CKM 2016 Workshop

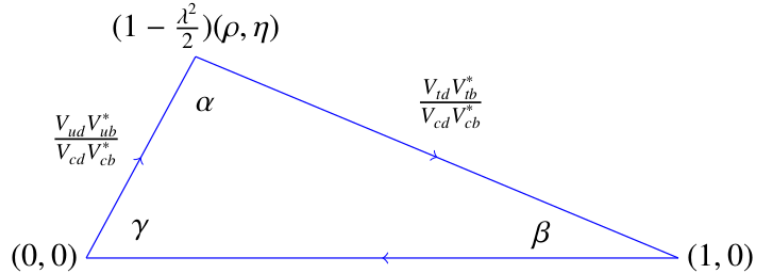
Measurement of γ from $B_u \to DK^{(*)}$ decays and $B_c^+ \to D^0 h^+$ mode in LHCb

Frederic Machefert, LAL(Orsay)
On behalf of the LHCb collaboration

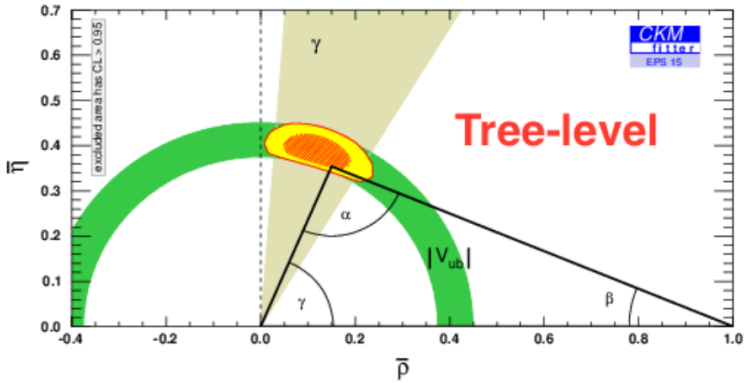
Introduction

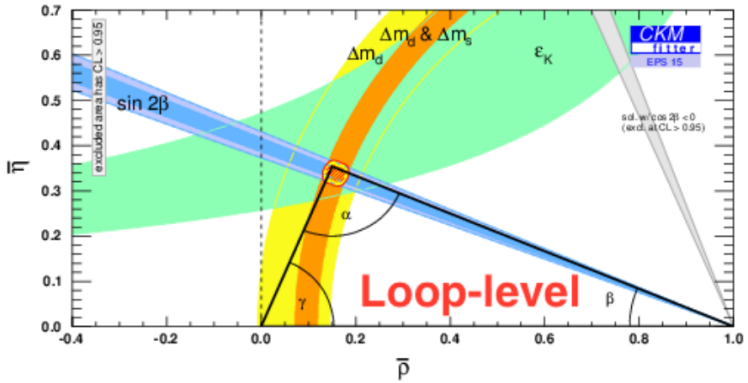
The γ angle

$$\gamma \equiv \arg\left(-\frac{V_{ud}\cdot V_{ub}^*}{V_{cd}\cdot V_{cb}^*}\right) \simeq \arg\left(-\frac{V_{ub}^*}{V_{cb}^*}\right)$$



- The angle γ can be measured when the b→u and b→c type decays interfere to exhibit CP violation
- γ can be measured in CPV tree decays with tiny theory uncertainties [JHEP01 051]
  - No V_{tx} term → the only angle that that be measured without penguin pollution (indirect measurements contain loops)
- $B \to D^{(*)}K^{(*)}$ decays satisfy those criteria and some potentially give large CP violation





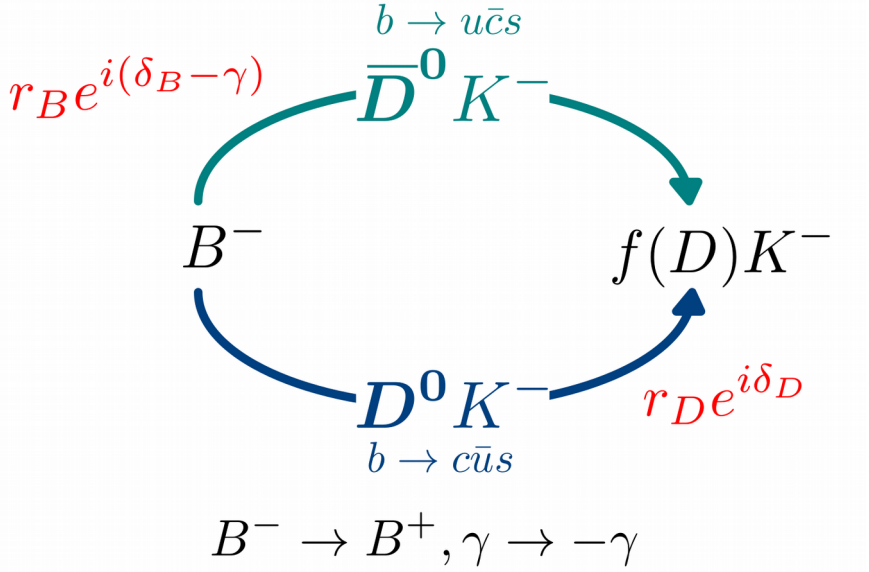
Babar
Belle
LHCb

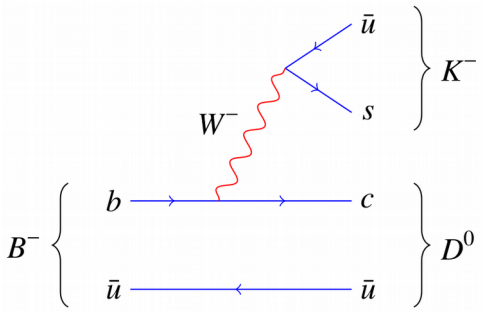
$\Rightarrow$ $\gamma = (73.2^{+6.3}_{-7.0})^\circ$ (direct)

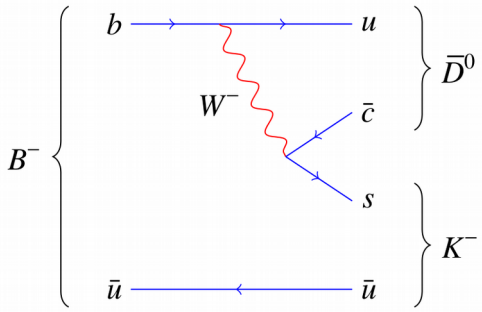
$\gamma = (66.85^{+0.94}_{-3.44})^\circ$ (indirect)

Standard Candle [PRD 92(3) 033002]
LHCb has to measure it
at degree-level precision

The methods to measure γ







$$\gamma \equiv \arg\left(-\frac{V_{ud}\cdot V_{ub}^*}{V_{cd}\cdot V_{cb}^*}\right) \simeq \arg\left(-\frac{V_{ub}^*}{V_{cb}^*}\right)$$

- The typical CP violation observables which are measured are
  - Charge asymmetries

$$A = \frac{\Gamma(B^- \to f_D K^-) - \Gamma(B^+ \to \bar{f}_D K^+)}{\Gamma(B^- \to f_D K^-) + \Gamma(B^+ \to \bar{f}_D K^+)}$$

  - Partial width ratios

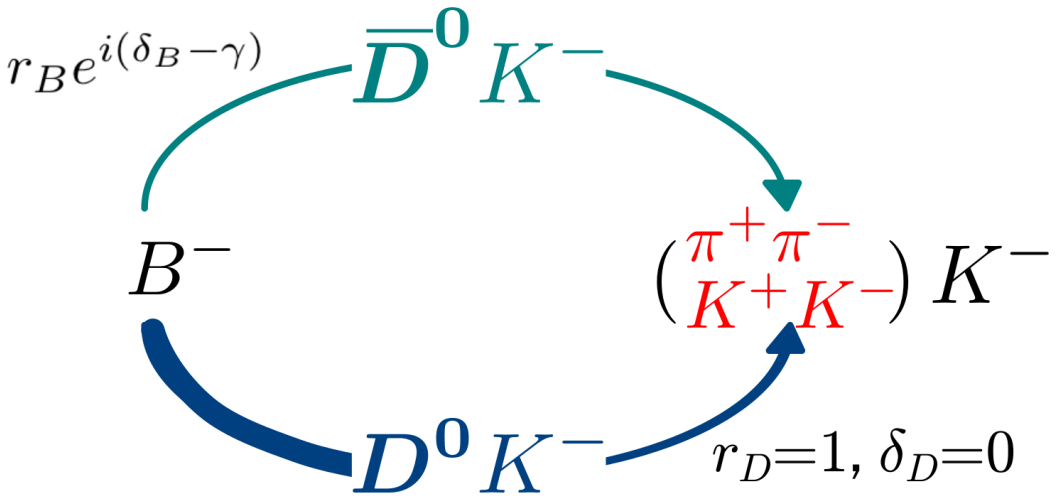
$$R = \frac{\Gamma(B^- \to f_D K^-) + \Gamma(B^+ \to \bar{f}_D K^+)}{\Gamma(B^- \to f'_D K^-) + \Gamma(B^+ \to \bar{f}'_D K^+)}$$

$$\frac{A(B^- \to \overline{D^0} K^-)}{A(B^- \to D^0 K^-)} = r_B e^{i(\delta_B - \gamma)}$$

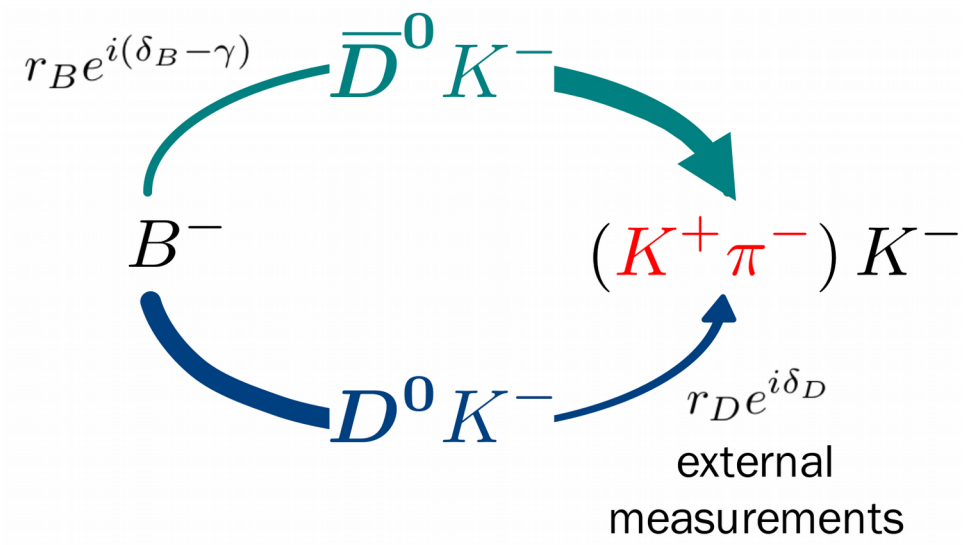
- The hadronic parameters (measured) are
  - Amplitude ratio r_B
  - Strong phase difference δ_B
- Many methods using different D decays (D decay parameters needed)

GLW versus ADS methods

GLW: CP eigenstates
Gronau, London, Wyler
[PLB 352 (1991), 483]
[PLB 265 (1991), 172]



ADS: large interference
(=large asymmetries)
[PRL 78 (1997) 3257]



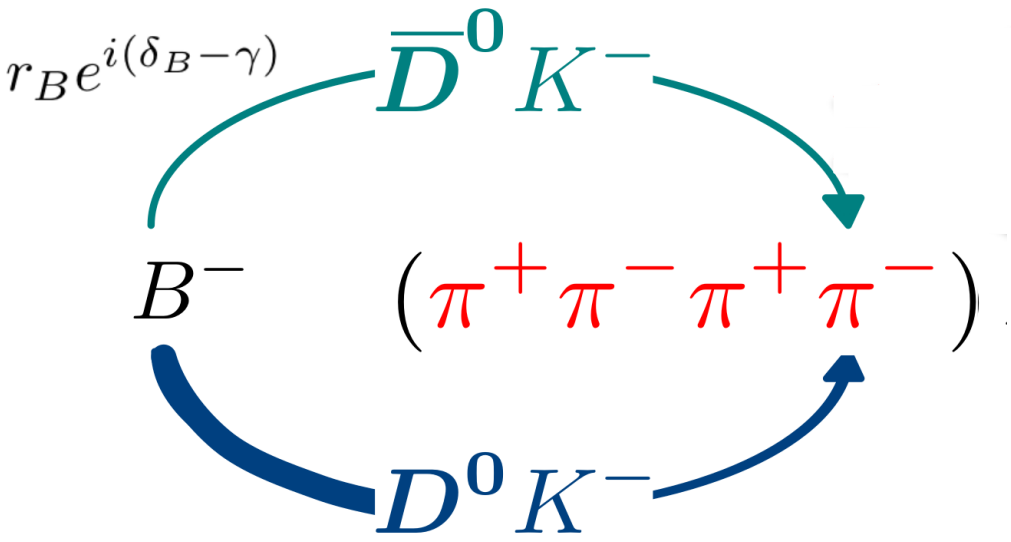
Favoured and suppressed decays in both
Interfering decay amplitudes

$$\text{GLW:}\quad \Gamma\left(B^{\mp}\to f_D K^{\mp}\right)\propto 1+r_B+2r_B\cos\left(\delta_B\mp\gamma\right)$$

$$\text{ADS:}\quad \Gamma\left(B^{\mp}\to f_D K^{\mp}\right)\propto\left(r_D^f\right)^2 r_B^2+2r_B r_D^f\cos\left(\delta_B+\delta_D^f\mp\gamma\right)$$

GLW versus ADS methods: D four body decays

Quasi - GLW



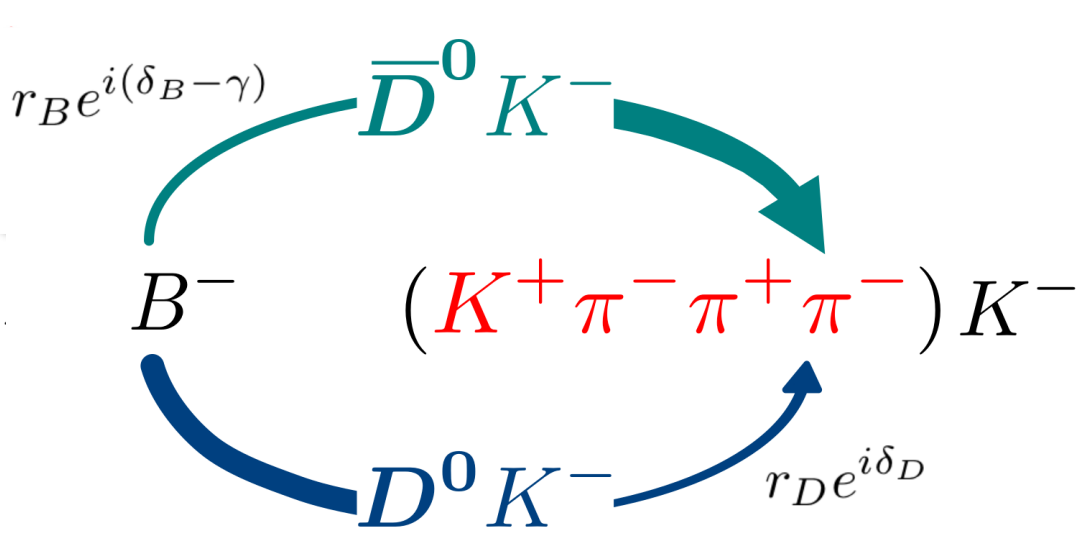
Fractional CP-even content

$F_+ = 0.737 \pm 0.028$

$2F_+ - 1 \sim 0.5$

[M. Nayak et al. Phys. Lett.B740(2015) 1]
[Malde et al. PLB 747 (2015) 9]

