Luminosity Optimization techniques for Future Linear Colliders: experimental tests in ATF2-3

Toshiyuki OKUGI, KEK 2025/ 5/ 15 2025 Joint workshop of FKPPN and TYL/FJPPN

Accelerator Test Facility (ATF)

- Designed, constructed, and beam tested thought ATF international collaboration
- Researchers and students from more than 20 countries have participated.



Major Institutions Participating in the ATF



Institute of High Energy Physics

アメリカ(USA)

SLAC国立加速器研究所 ローレンス・バークレー国立研究所(LBNL) フェルミ国立加速器研究所(FNAL) ローレンス・リバモア国立研究所(LLNL) ブルックヘブン国立研究所(BNL) コーネル大学(Cornell Univ.) ノートルダム大学(Notre Dome Univ.)

日本(Japan) 高エネルギー加速器研究機構(KEK) (Tohoku Univ.) 東北大学 (Univ. of Tokyo) 東京大学 早稲田大学(Waseda Univ.) 名古屋大学(Nagoya Univ.) 京都大学 (Kyoto Univ.) 広島大学 (Hiroshima Univ.) 中国(China) 中国科学院高能物理研究所(IHEP) 韓国(Korea) ポハン加速器研究所(PAL) キョンプク大学(KNU)

インド(India)

ACCELERATOR

Raja Ramanna Centre for Advanced Technology



ATF damping ring

• Highly quality (low emittance) beam generation





Equivalent emittance to ILC !

Y. Honda et al., Physical Review Letters 92 (2004) 054802.

ATF2 beamline

• Final focus beamline

- Design to be corrected of various beam aberration.



ILC FFS - ATF3 objective and collaboration

- Based on the ATF international collaboration.
- Pursue the necessary R&D to maximize the luminosity potential of ILC.
- Assessment of the ILC FF system design from point of view of beam dynamics and technological/hardware choices long-term stability operation issues.

Major Research Topics at the ATF3 Project

- Multipole field error mitigation
- Wakefield mitigation
- Beam instrumentation
- Beam stable operation

Multipole field error mitigation

- Easy to make conditions with greater multipole impact than ILC
- Ideal accelerator to test the effect of the multipole field error



Ultra low beta* at ATF2 beamline

Andrii Pastushenko (CERN) @LCWS2024

- *Research on multipole field control more difficult than ILC.*
- Applied to beam focusing for accelerators such as CLIC.



Small beam size achievements (June 2019)

Octupole magnet fabricated by CERN for use in this research



OCT1FF



OCT2FF

Multipole field error mitigation

- The nonlinear field at septum magnet was large
- The effects can be reduced by controlling the beam orbit at the magnet



Hardware preparation for wakefield mitigation and correction

Skew Sextupole magnets

2023 Design/manufacture/delivery

2024 Installation and beam studies with the magnets



Final focus magnet

2024 Design/manufacture/delivery

2025 Installation and beam studies with the magnets



Magnet mover control system

2023 Prototyping and test

2024-2027 Install to ATF beamline step-by-step

2024 5 FF sextupole and 3 FF quadrupole movers



Wakefield mitigation

50

0.00

0.25

0.50

0.75

Bunch charge [nC]

- Larger IP beam size growth than ILC
- Ideal accelerator to test the effect of the wakefield to nanobeam



Bunch Length	0.3 mm	7.0 mm	0.5	0.5
Emittance	0.16 pm	12 pm	8.7	1
Sum of β_y	390 km	61 km	2.5	6.7
Total			0.11	0.032

Larger impact than ILC

1.50

w=124.9±7.8 nm/nC

1.00

1.25

Wakefield study at ATF2 beamline



 -0.02
 0.00
 0.02
 0.04

 Distance from bunch center z[m]

- **JFY2023** : The effect of wakefield on ICF70 flange and the effect of RF mask to reduce it were tested with test chamber.
- JFY2024 : Based on the results, low impedance flanges, bellows were designed and fabricated, and beamline was updated.
- JFY2025: The effectiveness of the vacuum components in reducing the wakefield effect on the nano-beam will be tested.



ATF2 incoherent Cherenkov diffraction radiation

Kacper Lasocha (CERN) @LCWS2024

- Development of non-destructive beam size monitor for high power beams.
- Academic research for feature of Cherenkov diffraction radiation

Beam test results in 2023

- Characteristic tests of Cherenkov DR using beams. ٠
- Difficult to separate from Cherenkov light by beam tail. •
- Develop a device that includes a collimator to cut the beam tail • and resume testing from 2025 autumn.



1.0 GeV, 150 pC

Planned upgrade of ChDR setup



ATF2 Cavity BPM system with calibration pulse injection

Alexey Lyapin (RHUL) @LCWS2025

Calibration pulse injection

- Cavity-quad offsets: reduce the useful dynamic range.
- Regular calibrations required.
- Wakefields (as a consequence of the offsets).





Amplitude of the BPM signal (wakefield of cavity) was reduced by using calibration pulse injection.

Cavity BPM for ILC Main Linac

Laura Karina Pedraza (IFIC) @LCWS2024

Methods employed to enhance the spatial resolution and meet the Main Linac requirements.

Re-entrant cavity BPM



- **Resolution test is planed at the end of ATF2 linac** (from May 2025)
- A preliminary plan is underway to develop a prototype integrating the SCQ and BPM assembly into a test cryostat.

- The Saclay design is under evaluation to enhance BPM sensitivity and spatial resolution
- Simulation of the read-out system in MATLAB to asses the influence of all components on the overall system performance
- BIR-ME 3D method estimates the cBPM output signal with careful definition of the beam.



Timing system upgrade

Alex Aryshev (KEK)



Peak-to-Peak data below shows about 2 times improvement!

e- charge at:	2023	2024
Linac End	~0.01	~0.005
IP	~0.01	~0.005

KEK ATF Linac klystrons High-Power RF field phase and amplitude stability.

Konstantin Popov (KEK)





White Rabbit + IDROGEN board based low-level RF system

Test at ATF accelerator in collaboration of KEK and IJClab

- New proposal to the ATF international collaboration
- To be discussed the approval at ATF technical board meeting.
- The system test will be performed at ATF after the program was approved.

KEK:

Laser synchronisation – concept

Master Oscillator (510MHz/51), Rubidium



Developments made in parallel at IJCLab and KEK: IJClab:

- Standalone tests with phase noise measurements
- Test new developments on the IDROGEN board quickly

H. Kaji, D. Charlet

- WhiteRabbit allows to minimize implementation cost
- A simple fiber to bring to the laser
- No expensive/complicated fiber length compensation system to implement



- Test within KEK environment for instance at ATF
- Possibility to test with 4km fibre loop easily (shown in Oct'24)
- Possibility to test accelerator/laser synchronisation \rightarrow rescheduled for June at ATF

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