Studies of hadronic B decays to final states containing open charm mesons at LHCb

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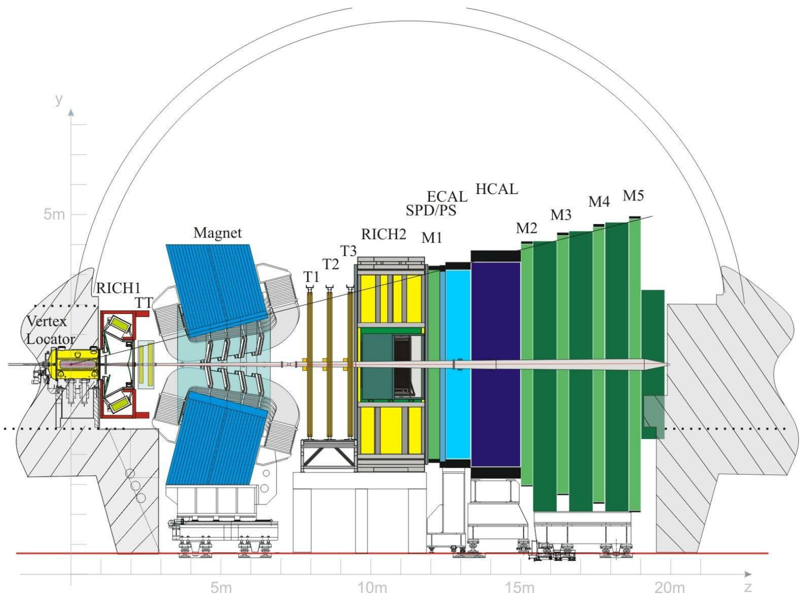
on behalf of the LHCb collaboration

Heavy flavour physics at LHCb

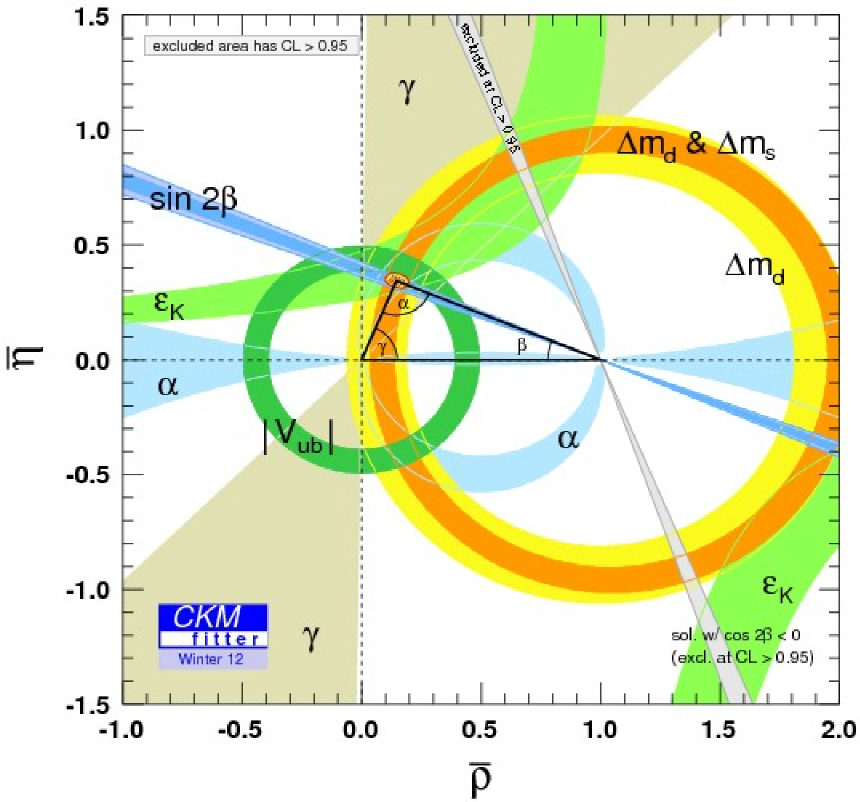
- LHCb detector well suited for the study of heavy flavoured hadronic decays, thanks to:
  - Geometry, $2 < \eta < 5$.
  - Vertex locator:
    - Precise reconstruction of primary and secondary vertices (resolution = 45 fs for $B_s \rightarrow J/\psi\ \varphi$ and for $B_s \rightarrow D_s\ \pi$).
  - RICHs particle identification detectors:
    - Excellent $K - \pi$ separation (K identification efficiency = 95 % with 5 % of pion misidentification).
  - LHC collision energy:
    - All type of B hadrons produced ($B^{\pm}$, B^0, B_s^0, b-baryons, $B_c^{\pm}$).
    - Big boost, long-lived particles fly over long distances.
      - Easy secondary vertex separation.
  - Hadronic trigger (HCAL+ECAL):
    - Able to select B decays to open charm purely hadronic final states.



Heavy flavour physics at LHCb

- B → D X decays at LHCb:
  - Important for precise CKM γ measurements at tree level.
    - *c.f.* A. Powell's presentation this afternoon.
  - Check CKM mechanism consistency (New Physics effects).
  - Observations of new decay modes.

- Outline of this talk:
  - $B^0 \to D K^{*0}$
  - $B_{(s)}^0 \to \overline{D}^0 K^+ K^-$
  - $\overline{B}_s^0 \to D \overline{D}'$



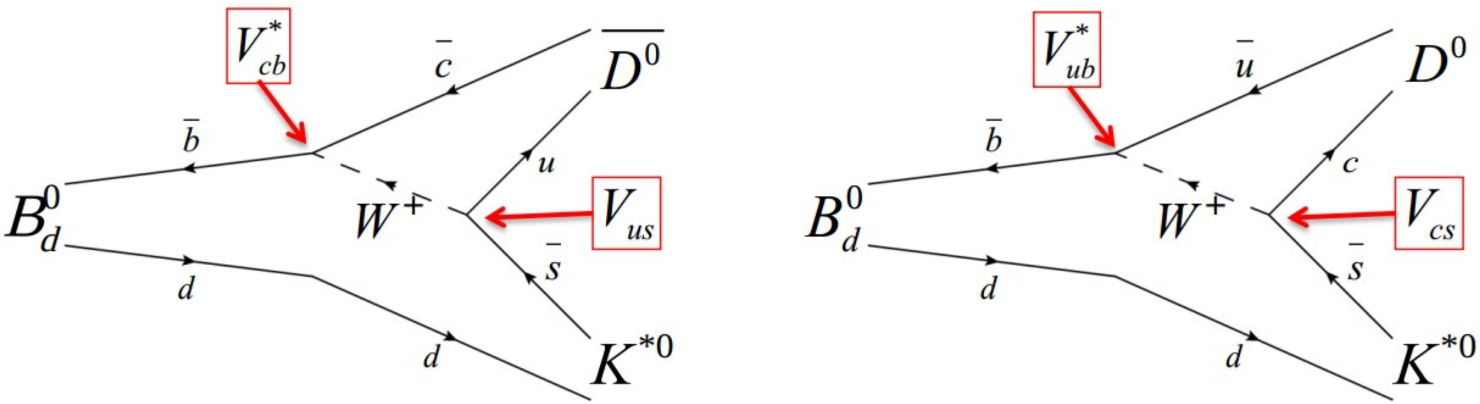
$B^0 \rightarrow D K^{*0}$

LHCb-CONF-2012-024

Preliminary

$B^0 \rightarrow D\ K^{*0}$

- Sensitivity to the CKM weak phase γ:



  - Both decays colour suppressed → enhanced interference.
  - Small branching fractions.
  - Different methods to extract γ:
    - GLW (M. Gronau, D. London, D. Wyler): D → K K (CP eigenstates)
      (Phys. Lett. B253(3-4), 483 – 488 and Phys. Lett. B 265(1-2), 172 – 176)
    - ADS (D. Atwood, I. Dunietz, A. Soni): D → K π (flavour specific final state)
      (Phys. Rev. D 63(3), 036005 and Phys. Rev. Lett. 78(17), 3257–3260)
    - GGSZ (A. Giri, Y. Grossman, A. Soffer, J. Zupan): D → multi-body decay
      (Phys. Rev. D 68(5), 054018)
  - $K^{*0} \rightarrow K^+ \pi^-$ → self-tagged decay.