Quasi - ADS



Coherence factor

$\kappa^{3\pi}_D = 0.43^{+0.17}_{-0.13}$

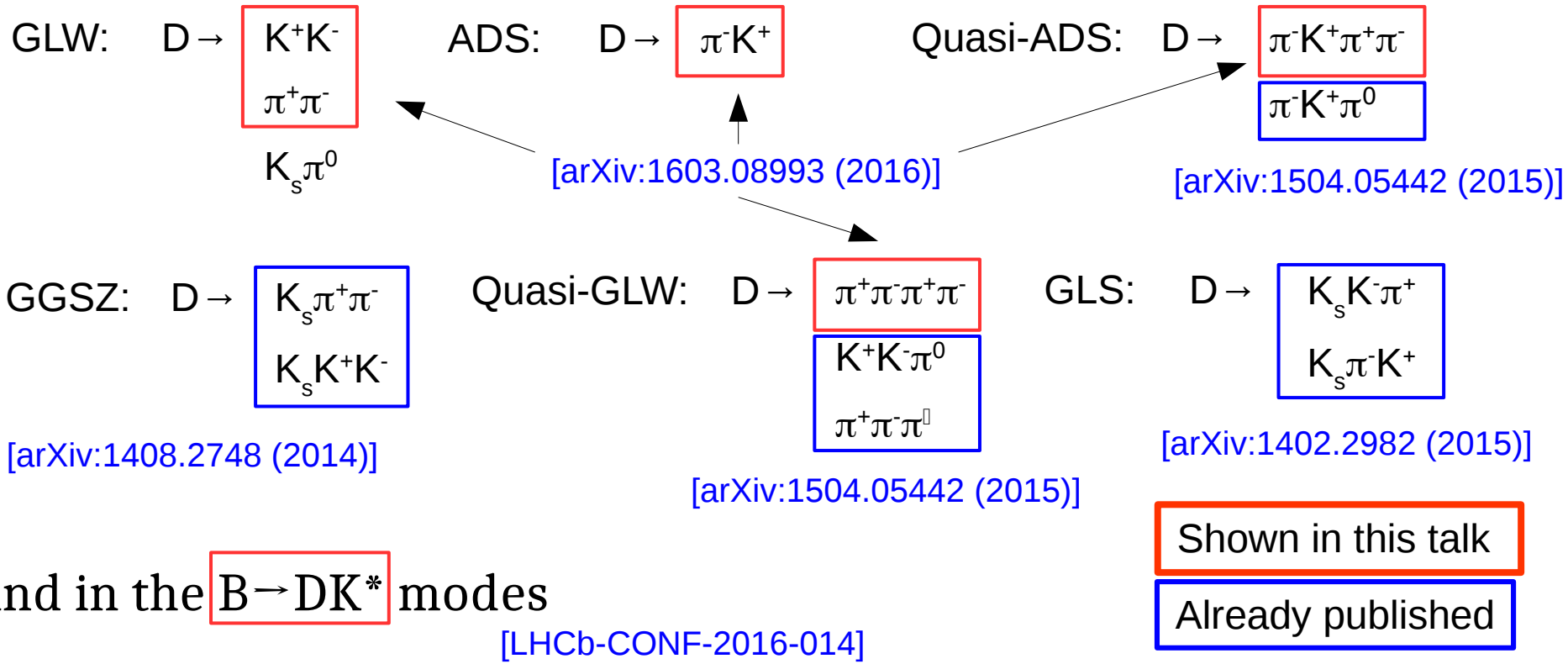
[Atwood and Soni, PRD 68 (2003) 033003]
[arXiv:1602.07430]

$$\text{GLW:}\quad \Gamma\left(B^{\mp}\to f_D K^{\mp}\right)\propto 1+r_B+\left(2F_+-1\right)2r_B\cos\left(\delta_B\mp\gamma\right)$$

$$\text{ADS:}\quad \Gamma\left(B^{\mp}\to f_D K^{\mp}\right)\propto \left(r_D^f\right)^2 r_B^2+2r_B r_D^f \kappa_D^f \cos\left(\delta_B+\delta_D^f\mp\gamma\right)$$

Measurements from LHCb in the charged modes

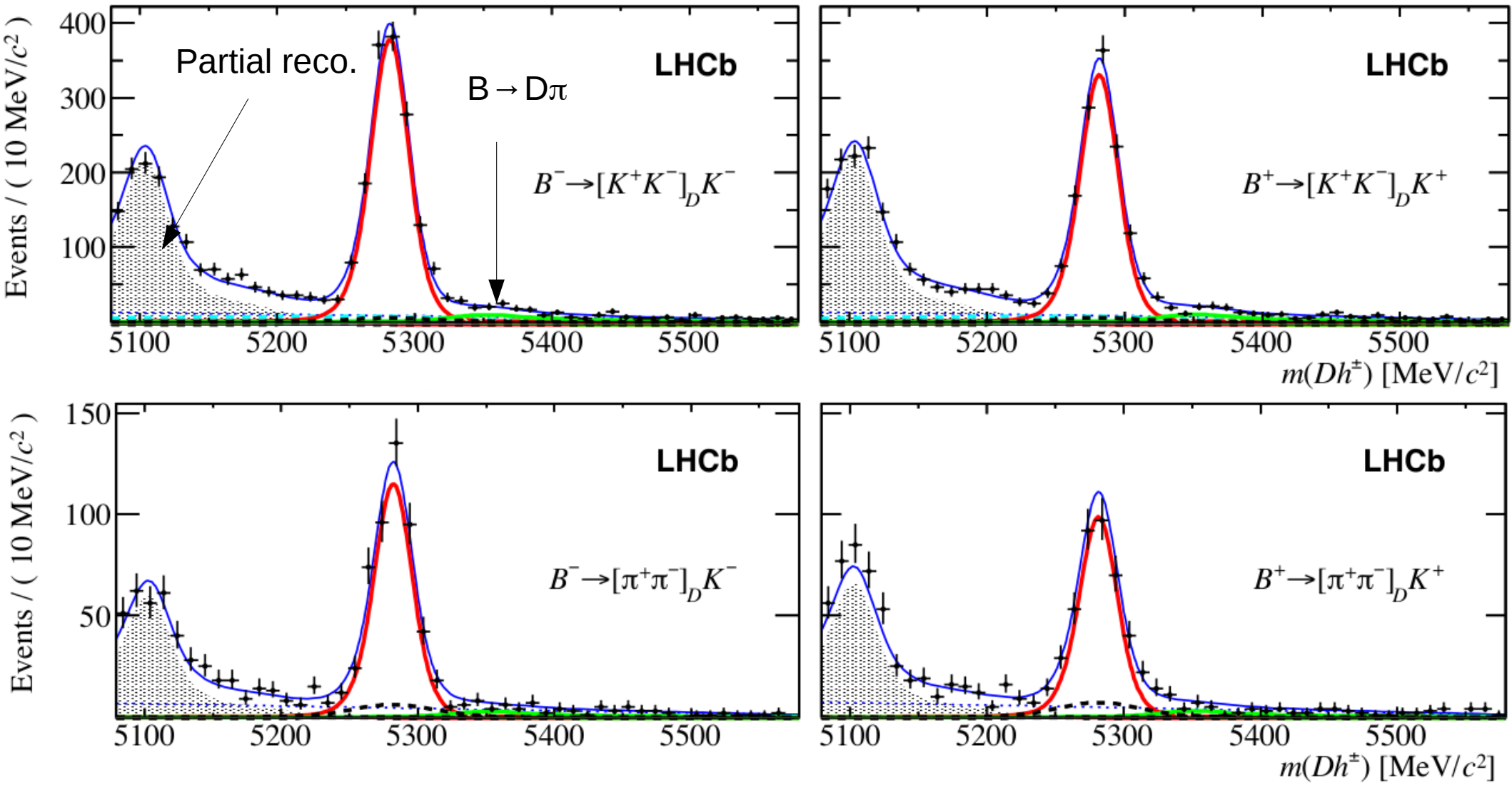
- Several methods permit to exhibit the interference in $B \to DK$



- and in the $B \to DK^*$ modes [LHCb-CONF-2016-014]
  - Analysis based on $4\,fb^{-1}$
    - $1\,fb^{-1}$ collected during the Run 2 (2015-2016)
      - Higher cross-section, improved PID and online selection
        - x3 signal rate increase with respect to Run 1

(quasi-) GLW modes

GLW modes: D→KK, D→ ππ

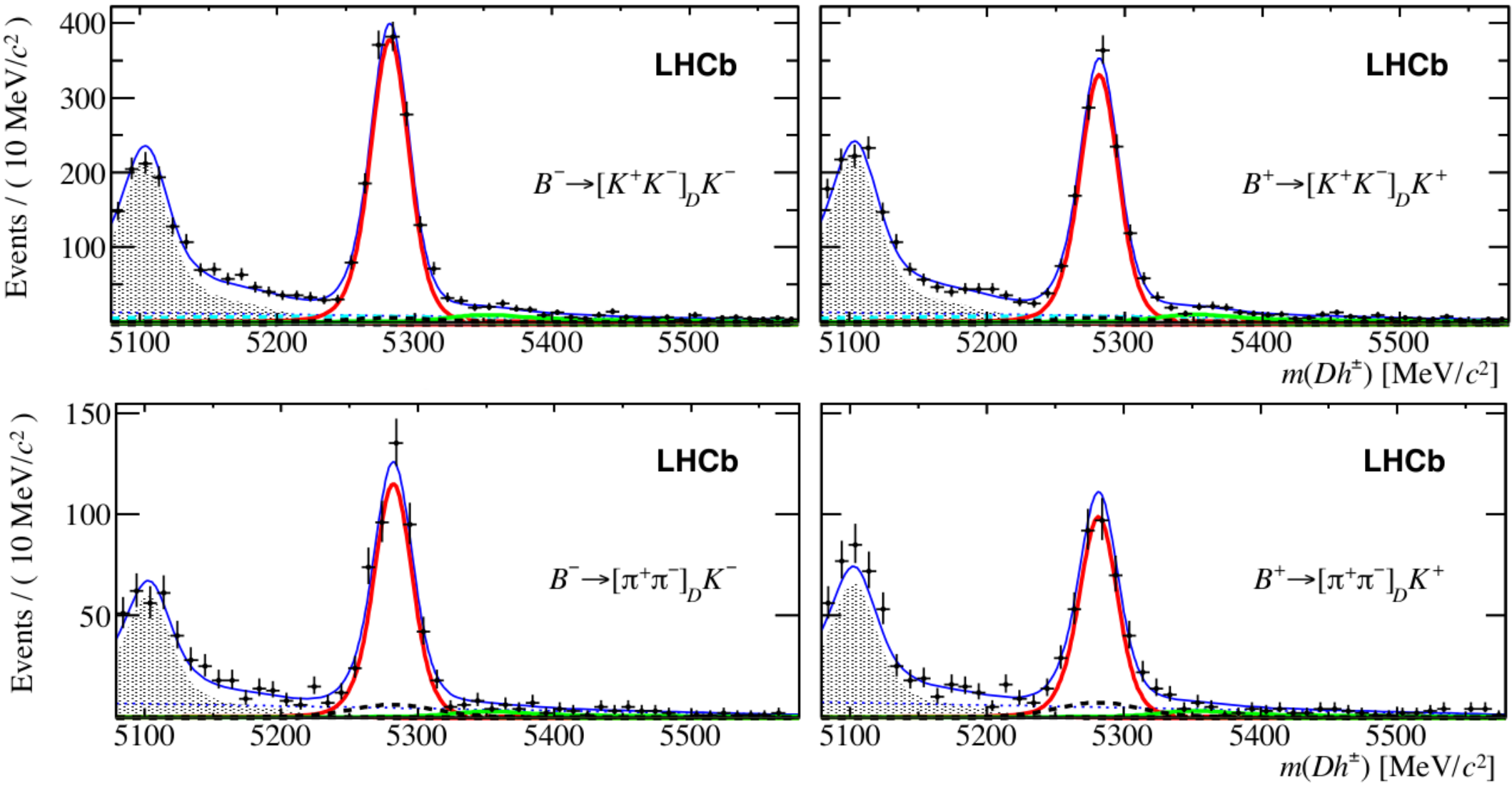


- B meson yields are
  - D→ KK mode: 3816 ± 92 (B^++B^-)
  - D→ ππ mode: 1162 ± 48 (B^++B^-)

[arXiv:1603.08993 (2016)]

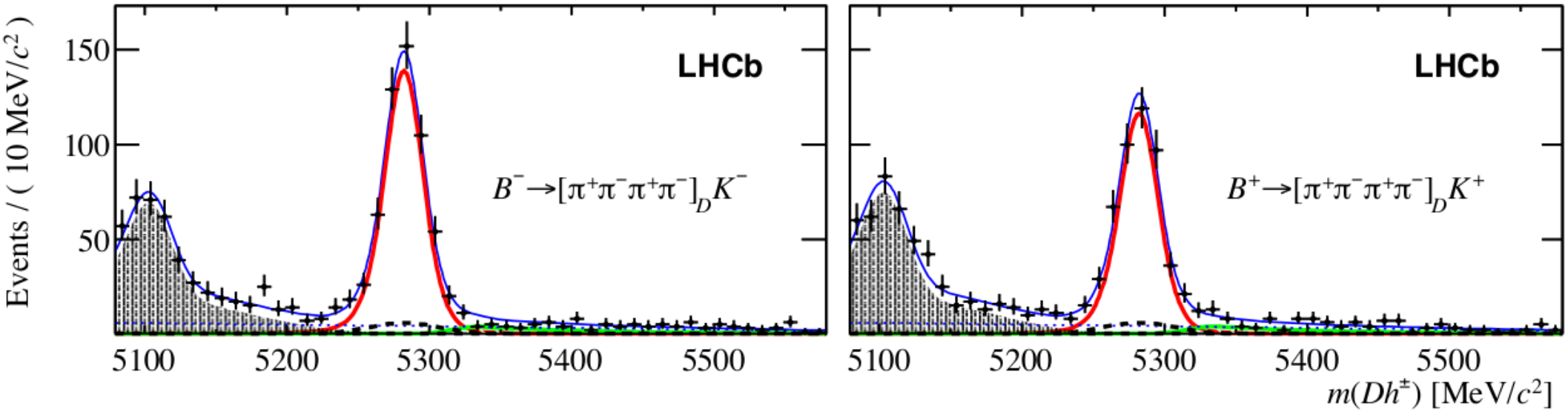
3.0 fb^{-1}

GLW modes: D→KK, D→ ππ



- $A^{KK}_K = 0.87 \pm 0.020 \pm 0.008$ [arXiv:1603.08993 (2016)]
- $A^{\pi\pi}_K = 0.128 \pm 0.037 \pm 0.012$

