Critical Path to Impact Fast Ignition ––Suppression of the Rayleigh-Taylor Instability––

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Jpn-US WS on HIF and HEDP
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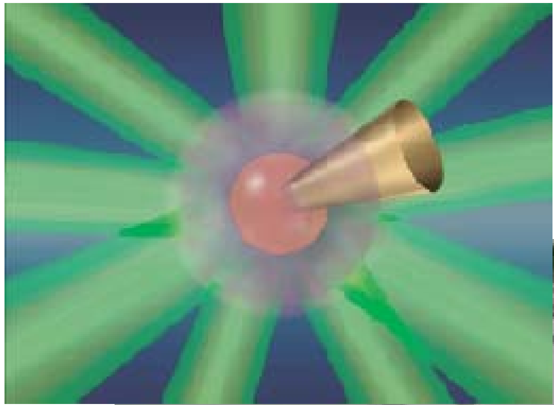
Compression



Fast Heating

Ignition&Burn

Outline

1. Introduction to impact-fast-ignition

2. Suppression of the RT instability

3. First intened exp't

4. Future experiment

Sufficient suppression of the Rayleigh-Taylor instability

1. increases compressed density.

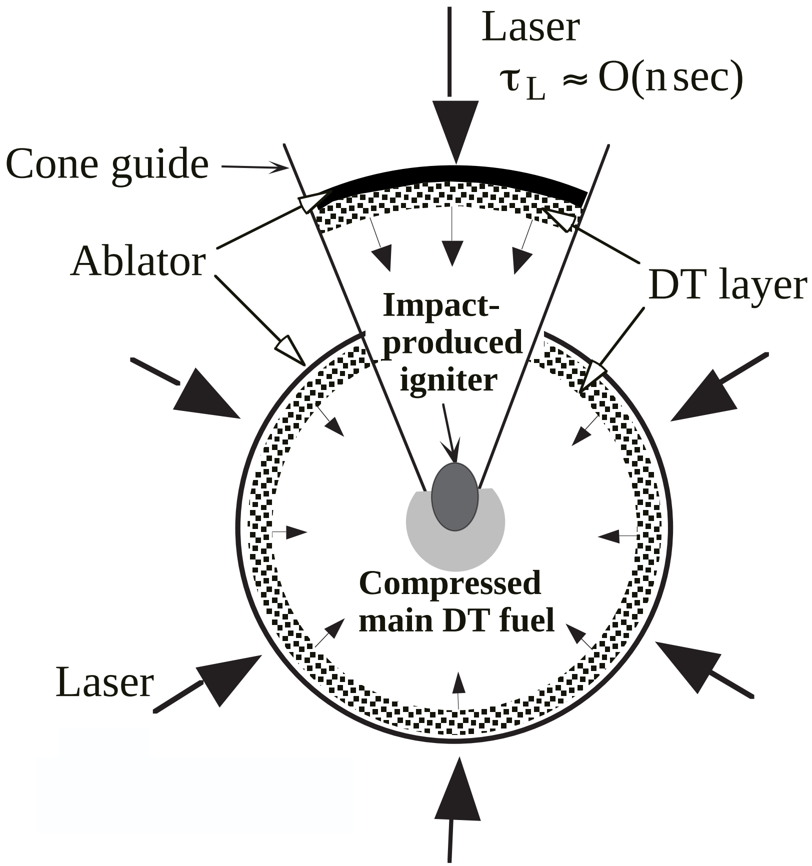
2. revives an old ignition idea:

Super velocity (10^8 cm/s) implosion can configure a hot-spark without a main fuel so as to ignite at very low laser energy (30-100 kJ).

This idea was rejected by two major criticisms:

- No pathway towards high gain.
- The Rayleigh-Taylor instability limits the maximum implosion velocity.

Pathway towards high gain
–– Impact Fast Ignition ––



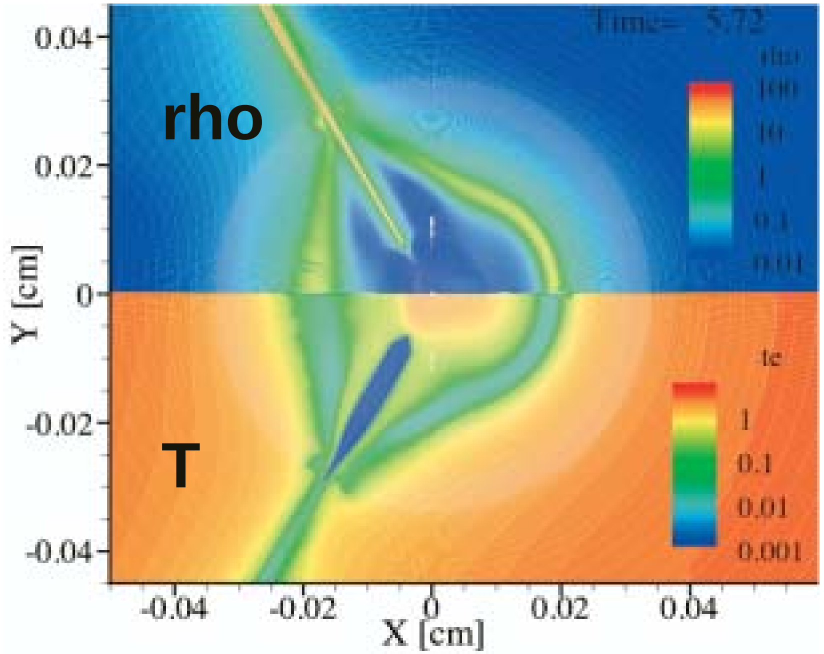
1) High gain

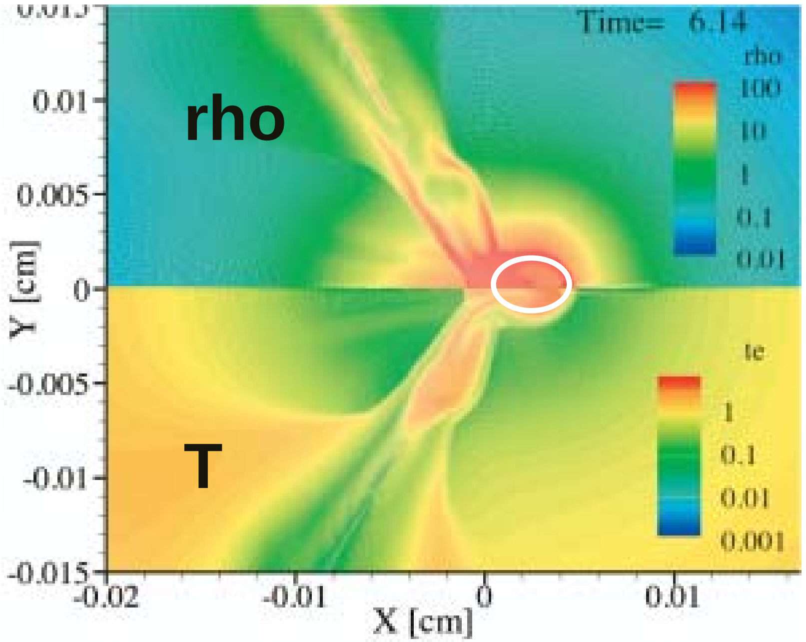
2) Simple Physics

3) Low Cost

Murakami, NIM-A '05

2D Hydrodynamic Simulation





Isocontour map at a time shortly before the impact

Isocontour map at peak comp-ression shortly after the impact

A high-density spark plug is created by impact collision.

Suppression of RT is the critical issure.

- ✓ **Double ablation (Fujioka, PRL04)**
- ✓ **Cocktail color (Ohtani, submitted)**
- **High-Z layer (NRL)**
- **Picket (Rochester, NRL)**

