Present Status of Fast Ignition Research and Prospects of FIREX Project

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Outline

- Introduction; laser facilities and fast ignition
- Fast ignition experiment at ILE, Osaka University
- Related relativistic laser plasma research
- FIREX projects and road map to laser fusion reactor
- Summary

Fast ignition concept is attractive, because a high gain is expected by small size laser

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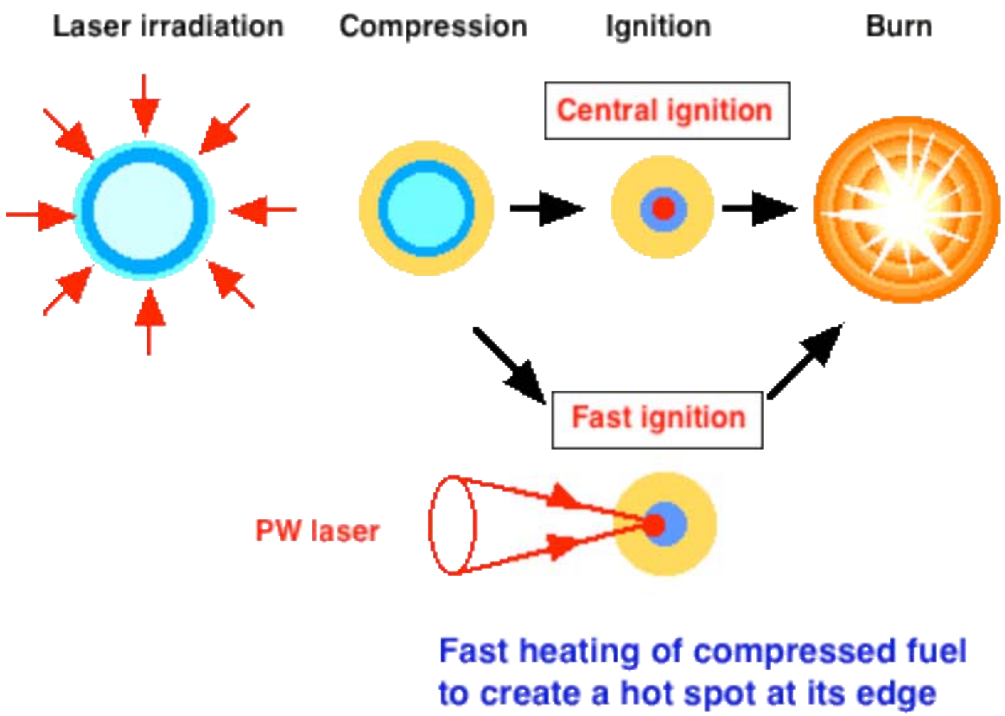
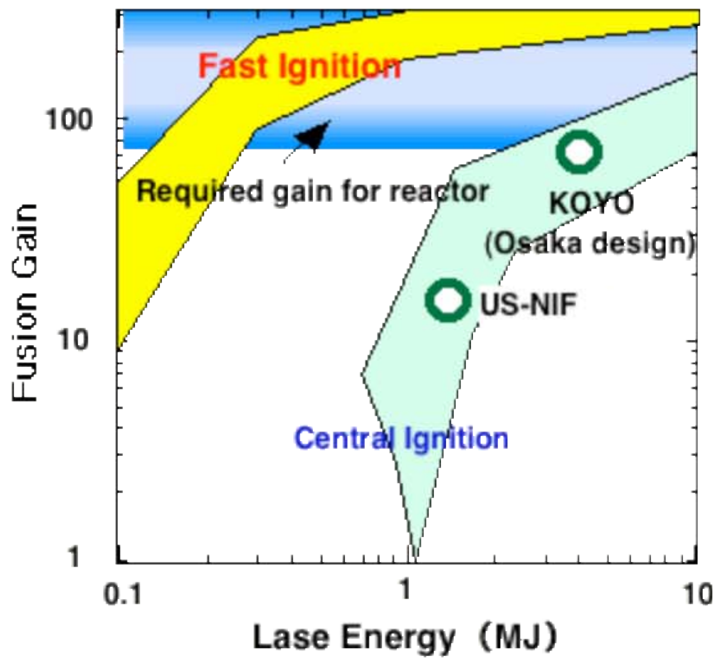
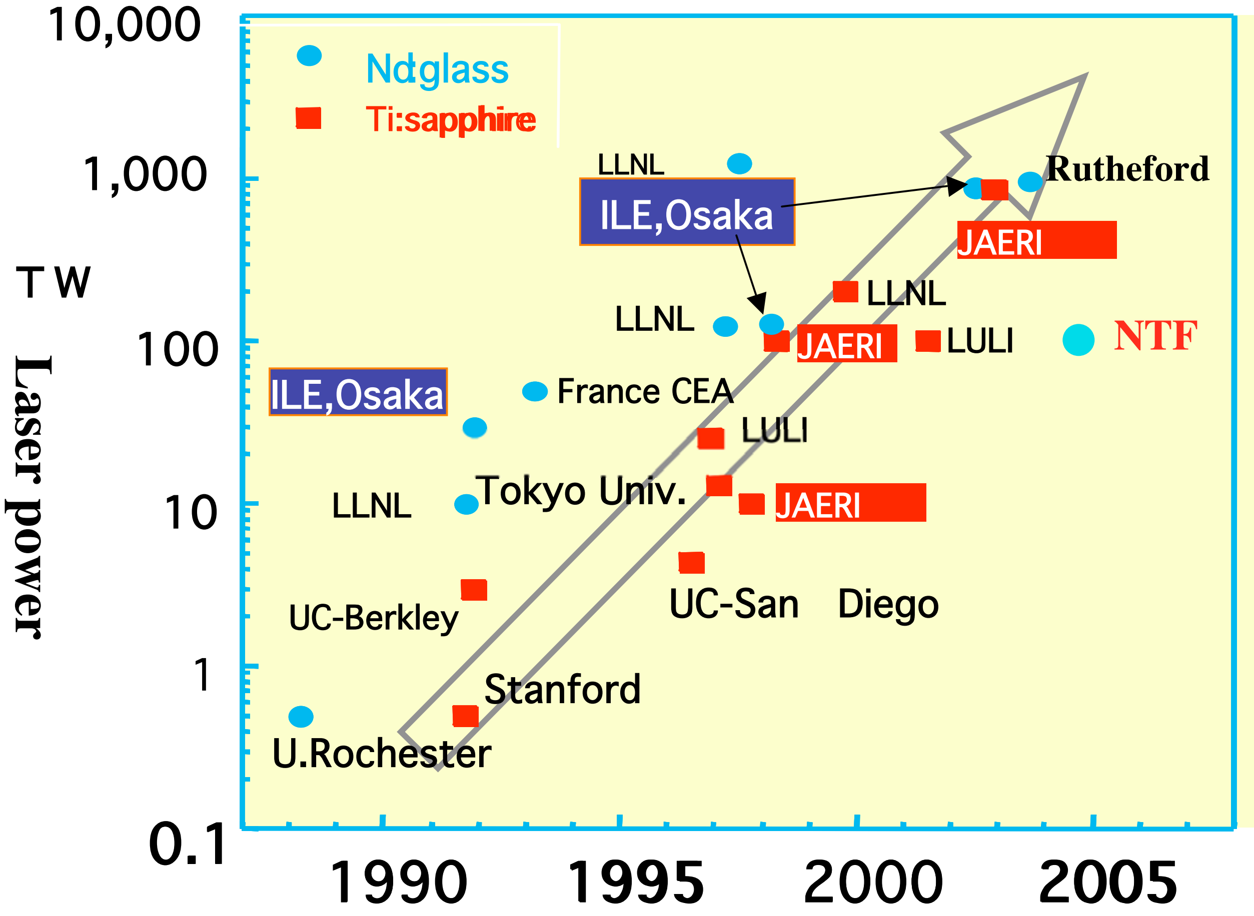
Fast ignition : Processes for compression and heating are separated.





How is fast ignition realistic?

