THE BELLE DETECTOR AT THE KEK B-MESON FACTORY

ANGELINA M. BACALA
Department of Physics, MSU-Iligan Institute of Technology
Iligan City 9200

ABSTRACT

The KEK B-meson Factory is a high energy electron-positron collider being constructed in the 3-km circumference underground tunnel of the National Laboratory for High Energy Physics (KEK) in Tsukuba, Japan. This new accelerator is designed to provide a hundred million pairs of B and B-meson each year. It will start data runs in early 1999.

The BELLED Detector is a giant particle telescope to be built at the KEK B-meson Factory by a collaboration of about 250 scientists from 45 institutions in 8 countries. The BELLE Detector will record the collisions of the asymmetric high energy lepton collider: an 8 GeV electron beam onto a 3.5 GeV positron beam. The data are expected to solve the long-standing puzzle of CP violation in elementary particle physics.

INTRODUCTION

There are two B-meson factories being built in the world. These new generation machines designed to produce millions of B-mesons per year are called the **PEP II** collider at the Stanford Linear Accelerator (SLAC) in California, USA and the **KEKB** located at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan. A huge particle detector that will observe the decays of the B-mesons at SLAC is called **Babar** while it is the **BELLE** Detector at KEKB. The objective of these experiments is to perform definitive tests of the Kobayashi-Maskawa model for CP violation in the decays of B-mesons. Both are expected to take physics data runs in early 1999.

The KEK B-Meson Factory (KEKB)

The KEKB is an asymmetric, two ring e^+e^- collider. The 3.5 GeV e^+ ring and the 8 GeV e^- ring are placed side by side inside the TRISTAN tunnel at KEK 100m underground which has a circumference of about 3 km. The two rings cross at two points but collide at only one point where the BELLE Detector is located. In each ring, 5000 bunches are stored giving the currents for the electron and positron at

1.1 and 2.6 A respectively. All the ring parameters (some are given in Table 1) were chosen so as to produce the required luminosity of 10^{34} cm^{-2} sec^{-1}. This goal luminosity will allow the production of 10^8 B-meson pairs per year which is the required number for the study of CP asymmetries. One of the most important features of KEKB is the finite crossing angle of ±11 mrad, in contrast to PEP II's design of zero crossing angle. Fig. 1 shows the layout of the two rings of KEKB.

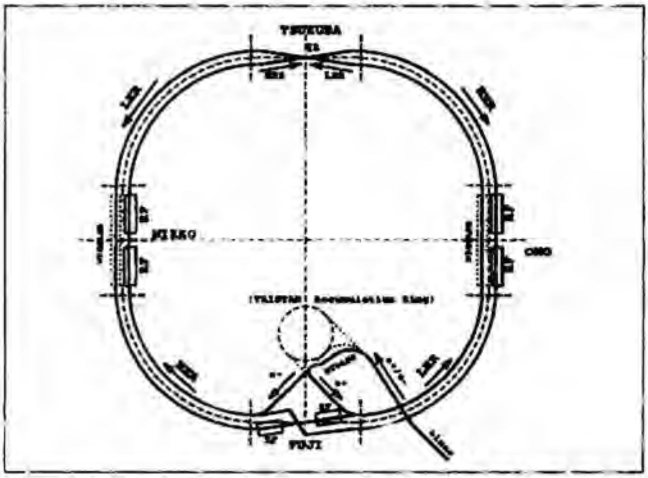

Figure 1. Configuration of the KEKB accelerator system.

Table 1. The Machine Parameters of KEKB and PEP-III high-energy electron-positron colliders.

