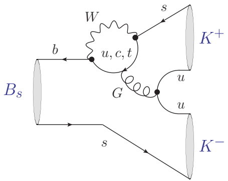
In Pursuit of New Physics with $B_s^0 \to K^+K^-$

Rob Knegjens (Nikhef)



R. Fleischer and R. Knegjens, arXiv:1011.1096 [hep-ph]

Overview

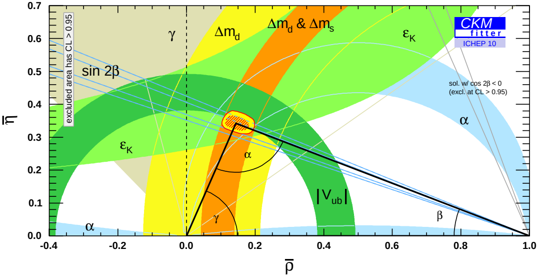
- The CPV phase in $B_s - \overline{B}_s$ mixing is senstive to New Physics
- $B_s \to K^+K^-$ can probe this phase, but has problematic hadronic nature
- Utilize U-spin symmetry
- Find target regions for observables relative to the mixing phase

Precision Flavour Physics

- CP violation in B meson decays lets us probe the flavour interactions of quarks

$$B_d^0 \ni (\bar{b}\ d), \quad B_s^0 \ni (\bar{b}\ s)$$

- B_d-factories: CKM matrix is the **dominant source** of flavour and CP violation



$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Precision Flavour Physics

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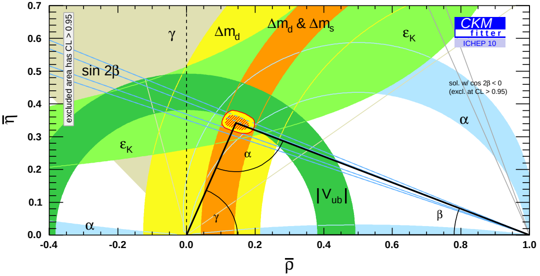
- B_d-factories: CKM matrix is the **dominant source** of flavour and CP violation
- **LHC era**: experimental sensitivity will improve from 10% to 1%
- Hope to find New Physics in B meson interactions

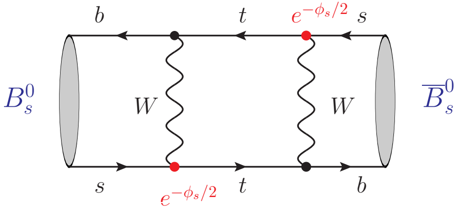


$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

New Physics in B_s^0 mixing

- Quantum nature of B_s mesons allows them to mix

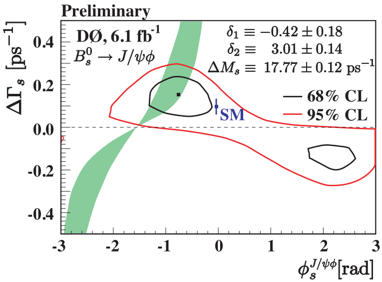
$$|B_s(t)\rangle = g_+(t)|B_s\rangle + g_-(t)|\overline{B}_s\rangle$$

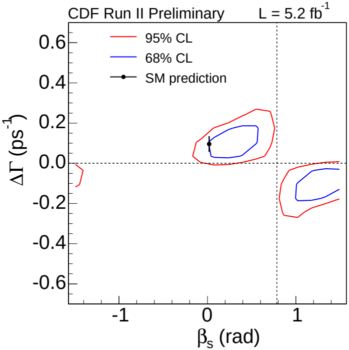


- In Standard Model amplitude is supressed and the CP violating phase is tiny $\phi_s = -2°$
- This makes it **very sensitive** to New Physics appearing in the loop
  - 4th generation fermions
  - Z' bosons
  - Sparticles

New Physics in B_s^0 mixing

- CDF/D0 at the Tevatron have already measured a deviation of $\sin \phi_s$ from the SM through the $B_s \to J/\psi\phi$ channel





Measuring the mixing phase ϕ_s

- Look at B_s decays into **CP eigenstates**: $\mathcal{CP}(f) = \pm f$

$$\text{e.g.} \quad B_s \to K^+K^- \quad \text{and} \quad \overline{B}_s \to K^+K^-$$

