TWO-PULSE THOMSON SCATTERING SYSTEM FOR MEASUREMENTS OF FAST FLUCTUATION OF ELECTRON DENSITY PROFILE IN MULTI-MIRROR TRAP GOL-3

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Introduction

In recent years, considerable progress has been achieved in studying of the beam-plasma system in the GOL-3 multimirror trap [1]. New interesting effects, such as fast ion heating, suppression of longitudinal electron heat transport, excitation of large-scale plasma density fluctuations, and the generation of neutron flux oscillations at ms-time scale were found [1, 2].

Fig. 1. Multi-mirror trap GOL-3.

To describe these effects, various models have been proposed that require additional experimental verification. In papers [3, 4] the main attention was focused on measurements of plasma electron distribution function details with Thomson scattering (TS). In these experiments a single pulse laser was employed that makes possible observation of fast dynamics of the distribution function only on shot-by-shot basis. Nd-glass laser produced 20J single laser pulse in a system of master oscillator and two amplifiers and enable detection of plasma electrons with energy up to 20 keV [3]. New laser should extend this ability to several spatial locations in radial and/or axial directions and for at least two laser pulses during a single plasma shot. Generally, information on axial variation of plasma parameters is essential for mirror plasmas. TS can fit this requirement with the use of the LIDAR layout [5], or simply by forcing a probe laser beam to pass trough plasma several times each time at different axial location. In this work, setup of the new Thomson scattering diagnostics is described. First results from measurements of the electron density fluctuation in the GOL-3 multimirror trap are presented.

Thomson scattering diagnostic

The standard multi laser approach to temporally resolved TS [6] is too expensive with 10-30J lasers. Besides relative large single beam diameter (40mm) for such lasers makes combined laser beam cross-section too large to use it in TS. We employ two-module master generator that produces two coaxial laser pulses for upgraded laser system. Diagram of this generator is shown in Fig 2.

