Studies of hadronic B decays at LHCb

Flavor Physics & CP Violation
FPCP
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for the LHCb collaboration

LHCb

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Outline

Recent results on branching fractions measurements

- $B^+ \rightarrow D^+_s \Phi$: annihilation diagram, sensitive to new physics
- Double charm decays, $B \rightarrow DD'$: measure γ, Φ_s, $\Delta\Gamma_s$
- $B^0_s \rightarrow D^{*\mp}\pi^\pm$: weak exchange decay, help understand rescattering effects in other modes
- $B^0 \rightarrow D^{*-}\pi^+\pi^-\pi^+$: can be used as normalization channel for $B^0 \rightarrow D^{*-}\tau^+\nu_\tau$
- $B^0_s \rightarrow D^0K^-\pi^+$ and $B^0 \rightarrow D^0K^+\pi^-$ decays: measure γ

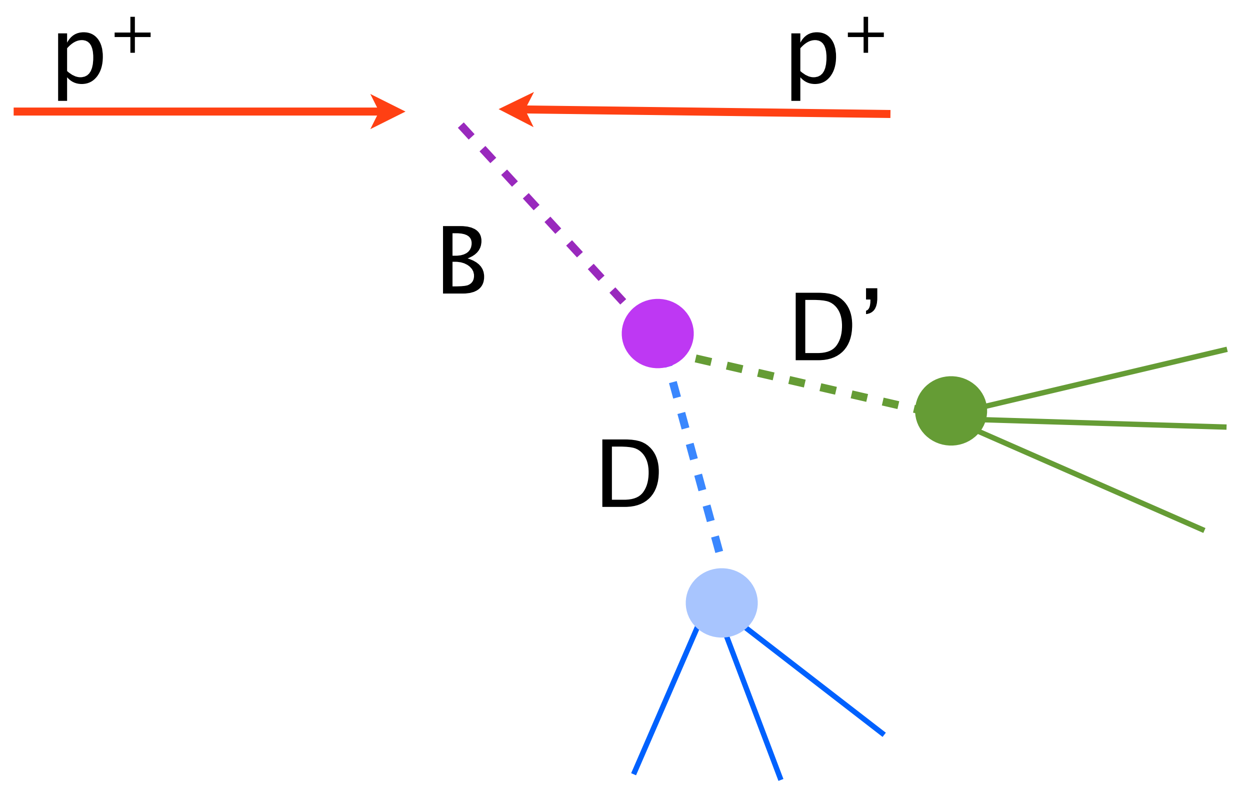
Outline

Rec

- ★ Open charm decays of b hadrons offer a means by which both the electroweak and QCD sectors of the Standard Model (SM) may be tested
- ★ Measuring their Branching Fractions can help us to understand these processes better. In particular one can study if for certain suppressed modes long-distance processes are dominant
- ★ Beyond measurements of CPV and the phases derived from the CKM matrix and rescattering effects, rare $B \rightarrow DX$ decays may be used to search for new physics in decays mediated via annihilation or exchange processes.

General strategy

- Requirements on vertex separation, pointing quantities to ensure D candidates originate from B decay
- Cross feeds are suppressed using PID information and kinematics
- Multivariate selections combining topological information to suppress light-quark background



- The branching fraction ratios are calculated normalized to decay modes with the same final states (systematics largely canceled)

$$\frac{\mathcal{B}(B^0_s \to D^+_s D^-)}{\mathcal{B}(B^0 \to D^+_s D^-)} = \frac{f_d}{f_s}\,\epsilon_{rel}\,\frac{N_{B_s \to D^+_s D^-}}{N_{B \to D^+_s D^-}}$$

b fragmentation fraction ratio from: LHCb measurement arXiv:1301.5286

Accounts for geometric acceptance, detection and trigger efficiencies

Yields extracted from the invariant mass distributions

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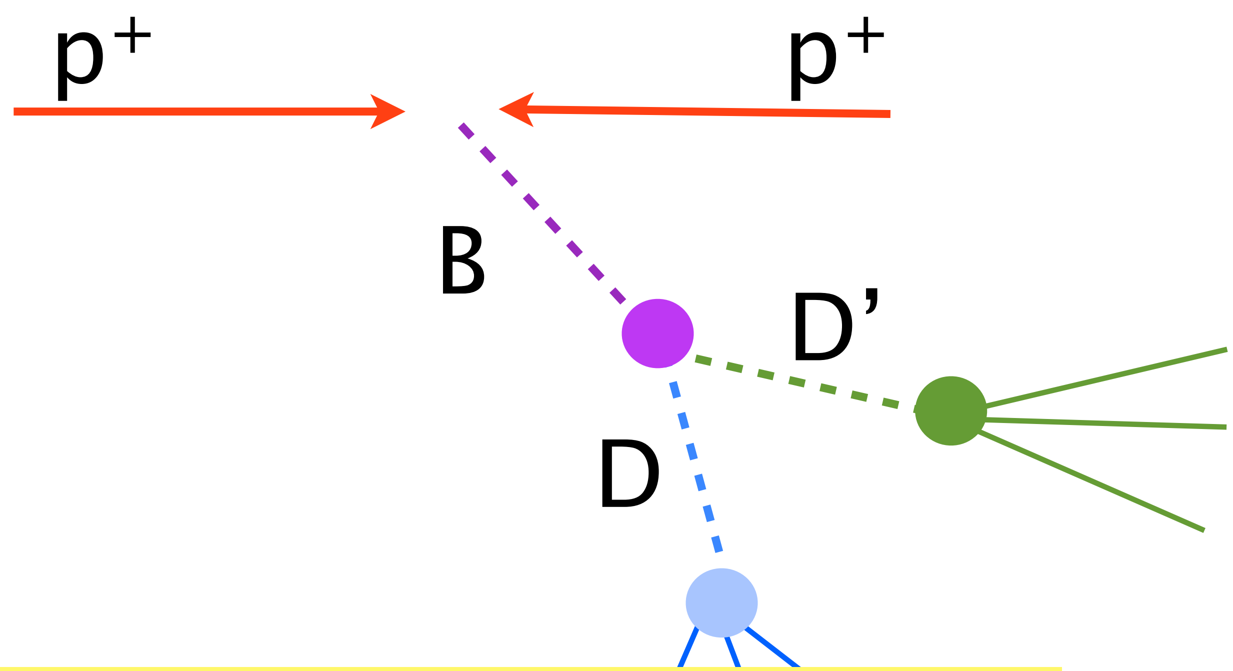

★ All the analysis use the 2011 data set corresponding to **1fb** $^{-1}$

modes with the same final states (systematics largely canceled)

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Yields extracted from the invariant mass distributions

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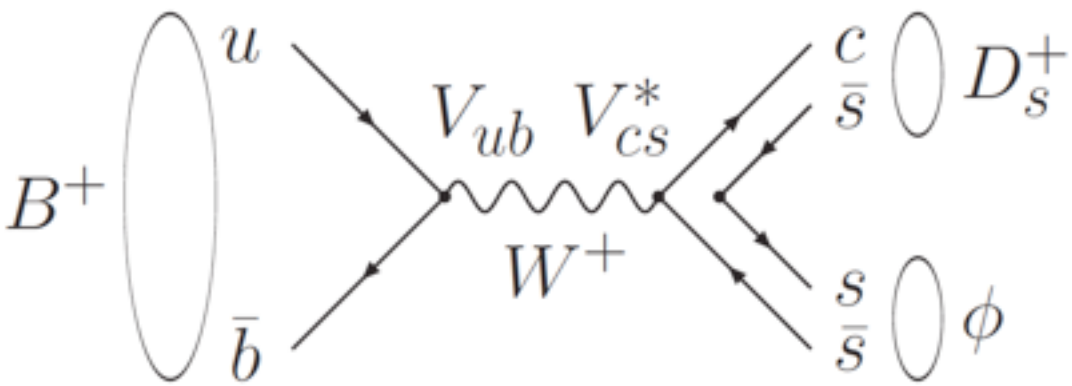
Accounts for geometric acceptance, detection and trigger efficiencies

Search for the decay $B^+ \to D^+_s \Phi$

LHCb-PAPER-2012-025
arXiv:1210.1089

- Occurs only via annihilation of the B meson constituent quarks in SM
  - highly suppressed in the SM: BF predictions (neglecting rescattering) are (1-7) x 10 $^{-7}$

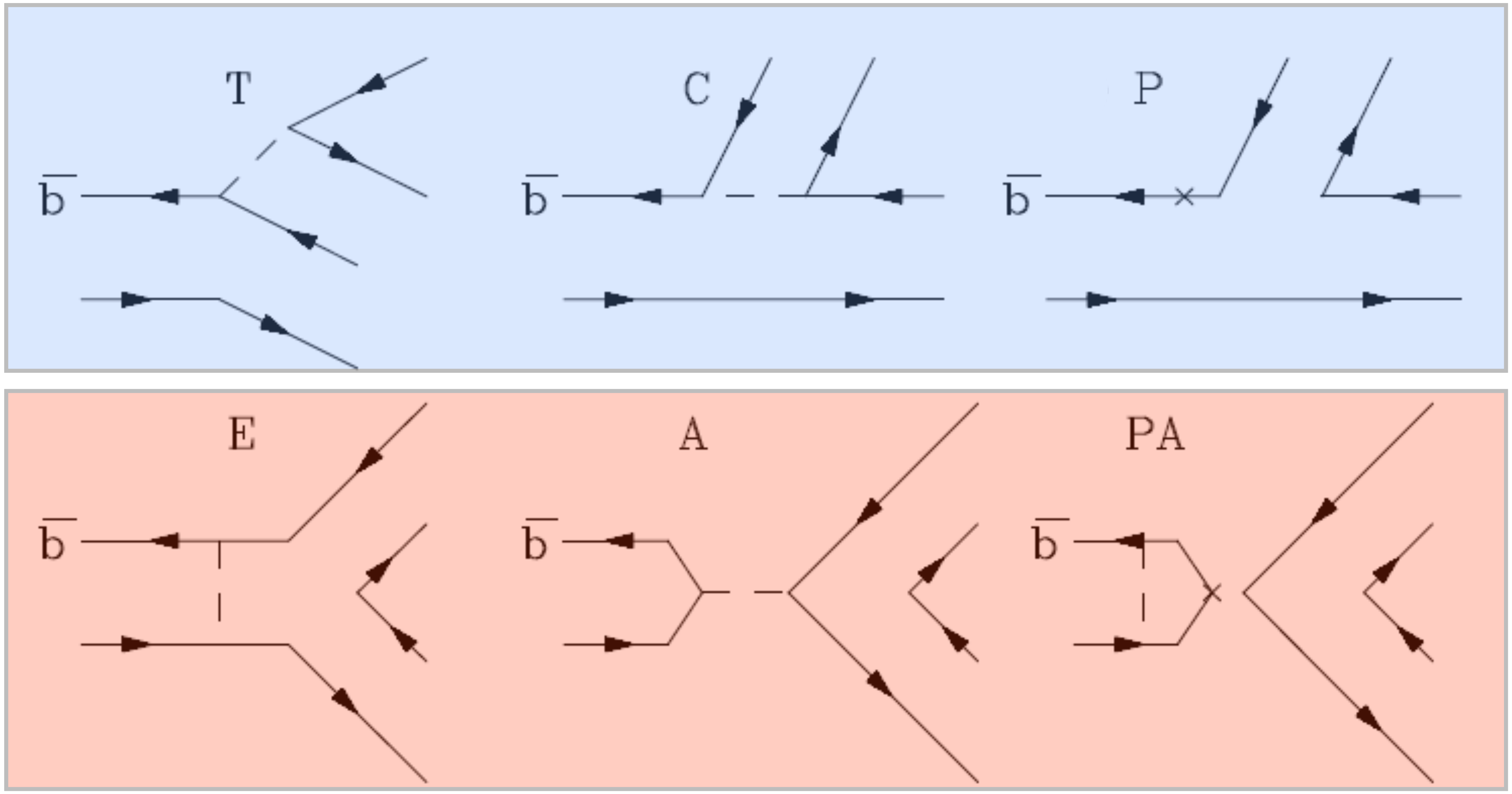


Never seen before!

