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Determination of γ with $B_s \rightarrow D_s K$

5th Annual Workshop of the Helmholtz Alliance
“Physics at the Terascale”

Maximilian Schlupp

Introduction

- Unitary CKM matrix

$$V_{\mathrm{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- can be described by three mixing angles and one (CP-violating) phase
- Wolfenstein parametrization

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

Introduction

- Unitarity of the 3x3 CKM matrix implies e.g.

$$\sum_i V_{ij} V_{ik}^* = \delta_{jk}$$

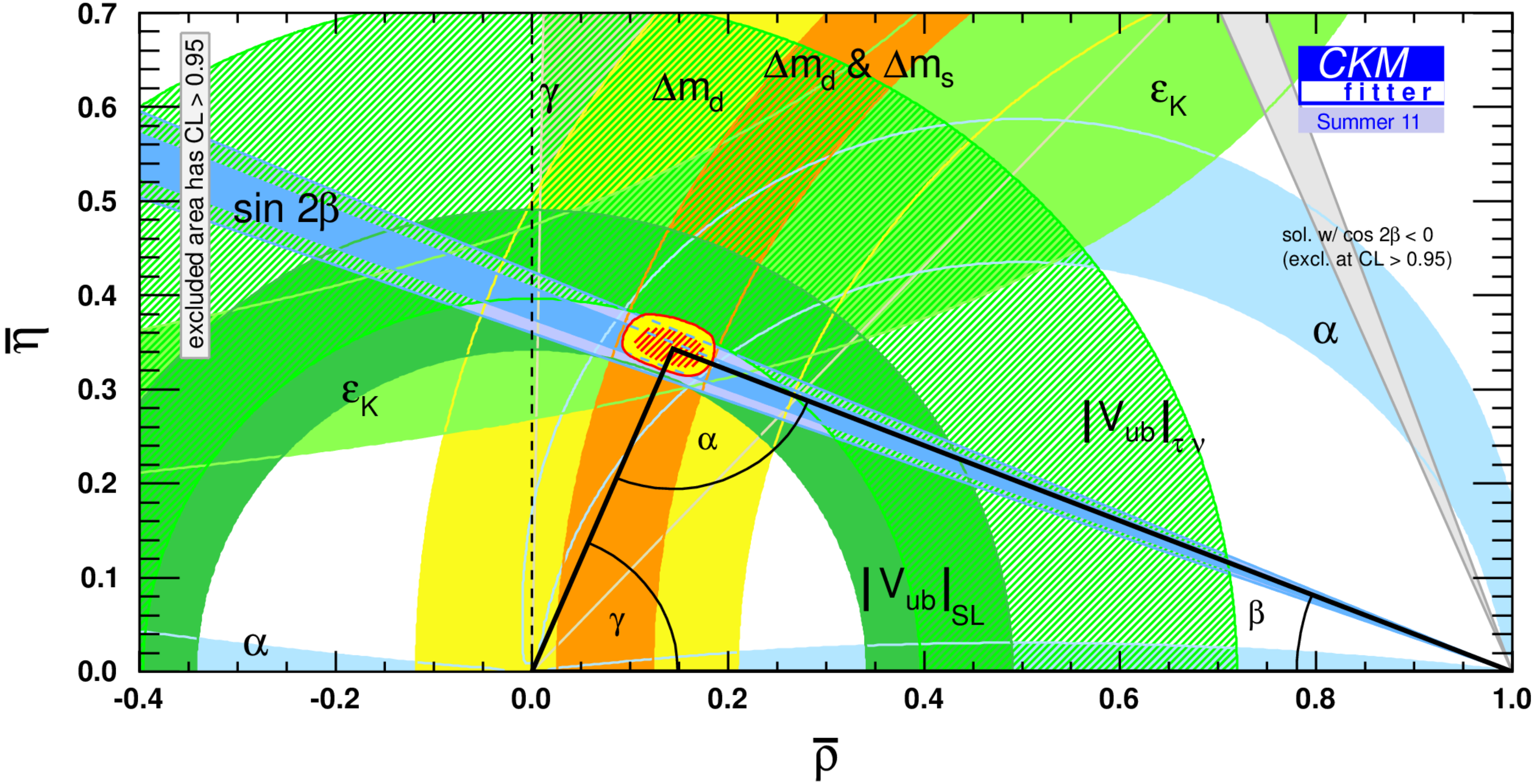
- This translates into several unitarity conditions; most commonly used

