8 Nuclear Instruments and Methods

8.1 Tandem Accelerator

8.1.1 Tandem Accelerator Operation

E.P Carter, J. Dunham, R.M. O’Quinn, C.R. Westerfeldt, and S. Williamson

The TUNL FN tandem accelerator was operated 128 days for 2742 hours at terminal potentials ranging from 0.45 MV to 6.7 MV during the period 8/1/1999 to 7/31/2000. Beams accelerated during this period include polarized and unpolarized protons and deuterons, and also $^3$He and $^{12}$C. The terminal operating potential during the reporting period is shown graphically in Figure 8.1–1.

Figure 8.1–1: Terminal operating potential as a function of time.
There were two scheduled accelerator maintenance periods this reporting period, and five separate one-day repairs. The corona feedthrough and needle assembly were replaced four times without a tank opening when corona regulation became very unstable. The reason for this instability is still unknown. The tandem was opened for a 10-day maintenance in April 2000. All of the charging, idler and pickoff pulleys were replaced in the Pelletron charging system and a rebuilt GVM was installed on the tank as a backup. In June, another opening was made to install a new batch of (75) stripper foils and examine the terminal steerer assembly. The steerer was removed and cleaned as we suspected a short to ground on one of the steerer plates due to a broken foil or carbon build-up. During the maintenance period, the charging systems were examined to determine the cause of what seemed to be excess terminal voltage ripple caused by unstable charging currents. It was discovered that the low-energy charging chain delivered a very unstable current to the terminal. The reason appears to be that the contact between the charging wheels and the chain is poor due to a mechanical problem. As time was short, we could not remove the problem part and have
it repaired in the machine shop. Instead we installed a simple RC filter at the terminal end which introduced a 100 millisecond integration of the arriving charge. The results were a dramatic improvement in the terminal stability. The modified corona needle system was replaced with an original HVEC set at this time and corona stability seems to have improved, although it is still not optimal.

A histogram showing the fraction of experimental time spent at various terminal potentials is given in Figure 8.1–2.
8.2 KN Accelerator

8.2.1 KN Accelerator


The TUNL KN high energy-resolution accelerator was operated 79 days, for a total of 615 hours during the period August 1, 1999 through July 31, 2000 at terminal potentials ranging from 1.3 MV to 2.4 MV. Three machine openings were made during this period for reasons including: replacement of the ion source bottle, replacement of the rf oscillator tubes, and several minor electrical problems. A plot of the operating potential of the accelerator for the reporting period is shown below in Figure 8.2–1.

![Figure 8.2–1: Terminal operating potential as a function of time.](image-url)

In Figure 8.2–2 we present a histogram depicting the number of days of operation as a function of terminal potential.

¹Tennessee Technological University, Cookeville, TN.
8.2.2 Laboratory Improvements and Modifications


During the 4th quarter of 1999 the TUNL-HRL high-resolution control system was upgraded. The failing National Instruments ATM-IO-16 PC card which interfaces with most of the important high-resolution system components was replaced. It was determined to be more cost effective to replace the unit than to have it repaired. The newer version of this piece of hardware, however, placed additional demands on the control PC. Namely, that the PC run the most current version of LabView and hence a more current version of the Windows operating system. The new software also required the upgrading of the CPU. The upgraded system executes the control loops considerably faster than the old and retuning of the PID software was needed. The front panels for the LabView VI’s (programs) have been redesigned making operation of the control system more efficient. It is expected and indeed preliminary results suggest the HRL control system upgrade will enhance the

\footnote{Tennessee Technological University, Cookeville, TN.}
system’s already superlative resolution. Future plans for the control system include the use of an optical isolation system to protect vital components from damaging transient signals. Also, if an academic license is obtained for LabView it would be possible to migrate the system to the Linux or possibly Macintosh operating system. The goal would be to reduce intrinsic latency in the control loops and thus further improve the system’s resolution.

