ATF RESULTS AND ATF-II PLANS*

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Abstract
The ATF (Accelerator Test Facility at KEK) International Collaboration has been launched formally under the MoU (Memorandum of Understanding) from August 1, 2005, so as to maximally contribute to the world design and development efforts in the areas of particle sources, damping rings, beam focusing and beam instrumentation towards the International Linear Collider (ILC) project. I will give a talk on the recent ATF results and future plans of ATF-II project.

ATF International Collaboration group will give a right direction regarding the development of fast kicker for ILC damping ring and clear experimental results on fast ion instability with very flat beam. Several considerations for ATF-II beam commissioning strategy will be discussed with the explanation of the beam instrumentation.

OUTLINE OF ATF AT KEK

The Accelerator Test Facility (ATF) at KEK comprises a multibunch-capable RF gun (with up to 20 bunches, spaced by 2.8ns, per pulse), an 1.3GeV S-band injector linac, a damping ring, and a beam diagnostic section (EXT) [1]. Each part directly contributes to the development of technologies relevant to high luminosity linear colliders. ATF at KEK is a research center for studies of issues concerning the injector, damping ring and beam delivery systems for ILC. Fig.1 shows a schematic plan view of ATF [2, 3, 4]. The multibunch scheme is essential to boost the rf-to-beam transfer power efficiency in the accelerator.

ATF generates, accelates, damps, and extracts a train of 20 bunches with $1x10^{10}$ electrons/bunch and 2.8ns spacing or optionally extracts 3 bunches train with 154nsec bunch spacing. The achievable normalized emittance is 3.8μm horizontally and 0.0125μm vertically, and an energy spread 0.08% and the bunch length 8mm for the multibunch beam. The small emittance from the damping ring has been achieved by special design of a strong focusing lattice with precise alignment of components and beam orbit control. The nonlinear behavior of the beam has to be well understood to provide enough dynamic aperture under such strong focusing conditions.

After the technology choice for ILC Main Linac, we proposed ATF-II project as a test beam line using very flat beam from the ATF damping ring to realize 37nm vertical beam size at the final focus point stably. Then, we have established an International Collaboration of ATF (including ATF-II project) with many institutes and it was launched on Aug. 1st 2005. Now several other institutes were added to join into this collaboration.

The International Collaboration of ATF is based on the Memorandum of Understanding (MoU) which defines the organization of the international collaboration to carry out the research programs at ATF and its extension ATF-II, so as to maximally contribute to the world design and development efforts in the areas of particle sources, damping rings, beam focusing and beam instrumentation towards the Engineering Design Report (EDR) of ILC. We are adding the MoU, the chart of the organization and related material into new ATF Web Site (http://atf.kek.jp/collab/ap/).

As evidence from this MoU, the construction and operation of ATF-II will be executed in the framework of the International Collaboration of ATF. The management of activities of ATF-II will be carried out under the supervising bodies as described in the ATF MoU.

I describe mission of ATF/ATF-II and the ATF results in the following sub-sections. Also, I explain the important ongoing research programs at ATF damping ring and the plans of ATF-II [5].

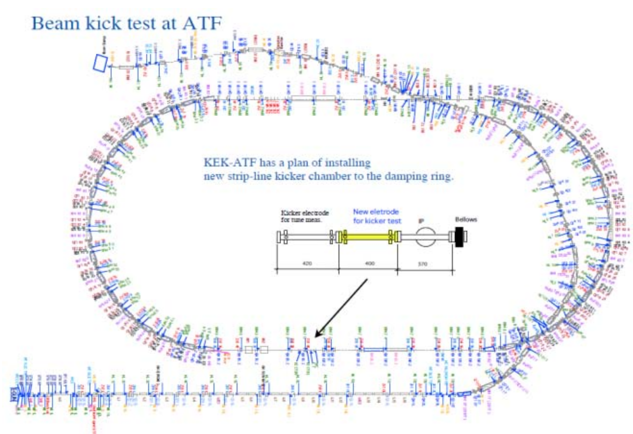

Fig.1: Schematic plan view of ATF.

MISSION OF ATF/ATF-II

ATF is to establish the technologies associated with producing the electron beams with the quality required for ILC and to provide such beams to ATF-II in a stable and reliable manner.