$B^0 \to D K^{*0}$ analysis

- Based on 2011 LHCb data sample: 1.0 fb^{-1}.
- Cut-based selection: kinematics, vertex quality, PID ($DLL_{K-\pi}$).
- Background from charmless decays (such as $B^0 \to K^- \pi^+ K^{*0}$, etc.) removed by D meson flight distance significance cut.
- $D_{(s)}^- h^+$ contributions vetoed.
- $D^{*0} K^{*0}$ partially reconstructed background ($D^{*0} \to D^0 \pi^0/\gamma$) and $D^0 \rho^0$ cross-feed (π misidentified as K) modeled in the fit to the invariant mass.
- Unbinned maximum likelihood fit to the invariant mass distribution.
  - Signal and background shapes modeled from simulation.
  - Dominant systematic uncertainty comes from the fit model.

$D \to K^+ K^-, K^- \pi^+$

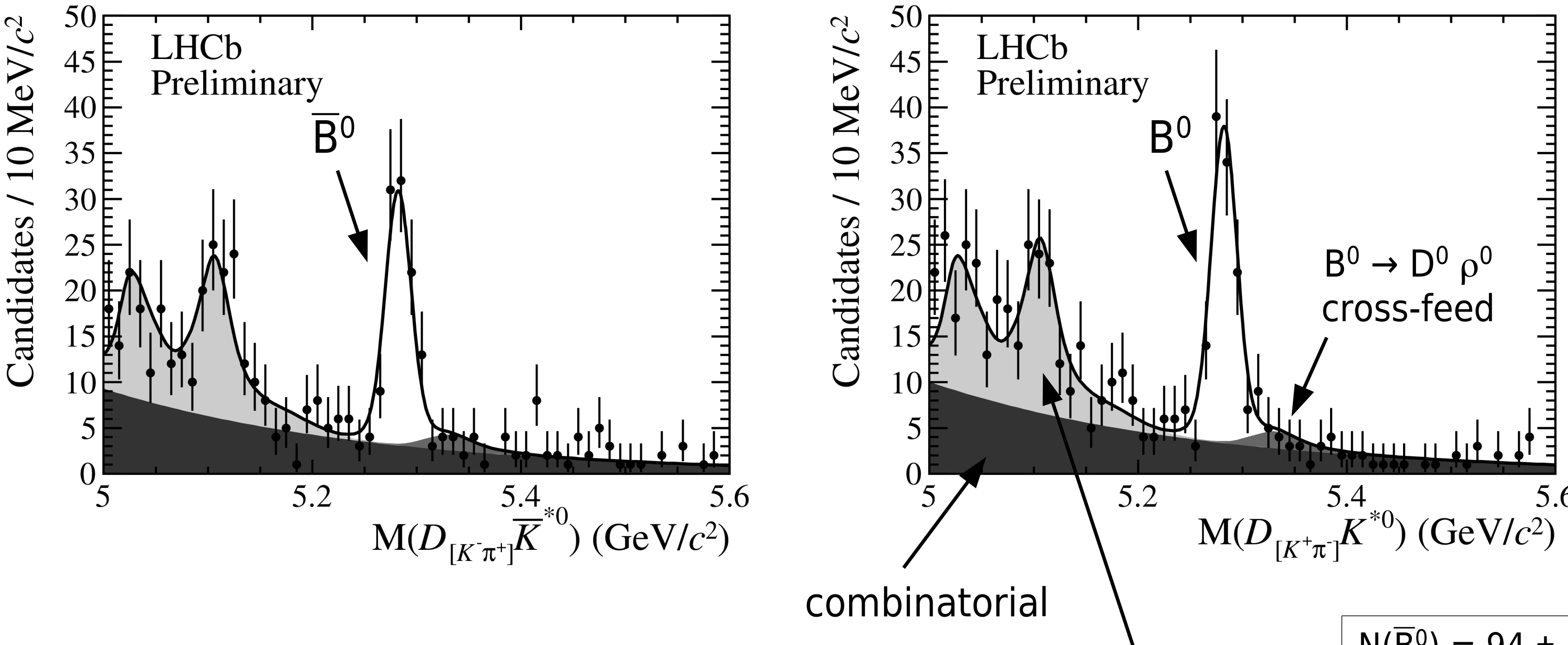
$$\mathcal{A}_d^{KK} = \frac{\Gamma(\overline{B}^0 \to D_{[K^+K^-]}\overline{K}^{*0}) - \Gamma(B^0 \to D_{[K^+K^-]}K^{*0})}{\Gamma(\overline{B}^0 \to D_{[K^+K^-]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+K^-]}K^{*0})}$$

$$\mathcal{R}_d^{KK} = \frac{\Gamma(\overline{B}^0 \to D_{[K^+K^-]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+K^-]}K^{*0})}{\Gamma(\overline{B}^0 \to D_{[K^-\pi^+]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+\pi^-]}K^{*0})}$$

$$\mathcal{A}^{\text{fav}} = \frac{\Gamma(\overline{B}^0 \to D_{[K^-\pi^+]}\overline{K}^{*0}) - \Gamma(B^0 \to D_{[K^+\pi^-]}K^{*0})}{\Gamma(\overline{B}^0 \to D_{[K^-\pi^+]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+\pi^-]}K^{*0})}$$

$$\mathcal{A}_s^{KK} = \frac{\Gamma(\overline{B}_s^0 \to D_{[K^+K^-]}K^{*0}) - \Gamma(B_s^0 \to D_{[K^+K^-]}\overline{K}^{*0})}{\Gamma(\overline{B}_s^0 \to D_{[K^-\pi^+]}K^{*0}) + \Gamma(B_s^0 \to D_{[K^+\pi^-]}\overline{K}^{*0})}$$

