SLAC–PUB–10671
August 2004

# BaBar Status and Future Plans*

Marcello A. Giorgi
INFN & Università di Pisa (Italy)
Via Buonarroti, 2 I-56127 Pisa, Italy

and

Stanford Linear Accelerator Center
Stanford University
Stanford, CA 94309 USA

On behalf of BaBar Collaboration

Submitted to the 2nd International Conference on Flavor Physics
and CP Violation (FPCP 2003),
3 June 2003 - 6 June 2003, Paris, France

*Work supported by Department of Energy contract DE-AC02-76SF00515.

# *BABAR* status and future plans

*Marcello A. Giorgi*
INFN& Università di Pisa (Italy)
Via Buonarroti, 2 I-56127 Pisa, Italy
and SLAC
P.O. Box 20450 Stanford, CA 94309
On behalf of BaBar Collaboration

The status of BaBar experiment is described after 4 years of run together with some of its physics achievements, future plans, possible physics goals toward the end of the present decade and upgrades to the detector are discussed.

## 1 Introduction

The *BABAR* experiment is a true international enterprise. Its members are 579 physicists from 75 institutions of 10 countries, nearly half of the collaboration is from USA and half from outside countries, mainly from Europe. The *BABAR* detector in Interaction Region 2 of PEPII has been in full operation since November 1999, after receiving its first beam in May 1999. The goals of the experiment are to perform a comprehensive study of CP violation in the $B_d$ meson system, to carry out high-sensitivity searches for and measurements of rare B decays, and to make precision measurements in the charm and $\tau$ sectors. After the discovery in 1964 of the CP violation in the famous K meson Brookhaven experiment [1] the mission of *BABAR* was originally focused on establishing CP violation in the b flavor sector. This goal was achieved in 2001 when *BABAR* [3] has firstly observed CP violation in $B_d$ decay, soon after confirmed by Belle [4].

PEPII machine was performing particularly well in Run I, II and III delivering to *BABAR* before June 10, 2003 about $133fb^{-1}$ of integrated luminosity. *BABAR* has shown a very high efficiency (97%) and has collected nearly 123 million B meson pairs at the Y(4S) resonance and an additional 12 $fb^{-1}$ taken 40 MeV below the resonance (figure 1). The *BABAR* physics program is now focused on three main targets:

- perform a comprehensive set of CP-violating asymmetries in B meson decays;
- study of rare decay processes;
- perform detailed studies as contribution to the understanding of the dynamics of processes involving heavy quarks.

The first two goals focus on testing the Standard Model, measuring its parameters, and searching for the effects of new physics, while the third goal is designed to build a solid foundation by elucidating the interplay between electroweak and strong interactions in heavy quark processes.

