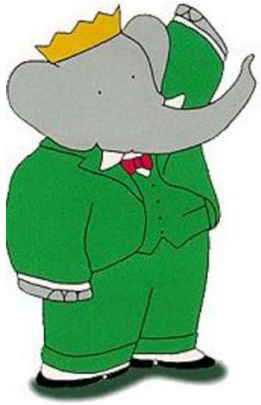
DPF 2009
2009 Meeting of the Division of Particles and Fields of the American Physical Society (DPF 2009)
26-31 JULY 2009
Wayne State University, Detroit, MI

Charmless hadronic B decays into V, A and T final states at BaBar



Paolo Gandini
Università Studi di Milano & INFN

Istituto Nazionale di Fisica Nucleare

Talk on behalf of the BaBar Collaboration

Outline

Measurements of Charmless Hadronic B decays at BaBar powerful tool to

- **Test Standard Model**
- **Search New Physics**

B → VV, VA, AA Decays
measurements of
POLARIZATION

→ f_L **LONGITUDINAL POLARIZATION FRACTION**

Polarization Puzzle

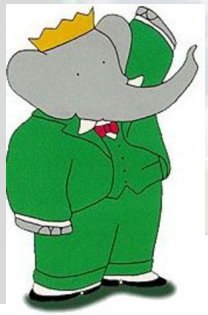
Polarization Measurements

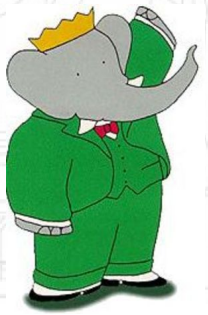
$B^0 \to a_1(1260)^+ a_1(1260)^-$ NEW!

$B \to b_1\rho,\ b_1K^*(892)$ NEW!

$B \to \omega K^*,\ \omega f_0\ ,\ \omega\rho^0$

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





"Polarization Puzzle"

Considerable attention on charmless B decays into final states containing two spin-1 mesons

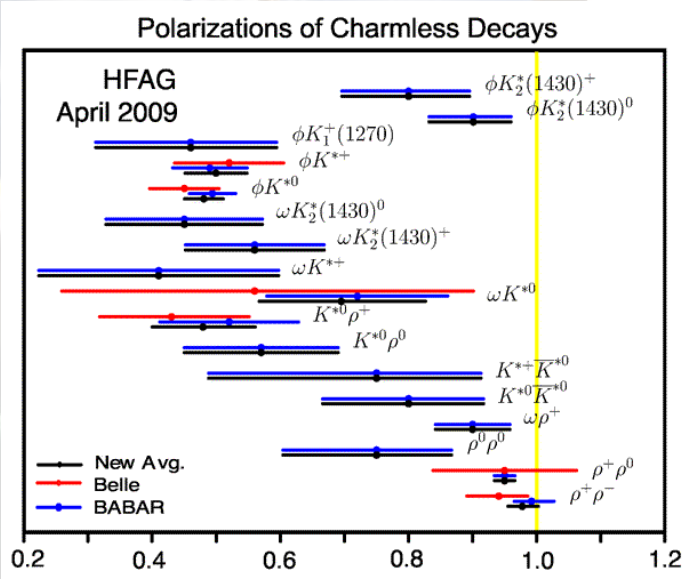
B → VV, VA, AA

THEORETICAL INTEREST

EXPERIMENTAL RESULTS

- *Naïve Helicity Arguments* $f_L \approx 1$

  *For both **tree** and **penguin** decays*



- $B \to \rho\rho$ *respect the pattern*
- *Large polarization for other decays* ($K^{*0}K^{*0}$, $\omega\rho^+$, ρK^{*+})
- *Some penguin dominated decays show different behavior*

$f_L \approx 0.5$ for φK^* and ρK^*

New modes to investigate to shed light on the problem…

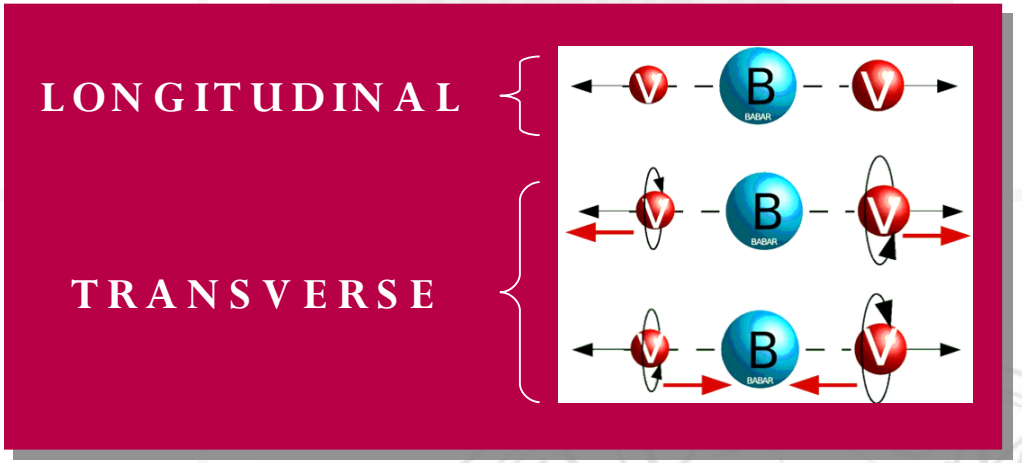
f_L & Helicity Amplitudes

How to extract Longitudinal Polarization? → ***Introduce angular information***

- Decay: 0 → 1 1 *(Spin-0 → Spin-1 Spin-1)*

It can be described in terms of 3 different Helicity Amplitudes } (A_{-1}, A_1, A_0) *Helicity Amplitudes*

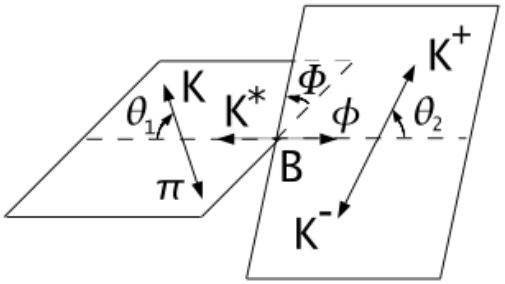
- Limited number of signal events to perform a complete angular analysis
- Decay amplitude can be expressed in terms of a single non-trivial parameter f_L



