# Geophysics Interferometer (GIF)


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# Project Overview & Status

Definition and scope

1.Construction of two fixed-mirror interferometers (1.5km x 2) along KAGRA, for both geophysical observation and KAGRA baseline monitor.

2.Arrangement of sensors and benchmarks for monitoring environment parameters of the tunnel, rooms, and instruments

Current status

1. Documents of retro-reflectors and vacuum chambers are being prepared for bids.

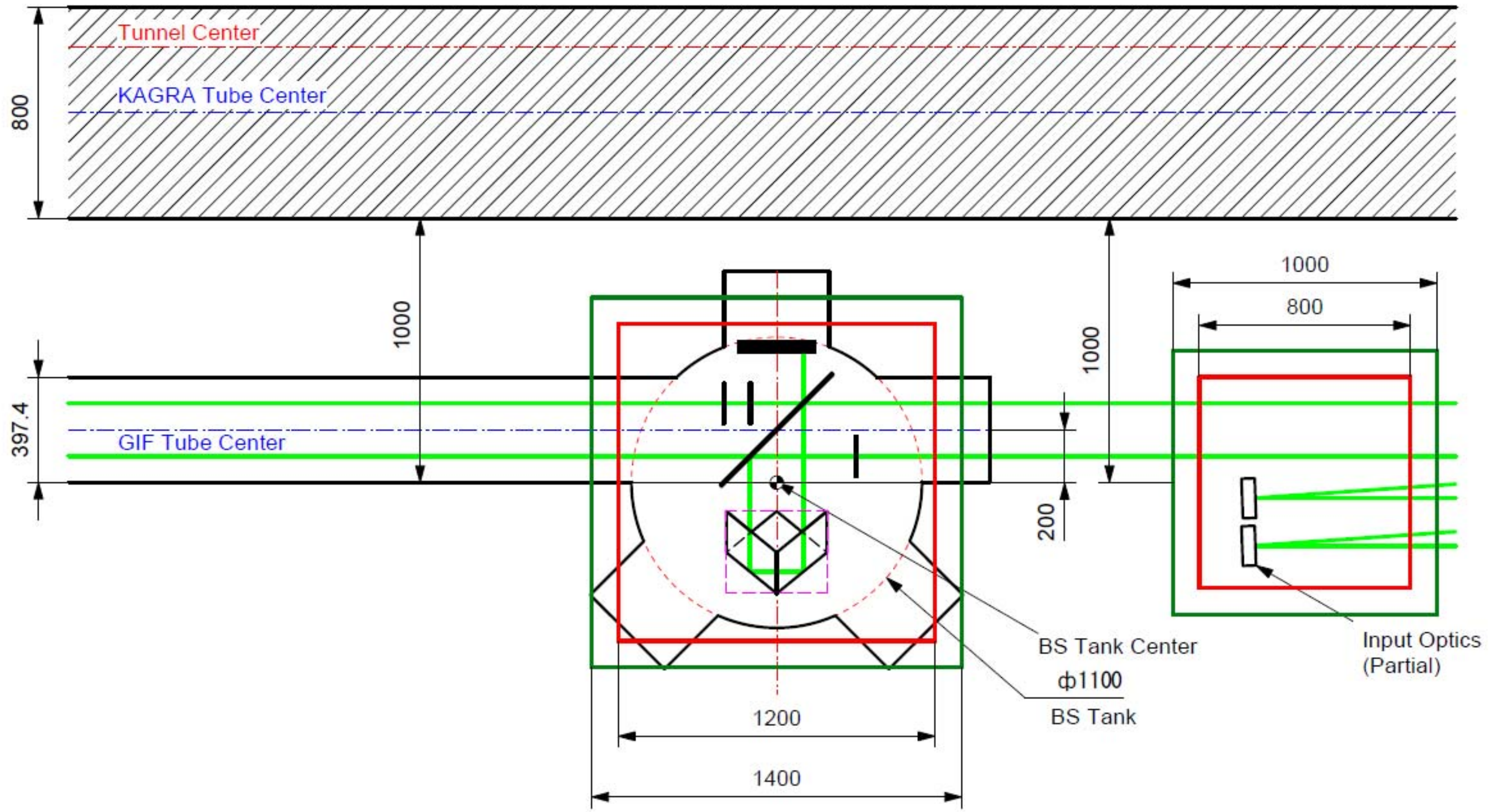
2. Layout around a vacuum chamber is shown below.

