FIREX project
Status and prospect

- Strategy of Fast ignition research
- Recent progresses on fast ignition in ILE
- Next 5 years prospects

Institute of Laser Engineering, Osaka University
Yasunobu Arikawa, and FIREX-group

ILE Osaka

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A. Sunahara

Perdue University, USA

Y. Mori

Graduation school for the Creation of New Photonics Industries,

Acknowledge:
IFE forum, FIREX project, Laser fusion strategy meeting,
Kakenhi and NIFS collaborative reserch

Outline

1. In fast ignition,8 kJ heat-energy deposition is required to the ignition,
   Since the implosion of FI has been achieved, we have been focusing to the heating.

2. After several progress (2015~2018) at ILE-Osaka, the highest deposition-energy of > 80J (by 1.5kJ laser energy) was achieved.

3. News and future prospect
   - The frequency converting of LFEX laser was succeeded.
   - ”FIREX advisory board” was established.
   - 8kJ / 16Hz laser “J-EPoCH” R&D was started.
     A program of fusion-energy reactor demo has been proposed.

Fast ignition is an alternate approach having higher efficiency

ILE, Osaka

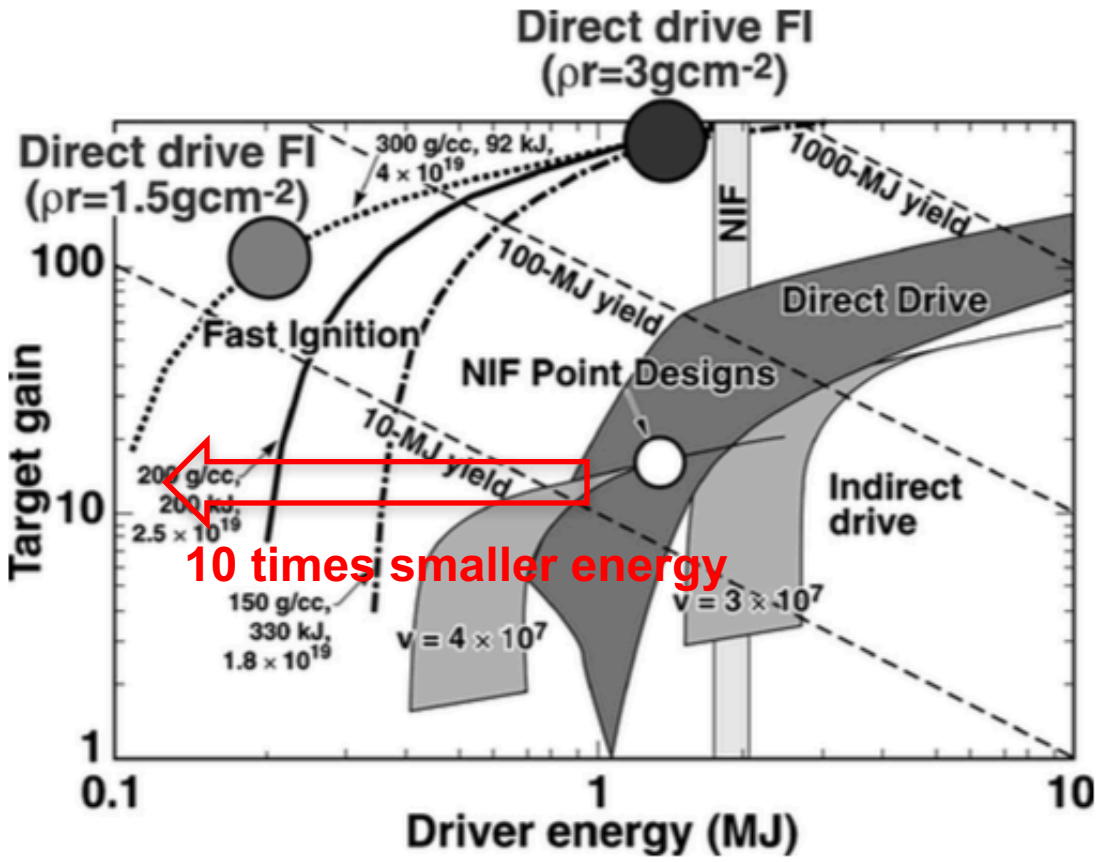
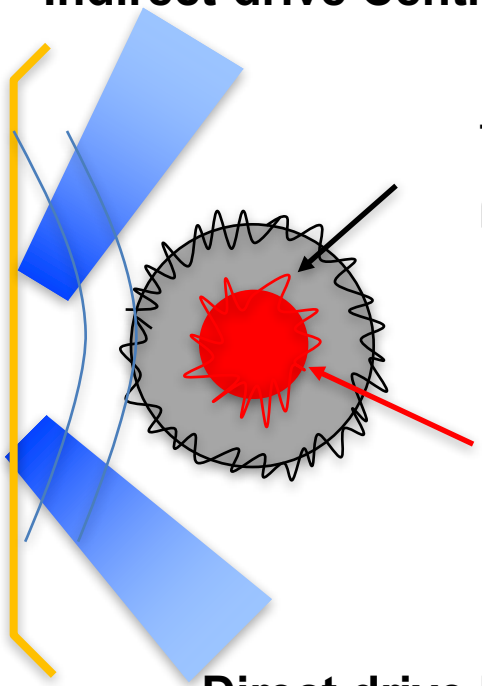


FIG. 5. Gain estimates for direct-drive fast ignition targets from a simple analytic model compared with numerically modeled CHS ignition designs for NIF. The FI gain curves are labeled with fuel density, energy, and $I\lambda^2$ in the ignitor laser beam, assuming a wavelength of 0.53 μm.

M.H.Key, Phys. Plasmas 14, 055502 (2007)

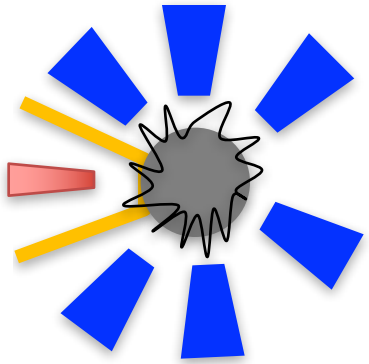
Indirect-drive Central ignitions



Main fuel
Ti <1keV
ρR>1.5 g/cm^2

Hotspot (Ignitor)
Ti >5keV
ρR>0.3 g/cm^2
Created by main fuel.

Direct drive Fast ignition



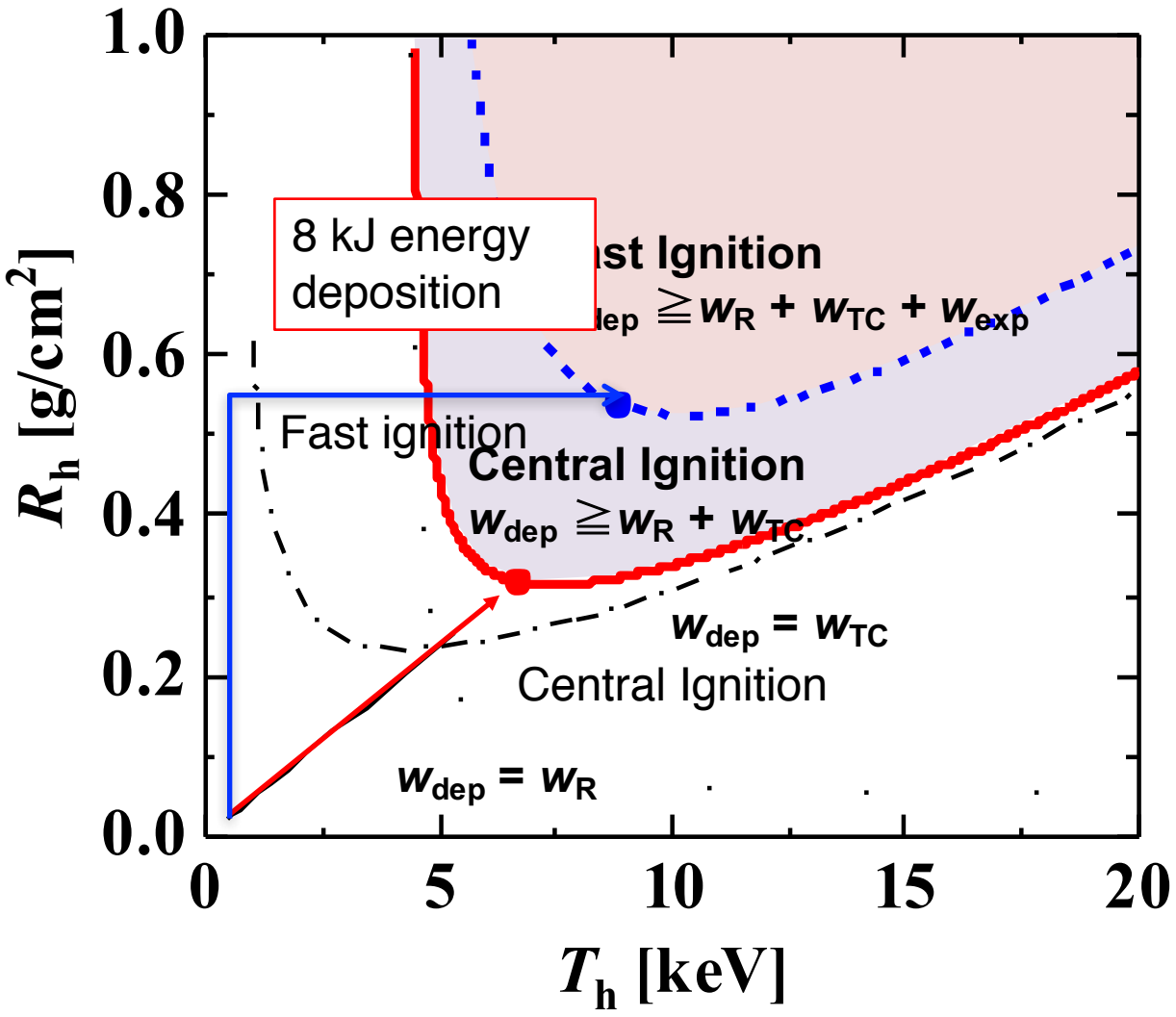
Ignitor
ρR > 0.3 g/cm^2
Ti ~0.1keV
+ external heating → >5KeV

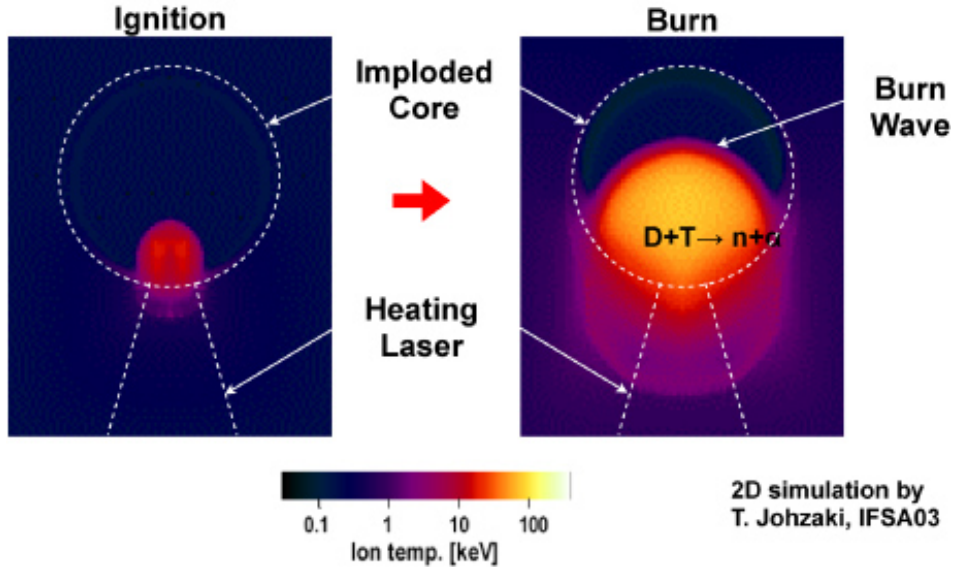
FIREX project strategy

ILE, Osaka

Alpha heating=Radiation loss + Thermal conduction loss + Expansion loss

0 in Central ignition





・**Once a burn wave stands, fusion energy gain is scalable to the size of fuel (ρR).**