Work in progress includes: the replacement of the accelerator source focus power supply with a redesigned circuit which should dramatically reduce the ac energy ripple on the extracted beam from the terminal ion source, and the replacement of a troublesome oil diffusion pump system on the electrostatic analyzer with a used/refurbished cryopump obtained from the University of Pennsylvania at low cost. If successful, we hope to replace the oil diffusion pump on the elastic scattering chamber also. This should reduce the hydrocarbon contamination of our thin targets - which typically limits their useful lifetime.
8.3 Polarized Ion Source

8.3.1 Atomic Beam Polarized Ion Source

_ T.B. Clegg and J.D. Dunham_

Patterns of use of TUNL’s atomic beam polarized source almost exactly matched those in the previous year. During the period 7/1/99–6/30/00, the source provided polarized (unpolarized) beams for experiments for 45% (10%) of the calendar days, with an additional 15% of the calendar days scheduled for routine maintenance. Experiments using beams from the source in the low-energy experimental area occupied 33% of the calendar days, while provision of polarized beams for the tandem accelerator occupied 22% of the days. Detailed use was as follows: 52 (66) days were used for polarized H⁺ (H⁻) operation; 21 (27) days were used for polarized D⁺ (D⁻) operation; and 35 days were used with unpolarized H± beams. No major changes in source hardware nor unusual difficulties with source operation have occurred.

8.3.2 Experimental Tests of a Lamb-Shift Polarimeter Used with an Atomic Beam Polarized Ion Source

_C.R. Brune, T.B. Clegg, J.D. Dunham, and C.D. Roper_

Following the description in last year’s Progress Report, a manuscript was prepared for submission to Reviews of Scientific Instruments describing the experimental experience with the on-line Lamb-shift polarimeter installed on the polarized source. The abstract reads as follows:

“A summary is provided of experience gained using a Lamb-shift spin-filter polarimeter to monitor the nuclear polarization of H or D ion beams from an atomic-beam polarized ion source. Comparison is made of the polarization measured by the polarimeter and by subsequent nuclear scattering processes. For positive ion beams, agreement is excellent. Explanation is provided for discrepancies observed when negative ion beams are used.”

8.3.3 Research Leading to an Improved Ionization Scheme for Polarized H and D Atoms

_T.B. Clegg, J. Chiu, J.D. Dunham, S.B. Gilliam, S. Lemaître, P. Santos, and B.J. Smith_

The Stored Atoms Polarized Ion Source (SAPIS) testbench whose construction was described in last year’s Progress Report has been used to investigate the feasibility of building a more efficient plasma jet ionization system for spin-polarized H or D atomic beams [Cle96, Lem00]. Such a device would utilize the very large charge-exchange cross section for
H\(^+\) + D\(^0\) → H\(^0\) + D\(^+\) (or D\(^+\) + H\(^0\) → D\(^0\) + H\(^+\)) which rises to \(\sim 5 \cdot 10^{-15}\) cm\(^2\) at relative energies of a few eV. Such an ionizer has become feasible at TUNL because of our recent development of a quasi-neutral plasma beam containing \(\sim 3\) mA of positive H ions confined inside a column 5 mm in diameter.

It is also planned later to investigate the possibility of the direct production of a negative polarized ion beam via the charge exchange reactions H\(^-\) + D\(^0\) → H\(^0\) + D\(^-\) and D\(^-\) + H\(^0\) → D\(^0\) + H\(^-\)) respectively, which exhibit comparable cross sections as the reactions mentioned above.

The plasma-jet emerges from an ECR discharge and is guided along the axis of a uniform 1 kG solenoidal magnetic field. It then enters a 23 cm long, 1 cm diameter Teflon tube (storage cell) whose entrance is 7 cm downstream from the plasma chamber exit. Ions emerging from the opposite end of the tube are accelerated and formed into a beam. To examine the efficiency of the charge-exchange process, unpolarized D (H) atoms have recently been injected at the middle of the tube. Based on experimental results, we will assess the feasibility of injecting instead polarized D (H) atoms to produce polarized ion beams.

