Stable Electron Beams by Laser Wakefield Acceleration (LWFA) and the ImPACT Program in JAPAN

Tomonao HOSOKAI (ImPACT-UPL, Project-1 LWFA R&D Team PI)

> Stratagy Management and Support Office,
Graduated School of Engineering, Osaka University
> Photon Pioneers Center, Osaka University

IPAC17@Cope hagen 15-19 May 2017

ImPACT - UPL (Ubiquitous Power Laser)

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

PM: Yuji Sano
JST,
TOSHIBA Corp

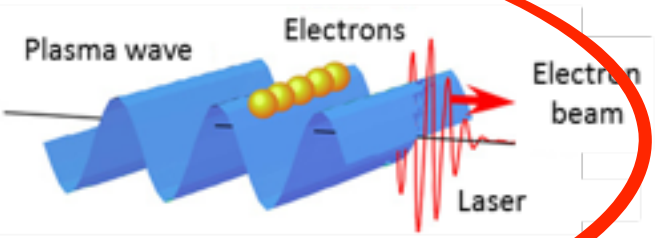
- In 2014, the cabinet office of the Japanese government launched the **ImPACT** program for promoting innovative and high-impact R&Ds.
- A five-year foundation until JFY2018
- Total budget 55 billion JPY ($480M)
- 16 programs are running

ImPACT - UPL (Ubiquitous Power Laser)

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

PM: Yuji Sano
JST,
TOSHIBA Corp

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

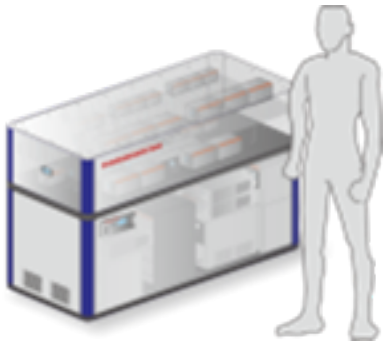


Laser wakefield acceleration of electrons


Ultra-compact XFEL

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


Handheld laser


Tabletop laser

Project1: Overall Configuration @ LWFA Platform

PM: Yuji Sano
JST, TOSHIBA Corp.

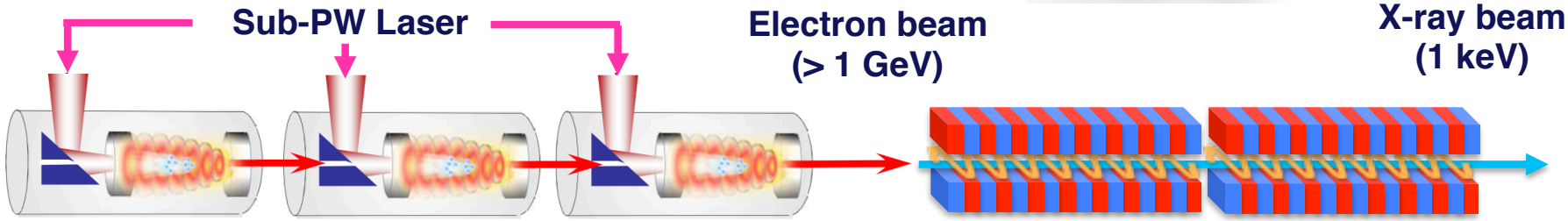
Repeatable GeV-class accelerator with staging LWFA scheme.

Criteria：Acc.length < 10cm、Energy Gain >1GeV, Energy Spread <1%, beam divergence <1 mm-mrad、Pulse duration ~10fs, Repeatable

Project 1B: Integrated platform for laser acceleration
Issue: Multi-stage acceleration and generation of 1 keV X-ray beam by a microundulator with a length of 10 m or less/platform development

LAPLACIAN
Laser Acceleration Platform as a Coordinated Innovative Anchor

革新的研究開発推進プログラム ImPACT
Impulsing Paradigm Change through Disruptive Technologies Program



Osaka PhoPs
Photon Pioneers Center, Osaka University

Project 1A: Laser acceleration elemental technologies
Issue: Electron acceleration exceeding 1 GeV and modularize it as a plasma device

KPSI
Kansai Photon Science Institute
QST

Project 1D: Beam measurement and control
Issue: Control of laser and electrons, and injection of electron to undulator

RIKEN

Project 3J: XFEL demonstration assessment
Issue: User demonstrations of laser acceleration XFEL.

KEK

Project 1C: Microundulator
Issue: Ultra-compact undulatory generating 1 keV X-ray beam

TOHOKU

Project 3L: Evaluation of Microundulator

PROJECT 1A

ImPACT LWFA Research Team @ PhoPs, Osaka Univ.

Laser Acc. Group

T. HOSOKAI[1, 2], T. OTSUKA[2], J. OGINO[2], N. PATHAK[2],
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K. SUEDA[2], Z. JIN[2],
M. YANO[1] (D1), A. UENO[1] (M2), H. TORAN[1] (M1)

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QST

S. YAMAMOTO
KEK

M. YABASHI
RIKEN

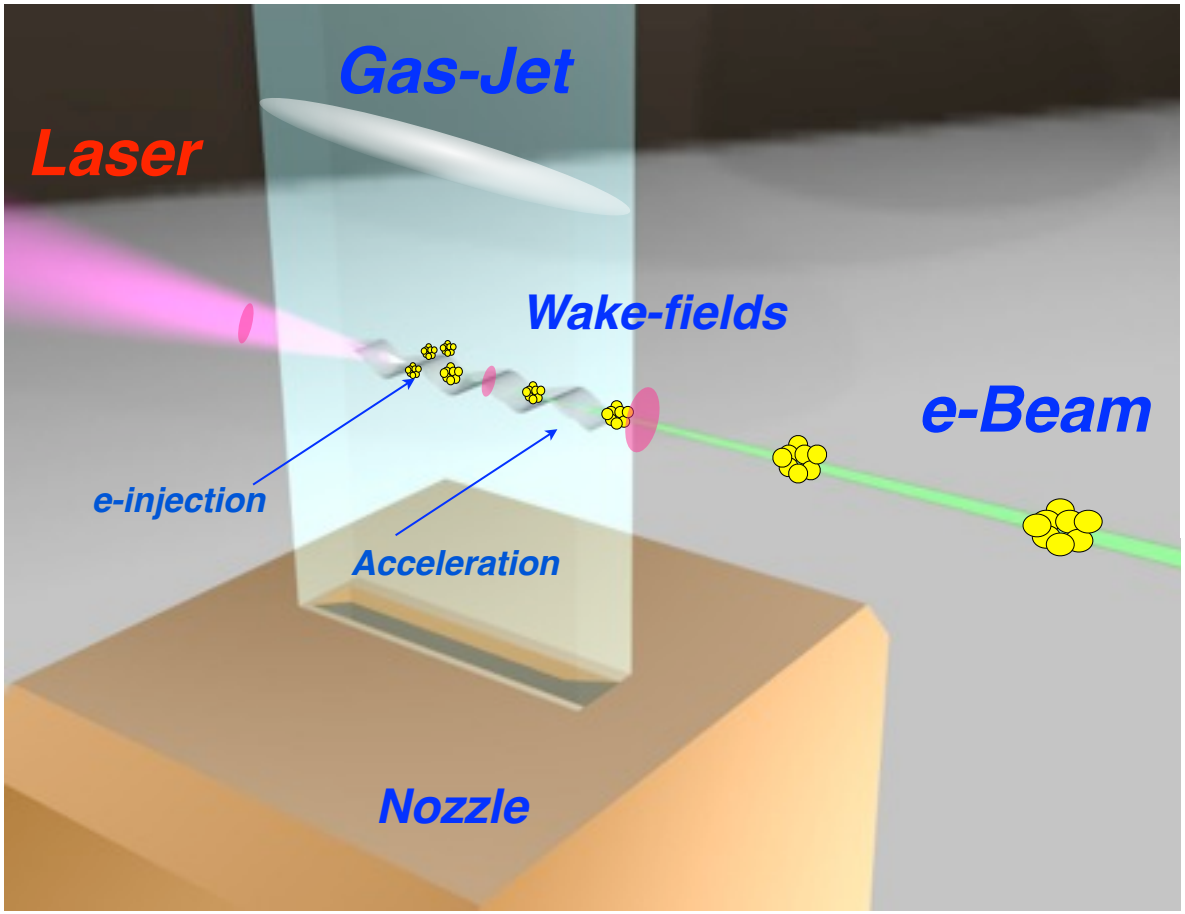
Osaka University

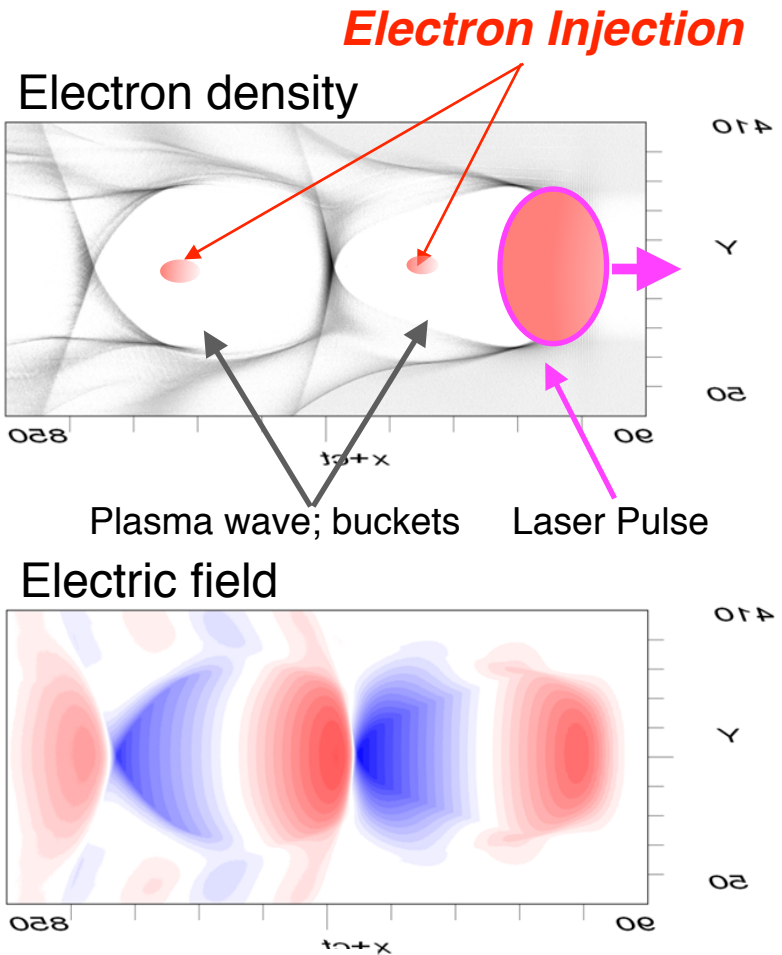
[1] Graduate School of Eng., Osaka University

[2] Photon Pioneers Center, Osaka University

Osaka PhoPs
Photon Pioneers Center, Osaka University

Laser Wake-field Acceleration (LWFA)



