BABAR/PEP-II Origins: The Collider

Presentation by Jonathan Dorfan

at the

BaBar 25th Anniversary

December 11, 2018 at SLAC
This talk is dedicated to the memory of colleagues whose contributions to PEP-II were invaluable.

Burt Richter
Bob Bell
Bill Davies White
Mike Zisman
Hobey DeStaebler
John Rees
**HiLum PEP**

- In the mid 1980s the TPC collaboration at PEP, led by its co-spokesman Elliott Bloom, were pushing SLAC to upgrade PEP in pursuit of high statistics studies of B mesons and τ leptons. The proposal was called *HiLum PEP*.

- *HiLum PEP* was not adopted by SLAC.

- Burt coined the phrase “Boutique Physics”, which was not meant as a compliment.

- It took about 8 years to turn Burt into a supporter of “Beauty/CP Physics”, but once on board, he was a powerful advocate.
- Discussions with Ikaros Bigi and Tony Sanda
- "Crazy Asymmetric Idea" just what was needed for CP studies
- Could be done by modifying PEP
  - Two rings: give high luminosity
  - $Y(4S)$: gives high cross section and $B^o\bar{B}^o$ in coherent state
  - Asymmetry: separated vertices give time evolution
This led to at least 21 $e^+e^-$ B Factory concepts and proposals ($19 \Upsilon(4S) + 2 Z0$) and several hadronic machine approaches (HERA-B, …

Two colliders, PEP-II and KEKB, were ultimately built. Pier Oddone’s concept of using an asymmetric $e^+e^-$ collider to boost the distance between the two decay vertices was, in the end, the most successful approach.
Next thrust: Apiaries.....

- APIARY 1: June 1988
B-Factories: A Personal Overview

PIER ODDONE

Lawrence Berkeley Laboratory
University of California at Berkeley
Berkeley, California 94720

INTRODUCTION

At the conclusion of this Workshop, three of the participants, Karl Berkelman, Claudio Pellegrini, and I, were asked to give brief, personal overviews of the development of B-factories. In the following pages I summarize the reasons for the choice of an assymetric B-factory based on storage rings, a facility that I believe will be necessary for the full exploration of CP violation in B-meson decays.
Review of Caltech Workshop and Some Parametric Questions for a High-Luminosity Asymmetric B-Factory Collider

FRANK C. PORTER

Charles C. Lauritsen Laboratory of High Energy Physics
California Institute of Technology
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CONCLUSION

The possibility of constructing an $\mathcal{L}_{pk} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ asymmetric storage-ring $B$-factory no longer seems so remote as it appeared a year ago. There remain many challenges, but with the mounting enthusiasm in both the accelerator and particle physics communities, and the lure of an outstanding physics program, I am confident that solutions will be found.
How I Got Involved

• In 1989, MarkII completed its running at SLC
• George Trilling encouraged me to join the SDC collaboration – but
  the lure of $\mathcal{CP}$ was stronger
• There was a need to form an engineering/R&D effort in support of
  the asymmetric B Factory accelerator studies ongoing in California
• Fortunately, Burt did not take away the MarkII operating budget
  from me: rather he let me invest it in an engineering-based effort
  working initially with LBL and Caltech, and soon thereafter adding
  LLNL, on what ultimately became the PEP-II machine
• In 1990-1993 we made R&D demonstration projects a very strong
  adjunct to the development of the Conceptual Design
There was a substantial need to “Educate” and “Convince” the SLAC Leadership and the SLAC Community: Colloquium March 1990

**Physics Requirements**

1. Integrated luminosity of \( \geq 30 \text{ fb}^{-1} / \text{year} \)
   This corresponds to
   \[
   L_{\text{peak}} = 3 \times 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}
   \]
   \[
   2 \times 10^7 \text{ seconds}
   \]
   \[\varepsilon \approx 50\%
   \]

2. Two storage rings colliding asymmetrically at Y(4s) with \( E_{\text{hi}} \geq 8 \text{ GeV} \)

3. Beampipe radius \( \leq 3 \text{ cm} \)

4. Detector well instrumented for
   
   \[-0.95 \leq \cos \theta_{cm} \leq 0.9\]
   
   This corresponds to restricting the machine components to \( \theta_{\text{lab}} \leq 300 \text{ mrad} \) in forward direction
The Three-Lab collaboration was formally established in 1991 with an Advisory Group Reporting to the 3 Lab Directors.

