13th ICENES
Istanbul, Turkey

June 7th 2007

"Fast Ignition Studies at Osaka University "

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&

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Plenary in Session 11

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- Special Thanks for C. Barty and M. Rushford at LLNL.

My talk will include

- Successful Fast Ignition Experiment w/ 1kJ Laser
- Physics Issues
- Nest Step with 10 kJ Fast Heating Laser

Introduction

- Gold cone was used to guide a fast heating laser pulse in order to heat a highly compressed plasma core up to 1 keV.
- 30 % coupling efficiency was indicated in the experiment from the heating laser to the core. Based on this high efficiency 10 kJ PW laser is now under construction to test even higher fast heating temperature up to several keV at the Inst. Laser Engineering. This is close to fast ignition.
- One important issue is to understand the physics of this high efficiency and another is to study the both electro-static potential formation at around the target affecting on the relativistic hot electron energy transport.

Compression and heating can be separated in fast ignition.

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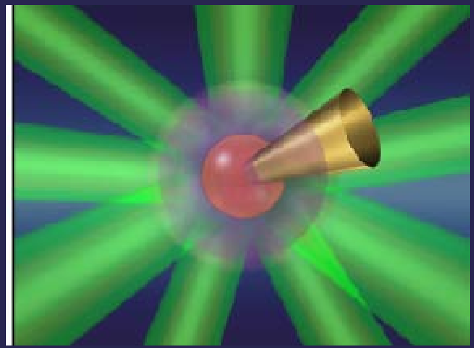


Compression by multiple laser beams

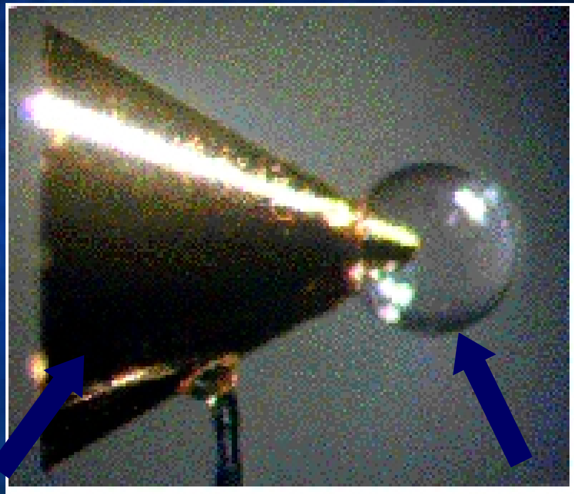
Heating by ultra-intense laser pulse

Ignition & Burn

Fast ignition experiments of cone-guiding heating of imploded high density core

The experiments were carried out with a Au-cone CD shell.
The CD shell was imploded with 9 beam of the GEKKO XII laser.

PW laser for heating
1 beam / 300 J
1.053 um / 0.5ps
~10^{19} W/cm^2



GXII laser for implosion
9 beams / 2.5 kJ/0.53 um

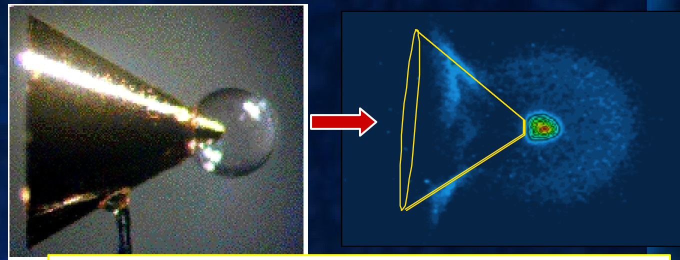
1.2ns Flat Top w/ RPP

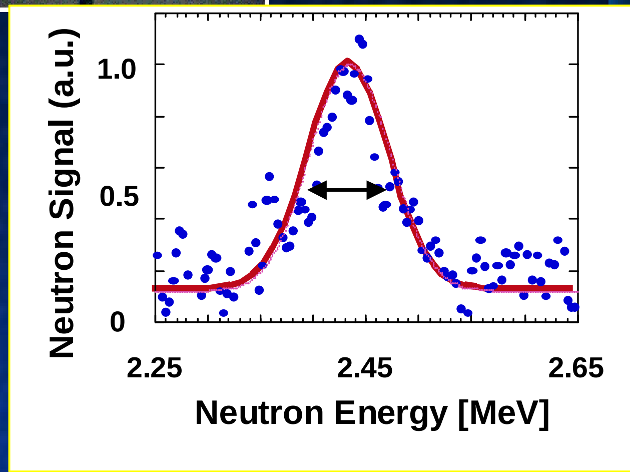
Au cone
30 ^{o} open angle (the picture: 60deg)
Thickness of the cone top: 5um

CD shell
500umf/6-7umt

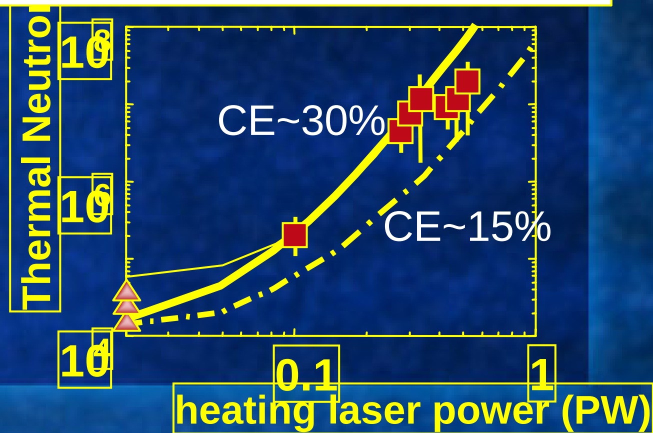
Fast ignition works with gold cone guiding

- The exist of the cone does not reduce the core plasma density much (~80%)
- Laser to core plasma thermal energy coupling conversion efficiency 20%~30%
- Core plasma temperature 1keV at 50-70g/cc due to enforced heating
- Thermal neutron yields increased from 10^4 to 10^7
- Cone may focus the heating laser light and hot electrons from the cone wall to the cone inner tip

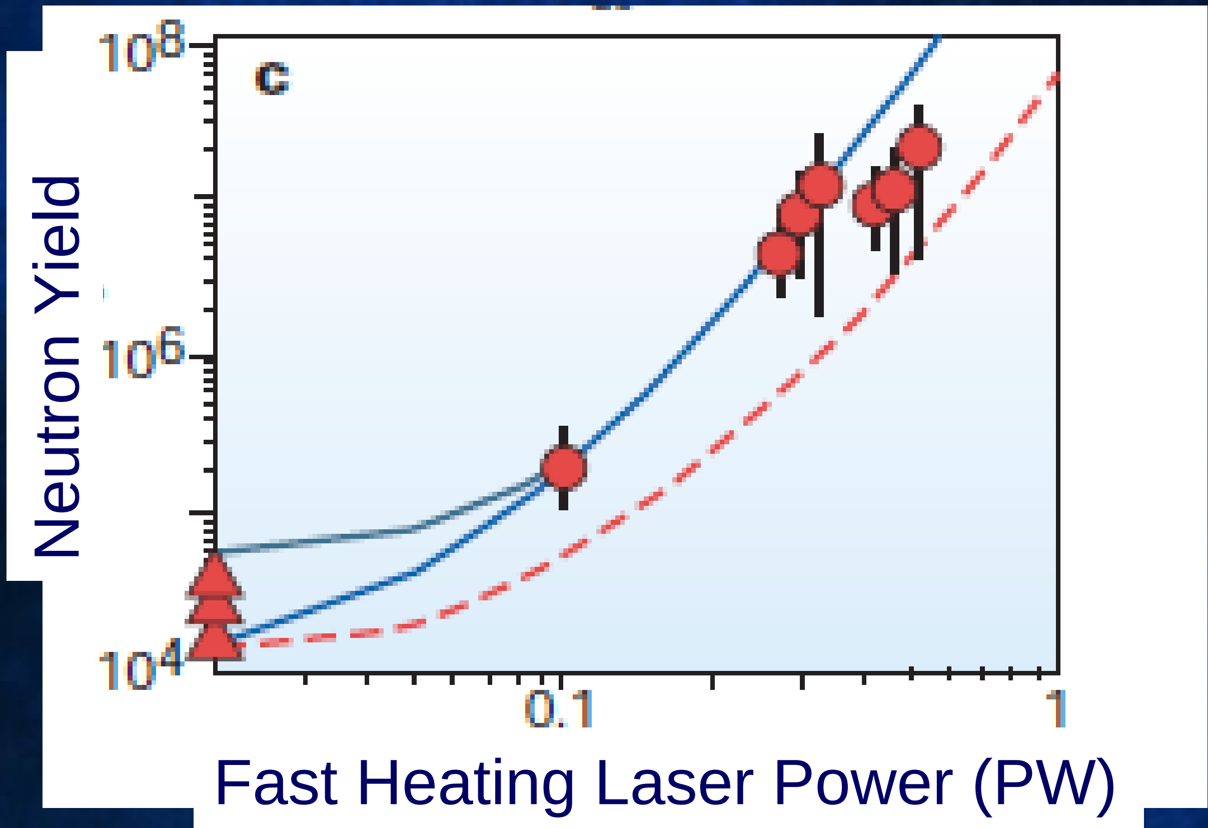




R.Kodama *et al.* Nature **412** 798-802 (2001); **418**, 933 (2002)



DD neutron increase was three orders of magnitude via. fast heating



Sub-ignition condition

Fast ignition is considered to have a sub-Ignition
(Temp. 5-10 keV、gain<0.1) at 10 kJ and ignition at 50 kJ.

