ANAR2017: Advanced and Novel Accelerators for High Energy Physics Roadmap Workshop 2017

Review of Advanced Accelerator Development in Japan

Kansai Photon Science Institute (KPSI)
National Institutes for Quantum and Radiological Science and Technology (QST)

Masaki KANDO

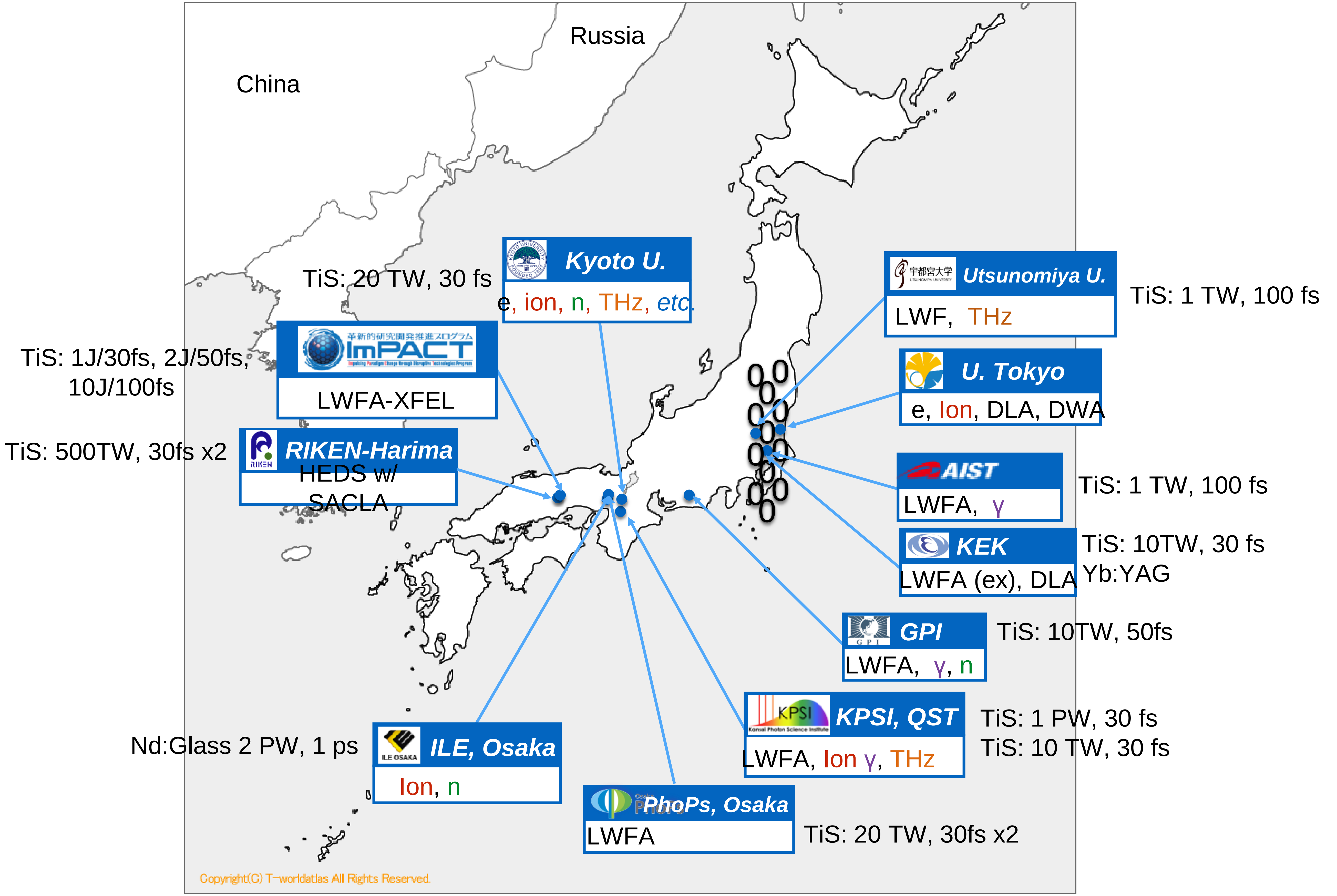
on behalf of the laser acceleration researchers in Japan

2017-04-27 14:00-14:30 CERN

Contents

- Working teams in Japan
- Ongoing large-scale-fund : ImPACT
- Summary

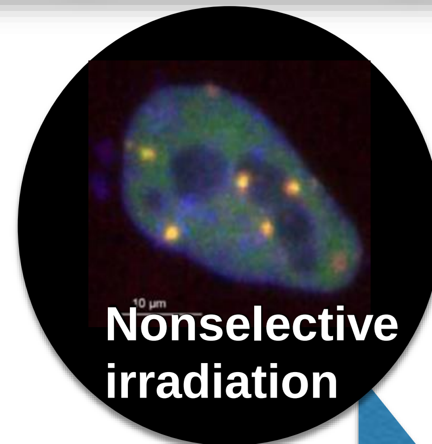
Laser-Acceleration facilities in Japan



Status report of each facilities in Japan

Dielectric accelerator for radiobiology research
at University of Tokyo & KEK

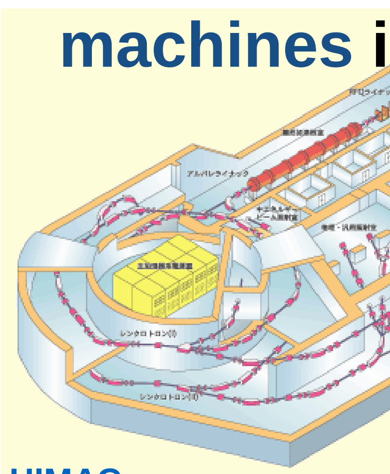
Present problem to conduct basic studies of radiobiology and radical chemistry is less machine-time allocation.
Micro-beams are delivered by big machines in the present situation.



A tabletop micro-beam machine makes it possible to irradiate a target site in a living cell.

Single proton, ion or 100 electrons
A few MeV energy

K.Koyama, et al., J. Phys. B: At. Mol. Opt. Phys, 47, 234005 (2014) .



A glass capillary is adopted to achieve the selective irradiation.

However, scraping off a major part of the beam to produce the micro-beam.

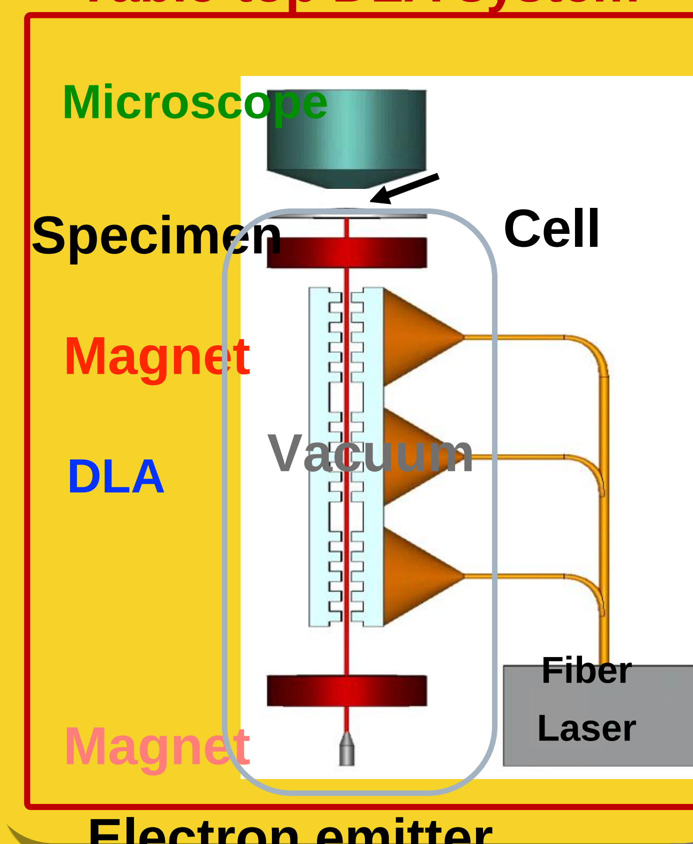
M. Uesaka, et al., Rev. Accel. Sci. and Tech., 9, 235 (2016) .

Producing the micro-beam with a sub-micron channel of the accelerator

Dielectric Laser Accelerator (DLA) for electrons
The evanescent field around the grating surface accelerates electrons.

Dielectric Wall Accelerator (DWA) for ions
High-voltage short pulses applied across a series of dipole electrodes accelerate ions.

Table-top DLA system

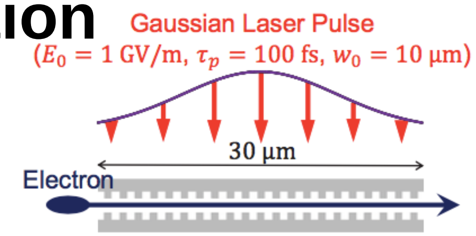


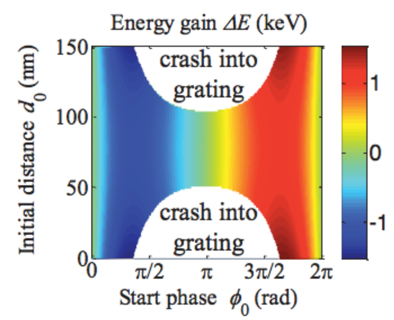
Present / Future of Dielectric Accelerator Research at KEK & U.T.

