Around the Laboratories

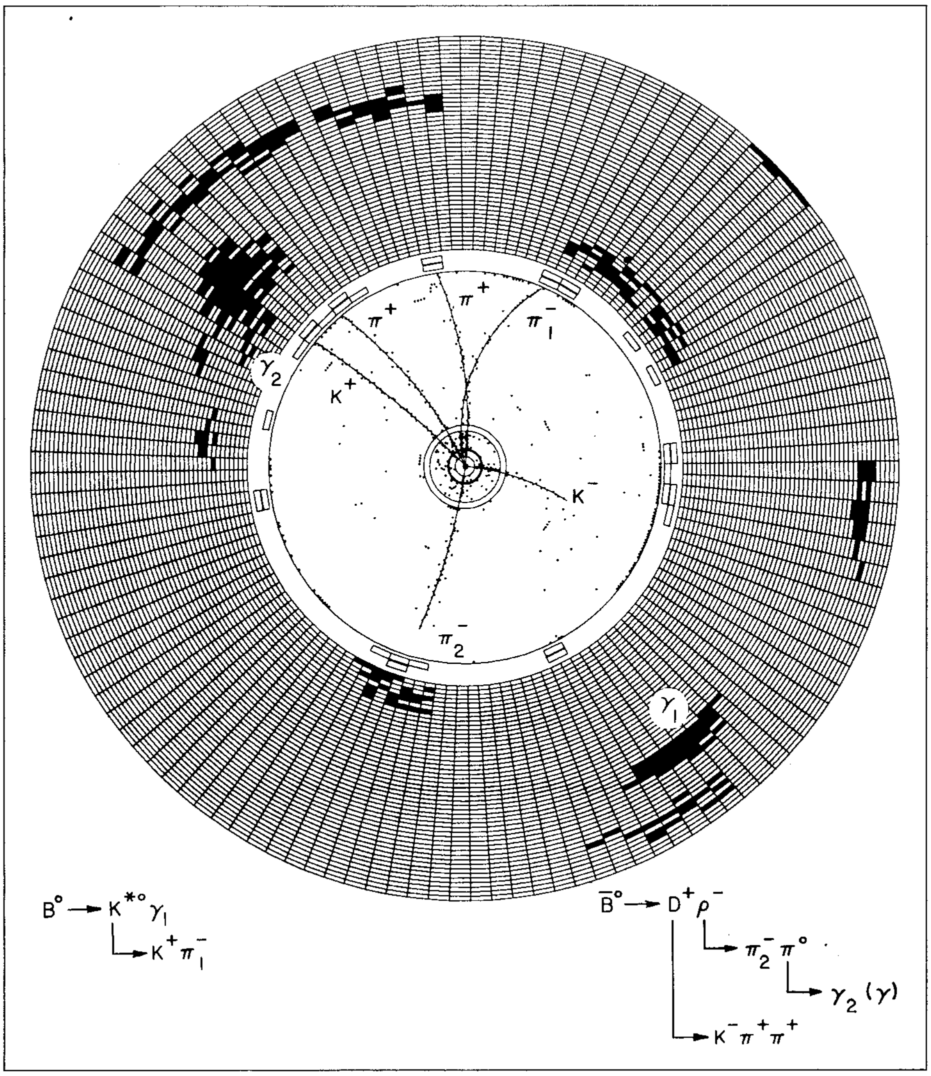
CORNELL
CLEO discovers B meson penguins

The CLEO collaboration at Cornell's CESR electron-positron storage ring has discovered a rare type of B meson decay in which only a high energy photon and a K* meson are produced. These decays provide the first unambiguous evidence for an alternative route for heavy quark decay that has been given the whimsical name "penguin diagram".

In the mid-1970s penguin diagrams were proposed to explain the puzzling strangeness quantum number selection rules in the decay of K mesons. At the same time it was realized that penguin diagrams could also be important in the CP violation seen in neutral K meson decay. CP violation, an asymmetry between matter and antimatter, is an essential ingredient in understanding why there is much more matter than antimatter in the universe. CP violation introduces a definite direction to the arrow of time, which could otherwise point equally forwards or backwards. In addition, penguin decays are very sensitive to some extensions of the Standard Model of weak decay.

