**The Twelfth KEKB Accelerator Review Committee Report**

## Introduction

The Twelfth KEKB Accelerator Review Committee meeting was held on March 19-21, 2007. Heino Henke and Shin-ichi Kurokawa were unable to attend this meeting. Appendix A shows the present membership of the Committee.

The Twelfth Committee meeting followed the usual format of oral presentations by the KEKB staff members and discussion by the Committee members. The Agenda for the meeting is shown in Appendix B. The first day started with KEKB performance and, in particular, the progress on commissioning the crab cavities. The Upgrade Studies were then presented and continued on the second day. The Committee was again impressed by the high standard of the talks, both the technical content and the presentations themselves. The recommendations of the Committee were presented to the KEKB staff members before the close of the meeting. The Committee wrote a draft report during the meeting that was then improved and finalized by e-mail among the Committee members.

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**Executive Summary**

**A) Foreword**

KEKB continued to make excellent progress since the last Committee meeting. The peak luminosity has increased to a new world record of 1.71 x $10^{34}$ $cm^{-2}s^{-1}$, 71% above the design luminosity of $10^{34}$ $cm^{-2}s^{-1}$ (at this time last year it was 1.627 x $10^{34}$ $cm^{-2}s^{-1}$ and the year before it was 1.52 x $10^{34}$ $cm^{-2}s^{-1}$). The Committee congratulates the entire KEKB project staff on this new record. However, it is clear that the luminosity is almost saturated and it will need a new initiative like the crab cavities to make a significant improvement over the present record. The BELLE detector has accumulated 710 $fb^{-1}$, another world record (563 $fb^{-1}$ at the last meeting) and has published, or submitted for publication, a total of 206 papers in refereed journals (163 at the last meeting).

The meeting was devoted to the present status of KEKB, the accelerator physics limitations to the luminosity and, in particular, progress with the crab cavity – a world first! There were also many talks on the R&D for upgrading KEKB to a luminosity of 6-8 x $10^{35}$ $cm^{-2}s^{-1}$. Unfortunately, there was still no news on the plans for the SuperKEKB project as the proposal for SuperKEKB has not been actively pursued by KEK. This is because the laboratory is committed to completing J-PARC as soon as possible, and this takes most of the (reduced) budget. The Committee continues to endorse the proposal for SuperKEKB, particularly in light of the number of High Energy Facilities that are planned to close in the next two to three years (HERA, PEP-II, and Tevatron). The Committee hopes that funding will become available for upgrade KEKB, as this would keep KEK at the forefront of High Energy Physics research for the next two decades.

The KEKB machine group has done an enormous amount of excellent work, and is to be congratulated on the impressive results that have been achieved.

**B) Summary**

KEKB continued to make excellent progress over the last year, with new luminosity records: highest peak luminosity: 1.712 x $10^{34}$ $cm^{-2}s^{-1}$, highest daily integrated luminosity: 1.232 $fb^{-1}$, highest seven-day integrated luminosity: 7.81 $fb^{-1}$, and highest 30-day luminosity: 30.21 $fb^{-1}$. The luminosity increased slowly until December, but as predicted, no large improvements were seen, despite testing many different ideas. The crab cavities were installed during a shutdown in January and commissioning was continuing at the time of the Review. The implementation of crab cavities is a world first and is an indication of the capabilities of the KEK staff.

The Belle detector has now accumulated 710 $fb^{-1}$, of which 147 $fb^{-1}$ were obtained since the last Review. The "Oide scenario" made several years ago was that 750 $fb^{-1}$ would be accumulated by this time – a very accurate forecast. The agreement would have been even better, but the budget forced a reduction in operations from 274 days in FY05 to 227 days in FY06 (a ~20% reduction). The crab cavities should increase the luminosity accumulation rate when they are fully commissioned, and if everything proceeds according to plan, the time lost to commissioning should made up by the time of the next Committee meeting. KEKB still appears to be on track to accumulate 1 $ab^{-1}$ by summer 2008.

Most of the running this year has been at the Upsilon 4S state, but the accelerator was tuned to the Upsilon 5S state for a successful three-week run. This is an exciting new Physics opportunity for BELLE.

The Belle detector is generally working well but has been upgrading the data acquisition system to reduce the deadtime. Backgrounds are low, and losses during beam injection are small. Continuous injection has been acceptable to the detector but has necessitated suppressing 3.5 ms of data taking during each injection cycle. Overall, the Belle collaboration is extremely pleased with the quality and quantity of the beam being provided by the accelerator.

## C) Recommendations

**Last year, the Committee made many recommendations, and the KEKB staff has addressed all of them. Some of these related to the priorities of the program and are reiterated below, together with recommendations for continuing the work that has already been started.**

1. While the Committee believes that the crab cavity program will be successful, it requests that the KEK management create a road map for KEKB operations under two different scenarios:
    a. The crab cavity is successful and KEKB operations continue at ~400 $fb^{-1}$ per year.
    b. If after considerable effort, the crab cavity is unsuccessful, KEKB operations continue at ~200 $fb^{-1}$ per year.

    It would also be extremely helpful for planning and optimizing operations if the KEK management could provide an indication of the kind of information that would influence a decision on SuperKEKB
2. The Committee endorses the studies to design a major luminosity upgrade (SuperKEKB) aimed at a luminosity of 8 x $10^{35}$ $cm^{-2}s^{-1}$ and recommends that they be continued.
3. The Committee strongly endorses the plan to continue preparations for simultaneous injection in all four rings.
4. The Committee recommends continuing the studies of a movable mask which is 'electrically invisible' (rod with ceramic support) and has a much lower loss factor. A significant amount of R&D remains to demonstrate a reliable, operational movable mask with a reduced loss factor.
5. The Committee feels that HOMs is one of the limiting factors in increasing the current. Detailed studies of the vacuum components including proper damping and component cooling should be continued. Continued follow-up of the failures of the standard vacuum components should be made to establish critical operating parameters, and to put limits on them.

**The Committee has made new recommendations throughout the different sections below. Highlights of these recommendations are summarized here.**

6. The Committee recommends extended alternating high and low beam current studies to improve the chances of success with crab cavities and to make sure there is sufficient beam study time to obtain satisfactory results and complete understanding. BELLE could take data during the high current running.
7. The Committee recommends that KEK participate in the multi-laboratory studies of a Super-B Factory based on extremely low emittances and long bunches colliding at a large angle with a "crab waist."

8. The Committee recommends that the KEK management provide the necessary support to create the Fuji test beam line facility.

