PROCEEDINGS OF SCIENCE

Use of the HIFROST Dilution Refrigerator for the T_{20} Experiment

Matthew Roberts,[a,*] **Blaine Norum,**[a] **Dustin Keller,**[a] **Robert Pywell,**[b] **Bradley Sawatzky,**[c] **Haoyu Chen,**[a] **Donald Crabb,**[a] **Thomas Krahulik,**[a] **Calvin Howell**[d] **and Mohammad Ahmed**[e]

[a] *University of Virginia, 382 McCormick Road, Charlottesville, VA USA*

[b] *University of Saskatchewan, Saskatoon, Canada*

[c] *Thomas Jefferson National Accelerator Facility, Newport News, VA USA*

[d] *Duke University, Durham, NC USA*

[e] *North Carolina Central University, Durham, NC USA*

E-mail: mjr6mc@virginia.edu

I discussed the importance of the T_{20} quantity, a tensor analyzing power, and the basic experimental setup for a measurement of $\overleftrightarrow{d}$ ($\vec{\gamma}$, n)p, the deuteron photodisintegration. Multiple measurements have suggested the existence of a channel around 9 MeV above two nucleon masses. This diverges from calculations from current nuclear theory, and this experiment will focus on this new channel and yield information on the nature of any discrepancy. This experiment will immediately follow the experiment of the GDH measurement on the deuteron and use a lot of the same equipment. While the target will be polarized in the GDH experiment, the target will have the tensor component enhanced for the T_{20} experiment. I will discuss the status of the experiment, as well as the current status of the dilution refrigerator, and the progress being made.

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*Speaker

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1. Physics Motivations

The deuteron is the simplest nuclear system, but there are still some questions about the deuteron that we have not been able to answer. One such question involves the tensor analyzing powers, which give insight into the spatial orientation of the nucleons and some QCD effects. While some measurements on these analyzing powers have been made, there are currently no measurements below incident photon energies below 40 MeV. The main reason we are looking in this low energy region is to study a discrepancy that was found in the region. One set of data where this discrepancy appears is the work of Nath et al.[1]. While measuring the polarization of photo-neutrons from a deuteron target, they observed a disagreement with Arenhovel's calculations [2] starting at a photon energy of 12 MeV, or an internal energy of about 9 MeV in the nucleon-nucleon system. They noted that contributions to the E_1 amplitude of the deuteron were not exactly known, so they were unable to make any guesses as to what caused the disagreement. Years later, a group at the Moscow Meson

