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PROPOSAL OF THE NEXT INCARNATION OF ACCELERATOR TEST FACILITY AT KEK FOR THE INTERNATIONAL LINEAR COLLIDER

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Abstract

To reach design luminosity, the International Linear Collider (ILC) must be able to create and reliably maintain nanometer size beams. The ATF damping ring is the unique facility where ILC emittances are possible. In this paper we present and evaluate the proposal to create a final focus facility at the ATF which, using compact final focus optics and an ILC-like bunch train, would be capable of achieving 37 nm beam size. Such a facility would enable the development of beam diagnostics and tuning methods, as well as the training of young accelerator physicists.

MOTIVATIONS AND GOALS FOR THE INTERNATIONAL ATF2 PROJECT

The future International Linear Collider (ILC) must focus electron and positron beams to sizes as small as a few nanometers at the Interaction Point (IP), and stablize them to the sub-nanometer level. Experience with handling, measuring and tuning such tiny beams would be invaluable preparation for future ILC performance. The Accelerator Test Facility (ATF) at the KEK laboratory in Tsukuba, Japan, is the unique facility worldwide with ultra-low emittance beams extracted from the damping ring. The goals of the proposed ATF2 facility are to focus the beam to 37 nm size using the compact final focus optics, develop experience with reliably achieving and maintaining small beam sizes, provide a test bed for ILC instrumentation and Beam Delivery System (BDS) related studies, create a facility to train young physicists, and finally be a model of design, construction and operation of a truly international facility.

The ATF2 facility will be a continuation of the successful results achieved at the Final Focus Test Beam [1]. The FFTB, which achieved a beam size of 70 nm, provided invaluable experience and confidence in the final focus system design and operation. However, it could not address questions of reliably maintaining the beam size over the long term or of beam stability. Between 1994 and 1997, there were a number of short runs of 1-3 week duration. The small beam size was achieved in about half of the runs. The measured beam size was also much larger than the 40 nm value expected given the input beam emittances. The difference was attributed to significant jitter of the focused beam and was partly due to limited accuracy of tuning the linear optics and the aberrations [3]. Since FFTB runs were not compatible with SLC operation, detailed investigations of these important issues could not be pursued.

Table 1: The achieved ATF beam parameters and the parameters for the ATF2, goals **A** and **B**. The ring energy is $E_0 = 1.28$ GeV, the typical bunch length and energy spread are $\sigma_z \sim 8$ mm and $\Delta E/E = 0.08$ %.

	Measured	(**A**)	(**B**)
Single bunch			
N_{bunch} (10^{10})	0.2-1.0	0.5	-
DR $\gamma\varepsilon_y$ $(10^{-8}$m)	1.5	3	-
Extr. $\gamma\varepsilon_y$ $(10^{-8}$m)	3.0-6.5	3	-
Multi bunch			
N_{bunch} (10^{10})	0.3-0.5	0.5	0.5
$n_{bunches}$	20	1-20	3-20
DR $\gamma\varepsilon_y$ $(10^{-8}$m)	3.0-4.5	3	3
Extr. $\gamma\varepsilon_y$ $(10^{-8}$m)	-	3	3
IP σ_y^* (nm)		37	37
IP $\Delta y/\sigma_y^*$ (%)		30	5

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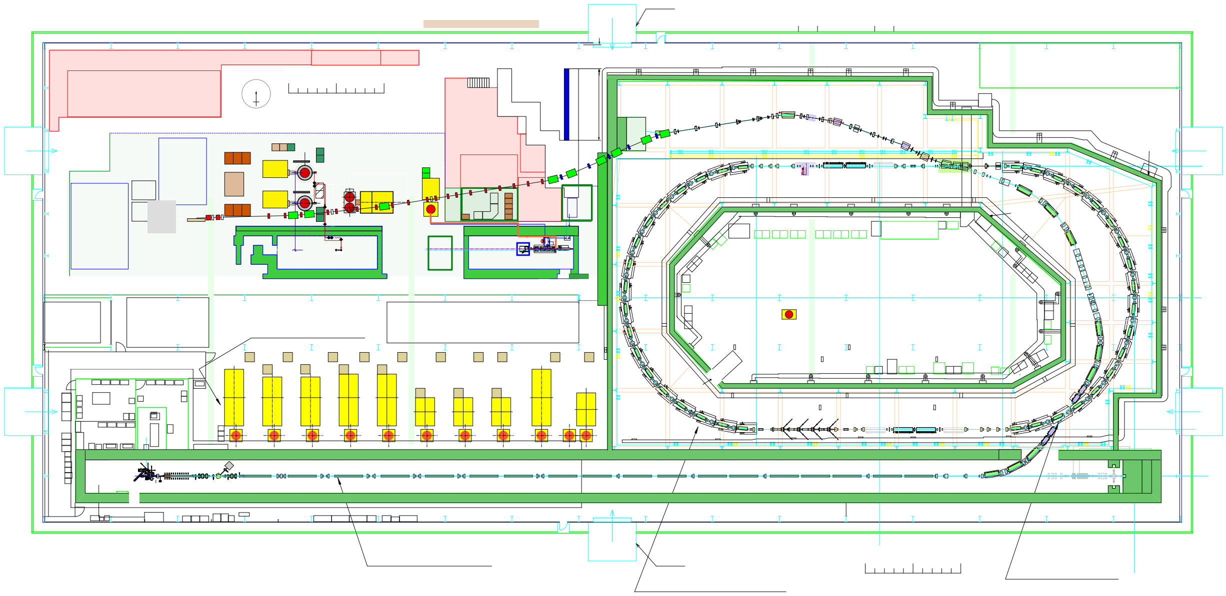

