Abstract. The first measurements of tensor observables in $\pi\vec{d}$ scattering experiments were performed in the mid-80’s at TRIUMF, and later at SIN/PSI. The full suite of tensor observables accessible in $\pi\vec{d}$ elastic scattering were measured: $T_{20}$, $T_{21}$, and $T_{22}$. The vector analyzing power $iT_{11}$ was also measured. These results led to a better understanding of the three-body theory used to describe this reaction. A direct measurement of the target tensor polarization was also made independent of the usual NMR techniques by exploiting the (nearly) model-independent result for the tensor analyzing power at 90° in the $\pi\vec{d} \rightarrow 2p$ reaction. This method was also used to check efforts to enhance the tensor polarization by RF burning of the NMR spectrum. A brief description of the methods developed to measure and analyze these experiments is provided.

1. Introduction
This article relies on the “Madison convention” [1]. Target vector and tensor polarizations are denoted by $p_z$ and $p_{zz}$ respectively. The tensor polarization of a recoil deuteron from $\pi d$ elastic scattering measured in a double scattering experiment from an unpolarized target using a polarimeter is denoted $t_{20}$. The vector ($iT_{11}$) and tensor analyzing powers ($T_{20}$, $T_{21}$, and $T_{22}$) are the observables measured in a $\pi\vec{d}$ single scattering experiment from a polarized deuteron target (without a polarimeter). The composite observables $\tau_{21}$ and $\tau_{22}$ are defined below.

The starting expression for the tensor analyzing powers is

$$\frac{\sigma_{\text{pol}}}{\sigma_{\text{unpol}}} = (1 + a_{11}iT_{11} + a_{20}T_{20} + a_{21}T_{21} + a_{22}T_{22})$$

where

$$a_{11} = \sqrt{3} p_z \sin(\alpha) \cos(\beta)$$

$$a_{20} = \frac{p_{zz} 3 \cos^2(\alpha) - 1}{2}$$

$$a_{21} = \sqrt{3} p_{zz} \sin(\alpha) \cos(\alpha) \sin(\beta)$$

$$a_{22} = -\frac{\sqrt{3}}{2} p_{zz} \sin^2(\alpha) \cos(2\beta).$$

The Euler angle $\alpha$ describes the angle between the incoming beam axis (z) and the target magnetic field $\vec{B}$. The Euler angle $\beta$ describes the angle between the y-axis ($\vec{k} \times \vec{k}'$) and the...
projection of $\vec{B}$ on the x-y plane. $\sigma_{\text{pol}}$ and $\sigma_{\text{unpol}}$ refer to the scattering cross sections measured with the target polarized or unpolarized.

To measure $T_{20}$, the target magnetic field is aligned along the incident beam axis ($\alpha = 0$, $\beta$ undefined) to eliminate the contributions from the other $T_{ij}$. Then

$$T_{20} = \frac{\sqrt{2}}{p_{zz}} \left[ \frac{\sigma_{\text{pol}}}{\sigma_{\text{unpol}}} - 1 \right]. \quad (6)$$

This was first measured in [2]. More results appeared in [3] and [4].

With $\alpha = 54.7^\circ$ to eliminate $T_{20}$, and $\beta = 90^\circ$ to eliminate $iT_{11}$, an observable is obtained sensitive mostly to $T_{21}$ but with some admixture from $T_{22}$. In practice, due to the split coil geometry of the target magnet, $\alpha$ had to be chosen to be $45^\circ$, which also introduces a small $T_{20}$ admixture. Then the composite observable

$$\tau_{21} \equiv T_{21} + \frac{1}{2} \left[ \frac{T_{20}}{\sqrt{6}} + T_{22} \right] = \frac{2}{\sqrt{3}p_{zz}} \left( \frac{\sigma_{\text{pol}}}{\sigma_{\text{unpol}}} - 1 \right) \quad (7)$$

is used to access $T_{21}$. This was first measured in [5], and later in [3] and [4].

