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Status of Inertial Fusion Energy Program in China

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Outline

I. Introduction

II. Laser drivers and LARED codes

III. Latest advances in Target physics

IV. Fast ignition studies

V. Final remarks

I. Introduction

Chinese program for inertial confinement fusion (ICF) is toward inertial fusion energy (IFE) to be carried out in mid-century and other applications.

Target physics (theory and experiment), driver technologies and architectures, precisely diagnostic system establishment, and precise target fabrication have been coordinately developed since 1993.

The goal of the first roadmap is for fusion ignition and plasma burning in about 2020.

I. Introduction

China is performing an ignition and gain project.

II. Laser drivers and LARED codes

1. SG-II laser
2. SG-III prototype and SG-III laser
3. National ignition driver SG-IV
4. Other drivers for candidates
5. LARED codes and functions (2D and 3D)

II. Laser drivers and LARED codes

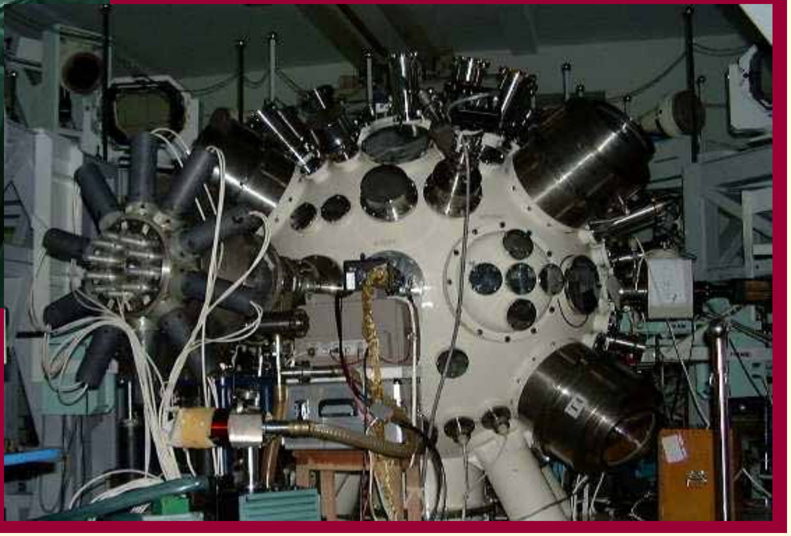
SG-II laser (over 2500 shots) will be upgraded to be SG-IIU with 18kJ, 3ω, 3ns, operating in 2008.

SG-II Laser Faclity

Laser bay

8 beams, 1ns, routine output energy of ≥6kJ (1ω) and ≥3kJ (3ω)

Target chamber



II. Laser drivers and LARED codes

PW laser (operating in 2008) coupled with SG-IIU for fast ignition

PW laser bay (2ps,1.5kJ) **Building**

II. Laser drivers and LARED codes

SG-III prototype operating (4-pass, 8 beam, 3ns, 3ω, 2.75kJ/beam)
physical experiments: 150 shots

II. Laser drivers and LARED codes

SG-III and SG-IV laser constructions

SG-III laser (64 beams, 200kJ, 3ns) to be operating in 2010, will serve for target physics investigation of both direct-drive and indirect-drive ignition. Design has been completed.

National ignition driver, SG-IV laser with laser energy of 1.5 MJ to be operating in about 2020 will serve for central ignition and high gain fast ignition. Architecture is being planned.

II. Laser drivers and LARED codes

Other drivers for candidates

- KrF excimer gas laser H-1 is operating and will be advanced

- Z-pinch device with about ten MA peak load current is under the way of construction.

II. Laser drivers and LARED codes

LARED codes and functions (2D and 3D)

Name	Functions
LARED－P	2d & 3d particle code (PIC) for laser plasma interaction
	3d hybrid fluid-PIC (HF-PIC) code for the charged particle transport in overdense plasmas
LARED－H	2d code for hohlraum physics
LERAD－R	2d code for radiation transport
LARED－I	2d code for indirect-driven implosion dynamics, ignition and burning propagation
LARED－D	2d code for direct-driven implosion dynamics, ignition and burning propagation
LARED－S	2d & 3d code for hydrodynamic instability

III. Latest advances in target physics

1. Implosion experiments on SG-II laser and LARED simulations
2. Equation of state
3. Hydrodynamics instability
4. Fast ignition

