

# Fermilab Holometer Status Report



Jason H. Steffen  
for the Holometer collaboration  
(Fermilab E-990)

Patras Workshop

July 2012

# Fermilab Holometer Collaboratio

Fermilab: Aaron Chou, Craig Hogan, Hank Glass, Gaston Gutierrez, Craig Hogan, Chris Stoughton, Ray Tomlin, James T. Volk, William Wester

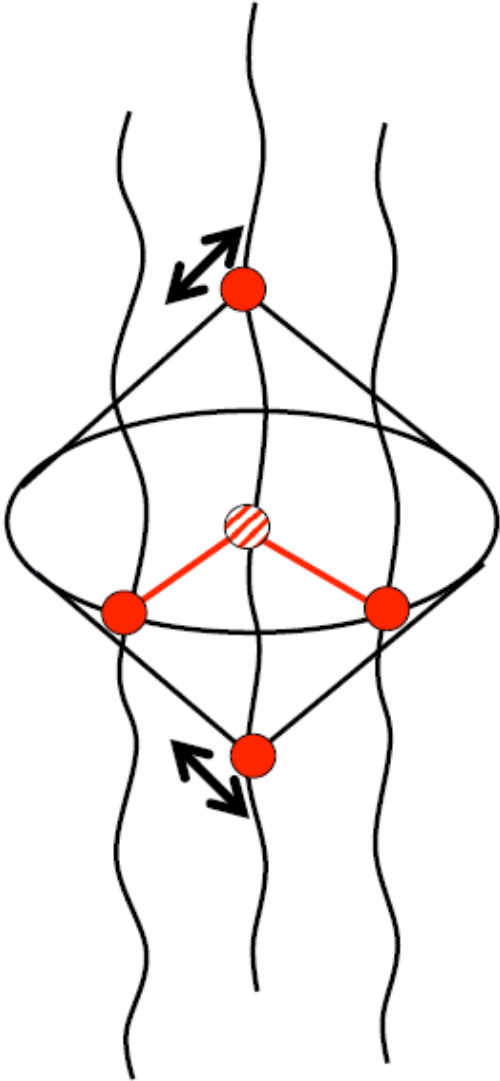
University of Chicago: Stephan Meyer, Ben Brubaker (now at Yale), Brittany Kamai, Bobby Lanza, Lee McCuller

MIT: Rainier Weiss, Sam Waldman (now at SpaceX)

University of Michigan: Dick Gustafson

Northwestern: Jason Steffen (formerly Fermilab)

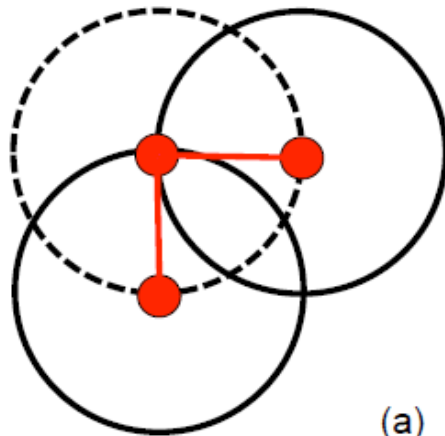
# Holometer Experiment Overview



A single interferometer probes the spacetime that is enclosed within a cone-shaped spacetime volume.

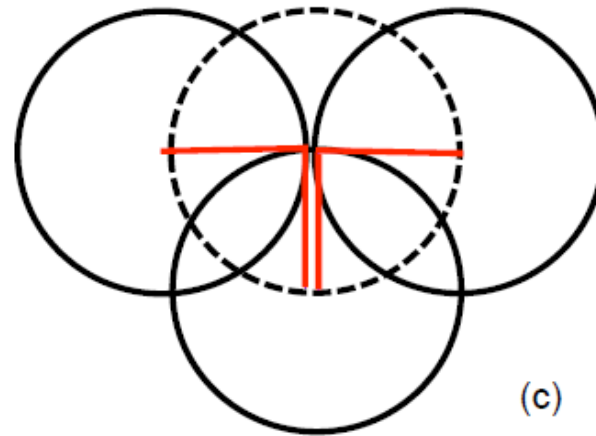
With two, nested interferometers we can compare two simultaneous measurements of the same volume.

# Holometer Experiment Overview



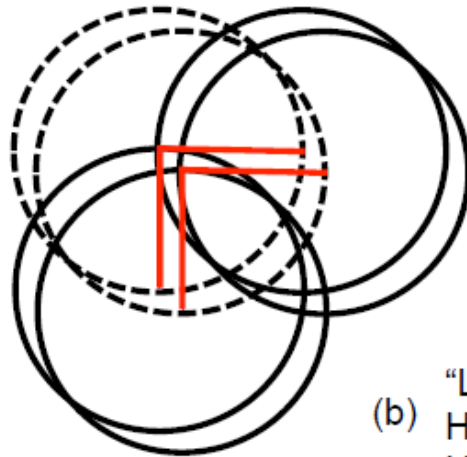
Top view of diamonds for one interferometer

(a)



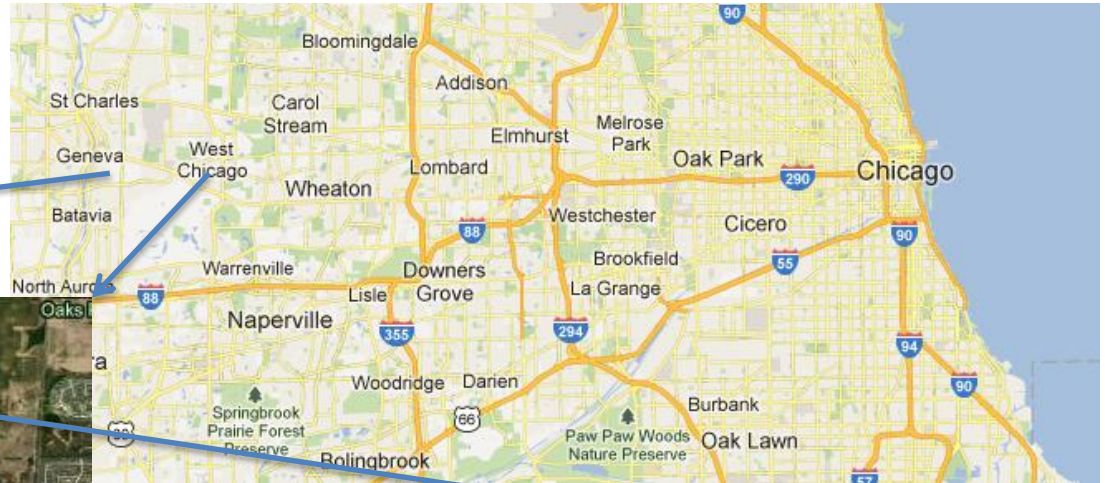
(c)

