

A system for 3D momentum imaging of molecular dissociation induced by fast, heavy-ion collisions

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The development of detector systems with both fast timing and two-dimensional position determination capabilities has generated new interest in the excitation of molecules by photons, electrons and ions. In experimental investigations of dissociation processes leading to the formation of charged product ions, it is now possible to measure the three-dimensional vector momentum of each ion with high resolution and efficiency. This is accomplished by coupling together large diameter microchannel plate detectors with multi-array delay-line anodes [1].

During the past year, we have designed and constructed a system for recoil-ion momentum spectroscopy of molecular dissociation induced by fast heavy-ion collisions. A schematic diagram of this system is shown in Fig. 1.

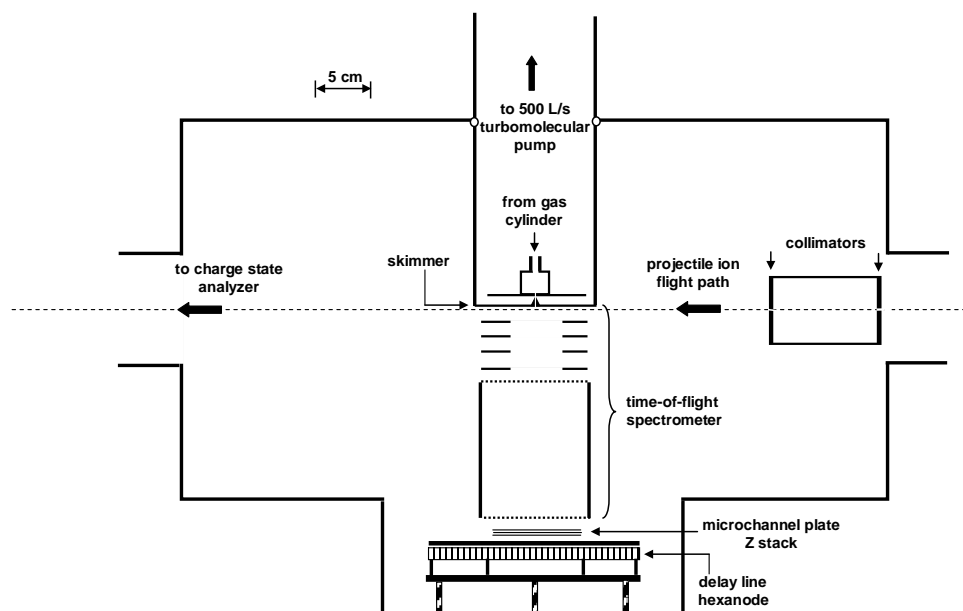


FIG. 1. A schematic diagram of the system for recoil-ion momentum spectroscopy of molecular dissociation induced by heavy-ion collisions.

A target gas jet is crossed with the heavy-ion beam in the interaction region. Charged fragments produced in collisions between heavy ions and gas molecules are accelerated by a uniform electric field into a time-of-flight (TOF) spectrometer and impact the surface of a triple set (Z-stack) of resistance-matched, 80 mm diameter, microchannel plates generating fast timing signals for the TOF measurements. The localized electron jets emerging from the back of the Z-stack are projected onto three overlapping arrays of delay lines comprising the anode. Each delay-line array consists of a signal and reference wire pair. Hence, an ion impact generates six anode signals, and based on their relative timing, the two impact position coordinates of the ion (x and y) can be determined. The redundancy of position signals enables reliable analysis of simultaneous multi-hit events.

Target gas is fed through a small microchannel plate collimator having 10 μm diameter parallel channels onto a 0.89 mm diameter skimmer producing a gas jet of approximately 2 mm diameter in the interaction region. A 500 L/s turbomolecular pump maintains the vacuum in the gas chamber at 4×10^{-4} torr, while the main chamber is maintained at 1×10^{-6} torr by two 2400 L/s diffusion pumps. The acceleration region is formed by five parallel aluminum rings interconnected by 10.0 M Ω resistors that step the voltage on the top plate down to ground potential at the flight tube in equal increments. The length of the acceleration region is 61 mm and the length of the flight tube is 122 mm. These dimensions satisfy the Wiley-McLaren space focusing condition.

The heavy-ion beam is directed through a 250 $\mu\text{g}/\text{cm}^2$ Al stripper foil and the desired charge state is selected by means of a bending magnet. The charge-selected beam then passes through two 1 mm diameter collimators before interacting with the gas jet. It then passes on through a post-collision charge state analyzing magnet into a one-dimensional position sensitive microchannel plate detector or alternatively into a plastic scintillation detector, either of which provide fast timing signals for the TOF measurements.

Signals from the projectile detector, the Z-stack, and the anode lines proceed through fast amplifiers and constant fraction discriminators to an eight-channel, multi-hit time-to-digital converter (TDC) interfaced to a personal computer. The timing signal from the projectile detector provides the trigger for the TDC. The TDC measures the time relative to the trigger for all signals that arrive within a fixed time interval, which in the test run described below extended from 500 ns before the trigger to 6000 ns after the trigger. The event is stored if at least one Z-stack signal is present.

The system was tested by examining the dissociation of carbon monoxide molecular ions produced in collisions with 2.5 MeV/amu Xe^{35+} projectiles. In these measurements, the acceleration field was set to 24 V/mm and up to three charged molecular fragment hits per event were recorded. A two-dimensional TOF map for coincident ion pairs is shown in Fig. 2. The various islands in this figure contain coincident events for specific charge division pathways. For example, the most intense island near the top right corner of the figure contains events for the dissociation reaction $\text{CO}^{2+} \rightarrow \text{C}^+ + \text{O}^+$, and the island near the center of the figure contains events for the dissociation reaction $\text{CO}^{4+} \rightarrow \text{C}^{2+} + \text{O}^{2+}$. Analyzable data was obtained for molecular ion charges as high as 9+.

