Hydrodynamics of laser-produced high-energy-density plasma under magnetic field to open a new frontier in HEDP physics

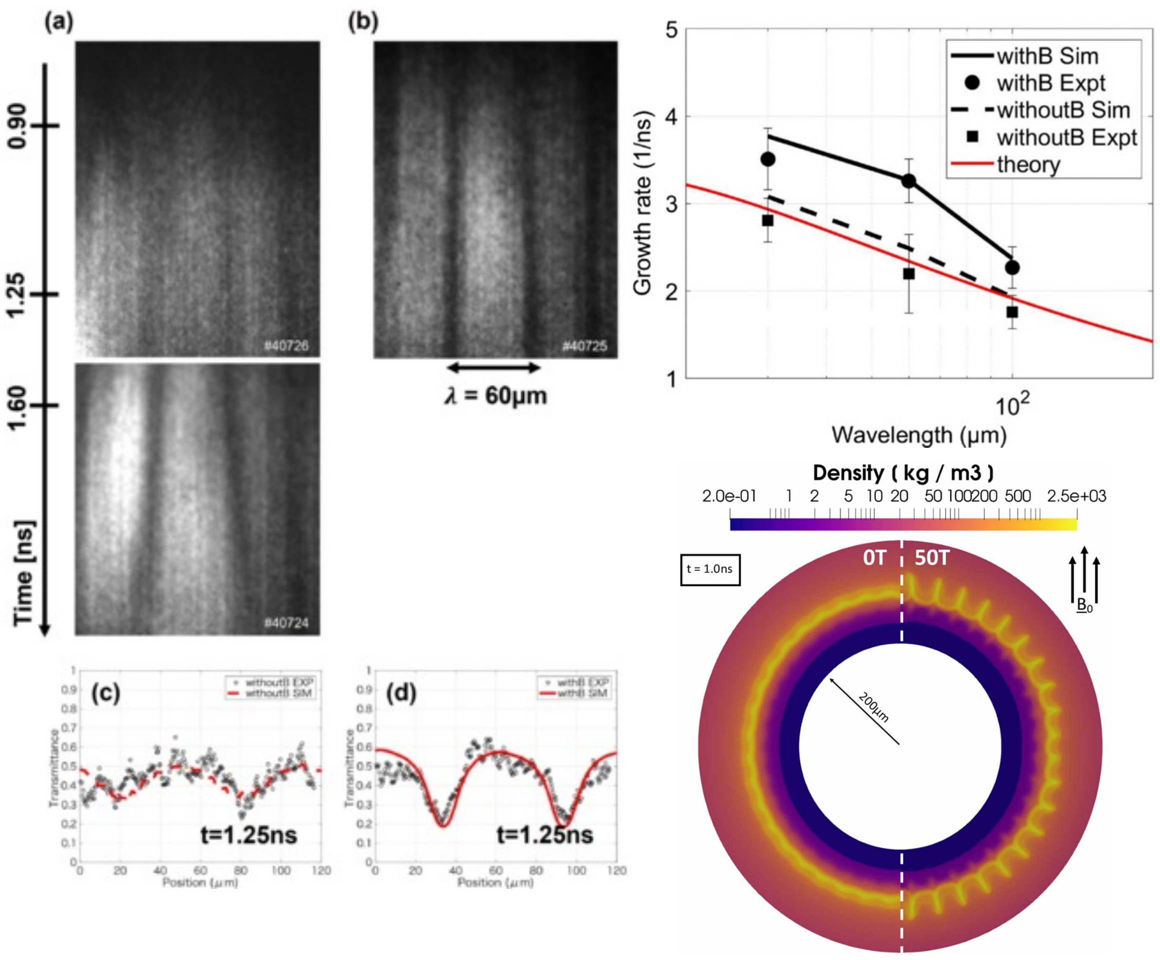
Shinsuke FUJIOKA
Institute of Laser Engineering, Osaka University
&
Philippe NICOLAI
CELIA, University of Bordeaux

J. J. Santos, Ph. Bradford, D. Raffestin, C. Vlachos (CELIA)
L. Le-Deroff, C. Rousseaux, T. Caillaud (CEA)
X. Han, R. Takizawa, K. F. F. Law (Osaka Univ.)
H. Morita (Utsunomiya Univ.)
Z. Berkson (Univ. Calfornia)

External B-field reduces uniformity of the implosion. However, B-field increase fusion performance on the NIF.

Experimental observation of enhanced growth of RT instability in external magnetic field.

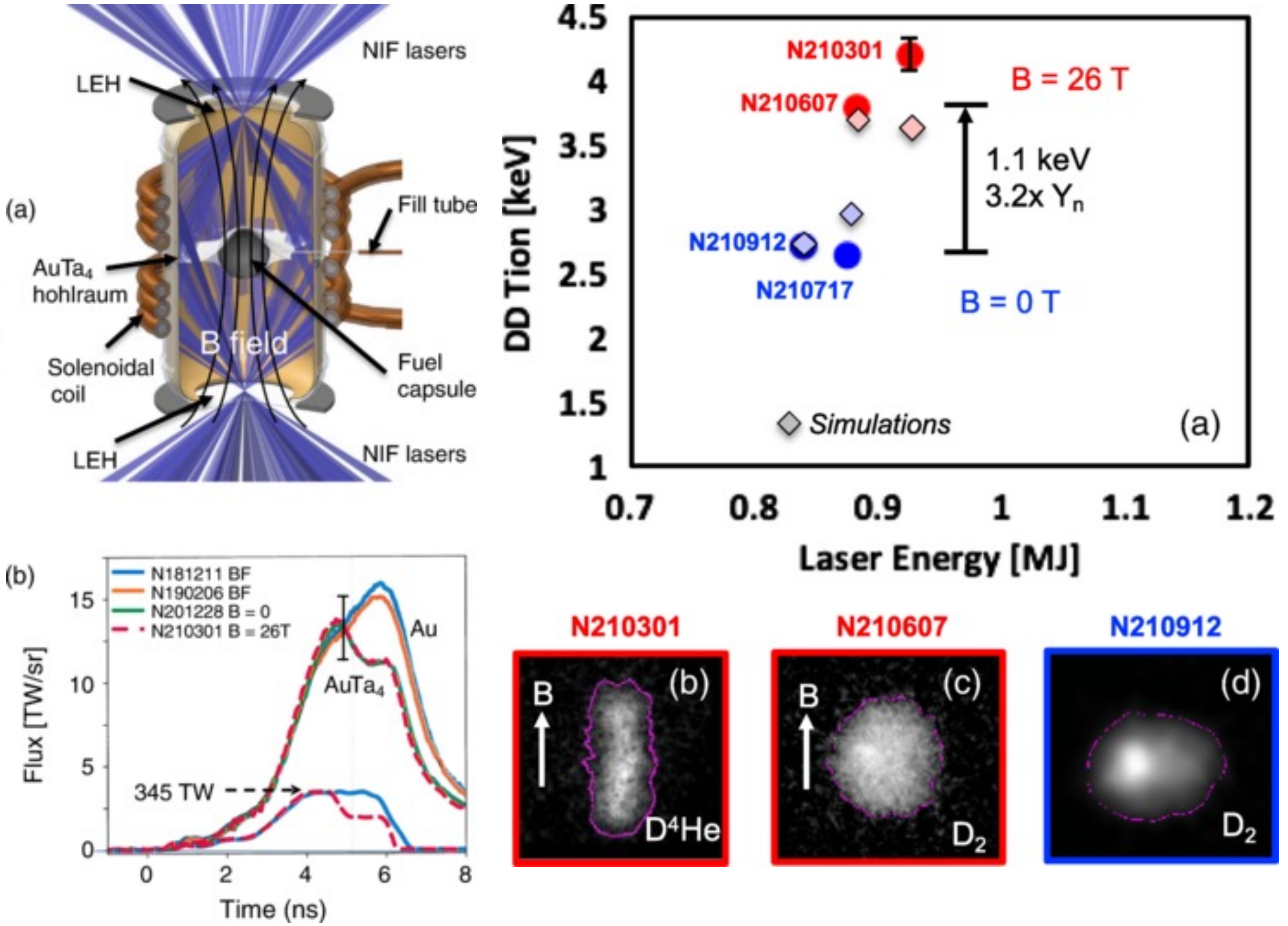
K. Matsuo, T. Sano, H. Nagatomo, ..., **S. Fujioka** *et al.*, PRL 127, 165001 (2021).



Reference: C. Walsh *et al.*, PPCF (2020).

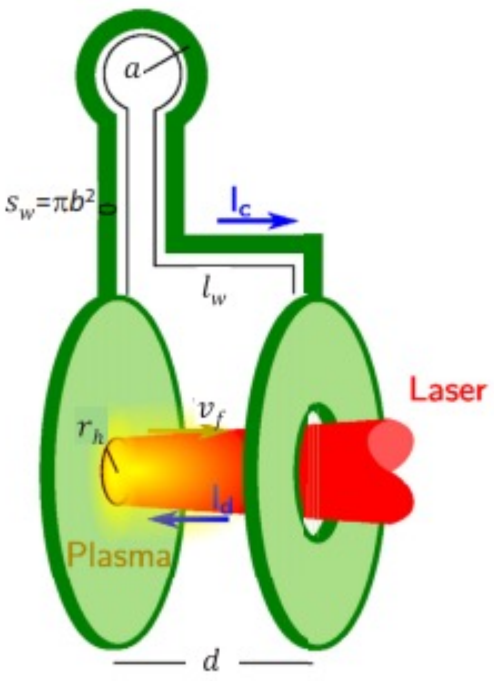
Integrated implosion experiment of external B-field assisted ICF concept on NIF

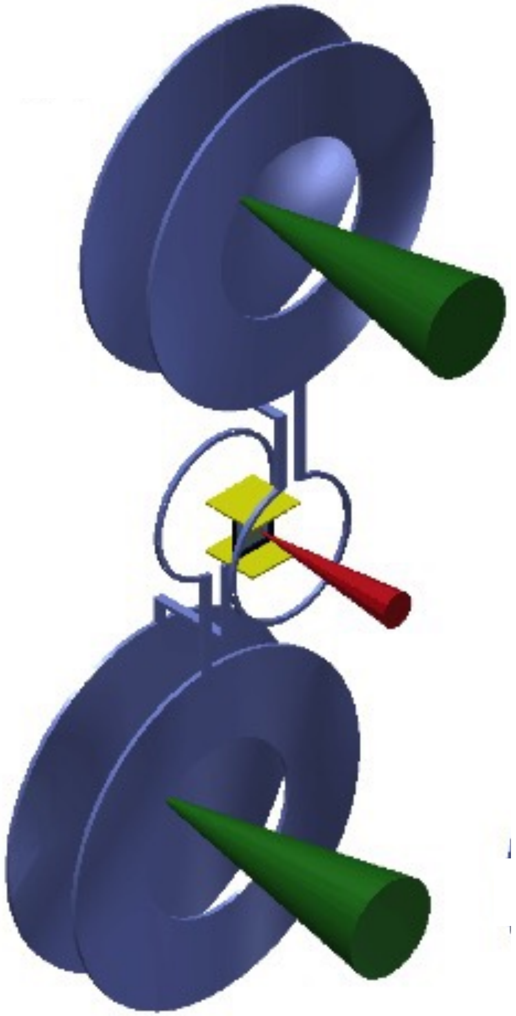
J. D. Moody, B. B. Pollock, H. Sio, ..., **S. Fujioka** *et al.*, PRL 129, 195002 (2022).



