Search for the Decay Modes $B^+ \to D^+K^0$ and $B^+ \to D^+K^{*0}$ with the *BaBar* Experiment

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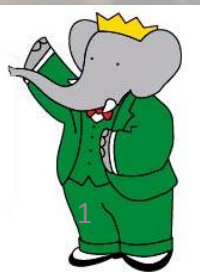
On behalf of the *BaBar* Collaboration

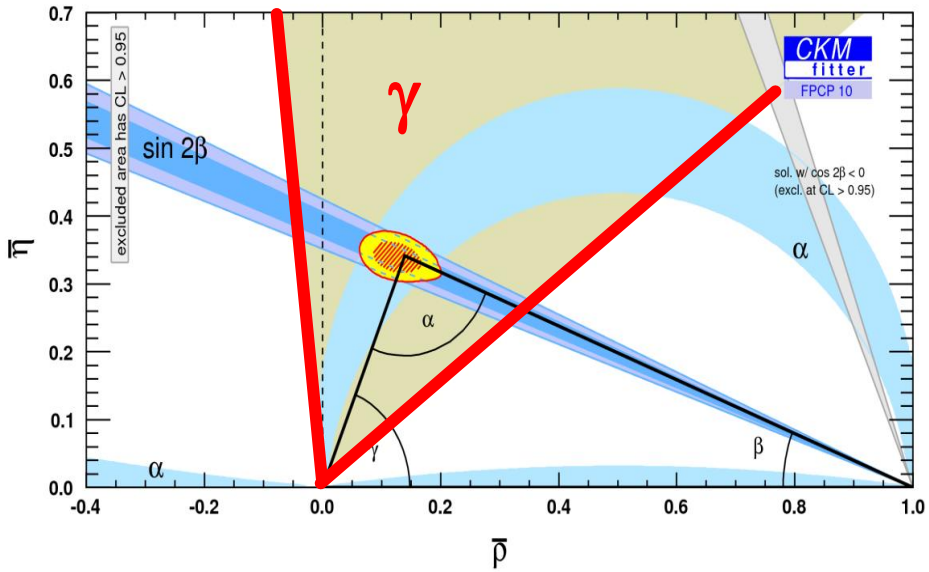
ICHEP 2010 – Paris



Motivations

Measurement of γ angle in CKM triangle:
Still challenging, large uncertainty
Flagship analysis in *BaBar*

http://ckmfitter.in2p3.fr
Eur. Phys. J. C41, 1-131 (2005)



Measurement with $B^+ \to \tilde{D}^0 K^+$:

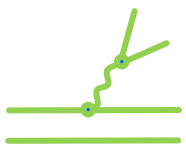
Interference: $B^+ \to \overline{D}^0 K^+$ and $B^+ \to D^0 K^+$

Sensitivity on γ then driven by:

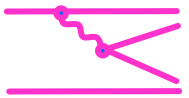
$$r_{D^0K^+} = \frac{|A(B^+ \to D^0 K^+)|}{|A(B^+ \to \overline{D^0} K^+)|} = \frac{|V_{cs}V_{ub}^*|}{|V_{us}V_{cb}^*|} \times \frac{|\overline{C} + A|}{|\overline{T} + C|}$$

Annihilation

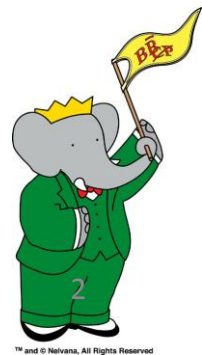
Tree



Color-suppressed

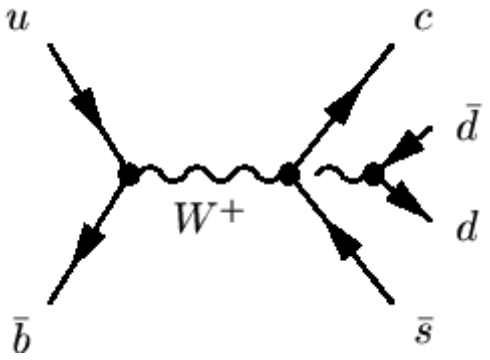


➔ Amplitudes must be under control



Motivations (2)

