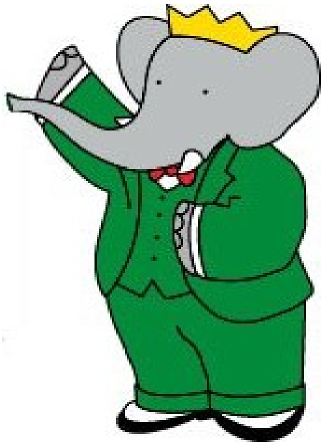
Recent *BABAR* measurements of hadronic *B* branching fractions

Alessandro Gaz
University of Colorado



Representing
the *BABAR* Collaboration

July 21st 2010

EPS 2011, Grenoble, France

Introduction

- Hadronic *B* Decays are fundamental tools to study the CKM Matrix paradigm and precisely measure its parameters;
- Benchmark to test the predictions of different theoretical frameworks: QCD factorization, perturbative QCD, SCET...;
- Measurement of rare decays can provide constraints on very suppressed amplitudes (e.g. weak annihilation) and on the existence of non-standard contributions;
- Decays of *B* mesons to final states containing baryons are in general poorly understood by the theory: experimental input can lead to the development of more reliable models;
- All the measurements I will present today are based on the full BaBar dataset, consisting of ~465 M $B\bar{B}$ pairs.

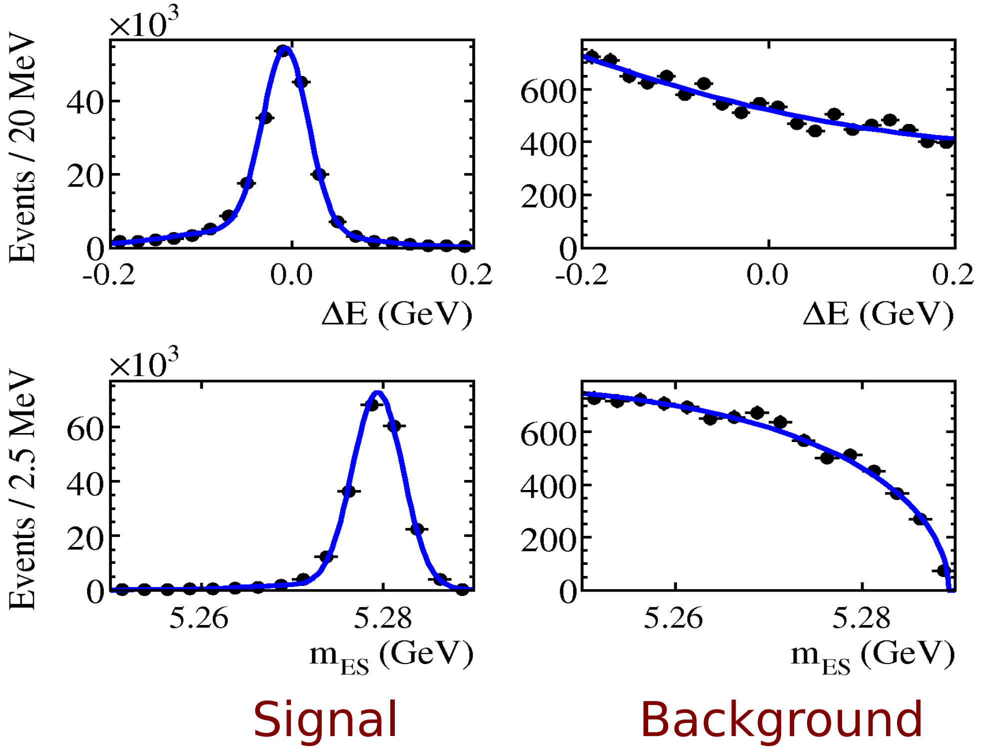
In this talk only decays with a charmed meson/baryon in the final state will be presented. For Charmless Hadronic Decays, please see Eugenia Puccio's transparencies in this morning's session.

Kinematics of B decays

- Fully reconstructed B mesons: two variables are commonly used (exploiting the precise knowledge of the beam energy):

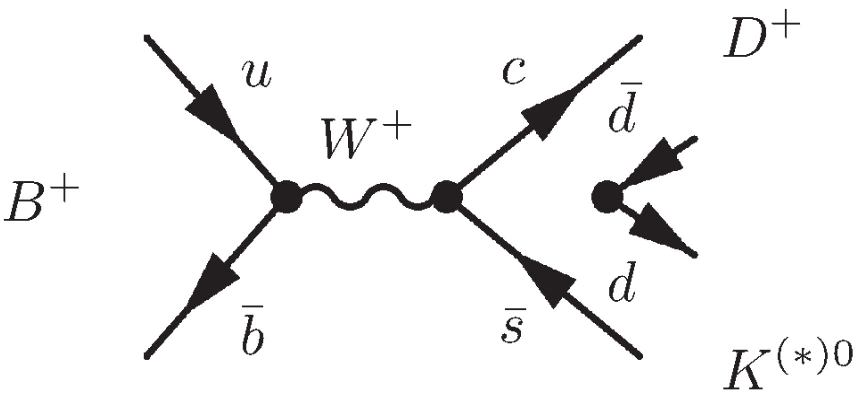
$$\Delta E = E_{meas} - E_{beam}$$

$$m_{ES} = \sqrt{E_{beam}^2 - \mathbf{p}_{meas}^2}$$



- Dominant background: $q\bar{q}$ ($q = u, d, s, c$), exhibiting a jet-like topology ($B\bar{B}$ events are more "spherical"). We separate/suppress the continuum background combining several variables sensitive to the event shape into a Fisher discriminant.

