Inclusive $B_s \to X_{cs}\,\mu\,\nu$: hadronic mass moments at LHCb

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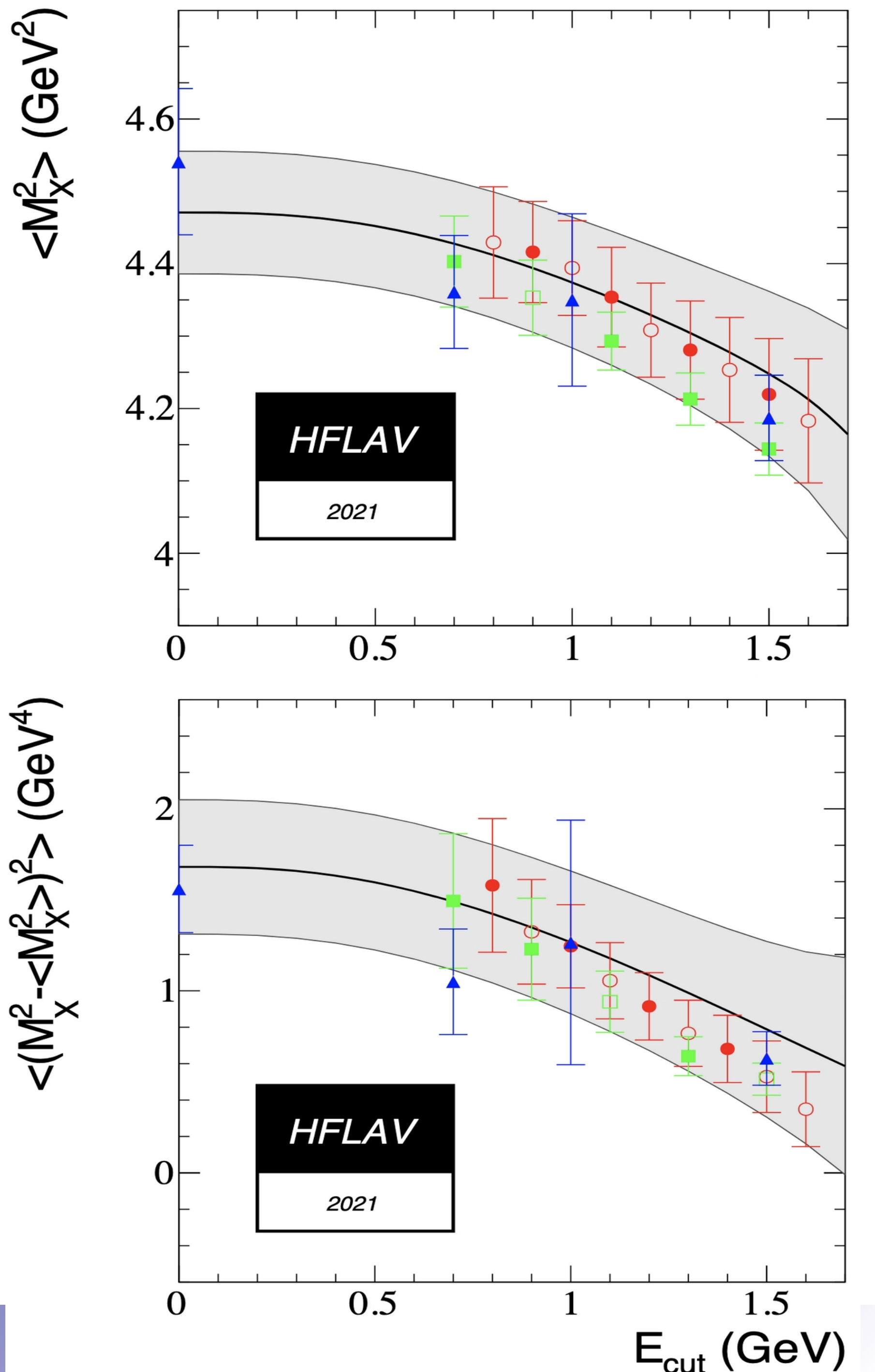
Global fits of inclusive V_{cb} with $B \to X_c \, l \, \nu$

- Inputs from Belle, BaBar, CLEO, Delphi and CDF
- Moments of the hadronic mass distribution Mx and lepton momentum spectrum
  - Delphi E_{cut}=0
  - CDF E_{cut}=0.7 GeV
- Hadronic moments not enough for measuring $|V_{cb}|$, but crucial input to determine non-pert parameters



$B^- \to X_c^0\, l\, \nu$ at CDF

PRD71(2005) 051103

- Hadronic system X_c: split in three contributions
  - D, D*, D** (it is the rest: resonant and non-resonant contributions)
- Differential mass-squared spectrum

$$\frac{1}{\Gamma_{sl}}\frac{d\Gamma_{sl}}{ds_H} = \frac{\Gamma_0}{\Gamma_{sl}} \cdot \delta(s_H - m^2_{D^0}) + \frac{\Gamma_*}{\Gamma_{sl}} \cdot \delta(s_H - m^2_{D^{*0}}) + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) \cdot f^{**}(s_H),$$

