Thoughts on **BaBar** and Babar

David Hitlin
Caltech
Panofsky Prize Symposium
SLAC
January 13, 2016
(Not quite) random thoughts

- Given the previous presentations and the title provided me, I have not prepared a linear presentation, starting here and going there, but rather will briefly touch on a few topics, some of which may or may not have been previously mentioned.

- I think we all realize how remarkable the PEP-II and BABAR experience has been:
  - We’ve produced important science that will have a lasting impact.
  - We became, in short order, a focused international team that designed and built an innovative experiment (and a high luminosity asymmetric collider) in a remarkably short time.
    - This achievement earned a DOE Project Management Award in 2000. Due to a truck blocking traffic in Arlington VA, Jonathan and I nearly missed the award presentation recognizing our prowess in getting things done on time.
  - We quickly became a formidable physics-producing machine, adhering to high standards (more than 550 papers to this point), and only one violation (?) of the Standard Model.
  - We’ve educated a generation of young physicists who have gone on to make an impact on current experiments.
  - We’ve even had some fun along the way.
Histoire de BABAR

from initial sketch to publication
The situation in the mid ’80’s

- In 1981 Bigi and Sanda showed that a measurement of CP violation in $B^0$ meson decay to CP eigenstates could be clearly interpreted, without theoretical uncertainties due to hadronic structure, directly in terms of CKM parameters.

- The prospect of a clean CPV measurement in $B^0$ decays was exciting; perhaps the Standard Model prediction of the strength of CP violation would fail.

- With the observation in ’83 of a long $B$ meson lifetime by Mark II and MAC and in ’87 of substantial $B_d$ mixing by ARGUS and UA1, it became clear that one could actually contemplate measuring CP-violating asymmetries in $B^0$ meson decays.

- Doing so would require flavor-tagging a $B$ meson and then distinguishing mixed from unmixed decays, which could be done using $B$’s produced in $e^+e^-$ annihilation or in hadronic collisions.

- However, in $e^+e^- \sim 10^7-10^8 \; B^0 \bar{B}^0$ pairs would be needed, a 2 to 3 order of magnitude increase in the then-existing data sample.

- Exploiting the quantum correlations of $B^0 \bar{B}^0$ pairs produced in $\Upsilon(4S)$ decays in $e^+e^-$ seemed like a particularly elegant approach, but separating the decays was difficult, as the $B^0$ lifetime in the laboratory corresponds to a distance of 19$\mu$m.

- Thus making this measurement required not only an asymmetric energy $^*$ $e^+e^-$ collider of unprecedented luminosity, but also a detector with excellent vertex and exclusive state reconstruction.
The unitarity triangle construction clearly illustrated the Standard Model tests that would be made possible with a measurement of $CP$-violating quantities in the $B$ meson system, but which triangle? The top quark mass was not known.

Dib, Dunietz, Gilman and Nir 1989
### Thirteen ways of looking at a blackbird (and seven more)

<table>
<thead>
<tr>
<th>Y(4S) Storage Rings</th>
<th>Y(4S) Linac-Ring Collider</th>
<th>Y(4S) Recirculating Linear Collider</th>
<th>Z Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symmetric</td>
<td>Asymmetric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSI (2)</td>
<td>APIARY</td>
<td>Grosse-Wiesmann</td>
<td>ARES</td>
</tr>
<tr>
<td>Novosibirsk</td>
<td>CITAR</td>
<td>JLAB</td>
<td>UCLA</td>
</tr>
<tr>
<td>KEK accumulator</td>
<td>PEP-II</td>
<td></td>
<td>TBA</td>
</tr>
<tr>
<td>CESR Plus</td>
<td>PETRA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISR Tunnel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KEK accumulator</td>
<td>KEKB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CESR-B</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Before and after Snowmass ’88

In California, there were two sets of activities, both based on the Oddone asymmetry concept:

