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Status of GAMMA 10/PDX Thomson scattering system

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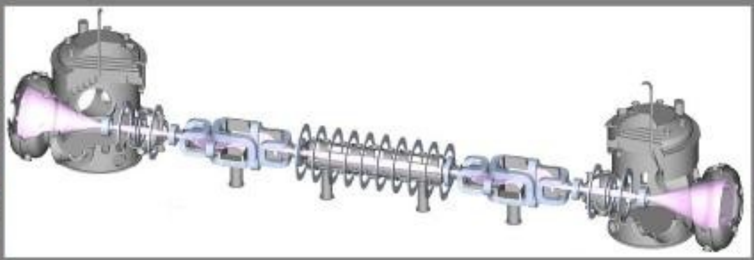



Contents

1. Introduction

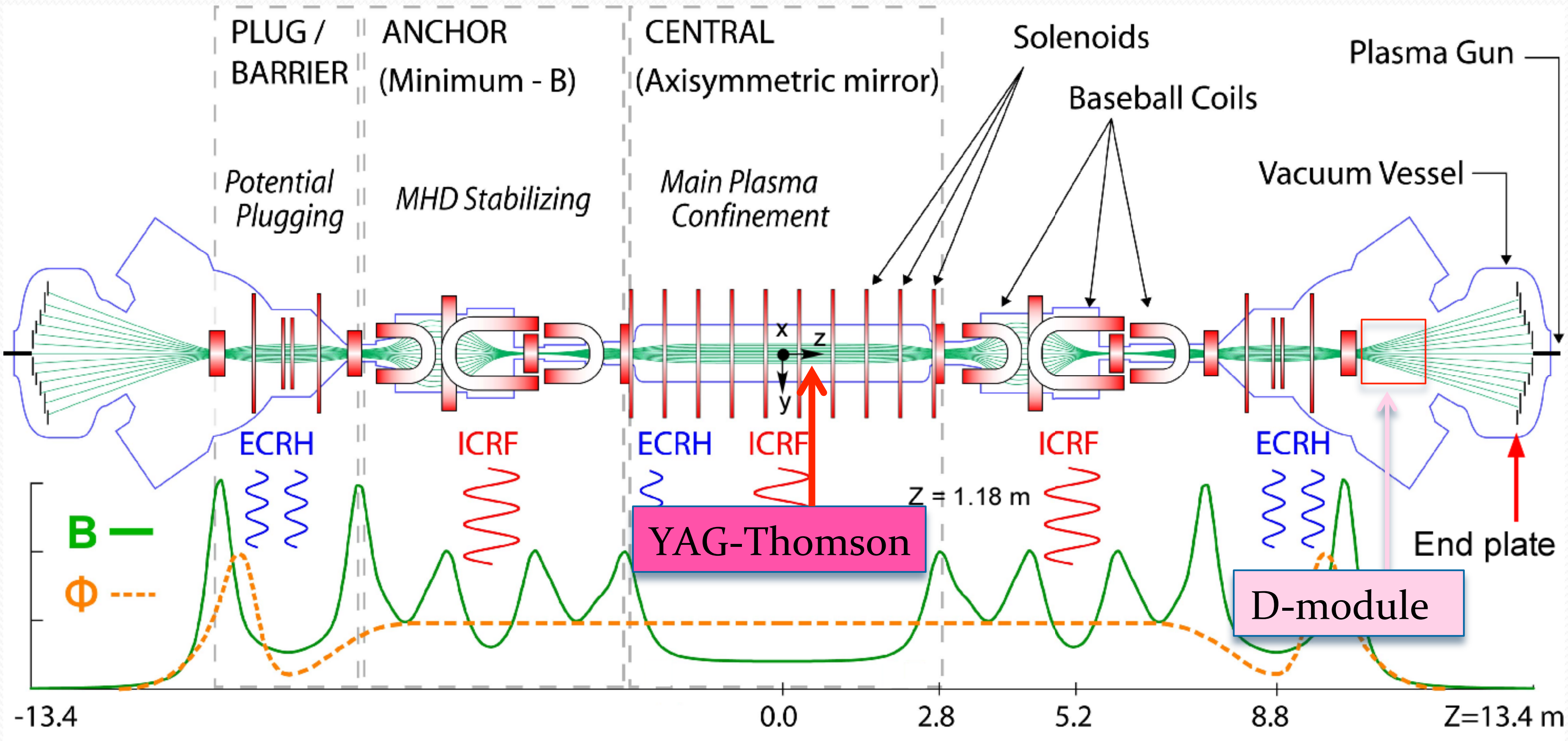
- *Thomson scattering (TS) is the most reliable diagnostic to measure the electron temperature and electron density. In the tandem mirror GAMMA 10/PDX, the yttrium-aluminium-garnet (YAG)-TS system was constructed with the large solid angle of TS collection optics. In GAMMA 10/PDX, the plasma density is low compared with other fusion plasma devices, about 2×10^{18} m^{-3}. We used high speed oscilloscopes for direct acquisition of TS signals, because we have to check the TS signals shot-by-shot.*
- *For increasing the TS signal intensity, improved optical collection system and the multi-pass TS system are considered.*
- *The radial electron temperatures and densities of six radial positions in GAMMA 10/PDX are successfully obtained.*
- *We constructed the acquisition program for six oscilloscopes to obtain the 10-Hz TS signals in a single plasma shot. Then we can obtain the time dependent electron temperatures and densities in a single plasma shot.*
- *Moreover, we are developing the multi-pass TS system for increasing the TS signals to improve the measurement accuracy and high time resolved electron temperatures.*

1-2. GAMMA 10 TS system

1980220	1983			2000			2008	2009	2010	2011	2012	2013	2014	2015	2016
GAMMA 10									GAMMA 10/PDX						
	Ruby-laser Thomson (TS) scattering system														
							YAG-Thomson scattering system								
										Double-pass TS system					
											Multi-pass TS system				

- In GAMMA 10, a ruby-laser TS system had installed to measure the electron temperature. However, the system experienced problems and removed.
- In fund year (FY) 2008, we started to design YAG-TS system for measuring electron temperature and density in a single plasma shot. The requirement of TS system in GAMMA 10 is to obtain the electron temperature and density in a single laser shot in a single plasma shot. We designed GAMMA 10 YAG-TS system and installed.
- We started to obtain TS signals in GAMMA 10 from FY 2009.
- We are constructing the multi-pass TS system for increasing the TS signals from FY 2011.

