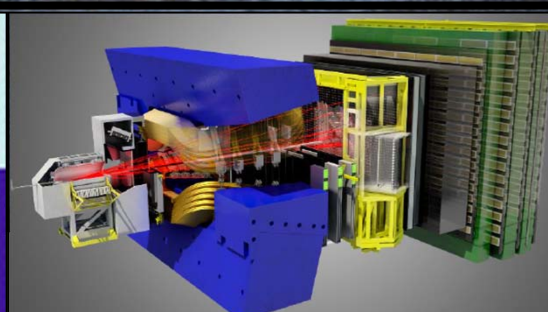
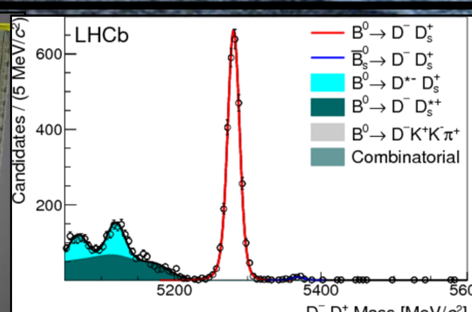
Studies of hadronic B decays to open charm mesons at LHCb

Steven Blusk, Syracuse University
(on behalf of the LHCb collaboration)





DPF 2013, UC Santa Cruz, Aug. 13-18, 2013.

Introduction

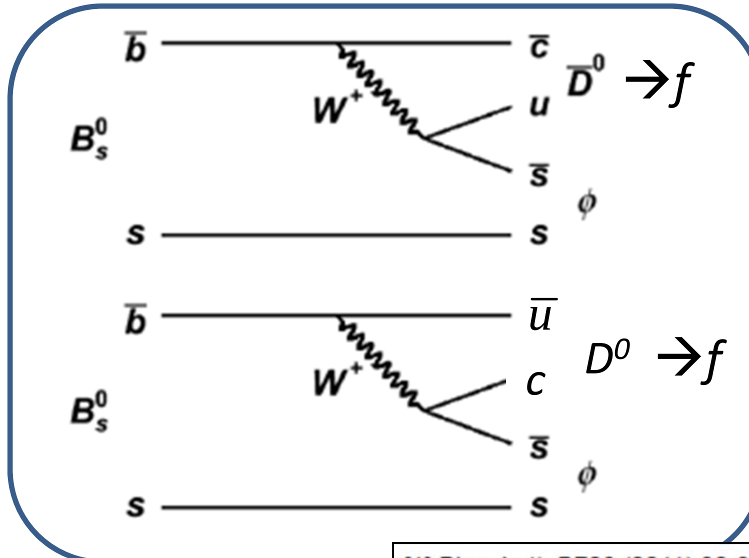
- A number of "firsts" emerging in the study of hadronic B decays to open charm.
  - Going beyond the "$Dh^{\pm}$" modes, we're exploring 5, 6, and 7 particle final states.
  - Provide additional probes of CKM parameters
    - **Ultimate precision on γ/ϕ_3 must take advantage of many b-hadron decays**
  - Study of strong interaction dynamics.
  - Made possible due to:
    - **large σ_{bb} @LHC, and**
    - **excellent capabilities of LHCb to trigger on and fully reconstruct high multiplicity final states.**

- Here, we discuss some of the recent results from LHCb on **B→DX**..

- All results based on 1 fb^{-1}, unless otherwise noted.

First observation of $B_s \rightarrow D^0\phi$

- Motivation: γ determination using TI (ala $B^- \rightarrow D^0K^-$) or TD (as in $B_s \rightarrow D_sK$) analyses.
  - Both are **theoretically clean**.
  - Start with $D^0 \rightarrow K\pi$. More final states needed for TI γ determination.



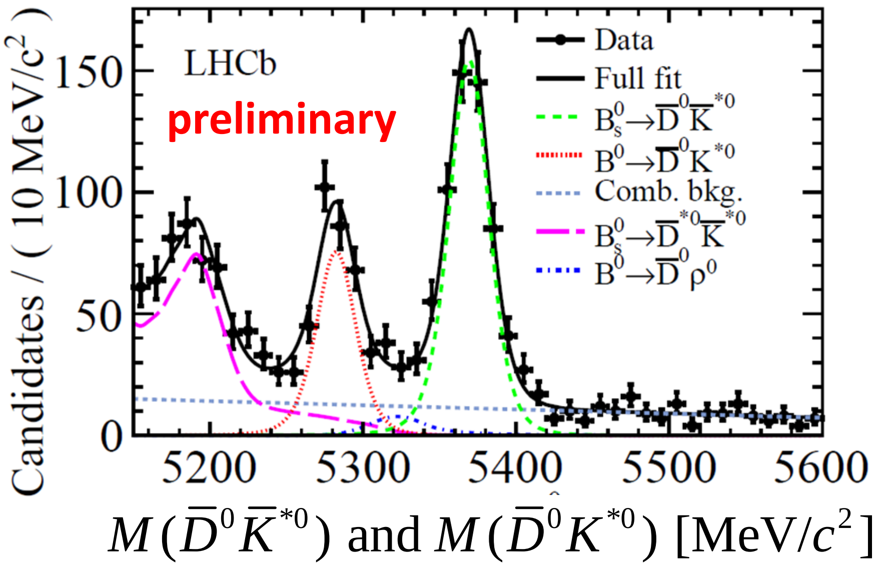
[1] Phys.Lett. B706 (2011) 32-39
[2] Phys.Rev. D85 (2012) 114015
[3] Phys.Lett. B253 (1991) 483-488
[4] Phys.Rev. D69 (2004) 113003
[5] Phys.Lett. B649 (2007) 61-66

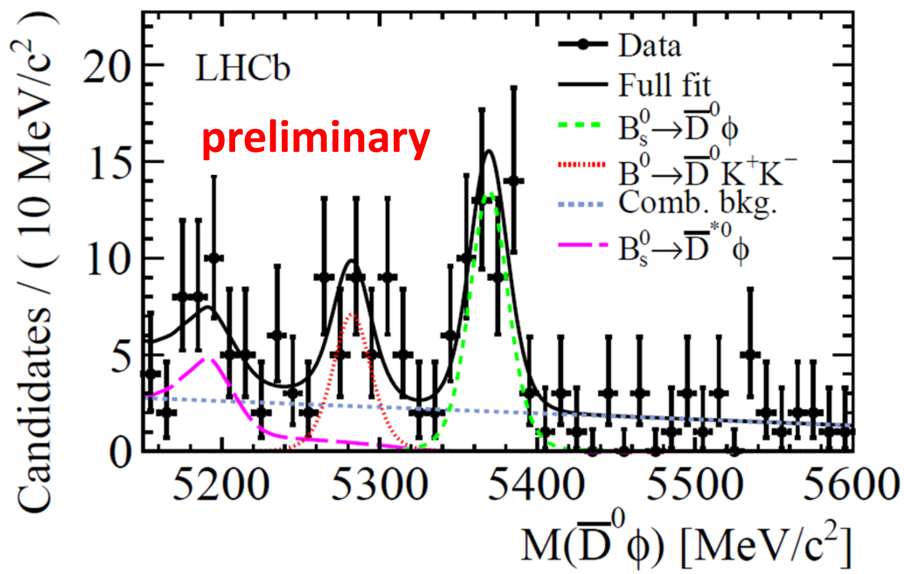
- First goal is to observe the decay and measure rates.
  - Normalize to $B_s \rightarrow \bar{D}^0\bar{K}^{*0}$

- Also improve measurement of $\mathcal{B}(B_s \rightarrow \bar{D}^0\bar{K}^{*0})$, normalized relative to $\mathcal{B}(B^0 \rightarrow \bar{D}^0K^{*0})$.