Principles of the capacitor coil target for magnetic field generation

Tikhonchuk et al, 2017

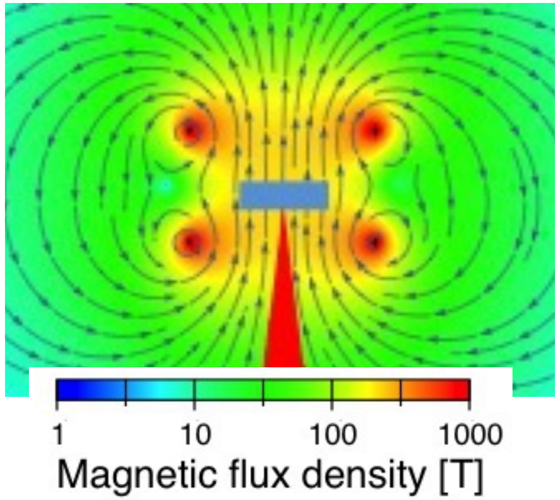




The electron ejection induces a current in the coil, generating of a magnetic field

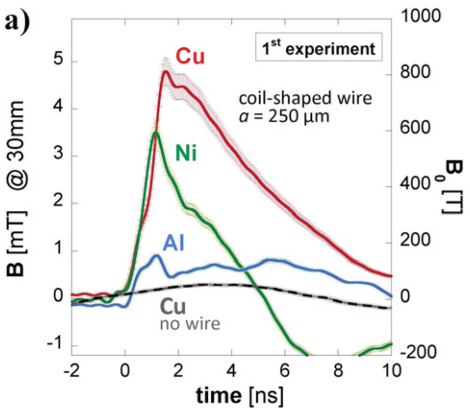
Two capacitor coils allow a homogeneous magnetic field

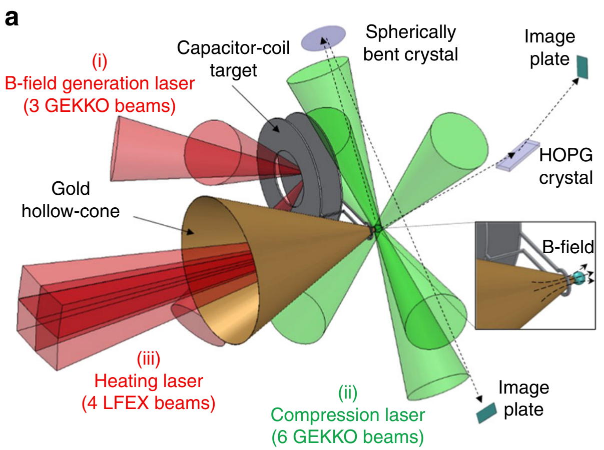
Open geometry but the laser spot has to be smaller than the coil diameter

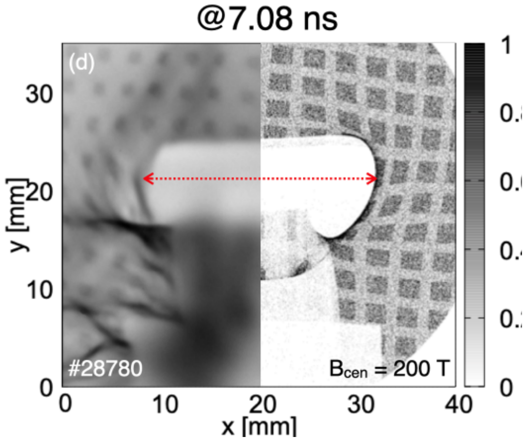


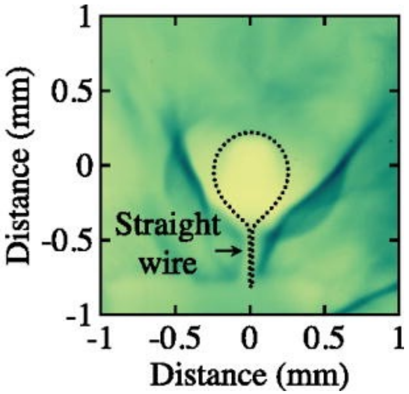
Magnetized hydrodynamic instability experiment on Mega-joule facility is a new regime of high-energy-density physics.

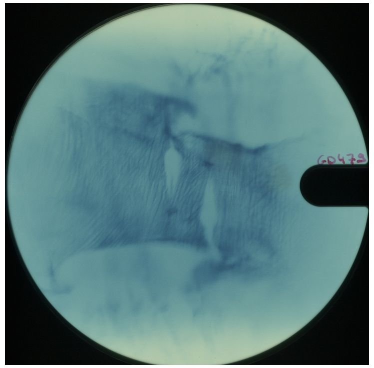
Santos *et al.*,	Sakata *et al.*,	Morita *et al.*,	Lan et al.,	Fujioka *et al.*,
At LULI2000	At GEKKO-LFEX	At OMEGA-EP	At OMEGA	At LMJ
E_L = 500 kJ	E_L = 1.8 kJ	E_L = 5.0 kJ	E_L = 1.3 kJ	E_L = 12 kJ
l_L = 1.054 μm	l_L = 1.054 μm	l_L = 0.351 μm	l_L = 0.351 μm	l_L = 0.351 μm
t_L = 1 ns (flat-top)	t_L = 1.2 ns (Gaussian)	t_L = 10 ns (Flattop)	t_L = 1 ns (Flattop)	t_L = 3 ns (Flattop)









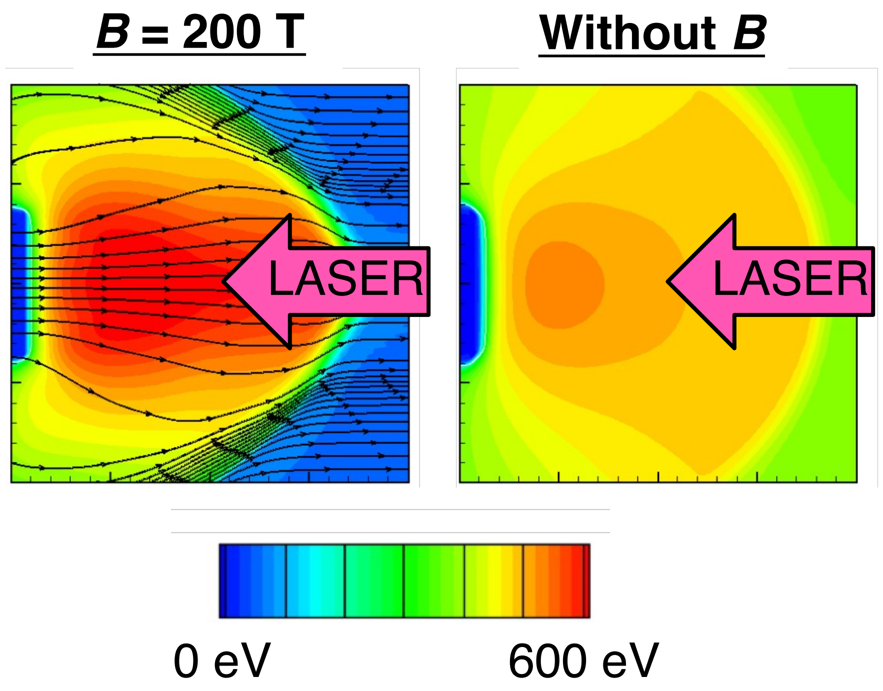


800 T@peak	600 T@peak	200 T@peak	50 T@peak	?

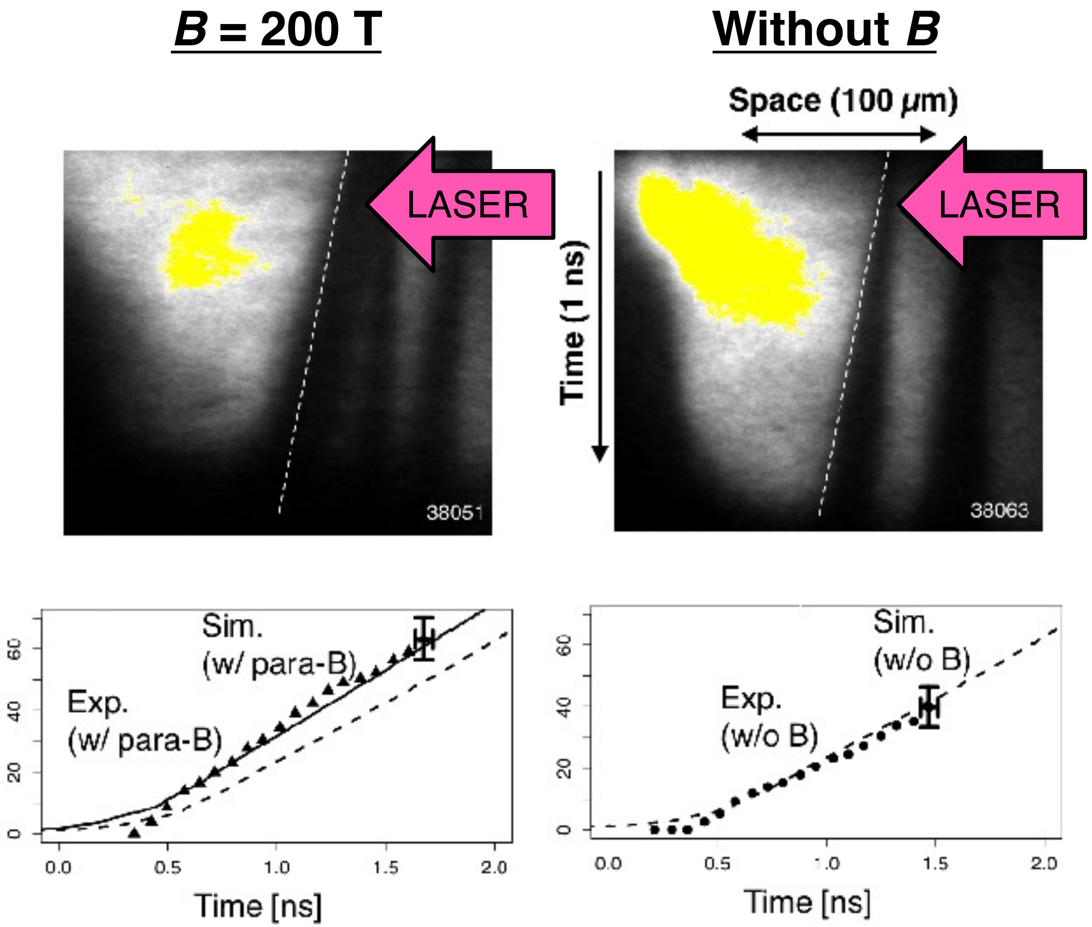
Previous result : The ablating plasma temperature increases owing to reduction of the thermal conductivity.

