γ and B→DK

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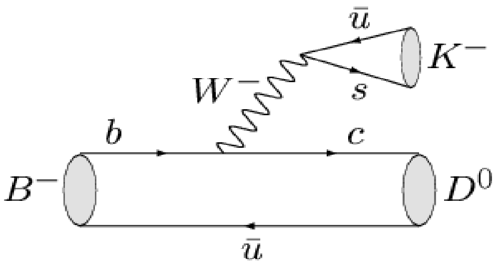
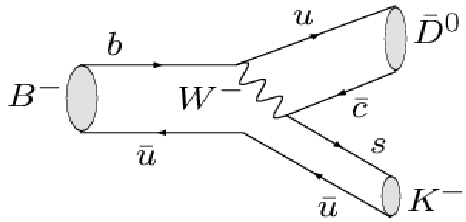
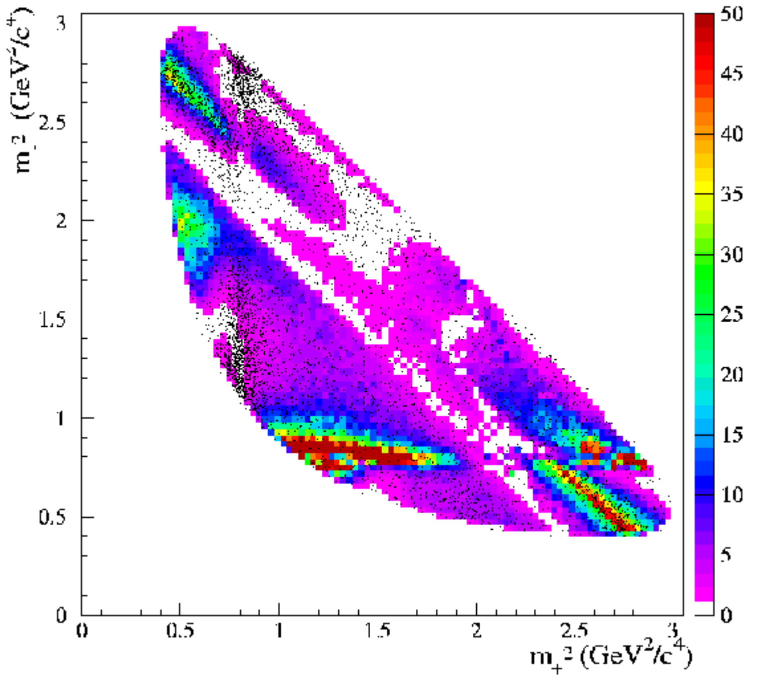
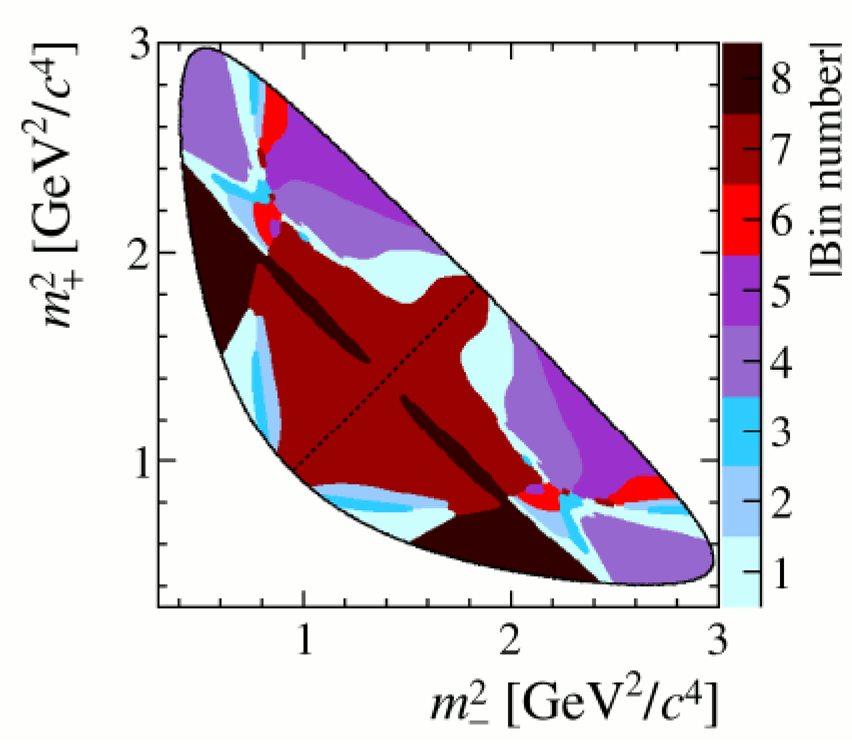
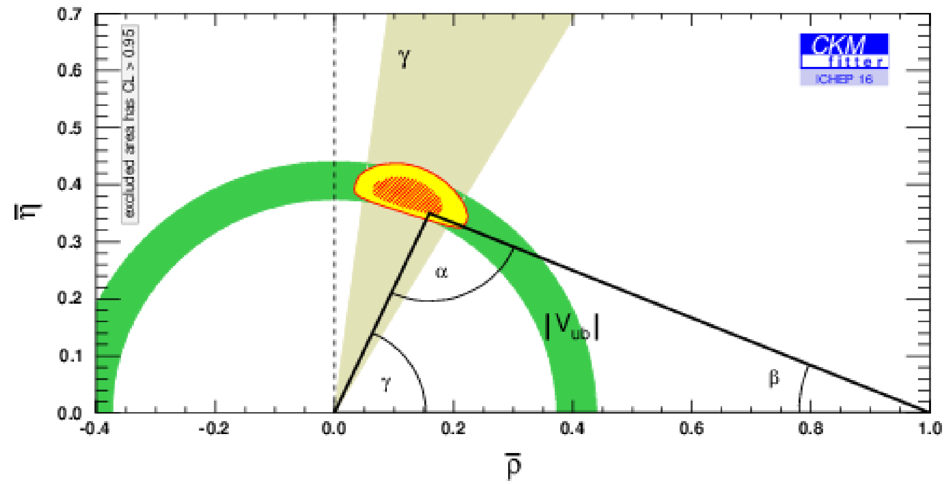
2019/05/28