Although penguin diagrams were first proposed to explain an effect in K meson decay, the K system gives no unique signature for them, and verification of penguin processes meant looking elsewhere.

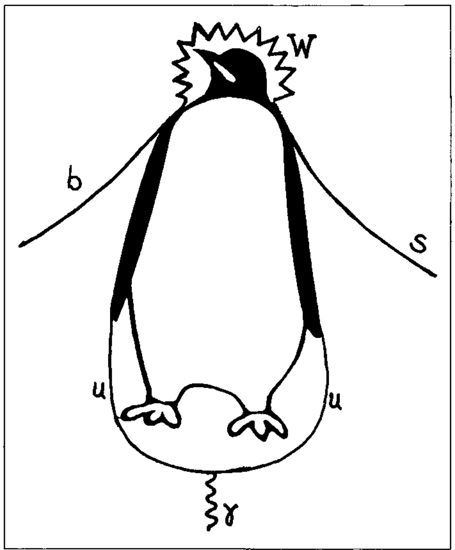
In the Standard Model, quarks decay under the influence of the weak force, emitting a W boson. Since the W is charged, the charge of the initial quark differs from that of the final quark, so the charge of the quark changes as well as its flavour.



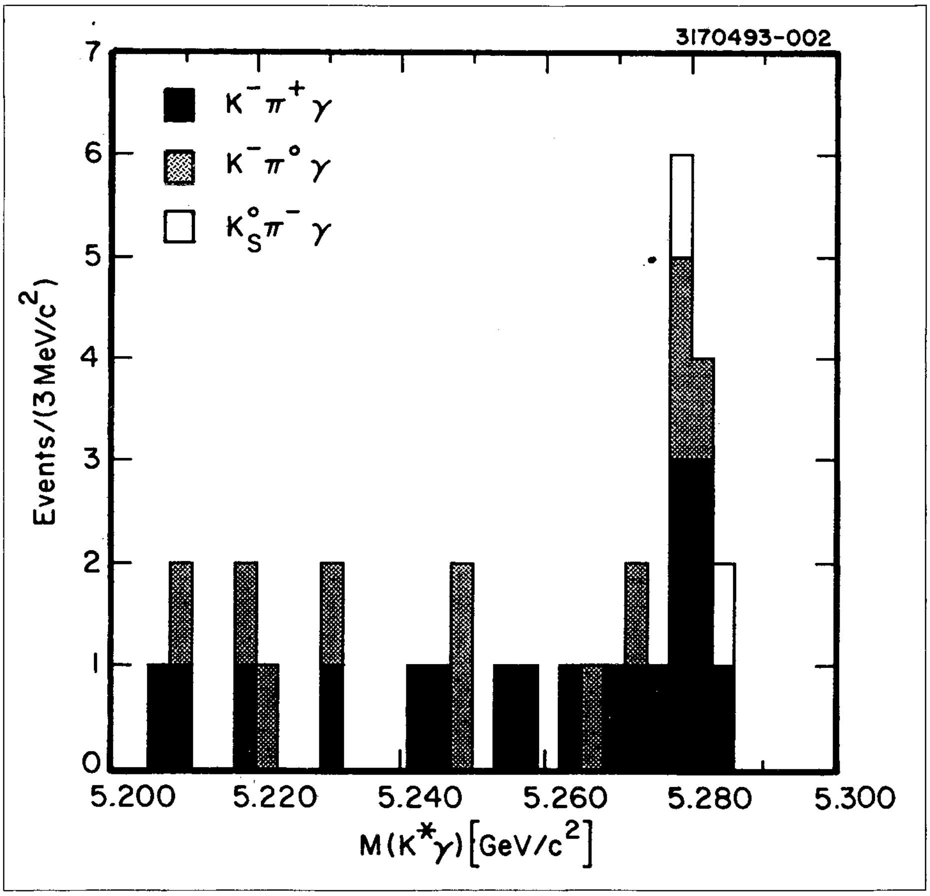
Computer display of a CLEO event in which all of the particles produced in the decays a B meson pair have either been observed or inferred. One B decayed in an electromagnetic penguin mode; the other decayed conventionally. The curved tracks in the large inner circle are the tracks of the charged particles in a drift chamber in the 1.5 T magnetic field. The outer region with its radial-angular segments is the "barrel" portion of the CLEO II cesium iodide electromagnetic calorimeter. Each segment represents a counter as it would appear in perspective if one were looking down the barrel. The photons in the event are indicated; the other black segments are due to charged particles in the counter or usual background signals from stray particles from other sources.

