High energy and high average power laser for plasma diagnostics

'Efficient second harmonic generation with pico-seconds pulses from a chirping TRAM regenerative amplifier'

Ryo Yasuhara
National institute for fusion science

Collaborators

National Institute for Fusion Science
I. Yamada

Plasma Research Center, University of Tsukuba
M. Yoshikawa

Institute of laser engineering, Osaka university
Junji Kawanaka, Takahisa Jitsuno

Institute for laser technology
Hiroaki Furuse, Shinji Motokoshi

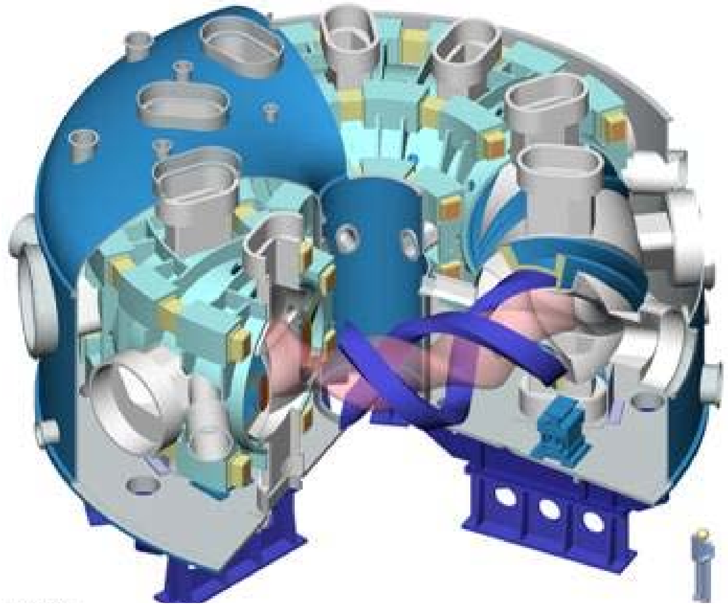
Nagoya university
Shin kajita, Masaya Sato

Contents

- Introduction and laser Thomson scattering for plasma diagonostics
- Development of high energy and high repetition probe laser system for plasma diagnostics
- Laser induced damage in nuclear fusion application

About National institute for fusion science

LHD：Large helical device

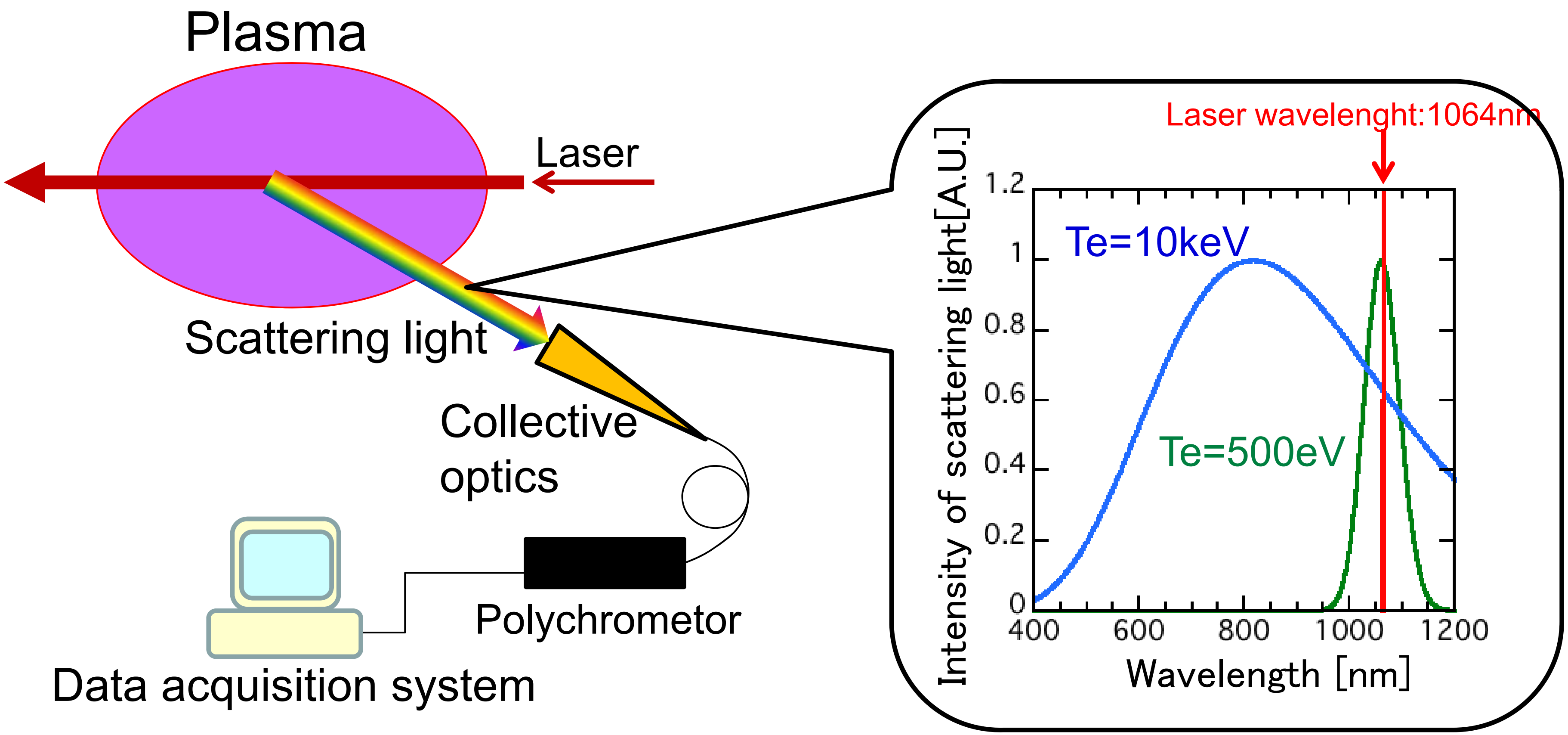


To conduct fusion-plasma confinement research in a steady-state and important research issues for plasma physics.

Our institute focused on the basic study about the magnetic confinement fusion and the inertial fusion. In this research, high energy and high average power laser is very important.

Laser Thomson scattering method

- Thomson scattering diagnostics is one of the most reliable methods for determining the local electron temperature and density in fusion plasmas.

