MEASUREMENT OF $B \rightarrow \bar{D}^{(*)} D^{(*)} K$ BRANCHING FRACTIONS AT BABAR

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OUTLINE

MEASUREMENT OF $B \to \overline{D}^{(*)}D^{(*)}K$ BRANCHING FRACTIONS AT BABAR

This is a new result from BaBar, all results are preliminary
(to be submitted soon to Physical Review D)

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

Plan of the talk

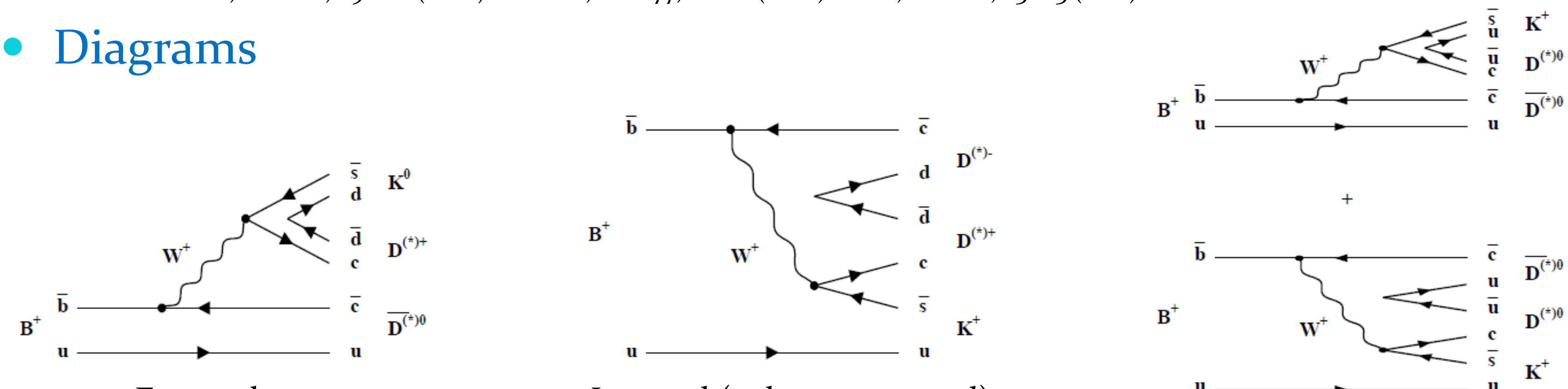
- Motivation
- Event selection
- Data fits
- Branching fractions
- Systematics
- Results

MOTIVATION

- For a long time, there was a theoretical inconsistency between the B decays into charm particles (charm counting) and the B semileptonic branching fraction
- In 1994, it was realized that an enhancement was needed in $b \to c\bar{c}s$ to avoid the inconsistency
  - Buchalla *et al.* predicted sizeable branching fractions for $B \to \bar{D}^{(*)}D^{(*)}K(X)$
    PLB 364, 188 (1995)
- In 2003, with 76 fb^{-1}, BaBar reported the observation (or limits) on the 22 $B \to \bar{D}^{(*)}D^{(*)}K$ final states PRD 68, 092001 (2003)
  - $BF(B^0 \to \bar{D}^{(*)}D^{(*)}K) = (4.3 \pm 0.3 \pm 0.6)\%$
  - $BF(B^+ \to \bar{D}^{(*)}D^{(*)}K) = (3.5 \pm 0.3 \pm 0.5)\%$
- In 2006, BaBar studied inclusive B decays to charm particles PRD 74, 091101 (2006)
  - Charm counting now **in agreement** with semileptonic branching fraction
  - $b \to c\bar{c}s$ transition containing a $\bar{D}$ meson (**wrong-sign D** production)
    - $BF(\bar{B}^0 \to \bar{D}X) = (10.4 \pm 1.9)\%$
    - $BF(B^- \to \bar{D}X) = (11.1 \pm 0.9)\%$

MOTIVATION

- In addition, $B \to \bar{D}^{(*)}D^{(*)}K$ events are interesting for varieties of studies
  - Test of **isospin relations** M. Zito, PLB 586, 314 (2004)
  - **Time-dependent CP asymmetry** to measure cos 2β using $B \to D^{*-}D^{*+}K^0_S$
    BaBar, PRD 74, 091101 (2006) Belle, PRD 76, 072004 (2007)
  - Great potential to study **resonances** decaying to $\bar{D}^{(*)}D^{(*)}$ or $D^{(*)}K$
    - **ψ(3770), D_{s1}(2536), D_{sJ}(2700), X(3872)**
      Belle, PRL 100, 092001 (2008) BaBar, PRD 77, 011102 (2008) Belle, PRD 81, 031103 (2010)
- Diagrams



External

Internal (color suppressed)

External + internal

- This talk: measurement of the 22 $B \to \bar{D}^{(*)}D^{(*)}K$ branching fractions
  - Using a technique valid whatever are the **contributions of resonant states**

