Resent experiment with compact mirror cell at the Gas Dynamic Trap

A.V. Anikeev[1], P.A. Bagryansky[1], A.A. Ivanov[1], A.V. Kireenko[1], A.A. Lizunov[1], S.V. Murakhtin[1], V.V. Prikhodko[1], A.L. Solomakhin[1], A.V. Sorokin[1] and K. Noack[2]

[1]*Budker Institute of Nuclear Physics, Prospect Lavrent'eva 11, 630090 Novosibirsk, Russia.*

[2]*Forschungszentrum Rossendorf, Postfach 51 01 19, 01314 Dresden, Germany.*

The concept of the **S**ynthesised **H**ot **I**on **P**lasmoid (SHIP) experiment in the additional compact mirror (CM) cell at the Gas Dynamic Trap (GDT) facility of the Budker Institute was presented at the 29th EPS Conference [1]. It is aimed at the investigation of strong anisotropic hot ion plasmas for modelling the region of high neutron production in a GDT based fusion neutron source proposed by the Budker Institute [2] and study the basic plasma physics of open magnetic traps. In the next two years the SHIP mirror cell was constructed and several numerical simulations were made by means of the **I**ntegrated **T**ransport **C**ode **S**ystem (ITCS) to determine the best experimental scenario for getting high plasma parameters. In December 2004 the experimental activity at the GDT-SHIP facility has been started. The first experiment on study of SHIP plasmas with moderate parameters of neutral beam injection was presented at 32nd EPS Conference [3] and in Ref.[4]. During last two years, the new power supply of the neutral beam injection system at GDT was installed and the parameters of neutral beams sufficiently increased with the prolongation of the beam pulse from 1 to 4 ms. This contribution presents the results of the resent experiment with powerful neutral beam injection to the compact end mirror cell of GDT.

The experiments are performed in a small mirror section that is installed at one side of the GDT. (See Fig.1) The magnetic field on axis is in the range of 2.5 Tesla and the mirror ratio amounts ~ 2. The section is filled with warm background plasma streaming in from the

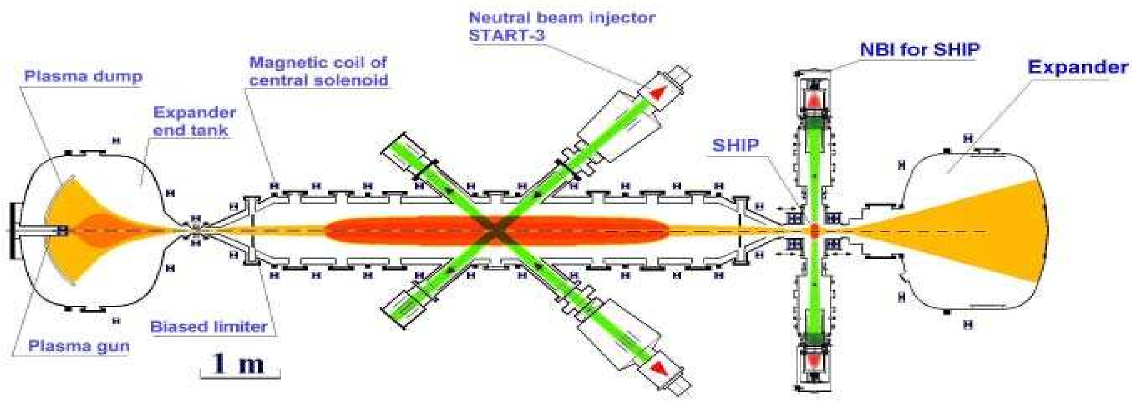

Fig. 1. *SHIP experiment at the GDT device.*

central cell. This plasma component with density of about 10^{13} cm^{-3} is Maxwellian and has electron temperature of about 100 eV. The two new focused injectors perpendicularly inject hydrogen atom beams with the energy of 20 and 25 keV and total current up to 40 atom amperes in the 4 ms pulse. The time evolutions of the total injected (red) and captured (blue) power are shown in Fig.2. The diameter of the beams in the focus point is about 9 cm. The power density of the neutrals deposited to plasma in the compact mirror cell is about 20 kW/cm^3. Ionisation of the beams generates the high-energetic strong anisotropic ion component with the density much more that it is of warm ion and with the mean energy about 15 keV.

