COST STSM: SCIENTIFIC REPORT

Applicant: Samuel Eden, Institut de Physique Nucléaire de Lyon (IPNL)
Host: Stephen Price, University College London (UCL)
Period: from the 2nd to the 7th of September 2004

Aims and context for the working visit

The principle aim of this working visit was to discuss the position-sensitive system which Professor Stephen Price and his co-workers use to detect ions produced in collisions between dication projectiles and neutral molecular targets. The Particle-Matter Interactions (IPM) Group at IPNL are currently developing an experiment to observe the proton-impact fragmentation of mixed clusters comprising a DNA base molecule and *n* water molecules. This visit provided the opportunity for the IPM group to benefit from the extensive experience of Professor Stephen Price in the design and operation of sophisticated coincidence mass spectrometry experiments.

The working visit also enabled me to carry out research at the British Library both into technical issues related to the new experiment and for the analysis of measurements currently being made for proton collisions with gas phase DNA bases. For access to specialist papers, books, and patent material, the British Library is a unique resource from which I am fortunate to have benefited greatly as a post-graduate student at University College London.

Description of work carried out during the visit

The central part of the STSM programme was the meeting with the group of Professor Stephen Price to discuss their ion detection system at University College London. This meeting included a laboratory visit. The members of the group gave a thorough explanation of the workings of the position sensitive detector in the context of current and recent experiments. Details which were unavailable in the literature have enabled me to gain a better understanding of the potential which a similar detection system could have for the experiment under development at the IPNL.

Following the meeting, my research at the British Library enabled me to identify further details of the detection system at UCL from technical documents for the commercial components incorporated into the experiment. I was also able to investigate related experiments carried out elsewhere. In particular, my literature search focused upon the possibility of adapting the UCL system for the coincident detection of electrons and neutrals, as well as ionic fragments.

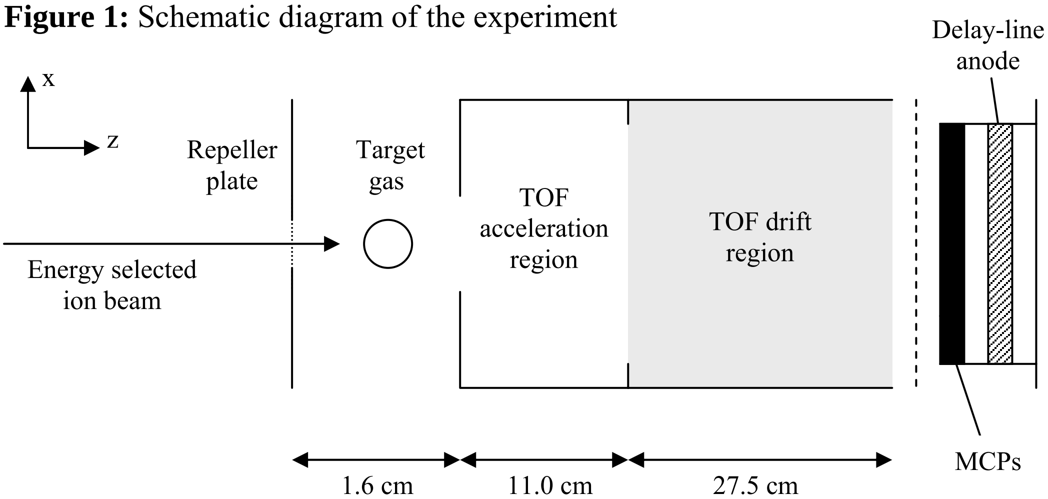
Description of the main results obtained

1. The experiment at UCL (Professor Stephen Price and coworkers):

1.1 Overview

In this experiment a pulsed, energy selected beam of dications interacts with a neutral collision gas in the source region of a time-of-flight mass spectrometer. Product ions are detected in coincidence at a position-sensitive detector (PSD). The reaction dynamics and kinematics can be deduced from the velocity vectors of the product ions. The incident energy of the ion beam is low – of the order of a few eV. The dication beam is pulsed, as is the positive charge on the repeller plate.

