Hadronic B decays to open charm and time-independent γ results at LHCb

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on behalf of
The LHCb collaboration

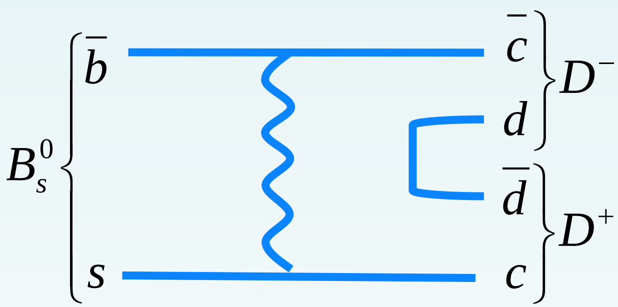
BEAUTY 2013

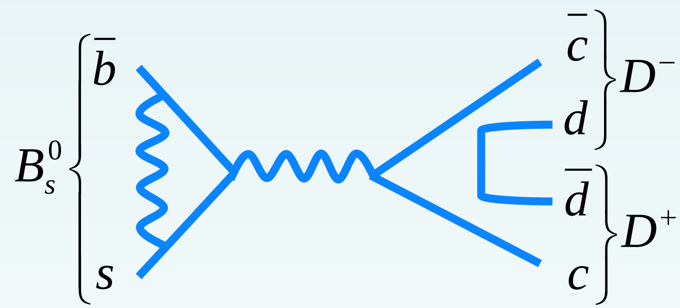
Hadronic B decays to open charm

[LHCb-PAPER-2012-050;
arXiv:1302.5854]

Studies of $B \to D\bar{D}'$ decays

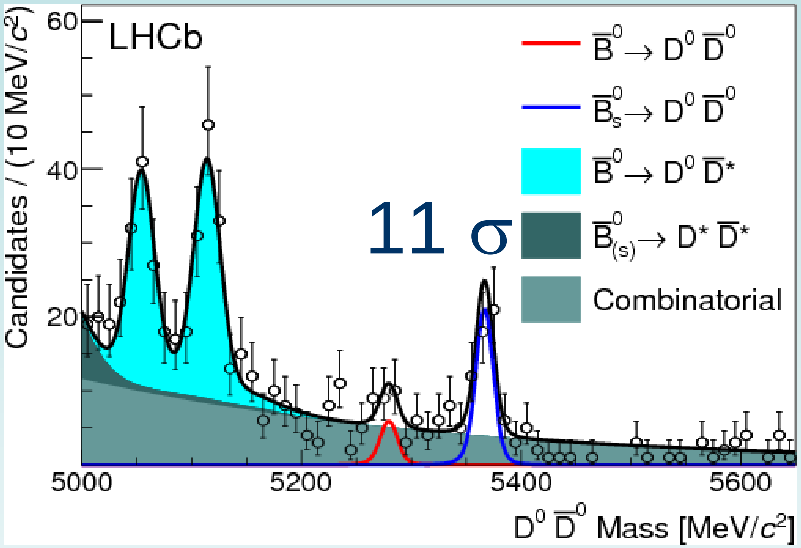
- $\int L dt = 1 fb^{-1}$ at $\sqrt{s} = 7 TeV$
- Can be used in future to measure γ; $B^0 \to D^+ D^-$ to determine B^0 mixing phase; $\bar{B}_s^0 \to D_s^+ D_s^-$ to determine B_s^0 mixing phase and information on $\Delta\Gamma_s$
- $\bar{B}_s^0 \to D^0 \bar{D}^0$, $\bar{B}^0 \to D^0 \bar{D}^0$ and $\bar{B}_s^0 \to D^+ D^-$
  - provide information on different processes expected to contribute to B decays (short-range: weak exchange and penguin annihilation diagrams; long-range: rescattering)



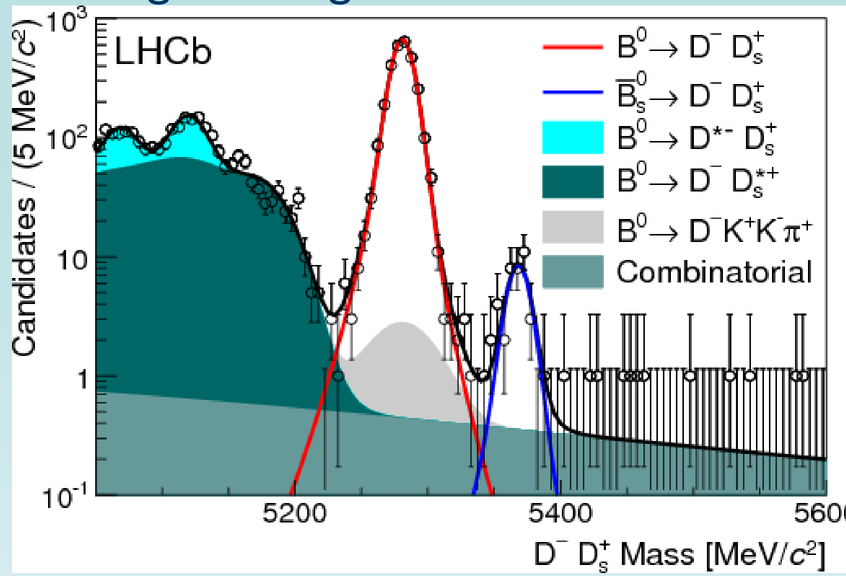


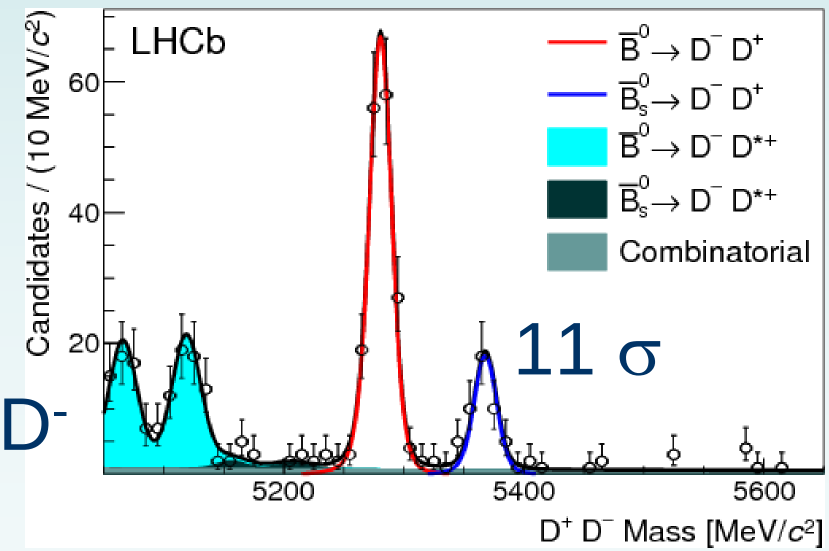
First observations

$\overline{B}_s^0 \to D^0\overline{D}^0$



$\overline{B}_s^0 \to D_s^+D^-$ 10 σ





$\overline{B}_s^0 \to D^+D^-$

[LHCb-PAPER-2012-050; arXiv:1302.5854]

[LHCb-PAPER-2012-050; arXiv:1302.5854]

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^+ D^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D^-)} = 1.08 \pm 0.20(stat.) \pm 0.10(syst.)$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D^-)}{\mathcal{B}(B^0 \to D_s^+ D^-)} = 0.050 \pm 0.008(stat.) \pm 0.004(syst.)$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^0 \overline{D}^0)}{\mathcal{B}(B^- \to D^0 D_s^-)} = 0.019 \pm 0.003(stat.) \pm 0.003(syst.)$$

$$\frac{\mathcal{B}(\overline{B}^0 \to D^0 \overline{D}^0)}{\mathcal{B}(B^- \to D^0 D_s^-)} = 0.0014 \pm 0.0006(stat.) \pm 0.0002(syst.)$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D_s^-)}{\mathcal{B}(B^0 \to D_s^+ D^-)} = 0.56 \pm 0.03(stat.) \pm 0.04(syst.)$$

$$\frac{\mathcal{B}(B^- \to D^0 D_s^-)}{\mathcal{B}(B^0 \to D_s^+ D^-)} = 1.22 \pm 0.02(stat.) \pm 0.07(syst.)$$

World average BFs (PDG) for normalisation modes:

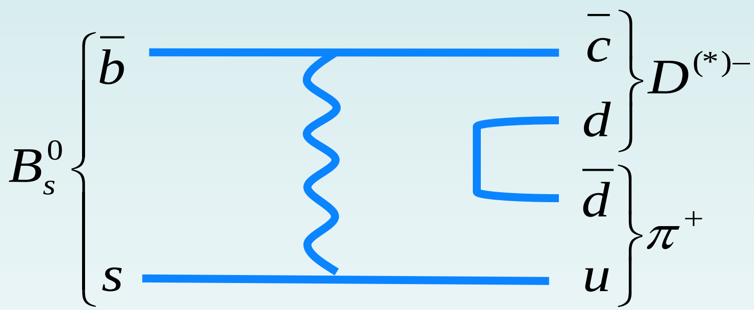
$$\mathcal{B}(B^0 \to D_s^+ D^-) = (7.2 \pm 0.8) \times 10^{-3} \quad \mathcal{B}(B^- \to D^0 D_s^-) = (10.0 \pm 1.7) \times 10^{-3}$$

$$\mathcal{B}(\overline{B}^0 \to D^+ D^-) = (2.11 \pm 0.31) \times 10^{-4}$$

[LHCb-PAPER-2012-056; arXiv:1302.6446]