Double Ablation

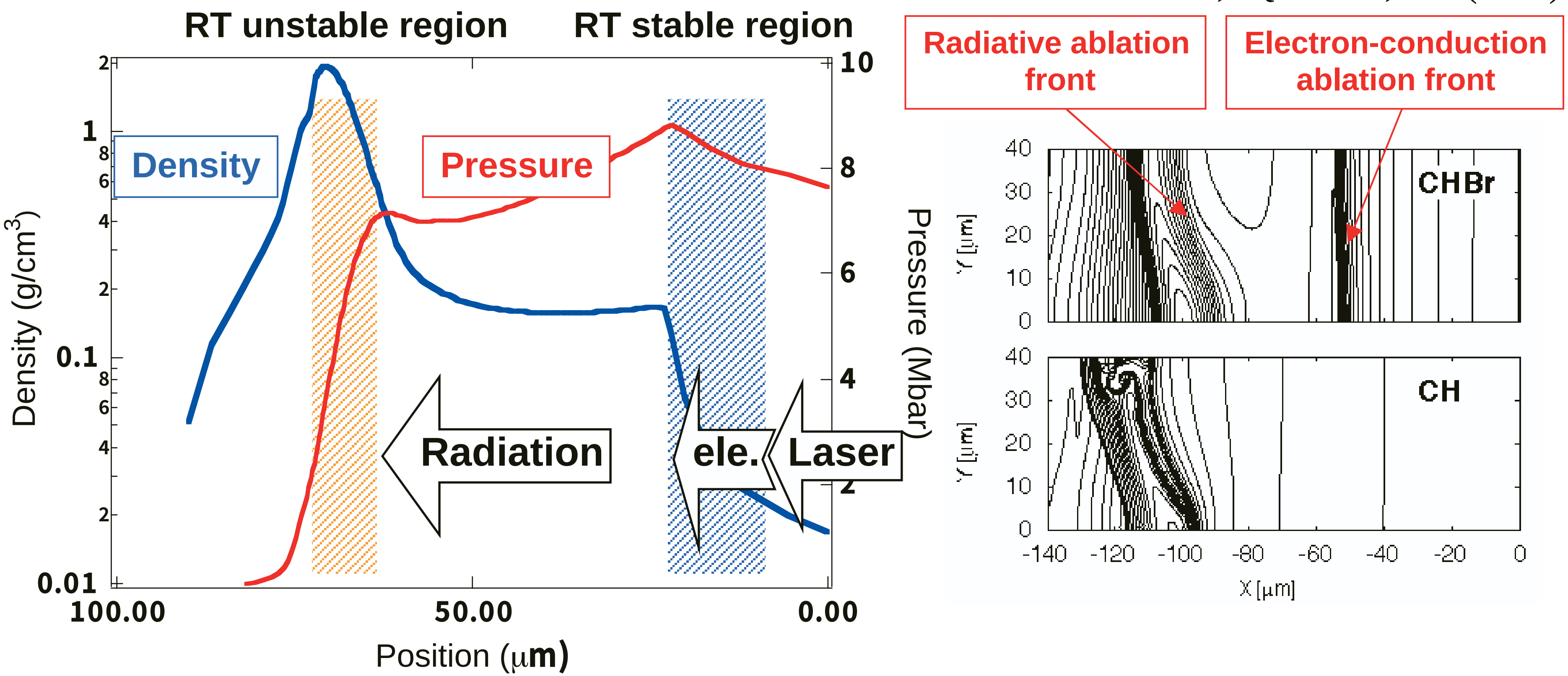
**When targets are doped with high-Z material,
x rays from the high-Z generate a new ablation surface.**

ILE OSAKA

1D simulation (ILESTA-1D)

2D simulation (RAICHO*)

* N. Ohnishi *et al.*, JQSRT **71**, 551 (2001)



**X-ray-ablation is generally stable because of large mdot and L.
Electron ablation is stabilized by large mdot in upper stream
and low ablation velocity.**

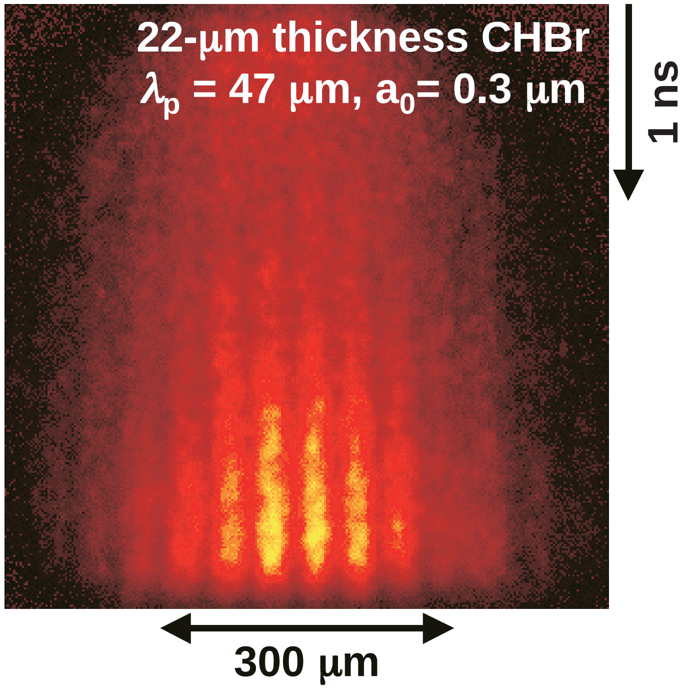
RT exp't with perturbed CHBr target

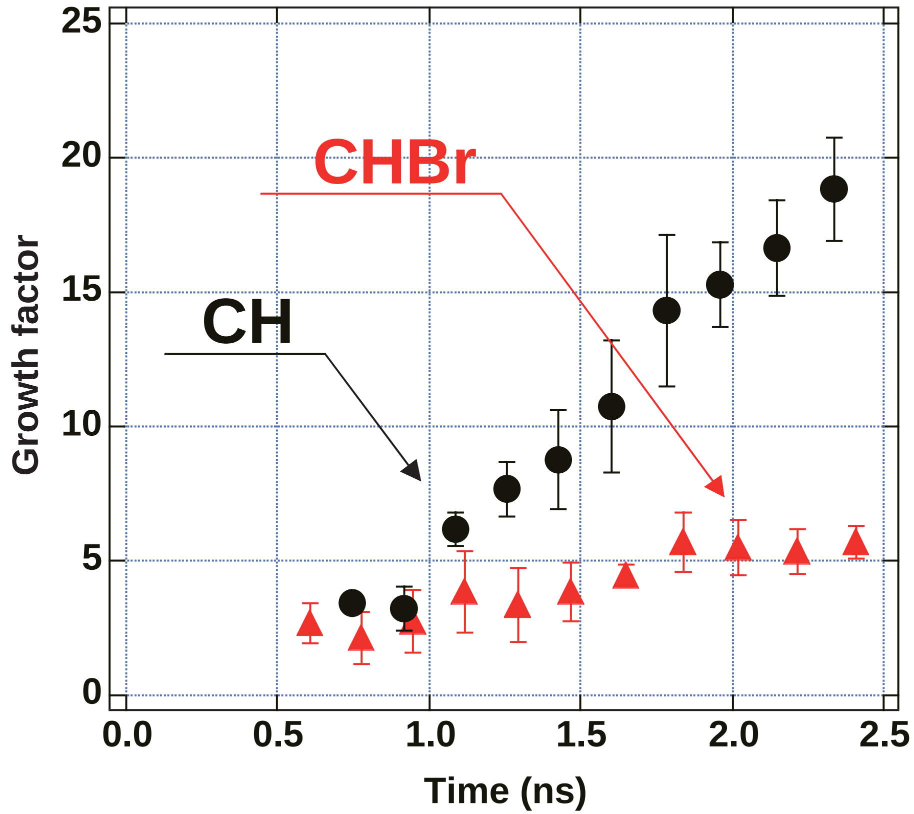
Growth of perturbations in a CHBr target is lower than that of the CH target.

S. Fujioka
(ILE. Osaka)

* R. Betti *et al.*, PoP **5**, 1446 (1998)

	I_L (TW/cm^2)	g ($\mu m/ns^2$)	L_m (μm)	ρ_a (g/cm^3)	m ($g/cm^2\ s^{-1}$)	V_a ($\mu m/ns$)	Fr
CHBr	61	42	2.6	2.4	6.9 x 10^5	2.9	0.36

