SACLA Facility Evolution

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Outline: SACLA Facility Evolution

- Compact SASE Source: Concept
- Project History
- Unique Properties: Colocation and Concurrency
- Early Achievement
- Evolution
- Future Plan
- Concluding Remarks

When the discussion toward the SASE XFEL was commenced both in the US and Europe in late 90's, we were in the middle of SPring-8 commissioning. After a discussion meeting for TESLA XFEL at DESY in 1999, a short conversation at a smoking place in the SPring-8 campus between Hideo Kitamura, being in charge of undulator development, and Tetsuya Ishikawa, in charge of X-ray optics development, prefaced the later SACLA XFEL Project, named SPring-8 Compact SASE Source (SCSS) project at the beginning.

“Compact SASE Source”

- Given the SASE XFEL is really wonderful light source, it is not enough to have only a few sources around the world!
- Fewer users per source require “more” sources to fulfill the users’ demands.
- Smaller sources need less cost, smaller land, and shorter period of construction.

History of 3rd generation SR sources showed us a solution!

3rd Generation X-ray SR Sources

- SR sources optimized for the use of undulator radiation are defined as the 3rd generation SR sources.
- The first 3rd generation X-ray SR sources appearing in 1990s (ESRF, APS and SPring-8) employed higher energy electron storage rings because of the immature undulator technology.
- Undulator technologies developed in these early sources enabled to operate “shorter-magnetic-period” undulators which could produce hard X-rays with lower energy electrons.
- New “fashion” of 3rd generation SR sources appeared for hard X-rays by using shorter period undulators combined with medium energy storage rings, as exemplified by SLS, DIAMOND, SOLEIL , ALBA, NSLS-II, Shanghai Light Source, PLS-II, TPS and others.

Solution for "Compact SASE Source"

- Lower electron energy may be feasible if we could use the short-period in-vacuum undulator instead of the conventional out-of-vacuum undulator.
- In addition, if we use a higher energy gradient accelerator tube, the LINAC length may be further reduced.
- RIKEN XFEL with 8 GeV LINAC is the first step for the 'COMPACT SASE SOURCE', but our dream is to construct an XFEL with < 1 GeV LINAC.

SPring-8 Compact SASE Source (SCSS) Concept

Use of short-period undulator

↓

Suppression of acceleration energy

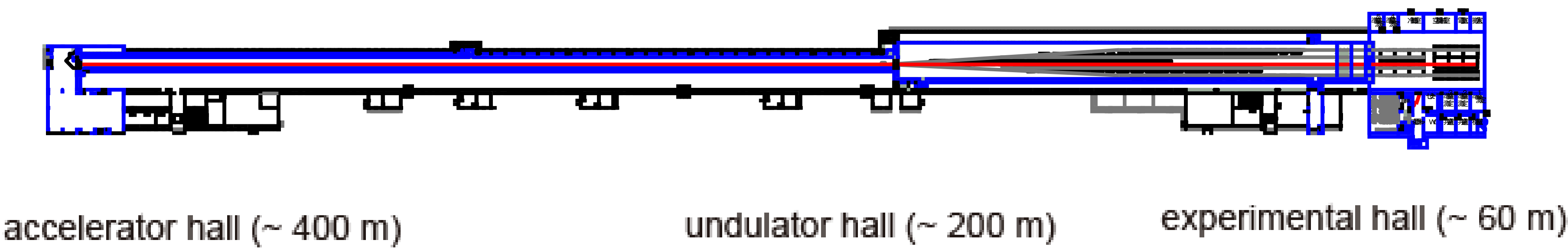
+

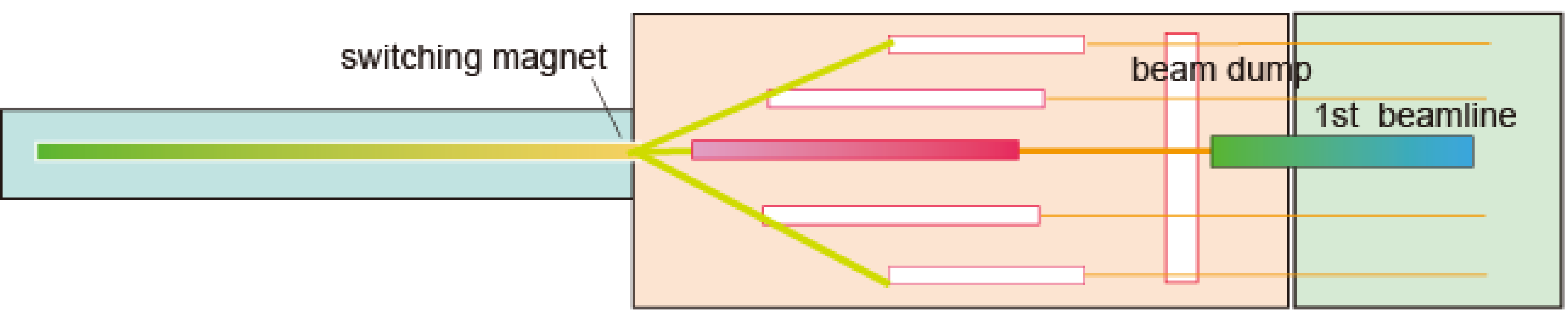
Use of high-gradient linac

=

Total length of 700 m

$$\lambda_{photon} = \frac{\lambda_{magnet}}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$





Project History

• Nov. 1999	Kitamura-Ishikawa Conversation
• Jul. 2000	R&D Proposal to RIKEN
• Apr. 2001	SCSS R&D Project launched
• Apr. 2004	Prototype Construction started
• Feb. 2005	8 GeV User Facility proposed
• Apr. 2006	8 GeV User Facility approved
• Jun. 2006	256 MeV Prototype lased
• Feb. 2011	SACLA RF conditioning started
• Apr. 2011	SACLA beam commissioning
• Jun. 2011	SACLA first lasing
• Feb. 2012	User Operation started

SACLA

(SPring-8 Angstrom Compact free electron LAser)