Ref: H.Azechi, T. Johzaki, Plasma Fusion Research (Japanese) (2005)

FIREX project strategy

ILE, Osaka

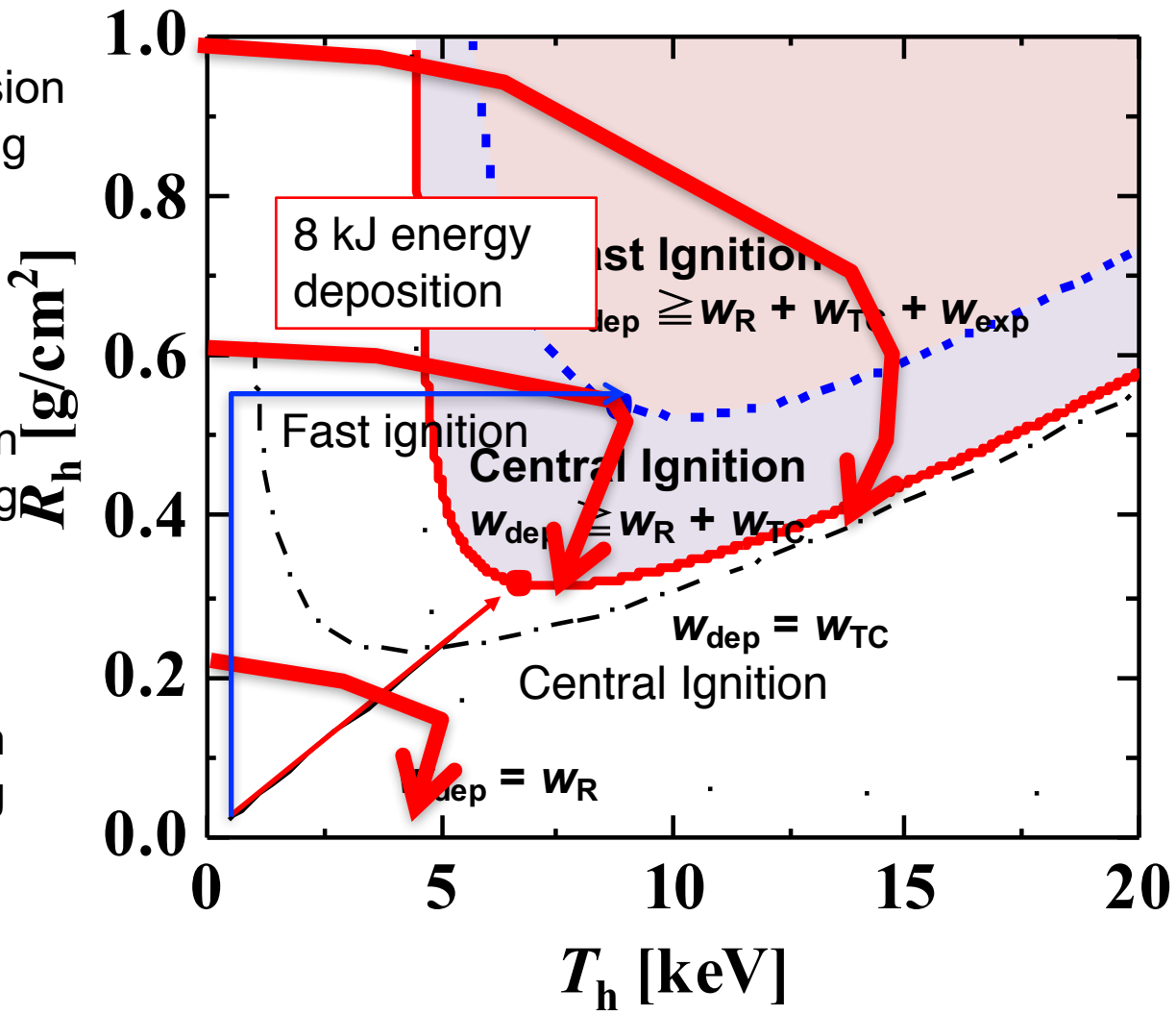
Alpha heating=Radiation loss + Thermal conduction loss + Expansion loss

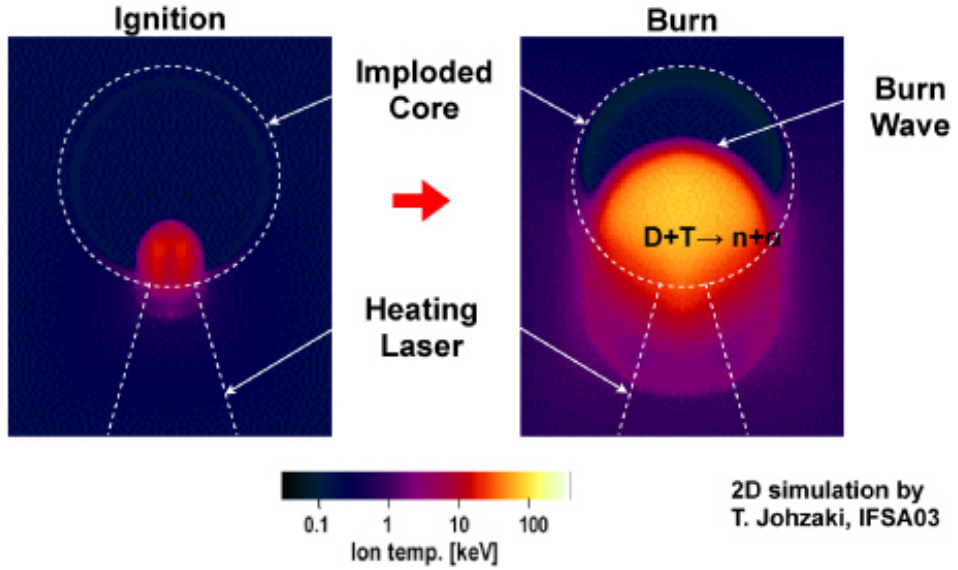
0 in Central ignition

Gain 100
500 kJ Implosion
200 kJ Heating

2030~
Gain :2
FIREX-II
50kJ Implosion
100 kJ Heating

~2022
FIREX-I now
3kJ Implosion
10 kJ Heating





・Once a burn wave stands, fusion energy gain is scalable to the size of fuel (ρR).

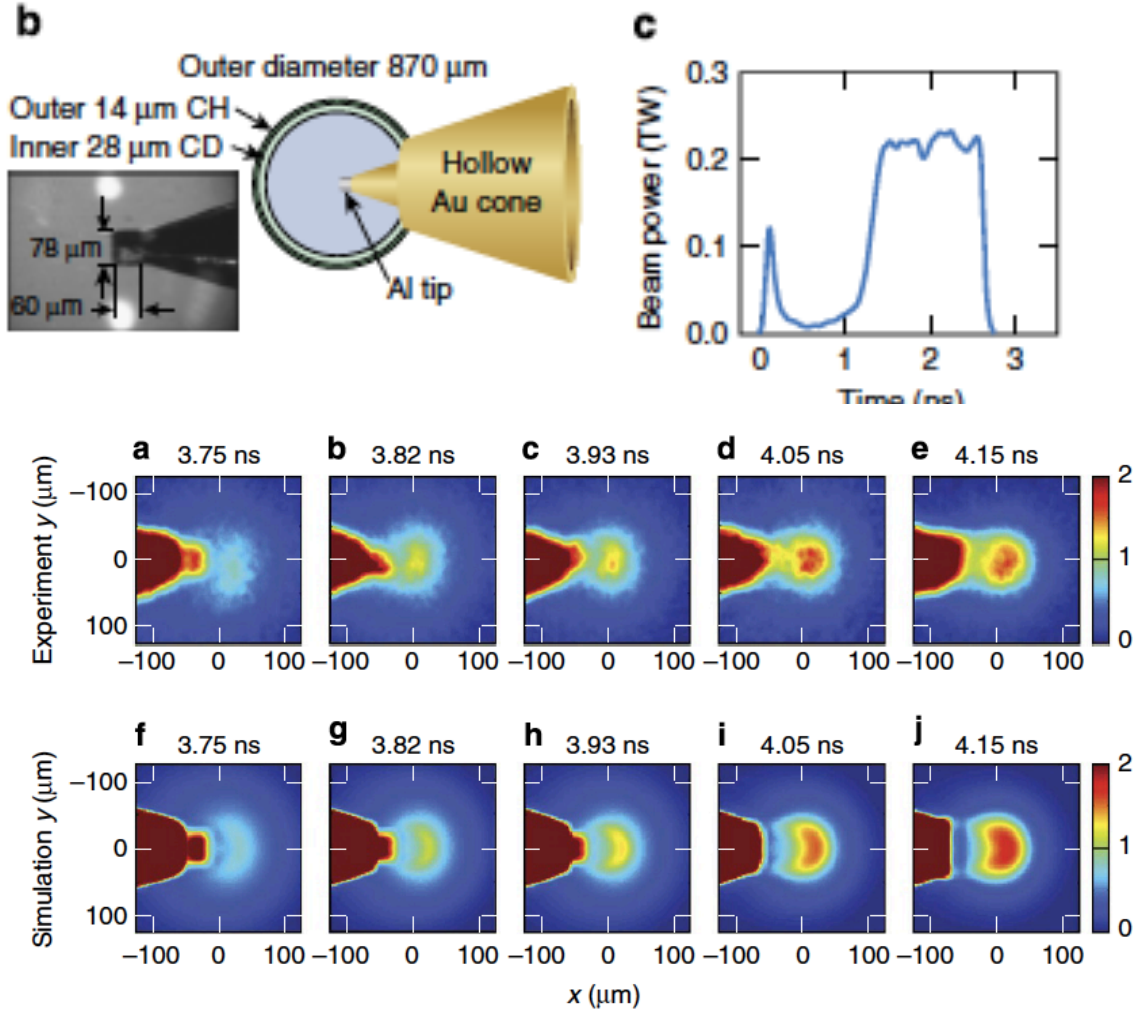
Ref: H.Azechi, T. Johzaki, Plasma Fusion Research (Japanese) (2005)