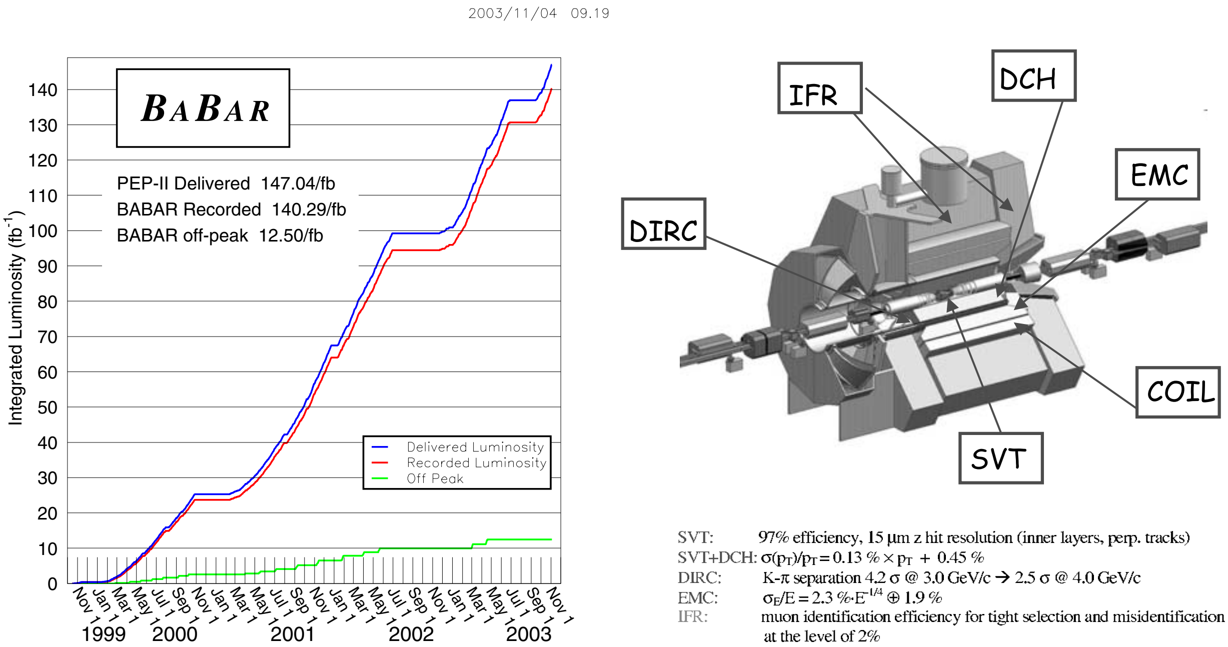


Figure 1: *BABAR* integrated luminosity since May 1999(left), the *BABAR* detector(right)

## 2 *BABAR* Detector

The $4\pi$ detector (figure 1), with excellent vertex detection and particle identification, and the asymmetric energies of the PEP II beams, were specifically designed for precise measurements of CP-violating time-dependent asymmetries expected in the B system, however it is an excellent environment for a more general study of flavor physics and rare $\tau$ channels.

The apparatus was optimized for the measurement of time independent asymmetries in the decay of $B$ and $\overline{B}$ mesons. The principle of the measurement is shown in the following fig 2. The figure illustrates the decay of one $B$ semileptonic (with $\mu^-$) and the other $B$ meson into a CP eigen-state ($J/\psi\ K^0_S$).

The time dependent rate can be expressed in the following formula

$$dN \propto e^{-\frac{|\Delta t|}{\tau_B}} (1 \pm D(S \sin(\Delta m \Delta t) - C \cos(\Delta m \Delta t))) \otimes R \qquad (1)$$

the coefficients S and C are defined as $S = \frac{2\mathrm{Im}\lambda}{1+|\lambda|^2}$ $C = \frac{1-|\lambda|^2}{1+|\lambda|^2}$ and $\lambda$ is defined as $\lambda = \eta_{CP} \frac{q}{p} \frac{\overline{A}_{CP}}{A_{CP}}$ and $\eta_{CP}$ is the eigenvalue of CP eigenstate q/p is related to the $B^0$ $\overline{B}^0$ mixing and the Standard model predicts its value very close to unity

$$\left|\frac{q}{p}\right| - 1 \approx 4\pi \frac{m_c^2}{m_t^2} \sin\beta \approx 5 \times 10^{-4} \qquad (2)$$

therefore $\left|\frac{q}{p}\right| \neq 1$ implies both CP and T violation in mixing. $S \neq 0$ implies the CP violation in the interference between mixing and decay, $C \neq 0$ implies direct CP violation in decay and defining z as

$$z = 2\frac{\delta M - (i/2)\delta\Gamma}{\Delta m - (i/2)\Delta\Gamma} \tag{3}$$

$\neq 0$ implies CP and CPT violation. In the usual analysis for channels with charmonium $S = \sin 2\beta$ and it is assumed z =0, $\left|\frac{q}{p}\right| = 1$.

