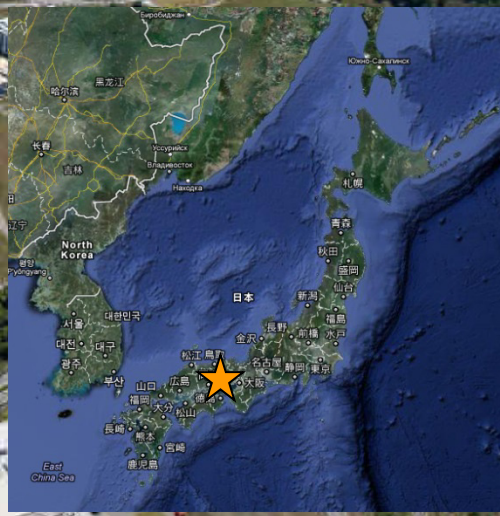
FEL 2015

SPring-8 Angstrom Compact free electron LAser

Status of SACLA

(EUV~SX)



Makina YABASHI

RIKEN SPring-8 Center

on behalf of the SACLA facility

yabashi@spring8.or.jp

August 26, 2015 @Daejeon, Korea

Contents

1. Recent status
   - Machine, beamline, user activities
2. Topic: Two-color XFEL & Ka atomic laser
3. Perspective


SACLA @SPring-8
User Operation: March 2012~
User time: 3600 h/year (FY2014)
Number of users: 678 (FY2013)

2015/2/15 **SACLA Operation Status** 14:13:30

Operation Mode	
BL3 User Operation	
Hutch in Use	
BL3 EH2	4 ~ 15 keV for routine user operation
Pulse Energy	Photon Energy / Wavelength
159.0 micro J/pulse	14.3 keV / 0.086 nm
Repetition Rate	Intensity Fluctuation in 30 shots (STD)
30 Hz	13.3 %

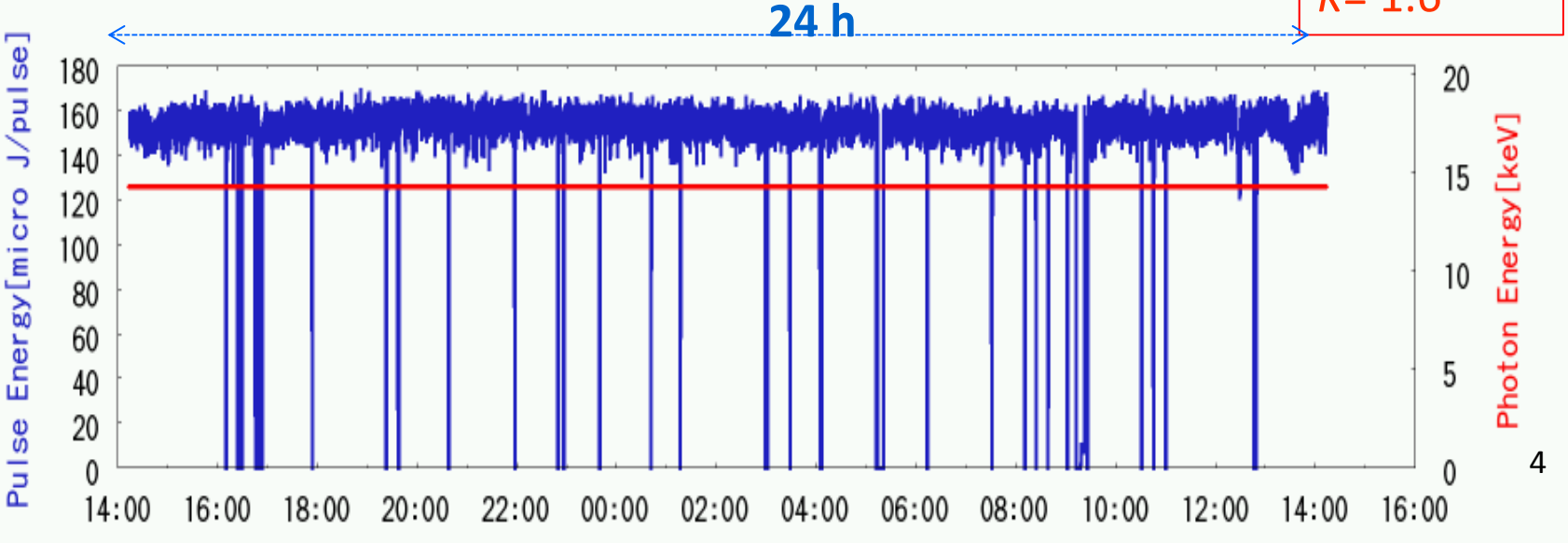
~ 500 uJ @ 10 keV

<10 fs pulse duration

60 Hz test in progress

E_B=8.0 GeV

K= 1.6



2015/2/15 | SACLA Operation Status | 14:13:30

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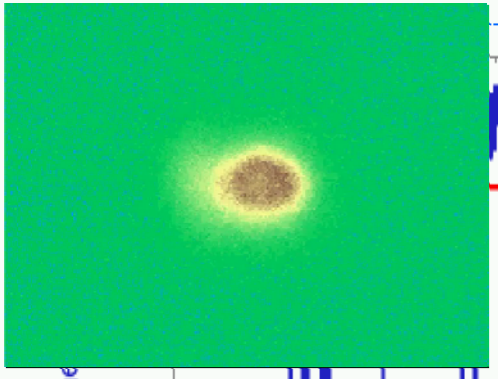
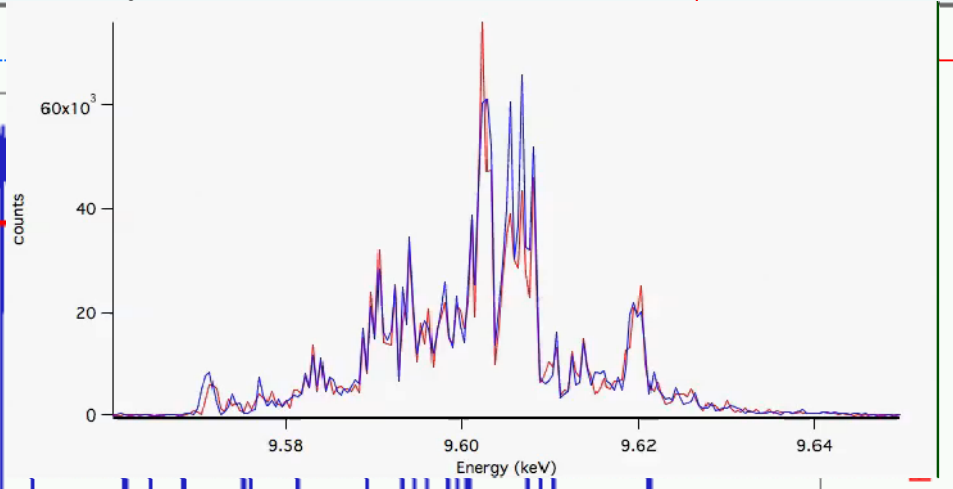
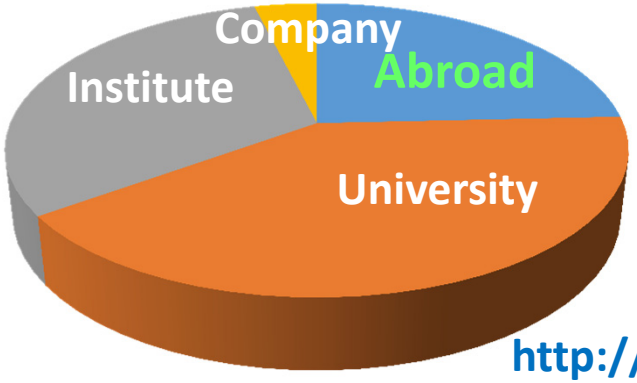




