



WBSC6

AUTHOR(S)	DATE	Document Change Notice, Release or Approval
Doug Cook, Dennis Coyne, Eric Gustafson, Eric James, Scott Shankle	2 Feb 2012	see LIGO DCC record Status

Instructions on the use of this document:

- 1) Use, and complete, this document on a laptop computer while the work is proceeding. When operating in a cleanroom, use a cleanroom compatible laptop. This procedure must be available at all times during the alignment process. In addition, all of the applicable documents must also be available for reference during the procedure from the laptop computer.
- 2) Use this alignment procedure as a check list for preparation and during the alignment; As each step is completed, enter the name of the person completing the work (or approving or checking the step), as well as the date and any comments or notes. In particular, note any discrepancies or deviations and augment with any missing definition. **ALL NOTES MUST BE RECORDED IN THE COMPLETED VERSION OF THIS DOCUMENT (NOT IN OTHER NOTEBOOKS OR FILES).** If the additional notes are too cumbersome to include within the body of this completed procedure, then electronically attach them to the completed procedure.
- 3) Once completed, file the document in the LIGO Document Control Center (DCC) as the next highest version of the procedure and add a note that this is a completed/finished procedure.
- 4) File any significant notes or data from the completed procedure in the electronic logbook (such as any deviations); as a minimum note in the electronic logbook that the alignment was completed in accordance with this procedure (cite document number and revision).

Contents

1	SCOPE	2
2	APPLICABLE DOCUMENTS	2
3	COORDINATE SYSTEMS/REFERENCES	3
3.1	BSC Chamber	3
3.2	Mechanical Test Stand	3
4	PREREQUISITES FOR CARTRIDGE ALIGNMENT	3
5	REQUIRED EQUIPMENT LIST	4
6	PROCEDURE FOR CARTRIDGE ASSEMBLY ALLIGNMENT	5
6.1	Cartridge set-up	9
6.1.1	Check optics table level on the BSC mechanical test stand	9
6.1.2	Approximately align the Cartridge Assembly elements with the templates	9
6.2	H2 ETMy	10
6.2.1	Setup the ETM Retro-reflector Assembly	10
6.2.2	Setup Total Station and Laser Autocollimator	12
6.2.3	Set the ETM longitudinal position	12
6.2.4	Set the ETM horizontal position	13
6.2.5	Coarse Align the ETM Yaw	13
6.2.6	Iterate/re-Check	14
6.2.7	Check the ETM vertical position	15
6.2.8	Fine Align the ETM Yaw	16
6.2.9	Align the ETM pitch	16
6.2.10	Check the CP to ETMy Gap	17
6.3	Transmission Monitoring Assembly (Transmon)	17
6.3.1	Set up IR Laser Autocollimator for Transmon Alignment	17



WBSC6

6.3.2 Check the Transmon vertical position..... 18
 6.3.3 Check the Transmon horizontal position..... 18
 6.3.4 Check the Transmon yaw 19
 6.3.5 Check the Transmon pitch..... 19
 6.3.6 Check the Transmon roll 20
 6.3.7 Iterate/re-Check..... 20
 7 ALIGN THE CARTRIDGE ASSEMBLY IN THE BSC CHAMBER (IN SITU)..... 21
 7.1 Level the Optics Table and set its vertical position 21
 7.2 Setup the Total Station and Laser Autocollimator..... 21
 7.3 Measure Pitch & Yaw Errors..... 22
 7.4 Fine Pitch & Yaw Error Correction..... 23
 8 Align Arm Cavity Baffle (ACB) Assembly 23

1 SCOPE

The scope of this procedure is alignment of the optical elements of the WBSC6 chamber, which includes alignment of the following optical elements:

- 1) H2 ETMy (part of the quad suspension assembly, [D0900419](#))
- 2) Arm Cavity Baffle (ACB; [D0901376](#))
- 3) Transmission Monitoring Assembly ([D0901880](#))

This procedure starts with the preliminary alignment of the optical payload elements of the WBSC6 chamber in the “cartridge assembly” and then proceeds to the alignment of these same optical payload elements within the WBSC6 chamber. The “cartridge assembly” is comprised of the BSC ISI system with all of the payload elements (which are capable of fitting onto the test stand) integrated onto the optics table and the stage 0 structure of the BSC-ISI. The cartridge assembly is integrated and aligned while on the BSC mechanical test stand. The cartridge is then lifted, flown to the chamber and lowered into position onto the BSC support tubes.

This procedure does not cover the procedures for installing assemblies onto the BSC-ISI platform or for balancing and leveling the BSC-ISI optics table; these procedures are defined in separate documentation.

This procedure does not cover internal alignment of the Transmission Monitoring Assembly (Transmon) components with respect to each other or to the Transmon structure. This procedure is limited to aligning the Transmon Assembly with respect to the BSC6 cartridge.

2 APPLICABLE DOCUMENTS

Listed below are all of the applicable and referenced documents for the initial alignment procedures. This list gives the latest revisions of the documents; Within the alignment steps, only the document number (and not the revision) is quoted.

Document No.	Rev.	Document Title
E0900047		LIGO Contamination Control Plan

**WBSC6**

T1000230		AOS Initial Alignment Requirements Final Design Document
T080307		Initial Alignment System Design Requirements Document
T1000447		Flow Chart AOS/IAS H1, H2 & L1 ETMs Alignment
D0900512		aLIGO Systems, BSC6-H2 Top Level Chamber Assembly
D0901346		aLIGO SUS Quad Assembly Top Level
E1100537		Transmission Monitor Telescope Suspensions Final Design
D1101260		Rough Alignment Tool Layout, BSC-6
D970210-v2		ASC Monument Locations - Washington Site
T1100318-v1		Total Station modifications for stabilizing unit when Laser Autocollimator is Attached
D1200076		Alignment Monument Layout, LHO Y-End Station, BSC Mechanical Test Stand
T080230		Quad Pendulum Structure Pushers
M1100068		BSC Door Removal and Installation Procedure

3 COORDINATE SYSTEMS/REFERENCES

3.1 BSC Chamber

The local BSC chamber coordinate system origin is the point where the horizontal, cylindrical axes of the main access portals meet. The local BSC chamber coordinate system axes are aligned to the local gravity vector. Z is vertical (+Z is up). X and Y are both horizontal and approximately aligned to the global coordinate axes (as defined in [T980044](#)). The local BSC chamber coordinate system origin is nominally located 65.421 in [1661.7 mm] below the BSC-ISI optics table surface.