Integration on ϕ, the angle between the two planes of decaying particles

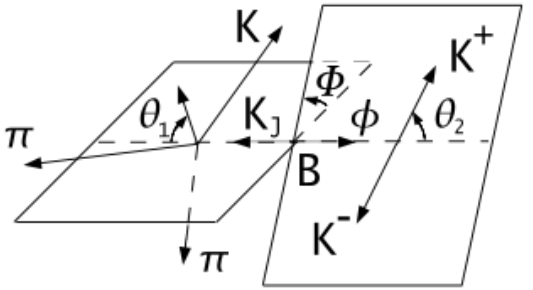
J^p of particles → different angular distributions

2-Body Decays



angle between **daughter flight direction** and flight direction of mother in its cms

3-Body Decays



angle between **normal to decay plane** and flight direction of mother in its cms

Analysis Technique: ML fits

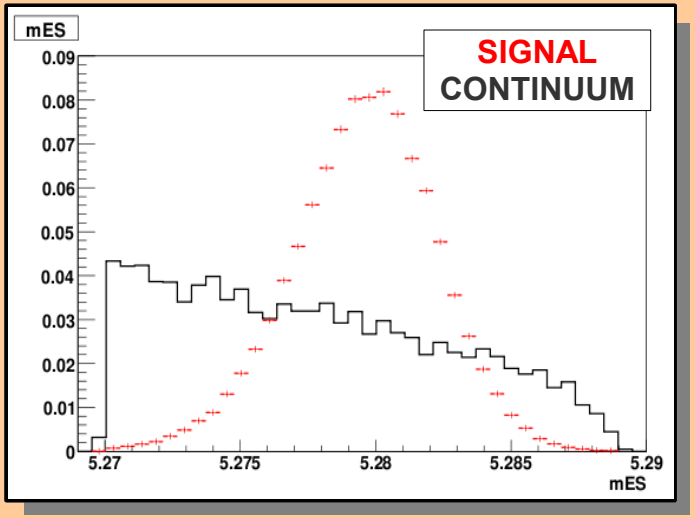
$$m_{ES} = \sqrt{\frac{1}{4}s - p_B^2}$$

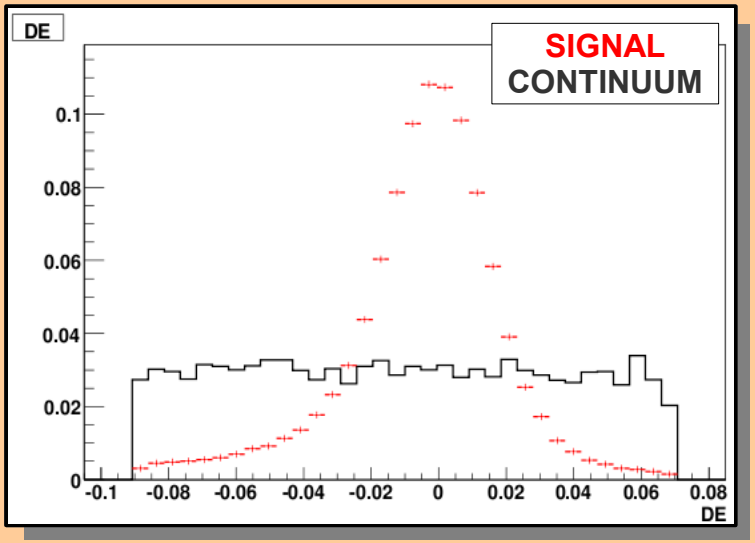
energy substituted mass of the B meson.

$$\Delta E = E_B - \frac{1}{2}\sqrt{s}$$

Difference between B measured E and half of the CMS energy

HIGH DISCRIMINATING POWER



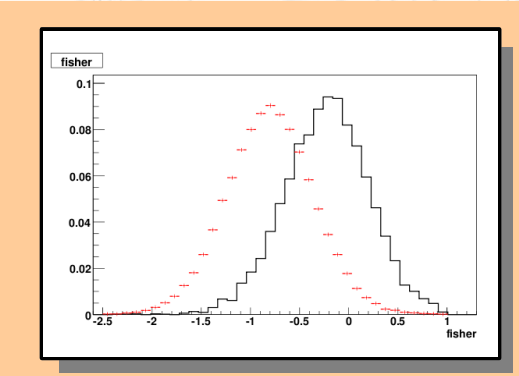


Event shape variables → combined into FISHER DISCRIM / NEURAL NETWORK

qq events: ***Jet-like***

BB events: ***Spherical***

INVARIANT MASSES of particles, angular info ...



Maximum Likelihood fits

NEW ! $B^0 \to a_1(1260)^+ a_1(1260)^-$ arXiv:0907.1776 **Sub. PRL**

Previous experimental info: **BF Upper Limit 2.8 x 10^{-3} (90% CL) by CLEO (1989)**

BF & f_L Theoretical expectations

QCD factorization framework

Branching Ratios and Polarization in B → VV, VA, AA Decays H. Y. Cheng and K. C. Yang
PRD **78**, 094001 (2008)

$$BF = 37.4^{+16.1+9.7}_{-13.7-1.4} \times 10^{-6}$$
$$f_{LN} = 0.64^{+0.07}_{-0.17}$$

Naive Factorization + improved form factors

Nonleptonic two-body B-decays including axial-vector mesons in the final state G. Calderon, J.H. Munoz and C.E.Vera
Phys. Rev. D76, 094019 (2007)

$$BF = 6.4 \times 10^{-6}$$

First Observation of this mode
B → AA decay

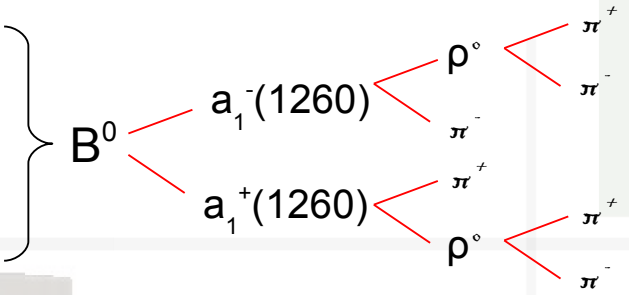
NEW !