$BF(B^+ \to D^+K^{(*)0})$

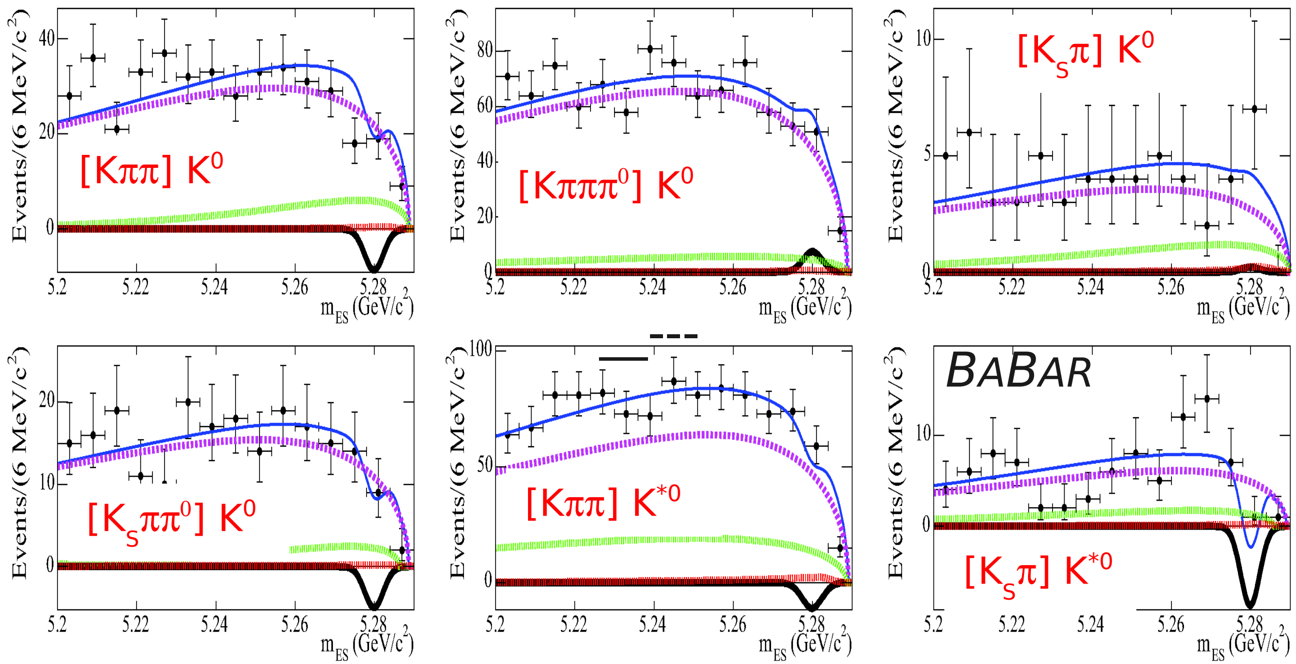


PRD 82, 092006 (2010)

- Motivations: neither of the constituent (anti)quarks appear in the final state. These decays proceed through weak annihilation diagrams;
- BF's expected to be of the order of $\sim 10^{-6}$, but rescattering (mainly through $D_s^+\pi^0$) may play a major role;
- We use $K^0 \to K_S^0 \to \pi^+\pi^-$, $K^{*0} \to K^+\pi^-$ and up to 4 D^+ decay modes ($K\pi\pi$, $K_S\pi$, $K\pi\pi^0$, $K_S\pi\pi^0$);
- Dominant peaking background: $B^+ \to D^+\rho^0$, reduced with a cut on the $\pi\pi$ helicity: we require $\cos\theta_H < 0.9$ (0.8 for $K\pi\pi$);
- We expect less than 1 peaking background event in each signal region.

$BF(B^+ \to D^+K^{(*)0})$

- The signal yield is extracted through a ML fit on the variables m_{ES} and Fisher;
- The yields observed are compatible with 0;
- Dominant systematic uncertainty from parameterization of probability density functions;



- Results: significant improvement in the UL of $B \to D^+K^0$ over previous BaBar publication and first UL for $B \to D^+K^{*0}$:

$$\mathcal{B}(B^+ \to D^+K^0) = (-3.8\,^{+2.5}_{-2.4}) \times 10^{-6},$$
$$\mathcal{B}(B^+ \to D^+K^{*0}) = (-5.3 \pm 2.7) \times 10^{-6}$$

$$\mathcal{B}(B^+ \to D^+K^0) < 2.9 \times 10^{-6}$$
$$\mathcal{B}(B^+ \to D^+K^{*0}) < 3.0 \times 10^{-6}$$

Systematic uncertainties are included

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

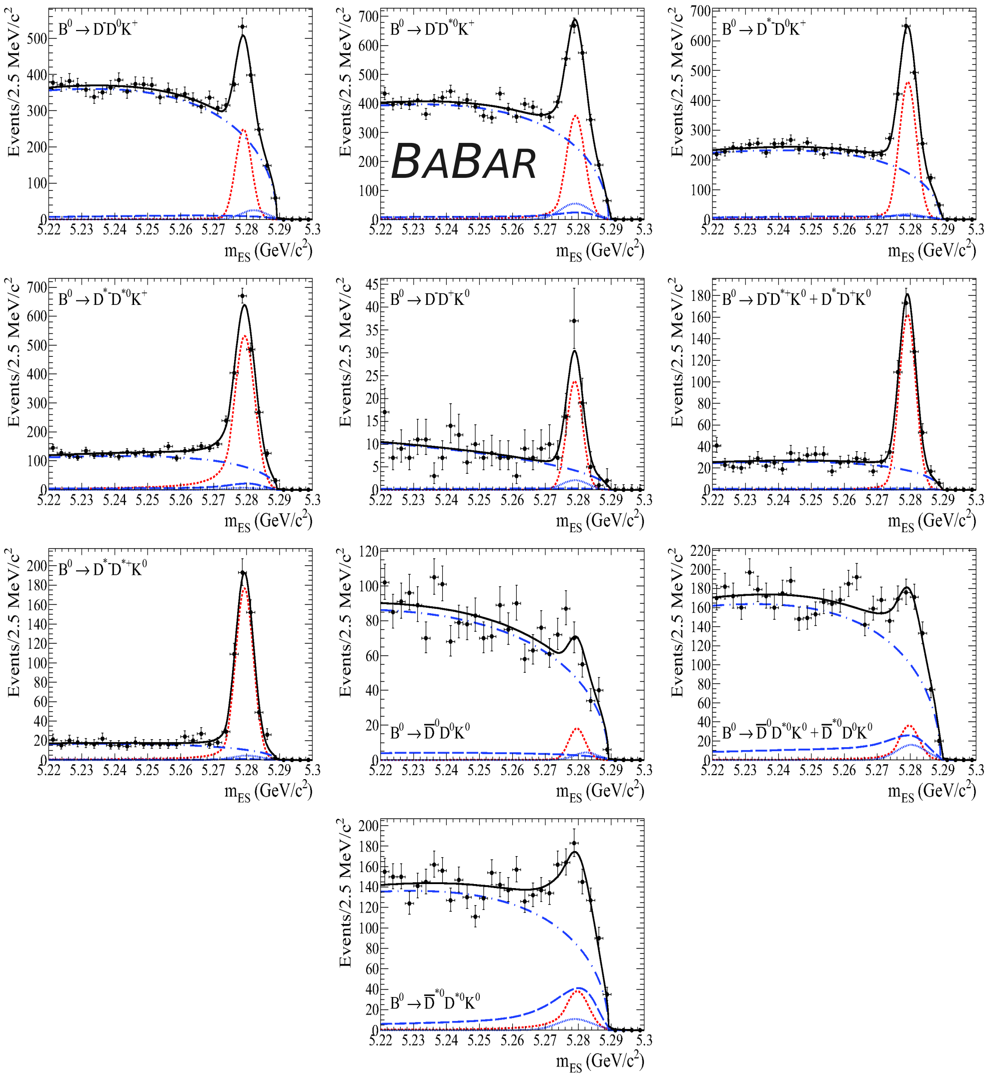
PRD-RC 83, 032004 (2011)