Quasi-GLW: $D \to \pi\pi\pi\pi$ – First Analysis of this mode



- $A^{\pi\pi\pi\pi}_{K} = 0.100 \pm 0.034 \pm 0.018$
- Compared to the 2-body GLW mode, the interference is diluted by the fractional CP-event content, $(2F_+ - 1) \sim 0.5$ [arXiv:1504.05878]

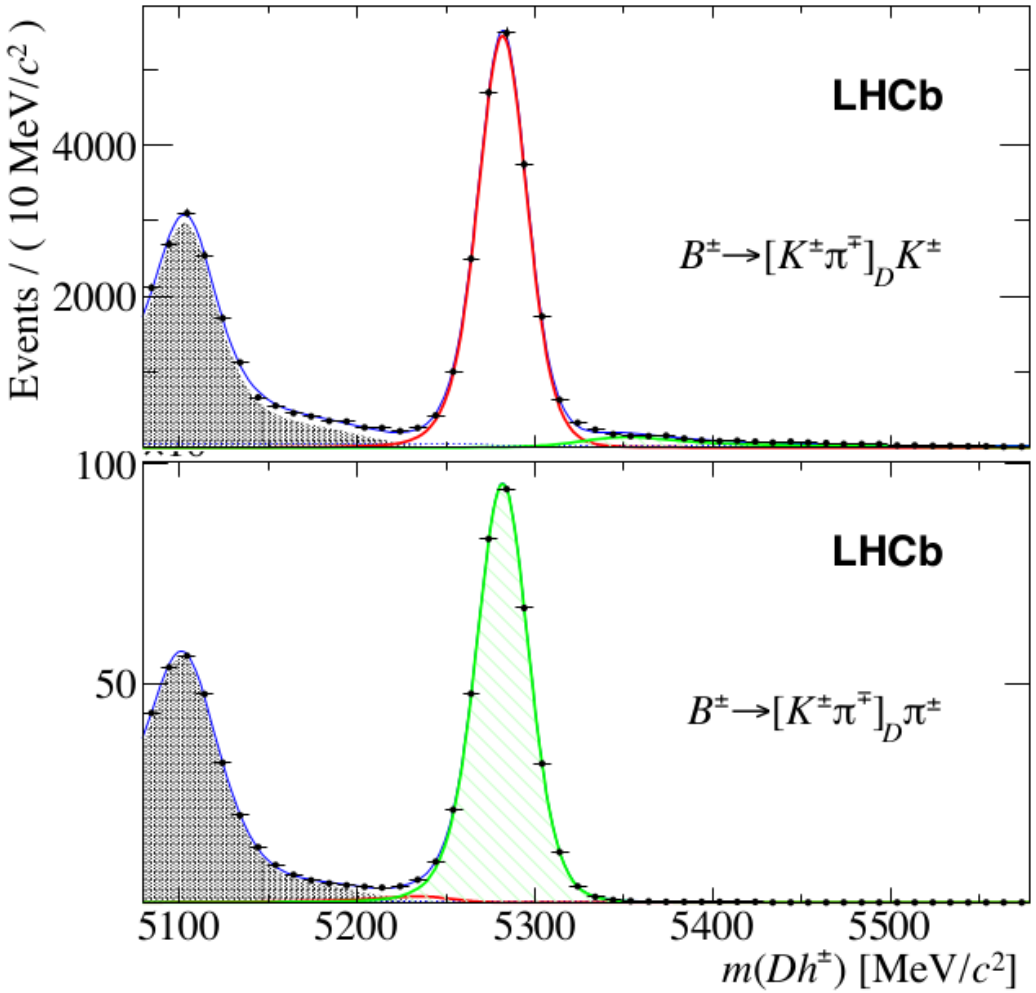
[arXiv:1603.08993 (2016)]

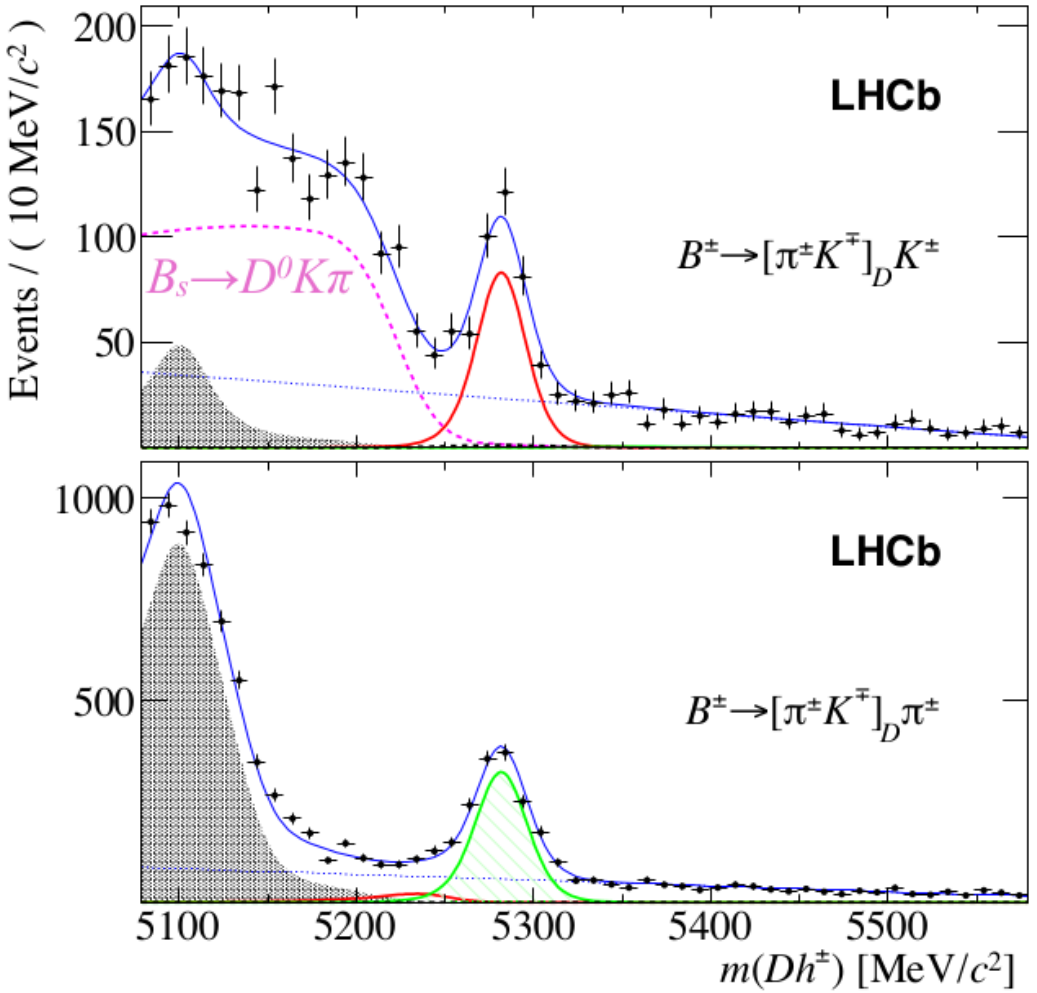
(quasi-) ADS modes

ADS 2-body

- 29500 $B^{\pm} \to DK^{\pm}$, $D \to K^{+}\pi^{-}$
- 550 $B^{\pm} \to DK^{\pm}$, $D \to \pi^{+}K^{-}$

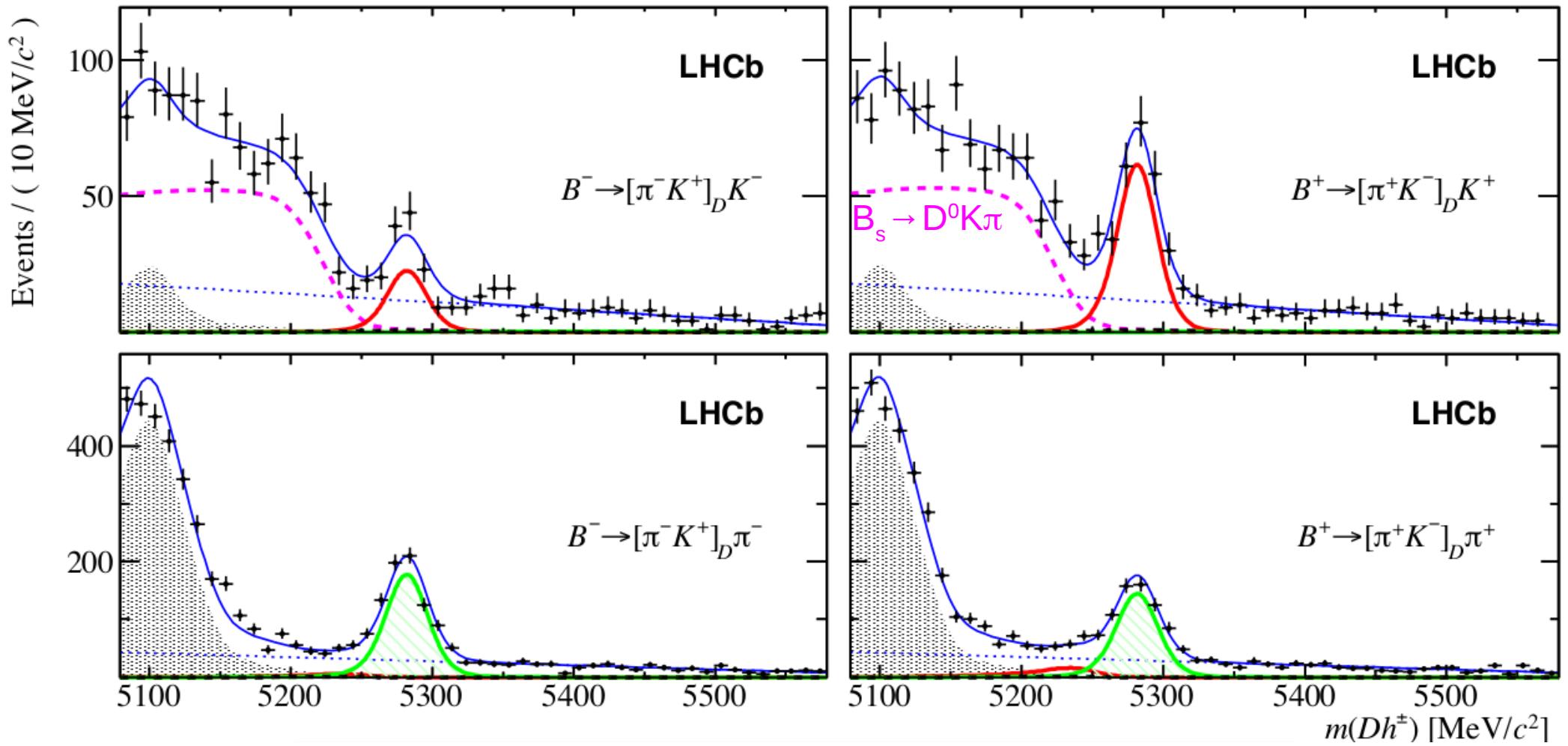
Seen by LHCb only





[arXiv:1603.08993 (2016)]

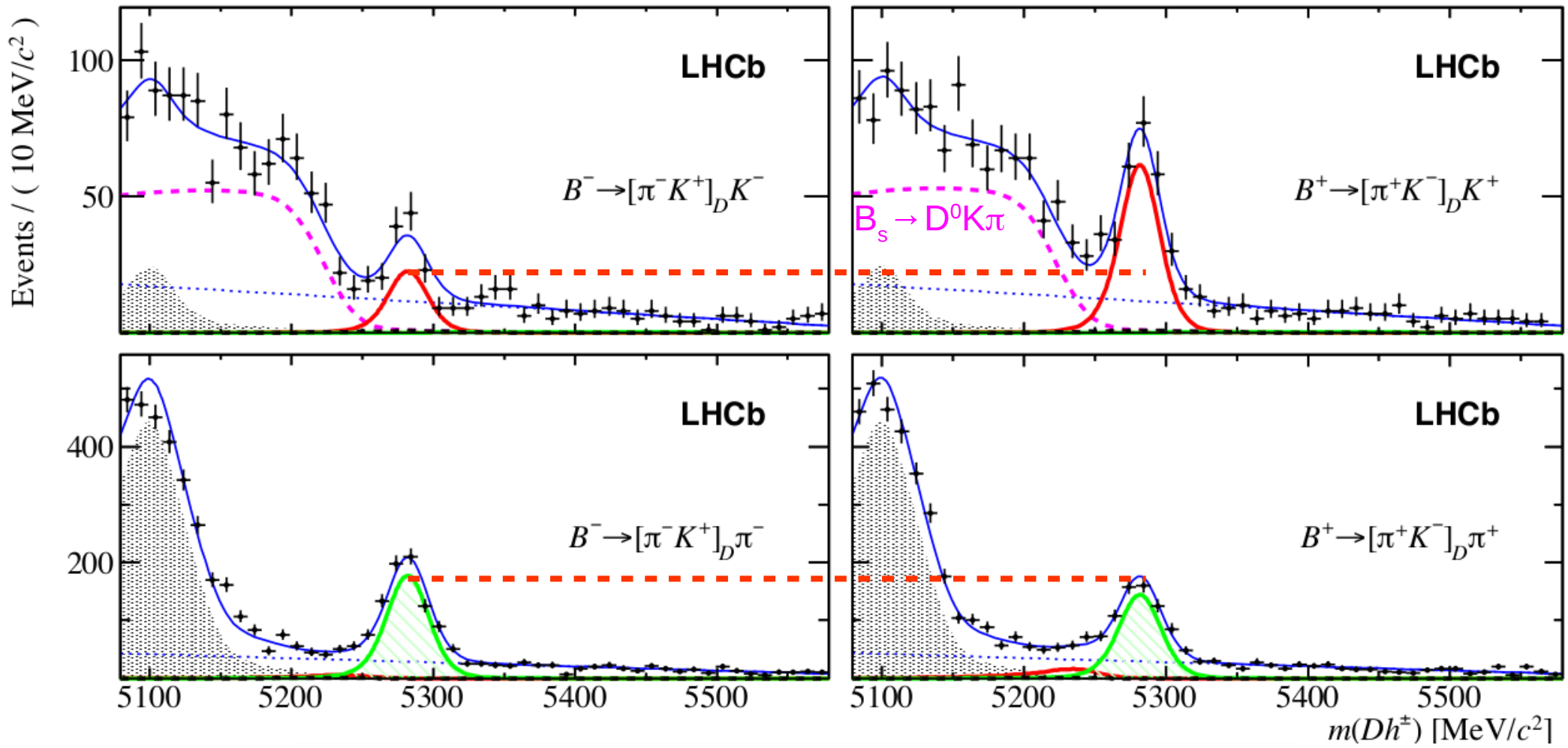
ADS 2-body



- $A^{\pi K}_{ADS(K)} = -0.403 \pm 0.056 \pm 0.011$

[arXiv:1603.08993 (2016)]