## B) Findings and Recommendations

### 1) Overview

KEKB has performed well last year; the record peak luminosity of 1.781 x $10^{24}$ is extremely impressive. As expected, the luminosity is about saturated and there is unlikely to be much increase in luminosity without a major change in configuration. The many years of investment in the crab cavities has finally paid off, and two cavities were completed, tested, installed, and successfully commissioned during a long shutdown in January and February. Beam commissioning with crab cavities is going well but several mysteries still present them selves.

The importance of this new capability cannot be underestimated. The idea is now 23 years old, and the conceptual design for the actual cavities is 15 years old. However, no other laboratory has been able to carry out the necessary development, and results from KEK are eagerly awaited. Given the short amount of commissioning time, the results are extremely encouraging with a 15% increase in specific luminosity having already been demonstrated.

The plan to continue commissioning for 2-3 weeks of low current studies then 1 month of high current crab cavity study may be too restrictive. A more productive approach would be to alternate 2 week of low current operation and 2 weeks of high current operation until all avenues have been studied. For example, there may be high current effects which need some time to fix and then try again.

The many R&D activities aimed at upgrades and future accelerators are very important and have produced significant new capabilities (e.g. *in-situ* SEY measurements) and component improvements. The design of SuperKEKB is progressing well with exciting IR concepts under investigation. We suggest continuing to improve the design in the context of the emerging global Super B-Factory collaboration until the laboratory is able to commit to a specific course of action.

### 2) Beam Commissioning before Crab Cavity

KEKB is a mature machine with an outstanding record of advances that have made it the undisputed highest luminosity collider world wide, as well as exceeding its own design goals by over 70%. This is a remarkable achievement that has the highest respect and commendation of this Committee.

It is not at all surprising that the luminosity is beginning to approach an asymptotic level. This was foreseen, and plans to add crab compensation to the beams crossing angle to enable a large factor improvement in luminosity were made long ago. Still, measurable improvements in performance have been made in several areas since the last meeting of this Committee. Better understanding of optics and improvements in operating point were factors, as well as improved hardware reliability.

In the past year peak luminosity has increased from 16.27 to 17.12 x $10^{33}$-$cm^{-2}$-$sec^{-1}$ and integrated luminosity per day from 1.18 to 1.23 $fb^{-1}$. Constraints on operating time reduced the number of HEP days from 274 to 227. Nevertheless, the total integrated luminosity has reached 710.3 $fb^{-1}$. During operations, frequent topping up has kept the luminosity duty factor close to 1. Beam aborts continue to be reduced, and the reliability of hardware components has improved during this year.

The decrease in number of operating days in 2006 is distressing, as is the outlook for 2007 due to budget constraints. In spite of this constraint, the KEKB staff has delivered an impressive integrated luminosity.

Several changes in optics and tuning techniques were explored. A slight lowering of HER tunes and the introduction of sextupole tuning as part of coupling reduction have improved the luminosity by a few percent. The sextupole effect is not understood, though orbit control may be a factor (as presented by Fukuma). Discovery of a skew quadrupole power supply in the LER that took on unpredictable (minimum) values has improved luminosity recovery time after accelerator maintenance periods.

However, it was found that lowering the LER horizontal emittance from 18 to 10nm did not produce the expected performance benefit due to coherent beam-beam effects which limited the bunch current. Increase the strength of 1452 electron cloud suppression solenoids did not produce observable benefits, and a trial with smaller $\beta^*_X$ in both rings resulted in short beam lifetimes in the limited tuning time available.

The process of improving performance of such complex systems must involve some trial-and-error. We applaud the continuing initiatives of the KEKB accelerator staff to find improvements in machine operating parameters.

A significant investment in hardware reliability was made with the installation of supports to prevent flexing of vacuum bellows and their sliding RF fingers caused by temperature cycles during beam current changes. The measured motion was reduced by a factor 2-2.5 in 80 bellows. However, since the supports have not completely prevented failures, further improvements are being explored.

The Committee recognizes the talented and dedicated work to improve KEKB operations.

The present focus is correctly on successful implementation of crab compensation of the crossing angle. In addition we encourage continued work to improve reliability and tolerance to high currents at short bunch lengths.

Recommendations:

1) Continue the study of the role of sextupole strengths in tuning coupling and luminosity.

2) Continue parameters exploration to search for luminosity gains, big or small. Do not be discouraged that many changes may turn out to be unproductive.

3) Continue the emphasis on improving reliability through reduction of beam aborts, recovery time, and hardware failures.

## 3) Belle Status

With KEKB consistently providing high luminosities, Belle has been collecting data at a high rate, accumulating a total of 710/fb at the time of this meeting. An Ypsilon (5S) run was also carried out at a reduced beam intensity. During FY2006, thirty-two papers describing physics results at Belle were published.

Belle reduced its unscheduled downtime significantly since 2005. In 2006 hardware problems in Belle kept the machine off less than 1% of the year compared to over 7% the previous year.

While the present DAQ system is adequate even for the impressive luminosity delivered by KEKB, the higher luminosity possible with the crab compensation would result in excessive dead time. Therefore a new "Copper" DAQ with a pipelined architecture has been designed. The Belle team is presently upgrading to this system that, when completed, is expected to shorten the dead time per event by a factor of 10 from 30 microseconds to 3 microseconds, assuring efficient data acquisition for foreseeable upgrades to KEKB luminosity.

One of the most significant recent results from Belle has been the detection (with 3 sigma resolution) of D0-D0bar mixing by measuring the lifetime differences between the various decay modes of D0. In addition, Belle data confirmed the B-Bbar entanglement and thus established quantum mechanics in the 10 GeV energy regime. A third significant accomplishment to search for dark matter candidate showed a negative result with a new upper bound of dark matter production at 1 GeV level.

Belle accumulated 275 million B-Bbars up to 2005, 535 million B-Bbars up to 2006, and is aiming for 1 billion B-Bbars soon. With the expectation that the luminosity might be doubled with a successful operation of the crab cavities, the Belle-KEKB team has adopted a strategy to allow sufficient operation and machine study time for commissioning the crab cavities. The Committee endorses this strategy, and wishes to re-emphasize the fact that the crab cavity is a pioneering R&D project. Sufficient study time should be provided to reach its maximum benefits. This is the case even with a reduced KEKB budget in the present fiscal year.

#### 4) BPM Displacement Monitor

Although the BPMs in KEKB rings are fixed to quadrupoles, the thermal stress from beam heating causes motion of the BPM relative to the magnets, and particularly, the sextupoles. KEK staff has developed, carefully characterized, and are implementing capacitive gap detectors to monitor changes in relative position between the sextupoles and the BPMs so that offsets can be applied to correct the beam position measurements.

Data show that moderately fast horizontal movements of the BPMs relative to nearby sextupoles of up to 0.9 mm take place during beam aborts, and somewhat smaller motions occur during machine startup periods. The vertical movements are an order of magnitude smaller. Simulation and measurements correlating changes in betatron tune with this motion confirm the link to beam properties.