Physics Start Date	KEKB (KEK) 1999	PEP-II (SCLAC) 1999
Max. beam energy (GeV)	e^-e^+: 8 × 3.5	e^-e^+: 9 × 3.1
Luminosity (10^{30} cm^{-2} sec^{-1})	10000	3000
Time between collisions (μs)	0.002	0.0042
Crossing angle (μrad)	±11,000	0
Bunch length (cm)	0.4	1.0
Bunch spacing (m)	0.59	1.26
Beam size ($μm^2$)	260 × 7	155 × 6
Bunches per ring per species	5120	1658
Average beam current (mA)	e^-/e^+: 1100/2600	990/2140
Circumference or length (km)	3.016	2.2
Dipoles in ring	e^-/e^+: 116/112	e^-/e^+: 192/192
Quadrupoles in ring	e^-/e^+: 452/452	e^-e^+: 299/326

Parity Violation, Charge Conjugation Violation, CP Invariance

Parity (P) is the operation of spatial refection, effecting the transformation on the position vector: $\mathbf{r} \rightarrow -\mathbf{r}$. P invariance means that the laws of physics are the same in a right-handed or left-handed system. For a long time the conservation of parity was believed to be a universal law of nature like angular momentum conservation. In the system of elementary particles, when parity invariance holds, particle production with a left-handed, polarization and that of a right-handed polarization occur at the same rate. However, in a 1957 experiment by Wu et al., parity violation was established in the β-decay of a sample of cobalt-60 nuclei. It was observed that fewer electrons are emitted in the backward hemisphere than in the backward hemisphere with respect tot he spins of the decaying nuclei; the so-called forward-backward decay asymmetry.

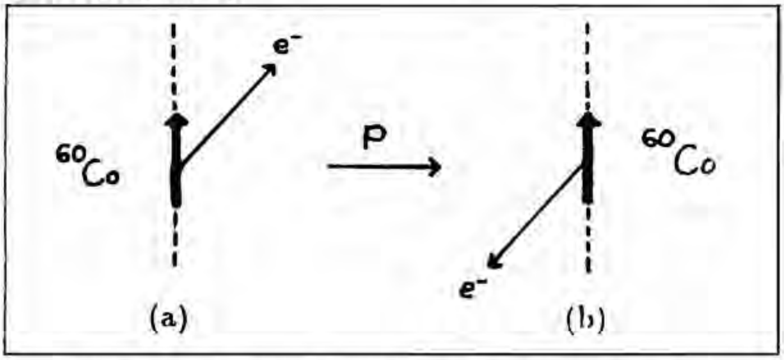

Figure 2. Effect of a parity transformation on C^o_{60} decay. Parity invariance requires the rates for processes (a) and (b) were equal.

Charge conjugation (C) reverses the sign of charge and magnetic moment of a particle leaving all other coordinates unchanged. Charge conjugation invariance means, as in P, that the same laws of physics is found in the system where one changes the particles to antiparticles. Violations of charge conjugation invariance is exemplified by the neutrinos and antineutrinos emitted in β-decay. Applying the charge-conjugation operation to the ν-state in Fig. 3(a), a left-handed antineutrino is obtained, Fig. 3(b). This however does not occur in nature. All neutrinos are left-handed and all antineutrinos are right-handed. But if in addition, we make the spatial inversion of the state in Fig. 3(b), we end up with a right-handed antineutrino, Fig. 3(c), which is observed. Thus the weak interactions are not invariant under C or P separately but they exhibit invariance in the conbined operation CP.

CP invariance has been verified in a wide variety of experiments involving weak interactions. It was believed that all types of interaction were invariant under the combined operation CP; like the weak interactions which are known to violate C- and P-invariance separately, but to respect CP-symmetry. In 1964, however, it was discovered by Christenson *et al.* that the long-lived neutral *K* meson which usually decays

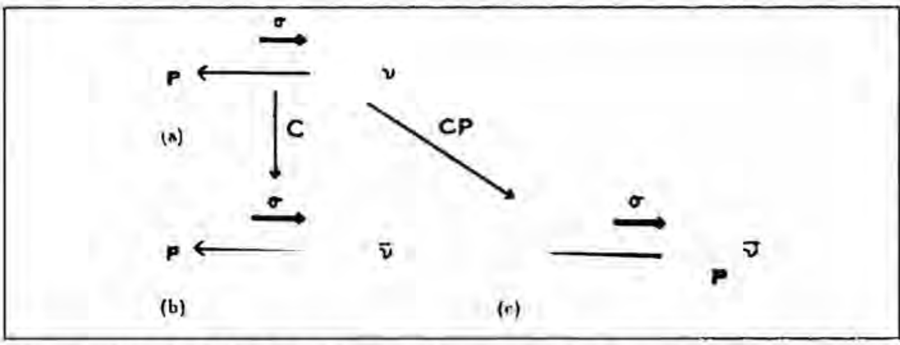

Figure 3. Result of the C- and P-operations on neutrino states.

