Auxiliary Optical Systems – Initial Alignment System (IAS)

Technical Presentation

aLIGO NSF Review

LIGO Livingston Observatory

24-28 April 2011- Doug Cook, et al

LIGO-G1100430

Initial Alignment

- **Initial Alignment** - IAS is a component of the Auxiliary Optics System (AOS) for Advanced LIGO (aLIGO).
- **The Principal Scope** - IAS system is to align the *Primary Optics* of the aLIGO using the proven methods and experiences developed for iLIGO
  - **IAS -** comprises the necessary *equipment* and *procedures* for setting the initial positions and the angular alignments of the Primary Optics.
  - **IAS** - responsible for re-establishing the *local* survey monuments and *global* positions that the Primary Optics will be positioned and aligned to.
  - **IAS** - responsible for enabling all other optic systems to be aligned to the Primary Optics by providing targets or pre-aligned Primary Optics
  - **IAS** - alignment activities are performed under the direction of the *Installation* (INS)team.

Initial Alignment Design Concept 1

1. **Basic Strategy:**
   - **Monuments:** Create new precise permanent reference survey monuments
     - ➢ Based on the vacuum envelope placement.
   - **The Seismic (ISI) optic tables:** Table coordinates and angles are aligned first (with a substitute payload)
     - ➢ Set using a “Total Station” Theodolite and optical level
     - ➢ Set table *elevations, rotation, translation and beam axis position*
   - **Assembly Balancing:** The primary optics are hung roughly at their proper balance angles relative to their structures during the suspension assembly and captured.
     - ➢ The Quad suspensions undergo rebalancing after the silica fibers are welded just prior to each chamber installation.

Initial Alignment Design Concept 2

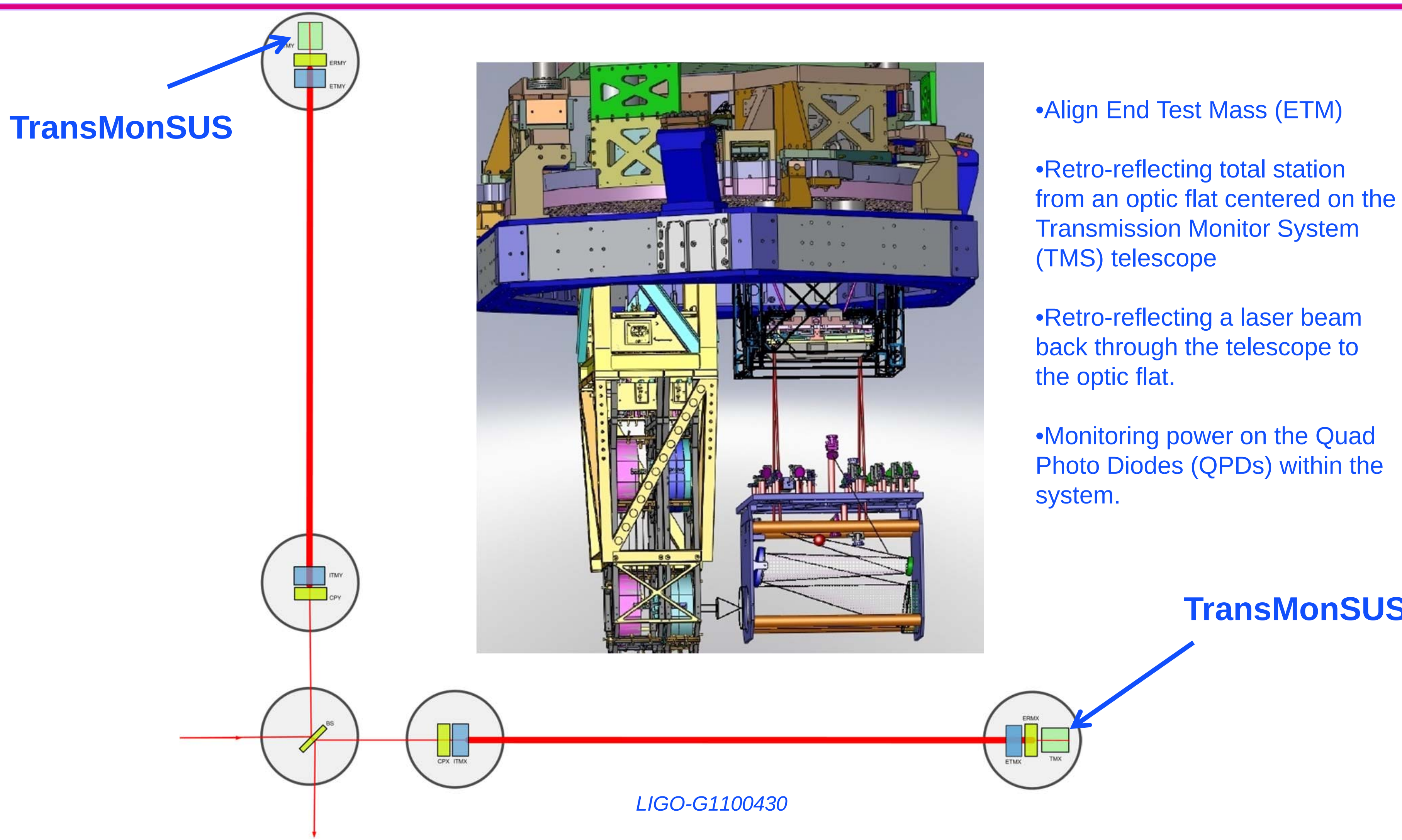
- **Approximate Alignment** – Using *Templates* to "dead reckon" suspension positions on HAM and BSC tables.
  - Baseplate edges are first accurately measured from HR optic faces and optic axis and provide reference features (see below)
- **Cartridge Alignment:** Co-align major payload elements sharing the same BSC optics table as an assembly before installation into the BSC chamber.
  - This is known as the "cartridge assembly".
  - Templates and survey techniques are use to position the payloads.
- **Precise alignment in situ** : Using high precision specialized survey equipment.
  - For BSC chambers, this means moving the *cartridge assembly* as a rigid body (using HEPI as the alignment actuator).
  - For HAM chambers this means aligning each individual assembly on a HAM optics table.
  - Longitudinal, lateral translation, vertical coordinates of the *primary optics* are first positioned to absolute global references aligned to pre-established, surveyed monuments

Initial Alignment Design Concept 3

- **Integrated alignment check:** Once the optical elements have each been aligned based on survey monuments, we check and adjust the optics *relative* to one another.
  - Optical reference is derived from the test mass high reflectance (HR) face(s).
  - This is accomplished using autocollimators projecting though each particular group of elements.
- **IO Beam path:** IAS will Establish the input beam propagation into the Michelson interferometer.
  - This alignment will need to be coordinated with the IO team to assure the IO output beam and the IAS backward propagating beams co-align with each other.
- **Alignment of beam dumps and baffles** associated with the primary optics
- **Alignment Support** for optical payloads as they are integrated onto the seismically isolated tables. (This is generally the responsibility of each subsystem)

. e.g. see next slide

IAS Alignment Support
Transmission Monitoring Suspension Assembly



- Align End Test Mass (ETM)
- Retro-reflecting total station from an optic flat centered on the Transmission Monitor System (TMS) telescope
- Retro-reflecting a laser beam back through the telescope to the optic flat.
- Monitoring power on the Quad Photo Diodes (QPDs) within the system.