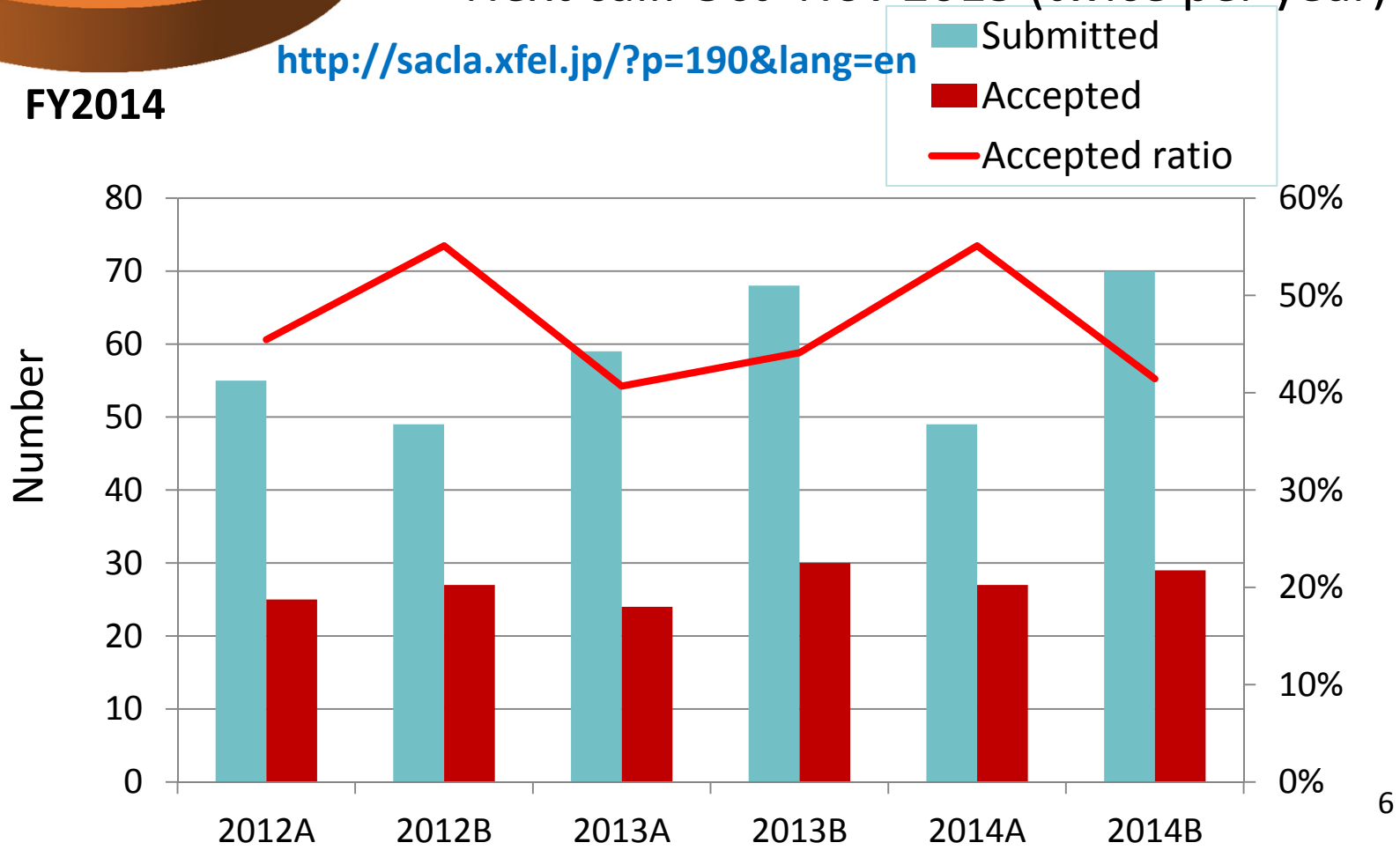
User Proposal Statistics



FY2014

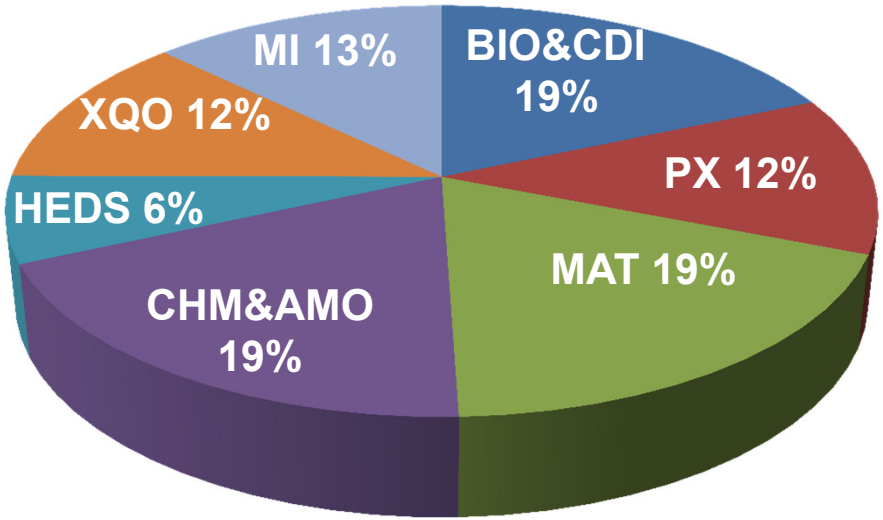
- ~60 proposals accepted per year
- Acceptance ratio: 40~55%
- ~25% from foreign PI
- Next call: Oct~Nov 2015 (twice per year)

http://sacla.xfel.jp/?p=190&lang=en



Research fields at SACLA (FY 2013&2014)

FY 2013



BIO: Imaging biology

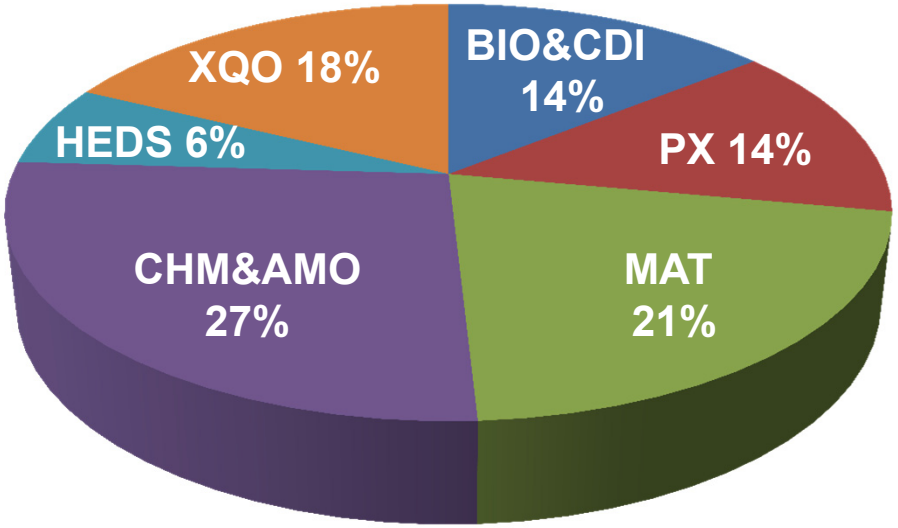
CDI: Coherent diffraction imaging

PX: Protein crystallography

MAT: Ultrafast materials science

CHM: Ultrafast chemistry

FY 2014



AMO: AMO science

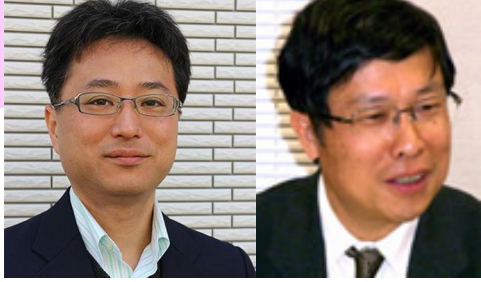
HEDS: High energy density science

XQO: X-ray quantum optics

MI: Methods and instrumentation

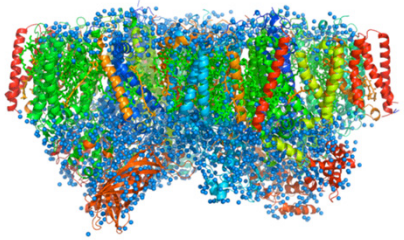
Damage-free protein structural analysis

- Photo-system II (PS II): Protein complex to govern photosynthetic process
- Highly complex and highly radiation sensitive
- Structure determined by SPring-8, though still controversial



Dr. Ago

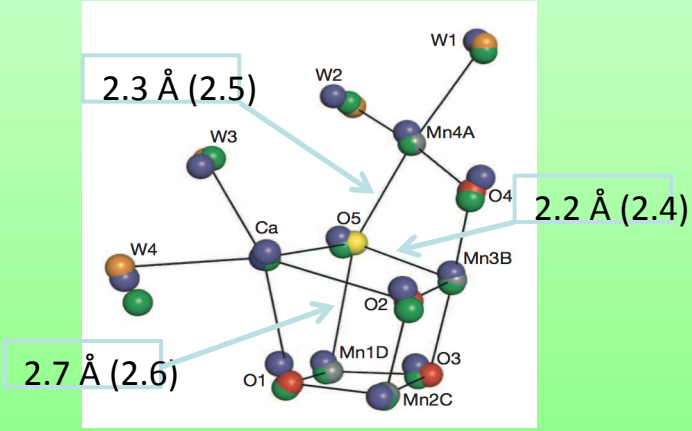
Prof. Shen (Okayama U)