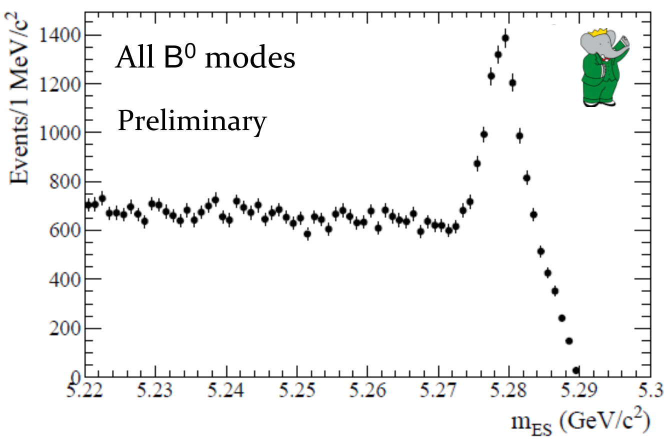
EVENT SELECTION

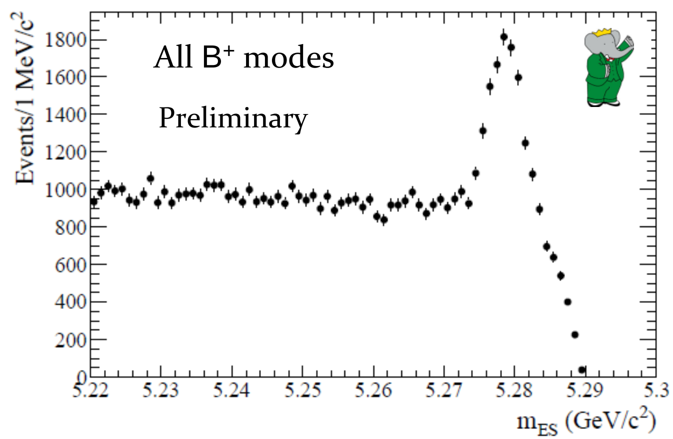
- Using full BaBar data sample: 429 fb^{-1}, $N_{B\bar{B}} = (470.9 \pm 0.1 \pm 2.8) \times 10^6$
- Exclusive reconstruction:
  - $D^0 \to K^- \pi^+$, $D^0 \to K^- \pi^+ \pi^0$, $D^0 \to K^- \pi^+ \pi^- \pi^+$
  - $D^+ \to K^- \pi^+ \pi^+$
  - $D^{*+} \to D^0 \pi^+$, $D^+ \pi^0$ (reconstructing $D^+ \pi^0$ only for modes with $D^{*-} D^{*+}$)
  - $D^{*0} \to D^0 \pi^0$, $D^0 \gamma$
  - $K^0_S \to \pi^+ \pi^-$
- For modes having a D^0 and a $\bar{D}^0$ in the final state
  - At least one of them required to decay to $K^- \pi^+$ for most of the modes
- Every final state (112 in total) have different level of background
  - Each final states **optimized** separately, maximizing the significance $S/(S+B)^{1/2}$ on simulation
- Selection of $D^{(*)}$ and K mesons based on
  - Mass, energy of decay products, vertexing, particle identification, …

EVENT SELECTION

- Selection of B meson based on
  - **Topological** variables to suppress continuum events
  - $\mathbf{m_{ES}}$ and **ΔE** variables
    - $m_{ES} = \sqrt{s/4 - p_B^{*2}}$, peaking at the B mass
    - ΔE = difference between the B energy and the beam energy, peaking at zero
      - Cutting on this variable after the choice of the best candidate
- When several B candidates: choosing the one with the smallest |ΔE|

- m_{ES} distributions after the complete selection





- Fit of m_{ES} distributions to extract the signal yields and the branching fractions

DATA FITS

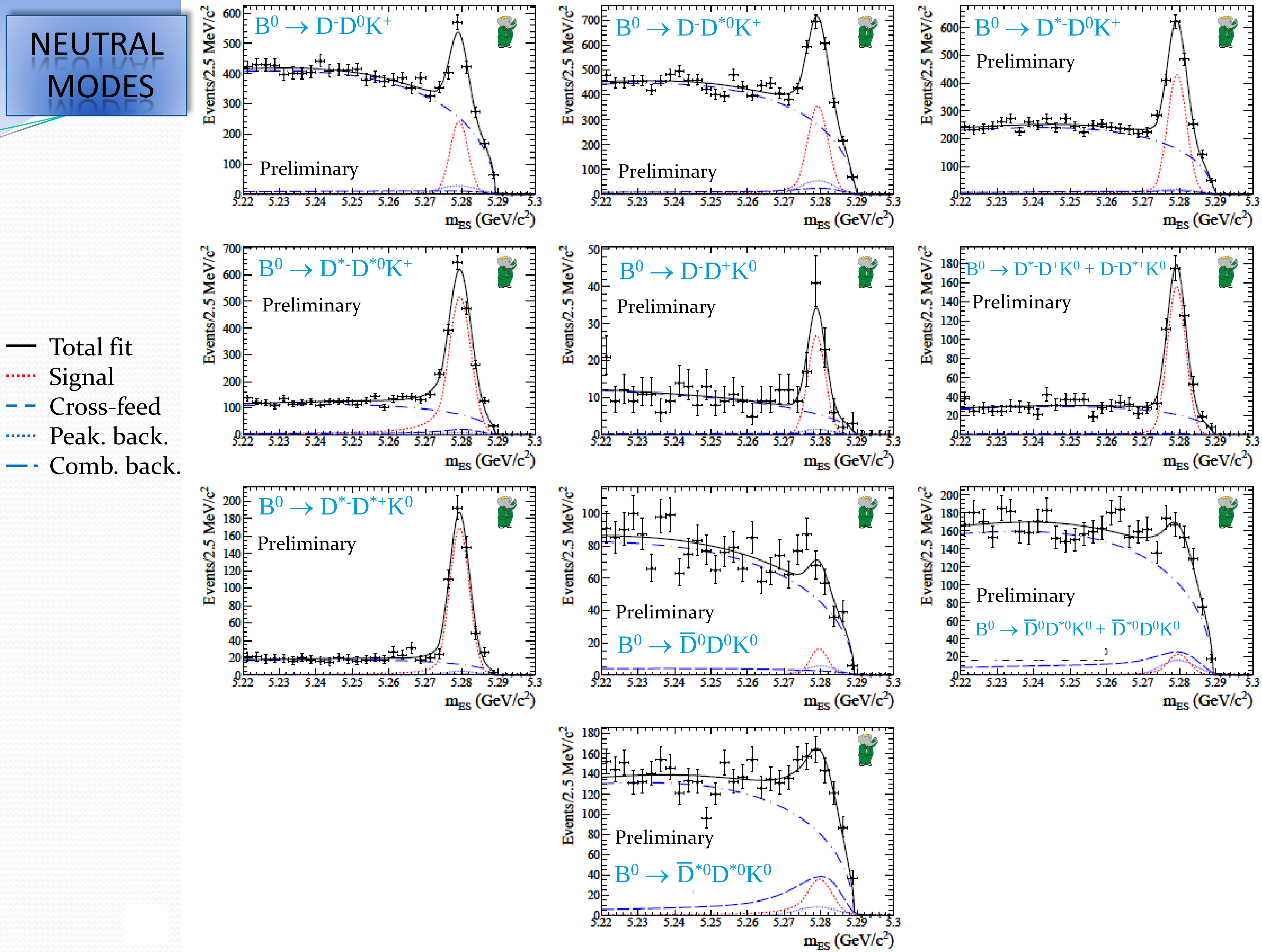
- Determine first the shape of the 4 contributions
  - Each shape taken and fixed from the **simulation**, except combinatorial background