- $B_s(t) \to f$:

$$B_s \to f \quad \text{or} \quad B_s \stackrel{\text{mix}}{\to} \overline{B}_s \to f \quad \text{or} \quad B_s \stackrel{\text{mix}}{\to} \overline{B}_s \stackrel{\text{mix}}{\to} B_s \to f \quad \text{etc.}$$

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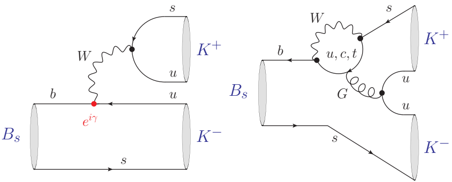
- Can extract **CP observables** from the decay rates:

$$\frac{\Gamma(B_s(t) \to f) - \Gamma(\overline{B}_s(t) \to f)}{\Gamma(B_s(t) \to f) + \Gamma(\overline{B}_s(t) \to f)} = \left[\frac{\mathcal{A}_{\text{CP}}^{\text{dir}}(B_s \to f) \cos(\Delta M_s t) + \mathcal{A}_{\text{CP}}^{\text{mix}}(B_s \to f) \sin(\Delta M_s t)}{\cosh(\Delta\Gamma_s t/2) + \mathcal{A}_{\Delta\Gamma}(B_d \to f) \sinh(\Delta\Gamma_s t/2)} \right]$$

- $\mathcal{A}_{\text{CP}}^{\text{mix}}(B_s \to f)$ gives mixing induced CPV i.e. ϕ_s

The $B_s \to K^+K^-$ decay

- Both tree and penguin contributions:



$$\mathrm{Ampl}(B_s \to K^+K^-) = \sqrt{\epsilon}\; e^{i\gamma}\; \mathcal{C}\left[1 + \frac{1}{\epsilon} d e^{i\theta} e^{-i\gamma}\right]$$

$$\text{e.g.} \quad \mathcal{A}_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to K^+K^-)$$

$$= \frac{d^2 \sin\phi_s + 2\epsilon d\cos\theta \sin(\phi_s + \gamma) + \epsilon^2 \sin(\phi_s + 2\gamma)}{d^2 + 2\epsilon d \cos\theta \cos\gamma + \epsilon^2}$$

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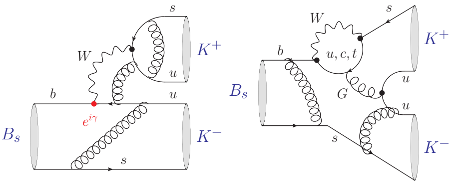

$$\mathrm{Ampl}(B_s \to K^+K^-) = \sqrt{\epsilon}\; e^{i\gamma}\; \mathcal{C}\left[1 + \frac{1}{\epsilon} d e^{i\theta} e^{-i\gamma}\right]$$

e.g. $\mathcal{A}_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to K^+K^-)$

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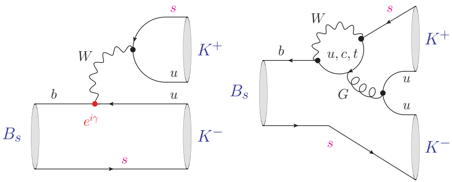
- But d, θ are non-pertubative hadronic parameters...

U-spin flavour symmetry



- U-spin: $SU(2)$ subgroup of $SU(3)$ strong flavour symmetry that relates d and s quarks
- Analagous to iso-spin relation between u and d quarks

$$B_s \to K^+K^- \overset{U\text{−spin}}{\longleftrightarrow}$$

- For exact U-spin, CP conserved hadronic parameters d and θ equal

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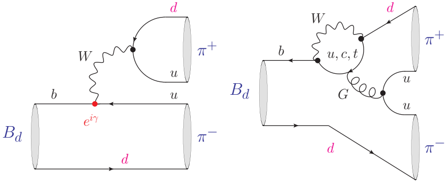

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$$B_s \to K^+K^- \stackrel{U-\text{spin}}{\longleftrightarrow} B_d \to \pi^+\pi^-$$