The B Factory Advisory Group continues to be a very valuable forum for guiding the machine and detector development for PEP-II. The group met recently and agreed to maintain its bi-monthly meetings, which are held every other Friday in the Yellow room at SLAC at 2:30pm. Two members have left the group — Andrew Hutton and John Rees. We welcome as a new member David MacFarlane from McGill. His first meeting was last week — the speaker-phone arrangement seems satisfactory. The present membership is attached.

Distribution:
Burton Richter, Director SLAC
Charles Shank, Director LBL
John Nuckolls, Director LLNL
B Factory Advisory Group

Members of the B Factory Advisory Group in May 1992:
Bloom, Dorfan, Chattophadyay, Barletta, Bell, Hitlin, Leith, Oddone, Porter, MacFarlane, Witherell and Zisman
Progress Towards a Conceptual Design

- Conceptual design history
  - design started in earnest in December 1989
    - coordinated by A. Hutton at SLAC and MZ at LBL
  - goal was to produce a conceptual design for asymmetric B factory in PEP tunnel
    - $\mathcal{L} = 3 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
    - 9 GeV x 3.1 GeV
  - goal was reached after 1-year design study
    - held (self-inflicted) internal reviews on key design aspects
      - lattice, IR, vacuum system, RF and feedback
      - international experts validated our key design concepts
    - message here is that we have tried to be complete and careful in our design work
      - ...or maybe we’re masochists
    - continue to rely on reviews of R&D activities
      - suggests the second explanation is correct
  - CDR completed in February 1991
    - DOE review of project in March 1991
      - the last “Temple” review
      - review report was very favorable
      "The B Factory team has presented a credible design, and it is the judgment of this Committee that there is a high probability of attaining the physics goals."

- THE REVIEW PANEL DEEMED THE PROJECT:
  - technically feasible as designed
  - endorsed the cost estimate and called for modest (3%) increase in contingency
  - endorsed the schedule
  - was complimentary regarding quality of engineering solutions
  - endorsed the proposed management plan
  - endorsed the technical strength which the three-lab approach brings to this challenging project

Chairs were:
Willeke, Eichler, Grobner, Boussard

Slides taken from Mike Zisman’s talk to Witherell Subpanel
1990-1994: Garnering Community and Government Support and Approval

APRIL 90, SCIULLI SUBPANEL REPORT:

"The Subpanel strongly endorses the physics aims of a B Factory and recommends a vigorous research and development effort leading to a proposal to build such a facility"

HEPAP MEETING JUNE 4,5 1991:

Letter of transmittal, July 3,1991, to Dr. James Decker:

"The major item of discussion at this HEPAP meeting revolved around the question of e+e- B Factories and their ability to resolve the question of CP violation. ....

......The Panel is convinced that understanding the origin of CP violation is one of the central goals of particle physics. Moreover it is our opinion that this important question can be addressed in much more breadth by the e+e- machines than by hadron colliders........Thus we reaffirm strongly the importance of the physics goals of B factories.

In summary,......The one major new development, a much greater confidence in the technical feasibility of the B Factories, leads us to urge the funding agencies to try to find a way to begin construction of such a facility in the near future...."
1992 Witherell HEPAP Subpanel

- Witherell Subpanel met at SLAC on February 21-22, 1992 having just been at SSC

- The afternoon before the Subpanel arrived, I became aware of discussions amongst some of the Subpanel members:
  - SSC was short about $120M a year of operating funds: closing down SLAC was the most expedient way to solve the problem

- I found Burt and warned him that unless he could put up a credible, near-term scientific scenario – namely to offer up a sizeable chunk of the Lab. to allow the B Factory to go ahead ASAP - SLAC was extremely vulnerable to closure
Summary

Witherell Subpanel of HEPAP
February 22, 1992

Burton Richter
Director
Stanford Linear Accelerator Center
We have presented to you today:

- A vision of the long term.
- A program for 1993–1997 within a constrained budget (constant purchasing power model).

- Opportunities for HEP experiments with SLC as appropriate, new fixed-target opportunities, support for users working elsewhere.
- An accelerator improvement project to turn PEP into a B-Factory for CP studies.
- An aggressive program of linear collider R&D, including linac experiments and technology development coordinated with the rest of the world.

