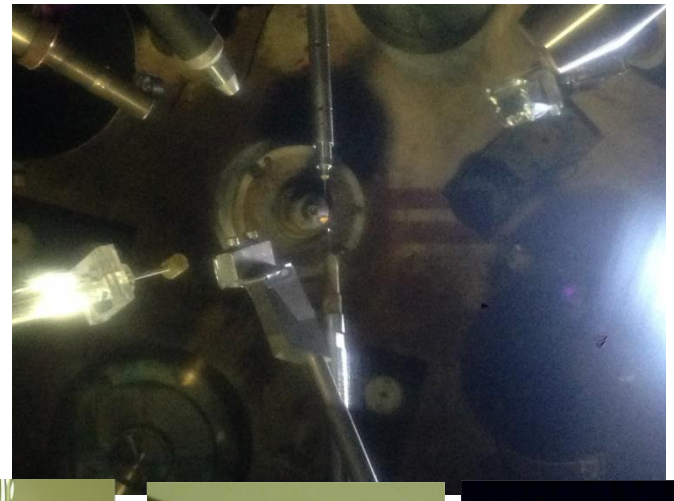
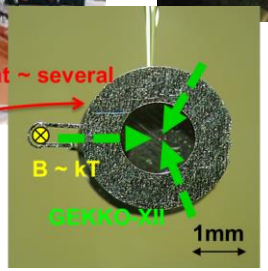
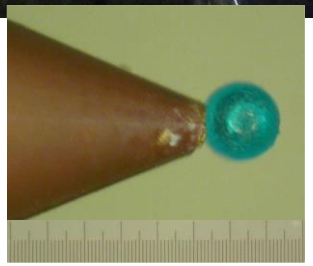
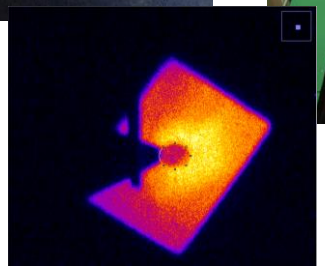
First experimental demonstration of isochoric heating of a dense plasma core with assistance of external kilo-tesla magnetic field









Shohei Sakata
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International Symposium
TOPICAL PROBLEMS OF NONLINEAR WAVE PHYSICS
(NWP-2017)

S. H. Lee, K. Matsuo, K. F. F. Law, Y. Iwasa, Y. Arikawa, A. Yogo, A. Morace, Y. Abe, S. Kojima, T. Gawa, S. Tosaki, Y. Fujimoto, T. Jitsuno, J. Kawanaka, M. Hata, Y. Hironaka, K. Mima, M. Murakami, N. Miyanaga, H. Nagatomo, M. Nakai, Y. Nakata, K. Nishihara, H. Nishimura, T. Norimatsu, T. Sano, Y. Sakawa, Y. Sentoku, K. Shigemori, K. Tsubakimoto, H. Shiraga, S. Tokita, K. Yamanoi, H. Azechi, R. Kodama, S. Fujioka

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Institute of Physics, China

J. Santos, M. Bailly-Grandvaux, D. Batani, R. Bouillaud, P. Forestier-Colleoni, S. Hulin, Ph. Nicolaï, V. Tikhonchuk

CELIA, Univ. Bordeaux, France

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J.L. Dubois, J. Gazave, D. Raffestin and J. Ribolzi.

CEA, France

M. Chevrot, S. Dorard, E. Loyez, J.R. Marques, F. Serres

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Universidad Politécnica de Madrid, Spain

Contents

- Magnetically assisted fast ignition (MAFI) concept :
  A new path way to create extremely high energy density (HED) state.

- Generation of kilo-Tesla level magnetic field due to laser - driven capacitor-coil .

- Demonstration of guiding of relativistic electron beam (REB) in a planner geometry.

- Demonstration of 「magnetically assisted fast ignition」.

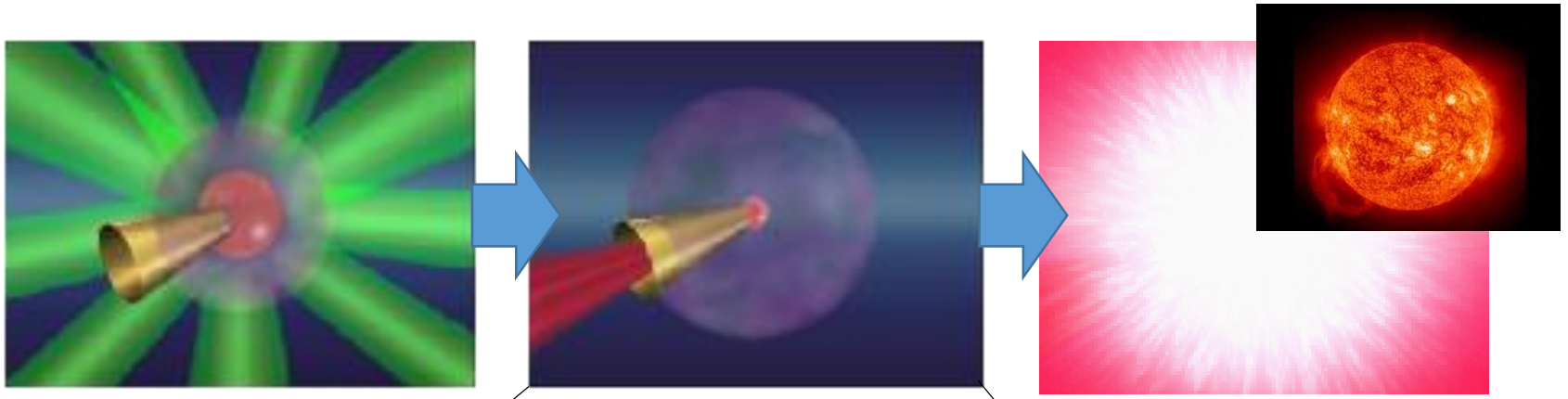
Fast ignition concept

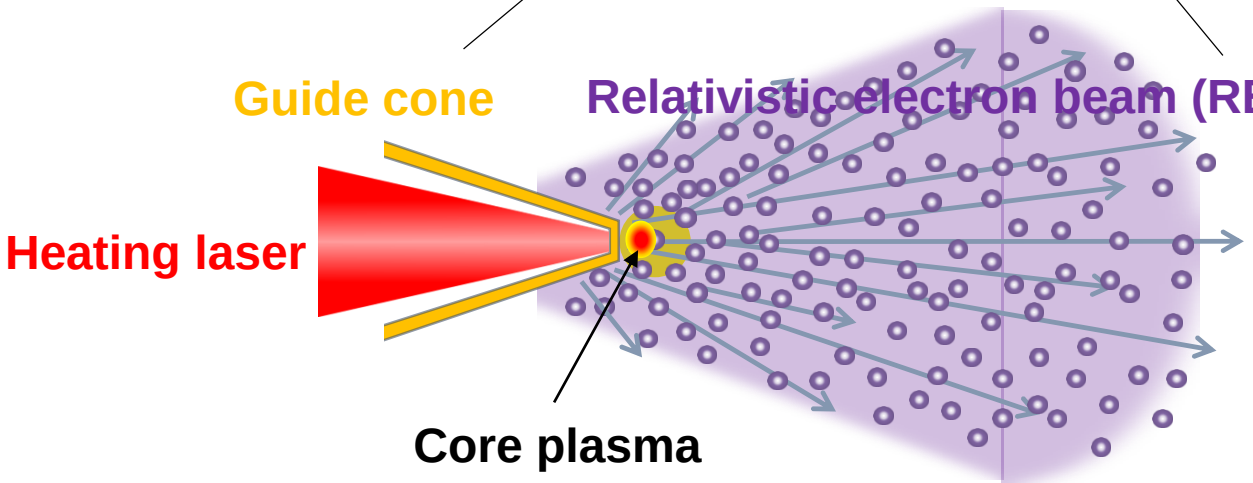
Fast ignition* : One of the attractive scheme for creation of HED plasmas.