- The preliminary fast ignition concept was proposed by T.Yamanaka(1983;internal report) and N.Basov(1992; J. Sov. Laser Res.)
- Recent development of peta watt laser technology leads to realistic Fast Ignition concept proposed by Max Tabak in 1994 (Physics of Plasmas)



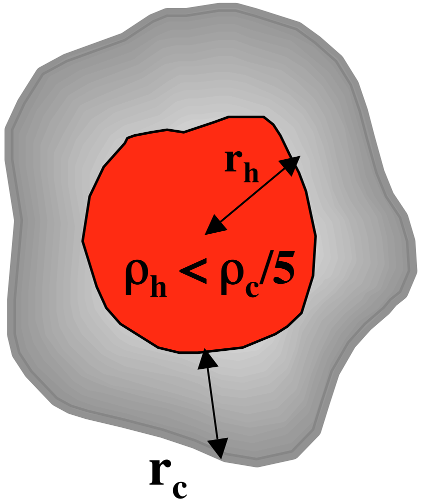
Why does fast ignition achieve high gain with small laser?

Comparison of fast ignition fuel mass with central ignition fuel mass

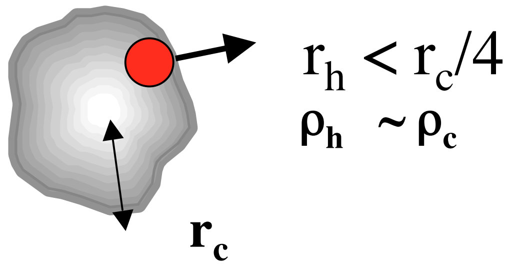
$\rho_h r_h$ = roughly constant for ignition ~ 0.4g/cm^2

Central Ignition
Isobaric

$r_c + r_h \sim 2r_c$



Fast Ignition;
Isochoric



Total mass of the high gain plasma is less than 1/8.
High gain could be achieved by 200kJ laser driver.
Further, the high implosion uniformity requirment is not sever.

However, ρ = 200~300g/cc, r_h = 25~17 μm
-----plasma life time $\tau = r_h/c_s$ = 10ps, spark energy; E_h = 15~ 7 kJ
Laser power; P_L > 1.0 PW, Laser Intensity; $I_L \sim 10^{20}$ W/cm^2

Critical issues; towards fast-ignition&burn

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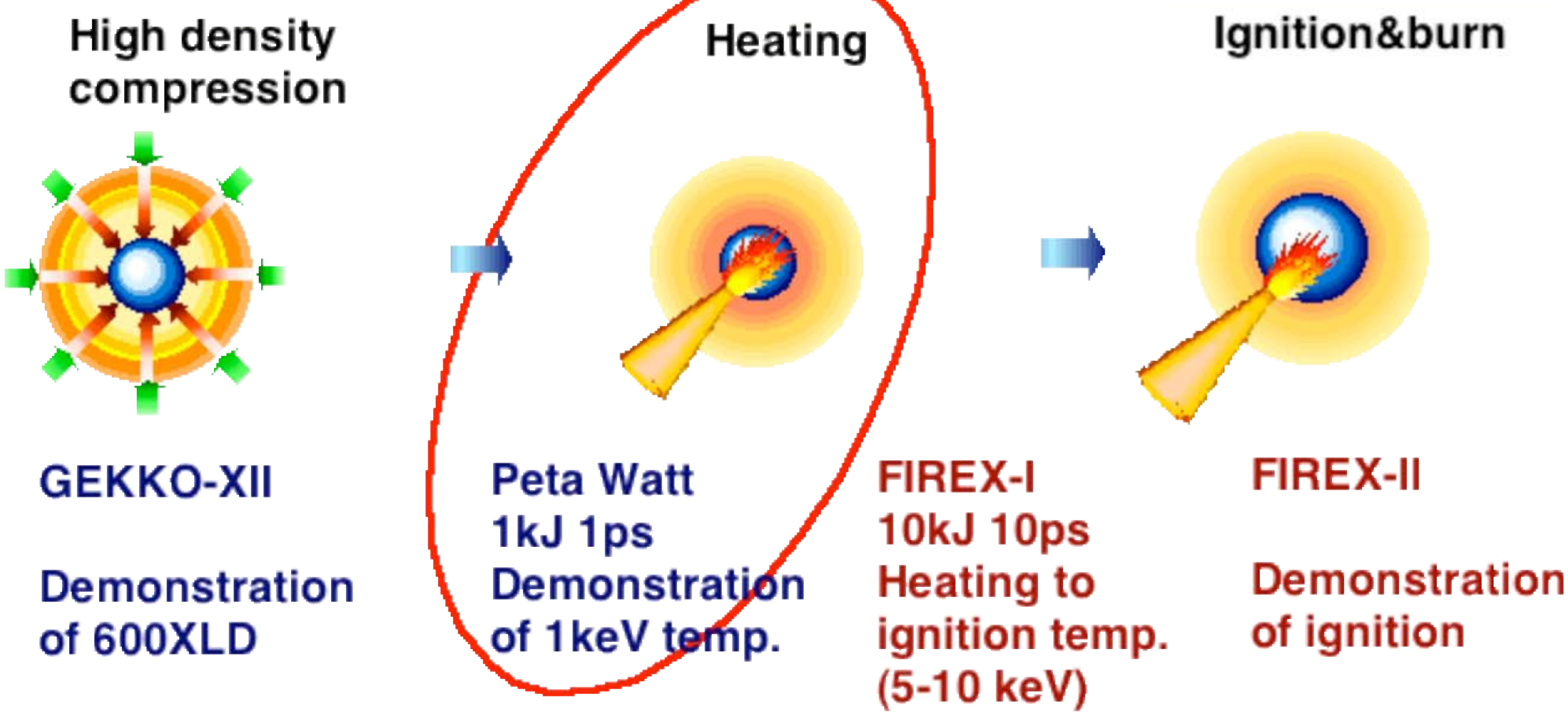
High density isochoric implosion	Multi peta watt laser heating ; mechanisms and scaling law on laser pulse energy and width



Achievement in 2002

ILE, Osaka has unique capability to conduct Fast Ignition model experiment, since 1998.

GEKKO laser: 12 green laser beams since 1983
E= 5 kJ, t = 1-2 nsec.
Uniform irradiation for high density compression.

PW laser: 1 beam
At 1 micron.
PW laser pulse is utilized for heating experiment

PW Laser System Performance

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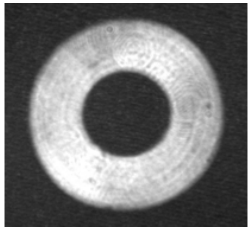
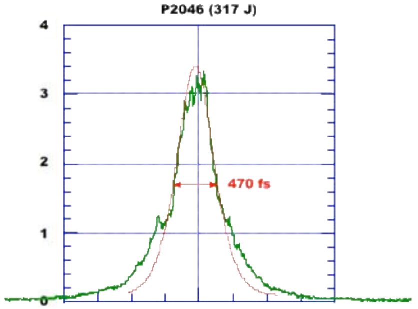
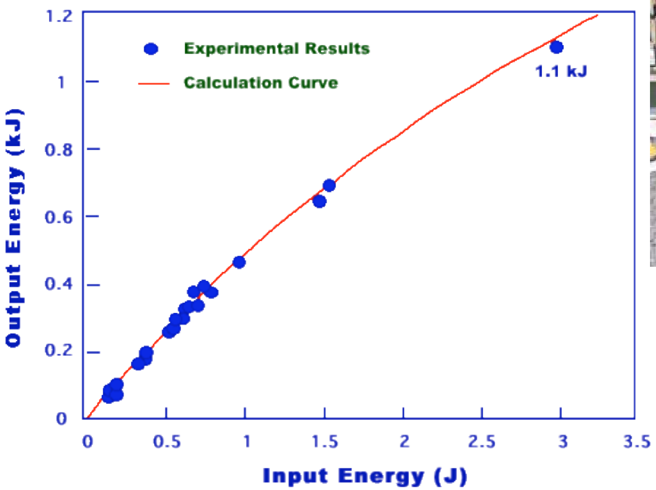
The PW laser is perfectly synchronized with GXII system. The maximum output laser energy is 1.1kJ with FF of 62%. The compressed pulse duration is 0.47- 0.8 ps and focusing spot size is about 30μmϕ through a deformable mirror. PW was realized on targets with 420J and 0.5-0.8ps.

