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A SEGMENTED TARGET CHAMBER FOR (n,p) STUDIES AT TRIUMF†

R.S. Henderson¹⁾, W.P. Alford²⁾, D. Frekers³⁾, O. Häusser⁴⁾, R.L. Helmer²⁾
K.H. Hicks⁴⁾, K.P. Jackson, C.A. Miller⁵⁾, M.C. Vetterli, S. Yen

TRIUMF, 4004 Westbrook Mall, Vancouver, B.C., Canada V6T-2A3

- 1) also associated with University of Melbourne, Australia
- 2) also associated with University of Western Ontario
- 3) also associated with University of Toronto
- 4) also associated with Simon Fraser University
- 5) also associated with University of Alberta

Abstract

We have developed an (n,p) target chamber consisting of six target layers sandwiched between seven gas detector layers. This target chamber is now commonly used with the new (n,p) facility at TRIUMF. With this arrangement, large total (n,p) target thicknesses ($> 1\text{g/cm}^2$) can be used and yet the target contribution to overall energy resolution is moderate, typically less than 500 keV. The simultaneous accumulation of data from six target layers has proven to be highly advantageous with a number of applications, such as: 1) using multiple thicknesses of one target material, 2) including a target of known cross-section in the target stack for normalization, 3) adding a target to obtain simultaneous spectra for later subtraction of contamination lines and 4) the use of several target materials at once.

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1. Introduction

The TRIUMF charge-exchange spectrometer system [1,2] is based on the existing Medium Resolution Spectrometer (MRS). The spectrometer is instrumented with a detection system which provides particle identification and full ray-trace capabilities.

A layout of the system as it is used in charge-exchange measurements is shown in Fig. 1. Neutrons are produced in the primary target (Tpn) mounted inside a sweeping magnet. After passing through this target the proton beam is deflected through 20 degrees and focused into a beam dump. The neutrons from the primary target are incident on a secondary target (Tnp), 92 cm downstream, and the protons from the (n,p) reaction observed in the MRS.

(p,n) mode

In the (p,n) mode the primary target (Tpn) is the target of interest and is located above the MRS pivot. The secondary target (Tnp) is required only to convert the neutrons into recoil protons, which are analysed in the usual MRS detection system. This recoil proton radiator is at the entrance to the MRS, and consists of a 2cm thick scintillator (RS). A signal derived from the energy loss in the scintillator (about 10 MeV for 200 MeV protons) is used to correct the proton energy measured by the spectrometer. FWHM energy resolution of 1 MeV on-line and 780 keV off-line have been achieved. This is consistent with components from the incident proton beam energy spread, the energy loss in the primary target and the scintillator energy resolution. A thin (0.16 cm) scintillator (VS) located just upstream from the recoil scintillator is used to veto incident charged particles.

(n,p) mode

In the (n,p) mode a nearly monochromatic neutron beam is produced in the ⁷Li primary target (Tpn). The secondary target (Tnp), located at the MRS pivot, is the target of interest. The detector system is modified in two ways: First, in addition to

the standard front end chamber (FEC0) a second such detector (FECM) is added 27 cm upstream for better ray-tracing and a 0.08 cm thick scintillator (FES) can be added for use in the fast trigger. Secondly, since there is no energy loss signal directly available from the T_{np} target, an (n,p) target chamber was developed which contains six target layers and seven detector layers. This target assembly greatly enhances the capabilities of the (n,p) facility and will be described in detail in the following.

2. Segmented Chamber Design

The spatial constraints on a segmented target arrangement at the MRS pivot are severe, in particular the proximity of the sweeping magnet yoke and the 20 degree beam line to the beam dump. The other constraints and requirements are:

- a) The spectrometer must be able to be rotated through an angle range of -5 to +30 degrees. This requirement is difficult to satisfy since the magnet yoke is only 9.8 cm away from the spectrometer pivot point.
- b) It was considered that to be worthwhile the chamber should contain at least six target layers.
- c) A gas veto detector before the first target layer was necessary. This detector layer (V_v) is used together with the veto scintillator (V_s) to reject any event which involves a charged particle entering the detection system.
- d) The detector layers should be as efficient as possible, to allow reliable determination of the target layer in which the proton is produced.
- e) There should also be three target positions for each of the six target layers. The target layers need not move individually but rather as a unit. To allow for this movement and for the target thickness, a space of 6.3 mm between detector layers was chosen. Target layers 3.2 mm thick have been used and there is sufficient clearance for 4.8 mm thick layers.

