Summary of the ATF2 ILC Programme Review 3-4.04.2013

24th May, 2013

# Introduction

This report summarises the findings and recommendations from a 1½ day comprehensive review of the ATF2 programme, held at KEK on 3-4.04.2013. The review was commissioned by the Executive Committee (EC) of the GDE, and was specifically focused on the progress made towards achieving the two primary ILC-related goals for ATF2 as documented in the published *ILC R&D Plan for the Technical Design Phase* (rel 5):

1. achieving a vertical beam size of 37 nm at the focal point;
2. stabilising of that beam to nanometre levels (over various time scales).

The above originally stated GDE goals have been slightly modified (reinterpreted) by the ATF2 collaboration:

**Goal 1**: Achievement of 37 nm beam size

1. demonstration of a compact final focus system based on local chromaticity correction;
2. maintaining the small beam size over an extended period of time.

**Goal 2**: Control of beam position

1. demonstration of beam trajectory stabilisation with nanometre precision at the IP;
2. establishment of techniques for controlling beam jitter at the nanometre level with an ILC-like beam.

The review itself was jointly organised by the GDE project management together with the KEK LC office. The membership of the international review committee is given in the table below.

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| Barry Barish | Caltech / GDE |
| Alex Chao | SLAC |
| Olivier Napoly | CEA Saclay |
| Katsunobu Oide | KEK |
| Marc Ross | SLAC |
| Andrei Seryi | JAI |
| Rogelio Tomas Garcia | CERN |
| Nicholas Walker (chair) | DESY |
| Akira Yamamoto | KEK |

The charge to the committee from the GDE EC is given in the Appendix.

The review was organised into five technical sessions:

1. Damping ring (ATF) performance
2. Accelerator physics issues
3. ATF2 beam optics design and performance
4. Achieving the stability goal (goal 2)
5. Instrumentation and diagnostics

A sixth session was included on management and collaboration issues. The agenda and all the presentations can be found at

<https://ilcagenda.linearcollider.org/conferenceOtherViews.py?view=standard&confId=5973>.

This report is based on the deliberations of the review committee during the review itself and subsequent presented close-out presentation. The next section (Section 2) gives a top-level executive summary of the top-level findings of the committee, while Section 3 gives specific details for the five themes listed above. Section 4 discusses management and collaboration issues. Finally Section 5 briefly discusses future plans.

The committee would like to thank our KEK hosts and all the ATF2 collaborators for a well-organised and enjoyable review.

# Top-level findings (executive summary)

Overall the committee was impressed with the progress made towards achieving the goals and would like to congratulate the ATF2 collaboration for their achievements. In particular the recent progress on Goal 1 is impressive: The extensive upgrades and improvements to the machine itself, including critical sub-systems such as the IPBSM, together with the organised approach to shifts and personnel training, have resulted in significant gains in terms of understanding and characterising the accelerator, resulting in a best-recorded beam size of 64 nm.

It was clear from the review that the issues of impedance and wakefields have become an important focus in understanding the limitations in achieving Goal 1. The committee understands that the low beam sizes achieved are all at significantly lower single-bunch charge than the original design value of 1010 electrons per bunch. However, the committee also made the following observations with respect to Goal 1:

* From a diagnostic point of view (in particular the IP laser beam-size monitor) there appears to be no significant gain in increasing the bunch charge; the resolution and S/N at the lower bunch charge appears to be adequate.
* Subsequently, a demonstration of the beam optics and aberration tuning (Goal 1a) can be made at the lower bunch charges.

The committee therefore endorses the best achieved results as a successful demonstration of the compact final focus optics and both the linear optics tuning and high-order aberration compensation schemes involved. The committee notes that the application of the tuning algorithms have successfully demonstrated over an order of magnitude reduction in the beam size from the initial un-tuned state.

The committee recognises that the last factor (<2) in achieving Goal 1 will be challenging, not only in terms of optics tuning but also for the instrumentation (IP BSM), where there still appears to be issues to be resolved.

The committee notes that the issue of beam size stability (Goal 1b - originally part of the GDE goal 2) has not as yet been substantially addressed experimentally (although simulations results have been presented). This is understandable given the attention to first achieving small beam sizes. However, the goal of monitoring the beam size stability over long periods remains an important one, taking ATF2 beyond that which was achieved at FFTB.