Referring to the testbench described in last year’s Progress Report (see also Fig. 8.3–1), microwaves at 2.45 GHz enter through a vacuum tight Aluminum-Oxide (AlO)-window into the ECR plasma-chamber which is completely lined with Boron Nitride (BN). The plasma beam emerges through a 8.5 mm diameter, 35 mm long Macor channel attached to the BN-chamber. A low carbon steel collar around the water-cooled plasma chamber reduces the axial magnetic field from about 1 kG to below the 875 G needed for the ECR condition inside the plasma chamber.

![Figure 8.3-1: Scheme of the new polarized ion source.](image)

Using BN as a liner for the plasma chamber has two principal purposes. First, it was shown that the usage of BN improves the proton fraction of ion beams produced from a hydrogen plasma [Wil97].

Second, the ECR-plasma can be biased to the beam potential while it remains electrically
insulated from the grounded vacuum chamber. Via a high voltage feedthrough, the variable bias voltage is connected to an electrical shield which is in contact with the drifting beam exiting the plasma chamber as well as the extraction electrode at the exit of the storage cell (Fig. 8.3–1). Since the plasma touching the shield is an excellent electrical conductor, the same bias voltage defines the plasma potential along the storage cell axis and back into the ECR chamber. Consequently, the charge exchange inside the electrically insulated storage cell occurs at a variable beam potential. Acceleration of the emerging beam to ground potential provides for beam energies up to 10 keV.

Guided by the axial field the plasma beam passes through the storage cell. Teflon covers the inner wall of the cell. Neutral atoms of the other kind (i.e., D⁰ for an H⁺-plasma beam, and vice versa) enter into the cell at the T-junction. These atoms are delivered by an RF-dissociator (similar to that described in [Koc95]) mounted above the storage cell.

To obtain a small atomic flux comparable to the currently available polarized atomic beams, and to limit the pressure inside the storage cell to about 1 × 10⁻⁵ mbar while maintaining the high pressure necessary for the dissociator RF-discharge (≈0.5–1 mbar), the dissociator’s inner glass tube is reduced to a ~0.1 mm diameter capillary at its exit. The conductance of the capillary was measured to be 3.8×10⁻⁵ l/s.

The large electrical potential across the acceleration gap at the right side of the storage cell separates the positive ions leaving the storage cell to the right from the accompanying negative charges (electrons) in the drifting plasma jet.

Two beam profile monitors (BPM) for the accelerated ion beam consist of straight 0.8 mm diameter wires which are moved across the beam. These are located 22 cm and 42 cm, respectively, downstream of the acceleration gap (Fig. 8.3–1). The electrical current produced on the scanner wires by the impinging ions and secondary electrons is measured. This current is proportional to the beam intensity integrated along the wire.
Beyond these profile monitors, species present in the ion beam can be selected by an analyzing magnet and collected in a downstream Faraday cup (Fig. 8.3–1).

\[ x'' = \sqrt{\epsilon \beta} \]

\[ x_{\text{max}} = \sqrt{\epsilon \beta} \]

\[ \text{Area} = \pi \epsilon \]

Figure 8.3–3: Measured parameters of the beam in transverse phase space \((x, x')\) defining the emittance ellipse \(\epsilon = \gamma x'^2 + 2\alpha xx' + \beta x'^2\).

Two different types of measurements were made using the new testbench. First, ions were extracted and accelerated from the plasma jet after it passed through the storage cell. Using a 5 mm diameter aperture at the exit of the storage cell (Fig. 8.3–1) up to \(I_p = 2\) mA ion beam current was extracted with an accelerating voltage of \(\sim 10\) kV. High values of \(> 95\%\) are routinely measured for the fraction of \(H^+\) (or \(D^+\)) in this beam. Using the beam profile monitors and the downstream Faraday cup (Fig. 8.3–2) it was possible to measure both the beam width \(x_{\text{max}}\) and the divergence \(x''\) when the beam profile monitor was at the center of the beam. From Fig. 8.3–3 it is obvious that the product \(x_{\text{max}} x''\) yields the beam emittance \(\epsilon\). The measured normalized emittance of the total beam was typically \(\epsilon_n = 0.3 \pi\) mm mrad. This compares with at least \(0.6 \pi\) mm mrad for beams from the present TUNL polarized source.

