Chapter 1

Polarized $^3$He Target

The polarized $^3$He target is an upgrade of the original Hall A polarized $^3$He target. It also takes advantage of improvements made for the $G_E^n$ experiment, including the hybrid optical pumping.

The upgrade includes:

1. Adding a pair of Helmholtz coils to provide vertical magnetic field;
2. Adding a pair of longitudinal RF coils for adiabatic fast passage (AFP) in vertical direction;
3. A new oven system (similar to the $G_E^n$ oven) to allow higher temperature, a larger pumping chamber size up to 3.5 inches and three directions of optical pumping;
4. A new support structure and an enclosure;
5. A new laser optical system to allow polarization in all three directions;
6. A system enable fast spin-flip and laser polarization rotation (about every 20 minutes);
7. An improved polarimetry system with FM-sweep NMR at both target and pumping chambers.
8. A new compass for vertical field measurement;
9. An extended magnetic shielding to minimize BigBite fringe field at the target location.

The lay out of the target is shown in Fig. 1. Main features and major subsystems will be discussed below.

1.1 Design

To accommodate all four experiments, transversity, $d_2^y$, $A_y$ and $(e, ed)$, we need to have optical pumping in all three directions and leave clearance for scattered particles to reach the HRS and the BigBite spectrometers.
Figure 1.1: Overview of the polarized target layout with the new vertical coils.
1.2. NEW HELMHOLTZ COILS AND RF COILS FOR VERTICAL POLARIZATION

The space constraints and all the upgrades needed for the new experiments make the design a challenge. It was on the critical path when it was estimated (from the $G_n^e$ design experience) three months ago that it would need over 90 person-weeks designing manpower. By minimizing unnecessary changes and taking full advantage of previous experience from both the standard polarized $^3$He target and the $G_n^e$ target, the design has progressed very well. The configurations for all four experiments were laid out. The design has been completed for the following items:

The vertical Helmholtz coil and support structure; the longitudinal RF coils; the new oven system; a temporary support for the oven system in the target lab, target collimator; a replacement support structure for the two pairs of horizontal Helmholtz coils; an extended magnetic shielding on BigBite.

The conceptual design on the laser optics is complete. The conceptual design of the vertical compass has been completed by the Kentucky group. The remain design tasks are The main support structure (including the supports for the driver, collimator, RF coils, reference cell and the enclosure with windows); target ladder and pick-up coils; laser optics lines (including EPR, spectra-analyzer); laser optics line support; personnel access support; safety interlock; Compass mounts. The estimated manpower needed to complete the remaining design tasks is less than 20 person-weeks.

1.2 New Helmholtz coils and RF coils for vertical polarization

The order for the vertical coils was placed jointly from UIUC and from JLab to Walker Scientific about two months ago. It is scheduled to arrive in April. The support with alignment feature is being manufactured and will arrive in late March. The plan is to have it assembled, aligned and tested in the new target lab before it is integrated into the target system. The vertical coils will also be operated to provide 25-32 gauss field. The existing power supply used for the $G_n^e$ magnet will provide enough current/voltage for the new coils.

The new RF coils have been ordered from the same company. The support for the RF coils is yet to be detailed, but the clearance has been checked for all four experiments.

1.3 Fast spin-flip and BigBite fringe field

The fast spin-flip is necessary for single target spin asymmetry experiments (such as the transversity and the $A_y$ experiments). To accomplish this, an RF-sweep with AFP technique is used to flip the target spin every 20 minutes. The pumping laser polarization is also flipped with a rotation of a wave-plate by 90 degrees. All instruments needed are in hand. The technique has been developed and tested in the target lab. Due to AFP loss of polarization, the maximum polarization reached with fast spin-slip will be lower than the regular target without fast spin flip by about an amount of 5 – 10% (relative). In-beam polarized of 50% was reached in $G_n^e$. Even with the reduction from spin-flip, the target polarization should
still be comfortably above 40%, the value used in the proposal. The reduction depends on the AFP loss, the spin-up time and the time interval for spin-flip. The hybrid optical pumping technique increases the spin-up time by about a factor of 2. The AFP loss depends on the field gradients. With this target in the target lab, the average field gradient is less than 10 mg/cm, resulting in AFP loss of 0.3 – 0.5%. In the hall, the fringe field from the BigBite may increase the gradient at the target region. Effort is underway to minimize the fringe field. A wide shielding has been designed, which is expected to reduce the BigBite field by a factor of 2. From Tosca calculations and fringe field mapping (with the narrower shielding), the field gradient due to the fringe field are at the level which will affect the maximum polarization, but not significantly. A mapping is planned after the new shielding is manufactured and installed. If it turns out to be necessary, further improvement can be implemented with an addition of correction coils as an active shielding.

1.4 Target oven and cells

A new target oven (see Fig. 2) has been designed and manufactured. It is being assembled in the target lab for testing. It can accommodate pumping chamber size up to 3.5 inches and temperature up to 300°C. It has optical windows to allow three directions of optical pumping with EPR and spectro-analyzer viewing. Mirrors are mounted on the oven to allow two directions of pumping at any given moments.