- Motivation: $B \to D^{(*)}D^{(*)}K$ decays have a sizable branching fraction (a few %), important to account for the inclusive hadronic branching fraction;
- Several different amplitudes concur, important to verify that the pattern matches the predictions;

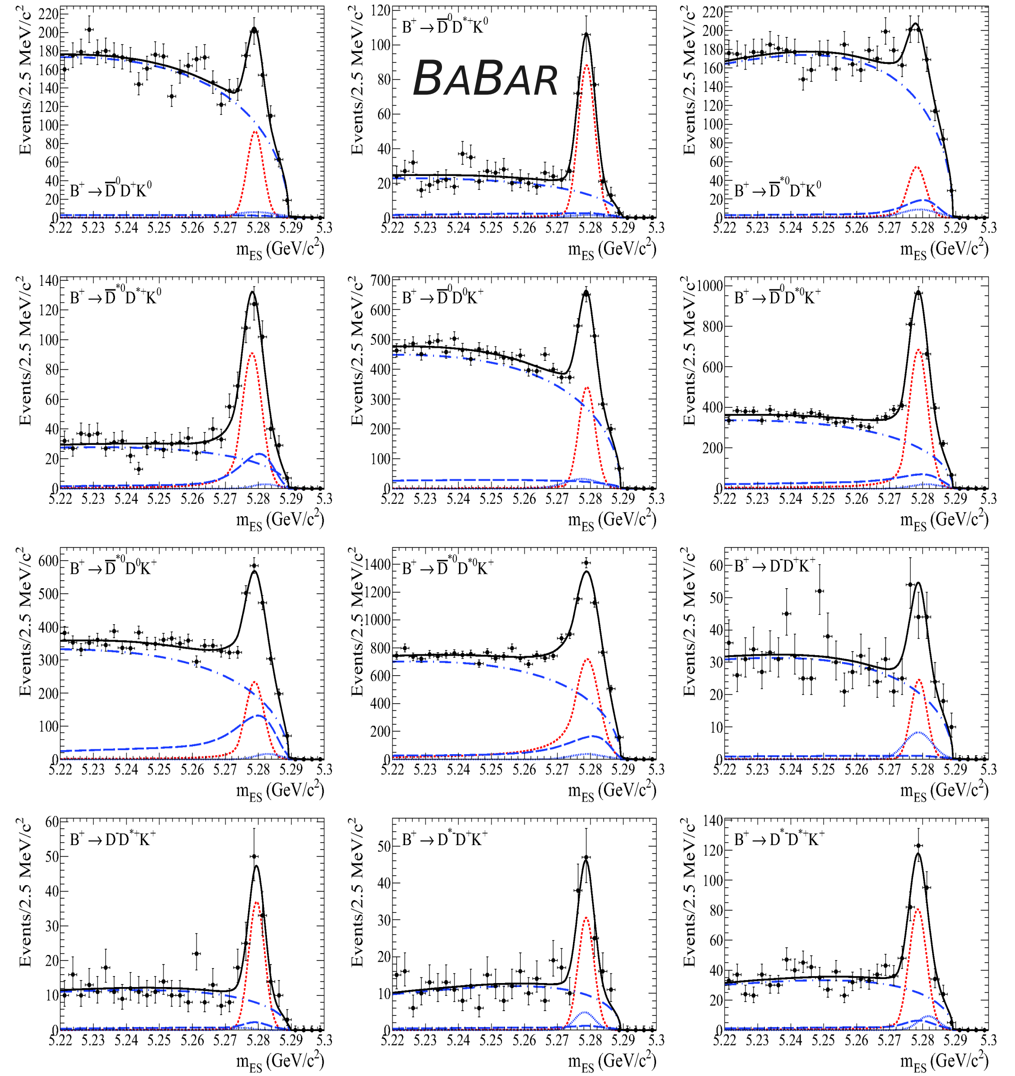
Neutral B mode	Charged B mode
$B^0 \to D^- D^0 K^+$	$B^+ \to \overline{D}^0 D^+ K^0$
$B^0 \to D^- D^{*0} K^+$	$B^+ \to \overline{D}^0 D^{*+} K^0$
$B^0 \to D^{*-} D^0 K^+$	$B^+ \to \overline{D}^{*0} D^+ K^0$
$B^0 \to D^{*-} D^{*0} K^+$	$B^+ \to \overline{D}^{*0} D^{*+} K^0$
$B^0 \to D^- D^+ K^0$	$B^+ \to \overline{D}^0 D^0 K^+$
$B^0 \to D^- D^{*+} K^0 + D^{*-} D^+ K^0$	$B^+ \to \overline{D}^0 D^{*0} K^+$
	$B^+ \to \overline{D}^{*0} D^0 K^+$
$B^0 \to D^{*-} D^{*+} K^0$	$B^+ \to \overline{D}^{*0} D^{*0} K^+$
$B^0 \to \overline{D}^0 D^0 K^0$	$B^+ \to D^- D^+ K^+$
$B^0 \to \overline{D}^0 D^{*0} K^0 + \overline{D}^{*0} D^0 K^0$	$B^+ \to D^- D^{*+} K^+$
	$B^+ \to D^{*-} D^+ K^+$
$B^0 \to \overline{D}^{*0} D^{*0} K^0$	$B^+ \to D^{*-} D^{*+} K^+$

- 22 decay modes: since cross-feed is an issue (mostly from loosing the soft pion from the decay of the D^*) it is fundamental to measure all the branching fractions in the same analysis;
- Events selected with tight cuts on the masses of the intermediate resonances and ΔE;
- Signal extracted through an unbinned ML fit on the m_{ES} variable.