3. Sample environment sensors (thermometer, hygrometer, and barometer) are being tested in the CLIO site.

# Layout

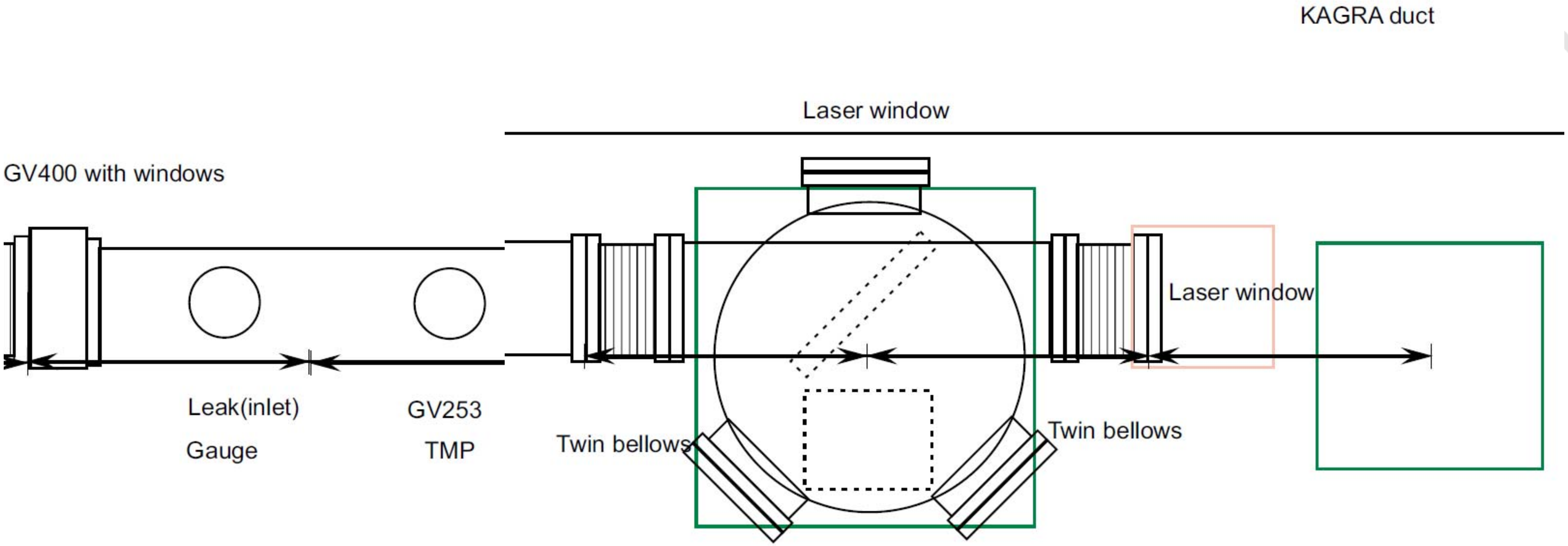
## Optical layout and vacuum chamber

**Vacuum chamber (inner dimension): diameter 1100mm, height 1000mm**



# Layout

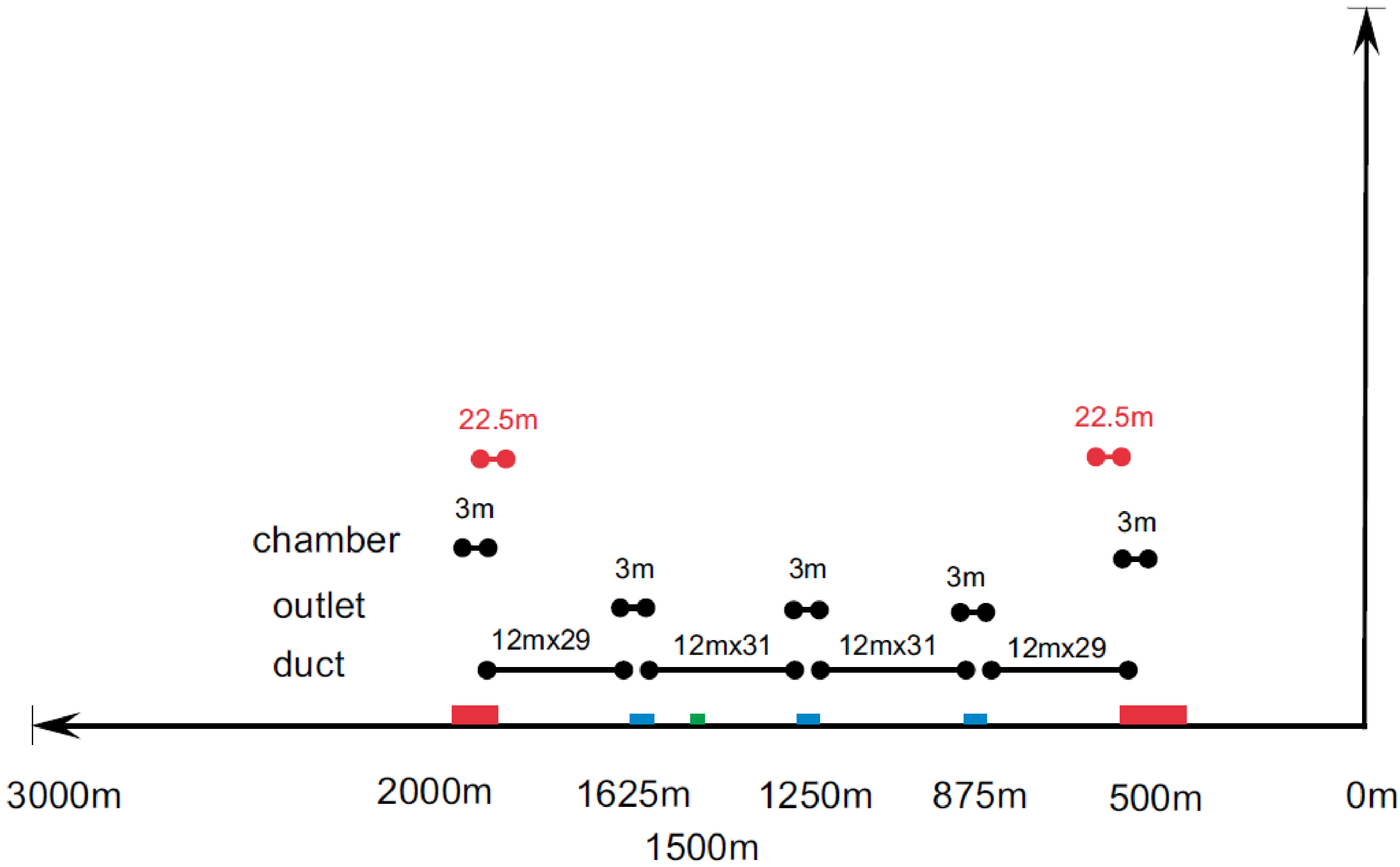
Layout around a vacuum chamber




One arrow indicates 1 meter.