DLA

Z. Chen, et al., Rev. Laser Eng., 48, 97 (2017) .

- Simulation for non-relativistic electrons
  Field and Motion

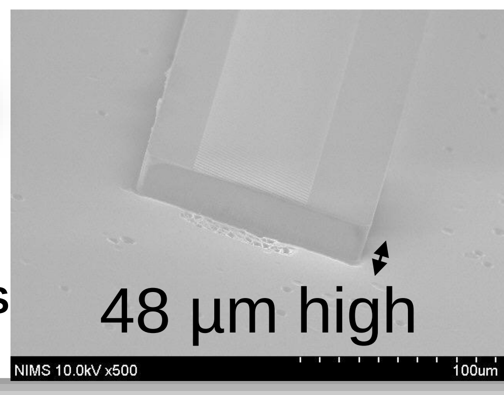


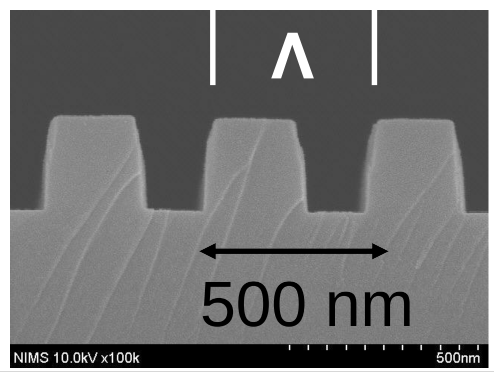


- Fabrication of sub-micron gratings
  to accelerate 50-keV electrons

$$v/c = \Lambda/\lambda_L$$

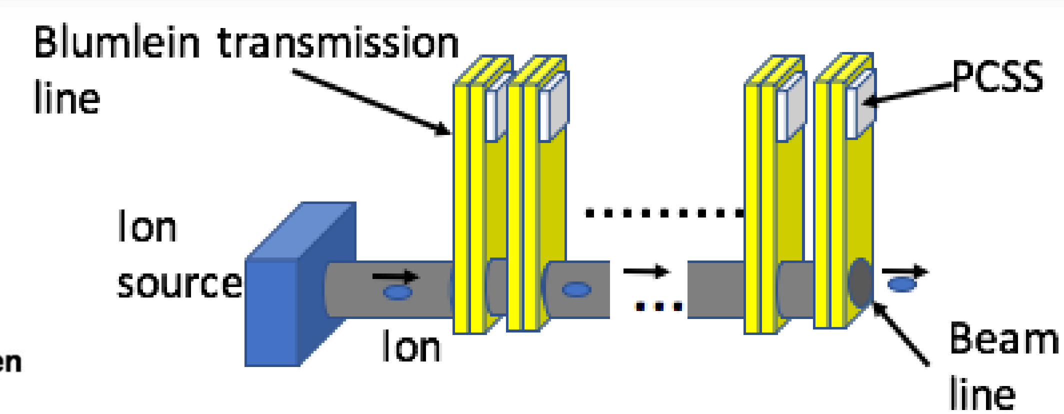
Fabricated at the NIMS nonfab-platform.





DWA

- Photoconductive switch (GaAS)
  - Experiments;
    - breakdown voltage; >10 kV
    - Switching time vs. laser fluence (on going)
- Short pulse generation
  - Designing & test of the transmission line



Schematic drawing of the DWA

Ion will be delivered by the laser produced plasma.

In 3 - 5 years, Acceleration experiments

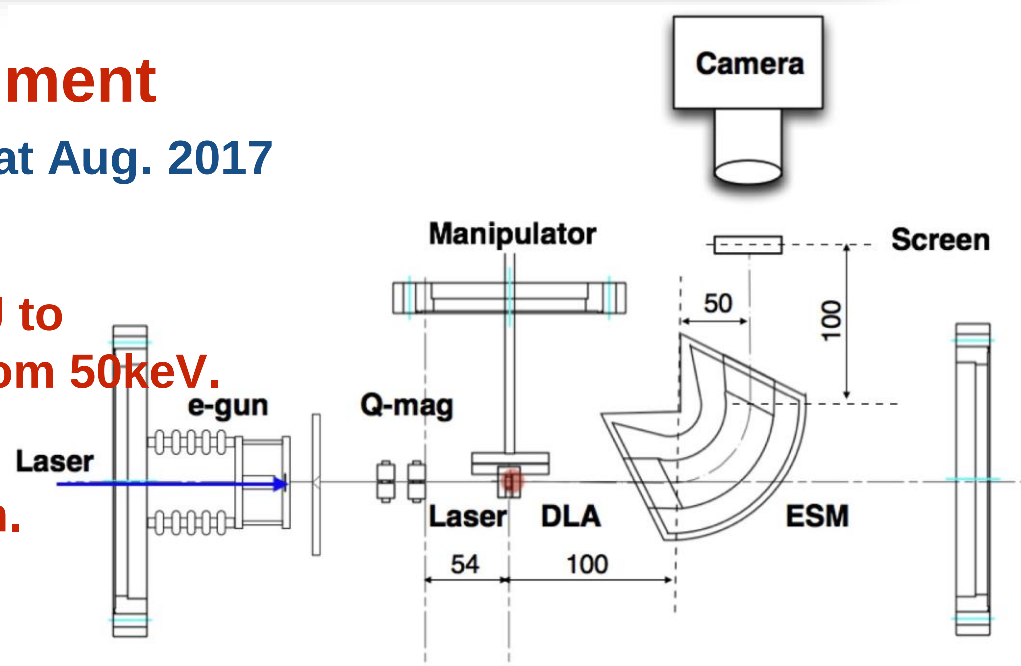
Acceleration Experiment

Begin at Aug. 2017

In 3 - 5 years,

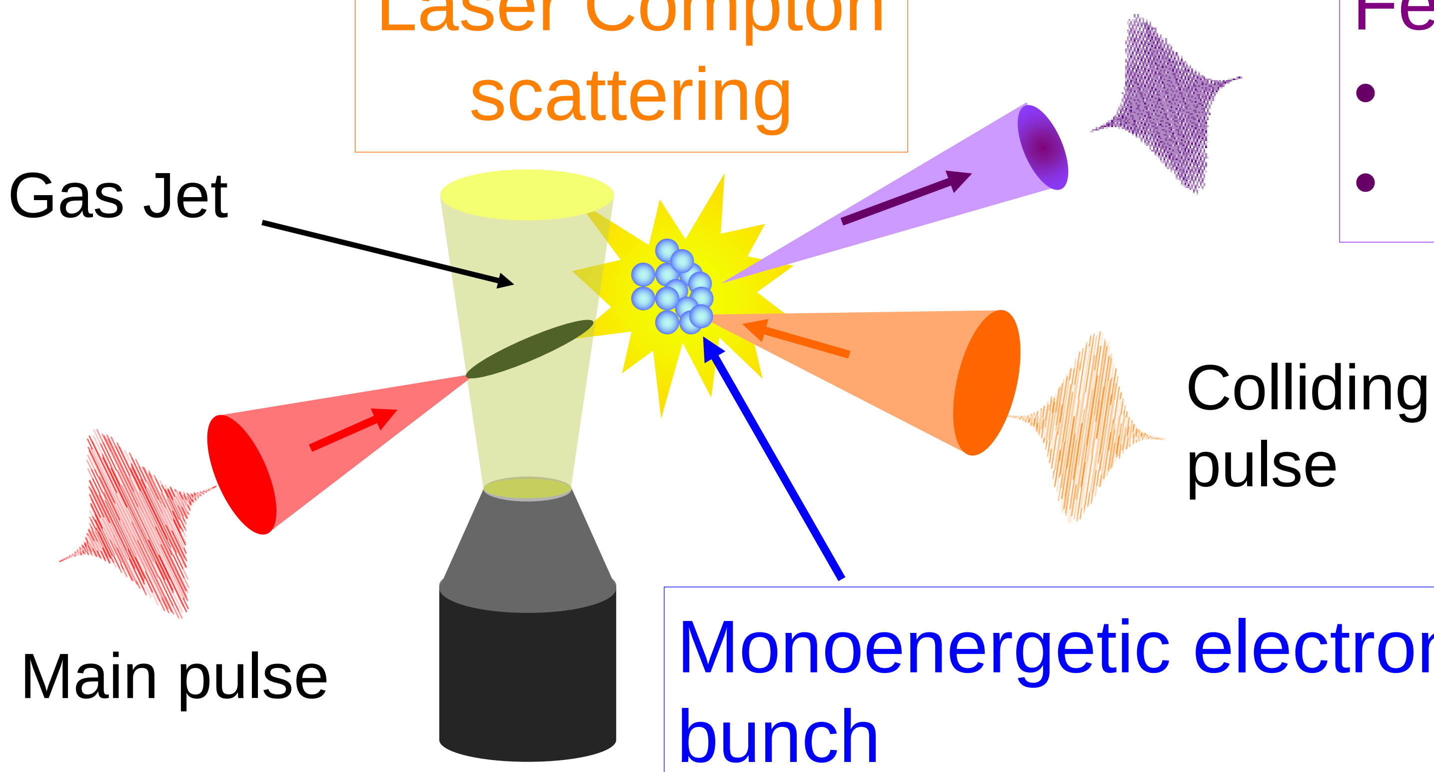
Total laser energy 88mJ to
Obtain 1MeV electron from 50keV.