Annihilation diagram:



- Expected amplitude: A ~ ($\sin\theta_c$)^5
- No hadronic annihilation decay seen so far:

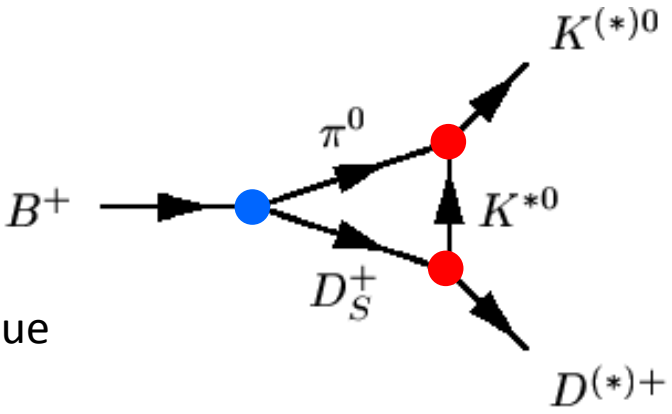
  BF($B^+ \to D^+ K^0$) < 5×10^{-6}@ 90% C.L. ,

  [*BaBar, 226x10^6 $B\bar{B}$, PRD 72, 011102 (2005)*]
- Ordinarily neglected in theoretical calculations

But…

- **Weak process** may be enhanced by **strong rescattering effect**

  PRL 78, 3999 (1997)
- Branching ratio may reach non-negligible value



Negligibility of annihilation diagram must be confirmed

Check with $B^+ \to D^+ K^{(*)0}$ (proceed through annihilation only)

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

B mesons from $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ with PEPII accelerator (SLAC), reconstructed with *BaBar* detector

$B^+ \to D^+ K^0$

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

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

- B^+
  - D^+
    - $K^-\pi^+\pi^+$
    - $K^0_s\pi^+$
  - $K^{*0} \to K^+\pi^-$

4-vectors of decay daughters summed to build mother candidate and mass-constrained

Main backgrounds:

- $e^+e^- \to$ quark anti-quark (quark=u,d,c,s)
- $e^+e^- \to B^0\overline{B}^0$ and B^+B^- : generic B decays,
- B decays with similar final states (peaking background in signal region)

For D^+K^0:

$B^0 \to D^- \rho^+$ ($\rho^+ \to \pi^+\pi^0$)
$B^0 \to \overline{D}^0 K^0$
$B^0 \to \overline{D}^{*0} K^0$

For D^+K^{*0}:

$B^0 \to D^- \rho^+$
$B^0 \to D^- K^{*+}$
$B^0 \to D^- a_1^+$

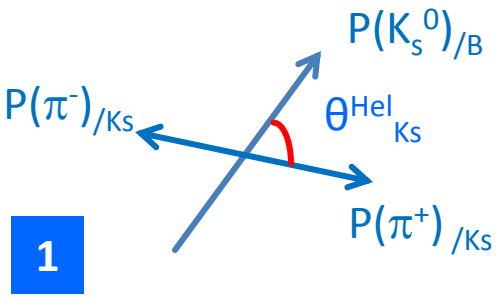
Selection of $B^+ \to D^+ K^{(*)0}$

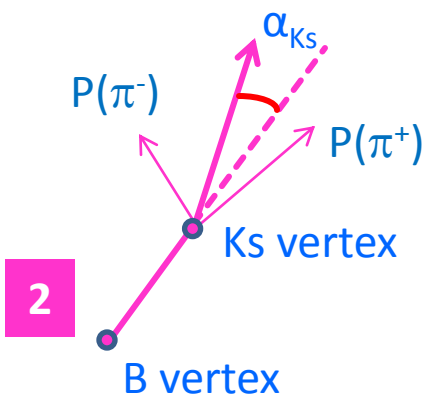
Selections ➔ maximizing $S/\sqrt{S+B}$ with high statistics Monte-Carlo simulations

