Fast Ignition Program in Japan
"Progress of Fast Ignition Project; FIREX"

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2006.9.27&28 at Washington D.C., USA

ILE became a National User's Facility for High Energy Density science on 2006.4
Fusion , Laser Astrophysics, EUV, and so on are main projects

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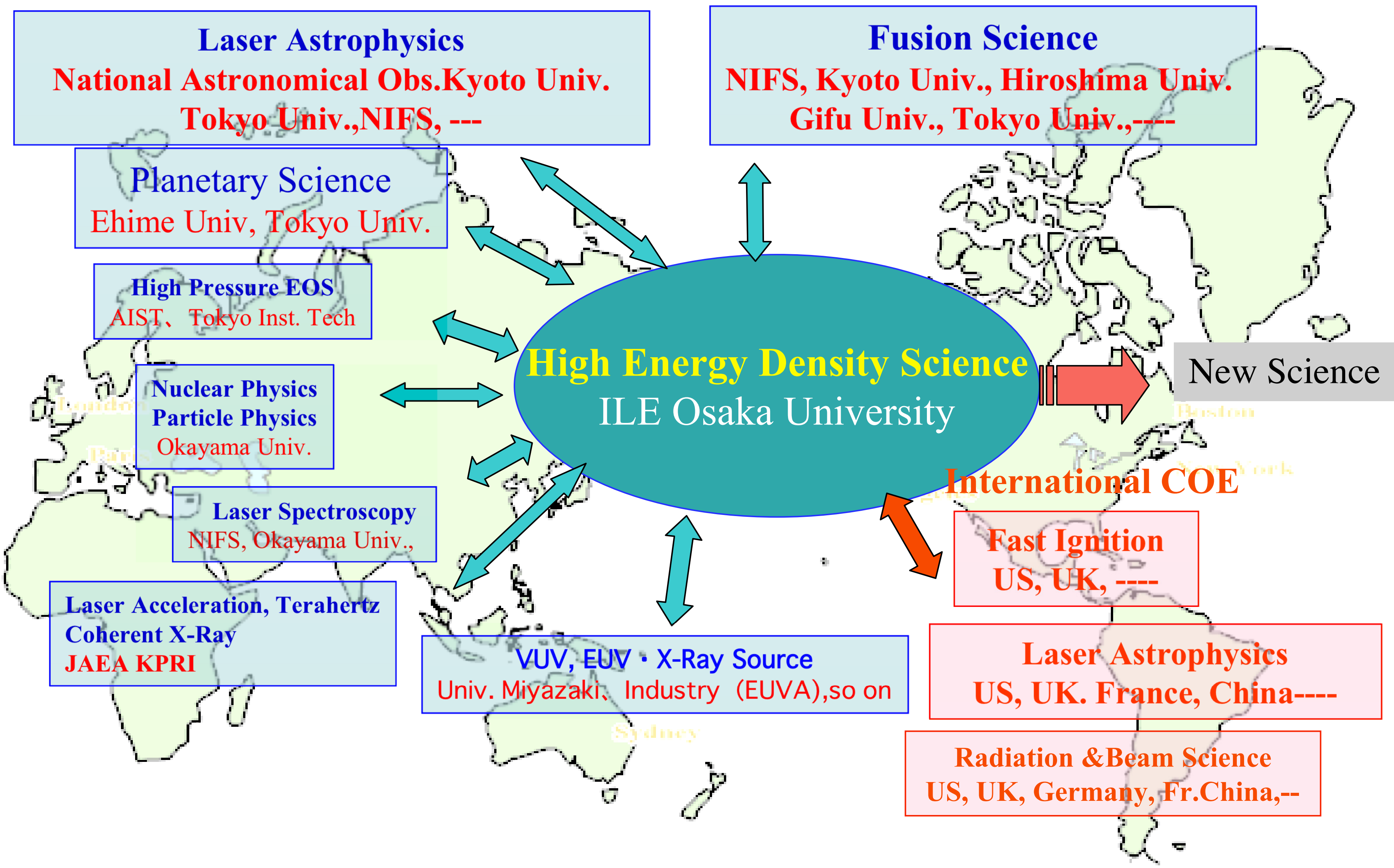

Back ground and outline of this talk

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- Fast Ignition Laser Fusion Research was selected as one of the 4 high priority fusion projects in Japan: Tokamak, Laser, LHD, Reactor Tech. In 2003.
- FIREX project has been a collaboration program among NIFS, Osaka Univ., and other universities since 2003.

1） Introduction

2） Present status of FIREX research

3） Recent topics

4） Future plan

Plan of FIREX Project

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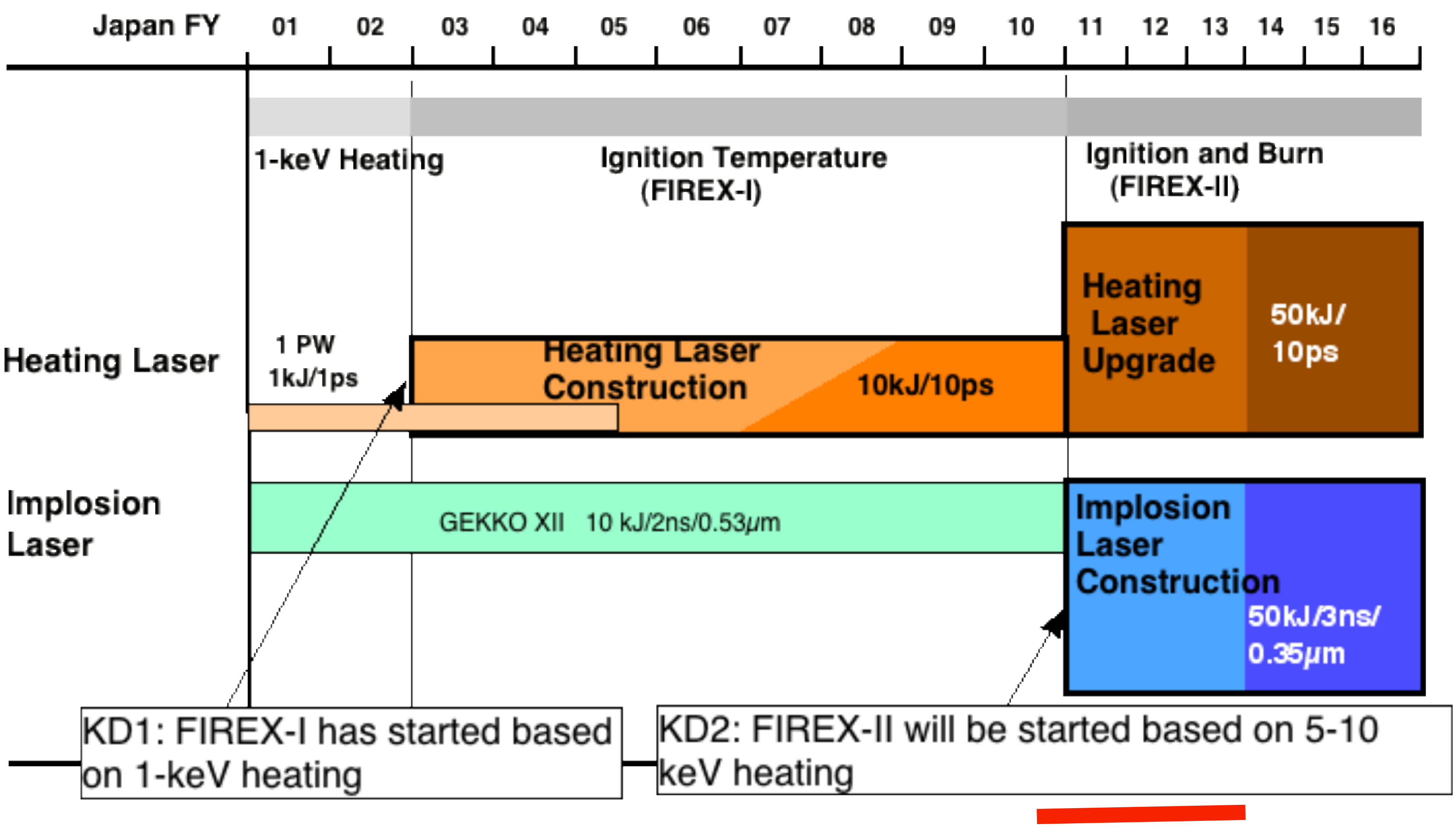

