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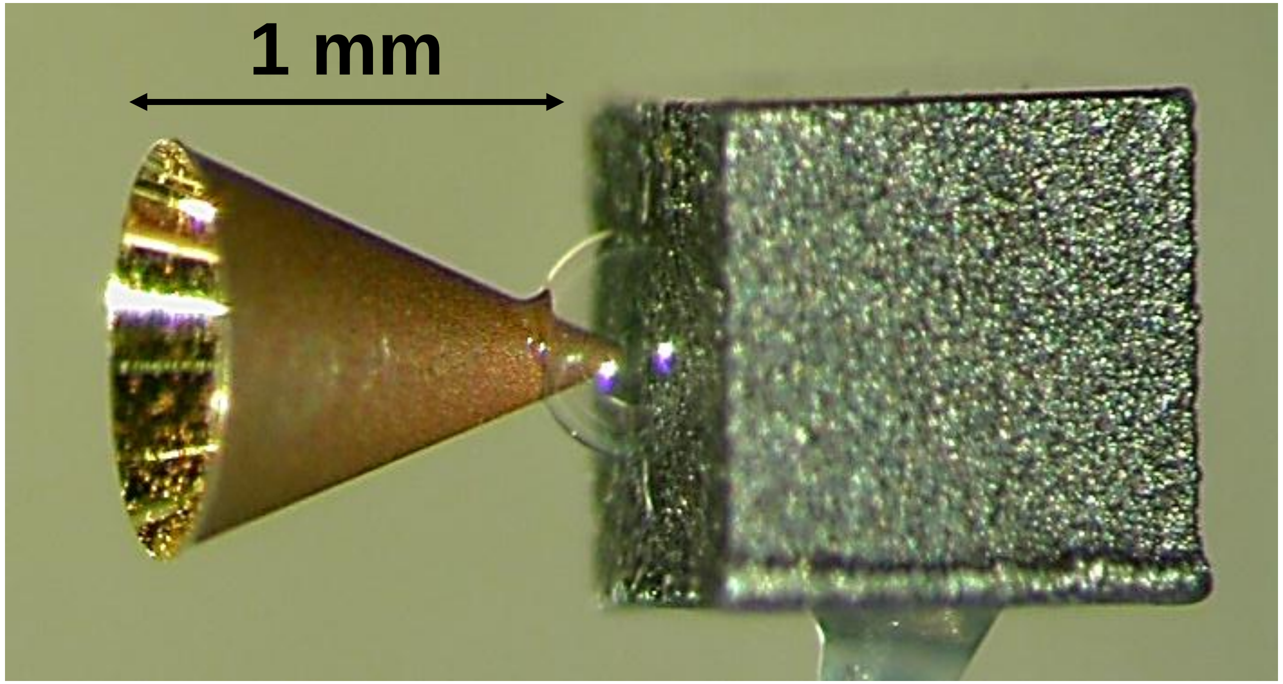
Experimental Platform for Efficient Heating of Fusion Fuel with Fast-Ignition Scheme



Shinsuke Fujioka*
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IAEA Fusion Energy Conference 2014

Summary

Slope temperature and divergence of relativistic electron beam (REB) must be controlled for efficient heating of fusion fuel.

- ✓ Fast-Ignition Realization EXperiment (FIREX) was performed on GEKKO XII - LFEX laser facility.
- ✓ There are three difficulties of the fast-ignition scheme, namely "shut-in", "diverging" and " unstoppable" of REB.
- ✓ All physical parameters of the REB were measured to evaluate absolutely the heating efficiency.
- ✓ The most critical problem is generation of too energetic REB (> 15 MeV) in a long-scale preformed plasma.
- ✓ Plasma mirror will be installed to suppress generation of too energetic REB.
- ✓ Guiding of REB was demonstrated with sub-kT external B-field.

Three difficulties in fast-ignition scheme; “shut-in”, “diverging”, and “unstoppable” of REB.

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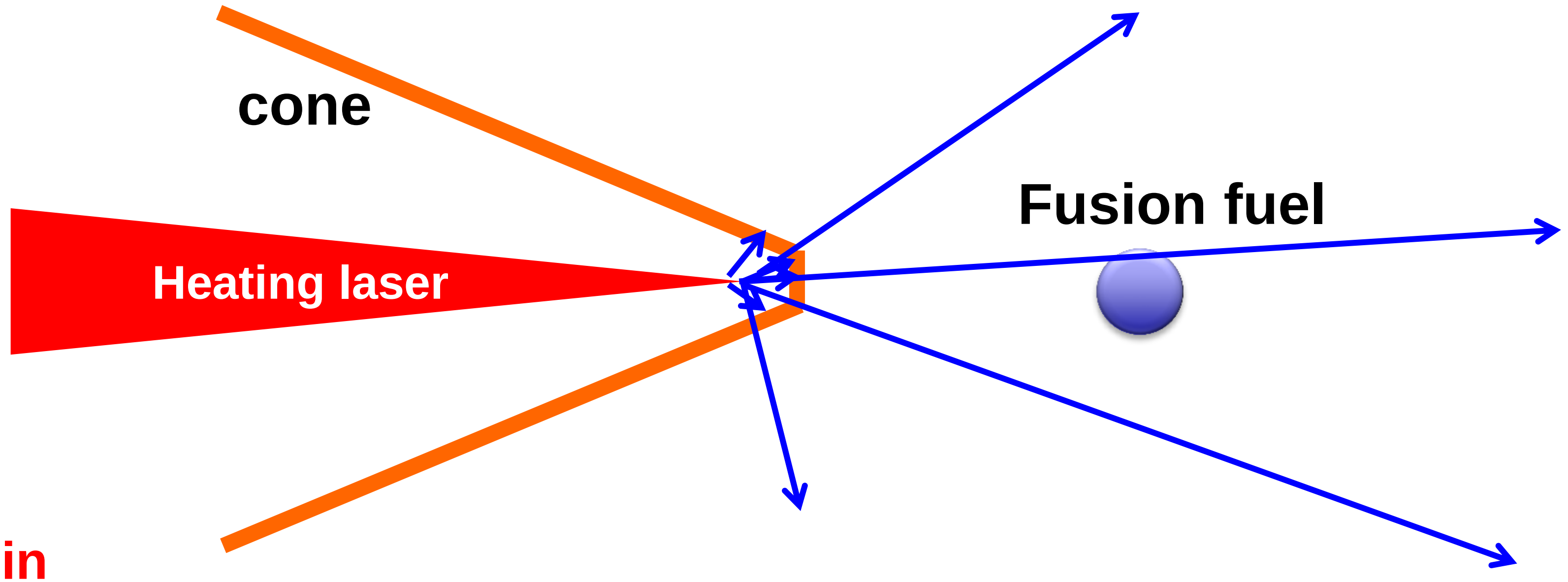

Shut-in

A few MeV electrons, which may heat efficiently a fuel core, are absorbed in the cone wall itself. Most of these absorbed electrons are not ejected from the cone.