In decoupling Goal 1 from the bunch charge, a third almost independent goal of understanding and characterising the wakefield effects (emittance preservation) in ATF2 has become important. The committee acknowledges the existing efforts to measure, characterise and understand the sources of wakefield emittance growth and strongly encourages further efforts in this area. Although progress has been made, the presented results clearly show that a large fraction of the effect in the FFS itself is not understood. A programme to identify experimentally the source of the wakefield kicks needs to be implemented, and the impedance calculations of all known vacuum system components should be made (currently on-going), so that more comprehensive and complete simulations can be performed. Inexpensive hardware modifications such as bellows shields should also be considered.

The plans for Goal 2 (stabilising beam centroid jitter at the focal point at the nanometre level) seem well in hand, in particular the development of the new high-resolution nanometre-BPMs IP chamber at LAL which is due to be installed this summer. However, unlike Goal 1, the committee feels Goal 2 cannot be so easily decoupled from the bunch charge (wakefield) issues, since a higher bunch charge is needed to achieved the required beam position resolution of the IP nanometre BPMs being developed by KNU. Furthermore the committee felt that the detailed goals require further clarification. A particular concern is that much of the demonstration relies heavily on the successful development and commissioning of the IP BPMs and the chamber, which themselves have several challenges. The committee notes that there is a danger that the programme becomes more a demonstration of the nanometre BPM systems (devices which themselves are not required for ILC) than the beam stabilisation itself, especially since the kicker and feedback systems (FONT) have already been successfully demonstrated. The need to move the optical waist focal point is also an unfortunate requirement - and making sure the focal point is indeed at the BPM will be challenging. The committee proposes that more details are required concerning what the expected overall performance should be, and what exactly will be measured and quantified.

Finally the committee would like to acknowledge the systematic programme of hardware upgrades which have been made over the last year. Not least the speedy recovery from the 2011 earthquake, which can be considered a major achievement in itself.

The above briefly summarises the overall findings of the committee. However there were many details which were presented, the total sum of which have led to the conclusions above. It is impossible for the committee to comment explicitly on every single aspect or issue presented. However, the next section will attempt to summarise more of the poignant details and concerns identified by the committee during the review.

# Detailed observations and recommendations for Goals 1 and 2

Section 2 summarises the overall findings of the committee. However there were many details which were presented, the total sum of which have led to the conclusions above. It is impossible for the committee to comment explicitly on every single aspect or issue presented. However, the next sections will attempt to summarise more of the poignant details and concerns identified by the committee during the review.

## Damping ring performance

### General

The ATF linac and damping ring systems that feed beam to ATF2 need to provide a stable beam of nominal intensity with the required emittance and optical parameters. The beam must be stable to varying degrees over time scales ranging from pulse-to-pulse to multi-hour or multi-day. Several reports devoted to these upstream systems were included in the review in order to provide an assessment of their ability to satisfy these requirements. The review charge specifically asks:

* does the ATF routinely provide a stable low-emittance beam to allow ATF2 tuning to proceed in an efficient manner?

The committee noted that goal 2 may be viewed as a test of the upstream systems to provide stable beam. Furthermore if the pulse-to-pulse stability is too poor then the tuning process will not converge and the emittance will also be unstable.

The committee was pleased to see that the required emittance (10-12pm or smaller) was now routinely achieved, and that stability was – in general – sufficient for ATF2 tuning, although clearly there are areas which can be improved. The committee also noted that running with more than 20 bunches has not been attempted for several years, with only single-bunch operation (Goal 1) or 2-3 bunches for FONT experiments (stability) being routine. Although the committee agrees that ‘long bunch trains’ are not specifically required for either Goal 1 or Goal 2 as stated, it recommends that a multibunch programme be reconsidered in the future, especially as an extension to Goal 2 as well as for damping ring kicker R&D studies.

### Linac

The following issues were noted for the ATF linac system:

* The linac trajectory varies by as much as a few mm during a few hour period. The linac energy also varies over a similar time period.
* The linac klystron / modulator large, common HVPS is to be replaced during summer 2013 due to its age and reliability performance. However, the current HVPS stability is 0.2%, and does not appear to be the source of instability.
* The reported linac trajectory instability may be caused by the regulation of the cooling water for the gun cavity, accelerating structure and high-Q device (SLED):
	+ improvements to the water cooling systems should make this better;
	+ in addition, a simple beam-based energy feedback on the injector should be considered (if not already foreseen).
* An intensity cut is made during IPBSM scans to avoid the wake field effect, (0.5‑2.0×109 has been used most recently). Usually, the injector can keep the IP intensity stable within 1 shift or more, after which the cut rate slows the IPBSM scanning. Hence improving charge stability over a longer time scale will aid optics tuning at the IP.