Long-term Vision

Main elements of HEP program in 2005:

- The U.S. high energy physics program includes a significant electron component as well as the SSC.
- The NLC is under construction and soon to turn on. SLAC is heavily involved in machine construction and detector development wherever the facility is located.
- PEP II has produced 100-200 $fb^{-1}$ and CP violation is becoming much better understood.
B-Factory Program

- It is a very important missing element in the standard model.
- It is a difficult machine.
- \( \mathcal{L} \geq 3 \times 10^{33} \) is required to do CP.
- \( e^+e^- \) is needed to do the full problem.

Can be done within constraint of constant purchasing power SLAC budget. Requires refocusing of the laboratory and sharing people between operations and maintenance and \( B \) project.

We have been working on this in the U.S. for many years. There is a large U.S. (and foreign) user interest. We should do it.

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We would like you to endorse:

- The vision for the 2000's.
- The NLC R&D program.
- The \( B \)-Factory as an accelerator improvement project to start as soon as possible.
The good times may have stopped rolling for high-energy physics. Not only is the Superconducting Super Collider in grave trouble politically and financially, but the US high-energy physics program is facing a possible cutback in its annual budget by $300 million in fiscal 1993. But when the subpanel looked at the number of experiments existing today, it was estimated that the annual budget would be reduced by at least 25%. The origin of CP violation is one of the most fundamental questions in high-energy physics today.

**Witherell Subpanel Recommendation**

In the middle and upper budget scenarios, the subpanel recommended “construction of a symmetric B-factory in the existing PEP tunnel at SLAC...” commenting that “The origin of CP violation is one of the most fundamental questions in high-energy physics today.”
Stanford-Cornell Shootout

• 1994 Bush outgoing budget proposal included $36M for a DOE B Factory. The Clinton 1994 budget proposal similarly included $36M for DOE to commence construction at SLAC

• Senate Finance Chair Daniel Moynihan (D,NY) had the SLAC designation removed from the Senate Bill and convinced OMB Director Panetta to compel an impartial review of the two competing proposals: PEP-II and CESR-B

• In May 93, DOE and NSF convened a 12-person, one month review under the Chairmanship of Stanley Kowalski of MIT Bates Lab. The review did not rank the projects and concluded that either project was capable of achieving the desired luminosity
Stanford-Cornell Shootout

• President Clinton announced in SF on October 4, 1993: “Today, Energy Secretary Hazel O'Leary and my science advisor, Jack Gibbons, have given me their recommendations for the B-factory. After much study and serious comparisons of all proposals, the recommendation is that the B-factory go to the Stanford Linear Accelerator Center (SLAC)."

• "I have selected Stanford because the Department of Energy has a much higher margin of confidence in the ability of the Stanford proposal to meet the project’s extremely high performance requirements, as well as to meet its proposed cost and schedule,“ said Secretary O’Leary

• Cornell University President Frank Rhodes reacted sharply to the decision and called upon the Department of Energy to release the review panel's report. Rhodes said in a press release that Cornell was "hard pressed to understand how in these difficult fiscal times the federal government can justify awarding the project to a facility where it will cost $100 million more to accomplish the same scientific objectives than it would if built here at Cornell."
Stanford-Cornell Shootout

• Pier Oddone: "I am delighted that Secretary O'Leary has decided to put the B-factory in the Bay Area. I want to thank her, the President, the Department of Energy, the National Science Foundation, and the many colleagues who worked together during the review of the two proposals to provide a technically sound basis for this decision. .... I would also like to salute our colleagues at Cornell University. They have a great laboratory and have given us some very tough competition. We hope that they will join us in building and using this exciting new accelerator."

• I am purported to have said: "The government has done the wise thing. SLAC is the premier electron lab in the world; a continued investment in this lab makes real sense. ........ I'll celebrate when we have the check in hand. President Clinton’s announcement is a tremendous step, but we must be patient. When we get approval from the Senate and the House, then I’ll drink my champagne. But for now, it's on ice."
SLAC WINS B-FACTORY COMPETITION
Department of Energy’s Reasoning on B-Factor Selection

As reported in FYI #136, the Department of Energy has decided to construct the B-factory at the Stanford Linear Accelerator Center. This decision implements an April 1992 recommendation of the High Energy Physics Advisory Panel to construct a B-factory, and follows a joint DOE and National Science Foundation study of competing SLAC and Cornell University proposals.