240 laser pulses in 6 mm.



X-ray generation by laser Compton scattering using monoenegetic electron bunch

Laser Compton scattering

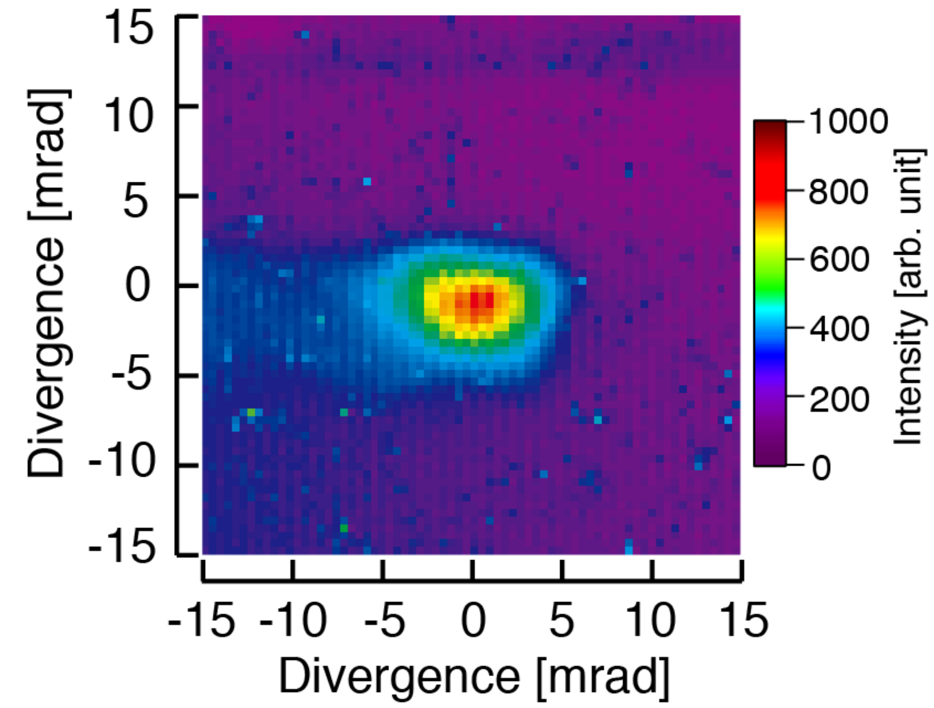


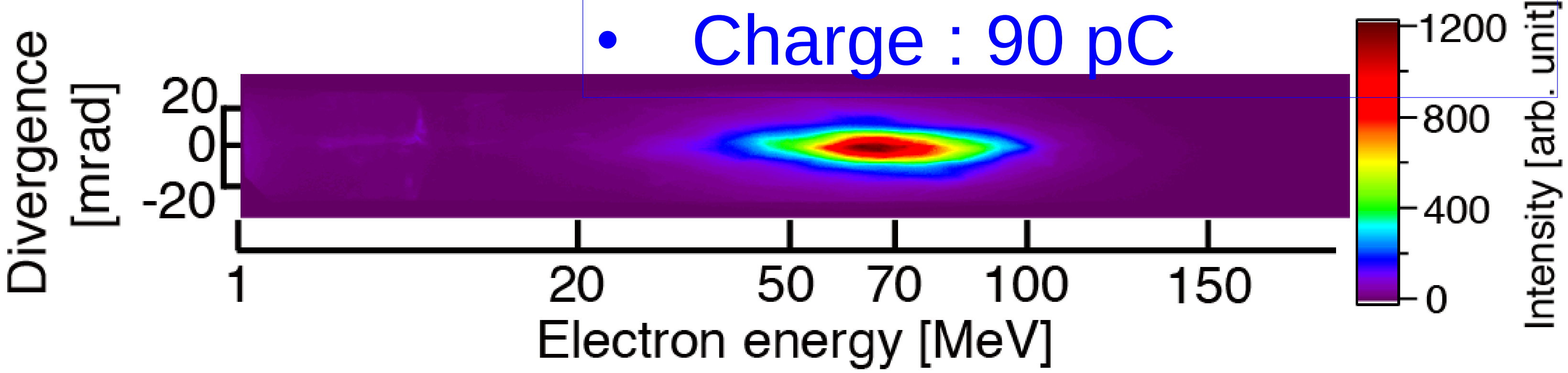
Femotosecond X-ray pulse

- Energy: 60 keV
- X-ray yield : $2x10^7$ /pulse

Monoenergetic electron bunch

- Energy : 65 MeV
- Charge : 90 pC





[Ref.] E. Miura et al.,
Appl. Phys. Express **7**, 1046701 (2014).

Next step : Demonstration of MeV X-ray generation

- Generation of higher energy (> 200 MeV) monoenergetic electron bunch
- Using second harmonic light (400 nm) as a colliding pulse

Ultra-intense laser-produced sub-ps X-ray pulses can detect backscattered signals from objects hidden in aluminium containers

JOURNAL OF APPLIED PHYSICS **114**, 083103 (2013)

Standoff detection of hidden objects using backscattered ultra-intense laser-produced x-rays

H. Kuwabara,[1] Y. Mori,[2,a)] and Y. Kitagawa[2]
[1]*IHI Corporation, 1, Shin-Nakahara-cho, Isogo-ku, Yokohama 235-8501, Japan*
[2]*The Graduate School for the Creation of New Photonics Industries, 1955-1 Kurematsucho, Nishiku, Hamamatsu, Shizuoka 431-1202, Japan*

(Received 30 May 2013; accepted 6 August 2013; published online 22 August 2013)

Ultra-intense laser-produced sub-ps X-ray pulses can detect backscattered signals from objects hidden in aluminium containers. Coincident measurements using primary X-rays enable differentiation among acrylic, copper, and lead blocks inside the container. Backscattering reveals the shapes of the objects, while their material composition can be identified from the modification methods of the energy spectra of backscattered X-ray beams. This achievement is an important step toward more effective homeland security.

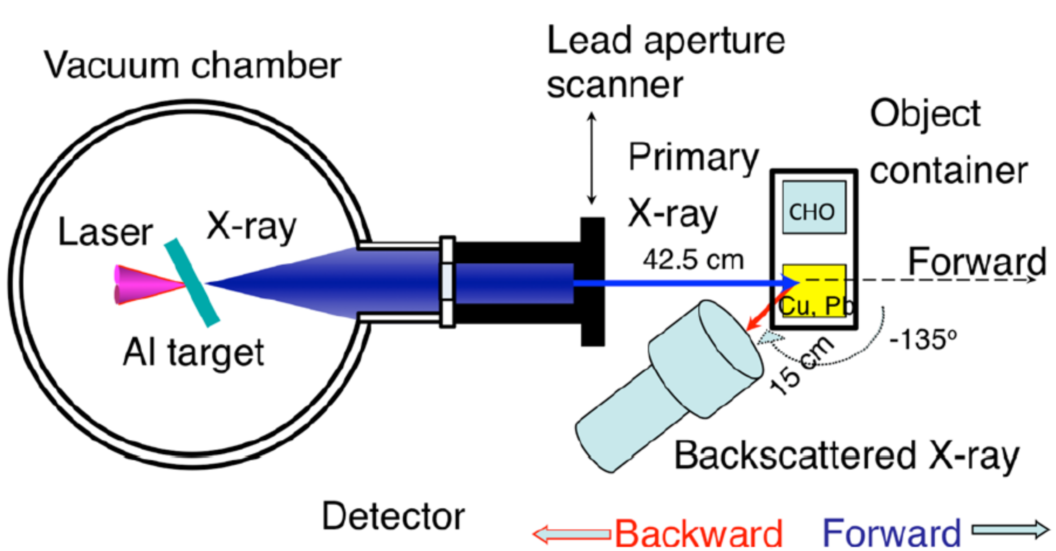


FIG. 1. Setup for backward imaging experiments. A laser (left) generating picosecond pulsed X-rays in the vacuum chamber is focused on an aluminium target. The X-rays penetrate the vacuum window and travel through a movable lead collimator (centre) to scan objects in the aluminium container (right). Backscattered X-rays reach the scintillation detector (centre, bottom).

