Electron detachment spectroscopy on a fast ion beam using a magnetic bottle.

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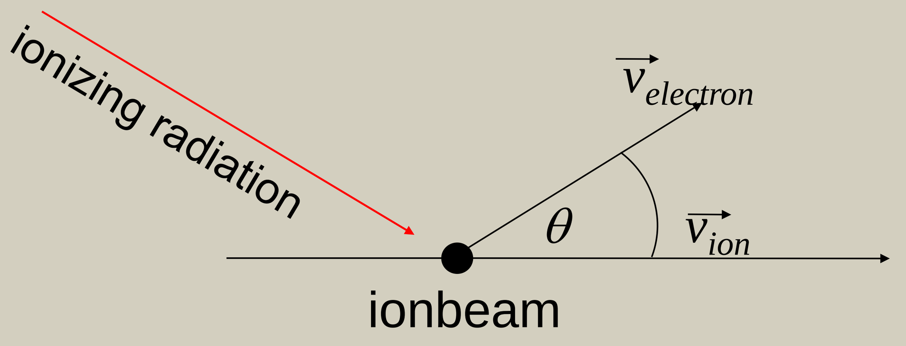
Electron spectroscopy on a fast ion beam inevitably leads to a kinematical broadening of the electron energy spectra. Earlier this has been seen as a problem since it degrades the electron energy resolution [1]. Here we show that the situation can be advantageous as a proper analysis of the emerging line shapes still allows to extract the rest-frame electron energy. Moreover it yields the angular distribution parameter β of the emitted electron.



$$Eq.1: v_{ef} = \sqrt{v_{ion}^2 + v_{electron}^2 + 2 v_{ion} v_{electron} \cos\theta}$$

Fig.1: The dependence of the effective electron velocity v_{ef} on the ion-beam velocity, the electron velocity in a resting reference frame and the emission angle.

Two approaches to use the broadening effect

Analytical approach

By combining the expected kinematic broadening with the β – parameter dependent formulation of the distribution of emission angles one can calculate the expected time of flight distribution of the electrons:

$$Eq.2: t = L / \sqrt{v_i^2 + v_e^2 + 2 v_i v_e \cos\tilde{\theta}}$$

$$Eq.3: P(\tilde{\theta},\beta)\, d(\cos\tilde{\theta}) = \left[\frac{1}{2} - \frac{\beta}{4} + \frac{3\beta}{4}\cos^2\tilde{\theta}\right] d\cos\tilde{\theta}$$

$$Eq.4: P(t,v_e,v_i,\beta)\,dt = \frac{1}{4}\frac{v_e}{v_i}\left[1 - \frac{\beta}{2} + \frac{3\beta}{8}\left(\frac{v_e}{v_i}\right)^2\left[1 + \left(\frac{v_i}{v_e}\right)^2 - \left(\frac{L}{tv_e}\right)^2\right]^2\right]\left(\frac{L}{tv_e}\right)^3 \frac{v_e}{L}\,dt$$

The time of flight distribution of photoelectrons (Eq.4) can be derived by combining Eq.2 and 3. Eq.2 describes the time of flight of an electron vs. the emission angle relative to the moving ion beam. Eq.3 gives the distribution of the emission angles of the photoelectron. L denotes the length of the drift tube, β ϵ [-1,2] is the anisotropy parameter, and θ is the emission angle towards the ion beam [2].

Simulation / ray tracing

A ray trace simulation which takes the magnetic field into consideration can reproduce the expected time of flight distribution. Eq.1 and Eq.3 are used for the electron start conditions.