Second, charge exchange measurements have just begun with deuterium from the dissociator injected into the storage cell (see Fig. 8.3–1) and with the \(H^+\) plasma jet travelling through the cell. The actual flux of \(D_0\) from the dissociator depends on the dissociation degree which has not yet been measured. However, by measuring the \(H^+\) (from plasma jet) and \(D^+\) (from \(H^+ + D^0 \rightarrow H^0 + D^+\)) mass fractions in the extracted and accelerated ion beam, the total ionization efficiency \(\eta = \sigma_{\text{eff}}I = I(D^+)/I_p(H^+)\) has been found to be \(\leq 0.06\).

This value already suggests a minimum efficiency matching that of TUNL’s existing polarized ion source, where ionization occurs by the process \(H^0 + e \rightarrow H^+ + 2e\) [Cle:95]. Measurement of the degree of dissociation of deuterium will be performed in the near future.
to obtain a better understanding of $\sigma_{\text{eff}}$ for D$_0$ atoms using the plasma jet.


8.3.4 An Application for a Hydrogen Beam Plasma: Control of Carbon Nanotube Nucleation Rate

T.B. Clegg, S. Lemaitre, P. Santos, and B. Stoner$^1$

Carbon nanotubes can form when hemispherical beads of iron of 1 to 30 nm in diameter are placed on a diamond surface and held near 750 C in the presence of hydrogen. However, the actual nucleation process for these nanotubes is not well understood. It is known that at this temperature, carbon from the diamond is soluble in iron. Thus, it is believed that carbon atoms move within the iron and coalesce on the bead’s surface. Any hydrogen present then preferentially etches away non-graphitic surface carbon and leaves one or more graphite-like layers covering the hemispherical bead. It is postulated then, that as more carbon migrates to the surface, strain within these layers causes their ‘lift off’ from the center of the bead, nucleating the growth of single- or multi-walled tubular structure(s) which are still affixed to the surface at the periphery of the bead.

In an effort to verify this process, an experiment is being prepared to try to control the rate of this nanotube growth. By varying the diamond substrate temperature to control carbon mobility, and by varying the H$^+$ ion flux at the bead’s surface to control the rate of graphite formation, a series of measurements will investigate whether rates of nucleation, ‘lift off’, and nanotube growth can be sufficiently throttled to reveal clearly actual nanotube nucleation.

These experiments will be performed using the H-ion jet plasma produced by the ECR discharge source on TUNL’s SAPIS testbench (see Section 8.3.3). This jet plasma is being

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$^1$University of North Carolina-Chapel Hill and MCNC, Chapel Hill, NC.
developed and is primarily intended as an efficient possible future ionizer of nuclear polarized H or D atoms. However, diagnostic measurements made on this plasma (reported above) showed that it provides an intense calibrated thermal flux of H$^+$ ions. It then provides an attractive source of hydrogen ions for the test described above.

All parts necessary for the nanotube growth experiment have been designed and fabricated. The hardware introduces twelve heated diamond samples into the testbench for independent time exposures to the H$^+$ beam. The design thermally isolates the samples from the movable rod to which the external sample manipulator is attached. Parts are being installed on the testbench and initial measurements will begin soon.
8.4 Polarized Target

8.4.1 Modification of the Dynamically Polarized Deuterium Target

R.D. Foster, C.R. Gould, D.G. Haase, D.M. Markoff, J.O. Poole, and W. Tornow

We have designed and are constructing modifications to the existing TUNL dynamically polarized deuteron target so that the target polarization will increase to 30–40%. The testing of the modifications will be done in Fall, 2000. The target was previously used for several measurements of the spin dependence of the $\bar{n}$-$\bar{d}$ transmission for neutron energies from 5 to 12 MeV. It is our objective to use the target to measure the spin-spin total cross-section $\sigma_{ss}$ for $\bar{n}$-$\bar{d}$ transmission. We will focus on determining the energy at which $\sigma_{ss}$ goes to zero, which is a precision test of nucleon-nucleon potential models and possible three-nucleon interactions. Vector polarizations of 13% were realized at 500 mK in a 2.5 T magnetic field. The polarization axis of the target may be set in the horizontal plane and parallel (antiparallel) to the neutron beam momentum.