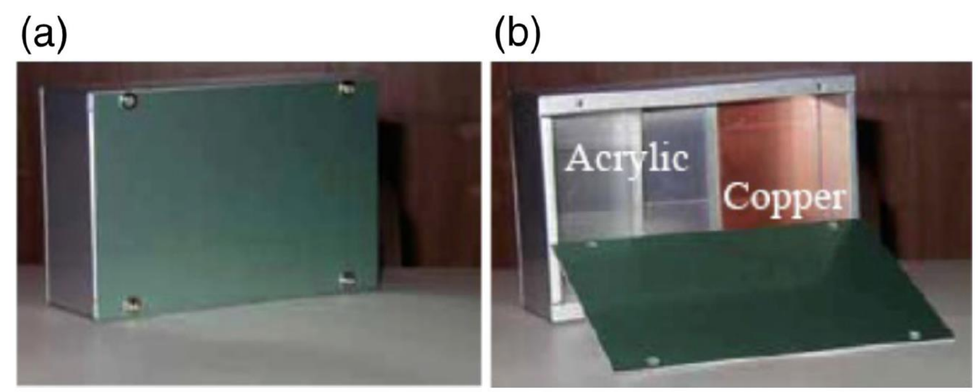


FIG. 3. (a) Aluminium container (0.8-mm thick) in which the objects are hidden. The container dimension is 150 mm × 100 mm × 50 mm. (b) Inside the container are a 30-mm-thick acrylic resin block (left) and a block of either 5-mm-thick copper or 1-mm-thick lead (right).

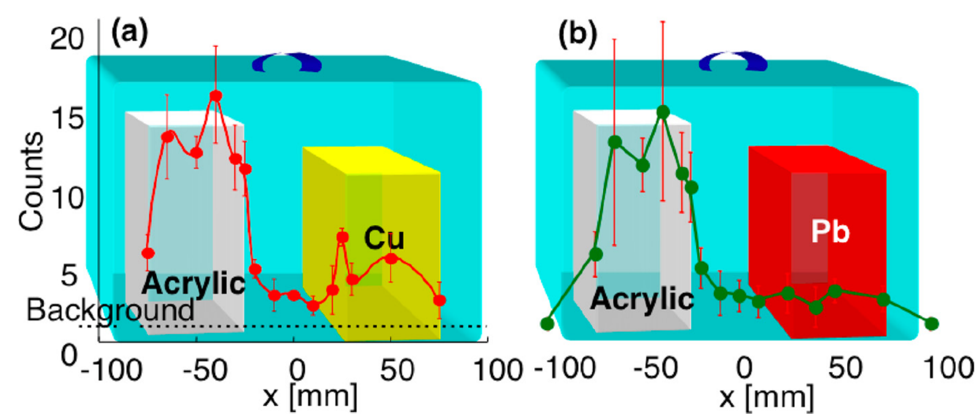


FIG. 4. Backscattered X-ray images show the inside of the container for (a) acrylic resin (left) and copper (Cu, right) and (b) acrylic resin (left) and lead (Pb, right). The horizontal dotted line in (a) gives the level of background noise (1 count). One measured point was obtained from 1000 shots over a 100-s interval. To confirm the data, we repeated these shots three times for case (a) and five times for case (b).

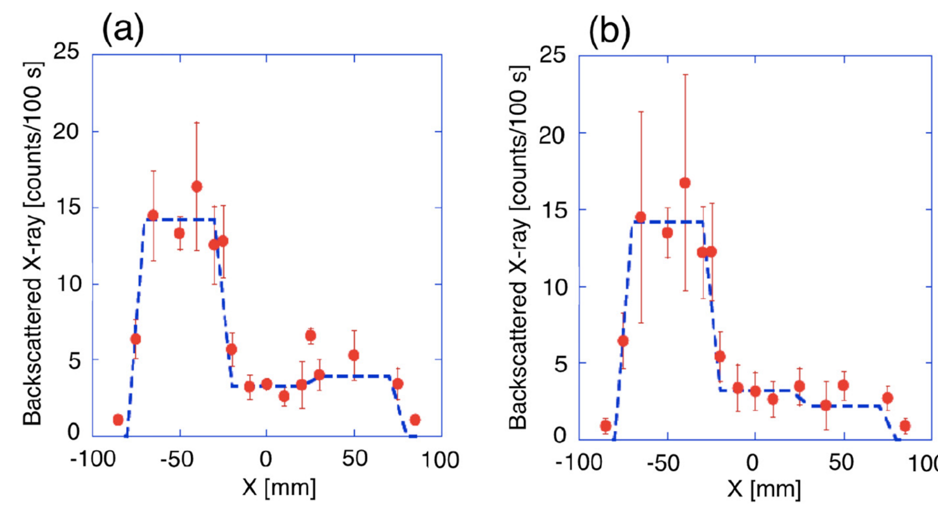
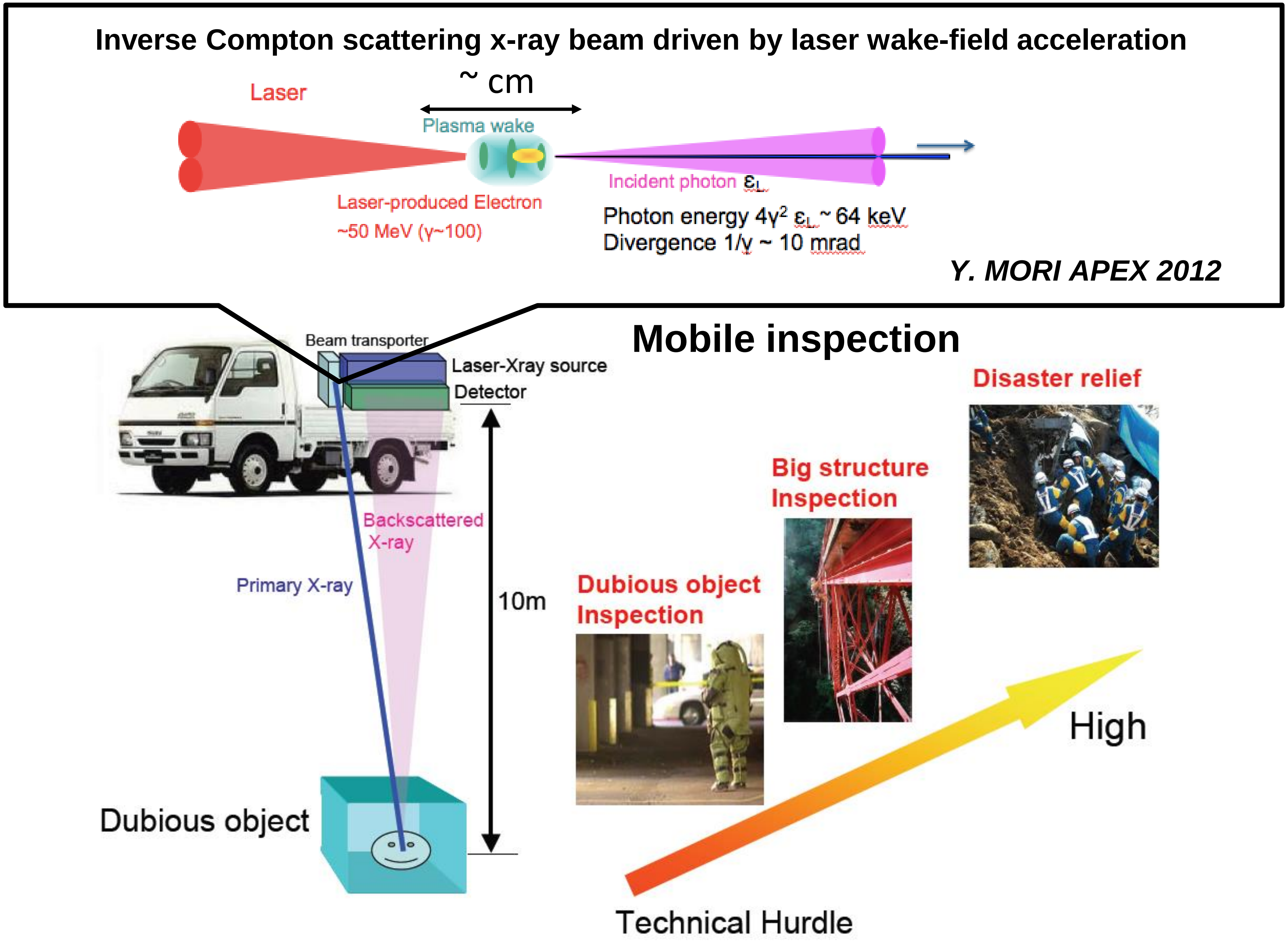


FIG. 6. Comparison of experimental results with model calculations. Solid circle: experimental data from Figs. 4(a) and 4(b). Dashed line: calculations: (a) acrylic and copper; (b) acrylic and lead. In (a) and (b), plateaus between 70 and 25 mm are from acrylic. In (a), plateau between approximately and mm is from Cu. In (b), plateau between approximately and mm is from Pb.

H. Kuwabara, Y. Mori*, and Y. Kitagawa, J. Appl. Physics **114** 083103 (2013).

Laser wake-field acceleration can fabricate a compact X-ray pencil beam system through the inverse Compton scattering.
This is applicable for a mobile Laser Backward X-ray inspection; strongly required for homeland securities, industrial inspections and disaster fields.