$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$$

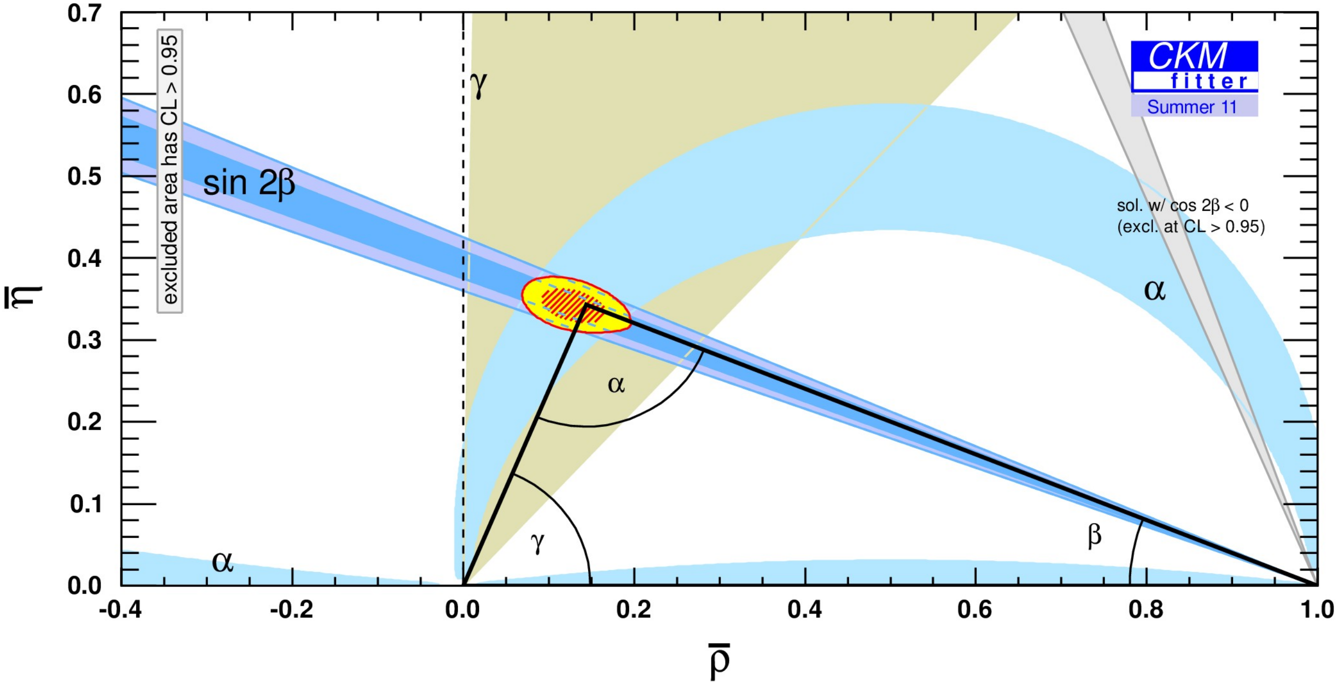
- Normalized to the best-known element

$$V_{cd} V_{cb}^*$$

Introduction



Introduction



$\gamma=(67.3^{+4.2}_{-3.5})°$ (CKM global fit) $\gamma=(68^{+10}_{-11})°$ (direct)