"T" configuration  
No overlap of diamonds  
from end mirrors  
No signal correlations



(b) "L" configuration  
Highly entangled diamonds  
Highly correlated signals

# Holometer Site Information



# Holometer Site Information



The MP tunnel (Meson Polarized) was retrofitted to create a >100m laser laboratory.

Three interlocked entrances.

Three clean rooms (two are moveable).

# Holometer Construction



The east arms terminate in the newest Fermilab building.

Interlocked with the tunnel lab.

Climate controlled and lighted.

Clean room.

Concrete slab floor rests on 3 pillars driven ~2m deep.

# Holometer Construction

All arms are insulated for baking and temperature control.

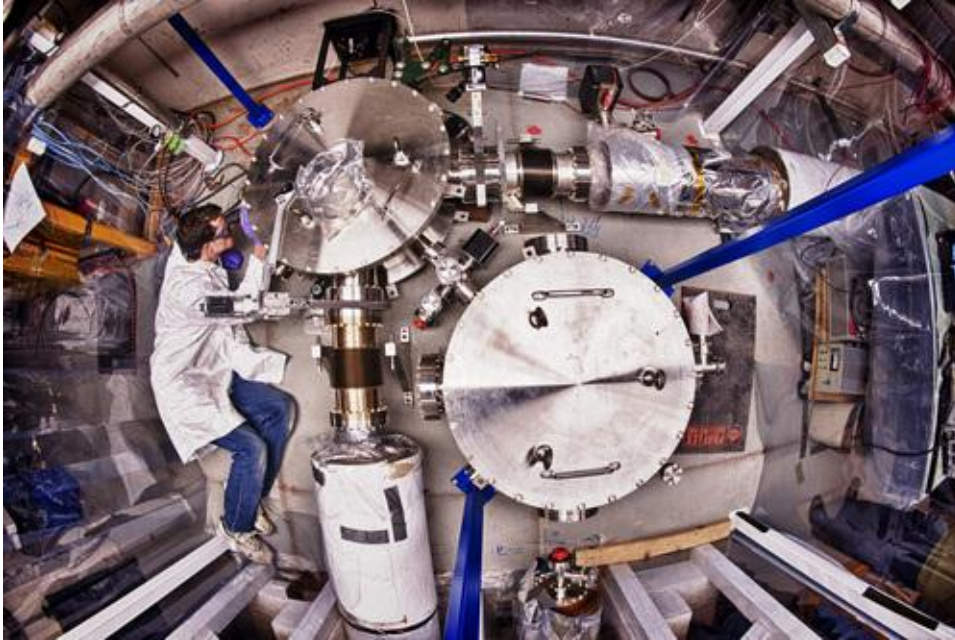
Outdoor arms pass by the Holometer control room (portacamp 49).

Outdoor arms were prepared and assembled in November 2011.





# Holometer Construction



Corner stations located inside the tunnel, within a clean room.