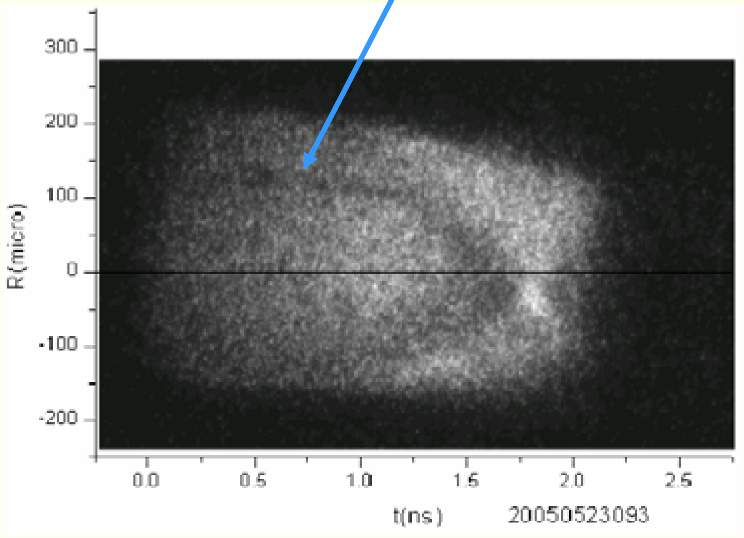
III. Latest advances in target physics

Indirect-drive implosion experiments on SG-II laser and LARED simulations

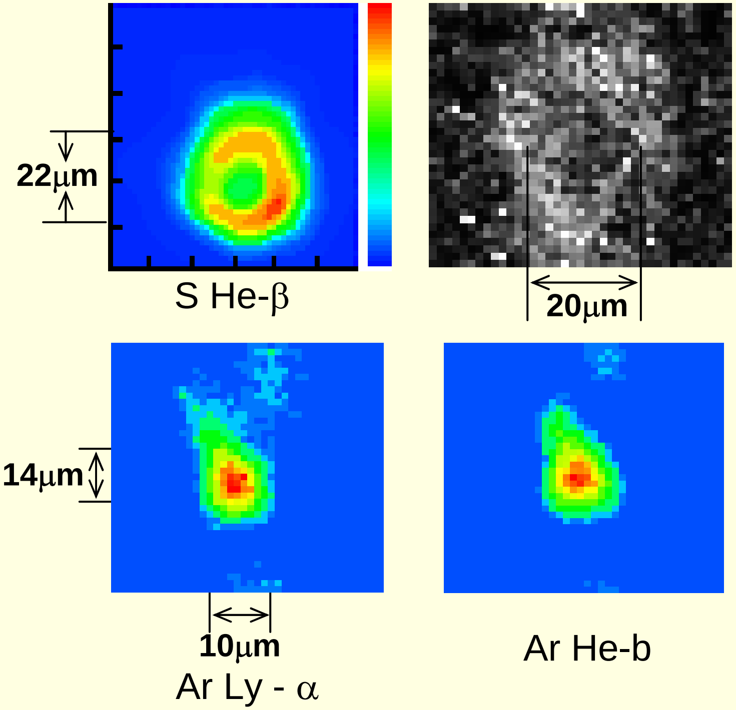
Diagnose interface between capsule shell (doped S thin film) and fuel compression (doped Ar) to precisely understand implosion dynamics.