Requirements – High Accuracy

Primary Optic placement and alignment tolerances

- **The IAS design requirements are defined in T080307.**
  - The requirements are similar to those for initial LIGO
  - Tighter positional tolerances on the recycling cavity optics are required.
  - Since iLIGO alignment was successful, little risk for advanced LIGO IAS.
- **The Basic Alignment Requirements relative to the beam tube axis are:**
  - Axial positioning to within ± 3 mm
  - Transverse positioning to within ± 1 mm for the ITMs and ETMs,
  - Transverse positioning to within ± 1 mm vertically and ± 2 mm horizontally for the PRM, PR2, SRM and SR2,
  - Transverse positioning to within ± 3 mm for the BS, FM, PR3 and SR3 optics.(relative to the main beam path)
  - Angular pointing to within 10% of the actuator dynamic range, which corresponds to ± ~100µrad generally.

Alignment References

- The original **iLIGO** survey monuments will remain.
- In order to achieve the accuracy needed in the aLIGO
  - IAS will survey and place more permanent and precise monuments.
  - IAS will epoxy new s/n’d engraved brass markers to the floor. (“H1”, “L1” and “H2” identifiers)

- We will retain the monuments created to date.
  - Including their numbering/naming
  - Standardize all monuments by creating a new database maintained in the Document Control Center (DCC).

Survey Monuments and Beam Offset Lines

- Sighting ~200 meters down the beam tube to establish an “offset” axis parallel to the beam tube centerline surveyed to and accuracy of ~15µrads.

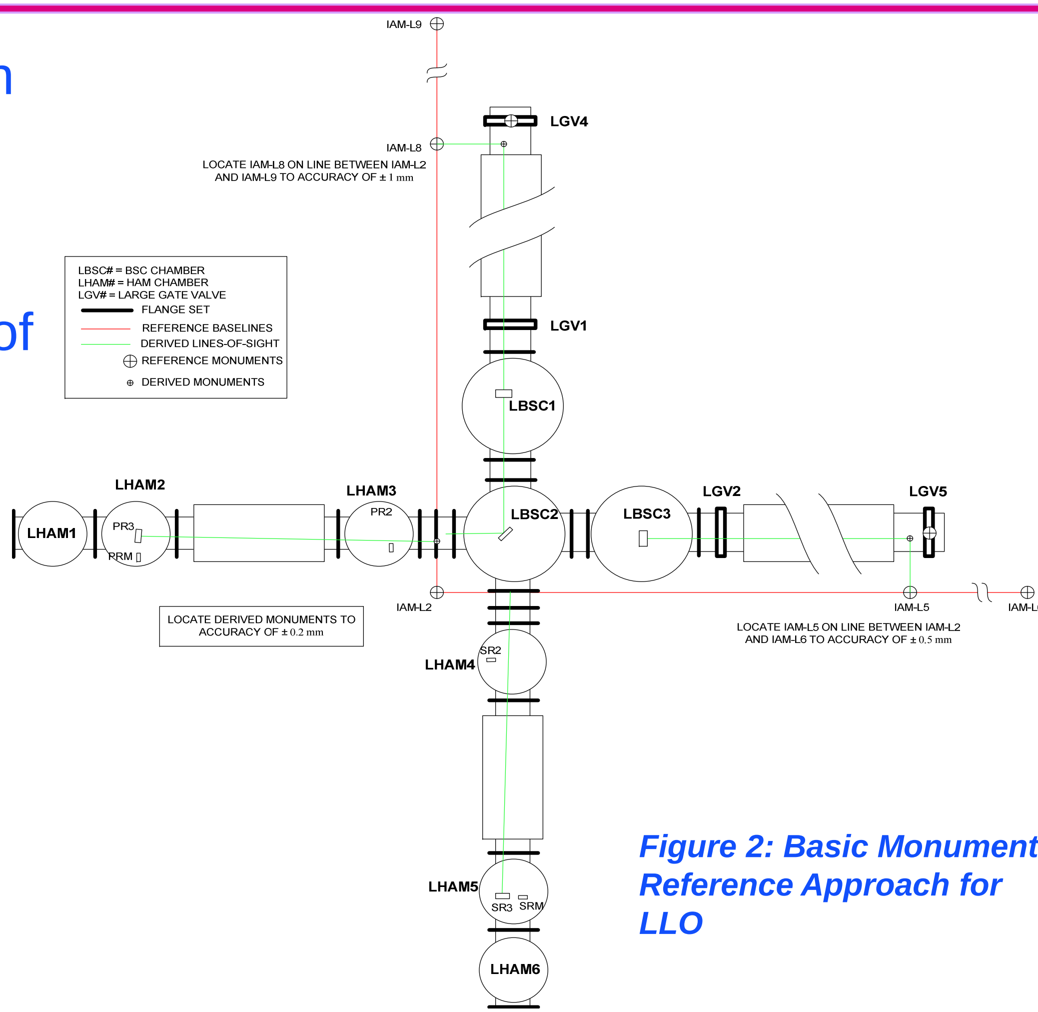


Figure 2: Basic Monument Reference Approach for LLO

Survey Monuments and Beam Offset Lines

X and Y - Azimuth
"Offset" monuments are established from the existing monuments that were used to position the beam tubes and chambers and are placed to permit convenient sighting and measurement of primary optics.

These axial and transverse positional coordinates are referenced to the global coordinates set by the beam tubes.

These new monuments are visible from key positions on each primary optic's normal beam vector, placed near removable spools of the vacuum envelope.

***Zoffset* Local Elevations** will be in relation to the Beam Splitter (BSC2) chamber centerline ("0") and offsets will be logged and wall targets placed for each chamber's relationship elevation and then corrected for the Global positions, accounting for the curvature of the earth.