ATF-II is effectively to use the beams extracted from ATF at a test final focus beamline which is similar to what is envisaged at ILC. The goal is to demonstrate the beam focusing technologies that are consistent with ILC requirements. For this purpose, ATF-II aims to focus the beam down to a few tens of nm (rms) with a beam centroid stability within a few nm for a prolonged period of time.

Both ATF and ATF-II is to serve the mission of providing the young scientists and engineers with training

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opportunities of participating in R&D programs for advanced accelerator technologies.

ATF RESULTS

There are a lot of developments on beam instrumentation at ATF since 1993. The detail report is given by reference of [6]. This section covers the outline of achievements.

Emittance Measurements at EXT

Intensive studies on the vertical emittance with the wire scanners in EXT have been ongoing since March (2000) [7]. An important observation we made during this time is that there appears to be a source of x-y cross plane coupling somewhere between the extraction point of the damping ring (DR) and the wire scanner region in EXT. The measured vertical emittance is approximately (1.1+/-0.1)x10^{-11} m for the beam intensity of (2.0+/-0.2)x10^{9} electrons per bunch. The emittance is found to grow to (2.2+/-0.1)x10^{-11} m at the beam intensity of (8.0+/-0.3)x10^{9} electrons per bunch, however. In these measurements, the x-y beam profile showed a tilting of a few degrees, as observed by using 10 degree wires. The quoted vertical emittance in these plots might be further reduced by re-optimizing the setting of skew magnets. Obviously, repeated measurements and careful studies are needed, and the results shown here should be considered preliminary. It appears that the following points play an important role.

1. Tuning with skew knobs in the arc sections of the DR for reducing the betatron coupling in the ring.
2. Careful corrections for residual dispersion in EXT.
3. Additional cross-plane coupling correction using a skew quadrupole magnet in EXT, upstream of the wire scanners.

Beam Tuning and Diagnostics in Damping Ring

COD and Dispersion: The program SAD is used in orbit and dispersion corrections, for calculating new setting of the steering magnets. The results of the COD correction in DR were 2mm (peak to peak) horizontally with 1mm expected from simulations and 1mm vertically. The dispersion in the DR is measured as difference of orbits with different RF frequencies. The dispersion correction in the ring worked and typical r.m.s. of the vertical dispersion after the correction was about 5 mm which is close to our target.

X-Y Coupling Corrections: To correct x-y coupling, trim coils of the all sextupole magnets are connected to produce skew quadrupole field. A global correction of the coupling is essential to achieve the smaller emittance. We tried a global coupling correction minimizing vertical COD response to horizontal steering. The orbit coupling was clearly reduced and some reduction of the vertical emittance was observed after the correction. We also tried a coupling correction by 4 dedicated skew quadrupoles and achieved some reduction in the vertical beam size at the SR source point.

Local orbit bumps were also used for low vertical emittance tuning. Setting many bumps one-by-one the vertical beam size was monitored using SR-interferometer.

We tried new coupling correction using orbit response matrix (ORM) analysis. It has been confirmed that ORM analysis is a technique used to diagnose and correct optics errors in storage rings. Recently, we achieved and confirmed the normalized vertical emittance of 0.015µm at a bunch charge of (7.0+/-0.2)x10^{9} electrons in the ATF ring by ORM analysis and the laser wire monitor [8,9].

New Extraction Kickers with a Flat-top Longer than 300ns

A project to replace the extraction kicker system in the ATF damping ring was collaboration between KEK and SLAC. A SLAC epoxy kicker system was prepared. At the same time, a modification to the kicker pulse was introduced so that flat-top of pulse lengths 340ns was achieved. This allows us to experimentally examine the implications to the beam instrumentation hardware and component stabilization issues in conditions similar to ILC. A team of accelerator physicists from KEK and SLAC succeeded in extracting 3 bunches of electron beam at 154 ns duration and 2 bunches at 336 ns duration in Fall, 2005 (Fig.2), a milestone in realizing the beam control operation mode required in the ILC.