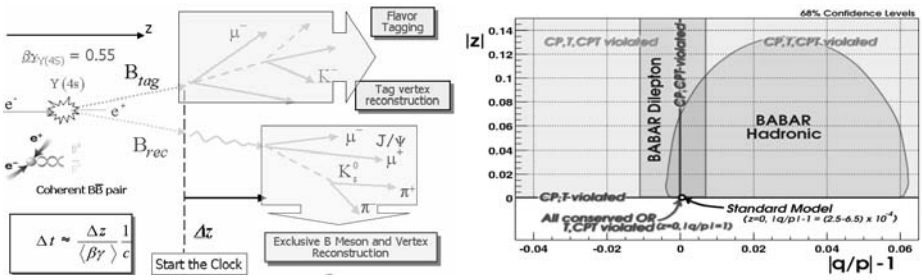


Figure 2: Schematic representation of the CP violation measurement in the $J/\psi\ K^0_S$ decay mode (left), Result from the unbiased analysis in the $|z|$, $|q/p| - 1$ plane(right)

In an unbiased analysis the parameters z,$\lambda$, q/p, $\Delta\Gamma/\Gamma$ are left free in the fit to $B^0 \rightarrow$flavor and $B \rightarrow CP$ eigenstates

$$\begin{aligned}
\mathrm{sgn}(\mathrm{Re}\lambda_{CP})\tfrac{\Delta\Gamma}{\Gamma} &= -0.008 \pm 0.037\ (\mathrm{stat.})\ \pm 0.018\ (\mathrm{syst.})\ [-0.084, 0.068],\\
|q/p| &= 1.029 \pm 0.013\ (\mathrm{stat.})\ \pm 0.011\ (\mathrm{syst.})\ [1.001, 1.057],\\
(\mathrm{Re}\lambda_{CP}/|\lambda_{CP}|)\,\mathrm{Re}z &= 0.014 \pm 0.035\ (\mathrm{stat.})\ \pm 0.034\ (\mathrm{syst.})\ [-0.072, 0.101],\\
\mathrm{Im}z &= 0.038 \pm 0.029\ (\mathrm{stat.})\ \pm 0.025\ (\mathrm{syst.})\ [-0.028, 0.104].
\end{aligned}$$

The above intervals are statistically referred to 90%C.L. The results are presented in the following fig. 2. With present statistics the result is compatible with the usual analysis and $\sin(2\beta) = 0.741 \pm 0.067_{\mathrm{stat}} \pm 0.033_{\mathrm{syst}}$.

The $\sin 2\beta$ measurement of *BABAR* is reported in the left hand side of figure 3 inside a more general CKM fit. Results are CKM compatible. The $\sin 2\beta$ situation can be summarized in the right hand side of figure 3 where possible discrepancies (indication of new physics) can come from channels as $B_d \rightarrow \Phi K_S$ whose amplitude is a pure penguin $b \rightarrow s\bar{s}s$ ,where the loop can be sensitive to contributions from new heavy quanta.

To complete the present short summary on CP achievements, preliminary results on $\pi\pi$ [5] are reported. From time dependent analysis $S_{\pi\pi}$(the coefficient of $\sin(\Delta m\Delta t)$) and $C_{\pi\pi}$( the coefficient of $\cos(\Delta m\Delta t)$) are measured. $S_{\pi\pi}$ in absence of penguin pollution is proportional to the $\sin 2\alpha$, since there is penguin pollution instead of $\alpha$ it contains $\alpha_{eff} = \alpha + \delta$ where $\delta$ is a strong phase, $C_{\pi\pi}$ is the term related to direct CP violation in the decay.

Based on equal statistics of 80 $fb^{-1}$ the central values of BaBar and Belle[6] appear quite different (tab. 1), they are however not statistically inconsistent.

