Letter of Intent: Large Angle Beamstrahlung Detector at SuperB

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Abstract

We are interested in building a Large Angle Beamstrahlung Detector (LABM), which is also being built for SuperKEKB, for the SuperB accelerator. The device could already be tested at the Daphne accelerator in Frascati, with an extended data taking in the second half of 2013. The interest for the Cabibbo laboratory would be the acquisition of a technology with measurement capabilities both unique and crucial for future B factories.

I. INTRODUCTION

It is well known that the major technical challenge of the future Super B factories is to produce and maintain colliding beams of a size never achieved before. Whereas current e^+e^- storage rings produce beams with transverse heights $\sigma_y \sim 3$ μm and widths $\sigma_x \sim 350$ μm, the new factories nominal parameters are 50 nm and 10 μm respectively. Even at the relatively large sizes of today's beams, transverse mismatches such as those shown in Fig. 1 reduce and ultimately limit the machine's luminosity. In particular, at KEK the low energy ring (LER) had a consistently higher σ_y than the high energy ring (HER), and it was found necessary at times to monitor and adjust the relative beam sizes of the LER and HER beam sizes in order to maximize the luminosity.

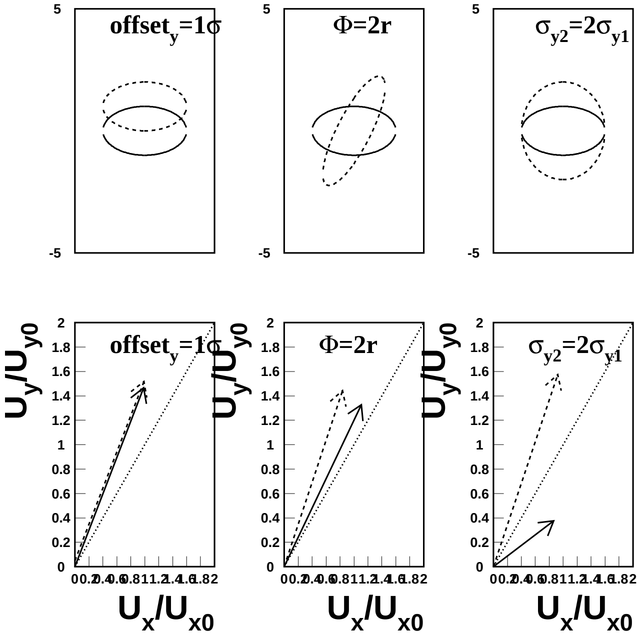

FIG. 1. Beam-beam mismatches and the equivalent beamstrahlung diagram patterns. One beam is going into the page, the other is coming out of the page. First column: beams are offset. Second column: one beam is rotated. Third column: one beam is unfocussed. The diagrams are built by plotting the large angle beamstrahlung yield, for each beam (solid or dashed arrow) and the yield for each polarization U_x, U_y.

At SuperB and SuperKEKB, we will be working with truly pioneering storage rings, and beam-beam mismatches such as those shown in Fig. 1 are to be expected. If the luminosity is to improve over a relatively short time, the beam configurations need to be measured and monitored directly and passively, and any beam-beam mismatch needs to be uniquely identified.

The LABM provides just such a set of direct and passive measurements, which are illustrated in the second row of Fig. 1 and depict how the polarized large angle beamstrahlung radiation, collected over a restricted azimuthal angle, changes when the transverse beam parameters change. The vectors are constructed by plotting the measured radiated polarized energies U_x, U_y, divided by calculable normalization constants (which are equal to one in the case of collinear beams) for each beam. The vector pattern is unique for each mismatch, and the diagram identifies which beam needs to be corrected, the type of correction, and how much correction is needed [1]. The LABM concept has been extensively tested at CESR and papers and presentations about it are collected at the website [2].

At the future B factories, beamstrahlung is abundantly produced (7.0 and 1.9 kW total radiated power for the SuperB HER and LER respectively), and small (2×2.8 mm^2) 45 degrees mirrors placed inside the Beam Pipe at 7 and 8 mrad and located at ±90 degrees in azimuth will intercept of the order of 10^{12} beamstrahlung visible photons per second at nominal conditions. Such abundant signal will provide a lot of opportunity to precisely measure beam parameters.

II. LABM MOTIVATION.

This Section lists specific measurements which become available when the LABM is part of the diagnositc arsenal of a machine. At SuperB, we assume that instrumentation will mostly be derived from KEKB instrumentation. Other beam monitors of interest may be the Arcs Beam Interferometers in the visible and X-ray bands (AI), the Luminosity Monitor (LM), and the Beam-Beam Deflection (BBD) measurements using the Beam Position Monitors near the Interaction Point (IP).

