SUMMARY OF IR AND MDI SESSION

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Abstract

A brief summary of talks in IR and MDI session is given. Also features and issues on the IR design in the future colliders are summarized.

INTRODUCTION

In this session, 5 talks were given on 4 colliders; *i.e.*, SuperKEKB, CEPC, FCC-ee and eRHIC. The talks are listed below.

- “Issues on IR Design at SuperKEKB" by Yukiyoshi Ohnishi (KEK)
- “IR Design and MDI at CEPC" by Qinglei Xiu (IHEP)
- “FCC-ee Interaction Region Magnet Design" by Michael Koratzinos (Unige)
- “The eRHIC Interaction Region Magnets and Machine Detector Interface" by Brett Parker (BNL)
- “FCC-ee MDI" by Manuela Boscolo (INFN-LNF)

In this summary, a brief summary for each talk is given firstly and then a summary of the whole session is given.

SUMMARY OF EACH TALK

Issues on IR Design at SuperKEKB

SuperKEKB has a relatively large (full) crossing angle of 83 mrad to squeeze the IP vertical beta function down to ~ 0.3 mm with “Nano-Beam Scheme". L^* is chosen as ~0.76 m. The strength of the detector solenoid is 1.5 T and the field is cancelled with compensation solenoid magnets so that the integral of the field along the beam line is zero on both sides of the IP. A challenge is to keep enough dynamic aperture and the enough Touschek beam lifetime with the extremely small IP beta functions. For this purpose, many corrector coils are installed in IR including the cancelling coils of the leakage field from the opposite beam. Octupole and skew-sextupole coils are also wounded for wider dynamic aperture. In the simulation, the target beam lifetime of ~ 600 s from the Touschek effect has been obtained for both rings without the beam-beam effect by optimizing many parameters including the octupole , skew-sexupole and sexupole magnets. A serious issue presented is that the dynamic aperture in the horizontal direction shrinks largely with the beam-beam effect particularly in LER. The beam lifetime can be decreased down to less than 100 s. A particle with a large horizontal offset collides with the other beam at the position where the vertical beta function is large and the vertical oscillation is induced when the particle is lost in the simulation. This phenomena can be suppressed with the crab waist scheme. But the nonlinearity of the sexutpoles for the crab waist scheme reduces the dynamic aperture very seriously combined with other IR nonlinearity particularly with the fringe field of the final focus quadrupoles. This is an unsolved problem and the conclusion of the speaker is “ The transfer map between the IP and the crab waist sextupole should be linear. Development of a cancellation technique for the nonlinear field is necessary."

IR Design and MDI at CEPC

A preliminary IR design of CEPC was shown. The (full) crossing angle is 30 mrad. The vertical beta function at the IP is 1.2 ~ 1.3 mm. The strength of the detector solenoid is 3.5 T and the field is cancelled with compensation solenoid and is shielded with the screening solenoid. L^* is chosen as ~1.5 m. A preliminary design of the final focus quadrupole (QD0) with Serpentine coil layers was shown. The problem with the present design is the cross talk of the two QD0’s for the two beams. The cross talk should be decreased by adding shield coils. The simulations on the beam background were done on the three types of the background, the synchrotron radiation (SR), the beam loss and Beamstrahlung. Of the 3 types of background, the SR background is the most serious. The critical energy of SR is assumed to be ~ 1 MeV. If this value is for the SR from the last bending magnet, this seems too high considering the experiences at LEP. Collimators for synchrotron radiation from the dipole are designed. The particle loss from the radiative Bhabha process was simulated and the preliminary design of collimator for this background was made. The energy deposition to the collimator should be estimated. In the talk, it was stressed that the mechanical support may be a new challenge for IR design due to the limited space for the support.

FCC-ee Interaction Region Magnet Design

The IR magnet design of FCC-ee was shown. The (full) crossing angle is 30 mrad. The vertical beta function at the IP is 1 ~ 2 mm. The strength of the detector solenoid is 2 T. L^* is chosen as ~2.2 m. A border between the accelerator and the detector has been set at ±100 mrad. Two big challenges for the IR magnet design are vertical emittance creation from the IR vertical dispersion and very tight space for two final focus quadrupoles sitting ~6 cm apart. As for the vertical emittance, the emittance budget is very tight and is 1 pm for most of energies. By introducing two magnetic elements; *i.e.* the screening solenoid and compensating solenoid and localizing the dispersion near the IP as much as possible, the emittance blowup has been successfully suppressed to only 10 % of the emittance budget for 2 IPs. As for very tight space for the final focus quadrupoles, the influence of one quadrupole to the other beam might be problem. To

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cope with this problem, two options of magnets have been proposed; *i.e.* Modified Panofsky type quadrupole and a Canted-Cosine-Theta (CCT) magnet. The former has a disadvantage that no correction coils can be inserted. The latter seems to fulfill all requirements as the final focus quadrupole; (1) Compact design, (2) Correction coils can easily be incorporated and (3) Can be designed so that the twin aperture design can each have a pure quadrupole component. For further study, a prototyping work is needed for the final focus quadrupole.

