JLC BEAM DELIVERY SYSTEM

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On behalf of ACFA-IR subgroup, recent activities of our group are reported. A beam halo was estimated by gas scattering through main linac and final focus(FF) system. A compact FF-optics was evaluated by SAD program and designs of warm and superconducting FF quadrupole magnets were updated since the JLC-1 green book. An iron structure was optimized for the detector-solenoid at higher magnetic field of B=3 Tesla. Analyses on the support system of final doublet have been completed for both cases of single support tube and two cantilevers, then the prototype will be constructed in this year. Performances of luminosity monitor and active mask were demonstrated with an emphasis on the fine segmentation in azimuthal angles by Monte Carlo simulations. A new masking system was proposed for the B=3 Tesla. Finally, the beam extraction line was designed with capabilities of measuring energy distribution and polarization, and neutron background was also estimated.

The ACFA-IR subgroup consists of experimental, accelerator physicists and engineers as seen in a web page of http://acfahep.kek.jp/member/subg/ir.html. We started the ACFA-FFIR meeting in last December after the second ACFA-LC workshop, which succeeded and expanded a series of JLC-structure meetings. The JLC-structure meeting has been formed in order to study the iron structure for the detector solenoid of B=3 Tesla after the first ACFA-LC workshop, where an increase of magnetic field from 2 to 3 Tesla was proposed to reduce backgrounds in detectors[1]. Minutes of the ACFA-FFIR meeting can be read on a web page of http://acfahep.kek.jp/subg/ir/minutes.html. Since a general layout of the beam delivery system and detailed descriptions of backgrounds have been presented at the previous workshops[1,2], I would like to report activities of our group since the last workshop.

1 Machine backgrounds

If beams keep perfect Gaussian distributions passing through the linac and beam delivery system, there would be no problem on machine backgrounds such as synchrotron radiations and muons. However they must develop halos by scattering on residual gas and thermal photons. The beam halos may generate uncontrollable amounts of synchrotron radiations at final focus magnets, which degrade detector performance too much. Therefore, they must be collimated upstream of IR for the radiations to be prevented from scattering on the final focus magnets, where muons are produced by them hitting the collimators. The muon rate can be reduced to a tolerable level by attenuators[2]. There are two possible positions for the collimation before or after the main linac, so called pre- or post-linac collimation. The pre-linac collimation is preferable since the length is shorter and also independent on the final beam energy. This statement must be true if a probability of halo regeneration is tolerably small at the main linac. For the halo formation, major processes are Compton scatterings on residual gas and thermal photons at the linac and beam delivery system, although the gas scattering dominates at vacuum pressure of 10^{-8} torr[4]. The regeneration probability(P_{halo}) can be analytically expressed by Eq.1 for the collimation depth of $n_x\sigma_x \times n_y\sigma_y$ with an integration along the beam line ($\int ds$), where the residual gas is CO of Z=14 and the density of $N_{gas} = 3.6 \times 10^{22} P(torr)$, the electron classical radius of $r_e = 2.8 \times 10^{-15}$m, $\epsilon_{x(y)}$ and $\beta_{x(y)}$ are emittance and beta function, respectively. The normalized emittance is $\gamma\epsilon_{x(y)} = 3 \times 10^{-8(-6)}$m·rad.

$$P_{halo} = N_{gas} \frac{4\pi Z^2 r_e^2}{\gamma^2 n_{x(y)} \epsilon_{x(y)}} \int \beta_{x(y)} ds \tag{1}$$

We set the vacuum pressure $P = 10^{-8}$torr and collimation depths of $n_x, n_y = 6, 40$.

For the case of pre-linac collimation, the probabilities are $P_{halo}^{x(y)} = 2(5) \times 10^{-7}$ in the main linac of $s = 11.5$km replacing the beta-functions with average values of $\beta_{x(y)} = 100$m in the integral of Eq.1. For the post-linac collimation, the probabilities are estimated to be $P_{halo}^{x} = 3.6 \times 10^{-7}$ and $P_{halo}^{y} = 1.3 \times 10^{-5}$ in the final focus system of 588.4m long at E_{beam} =250GeV. The results show that the pre-linac collimation would increase probabilities by 60% at most. Therefore, the post-linac collimation can be simplified and shorter for a purpose of machine protection where an energy collimation is only important. The calculations are too simple to conclude at this moment, so we have started to study the halo issues by a detailed simulation employing SAD.