1. The fuel is imploded by ns long pulse laser.

2. At the maximum compression timing, a high-intensity short-pulse laser is injected to the core plasma.

Implosion **Heating** **Ignition**

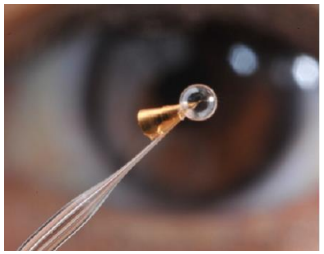




*M. Tabak, *et al*.,Phys. Plasmas **1**, 1626-1634 (1994).

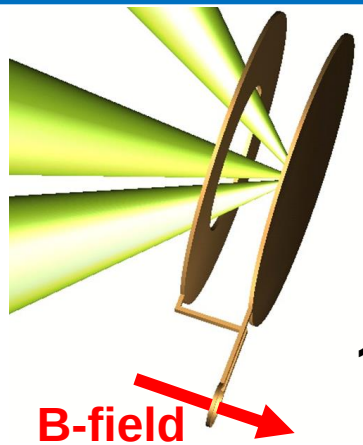
「Magnetically assisted fast ignition*」 was proposed to enhance the heating efficiency with external kilo-Tesla magnetic field.
To realize this, kilo-Tesla level magnetic field is required.

Cone-guided target



+

Laser-driven capacitor coil**



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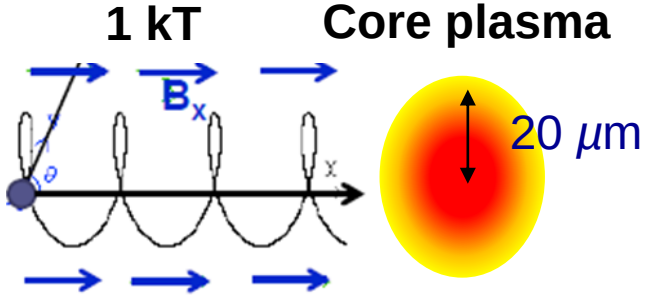
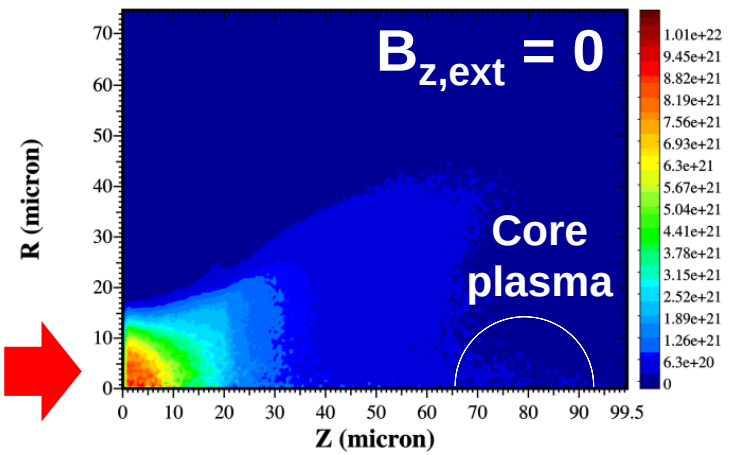
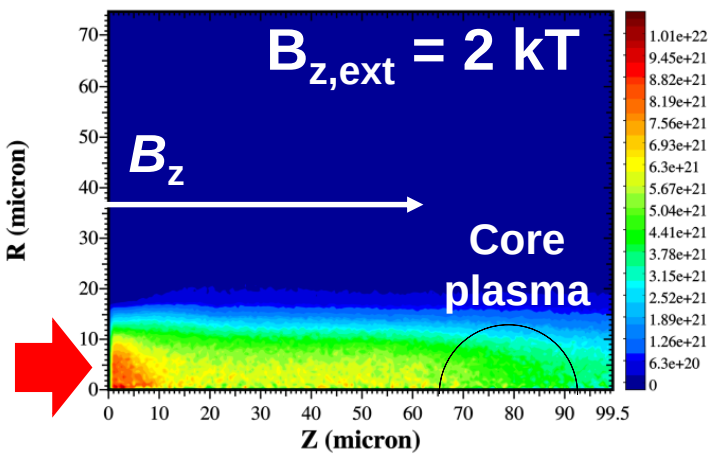


1 MeV electron ~ gyro radius: 10μm

REB transport simulation

#Simulation by Prof. Honrubia.





*T. Johzaki, *et al*. PPCF **59**, 014045 (2017).,
*S. Fujioka *et al, Phys. Plasmas* **23**, 056308 (2016).