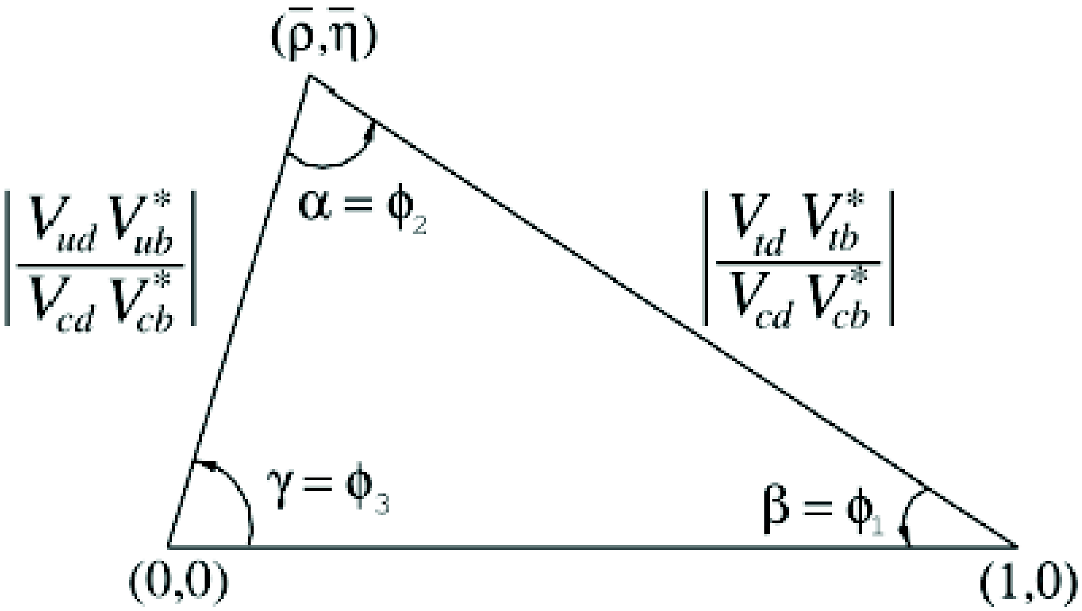








Motivation

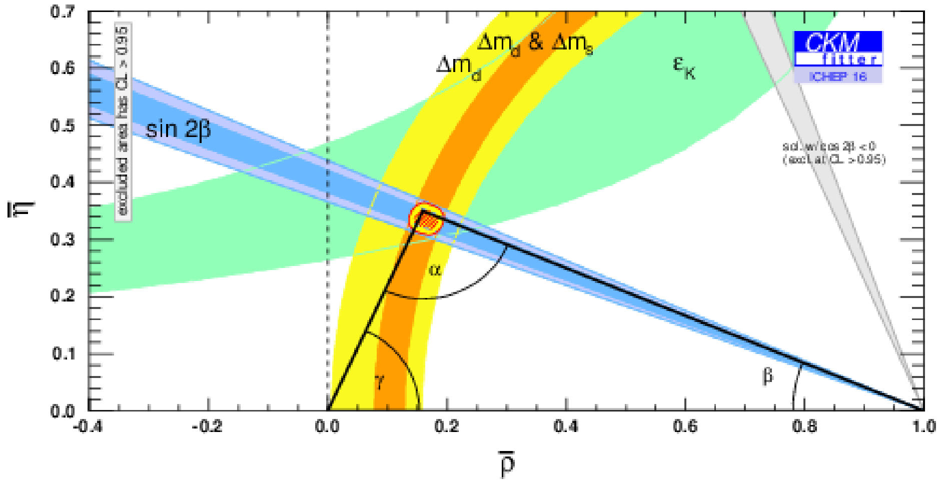


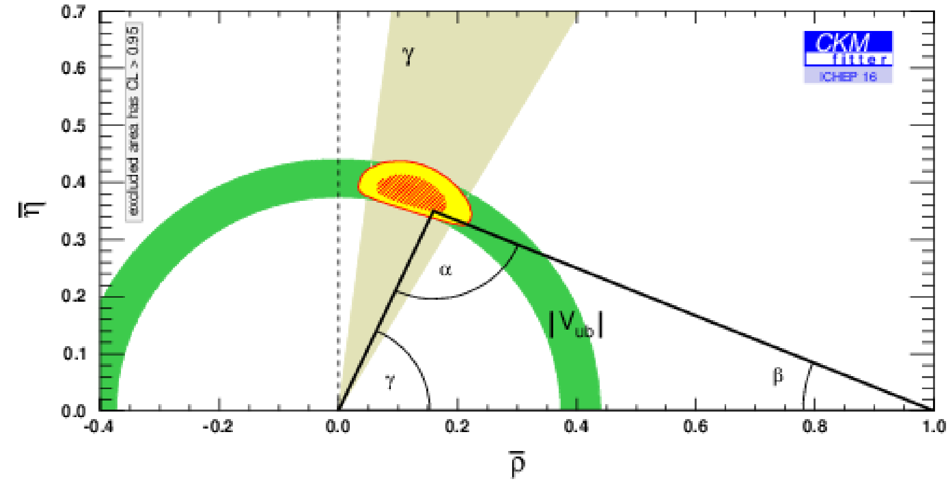
$$\alpha \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right),\ \beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right),\ \boldsymbol{\gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)}$$

In Wolfensteing parameterisation, up to order λ^4, all the CKM elements involved are real except V_{ub}^* and V_{td}:

$$\alpha \approx \arg\left(-\frac{V_{td}}{V_{ub}^*}\right),\ \beta \approx \arg\left(-V_{td}^*\right),\quad \boldsymbol{\gamma \approx \arg\left(-V_{ub}^*\right)}$$

Motivation





Loop processes more easily
altered by presence of NP
constraints on the apex of UT currently
more stringents from loop measurements

Loop vs Tree

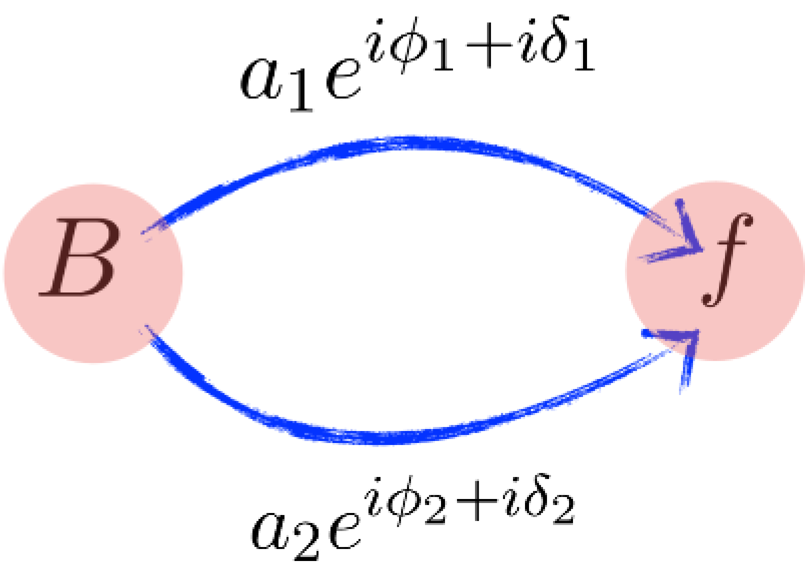
Why γ is a key goal ?