Other data show that there is motion of the BPM relative to the quadrupole of roughly 2/3 this amount. We observe that, while there is a direct (and rather robust) mechanical connection of the BPM to the quadrupole, the structure appears insufficient to compete with the thermal stress produced on the chamber.

A simple and precise capacitive gap detector with a resolution of 0.2 μm and a range of 0.5 – 2.5 mm has been developed at KEK. The reproducibility of the sensor is about 1 μm and the contribution from the non-corrected non-linearity is +/- 2 μm over the measurement range. Currently the biggest source of error is the thermal movement of the fixing arm which is 20 μm/10 deg. (horizontal) and 5 μm/10 deg. (vertical) which, with a tunnel temperature stability of about 1 degree correspond to errors of 2 μm in the horizontal and 0.5 μm in the vertical directions. If necessary, these errors could be reduced by designing fixing arms with better thermal properties, a solution proposed by the KEKB staff.

The plan to measure the BPM positions relative to the sextupoles and correct the BPM offset accordingly should provide the means to compensate for the errors described above.

Since the gap detectors will be essential elements in maintaining accurate orbits, the reliability of their operation is quite important. Algorithms to detect malfunctioning gap detectors will be necessary.

Comments:

1) The plan presented is a good approach to mitigate the effects of beam duct motion

2) The algorithm to correct the BPM data based on the capacitive gap detector readouts must be robust; bad data from the gap detectors must be identified and appropriate compensation made.

## 5) Crab Cavity Overview

The main attraction for the Twelfth KEKB Accelerator Review was the completion, testing and initial operation of the two crab cavities, one placed in each ring. The Committee is very gratified to see this development, which has been the subject of recommendations for several years. Before proceeding to more detailed observations and discussions, the Committee would like to note the tremendous amount of creative engineering and effort that has gone into the successful implementation of these systems. Even in the very earliest days of their operation, the cavities have demonstrated some of the potential for increasing luminosity that was the reason for their construction. The KEK machine group has our very high regard for this tremendous effort.

After some initial difficulties in assembly, tooling improvements enabled a smooth assembly of both cavities. Initial testing at the D10 Test Stand began with a very careful cooldown, motivated by a desire to avoid generating vacuum leaks through thermal stresses accompanying a too-rapid cooldown. This approach was completely successful and no leaks were created.

Some performance issues first appeared in the horizontal test. (That such issues should arise in the first operation of a new and innovative cavity design is not surprising. It is somewhat surprising that the cavities work as well as they do!) In particular, problems of range, linearity and backlash were first observed with the HER cavity tuner. In this cavity, the tuner difficulties were removed by replacement of the main copper bellows with a thinner and more flexible stainless steel bellows. The completed cavity more than met the gradient and $Q_0$ requirements. Quality RF contacts are essential to the performance of the cavity, and improved RF contact springs were installed when the bellows were replaced. After the repair, the HER cavity tuning and field phase stability were excellent.

Assembly of the LER cavity was briefly delayed by field-emission limited performance of the cavity. This problem was quickly and effectively dealt with by reprocessing the cavity, after which its performance in vertical test was even better than that of the HER cavity. However, horizontal tests of the LER cavity revealed significant problems with the range and linearity of the cavity tuning system, and significantly higher tuning loads. Reinforcement of the external mechanical structure and attempts to reduce friction have so far not been effective in improving its performance. The next step is to reinforce the support bolts, which will be done at the next appropriate maintenance down. The alignment of the tuner components should also be checked as misalignment could cause the observed symptoms.

A second issue, probably connected to the tuning problems with the LER cavity, is a substantially larger (~x4) spread of tuning phase errors. Neither of these problems has limited operation of the LER cavity. The desired resonant frequency can be achieved, and since the driving klystron has sufficient capacity, the low-level RF feedback system is able to maintain field amplitude and phase within acceptable bounds.

Most recently, the LER cavity has suffered a reduction in the maximum field it can sustain with an acceptable level of trips. This behavior is similar to that observed in horizontal tests of the HER cavity, where it was corrected by warming the cavity to 80 K and pumping away an accumulation of hydrogen and carbon monoxide. A similar outgassing process is planned for the LER cavity during the next suitable maintenance down.

The crab cavities are presently capable of supporting the crab luminosity optics development program. The Committee believes that this development should continue, but can foresee certain cavity failure modes that would justify removal of the cavity or cavities for repair and modification:

1. Tuner failure that would make it impossible to tune the cavities to the operating frequency,
2. An increase in the magnitude of the tuner phase fluctuations to the point where the RF system is no longer capable of maintaining field amplitude and phase within acceptable bounds,
3. Further reduction of the achievable LER kick voltage to the point where the cavity can no longer support the optics development program, coupled with a failure of the outgassing cycle to recover cavity performance, or
4. Catastrophic deterioration of the beamline vacuum.

Unless one of these major failures occurs, the crab cavities can continue to support the beam commissioning activities and the subsequent Physics program.

## 6) RF Design of Crab Cavity

Considerable efforts have been made on the tricky subject of damping both higher order and lower order modes in the crab cavity, while leaving the main deflecting mode untouched. The result has been a complex, elegant solution which provides sufficient impedance reduction at normal operating beam currents with the existing transverse damping system. If however this damping system performs less well than anticipated and cannot guarantee the stability of modes with growth times longer than 1 ms, then the impedance of the horizontally polarized TE-$\lambda/4$ mode, the most dangerous mode, may limit the beam current.

To prepare for this eventuality a proposal to increase the damping by rotating the slot coupler at the end of the coaxial line has been suggested. Measurements have shown that a rotation of 60°, while splitting the mode into two, nonetheless provides a solution for damping these modes while leaving the other modes relatively unaffected. A model cavity has been made, simulations have been performed, and both have been compared with the HER cavity results. Despite these positive results, there is still some discrepancy between the measured and simulated Q values. The Committee encourages the team to try and understand these differences, especially those between the HER and the model (these values straddle the simulation values). The power flow along the line and the power densities at different points seem to be under control, so if the impedance discrepancies can be sorted out this seems to be a good and simple solution to improving the impedance reduction.

## 7) Cryogenics, etc

The crab cavity cryostat is complex and well-engineered and -instrumented. It performed well in cryogenic operation of the crab cavities, so much so that, in the excitement of first cavity and beam measurements, its excellent performance went largely unremarked.

Static heat leak measurements were carried out. Within experimental error, the two cavities were nearly the same, indicating reasonable control of the assembly process. Heat leaks for both cavities were roughly a factor of two higher than the predicted value, but this discrepancy is almost routine for first articles of any cryostat design, and expected for a design of this complexity.

