Impact of Air Cooling on Mechanical Stability of STS Ladders for CBM Experiment

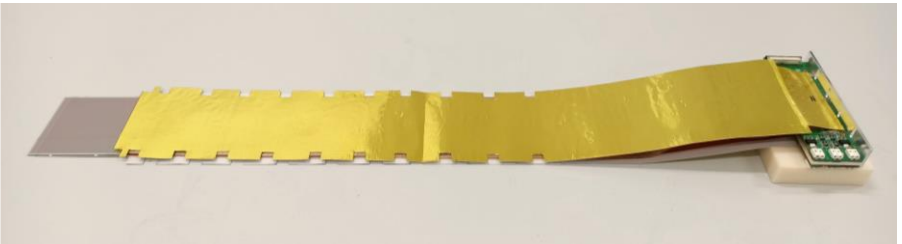
S. Mehta[1] for the CBM collaboration

[1] Eberhard Karls Universität Tübingen (DE)

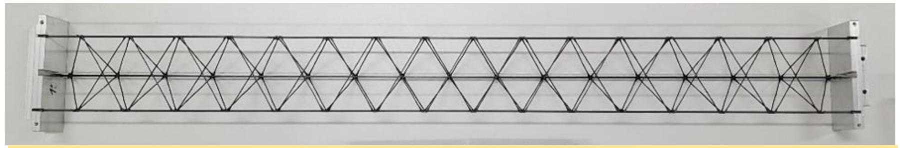
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

MATHEMATISCH-NATURWISSENSCHAFTLICHE FAKULTÄT
Physikalisches Institut

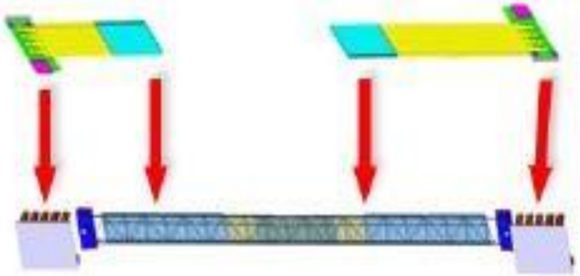
Introduction to ladders for STS



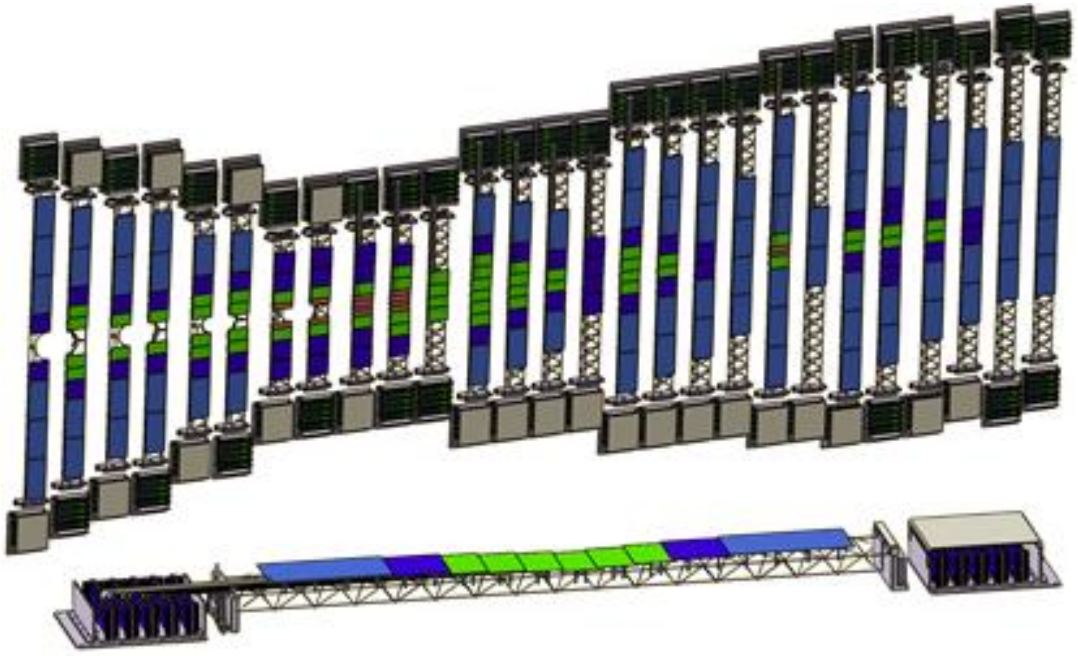
Fully assembled STS module



Carbon Fiber (CF) Ladder –support structure for modules



Modules are mounted on ladder



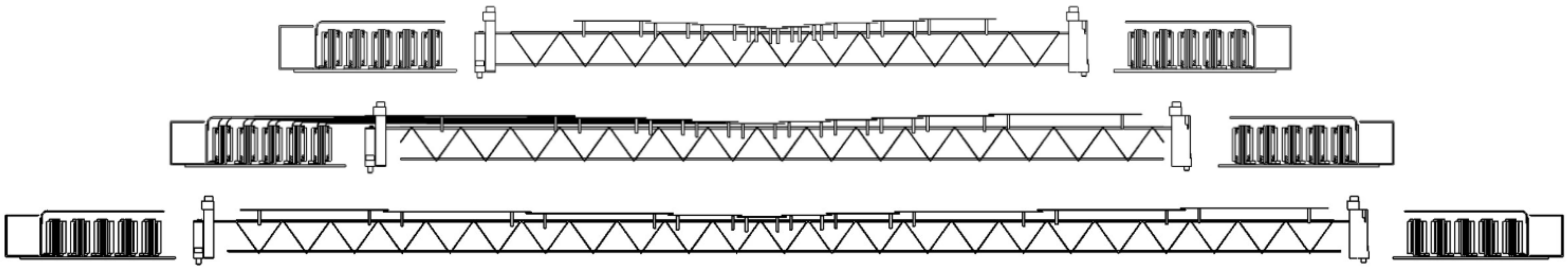
876 modules will be assembled on 106 CF ladders in STS

27 STS ladder variants without cut out holding 8-10 modules per ladder
16 ladder variants with central opening to be fixed across the beam pipe

- Silicon Tracking System of CBM experiment is designed to provide good momentum resolution (< 1.5 %) with tracking efficiency (< 97 %) -> Low material budget
- Experimental challenge for STS: Optimize material of the components under acceptance region and acquire the mechanical stability for good particle tracking.

Requirements of Ladder in STS integration

- Final position accuracy of sensors better than 100 µm
  - To acquire good particle tracking and usage of track based alignment softwares
- Ladder shape has to be compatible with sensor/module mounting
  - Base of ladder has to be wide enough to fit the micro-cable stack
- Bending under the module load has to be small to satisfy position precision requirement
- Assembled detector ladders have to exhibit vibration behavior with Eigen frequency different from system frequency

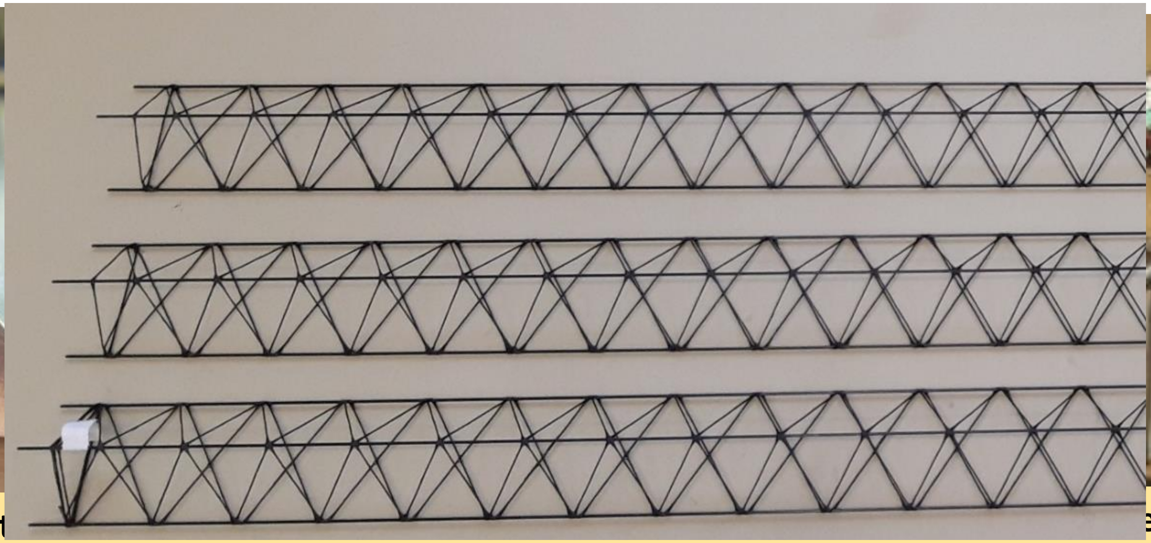


Side view of STS ladders after assembling of modules for different ladder lengths

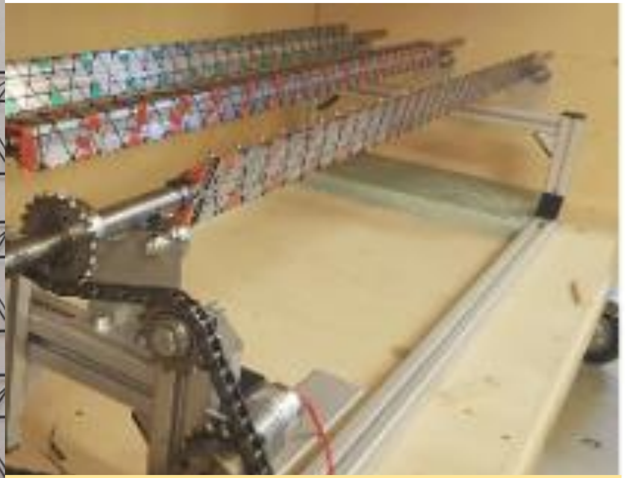
To acquire required precision accuracy, it is important to understand ladder behavior before and after assembly

Carbon fiber ladder – production and readiness

Hub for winding fibre on carbon t
with side pieces

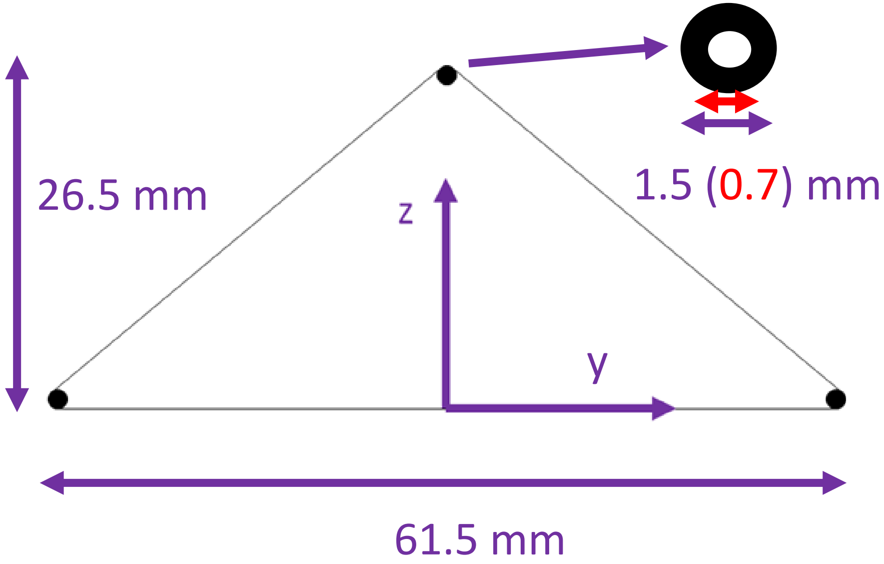


Ladders after the production

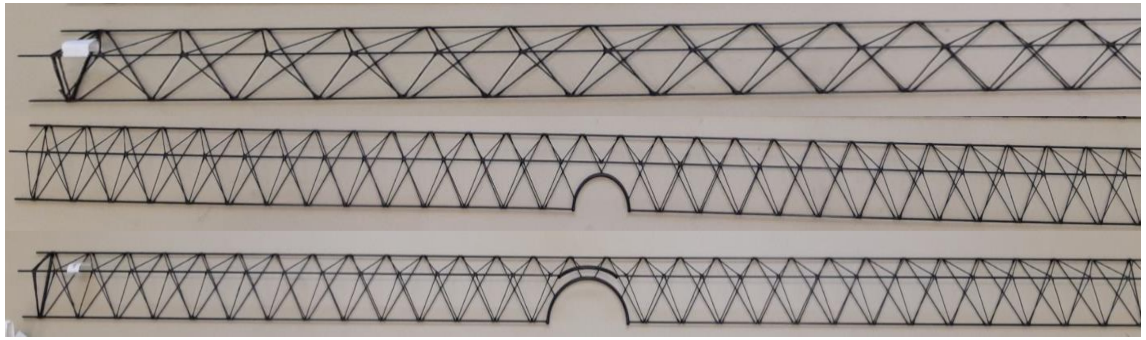


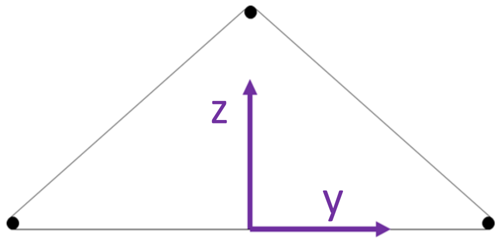
evice for winding the cores

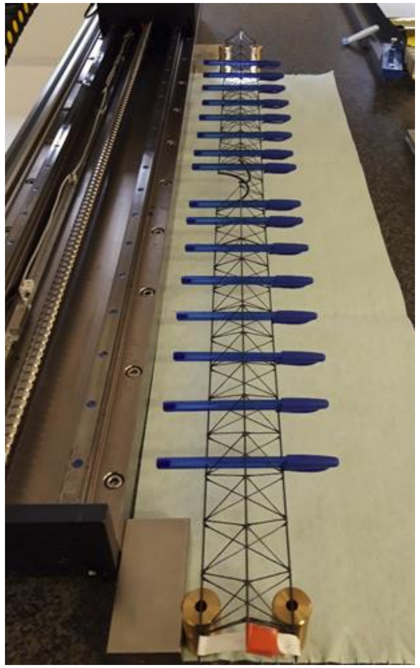
- Ultra light carbon fiber ladders are produced by ICM composites using the winding technique
- Modular approach was taken for ladder production
- Simulated amount of material for STS stations corresponds to 0.3 % to 1 % X_0
- Specifications of CF ladder:
  - Outer/inner diameter – 1.5/0.7 mm
  - Mass – 14.8 g (1200 mm length)
  - Base of ladder – 61.5 mm, height 26.5 mm