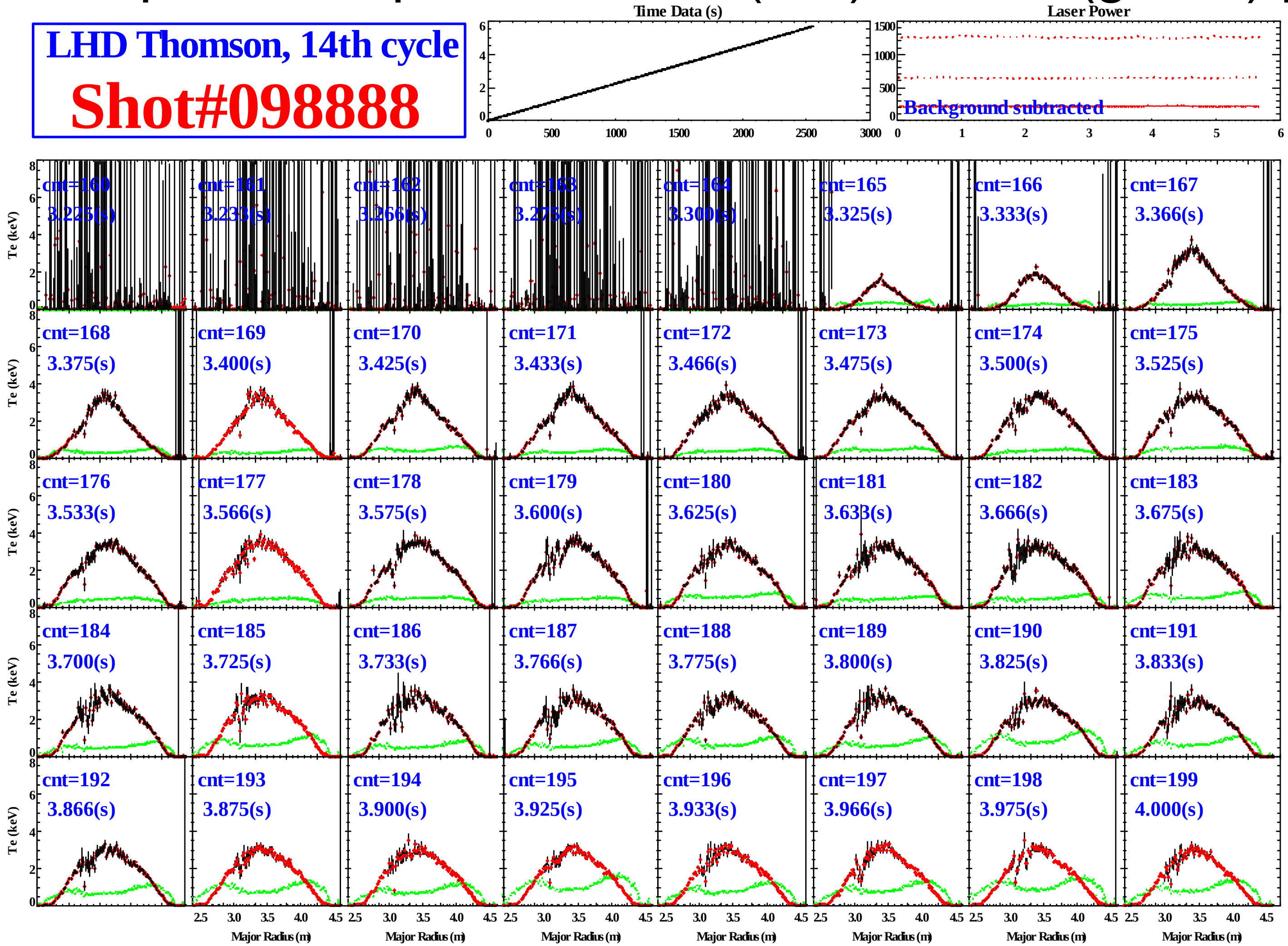


LHD Thomson Scattering

- LHD TS has following features:
  - **Multi-laser System**
    - Currently, we use 4 flash lamp pumped Nd:YAG lasers.
    - 2J / 10Hz Laser X 2
    - 1.6J /30Hz Laser X 1
    - 0.5J / 50Hz Lasers X 1
  - **Backward Scattering Configuration**
    - Scattering angle at the plasma center = 167^{o} .
  - **(5+1) Wavelength-CH Polychromators**
    - 1-5 CHs detect Thomson scattering signals.
    - The 6^{th} CH is installed for absolute Rayleigh calibration.
  - **FASTBUS Data Acquisition System**

LHD Thomson Scattering

- The example of snap shots of Te (red) and ne (green) profiles



Development of a probe laser for the Thomson scattering system

- Thomson scattering diagnostics is one of the most reliable methods but….

Thomson scattering cross section is very small: $6.65 \times 10^{-25} cm^2$

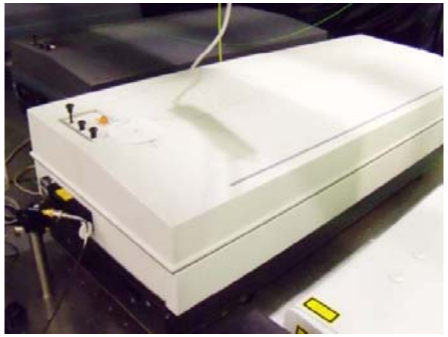
Over 1 J in 10 ns lasers are needed for Thomson scattering system. Signal to noise ratio and repetition rate of TS are limited by a probe laser .

We are try to develop the advanced TS probe laser system by following methods.

- Multiple laser system
- Multi-pass laser probing method
- Development of the new laser system