A limitation on the previous measurements was the attainable deuteron polarization. The polarization can be increased by lowering the target operation temperature from 500 mK to 200 mK where we expect polarizations of 30–40% [dB76]. A new target refrigerator has been designed that employs a dilution refrigerator [van90] with a plastic continuous heat exchanger [Fro92]. The figure-of-merit in a neutron transmission experiment is $P^2t^2$ where $P$ is the target polarization and $t$ the target thickness. To increase the effective target thickness - and the NMR filling factor - we will experiment with a fully deuterated ("D8" 1,2-propanediol) target material cast in the form of slabs rather than 1 mm diameter beads [van88]. Together these modifications should increase the experimental figure-of-merit by a factor of five to ten. A Summer 2000 Research Experiences for Undergraduates student, Alex Mayer, collaborated in designing and writing the computer control programs for the new target.

The deuteron polarization is measured directly through continuous-wave deuteron NMR at 16.5 MHz. Because the NMR signal is quite weak, we have written a non-linear fitting program which more effectively determines the target polarization through comparison with the theoretical deuteron lineshape and the frequency response of the NMR circuit.


8.5 Gas-Jet Target

8.5.1 Improvements to the Gas-Jet Target


The gas-jet target has undergone significant improvements during the past year. As was previously reported in [Fis99], the stage 2 and 3 roots blowers were found to be contaminated with gear-case oil which severely diminished their pumping speed. These pumps have been replaced with new Leybold 1000 m³/h roots blowers resulting in vastly improved pumping speed. With an input pressure of about 3 bar (double of what was reported in [Fis99]), the vacua measured in the various pumping stages was an order-of-magnitude better than when pumping with the contaminated pumps. The chamber vacuum, however, is still an order-of-magnitude worse than reported by the Erlangen group [Bit79]. We are investigating improving the efficiency of the large 6000 l/s diffusion pump to hopefully reach a chamber vacuum of around 5 × 10⁻⁷ Torr. With such improvements, we would like to reach an input pressure of around 5 bar.

Despite the less than optimal vacuum conditions, we were able to perform a number of tests on the jet. A 3-MeV proton beam from the Tandem was tuned down the 44° beamline to the gas-jet target. By moving a 1 mm diameter aperture across the incident beam, a density profile of the gas jet was obtained from the elastic scattering yields measured with detectors mounted in the chamber. The jet boundary is observed to be sharp, with a width of about 1.5-mm. (see Figure 8.5–1.) The effect of the gas-jet density profile due to different size and shape nozzles, nozzle position and pressures, and catcher positions is being investigated.

A method to perform such density profile measurements of the gas jet when the tandem beam is not available, is desirable. We have chosen to do this using an electron gun. Possible methods include using the electron beam as an attenuation probe, an energy-loss probe, a fluorescence probe, or as a large-angle scattering probe [Tie79]. Existing electron guns at TUNL currently not in use are being tested, and we are engineering how to attach such a gun to the existing target chamber.

We have also performed a measurement of the target thickness of the gas jet. From a 3 MeV proton beam scattered off the target gas ⁴He, and using the previously measured ⁴He(p,p)⁴He cross section, we obtain a thickness of ~ 2.0 × 10¹⁸ atoms/cm². If this target density is reproduced with hydrogen as the target gas, the target would be ~ 10 times greater than that of solid hydrogenated carbon foil targets [Bla00]. Pending approval by the Duke University safety inspectors, we hope to run the jet with Hydrogen as the target.

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gas before the end of this year.

![Graph](image)

**Figure 8.5-1:** (a) Typical spectrum from elastic scattering of 3 MeV protons off a $^4$He gas jet at $\theta_{lab} = 50^\circ$. (b) Gas-jet density profile at various input pressures.