### Damping rings (stability)

* There is minimal effect on ATF2 tuning when the extraction trajectory is kept stable.
* Feedback is sometimes used for the ring. The orbit feedback erroneously caused energy changes while trying to fix the orbit.
* During short downtime periods the ring magnets are left on. This keeps the ring environment stable (however, the committee noted that ring alignment checks are done with the magnets off).
* Continuous operation requires extra resources and effort but appears to be worthwhile.

### Damping rings (emittance performance)

* ATF (pre-dating AFTF2) has achieved small emittances in the past (<8 nm at 1010 bunch charge). The goal for ATF2 (10pm) has been relaxed from the original ATF goal:
	+ the committee noted that in the recent ATF2 run this goal was exceeded, with the ring achieving 8pm at low bunch charge;
	+ lower emittance offers the possibility for small IP beam sizes below that stated in Goal 1.
* There appears to still be a discrepancy between the SR-based monitors (XSR and IF) and the laser wires (up to a factor of 4 reported). Such discrepancies need to be understood to provide confidence in the ring emittance measurements.
	+ The ring emittance measurement is based on an estimate of the beta function at the XSR source point. This is difficult to verify and may be a source of variability.
	+ A rigorous and consistent error treatment should be used for these measurements (a general statement also applying to ATF2 measurements themselves).
* Upgrades to the BPM electronics (in particular) as well as careful ring alignment appear to have allowed consistent and repeatable 10-12pm performance to be achieved (As measured with the XSR monitor.)
* It was noted that the reported ring emittance dependence on bunch charge looks too weak to explain the observed current dependence in the extraction line (see 3.2).
* The committee was unclear on the exact survey and alignment requirements for the ring, particularly given the beam-based correction methods employed.

### Extraction systems (kicker, septum and EXT beamline)

The extraction system comprises of the extraction kicker and septum section in the ring itself, and the so-called EXT beamline, which makes up for about half the real estate of the ATF2 beamline (upstream of the Final Focus itself). The EXT provides both full 4D *x*–*y* coupling correction (four skew-quads) and a 2D (projected) emittance measurement station consisting of four beam size measurements (equipped with OTR and wire scanners; the OTR scanners provide <*xy*> tilt information). An additional 2 skew-quadrupoles in the dispersion region immediately downstream of the septum (‘inflector’) also provide vertical dispersion correction as well as additional (single phase) coupling correction (sum and difference operation mode respectively).

* The committee notes that the linear optics in this region is well understood, and the models used appear in very good agreement with measured data. The committee was pleased and impressed with the systematic studies and analysis which have been performed, many of which have led to improvements.
* The removal of the second kicker KEX2 (which had a relatively large sextupole component, experimentally verified using orbit analysis) and its replacement with a strong dipole corrector has allowed the use of a pair of vertical correctors to provide a second phase of dispersion correction (compared to the skew-quads in the inflector). The combination appears to work extremely well.
	+ The committee notes that the two-kicker system was originally intended to minimise (cancel) kicker errors. The increase in beam jitter after the removal of KEX2 appears to be marginal, but it is not clear from the measurements presented if KEX2 was the only effect.
* The committee notes that the performance of the emittance measurement station in the EXT is critical to the overall goals of the programme, and that great care needs to be made in understanding possible sources of random as well as systematic errors.
* The OTR emittance measurements appear to be ~15% higher than that measured with the WS. Although larger than the reported error bars, it seems not to be excessive.
* Extracted emittance (as presented) is consistently higher than that measured in the ring. The former has a large scatter. The committee acknowledges that this is a fundamental issue of ‘pulsed’ operation versus storage-ring mode. However for ATF2 (and ILC) it is the pulsed extracted emittance that counts.
* The observed bunch charge dependence in the EXT emittance of 2—2.5pm per 109 has been consistently measured over time, and is higher than that observed in the damping ring (by a factor of 2—3). While this is tempting to attribute to impedance effects in the extraction line, it is not clear if some (or all) can be attributed to systematic effects in the OTR or WS monitors. Attempts should be made to further investigate.
* The proposed coupling correction method of tuning individual skew quads with beam tilt on their corresponding OTR appears a very effective and time saving approach.
* Performing the beta matching upstream of the OTR screens so that the results can be directly measured and confirmed clearly makes sense.
* Remaining issues with kicker and bend magnet alignment (rolls) should be further investigated, although the committee notes that the linear aberrations from these errors should in principle be corrected by the available emittance tuning.

