Penguin decays at LHCb

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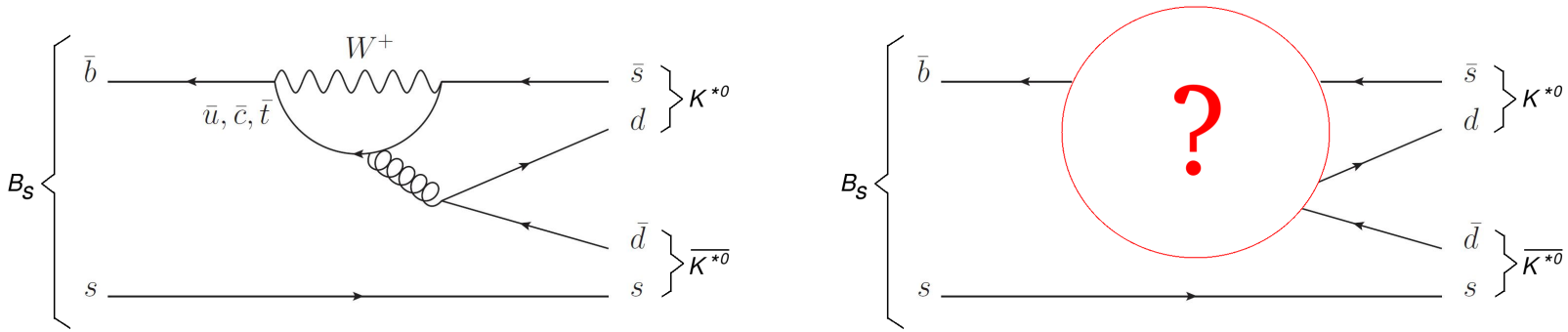
Outline

Introduction

- Loops are particularly sensitive to New Physics: New heavy particles entering the loops ⇒ Observable deviations from SM



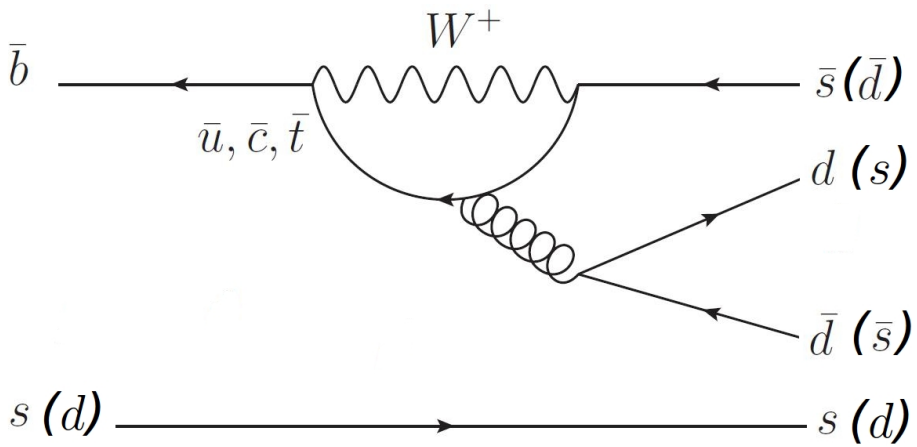
- CP-violation: Weak phases $sin(2\beta)$ ($B^0 \to \phi K_S$) or ϕ_S ($B_s^0 \to K^{*0}\overline{K}^{*0}$, $B_s^0 \to \phi\phi$)
- $B \to VV$ polarization puzzle: Observed $f_T/f_L \simeq 1$ in $B^0 \to \phi K^{*0}$, in opposition to the expectation that $f_T \ll f_L$
- Bd penguin decays studied at other experimens (B-factories, CLEO), new interest in Bs penguin decays.

