The DOE Perspective on the B Factory

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SLAC
NATIONAL ACCELERATOR LABORATORY

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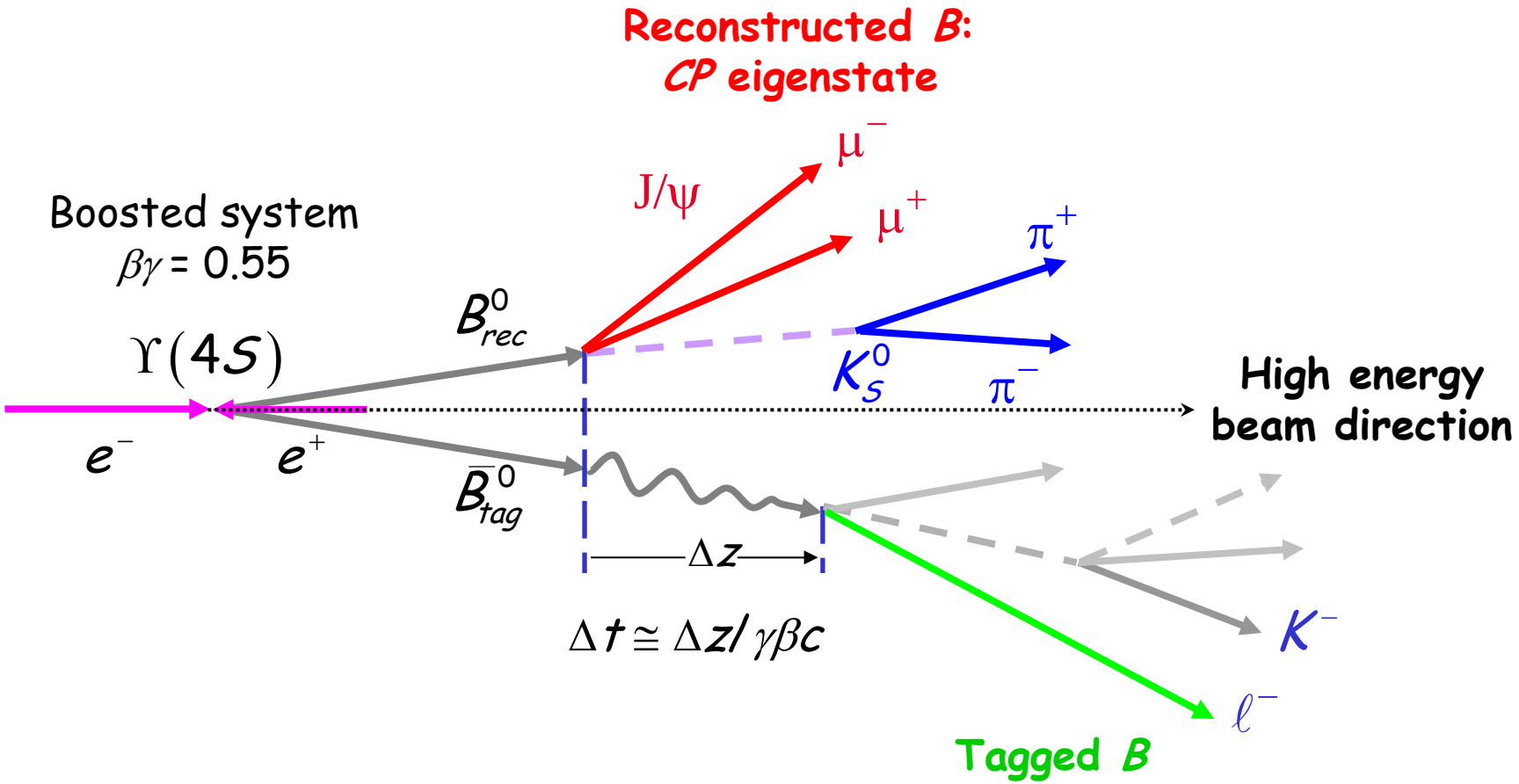
John Kogut (OHEP)