The gas-cleaning and recirculation compressor is also receiving attention. We hope to either begin refurbishing the existing compressor/cleaning assembly or have a new, more modern system (including a smaller, cleaner compressor) running during the upcoming year.

Measurements of the cross sections of $p$-$^3$He elastic scattering at low energies using the gas-jet target are scheduled for the next year. Also, measurements of the analyzing power of $p-p$ elastic scattering are being explored.

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8.6 Sputter Source

8.6.1 Negative-Ion Sputter Source

C.R. Brune, E.P. Carter, A. Danner, J.D. Dunham, D. Niederloehner, and R.A. Schwentker

In December 1999 a General Ionex Model 860 negative-ion cesium sputter source was made available to TUNL by Lawrence Livermore National Laboratory (LLNL). This source supplies intense beams of negative ions for nearly all elements, with the exception of noble gases. The beams produced are of excellent quality (normalized emittance $\approx 1.5\pi \text{mm-mrad-MeV}^{1/2}$) and are widely used for injection into tandem accelerators. This source greatly increases the variety of experiments which can be carried out at TUNL. In addition, the source can be used for the production of implanted targets.

The source has been installed in the place of the DENIS II duoplasmatron which is used to make unpolarized H$^-$ and D$^-$ beams for the tandem. This location takes advantage of the safety cage, interlocks, transformer, frame voltage power supply, and oil cooling which were already in place for DENIS II. The source obtained from LLNL was in excellent condition and complete, with the exception that power supplies were not included. The supplies thus had to be obtained from surplus or purchased new. Hardware was fabricated in order to mount the source onto the existing beamline, and the einzel lens system was modified to be compatible with the new source. The energy of the beams produced by the source is nominally 50 keV. We also point out that the low-energy analyzing magnet has an unused port which could easily be set up for producing implanted targets.

To date the following currents have been obtained for analyzed beams on the low-energy cup: 2 $\mu$A of H$^-$ and D$^-$ and $> 10$ $\mu$A of $^{12}\text{C}$ and $^{16}\text{O}$. These intensities are roughly an order of magnitude smaller than expected for this source. The shortfall is most likely due to inadequate cooling of the cathode, a problem which will be addressed in the immediate future. At the present time we are switching between the sputter source and DENIS II based on the experimental needs ($\approx 3$ hour operation). Once higher H$^-$ and D$^-$ are realized from the sputter source, we will investigate the possibility of using the sputter source exclusively. We have also designed a system for remotely controlling the source power supplies via LABView running on a computer located in the control room.
8.7 Microchannel-Plate Detector

8.7.1 Nuclear-Recoil Detection with Microchannel Plates

P.F. Bertone, A.E. Champagne, C. Iliadis, J. Mosher, J.G. Ross, and A. Stephan

Low-energy studies of \((p,\alpha)\) reactions on sd-shell nuclei at energies \(E_p \leq 500\) keV are frequently performed by bombarding water-cooled beamstop targets with high-intensity proton beams. A charged-particle detector, mounted in close geometry to the target, is then used for the detection of the reaction \(\alpha\) particles. For many exothermic \((p,\alpha)\) reactions the \(Q\)-value is about 2 MeV and, therefore, metal foils of thicknesses 1–2 \(\mu\)m are placed in front of the charged-particle counter to reduce the large number of elastically scattered protons reaching the detector. The \(\alpha\) particles lose most of their energy while penetrating the metal foil, consequently appearing in the particle spectra in a region of high background caused by protons and contaminant reactions. This background prohibits the detection of very weak resonances of astrophysical importance.