Backlighting camera image to show Interface motion

Interface convergence

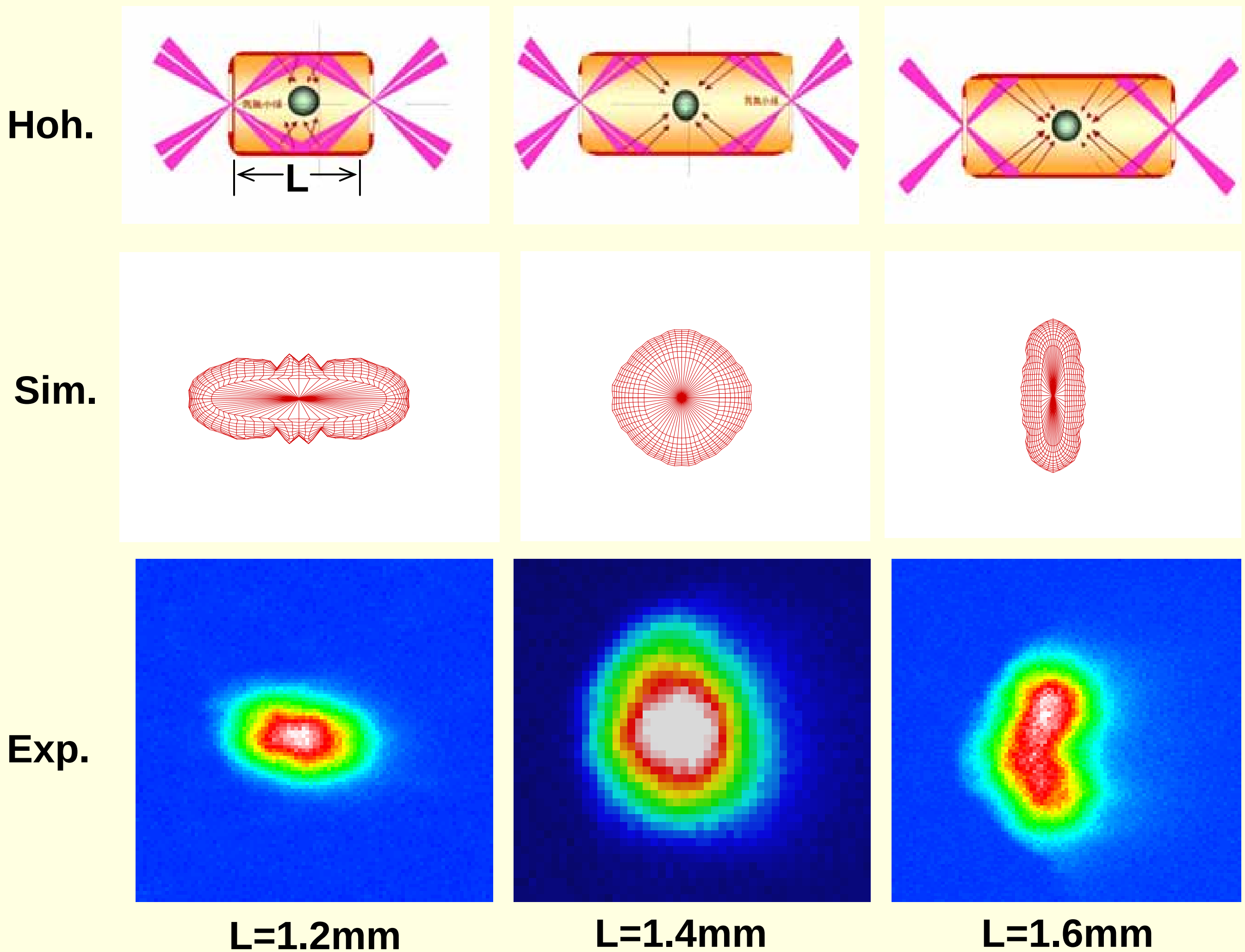


Pin-hole (ϕ 5 μ m) image, resolution 6 μ m



III. Latest advances in target physics

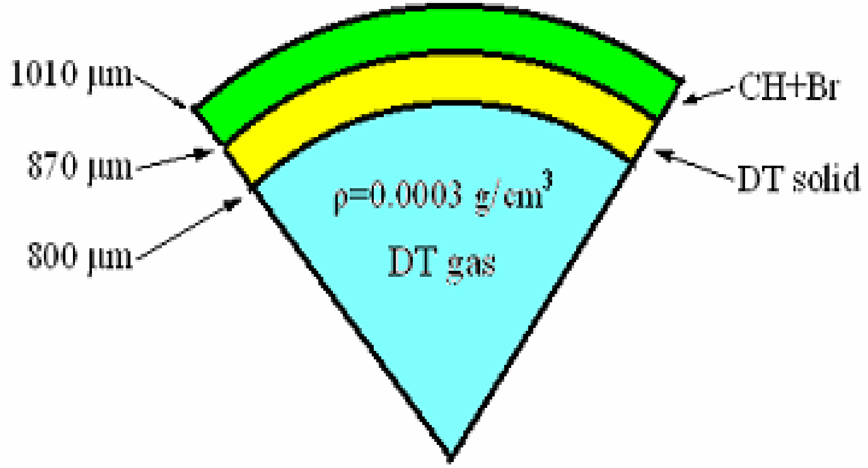
Capsule deforming experiment on SG-II and LARED simulation