NIF ignition

4

600g/cc implosion and high efficiency heating of imploded target to 1keV

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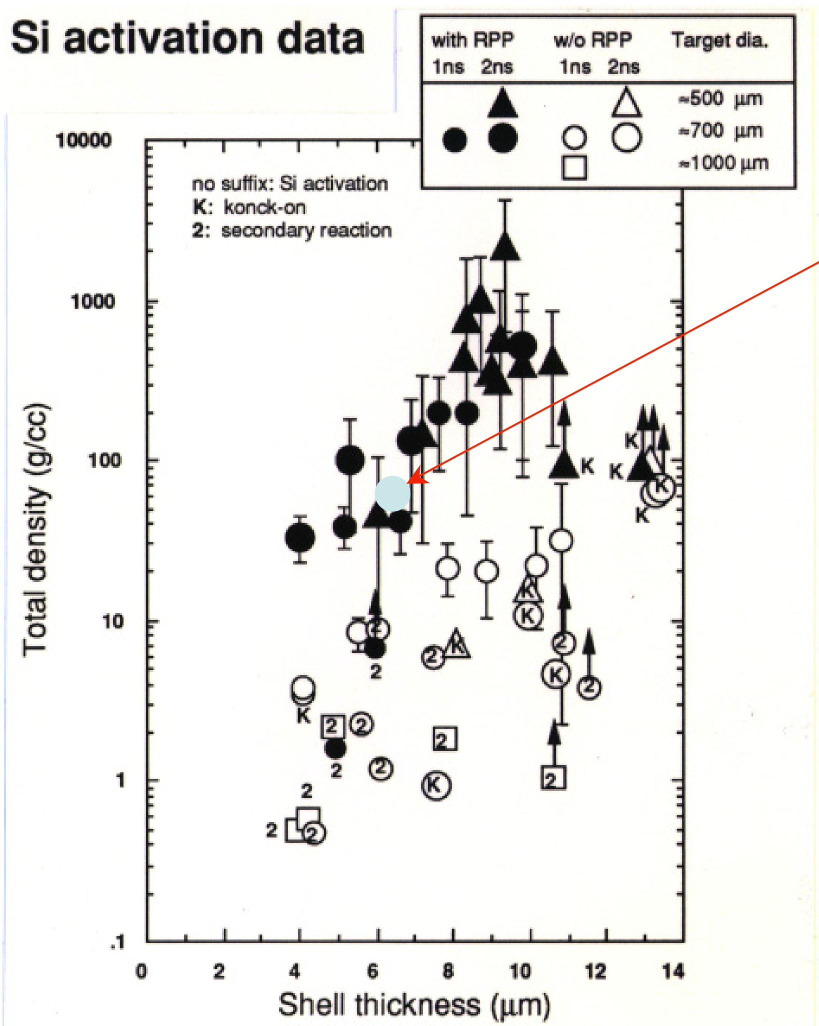
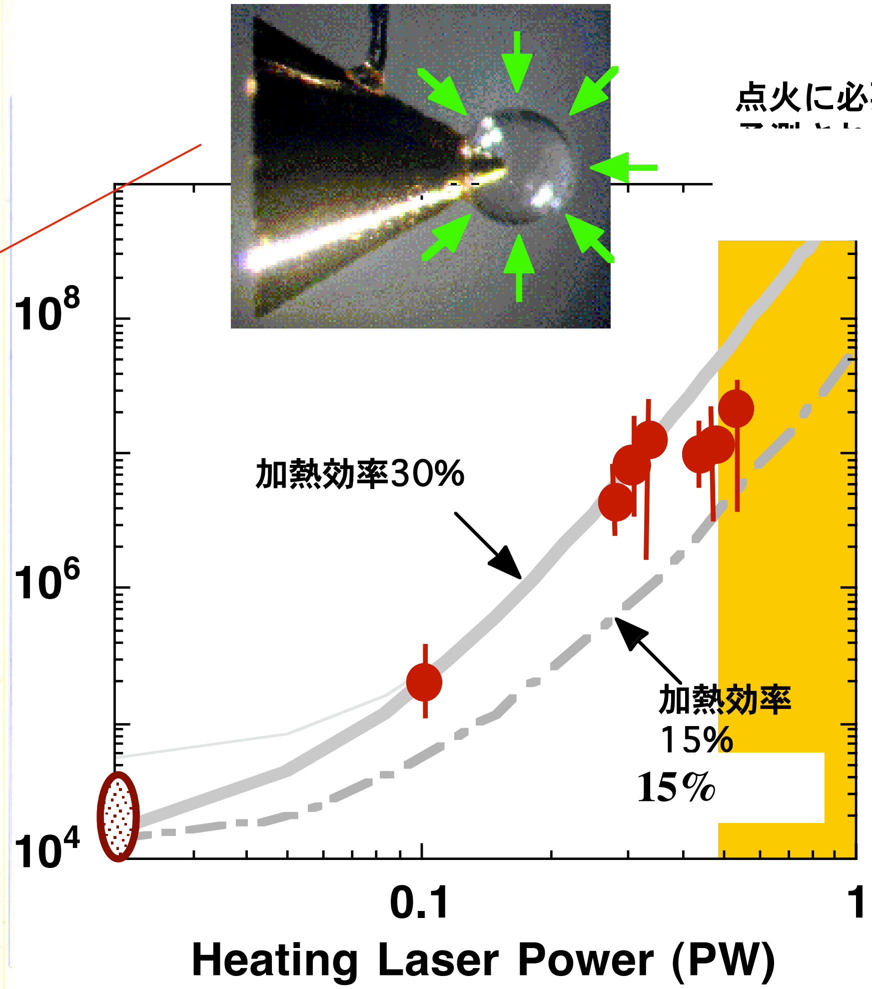
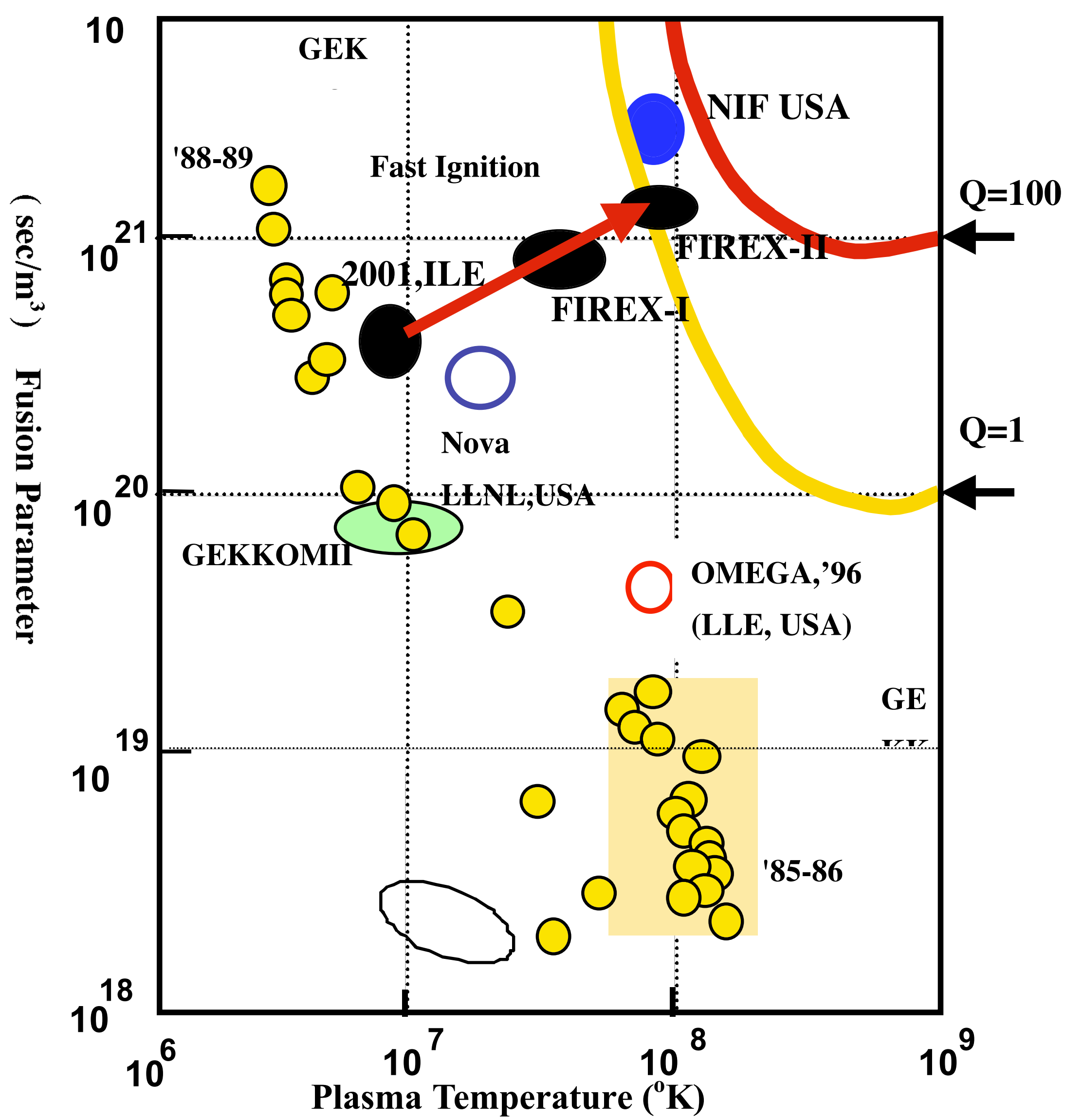