$B^0 \to a_1(1260)^+ a_1(1260)^-$ arXiv:0907.1776

Sub. PRL

B^0 meson reconstructed in final state $a_1(1260)^+ a_1(1260)^-$

- $B^0 \to a_1(1260)^+ a_1(1260)^-$
- $a_1(1260)^\pm \to \rho^0(770)\,\pi^\pm$
- $\rho^0(770) \to \pi^+\pi^-$



$a_1 \to 3\pi$

We do not separate the dominant ***P-wave $(\pi\pi)_\rho$*** *from suppressed* ***S-wave $(\pi\pi)_\sigma$***

Included in systematic uncertainties

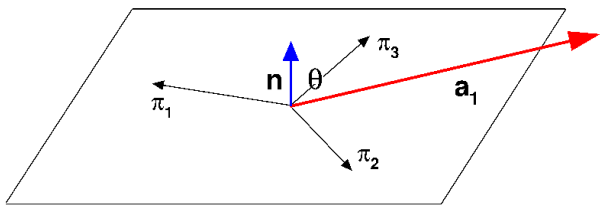
Specific component for non resonant background

Angular information included in ML fit to extract polarization:

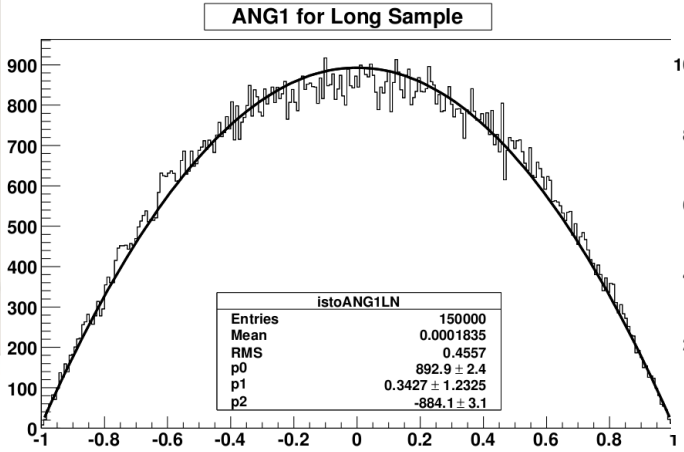
Helicity formalism

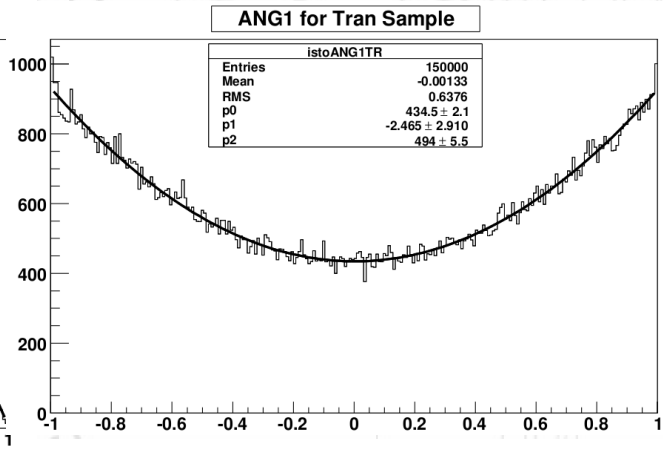
(after Integration on Φ)

$$\frac{d\sigma}{d\cos\theta} \propto f_{LN}(1-\cos^2\theta) + (1-f_{LN})\frac{1}{2}(1+\cos^2\theta) \qquad f_{LN} = \frac{|A_0|^2}{\sum_{i=-1}^{1}|A_i|^2}$$



cosine of the angle between normal to decay plane and a1 flight direction in a1 rest frame frame





NEW !

$B^0 \to a_1(1260)^+ a_1(1260)^-$ arXiv:0907.1776

Sub. PRL

Results

(465 ± 5 M $B\bar{B}$ pairs)

Signal yield	545 ± 118
Signal yield bias	$+14$
f_L bias	-0.06
ϵ_L (%)	9.0
ϵ_T (%)	10.0
S (σ)	5.0
$\mathcal{B}$ ($\times 10^{-6}$)	$11.8 \pm 2.6 \pm 1.6$
f_L	$0.31 \pm 0.22 \pm 0.10$

Observation with a significance of 5σ

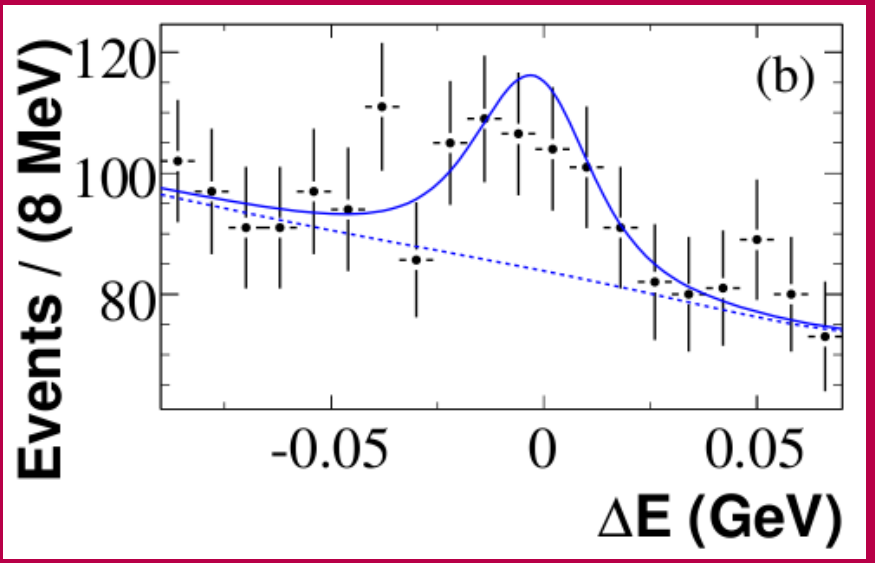
Assuming:

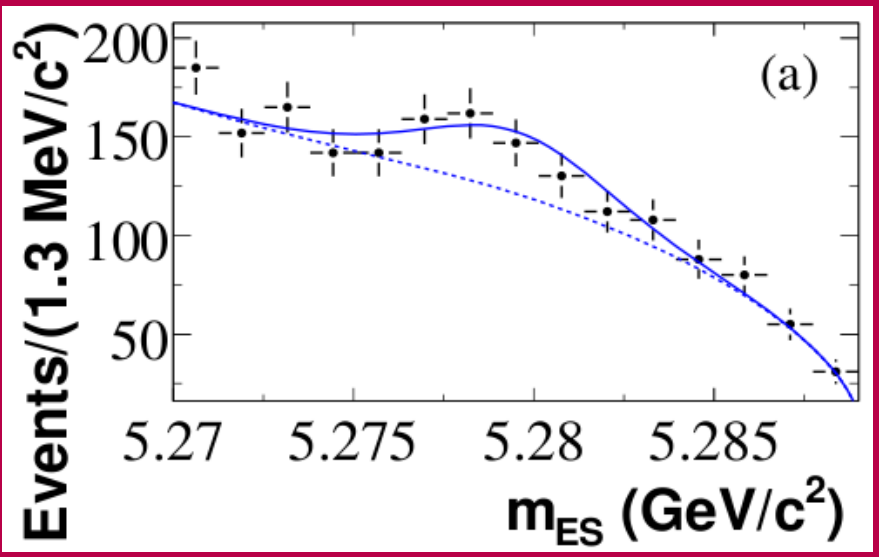
$$BF(a_1^+ \to \pi^+\pi^-\pi^+) = BF(a_1^+ \to \pi^0\pi^0\pi^+)$$
$$BF(a_1^\pm \to (3\pi)^\pm) = 100\%$$

$BF(10^{-6}) = 47.3 \pm 10.5 \pm 6.3$

General agreement with QCD factorization

Projections





NEW !

$B \to b_1\rho,\ b_1K^*(892)$ arXiv:0907.3485

Sub. PRD-RC

Predicted high BF for these modes in QCD factorization (up to 33 x 10^{-6})

Both neutral and charged B decays considered

No previous searches reported

$b_1 \to \omega\pi$

Angular distribution:

LN $$f_L \left[\cos^2\theta_A + \left|\frac{C_1}{C_0}\right|^2 \sin^2\theta_A\right] \cos^2\theta_V +$$

TR $$(1-f_L)\frac{1}{4}\left[\sin^2\theta_A + \left|\frac{C_1}{C_0}\right|^2 (1+\cos^2\theta_A)\right] \sin^2\theta_V$$

with:

$$\frac{C_1}{C_0} = \frac{1+(D/S)/\sqrt{2}}{1-\sqrt{2}(D/S)}$$

$$D/S = 0.277 \pm 0.027$$

from PDG

Welcome to BABAR

Results

(465 ± 5 M $B\bar{B}$ pairs)

Mode	Y (evts)	Y_0 (evts)	ε (%)	S (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ U.L. (10^{-6})
$b_1^-\rho^+$	-33 ± 10	4 ± 2	3.0	–	$-1.8 \pm 0.5 \pm 1.0$	1.4
$b_1^0\rho^+$	-18 ± 5	-4 ± 2	1.1	–	$-3.0 \pm 0.9 \pm 1.8$	3.3
$b_1^+\rho^0$	37 ± 25	8 ± 4	3.6	0.4	$1.5 \pm 1.5 \pm 2.2$	5.2
$b_1^0\rho^0$	-8 ± 19	5 ± 3	2.4	–	$-1.1 \pm 1.7^{+1.4}_{-0.9}$	3.4
$b_1^-K^{*+}$				1.7	$2.4^{+1.5}_{-1.3} \pm 1.0$	5.0
$b_1^-K^{*+}_{K^+\pi^0}$	3 ± 8	-5 ± 3	0.8	0.9	$1.8 \pm 1.9 \pm 1.4$	
$b_1^-K^{*+}_{K^0_S\pi^+}$	17 ± 9	4 ± 2	0.9	1.5	$3.2 \pm 2.1^{+1.0}_{-1.5}$	
$b_1^0K^{*+}$				0.1	$0.4^{+2.0+3.0}_{-1.5-2.6}$	6.7
$b_1^0K^{*+}_{K^+\pi^0}$	-8 ± 7	-3 ± 2	0.5	–	$-2.2 \pm 3.0^{+5.0}_{-2.3}$	
$b_1^0K^{*+}_{K^0_S\pi^+}$	3 ± 4	0 ± 0	0.4	0.4	$1.6 \pm 2.5 \pm 3.3$	
$b_1^+K^{*0}$	55 ± 21	15 ± 8	2.8	1.5	$2.9 \pm 1.5 \pm 1.5$	5.9
$b_1^0K^{*0}$	30 ± 15	-6 ± 3	1.7	2.0	$4.8 \pm 1.9^{+1.5}_{-2.2}$	8.0