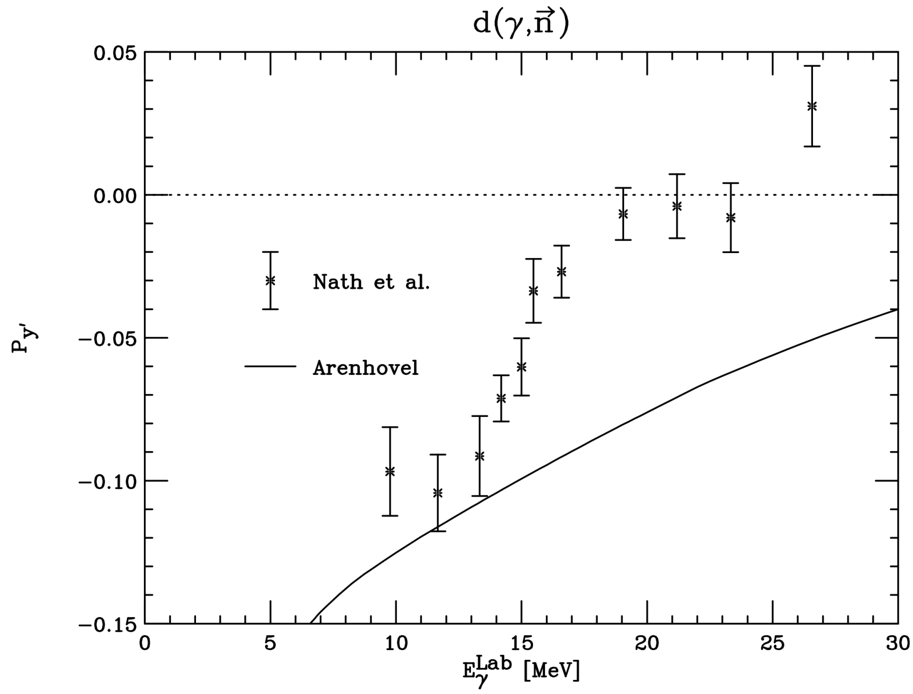

Figure 1: Results from Nath, measuring the polarization of photo-neutrons as a function of the incoming photon energy, along with the theoretical model, highlighting the departure between the two[1].

Facility found spikes in the missing mass graph for the reaction $pd \rightarrow ppX$ in the low energy region [3]. They predicted that a similar phenomenon should occur in the reaction $\gamma d \rightarrow \pi^+ X$, data for which was collected by the LEGS collaboration a few years later[4]. The peaks of the top and middle graphs in Fig. 2 align very closely, which suggests that there is some inelastic channel that creates an unknown intermediate particle that decays into the final products. The graphs in Fig. 2 show the frequency of counts as a function of the missing mass in the reaction (X in the top graph and nn in the middle and bottom graphs). This unknown particle, which we call the D*, has its first peak in the LEGS data around 1887 MeV, or about 9 MeV above the rest mass of two nucleons. This matches the results from Nath et al., especially since the peaks in the LEGS data were present

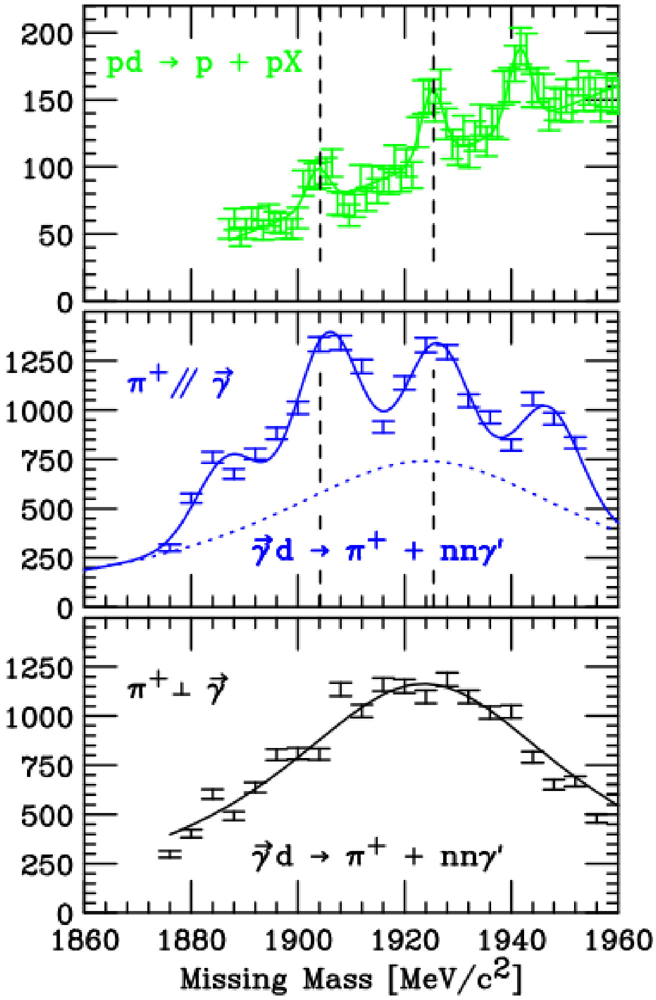

Figure 2: Fil'kov's Results (top)[3] compared to the data collected by the LEGS collaboration (middle and bottom)[4].

