Closed-loop simulations of the thermal experiments in LISA Pathfinder

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Organisation of the talk

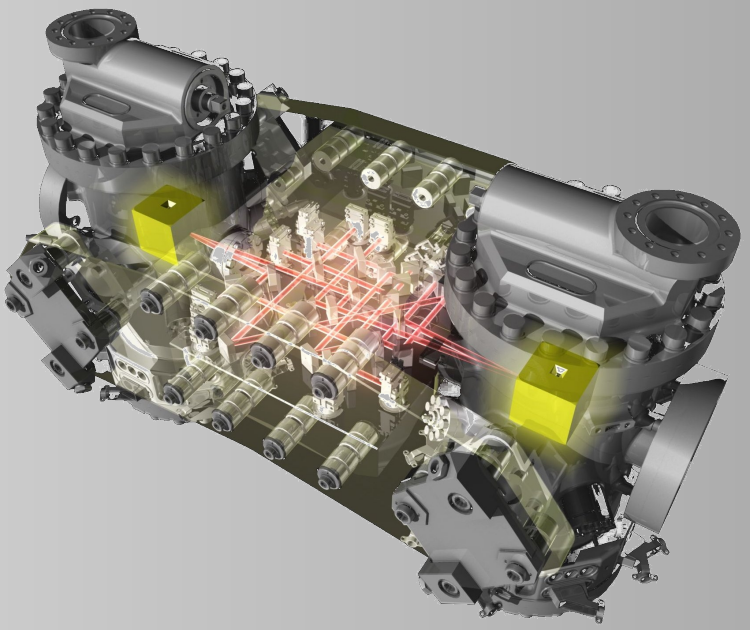
1. Thermal Diagnostic Experiments

2. Models for the experiments

3. Injection to the LTP model

4. Simulations
   - Electrode Housing (EH) heating case
   - Optical Window (OW) heating case
   - Temperature noise injection

5. Summary



LTP Thermal Diagnostics experiments

Motivation:

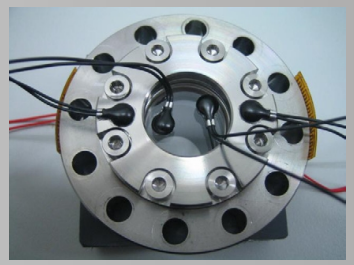
The performance LISA Pathfinder's (LPF) Interferometer (IFO) is sensitive to thermal fluctuations in the environment

A series of **Thermal Diagnostic experiments** are planned to be done in-flight in order to study the system response in front of different thermal fluctuations.

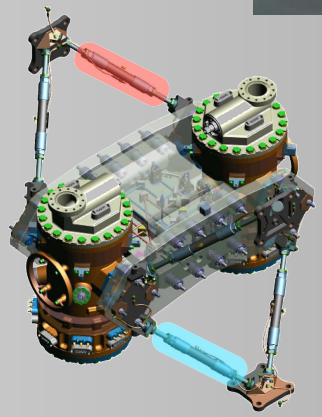
LTP Thermal Diagnostics experiments

*Different experiments for each **thermal-sensitive elements** in the LTP*

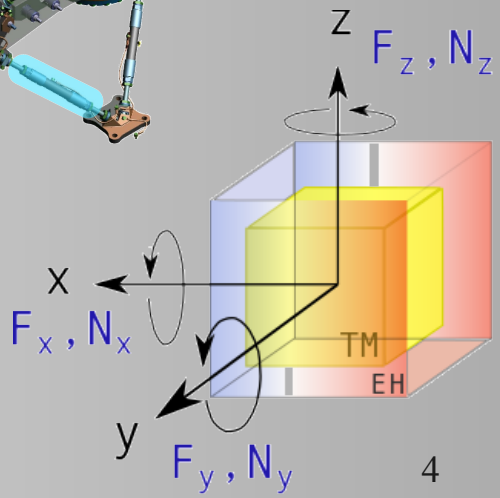
Optical Window (OW) Thermal experiments → **Optical path length modification** of the **Optical Window** glass.



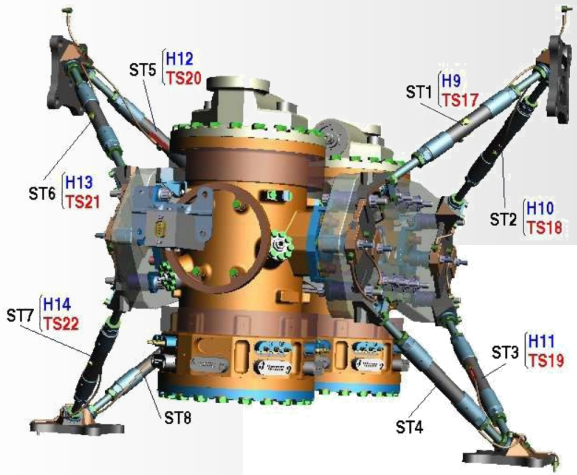
Struts (STR) Thermal experiments → **Thermo-elastic distortions** of the **Optical Bench**



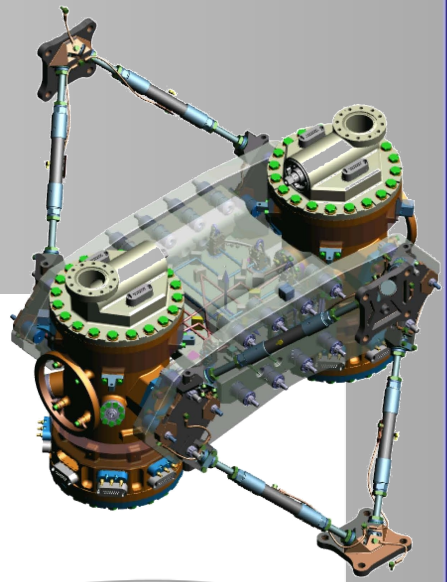
Electrode Housing (EH) Thermal experiments → **Forces** and **Torques** on the **Test Masses**.
(through different thermal effects)