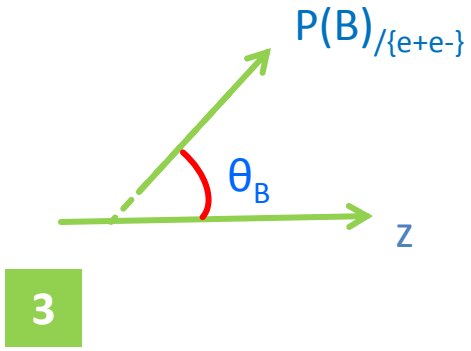
Assume branching fraction of $B^+ \to D^+ K^{(*)0}$ = **5×10^{-6}** (previous upper limit by BaBar)

PRD 72, 011102 (2005)

- Tracks origin constrained to same vertex
- Mass of D^+ candidates
- Mass, energy, shower shape, momentum of π^0 candidates
- Mass of K_s^0 candidates
- Peaking background rejected with K_s^0-related variables:
  - Helicity angle θ^{Hel}_{Ks} **1**
  - Flight Angle α_{Ks} **2**







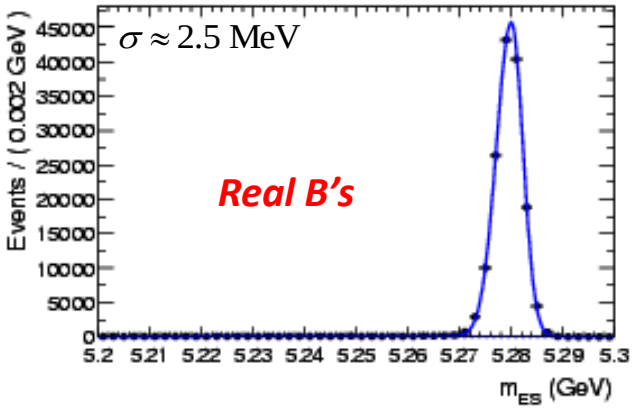
- Mass of K^{*0}
- Helicity angle of $K^{*0} \to K\pi$ similar to **1**
- B^+ built by combining D^+ and $K^{(*)0}$, constraining them to same origin vertex
- Angular distribution $\cos(\theta_B)$ **3**

Selection of $B^+ \to D^+ K^{(*)0}$ (2)

Use kinematics of $e^+e^- \to \Upsilon(4S) \to \overline{B}B$ for selection of B signal *SLAC-418, LBL-5379 (1993)*

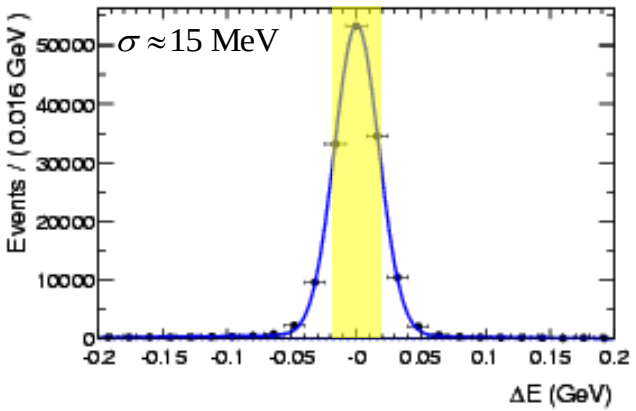
Beam-Energy Substituted Mass

$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$



Energy Difference

$$\Delta E = E^*_B - E^*_{beam}$$



Keep B candidates with ΔE close to zero (yellow band)

Eventually keep only 1 B / event:

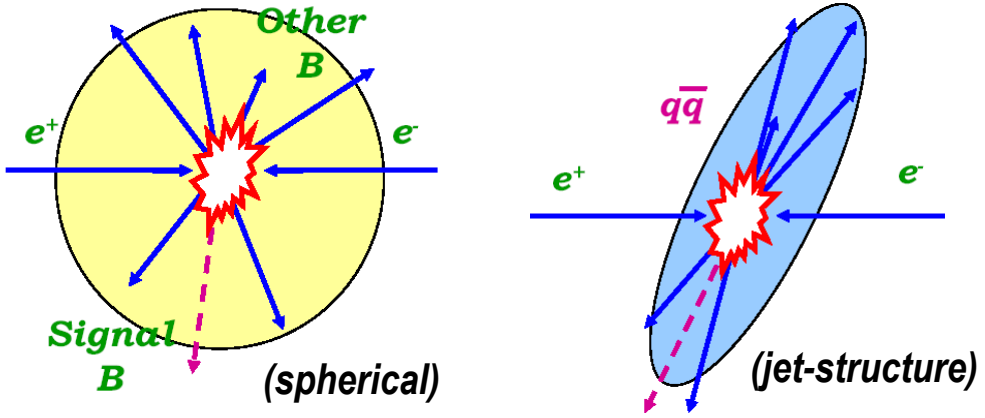
[D^+ mass closest to PDG value] or [ΔE closest to 0]

Overall efficiency on signal MC :

- $B^+ \to D^+ K^0$: 5 – 21 %
- $B^+ \to D^+ K^{*0}$: ~10 %

Selection of $B^+ \to D^+ K^{(*)0}$ (3)

Largest background from $e^+e^- \to q\bar{q}$, q=u,d,s,c (produce very high momentum mesons D^+, $K^{(*)0}$)

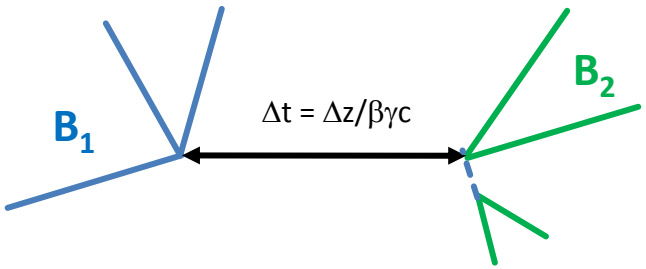


Different event topologies

Described by shape variables:
L_0, L_2, $|\cos(\theta_{thrust})|$
(cf. backup slides for definition)

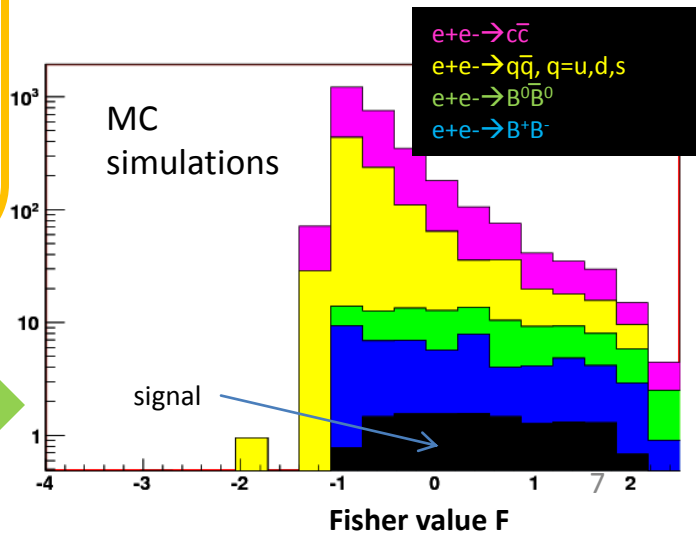
$e^+e^- \to q\bar{q}$ MC distributions checked with off-resonance data

Use time difference $|\Delta t|$ between the two B's



Combined in a Fisher discriminant:

$$F = a_0 + a_1 \cdot L_0 + a_2 \cdot L_2 + a_3 \cdot |cos(\theta_{thrust})| + a_4 \cdot |\Delta t|$$