Diverging

Electron beam have a large divergence angle (> 100 deg.). Energy flux of the e-beam decreases significantly during transport.

Unstoppable

Too energetic electrons are generated by laser-plasma interactions, those electrons do not deposit their energy within the fuel.

Fast Ignition Basic Experiment Platform

Divergence, energy distribution and flux of REB are measured by using x-ray convertor attached target.

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X-ray shadowgraph

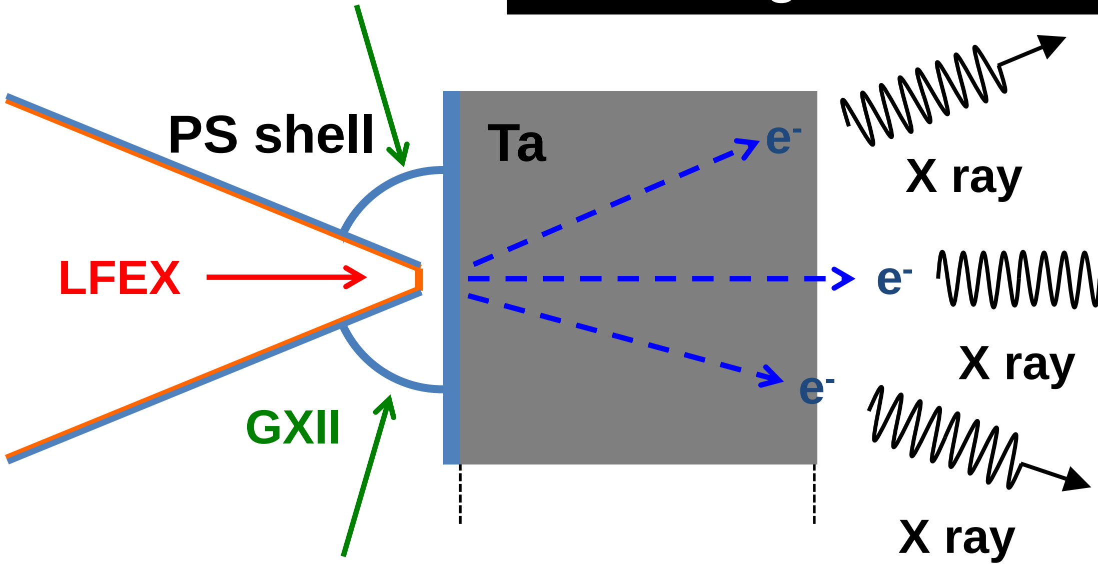
Absolute x-ray yield measurement

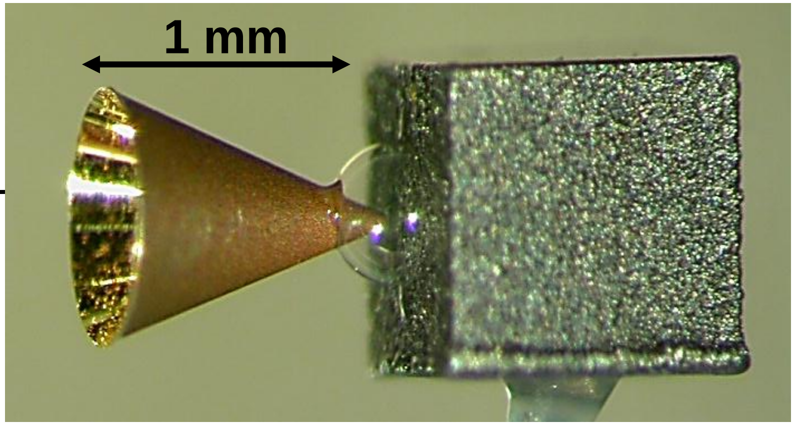
Heating Efficiency = [Laser- Electron Conversion Efficiency X Electron Transmittance] X [Fuel cross section] / [E-beam cross section @fuel] X [2 x fuel areal density] / [Range of e-beam]

Kα imaging with a tracer layer

T_e measurement with hard x-rays

Fast ignition basic experiment





Fast Ignition Basic Experiment Platform

ρR_{max} = 54 mg/cm^2 and ρ_{max} = 22 g/cm^3 are obtained with a plastic ball with asymmetric-spherical irradiation.