Development of a multi-laser system

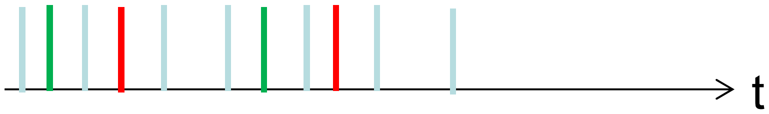
Multi-laser system



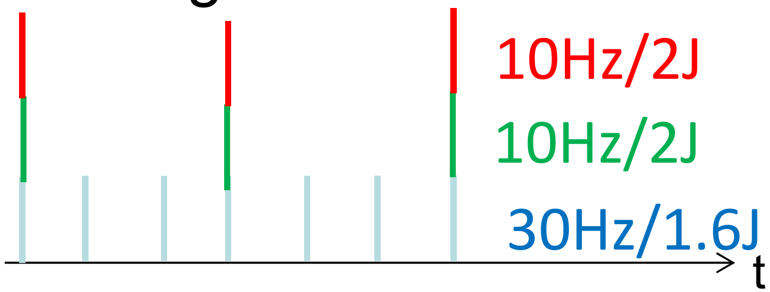
1.6 J x 30Hz laser

Two 2J x 10Hz lasers

Laser operation mode1 :
For high time resolution

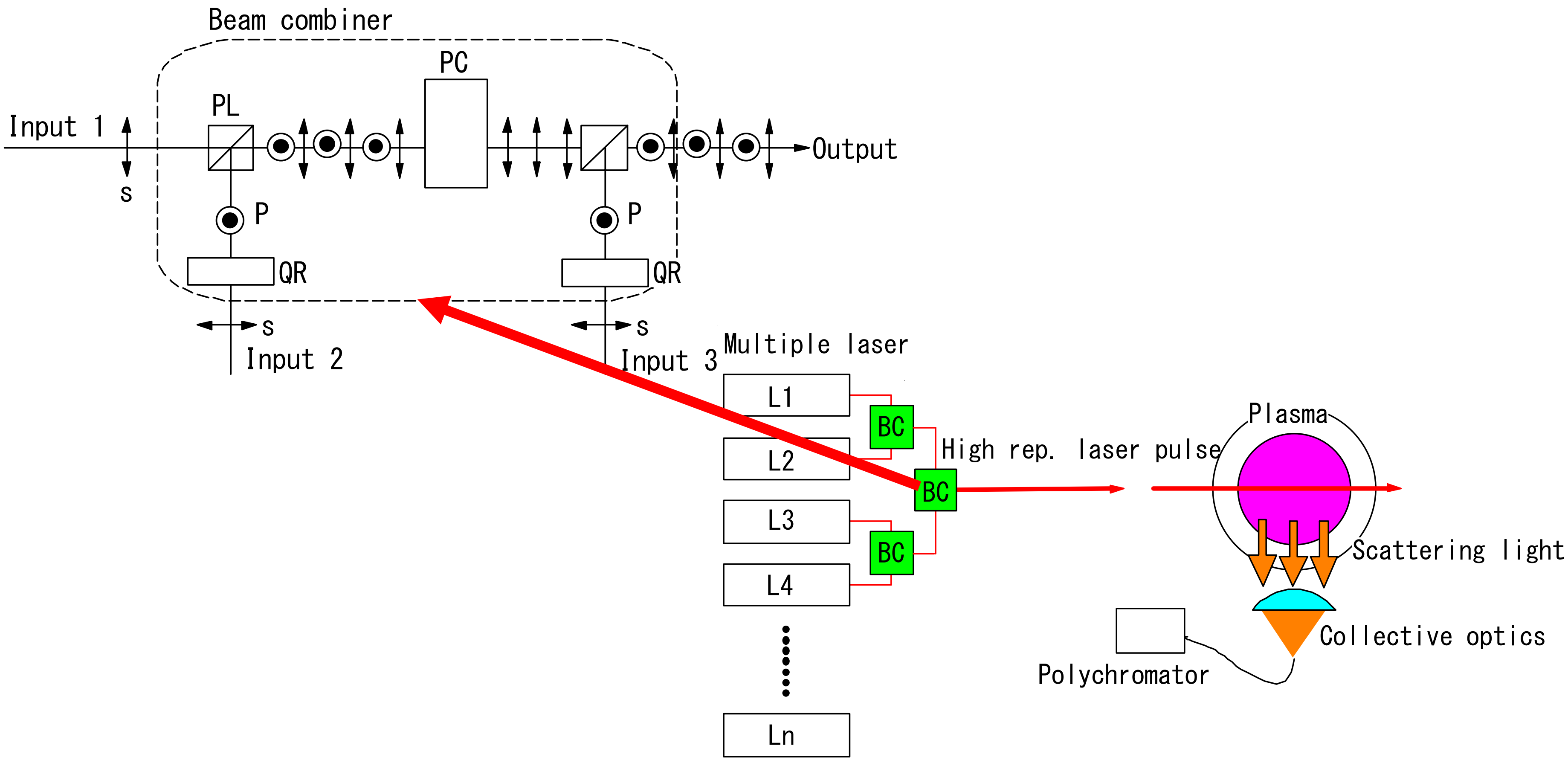


Laser operation mode2 :
For high S/N ratio

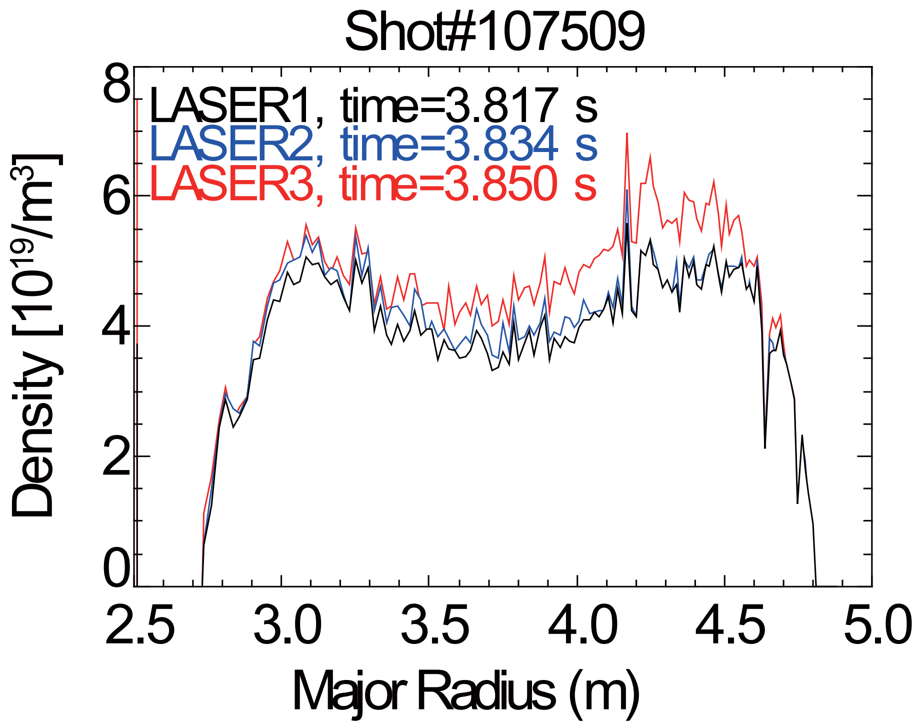


Co-axially polarization beam combining method

To minimize the multiple-laser error, we proposed the co-axially beam combining system which employs Pockel's cells and the polarizers to combine each pair of orthogonally polarized laser beams.



Electron density profiles at steady state plasma measured by multi-laser system



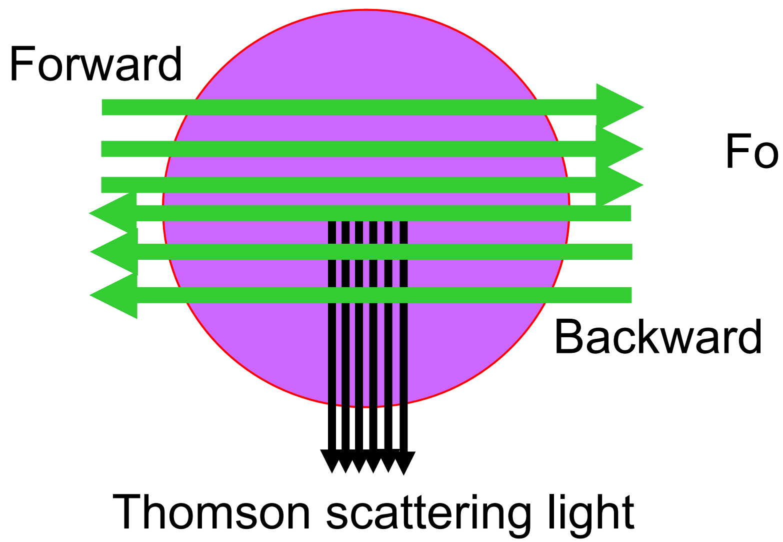
This figure shows good agreement between the ne profiles measured by coaxially laser 1 and 2.

In contrast, the ne profile measured by laser 3 is different. That has a different laser beam axis.

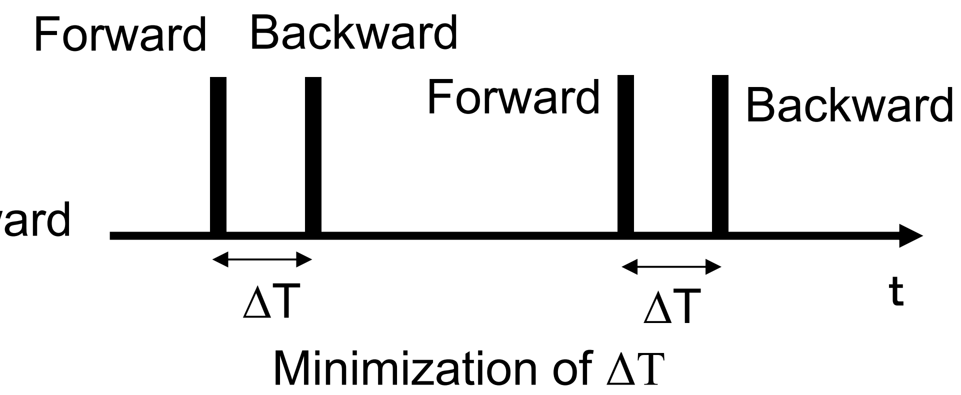
R. Yasuhara et al., PFR (2012)

Multi-pass probing system for Thomson scattering

A multi-pass Thomson scattering method



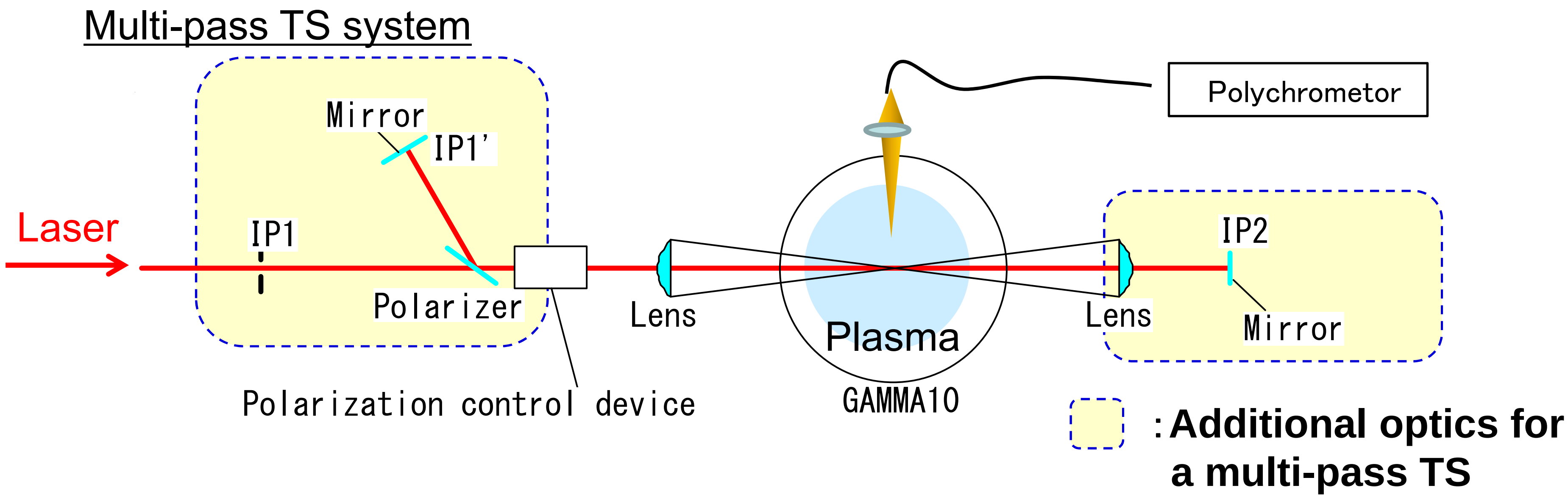
Increasing scattering light



Improvement of time resolution

A multi-pass TS system allows the laser pulse to be focused several times onto the plasma, thus increasing the scattering photon number or increase the time resolution of the scattering light from the plasma.