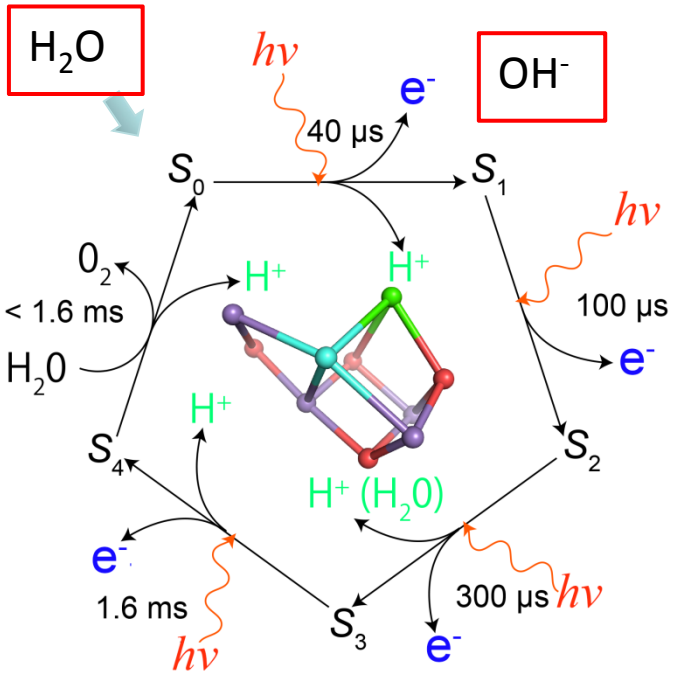


Suga, Shen et al., Nature **517**, 99 (2014)

FRA01
Suga-san

- SACLA: damage-free analysis with fs X-ray pulses
- Structural analysis at 1.95 Å resolution
- Slightly different structure, but almost similar to that analyzed by SP8; “Distorted chair” shape is an intrinsic and essential structure for reaction





Ultrafast chemistry

Prof. Adachi (KEK)

Prof. Ihee (KAIST)

LETTER

doi:10.1038/nature14163

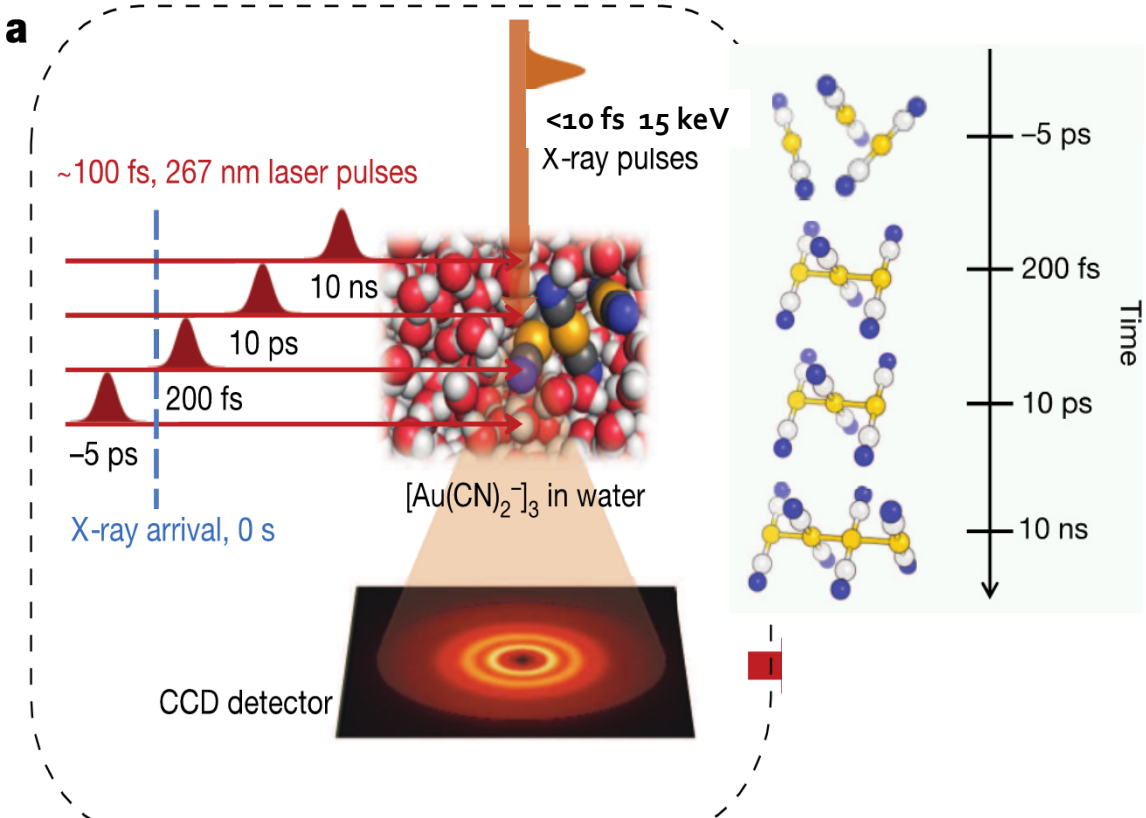
Direct observation of bond formation in solution with femtosecond X-ray scattering

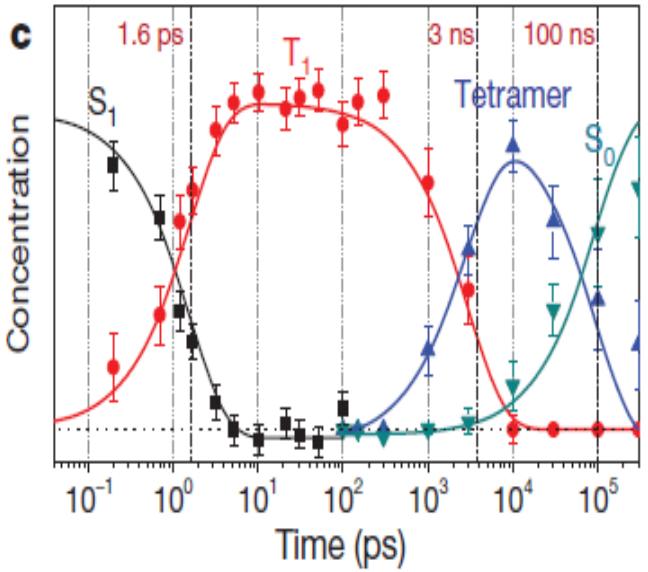
Kyung Hwan Kim[1,2]*, Jong Goo Kim[1,2]*, Shunsuke Nozawa[3]*, Tokushi Sato[3]†*, Key Young Oang[1,2], Tae Wu Kim[1,2], Hosung Ki[1,2], Junbeom Jo[1,2], Sungjun Park[1,2], Changyong Song[4], Takahiro Sato[4]†, Kanade Ogawa[4]†, Tadashi Togashi[5], Kensuke Tono[5], Makina Yabashi[4], Tetsuya Ishikawa[4], Joonghan Kim[6], Ryong Ryoo[1,2], Jeongho Kim[7], Hyotcherl Ihee[1,2] & Shin-ichi Adachi[3,8]

- **Pump-probe WAXS measurement with UV laser excitation**
- **Bond formation process of gold complex in liquid**

K. H. Kim *et al.*, *Nature* **518**, 385 (2015)

FRA02
K.H. Kim-san





New setup for advanced photon diagnostics

Katayama-san (SACLA)

SS spectrometer branch

1D-focus

Main beam

Steering mirror

1D-focus

Main beam

Transmission grating

XFEL

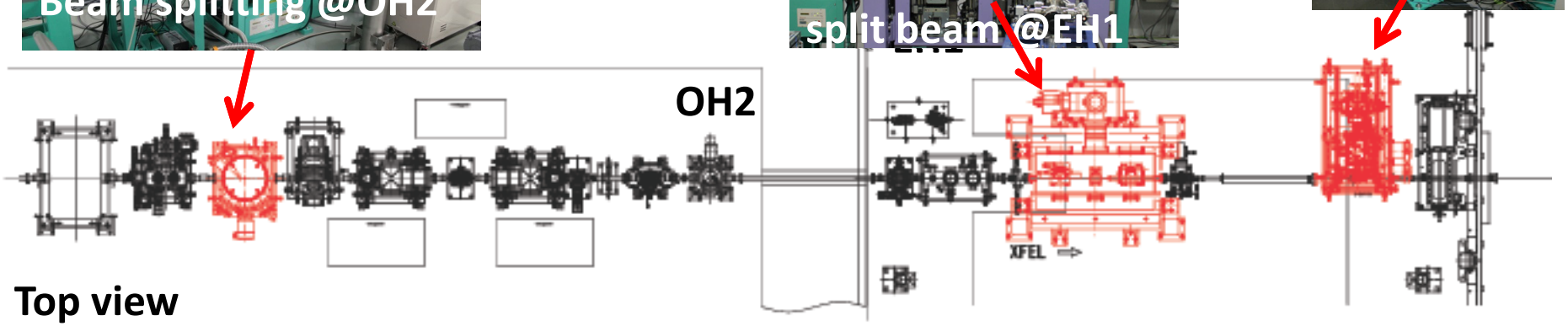
1st

0th

-1st

Ch. David (PSI)