These considerations led to the construction of the six sided gas box shown in Fig. 2. As indicated in the side and rear views, the gas box is designed with an upper and lower gas-seal flange, entrance kapton window and side-view acrylic

windows.

The seven detector layers are mounted on the upper plate and lowered into the gas box. This upper plate contains eight hermetically sealed SHV sockets to allow high voltage to be applied to each detector layer separately. This is useful since the 'loss' of one detector layer is less critical than in most detector applications. It results in a poorer energy loss correction for two of the target layers, which may still be preferable to halting the experiment even for a short period of time. The upper plate also contains eight 34 pin headers, with 8 signal outputs each. Ribbon cables and 34 socket connectors provide for an output connection from the detector layers to the plate and from the plate to 16 channel discriminator boards. The detector layers are separate, identical, and positioned using brackets attached to the plate. This allows for layers to be quickly removed and replaced, should any problem develop with a particular layer. A complete upper plate and detector assembly is kept ready as a spare. The target assembly is mounted on the lower plate and is designed to be raised into the gas box. The target layers are supported by 1.6 mm thick by 18.7 cm diameter G10 target discs, which rotate on a common shaft and provide three target positions for each layer. The apertures in these target discs are 58 mm(Hor) by 62 mm(Ver) when in position. A motor and position switch assembly are mounted on the outside of the lower plate, the movement being transferred into the gas box via a rotating seal. Inside the gas box, worm and spur gears transfer the motion into a target shaft rotation. Since the gear motion is always in one direction, backlash is not a problem. The assembly is designed for quick removal of the target discs from the axle, to which they are keyed. A spare set of target discs allows for the advance preparation of an alternate set of targets ready for use.

Since the target assembly and the detector assembly interleave, there is the danger of causing damage when inserting either assembly when the other is already present. For this reason both the upper and lower flanges contain three dowel pins, which guide the insertion and removal of the assemblies during the interaction distance. Inspection of the interleave region through the side-view acrylic windows

is useful for assembly and check of clearances during a test of target rotation.

3. Detector Layer Construction

The detector assembly consists of seven MWPC's, Y_v (the gas veto) and Ya through Yf. These detector layers consist of one wire plane (wires vertical) and two cathode foils as described in Table 1. The wire plane consists of alternating anode and cathode wires with a drift distance of 2.5 mm. The cathode planes are 6.25 μ m thick aluminized mylar spaced 3.18 mm from the wire plane.

These wire planes were previously developed for the front end chambers (FEC0 and FECM) and have an 8.0 x 8.0 cm active area, with 16 active anodes. However in this application, less than 4.0 cm is required in the horizontal direction. For this reason only the center eight active wires are read out. Since the remaining eight wires are active but not read out, it was decided to suppress the avalanche process in these areas to reduce the possibility of detector breakdown. This is achieved by masking the unwanted areas with an insulating kapton foil (25 μ m thick) between the wire plane and each of the cathode foils. This masking technique is very reliable; however, the cutoff edge is not sharp. The edge region is of width comparable to the 3.18 mm wire-plane to cathode-plane distance.