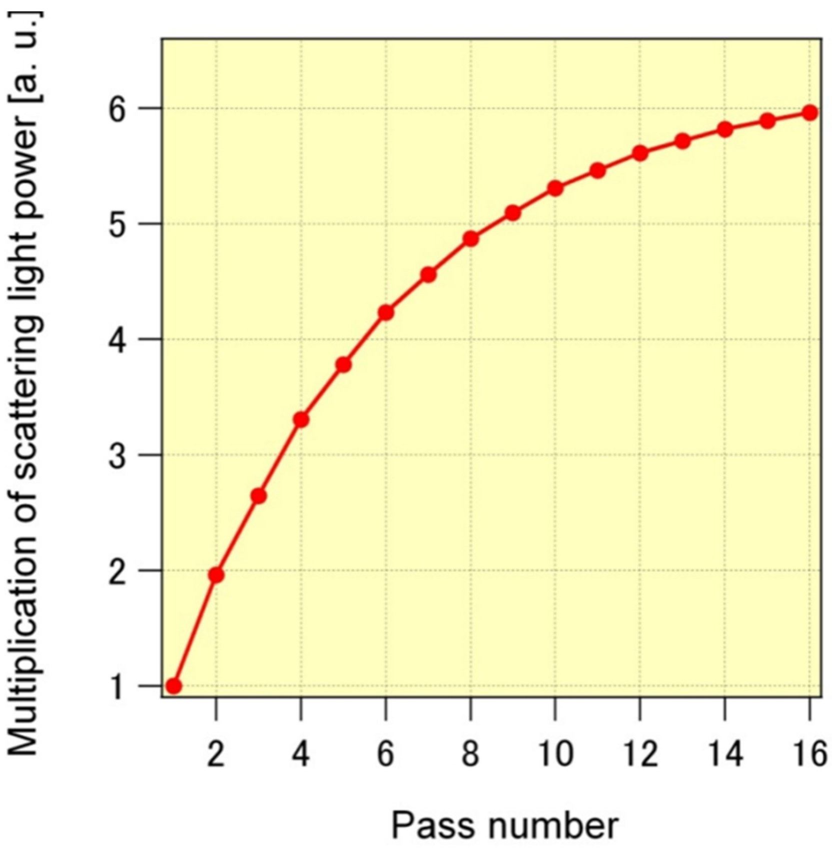
New method: Polarization controlled multi-pass system



Features

- Image relay configuration
  (To maintain the laser beam quality)
- Coaxial multi-beam pass
- Polarization switching

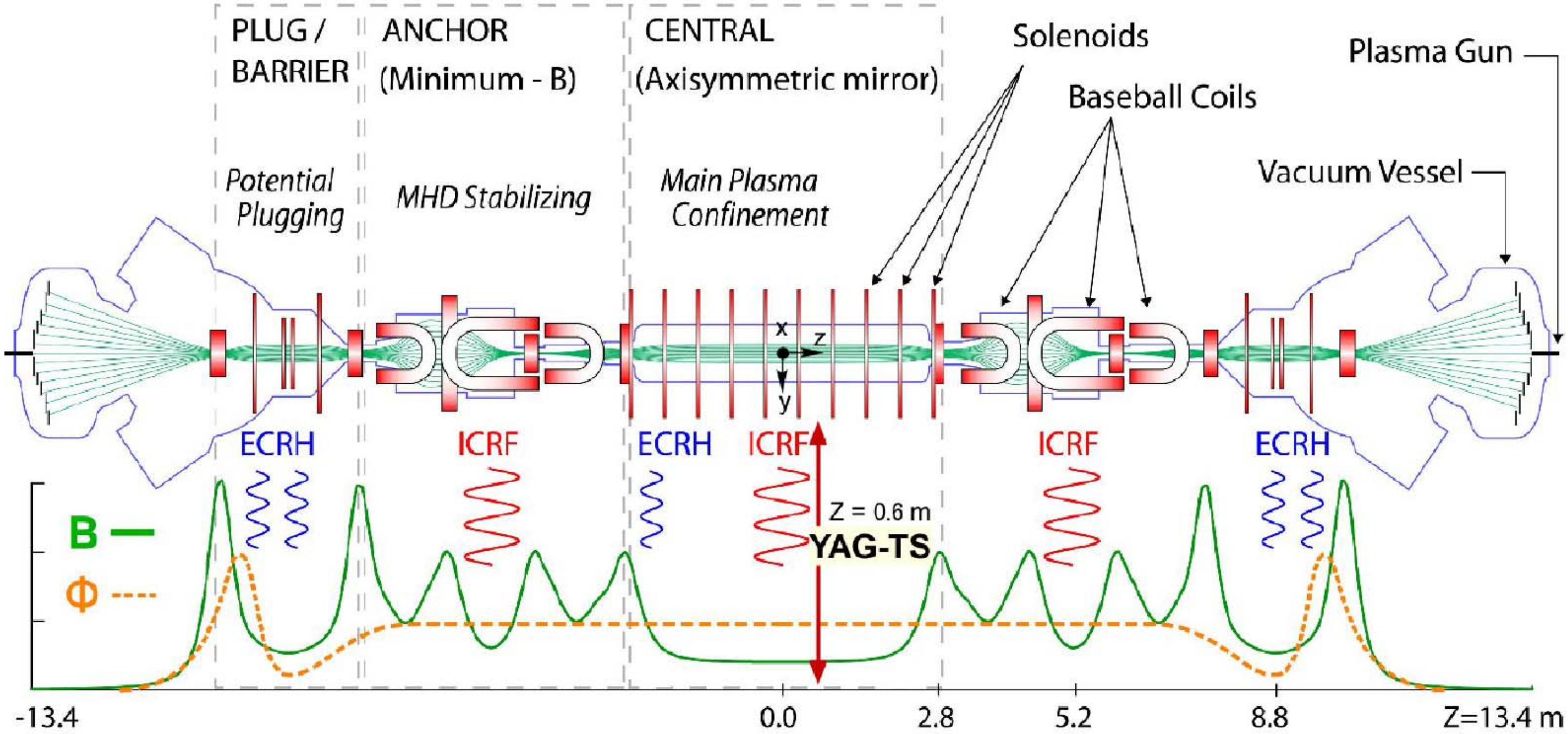
Estimation of the multiplication of the scattering light



- The multiplication of the scattering light as a function of a pass number from the result of the optical design.

- At the 2 pass was the twice larger and the sixteenth pass configuration, scattering light was about six times larger than the single pass configuration.

