Final Technical Report

The George Washington University

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# Development of Liquid Hydrogen Target and Data Acquisition System for MUSE

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William Briscoe - PI

# Task 1 - Development of LH2 Target

## a Description

Liquid hydrogen targets in vacuum systems are a mature technology, and the MUSE target is a relatively easy target to design, construct and operate, as the beam power deposited in the target is only a few $\mu$W. The target system is somewhat complicated by the physics need for a target ladder that allows the beam to strike either a cryogenic cell, a dummy target for wall backgrounds, a carbon target for positioning, or no target at all – an empty target position – and by the experimental requirement for large, thin vacuum windows. Thus, the MUSE target is an issue in need of appropriate engineering and safety studies. With *one-time* R and D funding and guidance from the Department of Energy, the collaboration has engaged with two independent designers (Walter Fox of Indiana University (IU) and Dany Horovitz, a consultant to Hebrew University of Jerusalem (HUJ)) to produce conceptual designs of the target system. These designers have completed their tasks at the time of this proposal, and the collaboration expects to pick a baseline design in early 2016. Portions of the text below have been extracted from their reports. While both present conceptual design drawings, each emphasized different aspects of their studies and they thought important. In particular IU provided a very nice safety discussion and HUJ provided a detailed discussion of the integrity of the larger-than-ordinary windows.

The cryogenics group at PSI has agreed to review the chosen conceptual design for compliance and safety issues. Funding from this proposal would then be used to generate the construction/engineering design, which would allow components to be purchased and the construction of the target to proceed. The PSI cryogenics group has agreed to assist the GW group in assembling and commissioning the target at PSI, and that PSI will continue to assist the group in the control and operations of the target once it is assembled.

### a.1 Conceptual Design

In MUSE muons and electrons are scattered off of a relatively small, thin wall, cryogenic liquid hydrogen target cell of about 50 $cm^3$ (0.05 L) volume. We discuss here the concept designs we have received and the related configuration and safety concerns of the target, cryogenics, vacuum system and operation at PSI.

#### a.1.1 Target Array

The dominant requirement for the target system, as defined by the physics of the experiment, is that the scattered particles be accepted over the very large solid angle subtended by the detectors. In addition, four target positions are required for the operational LH2 cell, a backup cell used as a dummy target, a carbon foil and an empty position. This implies either a movable internal target ladder inside a fixed vacuum chamber or that the entire chamber is capable of vertical travel while in operation. For a fixed chamber allowing the cold head to travel up and down with the target ladder over the necessary distance of about $18''$ requires a large edge-welded bellows with $5'' - 6''$ inner diameter (ID) with an elastic range from about $6'' - 24''$. Such a bellows expensive, possibly susceptible to damage and squirm. Of the two conceptual designs, one is presented that would have the target ladder move within the fixed scattering chamber and the other would have the entire system moving as a unit.

**Conceptual Designs:** Walter Fox (IU) presented a conceptual design in which the entire target system up and down on external linear rails. This basic configuration is shown in Fig. 3. In this conceptual design, a CH110 cold head from Sumitomo Industries is suggested based on requirements that the cold head likely will have a separate remote drive motor to reduce vibrations. The bottom of the scattering chamber has an ISO 100 bolted flange with a gate valve and small turbo attached. All vacuum lines, He pressure lines, H2 piping and wiring are looped and flexible to allow the chamber to travel up and down while in operating mode. The entire target system can be lifted out under vacuum with the target full and cold, if the turbo valve is closed and the turbo lines disconnected; such an operation will require a highly detailed safety evaluation. No effort has been made to define internal target connections and support or the hydrogen liquefier chamber design. These will follow naturally once the target vessel configuration and operational cold head confirmed.