Measurements of the installed cavity $Q_0$ as a function of accelerating gradient replicated the results of isolated cavity tests, although with larger error bars resulting from the mismatch at the fundamental power coupler in a non-beam-loaded test. This is an additional testament to careful cavity handling and assembly.

All cryogenic controls and instrumentation worked as designed during horizontal testing and operation in the machine.

## 8) Horizontal Tests for Crab Cavities

A complete pre-commissioning of both the LER and HER cavities was undertaken in the horizontal test stand prior to installation in the machine tunnel. The global result was very good: both cavities achieved the expected deflecting voltage. However various differences between the cavities became evident during these measurements.

The major issue found was a problem with non-smooth movement of the HER tuning mechanism and an inability to tune the cavity to the correct frequency. These were solved by a new less rigid thin-wall stainless steel bellows to allow more tuning stroke and an improved sliding base mechanism.

Coupler conditioning at room temperature proceeded normally for both cavities.

Anomalous behavior of the LER cavity was seen during cool-down. The pressure apparently remained at $10^{-5}$ Pa until around 40 K when it dropped abruptly to a few $10^{-7}$ Pa. The explanation might be carbon monoxide freezing at low temperatures, or perhaps a problem with the instrumentation. It is interesting that more or less the same behavior was found later in the ring.

When cold, the LER cavity showed better RF voltage conditioning performance than the HER. The HER had to be warmed to 80 K, resulting in the outgassing of substantial quantities of hydrogen and carbon monoxide, and then cooled again, before 1.8 MV could be reached. In the LER 1.9 MV was achieved with no problem. Later, in the ring, the LER cavity performance degraded and it is hoped that warming the cavity to 80 K will have the same impact as was seen in the HER during horizontal tests. This should be tested at the earliest convenient time.

The last major difference between the two cavities was the behavior of the tuner and RF noise. The residual phase noise on the RF when the tuner loop was closed is much higher in the LER than the HER cavity. This was again found in the ring during beam operation but the RF feedback system reduced the effect as seen by the beam and it could be controlled. The effect is probably related to an apparent “sticking” or “backlash’ in the tuner mechanism, seen as a hysteresis curve in other measurements of frequency versus tuner position. This in itself can provide “noise” but more likely creates regions where the tuner loop is inactive and does not compensate for externally induced vibrations or electronic noise. It is important to study this matter and understand it, firstly by ensuring that the electronic systems are working correctly and secondly, when possible, by opening the cryostat and examining the tuner mechanism.

## 9) Installation of the Crab Cavity

After the horizontal measurements of the LER and HER crab cavities, these cavities were successfully and safely installed in the D11 and D10 tunnel sections, respectively. The installation was really not easy due to the very heavy weight of the cavity, the narrow passage and the limited access. The installation was done by using a carrier for the LER cavity and a tirroller for the HER cavity. Six support legs are used for HER cavity, four for weight support and two to ensure flatness. Finally these two cavities were well aligned to a reference line defined by the quadrupole magnets.

## 10) Commissioning of Crab RF System

This has been a most successful RF system commissioning and we would like to congratulate the entire RF team for getting this complex SCRF deflecting cavity, its RF power system and the associated beam-control electronics to work so well in such a short time. The result of all this hard work is an excellent crab RF system providing a deflecting voltage for each beam sufficient to create the desired crabbed bunches. The amount of measurement data and analysis carried out in the short time that beam has been available is also very impressive.

Now that the cavities are installed in the machine and interacting with the beam, it is normal that different problems should arise, but in fact there have been few problems so far.

The issues can be summarized as a fairly large horizontal offset, 4 mm for the HER and 2 mm for the LER, backlash phenomena in the tuning system of the LER cavity which leads to a phase jitter on the RF, various gas outbursts and the necessity to choose bunch patterns to avoid beam induced voltage on the accelerating mode. The cavity electrical centre offset can be compensated by a suitable orbit bump to reduce the klystron power to a minimum but the reason for the offset between the electrical and physical centers should be found. As far as the beam is concerned, the LER cavity phase jitter is compensated by the RF feedback and is therefore under control. However it does put an increased load on the klystron and with the different transient operating conditions may also be a cause of some vacuum outbursts from the coupler or the cavity. It is clearly necessary in the medium term to find the cause of this jitter and correct it. The vacuum outbursts can also be due to a gradual cleaning of the cavity surfaces. It is worrying that the LER performance seems to be degrading, but the suggestion has been made this may be recovered by heating the cavity to 80 K as was done with the HER cavity. This should be checked as soon as the beam tests have been completed. It is also clear from the trips that the LER is less reliable – this may be related to the tuner problem. On other fronts, such as the HOM power, everything seems very satisfactory.

It will surely be a challenge to maintain reliable Crab cavity operation as the total beam current is raised when increasing the number of bunches and going to the maximum bunch intensity. The Committee is confident that the RF cavity team will continue to be successful and surmount new issues as they arise.

## 11) Beam Commissioning with Crab Cavity

Beam commissioning with crab cavities is going well in KEKB and the Committee strongly supports these tests. This commissioning with crab cavities is very important not only for KEKB to ultimately produce more luminosity but also for the field of accelerator physics in general. These tests will help show whether the consequences of the beam-beam interaction resulting from crossing angle collisions can be corrected with crabbed or tilted bunches, generated in the KEKB case by transverse RF voltages.

Several observations have been obtained with these crab cavity commissioning tests. A new vertical tune shift record in the KEKB HER to 0.078 has been achieved and is a strong indication that crab cavities do improve the beam-beam interaction. The fractional vertical tunes were moved to higher values from about 0.535 to 0.585 to increase the luminosity which was also predicted by beam-beam simulations. The horizontal offset of the two beams at the IP needs to be kept below 40 microns to maintain the luminosity. This level should be rechecked with additional measurements as a function of horizontal and vertical crossing angles. The specific luminosity drops slowly with the product of the bunch currents and is higher with crab cavities than without by about 20% historically but about 50% with the particular accelerator parameters used in these tests. The lifetime drops sharply at mid-currents and may be related to the vertical tunes shifts, or perhaps horizontal tune shifts, reaching new levels. This sharp drop should be studied in detail.

There is a question whether transverse wake fields in the crab cavities can cause different bunches to have different trajectories and thus different luminosities. We recommend that checks be made to see if the luminosity is the same for all of the 51 bunches in the train and, if not, investigate the cause.