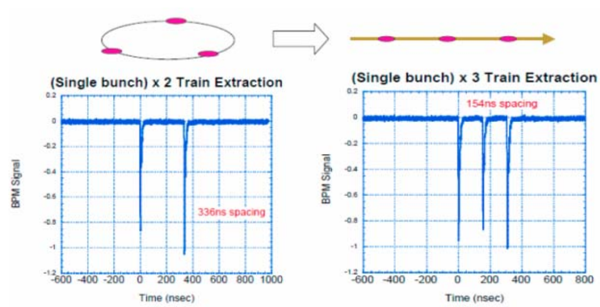

Fig.2: ILC-like beam extraction at ATF.

Beam Position Monitors

Fig.3 shows the schematic design of a beam position monitor unit that has been used at the ATF damping ring. In 2005-2006, collaborators from SLAC tested a new signal processing circuit which average the BPM signals over a prescribed number of turns for improved resolution. Fig.4 overlays the measured beam position data from the BPMs with existing and test circuits. A dramatic improvement, close to a sub- µm level at 10^{10} e/bunch beam intensity, has been demonstrated. We will improve all signal processing circuits of the damping ring BPM by the end of 2008 in order to reduce vertical emittance near 1pm with FNAL and SLAC.

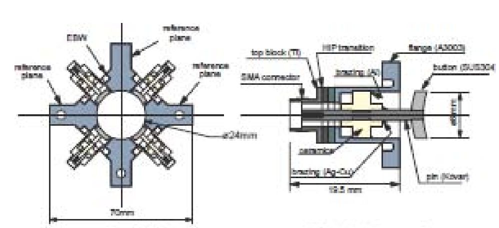

Fig.3: Schematic view of an ATF damping ring BPM.

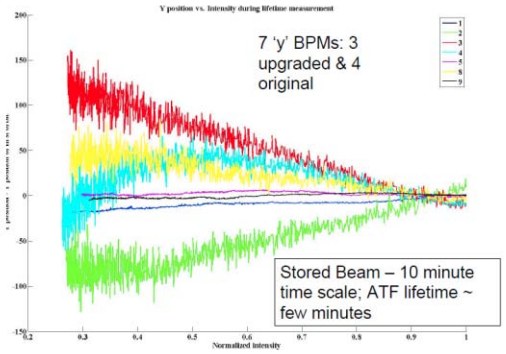

Fig.4: Position data of the stored beam, as function of the bunch intensity. Data from BPMs with the old, existing readout circuits and with new test circuits are overlaid.

Cavity BPM

Transverse dipole modes are useful to measure the beam positions because their field strength are proportional to the product of beam charge and the beam offset with respect to the electrical center. The beam signal is read out through a selective coupler which couples only with the dipole mode. Its strong and narrowband signal enables us to measure the beam position with ~nano-meter resolution. Mechanical rigidity and reliability of the electric center are also advantages of cavity BPMs. This types of BPMs are expected to play important roles in ATF-II and future accelerators.

Signal strength depends on the choice of cavity frequency. Considering the relatively long bunch length, C band frequency was estimated to be the most sensitive in ATF-EXT. All types of cavity BPM developed in ATF use ~6 GHz.

nano-BPM: Three-BPM method is an usual technique to study very high resolution BPMs. A triplet of BPM are supported by a rigid frame so that the relative position of the three is mechanically stable. A precise mover system is needed to align the BPMs in a straight line within 10 μm. Two of the three are used to monitor the beam orbit and they predict the beam position at the remaining BPM. Comparing the actual measurement with the prediction, resolution of the BPM can be estimated. Two sets of BPM triplet systems have been developed in the extraction line. A fast digital waveform recorder samples the down-converted BPM signals. Using an analysis procedure of fitting or digital down-conversion, the data is converted to beam positions. The other one (downstream) has active stabilization movers using optical interferometers. As for the electronics, this system uses a fast analogue electronics which directly rectifies the signal into beam positions. Calibrating the scale by moving one of the BPM with known amount, the residual between the measurement and prediction can be estimated. Both of the systems have proved position resolutions smaller than 16 nm [10].

Beam Size Monitors

X-ray SR Monitor: Imaging its source point on a screen, synchrotron radiation (SR) can be used to measure the beam profile. Since the beam size in the arc sections of the DR is too small to image with a visible light due to the diffraction limit, we have developed an X-ray optical system [11]. SR from a bending magnet is first reflected by a monochromator of Si crystal to choose 3.24 keV X-ray, then transported through a magnification optics which consists of two Fresnel Zone Plates (FZP). It was designed to realize a x20 magnified image of the source on an X-ray CCD camera. This monitor can measure beam size as small as 5 μm with 1 μm resolution, and is now routinely used in beam operation.