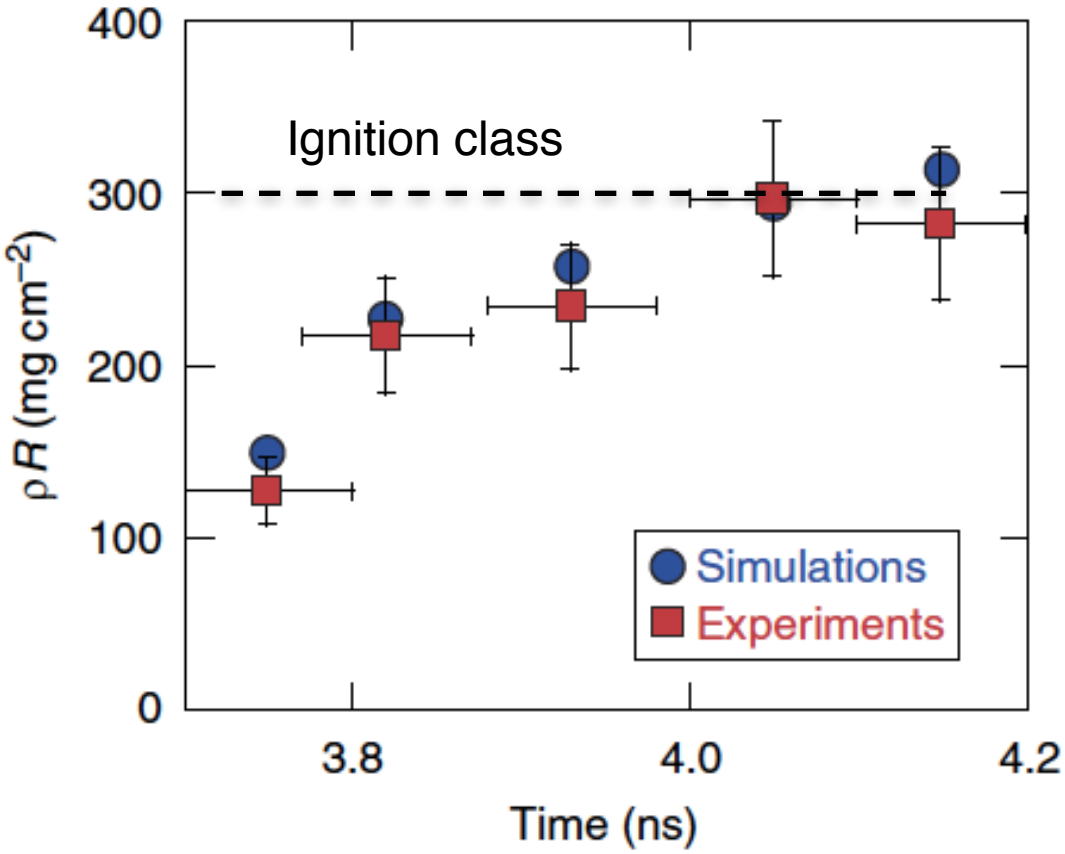
Fast ignition implosion has been achieved, thus ILE-Osaka has been focusing to “heating”

ILE, Osaka

OMEGA Experiment

0.3 g/cm^2 ρR was achieved with CD fuel, by E:18 kJ λ:0.35μm laser.





NIF’s experiment with ρR ~1.2g/cm^2 is already far enough for the ignition.

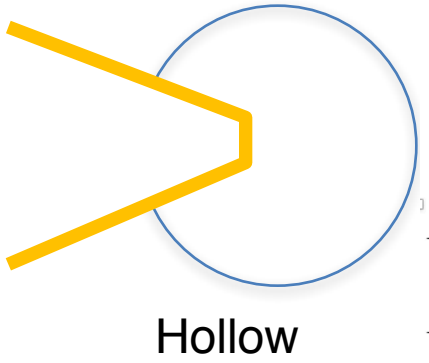
W.Theobald et al., Nature communications, 10.1038, (2014)

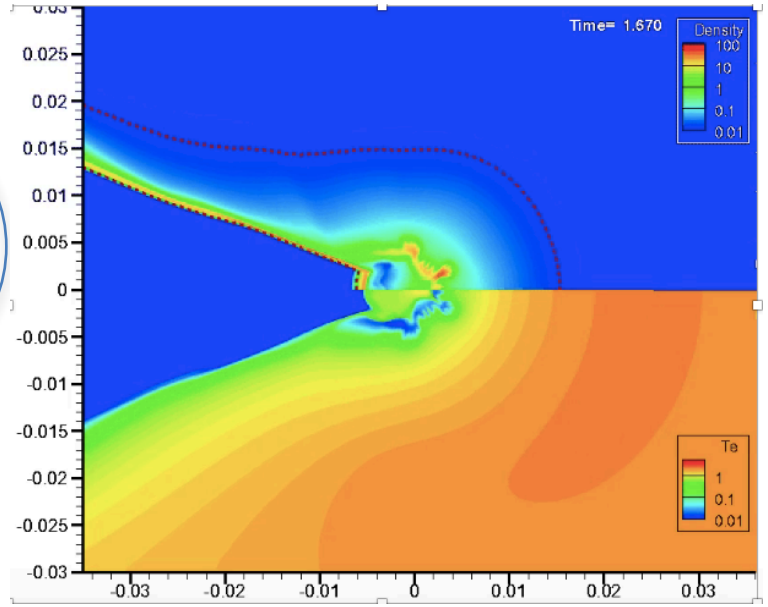
Recent major progress on fast ignition at ILE-Osaka
1. Shell to solid, with direct heating window

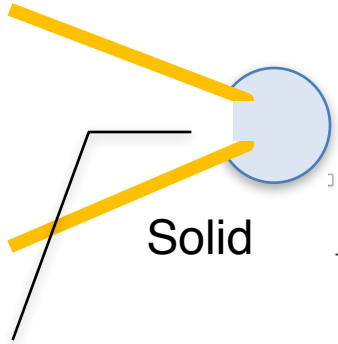
Before 2014

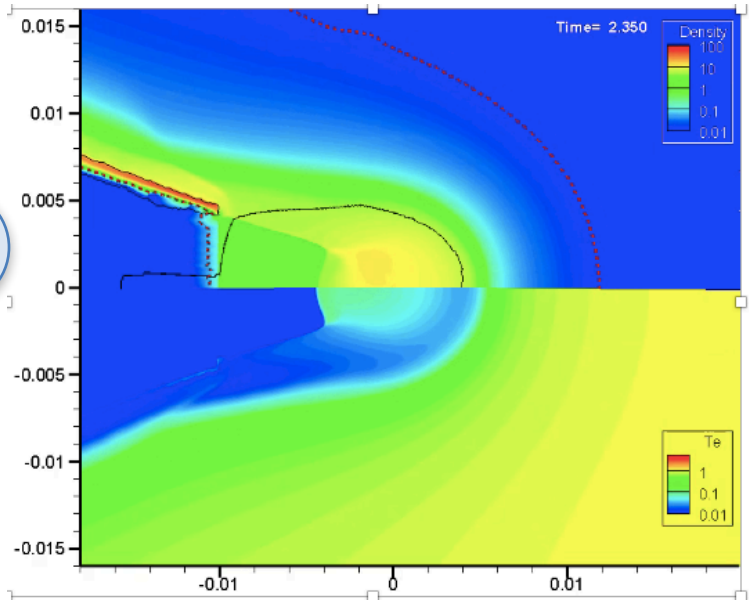
Solid target enables us to achieve more stable compression

After 2015









The design changes

- **Fast implosion → Slow compression : No Rayleigh-Taylor instability**
- **Direct heating window : Laser can directly heat the fuel**
- **Solid DT ice → Liquid DT : Less complex in the fabrication**
  4 kelvin 25 kelvin → much easier cooling system
- **A lot of benefits in current room temperature plastic targets**

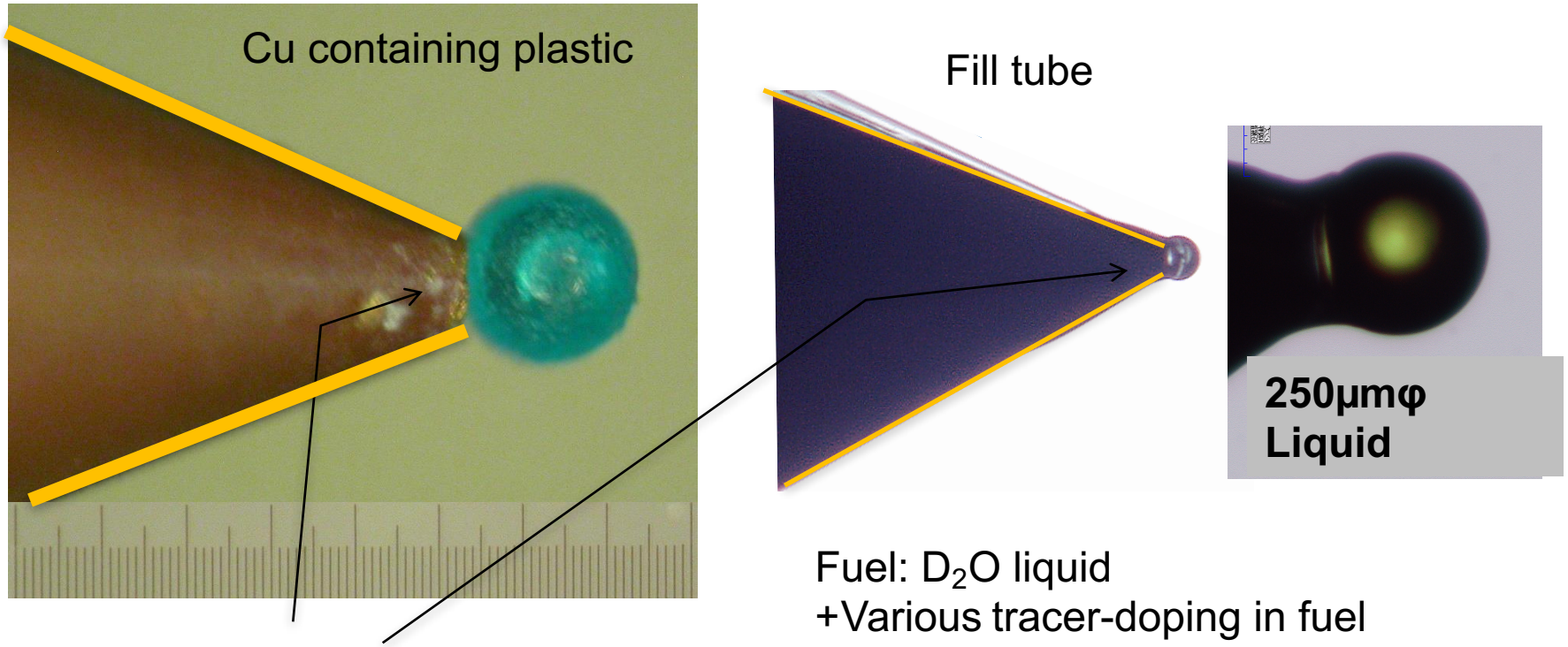
S.Fujioka, Y.Arikawa, etal.,
Physics of Plasmas 23, 056308 (2016)

Recent progress
2015~2018

Solid target design; more flexible tracer-ion-doping, direct heating window

ILE, Osaka

Room temperature targets



Direct heating window

Possible Diagnostics
- Electron Te
He-α X-ray lines
- Coupling efficiency
k-α X-ray line
- Ion Ti neutrons.
DDn, DTn,
activation

Fuel: D_2O liquid
+Various tracer-doping in fuel
D_2O solution+ Ti, Cu, T_2O Tritium (*planned in 2020)
or any material