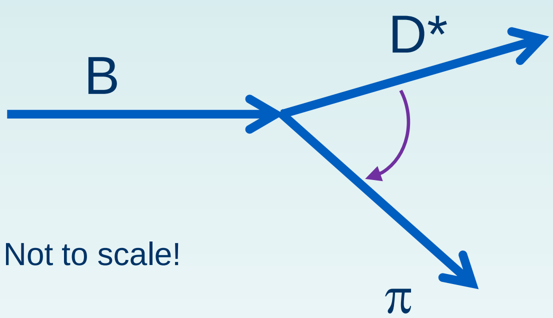
Search for $B_s^0 \rightarrow D^{*-}\pi^+$

- $\int L dt = 1 fb^{-1}$ at $\sqrt{s} = 7 TeV$
- Decay expected to be mediated by weak exchange and to have little rescattering → should aid understanding of the contributions to $B_s^0 \rightarrow D\bar{D}$' and $B_s^0 \rightarrow \pi\pi$ decays [PRD 87 (2013) 036008]



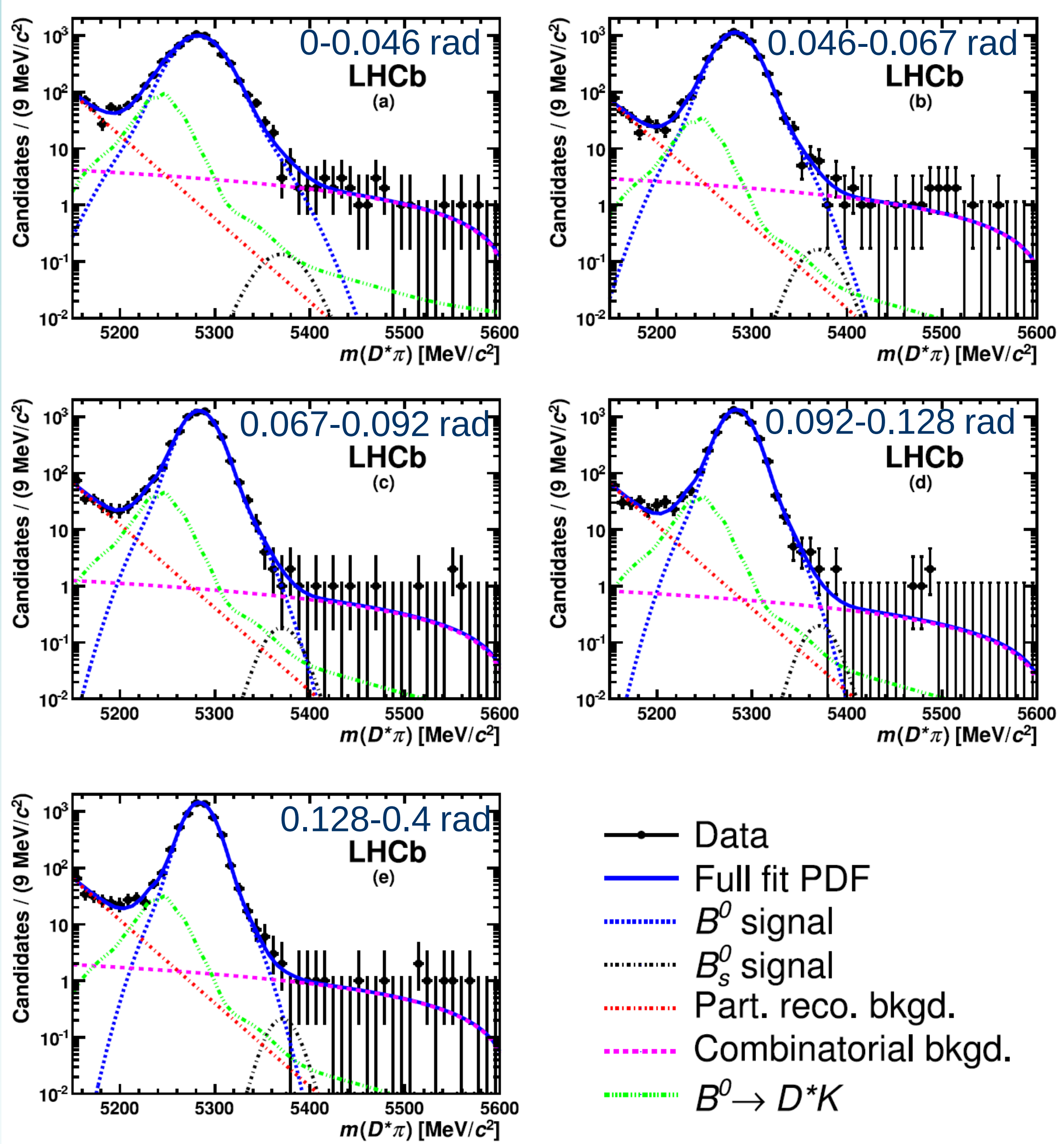
- Use $B^0 \rightarrow D^{*-}\pi^+$ as normalisation decay (several orders of magnitude more abundant)

- Bin the data in angle between D* and π momenta (lab. frame); width of B^0 peak found to be correlated with this



Not to scale!

Gain 20% in sensitivity



[LHCb-PAPER-2012-056; arXiv:1302.6446]

- No significant signal observed
- Set upper limits on branching fraction at 90% and 95% confidence levels:

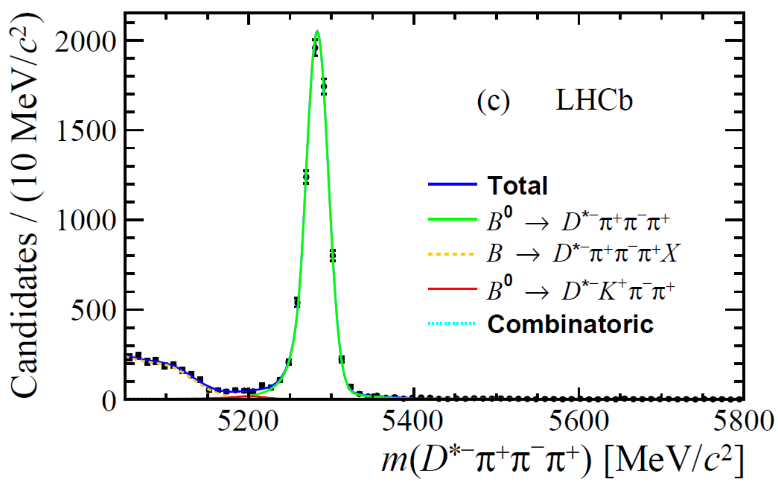
$$B(B_s^0 \to D^{*-}\pi^+) < 6.1(7.8)\times 10^{-6}$$

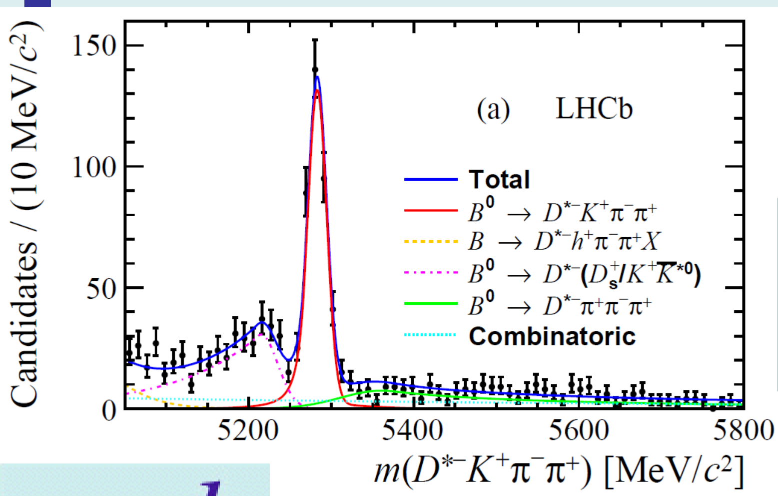
- Branching fraction limit implies rescattering may make substantial contributions to $B_s^0 \to D\bar{D}'$ and $B_s^0 \to \pi\pi$ decays

[PRD 87 (2013) 036008]

[LHCb-PAPER-2012-046; arXiv:1303.6861]

$B^0 \to D^{*-}\pi^+\pi\pi$, $B^0 \to D^{*-}K^+\pi\pi$ branching fractions





$B^0 \to D^{*-}\pi^+\pi\pi$ potential normalisation channel for $B^0 \to D^{*-}\tau^+(\pi^+\pi\pi\overline{\nu}_\tau)\nu_\tau$ decays (excess over SM BF expectation recently observed at BaBar) [PRL 109 (2012) 101802]

$$\frac{B(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}{B(B^0 \to D^{*-}\pi^+)} = 2.64 \pm 0.04(stat.) \pm 0.13(syst.)$$

$B^0 \to D^{*-}K^+\pi\pi$

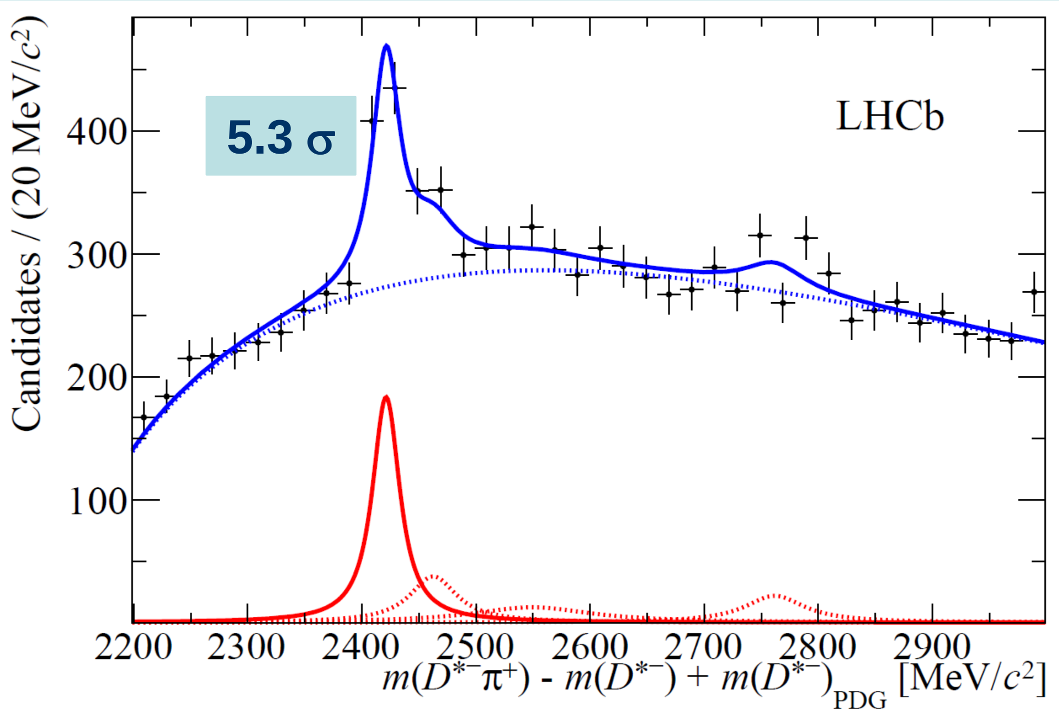
FIRST OBS.