At the beginning

- ***Opportunities emerge from early b-physics experiments***
  - Discovered long *b*-quark lifetime at SLAC (1983) and large rate for matter-antimatter mixing in neutral *B* mesons (1987)
    - *CP* violation effects in *B* meson decays were numerous, predictable within the Standard Model, and often large and experimentally accessible
    - Opportunity to understand the origins of *CP* violation in nature's fundamental forces and its connection to the cosmological puzzle of matter dominance in the universe today
    - Terra incognito: little exploration of *CP* violation at the time
- ***A new kind of asymmetric energy e^+e^- collider***
  - Asymmetric-energy and resulting boosted *B*-anti-*B* meson system
    - A new collider design, based on large numbers of electron and positron bunches in two separate storage rings to provide the required numbers of *B* mesons

Kinematics that enable CP measurements



Developing the case for the B Factory

- ***Scientific case and possible technical approaches were developed in the period 1987-1993***
  - World-wide effort to develop the physics case and examine alternative technical approaches, including asymmetric colliders, Z^0 factories, linac-on-ring and linac-on-linac ideas
  - Snowmass study in 1988 was seminal in sorting out the optimal accelerator approach among these competing options
  - Workshops from 1989-1993 refined the asymmetric energy approach and experiment design, and established proto-experimental communities
    - To name a few: workshop reports SLAC-353 and SLAC-352 (Oct 1989), SLAC-373 (Mar 1991), and SLAC-400 (1992); PEP-II CDR SLAC-372 (Feb 1991) and SLAC-418 (Jun 1993)
  - These efforts positioned a number of potential host laboratories (DESY, CERN/PSI, Cornell, KEK, Novosibirsk, and SLAC) to develop costed, technically detailed proposals for review and funding consideration

Steps towards B Factory funding approval

- *Competing proposals for a B Factory were developed around the world: DESY, CERN/PSI, Cornell, KEK and SLAC*
  - 1990 HEPAP Subpanel led by Frank Sciulli recommended that the physics aims of a B Factory be studied and a vigorous R&D program be funded
  - 1992 HEPAP Subpanel led by Mike Witherell considered a *B* Factory under all funding scenarios and recommended that such a facility be built at SLAC starting in FY94 if $20M extra funding could be found
  - In July 1993 SLAC was recommended as the US site for a *B* Factory by a DOE/OHEP and NSF review committee chaired by Stanley Kowalski (MIT)
  - Shortly after cancelling of the SSC in fall 1993, Congress recommended new resources and the start of the *B* Factory as a Presidential initiative with $36M in FY94 & a 4-year funding profile
  - A 1994 HEPAP Subpanel led by Sid Drell, on closing down the SSC, recommended strong investments in the LHC effort in Europe, while pushing ahead with the Main Injector at FNAL and *B* Factory at SLAC

The B Factory construction project

- ***PEP-II was constructed by LLNL, LBNL, and SLAC , beginning in earnest in late 1993 with a project budget of $177M***
  - A management team was formed to carry out the PEP-II project under the leadership of Jonathan Dorfan (SLAC), Tom Eliof (LBNL) and Robert Yamamoto (LLNL)
  - The High Energy Ring, involving refurbished PEP magnets, new vacuum & rf systems, was finished first in 1997, with a beam stored on June 5th, 1997
  - The Low Energy Ring, involving new magnets, vacuum and rf system, was finished second in 1998, with a beam stored on July 16th, 1998
  - First collisions were observed on July 23, 1998 at 12:05 pm, completing the project ahead-of-time and on-budget
  - *BABAR* was rolled on-line in spring 1999, with first physics collisions on May 26, 1999
- ***PEP-II luminosity grew rapidly in the first year of operation, with the design goal of $3x10^{34}$ $cm^{-2}s^{-1}$ achieved in Oct 2000***

The international BABAR team

- ***BABAR was constructed and operated as an international collaboration from the start***
  - SLAC followed the European model and formed an International Finance Committee, which supported funding of common construction elements, and then operation, of the detector
  - An Interim Steering Committee helped define how the collaboration would function and managed the R&D program
  - R&D was supported by SLAC/OHEP to develop the needed technologies for a detector to survive in the environment of the *B* Factory
- ***Designing and building BABAR***
  - The *BABAR* Collaboration moved quickly through Letter of Intent (June 1994) and Technical Design Report (March 1995) under the leadership of David Hitlin (Caltech) as first Spokesperson
  - The $68M DOE detector construction project with matching outside US contributions was completed on-time and on-budget in March 1999