Laserwire monitor: To reliably measure beam emittances in DR, a direct way to measure the beam size was developed [12]. This monitor uses a thin laser beam to scan the electron beam in the transverse direction. backward-Compton scattering produces gamma rays in the forward direction of the electron beam. The beam profile can be obtained by scanning the laser across the beam. To be able to measure a small beam size, laser beam has to be well focused. A cw laser of 532 nm wavelength is injected into a high finesse optical cavity of nearly concentric configuration to stably realize such a small spot while enhancing the effective laser power by ~1000 times. By identifying the bunch number with the incoming timing of the scattered gamma rays, this monitor can separately measure each bunch of the multi-bunch beam at the same time. This monitor can measure 5μm beam size with a good accuracy since the laser spot size is known precisely. Since it takes ~5 minutes to complete a scan, accurate beam orbit monitoring to remove the effects of beam position drift is necessary to further improve the system.

Laser-wire system in the extraction line: To apply the laser wire technique in a single path beam line, a different approach of laser system has been developing in the extraction line [13]. A laser beam is focused with a specially designed lens system to have a μm spot size, and is used to scan across the electron beam. To obtain enough signal in single collision, a pulsed laser of high peak power is necessary. Timing system is also important to establish a stable collision. Laserwires are expected to become main beam size monitors in ILC. The collision chamber shown in Figure 5 has been installed and tests are underway.

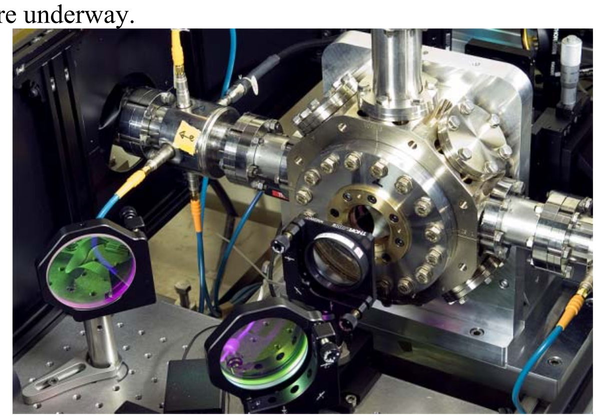

Fig.5: Laser wire at the extraction line.

ODR monitor: A beam size monitor based on the optical diffraction radiation (ODR) has been developed in the extraction line [14]. ODR is a kind of wake-fields generated by a passage of a beam near a conductive object. A metal plate with a slit is installed in the beam line with 45 degree angle to the beam. When an electron beam passes through the slit, radiations of visible light are emitted toward perpendicular direction of the beam from both edges of the slit. They generate an interference pattern of double peak in its angular distribution. The beam size can be estimated from the contrast of the pattern. A low-noise cooled CCD camera detects the image of the radiation shot by shot. This monitor can measure beam size as small as 15 μm. Flatness of the target, controlling beam position in the slit, and shielding the background of synchrotron lights from magnets in the upstream are important to do a reliable measurement.

Bunch Length Monitors

Bunch length and longitudinal motion of bunches are useful to investigate impedance and instabilities in the DR. The injected bunch length from the linac of 10 psec is lengthened to ~25 psec in the equilibrium of the DR.

SR measurement with a streak camera: Time structure of electron bunch is imprinted in the time structure of the SR. SR light from a bending magnet of the DR is transported to a streak camera. It converts the light into photo-electrons, and projects the time axis into a transverse profile as an image. This system is also used to measure longitudinal motion of the bunch circulating in the DR with a synchronized scanning setup to the beam revolution.

CSR monitor: Short bunched beams in the first few turns after DR injection emit a coherent synchrotron radiation (CSR) of THz region (shown in Figure 6). In order to study the properties of CSR a transport line for the radiation and a schottky barrier diode detector is installed at the end of the straight line of the DR. Since the strength of the coherent radiation strongly depends on the peak intensity of the bunch, it might become a good tool to check the bunch length of the incoming beam.