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



$B^0 \to D^{*0} K^{*0}$
partially reconstructed

$N(\overline{B}^0) = 94 \pm 11$
$N(B^0) = 108^{+12}_{-11}$

Favoured, control mode
No CP asymmetry expected

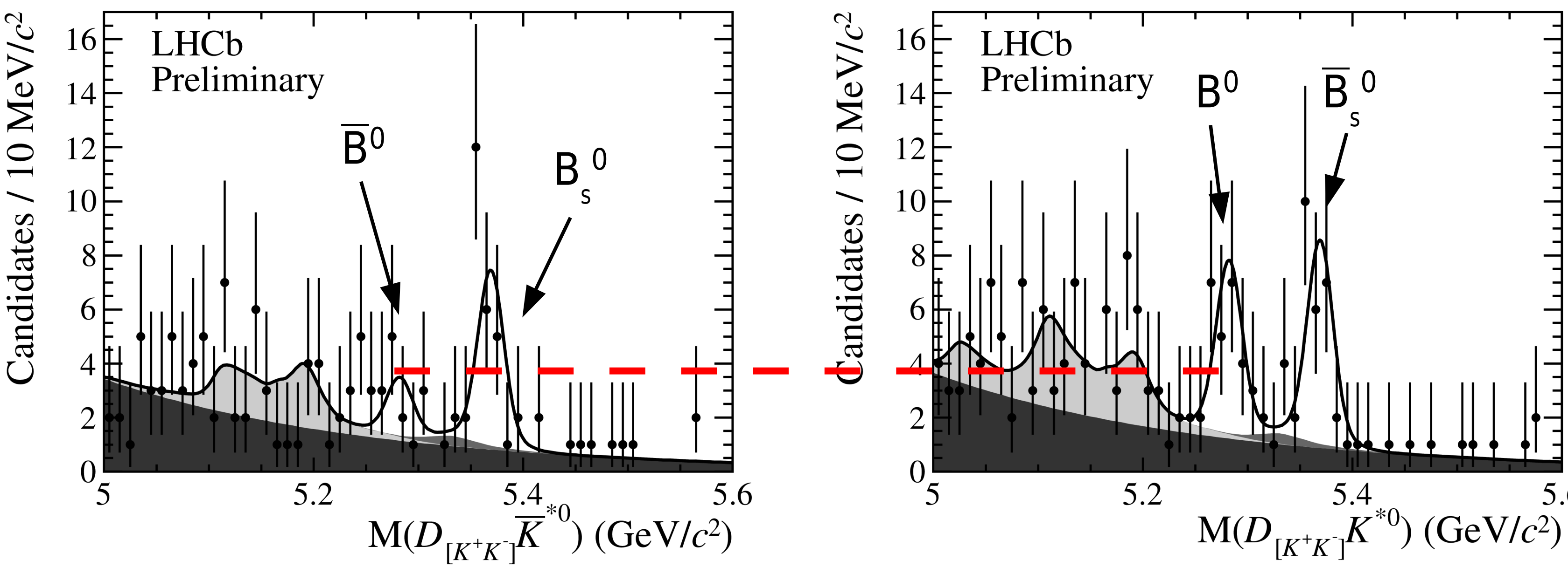
$$\mathcal{A}_d^{\rm fav} = -0.08 \pm 0.08\ (\rm stat) \pm 0.01\ (\rm syst)$$

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

new LHCb result

Preliminary

LHCb-CONF-2012-024



$$\mathcal{A}_d^{KK} = -0.47^{+0.24}_{-0.25}\ (\text{stat}) \pm 0.02\ (\text{syst})$$

$$\mathcal{A}_s^{KK} = 0.04 \pm 0.17\ (\text{stat}) \pm 0.01\ (\text{syst})$$

$$\mathcal{R}_d^{KK} = 1.42^{+0.41}_{-0.35}\ (\text{stat}) \pm 0.07\ (\text{syst})$$

5.1 σ B^0 signal ($B^0 + \overline{B}^0$)

$N(\overline{B}^0) = 7 \pm 4$
$N(B^0) = 20^{+6}_{-5}$
$N(B_s^0) = 22^{+6}_{-5}$
$N(\overline{B}_s^0) = 24^{+6}_{-5}$

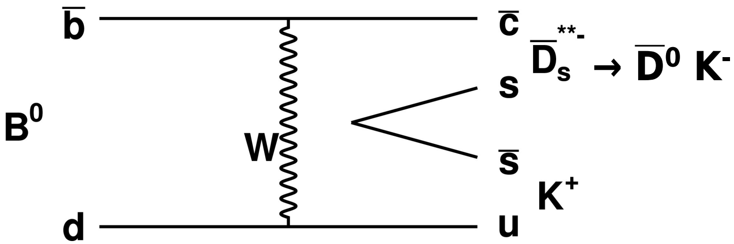
1st measurement in the $B^0 \to D(K^+K^-)K^{*0}$ system

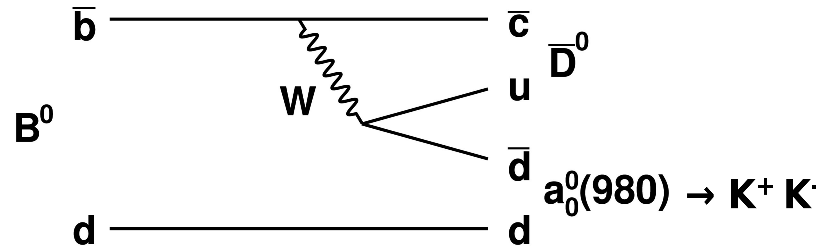
$$B_{(s)}^0 \rightarrow \overline{D}^0 K^+ K^-$$

LHCb-PAPER-2012-018

To be submitted to PRL

$B_{(s)}^0 \to \overline{D}^0 K^+ K^-$ analysis





- $B_s^0 \to \overline{D}^0 K^+ K^-$ can improve sensitivity to γ by a Dalitz plot analysis.
- $B_{(s)}^0 \to \overline{D}^0 K^+ K^-$ have not been observed previously.
  - *BR* measurement normalised to $B^0 \to \overline{D}^0 \pi^+ \pi^-$.

- Analysis based on 575 pb^{-1} of 2011 LHCb data.
- Selection optimised with neural network on weighted distributions of several discriminating variables.
- D^{*-} contributions vetoed, other backgrounds modeled in the final fit.
- Charmless peaking contribution substracted from the fitted yields.
- Efficiency computed as a function of the position in the $\overline{D}^0 K^+ K^-$ Dalitz plot.
- Dominant systematic uncertainty comes from the fit model.

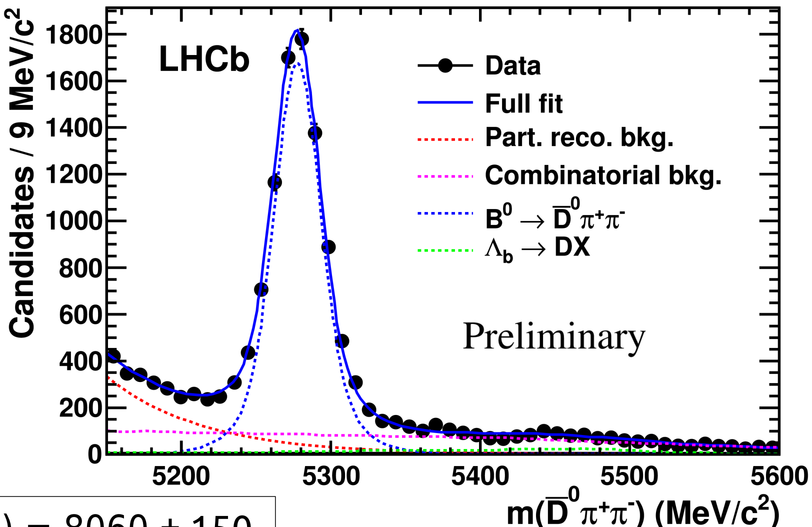
$B_{(s)}^0 \to \overline{D}^0 K^+ K^-$

new LHCb result

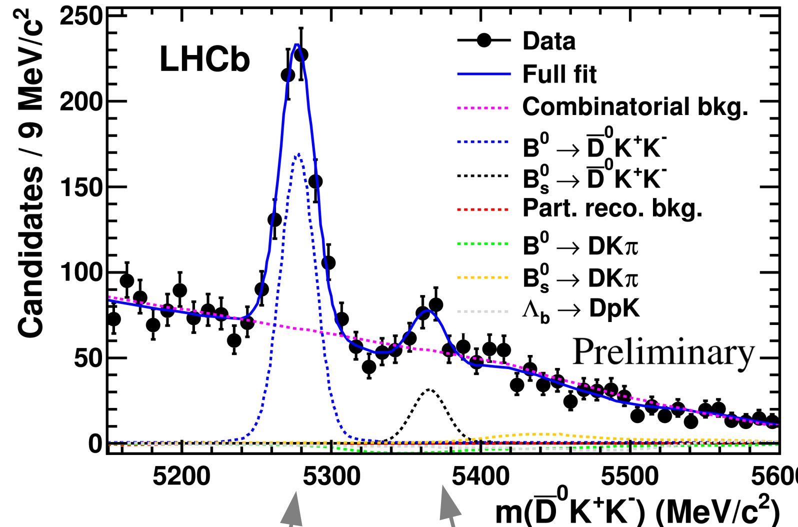
Preliminary

LHCb-PAPER-2012-018

1st observation



N(B^0) = 8060 ± 150



5.8 σ (B^0)

3.8 σ (B_s^0)