3.2 Mechanical Test Stand

The local mechanical test stand coordinate system origin is located 65.421 in [1661.7 mm] below the BSC-ISI optics table surface and centered between the row of mounting holes which interface to the BSC-ISI stage-0 structure (and represent the support tubes installed into the BSC chambers). The local mechanical test stand coordinate system axes are aligned to the local gravity vector. Z is vertical (+Z is up). X and Y are both horizontal and approximately aligned to the global coordinate axes.

4 PREREQUISITES FOR CARTRIDGE ALIGNMENT

- The BSC mechanical test stand must be set so that the interface plane with the BSC-ISI stage 0 is horizontal.
- The features of the BSC mechanical test stand which interface to the BSC-ISI platform shall be used to establish a centerline and two offset lines with alignment monuments/references in the floor, as depicted in the D1200076 (see also Figure 1).
- An appropriate clean room should be installed over the test stand. (see Figure 1)

WBSC6

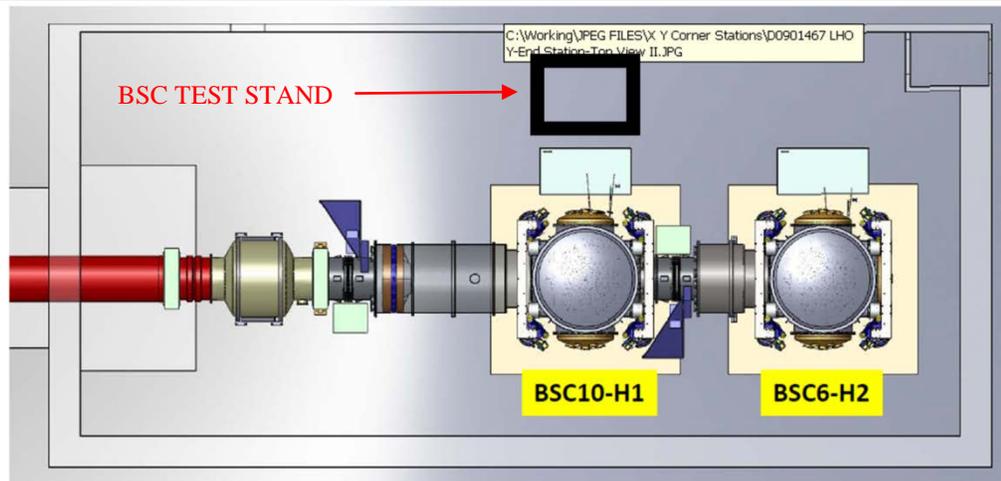


Figure 1 Test Stand location within the Y-End Station VEA

- The BSC-ISI must be placed, and bolted, to the test stand, offset from the center of the test stand by -179.0 mm in the y-direction. This allows the TMSy to be integrated into the cartridge assembly while on the test stand.
- All payload assemblies must be acceptance tested (to the extent possible and planned) prior to integration into the cartridge assembly.
- The ETMy suspension must be capable of being electronically damped while on the test stand and later when in the chamber.
- All IAS operations on the cartridge assembly are to be made with the BSC ISI in its locked mode. Verify that the ISI is locked.

completed, approved or checked by:

date:

comments (optional):

5 REQUIRED EQUIPMENT LIST

- Total station (either a Sokkia Set2BII or a Sokkia SetX1 modified per [T1100318](#)) with tripod stand
- Laser autocollimator (Newport LDS Vector and LDS1000 controller)
- Optical level (Sokkia B2o AutoLevel with micrometer option, or equivalent) with tripod stand
- Precision bubble level
- Optical Transit Square (Brunson model 75-H) with stand
- Mechanical locating templates for ETMY suspension and TMS assembly ([D1101050](#) -5 through -8, cleaned to Class B per [E0900047](#) and E960022)
- Precision pushers ([D060052](#), cleaned to Class B per [E0900047](#) and [E960022](#))
- Mover assemblies ([D1100018](#), cleaned to Class B per [E0900047](#) and [E960022](#))

**WBSC6**

- Retro reflector assembly ([D1101340](#), cleaned to Class B per [E0900047](#) and [E960022](#))
- Coordinate Measuring Machine (CMM, Romer model Infinite 2.0, or MicroScribe 6MX) or a Depth Gauge with plastic probe tip (and sufficient range to measure the distance from the optic to the retro-reflector)
- BSC table height target (D1101611).
- Various optical or tripod stands

6 PROCEDURE FOR CARTRIDGE ASSEMBLY ALIGNMENT

The reference monuments for the cartridge assembly on the test stand are given I D1200076, and in Figure 2 for convenience.

The WBSC6 cartridge assembly is depicted in Figure 3. The major optics assemblies integrated into the WBSC6 cartridge are the Y End Test Mass (ETMy) and End Reaction Mass (ERMy), both parts of the suspension assembly (D0901346). The Arm Cavity Baffle which is destined for the WBSC6 chamber, is not part of the cartridge assembly as it interferes with the test stand. It will be installed separately.

The positions and Lines Of Sight (LOS) for the WBSC6 cartridge assembly alignment are depicted in Figure 4.



WBSC6

When the Test Stand was reset it was found to be 0.008" to the RIGHT (→) of centerline