$s_H = m(X_c)^2$

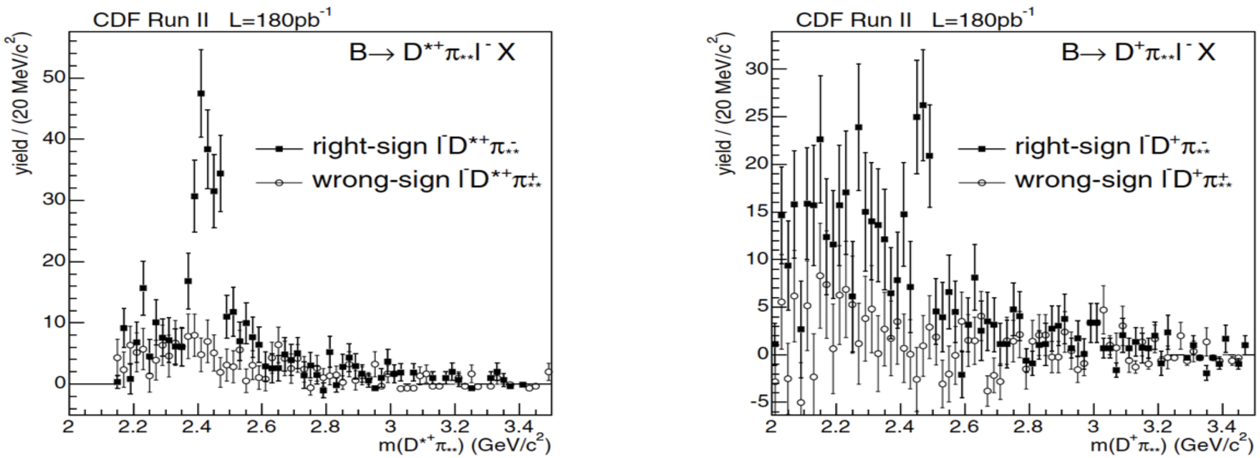
Γ^0, Γ^*, Γ_{sl} known, from PDG
need to measure $f^{**}(s_H)$

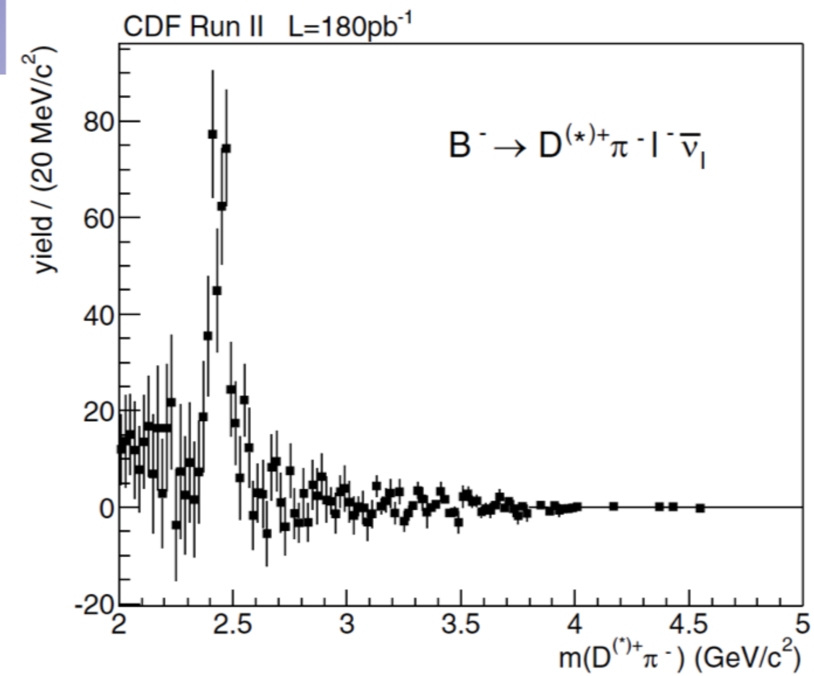
Proxy: use only charged modes
$D^+\pi^-$, $D^{*+}\pi^-$

Basic assumptions
- $D\pi + D^*\pi$ saturate the inclusive
- contributions from decays with neutrals
Included assuming isospin factors