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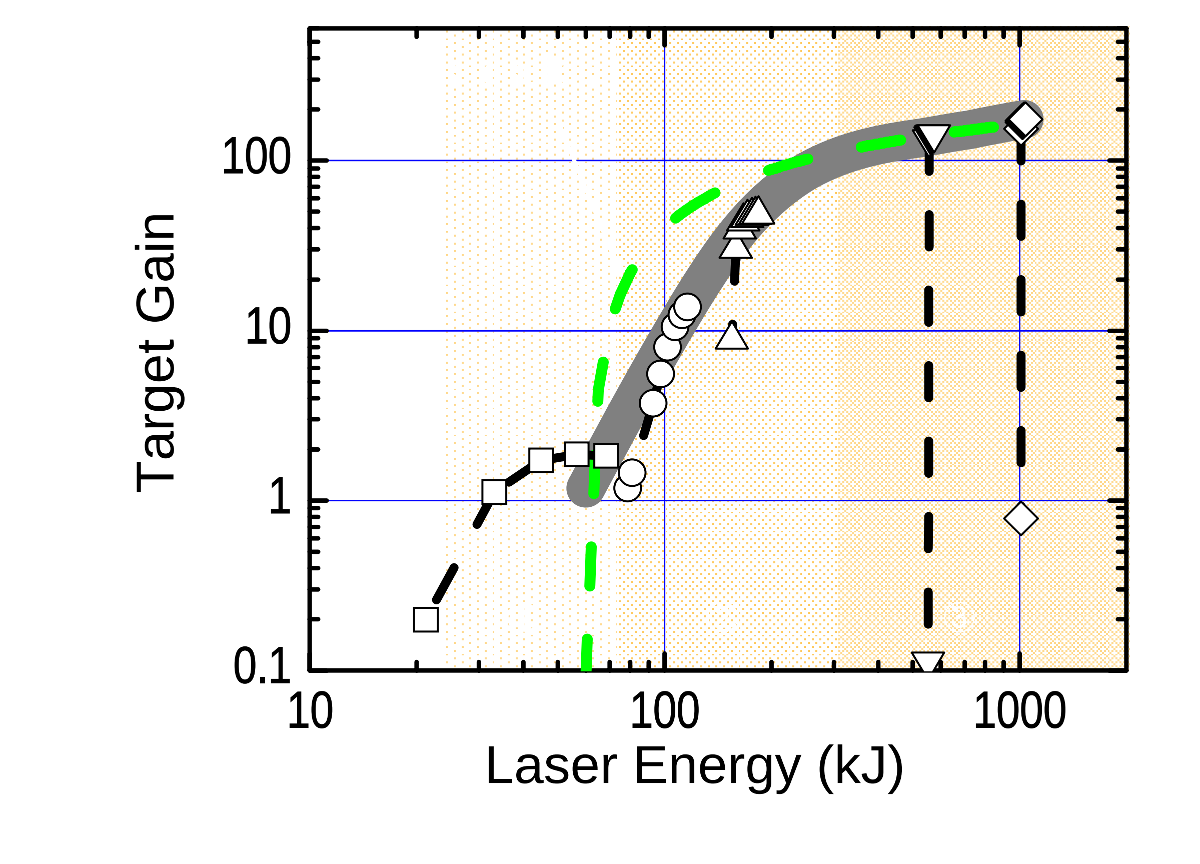


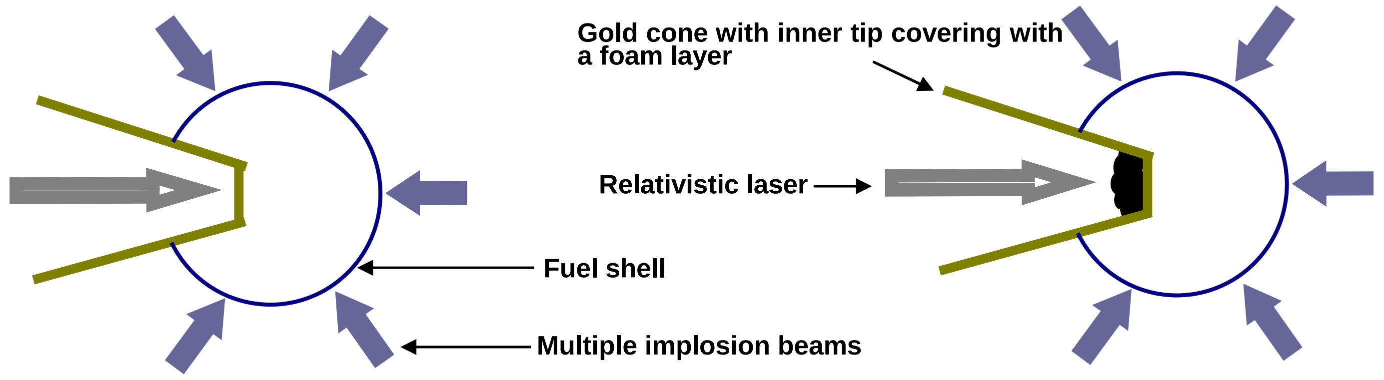
After T.Johzaki, ILE, Osaka U.

Physics Issues

- Electron heating mechanisms of compressed cores?
- Even more higher efficiency possible?
- Cone physics?
- Electro-static & magnetic fields effect?

Gold foam inside the cone is proposed for better coupling.

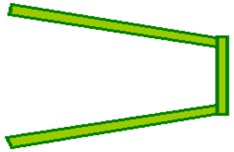
- To increase the heating efficiency of the core plasma, we propose a foam cone-in-shell target design.



•Phys. Rev. Lett., A.L.Lei, K.A. Tanaka et al., 96, 255006(2006).

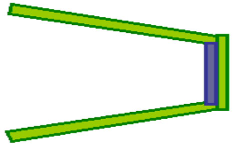
Element experiment demonstration of the improvements of the foam-in-shell target design for fast ignition

- **ILE target group are now fabricating the foam cone and foam cone-in-shell target.**

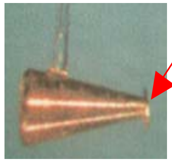


Designed gold cone target.

Fabricated gold cone target.



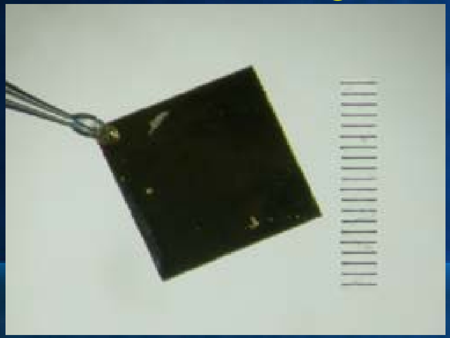
Designed foam cone target. The tip consists of gold foam and solid gold.

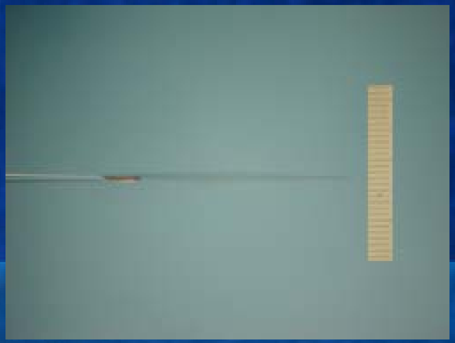


The tip looks like a plate and its size is too large.

Fabricated foam cone target.

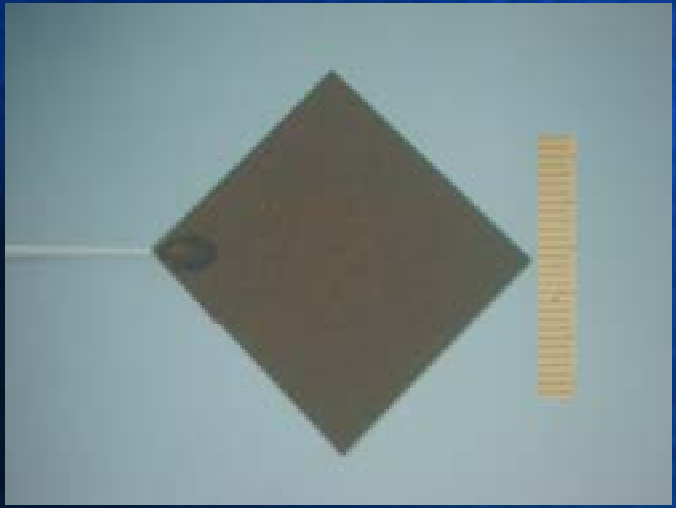
- **We used planar targets in the element experiments. Planar configuration does not change the physics behind the cone tip.**
  - **-to measure –e yield**
  - **-to measure –e temperature**
  - **-to measure –e beam divergence**





Element experiment 1:monitoring the heating of the target rear and measuring –e energy spectra