Extraction of Number of Signal Events

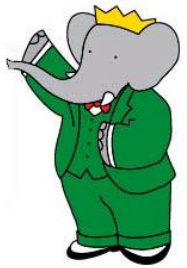
2D maximum likelihood fit: m_{ES} x Fisher

465x10^6 $B\bar{B}$

Background yields compatible with **expectations**

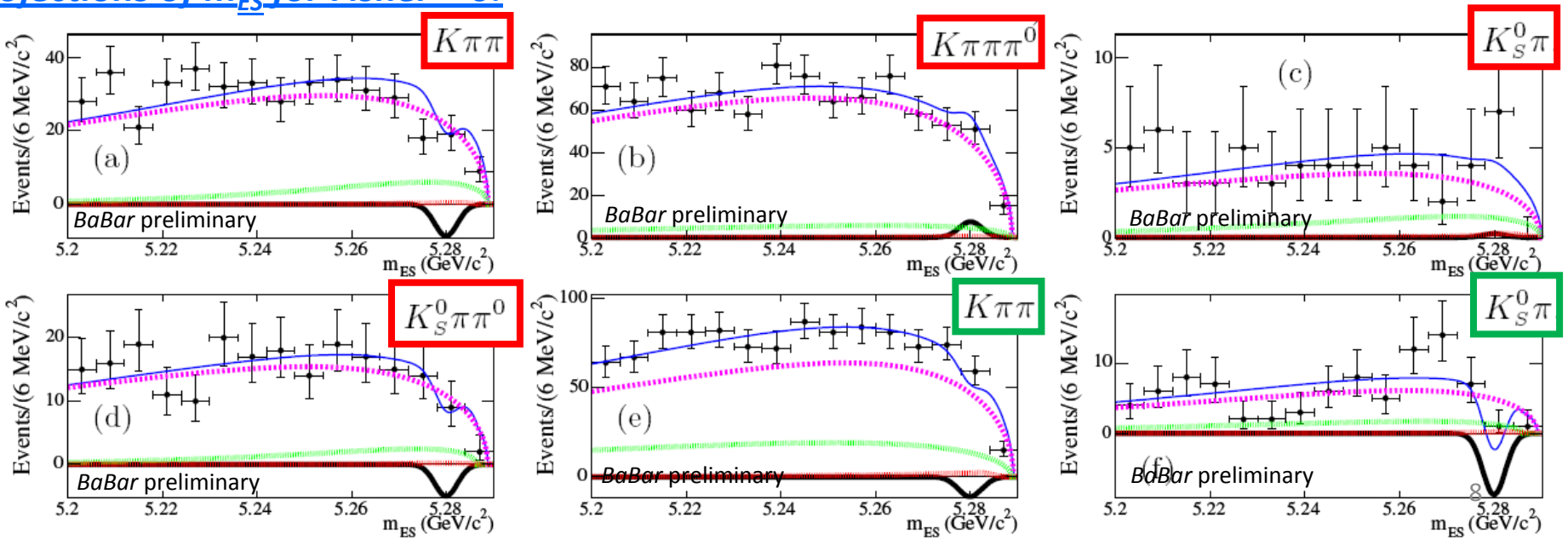
Signal yield compatible with **0**

Decay mode	N_{sig}	$N_{B\bar{B}}$	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	$-14\ ^{+\ 9.2}_{-\ 6.2}$
$B^+ \to D^+K^{*0}$				
$K\pi\pi$	$-15.6\ ^{+\ 8.7}_{-\ 7.1}$	463 ± 63	6338 ± 98	$-5.0\ ^{+\ 2.9}_{-\ 2.1}$
$K^0_S\pi$	$-11.4\ ^{+\ 3.5}_{-\ 2.4}$	35 ± 15	547 ± 27	$-33\ ^{+\ 10.2}_{-\ 7.0}$



Projections of m_{ES} for Fisher > 0:

Fit projection, signal, $B\bar{B}$, $q\bar{q}$, peaking background



in unit of 10^{-6}

Uncertainties on Branching Ratio

Statistical unc.