- All results are **preliminary**, see LHCb-PAPER-2013-035

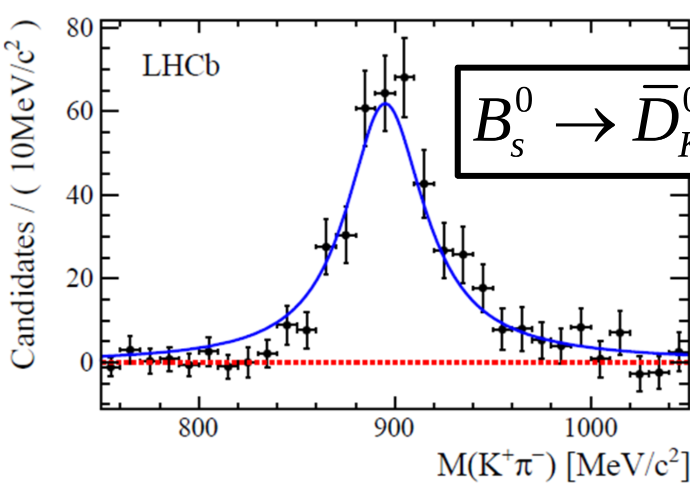
Signals in data



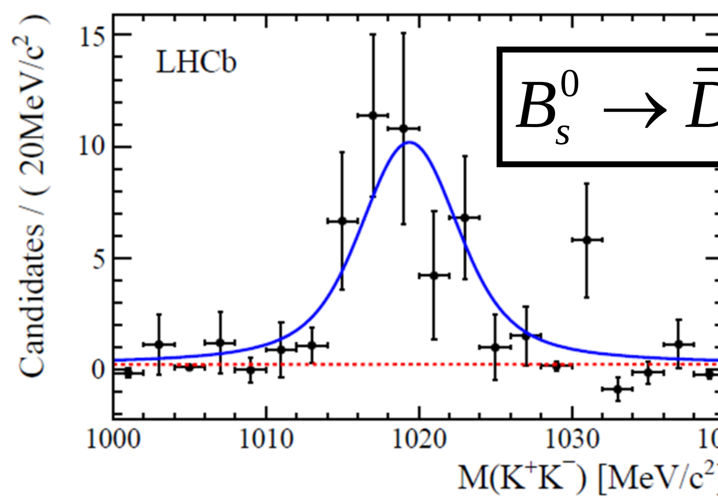


$$N(B_s^0 \to \bar{D}^0 \bar{K}^{*0}) = 535 \pm 30$$
$$N(B^0 \to \bar{D}^0 K^{*0}) = 260 \pm 24$$

$$N(B_s^0 \to \bar{D}^0 \phi) = 43 \pm 8$$
7.1σ significance



$B_s^0 \to \bar{D}^0_{K\pi} \bar{K}^{*0}$



$B_s^0 \to \bar{D}^0 \phi$

Results on branching fractions

$$\frac{\mathcal{B}(B_s^0 \to \bar{D}^0 \bar{K}^{*0})}{\mathcal{B}(B^0 \to \bar{D}^0 K^{*0})} = 7.8 \pm 0.7_{stat} \pm 0.3_{syst} \pm 0.6_{fs/fd}$$

Using $B(B^0 \to \bar{D}^0 K^{*0})_{PDG} = (4.2 \pm 0.6)\text{x}10^{-5}$,

Source	$\mathcal{R}_{K^{*0}}$	$\mathcal{R}_{\phi}$
PID	-	0.002
Trigger	-	0.003
Flight distance	-	0.002
Selection	-	0.002
Simulation statistics	0.10	0.001
Fit bias	0.03	0.001
Signal model	0.04	0.001
Background model	0.01	0.001
Charmless correction	0.10	0.003
Non-resonant correction	0.22	0.004
ϕ branching fraction	-	0.001
Total	0.26	0.007

$$\mathcal{B}(B_s^0 \to \bar{D}^0 \bar{K}^{*0}) = \left(3.3 \pm 0.3_{stat} \pm 0.1_{syst} \pm 0.3_{fs/fd} \pm 0.5_{B(B^0 \to \bar{D}^0 K^{*0})}\right)\text{x}10^{-4}$$

(Consistent with & more precise than previous LHCb measurement)

Also $B_s \to \bar{D}^0 \phi$ observed & measured for the 1st time:

$$\frac{\mathcal{B}(B_s^0 \to \bar{D}^0 \phi)}{\mathcal{B}(B_s^0 \to \bar{D}^0 \bar{K}^{*0})} = 0.069 \pm 0.013 \pm 0.007$$

Leading to the absolute branching fraction:

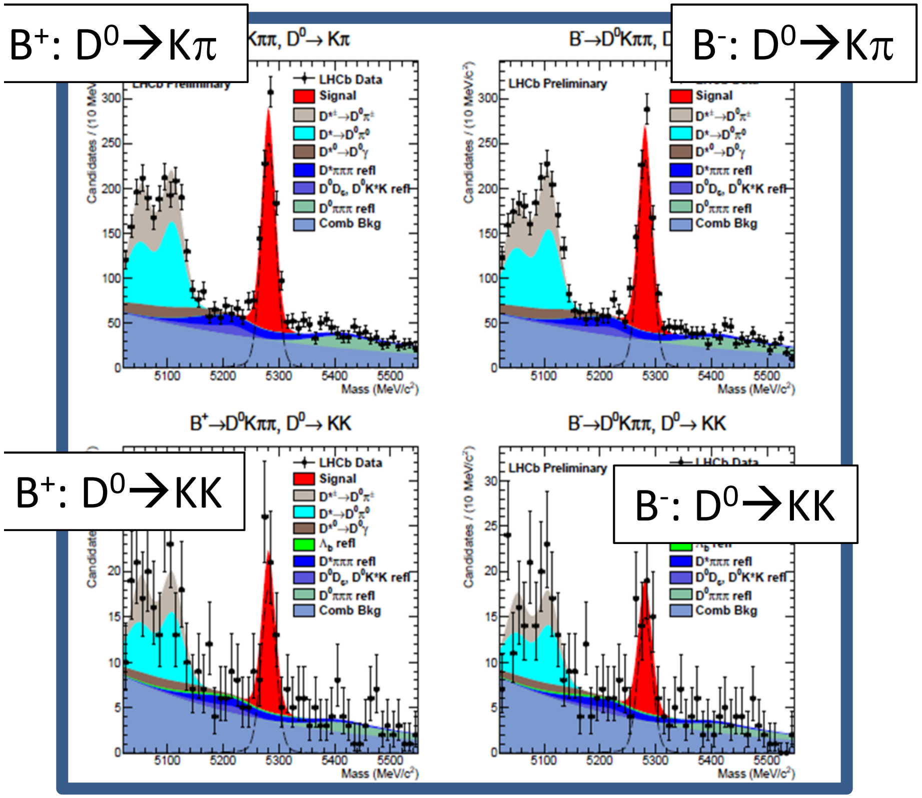
$$\mathcal{B}(B_s^0 \to \bar{D}^0 \phi) = \left(2.3 \pm 0.4_{stat} \pm 0.2_{syst} \pm 0.5_{B(B_s^0 \to \bar{D}^0 \bar{K}^{*0})}\right)\text{x}10^{-5}$$