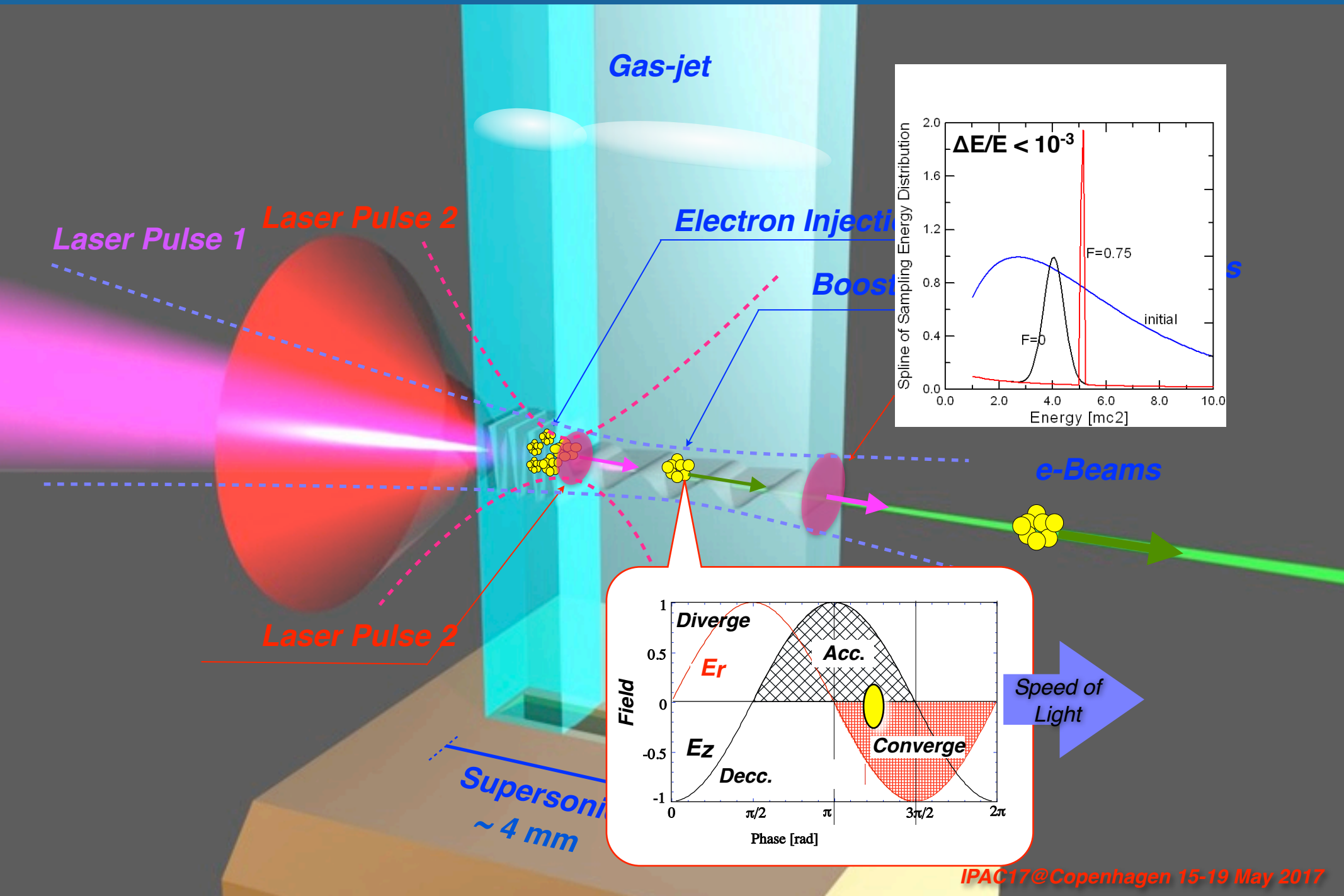


A.Zhidkov, et al

Potential of LWFA

- Ultra-high gradient >100 GV/m
- high- Charge > ~nC/pulse
- Ultra-short pulse< ~few fs
- small divergence < 0.1 mrad

Staging LWFA



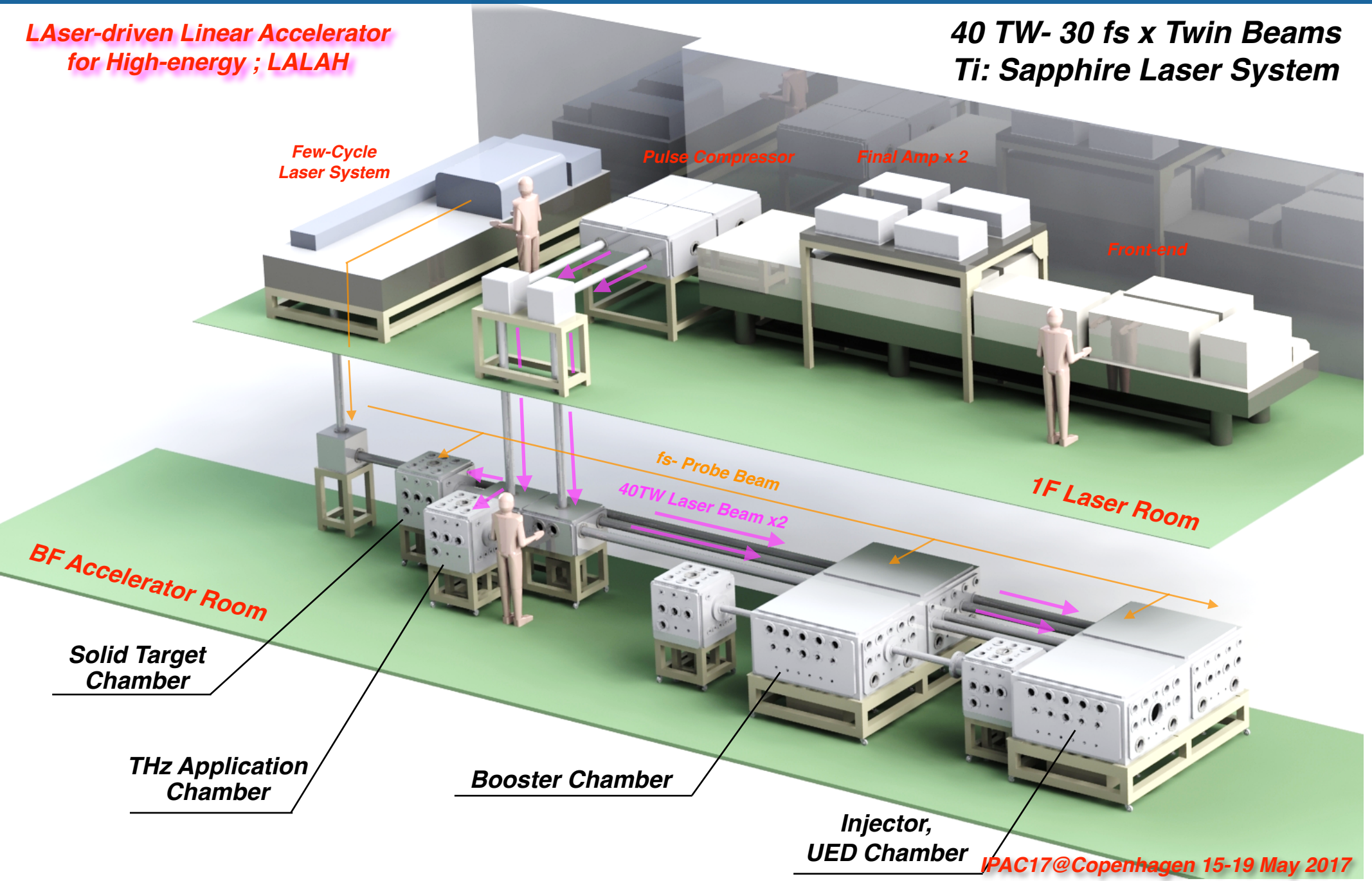
PROJECT 1A

Laser Facility @ PhoPs (Osaka University Campus)

革新的研究開発推進プログラム ImPACT Impulsing Paradigm Change through Disruptive Technologies Program

LAser-driven Linear Accelerator for High-energy ; LALAH

40 TW- 30 fs x Twin Beams Ti: Sapphire Laser System



IPAC17@Copenhagen 15-19 May 2017

PROJECT 1A

Laser Facility @ PhoPs (Osaka University Campus)

革新的研究開発推進プログラム ImPACT Impulsing Paradigm Change through Disruptive Technologies Program

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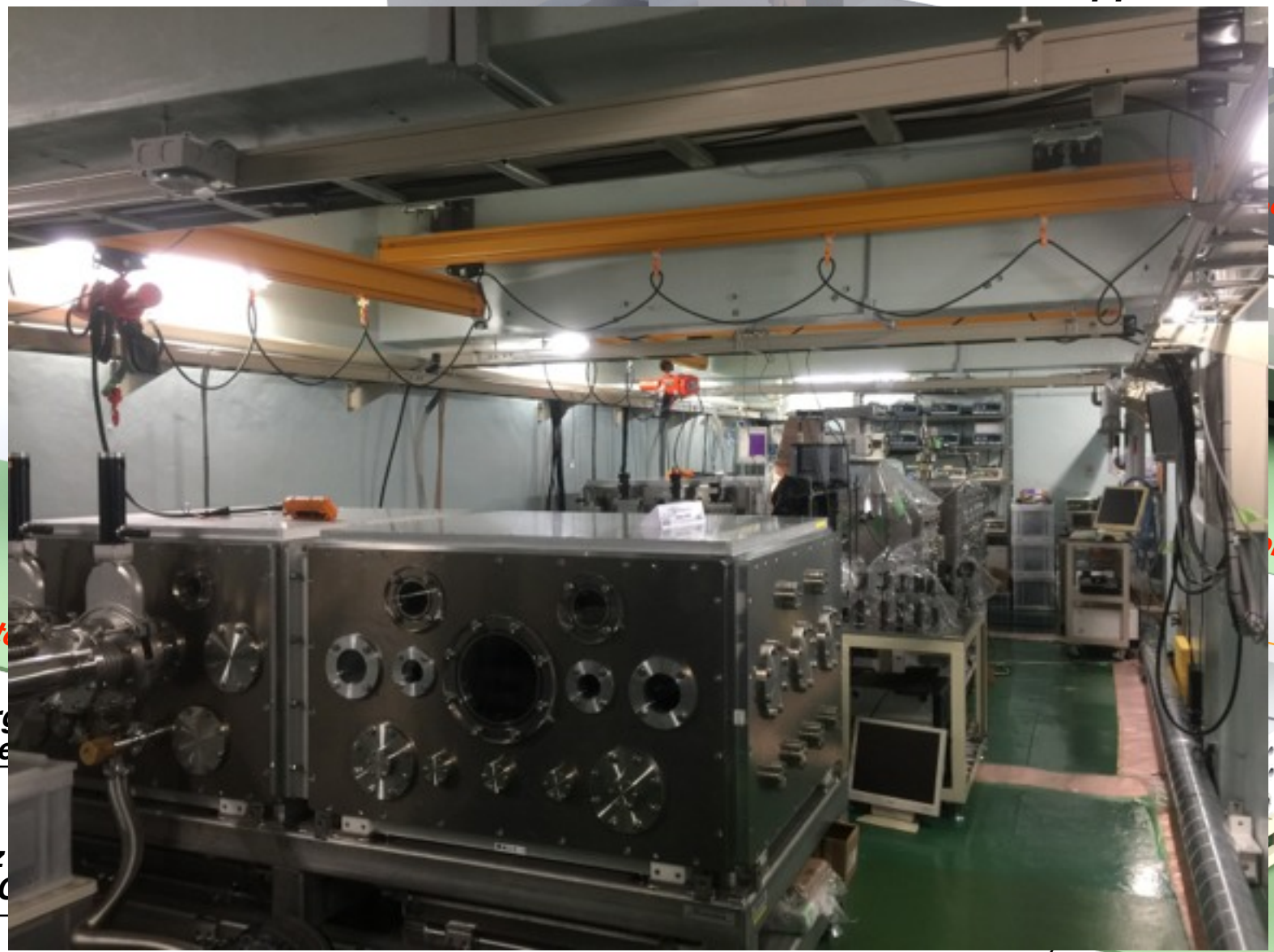