## Accelerator physics issues (impedance and wakefield effects)

As noted in Section 2, the committee believes that Goal 1 can be successfully addressed at low bunch charge. However, the observed bunch charge dependent effects must be further quantified, understood and eventually mitigated, especially with Goal 2 in mind. Understanding impedance control in the FFS where the beta-functions are very large is also a relevant ILC goal in its own right.

The charge-dependent emittance increase in the EXT (~2.5pm/109) – while undesirable – does not appear to be the main cause of the dependence on the IP beam size (IPBSM modulation), which shows a much stronger effect (greater than a factor of 5).

Furthermore initial modelling of wakefield sources cannot account for the strong dependence seen, although the committee notes that the data as presented shows considerable variation, given that the overall set-up (including the ATF emittance) are not always consistently reproduced. With the exception of one data set, the presented IP current dependence does not appear to be so strong, with the apparent extrapolated zero-current beam size still dominating the observed ‘growth’. Much of this is almost certainly dependent on the state of the tuning. Care needs to be made in presenting consistent data with carefully detailed machine state, including DR emittance, EXT emittance and IP beam size, including errors (a general statement).

While the data is compelling, care should be taken in understanding possible current-dependent instrumentation issues, especially for the IPBSM on which so much depends. The committee agrees with the presented conclusions that more systematic studies are required before making any definitive statements on these effects. With that said, in general, the EXT/FFS vacuum chamber was not built with careful impedance control, and the committee feels that several recommendations can be made:

* Complete the work on impedance budgeting. Include more potential sources of impedance for completeness. In addition to completing the standard list of vacuum chamber items, attention should also be given to installation offsets of the vacuum chambers, of which there may be many (some were observed during the visit to ATF2), especially at the junctions at the bellows. Some of those installation offsets can be as large as a couple of mm, which is quite significant because of its asymmetry (see below).
* Include longitudinal wakefields which will induce a localised additional energy spread, especially in the high-dispersion high-beta sections of the FFS where the additional energy error will not be chromatically compensated.
* Smooth out the vacuum chamber as much as possible. Insert sleeves for the bellows and vacuum ports as a minimum effort. Pay special attention to asymmetric devices – and where possible attempt to symmetrise these as best as possible. These asymmetric devices also need to be modelled correctly in the simulations.
* Consider installing a remotely translatable dedicated impedance located at a position with large y to act as a wakefield tuning knob (ideally two spaced 90-degrees apart). The presented experiments using a reference cavity BPM appear to show the impedance of the device is well understood and that such a scheme could be made to work. Closed orbit bumps can also be considered but these will also generates dispersion.
* Wakefield-induced emittance growth is expected to be very sensitive to injection jitters that cause free betatron oscillations. The y and y’ jitter exiting the damping ring require special attention. It is suggested to calculate their required jitter tolerances and to see if these tolerances are met in practice. (Note that intentionally introduced betatron oscillation can also be used to tune the emittance growth.)
* Using orbit analysis and/or MIA (model-independent analysis) –coupled with changing the bunch charge – should be considered to see if strong point-lie source of wakefield kicks can be identified. This is most likely to be useful in the EXT. The single-phase-like nature of the FFS may well cause problems for such an analysis.

## Accelerator physics issues (magnetic multipoles)

The committee was pleased to see the systematic study of the known multipole components of the magnets in the FFS. The simulations clearly indicated that most if not all of the multipole components were beyond tolerance, in some cases by factors of 2 up to an order of magnitude. The replacement of QF1FF (the most critical magnet) in November 2012 has mostly mitigated the multipole effects. Cancelling the magnet non-linearity will make it possible to investigate the properties and the limitations of the local chromatic correction optics at 35 nm and eventually smaller spot sizes. The committee notes that more magnets need to be replaced or swapped for the more demanding ultra-low  optics for CLIC. Although the plans put forward for a larger x\* optics seem reasonable, the committee believes that it is important to eventually return to the original demagnification in the horizontal plane for a complete demonstration of the FFS optics, especially given the interplay of the horizontal demagnification on higher-order terms affecting the vertical beam size.

