Recent Progress of FIREX Project and Related Fusion Researches at ILE, Osaka

Kunioki Mima
Institute of Laser Engineering, Osaka University
IAEA-FEC 2006, Oct. 18, at Chengdu, China

Back ground and outline of this talk

ILE OSAKA

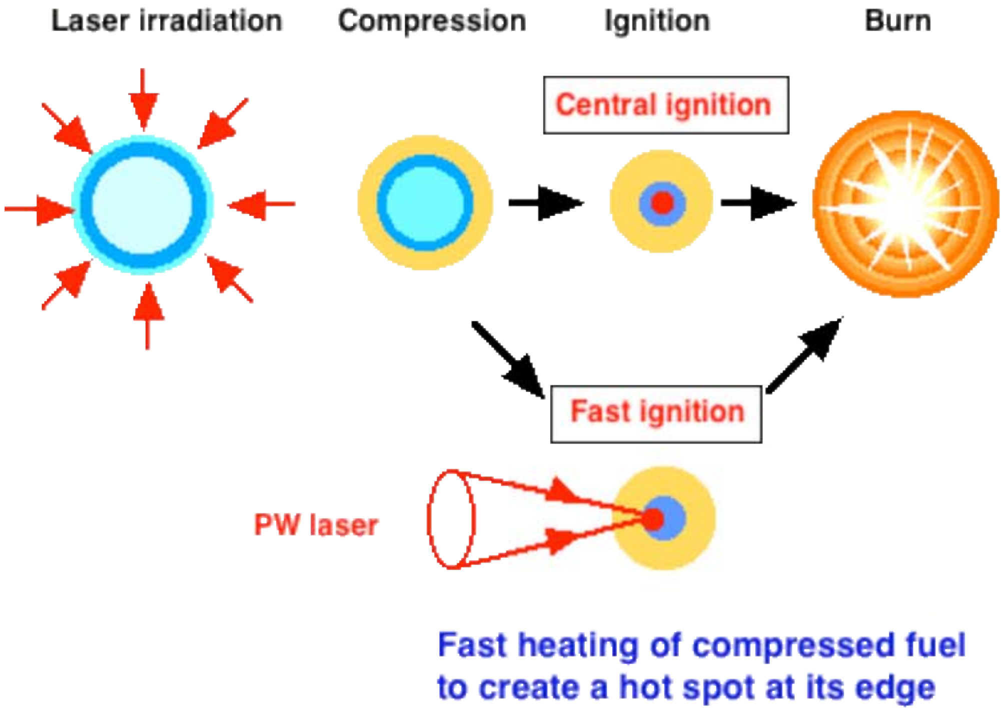
- Fast Ignition Research was selected as one of the 4 main fusion projects of Japan in 2003.
- FIREX (Fast Ignition Realization Experiment) project has started in 2003 as a collaboration program among Osaka Univ., NIFS, and other universities.

1) Introduction
2) Present status of FIREX project
3) Recent related topics
4) Future plan

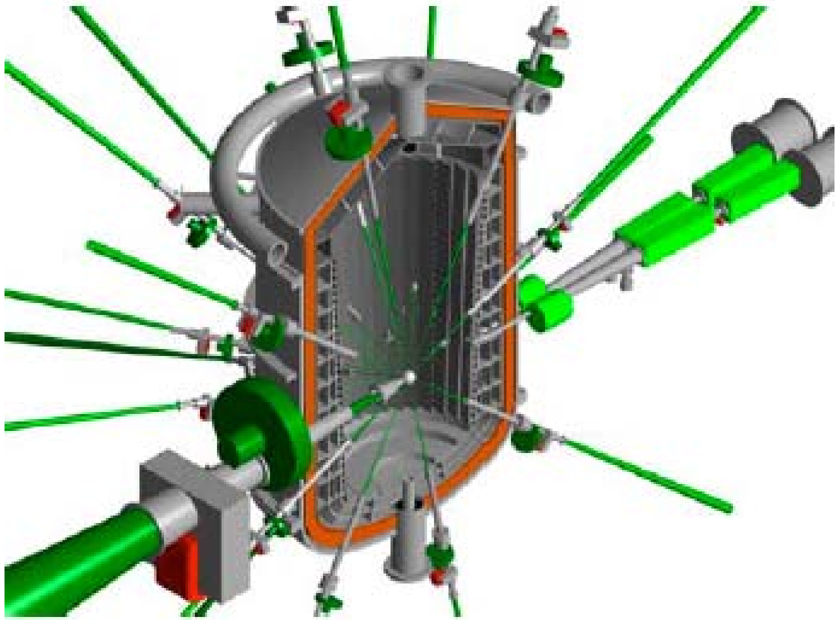
Fast ignition is attractive because of high gain with a smaller laser

ILE OSAKA

◆Fast ignition: Processes for compression and ignition are separated.