N(B^0) = 558 ± 49

N(B_s^0) = 104 ± 29

$$\frac{\mathcal{B}\left(B^0 \to \overline{D}^0 K^+ K^-\right)}{\mathcal{B}\left(B^0 \to \overline{D}^0 \pi^+ \pi^-\right)} = 0.056 \pm 0.011\,(stat) \pm 0.007\,(syst)$$

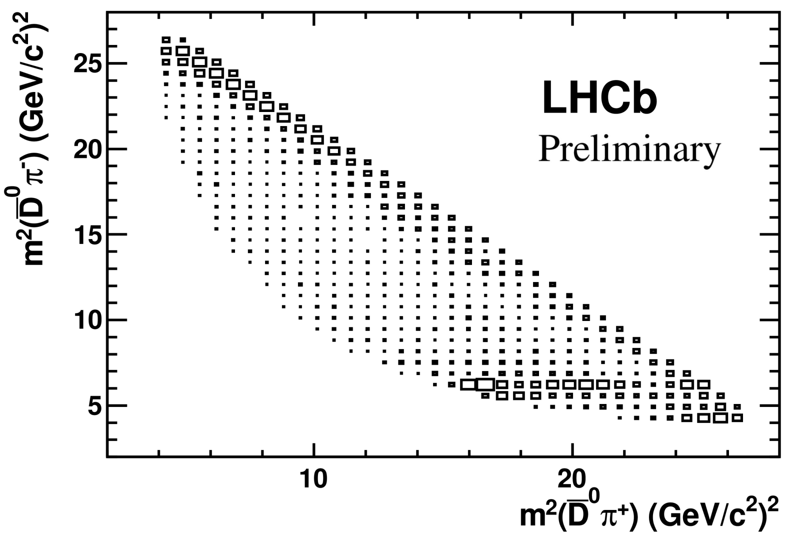
$$\mathcal{B}\left(B^0 \to \overline{D}^0 K^+ K^-\right) = (4.7 \pm 0.9\,(stat) \pm 0.6\,(syst) \pm 0.5\,(BR(B^0 \to \overline{D}^0 \pi^+ \pi^-))) \times 10^{-5}$$

$$\frac{\mathcal{B}\left(B_s^0 \to \overline{D}^0 K^+ K^-\right)}{\mathcal{B}\left(B^0 \to \overline{D}^0 K^+ K^-\right)} = 0.90 \pm 0.27\,(stat) \pm 0.20\,(syst)$$

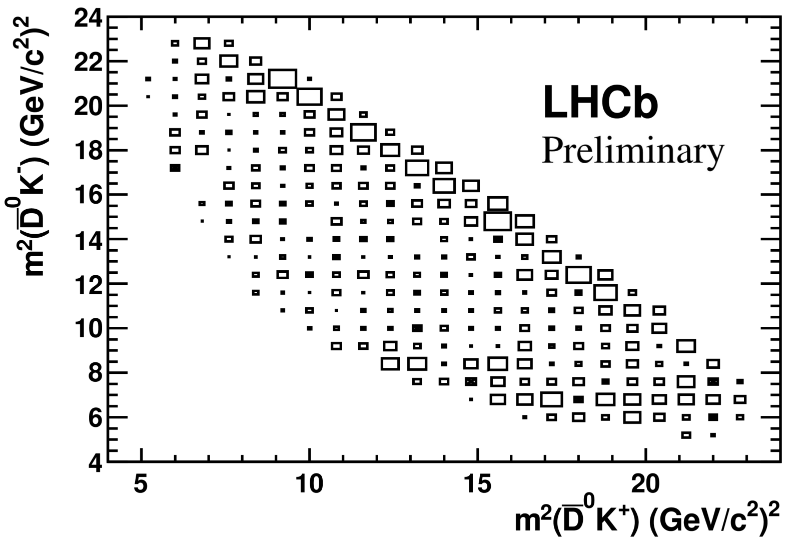
← f_s/f_d from Phys. Rev. D 85, 032008 (2012)

Dalitz plots

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



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



- Contributions from:
  - $\rho(770)^0$
  - $f_2(1270)$
  - $D_2^*(2460)^-$

- Contributions from:
  - $D_{s2}^*(2573)^-$
  - Excess at low $K^+ K^-$ invariant mass.