GPI

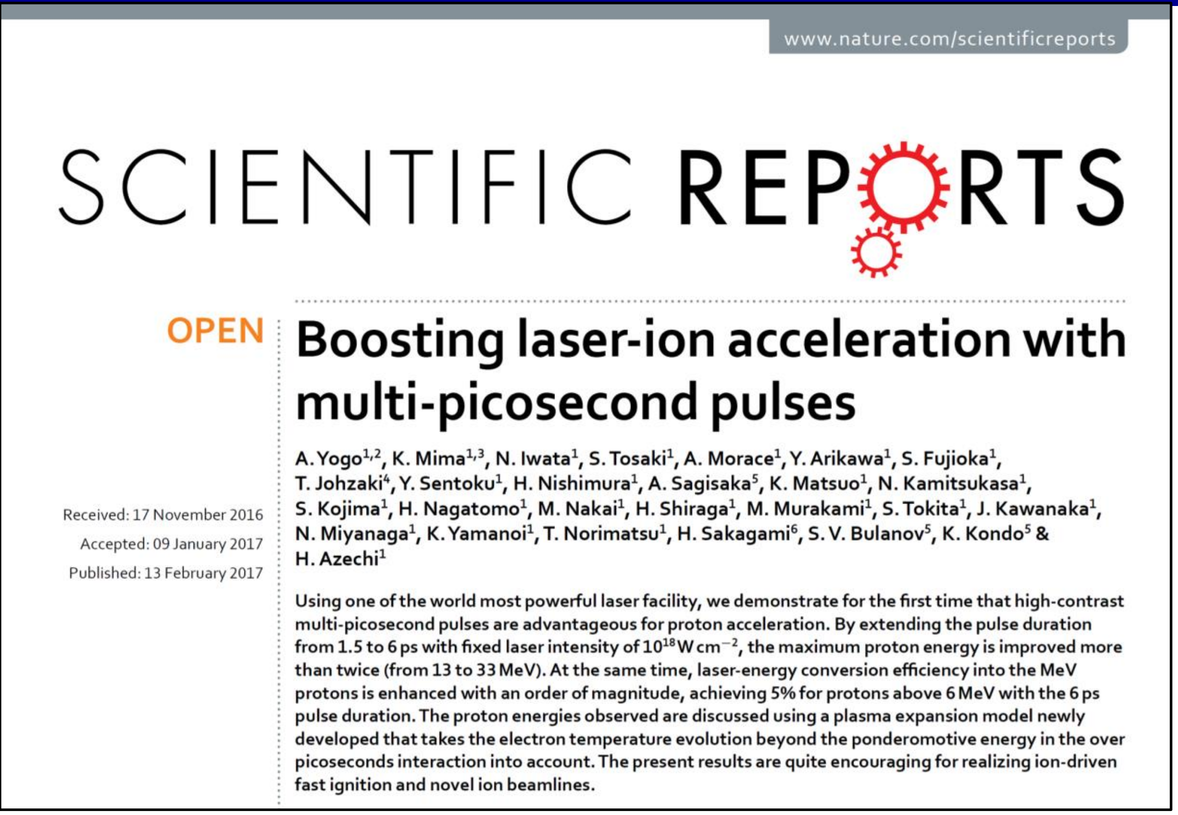


ILE, Osaka U. FY2016 Highlights

AIST

ILE OSAKA

Laser driven ion generation with LFEX


www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Boosting laser-ion acceleration with multi-picosecond pulses

A. Yogo[1,2], K. Mima[1,3], N. Iwata[1], S. Tosaki[1], A. Morace[1], Y. Arikawa[1], S. Fujioka[1], T. Johzaki[4], Y. Sentoku[1], H. Nishimura[1], A. Sagisaka[5], K. Matsuo[1], N. Kamitsukasa[1], S. Kojima[1], H. Nagatomo[1], M. Nakai[1], H. Shiraga[1], M. Murakami[1], S. Tokita[1], J. Kawanaka[1], N. Miyanaga[1], K. Yamanoi[1], T. Norimatsu[1], H. Sakagami[6], S. V. Bulanov[5], K. Kondo[5] & H. Azechi[1]

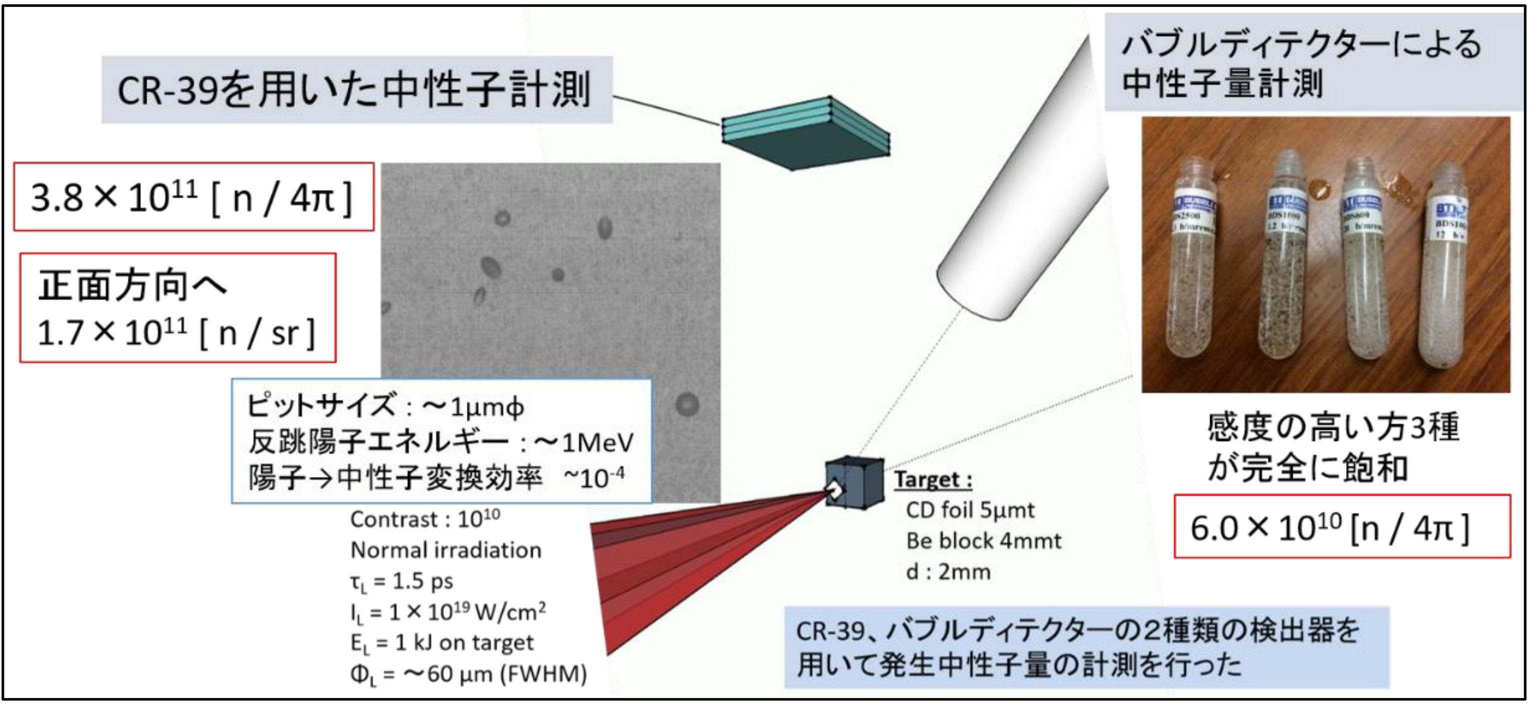
Received: 17 November 2016
Accepted: 09 January 2017
Published: 13 February 2017

Using one of the world most powerful laser facility, we demonstrate for the first time that high-contrast multi-picosecond pulses are advantageous for proton acceleration. By extending the pulse duration from 1.5 to 6 ps with fixed laser intensity of 10^{18} W cm^{-2}, the maximum proton energy is improved more than twice (from 13 to 33 MeV). At the same time, laser-energy conversion efficiency into the MeV protons is enhanced with an order of magnitude, achieving 5% for protons above 6 MeV with the 6 ps pulse duration. The proton energies observed are discussed using a plasma expansion model newly developed that takes the electron temperature evolution beyond the ponderomotive energy in the over picoseconds interaction into account. The present results are quite encouraging for realizing ion-driven fast ignition and novel ion beamlines.