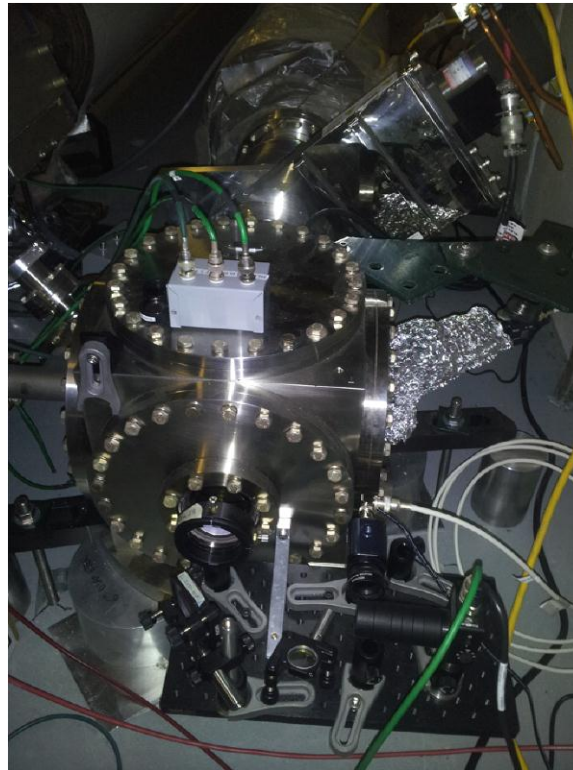
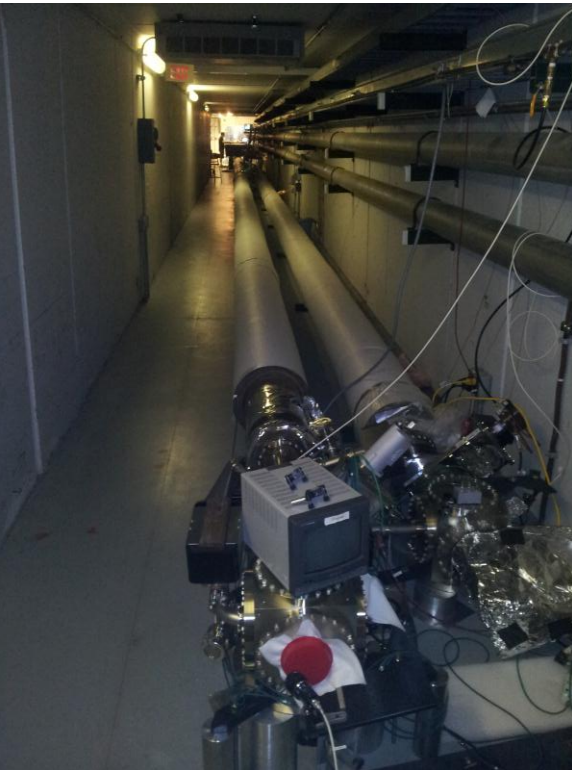
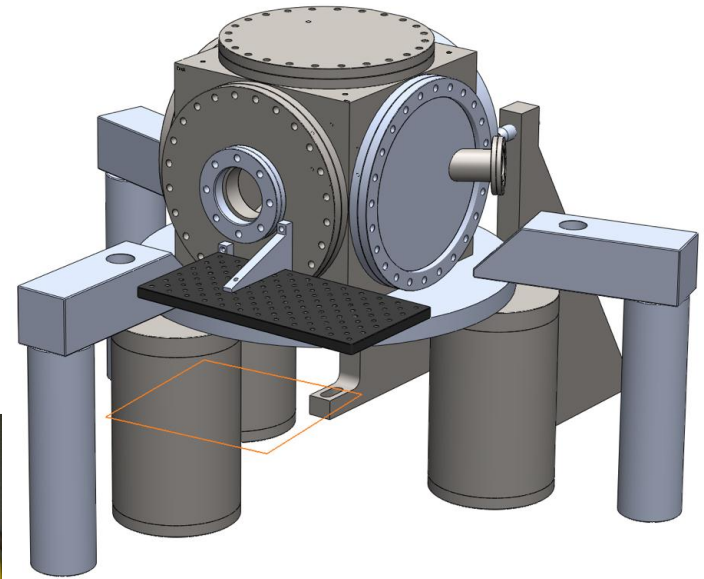
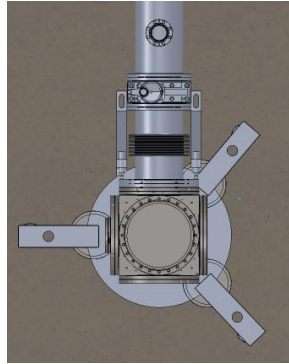
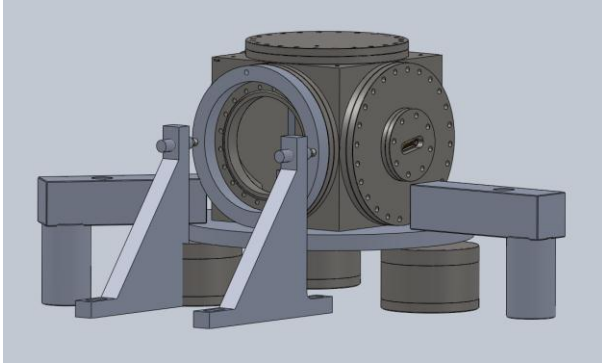
“T” interferometer is outside the “L” interferometer.

Two optical tables are near the corner stations.

Electronics racks and work spaces are opposite the optical tables.



# Holometer Construction



End stations made from 10" cubes.

End mirror mount is attached to the upper flange.

# Holometer Vacuum Assembly



Hydrocarbons is the primary concern with the vacuum system.

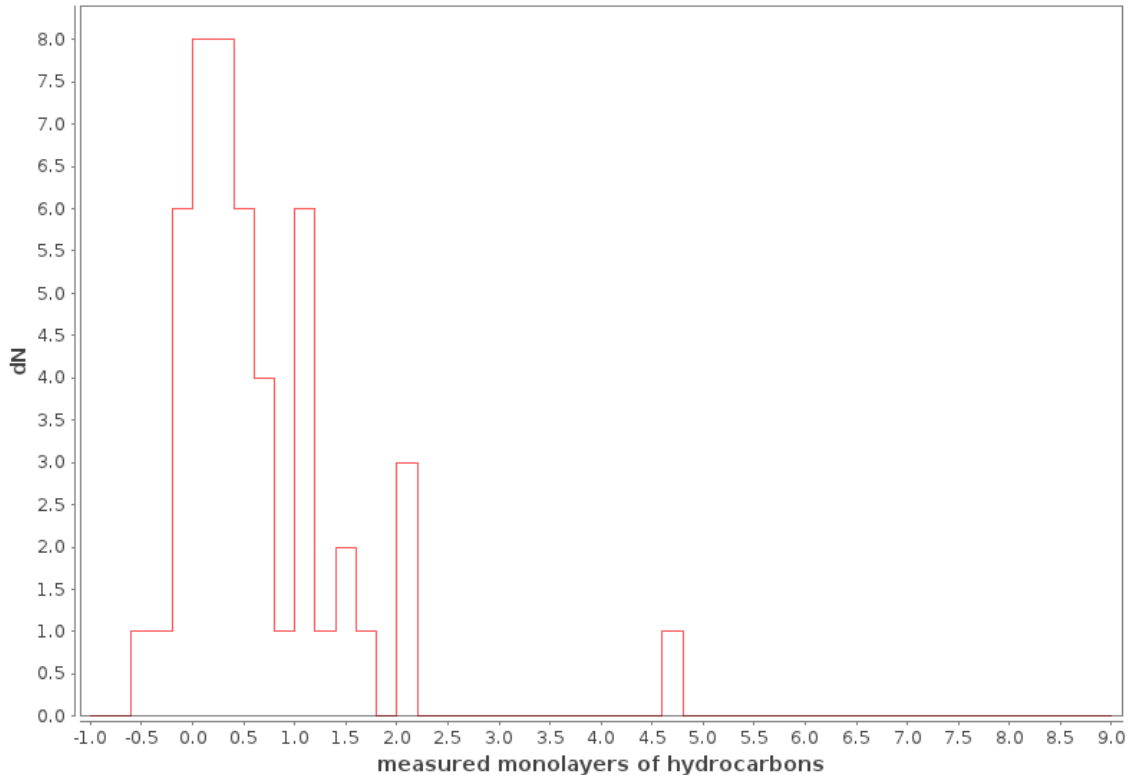
For prototype assembly we re-cleaned all of the arriving parts (trust but verify).