- **Target types: 20um Mo with front surface coating with 2um thick solid Au or 2um thick 20% solid density Au foam**
  - **-micro-structured targets (nanoparticles, foams, etc) experimentally demonstrate high laser absorption. Expected more hot electrons generated.**
  - **-gold foam used: (expected) to avoid severe suppression of hot –e transport in high-Z thin foam.**



Planar targets used

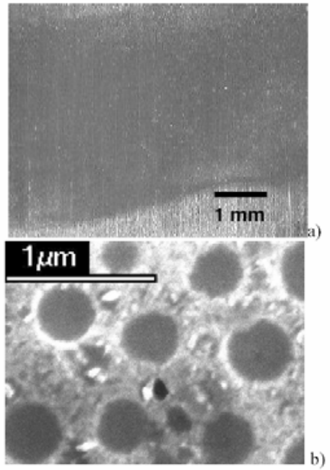


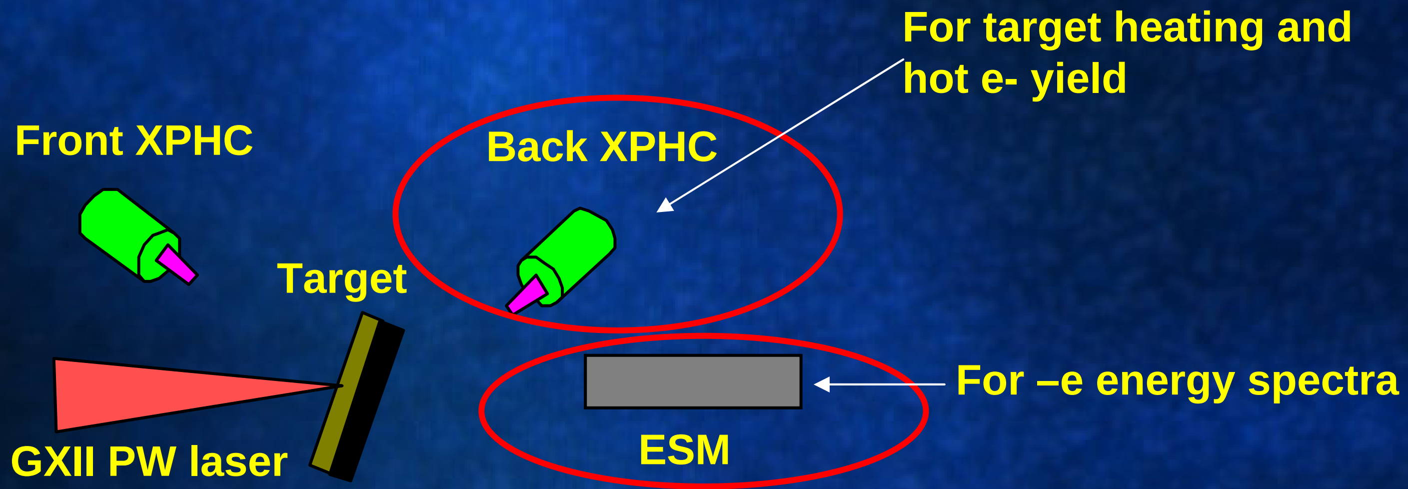
Figure 6. Optical image of gold foam (a) and its SEM image (b). Its thickness was 2 μm and the density was 23 % of bulk gold.

gold foam material

K. Nagai et al., Fusion Sci. & Tech. 49, 686 (2006)

Element experiment 1:monitoring the heating of the target rear and measuring –e energy spectra

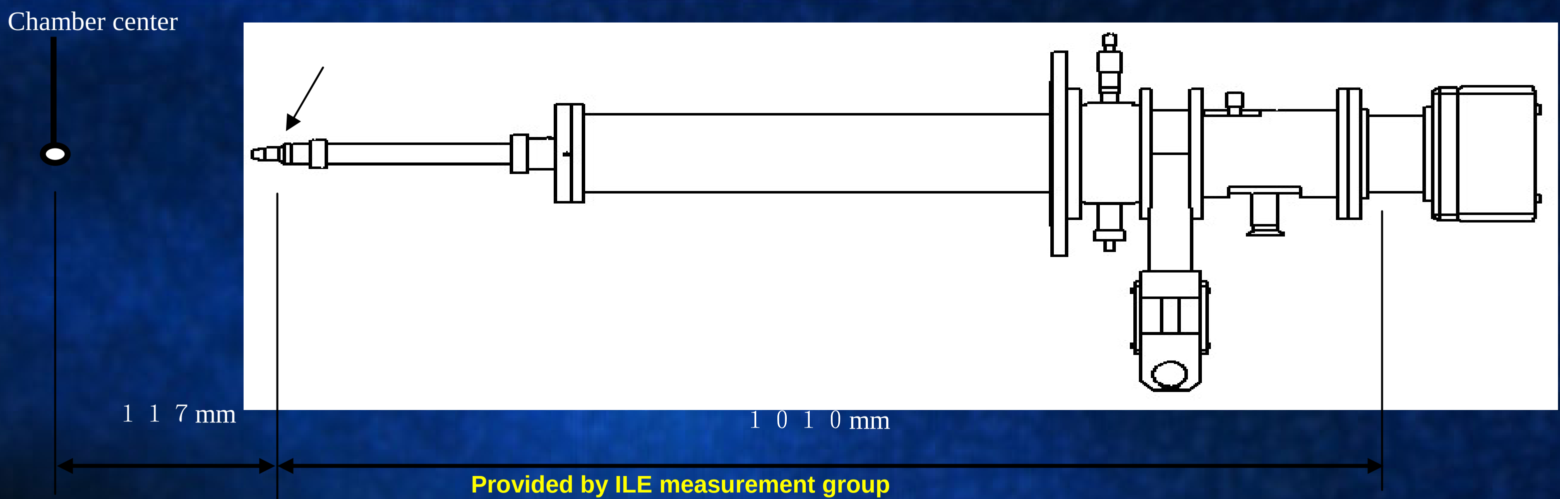
- **Experimental setup:**
  - **-GXII PW laser: ~0.6ps/1.053um/~100J on targets/~70um focus/OPCPA 10^{-8} contrast ratio/f7.6/p-pol/26deg incidence**
  - **-planar targets: 2um Au+20um Mo, and 2um Au foam+20um Mo**
  - **-front XPHC: 18um size pinhole/40um Be filter/KeV x-ray range/M=~8.6**
  - **-back XPHC: 200um size pinhole/40um Be/KeV x-ray range**
  - **-ESM: along the laser axis, energy range 1~100MeV.**



Element experiment 1:monitoring the heating of the target rear and measuring –e energy spectra

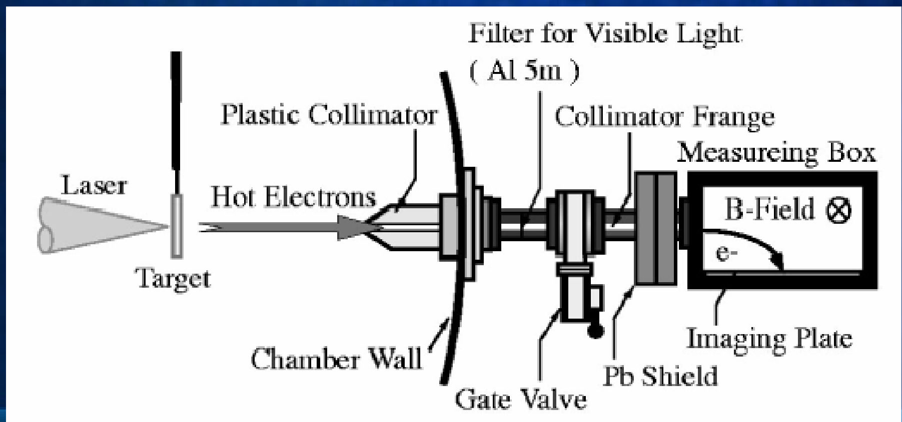
- **Experimental diagnostics:**

  -XPHCs:



Provided by ILE measurement group

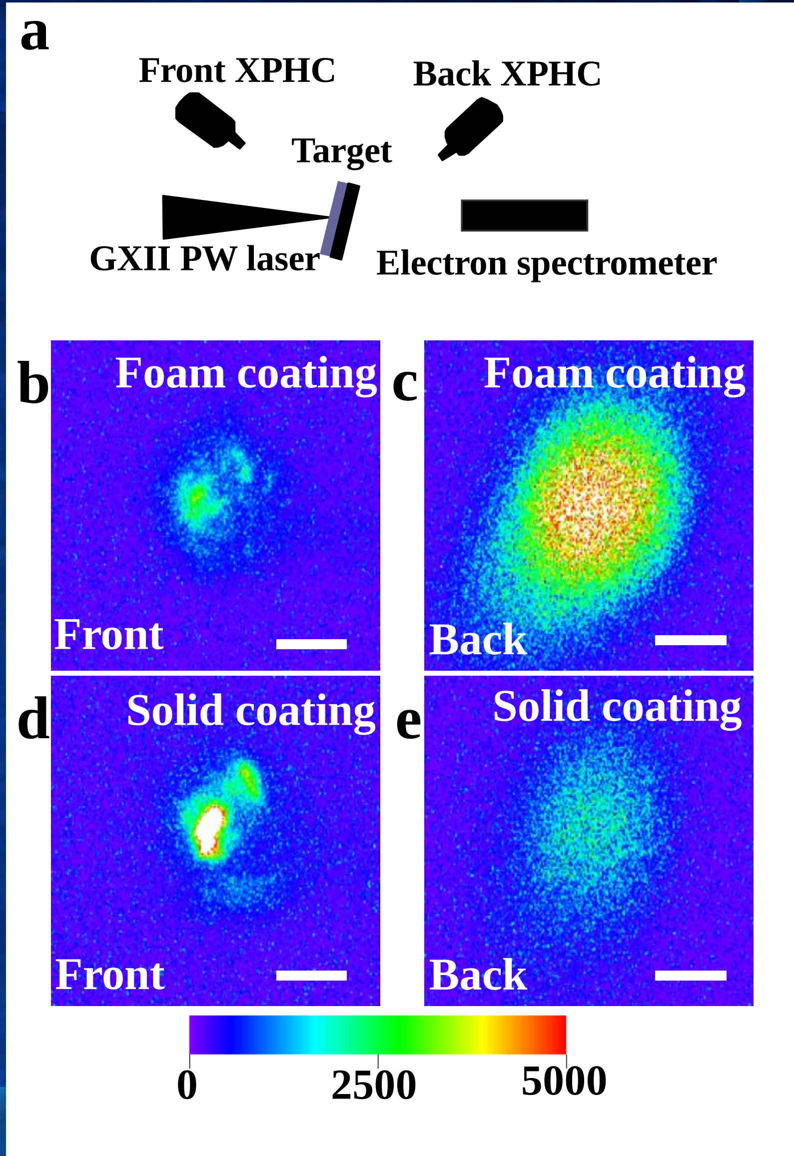
-ESM:



K. A. Tanaka *et al.*, Rev. Sci. Instrum. 76, 013507 (2005)

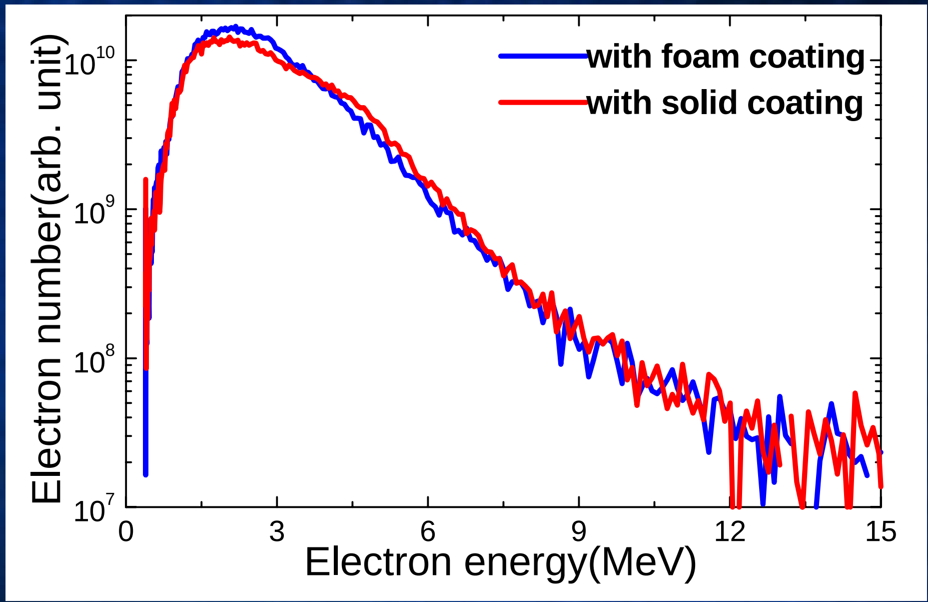
Au foam coating enhances laser absorption and hot electron generation

- Hot -e yield measurement via the back x-ray emission from the target rear due to the heating from hot –e beams
  - -weak front x-ray emission from the Au foam-coated target. This is due to the low density of the foam.
  - -stronger back x-ray emission from the Au foam coated target. This is attributed to higher laser absorption and more hot electrons generated with the foam coated target. Back x-ray emission is caused by the hot –e beam heating of the target rear.
  - -target is thick so that the front x-ray emission may not be responsible for the enhancement of back x-ray emission with foam coated target. Moreover, if it happens, one would expect weak x-ray emission from the foam coated target rear, contrary to the experimental results.
  - -narrow band-width x-ray image diagnostics needed to give the relative hot –e yield through assuming Plankian emission from the target rear.
  - -quantitative models and simulations needed



Au foam coating does not change the hot – electron energy spectral characteristics

- **Hot -e energy spectra are very similar for solid gold coated and gold foam coated targets, showing a temperature ~1.5 MeV, a typical value for solid aluminum targets**



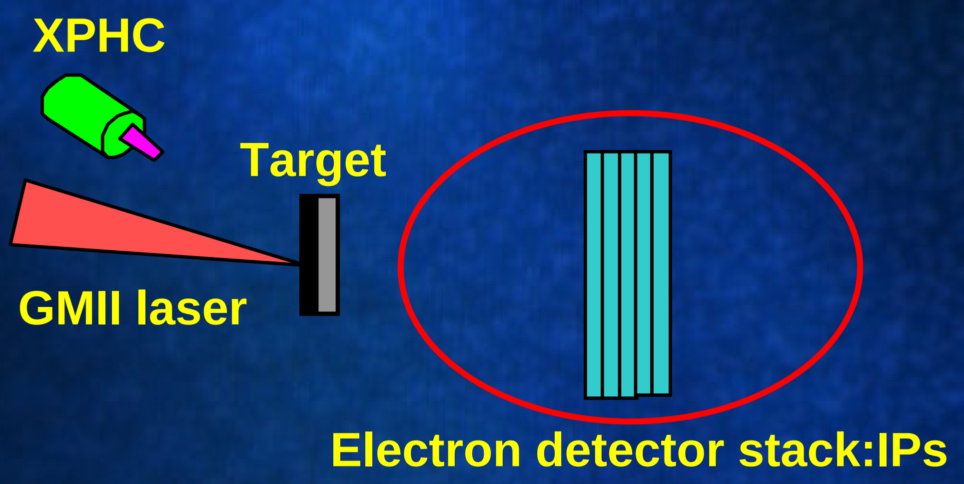
- **There is a question: why there is no comparable increase in the amount of hot electrons observed with Au foam coated target?**

  In vacuum electrons escaping from the target is fully limited by the static potential.

  [T. Yabu-uchi et al., submitted to Phys. Rev. E.]

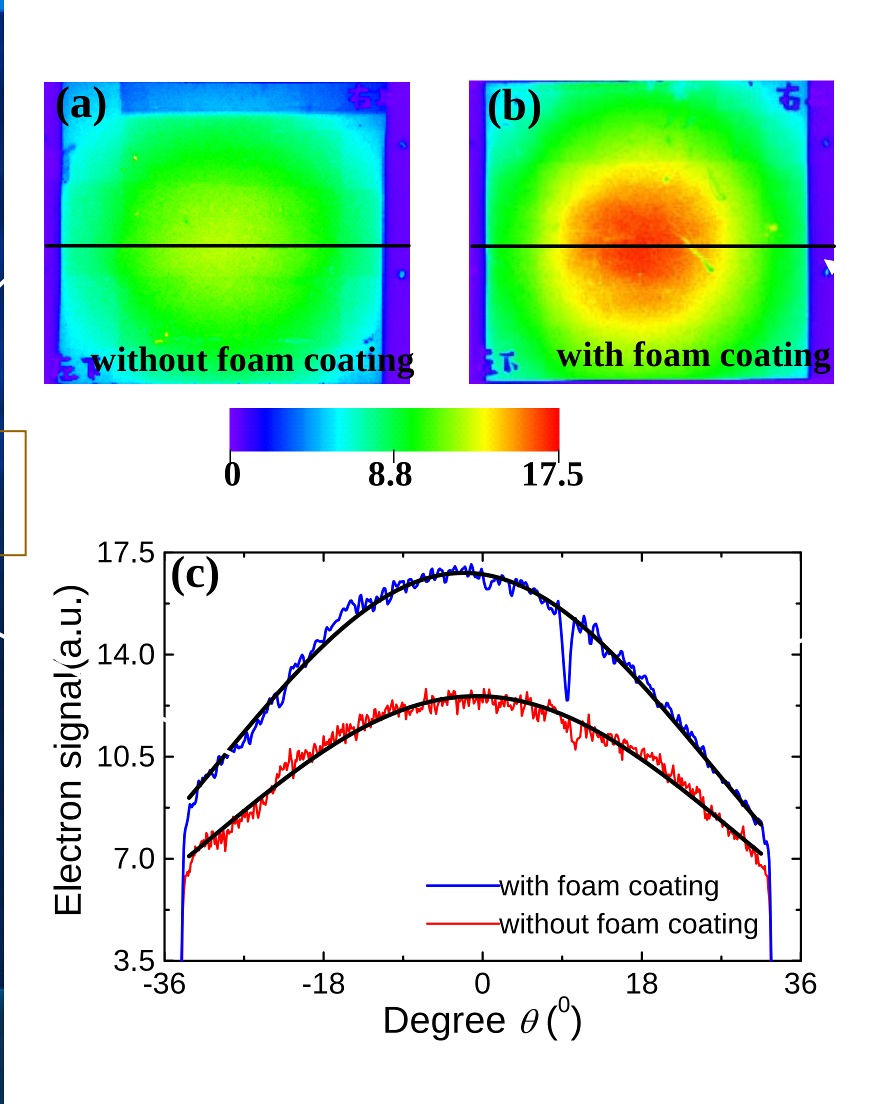
Element experiment 2: measuring –e beam divergence