Statistical uncertainty dominates

Decay mode	$N_{\rm sig}$	$N_{B\overline{B}}$	$N_{\rm cont}$	$\mathcal{B}$
$B^+ \to D^+ K^0$				
$K\pi\pi$	$-11.9\ ^{+\ 6.7}_{-\ 5.6}$	70 ± 27	2690 ± 57	$-4.2\ ^{+\ 2.4}_{-\ 2.0}$
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$K^0_S\pi$	$-11.4\ ^{+\ 3.5}_{-\ 2.4}$	35 ± 15	547 ± 27	$-33\ ^{+\ 10.2}_{-\ 7.0}$

Systematic unc.

With off-resonance data

From control sample in data

$\overline{B}^0 \to D^+\pi^-$

$\overline{B}^0 \to D^+\rho^-$

	$B^+ \to D^+K^0$				$B^+ \to D^+K^{*0}$	
	$K\pi\pi$	$K\pi\pi\pi^0$	$K^0_S\pi$	$K^0_S\pi\pi^0$	$K\pi\pi$	$K^0_S\pi$
PDF - MC ← Largest one	$^{+0.8}_{-0.8}$	$^{+6.2}_{-3.4}$	$^{+5.3}_{-4.4}$	$^{+7.3}_{-8.8}$	$^{+0.6}_{-0.9}$	$^{+3.1}_{-3.6}$
Data-MC PDF shapes:						
Continuum background	0.2	0.4	1.4	0.5	0.1	1.7
$B\overline{B}$ background	0.7	1.6	2.5	5.0	1.0	4.4
Signal	< 0.05	9.2	5.6	0.9	0.9	3.1
Efficiency error:						
Reconstruction efficiency (MC)	0.1	0.6	< 0.05	0.9	0.1	0.5
Data-MC	0.2	0.8	< 0.05	0.5	0.2	0.3
Peaking background	< 0.05	0.5	0.2	0.2	< 0.05	0.1
$\mathcal{B}$ errors	0.3	0.3	< 0.05	0.4	< 0.05	0.1
Combined	$^{+1.1}_{-1.3}$	$^{+11.3}_{-11.8}$	$^{+8.2}_{-9.3}$	$^{+9.0}_{-12.5}$	$^{+1.5}_{-1.8}$	$^{+6.4}_{-7.9}$

Upper Limits on Branching Ratio (BR)

- **No signal observed in $B^+ \to D^+ K^{(*)0}$**
- Combination of BR measured with the different D^+ modes:

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

- **Upper limit set on BR using Bayesian approach**

Likelihood $\mathcal{L}_i^{final}$ of BR for each decay mode "i": $\mathcal{L}_i^{final} = \mathcal{L}_i * \mathcal{G}_i$
$\mathcal{G}_i$ = Gaussian with width equal to systematic uncertainty
$\mathcal{L}_i^{final}$ finally combined in one likelihood $\mathcal{L}^{total}$
Confidence Level measured by integrating $\mathcal{L}^{total}$ (flat prior for BR ≥ 0)

$$BR_{B\to DK} < 2.9 \times 10^{-6} \text{ at } 90\% \text{ C.L.}$$
$$BR_{B\to DK^*} < 3.0 \times 10^{-6} \text{ at } 90\% \text{ C.L.}$$

465x10^6 $B\bar{B}$

➔ *[hep-ex]arxiv:1005.0068, Submitted to Phys. Rev. D* ➔

Improvement of limit for $B^+ \to D^+ K^0$
First search for $B^+ \to D^+ K^{*0}$

Conclusion

- Measurement of $B^+ \to D^+ K^{(*)0}$ **branching ratios** of interest for
  - CKM angle γ measurement
  - constraining QCD models for annihilation diagrams
- Search with whole *BaBar* dataset **465×10^6 $B\bar{B}$**
- Uncertainty dominated by statistical uncertainty
- **No signal observed**
- **Upper limit** set on branching ratio with Bayesian statistics