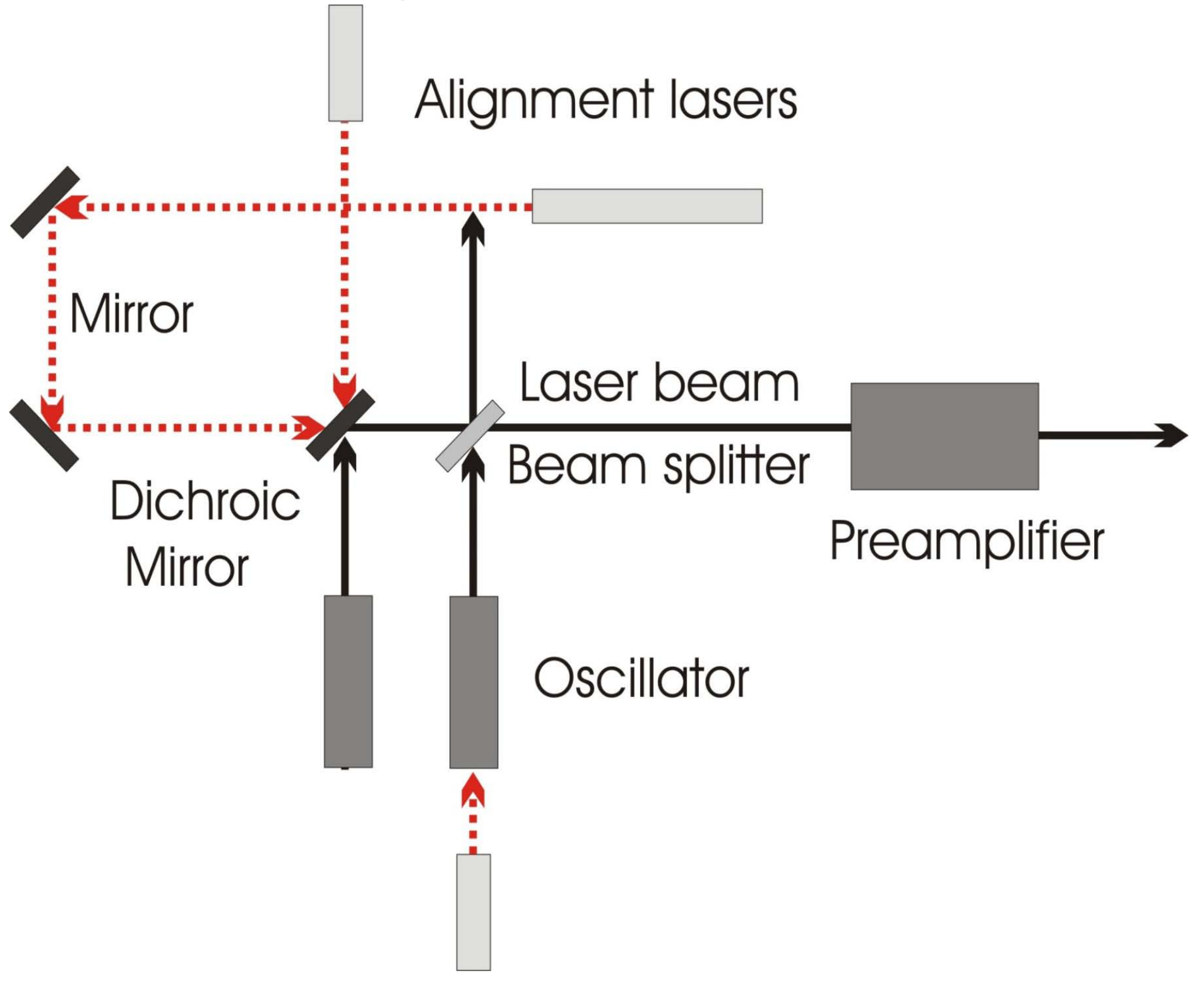

Fig. 2. Scheme of the two-pulse generator.

The modules are equipped with phosphate Nd-glass rods and optical Q-switches based on the Pockels cells. Each oscillator produces a single laser pulse (20-40ns, 10-30mJ, 2mm diameter (d), 1054nm). Then the beams are combined by mirrors and beam splitter (see Fig. 1). Time interval between two pulses can be varied from 0.1 to 100 µs. After passing preamplifier the 2mm diameter beam is directed to input of 5-pass telescopic phosphate glass amplifier and finally to silicate glass output amplifier. The total gain of two stages is order of 10^3 with the gain of the first stage near 200. The amplification of the first stage is strongly nonlinear with considerable gain saturation by the first pulse. As the gain for second laser pulse is several times lower it is compensated by respective increase of second laser pulse energy injected from master oscillator. In addition, variation of first amplifier gain mostly affects the first pulse amplitude while variation of second stage gain influences the output energy of both pulses evenly. Slight adjustment of gains of two amplifier during experimental campaign permits to keep the energy for two laser pulses equal. More detailed description of amplifiers is given in [3]. The parameters of the output laser beam in each pulse are as follows: E=10- 20 J, t= 20-40 ns and d = 40 mm.

A schematic of Thomson scattering diagnostics is shown in Fig. 2. The laser beam crosses the plasma normally to the magnetic field initially at about z=4m from the input of relativistic electron beam (REB) into plasma column. Then the laser beam is redirected by mirrors and crosses the plasma again at z=2m. The laser beam plasma is focused near the plasma axis to the focal spot diameter a=0.2mm