Deemed too costly for the balance of the holometer.

Now employ Fourier Transform Infrared Spectroscopy (FTIR) method used for LIGO.

# Holometer Vacuum Assembly

FTIR Summary



Flow a solvent down the pipe.

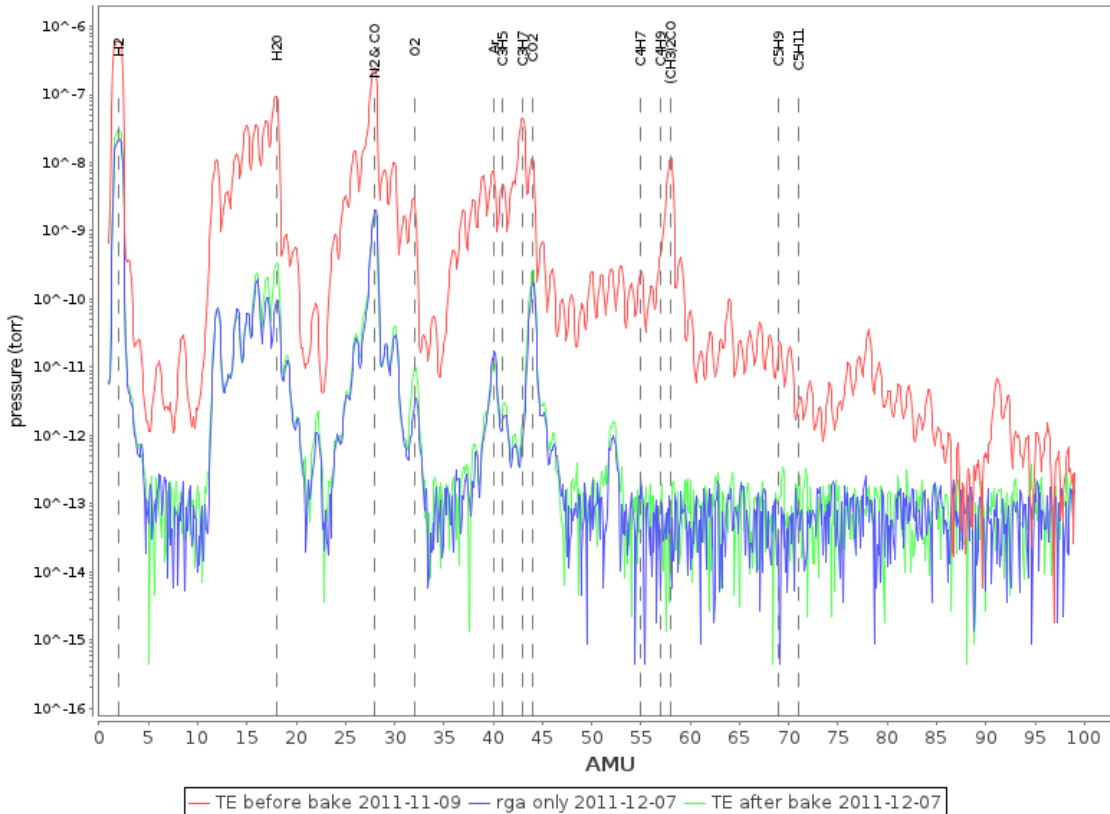
Measure the concentration of hydrocarbons in the solute with FTIR.

Convert the result to “number of monolayers”.

5 monolayers is the specification for the manufacturer.

# Holometer Vacuum Assembly

TE Arm Bake

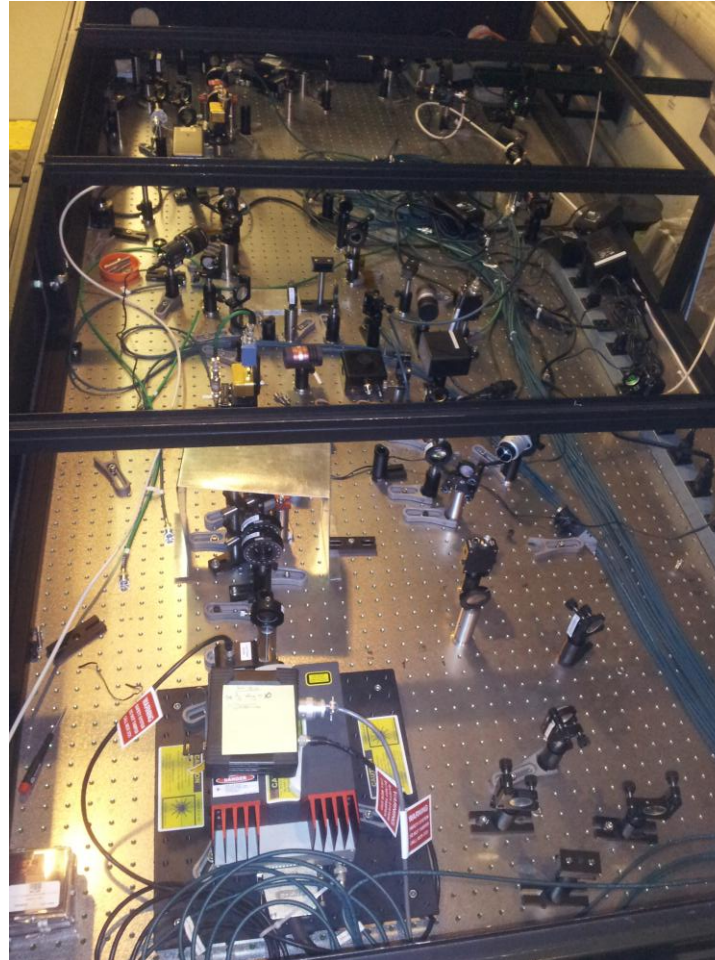
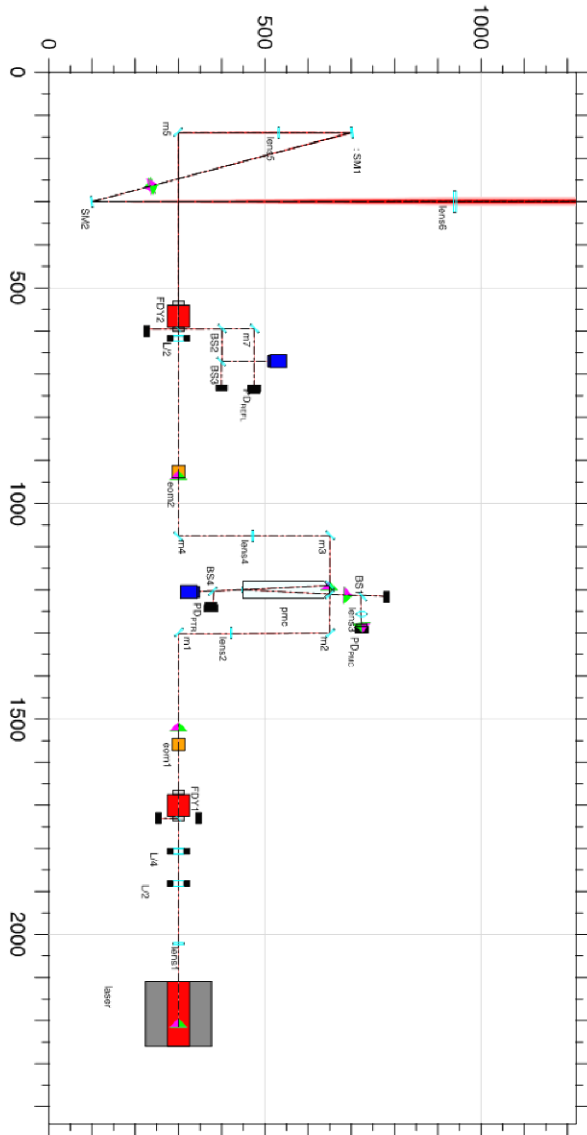