Azechi,1990



Kodama, Nature 2002

FIREX project toward Fast Ignition



FIREX-I Milestones

F. Year	Laser construction	Milestones
2005	Completion of LFEX amplifier	
2006.5	14.4kJ out-put energy	
2006.9	Compressor construction	1) Cryogenic DD target implosion hydrodynamics exp. 2) Cryogenic foam shell cone target fabrication 3) Completion of FI3 and cone target design
2007.3	1 beam experiment	D_2 exp. ~2kJ input
2008.3	4 beam experiment	D_2 exp. ~10kJ input
2009		D_2 5keV heating
2010		DT experiment aiming at Q=0.1

Specification

Overall laser specifications required for FIREX-I

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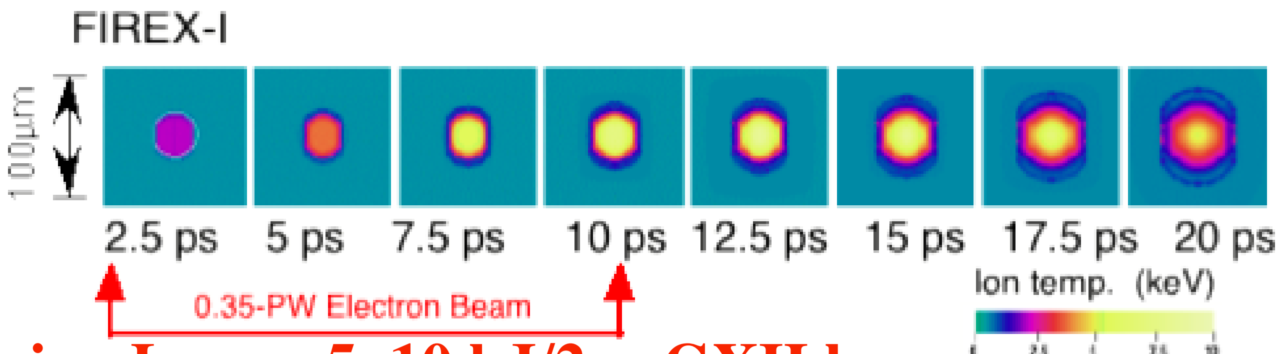
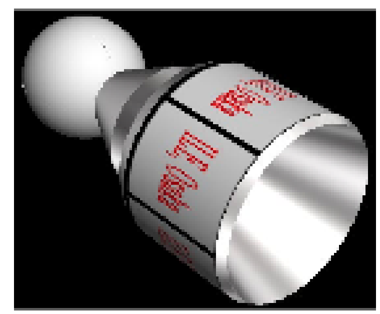


Implosion Laser; 5~10 kJ/2ω GXII laser

Heating laser; LFEX



Wavelength: 1053 nm (Nd: glass laser)
Pulse energy: 10 kJ
Pulse width: 1-20 ps (FWHM)
10 ps (typical)
Pulse shape: trapezoid with <2 ps rise time
Focal spot: 20-30 μm (≥50 % encircled energy)

Option: 10 kJ/1 ps, 5 kJ/0.5 ps (for high-field science)