2. GAMMA 10/PDX tandem mirror



$n_e = n_i \sim 2\times10^{18}\ m^{-3}$

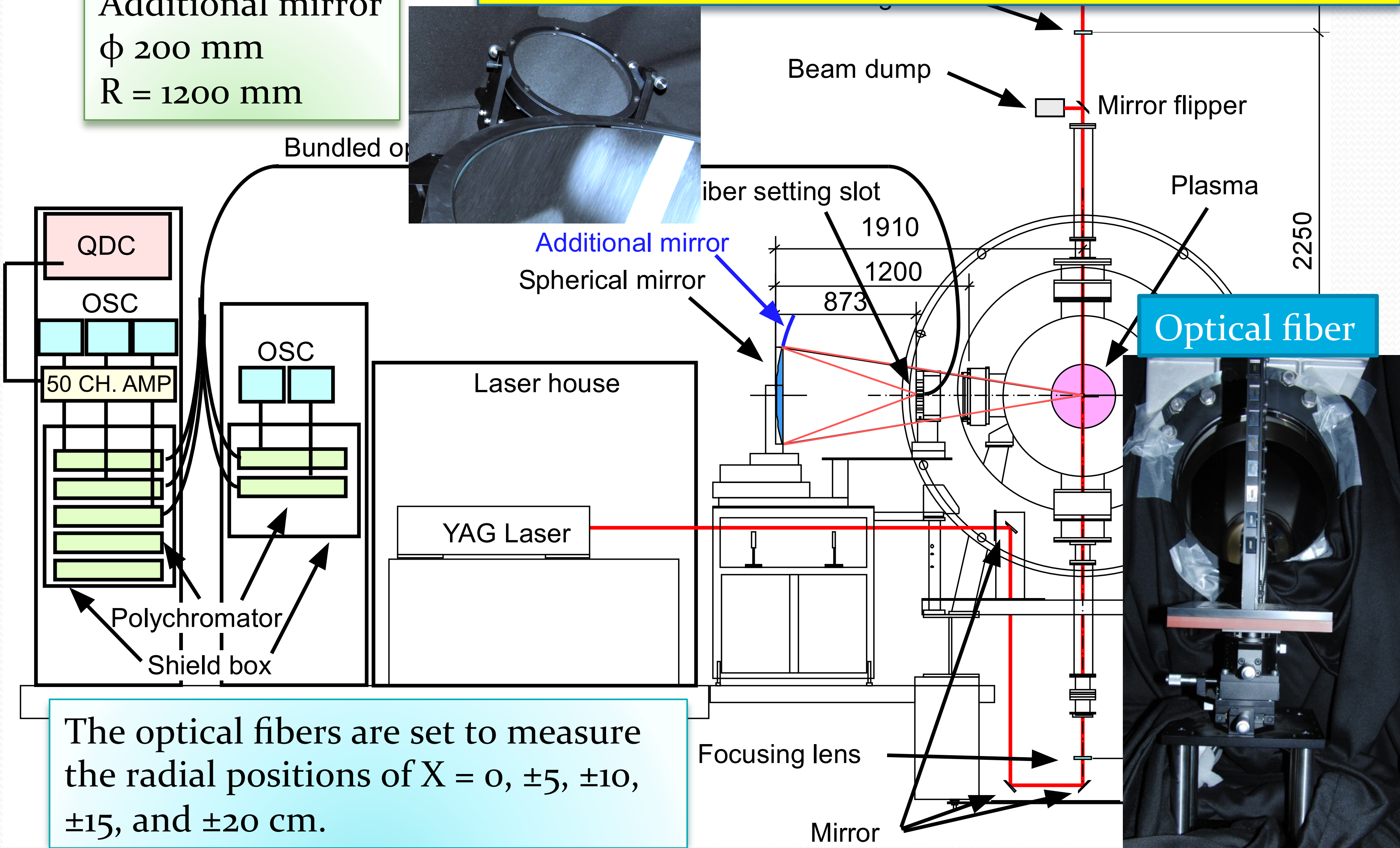
$T_e \sim 20 \sim 80$ eV

$T_i \sim 5$ keV

2-2. G10/PDX-TS system side view

Mirror : ϕ600, f = 873, R = 1200 NA = 0.19 M = -0.459
Fiber : input 2 x 7, output ϕ4.8, NA 0.47
Solid angle: 0.078 str

Additional mirror
ϕ 200 mm
R = 1200 mm



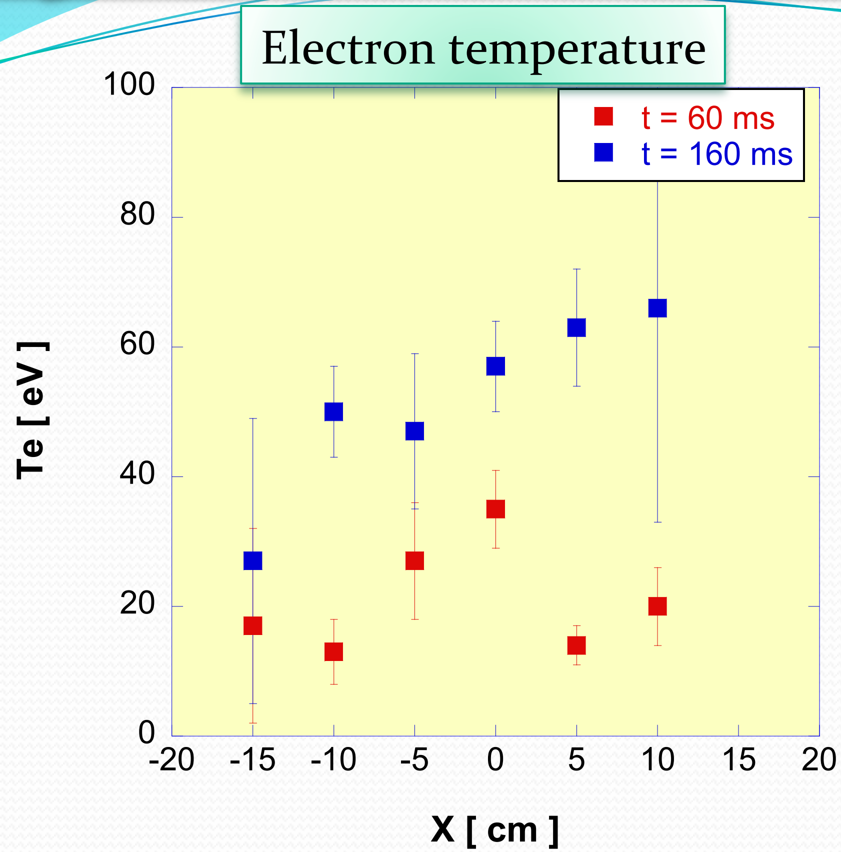
The optical fibers are set to measure the radial positions of X = 0, ±5, ±10, ±15, and ±20 cm.

