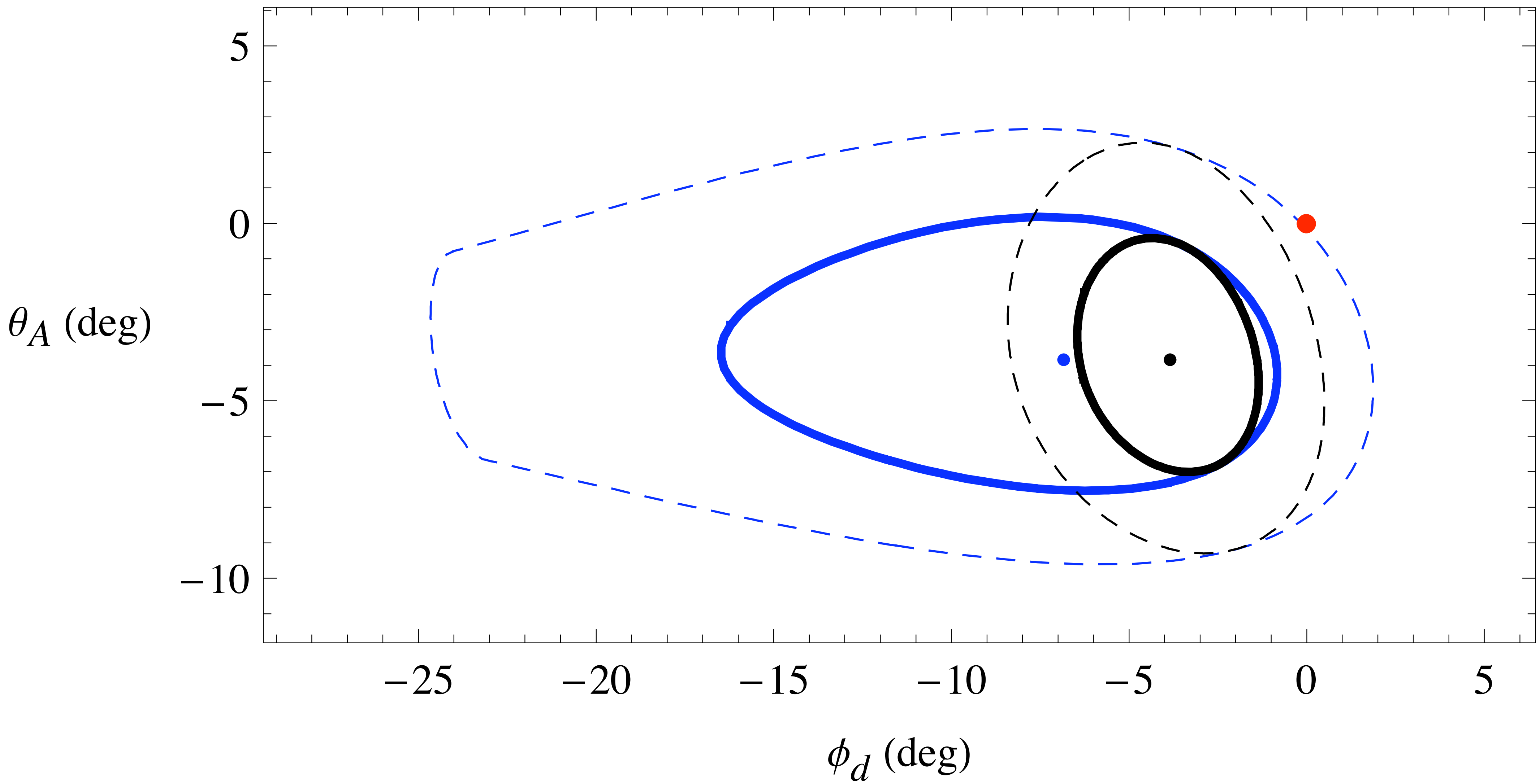
- Without V_{ub}: $$\begin{aligned}\phi_d &= (-7.5 \pm 4.6)^\circ \\ \theta_A &= (-3.7 \pm 2.5)^\circ\end{aligned}$$

Model Independent Analysis



- With V_{ub}: $$\begin{aligned} \phi_d &= (-3.8 \pm 1.9)^\circ \\ \theta_A &= (-3.7 \pm 2.5)^\circ \end{aligned}$$