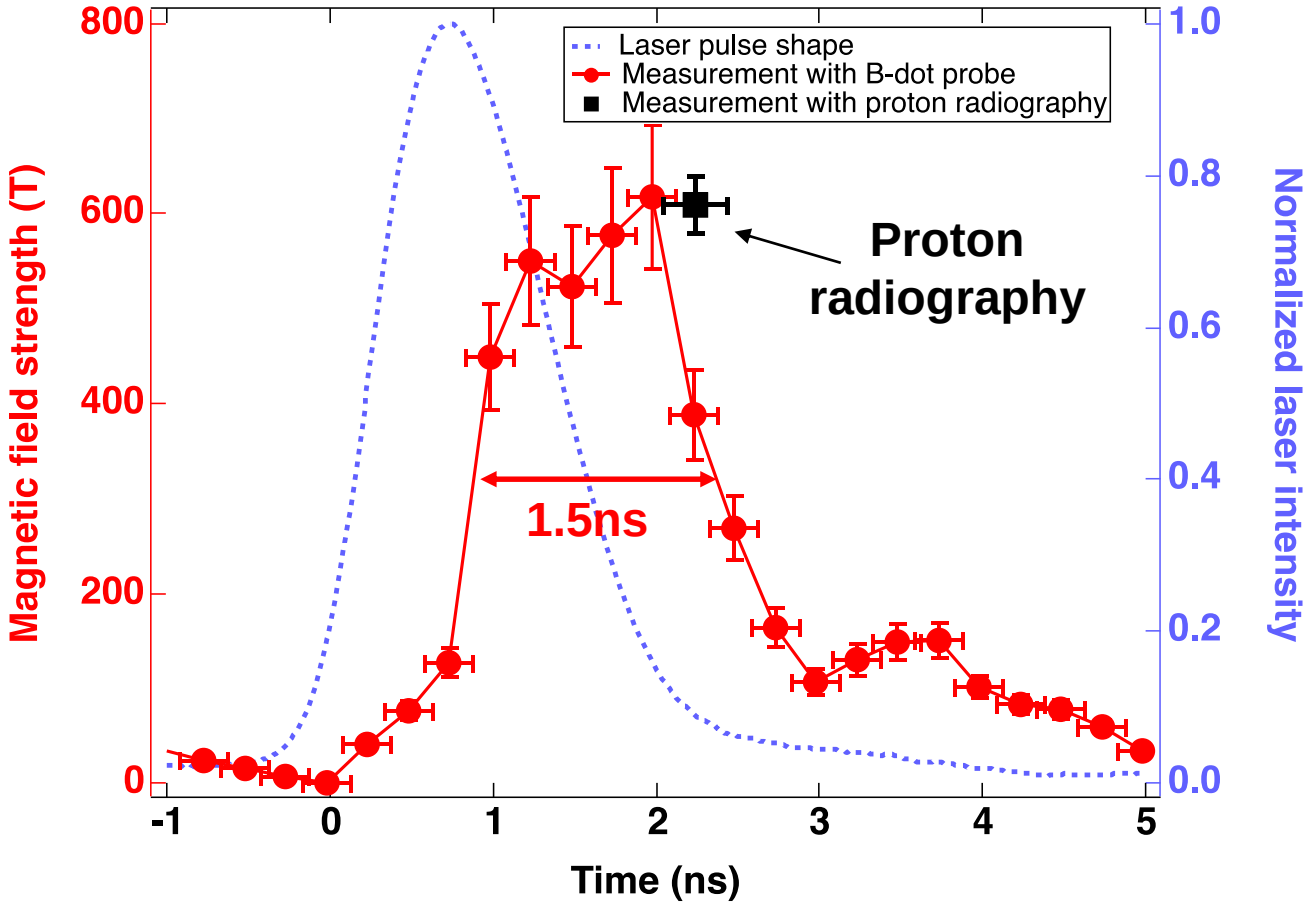
S. Fujioka *et al,* Sci. Rep. **3, 1170 (2013).

Demonstration of guiding of REB with assistance of external magnetic field

Magnetic field was measured by B-dot probe and proton radiography. 600 T magnetic field* was obtained.

Temporal history of B-field measured with B-dot probe

600 T of the peak magnitude and 2 ns of the duration

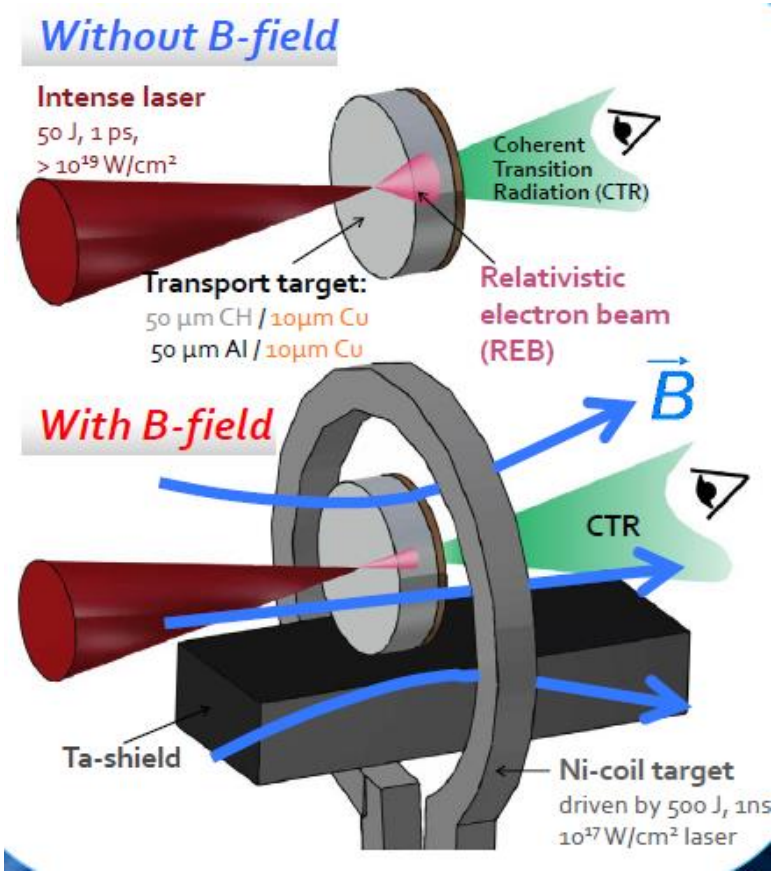


*K. F. F. Law *et al.*, *Appl. Phys. Lett.* **108**, 091104 (2016).

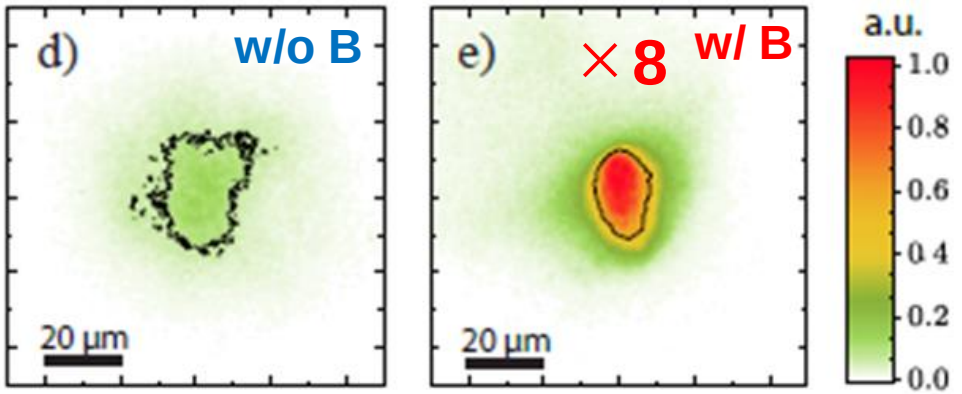
Guiding of REB by external magnetic field

Coherent transition radiation (CTR) was used to diagnose REB divergence. Pinching image of CTR with B-field was obtained.

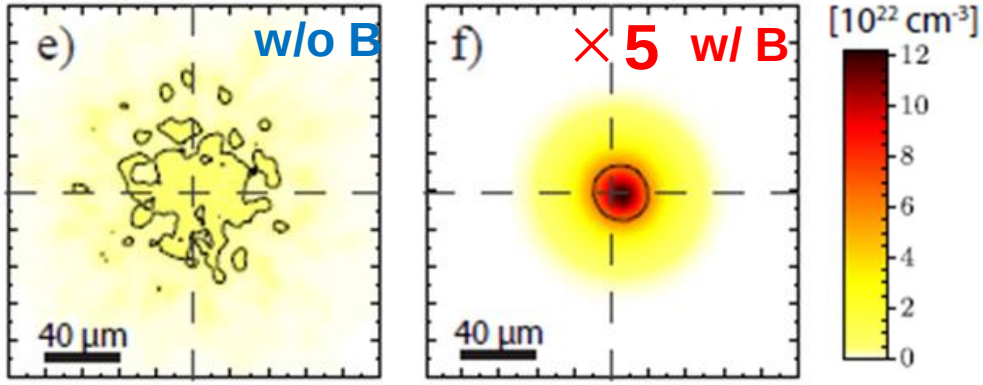
Experimental set up @ LULI



Spatial profile of Coherent transition radiation (CTR)