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



Neutral modes



Charged modes

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

- The amount of cross-feed in each channel is obtained with an iterative procedure which takes into account the branching fractions of all the other channels in the previous iteration;
- The peaking background is fixed using the MC predictions;
- Some decays proceed through resonances: in computing the BF's we take into account the variations of efficiency across the $D^{(*)}D^{(*)}K$ Dalitz Plot;
- Combining all modes:

$$BF(B^0 \to D^{(*)}D^{(*)}K) = (3.68 \pm 0.10 \pm 0.24)\%$$
$$BF(B^+ \to D^{(*)}D^{(*)}K) = (4.05 \pm 0.11 \pm 0.28)\%$$

The full results table is in the backup slides

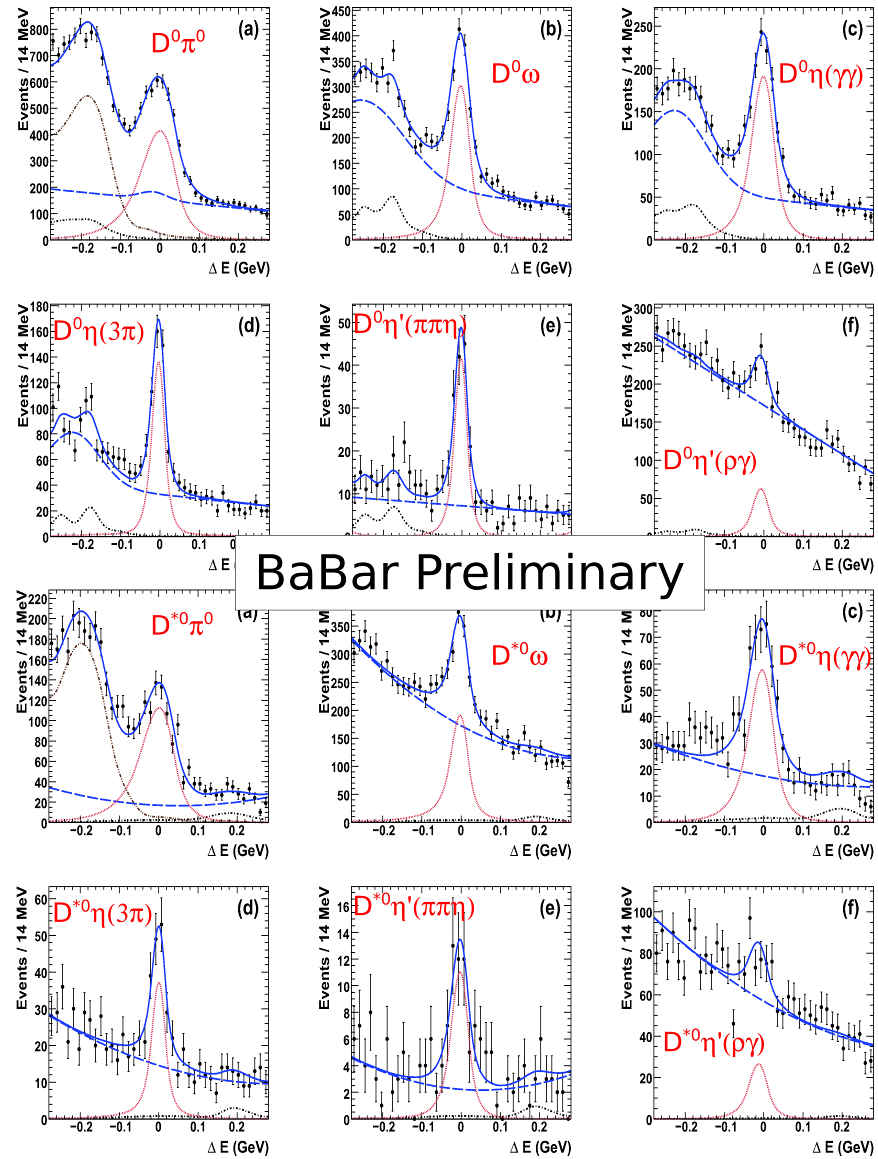
- No evidence of isospin breaking has been observed.

$B \rightarrow D^{(*)0}h^0$

New!

- $h^0 = \pi^0, \omega, \eta, \eta'$;
- Color suppressed decays, evidence for non-factorizable contributions;
- $B^- \rightarrow D^{(*)0}\rho^-$ is used as data control sample (and constitutes a source of peaking background for the π^0 modes);
- Crossfeed estimated with an iterative procedure;
- Signal yields extracted with an unbinned ML fit to the ΔE variable.

To be submitted to PRD

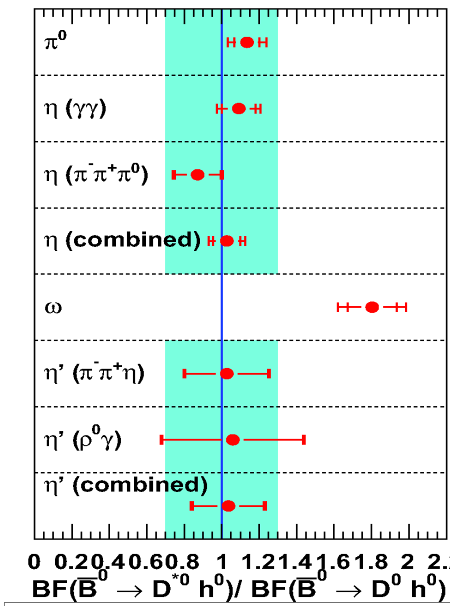


$B \to D^{(*)0} h^0$

New!