Competition for this facility was keen, but judging from the six-page statement by Secretary Hazel O’Leary entitled, “Selection of the Preferred Site for the B-Factory,” the decision was not as close as some expected it might be. Last April, Office of Management and Budget Director Leon Panetta requested that DOE and NSF perform a technical review of the two proposals. The committee, chaired by Stanley Kowalski of MIT, evaluated, but did not rank, the two proposals. That ranking, and the final decision, was left to O’Leary.

In her October 4 statement, O’Leary cited three “risk factors” bearing on her selection: schedule risk, performance risk, and cost risk. In each of the three areas, O’Leary’s statement clearly favored the SLAC proposal. This proposal, which involves a collaboration with Lawrence Berkeley Laboratory and Lawrence Livermore National Laboratory, was favored in the area of schedule risk, O’Leary said, because, “The SLAC proposal represents an extremely powerful combination of scientific and engineering talent which resides among three Department of Energy laboratories.”

O’Leary expressed concern about Cornell’s ability to complete the project on time, her report stating, “…the Cornell proposal does not have an adequate safety margin for remaining on its planned schedule.”

O’Leary’s assessment of the comparative performance risk of the two proposals followed along the same track. After describing the “very stringent” performance requirements for the B-factory, she said that “the smaller tunnel at Cornell forces a technically riskier design,” which “will generate an unprecedented level of synchrotron radiation,” as well as requiring a never-attempted collision scheme.

DOE’s analysis of cost risk also favored SLAC. Although Cornell’s proposed budget was considerably smaller, DOE warned of schedule slippage on the order of six months to a year, “with an associated cost risk of $10 million to $20 million.” O’Leary said that Cornell’s cost contingency for unexpected problems was too low.

Other the heading of “Other Factors,” DOE found that SLAC “is well prepared to handle the approximately 300 physicists expected to utilize the B-factory.” Finally, the statement noted, “The unique work force which resides at SLAC has been established over a period of 30 years and represents a national repository of expertise that cannot be easily replicated. However, in a fashion unlike that of Cornell’s Laboratory of Nuclear Studies, the fate of SLAC and its personnel will be strongly impacted by this decision.”

Construction of the $170 million B-factory (plus an additional $60 million for a new particle detector) will begin this fall, with its completion scheduled by late 1998.
Three lab team: SLAC, LBL, LLNL
The Sponsor: DOE

John O’Fallen: The believer

On-Site Oversight Office

Danny Lehman: Uber “Auditor”

Reilly, Kevin  Franzwa, Bill  Treacy, David
The Funders: Congress
PEP-II Central Management

Special Assistant
Safety
Data Management
Administration
Whatever Needed To Be Done
PEP-II Construction “System Managers”

- High Energy Ring
- Low Energy Ring
- Injection
- Controls
- Backgrounds, Interaction Region
- RF
- Utilities
- Installation
LER Magnets and Aluminum Vacuum System (LBNL, SLAC)

Magnets made by our Chinese IHEP collaborators

Antechambers
Reduce Electron-Cloud-Instability

High power photon stops

LER SR power = 2 MW.
PEP-II Copper Vacuum System (SLAC)

Cu chambers absorbing 100 W/cm of synchrotron radiation

Total SR power = 5 MW in the HER
Bunch-by-Bunch feedback kickers
(LBNL/SLAC)

Transverse

Longitudinal

October 27, 2008

PEP-II BaBar Symposium
Interaction Region Magnets, Vacuum in Support Tube (SLAC)
Strategy of *Staged Completion and testing* of the major subcomponents with real beam

- $e^-$ ($e^+$) at end of New Injection Lines: Oct ’95 (97)