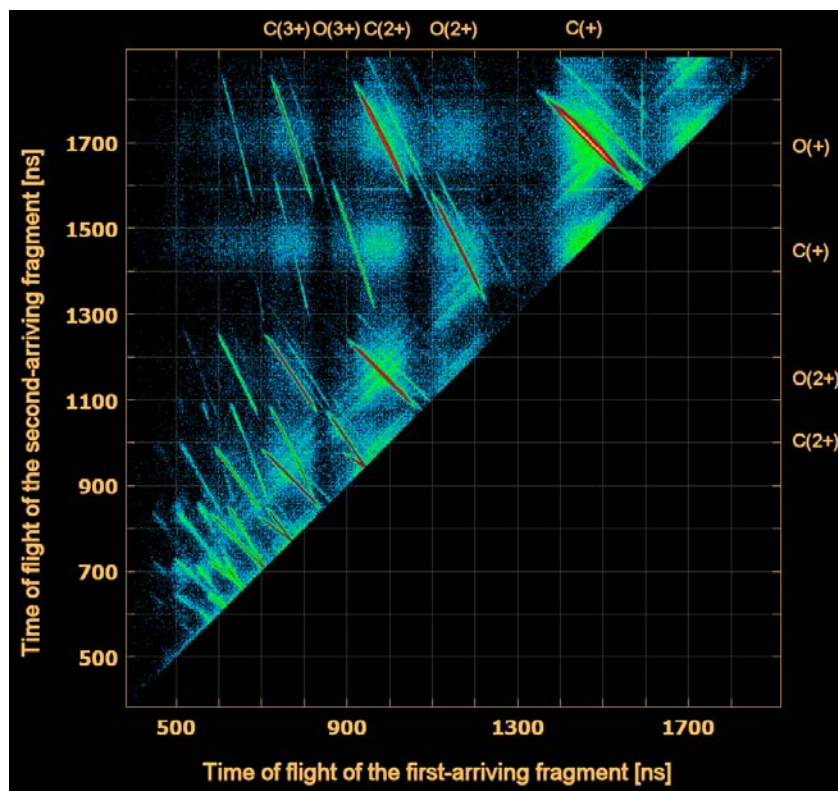


FIG. 2. Two-dimensional TOF map for the dissociation of CO molecular ions.

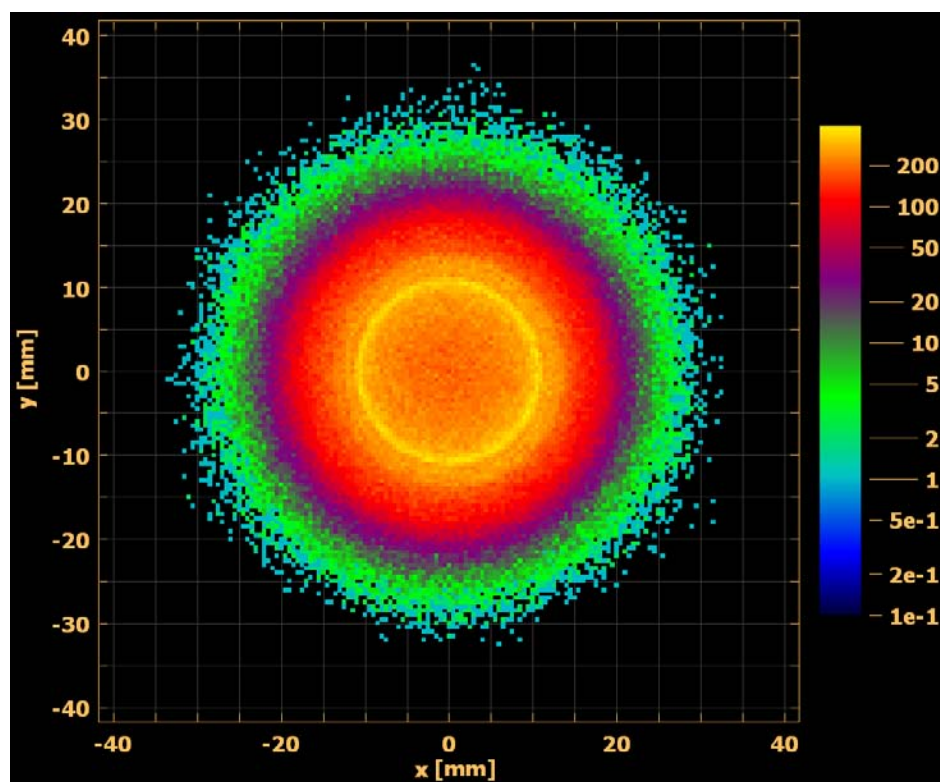


FIG. 3. Position distribution of O^+ ions in coincidence with C^+ ions.

The xy position distribution of O^+ ions detected in coincidence with C^+ ions is shown in Fig. 3. The position bin size is $0.5 \text{ mm} \times 0.5 \text{ mm}$ and the coordinates are measured relative to the center of mass of the parent molecular ion. The rings that appear in this figure are caused by structure in the distribution of oxygen ion kinetic energies. Results of these measurements are presented in the report that follows this one.

[1] J. Ulrich, R. Moshhammer, A. Dorn, R. Dorner, L. Schmidt, and H. Schmidt-Bocking, Rep. Prog. Phys. **66** (2003) 1463.

[2] <http://www.roentdek.com>