

## Heavy Ion Beam Probe (HIBP) diagnostics design study for GLOBUS-M tokamak

A.V. Melnikov, S.V. Perfilov

*Nuclear Fusion Institute, RRC «Kurchatov Institute», Moscow, Russia*

### INTRODUCTION

Many existing facilities and the ITER tokamak-reactor under design have tight aspect ratio. The spherical torus GLOBUS-M is the next step in this direction. The Heavy Ion Beam Probe (HIBP) diagnostics could be very useful there [1].

Motivation of the spherical tokamak - HIBP alliance is the following.

The spherical tokamaks are oriented to researches in support of the tokamak-reactor and to the investigation of main tokamak problems such as disruptions and  $\beta$  increase. The economically- beneficial reactor should operate with a high plasma confinement (H-mode). An important role in the L-H transition, which was obtained in all tight aspect ratio tokamaks, is played by the radial electric field  $E_r=d\Phi/dr$  ( $\Phi$  is the plasma potential). Therefore  $\Phi$  measurements by HIBP could be very important for understanding the physical nature of this effect.

HIBP is a non-perturbative local multipurpose diagnostics that allows us to monitor the temporal evolution of 2D distributions of several plasma parameters, such as the electric potential  $\Phi$ , the density  $n$ , the poloidal field  $B_p$  and the electron temperature  $T_e$ . HIBP allows us to measure the fluctuations  $\Phi$ ,  $B_p$  and  $n$ , which may cause the anomalous transport. The investigation of the plasma electric potential can be provided by HIBP only [2].

Tight aspect ratio tokamaks have a set of additional coils for the plasma shaping. Therefore the inner part of the torus is often not seen by traditional chord diagnostics. HIBP is convenient for spherical tokamaks, where the space is limited, because it needs curvilinear access routes.

Up to now the HIBP was used in tokamaks with high aspect ratio (ST, TM-4, T-10, TEXT, RENTOR, JIPPT-IIU, ISTTOK, TJ-1, JFT-2M).

The operation of the HIBP is based on the injection of a single charged ion beam (primary) into the plasma across the supporting field and on the registration of the double charged particles (secondary) born due to collisions with the plasma electrons and escaping the plasma. The area of the secondary ionization in plasma is the sample volume, the local point of the plasma potential measurements. The position and the size of the sample volume are determined by calculation of the trajectories of probing particles.

Here we propose the HIBP project for Spherical Torus GLOBUS-M to establish the systematic researches of the radial electric field  $E_r$  structure and temporal evolution as an idea to investigate both the reactor-related physics (H-mode), and the basic plasma physics (nature of the anomalous transport).

### HIBP OPTIMIZATION

The local point of the plasma potential measurements (sample volume) is the point of the secondary ionization of probing particle in plasma. By varying the beam parameters: energy  $E$  and injection angle  $\alpha$ , one can transfer the sample volume across the plasma column. The variation in one of these parameters allows us to detect secondary ions coming from some curve ("detector line"). A family of equal angle lines together with the equal

energy lines covers the plasma cross section by a “detector grid”.

The shape and the size of the detector grid can be optimized for the following goals:

- (1) to carry out the beams through the ports of the facility;
- (2) to find a detector line connecting the center and the edge of the plasma;
- (3) to find a detector grid covering the maximal plasma cross section;
- (4) to choose the probing pattern to minimize the beam energy range.

The HIBP proposal is a reasonable compromise between these goals.

#### DESCRIPTION OF THE POSSIBLE PROBING SCHEMES FOR GLOBUS-M

The trajectories of probing particles are calculated by a numerical solution of the motion equation in the full magnetic field of the tokamak. The calculation was made for the standard Globus-M regime ( $I_{pl} = 300$  kA and  $B_0 = 0.6$  T) with  $Cs^+$  as a primary beam ions. Three possible probing schemes for GLOBUS-M were found. The first one is presented in Fig. 1,a (probing trajectories), 1b (detector grid). We have used the traditional HIBP scheme. The upper x-point port is used for injection and the horizontal port is used for the detection. The second scheme (Fig. 2a,2b) differs from the first one in the port combination. The upper RF-heating port is used for injection here. In the third case (Fig. 3a,3b) a quite different scheme is used. The horizontal port is used for injection and the lower x-point port is used for the detection. Due to the plasma current the trajectories of the probing particles become spatial curves. However, one can rule the particles by variation of the toroidal injection angle  $\beta$  to reach the detector [3]. The equatorial projections are presented in Fig. 1c,2c,3c.