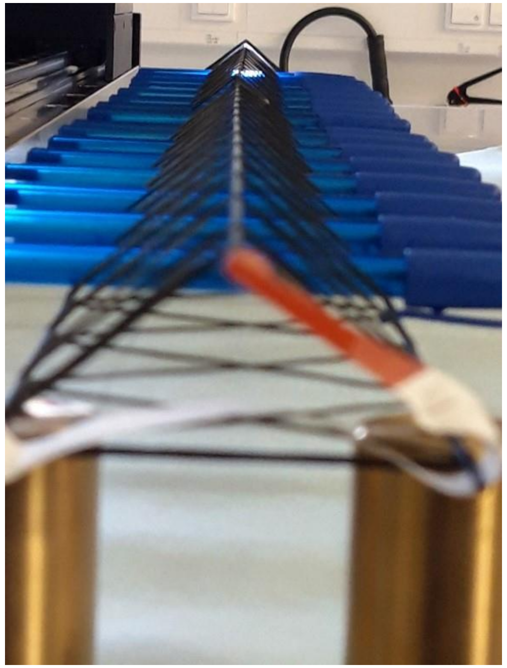


Characterization of ladders after production

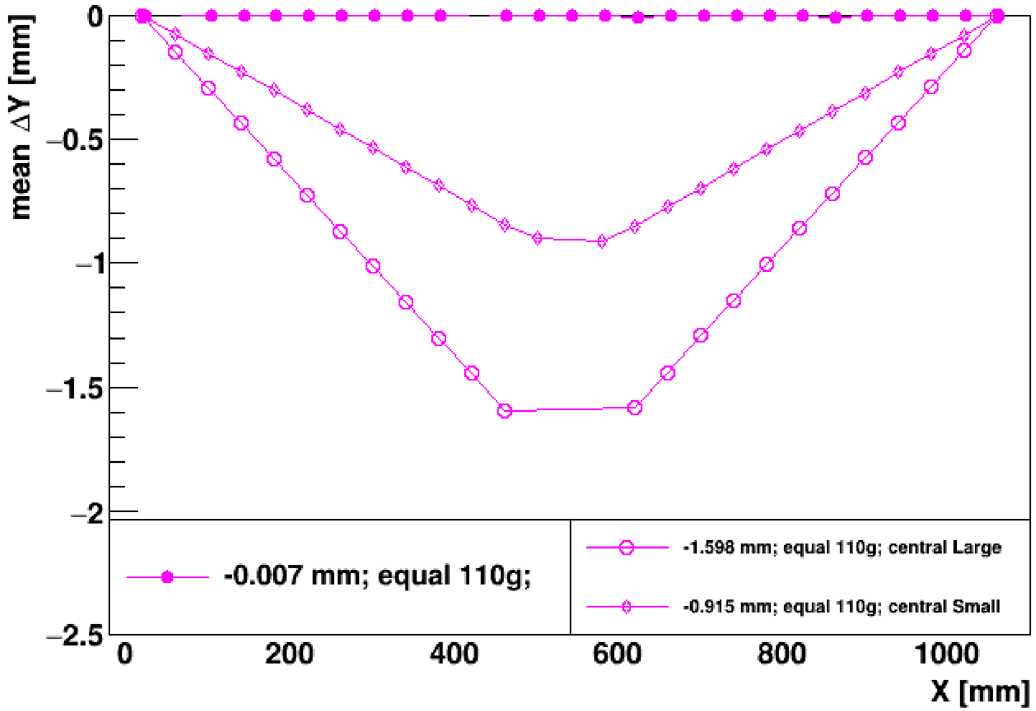








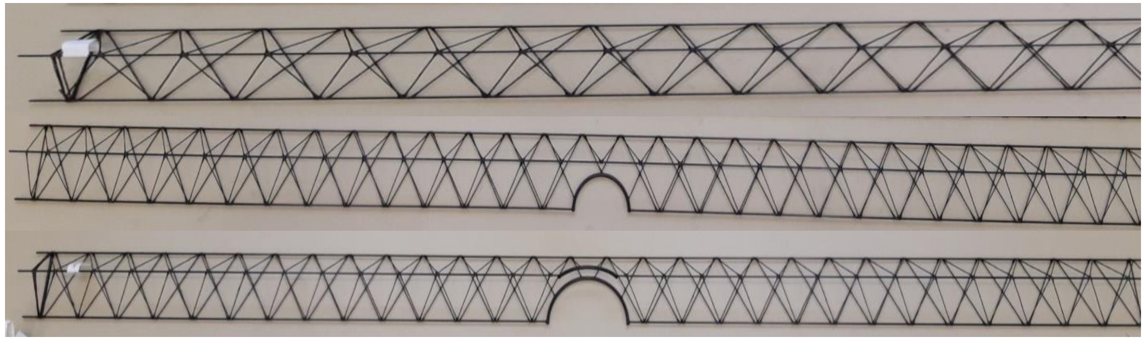
Ladder under load equivalent to weight of sensor and micro-cables

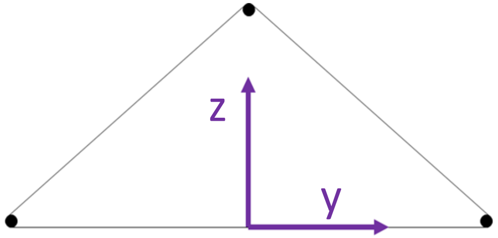


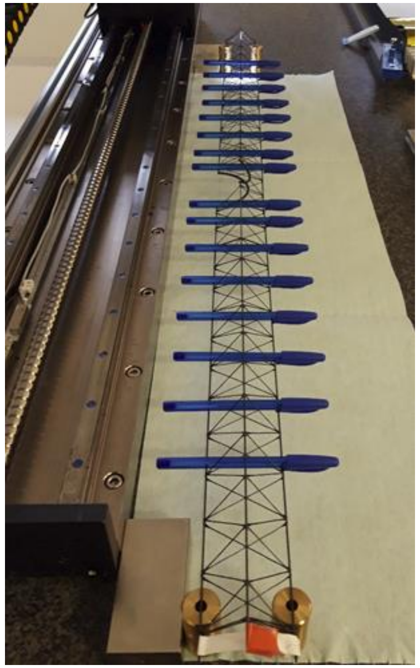
Deformation in ladder in y-direction under load

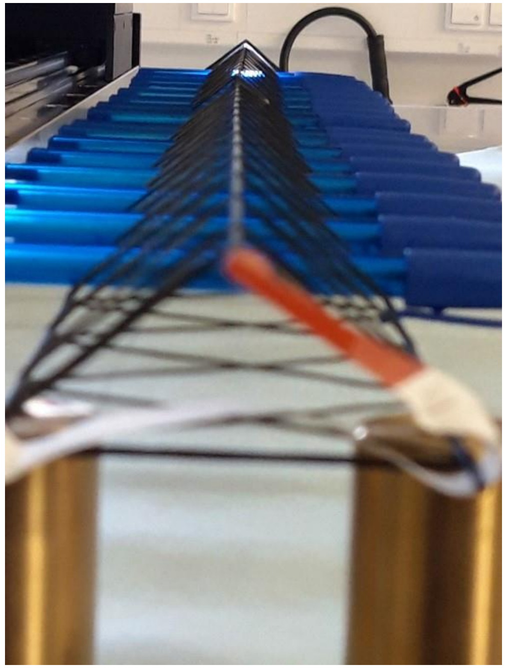
Maximum deviation due to larger beam-pipe cutout for longest ladder under maximum load (~110 g) is ~ 1.598 mm in y-axis

Characterization of ladders after production

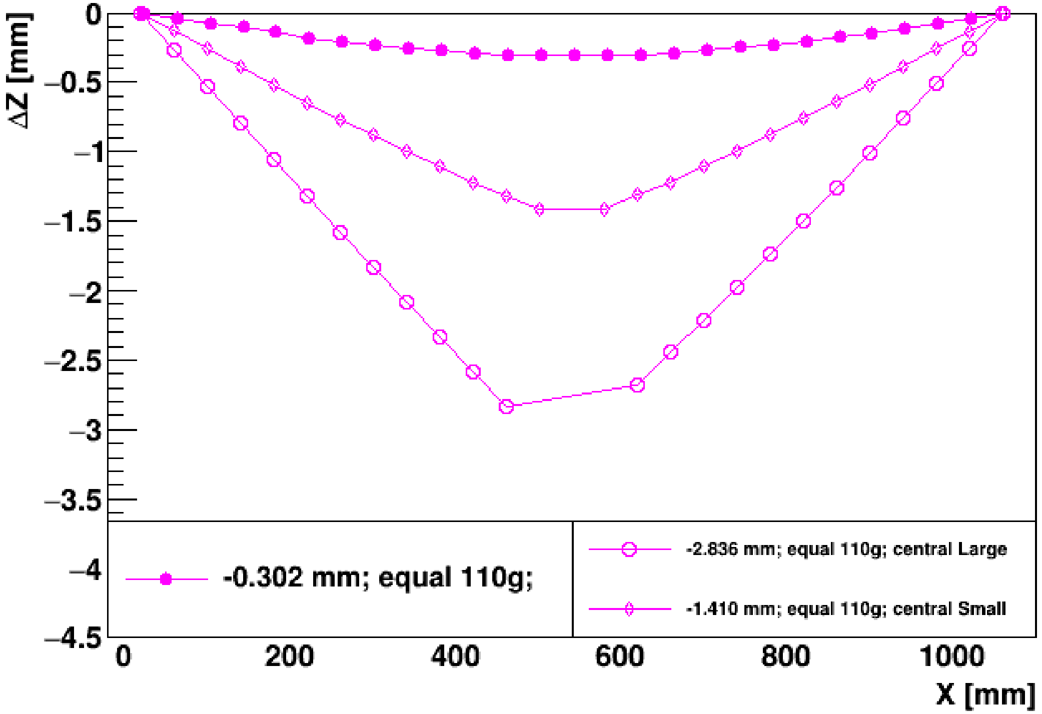








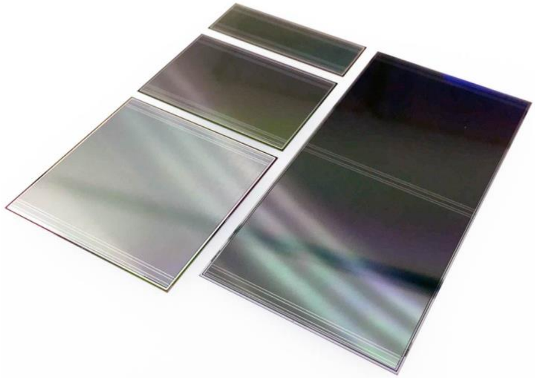
Ladder under load equivalent to weight of sensor and micro-cables



Deformation in ladder in Z-direction under load

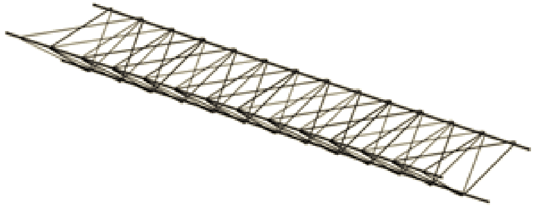
Maximum deviation due to larger beam-pipe cutout for longest ladder under maximum load (~110 g) is ~ 2.836 mm in z-axis