- Signal
  - **Crystal Ball** PDF (Gaussian + tail on the low side)
- Cross-feed
  - Events from all the $\bar{D}^{(*)}D^{(*)}K$ modes, except the one we reconstruct, that pass the complete selection, reconstructed in the given mode
  - **Non negligible** part peaking in m_{ES}
- Combinatorial background
  - Described by an **Argus** PDF
- Peaking background
  - Events **peaking** in m_{ES} not due to the cross-feed
  - Described by a **Gaussian** PDF

DATA FITS

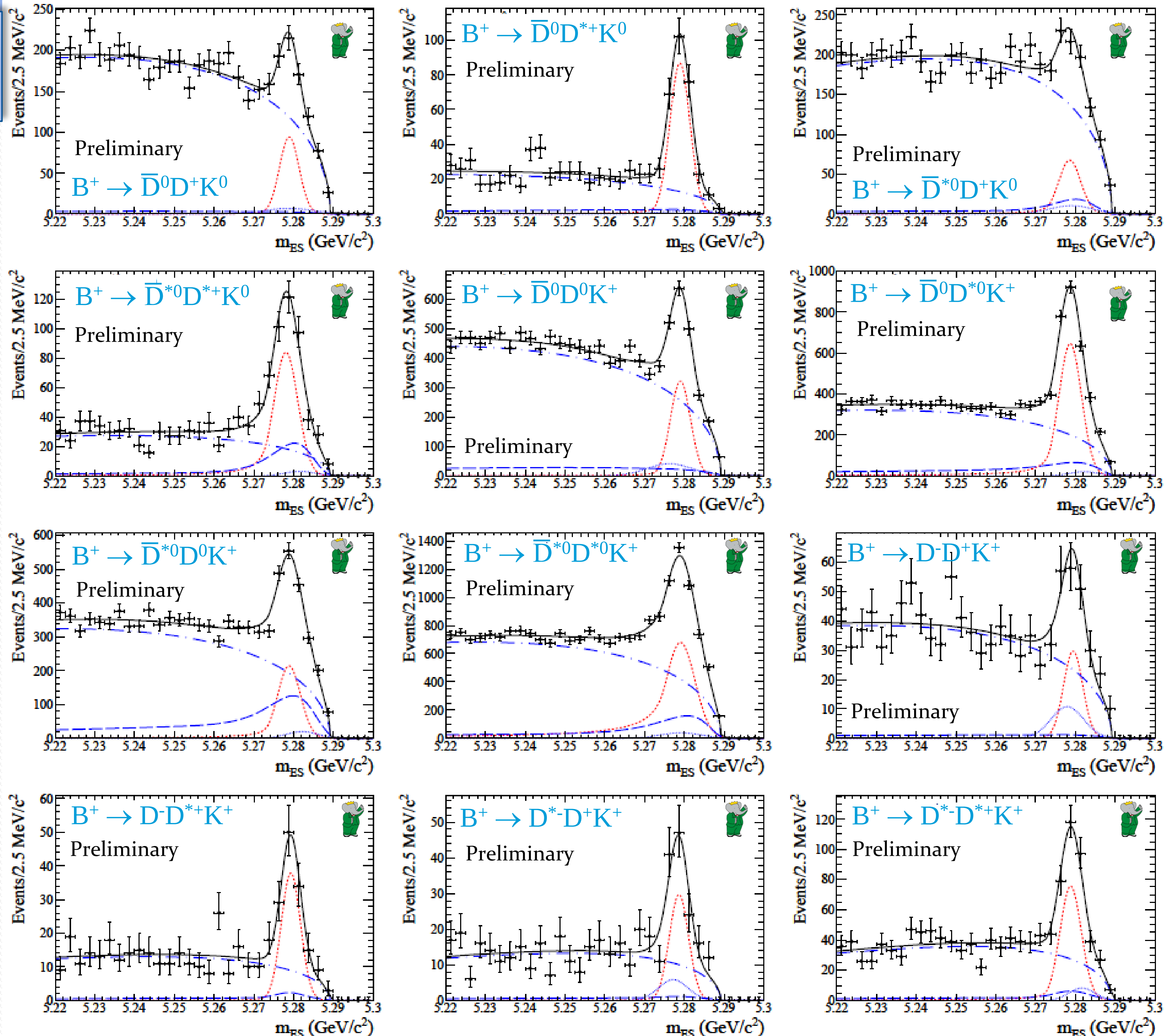
- Total fits with 4 free parameters
  - **Signal**: yield and mean
  - **Combinatorial background**: yield and Argus shape
- Iterative procedure performed because of the large proportion of cross-feed events
  - Each channel **depends** on the branching fractions of others
  - **4 iterations** needed to converge