#### THE COMPARISON OF THREE PROBING SCHEMES

We have analyzed the following parameters of the probing schemes: possibility of reaching the center of the plasma, radial length of the detector lines,  $E=const$  and  $\alpha=const$ , maximal value of the primary beam energy (see Table 1).

**Table 1**

#	$E=const, \Delta\rho$	$\alpha=const, \Delta\rho$	Reach the center, $\rho_{min}$	$\Delta E, keV, Cs^+$
1	$0 < \rho < 0.3$	$-1 < \rho < 0.3$	+, $\rho_{min}=0.00$	20-80
2	$0.03 < \rho < 0.2$	$-0.3 < \rho < 0.8$	-, $\rho_{min}=0.03$	12-40
3	$-0.6 < \rho < 1$	$0.05 < \rho < 0.5$	-, $\rho_{min}=0.05$	40-120

Here we have symbolically marked a radius of the inner torus part as a negative one.

The radius range for the line of equal angle allows us to determine the quality of the radial plasma parameter profiles obtained from shot to shot. The radius interval for the line of equal energy is much more important because it allows us to evaluate the radial plasma parameter profiles that we can get in one shot by fast scanning of the injection angle. The only limitation to the energy range values is the existent equipment. The energy range is comparatively small for all the presented schemes. A compact commercial equipment could be used. The possibility of reaching the center of the plasma is very important characteristic of the scheme. We can reach the center only in case of using the scheme #1. But in case of using the scheme #2 or the scheme #3 we can approach the center close enough to make this disadvantage to be negligible.

The main advantage of the first scheme (Fig. 1abc) is an opportunity to get the data from the inner part of the torus (radius interval  $-1 < \rho < 0.3$ ) from shot to shot. This area is usually not seen by typical chord diagnostics. However, this scheme has two imperfections. Firstly, we couldn't get any signal from the outer part of the torus. Secondly, the radius

interval for the line of equal energy is so narrow ( $0 < \rho < 0.3$ ), that the profile obtained in one shot wouldn't be enough representative.

On the contrary, we can observe the outer part of the torus, using the second scheme (Fig. 2abc). The radial interval is also tight for the line of equal energy.

The most promising scheme is the third one (Fig. 3abc). The detector line of equal energy, 120 keV, allows us to get the plasma parameter profiles in one shot and the radius range is wide ( $-0.6 < \rho < -0.05$ ) and ( $0.05 < \rho < 1$ ). It allows us to investigate «inside-outside» asymmetry. So, this scheme is a hot favorite in the final choice.