Electron density at rear surface（simulation）



*M. Bailly-Grandvaux *et al.*, submitted to *Nature Comm.*

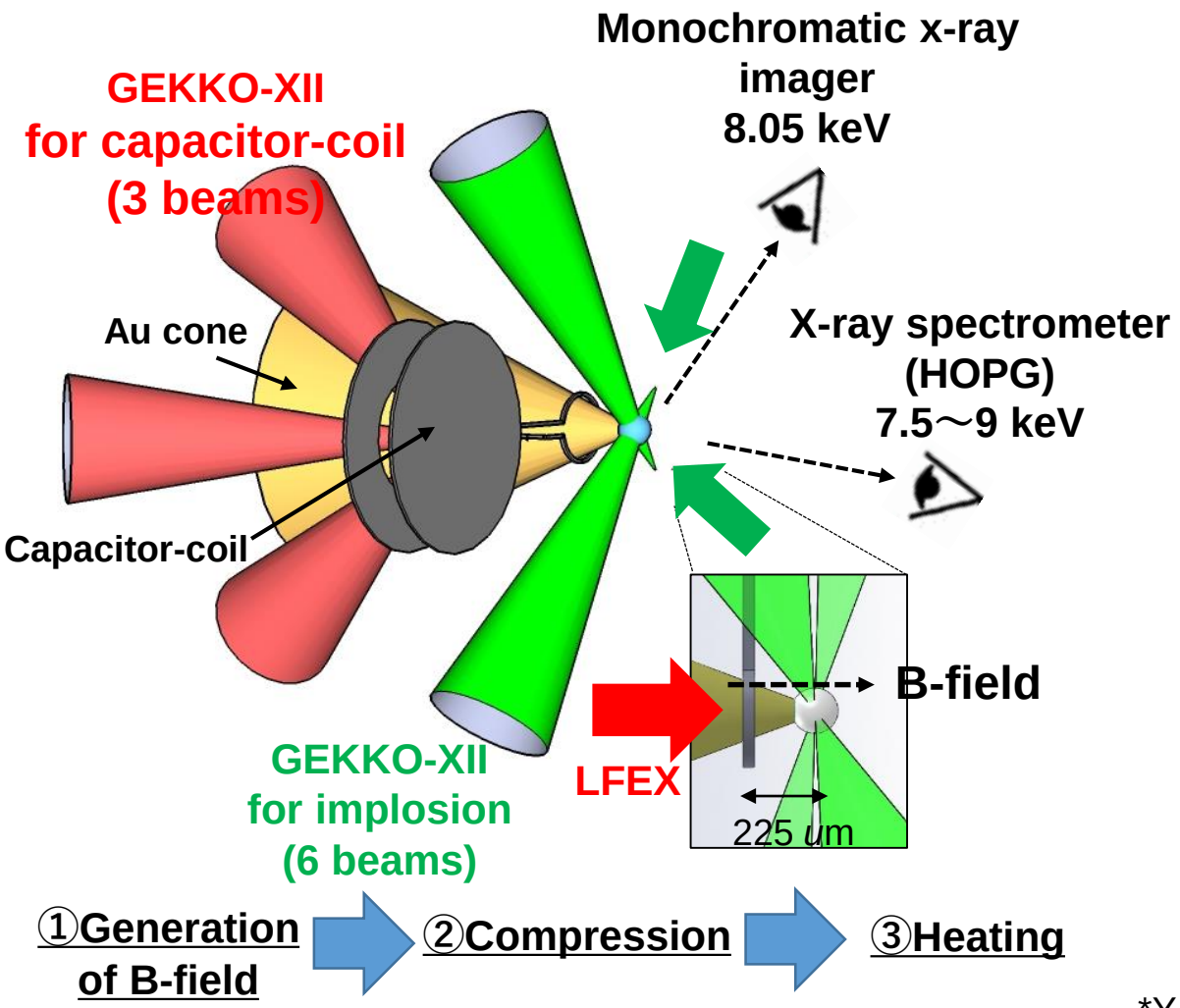
Demonstration of isochoric heating of a dense plasma with assistance of external magnetic field @ GEKKO-XII & LFEX laser facility

Magnetically assisted Fast ignition experiment

Copper contained solid sphere was installed to visualize REB transport and measure the electron plasma temperature.

A solid sphere mitigate large mirror magnetic field and hydrodynamic instability.

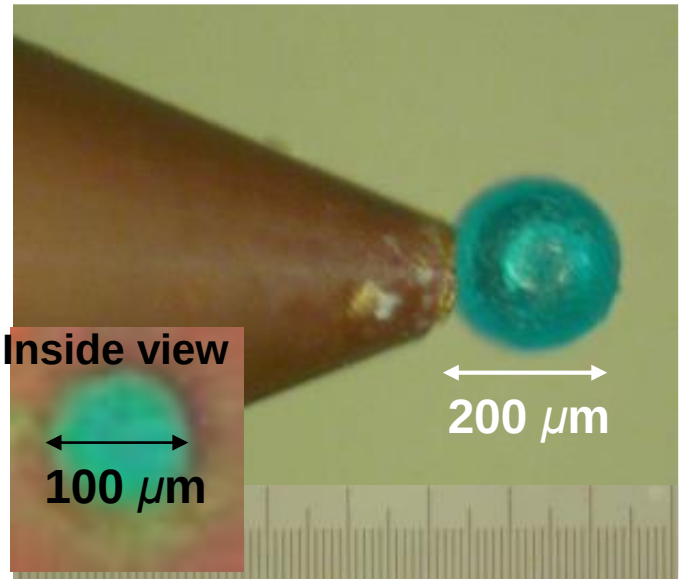
Experimental set up



①Generation of B-field → ②Compression → ③Heating

Cu(II) olate solid sphere*

$(C_{17}H_{33}COO)_2Cu$, 1.06 g/cc,
0.93 at%, 10 w%



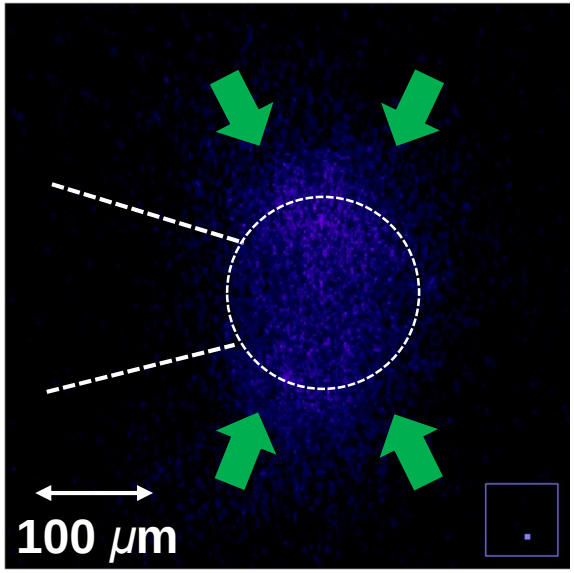
*Y. Iwasa *et al*., in preparation for submission.

