Studies of the decay $B^0_s \rightarrow D_s^+ K^-$

Barbara Storaci
on behalf of the LHCb Collaboration

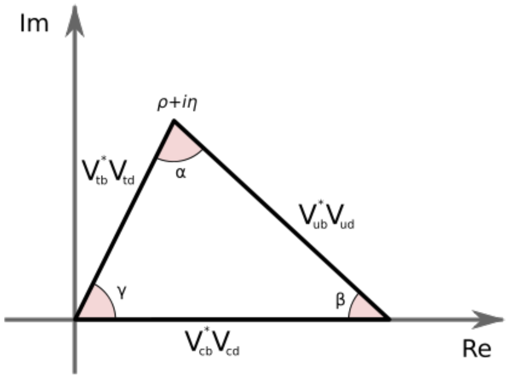
Motivation

Why is $B^0_s \to D_s^+K^-$ interesting?

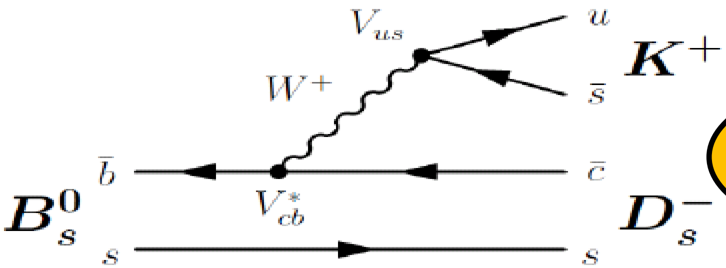
- Test SM through CKM-unitarity triangle
- γ the least constraint parameters by direct measurements
- Clean time-dependent measurement with $B^0_s \to D_s^+K^-$
- BR($B^0_s \to D_s^+K^-$) still poorly known, ± 23%

[K. Nakamura et al. (Particle Data Group), Journal of Physics G37, 075021 (2010)]

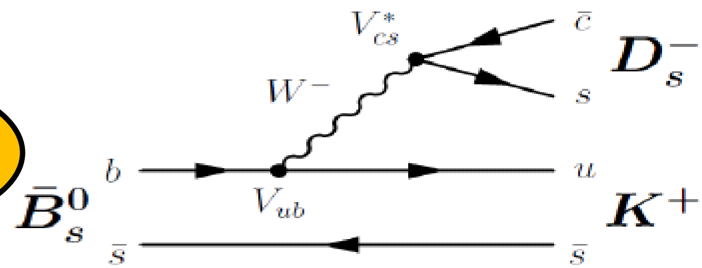
- → **Today the World Best Measurement of its BR**



Time Dependent Measurement

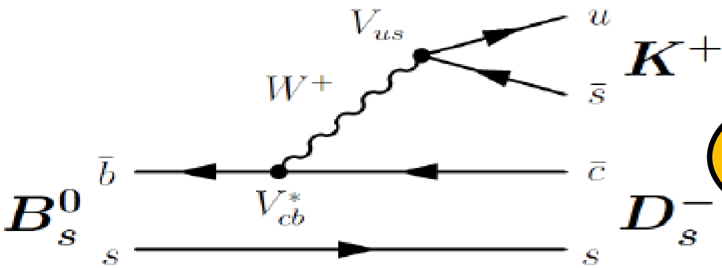


γ = weak phase btw. V^*cb Vub



- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B^0}_s$
- Large interference expected

Time Dependent Measurement



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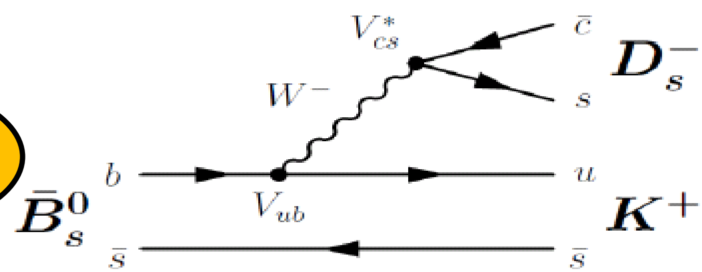
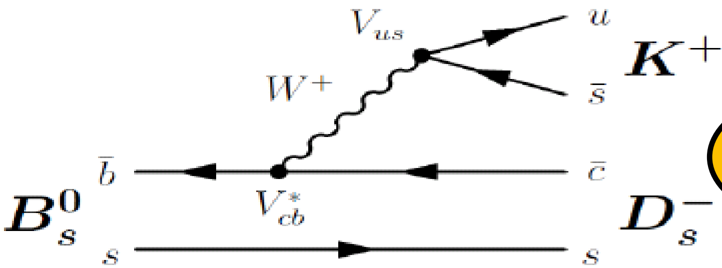


- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B^0}_s$
- Large interference expected

Key ingredients:

- Large b production rate

Time Dependent Measurement



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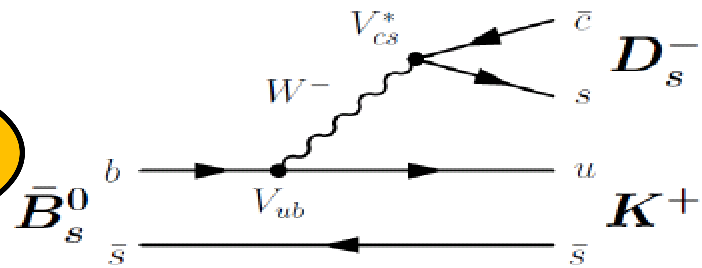
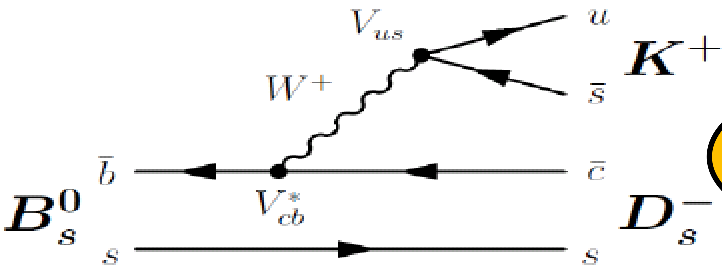


