Status and Prospect of Laser Fusion Research at ILE Osaka University

- Introduction of a Fast Ignition project: FIREX project
- Recent Progress of the fast ignition research
- Prospect of the next generation laser facility: J-EPoCH project

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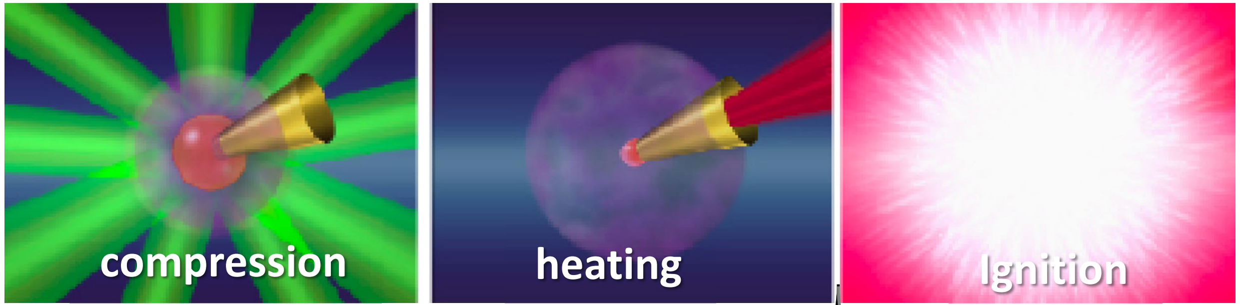
FIREX I project is now under going at ILE Osaka

Advantage of the FI scheme:

Heating and compression processes are separately optimized, resulting in simple combination of the optimized conditions for efficient fusion process.



FIREX:
Fast Ignition Realization Experiment

Now

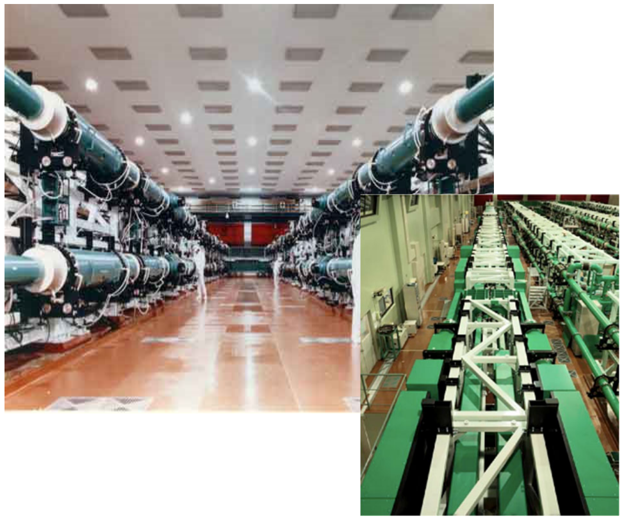
Future

FIREX I : Scaling to efficiently realize the Fast Ignition

FIREX II : Ignition and Burning

◆ Single shot facility

Multi-kJ/ns laser **GEKKO-XII**

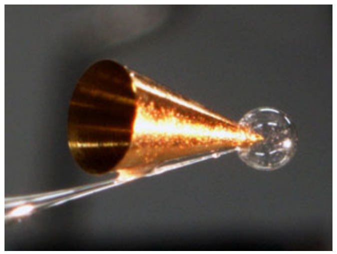


kJ/short pulse laser **LFEX**

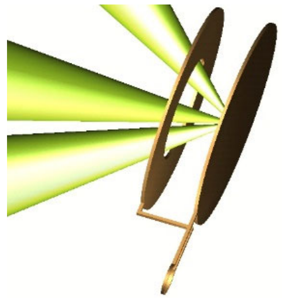
\+

◆ **Heating with plasma devices**

- **Cone guiding of heating laser pulse**
- **Guiding of REB with laser induced magnetic field.**



R. Kodama et al., Nature (2001)
R. Kodama et al., Nature (2002)



S. Fujioka et al., Sci. Rep (2013)
S. Fujioka *et al.*, Phys. Plasma (2016)

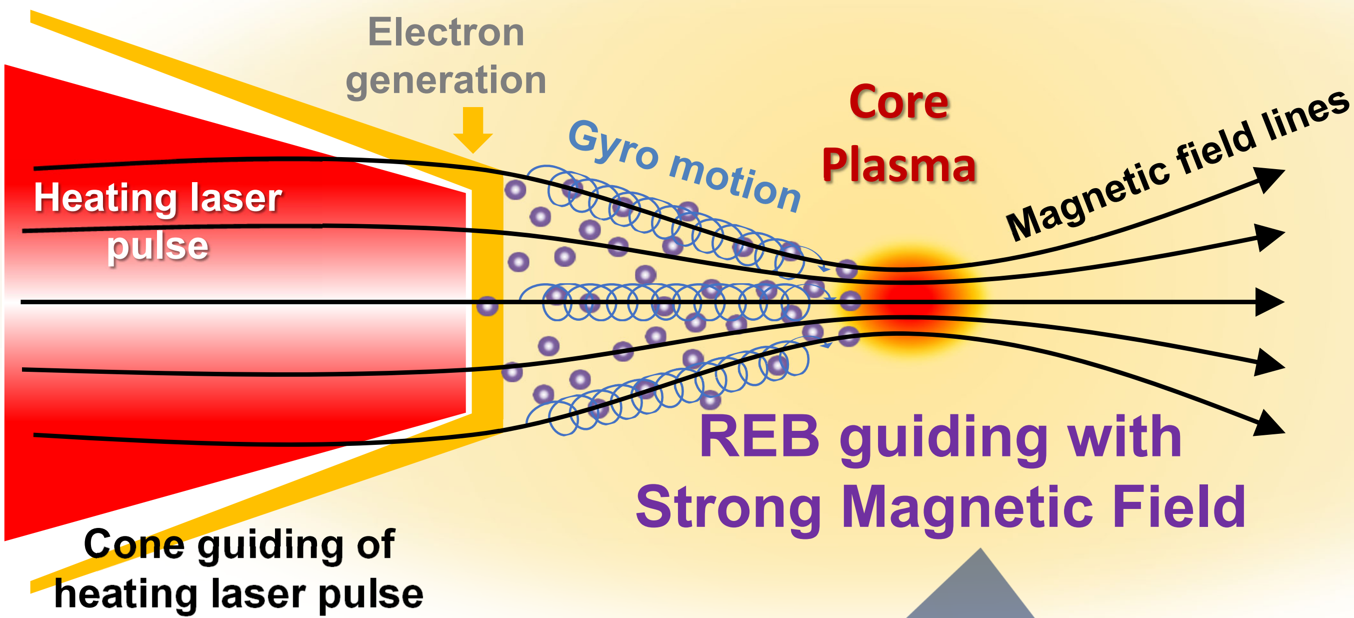
◆ **New scheme of fuel compression**

H. Sawada *et al.*, Appl. Phys. Lett. (2016)

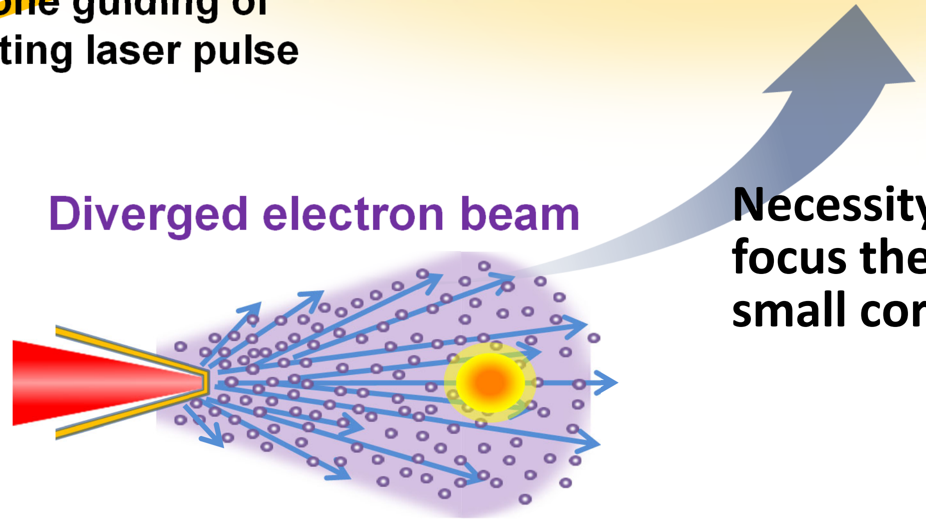
Scaling for efficient ignition with the FI scheme

