# CONFINEMENT, ACCUMULATION AND DIAGNOSTICS OF LOW ENERGY ION BEAMS IN TOROIDAL FIELDS

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*Abstract*

An optimized design of a stellarator-type storage ring for low energy ion beams was numerically investigated. The magnetic field variation along the circumference and therefore magnetic heating is suppressed by using simple circular correction coils. Particle-in-Cell (PIC) simulations in a magnetic flux coordinate system show the ability of high current ion beam accumulation in such a configuration with unique features for clockwise and anticlockwise moving beams. Additionally scaled down experiments with two 30 degree room temperature toroidal segments were performed to demonstrate toroidal transport and to develop optical beam diagnostics. Properties of multi-component beams, redistribution of transversal momenta in the non-adiabatic part of the experimental configuration and investigation of strongly confined beam induced electron clouds will be addressed.

## INTRODUCTION

The properties and special particle dynamics in a Figure-8 low energy storage ring (Fig.2) were discussed in a previous report IPAC[1]. For an optimum injection of 150keV protons or of highly charged ions an adiabatic compressor with a slowly varying magnetic field is needed in front of an ExB injector (Fig.1).

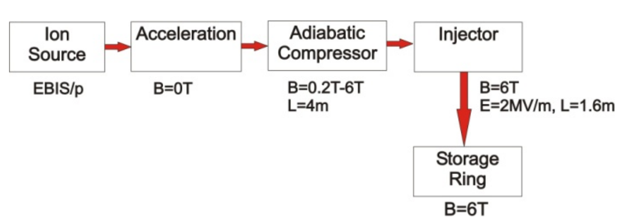


Figure 1: General view of an injection scheme.

It allows controlled beam focusing and beam transition from the 0.2 T to 6.0 T region without any disturbance or reflexion of ion beams. Due to these changes, the injection area was redesigned and the whole magnetic flux structure recalculated.

## DESIGN ASPECTS

The magnetic field structure analysis is done by the field line tracing method following by decomposition in fourier frequency space. The 1D-signal of vertical space frequency is shown on Fig. 3. The two basic frequencies ($f=21\cdot f_0$, $F=76\cdot f_0$ in terms of the sampling frequency $f_0=5.3\cdot 10^{-2}$ $m^{-1}$), belonging to the poloidal and toroidal motion respectively and their harmonics are clearly identified.

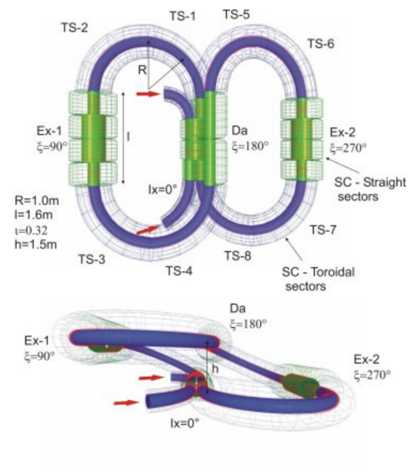


Figure 2: The Figure-8 low energy storage ring with guiding magnetic field.

The ratio of frequency numbers gives the poloidal rotation number iota $\iota=f/F=21/76=0.276$ which differs from the previous design and is more away from 1/3 and 3/10 resonances.

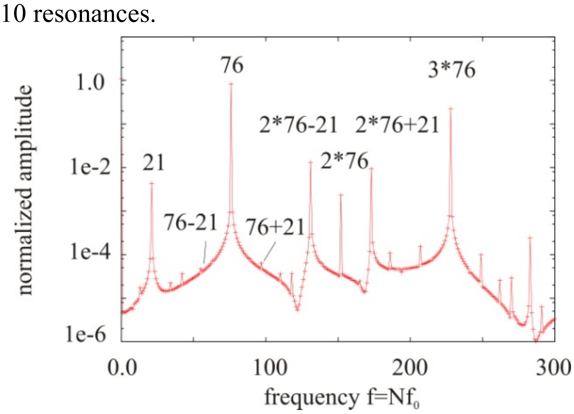


Figure 3: Basic frequencies and their harmonics for magnetic flux structure.

A more detailed analysis of the injection area is planned to find an optimum setting for the correction coils.

## TOROIDAL ION BEAM TRANSPORT

### *Experimental Settings*

For an experimental investigation of a beam transport through the inhomogeneous toroidal magnetic field an experimental setup was built. The main parameters are listed in Tab.1 while the general setup is shown on Fig.4.

It consists of a volume type ion source, a matching solenoid, two toroidal sectors and diagnostic elements. A detailed description was already given in [2].