- Final state $D_s^- K^+$ accessible by both B^0_s and $\bar{B}^0_s$
- Large interference expected

Key ingredients:

- Large b production rate ~60 kHz bb

Time Dependent Measurement



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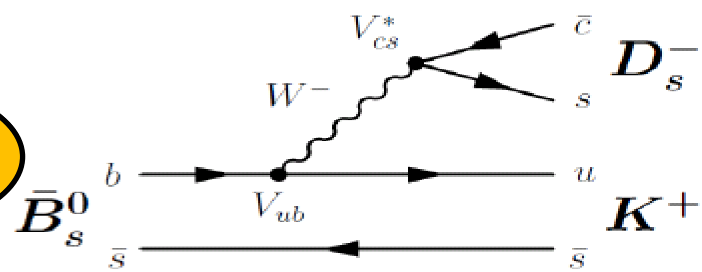
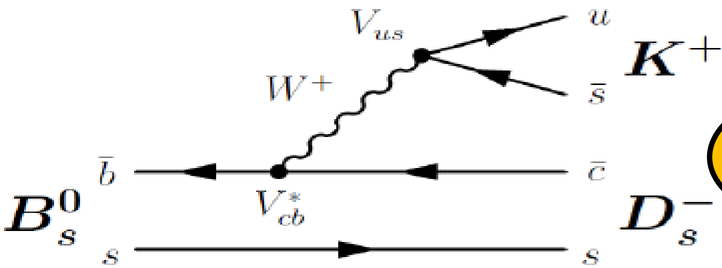


- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B}^0_s$
- Large interference expected

Key ingredients:

- Large b production rate ~60 kHz bb
- Excellent Proper Time Resolution

Time Dependent Measurement



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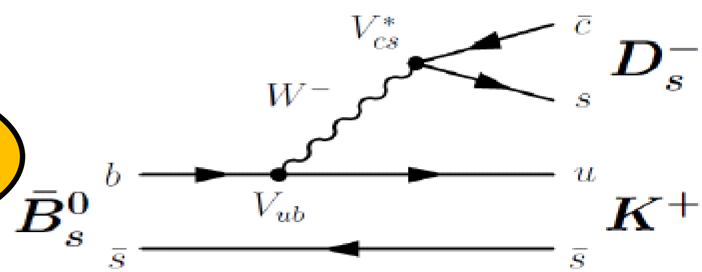
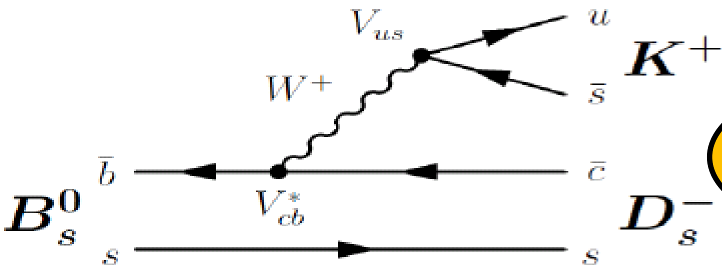


- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B^0}_s$
- Large interference expected

Key ingredients:

- Large b production rate ~60 kHz bb
- Excellent Proper Time Resolution ~50 fs

Time Dependent Measurement



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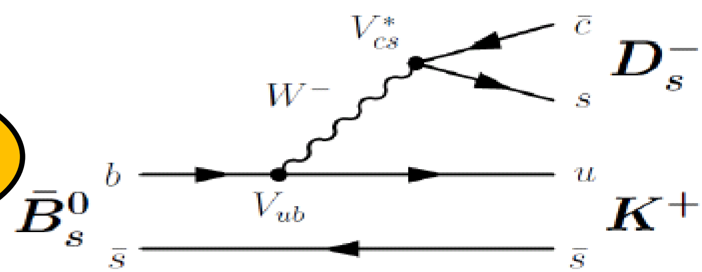
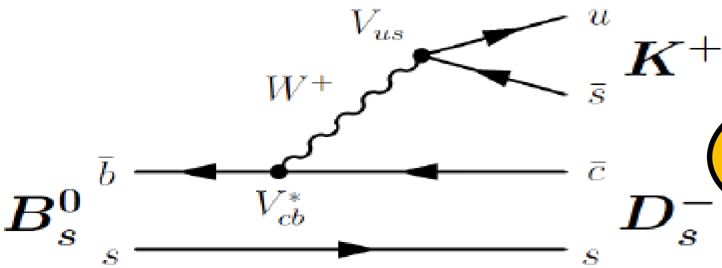


- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B}^0_s$
- Large interference expected

Key ingredients:

- Large b production rate ~60 kHz bb
- Excellent Proper Time Resolution ~50 fs
- Excellent Particle Identification (PID)

