**LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY**

*LIGO Laboratory / LIGO Scientific Collaboration*

LIGO- T060039-00 | *ADVANCED LIGO* | 17 Mar 2006

# Caltech controls method for suspending masses

Mark Barton, Tim Hayler, Calum Torrie, Russell Jones, Michael Perreur-Lloyd,
Caroline Cantley, Janeen Romie, Norna Robertson

Distribution of this document:
LIGO Science Collaboration

This is an internal working note
of the LIGO Project.

**California Institute of Technology**
**LIGO Project – MS 18-34**
**1200 E. California Blvd.**
**Pasadena, CA 91125**
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

**Massachusetts Institute of Technology**
**LIGO Project – NW17-161**
**175 Albany St**
**Cambridge, MA 02139**
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

**LIGO Hanford Observatory**
**P.O. Box 1970**
**Mail Stop S9-02**
**Richland WA 99352**
Phone 509-372-8106
Fax 509-372-8137

**LIGO Livingston Observatory**
**P.O. Box 940**
**Livingston, LA 70754**
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

pre01: includes “3 and 1” assembly, LIGO-T050034-03, as an appendix.

# 1 Introduction

## 1.1 Scope

This document summaries the apparatus and methods used to assemble the controls prototype during the period October 2005 to February 2006, covering the various assemblies of the suspension from the dirty and clean builds at Caltech to the installation on the test stand at LASTI. It is written as an instruction manual, and could serve as such if the prototype were ever reassembled from scratch, but it is intended primarily as a historical record. Unless otherwise noted every step described has actually been tried. In a few cases untried but obvious improvements are suggested as a guide to future assembly procedures for the noise prototype.

## 1.2 Version History

"pre03" (actually pre00-20060220) Assorted edits by Mark B. (The LIGO document number T060039 was assigned. Since we're working up to the -00 revision, the "pre03" annotation that was attached is a misnomer.)

"pre04": (actually pre00-20060301) Includes comments and pictures from Calum!

pre00-20060308 – more edits by MB

# 2 Procedure

## 2.1 Lower structure pre-assembly

### 2.1.1 Lower structure pre-assembly tooling

(a) Optic table with ¼-20 threads at 1" pitch, table dimensions 1.75" x 35" x 47"

(b) (Optional) Lazy Susan bearing 10" OD

(c) (Optional) Optics breadboard with ¼-20 threads at 1" pitch, table dimensions 0.5" x 24" x 24"

(d) Short palette allows assemblies to be lifted by fork lift trolley.

(e) Two rails with rollers mounted on the optic table (item (c))

(f) Two carriages to mount each chain of the suspension (lower structure is dog clamped to the carriage).

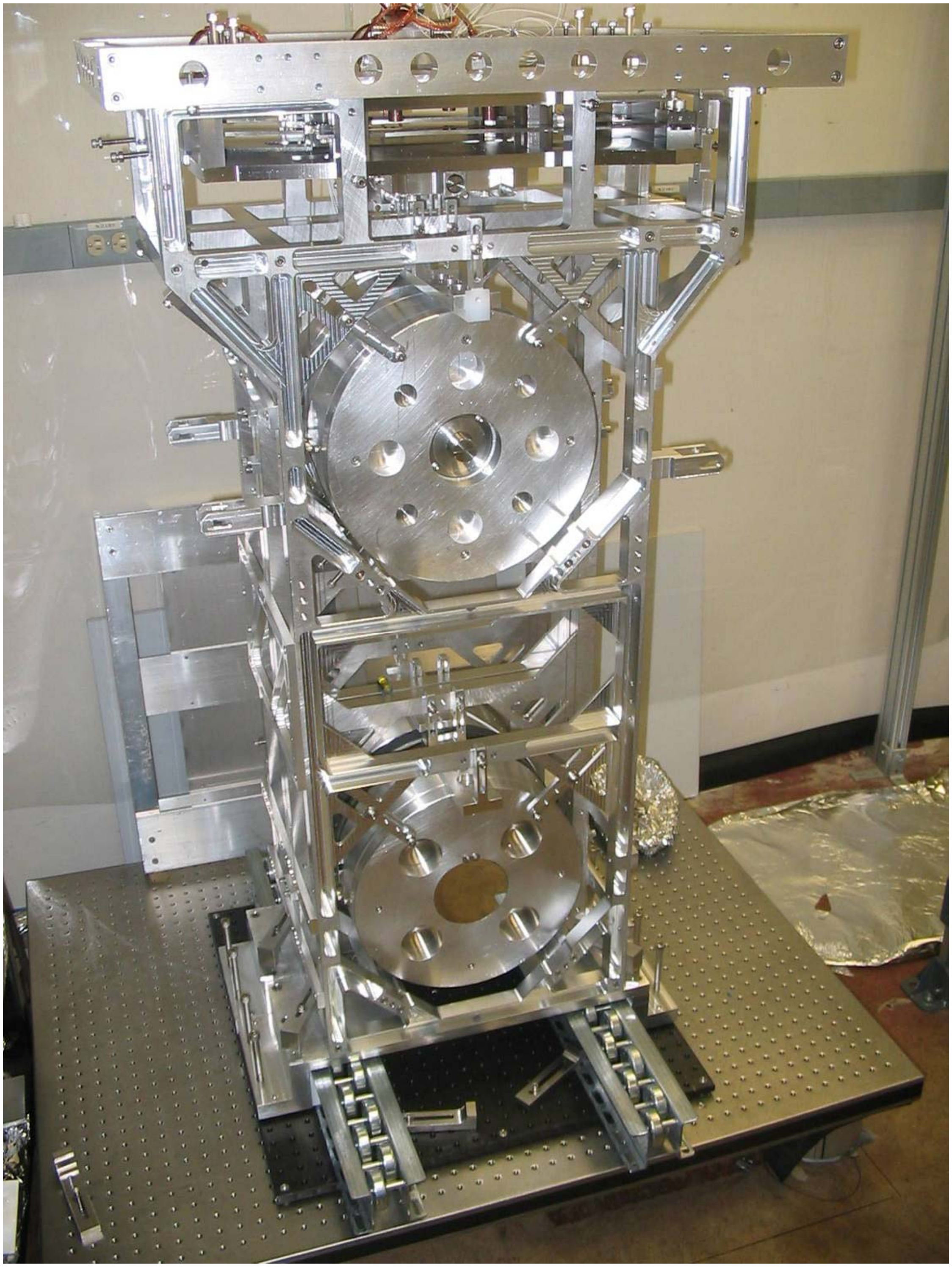


Fig 1. Lower structure on rails. (CT)

### 2.1.2 Set up lower structure

1. Put the Lazy Susan on the optical table and the breadboard on top. For safety, secure the breadboard to the optical table with screws at the centre of the front and back edges until such time as the ability to rotate the breadboard is actually required.
2. Add rollers to the breadboard and secure with dog-clamps.
3. Put the carriages on the rollers.
4. Clamp the structure onto the carriage.

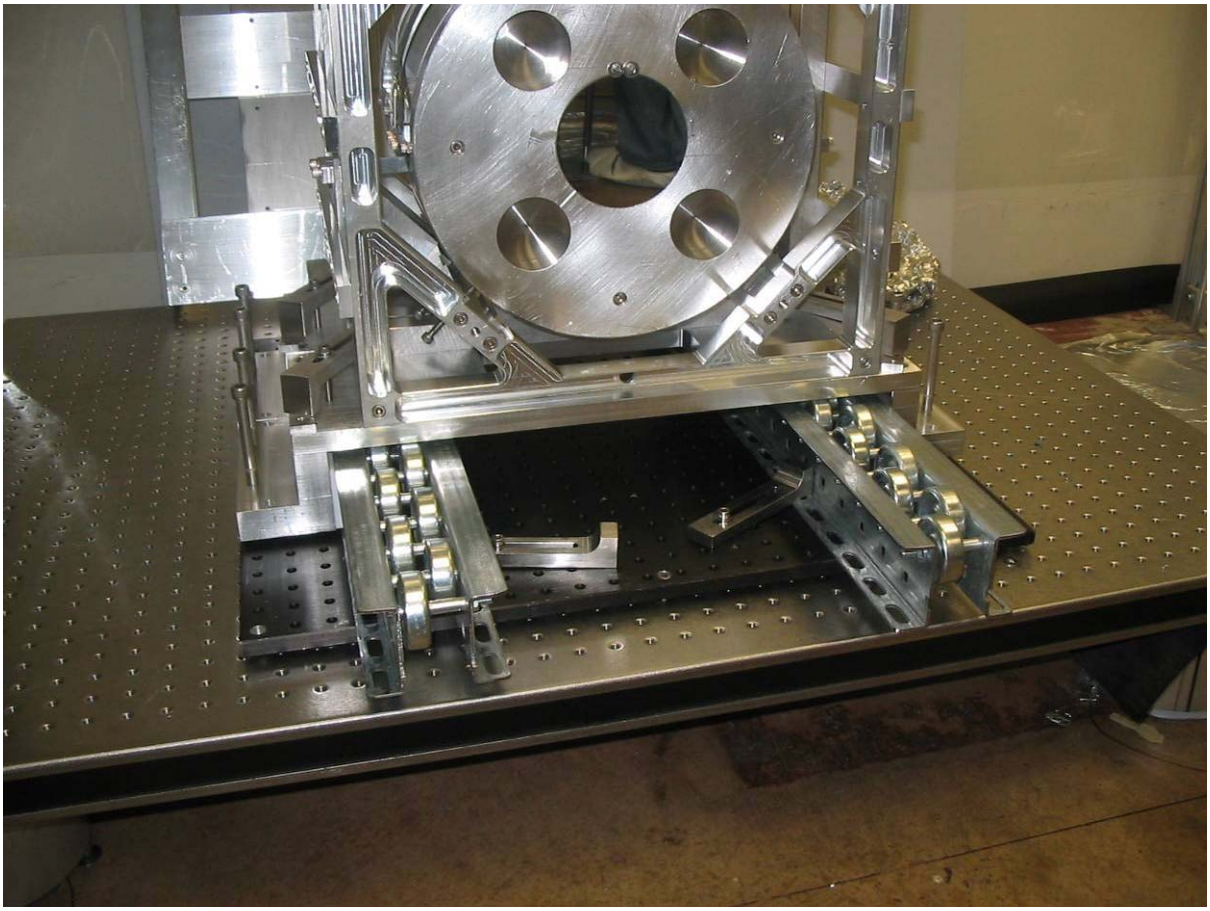


Fig 2. Lower structure clamped by dog clamps onto the carriage. (CT)