H2 monuments must be derived from the H1 X and Y arm baselines

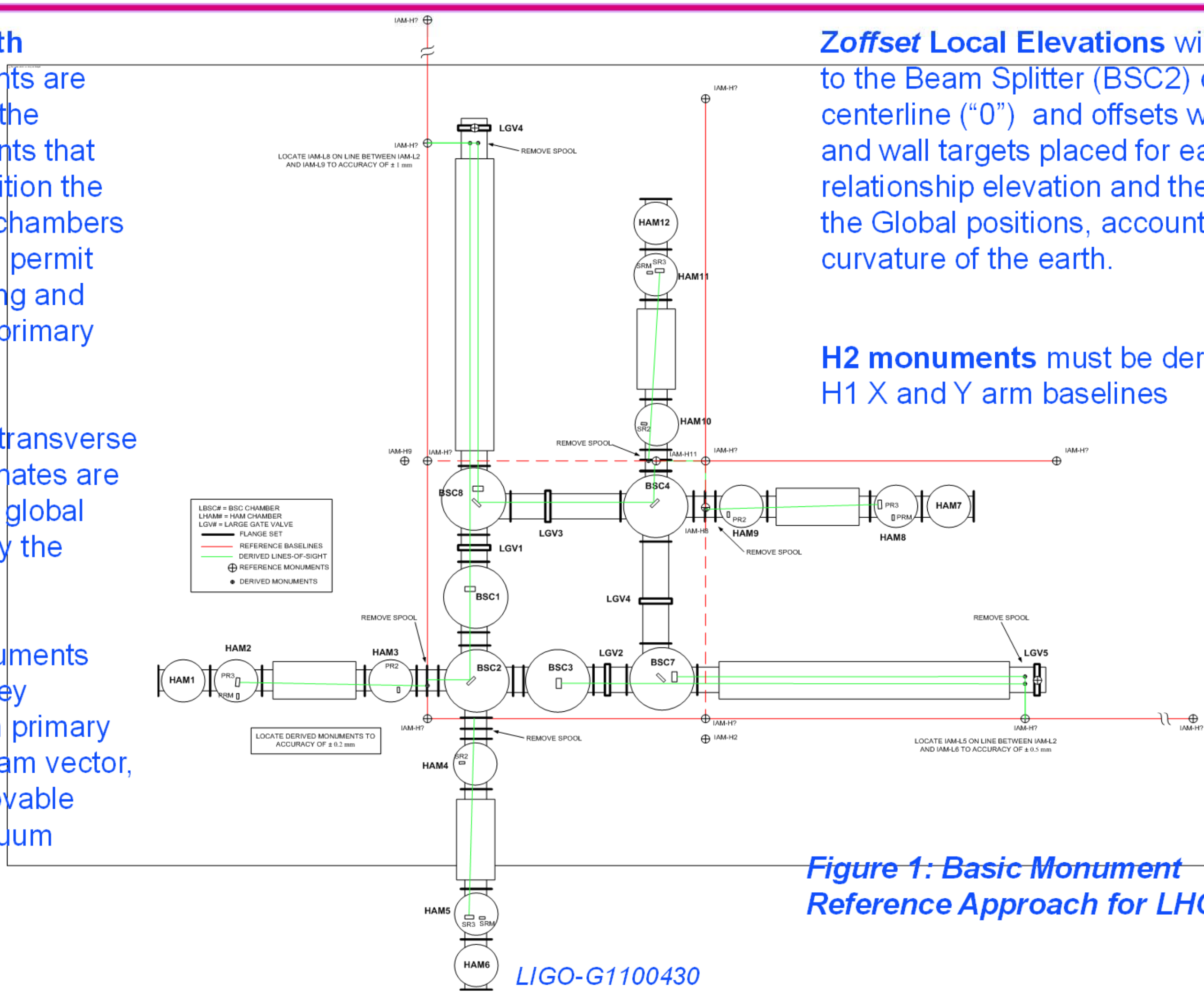


Figure 1: Basic Monument Reference Approach for LHO

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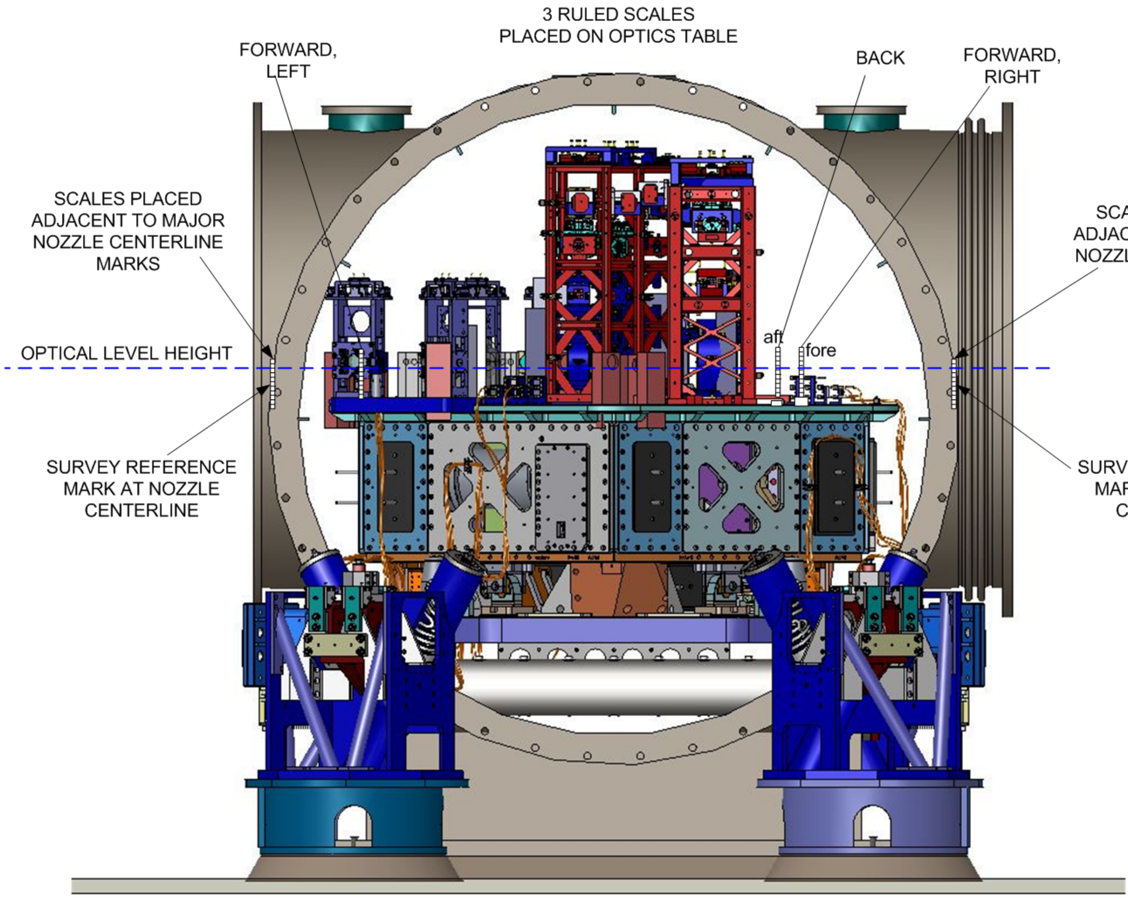
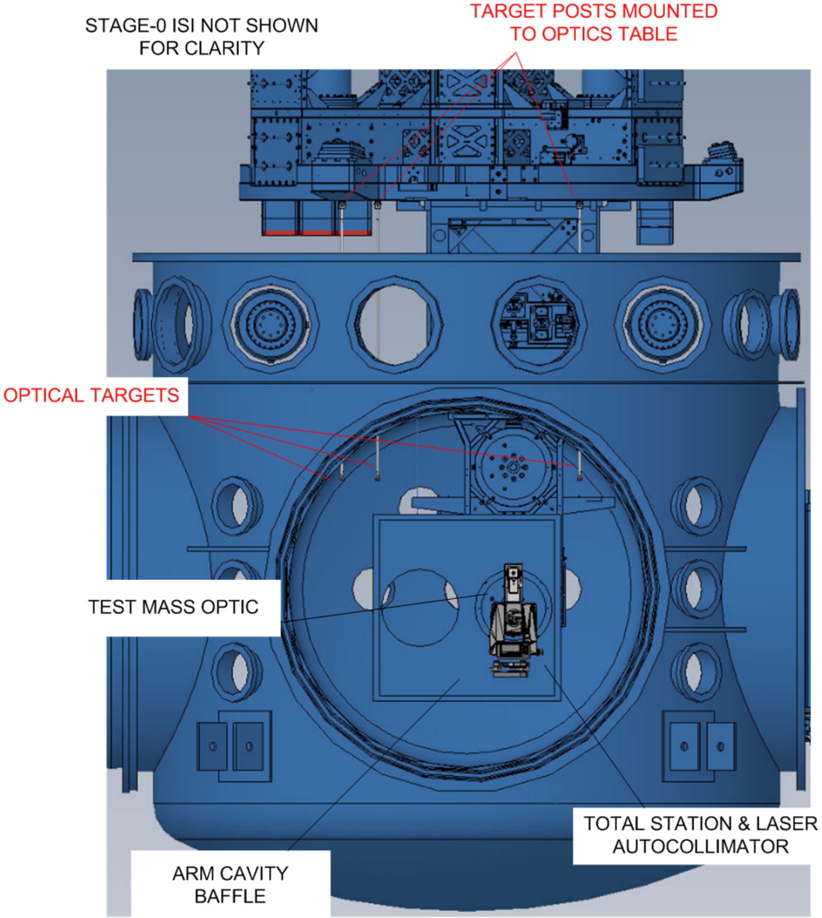
Alignment of ISI optic tables