Y-end VEA

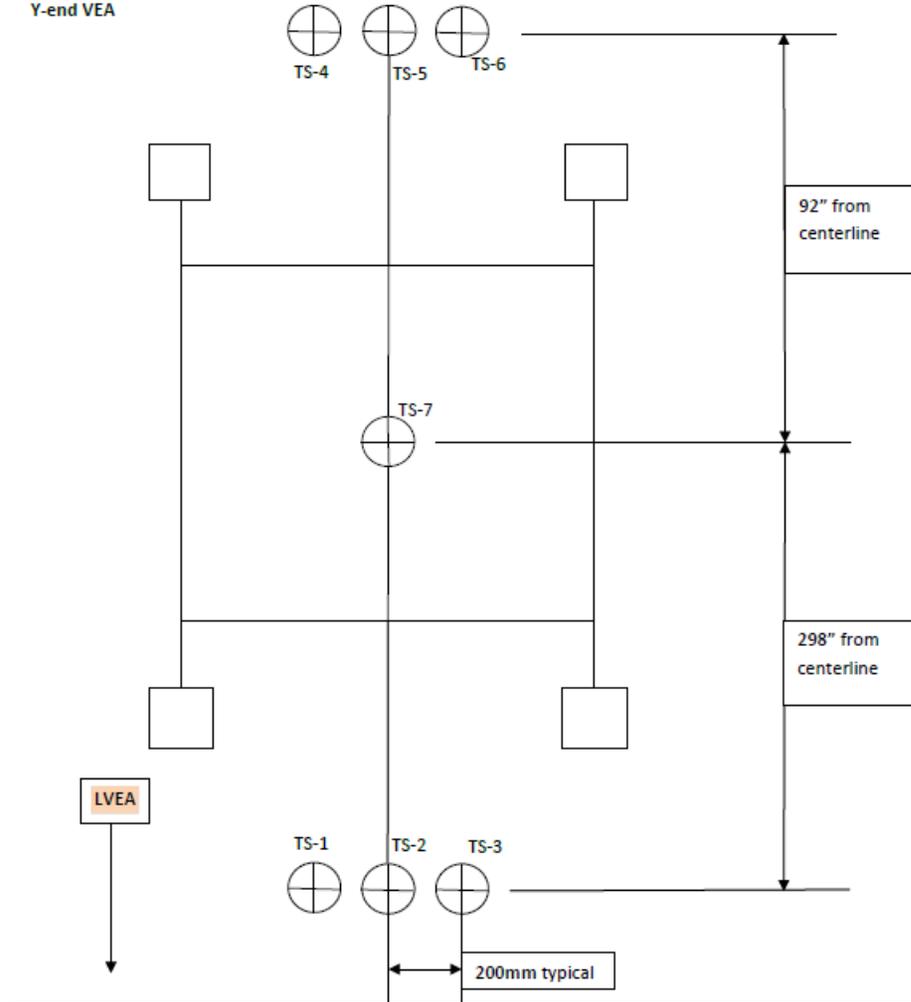


Figure 2: Monument Layout for Y-End Station Test Stand (from D1200076)



WBSC6

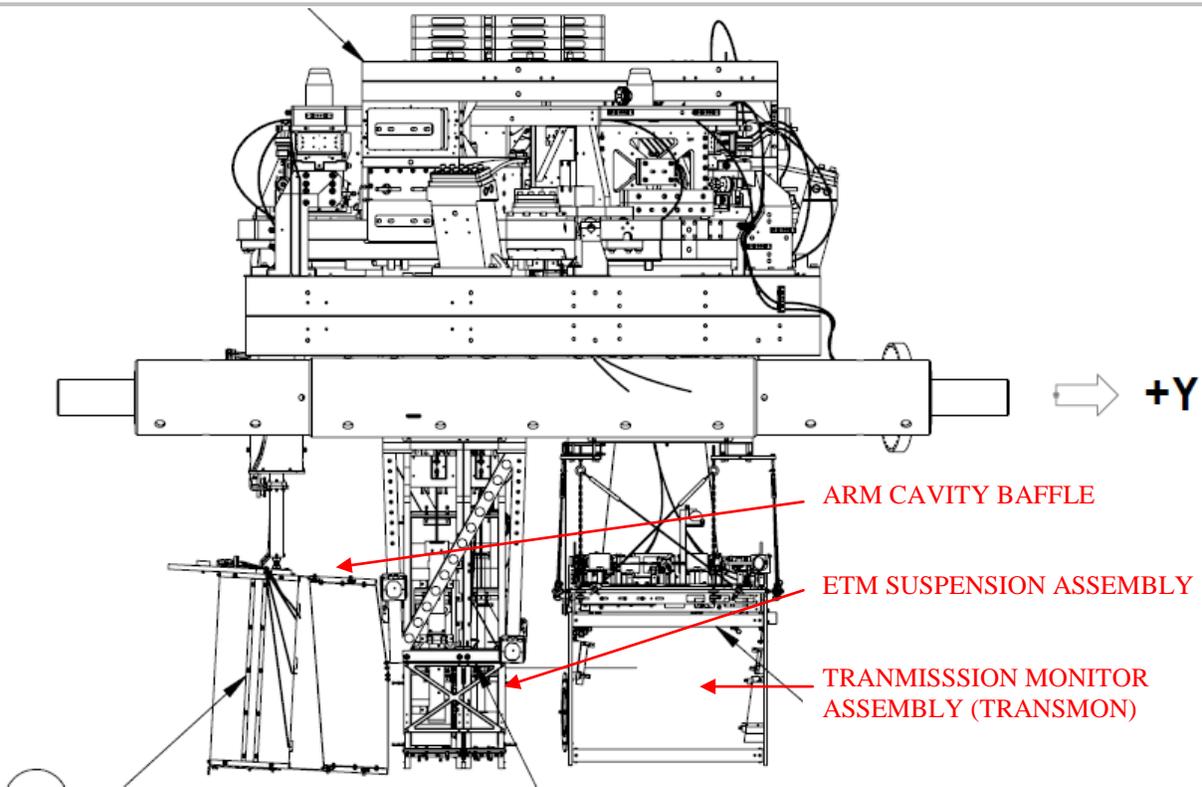


Figure 3: The WBSC6 cartridge assembly (from D0900512)

The Arm Cavity Baffle (ACB, D0901576) will not be a part of the cartridge assembly since it interferes with the test stand.