One technique which provides background reduction is the detection of the emitted \(\alpha\) particles in kinematic coincidence with their corresponding recoil-reaction partners. This method requires the use of transmission targets and, therefore, proton beam intensities are limited to \(\leq 1\) \(\mu\)A. However, with reduced background fewer events are needed in order to observe weak \(\alpha\)-particle peaks. At low proton bombarding energies, the recoil nuclei have small kinetic energies and, consequently, conventional detectors such as surface-barrier counters are not useful in this case. Here, we describe a technique in which the slow recoil nuclei are detected directly with a microchannel-plate detector. The measurements are challenging since the recoil nuclei of interest have to be observed with the microchannel-plate detector at high proton induced background count rates up to \(\approx 10^7\) /s.

The present experiments were carried out at TUNL. The 200 kV mitin-tandem accelerator provided proton beams up to 1 \(\mu\)A on target in the energy range \(E_p \leq 480\) keV. Transmission targets were prepared by evaporating LiF, CaF, NaCl and \(C_3H_6N_6\) from tantalum boats onto carbon backing foils. The proton beam entered a scattering chamber through a 3 mm diameter collimator, passed through the transmission target, and was stopped on the opposite side of the chamber. Proton beam intensities on target were 1–200 nA. The detection system consisted of a silicon surface-barrier (SSB) detector and a microchannel-plate (MCP) detector. The SSB detector was positioned at angles of \(\theta_{SSB} = 40^\circ - 85^\circ\) with respect to the proton-beam direction. A 2.2 \(\mu\)m thick Havar foil was placed in front of the SSB detector in order to prevent the large number of elastically scattered protons from reaching the counter. Recoil nuclei corresponding to the emitted \(\alpha\) particles were detected using a microchannel-plate detector in a Chevron configuration with a metal anode. The MCP detector had an active area of 1256 mm\(^2\) and was mounted at an angle of \(\theta_{MCP} = 131^\circ\) from the target. Energy spectra for the \(^{19}\text{F}(p,\alpha_2)^{16}\text{O}\) reaction, measured with a proton
beam of energy $E_p = 346$ keV and intensity 50 nA incident on a 9 keV thick CaF$_2$ target, are displayed in Fig. 8.7-1(a) and (b). The SSB detector was positioned at angles of 40° and 85°, respectively. Reaction $\alpha$ particles resulting from the $E_R = 340$ keV resonance are apparent in the low-energy part of both spectra. The associated time-of-flight difference spectra are displayed in Fig. 8.7-1(c) and (d). The peak shown in Fig. 8.7-1(c) results from true coincidences between $\alpha$ particles observed with the SSB detector providing a start signal for the TAC, and corresponding $^{16}$O recoil nuclei observed with the MCP detector providing the stop signal. The FWHM of the TAC spectrum peak amounts to about 13 ns and is mainly determined by geometrical differences in recoil flight paths to the MCP detector. In agreement with expectations, no peak is observed in the TAC spectrum displayed in Fig. 8.7-1(d) since kinematic coincidences are not possible with the SSB and MCP detectors located at $\theta_{SSB} = 85^\circ$ and $\theta_{MCP} = 131^\circ$, respectively.

Figure 8.7-1: Energy (a,b) and time spectra (c,d) at two different SSB detector positions, observed with 50 nA proton beam intensity at the $E_R = 340$ keV resonance in $^{10}$F($p,\alpha$)$^{16}$O. A true coincidence peak is clearly visible in part (c) of the figure.

We have demonstrated the usefulness of a microchannel-plate detector for measurements of low-energy recoil nuclei in the presence of high background count rates. Absolute MCP detection efficiencies have been measured with a 1 nA proton beam current, resulting in values of $\eta_{MCP} = 67\%$ to 85$\%$ for ion energies of 357 keV to 8250 keV, respectively. Microchannel-plate detection efficiencies have also been measured at elevated background count rates caused by protons elastically scattered from the target. It has been shown that for incident proton beam currents of 1 nA to 200 nA the values of $\eta_{MCP}$ decrease by factors
of $\approx 1.2$–$1.8$, depending on ion energies and masses, due to a reduction in MCP detector gain.

Our results indicate that the experimental technique described in this work can be used for the measurement of weak $(p,\alpha)$ resonances with strengths in the $10^{-5}$ eV range. A paper describing in detail our formalism and procedure has recently been submitted for publication.