Integration and Optical Inspection of ladders

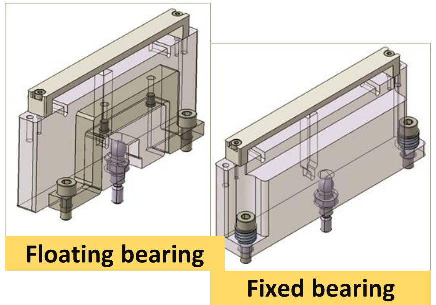


Assembly procedure of mounting modules on ladder

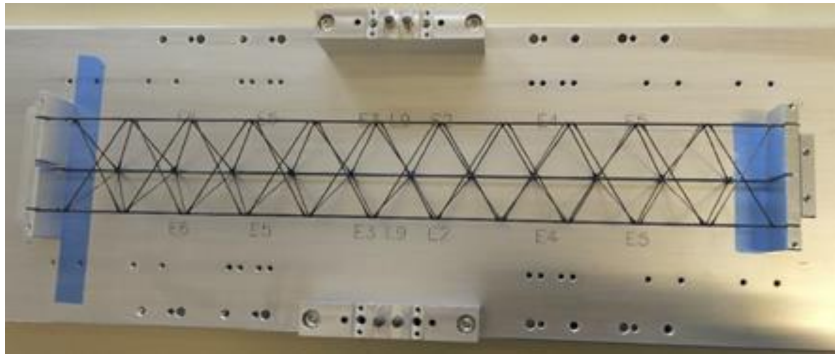
Ladder fixation to bearings



Light weight CF ladder – support structures for the modules

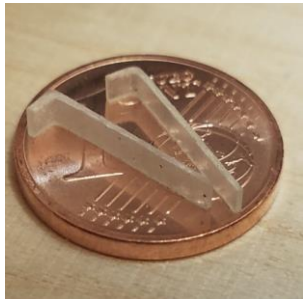


Bearings: Side connectors for ladder fixation

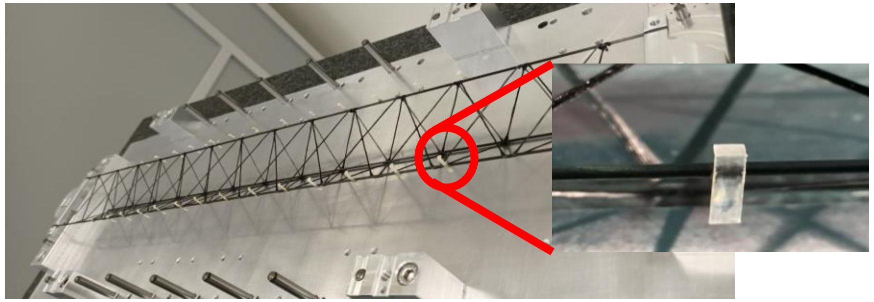


Ladder mounted on a baseplate

Gluing of L-legs (support structures for sensors) on ladder

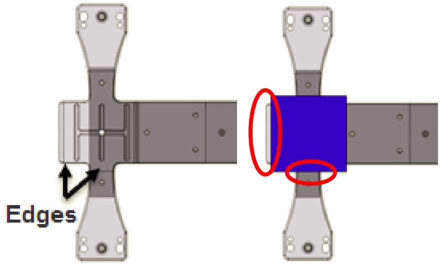


L-shaped, glass fiber structures

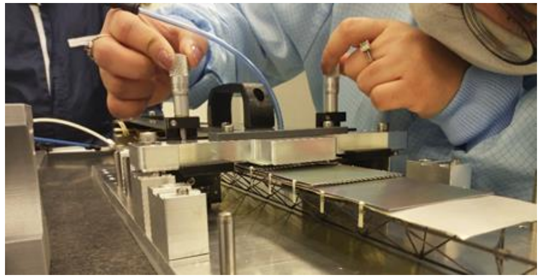


L-legs glued onto the ladder

Mounting of modules on ladder



Positioning of sensors defined by the edges of the tool

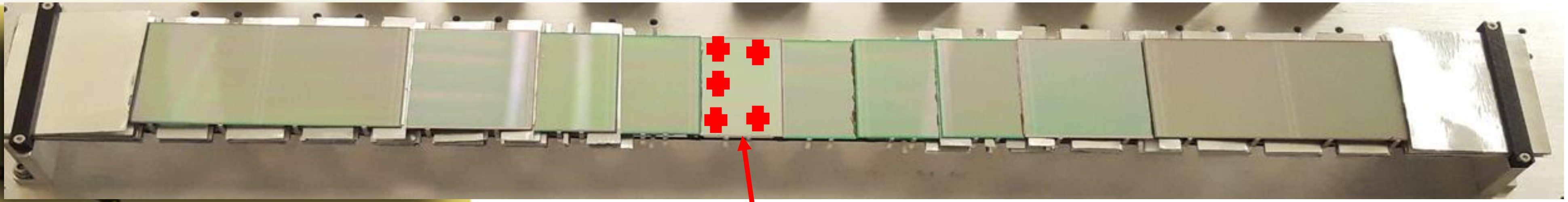


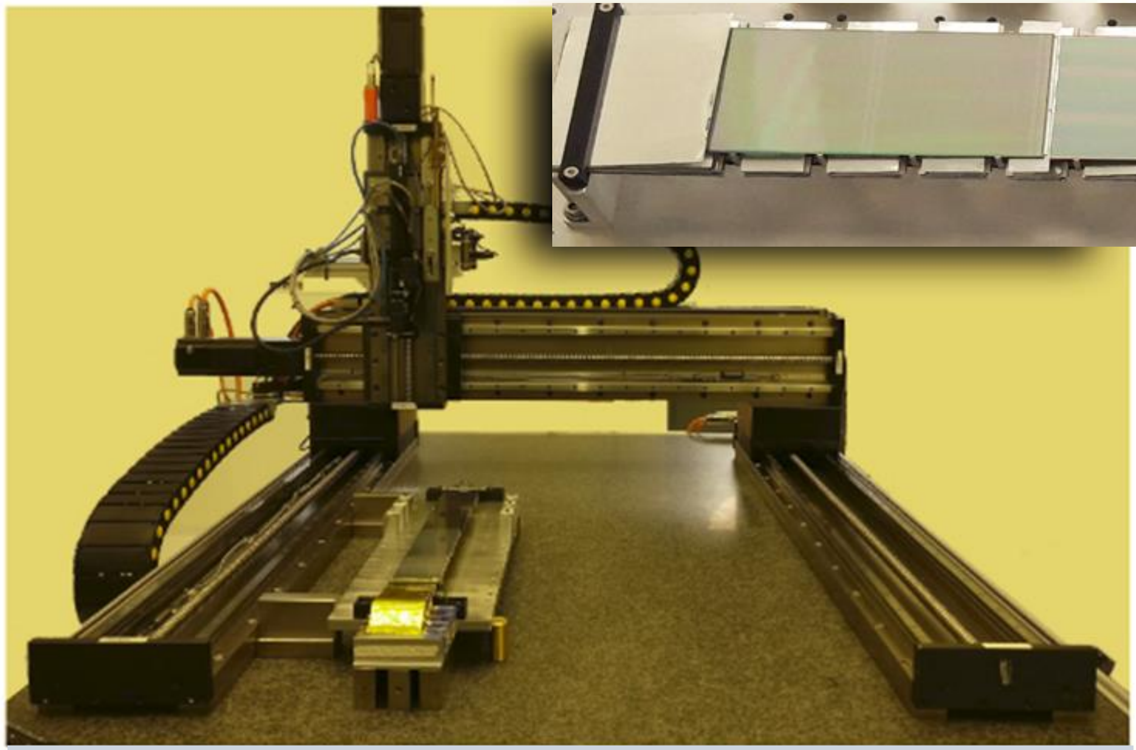
Positioning block defines the correct sensor position

- Specific tools has been designed to precisely position the modules on ladder
- During the assembly process, different glues has been used which brings delay in assembly considering glue curing time
- Assembling a complete ladder, consisting of maximum 10 modules, takes approximately 7-8 days with a total working time of around 20 hours

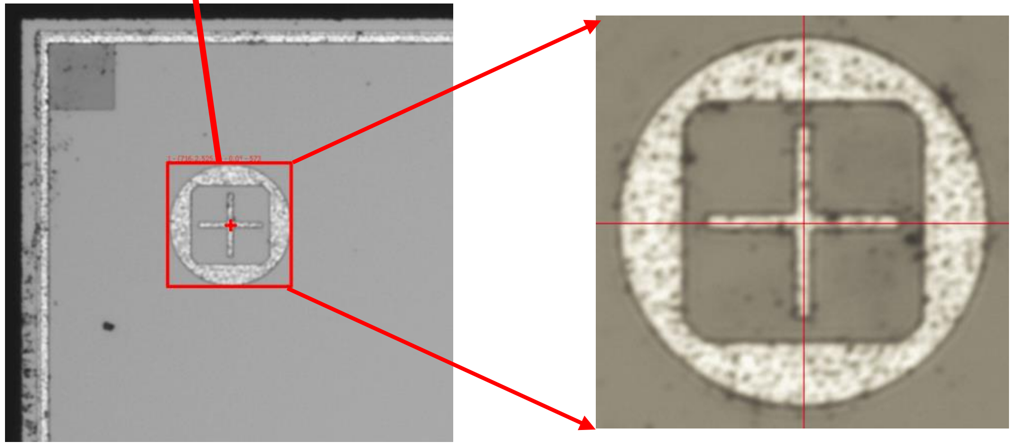
All the ladders for STS are assembled using the same assembly technique to obtain the mounting precision within 100 µm

Optical metrology of ladder after assembly





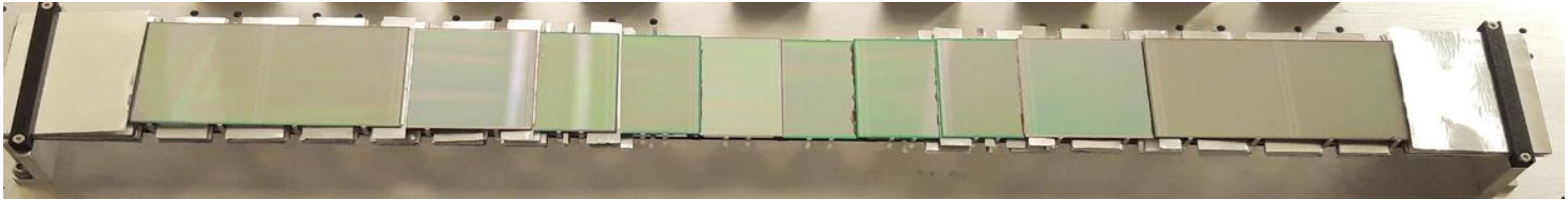
Ladder assembled with 10 modules mounted on the XYZ granite table

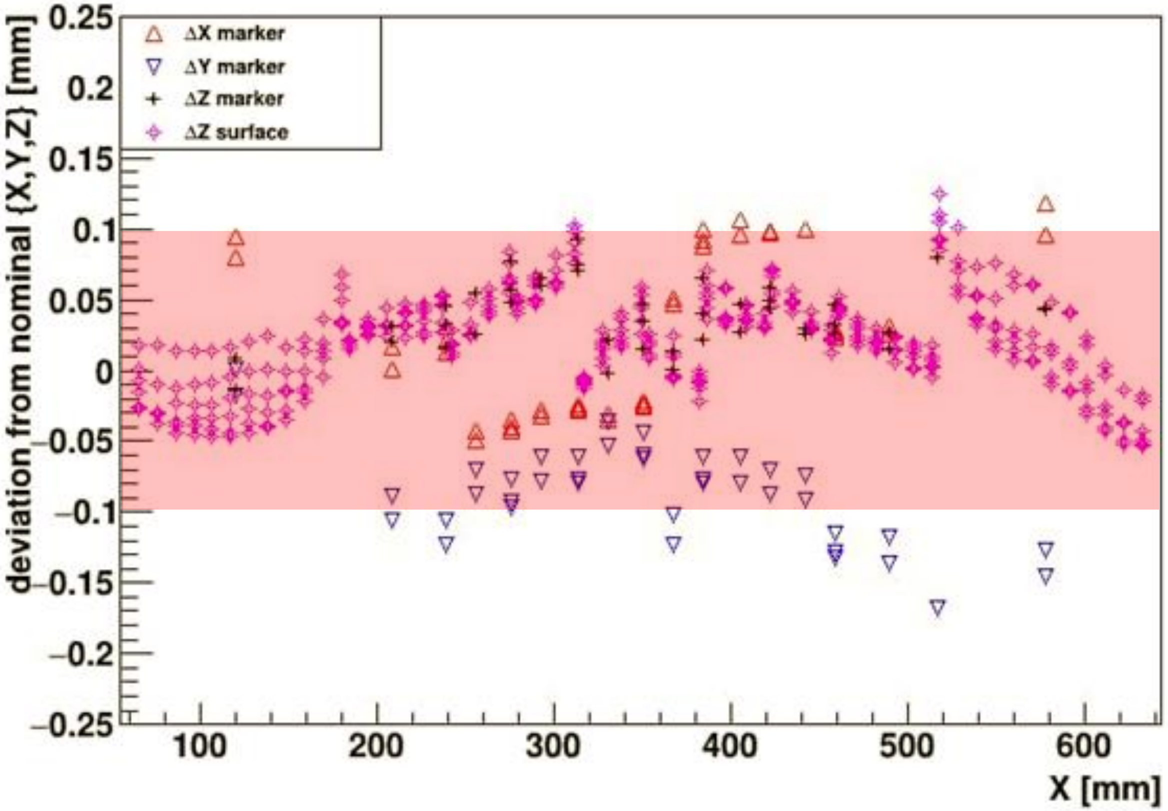


- Contactless optical 3-D metrology of silicon sensors, equipped with a movable camera
- LabVIEW program is used to operate table for optical metrology
- Pattern recognition technique is used for height and position measurement

After the assembly of each ladder, optical inspection will be performed to ensure the accuracy of mounting precision

Optical metrology: results for full ladder



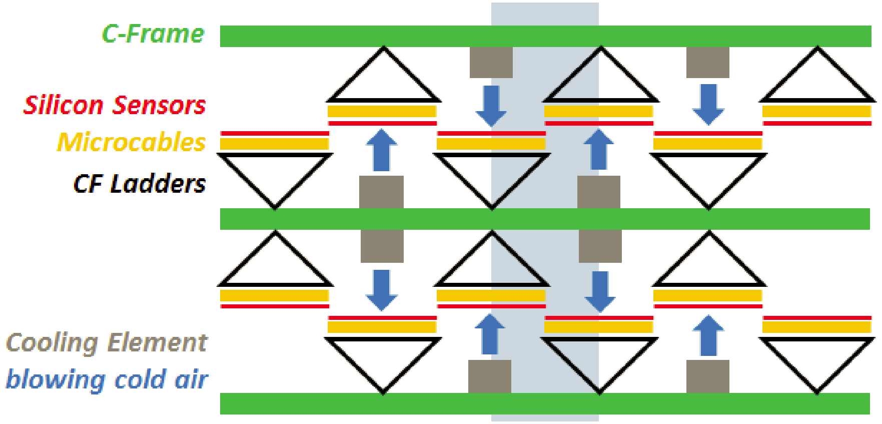


Assembly procedure has been developed to ensure that mounting accuracy of silicon sensors is achievable within ± 100 µm

Vibration of assembled ladder under air cooling

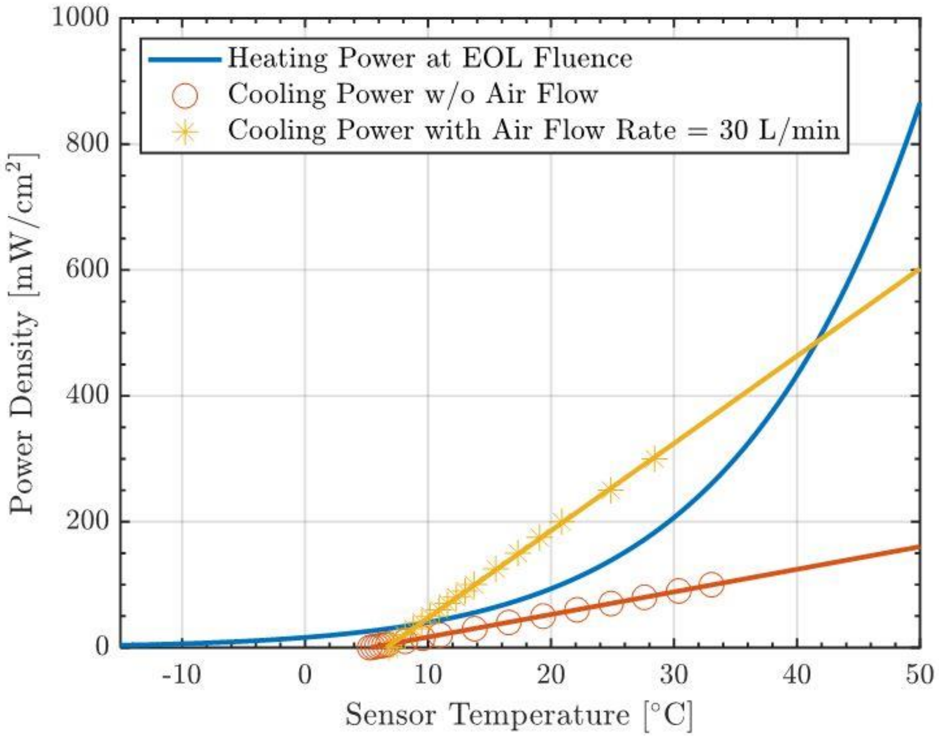
Brief introduction to air cooling

- Only the inner most sensors of all station (x,y, ≤ ± 10 cm), requires active air cooling
- The peripheral sensors of all stations are aimed to be cooled by natural convection
- Cooling power should be sufficient to be away from thermal runaway