Colocation and Concurrency

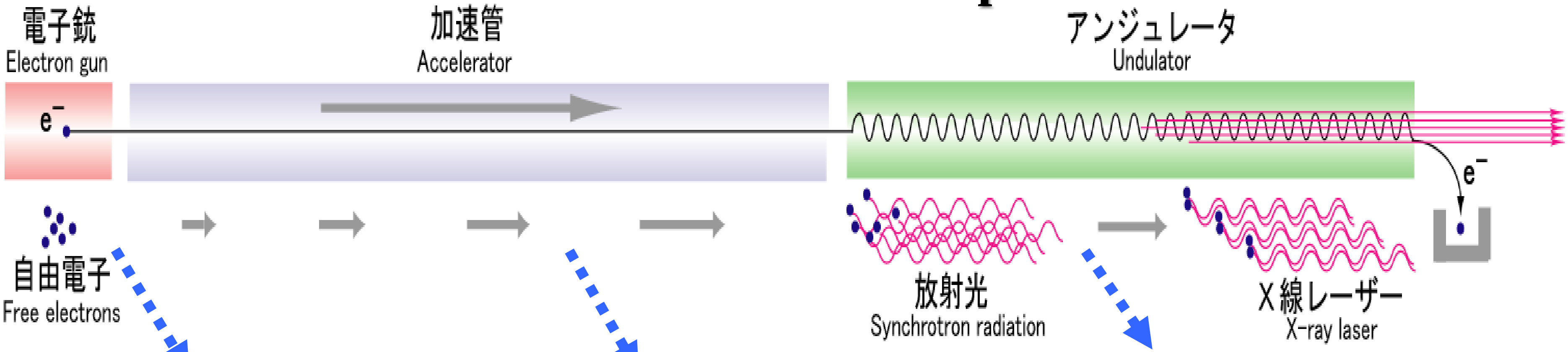
X-Ray Free Electron Laser with 8 GeV electron Liniac
With 700 m length with experimental building
Completed in March 2011
Open for public users both domestic and international

What’re new in SACLA?

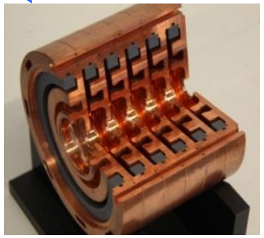
The first XFEL that co-locate with 3rd generation SR source.
The first “compact” XFEL with 700 m length.