BF Accelerat

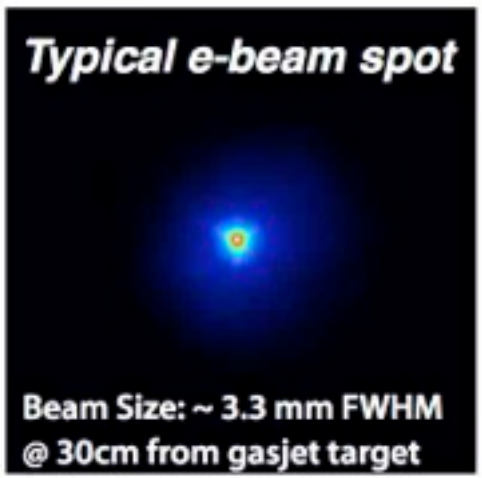
Solid Targ
Chambe

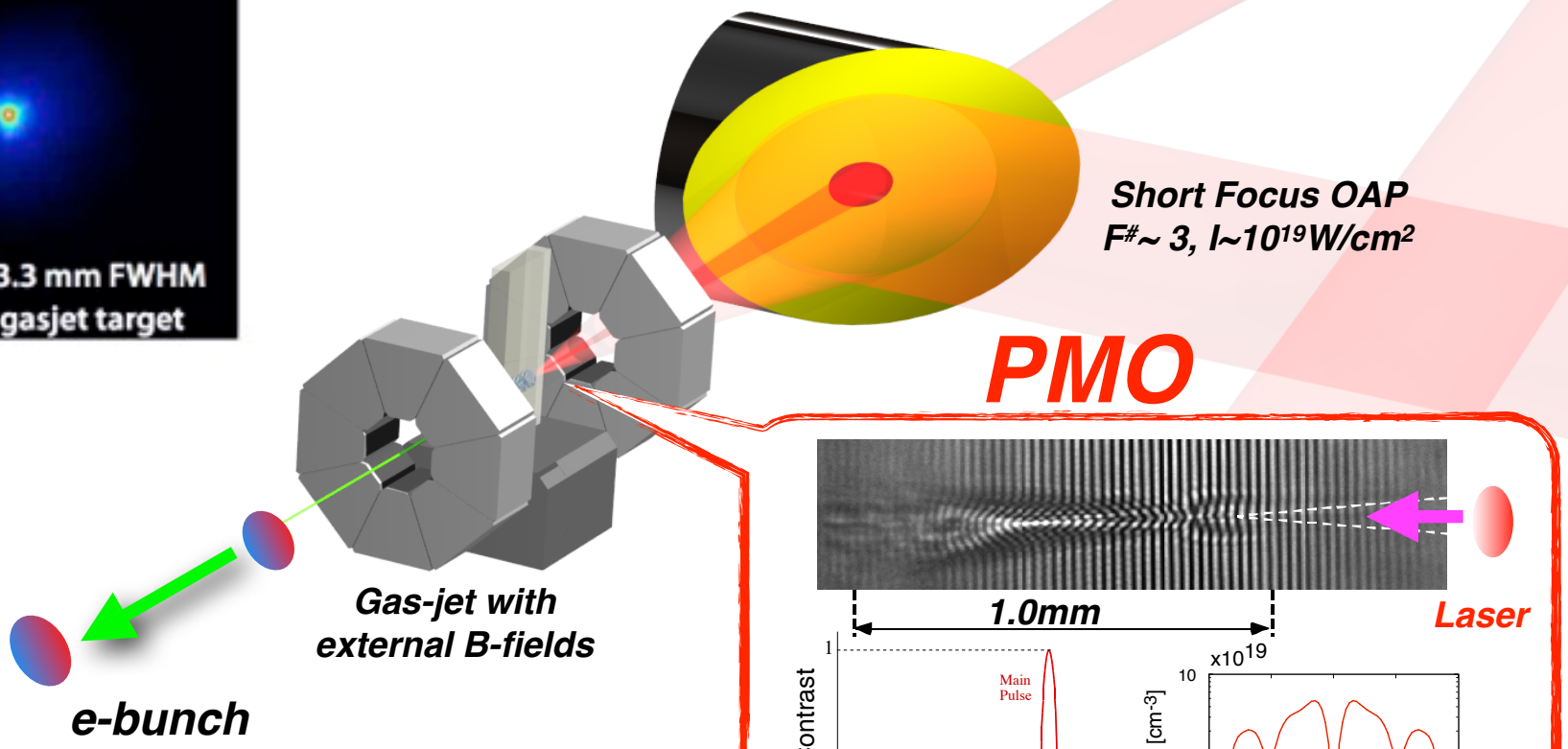
THz
C

UED Chamber

2. Plasma micro-optics (PMO)

Y.Mizuta,*etal*, Phys.Rev.ST, 15, 121301 (2012)



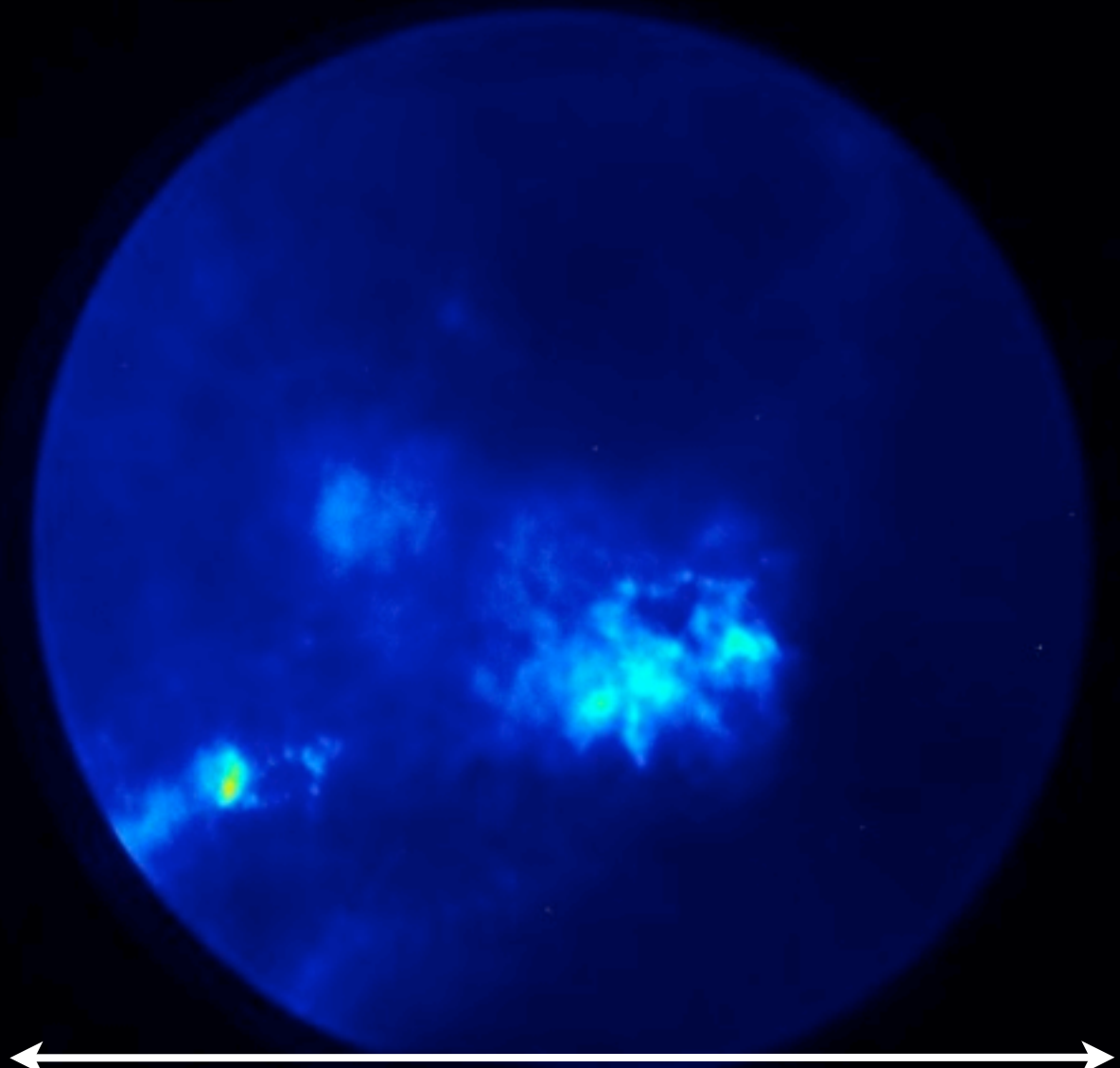


T.Hosokai,et al.,Phys Rev.Lett. 97, 075004 (2006)

T.Hosokai, et al., Appl. Phys. Lett. 96,121501 (2010)

nomagnet-He3MPa-600mJ-CFR200-638-ch4-285500-gasjet-best1.tif

Typical e-Beam Profile w/o PMO



Gasjet target
He 3MPa
Nozzle type
1.2mm(laser axis) x 4mm

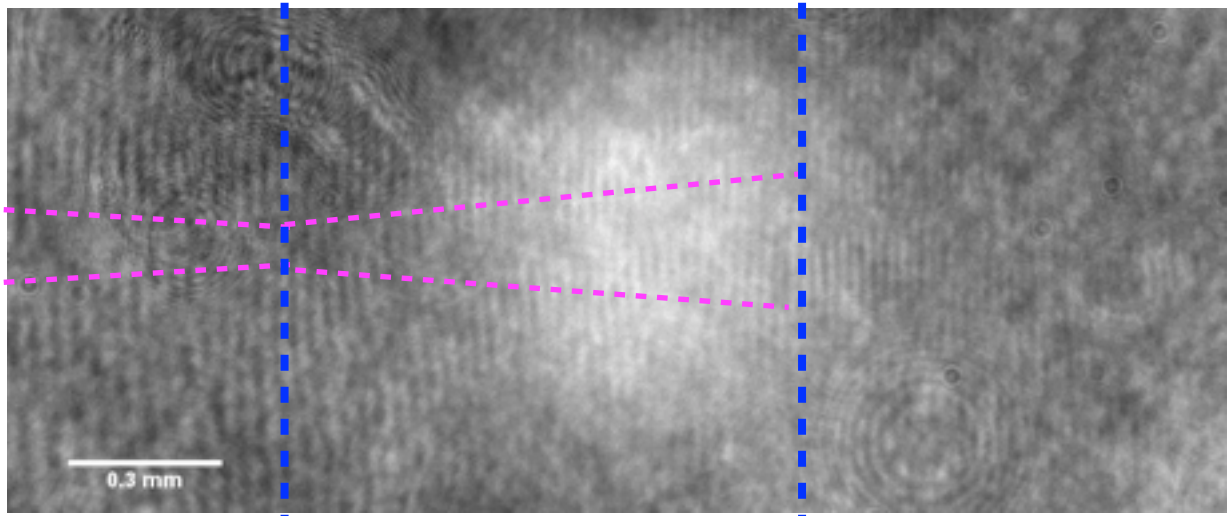
Laser pulse
Energy 600mJ
Pulse duration 25fs

Detector size: Φ13cm (746pixel)

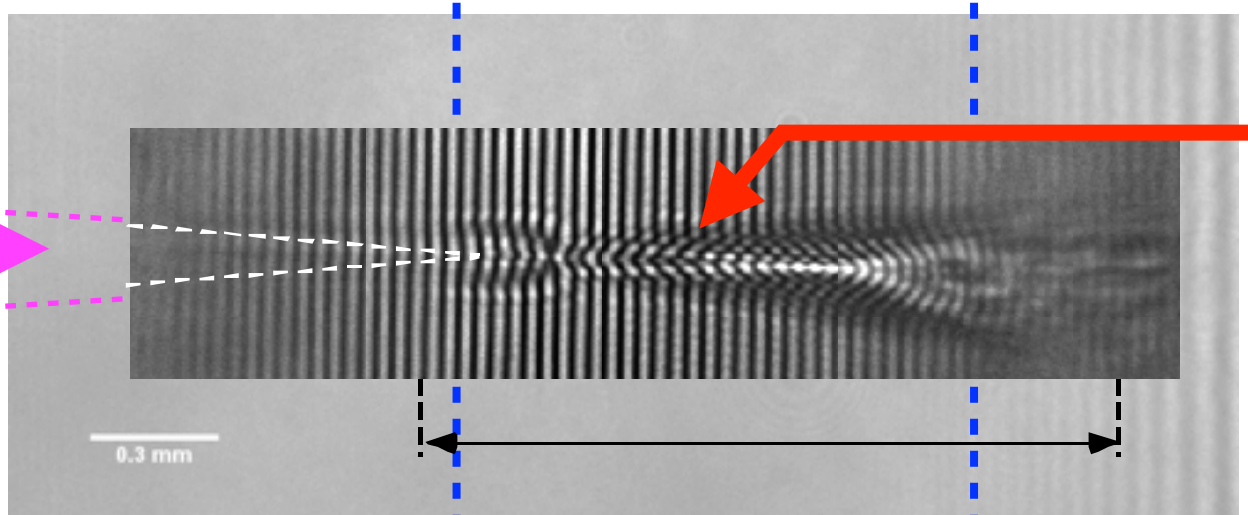
Plasma Micro- Optics
Key techniques for stable/Repeatable beam generation