## ATF2 beam optics design and performance

The ATF2 beam optics represent a scale model of that foreseen for the ILC. Despite the overall difference in geometry, the characteristics of the lattice are very comparable to that of the ILC (for example chromaticity), and ATF2 provides an excellent test-bed for the required tuning algorithms and beam-based alignment techniques. The committee was pleased to see the detailed and realistic Monte Carlo simulations that have been performed on the expected performance of the ATF2 under realistic conditions. Furthermore these simulations have been extensively cross-checked using several simulation codes – important given the demanding non-linear optics nature of a LC final focus system. The simulations presented have shown that in principle ATF2 should be able to achieve its goals, providing there are no other sources of error present in the system. The presented simulations do underline the need for care with respect to understanding the diagnostics, and in particular the IPBSM, where the rotation angle of the interferometer has been shown to limit the achievable beam sizes. The extensive simulation models that have been developed will enable better understanding of the experimental results as and when they become available, and are a powerful tool in helping to develop remedial strategies as problems are identified, as well as understanding the ultimate performance capacity and limitations. Although no direct experimental measurements of beam size stability over time have been presented, simulations using realistic measured vibration (ground motion) spectra have been made. They indicate a typical 0.5 nm/hour growth rate assuming trajectory feedback control along the beamline. The committee notes that this is likely a lower limit, since it does not include drifts in instrumentation (diurnal temperature effects etc.) which may well dominate. Further stabilisation will require routine optics tuning using the available knobs and algorithms, and such systems will eventually need to be automated using ‘dither type’ feedback. Demonstration of long term beam size stability is an important goal of ATF2, and should be included in future plans. The committee acknowledges that demonstrating the necessary stability goes to the very heart of many of the observations made, and has ramifications for all of the ATF/ATF2 sub-systems.

The success of the late 2012 and early 2013 runs using the nominal 10×x optics (as opposed to the optics adjusted to minimise the impact of magnetic multipole errors) indicate the success of the analysis resulting in the replacement of QF1FF, as well as the addition of four new skew-sextupoles for geometric aberration tuning. The skew-sextupoles appear to have been included as a result of the simulation analyses made, but it was reported that they were not needed in the February 2013 run (a problem with the power supplies was reported in one presentation.). The committee is unclear exactly what the status of these tuning knobs are or how they are now intended to be used. The committee recommends a programme to fully understand and characterise the need and best use of these new knobs.

The experimental runs have also highlighted the importance – and limitations – of the IP laser interferometer beam size monitor (IPBSM). The committee acknowledges the impressive progress made with the IPBSM but note there are still issues. Beyond understanding the systematics of the monitor itself, understanding and controlling the beam-induced backgrounds in this device are clearly important, and challenging given the broad nature of the different issues which apparently play a role here. Examples of issues are: the sensitivity to the optics from the backgrounds; the laser itself and the reported sensitivity on the modulation depth on the laser beam profile; and the need to carefully set-up the fringes at the required location and within the specified rotation tolerance. The committee was impressed with the step-wise progress that has been made with the laser monitor over the last runs, but clearly there is concern that the device can be made to function routinely and efficiently as needed for the optics tuning. Given its importance to the overall programme, all efforts to sufficiently support the development of the IPBSM into a routine turn-key device should be made.

The linear optics of the ATF2 beamline seems to be very well understood and characterised by several methods. Corrections such as dispersion and cross-plane coupling work well. Tuning coupling at the OTR screens and then on IP beam divergence indicate no major coupling source in the final focus system itself. Orbit response checks extremely well against the model, and the orthogonal linear tuning knobs constructed from linear combinations of sextupole movers work very well. It was noted that beam size tuning at the IP, i.e. maximising the modulation signal, can still be performed with relatively poor modulation. Only the absolute beam size is difficult to obtain.

The culmination of this systematic work achieved in a measured upper-limit of 65nm vertical beam size at the IPBSM in February 2012. The committee acknowledges this as a clear demonstration of the compact final focus optics, together with the systematic linear tuning algorithms which have been developed.

## Achieving the stability goal (goal 2)

Goal 2 has been interpreted by the ATF2 collaboration as the stabilisation of the beam jitter at the IP waist to ~2nm RMS. This is effectively a further test of the FONT fast-feedback system in a configuration not dissimilar from that envisioned for the ILC. Unlike the ILC, however, the feedback signal cannot be derived from the beam-beam kick, and therefore requires precision (nm-level) BPM to actually measure the beam jitter at the focal point directly. This presents several major challenges which are specific to the ATF2 experiment and not directly applicable to ILC. The committee acknowledges that in many respects, the ATF2 demonstration is more demanding.

