Multi-Scale Simulations for Fast Ignition and Related Laser Plasma Physics

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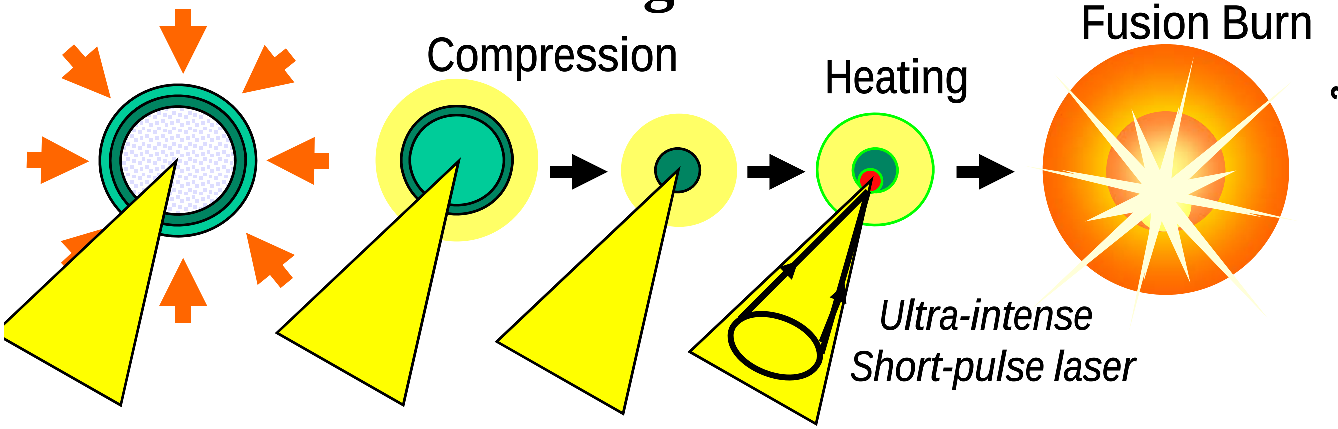
2008 U.S.-Japan Workshop Progress of Multi-Scale Simulation Models

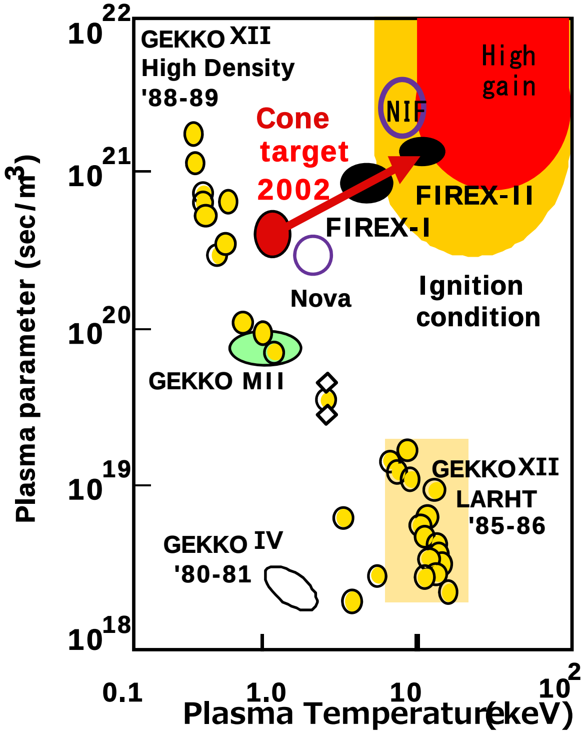
Background

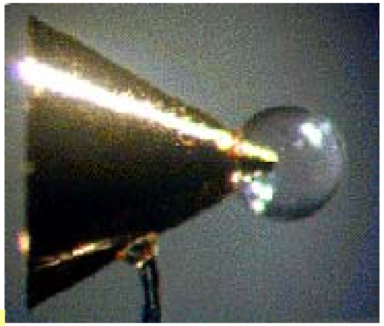
- Fast Ignition Realization EXperiment (FIREX) project is carried on at ILE Osaka University.
- Understanding the physics in Fast Ignition and target designs for FIREX-I is required.
- Fast Ignition scheme is different from conventional Central hot-spot ignition scheme.
- Physics in the Fast Ignition is very wide range and complicated. (Radiation hydrodynamics, Laser Plasma Interaction, Hot electron transport)
- Computer simulation is strong tool for the detail analysis.