# Vacuum System

**Arrangement of vacuum ducts …. 22.5m x 2 are lacking for 1500m**



# Environment Monitor (EM)

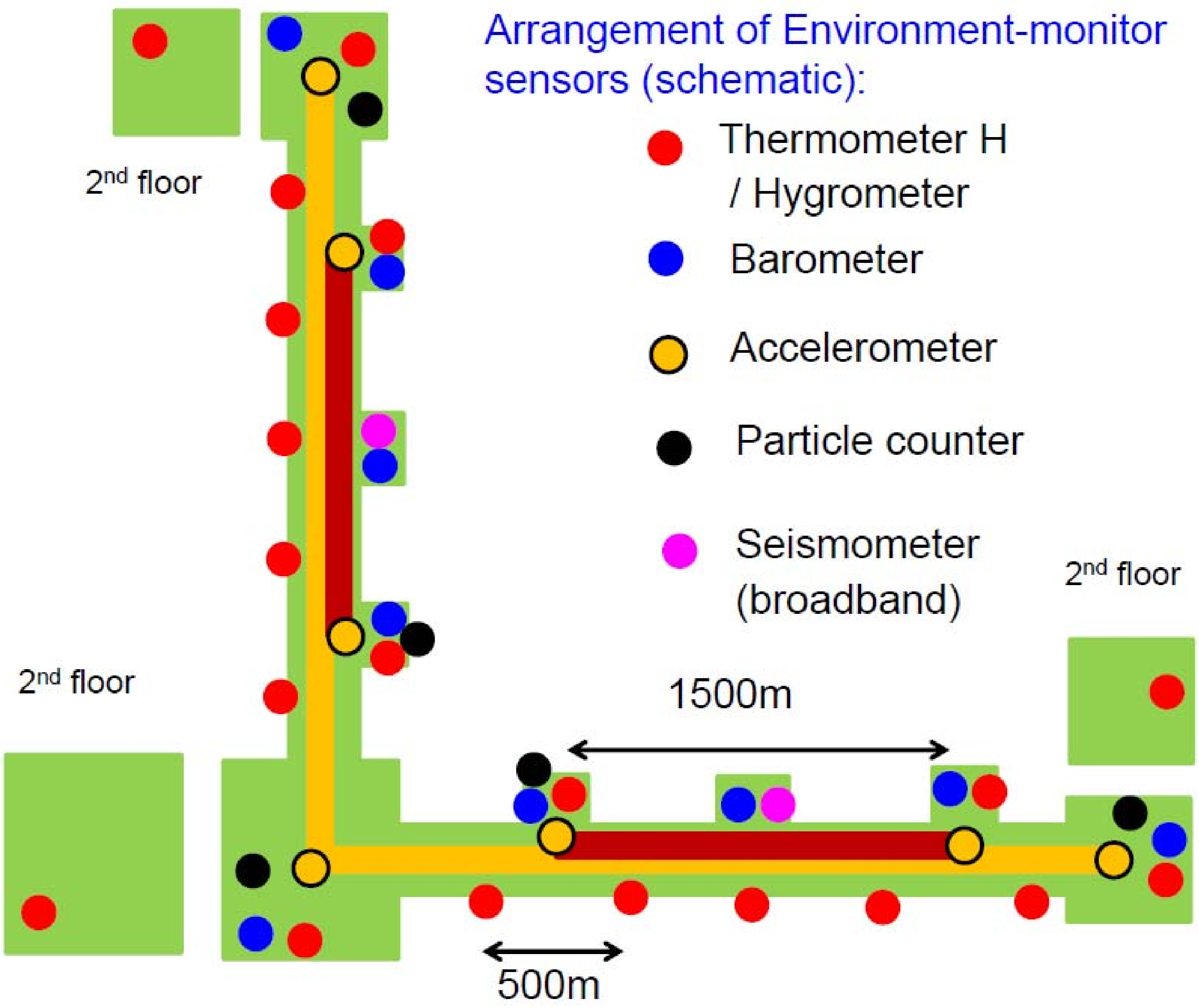
Definition & Scopes

Environment condition of the tunnel, rooms, and instruments need to be monitored for ensuring stable operation of detectors, correction of data analyses, and detection of anomalous operation.