γ is least well measured parameter of UT
Theoretically pristine
with LHCb and Belle II the ideal degree level precision is possible

Direct CPV (CPV in decay)

$$Asym_f \equiv \frac{\Gamma(\bar{B}\to\bar{f}) - \Gamma(B\to f)}{\Gamma(\bar{B}\to\bar{f}) + \Gamma(B\to f)} = \frac{1 - |A_f/\overline{A_f}|^2}{1 + |A_f/\overline{A_f}|^2}$$

In order to have non-vanishing CP asymmetry, $Asym \neq 0$, the $B\to f$ decay amplitude needs to receive contributions from (at least) two different terms with differing weak, $\phi_{1,2}$, and strong phases, $\delta_{1,2}$



$$A_f = a_1 e^{i\phi_1 + i\delta_1} + a_2 e^{i\phi_2 + i\delta_2},$$
$$\bar{A}_f = a_1 e^{-i\phi_1 + i\delta_1} + a_2 e^{-i\phi_2 + i\delta_2}.$$

Direct CPV (CPV in decay)

$$A_f = a_1 e^{i\phi_1 + i\delta_1} + a_2 e^{i\phi_2 + i\delta_2},$$
$$\bar{A}_f = a_1 e^{-i\phi_1 + i\delta_1} + a_2 e^{-i\phi_2 + i\delta_2}.$$

The weak phases are due to CKM phase in the SM Lagrangian and change the sign under CP transformation, while the strong phases are due to on-shell rescattering of particles (pions, etc) and are thus CP even, the same as QCD interactions. The CP asymmetry is, in sinplifying limit $a_2/a_1 \ll 1$,

$$\mathcal{A}_f = \frac{a_2}{a_1} \sin(\phi_2 - \phi_1) \sin(\delta_2 - \delta_1) + \mathcal{O}(a_2^2/a_1^2).$$

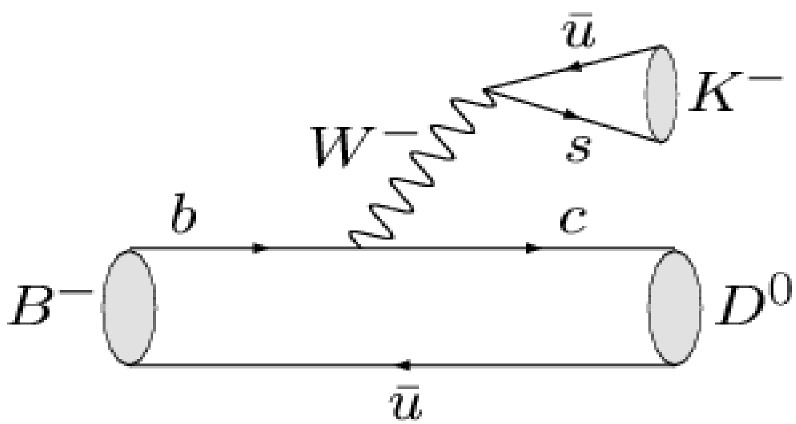
The CP asymmetry vanishes in the limit where either

(i) there is only one contribution to the amplitude $a_2 \to 0$
(ii) if the weak phase difference vanishes, $\phi_2 - \phi_1 \to 0$
(iii) if the strong phase difference vanishes, $\delta_2 - \delta_1 \to 0$

γ measurements from $B^{\pm} \rightarrow DK^{\pm}$

- Theoretically pristine $B \rightarrow DK$ approach

- Access γ via interference between $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow \bar{D}^0 K^-$



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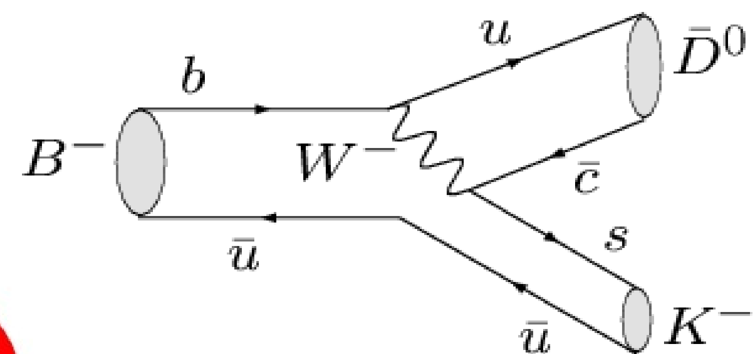
$B^- \rightarrow D^0 K^- \sim V_{cb} V_{us}^*$

$\sim \mathbf{A\lambda^3}$



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$B^- \rightarrow \bar{D}^0 K^- \sim V_{ub} V_{cs}^*$

$\sim \mathbf{A\lambda^3(\rho + i\eta)}$

CKM elements involved are $\frac{V_{cs} V_{ub}^*}{V_{us} V_{cb}^*}$ while $\gamma \equiv \arg\left(-\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*}\right)$

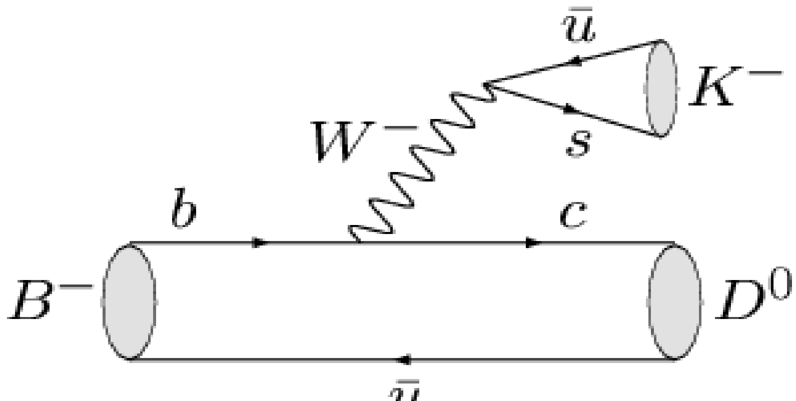
$$\Rightarrow \frac{V_{cd} V_{cs}}{V_{ud} V_{us}} = -1 + \frac{A\lambda^4}{2} - A^2 \lambda^5 \left(\rho + i\eta - \frac{1}{2}\right) + O(\lambda^6)$$

$\Rightarrow$ leading order correction on γ is of the order $\lambda^5 \sim 10^{-4}$ (negligible)

γ measurements from $B^{\pm} \to DK^{\pm}$

◦ Theoretically pristine $B \to DK$ approach

◦ Access γ via interference between $B^- \to D^0 K^-$ and $B^- \to \overline{D}^0 K^-$



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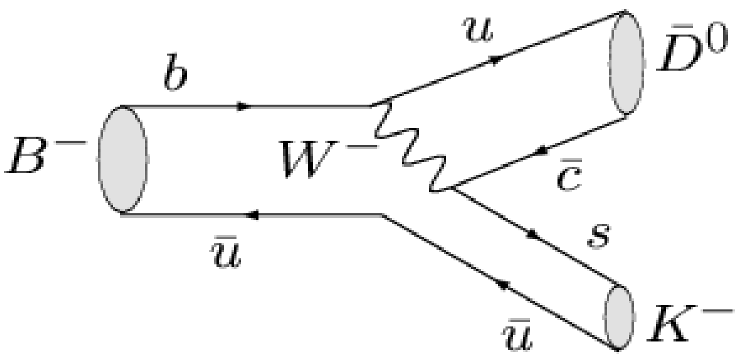
$B^- \to D^0 K^- \sim V_{cb} V_{us}^*$