$B_s^0 \to K^{*0}\overline{K}^{*0}$

- Very interesting for precision *CP*-violation studies, where $B^0 \to K^{*0}\overline{K}^{*0}$ channel is used to control the theoretical error (Ciuchini, Pierini and Silvestrini, hep-ph/0703137 ; Bhattacharya, Datta, Imbeault and London, hep-ph/1203.3435 (2011); Descotes-Genon, Matas and Virto, hep-ph/1111.4882 (2011))

$$\text{Standard Model} \Rightarrow \text{Negligibly small } \phi_S.$$

- U-spin rotations, $d \leftrightarrow s$, are genuine flavour symmetries. Standard EW and QCD physics predict small breaking ($\lesssim 10\%$)

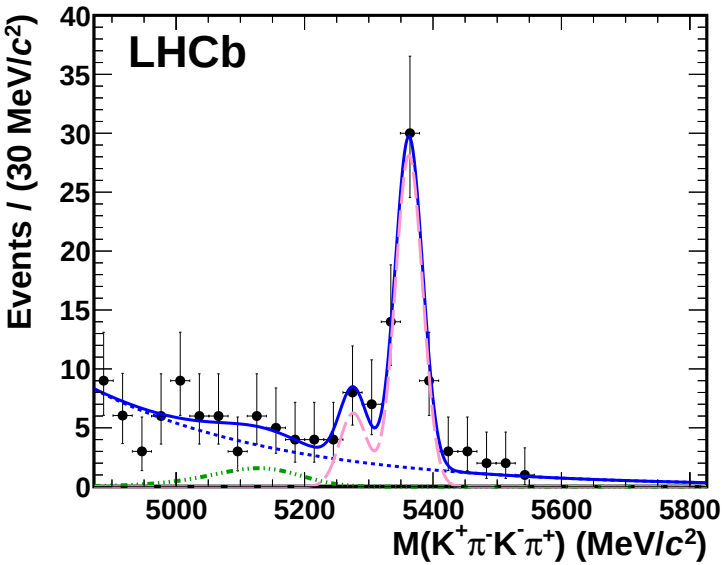


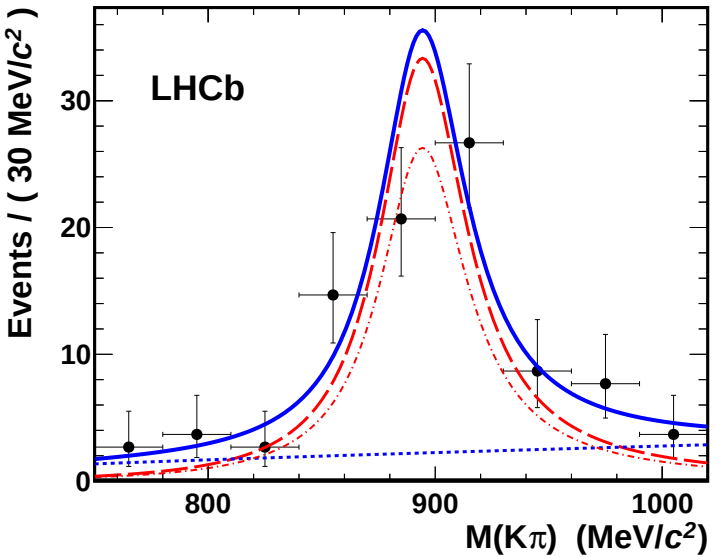
$B_s^0 \to K^{*0}\overline{K}^{*0}$: Observation

- First observation with $35 pb^{-1}$ of 2010 data with very good signal to background ratio

$$\mathcal{B}(B_s^0 \to K^{*0}\overline{K}^{*0}) = (2.81 \pm 0.46(stat) \pm 0.45(syst) \pm 0.34(f_s/f_d)) \times 10^{-5}$$

- S-wave component in $\pm 150\,\mathrm{MeV}/c^2$ window around K^{*0} mass $\sim 15\%$

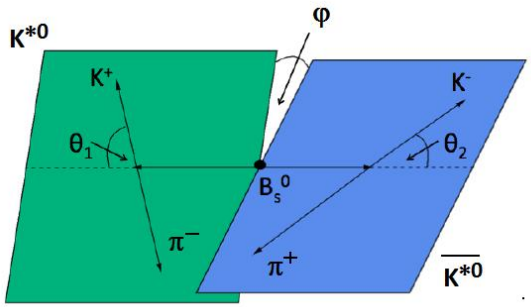




LHCb Collaboration, R. Aaij et al., Phys. Lett. B709 (arXiv:1111.4183)