Other interesting modes for γ

Time-independent

$B^- \rightarrow DK\pi\pi$, ADS, GLW

(LHCb-CONF-2012-021)

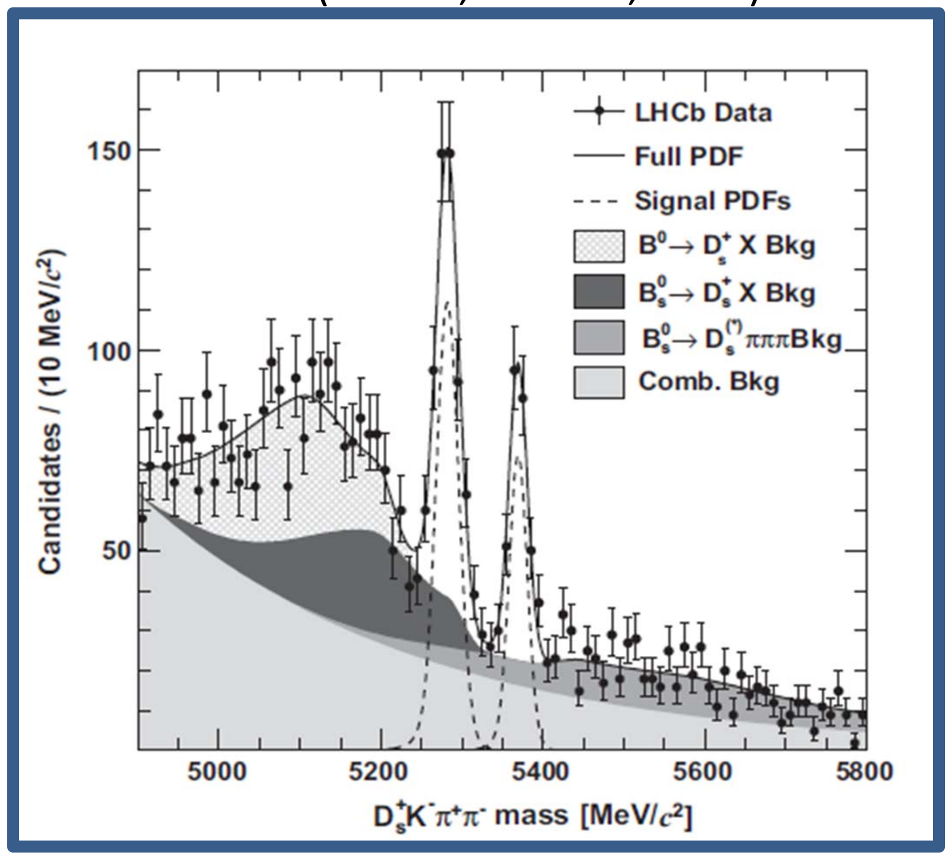


$$A_s^{CP+} = -0.14 \ \pm 0.10 \ (\text{stat}) \pm 0.01 \ (\text{syst})$$
$$A_s^{K^-\pi^+} = -0.009 \pm 0.028(\text{stat}) \pm 0.013(\text{syst})$$
$$A_d^{CP+} = -0.018 \pm 0.018(\text{stat}) \pm 0.007(\text{syst})$$
$$A_d^{K^-\pi^+} = -0.006 \pm 0.006(\text{stat}) \pm 0.010(\text{syst}),$$

Time-dependent

$B_s \rightarrow D_sK\pi\pi$, $D_s \rightarrow KK\pi$

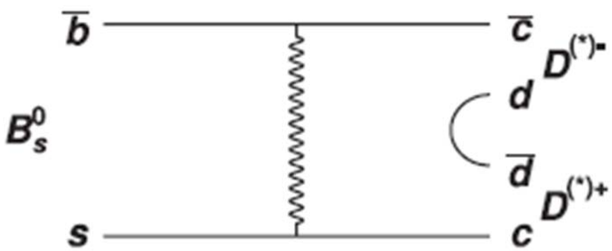
(PRD**86**, 112005, 2013)



$$\frac{\mathcal{B}(\bar{B}_s^0 \rightarrow D_s^+K^-\pi^+\pi^-)}{\mathcal{B}(\bar{B}_s^0 \rightarrow D_s^+\pi^-\pi^+\pi^-)} = (5.2 \pm 0.5 \pm 0.3) \times 10^{-2}$$

Searches for decays proceeding via W-exchange & penguin annihilation

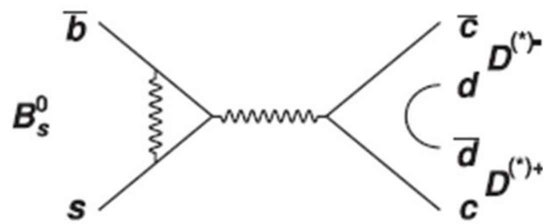
$$B \to D^{(*)}\bar{D}^{(*)}$$



Weak exchange

O(λ²)

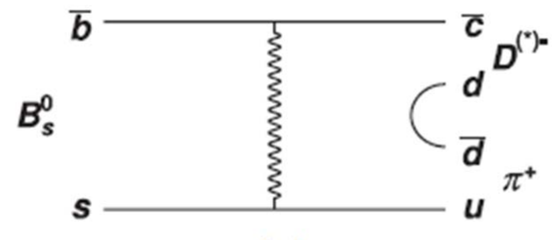
$$B \to D^{(*)}\bar{D}^{(*)}$$



Penguin annihilation

O(λ²)

$$B_s^0 \to D^{(*)-}\pi^+$$



Weak exchange

O(λ³)