Time Dependent Measurement



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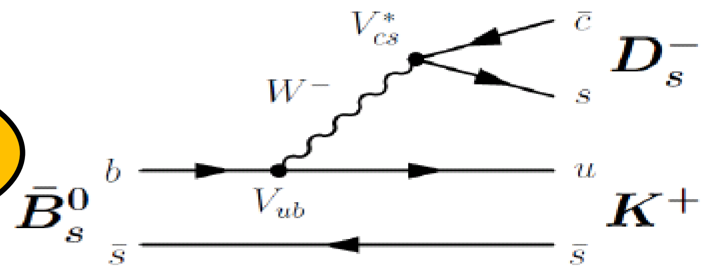
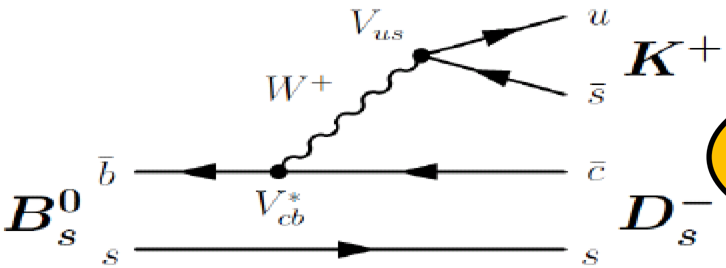


- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B^0_s}$
- Large interference expected

Key ingredients:

- Large b production rate ~60 kHz bb
- Excellent Proper Time Resolution ~50 fs
- Excellent Particle Identification (PID) ε_K~95% , O(<5%) π-K misid

Time Dependent Measurement



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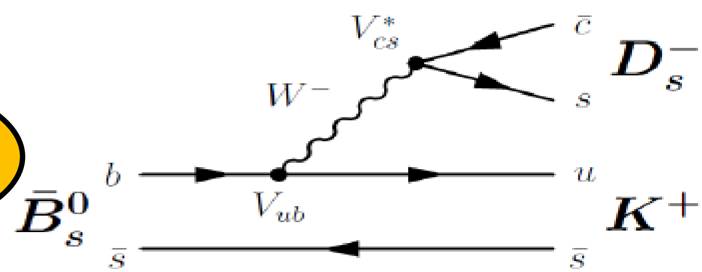

- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B}^0_s$
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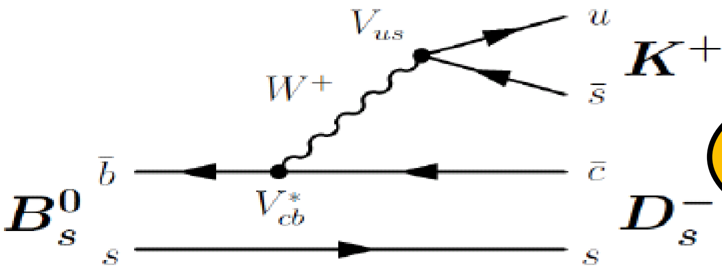
Key ingredients:

- Large b production rate ~60 kHz bb
- Excellent Proper Time Resolution ~50 fs
- Excellent Particle Identification (PID) ε_K~95% , O(<5%) π-K misid
- Sensitivity to hadronic final states

Time Dependent Measurement



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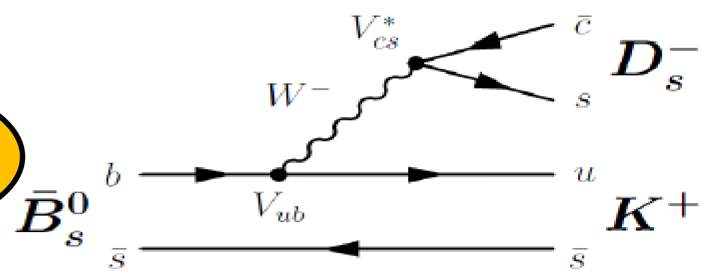
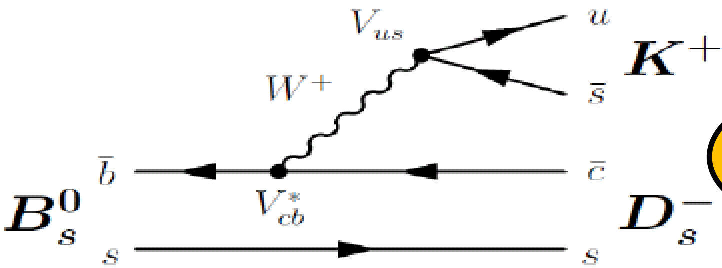


- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B}^0_s$
- Large interference expected

Key ingredients:

- Large b production rate — ~60 kHz bb
- Excellent Proper Time Resolution — ~50 fs
- Excellent Particle Identification (PID) — ε_K~95% , O(<5%) π-K misid
- Sensitivity to hadronic final states — specific hadronic trigger

Time Dependent Measurement



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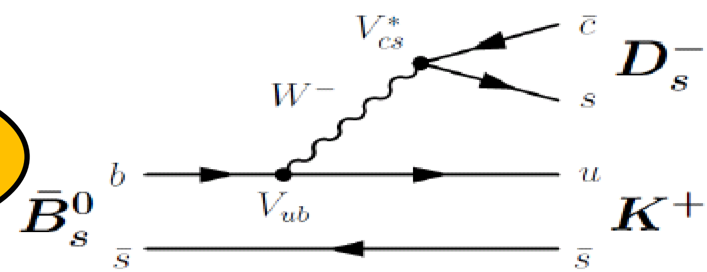

- Final state $D_s^- K^+$ accessible by both B^0_s and $\overline{B^0}_s$
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First step is the Branching Fraction measurement !