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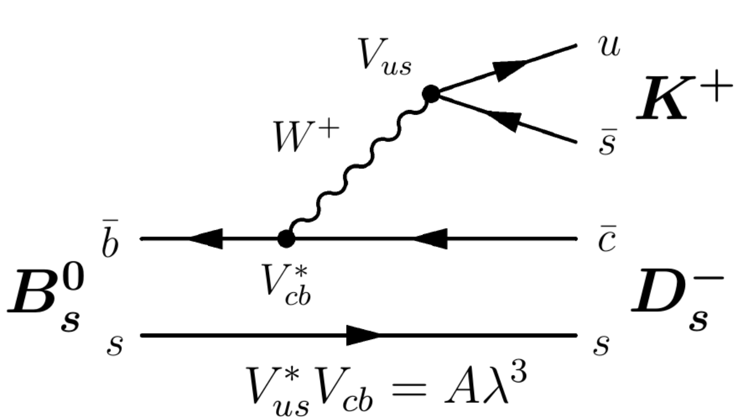
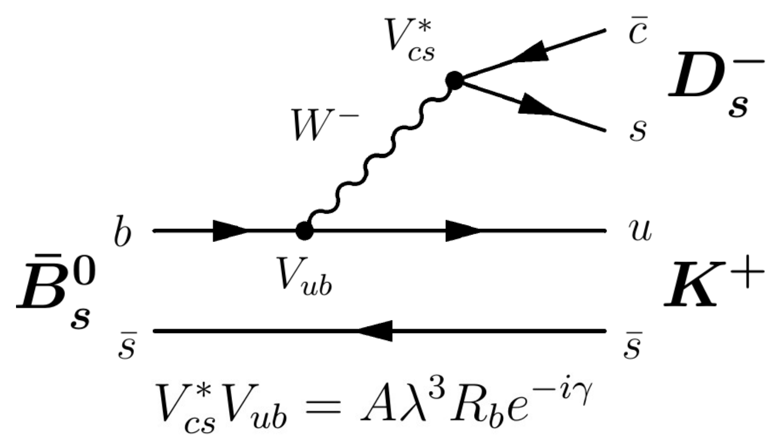
Extracting γ from B_s decays

- In order to measure γ one needs decays containing V_{ub}

$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

- One possibility $B_s \to D_s K$





Extracting γ from B_s decays

R. Fleischer; CERN-TH/2003-084, hep-ph/0304027
S. Cohen, M. Merk, E. Rodrigues; LHCb Note 2007-041

- Why $B_s \rightarrow D_s K$?
  - Theoretically clean $|B_{H,L}\rangle = p|B_s^0\rangle \mp q|\bar{B}_s^0\rangle$

$$\lambda_{D_s^- K^+} = \left(\frac{q}{p}\right)\frac{\bar{A}_{D_s^- K^+}}{A_{D_s^- K^+}} = \left(\frac{V_{tb}^* V_{ts}}{V_{tb} V_{ts}^*}\right)\left(\frac{V_{ub} V_{cs}^*}{V_{cb}^* V_{us}}\right)\left|\frac{A_2}{A_1}\right| e^{i\Delta_{T1/T2}} = |\lambda_{D_s^- K^+}| e^{i(\Delta_{T1/T2} - (\gamma + \phi_s))}$$

$$\bar{\lambda}_{D_s^+ K^-} = \left(\frac{p}{q}\right)\frac{A_{D_s^+ K^-}}{\bar{A}_{D_s^+ K^-}} = \left(\frac{V_{tb} V_{ts}^*}{V_{tb}^* V_{ts}}\right)\left(\frac{V_{ub}^* V_{cs}}{V_{cb} V_{us}^*}\right)\left|\frac{A_2}{A_1}\right| e^{i\Delta_{T1/T2}} = |\lambda_{D_s^- K^+}| e^{i(\Delta_{T1/T2} + (\gamma + \phi_s))}$$

$$\longrightarrow \gamma + \phi_s = \frac{1}{2}[arg(\bar{\lambda}_{\bar{f}}) - arg(\lambda_f)]$$