$\sim A\lambda^3$



color suppressed

$B^- \to \overline{D}^0 K^- \sim V_{ub} V_{cs}^*$

$\sim A\lambda^3(\rho + i\eta)$

relative magnitude of suppressed amplitude is r_B

$$r_B = \frac{|A_{suppressed}|}{|A_{favoured}|} \sim \frac{|V_{ub} V_{cs}^*|}{|V_{cb} V_{us}^*|} \times [\text{color supp}] = 0.1 - 0.2$$

relative weak phase is γ, relative strong phase is δ_B

$\Rightarrow$ for $D\pi$: same dependence to γ, but different $r_B \sim 0.01$ $(V_{us} \to V_{ud},\ V_{cs} \to V_{cd})$

γ measurements from $B^{\pm} \to DK^{\pm}$

- Reconstruct D in final states accessible to both D^0 and $\overline{D}^0$
  - $D = D_{CP}$, CP eigenstates as K^+K^-, $\pi^+\pi^-$, $K_S\pi^0$

    GLW method (Gronau-London-Wyler)
  - $D = D_{sup}$, Doubly-Cabbibo suppressed decays as $K\pi$

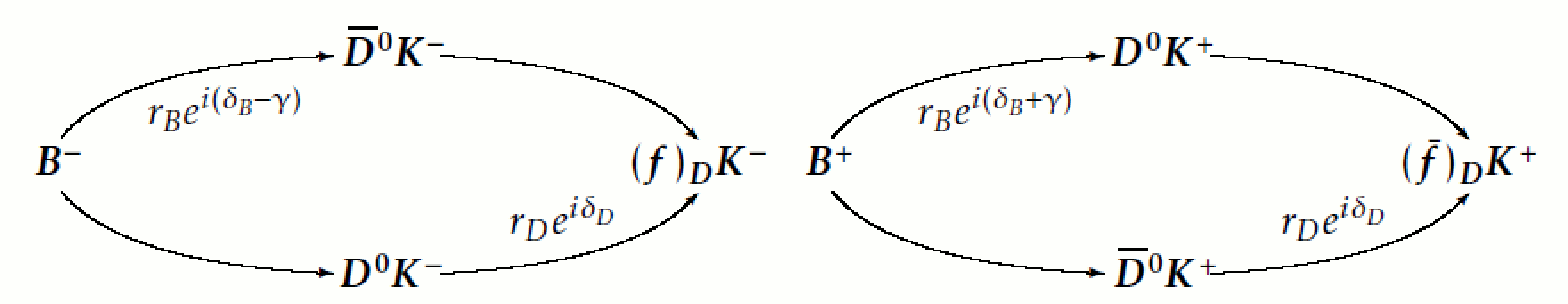
    ADS method (Atwood-Dunietz-Soni)
  - Three-body decays as $D \to K_S\pi^+\pi^-$, $K_S K^+ K^-$

    GGSZ (Dalitz) method (Giri-Grossman-Soffer-Zupan)
- Largest effects due to
  - charm mixing
  - charm CP violation

  } negligible

  Y.Grossman, A.Soffer, J.Zupan [PRD 72, 031501 (2005)]
- Different B decays (DK, D^*K, DK^*)
  - different hadronic factors (r_B, δ_B) for each

γ , first principles…



$$A(B^-\to D^0K^-)=A_B \text{ and } A(B^-\to \overline{D}^0K^-)=A_Br_Be^{i(\delta_B-\gamma)}$$
$$A(B^+\to \overline{D}^0K^+)=A_B \text{ and } A(B^+\to D^0K^+)=A_Br_Be^{i(\delta_B+\gamma)}$$

amplitudes of the subsequent D^0 and $\overline{D}^0$ decays to a common final state f

$$A(\overline{D}^0\to f)=A_D \text{ and } A(D^0\to f)=A_Dr_De^{i\delta_D}$$

assuming direct CPV in D decays negligibly small: $A(D^0\to f)\equiv A(\overline{D}^0\to \bar{f})$ and $A(\overline{D}^0\to f)\equiv A(D^0\to \bar{f})$

$$A(B^-\to D(\to f)K^-)\equiv A(B^-\to D^0K^-)A(D^0\to f)+A(B^-\to \overline{D}^0K^-)A(\overline{D}^0\to f)$$
$$=A_BA_Dr_De^{i\delta_D}+A_Br_Be^{i(\delta_B-\gamma)}A_D,$$
$$A(B^+\to D(\to \bar{f})K^+)\equiv A(B^+\to \overline{D}^0K^+)A(\overline{D}^0\to \bar{f})+A(B^+\to D^0K^+)A(D^0\to \bar{f})$$
$$=A_BA_D+A_Br_Be^{i(\delta_B+\gamma)}A_Dr_De^{i\delta_D}.$$

γ, first principles…

rates of $B^- \to D K^-$ and $B^+ \to D K^+$

$$\left|A(B^- \to D(\to f)K^-)\right|^2 = |A_B|^2|A_D|^2\left[r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B - \gamma - \delta_D)\right],$$

$$\left|A(B^+ \to D(\to \bar{f})K^+)\right|^2 = |A_B|^2|A_D|^2\left[r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \gamma - \delta_D)\right].$$

if D final state f is CP eigenstates (GLW method):
$r_D = 1$, and $\delta_D = 0$ (π) for CP-even (odd) eigenstate

$$A_{CP} = \frac{\Gamma(B^- \to D(\to f)K^-) - \Gamma(B^+ \to D(\to \bar{f})K^+)}{\Gamma(B^- \to D(\to f)K^-) + \Gamma(B^+ \to D(\to \bar{f})K^+)},$$

$$A_{CP+} = \frac{2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 + 2 r_B \cos\delta_B \cos\gamma} \qquad A_{CP-} = \frac{-2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 - 2 r_B \cos\delta_B \cos\gamma}$$

B→DK± at Belle II

illustration with Belle B→D(Kπ)K analysis

KID<0.6 (pion-like)

$$N^{DK}_{\eta,\,KID>0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, \epsilon$$

$$N^{DK}_{\eta,\,KID<0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, (1-\epsilon)$$

$$N^{D\pi}_{\eta,KID>0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, \kappa$$