WBSC6

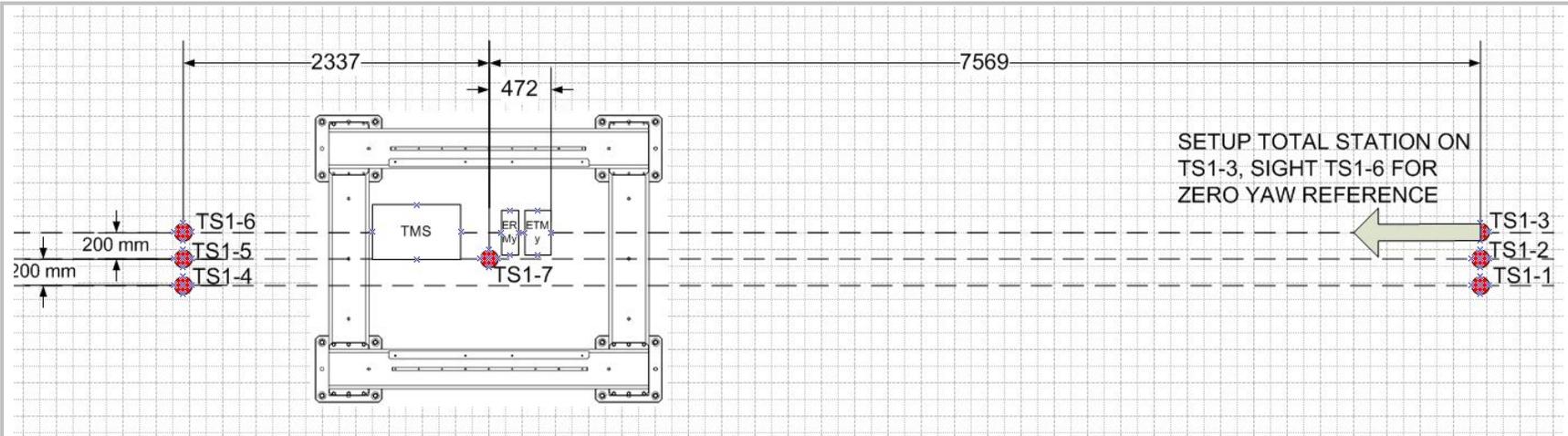


Figure 4: IAS Instrument Positions and Lines Of Sight (LOS) for the WBSC6 Cartridge Assembly Alignment



WBSC6

6.1 Cartridge set-up

6.1.1 Check optics table level on the BSC mechanical test stand

Datum: Local gravity

Equipment: Optical level on tall tripod and targets on invar rods suspended from the optics table

Accuracy: ± 100 microrad (0.1 mm differential height)

Procedure:

- Attach 3 invar rods with targets to the table (equal lengths sufficient to be seen by optical level on tripod). Position the rods so that all 3 can be observed from a single optical level position.
- Place optical level on a tall tripod and sight the relative difference in target heights to determine tip and tilt of optics table.
- Adjust ISI trim/balance mass per E0900357 (v20, section 1.84)
- Record table levelness:

Tip (rotation about x)	microrad
Tilt (rotation about y)	microrad

6.1.2 Approximately align the Cartridge Assembly elements with the templates.

Datum: Bolt holes in optical table per [D1101260](#)

Equipment: Alignment templates ([D1101050](#)). Each suspension has two sets of templates. Either set may be used but not both.

ETMY Suspension: Use either [D1101050-5](#) or [D1101050-7](#).

Transmission Monitoring Suspension: Use either [D1101050-6](#) or [D1101050-8](#).

Accuracy: Clearance in bolt holes

Procedure:

- Install [D1101050-5](#) or [D1101050-7](#) template per [D1101260](#)
- Install [D1101050-6](#) or [D1101050-8](#) template per [D1101260](#)
- If needed, install precision pushers ([D060052](#)) per [T080230](#) adjacent to ETM structures opposite of the templates.
- Push ETM and Transmon structures to contact the templates per [T080230](#).
- Lock down suspension structures.
- Remove all templates.



WBSC6

6.2 H2 ETMy

6.2.1 Setup the ETM Retro-reflector Assembly

Datum: Optical axis of the test mass.

Equipment: Retro-reflector assembly (D1101340), CMM or depth gauge with plastic contact

Note: This is the old retro-reflector assy; need D# for new assy

Accuracy: ± 0.2 mm

Procedure:

- Attach the retro-reflector assembly to the quad structure in front of the ETM HR face.
- Lock the rotation stage so that the retroreflector is not free to move.
Note: It is not necessary to center the retroreflector target to the optic centerline.
- Use a CMM, or depth gauge, to measure the Y distance (offset) between the reflecting plane reference on the retro-reflector to the test mass HR face (see Figure 7). The CMM probe, or depth gauge, is not to contact the HR face of the optic except along the outer perimeter
- Record the Offset (Y-distance).

Offset: distance from the ETM HR face to the Reflecting Plane of the Retro-reflector	43.9 mm
--	---------

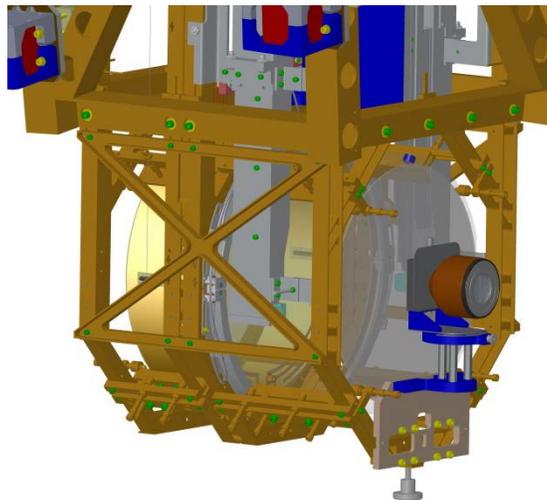


Figure 5: Retro-reflector Assembly attached to Quad Suspension Structure

N.B.: The current retro-reflector mount is different – figure to be updated to show new design.