$$\frac{B(B^0 \to D^{*-}K^+\pi^-\pi^+)}{B(B^0 \to D^{*-}\pi^+\pi^-\pi^+)} = (6.47 \pm 0.37(stat.) \pm 0.35(syst.)) \times 10^{-2}$$

$\int L dt = 1 fb^{-1}$ at $\sqrt{s} = 7$TeV

NEW

- Search for resonant structure in $B^0 \rightarrow D^{*-}\pi^+\pi\pi$



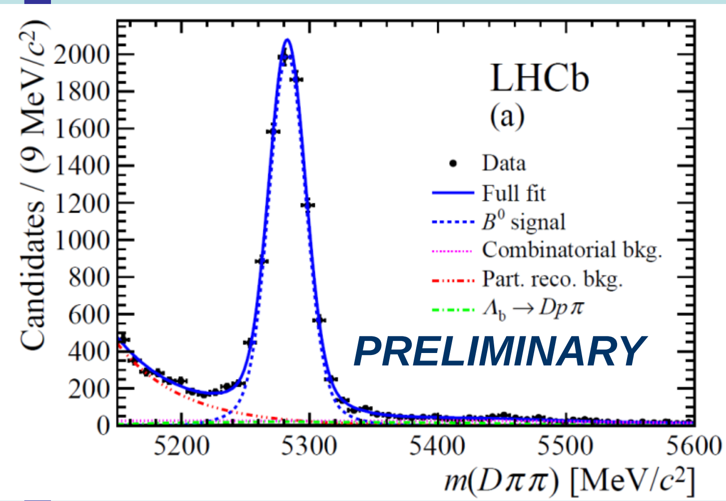
FIRST OBS.

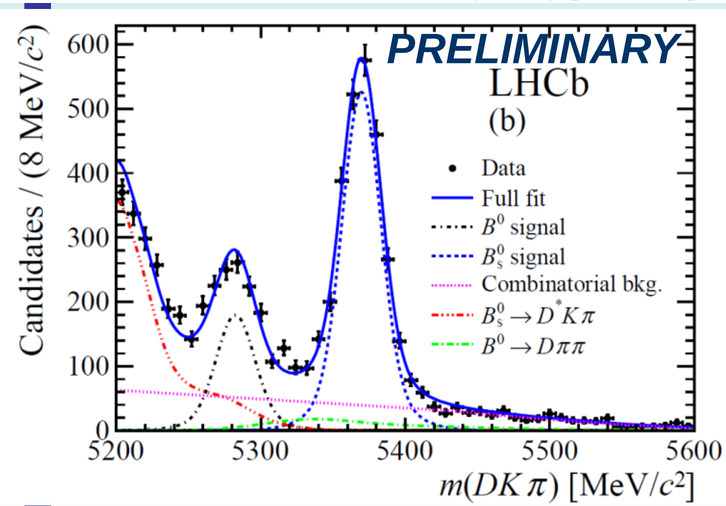
$$\frac{B(B^0 \rightarrow (\overline{D}_1(2420)^0 \rightarrow D^{*-}\pi^+)\pi^-\pi^+}{B(B^0 \rightarrow D^{*-}\pi^+\pi^-\pi^+)} = (2.04 \pm 0.42(stat.) \pm 0.22(syst.)) \times 10^{-2}$$

NEW

[LHCb-PAPER-2013-022
in preparation]

$B_{(s)}^0 \to DK\pi$ branching fractions





- Inclusive branching fraction measurements for $B_s^0 \to \overline{D}^0 K^- \pi^+$ and $B^0 \to \overline{D}^0 K^+ \pi^-$ decays
- $B^0 \to (D^0/\overline{D}^0) K^+ \pi^-$ decays sensitive to γ; $B_s^0 \to \overline{D}^0 K^- \pi^+$ large potential background

$$\frac{B(B^0 \to \overline{D}^0 K^+ \pi^-)}{B(B^0 \to \overline{D}^0 \pi^+ \pi^-)} = 0.106 \pm 0.007(stat.) \pm 0.008(syst.)$$

$$\frac{B(B_s^0 \to \overline{D}^0 K^- \pi^+)}{B(B^0 \to \overline{D}^0 \pi^+ \pi^-)} = 1.18 \pm 0.05(stat.) \pm 0.12(syst.)$$

PRELIMINARY

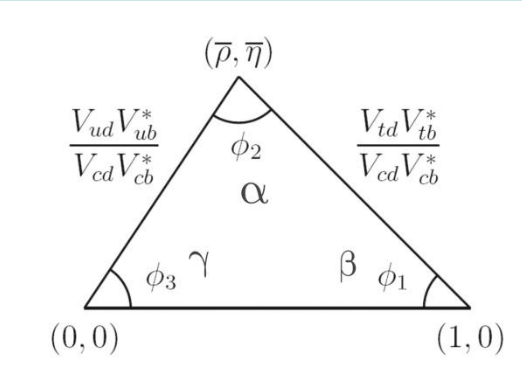
FIRST OBS.

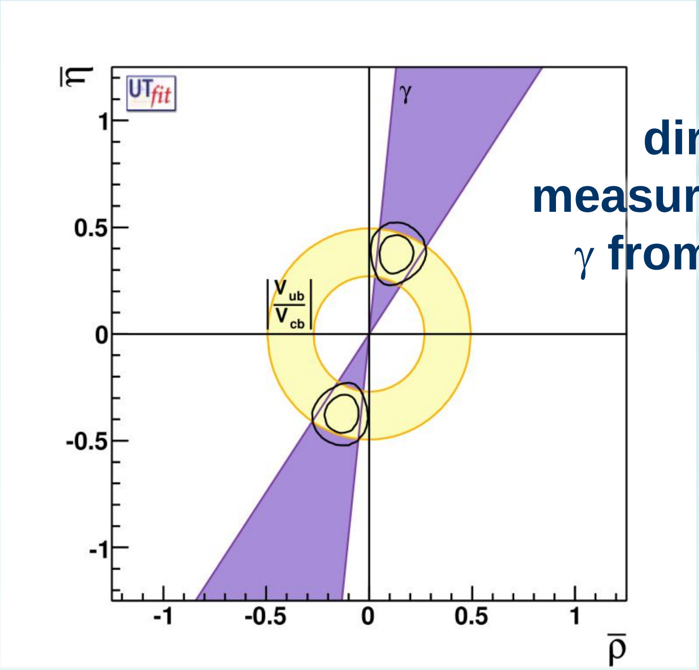
$\int Ldt = 1fb^{-1}$ at $\sqrt{s} = 7$TeV

Time-independent γ results

CKM angle γ

- Tightest experimental constraints on γ from loop processes, which are sensitive to new physics





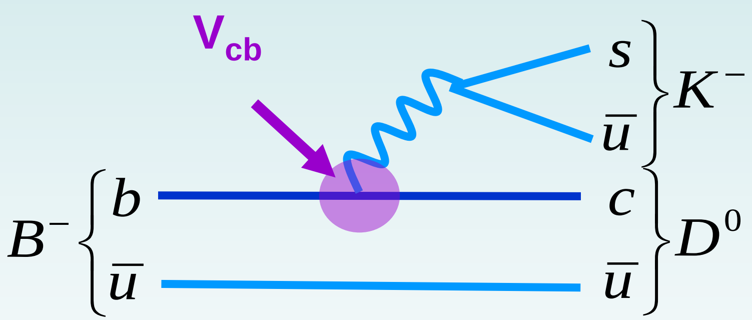
direct measurements: γ from trees

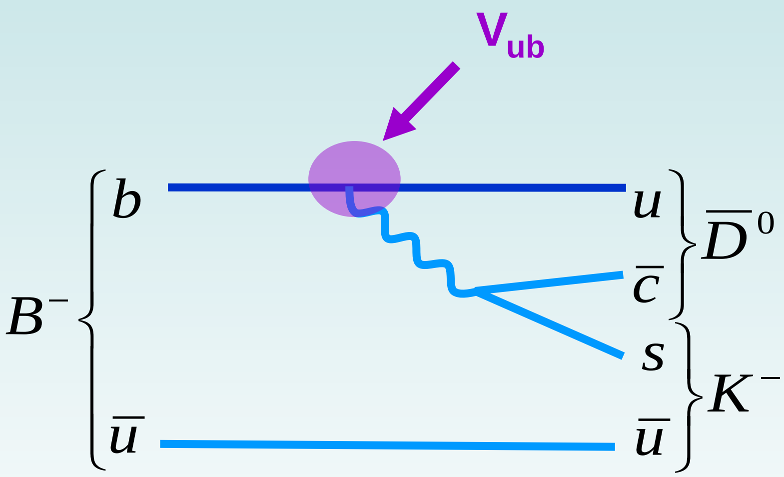
- Current average values from direct measurements:

$\gamma = (66 \pm 12)^\circ$ *(CKMfitter winter 2012)* $\gamma = (70.8 \pm 7.8)^\circ$ *(UTfit winter 2013)*

Time-independent B→DX measurements

- Sensitive to γ when D^0 or $\bar{D}^0$ decays to same final state, due to interference effects
- Exploiting weak phase difference γ between V_{cb} and V_{ub}
- e.g. for $B^- \to DK^-$





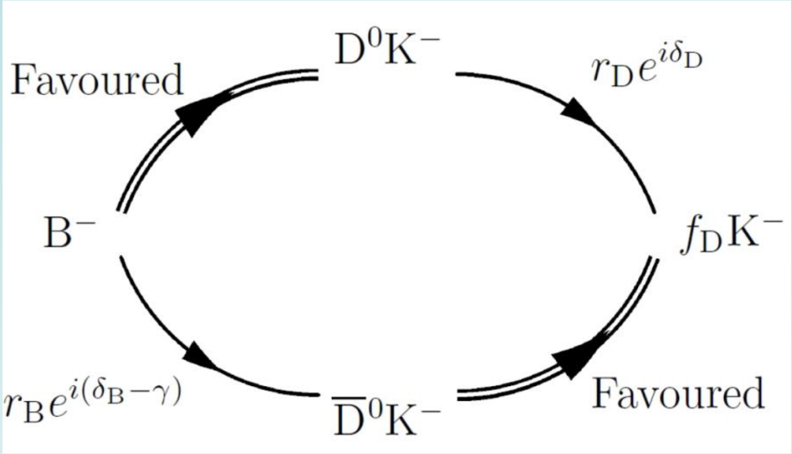
- No penguin loop contributions expected
- Also measure r_B (magnitude of ratio of amplitudes of interfering decays) and δ_B (strong phase difference)

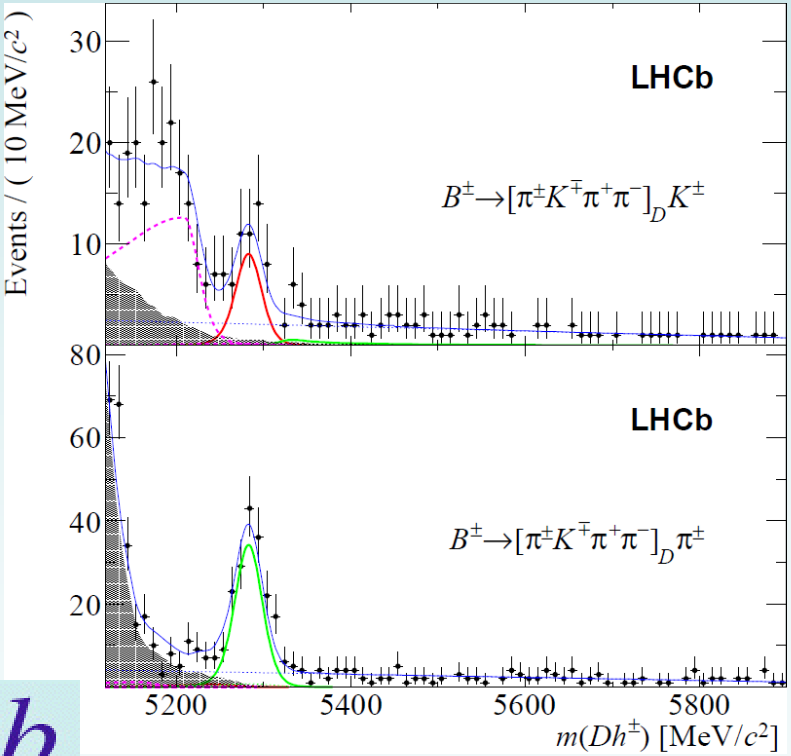
- At LHCb, perform
  - **time-independent measurements**
    e.g. $B^- \to DK^-$, $\bar{B}^0 \to D\bar{K}^{*0}$, $B^- \to DK^-\pi^+\pi^-$ [Gronau, PLB 557 (2003) 198]
    - GLW/ADS analysis [Gronau & London, PLB 253 (1991) 483; Gronau & Wyler, PLB 265 (1991) 172; Atwood, Dunietz & Soni, PRL 78 (1997) 3257; Atwood, Dunietz & Soni, PRD 63 (2001) 036005]
    - Dalitz plot analysis (GGSZ) [Giri, Grossman, Soffer & Zupan, PRD 68 (2003) 054018; Bondar, Proceedings of BINP Special Analysis Meeting on Dalitz Analysis, 24-26 Sep. 2002, unpublished]
  - **time-dependent measurements** *see M. Schiller*
  - **combination of LHCb γ measurements** *see M. Schiller*

Essential for benchmarking the SM

ADS analysis: $B^- \to D(K\pi\pi\pi)h^-$ ($h = K,\pi$)

- $\int L dt = 1 fb^{-1}$ at $\sqrt{s} = 7 TeV$
- Multi-body D decay: treated *inclusively* (no treatment of resonant structure)





First observation of suppressed ADS modes $B^- \to D(\pi^- K^+ \pi^+ \pi^-)K^-$ and $B^- \to D(\pi^- K^+ \pi^+ \pi^-)\pi^-$

- Observables: ratios and asymmetries
  - Ratios of suppressed to favoured decays most sensitive to γ, r_B and δ_B :

$$R_h^{K3\pi,\pm} = \frac{\Gamma(B^\pm \to [\pi^\pm K^\mp \pi^+ \pi^-]_D h^\pm)}{\Gamma(B^\pm \to [K^\pm \pi^\mp \pi^+ \pi^-]_D h^\pm)}$$

$$= (r_B^h)^2 + (r_D^{K3\pi})^2 + 2 r_B^h r_D^{K3\pi} \kappa_D^{K3\pi} \cos(\delta_B^h + \delta_D^{K3\pi} \pm \gamma)$$

- Combine ratios to obtain "traditional" ADS observables:

$$A_{ADS(K)}^{K3\pi} = \frac{R_K^{K3\pi,-} - R_K^{K3\pi,+}}{R_K^{K3\pi,-} + R_K^{K3\pi,+}} = -0.42 \pm 0.22 \qquad A_{ADS(\pi)}^{K3\pi} = \frac{R_\pi^{K3\pi,-} - R_\pi^{K3\pi,+}}{R_\pi^{K3\pi,-} + R_\pi^{K3\pi,+}} = 0.13 \pm 0.10$$

$$R_{ADS(K)}^{K3\pi} = \frac{R_K^{K3\pi,-} + R_K^{K3\pi,+}}{2} = 0.0124 \pm 0.0027 \qquad R_{ADS(\pi)}^{K3\pi} = \frac{R_\pi^{K3\pi,-} + R_\pi^{K3\pi,+}}{2} = 0.0037 \pm 0.0004$$

  - Constraint on r_B $\quad r_B^K = 0.097 \pm 0.011$

D decay parameters from CLEO-c [PRD 80 (2009) 031105]

NEW

[LHCb-CONF-2013-004]

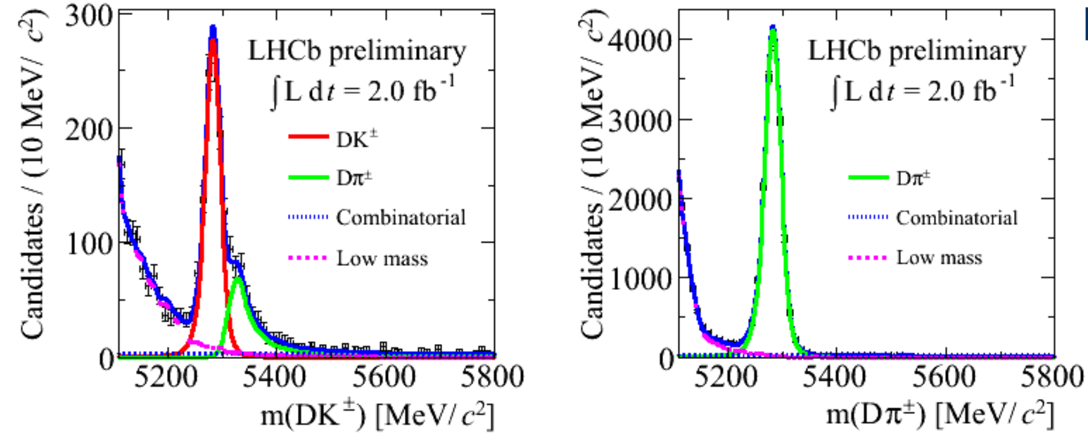
Dalitz (GGSZ) analysis: $B^- \to D(K_s\pi\pi, K_sKK)h^-$

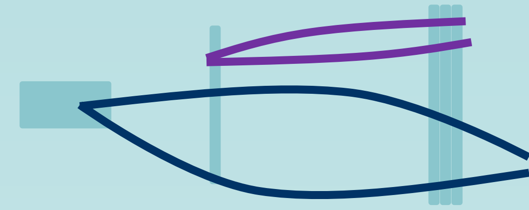
- $\int L dt = 2 fb^{-1}$ at $\sqrt{s} = 8 TeV$
- Determine γ from differences in amplitude of Dalitz plot of D decay from $B^- \to DK^-$ and $B^+ \to DK^+$
- Have to take resonant structure of multi-body D decay into account (variation across Dalitz plane)
- Observables:

$$x_\pm = r_B \cos(\delta_B \pm \gamma) \qquad y_\pm = r_B \sin(\delta_B \pm \gamma)$$