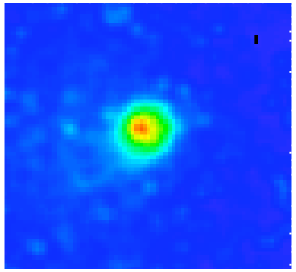


#1774 FF=62%
with a serrated aperture



#2045 τ_L = 470 fs





Spot size is 30μmϕ

Experiments of Cone-Guide Heating of Implosion Plasmas

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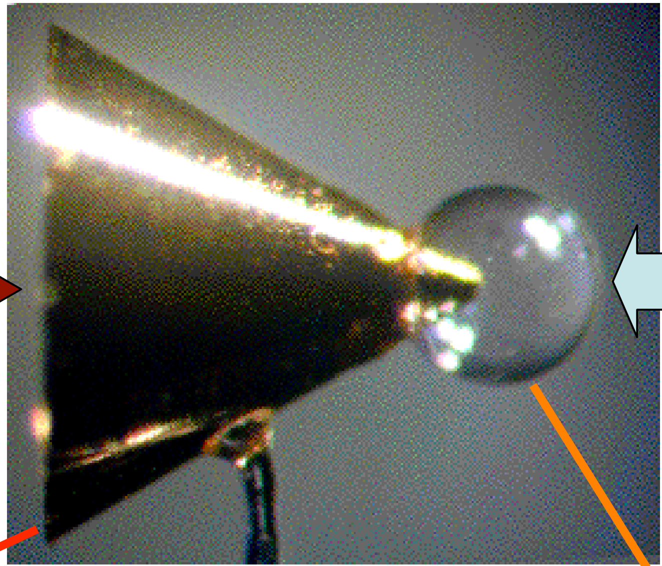
The experiments was carried out with a Au-cone CD shell.
The CD shell was imploded with 9 beam of the GEKKOXII laser.

PW for heating
1 beam / 300 J
1.053 μm / 0.5ps



GXII for implosion
9 beams / 2.5 kJ/0.53 μm

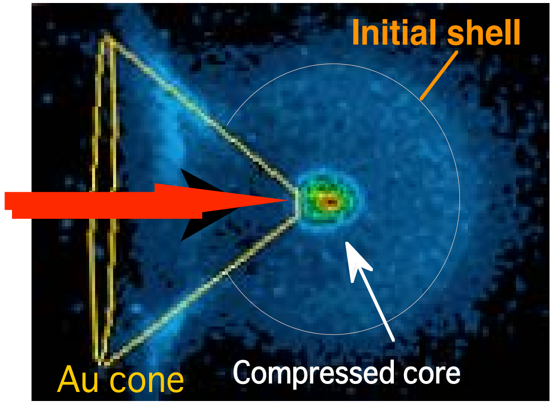
1.2ns Flat Top w/ RPP

Au cone
30 ° open angle (the picture: 60deg)
Thickness of the cone top: 5μm
Distance of the cone top: 50μm from the center

CD shell
500μmϕ/6-7μmt

By cone-guiding, heating laser can be introduced very near to the compressed core.

X-ray image of compressed target

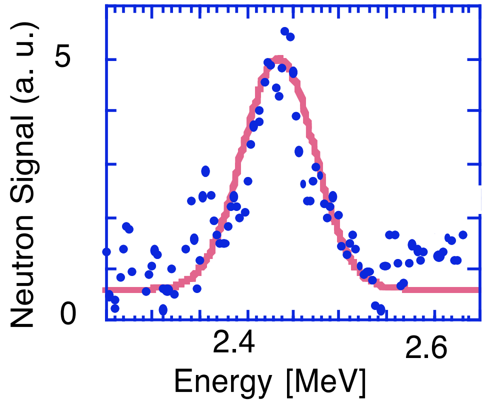


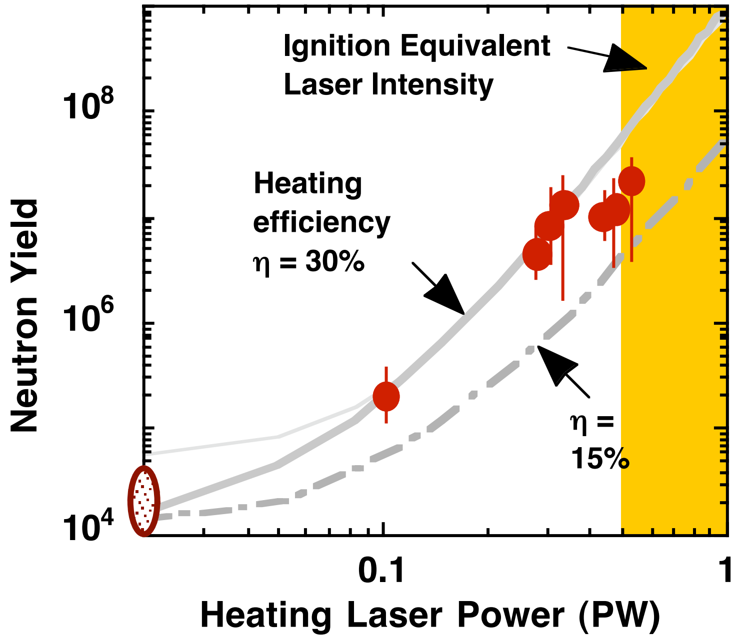
Efficient heating with η ~ 0.2 was demonstrated.

R. Kodama et al. Nature 2002.

Neutron spectrum by TOF ILE OSAKA

Ti ≈ 1 keV





Hot spot appears to flow out toward the cone tip.

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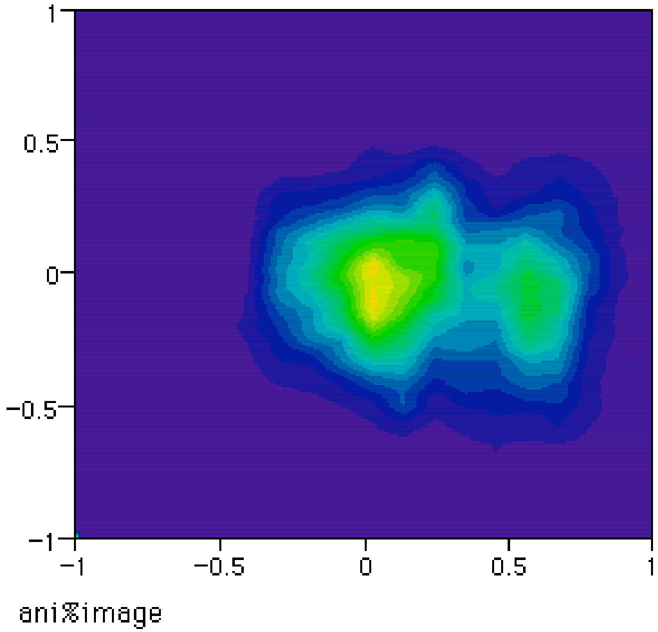
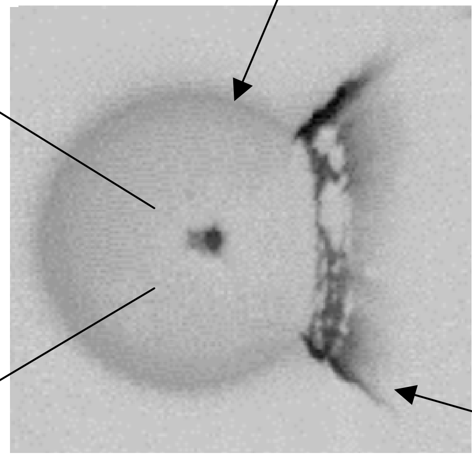
10 psec. X-ray frame Image (MIXS)



CH shell:1000 μmφ
25 μmt, D_2 0, 5 atm



Laser:
35 beams
15 kJ/1 ns SQ
($8x10^{15}W/cm^2$)

70deg Au cone

Shiraga/Fujioka/Tanaka/Kodama

Hot electron spectra show clear laser intensity dependence. Au cone (30°) shows increased hot electrons in the forward.