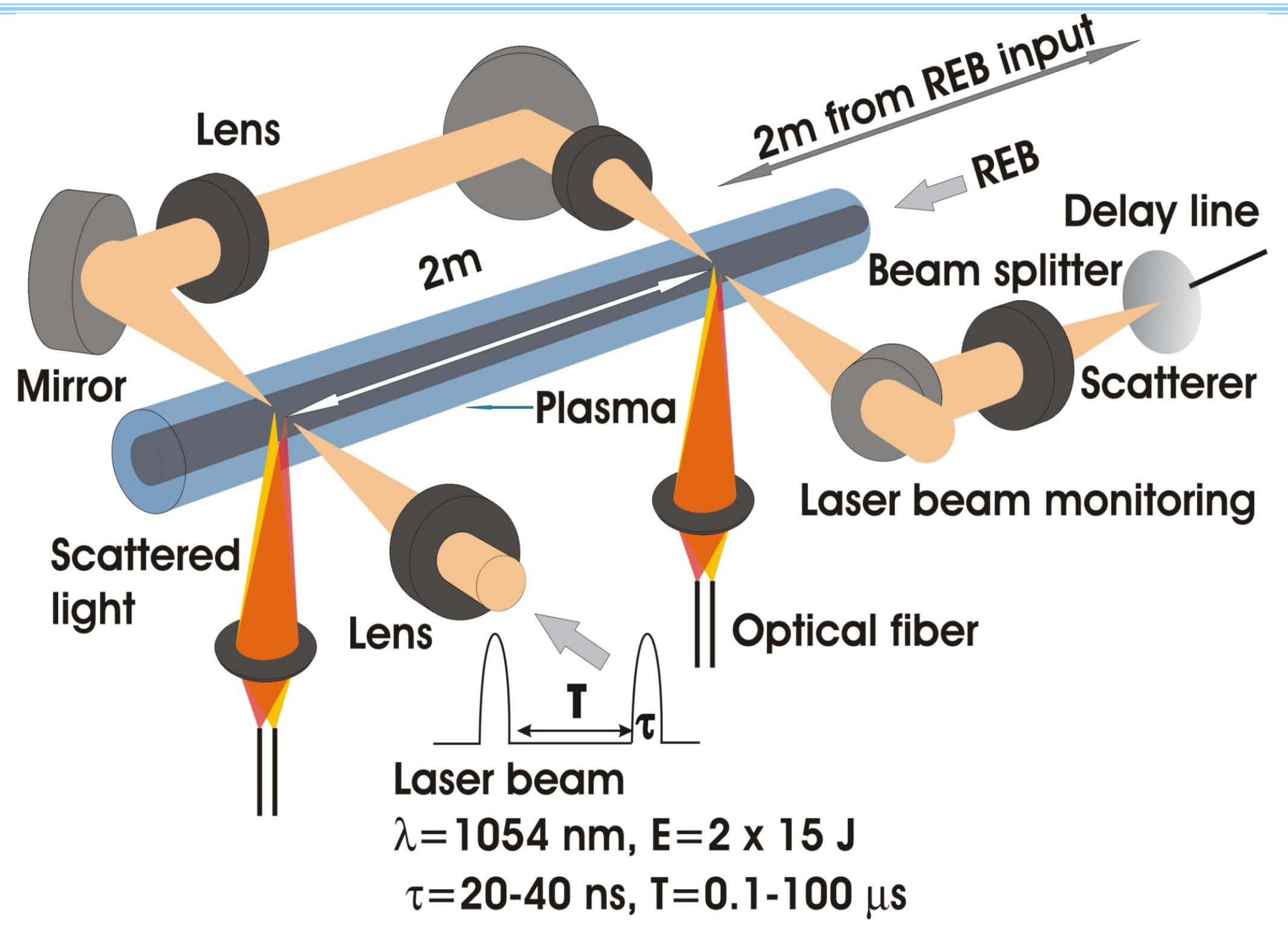

Fig. 3. The Thomson scattering system.

Scattered at 90° light is collected by lens into inputs of 1mm-diameter 40m length IR silica fibers and directed to the control room. Each fiber transmits light scattered from (0.2×0.2×4 mm^3) volume. In the presented experiments number of spatial locations was limited to 8 by the available detectors. They are radially separated positions of scatter volumes at z=2m. The laser power and the photodetector sensitivity were monitored using a fiber delay line, through which a fraction of laser radiation was fed to system of scattering radiation collection and illuminated all the recording channels.

Results of the first experiments

The experiments were performed with a plasma (n_e=10^{14} cm^{-3}) placed in a multimirror magnetic field (B_{min}= 3.5 T, B_{max}=4.8 T). Discharge plasma is heated with REB (E≈1 MeV, J≈30 kA, t=11ms)
Figure 3 shows typical waveforms of the scattered signals. The first and second spikes correspond to the scattered signals, whereas the third and fourth spikes, to the calibration signal supplied via the fiber delay line. Scattering radiation from eight points was registered. They are placed in second crossing laser beam with plasma at 2 m from relativistic electron beam input. The distance between adjacent scattering points was approximately 12 mm.
The background radiation and its fluctuations introduce significant noise in the signal.