Signal

- 0.37 fb^{-1} of LHCb data used (first part of 2011)

3 decays with the same topology

$$B^0 \to D^-(K^+ 2\pi^-)\pi^+$$
$$B_s^0 \to D_s^-(K^+ K^- \pi^-)\pi^+$$
$$B_s^0 \to D_s^{\pm}(K^{\mp} K^{\pm} \pi^{\pm})K^{\mp}$$

Meas. of BR($B_s^0 \to D_s^- \pi^+$) using fs/fd meas. In LHCb *arXiv:1111.2357 [hep-ex]*

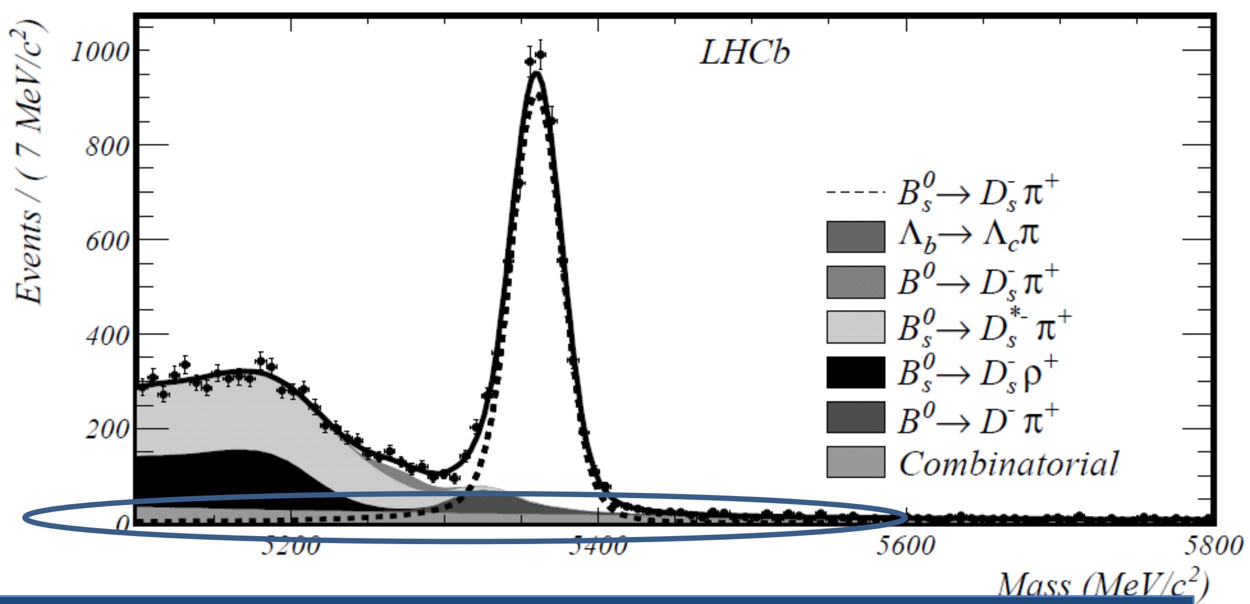
Meas. of BR($B_s^0 \to D_s^{\pm} K^{\mp}$)

✓ Same trigger, stripping and offline selection (using BDT) to minimize efficiency corrections
✓PID applied at the latest stage for distinguishing these decays channels

Backgrounds

1. Combinatorial Background:
   - Random π or K forming fake D or Ds
   - Real prompt D or Ds combined with random π or K to form a fake B^0 or B^0_s

Our selection is efficiently cutting it!

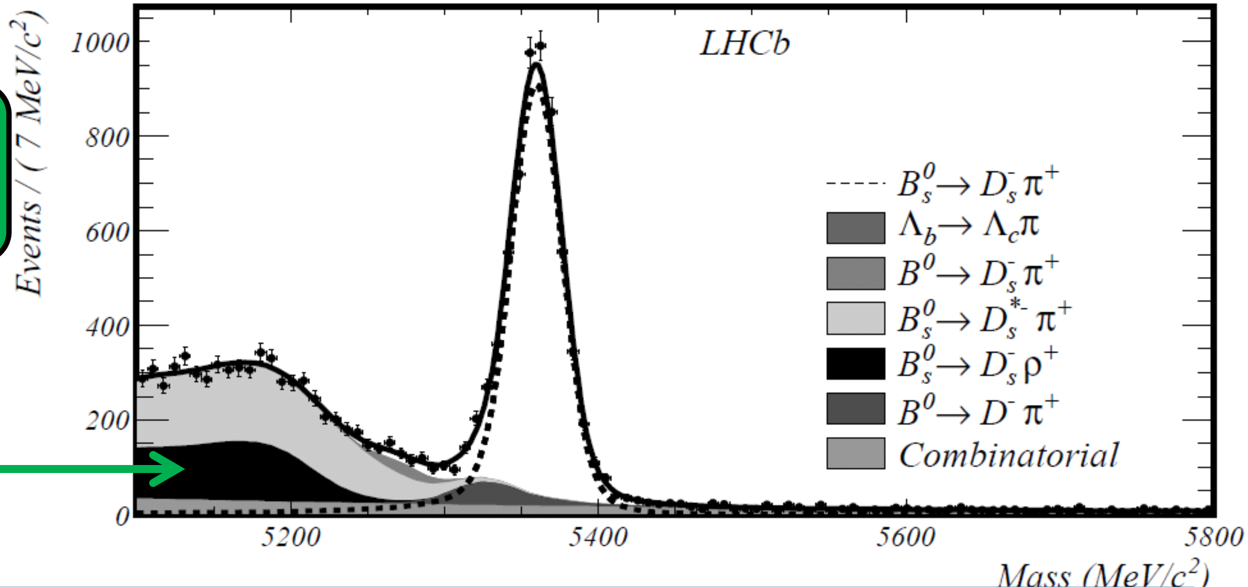


Backgrounds

1. Combinatorial Background:
   - Random π or K forming fake D or Ds
   - Real prompt D or Ds combined with random π or K to form a fake B^0 or B^0_s
2. Partially Reconstructed Background:
   - Lost one particle in the reconstruction, ex: $B_s^0 \to D_s^- \rho^+$ where the π^0 from the ρ^+ is missed