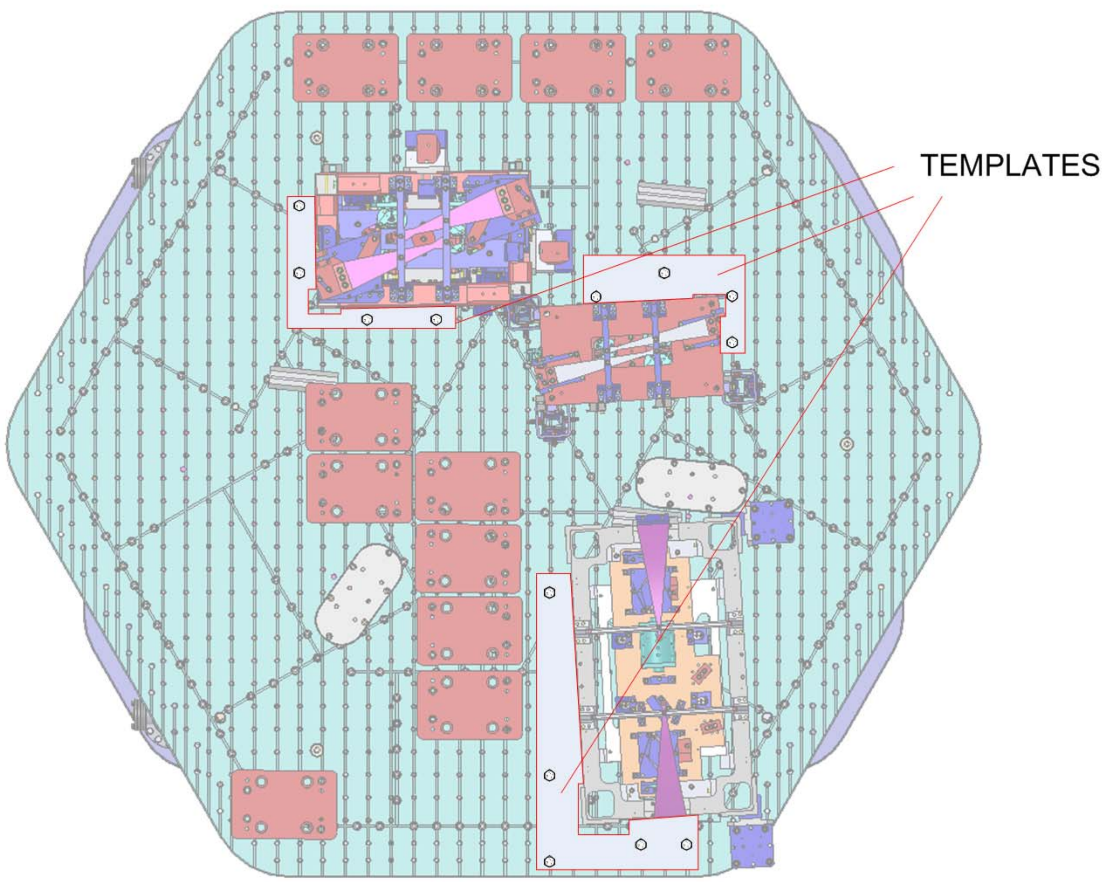
For aLIGO we will use bubble levels for initial leveling and quick checks, but optical targets and an optical level for precision leveling (~0.05 mrad).

Alignment of ISI optic tables



The Total Station/Autocollimator is depicted in a position/height to align the test mass optic. In order to set the table height and level an optical level will be placed on a tall tripod to view the optical targets on the table through the door opening