$B_s^0 \to K^{*0}\overline{K}^{*0}$: Angular Analysis

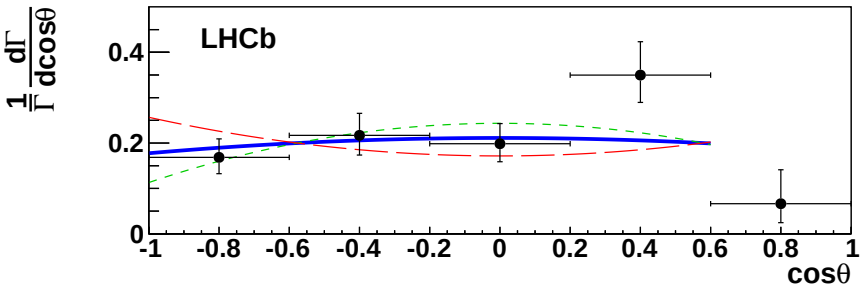
- $B \to VV$ decay: Three polarization amplitudes A_0, $A_{||}$ and $A_\perp$



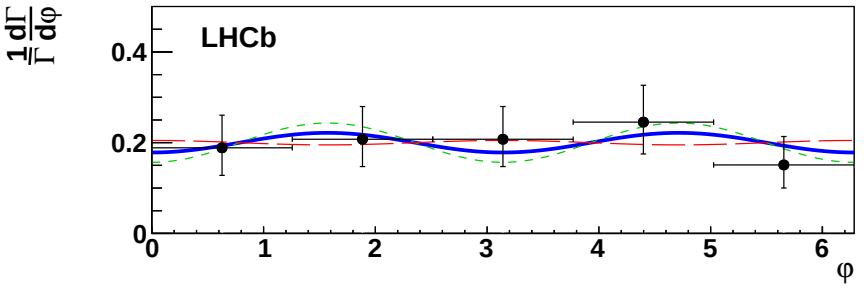
- Untagged, time-integrated angular fit to helicity angles.

$$|A_0|^2 = 0.30 \pm 0.12(stat) \pm 0.04(syst)$$

$$|A_\perp|^2 = 0.38 \pm 0.11(stat.) \pm 0.04(syst.)$$

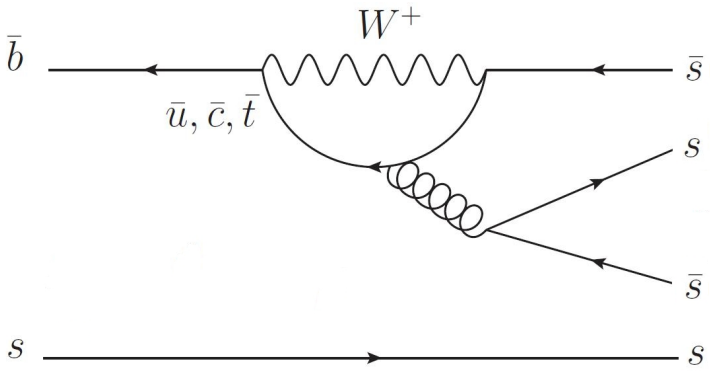


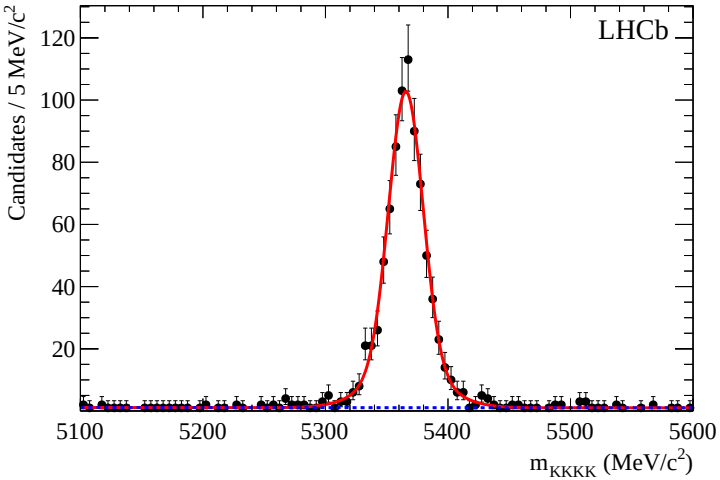
- Remarkable difference with its U-spin partner $B^0 \to K^{*0}\overline{K}^{*0}$ (BaBar:$|A_0|^2 = 0.80 \pm 0.12(stat) \pm 0.04(syst)$).