Guiding of the MeV REB into the Core Plasma to Efficiently Heat up the Compressed Plasmas with a Strong Magnetic Field

Taking account of the core size and MeV energy of the REB, we would need a magnetic field of more than kilo-tesla.



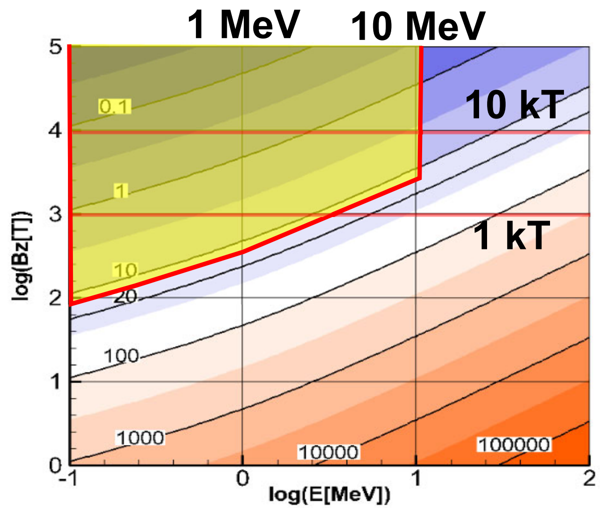
Diverged electron beam

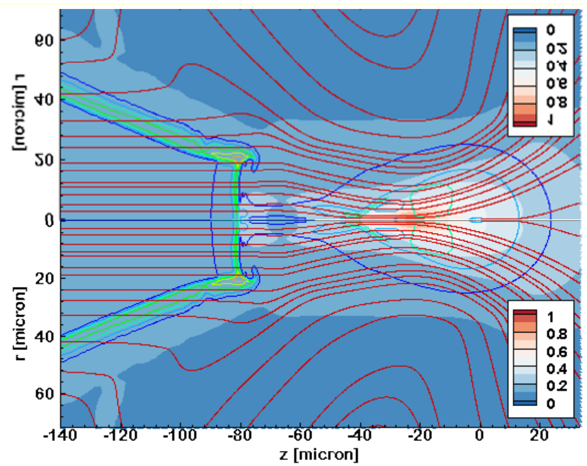


Necessity to guide or focus the REB into the small core plasma

Gyro-radius of electron

Gyro-radius of electron must be smaller than fuel core radius.





T. Johzaki *et al.*, Nucl. Fusion (2017).

Progress of Generation of Strong Magnetic Fields by High Power Lasers over the past 30 years

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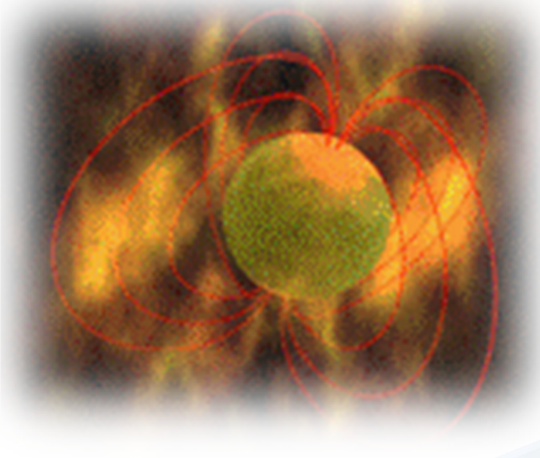


>10k T

Whispering gallery effect in relativistic optics
Y. Abe et al., JETP Letters (**2018**)

k T

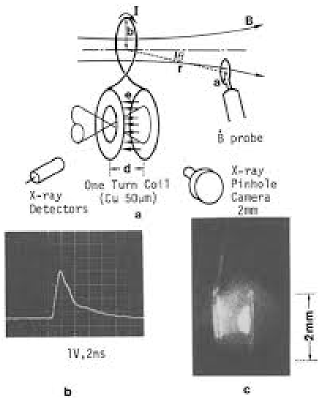
Kilotesla Magnetic Field due to a Capacitor-Coil Target Driven by High Power Laser
S. Fujioka et al., Sci Rep 30, (**2013**) 1170

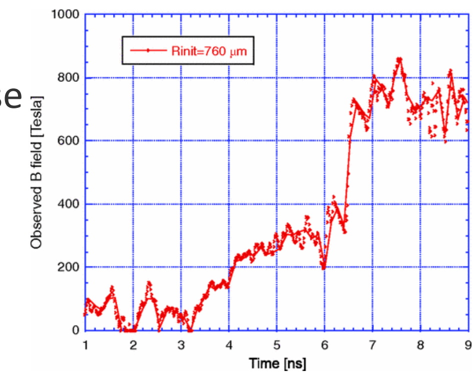
800 T

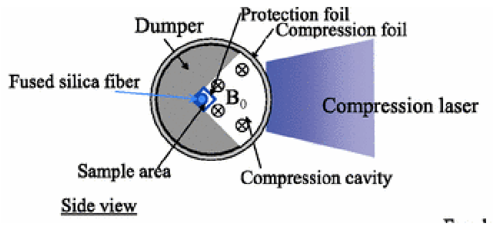
Strong Compression of a Magnetic Field with a Laser-Accelerated Foil
H. Yoneda, et al.,Phys. Rev. Lett. **109**, 125004 (**2012**)

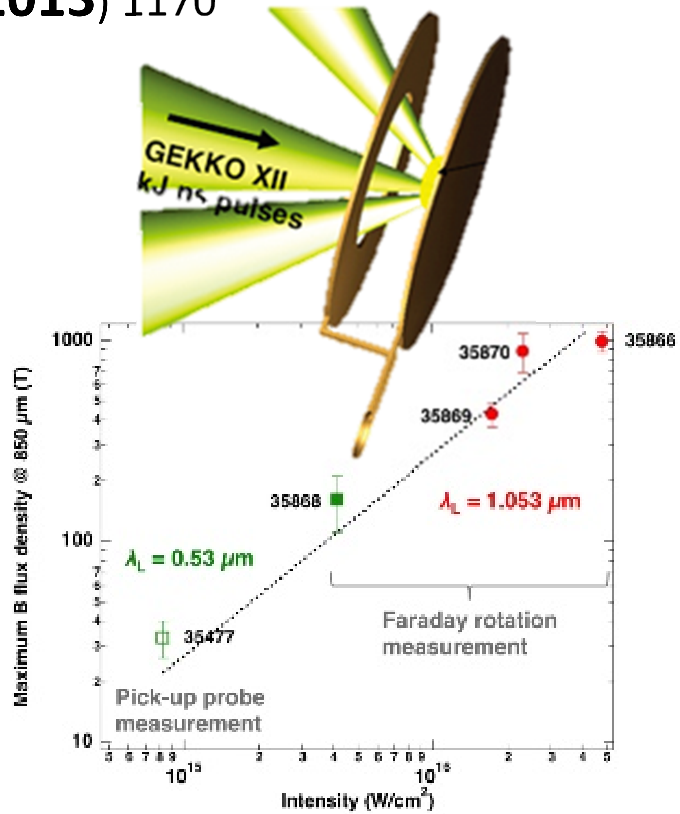
60 T

Generation of a strong magnetic field by an intense CO2 laser pulse
H. Daido, et al, Phys. Rev. Lett. **56**, 846 (**1986**)