Figure 1: Schematic diagram of the experiment



"The position of ionic arrivals at the PSD is electronically encoded by a dual delay-line anode, which is read, via appropriate amplification and discrimination, by a fast time-to-digital converter (TDC). Experimental data are transferred to a PC… The positional data gives each ion's *x* and *y* velocity components, and the deviation of the ion's TOF t_{expt} from the expected TOF t_0 for an ion of the same mass but with zero initial velocity gives the *z* velocity component. For each pair of ions detected, this procedure results in a pair of velocity vectors for an individual reactive event, which can then be transformed to the COM frame."

[Hu *et al.* 2002]

1.2 The Reaction Chamber / Source Region for the TOFMS

The repeller plate pulse is triggered by a multi-channel digital delay generator (DDG), which is itself externally triggered by a commercial waveform generator controlling the ion beam pulses. The DDG introduces an appropriate delay so that the repeller plate pulse coincides with the arrival of the dication pulse in the centre of the reaction region. The duration of the repeller plate pulse is controlled by a digital generator and allows all the ions of interest to leave the source region before the plate returns to ground potential. Typical repeller plate pulse rates are 30-50 kHz. The intensity of the dication beam is limited to ensure that significantly less than one unreacted dication is detected per repeller plate pulse. These operating conditions give a very good signal to noise ratio but do result in long running times (~ 12 h).

A significant source of error in terms of the time-of-flight and the nascent velocities of the fragments is associated with the determination of the exact position and time of the collision. This is related to the width of the gas jet and that of the ion bunch.

1.3 The TOFMS

The TOFMS is a two field device constructed to achieve second order focusing. Eleven equally spaced gratings, held at the appropriate potentials, are used to maintain field uniformity over this long acceleration distance. After passing through the field-free drift tube, the ions are accelerated to 2.2 keV to strike the PSD. The z velocity resolution is enhanced by pulsing the ion beam so that reactions only occur over a restricted range of the source region.

For a pulsed dication beam of 4 eV and a repeller plate voltage of 300 V, where the dication energy spread contributes minimally to the TOF peak width, the peak width of the unreacted dication in the TOFMS has a half-width of only 3ns. This indicates excellent space focusing.

1.4 The detection chamber

"A commercial microchannel plate (MCP) assembly with a dual delay-line anode is used to detect ions at the end of the TOF tube. The detector consists of a pair of rimless 86.6 mm diameter long life MCPs (chevron configuration, active diameter 83mm) supported by a pair of partially *metallized* ceramic rings and an anode composed of two wire-wound delay lines, one for the x dimension and one for the y dimension. The transient voltage pulse which occurs as the detector converts an ion arrival to an electron cascade, determines t_{expt}."

[Hu *et al.* 2002]

Each delay line is made up of a pair of wires wound on a *former* to make a plane perpendicular to the axis of the TOFMS. One wire of each pair, the *signal wire*, collects to pulse of electrons from the MCPs whilst the other, the *reference wire*, is biased to force the electrons onto the signal wire. The advantage of the delay-line anode is its capability to encode the positional information and the arrival time of each detected ion with high accuracy and at the high repetition rates required.

When an ion hits the MCP detector, the pulse of electrons hits the wires of the delay-line anode. The difference between the signal arrival times at the both ends of each signal wire is proportional to the position of the MCP in the respective dimension. Thus the positional information is encoded in four signal arrival times. As the propagation delay is constant (0.98 ns mm^{-1}), the sum of the four signal arrival times is always constant This criteria is used to distinguish real signals from electrical noise.

Each ion arrival thus generates five pulses: one at the back of the MCP detector (giving t_{expt}) and four from the two delay lines. The signal from the MCP back plate provides the timing reference for the positional signals.