Main Laser Facilities for Laser Fusion at ILE, Osaka

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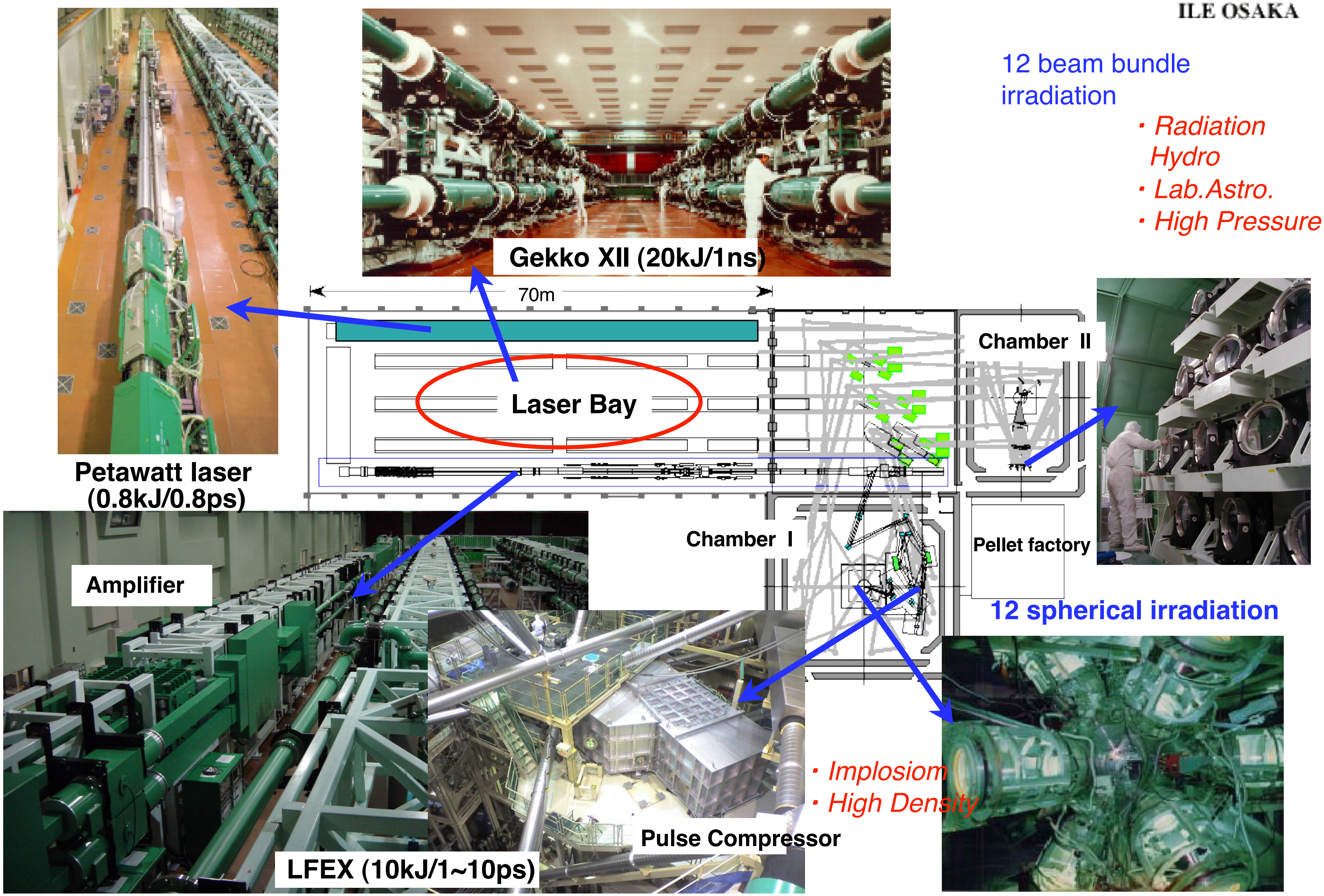
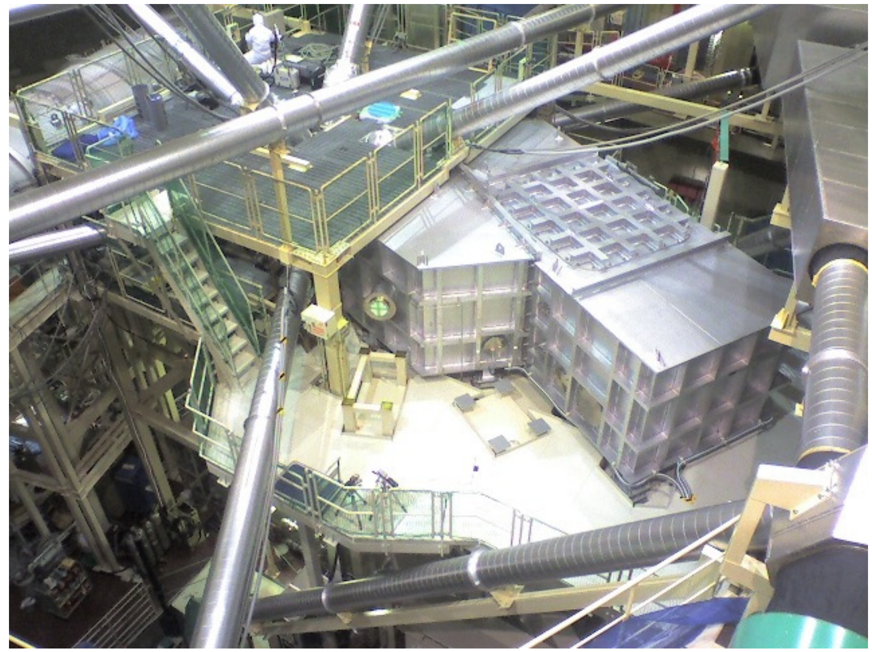
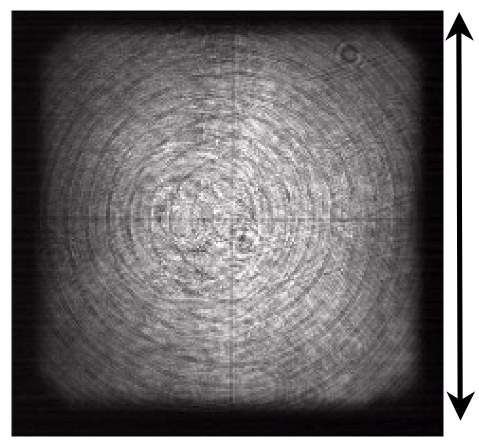


LFEX laser present status



05.5.17 1.2 kJ/1 beam
06.5.19 3.6 kJ/1 beam
(Full beam equivalent =14.4 kJ)
06.4.24 6.5 kJ/4 beam