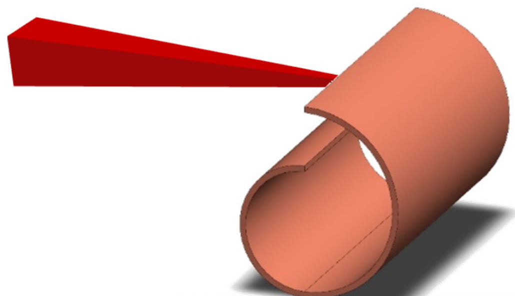


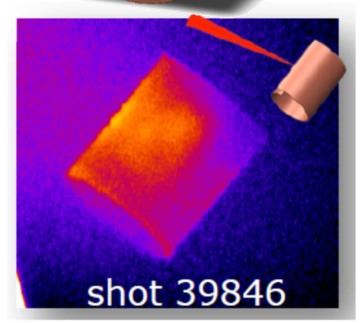


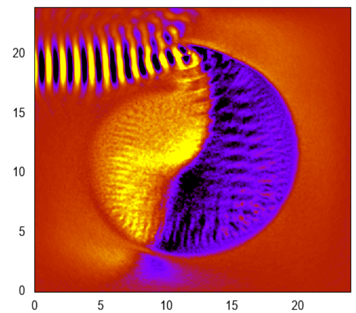




LFEX laser







Energy Coupling to the Core with the Magnetic Field was Improved by Twice of that without the Field.

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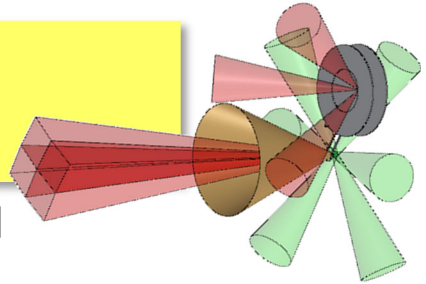
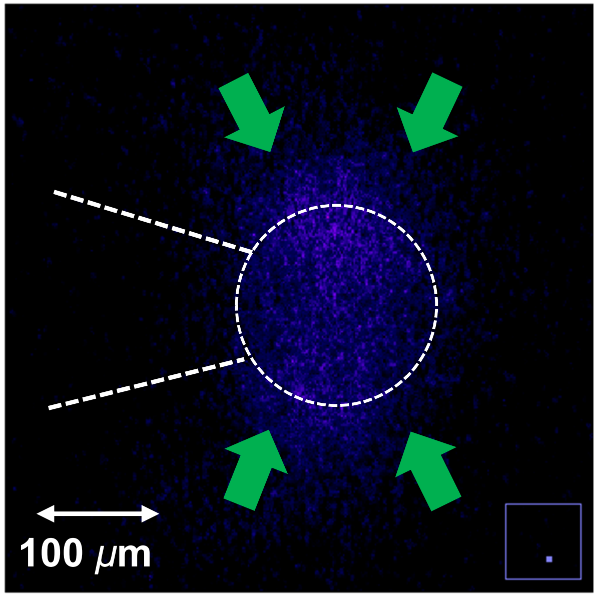
Energy coupling of the heating pulse to the core **4%** → **8%**

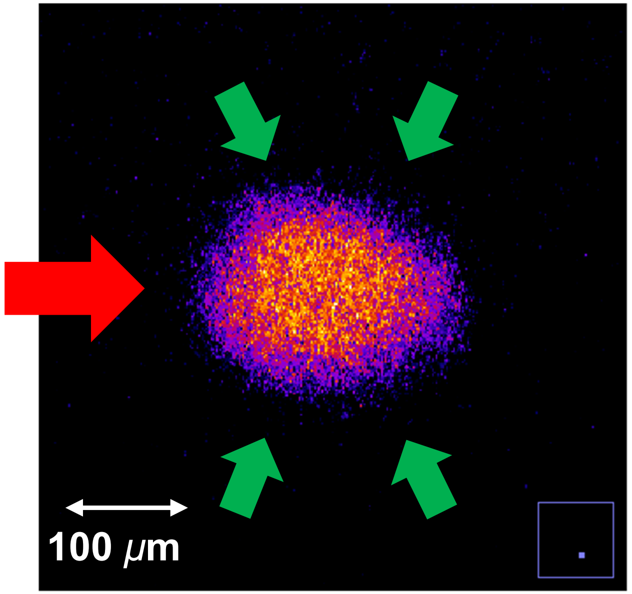


The coupling also depends on the electron stopping : the density of the compressed fuel as well as the temperature of heating electron beam.

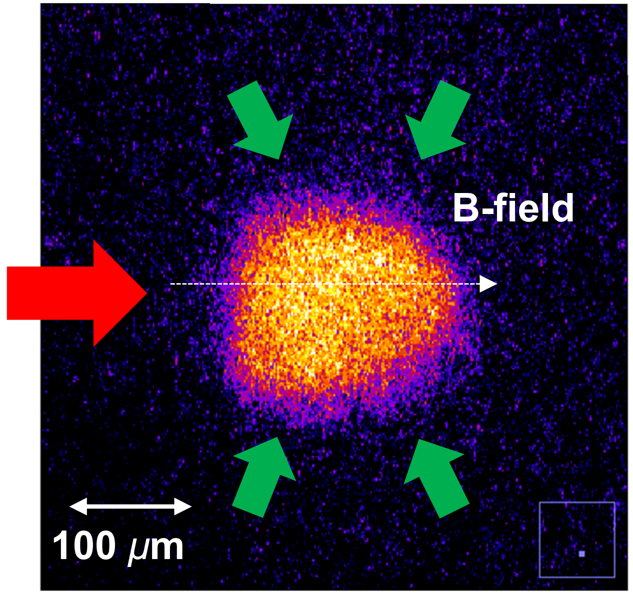
Only implosion



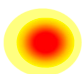
w/ heating



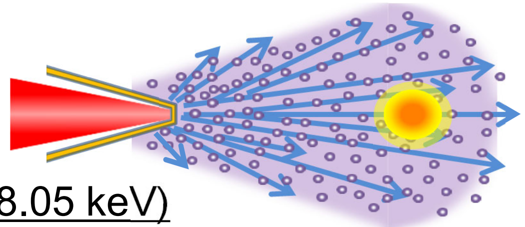
w/ heating + w/ B-field



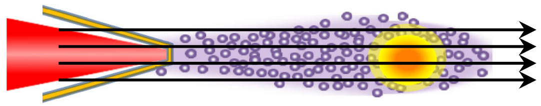
No heating pulse



Diverged electron beam



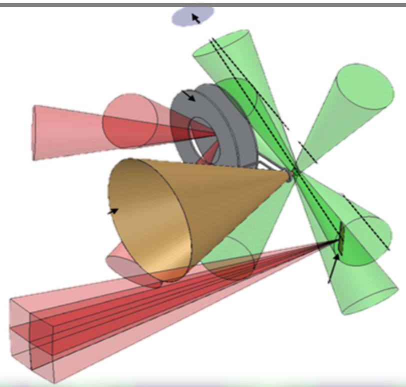
Guided electron beam



Magnetic field lines

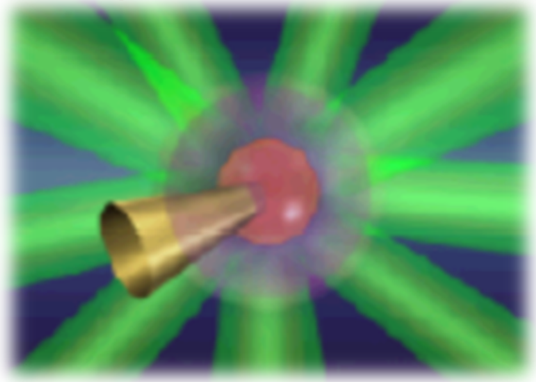
Raw spatial profile of monochromatic Ka (8.05 keV)