- **Target types: 10um Au foam+10um Au, 12um solid Au**
- **Experimental setup:**
  - **-GMII laser: ~0.6ps/1.053um/~10J on targets/~25um focus/OPCPA 10^{-8} contrast ratio/f3.8/p-pol/21deg incidence**
  - **-detector stack: placed 40mm away from the target, consisting 12 um Al, 500um plastic plate, and imaging plate**



Element experiment 2: measuring –e beam divergence

- **The Au foam coating does not increase the –e beam divergence.**
- **There is no filamentary structure observed with the foam coated target.**



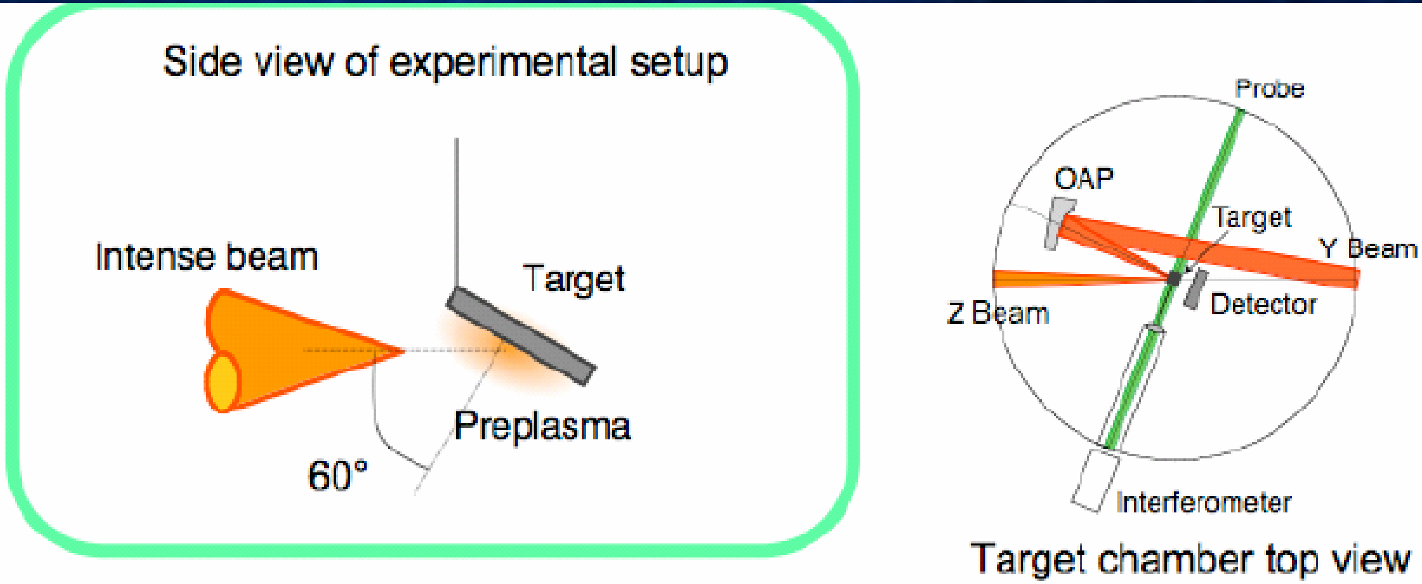
Electron images

72^0(FWHM) for solid Au target

68^0(FWHM) for foam coated target

Electron profiles
Fitted with Gaussian dist.

Cone physics is studied.
-Laser light hitting the cone surface with oblique incidence.-



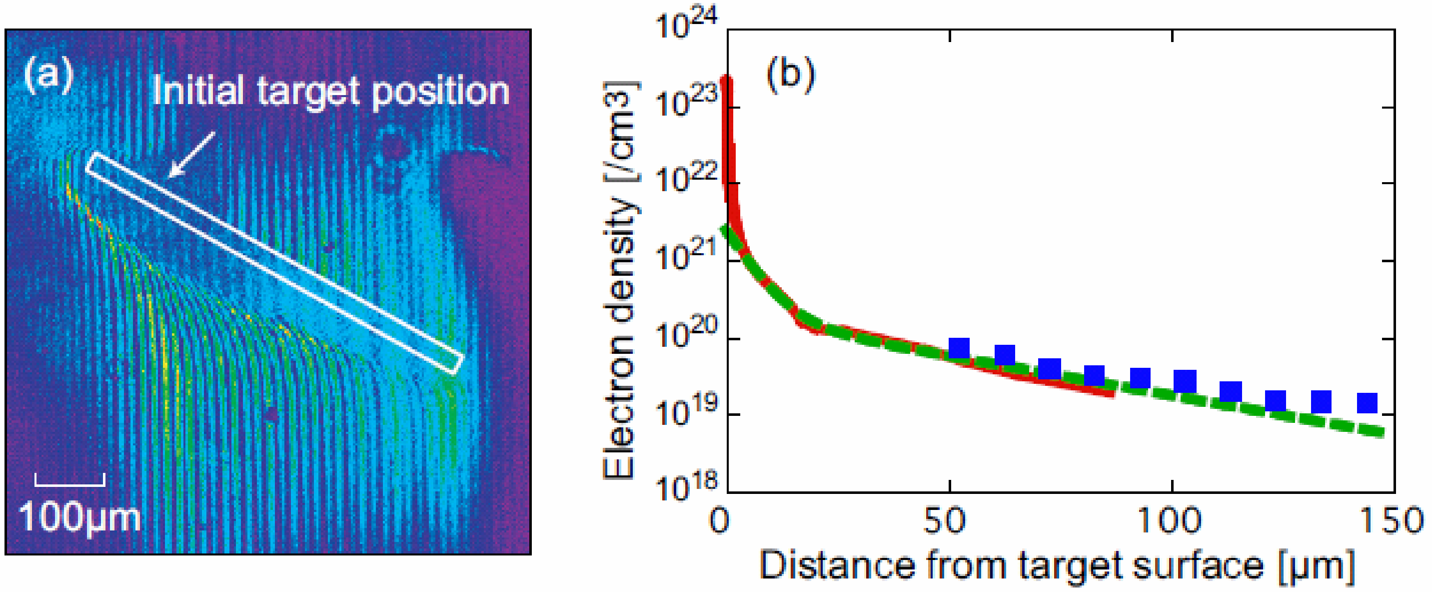
Gekko MII 30TW laser system, Osaka University:

Y Beam: Short pulse, 20J/600fs, λ=1μm, I~10^{18}Wcm^{-2}

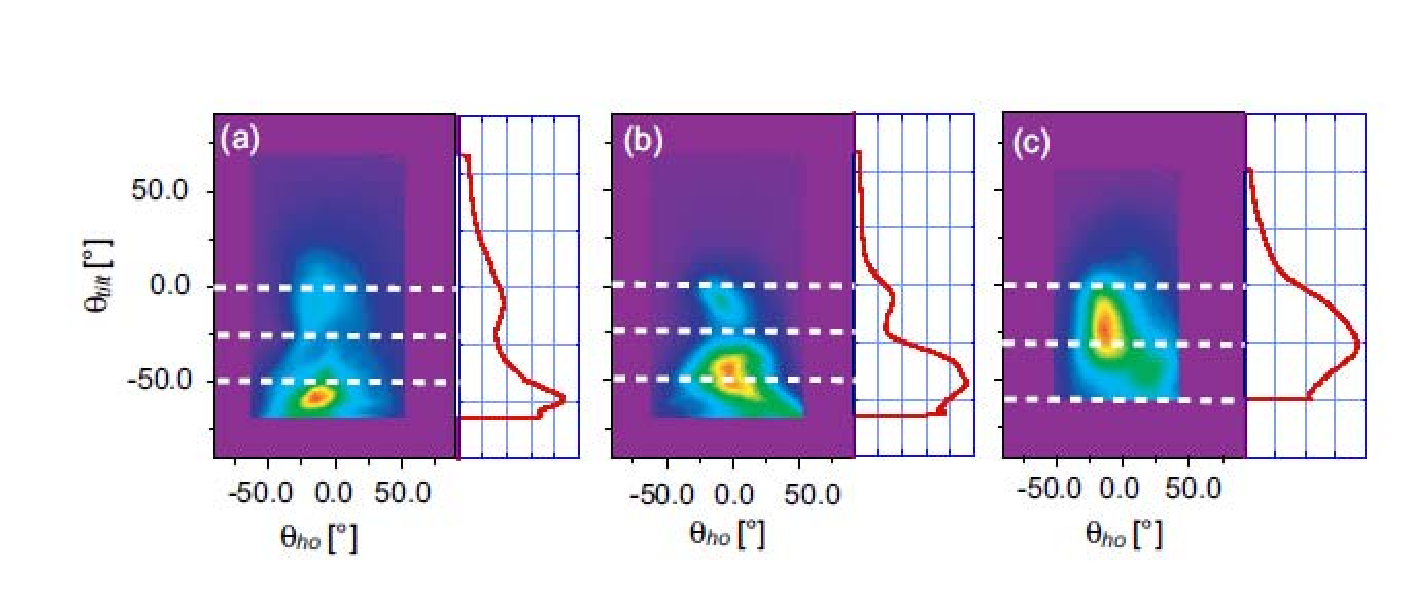
Z Beam: Long pulse, 1J/300ps, I~10^{12}Wcm^{-2}