The *BABAR* Collaboration

9 Countries
72 Institutions
554 Physicists

USA [35/276]
California Institute of Technology
UC, Irvine
UC, Los Angeles
UC, San Diego
UC, Santa Barbara
UC, Santa Cruz
U of Cincinnati
U of Colorado
Colorado State
Florida A&M
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 Oregon
U of Pennsylvania
Prairie View A&M
Princeton
SLAC
U of South Carolina
Stanford U
U of Tennessee
U of Texas at Dallas
Vanderbilt
U of Wisconsin
Yale

Canada [4/16]
U of British Columbia
McGill U
U de Montréal
U of Victoria

China [1/6]
Inst. of High Energy Physics, Beijing

France [5/50]
LAPP, Annecy
LAL Orsay
LPNHE des Universités Paris 6/7
Ecole Polytechnique
CEA, DAPNIA, CE-Saclay

Germany [3/21]
U Rostock
Ruhr U Bochum
Technische U Dresden

Italy [12/89]
INFN and U Bari
INFN and U Ferrara
Lab. Nazionali di Frascati dell' INFN
INFN and U Genova
INFN and U Milano
INFN and U Napoli
INFN and U Padova
INFN and U Pavia
INFN, SNS and U Pisa
INFN, Roma and U "La Sapienza"
INFN and U Torino
INFN and U Trieste

Norway [1/3]
U of Bergen

Russia [1/13]
Budker Institute, Novosibirsk

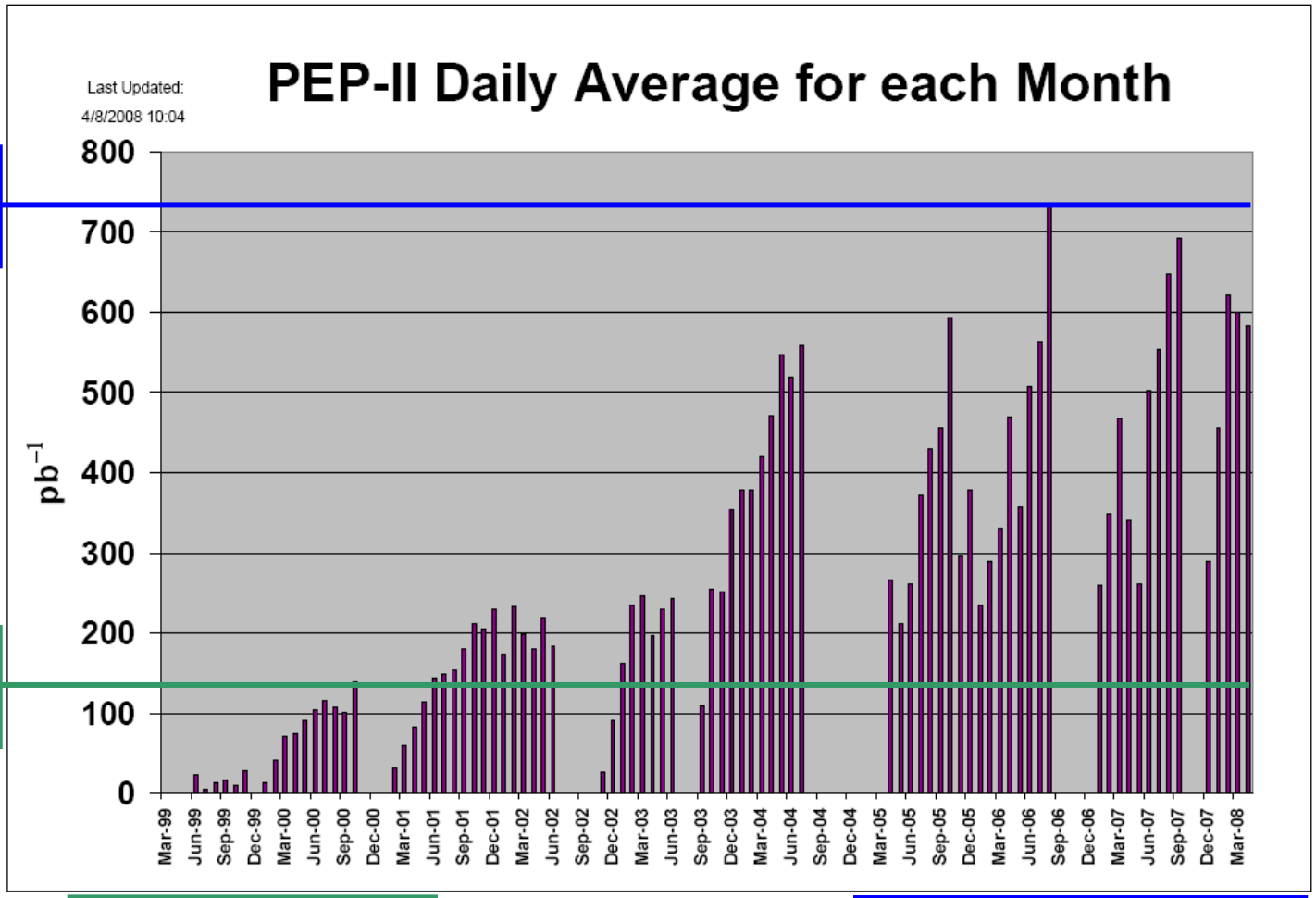
United Kingdom [10/80]
U of Birmingham
U of Bristol
Brunel University
U of Edinburgh
U of Liverpool
Imperial College
Queen Mary & Westfield College
Royal Holloway, University of London
U of Manchester
Rutherford Appleton Laboratory