- **SLAC/LBL**
  - **APIARY**: A new ~2 GeV ring colliding with PEP at ~12 GeV at $L \sim 2-5 \times 10^{32}$

- **The Southern California Consortium for a $B$ Factory**:
  - Caltech, UCLA, UCSD, UC Riverside, USC
  - **CITAR**: Two rings (~700 and ~1700m) with 12m bunch separation at $L \sim 1.2 \times 10^{34}$
  - UCLA: Recirculating linac

By 1989 people from both groups were working together on a viable design, and also working through SLUO to convince SLAC that there should be an asymmetric $B$ Factory in its future

- Other options were a linear collider, a $\tau$/charm factory and a charm photoproduction experiment in ESA

- Over a period of months, the design evolved to two equal circumference rings (one above the other) in the PEP tunnel, using many bunches and a head-on collision scheme
The Snowmass ’88 detector

Fig. 2. A detector for an asymmetric collider at the Y(4S).
Many trees were destroyed
SLAC and SLUO

cordially invite you
to attend the inauguration
of the
Detector Collaboration
for the
PEP-II Asymmetric B Factory
November 30-December 4, 1993
Stanford Linear Accelerator Center

The formation of a collaboration
to construct a detector optimized
for the study of CP violation
in the B meson system
at PEP-II will be discussed.

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Anna Pacheco, Mail Stop 95, SLAC,
Box 4404, Stanford, CA 94309
Phone 415 926 2700, FAX 415 926 2657
Email anamaria@slac.stanford.edu
Inauguration of the Detector Collaboration for PEP-II
November 30 - December 4, 1993

Plenary Session/Parallel Session Schedule

Workshop for the
Inauguration of the
Detector Collaboration for the
PEP-II Asymmetric B Factory
November 30-December 4, 1993

SESSION: Summaries

LECTORER: G. Wormser

TITLE: Computing Summary

DATE OF LECTURE: Saturday, Dec. 4
The BABAR Collaboration

10 Countries
77 Institutions
485 Collaborators

eventually > 600 collaborators

October 1995

USA [33/244]
California Institute of Technology
UC, Davis
UC, Irvine
UC, Los Angeles
UC, San Diego
UC, Santa Barbara
UC, Santa Cruz
U of Cincinnati
U of Colorado
Colorado State
U of Iowa
Iowa State U
LBNL
LLNL
U of Louisville
U of Maryland
U of Massachusetts, Amherst
MIT
U of Mississippi
Mount Holyoke College
Northern Kentucky U
U of Notre Dame
ORNL/Y-12
U of Pennsylvania
Prairie View A&M
Princeton
Rutgers
SLAC
U of South Carolina
Stanford U
U of Texas at Dallas
Vanderbilt
U of Wisconsin

Canada [7/25]
U of British Columbia
Carleton U and CRPP
McGill U
U de Montréal
TRIUMF
U of Victoria
York U

China [4/19]
Beijing Glass Research Inst.
Inst. of High Energy Physics, Beijing
Shanghai Inst. of Ceramics (SICCAS)
Tsinghua U, Beijing

France [5/44]
LAPP, Annecy
LAL, Orsay
LPNHE des Universités Paris 6/7
Ecole Polytechnique
CEA, DAPNIA, CE-Saclay

Germany [1/7]
Technische U Dresden

Italy [13/72]
INFN, Bari and U di Bari
INFN, Ferrara
Lab. Nazionali di Frascati dell' INFN
INFN, Genova
INFN, Napoli and U di Napoli
INFN, Padova
U di Pavia
INFN, Pisa, U di Pisa & Scuola Normale
INFN, Roma and U "La Sapienza"
INFN, Superiore di Sanita’, Roma
INFN, Torino and U di Torino
INFN, Trieste and U di Trieste