B mesons contain beauty (b) quarks, with charge -1/3, which ordinarily decay to charm (c) or up (u) quarks with charge +2/3. So far there has been no evidence for "flavour changing neutral currents" which would result in quark transformations without changing electric charge. In a penguin process, a b quark can also decay to an s quark via a one-loop process (2nd order effect) in which a W boson is emitted and then reabsorbed. Since the b and s quarks have the same charge, this process is an effective flavour

Penguins at work. When a quark transforms under the influence of the weak force, it necessarily changes its electric charge as well as its quark 'flavour'. In so-called 'penguin' processes, two such quark transformations couple back-to-back, providing an additional, but very rare route for quark transformation. In the process seen at Cornell an emitted photon is seen accompanied by a K meson, formed by the strange quark emerging from the penguin mechanism combining with a spectator up or down quark.*



The distribution of masses reconstructed from K, pi, and photon candidates for 'penguin' decay of B mesons seen by the CLEO detector at Cornell's CESR electron-positron collider. The 13 events in the peak between 5.274 and 5.286 GeV is the signal for the decay. Events at lower mass are due to random combinations of particles from other processes.



changing neutral current. Accompanied by the emission of a high energy photon, the decay is known as an electromagnetic penguin decay. B meson decays which result in only a K* meson and a high energy photon are a striking and unambiguous signature for this type of process.

Events in which a B meson decays to only a K* and a photon are rare - approximately one per 20,000 decays. Taking into account the inefficiencies of even the best detector, more than a million B mesons are needed to obtain an unambiguous signal. During the last two years, over 3 million B mesons were recorded in CLEO. At CESR, B mesons are produced in pairs without additional particles, so the events are very clean and the energy of the B mesons is fixed - a good environment for studying rare B decays.

Both the B and K* mesons decay much too quickly to be observed directly in the CLEO detector, so they must be reconstructed from their decay products. The search for these penguin decays starts with identification of a high energy photon in the detector in coincidence with a K and pi meson. If a number of other selection criteria are satisfied, the K and pi are checked to see if they are consistent with their being the products of the decay of a K*. If so, the reconstructed K* is combined with the high energy photon, and the total energy of these particles is compared to the energy of the CESR electron and positron beams. This constraint on the energy of the decay products eliminates nearly all background due to random combinations of K mesons, pi mesons, and photons that come from other processes.

Once these three candidate particles have been selected, the mass of the parent particle that might have produced them can be calculated. The peak in the mass spectrum at the B meson mass, 5.280 GeV, shows that many of the candidates actually resulted from the decay of a B meson. Of the 13 events in the peak, only about two are attributable to background.

These decays establish the existence of the electromagnetic penguin decay process, but theoretical understanding is not yet sufficient to make accurate calculations of specific processes. However reliable calculations can be made for the total rate including all electromagnetic penguin decays, and these calculations are sensitive to the existence and masses of the sixth (top) quark and a hypothetical charged Higgs boson, neither of which have been observed. Now that the existence of

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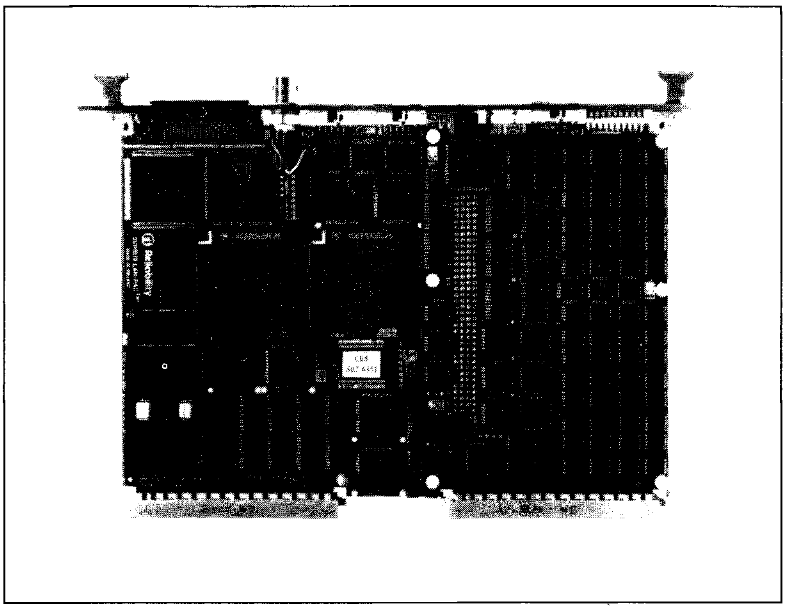