5. Raise the carriages off the rollers using the four bolts in the corners of each carriage as feet, and use dog clamps to restrict lateral movement.
6. Install Teflon pads onto the lower structure. Teflon pads make it easier to slide masses into the structure. Make sure the groove in the pads matches the groove in the structure (groove allows penultimate wire loops to pass under the penultimate mass). The pads under the test mass are thicker to give slack in the test mass wires.

### 2.1.3 Install masses

1. Install the upper intermediate (UI) mass of the reaction chain: Place two blocks (3"x 2" x 1") resting on the cross members that span between the face plates. With the help of an assistant, lift the mass up and over the structure, and lower it onto the blocks. Install the F-shaped brackets over the mass and install the bolts that hold the mass up to the brackets. Finally remove the blocks. Attach the UIM OSEMs if they are not already mounted but don't spend any time precisely locating them – only their mass is important in the next few sections. (When repeating this step for the main chain UIM, make sure the magnet assemblies are fully retracted – otherwise there is a risk of them being damaged.) The trim mass unit on the top of the UIM should not be installed yet – it interferes with the connection of the wires from the top mass in Section 2.3.
2. Route the wire loops of a penultimate mass wire assembly into the groove on the penultimate pads and under the central guide bolt. Do not attach the wire clamps it the UI mass blades yet.
3. Install the penultimate mass of the reaction chain on top of the wires. Attach the penultimate mass OSEMs if they are not already mounted but don't spend any time precisely locating them – only their mass is important in the next few sections. (When repeating this step for the main chain penultimate mass, make sure the magnet assemblies are *not* installed – there is too great a risk of them being damaged.)
4. Install the reaction chain test mass. The penultimate mass and test mass should either be installed with ergonomic arm (or for the case of the metal masses, assembled in the structure) so as to reduce the weight the installer has to handle to less than 10 kg!
5. Clock the two bottom masses using the pair of clocking tools. Each clocking tool has two fingers that extend to a preset length. Start with the fingers retracted a few millimetres. Bolt one tool on each side of the structure next to one of the masses, one with the fingers above the vertical center line of the mass and one with the fingers below. Misalign the mass slightly in roll so as to narrow the gaps between the fingers and the flats on the sides of the optic. Then extend the fingers fully so as to push on the flats, rotating the mass back to the properly clocked position. Repeat for the other mass.
6. Use the T shaped fingers to ensure the masses are correctly aligned in x.
7. Fit the test mass wires to the test mass and penultimate mass with their clamps.
8. Connect the penultimate wires to the UI mass: lower the UI mass on its stops using the bolts holding it to the F-shaped brackets. Additional adjustment can be made by pushing the blades down by their stops until they are flat. First connect one side of the penultimate wires to the UI mass by connecting blade wire clamps to blades, making sure the wires are threaded through the test mass wires. Before connecting the second side to the UI mass, again make sure the wires are threaded through the test mass wires, and then trace the wires from one side of the mass to the other making sure the wires do not cross, connect blade

wire clamps to blades. Put tension into the wires so that they enter the grooves in the break off at the penultimate mass.

9. Tension the wires supporting the penultimate mass by backing off the UI blade stops so that the UI blades move up. (If necessary move the UI mass up with stops or lab jack attached to an independent frame.) Partially pull out the Teflon pad under the penultimate mass until the back safety stops are able to replace the pad in supporting the mass, continue removing the pad until the front safety stops are able to support the mass. Now lower the safety stops until the penultimate mass suspends.

Fig 3. Teflon pads and safety stops

10. Suspend the test mass, remove the Teflon pads under the test mass in the same way as in (9) then lower the safety stops until the test mass hangs. Because of the additional weight on the suspension you have to once again lower the penultimate mass stops.
11. Repeat from Step 1 for the second chain

### 2.1.4 Suspend and adjust bottom two masses

1. Check the relative pitch of the penultimate mass and test mass: For each chain, immobilize the penultimate mass by bringing up the stops beneath it. Using a spirit level placed on top, level the penultimate mass in pitch by tweaking the stops. Move the spirit level down and check that the test mass is also level in pitch. In the case of a large error, remake the wires. In the case of a small error, move one of the wires out of its groove as it passes underneath the test mass so as to effectively shorten it. (When repeating this step for the main chain, the trick of moving the wire out of the groove is not available.)
2. Check the relative pitch of the UI and penultimate masses: For each chain, free the penultimate and test masses and immobilize the UI mass, ensuring it is level in pitch and roll. Check that the lower masses are then also level. In the case of a small error, adjust the pitch trim masses on the penultimate mass (NOTE: these are available on the controls prototype but won't be on the main chain of the noise prototype – we should eliminate the need by better control of fabrication or provide an alternative.)

Interjection: what wasn't done at this point but probably should have been was some sort of check on the longitudinal yaw of the lower masses relative to the UIM. The blade spring installation jig for the UIM blades is not very effective, so it's possible for the blade tips to be displaced forwards and backwards so as to produce a significant yaw of the lower masses. For small errors this can be corrected by rotating the wire clamps on the tips of the blades, but larger errors require the blade clamp bolts to be loosened and the blade tips moved. This latter adjustment is not possible with the UIM mass installed in the structure. Thus if the pendulum has to be reassembled from scratch, ideally a better jig will be designed and used. Failing that, or possibly as well, a check here would be desirable. What's mainly needed is a check that, with the UIM level and the lower masses hanging, the wires down from the UIM are centred front-to-back relative to the UIM. This was attempted with a depth gauge but it was difficult to do it accurately because the diagonal sections on the edges of the UIM mean there is no convenient reference opposite the blade tip in two of the four places one would want to measure. What would be good is some sort of simple template that would mate with a feature of the UIM (e.g., one of the holes in the bottom plate through which the wire passes) with a pair of notches through which the wires would pass if they were correctly centered.

### 2.1.5 Preparation for final installation

12. When the suspension is hanging correctly, lock all masses in position via blade stops, safety stops and clamps, there should be some tension in all wires. The UI blades should be in their nominal position.
13. Fit the T shaped pieces between the structures to stop the masses touching.
14. Move both chains together on rollers and fix the chains together using the five cylindrical spacers.
15. Raise the structure via the bolts on the carriage off the rollers.
16. Dog clamp the carriage to prevent it moving.
17. For transport ensure the mass are locked in all directions and the blades tips are held, such that the tension in the wires is reduced. The set of stops that need to be checked are as follows:
    a. PEN. / TEST MASS
        i. Front face 10, 2 and 6pm
        ii. Top, add LIGO number, line contact, see figure 16. (For transport use Teflon between the line contact and the mass.
        iii. 4 stops, 2 at 5pm and 2 at 7pm, reference figure 3
        iv. Between chains, add LIGO number, using T shaped bumpers
    b. UI MASS
        i. Blade stops
        ii. Top and bottom use F piece [insert LIGO number]

iii. Transverse and longitudinal use e-quake stops (in this case stainless steel SHCS with rounded ends and jam nuts)

## 2.2 Upper structure pre-assembly

### 2.2.1 Pre-assembly tooling

(a) Short (Aluminum) palette allows assemblies to be lifted by fork lift trolley (genie).

(b) Optical table / 3 table legs allowing ergonomic assembly!

(c) Fork lift trolley.

(d) Two lab jacks.