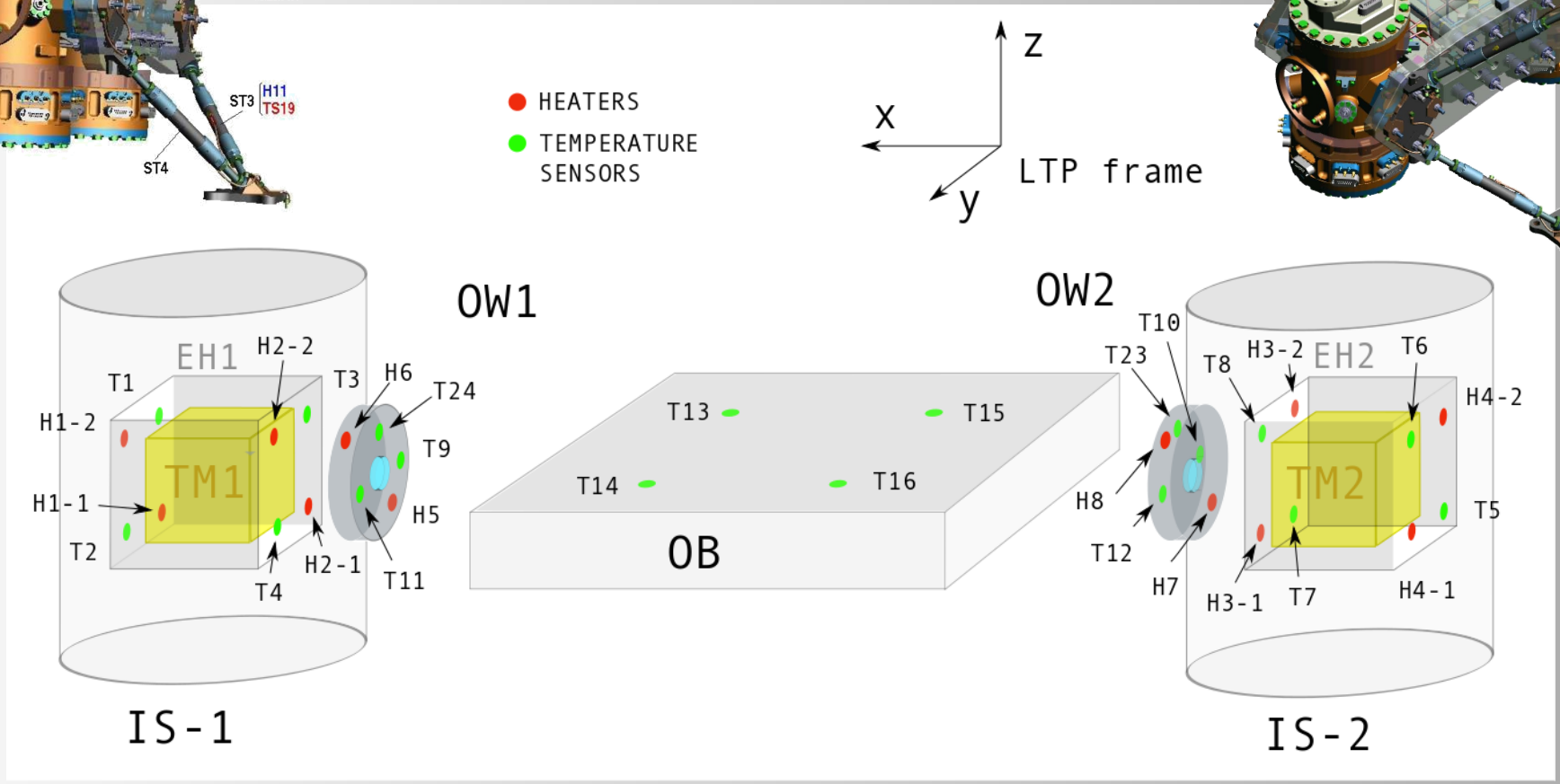


LTP Thermal Diagnostics experiments



14 **Heaters**
24 **Temperature Sensors**





Models for the experiments

How are we modelling them?

OW Thermal experiments → Model based on data from OW campaign in AEI Hanover (2007)

STR Thermal experiments → Model will be based on data from Thermo-Optical Qualification Model tests

EH Thermal experiments → Both theoretical expressions and data from Torsion Pendulum from UTN should be used for modelling.

Modelling: EH experiments

Temperatures gradients cause forces through different thermal effects

- **Radiometer effect.** In rarefied atmospheres, where the particles' mean free path is much longer than the system distance

$$\Delta F_{ij}^{RM} = w_{rm} \frac{1}{4} \frac{A_j p}{T} \Delta T_{ij}$$

- **Differential radiation pressure.** Infrared radiation

$$\Delta F_{ij}^{RP} = w_{rp} \frac{8}{3} \frac{\epsilon_{ij} A_j \sigma T^3}{c} \Delta T_{ij}$$

- **Asymmetric outgassing.** Particles flow emitted by surfaces exposed to low pressure

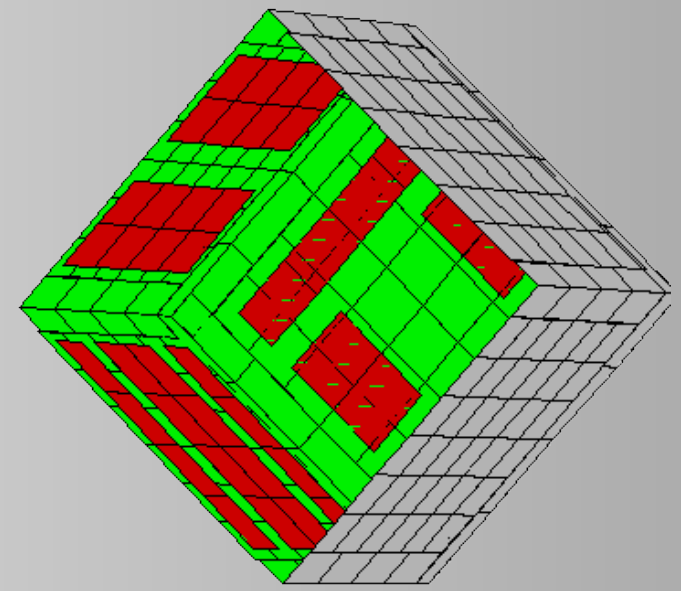
$$\Delta F_{ij}^{OG} = w_{og} \frac{Q_0 \Theta_{OG} e^{\frac{-\Theta_{OG}}{T_0}}}{C_{eff} T_0^2} \Delta T_{ij}$$

Modelling: EH experiments

So, first of all, temperatures...