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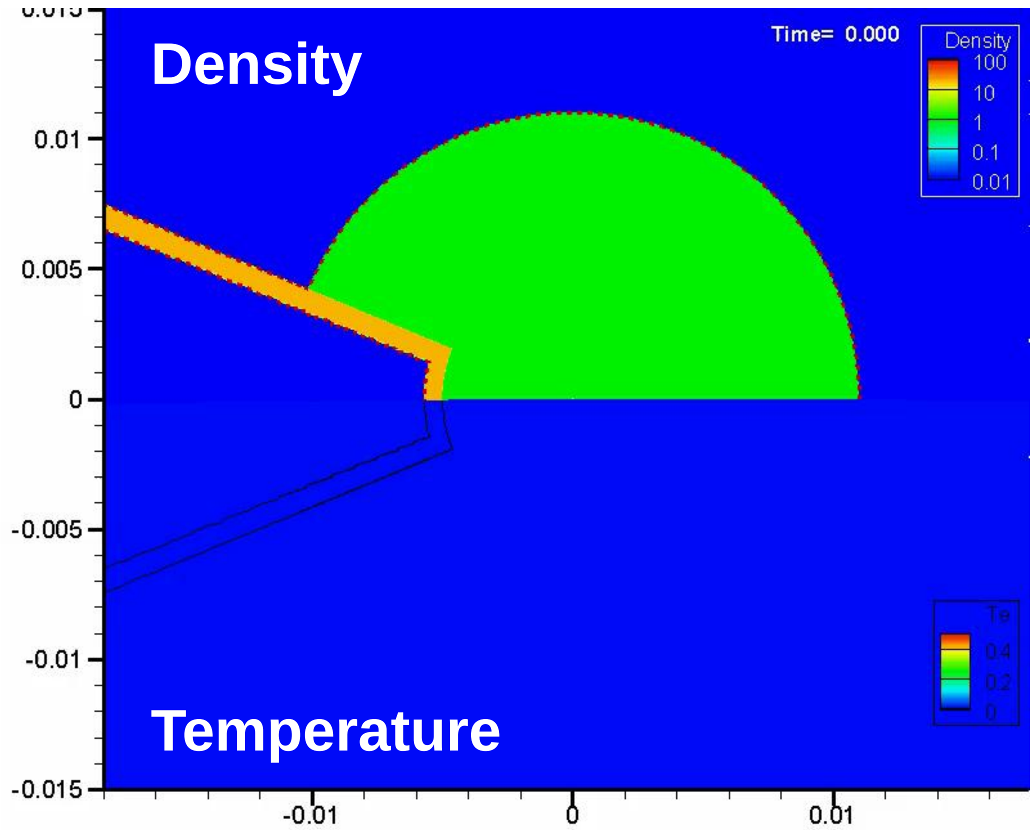
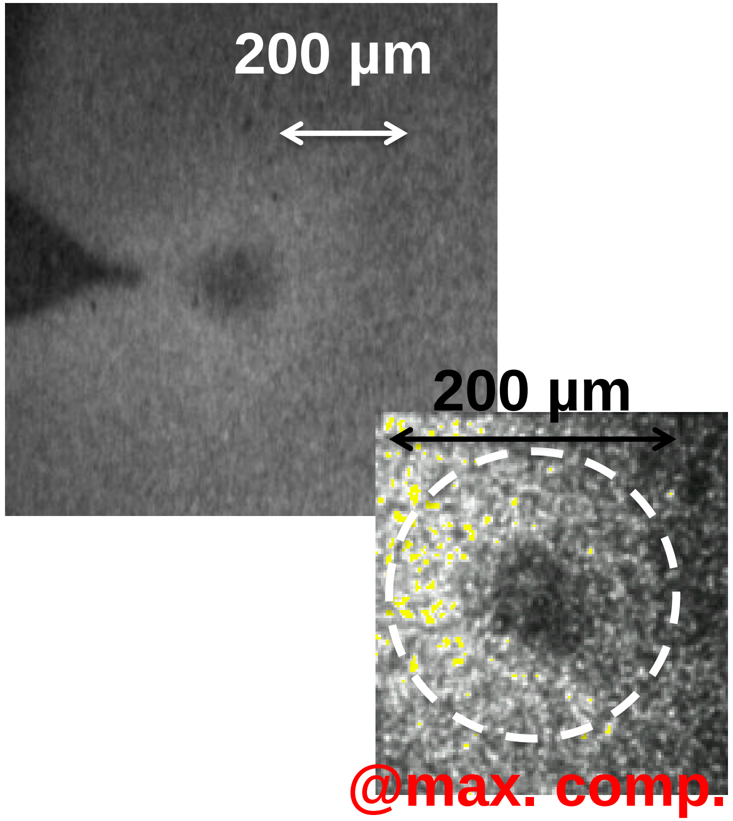
2D simulation



X-ray shadow of compressed plastic ball



Fast Ignition Basic Experiment Platform

Cross section of REB is measured by imaging Kα emission from a varied tracer layer.

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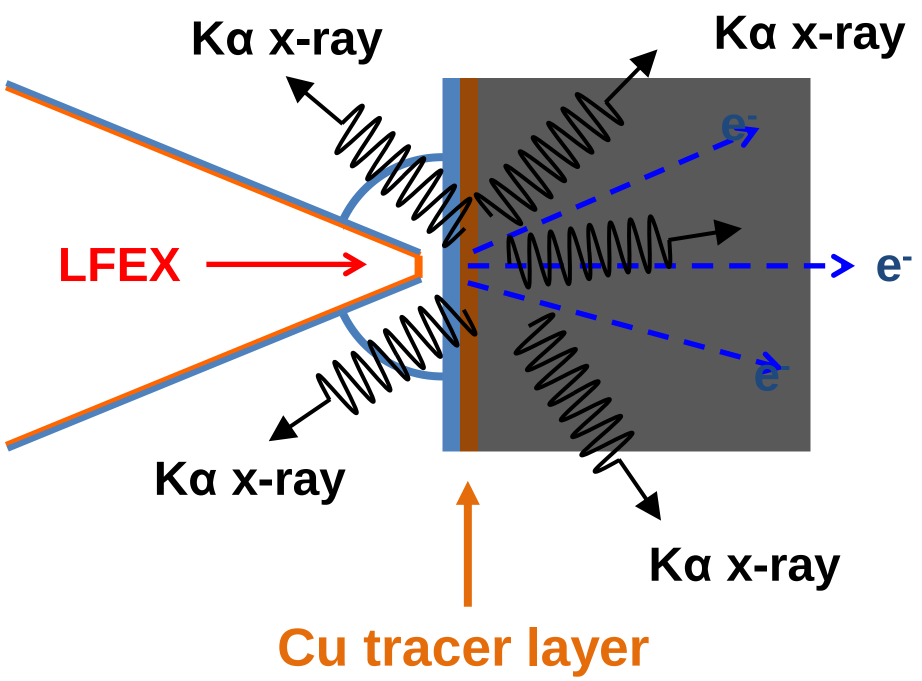
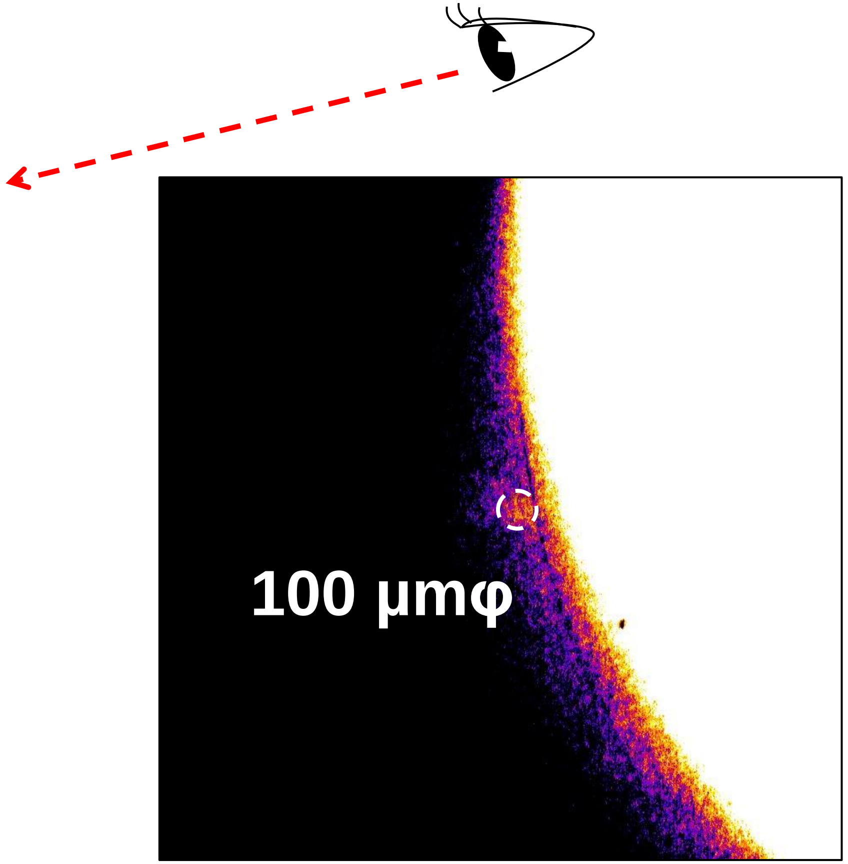
C/Cu/C block target