It is very important to conclude these beam commissioning tests with a definitive outcome, understanding all the details of the beam-beam interaction with crab crossing. The Committee is concerned that these tests may end too early. The plan for studies is to have 2 to 3 weeks more of low current studies and then one month of high current running. There may be a better strategy where every two weeks low current then high currents studies are alternately done. This scheme allows some time for the scientists to study the data already taken and for the high current effects to be discovered and cured by different team members. The beam experimenters need time to analyze the data, make plans for new proposed experiments, and then carry out the new experiments. This proposed alternating schedule gives some time to respond or fix accelerator components which cause trouble. Also, high current operation will include a different cast of personnel to understand the issues. We recommend alternating high and low current operation (beam tests) to improve the chances of success with crab cavities until a satisfactory result is obtained.

The horizontal beta functions at the IP in both rings are higher now than in the previous beam running. They are higher because, given the crab voltages, higher betas are needed to get the proper beam tilt angle at the IP. It would be very insightful in some way to change the horizontal betas at the IP with a different configuration to see the effect on the limit of specific luminosity and current limits. One method for this change may be to warm up both crab cavities to 80 degrees K, to clean them, and then cool them again. This cycling will likely increase the achievable peak voltage, as shown for the LER before, allowing the horizontal betas to be reduced.

The effect of the horizontal dispersion at the IP, on the order of 10 mm, should be checked for its effect on crab correction. Horizontal dispersion can make the horizontal beam-beam tune shifts sensitive to the horizontal beta function value.

Why the luminosity scans with voltage are so flat is a very interesting question when the beam-beam simulations seem to indicate a much sharper curve should be seen.

Many IP variables have been adjusted one at a time to try to improve the luminosity. A few have succeeded but most have had no effect. It may well be that combinations of variables may have a better chance for luminosity improvement. One example may be transverse offsets coupled with re-optimized vertical angles. Another possibility is that the beam at the IR is rotated around its longitudinal axis and does not collide head-on on the left and right edges. The suggestion is to adjust the skew quadrupoles that rotate the beam at the IP along with adjustments to the crab angle.

Tests could be performed to study the effect, if any, of crab bunch tilts on the Electron Cloud Instability around the LER ring. These tilts could affect the instability limits and size blow up as the electrons collect differently along the length of the bunch. These proposed tests may answer whether bunch tilts could affect how the electrons are trapped from head to tail in the bunches. Short bunch trains could help answer this question with out the need for high total current.

Recommendation: Continue to study why the luminosity scans with crab voltage are so flat since the beam-beam simulations indicate a much sharper curve.

Recommendation: Investigate whether all 51 bunches in the present beam tests have the same luminosity. If not, what is the cause?

Recommendation: Make a test of the crab crossing with adjusted lattice parameters such that the horizontal tune shifts are closer to the old values and not twice as high as in the present tests.

Recommendation: We recommend alternating high and low beam current studies to improve the chances of success with crab cavities and make sure there is sufficient beam study time to obtain satisfactory results and complete understanding.

## 12) Beam-Beam Effect with Crab Cavity

Beam-beam simulation predicted a serious enhancement in the luminosity performance of KEKB by implementing the crab crossing. This effectively compensates the crossing angle at the IP, thus switching the collision into a head-on mode. From the beam-beam simulations for the KEKB working point, the expected gain in the beam-beam parameter (and thereby in the luminosity) is about a factor of two. The experimental studies of the crab crossing so far show an increase of about 20% in the beam-beam parameter, providing that the geometric gain from avoiding the collision crossing is already subtracted. Some experimental results give asymmetric dependencies (e.g. HER beam lifetime vs. the horizontal collision offset) in cases where symmetry is expected, and this peculiarity has no explanation from the simulation yet.

To understand the discrepancy and continue optimization of the crab collision, it is desirable to obtain guidelines from more detailed simulations. The simulation results available so far, already show a very steep dependence of the luminosity on scanning one of the important machine parameters, e.g. the collision offset, or the residual crossing angle(s). A list of relevant parameters includes: i) residual crabbing angles of the bunches (i.e. the crab cavity voltages), ii) horizontal and vertical collision offsets, iii) the respective orbit crossing angles at the IP, iv) a full set of Twiss parameters (including x and y dispersions), and v) the set of transverse coupling coefficients $R_{1-4}$, etc.

The critical questions now are: with a multi-parametric scan, can we see a steepest ascent path to the maximum luminosity in simulations? And what is the best strategy of tuning the beam-beam performance with the crab collision?

The strong-strong 3D beam-beam simulation tools available at KEKB provide self-consistent distributions of colliding bunches, hence the data on the *beam size* blowup (and corresponding degradation of the specific luminosity) is readily available. The data on the expected *beam lifetime* (both from counting particles lost from the mesh and from far tails of the resulting distributions) is less reliable, because of small statistics. The available weak-strong simulation codes oriented for the lifetime evaluation can be used to provide this information.

The Committee puts an emphasis on the survey of the crab collision parameters by means of the beam-beam simulations and recommends multi-parametric analysis of the beam-beam simulation results, aiming to formulate an efficient strategy for experimental optimization of the crab collision regime.

## 13) Observation of Crab Crossing with Streak Camera

A streak camera has been installed in the synchrotron radiation monitor hut of each ring to permit direct observation of the crab angle at the location of the synchrotron radiation monitor. Horizontal and longitudinal beam profiles are measured to check the crabbing angle.

The longitudinal scale (time) is calibrated by Hamamatsu. The horizontal scale is calibrated using a +/- 2mm parallel bump at the synchrotron radiation monitor locations.

The crab angle has been measured with crab cavity off, and with crab on with normal and opposite phase. The sign of the crab angle has the same sign at the synchrotron radiation monitor location as at the IP. The correct crab sign has been verified.

The accuracy of the measurement of has been determined to be about 10%.

Measured LER crab angle values at the synchrotron radiation monitor locations are consistent with expected values, but the HER values are off by a factor of two for yet unknown reasons.

On the other hand, the observed orbit distortions with a 360 degree crab phase scan are in excellent agreement with crab kick voltage calibration.

Recommendation:

The Committee strongly recommends clarifying and identifying this discrepancy by additional cross-checks of streak camera calibration and beam optics functions as soon as possible. If the streak camera crab angle measurements are correct, this could certainly explain why the relatively narrow peak in luminosity enhancement expected from simulation for head on collisions has not yet been observed.

## 14) Recent Upgrade Studies of Vacuum Components

The ongoing work for the upgrade of vacuum components has been presented to the Committee. The previous design of the beam duct, which was based on a welded structure made out of pressed half-shells has been improved. The new design consists of a cold-drawn copper pipe without longitudinal welds. This guarantees tighter mechanical tolerances. The cross section consists of a circular beam channel with two ante-chambers for synchrotron radiation and to accommodate NEG strips. The proposal is to install a total of 30 m of this vacuum chamber in a wiggler section of KEKB during the coming summer. With the proposed symmetric cooling channels the transverse temperature gradient should be strongly reduced with respect to the old, asymmetric KEKB beam duct. Reduced thermal stress will ensure that that the straightness of the beam pipe is maintained under the increased synchrotron radiation load from the wigglers.