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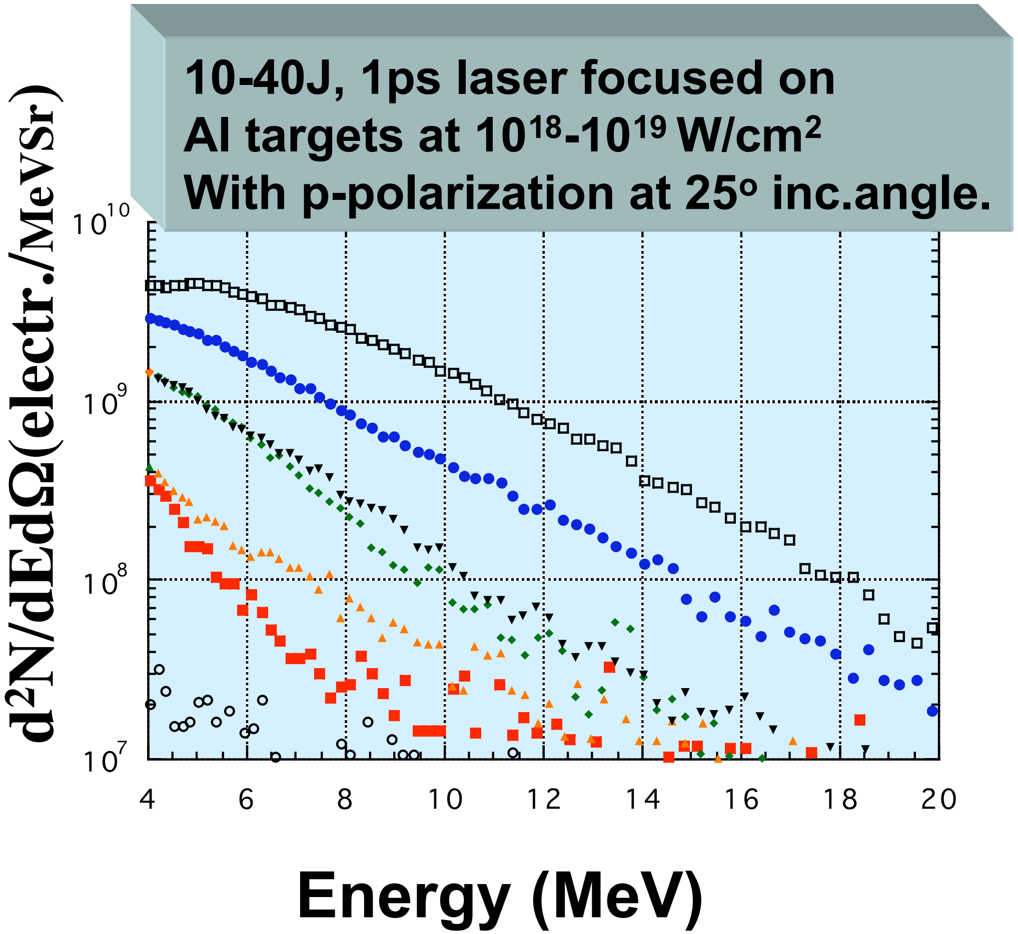
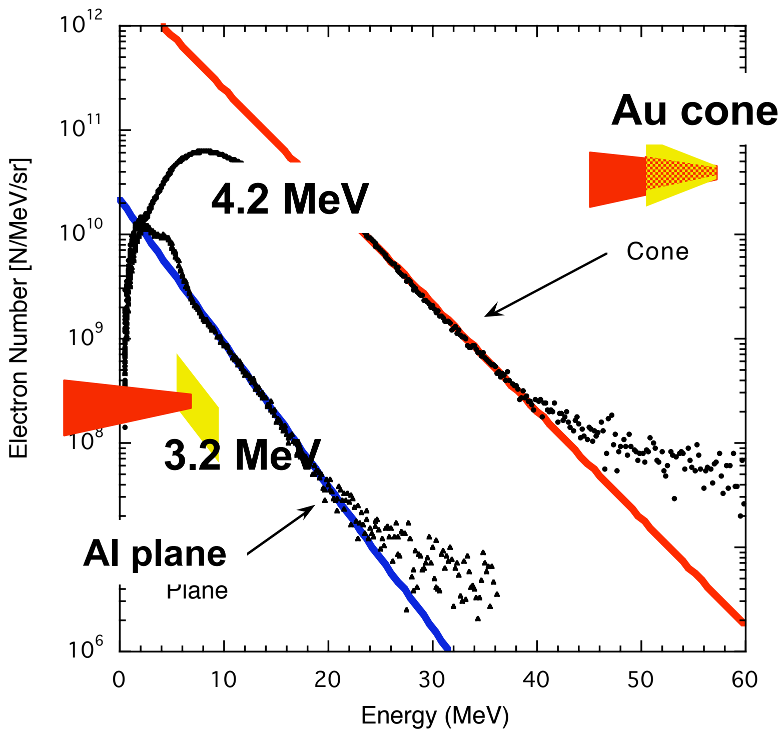
E=190 J
$I=5\times10^{18}$ W/cm^2





FIREX : Fast Ignition Realization Experiment

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1995 - 1999

- GEKKO MII CPA (25J, 0.4ps, 60TW)
- PWM laser (70J, 0.7ps, 100TW)

  Elementary physics related to fast ignitor (laser hole boring, super-penetration, MeV electrons, Self-guiding, Cone-guiding)

1999 - 2002

- PW laser (700J, 0.7ps, 1PW) + GEKKO XII

  Heating of imploded plasma up to 1keV by cone-guiding

2003 - 2008 : FIREX-I (Phase 1)

- New heating laser (10kJ, 10ps, 1PW) + GEKKO XII

  Heating of cryogenic target to 10keV

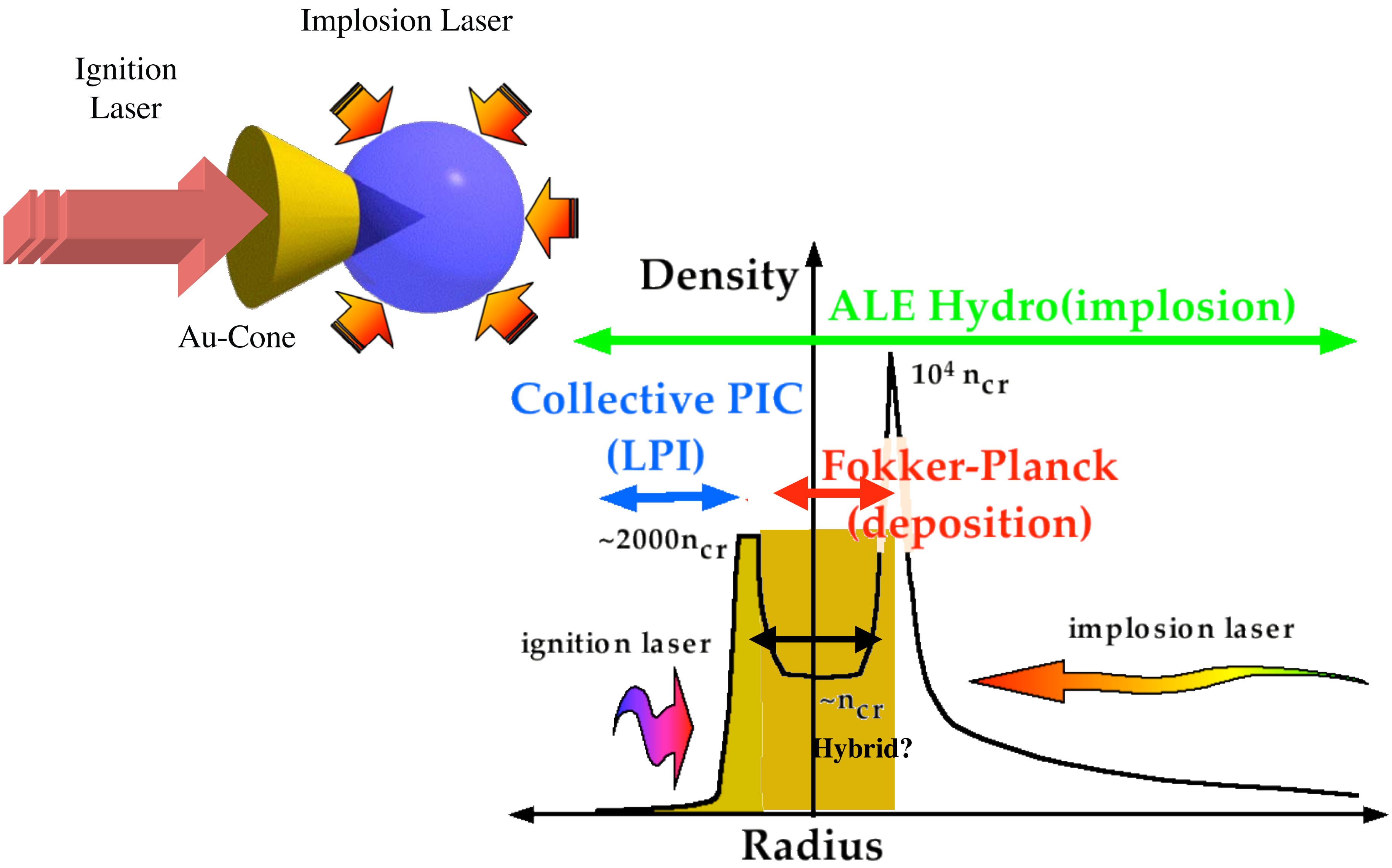
2009 - 2014 : FIREX-II (Phase 2)