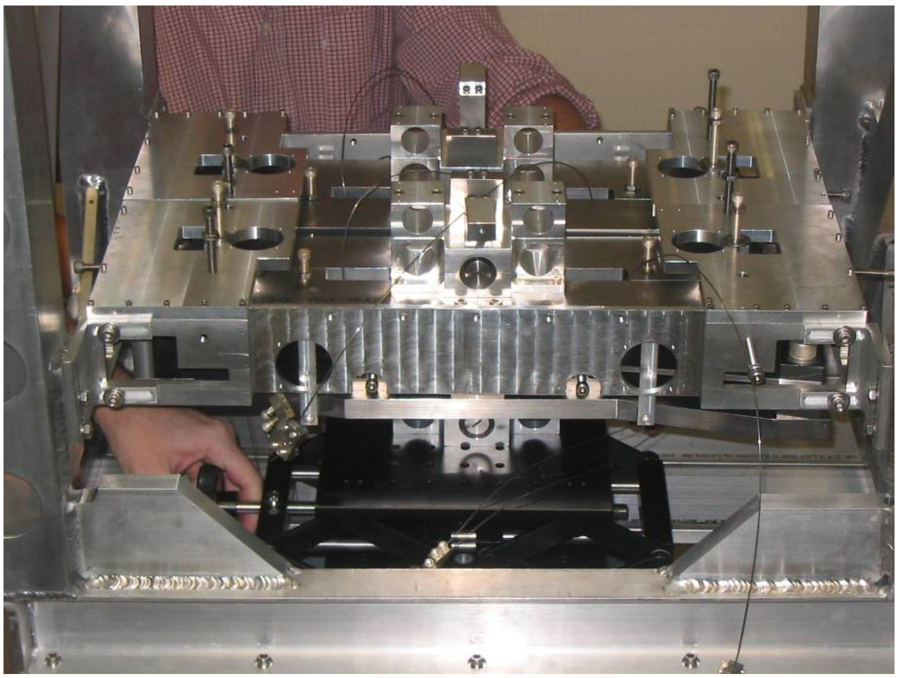


Fig 4. Top masses in the tablecloth

### 2.2.2 Installation of top blades into upper structure

Note: The top blades are supported by the upper structure, their position in the upper structure relative to the seismic table is critical in determining the final position of the optics in the vertical z dimension. For the purposes of setting the position of the top blades in the upper structure, the top surface of the structure becomes a datum representing the seismic table. An interface piece between the structure and the top blades sets their position in the z dimension. However the top surface of the upper structure is not known until all the welding is complete, and the top and bottom surface of the structure have been machined flat and parallel to each other, this makes it necessary for the final machining of the interface piece to be done after the upper structure is complete. The dimension from the tip of the top blade to the top surface of the upper structure (seismic table) is 106mm.

1. Set upper structure on palette.
2. Set interface piece on screws at correct height in upper structure, clearance holes on $3/8^{th}$ screws.
3. Install top blade cartridges.
4. Set top blades flat with the top blade stops.
5. Install tablecloth apart from top plates and hat [reference LIGO drawing number].
6. Set up two lab jacks on the palette cross-member, underneath where the top masses will go.
7. Ensure the local control magnets and eddy current damping units are *not* installed on the top masses.
8. Hold the two top masses together above the tablecloth and lower them at the same time until they rest on the lab jacks. This joint installation is necessary because their geometry is jigsaw-like making it impossible to install them inside the tablecloth boundary individually.

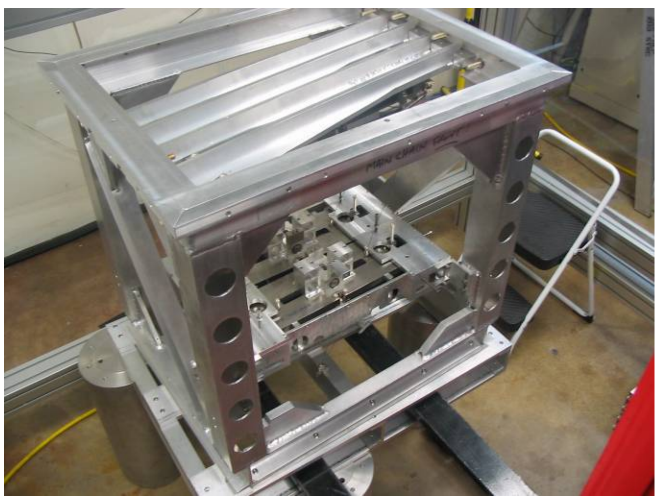


Fig 5. Upper structure with top stage and top mass installed, shown on aluminum palette supported on 3 table legs for ergonomic assembly. (CT)

9. Raise top masses on the lab jacks and connect the top mass wires to the top blades.
10. Lower lab jacks until there is some tension in the wires.
11. Fit the top plates to the tablecloth.
12. For each top mass insert the two large bolts which screw into the mass and hold it up to the tablecloth and the four smaller bolts that screw into the table cloth and hold the mass down away from the table cloth. The stops used here are SHCS with rounded ends and jam nuts.
13. Lock the top mass in position with the stops on the tablecloth so that there is tension in top mass wires. Make sure it is approximately the correct position in Z, symmetrical in X, Y and yaw, and approximately level in pitch and roll.

## 2.3 “3 in 1” Assembly

### 2.3.1 Installation of upper structure

1. Make sure the upper optic table is level in pitch and roll.
2. Raise the upper structure up onto the optic table using the fork lift trolley (genie).

Figure 6: see item 1 bove.

3. Bolt upper structure to optic table with dog clamps, 16, reference LIGO-D050178. (CT)

### 2.3.2 Installation of lower structure

1. Move the pre-assembled lower structure onto the forks of the fork lift trolley and move it underneath the upper structure. (In future iterations of this procedure it will be placed on the the installation tooling - see reference document by Ken Mailand and Calum Torrie TBC.)
2. Raise the lower structure so that there is about a 3/8” gap between the implementation ring and the upper structure.
3. Bolt the implementation ring to the upper structure. Spacers are needed between ring and structure to allow for a short upper structure resulting from greater than expected post-machining to meet the tolerances on the drawings. First insert all bolts and spacers, leaving each bolt loose about two turns so as not to interfere with the insertion of subsequent spacers. Then tighten all bolts.

4. Unbolt lower structure from implementation ring.
5. Raise the lower structure to the uppermost point on the implementation ring range (28mm range).

Figure 7: See item 7 above

6. Use the slack in the UI wires to connect them to the top masses.
7. Slacken the nuts on the bolts holding the top masses up so that there is plenty of scope (≈10 mm) for them to move downwards in the next step.
8. Lower the structure and remove the slack in the UI wires.
9. Structure should now be at the lowest point on the range.
10. Install the trim mass units on top of the two UIMs.

## 2.4 Adjustments on suspended masses

**Reference: Pendulum parameter descriptions and naming convention, LIGO-T040072-01-R**

### 2.4.1 Suspend and check bottom two stages

For both chains:

1. Remove upper stops from test mass and reaction mass.
2. Remove fingers from between test mass and reaction mass.
3. Back off lower stops from test mass and reaction mass until both are suspended.
4. Repeat preceding three steps for penultimate level.
5. Double-check relative pitch of lower three stages as in Section 11.

### 2.4.2 Suspend and adjust pitch of bottom three stages

For each chain:

1. Make sure the top mass is level in pitch and roll using a spirit level.
2. Free the bottom three stages and check the pitch of the UI mass with the spirit level.
3. If the UI mass is pitched, loosen the screws on one of the blade-tip wire clamps for the wires leading down to the penultimate mass and rotate it slightly so as to move the wire attachment point towards the edge of the mass that needs to be pitched down. If necessary, repeat with the other blade-tip wire clamp. (The extra checks suggested in the interjected commentary in Section 2.1.2 are intended to reduce the correction required here to the level where it can be done with small twists of the wire clamps rather than motions of the whole blades.)

### 2.4.3 Adjust pitch of all four stages

The pitch adjustment is done on the top mass by a displacement mechanism acting on the wire clamps, the mechanism is made up of two screws pushing on either side of the clamp about a pivot point, when one screw is released the other screw is free to push the clamp mechanism about the pivot point in the desired direction. The mechanism was designed to be used while the chains were separated; because the chains are hanging together half of the mechanism cannot be accessed. The following is a workaround.

For each chain:

1. Check that the lock screws for the wire clamps on the bottom of the top mass are in the centre of their range. (If not, loosen them, centre them and retighten them.)

Interjection: what is actually desirable here is some sort of check that the attachment points for the wires supporting the top mass are centred front-to-back relative to it. If this can be achieved then getting yaw right in subsequent steps should be straightforward. However it was difficult to do this well for lack of good reference surfaces to use with the depth gauge, so the position of the lock screws in their slots was used as a proxy. As with the UIM, a simple template that keyed with the top mass and had a slot through which the wire would pass when it was correctly centred would be very helpful. For the noise prototype it might well be good to eliminate the adjustment on one side completely. If the wire on one side is centred by design to usual machining tolerances, the other side should come close enough to central during the adjustment for pitch to make yaw right at the same time.

2. Free the bottom three stages.

3. Have an assistant hold the top mass, taking particular care not to let it move too far in pitch.
4. Remove the upper stops on the top mass and back off the others.
5. Loosen the lock screws for the wire clamp on one side.
6. Loosen the pusher screw for the loose wire clamp on your side.
7. Using a screwdriver or the like, lever the loose wire clamp toward you. (The mass will tend to pitch strongly toward you and your assistant should keep it under control.)
8. Tighten the pusher screw gradually until the pitch is corrected.
9. Very carefully tighten the lock screws.
10. Check that the level has not been disturbed. If it has, try repeating from Step 5, aiming off by the amount of any perturbation introduced by the lock screws.