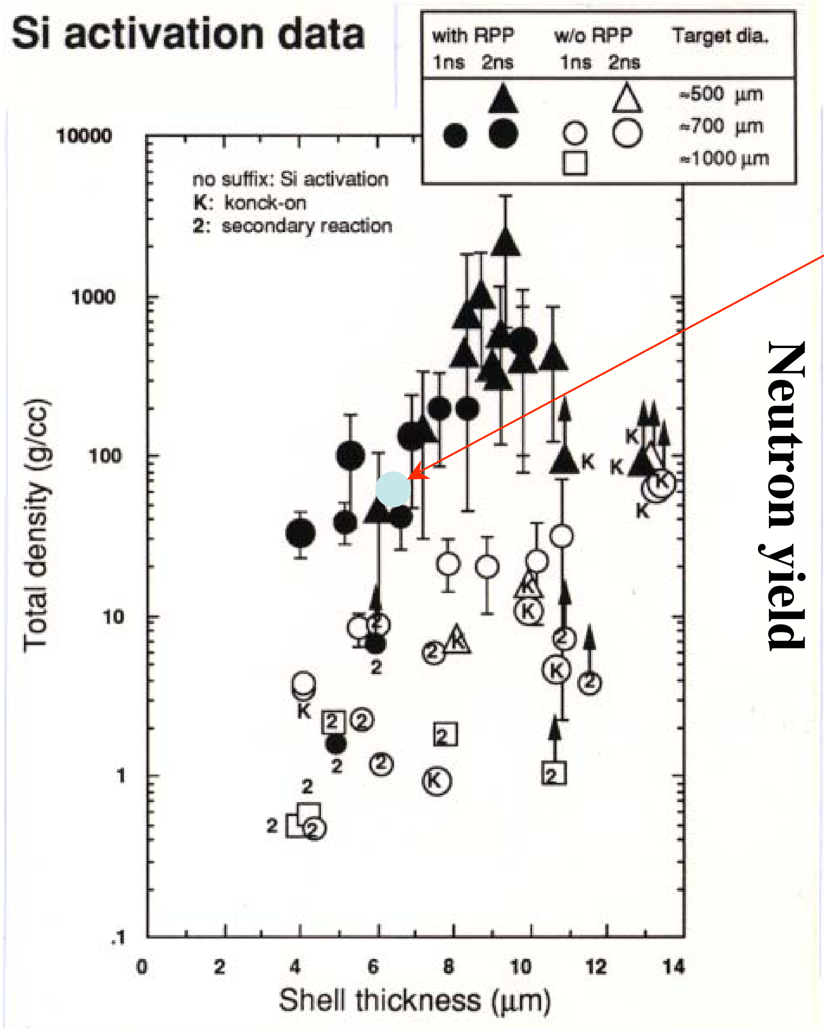


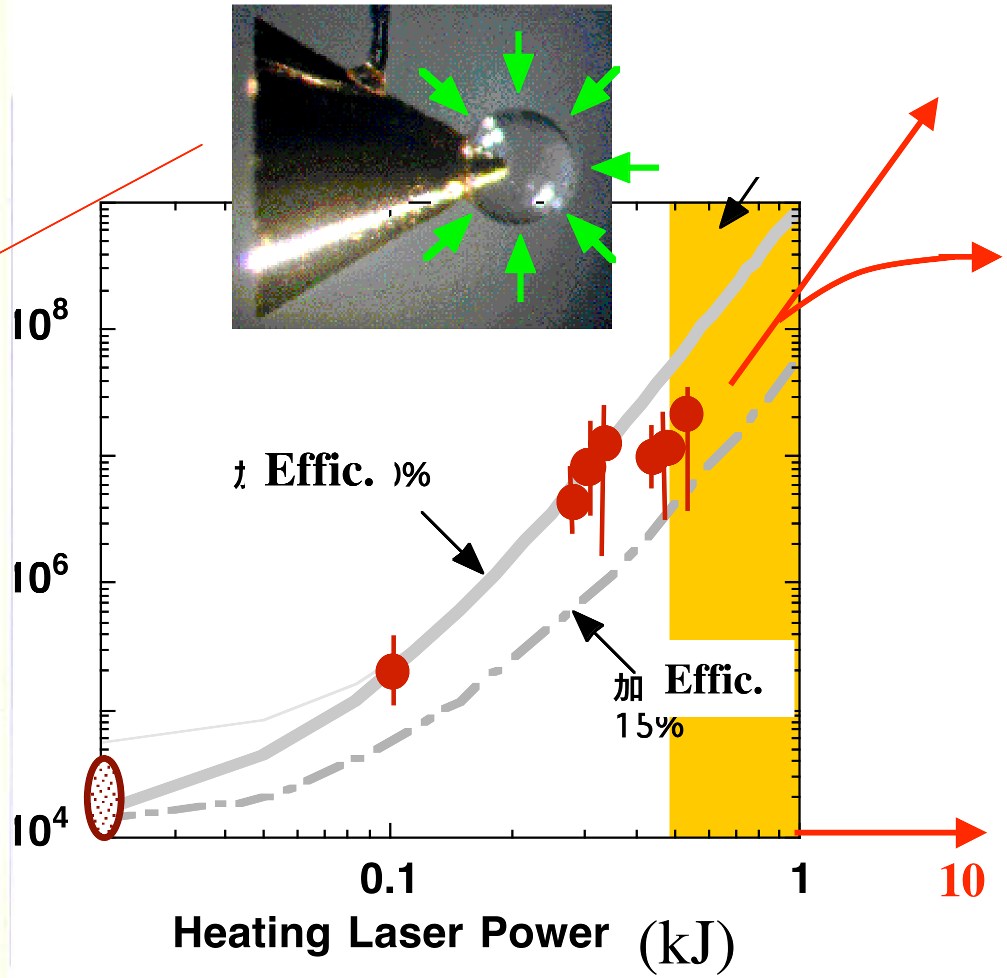
Laser Fusion Reactor KOYO-F



FT/P5/39: T.Norimatsu

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

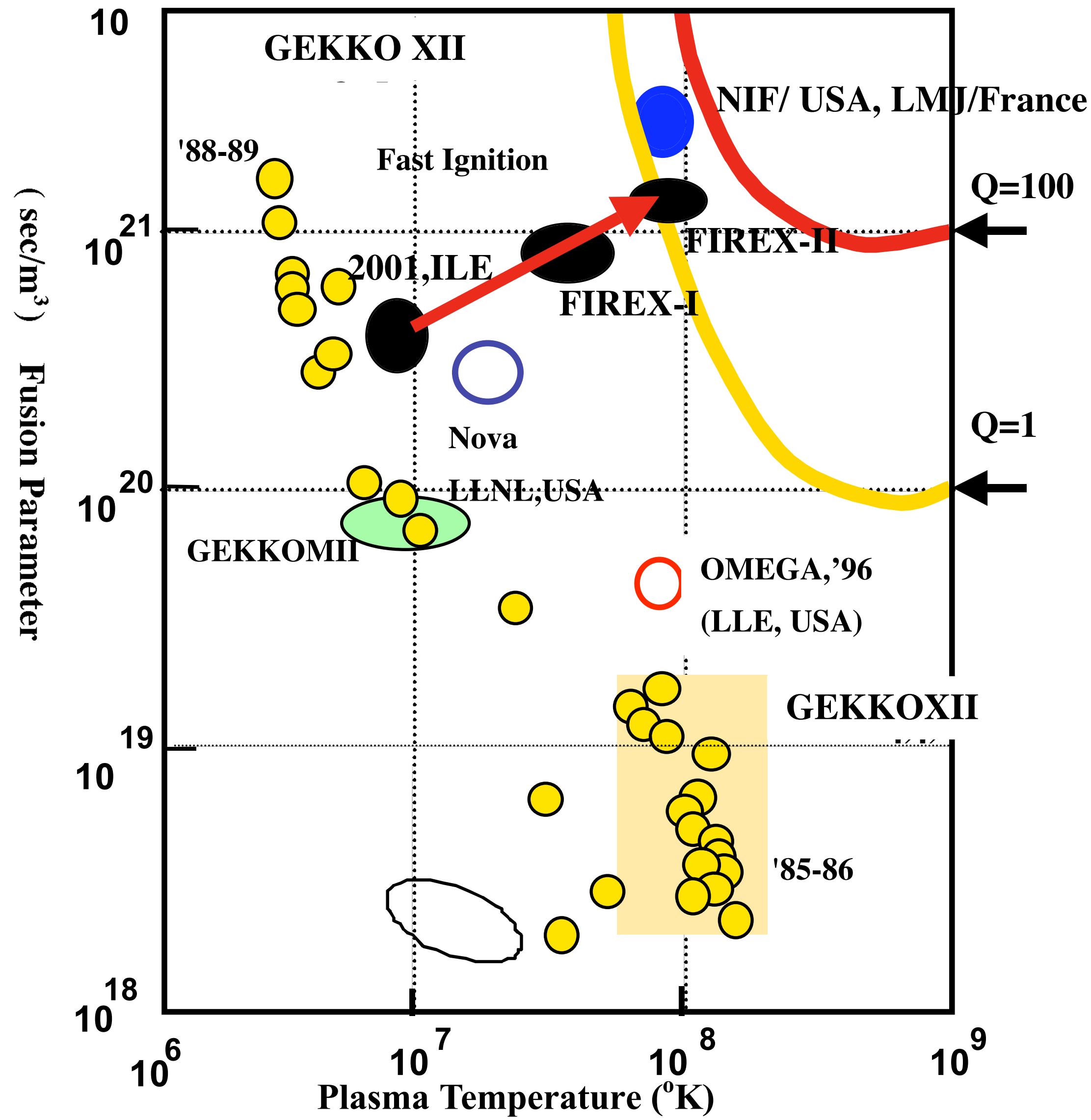




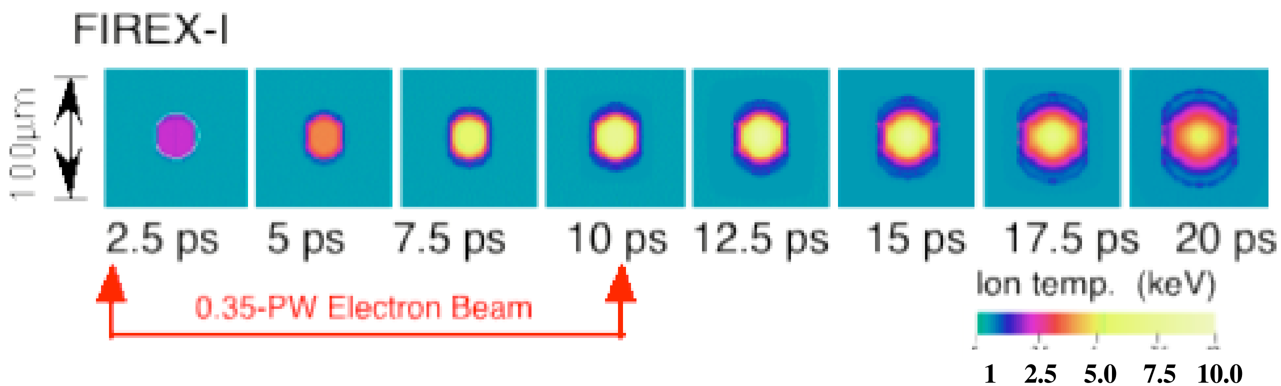
Azechi, Laser& Particle Beams 1990

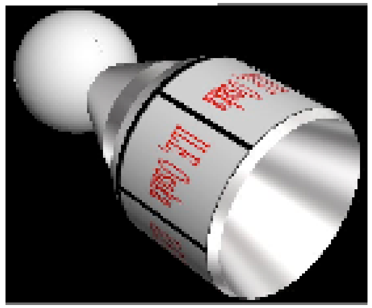
Kodama, Nature 2002

FIREX project is aiming at fusion burning with Fast Ignition



Heating Laser Specification for FIREX-I





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)