Fast Ignition and FIREX-I

Fast Ignition



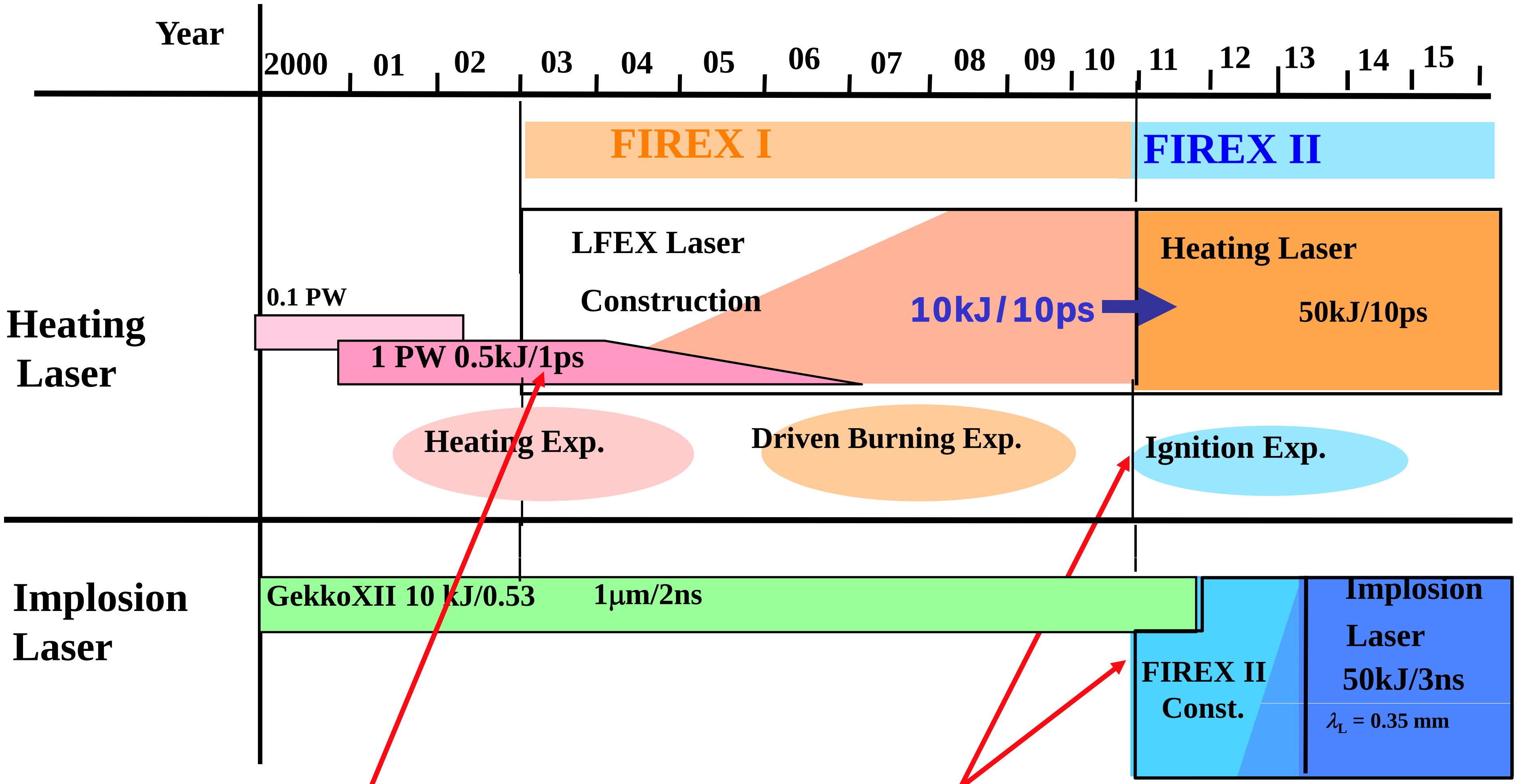




Heating (LFEX) ; 10 kJ in ω

Implosion (GXII) ; 2.5~6 kJ in 2ω

Schedule of FIREX project



Based on the 1keV heating (Nature '02), FIREX project has been started.