- New compression laser (50kJ, 350nm) + Heating laser (50kJ, 10ps)

  Ignition and burn, gain ~ 10

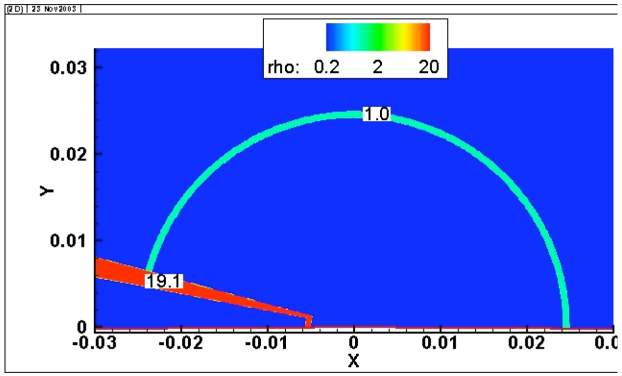
FI^3 Code Development

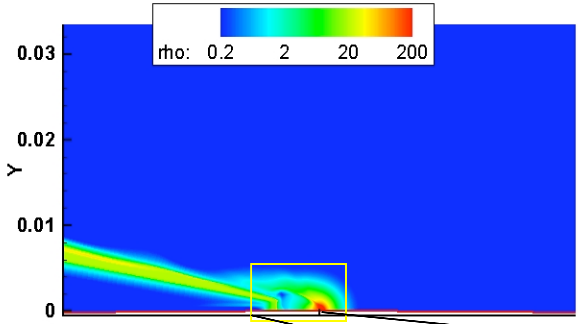
Fast Ignition Integrated Interconnecting code

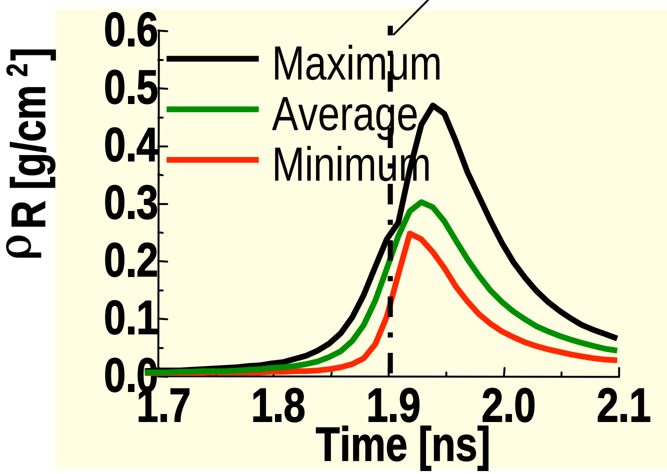


Compressed-Core Profile

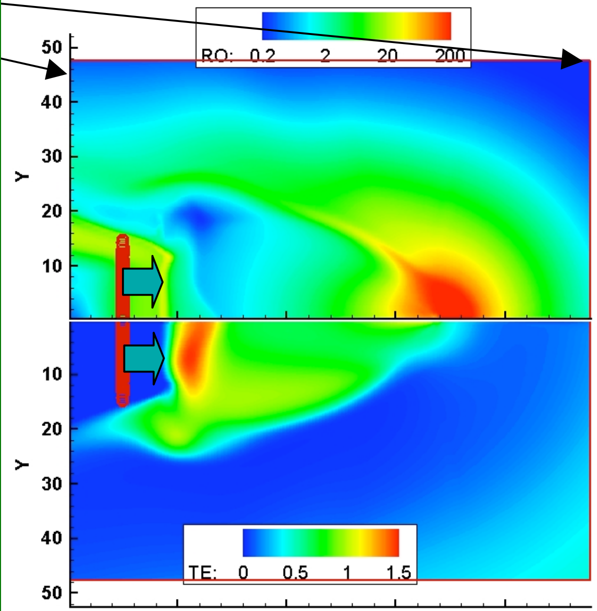
Implosion simulation of a canonical CD target
(2D ALE code “PINOCO” by Nagatomo)







RFP-Hydro simulations
REB was injected at inner surface of a gold cone.



F.P.Simulation for FIREX(Fast Ignition realization Experiment)

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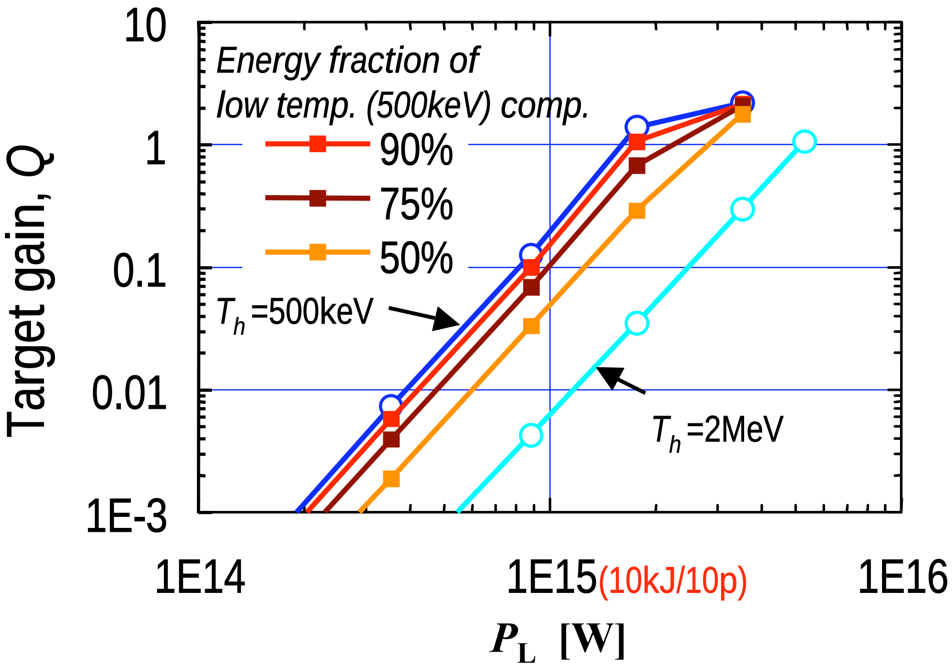
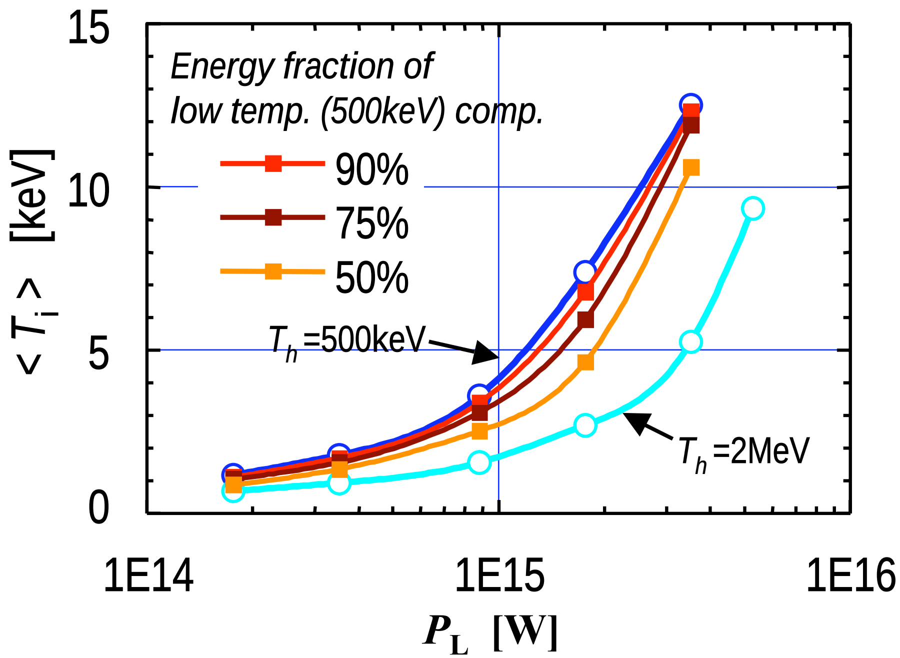
✓Beam electron energy spectrum has two slope temperature (500keV/2MeV)

✓ REB duration = 10ps

⇒ By assuming 30μmϕ beam spot and 40% coupling efficiency from laser to REB(corresponds to 25% heating efficiency)

Heating Laser power, $P_{Lh} = I_{REB} \times \pi r_b^2 / \eta_h$





Burning code predicts that gain of 0.2 is achieved in FIREX-I.