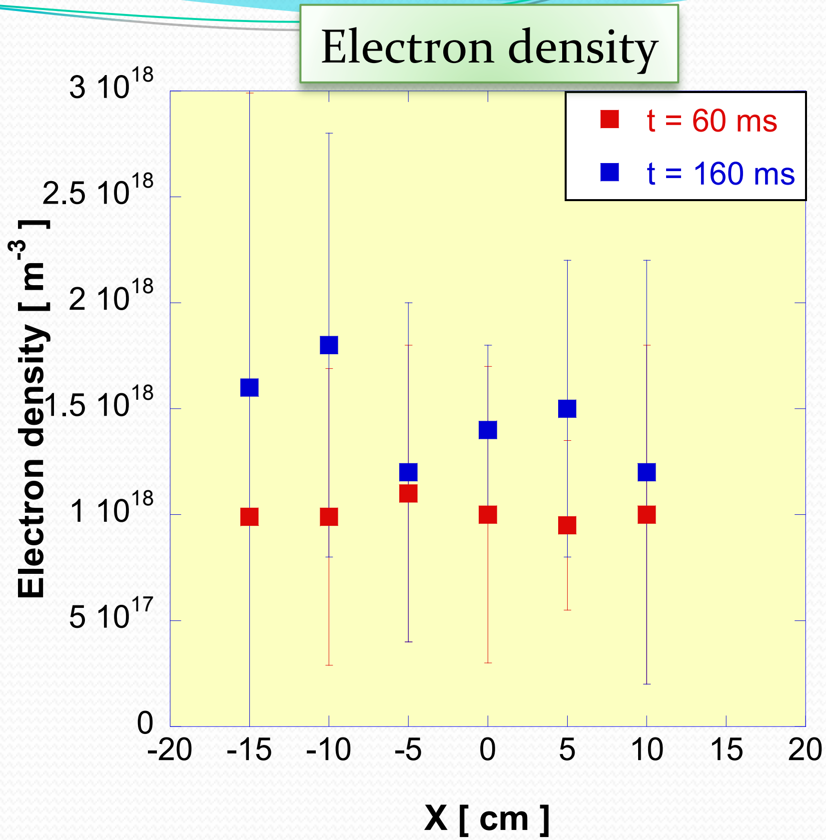
2-3. GAMMA 10-YAG-TS system

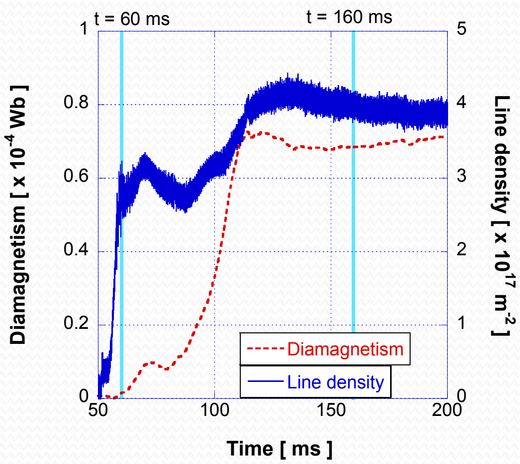
Typical performance of G10-Thomson system

1. Temperature range：0.02 ~ 2 keV (ΔT_e ~ 10 eV)
2. Observable range：±20 cm (0, ±5, ±10, ±15, ±20 cm, Δd ~1.5 cm)
   Now, we have six observing channels in a single laser and plasma shot.
3. Time resolution：~ 10 Hz (~ 10 ns)
4. Laser：Nd:YAG 1064 nm, 2 J/pulse(Powerlite 9010)
5. Collection system：Concave mirror (R ~ 1200 mm, ϕ = 60 cm and 20 cm) & 9 channel bundled optical fiber.
6. Spectroscopic system：5ch. filter polychromator with Si-APD, TS139 (PerkinElmer, C30950E), TS056, TS149, TS030, TS136 , TS002 (PerkinElmer, C30659-1060-3AH).
7. Data collection system：We use the high speed digital oscilloscopes (IWATSU DS5524).