While from the ILC perspective the critical elements of the test should be the fast feedback system (kicker and electronics), the most challenging component is the 2nm resolution BPM system and its integration into the IP. The current cavity BPMs have demonstrated 30 nm resolution (without attenuation) which is not sufficient. In addition they are too heavy to be supported in the new IP chamber currently under construction at LAL. A new cavity BPM and electronics has been developed by KNU to achieve both the 2nm resolution and the geometry and weight requirements. However, a higher bunch charge will be required than that currently used for Goal 1 to obtain the required resolution, and this immediately requires a better understanding and control of the beamline impedance issues. The large increase in beam size with higher bunch charge suggests strong impedance sources which will also significantly increase the (incoming) beam jitter. Furthermore, intensity jitter at these higher bunch charges could also couple to the transverse beam jitter via the wakefields. While in principle the feedback system can also suppress this, the amplified jitter may well ultimately prevent the stated (absolute) 2nm RMS goal.

A critical issue is the calibration of the BPMs at the required precision and maintaining this calibration over the lifetime of the experiment. The new chamber being constructed will use piezo-based mechanical adjustments for the three cavity BPMs to provide beam-based calibration. However, this in turn requires accurate calibration of the piezo movers, which is currently being done at LAL using laser interferometry. After this initial calibration, the committee understands than no such calibration will be possible in situ once the chamber is installed in the ATF2. Therefore steps must be taken to ensure that the initial calibration is maintained during transportation, installation, and finally over the foreseen period of the experiment. The calibration process itself seems long, and again care of systematic errors due to slow uncorrected drifts needs special attention. The committee feels there is significant risk in this, and careful analysis of possible errors that can be introduced should be made, and where possible, mitigation strategies be included into the hardware. In particular, the need to maintain the chamber and its subsystems at a very stable temperature should be carefully assessed.

The committee notes that the new IP chamber due for installation in the summer is a major addition to the existing IR, and in particular the IP BSM. Extreme care needs to be taken not to jeopardise progress towards goal 1 by installing this chamber. Furthermore, careful analysis of the impedance of all the beamline components should be made beforehand.

Since the feedback kicker can only correct a single phase of jitter (the IP phase), the focal point (waist) will need to be accurately moved to one of the three BPMs being used in the feedback loop. The precision with which this needs to be achieved is ≤*y*\* (0.1mm for the nominal optics). This is performed optically by adjusting the strengths of the final doublet (FD). Achieving this accuracy will be challenging, but presumably can be realised by minimising the measured RMS beam jitter at the BPM as the FD (waist position) is scanned. In principle the other two (out-of-phase) BPMs can be used to help, and accuracy and approach to tuning the FD to achieve the optimal phase should be assessed in order to give a better estimate of the possible performance that can be achieved.

The committee notes that basic concept and hardware for the FONT feedback system have already been successfully demonstrated using the upstream system, with a stabilisation achieved on the second bunch equivalent to <3nm at the IP. While not a direct measurement of beam stabilisation at this level, the extrapolation seems valid and the result a clear indication that the system can perform at the required level. The additional challenges of the IP experiment are therefore more related to measuring nm-level positions. Characterisation of the IP cavity BPMs will become paramount. It is important therefore to make clear statements as to the ILC specific measurements and goals that need to be made. Determination of system-wide parameters (noise floors, loop gain etc.) should be made. A careful catalogue the ILC-related feedback issues that are different in this set-up should be accessed, and a clear indication of how each one can be measured and/or demonstrated at the ATF2 experiment should be made.

The currently planned demonstration will be made with only two bunches, with the second bunch being fed back on. The true test of the FONT system will be in multibunch mode, where stability of the entire bunch train can be assessed, and the impact of (for example) the choice of gain can be measured. For the ILC it is expected that an initial correction of ~10 sigma will be needed (1000% jitter) of the first bunches, after which the system will be required to keep the beams stable at the 0.1-sigma level. Such performance can only be tested in multibunch mode at ATF. The committee notes in passing that there are many similarities in this respect to the intra-train feedback systems being developed for FLASH and the European XFEL, and what can be learnt from these systems for ILC should be also be investigated.

Finally, this system coupled with the upstream system can help characterise the sources of beam jitter in the ATF2. Moving high resolution BPMs to a location upstream (exit of the EXT line) would aid in separating injection from FFS sources. Installation of vibration sensors would further help characterisation of jitter sources by separating mechanical (i.e. vibration) from wakefield driven sources.