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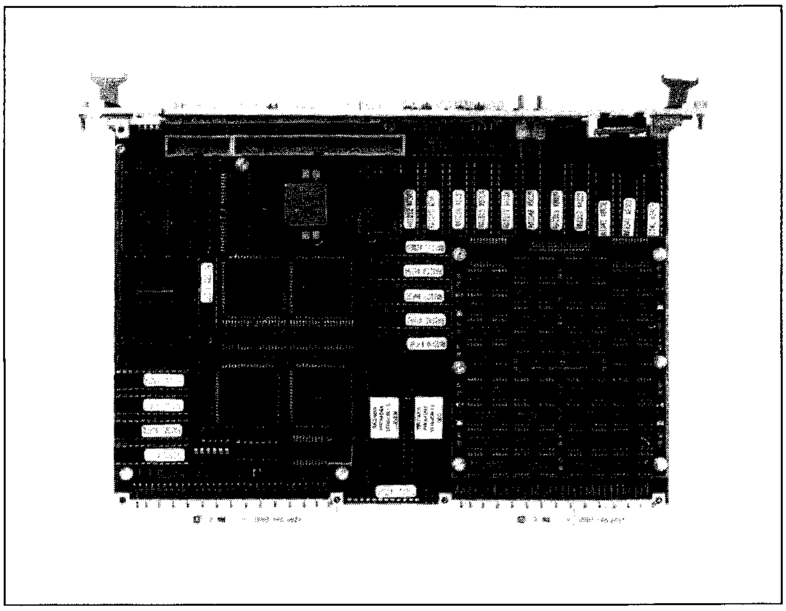

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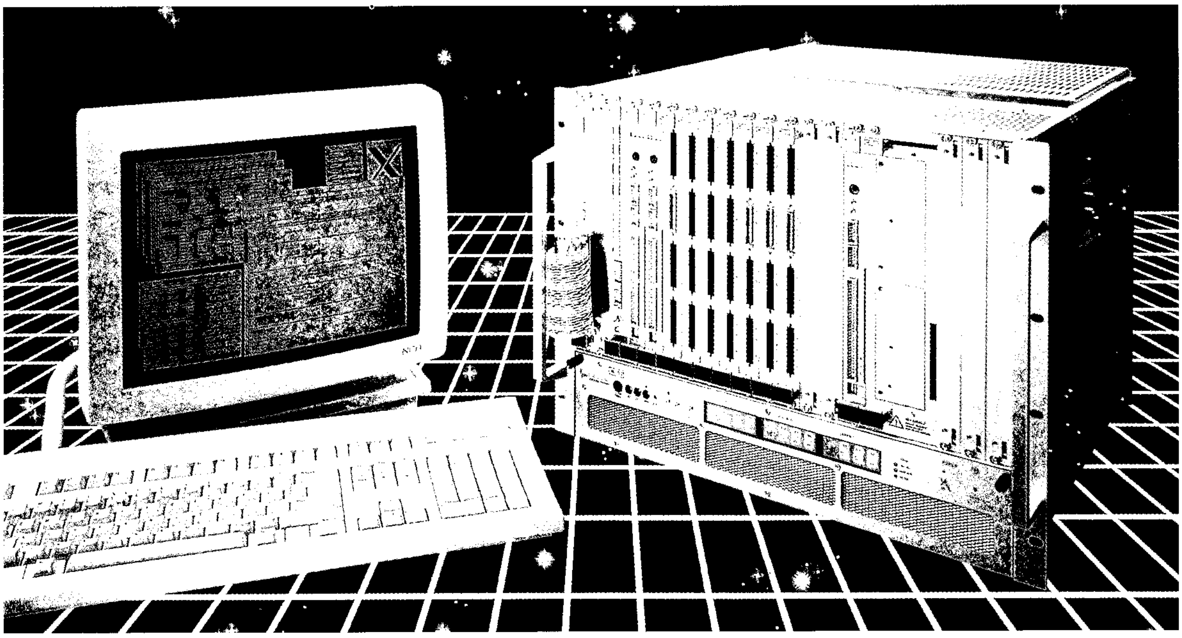

electromagnetic penguin processes has been established, conclusions derived from measurements of the rate of inclusive decays are substantially more significant.