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FIREX-I

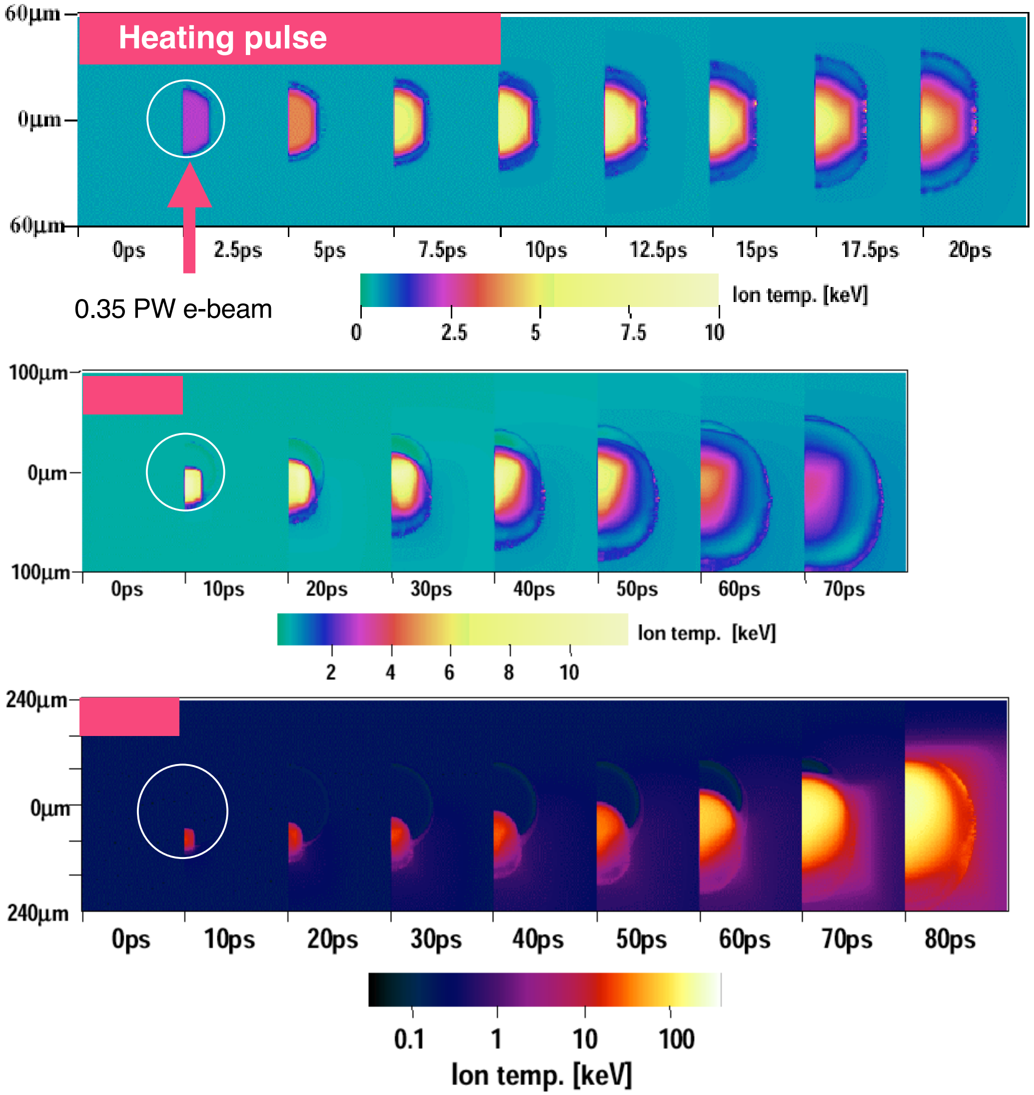
T~ 10keV
by 0.35PW input.
Gain ~ 0.2

FIREX-II

Gain ~ 8

High gain target

Gain ~ 150



Laser fusion research is progressing toward ignition and burn.

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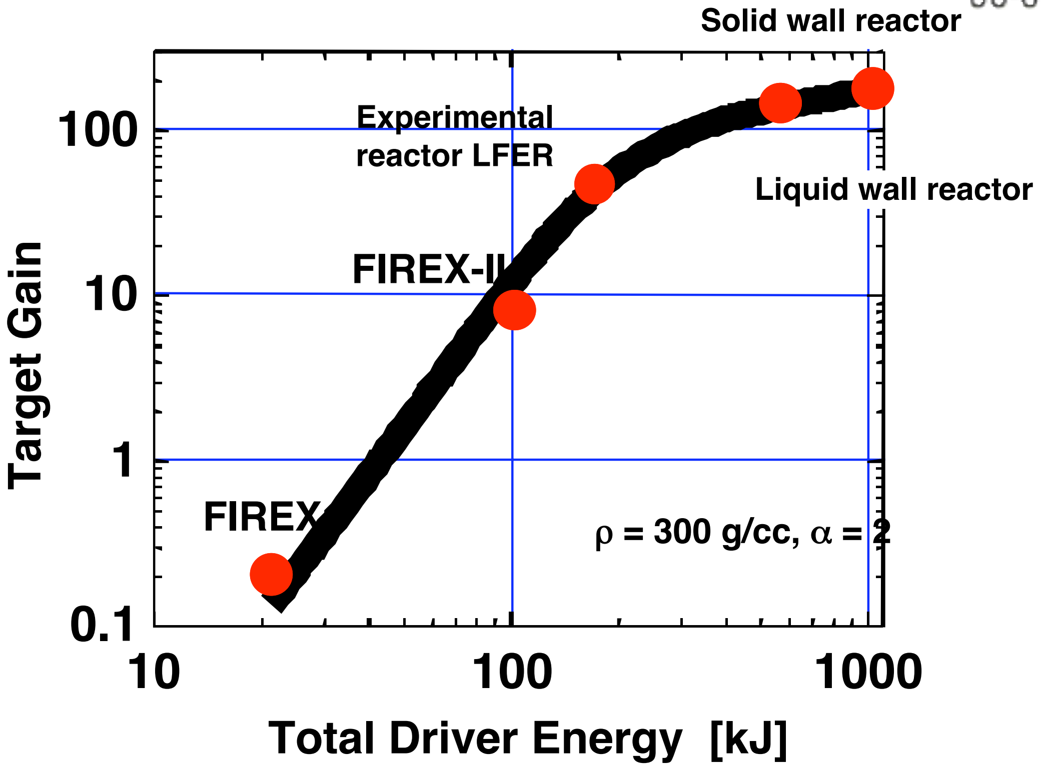
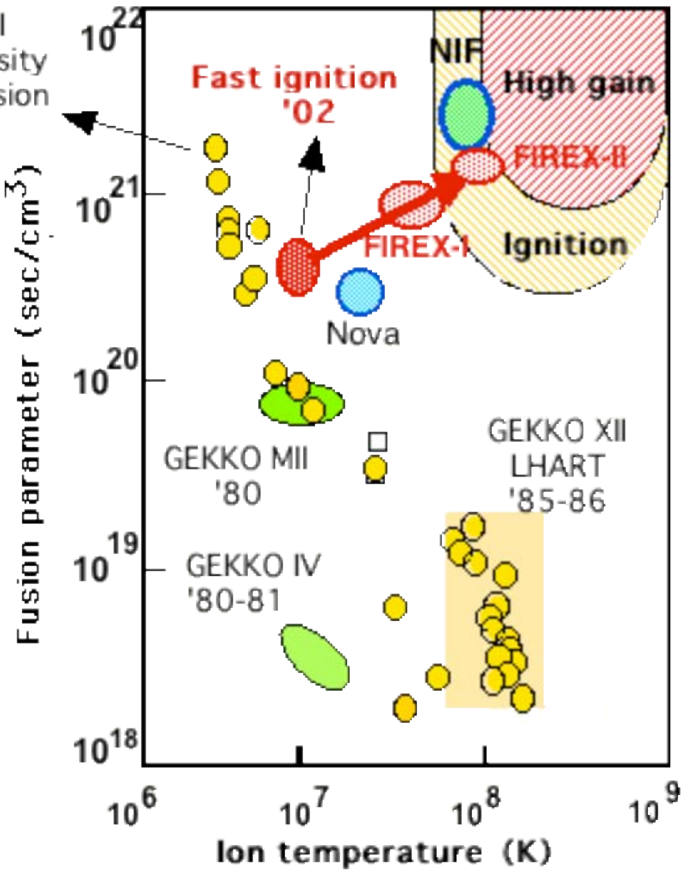
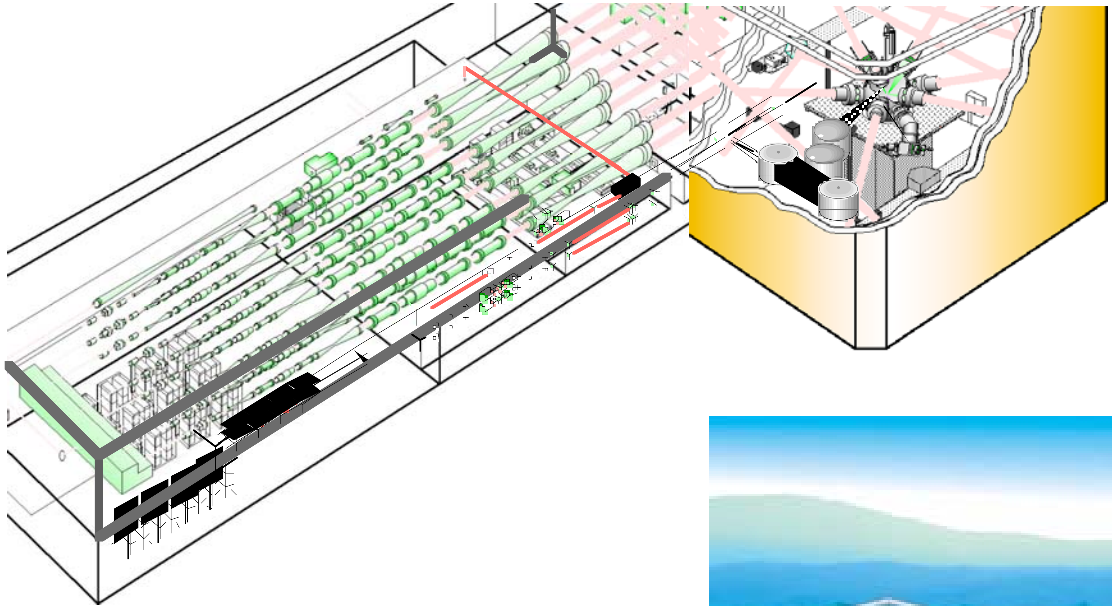
Gain x η_L x η_{ec} > 4 → Gain > 100