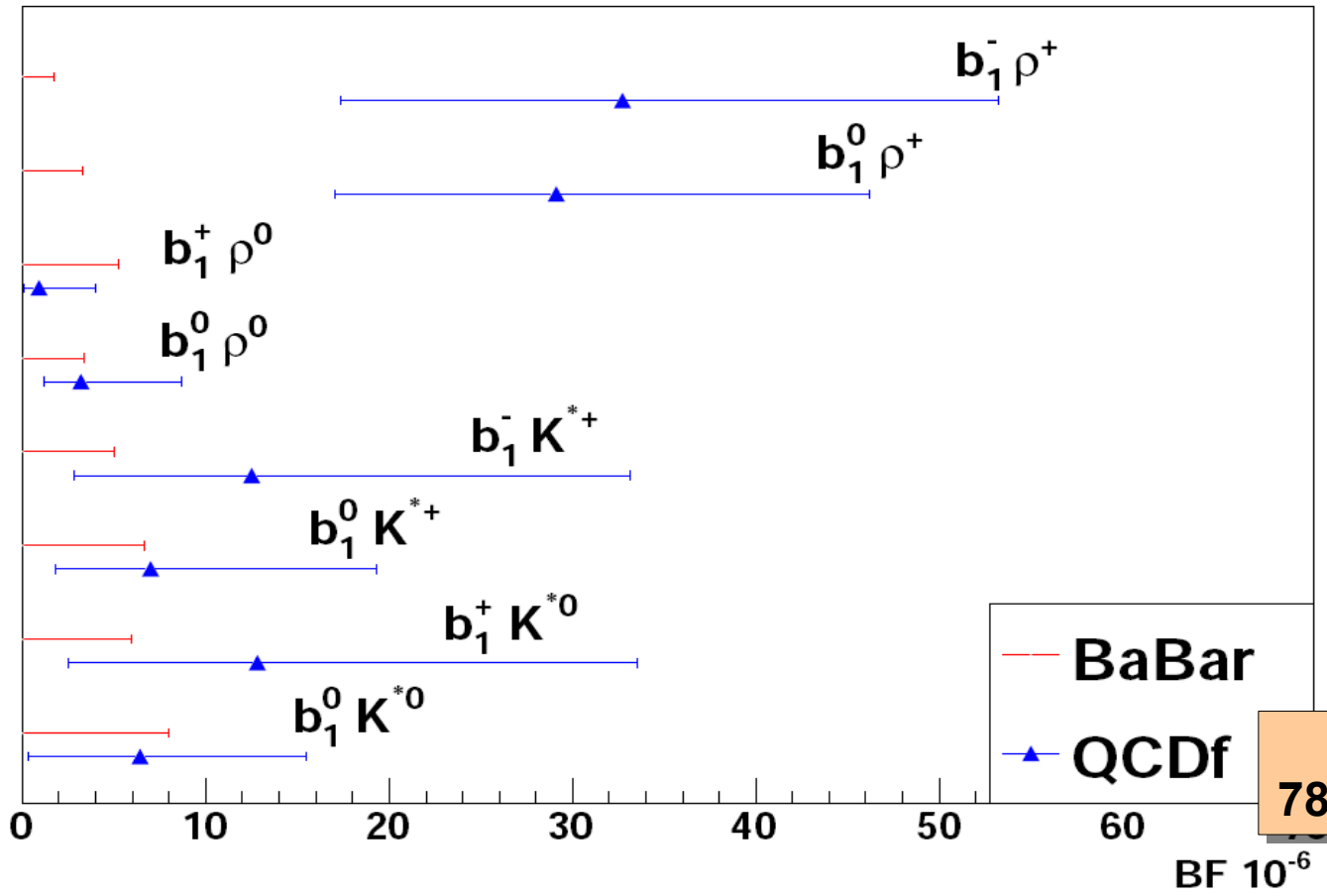
We don't observe any statistically significant signal

NEW !

$B \to b_1\rho,\ b_1K^*(892)$ arXiv:0907.3485

Sub. PRD-RC

- **BF($B \to b_1 P$)** with P=K,π in *good agreement with QCDF*
- **BF($B \to b_1 V$)** *< than related* b_1P modes



PRD **78**, 094001 (2008)

$B \to \omega K^*, \omega f_0, \omega \rho^0$ PRD 79, 052005 (2009)

Several modes investigated
$B \to$ VS, VV, VA
9 measurements!

- Tree dominated — **VV:** $B \to \omega\rho$
- Tree/penguin — **VV:** $B \to \omega K^*$
- $B \to \omega(\pi K)$ — **VT:** K^*_2
- $B \to \omega(\pi\pi)$ — **VS:** f_0

Polarization is extracted for all the VV and VT modes
but $\omega K^{*+}(K^{*+} \to K^0_S \pi^+)$ and $\omega\rho^0$ (signal yield is too small)

Different K sub-decays combined together*

Results (465 ± 5 M $B\bar{B}$ pairs)

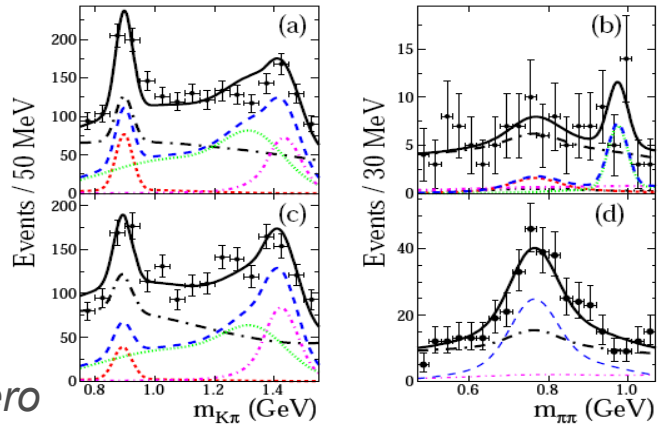
Mode	Y (events)	Y_0 (events)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	$\mathcal{S}$ (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ U.L. (10^{-6})	$\mathcal{A}_{ch}$
ωK^{*0}	101 ± 25	8 ± 4	15.2	59.5	4.1	$2.2 \pm 0.6 \pm 0.2$	–	$0.45 \pm 0.25 \pm 0.02$
ωK^{*+}					2.5	$2.4 \pm 1.0 \pm 0.2$	7.4	$0.29 \pm 0.35 \pm 0.02$
$\omega K^{*+}_{K^+\pi^0}$	72 ± 24	3 ± 2	10.4	29.7	3.7	4.8 ± 1.7		0.22 ± 0.33
$\omega K^{*+}_{K^0_S\pi^+}$	8 ± 16	0 ± 1	13.6	20.6	0.5	0.6 ± 1.2		–
$\omega(K\pi)^{*0}_0$	540 ± 47	49 ± 25	9.7	59.5	9.8	$18.4 \pm 1.8 \pm 1.7$	–	$-0.07 \pm 0.09 \pm 0.02$
$\omega(K\pi)^{*+}_0$					9.2	$27.5 \pm 3.0 \pm 2.6$	–	$-0.10 \pm 0.09 \pm 0.02$
$\omega(K^+\pi^0)^{*+}_0$	191 ± 36	18 ± 9	6.4	29.7	5.9	19.6 ± 4.1		-0.38 ± 0.19
$\omega(K^0_S\pi^+)^{*+}_0$	357 ± 39	34 ± 17	9.1	20.6	0.6	37.1 ± 4.5		-0.01 ± 0.10
$\omega K^*_2(1430)^0$	185 ± 32	19 ± 10	11.9	29.7	5.0	$10.1 \pm 2.0 \pm 1.1$	–	$-0.37 \pm 0.17 \pm 0.02$
$\omega K^*_2(1430)^+$					6.1	$21.5 \pm 3.6 \pm 2.4$	–	$0.14 \pm 0.15 \pm 0.02$
$\omega K^*_2(1430)^+_{K^+\pi^0}$	182 ± 30	6 ± 3	8.2	14.9	7.2	31.0 ± 5.2		0.17 ± 0.16
$\omega K^*_2(1430)^+_{K^0_S\pi^+}$	64 ± 25	10 ± 5	10.1	10.3	2.4	11.2 ± 4.9		-0.04 ± 0.35
$\omega\rho^0$	30^{+21}_{-18}	-3 ± 2	9.5	89.2	1.9	$0.8 \pm 0.5 \pm 0.2$	1.6	—
ωf_0	37^{+14}_{-12}	1 ± 1	14.4	59.5	4.5	$1.0 \pm 0.3 \pm 0.1$	1.5	—
$\omega\rho^+$	411 ± 43	27 ± 14	5.8	89.2	9.8	$15.9 \pm 1.6 \pm 1.4$	—	$-0.20 \pm 0.09 \pm 0.02$

