Utilization of ATF/ATF2 beam for R&D beyond Linear Colliders

ARYSHEV Alexander, KEK

ATF Review Meeting - September 29th 2020

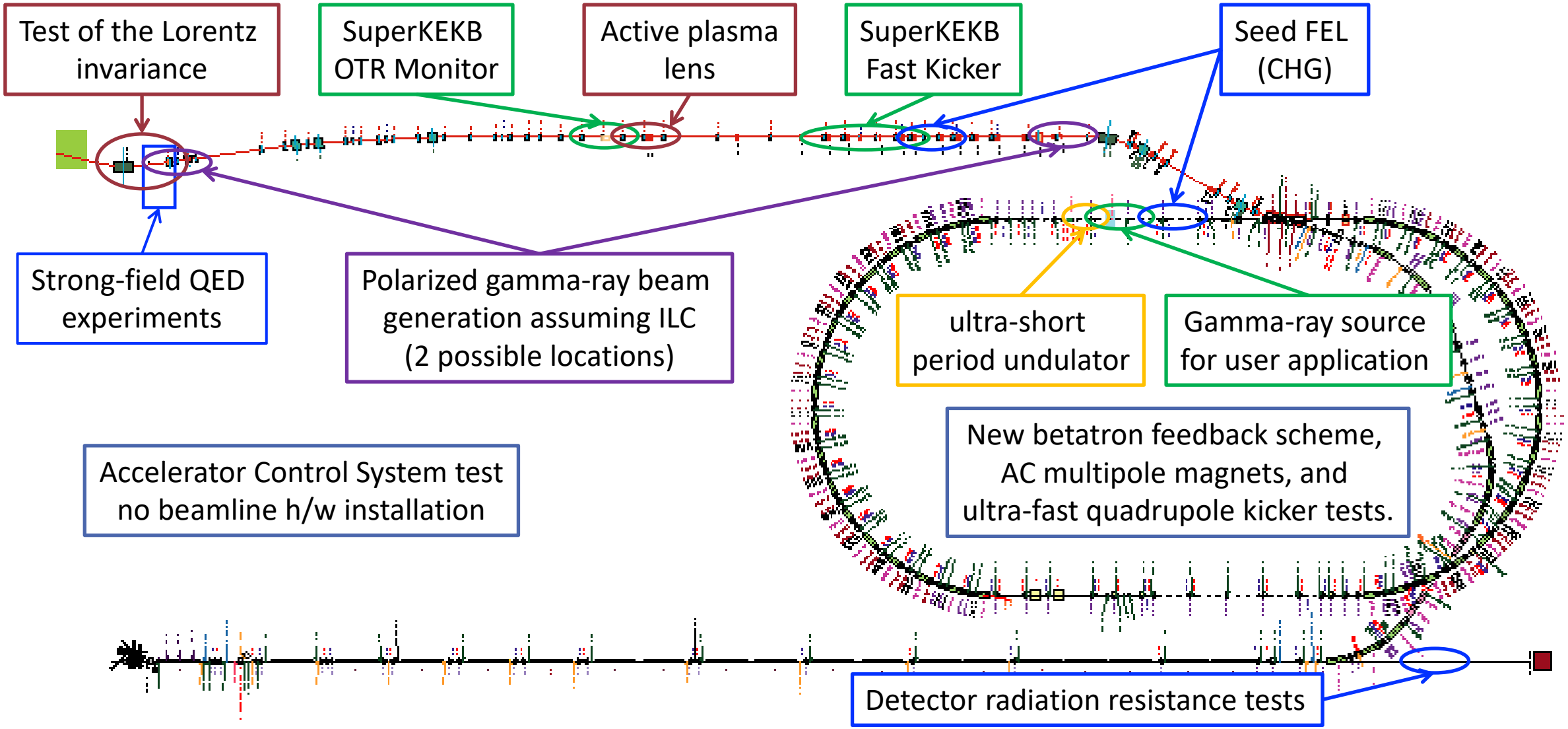
Introduction

- **ATF is a test accelerator** for technology development, which is flexible in operation and **can provide the opportunity to perform R&D** not only for LC technology development but also for other developments using electron beam.
- Therefore, we first sought **potential interest in the application and use** of ATF electron beam from the Japanese accelerator community (Mini-workshop to discuss potential projects was organized on 28 Aug. 2020).
- We will provide a **beam for these R&Ds** while the preparation of their experimental equipment is expected **by their own resources**.
- Some ideas were submitted by interested people. We expect that **overseas researchers** will also have the **same interests** when we spread the inquiry widely.

Submitted proposals

Implementation level
- Relatively simple
- Intermediate
- Difficult

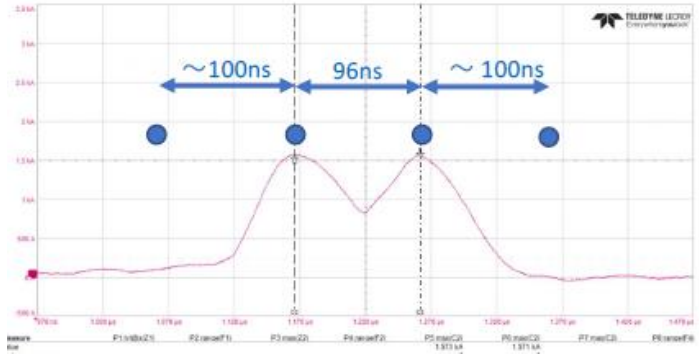
Project title	Person in charge	Funding	Term	Required ATF modifications	Location
Development of SuperKEKB Fast Kicker .	M. Tawada (KEK)	KEKB	Fall 2021 ~	minor	EXT-mid
Development of SuperKEKB OTR Monitor.	T. Mori (KEK)	KEKB	Fall 2021 ~	minor	EXT-end
New betatron feedback scheme, AC multipole magnets, and ultra-fast quadrupole kicker tests.	T. Nakamura (KEK/JPARC)	?	2021 ~	minor	DR
Accelerator Control System test.	Y. Kaji (KEK)	KEKB	2021 ~	minor	Timing system
Detector radiation resistance tests.	Y. Sugimoto (KEK)	KEKB	2021 ~	80MeV linac optics	Linac-end
Gamma-ray source for user application .	ATF group (KEK)	-	-	minor	DR north
Performance evaluation of ultra-short period undulator.	S. Yamamoto (KEK)	KEK-PF	2021 ~	minor	DR north
Polarized gamma-ray beam generation assuming ILC.	N. Muramatsu (Tohoku Uni.)	?	2023 ~	minor	EXT/FF
Electron beam focusing by active plasma lens.	M. Kando (Osaka U.)	?	2021 ~	New laser, LTL, vacuum bump chamber	EXT-end
Test of the Lorentz invariance.	T. Shima (Osaka Uni.)	JSPS ↑	-	BSM modification	FF
Demonstration of seed FEL (CHG).	Y. Honda (KEK)	JSPS ↑↑	-	EXT beamline modification	EXT-mid
Strong-field QED experiments.	Under discussion	JSPS ↑↑↑	-	ATF2 FF region upgrade and extension	FF


