Plasma edge current fluctuation measurements with the Atomic Beam Probe at COMPASS

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Introduction

The suppression or avoidance of large Edge Localized Modes (ELMs) will be inevitable in a future reactor and even in ITER, thus the understanding of the ELM destabilization mechanism is of particular interest for magnetically confined plasmas. Two plasma parameters, the plasma edge pressure gradient and the edge current density are identified as critical parameters for the ELM destabilization. While the plasma pressure gradient is routinely measured with high spatial and temporal resolution on fusion experiments, the plasma edge current measurement capabilities are limited.

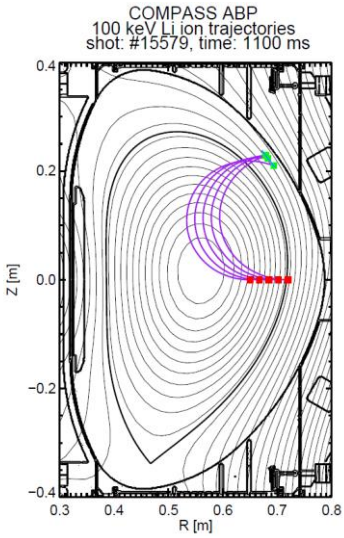

Figure 1: 100 keV Lithium ion beam trajectories (solid purple rectangles), ionization location (red rectangles), detector location (solid blue line), detector plane impact location (green circles).

The Atomic Beam Probe (ABP [1][2][3]) is an extension of the widely used Alkali atomic beam emission spectroscopy diagnostic [4] offering a novel solution for plasma edge current measurement. The atomic beam, which is injected into the plasma, is ionized due to the collisions with the plasma particles. The ions originating from the beam follow a curved path in the magnetic field and might hit the wall of the machine as shown in Figure 1. The toroidal impact location and the number of ions carry information about the toroidal plasma current distribution, the density profile and the electric potential in the plasma.

The inter-ELM ion distribution fluctuation measurement capabilities have been demonstrated previously [3] with limited spatial coverage due to lacking on proper analogue amplifier array. Measurement results with the full detector array, as well as the technique of the atomic beam diameter reduction for spatial localization improvement are presented in this paper. The capabilities of the ABP diagnostic are demostrated in two different test scenarios: a current ramp and a gas-puff experiment. A comprehensive ion beam simulation package

(ABPSimulator) is also presented which is being developed to support the understanding and the interpretation of the measurement results.

ABP system at COMPASS

An ABP system has been previously designed, built [1], laboratory tested [2], installed and commissioned [3] at the COMPASS [5] tokamak. The ABP detector consists of a 5x10 (vertical x toroidal) matrix of 4.8×1.8×0.8 mm Faraday Cups (FC) [2] as shown in Figure 2. A new, purpose designed 2x32 channel, 1 MHz bandwidth analogue amplifier has been installed in 2019. The ion current distribution is sampled with a 2x32 channel analogue to digital converter with 2 MHz. A systematic measurement series have been carried out at COMPASS to characterize the signal quality, the noise level and the grounding strategy of the new system. This included piggy back measurements during plasma discharges without beam, with different components of the measurement chain connected to identify main noise sources. Also gas test shots without magnetic field were done where the beam focusing was optimized and the beam diameter reduction was tested. Further beam into gas shots with toroidal field only were performed to find the beam on the detector. Piggy-back measurements in various plasma scenarios proved that the we can routinely hit the detector with the ion beam by steering the atomic beam. This work has been supported by extensive ion beam modelling efforts.

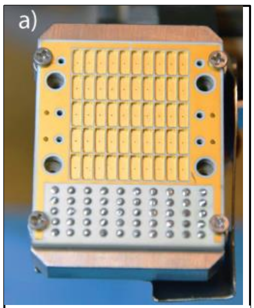

Figure 2: Detector with the 5x10 araday cup matrix.

ABP simulation

A comprehensive, modular, multi machine (COMPASS, ASDEX Upgrade) ABP synthetic diagnostic (ABPSimulator) is being developed to support the interpretation of the ABP measurements. It solves the equation of motion of charged particles in three dimensions in an inhomogeneous magnetic field, which is read from the magnetic equilibrium reconstruction of the given magnetic confinement device. The atomic beam is modelled ~~as a set of beamlets~~ with two-dimensional Gauss current distribution perpendicular to the beam. The points along the beamlets are the source points for the ion path calculation as shown in Figure 1. The detector is modelled as a plane, and the impact locations are calculated from the intersections of the ion paths and this plane. The ion distribution is calculated by summing the interpolated ion intensity on a grid from each radial slice of the beam.

Beam diameter reduction

Figure 3: Beam diameter reduction. The cylinder has different diameters hole on its wall. Their position can be set with a stepper motor.

The ions originating from a given radial, but different vertical positions of the atomic beam can end up at different locations on the detector, therefore the information from different radial positions will be mixed on the ABP detector. The larger the beam diameter, the bigger this smearing effect is, thus the reduction of the atomic beam is necessary in order to improve the spatial localization of the measurement. However, this results in lower ion current, and lower signal to noise ratio. The technique for the beam reduction has been published previously [6]: the beam diameter can be changed between 1 mm and 20 mm in 5 steps (1-3-5-10-20) using a special diaphragm as shown in Figure 3. The novelty is the routine usage of the system, and the results are summarized in Figure 4. The CCD image of the beam emission in neutral gas (above) along with a calculated beam intensity distribution (below) are shown for the full beam with 20 mm FWHM (left) and for the 5 mm reduced beam with 12 mm FWHM (right). Approximately 30 % of the beam goes through the 5 mm hole.