BaBar measurement
BF <1.9 x10 $^{-6}$ (90%CL)

- Can be generated by rescattering from a process whose amplitude is of the color suppressed tree form
- Contributions from new Physics could enhance the BF or produce large CP asymmetries: charged Higgs can mediate the annihilation diagram
- Interest in annihilation type decays with $|V_{ub}|$
  - tension between $|V_{ub}|$ and sin2β in unitary fit
  - Measured BF of the decay $B^+ \to \tau\nu$

Dominant amplitudes: color-favored tree (**T**) , color-suppressed tree (**C**) and penguin (**P**). These three amplitudes are approximately independent of the light "spectator" quark.

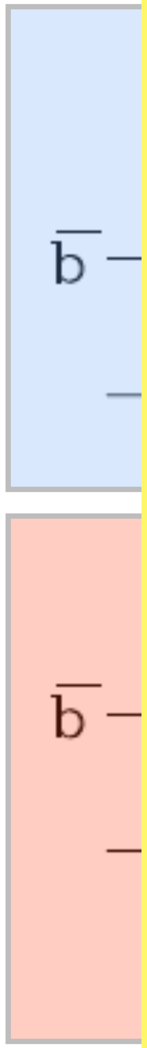


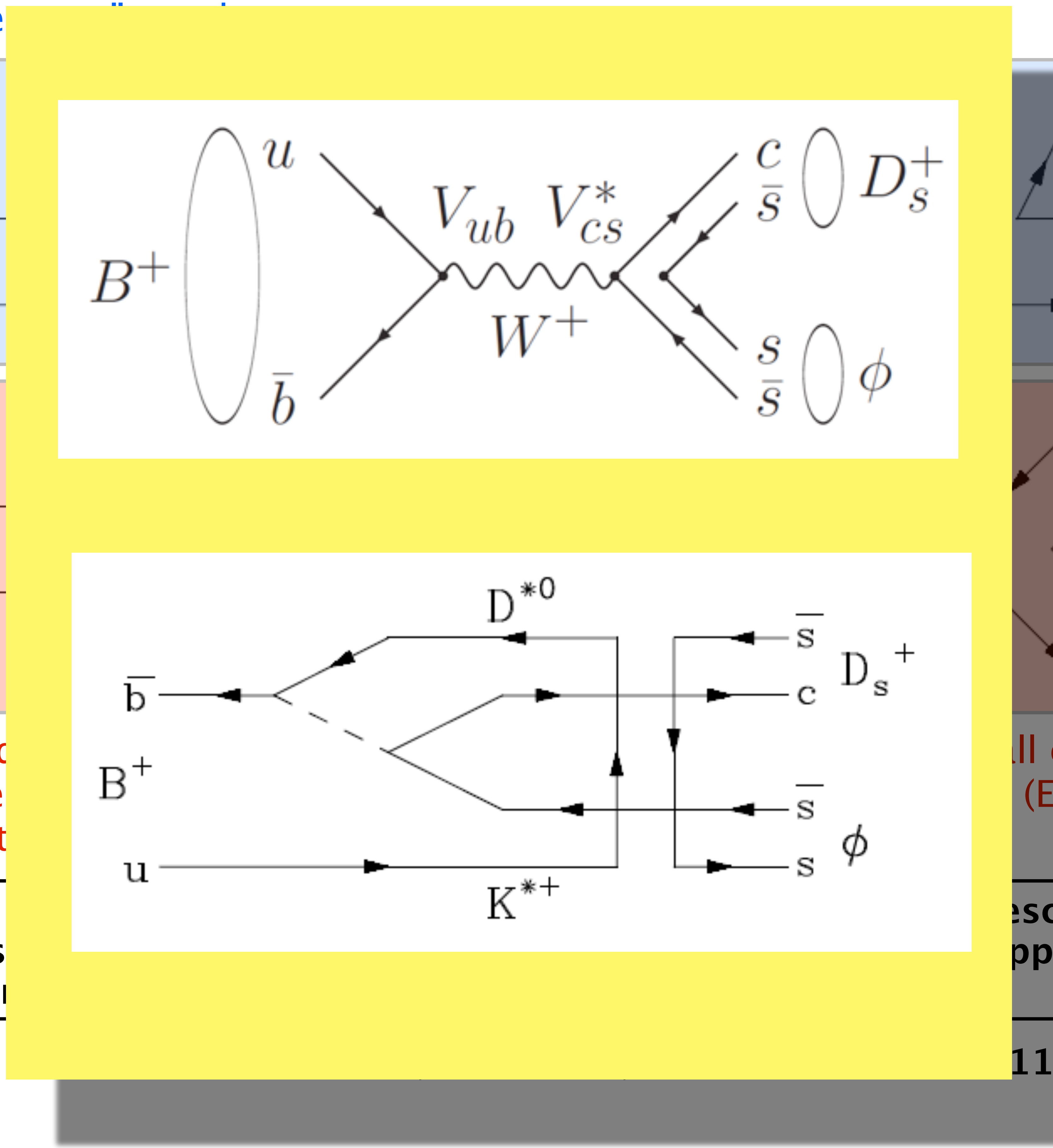
Amplitudes considerably suppressed in comparison with them, all of which require participation of the spectator quark, are exchange (E), annihilation (A), and penguin annihilation (PA).

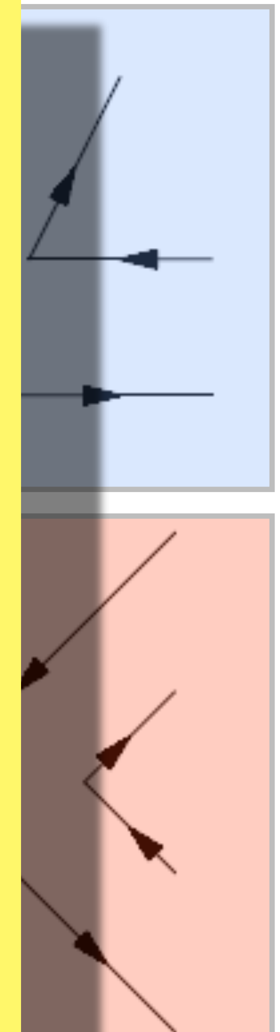
Effects of the amplitudes E, A, and PA can also be generated by rescattering from processes whose amplitudes are color-favored tree (T), color-suppressed tree (C), or penguin (P)

M.Gronau, D. London, J.L. Rosner. ArXiv:1211.5785v2 (2012)

Dominant amplitudes: color-favored tree (**T**) , color-suppressed tree (**C**) and penguin (**P**). These three amplitudes are approximately independent of the light "spe







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Search for the decay $B^+ \to D_s^+ \Phi$

LHCb-PAPER-2012-025
arXiv:1210.1089

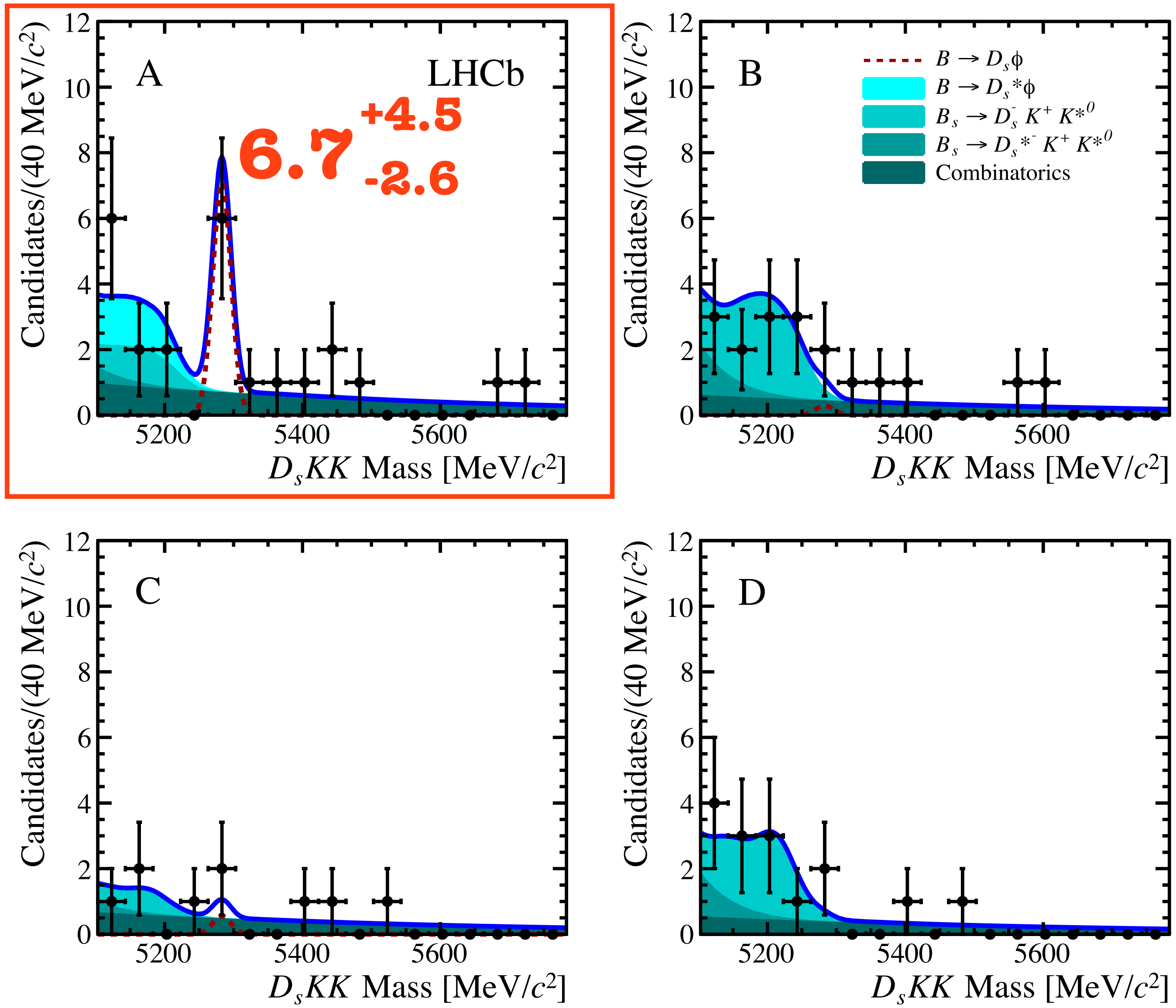
$B^+ \to D_s^+ (K^+ K^+ \pi^+) \Phi (K^+ K^-)$

- Normalized to:

  $B^+ \to D_s^+ (K^+ K^+ \pi^+) \overline{D}^0 (K^+ K^-)$

- Fit performed in 4 regions:

$\|\cos\theta_k\|$	$\|m_{kk}-m_\Phi\|$ (MeV/c^2) <20	(20,40)
>0.4	A	B
<0.4	C	D



$$B(B^+ \to D_s^+ \Phi) = 1.87 ^{+1.25}_{-0.73} \pm 0.19 \pm 0.32(\text{norm}) \times 10^{-6}$$

First observation with 3.6σ significance!