Test of the Lorentz invariance
SuperKEKB OTR Monitor
Active plasma lens
SuperKEKB Fast Kicker
Seed FEL (CHG)
Strong-field QED experiments
Polarized gamma-ray beam generation assuming ILC (2 possible locations)
ultra-short period undulator
Gamma-ray source for user application
New betatron feedback scheme, AC multipole magnets, and ultra-fast quadrupole kicker tests.
Accelerator Control System test no beamline h/w installation
Detector radiation resistance tests

SuperKEKB Fast Kicker tests (M. Tawada)

- **Stable extraction** of the low emittance beam from the damping ring is **important for increasing a performance of SuperKEKB**.
- **Two bunches separated by 90 ns** are extracted from the damping ring simultaneously. It is planned to use a **fast kicker** to correct the **orbit of the second bunch**.
- Since the **injector linac** and **damping ring** are **operating continuously** for the injections into the SuperKEKB and Photon Facility, the available R&D **beam time is very limited**.
- With its **low emittance beam** and **high precision cavity BPMs**, the **ATF2 beamline** is expected to be an **ideal test bench** for the development of SuperKEKB fast kicker.

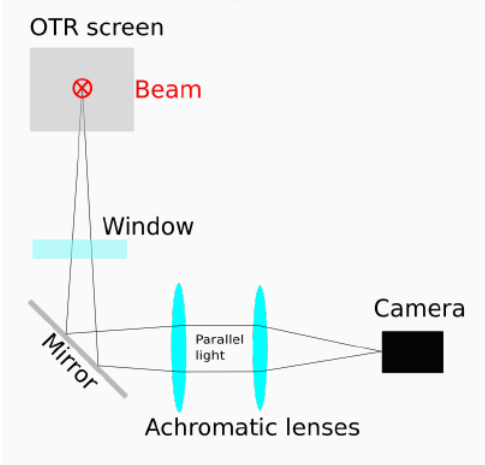
- Fast orbit Stripline kicker
- Electrode length: ～300mm
- Gap: 24mm
- Deflection: 100 urad
- Charging voltage: 10kV
- Pulse width: 10-20ns



- **Location @ ATF**: EXT line
- **Experimental tests**: Autumn or Winter 2021.

SuperKEKB OTR monitor test (T. Mori)

- **Optical Transition Monitor R&D at ATF2 beamline** is proposed because the R&D is not timely conducted by the **limited beam time** for study and also **limited access** to the beamline when the SuperKEKB is running.
- As the **ATF is much flexible** and **already succeeded** in development of OTR monitors it is expected to be an **ideal test bench** for the development of SuperKEKB OTR monitor.



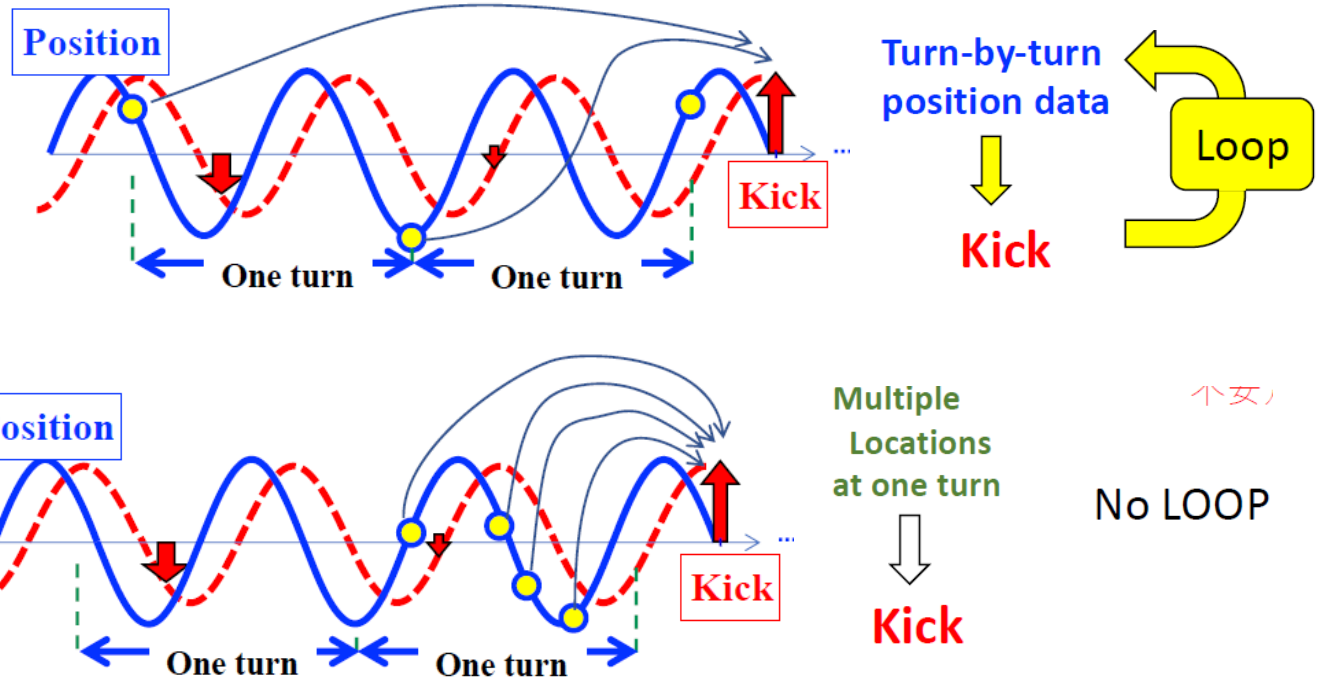
Proposed study @ ATF

- Resolution check of SuperKEKB-BT OTR setup.
- Optimization of the lens parameters suitable for a given monitor.
- Calibration and cross-check with existing ATF OTR monitor.