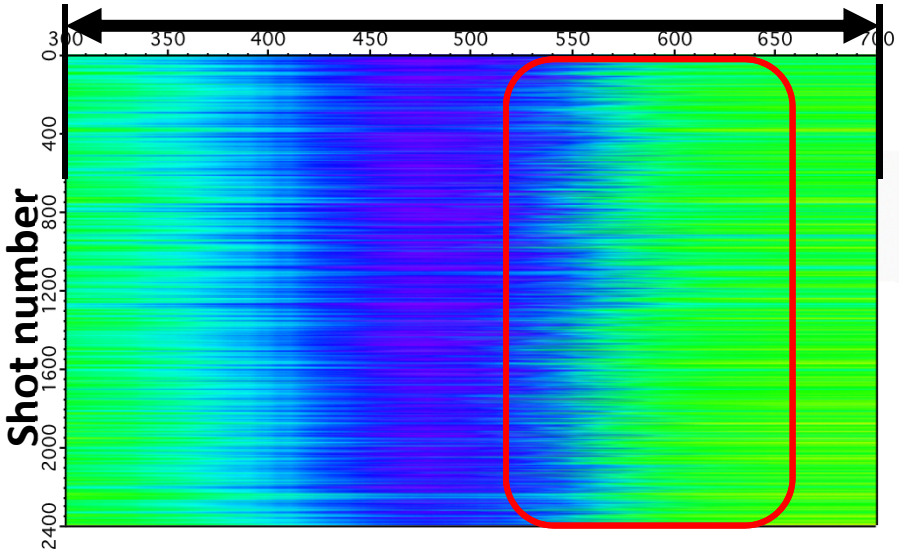
Arrival timing branch



Top view

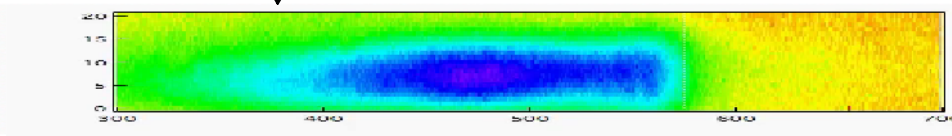
Time to space mapping

400 um ≒ 1.0 ps



Single shot image

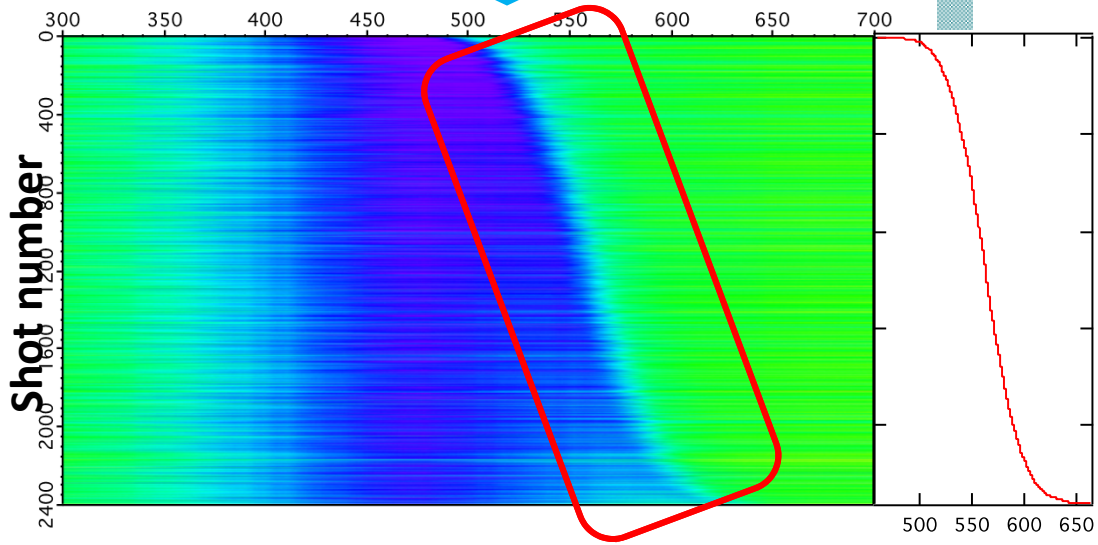
Sample : GIG(11um)/GGG

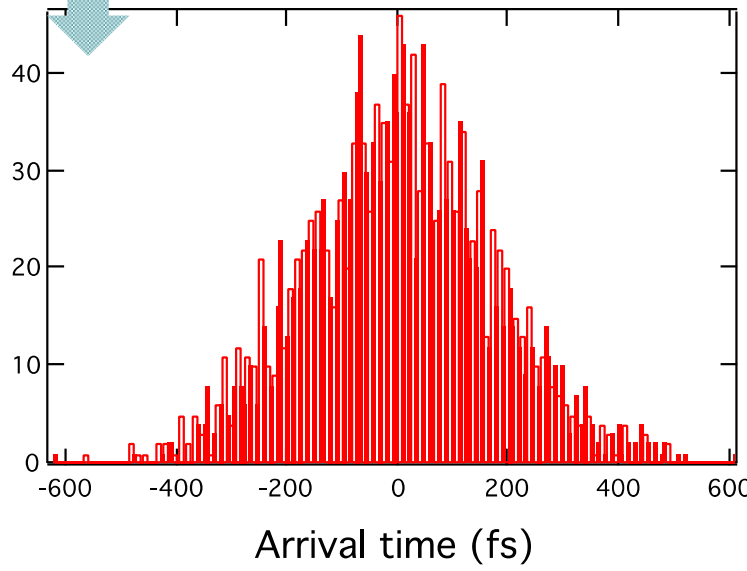


1D focus of XFEL beam (~10 um)
to increase excitation efficiency

Pulse energy to be used:
~7 μJ @ 10 keV

Sorting





Timing jitter: 168 fs (rms)

Instrumental function: ~5 fs

Major scientific Achievement (2013~)

Quantum X-ray optics & AMO

- Fukuzawa et al., PRL (2013). Multi-photon ionization of Xe
- Tamasaku et al., PRL (2013). Generation of double-core hole of Kr
- Tamasaku et al., Nature Photon (2014). Two photon absorption of Ge
- Inada et al., Phys. Lett. B (2014). Photon-photon scattering
- Shwartz et al., PRL (2014). X-ray second harmonic generation
- Yoneda et al., Nature Commun. (2014). Saturable absorption of Fe
- Juranic et al., OE (2014). THz streaking

Ultrafast chemistry

- Katayama et al., APL (2013). New D-XAS method
- Obara et al., OE (2014). TR-D-XAS
- Kim et al., Nature (2015). Femto-WAXS for observation of bond-making of Au

Femtosecond crystallography

- Sugahara et al., Nature Methods (2014). New grease-based injector for SFX
- Hirata et al., Nature Methods (2014). Damage-free crystallography
- Suga et al., Nature (2015). Structural determination of PS-II S_1

CDI/PCS

- Takahashi et al., Nano Letters (2013). Analysis of nanoparticles
- Jones et al., Nature Commun. (2014). Structural analysis of u-RNA sponges
- Kimura et al., Nature Commun. (2014). Imaging of live cells
- Xu et al., Nature Commun. (2014). CDI with highly symmetric nanoparticles
- Lehmkühler et al., Sci. Rep. (2014). Evaluation of transverse coherence

Ultrafast Materials Science

- Newton et al, Nano Letters (2014). Structural change of nano structures

http://xfel.riken.jp/research/indexnn.html

Major Technological Achievement from SACLA Facility

http://xfel.riken.jp/research/indexnn.html

Light source

- Ishikawa et al., *Nature Photon.* (2012). Lasing & Performance of Compact XFEL SACLA
- Tanaka et al., *Phys. Rev. ST AB* (2012). X-ray based alignment
- Hara et al., *Phys. Rev. ST AB* (2013). Pulse-to-pulse multienergy acceleration
- Hara et al., *Nature Commun.* (2013). Generation of two-color XFEL
- Tanaka et al., *PRL* (2014). Zeptosecond generation

X-ray beamline & optics

- Inubushi et al., *PRL* (2012). Pulse duration measurement with X-ray HR spectrometry
- Tono et al., *New J. Phys.* (2013). SACLA beamline
- Suzuki et al., *JSR* (2014). Application of phase retarder to control polarization of XFEL
- Koyama et al., *OE* (2013). Damage for XFEL optics
- Yumoto et al., *Nature Photon.* (2013). Application of KB optics to XFEL
- Osaka et al., *OE* (2013). Thin-Si-crystal development
- Mimura et al., *Nature Commun.* (2014). Highest intensity of X-rays with 50-nm focusing

X-ray diagnostics

- Kato et al., *APL* (2012). Absolute intensity measurement (with DESY/PTB/AIST)
- Kayser et al., *OE* (2014). Wavefront measurement (with PSI)
- Kameshima et al., *RSI* (2014). MPCCD development
- Sato et al. APEX (2014). Arrival timing measurement

Quantum X-ray optics

- Tamasaku et al., *PRL* (2013). Generation of double-core hole for Kr
- Tamasaku et al., *Nature Photon.* (2014). Two photon absorption of Ge

Femtosecond X-ray spectroscopy

- Katayama et al., *APL* (2013). New FXAS scheme
- Obara et al., *OE* (2014). Demonstration of TR-FXAS

CDI

- Song et al., *JAP* (2013). MAXIC, platform for CDI
- Jones et al. *Nature Commun.* (2014).