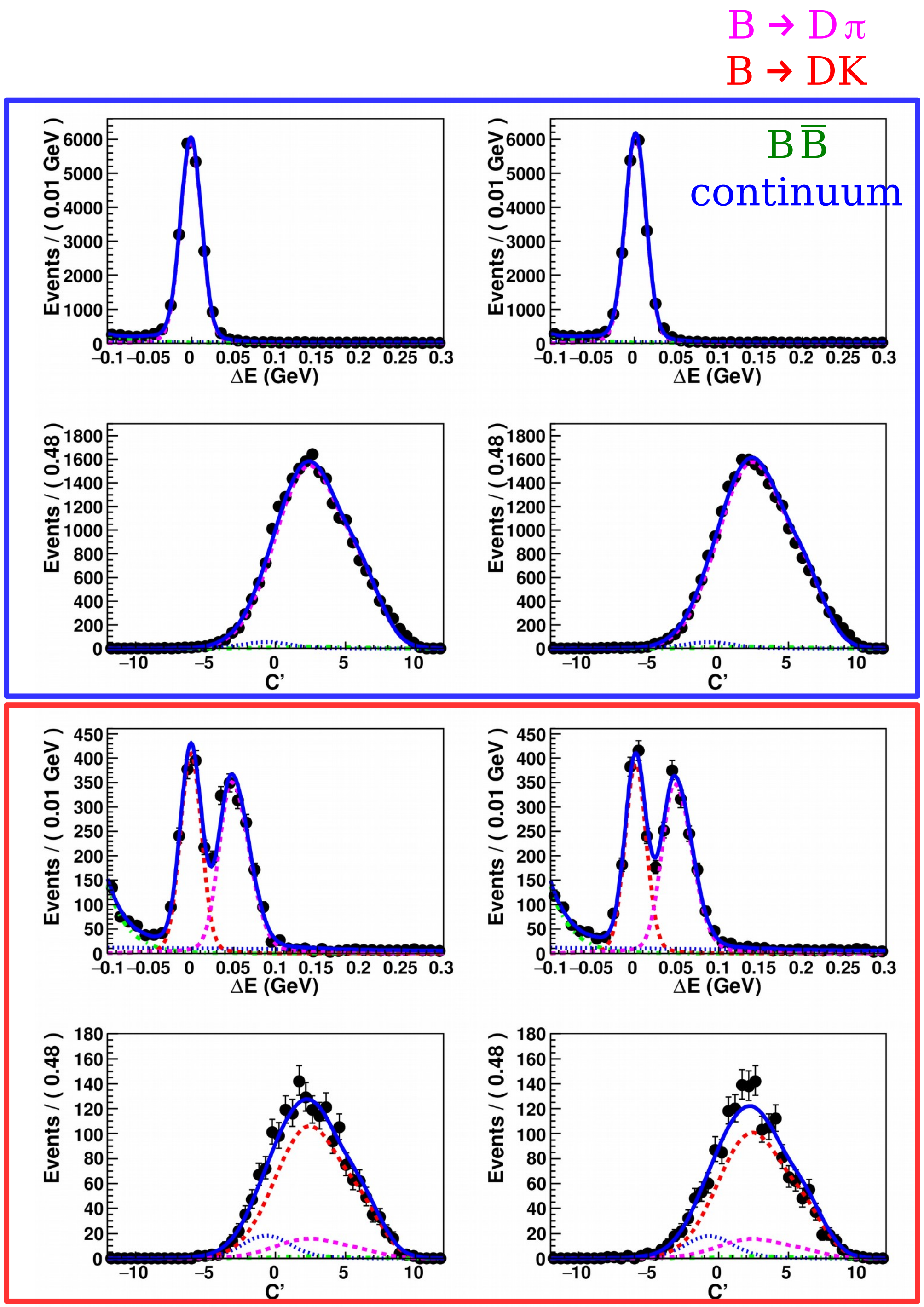
$$N^{D\pi}_{\eta,KID<0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, (1-\kappa)$$

KID>0.6 (kaon-like)

	kaon fake (1-ϵ)	kaon eff ϵ	pion eff (1-κ)	pion fake κ
MC	14.70 ± 0.06	85.41 ± 0.06	95.42 ± 0.03	4.47 ± 0.03
data	15.86 ± 0.40	84.32 ± 0.39	92.13 ± 0.46	7.94 ± 0.31

⇐

for Belle

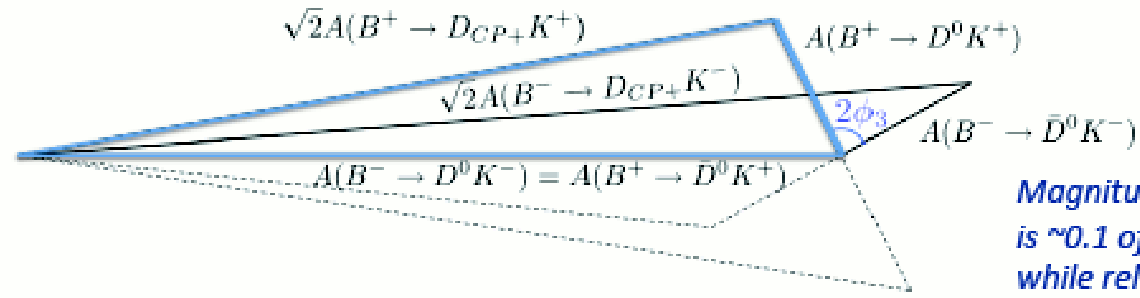


for Belle II: performances expected
to be as good (better ?) as for Belle MC...
one of the important outputs of current data taking (jury is still out)

GLW with $D_{CP}K$

D decays to CP eigenstates

- Amplitude triangle:



Magnitude of one side is ~0.1 of the others while relative magnitude of the others help ϕ_3 constraint.

Usually measured observables:

$$\mathcal{R}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D^0K^-) + \mathcal{B}(B^+ \to \bar{D}^0K^+)}$$

$$\mathcal{A}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}$$

Relation between $(A_{CP+}, A_{CP-}, R_{CP+}, R_{CP-})$ and (γ, r_B, δ_B)

$$A_{CP+} = \frac{2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 + 2 r_B \cos\delta_B \cos\gamma} \qquad A_{CP-} = \frac{-2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 - 2 r_B \cos\delta_B \cos\gamma}$$

$$R_{CP+} = 1 + r_B^2 + 2 r_B \cos\delta_B \cos\gamma \qquad R_{CP-} = 1 + r_B^2 - 2 r_B \cos\delta_B \cos\gamma$$

$\Rightarrow$ look for $R_{CP\pm} \neq 1$ and $A_{CP\pm} \neq 0$

The other charged B's decays…

$$B \rightarrow D^{*0} K,\ D^{*0} \rightarrow D^0 \pi^0, D^0 \gamma$$

- a new set of $(r_B, \delta_B) = (r_B^*, \delta_B^*)$…
- η_X, CP eigenvalue of X
  - $\eta_{D^*} = \eta_D \times \eta_{\pi^0/\gamma} \times (-1)^l$, l=angular momentum between D and π^0/γ
  - $\eta_{D^*} = \eta_D$ for $D^* \rightarrow D\pi^0$, $\eta_{D^*} = -1 \times \eta_D$ for $D^* \rightarrow D\gamma$