Monochromatic Kα image



Fast Ignition Basic Experiment Platform

Absolute energy sepectrum of REB was obtained from hard x-ray spectrum with 2-*T* assumption.

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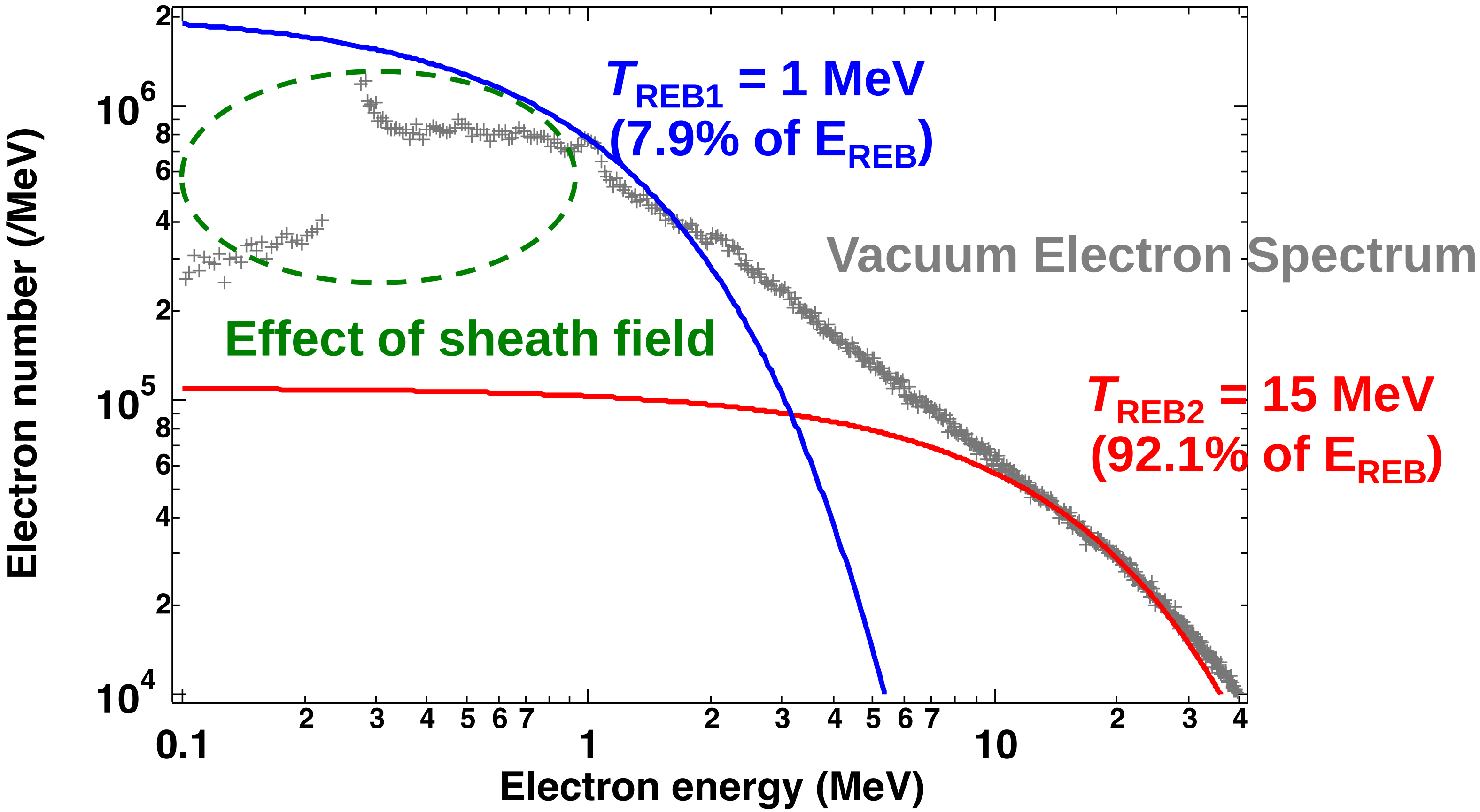
Energy distribution of REB measured with ESM & HEXS

$$f(E)dE = \left[\frac{19}{20}\cdot\exp\left(-\frac{E}{1}\right)+\frac{1}{20}\cdot\exp\left(-\frac{E}{15}\right)\right]dE$$



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Heating efficiency is evaluated with measured divergence, energy distribution and flux of REB.

Heating efficiency estimation

Laser- Electron Conversion Efficiency X Electron Transmittance X $\dfrac{\text{Fuel cross section}}{\text{E-beam cross section @fuel}}$ X $\dfrac{\text{2 x Fuel rho-R}}{\text{Range of e-beam}}$

Fuel cross section = $\pi\,(50/2\ \mu m)^2$

E-beam cross section @fuel = $\pi\,(100/2\ \mu m)^2$

2 x Fuel rho-R = $0.11\ g/cm^2$

Range of e-beam = $4.4\ g/cm^2$ (weighted for 1 & 15 MeV)

Heating Efficiency = 40 %* X 25 % X 2.5 % !!!

= 0.3%

Reduction of T_e is essential for efficient heating.

See details in the poster by Z. Zhang (IFE/P6-2, Thursday).

Too energetic electrons are generated in a long-scale plasma generated by foot of the heating laser pulse.