Conventional cone-tip which significantly loss the energy is not needed,
→ Higher heating efficiency

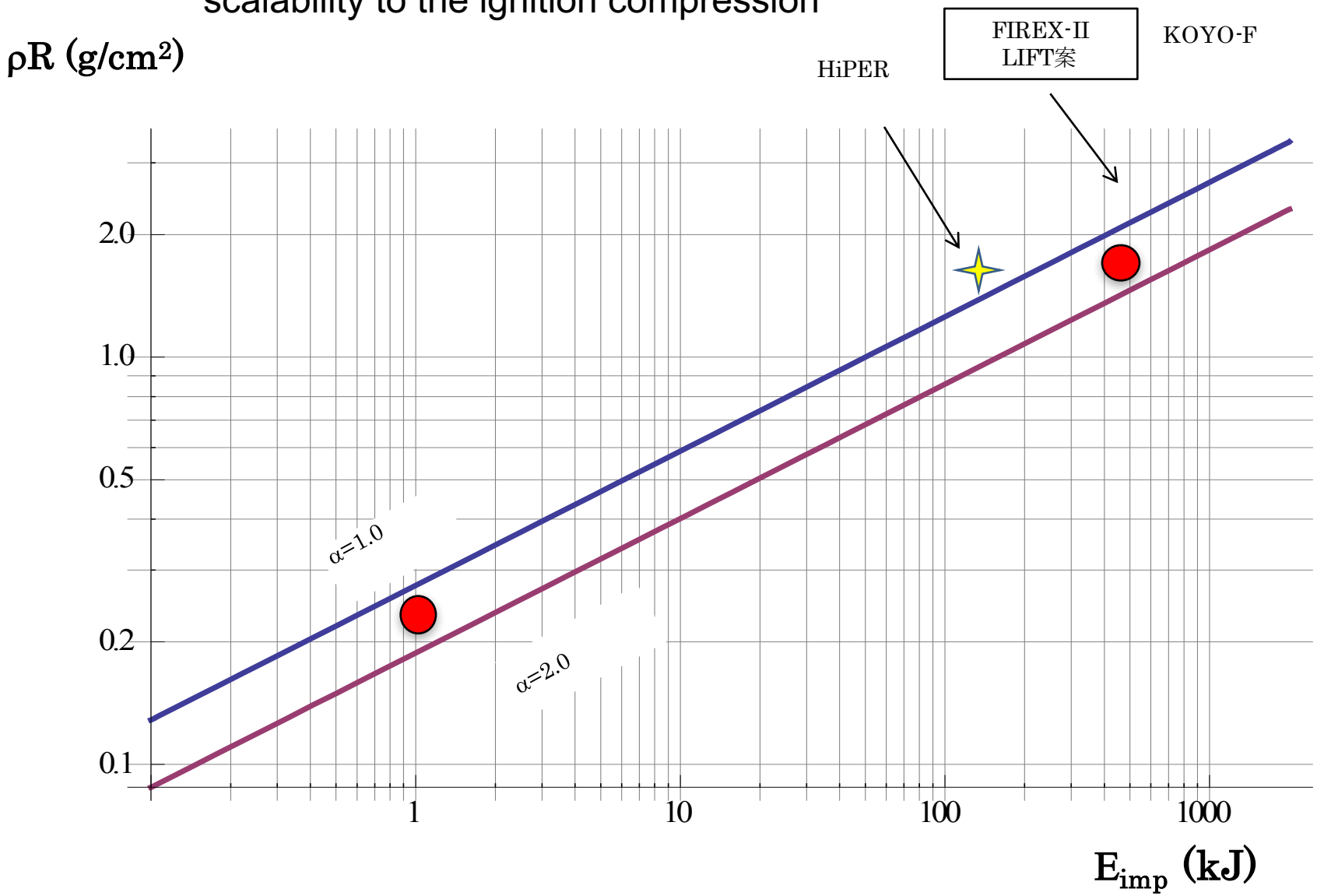
Y. Iwasa, et al., Fusion engineering and design, 125 89-92, (2017)
Y. Arikawa, et al.F*usion Science and Technology* accepted (2019)

Solid target compression is scalable to ignition

GEKKO XII 1kJ ρR> 0.2 g/cm² to ignition 500kJρR>1.5g/cm²

ILE, Osaka

scalability to the ignition compression



N.Nagatomo, et al., Nuclear Fusion, Volume 59, Number 10 (2019)

Recent progress
2015~2018

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ILE, Osaka

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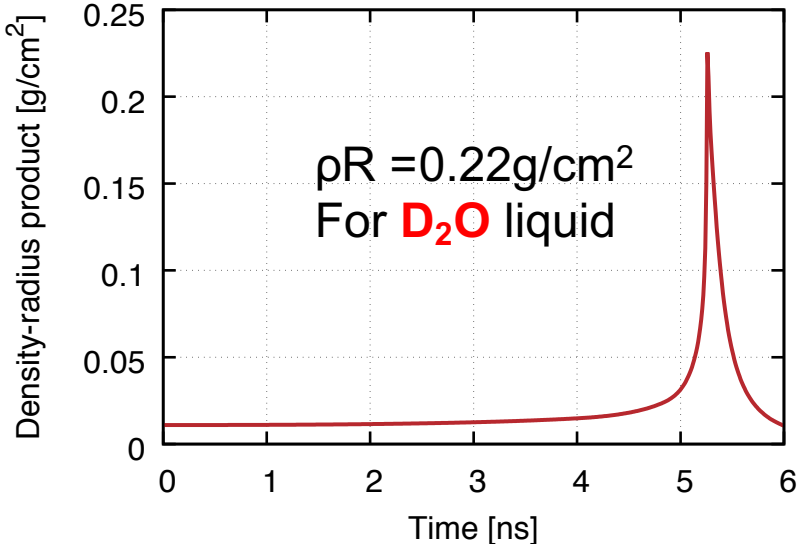
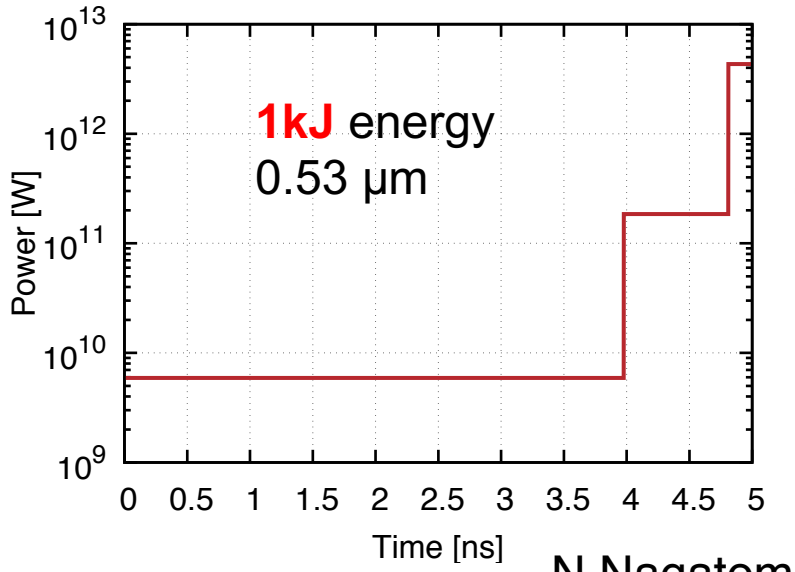
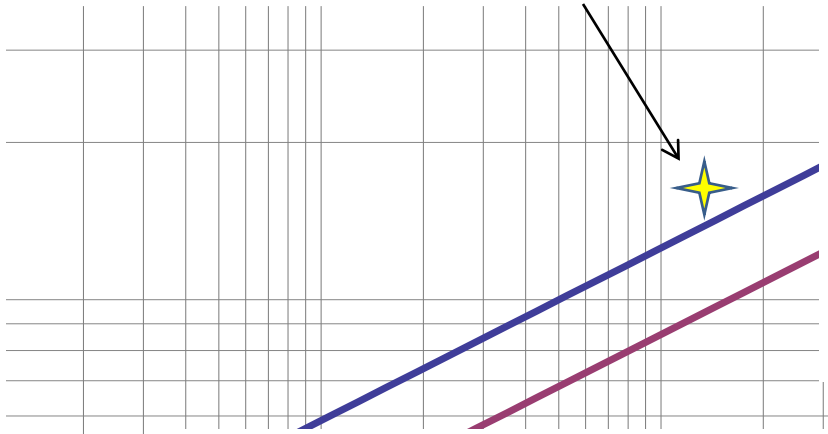
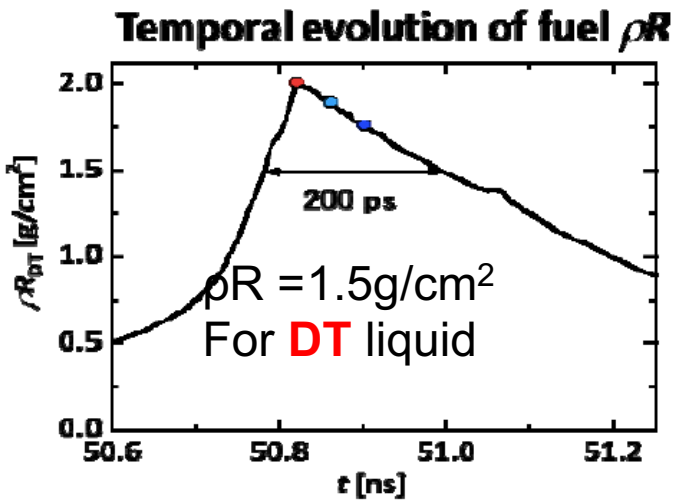
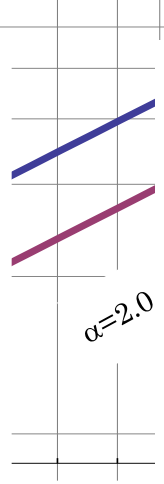
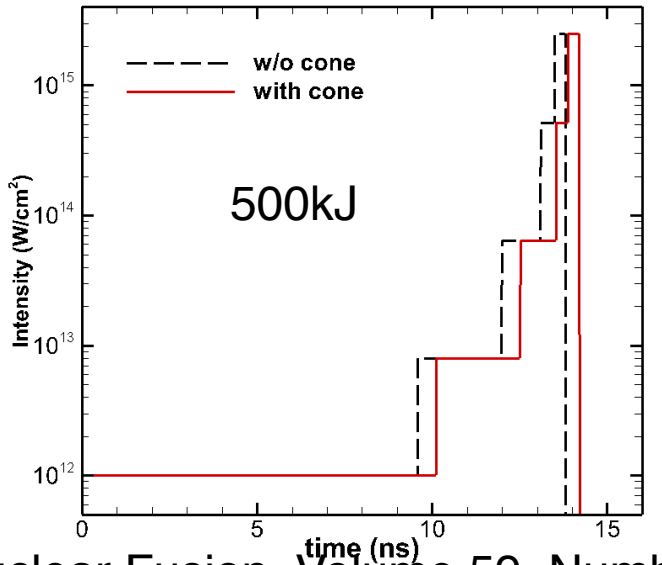