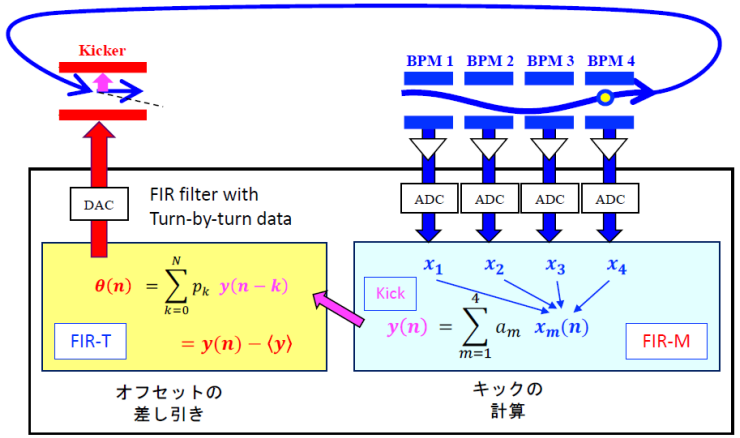
- **Experimental tests**: Autumn 2021
- **Required beam time**: ~half shift × 4
- **Location** @ ATF: EXT line

New betatron feedback scheme (T. Nakamura)

Basic principle



Proposed FB implementation



External budget requirement:

- Digital signal processor
- BPM and front end
- Kicker

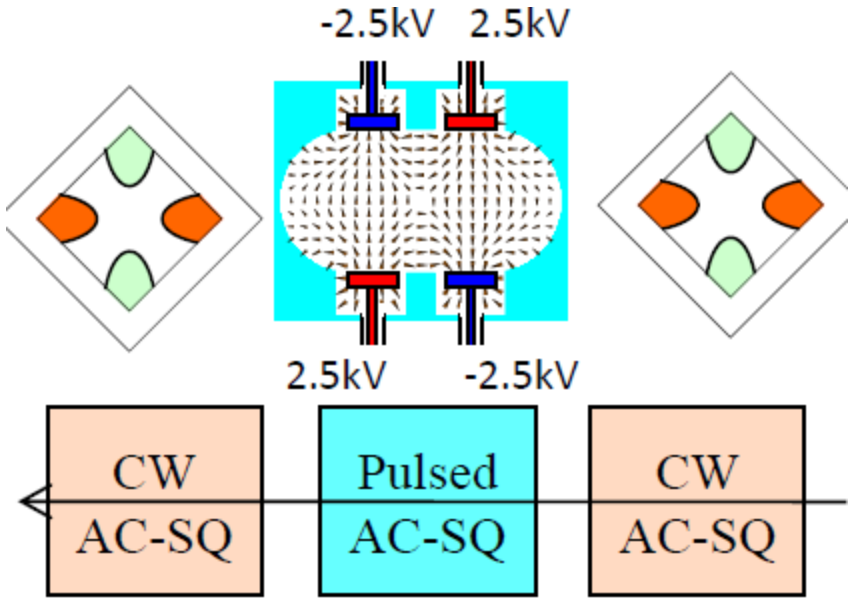
Location @ ATF: DR

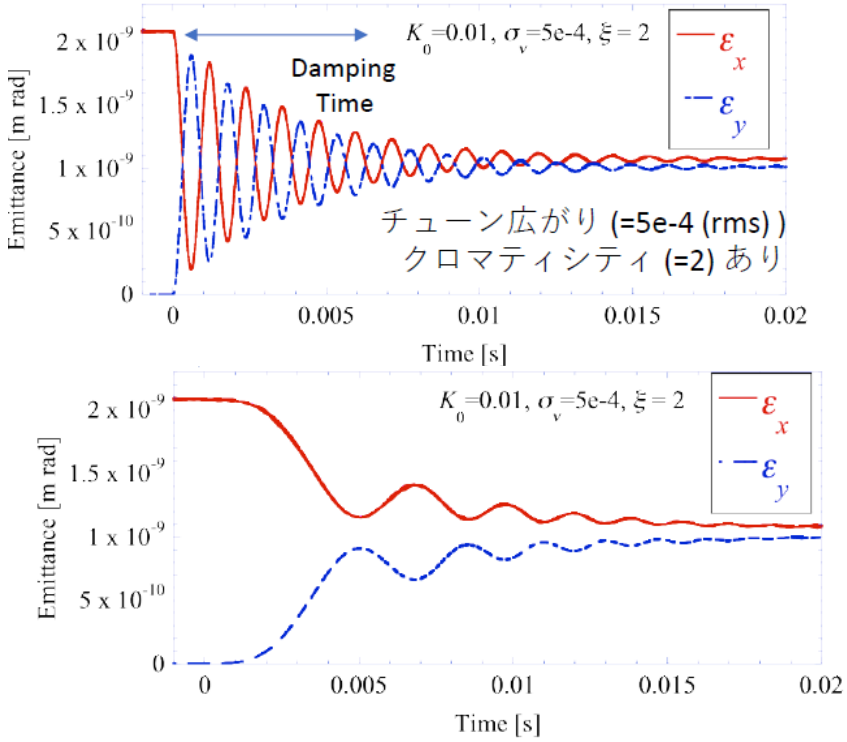
Experimental tests: not yet scheduled

Possibility for a Joint research with JASRI / SPring-8

AC multipole magnets study (T. Nakamura)

- With pulsed AC-SQ Partially negates the effect of CW AC-SQ
- Eliminate x-y coupling only in shooting bucket
- No vertical wraparound of the incoming beam