Top view of STS station | **Perforated tube**

Perforated tube based on the theory of impinging jets has been chosen as the cooling element running across the length of sensors

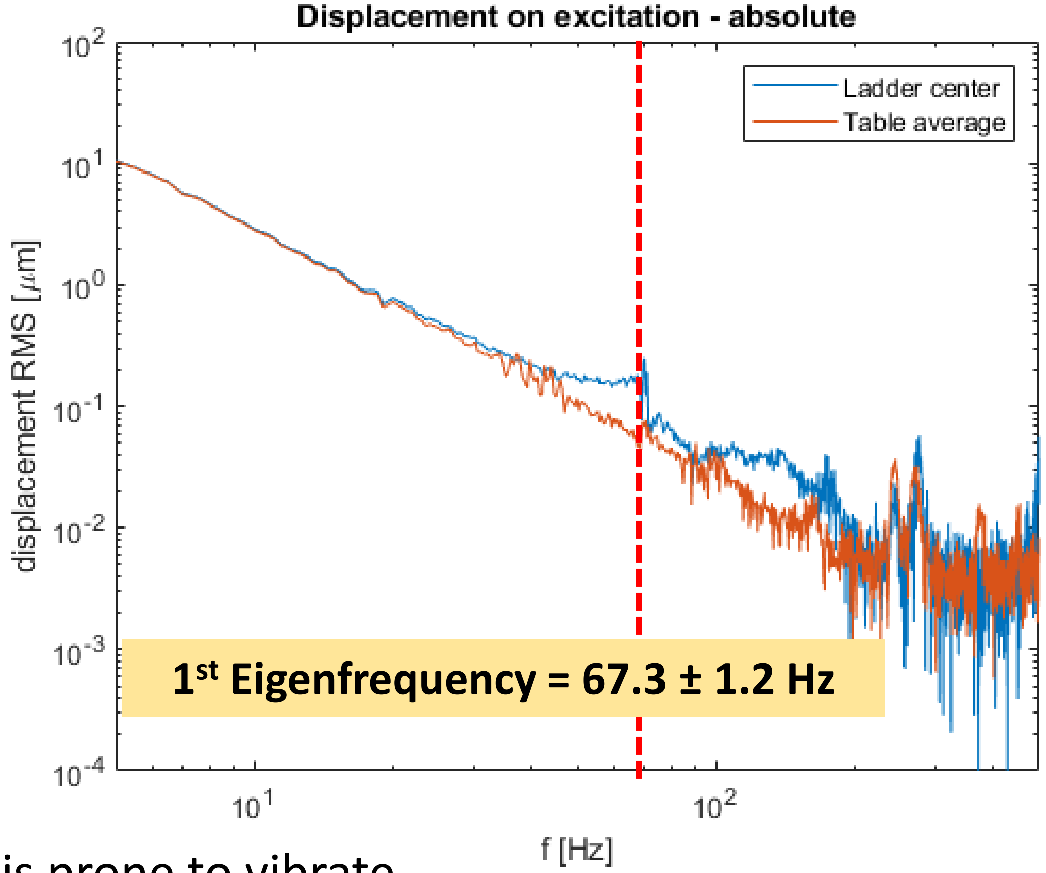


To be at safe margin from thermal runaway, sensors need to be cooled down at flow rate of 30L/min, which could affect the mechanical stability of ladder

More details: K. Agarwal talk, cooling in STS

Eigen frequency measurement of ladder

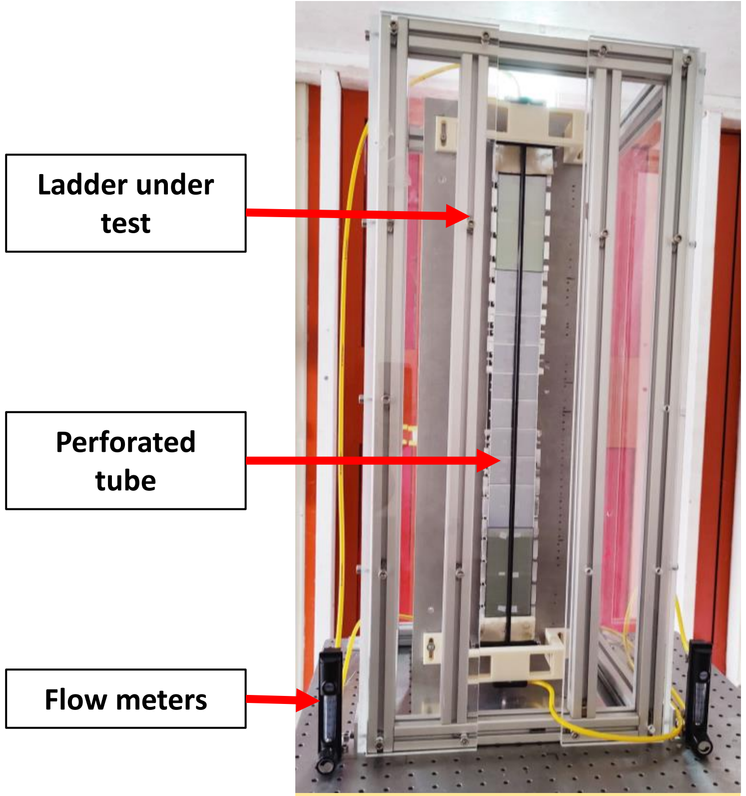
Ladder with dummy modules equipped on a shaker table



- Eigen frequencies are the frequencies at which system is prone to vibrate
- Shaker table at University of Oxford is used to produce the excitement in the ladder using accelerometers
  - Displacement at different eigen frequencies was measured
- 3 capacitive sensors were used to measure the displacement RMS

Next step: Cross check if the eigenfrequency is excited by air flow

Vibration measurements – setup description



Ladder under air flow

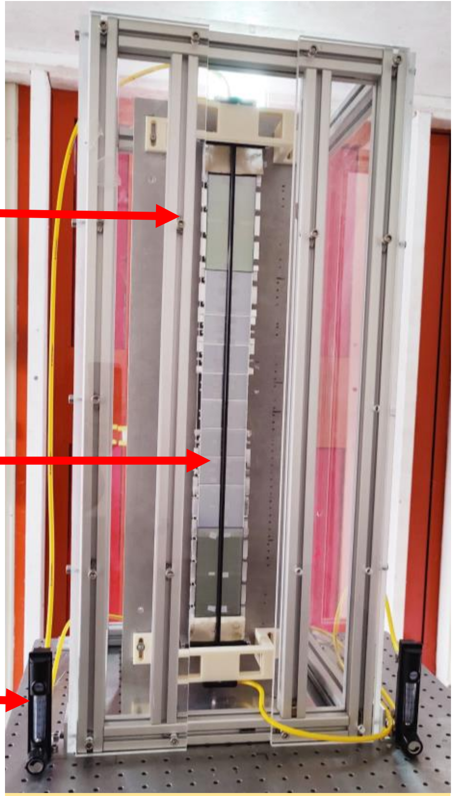
- Testing Procedure
  - A 10 module ladder was mounted on an optical bench to test for the performance under air flow using perforated tube
  - Flow meters at both end of tube were employed to regulate air flow

Vibration measurements – setup description

Ladder under test

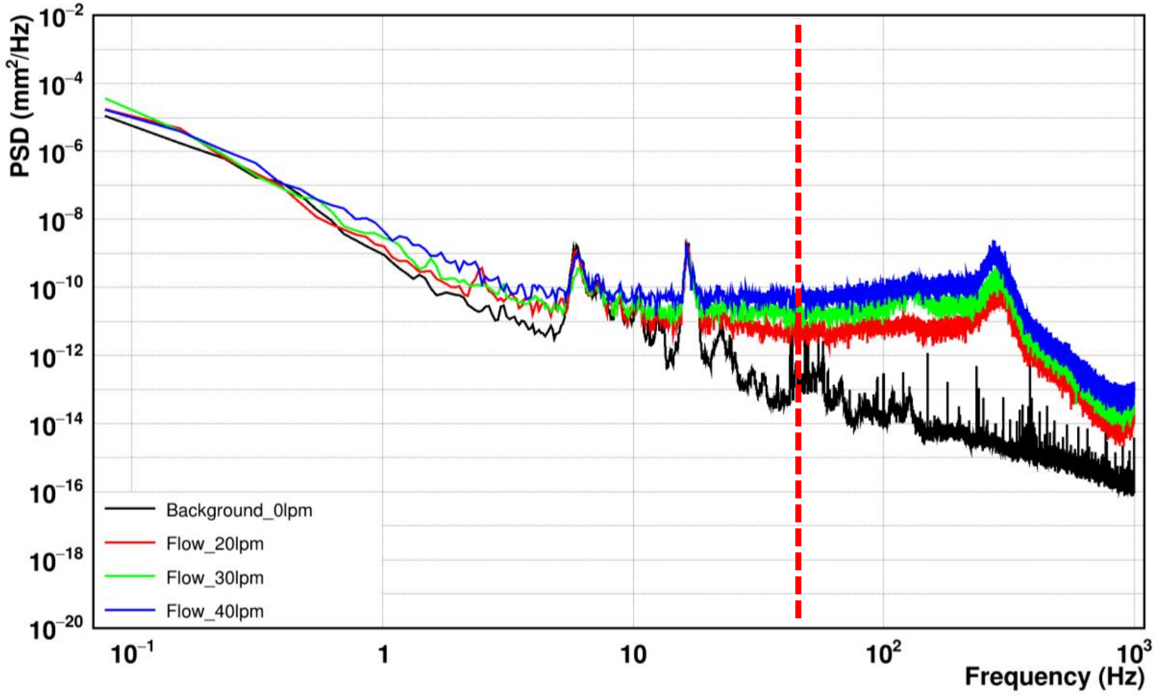
Perforated tube

Flow meters



Ladder under air flow

Setup for measurement

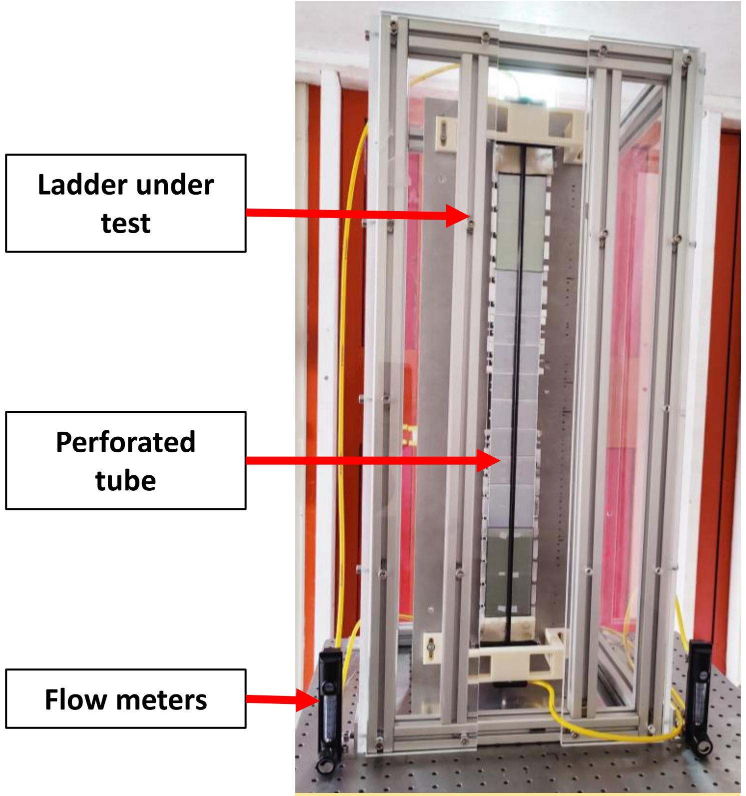


Power Spectral density with changing frequency for different air flow

- Laser doppler vibrometer is used to scan sensor surface
  - Non-contact measurement of surface with wide frequency range
  - Integrated with data acquisition and analysis software
  - Stand-off distance between laser and ladder was ~ 640 mm