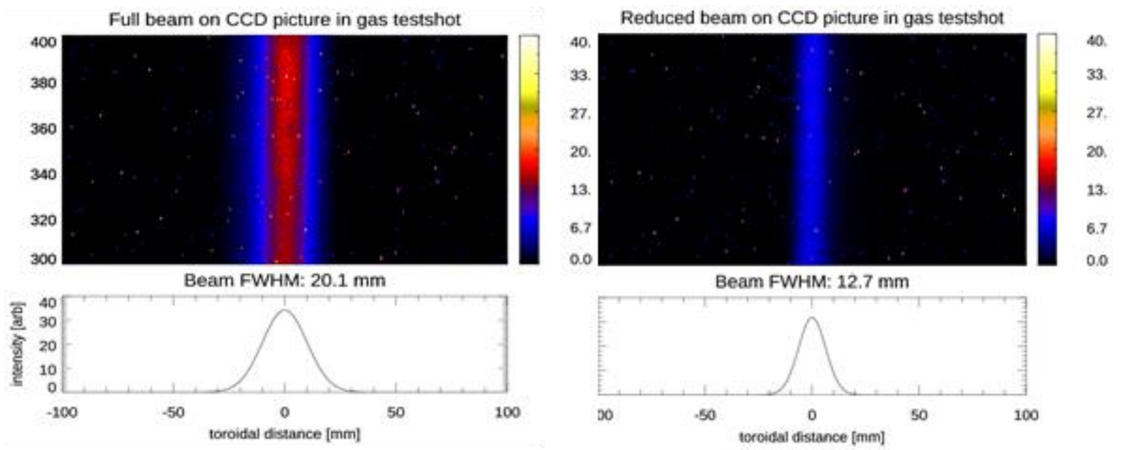

Figure 4: Beam emission in gas on a CCD camera image (above) and the beam intensity distribution calculated from the picture (below). Full beam without reducer (left) and with 5 mm reduction (right).

Current ramp experiment

Two test cases with slow (~10 ms time scale) current changes were carried out to validate the ABP diagnostic capabilities. First a plasma current step during a discharge experiment has been carried out, keeping other main plasma parameters, and shaping constant. COMPASS discharge #19655 was an Ohmic, 1.38 T, lower single-null, diverted plasma, with a current ramp from 180-250 kA during the discharge. The 66 keV, 5 mm reduced Sodium beam was

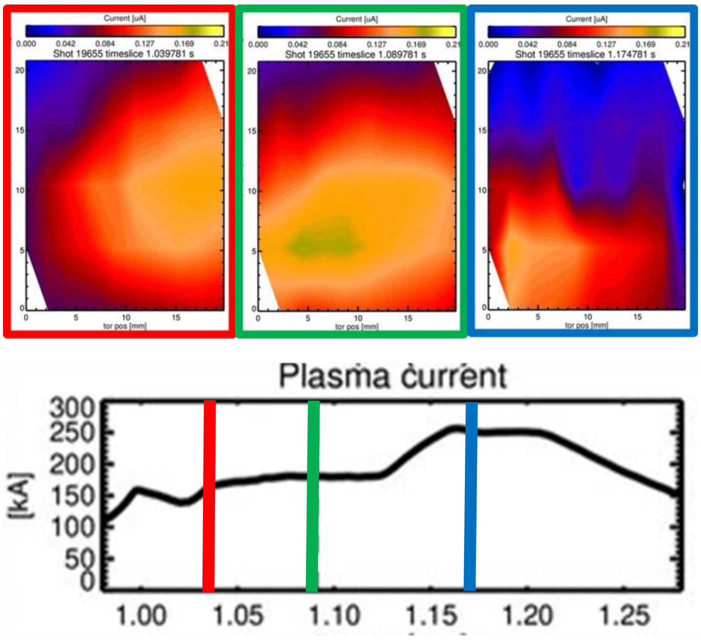

Figure 5: Ion beam distribution on the ABP detector array, at different times of the discharge. The frame color correspond to the time indicated in the reference plasma current time trace at the bottom.

injected into the plasma, utilizing1 kHz beam modulation for background subtraction. Figure 5 shows the background corrected, 5 ms integrated ion beam distribution on the detector at three different time instances during the discharge, indicated by the frame colors. The plasma current is shown below as a reference with the corresponding time intervals. The beam moves systematically as the plasma current is ramped. The maximum beam intensity is ~200 nA on a detector segment as expected. A gas puff for plasma edge cooling, and current re-distribution experiment is also presented in the poster along with synthetic diagnostic results for these experiments.

Conclusions and outlook

A 50 channel Atomic Beam Probe diagnostic has been installed and tested and successful dedicated experiments for system characterization have been carried out at the COMPASS tokamak. The results show systematic changes of the ion beam distribution on the detector for plasma current changes on the 10 ms timescale. Further experiments and modelling effort are needed to be able to reconstruct inter ELM current density distribution changes.

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