Table 1: Main Experimental Parameters

| **Parameter** | |
|---|---|
| Bending Radius R | 1300 mm |
| Magnetic field \|B\| | 0.6 T |
| Length of drift section L | 300 mm |
| Beam energy (protons) | 2-20 keV |

The subsequent study was concentrated on the improvement of diagnostic methods to achieve higher precision in beam detection during last year. Because of difficulties like signal distortion due to the composite beam transport ($H^+$, $H_2^+$, $H_3^+$ species) and due to the beam induced and trapped electron clouds, a new detection method is proposed.

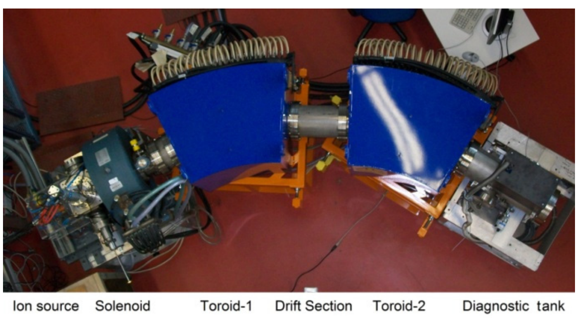


Figure 4: View on the setup of the toroidal beam transport experiment.

## *Suppressing of the Electron Clouds*

An alternative approach to suppress the secondary electron effects in toroidal beam transport experiments was investigated and applied last year. By injecting buffer gas into the vacuum chamber upcoming secondary electron effects, which overlay the ion beam signal on the phosphor screen of the detection system, can be partly suppressed and thus simplify the analysis. An experimental series was started to figure out, which buffer gas can provide an efficient suppression of electron cloud effects. Hydrogen, helium, nitrogen and argon gas were tested in a pressure range from 1E-5 to 20E-5 mbar. The results showed optimum properties for hydrogen gas (Fig. 5).

It was proven, that the measured buffer gas pressure has to be corrected due to the influence of unshielded magnetic fields of the toroidal magnets and a wrong gas calibration.

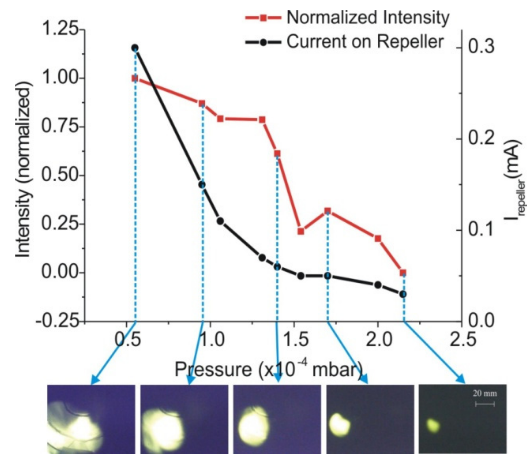


Figure 5: Dependence of measured beam profile on buffer gas pressure.

Particle-in-Cell (PIC) simulations were realized for the transport of a hydrogen beam through the whole experimental setup. The transport was simulated in three steps because the hydrogen ion beam consists of three independently moving ion species ($H^+$, $H_2^+$ and $H_3^+$ ions). The simulation results for the center of the beam at a beam energy of 10 keV are shown in Fig.6.

The beam gyrates along its path through the toroidal magnets. In the straight section between the two magnets there occurs a redistribution of the transversal momenta, which is depending on gyration frequency and longitudinal velocity of the species. Therefore, the radius of the gyration can change and the possibility for the formation of separated beamlets, consisting of two different ion species, could be realized.

The comparison of the theoretical prediction with experimental data is in a good agreement and could be demonstrated by the measurement shown on Fig.7.

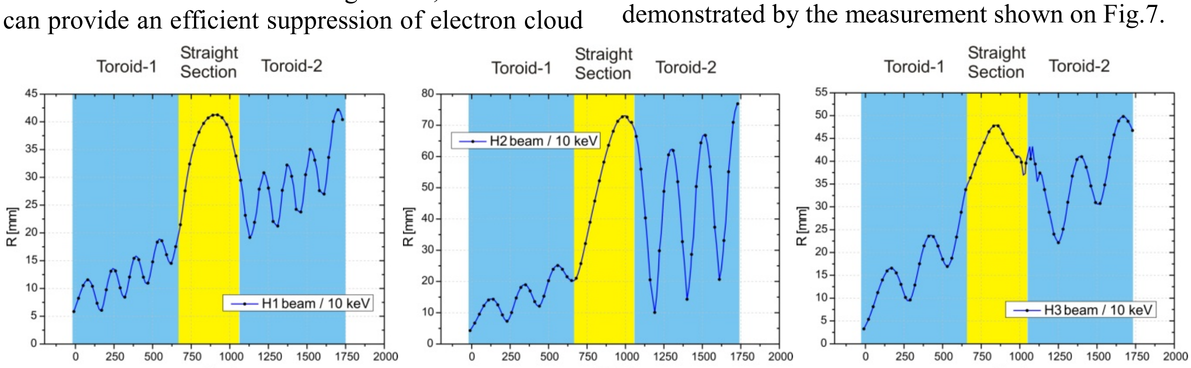


Figure 6: Center of beam motion as a result from PIC-simulation for $H^+$, $H_2^+$ and $H_3^+$ species (from left to right) along the toroidal transport section.