- Topology similar to the signal
- Sitting mostly on the left of the signal

$B_s^0 \to D_s^- \rho^+$



Backgrounds

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2. Partially Reconstructed Background:
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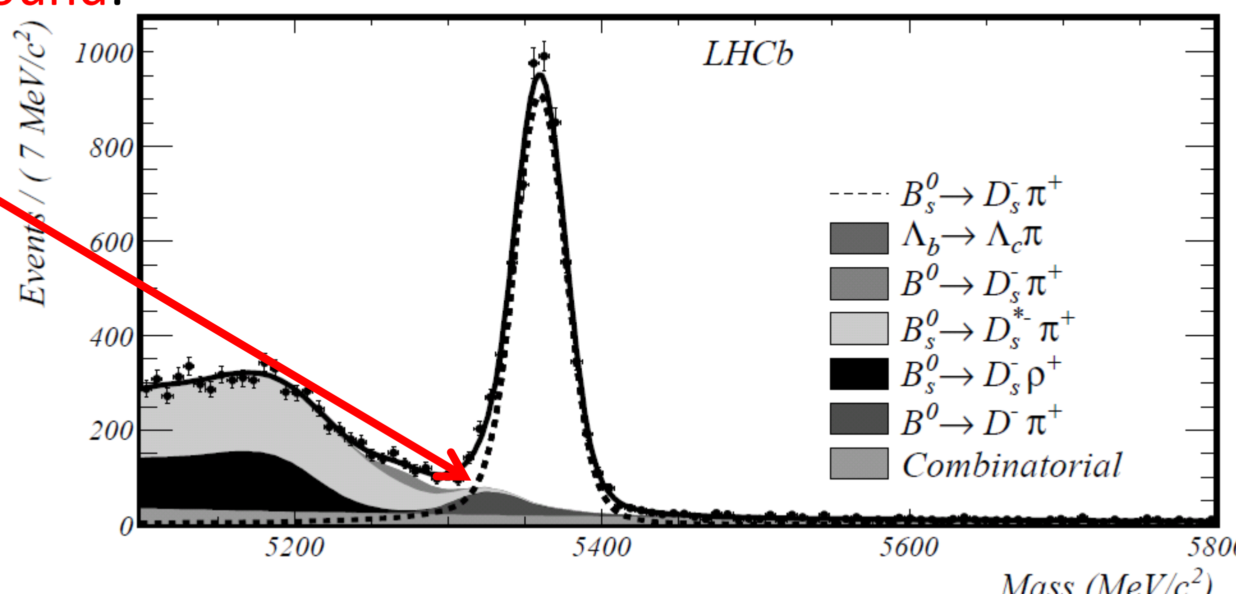
3. Misidentified Background:
   - $B^0 \rightarrow (D^- \rightarrow D_s^-)\pi^+$

     under $B_s^0 \rightarrow D_s^- \pi^+$

Sitting under the signal



Backgrounds

1. Combinatorial Background:
   - Random π or K forming fake D or Ds
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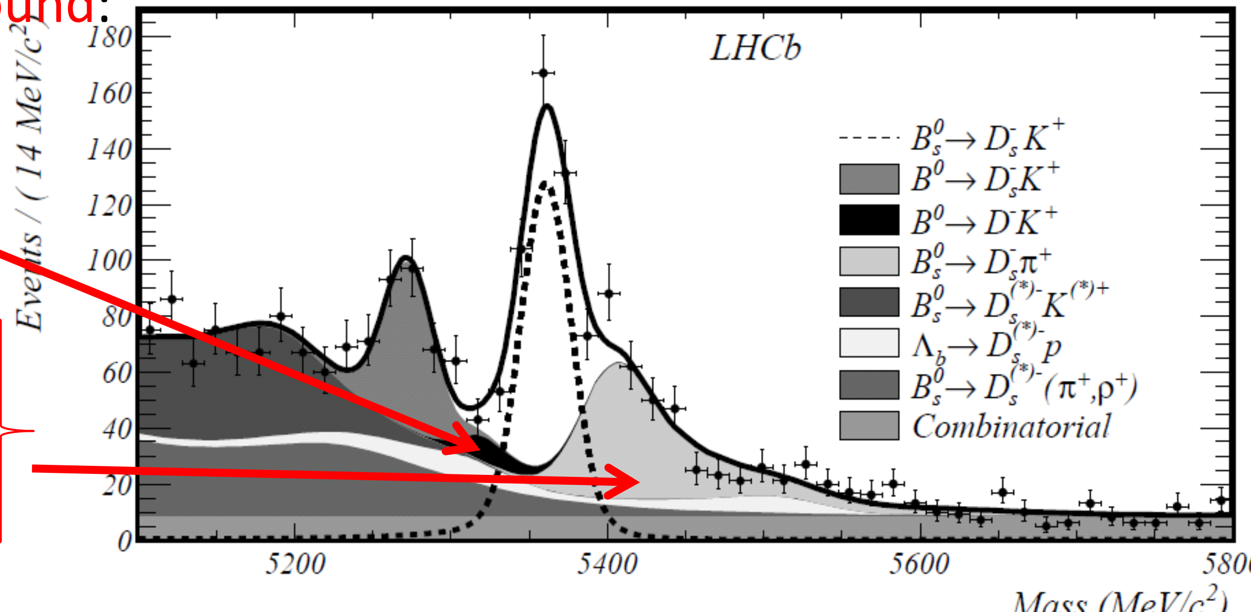
2. Partially Reconstructed Background:
   - Lost one particle in the reconstruction, ex: $B_s^0 \to D_s^- \rho^+$ where the π^0 from the ρ^+ is missed
3. Misidentified Background:
   - $B^0 \to (D^- \to D_s^-)\pi^+$ under $B_s^0 \to D_s^- \pi^+$
   - $B^0 \to (D^- \to D_s^-)K^+$ under $B_s^0 \to D_s^- K^+$
   - $B_s^0 \to D_s^-(\pi^+ \to K^+)$ under $B_s^0 \to D_s^- K^+$
   - $B^0 \to (D^- \to D_s^-)(\pi^+ \to K^+)$ under $B_s^0 \to D_s^- K^+$