The CLEO collaboration has also searched for electromagnetic penguin decays by looking for photons in an energy region where these decays should dominate. The number of photons observed is not significantly larger than the number expected from background electron-positron annihilation processes in which no B mesons are produced. The resulting upper limit, 5.4×10^{-4}, for the rate of inclusive electromagnetic penguin decays rules out a large class of models that include charged Higgs bosons with masses in the 100 GeV range. This result sharpens the focus of ongoing Higgs searches.

Further elucidation of the role of penguin diagrams in heavy quark decay requires much larger samples of B mesons. Cornell is currently upgrading the luminosity of CESR by at least a factor of five (December 1992, page 17). Cornell also has an asymmetric B Factory proposed as a further CESR upgrade (July/August 1991, page 8).

CERN
Materials science with radioactive isotopes from ISOLDE

Among the major physics objectives at CERN's ISOLDE on-line isotope separator is the growth field of nuclear solid state physics, where the goals are both technological and scientific. ISOLDE research entered a new era when the facility began operations last year in its new home at the 1 GeV Booster synchrotron (July 1992, page 5). Nuclear solid state physics accounts for about 30% of ISOLDE beam time, other research highlights being nuclear physics, atomic physics, nuclear astrophysics, and biophysics.

The achievements so far and ongoing goals of nuclear solid state research were covered in a recent workshop - 'Materials Science with Radioactive Isotopes' - held at CERN from 5-7 April. This carried on from where the 'Radioactive Implants in Materials Science' meeting in Bad Honnef left off in January 1992.

The main aims of the CERN meeting were:

- to show the outstanding possibilities offered by ISOLDE for solid state experiments using short-lived isotopes;
- to stimulate discussion between physicists using nuclear techniques and those employing other methods; and
- to look for collaboration opportunities between present ISOLDE users and other researchers: small teams could be strengthened to provide a very cost-effective way of exploiting ISOLDE beams.

Nuclear solid state physics at ISOLDE is mainly focused on the investigation of defects and impurities in semiconductors, but will also be used for metals, surfaces and interfaces, using nuclear techniques such as radiotracer diffusion, emission channeling, and Mössbauer or Perturbed Angular Correlation Spectroscopy (PACS).

The hitherto serious limitation of many nuclear methods due to a restricted range of chemically different suitable radioactive probe atoms can be easily overcome by ISOLDE's lengthy isotope menu.

Thus whole new classes of semiconductors become accessible for PACS, yielding information on the annealing of radiation damage after heavy ion implantation and on the hydrogen passivation of acceptor dopants. Emission channeling has been used to investigate the lattice site location of implanted lithium-8 (see front cover).

Radioactive isotopes also open up new techniques, for example the Conversion Electron Spectroscopy of Valence Electron Configurations (CESVEC), where the detection of conversion electrons by a high resolution beta spectrometer gives the energy state density of the probe atom's valence electrons.

Participants at meeting also heard how combining standard techniques like Deep Level Transient Spectroscopy (DLTS) with radioactive isotopes can overcome otherwise inherent 'chemical blindness' - the decay rate of the radioactive implant identifies the chemical species and gives the energy levels of chemical impurities. This trick can also be applied to optical techniques like photoluminescence or electric methods like the Hall Effect.

Summarizing at the end of the CERN workshop, R.C. Newman of the Interdisciplinary Centre for Semiconductor Materials Research at London's Imperial College pointed out that more collaboration between the nuclear and conventional technique communities would be useful, while non-nuclear techniques should exploit the advantages of radioactive isotopes to get additional information. 'The conference has made us aware of new possibilities,' he concluded.

(See front cover illustration)