- Branching fractions compatible with other experiments;
- BF($B \to D^{*0}h^0$)/BF($B \to D^0 h^0$) consistent with 1, within 30% uncertainty, as predicted by SCET;

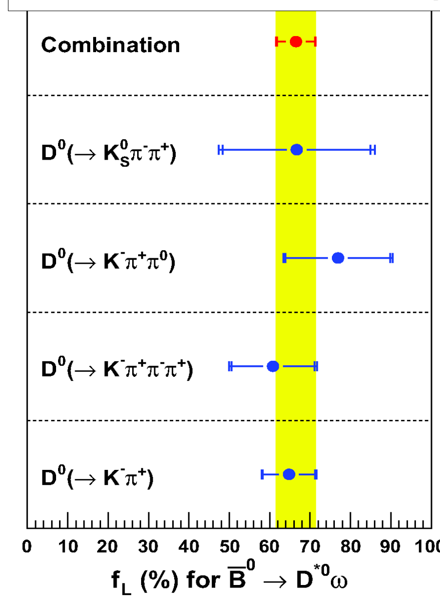
	$\mathcal{B}(\overline{B}^0 \to)$ $(\times 10^{-4})$
$D^0\pi^0$	$2.69 \pm 0.09 \pm 0.13$
$D^{*0}\pi^0$	$3.05 \pm 0.14 \pm 0.28$
$D^0\eta$	$2.53 \pm 0.09 \pm 0.11$
$D^{*0}\eta$	$2.69 \pm 0.14 \pm 0.23$
$D^0\omega$	$2.57 \pm 0.11 \pm 0.14$
$D^{*0}\omega$	$4.55 \pm 0.24 \pm 0.39$
$D^0\eta'$	$1.48 \pm 0.13 \pm 0.07$
$D^{*0}\eta'$	$1.48 \pm 0.22 \pm 0.13$



BaBar Preliminary

- For the $D^{*0}\omega$ mode, we also measure the longitudinal polarization fraction f_L. This is useful for a correct determination of the reconstruction efficiency and to study potential long-range contributions predicted by SCET which tend to decrease f_L;
- Result: $f_L = (66.5 \pm 4.7 \pm 1.5)\%$

significantly lower than HQET predictions ($f_L \sim 90\%$).



$B \to$ baryons - Motivations

- BF($B \to$ baryons) ~ 7%, but the sum of the known modes accounts for ~1%;
- In general, $B \to$ baryons decays are poorly understood theoretically, the study of as many exclusive decay modes as possible may provide insight on the different decay mechanisms;
- $B \to$ baryons decays may provide evidence of new/poorly known resonances;
- Threshold enhancement on the baryon-antibaryon invariant mass has been observed in several cases;
- Today:
  - Measurement of $BF(B \to \Lambda_c \bar{p} \pi^0)$ PRD-RC 82, 031102 (2010)
  - Measurement of $BF(B \to \Lambda_c \bar{\Lambda} K^-)$ To be submitted to PRD-RC

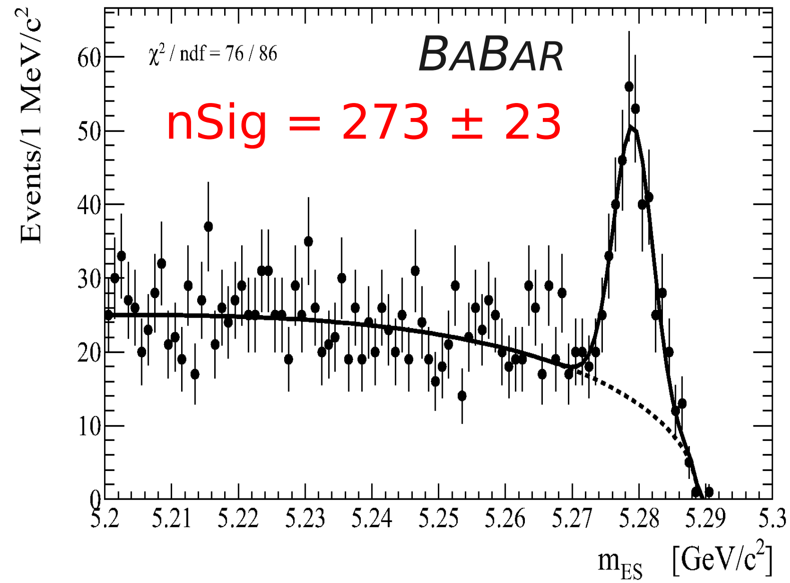
$B^0 \to \Lambda_c \bar{p}\, \pi^0$

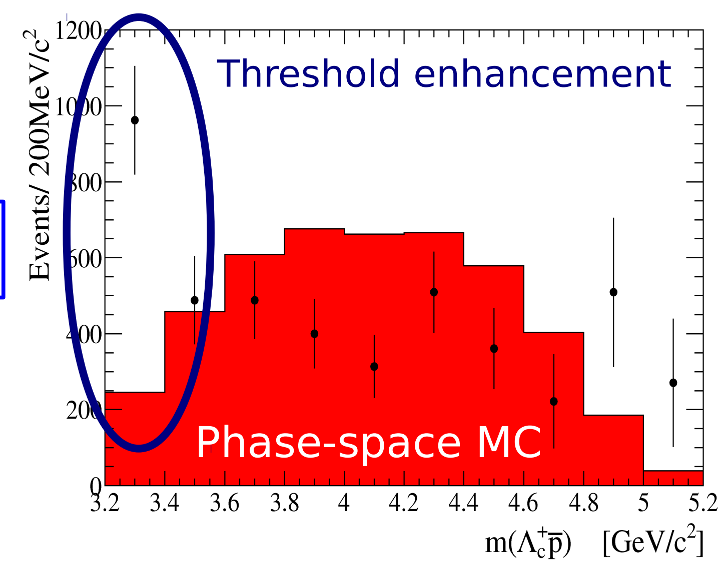
- Previous UL by CLEO (BF < 5.9 x 10^{-4});
- We reconstruct $\Lambda_c \to p\, K^- \pi^+$ (uncertainty on its BF is the dominant error);
- Peaking background: $B \to \Lambda_c \bar{p}\, \pi^-$, suppressed vetoing events with a π^- candidate compatible with this decay;
- Signal yield extracted from a fit to m_{ES};
- Result:

$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^0) = (1.94 \pm 0.17 \pm 0.14 \pm 0.50) \times 10^{-4}$$

(compatible with its isospin conjugate)

- No evidence of $B \to \Sigma_c \bar{p}$.