Some sensors are directly attached to instruments for monitoring any noises applied to the instruments to assess validity of the data, such as veto analyses.

The sensors are characterized by physical quantity, relative / absolute, dimension, measurement range, resolution, and frequency response.

# Sensor Locations



# EM Sensors

● already tested ● to be tested

| Group | Sensor | Rank | Dimension | Symbol | Range | Resolution | Response | Vendor | Room | Floor | Table | TR.y | ETM.y | etm.y | DAQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Y end Y3000m | | | | | | |
| | | | | | | | | | 1st floor | | | | | | |
| COMMON | Thermo | abs. | 300x300x120 | TH_A_1 | -50–50deg | 0.15deg | DC-0.1Hz | Yokogawa | | | | | | | |
| | +Hygro | abs. | | TH_A_1 | 0-100% | 3% | DC-0.1Hz | Yokogawa | | | | | | | |
| | Thermo | rel. | 20x20x300 | T_R_1 | -50-200deg | 0.0001deg | DC-1Hz | Tokyo Dempa | | | | | | | |
| | Thermo | rel. | 5x5x5 | T_R_2 | -55-150deg | 0.5deg | DC-0.3Hz | Texas Inst. | | | 3 | 1 | 1 | 1 | |
| | Baro. | abs. | 180x180x65 | B_A_1 | 850-1050hPa | 0.15hPa | DC-0.1Hz | Yokogawa | | | | | | | |
| | Accel. | abs. | 80x80x80 | Acc_A_1 | 20m/s$^2$ | 1.e-5m/s$^2$ | DC-500Hz | Japan Avi. Ele. | | 1 | | | | | |
| | Accel. | rel. | 15x15x15 | Acc_R_1 | 50m/s$^2$ | 1.e-2m/s$^2$ | 1-5kHz | Kistler | | | 3 | 1 | 1 | 1 | |
| | Velocity | rel. | 250x250x250 | Sel_R_1 | 1.3e-2m/s | 3e-10m/s$^2$/rHz | 8.3m-50Hz | Streckeisen | | | | | | | |
| | Velocity | rel. | 250x250x300 | Sel_R_2 | 1.5e-2m/s | 1e-10m/s$^2$/rHz | 4m-200Hz | Nanometrics | | | | | | | |