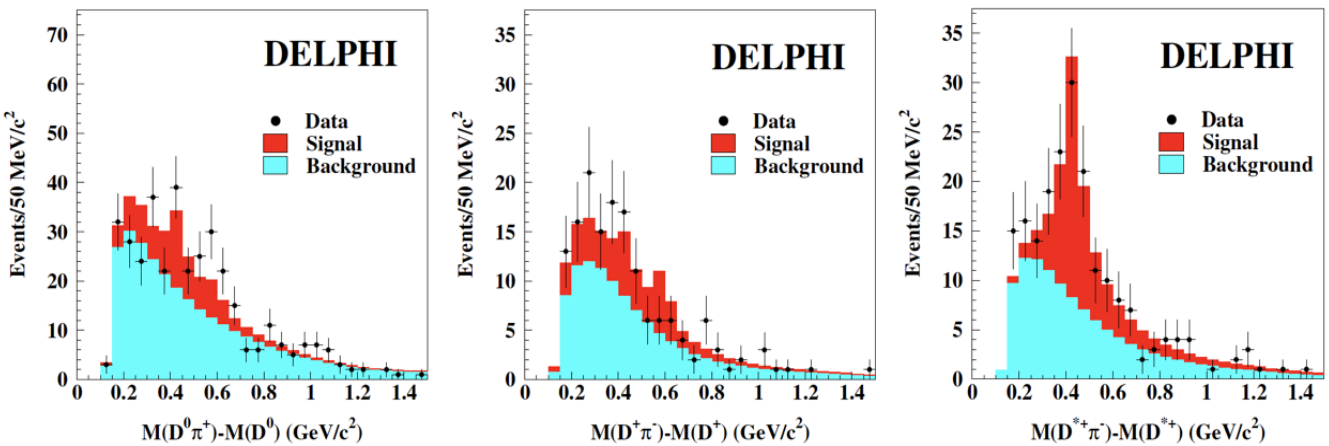
CDF and DELPHI analyses

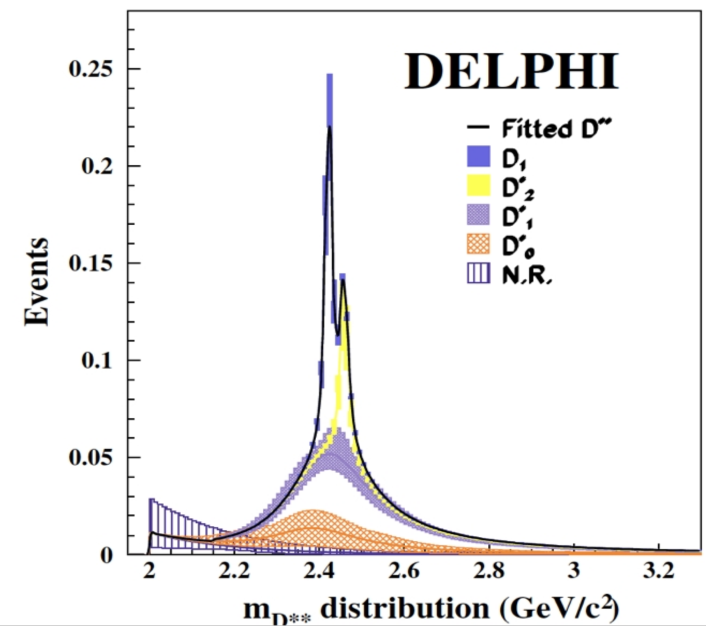
PRD71(2005) 051103





EPJC45(2006) 35





LHCb can repeat these measurements
- exploit the most recent knowledge on D**
- Decays $D_1 \to D\,\pi\pi$ and observation of $B \to D(^*)\pi\pi\, l\, \nu$

What about B_s?

Why inclusive B_s SL decays?

- Moments of the hadronic B_s have never been measured
- The inclusive decays of the B_s are described by the same OPE as those of the B meson
  - Sensitivity to the spectator quark? possible SU(3)F violation
  - Improve existing semileptonic width of B_s decays
  - Better knowledge of non-perturbative parameters (mainly ρ_D^3) can improve OPE calculation of the B_s total width
- At LHC B_s production is ¼ of B_d
  - In Run1-2 expected ~1.3M of $D_s\mu$ candidates with 90% purity
    - same selection used for $|V_{cb}|$)

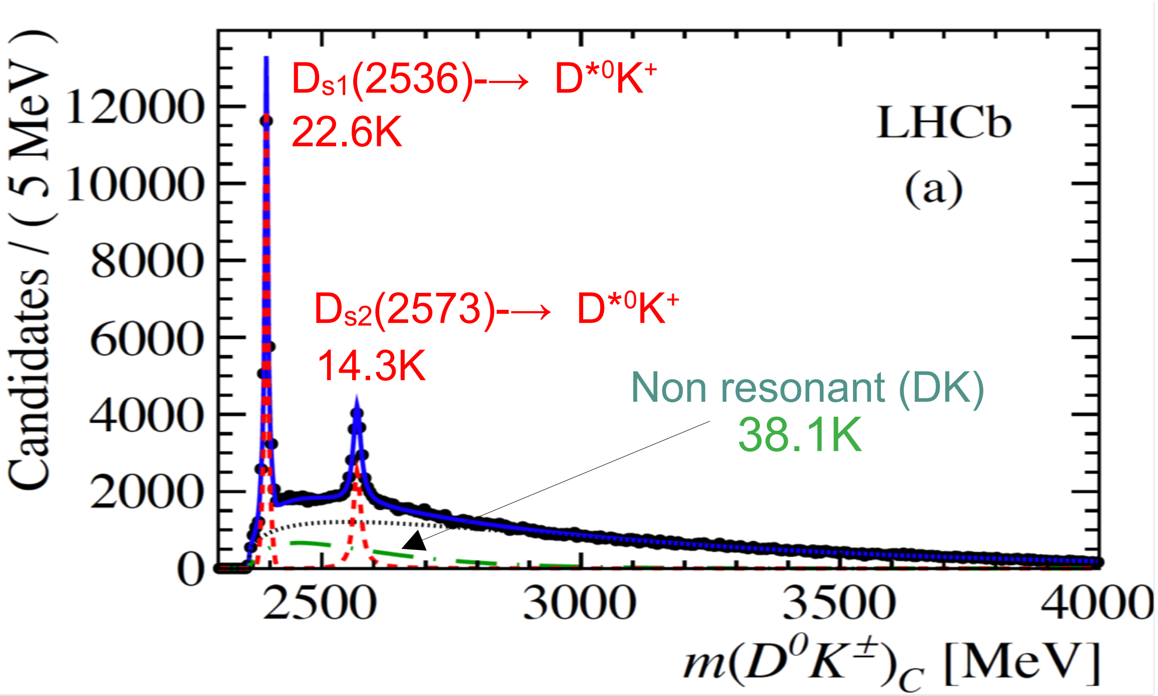
- At B-Factories B_s production requires special runs at the Y(5S)

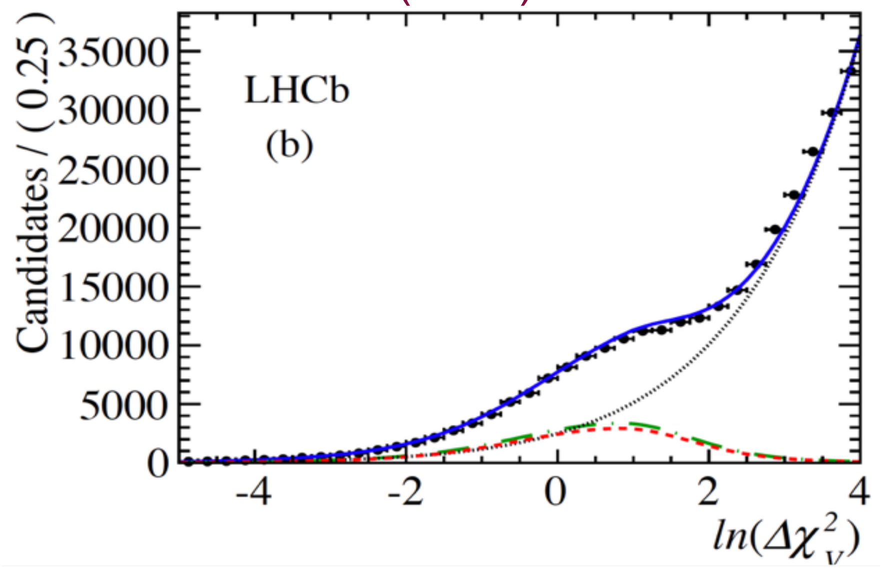
Y(5S)
~80% BB + B*B + B*B* + BBπ
17.6% $B_s^*B_s^*$
1.35% $B_sB_s^*$
0.5% B_sB_s