  - Tree-level diagrams
  - Very important SM benchmark measurement (LHCb exclusive)

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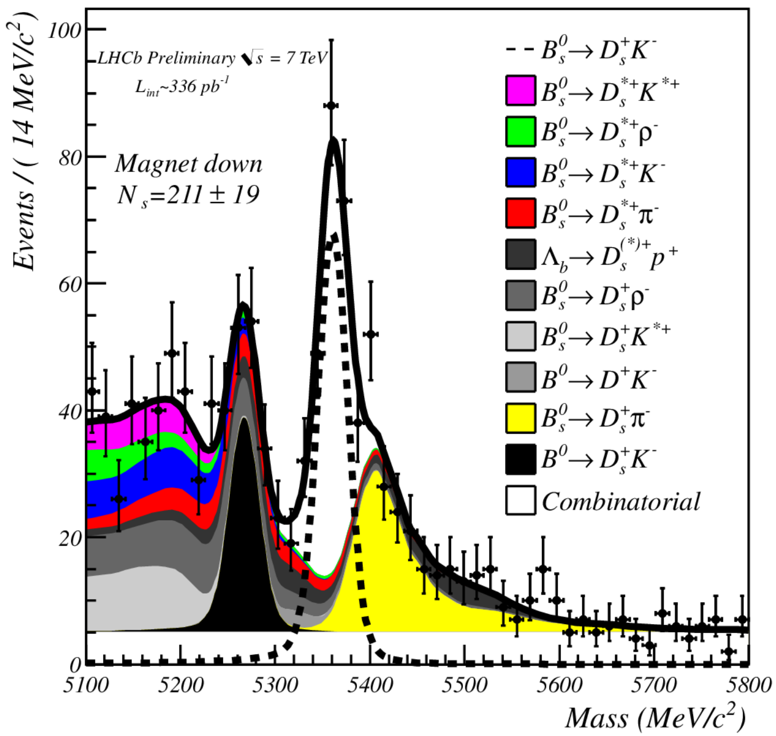
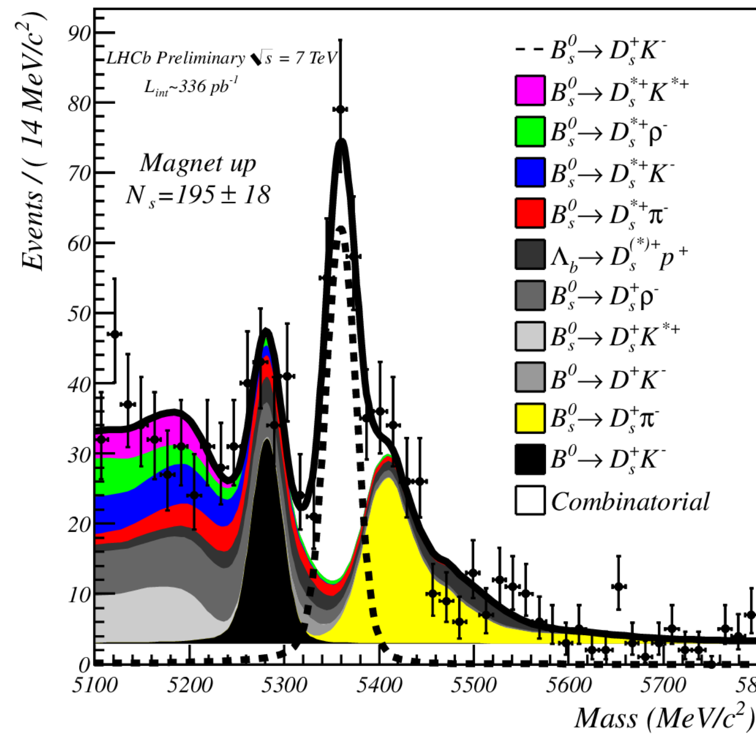
On the way to the first direct measurement of γ in $B_s \rightarrow D_s K$