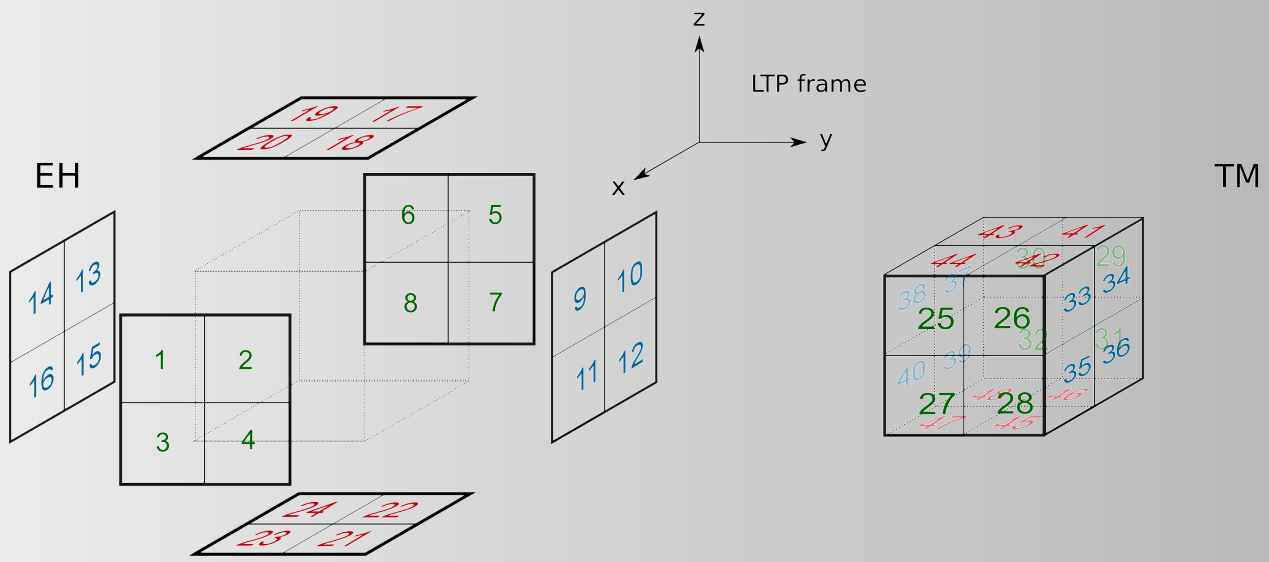
- An accurate **thermal model** required, coded in ESATAN Software.

- **Transfer function samples** from the temperature response at a node due to heat application to other nodes.
  - **Inputs:** heater location nodes.
  - **Outputs:** TS location nodes and nodes inside the Electrode Housing.

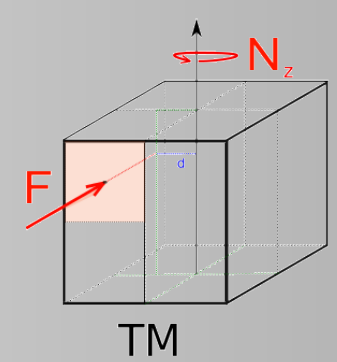


Modelling: EH experiments

- EH inner faces and TM surfaces discretised into isothermal *facets*



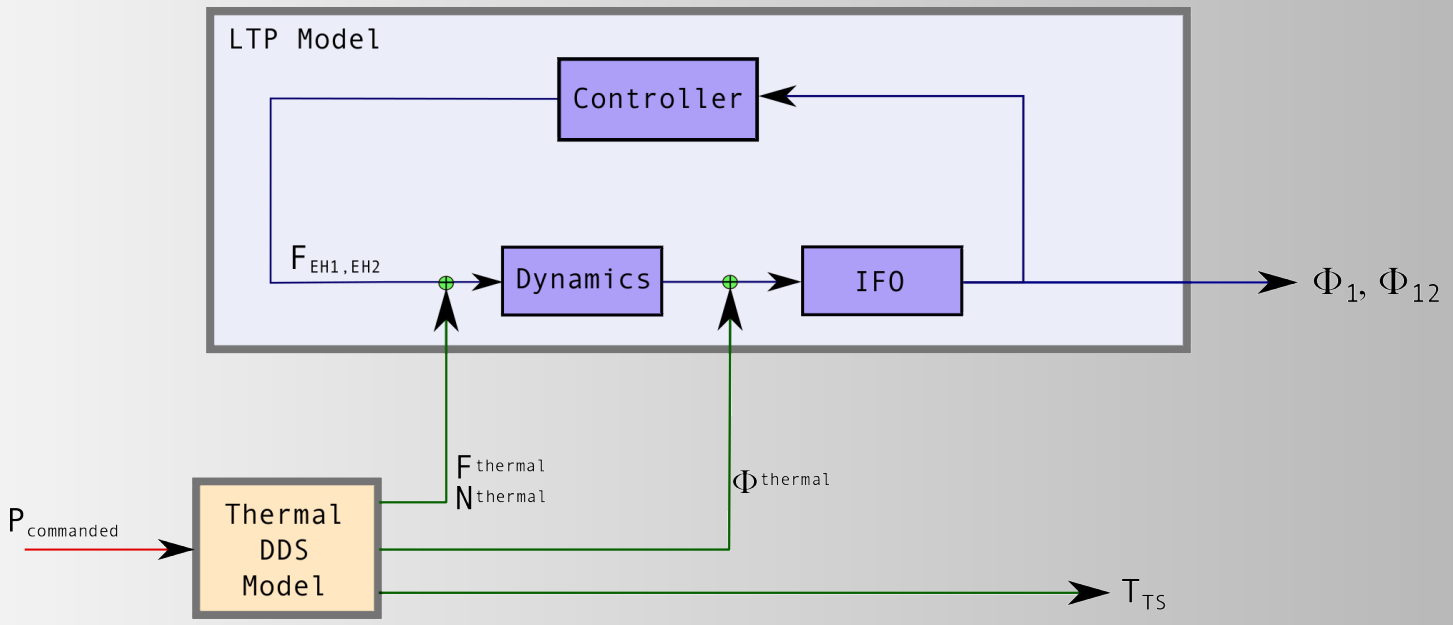
- Force contributions between each pair of EH-TM surfaces are computed individually
  - Multi-reflections treatment of such contributions
    - Assumption: *diffuse reflection*
  - Each force contributions expressed as *vectors*.