The electronic readout for these MWPC's is shown in Fig. 3. This consists of diode-protected single-transistor preamp circuits within 1 cm of the wire pads, these amplify and drive the signals to passive filter boards and LeCroy 7791 16-channel discriminator boards 60 cm away. The preamp circuits have a typical β value of 100. The signals from the discriminators are processed in LeCroy 4291B 32-channel TDCs. Unfortunately these TDC channels are at present operated in common-stop mode and have an effective dead-time of approximately 200 nsec per pulse, which causes a considerable electronic inefficiency at high count rate (see Section 5). In the future the 64 channels from the target box will be delayed by the time required to establish a probable event in the MRS (approx. 350 ns). With the TDC's operated in common-start mode, a pulse-pair resolution of approx. 20 ns should result. Alternatively a pattern unit (such as the LeCroy 2341A) could

be used instead of the TDC's, since spatial resolution better than the anode wire spacing (5 mm) has not been required from the target box.

4. Instrumental Background

The material of the detector layers, including the gases, will cause an instrumental (n,p) background which can only be removed by subtraction of a target-empty spectrum. To minimize this problem the detector thickness must be as small as possible, especially for materials such as hydrogen which have a large (n,p) cross-section (see Table 2).

Figure 4 shows the spectra from an empty target cell using two different gas mixtures. These spectra are normalized to the same total flux of 290 MeV neutrons. The upper spectrum was at a scattering angle of 0 degrees while the lower was taken at 2.5 degrees. In the latter spectrum kinematics causes the hydrogen peak to be seen at a small -Q value and broadened slightly.

The most troublesome background comes from hydrogen ($Q=0$ Mev), not only because of its large cross-section but because the kinematics of the H(n,p) reaction are such that this background peak moves and contaminates more negative Q value regions of the target (n,p) spectrum as the scattering angle increases. Using a gas mixture without hydrogen (mix. 4 say) allowed a reduction in the total amount of hydrogen present by a factor of five. The future use of 1.6 μ m thick cathode foils (with mix.4) will reduce the detector layer thickness by 32.5 percent from 3.84 mg/cm² to 2.59 mg/cm² and the total hydrogen contribution by a further 72 percent from 72.8 μ g/cm² to 20.7 μ g/cm². The Carbon-12 ground state is also observed at $Q=-12.6$ Mev. The change from mix.1 to mix.4 reduced the amount of carbon by a factor of two and the use of the thinner foils will further reduce the carbon contribution by 70 percent from 1.19 mg/cm² to 358 μ g/cm². It is anticipated that the hydrogen and carbon contamination peaks should then be as low as the general instrumental (n,p) background due to the other detector layer materials: oxygen, argon and the wire materials. At some point this background will limit measurable cross-sections, as Fig. 4 indicates this will be at the level of one (μ b/sr-

MeV)*(mole/cm³) per target layer. These units indicate the relative importance of the instrumental background to a target layer with X mole/cm³ and an (n,p) cross-section of Y μ b/sr*MeV.

5. Inefficiency

Knowing the target layer in which the proton is produced allows one to correct for the energy losses that the proton suffers in successive target layers. An inefficiency in the first detector layer through which the proton passes causes an incorrect energy loss assignment. This problem is more serious for a target stack of several materials. Then such an inefficiency leads to a wrong assignment of target material. For this reason a detector layer efficiency of 99 percent or better is desirable.

A variety of gas mixtures have been tested and their drift-time structures observed (see Fig. 5). A 50% Argon/50% Isobutane mixture was used in the initial facility tests and gave a good time structure without a substantial tail. However, mixtures with isobutane were excluded from later runs due to their hydrogen content. Argon/CO₂ mixtures were also tested. It was found that the drift structure improved as the percentage of carbon-dioxide was reduced from 56 to 20 and finally to 10 percent. These results indicate that the tails are probably caused by the poor drift field region (and associated low drift velocity) near the cathode wires, since the fall-off in drift velocity is known to occur at a progressively lower drift field as the percentage of CO₂ is reduced [3]. At present the (n,p) target box is operated with gas mixture 4 which consists of 89.2% Argon/10% CO₂/0.8% Isopropyl Alcohol. At standard temperature and pressure the operating voltage is 1175 volts.