32.5 cm

FIREX-target R&D

NIFS

Cryogenic target for FIREX-I project

-Foam cryogenic shell with Cone and DT fill tube-

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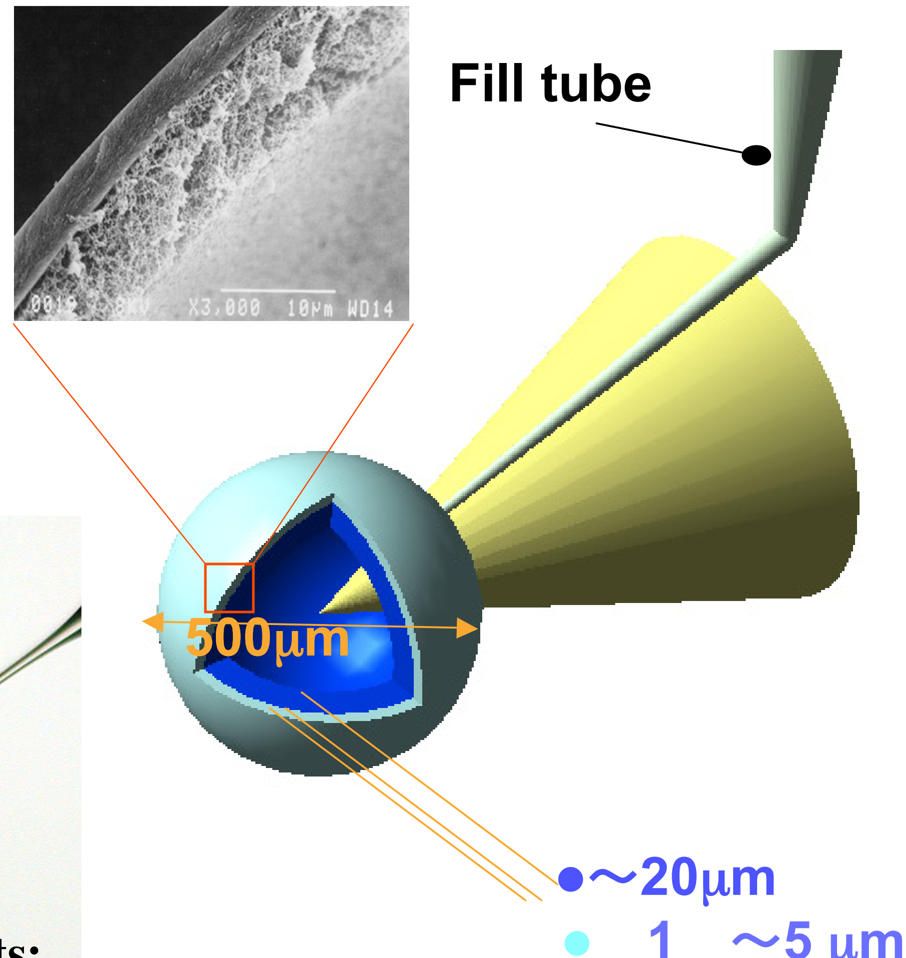
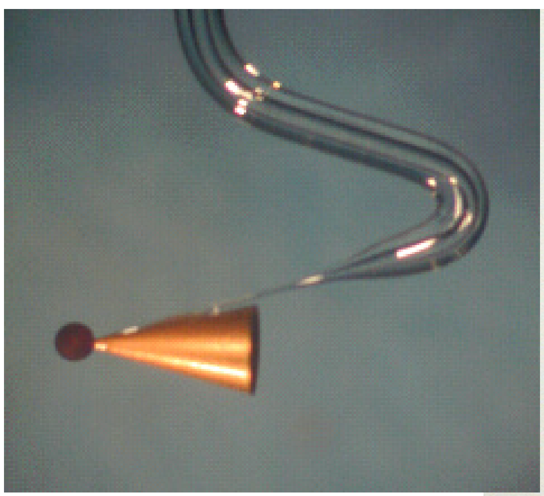
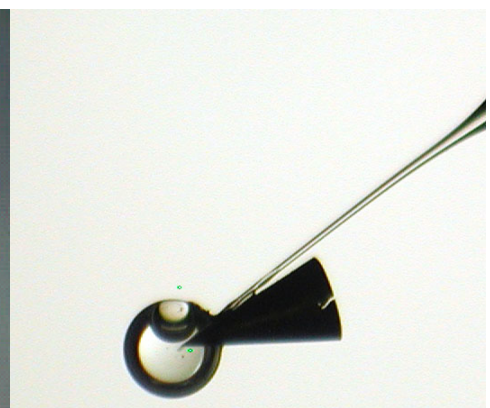
For FIREX-I

Cryogenic Target

- Diameter : 500µm
- Fuel layer : ～20µm
- With glass tube~10µm$^{\phi}$
- D_2 or DT fuel
- Foam density: ~10mg/cc







Model experiments;
Target daimeter:2mm$^{\phi}$, fill tube diameter:100µm$^{\phi}$
Foam density: 100mg/cc, working gas: H_2

FIREX-I target design-I

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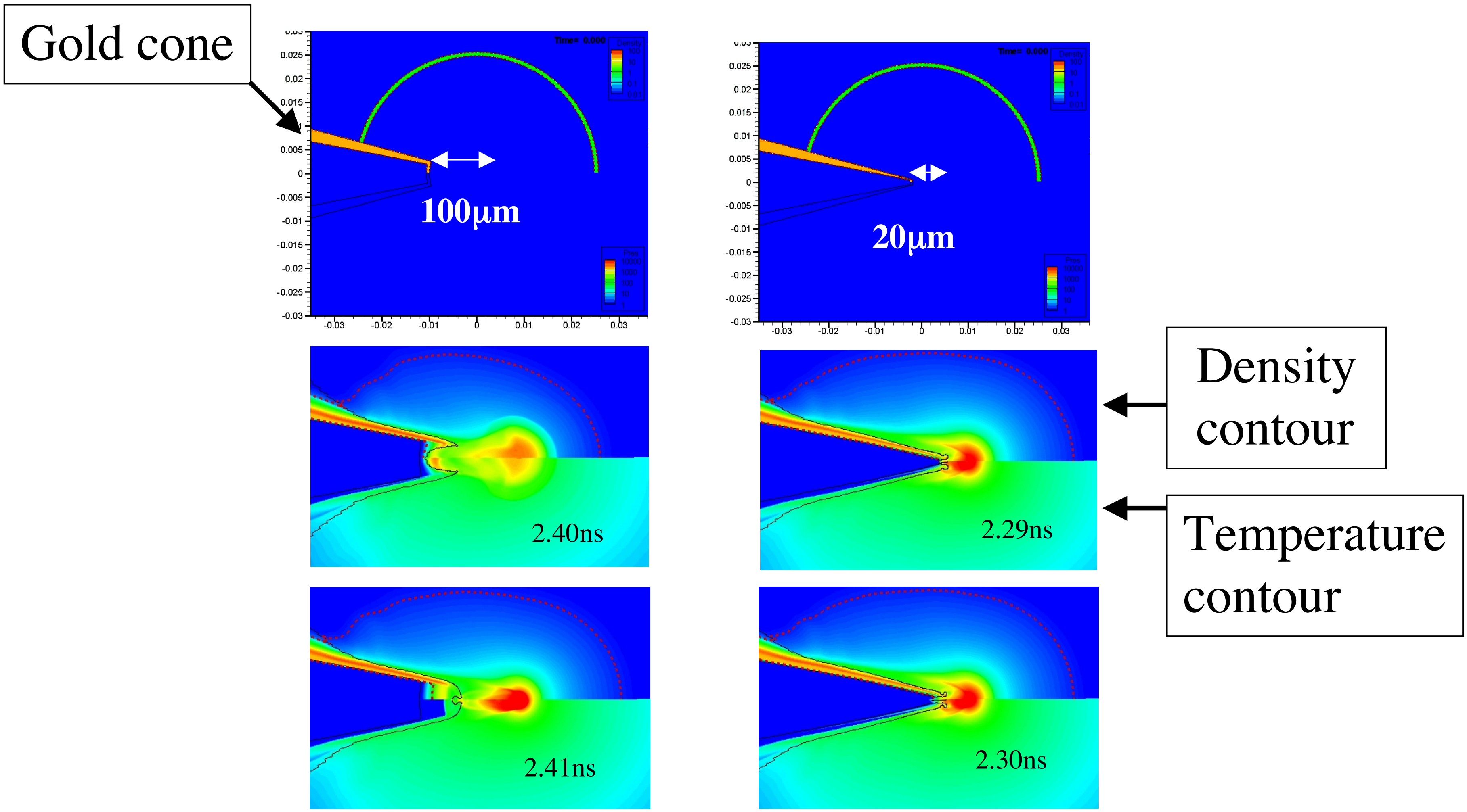
Cone target position dependence of implosion and cone break

The cone top breaking time is insensitive to cone top position.