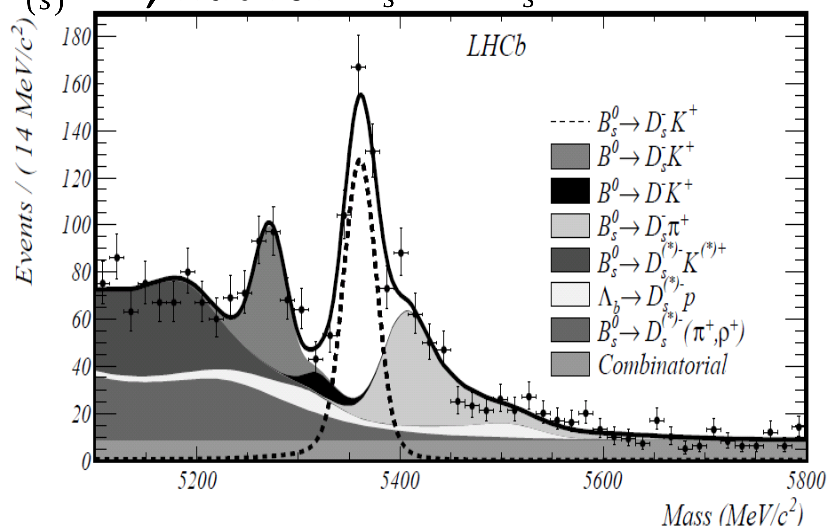


Fit Strategy

Signal shape: double crystal ball function

Background shapes:

- MisID: from data using a reweighting procedure to correct for the momentum dependency of PID selection
- Part. Reco: template from MC
  - Gaussian constraint on the yields if the BR known or estimable
- Comb: exponential shape for $B^0_{(s)} \to D^-_{(s)}\pi^+$, flat for $B^0_s \to D^\pm_s K^\mp$
  - Checked with wrong-sign sample



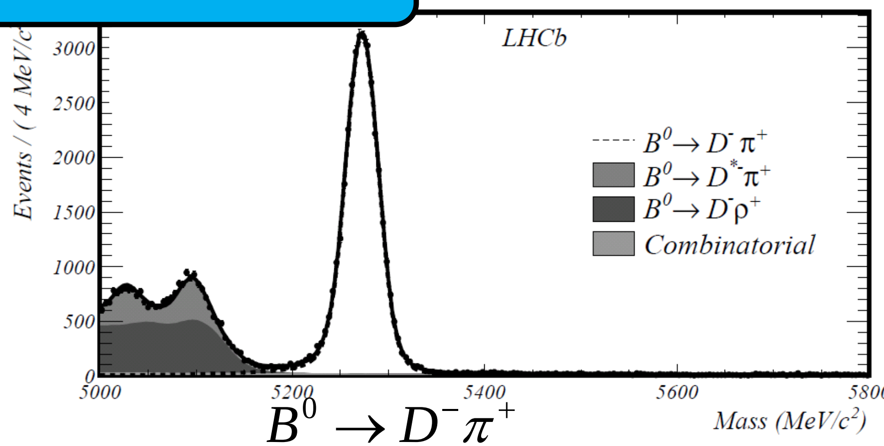
- Sample divided according to the magnet polarities to achieve maximum sensitivity
- Simultaneous fit: same signal shape for both polarities

BR($B^0_s \to D_s^- \pi^+$)

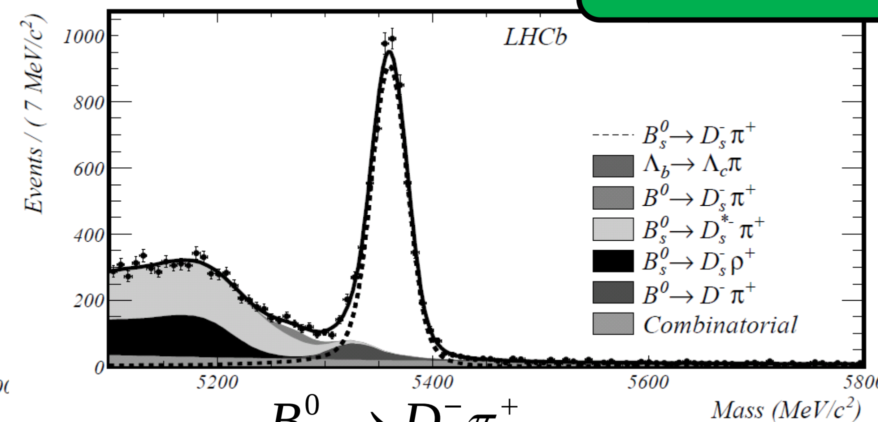
Ns(Down) = 20150 ± 152
Ns(Up) = 16304 ± 137

Both polarities together for illustrative purpose

Ns(Down) = 3369 ± 69
Ns(Up) = 2677 ± 62



$B^0 \to D^- \pi^+$



$B^0_s \to D_s^- \pi^+$

$$\mathcal{B}(B^0_s \to D_s^- \pi^+) = \mathcal{B}\left(B^0 \to D^- \pi^+\right) \frac{\epsilon_{B^0 \to D^- \pi^+}}{\epsilon_{B^0_s \to D_s^- \pi^+}} \frac{N_{B^0_s \to D_s^- \pi^+} \mathcal{B}\left(D^+ \to K^- \pi^+ \pi^+\right)}{\frac{f_s}{f_d} N_{B^0 \to D^- \pi^+} \mathcal{B}\left(D_s^+ \to K^+ K^- \pi^+\right)}$$