The beam pipe design incorporates a new flange design with the matching aperture. New flanges are of the MO-type (Matsumoto-Ohtsuka). The flange design has been tested to confirm the required leak tightness. The special feature is that the vacuum gasket is mounted flush with the inner wall of the beam pipe and this eliminates the longitudinal and transverse gap of conventional CF-flanges. The Committee agrees that this will be a very important next step to validate both the proposed beam duct design and the manufacturing method.

The Committee was updated on the recent progress made with the comb-type RF-bridges, which will be fitted into the vacuum bellows and gate valves. Machine tests have been encouraging and have shown a much reduced temperature rise. Nevertheless the concern persists that arcing between adjacent fingers could occur when the RF-bridges are not perfectly aligned.

Given the reported failure rate of the standard RF-bridges in KEKB during last year's and this year's meetings, the Committee recommends that the development of the new design should receive the necessary support so that components will be available as a replacement.

To reduce the secondary electron coefficient of the surface the new beam duct will be sputter coated with a thin layer of TiN. The effectiveness of this type of surface coating has been demonstrated by the extensive work of S. Kato. A dedicated facility is being set-up to coat up to 7 m long vacuum chambers in vertical position. The Committee recommends that this facility be used to coat existing standard vacuum chambers for KEKB to validate the long term behavior of the TiN layer under real machine conditions.

First results from a beam test of a prototype vertical movable mask for LER have been presented to the Committee. The aim of these tests has been to validate the HOM power estimates and to measure the resulting temperature rise of the absorber. Since the head can lose its power only by radiation, the estimated temperature becomes very high. On the prototype, the temperature could be measured through a window with a pyrometer. By this method, temperatures approaching, or even exceeding 600 C could be measured. After the tests, the metal coatings of Cu and/or Ti appeared to have evaporated.

The Committee is aware of the difficulty to find a good solution for the very demanding mask design and strongly encourages the continuation of this work.

### 15) Secondary Electron Yield

An impressive set of experimental results obtained with a dedicated system for in-situ measurements of the secondary electron yield (SEMS) has been reported by S. Kato. This system is specially dedicated to the surface measurements under uhv conditions and fitted in a straight section (Fuji) of the LER e+ ring. The merit of this experimental program is a direct comparison of earlier laboratory results (10. KEKB Mac) with in-situ measurements under real beam conditions and exposed to e-cloud. The system comprises a primary electron beam with a scanning capability, a monitor for the electron activity, a sample loading system and a solenoid magnetic field. The secondary electron yield and the surface characteristics of a sample can be measured before and after beam exposure. A dose of $10^{20}$ $e^{-}/cm^{2}$ can be accumulated within 2 weeks. With this dose, S. Kato finds a very significant reduction of the initial secondary emission yield (SEY) from about 1.8 to 1.1 and even less. In situ surface analysis after exposure reveals predominantly graphitic carbon on the surface, which agrees well with his earlier laboratory measurements. Graphite is known to have a low SEY. In terms of SEY, TiNx gives better results than copper and NEG samples.

The set of data include measurements of the angular dependence of the SEY, particularly at grazing incidence, as well as dependence on the primary energy; this data will be very valuable as input for electron cloud simulations.

In view of the very low SEY of graphite, S. Kato suggests that this material could even be used for vacuum chambers.

The Committee acknowledges the large effort which went into this work and hopes that more valuable results will be forthcoming.

### 16) Electron Cloud Measurement and Vacuum Chamber Design

Electron monitors, have been developed and installed in the pumping ports of many different vacuum chamber configurations in the LER. These monitors estimate the electron density near the beam by measuring the fast electron current above a predetermined energy threshold.

The electron current monitors are equipped with grids which act as a retarding field analyzer such that only electrons above a predetermined energy threshold, typically 1 keV, are measured.

The relation between electron cloud density near the beam axis and the measured anode current can be determined from the electron monitor geometry.

These electron cloud monitors permit in situ measurement of electron cloud densities with different chamber geometries, different levels of synchrotron radiation, different surface coatings, different bunch patterns and changes in secondary electron yield (SEY) as a function of in situ electron dose.

It has been quantitatively confirmed that

- The electron current is strongly correlated with the intensity of synchrotron radiation
- The antechamber design drastically reduces the electron cloud density
- The removal of photoelectrons in the antechamber geometry is not complete compared with locations where the synchrotron radiation is negligible
- Under synchrotron radiation, the effect of TiN coating alone is not as effective as the antechamber structure
- In areas with low synchrotron radiation intensity, the effectiveness of NEG and TiN coating has been measured
- Some inconsistency between the in situ SEY measurements and the electron cloud measurements has been revealed and need further study including simulation
- Under various bunch patterns, the average electron cloud density versus beam current is similar for different bunch patterns if the electron cloud density is plotted against linear density of stored current.
- If direct synchrotron radiation intensity is negligible, the density of electron cloud in a TiN coated chamber is lower than the critical density for the single bunch head tail instability

These measurements are extremely valuable for verification of electron cloud simulations and validation of the proposed measures to reduce electron cloud problems in future machines like Super-KEKB and ILC damping rings. The results are complementary to the laboratory studies of SEY and the in situ measurements of SEY of various materials and surface coatings. Further refinement and continuation of these studies can certainly be recommended.

It would be very interesting to obtain in situ measurements of electron cloud density at the beam axis for chambers with C-magnets mounted on the antechamber or for chambers with solenoid fields. However, the current design of electron cloud monitors is probably not well suited for this purpose, and some bright new ideas may be required.

## 17) Development of Pulsed Quadrupoles

Due to the photo-electron cloud effect in the LER, the vertical betatron tune is lower for the head of the bunch train than the rest of the bunch train and it causes some beam loss in the leading bunches. A fast pulsed quadrupole magnet with a ferrite core and a water-cooled ceramic chamber will be installed this year to enhance the LER luminosity by stabilizing the front part of the bunch train. The pulsed power supply needs a high repetition rate of 100 kHz with 100 A in a half sine waveform. It is a challenging task to realize the power supply. On the other hand, the non-collision pilot bunch in the HER is often lost at a lower horizontal betatron tune. The same kind of quadrupole magnet is planned to keep this bunch with a higher current of 175 A. The Committee endorses this experiment of stabilizing the bunch trains, but would like to se simulations of the effect to help guide the beam commissioning program.

## 18) QCS for SuperKEKB

The QCS-R for the super-KEKB was successfully tested at 4.2K. It met the current requirement of 1,187 A, and the quench location was identified at the $2^{nd}$ quadrant coils due to fabrication errors. The field measurements including high-harmonic components will be conducted this year. The corrector and the compensation solenoids are under fabrication, and they will be tested this year. The Committee is convinced that the magnet R&D program is progress smoothly as planned.