III. Latest advances in target physics

Preliminary design of ignition capsule for indirect drive to be on SG-IV

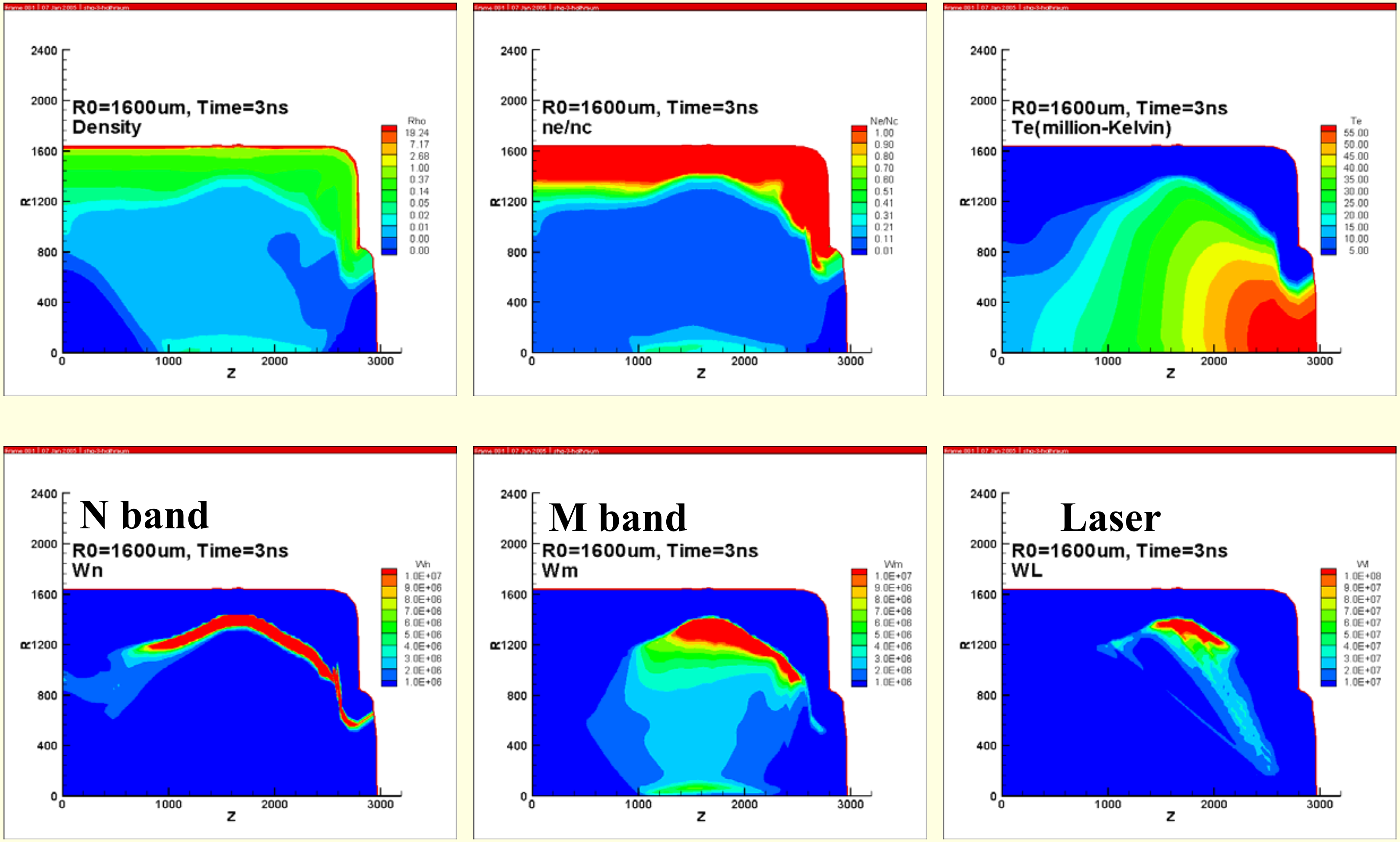
Laser energy of 1.0 MJ incident on hohlraum, Radiation temperature Tr=300eV(main pulse 4 ns). Fusion yield of 12.7 MJ is gained.