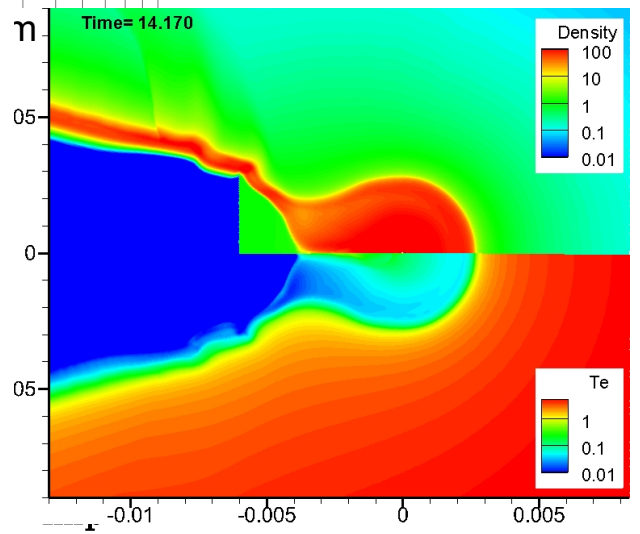












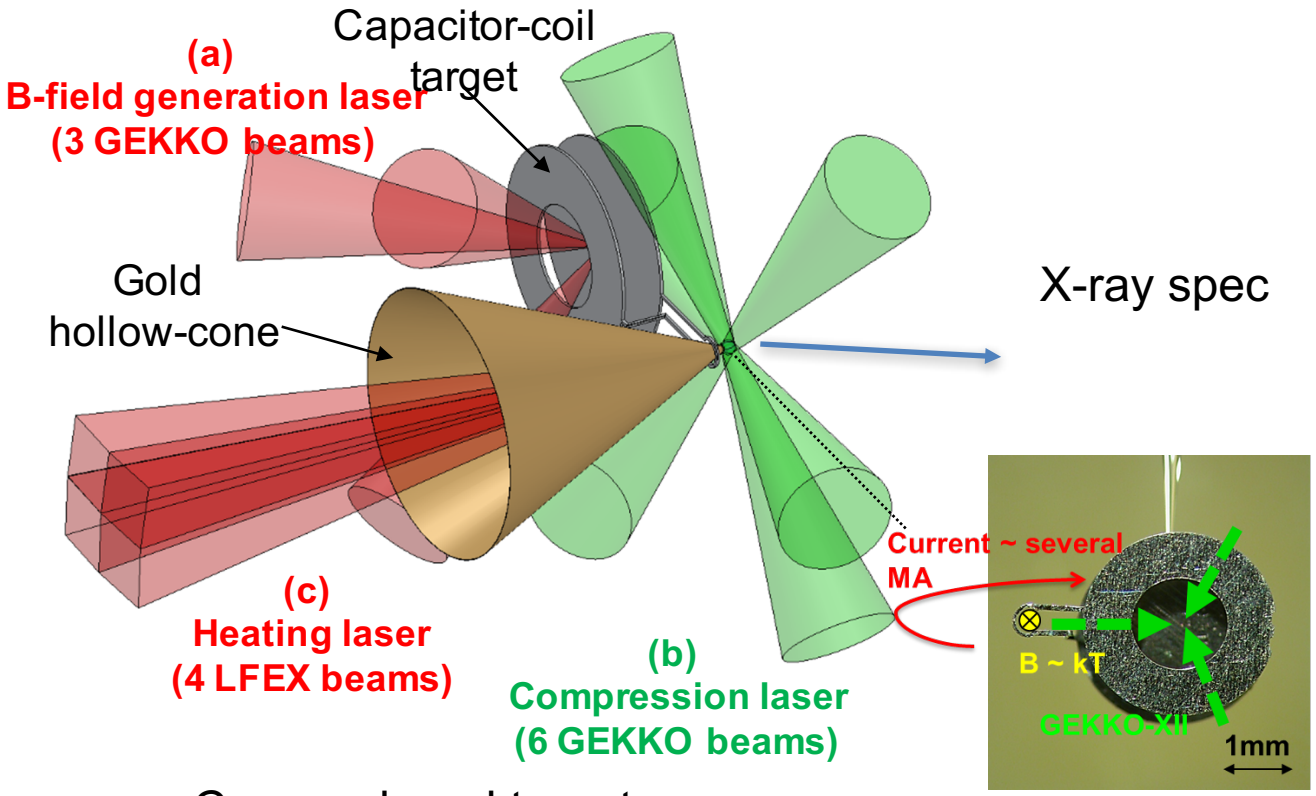
N.Nagatomo, et al., Nuclear Fusion, Volume 59, Number 10 (2019)

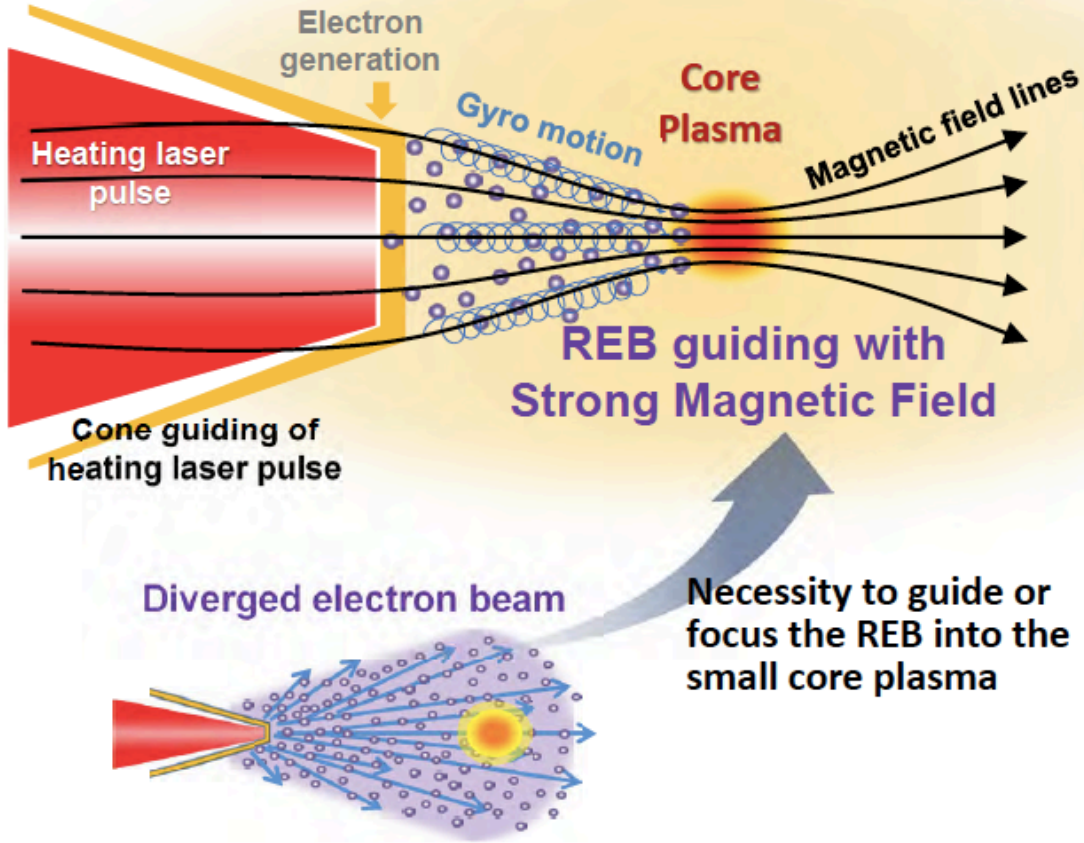
Recent progress
2015~2018

Recent major progress on fast ignition at ILE-Osaka
2. External magnetic field guiding

ILE, Osaka

Experimental set up





From the X-ray line spectrums, the electron temperature was estimated

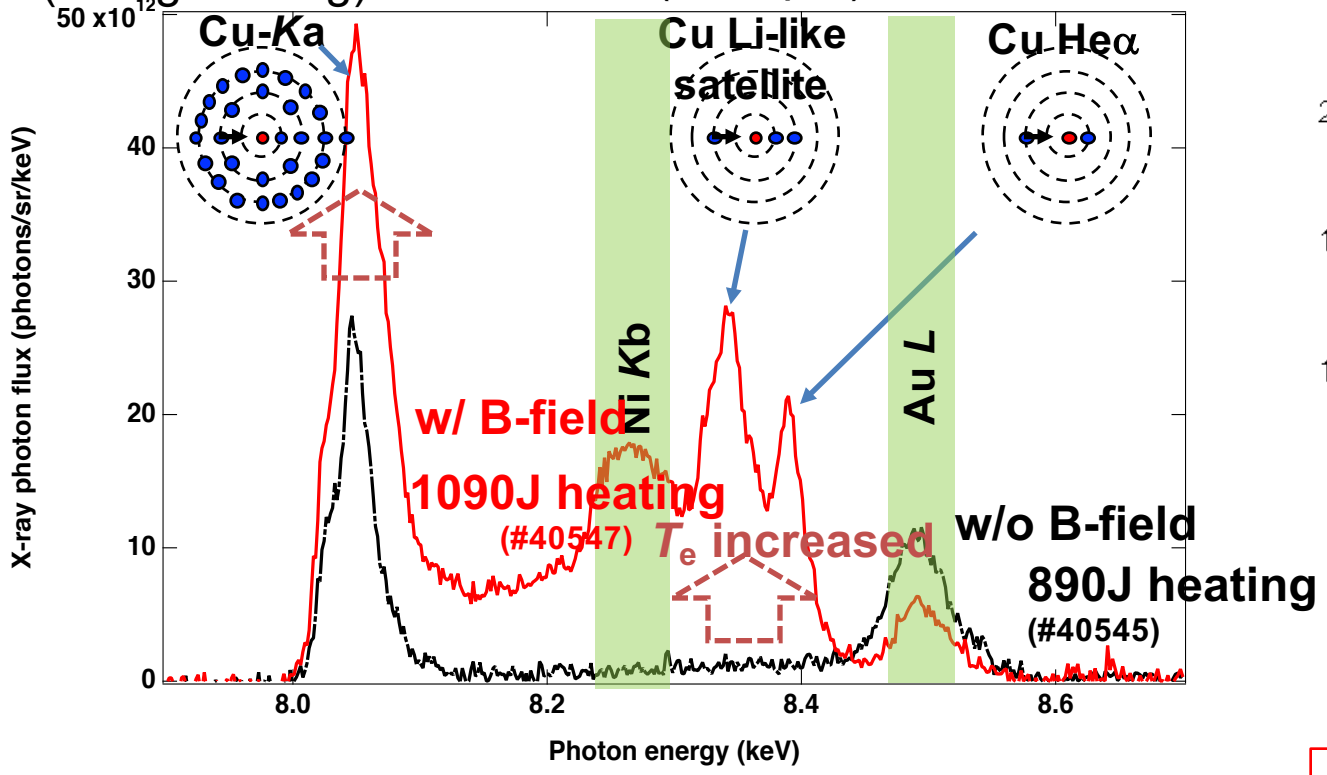
S.Fujioka, Y.Arikawa, etal.,Physics of Plasmas 23, 056308 (2016)
L.Law, et al., Appl. Phys. Lett. 108, 091104 (2016)

New targets achieved record deposition energy
Magnetic field doubled a heating, Direct heating created a hotspot