| | Velocity | rel. | 200x200x300 | Sel_R_3 | 1.3e-2m/s | 3e-10m/s$^2$/rHz | 3m-50Hz | Guralp | | | | | | | |
| | Acoustic | rel. | 15x15x20 | Mic_R_1 | 146dB | 14.6dB | 6.3-20kHz | Bruel and Kjaer | 1 | | | | | | |
| | Acoustic | rel. | 15x15x15 | Mic_R_2 | 140dB | 19dB | 20-20kHz | Ono Sokki | | | | | | | |
| | Mag. | rel. | 25x25x200 | Mag_R_1 | 70-1000uT | 6pT/rHz | DC-3kHz | Bartington | 1 | | | | | | |
| | Mag. | rel. | 100x100x100 | Mag_R_1 | 50uT | 0.1nT | DC-5Hz | Shimadzu | | | | | | | |
| | Particle | abs. | 150x100x100 | Par_A_1 | 0.2-5um | 0.2um | NA | MetOne | 1 | | | | | | |
| | Particle | abs. | 150x300x300 | Par_A_2 | 0.3-5um | | 10s-2h | RION | | | | | | | |
| VAC | Baro. | abs. | 180x180x65 | B_A_1 | 850-1050hPa | 0.15hPa | DC-0.1Hz | Yokogawa | | | | | | | |
| | Particle | abs. | 150x100x100 | Par_A_1 | 0.2-5um | 0.2um | NA | MetOne | | | | | | | |
| GIF | Thermo | abs. | 300x300x120 | TH_A_1 | -50–50deg | 0.15deg | DC-0.1Hz | Yokogawa | 1 | | | | | | |
| | +Hygro | abs. | | TH_A_1 | 0-100% | 3% | DC-0.1Hz | Yokogawa | 1 | | | | | | |
| | Thermo | rel. | 20x20x300 | T_R_1 | -50-200deg | 0.0001deg | DC-1Hz | Tokyo Dempa | | | | | | | |
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| | Acoustic | rel. | 15x15x20 | Mic_R_1 | 146dB | 14.6dB | 6.3-20kHz | Bruel and Kjaer | | | | | | | |
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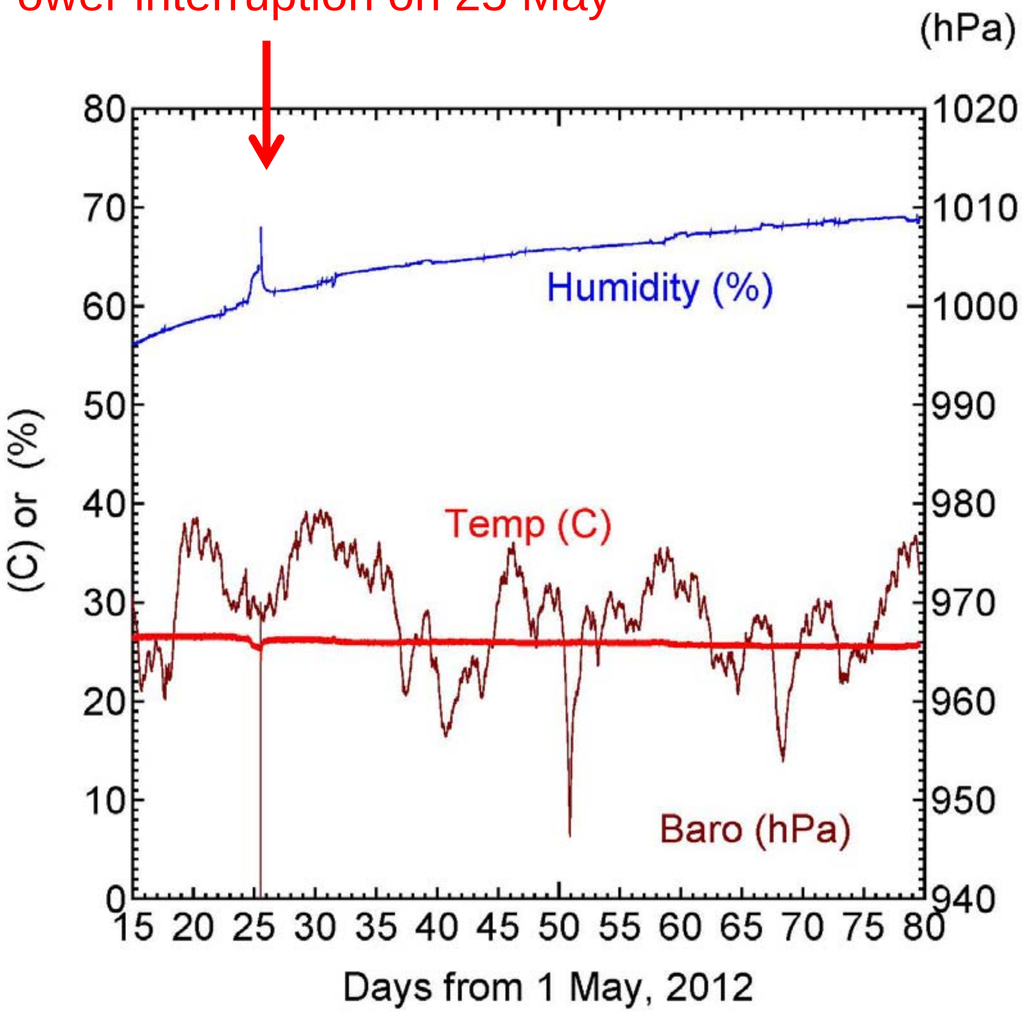
| | Particle | abs. | 150x100x100 | Par_A_1 | 0.2-5um | 0.2um | NA | MetOne | | | | | | | |
| | Particle | abs. | 150x300x300 | Par_A_2 | 0.3-5um | | 10s-2h | RION | | | | | | | |