Figure 1: ATF2 layout, the conservative version which assumes that crab-cavity tests continue in 2006.

Since the FFTB era, the ILC BDS design has changed significantly. The recently proposed compact final focus optics with local chromaticity correction [2] has better performance in a much shorter system and can more easily be extended to multi-TeV. This is now the basis of ILC BDS design but has never been tested experimentally. Prior to ILC construction, it will be important to obtain real experience with the compact final focus optics design. The ATF2 facility, to be built in 2005-2006 with first beams available in early 2007, would give important operating experience during preparation of the ILC Technical Design Report (TDR), construction and early years of operation, and will become the *alma mater* for the generation of physicists needed to complete the ILC design and operate the ILC.

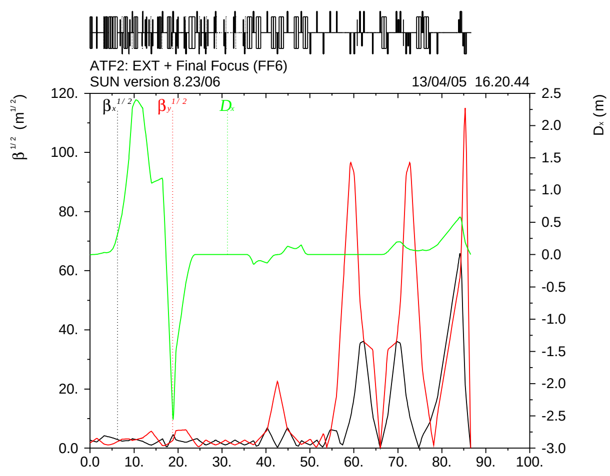

Figure 2: ATF2 Optics (“conservative” version, crab cavity space not released).

The ATF2 will address two major challenges of the ILC BDS: focusing the beams to nanometer size and providing sub-nanometer stability. The ATF has the high quality beams required to achieve these goals – it has successfully produced beams with the lowest emittance ever achieved, in both single and multi-bunch [4, 5] mode, which are very similar to those for ILC. Further development of hardware and diagnostics and improvement of the extracted beam quality are needed for ATF2. The schedule for ATF2 and hardware development will successively address the two major goals:

(A) Achievement of 37nm beam size.
- **(A1)** Demonstration of a compact final focus system based on local chromaticity correction [2].
- **(A2)** Maintenance and verification of the small beam size.

(B) Control of beam position.
- **(B1)** Demonstration of beam orbit stabilization with nanometer precision at IP.
- **(B2)** Establishment of beam jitter control techniques at nanometer level with ILC-type beam.

Ultimately, the ATF2 will aim at achieving the small beam size and nanometer beam stability simultaneously.

The high quality beams available at ATF2 would generate many other opportunities for experiments. As an option, a photon linear collider (PLC) test facility has been considered. At the PLC test facility, a photon beam would be produced with high intensity and multi-bunch structure similar to the ILC. Experiments could also be conducted to test QED in the strong field of a high intensity laser.

ATF2 DESIGN

Two possible final focus (FF) designs were considered for ATF2. The first was proposed in 2002 [6], and the second is the Next Linear Collider (NLC) compact final focus [7] scaled down in length. Both designs were evaluated for the proposal [8]. The first design has fewer magnets and would be less expensive, but the chromaticity correction is not purely local, the tolerances on magnet strength and position are tighter, the bandwidth is narrower and scaling to TeV energy is more difficult. Therefore, the NLC-like optics was chosen as a baseline design for the ATF2.