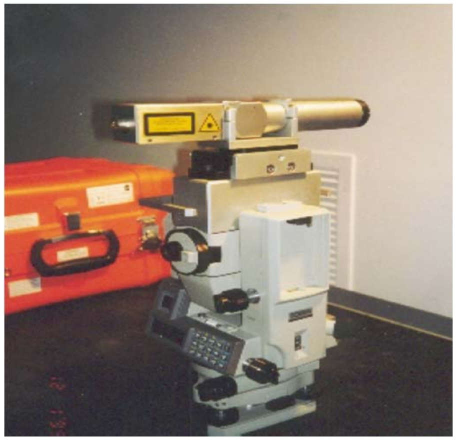
Approximate Alignment



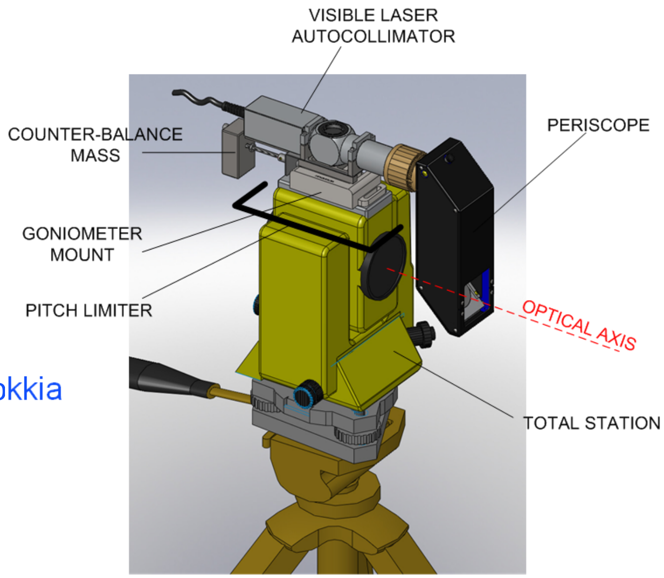
Approximate Alignment with Templates –

- **For the larger suspension assemblies, templates are installed on the optics table using appropriate tapped holes in the table surface.**
- **The optical assemblies are then placed on the table with mating surfaces at the base of the assemblies against the template.**
- **Once the optics assembly is clamped to the optics table, the templates are removed.**
- **At this point only a couple of dog clamps serve to keep the approximate payload alignment**

Precise alignment 1



Photograph of the laser autocollimator mounted on the Sokkia Set2B for iLIGO.



•The periscope mounted to the autocollimator places the autocollimator optical axis on the same axis as the Total Station.

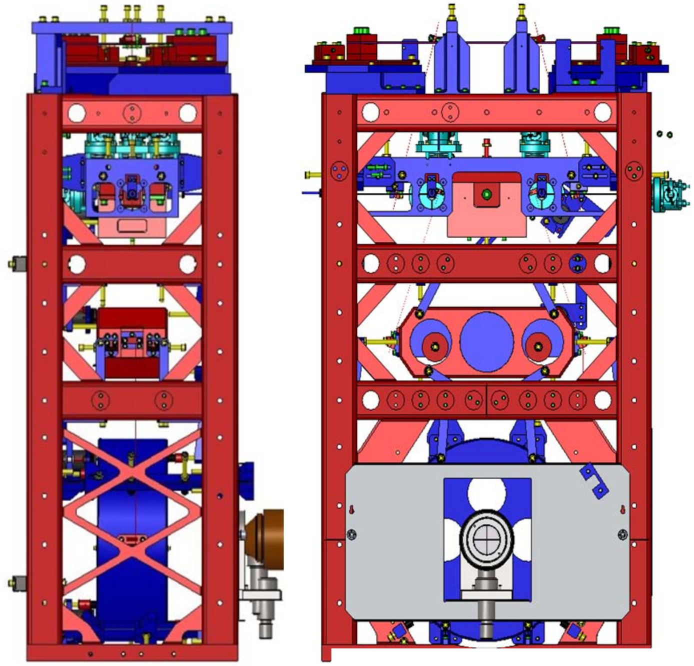
• A total Station is a Theodolite with distance measuring capability.

•Precise alignment of Primary Optics is performed with a Total Station, a retro-reflector with attached target and a laser autocollimator mounted on the Total Station

- ➢Establish the optical axis: Prior to installing onto a HAM-ISI optics table, establish the optical axis with zero OSEM bias commands.
- ➢Longitudinal position: The Total Station's electronic distance measurement (EDM) capability is used with the retro-reflector assembly to establish longitudinal position.
- ➢Lateral & Vertical position: The Total Station is used to establish lateral and vertical position by sighting on the target in the retro-reflector assembly on the suspension frames.

Precise alignment 2

Above: Retro-reflectors with attached ***cross-hair target***



Upper Right: The **temporary retro-reflectors** mounted to a HSTS structure.

Coordinate Measuring Machine (CMM) is used to measure and set the co-alignment of the retro-reflector to the optic and the offset distance to the optic face

Precision Alignment Equipment 1

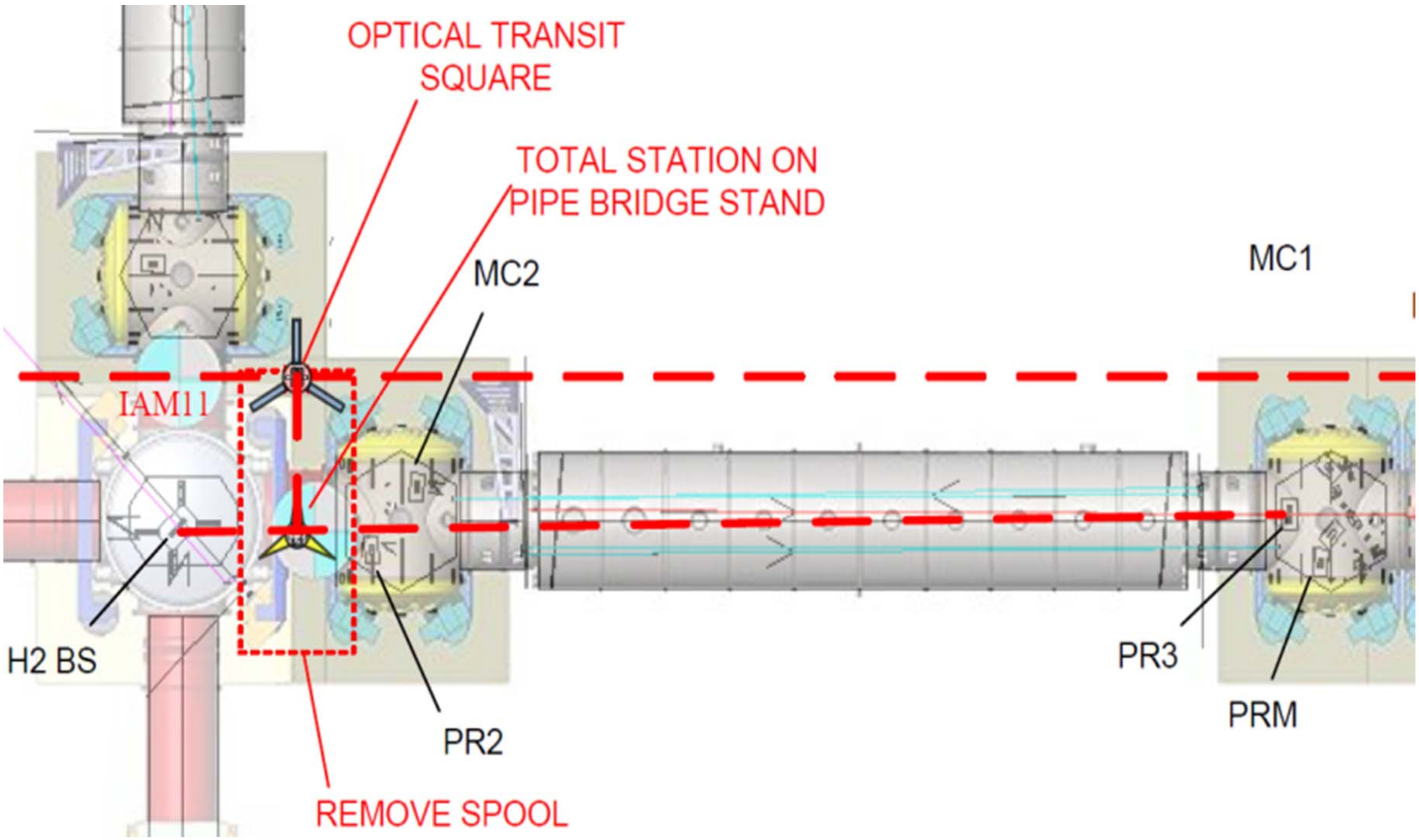
Brunson Optical Transit Square

Sokkia model SetX1
(new model)