NEUTRAL MODES



CHARGED MODES

- Total fit
- Signal
- Cross-feed
- Peak. back.
- Comb. back.



BRANCHING FRACTIONS

- $B \to \bar{D}^{(*)}D^{(*)}K$ events contain many resonances, some of them possibly unknown
  - Global **efficiencies** quite **different** between non resonant and resonant states
- We measure the branching fractions without any assumptions on the resonance contributions
  - Use the efficiency at the event position of the **Dalitz plane** and **reweight** the signal by this efficiency
  - Use **sPlot** to **isolate** signal contribution event-per-event
    NIM A 555, 356 (2005)
- Using $\mathcal{B} = \sum_i \frac{w_S(m_{ES}, i)}{N_{B\bar{B}} \times \langle \epsilon \mathcal{B}_{\rm sub} \rangle_i}$, $\langle \epsilon \mathcal{B}_{\rm sub} \rangle_i = \sum_j \epsilon_{ij} \times \mathcal{B}_{{\rm sub},j}$. $\mathcal{B}_{{\rm sub},j} = \mathcal{B}_{\bar{D}^{(*)}} \times \mathcal{B}_{D^{(*)}} \times \mathcal{B}_K$
  - where w_S are the **sWeights** for the signal PDF
  - ε_{ij} is the **efficiency** for the subdecays j at the Dalitz position of event i

SYSTEMATICS

- List of systematic uncertainties taken into account

Bigger

- **Peaking** background (~10% or bigger)
- **Particle** detection (~6-7%)
- **Uncertainties** on secondary branching fractions and $N_{B\bar{B}}$ (~5%)
- **Binning** effect of efficiency mapping
- Limited **MC statistics**
- **Signal** shape
- **Cross-feed**
- **Combinatorial** background
- **Iterative** procedure
- **Fit** procedure

Smaller

- All steps of analysis validated on MC simulation

RESULTS

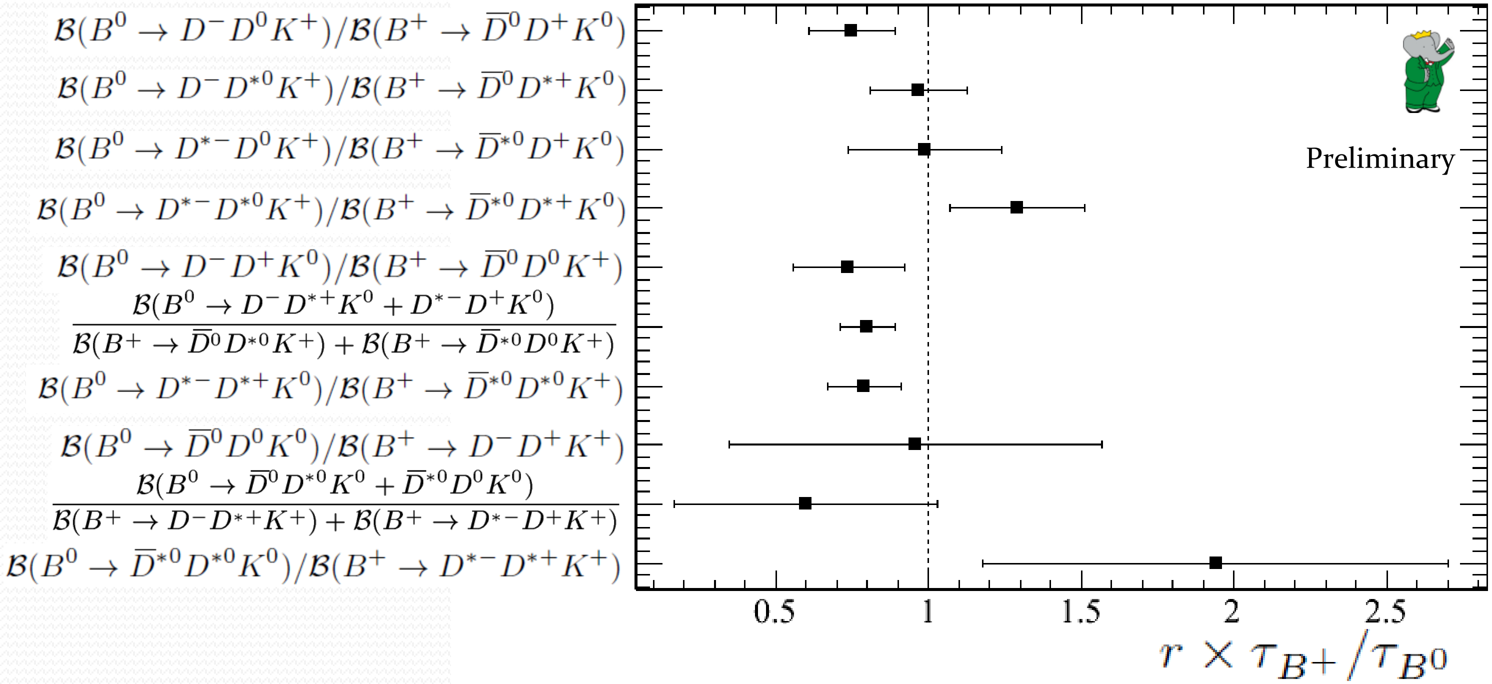
Observation of some color-suppressed modes