ADS 2-body



First observation of CPV in a single B→Dh mode : 8σ

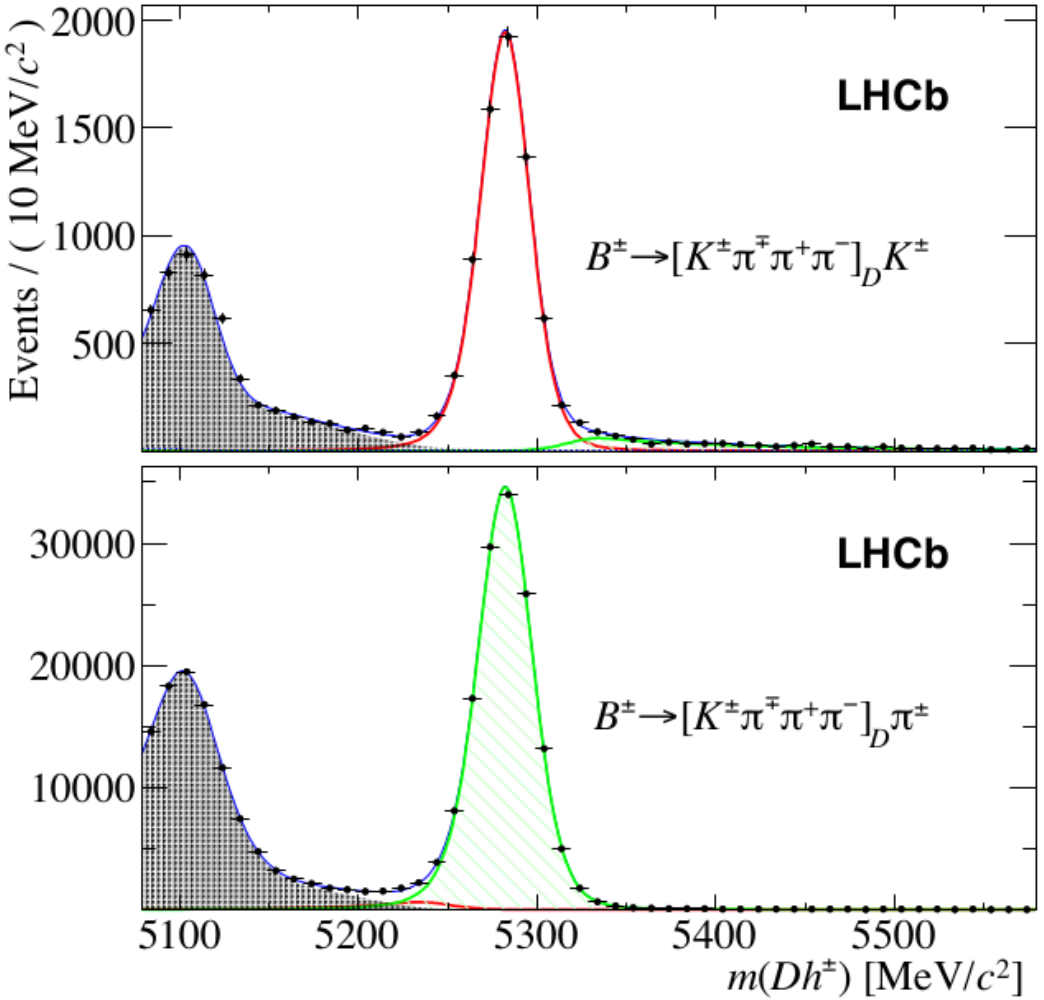
$$A^{\pi K}_{ADS(K)} = -0.403 \pm 0.056 \pm 0.011$$

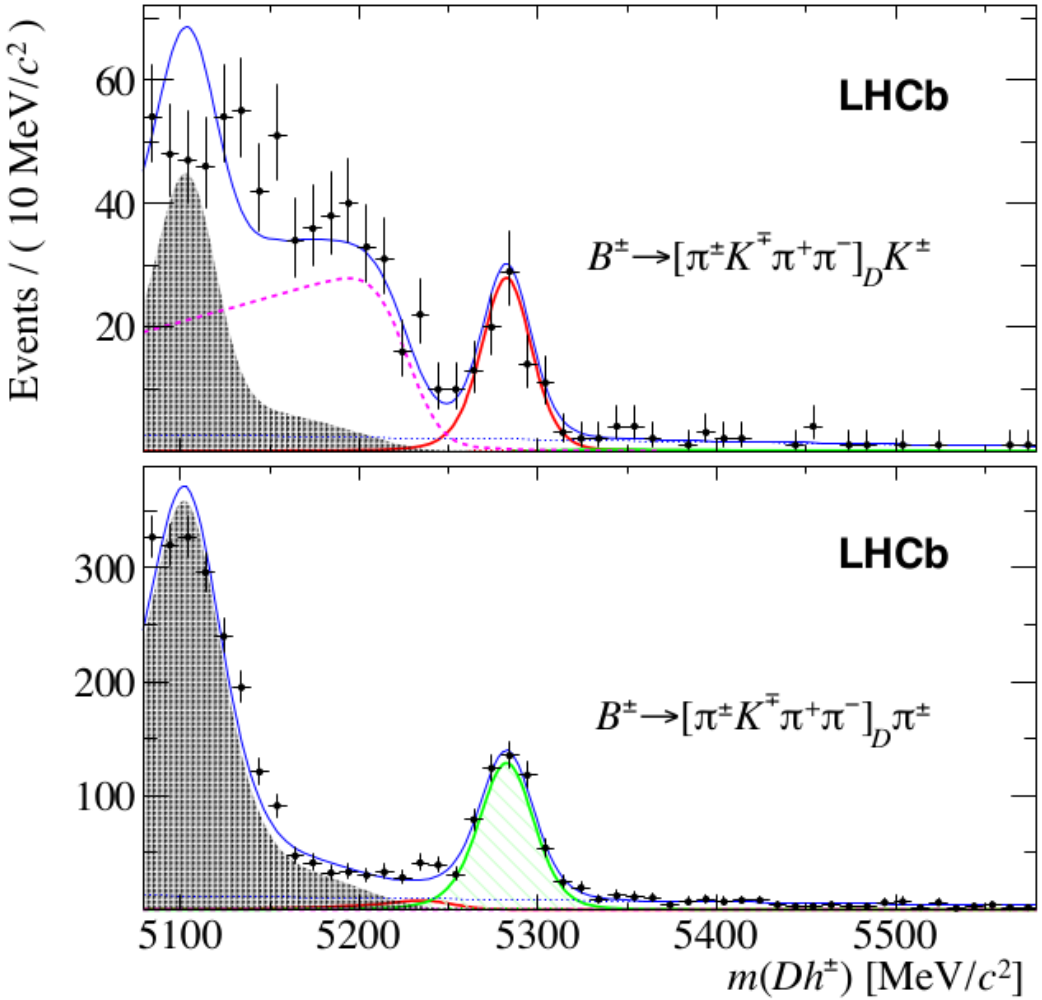
CPV in a rare decay: BR~10^{-7}

[arXiv:1603.08993 (2016)]

Quasi-ADS: $D \to \pi K \pi\pi$

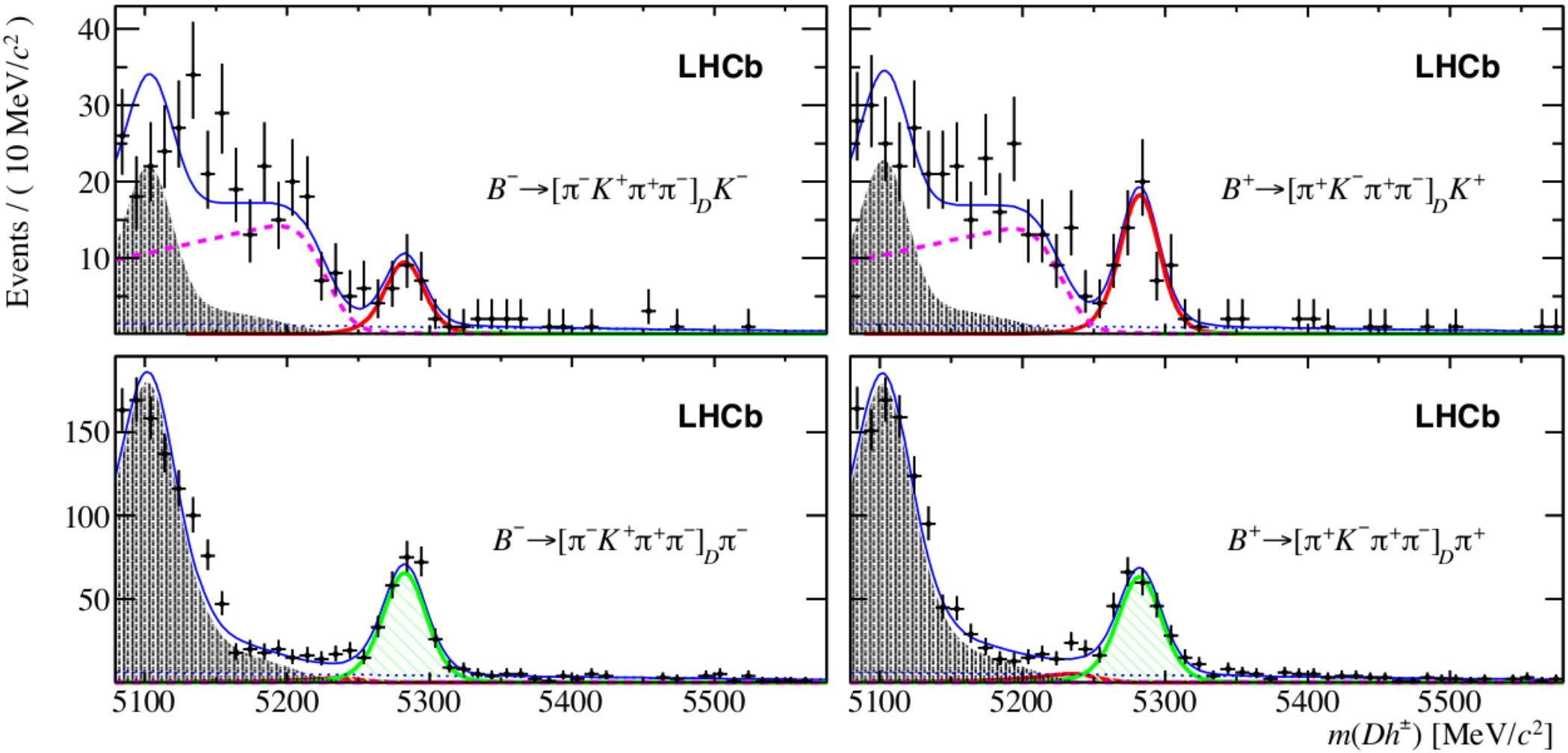
- 11300 $B^{\pm} \to DK^{\pm}$, $D \to K^{+}\pi^{-}\pi^{+}\pi^{-}$
- 160 $B^{\pm} \to DK^{\pm}$, $D \to \pi^{+}K^{-}\pi^{+}\pi^{-}$





[arXiv:1603.08993 (2016)]