The SRM and XRM would be located in the Arcs and would measure respectively σ_x using synchrotron radiation and σ_y using X-rays. Their main limitation is the fact that the beams are measured away from the IP, and diagnostics depends on a good knowledge of the transport matrix from Arcs to the IP. Since the transport matrix is itself a source of error, this method is often cross checked against other methods.

The LM measures zero degrees γ rays produced in radiative Bhabha scattering. Because it consists of a small calorimeter located far from the IP, this method was found to suffer from systematics due to changes in the beams angles. The LM also produces only one number, proportional to the luminosity. If the luminosity goes down, it offers no diagnostic power.

The BBD is limited to two quantities measured, the transverse offsets of the two beams centers. While more information can be obtained by scanning one beam through the other in a Linear Collider, this procedure is not available at a storage ring, because the new offset produces a new Twiss matrix for the machine.

The last two beam-beam mismatches in Fig. 1 can only be measured directly and passively with the LABM. Other measurements of interest include:

- cross checking both the AI and the BBD measurements with a single device. This may seem of secondary importance, but at KEKB feedback systems were designed only when two devices were sensitive to the same effect. In particular the Ground Motion feedback system should have both the LABM and BBD devices in coincidence.

- if disagreements with the AI are recorded, then elements of the transport matrix from the arcs to the IP will be measured.
- The LABM can measure the bunch lengths σ_z instantaneously through its spectral information[3], described in Section 3. This is important at the Super B factories, because the luminous region is only 200 μm long, which is comparable with the Silicon Vertex Detector resolution.
- The redundancy of measurements described in Section 3 can be used to measure and characterize the beam halo, in particular to measure separately the intermediate tails due to the beam-beam and to the Touschek effect. The device can also measure the relative alignment of the beam pipe and the beam, and the final quadrupoles and the beam. The better the alignment, the lower both the synchrotron and Touschek backgrounds.

Finally, in all manners of Machine Studies the possibility to get a direct, unambiguous response for an optical change by the operator should be invaluable in rapidly achieving high luminosity.

III. LABM DETECTOR.

The LABM detector is similar to the one built and operated at CESR [4], with important modifications that should decrease various sources of systematics by orders of magnitude.

The initial part of the device is a Beam Pipe Insert, shown in Fig. 2, and is virtually identical to the one developed for CESR. It contains metal polished mirrors welded to the Beam Pipe, vacuum windows on smaller, standard vacuum flanges [5].

The location of this piece and size of the mirrors are not sensitive parameters. Basically, this device should work precisely at any location corresponding to an angle between 6 and 12 mrad with respect to the direction of the observed beam at the Interaction Point. Technical drawings of the parts from Cornell are available for viewing.

This part collects light at the mirrors, sends it through the vacuum window in a vertical direction, where it strikes a remotely controlled second mirror (not shown). Mapping of the light intensity in the Beam Pipe is done by scanning the solid angle by changing the pitch and yaw of the second mirror.

The rest of the device consists of Optical Channels which transport the light to an Optics Box, where the light is split into polarizations and wavelength bands and counted (Fig. 3). Briefly, the light is split into two polarizations by a wide band Wollaston prism, and each polarization is spread onto four counters by a ruled grating, which maximizes the reflected intensity in the first order peak. By changing just the grating and the photodetectors, this device can monitor the intervals $225 < \lambda < 495$ nm (UV), $300 < \lambda < 660$ nm (VIS), and $400 < \lambda < 880$ nm(IR). The individual light beams are concentrated by light collectors so that both large photon counters (PMTs) and Si-PMTs can be used. It is noted that, at full luminosity, we plan to replace the UV PMT with nanotube photocathodes, currently developed at INFN Napoli, and IR and visible PMTs with Si-PMT. The photon counters are mounted on a vertical conveyor belts which allows online relative channel calibration (this

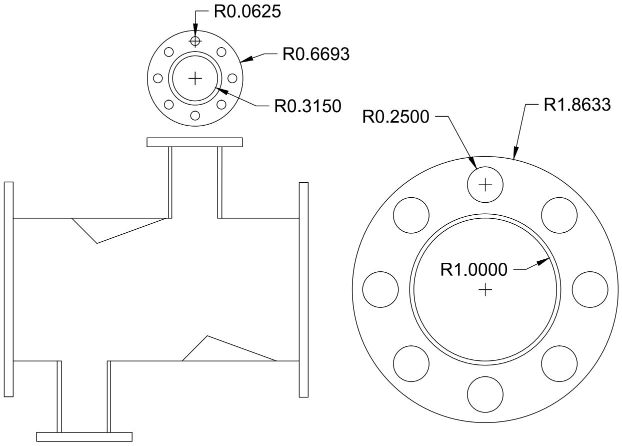

FIG. 2. Beam Pipe insert similar to the one built for CESR. 45 degrees mirrors reflect light out through vacuum windows and into the Optical Channels.