$B \to D(K_s \pi\pi)h$

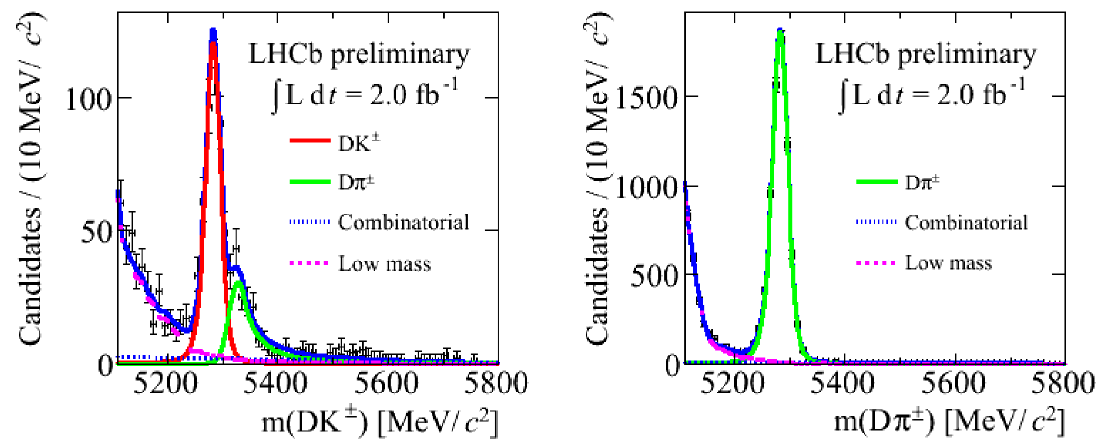
NEW

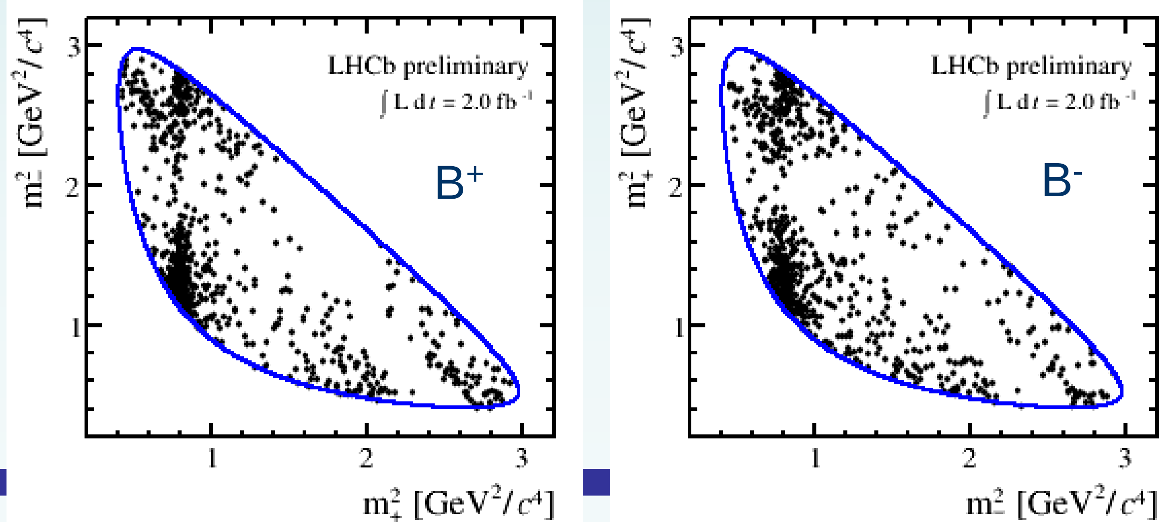




K_S without VELO (Si vertex tracker) daughter hits

K_S with VELO (Si vertex tracker) daughter hits



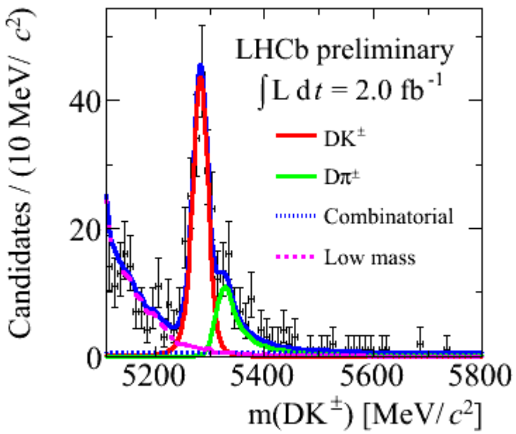


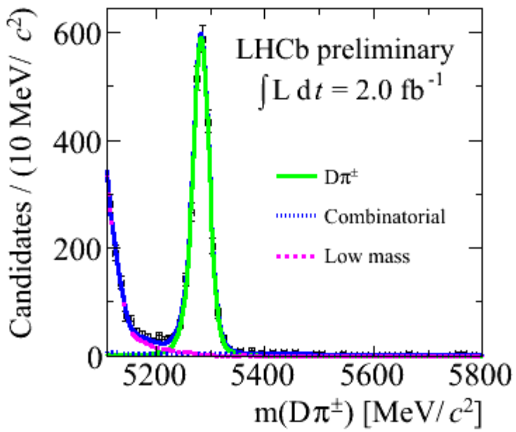
[LHCb-CONF-2013-004]

$B \to D(K_s KK)h$

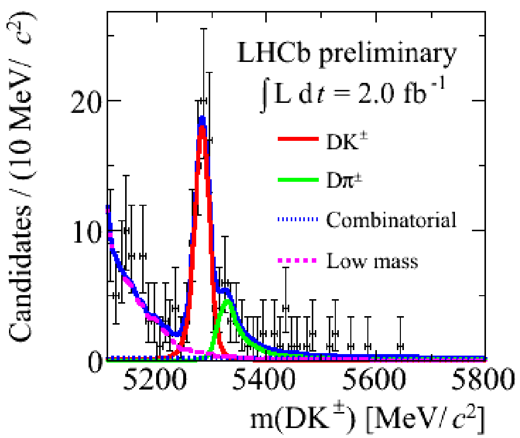
NEW

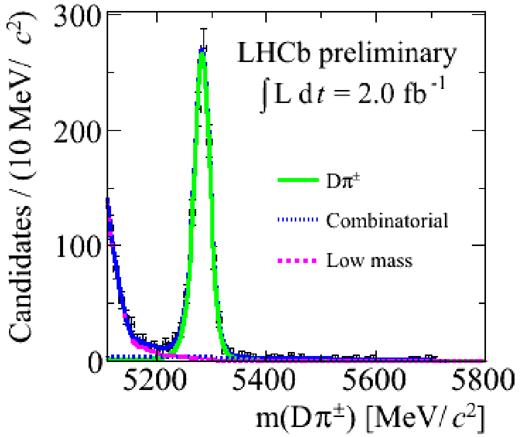
K_S without VELO (Si vertex tracker) daughter hits

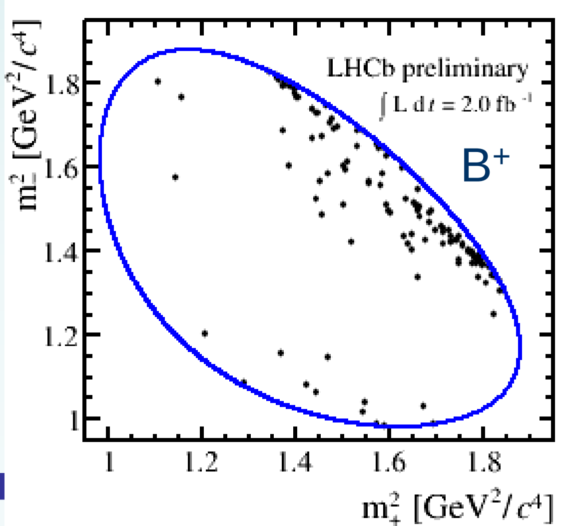


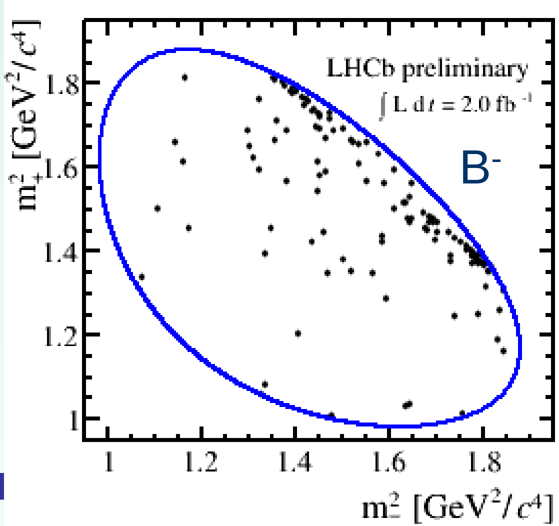


K_S with VELO (Si vertex tracker) daughter hits







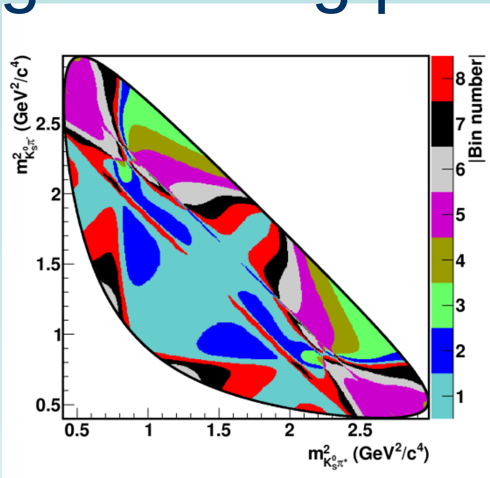


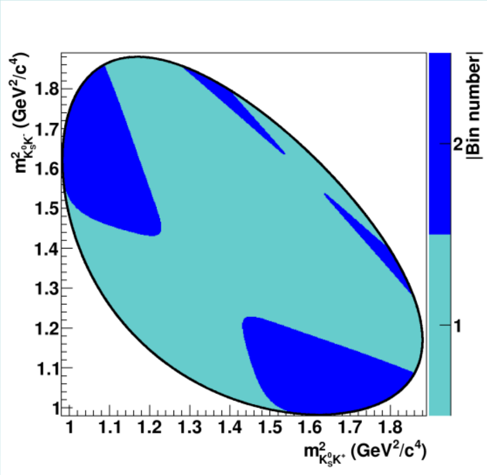
[LHCb-CONF-2013-004]