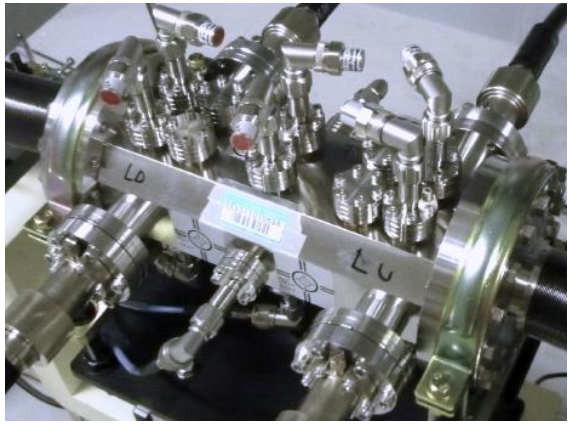
No AS-SQ correction

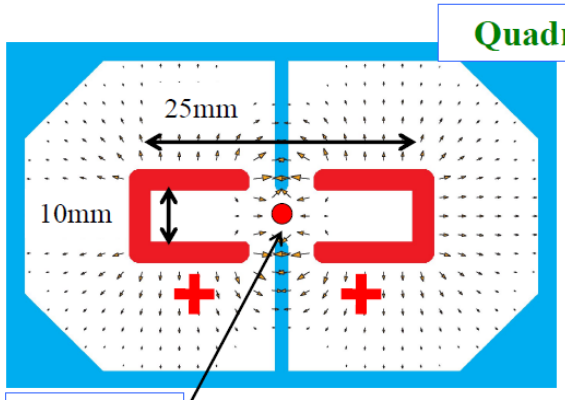
With AS-SQ correction

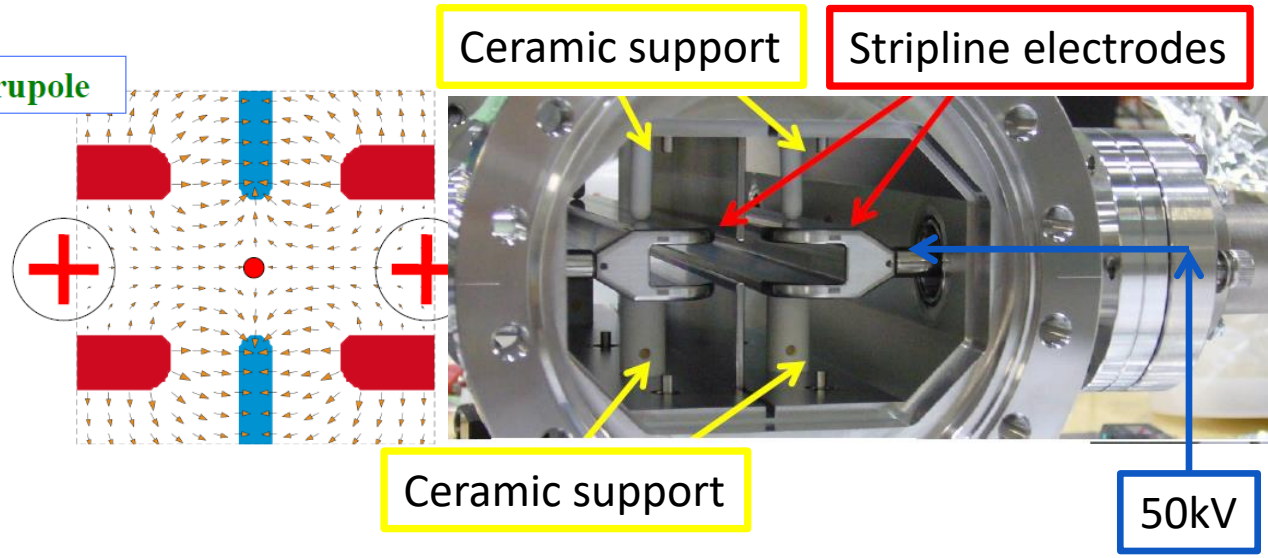
External budget requirement:
- Magnet manufacturing
- Power supplies

Location @ ATF: DR
Experimental tests: not yet scheduled

Ultra-fast quadrupole kicker tests (T. Nakamura)





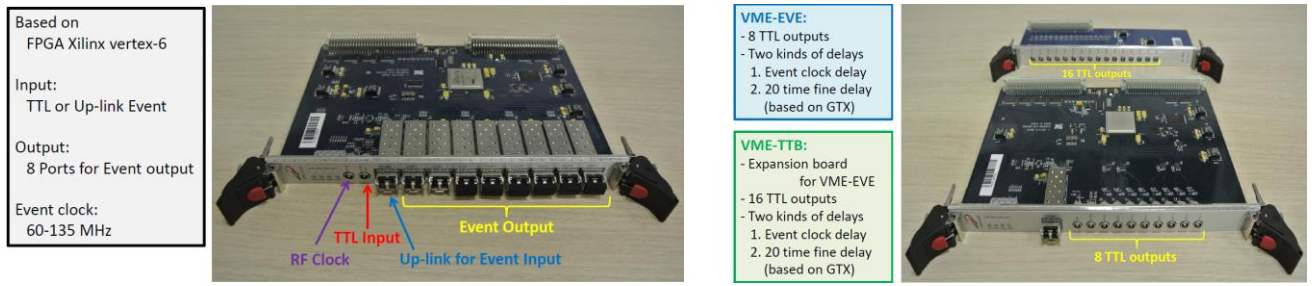


Three projects "**New betatron feedback scheme**", "**AC multipole magnets study**", and "**Ultra-fast quadrupole kicker tests**" proposed as the **ATF damping ring** is the **unique machine** in the world for the test of new concepts and devices, because of its **high-quality beam**, the **high-performance instruments** and its **variety of operation modes**.

Location @ ATF: DR
Experimental tests: not yet scheduled

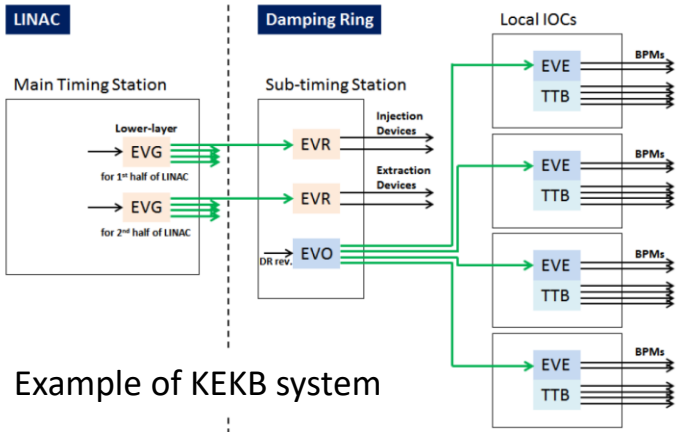
Accelerator Control System test (H. Kaji)

- The **White Rabbit system** is a multifunctional **high-speed control system** based on time synchronization between multiple nodes on the network.
- In **April 2020** it was **implemented** in the control system of the **SuperKEKB accelerator**.
- **ATF** will be a suitable start point at KEK and bring a knowledge and experience to **improve the control of KEK accelerators**.



Example VME cards developed in the SINAP and KEK collaboration

- **Further optimization can be tested at ATF** via sub-timing station at DR so injection/extraction timing for septum magnets is synchronized with injector - triggers.
- **Timing accuracy** of triggers from VME-EVE and VME-TTB are determined to **be ~15ps and ~12ps**, respectively.