With a Full Width Tenth Maximum (FWTM) to the drift structure of approximately 70 ns, the average pulse-pair resolution for a detector wire is 35 ns. This implies that a detector inefficiency of 1% would occur at a detector wire rate of 143 kHz (1.1 MHz per detector layer). To date these detectors have been used in conjunction with 4291B TDC's (see Section 3) but the pulse-pair resolution in each of these timing channels is approximately 200 ns (in common-stop mode), making them unsuitable for high rates. The observed variation of efficiency with count rate

is shown in Table 3 and is consistent with a resolving time of 180 ns plus a low rate residual of 0.6%. This suggests a chamber efficiency of approx. 99.4%.

Future (n,p) facility tests will try to address this problem. Other gas mixtures having a higher drift velocity and yet containing no hydrogen will be investigated. These include Helium/CO₂ and CF₄/CO₂. Helium mixtures have the advantage that they could also substantially decrease the detector layer thickness (see Table 2) and the instrumental background. With a higher drift velocity these chambers could have a pulse-pair resolution of less than 20 ns, without using the alternative of reducing the wire spacing and correspondingly increasing the number of output channels. When used in conjunction with a pattern unit readout having a similar pulse-pair resolution (see Section 3) a detector wire rate of 250 KHz (2MHz per detector layer) should be possible for a 1% detector inefficiency.

6. Target Options

The accumulation of (n,p) data from six target layers and three target positions allows several possibilities. The basic idea of course is to use a full stack of the target of interest to obtain the maximum statistics. However for some separated isotopes obtaining about 22 grams (five targets of area 6 x 3 cm and say 250 mg/cm² thick) may be difficult or prohibitively expensive. Thus on occasion a stack will not be full. Other target materials can then be added without problem, since the facility is not event rate limited and the added targets do not change the various detector singles rates. While the target layer identification allows for an average energy loss correction, the energy straggling problem remains. Thus energy resolution improves slightly for the more downstream targets, indicating auxiliary targets should be upstream. On the other hand the small detector inefficiencies cause some target layer misidentification, primarily to the next target position downstream. This could be a problem if a very small cross-section target is placed just downstream from a target with large cross-section. This implies that to avoid any 'contamination' of the spectra of the main target material, extra targets should be positioned downstream. The choice depends on the particular isotopes and on the importance of energy

resolution.

Another target option is the inclusion of a 'known' target within a stack (i.e. producing (n,p) transitions of known cross-section), for the simultaneous accumulation of a normalization spectrum. A normalization run with an entire stack of the 'known' target is also common, particularly for angles larger than 15 degrees. At 30 degrees parts of the neutron flux are passing through considerable amounts of material before striking the targets, as shown in Fig. 2 (top view). This will cause an attenuation of the neutron flux. Such an attenuation could be calculated for each area of each of the target layers, however it is simpler and probably more reliable to have a normalization run with the known stack for each angle. Thus a comparison between target layers in the 'known' stack is used to correct for relative differences in neutron flux. This technique of using a 'known' target layer and a 'known' target stack gives reliable normalization, without relying on good beam integration and the uncertainty of what percentage of the dispersed proton beam is striking the ^7Li strip target (Tpn). At present CH_2 targets are used as the 'known' targets.

In a similar way a stack position can be used to obtain a spectrum of contaminants for later subtraction. This is useful since many (n,p) targets may be used in the form of compounds, especially oxides. Of particular importance is the use of this subtraction technique to obtain the spectral shape of the incident neutron beam. Auxiliary targets of CH_2 and C are used and the $(\text{CH}_2\text{-C})$ spectrum generated. It is necessary to 'unfold' the long tail of this spectrum, associated mainly with the continuum response of ^7Li , from the spectra of interest to obtain the "true" spectra for monochromatic incident neutrons.