Probe beam: 20ps Pulse width, 50ps time interval after Y Beam

Pre-formed plasma



Pre-plasma target with increasing intensity

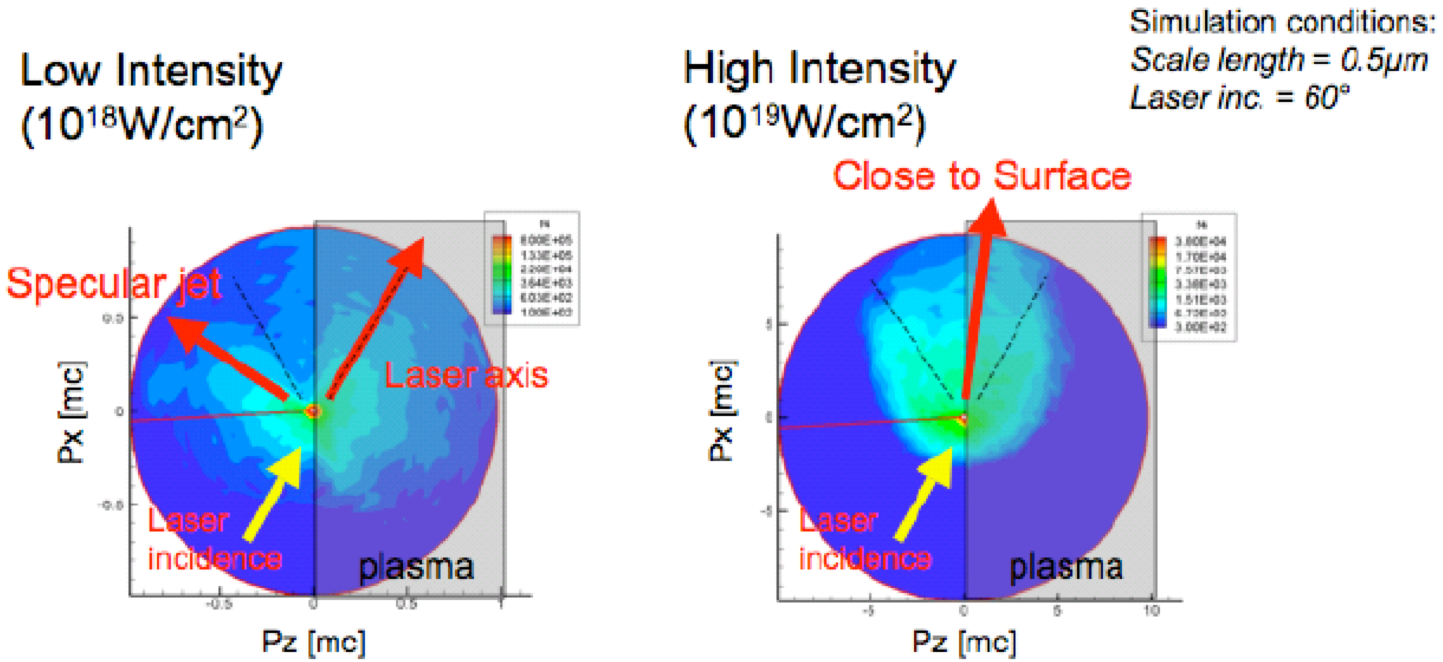


Laser axis
Target surface
Specular

(a) 10^{17}, (b) 10^{18}, and (c) 3 x10^{18} W/cm^2

PIC simulation shows surface hot electrons at 10^{19} W/cm^2

As laser intensity increase, fast electron distribution changes…

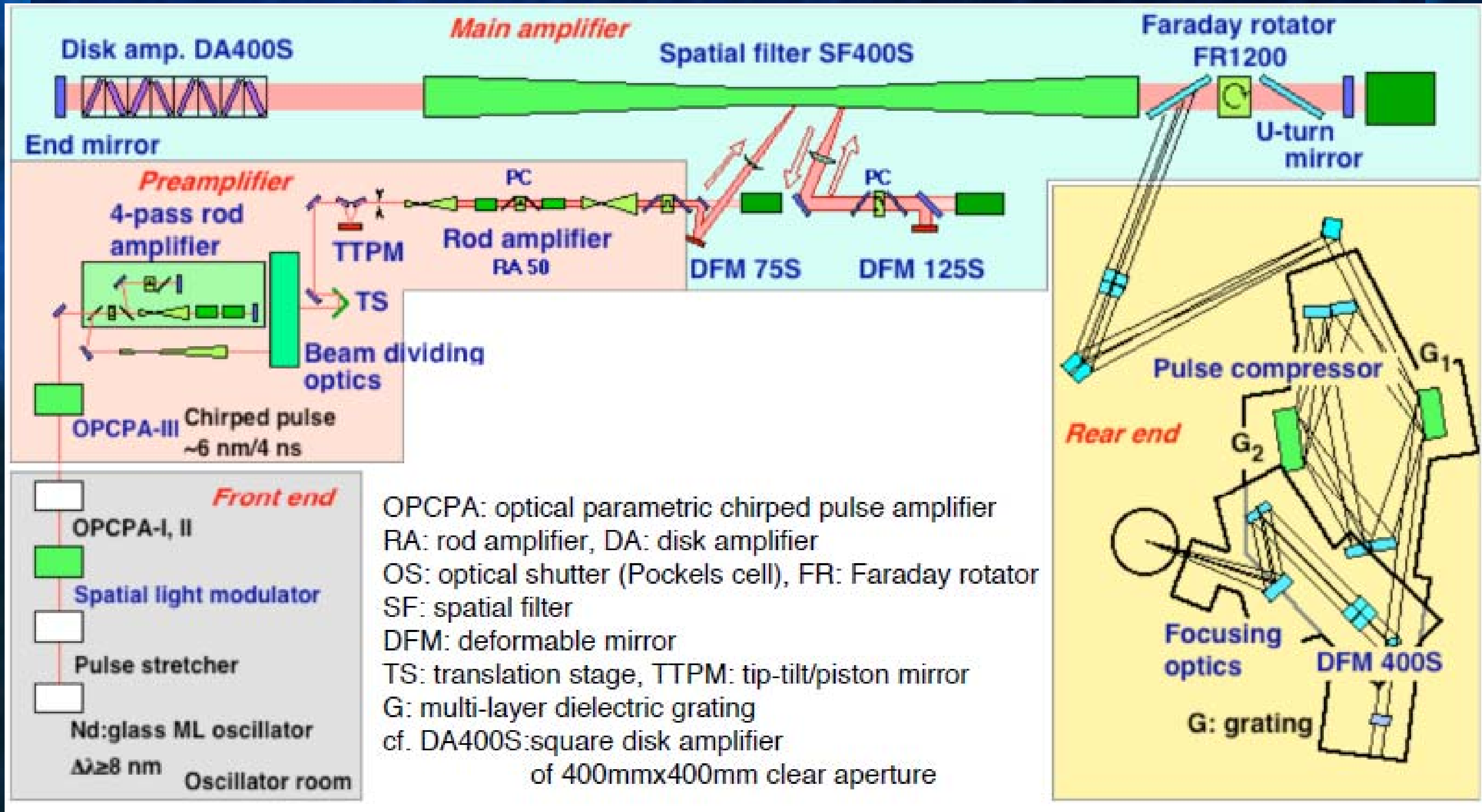


When the laser field is strong enough, strong magnetic field can be formed along the target surface which lead to surface electron flow

10 kJ 10^{15} W peak power laser for fast ignition under construction.

- Wavelength 1053 nm
- Energy = 10 kJ
- Peak Power = 10^{15} W
- Pulse Width = 1 – 10 psec.
- Beam Size = 4beam x 40 cm x 40 cm
- Focused Laser Intensity > 10^{19} W/cm^2

LFEX 10 kJ PW laser system at ILE Osaka



Fast heating laser needs short and energetic pulse.