Bake each arm to  $> 150\text{C}$  independently by flowing current down the pipe itself.

300 A at 10-12 V, 3-7 days with turbopumps running.

Combination of baking and FTIR specification yield acceptable hydrocarbon partial pressure ( $1\text{e-}12$  Torr).

# Holometer Optical System



Continuous 2 W Mephisto Nd:YAG input laser.

Mode cleaning ring cavity “pre mode cleaner”.

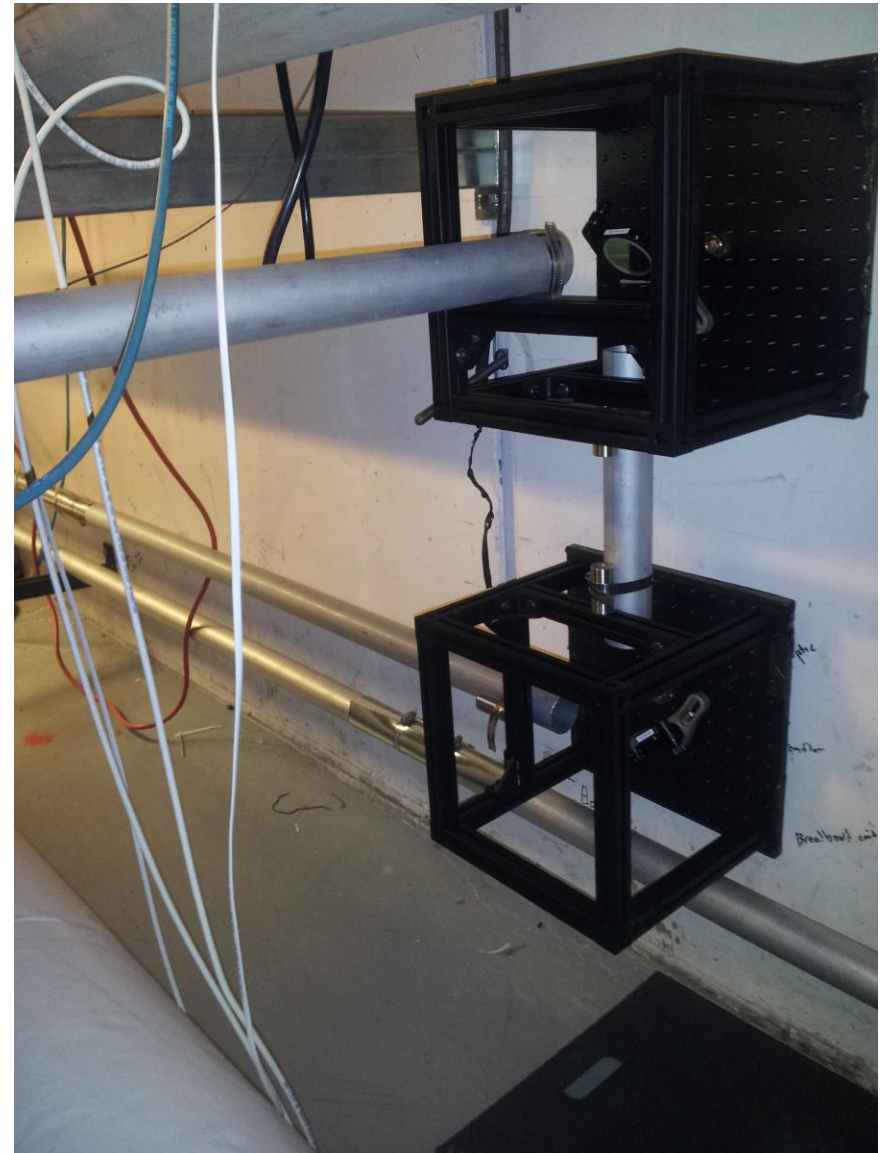
Sidebands added for mode cleaning and for power recycling.