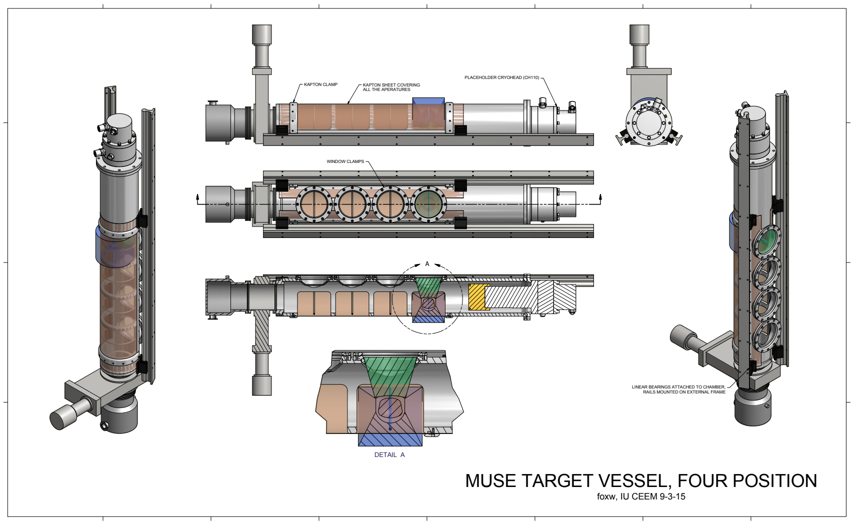


Figure 1: Conceptual design by Walter Fox

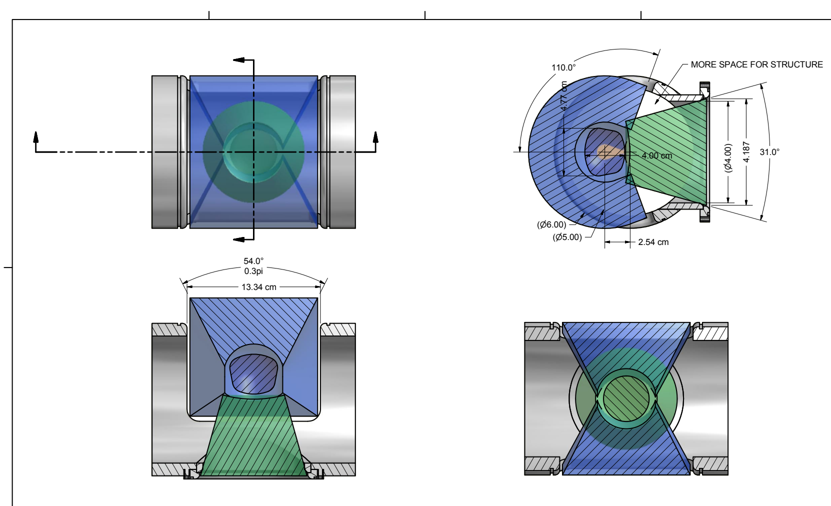


Figure 2: Detail of IU target cell

In the IU conceptual design the target vacuum chamber is tube 6″ outer diameter (OD) x 1/2″ wall with large entrance and exit apertures cut in it (see figure 3). Note the target cell is located 1″ downstream of chamber center to better match the desired apertures. These apertures are covered with thin windows of Kapton of sufficient thickness to withstand external atmospheric pressure. In order to space the target positions as close together as possible it is assumed that a single Kapton sheet will cover all of the downstream apertures and is clamped around the outer perimeter. This will require a sheet $\sim$ 17″ x 29″. This sheet is clamped and sealed around the edges onto an o-ring with segmented straight and curved clamps. Since the Kapton is expected to bow considerably under vacuum there is the option of inserting 3/16″ diameter support rails centered across the aperture to help reduce the intrusion of the Kapton into the target volume. The entrance windows are typical circular clamped Kapton with 5.75″ OD x 4″ aperture. The most concerning fabrication issue is warpage from welding; the apertures need to be cut under size and machined to size after welding. The entrance flanges are short, milled tube sections welded to flat flanges; one could machine these as a single piece and eliminate the weld. The bottom flange is a bolted ISO 100 and the top flange is matched to the selected cold head.

Dany Horovitz (HUJ) presents a conceptual design that allows the targets to move up and down internally, while keeping the vacuum chamber and connected apparatus fixed. This basic configuration is shown in Fig. 6. In his conceptual design, Dany Horovitz is not specific as to drive motor, or vacuum pumps, but the figures show the ports set aside for connections and the cold head and other mechanical components all above the scattering chamber proper. The large bellows and motion system are shown in the drawings. A RDK-500B cold head from Sumitomo Industries is suggested to provide more flexibility in target options.