Sokkia model Set2B

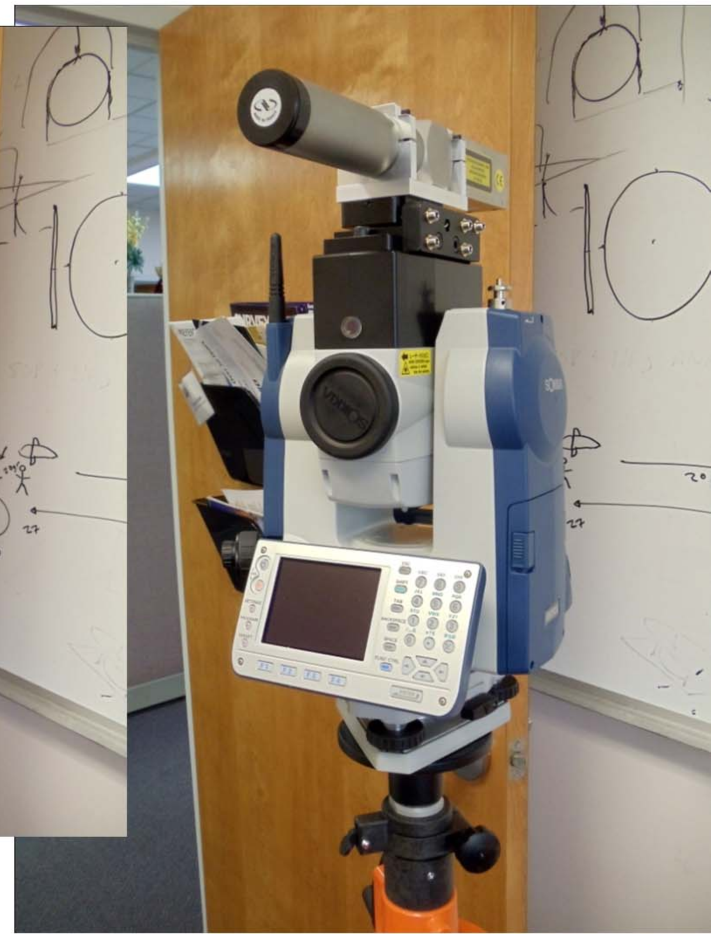
A distance-measuring Theodolite (Total Station) is used to both position and dial in correct angles for each primary optic

Optical Transit Square



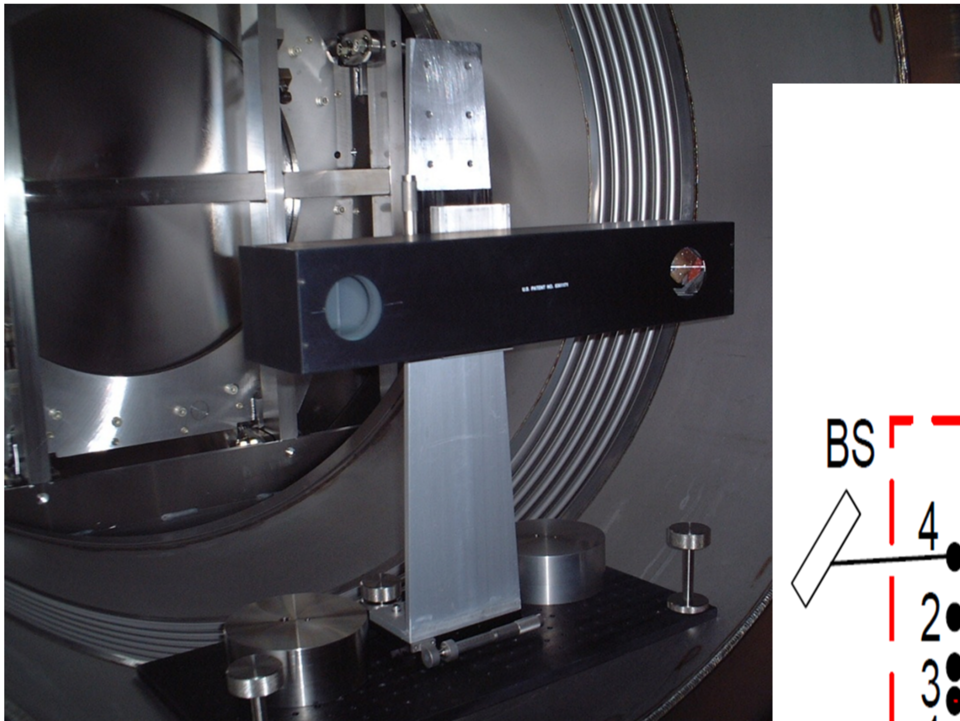
Precision Alignment Equipment 2

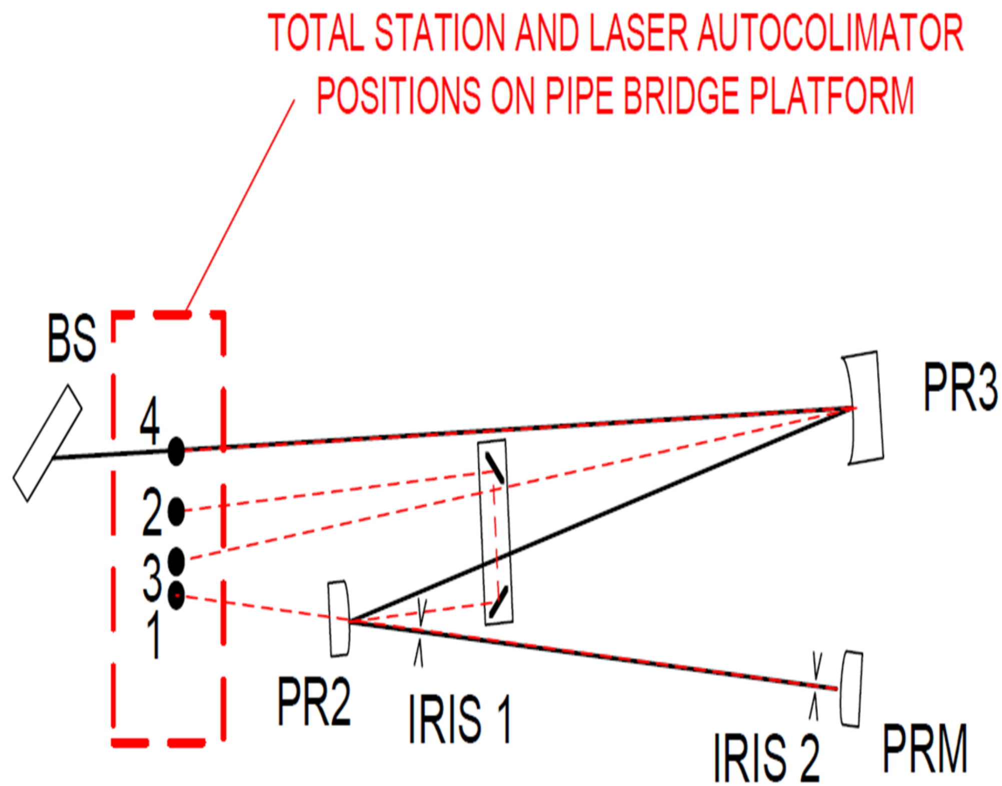
Goniometer base for aligning the **laser autocollimator** to the total stations