Electron temperature map

K. Matsuo *et al.*, Phys. Rev. E (2017).



Trajectory of the planar target



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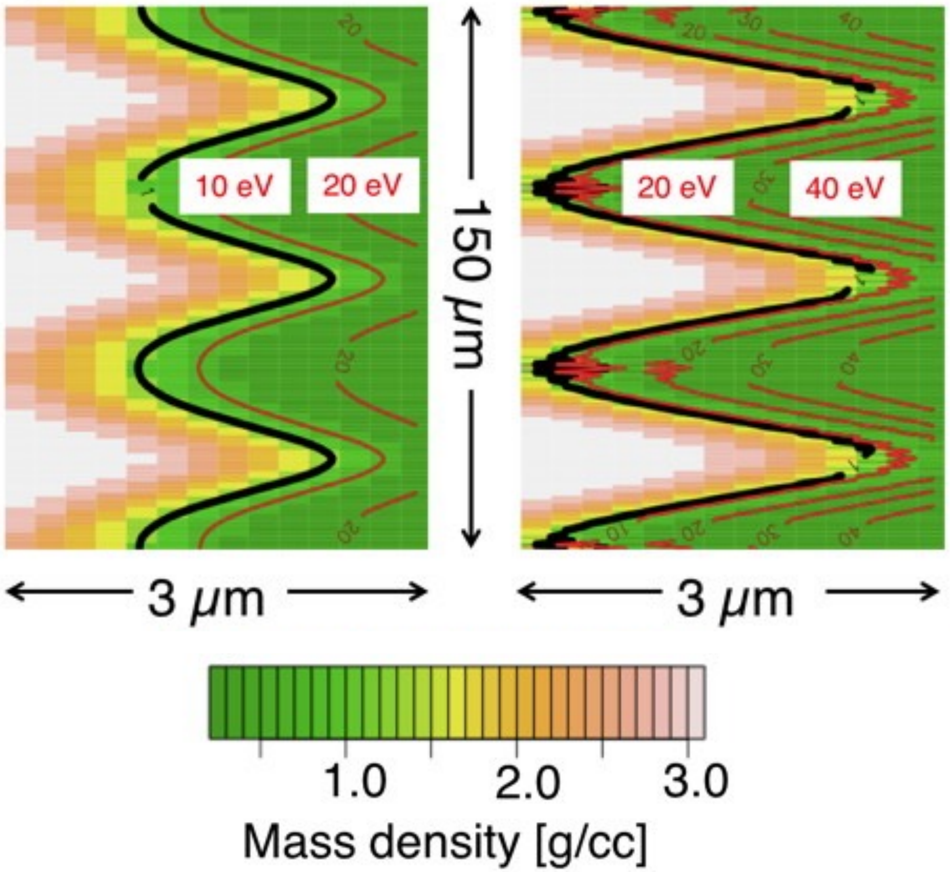
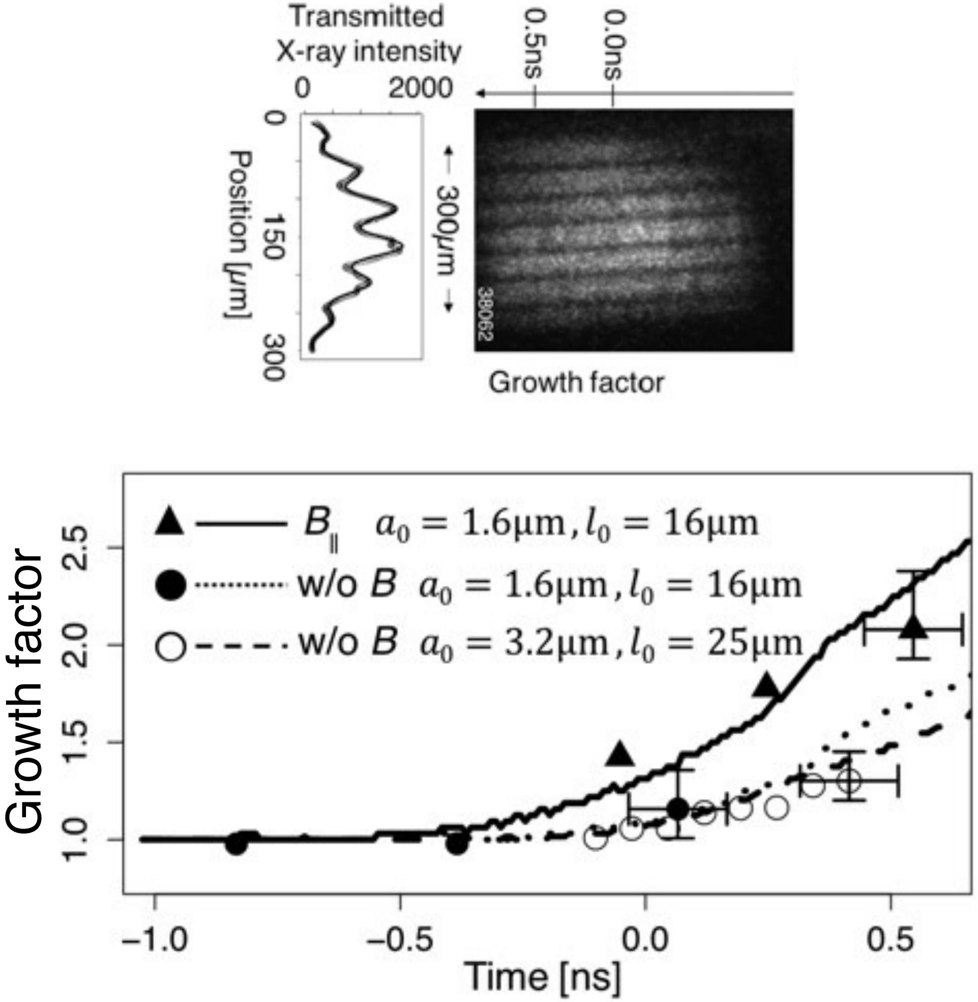
Previous result : Growth of ablative Rayleigh-Taylor(RT) instability was enhanced.

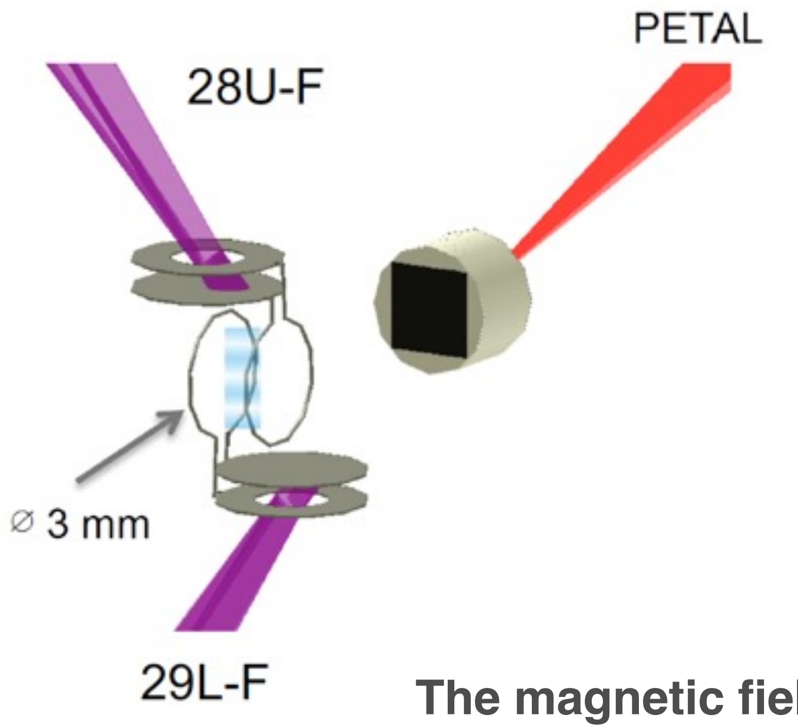
Two-dimensional density map of corrugated target

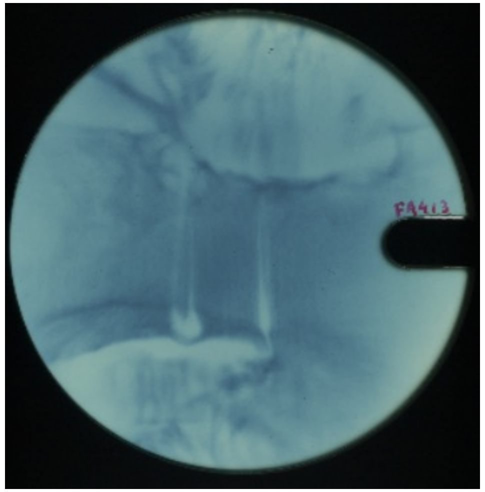


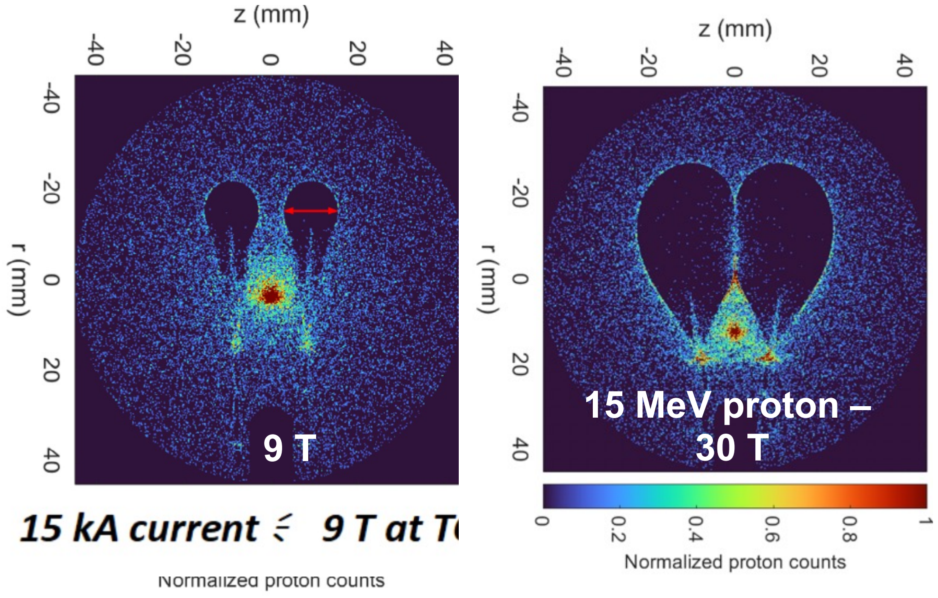
Temporal evolution of perturbation growth



