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# The Heavy Ion Beam Probing Development for WEGA Stellarator


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## Abstract.

The conceptual design for a Heavy Ion Beam diagnostic (HIBP) for the stellarator WEGA in Greifswald (Germany) is developed to provide the measurements of the radial profiles of the electric plasma potential, density and their fluctuations. Calculations of probing $Na^+$ beam trajectories were done for the various WEGA diagnostics ports with $B_0$ from 0.087T to 0.5T. They show that satisfactory access may be possible for C+-C- port combinations.

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## 1. Introduction

In the last years the Heavy Ion Beam Probe (HIBP) diagnostic became rather popular and measurement systems were set up at various magnetic confinement devices. The reason is that the HIBP has the possibility to perform measurements of several main plasma parameters in improved confinement regimes. Some of them are linked to electric and magnetic fields, which can be measured by this diagnostic in a unique way. Essential capability inherent to HIBP is investigations of the plasma parameters and their fluctuations from a center to edge of plasma column [1].

Radial electric fields play a key role in plasma turbulence and confinement. The best performance of fusion devices has been obtained in plasma regimes where ExB-shear stabilizing mechanisms are likely to play a role. Stellarators are inherently flexible devices, very well suited for the investigation of the complex phenomenology, that interrelates with electric field, instabilities, magnetic configurations and transport.

### 2. Basic Principles of the HIBP method.

The HIBP is based on the ion beam injection across the confinement magnetic field. Fig.1. When the beam of high-energy single charged ions passes through the plasma, some of the beam ions are ionized, predominantly by the electrons. The ionization takes place along the full path of the beam in the plasma volume. Because of their higher charge state, the secondary ions deviate from the primary beam and form a broad fan of ions leaving the plasma. The secondary ions that enter the detector aperture, originate from a small part of the primary beam in the plasma, called the sample volume, which has typical dimensions of 0.5÷1 $cm^3$ . The energy difference between the secondary ions leaving the plasma and the primary ions is equal to the electric potential φ at the sample volume. The intensity of the secondary beam is proportional to the electron density, $\boldsymbol{n_e}$, in the sample volume. The toroidal velocity of the secondary beam in the detector reflects the poloidal component of magnetic vector potential (poloidal magnetic field or plasma current density). The position of the sample volume can be rapidly changed by redirection of the probing beam with electrostatic sweep plates or by changing of the probing beam initial energy. The HIBP is operated as a continuous measurement in time, providing a high temporal resolution limited only by the possibilities of the acquisition electronics.

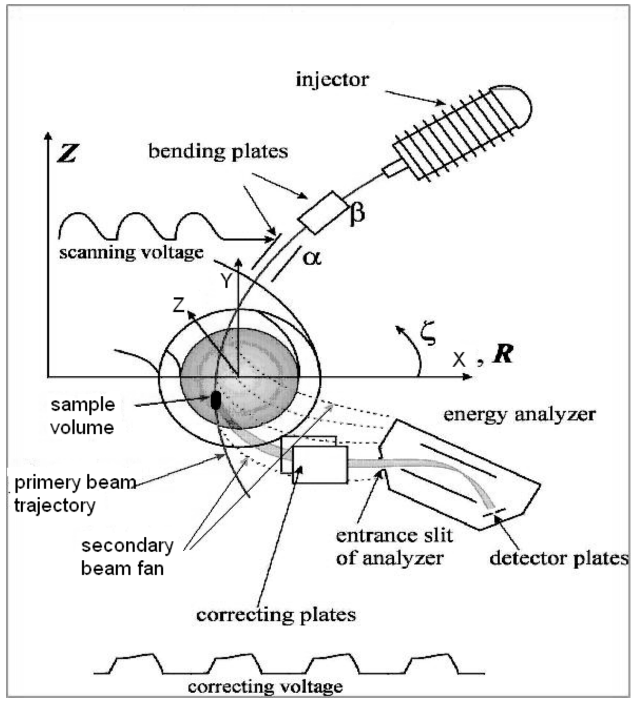


Fig.1. Basic principles.

