

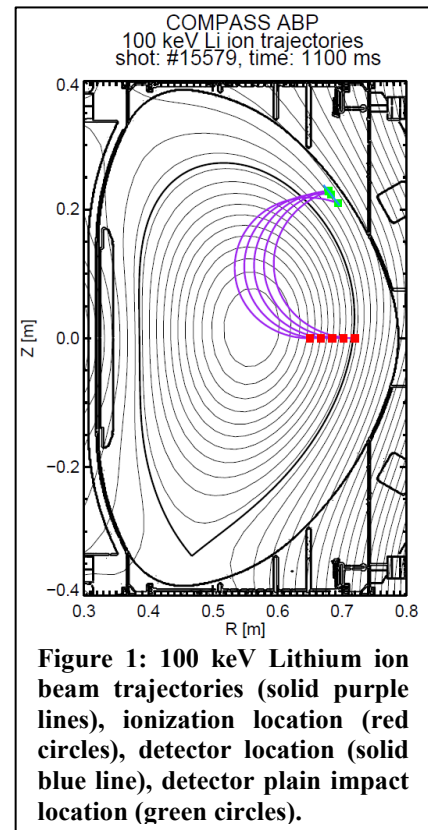
## Atomic Beam Probe diagnostic for plasma edge current measurements at COMPASS

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### Introduction

The measurement of the plasma edge current density distribution and temporal evolution during the edge localized mode (ELM) cycle is of particular interest in the field of magnetically confinement plasmas, since theoretical models recognize it as a key element for the trigger mechanism of the ELMs. The atomic beam probe (ABP [1]) is an extension of the beam emission spectroscopy (BES) diagnostic [2]. The beam atoms are ionized due to collisions with plasma particles, deflected through a curved path due to the magnetic field and may be detected close to the wall of the machine. The arrival location and the number of ions carry information about the toroidal plasma current distribution, the density profile and the electric potential in the plasma. Figure 1 shows the ion trajectories for a 100 keV Li atomic beam injection. The detector surface, marked with a blue line,



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

has to be placed inside the vessel close to the confined plasma region thus being exposed to high UV radiation and particle impact. Detecting the few microampere ion current close to the plasma edge requires a special detector. The measurements with a preliminary test detector head have been carried out, and a final detector head design was proposed based on these results [3]. The final detector head for the ABP was tested in the lab. The new setup utilizes a shallow Faraday cup matrix, produced with printed-circuit board technology, and a double mask for a secondary electron suppression. Results of the switching time, cross talk and fluctuation sensitivity test in the lab setup will be presented along with the first measurement in a new setup at the COMPASS tokamak [3].

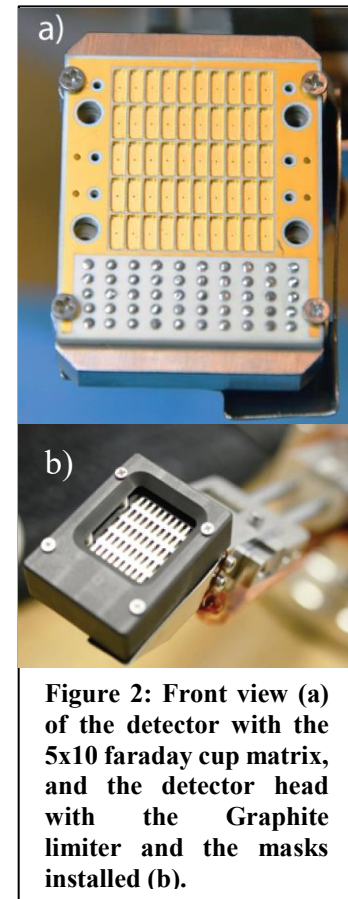
### ABP detector head and mask

The detector consists of the  $5 \times 10$  Faraday cup matrix as depicted in Figure 2 (a). The dimensions of each Faraday cup are  $4.8 \times 1.8 \times 0.8$  mm, the distance between the detectors is 0.4 mm in both directions. Computer simulation shows that the toroidal displacement of the ion beam in response to 1 kA edge plasma current is about 1 mm. The atomic beam is reduced to 5 mm diameter in the beam injector, thus, a 5 mm wide ion beam is expected on the detector surface. The detector size is a trade-off between the spatial resolution and the signal level. 2-3 points are sufficient to measure 0.1 mm changes of a distribution horizontally, while vertically no changes are expected due to the plasma current fluctuation. Therefore the detector size was chosen to be 1.8 mm horizontally and 4.8 mm vertically. Figure 2 (b) shows the final detector head which is installed at the COMPASS tokamak since February 2018. The main aim during the detector head design was to be able to collect ions from the