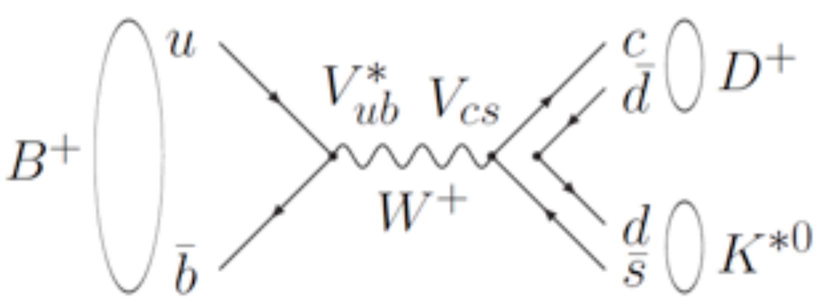
$$A_{cp}(B^+ \to D_s^+ \Phi) = -0.01 \pm 0.41 \pm 0.03$$

Consistent with SM predictions given the large uncertainties on both the theoretical and experimental values

$B^+ \to D^+_{(s)} K^{*0}$ and $B^+ \to D^+_{(s)} \overline{K}^{*0}$ decays

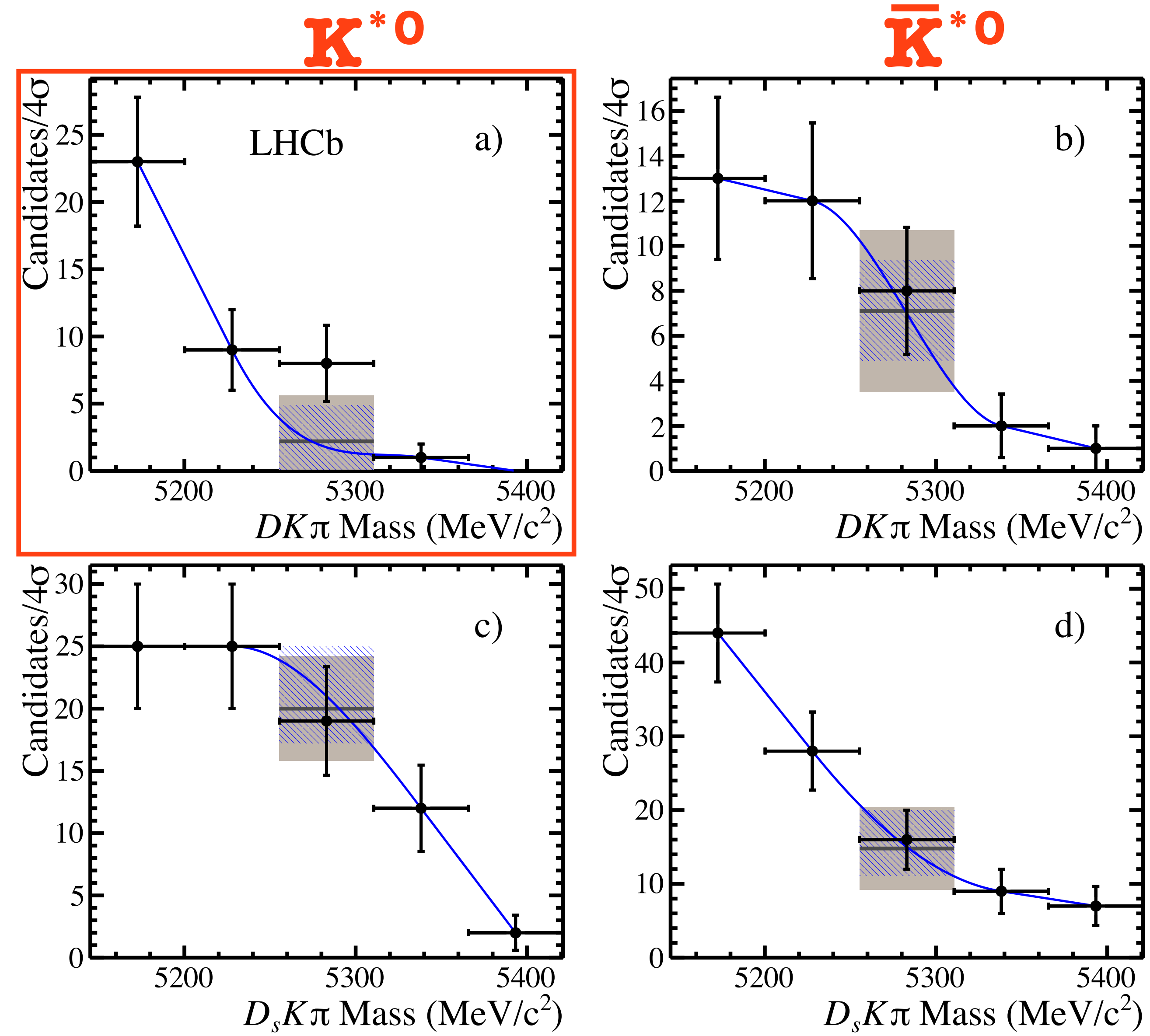
LHCb-PAPER-2012-025
arXiv:1210.1089

- Same Feynman diagrams:



Blue: interpolation

Grey: μ±σ background intervals



- Partially reconstructed background expected to be much larger due to the large K^{*0} mass window. Used sidebands to extract expected yield

Decay	n_{obs}	μ_{bkgd}	σ_{bkgd}	Upper Limit at 90% CL
$B^+ \to D^+ K^{*0}$	8	2.2	3.4	1.8×10^{-6}
$B^+ \to D^+ \overline{K}^{*0}$	8	7.1	3.6	1.4×10^{-6}
$B^+ \to D^+_s K^{*0}$	19	20.0	4.2	3.5×10^{-6}
$B^+ \to D^+_s \overline{K}^{*0}$	16	14.8	5.6	4.4×10^{-6}

No signal hypothesis excluded at 89% CL

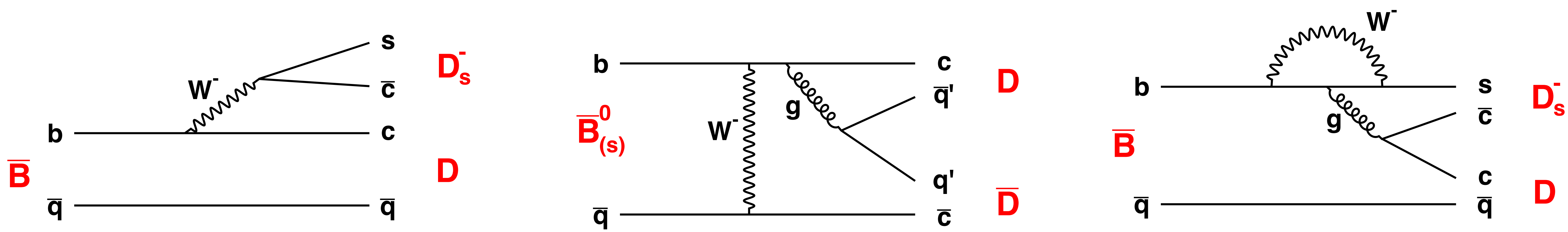
$$\mathcal{B}(B^+ \to D^+ K^{*0}) = 0.8^{+0.6}_{-0.5} \times 10^{-6}$$

Best limits set to-date!

Studies of $B_{(s)} \to D D'$ decays

LHCb-PAPER-2012-050
arXiv:1302.5854

- Double charm decays of B meson can be interested for a variety of reasons
  - $B_d \to DD$ and $B_d \to D_sD$ can be used to measure γ
  - $\sin 2\beta$ from $B^0_d \to D^+D^-$
  - $\sin 2\beta_s$ and $\Delta\Gamma_s/\Gamma_s$ from $B_s \to D_sD_s$
- In addition, the study of $B \to DD'$ can also provide better theoretical understanding of the processes that contribute to the B meson decay

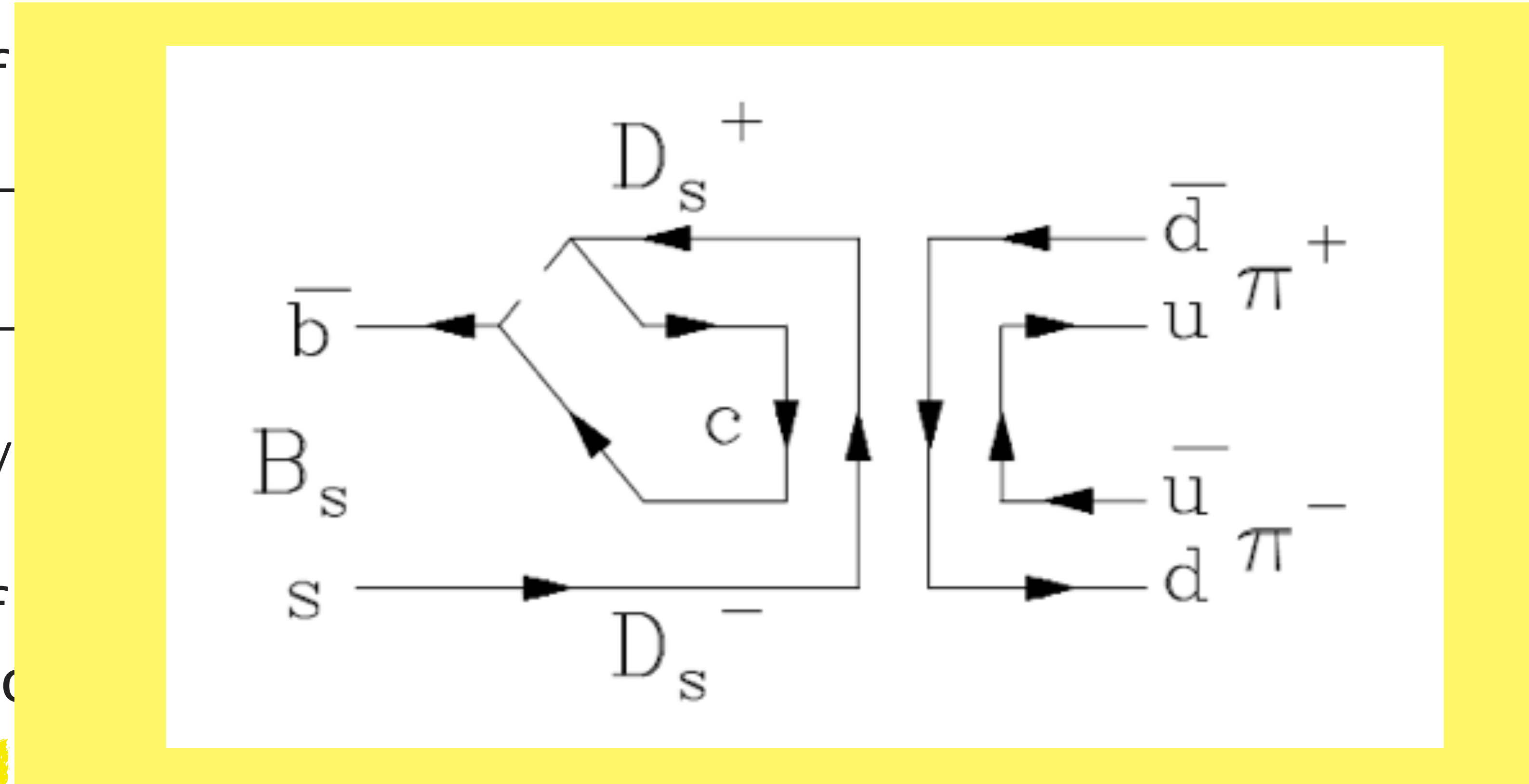


  - many of these decays are mediated by the W-exchange, penguin (short range) and **also rescattering (long range)**
  - important to know BF of these decays that might substantially alter branching fraction estimates based on the CKM matrix elements in processes that can be generated by rescattering through this modes

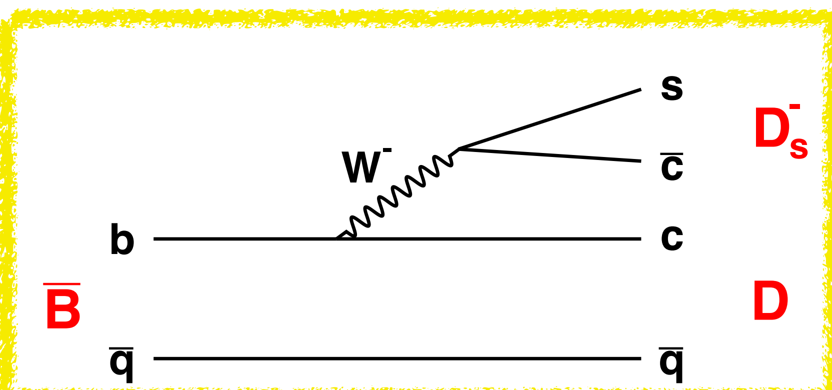
Studies of $B_{(s)} \rightarrow D\,D'$ decays