After 5keV heating in FIREX-I, FIREX-II is planned to start in FY.2011

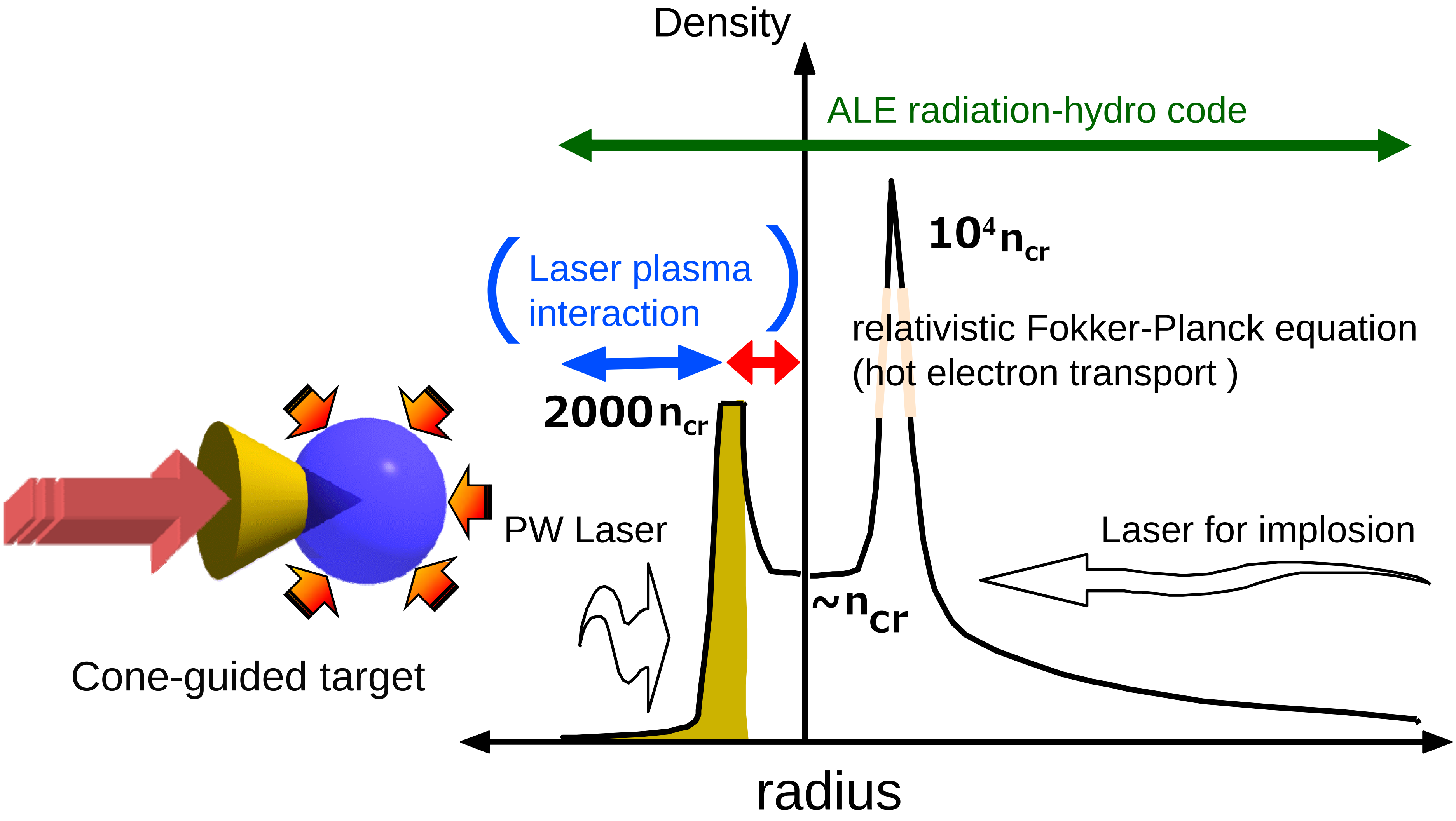
Outline

- FI^3 (Fast Ignition Integrated Interconnecting) System
- Optimization of cone tip material via Multi-scale simulation.
  - – Influence of cone (Laser Plasma Interaction)
    - Ionization effect on LPI
  - – Influence of cone (Hot Electron Transport)
    - Collisional effect on HET
  - – Implosion design with CH cone tip.
- Advanced Target design

Pulse duration of heating laser will be 10 ps (10 kJ).
It was 1 ps (1kJ) in previous peta-watt laser which was used in 2001 experiment.
The differences between1 ps and 10 ps are significant.