$P < P_{critical}$

F#~6



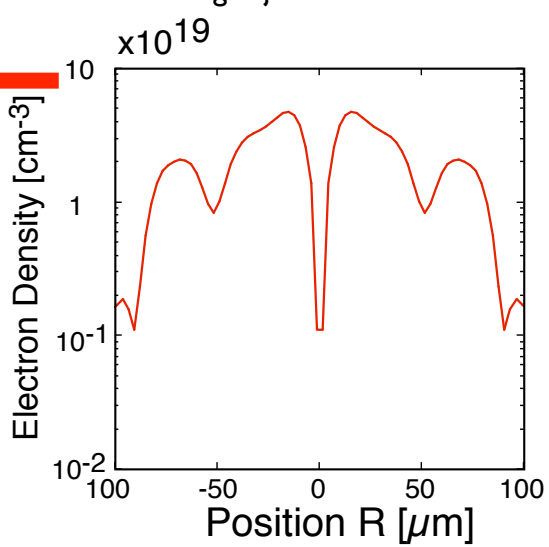
Pulse width ~ 300 fs
Typical contrast ~10^{-3}@4ps,
~10^{-6}@ns
Peak power ~ <10^{16} Wcm^{-2}
P_{total}~ 10GW (< $P_{critical}$)
Ar gas-jet: N~2x10^{19} cm^{-2}



F#~6

ps Laser pulse

Pulse width ~ 300 fs
Typical contrast ~10^{-3}@4ps,
~10^{-5}@ns
Peak power ~ <10^{16} Wcm^{-2}
P_{total}~ 10GW (< $P_{critical}$)
Ar gas-jet: N~2x10^{19} cm^{-2}



Gas boundary

Gas boundary

Y.Mizuta,*etal*, Phys.Rev.ST, 15, 121301 (2012)

B~0.2T, Energy 300mJ

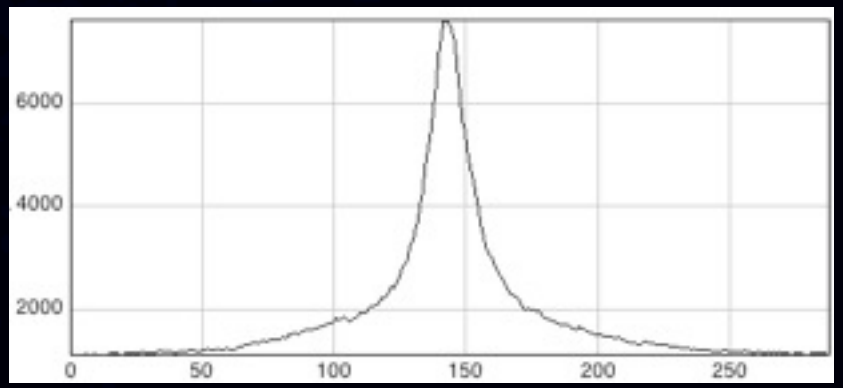
Typical e-Beam Profile with PMO

1 ***PMO provides well-collimated beam !***

Gasjet target
- He 3MPa
- Nozzle type
  - 1.2mm(laser axis) x 4mm

Magnet
- 0.2 T Ring type

Laser pulse
- Energy 300mJ
- Pulse duration 25fs

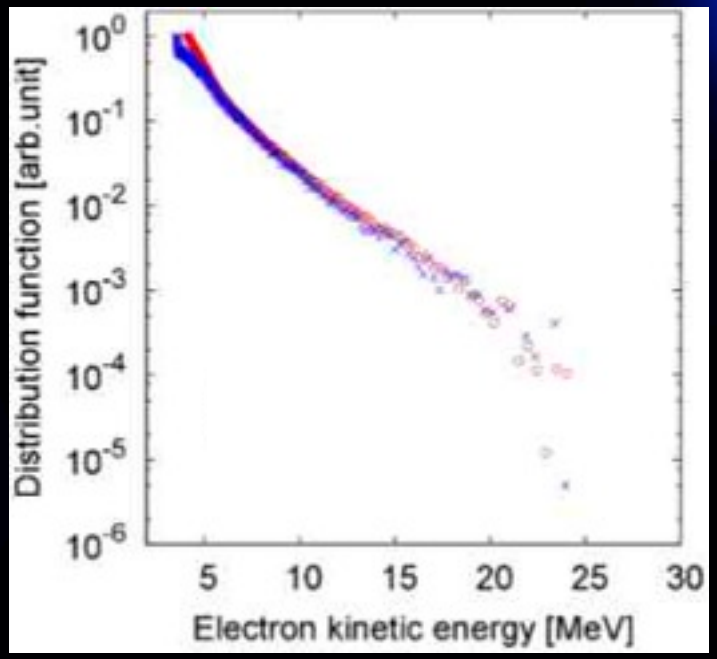


Beam Size: ~ 3.3 mm FWHM @ 30cm from gasjet target

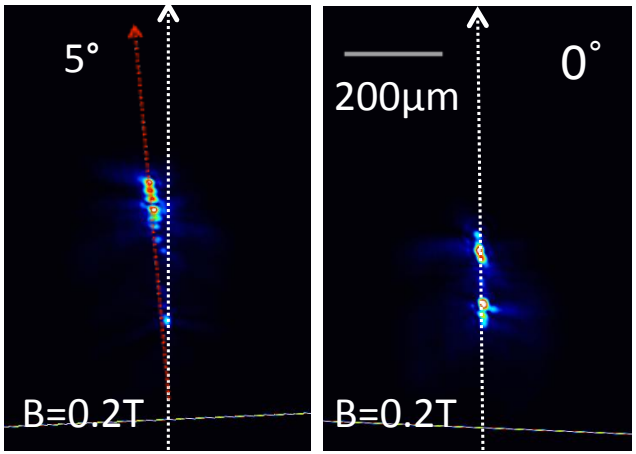
B~0.2T, Energy 300mJ

2

Energy spectrum

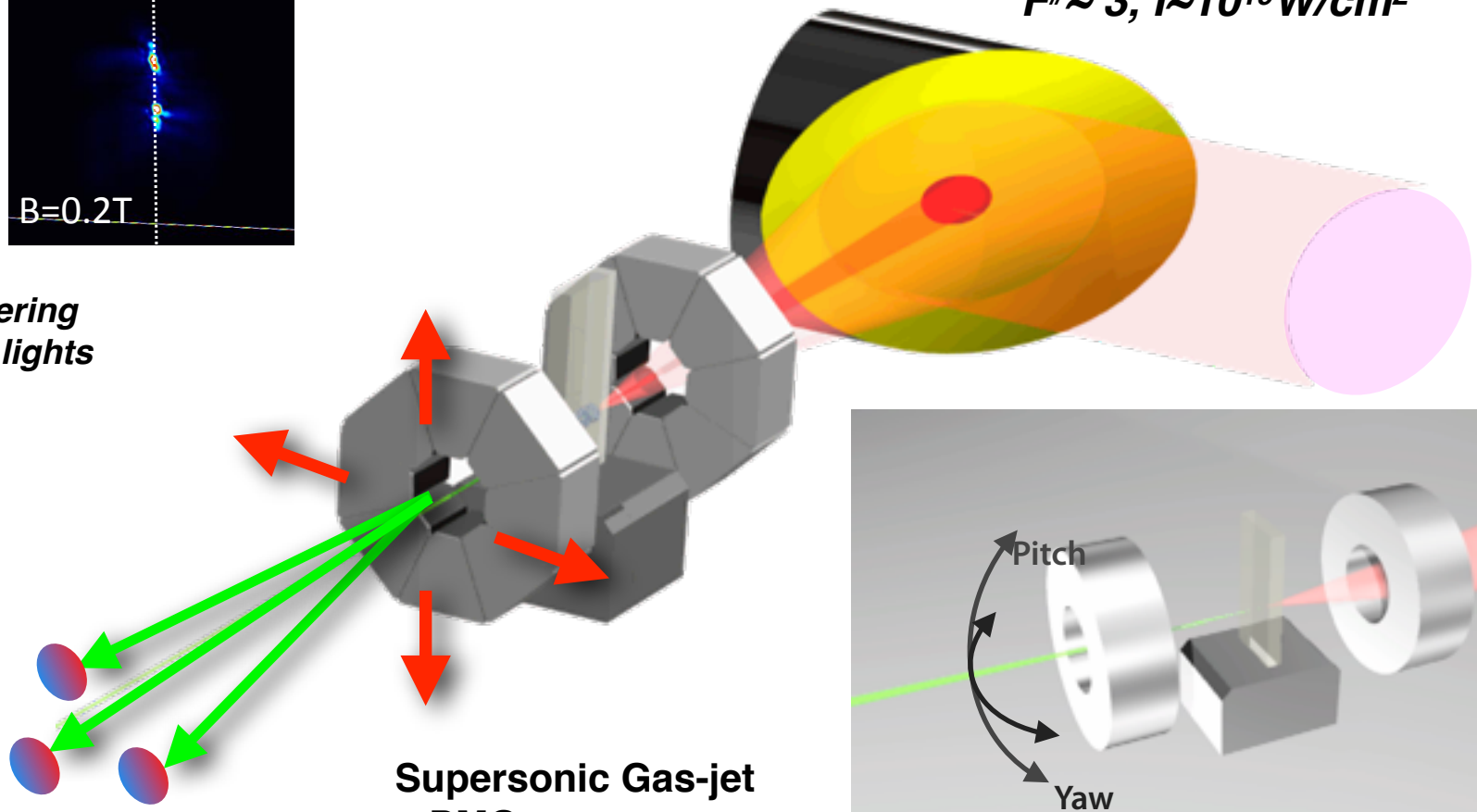


Steering of e-beams using PMO
Key technique for staging LWFA



Thomson Scattering Images of Laser lights

Short Focus OAP
F#~ 3, I~10¹⁹W/cm²



Supersonic Gas-jet + PMO

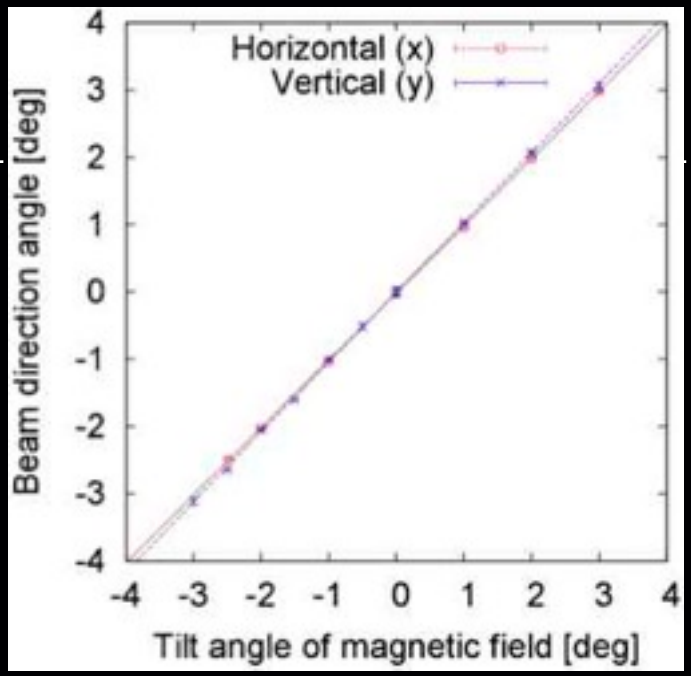
electron beams

Y.Mizuta,*et al*, Phys.Rev.ST, 15, 121301 (2012)
N.Nakanii,*et al*, Phys.Rev.ST, 18, 021303(2015)

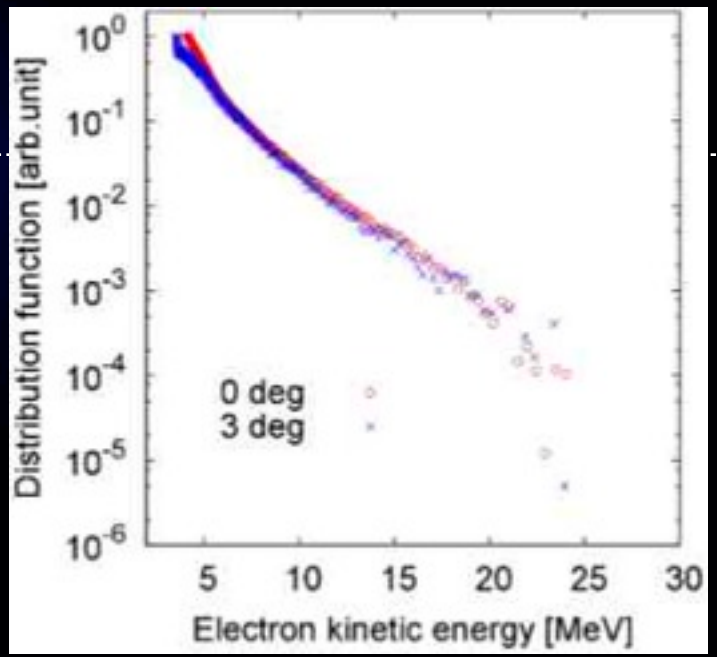
Rotation counterclockwise 3°

PMO allows us to steer e-beams as we wish !