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2. Topic: Two-color XFEL & Ka atomic laser
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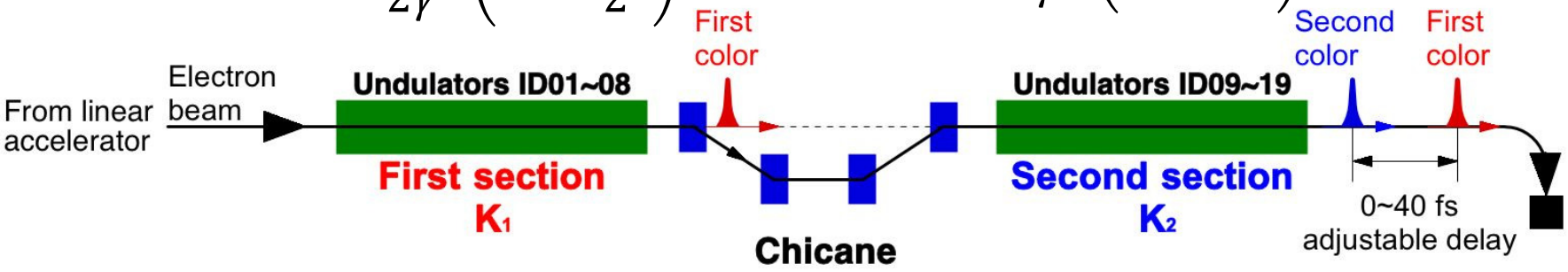
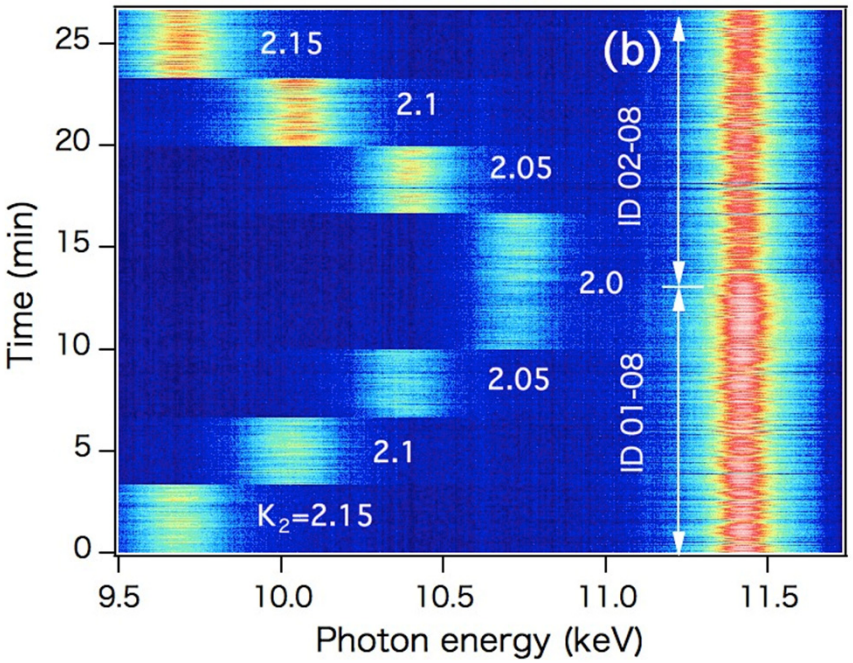
Two-color operation with variable-gap undulators

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





- 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

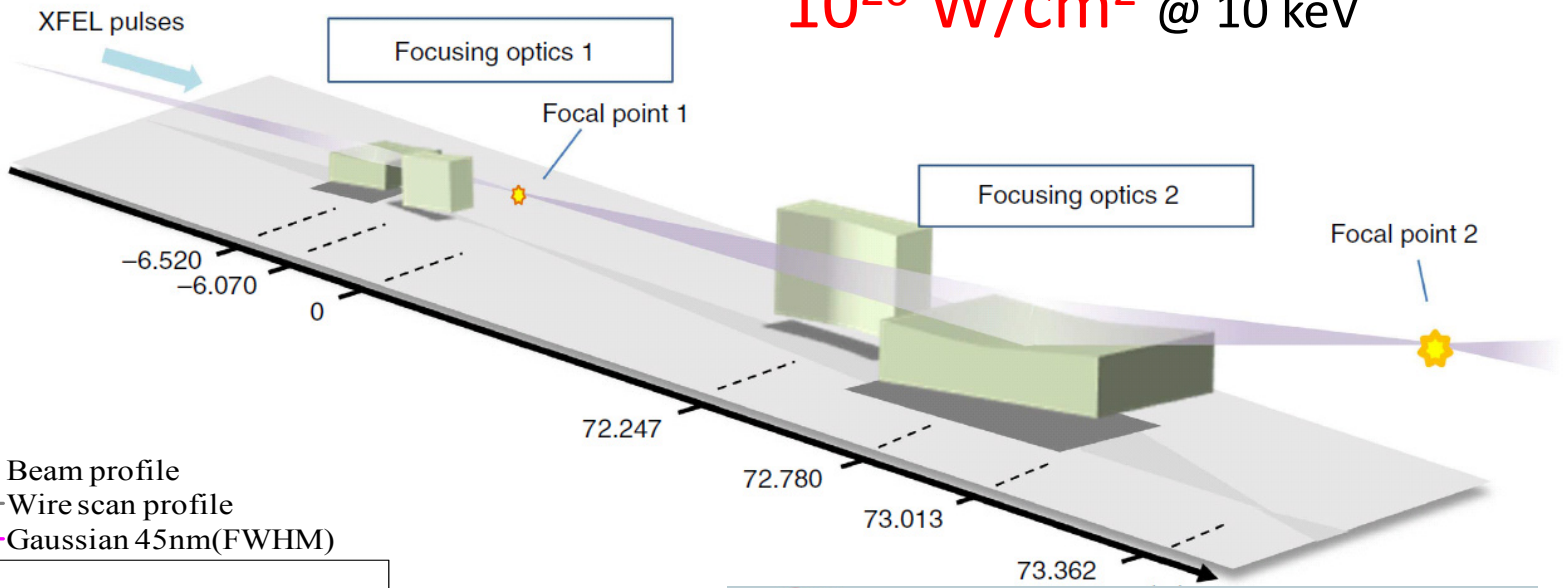
Two-colour hard X-ray free-electron laser with wide tunability

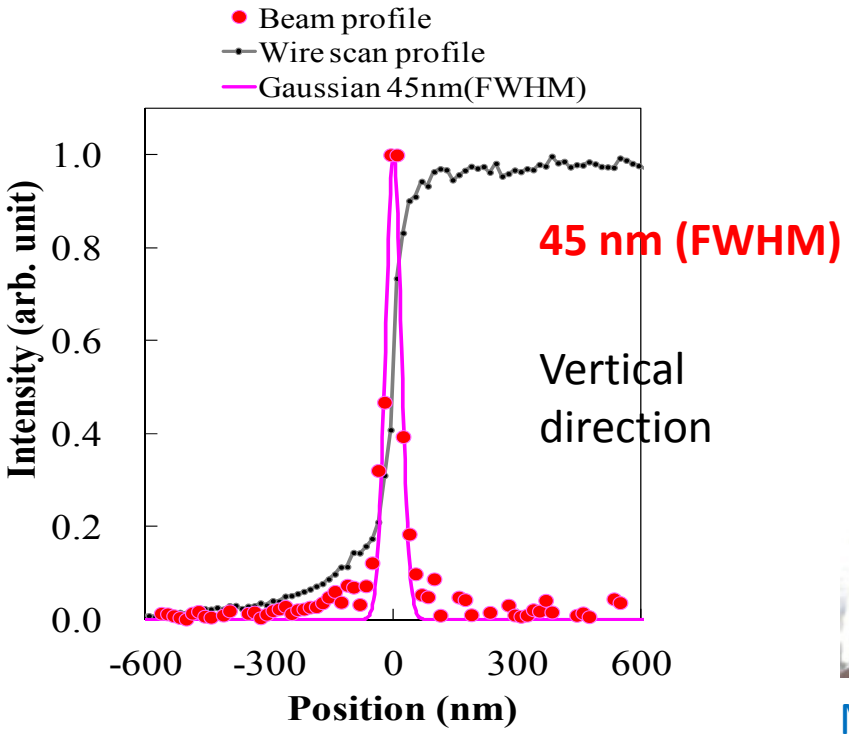
Toru Hara[1], Yuichi Inubushi[1], Tetsuo Katayama[2], Takahiro Sato[1,†], Hitoshi Tanaka[1], Takashi Tanaka[1], Tadashi Togashi[2], Kazuaki Togawa[1], Kensuke Tono[2], Makina Yabashi[1] & Tetsuya Ishikawa[1]