## Instrumentation and diagnostics

The committee acknowledges the importance of the instrumentation programmes that have been successfully implemented at ATF/ATF2. Development of high-resolution cavity BPMs has been an on going programme almost since the inception of ATF2. The BPM systems throughout the beamline are critical for orbit analysis, tuning and feedback control. The current cavity BPM systems (C- and S-Band) now appear to be quite mature, having demonstrated typically 200nm intrinsic resolution (30nm without attenuators), with low maintenance. Digital signal processing and a test-tone self-calibration have been successfully demonstrated, and shown to be essential for such a BPM system (long term stability). This system is now ready for beam jitter characterisation studies in association with Goal 2. With the recent identified wakefield beam dynamics issues, the committee strongly endorses the further evaluation (calculation) of the impedance of these BPMs (as well as other beamline components).

The OTR system at the exit of the EXT is also a key diagnostic system which has essentially been an R&D programme in and of itself. This system is critical since it provides the only full reconstructed emittance measurement in the ATF. It separates out the EXT from the FFS, and in turn allows direct evaluation of emittance growth due to extraction from the damping ring. The committee acknowledges the development progress which has been made over the years, and the systematic measurements that have been made indicate the system is now routinely working. However the committee notes that such a system must be turn-key and reliable to the extent that it can be trusted to give accurate and consistent measurements. Possible issues with systematic errors arising from intensity should be carefully evaluated, especially given the current focus on the wakefield effects. The committee also notes that the wakefield effect from the OTR screens themselves prevents a simultaneous measurement on a single bunch. Improvements are required to control camera gain, iris control, camera tilt and optical alignment.

Finally, the committee notes that the IP BSM is the most critical diagnostic and its performance is pivotal to achieving Goal 1, and acknowledges the challenges in making this complex device work. Systematic studies of the laser system performance (as well as recent upgrades) have demonstrated acceptable stability. Issues involving jitter sources (electron beam position, as well as timing jitter) have been evaluated although the committee understands there is more work to do here. (These jitters sources ‘increase’ the measured beam size.) The attempts to systematically quantify the ‘modulation reduction factors’ was also impressive and clearly such studies should continue. In particular the impact of ‘fringe rotation’ has been clearly demonstrated as one of the key errors that needs careful attention.

With the critical and challenging nature of this instrument, the committee strongly recommends that the require resources and beam time be allocated to carefully characterising and further developing it. While the recent observation of 65nm beam size shows that the IPBSM can be made to work well, it needs to be a robust and (if possible) turn-key device. The committee understands that further reducing the beam size by a factor of 2 will also require even more careful study and set-up of this device.

The review charge asks: What identified problems may limit performance? The review committee believe that thorough understanding of the IPBSM ‘modulation reduction factor’ is required in order to determine if this device is capable of performance required for ‘goal 1’ and recommend this be fully addressed in future reviews.

# Management and collaboration

ATF2 from its inception has been a formal international collaboration, governed by an International Collaboration Board and hosted by KEK. This collaboration makes use of (and supports) ATF/ATF2 operation for a diversified R&D programme, the success of which can be measured by the impressive list of associated PhDs, a third of which are from oversees students.

While the ILC goals discussed above have been the primary motivation, in many cases the various R&D programmes have had a ‘life of their own’. The committee feels that the recent (last 18 months) focus on specifically achieving the ILC goals, driven by a strong central KEK management, have directly resulted in the success reported here. The committee would like to once again congratulate the team, and encourage the management to further continue in this manner.

The committee notes that the current confirmed budget situation is ‘barely sufficient’ for the planned JFY 2013 programme, and leaves no contingency for unexpected hardware modifications or upgrade programmes. The committee would like to urge the KEK management (and the collaboration in general) to further support this important and valuable programme, and to try where possible to find additional funding.

In particular, the committee feels that achieving even the ILC goals as discussed above will require more time (and money) than is currently foreseen. It is unlikely that this programme will be successfully completed by the end of 2013.

The committee notes that in general the shifts run only Monday to Friday. Due to the nature of the final focus, the committee strongly suggests that weekend running should be considered in the future if possible. However, the committee acknowledges that the shift coverage is manpower driven rather than a question of (operations) funding.

With respect to the collaboration as whole, the committee feels the twice yearly general collaboration meetings are sufficient for top-level policy and programme management. However, key development aspects of the programme – like the new IP chamber – which interface several international groups, need to interact more often and be managed carefully. The committee felt from the presented material that there was a possible need for stronger coordination in such areas which could easily be addressed by additional meetings.