Preliminary

Mode	Signal yield N_S	Peak. back. yield N_{PB}	Cross-feed yield N_{CF}^{SR}	Branching fraction $\mathcal{B}$	Significance
B^0 decays through external W-emission amplitudes					
$B^0 \to D^- D^0 K^+$	622 ± 49	154 ± 53	72	$10.5 \pm 0.8 \pm 1.0$	7.7σ
$B^0 \to D^- D^{*0} K^+$	1120 ± 66	259 ± 79	141	$33.7 \pm 1.7 \pm 3.8$	7.1σ
$B^0 \to D^{*-} D^0 K^+$	1221 ± 54	101 ± 42	77	$22.5 \pm 1.0 \pm 1.7$	12.3σ
$B^0 \to D^{*-} D^{*0} K^+$	1838 ± 63	35 ± 29	106	$100.8 \pm 3.2 \pm 8.2$	11.4σ
B^0 decays through external+internal W-emission amplitudes					
$B^0 \to D^- D^+ K^0$	65 ± 10	6 ± 11	2	$8.1 \pm 1.2 \pm 1.2$	5.5σ
$B^0 \to D^- D^{*+} K^0 + D^{*-} D^+ K^0$	406 ± 25	0 ± 10	8	$59.8 \pm 3.5 \pm 3.7$	12.9σ
$B^0 \to D^{*-} D^{*+} K^0$	492 ± 27	20 ± 14	5	$77.7 \pm 4.2 \pm 6.5$	12.0σ
B^0 decays through internal W-emission amplitudes					
$B^0 \to \overline{D}^0 D^0 K^0$	42 ± 19	25 ± 28	19	$2.3 \pm 1.0 \pm 0.8$	1.8σ
$B^0 \to \overline{D}^0 D^{*0} K^0 + \overline{D}^{*0} D^0 K^0$	82 ± 39	78 ± 44	147	$6.9 \pm 3.1 \pm 3.7$	1.4σ
$B^0 \to \overline{D}^{*0} D^{*0} K^0$	161 ± 49	47 ± 30	217	$22.1 \pm 5.3 \pm 6.2$	2.2σ
B^+ decays through external W-emission amplitudes					
$B^+ \to \overline{D}^0 D^+ K^0$	240 ± 32	43 ± 24	18	$15.1 \pm 1.8 \pm 1.4$	6.2σ
$B^+ \to \overline{D}^0 D^{*+} K^0$	229 ± 19	10 ± 11	16	$37.2 \pm 3.0 \pm 2.2$	10.8σ
$B^+ \to \overline{D}^{*0} D^+ K^0$	205 ± 39	56 ± 36	93	$24.3 \pm 3.9 \pm 4.2$	3.4σ
$B^+ \to \overline{D}^{*0} D^{*+} K^0$	285 ± 27	13 ± 13	109	$83.8 \pm 8.0 \pm 8.9$	6.9σ
B^+ decays through external+internal W-emission amplitudes					
$B^+ \to \overline{D}^0 D^0 K^+$	855 ± 54	243 ± 85	154	$11.7 \pm 0.7 \pm 1.3$	7.9σ
$B^+ \to \overline{D}^0 D^{*0} K^+$	2072 ± 73	83 ± 55	392	$59.2 \pm 1.9 \pm 4.3$	12.3σ
$B^+ \to \overline{D}^{*0} D^0 K^+$	687 ± 59	77 ± 49	693	$20.8 \pm 1.6 \pm 1.9$	7.4σ
$B^+ \to \overline{D}^{*0} D^{*0} K^+$	3368 ± 140	202 ± 66	898	$105.6 \pm 3.5 \pm 12.1$	6.6σ
B^+ decays through internal W-emission amplitudes					
$B^+ \to D^- D^+ K^+$	73 ± 16	44 ± 22	8	$2.6 \pm 0.5 \pm 0.7$	2.9σ
$B^+ \to D^- D^{*+} K^+$	94 ± 13	0 ± 6	10	$6.3 \pm 0.9 \pm 0.6$	6.9σ
$B^+ \to D^{*-} D^+ K^+$	74 ± 13	22 ± 14	7	$6.1 \pm 1.2 \pm 0.9$	5.0σ
$B^+ \to D^{*-} D^{*+} K^+$	219 ± 23	27 ± 15	30	$12.2 \pm 1.2 \pm 1.1$	7.1σ

ISOSPIN INVARIANCE

- Checking the isospin invariance
  - **Amplitudes** should be **equal** interchanging the *u* and *d* quarks
  - Ratio of branching fractions *r* times the ratio of the charged to neutral B lifetime should be **equal to 1**