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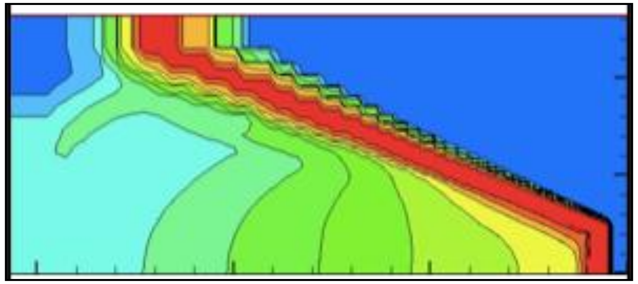
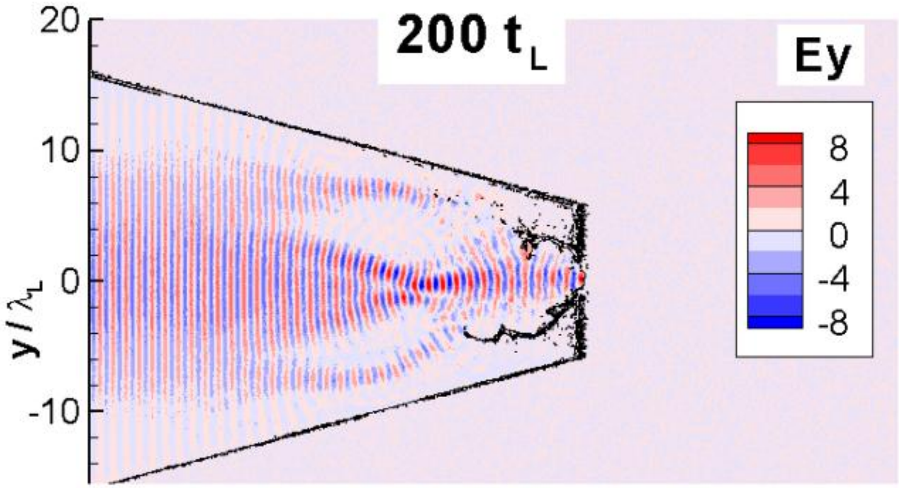
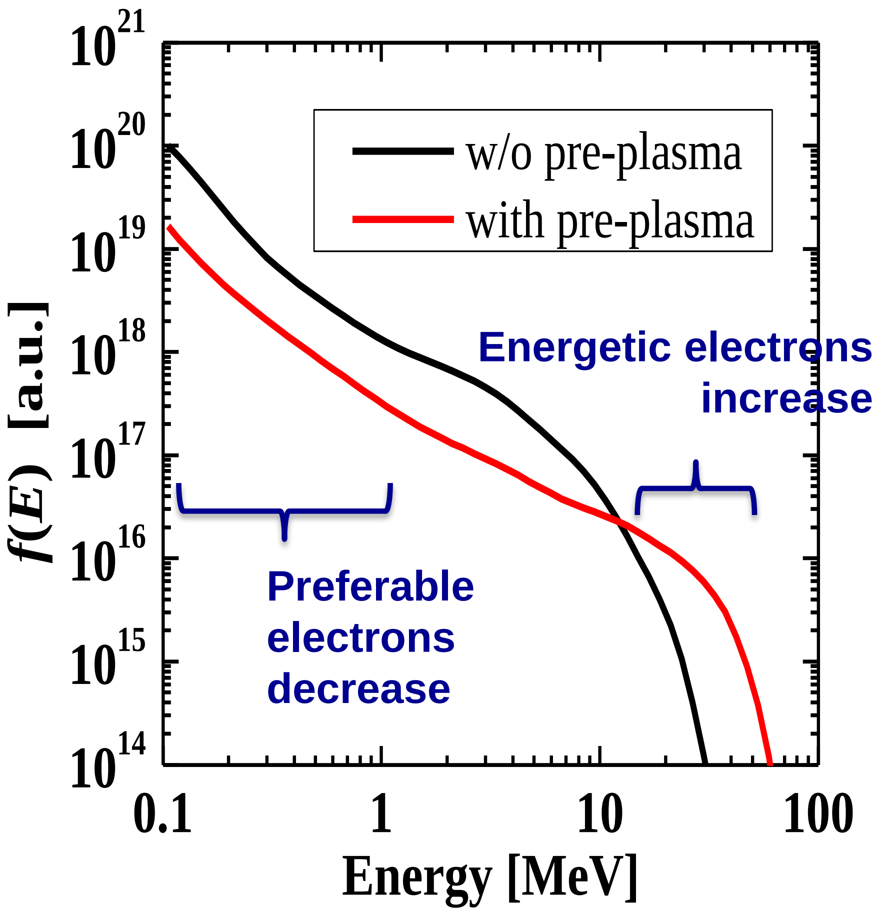
Long-scale plasma generated by foot pulse



Laser filamentation in a long scale plasma



Long-scale plasma generated by foot pulse



Foot pulse can be removed by using plasma mirror. It is a challenge to install plasma mirror to kJ lasers system.