in the graph where the π^+ is emitted parallel to the plane of the incident photon's polarization. The magnetic contributions are more suppressed in the parallel configuration, leaving mostly electric contributions. However, the data collected by both Fil'kov and the LEGS collaboration were not sufficient to prove the existence of the D*, and when an experiment tried to replicate Fil'kov's result for the structure at 1905 MeV, it failed to do so [5]. While this is discouraging, we still believe that probing this low energy region is still worth looking into, since we believe that the way they selected events in their data analysis may have supressed the events in question. In addition to the Fil'kov and LEGS papers, a paper by Khrykin et al.[6], also observed similar structures, but with a slightly different nucleon composition. The low energy region below pion threshold will be examined in detail in an upcoming experiment measuring the Gerasimov-Drell-Hearn or GDH integrand of the deuteron [7]. The GDH experiment will use a circularly polarized photon beam ranging from 6-20 MeV, and will be run at the Duke Free Electron Laser Laboratory. Once this experiment is done, we will immediately begin preparations for the T_{20} experiment.

2. Experiment

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\{1 - \sqrt{3/4}P_z sin\theta sin\phi T_{11} \\ + \sqrt{1/2}P_{zz}[(3/2cos^2\theta - 1/2)T_{20} \\ - (\sqrt{3/8}sin2\theta cos\phi T_{21}) \\ + (\sqrt{3/8}sin^2\theta cos2\phi T_{22})]\} \tag{1}$$

In equation 1, we have the equation for the differential cross section of an unpolarized photon hitting a polarized deuteron that depends on the unpolarized cross-section, the vector(P_Z) and tensor (P_{ZZ}) polarizations, the angle between the polarization and direction of the photon(θ), and the angle between the polarization and reaction planes (ϕ). The quantities T_{20}, T_{21}, and T_{22} are different projections of the tensor analyzing powers, but since we are only focusing on T_{20}, the experiment will be set up in a way where the contributions of the other two go to zero. We are looking into T_{20} specifically because the second and fourth order terms are dependent on electric multipoles, which would provide a good look into the discrepancies observed by Fil'kov and at LEGS. Since tensor polarization would enhance the d-state of the deuteron, giving us the chance to understanding short-range QCD effects[8]. This experiment will be performed at the Duke Free Electron Laser Laboratory (DFELL) with about 200 hours of beam time [8]. The beam will consist of circularly polarized photons ranging from 4-20 MeV. Data from the reactions will be collected by the Blowfish detector array, which consists of 88 liquid scintillating detectors placed at regular angular intervals. More details on the Blowfish Detector Array can be read in reference [9]. In addition to the polarized beam, the target material will be tensor polarized through Dynamic Nuclear Polarization or DNP, followed by proton-deuteron cross-polarization in order to fill up the m=0 spin state.

3. Our Dilution Refrigerator

The polarization will be maintained through the use of the High Intensity Gamma Source Frozen Spin Target (HIFROST) system, which consists of a dilution refrigerator to keep the target material cold, and a magnetic coil to help hold the target material polarization in place. A dilution refrigerator uses powerful pumps to cool the helium from 4K to 1K and the enthalpy of mixing of ^{3}He and ^{4}He to achieve temperatures on the order of 25-50 mK. In order to prepare for both the GDH and T_{20} experiments, we regularly practiced using the dilution refrigerator in a "cooldown" to prepare for the actual run. These cooldowns were also a method to optimize the ^{3}He/^{4}He mixture for the lowest temperatures possible, as well as diagnose any problems that may arise. Our dilution refrigerator was originally constructed at CERN in the 1970s [10], then sent it to Germany to be modified for neutron experiments. When it was sent to UVA, we removed the modifications and converted it back into a dilution refrigerator. Our group has had issues with getting this refrigerator ready, but our current problems with it began in late 2017 when a routine leak check found a leak in the still. Due to its location, the leak forced us to remove the entire dilution section of the refrigerator and build a new one. We carefully dissected the unit, and took measurements of the inner pieces as a reference for designing the new unit. While the leak was an extremely frustrating setback, it did give us an answer to a problem that had been plaguing our group for years. Previously, we were unable to get microwaves into our target chamber in order to polarize. While taking apart the unit, we finally discovered why. The waveguide that leads them into the target chamber had broken in half.