WBSC6

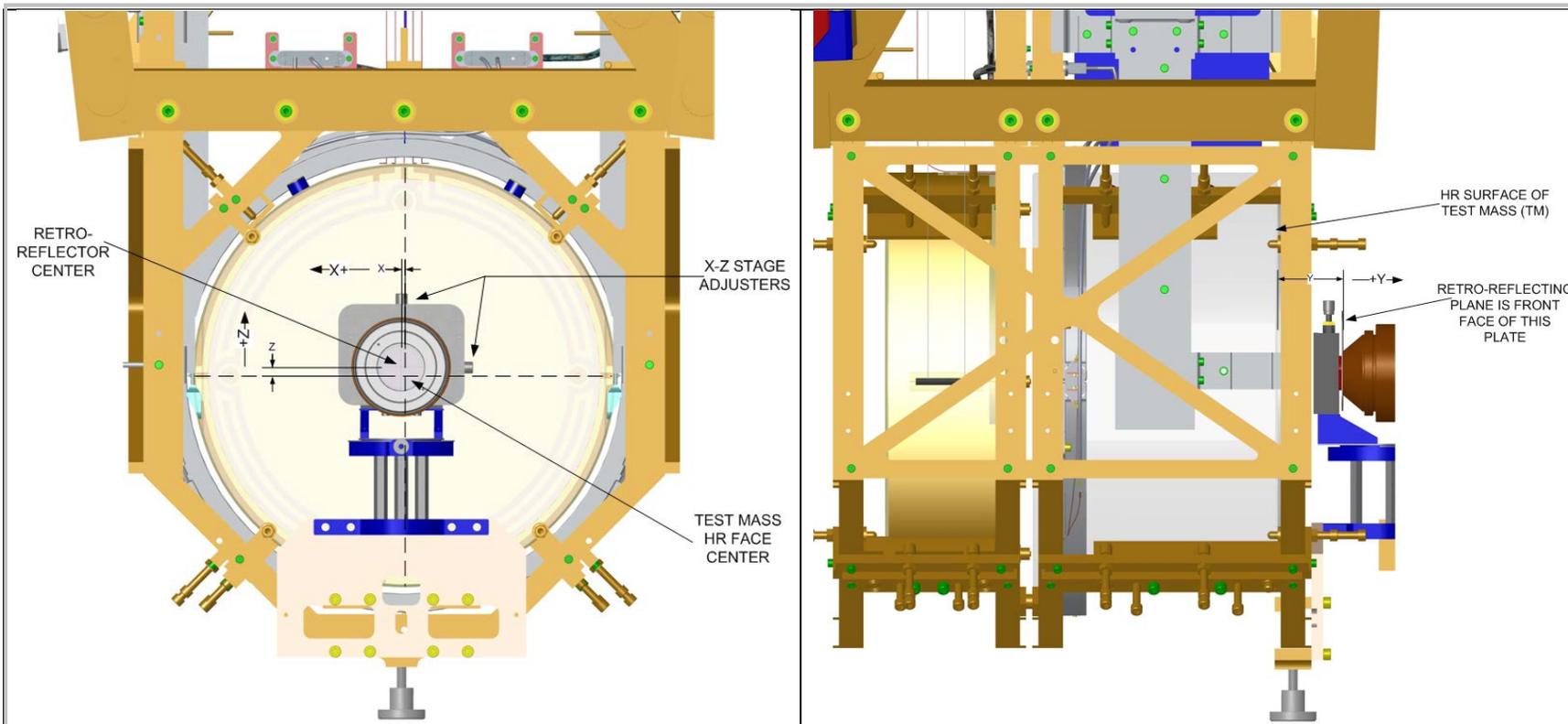


Figure 6: X, Y and Z offsets between the HR face center and the Retro-Reflector Center

N.B.: The current retro-reflector mount is different – figure to be updated to show new design.



WBSC6

6.2.2 Setup Total Station and Laser Autocollimator

Datum: Monuments TS1-3 and TS1-6 – axis 200 mm shifted from the centerline; Height target is placed on the precision length rod (D1101611) to set target to optic height below the optics table.

Equipment: Total station, Newport Laser Autocollimator (mounted on top of Total Station), height target (D1101611)

Accuracy: ± 1 mm, ± 40 microradians rss, alignment reference transfer (see [T1000230-v6](#), section 17)

Procedure:

- Set the total station to approximately 973 mm above the floor.
- Set the total station on TS1-3 and sight TS1-6 to define zero yaw angle.
- Attach the height target to the optics table on a hole which is set back from the edge of the table toward the total station about the same amount as the front (HR) face of the ETMy optic.
- Set the total station pitch up at 639 microradians (131.8 arcsec or 2' 11.8").
- Yaw the total station to sight the height target and adjust total station height to match the height target. The total station is now at a height such that its projected beam centerline should intersect the center of the HR face of the ETM (i.e. -80 mm Z)

6.2.3 Set the ETM longitudinal position

Datum: Total station EDM, Retro-reflector and offsets to the HR face (determined in section 6.2.1)

Equipment: Total station, retro-reflector

Accuracy: ± 3 mm

Procedure:

Use total station EDM to set the ETM position to 6917.9 mm (remember to account for the offset distance)¹

- Lock-down the optics and masses, of both suspension chains, with the earthquake stops according to the SUS procedure.
- Measure the ETMy longitudinal position (accounting for the offset).
- If the error in position is greater than ± 3 mm, then use the use the “mover assemblies” ([D1100018](#)) and “pusher assemblies” ([D060052](#)) to shift the longitudinal position of the quad structure as needed.

¹ This distance sets the HR face of the ETM at -472.3 mm in the y-direction from the optics table center, when the HAM-ISI system is offset from the center of the test stand -179.0 mm in the y-direction.

**WBSC6**

- Record the final position.

Retro-reflector to HR face offset (+)	43.9	mm
EDM distance (+)	6878	mm
Sum = ETM longitudinal position	6921.9	mm

6.2.4 Set the ETM horizontal position

Datum: Optical axis as established by the total station.

Equipment: total station, pusher assembly ([D060052](#)), mover assembly ([D1100018](#)).

Accuracy: ± 1 mm (corresponds to ± 140 microradians of yaw error when sighting the retro-reflector target)

Procedure:

- Lock-down the optics and masses, of both suspension chains, with the earthquake stops according to the SUS procedure.
- With the Total Station set at an elevation angle of 639 microradians (2' 11.8"), sight the left edge of the optic. Record the yaw angle.
- Sight the right edge of the optic. Record the yaw angle.

	Trial 1	Trial 2	Trial 3
Left optic edge (-A)	-23.46 mrad	-23.45 mrad	mrad
Right optic edge (+B)	23.71 mrad	23.73 mrad	mrad
Center error angle (A+B)/2	125 microrad	138 microrad	microrad
Center error distance 7041.3 * (A+B)/2	0.87 mm	0.96 mm	mm

- Use the "mover assemblies" ([D1100018](#)) and "pusher assemblies" ([D060052](#)) to shift the lateral position of the quad structure as needed, so that the retro-reflector center is centered in the theodolite (Total Station)

6.2.5 Coarse Align the ETM Yaw

Datum: Optical axis as established by the total station.

Equipment: Laser autocollimator mounted on top of the Total Station

Accuracy: ± 1 milliradians goal (limited by the repeatability in the pusher and clamping method)



WBSC6

Procedure:

- Peel back the First Contact™ at 12 o'clock.
- Use yaw bias commands to the SUS reaction chain (so as not to be confused with reaction chain reflected beams).
- Insure that the optics and masses, of the main suspension chain, are free (not clamped or on the mechanical or earthquake stops).
- Use the laser autocollimator to measure the TM optic yaw angle.
- Use the pusher assemblies to reduce the yaw angle to as close to zero as possible (< 1 mrad), using the SUS procedures. Note that the optics and masses should be clamped before attempting to move the Suspension frame/assembly on the optics table.
- Record residual yaw error.