ILE, Osaka

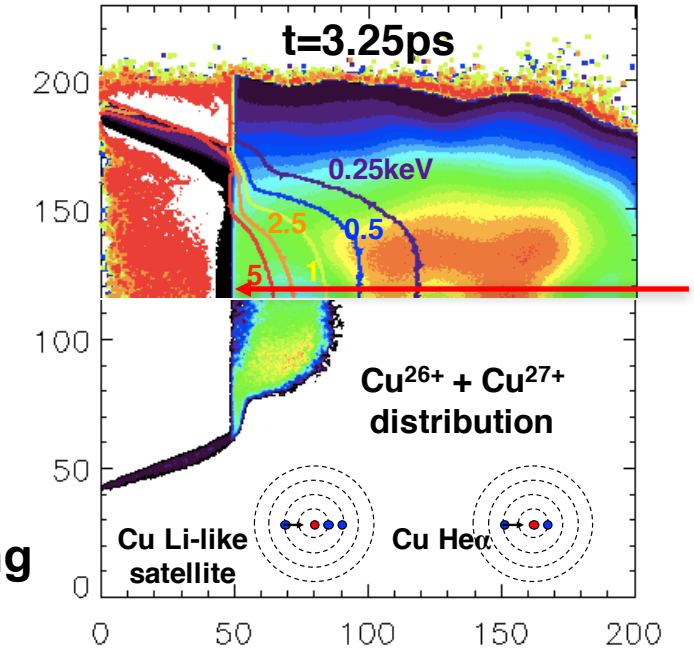
kα line shows
electrons collides to fuel
(=drag heating)

Highly ionized
ions shows 2keV /10g/cm^3
(Hot spot)



~80J heating by1500J laser at experiment
(50J drag heating + ~30J thermal diffusion)

2D-PIC simulation indicated
In locally core was heated to ~5 keV

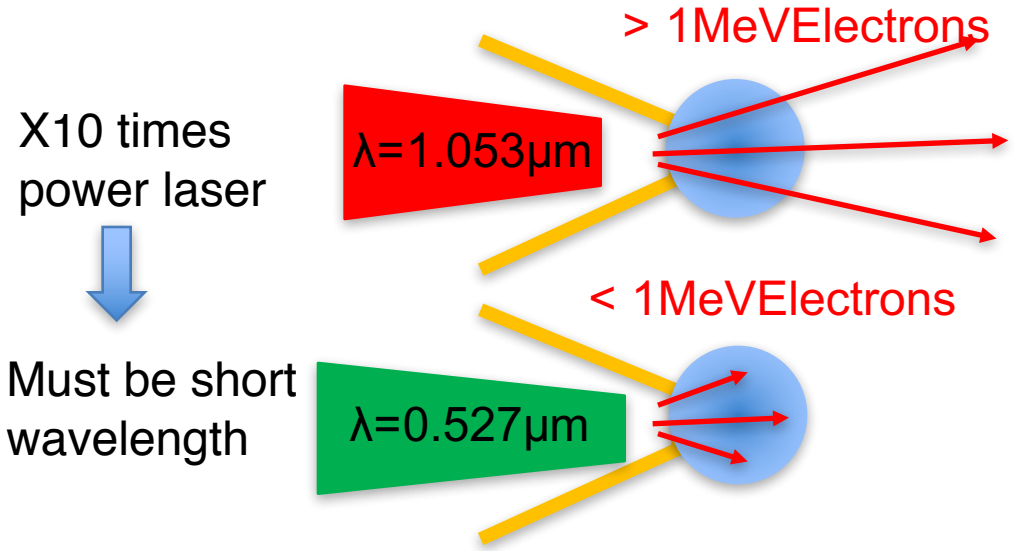


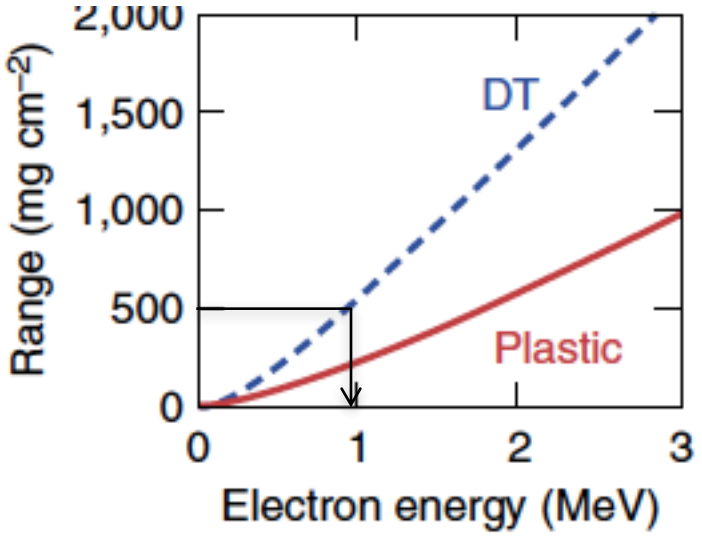
A hot spot
created by
thermal diffusing
5keV/10gcm^3
~10μm

In the simulation ~200J
drag heating+ thermal diffusion

S.Sakata, Nature.Comm. (2018)
K. Matsuo, Nature. Comm. (under review)

Demand for short-wavelength heating laser





Ignition requires : 8kJ/ 30μm /10ps
= ~10^{20} W/cm^2 laser intensity is needed

E_{ave} must be less than 1 MeV

however electron energy = $E_{ave} \propto \sqrt{I\lambda^2}$

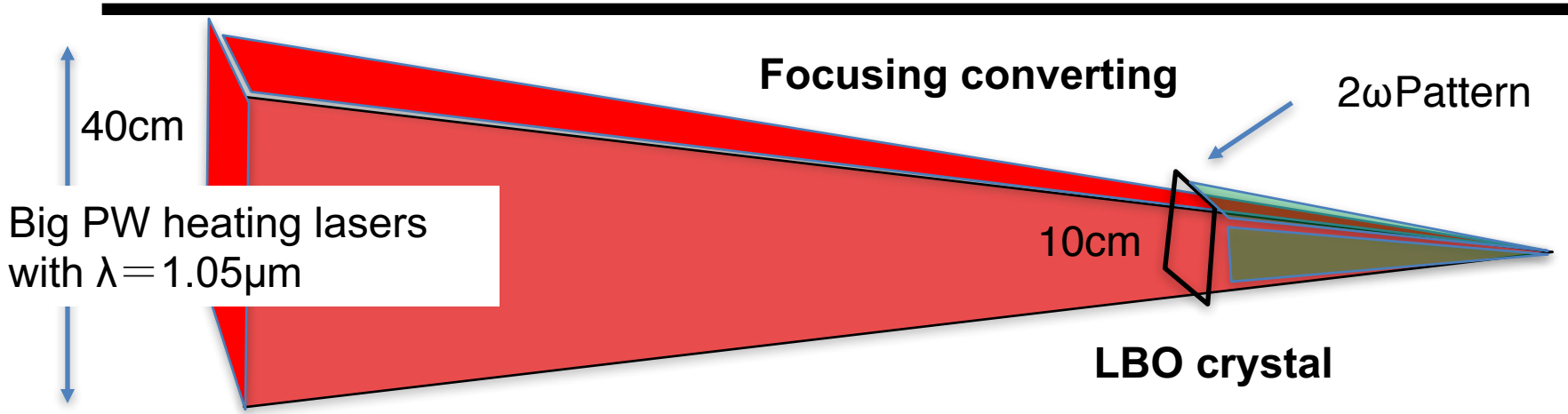
10^{20} W/cm^2 laser with λ=1.053μm will produce $E_{ave} \sim 7MeV$ which can not heat core up.

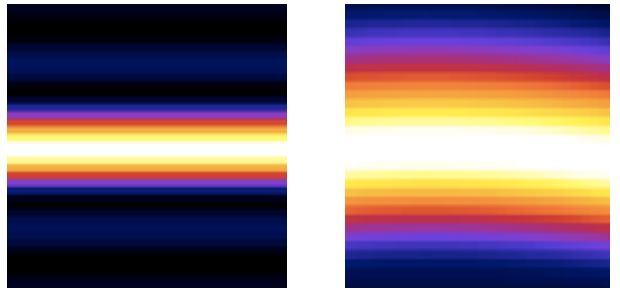
M. Key'
"There will be a need to use the $(I\lambda^2)^{0.5}$ scaling to reduce the electron energy by reducing the laser wavelength below 1μm. The second and third harmonics of the 1.05-μm Nd glass laser are desired, however, would require significant R&Ds. M.Key: Phys. Plasmas 14, 055502 (2007)

News and future
2019~

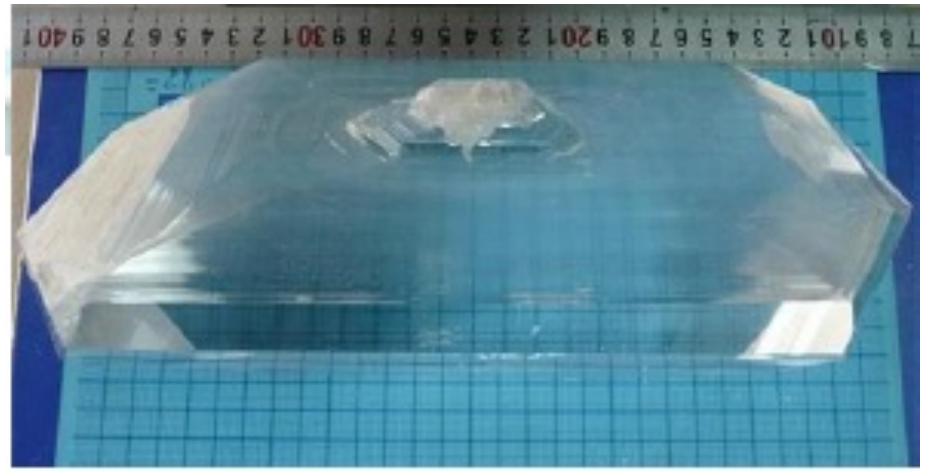
New frequency conversion with a small optics

ILE, Osaka

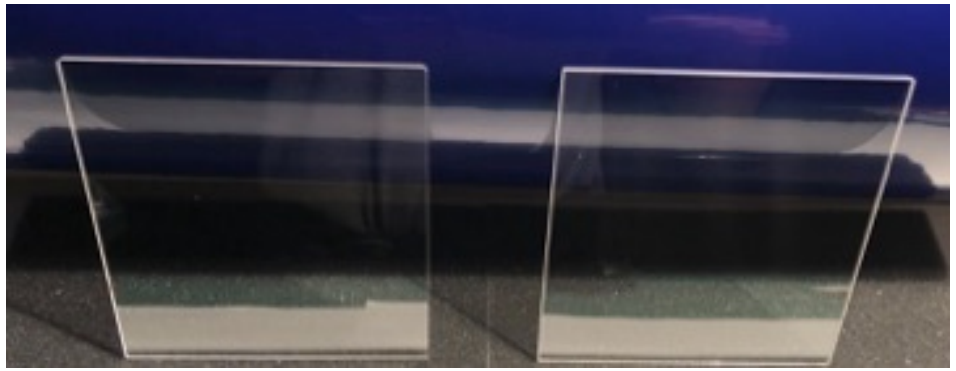




LBO realizes the “ focusing frequency conversion”
Recent largest LBO crystal has ~ 20cm



Thin (~ 0.5mm) LBO realize high intensity SHG
> 1.5 TW/cm^2.