Belle collected 124/fb at Y(5S):
- Semi-inclusive of B_s decays into D_s(*)
  PRD92(2015) 7, 072013
- Inclusive SL decays
  PRD87(2013) 7, 072008

How?

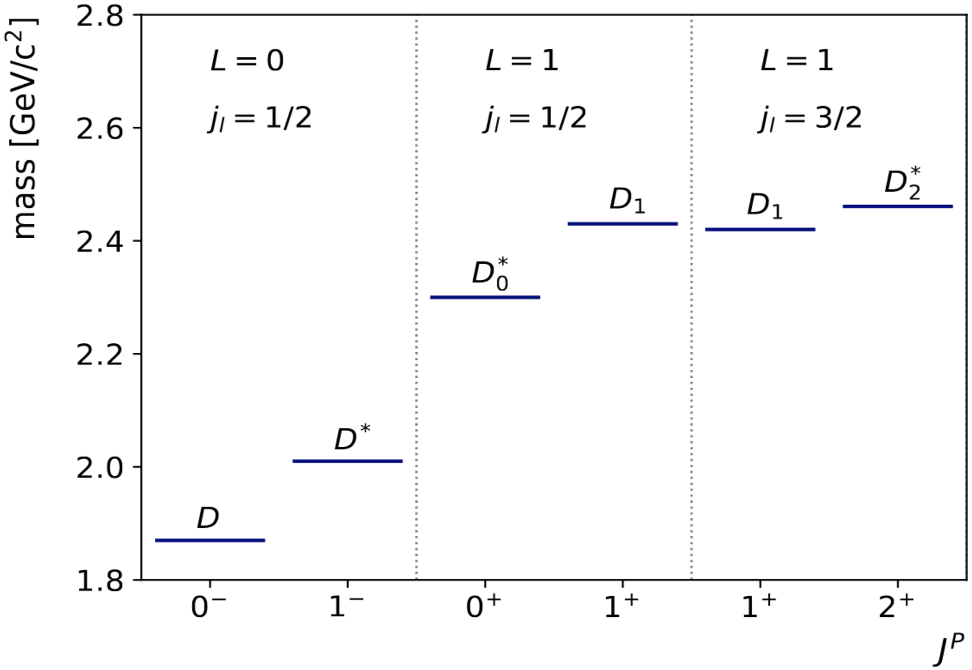
- Using approach similar to CDF/Delphi: total rate as sum of exclusive decays
- $B_s \to D_s X\ \mu\nu$ dominates
  - Non-resonant $B_s \to D_s \pi \mu\nu$ production should be suppressed
- $B_s \to DK\ \mu\nu$ form $M(X_{cs})$ above the m(D)+m(K) threshold
  - Both resonant and non-resonant contributions need to be measured