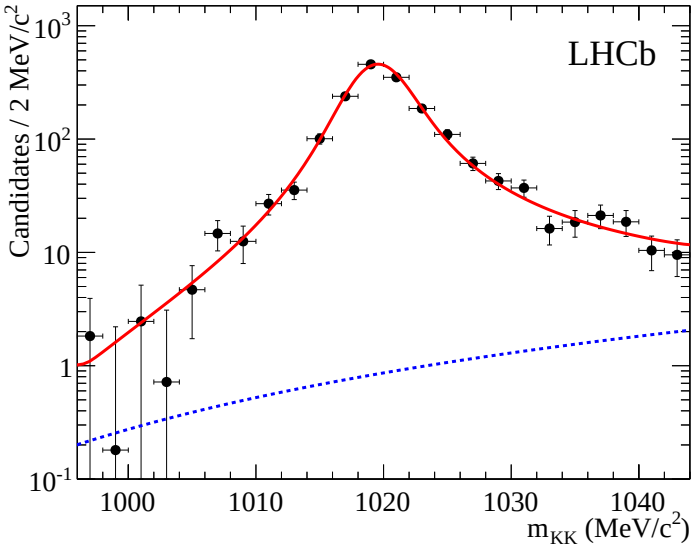


$B_s^0 \to \phi\phi$

- Golden mode for measurement of ϕ_s (Raidal, arXiv, hep-ph/0209091)
- 801 ± 29 candidates in the full 2011 dataset ($1 fb^{-1}$).
- S-wave component in $\pm 25\,\mathrm{MeV}/c^2$ window around ϕ mass $\sim 1.3\%$







$B_s^0 \to \phi\phi$: Angular Analysis

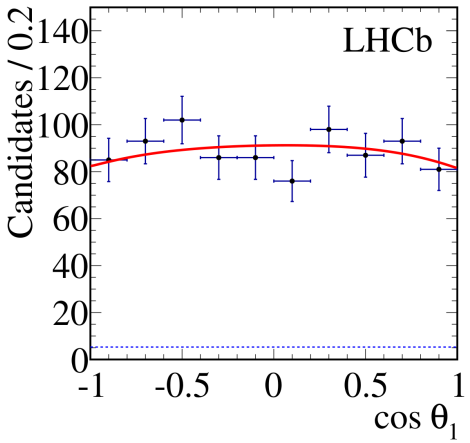
- Polarization amplitudes in good agreement with CDF measurement.

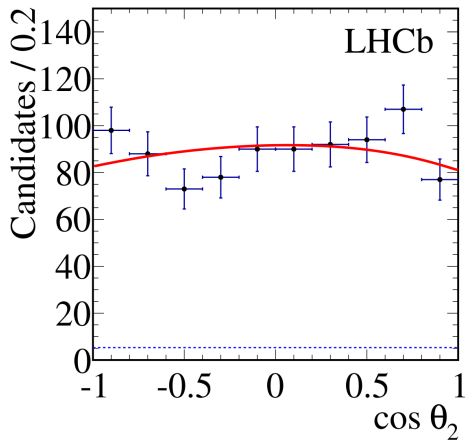
$$|A_0|^2 = 0.365 \pm 0.022(stat) \pm 0.012(syst)$$

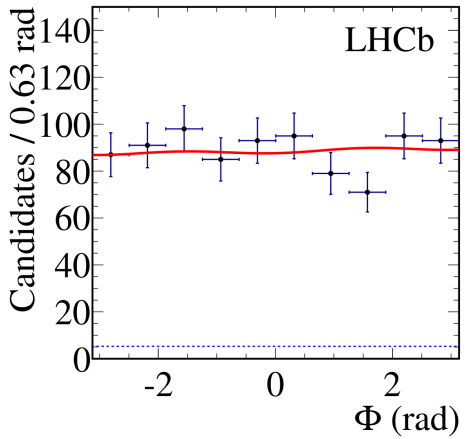
$$|A_\perp|^2 = 0.291 \pm 0.024(stat) \pm 0.010(syst)$$

$$cos(\delta_\parallel) = -0.844 \pm 0.068(stat) \pm 0.029(syst)$$

LHCB-PAPER-2012-004
(arXiv:1204.2813)