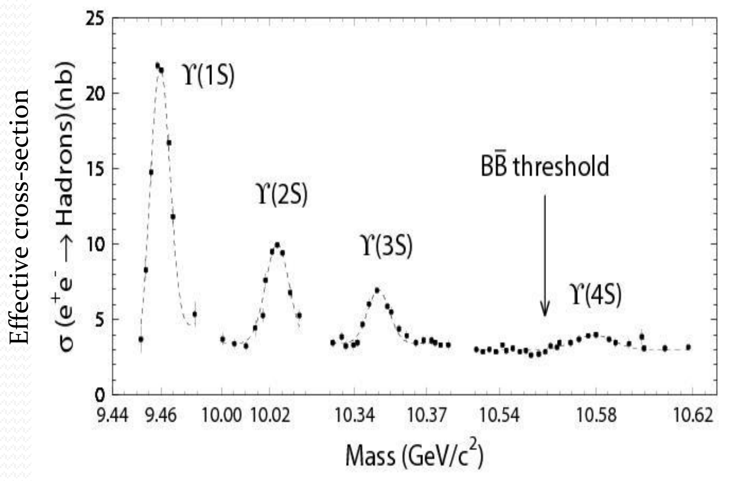


CONCLUSION

- The branching fractions of the 22 modes $B \to \bar{D}^{(*)}D^{(*)}K$ have been measured
  - This **supersedes** our previous measurements PRD 68, 092001 (2003)
- In particular, we observed some color-suppressed modes
- Summing the branching fractions
  - $BR(B^0 \to \bar{D}^{(*)}D^{(*)}K) = (3.44 \pm 0.09 \pm 0.23)\%$
  - $BR(B^+ \to \bar{D}^{(*)}D^{(*)}K) = (3.85 \pm 0.11 \pm 0.27)\%$
  - This **does not saturate** wrong-sign D production
- Isospin invariance respected within 2σ depending on the mode