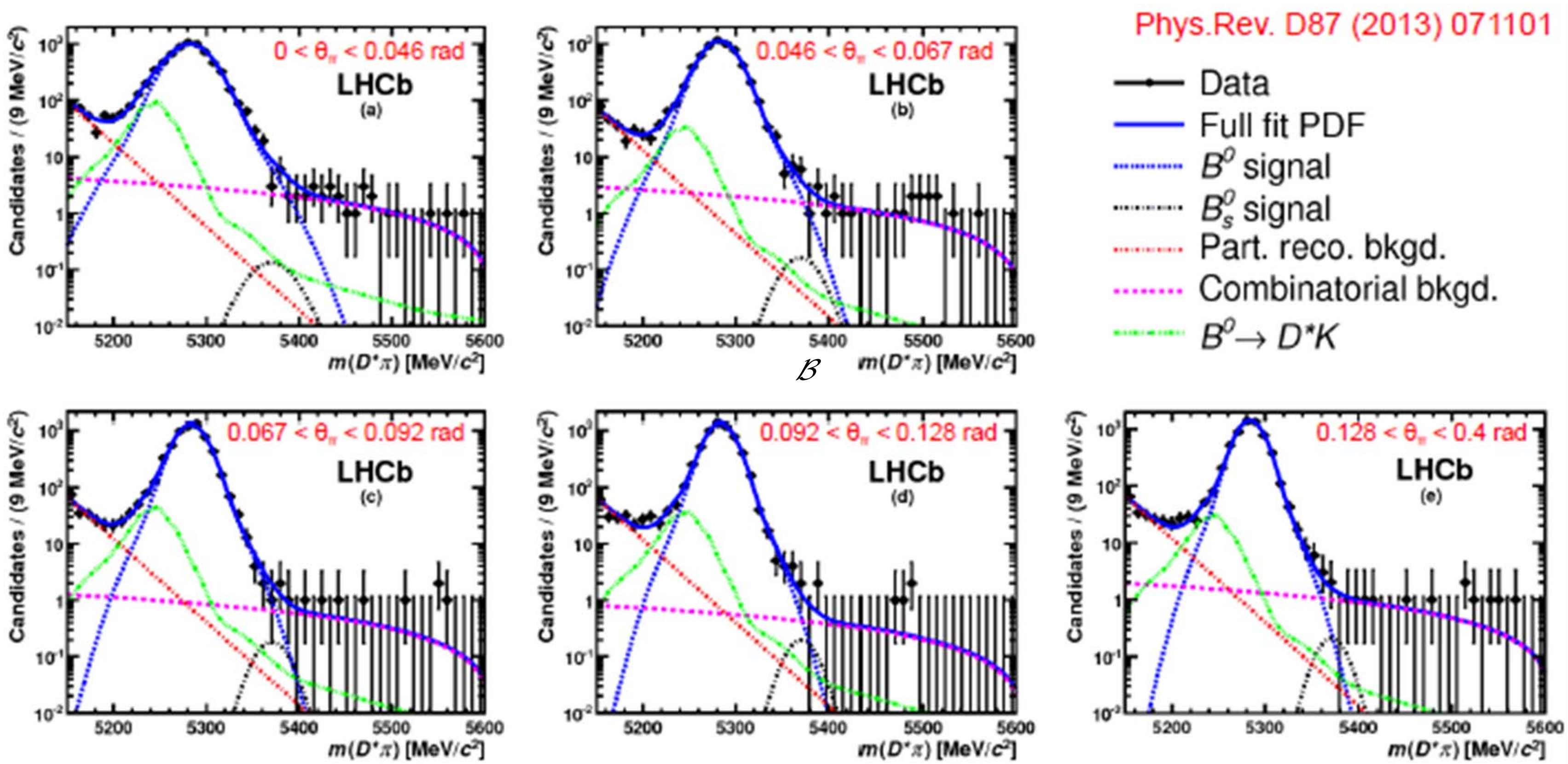
- **Limited information available on the role of these decays in hadronic B decays.**
  - $B^0 \to D_s^{(*)}K^{(*)}$ and $B_s \to \pi^+\pi^-$ are the only other observed decays that proceed through these suppressed diagrams.

- **Double-charm final states also of interest for CKM angle determinations, such as γ (combine several B→DD'), 2β ($B^0 \to D^+D^-$), and $2\beta_s$ ($B_s \to D_sD_s$)**

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

LHCb, PRD**87** 071101 (2013)

- Bin in the angle between D* and π in lab frame.
- Exploits better mass resolution with larger opening angle.



No signal observed, limits set: $\mathcal{B}(B_s^0 \rightarrow D^{*-}\pi^+) < 6.1 \text{ x } 10^{-6}$ (90% CL)

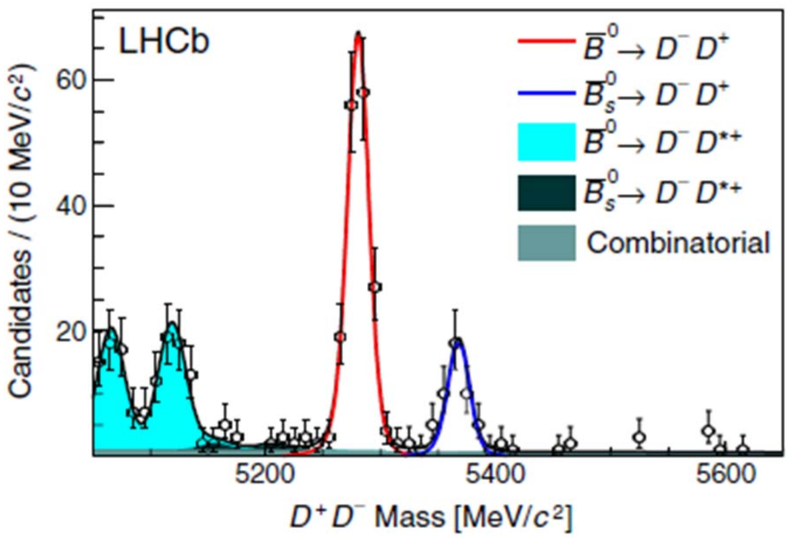
$\mathcal{B}(B_s \rightarrow D^*\pi)$ ~ $1 \text{x} 10^{-6}$ expected, from λ^2 x $B(B^0 \rightarrow D_s K)$.