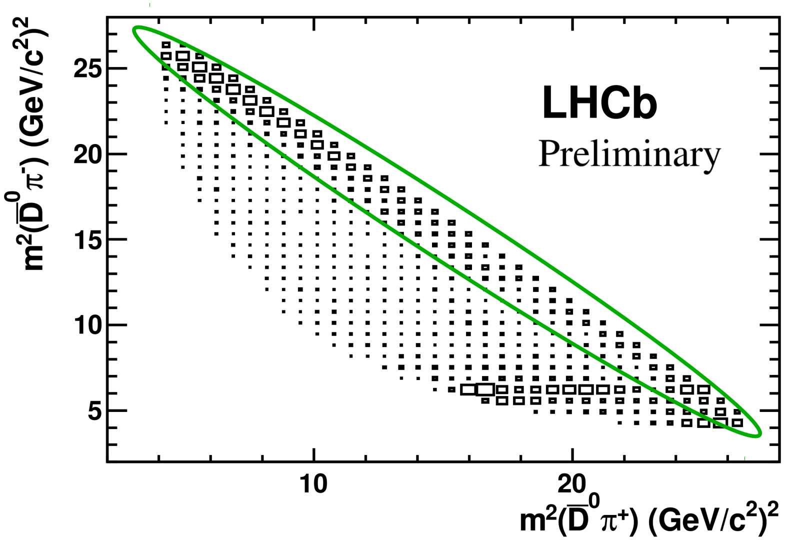
new LHCb result

Preliminary

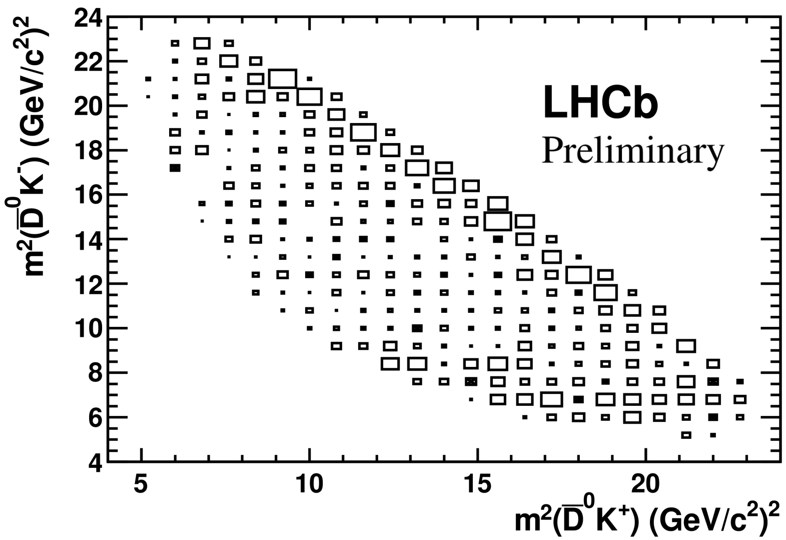
LHCb-PAPER-2012-018

Dalitz plots

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



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



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new LHCb result

Preliminary

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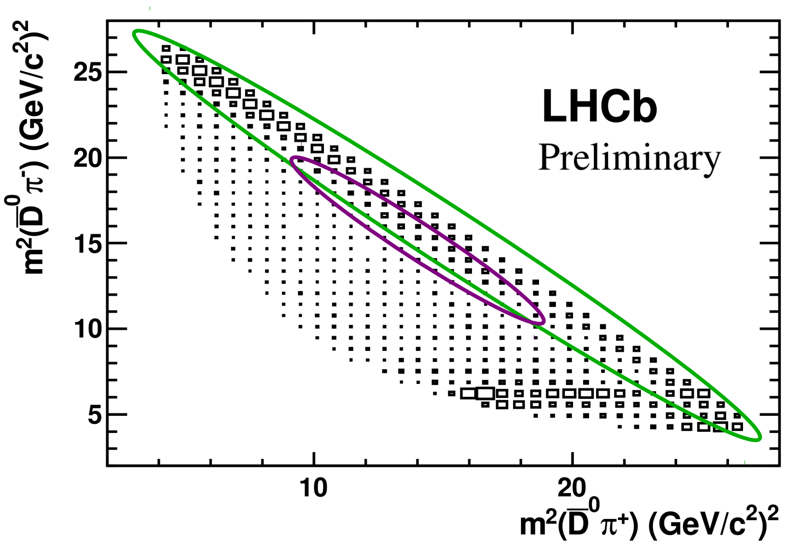
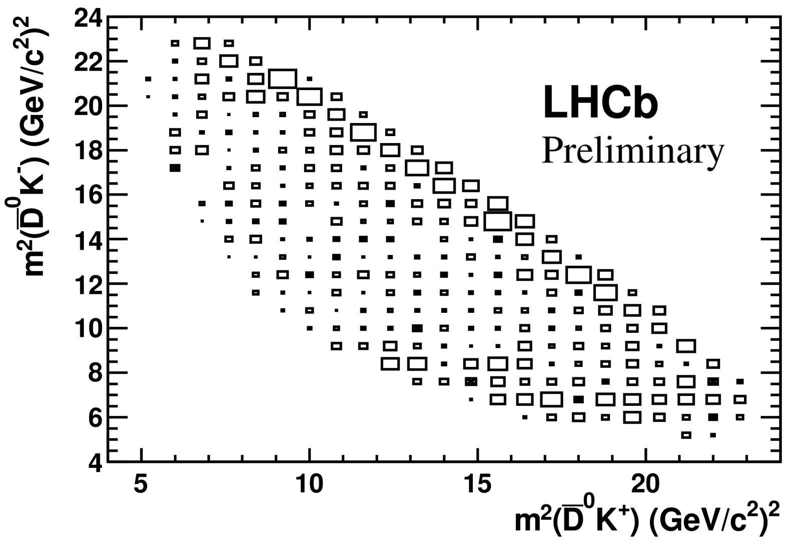
Dalitz plots

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



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



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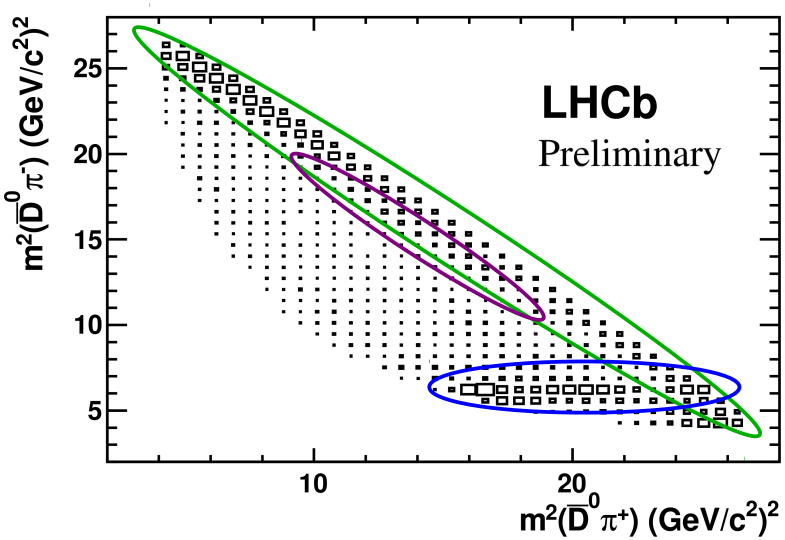
Dalitz plots

new LHCb result

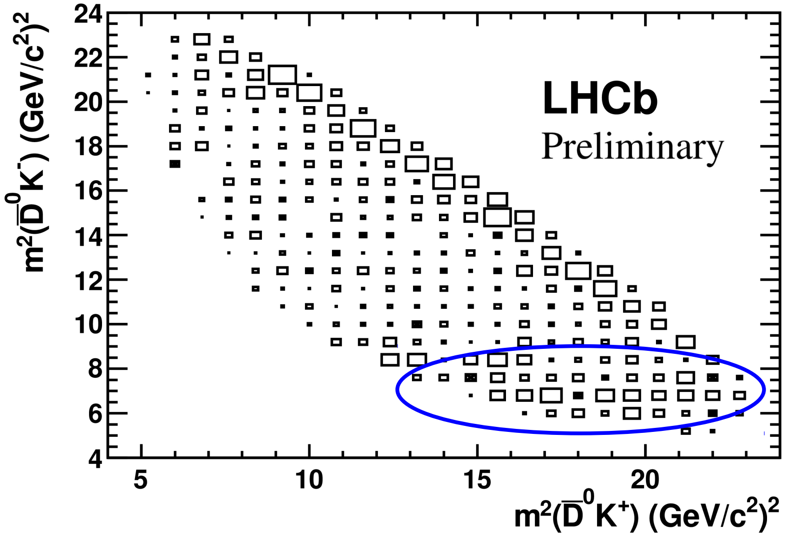
Preliminary

LHCb-PAPER-2012-018

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



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



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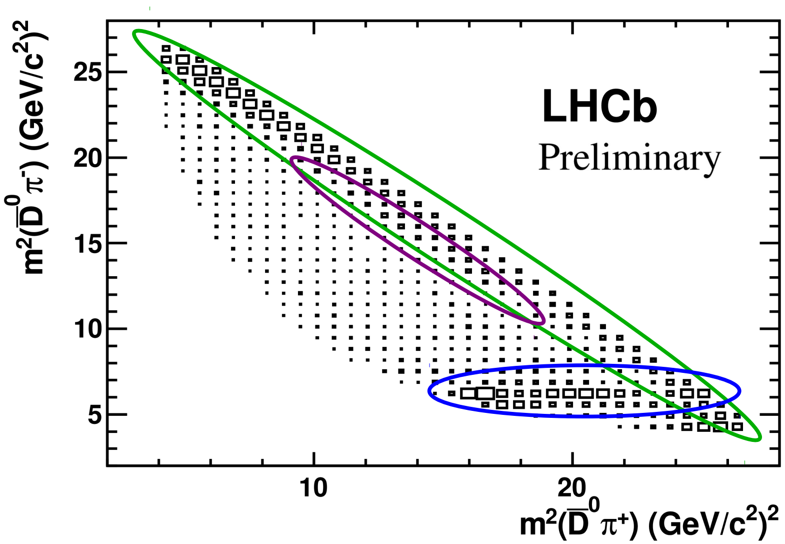
Dalitz plots

new LHCb result

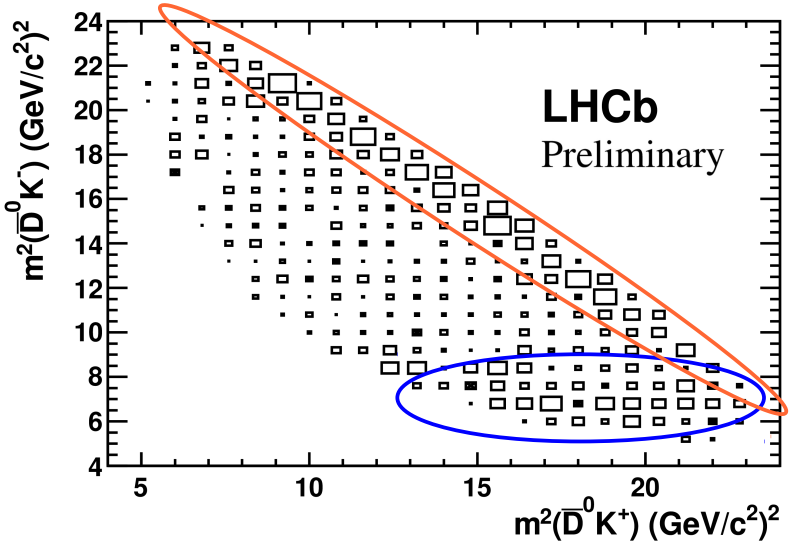
Preliminary

LHCb-PAPER-2012-018

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



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



- Contributions from:
  - $\rho(770)^0$
  - $f_2(1270)$
  - $D_2^*(2460)^-$

- Contributions from:
  - $D_{s2}^*(2573)^-$
  - Excess at low $K^+ K^-$ invariant mass.