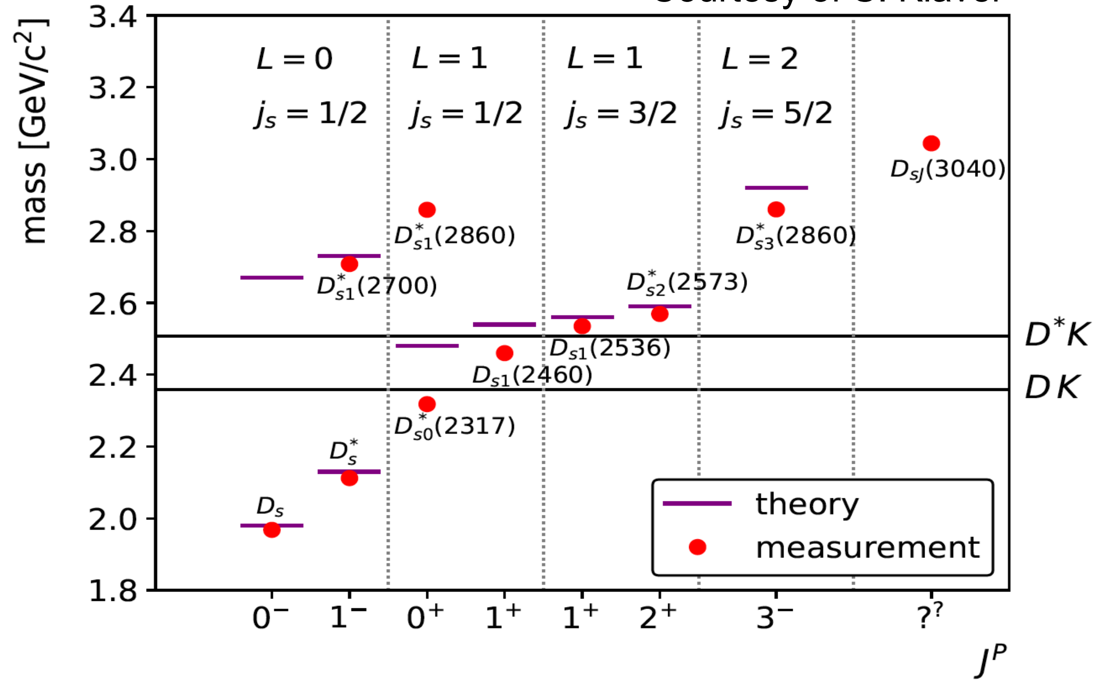


Spectroscopy of $(c\bar{d})$ and $(c\bar{s})$

Spectrum of excited D_s^{**} states different with corresponding D^{**} states



Courtesy of S. Klaver



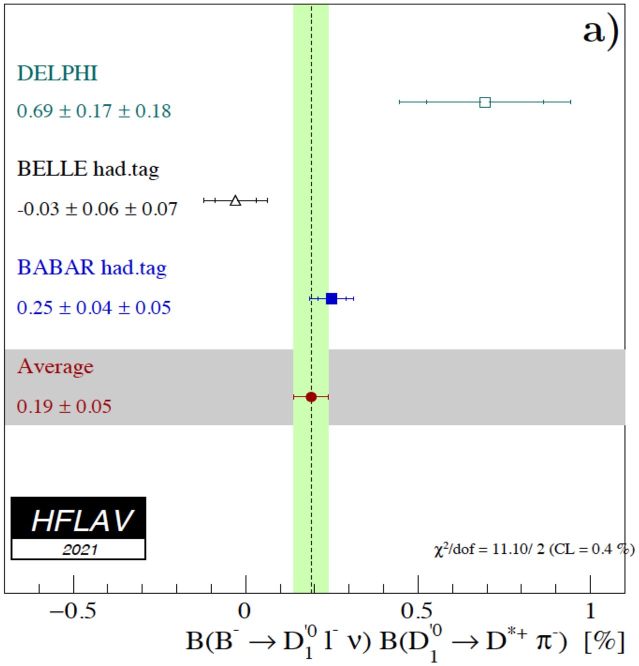
	J^P	Mass (MeV)	Width (MeV)	Observed decays
D_0^*	0^+	2352 ± 50	261 ± 50	$D\pi$
D_1'	1^+	2427 ± 36	384^{+130}_{-105}	$D^*\pi$
D_1	1^+	2421.3 ± 0.6	27.1 ± 2.7	$D^*\pi, D^0\pi^+\pi^-$
D_2^*	2^+	2462.6 ± 0.7	49.0 ± 1.4	$D^*\pi, D\pi$

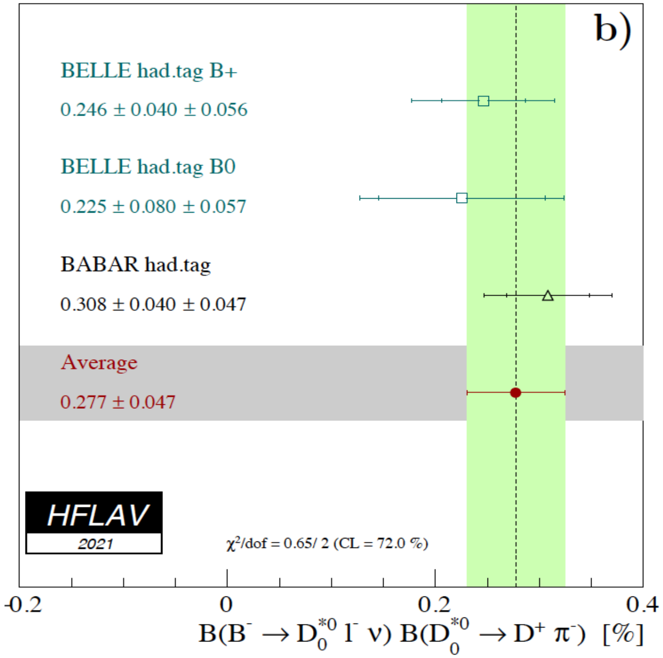
	J^P	Mass (MeV)	Width (MeV)	Observed decays
D_{s0}^*	0^+	2317.8 ± 0.6	< 3.8	$D_s^+\pi^0$
D_{s1}'	1^+	2459.5 ± 0.6	< 3.5	$D_s^{*+}\pi^0, D_s^+\gamma, D_s^+\pi^+\pi^-$
D_{s1}	1^+	2535.28 ± 0.20	< 2.5	$D^{*+}K^0, D^{*0}K^+$
D_{s2}^*	2^+	2572.6 ± 0.9	20 ± 5	D^0K^+