It is also possible that the segmented target chamber will be useful in the (p,n) configuration, see Fig. 1. At present this configuration uses a 2 cm thick recoil scintillator (RS), its dual purpose being to convert neutrons to protons for the MRS and to supply an energy loss signal. The recoil protons from the $\text{H}(n,p)$ reaction are only near $Q=0$ MeV, and so it is a clean response. However the carbon present in the scintillator (CH) also produces a recoil proton spectrum from the ^{12}B ground state

($Q=-12.6$ MeV) and excited states. This $\text{C}(n,p)$ spectrum contaminates the $\text{Li}(p,n)$ spectrum at negative Q values, as shown in Fig. 6. The carbon spectrum shown in the upper part of this figure comes from the (n,p) results and is present to indicate the extent of the carbon contamination of an otherwise clean (p,n) response.

The segmented target chamber could be used to replace this scintillator and produce a cleaner (p,n) system response. With the six target layers each consisting of 210 mg/cm^2 thick ^7LiH there is the equivalent hydrogen to 2 cm of CH. The lithium-7 isotope would be best since it has a very low (n,p) cross-section to the Helium-7 ground state [4]. Fig. 7 shows a Lithium-7 spectrum; for comparison a $^{12}\text{C}(n,p)^{12}\text{B}$ spectrum is also shown. These spectra indicate that there would be a factor of 40 improvement over the Carbon-12 ground state, and beyond this, up to an excitation energy of 30 MeV the improvement would typically be a factor of four. Unfortunately the front-to-back proton energy loss in a target layer would contribute 660 keV (at $E=350$ MeV) to the energy resolution. Also there is straggling of the proton energy in the converter layers of approximately 460 keV. This total contribution of 800 keV to the energy resolution is two to three times as large as that of a plastic scintillator. Still, there may well be experiments where reducing the carbon contamination is more important than maintaining good energy resolution, or perhaps thinner LiH layers could be used and the loss of Tpn target efficiency accepted. This option is readily available, requiring only a set of LiH targets (enriched in lithium-7).

7. Data analysis and modifications

A version of the TRIUMF analysis program LISA has been written for the (n,p) facility. In addition to the usual MRS raytracing routines this program specifically raytraces from the two FEC's back through the segmented target chamber. Correspondingly, a hit is acceptable only from the wire closest to the calculated track, for each detector layer. These spatial constraints reduce the problem of target layer misidentification, whereby an incoming neutron converts in one of the target layers but a coincident charged particle triggered one or more of the gas detectors

immediately upstream. Some misidentification is caused by the detector-readout inefficiency of the first detector layer struck by the proton from the (n,p) reaction (see Sections 5 and 6).

A second gas veto detector layer Y_v' has recently been added (not shown in Fig. 1). This second veto wire plane is immediately upstream and staggered with respect to the first (Y_v). Using two wire planes increases the efficiency of the veto and the staggering reduces the spatial resolution from 5 mm to 2.5 mm (using struck-wire information only). This is useful for raytracing events where an incoming neutron converts in one of the target layers but a coincident charged particle triggered the gas veto detectors (Y_v, Y_v'). Unless the two events are spatially close in Y_v-Y_v' , the good event from the target layer is recovered. Since the electronic readout at present includes TDC's, a true interpolated position in the veto (accurate to approx. 0.7 mm FWHM) is available. Data analysis to date suggest that 2.5 mm spatial resolution is sufficient.

The G10 target discs have been modified. Initially with a simple 58 mm (Hor) and 62 mm (Ver) cut-out they now have a considerably larger vertical aperture (see Fig. 1). Since there is no hardware selection of the (n,p) target region, a large percentage of the events written to tape probably involved H(n,p) reactions in the G10 discs or incoming charged particles outside the 6 cm vertical aperture of the veto scintillator (VS). The vertical aperture of the veto scintillator (VS) is to be increased from 6 cm to 9 cm.

8. Operation and conclusions

The segmented target chamber described here is operated with a gas mixture of 89.2% Argon, 10% CO₂ and 0.8% Isopropyl alcohol at 760 Torr and a voltage of 1175 V. Consisting of a sandwich of six target layers between seven detector layers, this (n,p) target chamber has operated extremely reliably in a number of experiments. Although chamber rates as high as 160 KHz per wire (1.3 MHz per detector layer) have been used without problems, the resultant 3.3% dead-time is considered too high and wire rates of 80 KHz are more typical.