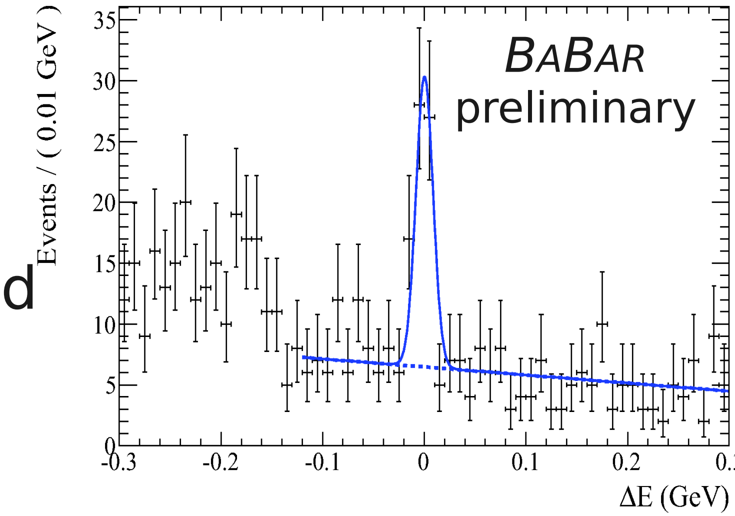


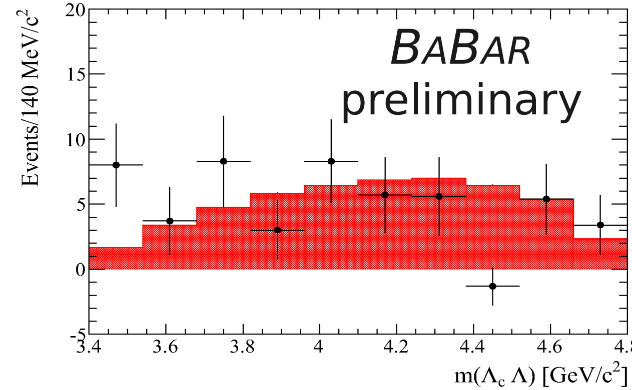
$B^0 \to \Lambda_c \bar{\Lambda} K^-$

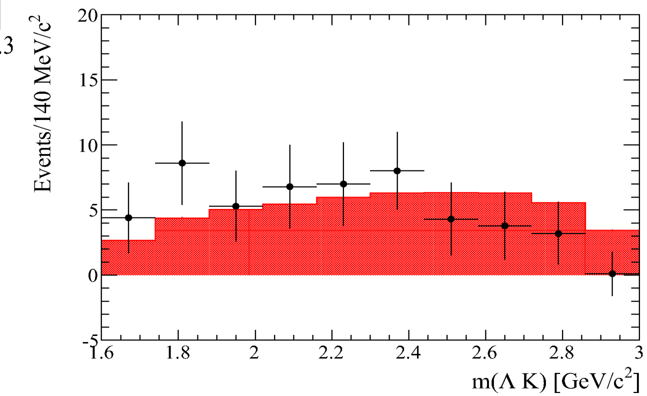
New!

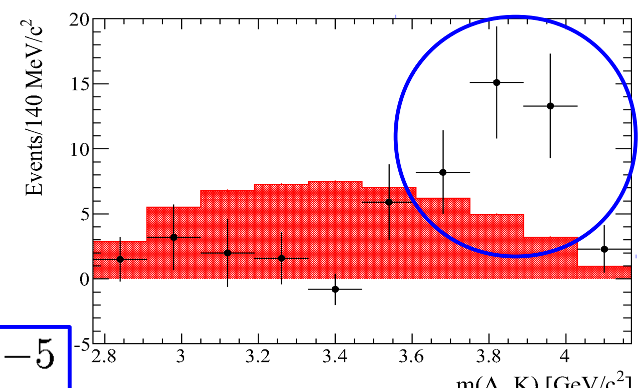
- Signal yield:
  51 ± 9 events
  (significance 8σ);
- Peaking background
  $B \to \Lambda_c \bar{p} \pi^+ K^-$
  suppressed with a cut on the distance of the Λ vertex;
- In the measurement of the BF, the efficiency is corrected accounting for the distribution of the invariant masses that we observe on the data;
- Enhancement in m($\Lambda_c K^-$);
- Result:

$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-) = (3.8 \pm 0.9_{\rm stat} \pm 0.2_{\rm sys} \pm 1.0_{\Lambda_c^+}) \times 10^{-5}$$