Finally, with $\alpha = 90^\circ$ to eliminate $T_{21}$, and $\beta = 0^\circ$ to maximize $iT_{11}$ and $T_{22}$ (but with some $T_{20}$ admixture), the composite observable

$$\tau_{22} \equiv T_{22} + \frac{T_{20}}{\sqrt{6}} = \frac{2}{\sqrt{3}p_{zz}} \left( \frac{\sigma_{\text{pol}}}{\sigma_{\text{unpol}}} - 1 \right) \quad (8)$$

can be defined. $\tau_{22}$ was first measured in [6]. A measurement of the full suite of observables $T_{20}$, $\tau_{21}$, and $\tau_{22}$ can be used to separate out the individual $T_{ij}$.

2. NMR Measurement of $p_{zz}$

The target tensor polarization $p_{zz}$ can be determined from knowledge of the vector polarization $p_z$ according to the usual expression

$$p_{zz} = 2 - \sqrt{4 - 3p_z^2}, \quad (9)$$

which is easily derived from the Brillouin formula with I=1. Thus the relative uncertainty in the tensor polarization $\Delta p_{zz}/p_{zz}$ is about twice the relative uncertainty in the vector polarization. The vector polarization can be determined either from comparison of the dynamically polarized NMR signal area $A(\text{dyn})$ to the thermal equilibrium NMR signal area $A(\text{TE})$, or from analysis of the NMR peak asymmetry [7]. In the former case, the thermal equilibrium polarization at temperature $T$ and magnetic field $B$ is

$$p_z(\text{TE}) = \frac{4 \tanh x}{3 + \tanh^2 x} \simeq \frac{2 \mu B}{3kT} \quad (10)$$

where $x = (\mu B)/(2kT)$, $\mu = 2.703 \times 10^{-14} \text{ MeV/T}$ is the deuteron magnetic moment, and $k$ is Boltzmann’s constant. For 0.5 K and 2.5 T, $p_z(\text{TE})=0.00105$. Then,

$$p_z(\text{dyn}) = \frac{A(\text{dyn})}{A(\text{TE})} p_z(\text{TE}). \quad (11)$$

In the latter case, with $R = \exp(-\hbar\nu_D)/(kT_S)$ denoting the ratio of the two NMR signal peaks (which are split by the hyperfine interaction of the deuteron quadrupole moment with the electric
field gradients associated with the two different molecular bonds), \( \nu_D \) the deuteron NMR signal frequency (16.6 MHz at 2.5 T), and \( T_S \) the deuteron spin temperature,

\[
p_z = \frac{1 - R^2}{1 + R + R^2}.
\]

To achieve even modest tensor polarizations of 0.20, vector polarizations of 0.50 must be achieved. For the deuterated butanol and propandiol targets used in the \( \pi d \) scattering programs at TRIUMF and SIN, this required migrating from \( ^3 \)He refrigerators with characteristic temperatures of \( \sim 0.5 \)°K to \( ^3 \)He/\( ^4 \)He dilution refrigerators with characteristic temperatures of \( \sim 0.05 \)°K. Values of \( p_z \sim 0.48 \) (\( p_{zz} \sim 0.18 \)) were routinely achieved in [3], [4], and [6].

3. Benchmarking NMR methods

Determining the tensor polarization from the vector polarization assumes the quadrupole moment contribution is negligible, that the distribution of spins can be described by a Boltzmann distribution (the equal spin temperature hypothesis), and that the NMR system used to measure \( p_z \) is linear over a wide range. For the first measurements in the \( \pi d \) program which relied on a tensor polarized target [2], the target tensor polarization determined with the NMR methods described above was verified by direct measurement, using a technique which did not rely at all on NMR signal methods. This was accomplished [8] by recognizing that at a center of mass angle of 90°, the tensor analyzing power \( T_{20} \) in the \( \pi d \rightarrow 2p \) reaction is maximal (\( -\sqrt{2} \)) and that this is a virtually model-independent result. Therefore,

\[
p_{zz} = \frac{\sqrt{2}}{T_{20}} \left( \frac{\sigma_{pol}}{\sigma_{unpol}} - 1 \right),
\]

where obviously the polarized and unpolarized cross sections refer to the measurement of \( \pi d \rightarrow 2p \) at 90° c.m.