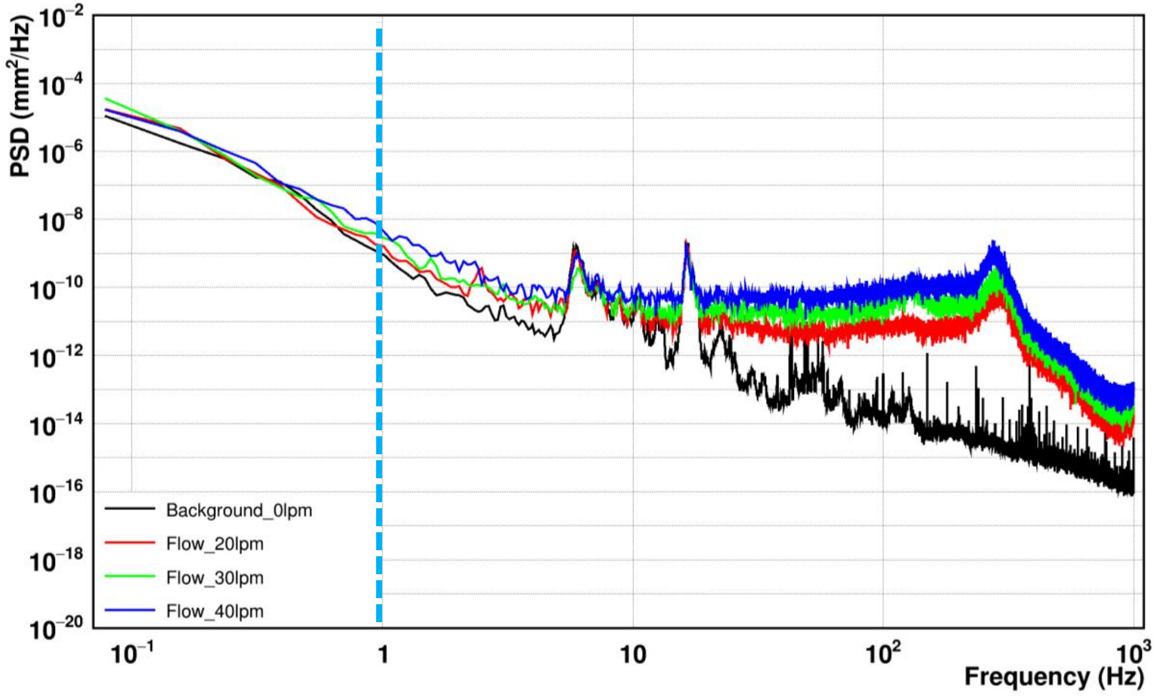
PSD spectra shows that eigen frequency of an assembled ladder is not excited because of air flow

Vibration measurements – setup description



Ladder under air flow

Setup for measurement



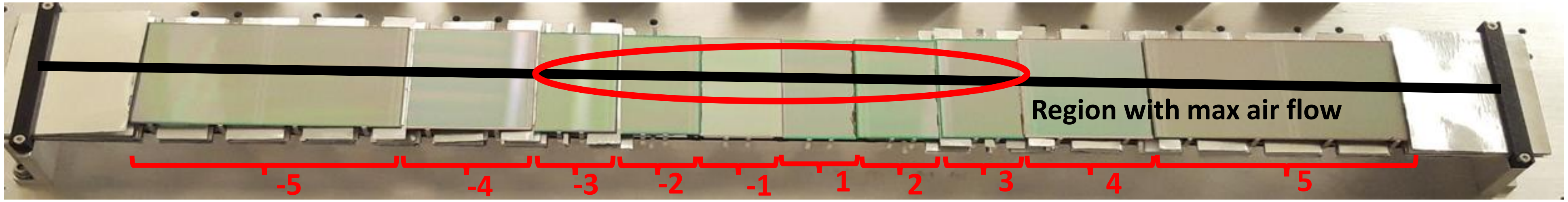
Power Spectral density with changing frequency for different air flow

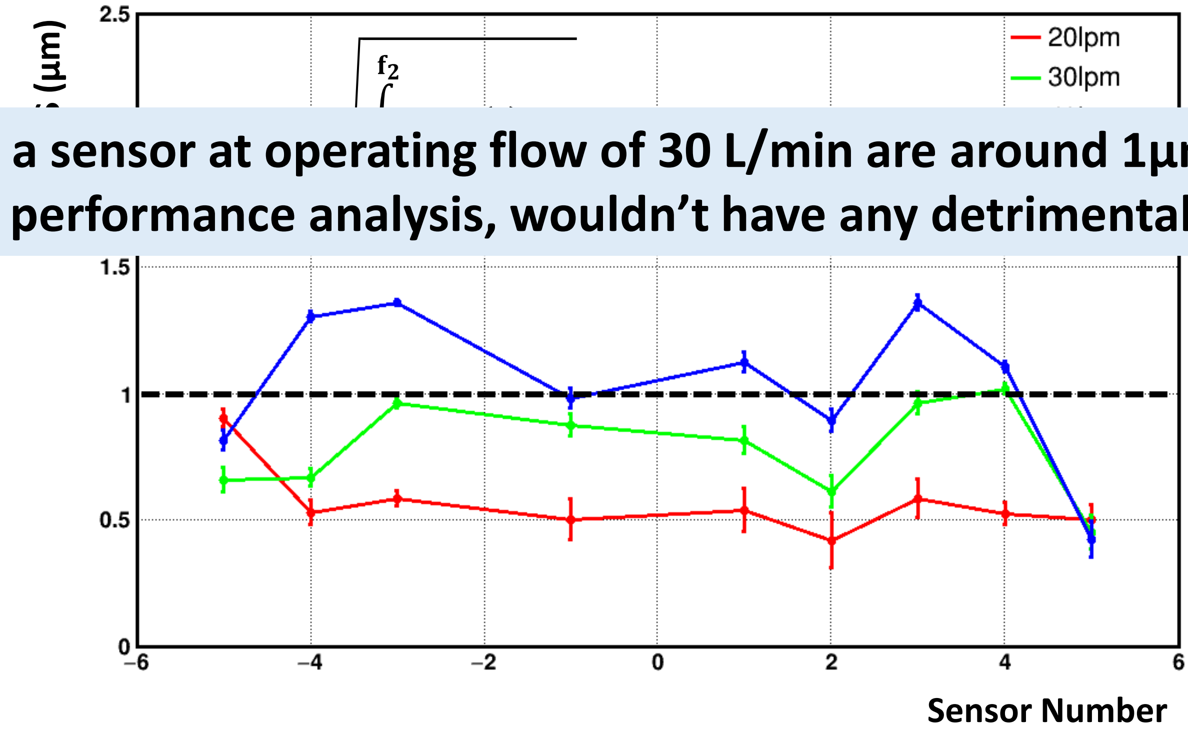
- Laser doppler vibrometer is used to scan sensor surface
  - Non-contact measurement of surface with wide frequency range
  - Integrated with data acquisition and analysis software
  - Stand-off distance between laser and ladder was ~ 640 mm

- Power Spectral Density (PSD) is used to calculate the random vibrations
- To eliminate the interference of background, frequency cut at 1 Hz is applied
- The presence of air flow leads to noticeable excitation in higher frequency ranges

It is important to optimize the amplitude of vibration at optimal flow rate (30 L/min)

Vibration measurements under air flow - results

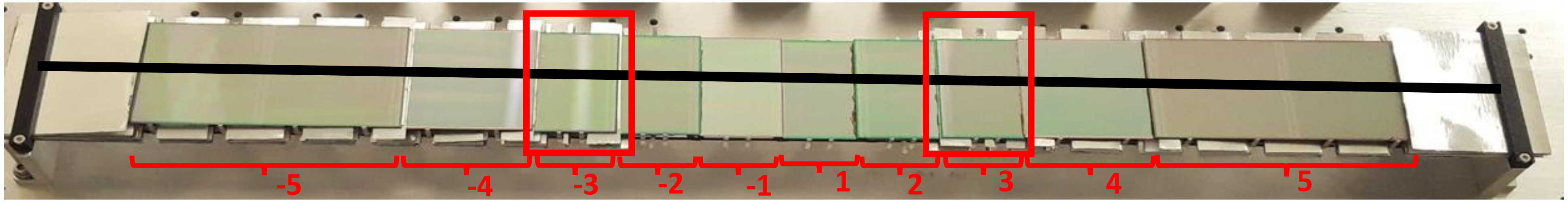


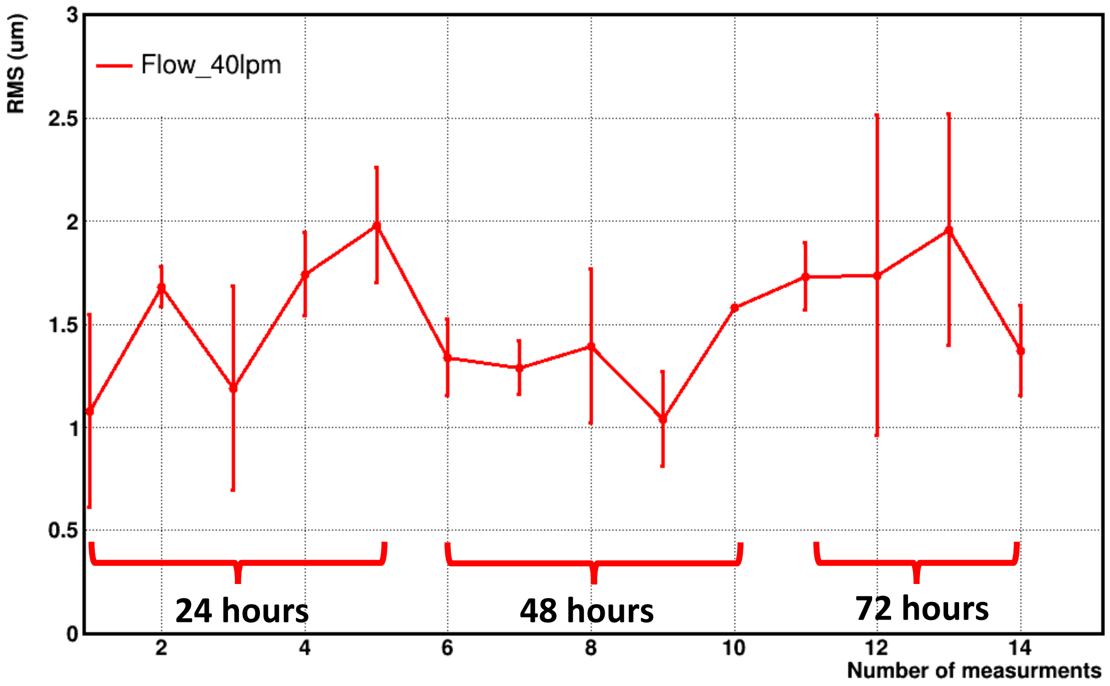


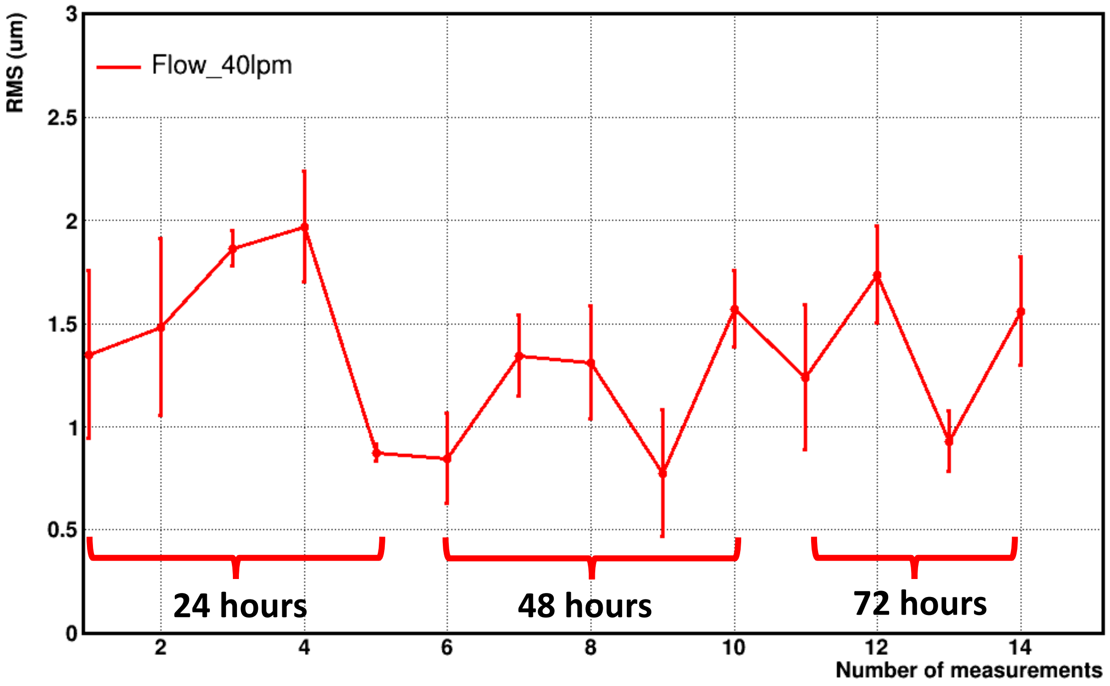
Maximum vibrations on a sensor at operating flow of 30 L/min are around 1µm, which from preliminary track performance analysis, wouldn't have any detrimental effects

- Plot shows the RMS values for over all vibration produced in the sensors along the ladder
- RMS is calculated by subtracting the measurements with flow and the background measurement (without flow)
- Sensors in the middle region vibrates more due to the higher flow in the middle region