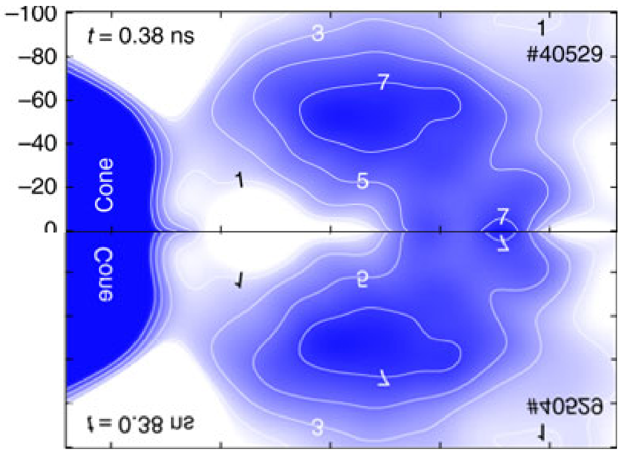
Energy deposition of the electron beam to the imploded core plasmas at different times.

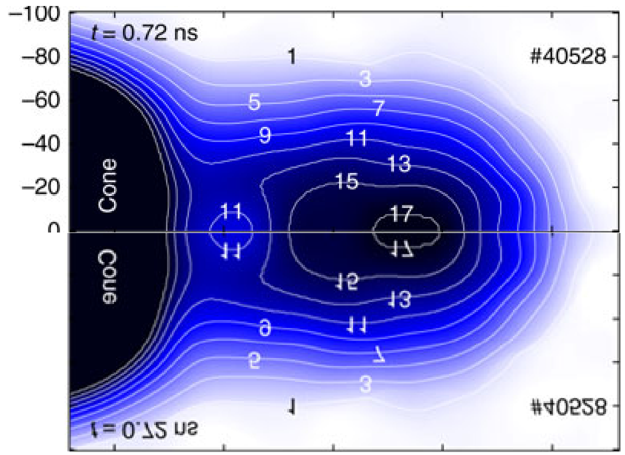


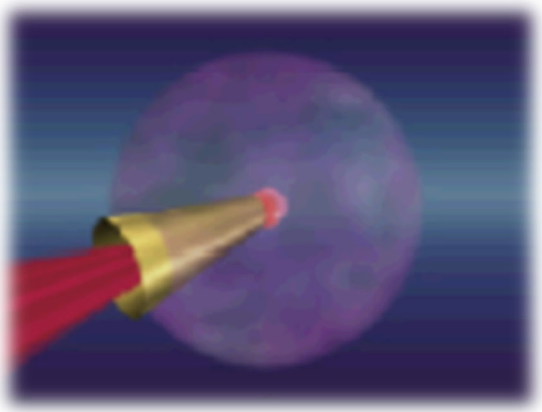
The isochoric heating of the compressed core [1] was improved by collimation of the REB with kilo tesla magnetic field generated by power laser[2].

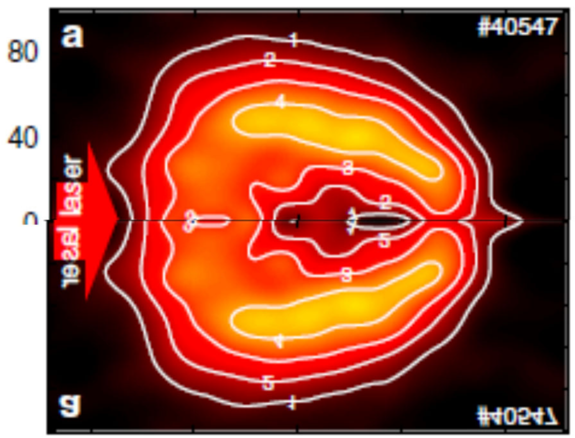
[1] R. Kodama et al., Nature **412**,798(2001)
[2] S. Sakata et al., Nature Comm. **9**, 3937 (2018)

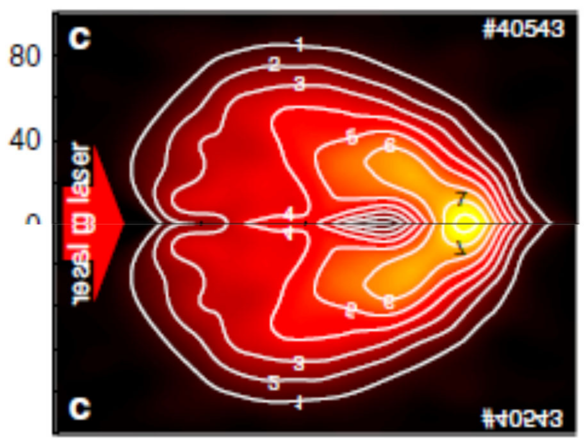












ρL=0.08 g cm^{-2} / ρ=5.7 g cm^{-3} at t = +0.38 ns,

ρL=0.16 g cm^{-2}/ρ=11.3 g cm^{-3} at t = +0.72 ns.

The Compressed Plasma with a density of 16 g/cm³ was heated by the REB guided by the kilo-Tesla Magnetic field to be 2keV.

Density profile@0.72ns

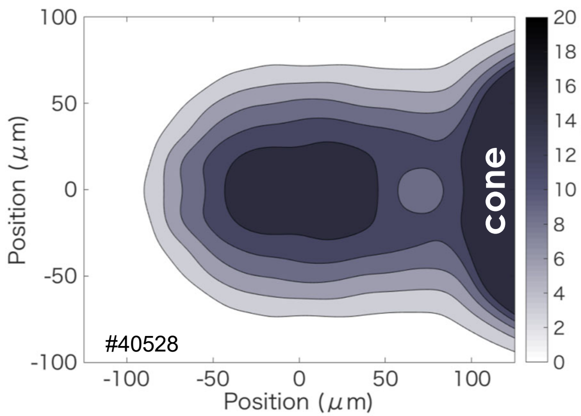
Plasma density profile was obtained with x-ray backlighting technique.