$B_s^0 \to \phi\phi$: Triple Product Asymmetries

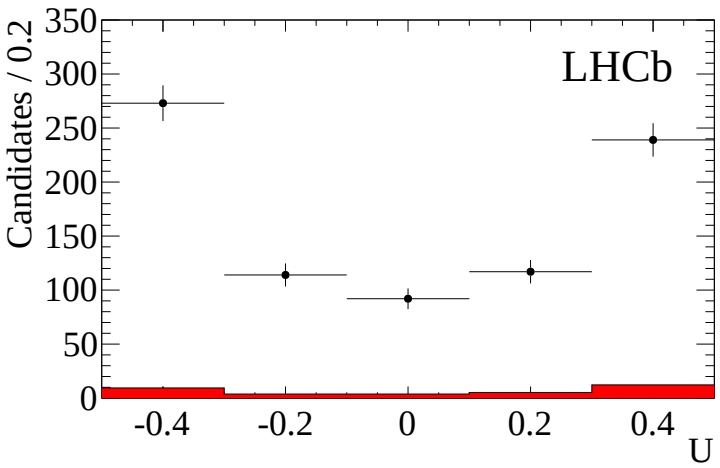
- Search for NP with no need of tagging or time-dependent analysis (Datta and London, arXiv:hep-ph/0303159)
- Interference terms $\Im(A_0^* A_\perp)$ and $\Im(A_\parallel^* A_\perp)$ are proportional to the tripple products:

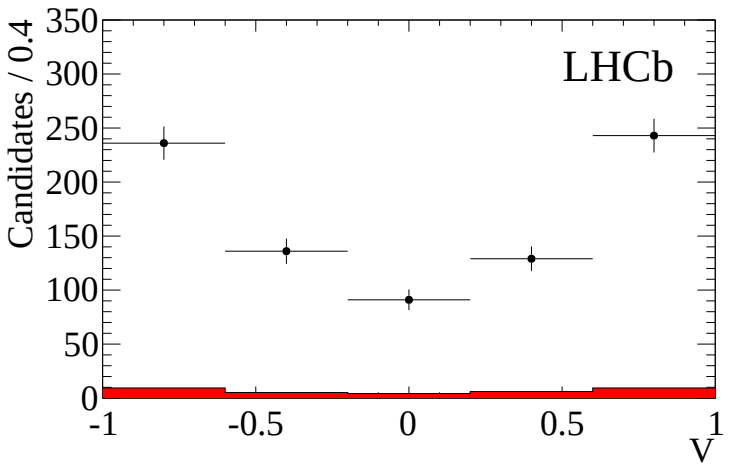
$$\begin{aligned} \text{U:} \quad & \sin\varphi = (\hat{n}_1 \times \hat{n}_2)\cdot\hat{p}_1 \\ \text{V:} \quad & \sin(2\varphi)/2 = (\hat{n}_1\cdot\hat{n}_2)(\hat{n}_1 \times \hat{n}_2)\cdot\hat{p}_1 \end{aligned}$$

- TP are odd under time reversal:
  Non zero TP asymmetries measurement may be a sign of *CP*-violation (*CPT* conservation)

$$A_U = \frac{\Gamma(U>0)-\Gamma(U<0)}{\Gamma(U>0)+\Gamma(U<0)} \qquad A_V = \frac{\Gamma(V>0)-\Gamma(V<0)}{\Gamma(V>0)+\Gamma(V<0)}$$

$B_s^0 \to \phi\phi$: Triple Product Asymmetries





- Results are in good agreement with CDF and consistent with the hypothesis of *CP* conservation.

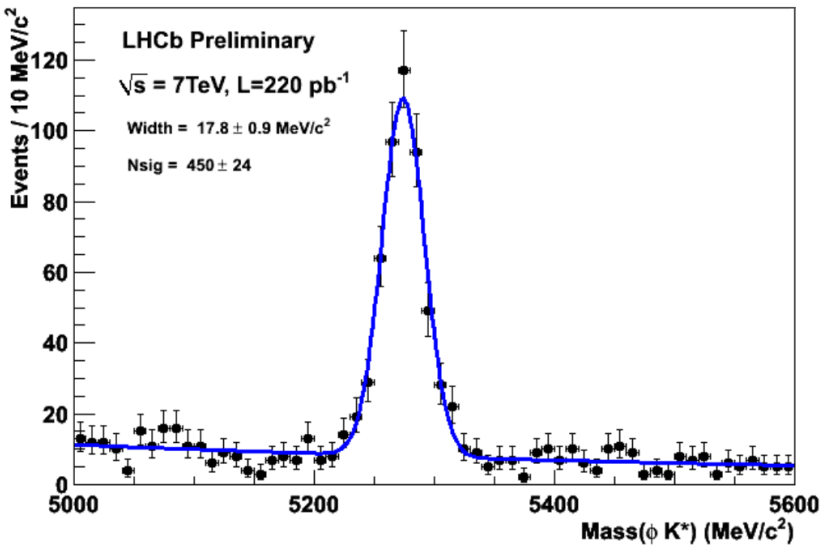
$$A_U = -0.055 \pm 0.036(stat) \pm 0.018(syst)$$