As discussed in Section 5, the detector-electronics inefficiency is highly rate dependent and mainly due to the use of common-stop TDC readout. By delaying the target box signals and using common-start TDC's or bit-pattern units the dead time per pulse can be reduced from approximately 200 ns to 20 ns. With such a change in readout electronics count rates per channel of 250 KHz (2 MHz per detector layer) would be expected to cause inefficiencies of approximately one percent.

The instrumental background arising from the target chamber (see Section 4 and Fig. 4) has been reduced to a low level by use of gas mixtures containing little hydrogen, and will be reduced further by using very thin aluminized-mylar cathode foils. This background should then be largely featureless with respect to excitation energy and less than one ($\mu\text{b}/\text{Sr-MeV}^*$)(mole/cm²).

The energy resolution of the (n,p) facility is at present typically 1 MeV on-line, and 925 keV off-line. This arises mainly from beam energy spread and target thickness contributions. A variety of target materials have already been used in the segmented target chamber without difficulty, including 3.18 mm thick carbon-13 powder targets and 2 mm lithium targets.

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Figure Captions

1. TRIUMF charge-exchange spectrometer, showing (p,n) and (n,p) configurations.
2. (n,p) Target Chamber. Top, side and front views showing the six-sided gas box section, and the use of two flange faces. Six target layers and seven detector layers are interleaved.
3. Circuit used to read out the individual wires in the detector layers. The BFR93A transistor, resistor and diode are mounted on the detector layers within 1 cm of the wire pads.
4. Comparison of background spectra with 50% Argon/50% Isobutane and 89.2% Ar/10% CO₂ /0.8% Alcohol gas mixtures in the (n,p) target chamber. These spectra are normalized to the same total flux of 290 MeV neutrons. The upper spectrum was at a scattering angle of 0 degrees while the lower was taken at 2.5 degrees.
5. Drift-time structures for the gas mixtures used.
6. Response of the (p,n) system for neutrons from ⁷Li. A ¹²C(n,p)¹²B spectrum is present to show more clearly the extent of the contribution from the carbon in the recoil scintillator (Tpn). The beam energy was 198 MeV.
7. Comparison of the ¹²C(n,p)¹²B and ⁷Li(n,p)⁷Be spectra at E = 198 MeV. They indicate the advantage of using ⁷LiH over the scintillator (CH) as a neutron-to-proton converter.

Tables

Table 1
Detector layer dimensions

anode wire: 12 um diameter gold-plated tungsten wire
cathode wire: 50 um diameter gold-plated Be-Cu
anode-cathode distance: 2.50 mm
cathode foils: 6.35 um thick aluminized mylar
wire-plane to cathode-plane distance: 3.18 mm
16 active anode wires
full active area: 8.0 x 8.0 cm
reduced active area: approx. 4.0 cm Hor. x 8.0 cm

Table 2
Detector layer thickness

Material	Thickness (μm)	Thickness (mg/cm^2)	Hydrogen ($\mu\text{g}/\text{cm}^2$)	Carbon (mg/cm^2)
aluminized mylar foils	2x6.3	1.67	69.4	1.110
Gas Mixtures	(mm)			
1) 50% Argon / 50% isobutane	12.7	2.62	267	1.285
2) 43.5% Ar / 56% CO_2 / 0.5% Alc*	12.7	2.27	2.1	0.370
3) 79.2% Ar / 20% CO_2 / 0.75% Alc	12.7	2.19	3.2	0.143
4) 89.2% Ar / 10% CO_2 / 0.8% Alc	12.7	2.17	3.4	0.080
5) 89.2% He / 10% CO_2 / 0.8% Alc	12.7	0.454	3.4	0.080

* Isopropyl alcohol

Table 3
Variation of efficiency with count rate

Detector wire rate (kHz)	Inefficiency (%)
41	1.4
87	2.2
158	3.3

Fig. 1

Fig. 2

Fig. 3

Fig. 5

Fig. 4

Fig. 6