3-1. Radial electron temperatures and densities

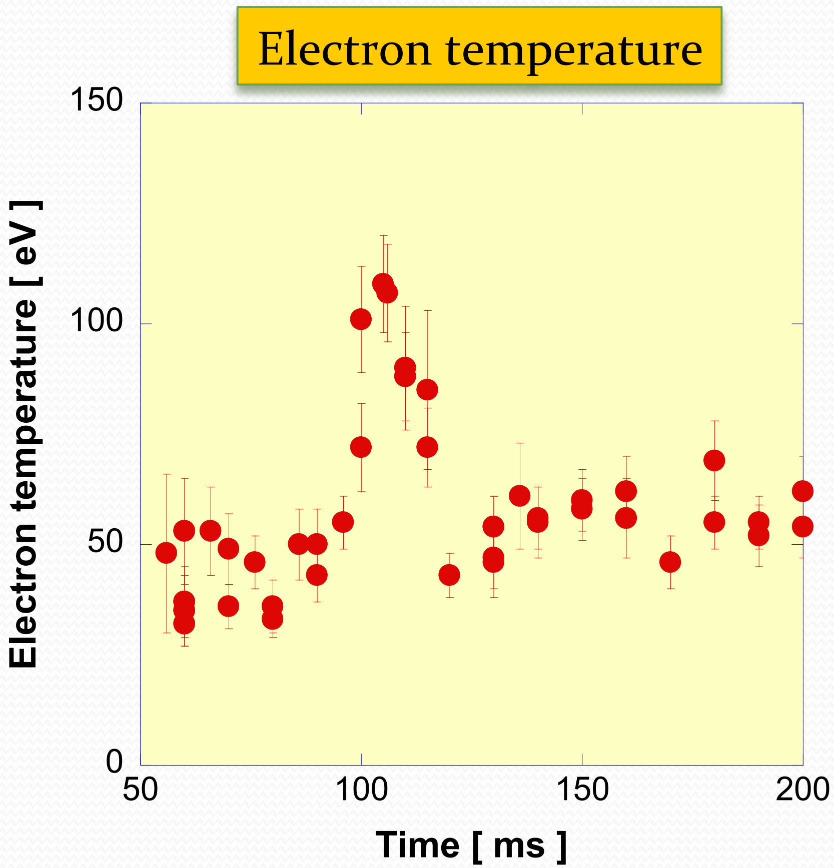


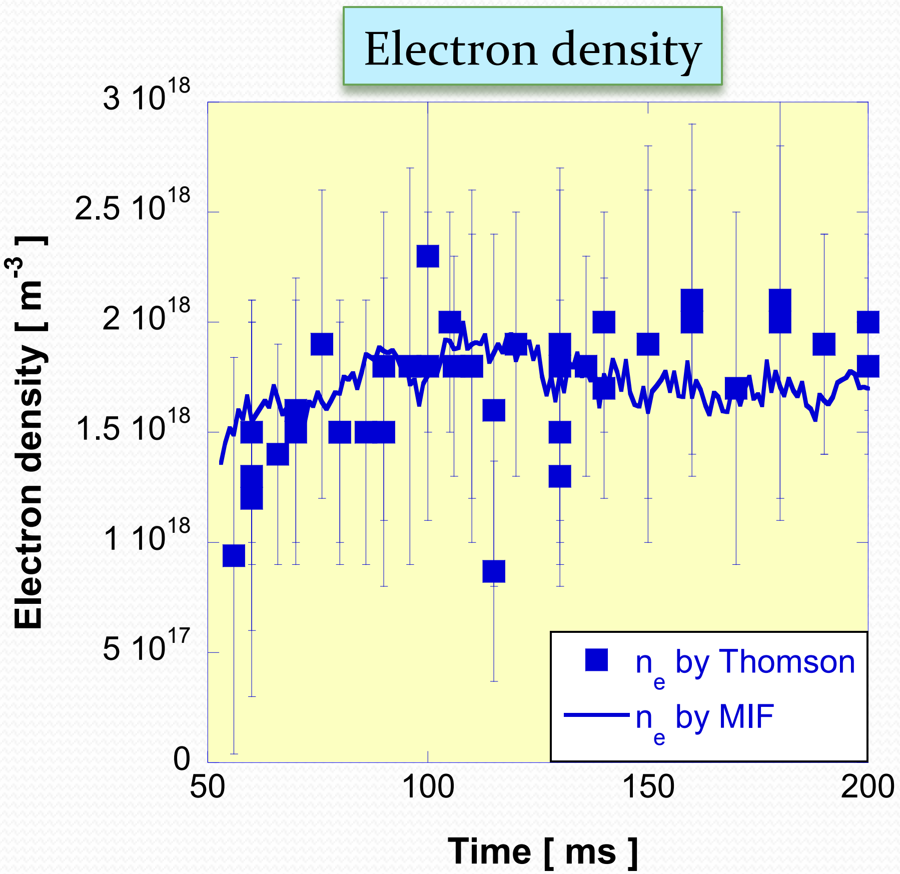




- Time dependent electron temperatures and densities of six radial positions are successfully measured simultaneously by TS system.
- The electron temperatures and densities at t = 60 ms and t = 160 ms at plasma center are about 35 eV, 60 eV, 1×10^{18} m^{-3}, and 1.4×10^{18} m^{-3}, respectively.

3-2. Time dependent electron temperature and density

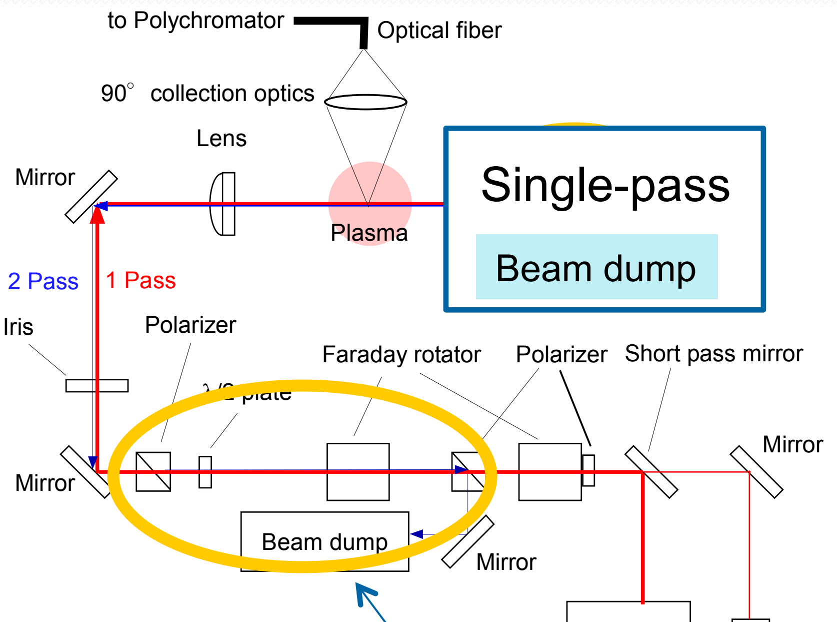




- Time dependent electron temperature and density are successfully observed.
- Electron densities by TS system are comparable to those by using the microwave interferometer (MIF) system.