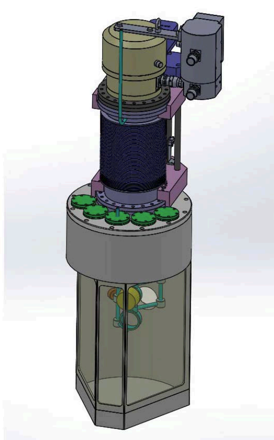

Figure 3: Horovitz Concept

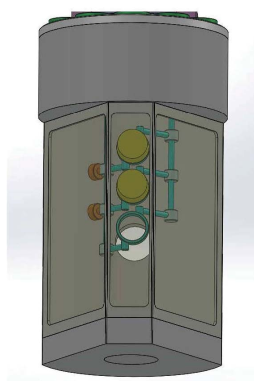

Figure 4: HUJ front view

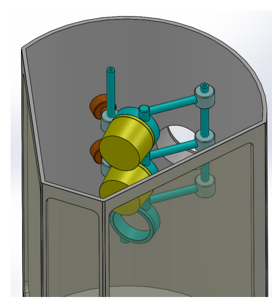

Figure 5: HUJ target ladder

The vacuum chamber is machined in a single piece in order to maximize rigidity and avoid welded and bolted joints, PSI has shown a preference to single piece machining. The support rods and fill tubing are placed to the sides and rear (upstream side) of the target ladder away from the interaction area and in the shadow of the supporting chamber walls, avoiding additional sources of background. All connections are to the top so the bottom of the scattering chamber is continuous with the upright walls.

The windows shown are three flat rectangular pieces of kapton glued to the frames and then pre-stressed under vacuum to its operational deformation. Previous experience at PSI show