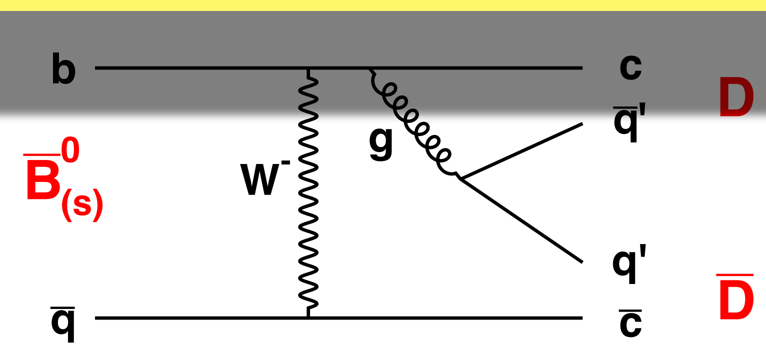
LHCb-PAPER-2012-050
arXiv:1302.5854

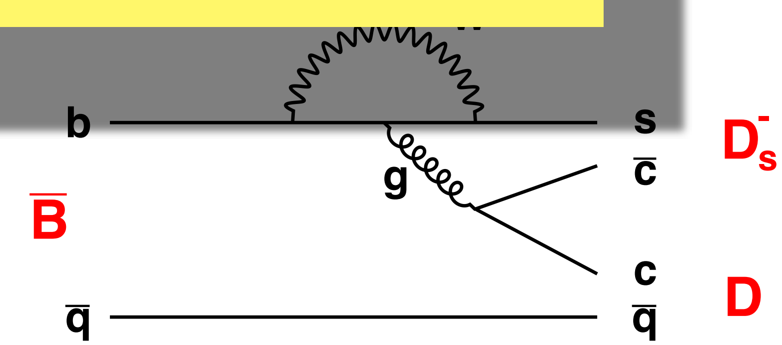
- Double charm decays of
  - $B_d \rightarrow DD$ and B_d–
  - sin2β from B^0_d–
  - sin2β_s and $\Delta\Gamma_s$/



- In addition, the study of
  understanding of the pr







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Studies of $B_{(s)} \to D D'$ decays

LHCb-PAPER-2012-050
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$\overline{B}^0_s \to D^+D^-$, $\overline{B}^0_s \to D^+_sD^-$, $\overline{B}^0_s \to D^0\overline{D}^0$, $\overline{B}^0 \to D^0\overline{D}^0$

$B^0 \to D^+D^-$, $B^0 \to D^+_sD^-$, $B^- \to D^0D^-_s$

with $D^0 \to K^-\pi^+\pi^-$ or $K^-\pi^+\pi^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D^+_s \to K^-K^+\pi^+$

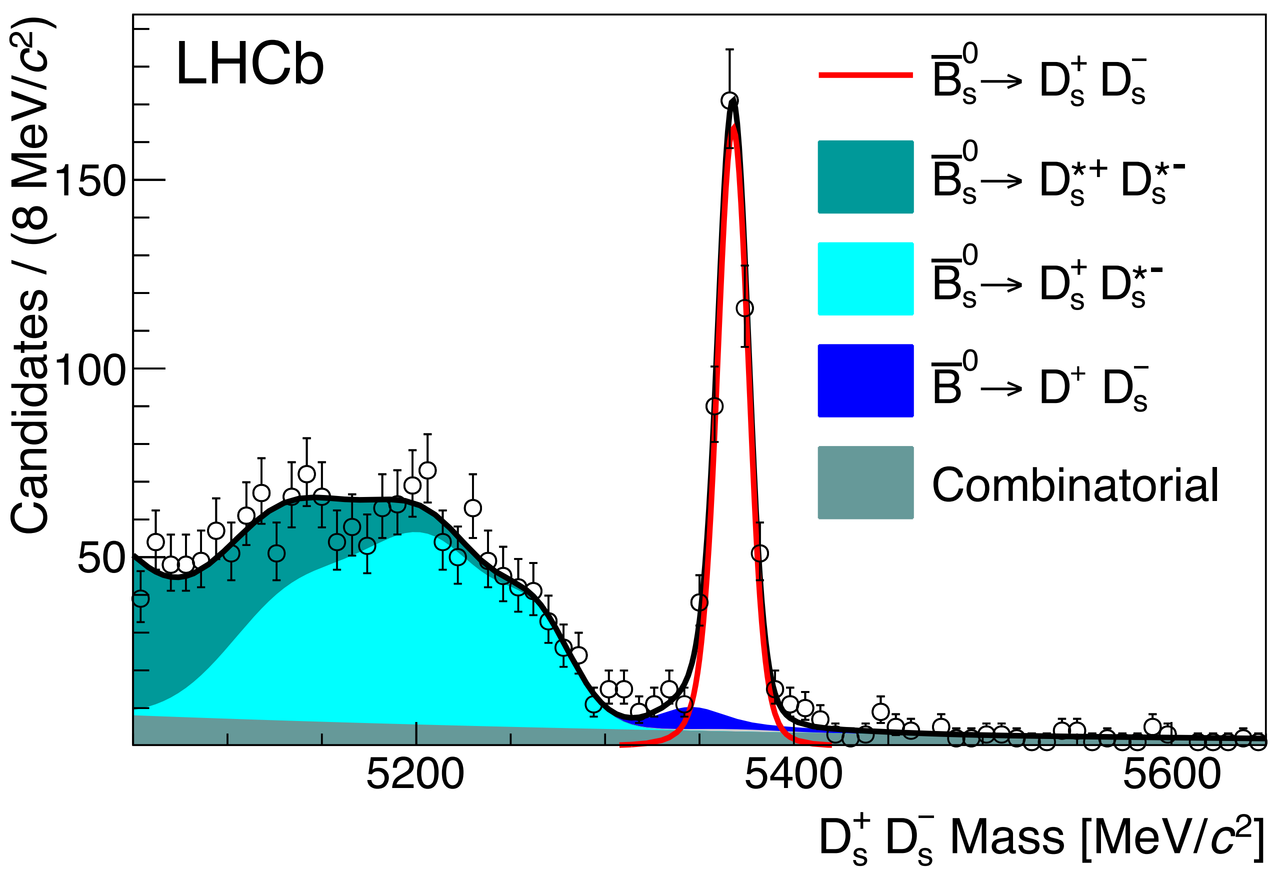
$B^0_s \to D^+_sD^-_s$

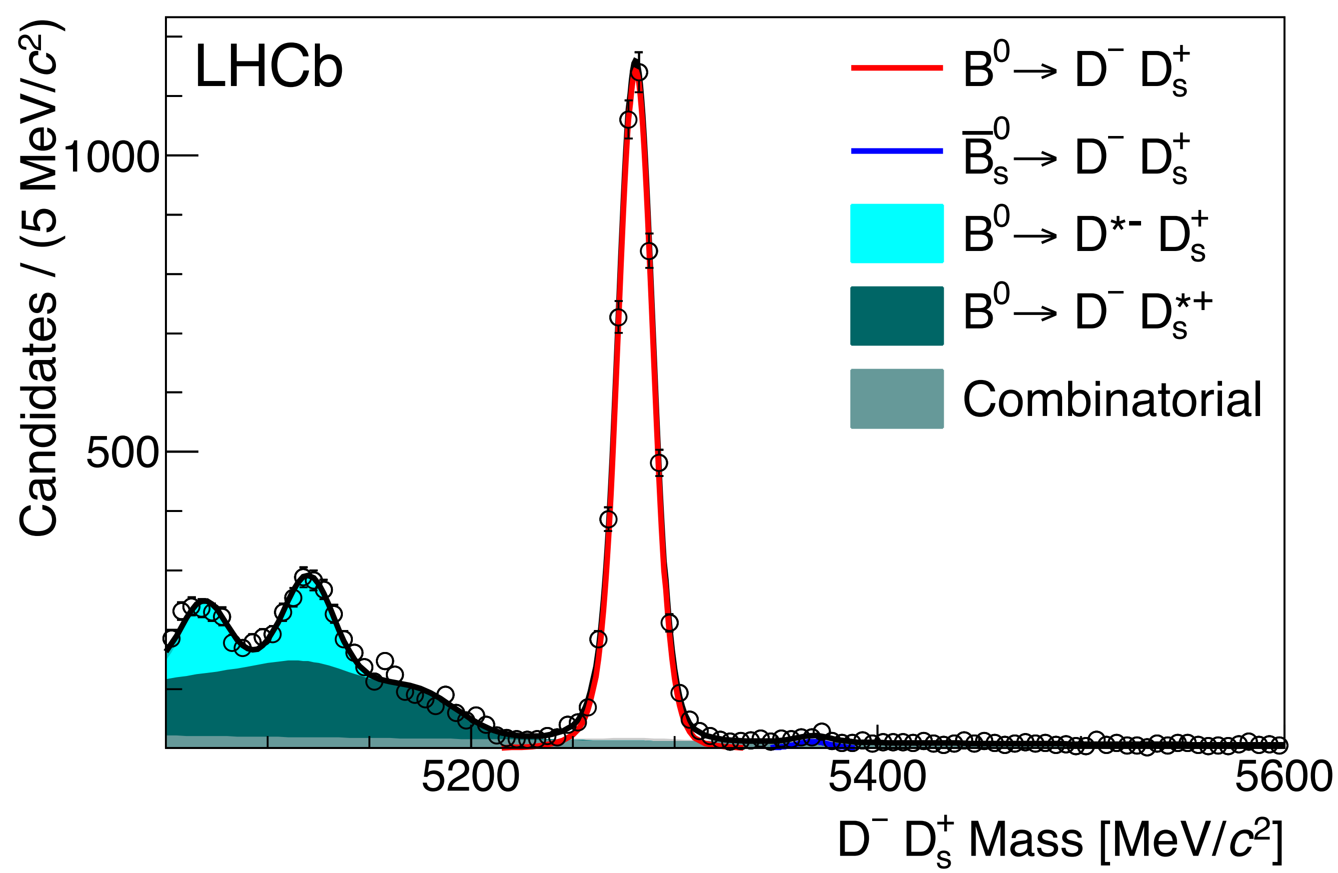
$B^- \to D^0D^-_s$

(already seen)