part not shown in Fig. 3), allowing the experimenter to study small counting asymmetries and relate them to changing beam conditions. The box and connected electronics can also be placed in the same area as the Beam Pipe Insert, as there is ample space to place a crate. The photon counters to be used consist of PMTs Hamamatsu R4095 (VIS), R-1160E(UV), and Si-PMT from Advansid (IR). All these photon detectors are in hand in sufficient numbers to conduct the test. PMT voltages that mimic the typical pulse height of a Si-PMT have already been evaluated using the WSU Test Bench Facility.

In total, two viewports per beam are envisioned (at the top and bottom of the beam pipe, or $\phi = \pm 90^o$). The light seen by each viewport is split into two polarizations and each polarizations into four bands. This totals 32 electronic channels.

The electronics consists of fast, low-bits ADCs connected to a FPGA array, which can be programmed to fill all sorts of histograms for offline analysis. These include integration over 1 msec, one histogram per bunch, or following a single bunch over time.

IV. MEASURABLES AT SUPERB.

There is a lot of work in progress on theoretical calculations of large angle beamstrahlung yields, with a paper expected this summer. Here we review some of the asymmetry measurements which can be done, and how they related to beam parameters.

As stated in the previous Section, one beam will be observed by two viewports, each of which will split light into 8 channels, each monitored by a photodetector. Photodetectors can be rotated around so that any one can look at the channel monitored by another one. By illuminating the set up with an unpolarized source, one can measure directly the relative optical efficiency of each channel and the relative quantum efficiency of each photodetector. The same procedure can be repeated during real data taking to insure a relative calibration

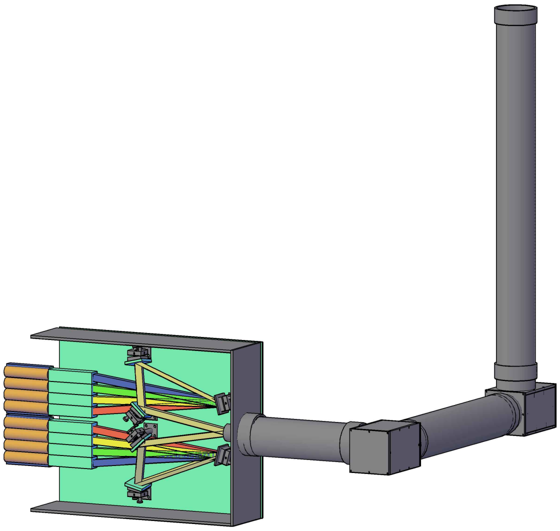

FIG. 3. Optical Channel and half of one Optical Box. The mixed light beam is immediately split into two polarizations, then each polarization is spread in four different bands which are collected and counted.

of 0.3% or better.

Once a calibrated device is available, one can first check that the beam and beam pipe are properly aligned. This is equivalent to reqeusting that any up-down counting asymmetry, over a long enough period of time to integrate ground motion, be zero

$$A_{ud} = \frac{U_u - U_d}{U_u + U_d},$$

where U_i is the measured counting rate for couter i. Over short periods of time, however (less or of order 1 msec), ground motion may induce the two beams to move vertically with respect to one another. A SuperKEKB note [6] indicates that the LABM has sensitivity similar to the BBD for time varying vertical offsets, through the combined statistical power of A_{ud} and the asymmetry that can be derived by the diagrams of Fig. 1, which is [1]

$$A_1 = \frac{U_y - U_x}{U_y + U_x}.$$

Therefore, the LABM and BBD can in principle be used as the two devices needed for automatic ground motion feedback.