Technologies materializing SACLA

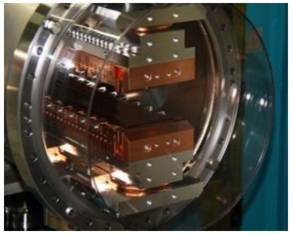
moderate cost & stable operation



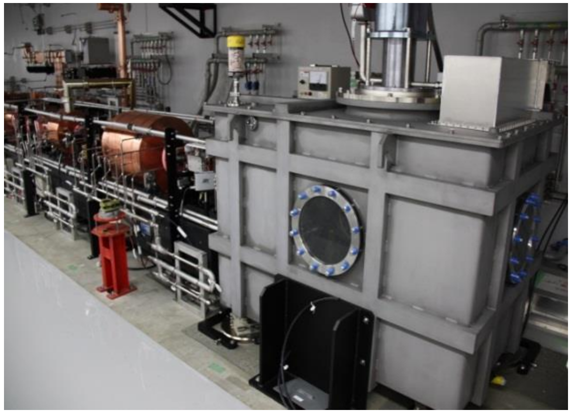
Low-emittance electron gun



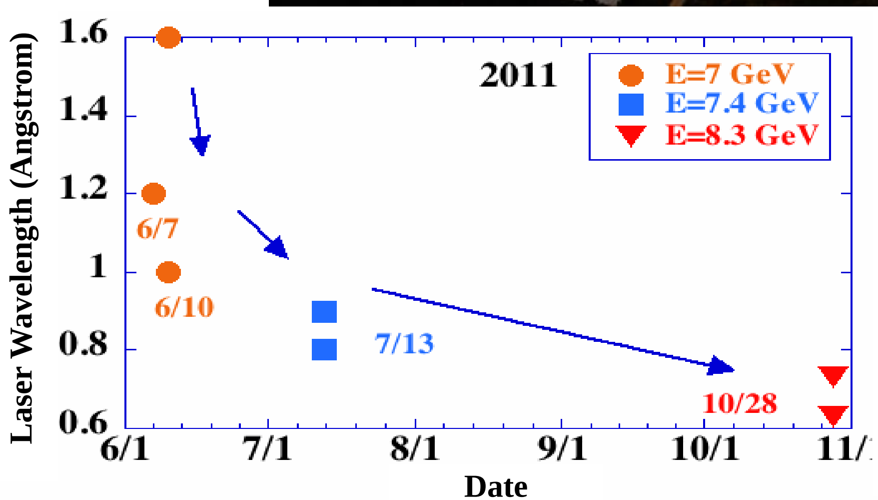
High-gradient C-band accelerator

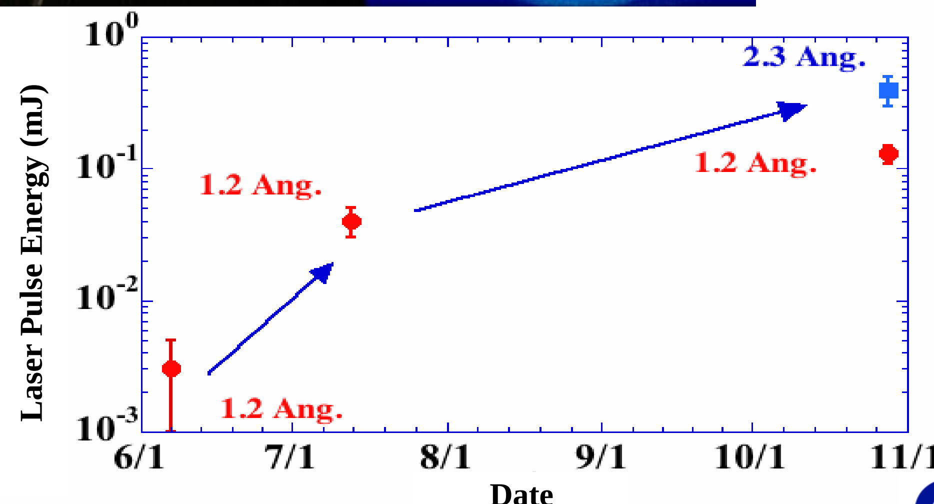


In-vacuum short-period undulator



Laser Broke 1.0 Angstrom Barrier





Project Paper appeared in *Nature Photonics*

nature photonics

LETTERS

PUBLISHED ONLINE: 24 JUNE 2012 | DOI: 10.1038/NPHOTON.2012.141

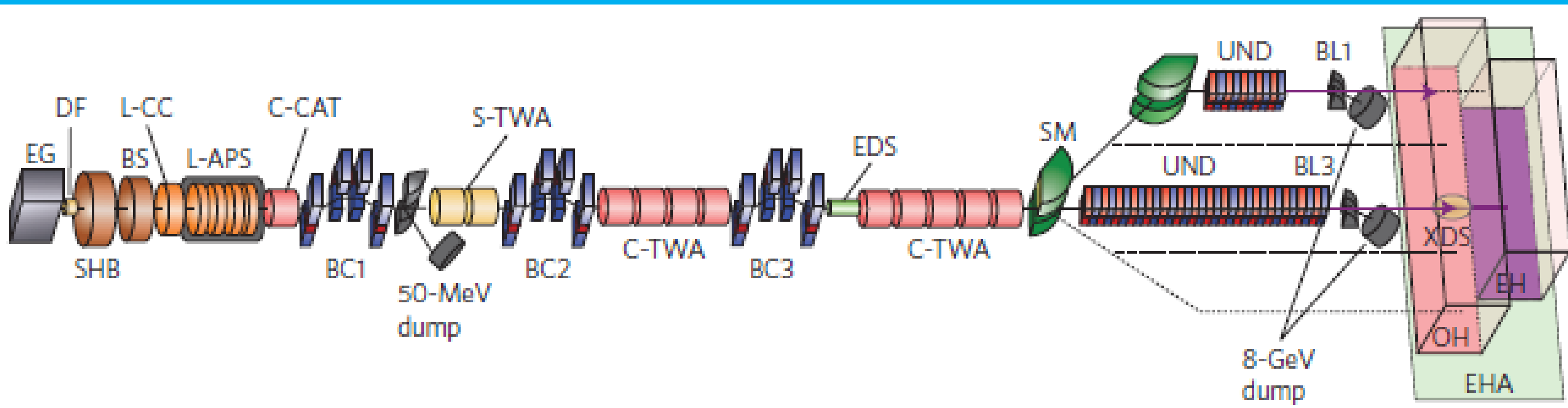
A compact X-ray free-electron laser emitting in the sub-ångström region

Hitoshi Tanaka and Makina Yabashi *et al.**

The free-electron laser, first proposed by Madey[1] in has significantly reduced laser wavelengths to the va ultraviolet[2,3] and soft X-ray regions[4]. Recently, an X-ray electron laser (XFEL) was operated at 1.2 Å at the Coherent Light Source (LCLS)[5]. Here, we report the succe generation of sub-ångström laser light using a compact source, combining a short-period undulator with an 8 GeV tron beam. The shortest wavelength attained—0.6

Table 1 | Main parameter list for SACLA.

Parameter	Present value
Electron beam	
Beam energy	8.5 GeV (maximum)
Bunch charge	~0.2–0.3 nC
Peak current, I_p	>3 kA
Energy spread (projected)	<0.1%



Evolution

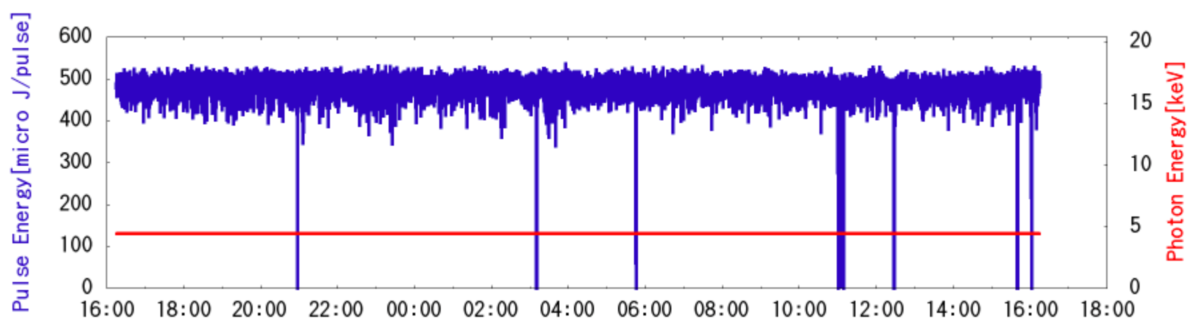
- 60 Hz User Operation
- Two-Stage Focusing
- Two Color Operation
- BL2 and On-Demand Switching
- SCSS+; Relocation and Upgrade of 256 MeV Prototype Machine
- High Power Laser Facility
- ImPACT: Laser Plasma Acceleration Platform

60 Hz User Operation: Just Started

[BL1] [BL2] [BL3]

2016/10/23	SACLA Operation Status	16:14:50

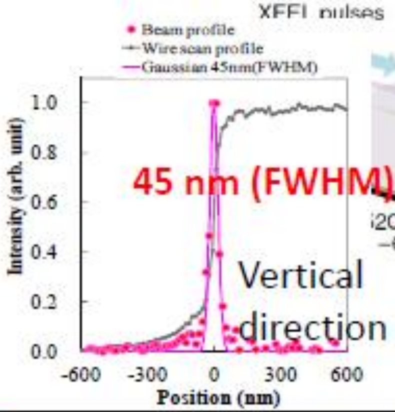
Operation Mode	
BL3 User Operation	
Hutch in Use	
BL3 EH4	
Pulse Energy	Photon Energy / Wavelength
509.2 micro J/pulse	4.4 keV / 0.279 nm
Repetition Rate	Intensity Fluctuation in 30 shots (STD)
60 Hz	11.1 %