FI^3 Project

Fast Ignition Integrated Interconnecting code



Density

ALE radiation-hydro code

Laser plasma interaction

$10^4 n_{cr}$

relativistic Fokker-Planck equation (hot electron transport)

$2000 n_{cr}$

PW Laser

Laser for implosion

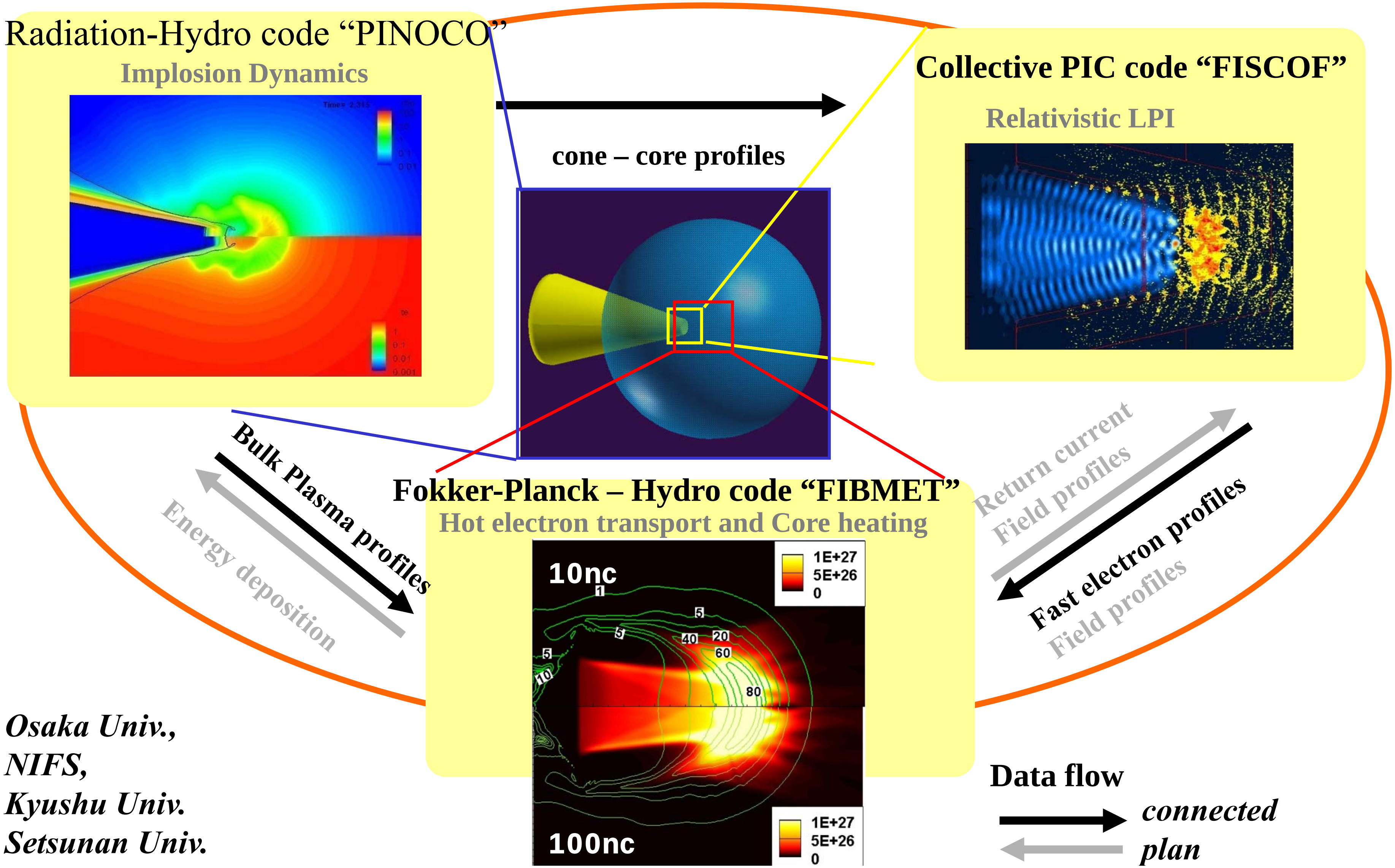
$\sim n_{cr}$

Cone-guided target

radius

FI^3 Project

Fast Ignition Integrated Interconnecting code Project



Radiation-Hydro code “PINOCO”

Implosion Dynamics

cone – core profiles

Collective PIC code “FISCOF”

Relativistic LPI

Bulk Plasma profiles

Energy deposition

Fokker-Planck – Hydro code “FIBMET”