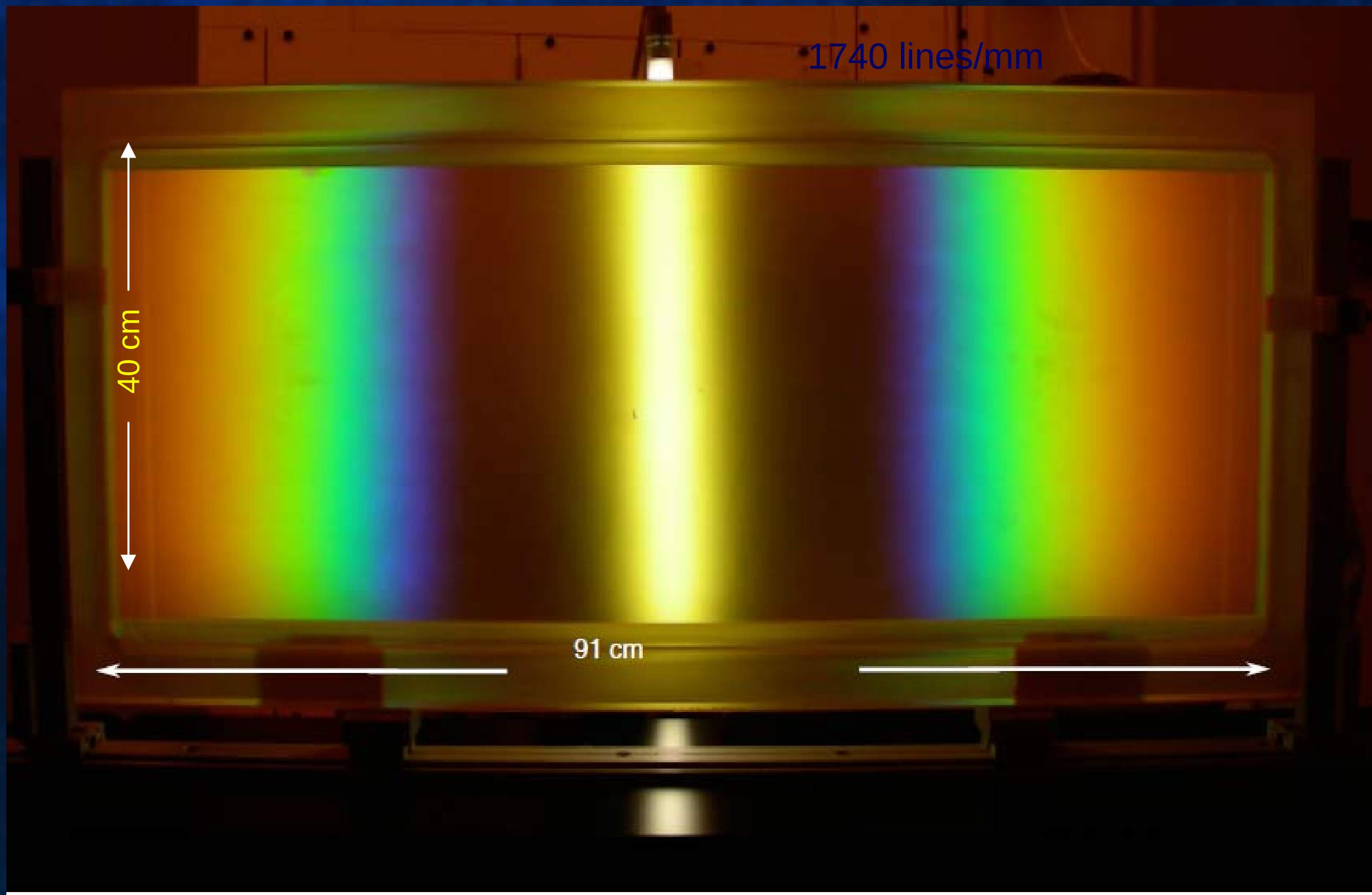
- Short pulse is created with pulse compression using,

$$\Delta \nu \Delta t = const.$$

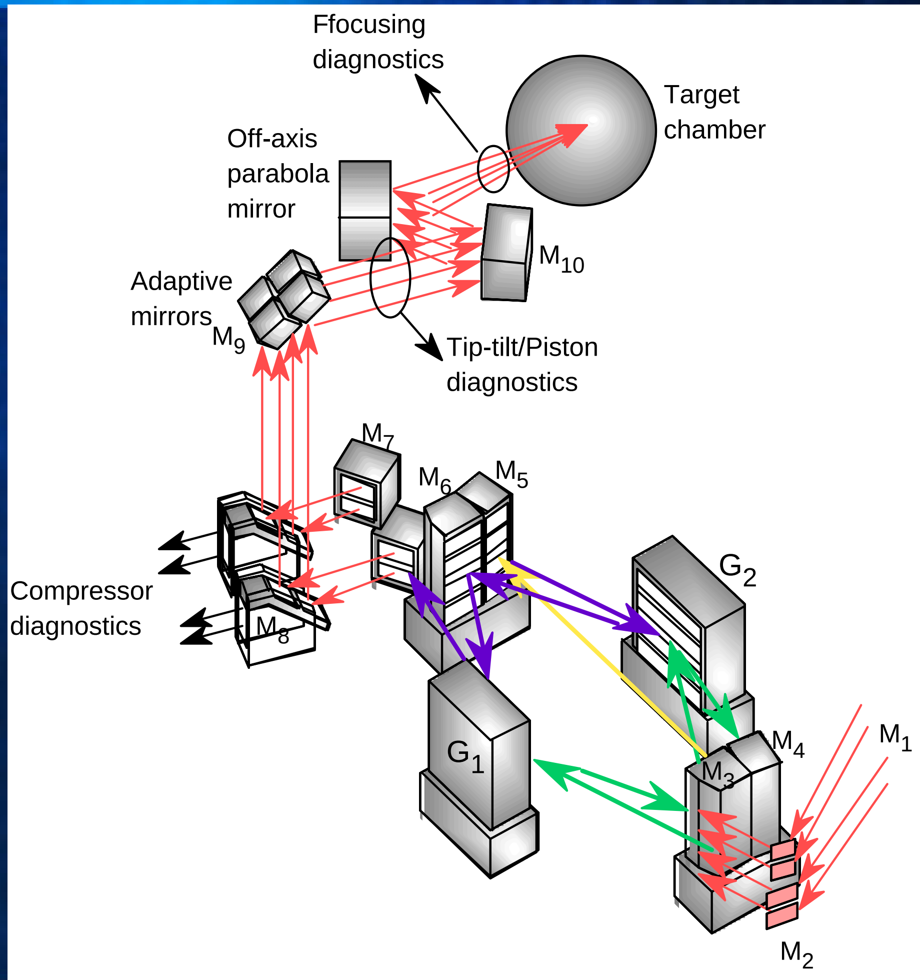
We use a large band width laser $\frac{1}{\Delta \nu} \propto \Delta \lambda \propto 40nm$

The laser pulse is oriented from blue to red and is amplified. Then the blue and red parts are put together by gratings for the pulse compression.