# Holometer Optical System

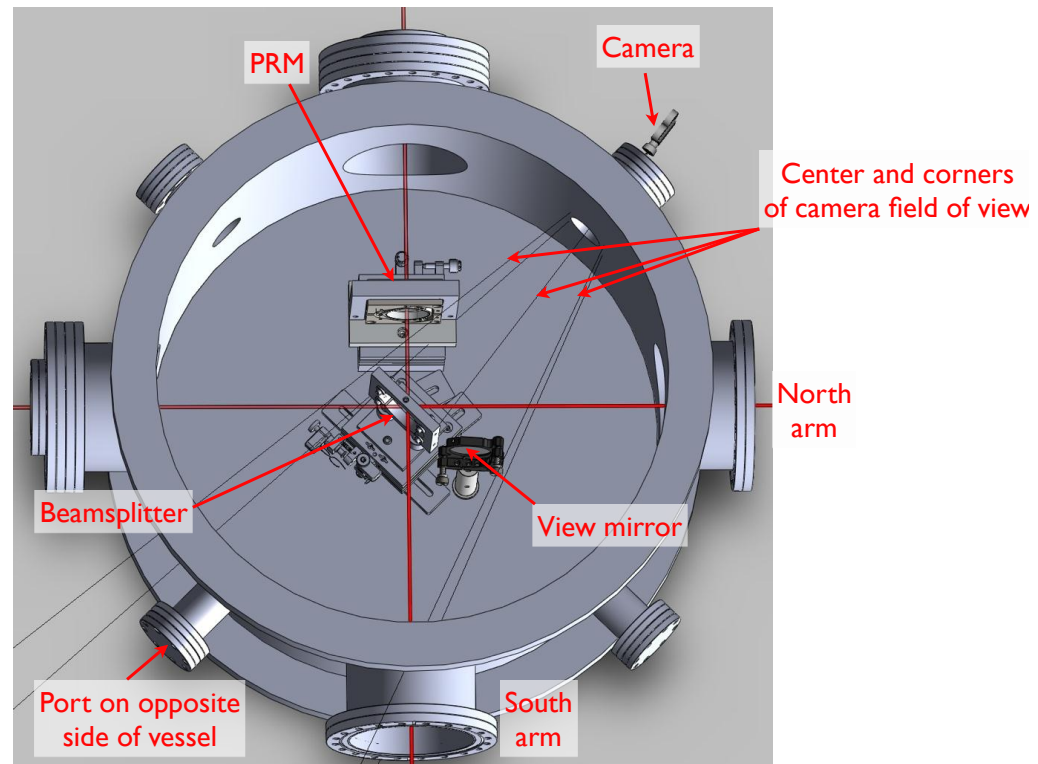
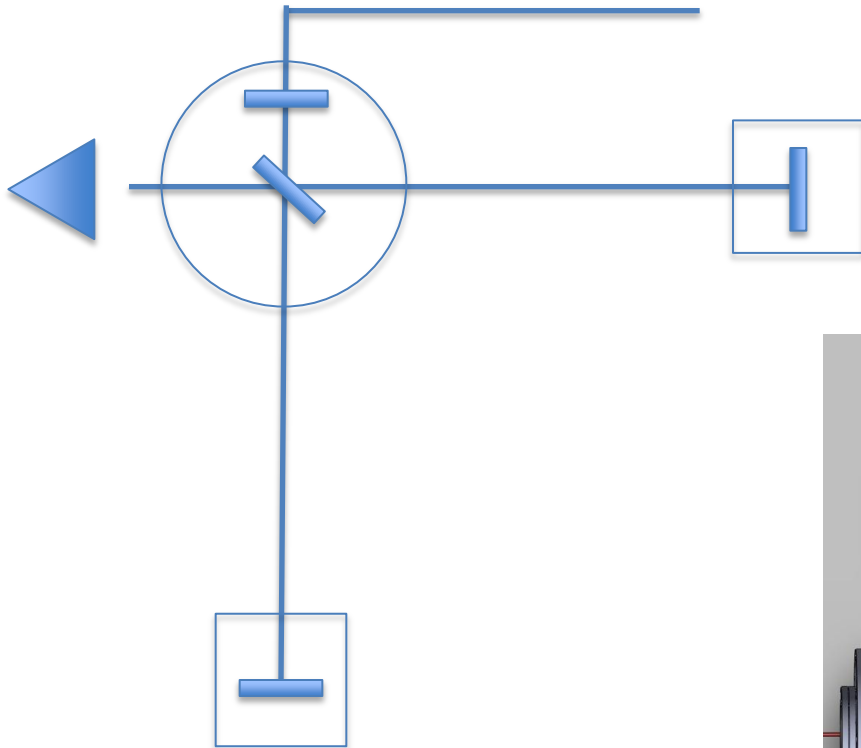
Beam exits the table and is directed to the interferometer using a multi-stage periscope fixed to the tunnel walls.

Aluminum pipes shield the beam from air currents and prevent beam cross contamination.

Tunnel walls are very thick yielding low ground noise.



# Holometer Optical System

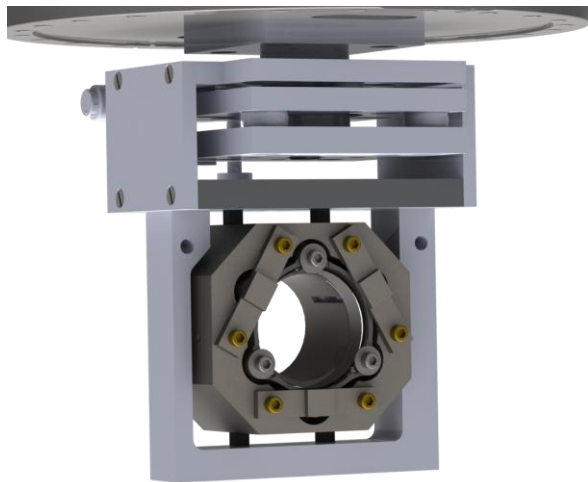
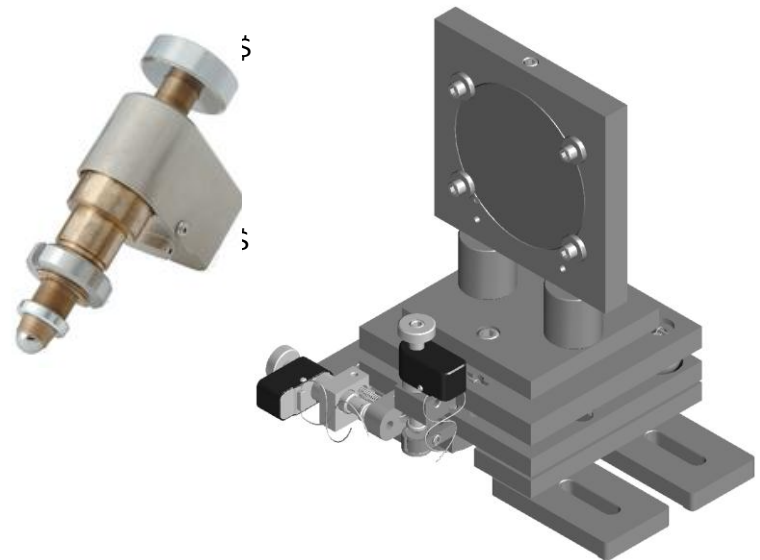