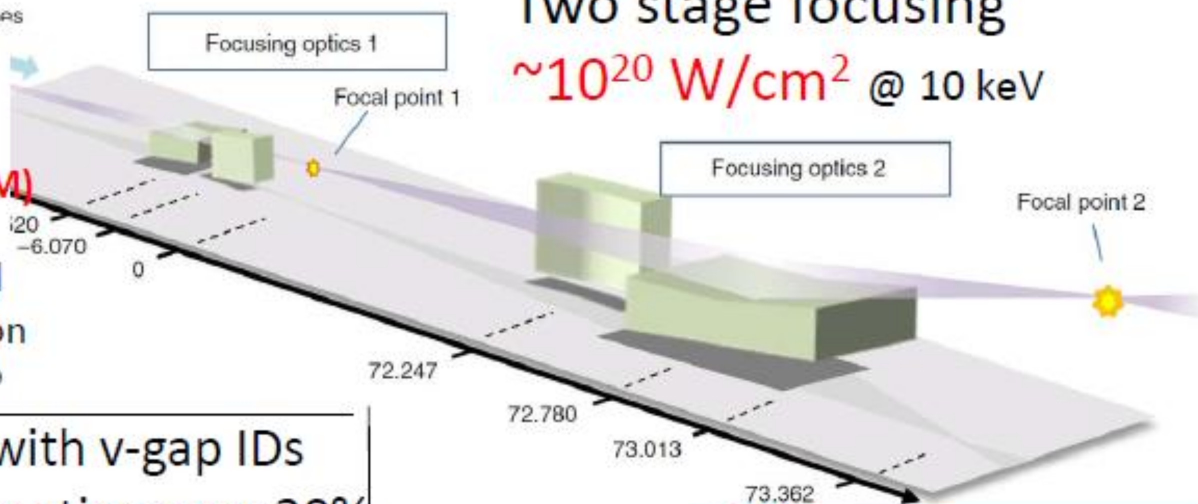


Optical Technologies for XQO

Two stage focusing

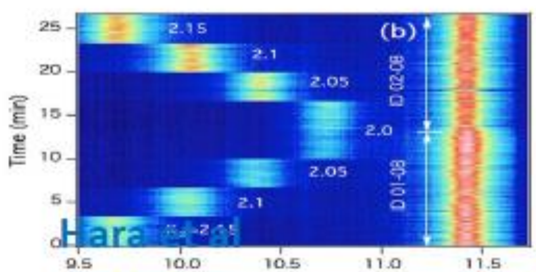
~10^{20} W/cm^2 @ 10 keV





Two-color SASE with v-gap IDs

Wavelength separation over 30% with delay up to ~ 100 fs



Hara et al

ARTICLE Nature Commun 4, 2919 (2013)

Received 8 Sep 2013 | Accepted 12 Nov 2013 | Published 4 Dec 2013

Two-colour hard X-ray free-electron laser with wide tunability

nature COMMUNICATIONS

ARTICLE

Generation of 10^{20} W cm^{-2} hard X-ray laser pulses with two-stage reflective focusing system

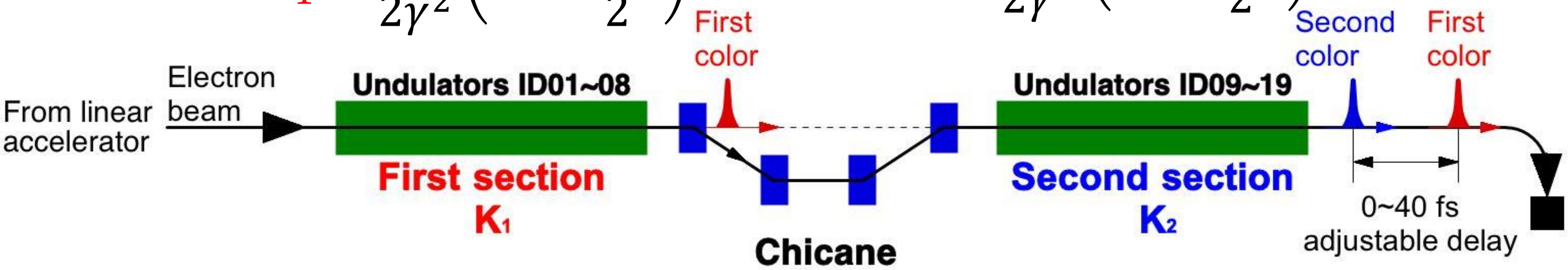
Mimura et al, Nature Commun 5 3539 (2014)

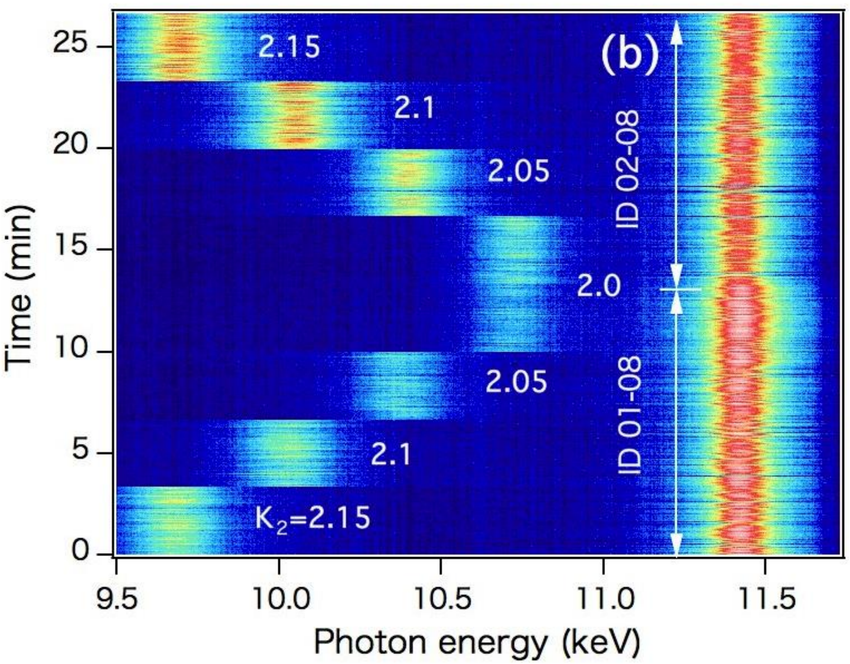



Mimura-san Yamauchi-sensei Ohashi-san Yumoto-san

Two-color operation with variable-gap undulators

$$\lambda_1 = \frac{\lambda_U}{2\gamma^2}\left(1 + \frac{K_1{}^2}{2}\right) \qquad \lambda_2 = \frac{\lambda_U}{2\gamma^2}\left(1 + \frac{K_2{}^2}{2}\right)$$





- Maximum photon energy separation: >30 %
- Time delay between two pulse can be adjusted between 0~40 fs with a sub-femtosecond resolution.