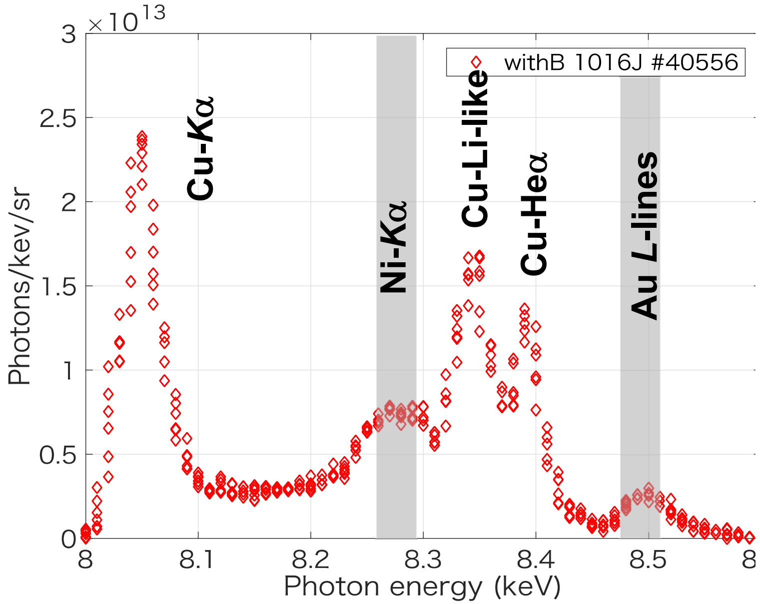
X-ray spectrum @0.72ns

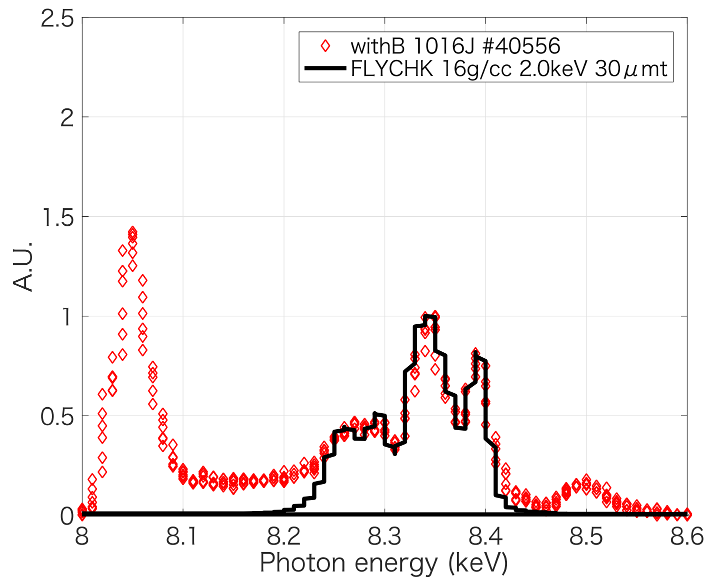
X-ray spectrum contains also emissions from a Ni coil and Au cone.

FLYCHK simulation

FLYCHK reproduces the spectrum.







Density: 10 - 17g/cm³

2 keV

The core with a pressure : > 20Gbar

Prospect of FIREX-I project by 2020

Fusion Plasma experiments as the FIREX I

Heating experiments:

Heating with a **2-color laser pulse** and/or a longer pulse to increase the **coupling efficiency** from the laser to the core plasma to be **>20% from 8%.**

Compression experiments:

Demonstration of **higher density with a solid ball target** with a tailored laser pulse to be **ρR >0.3 g/cm^2** from $\rho R \sim 0.1$ g/cm^2.

Reactor Technology Development

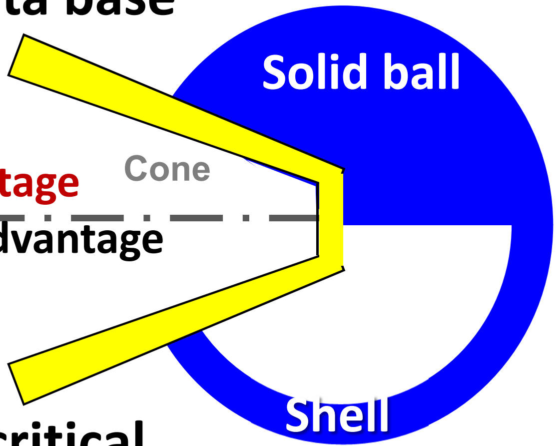
Fuel target fabrication technology

High repetition laser technology

Solid Fuel Ball is Compressed as a New Approach for the FI

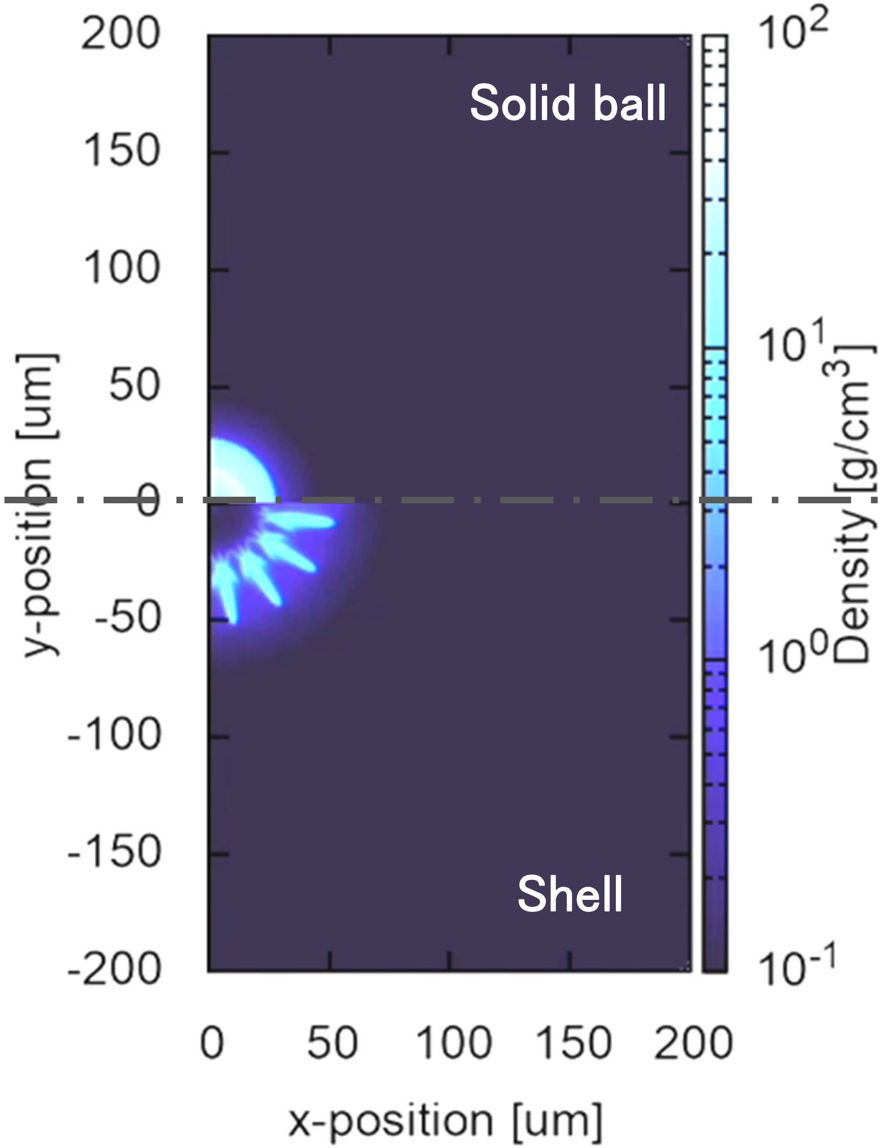
Solid fuel ball compression would have more advantages for the FI scheme as compared with the shell implosion.