$$\overline{B}_s^0 \rightarrow D\,\overline{D}'$$

LHCb-CONF-2012-009

$\overline{B}_s^0 \to D\,\overline{D}'$ analysis

- Laboratory for physics beyond the Standard Model.
- Sensitivity to the weak phase γ ($\overline{B}^0 \to D^+ D^-$, $\overline{B}_s^0 \to D_s^+ D_s^-$) (assuming U-spin symmetry, *c.f.* R. Fleischer, Eur. Phys. J. C 51 (2007) 849-858).
- Measure sin(2β) with penguin contributions ($\overline{B}^0 \to D^+ D^-$).
- Sensitivity to the weak phase ϕ_s and $\Delta\Gamma_s/\Gamma_s$ ($\overline{B}_s^0 \to D_s^+ D_s^-$).

- Based on 2011 LHCb data sample: 1.0 fb^{-1}.
- BDT trained on background substracted $\overline{B}_{(s)}^0 \to D_{(s)}^+ \pi^-$ and $B^- \to D^0 \pi^-$ data samples (signal) and D mass sidebands (background).
  - Kinematics, PID.
- Additional requirements on vertex quality, flight distance.
- Dominant systematic comes from the knowledge of f_s/f_d (Phys. Rev. D 85, 032008 (2012)).

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^+ D^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D^-)}$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D_s^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D_s^-)}$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D^-)}{\mathcal{B}(B^0 \to D_s^+ D^-)}$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^0 \overline{D}^0)}{\mathcal{B}(B^- \to D^0 D_s^-)}$$

$\overline{B}_s^0 \rightarrow D\,\overline{D}'$

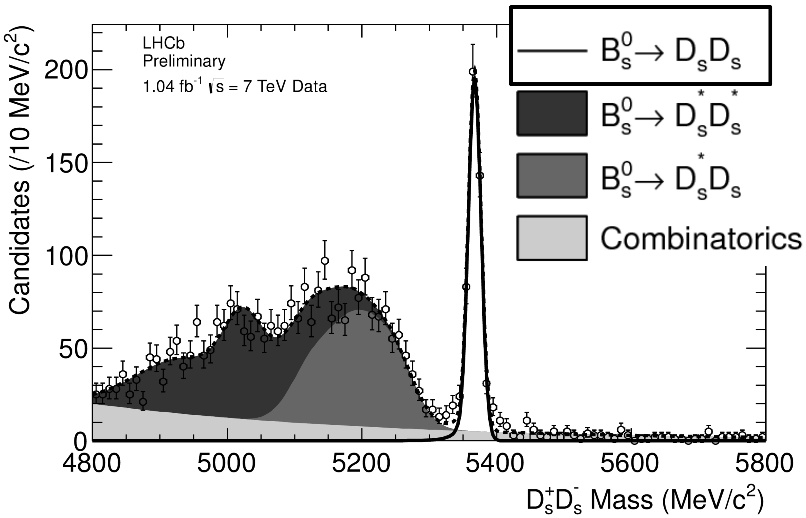
Preliminary

LHCb-CONF-2012-009

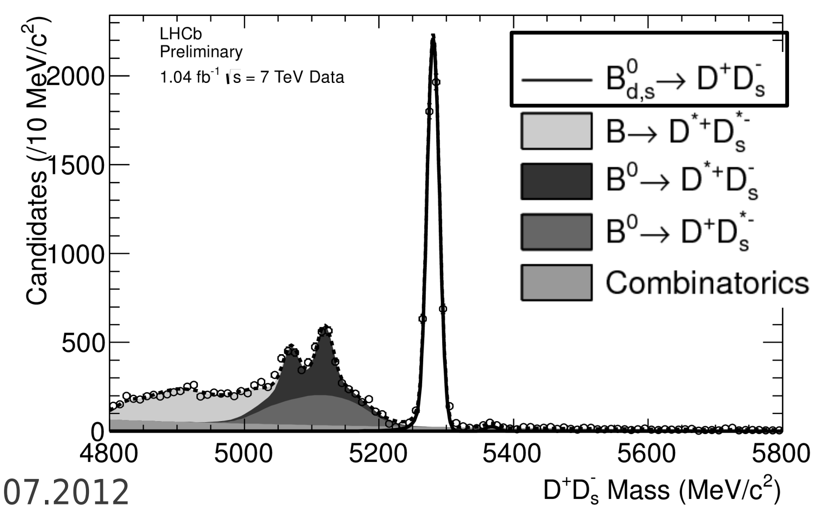
most precise

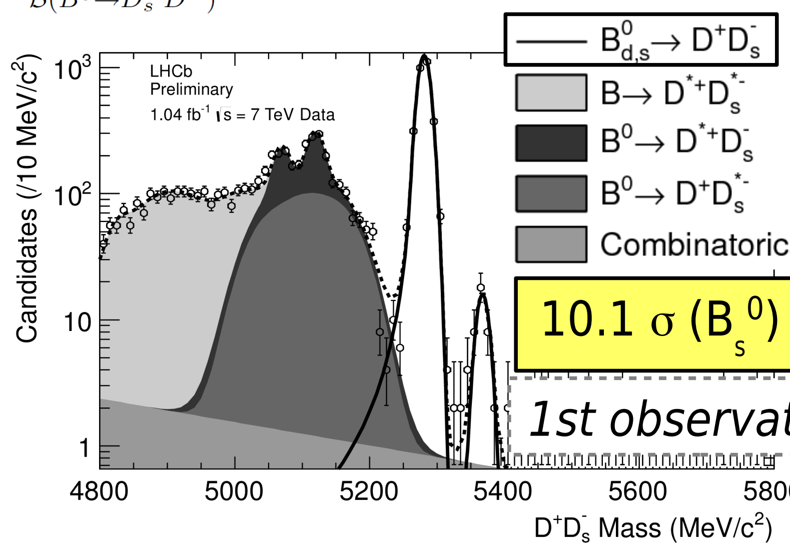
$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D_s^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D_s^-)} = 0.508 \pm 0.026(\mathrm{stat}) \pm 0.043(\mathrm{syst})$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D^-)}{\mathcal{B}(B^0 \to D_s^+ D^-)} = 0.048 \pm 0.008(\mathrm{stat}) \pm 0.004(\mathrm{syst})$$



Measurement	Numerator Yield	Denominator Yield
$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D_s^-)}{\mathcal{B}(\overline{B}^0 \to D^+ D_s^-)}$	477.0 ± 23.2	5261.9 ± 74.3
$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ D^-)}{\mathcal{B}(B^0 \to D_s^+ D^-)}$	37.7 ± 6.6	2936.4 ± 54.5