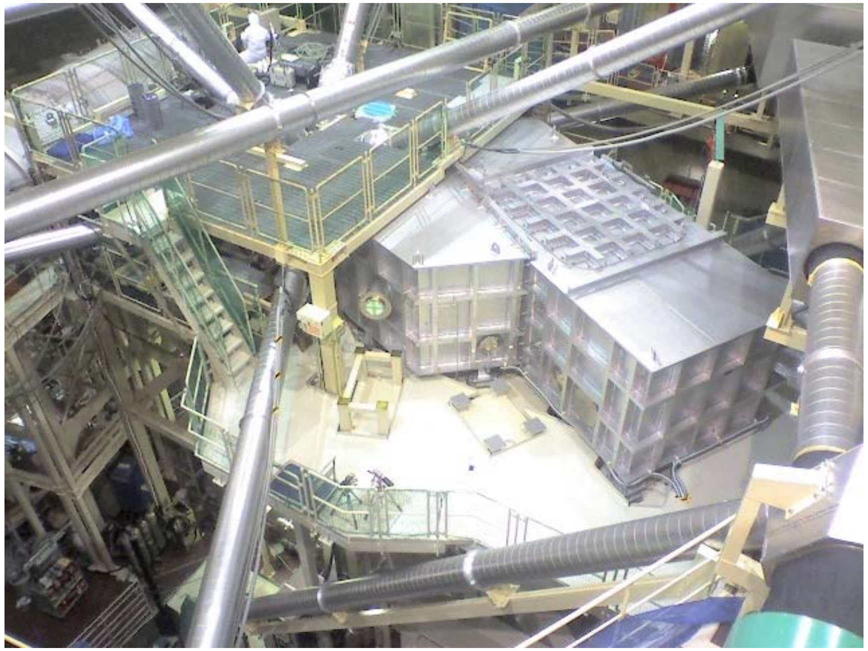
Option: 10 kJ/1 ps, 5 kJ/0.5 ps (for high-field science)
(Ion driven fast ignition)

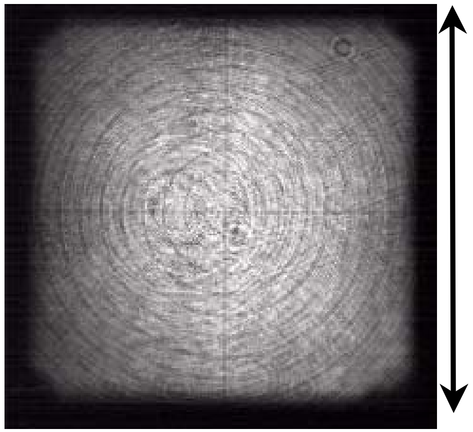
FIREX-I Project Milestone

ILE OSAKA

F. Year	Laser construction	plasma exp. & target fabrication
• 2003	FIREX-I laser construction started	
• 2005	Completion of amplifier	
• 2006.5	14.4kJ out-put energy	1) Cryogenic foam shell cone target fabrication and implosion test
• 2006.11	Compressorbeam alignment	
		2) Completion of FI3 and cone target design
• 2007.7	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

Present status of heating laser construction





32.5 cm

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

NIFS

Cryogenic target for FIREX-I

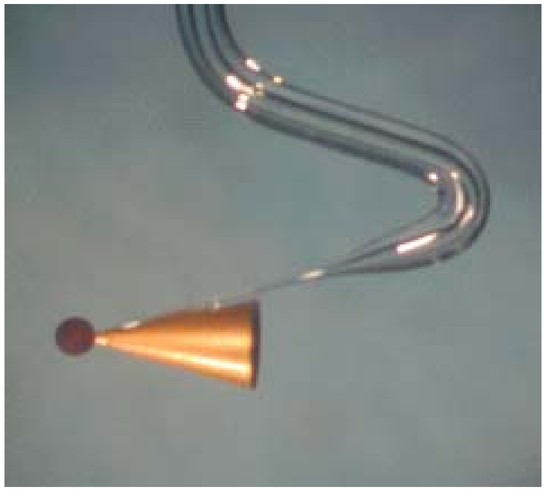
-Foam cryogenic shell with Cone and DT fill tube-

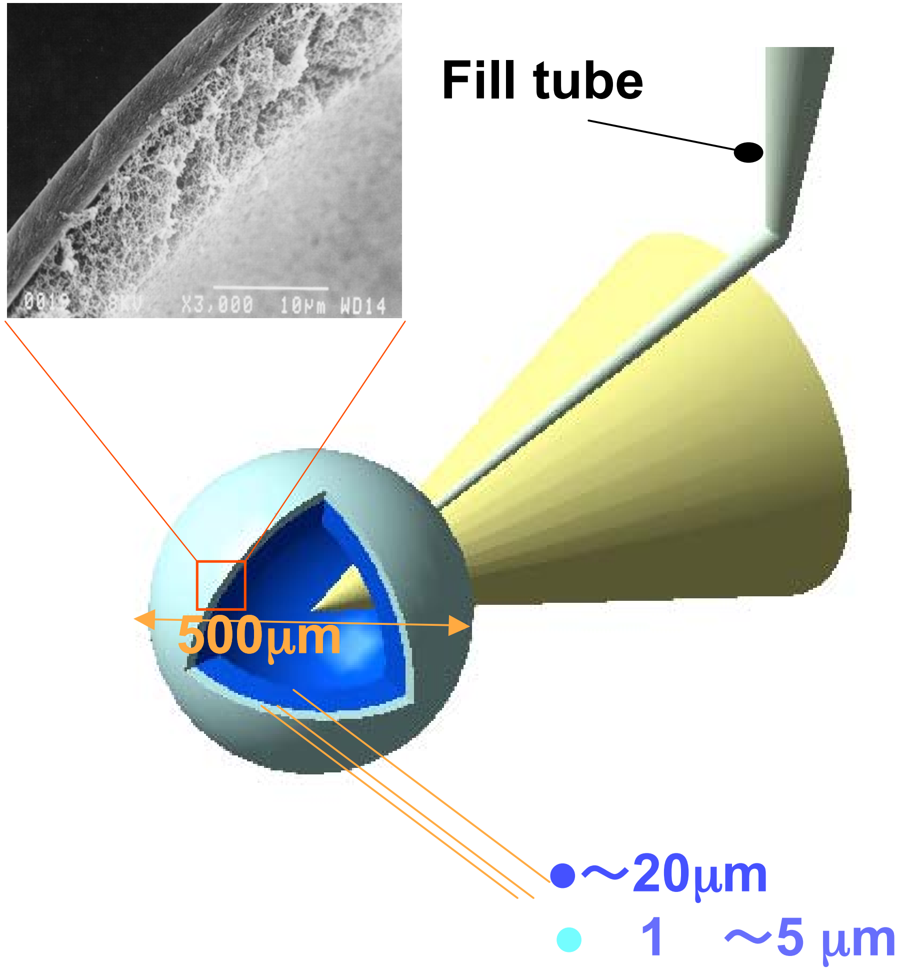
ILE, Osaka

For FIREX-I

Cryogenic Target

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





Present achievement;