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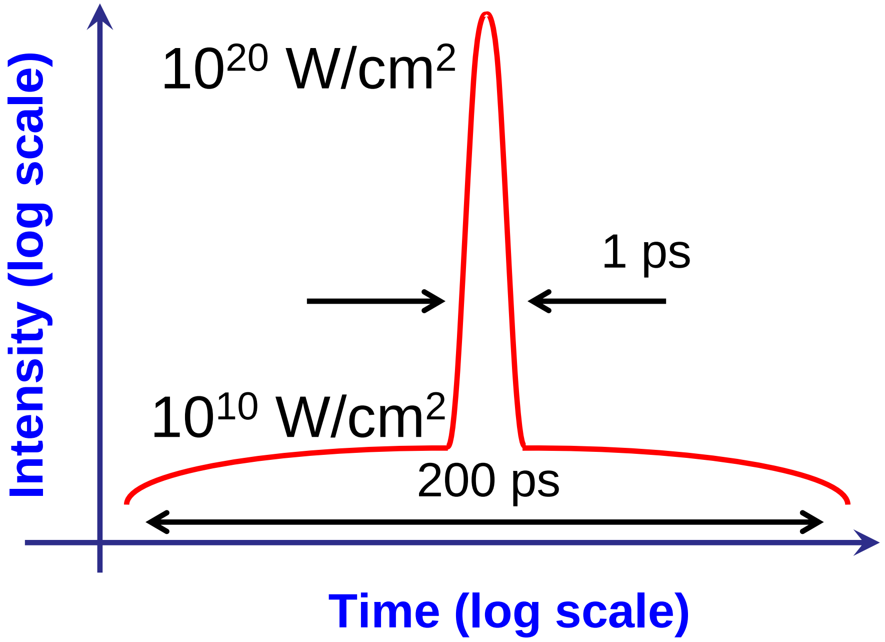
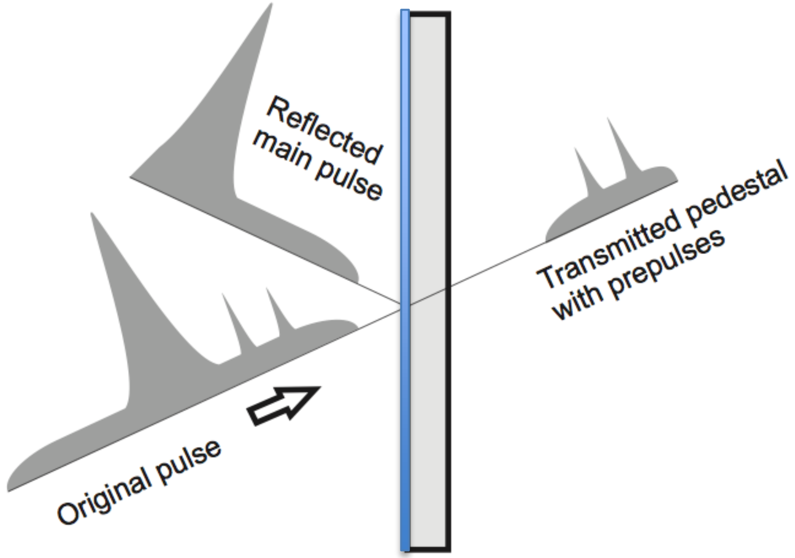
Typical shape of laser pulse



Principle of plasma mirror



See details in the poster by A. Morace (IFE/P6-4, Thursday).

Laser-generated relativistic electron beams can be guide by a few kT of externally imposed B-field

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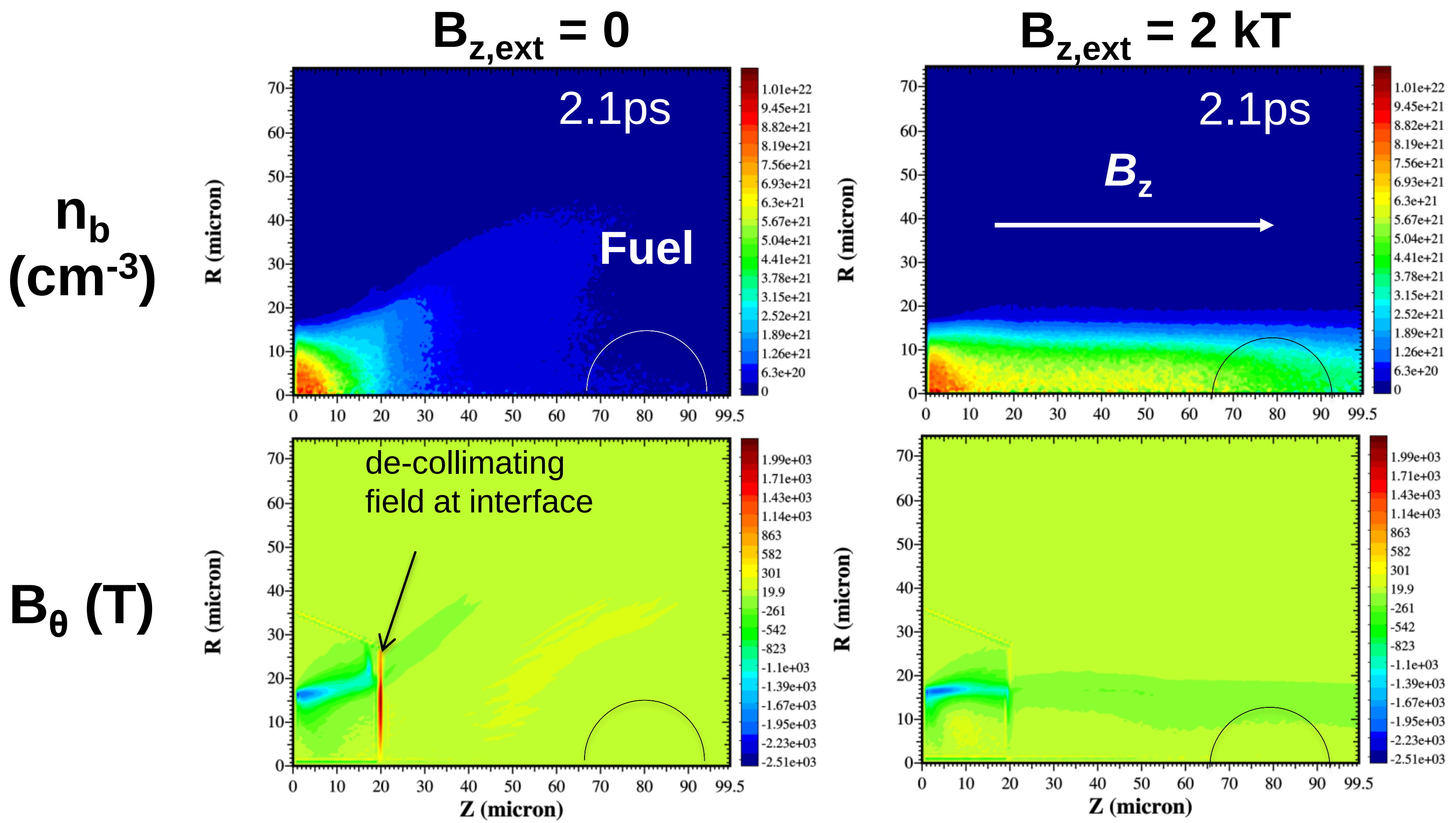
#Simulation by Prof. Honrubia.



See details in a poster by T. Johzaki (IFE/P6-5, Thursday).

1 kT B-field* was generated with a capacitor-coil target# and a ns-kJ laser.