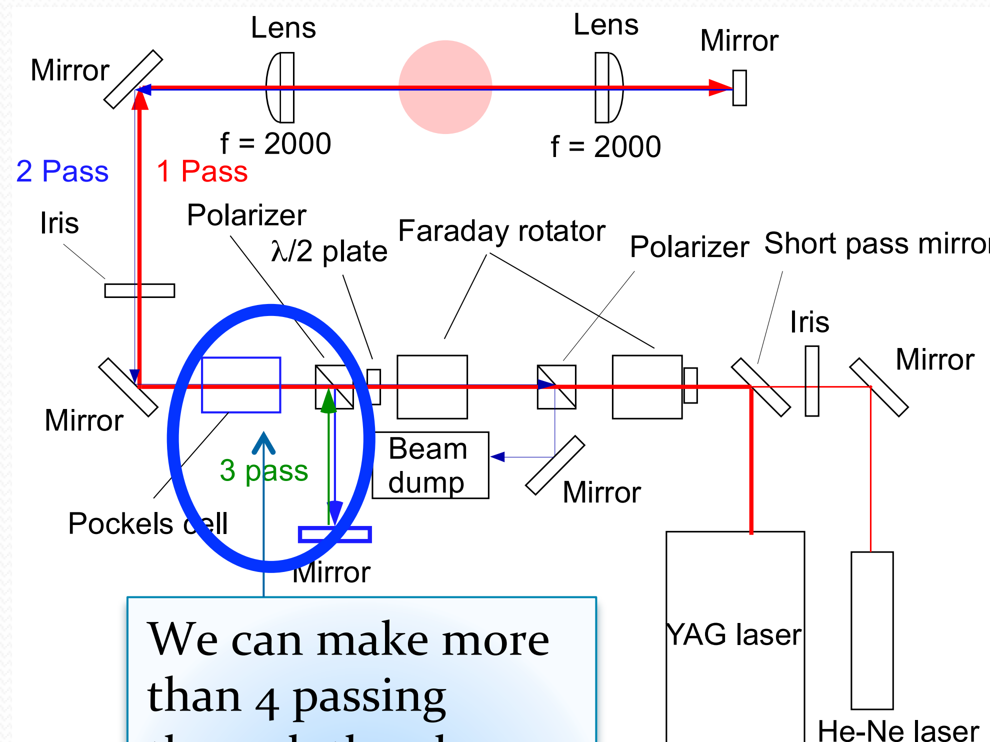
4-1. Multi-pass TS system in GAMMA 10/PDX

Double-pass system



2 passed beam is dumped by beam dump.

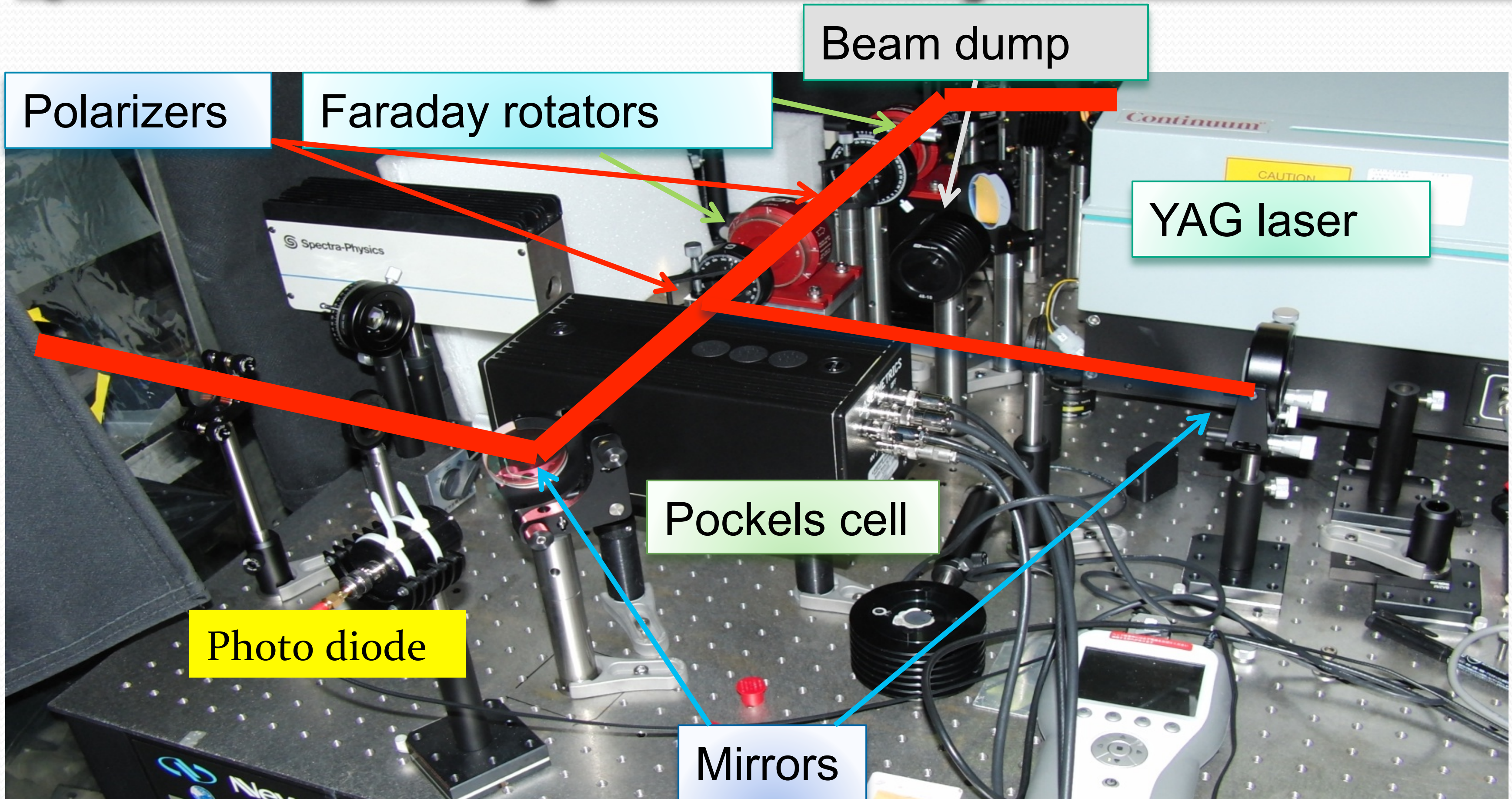
Multi-pass system



We can make more than 4 passing through the plasma.