### 3. Main objectives of the WEGA HIBP project and WEGA stellarator short information.

The idea of the WEGA HIBP project is to provide the plasma potential measurements in the reasonably wide plasma area, which can give various contributions for the WEGA scientific program. The main objective is the radial profiles of the plasma electric potential and electron density investigations. With the measurements of plasma electric potential (mean profiles and fluctuations) HIBP can contribute to the physical understanding of edge (H-mode) and Internal Transport Barriers (ITB). Density profile can be reconstructed from the secondary beam intensity profile.

WEGA is a classical 2 turn (l=2) stellarator with 5 periods of the magnetic field (m=5). Major radius R = 72cm, minor radius r = 19 cm. Toroidal field strength at the center of the camera B(0) is up to 0.3T in continuous and up to 0.9T in pulsed operation.

### 4. 3D trajectory calculations and optimization of the WEGA features

The main goals of the HIBP optimization was: (1) finding the probing beam properties (energy, angle of injection, type of ions and so on), providing the detector grid covering maximal plasma cross section; (2) minimization of the secondary beam trajectories dispersion at the vicinity of the analyzer entrance slit; (3) choosing the probing pattern in order to optimize (minimize) the beam energy range; (4) finding an opportunity to carry out the probing beam through existing diagnostic ports of the WEGA vacuum chamber. The complexity of the stellarator magnetic configuration was defined a quite strong three dimensional nature of the probing beam trajectories. The trajectory calculation code solves the 3-dimensional equation of motion in the magnetic and electric fields for probing ions using Runge-Kutta method with certain accuracy [2].

The example of the primary and secondary trajectories which are created along the primary beam trajectory is shown in Fig.2 for one of the operational regimes of the WEGA stellarator. The corresponding detector grid which was calculated by changing the energy and angle of primary $Na^+$ beam and for the secondary $Na^{++}$ ions which is projected into analyzer entrance slit is shown in Fig 3. The search of the best location of the detection point shows impossibility to obtain one position of this point for all operational regimes of the stellarator without the degradation of the detector grids or a by mechanical adjustments of the primary/secondary beam-lines and analyzer. Thus, position of the WEGA HIBP diagnostic equipment was optimized for operational regime of the stellarator for $B_{tor}(0)$=0.5T. The corresponding total primary beam angular deflection is about $4^o$ for all range of the scanning voltage.

A quite large angular range of the secondary ions, which are leaving plasma volume, is present in the secondary beam line due to influence of the poloidal and toroidal magnetic fields. This fact results to an active beam control system construction for primary and secondary beam lines [3,4,5] with significant requirements of beam adjusting in two dimensions. Five electrostatic deflection plates of primary and secondary beamlines were used in calculation for scanning and correcting the beam motion. The necessary control voltages on the plates were also calculated (Fig.4).