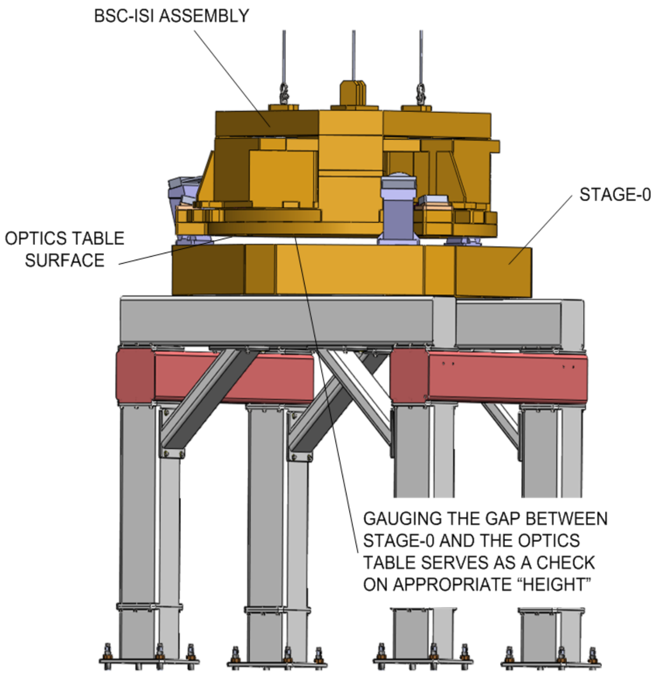
Sokkia model SetX1 with Newport Laser autocollimator mounted up

Lateral Transfer Retroreflector



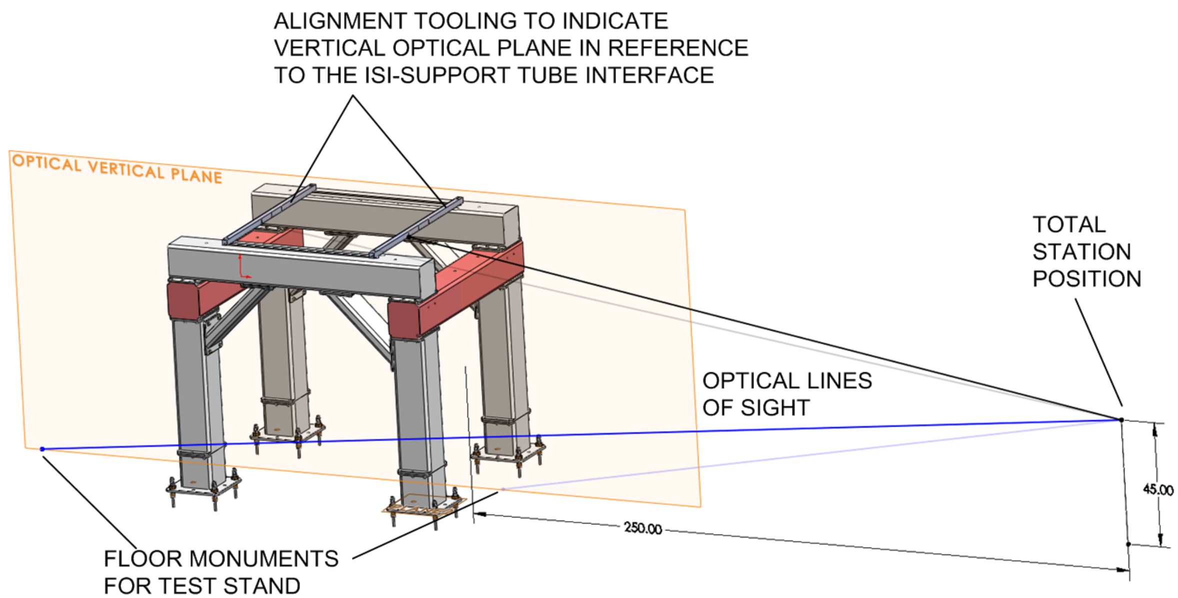


IAS Alignment - BSC Cartridge Installations 1



The BSC-ISI system does not have the capability to (readily) adjust yaw and horizontal plane positioning (x, y) while on the test stand.