beam and to minimize the effect of the secondary electrons which can cause spurious signal crosstalk between the detectors. A double mask design is used, therefore, the ions can only reach the detector at the Faraday cups which minimizes the secondary electron generation outside of them. The mask closer to the Faraday cup can be either biased or grounded, while the one further facing the plasma is grounded. As the magnetic field is close to parallel to the cup surface the electrons are primarily prevented from leaving the cup by their small Larmor radius. Additionally, the biased masks prevent flow along field lines leaving the cups. The 0.8 mm depth of the Faraday cups was chosen so that in most magnetic configurations field lines starting on the cup bottom cannot leave the cup.

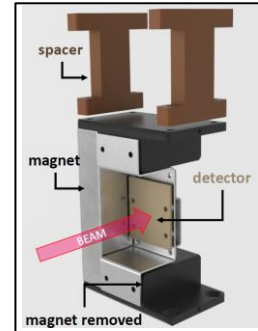
### Laboratory test measurements

A detector holder was designed to mimic the magnetic field conditions of the tokamak. Two Neodymium magnets with 500 mT surface induction were placed on 2 sides of a holder which is hung from the vacuum flange. The detector is placed in the middle of the magnets where the field is the strongest and the most homogeneous ( $410 \pm 10$  mT). The detector is perpendicular to the geometrical beam line axis. Figure 3 shows the CAD model with one magnet and the covering mask removed. A Li-BES beam injector with 30 keV energy and



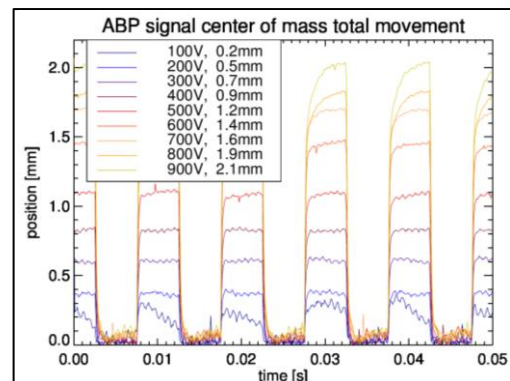
**Figure 2: Front view (a) of the detector with the 5x10 faraday cup matrix, and the detector head with the Graphite limiter and the masks installed (b).**

$\sim 1$  mA current modulated ion beam was utilized for the tests. For the biasing, the cross-talk and the fast switching test, the ABP head was placed in 5 m distance from the beam source, the whole  $\sim 3$  cm diameter beam was shot on the detector. The biasing voltage was varied for the biasing test between -300 V and 300 V in 100 V steps, and the average signal on the detectors was measured. Conclusion was that the secondary electrons has an effect ( $I_{\text{electron}}=100$  nA for  $I_{\text{ion}}=500$  nA), and can be suppressed with negative biasing. The beam modulation frequency was 100 kHz for the fast switching test, and it was found that the change-over time is  $\sim 2$   $\mu$ s. A special mask with only one opening



**Figure 3: ABP lab experiment CAD model with one magnet and the covering removed.**

and 100 Hz beam modulation was utilized for the cross talk test. The signals for the channel with the opening and one below are shown in Figure 5 for different biasing cases (0V, 300V, -300V). There is  $\sim 1.5\%$  cross talk with the bottom channel with the unbiased and the positively biased cases, while no cross-talk for the negatively biased case. The smallest detectable change in the ion distribution was characterized with a modified measurement