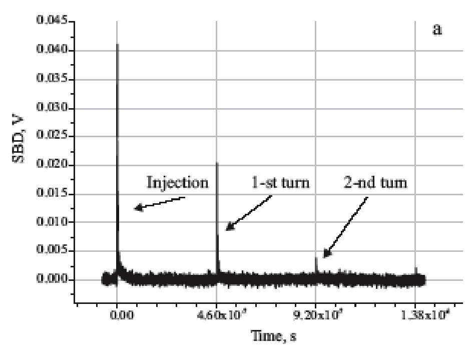

Fig.6: CSR intensity measured in the damping ring after injection.

Beam Control

Not only measuring the beam, but also acting on it is important to realize a high quality beam. Works to develop the feedback/feedforward system are underway in the extraction line.

FONT: In order to realize stable beam collision in ILC and stabilization in the virtual IP of ATF-II, a beam position feedback/ feedforward system has been developing. It consists of a strip-line BPM, a fast BPM processor board, and a strip-line kicker to give a correction on the beam orbit.

FONT4: Since the bunch spacing specified for ILC is ~190 or ~370 nsec, the very fast BPM processor is not necessary. Given time is long enough to design the system with a digital processors which should have more redundancies [15]. A processor board using a Field Programmable Gate Array (FPGA) has been developed for the tests with 3-bunches mode in ATF (Figure 7).

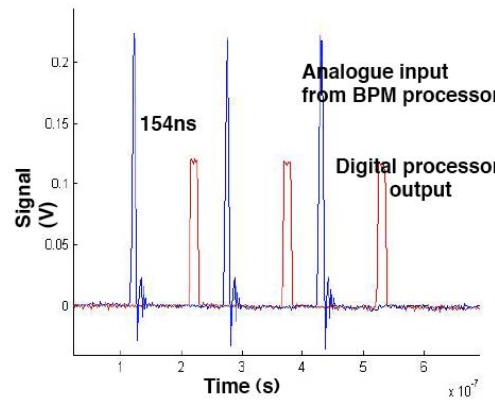

Fig.7: Response of the digital board for three bunches extraction with a spacing of 154 ns.

IMPORTANT ONGOING RESEARCH PROGRAMS AT ATF DAMPING RING

Development of a Fast Strip-line Kicker

In the ILC reference design report (RDR), the damping rings must store up to ~5120 bunches in a ~6 km circumference and provide the main linacs with the bunches spaced apart by ~190ns or ~370ns. Thus, the injection and extraction kickers have to realize 3.0nsec rise and fall times at a repetition rate of 3MHz or 6MHz. A collaboration was formed among KEK, SLAC, DESY, LBNL and LLNL in the Fall of 2004 to address this issue. In Spring, 2005, three flavors of pulse circuits (built by DESY, SLAC/LLNL and KEK) were used to test-drive a stripline kicker (prepared by KEK), which was installed at the ATF damping ring. Two strip line kicker system demonstrates the rise and fall times of 2.2 ns and 3.0 ns, respectively, as achieved with two commercially available 5kV fast pulses and with two 32.7cm long strip line kickers [16]. This R&D program will continue and will attempt to demonstrate the beam extraction, to check the stability and reliability, and to check the effects on previous and following bunches.

Future Plans of Fast Kicker R&D and Beam Instability Studies

R&D on fast kicker is going to check the performance of the system with 2.8ns 20-bunch 3 trains. Preliminary results indicate the possibility of beam extraction without

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kick effect into adjacent bunch. We consider more detail study of the system is necessary and we will prepare bunch-by-bunch extraction system for the ATF-II project.

The fast ion instability, micro-wave instability and non-linear beam dynamics studies are underway to obtain important information for the ILC damping ring design. Several international groups already proposed the plan and we are discussing the details on each study.

ATF-II PLANS

ATF-II

ATF-II is a scaled model of the ILC Beam Delivery System which transports, focuses and controls the low-emittance beam at an interaction point. Two major goals of ATF-II are: (1) to focus the beam vertically at 37nm with the local chromaticity correction scheme and (2) to control beam position with a few nm vertical jitter at the focus point, by taking advantage of the ultra-low emittance beam at ATF.