1.5 Signal processing

A five channel differential amplifier with an integrated constant fraction discriminator (CFD) is used to process the signals from the PSD. The timing of the signals from the differential amplifiers, relative to the repeller plate pulse, are recorded using a 32 channel CAMAC-based TDC with multi-hit capacity (LeCroy 3377). The TDC is started by the same pulse generator that controls the repeller plate. A short delay avoids the detection of RF noise from the repeller plate pulse. The times encoded by the TDC are read directly via a FERA (fast encoding and readout ADC system) interface to a memory unit (LeCroy 2367). This unit is capable of storing 512 kB of data at a rate of 100ns per cycle [LeCroy Technical Data Sheet 2367]. When the memory is full, the experiment is paused and the data are transferred to a PC via a SCSI interface.

The TDC is capable of recording multiple stop each time it is triggered so events involving multiple ion arrivals can be identified [Calandra *et al.* 2000, LeCroy Technical Data Sheet 3377].

The delay-line anode with fast data acquisition electronics allow the positional information to be collected at a much higher rate than conventional methods, such as using a CCD camera and a phosphor screen behind a MCP array.

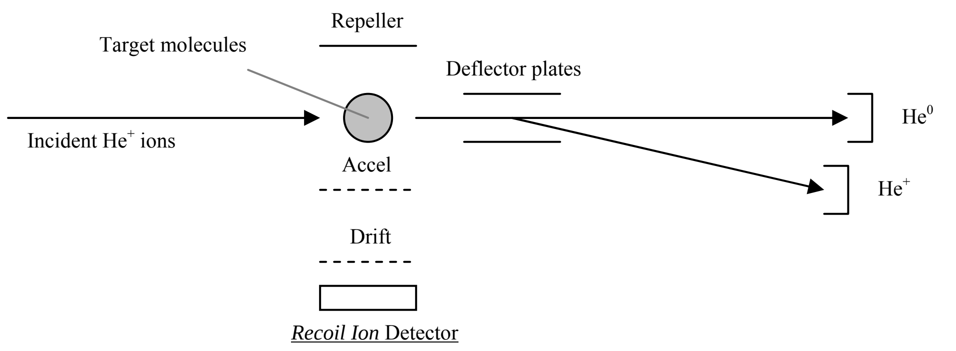
2. More detailed description of a multi-hit-delay-line-anode detector – in this case at the Universität Frankfurt

2.1 Overview of the detector

An MCP is equipped with a very fast delay-line-anode, analogous to the UCL system [Ali *et al.* 1999]. Incident He^+ ions at 200 keV are intersected with an effusive target gas beam. The resulting ions and ionic fragments are in an electric field (400 V/cm) over 20 mm before entering a 40 mm field-free drift region. Ions are then accelerated by about 2 keV over a 2 mm gap onto the MCPs. The incident He^+ ions are detected at a channeltron post-collision, providing the start pulse for the time-of-flight analysis.

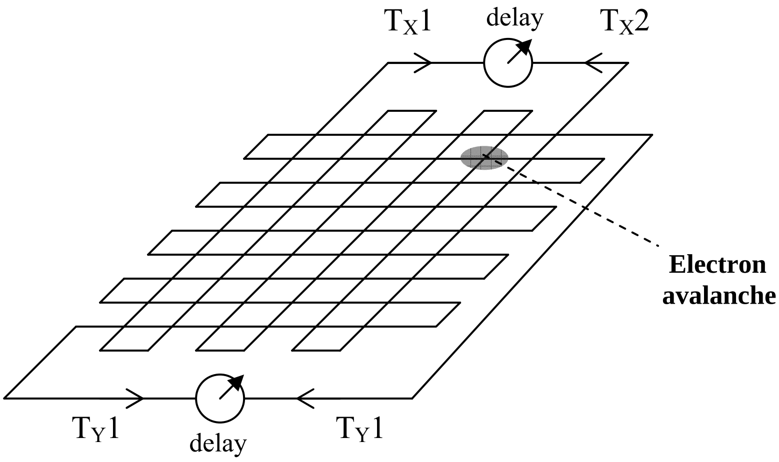
The generalised design is reminiscent of the VDG machine at IPNL (see figure 3 and section). The recoil ion detector consists of 2 MCPs and a delay-line-anode. The MCP signal gives the time of arrival of the target system ions.

