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Injection and manipulation of positron beam in a dipole magnetic field toward the creation of electron-positron pair plasmas

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Peculiar behavior of charged particles in a dipole field was first recognized in planetary magnetospheres. In the dipole magnetic field, the "inward transport" effects self-organize plasma structures so that the number density of particles becomes constant in the magnetic phase space [1]. In the strongly inhomogeneous dipole field, it creates a strongly peaked density profile in the real space. Besides its interesting physics in its own right, experimentally, the magnetic dipole is an ideal confinement configuration for various kinds of plasmas. Recent experiments in levitated dipole devices (RT-1 [2] and LDX [3]) demonstrated formation of high-β plasmas suitable for advanced fusion, as well as long-time trapping of non-neutral (pure electron) plasmas.

Here we report progress in creating electron-positron pair plasmas [4] in the dipole field geometry, focusing on their unique characteristics due to the mass symmetry [5]. In contrast to conventional linear non-neutral plasma traps, toroidal geometries can trap plasmas at any degree of non-neutrality. We plan to create electron-positron plasmas in levitated dipole and stellarator configurations, operated at the NEPOMUC intense slow positron facility [6]. Although excellent trapping properties are expected, in the dipole trap, charged particles must be injected into the confinement region across closed field lines. This is not straightforward especially for the case of positrons, where available beam intensity is by far weaker than that of electrons. In experiments with relatively high-density neutral and electron plasmas in the dipole, slow fluctuations of the plasma and beam work as an efficient driving force of inward transport [2,3]. However, such effects are not expected with low density positron beams at least in the initial injection phase, where the self-electric field is negligibly small. Here interaction of positrons with external fields is important. In order to study the injection and compression mechanisms of positrons in the dipole magnetic field, we are conducting experiments using a dipole trap with a permanent magnet at NEPOMUC [7,8] (Fig. 1), as a test bed to a superconducting levitated dipole experiment. In the permanent magnet dipole experiment, we have realized efficient (>90%) injection of 5 eV positron beam supplied from NEPOMUC, as shown in Fig. 2.

As a next step, we would like to spatially compress the injected positron cloud. We therefore applied fluctuating electric fields on the injected positron beam. As shown in Fig.1 (b), the outer electrode located at the edge confinement region was azimuthally segmented into 4 pieces. RF voltages were applied to each of the electrodes with 90° phase differences, which generate so-called rotating wall (RW) electric fields. Annihilation γ-rays were measured at a movable target probe inserted into the trapping region. By applying fluctuating RW electric fields so that the conservation of the third adiabatic invariant broke down, radial compression of positron orbits was observed. With RW fields in the CW direction (same as the toroidal circulation direction of positrons by curvature and grad-B drifts), efficient compression of positron orbits was realized in a relatively wide frequency range between toroidal circulation and vertical bounce frequencies of positrons.

References

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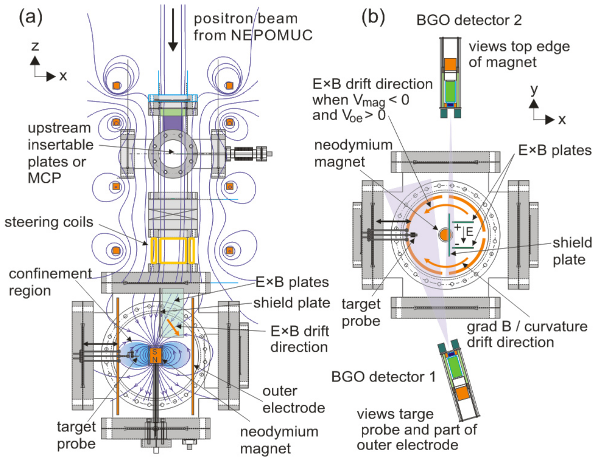

Fig.1 Schematic of a dipole experiment with a supported permanent magnet operated at the NEPOMUC facility.

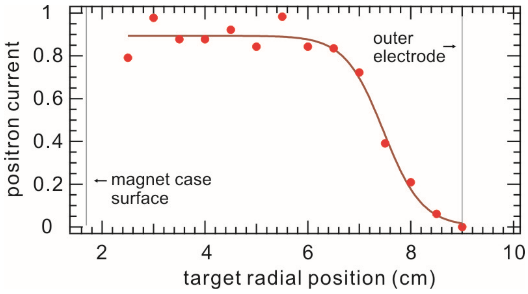

Fig.2 Radial profile of positron current measured with a target probe, normalized by the total injected current.