Model Independent Analysis



- Comparison: $\phi_d = \begin{cases} (-7.5 \pm 4.6)^\circ & \text{without } V_{ub} \\ (-3.8 \pm 1.9)^\circ & \text{with } V_{ub} \end{cases}$

$$\theta_A = (-3.7 \pm 2.5)^\circ$$

Correlation with other observables

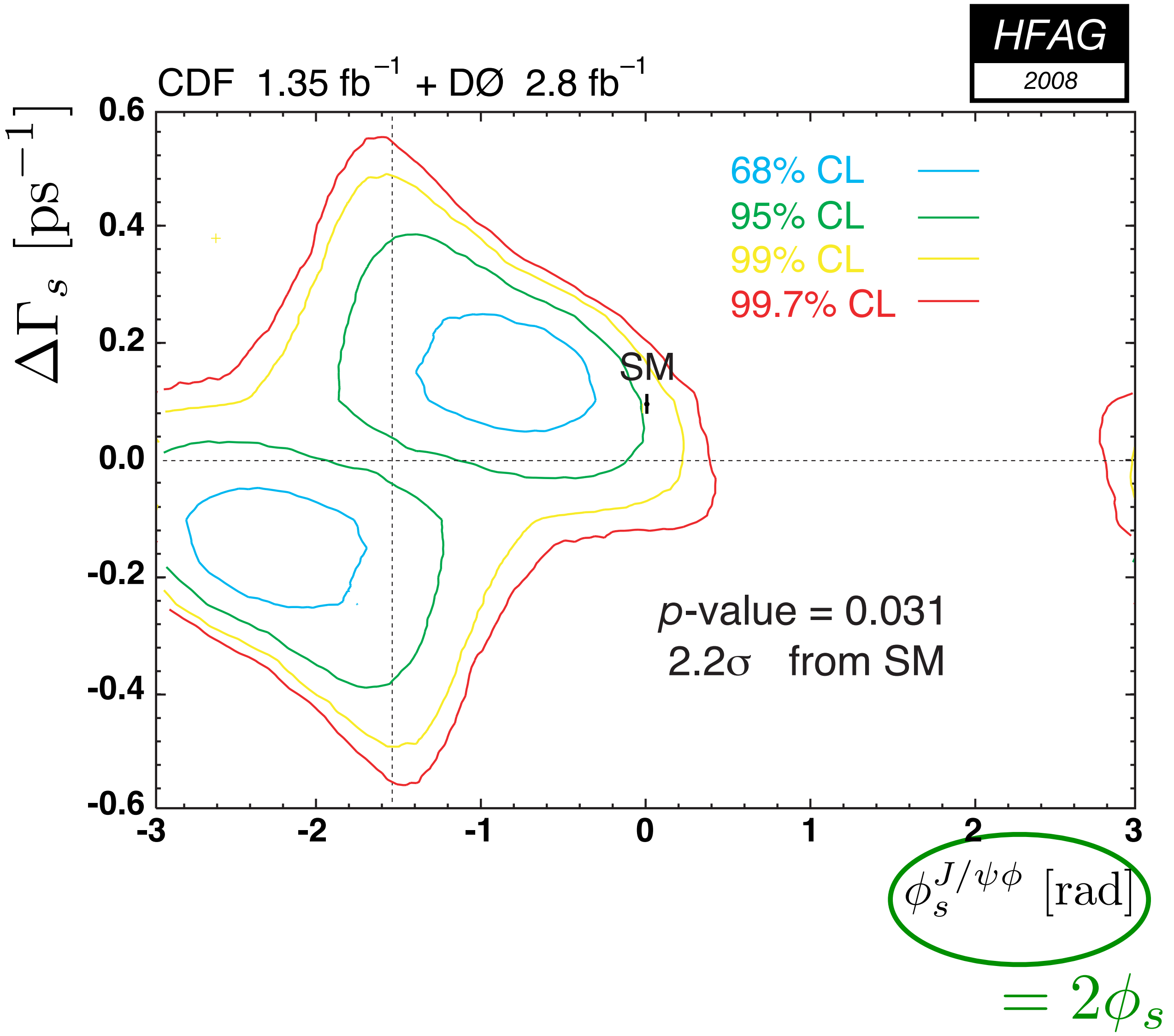
- Proper treatment of new physics effects in penguin amplitudes is better implemented with NP contributions to the *QCD penguin* (O_4), *EW penguin* (O_{3Q}) and *chromo-magnetic* (O_8) operators
- Correlation between the $b \to s\bar{s}s$ and Kπ asymmetries:

$$A_{CP}(B^- \to K^-\pi^0) - A_{CP}(\bar{B}^0 \to K^-\pi^+) = \begin{cases} (14.4 \pm 2.9)\ \% & \text{exp} \\ (2.5 \pm 1.5)\ \% & \text{QCDF} \end{cases}$$

- QCDF result very stable under variation of all the inputs
- Possible issue with large color suppressed contributions to the $K^-\pi^0$ final state

Correlation with other observables

- Recent CDF and D0 measurements of mixing induced CP violation in $B_s \to J/\psi\phi$ point towards a sizable phase in the B_s mixing amplitude



- $\phi_s = \left\{ \begin{array}{l} \left(-22^{+11}_{-8}\right)^o \\ \left(-68^{+8}_{-11}\right)^o \end{array} \right.$ [HFAG]

  [see also: UTfit 0803.0659]