In addition to the tremendous amount of $B\overline{B}$ *BABAR* has also recorded an equivalent sample of charm and $\tau$ pairs. It allows the study of rare decays including channels with lepton flavour violation, or $D^0\overline{D}^0$ mixing. One of the most exciting recent result of BaBar has been

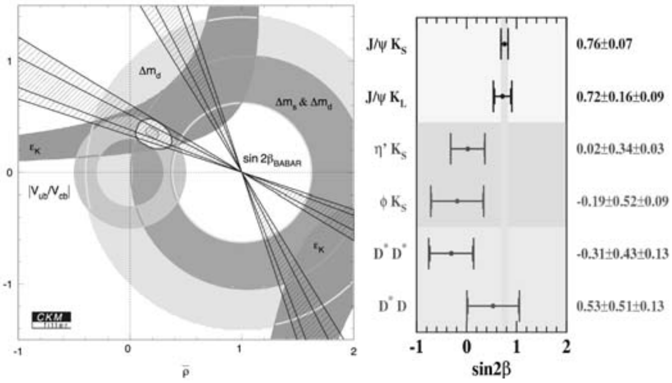


Figure 3: Fit of the CKM matrix (method as in [2]) including the $\sin 2\beta$ measurement from *BABAR* (left), summary of the $\sin 2\beta$ measurements in *BABAR* (center)

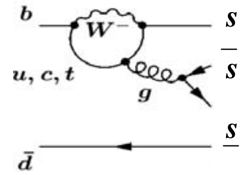


Figure 4: Feynman diagram of the $B^0 \rightarrow \Phi K^0_S$ decay mode

| Param | *BABAR* | Belle |
|---|---|---|
| $S_{\pi\pi}$ | $0.02 \pm 0.34 \pm 0.05$ | $-1.23 \pm 0.41(+0.05 - 0.07)$ |
| $C_{\pi\pi}$ | $-0.30 \pm 0.25 \pm 0.04$ | $-0.77 \pm 0.27 \pm 0.08$ |

Table 1: *BABAR* and Belle CP violation results for the $\pi\pi$ decay mode

the unexpected discovery of a new and intriguing particle with a mass of 2317MeV$/c^2$[7] later confirmed and studied by CLEO [8] and Belle[9][10] . This particle has been discovered in the decay channel $D^+_s\pi^0$. The left fig. 5 shows the signal of the new particle when $D^s_+(1980)$ is reconstructed in the channel $D^+_s \rightarrow K^+K^-\pi+$ ,where instead the plot on the right is obtained combining $\pi^0$ with $D^+_s(1980)$ coming from the decay into $K^+K^-\pi^+\pi^0$.

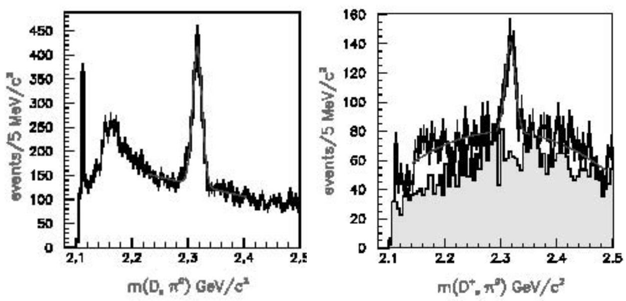


Figure 5: $D^+_s\pi^0$ invariant mass ditribution

If the state is identified as a $c\overline{s}$ meson and the $D^+_s\gamma$ , $D^+_s\pi\pi$ decay modes are absent then spin and parity are consistent with $0^+$, in addition the isospin violation in the observed decay mode is consistent with the measured small width of $8.6 + \pm 0.4$MeV$/c^2$.

# 3 Future Plans

The PEPII team has plans for upgrading the luminosity of the machine in this decade from the present peak value of about $5 \times 10^{33} cm^{-2} s^{-1}$ to some units in $10^{34}$ .

A new interaction region with a small crossing angle of the beams is also planned for 2005. It would allow a gain in the machine performance.

The machine upgrade plan has some very ambitious goals: integrate a luminosity of 0.5 $ab^{-1}$ by the end of 2006 and between 1 and 2 $ab^{-1}$ by the end of the decade. These increased luminosity allows some easy projections on the Physics achievements, some simple extrapolation on the precision measurement of $\sin 2\beta$ in golden modes with charmonium. After 2006 the statistic error becomes comparable to the systematic, that will become hard to reduce below 0.018.