GAMMA10 tandem mirror

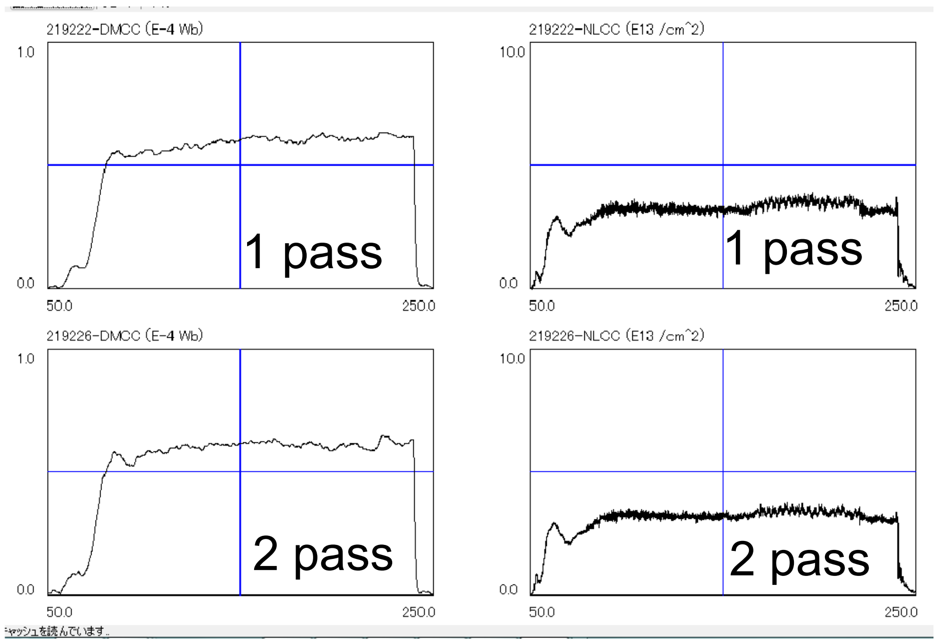


$n_e = n_i \sim 2 \times 10^{18}\ m^{-3}$
$T_e \sim 40 \sim 80$ eV
$T_i \sim 5$ keV

Result of double pass

We measured the scattering signal from 1 pass and 2 pass system at equivalent 2 plasma shots.

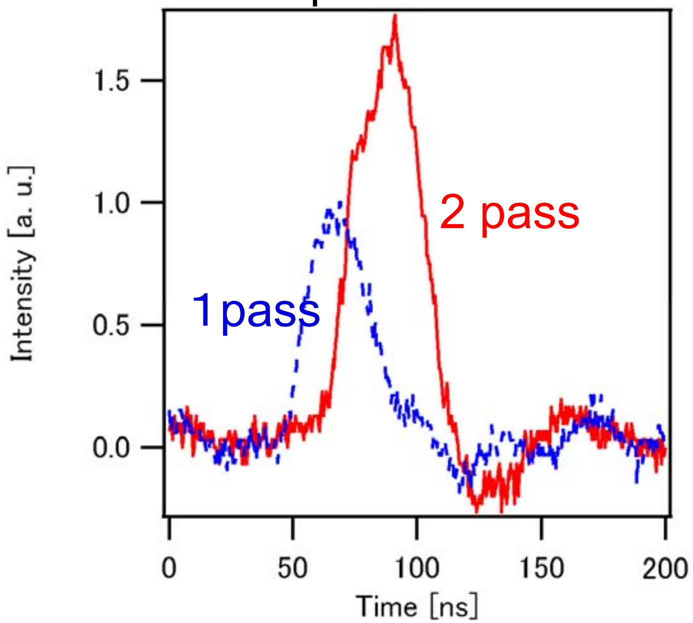
Line integrated density and Wp



Line integrate density and Wp is equivalent at the 2 plasma shots.

R. Yasuhara et al., RSI (2012)

Scattering light intensity at a single and double pass



The integrated scattering signal of double pass configuration is 2 times larger than the signal of single pass configuration.

Development of the new laser system

Thomson scattering laser system development for a magnet confinement fusion reactor

- At a magnet confinement fusion reactor, the number of ports on the vacuum vessel should be reduced.

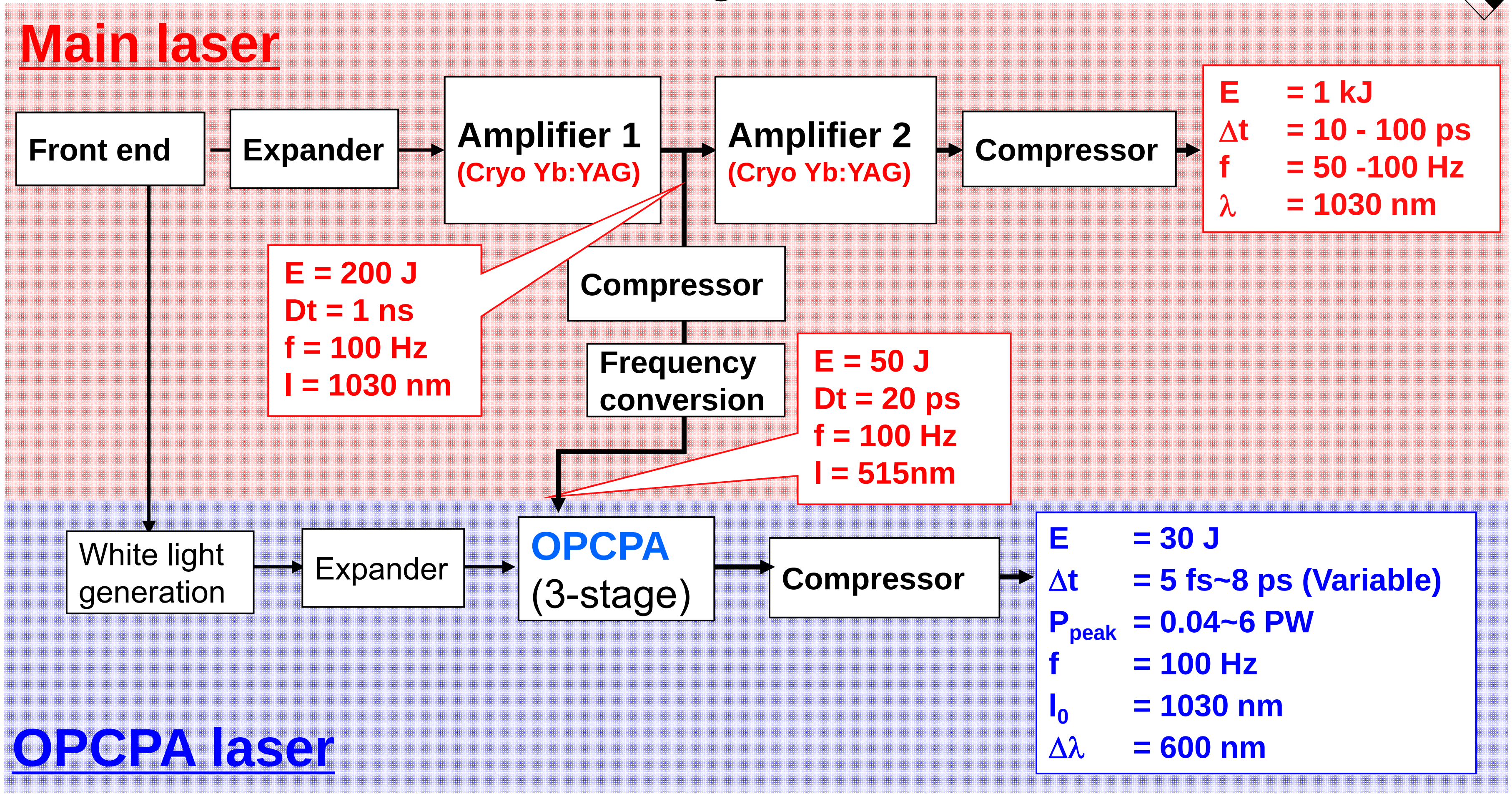
→ One of candidates to minimize the number of ports is LIDER technique. By using this technique we can get the electron temperature and electron density from single port.

However, LIDER Thomson scattering system needs a pico-second and Joule class with high repetition rate laser system.

And green laser light is preferable because of the sensitivity of a silicon photo detector.