	Trial 1	Trial 2	Trial 3
ETM yaw error	-2.72 millirad	0.45 millirad	0.06 millirad

6.2.6 Iterate/re-Check

Datum: Local gravity, optical axis as established by the total station.

Equipment: Optical level on tall tripod and targets on invar rods suspended from the optics table, total station

Accuracy:

levelness: ± 100 microrad (0.1 mm differential height)

lateral position: ± 1 mm

longitudinal position: ± 3 mm

yaw: ± 160 microradians

Procedure:

- Re-check table level
- Re-check the lateral & longitudinal position and yaw and iterate until all are within required accuracy (coarse accuracy for the yaw).
- Remove the retro-reflector and mount assembly from the ETM.

Once this step has been completed, the ETM “frame” has been set; All further adjustments to the ETM are on the suspension chains.



WBSC6

6.2.7 Check the ETM vertical position

Datum: Optical axis as established by the total station.

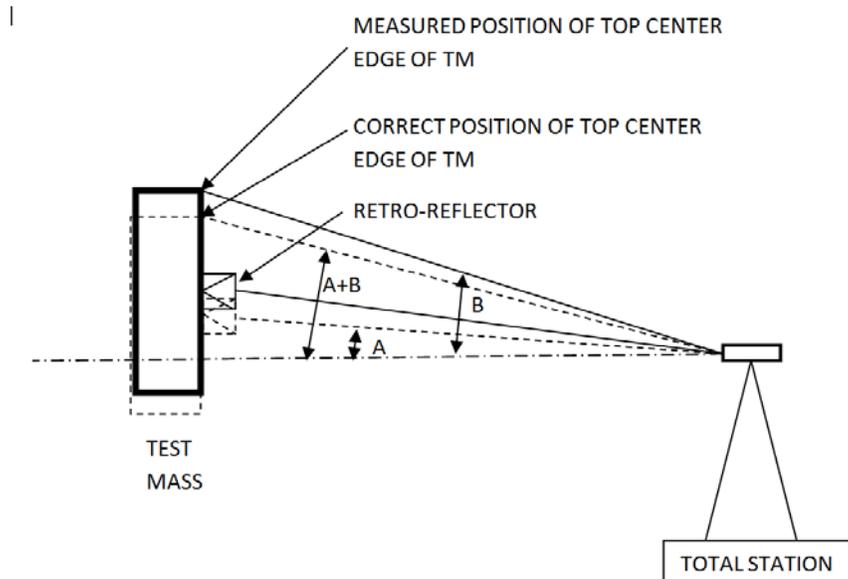
Equipment: Total Station

Accuracy: ± 1 mm (corresponds to ± 140 microradians of pitch error when sighting top and bottom edges of optic, on vertical centerline)

- With the Total Station at zero yaw angle, sight the bottom edge of the optic. Record the pitch angle.
- Sight the top edge of the optic. Record the pitch angle.
- The optic height was set during the SUS assembly and should be correct. However, if it is out of tolerance, then use the SUS procedure in E#?, section ?, to adjust the test mass height until it is within the required accuracy. See Figure 8

	Trial 1	Trial 2	Trial 3
Bottom optic edge (-A)	-24.48 mrad	-24.54 mrad	mrad
Top optic edge (+B)	24.60 mrad	24.56 mrad	mrad
Center error angle $E = (A+B)/2 - 639$ microrad	60 microrad	10 microrad	microrad
Center error distance $6917.9 * E$	0.4 mm	0.07 mm	mm

NOTE: Total station was set 0.2mm below desired height so above center error distances should be modified by -0.2mm





WBSC6

Figure 7: Determination of the height of the optic center

6.2.8 Fine Align the ETM Yaw

Datum: Optical axis as established by the total station.

Equipment: Laser autocollimator

Accuracy: ± 100 microradians (limited by air buffeting in the test stand/cleanroom environment)

Procedure:

- Use yaw bias commands to the SUS reaction chain (so as not to be confused with reaction chain reflected beams).
- Insure that the optics and masses, of the main suspension chain, is free (not clamped or on mechanical or earthquake stops).
- Then use the top blade adjusters to reduce the residual error further, using the SUS procedures
- Record the yaw error

	Trial 1	Trial 2	Trial 3
ETM yaw error	0.06 millirad	millirad	millirad

6.2.9 Align the ETM pitch

Datum: Optical axis as established by the total station.

Equipment: Total station

Accuracy: ± 100 microradians (limited by air buffeting in the test stand/cleanroom environment)

Procedure:

- Use yaw bias commands to the SUS reaction chain (so as not to be confused with reaction chain reflected beams).
- Set the total station pitch to 639 microradians (131.8 arcsec or 2' 11.8") UP. Using the LAC, measure the pitch error.

Initial ETM pitch error	563 microradians
-------------------------	------------------

- If the pitch error is < 100 microradians, record and re-adhere First Contact™ using fresh/wet First Contact™ and the procedure in [E1000079](#).
- If > 100 microradians, then adjust the upper intermediate mass pitch balance per SUS procedures.



WBSC6

Final ETM pitch error	-23 microradians
-----------------------	------------------

6.2.10 Check the CP to ETMy Gap

Datum: The ETMy AR face and the opposing face of the CP.

Equipment: Keyance System and Laser Autocollimator

Accuracy: ± 0.5 mm average/center distance, and ± 1.47 milliradians parallelism (corresponding to ± 0.25 mm over the diameter of the optic)

Procedure:

- Ensure that there are no pitch and yaw bias commands to either the SUS main or reaction chains.
- Measure & record the gap distance between the ETMy AR face and the opposing face of the CP with the Keyance System.
- If the gap is not within the allowed tolerance of the nominal 15 mm, then adjust per the SUS procedures.
- Measure the parallelism between the surfaces and if not within the allowed tolerance, then adjust per SUS procedures.
- Record the final gap parameters

Gap Distance	5.25 mm	
Gap Parallelism Error	Pitch	-0.87 milliradians
	Yaw	-0.28 milliradians

6.3 Transmission Monitoring Assembly (Transmon)

6.3.1 Set up IR Laser Autocollimator for Transmon Alignment

Datum: Optical axis (yaw and pitch) defined by the ETMy; Height defined by the height target (D1101611); lateral position defined by monument TS1-3

Equipment: Infrared (IR) Laser Autocollimator (IRLAC) on stand, height target (D1101611)

Accuracy: ± 1 mm

Procedure:

- Set up the IR Laser Auto-collimator (IRLAC) directly above the TS1-3 monument.
- Attach the height target to the optics table on a hole near the table edge toward the IRLAC.
- Peel back (or remove) the First Contact™ coating on the HR face of the ETM so that the center of the optic is exposed.
- Back-off the EQ stops so that the ETM is free.
- Engage ETM damping controls.