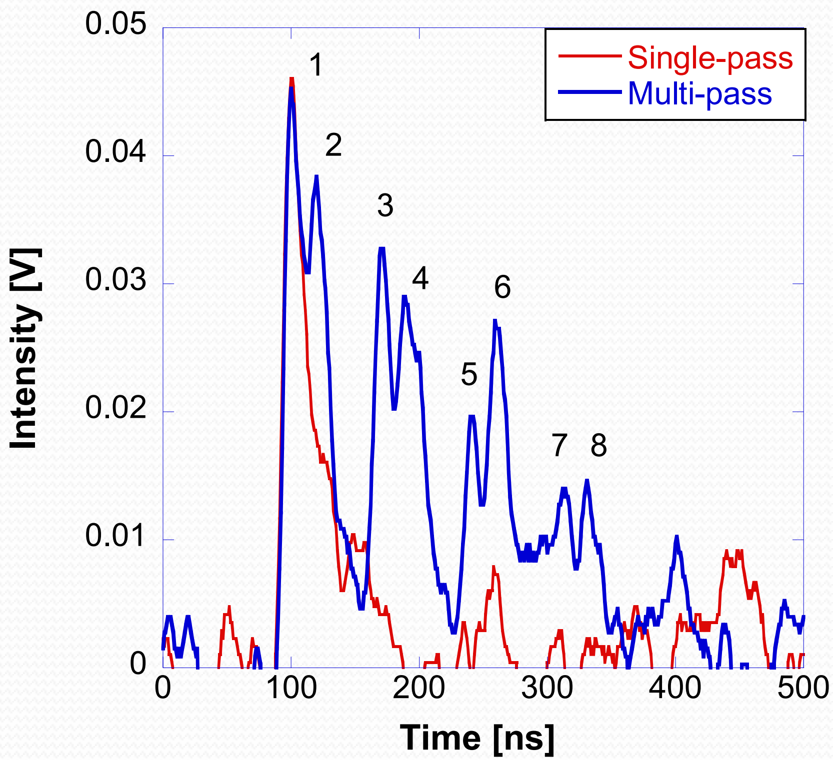
We have constructed the polarization controlled multi-pass system with image relaying system in the GAMMA 10 YAG-TS system. This system is easily constructed with adding a lens, reflection mirrors, and Pockels cell.

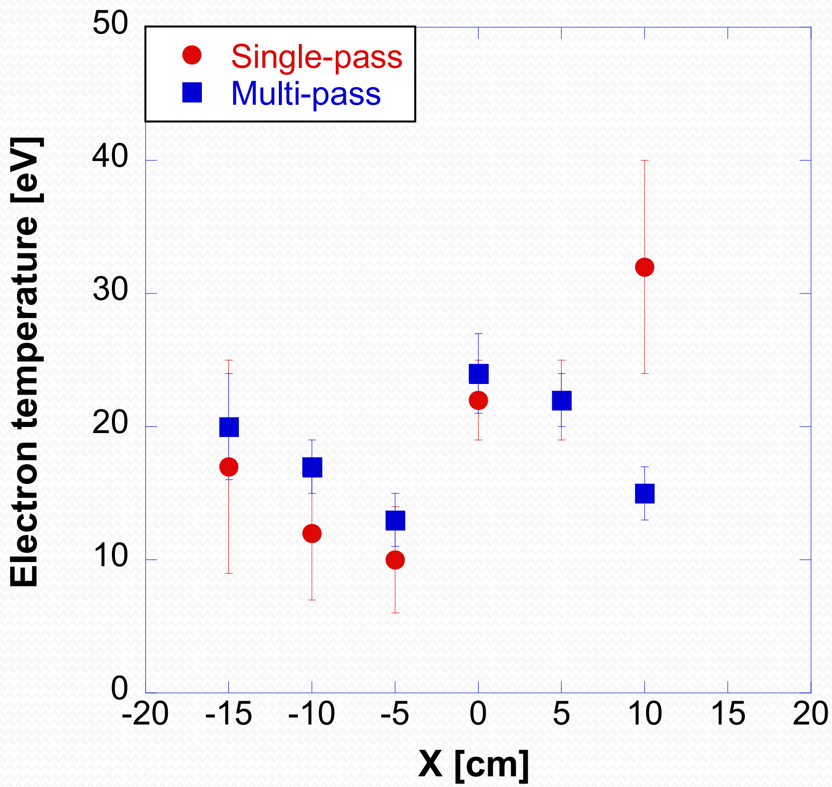
4-2. Multi-pass TS system



We are developing the multi-pass TS system with a polarization based system and image relay system based on the GAMMA 10-YAG-TS.