GENBU laser

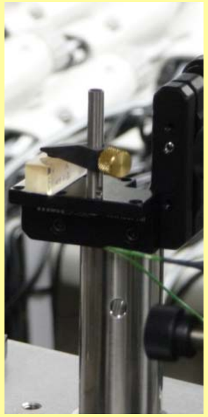
*GENBU = **G**eneration of **EN**ergetic **B**eam **U**ltimate*



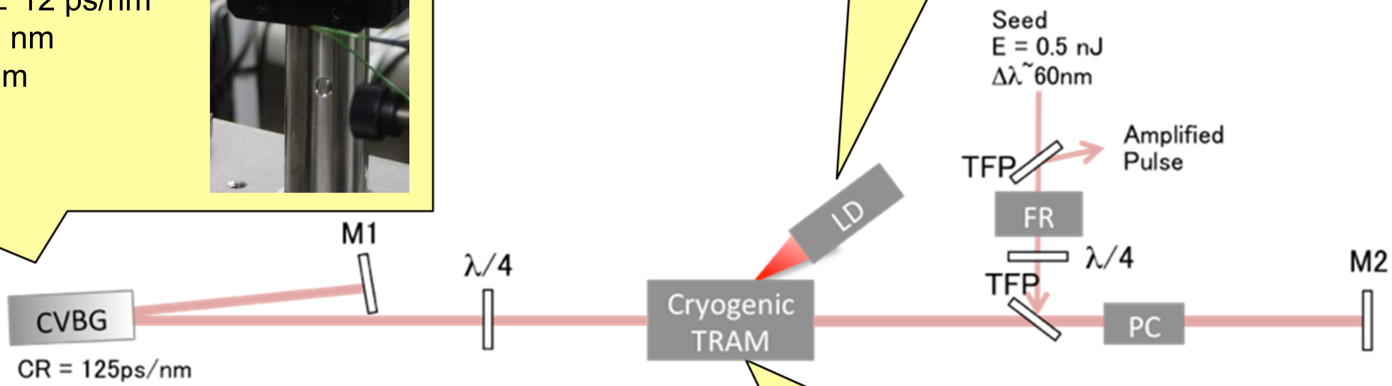
A part of GENBU system is suited for a probe laser of LIDER Thomson scattering system.

Cryogenic Yb:YAG regen. with CVBG

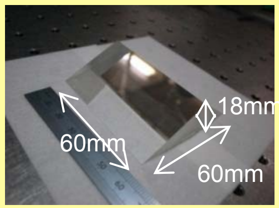
CVBG
8 mm x 8 mm x 25 mmt
60 ps/nm ± 12 ps/nm
λ_c = 1030.8 nm
$\Delta\lambda$ = 0.87 nm



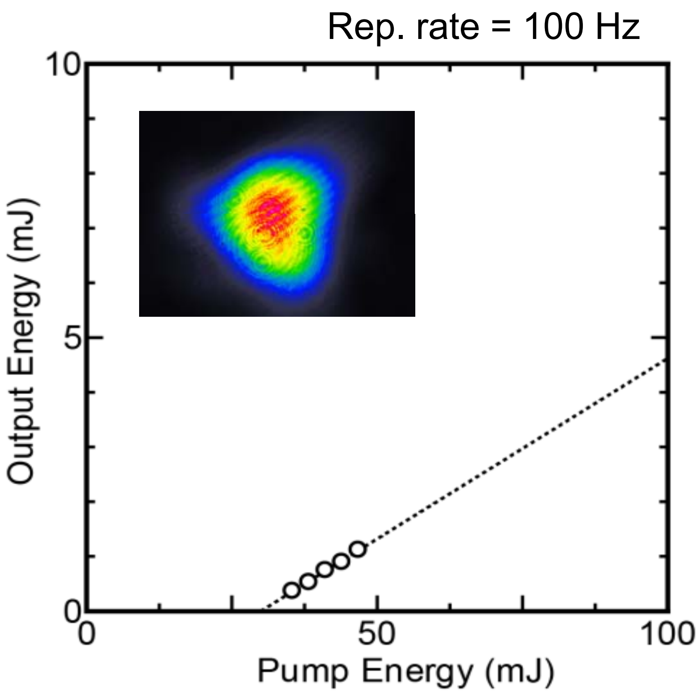
fiber-coupled LD
QCW
150W max., 700μs, 100Hz)

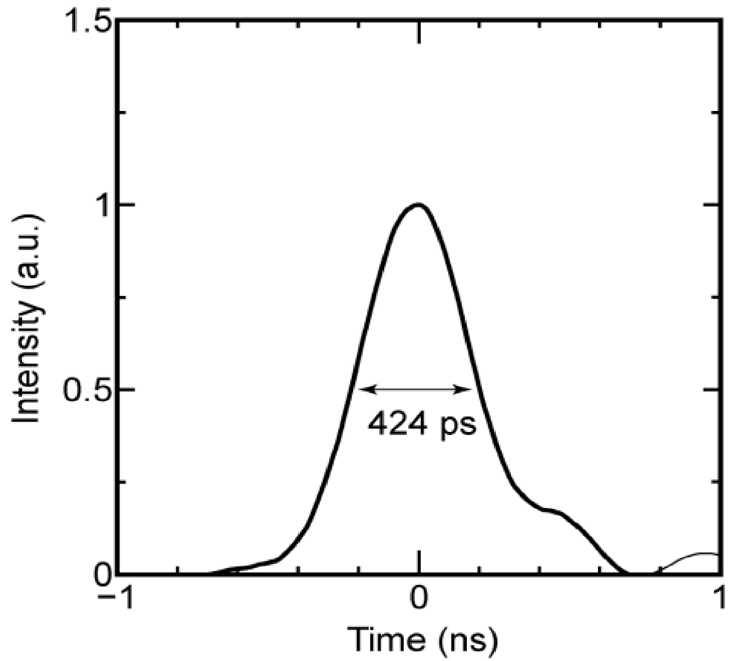


Cryogenic Yb:YAG TRAM
(Total-Reflection Active-Mirror)