NEW

[LHCb-CONF-2013-004]

- Model-independent method: bin Dalitz plane according to strong phase difference of D decay





- Perform simultaneous mass fits in each bin
- Input strong phase difference from CLEO-c (c_i, s_i)
- Yield in bin i

[PRD 82 (2010) 112006]

$$\Gamma_{\pm i}(B^-) = n^-(K_{\pm i} + r_B^2 K_{\mp i} + 2\sqrt{K_i K_{-i}}(x_- c_i \pm y_- s_i))$$

$$\Gamma_{\pm i}(B^+) = n^+(K_{\mp i} + r_B^2 K_{\pm i} + 2\sqrt{K_i K_{-i}}(x_+ c_i \mp y_+ s_i))$$

normalisation

eff. corrected yield of flavour-tagged decays in bin

NEW

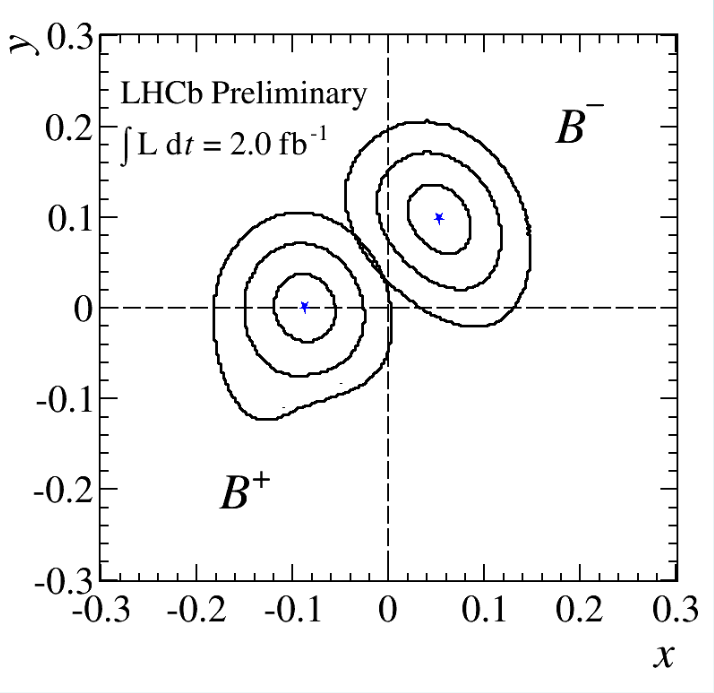
[LHCb-CONF-2013-004]

$$x_+ = -0.087 \pm 0.031(stat.) \pm 0.016(syst.) \pm 0.006(extl.)$$
$$x_- = 0.053 \pm 0.032(stat.) \pm 0.009(syst.) \pm 0.009(extl.)$$
$$y_+ = 0.001 \pm 0.036(stat.) \pm 0.014(syst.) \pm 0.019(extl.)$$
$$y_- = 0.099 \pm 0.036(stat.) \pm 0.022(syst.) \pm 0.016(extl.)$$

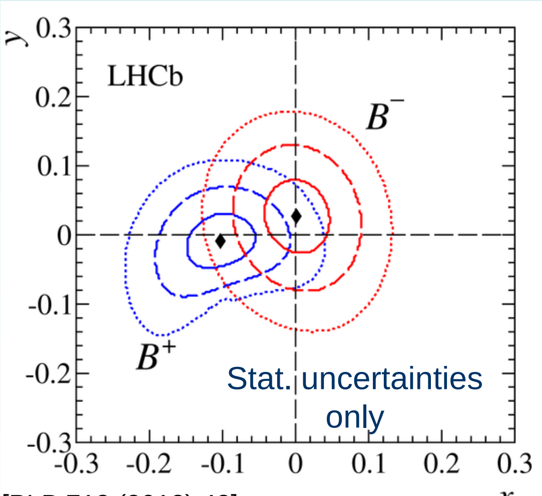
PRELIMINARY

MOST PRECISE TO DATE

Stat. uncertainties only



Previous result (∫Ldt = 1fb^{-1} at √s = 7TeV)



[PLB 718 (2012) 43]

NEW

[PLB 718 (2012) 43] [LHCb-CONF-2013-004]

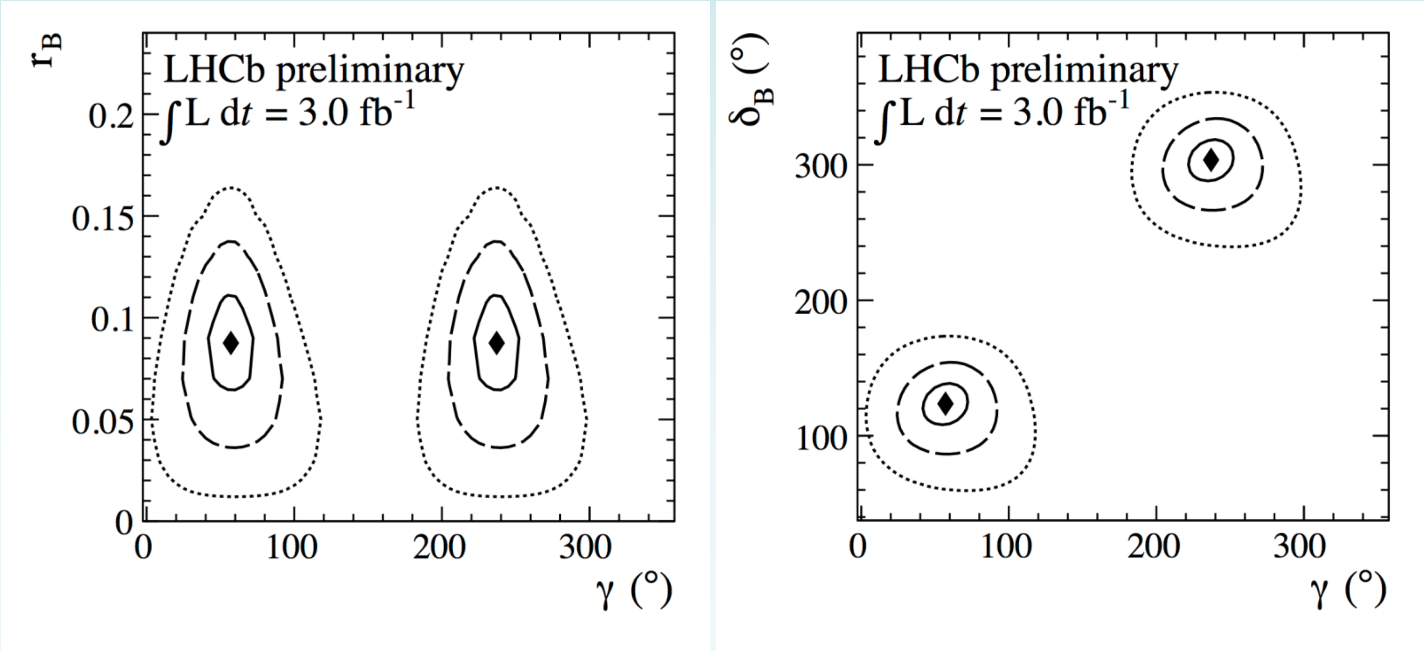
- Combine with previous result to give constraints on γ, r_B and δ_B:

$$\gamma = (57 \pm 16)^\circ$$

$$\delta_B = (124^{+15}_{-17})^\circ$$

$$r_B = 0.088^{+0.023}_{-0.024}$$

PRELIMINARY



Conclusions and prospects

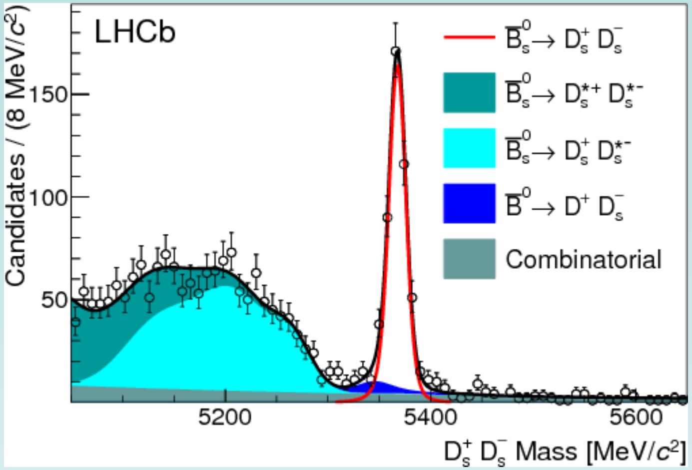
- LHCb is on its way to placing world's best constraints on CKM angle γ
- Several new B to open charm decay modes observed
- Only covered most recent results here

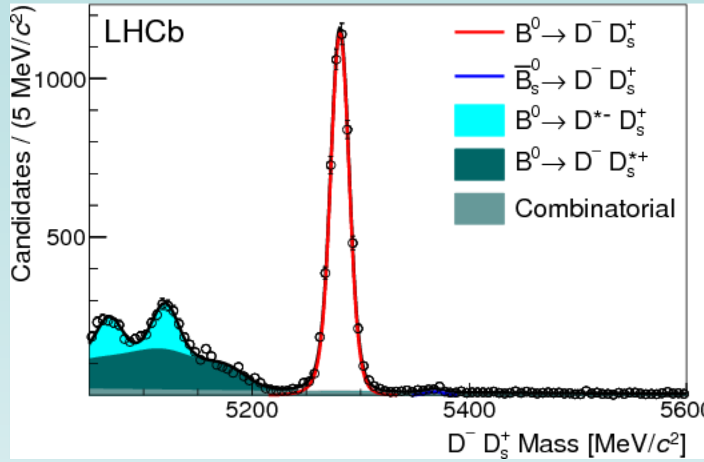
- **Coming soon:**
  - studies of new decay modes
  - further updates including 2012 data set (another ~2fb^{-1} at $\sqrt{s}$ = 8TeV recorded)