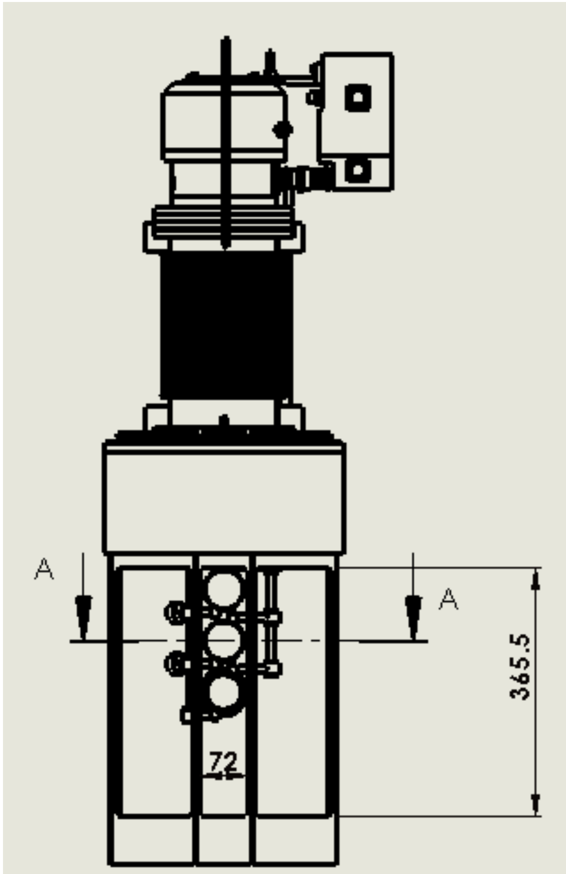


Figure 6: Horovitz upstream view

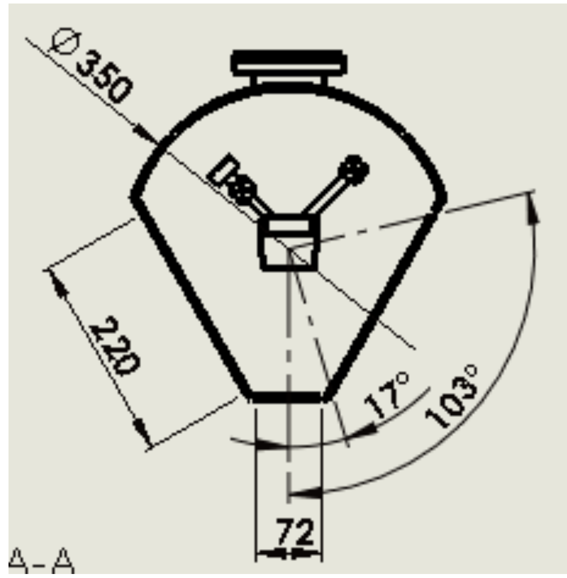


Figure 7: HUJ Bottom view

that the side panels could be made curved to assure more uniform thickness as seen by the scattered particles. A vacuum chamber with 120 $\mu m$ thick curved aluminized kapton windows has been operational at PSI since 1987. (Extra windows could be made as backups.) Window stress analysis studies have been performed by designer Dany Horovitz that show that with a fairly large safety factor 200 $\mu m$ thick kapton windows are acceptable for our set up. (He will repeat these calculation for 120 $\mu m$ thick windows.)

**Vacuum and Gas Handling System** The hydrogen target volume is $\sim 0.15$ L, which corresponds to a volume of liquid H2 (including liquefier) $< 0.6$ L or 600 $cm^3$. For a liquid density of 71g/L this is 42.6g of H2 or 21.3 mols. At STP this amount of gas will occupy about 5.25 $m^3$. If we start with this volume of H2 in a closed rigid container at STP then as the gas liquefies the pressure drops. Too avoid freezing a small pressure difference must be maintained. The IU report suggests that the use of a variable volume for the H2 where a balloon or limp bladder fills and empties with volume change while maintaining the H2 pressure near atmospheric. In addition to limiting the maximum pressure in the target vessel, the vacuum chamber would be designed to withstand target vessel detonation ($\sim 150$ psi). Vented gas would be monitored for hydrogen as the target is warmed up and the internal air is displaced.

The vacuum system includes a roughing pump backing the turbo pump and having valves to rough out chamber and H2 volume. An interlock is in place to prevent pumping the H2 volume if the scattering chamber is not at vacuum (or simultaneously being pumped) to prevent the target cell from collapsing.