Visualizing REB transport via Monochromatic Kα image

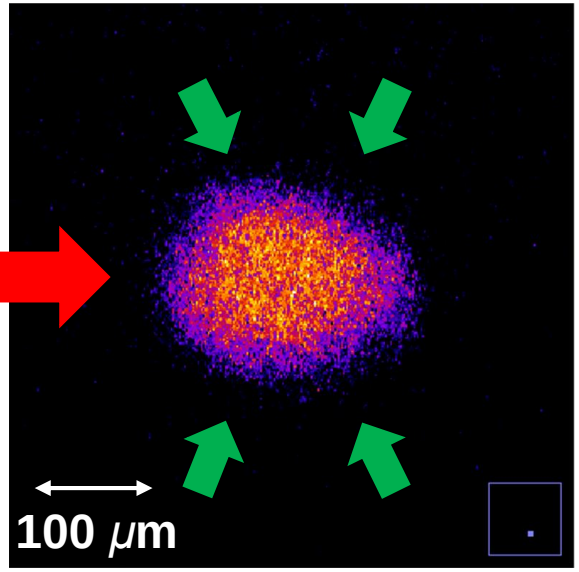
When external magnetic field was applied, enhancement of monochromatic Kα signal was observed.
This is the strong evidence that REB was guided into a dense plasma.

Raw images of distribution of monochromatic Kα (8.05 keV)

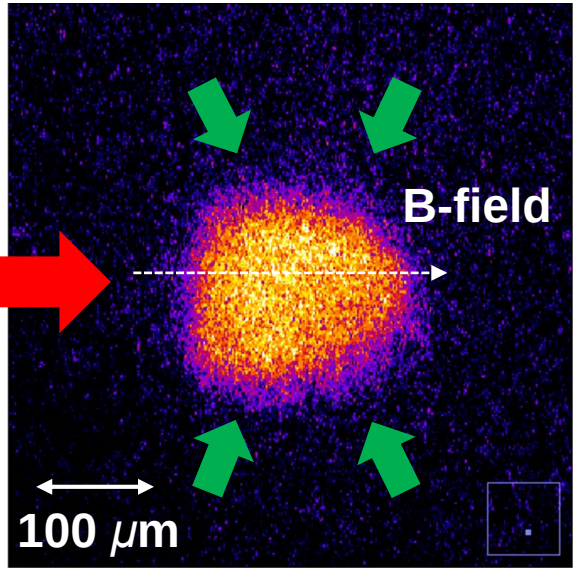
w/o heating (Only implosion)



w/ heating

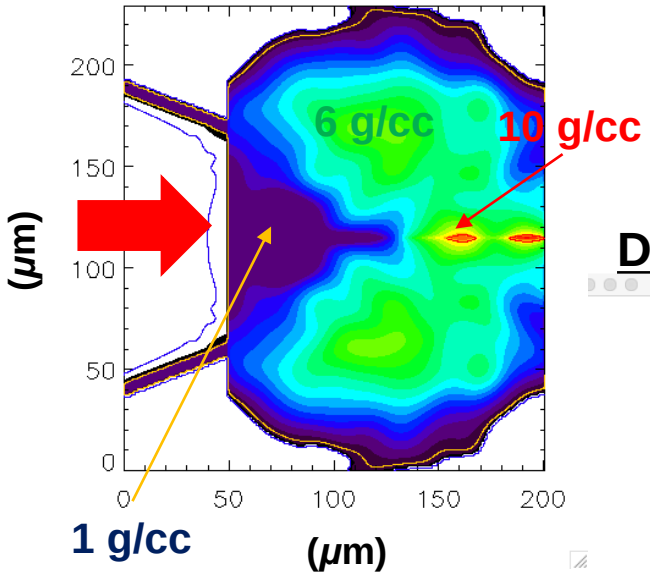


w/ heating + w/ B-field



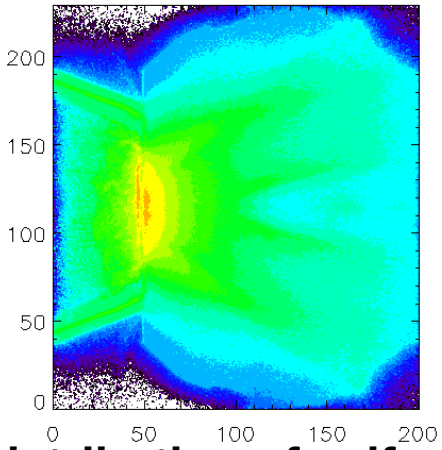
Guiding of REB in the dense plasma was confirmed by 2D PIC simulation*. Self-generated magnetic field also assist guiding of REB.

Pre-formed plasma & Density profile (experiment)