- First observation of $B_s \rightarrow D_s K$ in 2008 (CDF)
- Establish the signal at LHCb
- Measure the branching ratio of $B_s \rightarrow D_s K$





LHCb-CONF-2011-057

Branching Ratio measurement of $B_s \rightarrow D_s K$

- Get yields of the different floating components from the mass-fit

Parameter	Fit value	
	Magn. Down	Magn. Up
Num. $B^0 \rightarrow D_s^- K^+$	105 ± 18	91 ± 17
Num. $B_s^0 \rightarrow D_s^- \pi^+$ and $B^0 \rightarrow D^- \pi^+$	161 ± 22	158 ± 21
Num. $B_s^0 \rightarrow D_s^{\mp} K^{\pm}$	211 ± 19	195 ± 18
$B_s^0 \rightarrow D_s^{\mp} K^{\pm}$ mass mean (MeV/c^2)	5360.8 ± 1.8	5359.7 ± 1.8

336 pb^{-1}

Branching Ratio measurement of $B_s \rightarrow D_s K$

- Calculate the Branching Ratio

$$\frac{\mathcal{B}\left(B_s^0 \rightarrow D_s^{\mp} K^{\pm}\right)}{\mathcal{B}\left(B_s^0 \rightarrow D_s^{-} \pi^{+}\right)} = \frac{N_{B_s^0 \rightarrow D_s^{\mp} K^{\pm}}}{N_{B_s^0 \rightarrow D_s^{-} \pi^{+}}} \frac{\epsilon^{\mathrm{PID}}_{B_s^0 \rightarrow D_s^{-} \pi^{+}}}{\epsilon^{\mathrm{PID}}_{B_s^0 \rightarrow D_s^{\mp} K^{\pm}}} \frac{\epsilon^{\mathrm{Sel}}_{B_s^0 \rightarrow D_s^{-} \pi^{+}}}{\epsilon^{\mathrm{Sel}}_{B_s^0 \rightarrow D_s^{\mp} K^{\pm}}}$$

$$\frac{\mathcal{B}\left(B_s^0 \rightarrow D_s^{\mp} K^{\pm}\right)}{\mathcal{B}\left(B_s^0 \rightarrow D_s^{-} \pi^{+}\right)} = 0.0647 \pm 0.0044\,(\mathrm{stat.})\,{}^{+0.0039}_{-0.0043}\,(\mathrm{syst.})$$

World's most precise

CDF result: $0.097 \pm 0.018(\mathrm{stat}) \pm 0.009(\mathrm{sys})$

Branching Ratio measurement of $B_s \rightarrow D_s K$

- Together with the a former LHCb measurement of f_s/f_d and the relative yields of several B/B_s modes one can calculate $B_s \rightarrow D_s \pi$

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

$$\mathcal{B}(B_s^0 \to D_s^- \pi^+) = (3.04 \pm 0.19\ (\text{stat.}) \pm 0.23\ (\text{syst.})\ {}^{+0.18}_{-0.16}\ (f_s/f_d)) \times 10^{-3}$$

LHCb Collaboration; [arXiv:1106.4435] (PRL)

LHCb-CONF-2011-028

Branching ratio measurement of $B_s \to D_s K$

- Finally one can use the result from $B_s \to D_s \pi$ to calculate the absolute Branching Ratio for $B_s \to D_s K$