\( T_{20} \) in this expression was determined three independent ways. First, use was made of a published measurement of \( A_{yy} \) at 90° in the \( pp \rightarrow \pi d \) reaction [9], which yielded \( A_{yy} = -0.86 \pm 0.04 \) at \( T_p = 447 \) MeV. Then

\[
T_{20} = \sqrt{2} \frac{3A_{yy} - 1}{4} = -1.27 \pm 0.05.
\]

Alternatively, use was made of the results of partial-wave analysis. In the limit that \( a_2 \) (which feeds the \( ^1D_2 \) partial-wave) dominates, as expected on the (3,3) resonance,

\[
T_{20} = \frac{-\sqrt{2}}{70} \frac{(70 + 25P_2(\cos \theta) + 108P_4(\cos \theta))}{1 + P_2(\cos \theta)} = -\sqrt{2} \text{ at } 90^\circ.
\]

Three-body Fadeev equations also provide predictions. Combining all this information together, and accounting for the \( \pm 2.5^\circ \) angular acceptance in the experiment performed to measure \( p_{zz} \), a value of \( T_{20} = -1.28 \pm 0.03 \) was arrived at and used to determine the target tensor polarization \( p_{zz} \) via Eq. 13 with measurements of \( \sigma_{pol} \) and \( \sigma_{unpol} \) in pion absorption at 90° c.m.

The \( \pi d \rightarrow 2p \) measurement was performed [8] at TRIUMF using a 95% deuterated butanol target (\( C_4D_9OD \)) and a non-deuterated butanol target (\( C_4H_9OH \)) for background subtraction. The latter constitutes a perfect background target of the same size (\( \sim 1 \) mm) butanol spheres in the same 16x16x5 mm³ teflon basket immersed in the same \( ^3 \)He/\( ^4 \)He mixture, without the possibility of absorption on the hydrogen that substitutes for the deuterium. The superconducting split-pair solenoid was oriented with the magnetic field along the beam.
Measurement

Figure 1. Summary of RF burning results from [8]. Measurements 1&2 were obtained by direct measurement before burning (see text) using TOF and co-planarity data, respectively. NMR measurements 3 & 4 correspond to the peak ratio (Eq. 12) and area (Eq. 11) methods, respectively. Measurement 5 was estimated in [11] from analysis of the NMR signal after RF burning; no uncertainty was provided. Direct measurements 6 & 7 are the analogs of 1 & 2 after burning. Measurements 6 & 7 were repeated and are shown as measurements 8 & 9. Measurement 10 was also obtained after burning, but at 1.25 T instead of the 2.5 T used for all the other measurements. The weighted mean of all the direct measurements after burning (6–10) is shown as measurement 11.

direction. An opening angle of ±12.5° about 90° between the split-pair coils provided sufficient acceptance for the detection of the reaction products in coincidence. Two arms consisting of a pair of wire chambers and scintillation counters in each arm were used to make the measurement using both time-of-flight and co-planarity information.

The time-of-flight analysis yielded \( p_{zz} = 0.098 \pm 0.024 \) and the co-planarity method yielded \( p_{zz} = 0.100 \pm 0.022 \). This compared well with the more precise NMR information: \( p_{zz} = 0.083 \pm 0.008 \) using the ratio of dynamic and thermal equilibrium NMR signal areas, and \( p_{zz} = 0.095 \pm 0.008 \) using the NMR peak area ratio method of Eq. 12. This measurement established within its uncertainty that the NMR methods are valid for determining the tensor polarization of a target.

3.1. RF Burning

While the benchmarking setup described above was in place, measurements were also performed to study the potential enhancement of the target tensor polarization from RF burning the NMR spectrum. RF burning distorts the NMR signal, and it has been suggested [10] this is the result of dramatic enhancement in tensor polarization. However, it is difficult to know how much enhancement has taken place (if any), or what decay time is associated with the potentially enhanced signal. The only way to quantitatively test this is to avoid reliance on the usual NMR techniques, and instead determine the target polarization using the direct measurement technique described above in Sec. 3.

The NMR signal was burned [11] by applying RF to one pedestal until one peak was completely eliminated. From NMR signal analysis it was estimated that the tensor polarization had been increased by \( \sim 0.05 \), i.e. from \( \sim 0.09 \) before burning to \( \sim 0.14 \) after burning.
Measurements of the $\pi \vec{d} \rightarrow 2p$ reaction were performed as described in Sec. 3 over a period of 18 hours after burning, with the target in frozen spin mode (no $\mu$-waves) at 2.5 T.