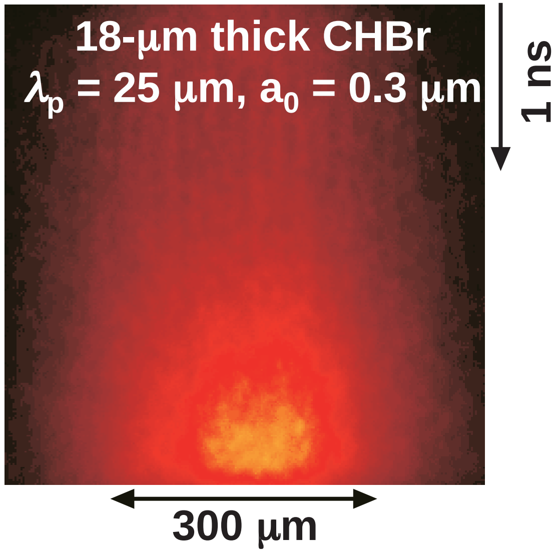


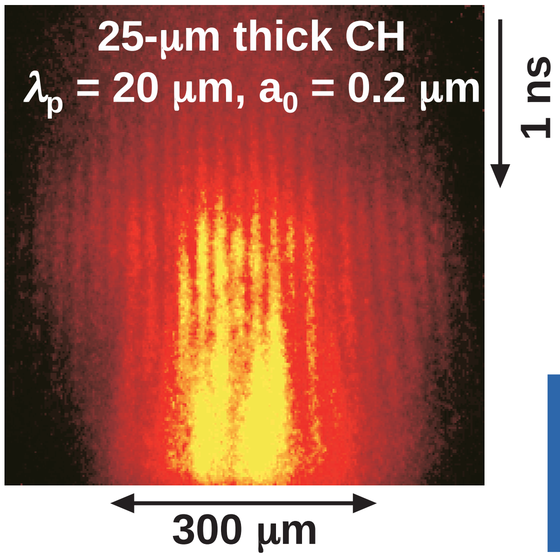


RT exp. with shorter wavelength perturbation

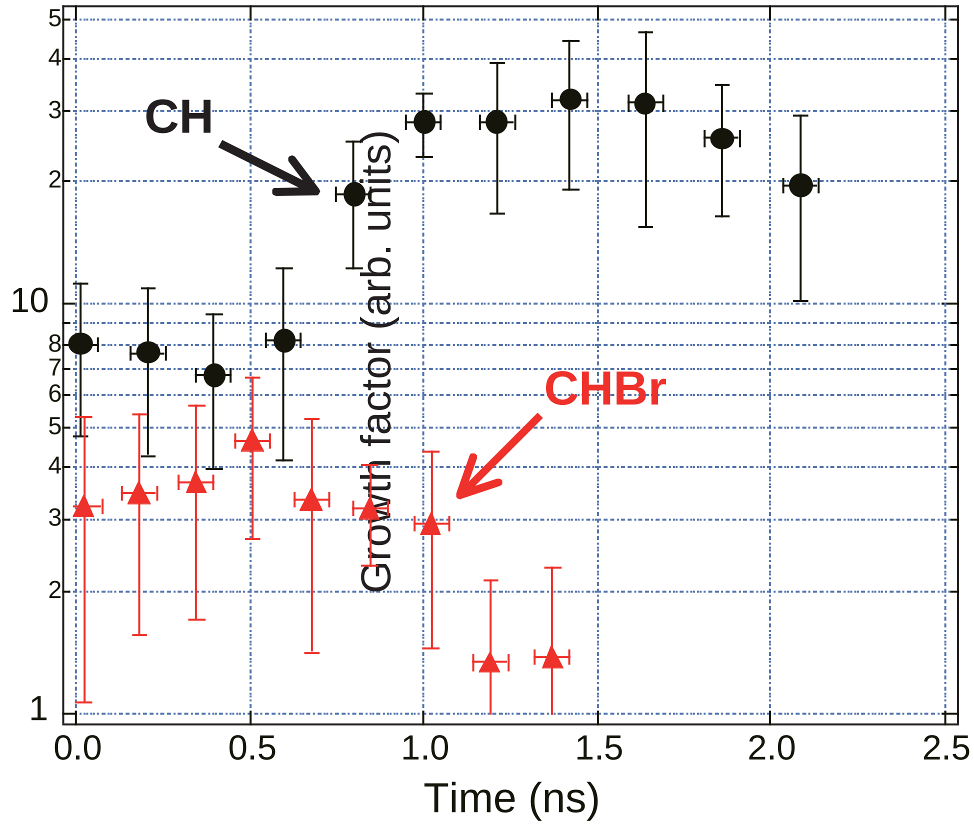
Growth of the perturbations in the CHBr target is strongly suppressed in comparison with that in the CH target.

S. Fujioka
(ILE. Osaka)





Temporal evolution of growth factor



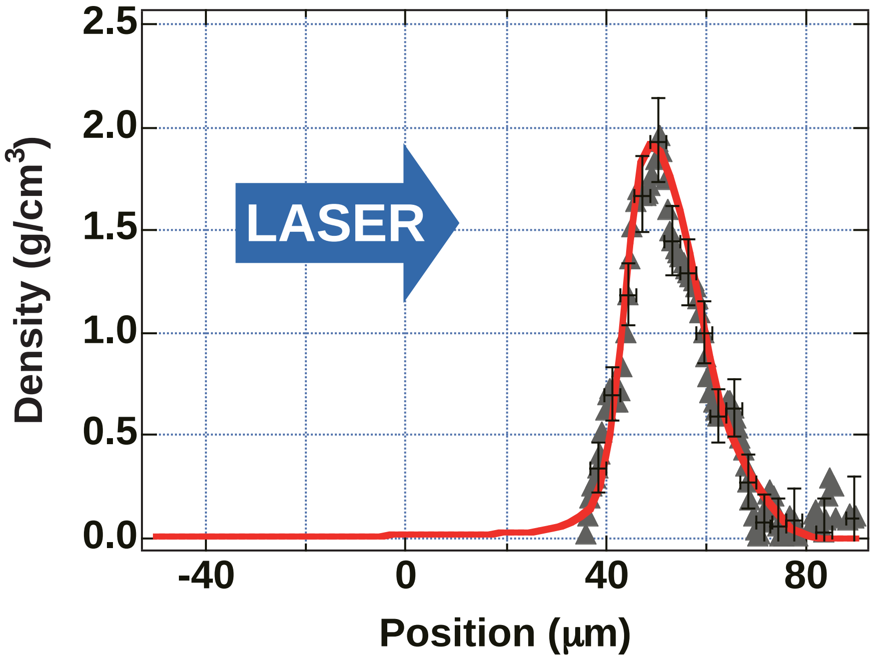
The theory predicts the RT growth rate to be 1.5 ns^{-1} in the CHBr target. This value is large enough to amplify the perturbation to be observable.

Density profile

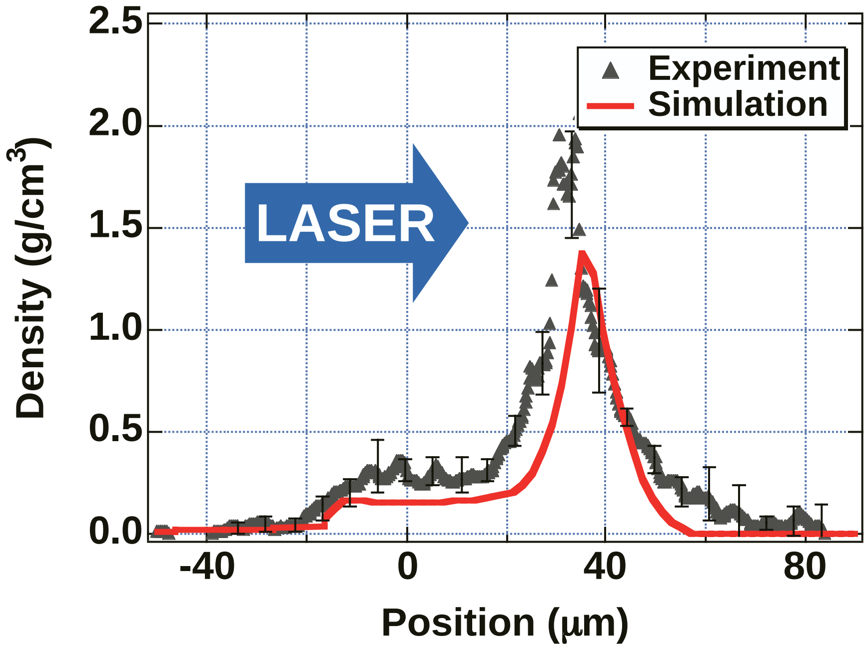
Note: 1. Double ablation is clealy observed.
2. The target density is only slightly lowered.