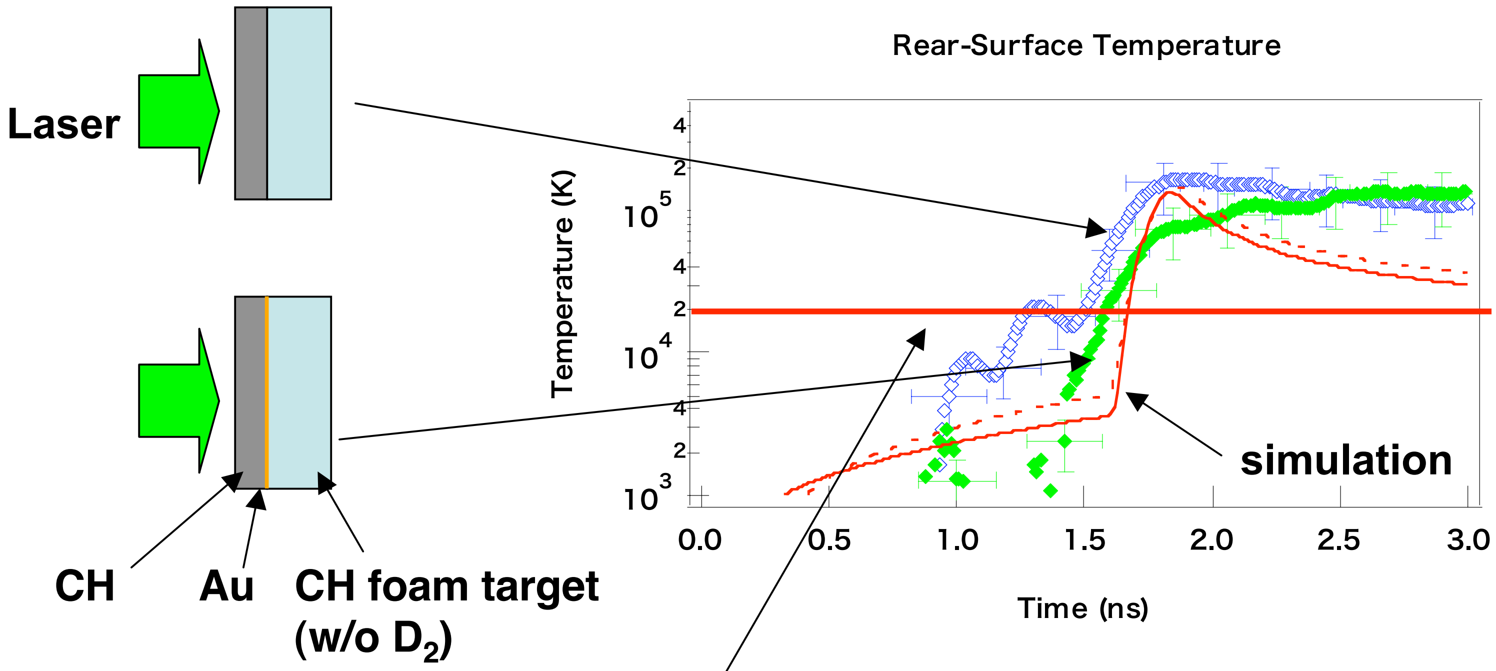
Fill tube diameter:30μm$^{\phi}$

Foam density: 100mg/cc, working gas: D_2

IF/P5-1(Thurs.), A.Iwamoto

Rear surface temperature before the shock arrival

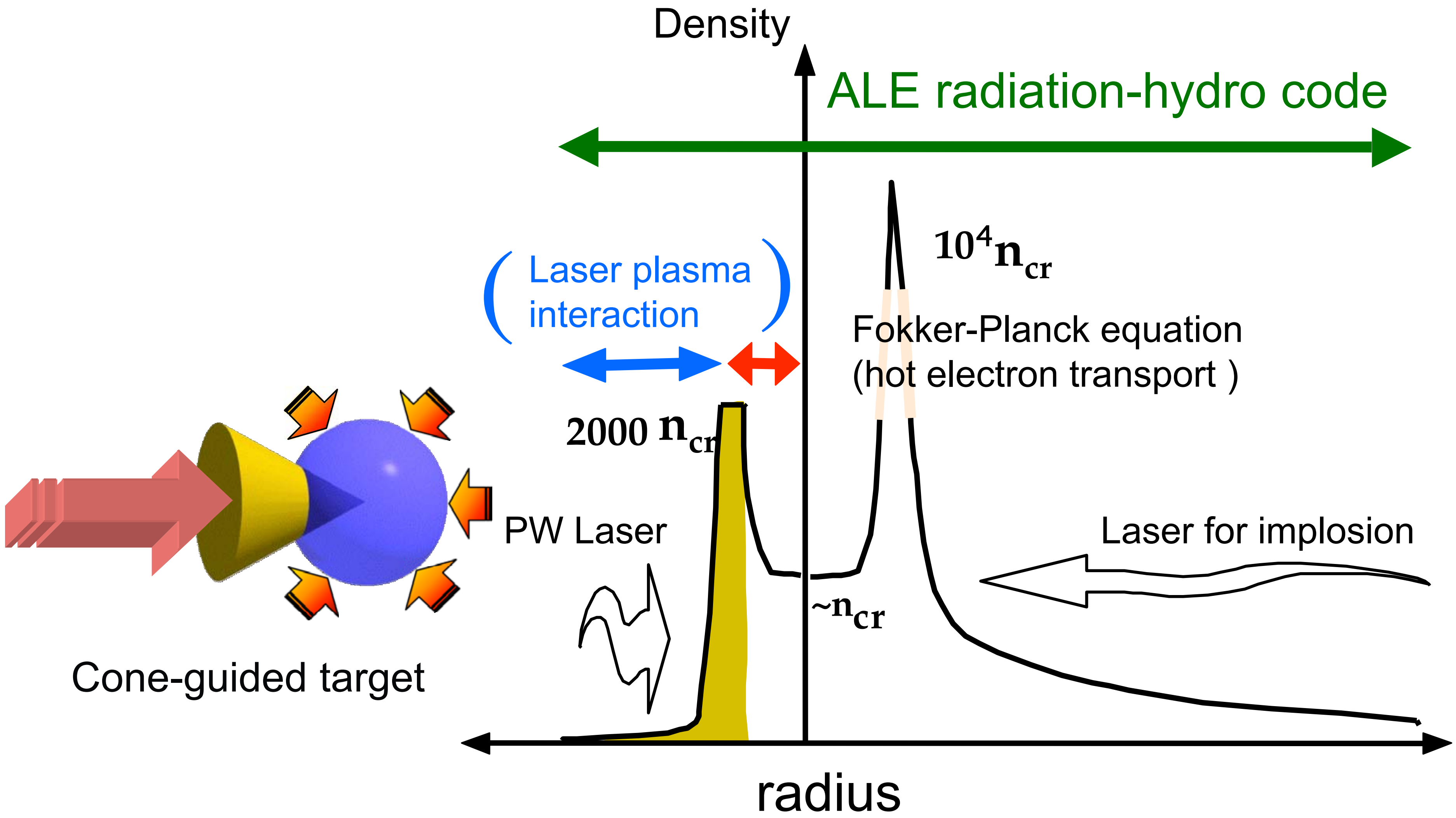
ILE OSAKA



- 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.