$\overline{B}^0_s \to D^+_sD^-_s$: 451±23

$B^0 \to D^-D^+_s$: 5157±64



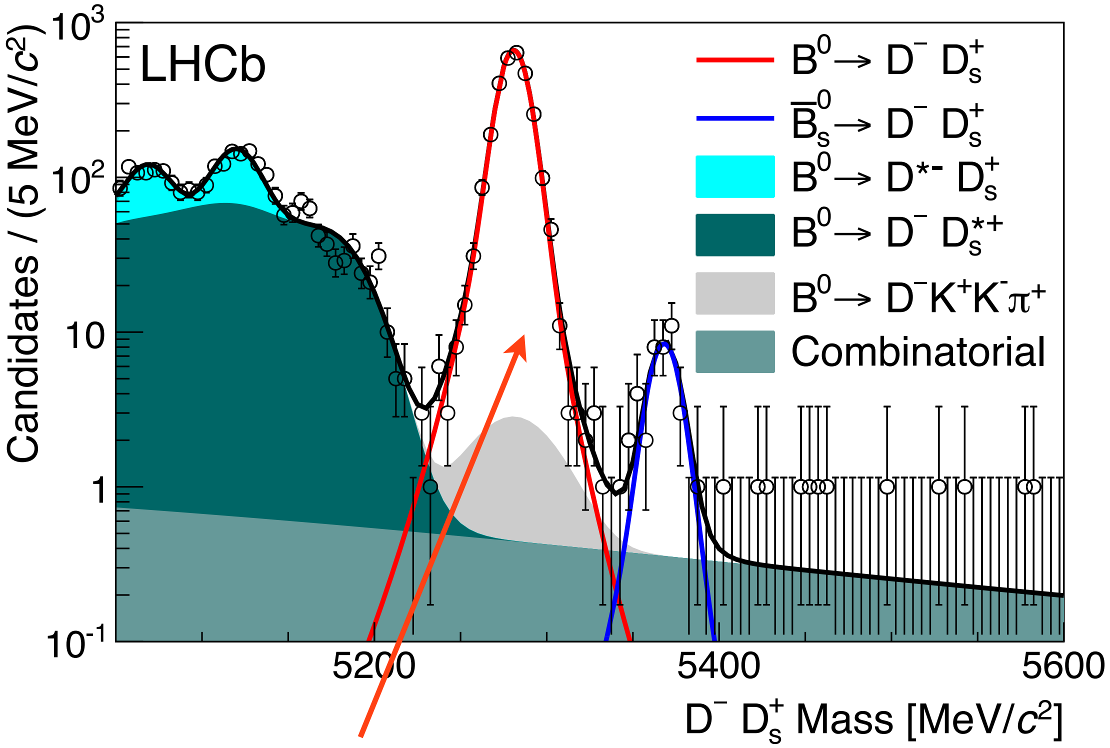


Studies of $B_{(s)} \to D\,D'$ decays

LHCb-PAPER-2012-050
arXiv:1302.5854

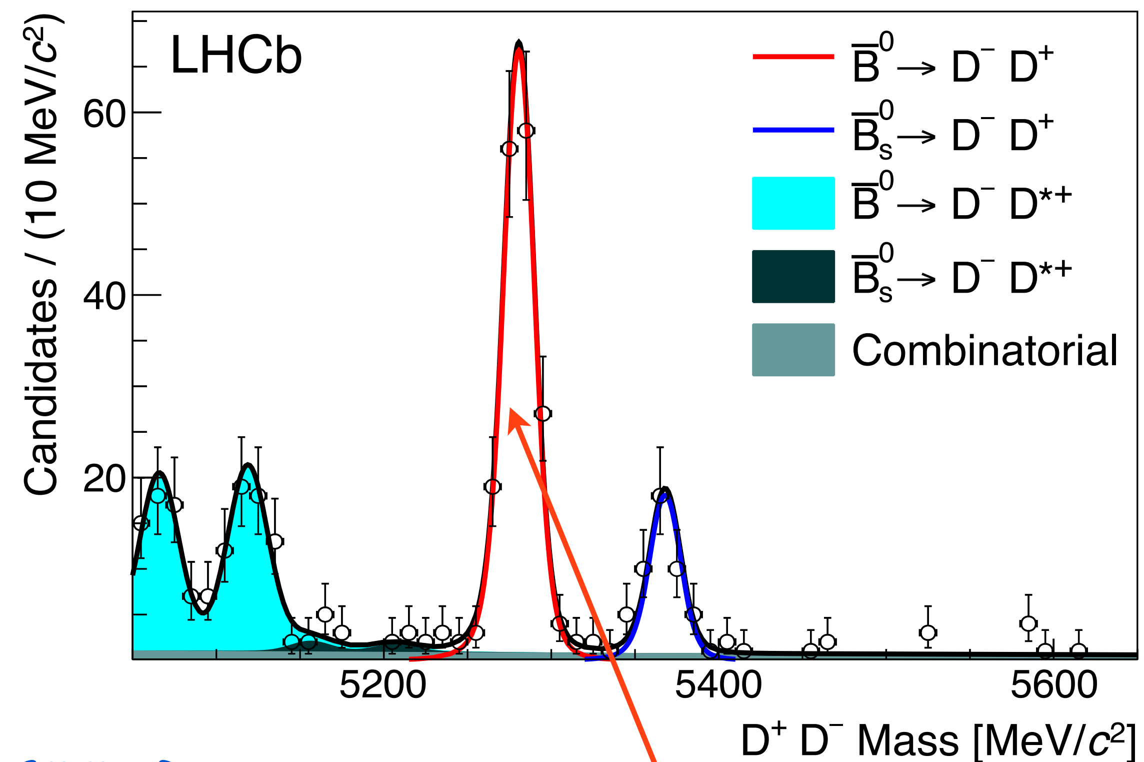
First observations!

$\overline{B}^0_s \to D^+_s D^-$: 36±6 (10σ)



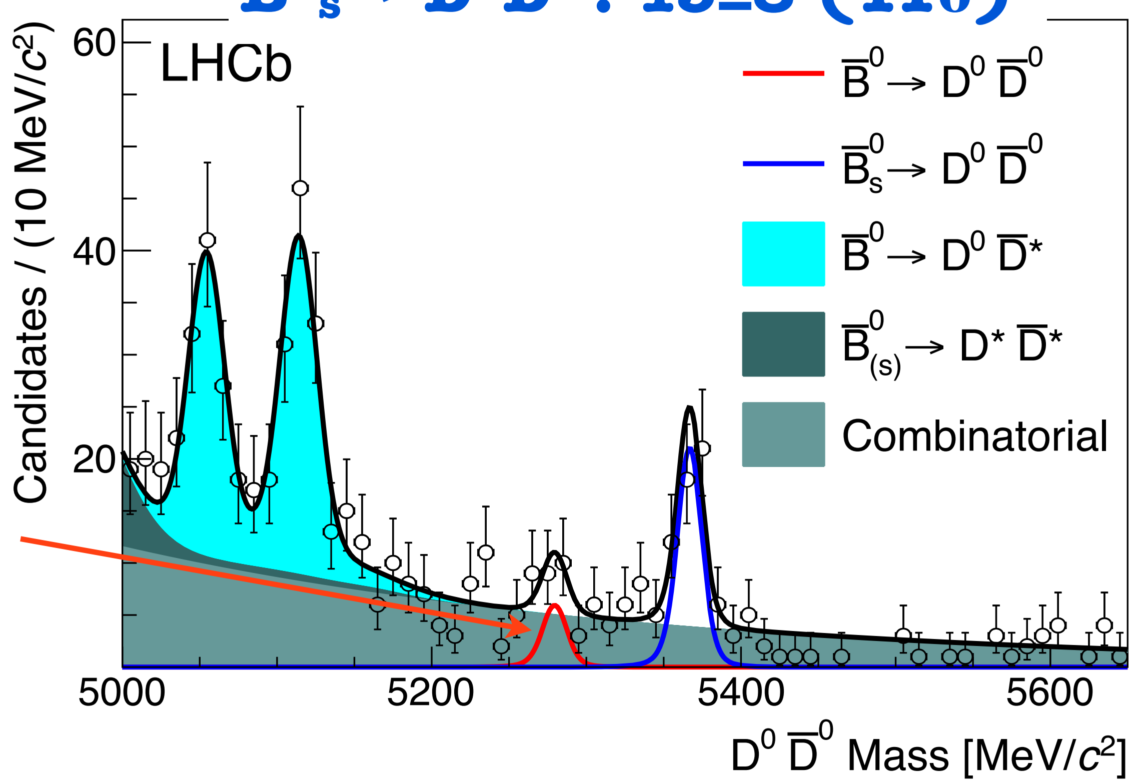
2832±53

$\overline{B}^0_s \to D^+ D^-$: 43±7 (11σ)



165±13

$\overline{B}^0_s \to D^0 \overline{D}^0$: 45±8 (11σ)



13±6 (2.4σ)

Studies of $B_{(s)} \to D D'$ decays

LHCb-PAPER-2012-050
arXiv:1302.5854

$B(\bar{B}^0_s \to D^+D^-)/B(\bar{B}^0 \to D^+D^-)$	$1.08 \pm 0.20 \pm 0.10$
$B(\bar{B}^0_s \to D^+_sD^-)/B(B^0 \to D^+_sD^-)$	$0.050 \pm 0.008 \pm 0.004$
$B(\bar{B}^0_s \to D^0\bar{D}^0)/B(B^- \to D^0D^-_s)$	$0.019 \pm 0.003 \pm 0.003$
$B(\bar{B}^0 \to D^0\bar{D}^0)/B(B^- \to D^0D^-_s)$	$0.0014 \pm 0.0006 \pm 0.0002$
$B(\bar{B}^0_s \to D^+_sD^-_s)/B(B^0 \to D^+_sD^-)$	$0.56 \pm 0.03 \pm 0.04$
$B(B^- \to D^0D^-_s)/B(B^0 \to D^+_sD^-)$	$1.22 \pm 0.02 \pm 0.07$

First observations!

strong hint for $B^0 \to \underline{D}^0D^0$

$R(BF) < 0.0024$ (90%CL)

Taking the world average for $B(B^0 \to D^+_sD^-) = (7.2 \pm 0.8) \times 10^{-3}$

$B(B^- \to D^0D^-_s) = (8.6 \pm 0.2 \pm 0.4 \pm 1.0\ (\text{norm})) \times 10^{-3}$

$B(\bar{B}^0_s \to D^+_sD^-_s) = (4.0 \pm 0.2 \pm 0.3 \pm 0.4\ (\text{norm})) \times 10^{-3}$

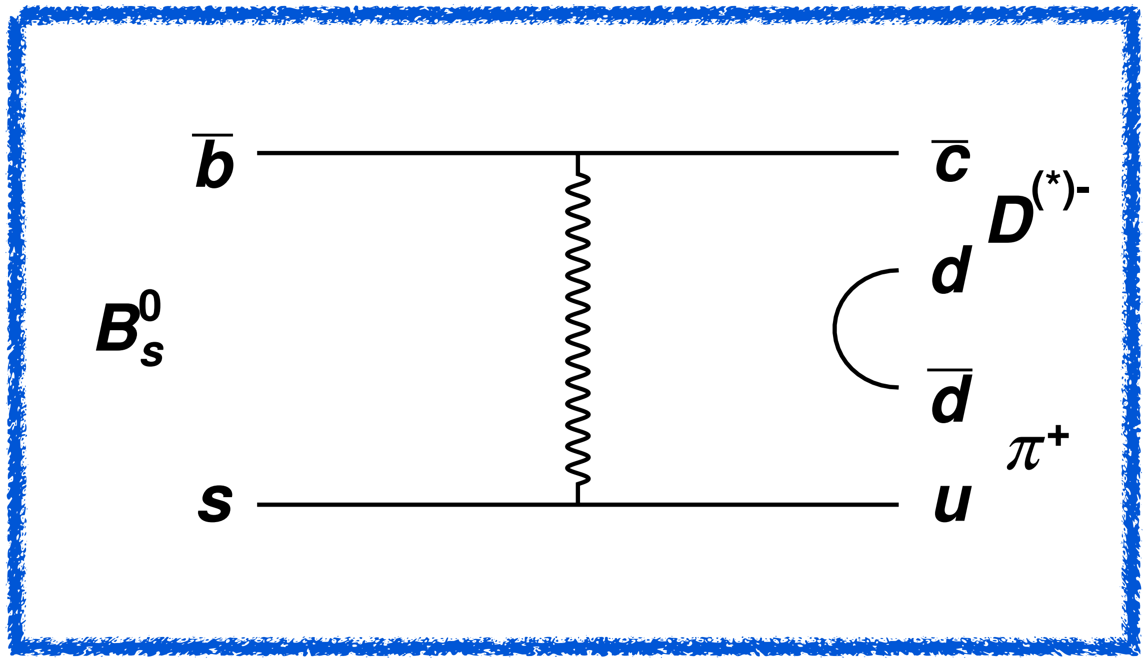
Consistent and more precise than the current world average

- Further measurements are needed to establish wether long-distance processes are dominant in these hadronic B decays

Search for the decay $B^0_s \to D^{*\mp}\pi^{\pm}$

LHCb-PAPER-2012-056
arXiv:1302.6446

- Pure weak exchange decay can be used to disentangle the contributions from different decay diagrams and from rescattering
- Rescattering contributions to this decay are predicted to be small

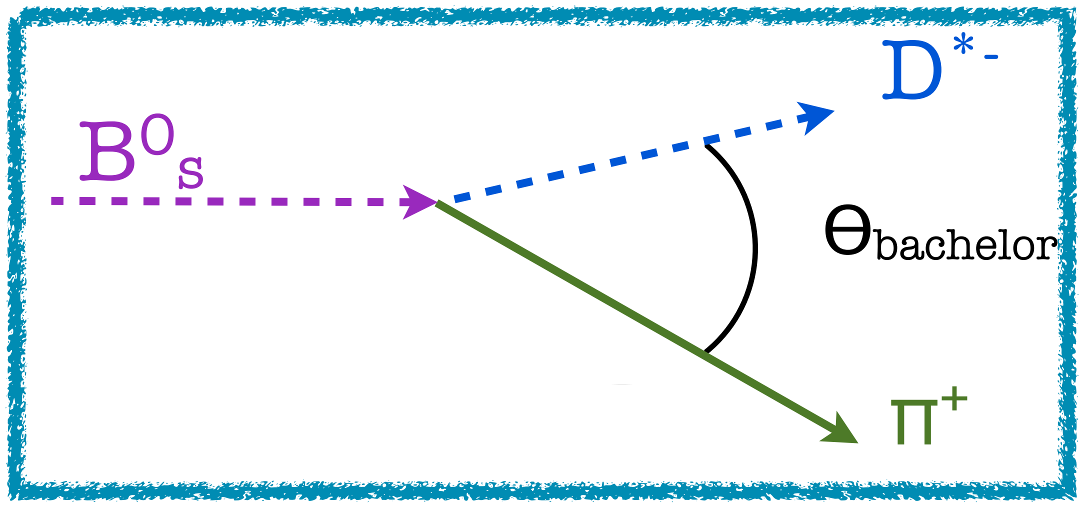


- Interplay with other decays: if **BR ($B^0_s \to \pi^+\pi^-$)** is driven by rescattering then the **BR ($B^0_s \to D^{*+}\pi^-$)** is expected small. If the **BR ($B^0_s \to \pi^+\pi^-$)** is driven by short-distance effects then **BR ($B^0_s \to D^{*+}\pi^-$)** could be much larger.