$B \to D^{**}\ell\nu$

- $B \to D^{**}\ell\nu$ Decay into narrow resonances consistent with prediction

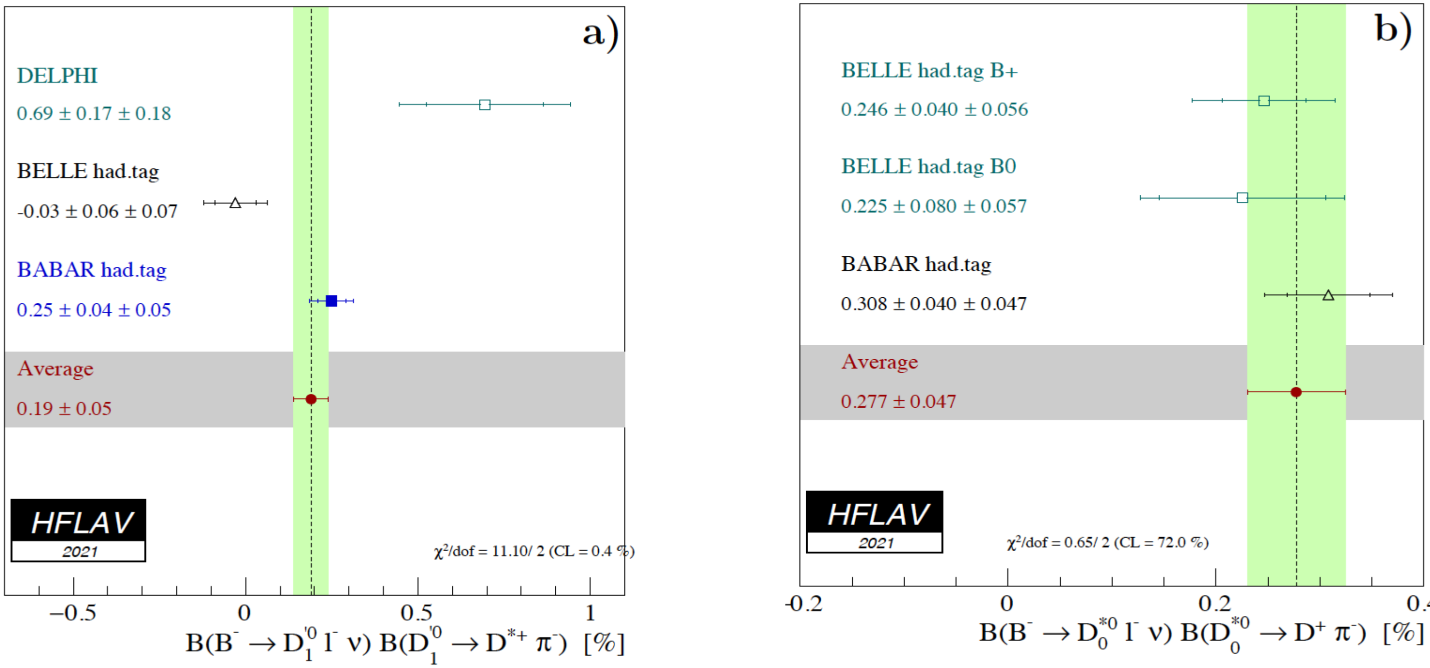
  - Decay into wide ½ states not so clear





B → D**ℓν .vs. Bs → Ds**ℓν

- B → D**ℓν Decay into narrow resonances consistent with prediction
  - Decay into wide ½ states not so clear



Becirevic et al. PRD87(2013) 054007

- Ds excited L=1 states are all narrow, so they offer a new path to understand puzzles with the D**
  - Moreover SL decays into Ds(2317) and Ds(2460) can shed light on the nature of these states

Navarra et. al. PRD92(2015) 014031
Zhao et. al. EPJC51 (2017) 601-606

- SL BF into 3/2 states have been measured by D0 and LHCb
  - Consistent with HQS predictions and B decays

PLB 698 (2011) 14-20

$$\frac{\mathcal{B}(\overline{B}{}^0_s \to D_{s2}^{*+} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}{}^0_s \to X \mu^- \overline{\nu})} = (3.3 \pm 1.0 \pm 0.4)\%$$

$$\frac{\mathcal{B}(\overline{B}{}^0_s \to D_{s1}^{+} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}{}^0_s \to X \mu^- \overline{\nu})} = (5.4 \pm 1.2 \pm 0.5)\%,$$

How to measure moments of M(Xcs)?

- Because of the narrowness of both L = 0 and L = 1 $D_s^{(*,**)}$ states, with high accuracy we can write the semileptonic differential m_H^2 spectrum

$$\frac{1}{\Gamma_{SL}}\frac{d\Gamma_{SL}}{dm_H^2} = \sum_{L=0}\frac{\Gamma_i}{\Gamma_{SL}}\cdot\delta(m_H^2 - m_i^2) + \sum_{L=1}\frac{\Gamma_i}{\Gamma_{SL}}\cdot\delta(m_H^2 - m_i^2) + \frac{\Gamma_{DK}}{\Gamma_{SL}}\cdot f^{DK}(m_H^2).$$

- Moments of $<(m_H^2)^n>$ become a weighted sum of the exclusive BF, plus moments of the mass distribution of the "residual" component

$$M_{2n} = \sum_{L=0}\frac{\Gamma_i}{\Gamma_{SL}}\cdot(m_i^2)^n + \sum_{L=1}\frac{\Gamma_i}{\Gamma_{SL}}\cdot(m_i^2)^n + \frac{\Gamma_{DK}}{\Gamma_{SL}}\cdot M_{2n}^{DK}$$

- Monte Carlo study is ongoing:
  - Master thesis at EPFL dedicated to the feasibility study has just started
  - Understand the needed steps to make a measurement

Quick glimpse

Moments with present knowns

Assumptions

1. $\mathcal{B}(B_s \to D_s^+) = (2.49 \pm 0.12 \pm 0.14 \pm 0.16)\%$
2. $\mathcal{B}(B_s \to D_s^*) = (5.38 \pm 0.25 \pm 0.46 \pm 0.30)\%$,

From LHCb $|V_{cb}|$ measurement considering correlations in the toy generation

3. $\mathcal{B}(B_s \to D_{s0}^*) = (0.39 \pm 0.07)\%$, assuming the same decay width of $B^0 \to D_0(2300)\ell\nu$
4. $\mathcal{B}(B_s \to D_{s1}) = (0.18 \pm 0.05)\%$, assuming the same decay width of $B^0 \to D_1'(2430)\ell\nu$