Figure 2: Schematic diagram of the experiment



The delay-line-anode is composed of two crossed double wire planes spirally wound over a copper plate. The wires are held with ceramic holders fixed on the edges of the copper plate. Wire planes are thus separated from each other and from the copper plate by about 1 mm. Each wire plane consists of two wires separated by almost 0.5 mm and held at held at slightly different potentials. These wires are called the *positive (p-) signal wire* and the *negative (n-) signal wire*. The wire planes are at 90° with respect to each other to provide positional information in 2 dimensions, as shown below:

Figure 3: Schematic diagram of a delay line anode



The electron avalanche produced by an ion hitting the MCPs passes through the wires on the anode. Two signals are produced from a short drop in the voltage as the electron avalanches passes. Thus the delays in the arrival time of the signals, due to the length of wire the signal has to travel to the detector, indicate the position of the electron avalanche.

Different voltages are applied to the p-signal wire (+700 V) and the n-signal wire (+500 V) in order to improve the time resolution of the delay measurements. The difference of the electronic signals from the wire ends of each pair is amplified using a fast differential amplifier. This corresponds to a possible position resolution of better than 0.1 mm.

Since the Time to Digital Converters (TDCs) used only have single-hit capability [unlike the UCL system], a fast switch device directs consecutive signals to separate TDC inputs. The time to resolve two consecutive signals originating from separate ions is 5 ns.

2.2 A similar detector system for a photoemission microscopy experiment (i.e. detecting electrons instead of ions)

This experiment combines a *transfer lens*, drift tube, and delay line detector to achieve time- and space- resolved detection [Oelsner *et al.* 2001]. A ROENTDEK delay line detector is used, "… allowing very fast two dimensional position imaging with computer supported signal processing. The delay line detector can be used instead of a CCD camera and has a superior time resolution in the sub-nanosecond range. In addition, its working principle is based upon single-electron counting thus yielding maximum detection efficiency."

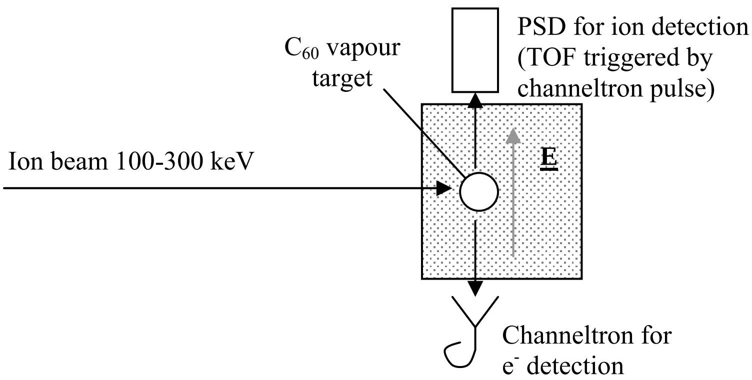
The delay line detector collects all electrons arriving at different times [Oelsner *et al.* 2001, Charts for RoentDek delay-line detector systems]

3. The experiment at the Universität Bielefeld (Lutz and coworkers)

Multiple ionisation and fragmentation of a target molecule by ion impact are studied using a position and time-sensitive multi-particle detector [Werner *et al.* 1995]. A three dimensional image of the breakup process can be obtained.

The report of Reinköster *et al.* [1998] relates to the fragmentation of C_{60} in collisions with H+ and other small ions at 100-300 keV. Slow ions and electrons generated by high energy ion impact upon a neutral target are separated by a weak electric field perpendicular (330 Vcm^{-1}) to the primary beam. Electrons are detected in a channeltron at one side of the of the interaction region; positive ions are accelerated towards the position- and time-sensitive multiparticle detector at the other side. The detector is essentially a channelplate multiplier with a crossed-wire anode structure. The first electron detected at the channeltron serves as a start pulse for the detection system. The position (x_i, y_i) and time-of-flight (τ_i relative to the start electron) of all cations produced in a single breakup are recorded.