Hara et al, Nature Commun 2014

Two-stage focusing system

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





45 nm (FWHM)

Vertical direction

nature COMMUNICATIONS

ARTICLE

Received 17 Sep 2013 | Accepted 4 Mar 2014 | Published 30 Apr 2014 DOI: 10.1038/ncomms4539

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

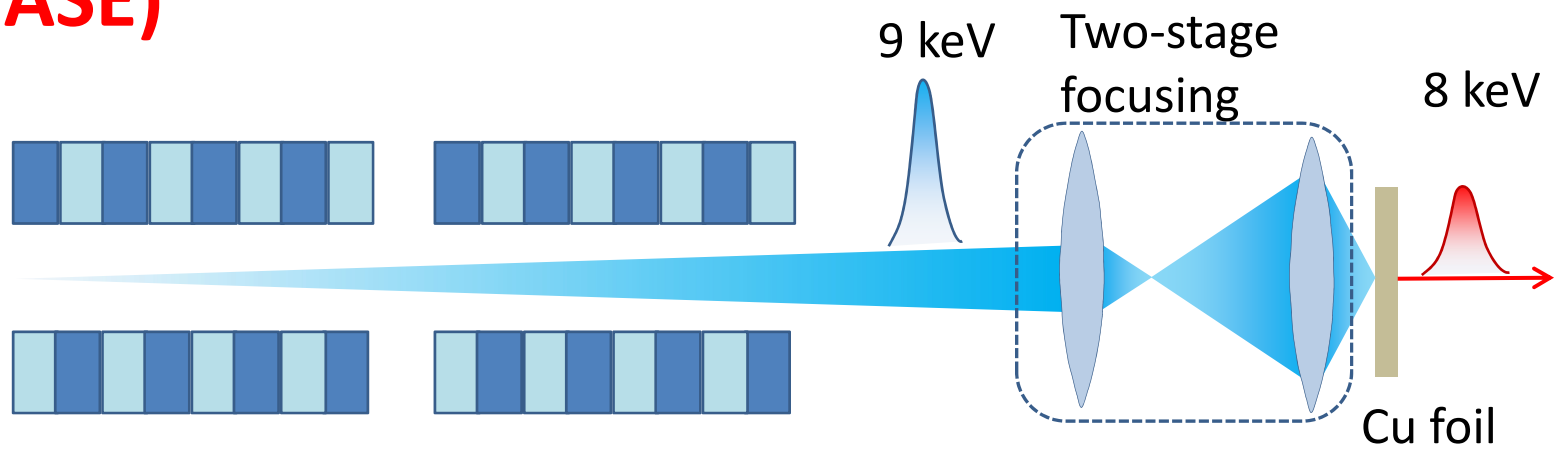
Hidekazu Mimura[1,*], Hirokatsu Yumoto[2,*], Satoshi Matsuyama[3,*], Takahisa Koyama[2], Kensuke Tono[2], Yuichi Inubushi[4], Tadashi Togashi[2], Takahiro Sato[4], Jangwoo Kim[3], Ryosuke Fukui[3], Yasuhisa Sano[3], Makina Yabashi[4], Haruhiko Ohashi[2,4], Tetsuya Ishikawa[4] & Kazuto Yamauchi[3]

Mimura et al, Nature Commun 5 3539 **(2014)**



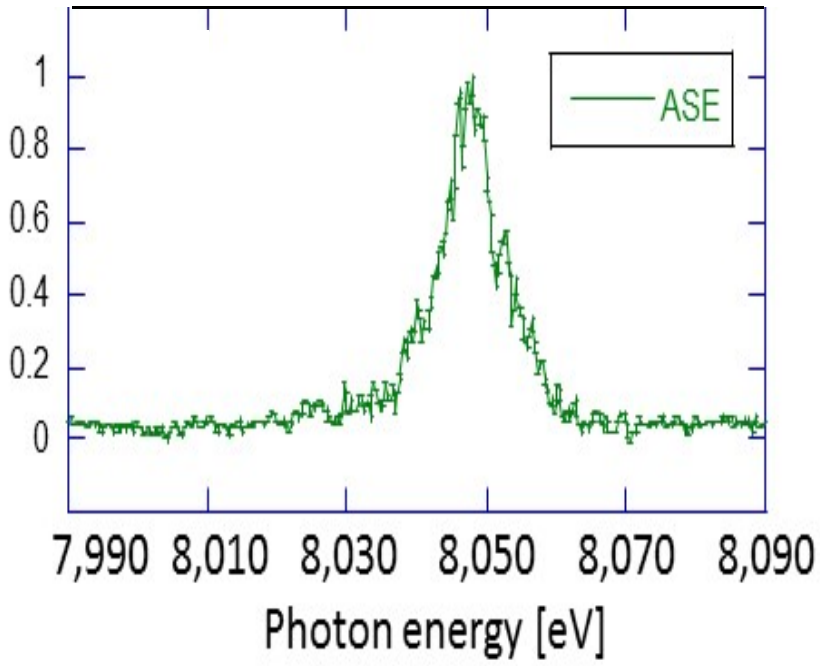

Mimura-san Yamauchi-sensei Ohashi-san Yumoto-san

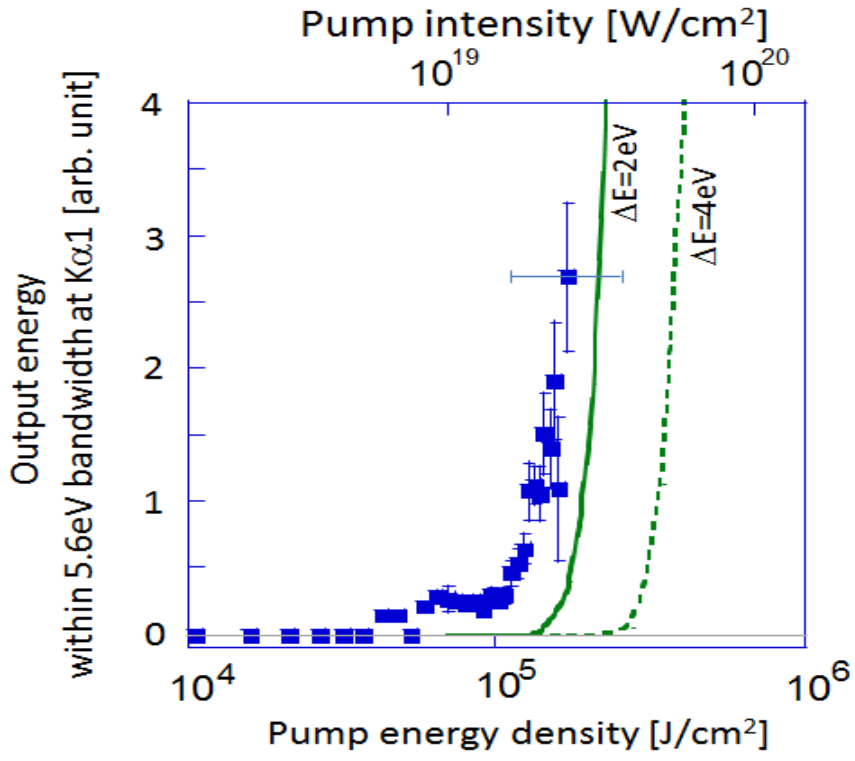
Achievement of Hard X-ray Cu-Ka atomic laser (ASE)



Yoneda, Inubushi *et al.*

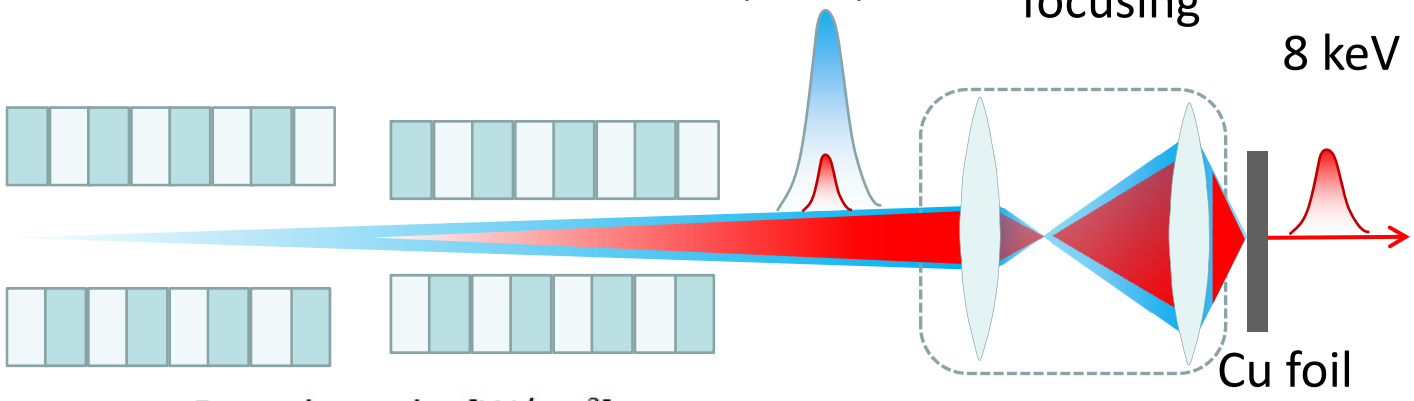
cf. Rohringer et al., Ne-Ka laser @849 eV