## 19) Crab Waist Optics

A novel mode of operation for high performance factories, referred to as crab waist, has been studied for Super-B. (Similar idea could conceivably be applied to Super-KEKB and even to a KEKB upgrade). In this mode of operation, the traditional head-on collision with hourglass effect is replaced by collision with a large crossing angle whose waist position is made to correlate with the horizontal position of collision. This crabbed waist is provided optically by two sets of sextupoles around the interaction point with proper betatron phases. A gain of luminosity then results, first from the small beam sizes and then from the crabbed waist, without a corresponding increase of beam intensity.

A significant effort has been invested at KEKB in search of an optimized lattice design including a crabbed waist. The crabbed waist has been satisfactorily produced. In addition to a crabbed waist, it has become necessary to take account of other associated nonlinear effects of the optics design. In particular, sextupole scheme optimizations, together in some cases with additional octupoles, have been tested. However, it was found that the introduction of the crab waist sextupoles significantly reduced the dynamic aperture of both the HER and particularly the LER. This lack of dynamic aperture not only cut into the beam lifetime, but also prevented smooth operation of beam injection. In the pursuit of the source of the loss of dynamic aperture, it was found that in some cases the fringe fields and the kinematic nonlinearities of the magnets between the sextupoles make significant contributions. The Committee feels this somewhat surprising result requires more scrutiny. Because of the lack of dynamic aperture, crab waist optics does not have an acceptable solution at the present time. This is known to the KEKB team, and more studies are planned. The Committee endorses the multi-parametric study suggested by the KEKB team. The Committee further emphasizes that this work could benefit greatly from collaboration with other labs.

## 20) Lattice Design for Super B

A comparison of the dynamic aperture in SuperKEKB and the Super-B accelerator designs has been made by the KEKB staff. This comparison includes the sextupoles for the crab waist beam-beam correction. Overall, SuperKEKB has more conservative lattice parameters with higher emittances and larger IP beta functions but, conversely, has higher beam currents and larger AC power. The Super-B collider concept has smaller emittances and IP betas, thus being less conservative, but conversely has correspondingly significantly smaller beam currents and AC power, but also potentially higher luminosity.

Many topics have been included in the simulations of the dynamic aperture. The effect of the sextupoles that provide the crab waist correction on the dynamic aperture has been studied. The crab waist sextupoles produce a non-linearity which can affect the dynamics aperture of the rings. These calculations show a sharp reduction in the dynamic aperture in the SuperKEKB ring geometry. The dynamic aperture gets smaller with increased crab sextupole but is acceptable without crab waist sextupoles. The non-linear effects of chromaticity have also been studied. Higher multipoles, in the form of octupoles, have been shown to degrade the dynamic aperture in the present configuration with the crab waist sextupoles.

Recommendation: The crab waist scheme for a Super-B Factory is a new idea that can save considerable construction costs as well as potentially producing higher peak luminosity. The Committee recommends a continued search for a magnetic lattice configuration with good dynamic aperture with the crab waist sextupoles turned on.

## 21) Beam-Beam Effects in Super B

The SuperB design approach pursued by Frascati-SLAC-KEK collaboration and based on collisions with a large Piwinski angle opens up the way to using a very low beta-y at the IP (~0.1 mm) without strong limitations on the colliding bunches' lengths (6 mm). A reasonably small horizontal size of the colliding bunches' overlap area can be reached due to the arc lattice providing a small horizontal emittance (< 1 nm). For a high luminosity ($\sim 10^{36} cm^{-2} s^{-1}$), an extremely small x-y coupling is needed to obtain the tiny vertical spot size at the collision point (~15 nm!). As a result, the horizontal beam-beam parameter is small, and the vertical one is raised to an achievable limit. The collision becomes effectively one-dimensional. The betatron coupling resonances are suppressed by using the crabbed-waist collision optics.

This low-emittance approach has a major advantage of employing moderate currents in colliding beams, at the expense of complications both in the arc and IR optics. However, the challenging set of the optics parameters has much in common with the task for the ILC Damping Rings, synergistic efforts should help to find solutions to critical problems in both projects (dynamic aperture limitation, complicated injection scheme, electron cloud instability and other collective effects).

A comparison of the high-current (SuperKEKB) and low-emittance (SuperB) approaches has been done, with new emphasis on the latter. Both envisage the crossing collision, so term-by-term analysis of the nonlinear ($4^{th}$ order) perturbations coming from the beam-beam kick with the crossing angle has been performed in order to reveal the most important terms. Special attention was paid to the effect from the crabbed waist sextupoles. They are shown to cancel some of the perturbation terms responsible for the nonlinear x-y coupling, but they tend to enhance the synchrobetatron terms. From the tune scan, the parameter range was found that the crab waist is efficient: mostly only for small synchrotron tunes.

For the low-beta and low-emittance option, the existing strong-strong simulation tool comes to the limit of available computer power because too many longitudinal slices are needed to model the bunch whose length is much longer than the vertical beam size at the IP. Only weak-strong simulation results are presently available for these studies.

The Committee supports the efforts for understanding which is the most efficient way to the super-high luminosity in SuperB projects, and formulating a coherent machine parameter list. The Committee reminds that the beam-beam simulation findings be confirmed by demonstration of a wide, realistic tolerance range in the appropriate multi-parametric space.

The Committee strongly recommends to continue and reinforce the existing collaboration on SuperB projects between LNF-INFN, SLAC, KEK and other laboratories.

### 22) Fuji Test Beam Line

The Fuji test beam line is a new test beam facility at KEK, which is planned to deliver a beam to the test station starting in September 2007. It uses the 100 m-long straight section of the HER ring in the Fuji interaction region. The “Turtle” simulation of the Bremsstrahlung photons from the beam due to residual-gas scattering shows predicts a flux of about $1.6\times10^{5}$ photons/second. Based on the Geant4 simulation these photons will be converted to an electron or positron beam using a tungsten converter of 3mm thickness. This gives a rate of about 200 Hz (continuous beam) and with an energy spread of 0.4%, at any energy between 0.5 GeV and 3.4 GeV. These is very good performance for the test beam. The converted particles will be extracted outside of the KEKB tunnel by additional magnets. This beam line can be operated about 240 days per year (KEKB operation time) without any performance degradation for the KEKB beam. It is really a very good idea to establish this new beam line by sharing with KEKB straight section. The Committee recommends that the KEK management provide the necessary support to create this beam line facility.