Figure 4: Simple diagram of the experimental system (*interpretation of written description*)



Details about the position sensitive detector are given by Becker *et al.* [1994]. To avoid the problem of not being able to detect several particles arriving “at the same time”, an array of independent anodes is used in combination with the MCP. The position and time resolution of the detector is 2.5 mm and 2 ns, respectively.

The wires in the anode (see sections 1 and 2) are replaced with an etched structure consisting of independent x- and y- wires. If an electron cloud from the plates hits at a crossing of two wires, coincident pulses on the wires will be generated and registered by a TDC. The detector is thus capable of resolving particles which arrive “at the same time” on different wires [Lutz group web page].

“An array of 256 squares was etched into a copper-plated epoxy-board, arranged in 16 columns and 16 rows. The rows are connected on top of the board while columns are connected on the rear surface using small vias. These wires are terminated by 50 Ω SMD detectors on each end; each other end is connected to transimpedance amplifier… An important advantage of this system is the large sensitive surface of each “pixel”. Typical signals show a pulse width of 3 to 5 ns and an amplitude of 10 to 30 mV. In contrast, with an anode structure using 32 × 32 gilded tungsten wires, each 50 *m in diameter, signal amplitudes of < 1 mV were observed. Moreover, the efficiency was less than 20% of that of the etched structure: only a comparatively small number of hit produced large signals in both the x- and the y- wire…”

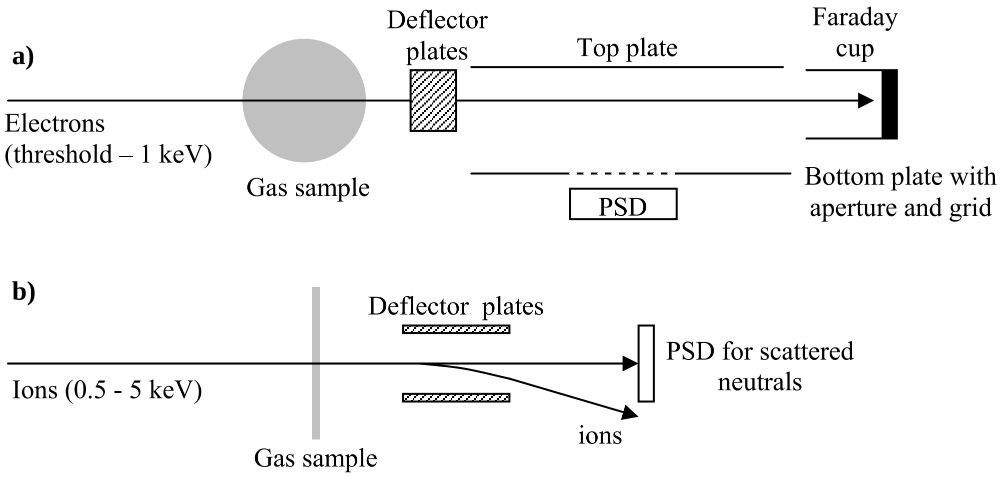
[Becker *et al.* 1994]

4. Other PSD Systems

4.1 Lindsay and coworkers at Rice University, Texas:

The group operate several experiments involving PSDs [Lindsay group web page]. The first detects cations produced by electron impact ionisation and is shown schematically in figure 5.a [Straub *et al.* 1998]. Electron pulses (20 ns, 2.5 kHz) enter a chamber filled containing the target gas at low pressure (~ 3×10^{-6} Torr) and are collected at a Faraday cup. Approximately 200 ns after the electron pulse, an electric field (480 Vcm^{-1}) is applied across the interaction region, acceleration positive ions towards the *bottom plate*. Some of these ions enter the aperture, are accelerated, impact a PSD, and are time-of-flight analysed. The detection positions provide information on the effectiveness of ion collection.

Figure 5: Schematic diagrams of two experiments at Rice University



A second experiment is shown schematically in figure 5.b [Lindsay *et al.* 1996]. The ion beam is not pulsed – the object of the experiment is to obtain charge transfer cross sections. In The deflector plates can be grounded order measure the total beam flux (ions and neutrals). The efficiency of ion and neutral detection at the PSD is the same.