Hot electron transport and Core heating

Return current

Field profiles

Fast electron profiles

Field profiles

Data flow

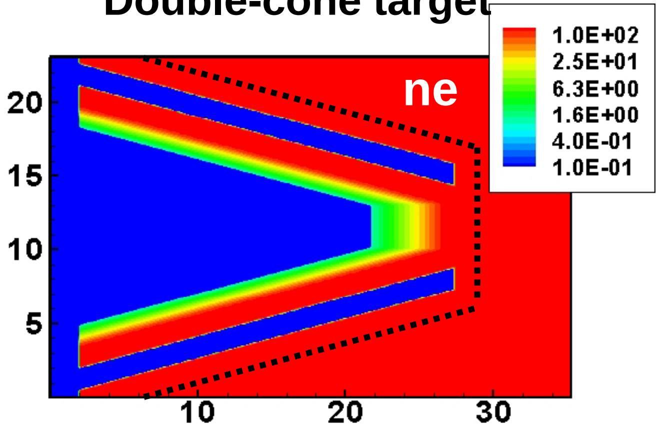
connected

plan

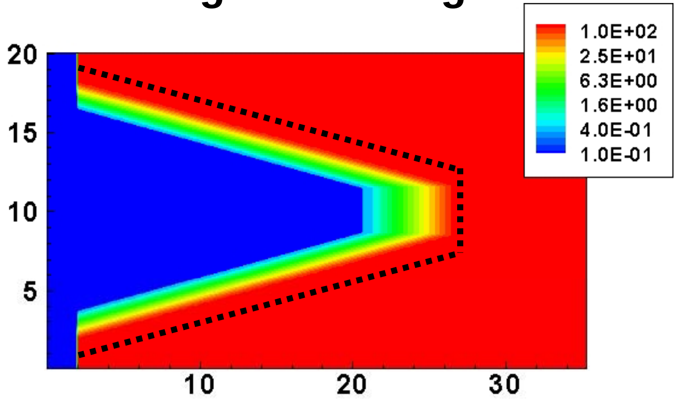
Osaka Univ.,
NIFS,
Kyushu Univ.
Setsunan Univ.

Double-cone target effectively focuses high energy electrons towards cone tip

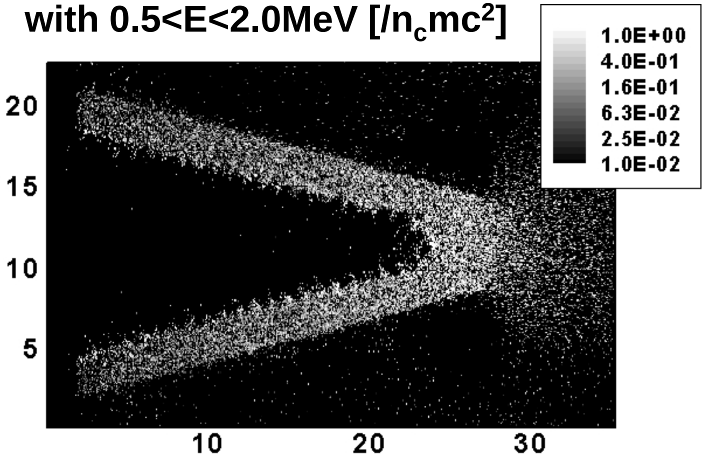
Double-cone target



Single-cone target



Energy distribution of electrons with 0.5<E<2.0MeV [/$n_c mc^2$]