ARTICLE

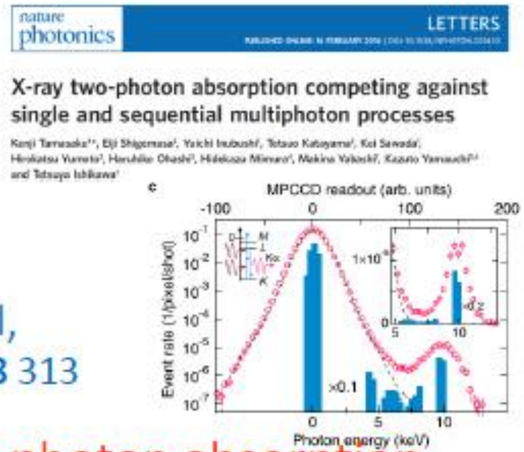
Received 8 Sep 2013 | Accepted 12 Nov 2013 | Published 4 Dec 2013 DOI: 10.1038/ncomms3919

Two-colour hard X-ray free-electron laser with wide tunability

Toru Hara[1], Yuichi Inubushi[1], Tetsuo Katayama[2], Takahiro Sato[1,†], Hitoshi Tanaka[1], Takashi Tanaka[1], Tadashi Togashi[2], Kazuaki Togawa[1], Kensuke Tono[2], Makina Yabashi[1] & Tetsuya Ishikawa[1]

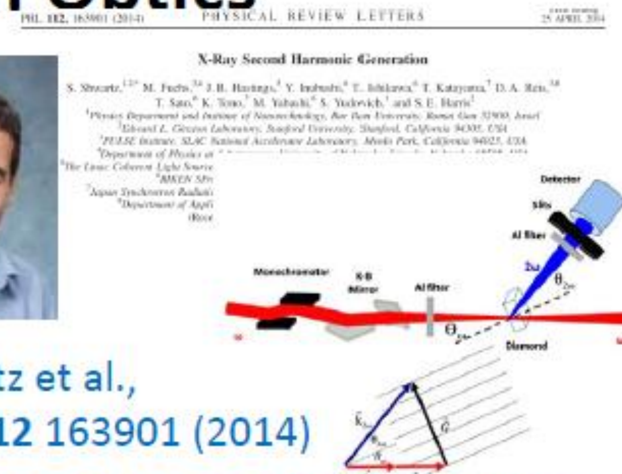
Hara et al, Nature Commun 2014

Ultrahigh intensity X-ray Quantum Optics



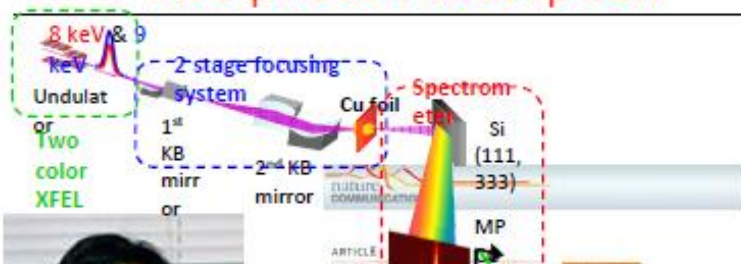
Tamasaku et al,
Nature Photon **8** 313 (2014)

Two photon absorption



Shwartz et al.,
PRL **112** 163901 (2014)

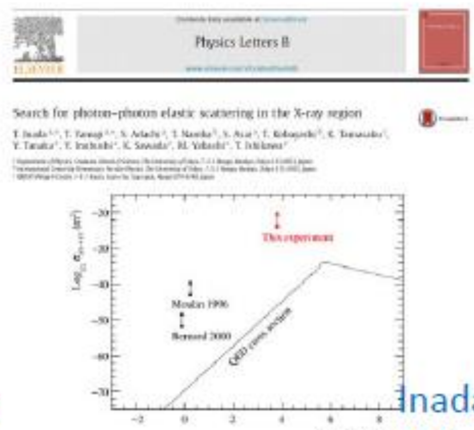
Second harmonic generation



Saturable absorption

Cu Kα atomic laser with 2-color (under review)

Yoneda et al.,
Nature Com (2014)
10.1038/ncomms6080



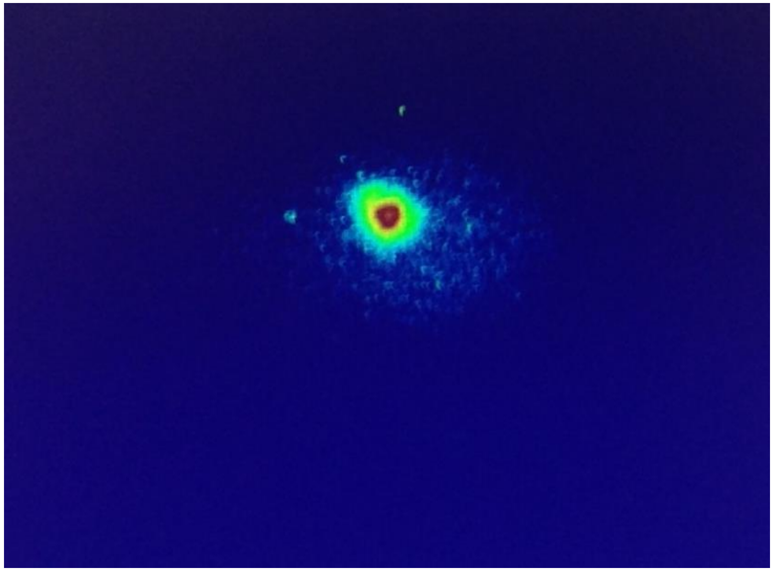
Asai-sensei
(U Tokyo)

Inada et al., Phys Lett B **732**, 356-359 (2014)