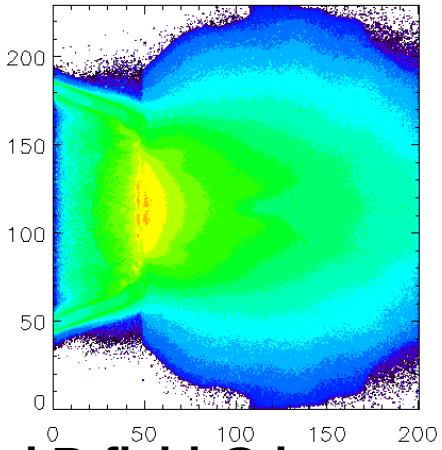


REB density distribution @ laser peak

w/o B-field

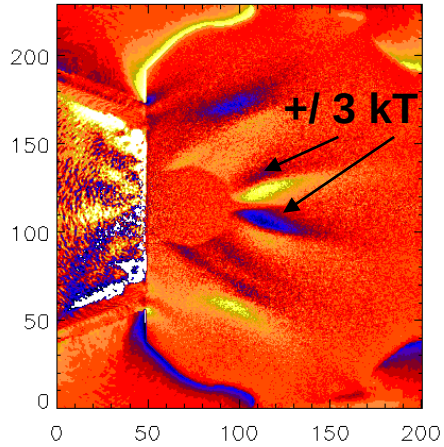


w/ B-field

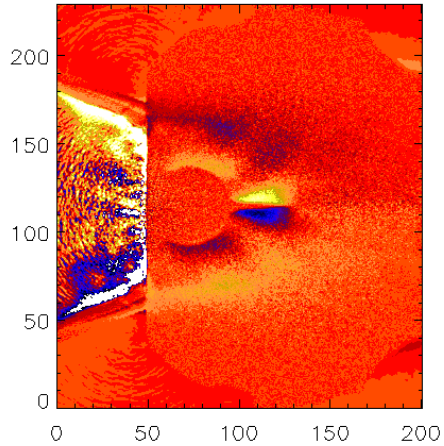


Distribution of self-generated B-field @ laser peak

w/o B-field



w/ B-field



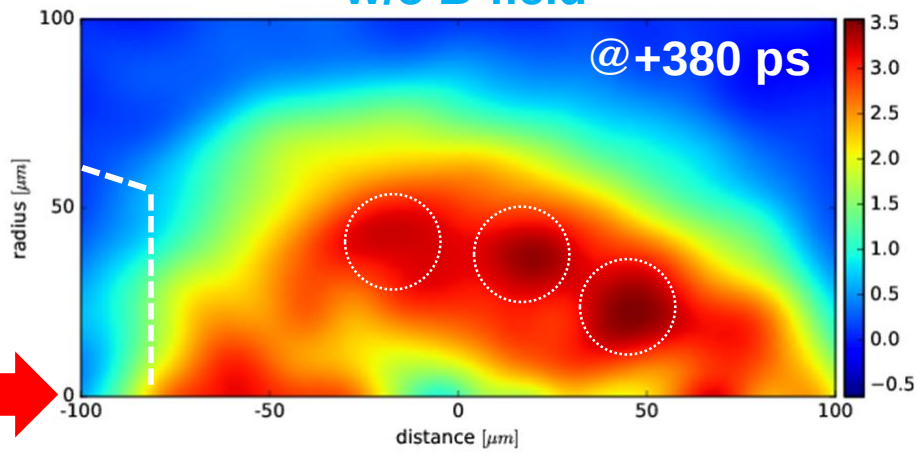
*Y. Sentoku and A. J. Kemp
J. Comput. Phys. 227, 6846 (2008).

Comparison with PIC results

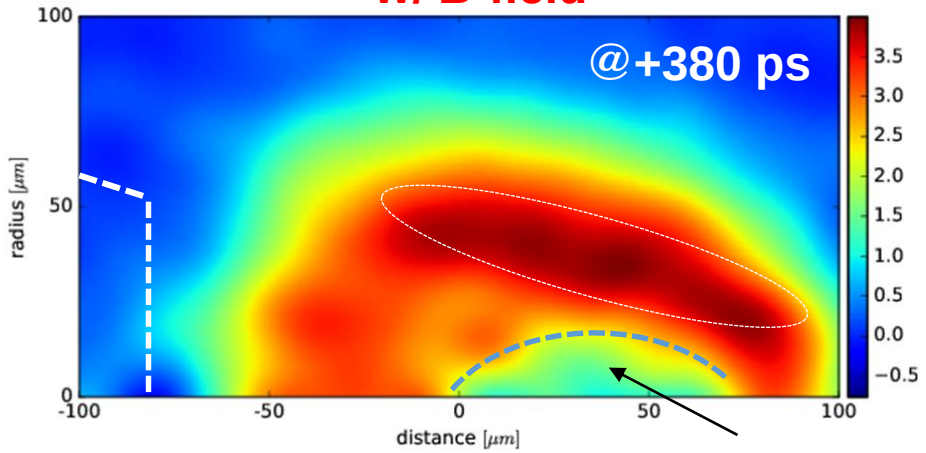
Bright pots were observed in the case of without B-field. On the other hand, Sifted region was observed at the center in the case of with B-field.
This predict that heating was occurred at high density region due to guidance of REB.