Using LHCb mesurement: $\frac{f_s}{f_d} = (0.268 \pm 0.008)^{+0.022}_{-0.020}$ ***arXiv:1111.2357 [hep-ex]***

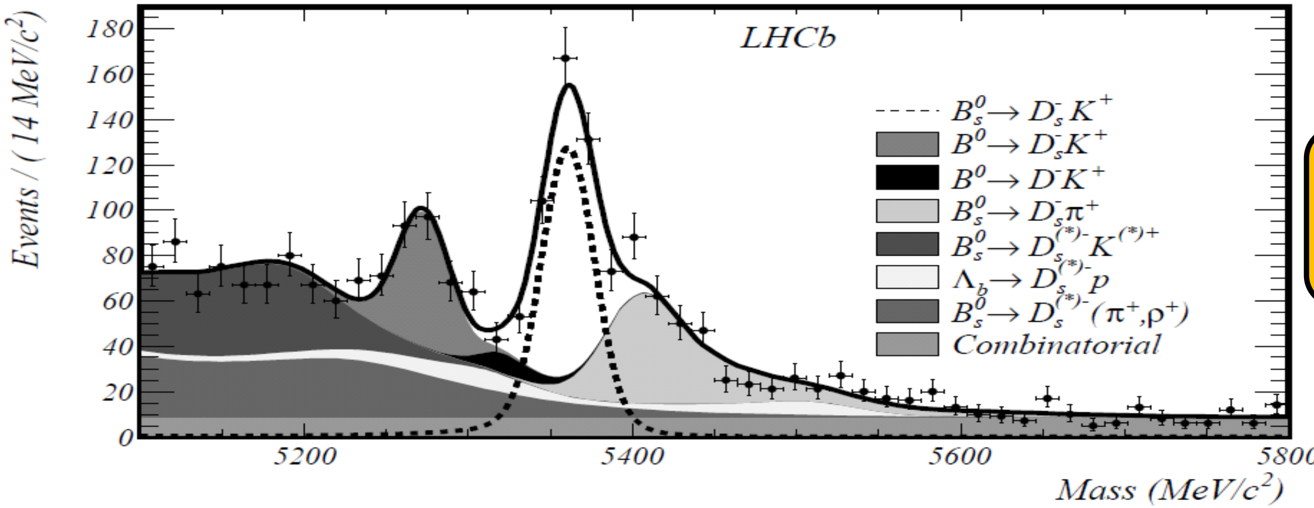
$$\mathcal{B}(B^0_s \to D_s^- \pi^+) = (2.95 \pm 0.05 \pm 0.17^{+0.18}_{-0.22}) \times 10^{-3}$$

Stat. *Syst.* *From f_s/f_d.*

Previous Best Measurement: **(3.2 ± 0.5) × 10^{-3}** ***[K. Nakamura et al. (Particle Data Group), Journal of Physics G37, 075021 (2010)]***

$BR(B^0_s \to D_s^+ K^-)$

Both polarities together for illustrative purpose



Ns(Down) = 209 ± 19
Ns(Up) = 195 ± 18

$$\frac{\mathcal{B}(B^0_s \to D_s^- K^+)}{\mathcal{B}(B^0_s \to D_s^- \pi^+)} = \frac{N_{B^0_s \to D_s^- K^+}}{N_{B^0_s \to D_s^- \pi^+}} \frac{\epsilon^{PID}_{B^0_s \to D_s^- \pi^+}}{\epsilon^{PID}_{B^0_s \to D_s^- K^+}} \frac{\epsilon^{Sel}_{B^0_s \to D_s^- \pi^+}}{\epsilon^{Sel}_{B^0_s \to D_s^- K^+}}$$

$$\mathcal{B}(B^0_s \to D_s^- K^+) = (1.90 \pm 0.12 \pm 0.13^{+0.12}_{-0.14}) \times 10^{-4}$$

Stat. Syst. From f_s/f_d.

Previous Best Measurement: (3.0 ± 0.7) × 10^{-4} *[K. Nakamura et al. (Particle Data Group), Journal of Physics G37, 075021 (2010)]*

Conclusions

- World best measurement of the BR($B^0_s \to D_s^-\pi^+$) and BR($B^0_s \to D_s^+K^-$) with 0.37 fb^{-1} collected in LHCb
  - **$B^0_s \to D_s^+K^-$** measurement in agreement with prev. measurements, error reduced to **~12%**
  - **$B^0_s \to D_s^-\pi^+$** : best known B^0_s mode now with an uncertainty of **~10%** (before was ~16%)
- Fist step through the measurement of γ with a $B^0_s \to D_s^+K^-$ time-dependent analysis
  - We already have 1.0 fb^{-1} of data collected last year

Backup


Our Disaster Recovery Plan
Goes Something Like This...
HELP!
HELP!
DILBERT
By Scott Adams

Gaussian Const. $B^0_s \to D_s^- K^+$

Table 3: Gaussian constraints applied in the $B^0_s \to D_s^- K^+$ fit.

Background type	Magn. Down	Magn. Up
$B^0_s \to D_s^{*-}\pi^+$	70 ± 23	63 ± 21
$B^0_s \to D_s^{*-}K^+$	80 ± 27	72 ± 34
$B^0_s \to D_s^-\rho^+$	150 ± 50	135 ± 45
$B^0_s \to D_s^-K^{*+}$	150 ± 50	135 ± 45
$B^0_s \to D_s^{*-}\rho^+$	50 ± 17	45 ± 15
$B^0_s \to D_s^{*-}K^{*+}$	50 ± 17	45 ± 15
$\Lambda_b \to D_s^- p + \Lambda_b \to D_s^{*-} p$	80 ± 27	72 ± 34

Systematic uncertainties

Table 4: The final systematic uncertainities for the measurement of the branching fractions of $B_s^0 \to D_s^- K^+$ and $B_s^0 \to D_s^- \pi^+$.