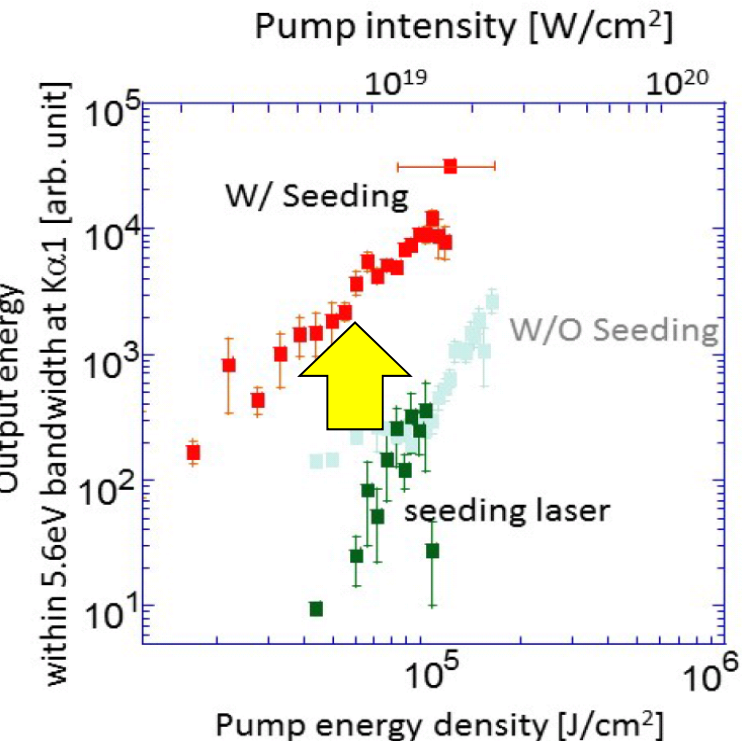


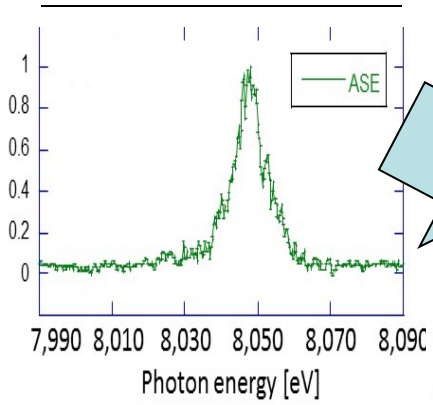


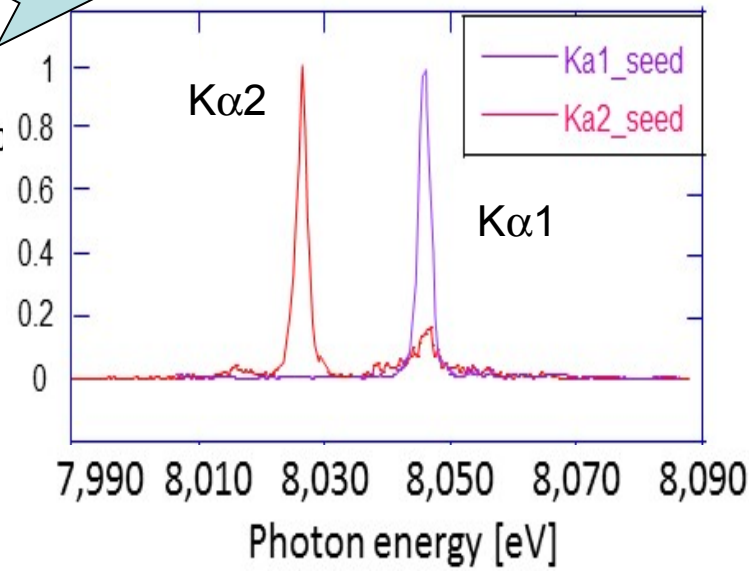
Achievement of Hard X-ray Cu-Ka atomic laser (seeding)

Yoneda *et al.*,
Nature in press









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Major Upgrades of SACLA

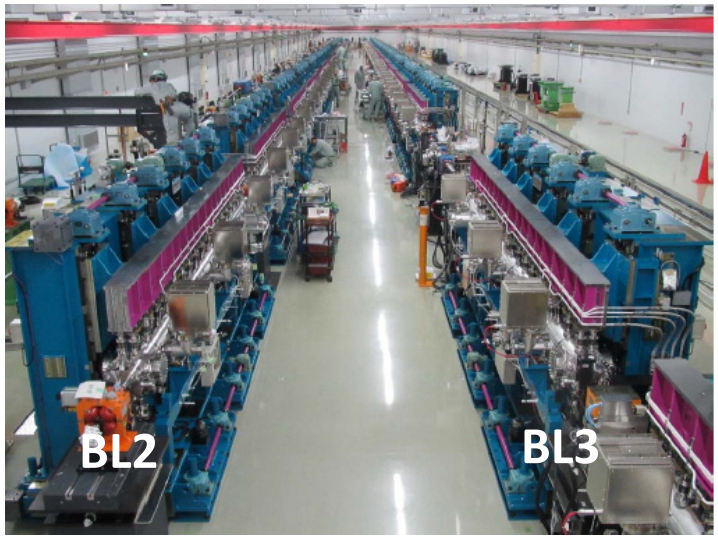
- Improvement of “quality”
  - Self-seeding with diamond crystal
  - High-power Lasers (40 TW, 500 TW x2) at SACLA

    HERMES Project led by Prof. R. Kodama (Osaka Univ.)
- Increase of “capacity”
  - Relocation of SCSS (SCSS+) for independent SX FEL source. Start commissioning in September
  - New XFEL beamline (BL2)
- Synergetic development
  - Injection of SACLA e-beam to SPring-8 II
  - Development of laser-wakefield accelerator for ultracompact XFEL@ SCSS tunnel: ImPACT project (the Cabinet office)

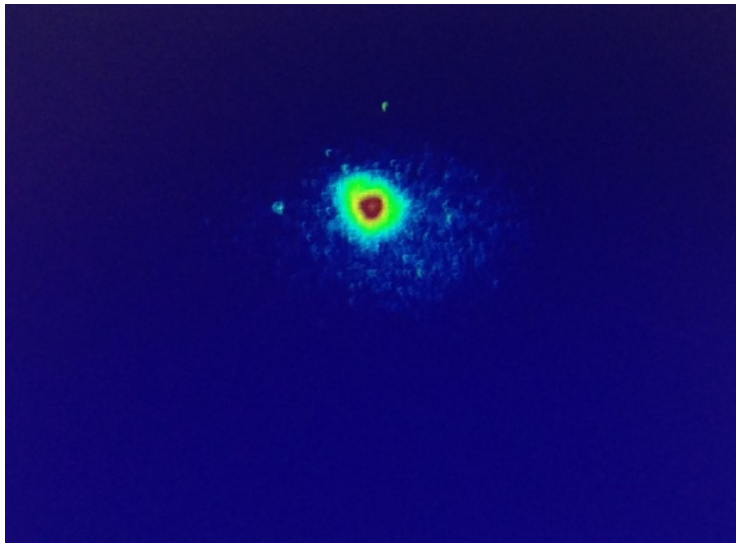
New beamline: BL2

Deficiency of beamtime severely limits research activities with XFEL

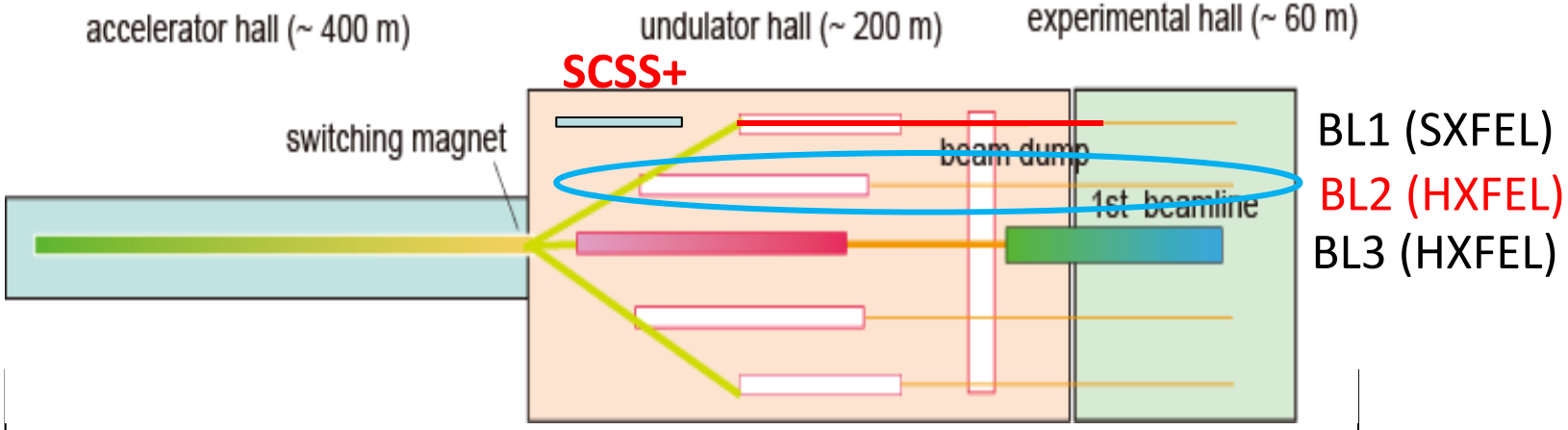
Construction of 2nd hard X-ray FEL beamline for increasing capacity