4-3. Radial profile of electron temperature

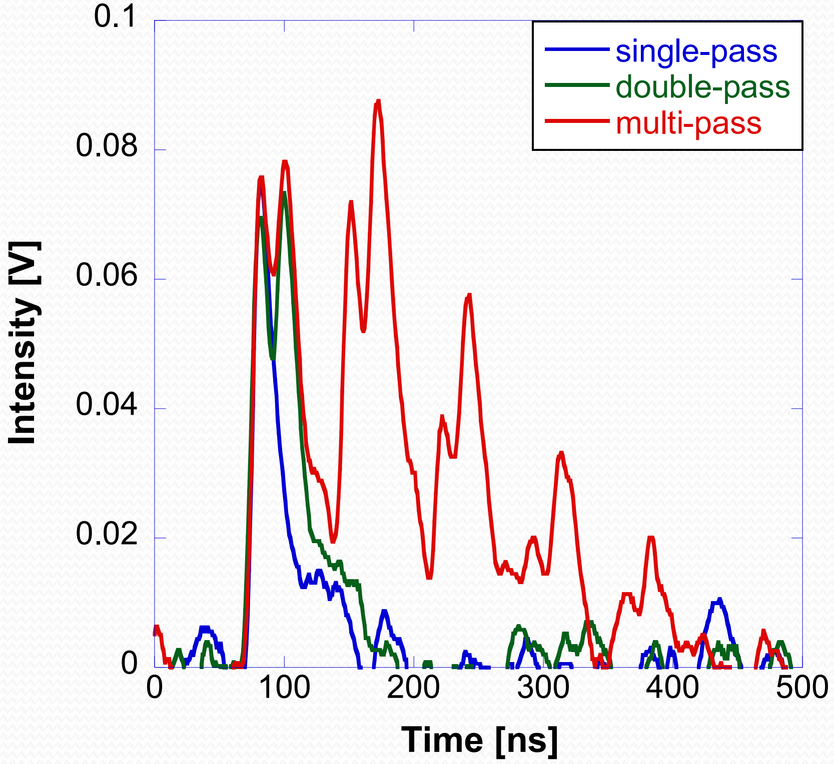




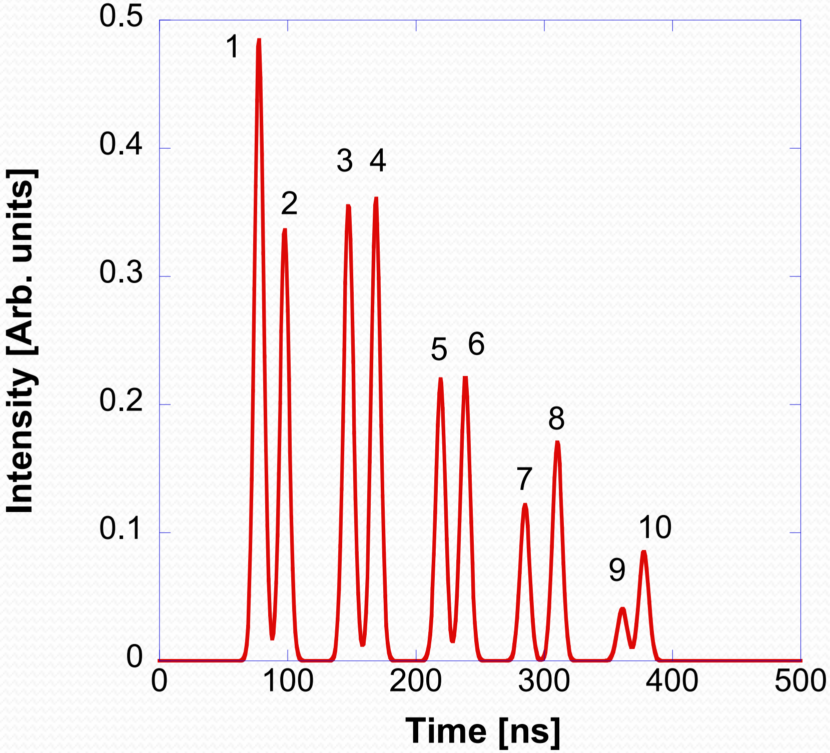
We are developing the multi-pass TS system of a polarization based system based on the GAMMA10 YAG-TS. The integrated TS signal of multi-pass system is about 5 times larger than that of 1st pass signal intensity. The radial profile of electron temperature was successfully obtained by using the MPTS system. The errors of electron temperatures in the multi-pass configuration are much smaller than those in the single-pass configuration.