Simulation: Injection to model

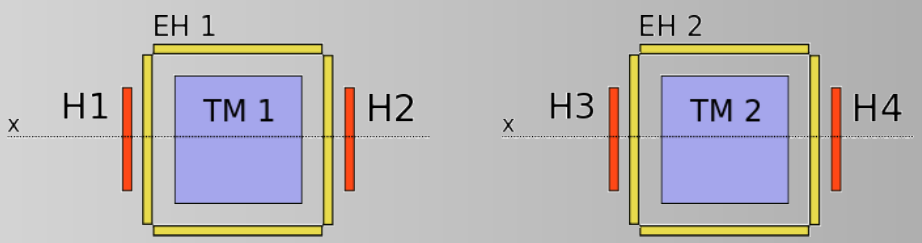
- Modelling of both EH and OW experiments by means of **State-Space Models** (SSM) blocks in the **LTPDA Toolbox** environment.
- Simulations by two steps:

  1. Computation of time series of temperatures, forces, torques, phase shifts caused by the activation of any combination of heaters.
  2. Injection of the outputs to the global SSM object of the LTP.



Example 1: EH experiment

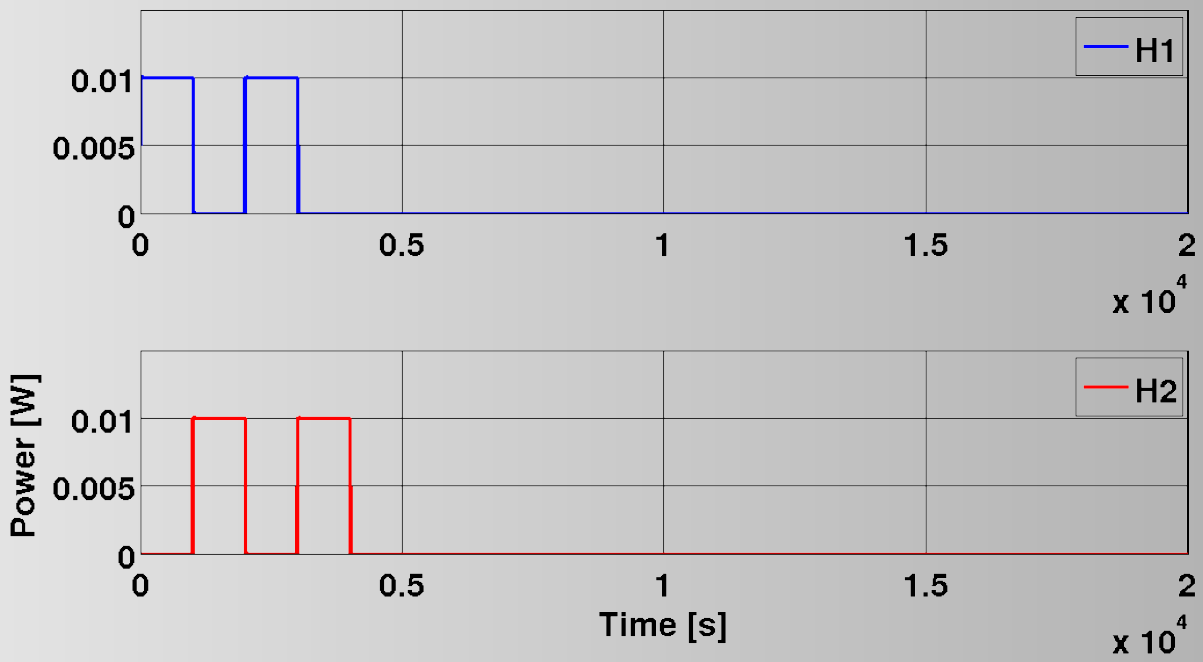
Typical input:
- Alternative pulses on H1 and H2
- Power: 10mW
- Frequency: 0.5mHz (pulses of 1000s)



Nominal values:

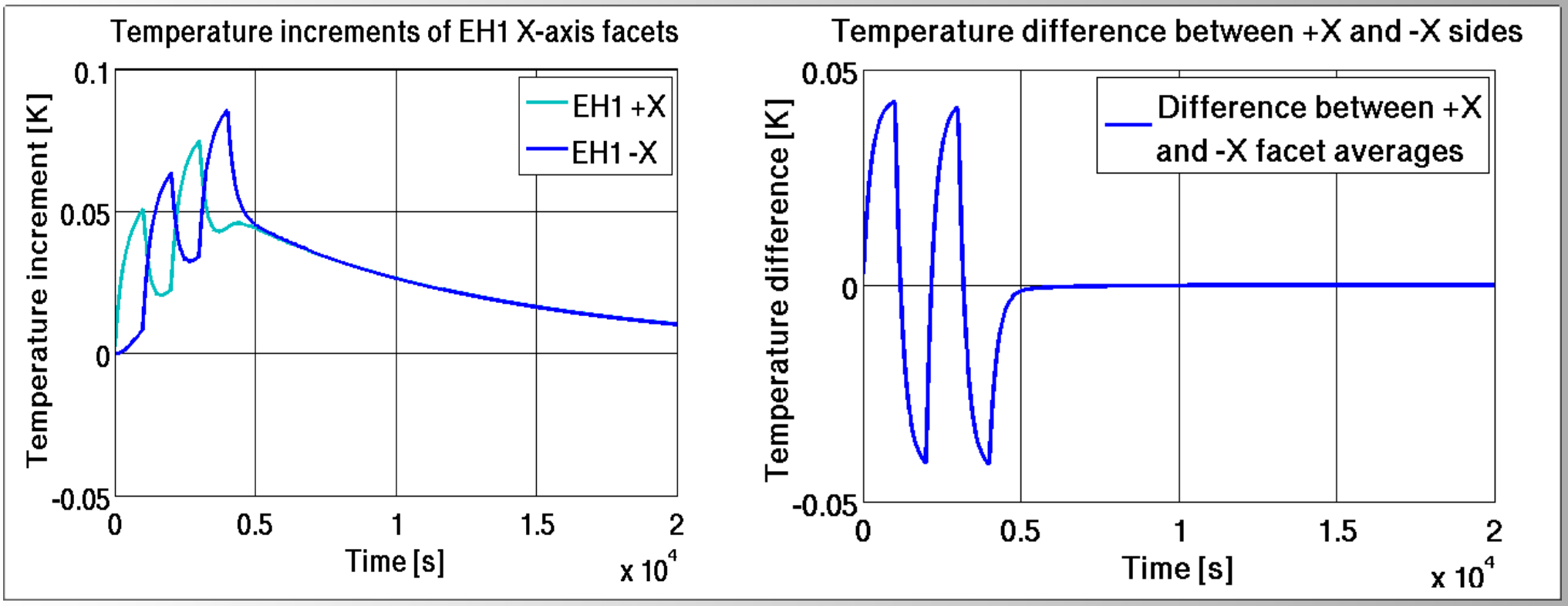
T_{system} = 293K

P_{static} = 10^{-5} Pa



Example 1: EH experiment

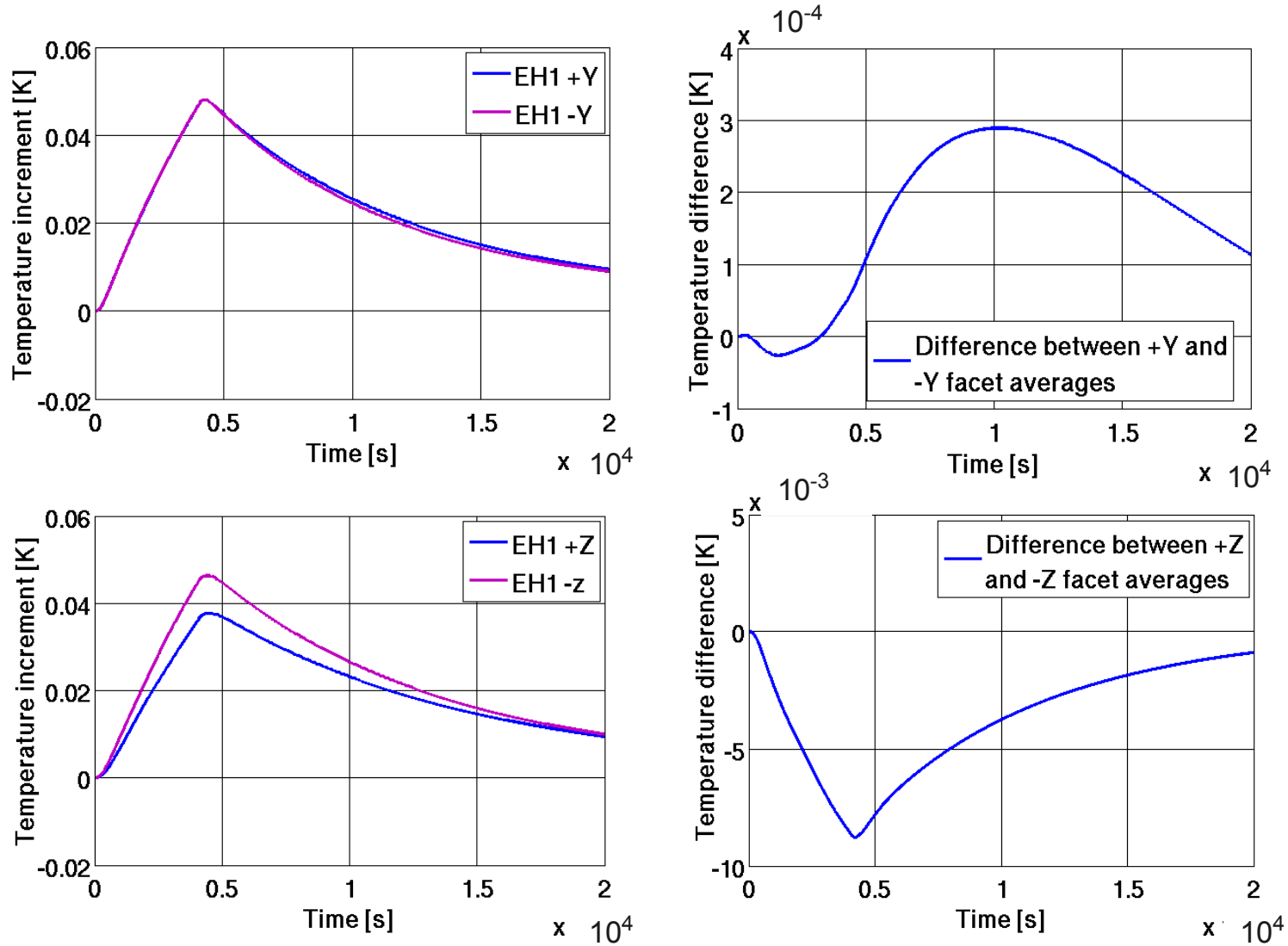
X axis:



Example 1: EH experiment

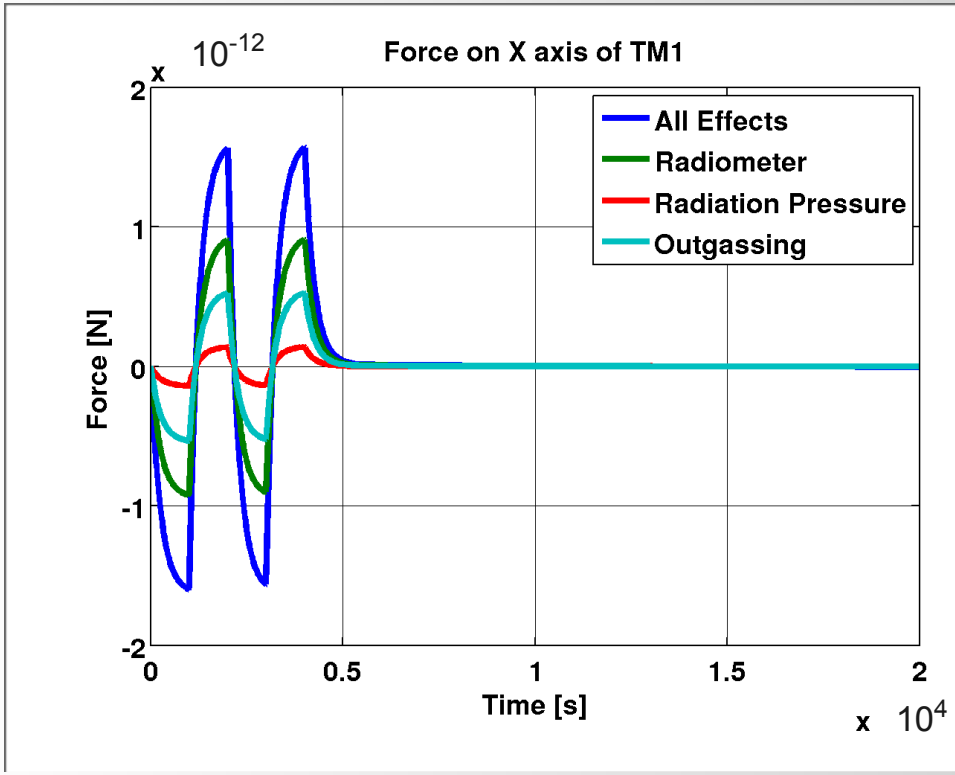
Y axis:

Z axis:

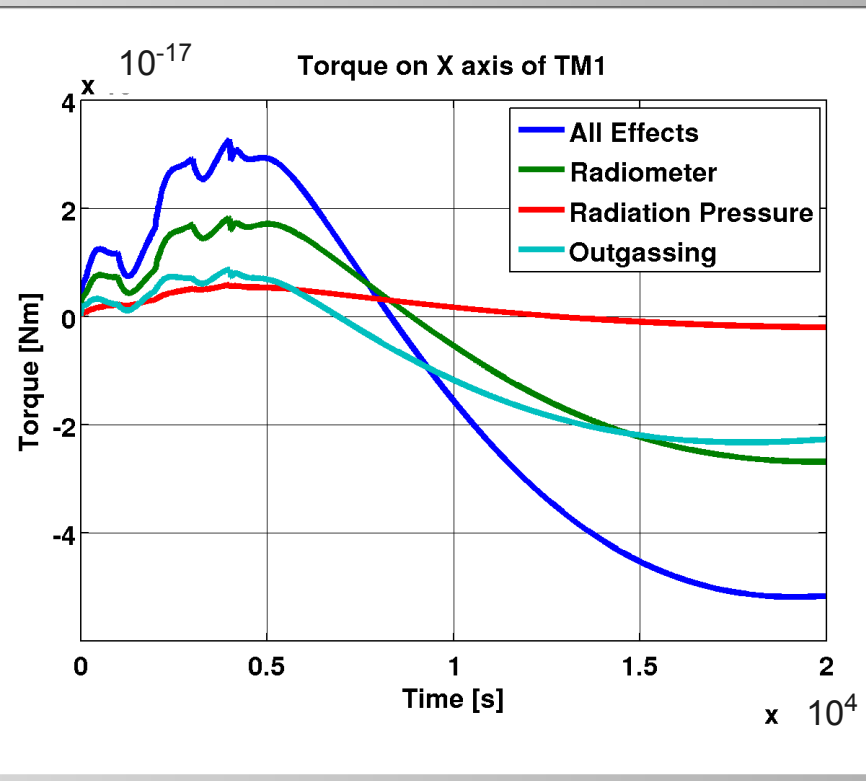


Example 1: EH experiment

Force on X axis:



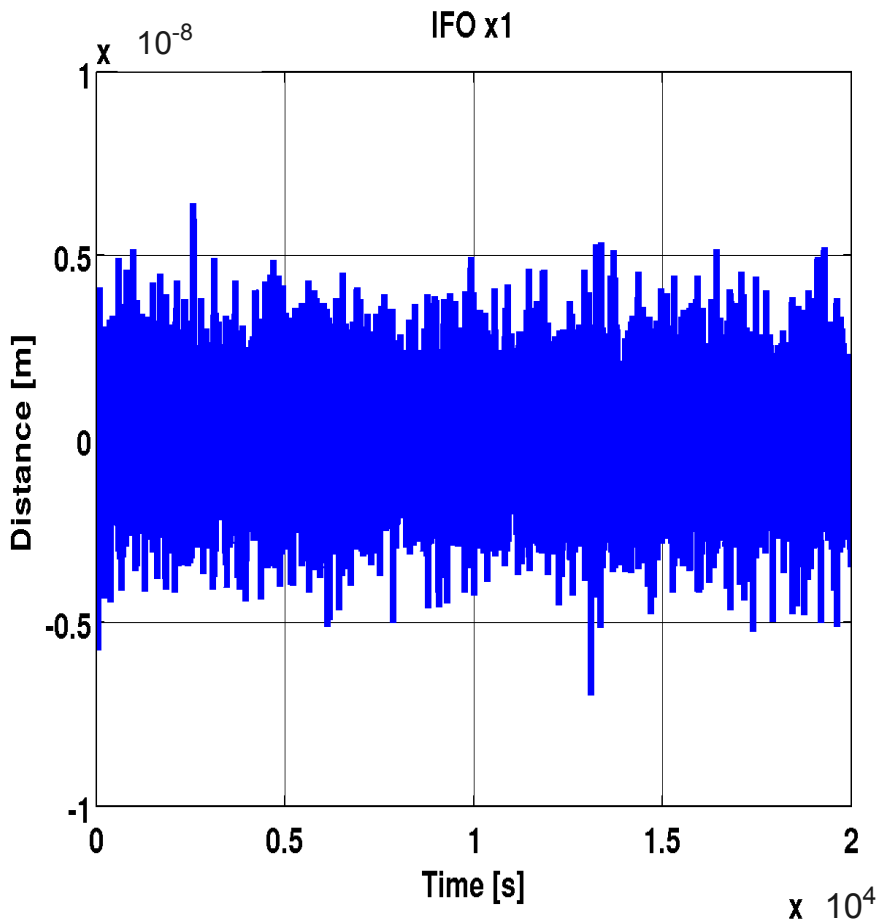
Torque on X axis (theta):

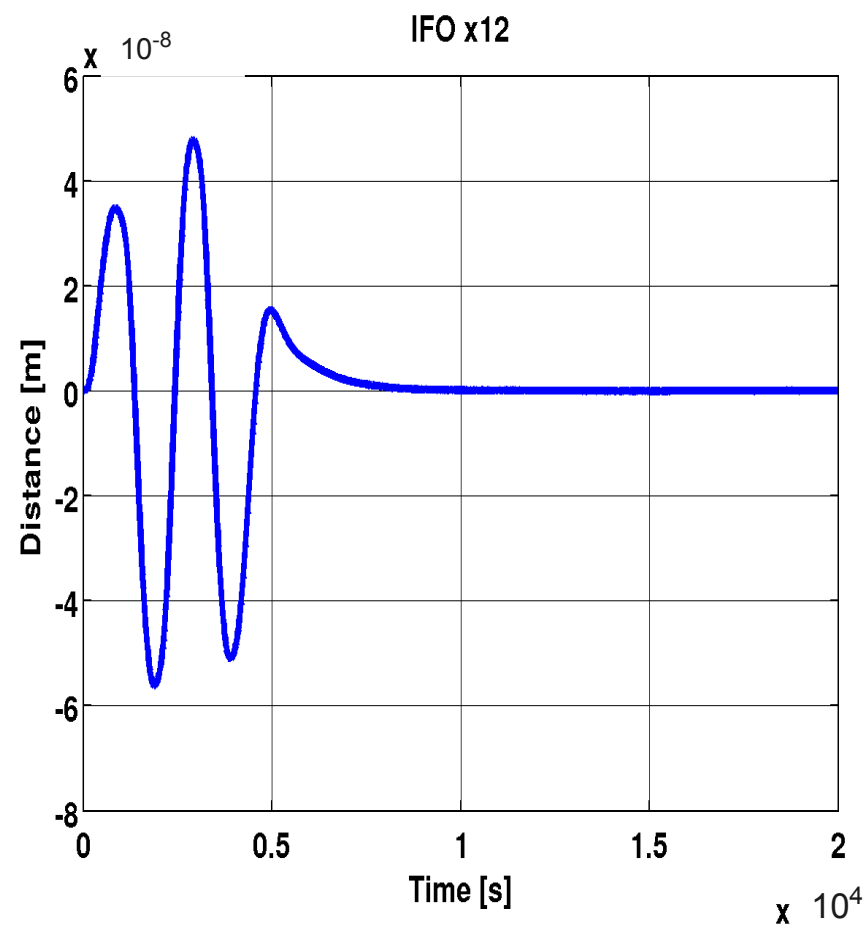


→ Forces of ~pN on the X axis!

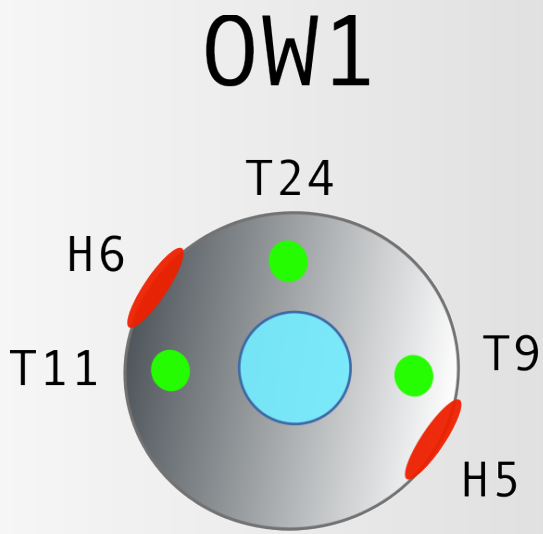
→ Torques around ~10^{-17} Nm on the X axis, negligible.