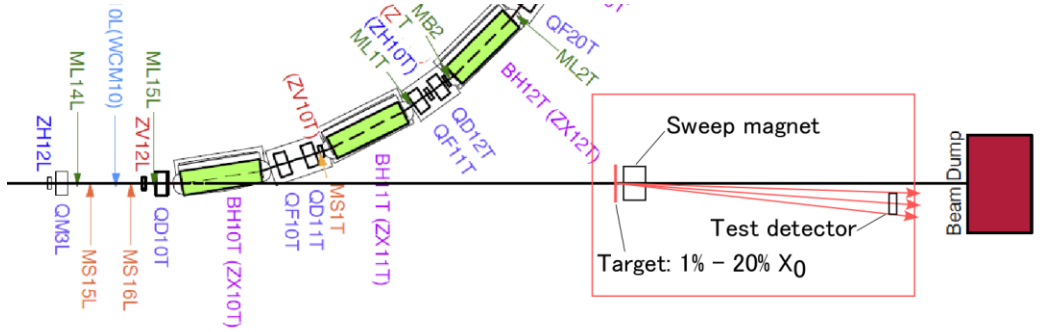
Example of KEKB system

Location @ ATF: Timing system racks
Experimental tests: not yet scheduled

Detector Radiation Damage Test (Y.Sugimoto)

- Test of the **radiation resistance** of detector by using low energy electron beam **at the ATF LINAC** is proposed. The electron beam with energy **80 to 100 MeV** will be injected into a target and the beam spread by the multiple scattering will hit the detector.
- Total amount of beam electrons demanded is from 10^{11} to 10^{15}. It corresponds to 3 sec to 90 hours of irradiation.
- The **present study** is conducted at the **Tohoku University**, **3-hours travel from KEK**. It is advisable to do R&D at **ATF** where the experiments can be done in a **more flexible and faster** way.
- Among the detectors which may be tested, there is a special interest in the **radiation tolerance of diamond sensors** and of a new generation of **cooled silicon sensors**. Single crystal CVD diamond sensors are currently used at SuperKEKB and foreseen at future colliders such as ILC or CLIC.

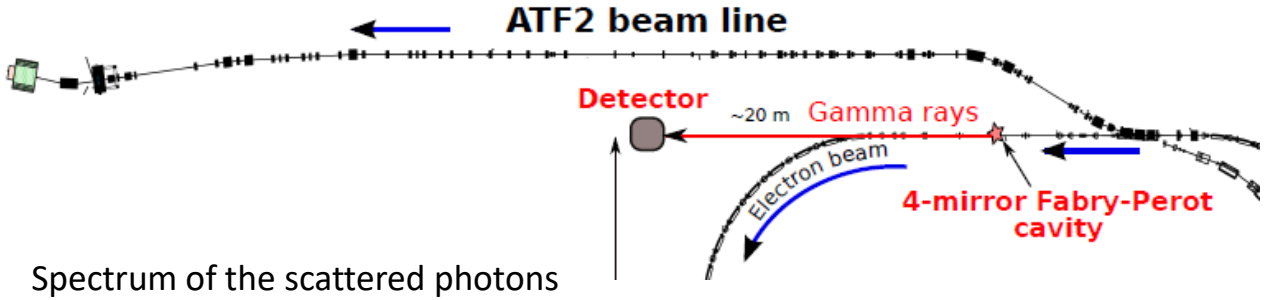
- Significant data on radiation damage exists using protons and neutrons, **but not electrons**.



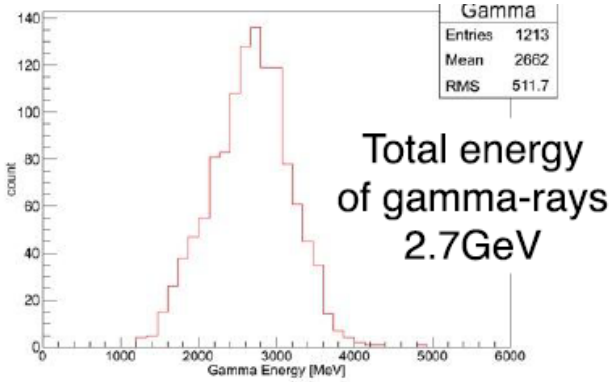
Location @ ATF: LINAC end beamline
Experimental tests: Spring 2021 ~

Gamma-ray source for user application (ATF group)

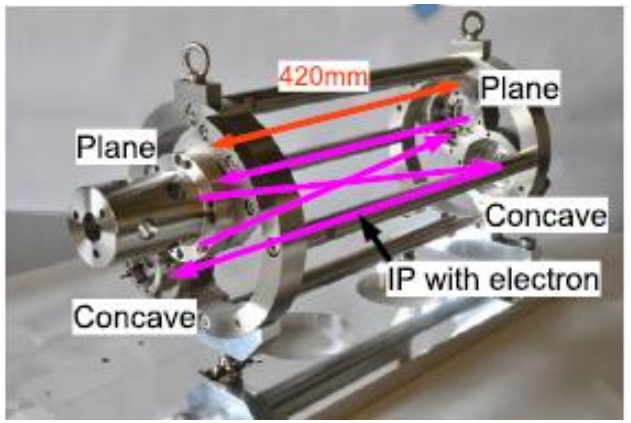
- A **γ-ray source based** on the **Laser-Compton scattering** (LCS) is in operation for the user application at the **Spring8 NewSUBARU** storage ring (E_e=1.5 GeV). It supplies γ-ray from **2 ~ 33 MeV** via changing laser wavelength and has an available flux of **10^7 photons/sec**.
- The **monoenergetic polarized γ-ray beam** is used for fundamental study of physics and engineering. On the study of photo-nuclear reaction, the reaction cross sections are measured to improve its data base that is used for designing an electron accelerator.
- The **optical cavity system** that realizes high density laser pulses was developed at **ATF DR** (E_e=1.3 GeV) for the R&Ds of polarized positron source and the laserwire monitors. It produced stable γ-rays by LCS of about **10^8 photons/sec** and energy of **10 ~ 30 MeV**.
- Therefore ATF has a potential to conduct R&Ds which requires such γ-ray beams.



Spectrum of the scattered photons



~100 photons/train observed !



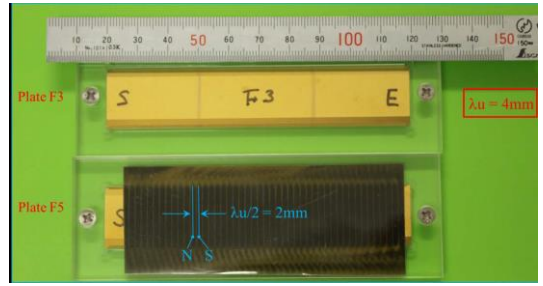
4-mirror optical cavity

Location @ ATF: DR north
Experimental run: not decided yet

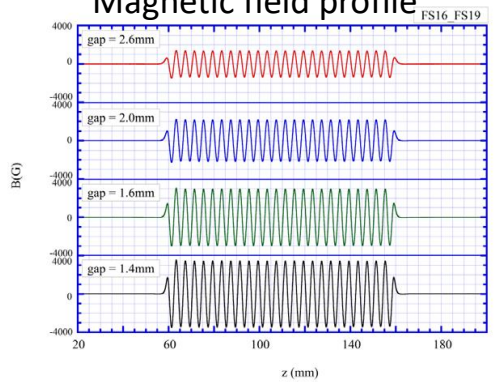
Very-Short-Period Undulator (S.Yamamoto)