into three pions, could occasionally decay into two pions which violate CP invariance. CP violation has not been observed outside of the *K* meson decay.

The B-meson, CP Violation

The bound states of *b* quark (b quark) and a lighter quark (lighter antiquark) are called B mesons (*B* mesons). Their masses are about 5 GeV; five times heavier than the protons. The b-quark is a down type quark of the third generation quark pairs and was first discovered in 1977 at Fermilab in proton-nucleon scattering experiments. In a survey of the *bb* system carried out at Cornell's Laboratory of Nuclear Studies, the Υ (4S) is the open *b* threshold where the *b* and *b* produced in the e^-e^+ annihilation pick up lighter quark pair from the vacuum and a form a pair of B mesons (Fig. 4).

In 1973, Kobayashi and Maskawa proposed to explain the origin of CP violation of *K* meson decays by introducing a third generation of quarks; giving six quarks in total. At that time, only three quarks were known to exist. The Kobayashi-Maskawa model explains the source of the CP violation in terms of the complex phases in the quark mixing parameters. This model also predicts that CP violation should occur in the B system as well.

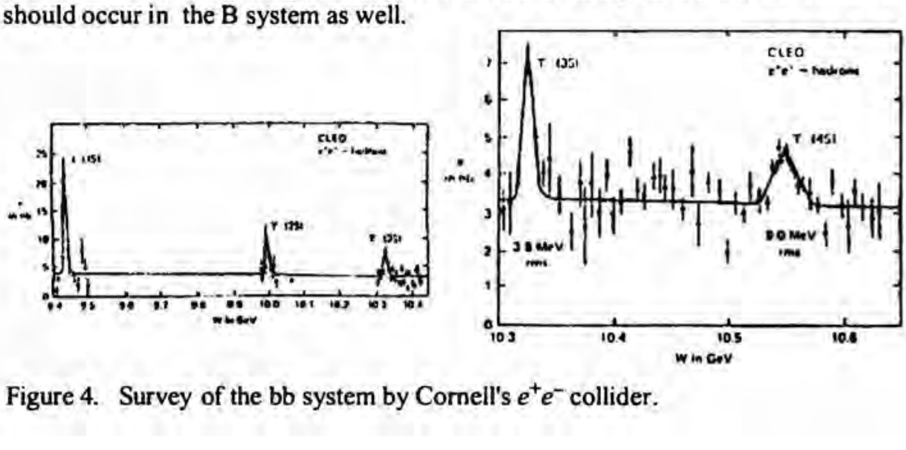

Figure 4. Survey of the bb system by Cornell's e^+e^- collider.

The fundamental importance of CP violation is now widely recognized. It may shed light on why the present-day universe is completely dominated by matter when right after the big bang, the universe consisted of exactly half matter and half anti-matter.

The BELLE Detector

Figure 5 shows the BELLE Detector now being constructed at KEK and which will be installed in the beamline of Tsukuba Hall in 1998. It consists of several tracking devices for charged particles, an electromagnetic shower counter for detecting γs and electrons and several different devices for identifying the particle types (π, K,μ, e).