In the 2022 campaign, no clear evidence of magnetic field







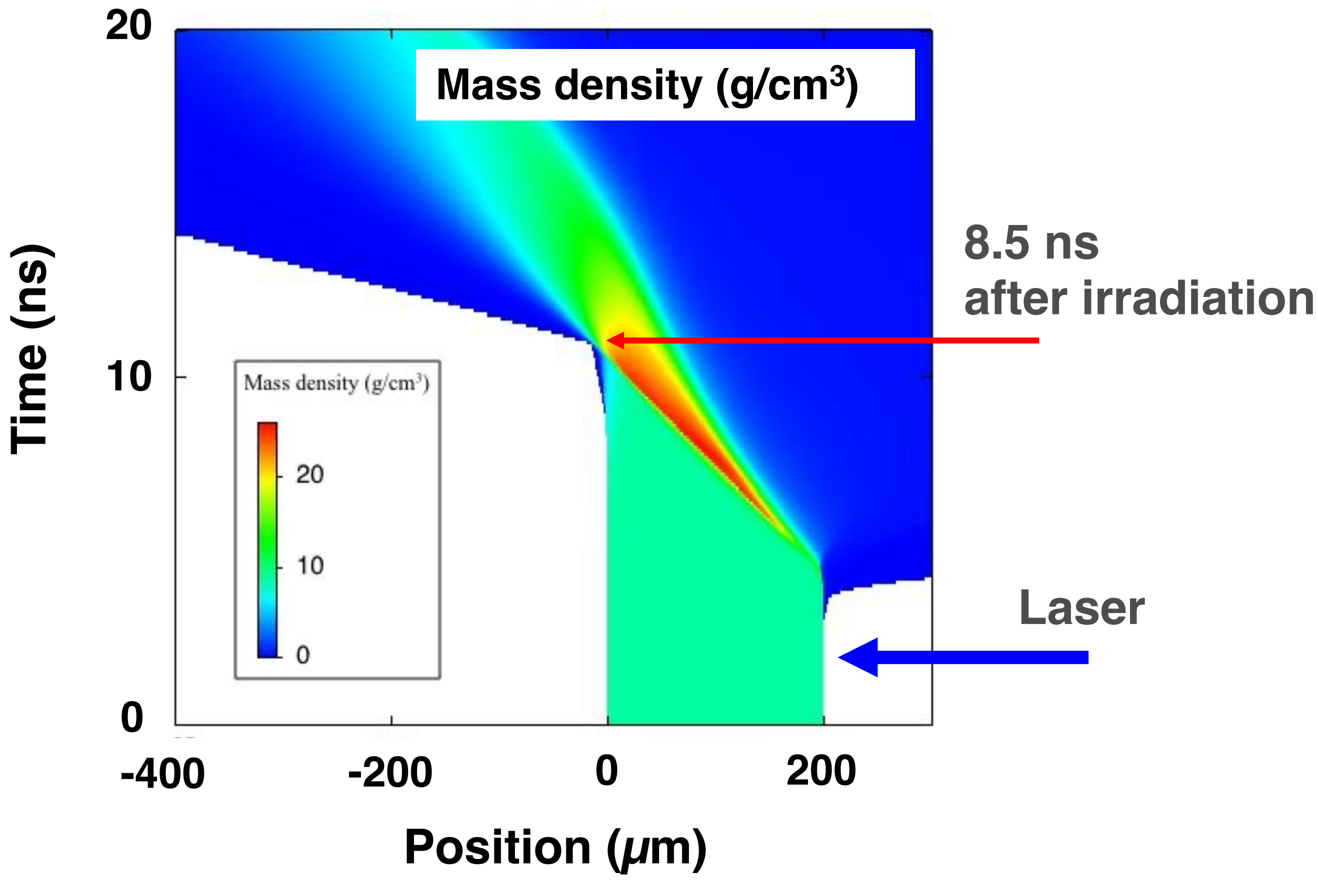
The magnetic fields have been probed thanks to the Petal driven proton beam
The characteristic shape induced by B field is not present
There is no variation as function of the proton energy

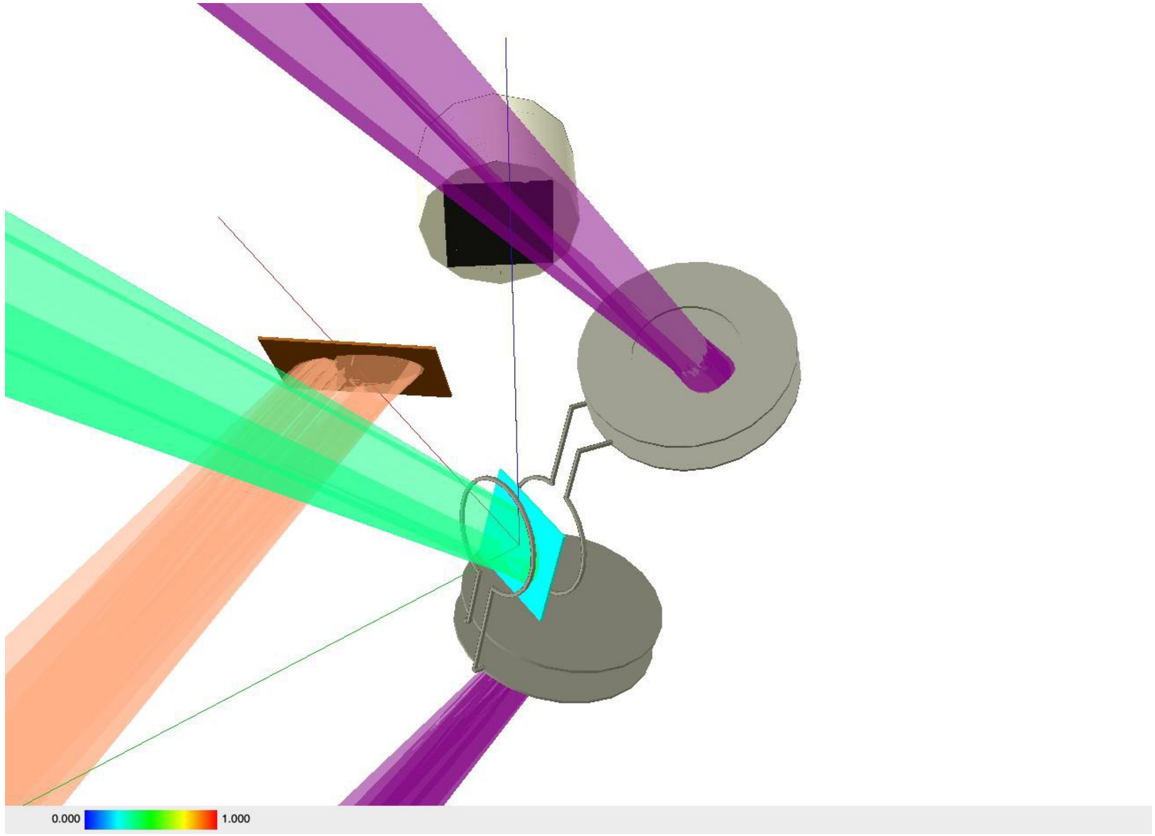
A possible destruction of the circuit induced by shock wave propagating through the disc capacitor may explain this absence of magnetic field

Based on 2022 experiment, we have changed the coil design. Thickness of foil was 200 μm, and diameter of the coil was 2.0 mm.

The foil thickness was increased from 75 microns to 200 microns to prevent the shock break out during the laser irradiation time (3 ns).

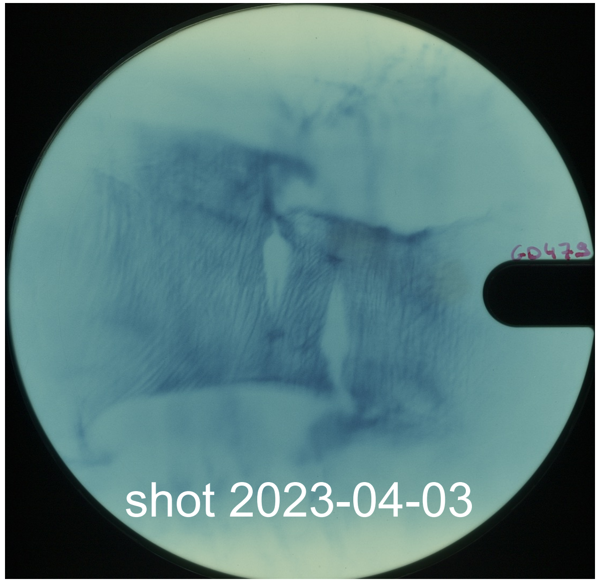
Coil diameter was reduced to 2 mm (to increase the magnetic field magnitude) and the distance between the two coils was 1 mm.



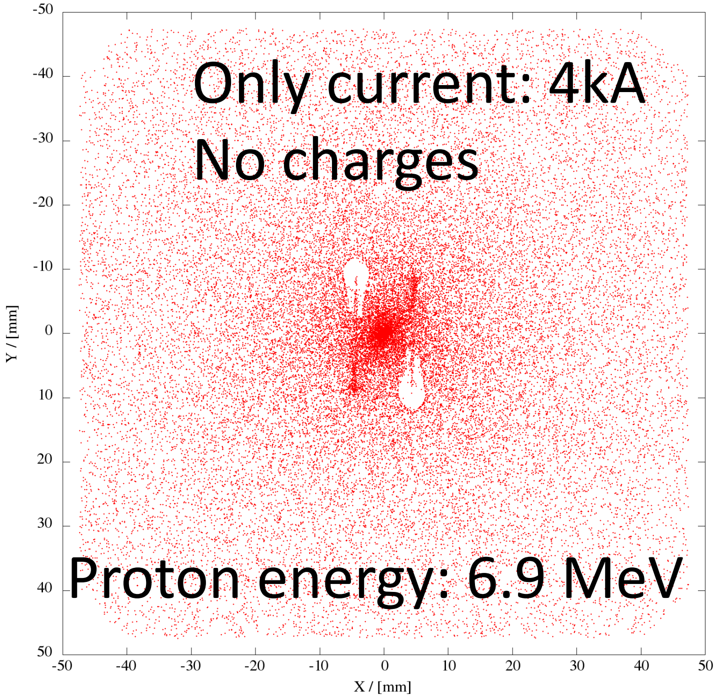


In the 2023 campaign, evidence of magnetic field presence

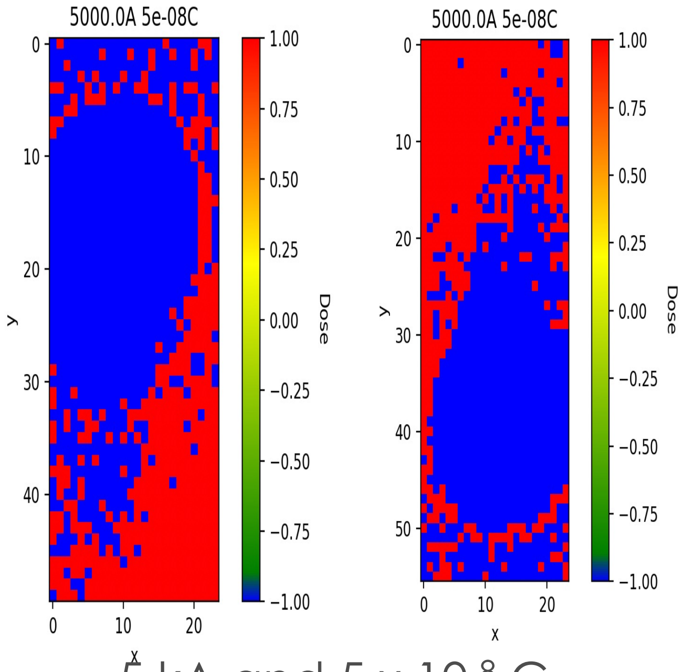
12 kJ energy on disc capacitor



Analysis by C. Vlachos
(CELIA, Univ. Bordeaux)



Analysis by Z. Berkson
(ILE, Osaka Univ.)