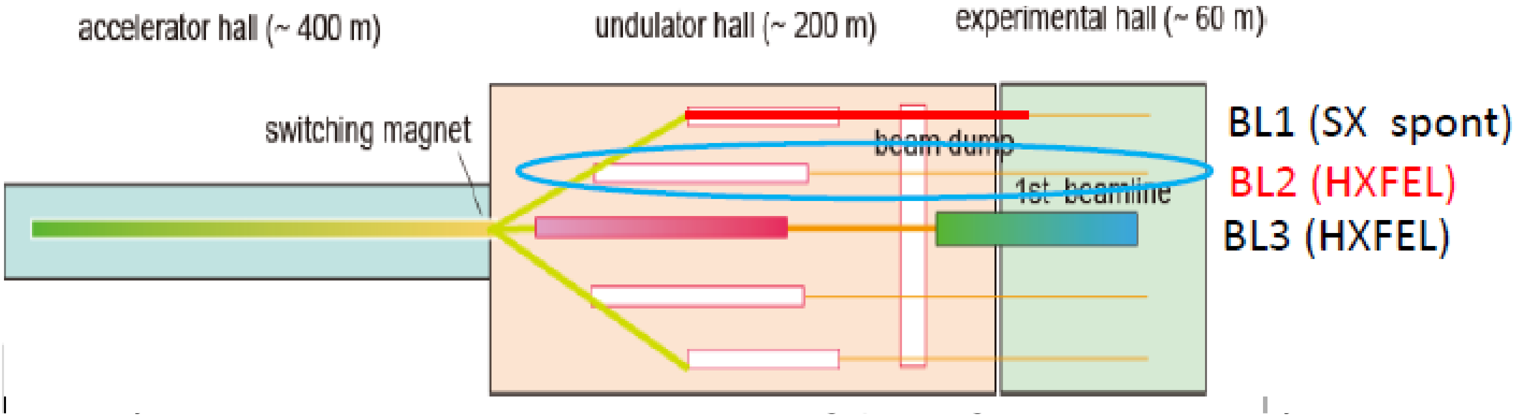
Photon-photon scattering

New Beamline: BL2

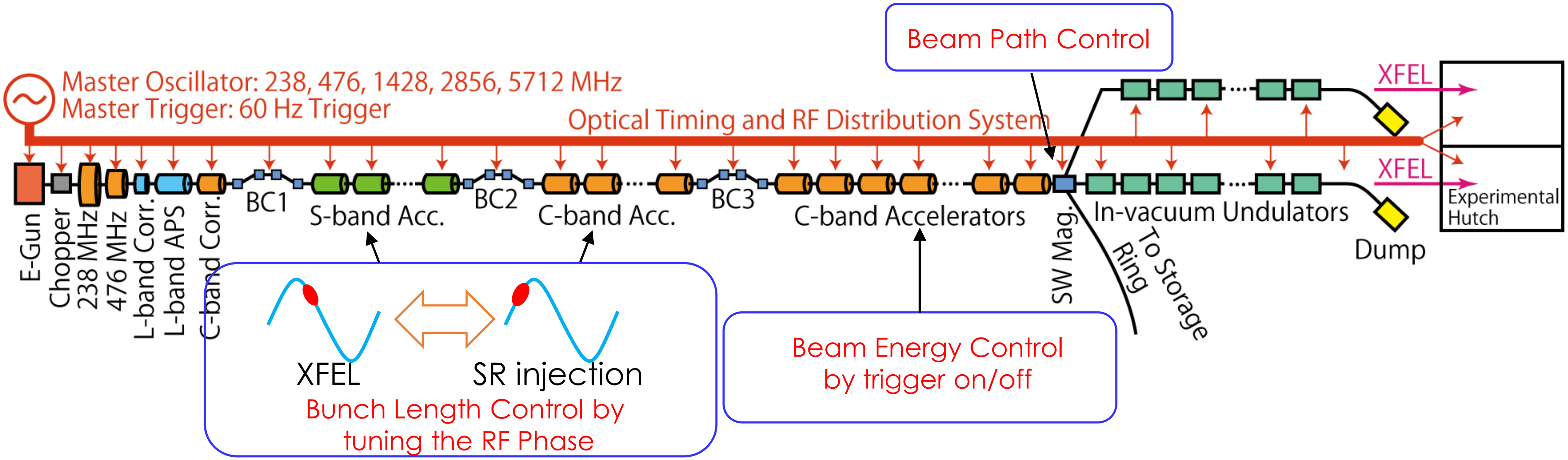
Undulators installed in summer 2014



First lasing on Oct 20th, 2014



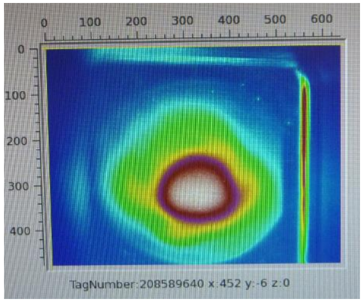
On-Demand Switching of Injection



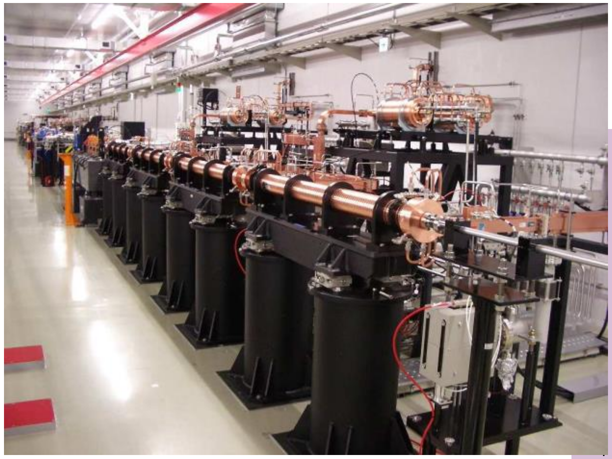
- Short Bunch Length for SACLA, Long Length for SPring-8.
  - RF phase control of the acceleration units upstream of the final beam compressor BC3.
- Beam Energy Control
  - On/Off switching of the RF triggers downstream of BC3.
- Beam Path Control
  - Switching Magnet Control
- CSR suppression at the Dogleg