Output power

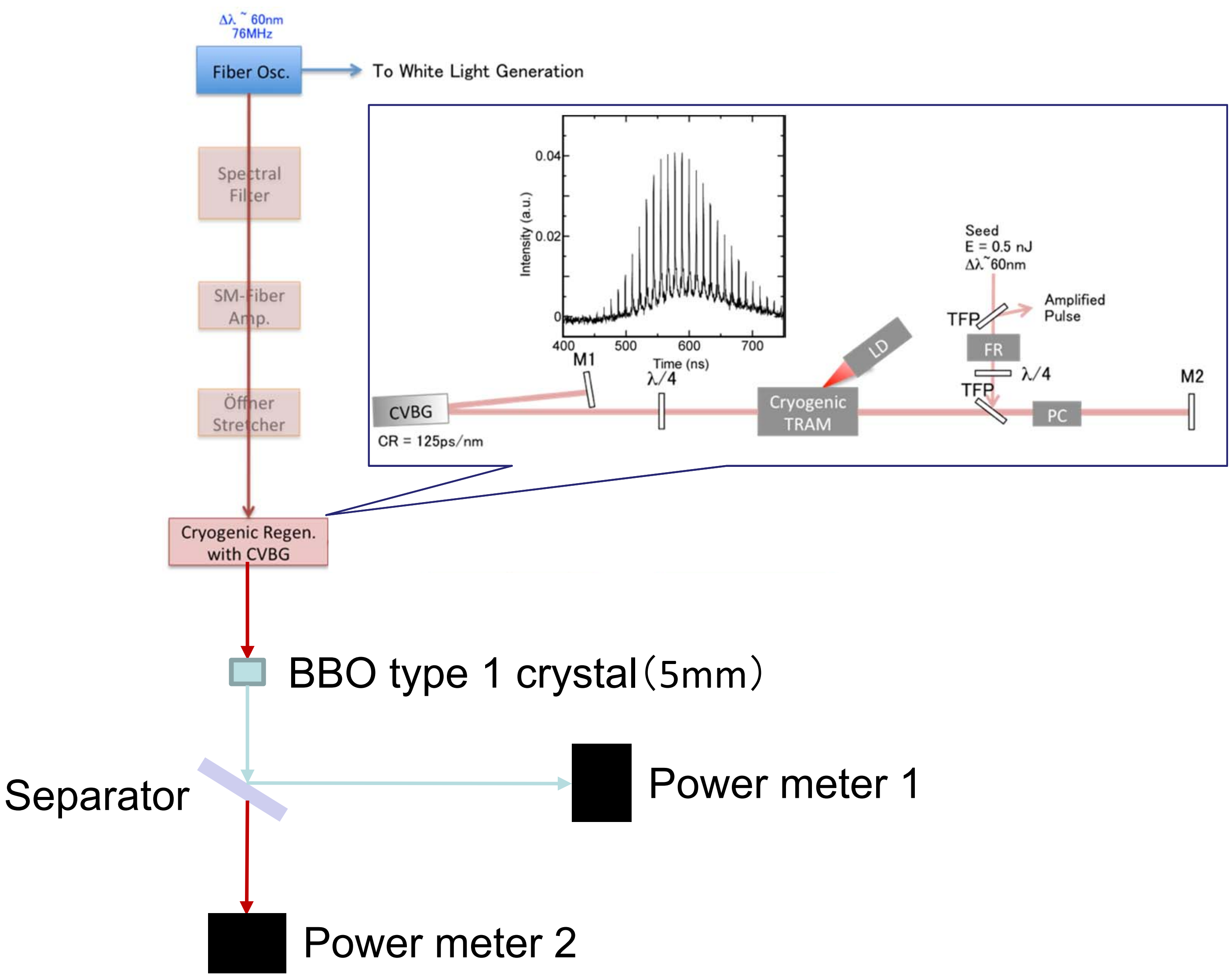




J. Kawanaka et al., ASSP 2012

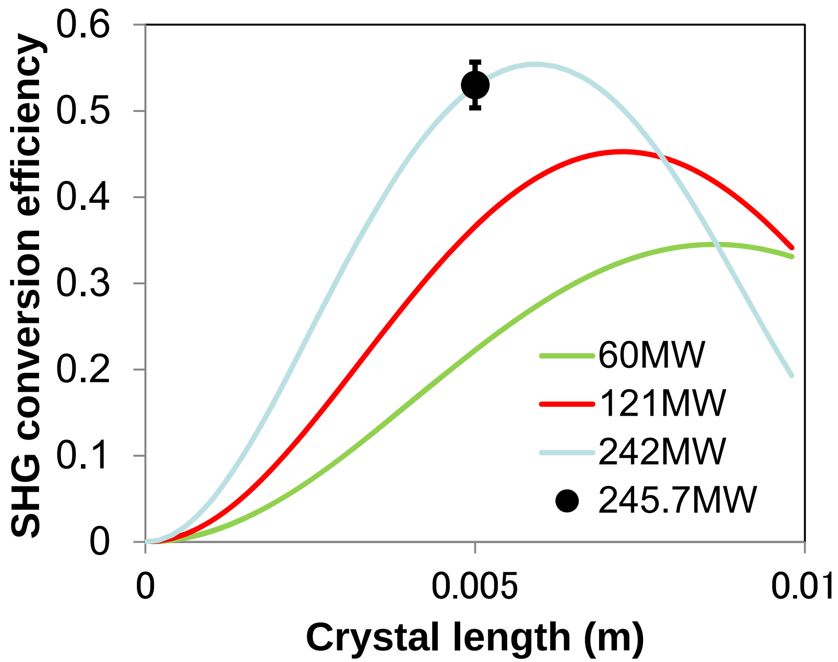
Milli-joule pulse energy is obtained.

SHG experiment



Result of experiment

Special thanks to Takashi Sekine

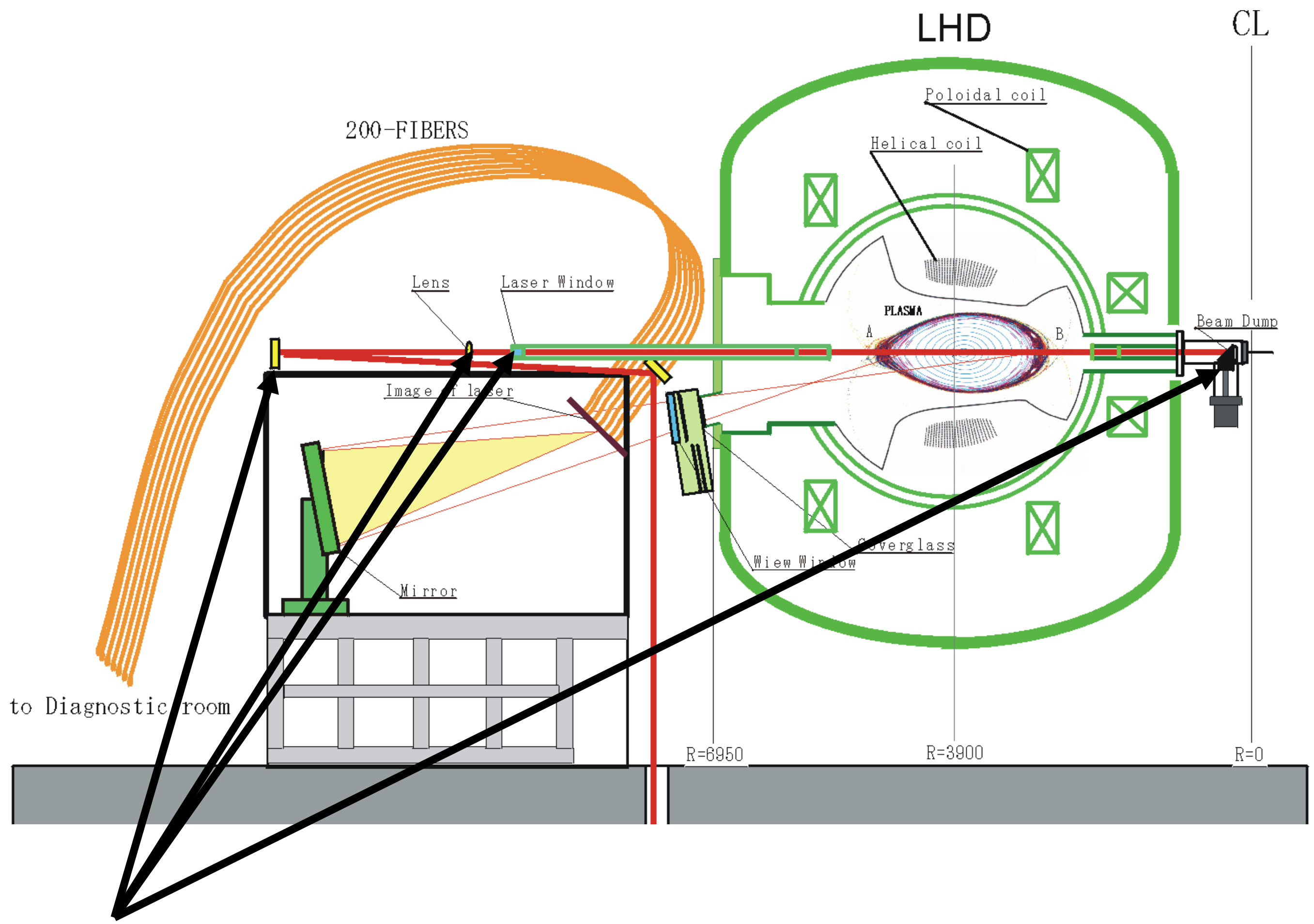


Beam diameter 0.9 mm、
BBO type1, Phase match angle
θ=23.33、φ=90

- We have demonstrated the 0.8 mJ, 10 Hz picosecond green laser pulses at 514.8 nm by using a 5 mm long BBO crystal after a chirping TRAM regenerative amplifier.
- A second harmonic conversion efficiency of 53 % was achieved when the pump energy was 1.5 mJ in 480 ps at 1029.8 nm.

Laser induced damage on the metal and the silica glass for the nuclear fusion application.

Fused silica window in LHD

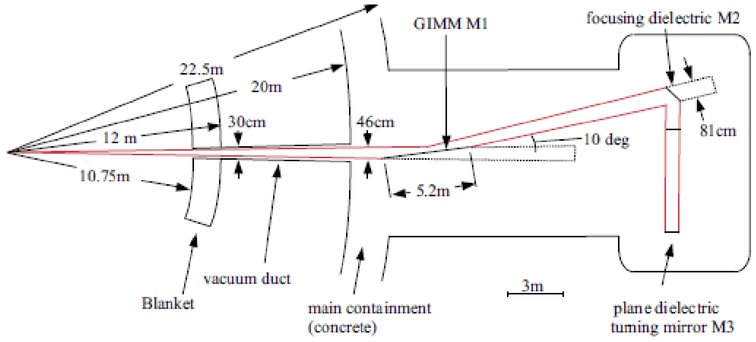


We use the fused silica windows in the laser beam line of TS as the vacuum window in LHD.

Those windows are irradiated by plasma.