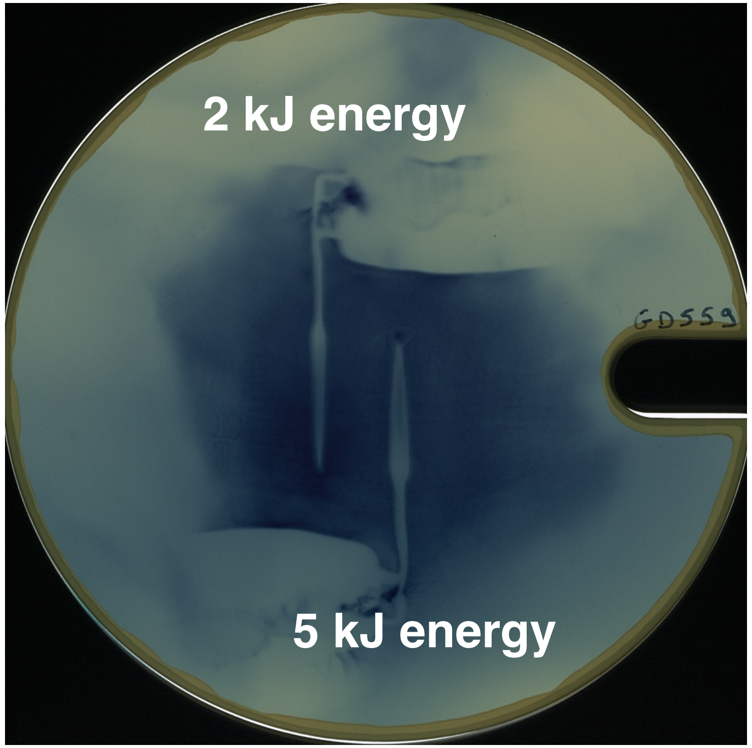


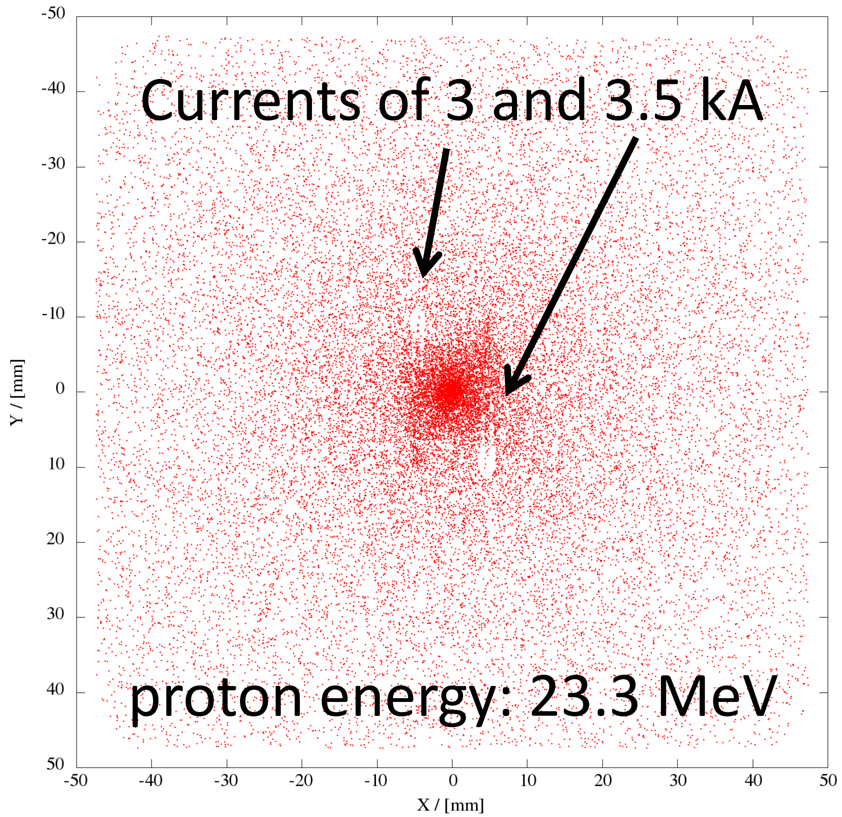
5 kA and 5 x 10^{-8} C

The characteristic shape induced by B field deflection is present (water drop)
A 4-5 kA current allows to reproduce the experimental image
This current corresponds to a maximum magnetic field magnitude of 3-4 T

The laser energy on capacitors has been reduced to go back to previous experiment conditions (Omega and Gekko lasers)

shot 2023-04-11

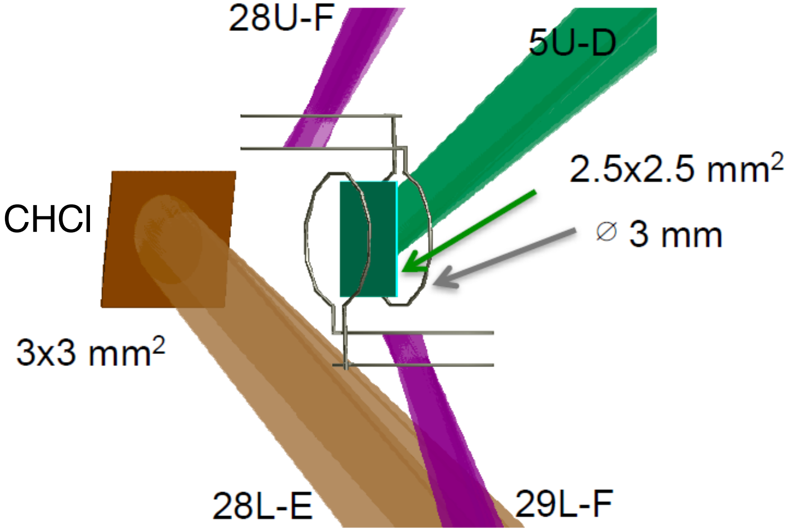




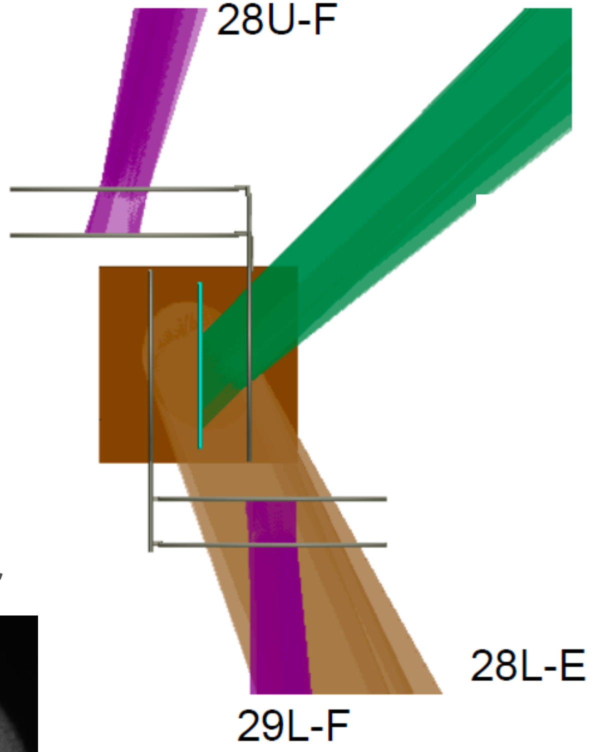
The magnetic field amplitude decreases slowly with laser energy

- **ERHXI**, x-ray imaging system **with 15 μm and 100 ps of spatial and temporal resolutions** for x-ray radiograph measurement. The edge-on radiography is used to measure a trajectory of a laser driven foil and shape of the front and rear surface perturbation of a laser-driven foil.