SCSS+, Relocation and Upgrade (800MeV) of SCSS

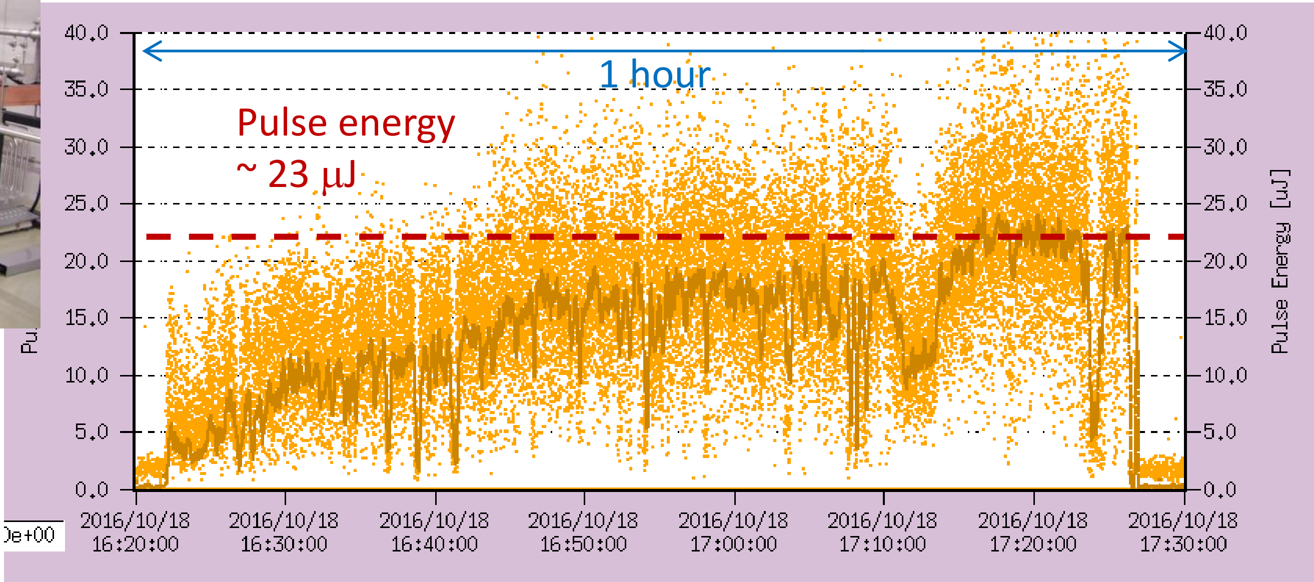
- Two C-band linac units was installed in this summer.
- Last week we started the commissioning with 800 MeV beam energy.
- Photon energy 110 eV (11 nm) (preliminary)
- SASE pulse energy ~ 23 μJ (preliminary)



SASE profile
Smaller divergence



C-band linac
42 MV/m,1.8 m x 4 columns



Inagaki's Talk for details

Tetsuya Ishikawa; 10/24/2016 XFEL Collaboration Meeting @ Pohang Accelerator Laboratory, Korea

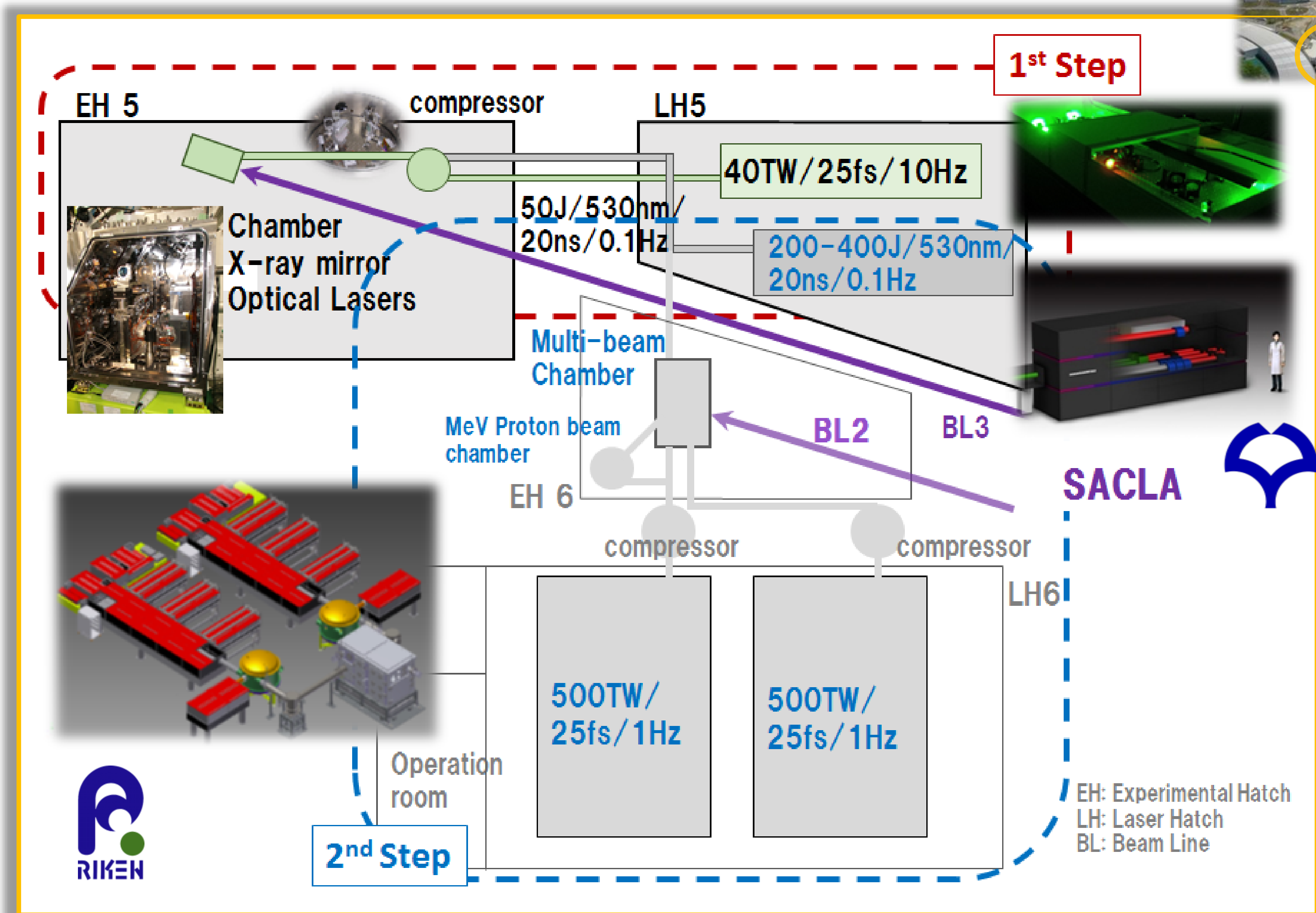
Concluding Remarks

- SACLA Project onset was revisited.
- The unique characteristics of SACLA is colocation and concurrent use with SPring-8.
- Some recent change was introduced.
- Now, SACLA offers 2 XFEL beams and 1 EUV FEL beam simultaneously.
- Detailed discussion on both photon usage and accelerator will be given by our colleagues in this meeting.