The target cells will be similar to the $G^n_e$ cells. The pull-offs will be on the side (see Fig. 3) to not block the laser path. Two different designs were made to accommodate different experimental configurations: one allows for vertical and transverse pumping directions and the other for longitudinal and transverse directions. The pumping chamber size is chosen to be 3-inch sphere. New contracts are in place with Princeton University and the glassblower at Princeton for manufacturing the cells. The William and Mary group (Todd Averett) and UVa group (Gordon Cates) will fill the cells and perform tests on the cells at their target labs. The full characterization and tests will be performed at JLab. The current plan is to produce one cell every two weeks until we have total of 20 cells (10 for each configuration). Cell production has started. Two cells have already been made and testing is underway.

1.5 Lasers and Optics

There are nine 30-watt lasers available at JLab, all have been used in the previous experiments and tests. Two replacement laser diodes are in hands. These lasers should be sufficient for testing and for initial running of the experiment. Two additional lasers will be procured as soon as fund is available to ensure the lasers will last through the whole period of running. User group will be able to provide their lasers as spares if needed. Since the $G^n_e$ experiment, we have gotten rid of the laser hut and used long (75m) optical fibers to transfer laser light from the new laser room next to the counting house into the hall. There are total of eight used long fibers of which three were broken. We have ordered 10 new long fibers for the upcoming experiments. Ten lines will be needed for pumping in two directions. The used
Figure 1.2: Target oven system with target ladder.
Figure 1.3: New cell geometry with a side pull-off.
1.6 Target ladder, driver, reference cell, support, enclosure and access

The target ladder will be similar to the original target ladder with modification to fit the new constraints. The optics target holder will be improved for rigidity in the electron beam environment. The driver will be the same as was used in the $G^m_e$ experiment.

The reference cell system will be the same as in the $G^m_e$ experiment. Three gases will be used: nitrogen, $^3$He and hydrogen. The same gas handling system will be used. The
reference cell support will be designed to have easy access for connecting/ disconnecting. A new enclosure will be designed to keep the laser environment inside and also to keep target in helium environment. Helium will be used as cooling jets to cool the target windows as were done before. The bottom will be a plate to be able to support the target collimator, the pick-up coils and the compass. An access platform will be designed to allow two people to be able to access and work on the target.

1.7 Target polarimetry

Both NMR and EPR will be used. During each spin-flip, an FM sweep NMR will be done parasitically. Because of this, dedicated NMR and EPR will be performed with longer time interval than they were used to be done before. The parasitic NMR requires NMR to be performed in the pumping chamber. New oven design has taken this into account and two pairs of pick-up coils are mounted on the oven window. FM sweep NMR has worked well for 3He cell. It will be calibrated with EPR. EPR has been tested to work reasonably well in the target lab. Further improvement is planned to have better reliability and smaller systematic uncertainty. It can also be calibrated with FM sweep NMR on water cell. The FM water calibration has been demonstrated to work at Kentucky (Wolfgang Korsch), but still to be worked out at JLab.

1.8 Manpower

Designing team: Al Gavalya, Susan Esp.
Installation: Ed Folts and his team.
Students/postdocs: Working in the target lab: first a postdoc (Lingyan Zhu, UIUC) and a student (Huan Yao, Temple), then switched to two students (Chiranjib Dutta, Kentucky, Joe Katich, William and Mary) and one postdoc (Xiaofeng Zhu, Duke), and recently the postdoc departed and a new student (Xiaohui Zhan, MIT) joined the effort.

Students from previous polarized 3He experiments have been providing valuable help.

Physicists: Todd Averett, William and Mary (part time); J. P. Chen, JLab; Wolfgang Korsch, Kentucky, short term visit (2 weeks/semester).

Off-site: cell manufacturing, Todd Averett/Sabine Fachs, William and Mary; Gordon Cates/Al Tobias, UVa.

Responsibilities:

• Overall: J. P. Chen Design: Al Gavalya/J. P. Chen
• Cells: Todd Averett/Gordon Cates
• Vertical coils and holding field: Joe Katich/Todd Averett
• Oven system, ladder, support, cell characterization: Joe Katich
• reference cell system: Todd Averett
1.9 Installation, commissioning and switchover

Installation will need 4-6 weeks (see Ed Folt’s installation timeline). After the target is moved into the hall, preliminary survey will be done first. Then it will be moved to the pivot. Survey the main frame. Install all components. Install the optical line support and platform. Install power and instrumentation cables. Check-out magnets. Measure field directions with survey group help. Install target ladder and target cells (reference and water). Survey target ladder. Install reference cell gas system and cooling jets. NMR water calibration. Laser safety inspection. Switch to $^3$He cell. Laser optics alignment. Polarize $^3$He target. Check out spectro-analyzer. Perform EPR measurement. The target is then ready for beam.

Elastic runs on polarized $^3$He will be taken to have a cross check of polarimetry. Since we have only transverse polarization for transversity experiment, a transverse asymmetry run with about 8-hour will be a first check. Later after switch to $d_2^m$ experiment, will take another 8-hour run in longitudinal configuration.

Switch-over between experiments (transversity to $d_2^m$ or $(e,e')d$ to $A_y$) will take 2 days to change the optics configuration and the target cell. Then we will need to pump up to high polarization. Will need RADCON group support for the switch-over.

1.10 Safety and documentation

Same as the previous experiments, there are a number of safety issues need to be considered, including safeties related to laser, fire, high pressure cell, radiation, hot surface, electrical and magnetic field.

All documents will be updated. Necessary trainings will be arranged. We will work with the JLab safety officers to ensure the proper procedures are in place.