$$BR_{B \to DK} < 2.9 \times 10^{-6} \text{ at } 90\% \quad \textbf{C.L.}$$

$$BR_{B \to DK^*} < 3.0 \times 10^{-6} \text{ at } 90\% \quad \textbf{C.L.}$$

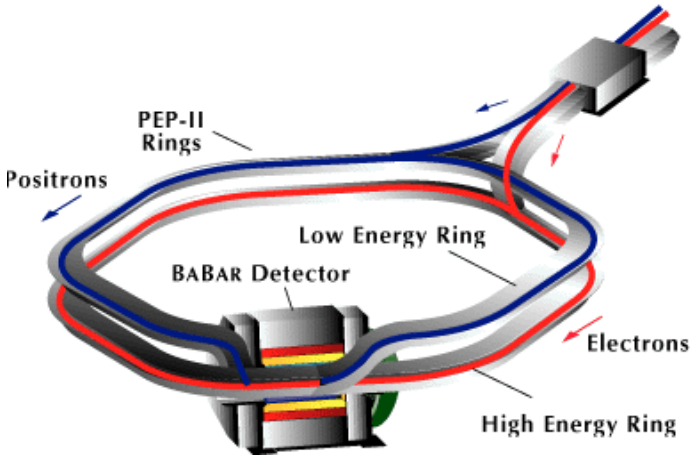
- **Improvement of limit for $B^+ \to D^+ K^0$ (5.5×10^{-6})**
  First search for $B^+ \to D^+ K^{*0}$
- Strengthens hypothesis of negligible contributions from annihilation diagrams