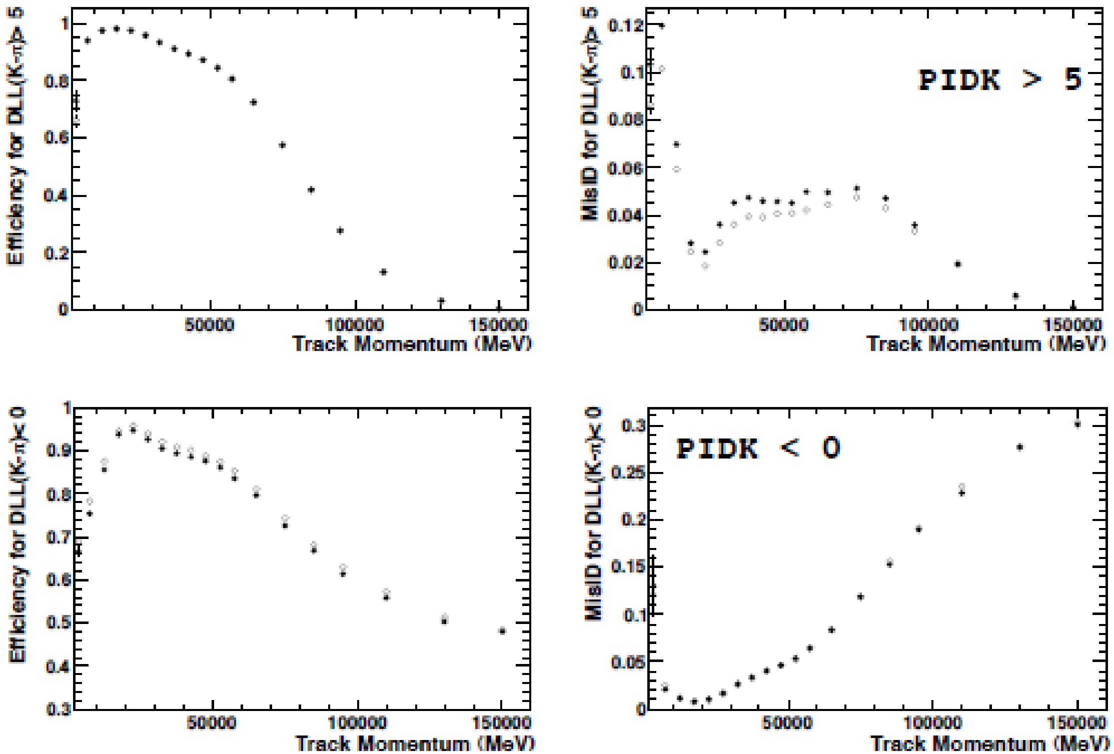
Source	Uncertainty
All non-PID selection ($B_s^0 \to D_s^- K^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	2%
All non-PID selection ($B^0 \to D^- \pi^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	2%
All non-PID selection ($B_s^0 \to D_s^- K^+$ wrt. $B^0 \to D^- \pi^+$)	3%
Fit model $B^0 \to D^- \pi^+$	1.0%
Fit model $B_s^0 \to D_s^- \pi^+$	1.4%
Fit model $B_s^0 \to D_s^- K^+$	2.0%
PID selection ($B_s^0 \to D_s^- K^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	1.8%
PID selection ($B^0 \to D^- \pi^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	1.3%
PID selection ($B_s^0 \to D_s^- K^+$ wrt. $B^0 \to D^- \pi^+$)	2.2%
Efficiency ratio ($B_s^0 \to D_s^- K^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	1.5%
Efficiency ratio ($B^0 \to D^- \pi^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	1.6%
Efficiency ratio ($B_s^0 \to D_s^- K^+$ wrt. $B^0 \to D^- \pi^+$)	1.6%
Total ($B_s^0 \to D_s^- K^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	±3.9%
Total ($B^0 \to D^- \pi^+$ wrt. $B_s^0 \to D_s^- \pi^+$)	±3.4%
Total ($B_s^0 \to D_s^- K^+$ wrt. $B^0 \to D^- \pi^+$)	±4.6%

PID selection efficiencies

Table 1: PID efficiency and misidentification probabilities, split by magnet polarity. The first two lines refer to the bachelor track selection, the third line is the D^- efficiency and the fourth the D_s^- efficiency. Probabilities are obtained from the efficiencies in the D^* calibration sample, binned in momentum and p_T. Only bachelor tracks with momentum below 100 GeV/c^2 are considered. The uncertainties shown are the statistical uncertainties due to the finite number of signal events used in the reweighting.

	PID Cut	Efficiency		MisID	
		Mag. Down	Mag. Up	Mag. Down	Mag. Up
K	$\text{DLL}_{K-\pi} > 5$	(83.5 ± 0.2) %	(83.3 ± 0.2) %	(4.5 ± 0.1) %	(5.3 ± 0.1) %
π	$\text{DLL}_{K-\pi} < 0$	(85.8 ± 0.2) %	(84.2 ± 0.2) %	(5.4 ± 0.1) %	(5.3 ± 0.1) %
D^-		85.7 ± 0.2	84.1 ± 0.2	N/A	N/A
D_s^-		78.4 ± 0.2	77.6 ± 0.2	N/A	N/A

PID calibration



PID performance performed on data from D* sample

- Evaluated eff. and midID rate on D* sample for the PID cuts applied in the analysis (in bins of p and pt)
- No dependence on track multiplicity since both signal and contr. channel are selected with the same trigger
- Different curve for magnet up and magnet down