The eRHIC Interaction Region Magnets and Machine Detector Interface

At eRHIC, they plan to collide an electron beam against a hadron beam. The electron beam energy is 2∼18 GeV. For the hadron beam, up to 275 GeV polarized protons or 110 GeV/u Au ions will be used. While a ring or an ERL will be newly constructed for the electron beam, one of present RHIC rings will be used for the hadron beam. The crossing angle is 22 mrad for the electron ring option or 14 mrad for the ERL option which can create a lower emittance electron beam. In both options, the crab crossing is assumed. L^* is about 5 m. The target luminosity is $\sim 10^{32-33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (Initial) and $\sim 10^{33-34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (after upgrade). A big challenge for the eRHIC IR magnet design is that the two step separation (electrons/hadrons and then charged hadrons/neutrons) and large required apertures. Solutions to this challenge are to use active shields for the e-ring option or sweet spot coils for the ERL option to minimize the leakage field from the final focus magnets for the hadron beam to the electron beam. The sweet spot coil technique seems very elegant in the sense that the coils contribute to ∼1/3 of the quadrupole field for the hadron beam. At present, they are midway through production of a 1 m long dipole sweet spot coil prototype in order to gain experience with such coil configurations.

FCC-ee MDI

The present status of the study on MDI for FCC-ee is reviewed. An emphasis was placed on the beam background due to SR. SR is the main constraint for the IR design and it drives the IR optics and the IR layout at FCC-ee. To mitigate the serious SR background to the detector, an asymmetric IR optics has been worked out. In this optics, the last bending magnets are located ∼100 m upstream the IP and ∼42 m downstream the IP. By placing the upstream bending magnet farther from the IP, the SR background was drastically decreased compared with the case of the 42 m distance. They consider this asymmetric optics as a baseline optics for the MDI studies. Requirements to the critical energy of SR have been set based on the LEP experiences. The critical energy of photons from the weak bending magnet (last bending magnet) should be less than 100 keV. Those for the other magnets in whole ring should be less than 1 MeV to minimize the neutron production. For the simulation of the SR background, several software tools have been developed. The beam-pipe geometry and their material have been designed. Detailed SR shielding and collimation studies have been being done. The studies of the SR background from far bending magnets have started. In the collider in this energy region, the luminosity detection is very important. Its design and integration to the IR design is a challenge. The study on the optimization of the position, size and optimal coverage of the luminosity detector, which could influence the choice of L^*, is going on.

SUMMARY OF SUMMARY

In the future e^+e^-(ep) colliders including SuperKEKB which has just finished non-beam-collision tuning, the IR design has become more difficult than the existing colliders. Since a much higher luminosity is required, the IP beta functions are much smaller and the final focus doublets are placed much closer to the IP. These requirements or constraints make the IR design much more difficult. In the following, features and issues on the IR design in these colliders are summarized.

Crossing Angle

All of the four colliders in the session have the horizontal crossing angle. In SuperKEKB, CEPC and FCC-ee, a large Piwinski angle is essential to squeeze the vertical beta function beyond the limit from the hourglass condition. eRHIC also needs a crossing angle instead of IR separator dipoles, since the dipoles would create a serious SR background, interfere with the physic detector and affect acceptance for forward neutrons and charged particles. The crab waist scheme will be adopted in FCC-ee and CEPC and the crab cavity scheme will be introduced in eRHIC. Motivations of both schemes are to compensate some harmful effects arisen from the crossing angle.

Lattice Nonlinearity from IR

One of the hard challenges for the IR design in the future colliders is to keep sufficient dynamic aperture. In CEPC and FCC-ee, a momentum acceptance of ±2% at 175 GeV is required to hold the large energy spread caused by Beamstrahlung. In SuperKEKB, the Touschek effect is important for the lifetime and so both a large momentum acceptance and an enough horizontal acceptance are required. By optimizing related parameters, required dynamic aperture is achieved in the simulation for a perfect machine at FCC-ee. Dynamic aperture at CEPC is under study. At SuperKEKB, a target beam lifetime from the Touschek effect of 600 s was achieved in the simulation without the beam-beam effect. However, the dynamic aperture shrinks largely with the beam-beam effect. If the crab waist scheme works, this shrinkage can be reduced. At SuperKEKB, however, nonlinearity of the crab waist sextupoles combined with the fringe field of the final focus quadrupoles reduces dynamic aperture seriously. In a talk in the optics issues session, Anton Bogomyagkov compared IR nonlinearity of several colliders as is shown in Table 1. In the table, μ'_y, α^k_{yy}, α^k_{yy} and α^S_{yy} denote the chromaticity by the final focus quadrupoles,