Implosion velocity	3.26×10^7 cm/s
Fuel mass	0.15mg
Ablator mass	1.87mg

III. Latest advances in target physics

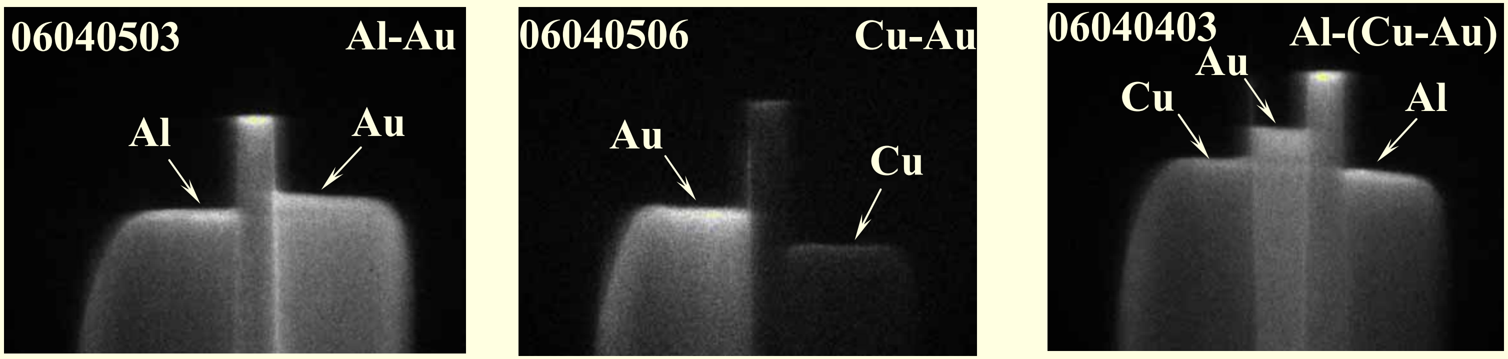
Hohlraum physics studies through using LARED-H simulation under SG-III conditions



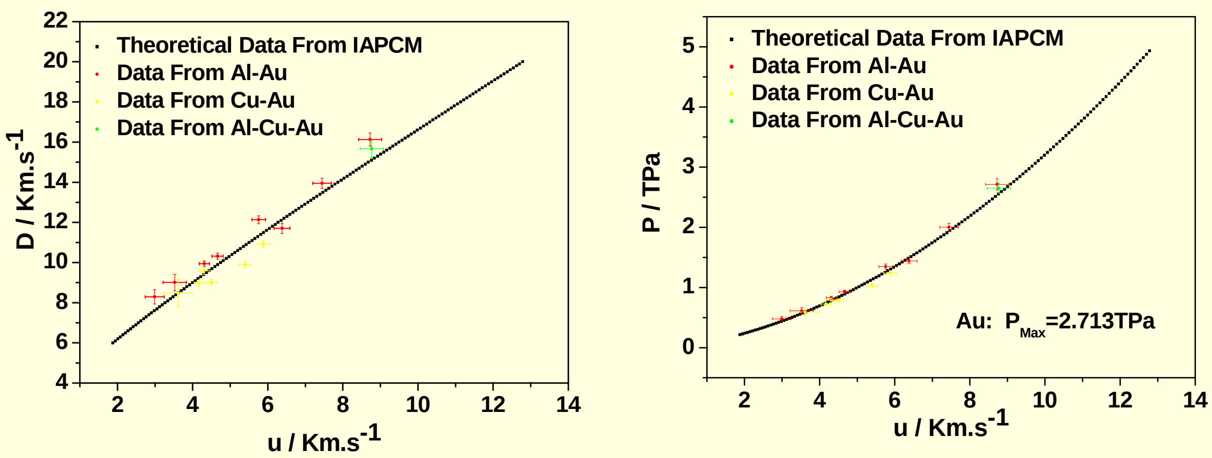
III. Latest advances in target physics

The measurement of Au hugoniot curves on SG-II

Experimental targets (Al-Au impedance-matched)



Hugoniot data of gold (shock wave velocity D and pressure P)