Finally, given the positive outcome (and feedback) from this review, the committee suggests that a more routine internal advisory committee be established, to monitor the progress on the stated goals.

# Future plans

While the future programme is not strictly part of the committee’s charge, a few observations can be made:

* As has already been stated, a complete achievement of the current ILC programme will likely go beyond the current JFY 2013 funding period. The committee understands the post 2013 funding is current being discussed, and the current plans are to attempt to broaden the R&D programme beyond ILC. While the committee understands this approach, it encourages the KEK management to keep the linear collider priorities at the forefront, given the unique and critical nature of ATF2 to this field.
* Beyond the existing (GDE) ILC goals – and funding permitting – there are additional LC programmes that should be considered. The plans for the ultra-low beta optics should be pursued. Although the committee recognises this is being driven by a CLIC demonstration, these parameters are clearly also useful for any linear collider, including ILC. The more demanding vibration suppression and ground motion measurement will equally provide additional margin for ILC.
* A further ILC-specific programme would be to reconsider the tests of the superconducting final doublet. This is a critical component for ILC, and the ATF2 offers the only true possibility to measure the magnetic field vibration at the required level. The committee understands that this would be a major undertaking for KEK, but it should be considered an important ILC priority.
* A further consolidation of the ATF/ATF2 system testing should be a priority, where the goal would be to use ultra-small multibunch beam, and beam sizes significantly less than 37nm (and with the required demagnification in both planes). Such a programme may require several hardware upgrade programmes. A realistic schedule with interim milestones should first be developed for such a programme.

# Closing remarks

The ATF2 programme was recognised by the GDE as one of the major beam test facilities for ILC R&D during Technical Design Phase, along with FLASH at DESY and CesrTA at Cornell. The final focus system of the ILC represents one of the major design challenges and is also a critical sub-system with respect to the ultimate luminosity performance. While the goals set for the programme have not been completely fulfilled within the GDE’s mandate, the committee is extremely pleased with the important progress that has been made towards them. Furthermore, the committee strongly recommends that this programme be maintained in the foreseeable future, such that the ILC goals can be clearly and unambiguously demonstrated, while also providing a unique linear collider facility for further R&D beyond those goals, further mitigating the risks associated with ILC and CLIC. The committee is confident that, given sufficient resources, the ATF/ATF2 will succeed and possible exceed its goals, and provide a strong development base for a future construction project.

# Appendix: Review Charge.

With the achievement of the milestone 70 nm vertical beam size in the recent December run, we believe that now is a good opportunity to take stock of the project and its goals. The review itself will be comprehensive and focused on both the status of the project and the next steps which need to be taken to achieve the as yet unachieved published ILC Technical Design Phase goals (37 nm vertical beam size, stabilisation). Furthermore, the importance of the ATF2 programme for ILC was acknowledge in the recent PAC TDR technical review. In particular the PAC report noted that “The lack of progress towards the 37 nm ATF2 IP goal is a concern. Several issues have already been resolved, and the currently scheduled modifications should lead to significant progress towards the goal.” This review is primarily to address this observation.

Specifically, the goals of the review are to:

1. evaluate and comment on progress made toward achieving the stated goals;
2. assess the current readiness of the ATF/ATF2 complex toward achieving the goals, including, for example, understanding of beam dynamics and expected instrumentation performance;
3. comment on lessons-learned at the ATF/ATF2 for the ILC complex and how these may be included in the ILC design;
4. discuss future plans and set milestones for the short and medium term towards achieving the ILC goals.

With the ILC goals in mind, the types of questions we will endeavour to answer are:

* Is the ATF2 machine well understood in terms of its accelerator performance (requirements, tolerances, tuning algorithms, diagnostics)?
* Does the ATF routinely provide a stable low-emittance beam to allow ATF2 tuning to proceed in an efficient manner?
* Given the current status and knowledge of the ATF2 hardware, what are the major challenges and possible hurdles to achieving 37 nm?
* What are the exact plans for demonstrating ‘stability’ and how will they be implemented?
* Given the answer to the above, what hardware upgrades (if any) need to be considered to mitigate identified problems which are limiting performance?
* If the above upgrades or modifications are not practical, what is the realistic performance expectations from ATF2?
* What are the KEK management’s plans and schedule for ATF2 to facilitate a successfully conclusion to this part of the programme? How will the broader international collaboration interact with these plans to achieve them?