I_{REB} (10^{20}W/cm^2)	
FIREX-II	1.4
IFER	1.4
Solid	2.6
Liquid	2.6



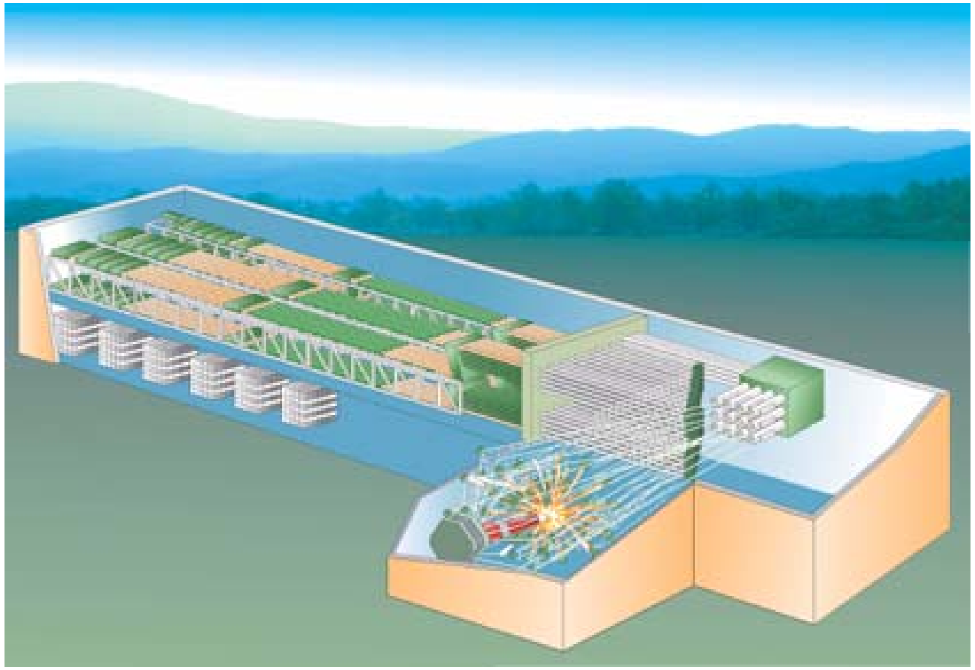


Fast Ignition Realization Experiment (FIREX) Project



FIREX I & II

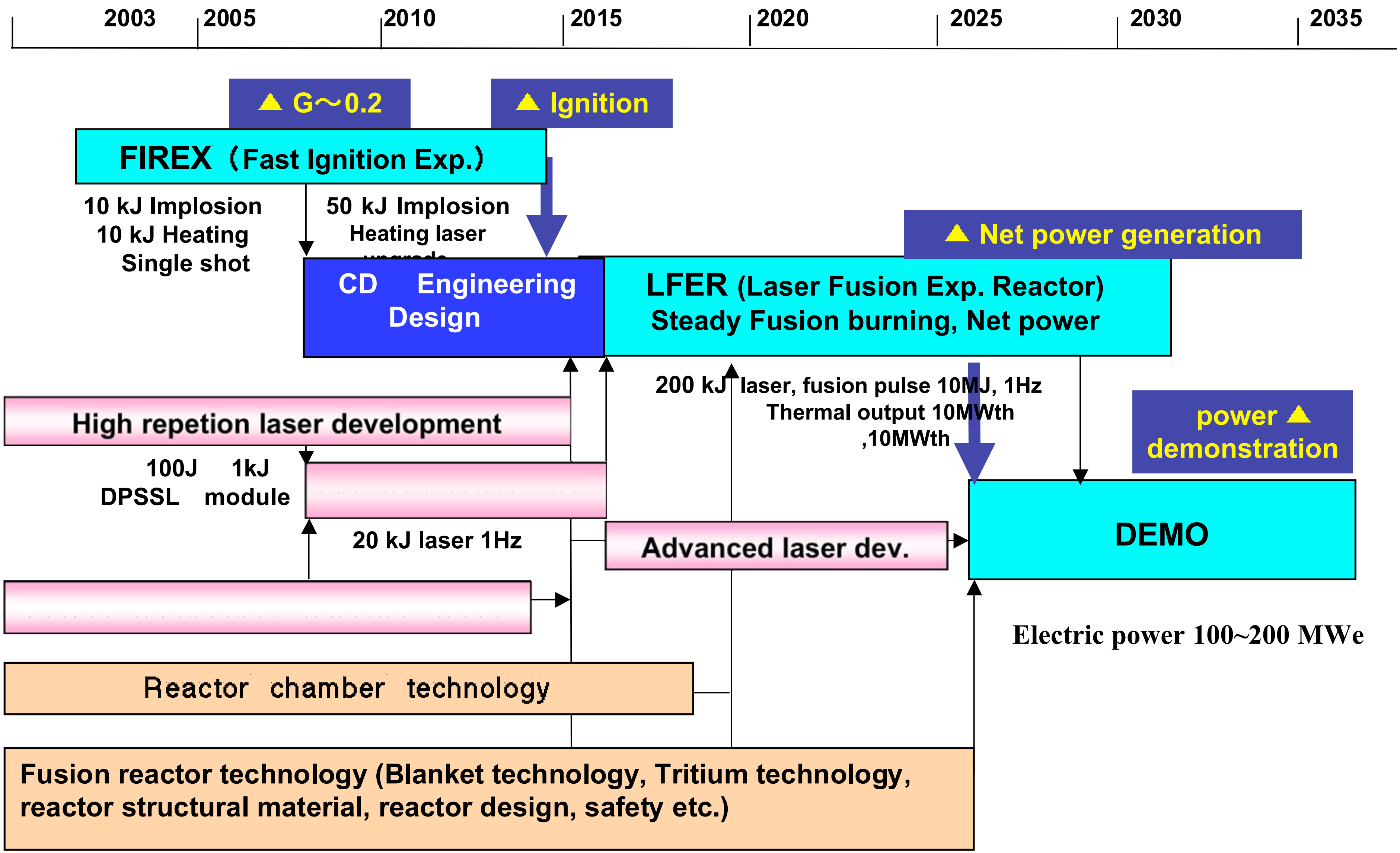
Principle of Fast Ignition will be Proved with the FIREX Project