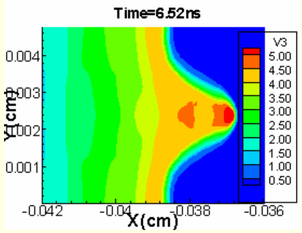


III. Latest advances in target physics

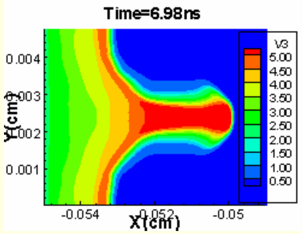
Ablative hydrodynamic instability in the preheating case investigated by numerical simulation

Ablation suppressed KH instability and Jet formed from ablative Rayleigh-Taylor instability

Weakly preheating

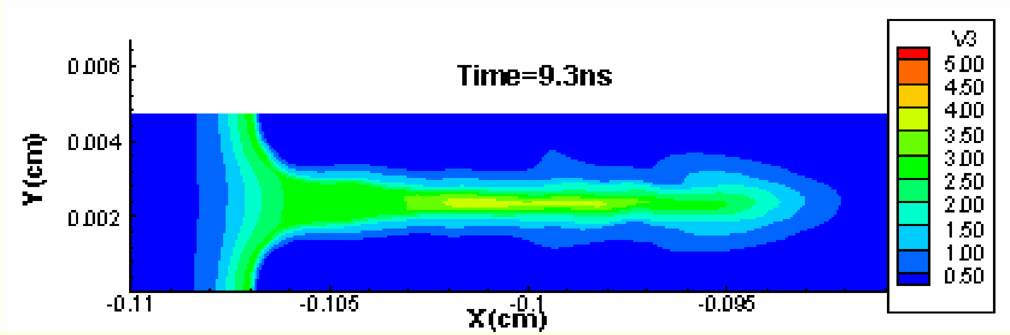


t=6.5ns



t=7.0ns

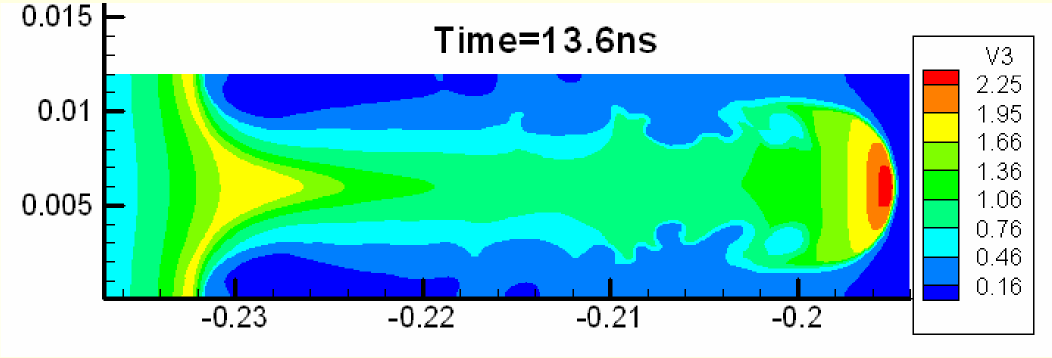
Middle



$\lambda_{cut-off} \approx 7\mu m$

$\lambda_0 = 49\mu m$

Strong

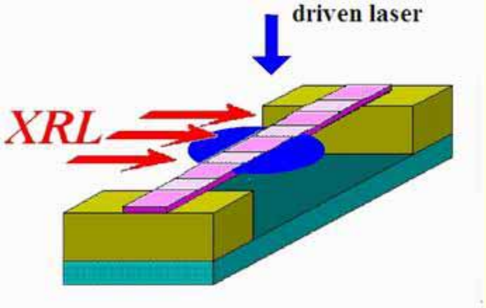


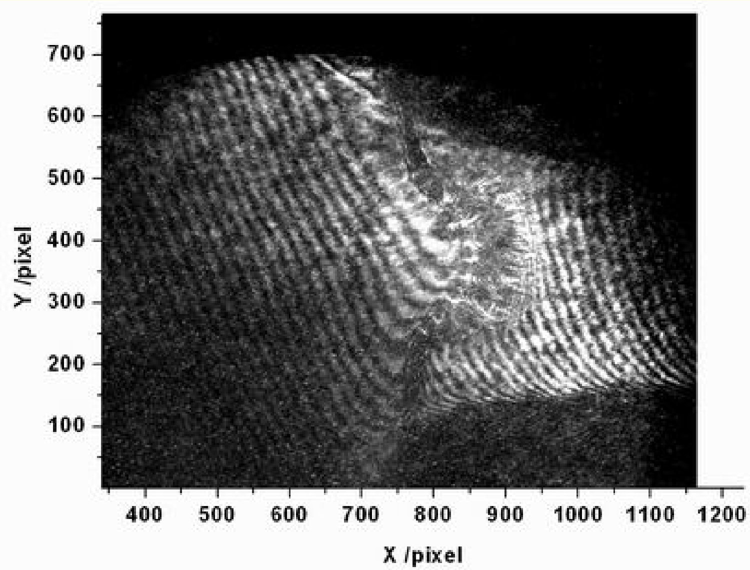
$\lambda_0 = 120\mu m$

III. Latest advances in target physics

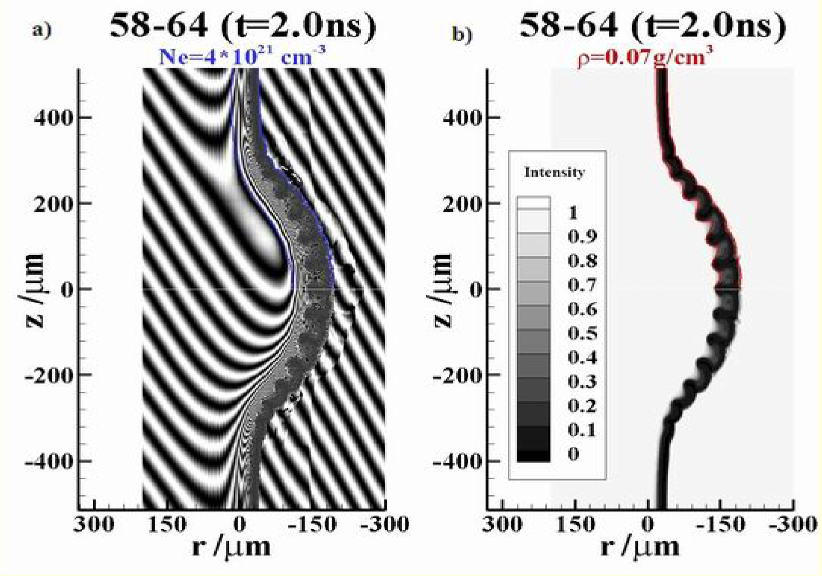
Soft X-ray laser (λ=13.9 nm) is used to diagnose hydrodynamic instability

The hydrodynamic instability of the plane target was observed by using soft X-ray laser (λ=13.9 nm) probe and by 2D simulations.





Experimental Mach-Zehnder interferogram of modulation target, soft X-ray laser (λ=13.9 nm) as a probe beam



(a) Interferogram from 2D simulation (b) transmissivity of X-ray laser (photo-electron and inverse bremsstrahlung absorptions)

IV. Fast ignition studies

1. Cone-shell implosion dynamics

2. Hot electron characters and transport in overdense plasma

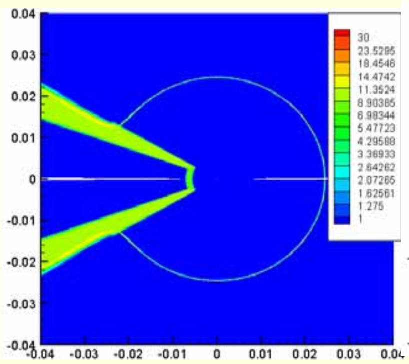
3. Proton beam generation and acceleration

IV. Fast ignition studies

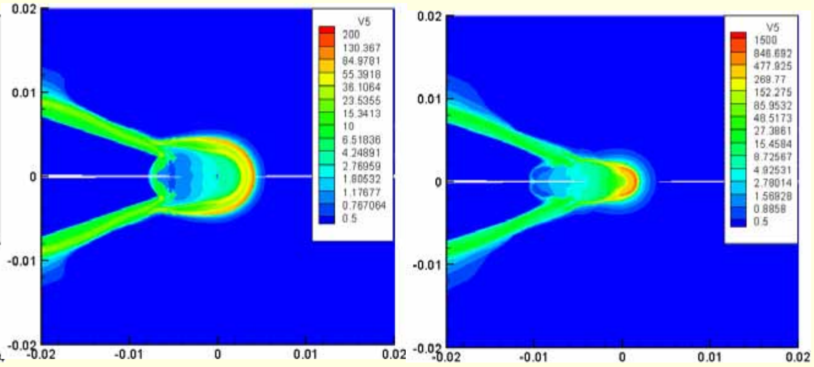
Implosion simulation under SG-IIU conditions (18kJ, 3ns)

Laser energy of 10kJ incident on capsule. CD shell density ρ_0= 1g/cm^3, R_{out}=325μm, ΔR= 25μm, Cu cone 60º, cone end to capsule center d=56μm. Inside, DT gas, 1mg/cc.