- Hydro Instability: smaller
- Achievable density : High enough
- Target quality: Relatively Lower level
- Fuel Target production: Simple
- Data base: rare data base



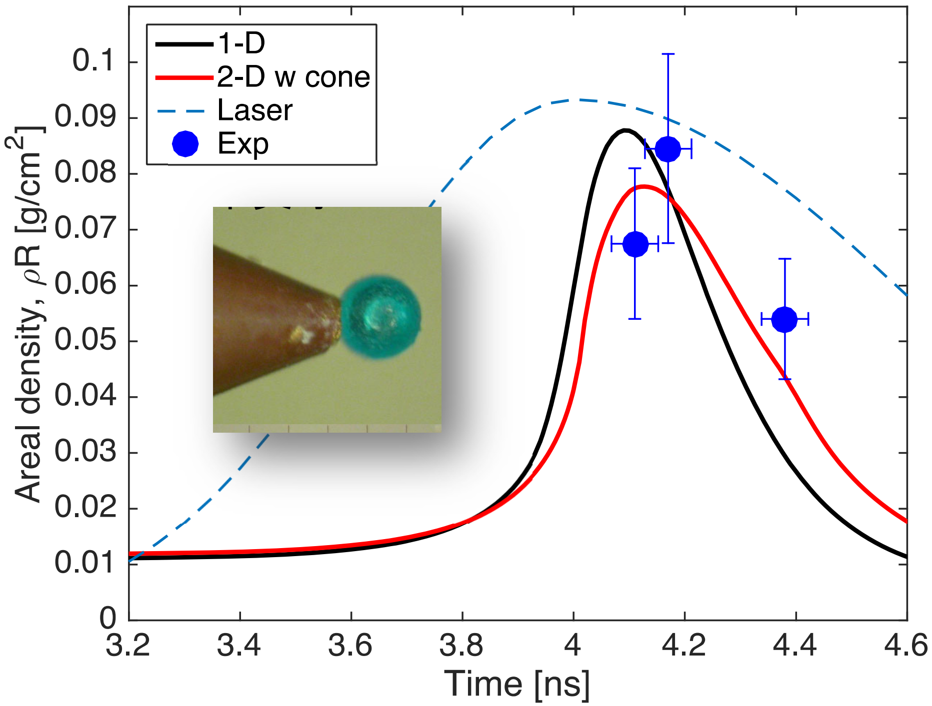
Red: advantage
Black: disadvantage

- Hydro Instability: critical
- Achievable density : High enough
- Target quality: High level
- Fuel Target production: Complexity
- Data base: many experiences



High Density could be obtained with Solid Fuel Ball Compression

Compression was demonstrated of Solid ball target

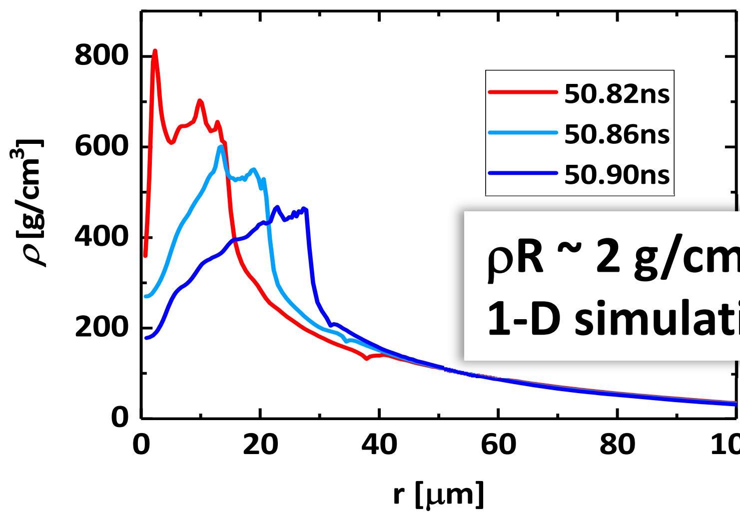


High density compression of solid ball, which could be hydro dynamically stable was experimentally demonstrated to be ρR ～0.1 g/cm².

H. Sawada *et al.*, Appl. Phys. Lett. (2016).

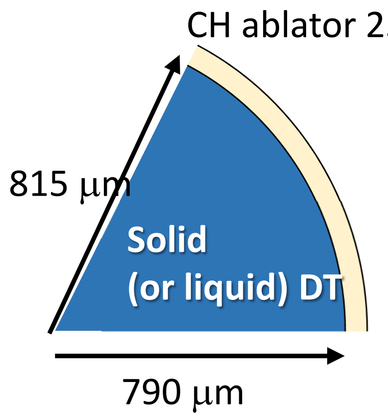
Solid ball target is scalable to the ignition with a tailored laser pulse.

Density profiles around max comp.

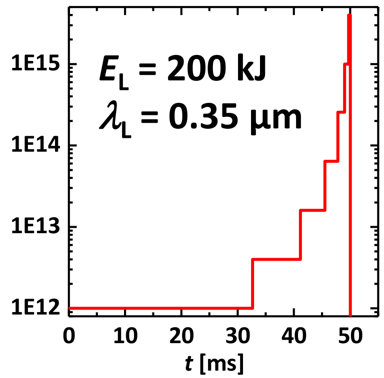


ρR ~ 2 g/cm² from 1-D simulation

Solid (or liquid) ball DT target with CH ablator



7 steps laser pulse



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Strategies and Expectations through the 2020s

◆Fusion Plasma Research as the FIREX-I project

Optimization of the heating and the compression schemes separately and demonstration of the integration towards FIREX-II for realization of the fast ignition.

◆Technology Development

Fuel Target Technology for the FIREX project:

Cryogenic target fabrication technologies are being developed, focusing on the FI scheme.

Laser Technology as the J-EPoCH project:

The J-EPoCH project is to realize a multi-purpose facility base on a high repetition 10kJ laser system consisted of 100Hz/kJ lasers, which has multi 10 PW lasers and multi-radiation sources based on laser accelerators.

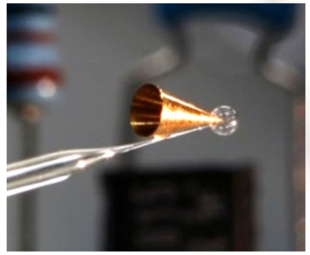
This facility will promote more the FIREX project as a new approach of the laser fusion research.

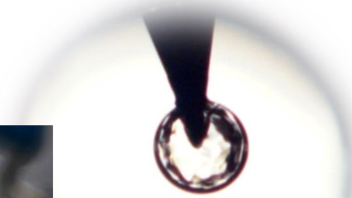
J-EPoCH：**J**apan **E**stablishment for a **Po**wer-laser **C**ommunity **H**arvest

Fuel target development focusing on the FI scheme

◆ Cone-attached Cryogenic fuel targets with a polystyrene shell and foam shell are being developed.

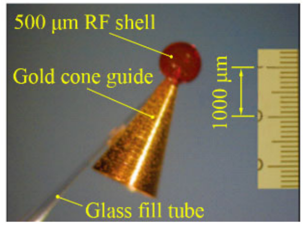
- The IR heating method has been modified for the FIREX target. **An ice layer with 95 % sphericity was achieved in a 800 µm PS shell** target by the combination of IR heating and cone temperature control.

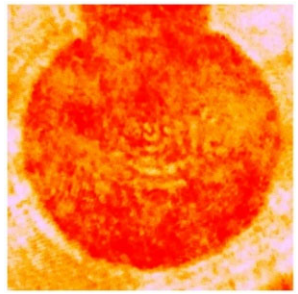




Ice layer with 95 % sphericity

- The solidification process without residual voids in a foam layer was examined based on simulation result. **The void fraction was reduced to be near 1 % in the foam shell.**

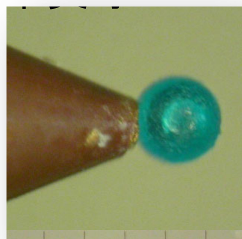


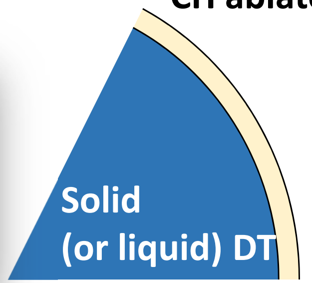


·**Both of the shells need more higher quality from a point of view of hydrodynamic instability of the shell implosion**

◆Solid or liquid fuel ball targets development is now on going.