A new unit was designed in SolidWorks, and allowed us the opportunity to make this new unit in a way that was more suited for our purposes. First, we wanted to follow the original design as it was used by Niinikoski et al.[10] at CERN as closely as possible given their success with it for their experiment. Once we had the basics of the design made, we made some changes for easier fabrication/welding and some for easier operation of the refrigerator. The first change was with the shape of the pumpout. It was difficult to weld the pumpout in place within our space constraints, and we were unwilling to shrink it at the cost of cooling power. The compromise to this dilemma was to change the shape of its cross-section into a rectangular shape with two round sides.The second was with a bevelled inlet for the ^{3}He line. Since the small tubing used for this line would break if exposed to the heat of a welding torch, the line must be added after the welding is finished. This

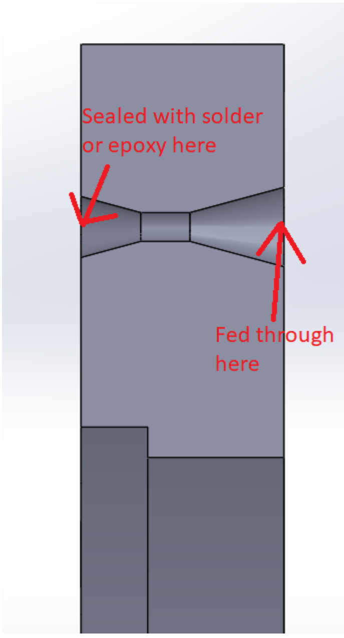

Figure 3: Side view of Bevelled Inlet

design choice makes it easier to thread the line through, and add the epoxy to seal it and keep it in place. Using Figure 3 as a reference, the ^{3}He line would be put inside the still, and using tweezers to hold them, the line would be pushed through the hole to the outside world (which would be on the left side of Figure 3). The funnel shaped holes serve two different purposes for either side of this interface. For the side facing the inside of the still (right side of Figure 3), it is to help locate the hole for us to feed the line through. For the side facing the outside world (left), it is for helping solder/epoxy to pool around the line and form a leak tight seal. The third change was to allow access inside of the still, which would enable us to address any problems with component inside, such as the still heater or the heat exchanger. As opposed to one solid part, the still is now sealed with an indium seal between two mating pieces of stainless steel. The final change was adding temperature

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sensors to the inside of the still as a way to monitor the liquid level inside of it.
With the design changes made we scheduled several trips to Jefferson Lab in Newport News, Virginia to get the parts of the unit welded together. The individual parts and the welding were done in parallel, in order to save time. Once the unit was welded together, we added the electronics and the ^{3}He line. The wires for the electronics traveled from the upstream unit to the still and the target chamber. The wires entered the still through a homemade feedthrough made from torlon and sealed with DP190 epoxy. The ^{3}He line was assembled inside the completed unit using small tubing made of nickel silver and cupronickel. The smaller nickel silver tubing forms a majority of the line, running from the inside of the still to outside the unit, where it mates with the rest of the line that is in the fridge. The slightly larger cupronickel tubing acted as a transition piece for the different sections of the line, which is held together and sealed using solder. The final section of the line is a sintered copper heat exchanger that was reused from the previous refrigerator. After leak checking it, it was attached to the line with solder and leak checked again as a whole. With both of these tasks done, we put the dilution unit into the refrigerator and began leak checking the assembly.