4-4. Time dependent electron temperature and density

TS signals

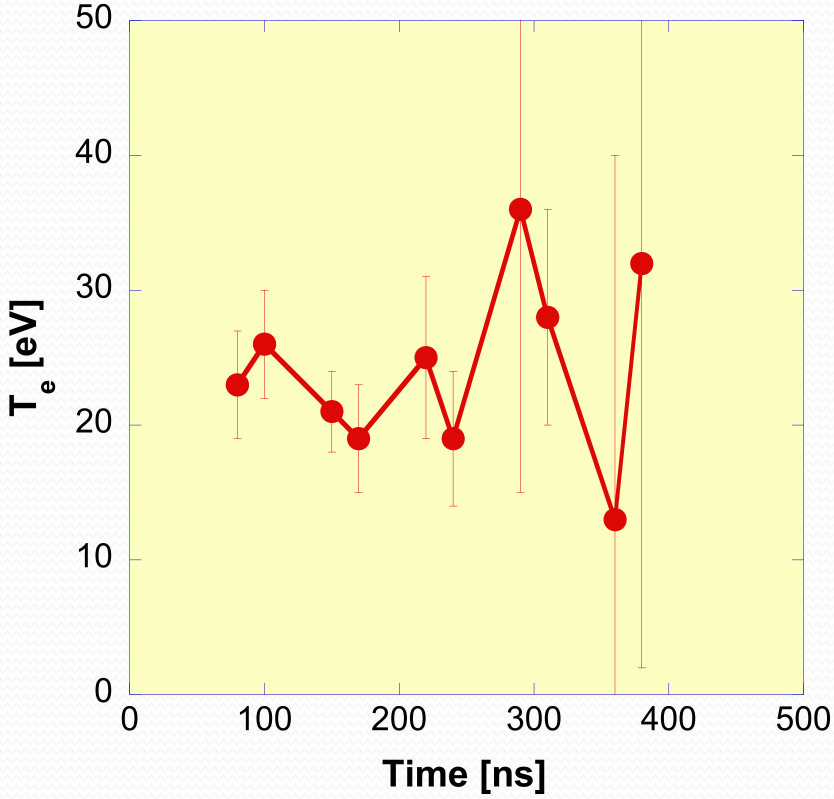


Calculated TS intensity



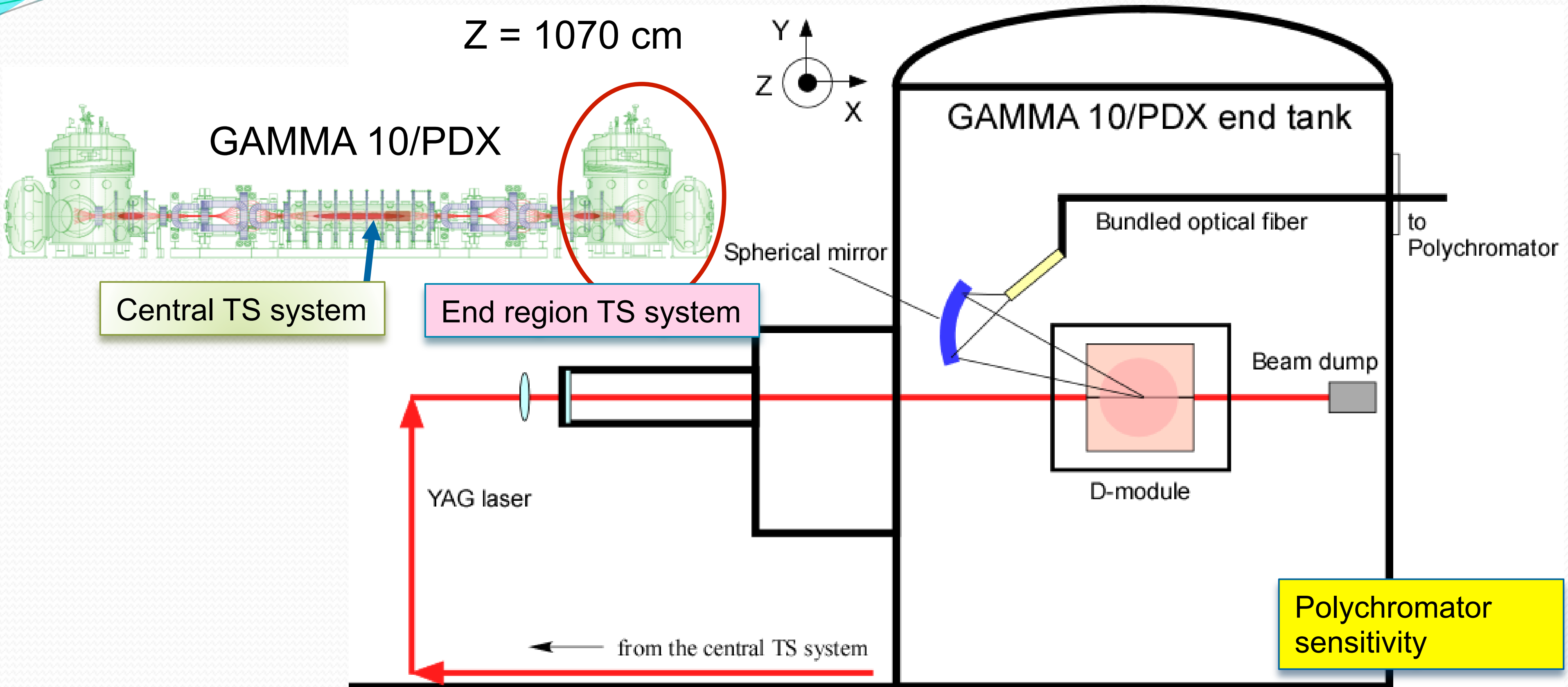
Time dependent TS signals show the fast time dependent electron temperatures and densities in 20 and 50 ns periods. By using the signal fitting method, calculated Multi-pass TS intensities are clearly obtained.

4-5. Time dependent electron temperature

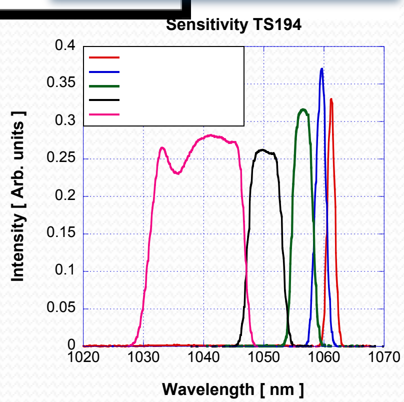


- By calculating each passing TS signal, we can obtain the time dependent electron temperature. The calculated electron temperatures from 7th-pass to 10th-pass have large error because of low signal to noise ratio.
- In GAMMA 10/PDX plasma, the electron collision time is about 700 ns. Then the electron temperature is almost constant of 22±2 eV during 400 ns from 1st-pass to 10th-pass.
- We successfully constructed the high time resolved electron temperature measurement system by MPTS in the order of MHz sampling.

5. End region TS system



Polychromator sensitivity



- 70 °back scattered TS signal measurement system.
- Laser: YAG laser of central cell TS system, 1064 nm, and 2J/pulse.
- Time resolution: 100 ms (10 Hz).
- Solid angle of optical collection system: 71 mstr.
- Electron temperature T_e: 0.5 ~ 50 eV, ΔT_e < 40 %.
- Electron density n_e: > 0.2 x 10^{17} m^{-3}.
- Observation position Y: 0 cm, ΔY ~ 3 cm.

6. Summary

- We have constructed **the GAMMA 10/PDX-TS system** by NIFS research collaboration program.
- We added the second collection mirror to obtain the larger TS signal intensity in the edge region. The TS signal intensities in the lower plasma region are increased by the additional mirror.
- **We can successfully measure the time dependent six positions electron temperatures and densities in GAMMA 10/PDX plasma with a single laser shot at the single plasma shot.**
- **We could successfully obtain the multi-pass Thomson scattering signals and get the 5 times larger Thomson scattering signal than that in the single-pass configuration. Moreover, the fast time dependent electron temperatures are successfully obtained.**

Acknowledgements

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