10cmx10cm=100cm^2 → > 250J conversion

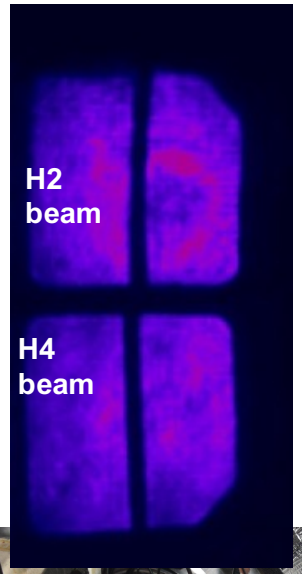
This method is scalable to up to 4 ω (266nm) harmonics.

Y. Arikawa, et al., in preparation,

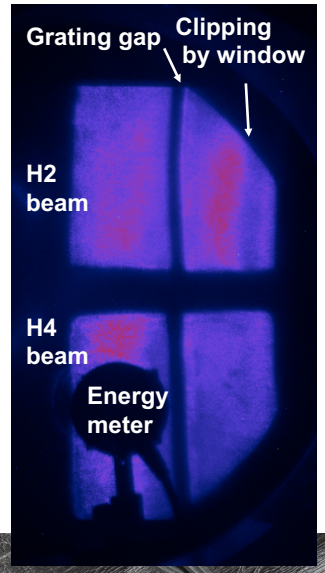
First demonstration of second harmonics on LFEX