### 23) First application of a tungsten single-crystal positron source at the KEKB injector linac

A single crystal tungsten target has been installed in the KEKB injector linac which has significantly improved the positron yield. The use of orientated crystals in positron sources is motivated by the enhanced gamma radiation along the crystallographic axes or planes and the corresponding enhancement in pair production.

While the idea has been presented many years ago, and several successful experiments have been performed at different laboratories, this is the first time an operational positron production facility has been equipped with a single crystal tungsten target.

The optimum target thickness for a single crystal tungsten target with its <111> crystal axis aligned with the beam direction, has been experimentally determined at the KEKB injector linac. The optimum thickness for maximum yield has been found to be about 10 mm compared with 14 mm for a conventional amorphous tungsten target.

The target axis is not moveable, but the target assembly has been precisely aligned and machined to insure its crystal axis is parallel to the beam axis.

The improvement in positron yield is remarkable:

- a 25% improvement in positron yield has been obtained
- a 20% reduction of energy deposited in the target has also been achieved

The target has so far been in operation for two months, and based on radiation damage studies done at SLC at SLAC, it is expected that the target will last at least a year with no degradation in performance.

This relatively simple and very effective improvement of positron yields works so well that it is surprising that it has not been done sooner.

## 24) Injector Upgrade

Phase 1 of the Injector Upgrade was completed last year with a new bypass transport line to the Photon Factory, reducing the beam switching time by one half. In order to serve four different machines continuously, the injector requires a common transport lattice and many other features, such as a positron target with an electron-bypass hole, pulsed switching magnets, and fast control of the klystron phases. In Phase 2, a fast beam-mode switch is planned for the KEKB electron ring and the Photon Factory, while Phase 3 includes the KEKB positron ring. With test runs this year, the injector group plans to establish routine operations, providing beams to all four rings simultaneously. The Committee is quite convinced that the Injector Group will accomplish all the planned schemes as scheduled. On the other hand, the top-up mode operation for the Photon Factory Accumulation Ring would be very difficult without an extensive budget.

## 25) Control Room with beam

The Committee was taken to visit the KEKB Control Room. It was clear that the number of computer screens had doubled since our last visit, and the screens were larger and displaying more information. The Control Room is extremely functional and at least twenty people were actively involved in the crab cavity commissioning. The control system provided automated parameter scans, a vital tool when searching for an optimum working point with at least twenty different parameters to vary.

It was clear that there was a very cooperative attitude between the physicists and engineers of KEK and the operators from Mitsubishi and this will be important as routine operations are turned back over to the operators.

The Committee was extremely impressed with the organization of the commissioning effort, which gives confidence that the commissioning will lead to successful routine operation with the crab cavities.

**Appendix A**

## KEKB Accelerator Review Members

| | |
|---|---|
| Andrew Hutton | JLab (Chairman) |
| Alexander Chao | SLAC |
| Warren Funk | JLab |
| Oswald Gröbner | CERN (retired) |
| Heino Henke | Technical University, Berlin – unable to attend |
| Trevor Linnecar | CERN |
| Won Namkung | POSTECH |
| Fleming Pedersen | CERN |
| Eugene A. Perevedentsev | BINP, Novosibirsk |
| David Rice | Cornell |
| John Seeman | SLAC |
| Wang Shuhong | IHEP, Beijing |
| Katsunobu Oide | KEK Secretary, Accelerator |
| Shin-ichi Kurokawa | KEK Secretary, Accelerator – unable to attend |

**Appendix B**

# Agenda of the twelfth KEKB Accelerator Review Committee

*March 19-21, 2007 in the Meeting room on the first floor of Building No.3, KEK*

| | | |
|---|---|---|
| 8:30- 9:00 | Executive Session | |
| 9:00- 9:10 | Welcome | F. Takasaki |
| 9:10- 9:25 | Overview | K. Oide |
| 9:25- 9:55 | Beam Commissioning before Crab Cavity | Y. Funakoshi |
| 9:55-10:15 | Belle Status | Y. Ushiroda |
| 10:15-10:35 | Coffee | |
| 10:15-10:35 | BPM Displacement Monitor | H. Fukuma |
| | =============== ***Crab Cavity*** ================ | |
| 10:55-11:30 | Crab Cavity Overview | K. Hosoyama |
| 11:30-12:00 | RF Design of Crab Cavity | Y. Morita |
| 12:00-13:00 | Lunch | |
| 13:00-13:20 | Cryogenics, etc. | K. Nakai |
| 13:20-13:45 | Horizontal Tests for Crab Cavities | Y. Yamamoto |
| 13:45-14:05 | Installation of Crab Cavity | M. Ono |
| 14:05-14:35 | Commissioning of Crab RF System | K. Akai |
| 14:35-15:10 | Beam Commissioning with Crab Cavity | H. Koiso |
| 15:10-15:30 | Coffee | |
| 15:30-15:50 | Beam-Beam Effect with Crab Cavity | K. Ohmi |
| 15:50-16:10 | Observation of Crab Crossing with Streak Camera | H. Ikeda |
| | ============= ***Upgrade Studies*** ============= | |
| 16:10-16:35 | Recent Upgrade Studies of Vacuum Components | Y. Suetsugu |
| 16:35-16:50 | Secondary Electron Yield | S. Kato |
| 16:50-17:05 | Electron Cloud Measurement and Vacuum Chamber Design | K. Kanazawa |
| 17:05-17:20 | Development of Pulsed Quadrupoles | T. Mimashi |
| | | |
| 17:30- | Reception | |
| 8:30- 9:00 | Executive Session | |

| | | |
|---|---|---|
| 9:00- 9:20 | QCS for SuperKEKB | N. Ohuchi |
| 9:20- 9:40 | Crab Waist Optics | A. Morita |
| 9:40-10:00 | Lattice Design for Super B | Y. Ohnishi |
| 10:00-10:20 | Beam-Beam Effects in Super B | K. Ohmi |
| 10:20-10:40 | Coffee | |
| 10:40-11:10 | Fuji Test Beam Line | J. Haba |
| 11:10-11:30 | First application of a tungsten single-crystal positron source at the KEKB injector linac | T. Suwada |
| 11:30-12:00 | Injector Upgrade | M. Satoh |
| 12:00-13:00 | Lunch | |
| 13:00-14:00 | Executive Session | |
| 14:00-15:00 | Seminar: Design of Super B (3G Seminar Hall) | P. Raimondi |
| | =============== ***Crab Tour*** ================ | |
| 15:00-15:30 | Control Room with beam | H. Koiso |
| 15:30-16:30 | Nikko Tunnel without beam | K. Hosoyama |
| 16:30- | Executive Session | |
| | | |
| 8:30- 11:00 | Executive Session | |
| 11:00- 12:00 | Close-out with KEKB Staffs | |
| 12:00 | Adjourn | |
| | | |