# Holometer Optical System

Power recycling mirror and beamsplitter are steered by picomotors.

Custom 3" beamsplitter mount.



End mirrors driven by piezo stacks.

Custom mounts supported from above.

Optical mounts in the interferometer are quite stable---no need for suspended optics.

# Holometer Optical System

We have maintained interferometer lock for several minutes.

Measured the power spectrum and are now tracking down noise sources.

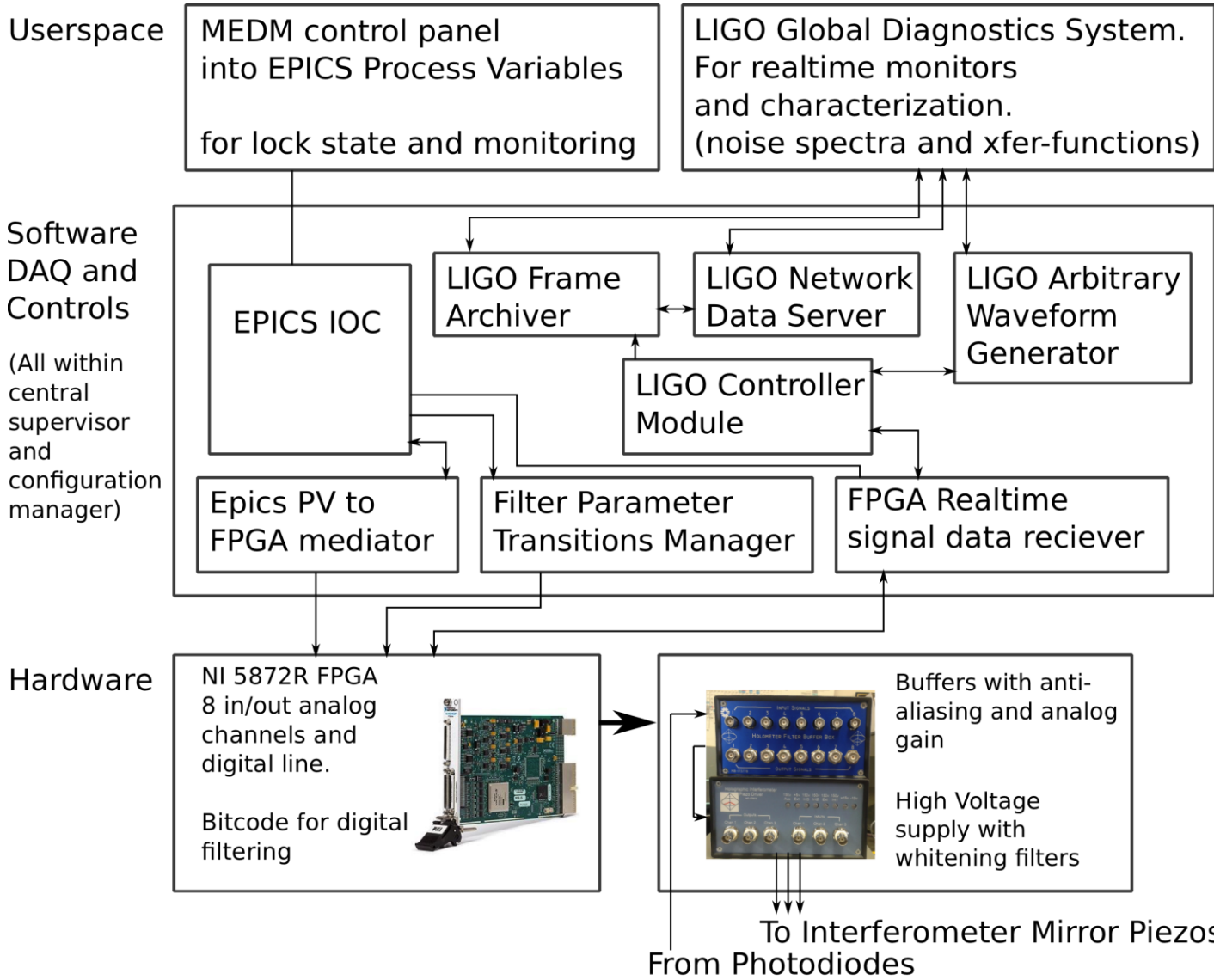
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# Holometer Control and Data



