

# THE ILC BEAM DELIVERY SYSTEM DESIGN AND R&D PROGRAMME

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## Abstract

The International Linear Collider (ILC) beam delivery system (BDS) has been designed and published in the reference design report (RDR)[1] by large international collaboration in framework of ILC-GDE (Global Design Effort). The BDS design is briefly described based on the RDR. There are dedicated test facilities, which are End Station A (ESA) and ATF2 at SLAC and KEK, respectively, as well as a proposed one of FACET at SLAC. Especially, ATF2 is a final focus test beam line for ILC in the ATF international collaboration. Since it is a scaled-down model of ILC-BDS with local chromaticity correction scheme, it is describe in some details.

## ILC BEAM DELIVERY SYSTEM

The International Linear Collider(ILC) is a 31km long  $e^+e^-$  collider with acceleration in superconducting cavities at the center of mass energy of 500 to 1000 TeV. The ILC Global Design Effort (GDE) has been established towards the international construction in 2005. GDE published the reference design report (RDR) in August 2007. Basic design of all systems are described with first cost estimation in RDR.

Beam delivery system (BDS) is the last part of ILC at the top energy, focussing to nanometer sizes for collisions with high luminosity. In this aspect, BDS is an area where accelerator and physics people must work closely for achievement of experimental goals, i.e. experimental determination of origin of electroweak symmetry breaking and precision studies of new physics. This collaboration is especially important to design the BDS in details. Therefore, it is called as Machine Detector Interface (MDI) in the BDS studies.

## General Layout

The BDS has total length of 4.4km for electron and positron beams. It has been designed for a single interaction region (IR) allowing two experiments with push-pull scheme and also for upgradable to 1TeV center-of-mass(CM) energy in the same layout.

Basic parameters are a distance from interaction point (IP) to first quadrupole magnet,  $L^*$  of 3.5-4.5m, horizontal crossing angle between two beams of 14mradian at IP, beam sizes at IP,  $\sigma_x^*/\sigma_y^*$  of 639/5.7nm and the maximum beam power of 18MW at 1TeV CM.

As shown in Fig. 1, the BDS consists of diagnostic section, polarimeter, fast kickers to extract beam to a tuneup dump, collimation section, final focus section and 300m long extraction line to the primary dump. First from the

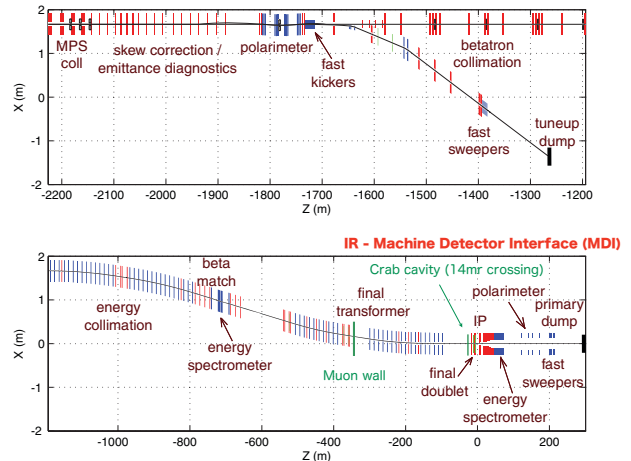


Figure 1: Layout of BDS functional subsystems[1].

main LINAC, emittance and polarization of beam are measured and horizontal and vertical coupling is also corrected with so-called skew correction in the diagnostic section. The collimation section consists of betatron collimation in phase space and energy collimation, where typical collimation depths in beam halo are  $8-10\sigma_x$  and  $60\sigma_y$ , and the downstream energy collimator can remove the degrade energy particles originating from the betatron collimation. The depths can be changed by adjustable gaps. The collimation section is important to control synchrotron radiations in IR. During the collimation, many muons could be generated. In order to prevent muons from penetrating the detector, a muon wall is installed at 330m upstream from IP, which is a 5m long magnetized iron at 1.5T. In this scheme, the halo can be tolerable up to  $10^{-3}$  of beam intensity. Crab cavity system is installed at 13.4m upstream from IP to recover luminosity loss due to the beam crossing.

Major issues for the BDS design are summarized as follow.

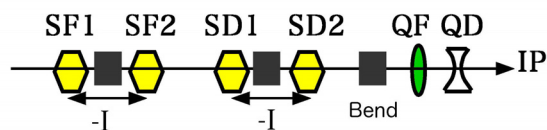
- Chromaticity ( $\xi$ ) correction of final doublet, where the beam size increase ( $\Delta\sigma^*/\sigma^*$ ) is proportional to the energy spread ( $\delta = (E - E_0)/E_0$ ) with a coefficient of  $\xi$ . The ILC  $\xi$  exceeds 10,000.
- Beam diagnostic and tuning with precise measurement of micron size beam, energy and polarization.
- Beam-beam effect at IP producing  $e^+e^-$  pair background and disrupted beam at IR and extraction line to the beam dump, respectively.
- Beam halo originating from the main LINAC requiring robust collimation for synchrotron radiations and muon wall for resulting muons.