For both experiments, the PSDs combine an MCP with a delay-line anode in the same way as described in sections 1 and 2. The position and time resolution achieved are 100 µm and 1 ns, respectively. To my knowledge, further details (commercial components, dead time, etc) are not available in the literature.

4.2 Hayden and coworkers at the Sandia National Research Laboratory, California

Analogous to the UCL system, this detector records the arrival time of ions in one dimension (TOF) and the initial velocities of the fragments after photodissociation [Davies *et al.* 1999]. The detector is described in detail by Vallerga *et al.* [1989].

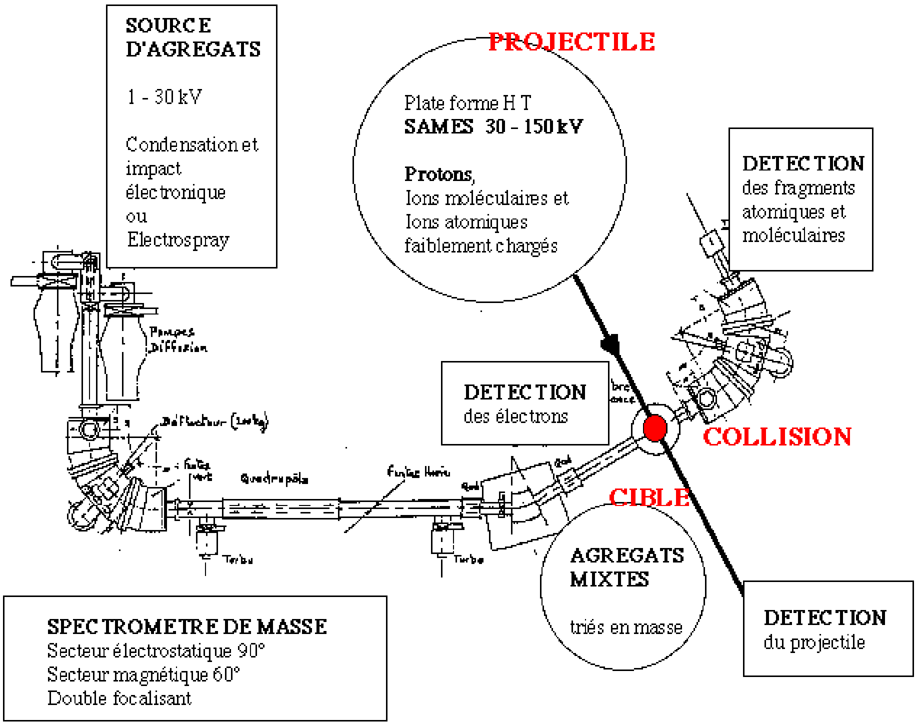
4.3 Becker and Coworkers at Fritz-Haber-Institut, Berlin

Angular distributions of fragment ion pairs are measured using MCPs and a multi-hit anode [Saito *et al.* 1996]. However, to my knowledge, details about the timing, the TDC, etc. are not available in the lterature.

5. The experiment at IPNL

The identification of the fragments of proton-cluster collisions will be carried out by a system of electrostatic deflectors and the application of time-of-flight mass spectrometry techniques. The aim is to study different channels against the number of water molecules in the cluster and against the impact velocity. Importantly, the detectors will be operated in coincidence.

Figure 6:
Schematic view
of the experiment



Investigation into the detection system for the experiment at IPNL is ongoing.

Future collaboration and projected publications resulting from the STSM

No specific plans are in place for collaboration between the IPM group at IPNL and the group at UCL. However, Professor Stephen Price stated that he would be happy to offer further advice relating to the detection system at UCL and future applications in our experiment. I have no doubt that we will consult him further during the design of our detection system. Should they wish, Stephen Price and his coworkers will be very welcome to visit the laboratory at IPNL in the future.

Once the experiment at IPNL has been constructed, a publication describing the specific techniques and apparatus will be prepared. This work will have benefited directly from the STSM described in this report.

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