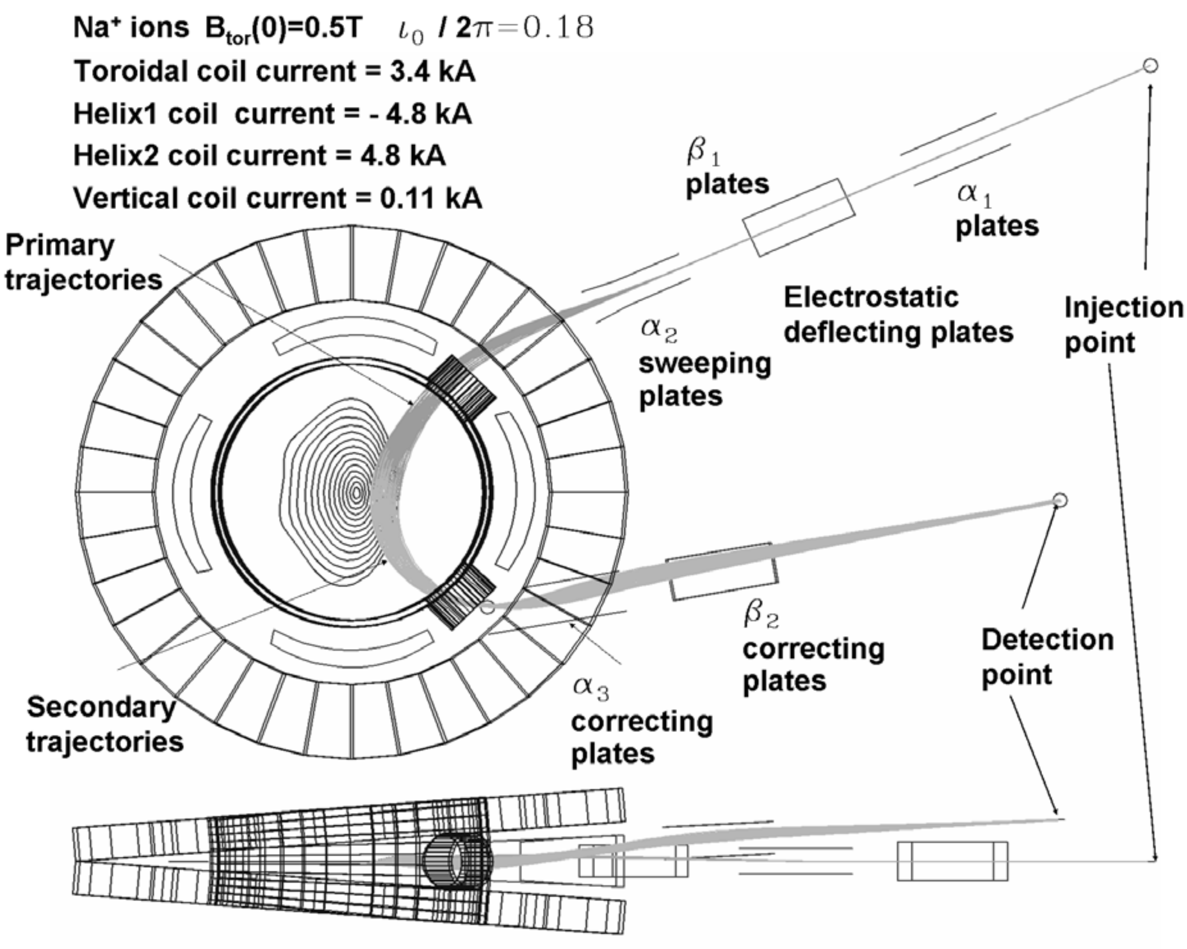


Fig. 2. Trajectory calculation for C+ C- ports :above- XY plane; below-XZ-plane.

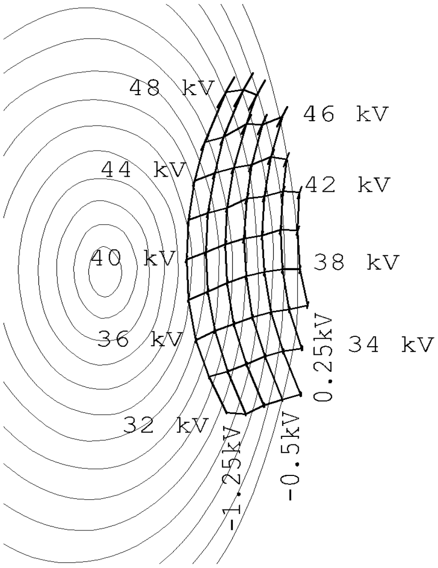


Fig. 3. Detector grid.
Bottom-up: change of accelerator voltage
Right-left: Change of deflection voltage $\alpha_2$