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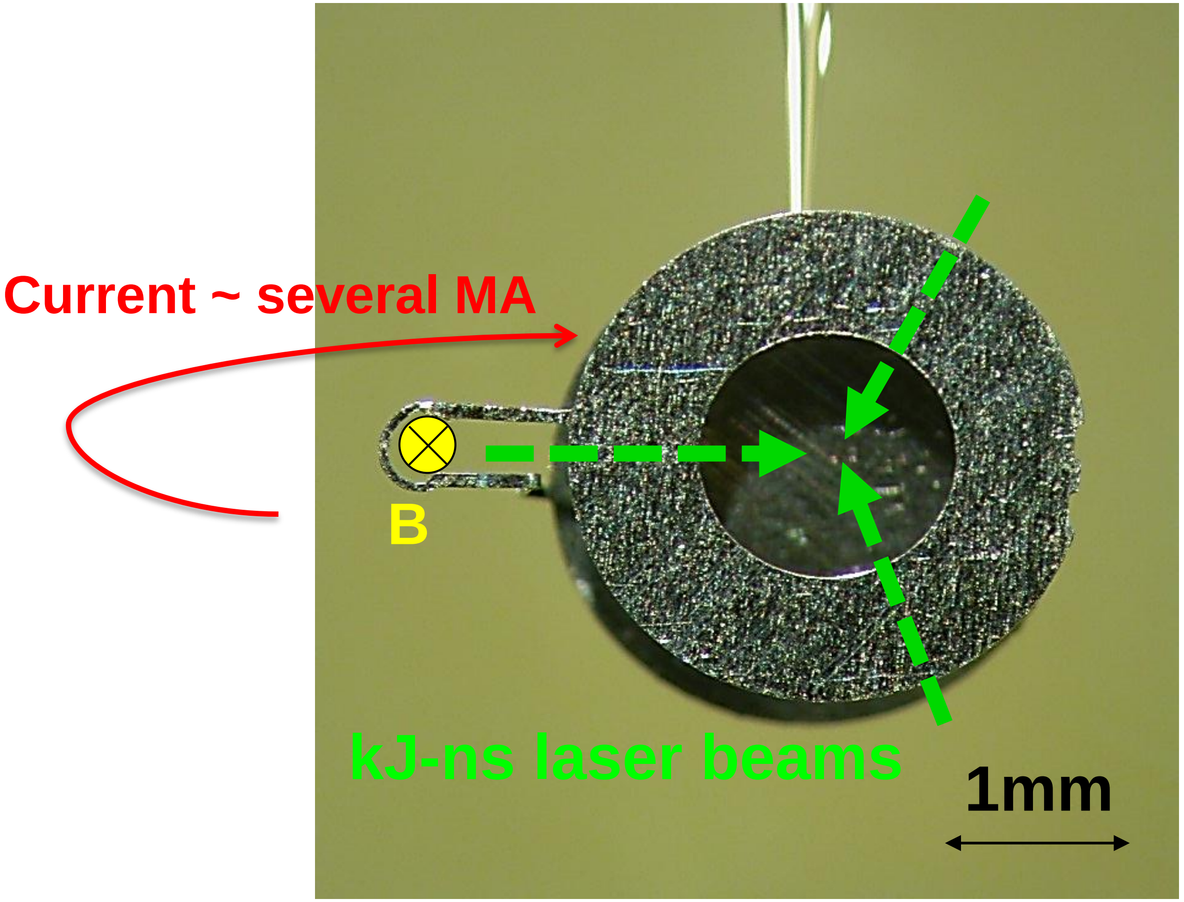
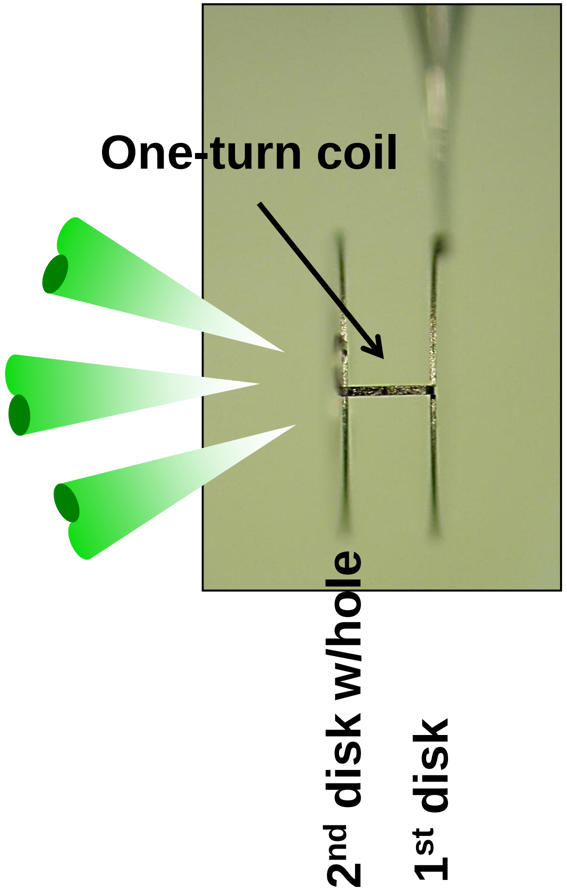
*S. Fujioka *et al*., Sci. Rep. (2013).
#H. Daido *et al*., PRL (1985), C. Courtois *et al*., JAP (2005),

Photo of capacitor-coil target





Laser-generated REB was pinched
by externally imposed kT magnetic field.

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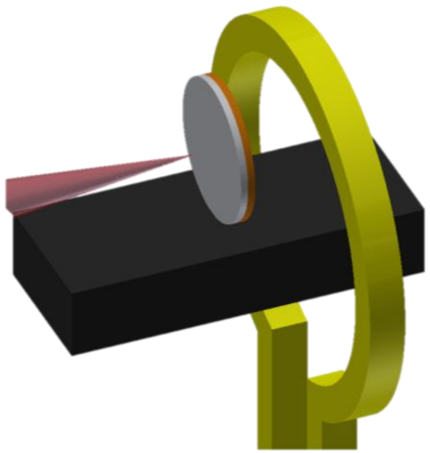
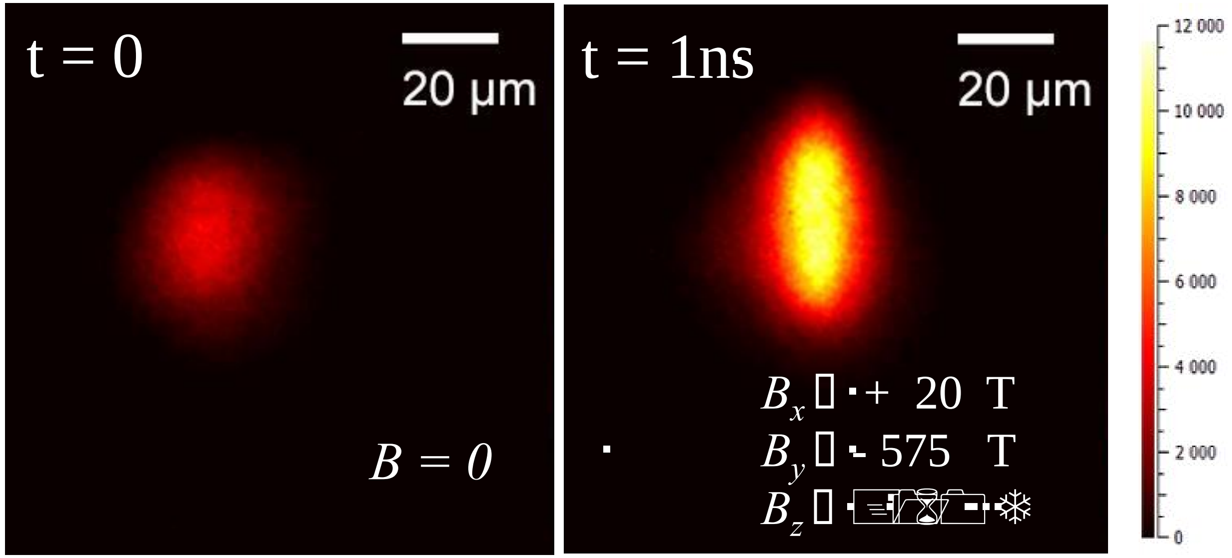
Experimental setup