Of course there are some decay channel as $b \to s\bar{s}s$ , where , within the Standard Model CKM, a time dependent asymmetry gives $\sin 2\beta$ as the charmonium channels (for example $B \to \Psi K^0_s$) . However penguin diagrams give contribution to decays and the loops in those diagrams are sensitive to the presence of new physics, particularly clean to make comparison with charmonium is the $B \to \Phi K^0_s$ channel that is a very clean pure penguin amplitude. The present BaBar measured value based on an integrated luminosity of 80 $fb^{-1}$ is[11] : $S = \sin 2\beta = -0.19^{+0.52}_{-0.50}(stat.) \pm 0.09(syst.)$.

| CKM parameters | *BABAR* Error(2 $ab^{-1}$) |
|---|---|
| $\sin 2\beta$(charmonium) | 0.015stat/0.018syst |
| $\sin 2\beta$(penguins $b \to s\bar{s}s$) | 0.10 stat |
| $\sin 2\alpha_{eff}(B^0 \to \pi^+\pi^-)$ | 0.06 stat |
| $\alpha_{eff} - \alpha(B^0 \to \pi^0\pi^0)$ | $< 10^o$ |
| $\sin(2\beta - \gamma)(B^0 \to D^*\pi^0\pi^0\ )$ | 0.15 |
| $\gamma\ (B \to DK)$ | $7^o$ |
| $\lvert V_{ub} \rvert$ | 1.4%+ Theor. Err.(now at best 10%) |

Table 2: Projected errors with 2 $ab^{-1}$

But in addition to the precise measurements on the CKM parameters we expect at the end of the decade with a total 2 $ab^{-1}$. The $e^+e^-$ Bfactory is in fact an unique laboratory that allows measurements with a pure B meson beam. Since at the $\Upsilon(4S)$ peak only pure $B\overline{B}$ mesons are produced, once one of the two, let us say B, is completely reconstructed what remains in the event (the recoil part) is a pure $\overline{B}$. This method makes accessible channels with neutrinos otherwise very problematic as in hadron machine experiments. The table 2 contains some possible rare decays accessible with BaBar and the estimate number of events reconstructed assuming a given Branching Fraction and a luminosity of 2 $ab^{-1}$

It is quite evident the complementarity between programs of future experiments exploring B sector at the hadron machines ( That includes for instance precision measurements involving Bs ) and what achievable with a Bfactory at several inverse ab of integrated luminosity.

| Channel | BF | *BABAR* Statistics(2 $ab^{-1}$) |
|---|---|---|
| $b \to s\gamma$ | $3.3 \pm 0.3 \times 10^{-4}$ | 44.0K<br>6.8KBtag |
| $B \to K^{*}\gamma$ | $510^{-5}$ | 24.0K |
| $B \to \rho(\omega)\gamma$ | $2 \times 10^{-6}$ | 1.2K |
| $b \to s\mu^{+}\mu^{-}$ | $6.0 \pm 1.5 \times 10^{-6}$ | 1.2K |
| $b \to se^{+}e^{-}$ | | 1.4K |
| $B \to K^{*}\mu^{+}\mu^{-}$ | $2.0 \pm 1 \times 10^{-6}$ | 0.5K |
| $B \to K^{*}e^{+}e^{-}$ | | 0.6K |
| $b \to s\nu\nu$ | $4.1 \pm 0.9 \times 10^{-5}$ | 30 |
| $B \to K^{*}\nu\nu$ | $5.0 \times 10^{-6}$ | 6 |
| $B \to \tau\nu$ | $5 \times 10^{-5}$ | 70 |
| $B \to \mu\nu$ | $5 \times 10^{-7}$ | 35 |
| $\tau \to \mu\gamma$ | | $< 10^{-8}$ |