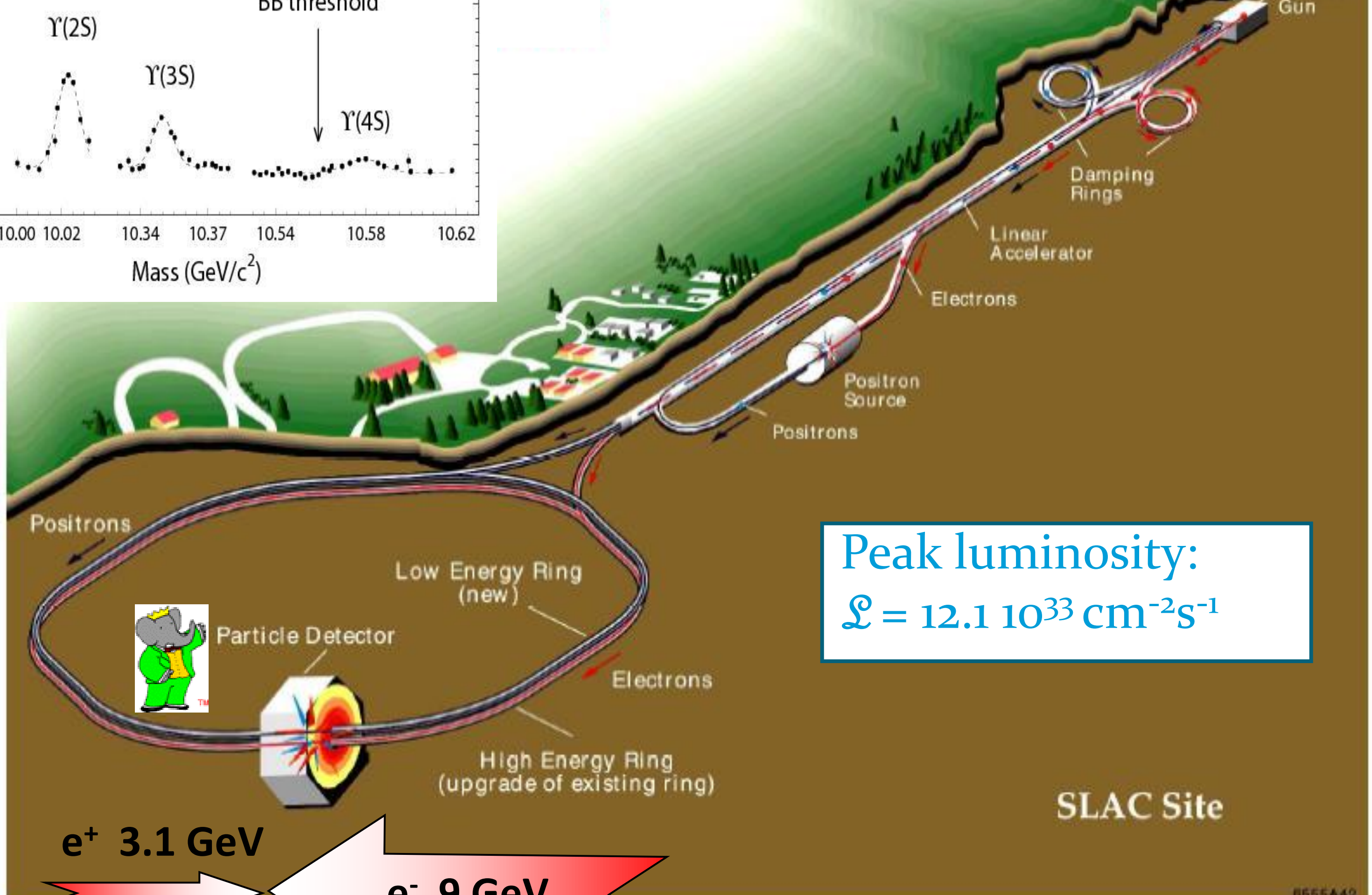
ADDITIONAL SLIDES

PEP-II AND BABAR



Center of mass: 10.58 GeV

$e^+ e^- \rightarrow \Upsilon(4S)\ (b\bar{b}) \rightarrow B\bar{B}$



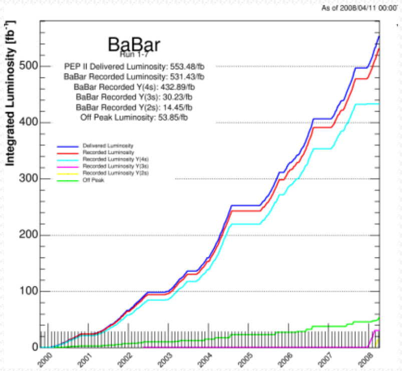
Peak luminosity:

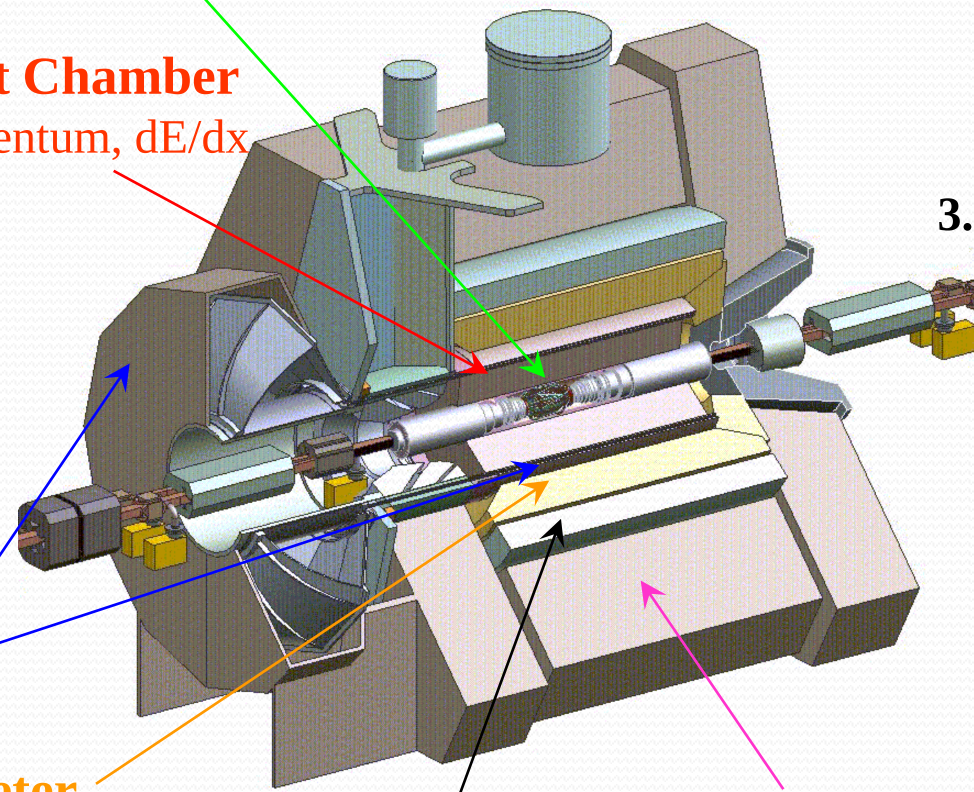
$\mathfrak{L} = 12.1\ 10^{33}\ cm^{-2}s^{-1}$