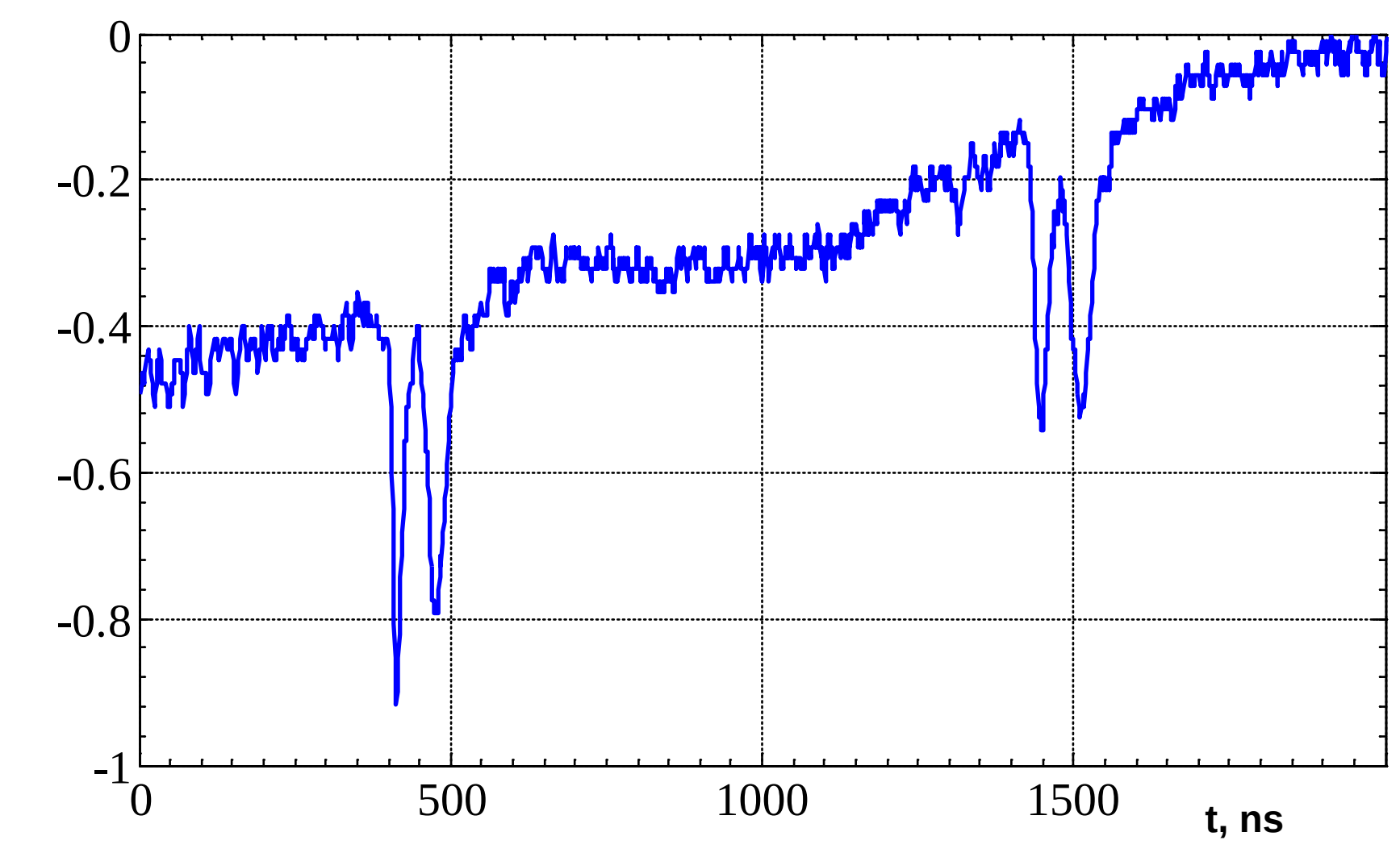

Fig. 4. Typical waveform of scattering signal.