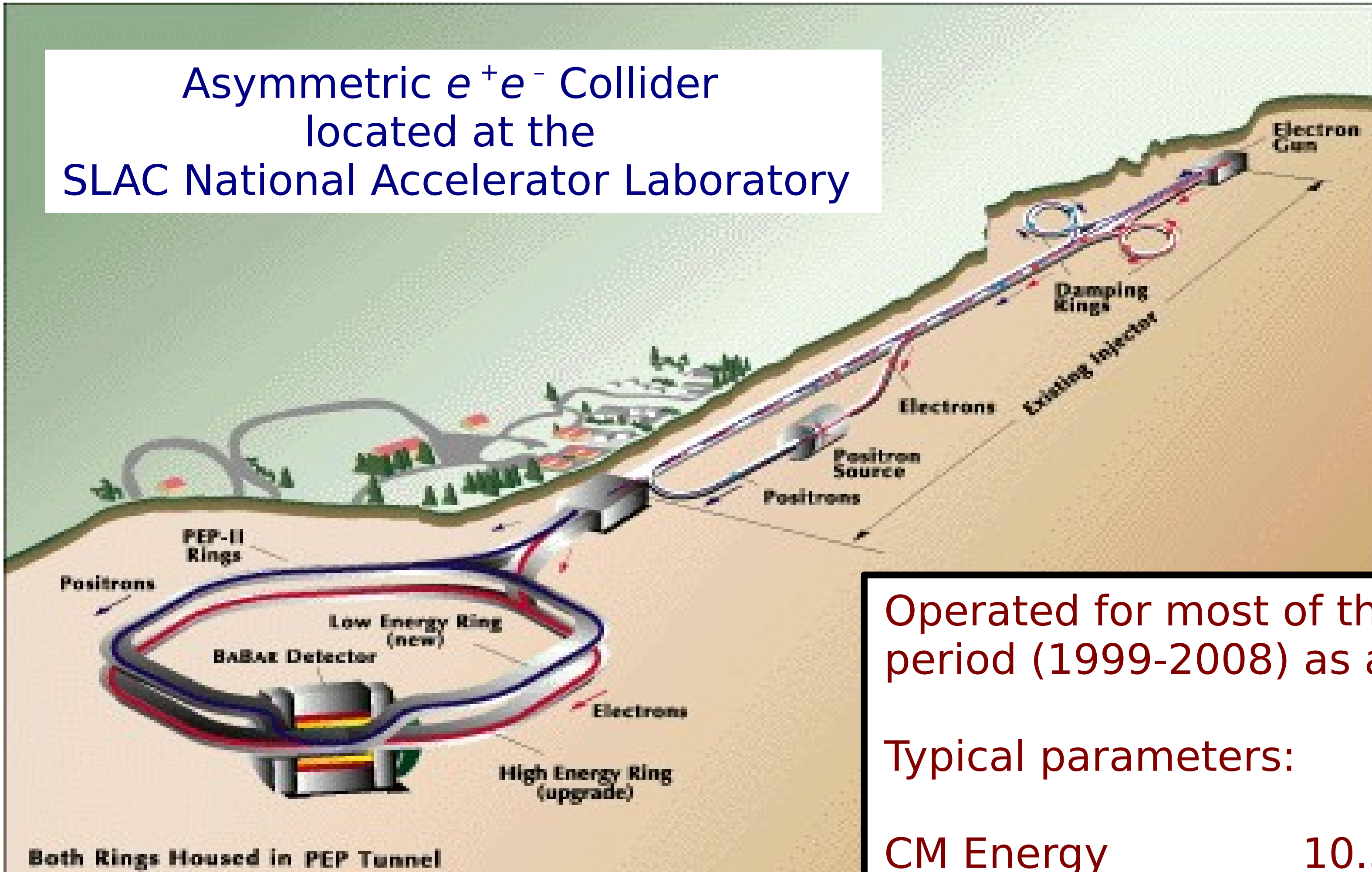


Conclusions

- After three years from the end of data taking, BaBar keeps producing interesting physics results;
- The precision measurement of Hadronic *B* Decays will help constraining standard and non-standard contributions in different theoretical frameworks;
- Most of the measurements I presented today are limited by statistics: plenty of room for improvement for the next generation of *B*-factories.

Backup Slides

The PEP-II Collider



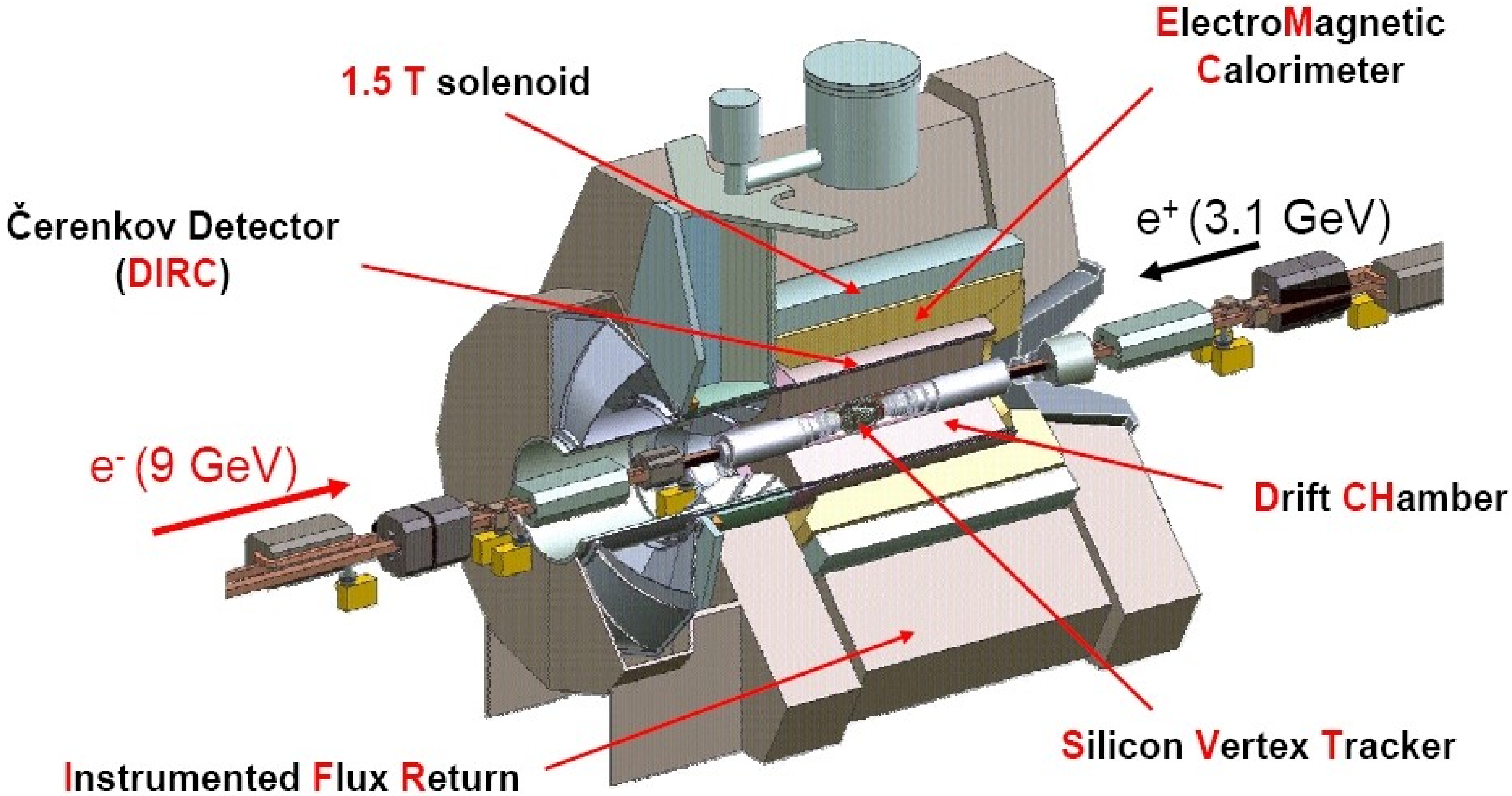
Asymmetric e^+e^- Collider
located at the
SLAC National Accelerator Laboratory

Operated for most of the data-taking period (1999-2008) as a B-factory.