Interjection: If there is no stable point, the correction for wire flexure and blade lateral compliance is probably off. If the instability is small, it can be corrected by adding extra trim mass to the UI mass or the penultimate mass. Adding the trim to the penultimate mass gives approximately twice the correction because it stretches two blade springs at once, but will not be applicable to the noise prototype.

### 2.4.4 Adjust longitudinal position, separation, and yaw

1. Check that the average separation and relative yaw between the chains is approximately the same at the test mass and penultimate mass levels. There can be a substantial yaw at both levels at this point, as long as it's the same. If not, there is probably some gross problem such as a stop not backed off.
2. Check that the average separation and relative yaw between the chains is approximately the same at the penultimate mass and UI levels. If not, try to improve matters by rotating the blade-tip wire clamps on one of the UIMs in opposite directions. If that is not enough, do the same with the other UIM. If that fails, the blades in the UIM may have to be loosened in their clamps and rotated. (Rotating the blades requires reversing the 3-in-1 assembly procedure and removing one or both UIMs from the lower structure!) After any such adjustments the pitch of the bottom three masses in the affected chains will have to be revisited as per Section 2.4.2.
3. Check that the average separation and relative yaw between the chains is approximately the same at the UI mass and top mass levels. If not, try to improve matters by rotating the blade-tip wire clamps on the top mass in opposite directions. If that fails, the blades in the top may have to be loosened in their clamps and rotated. (This can be done by inserting the lock screws to immobilize the mass with respect to the tablecloth, loosening the blade clamp bolts, and pushing on the tip to set the position. Before retightening the clamp bolts, check that the tip has not moved so far as to foul on the adjustment mechanism for the wires from the top blade springs.) After any such adjustments the pitch of all four masses will have to be revisited as per Section 2.4.3.

4. Check the relative yaw of the top two masses. If they are not parallel, first double-check the centring of the adjustable wire clamps on the top mass for the top wires – the lock screws should be centred in their slots. If not, revisit Section 2.4.3.
5. Then, use the top blade adjustment mechanisms to set longitudinal position, separation and yaw of the two top masses (the other masses should then be correct). A useful reference is the magnet attachment points on each end of both top masses, which should be centred horizontally in the circular ports for attachment of side local-control OSEMs. Some people find the "Betsy tool" (a Perspex sheet with holes matching the OSEM attachment holes and a set of crosshairs indicating the centre) to be helpful. The magnet attachment points track the tips of the corresponding top blade springs. Thus, …
6. For each spring:

(a) Loosen the lock screws on either side of the main clamp screws. (Note that this will cause the spring tip and one side of the entire chain to droop and should not be done if any magnets have been installed.)

(b) Loosen either the pusher or puller screw depending on the desired direction of motion. (Note that each blade cartridge pivots about its centre, so the base has to be moved in the direction opposite that desired for the tip.)

(c) Tighten the other screw until the blade has been rotated sufficiently to move the corresponding magnet attachment point into position. (If you run out of range, it may be possible to gain an extra mm or two by loosing the screws attaching the block holding the puller and pusher screws and moving it over.)

(d) Retighten the lock screws.

7. Check the gaps between the pairs of masses: it should be very close to 5 mm on each side at each of the four levels.
8. Adjust the vertical position of the tablecloth at front and back so that the magnet attachment points for the face OSEMs are centred vertically in the OSEM attachment ports. Again the Betsy tool may be helpful. (Horizontal centering is done in the next section.)

### 2.4.5 Adjust vertical height

1. Check that any vertical offset between the penultimate masses is the same as the vertical offset between the UIMs. If not, add or subtract mass from the reaction chain to make them equal. The amount of mass required will be about 500 g per millimetre of differential offset.
2. Do the same check between the top mass level and the UIM level. If the offsets are different, add or subtract trim mass to/from either of the UIMs as convenient. The amount of mass required will be about 300 kg per millimetre.
3. Check that the top masses are at the same height. If not, add or subtract trim mass to/from either of the top masses as convenient. The amount of mass required will be about 300 kg per millimetre.

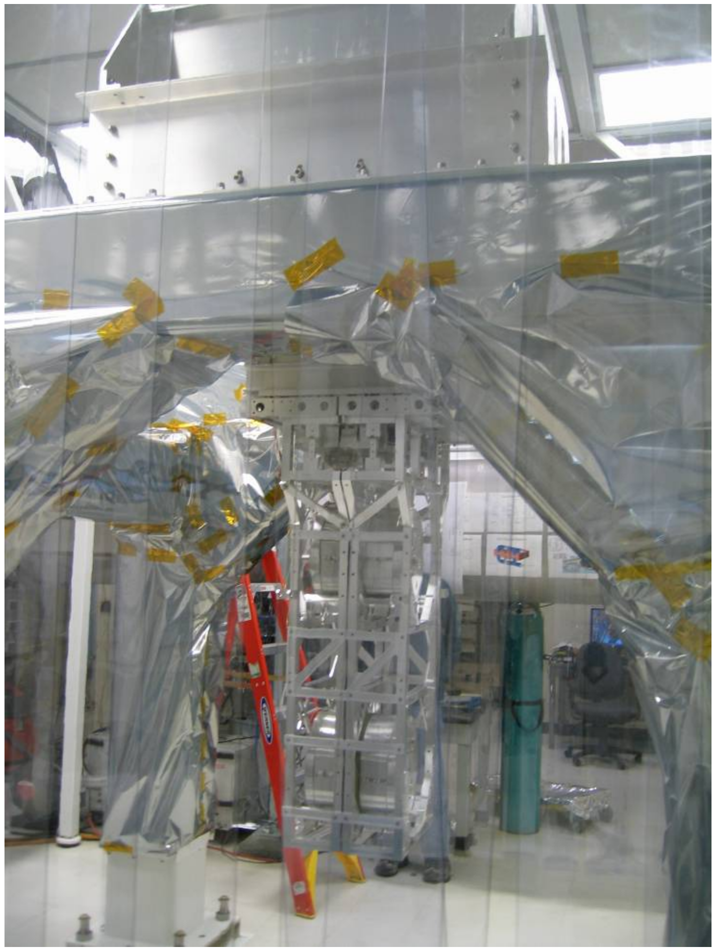


Figure 8: Quad suspended from the LASTI solid stack on the test stand (CT)

### 2.4.6 Adjust transverse position

Ideally a transverse adjustment should not be needed. However if the chains *are* misaligned in transverse (as they were in practice at Caltech) there is no alternative but to move the blade cartridges sideways. Some of the screw holes on the back chain have been slotted to allow this, but if something equally unfathomable happens and a contrary adjustment is required, more slots may have to be opened out, using clean tools.

1. Adjust the transverse position of the tablecloth until the magnet attachment points for the face OSEMs on the main chain top mass are centred horizontally in the OSEM attachment holes.
2. If the magnet attachment points on the reaction chain are not also lined up, measure the discrepancy.
3. Measure the gaps between the ends of the blade cartridges for the reaction chain to the inside of the frame at the top of the upper structure. Add or subtract the discrepancy measured in the previous step as appropriate so as to calculate the size the gaps need to be to bring the reaction chain to the correct position.

4. Loosen the bolts holding the two blade cartridges, and using a large screwdriver or the like, lever on the end of each cartridge until the gaps have been reduced or enlarged to the desired size.
5. Retighten the bolts.

# 3 Recommendations

The recommendation is to have a displacement mechanism on both stages. The top mass mechanism should be modified so that the displacement adjustment can be done entirely from the accessible side of the chain (push and pull mechanism).

The UI mass adjustment is recommended to move from the penultimate wire clamps on the blades of the UI mass to the UI wire clamps, a similar push pull mechanism to the one on the top mass would be ideal. {TH}

ANOTHER WAY TO SAY THIS IS: Adjustment to the tips of the ALL blades OR control of where they are has to be improved! (CT) It should be noted that the method of adjustment at the top blades is not ideal as the blade has to be “loosened” in order to utilize the push / pull mechanism and this in turn causes the suspension to sag which makes overall alignment difficult! (It should also be noted that the threads in the T section of the blade cartridge created problems using the push / pull mechanism!)

In the alignment (at LASTI) it was necessary to adjust the middle blades in situ. This was a result of the blades not being installed properly during the pre-assembly process. This in turn was due to the fact that the tooling did not work! (CT)

The ability to have +/- mass should be added to the design of the UI masses, as it is on the top masses (or equivalent).