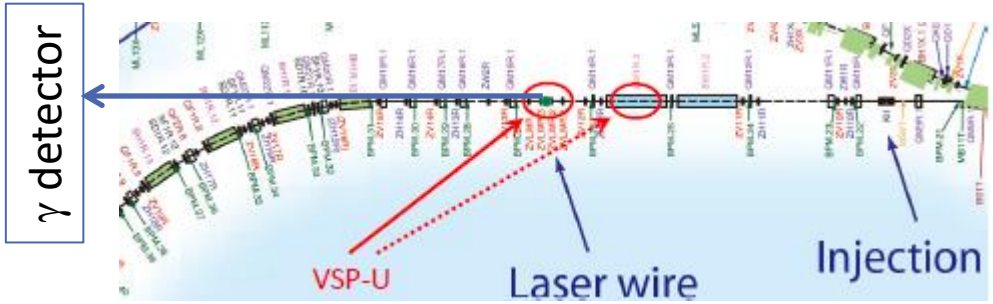
- The **undulator magnets** with a **very short** a few mm-**period** length has been developed to bring the **high energy radiation** and realize the **compact photon source**.
- Recently, the undulator magnet with 4 mm-period length **was developed** at KEK and **tested** at 50 MeV Tohoku University Linac.
- **Next step** of the development is the **performance evaluation** and demonstration of the higher average brightness, by **using the ring accelerator**.
- Since **the vertical gap** of the developed undulator magnet is only **1 - 3 mm in operation and 20 mm in standby**, **it is difficult to test it at the light-source rings** where several experiments are on-going simultaneously.
- The **ATF DR is capable to conduct this R&D** and make contribution to the future compact light sources developments.

Magnet assembly



Magnetic field profile



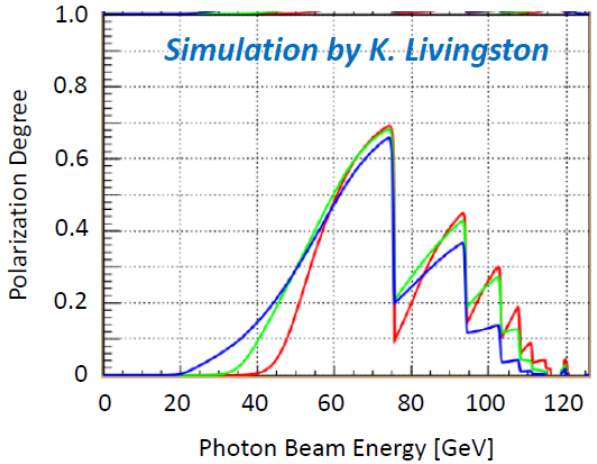


- **Location @ ATF**: DR north straight section
- **Experimental tests**: 2021 ~

Coherent bremsstrahlung as a source of high energy γ-ray beam with linear polarization (N. Muramatsu)

- As for an **application of ILC beam**, a polarized γ-ray generation by a beam with energy of around 75 GeV has been discussed. It will bring **a development**, for example, **on the hadron photoproduction experiment**.
- To generate **polarized γ-rays**, high-energy electrons are passed through a thin plate of diamond crystal (thickness 20-50 μm), and **coherent bremsstrahlung** is generated by adjusting the passage angle with a precision automatic stage.
- In this case, a high-quality (**low emittance**) electron beam **is required**.
- **ATF** is considered as the **only place in Japan** to promote the development of these coherent bremsstrahlung experimental studies before the ILC started.

- Using the **existing ATF2 extraction line**, a series of preparatory experiments are envisioned, including the **development of new technologies** for the future.

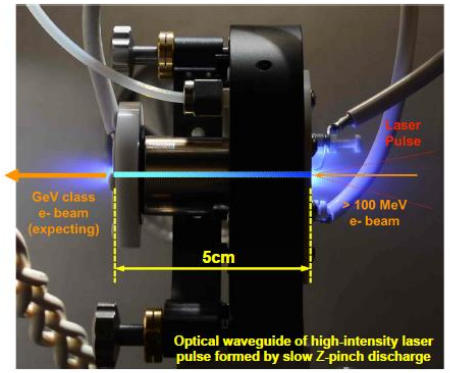


- **External budget is required**.
- **Location @ ATF**: DR
- **Experimental tests**: from 2023 ~

e^- beam focusing by an active plasma lens (M.Kando)

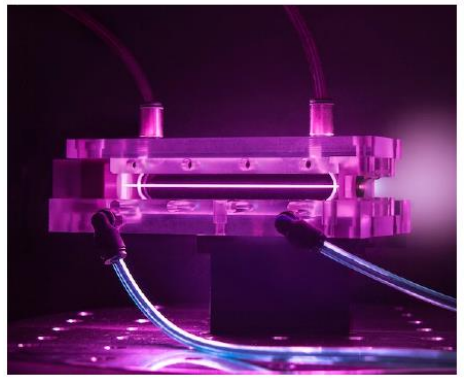
- Development of the **plasma lens** has been conducted for various application including the plasma accelerators. A **plasma-filled capillary** is realized in a channel **filled with a gas**, and applying the **current of several 100A between electrodes** at the end of a channel.
- Researchers of **Osaka University** has been developed a plasma channel, **1 mm in diameter, 50 mm long** and driven by a relatively high current, **order of kA**. They propose a development of the **electron beam focusing by the plasma lens**, which expects a **focal length of 27 mm for 1.3 GeV ATF beam**.
- The **ATF2 beam** can be used to **test the plasma channel** and results of focusing will be measured by the beam profile monitor.