Undulators installed in summer 2014



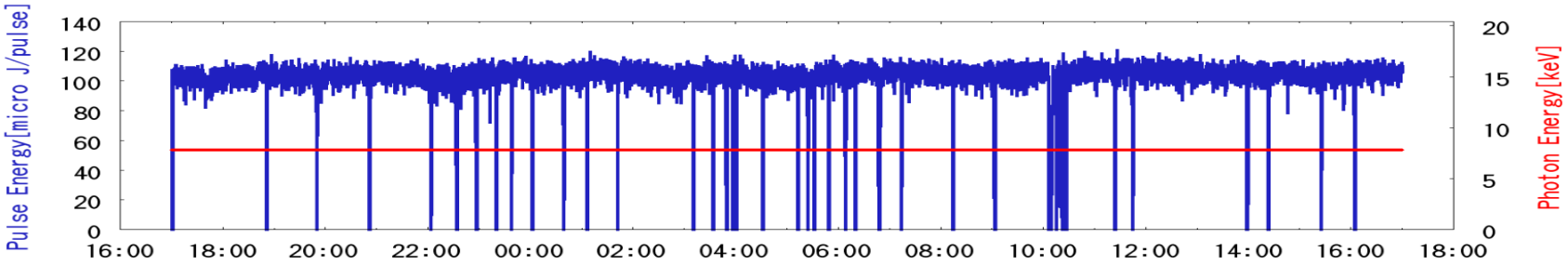
First lasing on Oct 20th, 2014

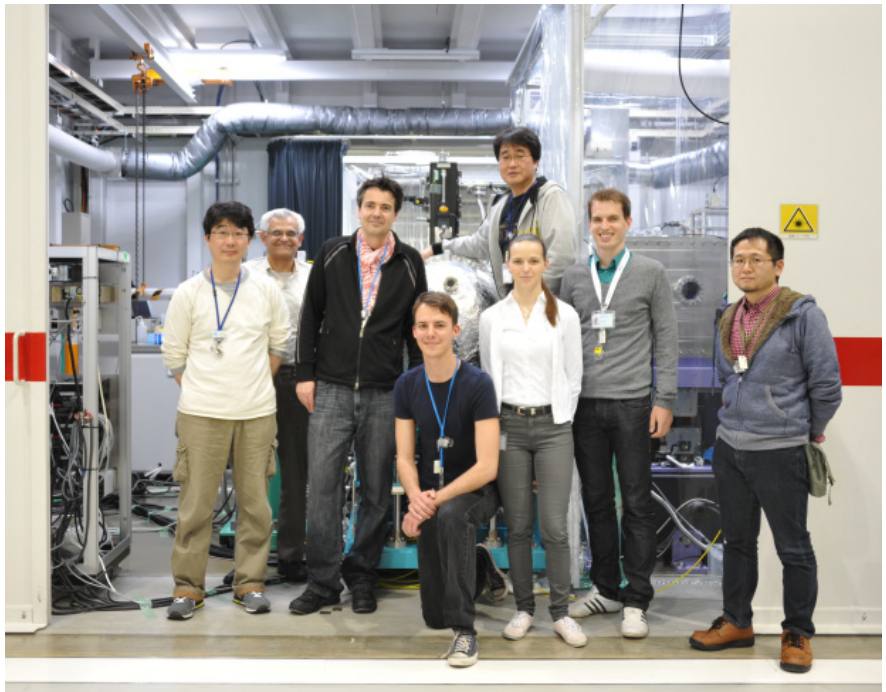


First user operation started on April, 2015

2015/4/19	SACLA Operation Status	17:00:10

Operation Mode	
BL2 User Operation	
Hutch in Use	
BL2 EH3,4b	
Pulse Energy	Photon Energy / Wavelength
110.1 micro J/pulse	7.8 keV / 0.158 nm
Repetition Rate	Intensity Fluctuation in 30 shots (STD)
30 Hz	11.3 %

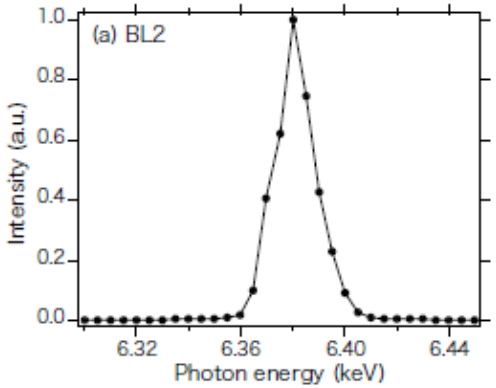




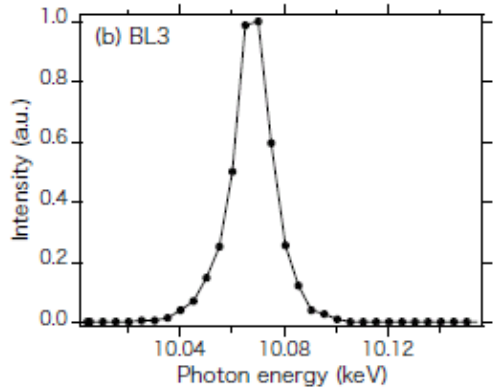
Hara-san (TUA03)

Multi-beamline operation

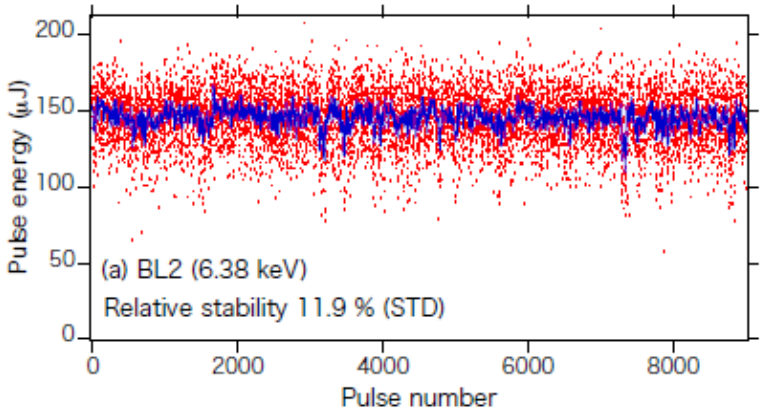
Electron beam energy 7.8 GeV, peak current 1.2 kA, repetition 30 Hz

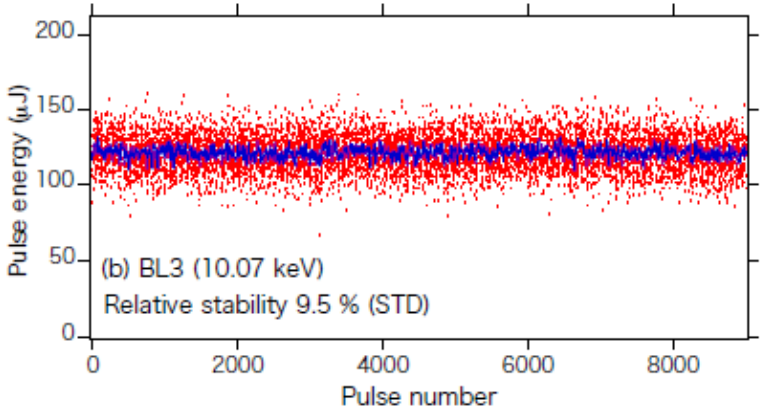


BL2
7.8 GeV
6.38 keV
15 Hz
K=2.85



BL3
7.8 GeV
10.07 keV
15 Hz
K=2.1





Summary & Outlook

- SACLA operated for users over 3 years; mostly reliable and stable operation
- Visible experimental achievements; special operation modes of SACLA, e.g., two-color, tight focusing, etc., produce unique result
- Successful test of pulse-to-pulse switching for multiple beamlines (BL2 & BL3); continue improvements towards high-current operation

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Thank you for your attention