## APPENDIX 1 Shipping

We shipped the quad assembled in 2 sections, each mounted on an aluminum pallet. Each ½ of the quad on its pallet were loaded into a crate that was pre-lined with clean "bags". Each quad was double wrapped in foil, as shown. (CT)

It should be noted that for future crates the feet should be tall enough and wide enough to allow a genie / pallet jack to pass underneath!! (CT)

Each stage in the quad was locked down using ¼-40 SHCS with jam and double jam nuts where appropriate. (CT)

Figure 9 and 10: Lower structure and masses fully assembled and prepared for shipping CT)

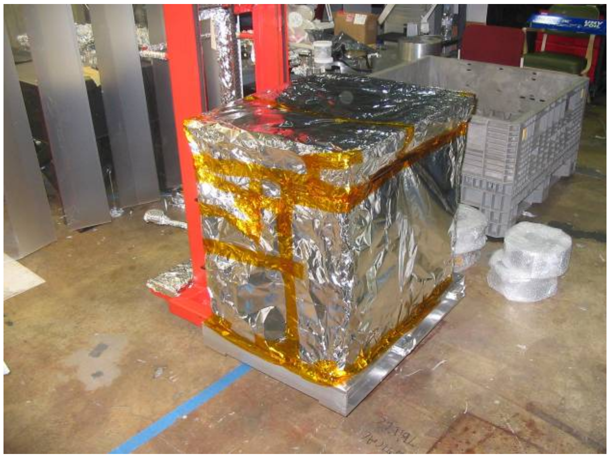


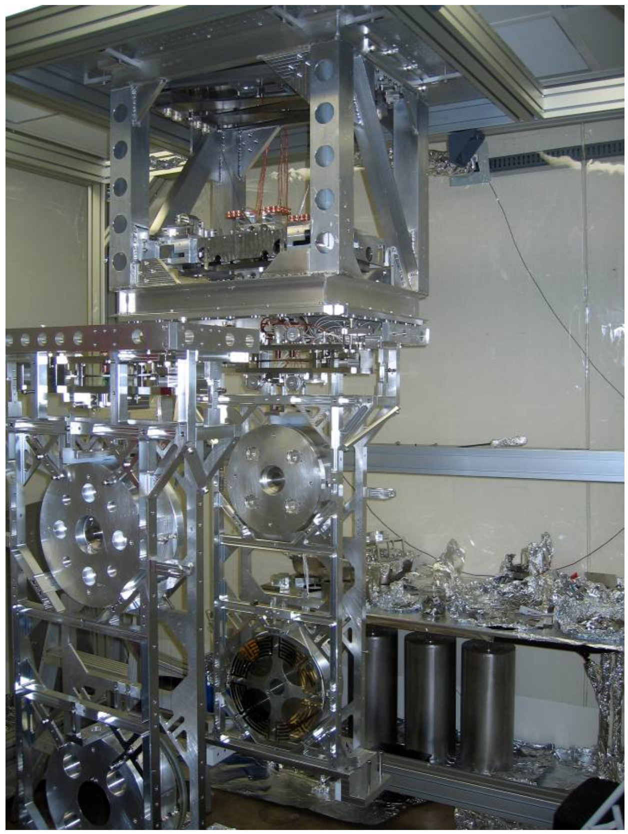

Figure 11 and 12 Upper structure wrapped and prepared for shipping, and its crate. (CT)


Figure 13 and 14: Lower structure moving into its crate and fully wrapped (CT)

## APPENDIX 2 Repair (single chain removal)

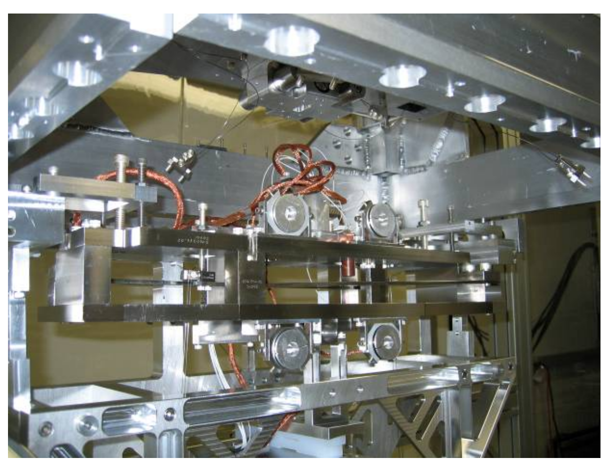
In the process of the assembly of the quad at Caltech and LASTI we had to remove one half of the lower structure for the following repair jobs:

1. re-soldering wires in the ESD at the test mass level.
2. Replacing OSEMS and OSEM brackets at the UI stage (will do this in APRIL!)



15

16



17

# T050034-03-D : ETM Controls Prototype: "3 &1" Assembly Technique plus additional discussion material

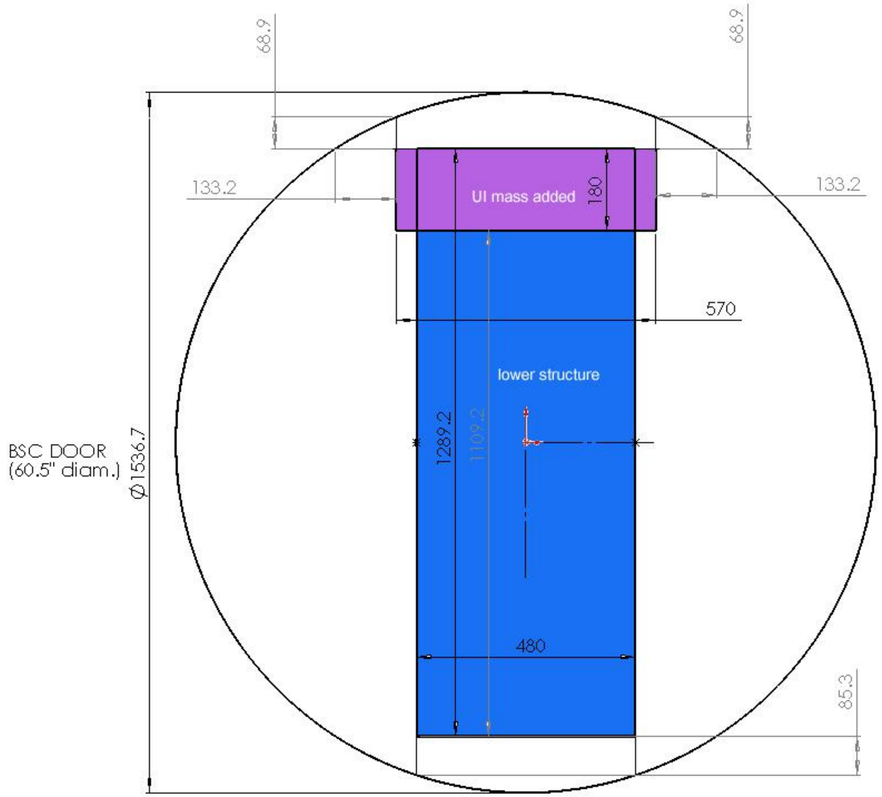
Authors: **R.A. Jones**, **C.I.E. Torrie**, M. Perreur-Lloyd, C.A. Cantley, N. Robertson

Rev 00 : - RAJ, Sept 2004

Rev 01 : - With comments by CIT 14th Sept 2004

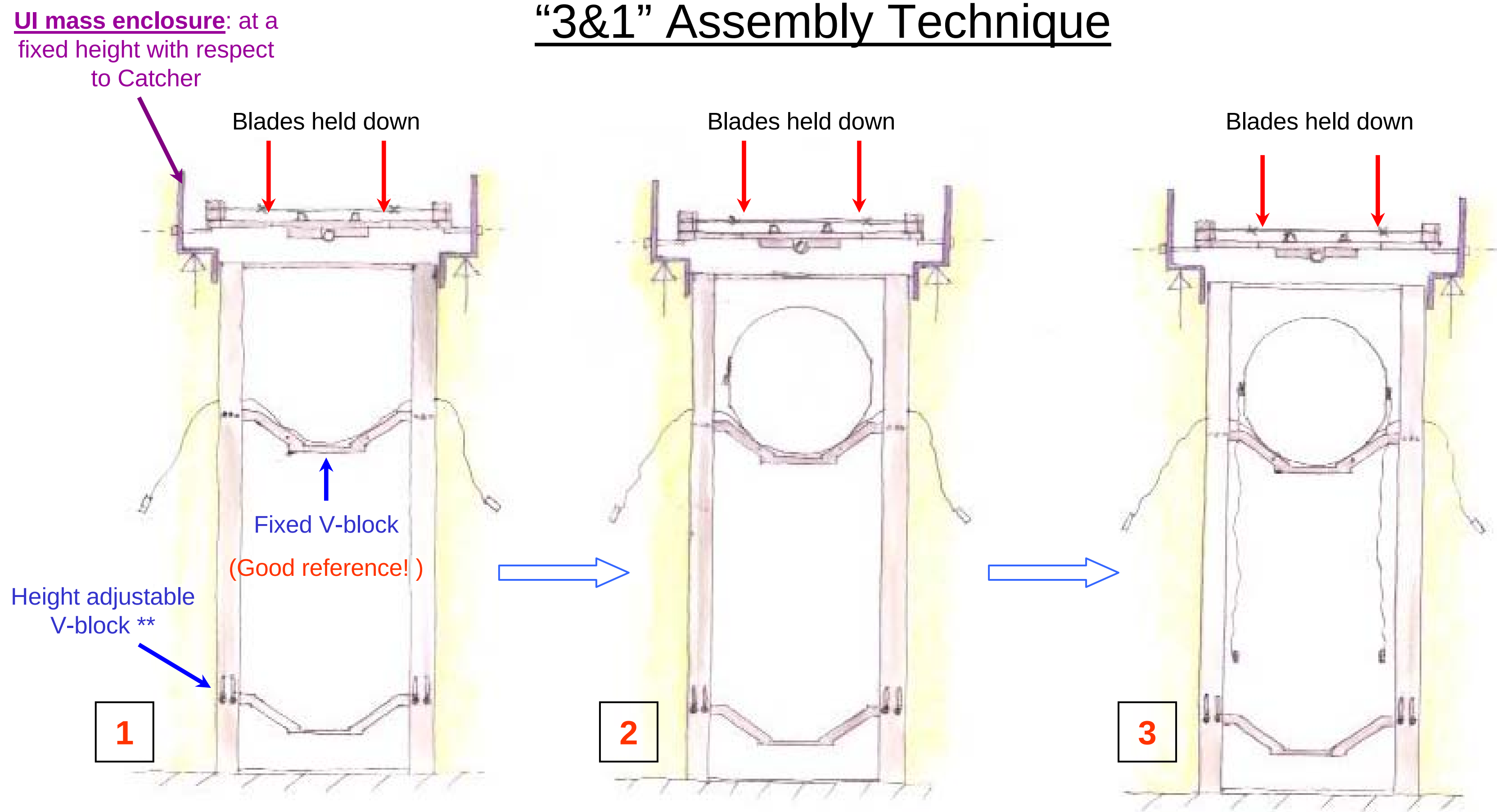
Rev 02 : - Additions for discussion 30th Nov 2004 (RAJ)