FI^3 Project
Fast Ignition Integrated Interconnecting code

ILE OSAKA

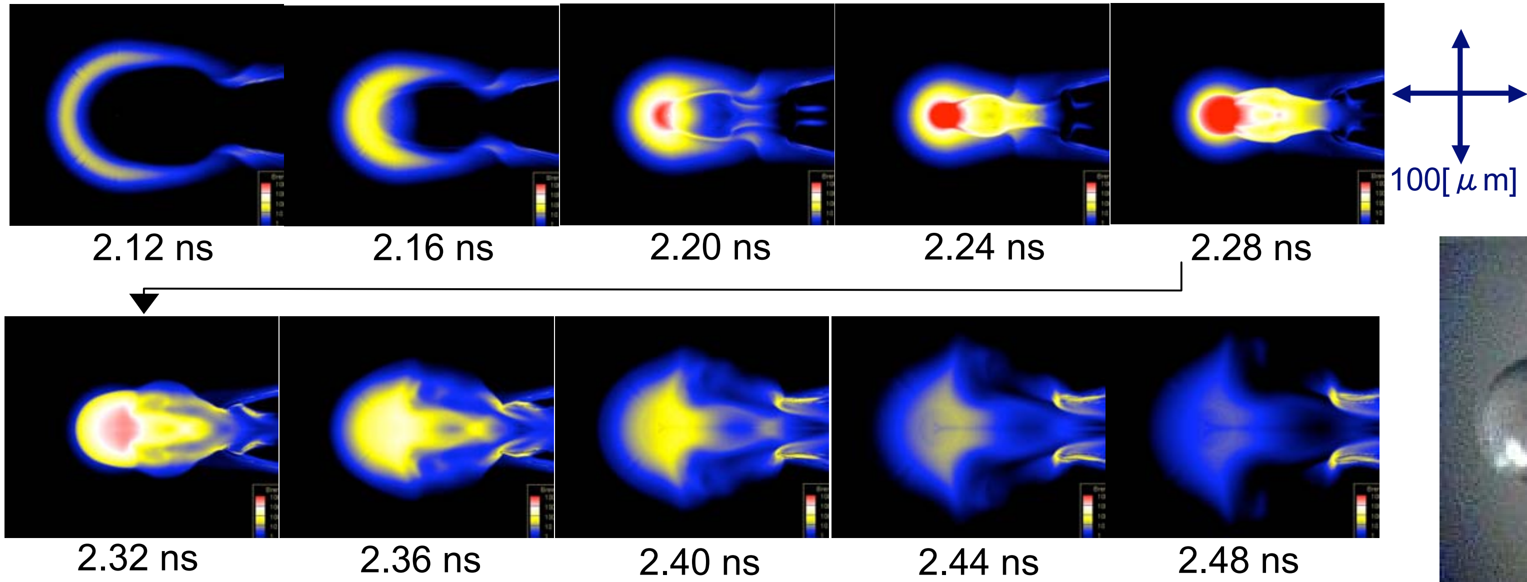


PINOCO-2D
Radiation-Hydro
code

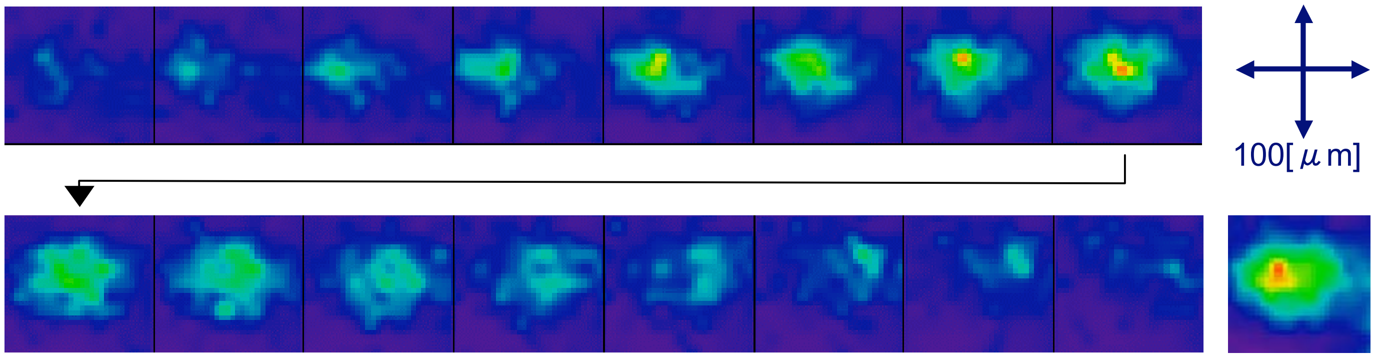
Bremsstrahlung Emission Profile of 2-D Fluid Simulation agree with experimental result (2D-SIXS).

ILE Osaka

Simulation (PINOCO) $n_e^2 x T^{1/2}$



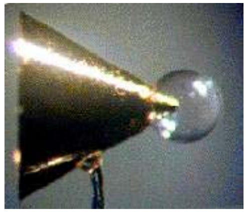
Experiment (tempral x-ray image at GXII, 2D-SIXS, Lee, et al)



●Resolution
time ~ 24[ps]
space ~ 20[μm]

Time integration

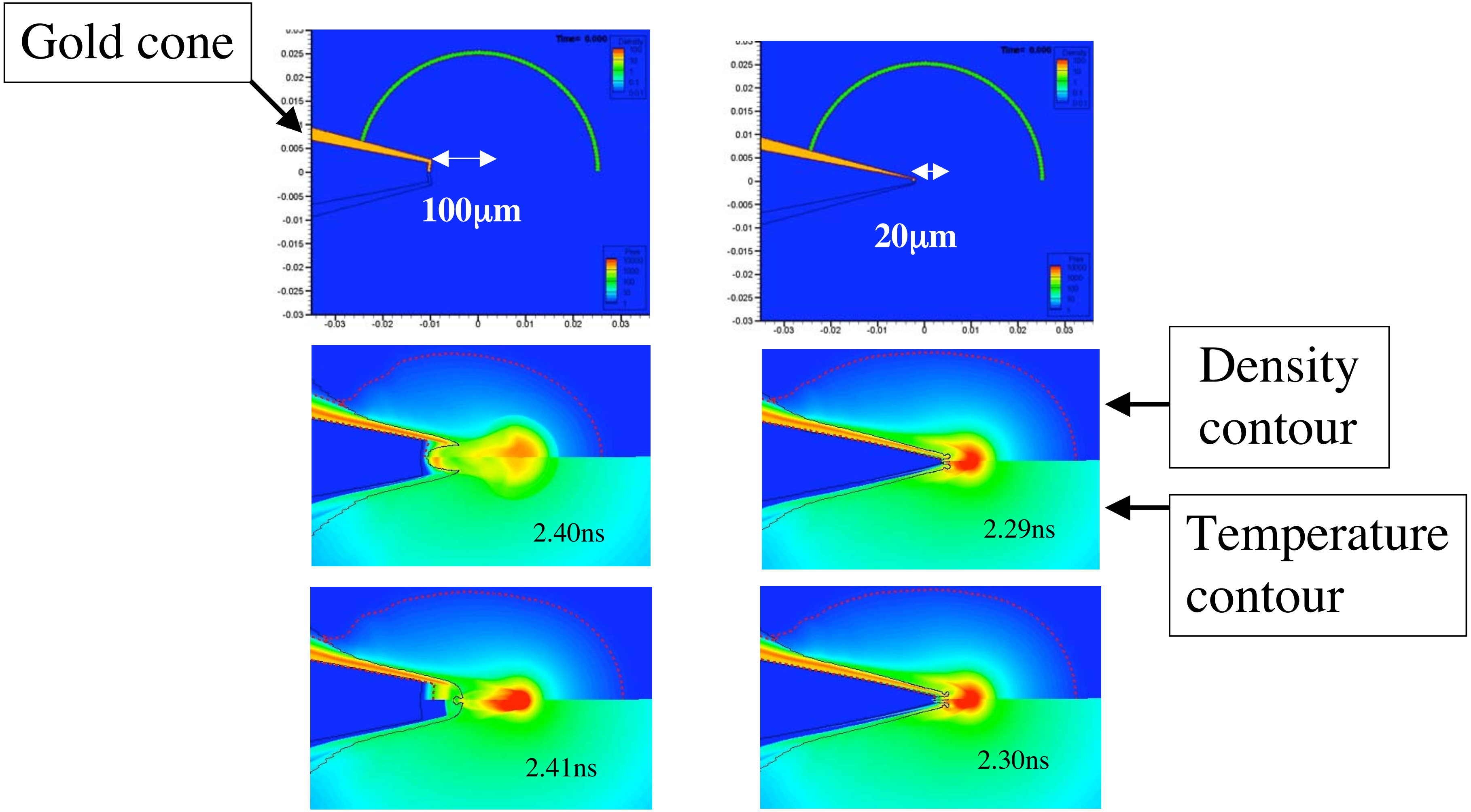
Temporal interval ~ 24[ps]