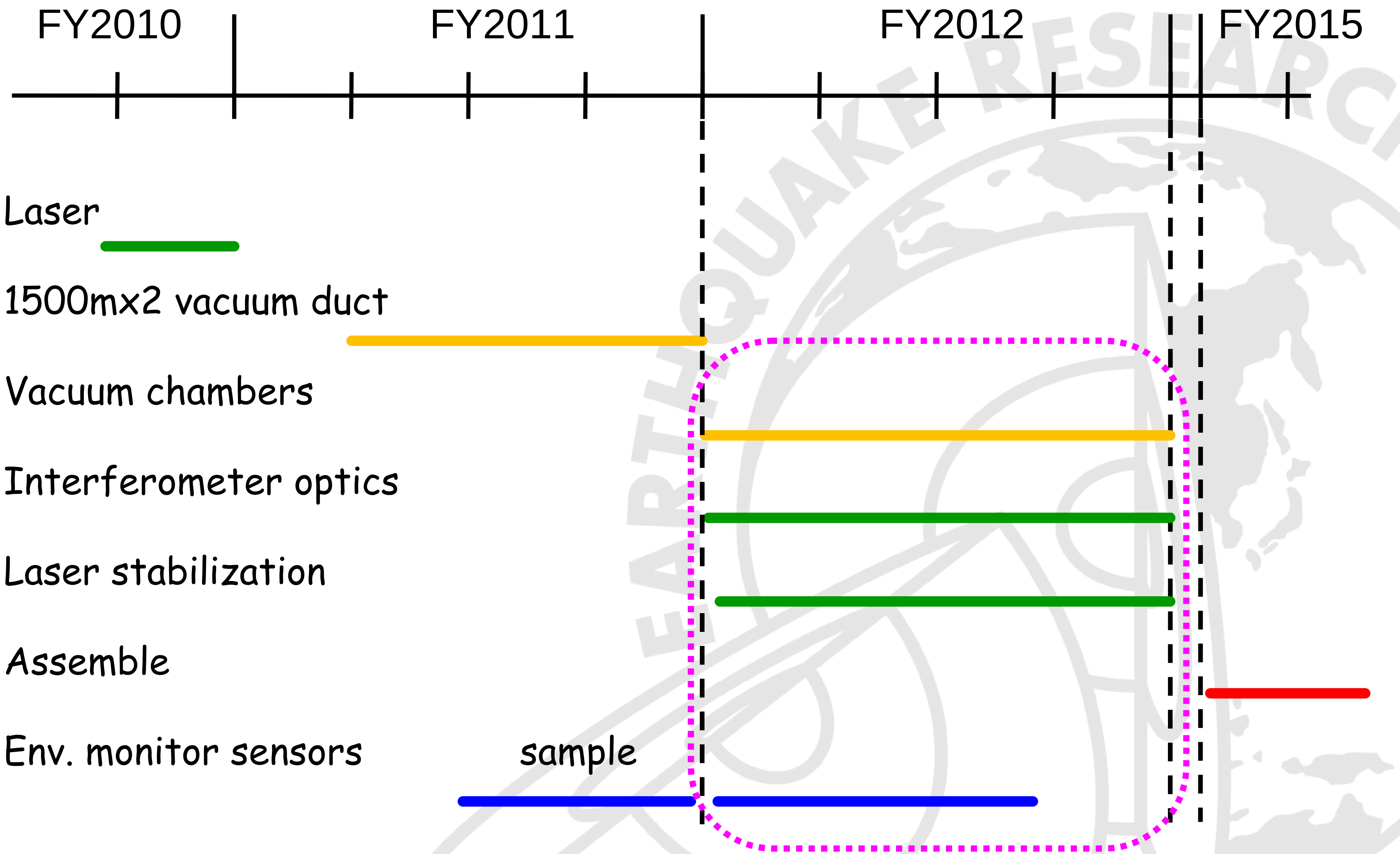
# EM Example

Temperature, humidity, and barometric pressure at CLIO

Power interruption on 25 May




# Schedule


FY2010
FY2011
FY2012
FY2015
Laser
1500mx2 vacuum duct
Vacuum chambers
Interferometer optics
Laser stabilization
Assemble
Env. monitor sensors
sample

# GIF Milestones

| | | related sub-groups |
|---|---|---|
| 2012.3 | vacuum pipes delivery | Vacuum |
| | optics final design | Tunnel |
| | EM sensor determination | Det Char |
| 2012.9 | vacuum valves / pumps delivery | Vacuum |
| | infra specification (clean booth, LAN) | Fac. Sup. |
| 2013.3 | optical components delivery | |
| | vacuum components delivery | Vacuum |
| | EM sensors delivery | Det Char |
| (2014.3) | tunnel excavated | Tunnel |
| 2014.6 | vacuum & granite base installation | Vacuum/ Fac. Sup. |
| 2014.12 | vacuum installation | Vacuum |
| 2015.3 | optics installation | |
| | EM-DAQ operation | Det Char |
| 2015.6 | test observation start | |
| | safety management | Fac. Sup. |
| 2015.9 | observation & maintenance | |
| (2018.3) | bKAGRA | |