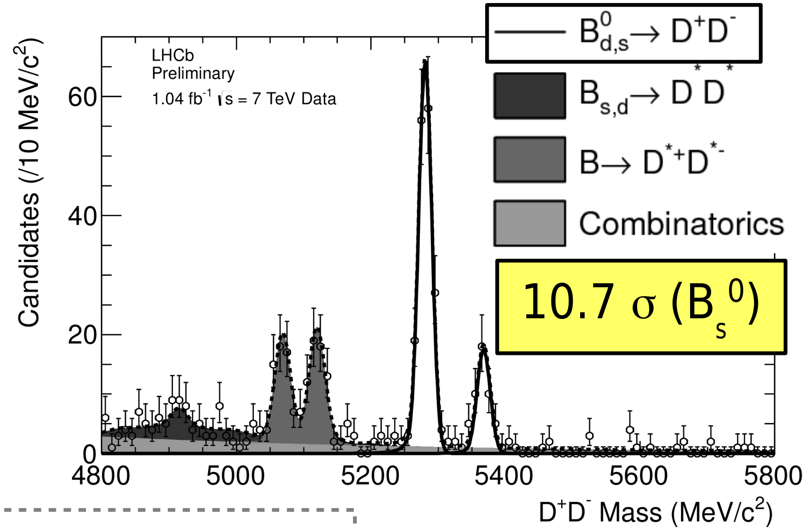
10.1 σ (B_s^0)

1st observation

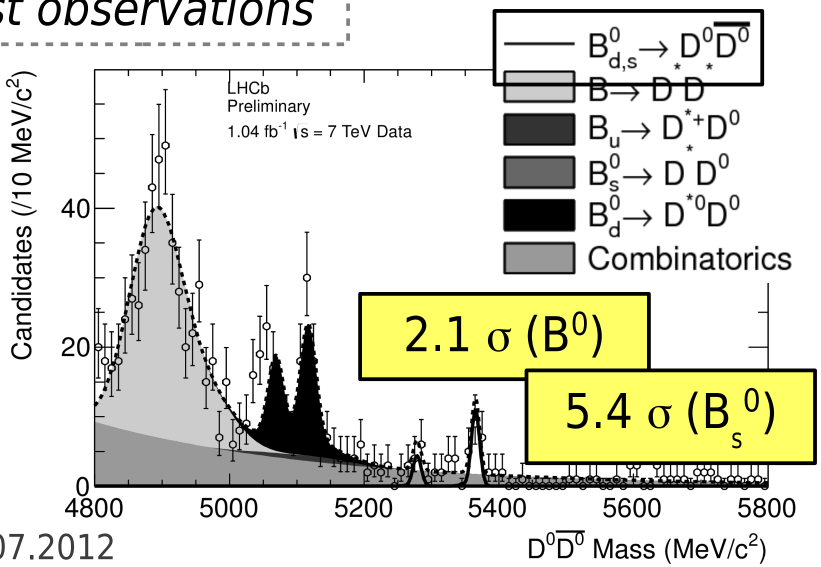
$\overline{B}_s^0 \to D\,\overline{D}'$

Preliminary

LHCb-CONF-2012-009



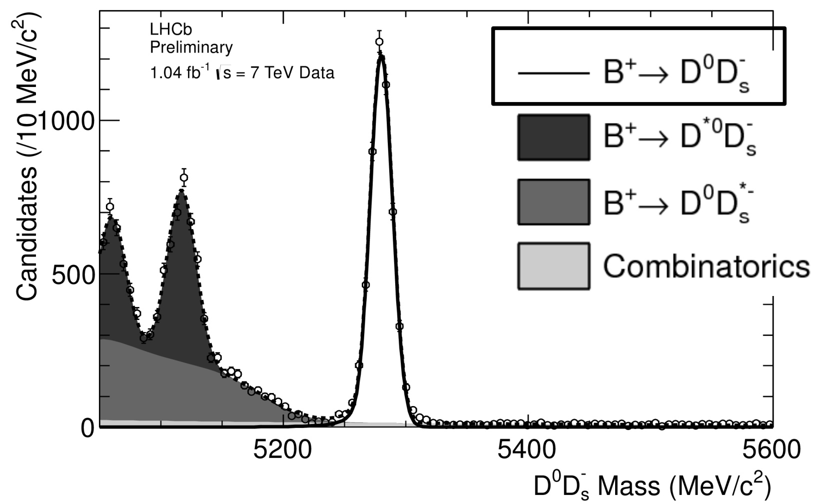
1st observations



$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^+D^-)}{\mathcal{B}(\overline{B}^0 \to D^+D^-)} = 1.00 \pm 0.18(\mathrm{stat}) \pm 0.09(\mathrm{syst})$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^0\overline{D}^0)}{\mathcal{B}(B^- \to D^0D_s^-)} = 0.015 \pm 0.004(\mathrm{stat}) \pm 0.002(\mathrm{syst})$$

Measurement	Numerator Yield	Denominator Yield
$\frac{\mathcal{B}(\overline{B}_s^0 \to D^+D^-)}{\mathcal{B}(\overline{B}^0 \to D^+D^-)}$	43.4 ± 7.1	161.8 ± 13.1
$\frac{\mathcal{B}(\overline{B}_s^0 \to D^0\overline{D}^0)}{\mathcal{B}(B^- \to D^0D_s^-)}$	17.2 ± 4.9	5182.0 ± 73.9



Conclusion

Conclusion

- LHCb experiment is in very good shape.
  - New results with the 1 fb^{-1} collected in 2011.
    - CP asymetries in $B^0 \to D K^{*0}$.
      - LHCb-CONF-2012-024
    - $B_{(s)}^0 \to \overline{D}^0 K^+ K^-$ first observation.
      - LHCb-PAPER-2012-018
    - $\overline{B}_{(s)}^0 \to D \overline{D}'$ first observation and most precise measurements of BR.
      - LHCb-CONF-2012-009
  - Many other results:
    - $\Lambda_b^0 \to D^0 p K^-$ (LHCb-CONF-2011-036)
    - f_s/f_d with $B^0 \to D^- K^+$ (Phys. Rev. Lett. 107 (2011) 211801)
- LHCb taking data in 2012:
  - 0.6 fb^{-1} recorded up to now, 1.5 fb^{-1} expected at the end of the year.
  - More new results and updates to come!

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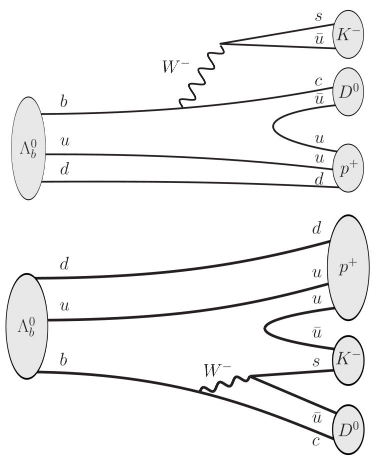
Back up