Long term measurements for ladder under flow

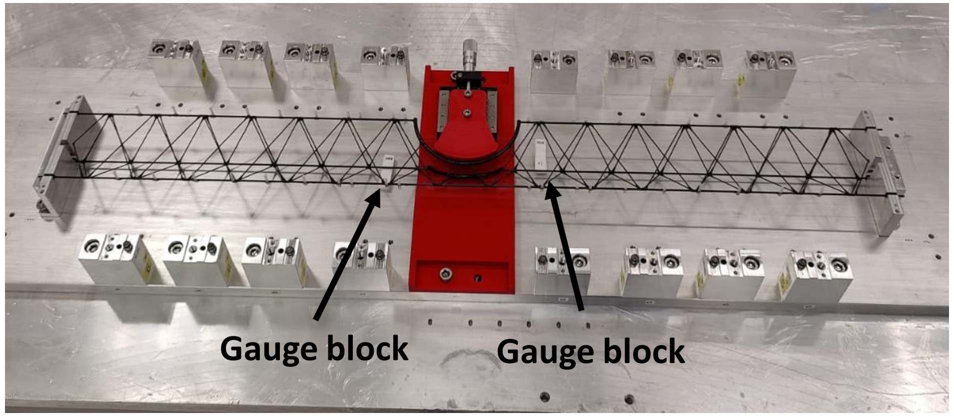


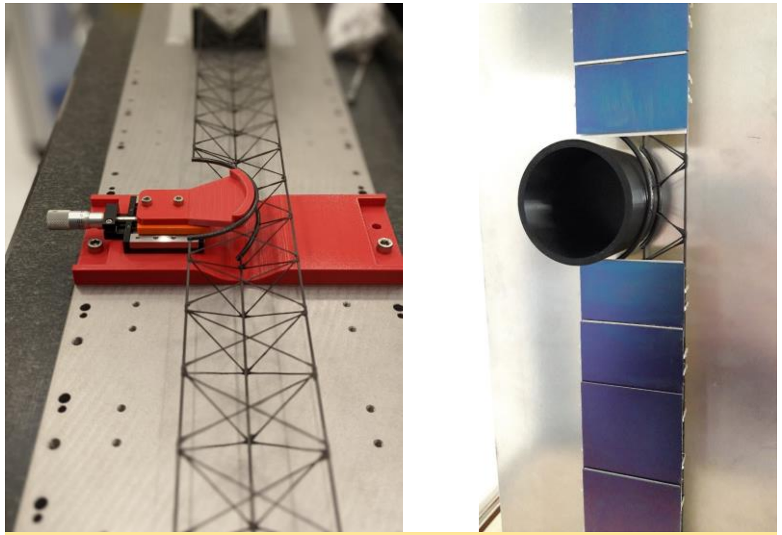




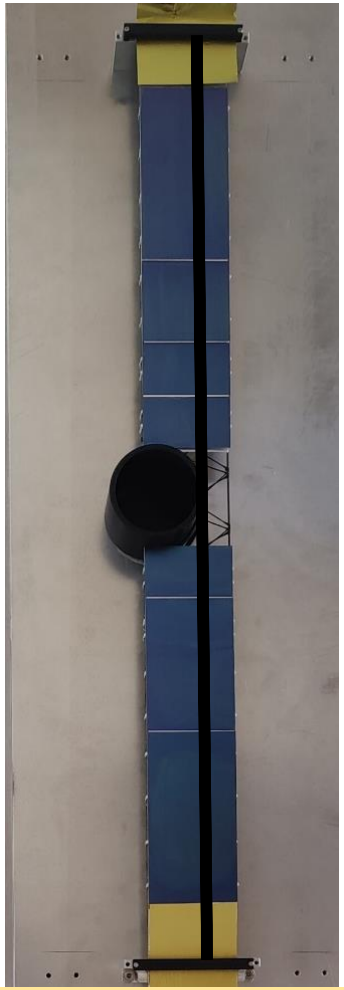
Long term measurement with continuous air flow at 40 L/min for 3 days – RMS is between 1- 2 µm, which ensures reproducible results

Central ladder – Special case

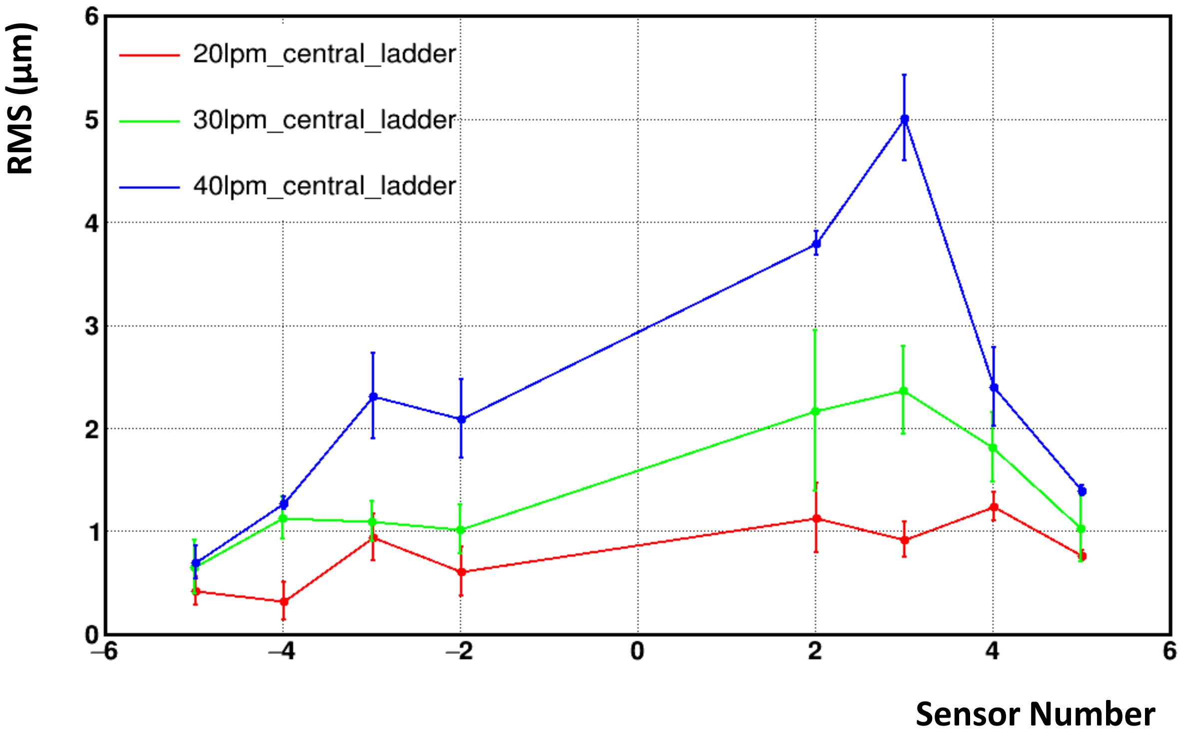




Specialized tool for supporting ladder cut-out during assembly



Ladder with cut-out

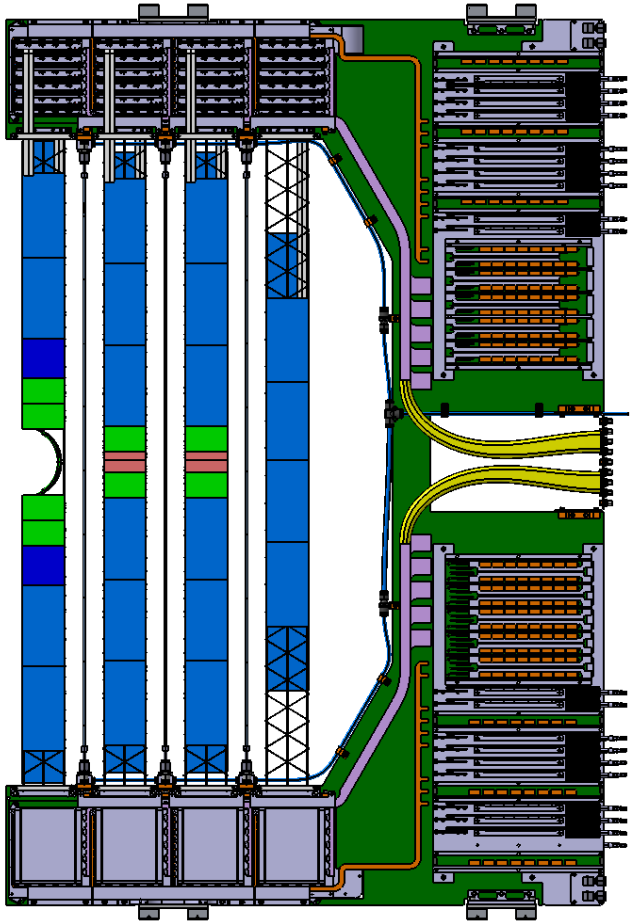


- Thickness of silicon wafers used was 30 % higher than original sensors
- Perforated tube is shifted by 1 cm because of presence of cut out for the beam pipe
- Shift in tube was expected to produce more vibrations

The amplitude of vibration in ladder with cut-out is more because of shift in the perforated tube closer to sensors

Result of air flow on ladder vibration

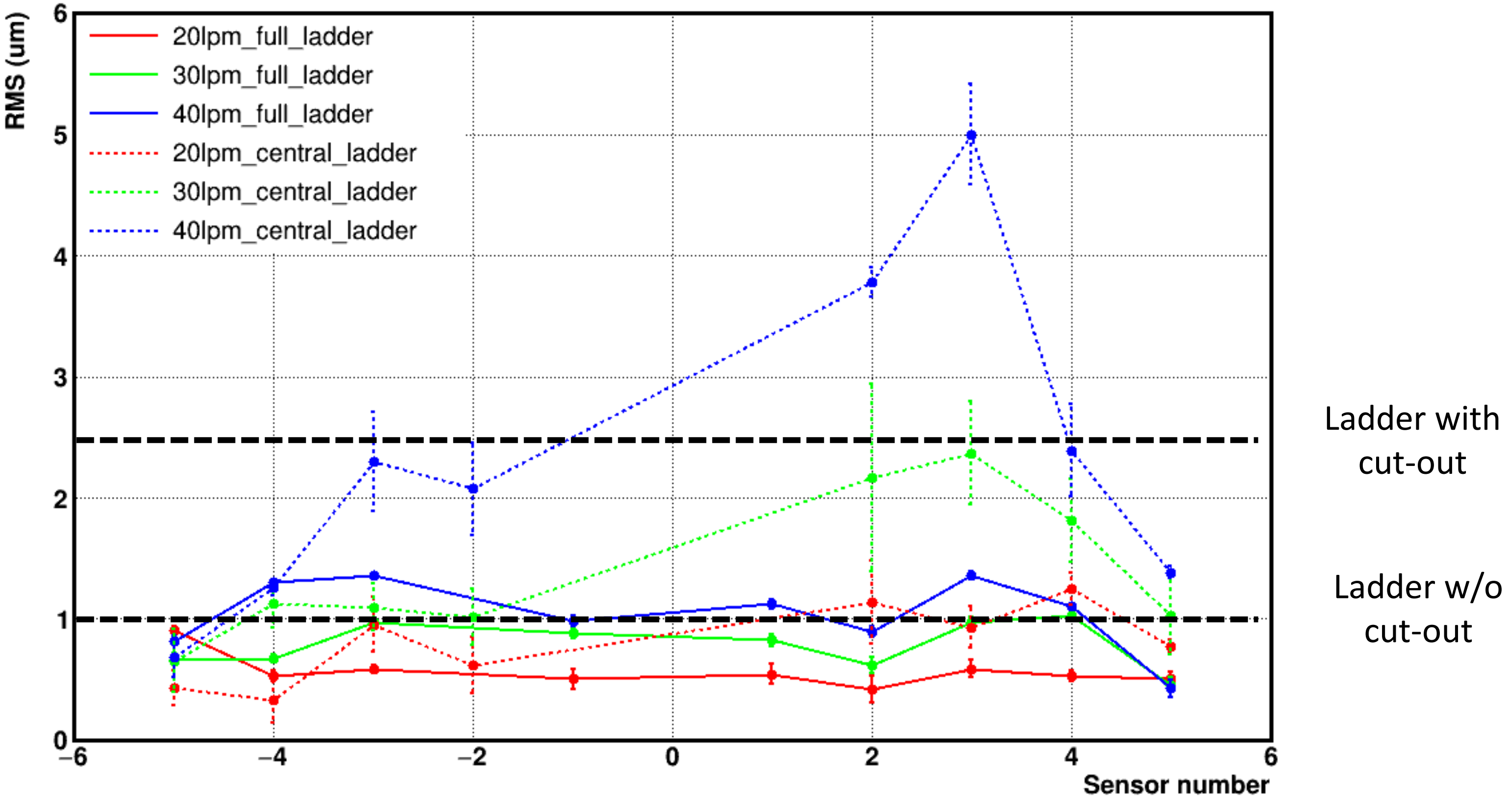
Ladder with and without cut-out



Drawing of ladders with and without cut-out assembled on C-frame along with perforated tube

Result of air flow on ladder vibration

Ladder with and without cut-out



Comparison of vibrations in ladders with and without cut-outs

Ladder with cut out shows more vibration then without cut out but amplitude of vibration is still affordable

Summary and Outlook

- Ladder assembly technique has been exercised to test for the stability and precision mounting of ladders
- The concept of low material budget CF- perforated tubes, which are active source of sensor cooling and could be the source of vibration, has been demonstrated
- Pre- liminary results shows vibration < 1 µm under nominal air flow, in correspondence with track alignment software
- Vibration testing of an assembled ladder at Uni. Oxford shows 67Hz eigenfrequency, which isn't excited by air flow
- Pre-liminary results from central ladders are not very detrimental but need to be optimized

Outlook

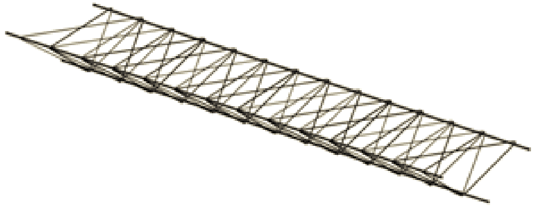
- Vibration studies needs to be performed for the whole C-frame to study the impact of neighboring perforated tube effecting vibration amplitude
- Studies to produce more stiffer ladders is ongoing aiming for minimal material budget
- Vibration impact of air flow needs to be cross checked for the central ladder with final ladder variants

Thank you

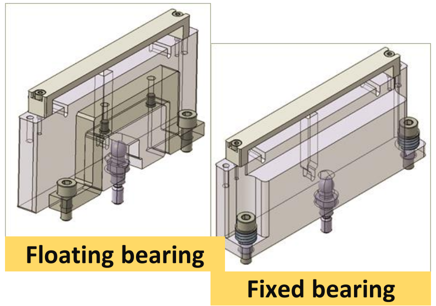
Back up slides

Assembly of ladder for STS

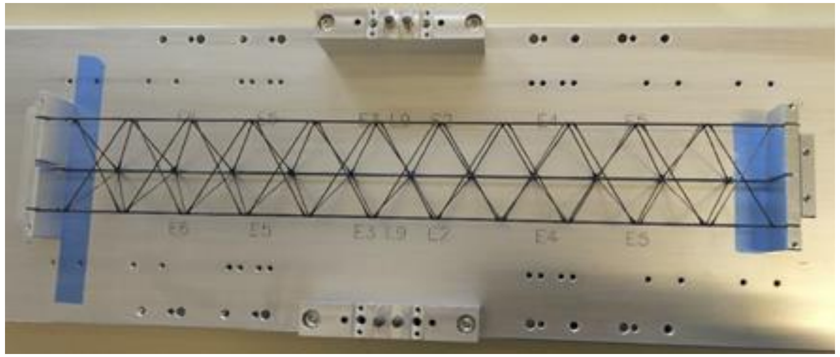
Ladder fixation to bearings



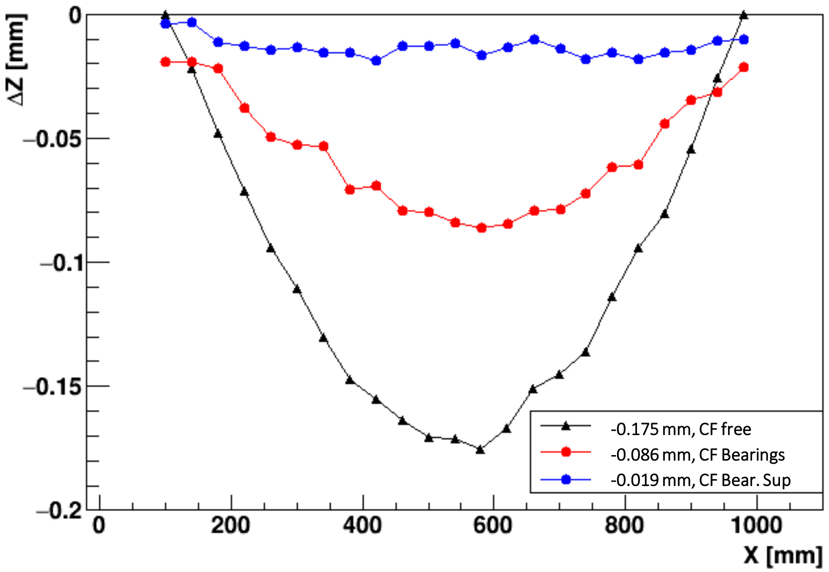
Light weight CF ladder – support structures for the modules