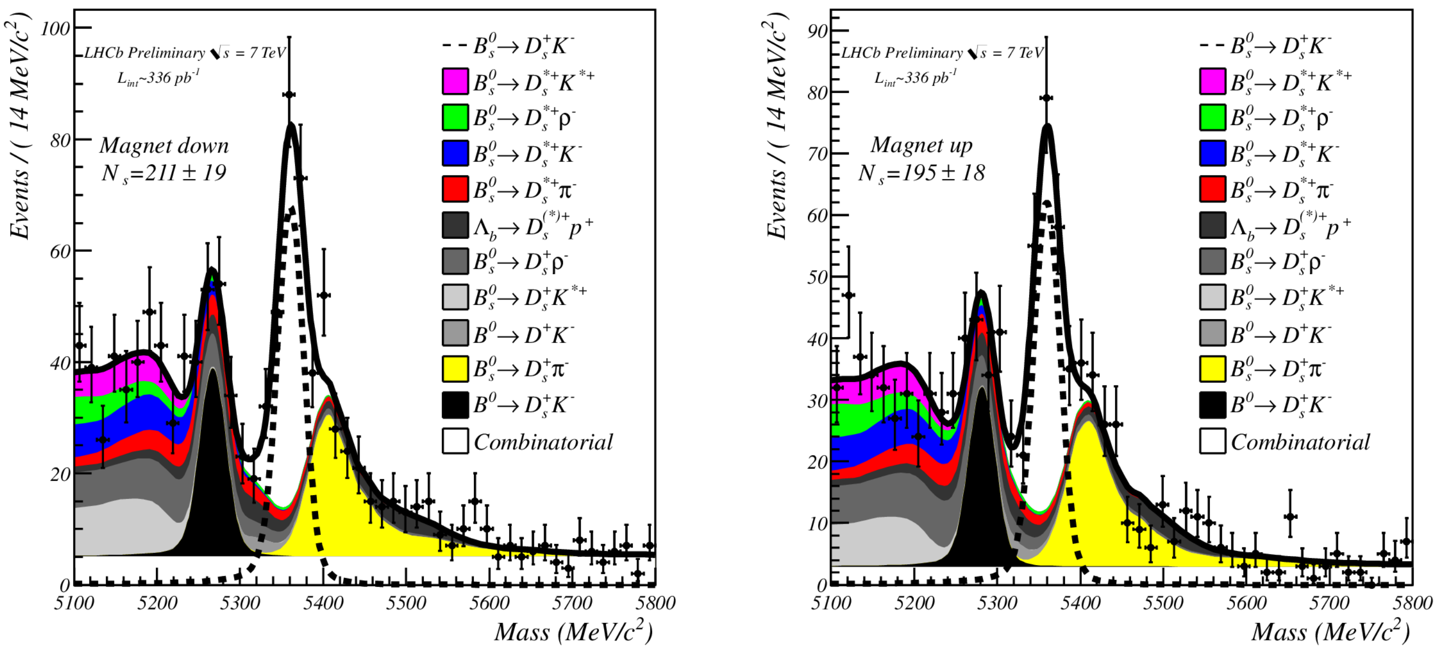
$$\mathcal{B}(B_s^0 \to D_s^{\mp} K^{\pm}) = (1.97 \pm 0.18\ (\text{stat.})\ ^{+0.19}_{-0.20}\ (\text{syst.})\ ^{+0.11}_{-0.10}\ (f_s/f_d)) \times 10^{-4}$$

World's most precise

- Details on the analysis can be found in LHCb-CONF-2011-057
- Paper in preparation

On the way towards γ

- Develop and validate a 2D fitter in mass and time



On the way towards γ

- Possibly many background components are leaking into the signal region
- Study time structure of these components
- Time acceptance and resolution has to be known
- Expected sensitivity $\sigma(\gamma+\phi_s)$=10-12° with 1-2 fb^{-1} (2007)
- First result winter-conferences 2012(?)

Conclusion & Outlook

- Short introduction (& motivation) to the determination of γ from $B_s \rightarrow D_s K$
  - Theoretically clean
  - Very important SM benchmark measurement
- Observation of $B_s \rightarrow D_s K$ at LHCb
- Most precise measurement of $B_s \rightarrow D_s K / B_s \rightarrow D_s \pi$

- Next steps
  - Study background in more detail
  - Develop 2D fitter in mass and time
  - Time acceptance and resolution
  - Aim for winter-conferences (?)

