Structure and Dynamics of Atoms, Ions, Molecules, and Surfaces:
4-Body Dynamics in Ion-Atom Collisions: towards (e,2e) Spectroscopy in Ions

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Recent progress and future plans:

Kinematically complete differential electron impact ionization cross sections for ions are, particularly in the relativistic regime, a formidable challenge to theory; however, such an experiment is not feasible using standard crossed beam technique due to low luminosity. We have now shown that in kinematically complete measurements of projectile ionization in ion-atom collisions the eN(ionizing interaction between the target nucleus and the projectile electron) and ee(target electron is considered quasifree and ionizes the projectile electron) channels can be separated. The kinematically complete measurement of the ee channel is equivalent to (e,2e) experiments measuring 5fold differential electron impact ionization cross sections of the projectile ion, but in inverse kinematics. For total and partial ionization already Wu et al/1/, Dörner et al/2/, based solely on the spectroscopy of recoil momenta and Zouros et al /3/ independently on resonance behavior of the ionization cross section, have demonstrated that the ionization of the projectile in an encounter with a target atom can proceed via the eN and the ee branch.

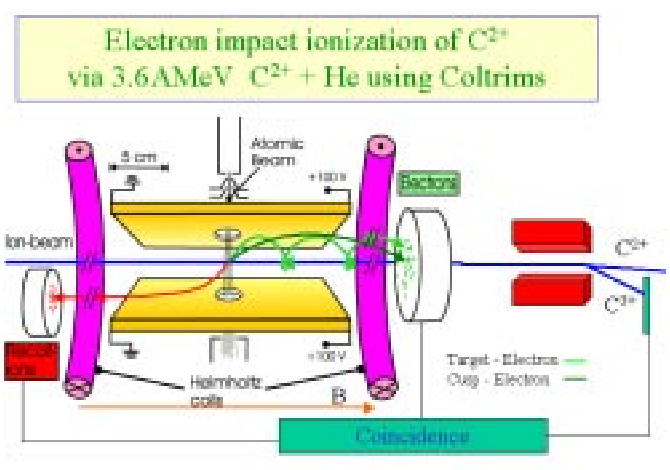

Fig.1. Experimental setup

The current experiment was carried out using the reaction microscope/4/ at the UNILAC at GSI. The setup is illustrated in fig.1. In the current setup the magnetic guiding field **B** was carefully configured to map not only slow electrons as usual but all fast electrons produced in the collision with velocities v_e close to the beam velocity v_{Proj} =12.a.u. and emitted into a narrow cone around the beam direction onto the 2D position sensitive multihit electron detector as well. Kinematic coincidences between a fast and a slow electron and a recoil ion are registered using standard fast electronics when a charge changed projectile $C^{2+} \rightarrow C^{3+}$ was detected in coincidence. A kinematically complete reconstruction of the momentum components of all collision partners is then possible.

It can be argued that ee and eN channels for projectile ionization shall exhibit distinguishing kinematical characteristics. In a collision where a projectile electron is ionized by the target nucleus an azimuthal angular correlation between the fast electron and the He ion recoiling with characteristic momentum is expected; the slow shake-off electron is not exhibiting an angular correlation with the He recoil.

When instead the interaction between projectile electron and He target electron effects the ionization the angular correlation is different: here the recoil remains a spectator with a momentum distribution characterized by the Compton profile. The angular correlation between the two active electrons is then clearly expressed. This is indeed born out by an analysis of the coincident events as given in fig.2.

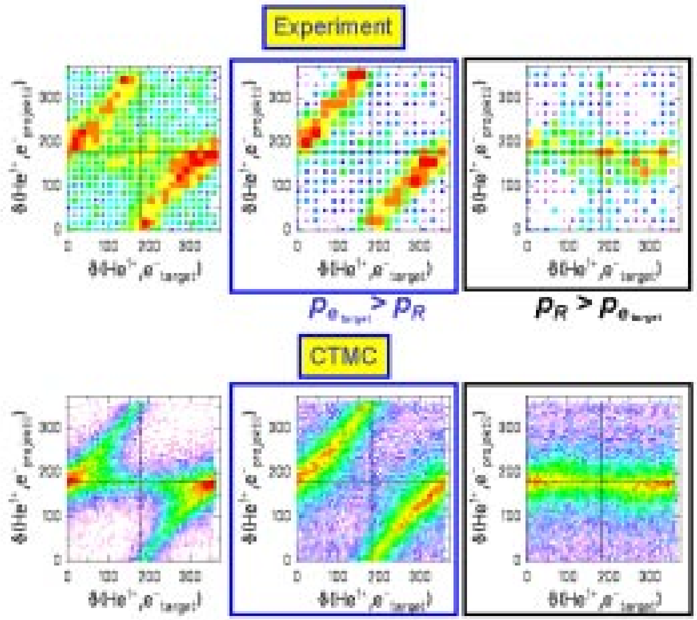

Fig.2. Azimuthal Correlation of Electrons withRecoil

In a 2D diagram azimuthal angles of the He^{1+} recoil ion with the slow target electron are mapped versus the azimuthal angle of the He^{1+} recoil with the fast electron. The top leftmost diagram in fig 3 contains all coincident events, in the top right most diagram, selecting $p_R > p_{e\text{-target}}$ it is apparent that He^{1+} and the fast electron are emitted 180^0 with respect to each other, a signature of the eN process. In the top center diagram events with very small recoil momenta $p_R < p_{e\text{-target}}$ are selected; the two diagonal lines indicate the strong azimuthal correlation $\Delta\varphi(e_{Proj},e_{target})=180^0$ between the slow and fast electron. We point out that at the current collision energy the ee channel dominates the ionization cross section. In the second row CTMC calculations by Olson et al. for the same reaction is given, they show excellent agreement with the data.

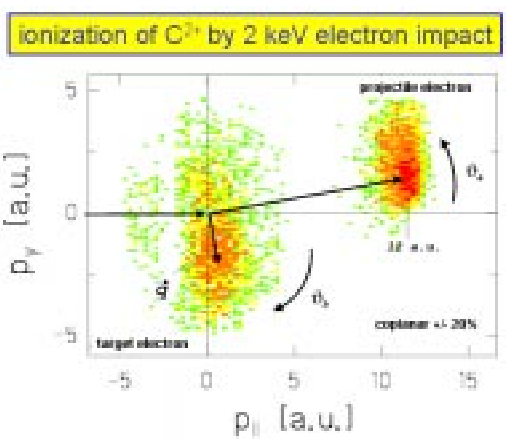

Fig.3. Scattering plane for electron impact ionization of C^{2+}

In fig. 3 the collision plane for equivalent ionization of $C^{2+}$by 2 keV electrons derived from the present experiment is presented, transformed into the C^{2+} restframe, no selection of a momentum transfer window is made due to lack of statistics. It is apparent that for the next experiment with enhanced statistics angular distributions for ionized electrons for a range of momentum transfers, i.e. full fivefold differential cross sections, can be derived.

This work was performed in collaboration with H.Kollmus, J.Ullrich, R.Moshammer.

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R. Moshammer, P. D. Fainstein, M. Schulz, W. Schmitt, H. Kollmus, R. Mann, S. Hagmann, and J. Ullrich

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