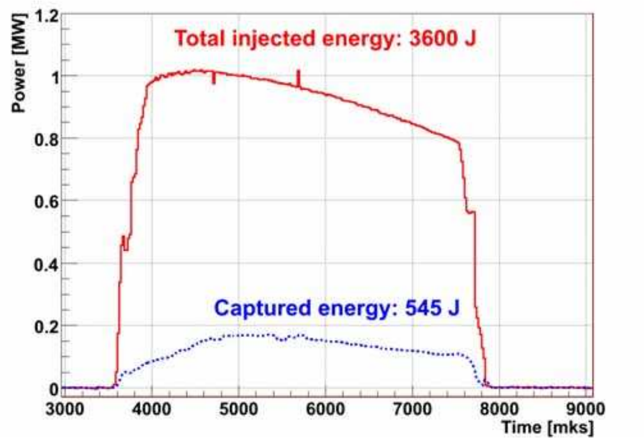

Fig.2 *Injected and captured power in the SHIP.*

Fig. 3 presents time evolutions of electron linear density during Neutral Beam Injection (NBI) into compact mirror cell (solid black line) and without injection (doted red line) measured by dispersion interferometer. Enhancement of electron density caused by neutral beams indicates build up and confinement of fast ions in this region during the NBI pulse. Comparison of electron linear densities with NBI and without NBI and the spatial profile of fast ion plasmoid measured by imaging energy analyzer of fast neutrals (see Fig.4) allowed us to estimate the maximal value of fast ion density

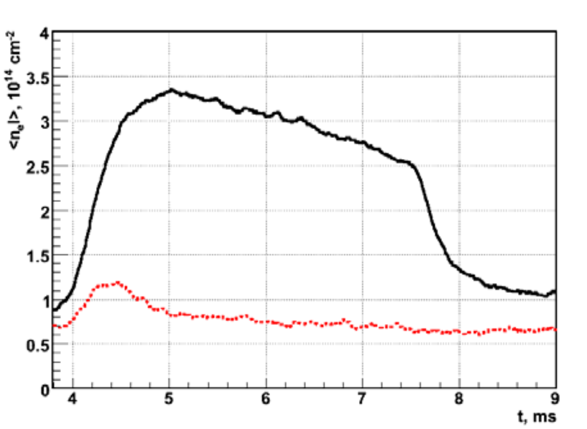

Fig.3 *Time evolutions of electron linear density in the SHIP cell during Neutral Beam Injection (solid black line) and without injection (red doted line).*

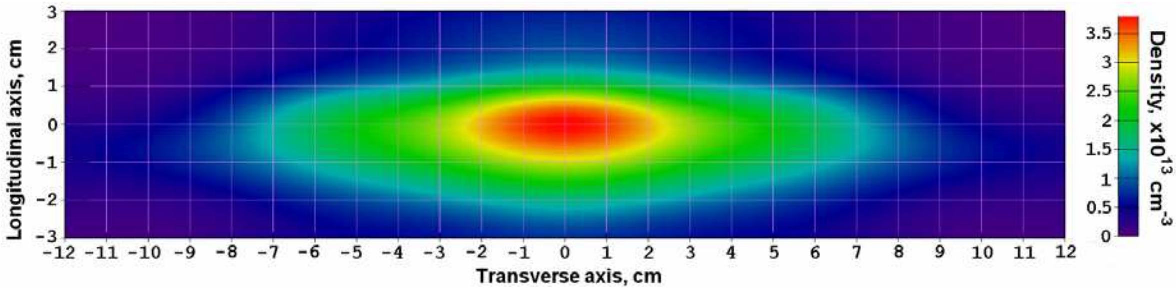

Fig.4 Spatial profile of SHIP fast ion density

n_f=3.8·10^{14} cm^{-2} and density of the warm streaming plasma n_w = 0.35·10^{14}cm^{-2} during NBI pulse. Unperturbed value of streaming plasma linear density (without NBI) is ≈·10^{14}cm^{-2}. Taking into account the results of estimation we can conclude that the maximal value of fast ion density is about 4 times greater than density of unperturbed streaming plasma and more them one order of magnitude higher than that of the warm ion density in the presence of NBI. In result we observed the plasmoid practically composed of hot anisotropic ions with the mean energy of about 15 keV and warm 100 eV electrons. Characteristic dimensions of plasmoid (at the 1/e level) are: 4 cm along the axis and 15 cm in the perpendicular direction

Build-up of anisotropic fast ion density in the compact mirror is accompanied by the rise of electrostatic potential on field lines occupied by ions. This potential barrier reduces the plasma outflow, which is clearly demonstrated in Fig.5 by the difference between on-axis ion flux density measured in the expander cell with and without SHIP. At the time point of 5-5.5 ms particle losses through the compact mirror cell to expander are about 4 times lower in the presence of injection in comparison with regime without NBI. This effect known as an ambipolar plugging leads to improvement of GDT central cell plasma confinement. Fig. 6 shows the dependence of the ambipolar effect as a ratio between the ion fluxes in expander vs the fast ion density in SHIP.