⇒ shift of π between both cases

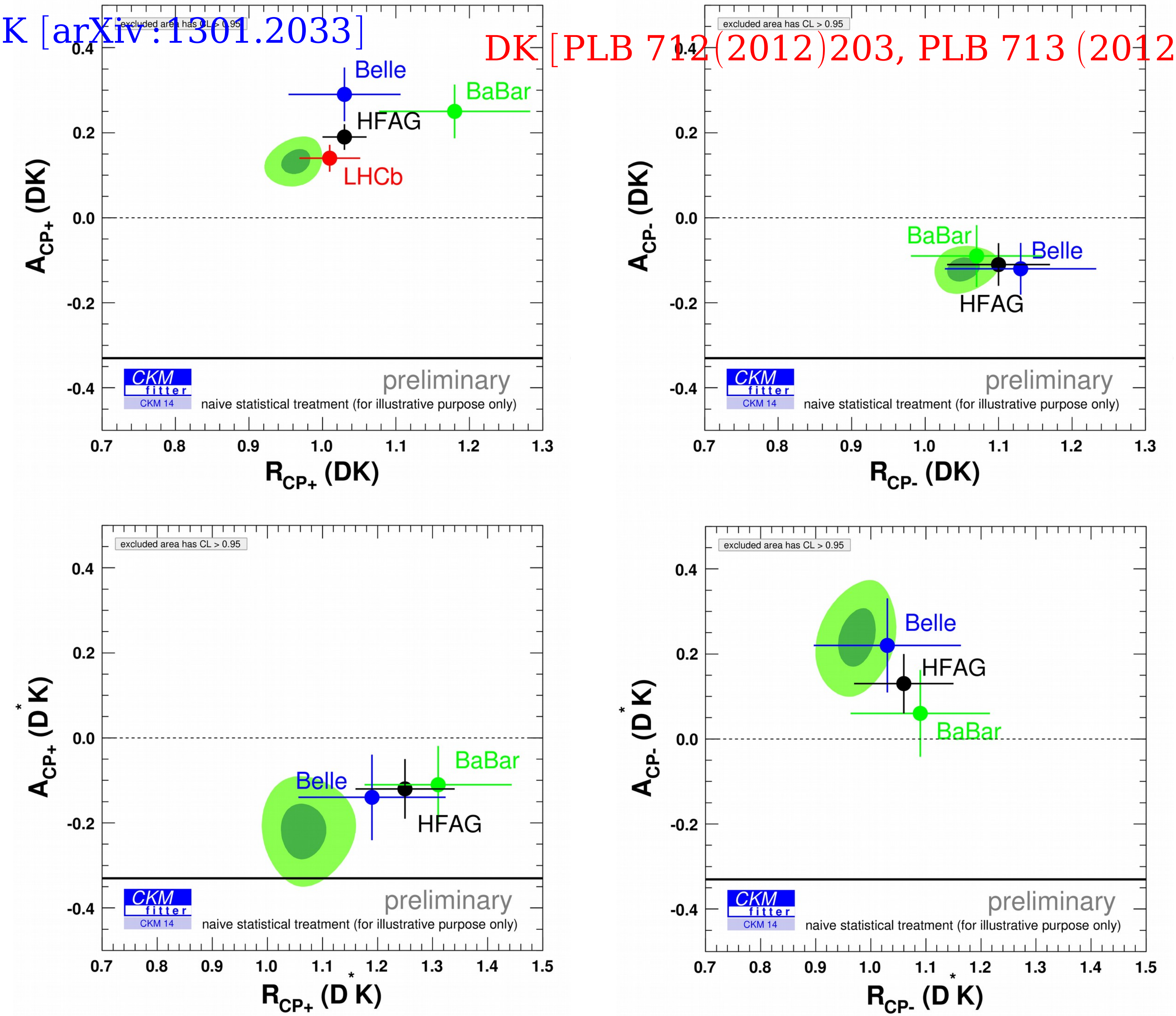
GLW observables (predictions vs measurements)

DK [PRD82(2010)072004], D^*K[PRD78(2008)092002], DK^* [PRDD80(2009)092001]

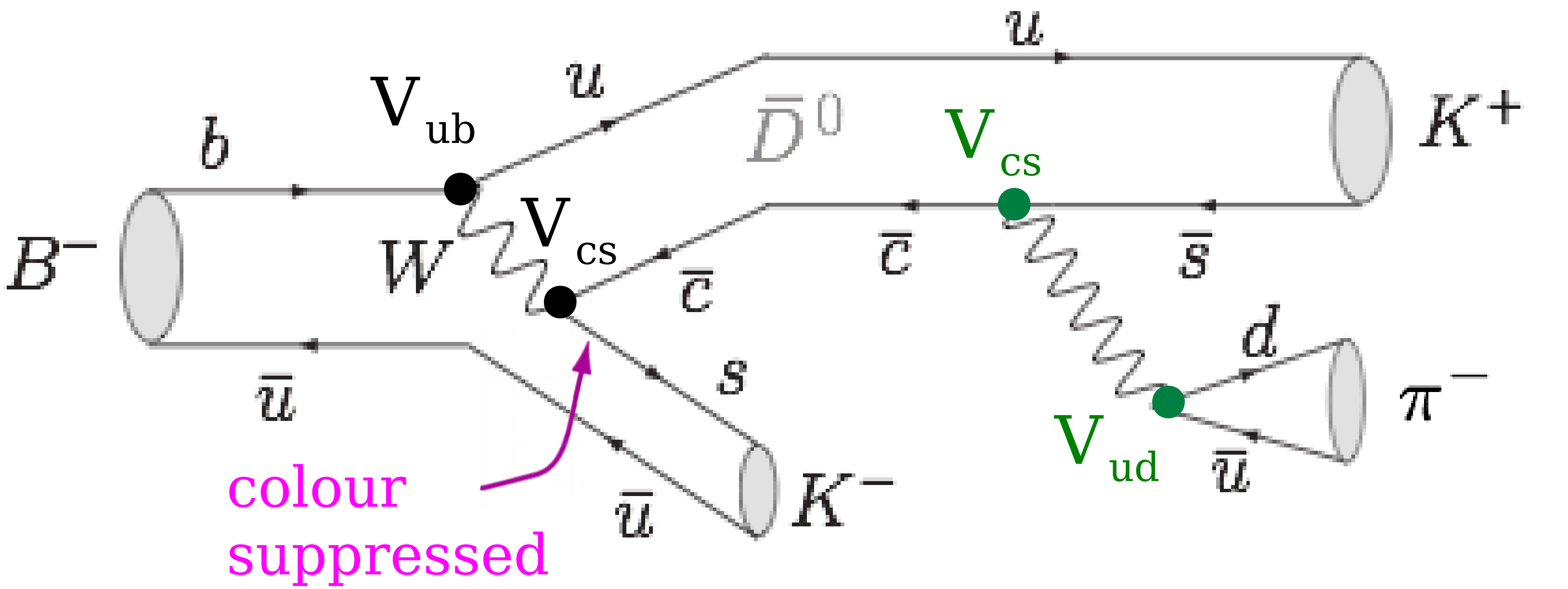
DK and D^*K [arXiv:1301.2033]

DK [PLB 712(2012)203, PLB 713 (2012) 351]