The H1 ITMs mount 90º to the support tubes



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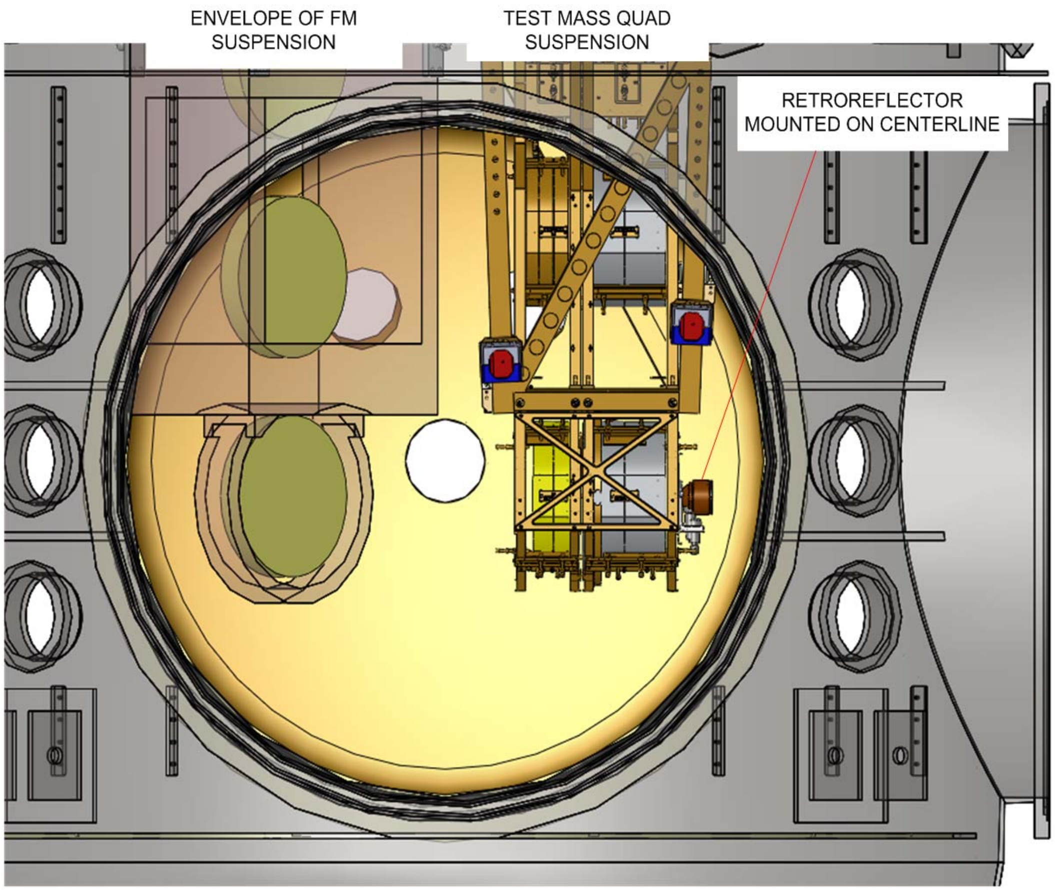
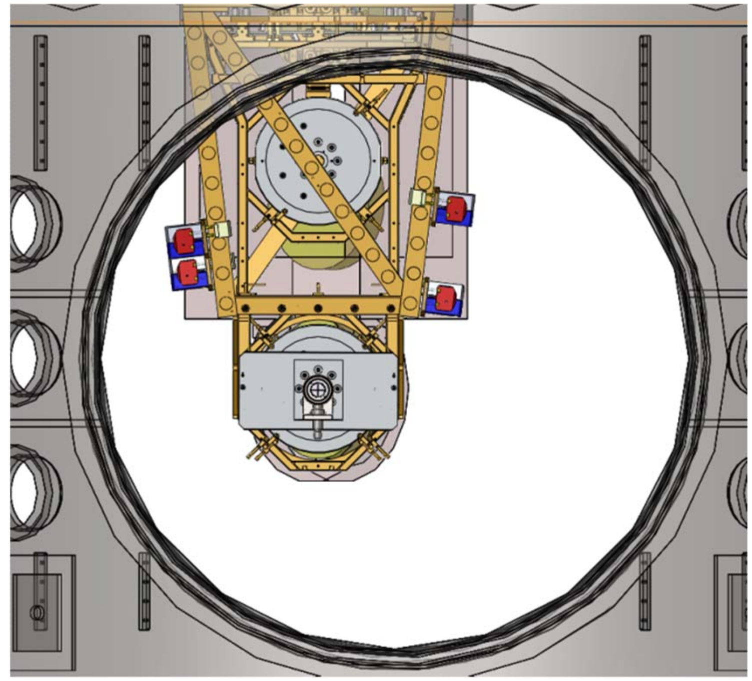
Cartridge Installation 2





Once installed in the BSC chamber, the HEPI static positioning capability can be used to adjust all six degrees of freedom of the optics table.

IAS Development Plans and Accomplishments 1

- IAS Final Design Review Approved - Jan 2011
  - With some required changes and additions ongoing
- Major equipment purchases completion anticipated by June 2011
  - 80% completed
- All fabricated parts in house, cleaned and bake completion anticipated by June 2011
  - 80% completed
- Testing of Autocollimators for Integrated Alignments completion anticipated by June 2011
- Quad suspension ‘Gap’ setting and balance technique and coordination plan with IAS (overlapping tasks with SUS subsystem) by June 2011
  - 50% completed

IAS Development Plans and Accomplishments 2

Update all drawings, flowcharts, detailed installation plans for each primary optic system

- ➢50% complete - ongoing

•Approved Hazard Analysis and laser SOPs prior to first installations

- ➢ 50% complete - ongoing

•Additional CMM training to develop expertise in its use

•Additional training or practice with new total stations.

•Working with journeyman survey contractors currently on site for added support when needed

Challenges: and Solutions 1

Challenges:

- Meeting scheduled plans developed by the INS group and defined in G1000013 (LLO) and G1000061 (LHO).

Solutions:

- Minimize unknowns and be aware of problematic issues when integrating with other subsystems.
- Detailed written step by step procedures will be written in advanced of each chamber installation with prerequisites.

Challenges:

- Line of sight issues (baffles or component clipping) or component delays may cause an additional venting of the vacuum system.

Solutions:

- Integrating with pertinent subsystems, proper communication and planning with INS teams.

Challenges: and Solutions 2

Challenges:

- Transmission and reflections from Primary Optics –
  - The relative alignment of the optics was checked for iLIGO with the COS infrared laser autocollimator. However the power was marginal, even with a 4W source was somewhat marginal. A higher power source will be sought for aLIGO.

Solutions:

- Testing before hand. (limited due to using iLIGO optics and autocollimators).
  - We're looking into other autocollimators.
  - The total station visible beam may work for this in some cases (PRM and SRM).

Challenges: and Solutions 3

Challenges:

- Swapping out ITMs and ETMs to replace optics or fibers will have it own set of issues as we will not remove them as a "cartridge" configuration.
  - It will require different procedures for alignment, different installation hardware as well as safety concerns

- **Solutions:**
- Careful planning and execution.
  - Proper protection of the optic and suspension
  - Protecting the other components in the chamber.
  - The use of an Ergo Arm. (tested and fit check)

IAS Project Plans and Organization 1

- Project Plans
  - On schedule for deployment for Long Arm Test – Sept.2010
  - On schedule of deployment for Short Michelson Test – June 2011
  - On schedule for deployment of three aLIGO IFOs – 2011 – 2012

- Project Organization
  - Dennis Coyne - aLIGO Chief Engineer - IAS Cognizant Engineer - Caltech
  - Eric Gustafson – AOS Lead
  - IAS Lead- Doug Cook– Hanford
  - Optic Engineer – Jason Oberling – Joins IAS team in May
  - ISI Lead - Hugh Radkins - Hanford (has extensive iLIGO survey alignment experience and will contribute as time permit)

» (continued)

IAS Project Plans and Organization 2

- Scott Shankel – Mechanical Engineer and Draftsman – Caltech
- Eric James – Mechanical Designer and Documentation Support – Caltech
- Gary Traylor - LLO support

- Outside contractor support for additional surveying as needed at LHO and LLO

Pertinent References, Definitions and Tables contained in the following:

T1000230 *Auxiliary Optics System (AOS) Initial Alignment System (IAS) Final Design Document*