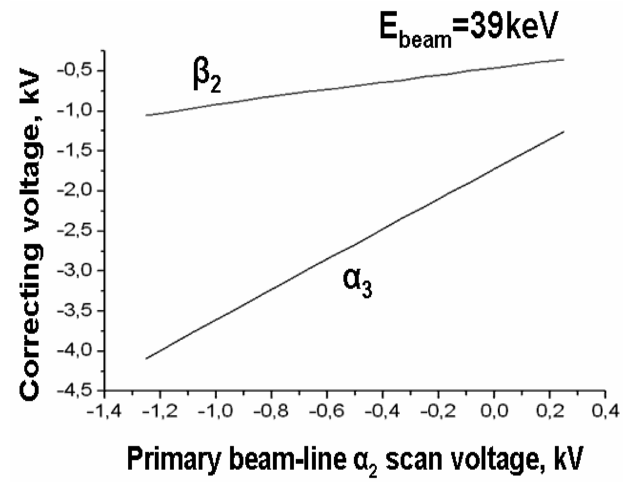


Fig.4. Control voltages.

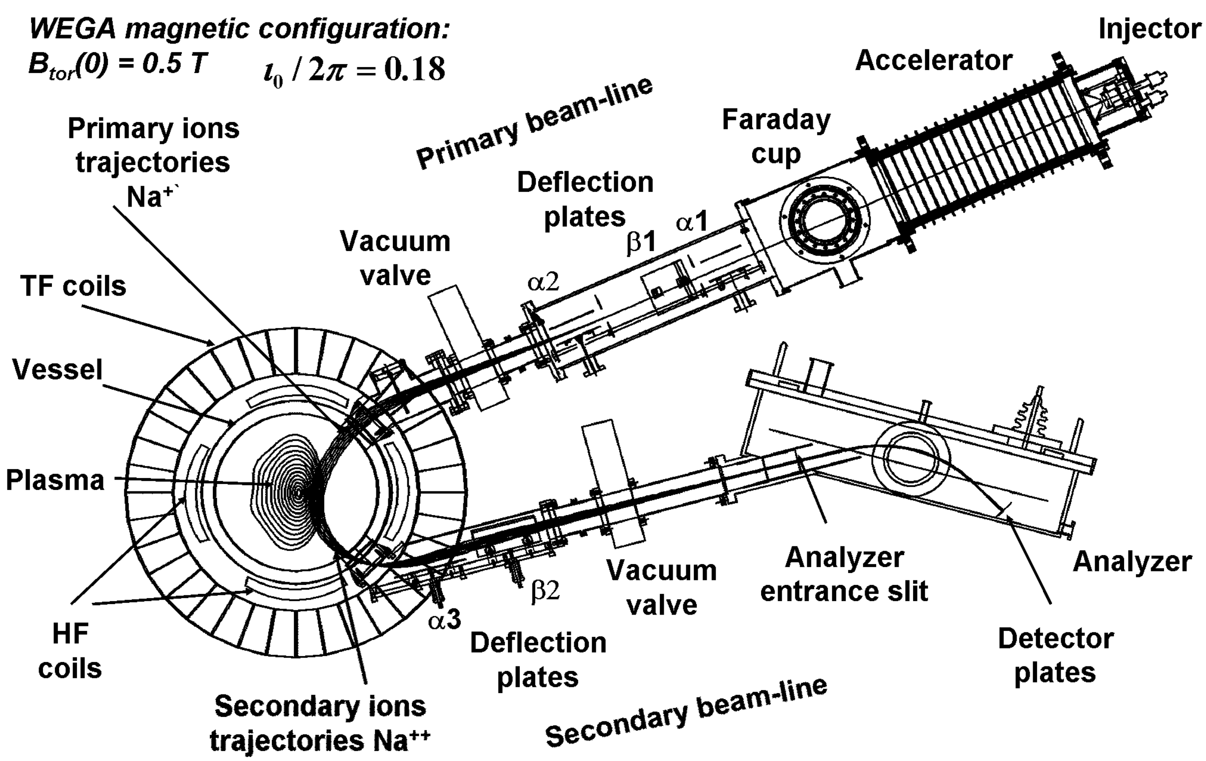


Fig.5. Schematic drawing of WEGA HIBP

**5. HIBP diagnostic equipment for WEGA**

Schematic view of the WEGA HIBP diagnostic equipment is shown on Fig.5.The injection system of WEGA (Fig.9) is built on the base of 100 keV sectional accelerating tube with solid-state thermo-ionic ion source and three electrode extraction-focus system. The method of plasma potential measurements by HIBP has quite complicated realization. Measurements of the secondary ions energy must have resolution capability $\Delta E/E_b \leq 10^{-4}$ or better, where $E_b$ is probing beam energy. The $30^0$ Proca-Green electrostatic energy analyzer [6] is used for it (see Fig.9). In the near future WEGA will be equipped with new gyrotron heating system and expected electron temperature will be in the range of 25÷50 eV. The equilibrium plasma potential will be approximately in this order. Thus, we expect 10-20% error of the plasma potential measurements. The diagnostic beam of $Na^+$ ions with energy up to 100 keV, intensity about 50 μA, 5 mm diameter is injected into the entrance of upper C+ diagnostic port (which is 1.5 meters from the emitter surface). The ion optic properties of the injection system were numerically simulated by SIMION-3D code. The high voltage tests did not indicate any sparking during accelerator operation in an open air.