# GIF Optics Main Features

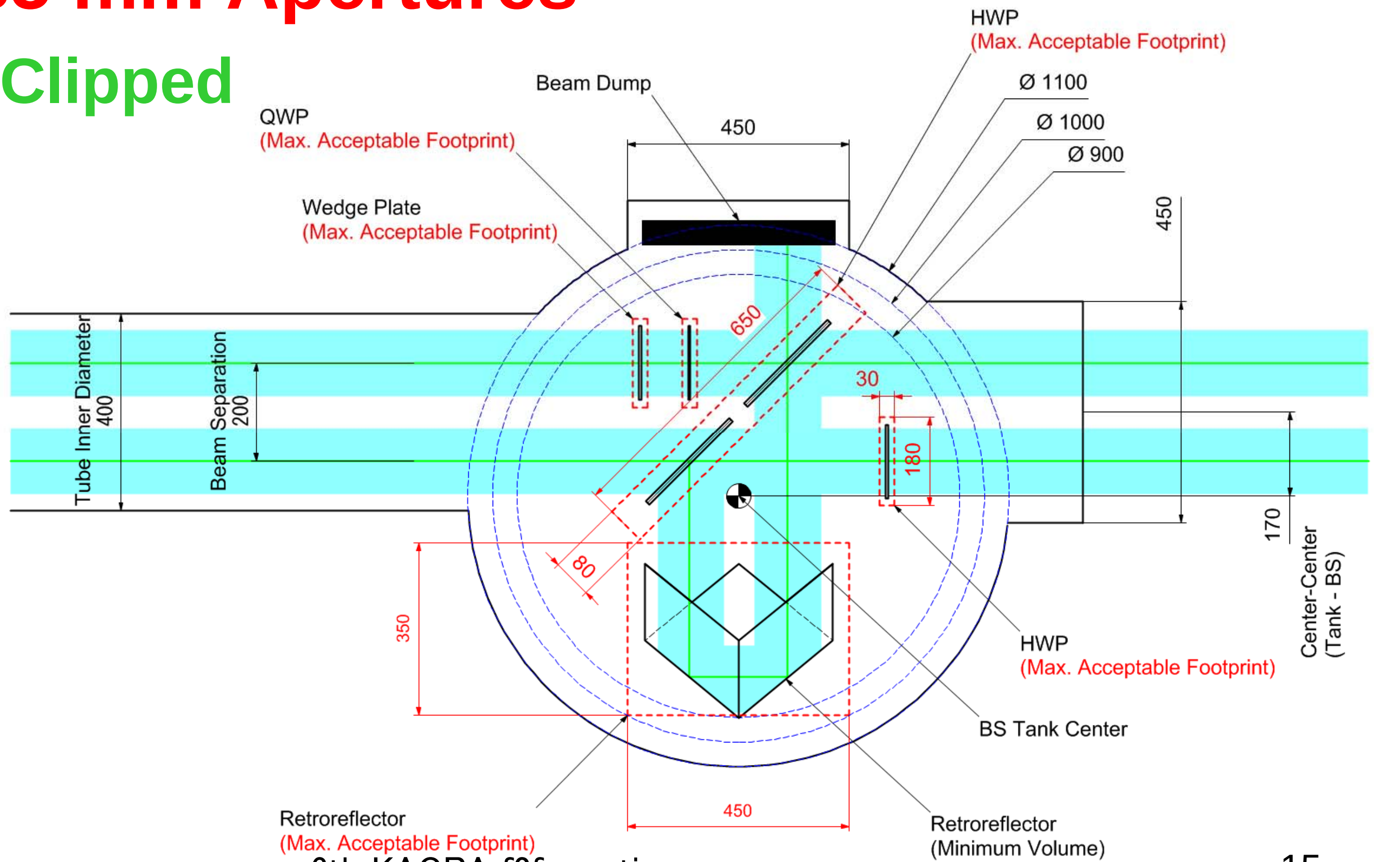
- **Asymmetric Michelson Laser Interferometer**
  - 1.5 km vs. 50 cm
  - Optics Attached to Bedrock
- **Iodine-stabilized Nd:YAG Laser**
  - $\lambda = 532$ nm
  - Stability (Ultimate Resolution): $10^{-13}$
- **Quadrature Detection**
  - Bi-directional Output
  - Wave Plates Inserted as Retarders
- **Retroreflectors as End Mirrors**
  - No Alignment/Length Control

# Beam Layout

- 200 mm Separation
  - To Fit into 400 mm Vacuum Tube
- Beam Waist at Arm End
  - Minimizes Retroreflector
  - For Better Symmetry (of input & return beams)
  - Minimum Spot Size at BS
    - Waist Size: 15.9 mm
    - Spot Size at BS: 22.5 mm
- Required Minimum Apertures
  - Retroreflector: 295.7 mm (12 inches)
  - BS: 237 mm per Spot

# Optics in Main Tank

- **15” Hollow Retroreflector**
- **BS Separated to 2 pcs.**
- **WP w/ 85 mm Apertures**
  - **Beam Clipped**



# Visibility

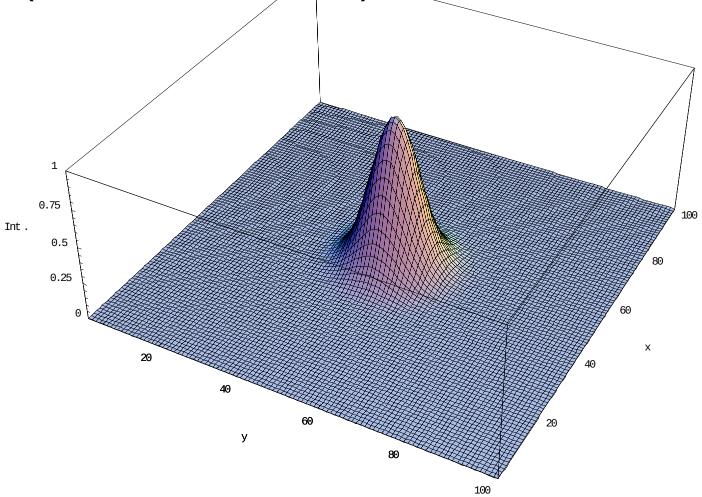
- **Limited due to IFO Asymmetry**
  - **Vis = 0.707 (Best w/ Ideal Optics)**
- **Causes of Visibility Degradations**
  - **Wavefront Distortion**
    - **Irregular Surface of Retroreflectors**
    - **Non-Parallelism of BS & Wave Plates**
  - **Power Loss**
    - **Contamination (Low Reflectivity, Transmissitivity)**
    - **Clipping at Wave Plates**
  - **Other Causes**
    - **Scattering etc.**