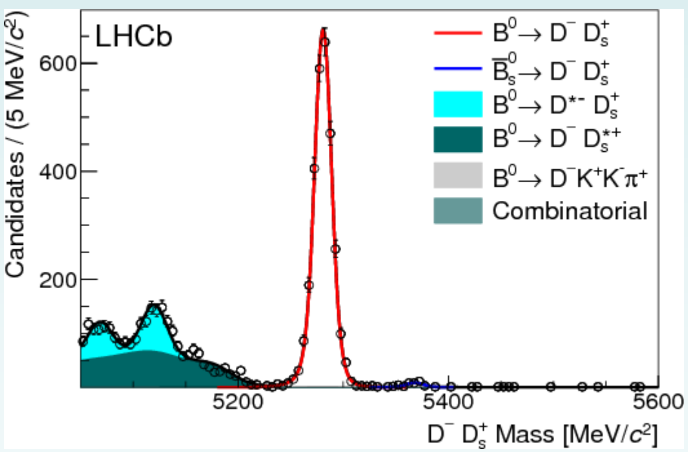
See M. Schiller's talk for time-dependent γ results and LHCb γ combination

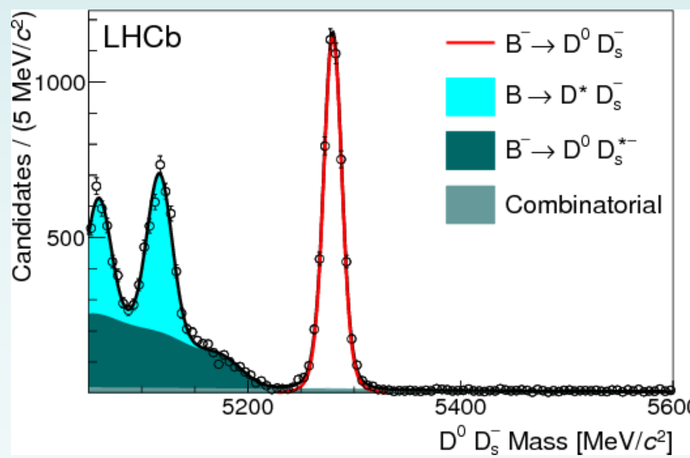
Backup: B→DD

[LHCb-PAPER-2012-050; arXiv:1302.5854]









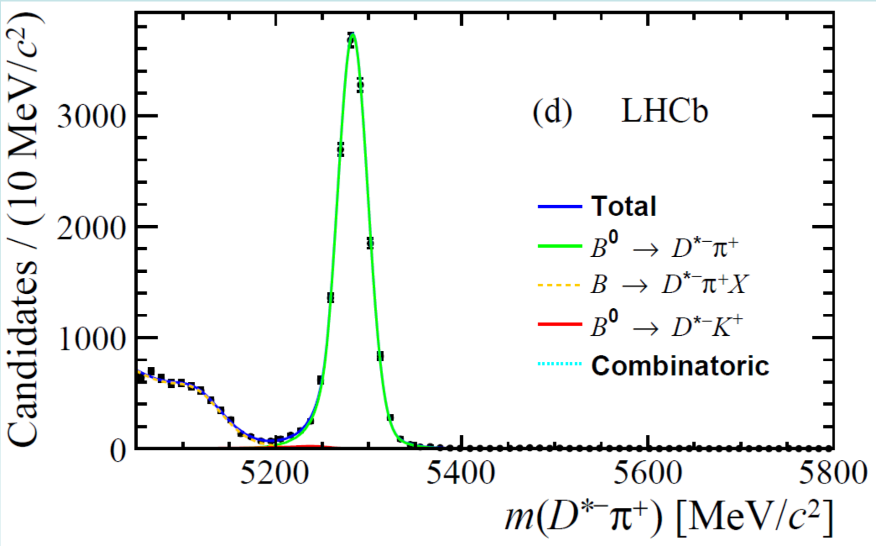
Backup: $B_s^0 \to D^{*-}\pi^+$

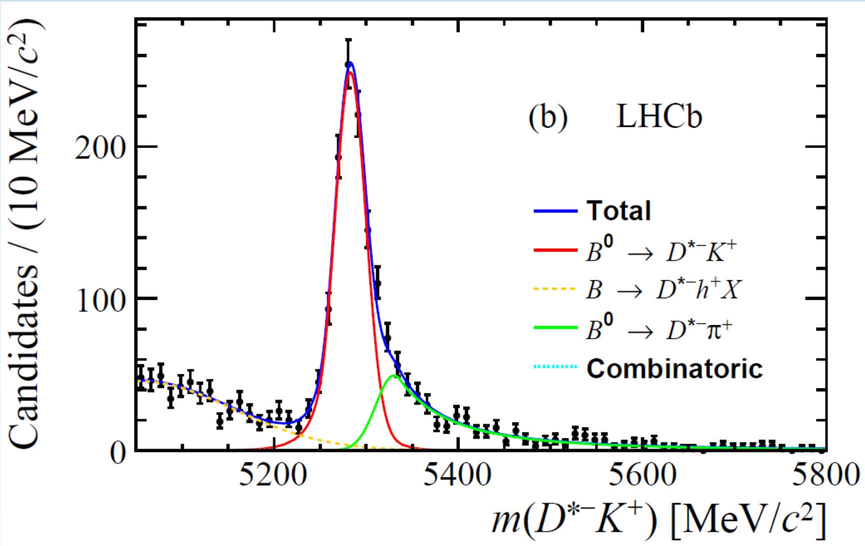
[LHCb-PAPER-2012-056; arXiv:1302.6446]

- Reminder: no *significant* signal observed
- Evaluate branching fraction from fitted yield

$$B(B_s^0 \to D^{*-}\pi^+) = (1.5 \pm 3.8(stat.) \pm 1.5(syst.)) \times 10^{-6}$$

Backup: $B^0 \to D^{*-}\pi^+\pi\pi$, $B^0 \to D^{*-}K^+\pi\pi$

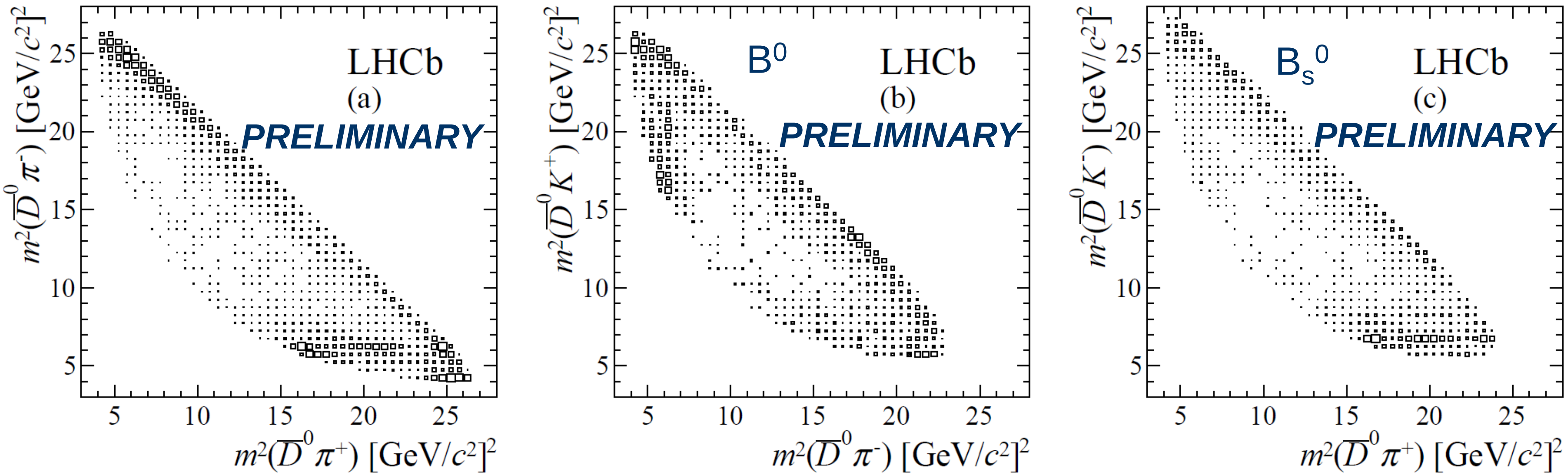




$$\frac{B(B^0 \to D^{*-}K^+)}{B(B^0 \to D^{*-}\pi^+)} = (7.76 \pm 0.34(stat.) \pm 0.26(syst.)) \times 10^{-2}$$

[LHCb-PAPER-2013-022
in preparation]