The ATF-II beam line in the latest design comprises 27 standard quadrupole magnets, a doublet of final quadrupole magnets, 5 sextupole magnets and 3 bending magnets. Fig.8 shows the layout of ATF-II. Each of the quadrupole and sextupole magnets features a cavity type BPM (Beam Position Monitor, QBPM) with 100nm position resolution. In JFY2005-2006, 28 standard Q-magnets and 26 QBPM were produced by groups at IHEP (China) and PAL (Korea), respectively. The electronics of QBPMs with digital readout have been designed at SLAC and are under construction there.

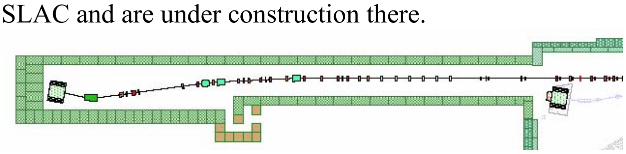

Fig.8: Layout of ATF2 beam line.

The schedule of ATF-II construction and beam commissioning/operation was fixed at 3rd ATF-II project meeting and approved by 3rd ICB and 4th TB. Beam commissioning of ATF-II will start on Oct. 2008. In the new beam line of ATF-II, cavity BPMs will be used as main monitors for operation.

ATF-II-BPM: Reliable beam position control within a few μm accuracy is required along the final focus beam line of ILC and ATF-II. The cavity BPM will be attached on quadrupole magnets of ATF-II [17]. It is a cylindrical cavity read out from four symmetric ports of waveguides coupled with slots. The front end electronics to downconvert the signal into 20 MHz is also developed. An online calibration/analysis system to extract beam positions has been developing.

IP-BPM: One of the major goals of ATF-II is to demonstrate stabilization of the beam position at the focal point (the virtual interaction point, IP) within a few nanometer. An ultimately high resolution cavity BPM located at the IP (IP-BPM) is necessary to prove it. Due to the special beam optics at the IP, several special considerations were needed in designing IP-BPM. To reduce the signal originated by the angle of the beam orbit, the length of the cavity in the beam direction was shorten compared with other cavity BPMs. To be free from cross-coupling between the dipole modes of different directions, the cavity has a rectangular shape with dipole mode frequencies 714 MHz apart. Tests in the extraction line has started recently. Our aim is the achievement of a few nm resolution with present confirmation of 8.7 nm.

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REFERENCES

[1] J.Urakawa, Proceedings of APAC 2007, FRXMA03, Indore, India, 2007.
[2] J.Urakawa, KEK/ATF Damping Ring, PAC97, pp.444-448, Vancouver, May 1997.
[3] Edited by H.Hayano et al., KEK Internal 2000-6 A (2000).
[4] J.Urakawa et al., presented at 17th International Conference on High-Energy Accelerators (HEACC98), Dubna, Russia, 7-12 Sep. 1998. KEK Preprint 98-154.
[5] ATF2 Proposal, Volume 1, CERN-AB-2005-035, CLIC note 636, DESY 05-148, ILC-Asia-2005-22, JAI-2005-002, KEK Report 2005-2, SLAC-R-771, UT-ICEPP 05-02 (2005), Volume 2, KEK Report 2005-9, CERN-AB-2006-004, DESY 06-001, ILC-Asia-2005-26, JAI-2006-001, SLAC-R-796, UT-ICEPP-05-04.
[6] Y.Honda, Proceedings of APAC 2007, WEZH102, Indore, India, 2007.
[7] J.Urakawa, H.Hayano and M.Ross, Proc. of Nanobeam 2002, p223.
[8] A.Wolski et al., ATF Reports-04-09, LBNL-57046, SLACPUB-11040, 2004.
[9] Y.Honda et al., Physical Review Letters, Vol.92, No.5, 054802-1 (2004).
[10] S.Walston et al., Proc. of this conference.
[11] H. Sakai et al., Proc. of EPAC06, Edinburgh (2006) p2784.
[12] Y. Honda et al., Nucl. Instr. Meth. A538 (2005) p100.
[13] L. Deacon et al., Proc. of this conference.
[14] P. Karataev et al., Nucl. Instr. Meth. B227 (2005) p158.
[15] P Burrows et al., Proc. of this conference.
[16] T. Naito et al., Proc. of this conference.
[17] J-Y. Huang et al., Proc. of APAC07.