The results were disappointing. The TOF technique yielded $p_{zz} = 0.10 \pm 0.017$ and the coplanarity technique yielded $p_{zz} = 0.11 \pm 0.018$, an enhancement relative to the unburned TOF/coplanarity results of only $p_{zz}$ (burned)/$p_{zz}$ (unburned) = 1.08 ± 0.3. Within the rather large uncertainties of the measurement, no significant enhancement from RF burning was observed. Similar results were obtained with a holding field of 1.25 T. Shorter time periods, or higher holding fields were not explored. The results are summarized in Fig. 1. The weighted mean of all five direct measurements performed after burning was 0.106±0.009.

4. Analysis Methods

Equations 6, 7, and 8 were used to determine the tensor observables in $\pi \vec{d}$ elastic scattering. Unpolarized cross sections were measured, as well as polarized cross sections with only one sign of target polarization. Other analysis methods were also explored which produce equivalent results, but probe potential sources of systematic error differently.

One variation was explored in [4] at SIN (now PSI). It consists of going back to Eq. 1 and recasting it in the form

$$\sigma(p_z) = A + BP_z + C p_{zz}$$

(16)

where $A = \sigma^0$, $B = \sigma^0 a_V i T_{11}$, & $C = \sigma^0 a_T T$, and $\sigma^0$ refers to the unpolarized cross section. For the case of $T = T_{20}$, $a_T = 1/\sqrt{2}$. For the case of $T = T_{21}$, $a_T = \sqrt{3}/2$. Several measurements with positive, negative, and zero $p_z$ provide a body of data to fit the coefficients $A$, $B$ and $C$. If $B \neq 0$, then either there is a problem with the measurement of $p_z$ or else the target magnetic field is misaligned with respect to the beam axis ($\alpha \neq 0$).

Another analysis variant was also explored [4] at SIN; a matrix method. Positive and negative vector polarization data were acquired interspersed with unpolarized data, as in the sequence ...,$\sigma^+$),(\(\sigma^+\),\(\sigma^{0+}\)),(\(\sigma^{0+}\),\(\sigma^-\)),(\(\sigma^-\),... Writing

$$\sigma^{\pm} = \sigma^{0\pm}(1 \pm a_V p_z^\pm i T_{11} + a_T p_{zz}^\pm T),$$

(17)

and adding and subtracting, one finds

$$a_T T = \frac{p_z^\mp (\sigma^+ / \sigma^{0+}) + p_z^\pm (\sigma^- / \sigma^{0-}) - (p_z^\pm + p_z^\mp)}{p_z^2 p_{zz}^\pm + p_{zz}^2 p_z^\pm}$$

(18)

and similarly for $a_V i T_{11}$. Then matrices of $a_T T$ can be constructed for each pair, as in $(\sigma^+, \sigma^{0+})$. With N pairs of $(\sigma^+, \sigma^{0+})$ and another N pairs of $(\sigma^-, \sigma^{0-})$, an NxN matrix can be formed whose diagonal elements are the time-ordered pairs. The weighted average of the diagonal elements is the result. Electronic drifts average out. The individual row and column averages provide a measure of the consistency of the data.

5. The Physics of the $\pi \vec{d}$ Experiments

Initially, interest in measuring the $\pi \vec{d}$ tensor analyzing power $T_{20}$ was motivated by an experiment [12] which used an unpolarized target and a $^3$He($d,p$)$^4$He polarimeter to measure the tensor polarization $T_{20}$ of the recoil deuteron in $\pi \vec{d}$ elastic scattering. Large oscillations in the observed angular distribution at an incident energy of 134 MeV were absent at neighboring energies as close as ±15 MeV away. The team which published these results claimed they constituted evidence for a narrow dibaryon resonance (a six-quark state of matter). Similar experiments were performed at LAMPF [13] and at TRIUMF [14] using the same technique (a $^3$He recoil deuteron polarimeter in a double scattering experiment with an unpolarized d target)
but no such evidence was found. The original group from SIN repeated their experiment [15] with a redesigned polarimeter, confirming and strengthening their original conclusions.