Norway [1/1]
U of Bergen

Russia [2/28]
Budker Institute, Novosibirsk
JINR, Dubna

United Kingdom [10/42]
U of Bristol
Brunel University
U of Edinburgh
U of Lancaster
U of Liverpool
Imperial College
Queen Mary & Westfield College
Royal Holloway & Bedford New College
U of Manchester
Rutherford Appleton Laboratory

Taiwan [1/3]
Academia Sinica
Project Management

Spokesman - D. Hitlin
Deputy Spokesman - R. Aleksan
Technical Coordinator - V. Lüth
Project Engineer - R. Bell

Collaboration Council

Chairman - L. Piemontese
Vice-Chairman - R. Wilson
Institution Representatives

Technical Board

Technical Coordinator (Chairman) - V. Lüth
Project Engineer - R. Bell
Chief Electronics Engineer - G. Haller
Chief Software Engineer - D. Quarrie
Integration Physicist - H. Lynch
PEP-II Representative - J. Dorfan
Safety Officer - P. O'Neill
Spokesman - D. Hitlin
Deputy Spokesman - R. Aleksan
System Managers:
  PEP-II/BABAR Interface - H. DeStaebler
  Vertex Detector - F. Forti/N. Roe
  Drift Chamber - D. MacFarlane
  DIRC PID - G. London/B. Ratcliff
  Aerogel PID - Y. Karyotakis
  CsI Calorimeter - R. Schindler
  IFR - C. Sciacca
  Magnet - R. Bell
  Electronics - A. Lankford
  Computing - N. Geddes/F. Porter

Executive Board

Canada - P. Taras
France - G. Wormser
Germany - K. Schubert
Italy - M. Giorgi
UK - J. Fry
US - K. McDonald
US - A. Seiden
US - M. Witherell
SLAC/US - W. Innis
LBL/US - M. Pripstein
Spokesman - D. Hitlin
Deputy Spokesman - R. Aleksan
Technical Coordinator - V. Lüth
PEP-II - J. Dorfan
### Common Fund Payments by Country
#### Spread by US Fiscal Year (K$)

<table>
<thead>
<tr>
<th>Country</th>
<th>FY95/96</th>
<th>FY97</th>
<th>FY98</th>
<th>FY99</th>
<th>Total Common Fund</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada NSERC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>305</td>
</tr>
<tr>
<td>France CEA</td>
<td>660</td>
<td></td>
<td></td>
<td></td>
<td>660</td>
<td>660</td>
</tr>
<tr>
<td>France IN2P3</td>
<td>462</td>
<td>132</td>
<td>66</td>
<td></td>
<td>660</td>
<td>660</td>
</tr>
<tr>
<td>Germany BMFT</td>
<td>660</td>
<td>115</td>
<td></td>
<td></td>
<td>775</td>
<td>775</td>
</tr>
<tr>
<td>Italy INFN*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,625</td>
<td>1,625</td>
</tr>
<tr>
<td>UK PPARC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>990</td>
<td>990</td>
</tr>
<tr>
<td>US DOE</td>
<td>3,578</td>
<td>1,779</td>
<td>2,100</td>
<td>828</td>
<td>8,285</td>
<td>8,285</td>
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<tr>
<td><strong>Total Common Fund</strong></td>
<td>5,360</td>
<td>2,079</td>
<td>2,722</td>
<td>1,514</td>
<td>13,300</td>
<td>13,300</td>
</tr>
</tbody>
</table>

*The effective INFN contribution profile is assumed to follow the profile of the superconducting coil*