The primary beam line includes three pairs of the electrostatic sweep plates for the adjusting and sweeping of the primary beam, Faraday cup (for ion current measurements) and five wire grid detector for beam diameter measuring and to determine the beam position in space. The active beam control by the secondary beam-line plates is extremely important due to three-dimensional nature of beam trajectories in the magnetic fields of WEGA. This control will be realized by programmable drive of the electrostatic plates with high speed high voltage amplifiers.

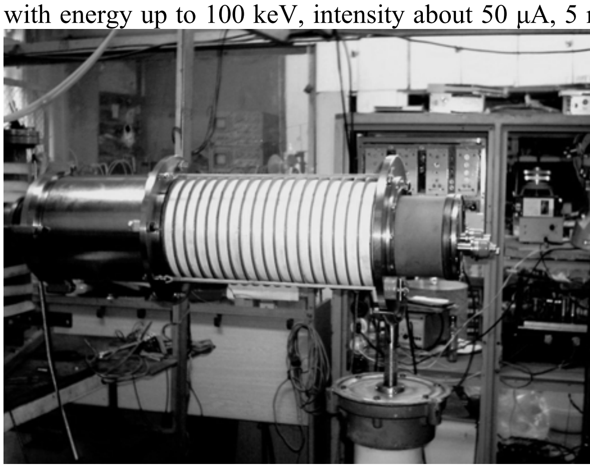

Fig. 6. 100 keV beam injector , ion current up to 40 μ*A*

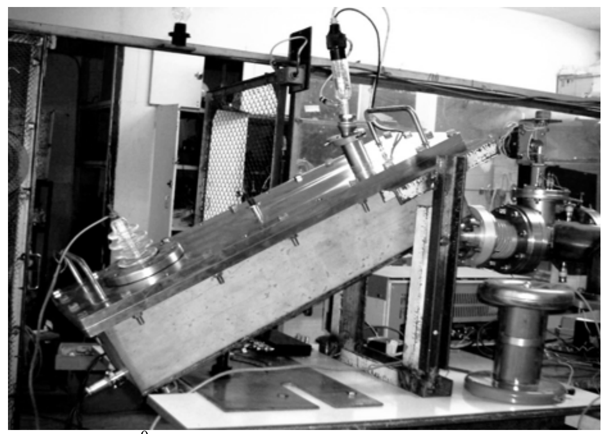

Fig. 7. $30^0$ Proca-Green electrostatic energy analyzer

**Conclusions.**

1. The optimized probing scheme for C+ C- port combination was found. 2. Radial range for sample volume for {0.5 T, 40 keV} is $0.3 < \rho < 1$, the geometrical limitations avoid us to reach the very center. 3. Focusing of the secondary trajectories in the horizontal place by magnetic fields of device will lead to necessity to construct rather complex secondary beamline. 4. Hardware of the HIBP for WEGA was manufactured and tested.

## Acknowledgements

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