Snapshot from 2001

The technical challenges of the B Factory

- ***Ambitious design goals for the PEP-II machine***
  - Factor of ~50 increase in peak luminosity over existing e+e- storage rings achieved by increasing the number of circulating bunches
  - Beam currents were factors of 20 higher than previous machines, with implications for backgrounds, high-order mode and synchrotron heating, outgassing and electron cloud effects
  - Two beam energies required two separate storage rings, brought into collision with spot sizes at the interaction point & tolerable backgrounds
- ***Ambitious design goals for the BABAR detector***
  - Tight integration with machine design due to background shielding and imbedded final focusing components
  - Challenges for particle identification, vertex reconstruction, large solid angle coverage despite boosted center-of-mass and goal of factory-like efficiency
  - Major computing challenges presented by multi-Petabyte data samples being analyzed by a large geographically distributed collaboration

Pushing the limits of PEP-II capability



Ultimately: 7x design

Design Goal: 135 pb^{-1}/day

Design achieved in 1st year

Ultimate peak luminosity: 4x design

The B Factory performance records

PEP-II Records

Last update:
April 8, 2008

Peak Luminosity

12.069×10^{33} $cm^{-2}sec^{-1}$ — August 16, 2006

1722 bunches 2900 mA LER 1875 mA HER

Integration records of delivered luminosity

Best shift (8 hrs, 0:00, 08:00, 16:00)	339.0 pb^{-1}	Aug 16, 2006
Best 3 shifts in a row	910.7 pb^{-1}	Jul 2-3, 2006
Best day	858.4 pb^{-1}	Aug 19, 2007
Best 7 days (0:00 to 24:00)	5.411 fb^{-1}	Aug 14-Aug 20, 2007
Best week (Sun 0:00 to Sat 24:00)	5.137 fb^{-1}	Aug 12-Aug 18, 2007
Peak HER current	2069 mA	Feb 29, 2008
Peak LER current	3213 mA	Apr 7, 2008
Best 30 days	19.776 fb^{-1}	Aug 5 – Sep 3, 2007
Best month	19.732 fb^{-1}	August 2007

Total delivered

557 fb^{-1}

PEP-II turned off April 7, 2008

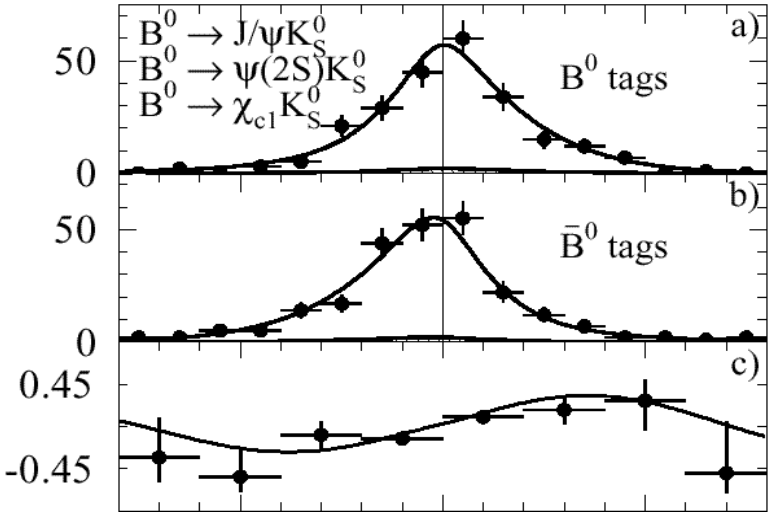
Incremental investments behind these records