Inverse Abel transformed image of monochromatic Kα

w/o B-field



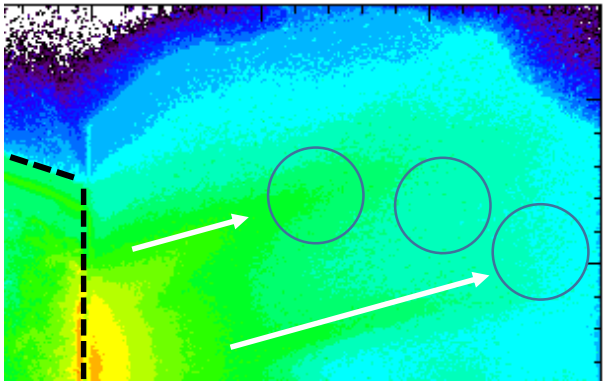
w/ B-field



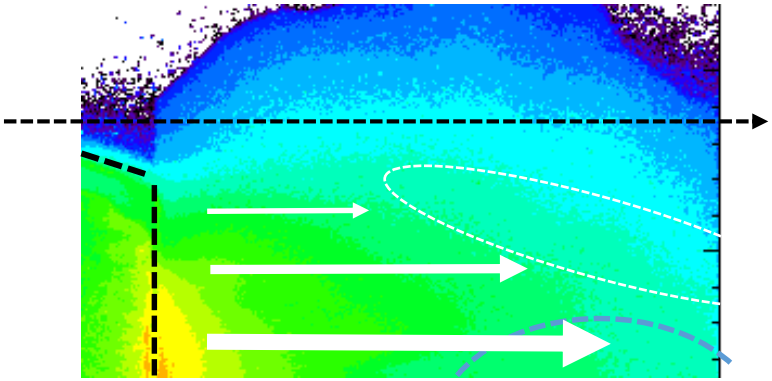
Shifted region

REB energy density by PICLS 2D simulation*

w/o B-field



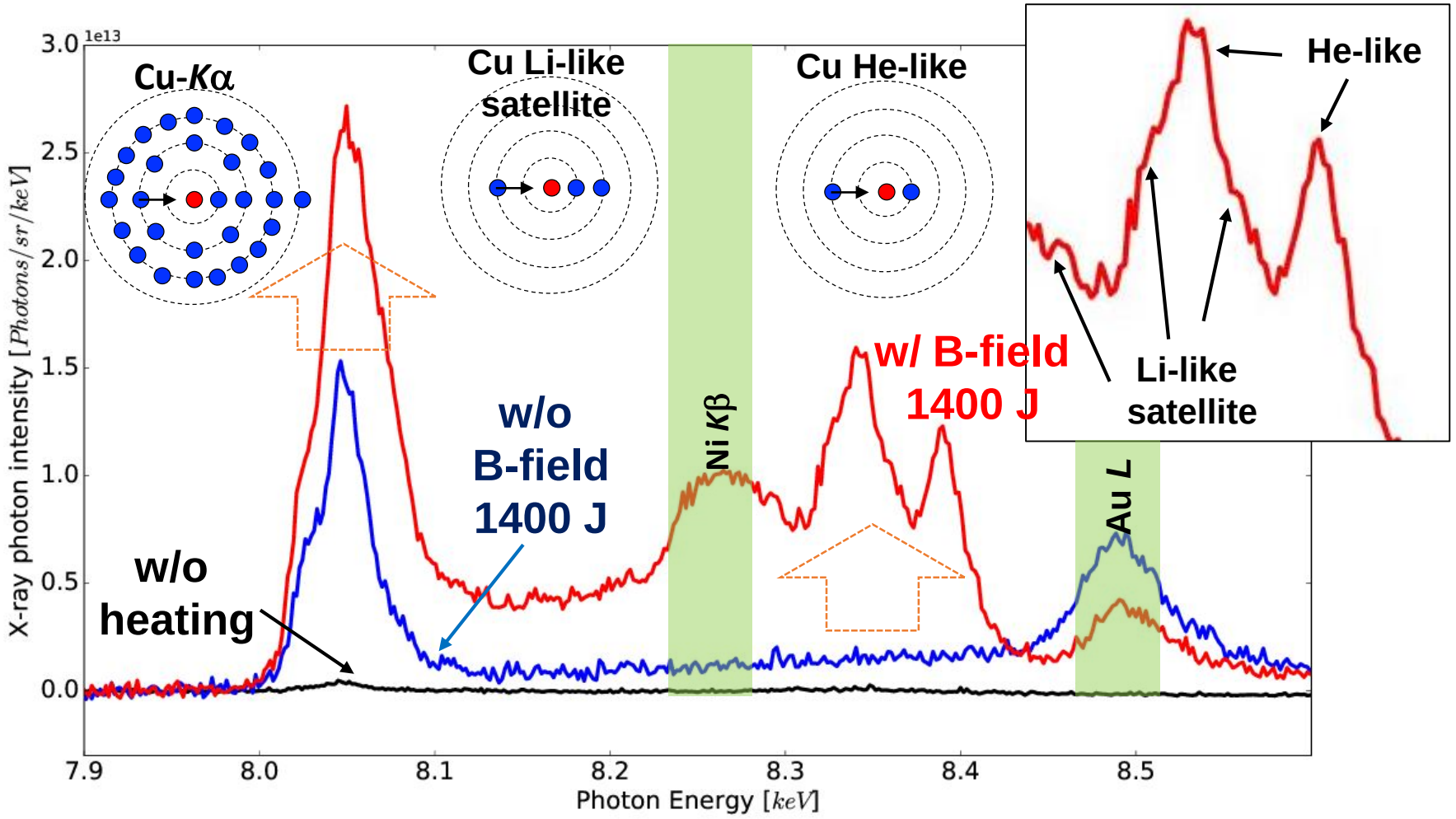
w/ B-field



Parallel B-field 1 kT

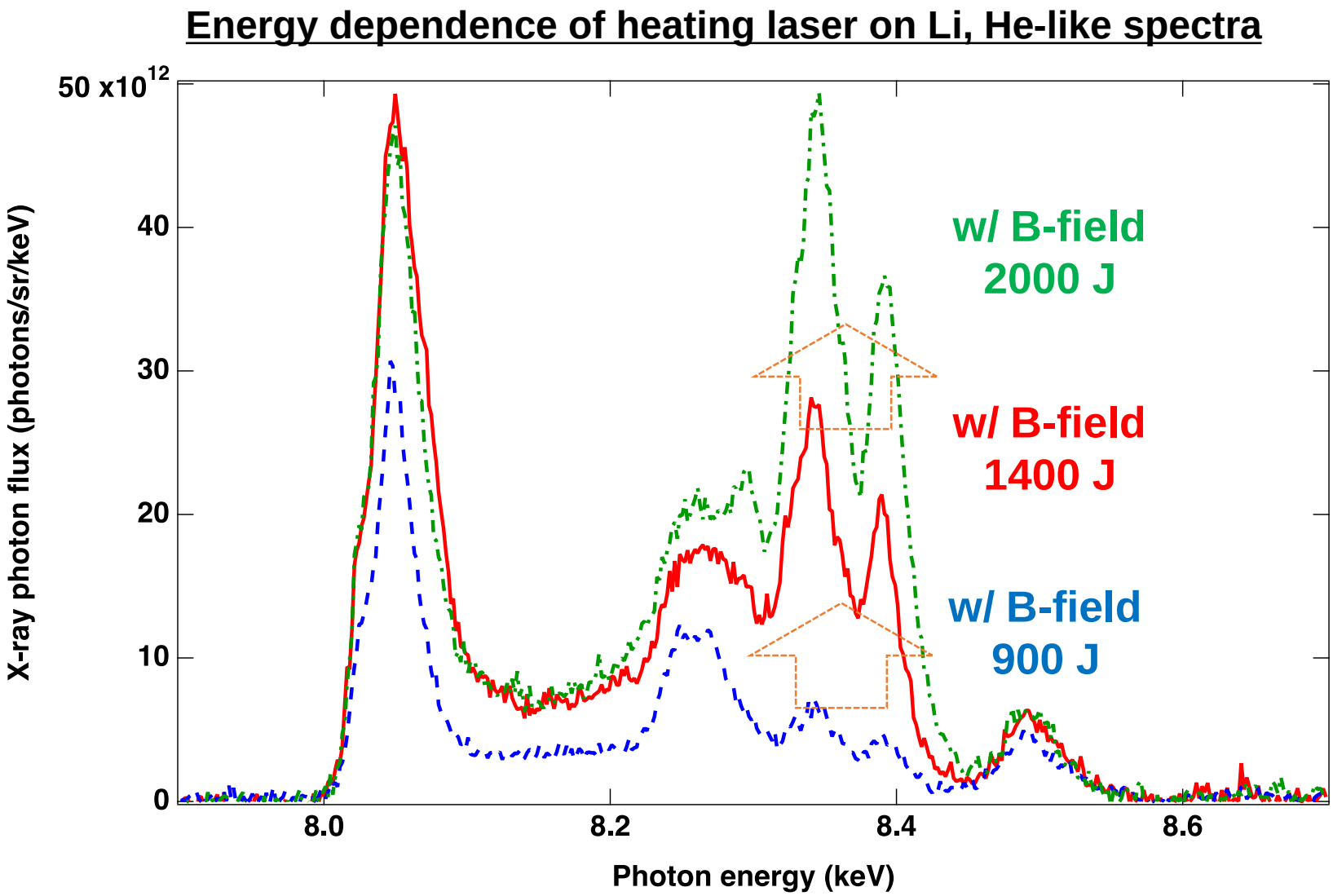
Increasing of Ka signal and Li, He-like lines were observed with external magnetic field. These results predict that enhancement of heating of plasma due to guiding of REB was occurred.