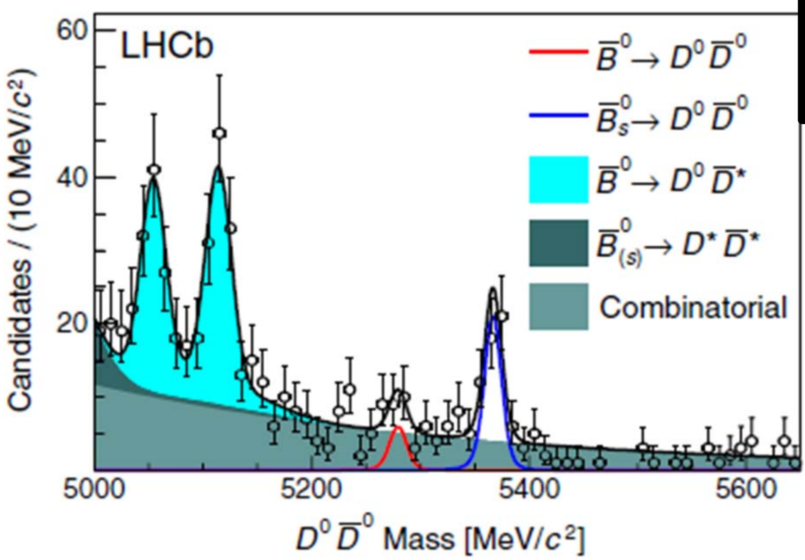
Double charm final states

Observation of $B_{(s)} \rightarrow D^+D^-$, $D^0\overline{D}^0$

PRD**87** 092007 (2013)

LHCb, PRD**87** 092007 (2013)





Relative BFs

$$\frac{\mathcal{B}(\bar{B}^0_s \rightarrow D^+D^-)}{\mathcal{B}(\bar{B}^0 \rightarrow D^+D^-)} = 1.08 \pm 0.20(\text{stat}) \pm 0.10(\text{syst})$$

$$\frac{\mathcal{B}(\bar{B}^0_s \rightarrow D^0\bar{D}^0)}{\mathcal{B}(B^- \rightarrow D^0D^-_s)} = 0.019 \pm 0.003(\text{stat}) \pm 0.003(\text{syst})$$

Absolute BFs

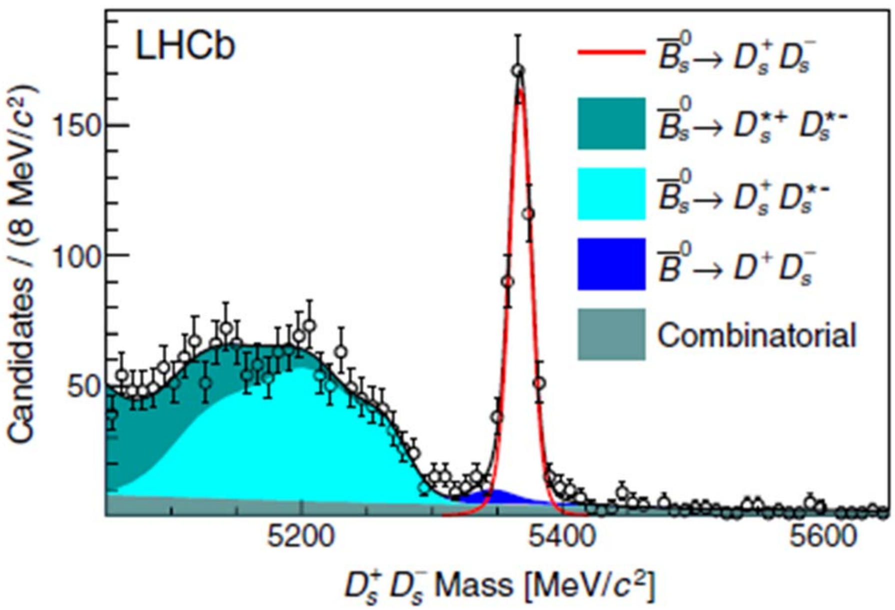
$$\mathcal{B}(\bar{B}^0_s \rightarrow D^+D^-) = (2.2 \pm 0.4(\text{stat}) \pm 0.2(\text{syst}) \pm 0.3(\text{norm})) \times 10^{-4}$$

$$\mathcal{B}(\bar{B}^0_s \rightarrow D^0\bar{D}^0) = (1.9 \pm 0.3(\text{stat}) \pm 0.3(\text{syst}) \pm 0.3(\text{norm})) \times 10^{-4}$$

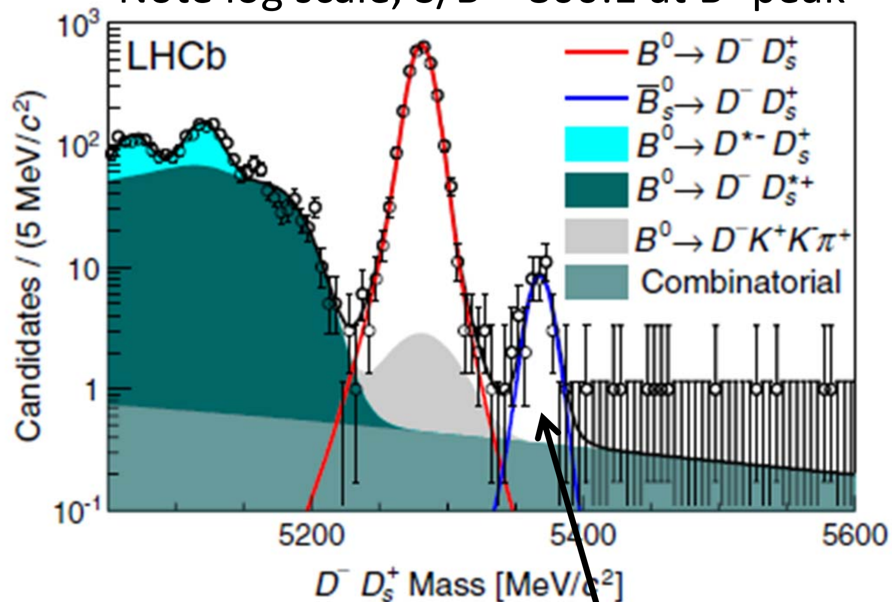
- $B_s \rightarrow D^+D^-$, $D^0\overline{D}^0$ consistent, would expect so.
- **~10X larger than $B^0 \rightarrow D_sK$**
- Consistent with both PQCD predictions, and those based on rescattering, but large theory errors.
- Look forward to more on these final states!

Other B→DD' signals / observations

PRD**87** 092007 (2013)



Note log scale, S/B ~ 800:1 at B^0 peak



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

Why is this ratio only ~0.5 ?

→ If TREE only, expect ratio ≈ 1?

Is this telling us something about PA and E contributions (which contribute to $B_s \to D_s D_s$, but not $B^0 \to D_s D$)

First observation of Cabibbo-suppressed $B_s \to D^- D_s^+$

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

≈ $\tan^2\theta_C$! as expected, tree dominant.