WBSC6

- Use yaw bias commands to the SUS reaction chain (so as not to be confused with reaction chain reflected beams).
- Yaw and Pitch the IRLAC so that it retro-reflects from the HR surface of the ETM.
- Yaw the IRLAC to project onto the height target and adjust IRLAC height to match target height. The IRLAC is now at a height so that its retro-reflected beam will intersect the center of the test mass (i.e. -80 mm Z)
- Yaw and Pitch the IRLAC so that it (again) retro-reflects from the HR surface of the ETM. The beam projected from the IRLAC is now on the optical axis and is projected through the ETM into the TMS telescope.

6.3.2 Check the Transmon vertical position

Datum: Optical axis as established by the IR Laser Autocollimator (IRLAC)

Equipment: IR Laser Autocollimator (IRLAC)

Accuracy: ± 6 mm?

Procedure:

- Retro-reflect the IRLAC beam from the ETM HR face, and project through the ETM and reaction mass into the Transmission Monitor (TransMon).
- Read position error signals (horizontal and vertical) from one of the TransMon sensors (which one?)
- If the vertical position error is > the allowed accuracy, then adjust the height of the TMS per the procedure in E#?, section #?
- Record the final residual vertical error:

NOTE: Not performed as written. Used a crosshair target designed by D. Cook with equal spaced gradients to estimate vertical and horizontal position error.

Transmon vertical error	0 mm
-------------------------	------

6.3.3 Check the Transmon horizontal position

Datum: Optical axis as established by the IR Laser Autocollimator (IRLAC)

Equipment: IR Laser Autocollimator (IRLAC), pusher assembly (D060052), mover assembly (D1100018).

Accuracy: ± 6 mm?

Procedure:

- Retro-reflect the IRLAC beam from the ETM HR face, and project through the ETM and reaction mass into the Transmission Monitor (TransMon).
- Read position error signals (horizontal and vertical) from one of the TransMon sensors (which one?)



WBSC6

- If the horizontal position error is $>$ the allowed accuracy, then adjust the lateral position of the TMS structure using the “mover assemblies” ([D1100018](#)) and “pusher assemblies” ([D060052](#)) to shift the lateral position of the TMS structure as needed

- Record the final residual horizontal error:

NOTE: Not performed as written. Used a crosshair target designed by D. Cook with equal spaced gradients to estimate vertical and horizontal position error.

Transmon horizontal error	+1.0 mm
---------------------------	---------

6.3.4 Check the Transmon yaw

Datum: Optical axis as established by the IR Laser Autocollimator (IRLAC).

Equipment: IR Laser Autocollimator (IRLAC), pusher assembly ([D060052](#)), mover assembly ([D1100018](#)).

Accuracy: ± 100 microradians

Procedure:

- Retro-reflect the IRLAC beam from the ETM HR face, and project through the ETM and reaction mass into the Transmission Monitor (TransMon).
- Read angular error signals (yaw and pitch) from one of the TransMon sensors (**which one?**)
- If the yaw is $>$ the allowed accuracy, then adjust the yaw angle of the TMS structure using the “mover assemblies” ([D1100018](#)) and “pusher assemblies” ([D060052](#)).
- Record residual yaw error:

NOTE: Not performed as written. Could focus through TMS telescope with total station onto the lower mirror of the periscope that directs light from the telescope onto the suspended TMS table. Measured the left/right angles of the edge of this mirror and used a MATLAB script written by V. Sannibale to calculate the position error of this mirror. Final mirror horizontal position error: **-1.3 mm**. Per K. Kawabe this was close enough to adjust with bias controls.

Transmon yaw error	microradians
--------------------	--------------

6.3.5 Check the Transmon pitch

Datum: Optical axis as established by the IR Laser Autocollimator (IRLAC).

Equipment: IR Laser Autocollimator (IRLAC)

Accuracy: ± 100 microradians



WBSC6

Procedure:

- Retro-reflect the IRLAC beam from the ETM HR face, and project through the ETM and reaction mass into the Transmission Monitor (TransMon).
- Read angular error signals (yaw and pitch) from one of the TransMon sensors (which one?)
- If the pitch is > the allowed accuracy, then adjust the pitch weights to zero the pitch error using the procedure in E#?, section #?.
- Record residual pitch error:

NOTE: Not performed as written. Could focus through TMS telescope with total station onto the lower mirror of the periscope that directs light from the telescope onto the suspended TMS table. Measured the top/bottom angles of the edge of this mirror and used a MATLAB script written by V. Sannibale to calculate the position error of this mirror. Final mirror vertical position error: **-0.67 mm**. Per K. Kawabe this was close enough to adjust with bias controls.

Transmon pitch error	microradians
----------------------	--------------

6.3.6 Check the Transmon roll

Datum: Optical axis as established by the IR Laser Autocollimator.

Equipment: IR Laser Autocollimator

Accuracy: ±100 microradians

Procedure:

- Retro-reflect the IRLAC beam from the ETM HR face, and project through the ETM and reaction mass into the Transmission Monitor (TransMon).
- Determine the roll error signal from one of the TransMon sensors (which one?), using the projected reticle pattern of the IRLAC
- If the roll is > the allowed accuracy, then adjust the TMS roll per the procedure in E#?, section #?
- Record residual roll error:

Transmon roll error	microradians
---------------------	--------------

NOTE: Step not performed.

6.3.7 Iterate/re-Check

Datum: Optical axis as established by the IR Laser Autocollimator.

Equipment: IR Laser Autocollimator

Accuracy:

vertical position: ±6 mm



WBSC6

horizontal position: ± 6 mm

yaw: ± 100 microradians

pitch: 100 microradians

roll: ± 100 microradians

Procedure:

- Re-check the vertical, horizontal, longitudinal, yaw, pitch, and roll positions and iterate until all are within required accuracy.

7 ALIGN THE CARTRIDGE ASSEMBLY IN THE BSC CHAMBER (IN SITU)

7.1 Level the Optics Table and set its vertical position

Datum: Local gravity, BSC-ISI capacitive position sensors

Equipment: Optical Level, 3 metering rods, BSC-ISI capacitive position sensors.