Accuracy of steering



Energy spectrum
Dependence on ejection angle



Rotation counterclockwise 3°

PMO allows us to steer e-beams as we wish !

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **18,** 021303 (2015)

Transient magnetized plasma as an optical element for high power laser pulses

Nobuhiko Nakanii,[1,2,*] Tomonao Hosokai,[1,2,3] Kenta Iwasa,[3] Shinichi Masuda,[1,2] Alexei Zhidkov,[1,2] Naveen Pathak,[1,2] Hiroki Nakahara,[3] Yoshio Mizuta,[3] Naoki Takeguchi,[3] and Ryosuke Kodama[1,3,4]

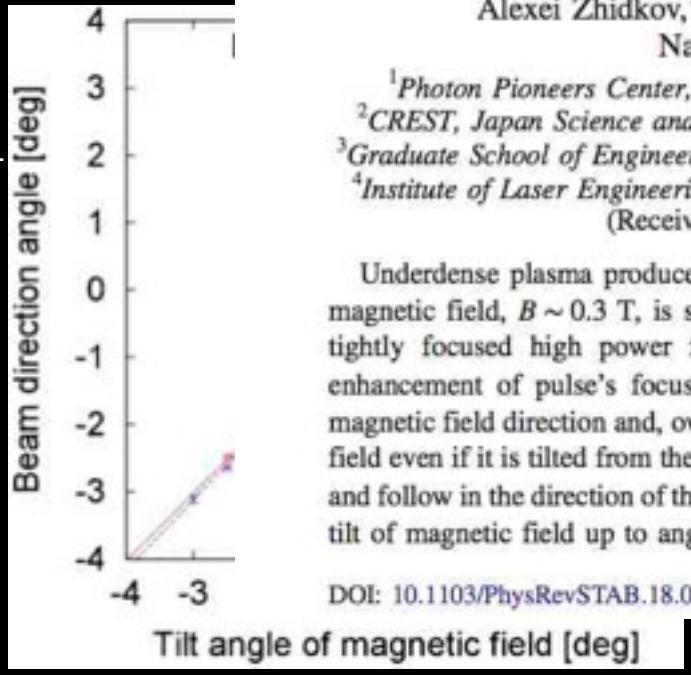
[1]*Photon Pioneers Center, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan*
[2]*CREST, Japan Science and Technology Agency, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan*
[3]*Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan*
[4]*Institute of Laser Engineering, Osaka University, 2-8 Yamada-oka, Suita, Osaka 565-0871, Japan*

(Received 9 October 2014; published 24 February 2015)

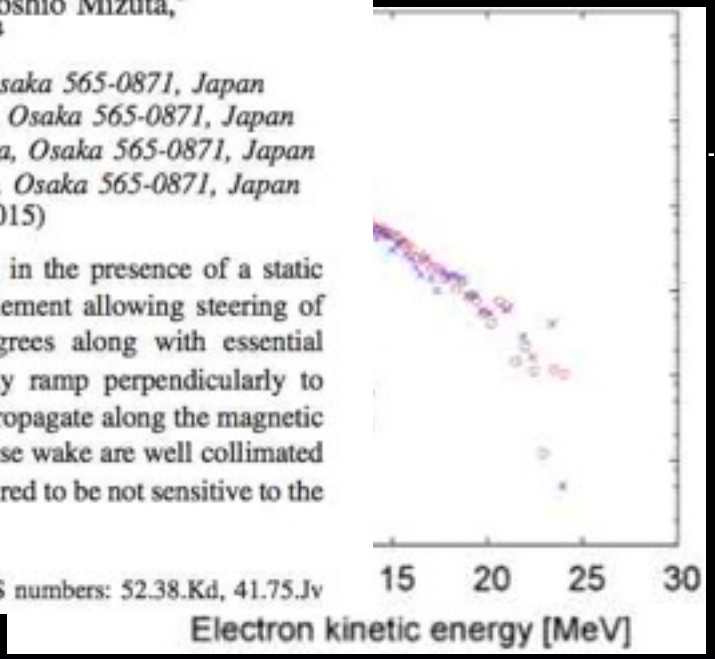
Underdense plasma produced in gas jets by low intensity laser prepulses in the presence of a static magnetic field, $B \sim 0.3$ T, is shown experimentally to become an optical element allowing steering of tightly focused high power femtosecond laser pulses within several degrees along with essential enhancement of pulse's focusability. Strong laser prepulses form a density ramp perpendicularly to magnetic field direction and, owing to the light refraction, main laser pulses propagate along the magnetic field even if it is tilted from the laser axis. Electrons generated in the laser pulse wake are well collimated and follow in the direction of the magnetic field; their characteristics are measured to be not sensitive to the tilt of magnetic field up to angles ±5°.

DOI: 10.1103/PhysRevSTAB.18.021303 PACS numbers: 52.38.Kd, 41.75.Jv

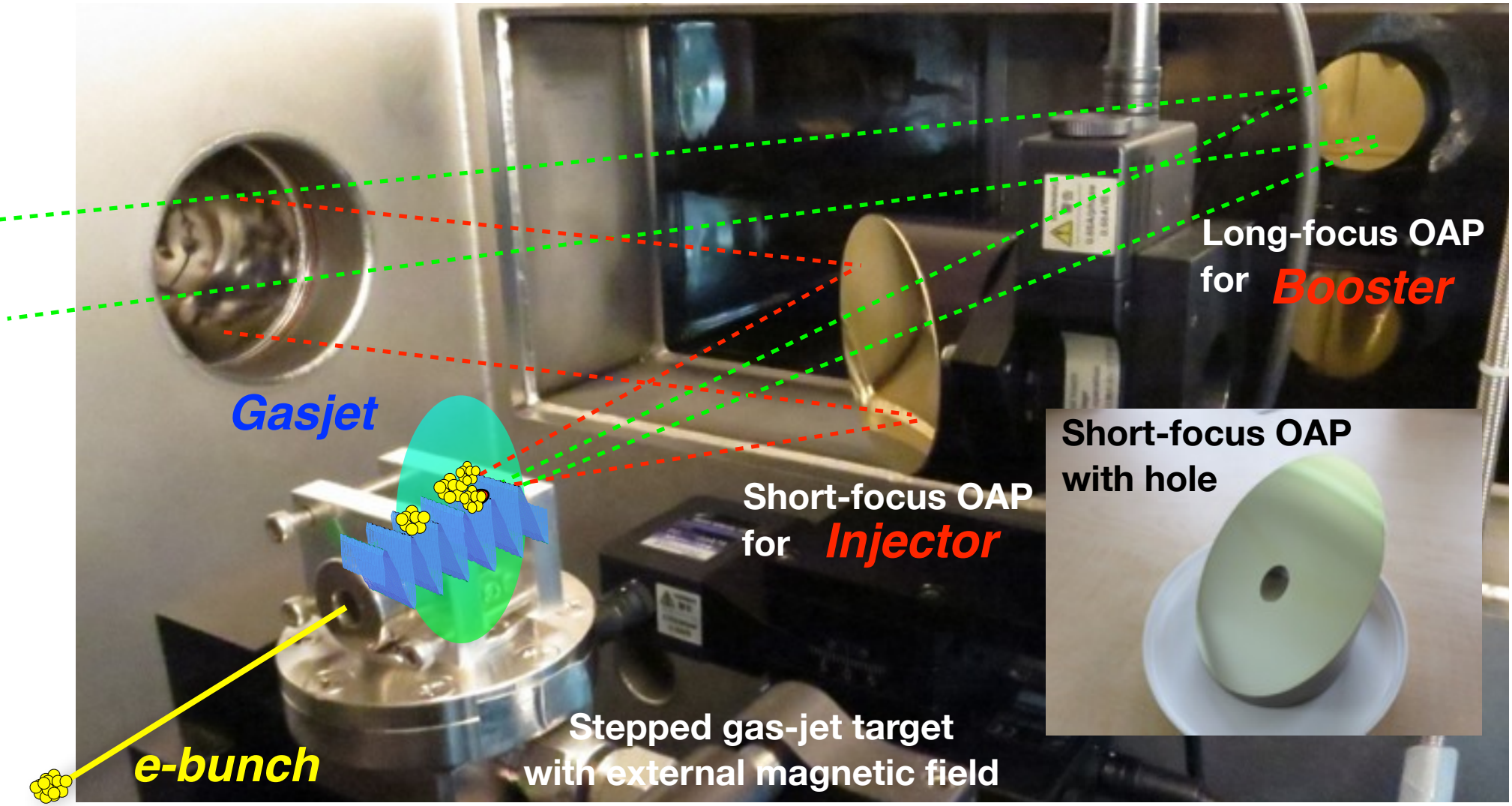
Accu



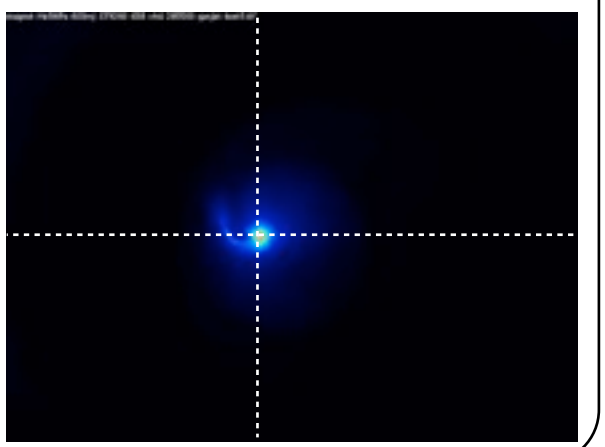
pectrum
ejection angle



Injector-Booster Scheme of LWFA (2-beam-driven staging LWFA)



Towards GeV-class Acceleration; Staging Acc. with Longer & Low-density Channel



Injected e-beam before Booster

Short Focus OAP
$F^{\#}\sim 3$, $I\sim 10^{19}$W/cm^2

Injector

Focusing Optics for e-Beam

Supersonic Gas-jet

Pulse-driven Solenoid

Pre-formed (Discharge) Plasma Channel ~5cm

Long Focus OAP
$F^{\#}\sim 20$-40, $I\sim 10^{18}$W/cm^2

GeV Class electrons

Booster
for Post acc.