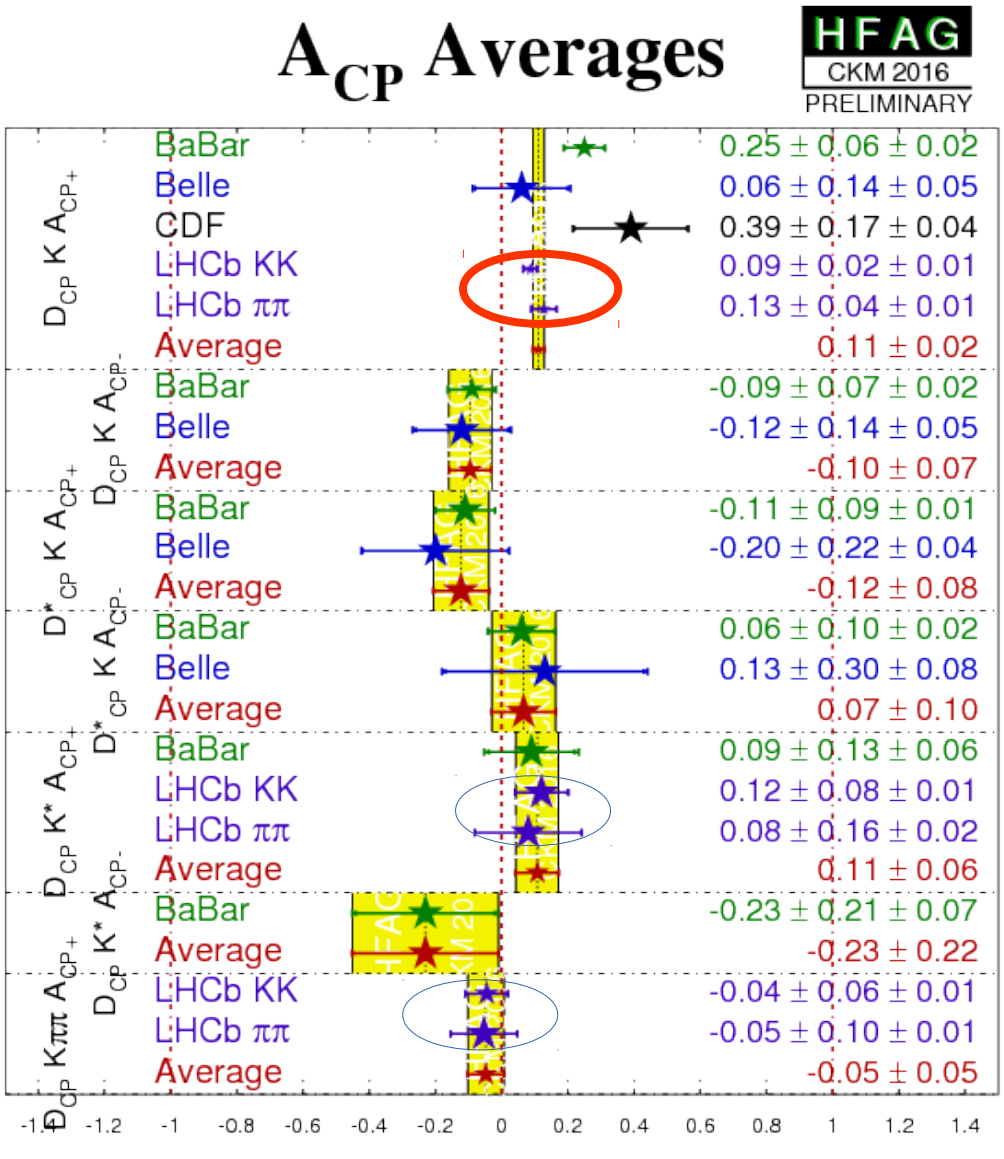
Quasi-ADS: D→ πKππ

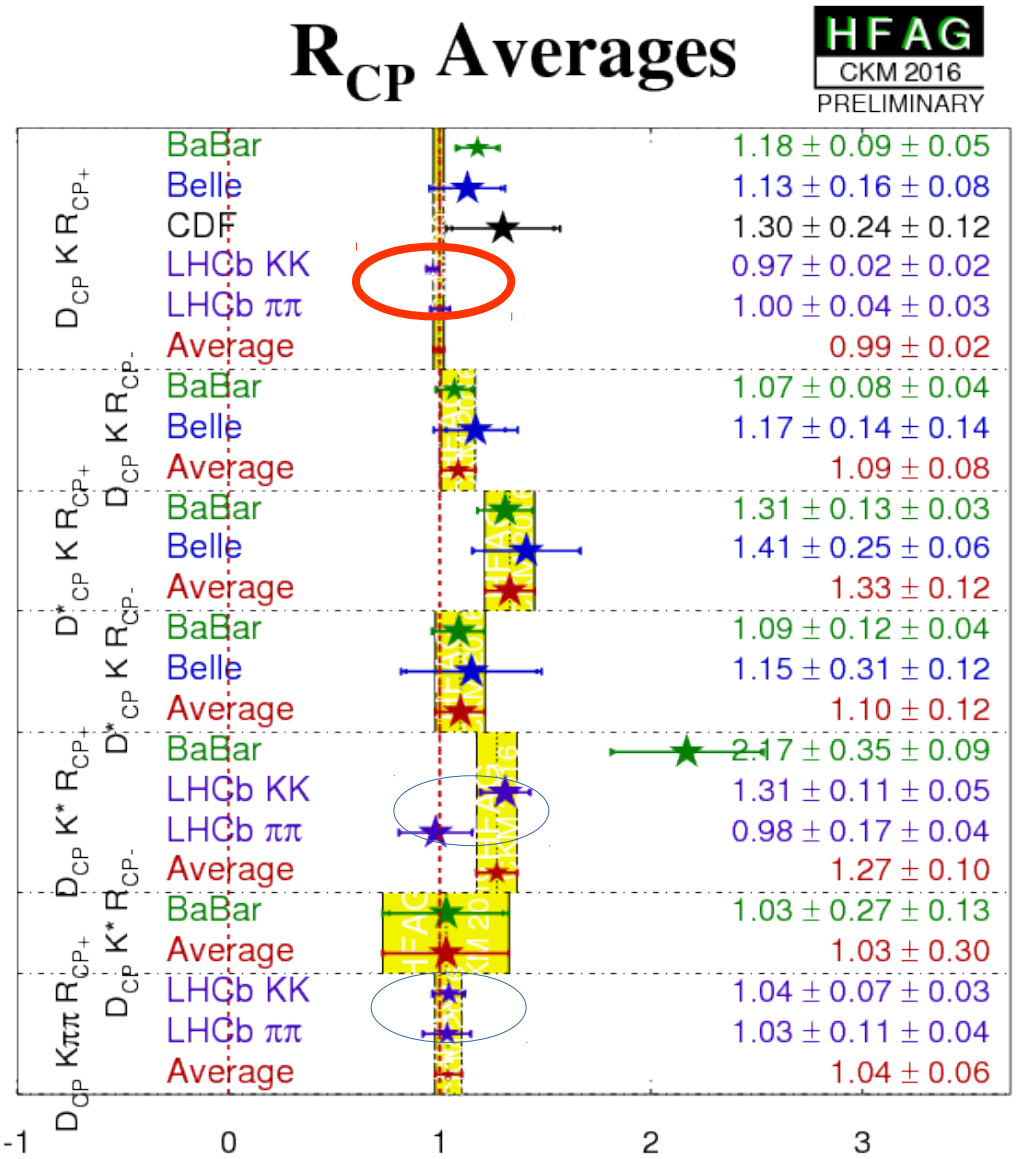


- $A^{\pi K\pi\pi}_{ADS(K)} = -0.313 \pm 0.102 \pm 0.038$
- A negative asymmetry is expected (same sign as for the 2-body ADS mode) from the value of δ_D [arXiv:1602.07430] ($A^{\pi K}_{ADS(K)} = -0.403 \pm 0.056 \pm 0.011$) [arXiv:1603.08993 (2016)]

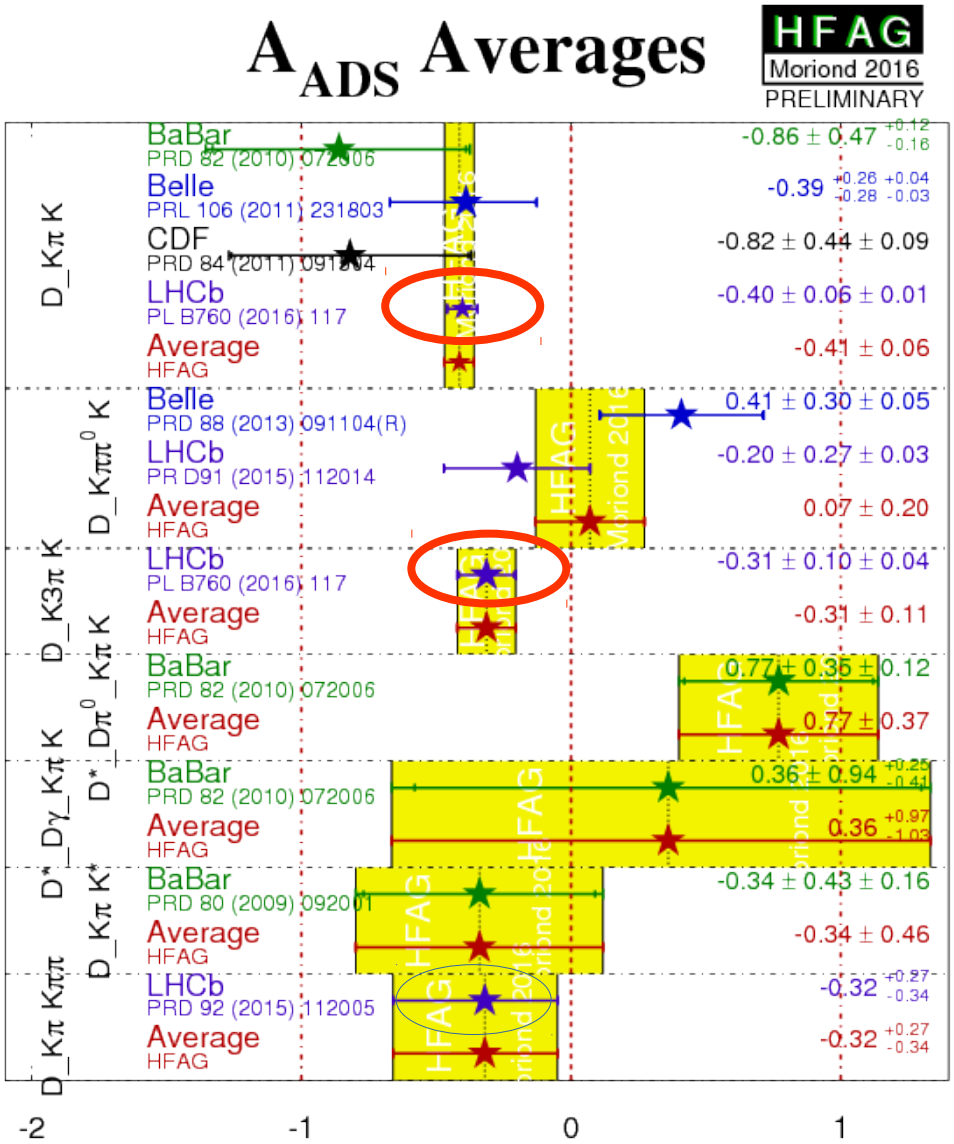
Summary $B^{\pm} \to Dh^{\pm}$, (quasi-)GLW/ADS modes Combination of the modes

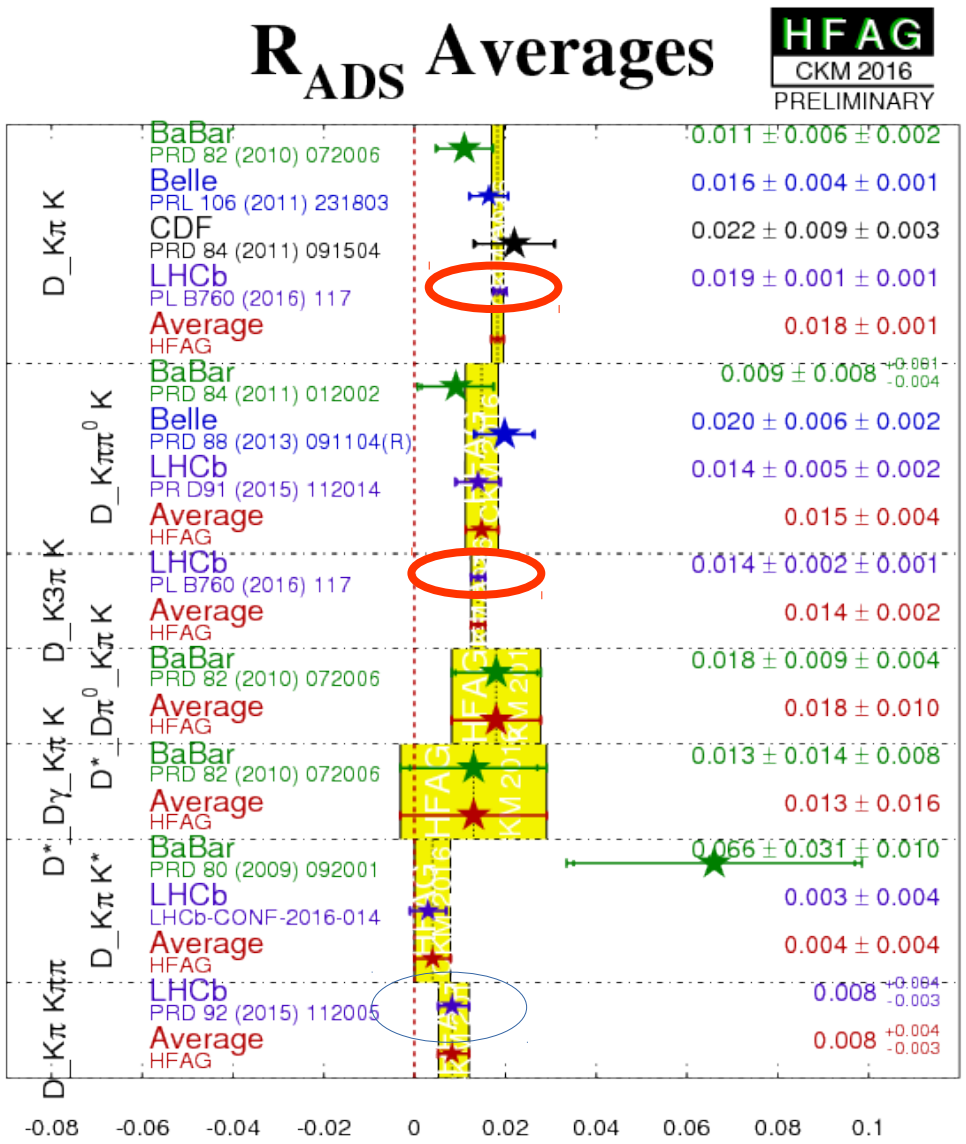
Summary of the B± → DK± modes: GLW





Summary of the $B^{\pm} \to DK^{\pm}$ modes: ADS





$B^{\pm} \to DK^{*\pm}$ mode

What is measured ?

[LHCb-CONF-2016-014]

- The method uses the same interference as before in a new B final state $B^{\pm} \to DK^{*\pm}$
  - CP-eigenstates of the D decay, "GLW" type: $D \to KK$, $D \to \pi\pi$
  - Combinations of fav./sup. B/D decays, "ADS" type: $D \to K\pi$
- The physical observables are

$$A_{K\pi} = \frac{\Gamma(B^- \to D(K^-\pi^+)K^{*-}) - \Gamma(B^+ \to D(K^+\pi^-)K^{*+})}{\Gamma(B^- \to D(K^-\pi^+)K^{*-}) + \Gamma(B^+ \to D(K^+\pi^-)K^{*+})}$$

~no interference, should be ~0

$$A_{KK} = \frac{\Gamma(B^- \to D(KK)K^{*-}) - \Gamma(B^+ \to D(KK)K^{*+})}{\Gamma(B^- \to D(KK)K^{*-}) + \Gamma(B^+ \to D(KK)K^{*+})}$$

… and the other "GLW" related $A_{\pi\pi}$

$$R_{KK} = \frac{\Gamma(B^- \to D(KK)K^{*-}) + \Gamma(B^+ \to D(KK)K^{*+})}{\Gamma(B^- \to D(K^-\pi^+)K^{*-}) + \Gamma(B^+ \to D(K^+\pi^-)K^{*+})} \times \frac{BR(D^0 \to K^-\pi^+)}{BR(D^0 \to KK)}$$

… and similarly $R_{\pi\pi}$

$$R^+ = \frac{\Gamma(B^+ \to D(K^-\pi^+)K^{*+})}{\Gamma(B^+ \to D(K^+\pi^-)K^{*+})}$$