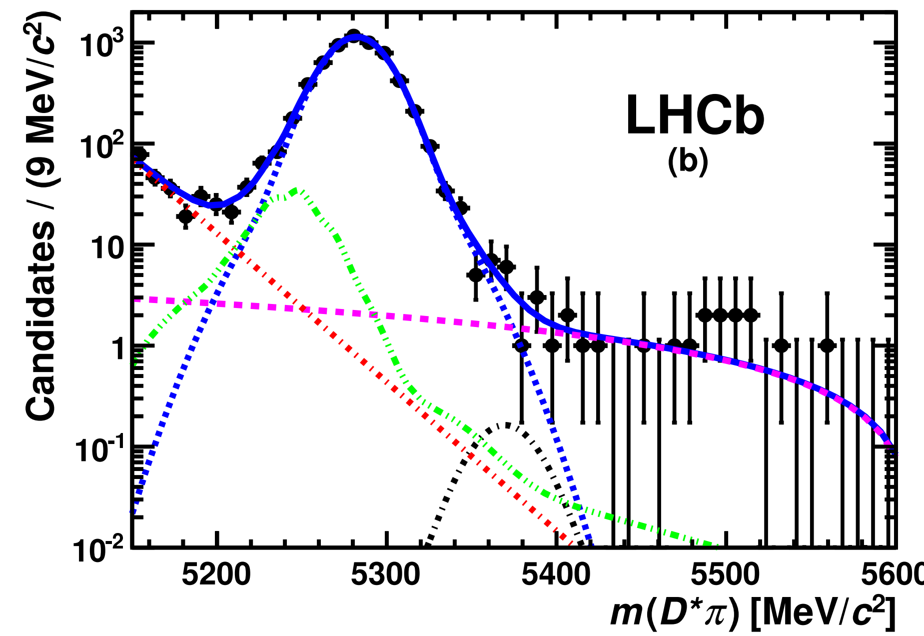
Search for the decay $B^0_s \rightarrow D^{*\mp}\pi^{\pm}$

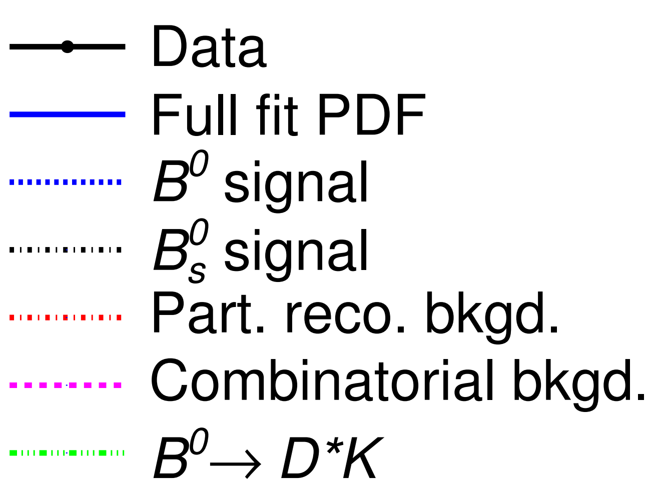
LHCb-PAPER-2012-056
arXiv:1302.6446

- Simultaneous fit to five bins based on the opening angle between the D^* and π momenta in the lab frame (increased sensitivity by 20%)

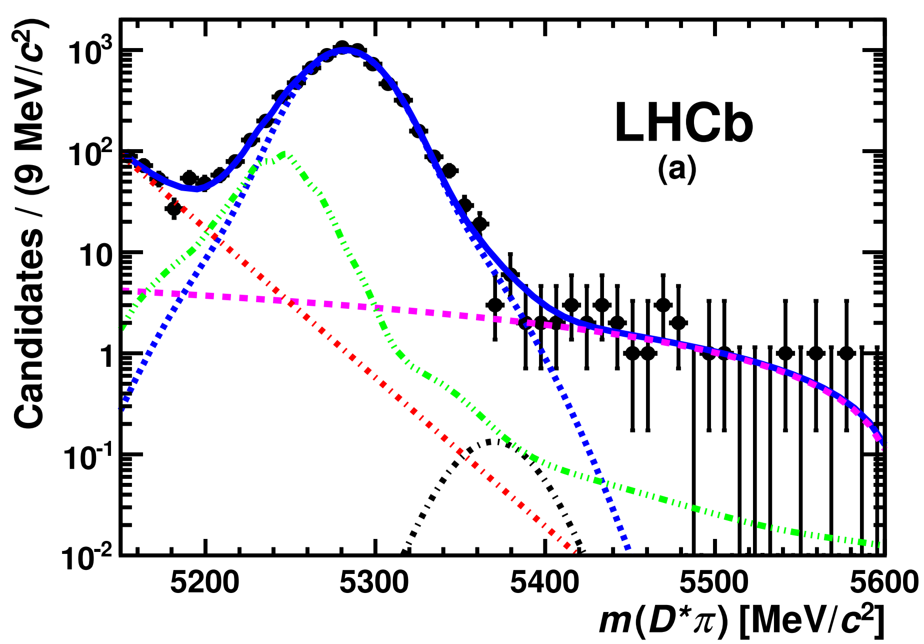


0.046–0.067rad

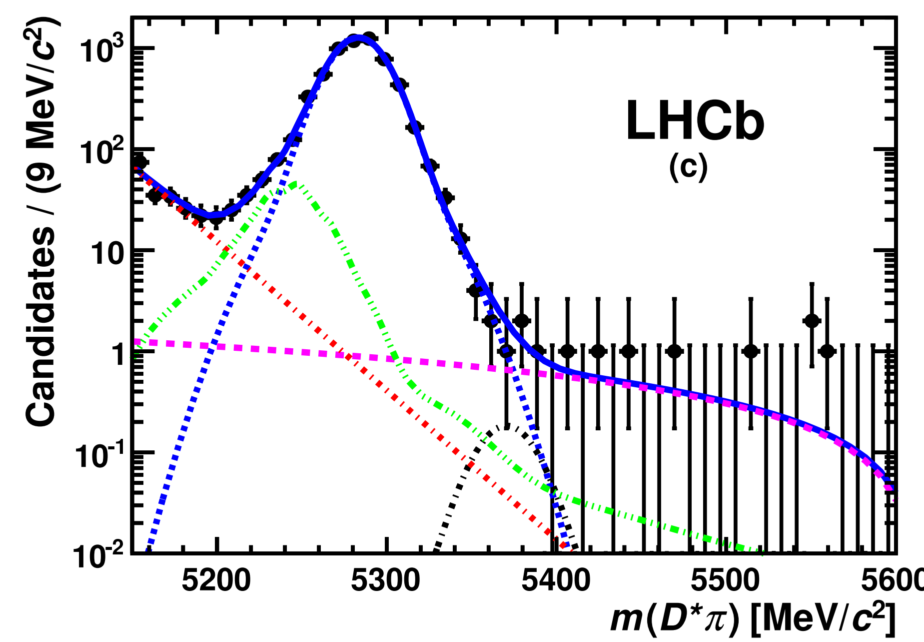




0.0–0.046rad



0.067–0.092rad



Search for the decay $B^0_s \to D^{*\mp}\pi^\pm$

LHCb-PAPER-2012-056
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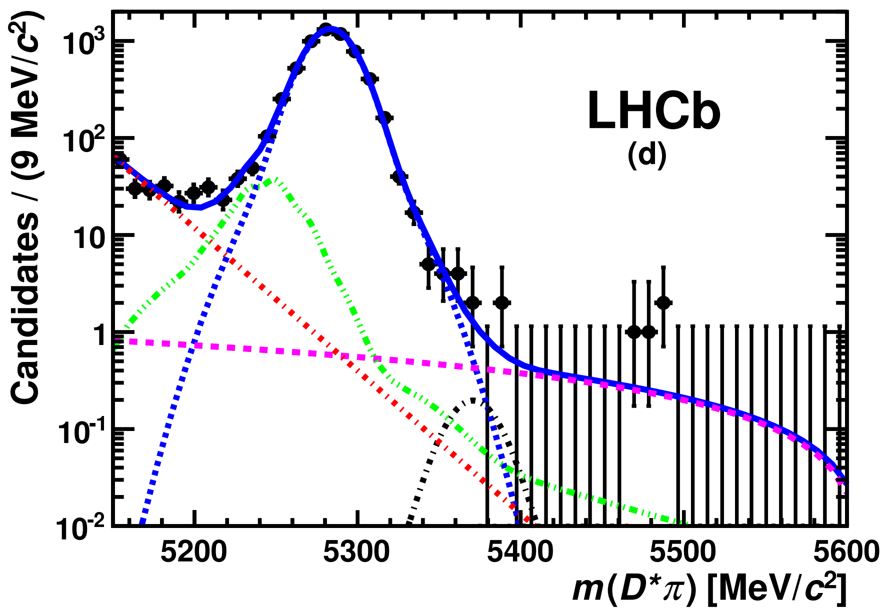
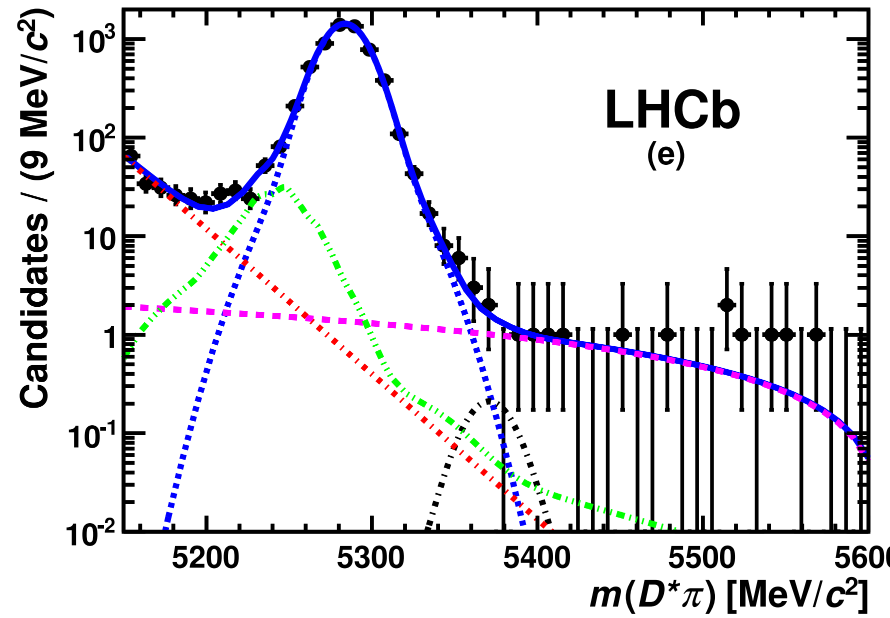


0.092–0.128 rad



0.128–0.4 rad

No significant signal observed

Using a Bayesian approach to set upper limits:

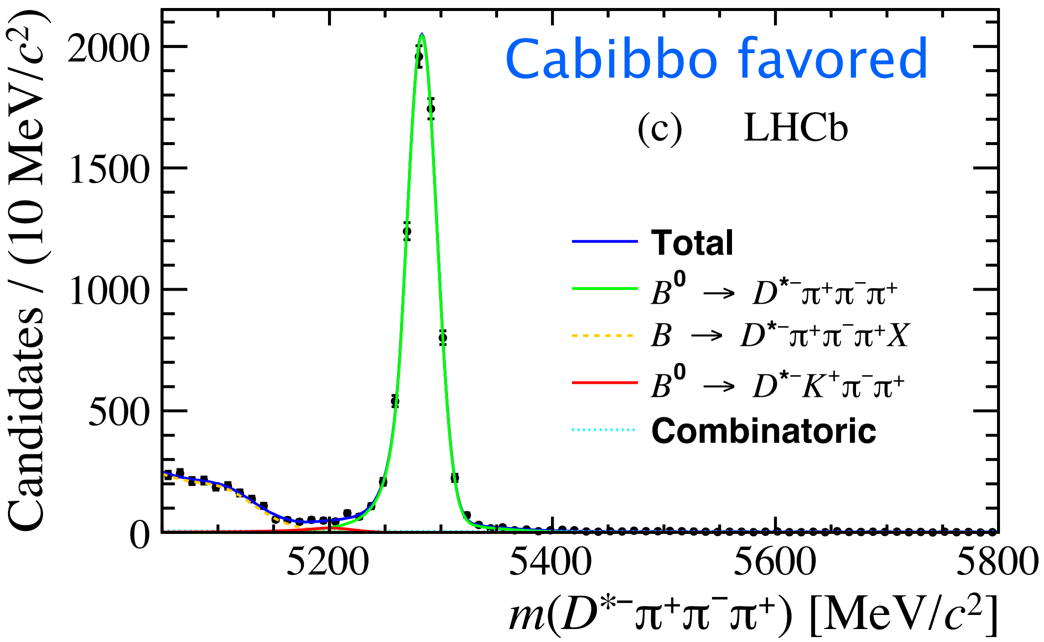
$B(B^0_s \to D^{*\mp}\pi^\pm) < 6.1\ (7.8) \times 10^{-6}$ at 90% (95%) CL.