2 Final focus system

A novel final focus design has recently been invented for high energy linear colliders by P. Raimondi and A. Seryi at SLAC[5]. The design is based on a realization of locally compensating the chromaticity of the final doublet by two sextupoles interleaved with the quadrupoles. It has two distinct features from an experimental point of view, that is, very short length (L=300m) and long distance from the IP to the final doublet ($\ell^* = 4$m) which are half and twice as long as those in the JLC design, respectively. Since the large ℓ^* decreases a field gradient of the final doublet, the aperture can be increased so that backgrounds would be significantly reduced. The large aperture can be tolerable for larger beam halo for the collimation depth to be shallower. In addition, the shorter L has less regeneration probability of beam halo. Therefore the total length of the beam delivery system consisting of the collimation and final focus systems may become shorter by several times. Because of so much advantages, we would like to implement the new optics in the JLC design. For the first step toward this end, a deck file of the new optics, which P. Raimondi provide us kindly, has been converted into a SAD format. At present, we are trying to verify these new features especially emphasizing on the tunability and tolerances.

Pole tip geometries of the conventional final doublet (QC1 and QC2) were evaluated in details by ANSYS program. The QC1 pole tips had to be thinner for synchrotron radiations to pass through without scatterings at the beam extraction line with 8 mrad horizontal crossing angle. The QC2 geometry was determined at the first time in order to be fitted with the compensation magnet inside the 80cmϕ support tube. The ANSYS calculations show very small non-linearity of less than 10^{-4} at the field gradients of 225 and 70 T/m for QC1 and QC2, respectively. Magnetic fields were also calculated along the extraction line and were taken into account for the extraction line design. We also investigated an option of superconducting final doublet. This option may be preferable for no need of compensation magnet, for larger apertures and less machine background issues as mentioned above, although intense synchrotron radiations emitted by the extracted beam are major issue.

3 Interaction Region

For the detector solenoid, higher magnetic field of B=3Tesla has been proposed to reduced background hits in tracking detectors at tolerable levels even for the higher luminosity upgrade and consequently detector sizes become smaller[2]. The iron structure has been optimized for uniform magnetic field of $\Delta B/B < 1.2\%$ at B=3Tesla inside the fiducial volume of the central tracking chamber and small leakage field along the beam line which is less than 100 Gauss beyond 10m from IP. Four layers of muon chambers are interleaved with iron plates both at the barrel and endcap parts. The endcap plates have an adequately large hole of 1.5m diameter for the support tube and its support structure.

At the 2nd ACFA-LC workshop in Seoul, the result of spectrum analysis has been reported for the case of single support tube[3]. It showed that relative displacements to be excited by ground motions, which have been measured at the TRISTAN tunnel, were completely negligible between two points separated by 4m. Since then, a new analysis has been executed on a system, where the two final focus doublets are independently supported by two identical cantilevers. If the system is stable in terms of ground motions, it is experimentally more preferable because of less material in detectors as well as easier assembling of the doublets and more straight forward installation. In the analysis, the cantilever is supported at three positions of 3.85m, 7m and 8m from the center of the system. For the support, rigid and soft cases were considered. The latter was supported by springs to the ground with the natural frequency of 15Hz, whereas the first was rigidly supported to the ground. The cantilever was assumed to be made of 80cm ϕ tungsten cylinder of 10 cm thick with the conical mask in front, and the total weight was 41 tons. Exciting the same ground motions as the previous analysis, whose amplitudes were 3μm, 1μm, 10nm and 5nm at 0.003, 0.1, 1 and 3Hz, respectively, vertical deformations were calculated at the three major natural frequencies of the cantilever system. The soft support was turned out to be more stable than the rigid one since the cantilever was so rigid that it would not be deformed locally. For the soft support, the largest movement was a smooth shift by 2.5 ± 0.2nm at the first natural frequency of 15 Hz. Good coherencies of ground motions have been observed at such short distance between two points in many places. Therefore, the results are encouraging. In this year, the prototype of support tube including the cantilever case will be made in order to experimentally verify these ANSYS calculations.

Performances of luminosity monitor(LM) and active mask(AM) have been investigated by Monte Carlo simulations. Angular coverages are $0.05 < \theta < 0.15$rad and $0.15 < \theta < 0.20$rad in LM and AM, respectively, so that they form a veto system of θ_{veto}^{min} =0.05 rad together with other calorimeters. The simulations show that both of LM and AM can clearly detect high energy electromagnetic particles (e^-, e^+, γ) injecting into the centers overlapping with e^+e^- pair backgrounds of 100 bunch crossings if they have fine segmentation in azimuthal angles. This study has demonstrated only a basic feasibility of LM and AM. Therefore, the optimization shall be needed as fine segmented devices as well as detector types, studying the minimum energies/angles to be detected and performances around boundaries between LM,AM and calorimeters, etc. Impressive progress of the pair monitor R&D was reported by G.S. Varner (Univ. of Hawaii) at this workshop.