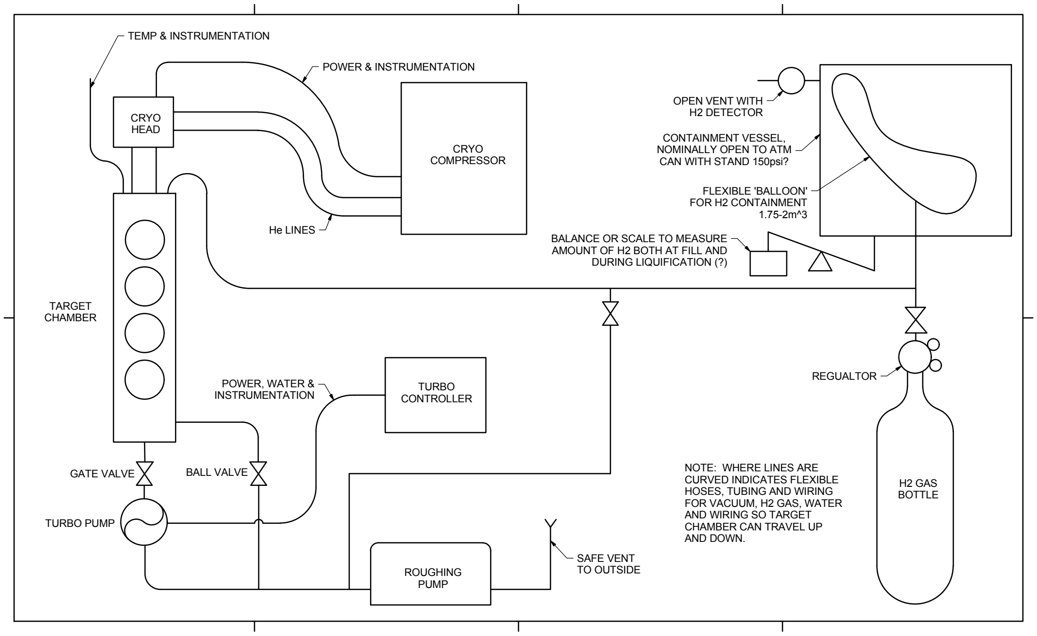


Figure 8: IU Gas Schematic

### a.1.2 Potential Failures and Safety:

Of primary concern is keeping the H2 contained and isolated. In any well-designed, low heat-load system, under normal operating conditions, liquefaction is a fairly slow process and as well as the corresponding warm up and evaporation. Normal, passive warm up would be accomplished by simply turning off the cold head. Thus, a loss of power would not be significantly different from the normal warmup process. Assuming that a reasonable vacuum persists in the absence of pumping, warming due to a power failure should not be catastrophic and the passive H2 volume should fill as in a normal warm up. Assuming that the system remains sealed and intact loss of power should not have serious consequences for the target.

Concerning loss of vacuum, there are two possible scenarios to consider, a slow loss of vacuum due to an accidental venting by an operator or a component failure, or a more sudden of a catastrophic window rupture. The warm up due to a slow loss of vacuum should not cause target rupture; the heat transfer from atmospheric gasses will be mitigated by the freezing out of these gases on the target surfaces forming an insulating barrier. The main concern here is to assure the return line to the H2 volume has sufficiently low flow resistance to keep the target gauge pressure close to atmospheric at the expected maximum boil-off rate. An easy and non-destructive verification test can be performed with an appropriate non-flammable gas. For a more violet event such as a window rupture is it is not clear if the shock wave would be enough to rupture the target cell. A vacuum window rupture followed by a target rupture (or vice versa) is probably the most serious accident to consider as it will result in mixing of the flammable H2 with atmosphere, producing the possibility of flying projectiles and fire. If the target is wrapped in multilayer insulation this shock wave should be significantly mitigated.

Tests should be performed with an appropriate non-flammable gas (*i.e.* Neon) to verify cell and chamber window integrity.

Lastly one should consider the possibility of a target rupture in the vacuum. If the scattering chamber windows remain intact then the consequences may be fairly mild as the boiling H2 is free to expand into the chamber as well as the H2 storage volume while being pumped out by the vacuum system. Considering that the Turbo valve is pressure interlocked to shut to prevent damage there should be more than sufficient volume to allow the expansion to room temperature and still remain below atmospheric pressure inside the system.

Part of the target cell certification requires both calculation and destructive tests of several target cells to establish a failure point and maximum allowable working pressure, above 15 psi with a large safety factor. Traditionally these targets operate at above atmosphere to assure atmospheric gasses do not bleed into the H2 volume, but if the H2 volume can be slaved to atmospheric pressure with a flexible balloon/bladder it would assure target overpressure cannot occur.

Other safety elements will be implemented such as monitoring of vacuum for H2 leaks, gas shielded (N2 or He) H2 lines, H2 atmospheric monitors in the area, use of a vented tent over the target etc. H2 lines and containment volume are designed to withstand detonation ($\sim$ 150 psi) but of course the vacuum windows will not. The possibly of vacuum window rupture is the most serious accident scenario to be examined and mitigated. The level of safety confidence will be defined by PSI; we have been in contact with the PSI target group and will continue to consult with them on these issue.

## Task 2

The Data Acquisition System (DAQ) components purchased by this grant include:

a) 6 TRB3 flexible boards and 80 PADIWA level discriminators to provide timing readout of detectors;
b) 9 Mesytec MQDC 32s; and nine signal convertors to enable charge readout of detectors;
c) Two Wiener VME crates; 2 CAEN PCI interface cards and 3 CAEN crate controllers and the necessary optical fibers to control and read out the crates to house and read out the MQDC 32s.
d) Three GS VUOLM cards to be used for trigger distribution and control interface between TRB3 and VME systems.

These electronics purchases enabled the construction of a local test stand, which was used for DAQ software development, and the read-out of all test detectors which were constructed: including Beam Cherenkov, Straw Tube Trackers, and scattered particle scintillator readout. The tests enabled the decision to switch from CAEN v792 readout to the better quality MQDC32 readout, the development of DAQ synchronization software, and the implementation of TRB3 scalar readout.