Consistent with Zero

5 observations
4 First Observations
2 evidences

General Agreement for BF with theoretical prediction
(SV an ST estimates are uncertain)

Invariant Masses



$B \to \omega K^*, \omega f_0, \omega \rho^0$ PRD 79, 052005 (2009)

Several modes investigated
$B \to$ VS, VV, VA

- Tree dominated — **VV:** $B \to \omega\rho$
- Tree/penguin — **VV:** $B \to \omega K^*$
- $B \to \omega(\pi K)$ — **VT:** K^*_2
- $B \to \omega(\pi\pi)$ — **VS:** f_0

Polarization is extracted for all the VV and VT modes
but $\omega K^{*+}(K^{*+} \to K^0_S \pi^+)$ and $\omega\rho^0$ (signal yield is too small)

Different K sub-decays combined together*

Results (465 ± 5 M $B\bar{B}$ pairs)

Mode	Y (events)	Y_0 (events)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ U.L. (10^{-6})	f_L
ωK^{*0}	101 ± 25	8 ± 4	15.2	59.5	4.1	$2.2 \pm 0.6 \pm 0.2$	–	$0.72 \pm 0.14 \pm 0.02$
ωK^{*+}					2.5	$2.4 \pm 1.0 \pm 0.2$	7.4	$0.41 \pm 0.18 \pm 0.05$
$\omega K^{*+}_{K^+\pi^0}$	72 ± 24	3 ± 2	10.4	29.7	3.7	4.8 ± 1.7		0.37 ± 0.18
$\omega K^{*+}_{K^0_S\pi^+}$	8 ± 16	0 ± 1	13.6	20.6	0.5	0.6 ± 1.2		0.5 fixed
$\omega(K\pi)^{*0}_0$	540 ± 47	49 ± 25	9.7	59.5	9.8	$18.4 \pm 1.8 \pm 1.7$	–	–
$\omega(K\pi)^{*+}_0$					9.2	$27.5 \pm 3.0 \pm 2.6$	–	–
$\omega(K^+\pi^0)^{*+}_0$	191 ± 36	18 ± 9	6.4	29.7	5.9	19.6 ± 4.1		–
$\omega(K^0_S\pi^+)^{*+}_0$	357 ± 39	34 ± 17	9.1	20.6	10.6	37.1 ± 4.5		–
$\omega K^*_2(1430)^0$	185 ± 32	19 ± 10	11.9	29.7	5.0	$10.1 \pm 2.0 \pm 1.1$	–	$0.45 \pm 0.12 \pm 0.02$
$\omega K^*_2(1430)^+$					6.1	$21.5 \pm 3.6 \pm 2.4$	–	$0.56 \pm 0.10 \pm 0.04$
$\omega K^*_2(1430)^+_{K^+\pi^0}$	182 ± 30	6 ± 3	8.2	14.9	7.2	31.0 ± 5.2		0.52 ± 0.10
$\omega K^*_2(1430)^+_{K^0_S\pi^+}$	64 ± 25	10 ± 5	10.1	10.3	2.4	11.2 ± 4.9		0.76 ± 0.26
$\omega\rho^0$	30^{+21}_{-18}	-3 ± 2	9.5	89.2	1.9	$0.8 \pm 0.5 \pm 0.2$	1.6	0.8 fixed
ωf_0	37^{+14}_{-12}	1 ± 1	14.4	59.5	4.5	$1.0 \pm 0.3 \pm 0.1$	1.5	—
$\omega\rho^+$	411 ± 43	27 ± 14	5.8	89.2	9.8	$15.9 \pm 1.6 \pm 1.4$	—	$0.90 \pm 0.05 \pm 0.03$

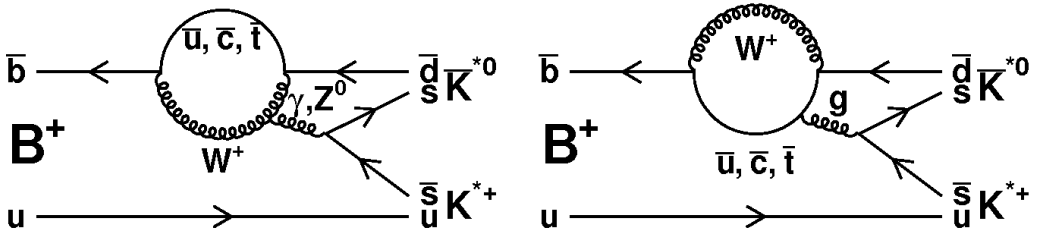
→ **Penguin dominated** (expected f_L~0.5)
High Uncertainty

→ **Penguin dominated** $f_L(\Phi K^*_2(1430)) \sim 1$

→ **Tree dominated** (expected f_L~1.0)
OK with previsions

$B^+ \to \overline{K}^{*0} K^{*+}$ PRD-RC 79, 051102 (2009)