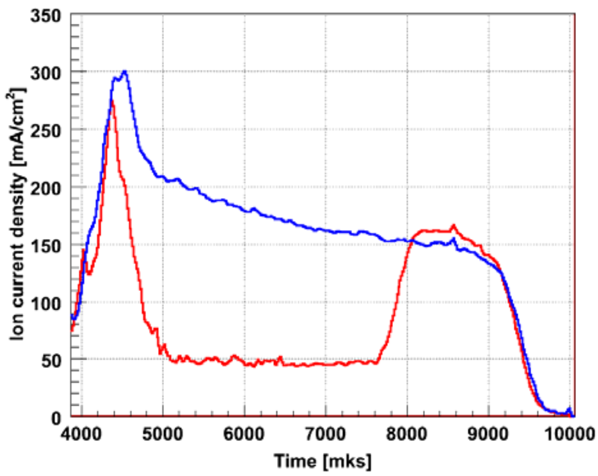

Fig. 5. *Time evolutions of ion flux density in the expander cell with NBI in the SHIP cell (**red**) and without NBI (**blue**).*

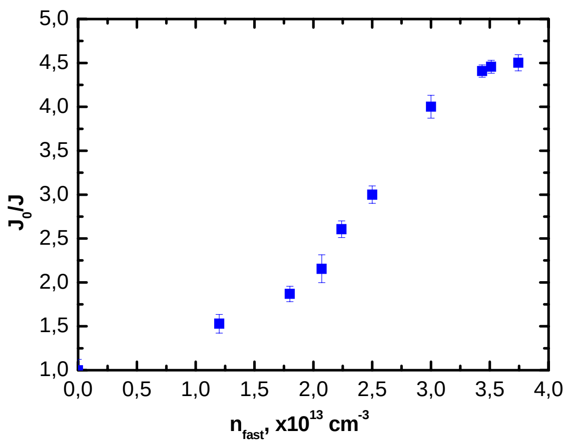

Fig.6 *Ion flux suppression vs fast ion density.*

During the high density of the fast ions build up in the small mirror section, strong high-frequency oscillations of plasma potential have been observed by special RF Longmuir probe. The main frequency of the fluctuation is about 37 MHz that corresponds to the ion-cyclotron frequency in the SHIP-cell midplane. These fluctuations of the plasma potential can be associated with the developing of micro-instability, which can affect to the

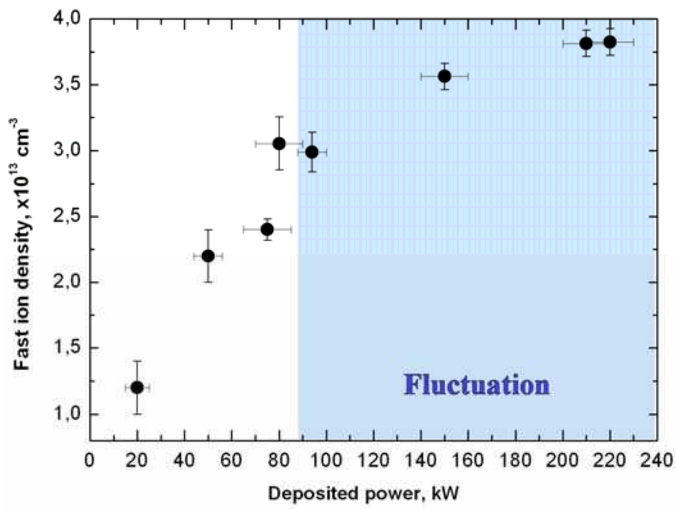

Fig.7 *Fast ion density vs. deposited to SHIP NBI power.*

fast ion density in the SHIP. Fig.7 shows the maximal fast ion density in SHIP vs. deposited (captured) power of the NBI. The fluctuations develop when the fast ion density in the compact mirror cell exceeds the value of 3 $\times 10^{13}$ cm^{-3}. A commonly used parameter characterizing the threshold of AIC instability is βA^2 where $A = \langle E_\perp \rangle / \langle E_\parallel \rangle$ is a plasma anisotropy [5]. In this point the parameter of βA^2 was about 50. Detailed study of the plasma fluctuation in SHIP will be made in next experiments with the compact mirrors at GDT.

Summarizing described above we can draw the conclusions as follows:

- The **S**ynthesised **H**ot **I**on **P**lasmoid experiment with 1 MW neutral beams power was carried out at the GDT device.
- The value of fast ion density in SHIP was four times greater than density of unperturbed streaming plasma and one order greater than the warm ion density in the presence of NBI.
- Ambipolar plugging was surely demonstrated in the SHIP experiment.
- The high level fluctuations of the plasma potential were observed when the SHIP density exceeds the critical value.

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References

[1] A.V. Anikeev, P.A. Bagryansky, A.A. Ivanov, K. Noack, *29th EPS Conference on Plasma Phys. and Contr. Fusion,* ECA **26B** (2002) P-4.098.
[2] P.A.Bagryansky, A.A.Ivanov, E.P.Kruglyakov, et. al., *Fusion Engineering and Design* **70** (2004) 13-33.
[3] A.V. Anikeev, P. A. Bagryansky, A. A. Ivanov, et. al., *32nd EPS Conference on Plasma Physics*, ECA **29C** (2005) P-5.077.
[4] A.V. Anikeev, P. A. Bagryansky, A. A. Ivanov, et. al. *Journal of Fusion Energy* **26** (2007) p.101-110.
[5] Casper T.A. and Smith G.R. *Phys. Review Letters* **48** (1982) 1015.