Hosokai type
Fast Z-pinch Discharge Capillary



$n_e \approx 7 \times 10^{18} - 1 \times 10^{19} \mathrm{cm}^{-3}$

Hooker type
Discharge Capillary



$n_e \approx 7 \times 10^{18} \mathrm{cm}^{-3}$

Examples of a plasma-filled capillaries

Need substantial external budget

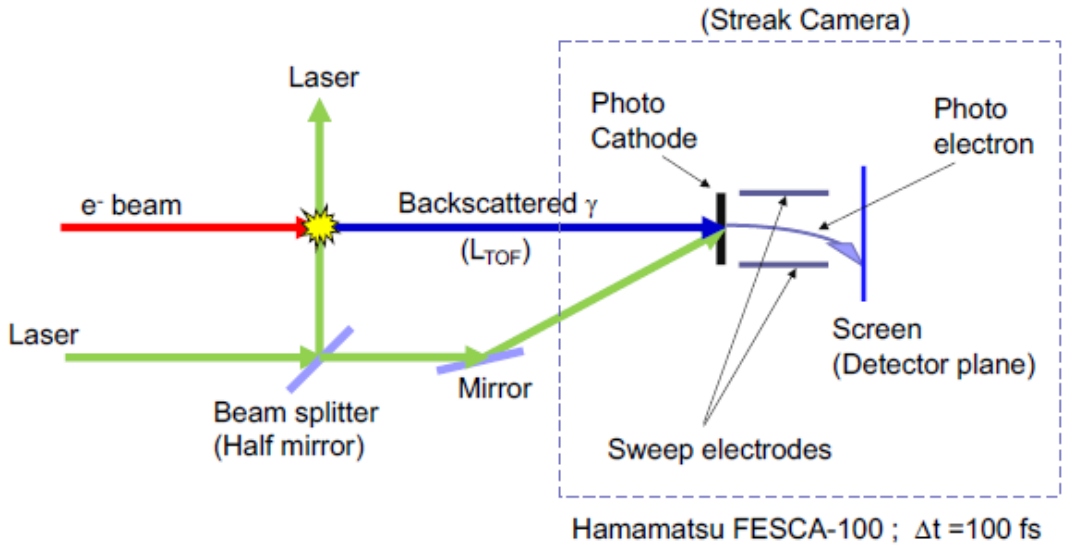
Location @ ATF: EXT line

Experimental tests: from 2021~

Test of the Lorentz invariance (T. Shima)

- Some types of the **quantum gravity theory** introduce **quantized space and time**, resulting in the **violation** of the **Lorentz invariance** in the sense of a **non-linear dispersion** relation **of light** propagating in vacuum.
- A **sub-picosecond photon beam** generated by the inverse Compton scattering of an electron nano-beam and a very short laser pulse will provide a **unique opportunity** to make a test of the Lorentz invariance on the Earth's surface at the precision of $10^{-5} \sim 10^{-6}$ which corresponds to the search for **new physics in the TeV energy region**.
- The electron nano-beam of ATF2 is considered to be the **best suited facility** for such a high-precision experiment concerning fundamental physics.

Proposed experimental scheme at ATF2 FF-IP



Need substantial external budget

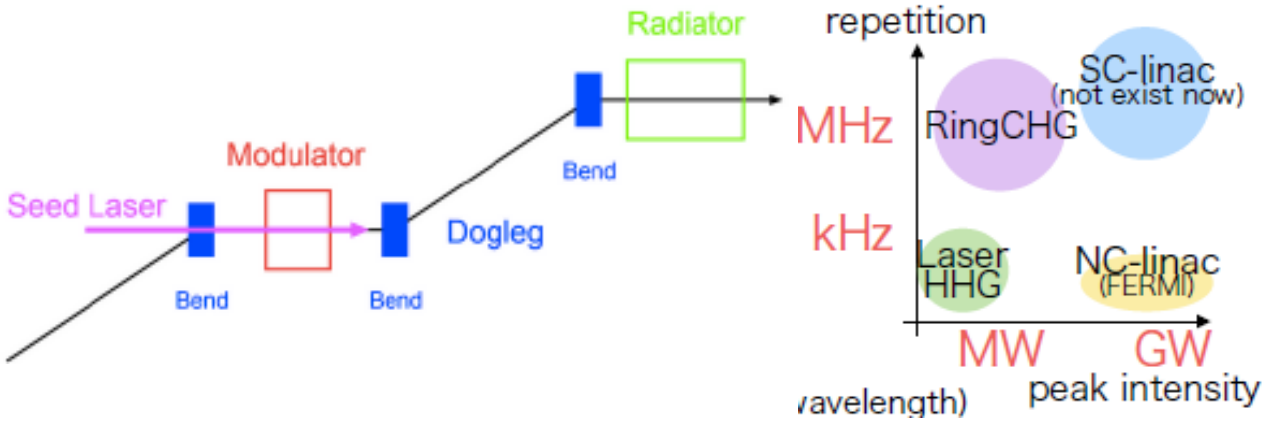
Location @ ATF: ATF2 FF IP

Experimental tests: not scheduled yet

Demonstration of seed FEL (CHG) Y.Honda

- The **conventional** scheme of **FEL does not work** for the beams in a storage ring by their **long bunch lengths**, **even** when the **beam emittances are as small** as those for linear accelerators.
- However, a **novel scheme** has been proposed to **compress the beam density** in the storage rings. The idea is that **the micro bunch structures** are generated by **applying the smaller energy modulation** than the intrinsic energy spread to the beams in storage rings.
- The **energy modulation** is produced by a **laser light in a specially designed dogleg layout**.
- In this method, the **extremely small vertical emittance** is **essential**, and the vertical emittance of the **ATF beam** is enough small to produce the micro bunch beam structure.

- To **confirm** the **micro bunch structure generation** by installing the dogleg and the laser at the **ATF extraction beamline**, the proof of principle experimental study is proposed.
- This can **open-up a possibility** for the future seed **FEL in the storage ring**.