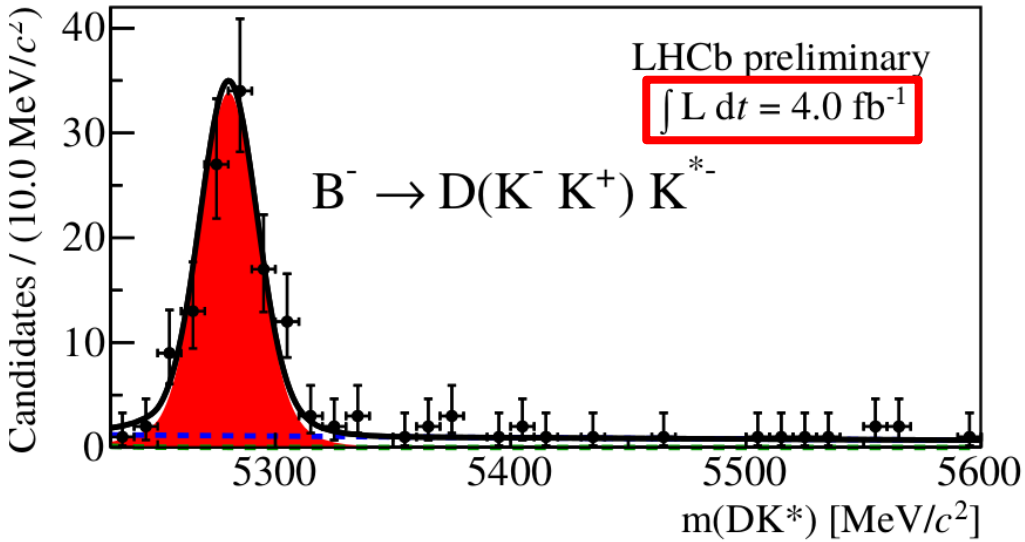
… and the other "ADS" related ratio R^-

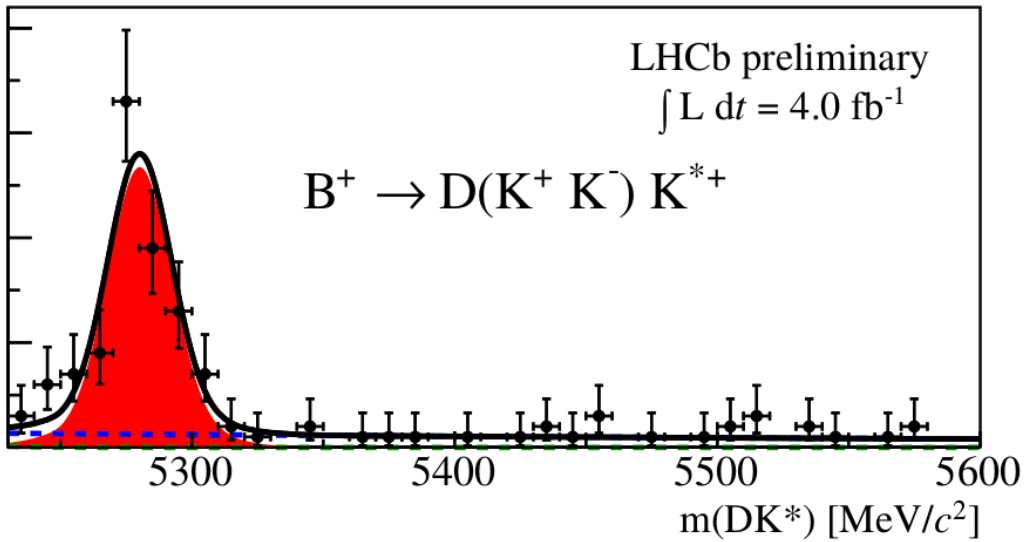
…that depend on r_B, δ_B, κ and γ

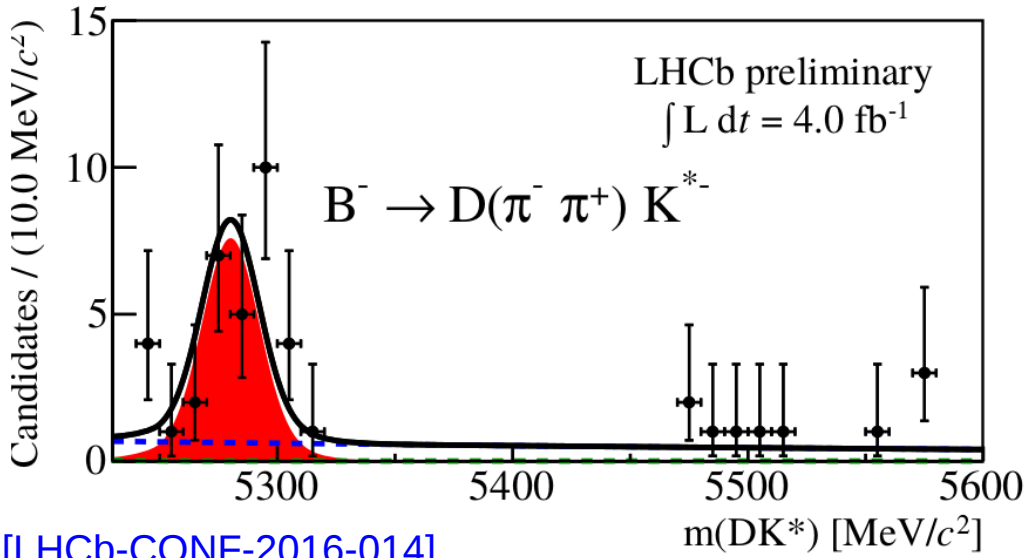
κ accounts for non-resonant DK(892)* bkg and is extracted from amplitude models

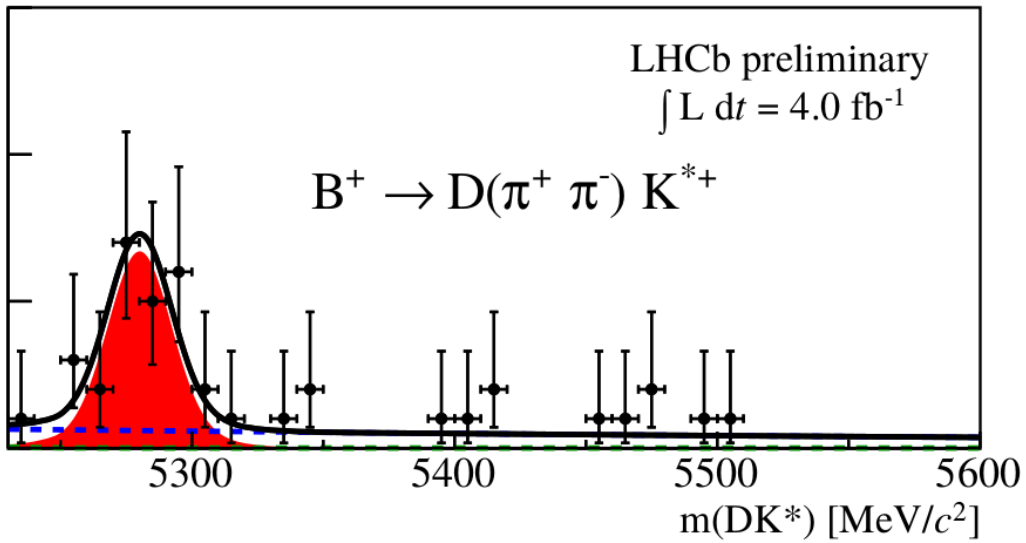
Different from the previous ones

CP-eigenstate modes





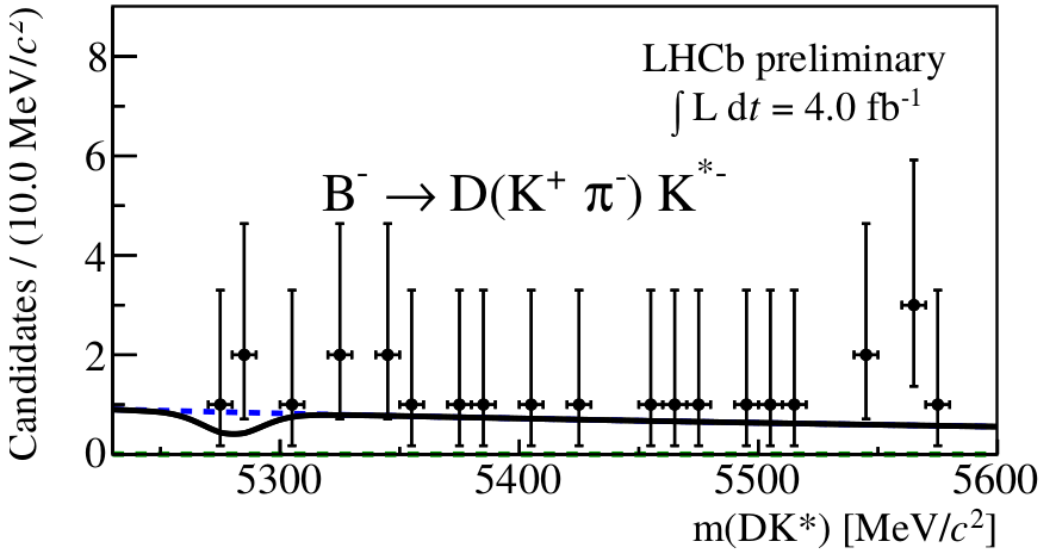


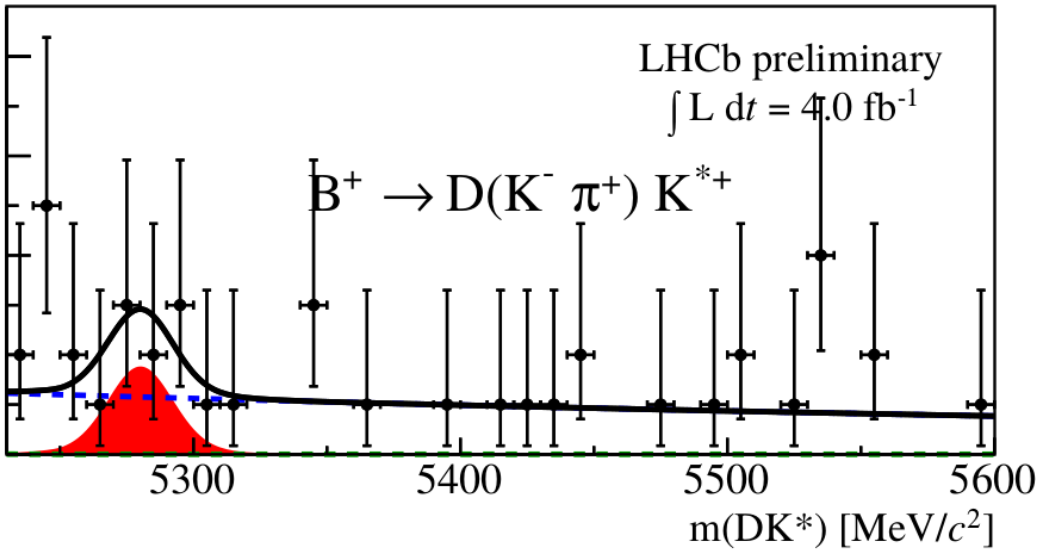


[LHCb-CONF-2016-014]

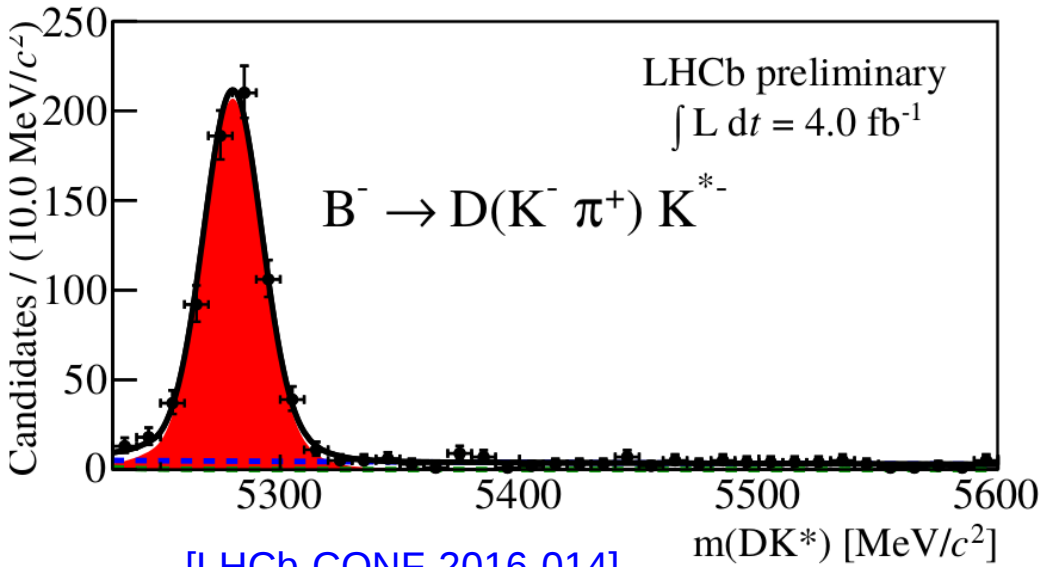
- $A_{KK} = 0.12 \pm 0.08 \pm 0.01$
- $A_{\pi\pi} = 0.08 \pm 0.16 \pm 0.02$
- $R_{KK} = 1.31 \pm 0.11 \pm 0.05$
- $R_{\pi\pi} = 0.98 \pm 0.17 \pm 0.04$

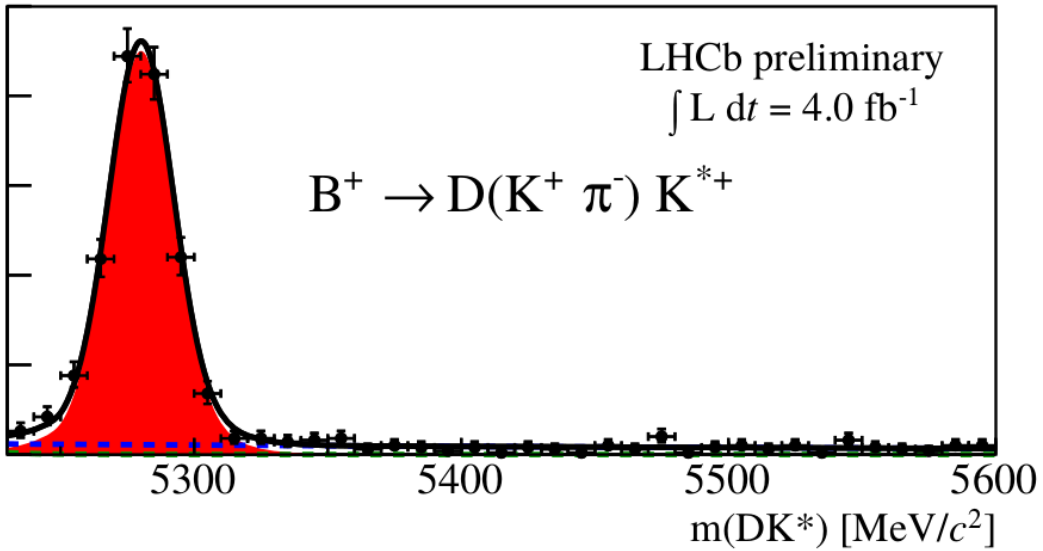
ADS modes





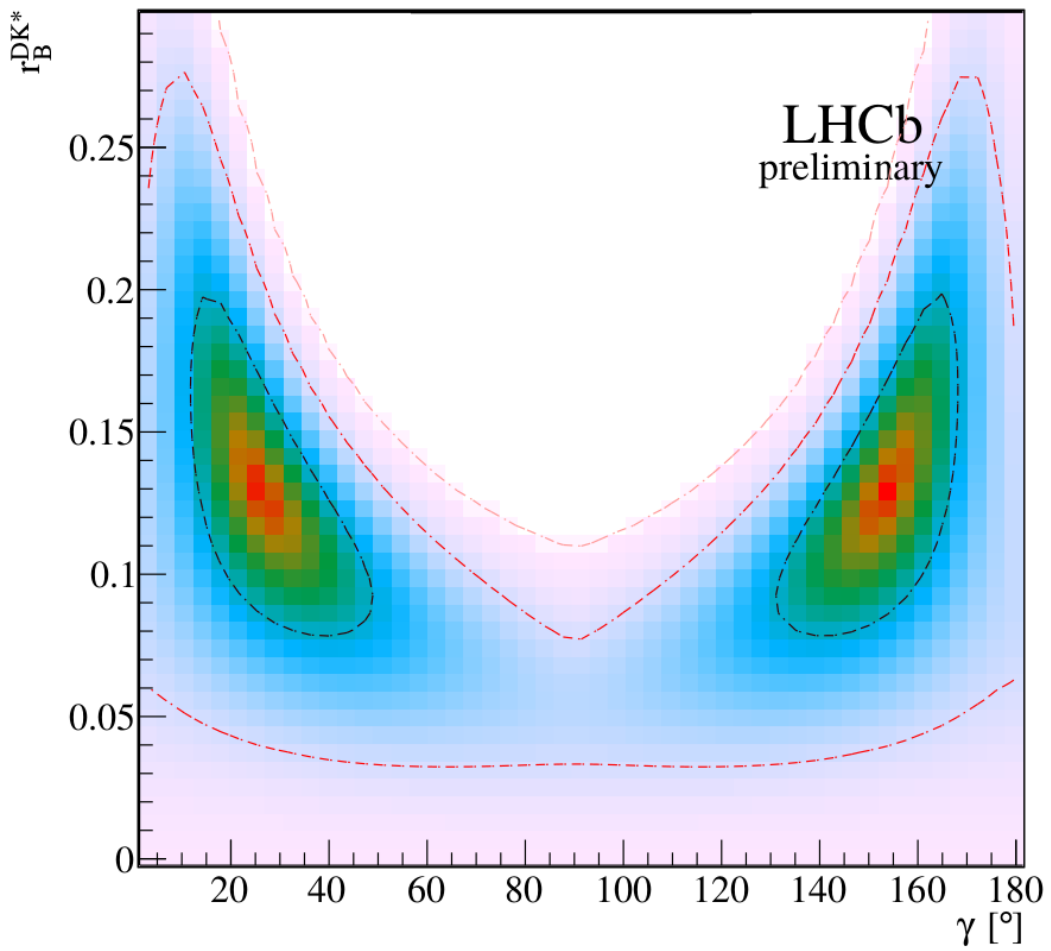
- $R^+ = 0.009 \pm 0.007 \pm 0.002$
- $R^- = -0.003 \pm 0.004 \pm 0.002$