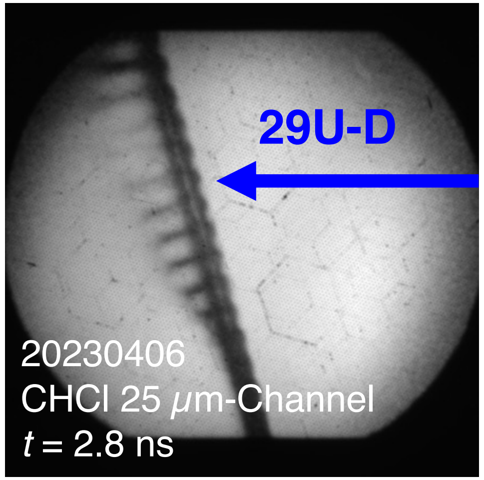
General view



SID16-GXI-1 view

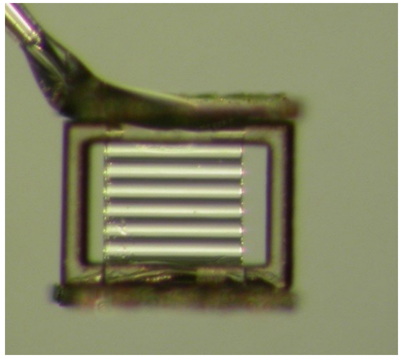


CH-Cl backlighter



perturbation wavelength
100 μm
Peak-to-valley
12 μm

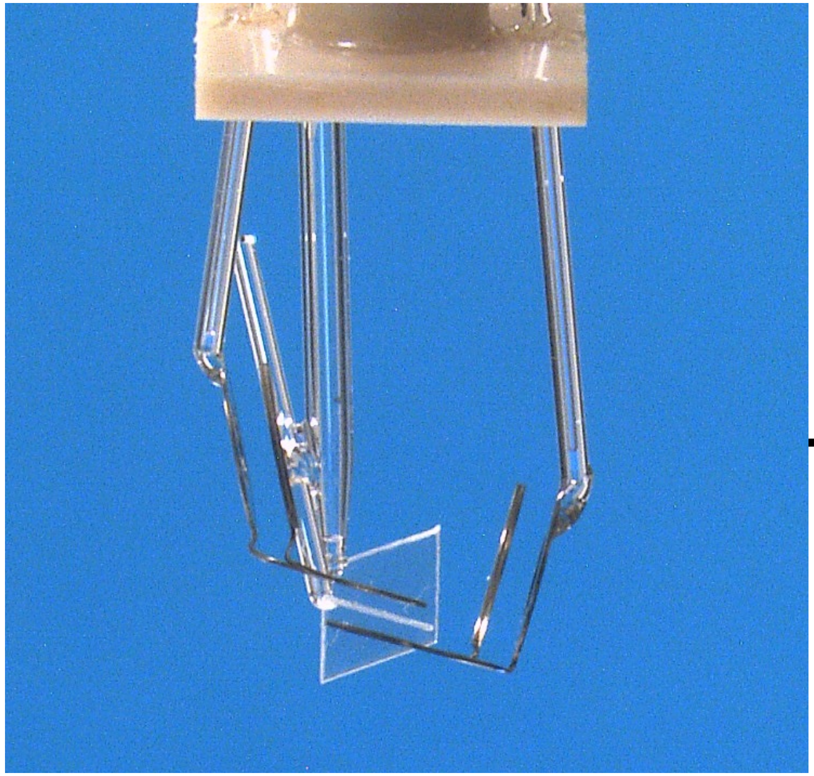
corrugated target

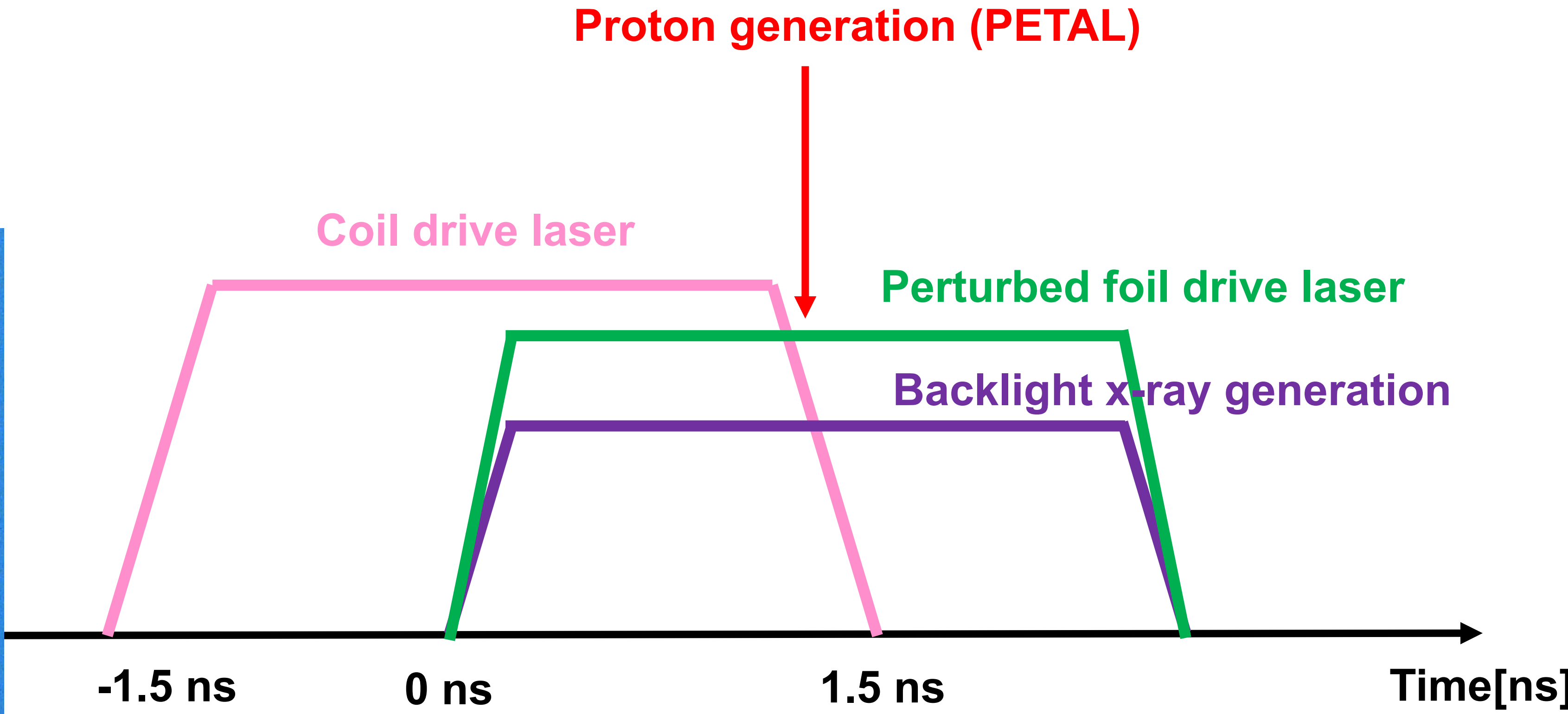


t = 0.0 ns is defined as the beginning of perturbed foil drive.
We used 4 laser groups in the experiment.

Perturbed foil

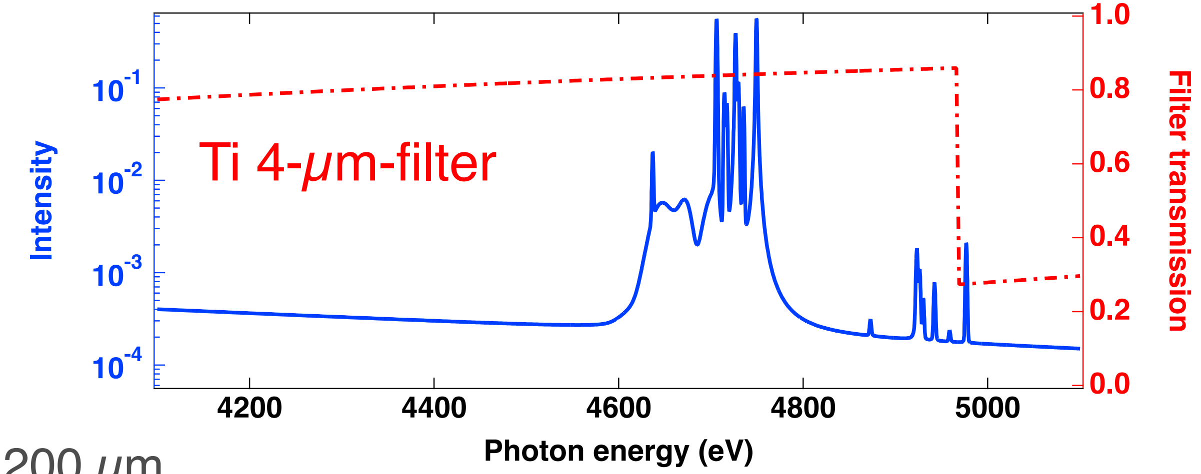
Material:	**Plastic**
Wavelength:	**100 μm**
Amplitude	**10 +/- 1 μm**
Thickness	**190 μm**



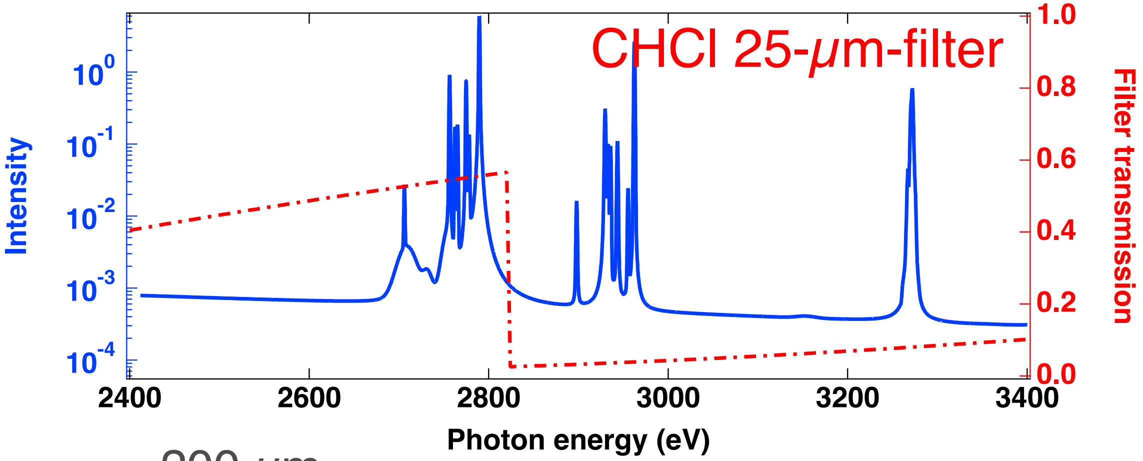


The substitution of the x-ray backlight source from Ti (2022) to CHCl (2023) and the new detector result in a significant improvement in the quality of x-ray radiography images.

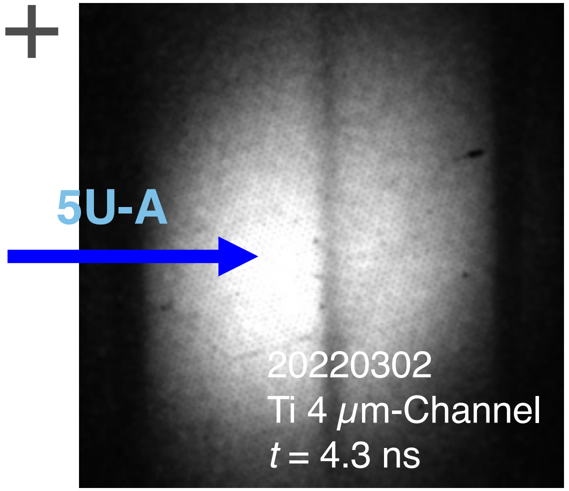
GXI-1 coupled with
Ti backlighter (2022 March)

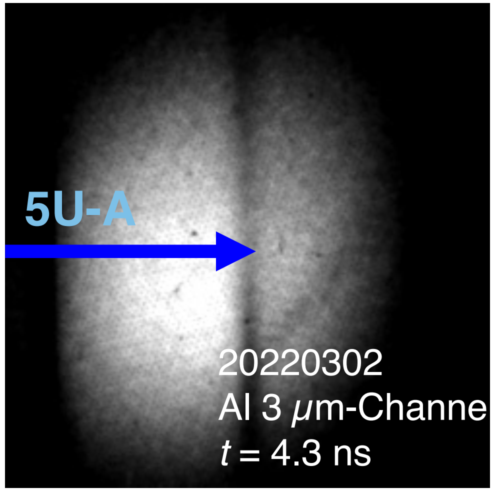


ERXHI coupled with
uPVC foils (C_2H_3Cl) backlighter (2023 April)

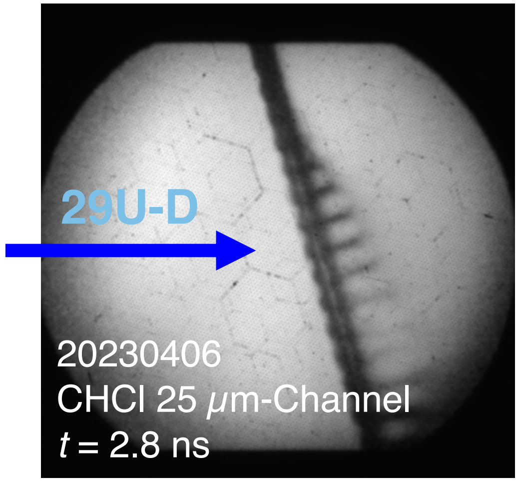


200 μm





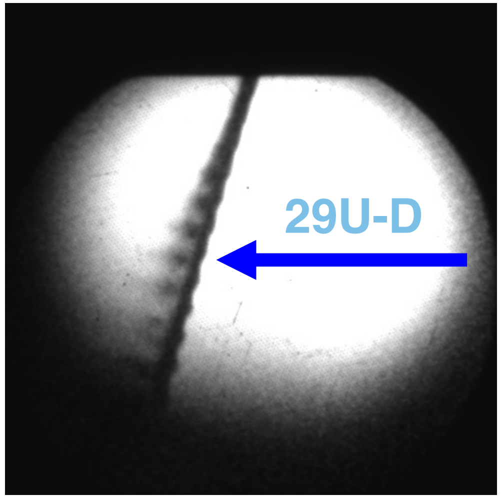
200 μm



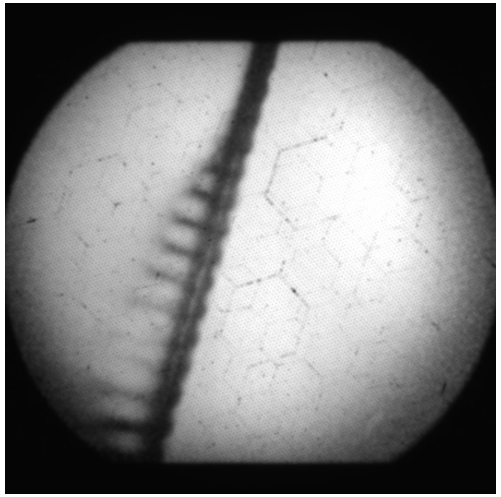
Less growth of Rayleigh-Taylor instability was found in the case without B-field application.