- ***Original design was engineered with headroom:***
  - Magnets, RF system, vacuum system, interaction region, backgrounds, beam instabilities, bunch-by-bunch feedbacks, injection, & controls
- ***Continuous upgrades and operational experience achieved x4 peak and x7 integrated luminosity beyond original design:***
  - Improved understanding electron cloud instability and application of 30 Gauss solenoid windings for LER
  - Seven additional RF stations & new IR vacuum chambers to handle higher currents
  - Additional cooling for IP Be chamber bellows, masking near the IR, and development of high power vacuum expansion bellows
  - Improved feedback kickers, RF controls and feedback systems
  - Development of continuous injection and mitigation of related backgrounds
  - Improved understanding of machine optics and modeling, leading to new quadrupole lattices improved x-y coupling control

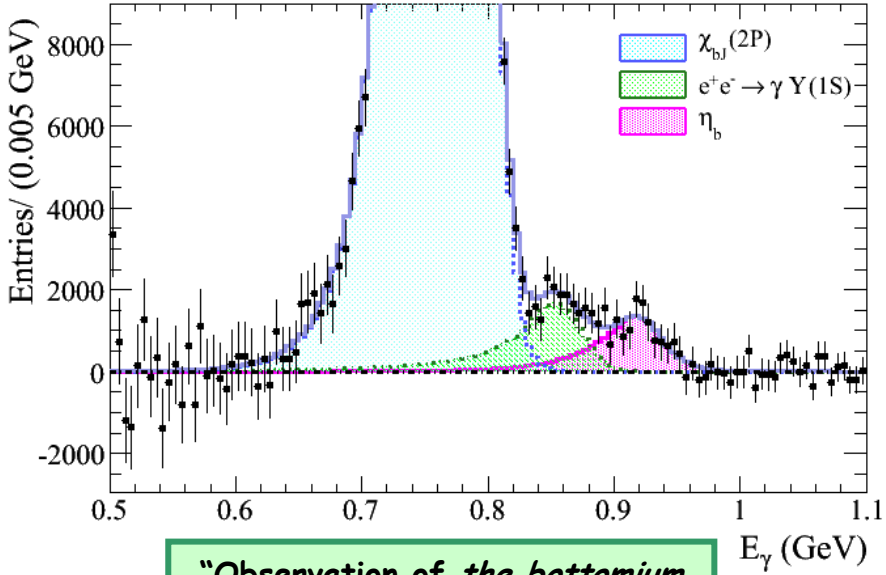
B Factory physics

- *Outstanding performance of the B Factory and BABAR have delivered outstanding science in more than 375 publications and over 200 graduate student theses*

1999 ---------- 2008



"Observation of *CP* violation in the B^0 meson system", PRL 87, 091801 (2001)



"Observation of *the bottomium ground state in the Decay Y(3S)->γη$_b$*", PRL 101, 071801 (2008)

Conclusions

- ***The science opportunity of the B Factory***
  - Made the case for the more than $300M initial investment required to execute this technically ambitious project
  - Motivated a strong laboratory partnership among LLNL, LBNL, and SLAC to construct PEP-II
  - Motivated the creation of a unique international partnership in the *BABAR* Collaboration, who designed, built and productively used the detector
- ***PEP-II and BABAR have delivered on their investments***
  - PEP-II pushed the limits of performance well beyond the original goals, enabling a much broader and richer physics program in the end
  - BABAR made important discoveries and together with BELLE have laid the foundations of heavy flavor physics
    - Validated the three family CKM matrix parametrization of the Standard Model, measured CP violating phase in myriad processes
    - Discovered flavor oscillations in D^0 decays
    - Discovered new puzzling heavy quark states of QCD
    - Placed precise constraints on models of New Physics