- For exact U-spin, CP conserved hadronic parameters d and θ equal

Utilizing the hadronic parameters

- So far only $\mathrm{Br}(B_s \to K^+K^-)$ has been measured
- Can combine U-spin with $\mathrm{Br}(B_d \to \pi^+\pi^-)$ to extract information on d, θ

$$K[d, \theta, \gamma] \equiv [\ldots] \frac{\mathrm{Br}(B_s \to K^+K^-)}{\mathrm{Br}(B_d \to \pi^+\pi^-)} = 51.8^{+12.7}_{-15.0}$$

- The $B_d \to \pi^+\pi^-$ observables are available ($\phi_d = 42.4^\circ$):

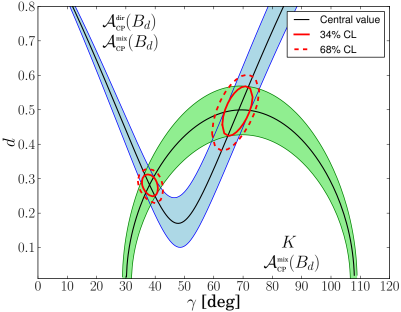
$$\mathcal{A}_{\mathrm{CP}}^{\mathrm{dir}}(B_d \to \pi^+\pi^-)[d, \theta, \gamma] = -0.26 \pm 0.10$$
$$\mathcal{A}_{\mathrm{CP}}^{\mathrm{mix}}(B_d \to \pi^+\pi^-)[d, \theta, \gamma] = 0.65 \pm 0.07$$

- 3 equations, 3 unknowns: so we can determine γ! [1]

[1] R. Fleischer, Phys. Lett B549 (9999)

Determining γ with U-spin symmetry

- Combining $\gamma - d$ contours gives an intersection:



- Find good agreement with fits of CKM matrix (CKMfitter, UTfit):

$$\gamma = (68.3^{+4.9}_{-5.7}\big|_{\rm input}{}^{+5.0}_{-3.7}\big|_{U-{\rm spin}})^\circ,$$

with U-spin breaking errors:

$$d_{K^+K^-}/d_{\pi^+\pi^-} = 1 \pm 0.15, \quad \theta_{K^+K^-} - \theta_{\pi^+\pi^-} = 0 \pm 20^\circ$$

Using γ as an input

- Use $\gamma = 68 \pm 7$ as an input for determining the $B_s \to K^+K^-$ **CP observables**

$$K[d,\theta]\big|_{\gamma} \equiv [\ldots] \frac{\mathrm{Br}(B_s \to K^+K^-)}{\mathrm{Br}(B_d \to \pi^+\pi^-)} = 51.8^{+12.7}_{-15.0}$$

- In addition, can use

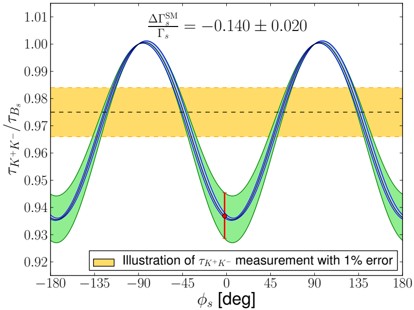
$$\mathcal{A}_{\mathrm{CP}}^{\mathrm{dir}}(B_s \to K^+K^-)[d,\theta]\big|_{\gamma} \overset{SU(3)}{\approx} \mathcal{A}_{\mathrm{CP}}^{\mathrm{dir}}(B_d \to K^{\pm}\pi^{\mp}) = 0.098^{+0.011}_{-0.012}$$

- 2 equations, 2 unknowns: can determine d and θ and thus $\mathcal{A}_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to K^+K^-)[\phi_s]$ and $\mathcal{A}_{\Delta\Gamma}(B_s \to K^+K^-)[\phi_s]$!

The effective lifetime

- First measurement at LHCb will be $\tau(B_s \to K^+K^-)$

$$= \frac{\int_0^\infty t\langle\Gamma(B_s(t) \to K^+K^-\rangle dt}{\int_0^\infty \langle\Gamma(B_s(t) \to K^+K^-\rangle dt} = 1 + \frac{1}{2}\mathcal{A}_{\Delta\Gamma}[d, \theta, \gamma, \phi_s]\left(\frac{\Delta\Gamma_s}{\Gamma_s}\right) + \dots$$