S. Fujioka
(ILE. Osaka)

CH @1.6 ns

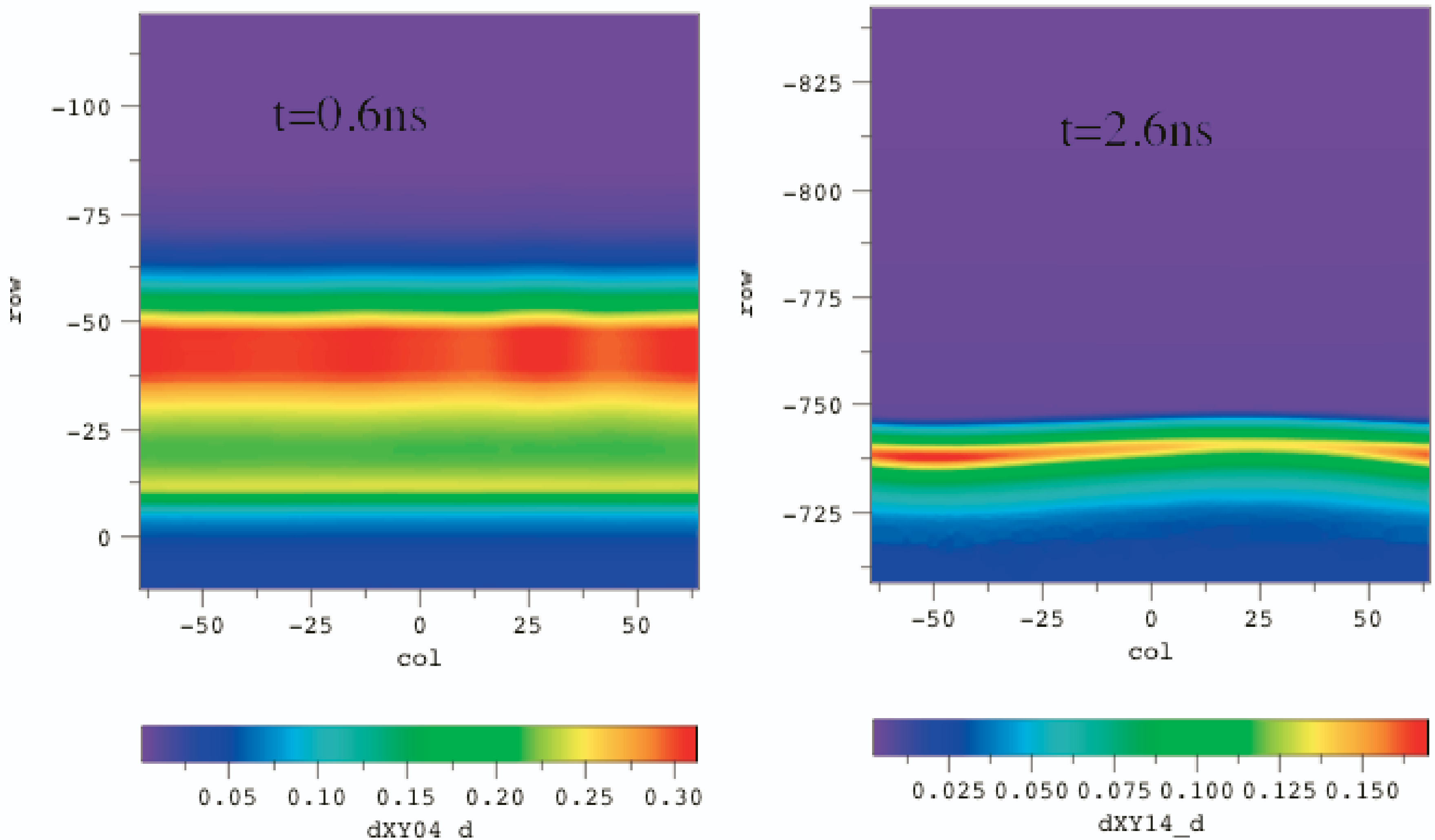


CHBr @1.4 ns



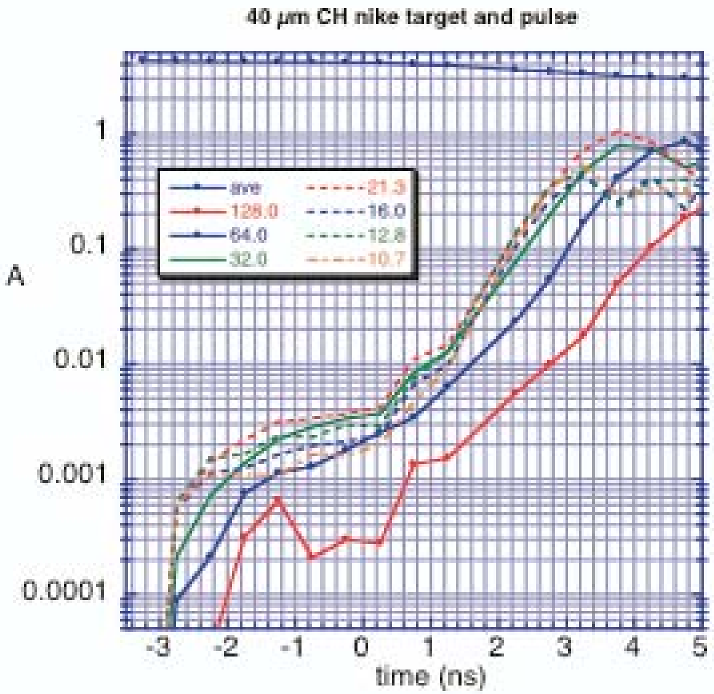
R-T analysis 13.5 μm CH(Br3%) target 400TW/cm^2

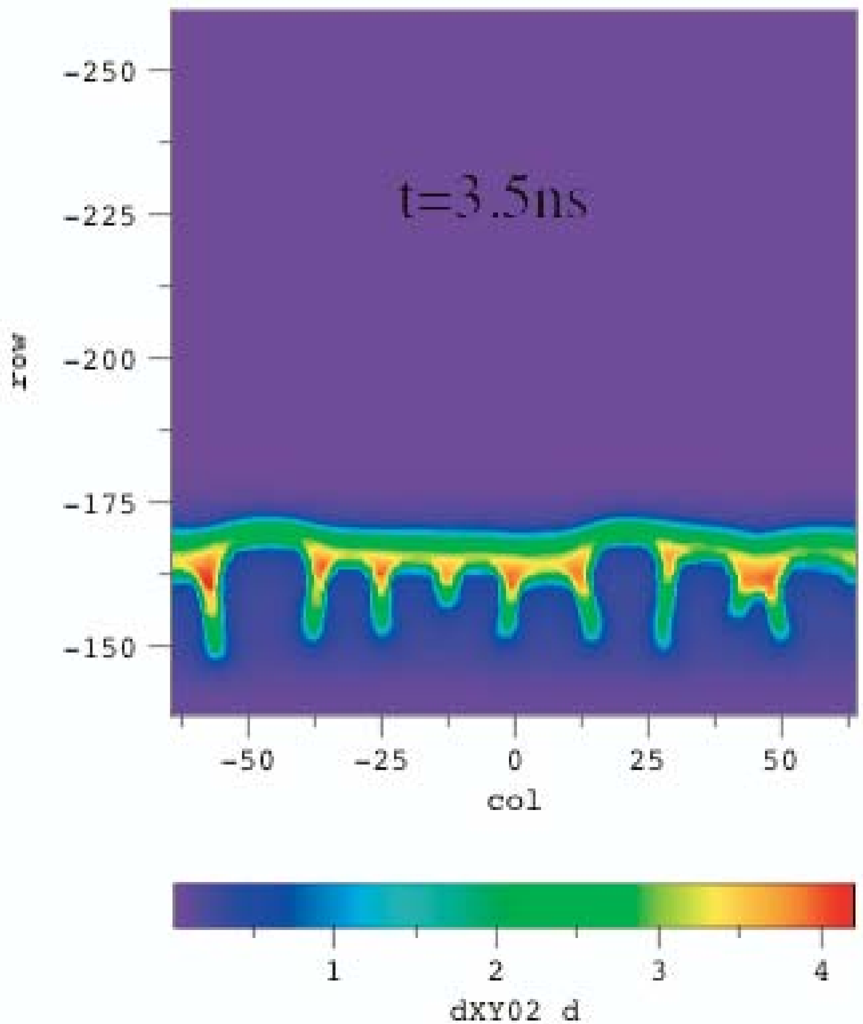
Δν = 0.5 THz



Completely independent 2D rad hydro-code has confirmed CHBr stability.