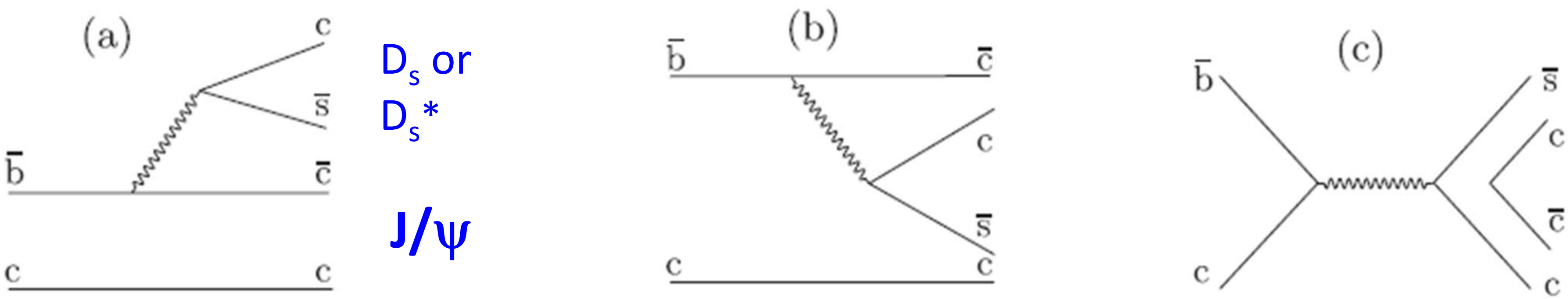
Large and clean signals !

Moving up: $B_c \rightarrow J/\psi D_s^{(*)}$

PRD**87**, 112012 (2013)

3 fb^{-1}

- Very little information yet available on B_c decays due to their low production rate.
- **Expect tree diagrams to dominate**



From naïve factorization, would expect…

$$\mathcal{R}_{D_s^+/\pi^+} \equiv \frac{\Gamma(B_c^+ \to J/\psi D_s^+)}{\Gamma(B_c^+ \to J/\psi \pi^+)} \approx \frac{\Gamma(B \to \bar{D}^* D_s^+)}{\Gamma(B \to \bar{D}^* \pi^+)},$$

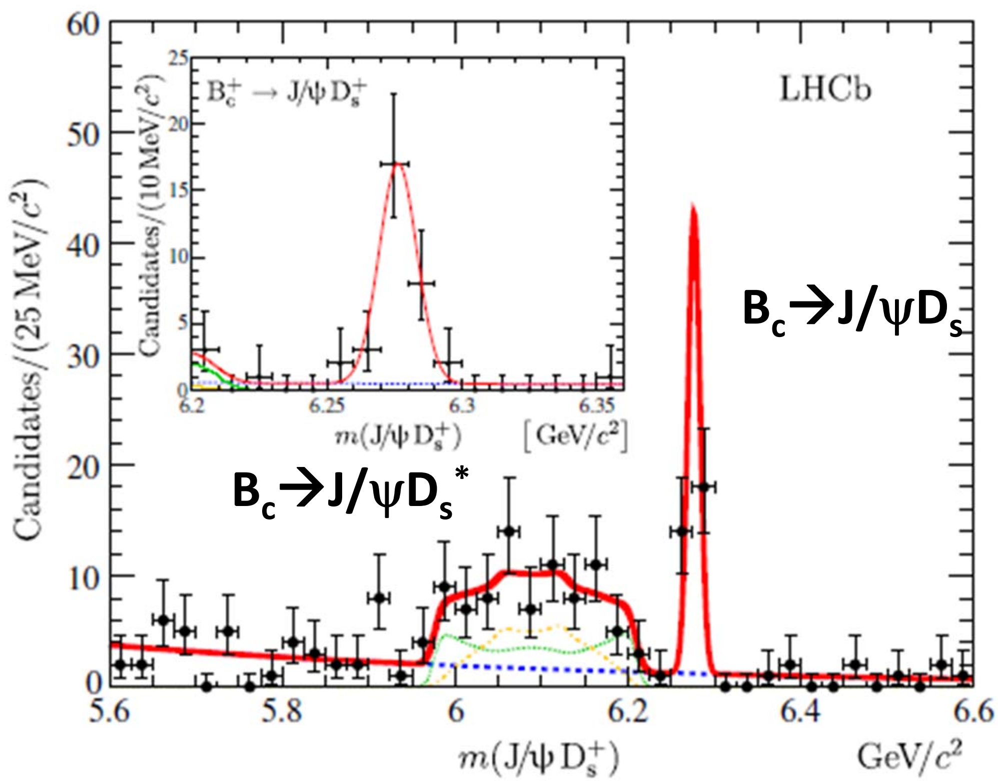
$$\mathcal{R}_{D_s^{*+}/D_s^+} \equiv \frac{\Gamma(B_c^+ \to J/\psi D_s^{*+})}{\Gamma(B_c^+ \to J/\psi D_s^+)} \approx \frac{\Gamma(B \to \bar{D}^* D_s^{*+})}{\Gamma(B \to \bar{D}^* D_s^+)},$$

$\mathcal{R}_{D_s^+/\pi^+}$	$\mathcal{R}_{D_s^{*+}/D_s^+}$	
2.90 ± 0.42	$2.20 \pm 0.35 \pm 0.62$	with B^0
1.58 ± 0.34	$2.07 \pm 0.52 \pm 0.52$	with B^+
1.3	3.9	V. Kiselev hep-ph/0308214
2.6	1.7	Colangelo et al PRD61 (2000)
2.0	2.9	Ivanov et al PRD73 (2006)
2.2	···	Dhir et al PRD79 (2009)
1.2	···	C.-H Chang et al PRD49 (1994)

Analysis

PRD87, 112012 (2013)

- Use $J/\psi \rightarrow \mu^+\mu^-$ triggered events;
  - J/ψ displaced from PV by > $3\sigma_{disp.}$
- Reconstruct $D_s \rightarrow \phi\pi$, $\phi \rightarrow KK$ candidates.
- Combine J/ψ and D_s candidates to form B_c candidates
  - J/ψ and D_s mass & vertex constraints imposed in fitting the decay.
- Excellent mass resolution due to large $M(J/\psi+D_s)$