4. The Problem

When we assembled the dilution unit in the refrigerator, we were unable to verify a leak-tight ^{3}He section. We initially believed it was the indium seal being made to seal it, due to seeing the indium consistently spilling out from where it was placed on to the flange, but over time, we began to suspect that there was another explanation. In our leak checking setup, we had a turbopump on one end of the fridge and the leak checker on the other. When we switched their locations, we noticed a non-negligible change in the observed leak rate. It was around this time that we also observed that the central tube, the structure that the heat exchanger is wrapped around, was misaligned and not perfectly perpendicular to the downstream face of the still. We hypothesized that this misalignment had something to do with our observed leak. With this hypothesis, we measured the leak rate in four different configurations, with the leak checker on the upstream and downstream ends of the fridge, and with and without the rope channel present. This rope channel acts as a guide for the helium mixture leaving the target chamber and forms a tight fit between the sleeve and the central tube. When the sleeve forms the indium seal with the rest of the dilution unit, it would force the central tube to be perpendicular with the downstream face of the still.
As shown in Table 1, the observed leak rate was two orders of magnitude higher when the leak

Table 1: The leak rates given here are in mbar/s

		Leak Checker Location	
		Upstream End	Downstream End
Rope Channel Present?	Yes	1.0×10^{-5}	1.0×10^{-7}
	No	2.4×10^{-7}	1.0×10^{-7}

checker was upstream and the rope channel was present. With these results, we believed that there was a leak in the unit, and it was in a location that was connected to the central tube. Since we were unable to find the leak before, we had to design and build an apparatus that would leave the upstream end exposed. In order to do so, we would have to seal off the ^{4}He section and test it. Once it was built, we attached the assembly and began pumping it down. However, we were unable to bring the pressure low enough for leak checking if the pumpout was left open. This definitively proved that there was a leak between the two sections of the fridge, and it was in a spot inaccessible for us to patch. We dissected the unit, and after some discussion, we realized where the most likely location the leak was. Unfortunately, we were not able to confirm this, since this realization came after we

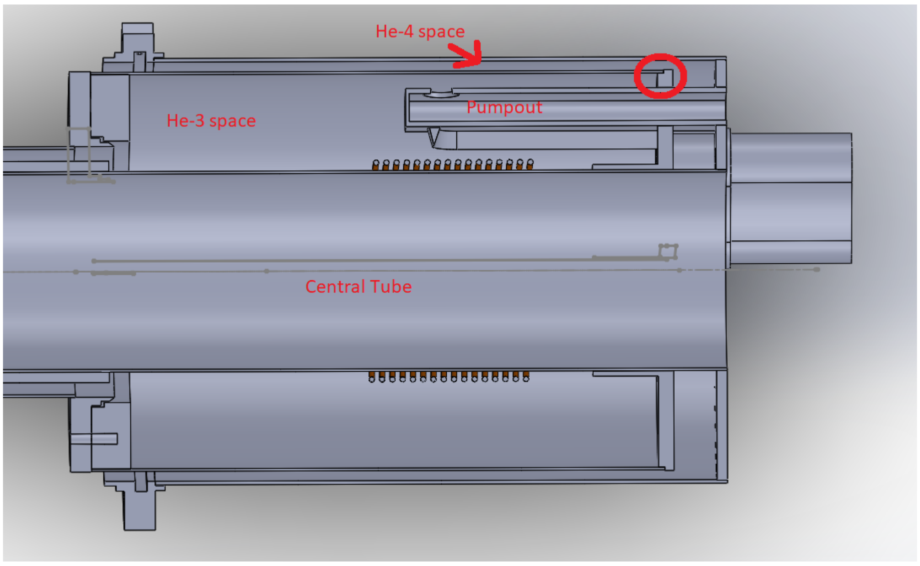

Figure 4: Inside look into the still

took the dilution unit apart, but the leak was most likely on the still can, close to the upstream face, as shown by the circle in Figure 4.

5. Conclusions and Next Steps

We believe that this leak occurred due to the misalignment of the central tube. When the sleeve makes the indium seal with the still, it forced the central tube back into alignment, which created a torque on the still. That torque ripped open the still can, creating the leak. When we thought about how to assemble this unit for the next iteration, we were unsure about how to prevent this from happening. After much consideration, we decided to consult with an outside firm, Meyer manufacturing, and have them build it. We gave them all of our designs, and explained how it functions to them. We will meet with them to answer any questions they have about it, and address any concerns they have about the assembly.

6. Acknowledgements

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