Rear surface temperature before the shock arrival

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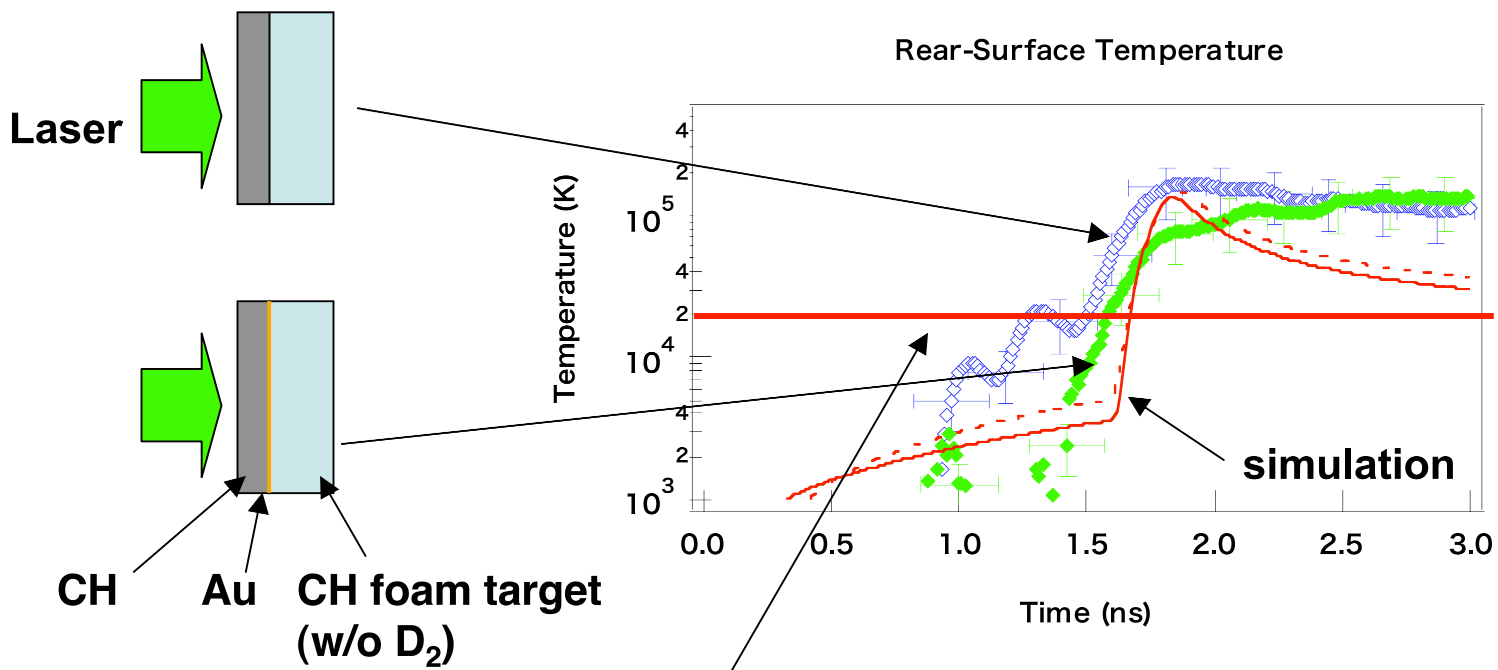


- Tolerable preheat level is less than Solid D_2 Fermi energy ~5 eV.
- Preheat level of standard target is marginal.
- Gold thin layer well reduces the preheat level!
- Degradation of cryogenic target compression will be due to non-uniformity.

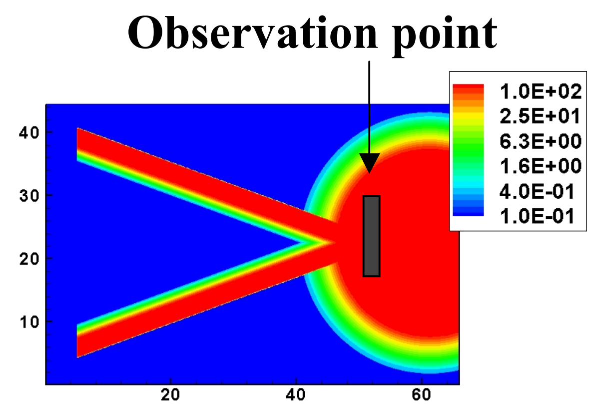
Gold cone design; Cone angle dependence with 2-D PIC simulations

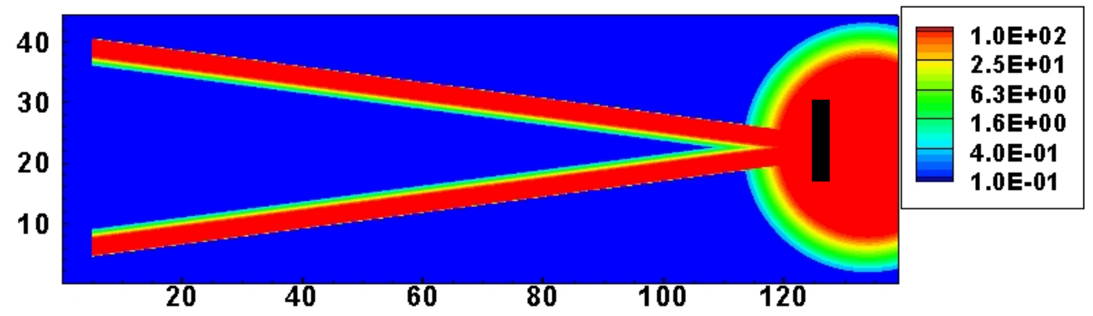
Target

- Cone target with angle of 15, 30, 40 deg.
- Density of 100 Nc with buffer region at rear.
- Initial temperature of 10 keV
- Immobile Ions

Laser pulse

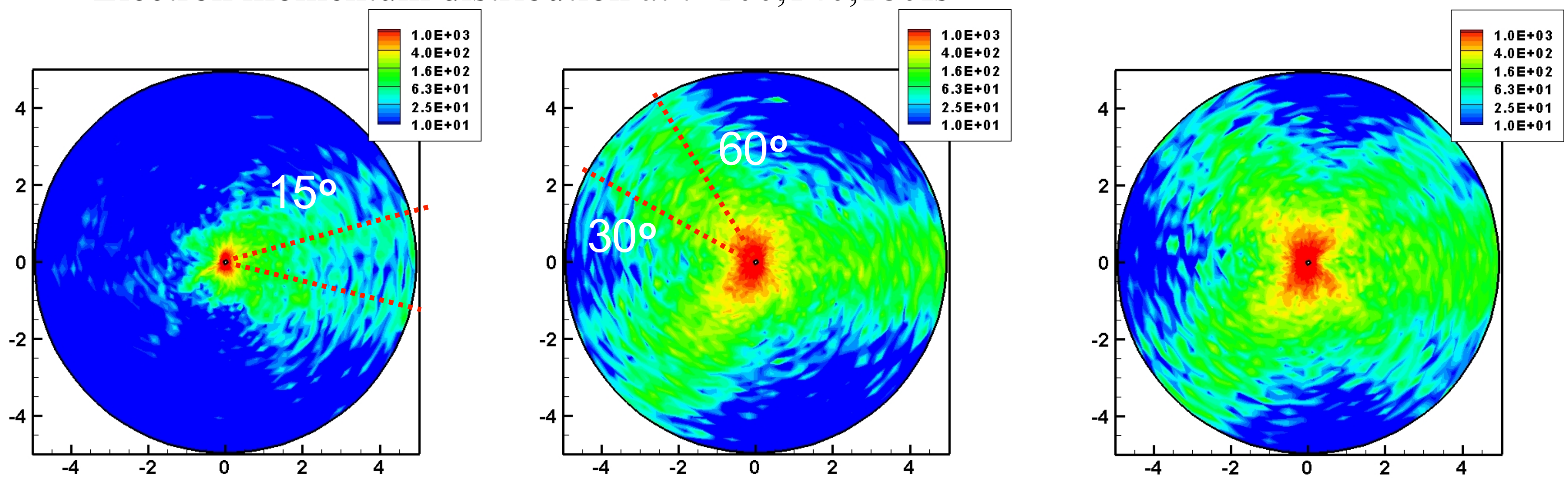
- Plane wave with intensity of 1.0×10^{20} w/cm^2
- Spot size of 10μm (FWHM)
- Linearly polarized