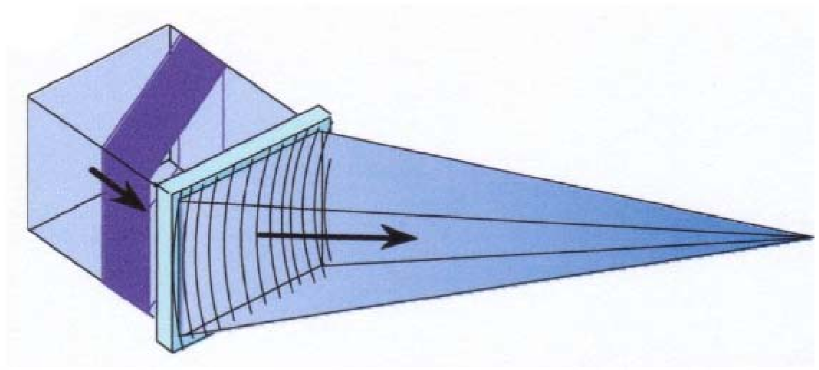
Final optics of inertial fusion applications

Metal based optics



L. L Snead et al. Fusion Sci. Technol. 56 (2009) 1069.

Fused silica based optics



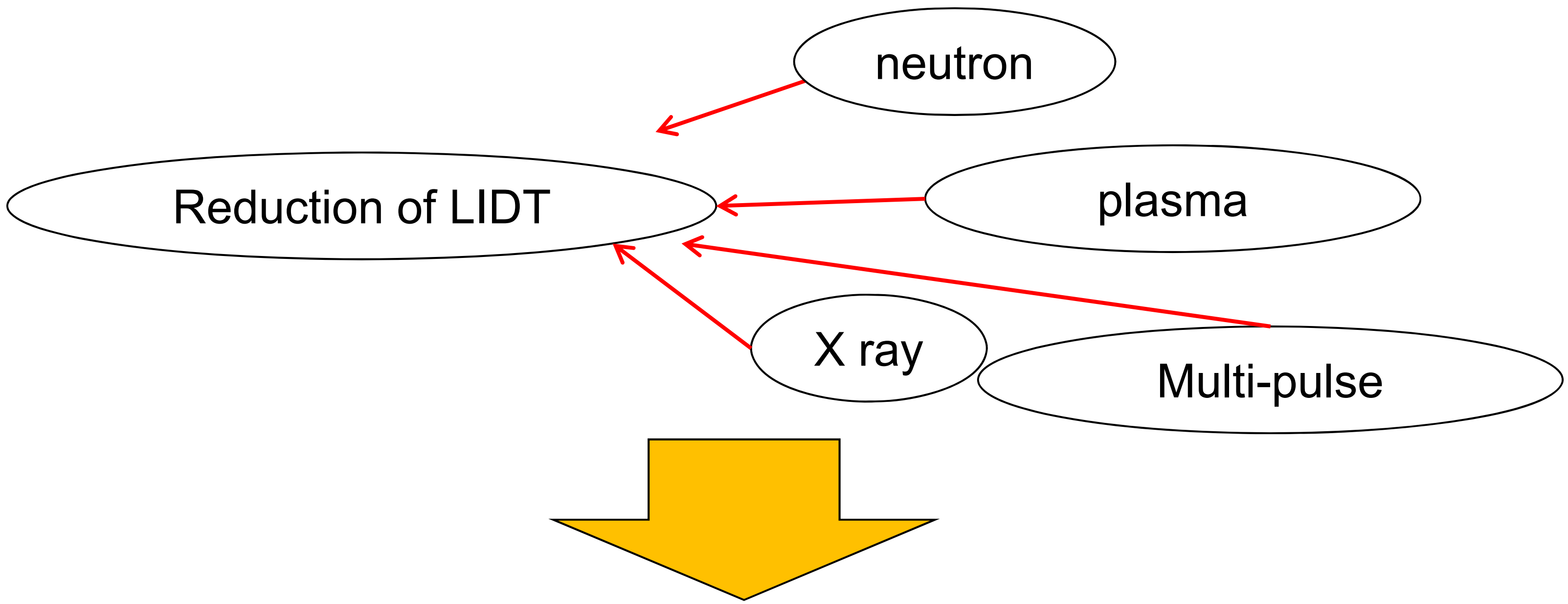
IFE forum, Osaka（2006)

Au, Cu, Fused silica and dielectric coated optics are proposed for final optics of IFE chamber.

It is very important to estimate the LIDT such optics in harsh environment.

LIDT at the severe environment

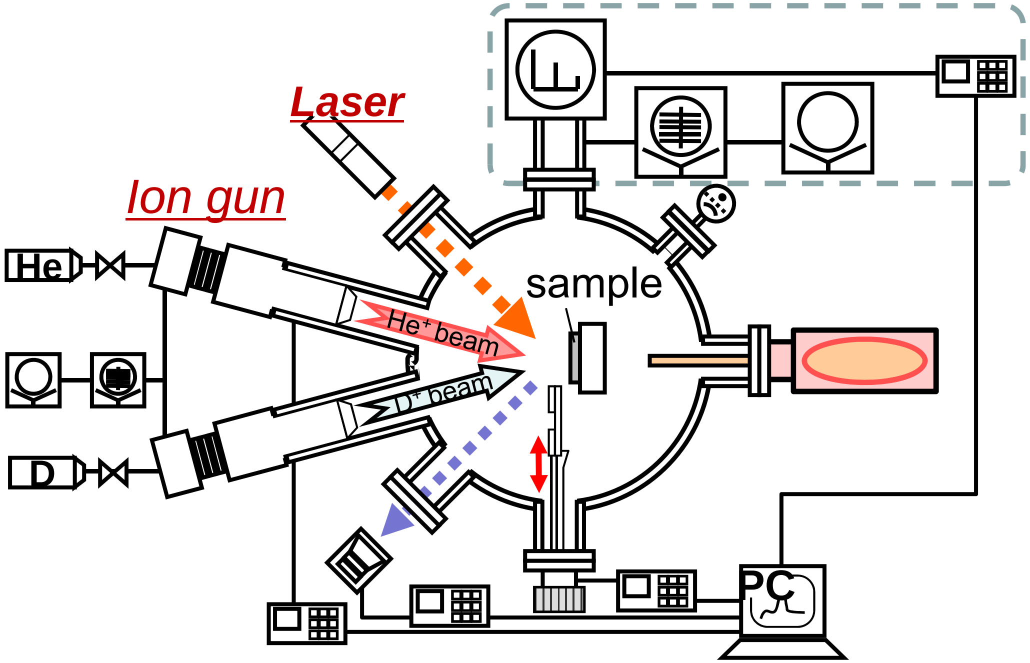
Can we estimate the laser induced damage at the harsh environment?



・To understand the effect of each issue for LIDT

Single shot LIDT of fused silica irradiated by He plasma

Material	Fused silica
Grade	ED-A (OH<200ppm)
Roughness	Roughness< 0.5nm
Diameter	30mm
TOSOH	



The sample was irradiated by the ion gun.

Condition
Ion energy 5keV,
Flux:10^{18} (He/m^2s),
Fluence:10^{21} (He/m^2)

Result of the measurement of LIDT

Wavelength	He irradiation	LIDT
1064nm	without	89.1 J/cm^2
	with	87.7 J/cm^2
355nm	without	24.9 J/cm^2
	with	19.7 J/cm^2

- At the wave length of 1 micrometer, the value of LIDT with He irradiation and without irradiation is almost same.
- At 355 nm LIDT of fused silica irradiated by He plasma is 20 % lower than without irradiation.

In our preliminary experiment, we can observe the significant reduction of the multi-pulse LIDT and the LIDT with plasma irradiation.
We should collect more data of the LIDT at the harsh environment to realize the nuclear fusion application.

Summary

- Advanced TS probe laser system of the multi-laser system and the multi-pass probing system is successfully demonstrated.
- A second harmonic conversion efficiency of 53 % was achieved when the pump energy was 1.5 mJ in 480 ps by using GENBU pre-amplifier
- To understand the effect of harsh environment on LIDT, we study about the multi-pulse effect on LIDT of cupper mirror and the LIDT of the fused silica with plasma irradiation.
- In our preliminary experiment, we can observe the significant reduction of the multi-pulse LIDT and the LIDT with plasma irradiation.