Fig. 5 show typical density profiles in two moments without temporal fluctuation. Time delay between laser pulses is about 80 ns

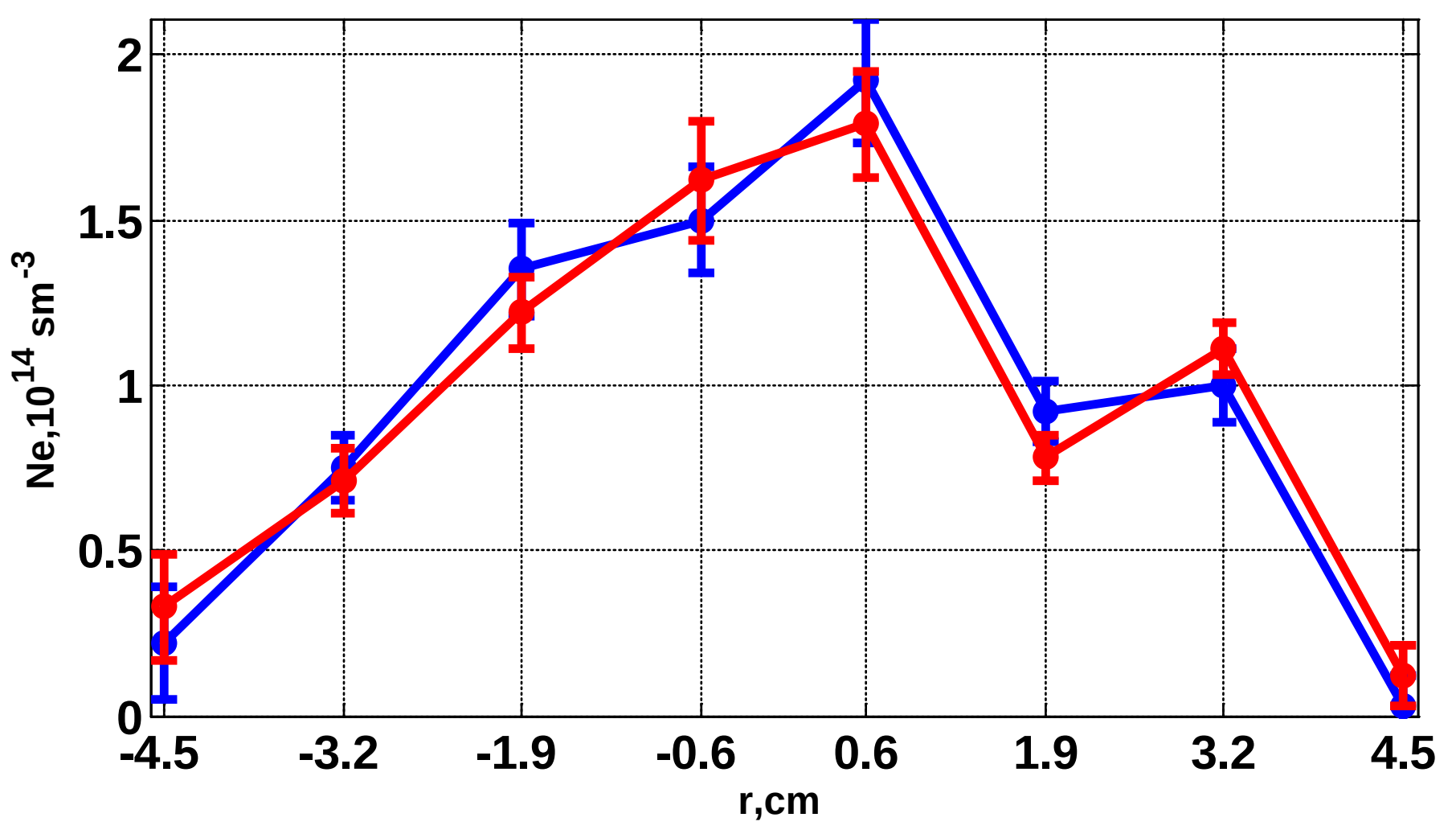

Fig. 5. Density profile at two sequential moments through 80 ns without dynamics.

The opposite case with the density fluctuations is shown in fig 6. Statistical error of density measurements is determined by the dynamics of the background radiation of the plasma and the some instability of the optical system. The errors from this instability have been estimated on the statistical spread of the Raleigh scattering amplitudes on the nitrogen with a concentration of about 10^{17} cm^{-3}. As a rule they made a significant contribution to the general measurement error.

