Time-dependent CP violation in $B^0_{(s)} \to h^+h^-$ decays

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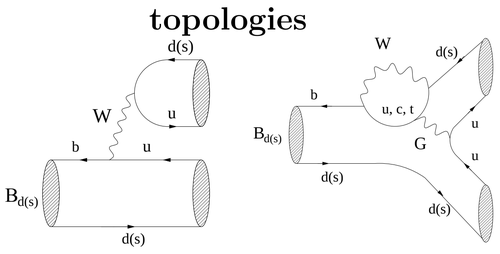
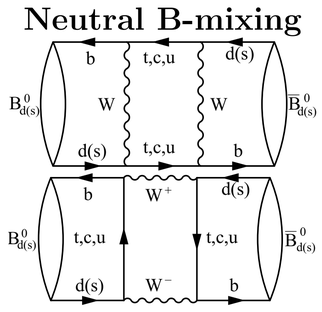
Physics motivation

- A rich set of physics processes contribute to the $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decays

Tree and penguin decay topologies



Neutral B-mixing



- Time-dependent (TD) CPV observables are sensitive to the CKM angle γ and the mixing phases ϕ_s and ϕ_d
- Presence of **loop diagrams**:
  - makes the CPV observables sensitive to New Physics [1]
  - results can be compared with decays dominated by tree-level

CPV observables

- TD CPV asymmetries of $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decays

$$A(t) = \frac{\Gamma_{\overline{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\overline{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} = \frac{-\mathbf{C_f}\cos(\Delta m_{d(s)}t) + \mathbf{S_f}\sin(\Delta m_{d(s)}t)}{\cosh\left(\frac{\Delta\Gamma_{d(s)}}{2}t\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_{d(s)}}{2}t\right)}$$

$$\mathbf{C_f} = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \qquad \mathbf{S_f} = \frac{2Im\lambda_f}{1+|\lambda_f|^2}$$

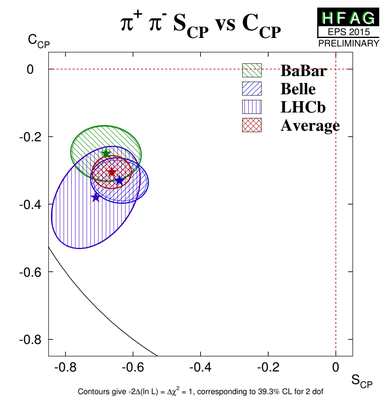
Direct CPV **Induced CPV**

- Time-integrated (TI) CPV asymmetries of $B^0 \to K^+\pi^-$ and $B_s \to \pi^+K^-$ decays

$$A_{CP}(t) = \frac{|\bar{A}_{\bar{f}}|^2 - |A_f|^2}{|\bar{A}_{\bar{f}}|^2 + |A_f|^2}$$

State of the art

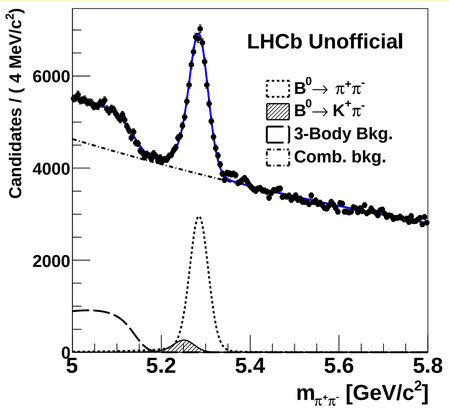
- First measurement of $\mathbf{C}_{\pi\pi}$ and $\mathbf{S}_{\pi\pi}$ on $B^0 \to \pi^+\pi^-$ performed by B factories [2,3]
- LHCb performed a measurement on the $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$ decays using data collected in 2011 (1 fb^{-1}) [4]



Analysis strategy

Event selection

- Particle identification (**PID**) requirements:
  - $\pi^+\pi^-$ & K^+K^-: reduce $B^0 \to K^+\pi^-$ to $\sim 10\%$ of the signal
  - $K^+\pi^-$: reduce cross-feeds to $\sim 10\%$ of $B_s \to \pi^+K^-$
- **BDT** optimisation:
  - Signal from MC samples
  - Background from upper mass sideband
  - FoM $= S/\sqrt{S+B}$



CP asymmetries of $B^0 \to K^+\pi^-$ and $B_s \to \pi^+K^-$

- TD measurement allows to disentangle the experimental effect due to $B/\bar{B}$ production asymmetry

$$A(t) \approx A_{\text{raw}} + A_P\cos(\Delta m_{d(s)}t) \qquad A_{\text{raw}} = A_{CP} + A_{PID} + A_D$$

- asymmetry introduced by **PID cuts**: $A^{K\pi}_{PID} = (-0.04 \pm 0.25)\%$
- **detection** asymmetry: (using $D^+ \to K^-\pi^+\pi^+$ and $D^+ \to K^0\pi^+$ as calibration modes)

$A^{K\pi}_D(B^0 \to K^+\pi^-) = (-0.900 \pm 0.141)\%$ $\qquad$ $A^{K\pi}_D(B_s \to \pi^+K^-) = (-0.924 \pm 0.142)\%$