H E R M E S Project at SACLA

High Energy density Revolutions of Matter in Extreme States

- 1st Step: 20-50J long pulse(0.1-10Hz) + 40TW short pulse(10Hz)
- 2nd Step: 200-400J long(0.1Hz)+ 500TW short(1Hz)x2bems
- Final step(- 2020-): expectation >kJ long + >10PW



HERMES

Laser Acceleration Platform as a Coordinated Innovative Anchor

LAPLACIAN
Laser Acceleration Platform as a Coordinated Innovative Anchor

Compact XFEL using Multi-Stage Laser-Plasma Accelerator combined with Micro-Undulators

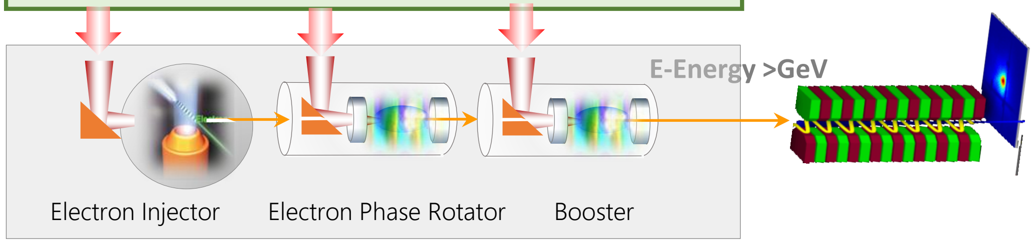
革新的研究開発推進プログラム ImPACT

Project 1B: Laser Acceleration Platform

【subjects】 Multi-Stage Laser Acceleration & X-ray Generation

200TW Multi-Beam
Platform Laser System

Beam Pointing Stability
< 1 μrad (r.m.s)



Acceleration Plasma Module
Beam Monitors
Micro-Undulator
Plasma Device Power Supply

Osaka PhoPs

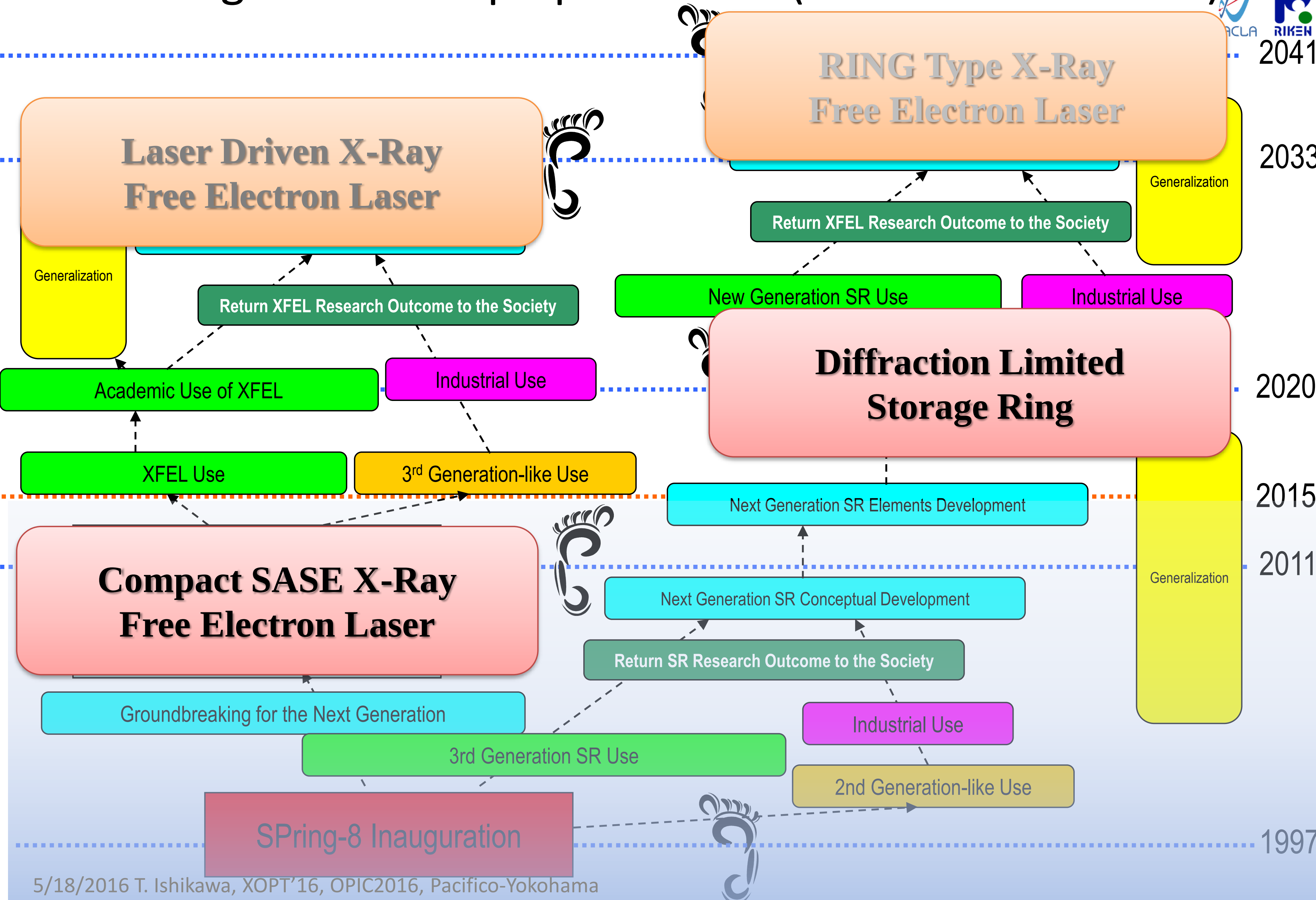
Open Call

KPSI Kansai Photon Science Institute

PF

RIKEN

SPring-8 Road Map up to 2041 (first shown in 2003)



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