FIREX-I target design

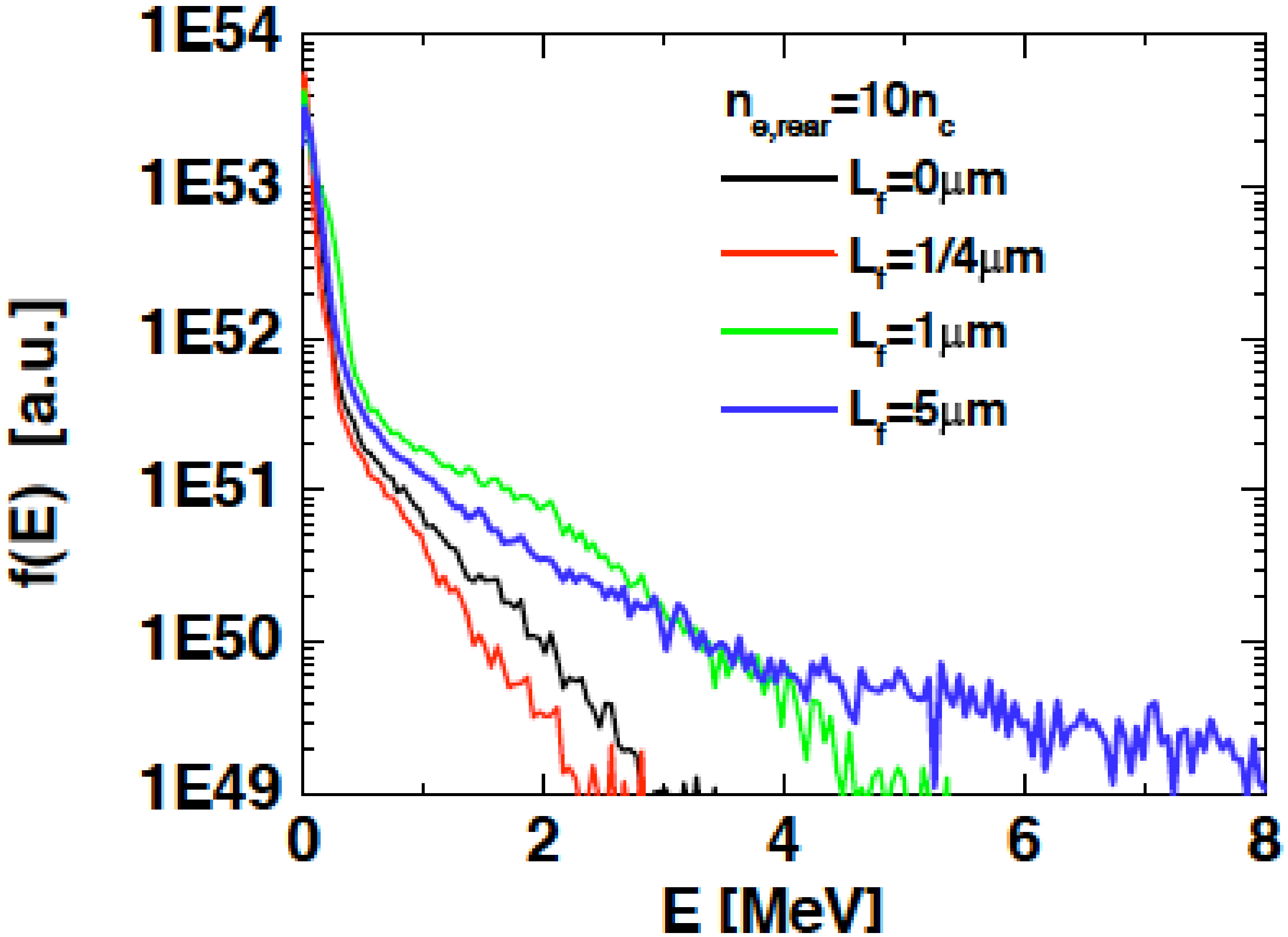
ILE OSAKA

Cone tip can survive till the maximum compression time.



Petawatt laser absorption and electron generation are sensitive to preformed plasma scale length

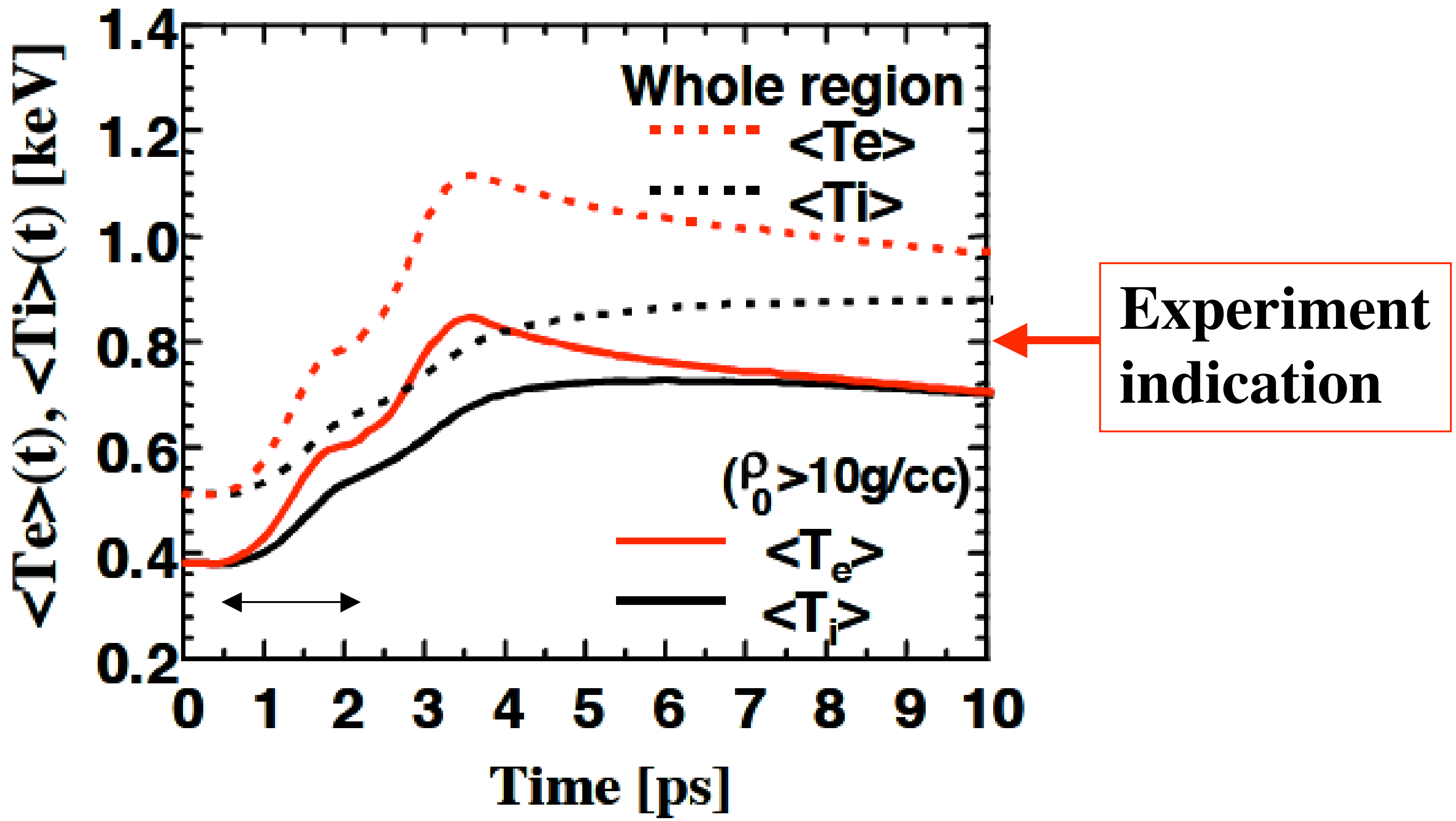
ILE OSAKA



Fast ignition experiments (Nature,2002,ILE and UK) are reproduced with ~1μm scale length

(Fokker Planck simulation combined with Hydro and PIC code)

