DIRC Bar Box Shipping Plan

J. M. Frye[1] and M. R. Shepherd[1]

[1] *Indiana University*

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The GlueX Collaboration is responsible for developing a plan to relocate four "bar boxes" that were used in the BaBar DIRC detector from SLAC to Jefferson Lab. The bar boxes are very fragile, each containing twelve synthetic quartz bars with multiple optical joints. Each of the twelve bars is composed of four smaller segments that are glued together. Any damage to the optical elements inside the boxes would be irreparable. For all practical purposes the value of the equipment is priceless. (Estimated replacement cost of a single box is in the range of 2-3 million USD.) An external review of the transport procedure was conducted on October 14, 2015 at Jefferson Lab. What follows below is a response to comments and recommendations from that review followed by a proposed plan for transporting the bar boxes.

I. RESPONSE TO REVIEWER COMMENTS

Comment: **It may be of value to use an acceptable quartz bar at SLAC and perform a road test to evaluate any damage.**

Response: Performing testing on any single bar is likely to be of minimal value. The most fragile components of the bar box are likely not the bars themselves but the optical epoxy joints that are between bars and between the bars and the window. In addition one really needs to test these joints and their fragility in the same environment that they exist within the bar box. That is they need to be supported and allowed to move in the same way. It is likely that the only suitable "test material" to study how fragile an entire assembly is would be the assembly itself.

There is value in performing an initial test with a single bar box such that should it fail, only one bar box is damaged. While such an outcome would be very unfortunate, it would be better than damaging four bar boxes. If there exists an inferior bar box of marginal quality with the same mechanical properties as the other bar boxes, it would make a suitable candidate for a road test. However, if all bar boxes are of equal "priceless" value, then we think "testing" with a box is not worthwhile and the plan should be to ship the first box alone to Jefferson Lab. Monitoring of the box will be done in transit and the option to return to SLAC after departing, should conditions be unfavorable, exists.

Comment: **The use of helical springs may be of value by eliminating the need to monitor air pressure in the shipping crate dampers.**

Response: Helical springs tend to have a very linear spring rate. The amount of displacement they experience produces a very predictable force response. Air springs, on the other hand, have a flatter initial force response that progressively becomes stronger with displacement. They tend to allow more travel initially while producing an ever increasing force response. This factor allows for air springs to soak up initial displacements without producing as much reaction force, that in turn gets transmitted to the bar box. They "ease in" to the reaction force. Air springs also have some inherent damping qualities that helical springs do not. For these reasons we would like to continue the development of the shipping crate using the air spring system. We envision continuous checking and monitoring of the shipment as a whole in transit by an experienced person traveling with the truck - therefore monitoring should not be problematic.

Comment: **Use of existing studies and specifications to determine expected shock and vibration levels should be investigated.**

Response: We agree that data exist on expected shock for various environments. This is in addition to the data that we have collected directly with the crate. The problem is not anticipating what type of shock we might expect, but instead estimating what a safe shock tolerance is on the bar box. As far as we know, there is no data to reference for this. Specifications that exist often define a level of shock that an item must be capable of withstanding and are geared towards guiding design of shock-resistant objects. This is not helpful in trying to understand what type of shock an existing bar box object may be able to tolerate.

We note overland transit has a repetitive motion with a characteristic ≈ 10 Hz frequency. We see this in our tests and our crate damps this oscillation, but it doesn't eliminate it. It is not obvious how to quantify an acceptable amplitude of this oscillation. To avoid driving fundamental resonances of the bar box, the box is firmly supported in a rigid inner crate.

Comment: **Given the fact that bar boxes are 15 years old, were exposed to radiation, possibly suffering from button friction or deformation, were never designed for a trip across the country, one has to be very cautious. We suggest careful planning and continued testing of the transportation mode for the bar boxes, potentially to include such things as local trips, cross-country trips, and multi-terrain trips, with thought to crate instrumentation.**

Response: We agree that caution is of the utmost importance. This comment also highlights why it is impossible to create a suitable replica for potentially destructive testing. There is no way to mimic the unique properties and history of the bar boxes. See the response to the first comment regarding our thoughts on local trips. More details about the shipping plan are in the next section.

Comment: **Transport testing to date has been done by university collaboration members. Consider enlisting subject matter experts at SLAC and JLab to further develop and test the transport plan.**

Response: We have used and plan to continue to use expertise at SLAC on the details of the bar boxes and have consulted with experts at Jefferson Lab who have shipped fragile cryomodules. We would welcome the advise of anyone with specific expertise on this problem.

Comment: **It would be worthwhile to look for any unusable or incomplete quartz bar (already damaged or dismissed demo) for defining the minimum acceptable shock parameter and the initial trip tests.**

Response: As previously noted, the most fragile aspect of the bar box is likely not the bar itself but the glued assembly of optical elements. Shock testing would only be helpful if one could test the assembly as a whole, but there are no assemblies that are suitable for such potentially destructive testing.

Comment: **It would be wise to exploit as much as possible tools and experience available at SLAC for the movement and installation of the quartz bars.**

Response: We plan to replicate the key features of the tooling used to pick up and orient the bars for installation. Transportation at SLAC from assembly to installation was done in a fashion that seems impossible to easily replicate for large distance scales: large flexible boom with human intervention to steady and damp oscillations.