Critical subsystems listed above have been researched and developed at test facilities and universities as described in subsequent sections.

### Local Chromaticity Correction

There are two schemes for chromaticity correction as shown in Fig. 2. Conventionally, chromaticity is counter-balanced by sextupoles in exclusive sections which would be located at far upstream at linear colliders. Geometric aberrations are compensated by pairing sextupoles with relative phase of  $180^\circ$  in transfer matrix. Therefore, the chromaticity is non-locally corrected. This scheme has disadvantages of large aberrations for off-momentum particles, while it has simple design and tuning for separated optics. Total length of this system increases in length to minimize energy spread generated in bending magnets together with two exclusive sections in horizontal and vertical directions.

#### (1) Non-local correction



#### (2) Local correction

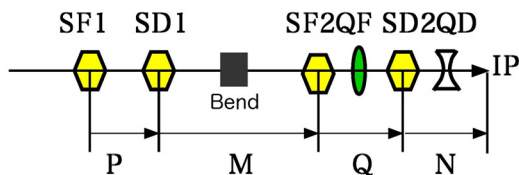


Figure 2: Optical layout of chromaticity correction

In order to overcome the disadvantages of the conventional scheme, the local correction scheme has been invented by P.Raimondi and A.Seryi[2]. Chromaticity is compensated by two sextupoles interleaved with a final doublet(FD), reducing number of bending magnets. The second order dispersion generated in FD is locally cancelled in the same way. Half of horizontal chromaticity is produced upstream of a bend. The second order geometric aberrations are cancelled by pairing two sextupoles upstream of the bend. The third order aberrations are cancelled by optimizing transfer matrixes between the sextupoles. The local correction system has been proven to have better performance in the bandwidth and shorter length. Therefore, it was adopted in the ILC BDS design.

Before the invention, a final focus test beam (FFTb) has been constructed and successfully verified the feasibility of the non-local chromaticity scheme at future linear colliders[3].

### Test Facilities, Activities at Universities

End station A at SLAC has been a test facility of ILC-BDS instrumentation R&Ds for 2006 through 2008. Beam

tests have been conducted for 4 weeks in each of 2006 and 2007 and will be done for 3-4 weeks in 2008. Test experiments include collimator studies of wakefields and damage, energy spectrometers based on BPM-measurements and synchrotron radiation profile-strip edge measurement, fast feedbacks, electro-magnetic interference studies and IR mock-up studies, etc.[4]. ESA provides 28.5GeV electron beam with beam parameters for bunch charge, energy spread and bunch length similar to the ILC parameters. Goal of the energy spectrometer studies is to verify a feasibility of 100ppm energy resolution at ILC. In the IR mock-up, performances of beam instrument such as BPMs were measured with backgrounds mimicking the ILC IR condition.

After the ESA, Facilities for Accelerator Science and Experimental Test Beams (FACET) was proposed at SLAC. FACET consists of Accelerator Science Facility (ASF) and ESA with new transport line. ASF will provide 24GeV and focused beam, where the major R&D is plasma wakefield accelerators (PWFA) as well as beam instrumentation. ESA will provide 12 GeV beam for R&Ds of beam instrumentation and ILC/LHC detectors .

ATF2 is a scaled-down model of LC-BDS final focus system with 1.3 GeV electron beam at KEK. Next section describes ATF2 in some details.

In addition to activities at the test facilities, following key systems have been researched and developed at laboratories and universities. To realize a strong beam focus with 14mrad crossing, compact final doublets have been actively developed based on superconducting and permanent magnets at BNL and Kyoto university, respectively. In the ILC case of  $L^*=3.5-4.5m$ , the final doublets will be installed inside detector. Also, the crab cavity has been developed by UK-FNAL-SLAC collaboration.

Since there are many common issues for future linear colliders , i.e. independently from the acceleration technology such as the final focus optics, crab cavity, collimation, fast feedback system and beam instrumentation , a collaboration with CLIC group is highly encouraged with strong synergy in the R&D efforts.

### ATF2

ATF2 is an international final focus test beam line for ILC in the frame work of the ATF international collaboration. The new beam line is under construction to extend the extraction line at ATF, KEK, Japan. ATF2 will be commissioned in this October, 2008.

