The BEAST Background Commissioning Experiment

Early in the design of KEK-B it was realized that backgrounds produced by the accelerator would impose significant constraints on the operation of the KEK-B machine as well as on the operation of the BELLE detector. Therefore, at the commissioning stage it is important to have a detector in place that is capable of measuring backgrounds. The goal is to use this detector to understand the backgrounds and then tune the machine so that backgrounds will be at a tolerable level at the beginning of BELLE roll-in and operation. The acronym BEAST for "Background Exorcism for A STable experiment" was suggested by Junji Haba as an appropriate name for a background commissioning experiment which precedes the BELLE experiment. The first results of background commissioning from BEAST are now available.

Backgrounds are produced by two mechanisms. These are interactions of the beam with residual gas in the vacuum chamber (henceforth referred to as particle backgrounds) and synchrotron radiation (SR) produced by tails of the beam. The particle backgrounds are due to two kinds of interactions: Coulomb scattering and bremsstrahlung of electrons (or positrons) off residual gas molecules in the vacuum chamber. The KEK-B machine uses a crossing angle geometry to avoid parasitic collisions between the incoming and outgoing beams. In this scheme, the incoming beams are centered on the magnetic axes of quadrupoles to avoid large synchrotron radiation backgrounds. Simulations confirm that this will lead to small SR backgrounds. Since the crossing angle provides sufficient separation of the beams, a strong bending magnet directly adjacent to the IP is not required; this feature should also maintain particle backgrounds at a manageable level.

There exist simulation tools which allow the size of all the types of background to be predicted. The background is expected to be dominated by bremsstrahlung particle backgrounds. The BELLE detector component which is most sensitive is the readout electronics for the silicon vertex detector. The initial silicon electronics uses the VA1 readout chip which begins to experience severe radiation damage problems at doses of 200 krad. The simulation predicts that at design beam current and vacuum pressure of 1 nTorr (N_2 equivalent), the dose will be about 25 krad per year of operation. In some accelerators, such as CESR, after considerable effort the observed backgrounds and simulations agree at the factor of two level. Nevertheless, there are large uncertainties in the background simulation for a new accelerator. These include: the final level of vacuum pressure that can be achieved as well as effects that are very difficult to simulate such as radiation doses during injection, misalignments and multiple turn effects.

It is therefore prudent to observe and measure the real backgrounds. The BEAST experiment was conceived and proposed by Dr. Saroj Sahu of the University of Hawaii (and graduate of Saga University in Japan) as a simple and flexible background commissioning detector. A collaboration of many institutions quickly formed to construct and operate the BEAST experiment. These institutions are KEK, two Australian universities: the University of Melbourne and the University of Sydney, the University of Hawaii, Cracow University in Poland, INP in Novisibirsk, Russia, and National Taiwan University.

To measure the backgrounds, the BEAST includes sandwiches of PIN diodes separated by a layer of Pb, MOSFETs to measure integrated doses, drift tubes to measure single particle rates and leakage currents, a partially instrumented BGO calorimeter, CsI(Tl) and pure CsI crystals and two ladders of silicon vertex detectors. The PIN diodes, drift tubes and the mechanical structure for the BEAST were built and assembled at the University of Hawaii. The MOSFETs were provided by the Melbourne group. The CsI(Tl) and CsI crystals were assembled by the Novosibirsk group while the BGO crystal calorimeter was built by the Taiwan group. The BEAST is located at the IP inside the concrete radiation shield. The DAQ system, which is critical for the actual operation of the BEAST, was prepared by the Melbourne group. Readout electronics modules, power supplies, gas and other facility support was provided by KEK.

The 12 diode packages are distributed to three locations along the beam in each of four phi quadrants. Some of the diodes are located at the same radial distance and z position as the silicon electronics in the final BELLE detector. The ratio of doses recorded in the front versus back diodes can be used to distinguish SR, which has energies in the keV range, from particle backgrounds in the MeV range. RTDs are included in the diode packages to allow temperature dependence of the diodes to be calibrated out. The diodes are attached to a metal layer above the beam pipe to avoid temperature dependent shifts from beampipe heating. MOSFETs are used to measure integrated doses. In these devices a shift in threshold voltage is proportional to the dose. (Two types of MOSFETs are used: K-type and R-type.) The K-type MOSFETs have enough dynamic range to cover doses up to 200 krad. Drift tubes which are Al cylinders with a single wire and filled with HRS gas are used to measure the rates expected in the BELLE drift chamber. The 53 tubes are distributed in two layers of 21 and 32 tubes at radial distance of 7 and 45 cm, respectively. Both pulse and total current signals are available from the drift tubes. The partially instrumented Extreme Forward Calorimeter (EFC) consists of 72 BGO crystals. These crystals are mounted on the front faces of the final focus (QCS) cryostats. They will be useful for measurements of the energy spectrum of particle backgrounds and will allow BEAST to trigger on Bhabbas when collisions occur. The CsI(Tl) and pure CsI crystals will be useful for measuring the energy spectra of particle backgrounds and testing the radiation sensitivity of these devices. The pure CsI crystals have faster signals but smaller pulseheights than the Tl doped crystals.

The DAQ system uses the UNIDAQ system and runs on a LINUX PC in the small BEAST electronics hut (known affectionately as the "BEAST Cage"). The DC voltages from diodes and from other detector components are read out using IOTECH modules. A user interface based on TcL allows the BEAST shift person to start and end runs as well as monitor background levels.

The background commissioning began in mid December 1998. BEAST shifts are manned 24 hours/day during commissioning. As soon as the beam made the first turns in KEK-B clear signals were observed in the BEAST detector. In the first week of operation many problems and bugs in BEAST hardware and software were found and solved. By the time, stable fills with currents of 10 mA in the HER were achieved, the BEAST was debugged and ready to analyze the background.

BEAST runs from Dec 21-Dec 27 have been analyzed. The run taken on the evening of December 25th was the most useful so far for background studies since this run has the largest dynamic range in HER beam current (10 mA to 1 mA) and the most stable conditions. The background in the diodes as a function of HER beam current was measured using data from this run. The background in a steady state fill was found to be a quadratic function of beam current. The background from particles is expected to be proportional to the product of beam current and vacuum pressure. Due to the outgassing of the vacuum pipe, the vacuum pressure increases linearly with beam current. Thus we expect such a quadratic dependence if the background is dominated by particle backgrounds rather than SR. This is also consistent with the ratio of front/back diodes which is found to be around 2.5.

In late December 1998, measurements of the instantaneous dose rates normalized to beam current and vacuum pressure were also obtained for the HER. The rate at the location of the silicon electronics is about 15 mrad/sec/A/ntorr. At present, the dose rates are about a factor of ten higher than the dose predicted from simulation. However, this conclusion and extrapolation depends on the assumption that the vacuum pressure will improve dramatically so that the final pressure at full beam current is 1 nTorr. In addition, there were many known problems with the beam optics during these early test runs.

The background during HER injection was also measured and found to be comparable to the background during steady state running. Again, this observation was made at an early stage of operation when beam losses during injection were large. In early January 1999, LER backgrounds were observed.

In the coming months, the BEAST will observe backgrounds during high current commissioning operations and plans close cooperation with the KEKB optics and vacuum groups to reduce the backgrounds to tolerable levels for the BELLE experiment.