X-ray spectra from Cu atoms in various case



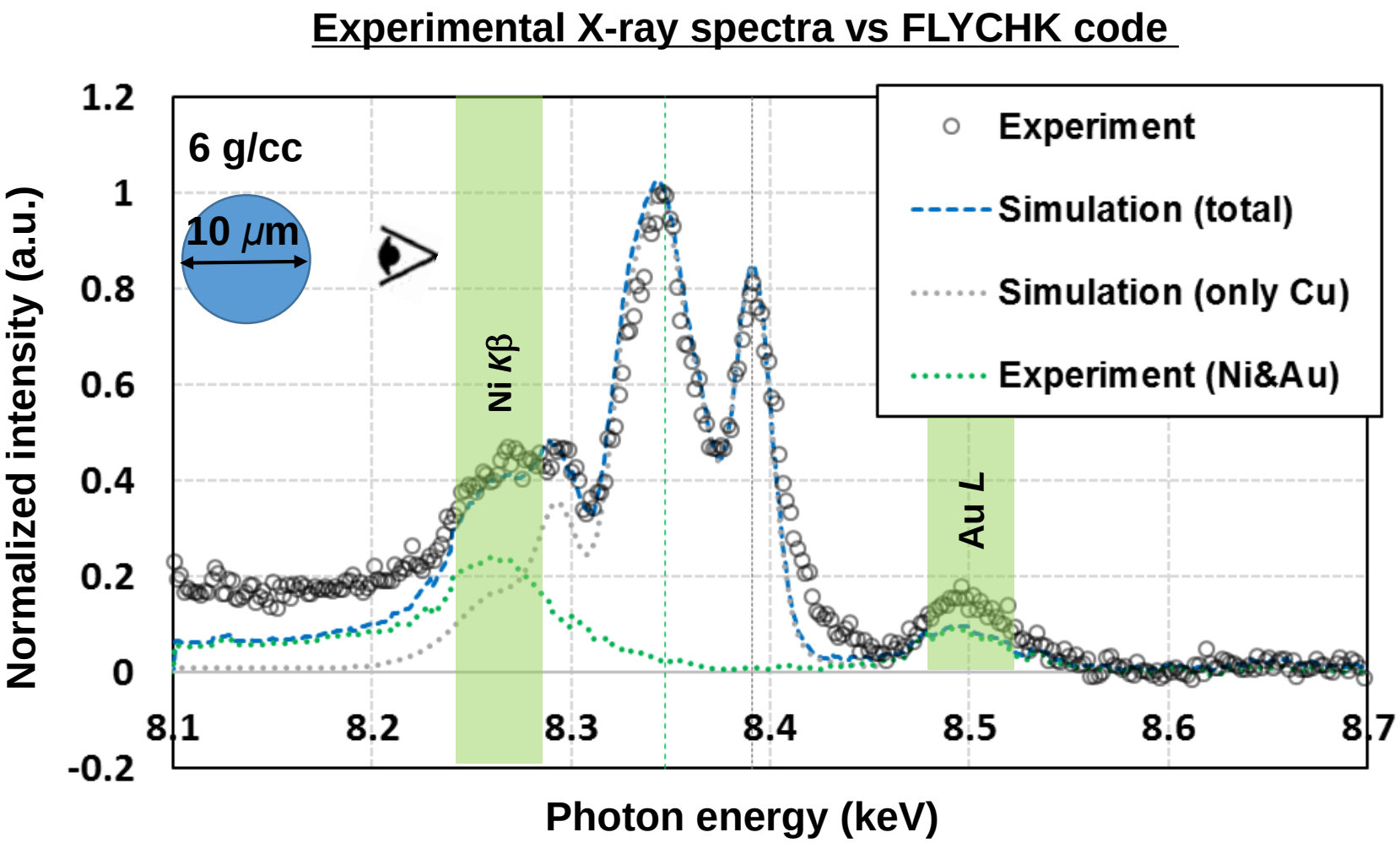
Energy dependence of heating laser

When increasing the energy of heating laser, Li, He-like signal increased. This predict increasing of electron temperature or heated region.



Comparison with FLYCHK code

The electron temperature was estimated by FLYCHK code with simple assumption. A very small region was heated up to be ~ 1.8 keV.



Coupling efficiency from heating laser to core plasma was estimated by empirical model* . The estimated value is ~ 5% in the case of with B-field.

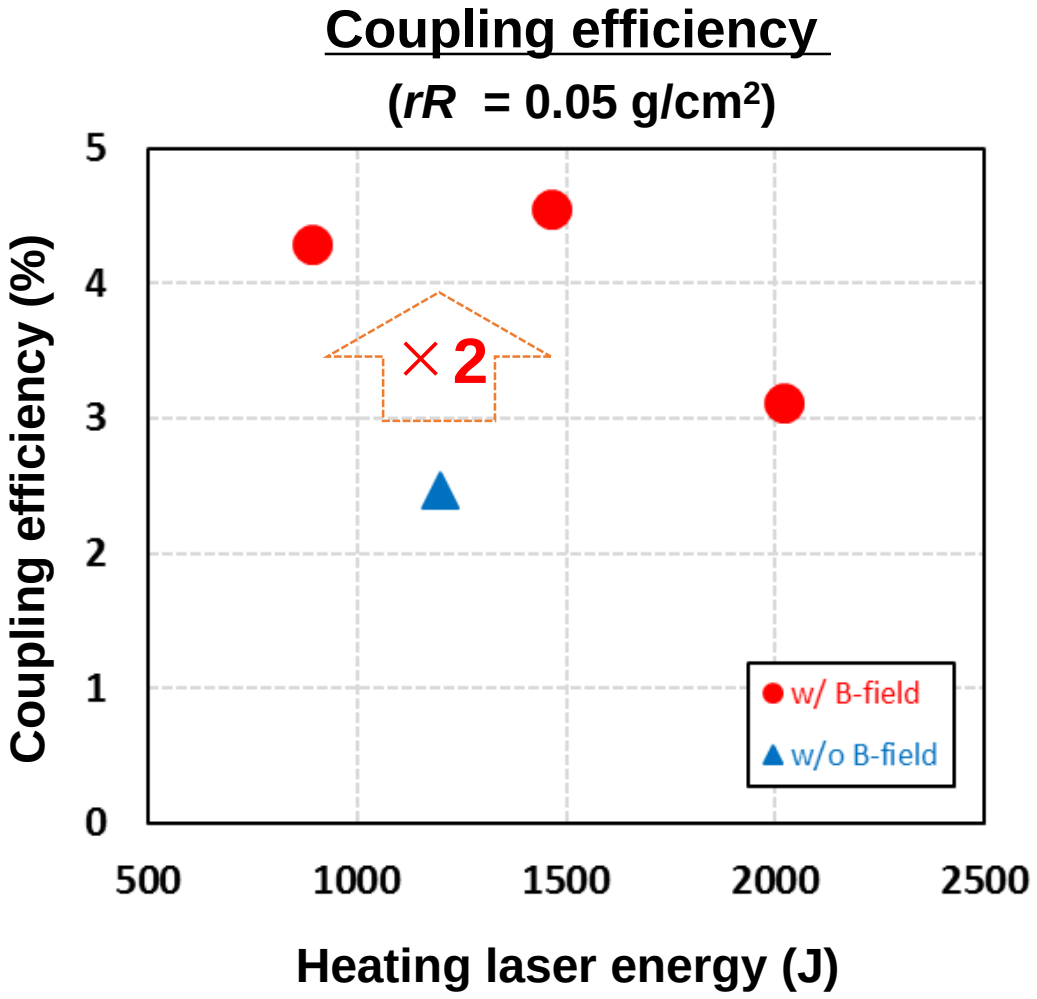
Deposited energy
(E_{dep} [J])

II

Absolute Kα photons
($N_{k\alpha}$(ph/sr])

×

Conversion coefficient
4×10^{-11} (J/ph/sr)



*L. C. Jarrot *et al.*,Nat. Phys. **12**, 499-504 (2016).

Summary

- We have demonstrated 「Magnetically assisted fast ignition」at the first time.
- The estimated plasma temperature is ~ 1.8 keV via X-ray spectra from Cu atoms.
- REB density distribution calculated by PIC simulation agree with monochromatic Kα images.
- Coupling efficiency from laser to dense plasma was estimated by empirical model, which is about 5 % with external magnetic field.

Acknowledgement

The authors would like to acknowledge the dedicated technical support by the staff at the GEKKO-XII facility for the laser operation, target fabrication and plasma diagnostics.

(Grant Nos. NIFS12KUGK057, NIFS11KUGK053, and NIFS15KUGK087) and the Institute of Laser Engineering at Osaka University (2015A1-19 and 2015A1-31), and by the Japanese Ministry of Education, Science, Sports, and Culture through Grants-in-Aid for Young Scientists (Grant Nos. 24684044, 26820396, and 25630419), Bilateral Program for Supporting International Joint Research by JSPS, and Grants-in-Aid for Fellows by JSPS (Grant Nos. 14J06592 and 15J00850).

Thank you for your attention !!

Спасибо !!