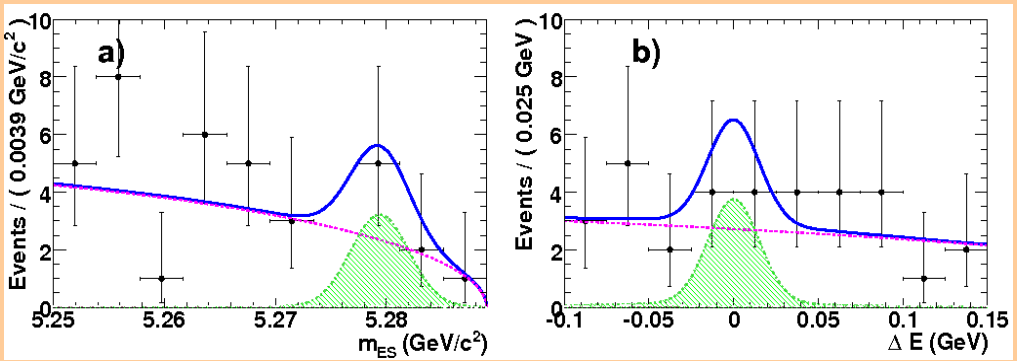
Decay through EW and GLUONIC b → d penguin



- *Related decays seen:*

$$B^0 \to K^{*0}\overline{K}^{*0}\ (1.28^{+0.35}_{-0.30} \pm 0.11) \times 10^{-6}$$
$$B^0 \to K^{*-}K^{*+}\ < 2.0 \times 10^{-6}\ @\ 90\%\ \mathrm{CL}$$

- *Analysis is performed with* $K^{*+} \to K^+\pi^0$ *and* $K^{*+} \to K_s\pi^+$
- *Non resonant background considered*



Predicted BF (QCD Factorization)

$(0.5^{+0.2+0.4}_{-0.1-0.3}) \times 10^{-6}$ Nucl. Phys. B 744, 64 (2007)

$(0.6 \pm 0.1 \pm 0.3) \times 10^{-6}$ PRD **78**, 094001 (2008)

(467 ± 5 M $B\overline{B}$ pairs)

Final State	$K^-\pi^+ K^0_S \pi^+$	$K^-\pi^+ K^+ \pi^0$
Yields (events):		
Total	1381	3201
Signal	$6.9^{+4.5}_{-3.5}$	$13.9^{+7.6}_{-6.4}$
$q\bar{q}$ bkg.	1365 ± 37	3169 ± 57
$B\overline{B}$ bkg. (fixed)	10	19
ML Fit Biases	-0.12	0.08
Efficiencies and $\mathcal{B}$:		
$\epsilon(\%)$	11.44 ± 0.08	7.40 ± 0.08
$\prod \mathcal{B}_i(\%)$	15.37	22.22
f_L	$0.72^{+0.23}_{-0.36} \pm 0.03$	$0.79^{+0.22}_{-0.36} \pm 0.03$
$\mathcal{B}$ $(\times 10^{-6})$	$0.85^{+0.61}_{-0.44} \pm 0.11$	$1.80^{+1.01}_{-0.85} \pm 0.16$
$\mathcal{B}$ Significance S (σ)	2.28	2.18
Combined Results:		
f_L	$0.75^{+0.16}_{-0.26} \pm 0.03$	
$\mathcal{B}$ $(\times 10^{-6})$	$1.2 \pm 0.5 \pm 0.1$	
$\mathcal{B}$ Significance S (σ)	3.7	
$\mathcal{B}_{\mathrm{UL}}$ $(\times 10^{-6})$	2.0	

Conclusions

Charmless hadronic B decays:
good place to check SM & look for NP

"Polarization Puzzle"

Tree-dominated decays seems to obey $f_L \approx 1$
Some Penguin-dominated VV modes have $f_L \approx 0.5$ (ΦK^*, ρK^*, ωK^*)
VT modes: $f_L(\Phi K^*_2(1430)) \approx 1$, but $f_L(\omega K^*_2(1430)) \approx 0.5$

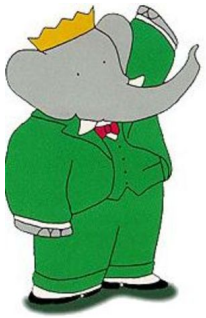
$B^0 \to a_1(1260)^+ a_1(1260)^-$

First observation of a B → AA mode
Big uncertainty on polarization fraction

$B \to b_1\rho,\ b_1K^*(892)$

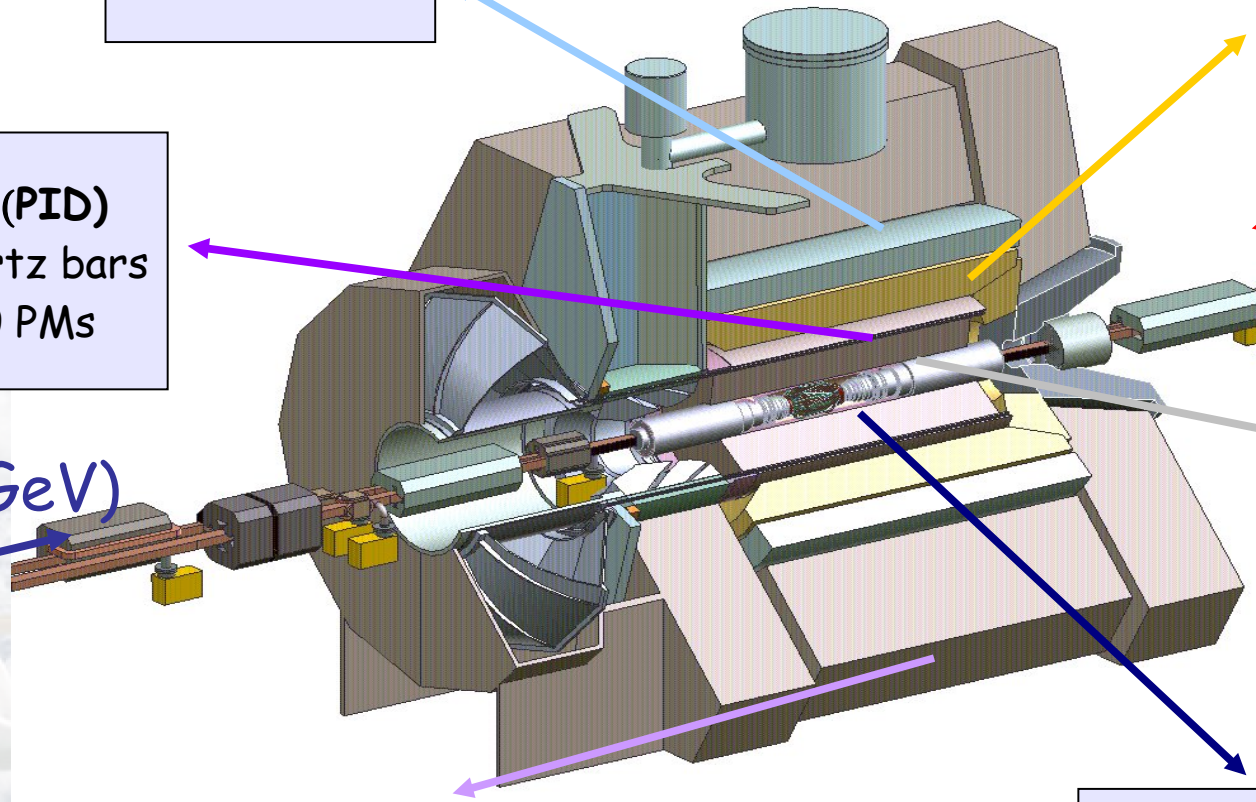
No significant signal found
BF(AV) modes < BF(AP) modes (AP well explained!)