The absence of a detectable signal could indicate that rescattering effects could make significant contributions to decays such as $B^0_s \to \pi\pi$ and $B_s \to DD'$

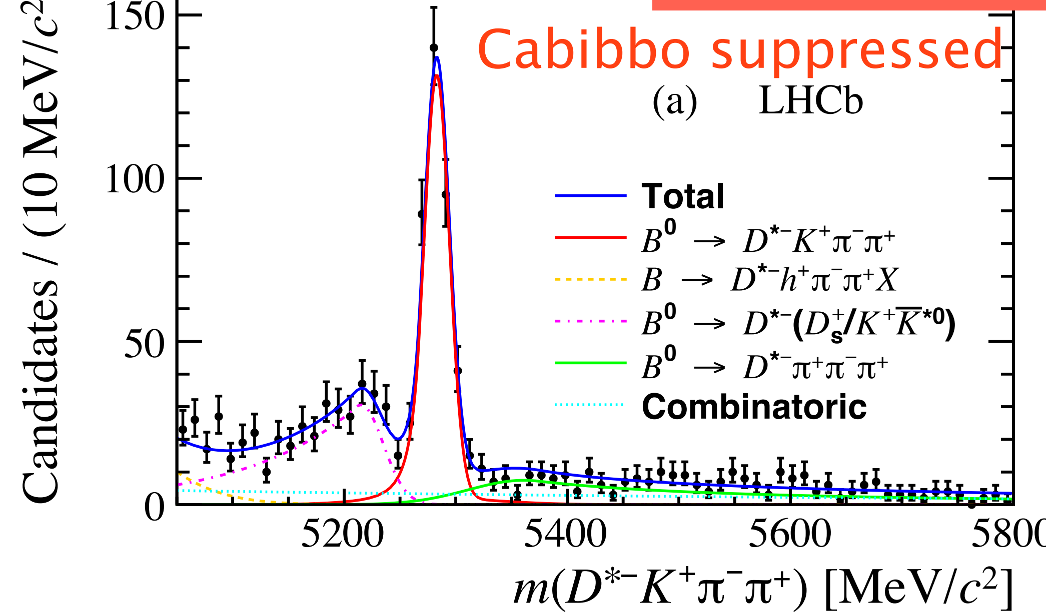
$B^0 \to D^{*-}\pi^+\pi^-\pi^+$, $B^0 \to D^{*-}K^+\pi^-\pi^+$ decays

LHCb-PAPER-2012-046
arXiv:1303.6861

- The decay $B^0 \to D^{*-}[(\bar{D}^0 \to K^+\pi^-)\pi^-]\pi^+\pi^-\pi^+$ is of interest because of its potential use as normalization mode for $B^0 \to D^{*-}\tau^+\nu_\tau$ with $\tau^+ \to \pi^+\pi^-\pi^+\nu$. Latter decay showed an excess over the SM BF prediction (PRL109(2012)101802, BaBar)



First observation!



$\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)/\mathcal{B}(B^0 \to D^{*-}\pi) = 2.64 \pm 0.04 \pm 0.13$

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

Using the world average $\mathcal{B}(B^0 \to D^*\pi) = (2.76 \pm 0.13) \times 10^{-3}$

$\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+) = (7.27 \pm 0.11 \pm 0.36 \pm 0.34\,(\text{norm})) \times 10^{-3}$

Improved current world average value $(7.0 \pm 0.8) \times 10^{-3}$ to $(7.19 \pm 0.43) \times 10^{-3}$

Using the new world average $\mathcal{B}(B \to D^*\pi\pi\pi) = (7.19 \pm 0.43) \times 10^{-3}$

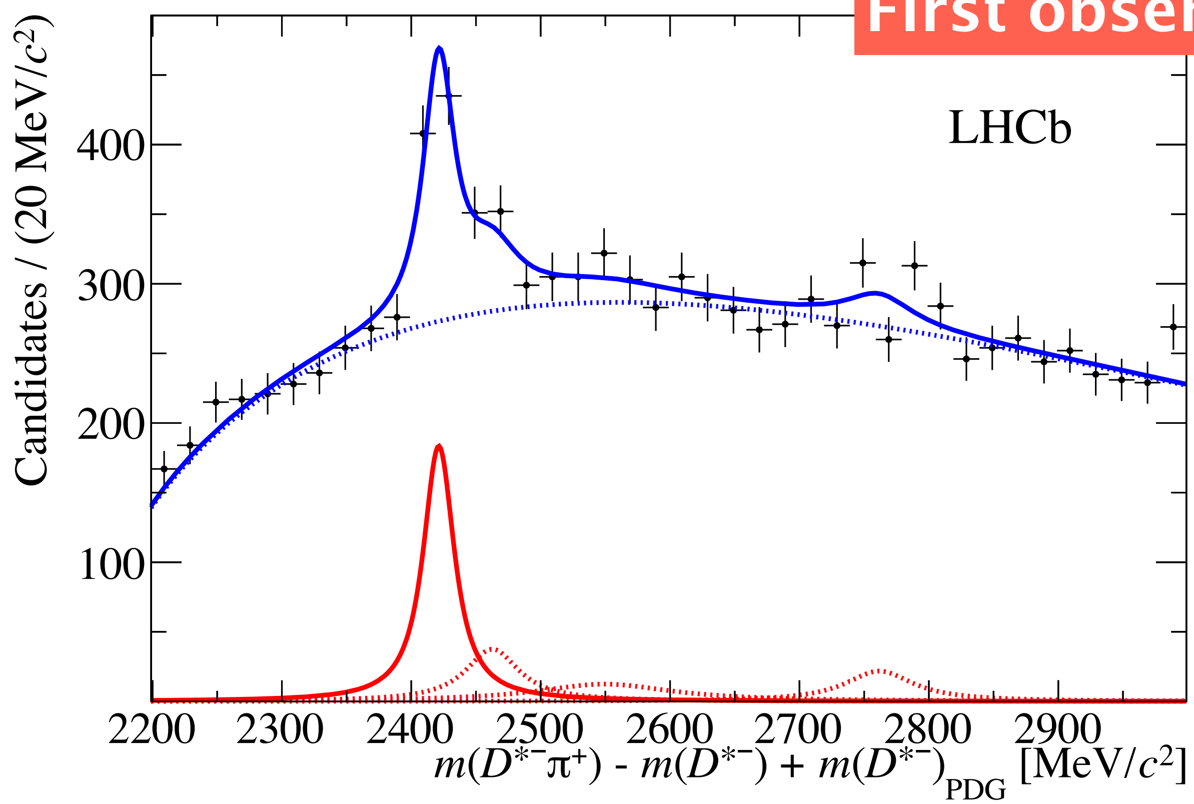
$\mathcal{B}(B^0 \to D^{*-}K^+\pi^-\pi^+) = (4.65 \pm 0.26 \pm 0.25 \pm 0.28\,(\text{norm})) \times 10^{-4}$

Search for exited charm resonance

LHCb-PAPER-2012-046
arXiv:1303.6861

- Search for excited charm by looking in the $D^{*-}\pi^+\pi^-\pi^+$ sample for $D^{**0} \to D^{*-}\pi$. For each $D^{*}\pi^-$ the corrected mass $M(D^{*}\pi^-) = m(D^{*}\pi^-) - m(D^{*-}) + m(D^{*-})_{PDG}$ is computed

First observation!



- First observation of the decay through $D_1(2420)^0$. Other resonants included in the fit but found to be negligible

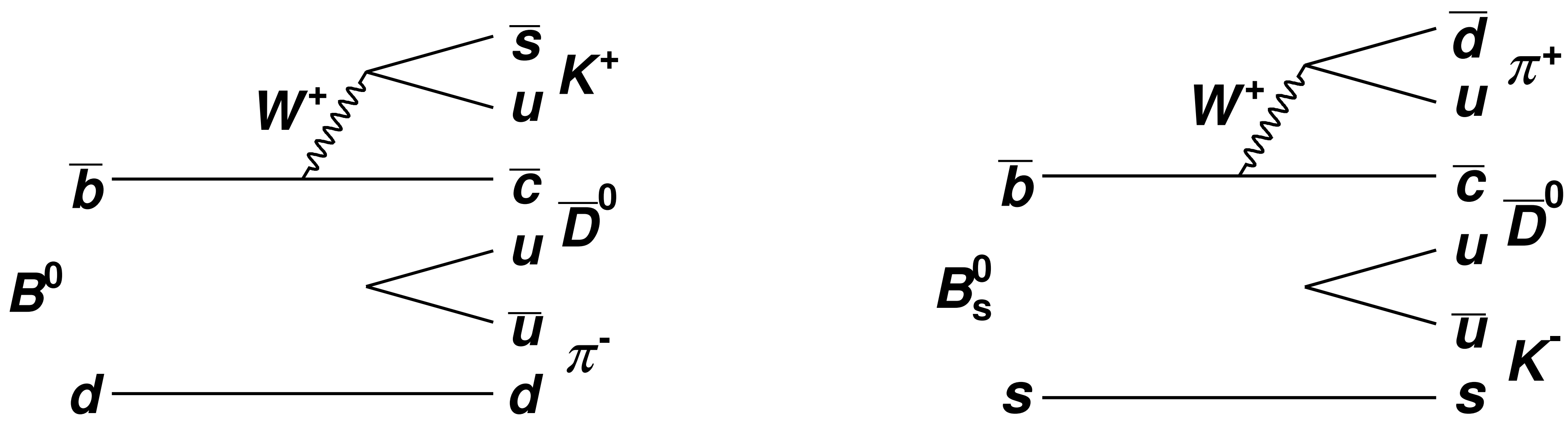
$B(B^0 \to D_1(2420)^0 (D^{*-}\pi^+)\pi^+\pi^-\pi^+) / B(B^0 \to D^{*-}\pi^+\pi^-\pi^+) = (2.04 \pm 0.42 \pm 0.22) \times 10^{-2}$

BF measurement of $B^0_s \to D^0 K^- \pi^+$

LHCb-PAPER-2013-022
arXiv:1304.6317

- The precise measurement of the angle gamma is one of the primary objectives of contemporary flavor physics. The use of additional channels to improve further the precision is of great interest

- The $B^0 \to D^0 K^+ \pi^-$ decay is particularly sensitive to the angle gamma: the interfering amplitudes ($b \to c\,\bar{u}\,s$ and $b \to u\,\bar{c}\,s$) are of the same order



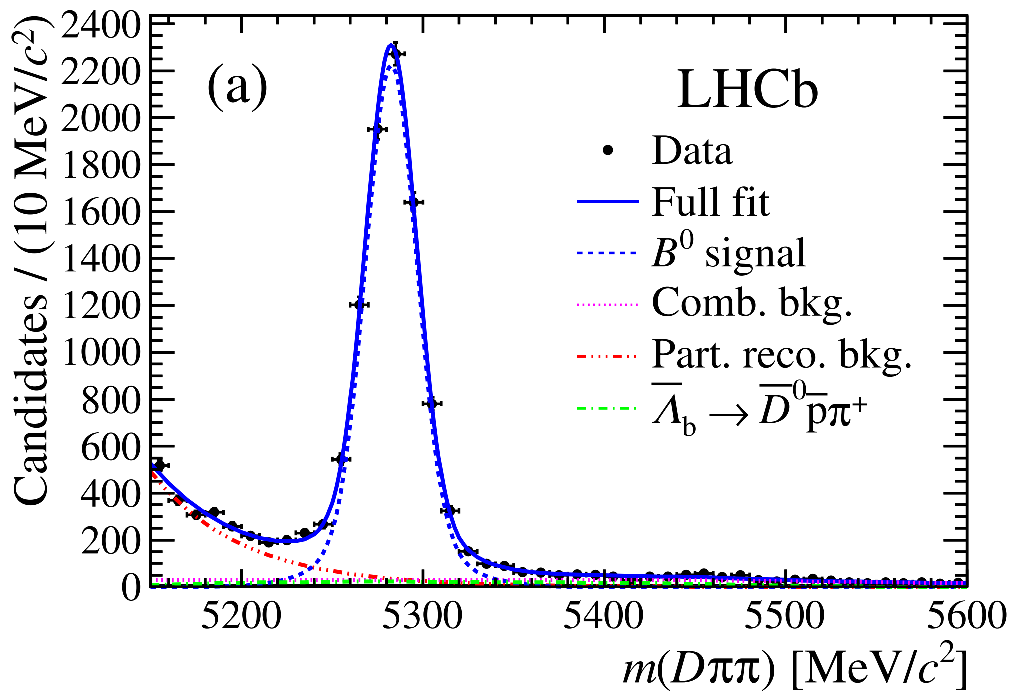
- Previous measurement from BaBar give $B(B \to DK\pi) = (88 \pm 15 \pm 9) \times 10^{-6}$. No measurement for the $B^0_s \to D^0 K^- \pi^+$ performed before.