Press releases
2016.2.13
TV news
NHK
Nikkei, Nikkan-Kogyo, Kyodo-Tsushin, *etc.*

Laser-driven neutron generation

JST・研究成果最適展開支援プログラム(A-STEP) H28.1〜



The world-highest neutron number in single shot!
(in preparation)

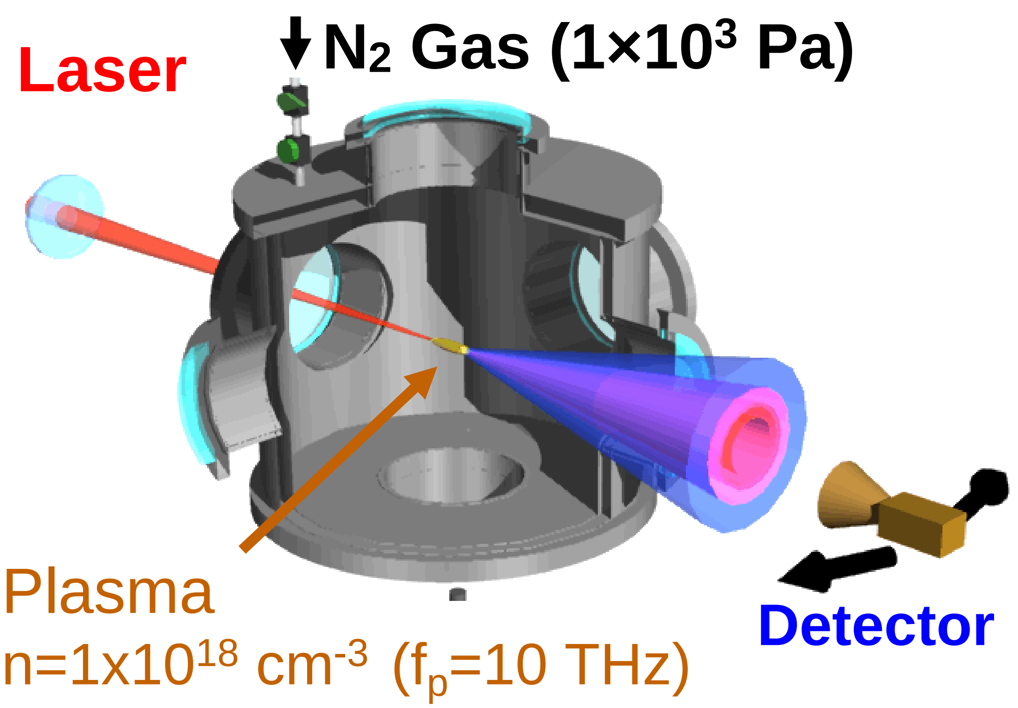
International Collaboration

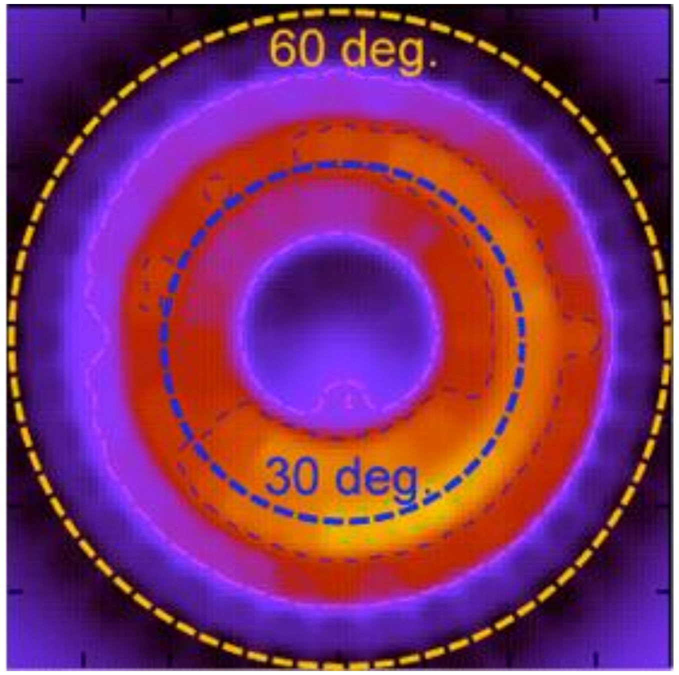
CAS, China
2016.10

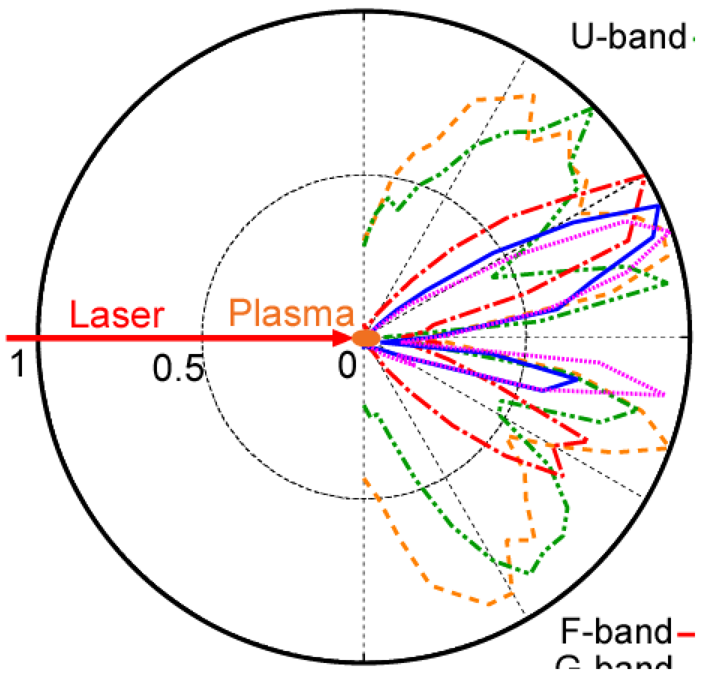
EU/ELI-Beamlines
2017.2
France/CEA
2016.12

