VARIABLE REPETITION RATE THOMSON SCATTERING SYSTEM FOR THE GLOBUS-M TOKAMAK

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Presentation outline

- What is the diagnostics aims?
- How it can be succeeded?
- What are results?
- What are the next steps?
- Conclusions

What is the diagnostics aims?

- **Plasma stability**
- **Auxiliary heating by NBI**
- **Auxiliary heating by ICR**
- **Plasma fuelling with pellet injection**
- **Plasma fuelling with plasma gun**

Requirements to diagnostics

Time:		**Multipulse laser:**
	• To cover whole discharge duration	• Pulse train duration up to 100ms
	• To study fast transient process <1ms	• Repetition rate more 1kHz
Space:	• To cover all plasma	• A set of spectral devices
Data:	• High accuracy	• System with low light losses • Sensitive detector
	• Online	• Flexible software
Cost:	• Reasonable frame	• ?

Acceptable options

Nd:glass laser:

- Pulse train of reasonable number of pulses (to cover whole discharge duration)
- Time spacing and amplitude could vary in the wide range

Spectral devices:

- High throughput filter polychromators

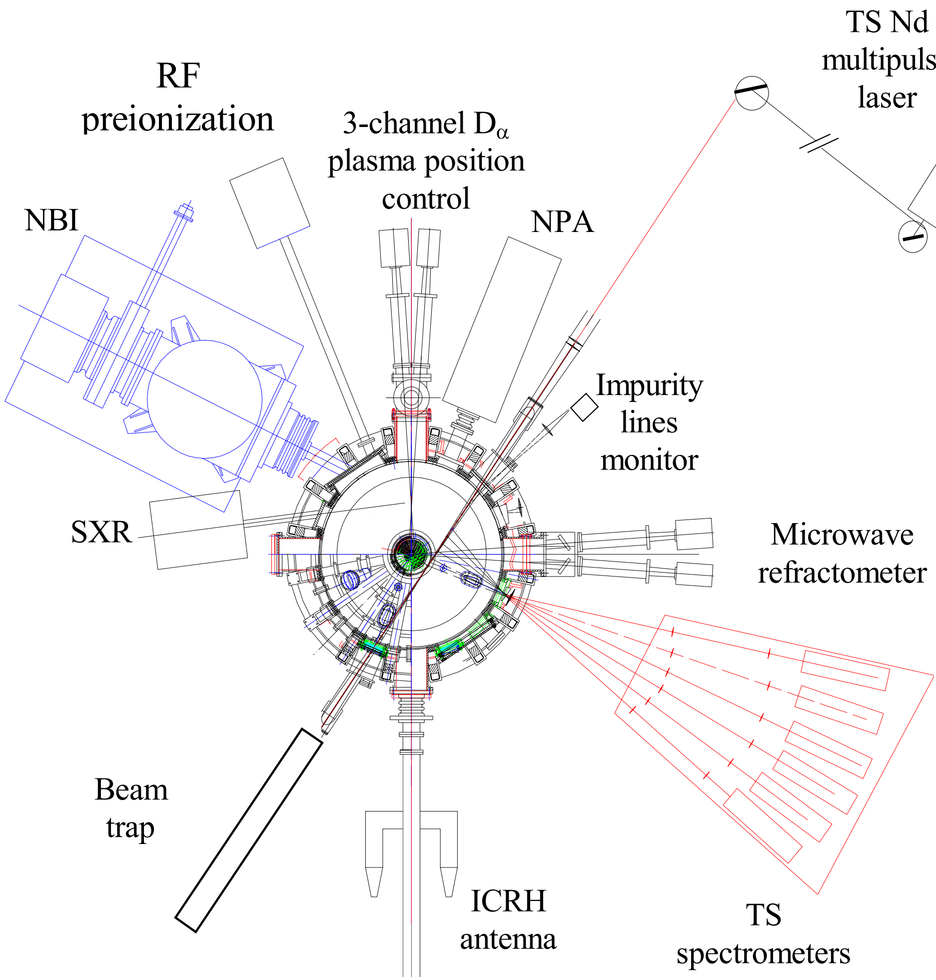
Detectors:

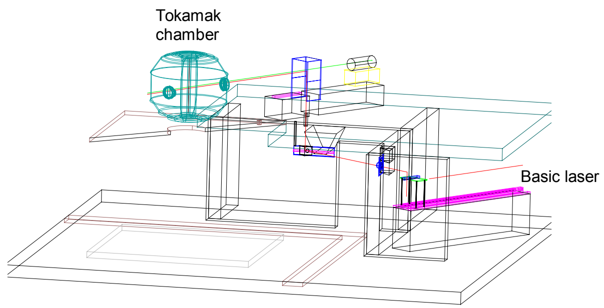
- High sensitive avalanche photodiodes
- Low noise amplifiers

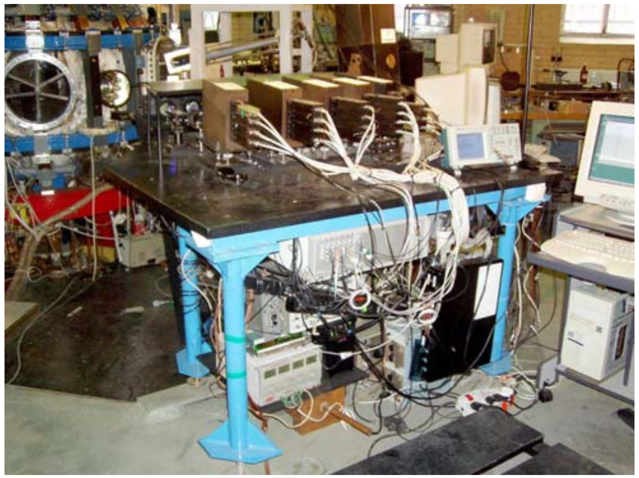
Digitizer:

- 40Ms/s, 12bits, multichannel

General layout

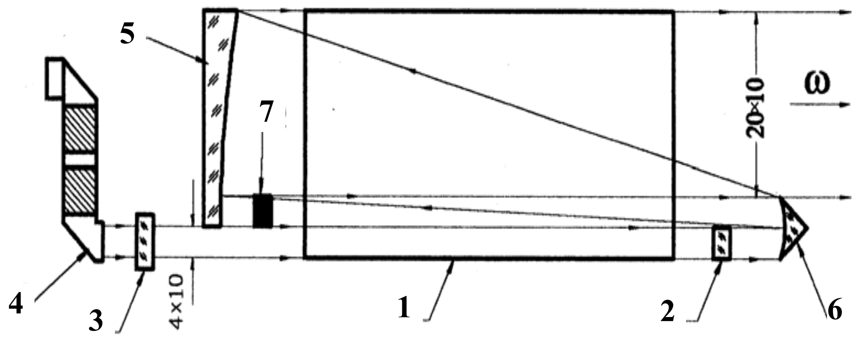






Variable repetition rate laser

Optical scheme



1- slab Nd:glass active element, 2, 3 master oscillator cavity reflector, 4- electro-optical shutter, 5,6- cylindrical reflectors of double pass optical arrangement, 7- beam dump,

Performance

- Compact design with joint in a common slab active element
- Reduced number of optoelectronic units
- Low pumping energy

Target specifications of the laser model

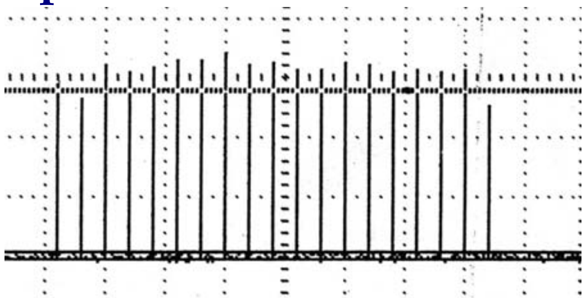
Laser operational mode	Extreme	Routine
• Pumping energy, kJ/pulse	• 3.1	• 1.3-1.8
• Output, J/pulse	• 12	• 1.5-3
• Number of train pulses	• 20	• 20
• Pulses time spacing range, sec	• $0.3{\cdot}10^{-3}{\div}0.3$	• $0.5{\cdot}10^{-3}{\div}0.3$
• Laser pulse duration, nsec	• 30	• 30
• Beam divergence, rad	• $\sim10^{-3}$	• $\sim10^{-3}$
• Wavelength, nm	• 1055	