Figure 7: Separation of $H^+$ and $H_2^+$ parts of the composite beam at the end of the toroidal transport section.

### *New Optical Diagnostics System*

An application of the photodiodes was proposed for the optical beam diagnostics. To detect the beam and determine several beam properties, a circular arrangement of photodiode array around the beam axis was designed (Fig.8).

The new system is more flexible, the silicon photodiodes are small and can be mounted easily without any complex electrical structures. They were tested successfully in the vacuum and the strong magnetic field in the experimental setup, with field maximum up to 0,7T.

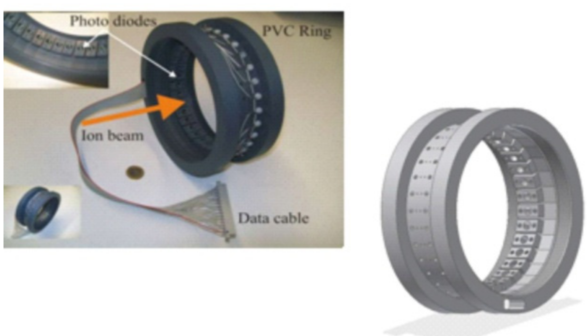


Figure 8: Optical diagnostic probe. Photodiodes are arranged on a cylindrical ring.

For the first calibration of the detector a light source with nearly homogenous glow was used. Different positions were tested and the source motion could be precisely determined within the detector.

Two calibration tests on different radii are shown on Fig.9. In a first test (Fig. 9 up) the position was changed through the points A2-J2-N2-X2 with detected signals on corresponding diodes. In a second test, by smaller radius A1-J1-N1-X1, the form of the signal is broadening, so 5-6 photodiodes have a significant signal. This effect is due to the solid angle acceptance of the photodiodes and the precision could be improved with small apertures on the photodiodes.

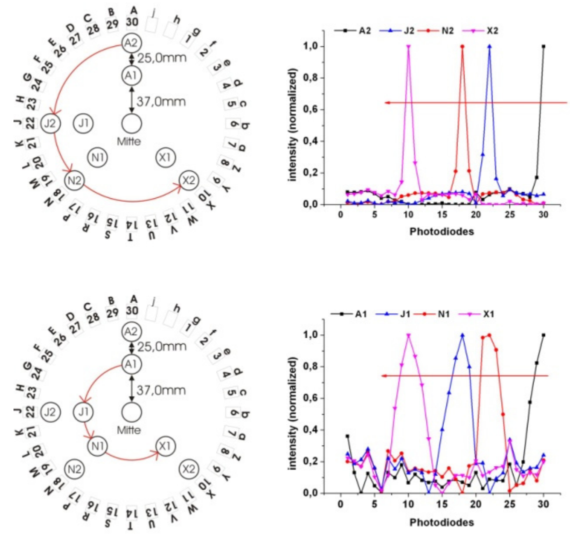


Figure 9: Position of test probe in a cylindrical geometry and corresponding photodiode signals.

As a result, it was possible to determine the position within a small interval of r and φ in all calibration experiments with a small sized optical test source. The next experiments with a real ion beam are planned for autumn.

## CONCLUSION

The guiding magnetic fields with curvature and field inhomogeneity show some special features with respect to the beam dynamics. It is necessary to avoid or to adjust non-adiabatic sections for the proper beam transport, due to the momentum redistribution between transversal and longitudinal planes. Here, the numerical simulations are in good agreement with scaled down transport experiments

The non-destructive diagnostic methods seem promising for an efficient detection of beam properties in an experimental setup as mentioned above, especially in preventing or reducing the secondary electron cloud generation. For future experiments it is crucial to reach high precision in beam position diagnostics with respect to the planned ExB injection systems with their small apertures.

## REFERENCES

[1] M. Droba et al., "Beam Accumulation in a Stellarator type Storage Ring", IPAC'10, Kyoto, July 2010, THPD082, p. 4473 (2010).

[2] N. Joshi et. al., "Scaled Down Experiments for a Stellarator Type Magnetostatic Storage Ring", IPAC'10, Kyoto, July 2010, THPEB005, p. 3885 (2010).