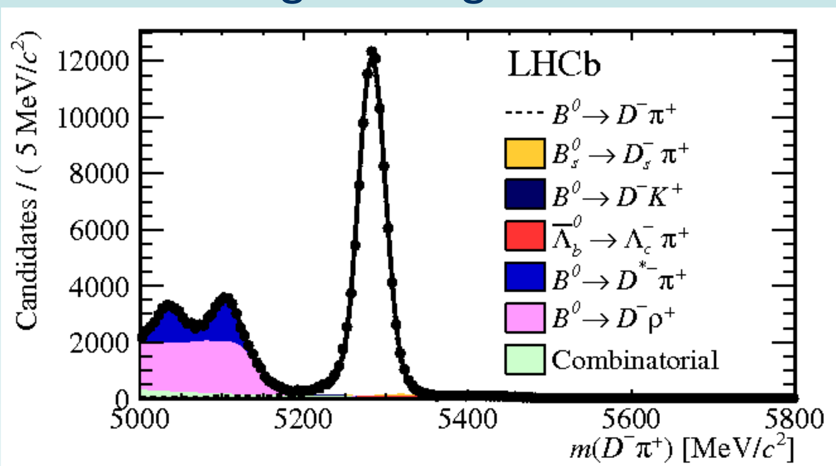
Backup: B→DKπ

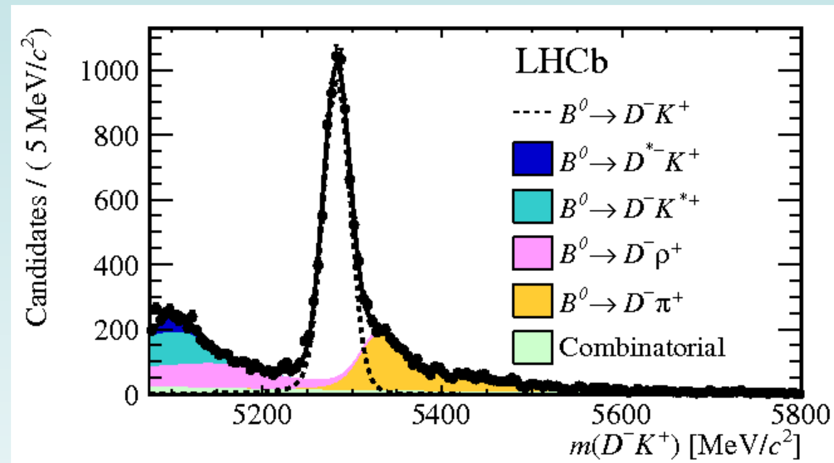


Backup: measurement of f_s/f_d

[LHCb-PAPER-2012-037; arXiv:1301.5286]

- $\int L dt = 1 fb^{-1}$ at $\sqrt{s} = 7 TeV$
- Vital input to B_s^0 branching fraction measurements
- Use $B_s^0 \to D_s^- \pi^+$ and $B^0 \to D^- K^+$ decays





$$\frac{f_s}{f_d} = 0.238 \pm 0.004(stat.) \pm 0.015(syst.) \pm 0.021(theo.)$$

← dominated by uncertainty on form factors

- Combine with semileptonic result: $$\frac{f_s}{f_d} = 0.256 \pm 0.020$$

[PRD 85 (2012) 032008]

[LHCb-PAPER-2012-037; arXiv:1301.5286]

$$\frac{f_s}{f_d} = \frac{\mathcal{B}(B^0 \to D^- K^+)}{\mathcal{B}(B_s^0 \to D_s^- \pi^+)} \frac{\varepsilon_{DK}}{\varepsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{DK}}$$

$$= \Phi_{PS} \left|\frac{V_{us}}{V_{ud}}\right|^2 \left(\frac{f_K}{f_\pi}\right)^2 \frac{\tau_{B^0}}{\tau_{B_s^0}} \frac{1}{N_a N_F} \frac{\mathcal{B}(D^- \to K^+\pi^-\pi^-)}{\mathcal{B}(D_s^- \to K^+K^-\pi^-)} \frac{\varepsilon_{DK}}{\varepsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{DK}}$$

phase space

decay constants

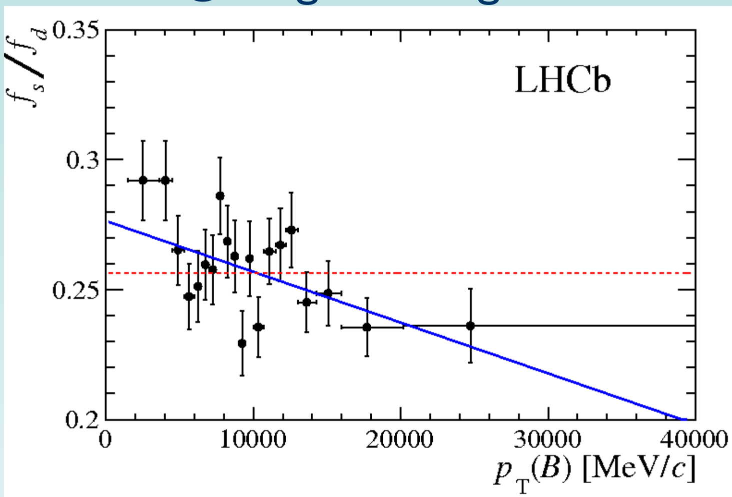
lifetimes

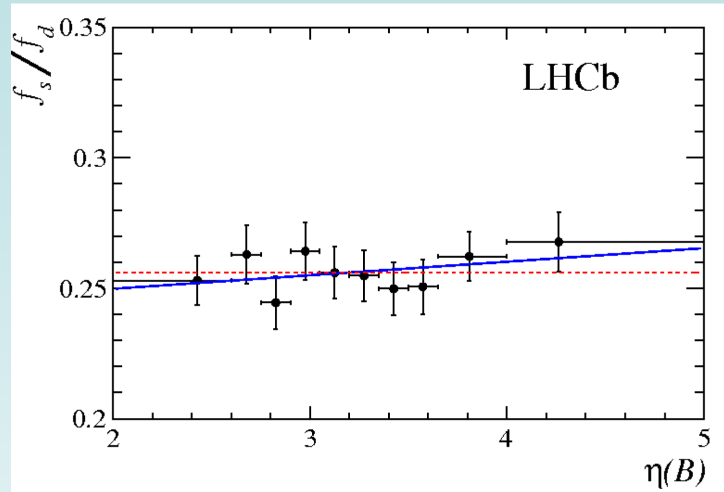
non-factorizable corrections

form factors

[LHCb-PAPER-2012-037; arXiv:1301.5286]

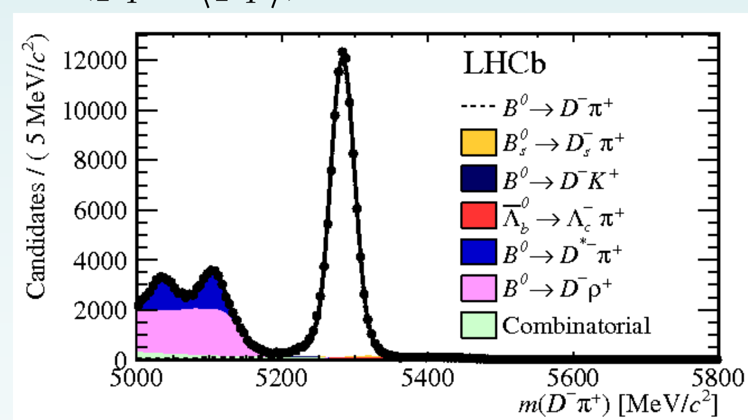
- Study dependence of f_s/f_d with B meson p_T and η using $B_s^0 \rightarrow D_s^- \pi^+$ and $B^0 \rightarrow D^- \pi^+$ decays





$$\frac{f_s}{f_d}(p_T) = (0.256 \pm 0.020) + (-2.0 \pm 0.6) \times 10^{-3} / GeV/c \times (p_T - \langle p_T \rangle)$$

$$\frac{f_s}{f_d}(\eta) = (0.256 \pm 0.020) + (0.005 \pm 0.006) \times (\eta - \langle \eta \rangle)$$

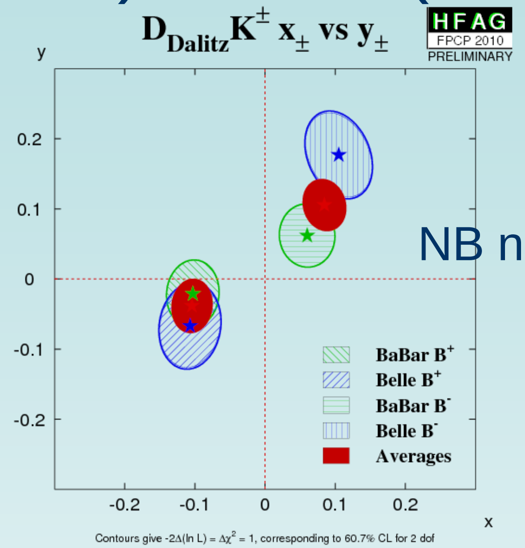


Backup: GGSZ

- HFAG average (Belle/BaBar) results (model-**dependent** method):

$$x_+ = -0.104 \pm 0.029$$
$$x_- = 0.085 \pm 0.030$$
$$y_+ = -0.038 \pm 0.038$$
$$y_- = 0.105 \pm 0.036$$

NB no model error



NB no model error

- Belle result (model-**independent** method):

$$x_+ = -0.110 \pm 0.043(stat.) \pm 0.014(syst.) \pm 0.007(extl.)$$
$$x_- = 0.095 \pm 0.045(stat.) \pm 0.014(syst.) \pm 0.010(extl.)$$
$$y_+ = -0.050^{+0.052}_{-0.055}(stat.) \pm 0.011(syst.) \pm 0.007(extl.)$$
$$y_- = 0.137^{+0.053}_{-0.057}(stat.) \pm 0.015(syst.) \pm 0.023(extl.)$$

[PRD 85 (2012) 112014]

$$\gamma = (77.3^{+15.1}_{-14.9}(stat.) \pm 4.1(syst.) \pm 4.3(extl.))^{\circ}$$

Previous result ($\int L dt = 1 fb^{-1}$ at $\sqrt{s} = 7 TeV$) [PLB 718 (2012) 43]

$$x_+ = -0.103 \pm 0.045(stat.) \pm 0.018(syst.) \pm 0.014(extl.)$$
$$x_- = 0.000 \pm 0.043(stat.) \pm 0.015(syst.) \pm 0.006(extl.)$$
$$y_+ = -0.009 \pm 0.037(stat.) \pm 0.008(syst.) \pm 0.030(extl.)$$
$$y_- = 0.027 \pm 0.052(stat.) \pm 0.008(syst.) \pm 0.023(extl.)$$

Stat. uncertainties only