$\Lambda_b^0 \to D^0 p K^-$

Preliminary

LHCb-CONF-2011-036

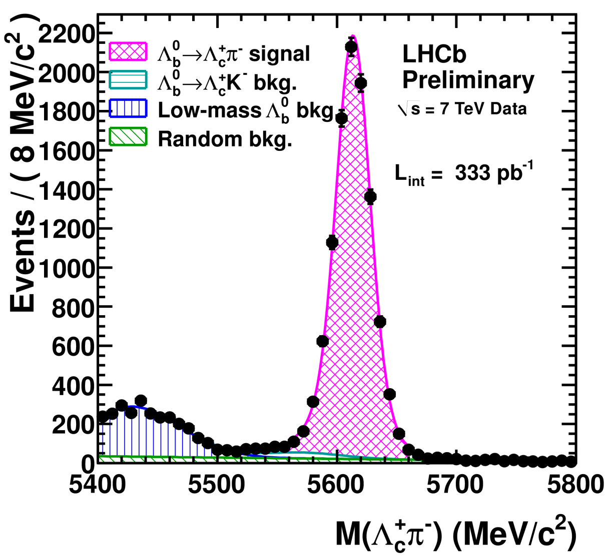


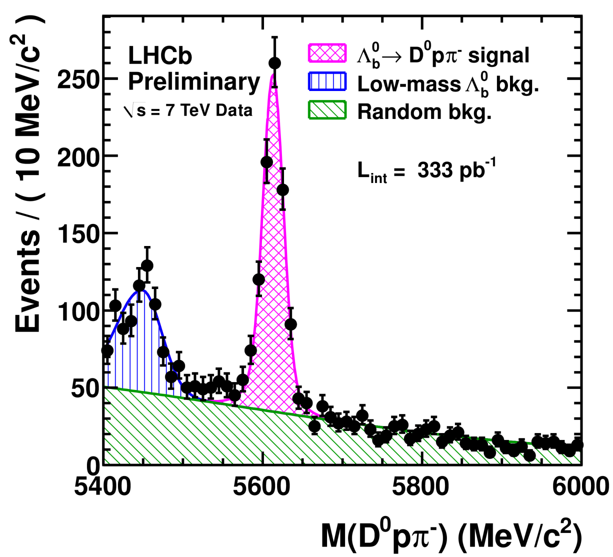
$$R_{D^0 p\pi^-} = \frac{\mathcal{B}(\Lambda_b^0 \to D^0 p \pi^-) \times \mathcal{B}(D^0 \to K^- \pi^+)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-) \times \mathcal{B}(\Lambda_c^+ \to p K^- \pi^+)} = 0.119 \pm 0.006 \pm 0.013$$

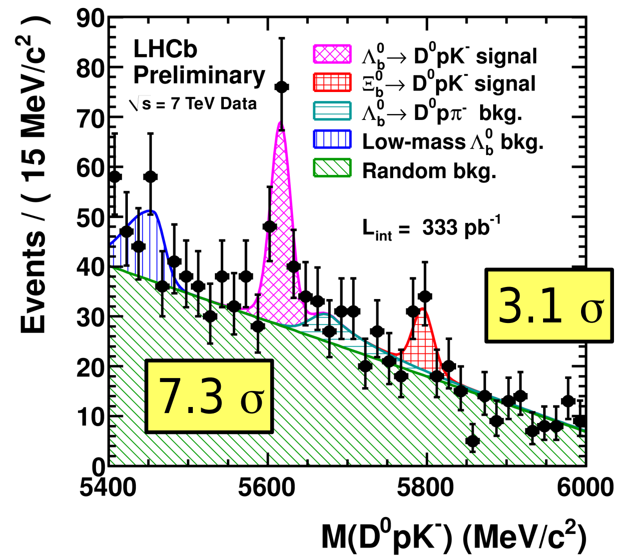
$$R_{D^0 p K^-} = \frac{\mathcal{B}(\Lambda_b^0 \to D^0 p K^-)}{\mathcal{B}(\Lambda_b^0 \to D^0 p \pi^-)} = 0.112 \pm 0.019\,^{+0.011}_{-0.014}$$

$$R_{\Xi_b^0} = \frac{f_{b\to\Xi_b^0} \times \mathcal{B}(\Xi_b^0 \to D^0 p K^-)}{f_{b\to\Lambda_b^0} \times \mathcal{B}(\Lambda_b^0 \to D^0 p K^-)} = 0.29 \pm 0.12 \pm 0.08$$

$$\Delta m_{\Xi_b^0} = m(\Xi_b^0) - m(\Lambda_b^0) = (181.8 \pm 5.5 \pm 0.5)\ \mathrm{MeV}/c^2$$

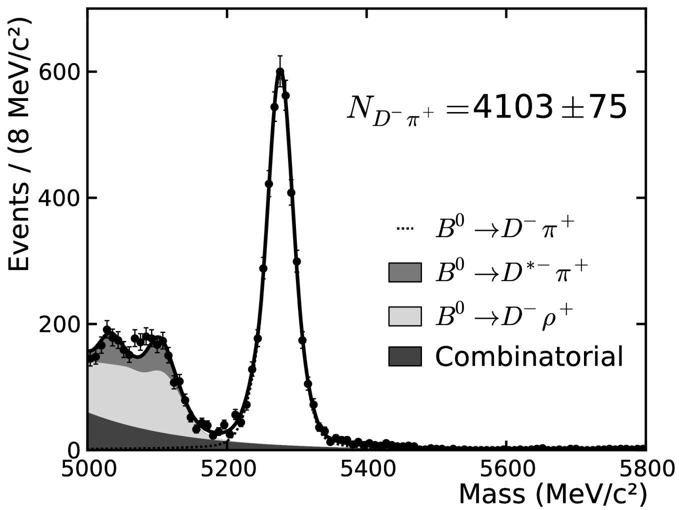


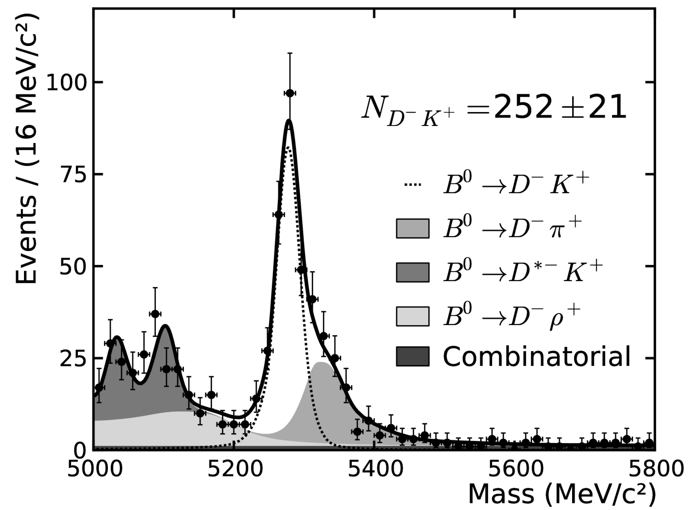


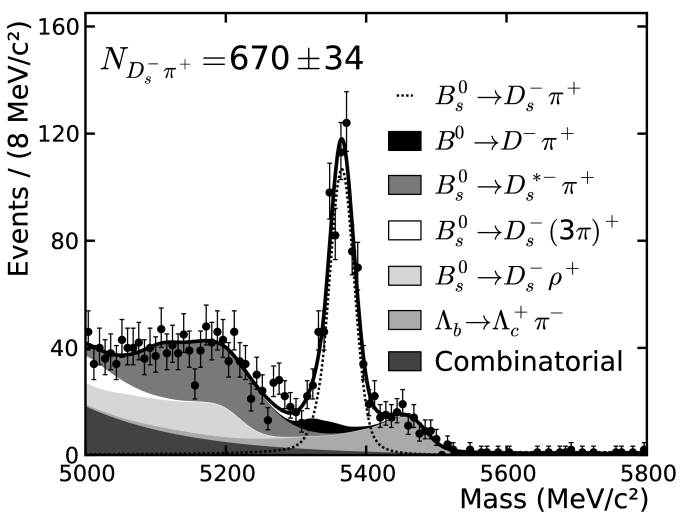


$B^0 \to D^- K^+$ for f_s/f_d

LHCB-PAPER-2011-006
arXiv:1106.4435
Phys. Rev. Lett. 107 (2011) 211801







$$\frac{f_s}{f_d} = \frac{N_{X_2}}{N_{X_1}} \frac{\mathcal{B}(B^0 \to X_1)}{\mathcal{B}(B_s^0 \to X_2)} \frac{\epsilon(B^0 \to X_1)}{\epsilon(B_s^0 \to X_2)}$$

$$f_s/f_d = (0.310 \pm 0.030^{\text{stat}} \pm 0.021^{\text{syst}}) \times \frac{1}{\mathcal{N}_a \mathcal{N}_F}$$

$$f_s/f_d = (0.307 \pm 0.017^{\text{stat}} \pm 0.023^{\text{syst}}) \times \frac{1}{\mathcal{N}_a \mathcal{N}_F \mathcal{N}_E}$$

$$f_s/f_d = 0.253 \pm 0.017^{\text{stat}} \pm 0.017^{\text{syst}} \pm 0.020^{\text{theor}}$$