Backup Slides

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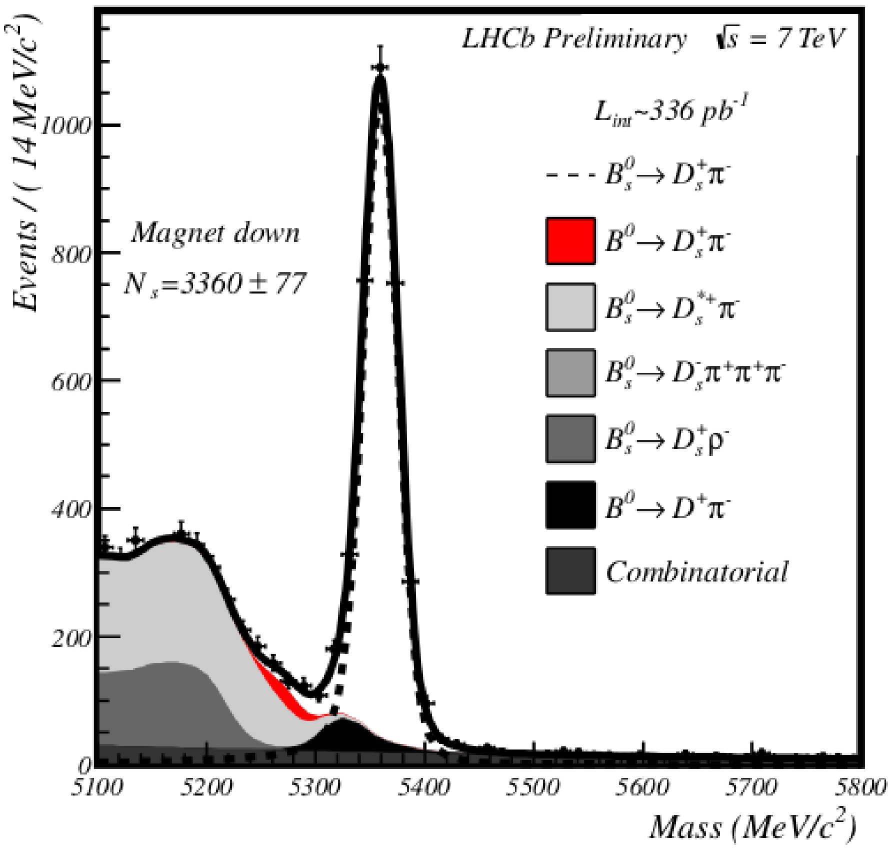
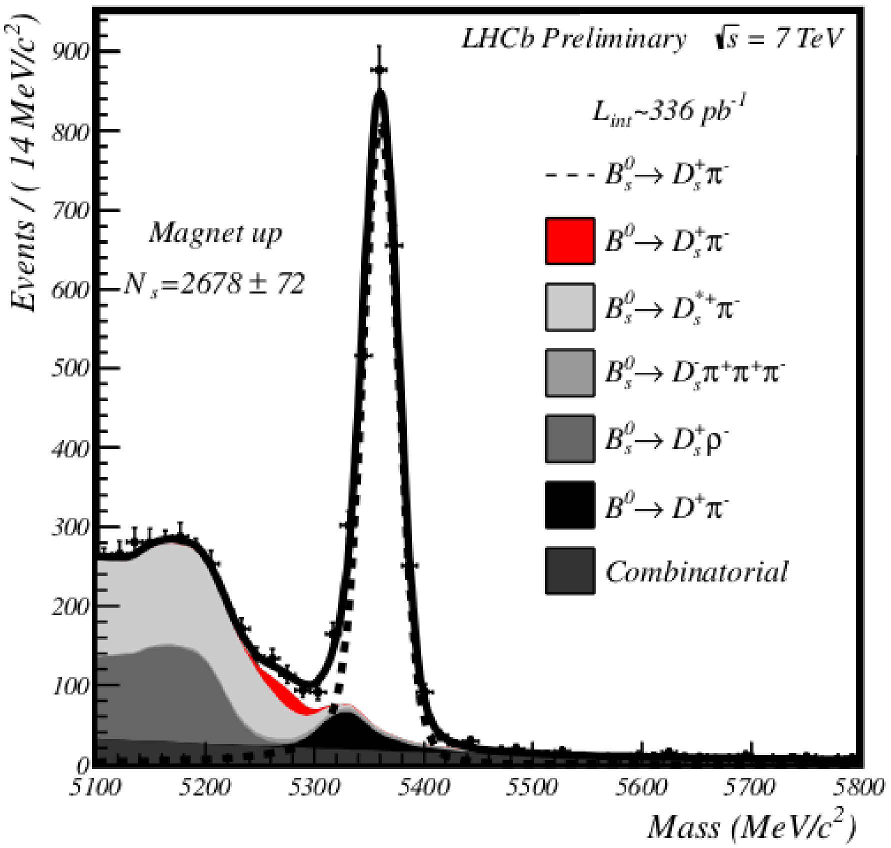
Backup