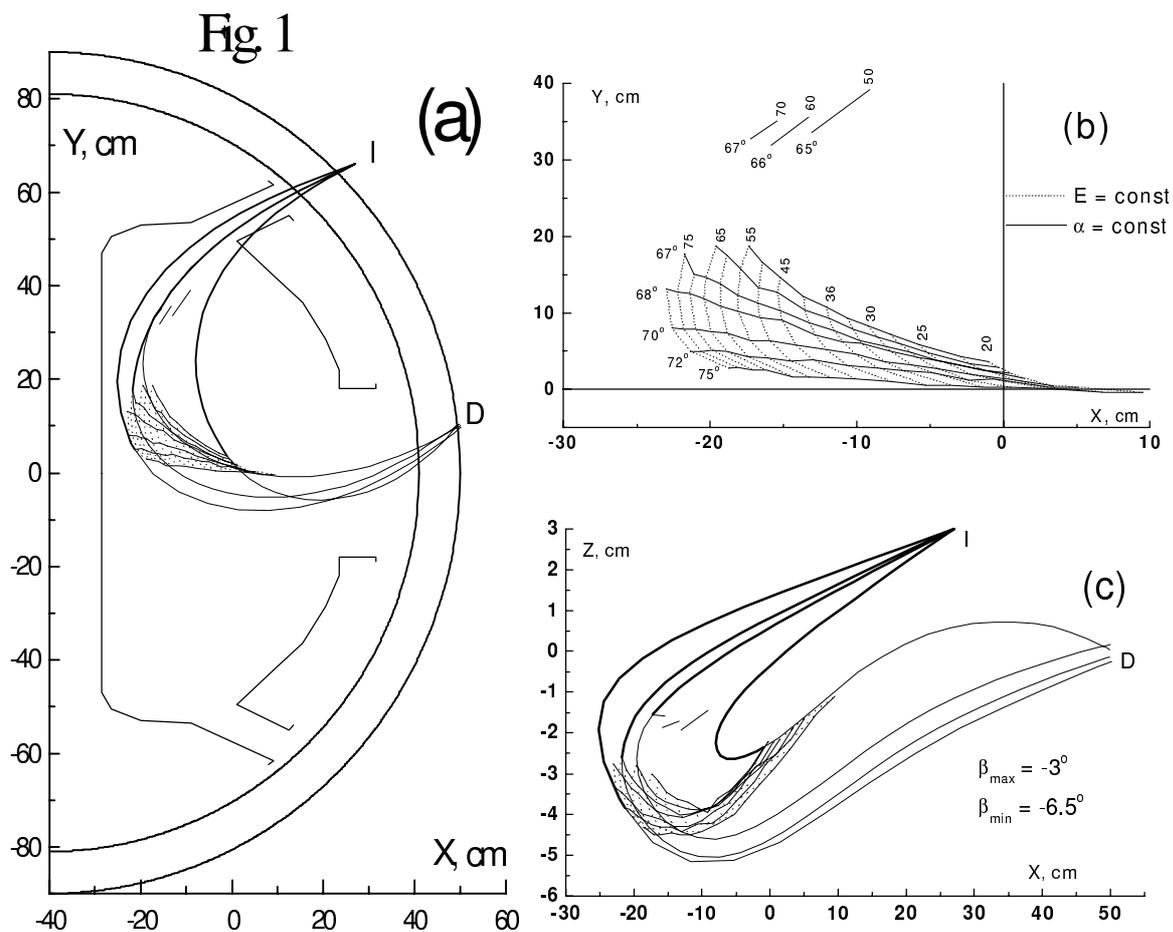
## CONCLUSION

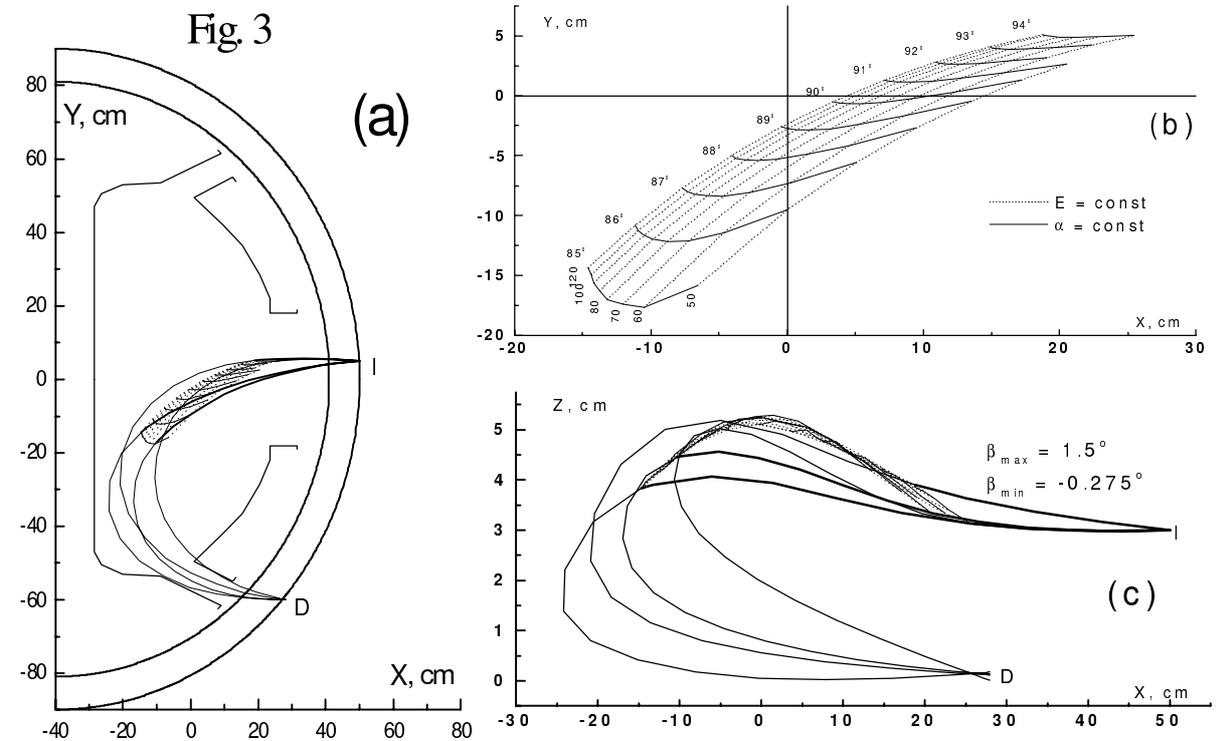
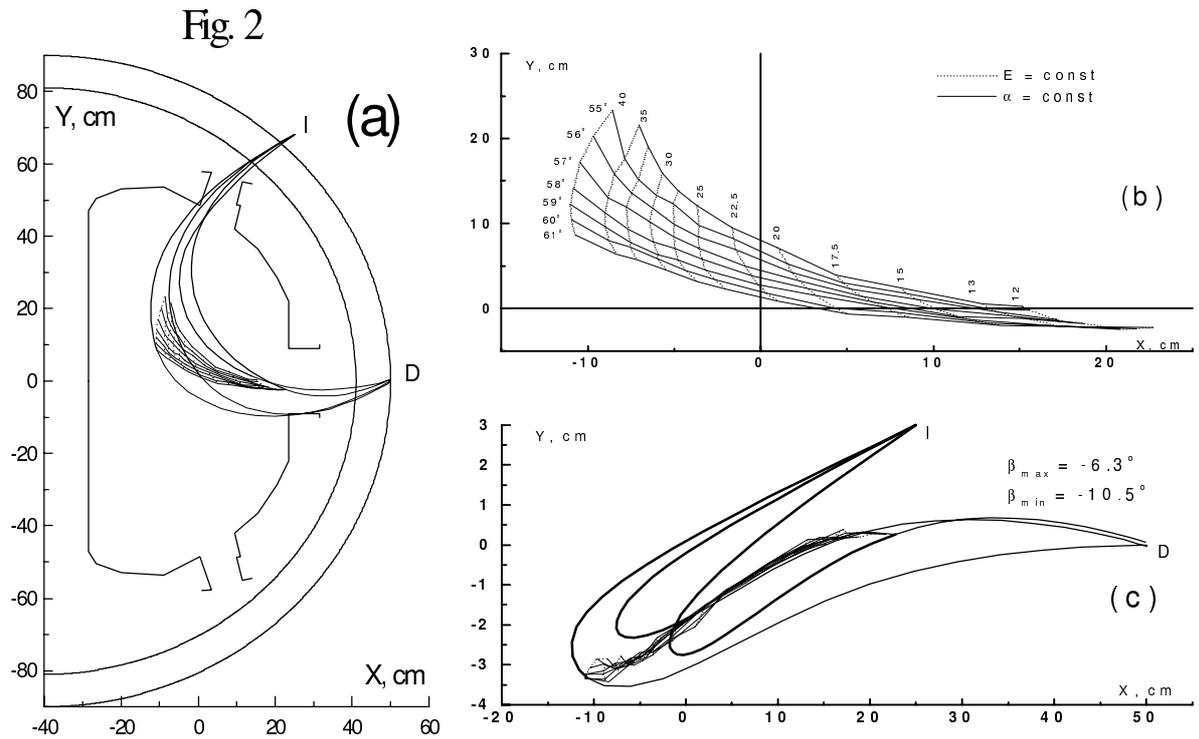
The HIBP diagnostics is applicable for the GLOBUS-M and a set of promising probing schemes has been found. The most promising scheme allows us to get the plasma parameter profiles almost along the plasma “diameter” with a small energy range.

The work is supported by RBRF grant N 99-02-18457.

## REFERENCES

- [1] A.V. Melnikov et.al. Rev. Sci. Instrum. 68, 316 (1997)
- [2] IEEE Trans. Plasma Sci. 22, (1994) (the entire issue)
- [3] A.V. Melnikov, Yu.N. Dnestrovskij, S.V. Perfilov, L.I. Krupnik in International Workshop on Spherical Torus '97 (A.F. Ioffe PTI, St. Peterburg, Russia, 1997), p. 651





I-injector, D-detector, fat line – primary trajectory, thin line – secondary trajectory