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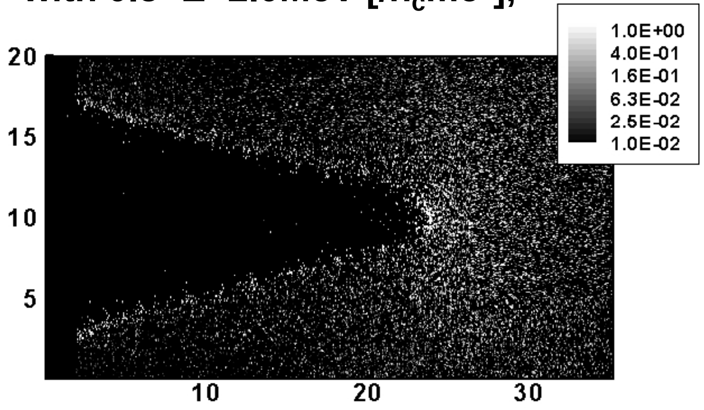
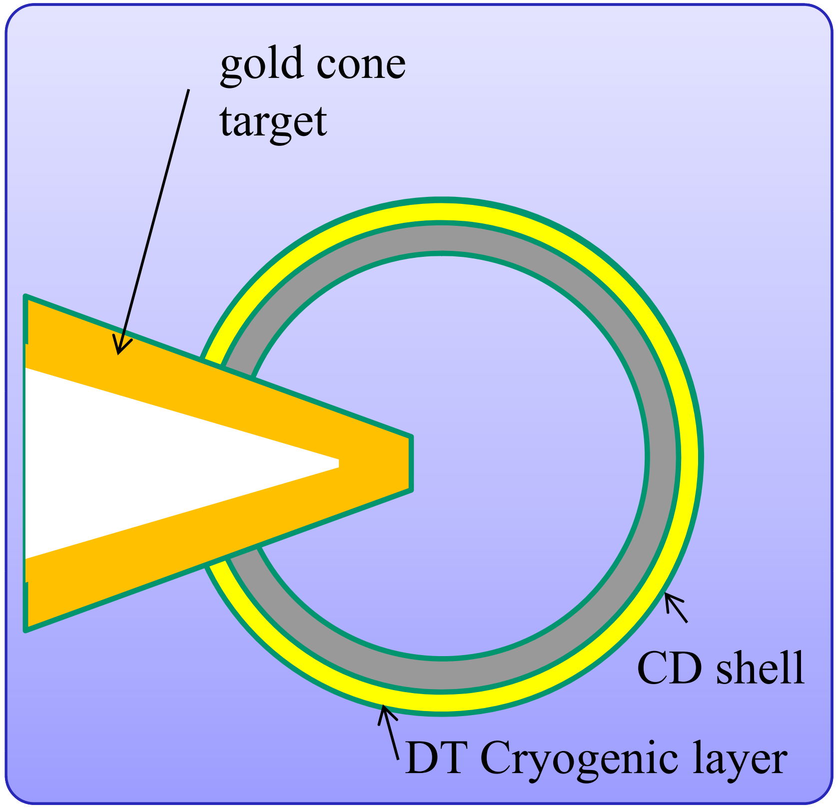


Double cone target sustain sheath field at the outer surface to prevent them spreading away. Electron energy flux propagate through the tip is 93 % of isolated cone case for double-cone, and 55 % for single-cone targets.. Assuming, A=197, Te=0.5keV, $c_s\ \tau$~0.2μm.

T. Nakamura PoP 2007

Overview of the advanced target for FIREX-I

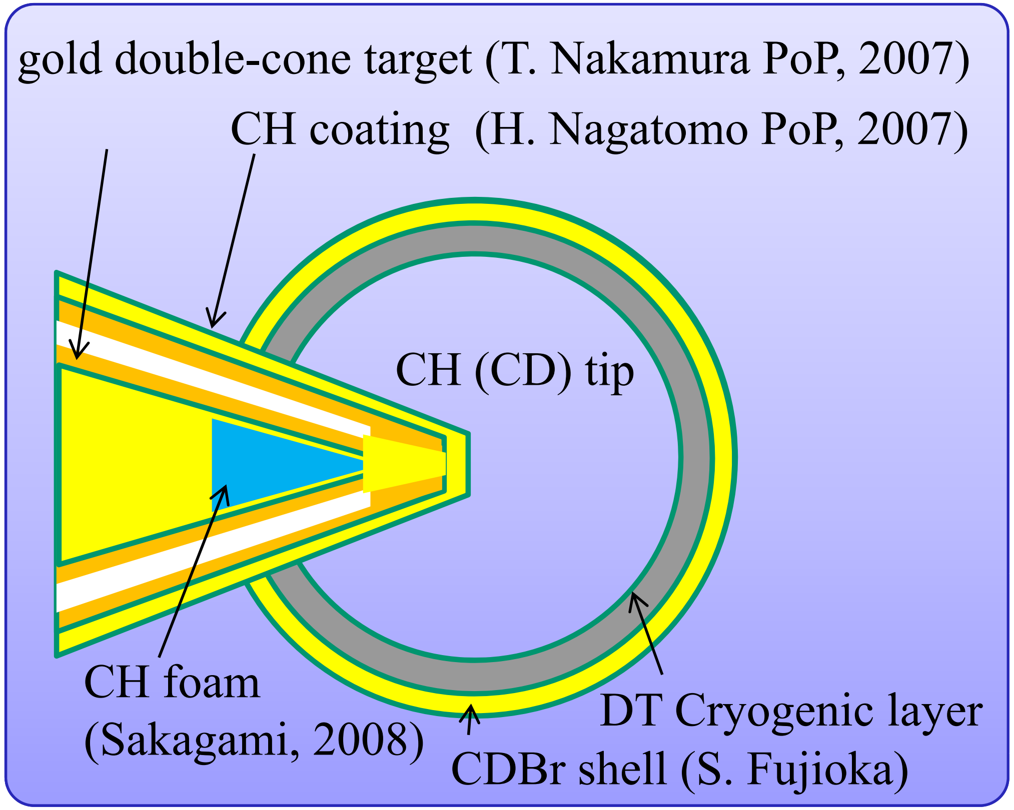


gold cone target

CD shell

DT Cryogenic layer

Simple target design



gold double-cone target (T. Nakamura PoP, 2007)