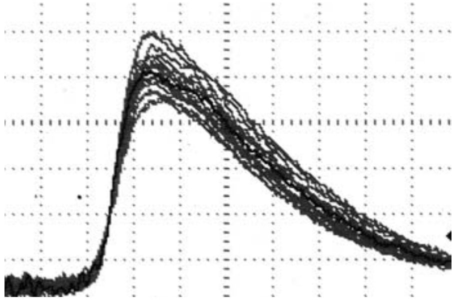
Laser temporal possibility

Pumping energy 1.5kJ

Pulse repetition rate 1kHz **10Hz**

5J

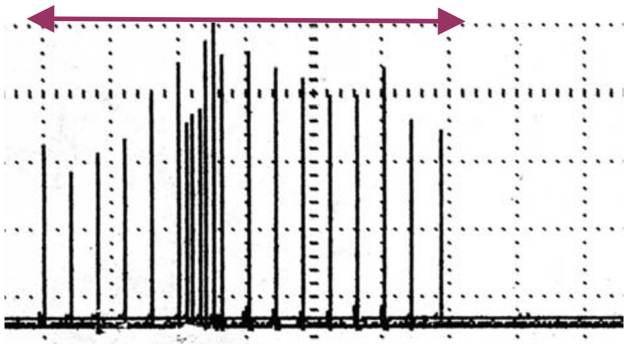




Pulse energy reproducibility in pulse repetition operation mode

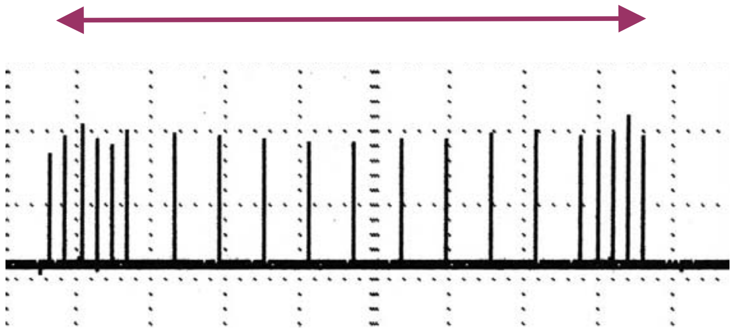
Pumping energy 1.35kJ

30msec



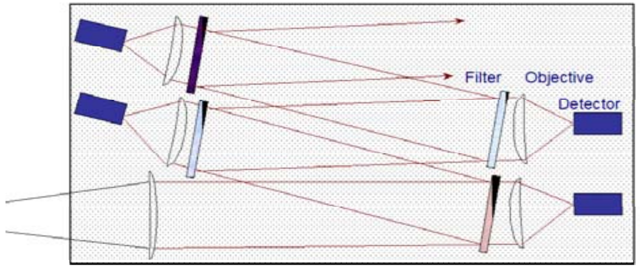
500Hz 2kHz 500Hz

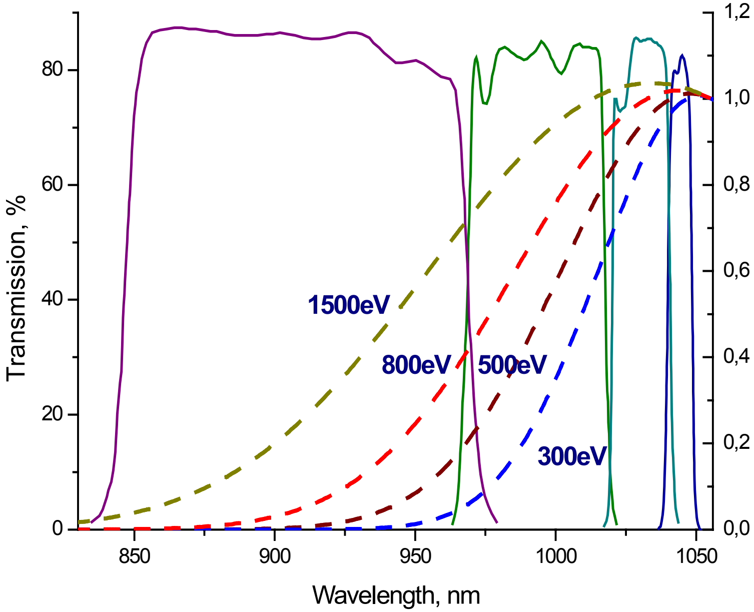
20msec

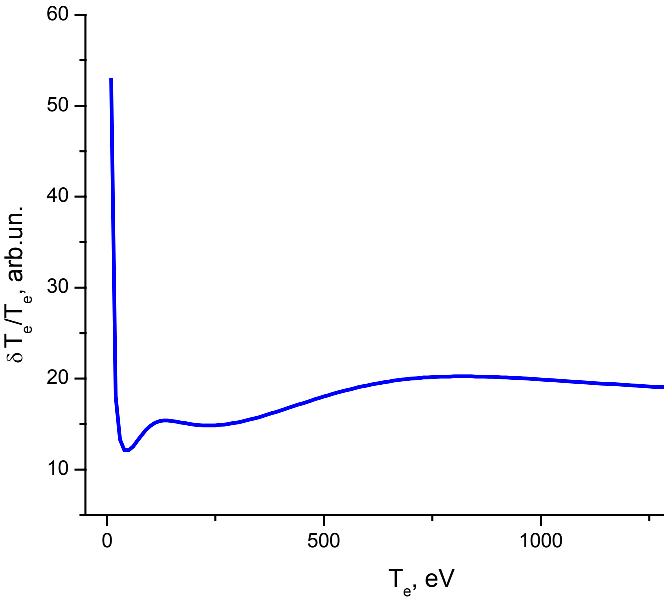


2kHz 660Hz 2kHz

TS filter spectrometers







Photodetectors

	PMT	PD	APD
Advantages	• High amplification • Bigscale photocathode • Relatively low cost	• High quantum efficiency • Low sensitivity to $\vec{B}$ • Simple operation • Low cost	• High quantum efficiency • High amplification • Low sensitivity to $\vec{B}$
Disadvantages	• Low quantum efficiency • High voltage power supply • High sensitivity to $\vec{B}$	• Extremely low noise amplifiers are needed	• High cost • Excess noise factor >2 • Temperature instability

Signal detection and processing

APD detectors noise

$$noise = \sqrt{\frac{I \quad \cdot F_M}{e} \cdot \tau}$$

The 30ns-TS signal -> very high speed ~1Gs/s extremely expensive digitizer

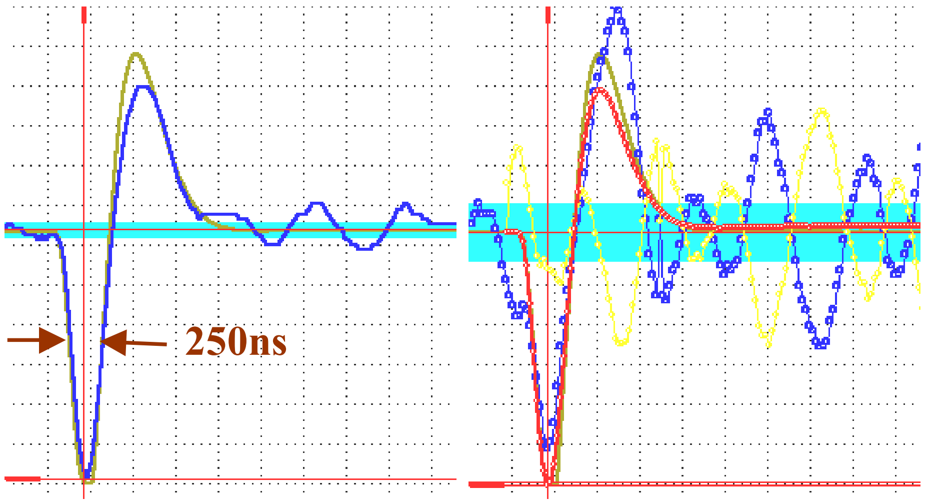
Economically sound ADCs 40Ms/s 12bits ADC -> pulse elongation up to 250ns.