W/o B-field application

t = 1.3 ns



t = 2.0 ns

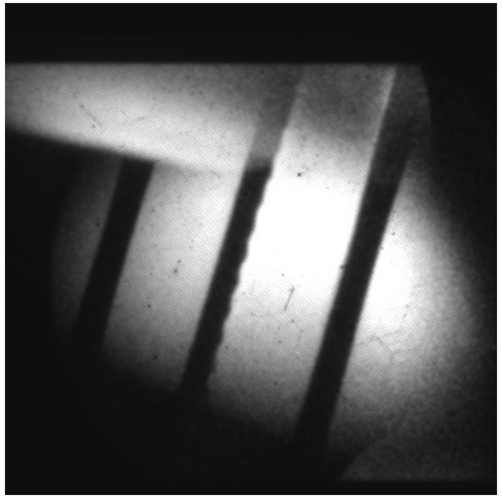


t = 2.7 ns

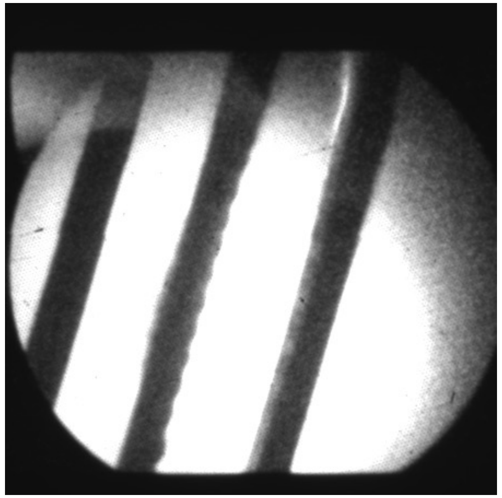
t = 3.4 ns

W/ B-field application

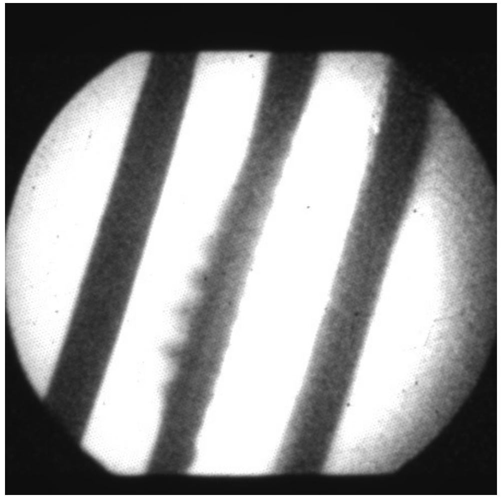
t = 0.6 ns



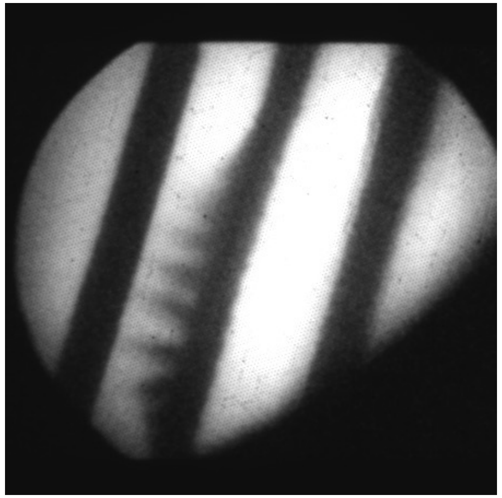
t = 1.3 ns



t = 2.0 ns



t = 2.7 ns



Significant nonlinear structures (= high aspect ratio) were found in the normal case. Irradiation of coil target suppresses the nonlinear growth significantly.

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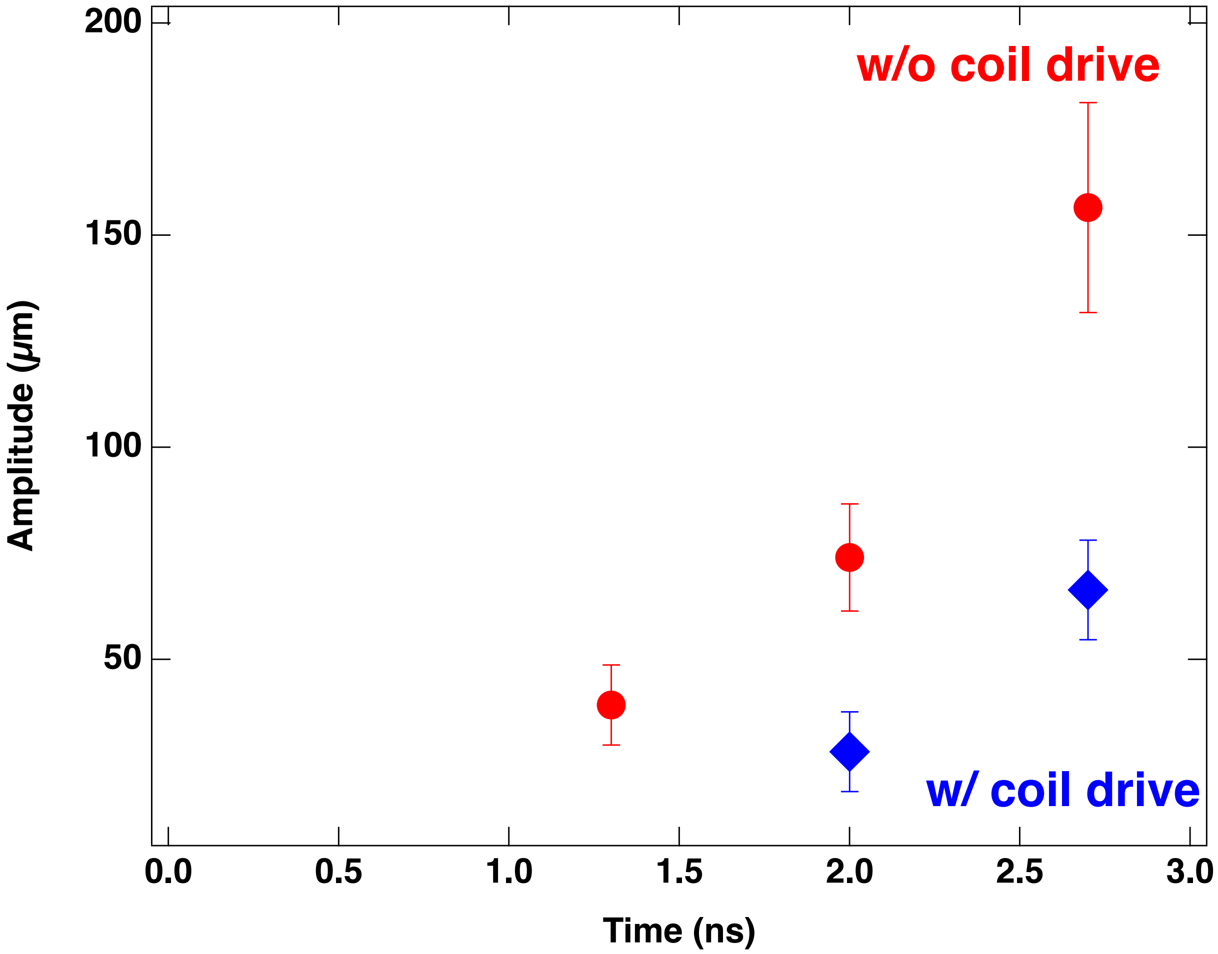
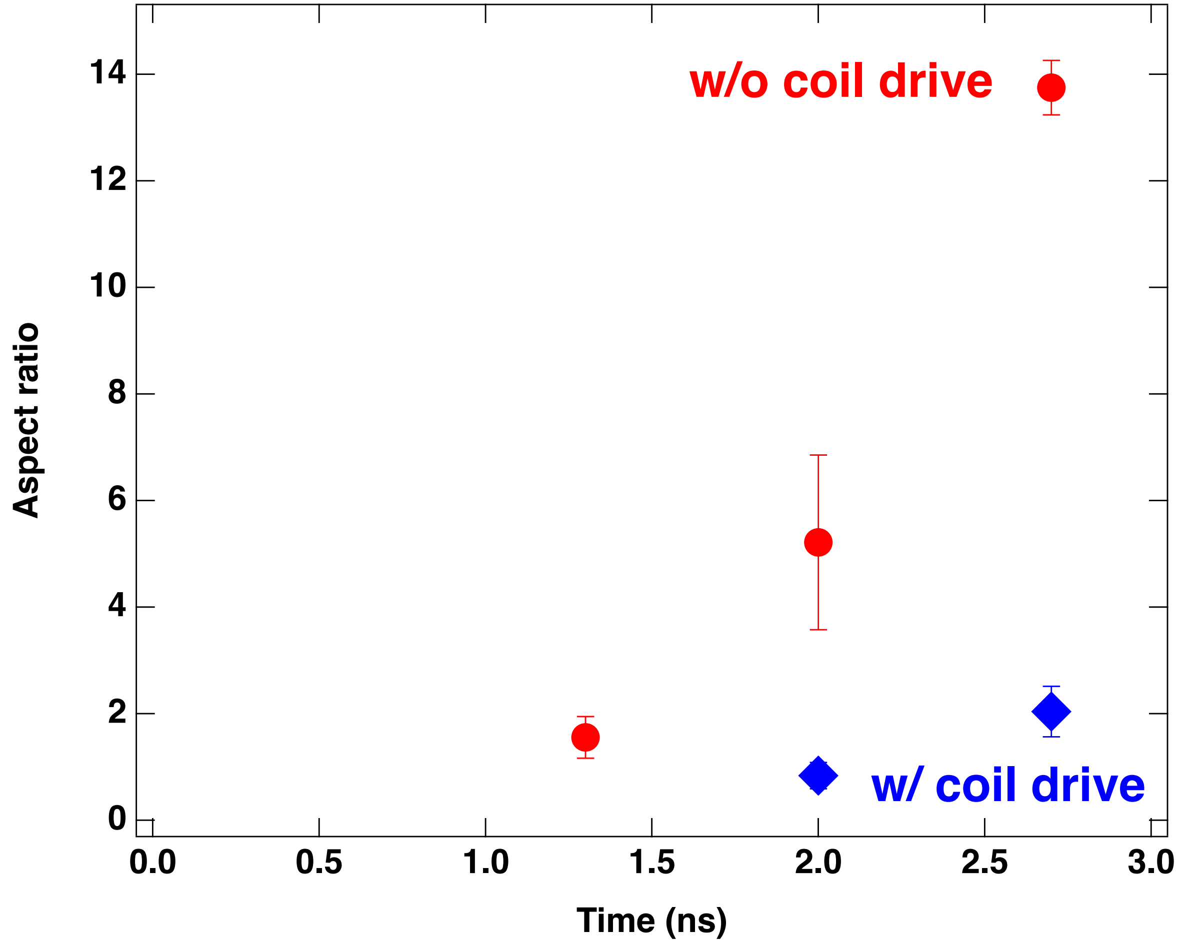
Perturbation amplitude vs time