Typical parameters:

CM Energy	10.58 GeV
e^+ Energy	3.1 GeV
e^- Energy	9.0 GeV
Max Luminosity	1.2×10^{34} cm^{-2}s^{-1}

The *BABAR* detector



$BF(B^+ \to D^+K^{(*)0})$

Decay mode	N_{sig}	$N_{B\overline{B}}$	N_{cont}	$\mathcal{B}$
$B^+ \to D^+K^0$				
$K\pi\pi$	$-11.9\ ^{+6.7}_{-5.6}$	70 ± 27	2690 ± 57	$-4.2\ ^{+2.4}_{-2.0}$
$K\pi\pi\pi^0$	$10\ ^{+10}_{-9}$	111 ± 51	6516 ± 94	$20\ ^{+20}_{-17}$
$K^0_S\pi$	$0.6\ ^{+5.3}_{-4.5}$	20 ± 14	381 ± 23	$0.7\ ^{+15}_{-13}$
$K^0_S\pi\pi^0$	$-6.7\ ^{+4.5}_{-2.8}$	36 ± 22	1270 ± 41	$-14\ ^{+9.2}_{-6.2}$
combined	-	-	-	$-3.4\ ^{+2.2}_{-1.8}$
$B^+ \to D^+K^{*0}$				
$K\pi\pi$	$-15.6\ ^{+8.7}_{-7.1}$	463 ± 63	6338 ± 98	$-5.0\ ^{+2.9}_{-2.1}$
$K^0_S\pi$	$-11.4\ ^{+3.5}_{-2.4}$	35 ± 15	547 ± 27	$-33\ ^{+10.2}_{-7.0}$
combined	-	-	-	$-5.3\ ^{+2.3}_{-2.0}$

$B \to D^{(*)}D^{(*)}K$ - Results

Mode	N_S	N_{PB}	N_{CF}^{SR}	$\mathcal{B}$	Significance
		B^0 decays through external W-emission amplitudes			
$B^0 \to D^- D^0 K^+$	635 ± 47	99 ± 54	65	$10.7 \pm 0.7 \pm 0.9$	8.6σ
$B^0 \to D^- D^{*0} K^+$	1116 ± 64	250 ± 69	137	$34.6 \pm 1.8 \pm 3.7$	7.6σ
$B^0 \to D^{*-} D^0 K^+$	1300 ± 54	93 ± 40	78	$24.7 \pm 1.0 \pm 1.8$	12.6σ
$B^0 \to D^{*-} D^{*0} K^+$	1883 ± 63	31 ± 28	112	$106.0 \pm 3.3 \pm 8.6$	11.4σ
		B^0 decays through external+internal W-emission amplitudes			
$B^0 \to D^- D^+ K^0$	58 ± 10	8 ± 11	2	$7.5 \pm 1.2 \pm 1.2$	5.1σ
$B^0 \to D^- D^{*+} K^0 + D^{*-} D^+ K^0$	422 ± 25	0 ± 12	7	$64.1 \pm 3.6 \pm 3.9$	13.4σ
$B^0 \to D^{*-} D^{*+} K^0$	511 ± 27	20 ± 13	5	$82.6 \pm 4.3 \pm 6.7$	12.5σ
		B^0 decays through internal W-emission amplitudes			
$B^0 \to \overline{D}^0 D^0 K^0$	46 ± 19	15 ± 19	19	$2.7 \pm 1.0 \pm 0.5$	2.3σ
$B^0 \to \overline{D}^0 D^{*0} K^0 + \overline{D}^{*0} D^0 K^0$	126 ± 39	70 ± 39	147	$10.8 \pm 3.2 \pm 3.6$	2.2σ
$B^0 \to \overline{D}^{*0} D^{*0} K^0$	170 ± 49	58 ± 31	231	$24.0 \pm 5.5 \pm 6.7$	2.2σ
		B^+ decays through external W-emission amplitudes			
$B^+ \to \overline{D}^0 D^+ K^0$	237 ± 30	40 ± 23	16	$15.5 \pm 1.7 \pm 1.3$	6.6σ
$B^+ \to \overline{D}^0 D^{*+} K^0$	233 ± 19	9 ± 10	17	$38.1 \pm 3.1 \pm 2.3$	10.7σ
$B^+ \to \overline{D}^{*0} D^+ K^0$	164 ± 37	48 ± 33	95	$20.6 \pm 3.8 \pm 3.0$	3.3σ
$B^+ \to \overline{D}^{*0} D^{*+} K^0$	308 ± 28	11 ± 12	113	$91.7 \pm 8.3 \pm 9.0$	7.5σ
		B^+ decays through external+internal W-emission amplitudes			
$B^+ \to \overline{D}^0 D^0 K^+$	901 ± 54	173 ± 77	153	$13.1 \pm 0.7 \pm 1.2$	8.6σ
$B^+ \to \overline{D}^0 D^{*0} K^+$	2180 ± 74	92 ± 50	409	$63.2 \pm 1.9 \pm 4.5$	12.5σ
$B^+ \to \overline{D}^{*0} D^0 K^+$	745 ± 60	61 ± 26	724	$22.6 \pm 1.6 \pm 1.7$	8.3σ
$B^+ \to \overline{D}^{*0} D^{*0} K^+$	3530 ± 141	186 ± 65	928	$112.3 \pm 3.6 \pm 12.6$	6.8σ
		B^+ decays through internal W-emission amplitudes			
$B^+ \to D^- D^+ K^+$	60 ± 15	35 ± 20	7	$2.2 \pm 0.5 \pm 0.5$	2.8σ
$B^+ \to D^- D^{*+} K^+$	91 ± 13	2 ± 7	10	$6.3 \pm 0.9 \pm 0.6$	6.7σ
$B^+ \to D^{*-} D^+ K^+$	75 ± 13	15 ± 9	6	$6.0 \pm 1.0 \pm 0.8$	5.1σ
$B^+ \to D^{*-} D^{*+} K^+$	232 ± 23	30 ± 14	31	$13.2 \pm 1.3 \pm 1.2$	7.4σ

$B \to D^{(*)0} h^0$