Conical THz radiation emission by laser plasma at Utsunomiya

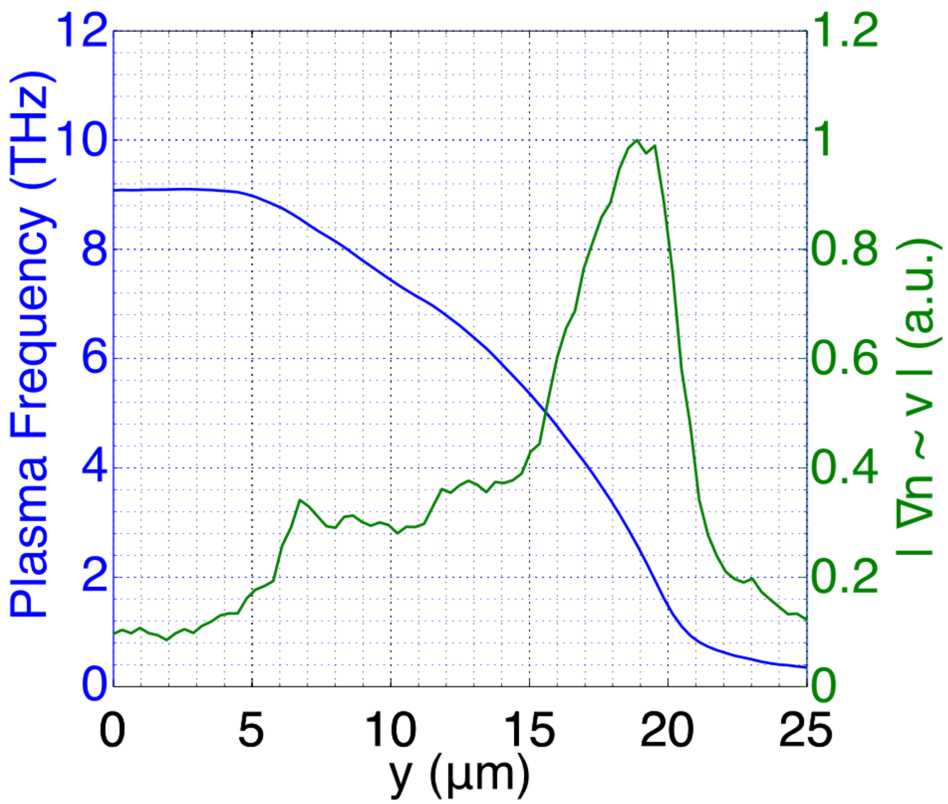
宇都宮大学
UTSUNOMIYA UNIVERSITY





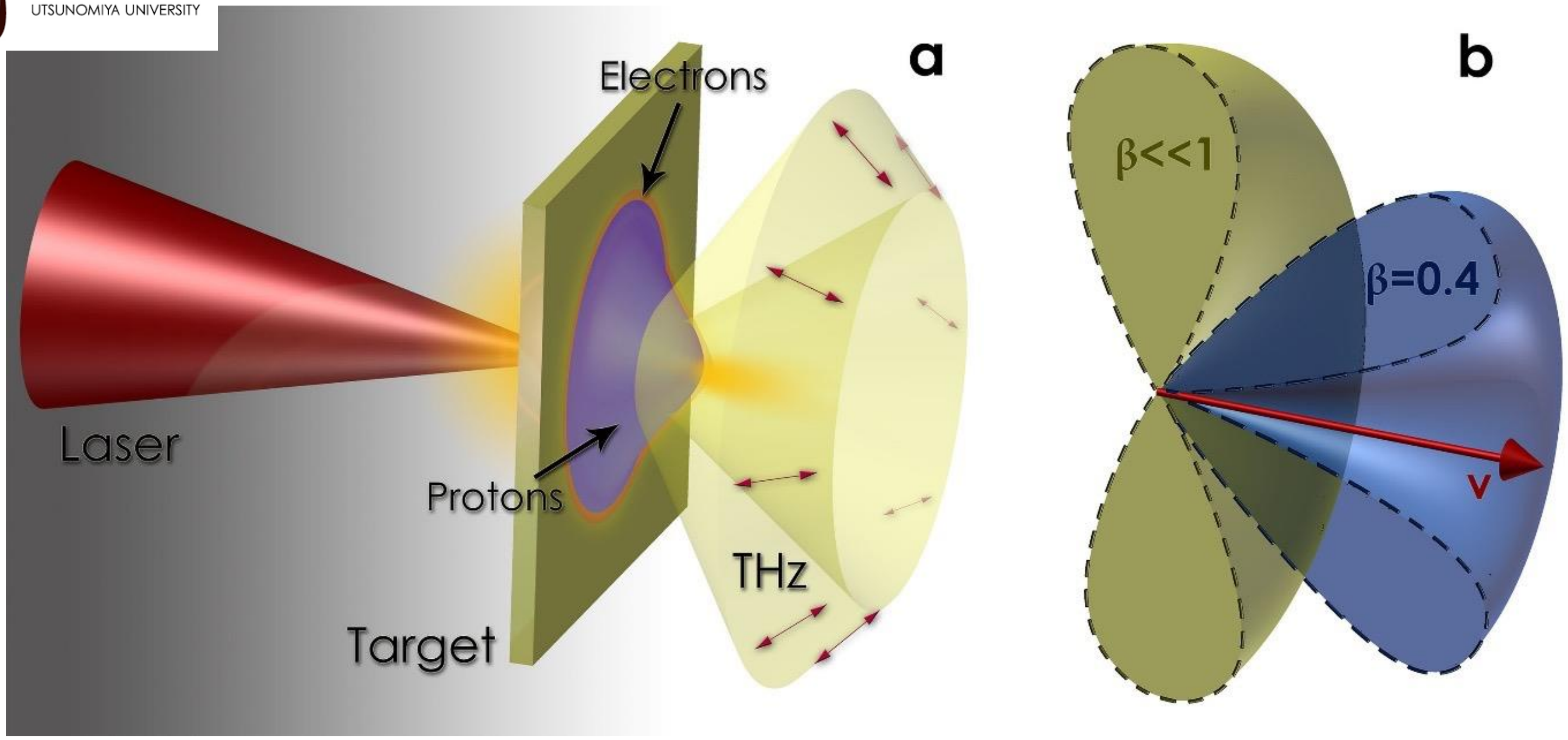


Conical forward THz radiation around 0.1 THz has been observed. However the frequency of the radiation is much lower than the expected value, plasma frequency ωp. 2D PIC simulation shows the radiation emitted the region where the density gradient is large, because the emitted radiation from the maximum density stronglydumped due to resonance absorption.



Highly Efficient Terahertz Radiation Generated from Laser-Solid Interaction at Osaka

宇都宮大学
UTSUNOMIYA UNIVERSITY



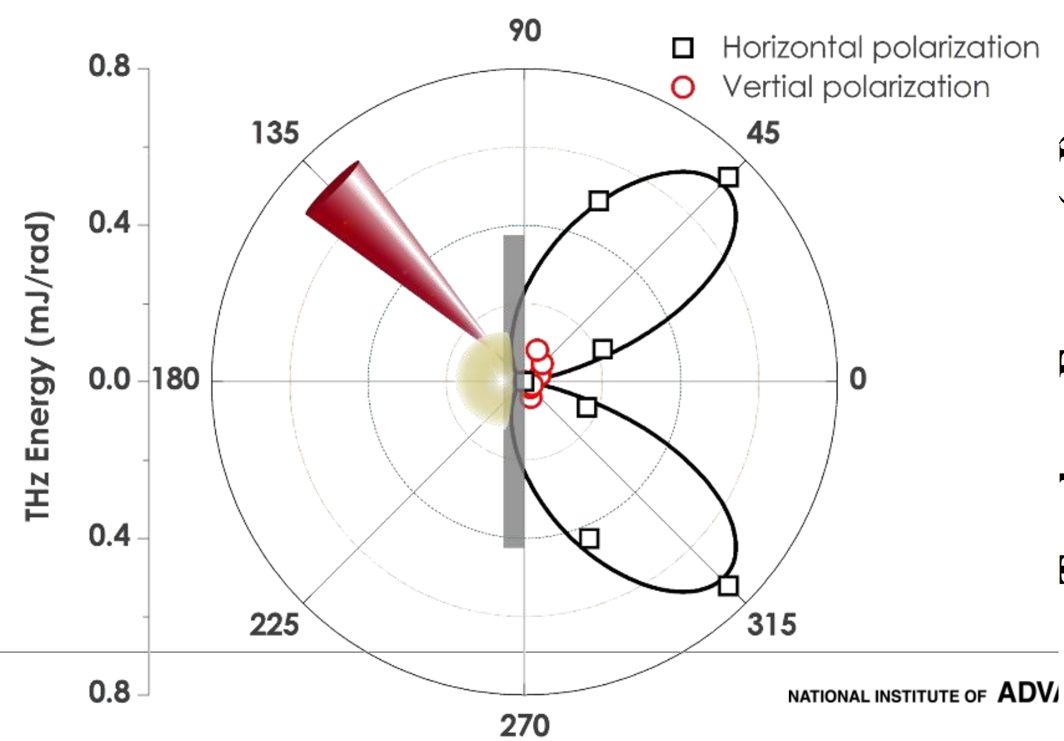
$$E = \frac{qr}{4\pi\varepsilon_0} \frac{\vec{r} \times [(c\hat{r} - \vec{v}) \times \vec{a})]}{(\vec{r} \cdot (c\hat{r} - \vec{v}))^3}$$

Radial polarization

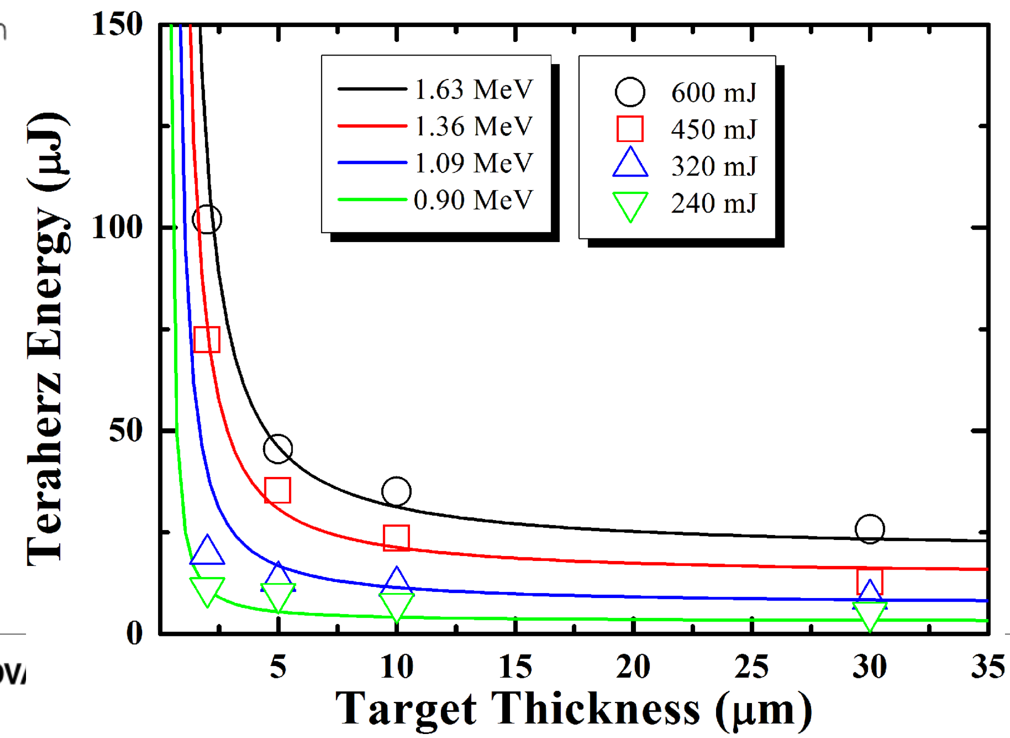
$$\frac{dP}{d\Omega} = \frac{\mu_0 q^2 a^2}{16\pi^2 c} \frac{\sin^2\theta}{(1-\beta\cos\theta)^5}$$

Relativistic dipole pattern

Measured THz Distribution



Electron Refluxing Enhance Effect



Target Thickness:
(600 mJ Laser Energy)
30 μm → 2 μm

Total THz Pulse Energy:
2.6 mJ → 10.5 mJ

Laser-to-THz c.e.:
0.43% → 1.7%

Highest Record.