Given this impasse on such a potentially important finding, at TRIUMF a program was initiated [2] to measure the tensor analyzing power $T_{20}$ with a tensor polarized target in a single scattering experiment, to avoid the same systematic errors which obviously plagued at least one of the three $t_{20}$ groups employing recoil polarimeters in double scattering experiments. If a tensor polarized target could be used in a single scattering $\pi d$ experiment, the measurements would have much better statistics and would be relatively free of systematic errors, at least free of the same systematic errors which had to be dealt with in the polarimeter experiments.

![Figure 2. Measurements of $\pi d$ elastic scattering observables in the (3,3) resonance region from [3]. The differential cross-sections are from [17] and [18]. The $iT_{11}$ data are from [19], the $T_{20}$ data are from [2] and [3], and the $\tau_{21}$ data are from [5] and [3]. The three-body calculations [20] show the predictions with (solid curves) and without (dashed curves) the $\pi N P_{11}$ contribution.](image)

A simple detector system was built employing scintillation counters for the coincident detection of the pion and recoil deuteron. The system provided a large solid angle (180 msr), and six-fold angle multiplicity. The time-of-flight (TOF) and pulse heights of the pion and deuteron were recorded. The recoil deuteron arms were composed of thin and thick deuteron counters sandwiching an aluminum absorber whose thickness was tailored to range out recoil deuterons, followed by a veto counter. The pion arms were each composed of a two-element scintillation counter telescope. The incident beam was directly counted in a coincidence of two thin in-beam
scintillation counters, and a split counter hodoscope was located downstream of the target. The latter was particularly useful in achieving the crucial alignment of the incident pion momentum with the target magnetic field.

The tensor analyzing power \( T_{20} \) and the recoil deuteron tensor polarization \( t_{20} \) can be related to each other [16] with the Wigner \( d \) functions \( d^k_{ij}(\theta_d) \) according to

\[
t_{20}^{\text{lab}}(\theta_d) = T_{20}^{c.m.}(\theta_d)d_{00}^2(\theta_d) - 2T_{21}^{c.m.}(\theta_d)d_{10}^2(\theta_d) + 2T_{22}^{c.m.}(\theta_d)d_{20}^2(\theta_d).
\] (19)

The rotation accounts for the fact that in the \( t_{20} \) measurements, the z-axis points along the recoil deuteron momentum, but in the \( T_{20} \) measurements, it points along the incident beam direction. A further change from \( t_{20}^{\text{lab}} \) to \( t_{20}^{c.m.} \) admixes in \( T_{21} \) and \( T_{22} \) components, which are small in the relevant angular range. The results of the tensor analyzing power measurements found no dibaryon oscillations in the measured angular distributions, and were consistent with the \( t_{20} \) results from [13] and [14], settling this particular dibaryon issue once and for all.

Comparison of the \( T_{20} \) measurements with 3-body Fadeev calculations showed that our understanding of the results was incomplete, however. To try and shed light on this aspect of the results, measurements of the other two tensor observables in \( \pi d \) scattering were performed. These also showed the puzzling result that calculations performed without the \( P_{11} \pi N \) partial waves described the results better than the calculations which included this term. The effect was especially pronounced in the \( T_{20} \) data, as shown in Fig. 2.

This 3-body problem was finally resolved when Jennings pointed out [21] that some of the diagrams (see Fig. 3) which contribute to this partial wave were not being included in the three-body Fadeev calculations. The nucleon pole (non-pole) terms are diagrams in which the pion is absorbed on and re-emitted from the same (different) nucleon. The non-pole terms are required to satisfy the Pauli principle in the intermediate state. The pole and non-pole contributions are large, of similar magnitude, but opposite sign and thus mostly cancel to give the small \( P_{11} \pi N \) phase shift.

For each of the two pole and two non-pole diagrams, there are differently time-ordered counterparts in which the pion legs are crossed instead of uncrossed. The crossed diagrams are essentially four-body in nature. Although both the crossed and uncrossed pole terms are included naturally as part of the \( P_{11} \pi N \) amplitude, the non-pole terms are not true pion absorption, but multiple scattering. Thus the crossed non-pole terms are not included, and since they are explicitly four-body diagrams cannot be treated by the three-body theory.