Table 3: Projected statistics with 2 $ab^{-1}$

# 4 Detector Upgrades

*BABAR* has evaluated possible improvements to the detector to allow the continuation of its experimental program with a peak luminosity greater than $10^{34}$. The result of the evaluation is that *BABAR* is a highly performing detector able to take data troughout this decade. The only possible intervention can refer to the innermost (SVT) and to the outermost (IFR) subdetector. SVT is 98% efficient. No effect of general degradation due to irradiation has been observed so far. SVT components have been tested for radiation hardness up to 4 MRad and they haven't shown any relevant effect. Radiation tests and accurate measurement of the indicators of damage, are still going on in our laboratories.

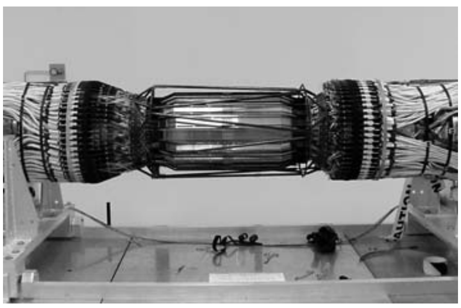

Figure 6: Silicon Vertex Tracker mounted on the B1 magnets during the 2002 shutdown

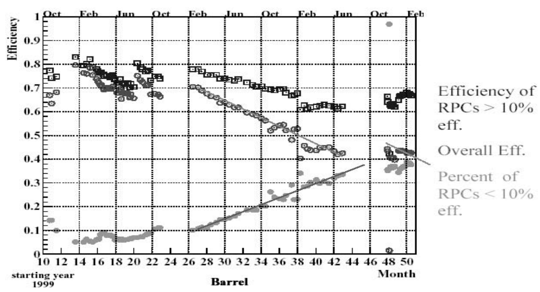


Figure 7: Barrel RPSs efficiency as a function of time since 1999

The possibility of replacement of some internal SVT modules laying on the horizontal plane has been however considered to take place at earliest by 2005, meanwhile almost 50% of all modules of SVT have been built as spare and are sitting on the shelf. The major upgrade intervention will in fact concern the IFR. In our present detector the sensor is made of bakelyte Resistive Plate Chambers, that haven' t demonstrated a sufficient robustness. Figure 7 shows the degradation observed in the efficiency of RPC since the installation of the system in 1999.

Recently *BABAR* has taken the decision to replace the bakelite RPC of the IFR barrel with chambers using more robust sensors (Limited StreamerTube) to increase the muon filtering capability, of the system by adding more absorber with the insertion of brass slabs in some of the gaps of the flux return of the magnet. Such intervention will take place in the down periods of summer 2004 and 2005.

# References

[1] J. H. Christenson, J. W. Cronin, V. L. Fitch and R. Turlay, Phys. Rev. Lett. **13**, 138 (1964).

[2] A. Hocker, H. Lacker, S. Laplace and F. Le Diberder, Eur. Phys. J. C **21**, 225 (2001) [arXiv:hep-ph/0104062].

[3] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **87**, 091801 (2001) [arXiv:hep-ex/0107013].

[4] K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **87**, 091802 (2001) [arXiv:hep-ex/0107061].

[5] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **89**, 281802 (2002) [arXiv:hep-ex/0207055].

[6] K. Abe *et al.* [Belle Collaboration], Phys. Rev. D **68**, 012001 (2003) [arXiv:hep-ex/0301032].

[7] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **90**, 242001 (2003) [arXiv:hep-ex/0304021].

[8] D. Besson *et al.* [CLEO Collaboration], Phys. Rev. D **68**, 032002 (2003) [arXiv:hep-ex/0305100].

[9] K. Abe *et al.*, arXiv:hep-ex/0307052.

[10] P. Krokovny *et al.* [Belle Collaboration], arXiv:hep-ex/0308019.

[11] B. Aubert *et al.* [BABAR Collaboration], arXiv:hep-ex/0207070.