ILE OSAKA

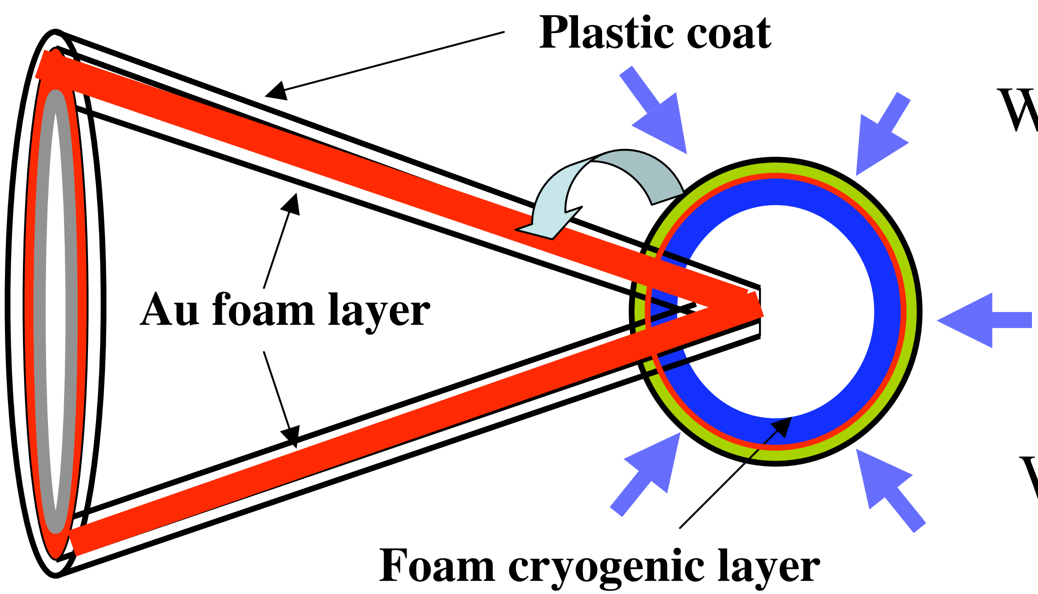


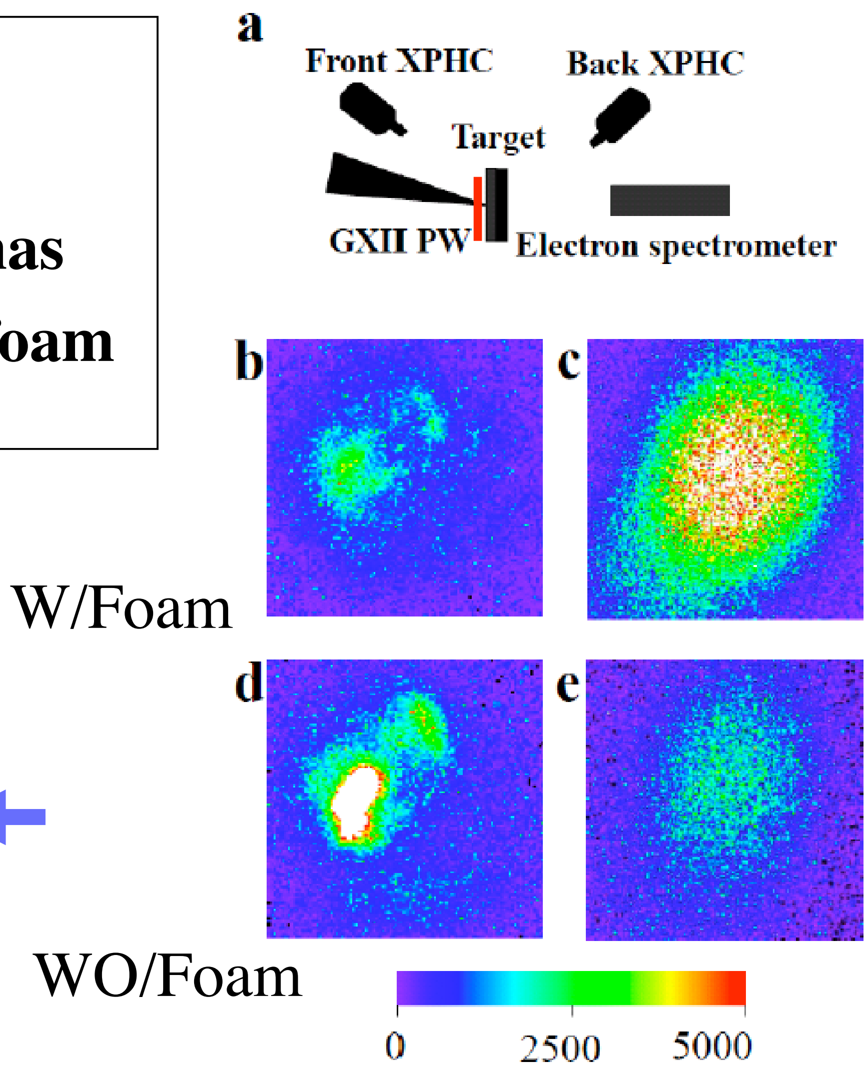
Note that delayed heating is found very important.

Advanced cone-target design for FIRE X-I

ILE OSAKA

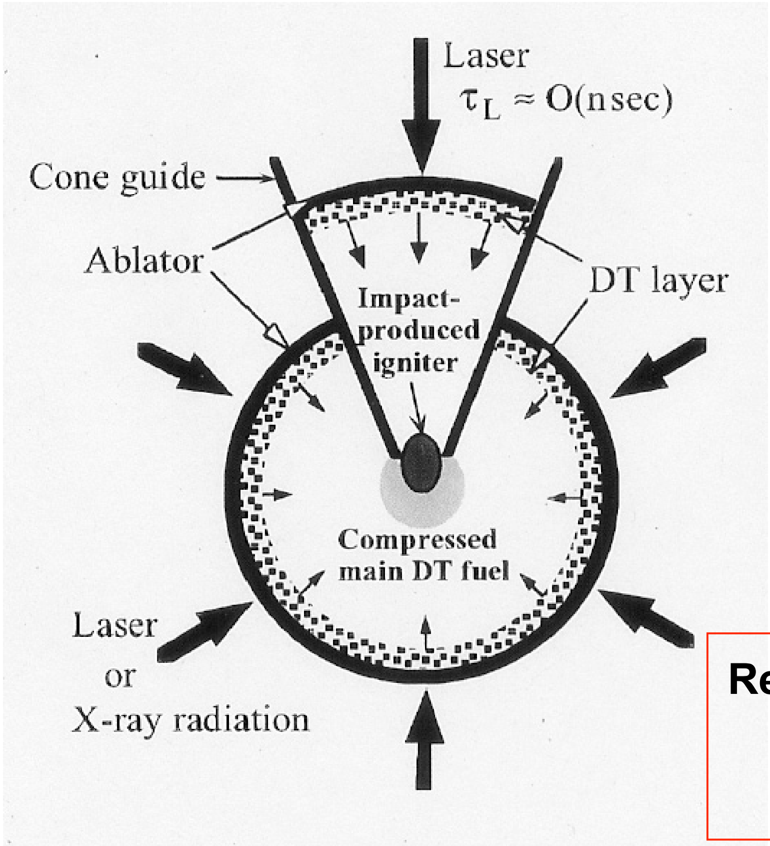
- Reducing the radiation loss by coating plastic on cone surface
- Tip of cone is close to core plasmas
- Inside of cone is coated by gold foam





A New Fast Ignition Scheme : "Impact Fast Ignition"

ILE Osaka



Target is composed of two components:

1. **A spherical pellet**
2. **Impactor: A spherical foil with cone guide**

Requirements for impact ignition

Main fuel: compression to 1000 times solid density

Impactor: acceleration to 1000 km/s

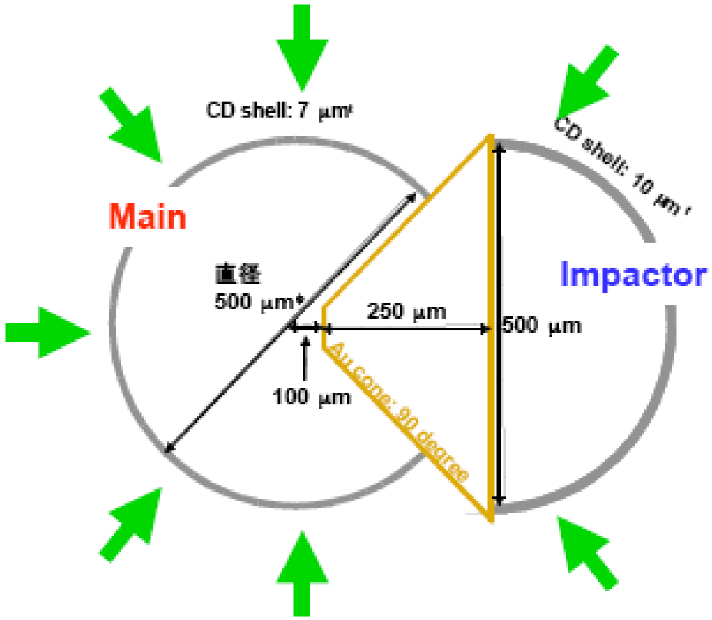
M. Murakami etal Nucl. Instrum. Meth. Phys. Res. A ***544****, 67 (2005).*