### ATF International Collaboration

Accelerator Test facility (ATF) has been established for generation of ultra low emittance beam for future linear colliders at KEK[5]. ATF consists of an electron source of RF gun, a 70m long injection LINAC, a 1.3 GeV dumping ring(DR) with 140m racetrack circumference and an extraction line (Fig. 3). It has started operation in 1997 and it has achieved the target emittance in 2001[6]. Since then,

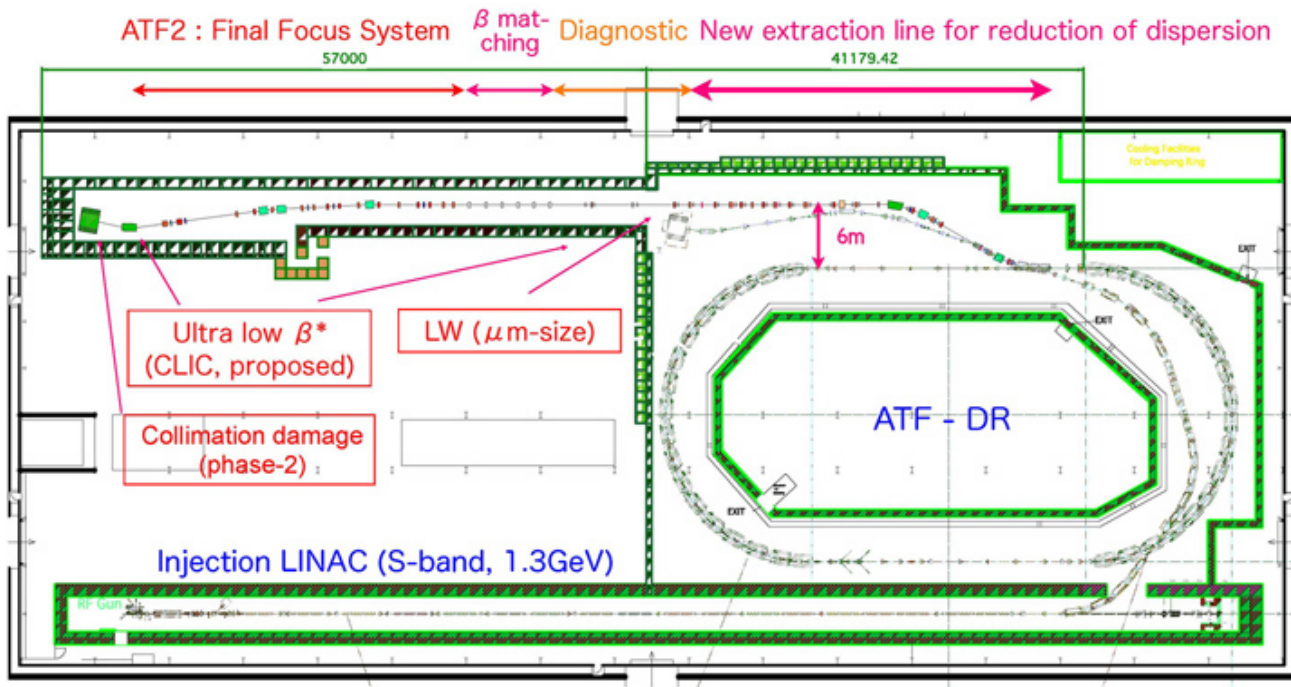


Figure 3: Layout of ATF and ATF2 beam line, where proposed R&Ds of low- $\beta^*$  final focus system (CERN, LAL, Daresbury, SLAC, KEK, IHEP), laserwire (LW, RHUL) and collimation damage studies (Birmingham university) are also listed.

many Japanese and international groups have researched and developed beam dynamics in DR and advanced beam instrumentation in the extraction line as well as DR by using high quality beams. To extend further progress in the internationalization, ATF international collaboration was organized with exchange of memorandum (MOU) in August, 2005. During a period of April 2006 and July 2007, ATF took in foreign researchers with 2,085 people-days excluding full-year researchers.

ATF2 has been proposed as a project of the ATF international collaboration. The proposal has more than 110 researchers from 25 institute in the world[7].

### Features and Goals

The ATF2 beam line consists of extraction, diagnostic,  $\beta$  matching and final focus sections, where the beam energy is 1.3GeV as shown in Fig. 3. The total length is  $\sim 90$ m.

The final focus section is scaled to the ILC one with essentially same number of magnets, where the lengths are  $\sim 30$ m and  $\sim 660$ m at ATF2 and ILC, respectively, as these two optics systems are shown in Fig. 4. Beam tuning methods to be developed will be the same as those at ILC. Also, beam instrumentation has been developed with ILC specifications such as beam position monitors with 100nm position resolution (QBPM by KEK, PAL, RHUL and SLAC), beam size monitors (laserwire system with 1 $\mu$ m resolution by RHUL and laser interferometer system for nanometer beam size measurement by Tokyo university), movers, high available power supply system (SLAC), fast feedback

system (FONT, Oxford university) etc. . Beam parameters of ILC and ATF2 are compared in Table .