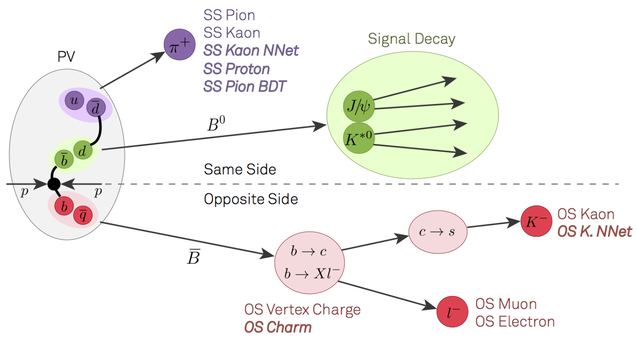
Flavour Tagging

Flavour Tagging plays a **crucial role**:

- $\mathbf{C}^{\text{obs}}_{\mathbf{f}}$ and $\mathbf{S}^{\text{obs}}_{\mathbf{f}}$ are connected to the mistag fraction ω
- **Sensitivity** on $\mathbf{C}^{\text{obs}}_{\mathbf{f}}$ and $\mathbf{S}^{\text{obs}}_{\mathbf{f}}$ is proportional to the tagging power $\varepsilon(1-2\omega)^2$ (where ε is the tagging efficiency)

e.g: $\mathbf{C}^{\text{obs}}_{\mathbf{f}} = (1-2\omega)\mathbf{C}_{\mathbf{f}}$

$$\sigma(\mathbf{C_f}) \propto \frac{1}{\sqrt{\varepsilon(1-2\omega)^2}}$$



SSp & SSπBDT: previously calibrated on $B^0 \to K^+\pi^-$
$\Longrightarrow$ combined in a unique SS tagger

OS & SS: calibrated on the $B^0 \to K^+\pi^-$ during the fit

SSkNN calibrated using $B_s \to D_s^-\pi^+$
$\Longrightarrow$ differences between two decay modes taken in account through a reweighting

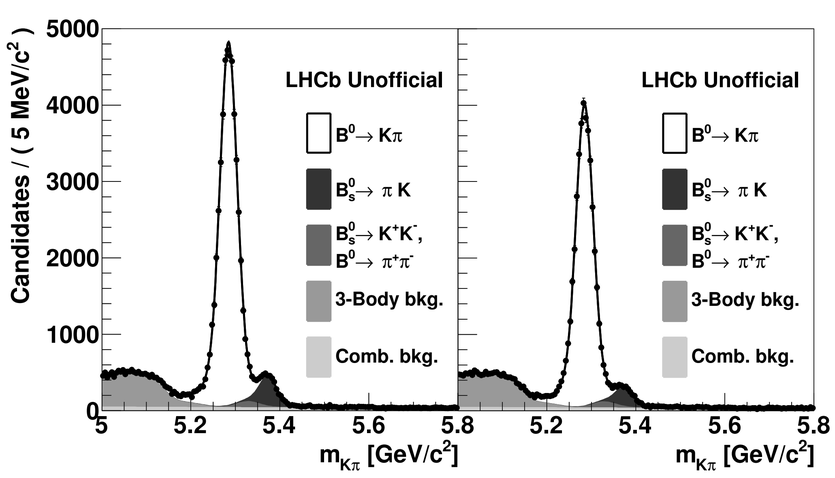
Tagger	$\varepsilon(1-2\omega)^2$
OS	$(2.94 \pm 0.17)\%$
SS	$(1.17 \pm 0.11)\%$
SSkNN	$(0.71 \pm 0.12)\%$
Total $B^0 \to \pi^+\pi^-$	$(4.08 \pm 0.20)\%$
Total $B_s \to K^+K^-$	$(3.65 \pm 0.21)\%$

LHCb Unofficial

Simultaneous fit (LHCb Unofficial)

- Determination of C_f, S_f, $A^{\Delta\Gamma}$ and A_{CP} from **multidimensional fits performed simultaneously** to the $K\pi$, $\pi\pi$ and KK spectra
- Observables: invariant mass, decay-time, decay-time error, flavour tagging decision and predicted mistag probability