	$B_s^0 \to D_s^\mp K^\pm$		$B_s^0 \to D_s^- \pi^+$		$\epsilon_{B_s^0 \to D_s^\mp K^\pm} / \epsilon_{B_s^0 \to D_s^- \pi^+}$	
	$\epsilon_{\rm cum}$ (%)	$\epsilon_{\rm rel}$(%)	$\epsilon_{\rm cum}$ (%)	$\epsilon_{\rm rel}$(%)	$\epsilon_{\rm cum}$ (%)	$\epsilon_{\rm rel}$(%)
Generator		16.56 ± 0.04		16.13 ± 0.15	1.03 ± 0.01	1.027 ± 0.01
Recon.+Strip.	9.06 ± 0.04	9.06 ± 0.04	9.02 ± 0.02	9.02 ± 0.02	1.00 ± 0.01	1.00 ± 0.01
BDTG>0.1	8.15 ± 0.04	90.0 ± 0.1	8.14 ± 0.02	90.3 ± 0.1	1.00 ± 0.01	1.00 ± 0.01
L0	3.96 ± 0.03	48.6 ± 0.3	3.89 ± 0.02	47.8 ± 0.1	1.02 ± 0.01	1.02 ± 0.01
Hlt	2.57 ± 0.02	64.8 ± 0.4	2.50 ± 0.01	64.2 ± 0.2	1.03 ± 0.01	1.01 ± 0.01
$p_{bach} < 100$ GeV	2.21 ± 0.02	86.1 ± 0.3	2.15 ± 0.01	86.0 ± 0.2	1.03 ± 0.01	1.00 ± 0.01
Total					1.058 ± 0.014	

Backup


LHCb Preliminary $\sqrt{s}$ = 7 TeV
L_{int}~336 pb^{-1}
$B_s^0 \to D_s^+\pi^-$
$B^0 \to D_s^+\pi^-$
$B_s^0 \to D_s^{*+}\pi^-$
$B_s^0 \to D_s^-\pi^+\pi^+\pi^-$
$B_s^0 \to D_s^+\rho^-$
$B^0 \to D^+\pi^-$
Combinatorial
Magnet down
N_s=3360 ± 77
Events / (14 MeV/c^2)
Mass (MeV/c^2)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$B_s^0 \to D_s^-\pi^+\pi^+\pi^-$
$B_s^0 \to D_s^+\rho^-$
$B^0 \to D^+\pi^-$
Combinatorial
Magnet up
N_s=2678 ± 72
Events / (14 MeV/c^2)
Mass (MeV/c^2)

Backup

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