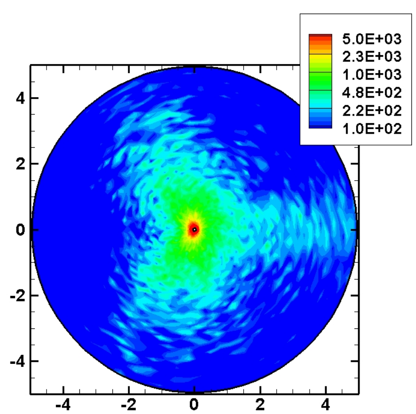


Electrons are accelerated at cone wing by incident and reflected laser fields

Electron momentum distribution at t=100,140,180fs



For 30-deg cone target, electrons are accelerated along the target surface (surface-acceleration), and the reflected field accelerates electrons along the propagation direction (ponderomotive acceleration).

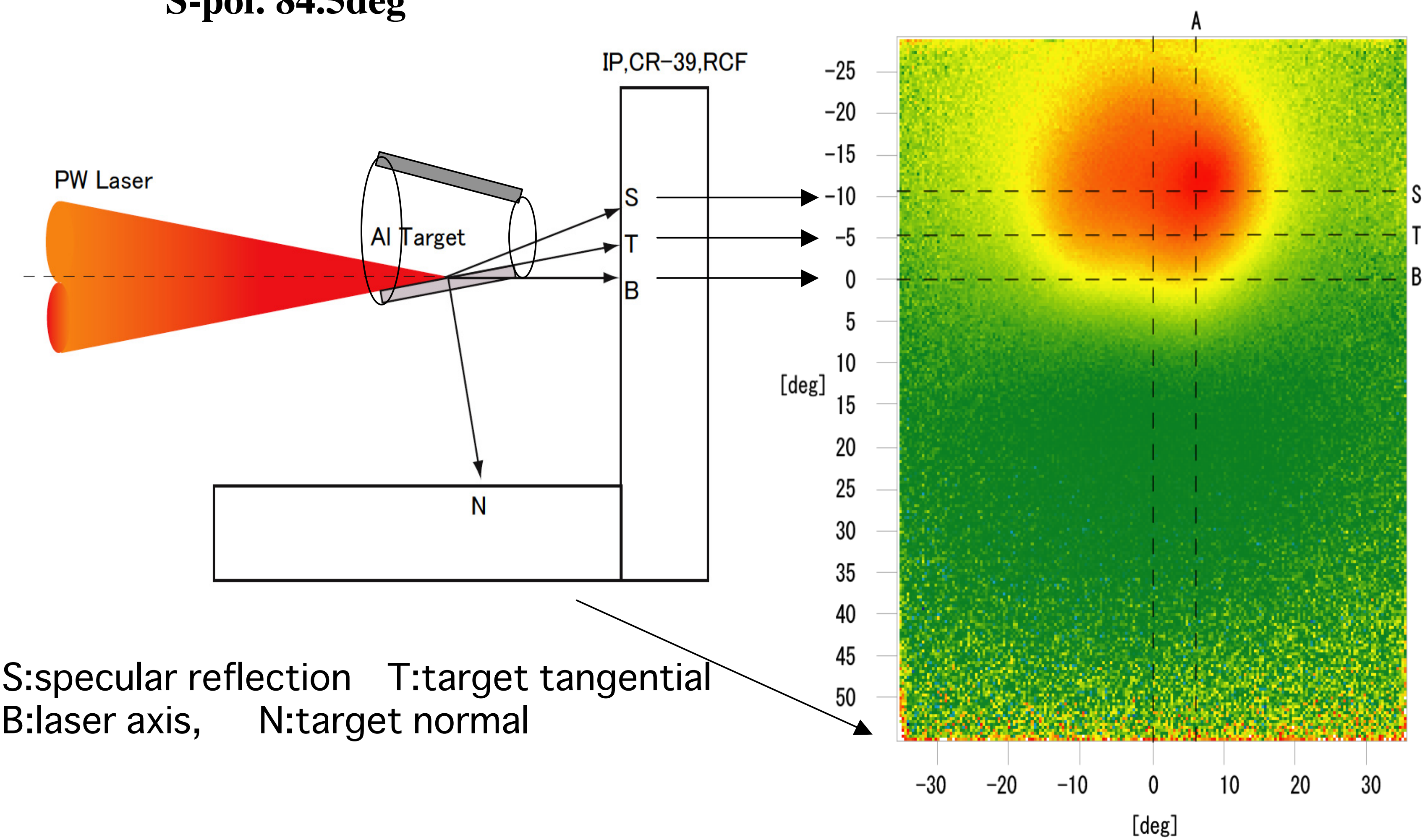


For 45-degree cone target, electrons are incident laser direction, and reflected wave direction.

High energy electron angular distribution in Cone Target

Laser 201.36J/0.5ps (0.5PW)
Target Al+SiO_2 Plane
S-pol. 84.5deg

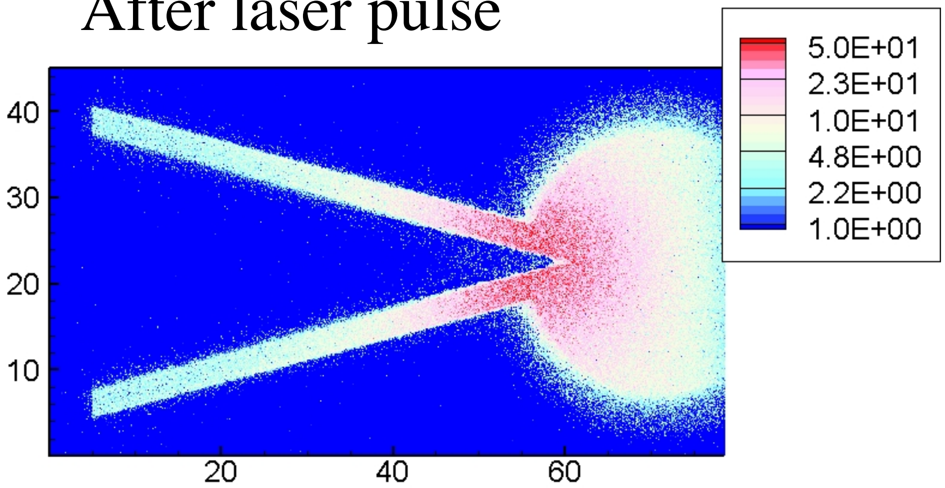
Angular distribution has 20～30° width around tangential direction.