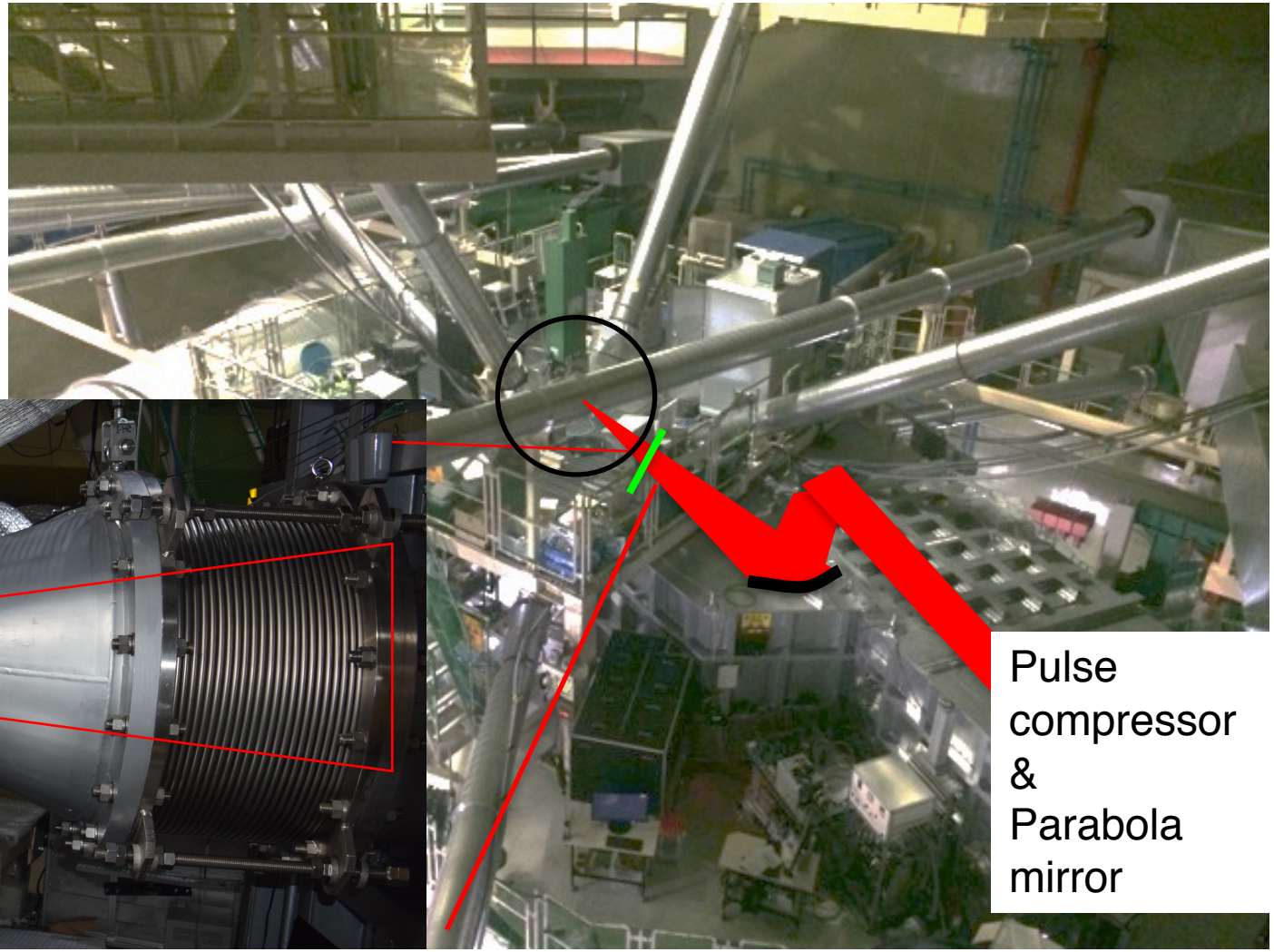
ILE, Osaka

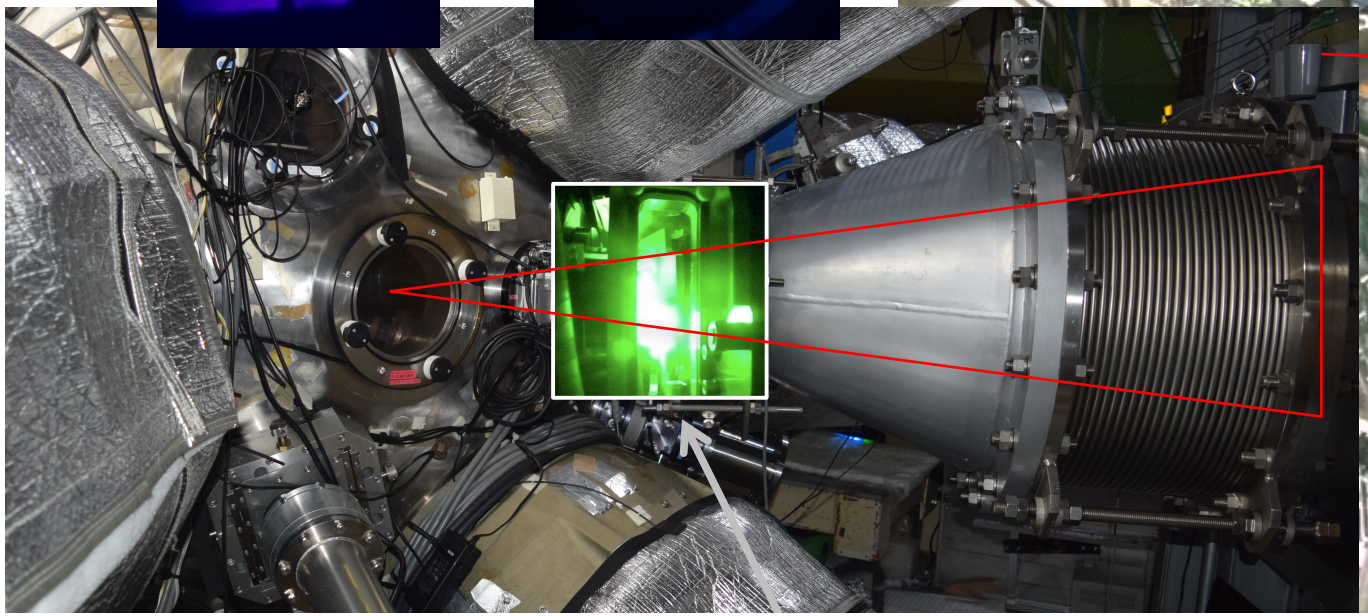
Input 1omega



2omega pattern



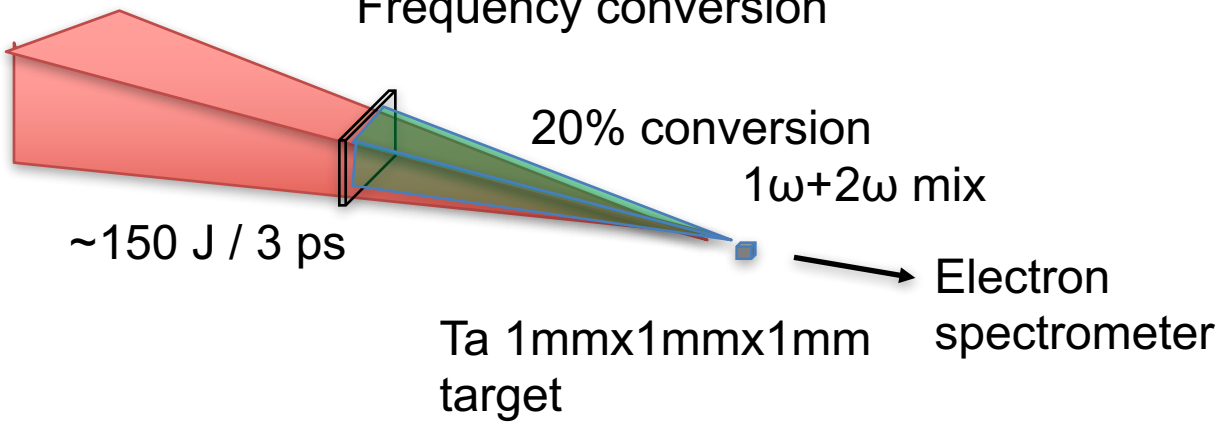


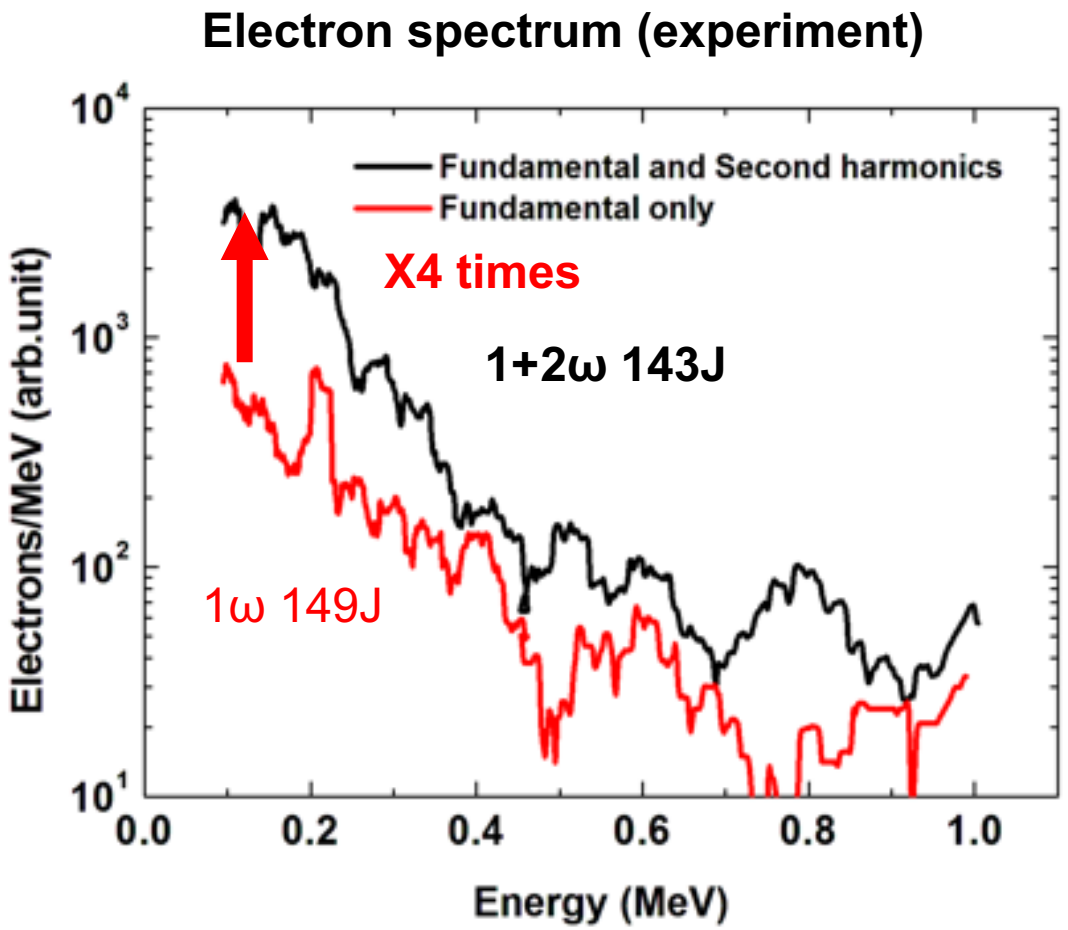


News and future
2019~

1ω(unconverted)+2 ω mixed laser successfully increased the electrons at < 1 MeV

ILE, Osaka





A short-wavelength (and color mixed) heating-laser was demonstrated.
Now we can think about to use short wavelength heating lasers for future.

Next years action planning

H.Yoneda /ILS-UEC
Y.Fukuda/QST
R.Kodama/ILE
Y.Mori/GPI

FIREX advisory board

S.Regan /LLE
H.Yamada/NIFS
K.Tanaka/ELI-NP
Y.Arikawa/ILE

ILE-Osaka
14 Univ.s,
4 Institutes, and
2 Companies

All-Japan IFE at Hamamatsu

“FIREX advisory board” was established for FIREX 5-year plan (2018~2022)

→ Improvement for the next experiment at 2020.Jan-Feb

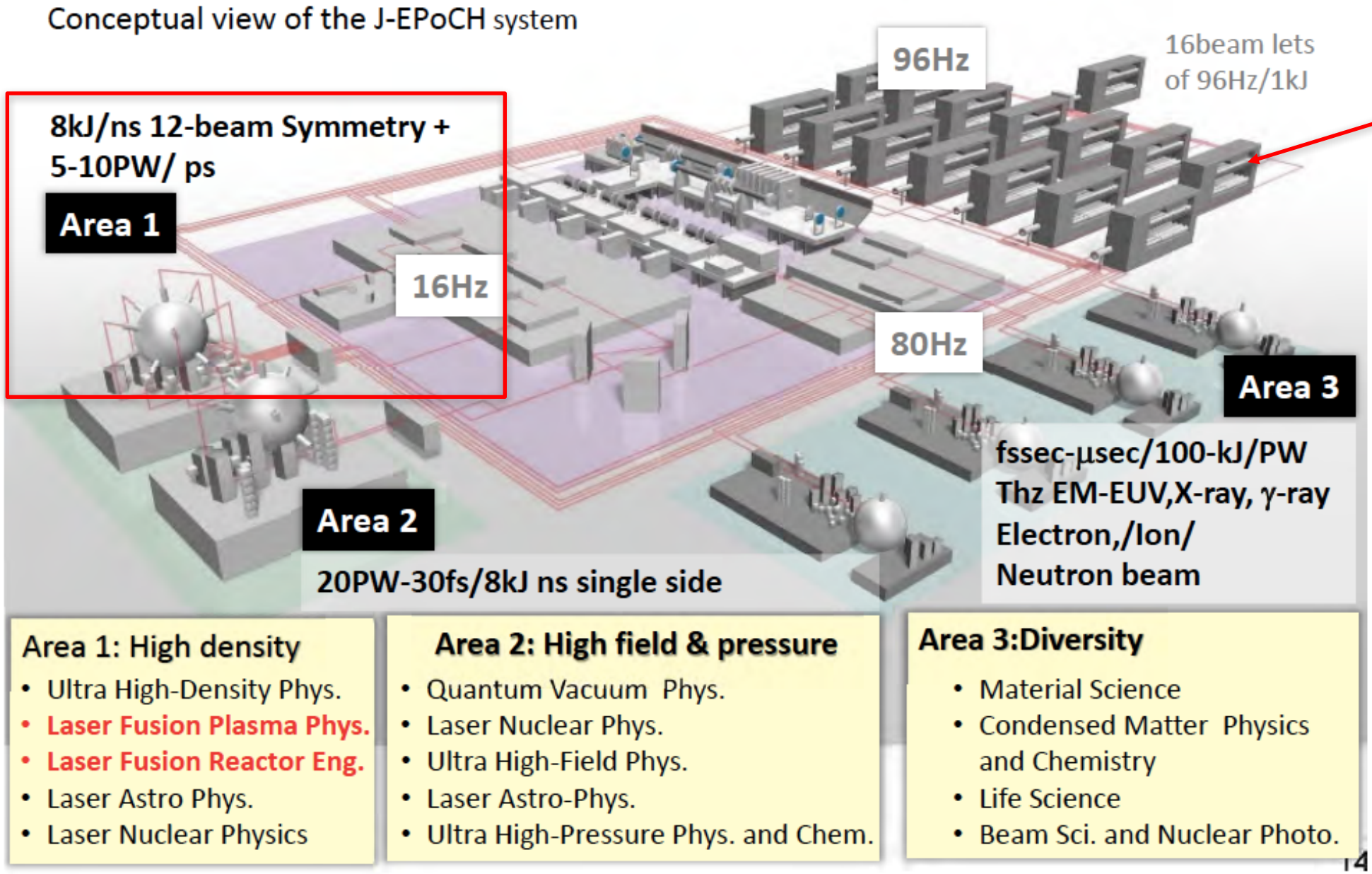
The results will be discussed at conferences (OPIC/HEDS 2020. April., FE-Rengo 2020.June).

“All Japan, inertial fusion energy meeting” was established for 10-year plan

Make a road map to the inertial fusion energy

8kJ/16Hz J-EPoCH laser development was started

ILE, Osaka



Single beam consists of multi-segmented beams

A segment 100J/100Hz was achieved in 2019.

News and future
2019~

Fusion energy reactor demo plan
1000 shots operation, 1Hz, 8 kJ, exploding pusher DT fuel,

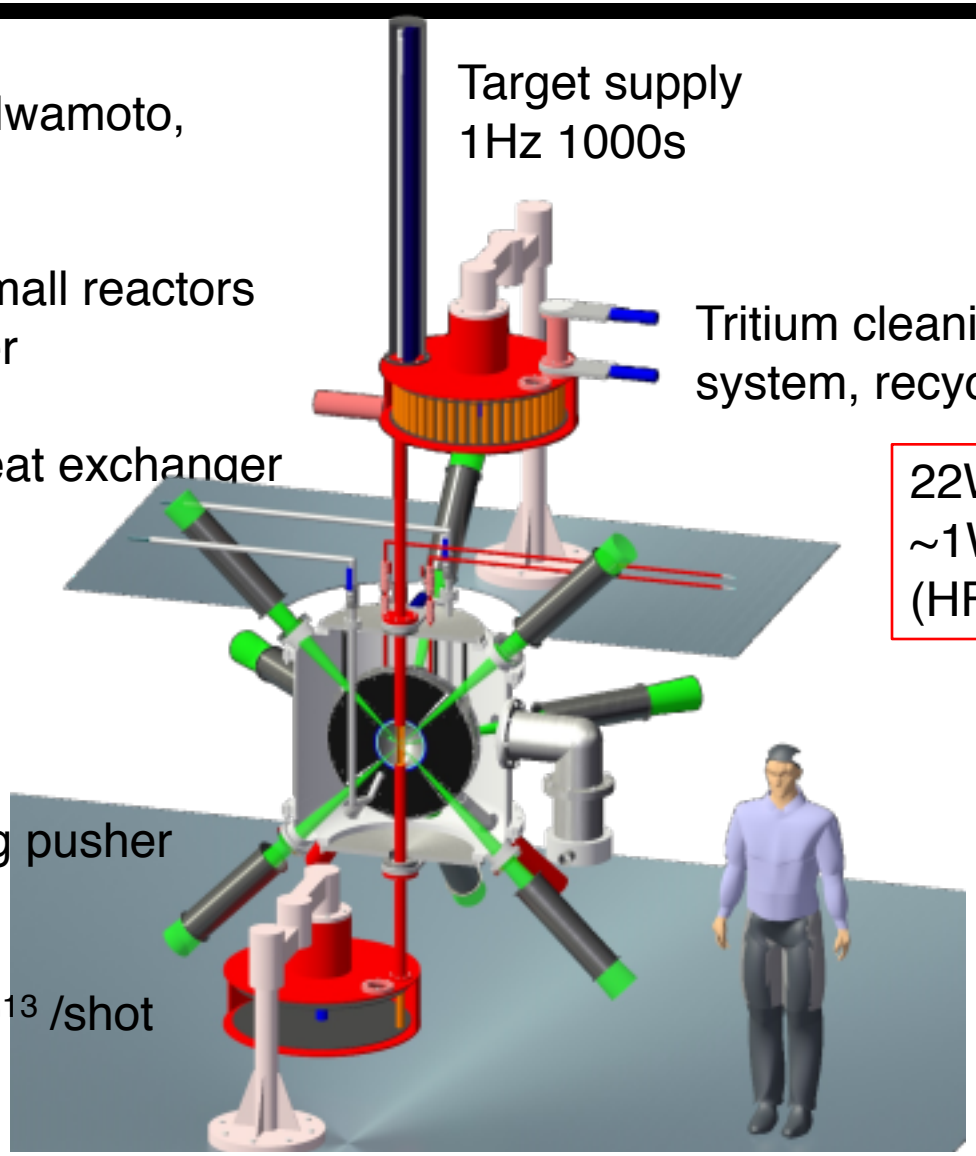
ILE, Osaka

Proposed by A. Iwamoto,

Target supply
1Hz 1000s

Detachable small reactors
66cm diameter
LiPb liquid
Neutron to heat exchanger

Tritium cleaning
system, recycling



22W fusion power output
~1W electricity → small LED emission
(HFC-245fa gas medium)

J-EPoCH laser
8kJ, 12beams / 1Hz

DT gas filled exploding pusher
Tritium 10^8 Bq/shot
0.3μg/ shot
Neutron production 10^{13} /shot

Not only plasma physics, reactor engineering can be started

Summary

1. In fast ignition,8 kJ heat-energy deposition is required to the ignition,
   Since the implosion of FI has been achieved, we have been focusing to the heating.

2. After several progress (2015~2018) at ILE-Osaka, the highest deposition-energy of > 80J (by 1.5kJ laser energy) was achieved.

3. News and future prospect
   - The frequency converting of LFEX laser was succeeded.
   - ”FIREX advisory board” was established.
   - 8kJ / 16Hz laser “J-EPoCH” R&D was started.
     A program of fusion-energy reactor demo has been proposed.