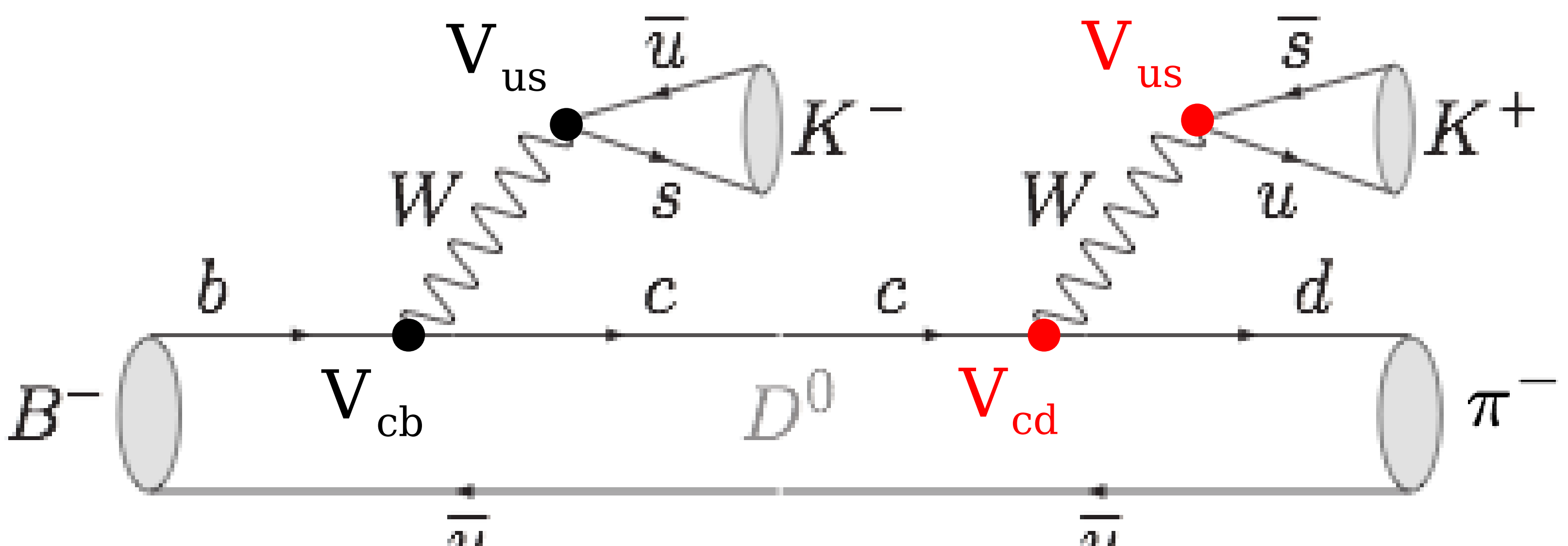
+ 22 obs.



ADS method measures ϕ_3 via the interference in rare $B^- \to [K^+\pi^-]_D K^-$ decays



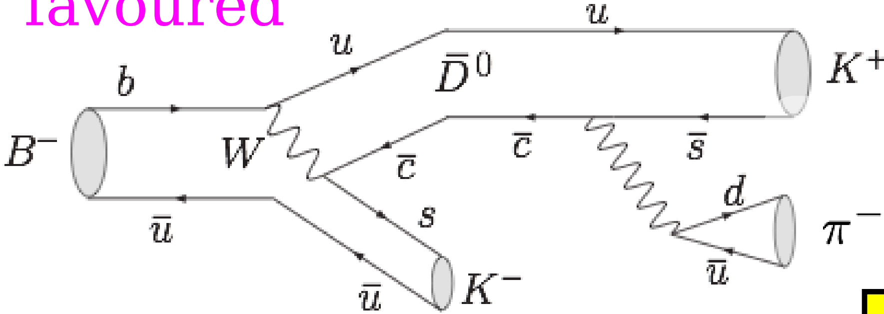
Cabibbo
favoured
D decay



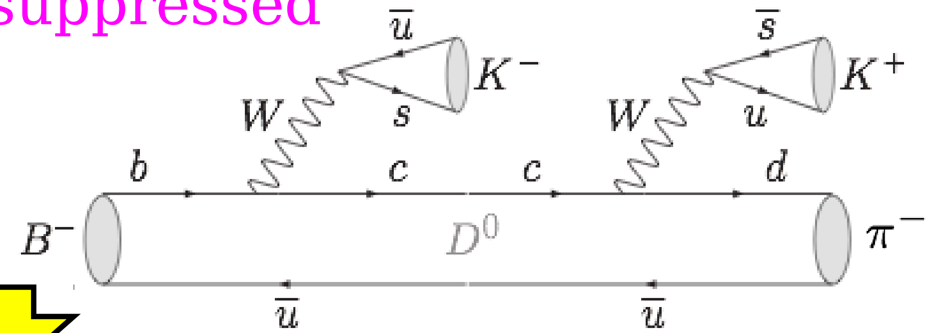
doubly
Cabibbo
suppressed
D decay

ADS rate and asymmetry (relative to the common decay):

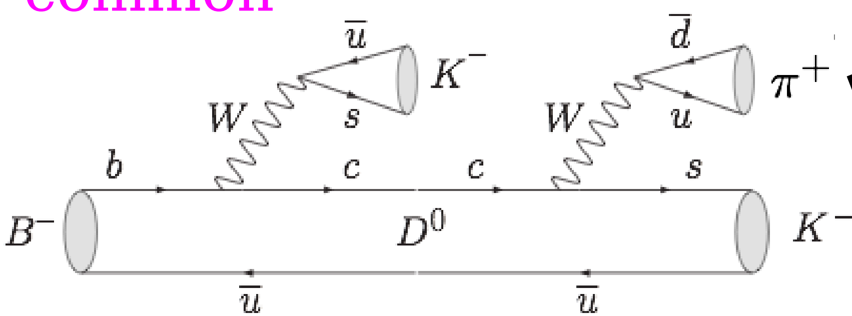
favoured



suppressed



common



$$\mathcal{R}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) + \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)}$$

$$= r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\phi_3$$

$$\mathcal{A}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) - \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)}$$

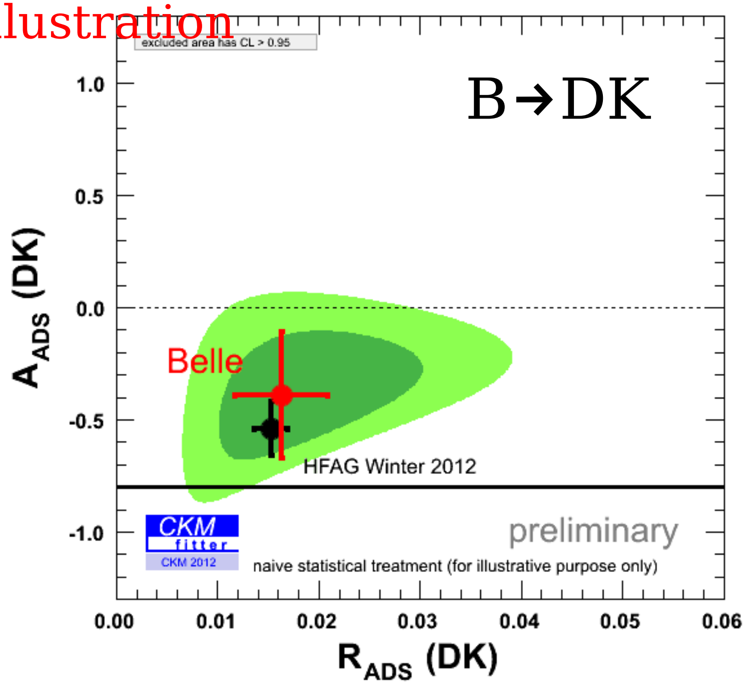
$$= 2\, r_B r_D \sin(\delta_B + \delta_D) \sin\phi_3 \,/\, \mathcal{R}_{DK}$$

where $r_D = \left| \frac{\mathcal{A}(D^0 \to K^+\pi^-)}{\mathcal{A}(\bar{D}^0 \to K^+\pi^-)} \right| = 0.0613 \pm 0.0010$