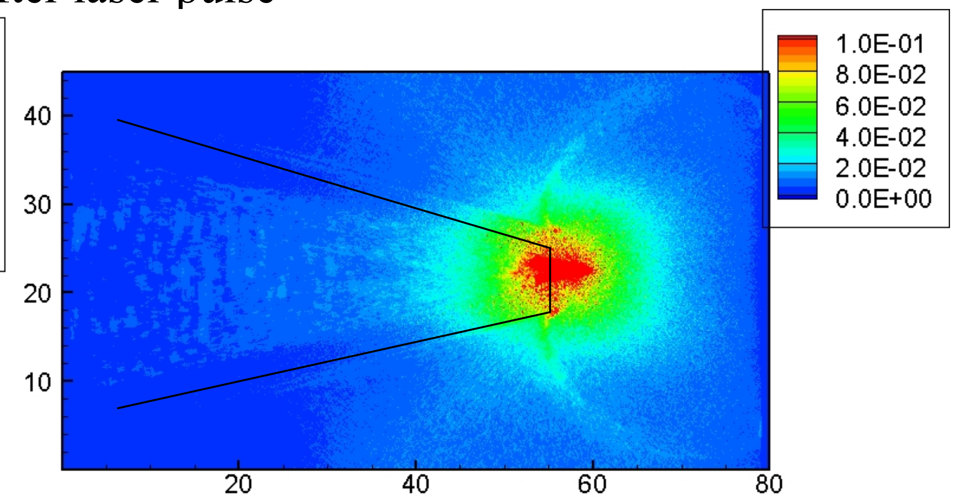
S:specular reflection T:target tangential
B:laser axis, N:target normal

High energy electrons are confined at cone tip

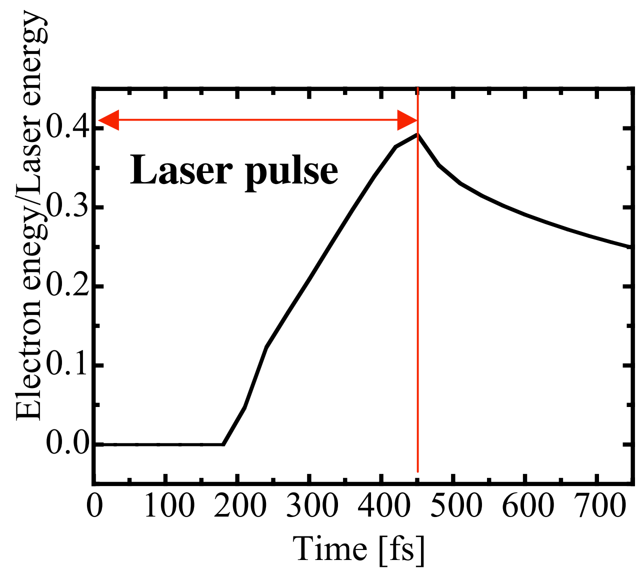
(energy density)/$N_c\, mc^2$
After laser pulse



(Quasi static field energy density)/$[(E_L{}^2+B_L{}^2)/2]$
after laser pulse



Temporal evolution of electron energy stored in cone



25% is stored for a long time

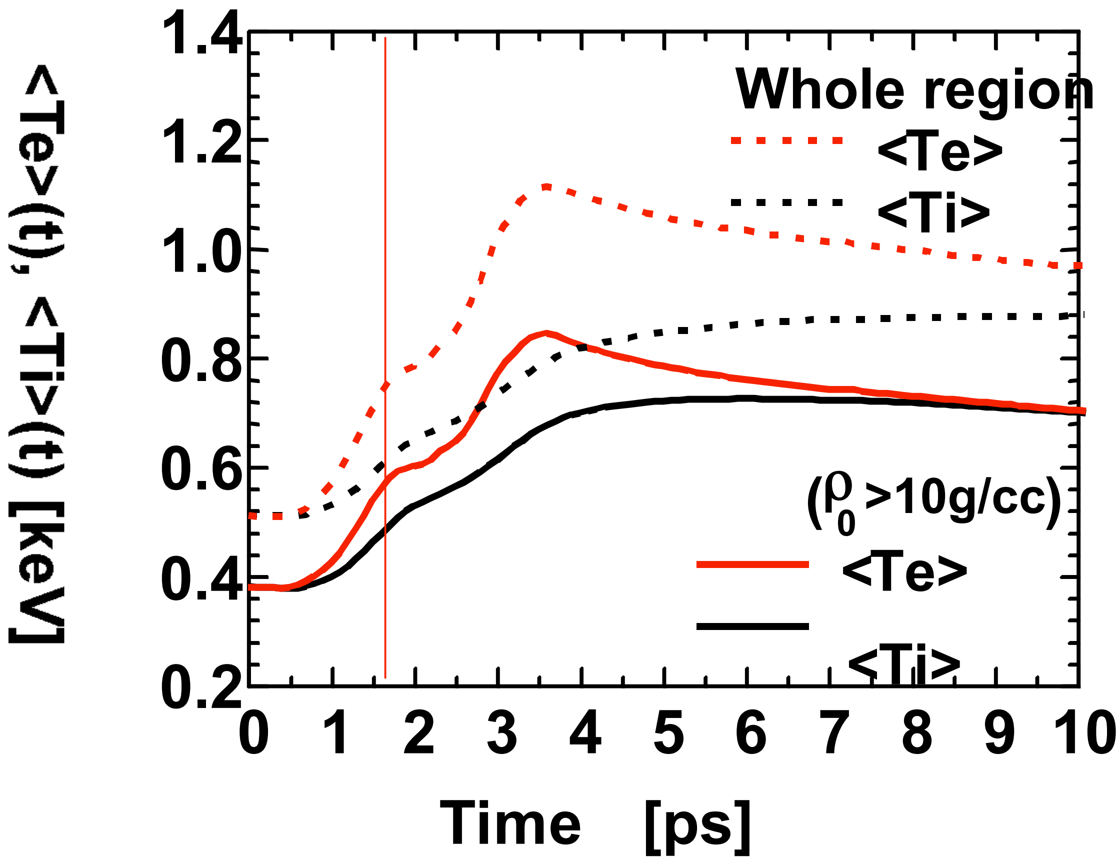
1. Cone angle dependence : absorption rate

	Flux ratio 1*	Flux ratio 2 *	Absorption rate (stored at tip)
15deg	**21.5%**	**2.2%**	**52 (25)%**
30deg	**18.0%**	**3.6%**	**55 (25)%**
40deg	**16.9%**	**4.0%**	**49 (26)%**

Flux ratio 1 denotes ratio $\int_\Omega S_x dydt \Big/ \int S_{laser} dydt$,Ω is observing area (10μm width)

Flux ratio 2 is for electrons with energy less than 2 MeV.

Fast ignition experiments (Nature,2002,ILE and UK) are reproduced



Note that delayed heating is very important for efficient heating

Summary

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- **Fast ignition researches in FIREX-I have been progressing. The one beam heating experiment will be in 2007 and full beam experiments will start in 2008.**
- **LFEX Laser construction is in final stage.**
- **Foam cryogenic cone shell target has been fabricated.**
- **Preheating level of a foam cryogenic D_2 later is controlled by adding a thin high Z layer.**
- **Integrated simulation code of cone shell target was developed. The simulation code is benchmarked by Kodama Exp. (Nature '01) on compression and heating of cone shell target.**
- **The simulations indicate $\rho r = 0.2$ g/cm^2 and T=5keV, 20% heating efficiency which mean Q=0.1 and $N_y = 10^{15}$.**