40 μm CH Nike target and pulse for comparison

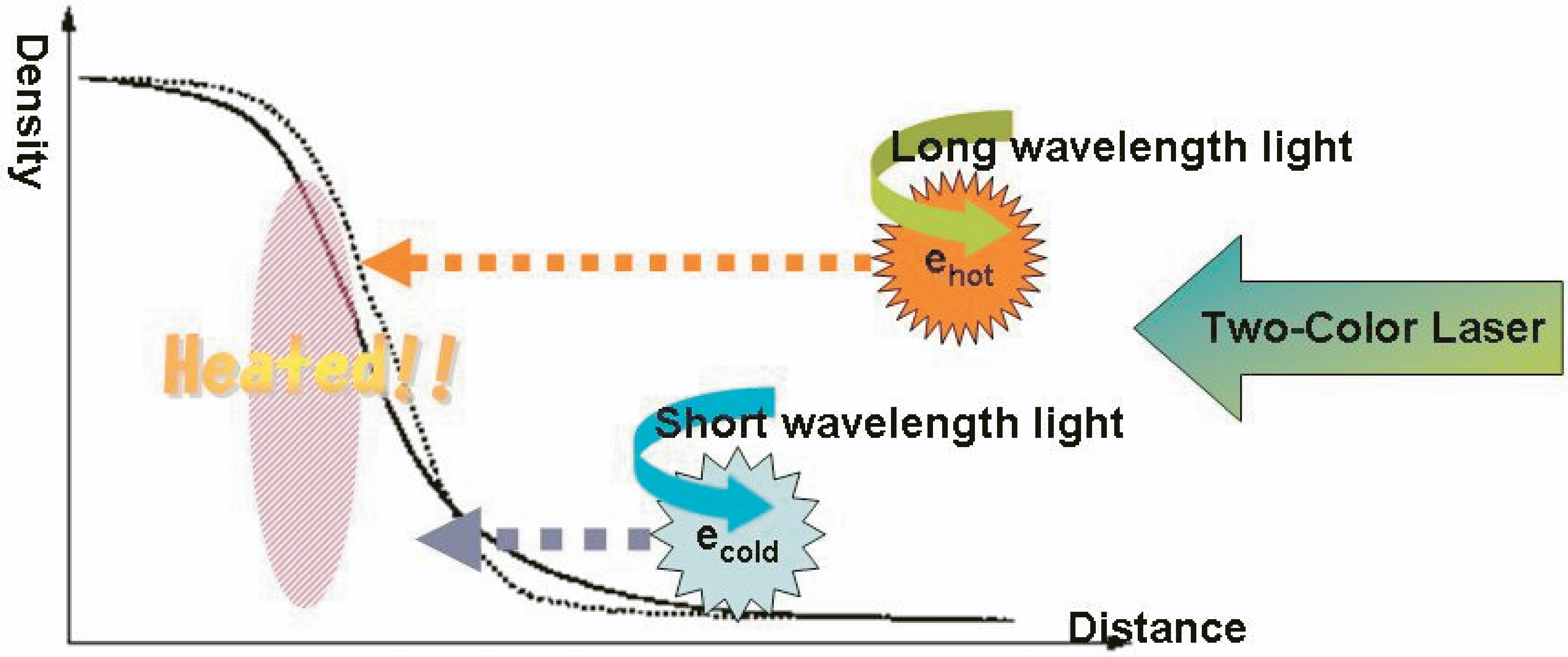




Non-local electron heats the ablation surface and lengthen density scale length

Growth rate of Rayleigh-Taylor instability

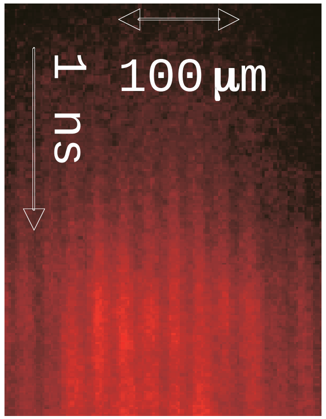
$$\gamma = \sqrt{\frac{kg}{1+kL}} - \beta k v_a \qquad \left(v_a = \frac{\dot{m}}{\rho_a} \right)$$

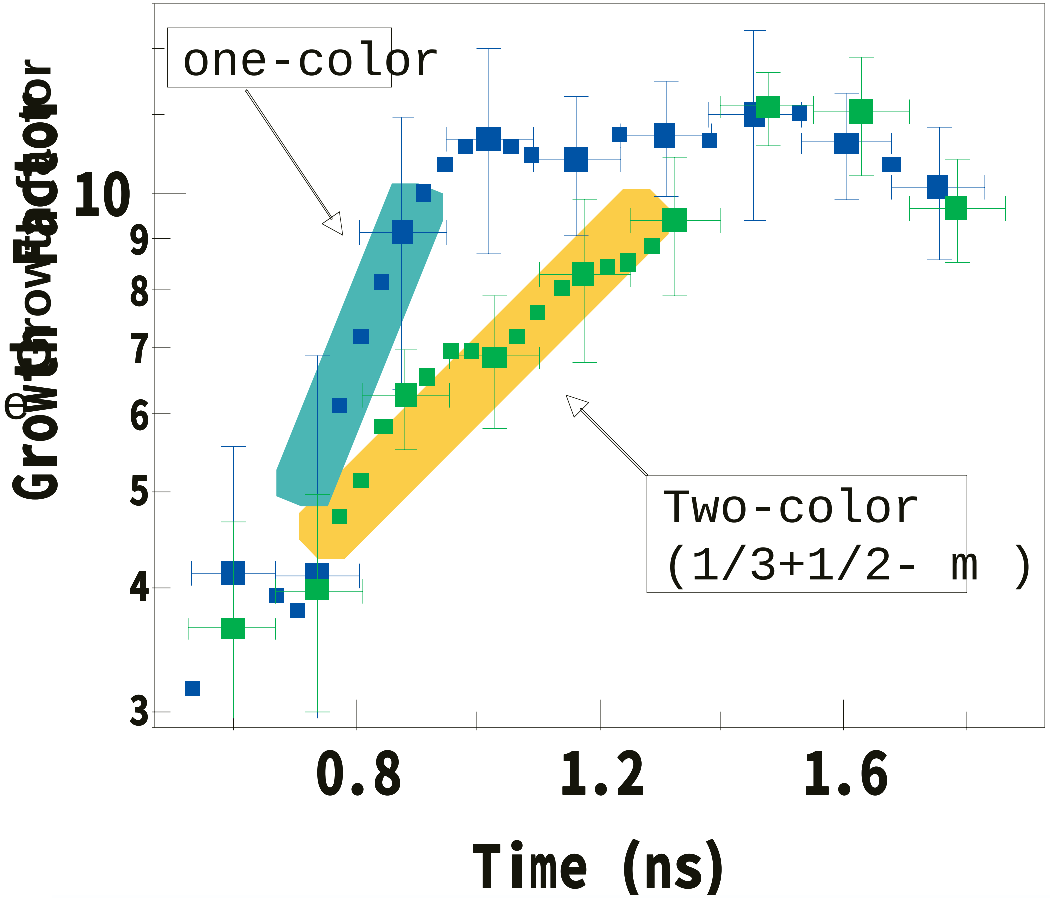


Dotted line: Single-color (short wavelength) density profile
Solid line: Multi-color density profile

Rayleigh-Taylgrowth rate is reduced by two-color laser irradiation.

Streaked image





■ : Single-color (λ= 1/3 µm) irradiation

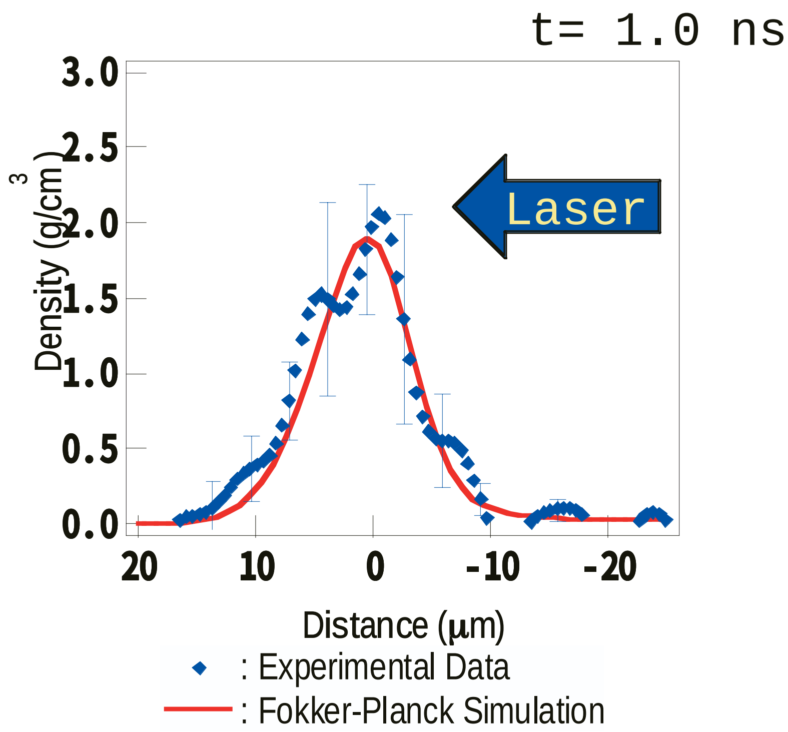
■ : Two-colors (λ= 1/3 and 1/2 µm) irradiation

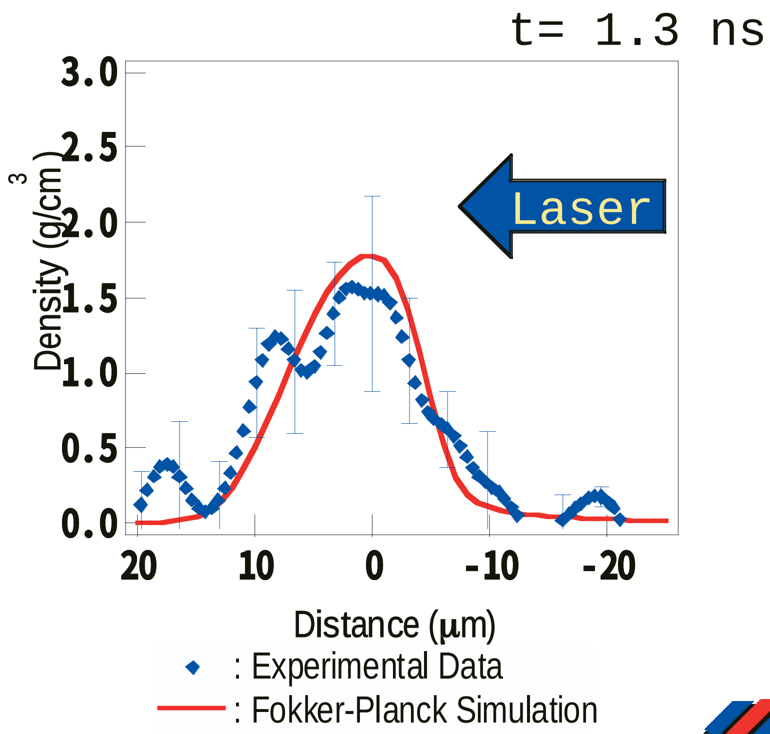
Multi-color irradiation sustains the peak d of the ablating target