From PDG

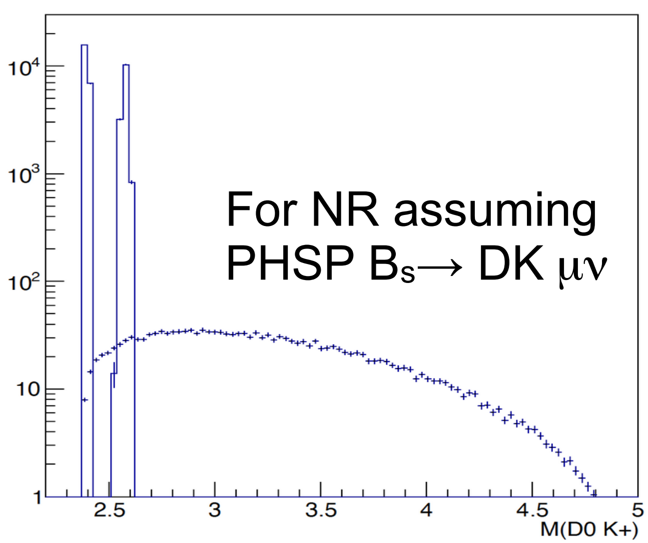
5. $\mathcal{B}(B_s \to D_{s1}^{'})/\mathcal{B}(B_s \to X) = (5.4 \pm 1.2 \pm 0.5)\%$
6. $\mathcal{B}(B_s \to D_{s2}^*)/\mathcal{B}(B_s \to X) = (3.3 \pm 1.0 \pm 0.4)\%$

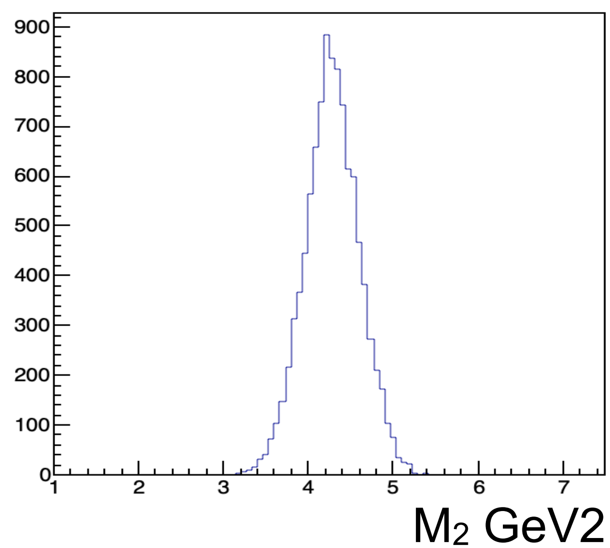
From LHCb: PLB 698 (2011) 14-20

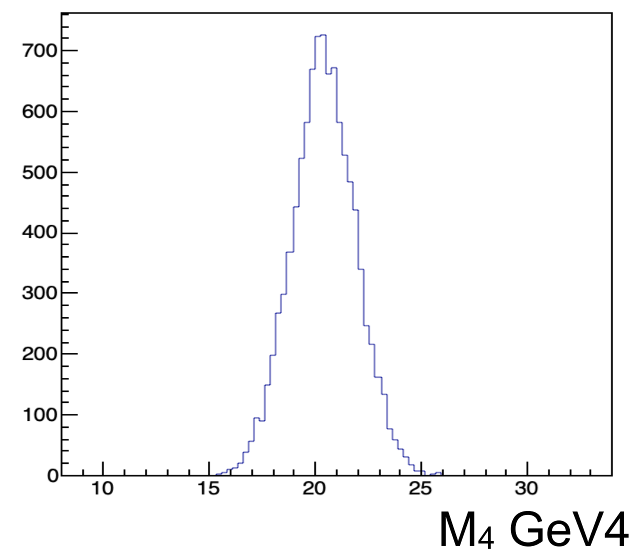
Inclusive SL assuming equal SL decay-width with B

7. Non-resonant DK with a rate consistent with LHCb measurement of fs/fd

	$M_2 = 4.28 \pm 0.32$ GeV^2
CDF	$M_2 = 4.440 \pm 0.078$ GeV^2

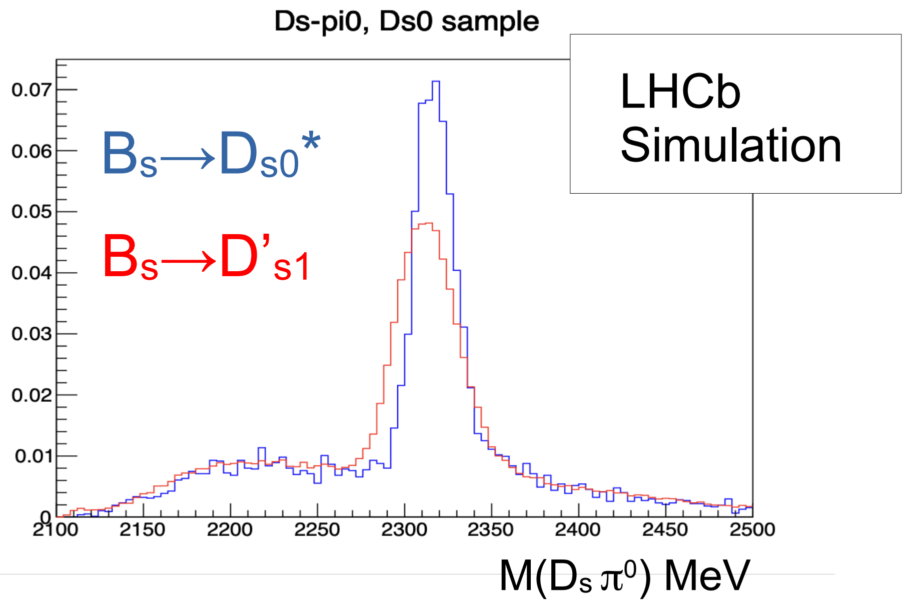






What has to be improved?