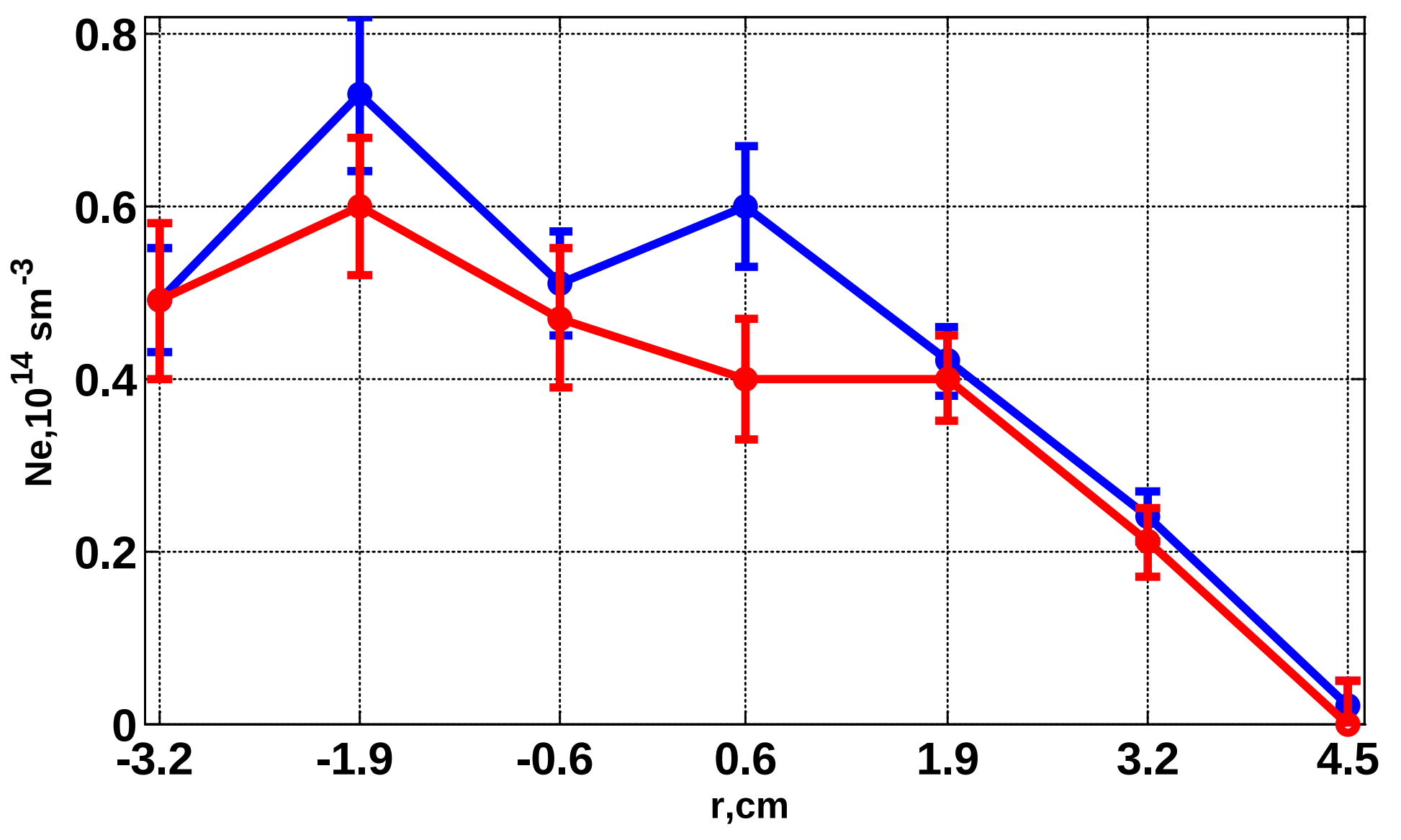

Fig. 6. Density profile at two sequential moments through 80 ns with density fluctuations.