e^+ 3.1 GeV

e^- 9 GeV

THE BABAR EXPERIMENT





SYSTEMATICS

Mode	Signal shape (a)	Cross-feed (b)	Peaking back. (c)	Comb. back. (d)	Fit bias (e)	Iter. proc. (f)	MC stat. (g)	Bins (h)	Particle detection (i)	BF + $N_{B\overline{B}}$ (j)	Total syst.
$B^0 \to D^- D^0 K^+$	0.2	0.1	0.7	0.1	0.0	0.0	0.4	0.2	0.5	0.3	1.0
$B^0 \to D^- D^{*0} K^+$	0.7	0.1	2.5	0.0	0.0	0.0	1.2	1.3	1.9	1.1	3.8
$B^0 \to D^{*-} D^0 K^+$	0.5	0.0	0.5	0.0	0.0	0.0	0.4	0.5	1.1	0.8	1.7
$B^0 \to D^{*-} D^{*0} K^+$	1.9	0.2	1.6	0.1	0.0	0.2	1.9	3.5	6.1	2.7	8.2
$B^0 \to D^- D^+ K^0$	0.1	0.0	1.0	0.0	0.1	0.0	0.1	0.1	0.3	0.5	1.2
$B^0 \to D^- D^{*+} K^0 + D^{*-} D^+ K^0$	0.9	0.0	1.2	0.1	0.0	0.0	1.2	0.8	2.2	2.0	3.7
$B^0 \to D^{*-} D^{*+} K^0$	1.1	0.0	2.2	0.0	0.1	0.0	2.8	2.3	3.9	2.7	6.5
$B^0 \to \overline{D}^0 D^0 K^0$	0.3	0.0	0.7	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.8
$B^0 \to \overline{D}^0 D^{*0} K^0 + \overline{D}^{*0} D^0 K^0$	0.3	0.4	3.6	0.0	0.6	0.1	0.5	0.3	0.3	0.2	3.7
$B^0 \to \overline{D}^{*0} D^{*0} K^0$	1.1	1.5	4.6	0.8	0.5	2.0	1.0	2.4	1.6	0.6	6.2
$B^+ \to \overline{D}^0 D^+ K^0$	0.4	0.0	0.9	0.1	0.2	0.0	0.3	0.6	0.5	0.5	1.4
$B^+ \to \overline{D}^0 D^{*+} K^0$	0.5	0.0	1.1	0.1	0.0	0.0	0.9	0.3	1.2	1.0	2.2
$B^+ \to \overline{D}^{*0} D^+ K^0$	0.7	0.3	3.7	0.3	0.2	0.3	0.8	0.6	1.2	0.8	4.2
$B^+ \to \overline{D}^{*0} D^{*+} K^0$	1.4	1.2	3.0	0.1	0.1	0.0	2.8	5.8	4.5	2.2	8.9
$B^+ \to \overline{D}^0 D^0 K^+$	0.2	0.0	1.0	0.0	0.0	0.0	0.2	0.3	0.5	0.3	1.3
$B^+ \to \overline{D}^0 D^{*0} K^+$	1.1	0.2	0.9	0.0	0.0	0.3	0.8	1.4	3.3	1.5	4.3
$B^+ \to \overline{D}^{*0} D^0 K^+$	0.4	0.2	0.8	0.3	0.1	0.2	0.5	0.7	1.2	0.6	1.9
$B^+ \to \overline{D}^{*0} D^{*0} K^+$	1.9	0.6	2.7	0.5	0.0	1.0	3.9	6.4	8.4	2.8	12.1
$B^+ \to D^- D^+ K^+$	0.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.7
$B^+ \to D^- D^{*+} K^+$	0.1	0.0	0.2	0.0	0.0	0.0	0.2	0.3	0.3	0.2	0.6
$B^+ \to D^{*-} D^+ K^+$	0.1	0.0	0.7	0.0	0.0	0.0	0.3	0.2	0.3	0.2	0.9
$B^+ \to D^{*-} D^{*+} K^+$	0.2	0.0	0.5	0.0	0.0	0.0	0.5	0.2	0.7	0.4	1.1

ISOSPIN INVARIANCE

Mode	r	$r \times \tau_{B^+}/\tau_{B^0}$
$\mathcal{B}(B^0 \to D^- D^0 K^+)/\mathcal{B}(B^+ \to \overline{D}^0 D^+ K^0)$	$0.70 \pm 0.10 \pm 0.09$	0.75 ± 0.14
$\mathcal{B}(B^0 \to D^- D^{*0} K^+)/\mathcal{B}(B^+ \to \overline{D}^0 D^{*+} K^0)$	$0.91 \pm 0.09 \pm 0.12$	0.97 ± 0.16
$\mathcal{B}(B^0 \to D^{*-} D^0 K^+)/\mathcal{B}(B^+ \to \overline{D}^{*0} D^+ K^0)$	$0.93 \pm 0.16 \pm 0.18$	0.99 ± 0.25
$\mathcal{B}(B^0 \to D^{*-} D^{*0} K^+)/\mathcal{B}(B^+ \to \overline{D}^{*0} D^{*+} K^0)$	$1.20 \pm 0.12 \pm 0.16$	1.29 ± 0.22
$\mathcal{B}(B^0 \to D^- D^+ K^0)/\mathcal{B}(B^+ \to \overline{D}^0 D^0 K^+)$	$0.69 \pm 0.11 \pm 0.12$	0.74 ± 0.18
$\frac{\mathcal{B}(B^0 \to D^- D^{*+} K^0 + D^{*-} D^+ K^0)}{\mathcal{B}(B^+ \to \overline{D}^0 D^{*0} K^+) + \mathcal{B}(B^+ \to \overline{D}^{*0} D^0 K^+)}$	$0.75 \pm 0.05 \pm 0.07$	0.80 ± 0.09
$\mathcal{B}(B^0 \to D^{*-} D^{*+} K^0)/\mathcal{B}(B^+ \to \overline{D}^{*0} D^{*0} K^+)$	$0.74 \pm 0.05 \pm 0.10$	0.79 ± 0.12
$\mathcal{B}(B^0 \to \overline{D}^0 D^0 K^0)/\mathcal{B}(B^+ \to D^- D^+ K^+)$	$0.90 \pm 0.43 \pm 0.38$	0.96 ± 0.61
$\frac{\mathcal{B}(B^0 \to \overline{D}^0 D^{*0} K^0 + \overline{D}^{*0} D^0 K^0)}{\mathcal{B}(B^+ \to D^- D^{*+} K^+) + \mathcal{B}(B^+ \to D^{*-} D^+ K^+)}$	$0.56 \pm 0.26 \pm 0.31$	0.60 ± 0.43
$\mathcal{B}(B^0 \to \overline{D}^{*0} D^{*0} K^0)/\mathcal{B}(B^+ \to D^{*-} D^{*+} K^+)$	$1.81 \pm 0.47 \pm 0.53$	1.94 ± 0.76