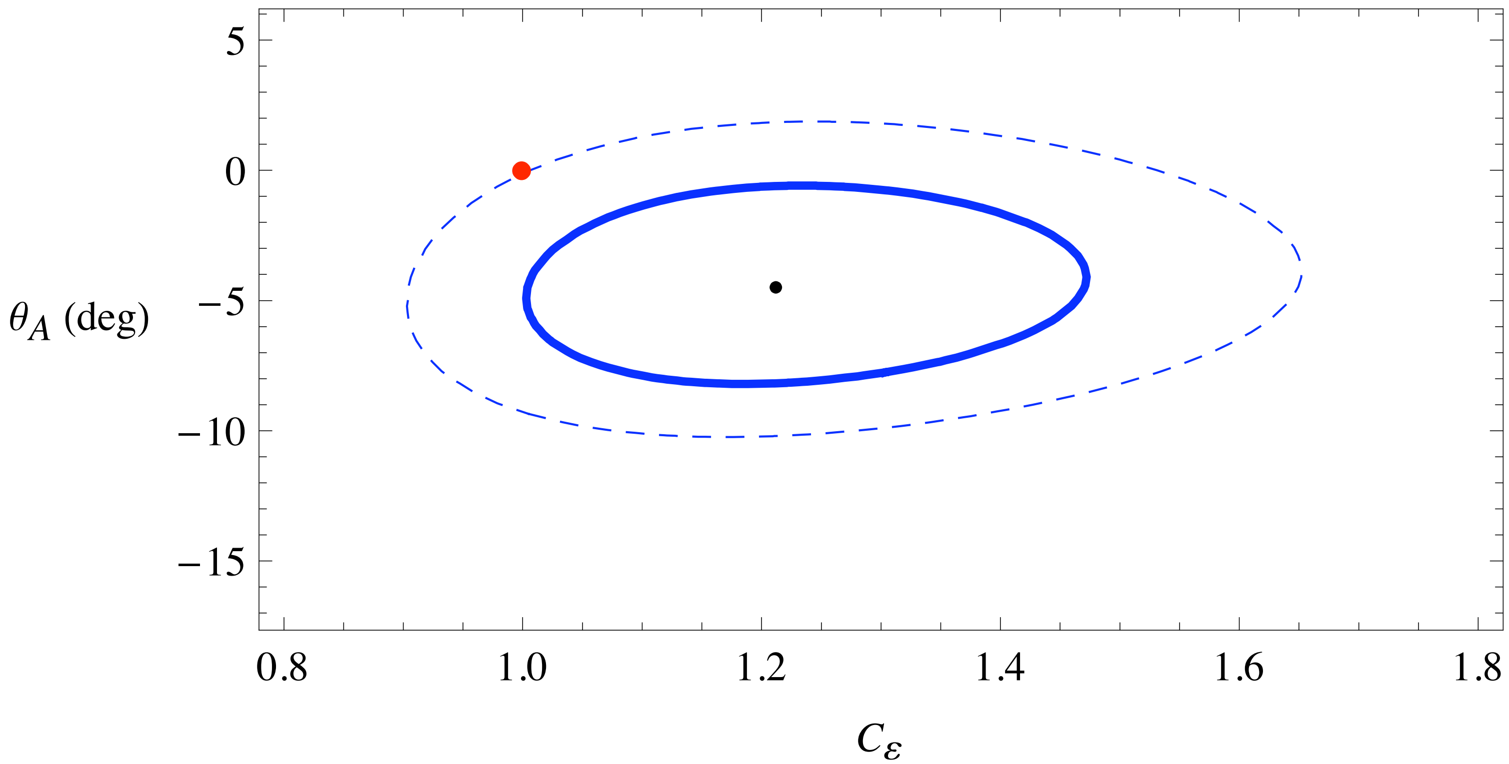
- Sign and magnitude of ϕ_s are similar to sign and magnitude of ϕ_d

- Possible common source?

  [Buras,Guadagnoli]

New physics in K system

- Alternative solution to the strain in the UT fit is NP in ε_K [Buras,Guadagnoli]
- A new phase in penguin amplitudes (θ_A) is still required
- Using a simple parametrization ($\varepsilon_K = \varepsilon_K^{\rm SM}\, C_\varepsilon$) we find:



$$C_\varepsilon = 1.22 \pm 0.15 \qquad \theta_A = (-4.6 \pm 2.3)^{\rm o}$$

Conclusions

- Thanks to the significantly improved accuracy in B_K [RBC +UKQCD, PRL'08], V_{ub} needs not to be used to get a meaningful constraint on $\sin(2\beta)$
- Strain between time dependent CP asymmetries, K and B mixing hints to new physics in the flavor sector:
  - *new phase in penguin $b \to s$ amplitudes*
  - *new phase in B_d or K mixing*
- Possibility to correlate these effects with new physics signals in *B_s mixing* and direct *CP asymmetries in the Kπ system*