Rev 03 : - Additions from discussion, 1st Dec 2004 (RAJ, MPL)




Initial sketch showing the insertion of a block-form Lower Structure through a BSC chamber door (RAJ, Aug 04)

# “3&1” Assembly Technique




**1**

- Catcher sitting in a fixed reference surface (e.g. low optical bench or “pallet”)
- Introduce *PARTIALLY ASSEMBLED* UI Mass + enclosure to Catcher.
- UI Mass fixed in a **LOWER position** wrt penultimate mass position*
- Wire loop in place+

**2**

- Install and align Penultimate mass (V block aids with this alignment procedure)

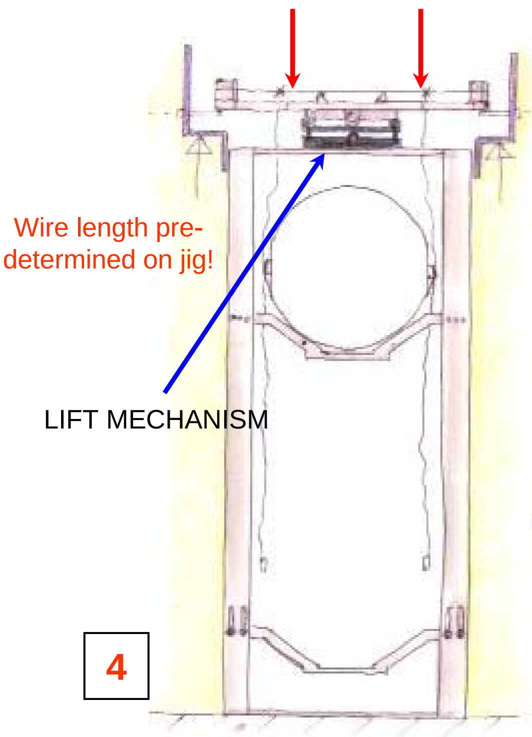
**3**

- Fix (final wire) clamp-wire clamp assemblies to each flat on the Penultimate mass

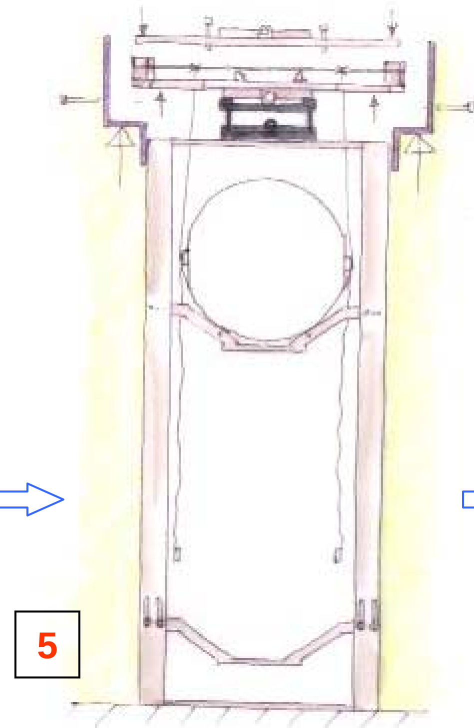
* DEFINITION OF LOWER POSITION = LESS THAN ACTUAL SEPARATION OF U.I. and PEN. MASS IN SUSPENDED STATE & ENOUGH ROOM TO ALLOW THE EASY ATTACHMENT OF THE CLAMPS TO THE BLADES

\+ IN ADDITION TO THE GROOVE / SLOT IN THE V-BLOCK WE WILL ALSO NEED TO HAVE A REMOVABLE CYLINDER THAT ALLOWS THE WIRE TO STAY IN THE POSITION YOU SHOW IN SKETCH 1 ABOVE, PRIOR TO THE ADDITION OF THE PEN. MASS. (ESSENTIALLY THE CYLINDER ALLOWS THE WIRE TO SIT IN AN ELONGATED “M” POSITION. THE CYLINDER AT THE BOTTOM OF THE “V” IN THE “M”!)

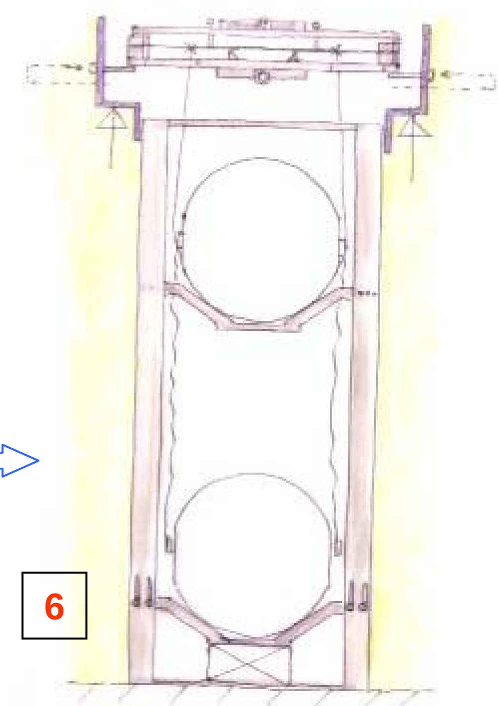
# "3&1" Assembly Technique




- Attach the blade wire clamps to the ends of the blades
- Install a LIFT MECHANISM using the top of the Catcher as a ref. surface

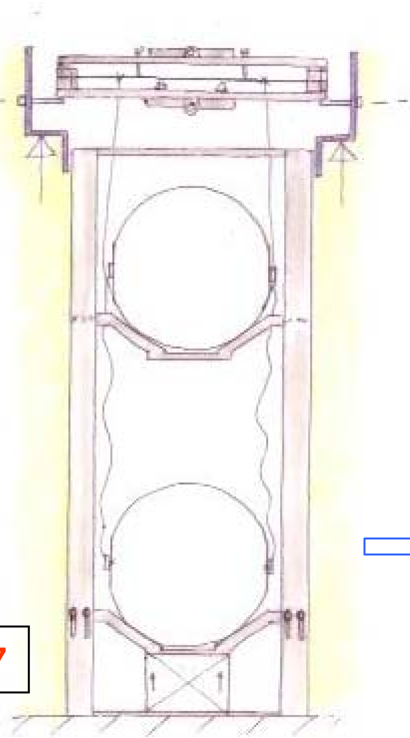



- Lift the UI Mass up to its final ( or close to) position – this would introduce tension to the wires
- Perhaps the clamp above the Penultimate mass should be in position during this operation
- Complete the assembly of the UI Mass (partial)

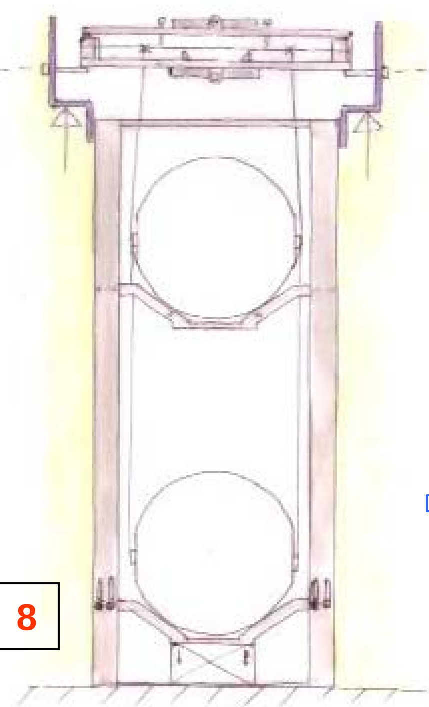



- Pin/fix the UI Mass in its final position, remove Lift mechanism
- Install and align Test Mass
- Introduce Lab Jack under the height adjustable V-Block