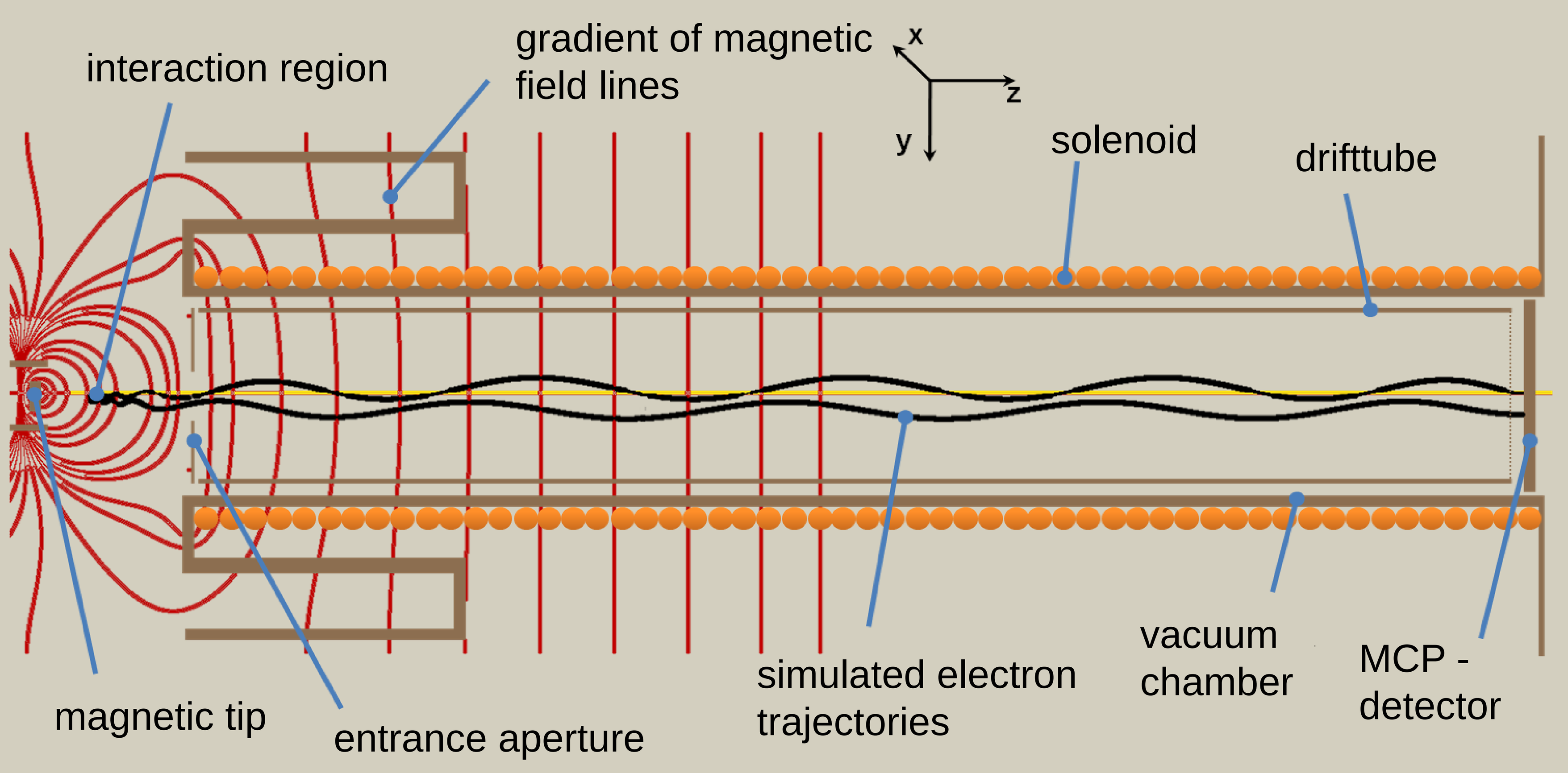


Fig. 2: Scheme of the electron time-of-flight spectrometer including the equipotential lines of the magnetic field and two simulated electron trajectories. The simulation can be seen as a numerical implementation of Eq. 4.

result

In the analytical approach it is assumed that the electrons are bent towards the detector instantaneously. The ray tracing approach mostly suffers from the approximate calculation of the magnetic field:

Domesle et al. [2] successfully expand the analytical approach using a parametric Monte Carlo simulation (Fig. 4a). We successfully used the ray tracing method to determine the beta parameter of the detachment process of OH- (Fig. 4b).