The BELLE detector was designed based on the following requirements:

- Angular acceptance
  The angular acceptance for both charged and neutral particles is $17^o < \theta < 150^o$.
- Vertex Resolution
  The accuracy with which the distance between two B meson verteces is measured should be better than 100 μm.
  Silicon Vertex Detector (SVD)
- Charge particle tracking
  Detection of low momentum particles with $p_t > 0.05$ GeV/c is good.
  Central Drift Chamber (CDC) in 1.5 T magnetic field
- Particle Identification
  Particle identification capability of π, K and e should be good enough. Aerogel Cerenkov counter (ACC), TOF counters and *dE/dx* in CDC
- Electromagnetic calorimetry
  High efficiency and good resolution, in particular, for low energy photons are necessary.
  homogenous CsI(TI) calorimeter.
- K_L and muon detection
  High detection efficiency and good resolution in angle measurements for K_L and muons are needed.
  return yoke instrumented with resistive plate counters

The B-mesons produced in KEKB are boosted along the beam direction and typically travel about 190 μm before they decay. The silicon vertex detector having a cylindrical configuration consisting of double-sided silicon detectors measures the z position with an accuracy of 80μm.

The central drift chamber (CDC) is a cylindrical device filled with helium gas and contains several thousand very thin wires set at positive voltage. This is placed inside a 1.5 T solenoidal magnetic field. This device measures the position, curvature, momentum and ionization energies of different particles.

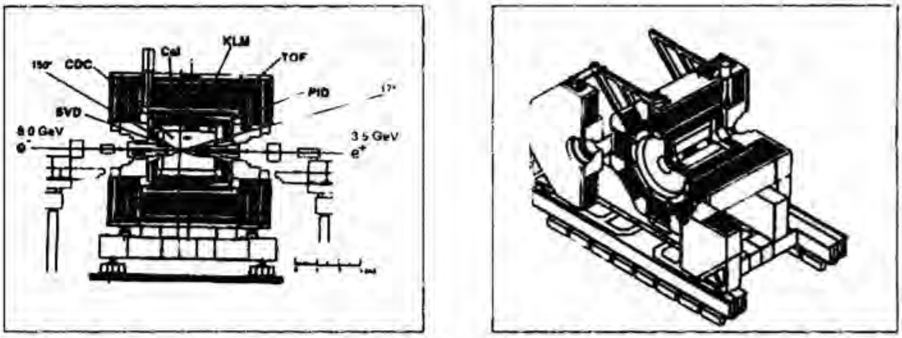

Figure 5. Side view and birdseye view of the BELLE Detector.

Low momentum K mesons can be distinguished from low momentum pions by the different spectra of cerenkov radiation which they generate when they traverse the aerogel cerenkov counter (ACC).

Electromagnetic calorimetry is provided by a highly segmented array of CsI(Tl) crystals about 9000 in number each about 30 cm long. The scintillation light produced when high energy particles traverse the crystals are collected by photodiodes attached tot he crystals and the amount of charge collected provides a precise energy measurement of the exiting particle.

The muons and neutral kaons can be identified by the charged particle tracking detectors sandwiched with the segmented iron. The muons travel through the iron without being absorbed unlike pions and kaons.

The BELLE Collaboration

The BELLE group is an international collaboration consisting of about 250 researchers from 40 institutions in 8 countries. During the March 22, 1997 meeting of the BELLE collaboration held at the University of Hawaii, the author was accepted as one of the collaborating members of the BELLE group.

REFERENCES

T. Nozaki, Nuclear Physcis **B50**, (1996)288-295.

K. Rybicki, BELLE Note # 139, September 17, 1996.

Particle Data Group, *Review of Particle Physics*, Physical Review **D54**, 1 July 1996.

BELLE Collaboration, *A Study of CP Violation in B Meson Decays*, Technical Design Report, March 1995, KEK Report 95-1.

K. Abe, B *Meson Factory and CP Violation*, KEK Preprint 93-119, September 1993.

B Physics Task Force, *Progress Report on Physics and Detector at KEK Asymmetric B Factory*, KEK Report 92-3, May 1992.

B Task Force, *Physics and Detector of Asymmetric B Factory at KEK*, KEK Report 90-23, March 1991.

D.H. Perkins, *Introduction to High Energy Physics*, Addison-Wesley (1981).

B.R. Martin and G. Shaw, *Particle Physics*, John Wiley & Sons (1992).