Comparison of the results obtained for $D^{(*)}K$ with expectations

where ''expectations'' are derived from the GGSZ observables, δ_D and γ_{UT}

for illustration



$$R_{ADS}(DK) = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma$$

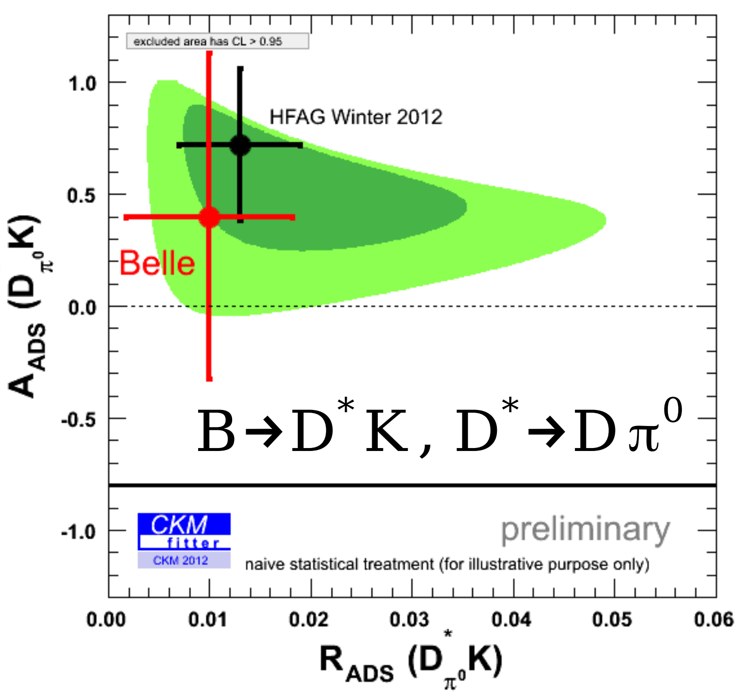
$$A_{ADS}(DK) = 2 r_B r_D \sin(\delta_B + \delta_D) \sin\gamma / R_{ADS}(DK)$$

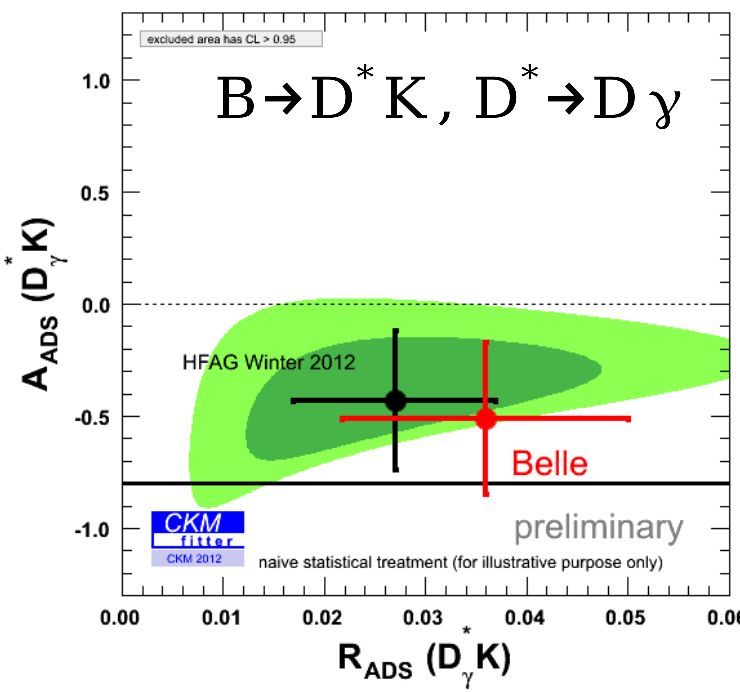
$$R_{ADS}(D^*_{\pi^0}K) = r_B^{*2} + r_D^2 + 2 r_B^* r_D \cos(\delta_B^* + \delta_D) \cos\gamma$$

$$A_{ADS}(D^*_{\pi^0}K) = 2 r_B^* r_D \sin(\delta_B^* + \delta_D) \sin\gamma / R_{ADS}(D^*_{\pi^0}K)$$

$$R_{ADS}(D^*_{\gamma}K) = r_B^{*2} + r_D^2 - 2 r_B^* r_D \cos(\delta_B^* + \delta_D) \cos\gamma$$

$$A_{ADS}(D^*_{\gamma}K) = -2 r_B^* r_D \sin(\delta_B^* + \delta_D) \sin\gamma / R_{ADS}(D^*_{\gamma}K)$$





Lot of interesting modes...

not used until now

D mode	$2F_+ - 1$	branching ratio ($\times 10^{-3}$)
$K^+ K^-$	+1	3.96 ± 0.08
$\pi^+ \pi^-$	+1	1.40 ± 0.03
$\pi^0 \pi^0$	+1	0.82 ± 0.04
$K^0_L \pi^0$	+1	10.0 ± 0.7
$K^0_S \pi^0 \pi^0$	+1	9.1 ± 1.1
$K^0_S \eta \pi^0$	+1	5.5 ± 1.1
$K^0_S K^0_S K^0_S$	+1	0.91 ± 0.13
$\pi \pi \pi^0$		14.3 ± 0.6
$K K \pi^0$		3.3 ± 0.1
$\pi \pi \pi \pi$		7.4 ± 0.2

D mode	$2F_+ - 1$	branching ratio ($\times 10^{-3}$)
$K^0_S \pi^0$	−1	11.9 ± 0.4
$K^0_S \eta$	−1	4.8 ± 0.3
$K^0_S \eta'$	−1	9.4 ± 0.5
$K^0_S K^0_S K^0_L$	−1	1.0
$\eta \pi^0 \pi^0$	−1	unknown
$\eta' \pi^0 \pi^0$	−1	unknown
$K^0_S K^0_S \pi^0$	−1	< 0.6
$K^0_S K^0_S \eta$	−1	unknown

D mode	branching ratio ($\times 10^{-3}$)
$K^0_S \pi^+ \pi^-$	28.3 ± 2.0
$K^0_S K^+ K^-$	4.6 ± 0.2
$K^0_L \pi^+ \pi^-$	
$K^0_L K^+ K^-$	
$K^0_S \pi^+ \pi^- \pi^0$	52 ± 6
$\pi^+ \pi^- \pi^0 \pi^0$	10.0 ± 0.9

current study with Belle promising promising →

challenging modes with K_L, two π^0's...