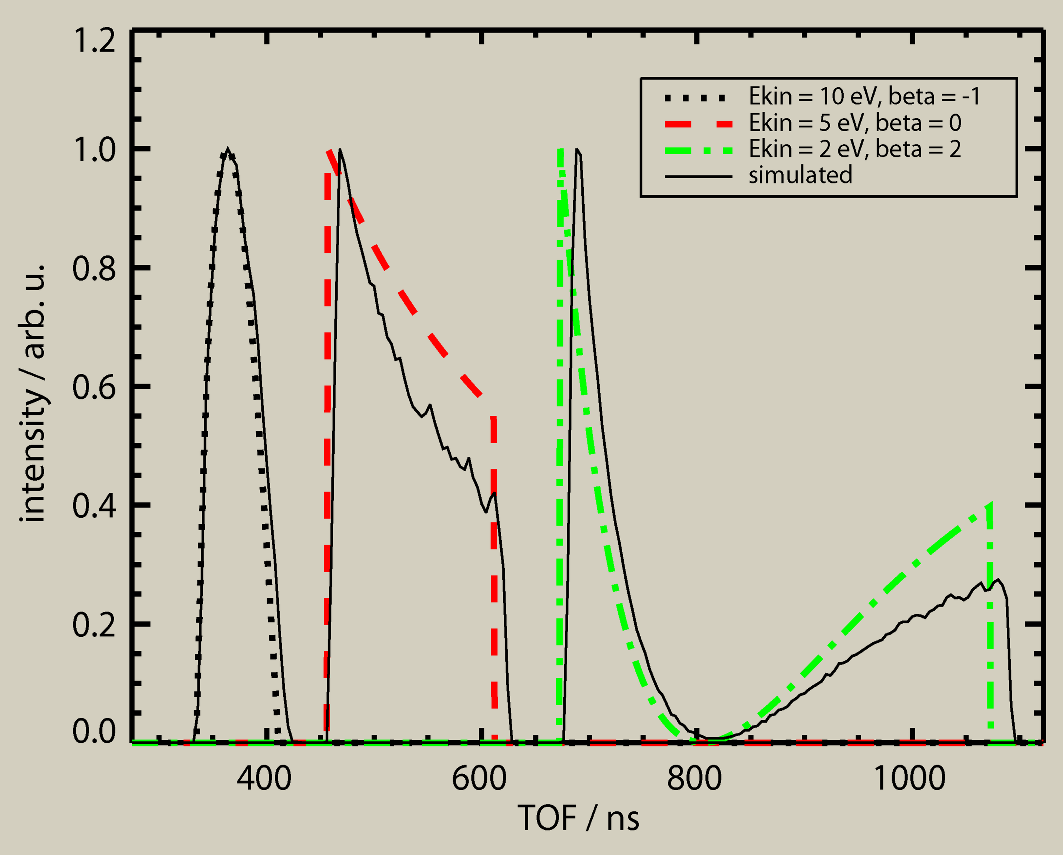
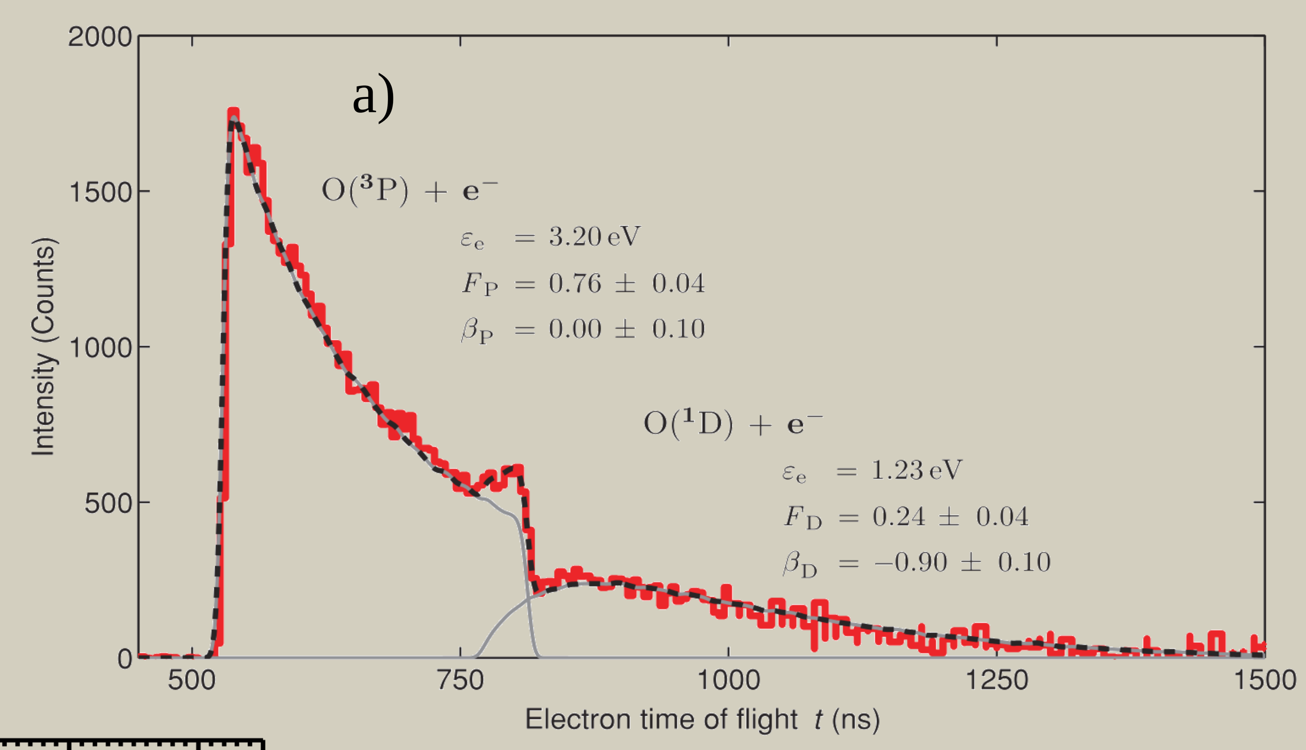
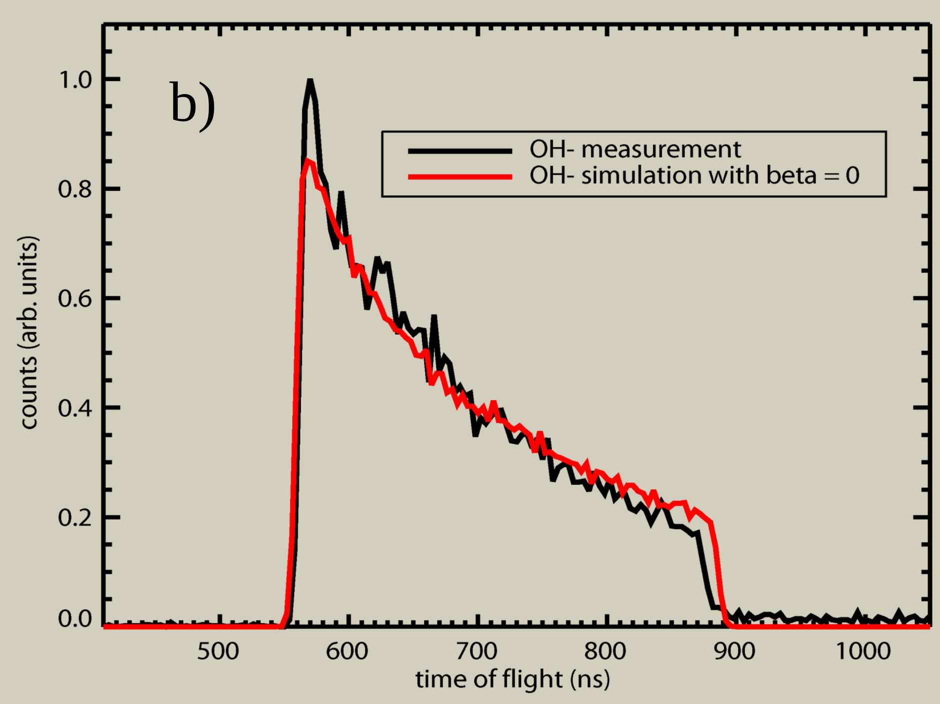


Fig. 3: Electron time of flight distributions for different electron energies and anisotropy parameters calculated using Eq. 3 (dotted lines) and simulated using Simion (solid lines). The kinetic energy of the ions was 4.8 keV.

application

Fig. 4 a): Electron t.o.f. distribution after photodetachment of O- at 266 nm. The red curve is the measured spectrum, gray and black show the calculated ones. From [2].





And b) Electron t.o.f. distribution after photodetachment of OH-, where the black curve shows the measurement and the red curve the simulation.

References:
[1]: P. Kruit and F. H. Read J. Phys. E 16, 313 1983
[2]: C. Domesle et al. Phys. Rev. A. 82, 3 2010