Figure 3. Examples of the standard pole (a) and non-pole (b) diagrams for the \( P_{11} \pi N \) partial wave. The corresponding crossed diagrams are shown in (c) and (d), respectively.
Jennings showed however that the omitted non-pole crossed diagrams would essentially cancel the contributions from the non-pole uncrossed diagrams which were included, thus explaining why the calculations without the $P_{11}$ partial wave described the data better than the calculations with (only part of) this partial wave.

6. Summary
The first measurements of tensor observables were obtained in the $\pi d$ system using tensor polarized targets of deuterated butanol and propandiol. After migration to dilution refrigerators, target vector polarizations of $p_{zz} = 0.48$ were routinely obtained, corresponding to tensor polarizations $p_{zz} = 0.18$. In pion beams of only a few MHz, the cooling powers required were typically only 3–4 mW. The polarizing fields were 2.5 T for these measurements, and temperatures of 50-70 mK were typical with the dilution refrigerators.

The impact of RF burning the NMR signal on the target polarization was explored. By definition this technique radically distorts the NMR signal, making polarization measurement problematic via the usual NMR techniques. Therefore, the target polarization after burning was determined without using the NMR signal at all. Instead, the known tensor analyzing power in pion absorption was exploited to measure $p_{zz}$ before and after RF burning. Unfortunately, no significant enhancement of the polarization was observed within the uncertainties after RF burning. The uncertainties were large enough, however, that some degree of enhancement cannot be ruled out. Higher polarizing fields, lower temperatures, and different target materials were not explored in this study, although they may have led to better results. One conclusion from this work is that independent techniques like the direct measurement described above are an absolute necessity to provide realistic target polarizations after RF burning. Reliance on NMR methods alone was confirmed for unburned targets, but is not an option for targets that have been RF burned in an attempt to enhance the polarization.

The measurement of the tensor observables in $\pi d$ elastic scattering completed a program that started by mapping the differential cross section and vector analyzing power over the (3,3) $\pi N$ resonance region. Techniques used to acquire and analyze the results of the tensor analyzing powers were presented. The measurements led to a better understanding of the three-body Faddeev calculations that were compared to the data. In particular the treatment of the $P_{11}$ $\pi N$ partial wave and the role of pion absorption in the theory were better understood as a result of these measurements.

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References
[1] Schwandt P and Haeberli W 1968 Nucl. Phys. A110 585
[2] Smith G R, et al 1986 Phys. Rev. Lett. 57 803
[3] Smith G R, et al 1988 Phys. Rev. C 38 251
[4] Ottermann C R et al 1988 Phys. Rev. C 38 2296
[5] Smith G R et al 1987 Phys. Rev. C 35 2343
[6] Ottermann C R et al 1988 Phys. Rev. C 38 2310
[7] Hamada O et al 1981 Nucl. Instrum. Methods A189 561
[8] Smith G R et al 1987 Nucl. Instrum. Methods A254 263
[9] Aprile-Giboni E et al 1984 Nucl. Phys. A 415 391
[10] De Boer W et al 1974 Phys. Lett. A 46 143
[11] Delheij P, Healey D, and Wait G D, TRIUMF report TRI-PP-86-027
[12] Ulbricht J et al 1982 Phys. Rev. Lett. 48 311; Gruebler W et al 1982 Phys. Rev. Lett. 49 444; König V et al 1983 J. Phys. G 9 L211
[13] Holt R J et al 1979 Phys. Rev. Lett. 43 1229; Holt R J et al 1981 Phys. Rev. Lett. 47 472; Ungricht E et al 1984 Phys. Rev. Lett. 52 333; Ungricht E et al 1985 Phys. Rev. C 31 934
[14] Shin Y M et al 1985 Phys. Rev. Lett. 55 2672
[15] Swiss Institute for Nuclear Research Annual Report No. NL18, 1984 (unpublished).
[16] Grein W and Locher M P 1981 J. Phys. G 7 1355
[17] Gabathuler K et al 1980 Nucl. Phys. A350 253
[18] Ottermann C et al 1985 Phys. Rev. C 32 928
[19] Smith G R et al 1984 Phys. Rev. C 29 2206
[20] Blankleider B and Afnan I R 1981 Phys. Rev. C 24 1572
[21] Jennings B R 1988 Phys. Lett. B 205 187