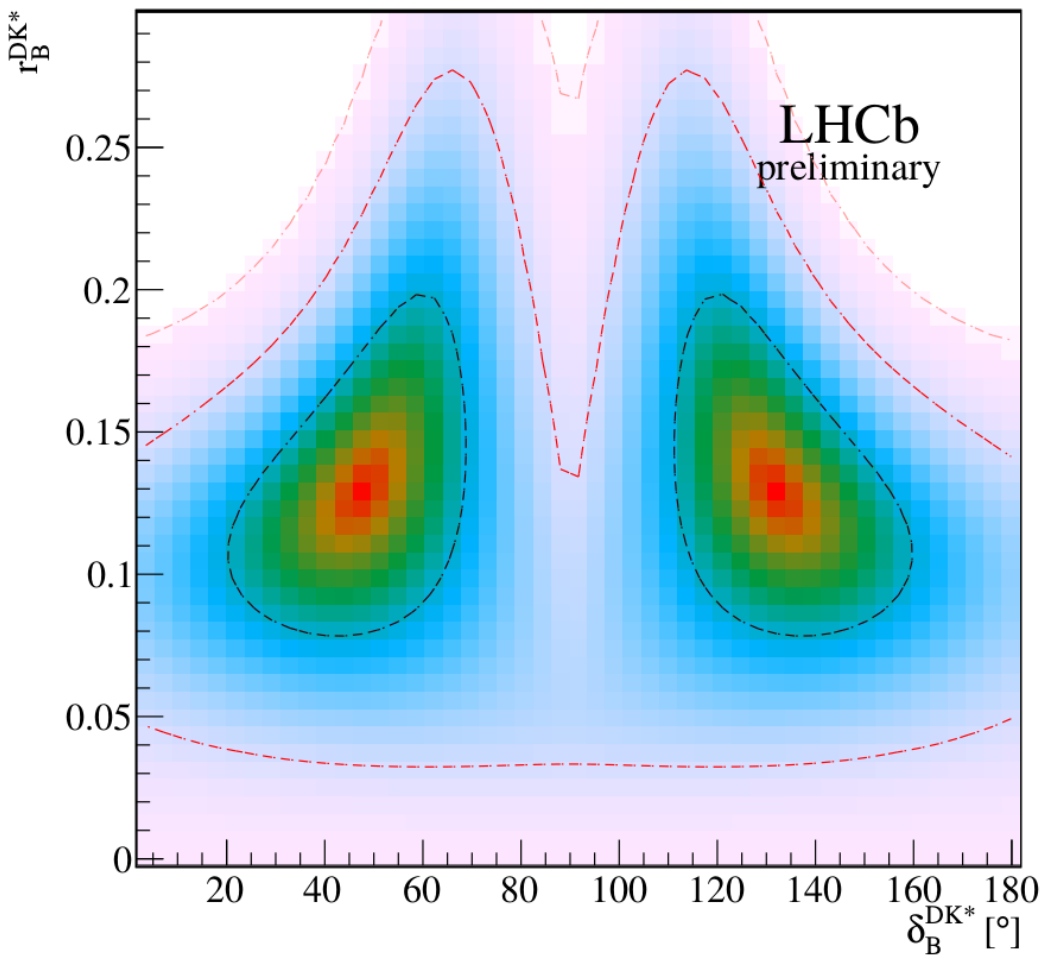




[LHCb-CONF-2016-014]

Interpretation in terms of γ





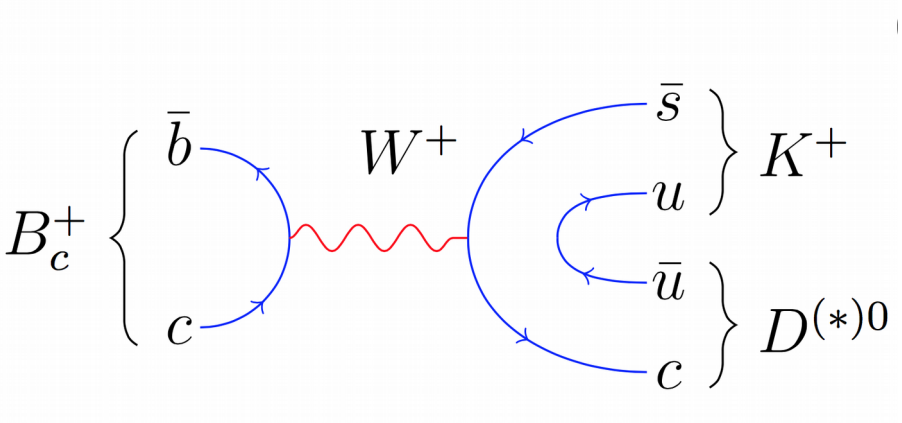
- The data sample is not large enough to exclude large regions of the parameter space, but the result is consistent with $\gamma \sim 70°$

[LHCb-CONF-2016-014]

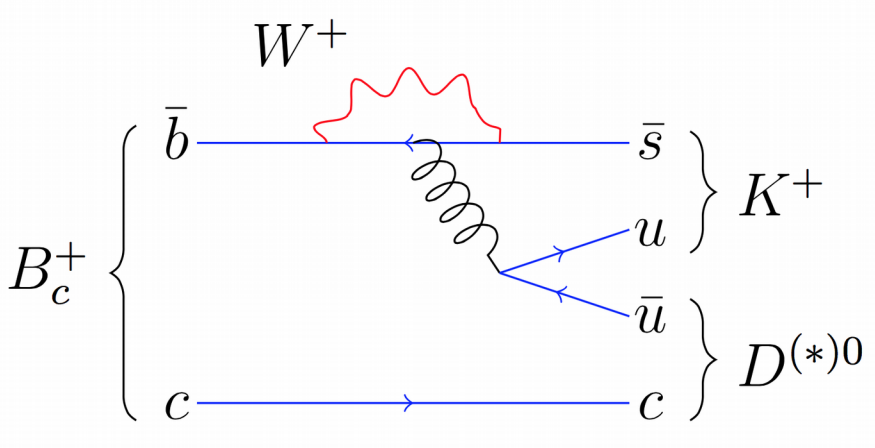
$B_c^+ \to D^0 K^+$ mode

Extends ADS-mode to higher m(D^0h^+) NEW!

- $B_c^+ \to D^0h^+$ decays probe processes that are as-yet unobserved with B_c mesons:



Annihilation



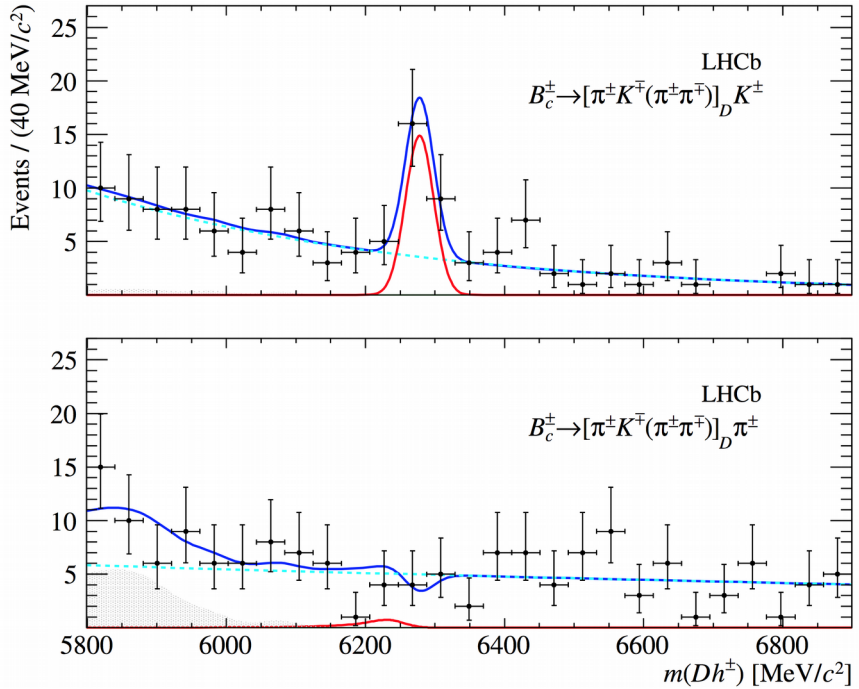
Penguin

- Extend the ADS-mode reconstruction to higher m(D^0h^+) invariant mass, using both $D^0 \to K^+\pi^-$ and $D^0 \to K^+\pi^-\pi^+\pi^-$ final states.
- Signal yields are normalized to the favoured $B_u^- \to D^0h^-$ mode to quote a branching fraction multiplied by the production ratio:

$$r_{B_c}^{D^{(*)}h} = \frac{f_c}{f_u} \times BR\left(B_c^+ \to D^{(*)0} h^+\right)$$

Results

- Signal observed in D^0K^+ with 5.1σ significance. Nothing in $D^0\pi^+$



$$r_{B_c}^{DK} = \left(9.3^{+2.8}_{-2.5} \pm 0.6\right) \times 10^{-7}$$

$$r_{B_c}^{D\pi} < 3.9 \times 10^{-7} \quad \text{at} \quad 95\%\,\text{CL}$$

- f_c/f_u is approx. ~1/200, this implies a branching fraction ~2×10^{-4}
  - Predictions are a factor ~3 smaller: 6.7×10^{-5} https://arxiv.org/abs/0905.0945v1
    4.8×10^{-5} Eur. Phys. J. C 5 (1998) 705

- f_c/f_u cancels when compared to equivalent $B_c \to J/\psi\pi$ result

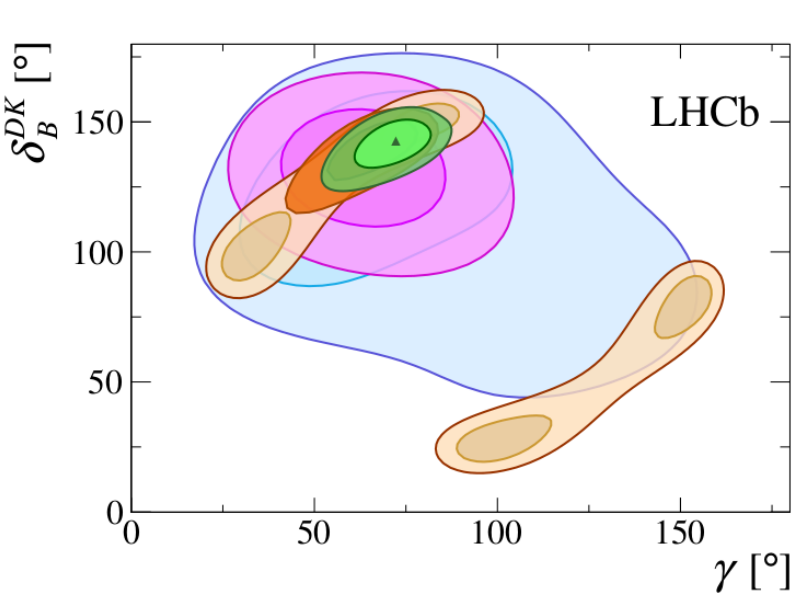
$$\frac{BR\left(B_c^+ \to D^0 K^+\right)}{BR\left(B_c^+ \to J/\psi\,\pi^+\right)} = 0.13 \pm 0.04 \pm 0.01 \pm 0.01$$

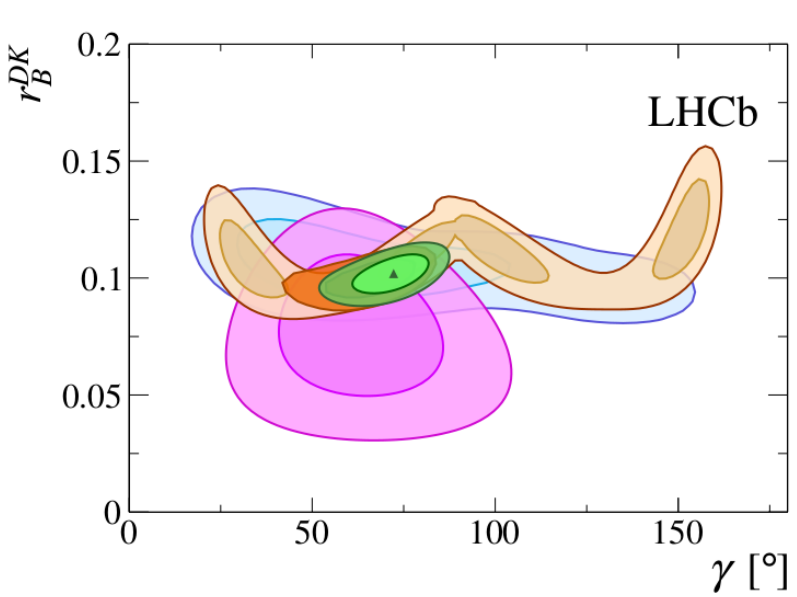
https://arxiv.org/abs/1411.2943

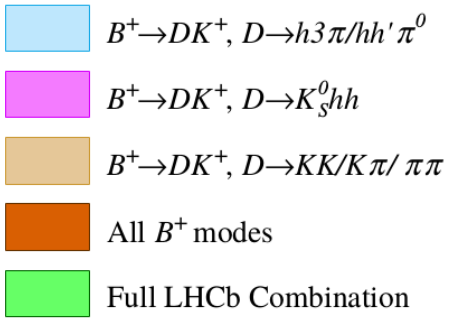
Conclusion

Conclusion

- The most precise γ measurement from a single experiment





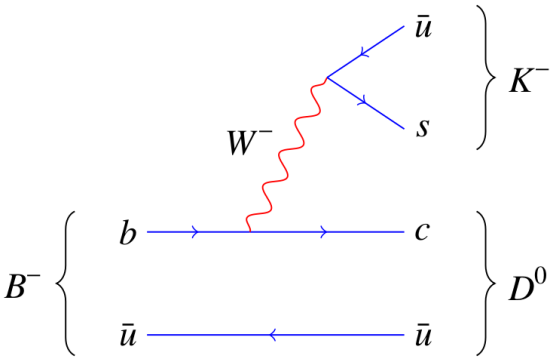


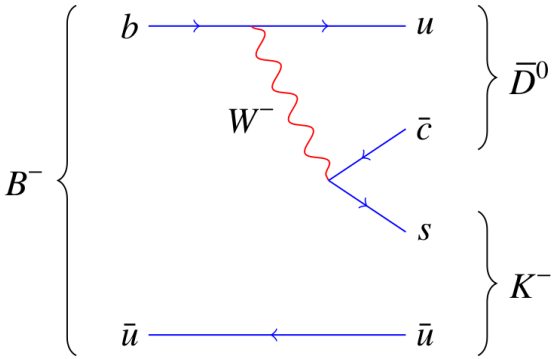
$$\gamma = \left(72.2^{+6.8}_{-7.3}\right)^\circ$$