### Summary of BABAR Non-US Finances
*(does not include Chinese/Russian in-kind contributions or discounts)*

<table>
<thead>
<tr>
<th>Country</th>
<th>Investment Request</th>
<th>Currency</th>
<th>Investment Request (M$)</th>
<th>Investment Granted (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada*</td>
<td>Total 3.7M $Canadian</td>
<td>2.76</td>
<td>0</td>
<td>Under discussion</td>
</tr>
<tr>
<td>France IN2P3</td>
<td>15M Franc</td>
<td>2.73</td>
<td>15 M FF</td>
<td>Approved</td>
</tr>
<tr>
<td>France CEA</td>
<td>15M Franc</td>
<td>2.73</td>
<td>15 M FF</td>
<td>Approved</td>
</tr>
<tr>
<td>Germany</td>
<td>5M DM</td>
<td>3.30</td>
<td>2 MDM though 97</td>
<td>Good prospects for +3 MDM</td>
</tr>
<tr>
<td>Italy</td>
<td>8B Lire</td>
<td>5.00</td>
<td>8B Lire + SC Coil</td>
<td>Approved</td>
</tr>
<tr>
<td>UK</td>
<td>2.475M £</td>
<td>3.84</td>
<td>2.475 M£</td>
<td>To go to Council</td>
</tr>
<tr>
<td><strong>Total M&amp;S in local accounting</strong></td>
<td>20.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Equivalent total M&amp;S + labor in US acc</strong></td>
<td>30.53</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Canada uses US-style accounting

11/13/95
The **BABAR Detector**

Si Vertex-Tracker, Drift Chamber, DIRC (Cherenkov), CsI-Calorimeter, Superconducting Coil, Iron Yoke + RPCs/LSTs
Preparing to do physics – four additional workshops
First Collisions in \textit{BaBar}  
Hadronic Event  
May 26, 1999
• After a plenary discussion at the Padova Collaboration Meeting in 1997 *BABAR* committed to employing blind analysis techniques, becoming one of the first major experiments to do so
• We also pioneered the use of sophisticated maximum likelihood and multivariate techniques that enabled us to extract maximum information from the data in an unbiased manner
• Ongoing analyses are applying even more sophisticated deep learning techniques, *e.g.*, Google Tensorflow, providing further sensitivity enhancements
How *BABAR* got its name

- The first use of the name was in 1990, spelled as *BaBar* (*not an acronym)*
- In 1992 the question of copyright was raised and we asked the SLAC™ Business Office to make inquiries
- In the Fall of 1993 I wrote to Laurent de Brunhoff extolling the virtues of *CP* violation measurements in the *B\bar{B}* meson system and the importance of investigating the origin of the matter-antimatter asymmetry
- He did not answer directly, but in December, 1993 I received a call from Nelvana, which held the licensing rights to Babar, offering a five year, renewable, royalty-free license for use of the Babar name and images
- The SLAC™ Business Office then concluded a formal agreement
- With the new initiative to form a detector collaboration for a detector for PEP-II it seemed wise to have the new group choose its own name
- An email vote was organized, with John Fry as Election Commissioner, and the name chosen by the proto-Collaboration Council, on May 12, 1994, was *BABAR*, with capitalization and relative letter size subsequently decided upon by the Interim Steering Committee:

```
def\babar{\mbox{\slshape B\kern-0.1em{\smaller A}\kern-0.1em B\kern-0.1em{\smaller A}\kern-0.2em R}}}
```
The license for the \textit{BABAR} name and logo came with rules:

From the Nelvana Style Manual:

\begin{itemize}
\item Generally elephants do not hold articles with their feet or hands; use trunks only. Articles can be tucked under arms.
\end{itemize}
T-shirts

- The first printing of the first limited edition BABAR T-shirt is now available. We have permission to print up to 500 copies.
- The order form is available on WWW.
- If you have not yet ordered yours, you may do so at the Registration Desk. The order will be filled with a new printing in a few weeks.