II. RESPONSE TO REVIEWER RECOMMENDATION

The sole recommendation regarding transport of the bar boxes in the review is: **Continue the development of the transportation plan, enlisting subject-matter-experts wherever possible, to further minimize risk including considerations of both static and dynamic loads.**

As noted above, it is difficult to assess the impact of dynamic loads. To be useful, any dynamic testing needs to involve a mechanically equivalent *assembly* of bars in a bar box. If no assembly exists, then the only suitable true "test" is to, after careful study of all possible risks, try to ship a single bar box cross country. If one of the boxes were clearly inferior to the others in such a way that possibly damaging it would constitute an acceptable loss to gain understanding in tolerance of the assembly, then it would be a candidate for doing preliminary testing by transporting this box locally around the bay area and retesting it. However, in the absence of such an inferior box, any local testing with a single bar box seems to just unnecessarily expose the box to increased handling and time on the road, both of which should be minimized. With this in mind, we suggest the following strategy for shipment.

- Tasks to complete prior to shipping.

    1. Construct a shipping crate, instrument with accelerometers and verify that under actual shipping conditions, *i.e.,* on a tractor trailer on the road, a mock bar box does not experience greater acceleration than the design goal: 3.0 g in the transverse plane (side-to-side and up-and-down) and 1.5 g longitudinally (fore-aft). These limits are based on finite element analysis with static loads and have a safety factor of at least ten. The transverse load is in excess of gravity – the FEA was performed with a 4 g load.

    2. Choose a shipping route. Preference is given to going south in CA and using I-10 as the major east/west route to avoid dramatic elevation changes associated with other transcontinental routes (I-80 or I-70).

        (a) Verify that the road grades combined with typical highway speed along this route do not result in a pressure differential between the inside and outside of the box that would rupture the over-pressure valve that is installed on the bar box. This will require estimates of the gas leakage rate for a typical bar box.

        (b) Verify that Al honeycomb structure is not adversely affected by maximum altitude along the route. This can be done by examining a representative sample of honeycomb material at altitude (in an airplane) or under vacuum. It was noted that, unlike the Al honeycomb structure that is frequently used in aircraft skin, the Al honeycomb used in the BaBar DIRC does not have vent holes to allow for equalization of pressure in the cavities inside the material.

        (c) The idea of driving routes in advance with an instrumented dummy load and trying to select the smoothest highway based on this data was suggested. However, it was concluded that the cost and complexity of doing this likely outweighed the potential benefit.

3. Decide on a method to maintain the dry environment inside each bar box. Continuous flush with an LN_2 dewar seems technically complicated as one needs to transport LN_2 along with the assembly. One may use pressurized N_2 from a bottle, but there is concern about contaminants (oil) that may adhere to and affect the optical surface of the bar. A final proposal is to use a sealed bag filled with N_2. Pressure variations with altitude in transit would cause inflating and deflating of this bag. If it leaks there is the potential to contaminate the gas inside with air or create a pressure differential, *e.g.*, if gas leaks out at higher altitudes but cannot leak back in at sea level. A final decision on the best approach has not yet been reached.
4. Devise a technique for conducting rapid inspection of optical joints in a bar box upon arrival at Jefferson Lab. This could possibly done by examining the properties of reflected light from a laser directed down each bar.

- Proposed shipping procedure.

1. Deliver a single shipping crate and mock bar box to SLAC. This crate should meet the specifications note above.
2. Contract refrigerated, air-ride, single use trailer. Load mock bar box in shipping crate and onto trailer. Drive the trailer on a several hour trip around roughest possible road surfaces near SLAC. Analyze accelerometer data and ensure that acceleration limits have not been exceeded.
3. Load a single bar box into the crate using lifting fixtures developed by SLAC. The box should be oriented with the window facing the rear of the truck such that a hard braking event would not tend to force the bars into the window. It should also be oriented with such the bars rest of fixed buttons.
4. Depart SLAC for JLab along agreed route. A person with technical expertise will accompany the shipment. This could be done in a separate vehicle as a lead or escort to scout out potentially severe problems with the road surface. After 1-2 hours stop and examine all accelerometer data to ensure that design limits above have not been exceeded. If there is strong evidence of an acceleration event that exceeds the design

limits return to SLAC to unload the bar box, evaluate for damage, and reassess the shipping strategy.

5. Continue trip and every 6 hours of driving, check accelerometer data, monitor pressure in air springs, and verify gas environment in each bar box is appropriate. Once some predefined “point of no return” has been reached, the shipment will continue to JLab. Acceleration data will continue to be monitored throughout the shipment as this may inform the shipment of the remaining boxes.

6. Upon arrival at Jefferson Lab, unload bar box and examine for damage to optical joints using a laser to search for reflection at a broken joint in the bar.

7. Store first bar box in designated location in Hall D and continuously purge with boil-off N_2 until ready for installation in the hall.

8. Upon verification of success, fabricate two additional, identical shipping crates and repeat the procedure for the remaining three bar boxes. This time all three boxes will be shipped simultaneously. Pre-shipment testing of crates with truck needs to take into consideration the fact that location of the crate on the trailer may affect the level of shock it is exposed to.

9. Conduct similar quality assurance checks of the remaining three boxes upon arrival at Jefferson Lab to ensure optical joints are intact. Store boxes in Hall D and purge with N_2 as was done with the first box.