CH coating (H. Nagatomo PoP, 2007)

CH (CD) tip

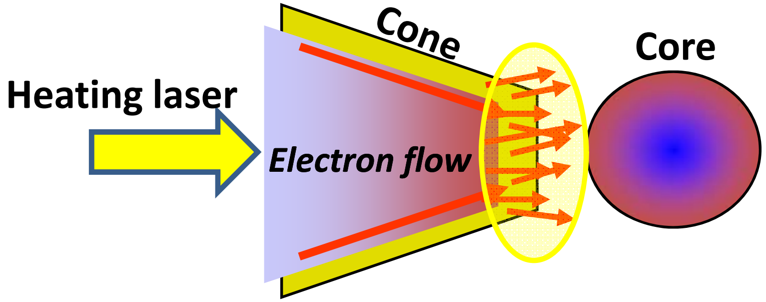
CH foam (Sakagami, 2008)

DT Cryogenic layer

CDBr shell (S. Fujioka)

Latest advanced target design

Is Au suitable for a cone material from the viewpoint of efficient core heating ?



The heating laser energy is 10kJ in FIREX-I and it will be ～100kJ in future fusion-burn experiments.

- A cone is heated up to Te ~ 10keV and reaches a highly-ionized state.
- The collisional scattering will affect the laser-plasma interactions and the following fast electron transport.

We evaluate the dependence of core heating properties on a cone tip material on the basis of coupled 1D simulations;

- **Collisional PIC ････ intense-laser plasma interactions**
- **Fokker-Planck ････ fast electron transport and core heating**

Viewpoint of LPI and HET

Is Au suitable for a cone material ?

We evaluated cone material dependence of core heating properties.

- **Laser matter interactions → 1D collisional PIC simulations**
- **Transport in cone tip → 1D Fokker-Planck simulations**

High-Z material (Au) case :

Fast electron generation

- density profile steepening & resistive damping of return current

  → **lowering the energy coupling of intense laser to fast electron**

Fast electron Transport

- energy loss due to collisional & resistive drags and scattering by ions

  → **lowering the number of relatively-low energy (~<1MeV) electrons and broadening their angular spread.**

⬇ **Using low-Z material (here, CH), these negative effects can be reduced.**

Core heating → **Rise in core temperature is twice higher in the CH cone case.**

At least for a cone tip material, Au is not suitable.
We propose use of a low-Z material (e.g. CH).

Overview of Rad-Hydro code

- two temperature,
    - ALE-CIP (CIP, RCIP, CCUP)
- thermal transport (electron, ion)
  - flux limited type Spiter-Harm
  - implicit (9 points-ILUBCG)
- Radiation transport
  - multi-group diffusion type (16~64 groups)
  - implicit (9 points-ILUBCG)
  - Opacity, Emissivity
    - local thermodynamic equilibrium (LTE)
    - non-LTE, collisional radiative equilibrium (CRE)
- Equation of state
  - electron ; Tomas-Fermi model
  - ion ; Cowan model

Fundamental Equations for Integrated Implosion Code (1)

- One fluid, two temperature fluid model.

(mass)

$$\frac{d\rho}{dt} = -\rho\nabla \bullet \mathbf{u}$$

(momentum)

$$\rho\frac{d\mathbf{u}}{dt} = -\nabla P$$

(ion energy)

$$\rho\frac{d\varepsilon_i}{dt} = -P_i\nabla\cdot\mathbf{u} - \nabla\cdot q_i + Q_{ei}$$

(electron energy)

$$\rho\frac{d\varepsilon_e}{dt} = -P_e\nabla\cdot\mathbf{u} - \nabla\cdot q_e - Q_{ei} + S_L + S_r$$

(radiation transport)

$$\frac{1}{c}\frac{dI^{\nu}}{dt} + \Omega\cdot\nabla I^{\nu} = 4\pi\eta^{\nu} - \chi^{\nu} I^{\nu} + S^{\nu} \Rightarrow$$