Spatial profile of transmitted REB



2D MHD-rad-hydro code is under development
for full simulation of B-assisted fast ignition scheme.

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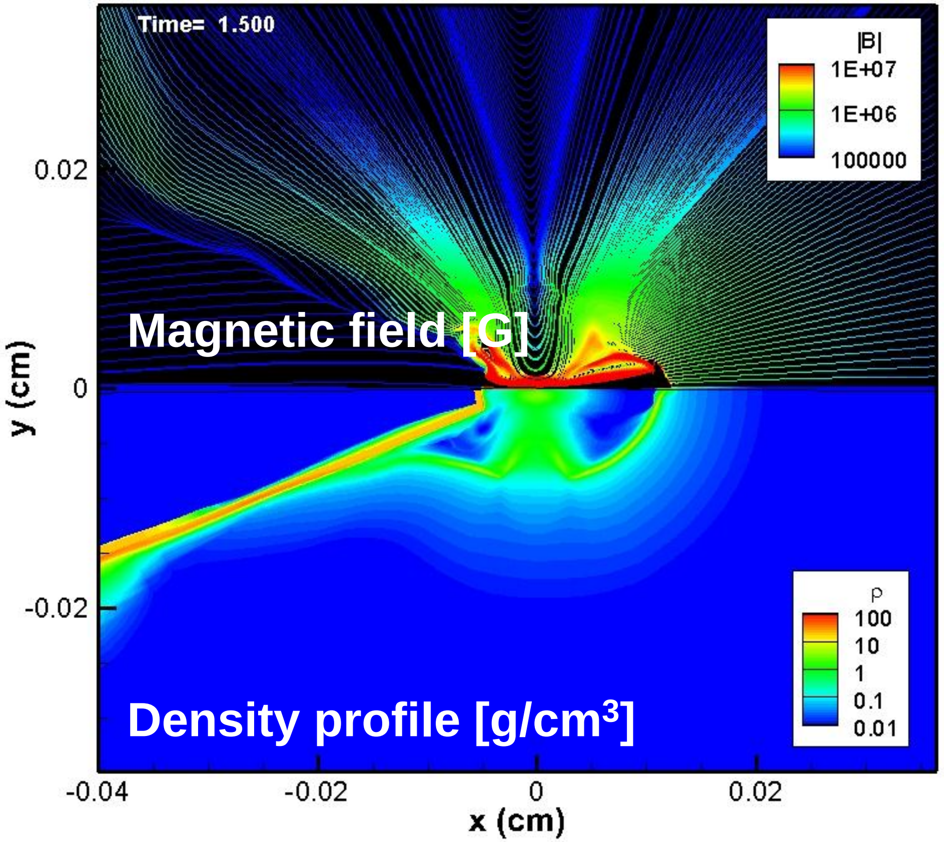
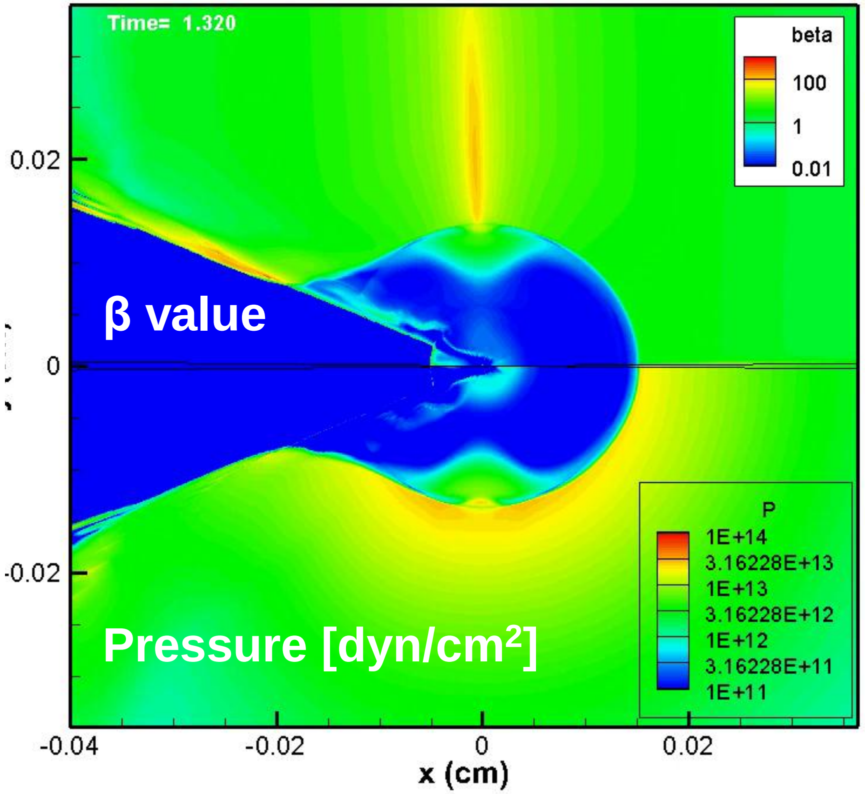
Computations by 2D MHD-Rad-Hydro code (PINOCO-MHD)





See details in the poster by H. Nagatomo (IFE/P6-6, Thursday).

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