The final focus beam line of the ATF2 is about 37 meters long extending the existing ATF extraction line as shown in Fig.1. The optics in Fig.2 has $L^* = 1$ m (distance from last focusing quadrupole to IP), $\eta' = -0.14$ (derivative of dispersion at IP) with IP beta-functions $\beta^*_{x/y} = 4/0.1$ mm. The beam parameters are shown in Table 1. The total chromaticity of this optics is approximately the same as in the ILC FF. The vertical beam size will be focused to 37 nm with the aspect ratio of about 100:1 similar to the ILC.

In addition to the final focus proper, the ATF2 design includes a snake-like optics with six bends which displace the final focus beamline to the South (toward the bottom of Fig.1). This may be necessary to avoid the KEK-B crab cavity test area (shown by a blue rectangular bar), assuming conservatively that the crab-cavity development continues into 2006. If the first crab-cavity tests are successful and the space is no longer needed, an "ideal optics" without the snake bends will be used.

To fully realize the ATF2 program and fulfill both goals **A** and **B**, a number of hardware developments and other improvements are needed to the ATF damping ring and extraction system.

For goal (**A**), an interferometer-based beam size monitor (BSM, also called Shintake monitor) will be installed at the IP. The laser will operate with higher modes than those used for the FFTB measurements [1]. To measure the beam orbit and maintain the beam size with feedback, the beamline magnets will be equipped with 100 nm resolution cavity-BPMs and will be placed on movers. Tuning methods will be established based on BSMs as well as BPMs. To achieve the goal (**B1**), a set of precision nano-BPMs will be installed at the IP. A set of BPMs with a resolution of better than 2 nm are now being developed by the Japan-US group. The possibility of combining the two goals, with both the BSM at the IP and nano-BPMs nearby to achieve both the small beam size and nanometer stability, is under investigation.

The beam quality must also be improved for ATF2. The present normalized emittance in the ATF extraction line is estimated to be 4.8×10^{-8} m, three times larger than that in the damping ring. The emittance can be improved to the nominal value of 3×10^{-8}m by correcting the x-y coupling. The beam jitter must be reduced to about 30% of the beam size for the goal (**A**), and 5% for the goal (**B**). The vertical beam jitter in the ATF extraction line is now typically about 30% of the beam size (up to 100% on the time scale of several minutes), which is much larger than the 10% beam jitter observed in the damping ring. The slow component is believed to come from the extraction kicker system, which may be improved by a double kicker scheme together with an additional feed-forward system. This is expected to reduce the jitter to the same level as in the damping ring.

The beam stability can be further improved with a new 300 nsec kicker which will make it possible to extract the beam-train in 3 bunches separated by 150 nsec. A fast feedback system being developed by KEK and UK groups, FEATHER and FONT, will be used to further stabilize the third bunch. The nano-BPM system will be able to verify the performance of the fast feedback system at the nanometer level. Further beam jitter control at nanometer level with ILC-type beam (goal **B2**), will require a very fast kicker with less than a nsec rise time and stable pulse height, which will make it possible to extract an ILC-type train, i.e. 20 bunches with about 300 nsec separation at 5Hz. These developments may continue during the ILC construction.

Finally, before installation of the ATF2 components, the floor under the new beamlines must be reinforced in a similar way as was done for the ATF damping ring. Studies with seismometers and tiltmeters have shown that the present floor in the ATF2 area is much less stable and has a large sensitivity to temperature variation. Reinforcement of the ATF2 floor will be done during Summer of 2006.

ATF2 COLLABORATION AND ATF2 SCHEDULE

The ATF2 test facility is being developed by an international team of more than sixty people worldwide, with the aim to produce a detailed proposal by mid-2005. The tentative schedule includes start of hardware construction (magnets, BPMs, etc.) in the Fall of 2005. Reinforcement of the ATF floor will happen in Summer of 2006, prior to the beamline installation. The first beams could be available in early 2007. The ATF2 construction plan is similar to a possible ILC model: the host laboratory (KEK) will be solely responsible for the conventional facility construction costs, while the beamline hardware will come as contributions from participating labs and institutions. This process may provide useful experience for the ILC.

SUMMARY

This paper describes the proposal for an international final focus ATF2 facility for consideration by the worldwide International Linear Collider collaboration. The ATF2 facility will benefit from the uniquely small beam emittances achievable at KEK ATF, and will provide valuable experience in achieving, maintaining and stabilizing nanometer scale beams. Such a facility will be invaluable for the successful design and operation of ILC, provide a test bed for development of instrumentation and accelerator physics ideas, train the next generation of accelerator physicists and promote truly international collaboration building a new facility.

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