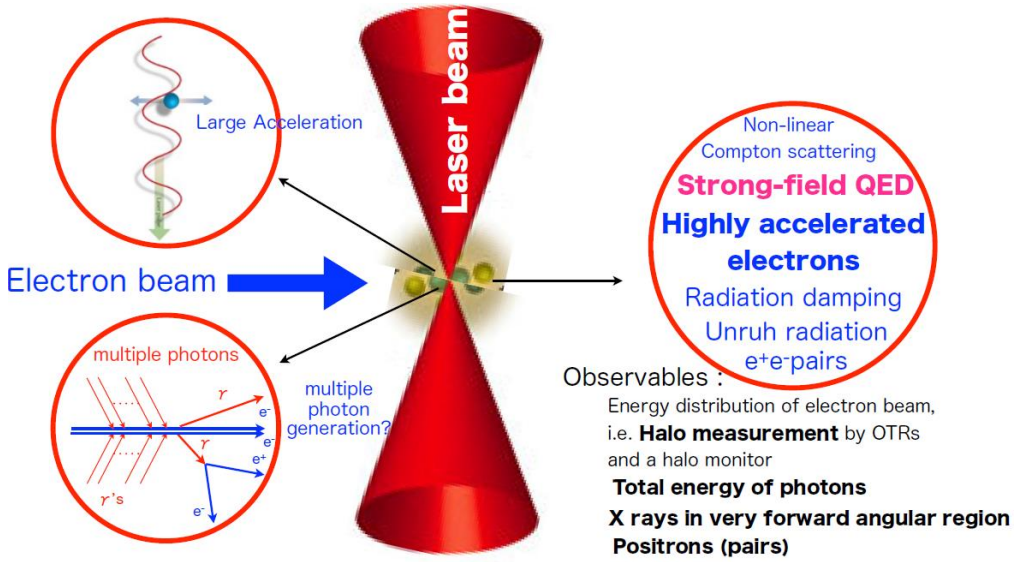
Need substantial external budget

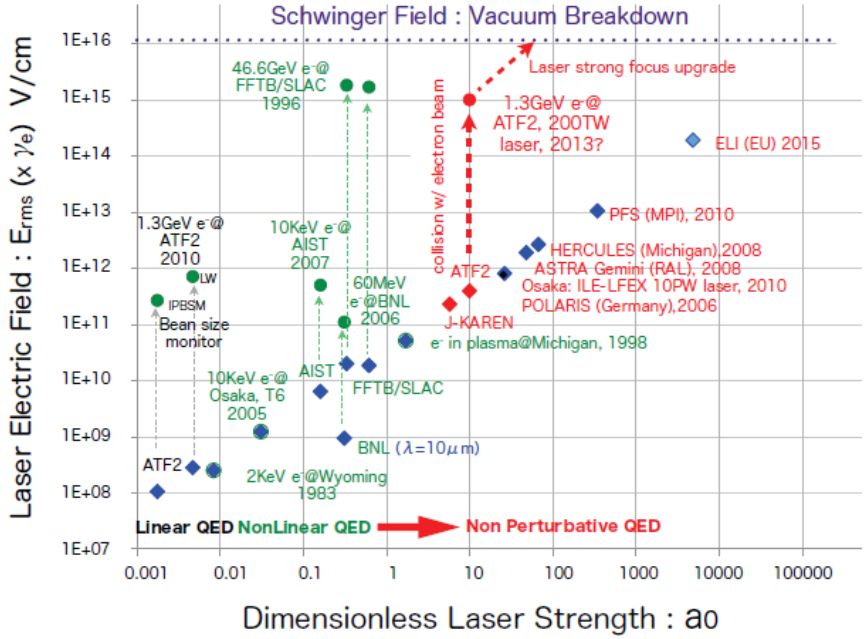
Location @ ATF: EXT line

Experimental tests: not scheduled yet

Strong-field QED experiments

- Following past experimental studies at SLAC, Michigan University, Osaka University and BNL **there is an idea** to perform a **strong–field QED experiment** for detailed investigation of collisions between the 1.28 GeV electrons and a 250 TW laser (λ = 800 nm, 25 fs).
- With the **present advances in laser technology**, and **stable nano–beam availability at ATF2**, new experiments to measure non–perturbative QED approaching the Schwinger critical field value can be considered.
- In addition to **non–linear** effects of **Compton scattering** with multiple photon absorption, the energy loss in the laser pulse, i.e. the **radiation damping** can be observed.
- The **ATF2 nano beam is also unique** for the **Unruh radiation** experiment which is generated by quantum effect near the event horizon, which is similar to Hawking radiation.

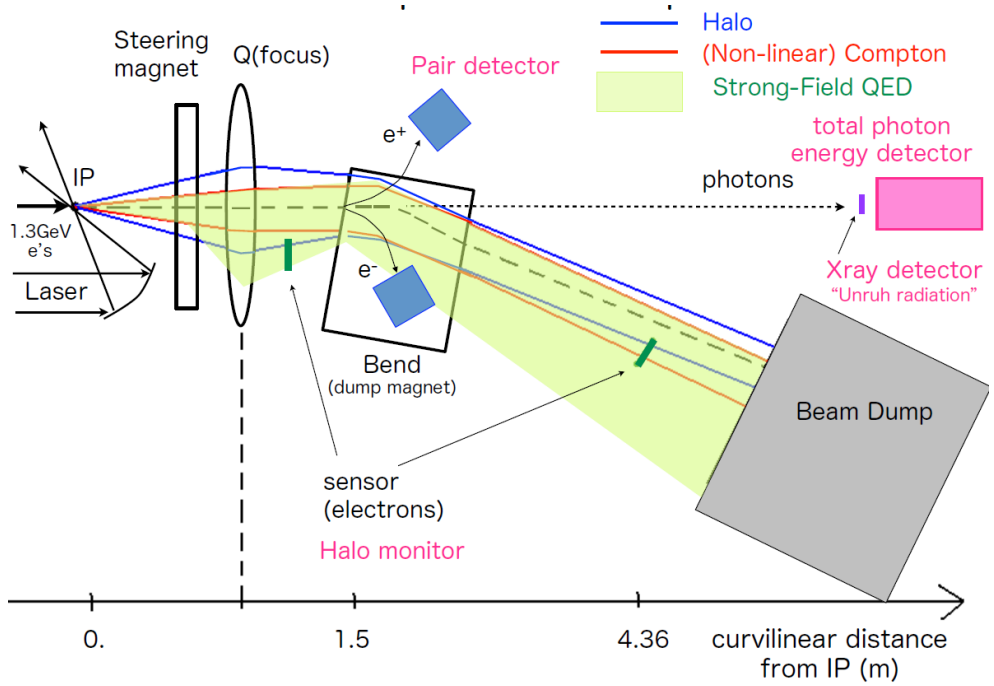




Strong-field QED experiments

- **The experimental condition** when an electron is accelerated in the laser high electric field and radiates in the same direction **can be realized at ATF2** with the **major upgrade** of the timings system, electron beam diagnostics (BSM monitor), incorporation of the 250 TW laser transport line and its final–focus system, development of the ultra–precise detectors, and several tens meter extension of the accelerator tunnel downstream of ATF2 IP.

Experimental schematics @ ATF2 FF IP



- M. Altarelli, et.al, "**Summary of strong-field QED Workshop**", held in DESY, Hamburg in August 2018. https://arxiv.org/pdf/1905.00059.pdf
- PIF 2010 https://inspirehep.net/conferences/981552
- T. Tauchi, KEK, "ACCELERATOR TEST FACILITY (ATF) AND FUTURE PROSPECT", PIF2010 proceedings.

Need substantial external budget

Location @ ATF: ATF2 FF IP

Experimental tests: not scheduled yet

Summary

- **ATF Beam operation is required** for the following purposes:
  - Complementary research works for other accelerators, including these at KEK and JPARC
  - Contribution to detector and light sources technology development
  - Experimental verification of the cutting-edge fundamental physics topics
- Availability of a **high quality stable electron beam** and **flexible machine operation schedule** open a wide possibilities to attract large amount of domestic and international research groups.
- In addition, the ATF facility is considered to play an important role for training of young generation physicists.
- Continuation of the ATF operation is important for many applied and fundamental aspects of modern science.