Bearings: Side connectors for ladder fixation

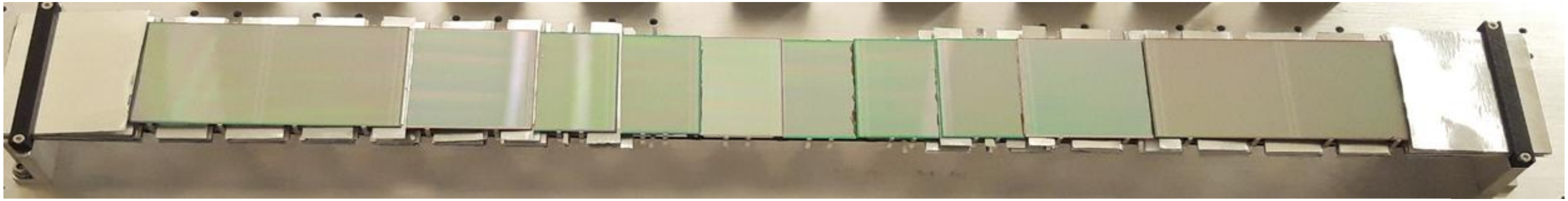


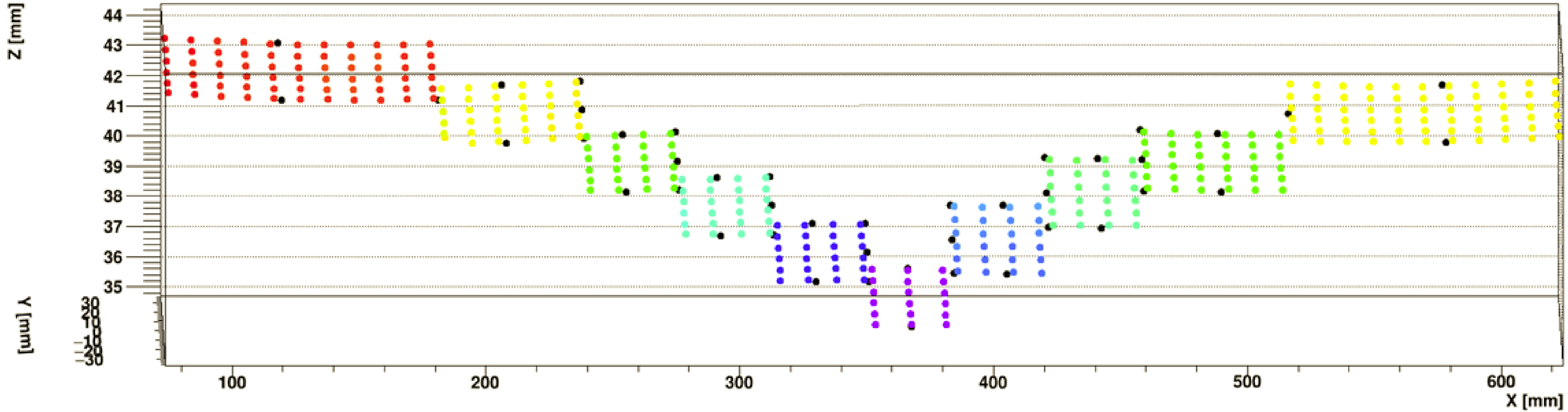
Ladder mounted on a baseplate



Displacement in Z is minimum when the ladder is fixed into the bearings and supported by the gauge blocks

Optical metrology: results for full ladder

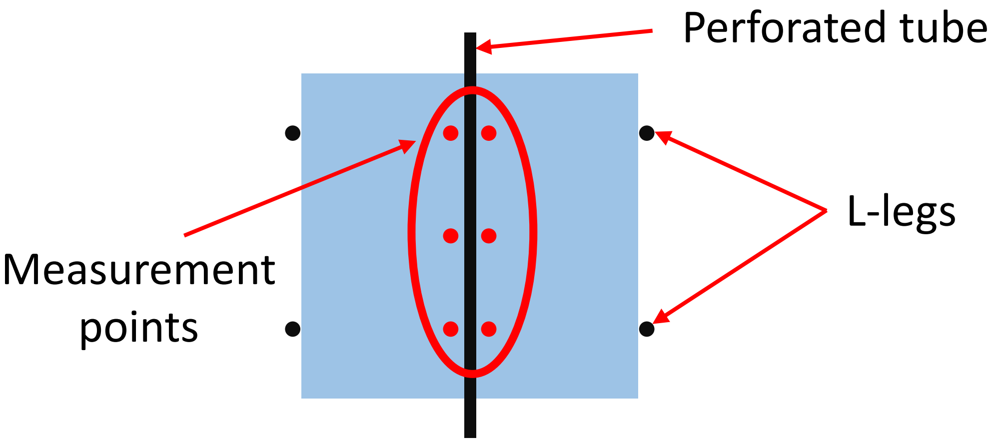




3-D view of the ladder

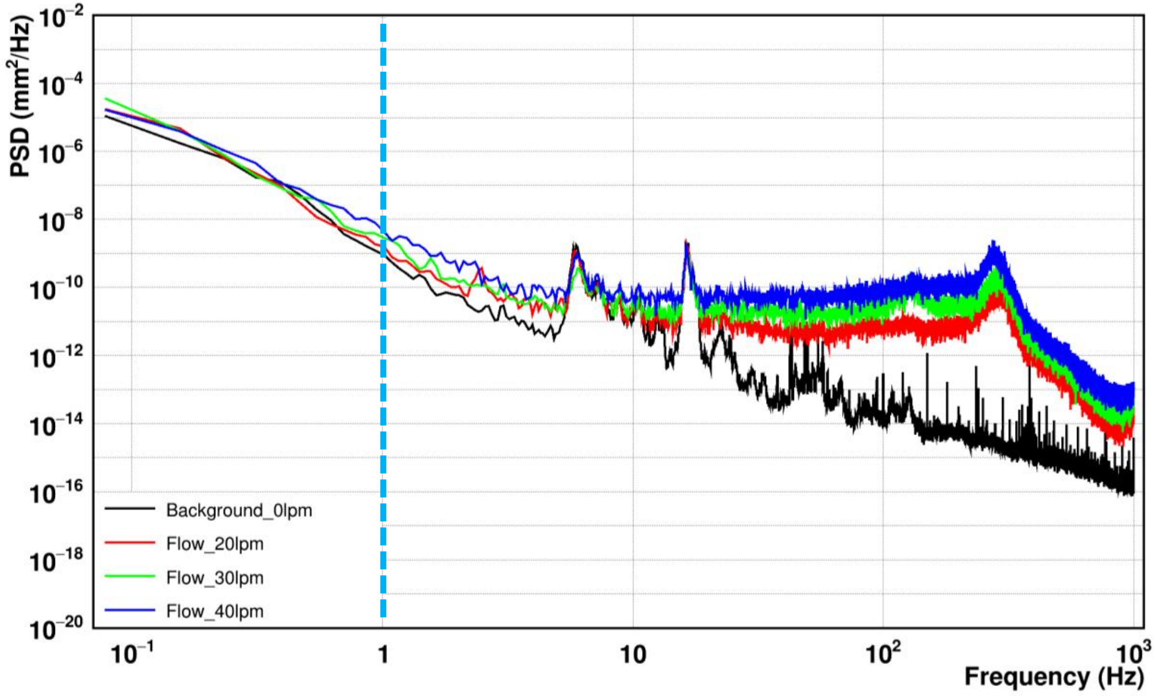
- Black dots refer to alignment markers on the sensor
- Different colors show surface scanning of sensors
- Successful demonstration of the concept of ladder mounting and optical inspection

Vibration measurements – analysis procedure



Flow rate in liter/minute

0_1 → 20_1 → 30_1 → 40_1 → 0_2 ↓ 0_3 → 40_2 → 30_2 → 20_2 → 0_4

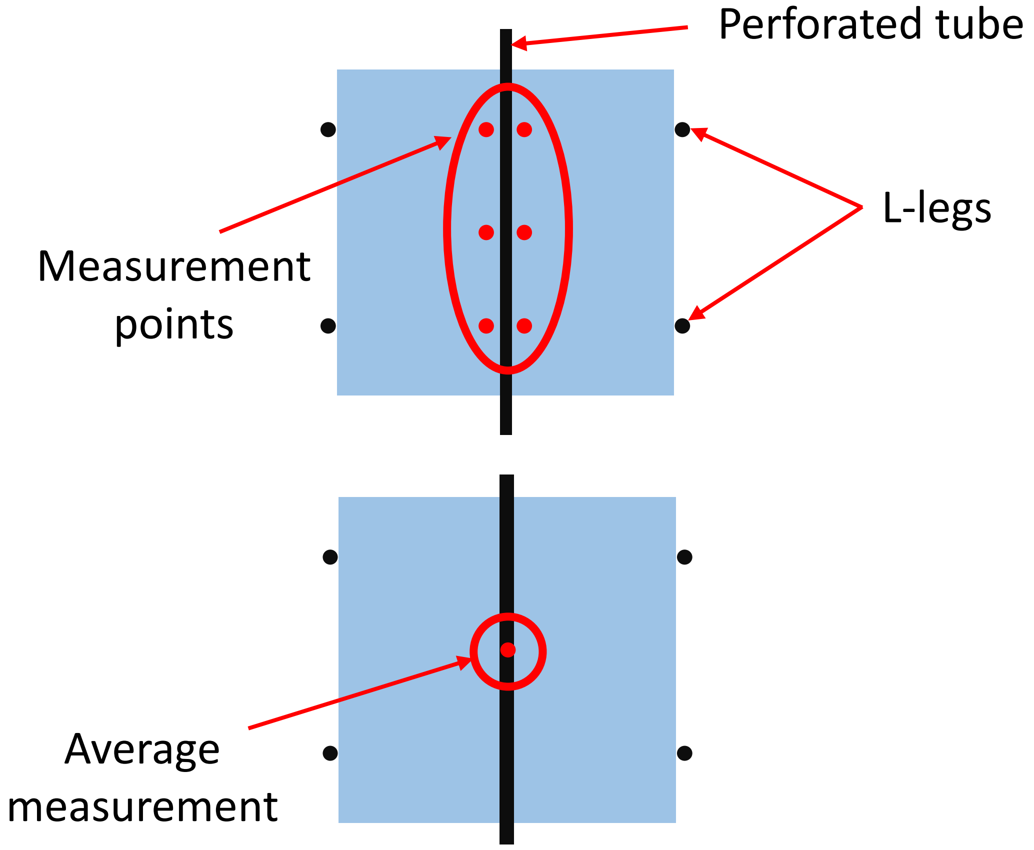


Power Spectral density with changing frequency for different air flow

- Power Spectral Density (PSD) is used to calculate the random vibrations
- Seismic noise contributes to the presence of high vibrations at lower frequencies
- To eliminate the interference of background, frequency cut at 1 Hz is applied
- The presence of air flow leads to noticeable excitation in higher frequency ranges

To measure the amplitude of vibration, PSD spectra has been analyzed for different air flow