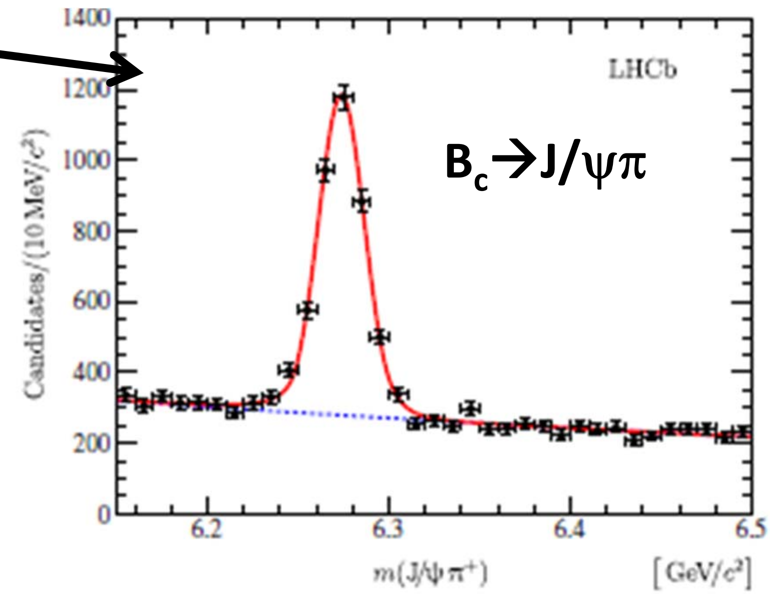
Unbinned maximum likelihood fit

Parameter	Value
$m_{B_c^+}$ [MeV$/c^2$]	6276.28 ± 1.44
$\sigma_{B_c^+}$ [MeV$/c^2$]	7.0 ± 1.1
$N_{B_c^+ \rightarrow J/\psi D_s^+}$	28.9 ± 5.6
$\frac{N_{B_c^+ \rightarrow J/\psi D_s^{*+}}}{N_{B_c^+ \rightarrow J/\psi D_s^+}}$	2.37 ± 0.56
$f_{\pm\pm}$ [%]	52 ± 20

Results on $B_c \to J/\psi D_s$

PRD87, 112012 (2013)

- Normalize with respect to $B_c \to J/\psi\pi$



$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} = 2.90 \pm 0.57 \pm 0.24$$

Closer to B^0 ratio (see below)

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^{*+})}{\mathcal{B}(B_c^+ \to J/\psi D_s^+)} = 2.37 \pm 0.56 \pm 0.10$$

Consistent with factorization…

$\mathcal{R}_{D_s^+/\pi^+}$	$\mathcal{R}_{D_s^{*+}/D_s^+}$	
2.90 ± 0.42	$2.20 \pm 0.35 \pm 0.62$	with B^0
1.58 ± 0.34	$2.07 \pm 0.52 \pm 0.52$	with B^+

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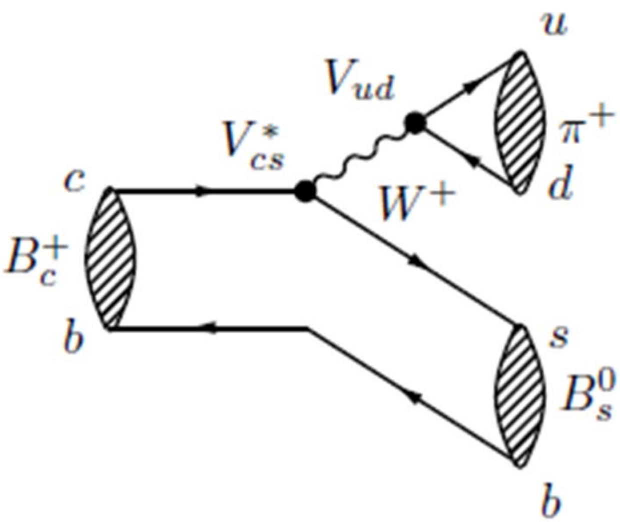
1.2	···	C.-H Chang et al PRD49 (1994)

Source	Uncertainty [%]
Simulated efficiencies	1.0
Trigger	1.1
Fit model	1.8
Track reconstruction	2×0.6
Hadron interactions	2×2.0
Track quality selection	2×0.4
Kaon identification	3.0
B_c^+ lifetime	1.0
Stability for various data taking conditions	2.5
$\mathcal{B}(D_s^+ \to (K^- K^+)_\phi \pi^+)$	5.6
Total	8.4

$B_c \to B_s\pi$

LHCb-PAPER-2013-034
(Preliminary)

3 fb^{-1}

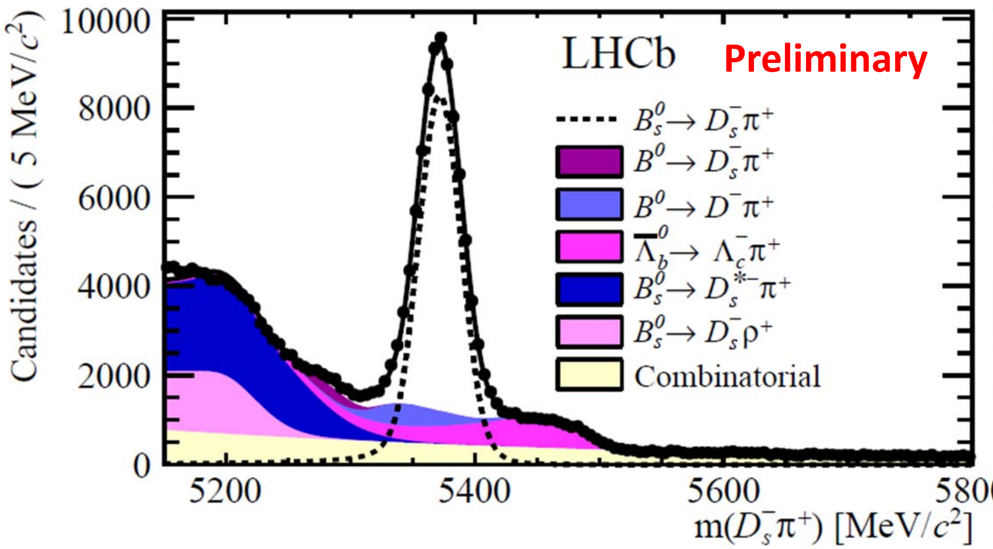


- All B_c decays to date obs'd via $b \to c \to \psi^{(\prime)}X$
- "Easily" triggered on using $\psi^{(\prime)} \to \mu^+\mu^-$.
- $c \to s$ mean $B_c \to B_sX$ ... more difficult to trigger on and reconstruct..

- This analysis reports the **first observation** of $B_c \to B_s\pi$.
- Wide range of theoretical predictions for the branching fraction, from a few percent to ~20%.
- Strategy is to take fully reconstructed B_s decays, add a π^+ and search for a peak at the B_c mass.
- Goal is to measure: $$\frac{\sigma(B_c^+)}{\sigma(B_s^0)}\mathcal{B}(B_c^+ \to B_s^0\pi^+)$$