# Surface Accuracy of Retroreflectors

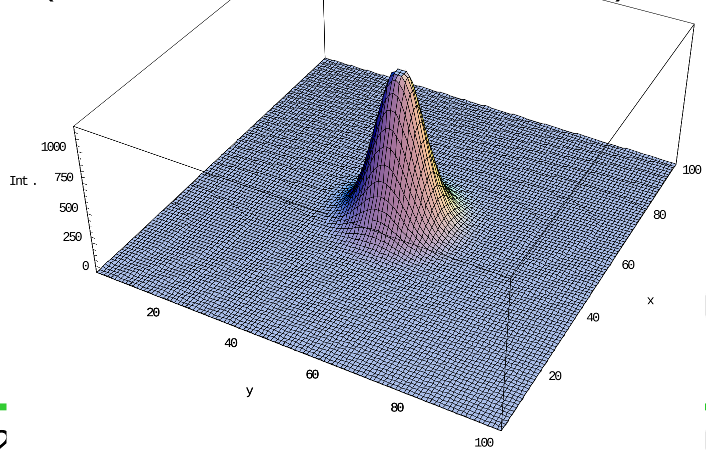
- **Realistic Numbers**
  - **A Manufacturer Specification (PLX)**
    - **0.3 λ Guaranteed**
    - **0.1 λ may be Possible (Best Effort)**
- **Estimating Visibility Degradation**
  - **Simple FE Model**
    - **Meshing over +/- 100 mm Wavefront**
      - 50 x 50, 100 x 100, 200 x 200, 500 x 500 Meshing Tested
    - **Random & Independent Surface Displacement**
      - follows Normal Distribution
        - Average: 0
        - STD: R x λ (Roughness Factor R = 0.1, 0.2, 0.3, …)

# Model Example

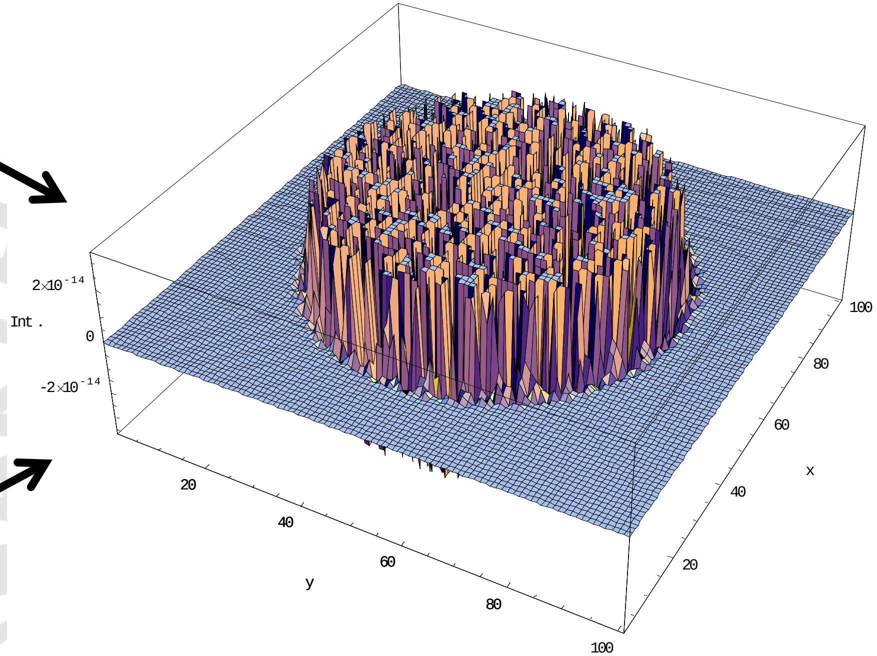
Output Beam Power
(Ideal Mirror Surface)




Output Beam Power
(Inaccurate Mirror Surface, R = 0.1)




Difference



# Results

## Visibility vs. Surface Inaccuracy

- Appropriate Mesh Number: 100 x 100
- Rapid Degradation Observed
  - Up to R~0.3
- Expected Visibilities
  - 0.53 +/- 0.02 (R=0.1)
  - 0.21 +/- 0.03 (R=0.2)
  - 0.05 +/- 0.03 (R=0.3)
  - cf. 0.71 (R=0)
- Beam Clipping
  - No Significant Impact