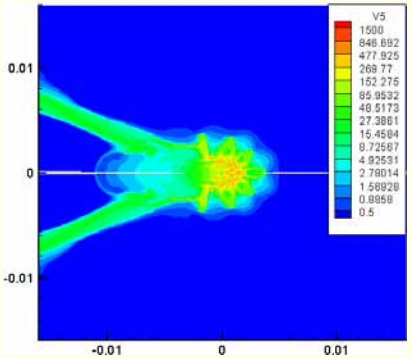
Initial



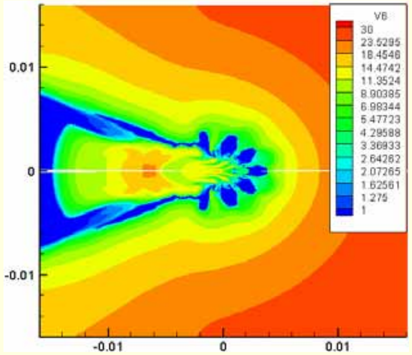
Density without RTI



Density with RTI



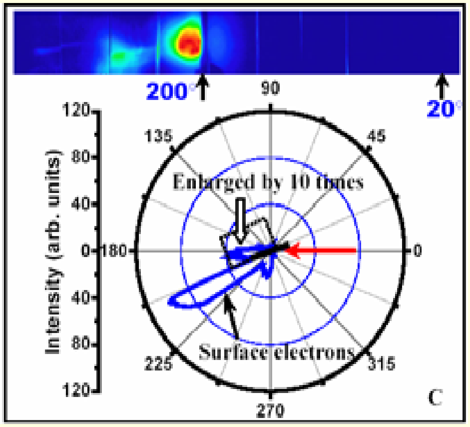
temperature with RTI

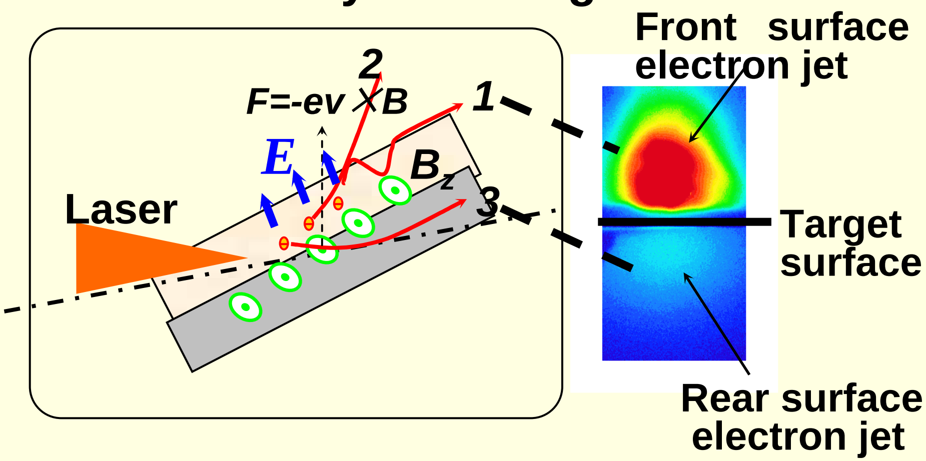


IV. Fast ignition studies

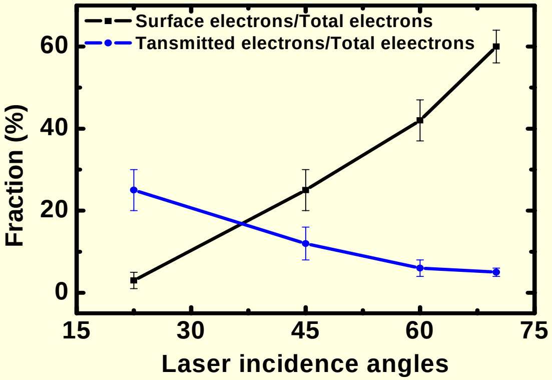
♦ Experiments show a well collimated electron jet along target surface

- A fast electron jet along the front target surface was observed experimentally when an intense laser pulse (~10^{19}W/cm^2, 30 fs) irradiates target with an incident angle≥70º. – direct confirmation of confusing effects of fast electrons by cone targets





- 2D PIC simulations: jets formed due to confinement of the surface quasistatic electromagnetic fields.

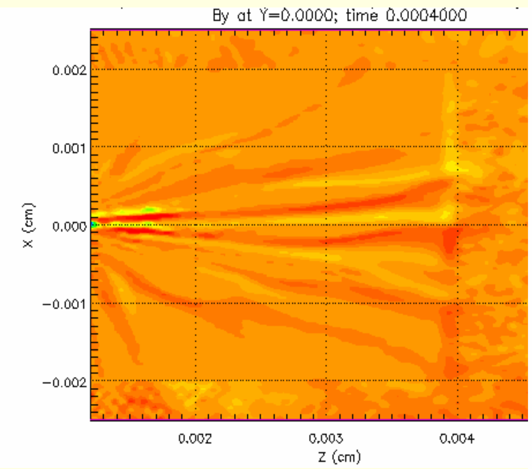


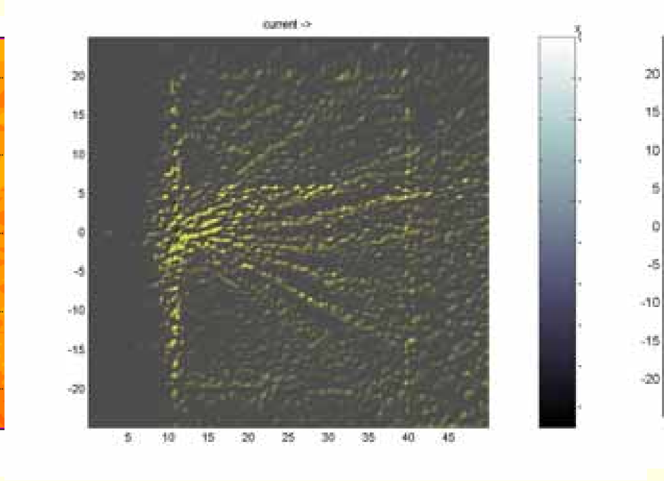
IV. Fast ignition studies

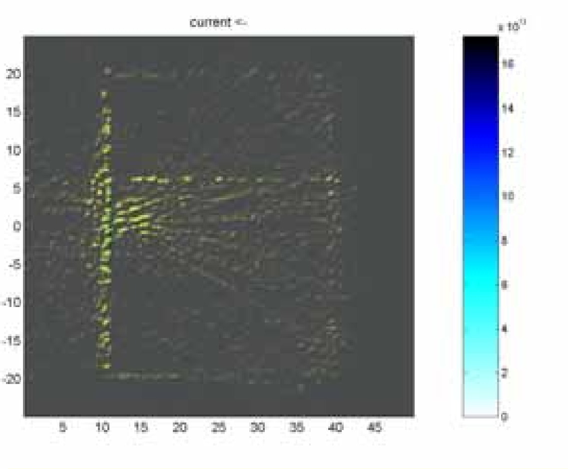
♦ **Hot electrons transport in overdense plasma (Al target) by 3D HF-PIC simulation (2D)**