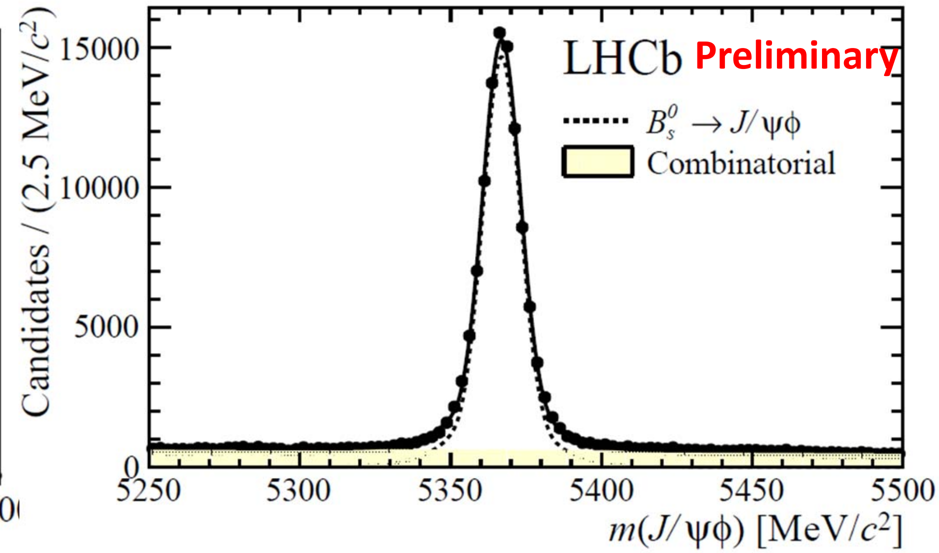
B_s candidates

$B_s \rightarrow D_s\pi$, $D_s \rightarrow KK\pi$



≈ 74,000 recon. $B_s \rightarrow D_s\pi$

$B_s \rightarrow J/\psi\phi$, $\phi \rightarrow KK$

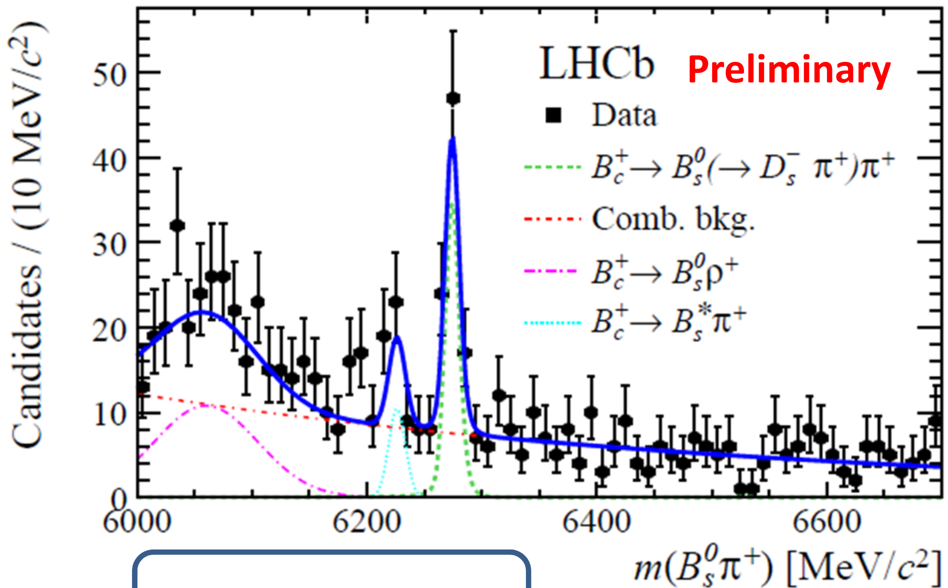


≈ 104,000 recon. $B_s \rightarrow J/\psi\phi$

- Form B_c^+ candidates
  - B_s selection: mass windows [5335-5407] for $D_s\pi$, [5330-5410] for $J/\psi\phi$
  - π^+: p_T>100 MeV, IP χ^2 > 2 & loose PID
- BDT used to distinguish signal from background.
- $\varepsilon(B_s)/\varepsilon(B_c)$ obtained from simulation, except PID (uses D^{*+} calib data)

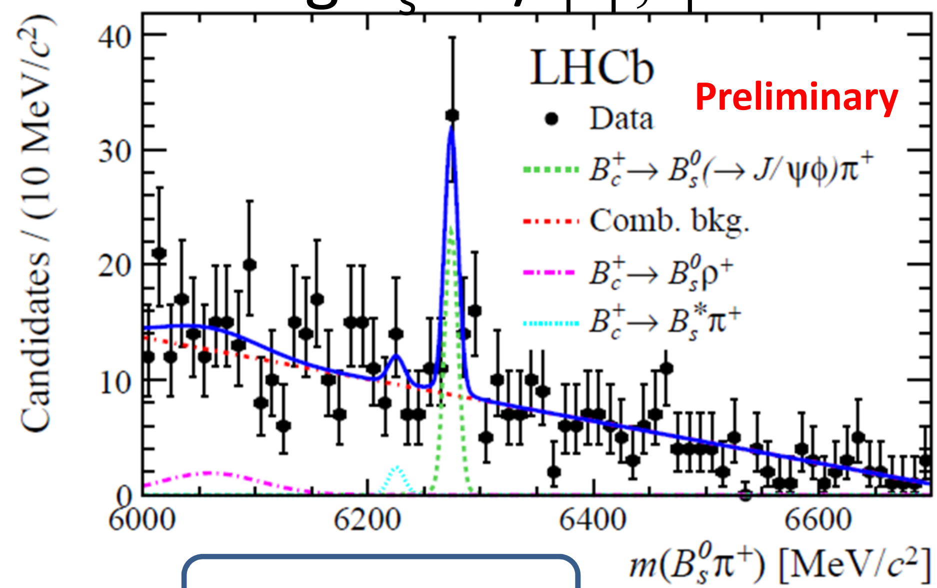
$B_c^+ \to B_s\pi$ data

Using $B_s \to D_s\pi$, $D_s \to KK\pi$



7.5σ (incl. syst)

Using $B_s \to J/\psi\phi$, $\phi \to KK$



5.5σ (incl. syst)

$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)}\mathcal{B}(B_c^+ \to B_s^0\pi^+) =$$

$$\left(2.51 \pm 0.40(stat)^{+0.23}_{-0.17}(syst)\right)\times 10^{-3} \qquad \left(2.20 \pm 0.49(stat) \pm 0.23(syst)\right)\times 10^{-3}$$

$$\frac{\sigma(B_c^+)}{\sigma(B_s^0)}\mathcal{B}(B_c^+ \to B_s^0\pi^+) = \left(2.38 \pm 0.35(stat) \pm 0.11(stat)^{+0.17}_{-0.12}(\tau_{B_c})\right)\times 10^{-3}$$

Assuming $B_c \to J/\psi\pi$ = 0.15% from Ivanov et al, from theory, leads to
$\mathcal{B}(B_c \to B_s\pi)$~10% but large uncertainty. Well within the wide range of predictions

Summary

- Many interesting measurements in $b \to cX$ decays performed with 1 fb^{-1} data sample.
- Several aimed at measuring γ or input to the combined γ determination.
- Large samples being used to probe Weak exchange, Penguin annihilation decays.
  - New double-charm final states uncovered..
  - Promising for CPV and CKM angle m'ments..
- New B_c decay discoveries, $B_c \to B_s\pi$, $B_c \to J/\psi D_s$
  - Excellent prospects for more B_c decay mode discoveries

Stay tuned for full 2011+2012
3 fb^{-1} results!