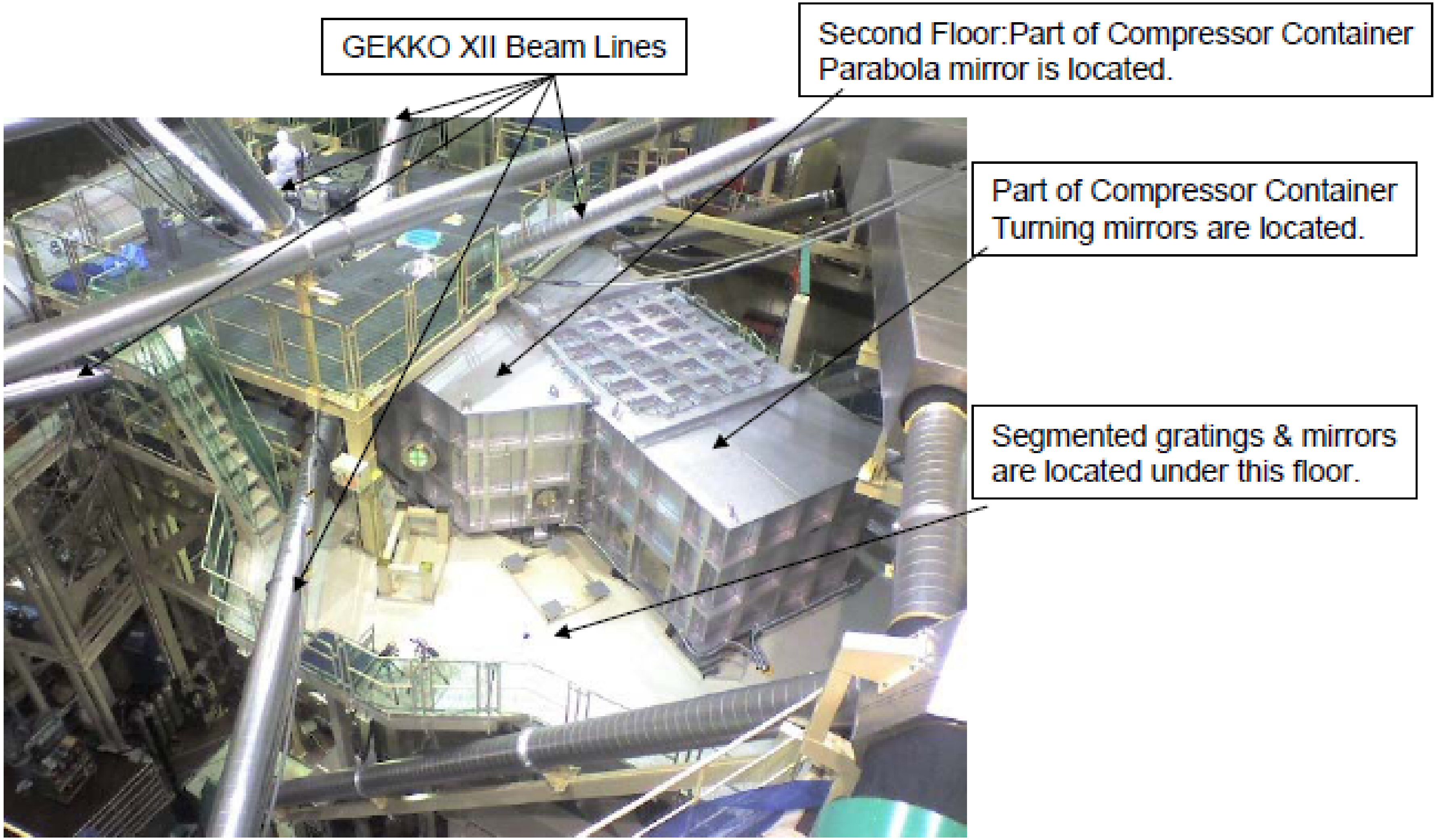
Large MLD grating of 1740 grooves/mm



Rear End of LFEX system



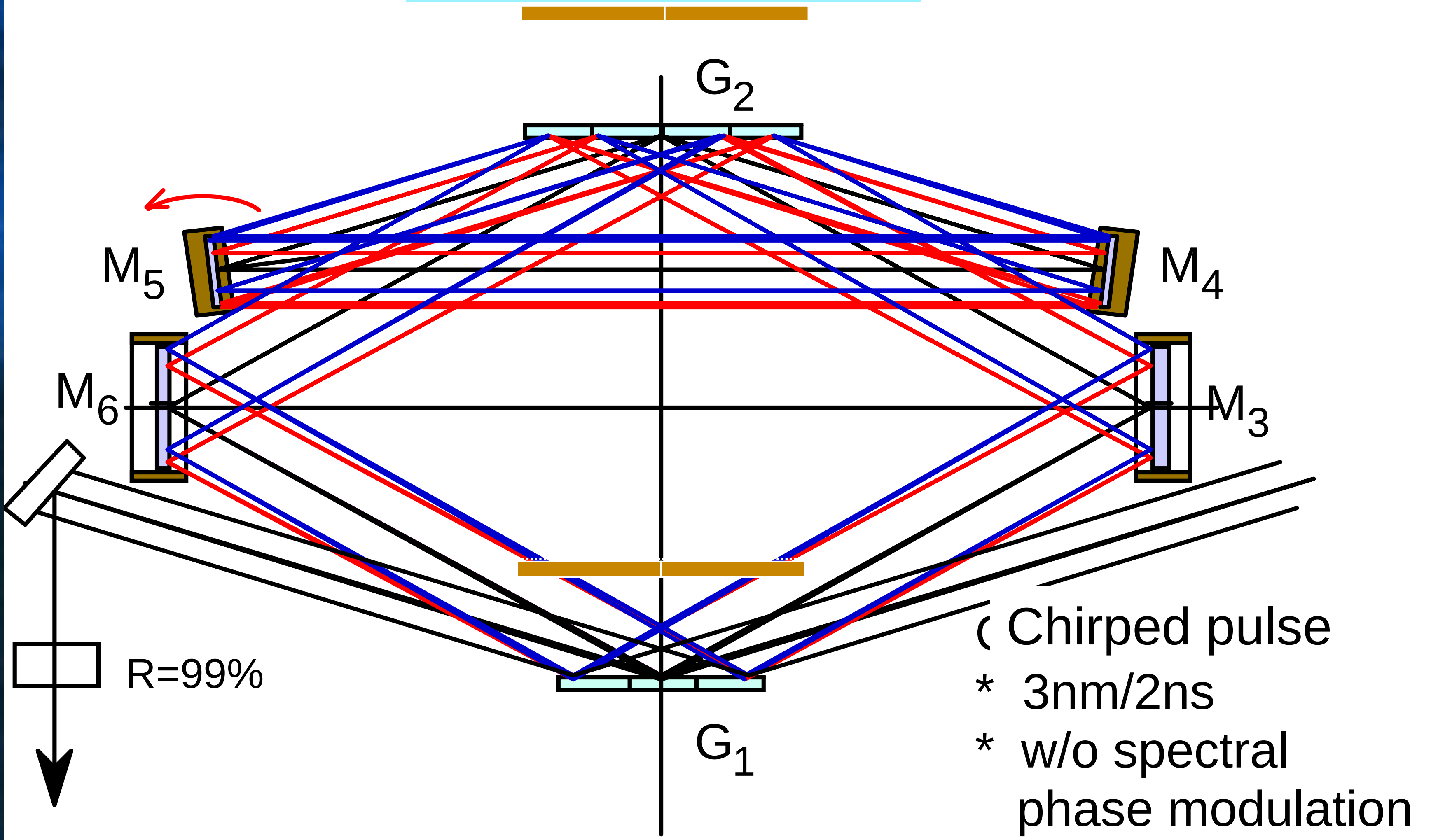
Grating Chamber has been installed.



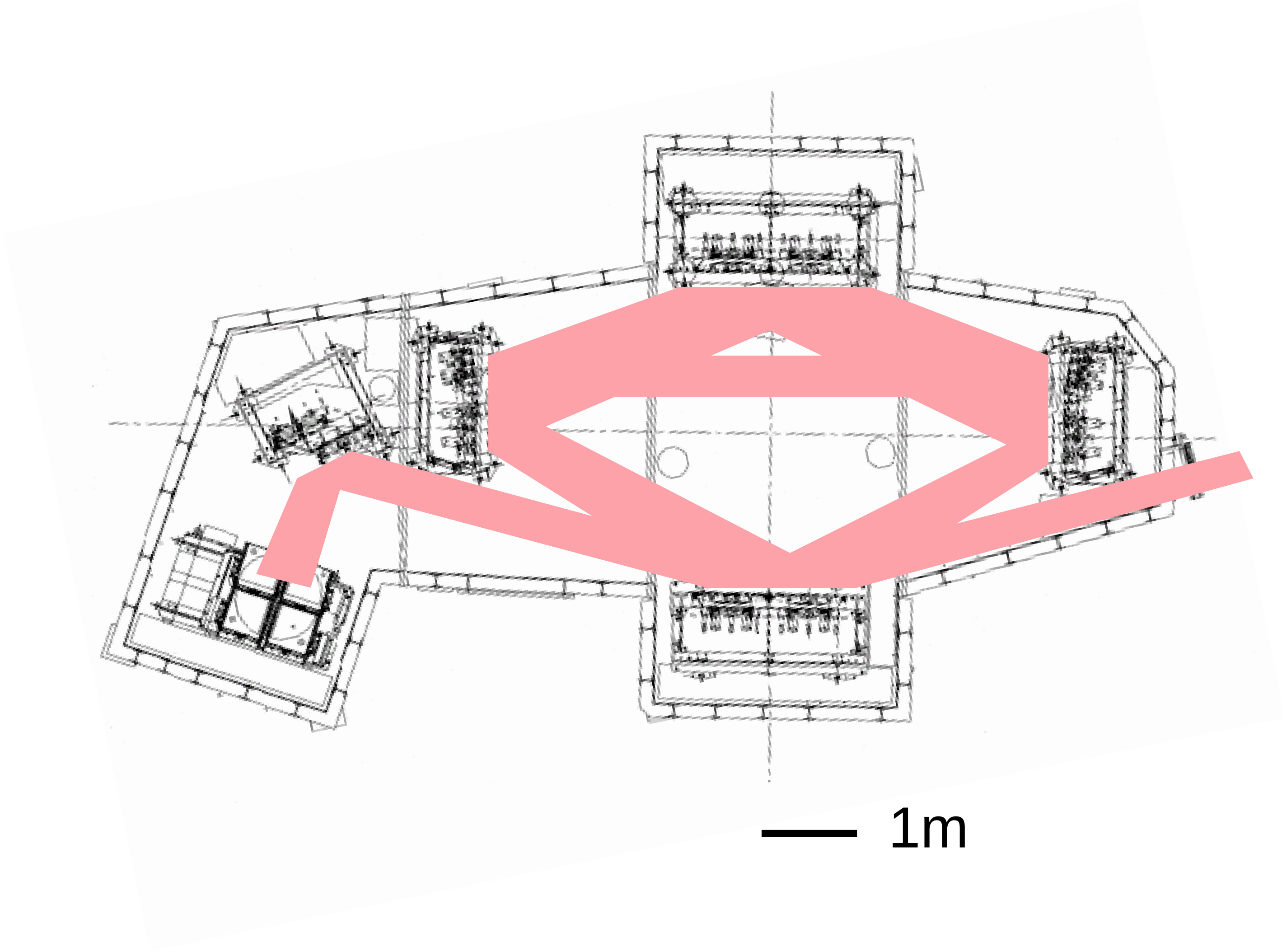
Diamond-shape double-pass compressor

(with large element gratings)

Overall stability check



FIREX Compressor Configuration



Summary 1

- Cone-guide method demonstrated the mechanism of fast ignition.

  R.Kodama *et al.* Nature **412** 798-802 (2001); **418**, 933 (2002)

- We propose a foam cone-in-shell target design to improve the laser energy deposition in the dense core plasma.

  Phys. Rev. Lett., A.L.Lei, K.A. Tanaka et al., 96, 255006(2006).

Summary 2

- Surface hot electrons observed at oblique incidence UIL experiment.
- Relativistic laser self-focusing increases laser intensity causing surface hot electrons.
- Several tens of MGauss field inferred

H. Habara, K.A. Tanaka et al., Phys. Rev. Lett. 97, 095004(2006).

Summary 3

- LFEX laser is under construction to test the fast sub-ignition condition.
- 10 % of ignition level should be achieved.

- We introduce many challenging optics technology to LFEX.
- LFEX will be completed in 2008.