Relativistic electron beam with divergence about 40 ° is generated in Al target interacting with laser ($I=3x10^{20} W/cm^2$, $r_0=3\mu$ m) by integrated simulation.

quasistatic magnetic field **forward current** **return current**





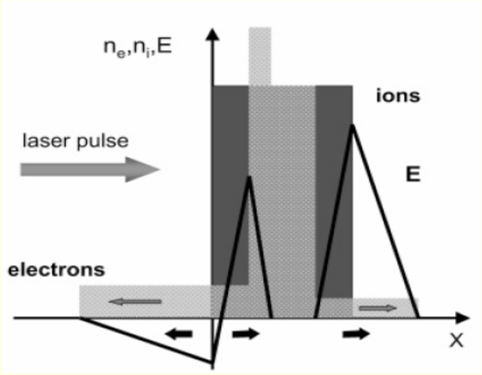


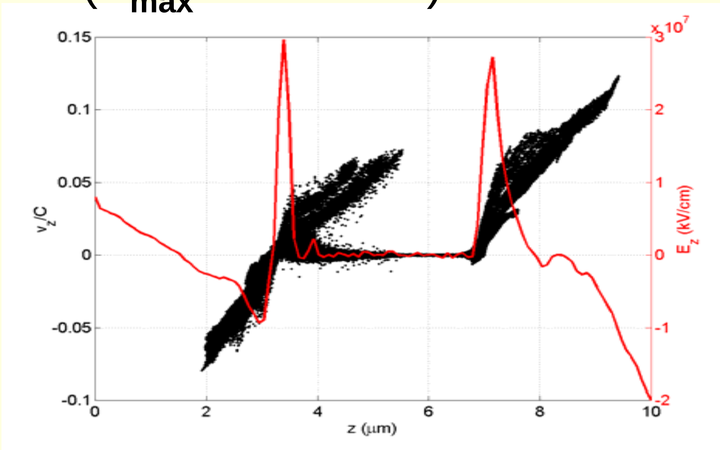
IV. Fast ignition studies

Mono-energy of proton beam is observed in the rear of CH target by 3D HF-PIC simulation (2D).

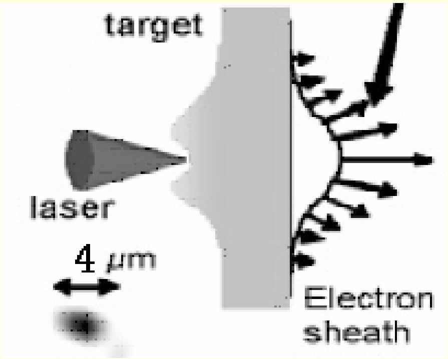
Laser intensity: $I=3x10^{20}W/cm^2$, CH thickness: $d=4\mu m$

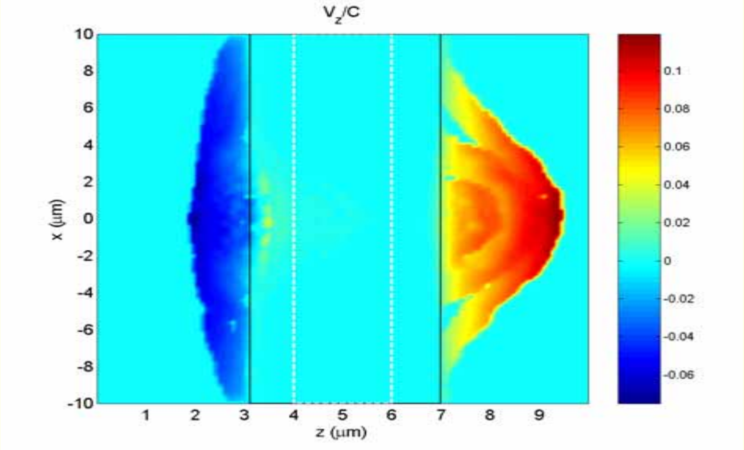
Electric fields (E_{max}=30GV/cm)





Velocity distribution (v_{max}=0.15c)





V. Final remarks

In the past years, a series of experiments for target physics have been conducted on SG-II, and a large number of numerical simulations using LARED code have been carried out under the parameters for SG-II and SG-III laser drivers. The ignition physics is in progress.

SG-IIU driver will serve experiments for target physics beginning at 2008 before SG-III working, and will couple with PW laser to investigate the hot spot formation for fast ignition.

V. Final remarks

SG-III driver will be operating in 2010 and be coupled with tens kJ PW lasers for fast ignition demonstration.

The ignition project is performed : architecture of the SG-IV driver with laser energy of 1.5 MJ for central ignition and high gain fast ignition is being planned, China is going toward high gain ignition and burning goal in about 2020 and may advance to carry out ignition goal in about 2015 if fast ignition is favorable.

Thanks!