Measurement technique / procedure



Sketch of sensor

Flow rate in liter/minute

$0_1 \rightarrow 20_1 \rightarrow 30_1 \rightarrow 40_1 \rightarrow 0_2$

$\downarrow$

$0_4 \leftarrow 20_2 \leftarrow 30_2 \leftarrow 40_2 \leftarrow 0_3$

$0avg = (0_1 + 0_2 + 0_3 + 0_4)/4$

$20avg = (20_1 + 20_2)/2$

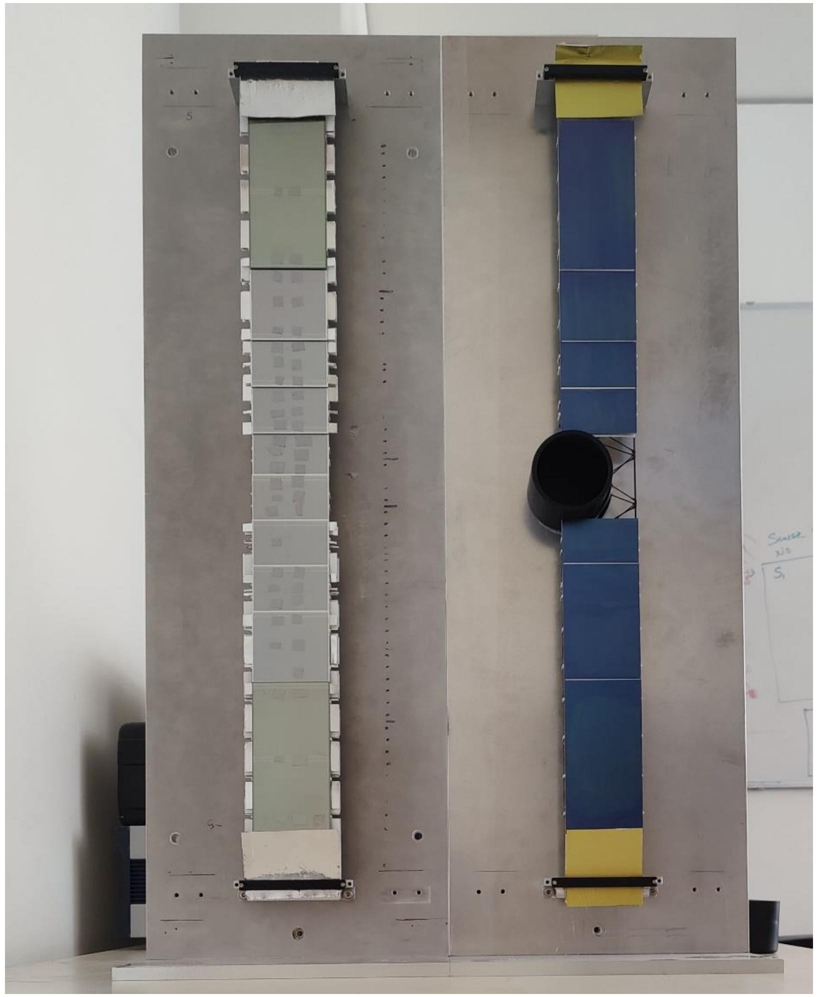
$30avg = (30_1 + 30_2)/2$

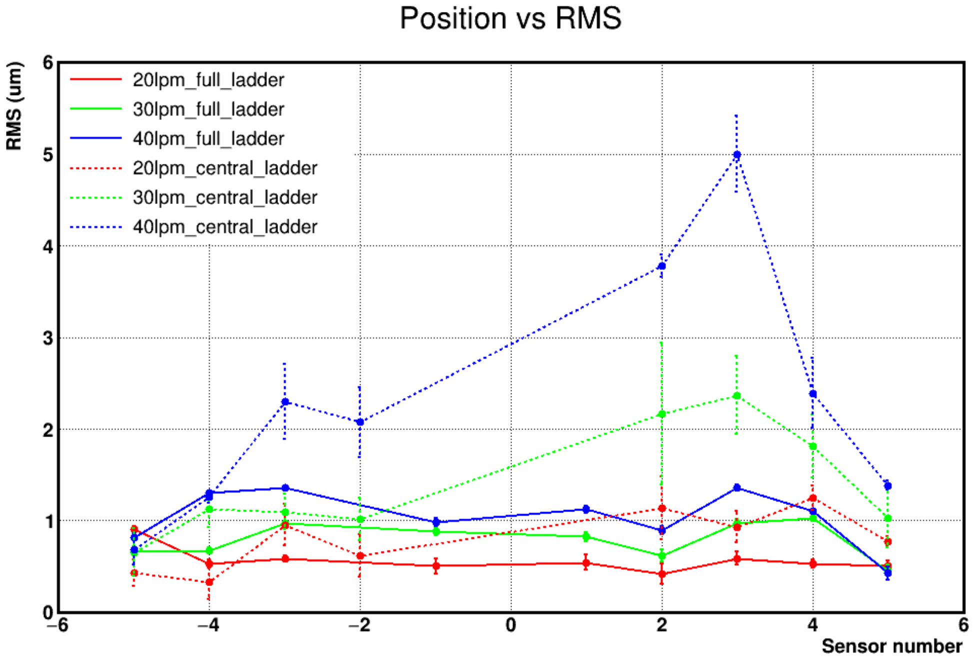
$40avg = (40_1 + 40_2)/2$

Averaging of data per flow rate for every point

- For each sensor, six points are measured along the sides of the perforated tube
- All the points are averaged at the end to get a final picture of vibration per sensor at different flow rates

Comparison

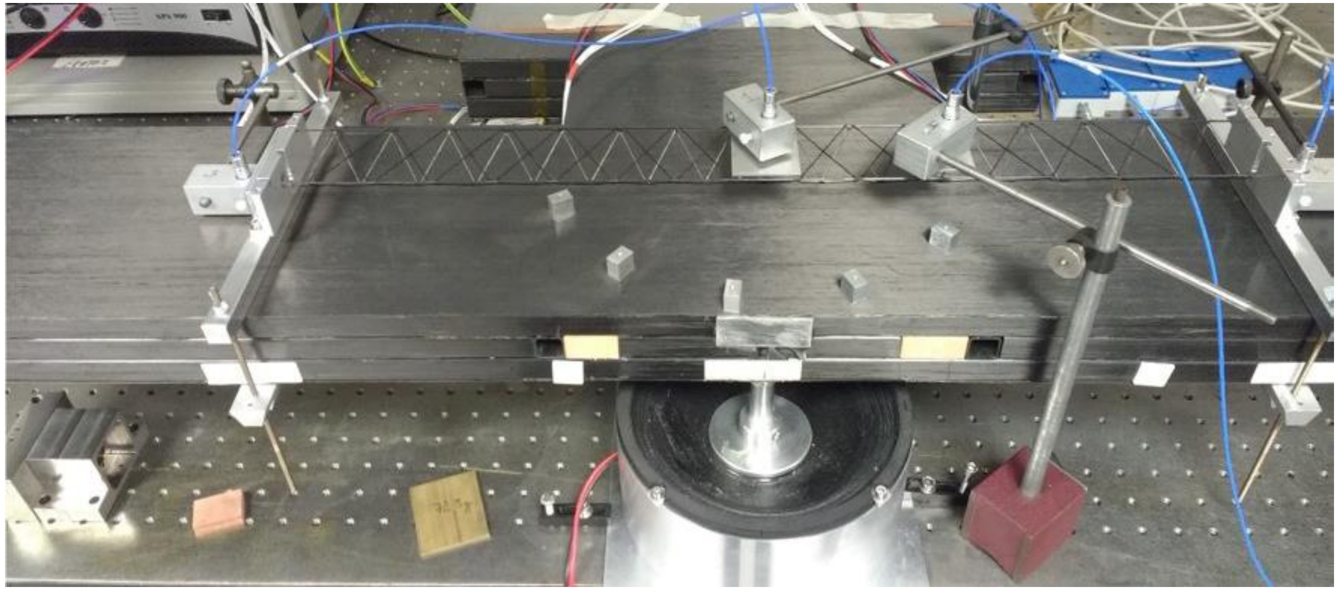




Position vs RMS
RMS (um)
Sensor number
20lpm_full_ladder
30lpm_full_ladder
40lpm_full_ladder
20lpm_central_ladder
30lpm_central_ladder
40lpm_central_ladder
0
1
2
3
4
5
6
−6
−4
−2
0
2
4
6

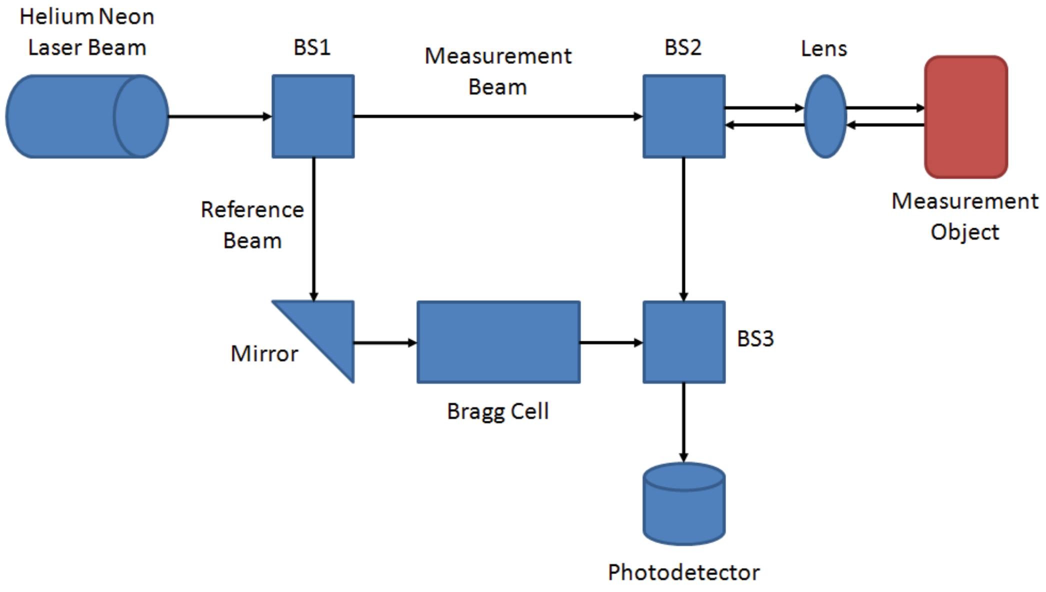
Shaker table for vibration measurement

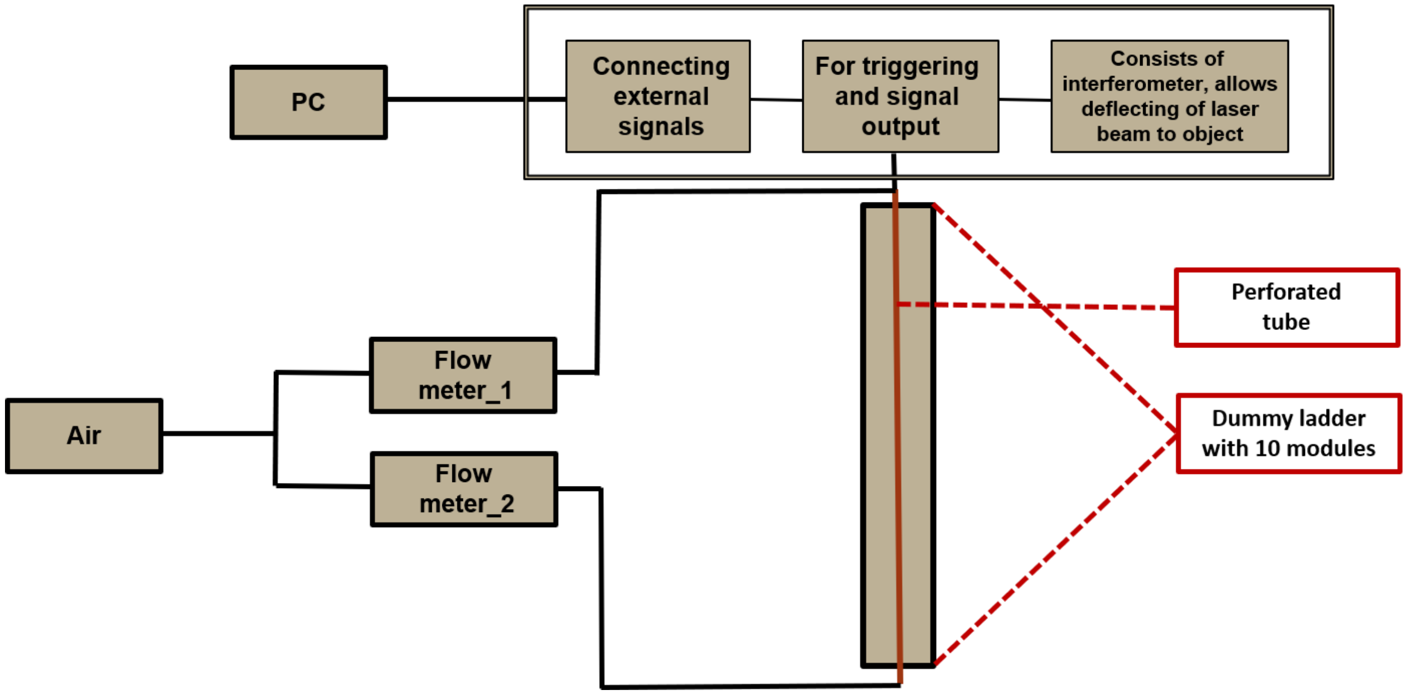
- A shaker table is used to simulate vibrations to test the durability of structures. The main components of shaker table are:
  - **Speaker:** Generates vibrations of specific frequency and amplitude. The speaker generates sound waves that travel through the structure being tested, producing the required vibrations for the testing process.
  - **Accelerometer:** The accelerometer measures the acceleration of the structure in different directions and provides data that can be used to analyze the behavior of the structure under vibration. It is used to measure the response of the structure to the input signal generated by the speaker.
  - **Displacement sensors:** It provides information on how much the structure moves in response to the vibration generated by the speaker.



Block diagram of the set-up for vibration measurement

- Working Principle: Basic principle of operation is Doppler Effect. A vibrometer is a two beam laser interferometer that measures the frequency difference between an internal reference beam and a test beam.
- The Velocity/Displacement of vibrating object is calculated based on the interference between the laser reflected from the vibrating structure and reference laser inside the laser head.





How is PSD calculated in LDV

- **P**ower **S**pectral **D**ensity (**PSD**) is used to characterize the random vibration signals.
- **P**ower- The magnitude of PSD is mean square value of the signal being analyzed. It does not refer to physical quantity power but since power is proportional to mean square value of the quantity
- **S**pectral- refers to spectrum of frequencies
- **D**ensity- magnitude of PSD is normalized to a single hertz bandwidth
- A PSD is computed in two steps:
  - By multiplying each frequency bin in an FFT by its complex conjugate which results in the real only spectrum of amplitude in g^2.
  - The amplitude value is then normalized to the frequency bin width to get units of g^2/Hz. By normalizing the result we get rid of dependency on bin width so that we can compare vibration levels in signals of different lengths.

Role of vibration in track reconstruction

- Hit is determined by the intersection of clusters in front and back side.
- Each cluster is characterized by the center position and its error.
- Errors in clusters position -> errors of the hit coordinates
- Ambiguities in hit construction in case of several clusters at a time.
- Vibrations in z direction induce effect in x and y direction: leads to activation of the strips.
- These activated strips contribute in the fake clusters -> hits and then eventually fake tracks, affecting reconstruction performance of STS.
- The effect in z direction is being examined with vibrations in x and y directions.

Conclusions from simulations

- Max vibrations in ladder/sensor can tolerate in z-direction?
- Steps performed in simulations: random shift of hits associated with the sensors in z- direction were introduced and simulations were performed using modified sts hit tracker between 1mkm – 10mkm.
- First results:
  - No vibration- Ghost probability : 0.053% | 22.34 tracks/event
  - 1 µm XY(~3.7 mkm Z)- Ghost probability : 0.054, 22.58 tracks/event
  - 10 µm XY(~37 mkm Z)- Ghost probability : 0.234, 121.22 tracks/event