Accuracy: 100 microradians (0.1 mm differential height)

Procedure:

- Make sure all payload and balance/ballast weight is on the BSC-ISI Assembly
- Attach 3 metering rods onto the Optics Table so that all 3 can be viewed from a single Optical Level position, on a tall tripod, through the open BSC door.
- Check the Optics Table levelness optically before unlocking BSC-ISI.
- Check the height of the Optics Table by referencing elevation mark **TBD** with the Optical Level
- If needed, adjust the table to be level using HEPI static adjustment per procedure [E040011](#), "HEPI Assembly and Installation Procedures"
- Unlock the BSC-ISI and compare the capacitive position sensors offset values to the offsets measured on the cartridge test stand. If necessary, adjust the balance mass to get the same capacitive position sensor offsets as achieved on the test stand.
- Confirm the Optics Table levelness (again) with the Optical Level

7.2 Setup the Total Station and Laser Autocollimator

Datum:

- Monuments IAM22, IAM25 and IAM26 (as defined in [D1100291](#)) – axis along the Y centerline
- Elevation mark **TBD** [*Need height references for the Y-end station*]



WBSC6

Equipment: Total Station; Newport Electronic Visible Laser Autocollimator (LAC); Brunson Optical Square; Metering Rods/Targets; 8” diameter Flat Mirror on a Newport Gimbal Mount and Tripod.

Accuracy: ± 1 mm, ± 40 microradians rss, alignment reference transfer (see [T1000230-v6](#), section 17)

Procedure:

N.B.: For the H2 One Arm Test (H2-OAT) we will do the alignment through the end door of the WBSC6 chamber (using a lateral transfer hollow retro-reflector) instead of through spool V049-4-A1 as defined in the IAS Final Design Document (T1000230) and layout drawing (D1002653-v1). As a consequence we will not be able to confirm the longitudinal, lateral or vertical position of the center of the HR face of the ETM; We will rely upon the positioning performed on the cartridge assembly on the test stand. When the ETM optic is replaced the alignment will be performed by removal of the spool piece as originally intended.

- Remove the end door of the WBSC6 per procedure [M1100068](#), “BSC Door Removal and Installation Procedure”
- Set the Total Station/ LAC over monument IAM26.
- Adjust the Total Station height to be -80.0 mm (global coordinate system) using elevation mark **TBD**
- Setup the large Flat Mirror with gimbal mount/tripod with an unobstructed view of, and a few meters from, the Total Station/LAC
- Co-boresight the Total Station and LAC with the Flat Mirror
- Setup the Brunson Optical Square directly over monument IAM25, at the same height as the Total Station, and sight IAM22 to get alignment parallel to the Y global axis
- Set the Total Station to be square to the Brunson Optical Square.
- Yaw the Total Station precisely 90 degrees and set this yaw angle reference to zero. Pitch the Total Station 639 microradians (2’ 11.8”) DOWN. (The Total Station is now pointing along a vector which is parallel to the arm cavity optical axis but shifted laterally 200 mm in the -X direction (and slightly off the vertical center)
- Set up the LTHR on its stand in the spool in front of the ETM so that it is horizontal (bubble leveled) and the LAC beam is well centered in its apertures

7.3 Measure Pitch & Yaw Errors

Datum: Optical axis as established by the total station.

Equipment: Newport Electronic, Visible Laser Autocollimator (LAC)

Accuracy: ± 10 microradians goal

Procedure:

- Peel back the First Contact™ at 12 o’clock.
- Insure that the optics and masses, of the main suspension chain, are free (not ‘clamped’ or on the mechanical stops or earthquake stops)
- Engage damping controls for the ETMy suspension



WBSC6

- Use the LAC to measure the ETM optic pitch and yaw error angles. All personnel should exit the chamber. Purge air flow should be off or minimized. Electronic damping should be active for the suspension. If necessary, use a low pass filtering amplifier and display the pitch and yaw on an oscilloscope with trace persistence and cursors to get the average angles
- If the yaw error is > than the allowed error, then use HEPI (per procedure [E040011](#), “HEPI Assembly and Installation Procedures”) to adjust the BSC-ISI yaw angle.
- If the pitch error is > than the allowed error, then use the SUS procedure ([E1000006](#)-v20, section 5, “Quad Suspension Metal-Build Assembly Procedure”) to adjust the pitch error.
- Record the pitch and yaw errors:

	Trial 1	Trial 2	Trial 3
Yaw error	320 microrad	320 microrad	microrad
Pitch error	-24 microrad	16 microrad	microrad

NOTE: Trial 2 was performed after the First Contact (FC) was removed from the ETMy. We found that the FC was affecting the pitch of the ETMy by approximately -250 μ rad. This was not compensated for during the WBSC8 alignment. The yaw error was signed off as OK for the H2OAT by P. Fritschel.

7.4 Fine Pitch & Yaw Error Correction

Datum: Optical axis as established by the total station.

Equipment: ETM Suspension actuation (BOSEMs), Newport Electronic Visible Laser Autocollimator

Accuracy: ± 10 microradians goal

Procedure:

- Use the Laser Autocollimator to measure the TM optic pitch and yaw angles. All personnel should exit the chamber. Purge air flow should be off or minimized. Electronic damping should be active for the suspension. If necessary, use a low pass filtering amplifier and display the pitch and yaw on an oscilloscope with trace persistence and cursors to get the average angles
- Use the TM Suspension controls interface to set pitch and yaw bias values to correct the residual errors
- Record the pitch and yaw bias values:

NOTE: Step not performed.

Pitch bias	Counts
Yaw bias	Counts

8 Align Arm Cavity Baffle (ACB) Assembly

N.B.: The ACB will not be installed or aligned for the H2-OAT



WBSC6

Datums:

Optical axis as established by the total station

Equipment: Total station, pusher assembly ([D060052](#)).

Accuracy: $\pm 2\text{mm}$

Procedure:

- Install and suspend the ACB from stage-0 of the ISI using procedure [E1100810](#), “Arm Cavity Baffle Installation Procedure”.
- Re-level table using HEPI (see section 7.1)
- Check horizontal alignment using the Total Station to sight on left & right edges of the baffle.
- Check vertical alignment using the Total Station to sight on top & bottom edges of the baffle
- If both vertical and horizontal positional errors are $< 2\text{mm}$, then proceed to next step. Otherwise, reposition using the pusher assemblies ([D060052](#)) per procedure [T080230](#) until the positional errors are within tolerance.