The density profile of laser-driven polystyrene

1/3µm wavelength
single-color laser irradiation

1/3µm and 1µm wavelength
two-color laser irradiation





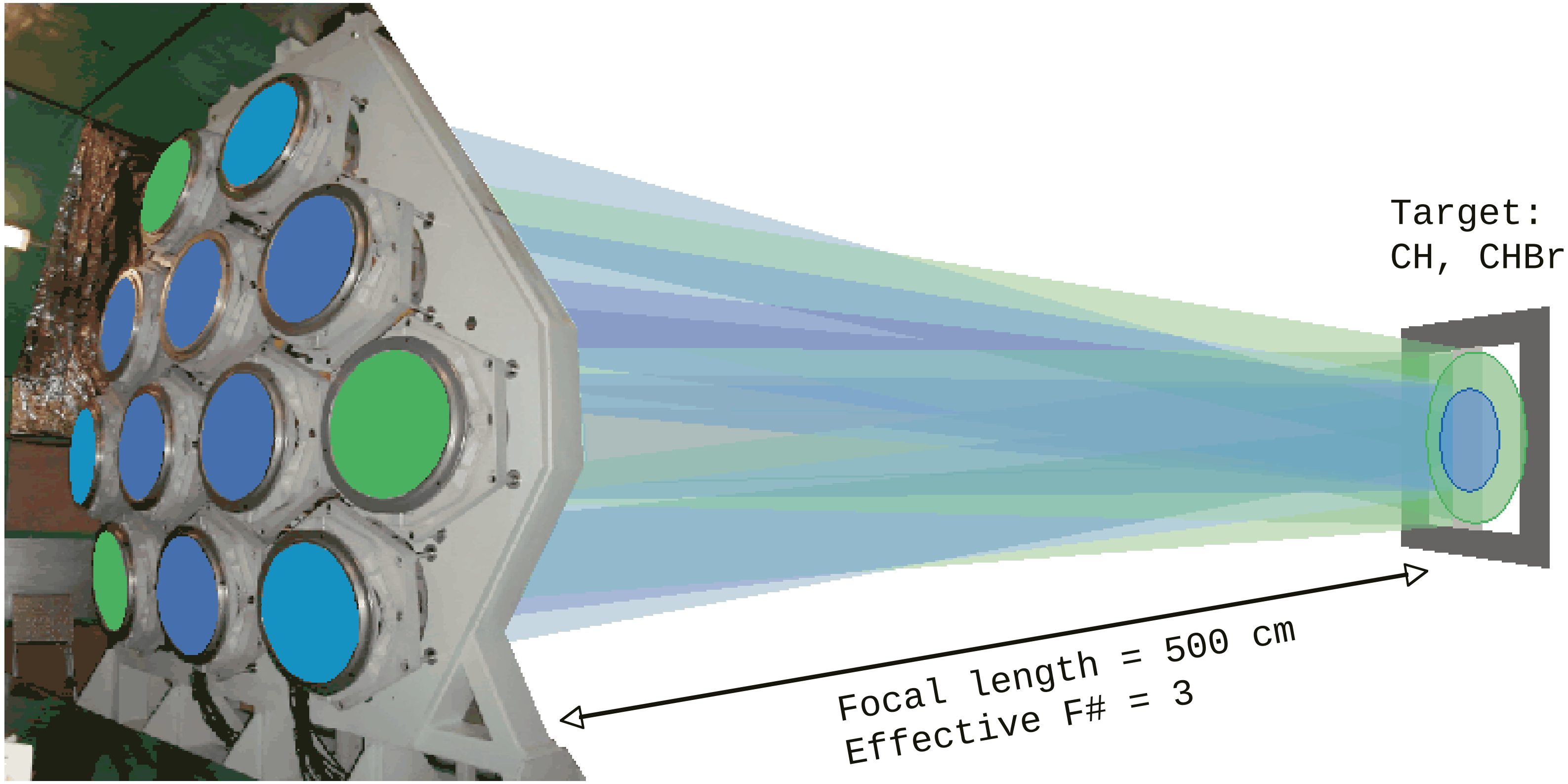
Experiments aiming at super velocity

HIPER-0.35μm and/or NIKE-0.25 μm are the facilities that can demonstrate super velocity.

HIPER

NIKE

High Intensity Plasma Experimental Research (HIPER)



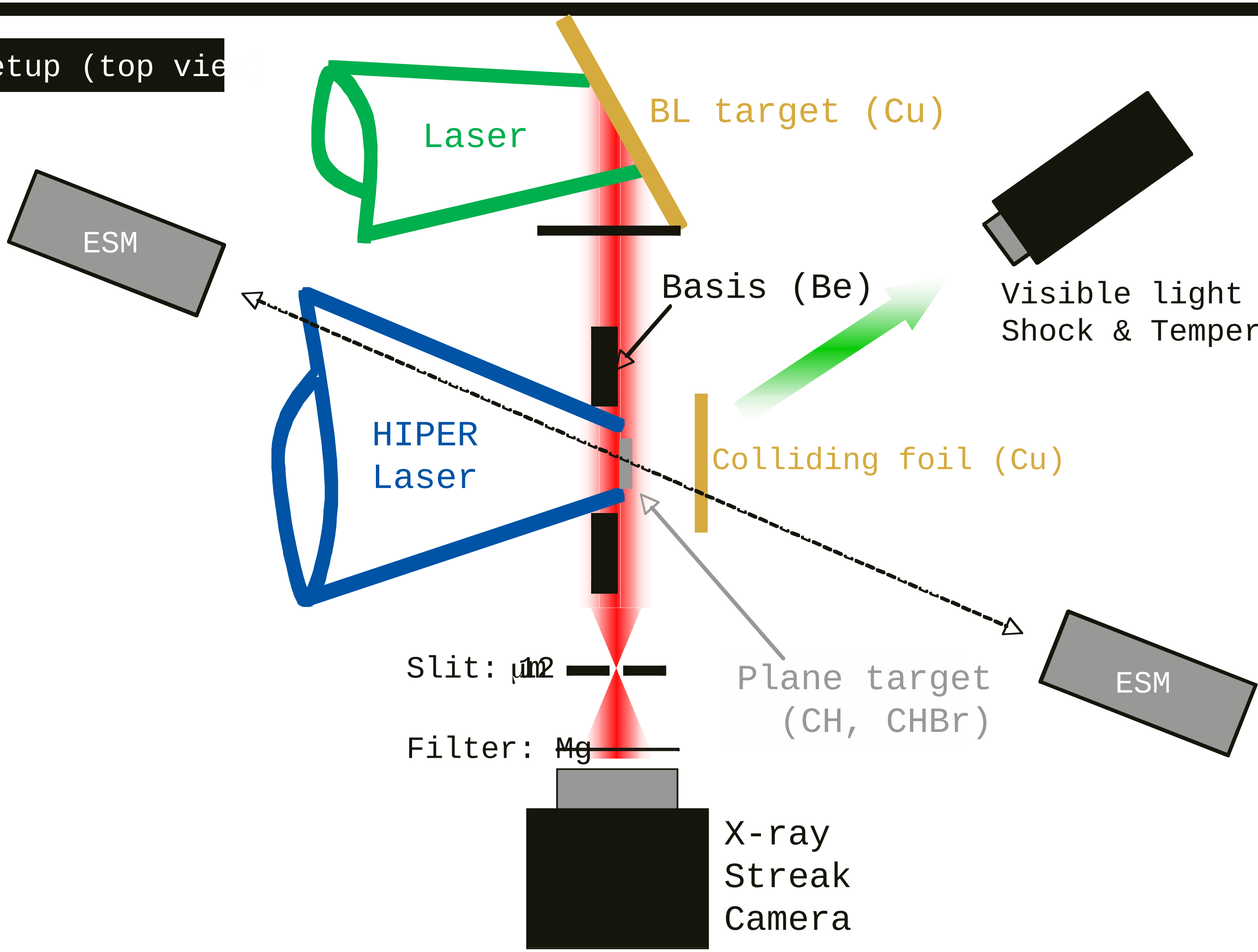
KDP

Main pulse
Wavelength: 0.35 µm (3ω)
Energy 1.5 kJ
Intensity: ~ 4×10^{14} W/cm^2
Beam smoothing: 2-D SSD+KPP