10-kJ PW Laser for FIREX-I(LFEX)

Road maps for laser fusion power plants

IIFE Forum
2003.2.20



Laser Fusion Experimental Reactor (LFER)

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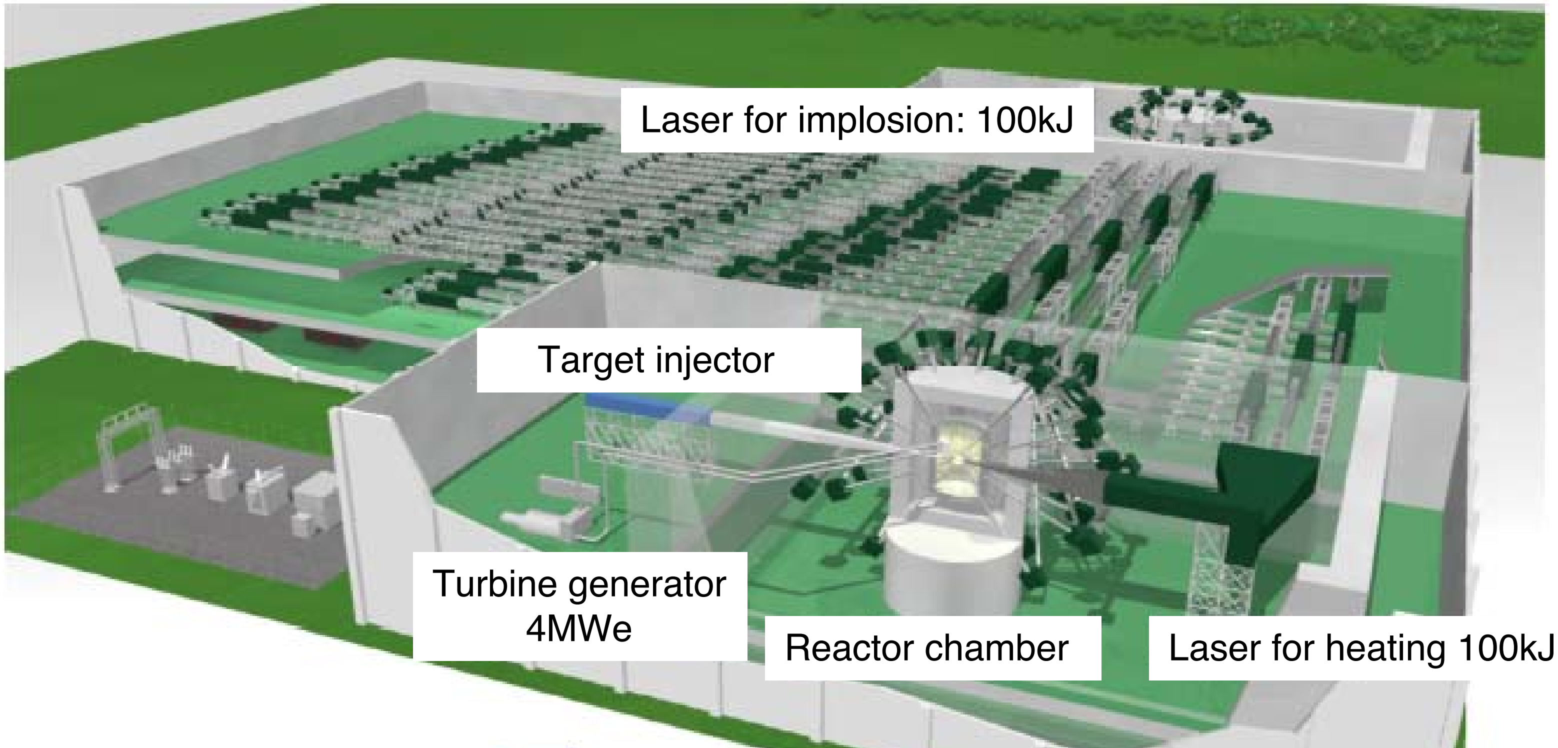

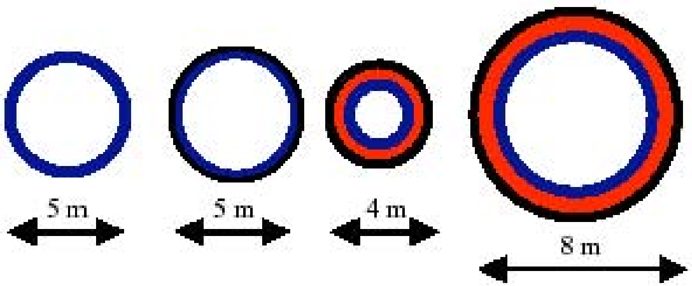

FIREX	LFER (10MJ, 1Hz)		DEMO
1MJ	Solid wall	Liquid wall	200MJ, 3Hz

Cryogenic foam target with cone and gas feeder for FIREX-1 experiment

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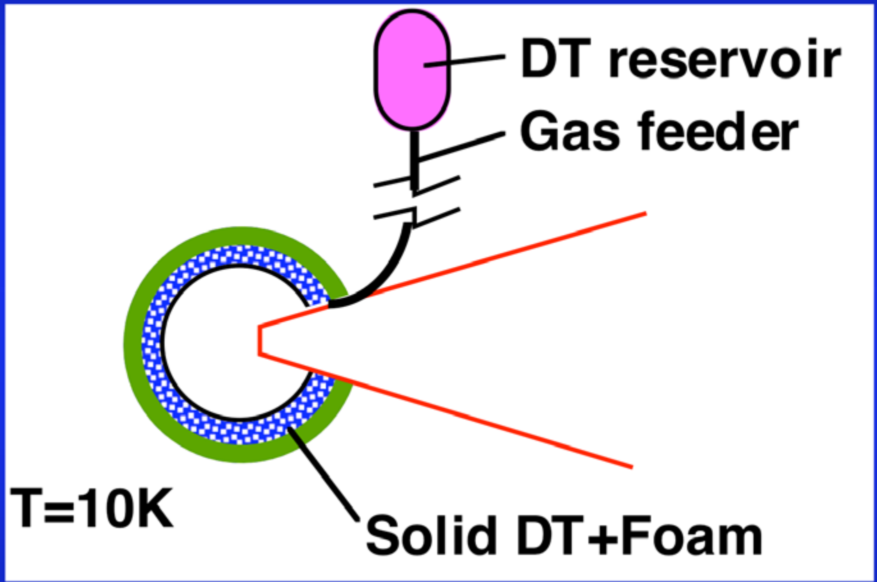

We are going to use foam technique to support solid DT layer and a gass feeder to load fuel in the shell.

Specifications for the accuracy of FI targetis not clear now but it is expected to be much relaxed than that for central ignition targets.

Use of foam can reduce the influence of the cone on thickness uniformity of the solid DT layer.

The gas feeder concept can eriminate burdens of handling high pressure DT gas.

Test Module is being constructed at NIFS.

Diameter	500 μm
Gas barrier	1 μm
DT layer	25 μm

Summary

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1. Imploded plasma heating with a peta watt laser has been successful in cone-shell target experiments.
   - Neutron yield was enhanced by 3 orders of magnitude by the heating of 0.4kJ/0.5PW laser.
   - Coupling efficiency of 20% from the heating laser to the core is achieved.
2. All the experimental results on the fast ignition with the PW laser is encouraging towards a relatively inexpensive and compact ignition facility.
3. We have started the FIREX (Fast Ignition Realization Experiment) project to demonstrate ignition and burn in laser fusion for the first time in the world. A new heating laser , 10kJ/10ps is under construction as the first phase of FIREX.
4. The FIREX lasers are required to be the national users' facility which will be operated by NIFS.
5. As the IFE reactor technology, developments of long life & high average power laser and chamber technology are critical issues.