- We start development of solid ball target and its compression experiment. Based on the simulation results, **solid (or liquid) ball DT target** with CH ablator will be developed for the FI experiment.





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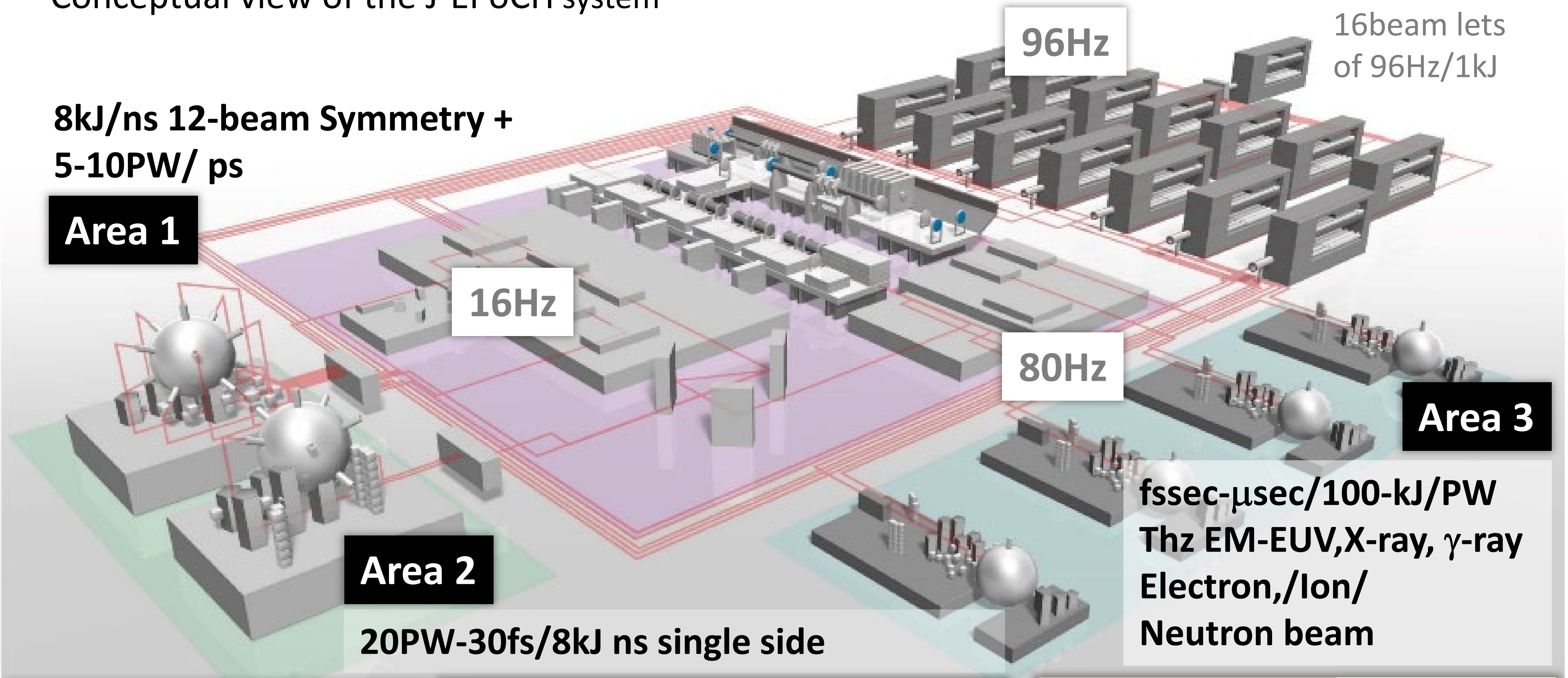
which has multi 10 PW lasers and multi-radiation sources with laser accelerators.
This facility will promote more the FIREX project as a new approach of the laser fusion research.
The system would expand the potential of high power lasers into more large field of science and industry and increases the number of people who support laser fusion.

***J-EPoCH**：**J**apan **E**stablishment for a **Po**wer-laser **C**ommunity **H**arvest

Power Laser Integration for the Next Generation,

which riches diversity and opens new field of sciences

Conceptual view of the J-EPoCH system



Area 1: High density

- Ultra High-Density Phys.
- **Laser Fusion Plasma Phys.**
- **Laser Fusion Reactor Eng.**
- Laser Astro Phys.
- Laser Nuclear Physics

Area 2: High field & pressure

- Quantum Vacuum Phys.
- Laser Nuclear Phys.
- Ultra High-Field Phys.
- Laser Astro-Phys.
- Ultra High-Pressure Phys. and Chem.

Area 3:Diversity

- Material Science
- Condensed Matter Physics and Chemistry
- Life Science
- Beam Sci. and Nuclear Photo.

High repetition Power Laser Development is a Critical Issues to Realize the J-EPoCH system.

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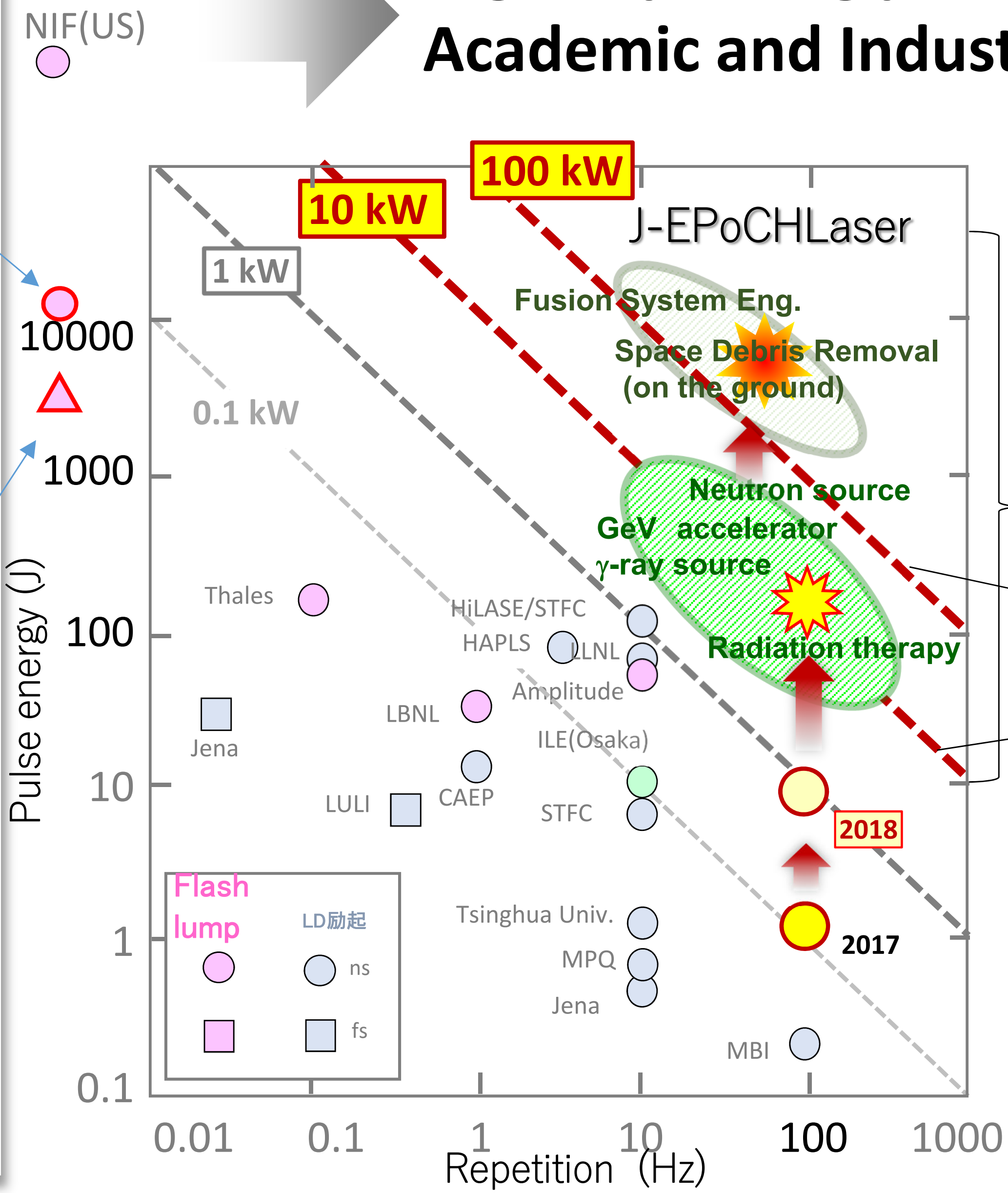
Big power laser facility for Science