Respective sacrifice of sensitivity ~3 counterbalanced by:

- increased laser pulse energy (up to 3J)
- big collection angle (~1/7)
- high throughput of polychromators (~80%)
- high APD sensitivity (80-40% for different wavelength)

Signal detection and processing

The correct signal recognizing under the noise presence – RMS-fitting to the no-noisy reference signal.



Averaging over 20 pulses **RMS-fit**

Calibration

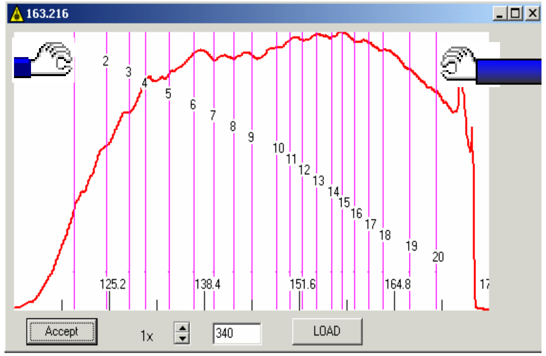
- **Spectral calibration – employing of compact scanning monochromator MDR-206 (routine procedure)**

  Verification- scattered light simulation

- **Absolute calibrations - Raman scattering in nitrogen for the sensitivity coupling of polychromator array; their absolute sensitivities derived using the data of microwave interferometer**

Multi-purpose software

- Drive over the all laser parameters (to set the pulse train temporal scenario, pulse energy and many others)
- Perform calibration
- Reconstruct TS signal
- Proceed data with resulting temporal/spatial distribution of n_e, T_e online

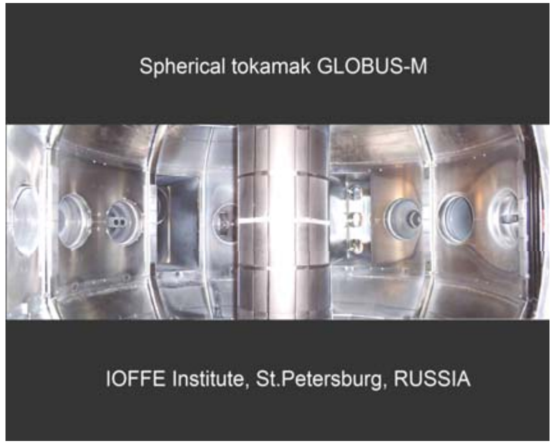


Complications

-HIGH LEVEL OF BACKGROUND

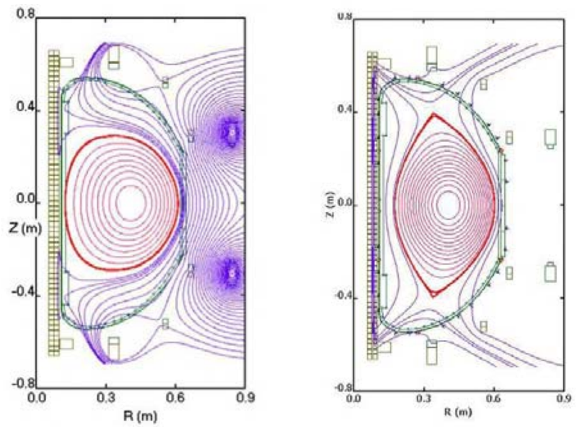
plasma light increased in spherical tokamaks

-HIGH LEVEL OF STRAY LIGHT



Globus-M:

- **Polished inner walls**
- **Intimacy wall and plasma border**



Complications mitigation

- **High contrast filters (Barr Associates)**
- **Notch filter (SPb product) (one spatial point)**
- **High transparent polarizer**
- **Laser wavelength stabilization using**

  Fabri-Perot interferometer

Results

Measurements:

- **Low and high densities regimes**

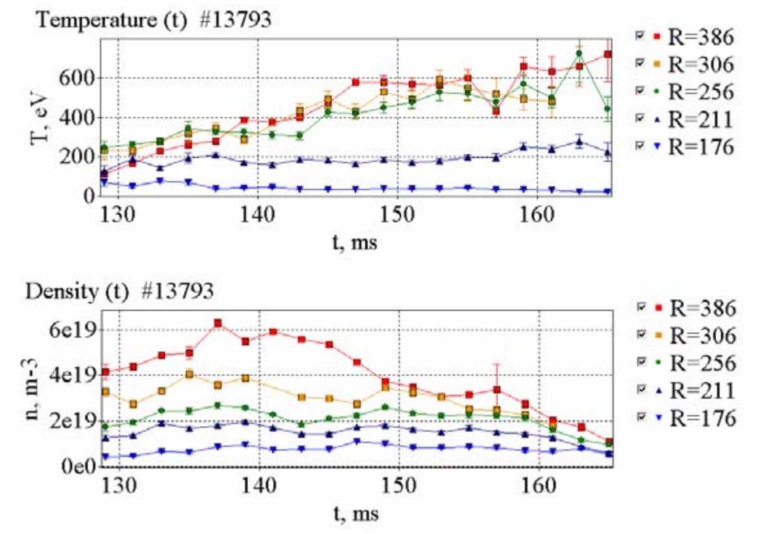
  Greenwald density limit is overcame

- **With plasma gun-**

  fast and deep jet penetration

- **Auxiliary heating – NBI–**

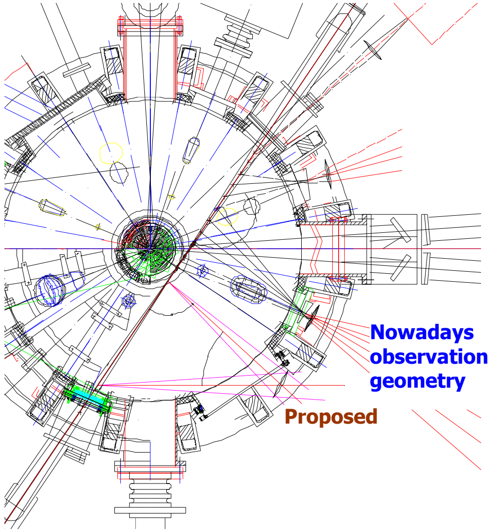
  valuable increasing of electron energy content

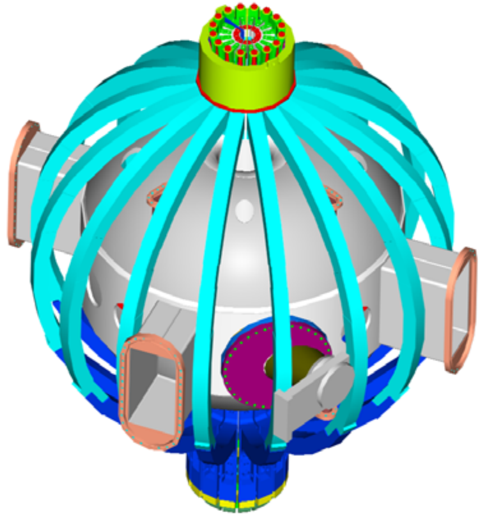


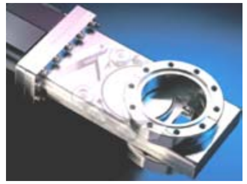
What are the next steps?

- **Light trap on the central column**
- **Increasing of spatial channels number**
- **New digitizers 500Ms/s and fast amplifiers**
- **New observation port**
- **New collection optics- achromatic objective and fibers**

What are the next steps?







- **Measurements from inner to outer plasma border**
- **Scattering angle increasing for outer border results in TS spectrum broadening**
- **Achromatic objective + fibers strongly simplify alignment of collection optics**
- **Possibility to easily spread spatial points over major radius**
- **Using of more reliable window protection**

Conclusions

- **TS system based on variable repetition rate Nd-glass laser has been designed and built**
- **The use of high throughput filter polychromators, low noise detection and dedicated software meets the planned scientific and technical objectives of the Globus-M program**
- **The extensive investigations of auxiliary heating, plasma transients and fuelling by jet injection has been performed**