(Flux limited diffusion method)

9 point ILUBCG

(laser absorption)

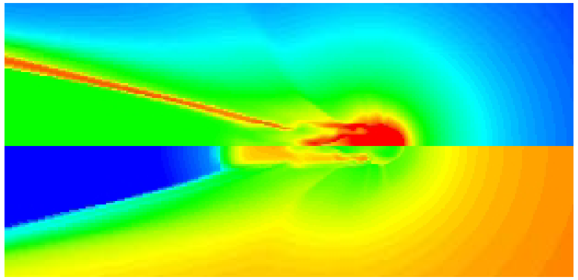
$$v_g \cdot \nabla I_L^k = -\nu_{abs} I_L^k \qquad S_L = \sum_k \nu_{abs} I_L^k / v_g^k \Rightarrow$$

1D Ray-tracing

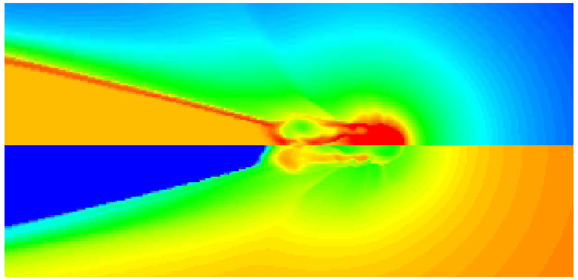
Results of rad-hydro simulations

- Timing of the tip destroyed maybe controlled if we optimize the pulse shape and irradiation pattern in space.

CD tip

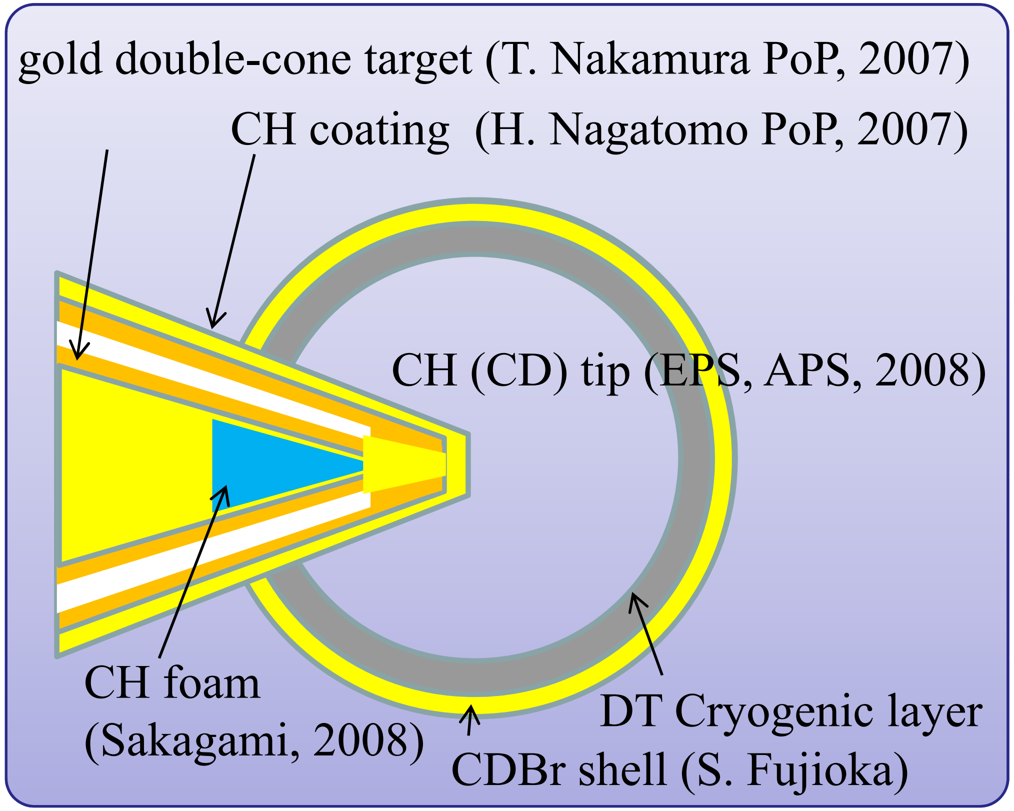


Au tip



Conclusion

- Malti-scale simulation play an important role in designing the fast ignition target.
- Detail specifications will be determined in near future.
- Some computational models or data connections are missing. Code development is continuing.
- FI3 will be applied not only for Fast Ignition but also other high energy density physics and other applications.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