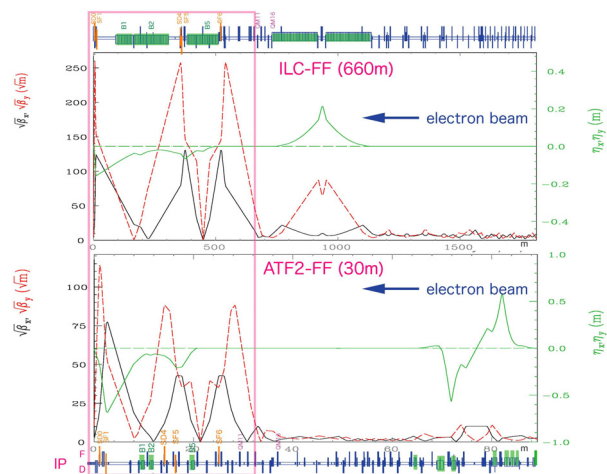


Figure 4: Comparison between the ILC and the ATF2 optics : lengths of final focus systems from the  $\beta$  matching section to IP are 660m and 30m at ILC and ATF2, respectively. Although the lengths are different by 20 times, optical functions are very similar.

First goal of ATF2 is the verification of final focus system with the local chromaticity correction by achievement of  $\sigma_y^* = 34$ nm, where  $\sigma_y^*$  is the geometrical vertical beam size at focal point (IP).

Second goal is to stabilize the beam focal point at a

Table 1: Beam parameters at ATF2 and ILC

Parameter	ATF2	ILC
Beam energy(GeV)	1.3	250
$L^*$ (m)	1	3.5~4.5
Emittance : $\gamma\epsilon_x/\gamma\epsilon_y$ (m·rad)	$5 \cdot 10^{-6}/3 \cdot 10^{-8}$	$1 \cdot 10^{-5}/4 \cdot 10^{-8}$
$\beta$ at IP : $\beta_x^*/\beta_y^*$ (mm)	4.0/0.1	21/0.4
$\eta'$ at IP : $\eta'_x$	0.14	0.094
Energy spread: $\sigma_E$ (%)	~0.1	~0.1
Chromaticity : $W_y$	~ $10^4$	~ $10^4$
Beam size at IP : $\sigma_x^*/\sigma_y^*$ ( $\mu\text{m}/\text{nm}$ )	2.8/34	0.66/5.7
Aspect ratio : $\sigma_x^*/\sigma_y^*$	82	115

few nano meter level for long period in order to assure the high luminosity. As listed in table , beam sizes are  $\sigma_x^* = 655\text{nm}$ ,  $\sigma_y^* = 5.7\text{nm}$  at IP, ILC. The vertical beam position must be stabilized at nanometer level at IP. High resolution cavity type BPM (IPBPM) is developed at ATF2 by KEK and KNU (Kyungpook National University, Taegu, Korea), whose resolution is targeted to be 2nm [8]. IPBPM will be install at IP, ATF2. Fast feedback system utilizing IPBPM signals will be installed near IP in order to demonstrate such stability, i.e. 5nm at least, by Oxford university.

ATF2 is designed and constructed by international collaboration. Also, the operation and beam tuning studies will be engaged in international cooperation.

### Present Status and Schedule

For the stability requirement, floor of the extended area was refurbished in summer shutdown of ATF, i.e. by end of September 2007. The floor will become to a monolith of 60cm thick concrete slab in the similar way of the ATF-DR floor.



Figure 5: ATF2 floor construction : A 0.6m thick concrete slab of 396m<sup>3</sup> will be supported by 0.6m thick beams, which are visible in this picture, and 38 piles with 0.7m diameter and 13m height, which were buried under the beams.

All quadrupole magnets, their support system, cavity-type beam position monitors have been constructed by IHEP(China), KEK, PAL(Korea), respectively. Many components such as the magnet movers and support system of final doublet are provided with in-kind contributions from SLAC and LAPP, respectively. The components are being installed in the new beam line after the floor completion.



Figure 6: ATF2 beam line under construction : all the quadrupoles and bends were installed with cable and cooling pipes.

In this summer, 2008, the extraction section is re-configured from the existing extraction line. At the same time, whole beam line of ATF2 will be completed. ATF2 beam line will be commissioned in October 2008.

### CONCLUSION

ILC BDS has been designed by large international collaboration in framework of ILC-GDE since 2005. There are R&Ds of critical subsystems such as final doublet, crab cavity, laser wire, collimation etc. Close collaboration between machine and physics people is essential especially in the IR design, and it has been successful; i.e. IR Interface Document. Test facilities ( ESA, ATF2 and FACET) will assure stable collisions of nanometer beams at future linear

colliders. Collaboration between ILC and CLIC should be promoted more than ever in the BDS R&Ds.

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