Preformed Plasma Chanel for Booster produced by Z-pinch Discharge (under development)

10 OPTICS LETTERS / Vol. 25, No. 1 / January 1, 2000

Optical guidance of terrawatt laser pulses by the implosion phase of a fast Z-pinch discharge in a gas-filled capillary

Tomonao Hosokai, Masaki Kando, Hideki Dewa, Hideyuki Kotaki, Syuji Kondo, Noboru Hasegawa, and Kazuhisa Nakajima

Advanced Photon Research Center, Kansai Research Establishment, Japan Atomic Energy Research Institute, 8-1 Umemidai, Kizu-chyo, Souraku-gun, Kyoto-fu 619-0215, Japan

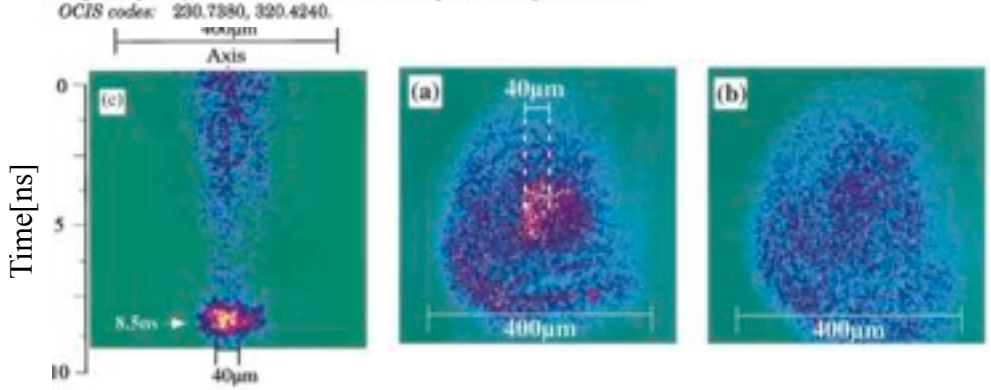
Kazuhiko Horioka

Department of Energy Sciences, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan

Received June 1, 1999

A new method of optical guidance by the implosion phase of a fast Z-pinch discharge in a gas-filled capillary is proposed. An imploding plasma column has a concave electron-density profile in the radial direction, just before a stagnation phase driven by a converging current sheet and a shock wave. The feasibility of optical guidance of a high-intensity (>1 × 10^{17} W/cm^2) Ti:sapphire laser pulse by use of this method over a distance of 2 cm, corresponding to 12.5 times the Rayleigh length, has been experimentally demonstrated. The guiding-channel formation process was directly probed with a He–Ne laser beam. The electron density in the fully ionized channel was estimated to be 2.0 × 10^{17} cm^{-3} on the axis and 7.0 × 10^{17} cm^{-3} on the peaks of the channel edge, with a diameter of 70 μm, as indicated by the experimental results, which were corroborated by a magnetohydrodynamics simulation. © 2000 Optical Society of America

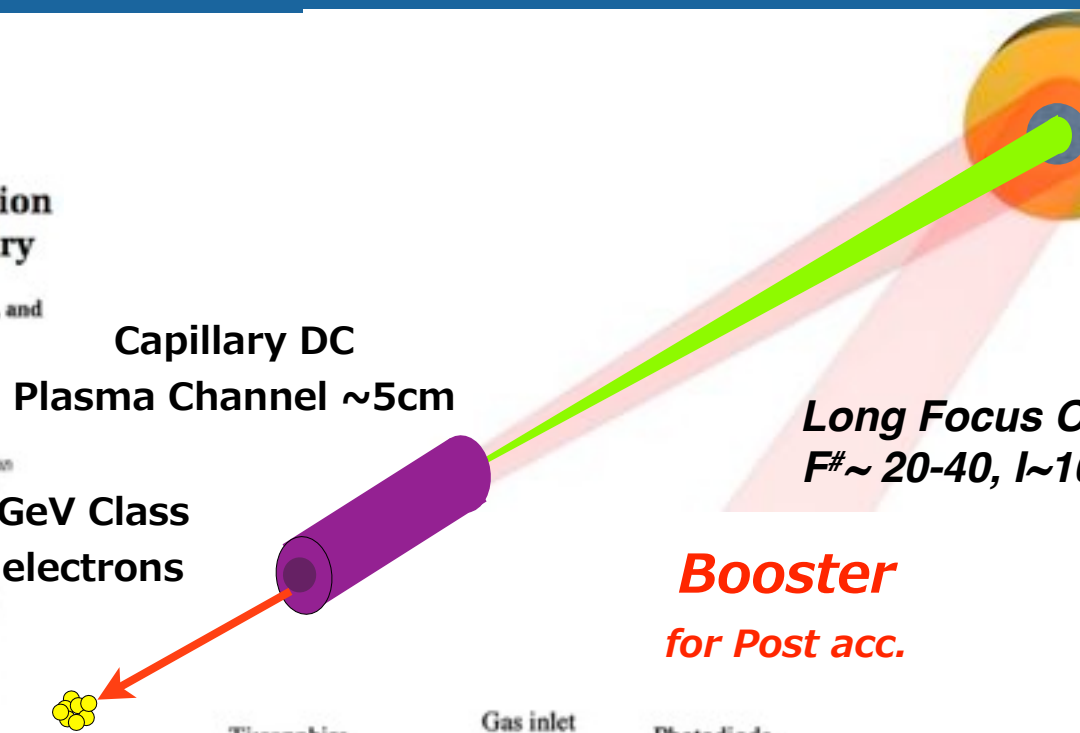
OCIS codes: 230.7380, 320.4240.

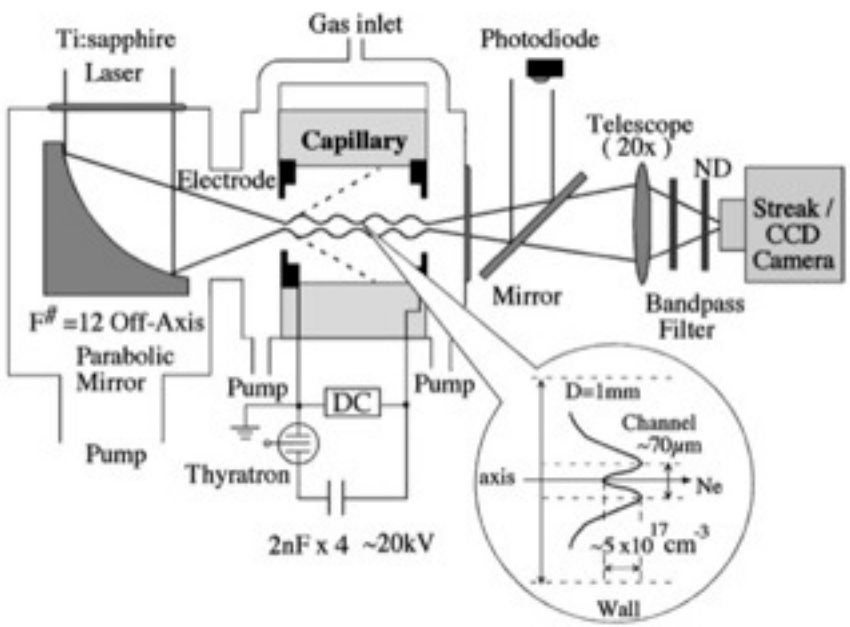


Streak Image of guiding channel formation

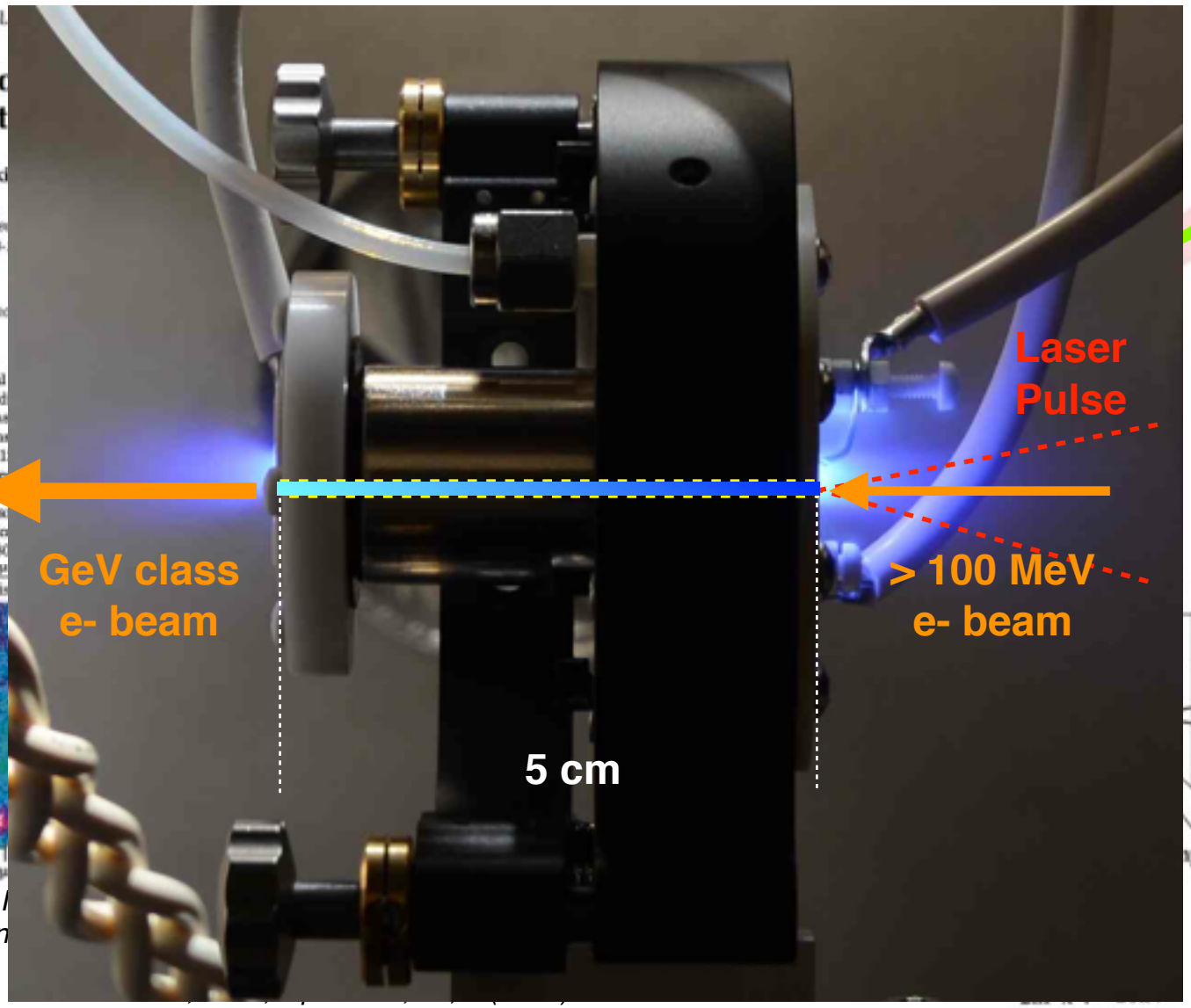
Images of guided Laser Intense Pulse

*T. Hosokai, et. al, Opt. Lett. , **25**, 1 (2000)*





Preformed Plasma Chanel for Booster produced by Z-pinch Discharge (under development)



10 OPTICS LETTERS / Vol.

Optical guidanc
phase of a fast

Tomonao Hosokai, Masaki

Advanced Photon Rese

Department of Energy Scienc

A new method of optical
is proposed. An implod
before a stagnation phas
guidance of a high-intens
2 cm, corresponding to 1
channel formation proce
ionized channel was
channel edge, with a dis
a magnetohydrodynamic

OCIS codes: 230.7380

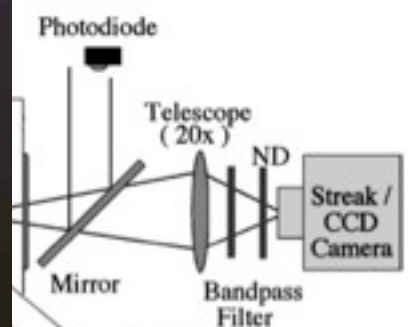
Axis

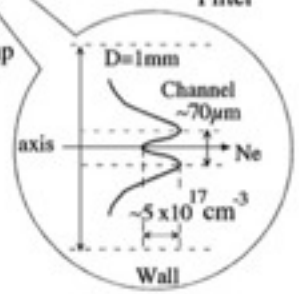
Time[ns]