Thank you for your attention !



Backup Slides

BaBar Detector



1.5T solenoid

EMC
6580 CsI(Tl) crystals

DIRC (PID)
144 quartz bars
11000 PMs

e^+ (3.1GeV)

e^- (9GeV)

Drift Chamber
40 layers

Instrumented Flux Return
Iron / Resistive Plate Chambers or
Limited Streamer Tubes
(muon / neutral hadrons)

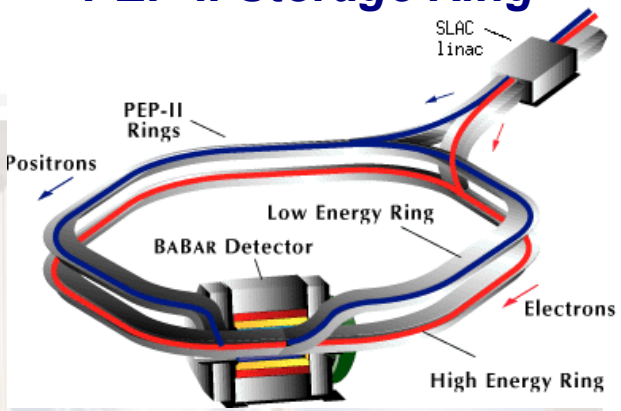
Silicon Vertex Tracker
5 layers, double sided strips

BaBar Collaboration 11 Country 80 Institutions

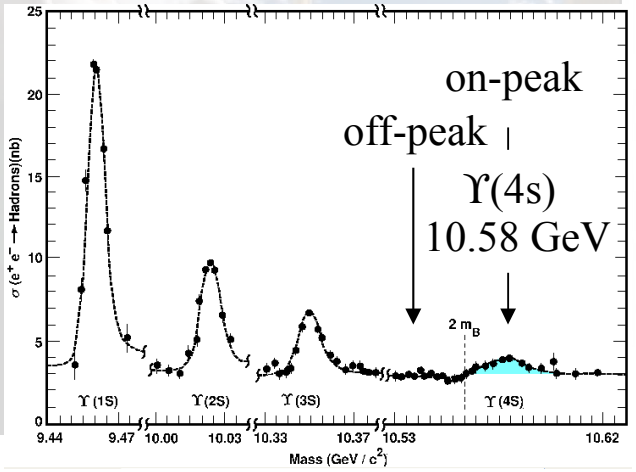
Datasets

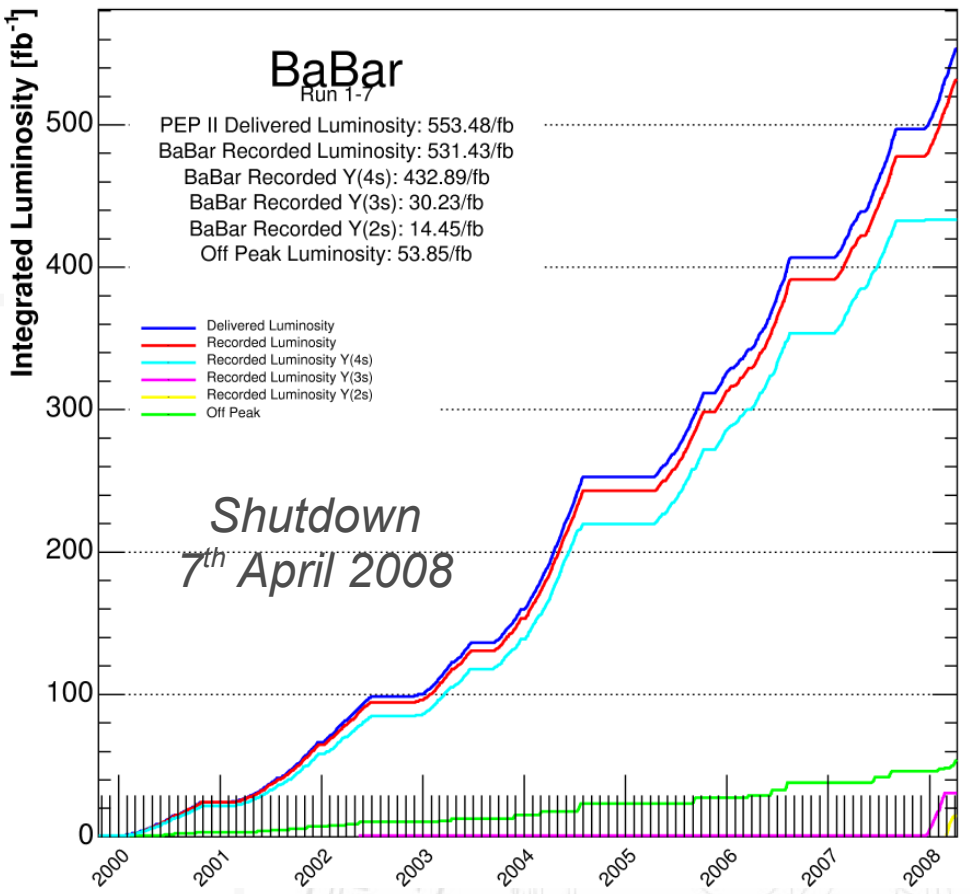
SLAC
NATIONAL ACCELERATOR LABORATORY

PEP-II Storage Ring



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





From December 2007

120 M Υ(3S) [11x Belle]
100 M Υ(2S) [12x Cleo]
+ *Scan above Υ(4S)*