Research Funding

Funding sources

- **KAKENHI**

  Most common, competitive research funding in Japan. TOTAL: ~2,300 M$
  Includes all science fields
  Several categories : 0.2M$/y - 1 M$/y, 3-5y

- **More goal-oriented, selected themes**

  Green Innovation, Life Innovation, ICT, Nanotech-Material

  CREST: Team, 0.5-1.2 M$/y, <5y

  PRESTO: one, 0.5-1 M$/y, <3y

- **More goal-oriented**

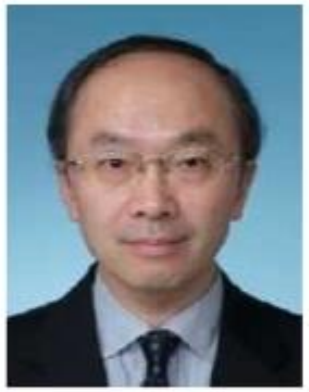
  ImPACT: Team, TOTAL 480M$, 15 projects approved
  5 y, 2014-2018

ImPACT Program

Toward LWFA-driven compact XFEL

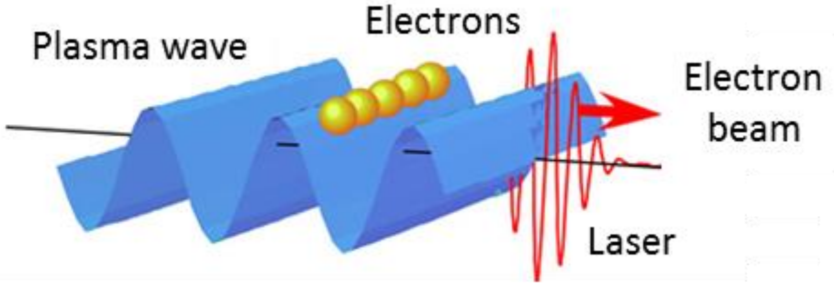
ImPACT - UPL (Ubiquitous Power Laser)

Ubiquitous Power Laser
for
achieving a safe, secure and longevity society



SANO (Toshiba)
Comfortable living environment

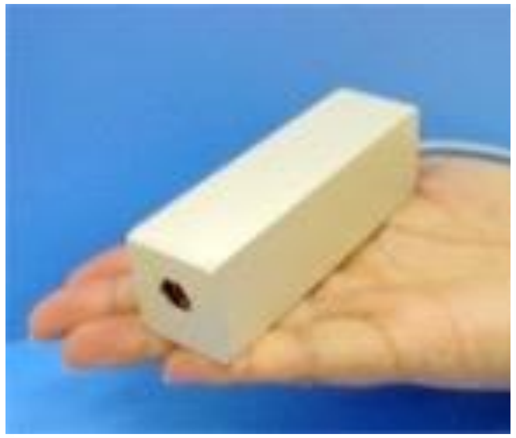
- **Project 1**: LWFA (Laser wakefield acceleration) of electrons and XFEL demonstration



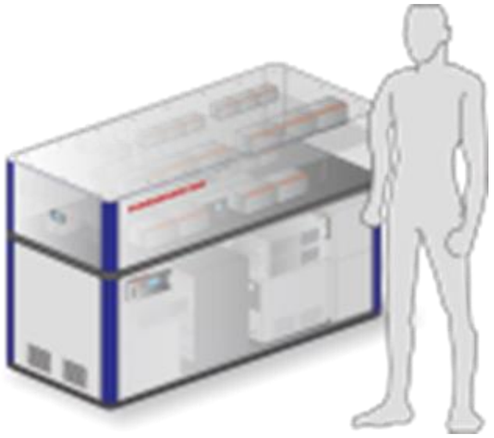
Laser wakefield acceleration of electrons

Ultra-compact XFEL

- **Project 2**: Development of ultra-compact optical pulse lasers for industry



Handheld laser



Tabletop laser

Yuji SANO
Annual MT Meeting@KIT Karlsruhe University
10 Mar. 2016

Integrated Platform for laser acceleration

LAPLACIAN: Laser Acceleration Platform as a Coordinated Innovative Anchor

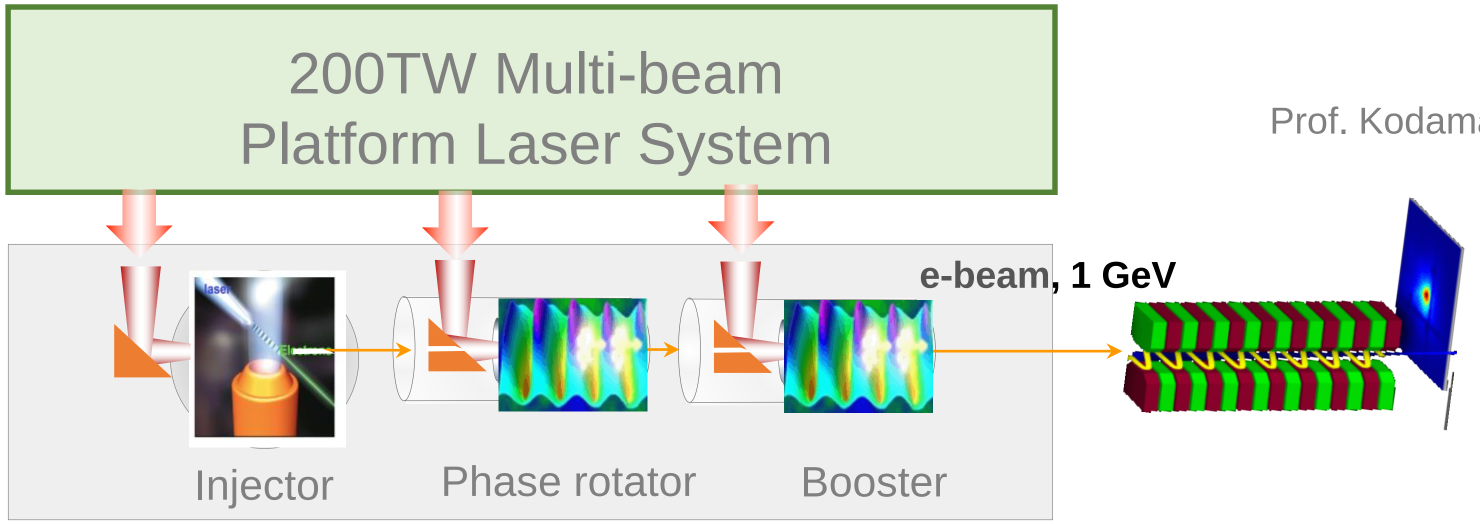
PM Dr. Sano
JST (Tokyo)

Harima Center for Photon Sciences, Osaka Univ. (SPring-8 site)

1B: Integrated platform for laser acceleration

Goal: Multi-stage and X-ray generation （Length <10m, **E_x~1keV**)

Prof. Kodama, Osaka Univ. (Suita)



LWFA module | plasma channel | Beam monitor | Micro-undulator

1A:
Laser acc. elemental tech.
Dev. of 1 GeV LWFA module

Prof. Hosokai, Osaka Univ. (Suita)

1D:
Wakefield & beam diagnosis
Diagnosis and Control of laser and beams

M. Kando, KPSI, QST (Kizu)

3J:
XFEL characterization
X-ray characterization after undulator

Dr. Yabashi, RIKEN Harima

1C:
Micro-undulator
Development of micro-undultaor

Prof. Yamamoto, KEK (Tsukuba)

3L:
Evaluation of micro-undulator
Test of micro-undulator

Prof. Hama, Tohoku Univ. (Sendai)

Conclusion (My personal view)

- There are **NO** concrete **plans** (funded plans) seeking for “Laser-driven High-energy accelerators” in Japan.
- BUT, there are many groups in Japan working on **Advanced Accelerator Concepts** or **closer topics**.
- Especially, RIKEN (who are managing “Light Sources” (SR, XFEL) are collaborating with us to construct **Laser-electron driven XFEL**.
- A small (but powerful) group is doing “AAC concepts” at **KEK**.
- More tends to (easier) applications such as Inverse **Compton Scattering X-rays** (gamma-rays), **XFEL**s, ion sources for cancer therapy, neutron sources for inspection, etc.
- These activities are **necessary** and **important** steps toward “High Energy Accelerators”.
- International Collaboration helps to build up the community in Japan.

Acknowledgement

Ustunomiya University : Prof. N. **Yugami**

Kyoto University Prof. S. **Sakabe**

University of Tokyo Prof. K. **Koyama**, Prof. M. **Uesaka**

National Institute of Advanced Industrial Science and Technology (AIST)

Dr. E. **Miura**

The Graduate School for the Creation of New Photonics Industries (GPI)

Prof. **Y. Mori**, Prof. Y. **Kitagawa**

Institute of Laser Engineering (ILE), Osaka University

Prof. A. **Yogo**

Photon Pioneers Center, Osaka University

Prof. T. **Hosokai,** Prof. R. **Kodama**

RIKEN SPring-8 Center: Dr. M. **Yabashi**

KEK : Prof. M. **Yoshida,** Prof. S. **Yamamoto**

Tohoku University : Prof. H. **Hama**

JST : Dr. Y. **Sano**