Experimental procedure

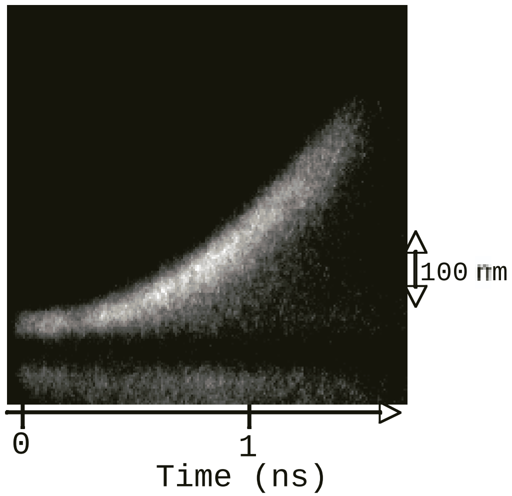
The target trajectory is measured by side-on backlighti

Setup (top vie

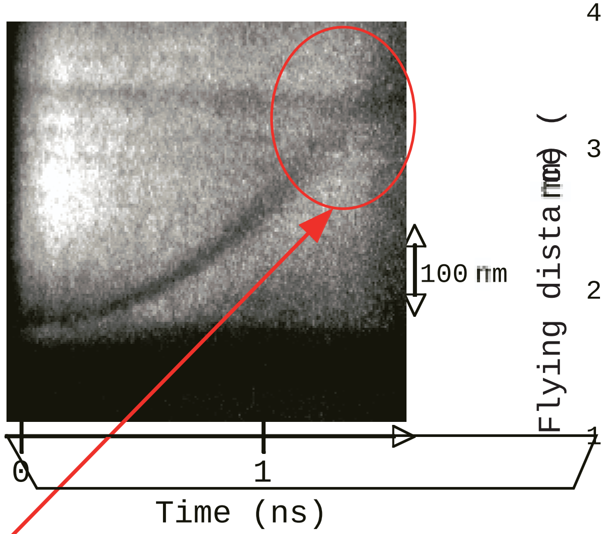


2-3 x 10^7-cm/s velocity was the limit for generic CH targets irradiated by 1/2-μm laser.

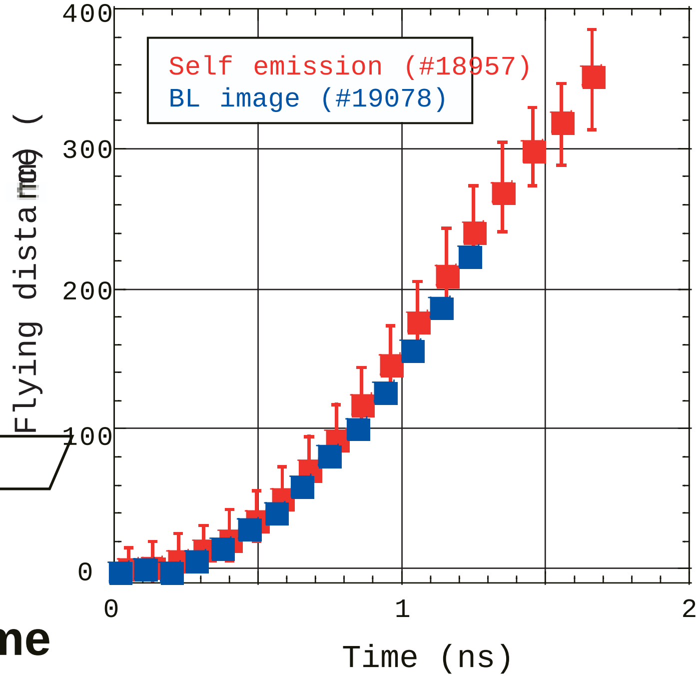
Self emission



x-ray backlighting



~10-μm CH @~10^{14} W/cm^2



Foil disassembly is observed at late time

10^8 cm/s-velocity must be achieve, if

- **RT-reduced targets**
- **1/3-μm laser at higher irradiance .**

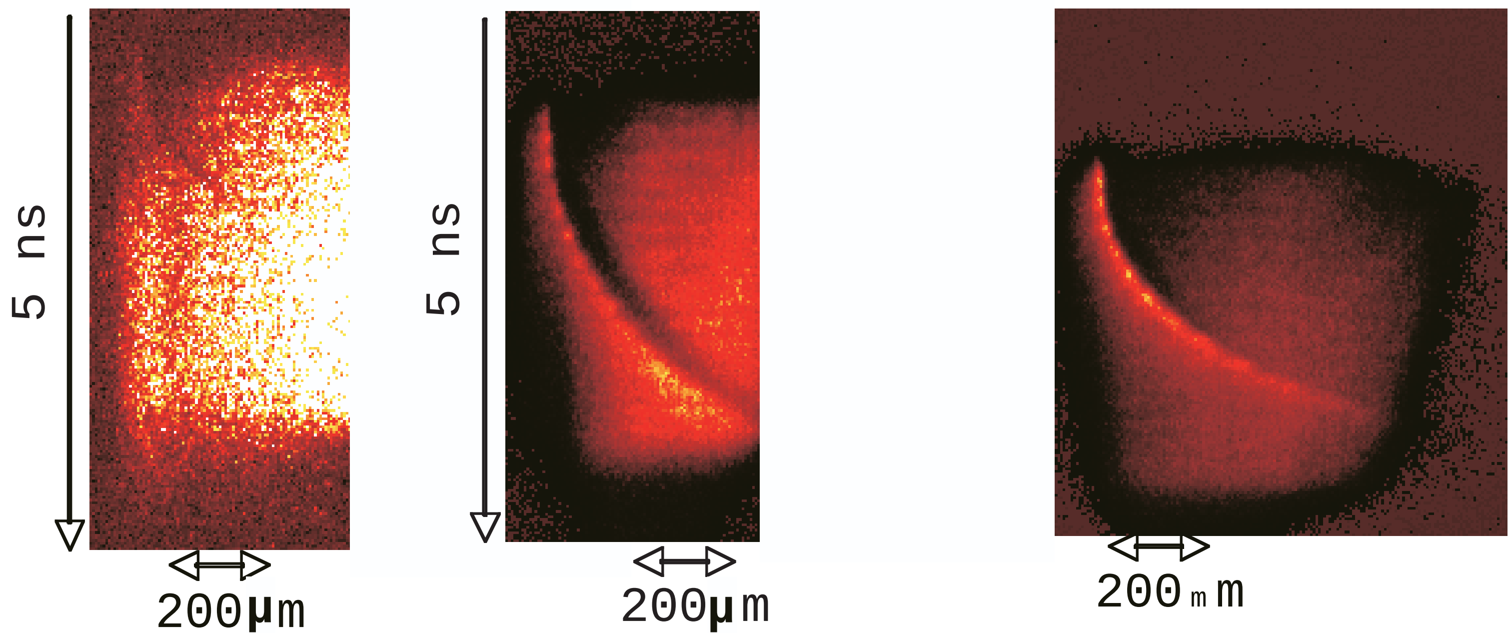
1/3-µm laser irradiation: Highest velocity of 580 km/s has been demonstrated at CHBr target.