Streak I
guiding chan

Long Focus C
F#~ 20-40, I~1

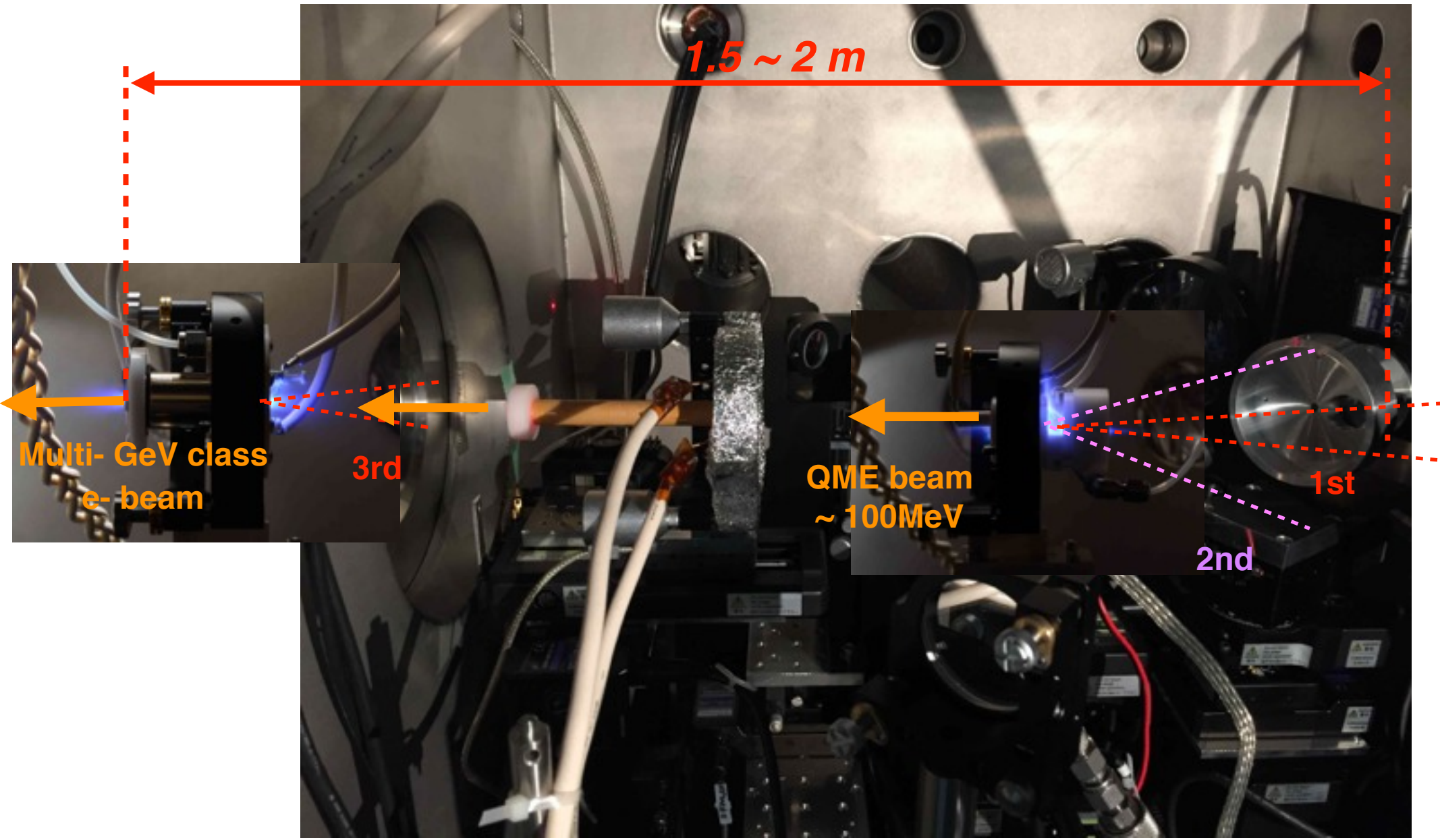
Booster
for Post acc.





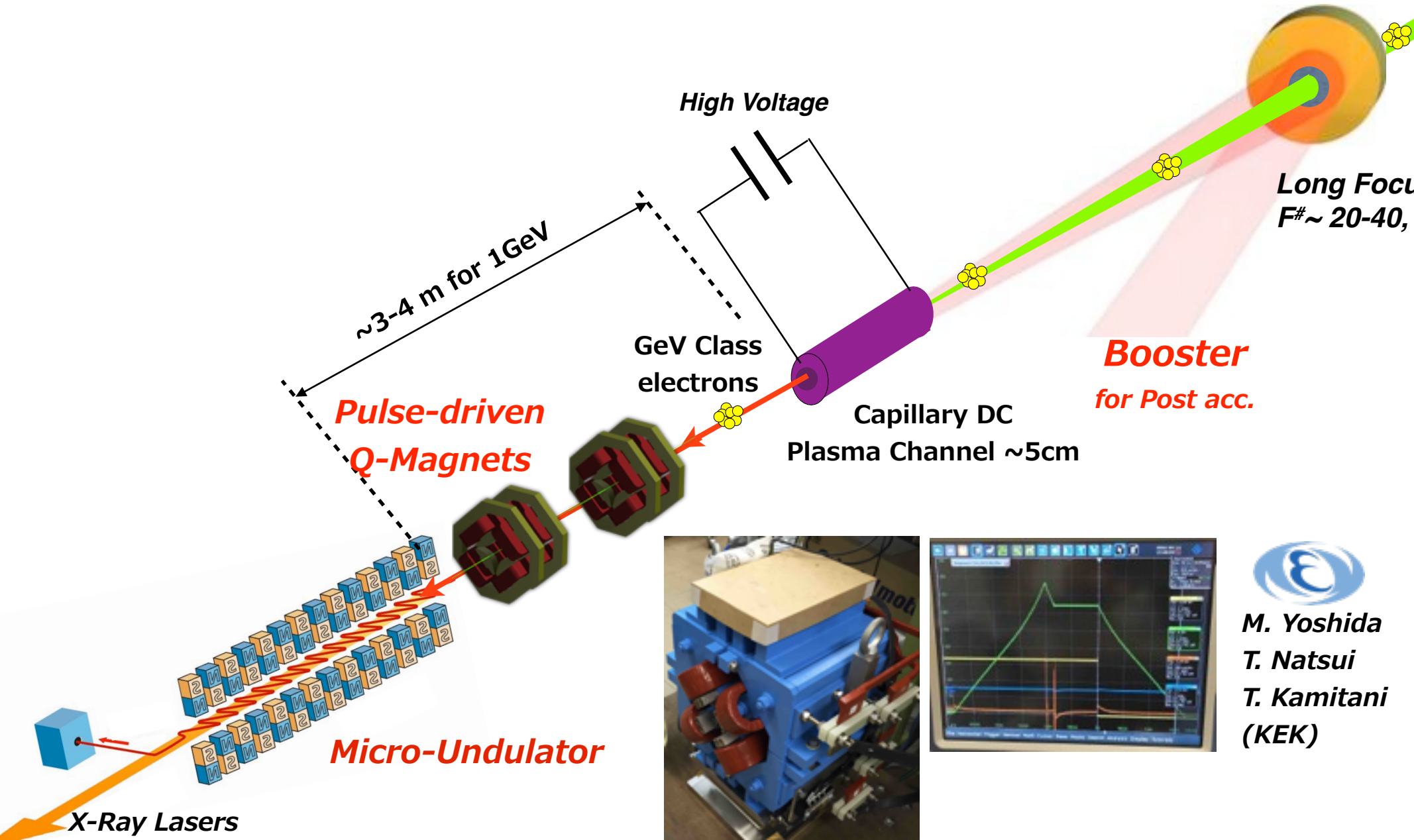
Electron Density Profile

Staging Acc. with Discharge Plasma Channels (under development)



Towards Laser-driven XFEL

革新的研究開発推進プログラム ImPACT
Impulsing Paradigm Change through Disruptive Technologies Program



M. Yoshida
T. Natsui
T. Kamitani
(KEK)

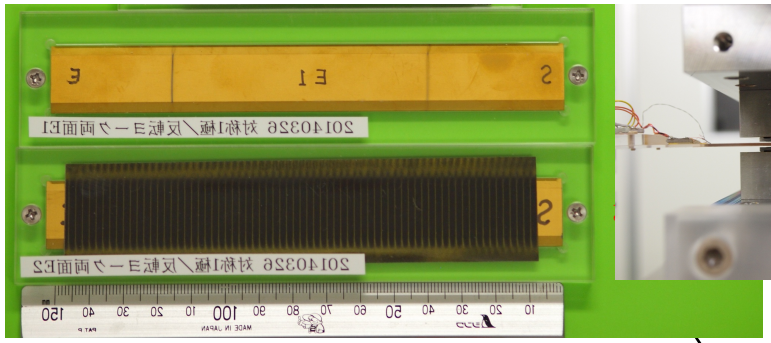
Towards Laser-driven XFEL

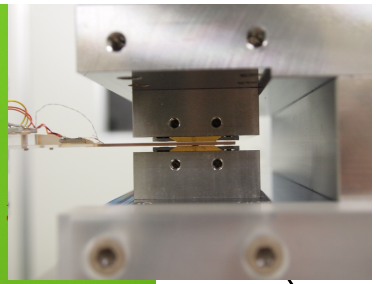
革新的研究開発推進プログラム ImPACT
Impulsing Paradigm Change through Disruptive Technologies Program

ImPACT-UPL; Pj1-1C: Micro-Undulator

S. Yamamoto
(KEK)

PF





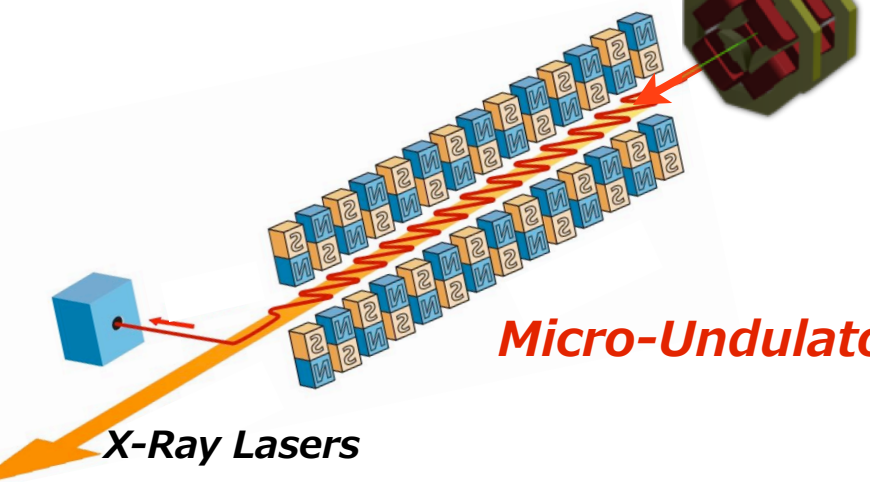
Long Focu
F#~ 20-40,

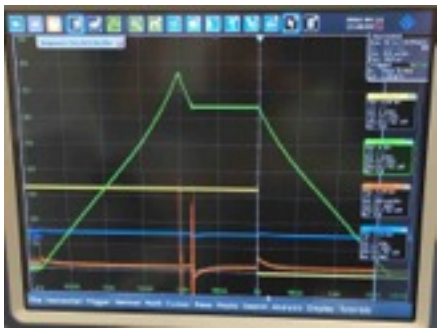
GeV Class
electrons

Booster
for Post acc.

Pulse-driven
Q-Magnets

Capillary DC
Plasma Channel ~5cm





M. Yoshida
T. Natsui
T. Kamitani
(KEK)

Towards Laser-driven XFEL

革新的研究開発推進プログラム ImPACT
Impulsing Paradigm Change through Disruptive Technologies Program

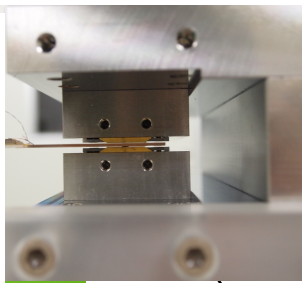
ImPACT-UPL; Pj1-1C:
Micro-Undulator

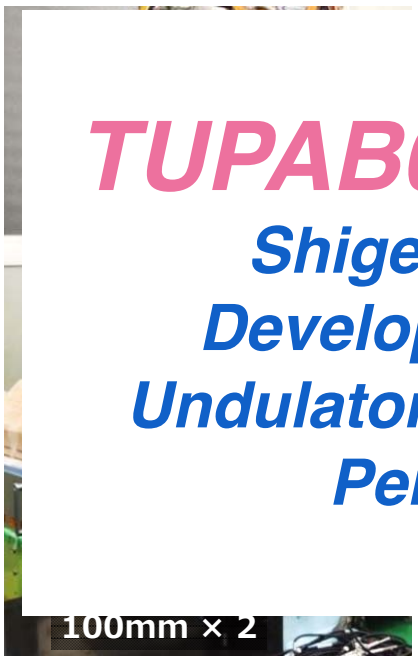
S. Yamamoto
(KEK)