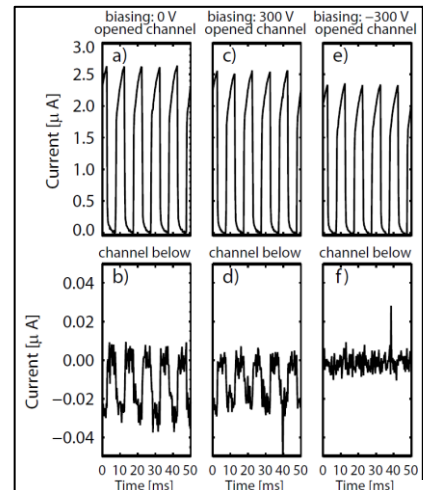


**Figure 4: Movement of the center of mass of the ion distribution for different deflection voltages.**

setup. The ABP detector was placed in 7 cm distance from a 5 mm beam reducer just after the beam deflection plates, so that the narrow beam could be modulated with 0.1 mm precision. A measurement series with 100 Hz deflection was carried out, changing the deflection voltage between measurements, and the center of mass (COM) of the ion distribution was calculated. Figure 4 shows the COM as a function of time, the line colors correspond to different deflection voltages. Down to 0.1 mm movement of the ion beam spot can be measured with the ABP detector, also 100 kHz fast movement detection has been demonstrated.

#### ABP setup for the COMPASS tokamak

The aim of the detector holder setup is to be able to move the detector, since the detailed modelling of different



**Figure 5: Cross-talk test - signals above show the signal level on the channel behind the opening on the mask while signals below show the signal level on the channel below the opening for various biasing: mask grounded (a,b), mask biased with +300 V (c,d), mask biased with -300V (e,f).**

plasma scenarios, beam energy and beam species showed that the detector position must be variable both vertically and horizontally to match the ion trajectories. To fulfill these requirements, an in-vessel setup was designed and it consists of the detector head, a horizontal actuator, a vertical actuator, an extension of the vacuum vessel and a manual actuator with proper scale to ensure position reproducibility.

### First COMPASS results

A successful Ohmic H-mode session ( $B_t=1.15$  T,  $I_p=150$  kA,  $n_e=4e19$  m<sup>-3</sup>) with large ELMs has been carried out with the new ABP detector at COMPASS with  $I_p$  ramp down. The ion signal to background ratio is 1:1 (2  $\mu$ A each) with the full beam and 1:10 with 5 mm reduced 90 keV Lithium beam. The beam distribution moves toroidally on the detector as expected during the ramp-down as shown in Figure 6: toroidal ion beam distribution as a function of time along with the plasma current as a reference below. The data are being analyzed and further experiments are to be proposed based on the first experience.

### Summary

A purpose designed experimental setup was built and measurement series were carried out in the laboratory to characterize the

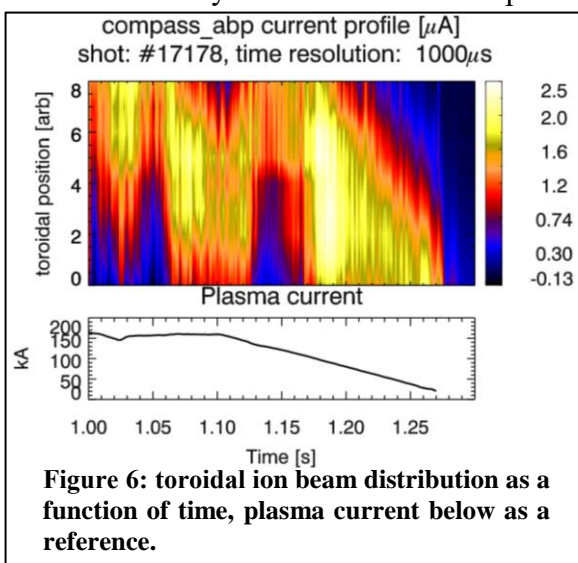


Figure 6: toroidal ion beam distribution as a function of time, plasma current below as a reference.

performance of the Faraday cup type atomic beam probe diagnostic. We found that the Faraday cup matrix design ABP detector equipped with the double mask is capable of the measurement of the expected  $\sim 100$  nA ion current. The masks are needed to shield the gaps between the detectors to avoid secondary electron generation, and the biased mask should be operated in the electron suppression mode. We demonstrated that the ion current distribution changes of  $\sim 0.1$  mm can be resolved at the microsecond time scale.

### Acknowledgments

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### References

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