$$A_V = 0.010 \pm 0.036(stat) \pm 0.018(syst)$$

Ongoing work and future plans

- 2011 data:
  - $B_s^0 \to K^{*0}\overline{K}^{*0}$: $M(K\pi)$-dependent angular analysis to ensure 1% level S-wave contribution systematics
  - Test of U-spin symmetry with simultaneous analysis of $B_s^0 \to K^{*0}\overline{K}^{*0}$ and $B^0 \to K^{*0}\overline{K}^{*0}$
  - $B^0 \to \phi K^{*0}$: Angular analysis, TP analysis
  - Search for $B_s^0 \to \phi\overline{K}^{*0}$

- 2011 + 2012 data: Tagged, time-dependent angular analysis to measure ϕ_S
- Key channels for LHCb upgrade: 50 fb-1 & improved hadron trigger, precision of 0.02 rad in ϕ_S

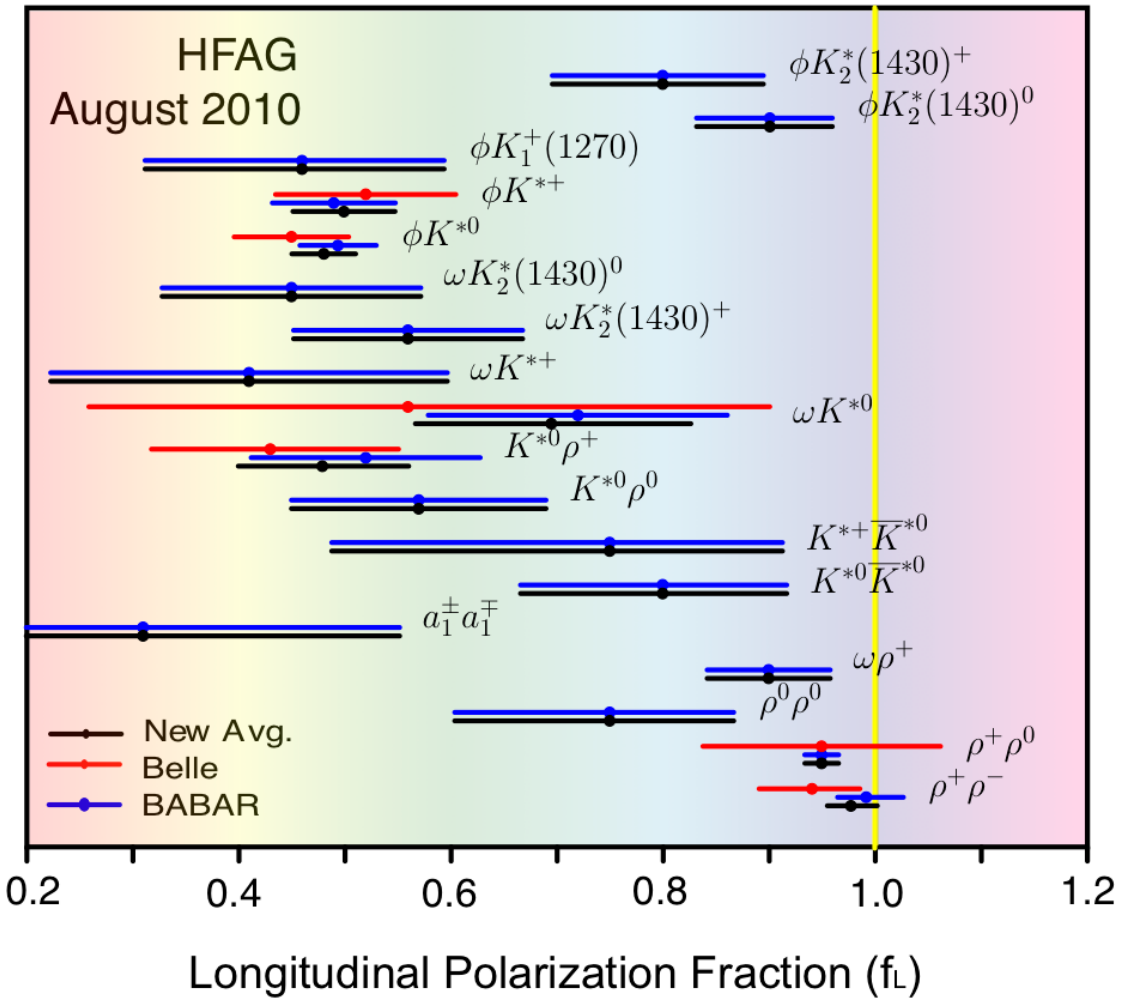


Conclusions

- First observation of $B_s^0 \to K^{*0}\overline{K}^{*0}$ with 2010 data. Polarization amplitudes and BR measurement.
- Analysis of $B_s^0 \to \phi\phi$ with 2011 data. Polarization amplitudes and Triple Products analysis.