A new mask configuration has been investigated at B=3 Tesla. For reevaluation of the configulation, the largest change was the endplate position of the central tracking chamber(CTC) among updated detectors[6]. The positions are 1.6m and 2.3m from the IP at B=3 and 2 Tesla, respectively. Since the ℓ^* of QC1 is 2m, the previous CTC must be shielded from huge number of secondary photons and neutrons by cylindrical tungsten mask of 10cm thick. The updated CTC may not need the cylinder part because the conical part is enough for the shielding. Detailed simulation shows that this guess was true, however the thinner cylinder produce larger energy deposits in the calorimeter. A more aggressive mask configuration was proposed with a smaller dead cone of 100 mrad and larger aperture by moving the thin end of the conical mask from 30cm to 100cm off the IP. The background hit rate was well below by simulations.

4 Extraction line

After collisions at E_{beam} =250GeV, beams are disrupted by the strong magnetic field of each on-coming beam, so called beamstrahlung process, and the beams are also accompanied by the beamstrahlung photons as well as synchrotron radiations and e^+e^- pairs. They must be transported to dumps with small losses to avoid any background problem at the detector. At the same time, we also require a beam diagnostic section in the extraction line, where the beam energy distributions and polarizations must be measured well.

The disrupted beam has several times larger emittance that the nominal beam. The angular spreads are $|\theta_{x'}| < 350\mu$rad and $|\theta_{y'}| < 200\mu$rad including low energy particles. In addition to 8mrad horizontal crossing, the beam is further bent for 2mrad in the magnetic fields off the QC1 and QC2 centers. A pair of quadrupole doublets are employed to focus the beams again at a distance of 75m from the IP, where the first and second doublets are set at 10.5m and 58m, respectively, as shown in Fig.1. Two horizontal bends(BH1,BH2)

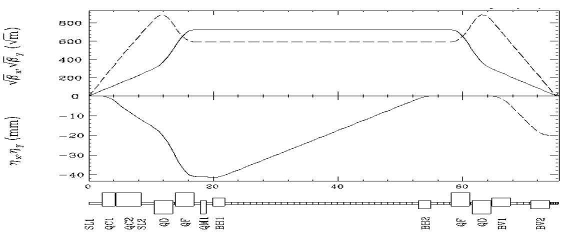

Figure 1. Optics of the extraction line.

are inserted between them for horizontal dispersion free(η_x=0) at the second focal point. After the second doublet, the beam is vertically bent for 3mrad by two bends (BV1, BV2) in order to produce the vertical dispersion of η_y=2cm at the second focal point. Therefore, it has a vertical distribution proportional to energy as $\eta_y \times \Delta E/E$, *i.e.* 200μm displacement at $\Delta E/E = 0.01$., there. Since the beam spot sizes are σ_y =1.7, 7.0 and 12 μm for $\Delta E/E$ =0, -0.005 and 0.01, respectively, the energy distribution can be measured by 10μm ϕ horizontal laser wire with the energy resolution of $O(10^{-3})$.

Energy losses have been also estimated along the extraction line, assuming relatively large apertures of the magnets and beam pipes up to about 40cmϕ. The total loss was calculated to be 0.93%, most of which were caused by low energy particles overfocused at the quadrupole doublets and took place at more than 30m downstream of the IP. We expect that a mask, which shall be set between the final focus doublet and the first extraction doublet, can shield the interaction region from a huge number of secondary backgrounds such as neutrons produced by the loss. Also, the apertures of magnets must be optimized to minimize the loss there.

Acknowledgments

I would like to thank all the members of ACFA-FFIR subgroup for their dedicated and enthusiastic works. I also appreciate all the participants for their stimulative discussions during this workshop. Finally, I sincerely thank the workshop organizers for their warm hospitality and the successful workshop.

References

1. T. Tauchi in *proceedings of The 1st ACFA Workshop on Physics and Detector at the Linear Collider*, pp.109-119, ed. T.Matsui and Y.Kuang (KEK Proceedings 99-12, September 1999).
2. T. Tauchi, submitted to proceedings of The 2nd ACFA Workshop, Seoul, Korea, 11/4-6,1999, which can be available from a web page of http://acfahep.kek.jp/subg/ir/talks/proceedings/acfa2nd.ir.ps.gz .
3. H.Yamaoka, *Design of solenoid magnet and support tube*, talk at the 2nd ACFA Workshop.
4. I. Reichel et al., presented at the ICAP98, Monterey, California, September 14-18, 1998, SLAC-PUB-8012, November 1998.
5. P. Raimondi and A. Seryi, SLAC-PUB-8460, May 2000, submitted to Phys. Rev. Lett.
6. Y.Fujii, *3T Detector Model*, in this proceedings.