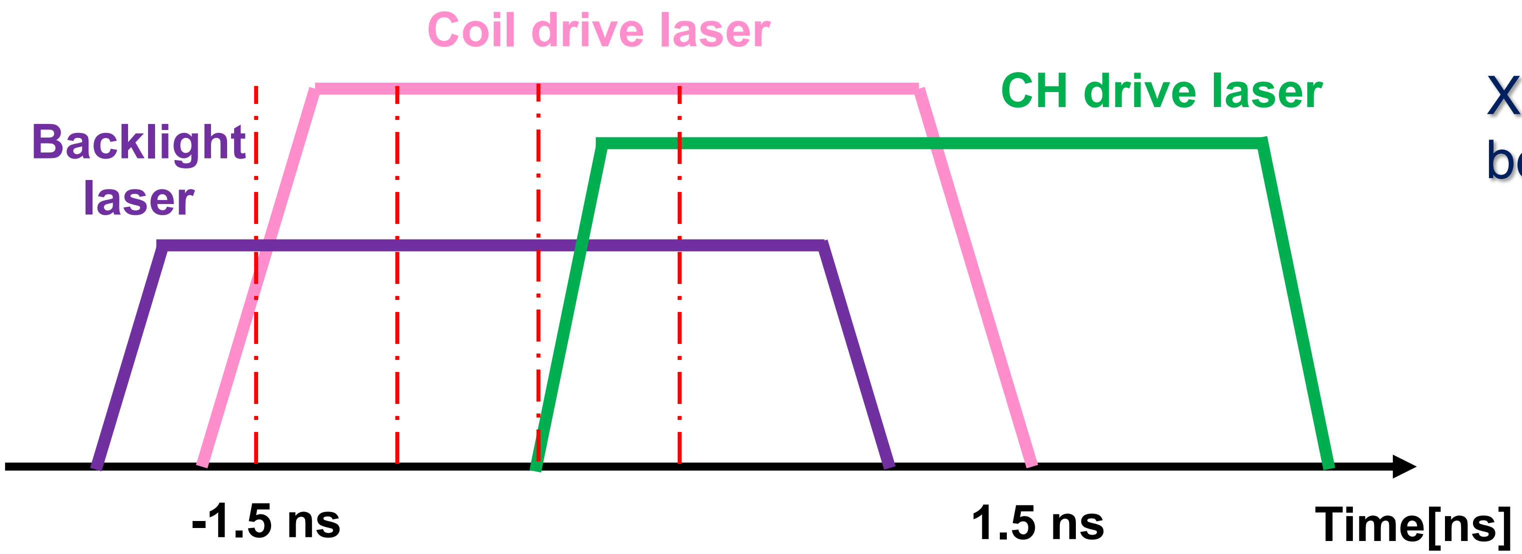


Perturbation aspect ratio vs time

Aspect ratio = height/width

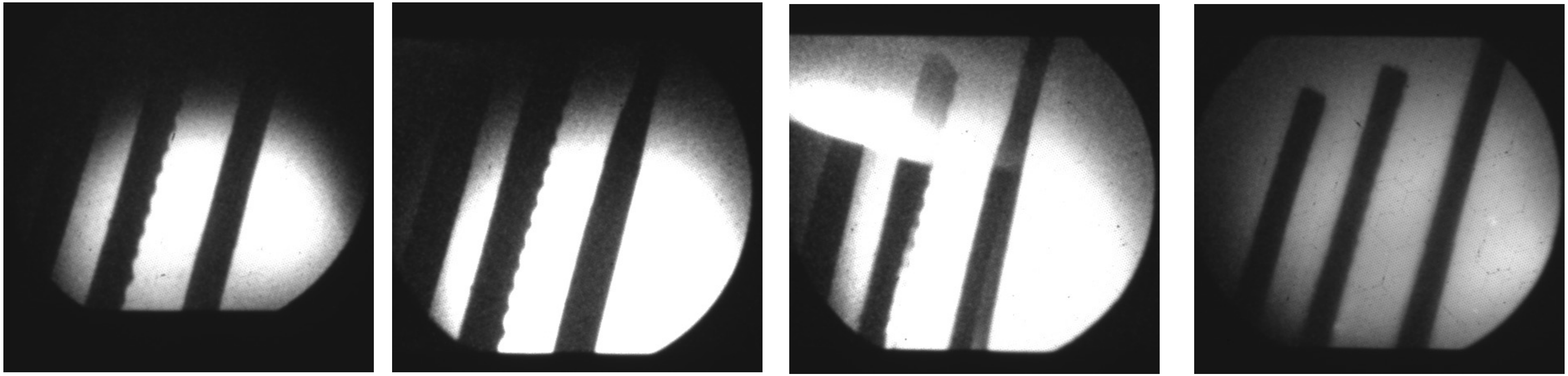


Preheating can reduce growth of perturbation.
Foil expansion before the laser irradiation was measured.



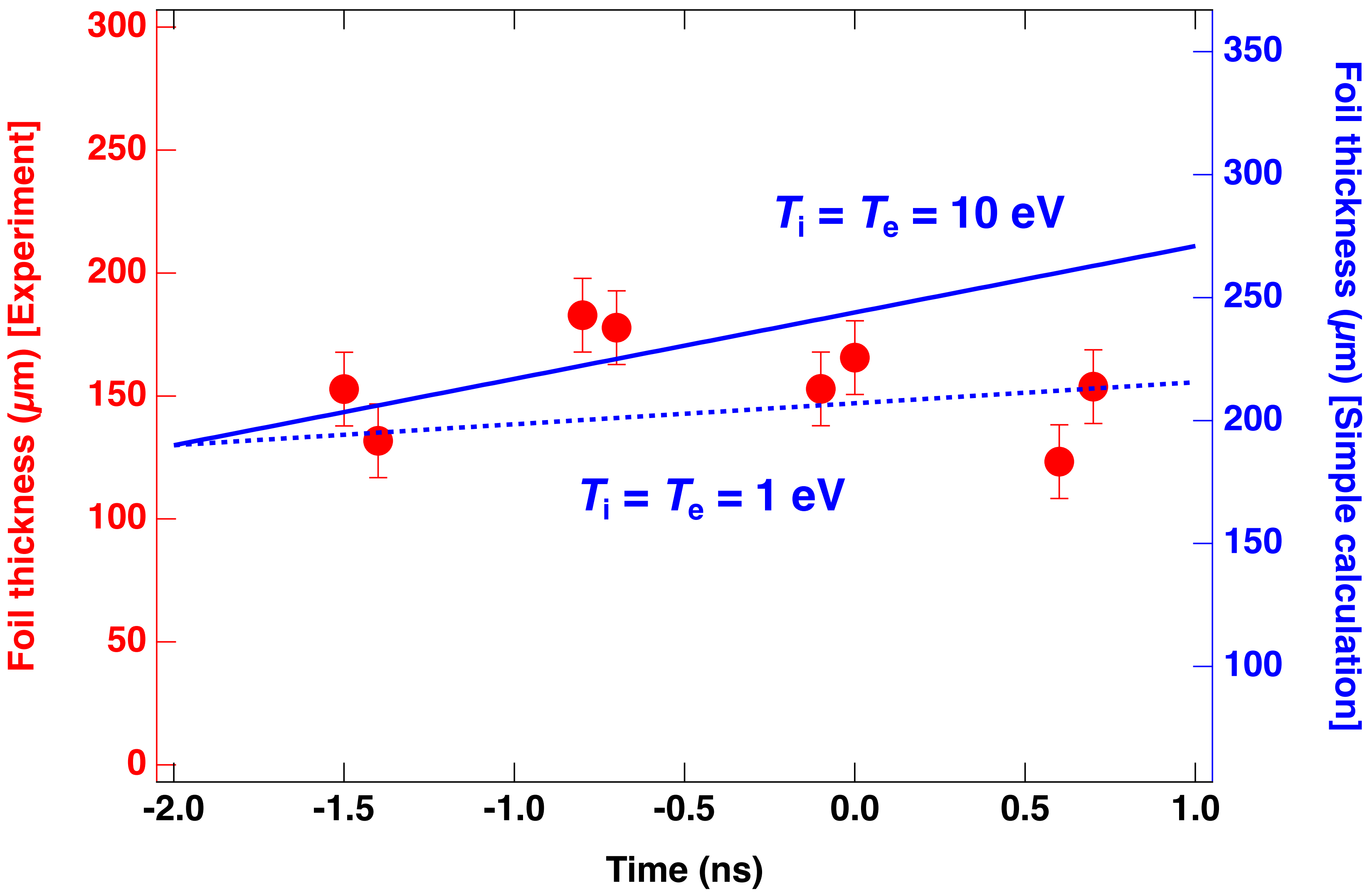
X-rays from laser-driven coil may be a source of preheating.

t = -1.5 ns | *t* = -0.8 ns | *t* = -0.1 ns | *t* = 0.6 ns



No clear expansion of the foil was observed in the shot, indicating the need for further detailed analysis to achieve a better understanding.

CH foil thickness vs time



Summary

1. The magnetic field strength reached 4T using a 12 kJ, 3 ns, 0.35 μm LMJ laser beam and a 2.0 mm-diameter Ni coil.

2. The coupling of ERHXI diagnostic and a CHCl backlight source (2.7 - 2.8 keV) has significantly enhanced the quality of x-ray radiography.

3. Compared to the normal configuration, LMJ irradiation of coil target exhibited a clear reduction in hydrodynamic instability growth. No B field effects expected.

4. There was no clear observation of significant expansion of the plastic foil after driving the coil but a small reduction of the peak-to-valley amplitude may explain results. Further detailed analysis is necessary to gain a better understanding.