- Extension of these analysis and new ones ($B^0 \to \phi K^{*0}$ and $B_s^0 \to \phi\overline{K}^{*0}$) expected with 2011 (&2012) data.
- Hadronic penguin decays are key channels for LHCb *CP*-violation analysis.

BACKUP

Polarization puzzle

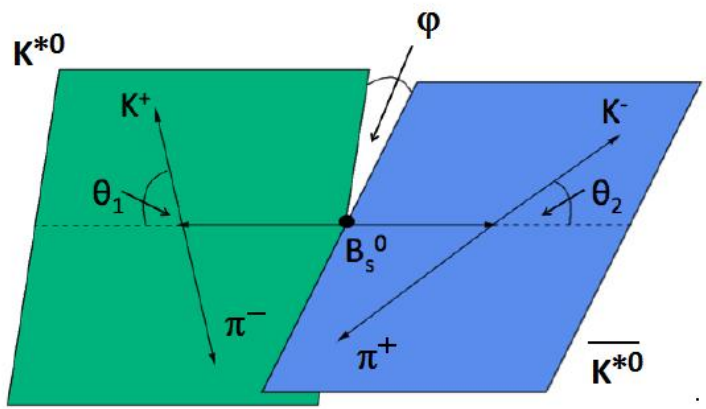


Angular distribution

$$I(\theta_1,\theta_2,\varphi)=\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_1\,\mathrm{d}\cos\theta_2\,\mathrm{d}\varphi}=\Bigg(\frac{1}{\Gamma_L}\quad|A_0|^2\quad\cos^2\theta_1\cos^2\theta_2+$$
$$\frac{1}{\Gamma_L}\quad|A_\parallel|^2\quad\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\cos^2\varphi+$$
$$\frac{1}{\Gamma_H}\quad|A_\perp|^2\quad\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\sin^2\varphi+$$
$$\frac{1}{\Gamma_L}\quad|A_0|\quad|A_\parallel|\cos\delta_\parallel\frac{1}{2\sqrt{2}}\sin 2\theta_1\sin 2\theta_2\cos\varphi\Bigg)$$

$$A_0=H_0$$
$$A_\parallel=\frac{1}{\sqrt{2}}(H_{+1}+H_{-1})$$
$$A_\perp=\frac{1}{\sqrt{2}}(H_{+1}-H_{-1})$$