The LABM is the sole device that can pick out a difference in vertical beam sizes between the two beams. The asymmetry of interest is, after corrections for unequal beam population and energy

$$A_2 = (U_{y1}/U_{y2}) - 1,$$

that is, an asymmetry in $y-$polarized light yield between beam 1 and beam 2. For collinear beams, the relation between this asymmetry and the waste parameter w, defined as

$$w = 1 - L/L_0,$$

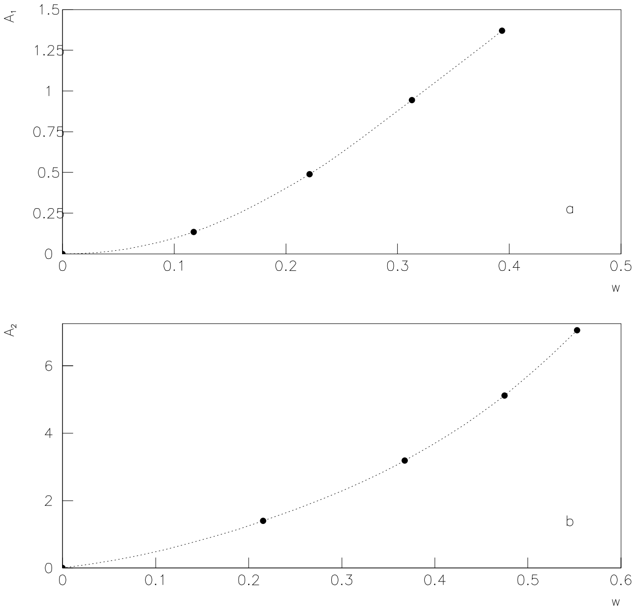

FIG. 4. Beam-beam asymmetries dependence on wasted luminosity. The quantities are defined in the text.

and first studied in Ref. [1], is shown in Fig. 4.

The spectral information is used to determine independently the signal and the background. From CESR, it is known that backgrounds are dominated by tail particles at large angle, while the signal has spectral features that allow a direct measurement of the beam length. For collinear beams, the spectrum at a given angle θ is

$$\frac{d^2U}{d\Omega d\lambda} \propto \exp -(\pi\sigma_z\theta^2/\lambda)^2.$$

It is noted that at SuperB tails are dominated by the Touschek effect, which is a single beam effect, so that they can be measured directly by running the machine with a single beam.

V. CURRENT STATUS.

The LABM detector for SuperKEKB, with the exception of the Beam Pipe to Optical Channel mechanical connection, is completely designed. A wood prototype has been completely tested and the first Optics Box is being built. Parts of the Optical Channels have been built and tested. The exact path of the Optical Channel is not yet known, so that only the elbows will be produced ahead of time, while the pipes will be produced shortly before installation. The website [2] offers pictures and drawings of the device.

VI. A POSSIBLE TEST PROGRAM AT DAPHNE.

There could exist the possibility of testing the LABM over an extended period of time (a few months) at DAPHNE. The test is to debug the device while observing passively the DAPHNE beam, but there are other points of interest which could help the SuperB program.

First, we note that the beamstrahlung at DAPHNE can be experimentally observed in one of the polarizations (Table I) and in the infrared and red bands. Generally, large beam crossing angles increase the $x-$polarized yield, while also significantly decreasing the typical wavelength at a given angle. These results have been obtained by software developed by WSU and Tabuk and have not been published yet. While observing large angle beamstrahlung may not be of help for the DAPHNE Machine Group, we can certainly provide them with an accurate map of the beam halo by scanning our device in angle. Second, we would like to eventually test the Nanotube-based photocathodes developed by Dr. Ambrosio at INFN Napoli, the sole device that has both UV sensitivity and can work at the really large rates which are expected at SuperB and SuperKEKB. In the process, we would involve more participants who are committed to SuperB and could become significant players later.

TABLE I. Daphne projected observed beamstrahlung rates. The following beam parameters were assumed: beam energy 500 MeV, bunch length 1.6 cm, bunch transverse dimensions of 200 and 24 μm respectively, crossing angle of 0.05 rad, beam populations of 3×10^{10}, and 110 bunches per beam. A flat, 20% photodetector efficiency is assumed, and observation is at $9 < \theta < 10$ mrad, and $88.5 < \phi < 91.5$ degrees.

Band	Rates (Hz)
U_x, $750 < \lambda < 900$ nm	1×10^6
U_x, $600 < \lambda < 750$ nm	3×10^5
U_x, $450 < \lambda < 600$ nm	3×10^4
U_x, $300 < \lambda < 450$ nm	2×10^2
U_y, $750 < \lambda < 900$ nm	3
U_y, $600 < \lambda < 750$ nm	< 1
U_y, $450 < \lambda < 600$ nm	< 1
U_y, $300 < \lambda < 450$ nm	< 1

VII. CONCLUSIONS.

In conclusion, we propose to operate the LABM at Frascati in the second half of 2013. One month of purely passive beam observation would provide a lot of information about the detector performance. A Beam Pipe modification, to allow extraction of light beams, is needed, but the group would otherwise bring a complete detector.

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