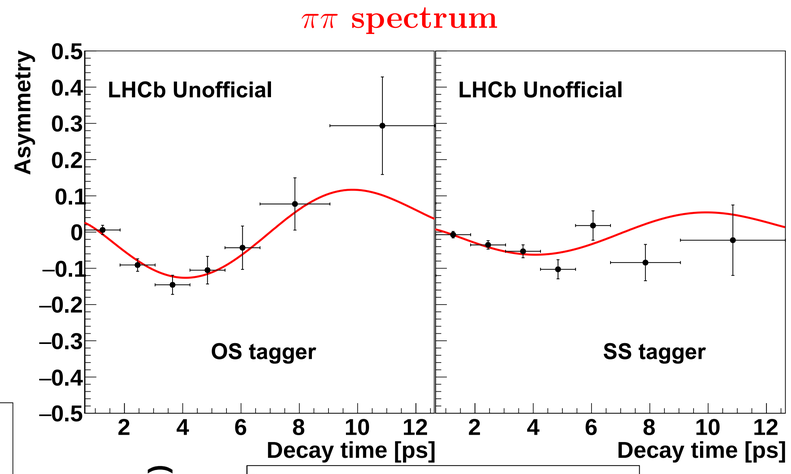
$K\pi$ spectrum

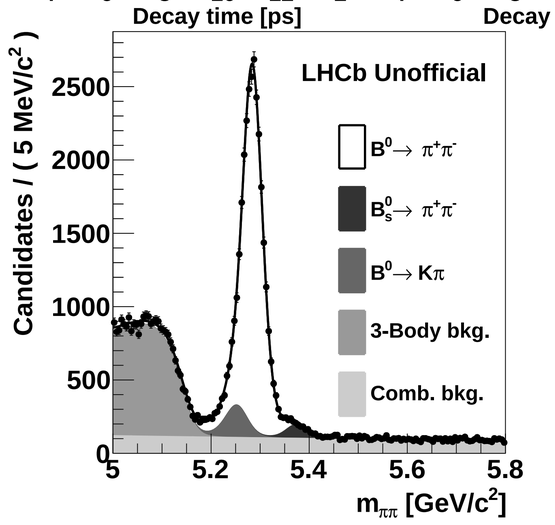


$\mathbf{K^+\pi^-}$ **final state** $\qquad$ $\mathbf{K^-\pi^+}$ **final state**

$A_{CP}(B^0 \to K^+\pi^-) =$	$-0.084 \pm 0.004 \pm 0.003$
$A_{CP}(B_s \to \pi^+K^-) =$	$0.213 \pm 0.015 \pm 0.007$

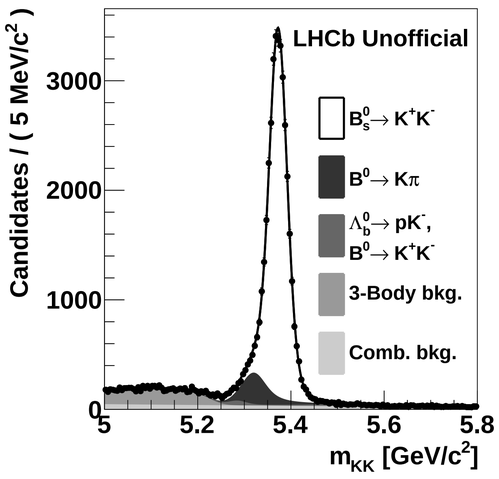
$\pi\pi$ spectrum

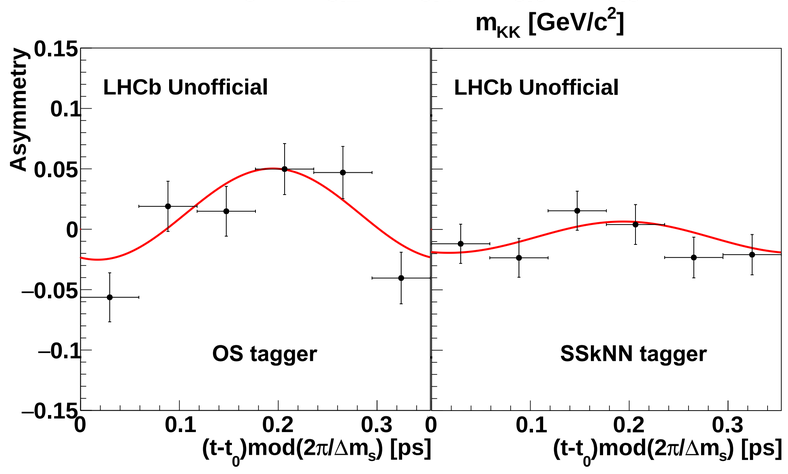




$C_{\pi^+\pi^-} =$	$-0.34 \pm 0.06 \pm 0.01$
$S_{\pi^+\pi^-} =$	$-0.63 \pm 0.05 \pm 0.01$

KK spectrum





$C_{K^+K^-} =$	$0.20 \pm 0.06 \pm 0.02$
$S_{K^+K^-} =$	$0.18 \pm 0.06 \pm 0.02$
$A^{\Delta\Gamma}_{K^+K^-} =$	$-0.79 \pm 0.07 \pm 0.10$

Conclusions

- Measurements are very well in agreement with previous results
- Most precise measurement of A_{CP} from single experiment
- Strongest evidence of TD CPV in B_s decays

References

[1] R. Fleischer, PLB 459 (1999) 306, *arXiv:hep-ph/9903456*
[2] BaBar Collaboration, Measurement of CP Asymmetries and Branching Fractions in Charmless Two-Body B-Meson Decays to Pions and Kaons, *PRD 87 (2013) 052009*
[3] Belle Collaboration, Measurement of the CP violation parameters in $B_d \to \pi^+\pi^-$ decays, *PRD 88 (2013) 092003*
[4] R. Aaij and al., First measurement of time-dependent CP violation in $B_s \to K^+K^-$ decays, *JHEP 10 (2013) 183*