x-ray backlighting | **Self emission**

#28864
CH 14µmt

#28865
CHBr 14µm t

#28872
CHBr 14µmt

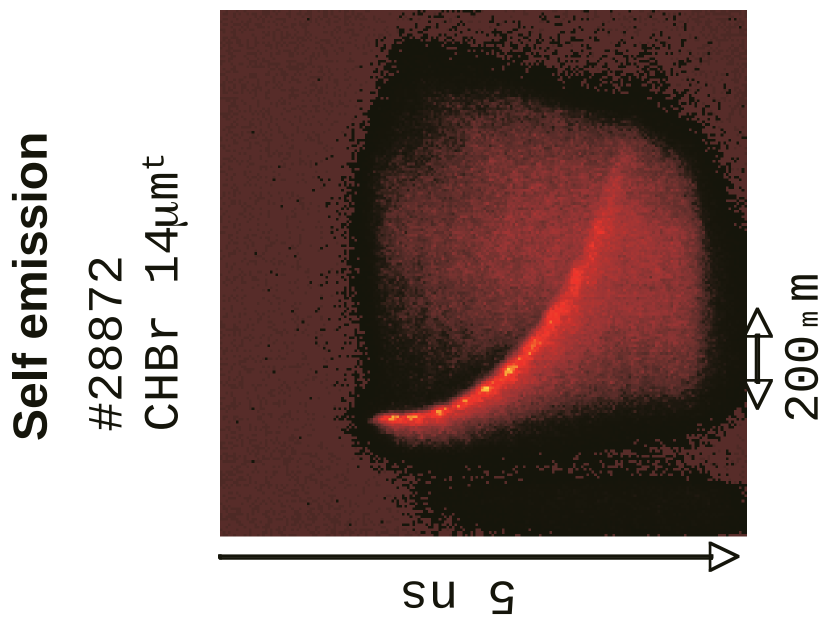


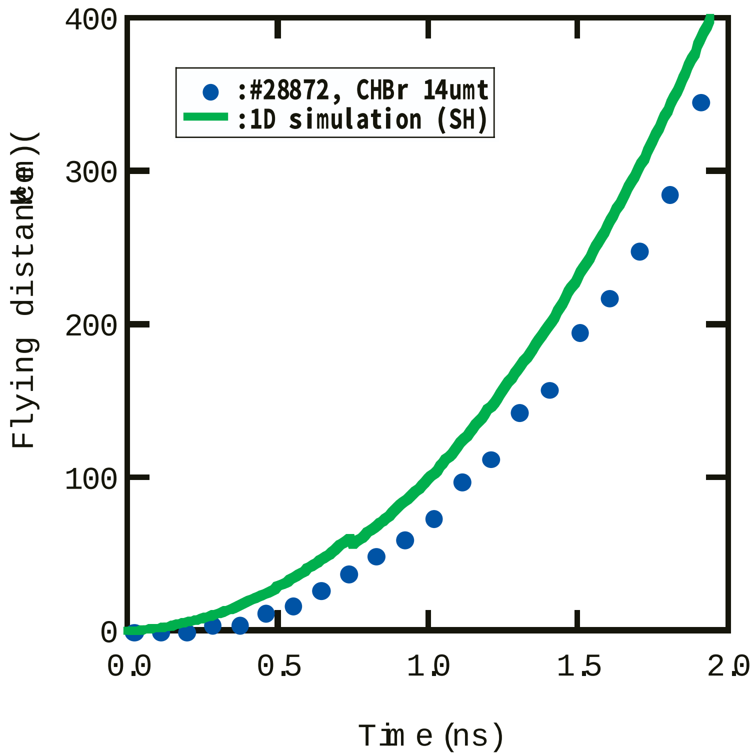
$I_L \approx 2\text{x}10^{14}$ W/cm^2

$I_L \approx 4\text{x}10^{14}$ W/cm^2

Periodic intensity variation is due to diagnostics

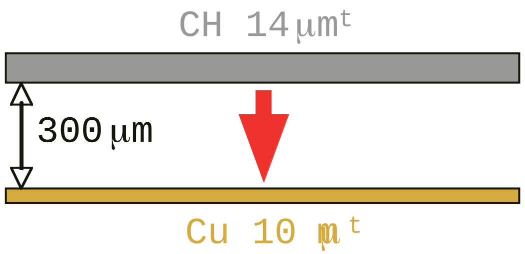
CHBr trajectory indicates 580 km/s velocity with slightly lower acceleration than prediction.



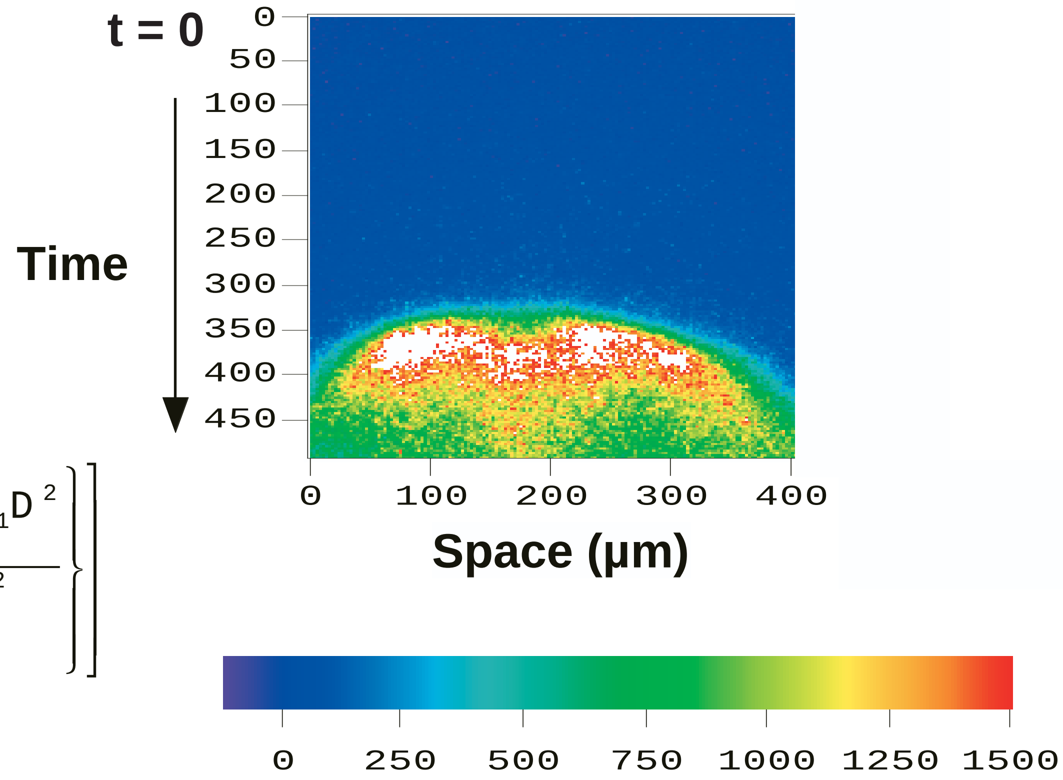


Future experiments

1. Inflight target density should be measured.



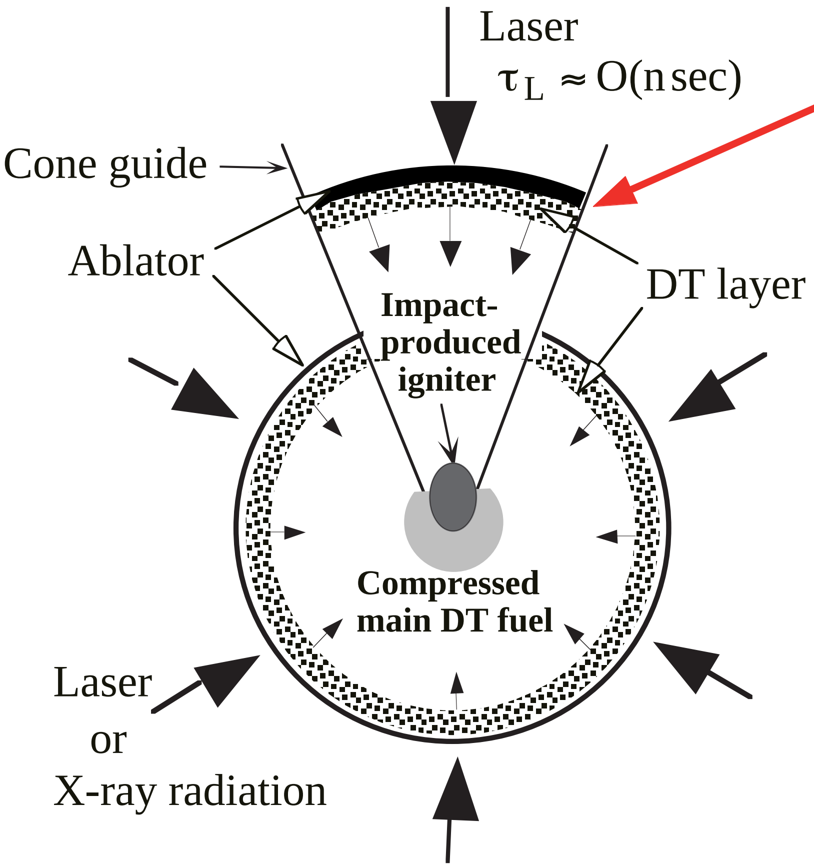
$$\rho_2 = \frac{\left(\frac{2}{\gamma+1}\cdot\rho_1 D^2 - p_2\right)}{\left(\frac{2}{\gamma+1}\cdot D - V\right)^2}\cdot\left[1-\left\{\frac{(\gamma+1)p_2+\frac{\gamma-1}{\gamma+1}\cdot 2\rho_1 D^2}{(\gamma-1)p_2+2\rho_1 D^2}\right\}\right]$$



Target density is determined from
D: shock velocity
V: flyer velocity

Test of diagnostics indicates reasonablly good uniformity.

Second critical element



Effective friction
cone expansion

dragging shell

Energy transmittance through a cone should be demonstrated.


With minor modification of FIREX-I,
We may perform integrated experiment.
FIREX-I
GEKKO-XII

summary

- Suppression of the Rayleigh-Taylor instability is the key requirement for impact-fast-ignition (IFI).

- Super velocity of 1000 km/s is the critical path to IFI.
  600 km/s velocity has been demonstrated at HIPER-0.35 μm experiments.

In future:

- Density data and faster velocity will be taken in the coming Jan. exp't.

- Energy transmittance through a cone will also be measured.

- Integrated exp't can be performed with minor modification of FIREX-I laser.

New concepts have been generated every 10 years.

5. Early 00's: Impact ig.? | Hot-ele based ig.

4. Mid 80's-90's: Fast ig. | Central ig.

3. Late 70's: Hot spark ignition | Volume ig.

2. Early 70's: Implosion

1. Early 60's: Birth of laser fusion