Multi-kJ/ns laser **GEKKO-XII**

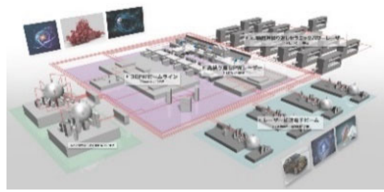
kJ/short pulse laser **LFEX**

High Rep. & Big power Laser for Academic and Industry Applications

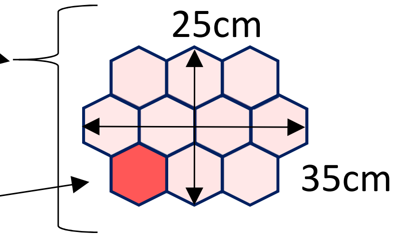


J-EPoCH

160beams /100Hz



Key Technology



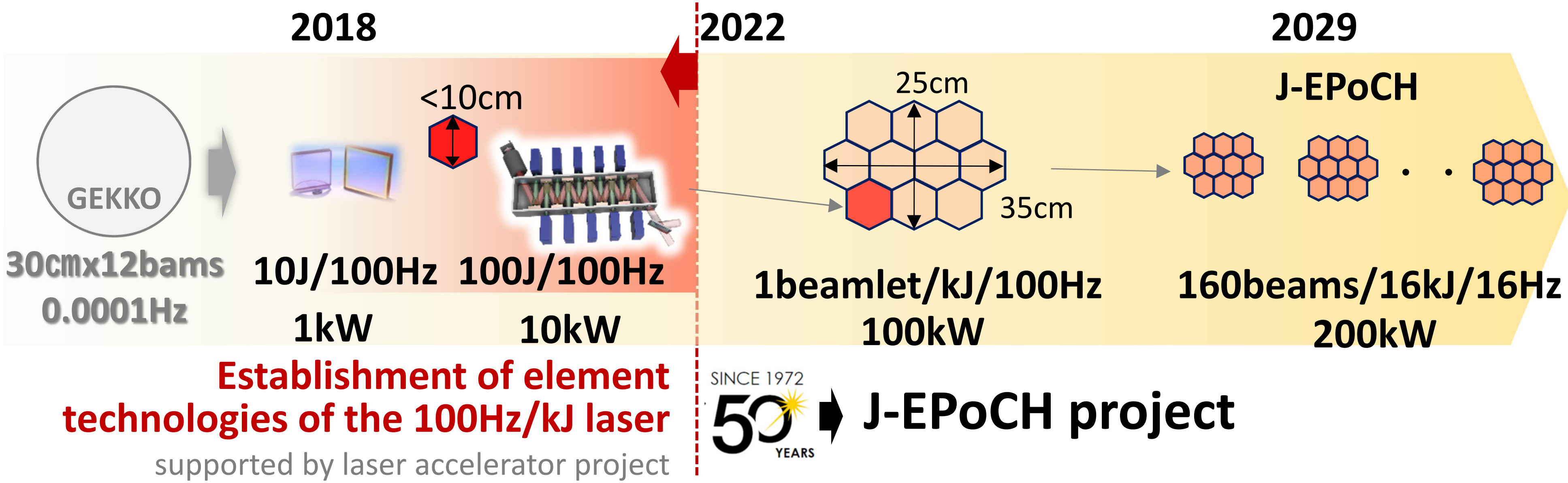
Beam Combining

Laser Ceramic

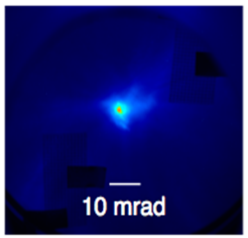
Laser Diode

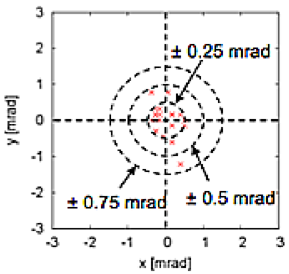
Road Map of the High Repetition Energetic Lasers to realize the J-EPoCH system

- Beam Combining Technology reduces the Beam Aperture Size, resulting in High repetition 10kJ system.

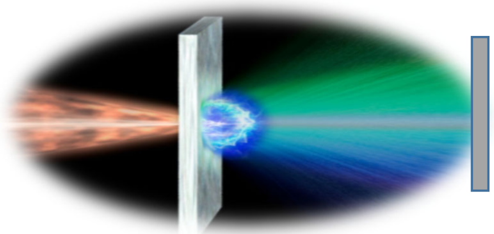


- Laser accelerator technology has been almost established
  - Laser plasma accelerator technologies, which are now developed under several programmatic projects, expand the potential of high power laser.
    e.g. X-ray source, g-ray source, ion source and neutron source





Well-Stable and reliable near GeV e-beam



Neutrons

$2x10^{11}$ n in 4π/pulse

Summary and comments

◆Plasma Research for the FI as the FIREX-I project

Investigation of the reliable scaling to realize efficient Fast ignition towards FIREX-II project.

◆Technology Development

Fuel Target Technology for the FIREX project:

Cryogenic target fabrication technologies are being developed, focusing on the FI scheme.

High Rep. Laser Technology as the J-EPoCH project:

Developing a 100Hz/100J high power laser to realize the J-EPoCH system
With this system, we expect a new stage of laser fusion research with big data based on the high rep. facility, from the single shot base facility.

➢ Extra Comments :

- The project name of **"EPoCH" is better than the "J-EPoCH" for the International Community** to get on the track towards achieving Millennium Development Goals .
- I expect more progress of US-Japan collaboration on HED science including laser fusion and power laser development **under a new frame work**.

Thank you for your attention!

Institute of Laser Engineering Osaka University (ILE-Osaka) is one of the world-leading laboratory developing laser technologies and researching the applications since the foundation of its forerunner under the Graduate School of Engineering, Osaka University in 1972.
Since then for 47 years, ILE-Osaka has independently developed one of the world's largest power laser facilities, and takes full advantage of this equipment in its research endeavors. In 2022, ILE will celebrate its 50th anniversary.