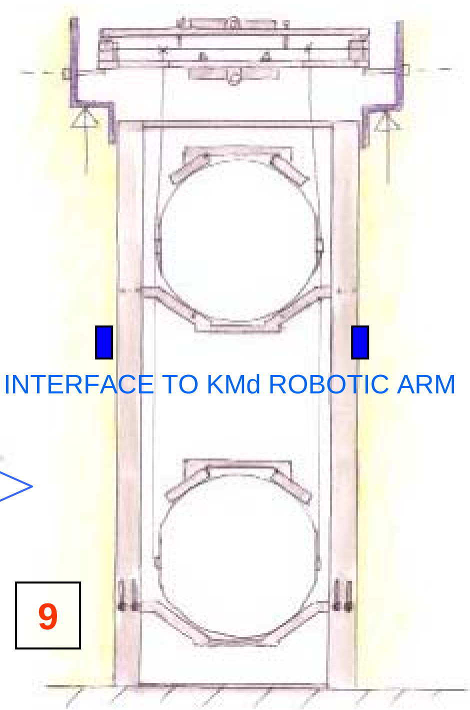
# "3&1" Assembly Technique



7



8




9

- Use Lab Jack (under the height adjustable V-Block) to lift Test Mass **(**leave vblock fixed. To do: add explanation of latest plan)**
- Connect clamp-wire-clamp assemblies to the Test Mass

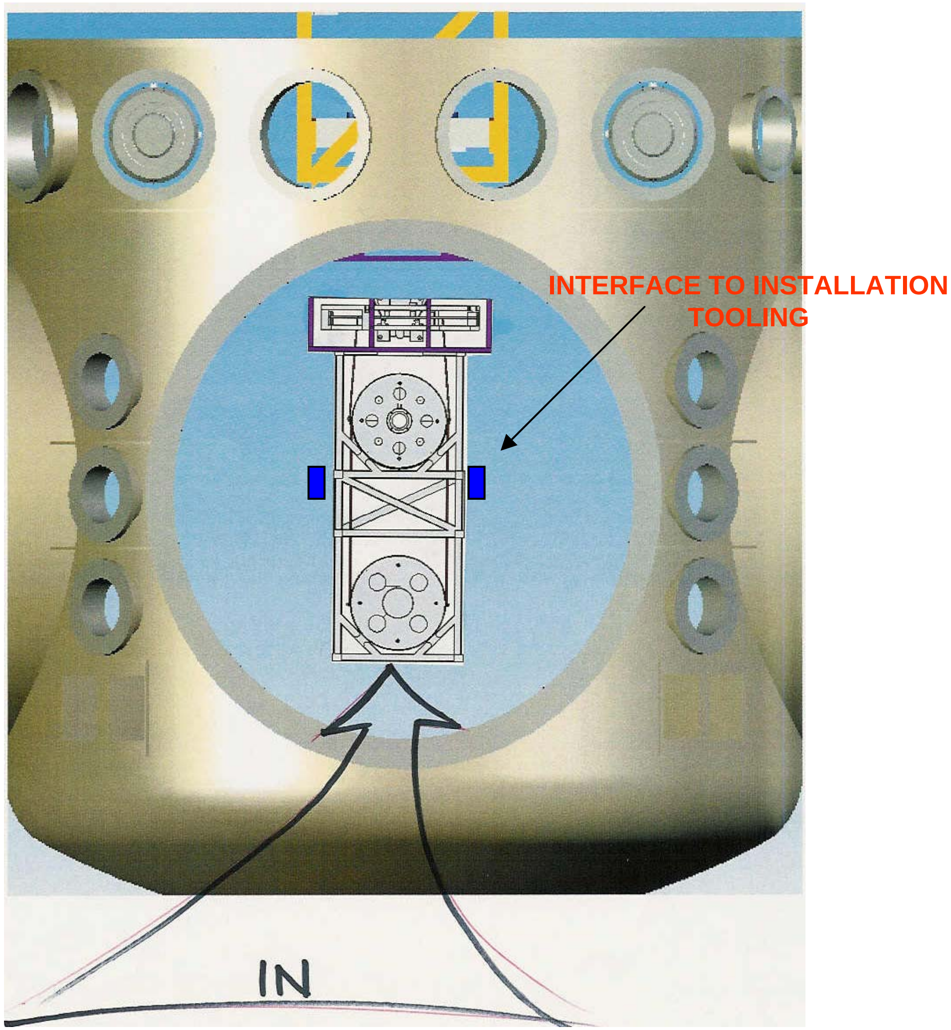
- Use Lab Jack (under the height adjustable V-Block) to lower the Test Mass back to its ideal position

- Remove Lab Jack
- Introduce clamping mechanisms above the Penultimate and Test Masses (the combination of V blocks and clamps has to take up some of the tension from the wires for transport)
- **Ready for Installation.**

# Discussion: Installing the lower section

**10**

- TAKE LOWER UNIT IN THROUGH BSC DOOR……use installation tooling




FRONT ELEVATION OF BSC CHAMBER

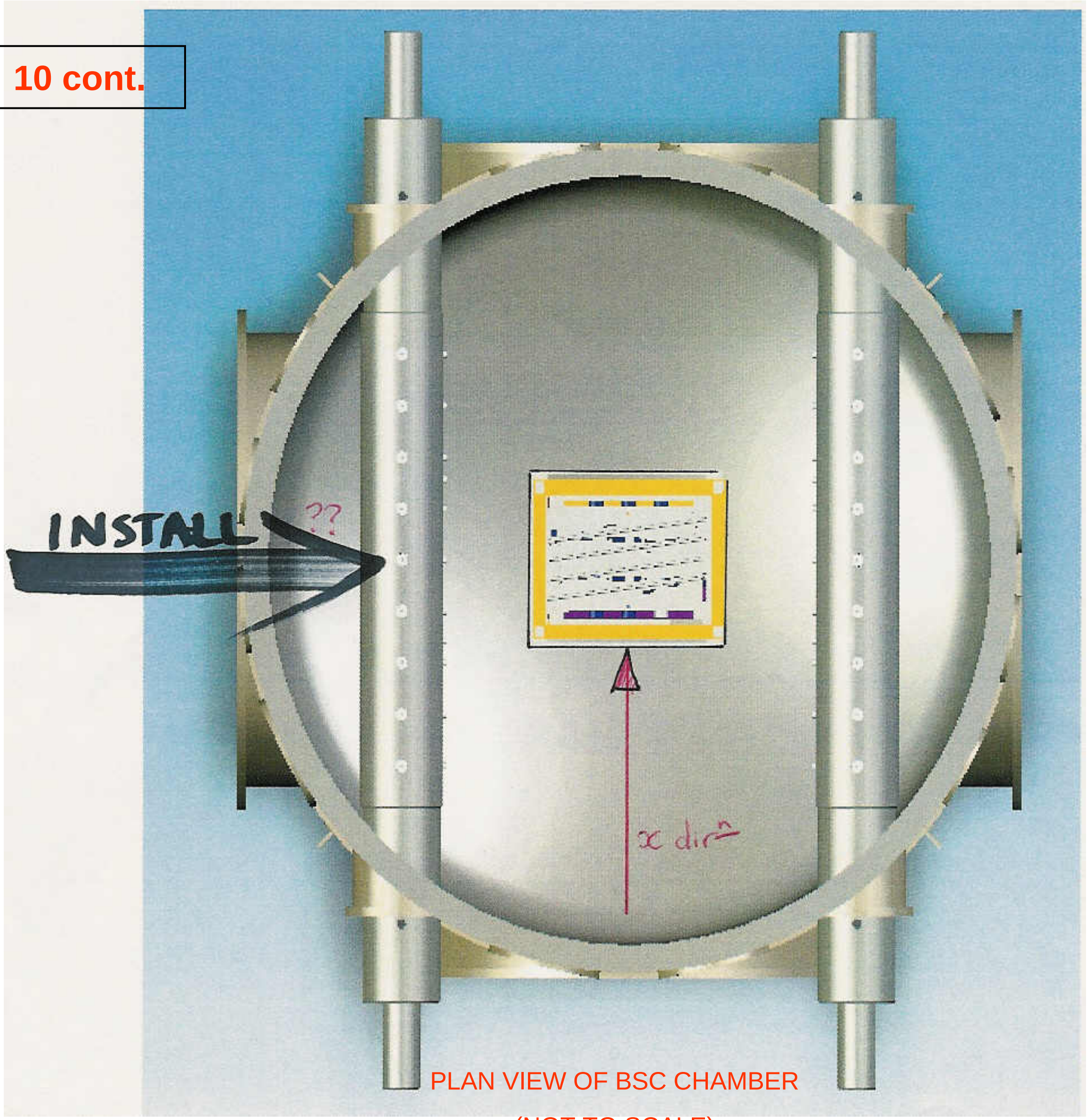
(NOT TO SCALE)

# Discussion: Installing the lower section

**10 cont.**

Quick questions:

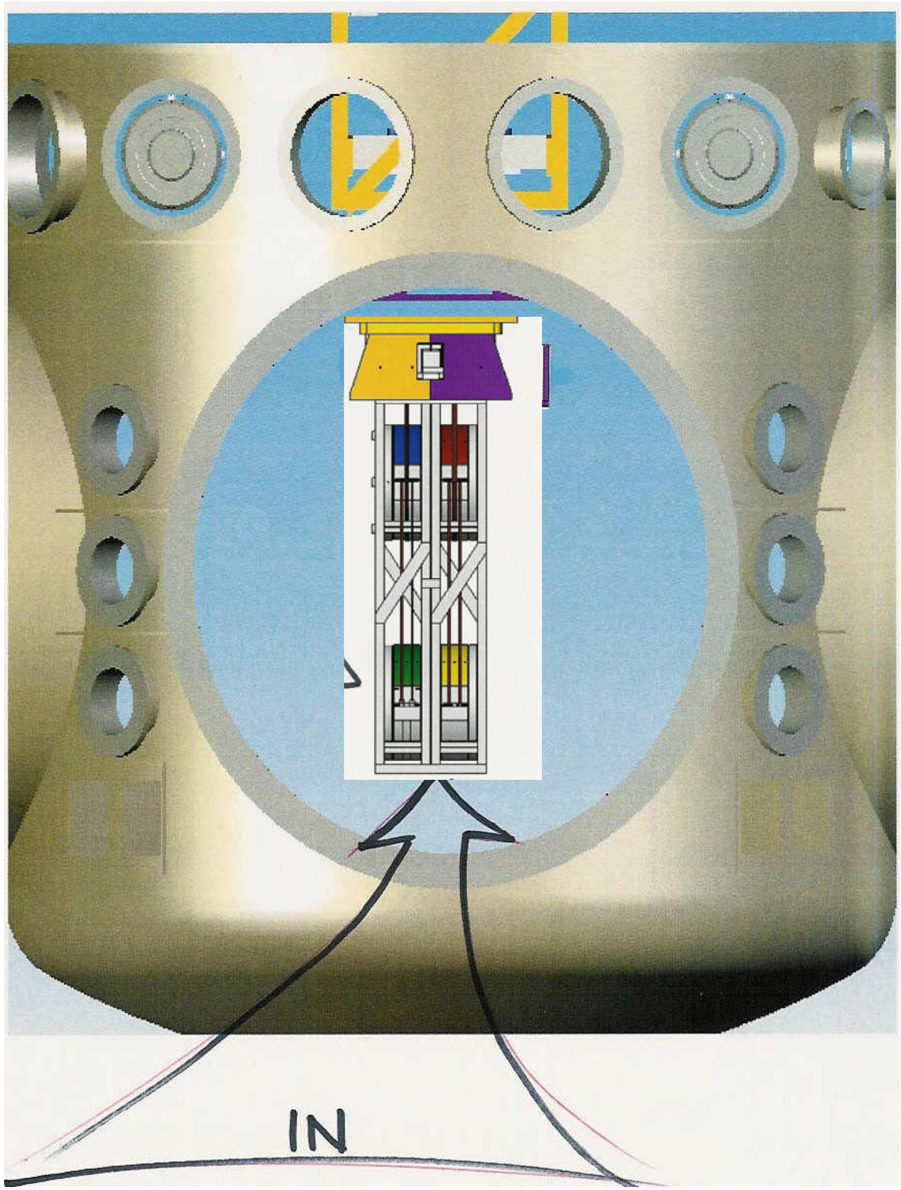
- Which direction is the beam coming from?
- From which doors can we gain access?




PLAN VIEW OF BSC CHAMBER

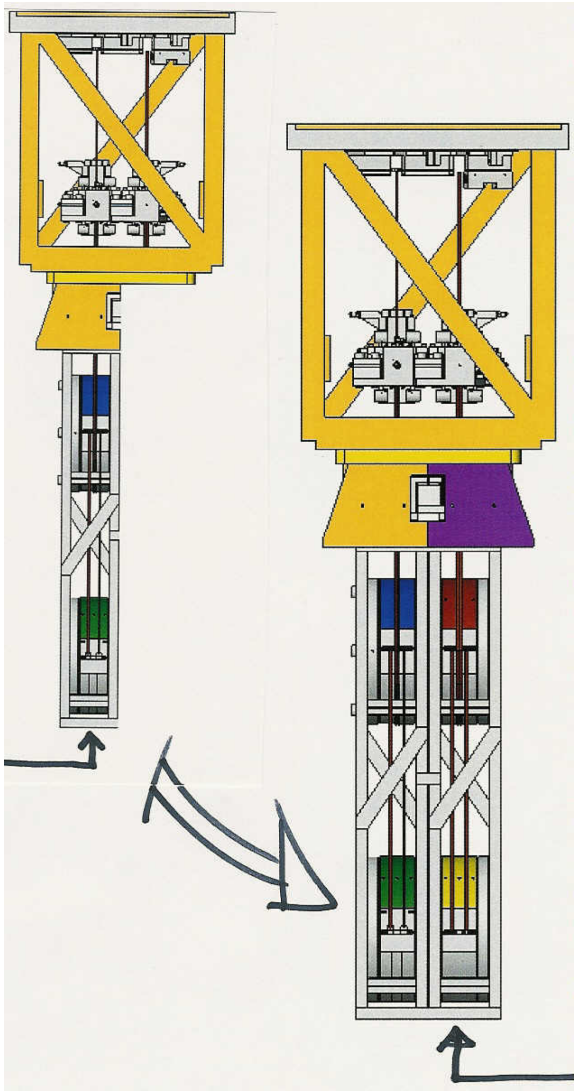
(NOT TO SCALE)

# Discussion: Installing the lower section

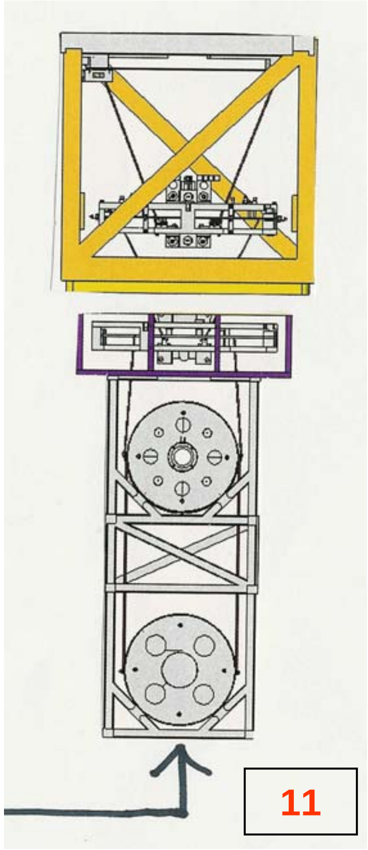



1. Do we have to rotate the lower unit by 90degrees inside the BSC chamber?
2. Can this be done?

   (in reference to E04073-00-E Oddvar's Installation fixture design requirements) If not does that mean that we have to lift each section into the chamber in the orientation shown?

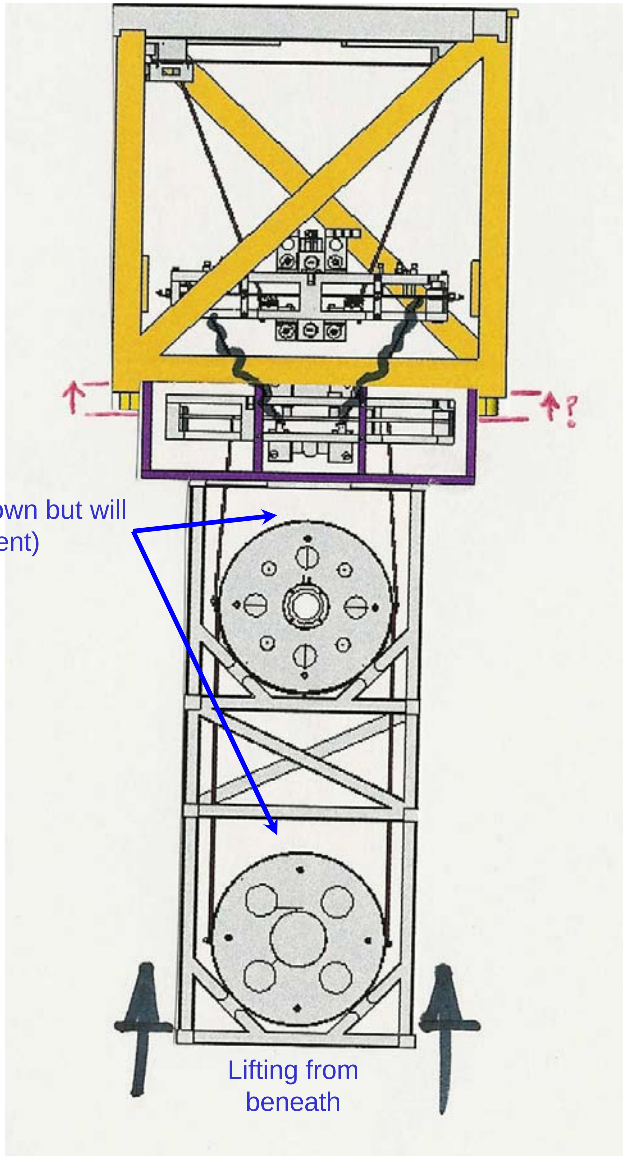


# Discussion: Installing the lower section




- Bring into the correct x-y position (using shuttle table etc.)
- Vertical linear translation to lift the lower unit up (note: E040473 mentions the limits on the range of motion [I.e. 2” > z < 4”]

(No clamps shown but will be present)




- This closes the gap between the UI mass and top mass to allow us to attach the wires
- What requirements does this place on the ‘Implementation Ring’ ! **Discuss.**