[arXiv:1611.03076]

- Latest B→DK measurements published include new modes
- B→DK* measurement done with 4fb^{-1}
  - not included in combination yet
- Continuing to expand the B and subsequent D modes analysed e.g.
  - B→D*K ADS/GLW/GGSZ analyses
    - B$^\pm$→D*K$^\pm$, D*→Dγ/π^0
      - D→KK/$\pi\pi$/Kπ/K$_s^0\pi^+\pi^-$ / K$_s^0$K$^+$K$^-$

Backup





$$\frac{A\left(B^- \to \overline{D^0} K^-\right)}{A\left(B^- \to D^0 K^-\right)} = r_B e^{i(\delta_B - \gamma)}$$

- The main hadronic parameters are the amplitude ratio r_B and the CP -conserving phase γ
- Several methods permit to exhibit the interference

GLW: D → K^+K^-, $\pi^+\pi^-$, $K_s\pi^0$

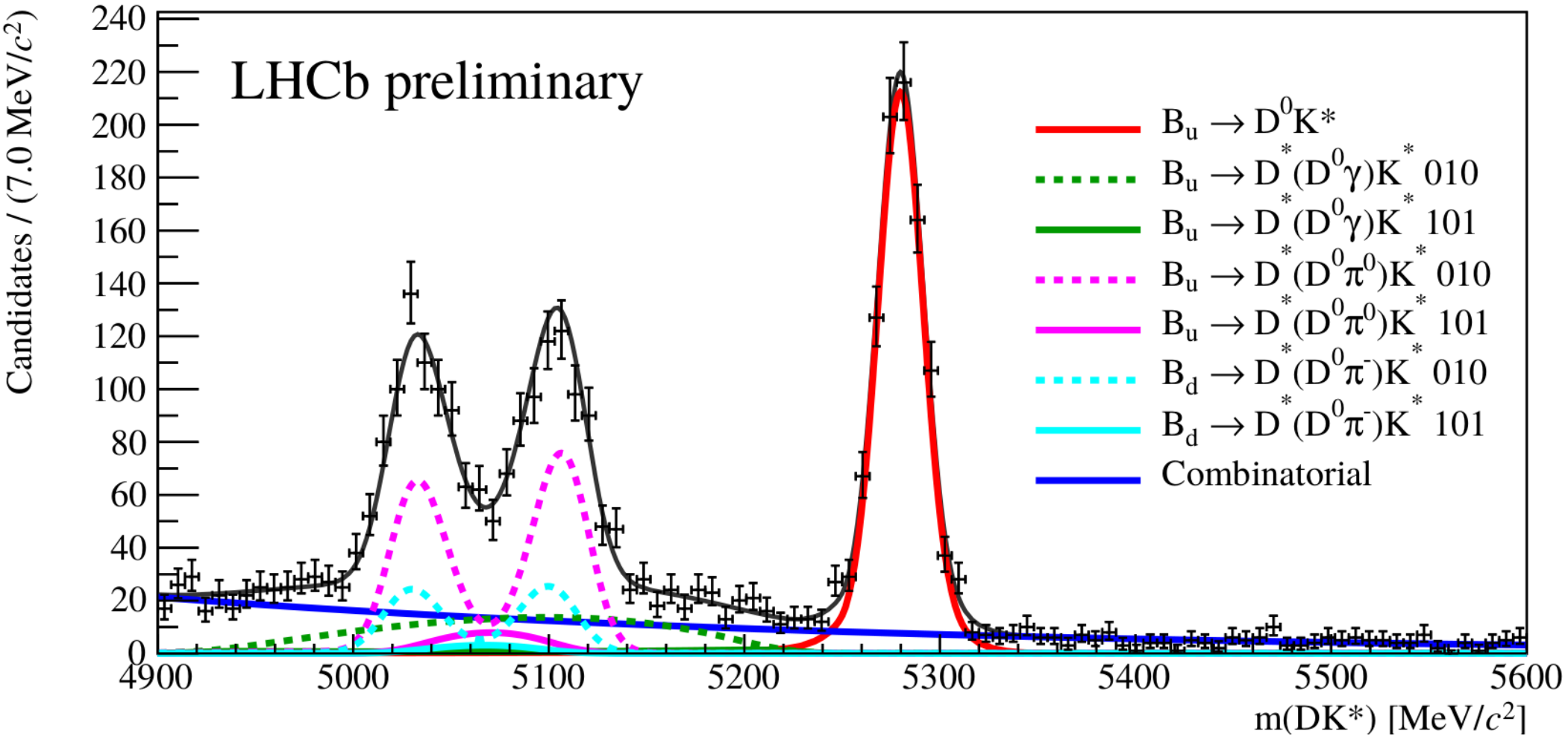
ADS: D → π^-K^+

Quasi-ADS: D → $\pi^-K^+\pi^+\pi^-$, $\pi^-K^+\pi^0$

GGSZ: D → $K_s\pi^+\pi^-$, $K_sK^+K^-$

Quasi-GLW: D → $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^0$, $\pi^+\pi^-\pi^0$

GLS: D → $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^0$, $\pi^+\pi^-\pi^0$

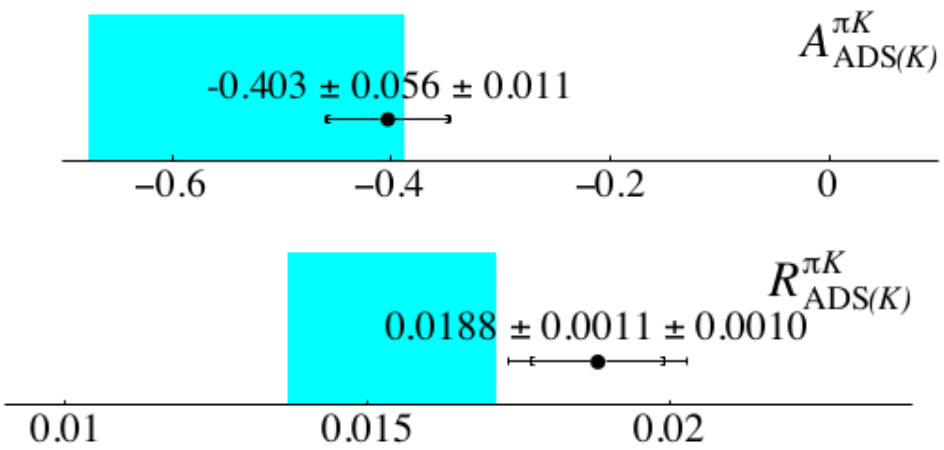

LHCb preliminary
Candidates / (7.0 MeV/c^2)
m(DK*) [MeV/c^2]
$B_u \to D^0 K^*$
$B_u \to D^*(D^0\gamma)K^*$ 010
$B_u \to D^*(D^0\gamma)K^*$ 101
$B_u \to D^*(D^0\pi^0)K^*$ 010
$B_u \to D^*(D^0\pi^0)K^*$ 101
$B_d \to D^*(D^0\pi^-)K^*$ 010
$B_d \to D^*(D^0\pi^-)K^*$ 101
Combinatorial

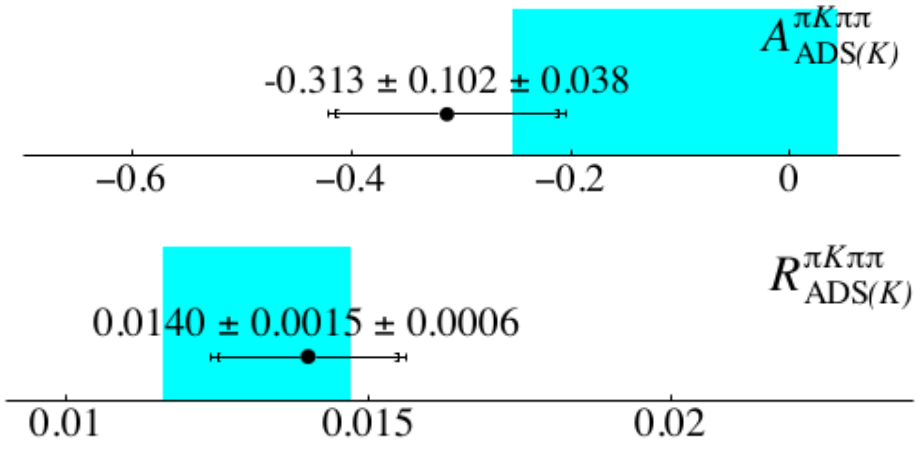
Summary of the $B^{\pm} \to DK^{\pm}$ modes

[arXiv:1603.08993]

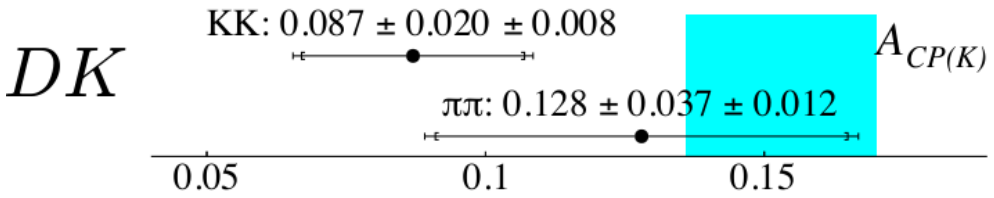
= SM 1σ expectation from knowledge of r_B, δ_B, γ

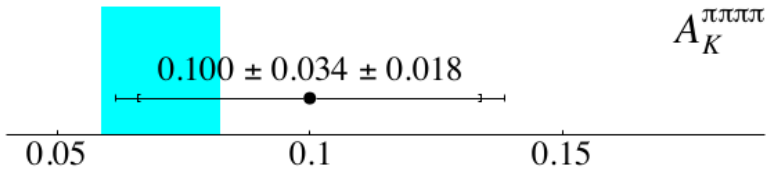
- Significant improvement in knowledge of the ADS observables:





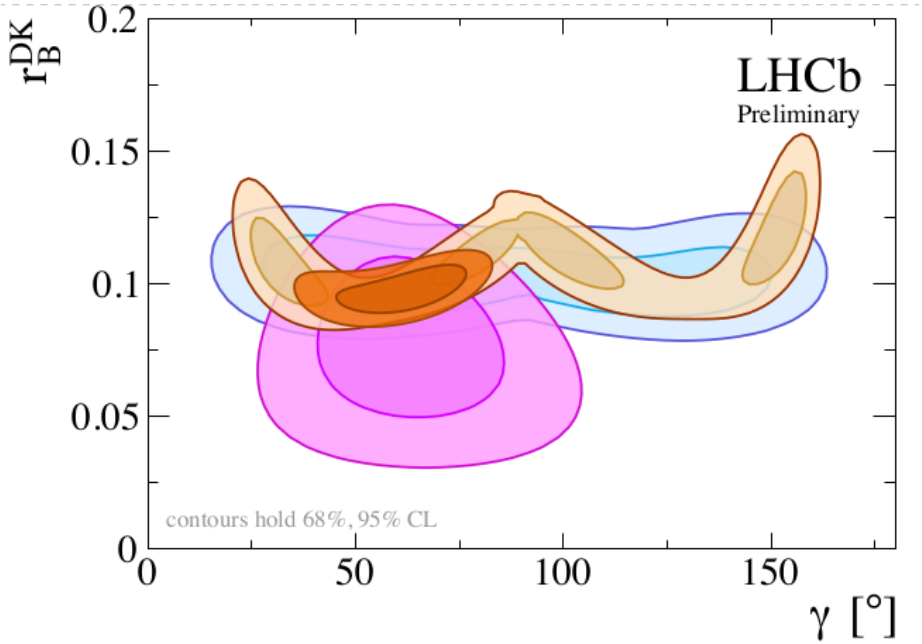
- DK charge asymmetries:

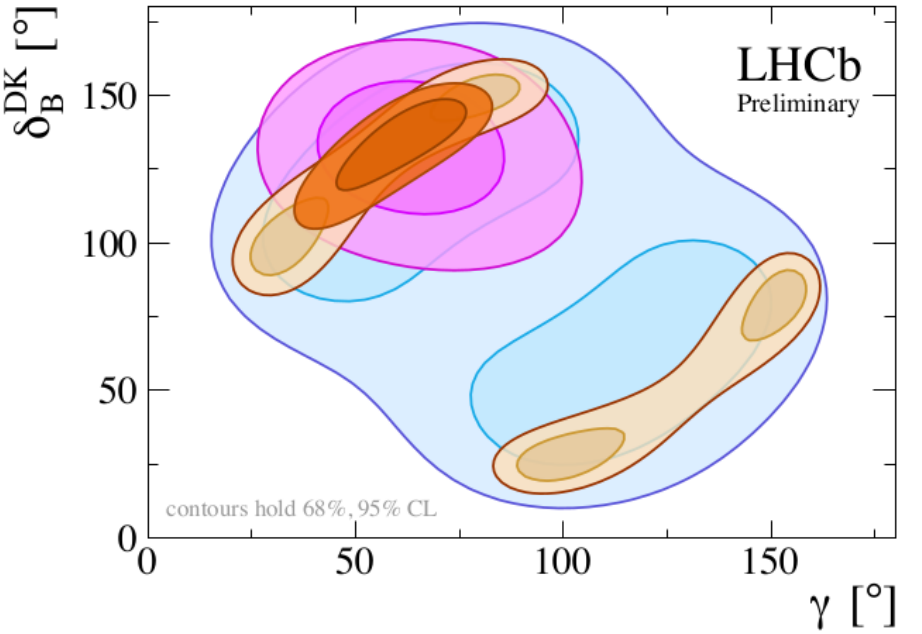




- Result of partial width consistent with expectation
- Dπ mode will provide constraints on upcoming DK+Dπ combination

Combination of the $B^{\pm}$ modes





$B^{\pm}$ combination

- $B^+ \to DK^+$, $D \to h3\pi/hh'\pi^0$
- $B^+ \to DK^+$, $D \to K_S hh$
- $B^+ \to DK^+$, $D \to KK/K\pi/\pi\pi$
- All B^+ modes