- $e^-$ beam through 1/3 of HER: May ‘97

- Stored $e^-$ beam in High Energy Ring: June ‘97

- $e^+$ beam to Low Energy Ring Arc 7 Temp. Dump: Jan 98
Measure/Characterize the backgrounds before Babar moved on line
<table>
<thead>
<tr>
<th>Detector</th>
<th>Purpose</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid State X-Ray Spectrometer</td>
<td>Synchrotron radiation spectrum</td>
<td>Colorado State U. + LBL</td>
</tr>
<tr>
<td>Silicon Diode Stacks</td>
<td>SR, lost-particle rate near beam pipe</td>
<td>Stanford U.</td>
</tr>
<tr>
<td>Straw Chamber (from Crystal Ball)</td>
<td>Lost-particles in tracking chamber</td>
<td>SLAC, Tennesee, Ecole Polytechnique</td>
</tr>
<tr>
<td>Scanning Crystal Ring</td>
<td>MeV photons from lost-particle showers</td>
<td>LAPP (Annecy) + Saclay (France)</td>
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<tr>
<td>Water Cherenkov + Scintillator Hodoscope</td>
<td>BaBar DIRC backgrounds</td>
<td>U. Cincinnati + LBL</td>
</tr>
<tr>
<td>Mini Time Projection Chamber</td>
<td>High-granularity tracking chamber near beam pipe</td>
<td>Orsay (France) + LBL + U. Cincinnati</td>
</tr>
<tr>
<td>Silicon Strip Detector (BaBar prototype)</td>
<td>SR, lost particles next to beam pipe</td>
<td>UCSD+UCSC+UCSB + LBL + INFN + ...</td>
</tr>
<tr>
<td>Calorimeter Module (BaBar prototype)</td>
<td>Energetic photons, tracks (&gt;100 MeV)</td>
<td>SLAC</td>
</tr>
</tbody>
</table>
2.962 \times 10^{35} \quad \frac{1}{130} on 780

5.82 \quad 3.032 \times 10^{33} \quad 1300 on 285

Mission accomplished!
1.2x10^{34}/cm^2/s !!

1875 mA/HER
2900 mA/LER
1722 bunches
≈154/fb
Mega - Congratulations!

100 fb⁻¹ for Run 4 couldn't be done?
PEP-II Turned Off April 7 2008
## PEP-II Final Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Design</th>
<th>Overall best</th>
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<tbody>
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<td>$I^+$ mA</td>
<td></td>
<td>2140</td>
<td>3213</td>
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<td>$I^-$ mA</td>
<td></td>
<td>750</td>
<td>2069</td>
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<tr>
<td>Number bunches</td>
<td></td>
<td>1658</td>
<td>1732</td>
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<td>$\beta^*_y$ mm</td>
<td></td>
<td>15-20</td>
<td>9-10</td>
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<tr>
<td>Bunch length mm</td>
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<td>$\xi_y$ tune shift</td>
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<td>3</td>
<td>12</td>
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<tr>
<td>Int lumi / day</td>
<td></td>
<td>130</td>
<td>911</td>
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</tbody>
</table>

- 4 times design
- 7 times design
## PEP-II Records

### Peak Luminosity

\[ 12.069 \times 10^{33} \text{ cm}^{-2}\text{sec}^{-1} \]

- **1722 bunches**
- **2900 mA LER**
- **1875 mA HER**

**August 16, 2006**

### Integration records of delivered luminosity

<table>
<thead>
<tr>
<th>Record Type</th>
<th>Value</th>
<th>Date</th>
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<tbody>
<tr>
<td>Best shift (8 hrs, 0:00, 08:00, 16:00)</td>
<td>339.0 pb(^{-1})</td>
<td>Aug 16, 2006</td>
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<td>Best 3 shifts in a row</td>
<td>910.7 pb(^{-1})</td>
<td>Jul 2-3, 2006</td>
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<td>Best day</td>
<td>858.4 pb(^{-1})</td>
<td>Aug 19, 2007</td>
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<tr>
<td>Best 7 days (0:00 to 24:00)</td>
<td>5.411 fb(^{-1})</td>
<td>Aug 14-Aug 20, 2007</td>
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<tr>
<td>Best week (Sun 0:00 to Sat 24:00)</td>
<td>5.137 fb(^{-1})</td>
<td>Aug 12-Aug 18, 2007</td>
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<tr>
<td>Peak HER current</td>
<td>2069 mA</td>
<td>Feb 29, 2008</td>
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<td>Peak LER current</td>
<td>3213 mA</td>
<td>Apr 7, 2008</td>
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<tr>
<td>Best 30 days</td>
<td>19.776 fb(^{-1})</td>
<td>Aug 5 – Sep 3, 2007</td>
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<tr>
<td>Best month</td>
<td>19.732 fb(^{-1})</td>
<td>August 2007</td>
</tr>
<tr>
<td>Total delivered</td>
<td>557 fb(^{-1})</td>
<td>PEP-II turned off April 7, 2008</td>
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