- Largest contribution to uncertainties from $B_s \to D_s^*/B_s \to D_s$ relative BFs: now error is at 10%
- No knowledges on $B_s \to D_{s0}^*$ and $B_s \to D'_{s1}$
- Measure their BF's relative to D_s/D_s^* seems feasible
  - $D_{s0}^* \to D_s\,\pi^0$ access also D_s^* and D'_{s1}1 through $D'_{s1} \to D_s^*\pi^0$ with missing photon from D_s^*



D_{s0}^*		D_{s1}	
2317.8 ± 0.5		2459.5 ± 0.6	
< 3.8		< 3.5	
$D_s^+\pi^0$	$100^{+0.}_{-20}$	$D_s^*\pi^0$	48 ± 11
$D_s^+\gamma$	< 5	$D_s^+\gamma$	18 ± 4
$D_s^*\gamma$	< 6	$D_s^+\pi + \pi^-$	4.3 ± 1.3
$D_s^*\gamma$	< 6	$D_s^*\gamma$	< 8
		$D_{s0}^*\gamma$	$3.7^{+5.0}_{-2.4}$

- Decays D'_{s1}, $D_{s1} \to D_s\,\pi^+\pi^-$ really interesting: expected to be very clean signal
- Some knowledge on D_{s1} and D_{s2}^* already available, further measurements are desirable
- NR DKX and higher mass states contribute to higher order moments, Dedicated measurement would be required

Outlook

- Intermediate steps needed for a -proper- measurement:
  - Determine D_s**'s production relative to D_s
  - Crucial to determine absolute BFs of the various D_s**
    - Belle(II) could give significant improvements on some of the channels involving neutrals
    - $D'_{s1} \rightarrow D_s^* \pi^0$ is known with 20% error
    - Branching fractions of D_{s1} and D^*_{s2} need to measured to go beyond the DK/D*K mode ($D_{s1} \rightarrow DsX$ and $D_{s1} \rightarrow DK\pi$ have been observed)
  - Improve non-resonant and higher mass states contributions
  - Study production of 5 body decays: $B_s \rightarrow D^0 K^+ \pi^- \mu \nu$, $D^0 K_s \pi^- \mu \nu$
    - he contribution to first orders moments M_2, M_4 should be marginal

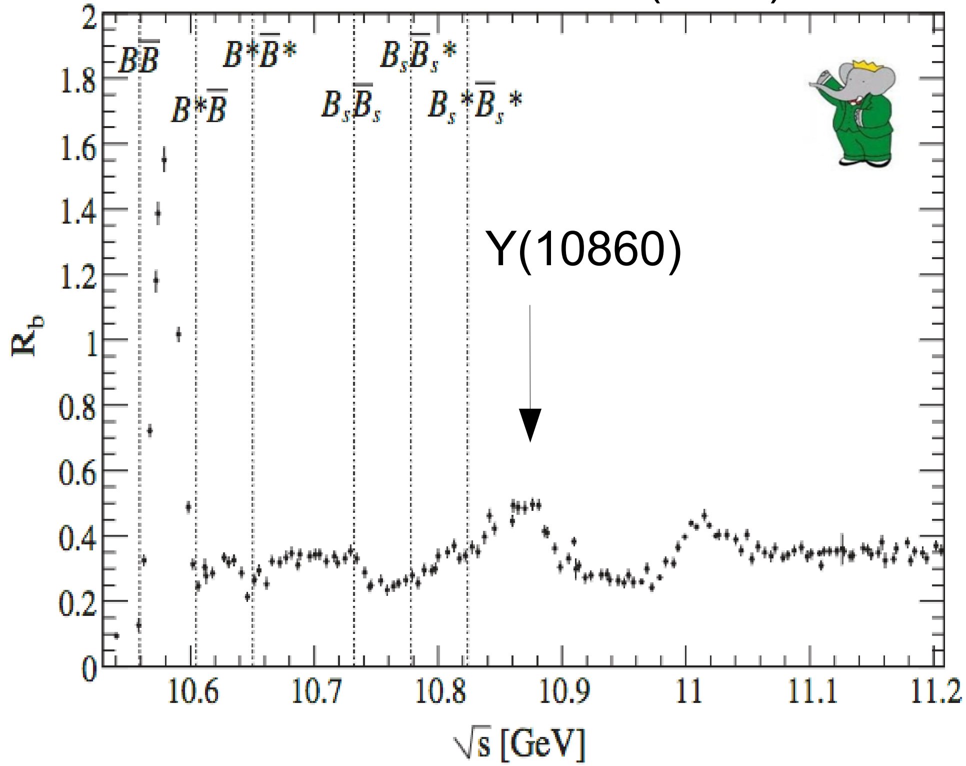
- Highly rewarding outcomes on the way:
  - 1/2 << 3/2 puzzle can probably be understood with D_s** states (?)
  - The P-wave states are separated in mass, their FFs shape can be extracted "easily"
  - B_s are well suited for R(D_s**) measurements

- Similar approach can be applied to Λ_b

B_s at B-Factories

- At B-Factories B_s production requires special runs at the Υ(5S)

BaBar PRL102,012001(2009)



Υ(4S)
~100% BB

Υ(5S)
~80% BB + B*B + B*B* + BBπ
17.6% $B_s^*B_s^*$
1.35% $B_sB_s^*$
0.5% B_sB_s

~ 1/5 decays into B_s

$m(B_s^*)-m(B_s) \approx 50$ MeV

Belle collected the largest sample at Υ(5S)
L = 121.4 fb^{-1} corresponding to $N(B_s) = 6.53 \times 10^6$
$\sigma(Y(10860) \to B_s^{(*)}\bar{B}_s^{(*)}) = (53.8 \pm 1.4 \pm 4.0 \pm 3.4)$ pb
Compared with $\sigma(Y(4S) \to B\bar{B}) = 1.06$ nb

Semi-inclusive of Bs decays measurement

$$B_s \to D_s^{(*)} \ell \nu_\ell X$$

PRD92,072013 (2015)