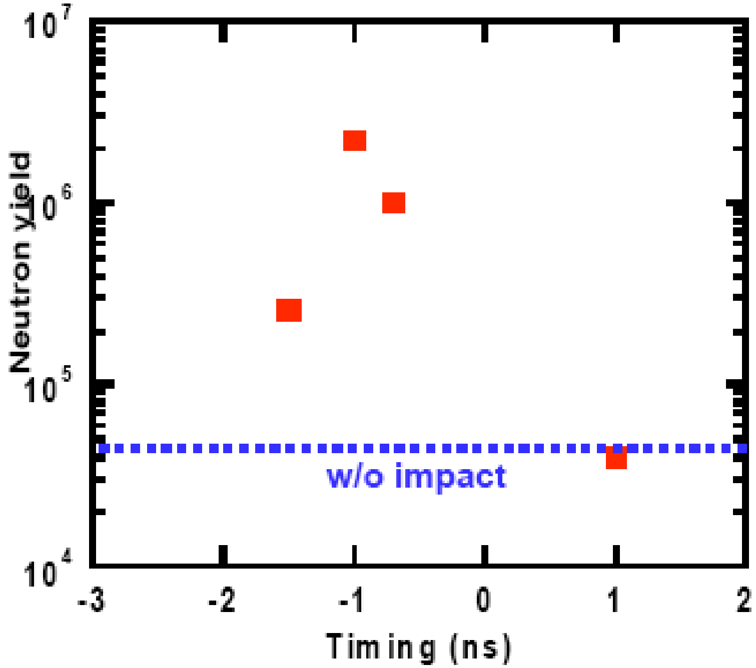
Experimental results

Neutron yield is enhanced by the impact of hemispherical CD.

ILE Osaka

Schematic of the impact heating experiment



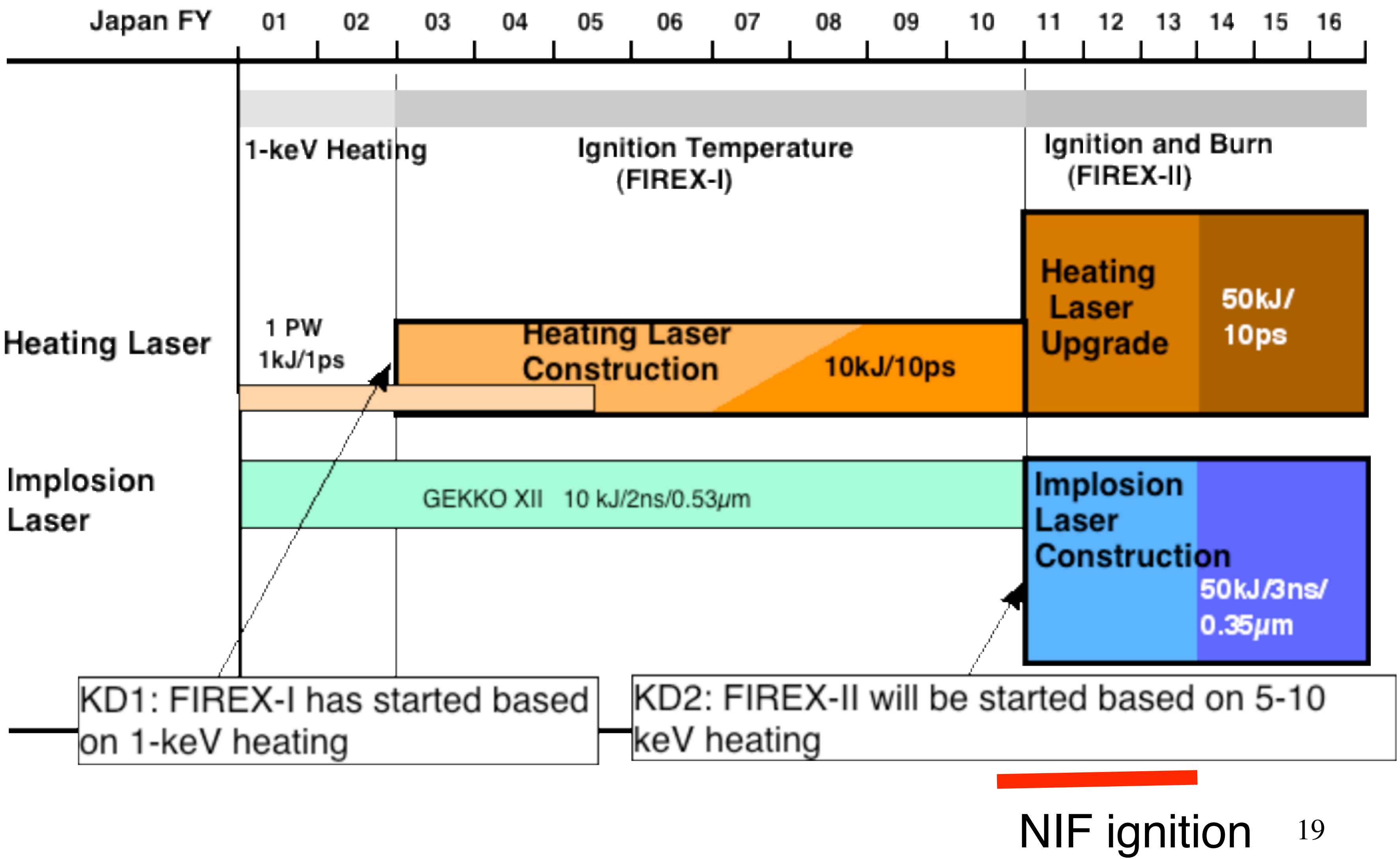


Main: 2ω, E = 3 kJ
CD shell 7 μm^t
Diameter = 500 μm$^\phi$
Impactor: 2ω, I < 200 TW/cm^2
Hemispherical CD 10 μm^t
Disameter = 500 μm$^\phi$

Neutron yield with impact is about a hundred times as large as that without impact.

Plan of FIREX Project

ILE OSAKA



Summary

ILE OSAKA

- Fast ignition researches in FIREX-I have been progressing.
  We plan that one beam experiment in 2007 and
  full beam experiments will in 2008 .
- Construction of peta watt laser for FIREX-I 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 for fast ignition was developed.
  The simulation code with Kodama Exp. (Nature '01)and recent experiments is successful.
- The simulations indicate $\rho r = 0.2\ g/cm^2$ and T=5keV, 20% heating efficiency which mean Q=0.1 and $N_y = 10^{15}$.
- A new fast ignition concept "impact fusion" is tested
  by recent experiments

Relevant presentations
(October 19th Thursday)

ILE OSAKA

- IF/1-1; H.Azechi, FIREX program Plan and Experiment
- IF/1-2R; K.A.Tanaka, Relativistic electron physics for Fast Ignition
- IF/P5-1; A.Iwamoto, Foam cryogenic target fabrication
- IF/P5/2; N.Miyanaga, Laser R&D and Construction for FIREX-I
- IF/P5-3; M.Murakami, Impact Fusion (New F.I.)
- IF/P5-4; H.Nagatomo, Integrated Fast Ignition code and experimental analysis
- FT/P5/39: T.Norimatsu, KOYO-F reactor conceptual design
- FT/P5/40; J.Kawanaka, IFE Driver Cooled Yb:YAG Ceramics Laser