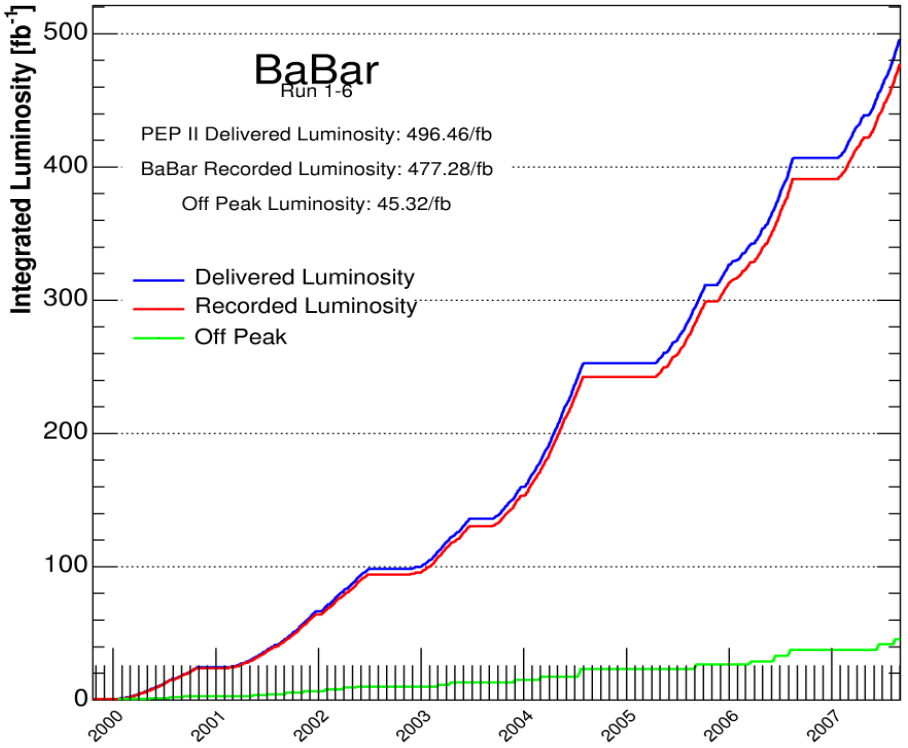
Backup Slides

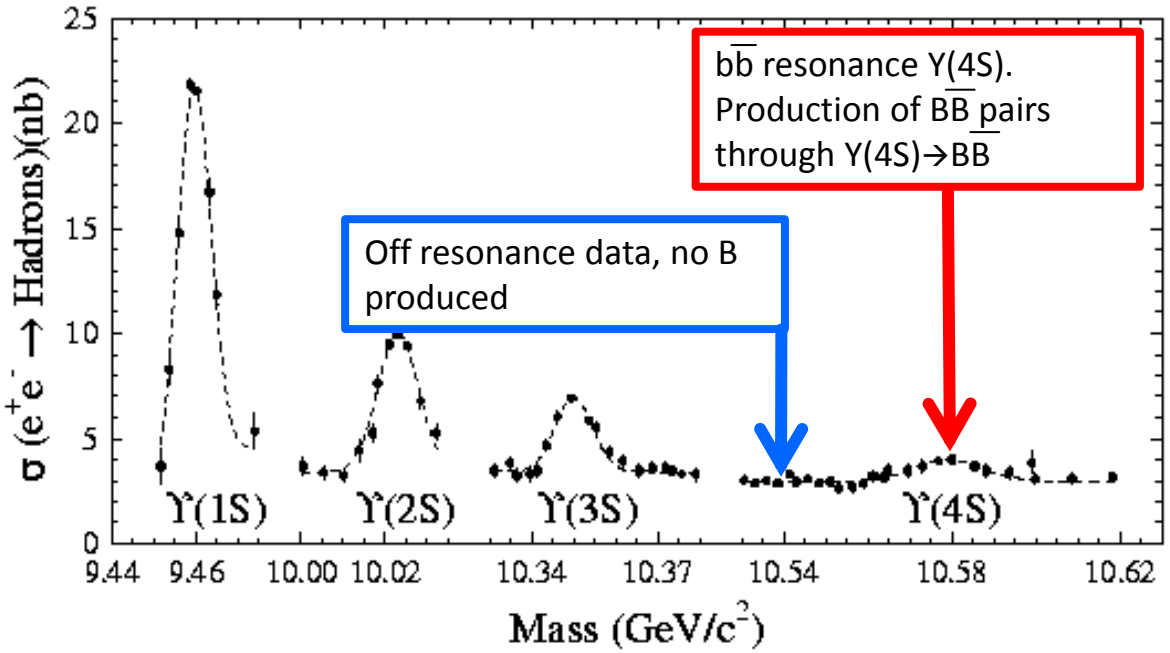
Definition of Event Shape Variables

The first variable is the cosine of the angle between the B thrust axis and the thrust axis of all the other reconstructed charged tracks and neutral energy deposits (rest of the event), where the thrust axis is defined as the direction that maximizes the sum of the longitudinal momenta of all the particles. The second and third variables are the event shape moments $L_0 = \sum_i p_i$, and $L_2 = \sum_i p_i |\cos\theta_i|^2$, where the index i runs over all tracks and energy deposits in the rest of the event; p_i is the momentum and θ_i is the angle with respect to the thrust axis of the B candidate. These three variables are calculated in the CM.

BaBar Data


PEP-II
Rings
Positrons
Low Energy Ring
BABAR Detector
Electrons
High Energy Ring


As of 2007/09/04 00:00
BaBar
Run 1-6
PEP II Delivered Luminosity: 496.46/fb
BaBar Recorded Luminosity: 477.28/fb
Off Peak Luminosity: 45.32/fb
Delivered Luminosity
Recorded Luminosity
Off Peak
Integrated Luminosity [fb⁻¹]
0
100
200
300
400
500
2000
2001
2002
2003
2004
2005
2006
2007


bb̄ resonance Υ(4S).
Production of BB̄ pairs
through Υ(4S)→BB̄
Off resonance data, no B
produced
σ (e⁺e⁻ → Hadrons)(nb)
Υ(1S)
Υ(2S)
Υ(3S)
Υ(4S)
Mass (GeV/c²)