Statistic analysis of the first experimental results

The Statistic errors are demonstrated in fig. 7a. Here is distribution of

Raleigh scattering signal fluctuations : $2\frac{n_2-n_1}{n_2+n_1}$.

n_1, n_2 are respectively signals in two time moments. In fig . 7b is the same value for scattering on plasma in during REB injection.

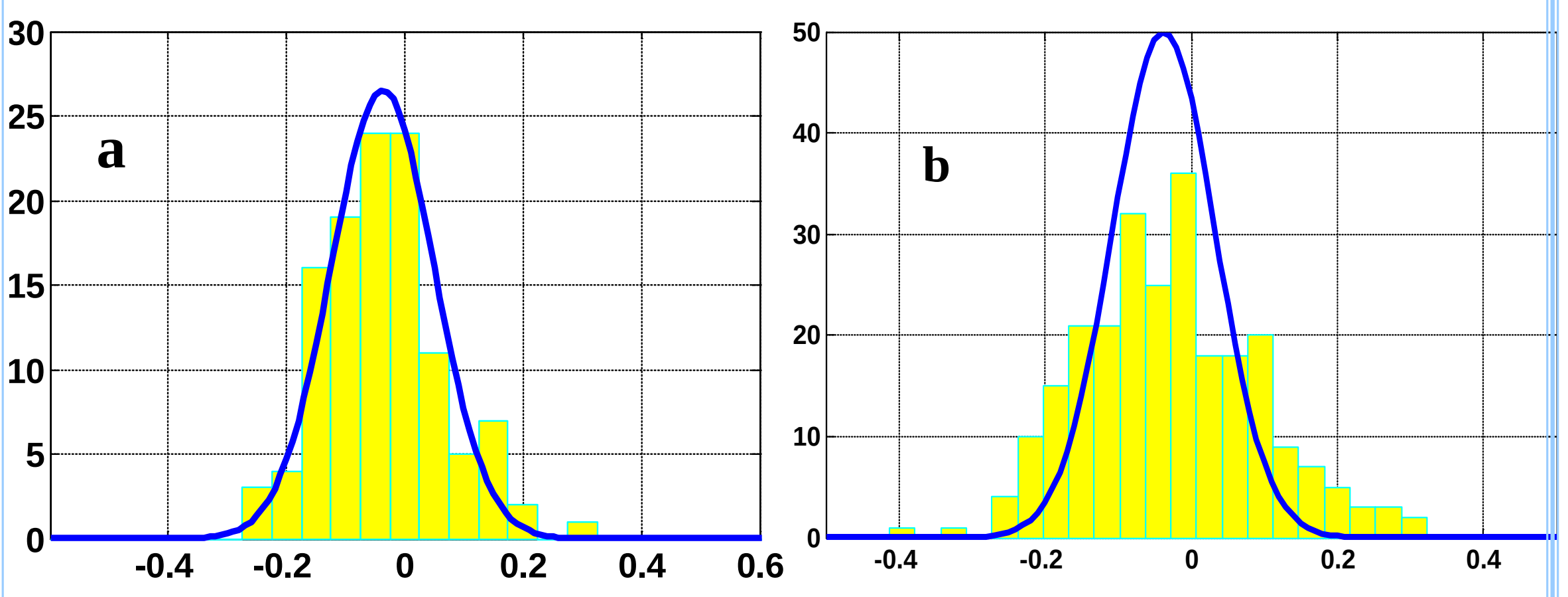

Fig. 7. Distribution of scattering signals fluctuation in two cases: a) scattering on nitrogen (total number of measurements 116), b) – on plasma with REB (total number of measurements 252). Blue curve is Gaussian distribution approximating the statistics errors.

The variance in second case is not very large in comparison with first. However, with such statistics Fisher's criterion and Kolmogorov-Smirnov test allow us at the 10% significance level to distinguish obtained distributions. Thus registered fluctuation most probably are caused some plasma processes.

Conclusion

The presented two pulse Thomson scattering system may be used for studying the fast density fluctuation. First experimental data show cases of fast variation of electron density profile which may correspond to different turbulence processes. However such approach requires big volume of statistics. For more clear and reliable results we plane investigate optic system instability and reduce of it. This will allow with more efficiency to obtain data on the density fluctuation and investigate their nature .

Acknowledgments

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