Normalization $\Rightarrow |A_0|^2+|A_\parallel|^2+|A_\perp|^2=1$

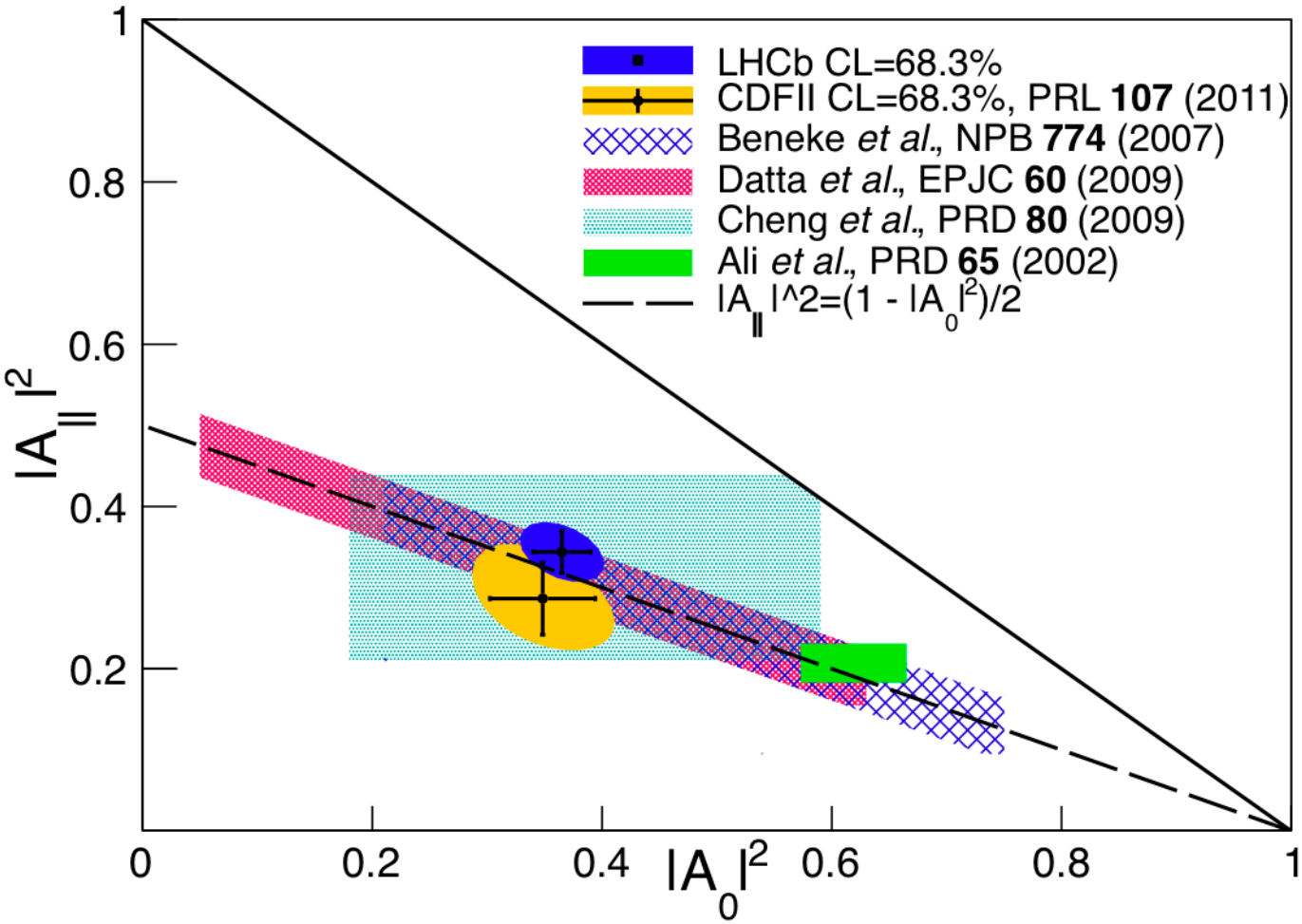


$B_s^0 \to K^{*0}\overline{K}^{*0}$ systematics

Table: Estimated systematic error sources in the $\mathcal{B}(BsKstKst)$ measurement.

Systematic effect	Error (%)
Trigger efficiency	11
Global angular acceptance	7.2
S-wave fraction	5
Background subtraction	4.7
$B_s^0 \to J/\psi K^{*0}$ and $J/\psi \to \mu\mu$ BR uncertainty	4.6
Selection efficiency	3.4
Total	15.9

Polarization amplitudes $B_s^0 \to \phi\phi$



$B_s^0 \to \phi\phi$ systematics

Source	$\lvert A_0\rvert^2$	$\lvert A_\perp\rvert^2$	$\lvert A_\parallel\rvert^2$	$\cos\delta_\parallel$
S-wave	0.007	0.005	0.012	0.001
Time Acceptance	0.006	0.006	0.002	0.007
Angular Acceptance	0.007	0.006	0.006	0.028
Trigger category	0.003	0.002	0.001	0.004
Background model	0.001	-	0.001	0.003
Total	0.012	0.010	0.014	0.029

$B_s^0 \to \phi\phi$ systematics

Source	A_U	A_V	Chosen uncertainty
Angular acceptance	0.009	0.006	0.009
Decay time acceptance	0.006	0.014	0.014
Fit model	0.004	0.005	0.005
Total			0.018