From the Sept. 1995 Collaboration Meeting Spokesman’s report
Purchased in the Clignancourt Flea Market, Paris, January 1996, before the Palaiseau Collaboration Meeting
CPV-related physics goals

- Our initial goal was to measure \( \sin2\beta \), \textit{i.e.}, to find evidence for \( CP \) violation in the interference of mixing and decay in the \( B \) meson system.
- We then made those measurements needed to over-constrain the Unitarity Triangle.
  - This required measurements of \( V_{ub}, V_{cb}, \Delta m_d \), and \( t_B \), as well as \( \sin2\alpha \) and \( \gamma \).
  - We were also able to resolve the trigonometric ambiguities.
- We were able to exploit other features of the entangled \( B^0 \bar{B}^0 \) state to observe \( T \) violation in particle decay.
- As the data sample increased, it became possible to investigate rare inclusive and exclusive penguin-dominated decays and to search for \( CPV \) in these decays, in which physics beyond the Standard Model is most likely to be observable.
  - Have we done this in \( B^{(*)} t n \) ?
Observation of $CP$ Violation in the $B^0$ Meson System

(BABAR Collaboration)

(Received 5 July 2001; published 14 August 2001)

We present an updated measurement of time-dependent $CP$-violating asymmetries in neutral $B$ decays with the BABAR detector at the PEP-II asymmetric $B$ Factory at SLAC. This result uses an additional sample of $Y(4S)$ decays collected in 2001, bringing the data available to $32 \times 10^6 \, B \bar{B}$ pairs. We select events in which one neutral $B$ meson is fully reconstructed in a final state containing charmonium and the flavor of the other neutral $B$ meson is determined from its decay products. The amplitude of the $CP$-violating asymmetry, which in the standard model is proportional to $\sin 2\beta$, is derived from the decay time distributions in such events. The result $\sin 2\beta = 0.59 \pm 0.14(\text{stat}) \pm 0.05(\text{syst})$ establishes $CP$ violation in the $B^0$ meson system. We also determine $|\lambda| = 0.93 \pm 0.09(\text{stat}) \pm 0.03(\text{syst})$, consistent with no direct $CP$ violation.
In perhaps our most important publication, we failed to use the babarsym.tex macros, as per the Exec Board and publication rules:

\textbackslash CP: \textbackslash \textasciitilde \textbackslash C \textbackslash \textasciitilde \textbackslash P$

\textbackslash babar: \textbackslash mbox{\textshapelowercase{B}\kern-0.1em\text{smaller A}\kern-0.1em\text{smaller A}\kern-0.2em} R
Eons ago in the parking lot of the Stanford Park Hotel

A bet was made between
Professor David Hitlin of the
California Institute of Technology
and
Professor Bruce Winstein of the
University of Chicago.

These esteemed scholars bet

One Case of Chateau Lynch-Bages

that a three standard deviation signal of CP violation would be seen in B meson decay by the end of the millennium. Professor Hitlin took the affirmative side.

Performing my duty,
Professor Robert Siemann
Stanford Linear Accelerator Center

1989

Year of the $b$ quark discovery
Chronology of $\sin 2\beta$ measurements

- BABAR (2000) (9.0 fb)$^{-1}$
- Belle (2000) (6.2 fb)$^{-1}$
- Belle (2001) (11 M $B\bar{B}$)
- BABAR (2001) (23 M $B\bar{B}$)
- BABAR (2001) (32 M $B\bar{B}$)
- Belle (2001) (31 M $B\bar{B}$)
- BABAR (2002) (88 M $B\bar{B}$)
- Belle (2002) (85 M $B\bar{B}$)
- Belle (2003) (152 M $B\bar{B}$)
- BABAR (2004) (227 M $B\bar{B}$)
- Belle (2005) (386 M $B\bar{B}$)
- BABAR (2006) (348 M $B\bar{B}$)
- Belle (2006) (535 M $B\bar{B}$)
- BABAR (2008) (465 M $B\bar{B}$)
- Belle (2011) (772 M $B\bar{B}$)

Current Average: $0.677 \pm 0.020$
At the Fifty Years of *CP* Violation Symposium – London 2014

*n.b.* The first (analog) photo in this series is of Pier, Jonathan and I at Blois in 1989.
EDS – Superbowl XXXIV
Can I have my beam tree now?