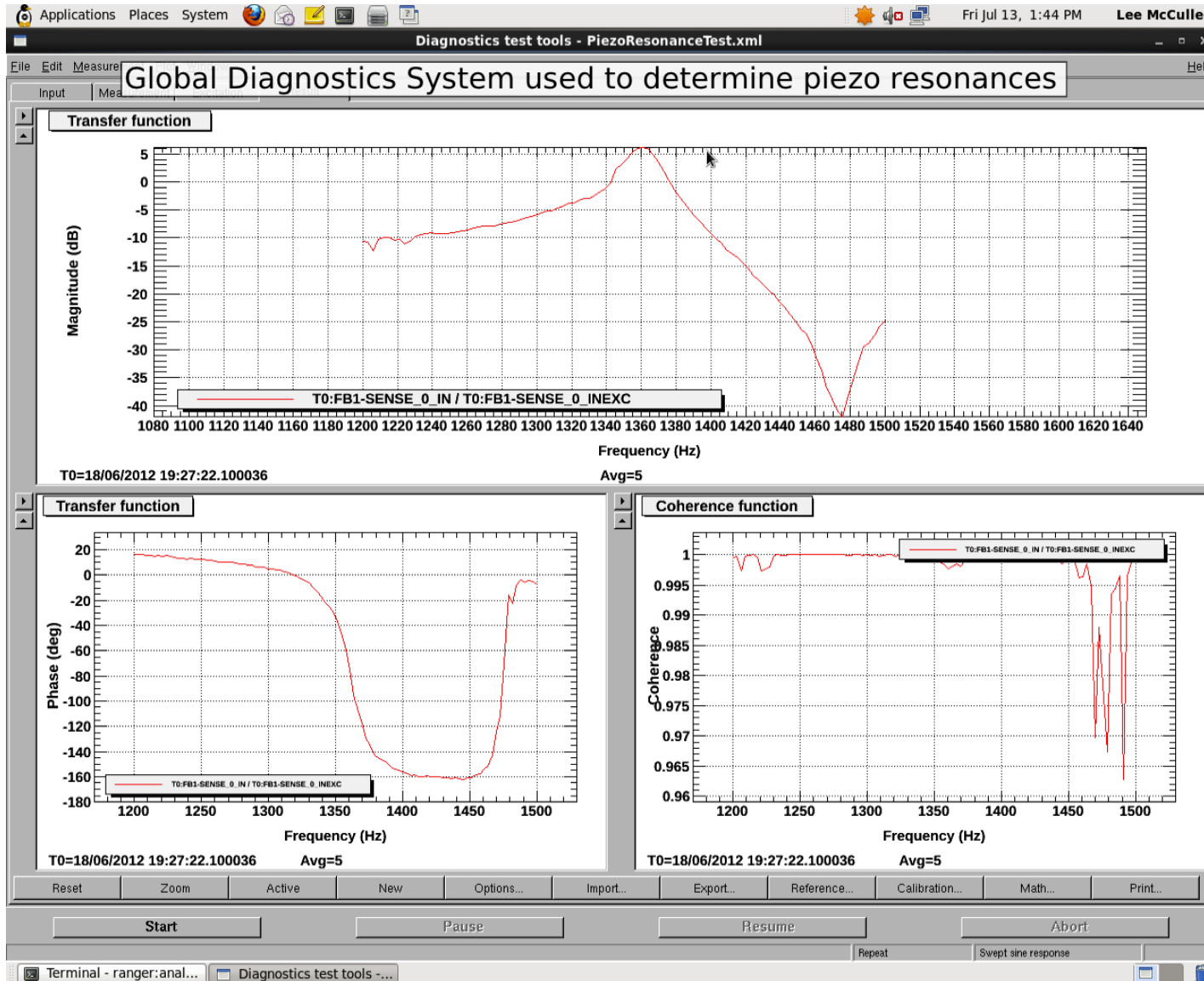
EPICS:

Experimental Physics and Industrial Control System

MEDM:

Motif  
EPICS  
Display  
Manager

# Holometer Control and Data



# Holometer Control and Data

The screenshot displays a complex control interface for a Holometer system, titled "DARM.adl". The interface is divided into several main sections:

- Central Control Monitor:** Located at the top left, it features four vertical plots for "CONTROL 0 DARM DC feedback", "CONTROL 1 DARM DC REMOVED feedback", "CONTROL 2 DARM DC feedback", and "CONTROL 3 DARM DC feedback". Each plot includes an "EXC MONITOR" and "IN MONITOR" display, along with "IN OFFSET" and "OUT MONITOR" values.
- Individual Filter Modules:** Two detailed views of filter modules are shown. The first, "TO\_FB1-FILT\_ACTUATOR\_5\_RAW.adl", shows a "Master Gain" block with five filter stages (FM1-FM5) and various input/offset parameters. The second, "TO\_FB1-FILT\_ACTUATOR\_5\_RAW.adl", shows a similar module with a "notch1340" filter and four stages (FM1-FM4).
- Multiple Filter Stages:** A section at the bottom left shows a grid of control parameters for "INPUT\_0\_RAW" through "INPUT\_7\_RAW" and "SENSE\_0\_RAW" through "SENSE\_7\_RAW".
- Mirror Angle Control (example of stage mixing):** A section at the bottom left shows control parameters for "T COMMON MIRROR ANGLE" and "T NORTH MIRROR ANGLE", including vertical and horizontal controls for "T C" and "T D" mirrors, and "T EAST PZT" actuators.
- Stage Mixing Matrices:** A large grid at the bottom right displays a matrix of values for "In 1" through "In 6" and "Out 6" through "Out 7". The values are primarily 1.00000 and -1.00000, indicating a mixing or routing matrix.

The interface also includes a "Terminal" window at the bottom, showing the command prompt with the file "DARM.adl" loaded.

# Holometer Plans

## Current:

- The first interferometer is operating reliably, now exploring the mechanical and electrical transfer functions and system noise sources.
- Implementing a servo system with all computers far from the ADCs and electronics.
- We are installing the injection optics and interferometer optics in the second system.

## Remaining major milestones:

- Finish assembly and commissioning of L interferometer.
- Finish assembly and commissioning of T-south interferometer.
- Begin science operations

# Conclusions

1. We have a stable and very good, clean vacuum in both interferometers. We were able to bake the vacuum system in place. Optics surfaces will remain good.
2. We have optics, mirrors and beamsplitters, and optics actuators that are working as expected so far - we have not really pushed them but so far so good.
3. We have interferometer injection and transfer optics that work well launching from a table 5 meters from the beamsplitter
4. We have extremely stable optics mounting. Mount drifts are low - we did not know if non-suspended mounts would work at all before we started.
5. We have developed a flexible FPGA digital servo system that we expect will be able to run all the systems we need to lock.
6. We have been able to lock differential arm length loop and common arm length loop simultaneously for periods of minutes with the digital servo in the first of our interferometers.