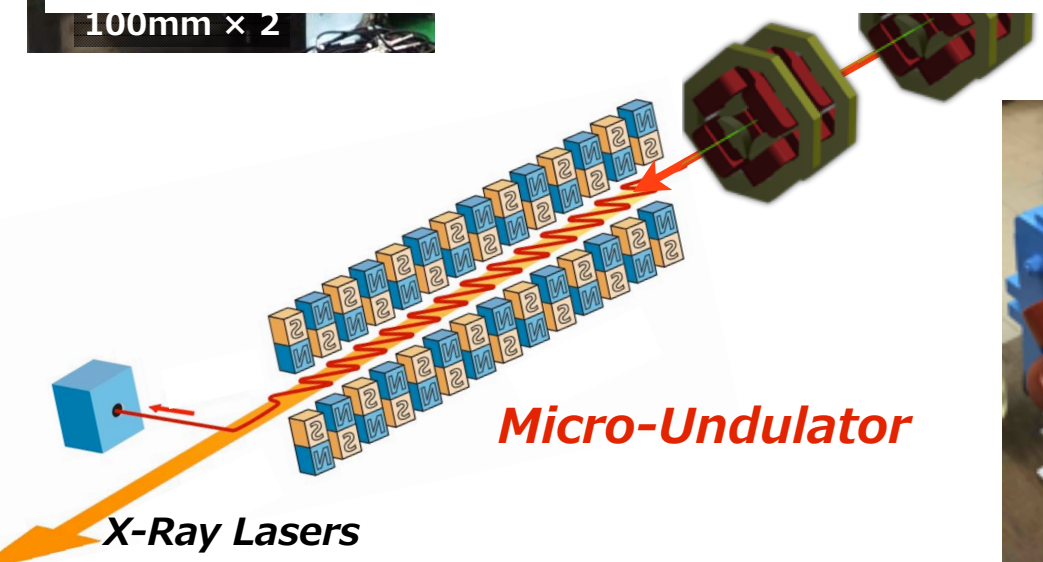
PF

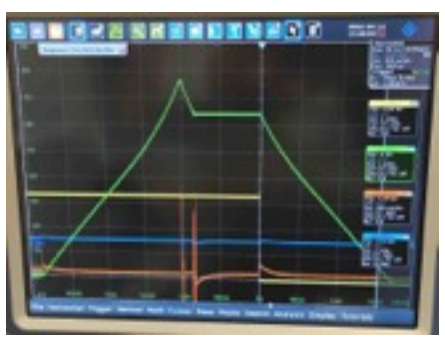
TUPAB061 (POSTER)

Shigeru YAMAMOTO,
Development of a Novel Undulator Having Very Short Period Lengths









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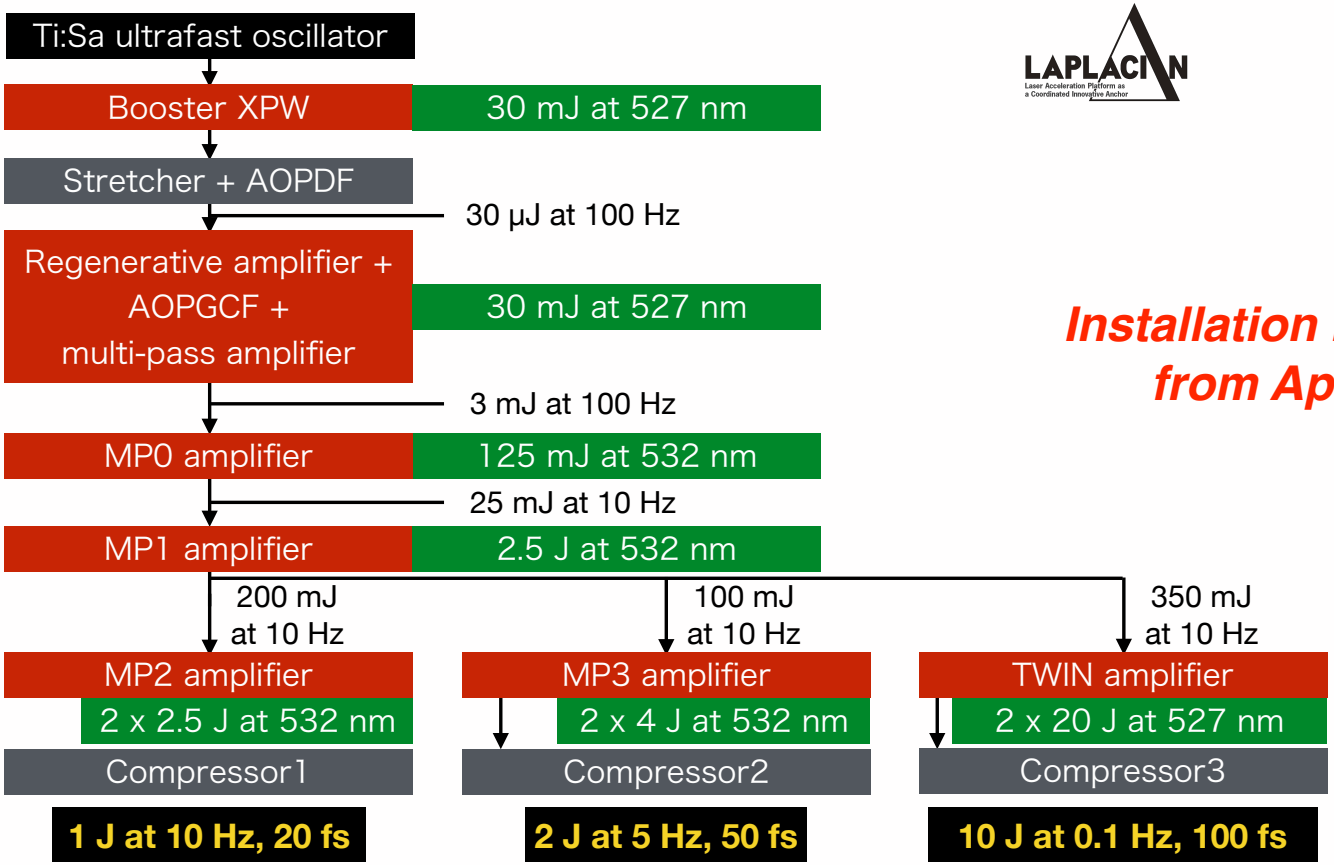
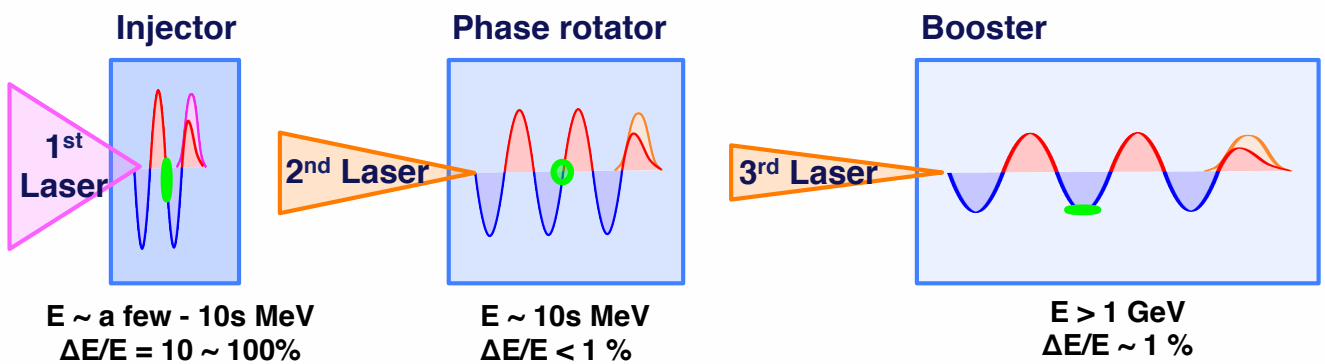
LWFA Platform @ SACLA (SP-8 Campus) under ImPACT-UPL Program



Installation has started from April 2017



LWFA Platform @ SACLA (SP-8 Campus)
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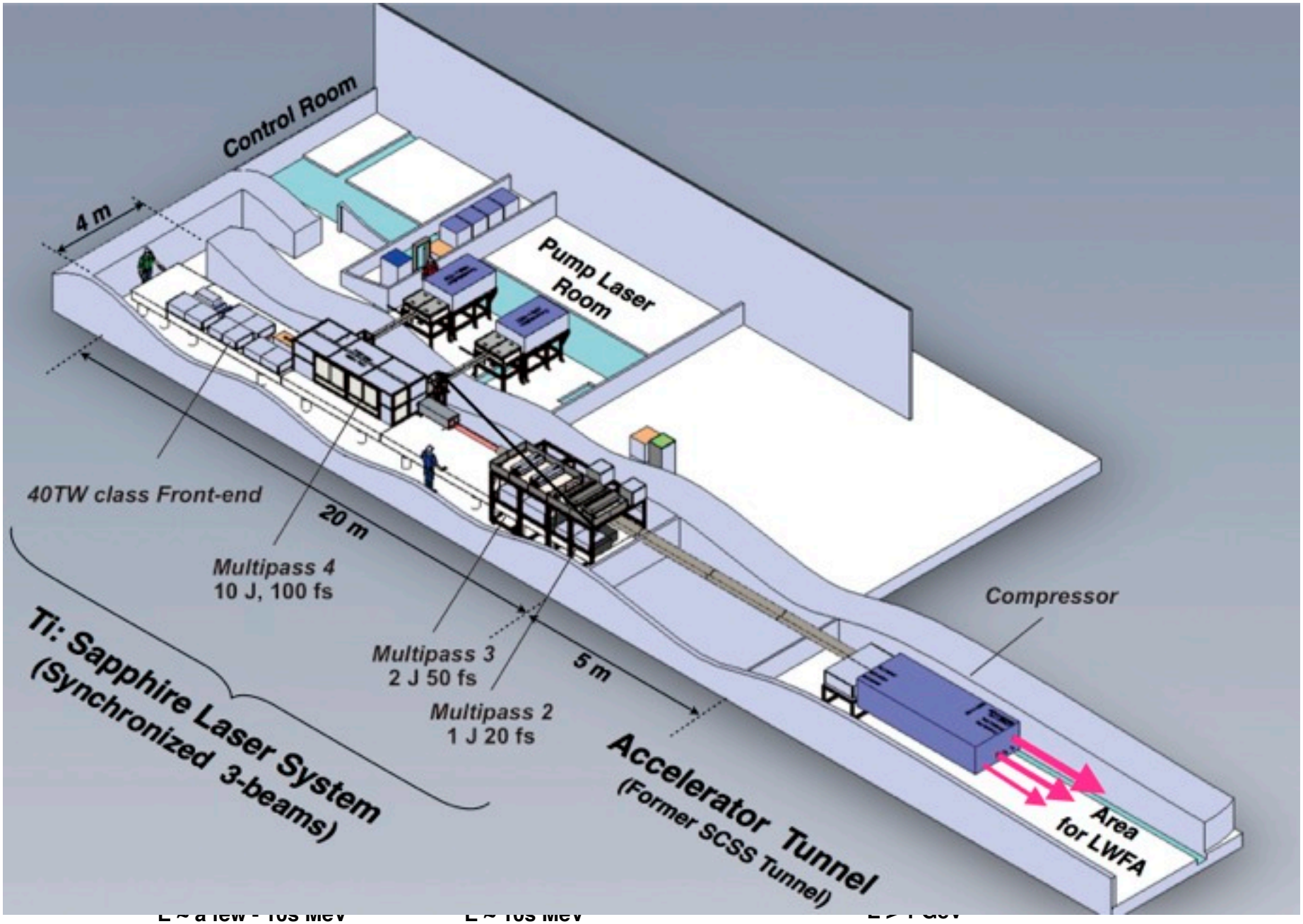

ΔE/E = 10 ~ 100%

ΔE/E < 1 %

ΔE/E ~ 1 %

LWFA Platform @ SACLA (SP-8 Campus)
under ImPACT-UPL Program

Accelerator Tunnel (SCSS) @ SPring8
April, 2016

ΔE/E = 10 ~ 100%

ΔE/E < 1 %

ΔE/E ~ 1 %

LWFA Platform @ SACLA (SP-8 Campus)
under ImPACT-UPL Program

LWFA Platform @ SACLA (SP-8 Campus)
under ImPACT-UPL Program

Summary

- ☑ **LWFA R&D program aiming for laser-driven tabletop XFEL(ImPACT-UPL) is on going, and LWFA platform is under constraction at SP-8 Campus in Japan.**
- ☑ **Staging LWFA (Injector-booster scheme) has been demonstrated. We believe this technique can be scalable to GeV class accelerators.**
- ☑ **Chanel guide LWFA with Preformed (discharge) plasmas has started.**

ACKNOWLEDGMENTS

This Research is supported by ImPACT R&D Program (Impulsing Paradigm Change through disruptive Technologies) promoted by the cabinet office of Japanese Government,and also supported by HERMES project (High Energy density Revolution of Matter in Extreme States).

革新的研究開発推進プログラム

ImPACT

Impulsing Paradigm Change through Disruptive Technologies Program

www.jst.go.jp/impact/sano

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