A Reaction Microscope with Toroidal Sectors

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Reaction Microscopes have established themselves as superbly suited for kinematically complete measurements of single and multiple ionization, transfer and excitation processes in the categories of ion-atom and electron-ion collisions [1]. They are utilised in a) dynamics of multiple ionization of atomic and molecular targets for very strong perturbations, b) kinematically complete cross sections for the fundamental process (e, 2e) for ions [2] and c) kinematically complete study of the short wavelength limit of the electron nucleus Bremsstrahlung. They permit to detect simultaneously the momentum vectors of all collision partners, e.g. of all electrons emitted and, too, of recoiling target ions with large solid angle close to 4π and momentum resolutions about 0.01 a.u. Moreover, in combination with an imaging forward electron spectrometer they cover a large range of momentum transfer q from small q for target ionization (outer shell) to large q for (inner shell) target and projectile ionization and electron capture. In the linear geometry the large area 2D position sensitive detectors for electrons and recoil ions are close to the beam axis. However, when a large dynamic range of cross sections is to be measured in a storage ring environment, one must remove the detectors from the immediate vicinity of the coasting beam in order to enable dispersion of unwanted high yields of recoil ions of low charge states and to reduce exposure of detectors to background. The attempt to preserve symmetry as much as possible in view of the wanted variability of parameters leads us to study a toroidal geometry for the low energy electron branch of a reaction microscope.

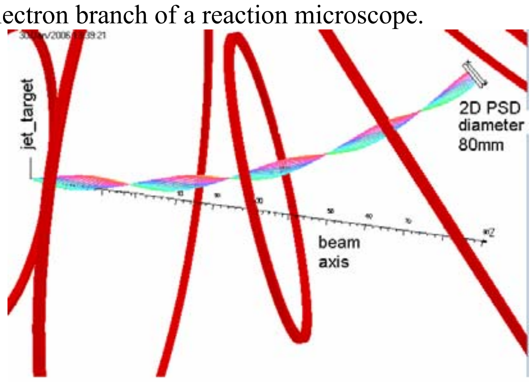

Fig.1 Helical trajectories of electrons in a section of a toroidal field generated by a configuration of 5 coils

Here we describe simulation calculations of a magnetic toroidal sector with 2D position sensitive detector for electrons using OPERA. Trajectories of electrons of the same longitudinal and transverse energy are shown below in Fig.1. A toroidal magnetic B field differs from the solenoidal field in that B is not a constant over the cross section, i.e., in the inner part of the toroidal sector the B field is higher than in the outer part $B(r)=\mu_0 IN/2\pi r$.

In a linear (conventional) reaction microscope, the helical motion frequency ω is independent of the azimuthal angle around the field axis. However, in the new toroidal geometry, as the B-field depends on the azimuth about the field axis, the cyclotron frequency now as well is related to the azimuth of emission $\omega=qB(r)/m$.

Additionally, also the distance traveled by the electron along the outer part is longer than the corresponding distance along the inner part of the toroidal sector, thus the time of flight also is related to the azimuth of emission.

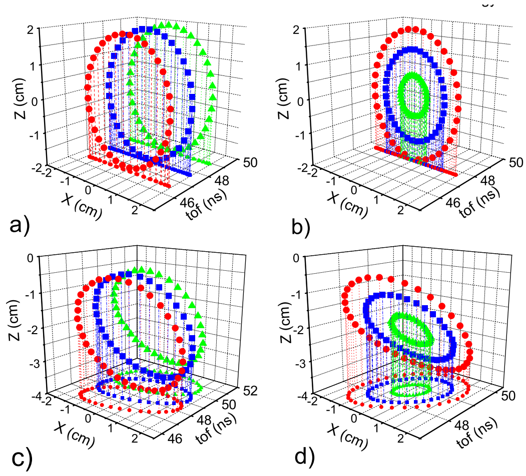

Fig.2 Transverse position and time of flight of electrons in the detector plane In the left column the transverse electron energy is 10 eV, triangle, square and circle correspond to 210, 200 and 190 V extraction voltage. In the right column the extraction voltage is 200V and transverse electron energies of 1, 5 and10 eV are chosen.

In a conventional reaction microscope, the longitudinal momentum (corresponding to the extraction energy) is determined by the time of flight (see Fig.2 b) while the transverse momentum (corresponding to the perpendicular energy) is determined by the radius or the position on the detector (see Fig.2 a). However, with a toroidal magnetic field the position is coupled with the time of flight (see Fig.2 c and d), the circles in (momentum-time) space evolves into an ellipse (Fig.2 c,d). Still this configuration conserves the symmetry almost entirely. A prototype for a toroidal sector will be tested using Unilac beams in X4.

[1] J. Ulrrich et al Rep. Prog. Phys. **66**(2003) 1463
[2] H. Kollmus et al., PRL**88**(2002)103202