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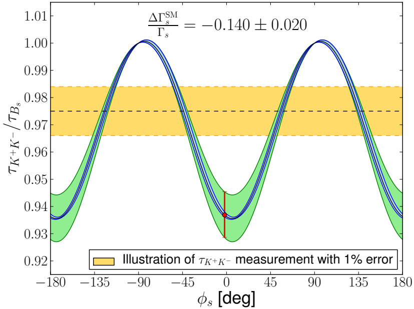
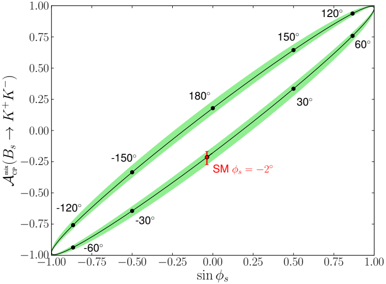
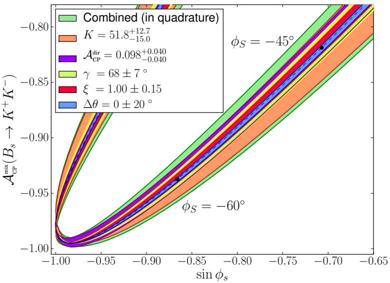


- SM prediction ($\phi_s = -2°$): $\tau(B_s \to K^+K^-) = 1.390 \pm 0.032\mathrm{ps}$

Mixing-induced CPV

- Next to be measured is $\mathcal{A}_{\mathrm{CP}}^{\mathrm{mix}}(B_s \to K^+K^-)$





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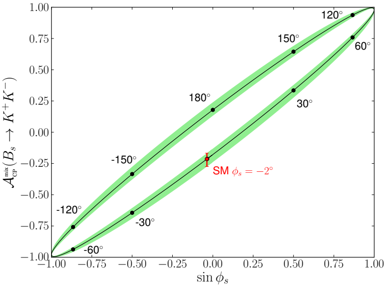
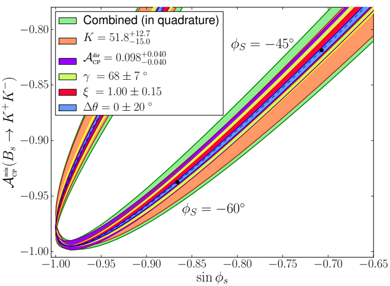


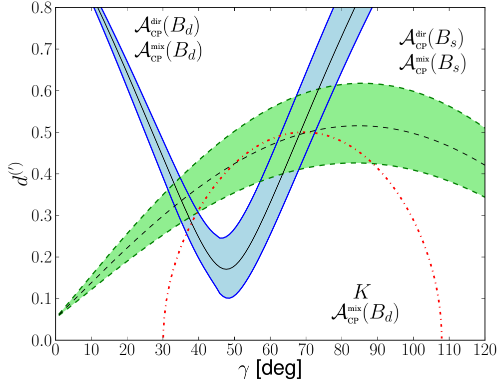


- Together with the $\sin\phi_s$ measurement from $B_s \to J/\psi\phi$ will allow unambigious determination of ϕ_s
- SM prediction:

$$\mathcal{A}_{\rm CP}^{\rm mix}(B_s \to K^+K^-)\big|_{\rm SM} = -0.215^{+0.041}_{-0.058}$$

Gamma Determination B_s

- The last measurement will be $\mathcal{A}_{\rm CP}^{\rm dir}(B_s \to K^+K^-)$

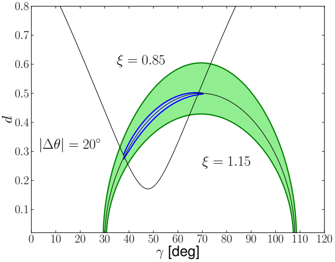


- This will allow a **consistency check** of *U*-spin breaking parameters

Summary

- U-spin symmetry is a powerful tool to relate the CP conserving hadronic parameters of the $B_s \to K^+K^-$ and $B_d \to \pi^+\pi^-$ decays
- This allows an extraction of the CKM angle γ with very good agreement to current fits
- It further allows us to relate the lifetime and mixing-induced CP observables to the B_s mixing phase ϕ_s and thereby probe New Physics.

Backup



$\xi = 0.85$
$|\Delta\theta| = 20^\circ$
$\xi = 1.15$
d
γ [deg]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0 10 20 30 40 50 60 70 80 90 100 110 120