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the detuning coefficient (amplitude dependent tune shift) from the kinematic term, that from the fringe field of the quadrupoles and that from the -I sextupole pairs, respectively. As is seen in the table, nonlinearity from the fringe field of the final focus quadrupoles of SuperKEKB is remarkably large compared with other colliders. To make the crab waist scheme work in SuperKEKB, reducing IR nonlinearity seems important. One possibility is to remake the final focus quadrupoles (QCS) with less nonlinear fringe field in future by making the length of the quadrupoles longer. They may need such kinds of upgrade plans. In FCC-1, nonlinearity from the sextupoles of the local chromaticity correction was very large. This nonlinearity comes from thickness of the sextupoles. This nonlinearity was drastically reduced by adopting thin superconducting sextupoles.

Table 1: Comparison of IR Nonlinearity of Several Colliders

	μ'_y	$\alpha^k_{yy}[m^{-1}]$	$\alpha^k_{yy}[m^{-1}]$	$\alpha^S_{yy}[m^{-1}]$
DAΦNE	-61	694	218	
Super-KEKB	-5400	1.8×10^6	9.8×10^6	-7×10^5
SuperB	-1060	1×10^6	2.8×10^5	-5.4×10^6
C Tau	-700	1.3×10^5	7.7×10^5	-7.2×10^5
FCC-1	-2800	4.5×10^5	1.9×10^5	-1.2×10^7

Vertical Emittance

In SuperKEKB, CEPC, FCC-ee, the design value of the vertical emittance is very small and then the emittance budget is very tight. In this situation, the vertical emittance created in the IR region should be minimized. In principle, it is inevitable that the detector solenoid plus the horizontal crossing angle cause the vertical kick particularly in the fringe region and the vertical dispersions. It is important to minimize the resultant vertical emittance by cancelling the detector solenoid properly. At SuperKEKB, they took a special care of the design of the compensation solenoid magnets. Since the vertical kick by the solenoid fringe is proportional to the derivative of B_z (solenoid field) in the longitudinal direction, the compensation solenoid was design so that the slope of B_z along the beam orbits in the fringe region should be sufficiently gentle. In the FCC-ee design, they carefully designed the compensation solenoid and the screening solenoid to minimize the vertical emittance. In this manner, the low emittance requirement poses some constraint to the IR design.

IR Magnet Design

One of the challenges for the IR design is the IR magnet design. The difficulty in the design comes from many functions packed within the very limited space, mutual interference of magnetic fields for the two beams, mutual interference of accelerator components and detector components and others. At SupeKEKB, in addition to the main quadrupole coils, many corrector coils were designed and fabricated. As of November 2016, the fabrication has almost finished. Many corrector coils are needed to compensate fabrication errors of the main quadrupoles and alignment errors or cancel the leakage field from the quadrupoles for the other beam. In the extreme machine like SuperKEKB, such compensation is very important. Some coils such as the octuple coils are used to improve dynamic aperture. All of the corrector coils except for the main quadrupole coils have been fabricated at BNL. The IR and magnet design at eRHIC is much different from that of e^+e^- colliders due to asymmetry of the hadron and lepton beams. The sweet spot coil technique seems a very unique and elegant solution for the ring-ERL option. BNL is one of the technical leader in the field of the superconducting magnet in the world. Its accumulated experiences should be learnt by other laboratories. The next step of the IR magnet design of FCC-ee is R&D works with a prototype magnet .

Detector Beam Background

The detector beam background is a very important issue related to the IR design. At FCC-ee and CEPC, the SR background is most important. It gives a strong constraint to the IR optics design. The tolerance to the SR has been determined considering the experiences at LEP. This should be confirmed by realistic simulations. Considering its big impact on the accelerator design, efforts on the detector side to increase tolerance of the detector against SR should be made. At SuperKEKB, the beam background from the Touschek effect, the Coulomb scattering and the radiative Bhabha process are important. To reduce the detector background, setting the collimators in the rings properly is very important. In Phase 2 commissioning, it is very important to validate the simulation tools.

Others

In CEPC and FCC-ee, the design of the luminosity detector is a big challenge. If the distance of the detector from the IP is short, the lack of knowledge of the precise position of the detector degrade the accuracy of the luminosity measurement. A careful attention should be paid to its design. Heating of the IR components due to SR and HOM is also important issue in the IR design. More engineering issues such as how to support the IR components or how to assemble them are important and should be studied in future for FCC-ee and CEPC.

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