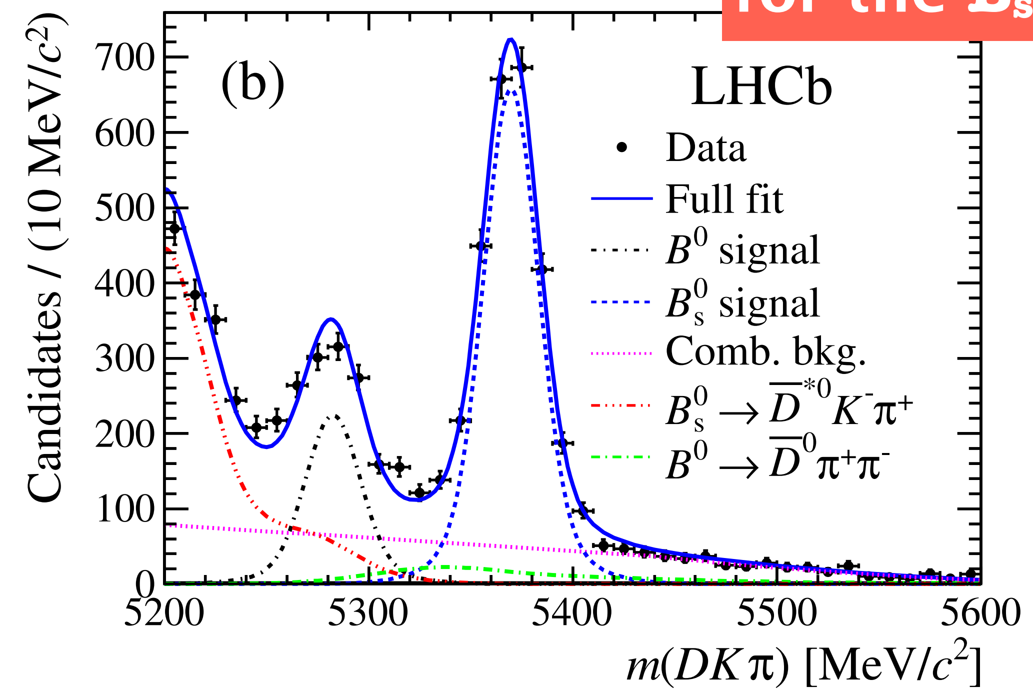
- $B^0_s \to D^0 K^- \pi^+$ and $B^0_s \to D^{*0} K^- \pi^+$ serious backgrounds for $B^0 \to D^0 K^+ \pi^-$, the Dalitz plot structure is unknown. Its BF needed to reduce systematic uncertainties in the determination of gamma.

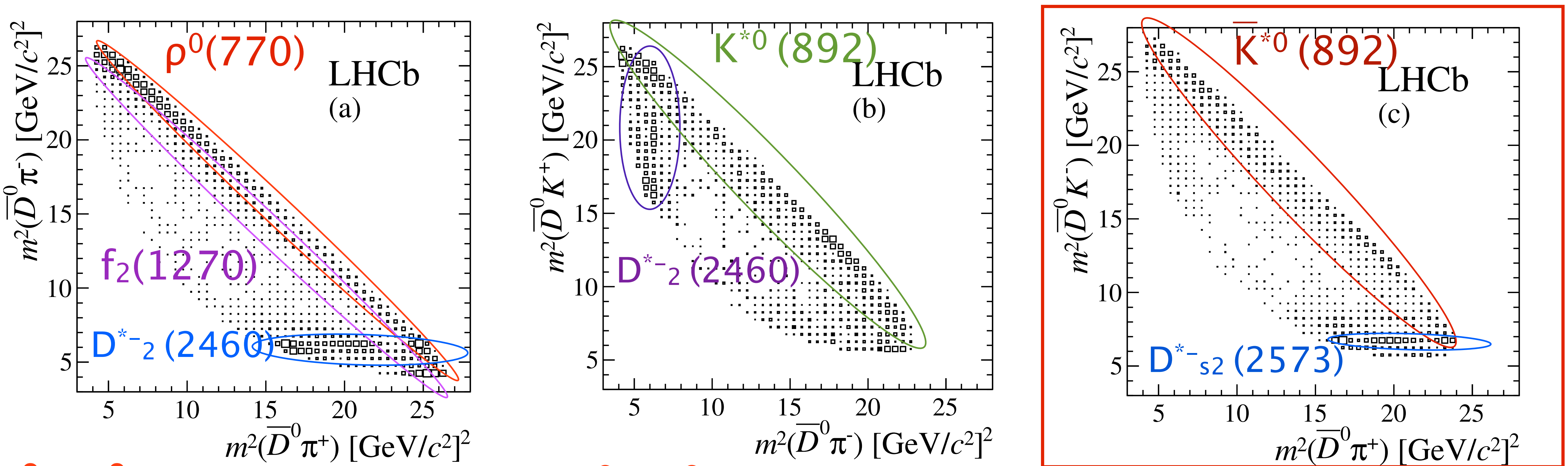
BF measurement of $B^0_s \to D^0 K^- \pi^+$

LHCb-PAPER-2013-022
arXiv:1304.6317

First observation for the B_s signal!







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

BF measurement of $B^0_s \to D^0 K^- \pi^+$

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- The decay $B_s \to DK\pi$ has been observed for the first time

$$\mathcal{B}(B^0_s \to D^0 K^- \pi^+)/\mathcal{B}(B^0 \to D^0 \pi^+ \pi^-) = 1.18 \pm 0.05 \pm 0.12$$

Using the world average value $\mathcal{B}(B^0 \to D^0 \pi^+ \pi^-) = (8.5 \pm 0.4 \pm 0.8) \times 10^{-4}$,

$$\mathbf{\mathcal{B}(B^0_s \to D^0 K^- \pi^+)} = (1.00 \pm 0.04 \pm 0.10 \pm 0.10(\text{norm})) \times 10^{-3}$$

- The $B^0 \to D^0 K^- \pi^+$ relative branching fraction is measured to be

$$\mathcal{B}(B^0 \to D^0 K^+ \pi^-)/\mathcal{B}(B^0 \to D^0 \pi^+ \pi^-) = 0.106 \pm 0.007 \pm 0.008$$

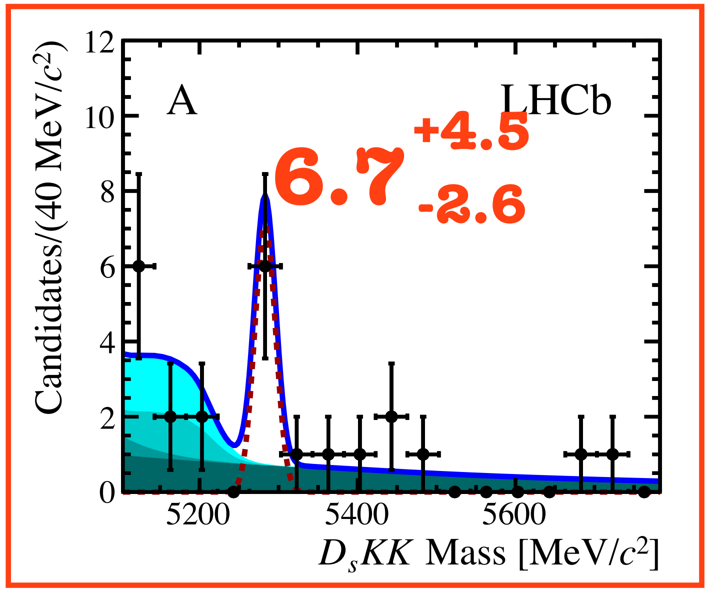
Using the value for $B^0 \to D^0 \pi^+ \pi^+$

$$\mathbf{\mathcal{B}(B^0 \to D^0 K^+ \pi^-)} = (9.0 \pm 0.6 \pm 0.7 \pm 0.9\,(\mathcal{B})) \times 10^{-5}$$

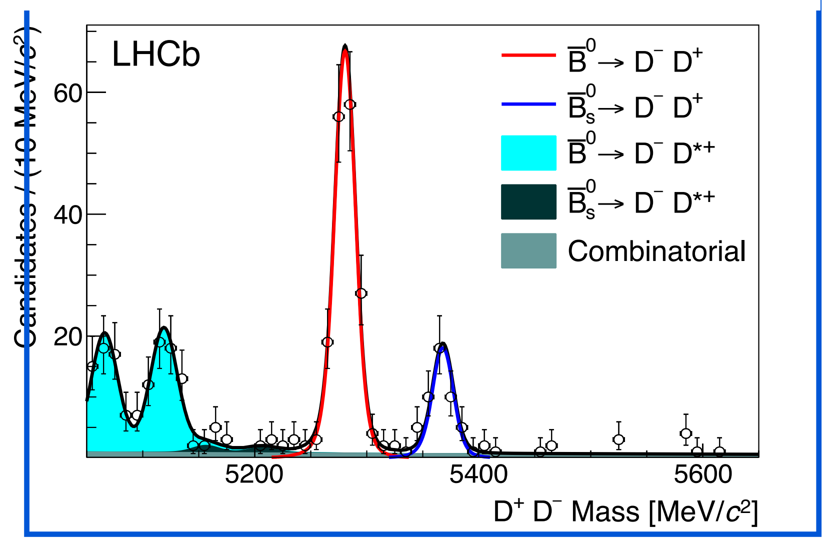
Which is the most precise measurement to date!

Summary

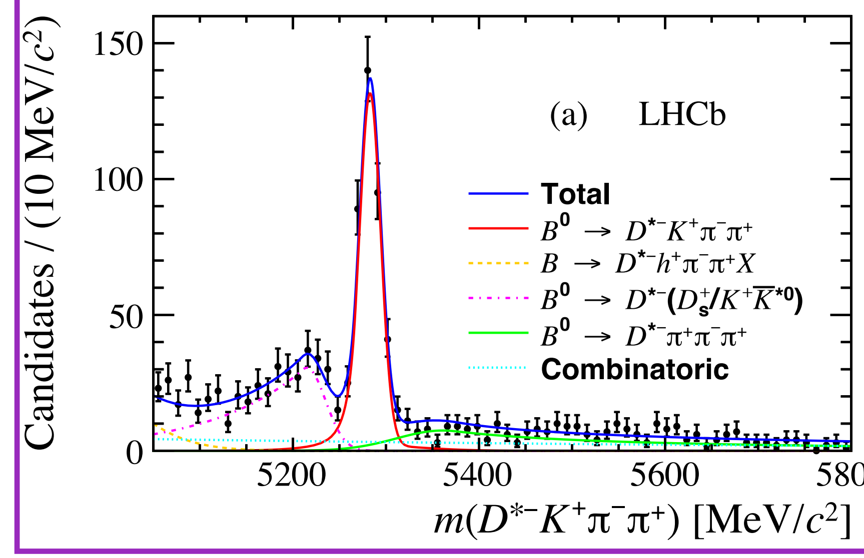
$B^+ \rightarrow D^+_s \Phi$



$B^0_s \rightarrow D^+D^-$: 43±7 (11σ)



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



$B^0_s \rightarrow D^+_s D^-$: 36±6 (10σ)
$B^0_s \rightarrow \overline{D^0} D^0$: 45±8 (11σ)

- Have presented a selection of recent results of hadronic B decays at LHCb
- Different decay modes that can be used to probe the CKM matrix elements and provide laboratory to study final state interactions
- Firsts observations of very suppressed modes and improved branching fraction ratios using the 2011 data set ($1fb^{-1}$)
- Still room for improvement! Measurements with the full 2011+2012 data are coming soon, stay tuned!

Thanks!