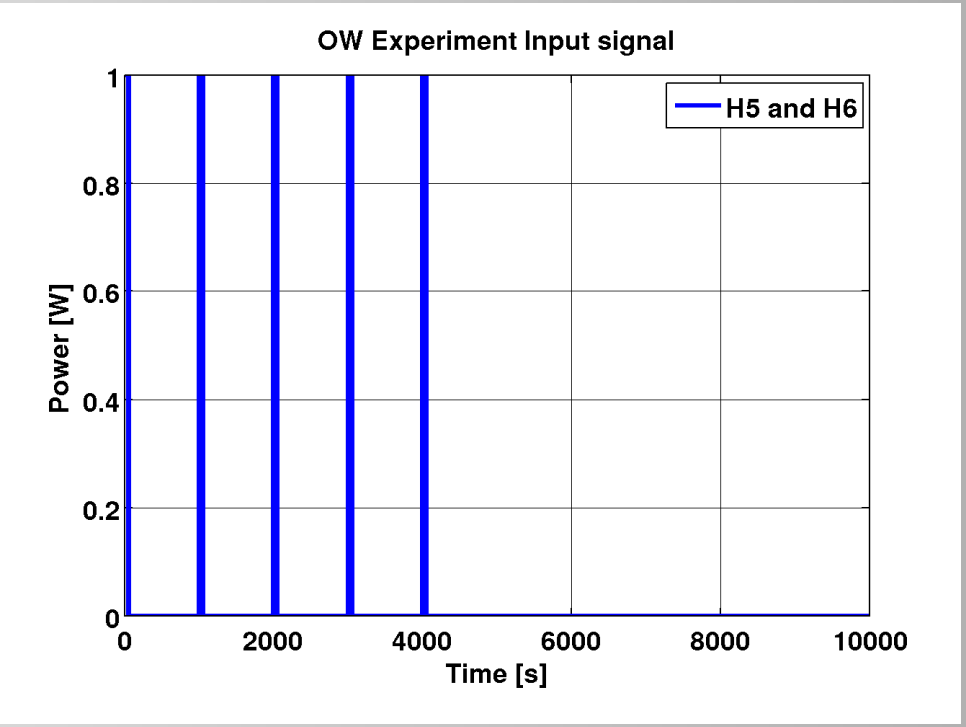
Example 1: EH experiment





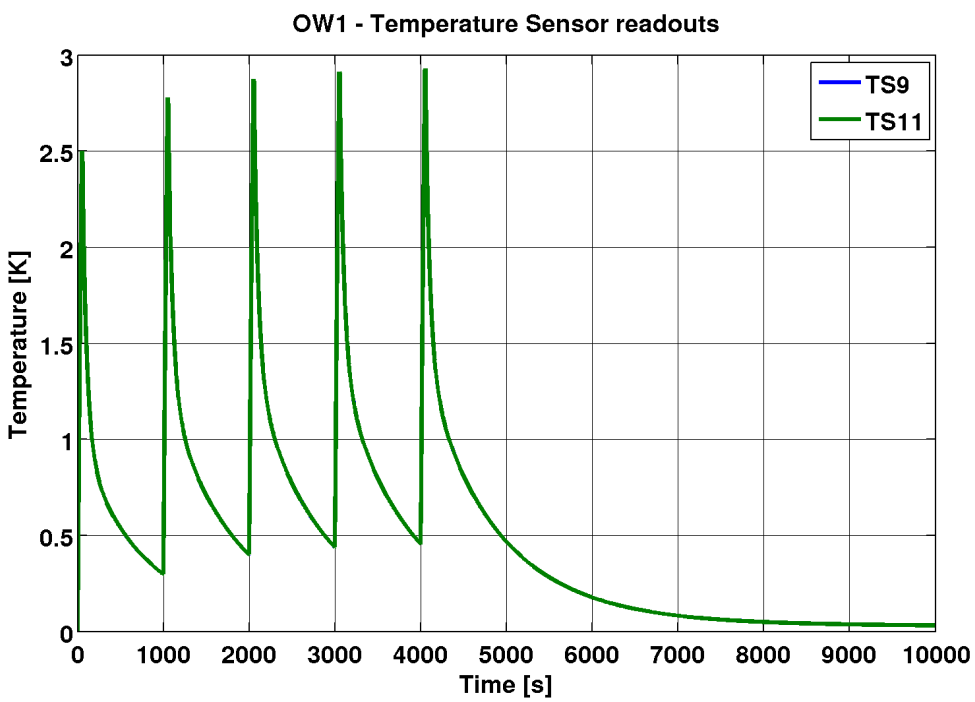
Example 2: OW experiment

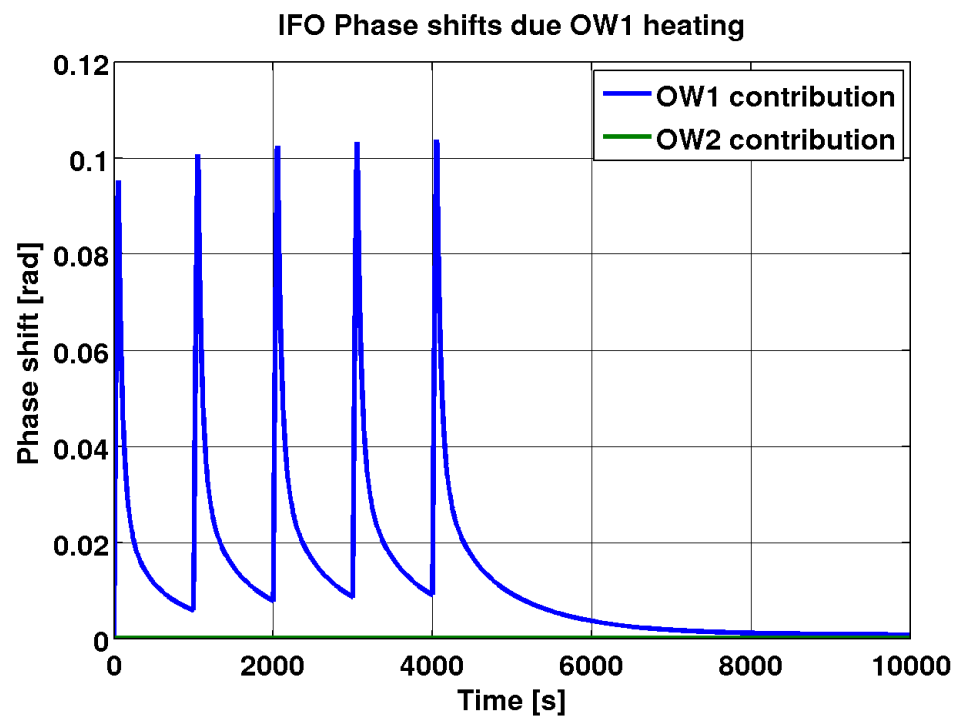




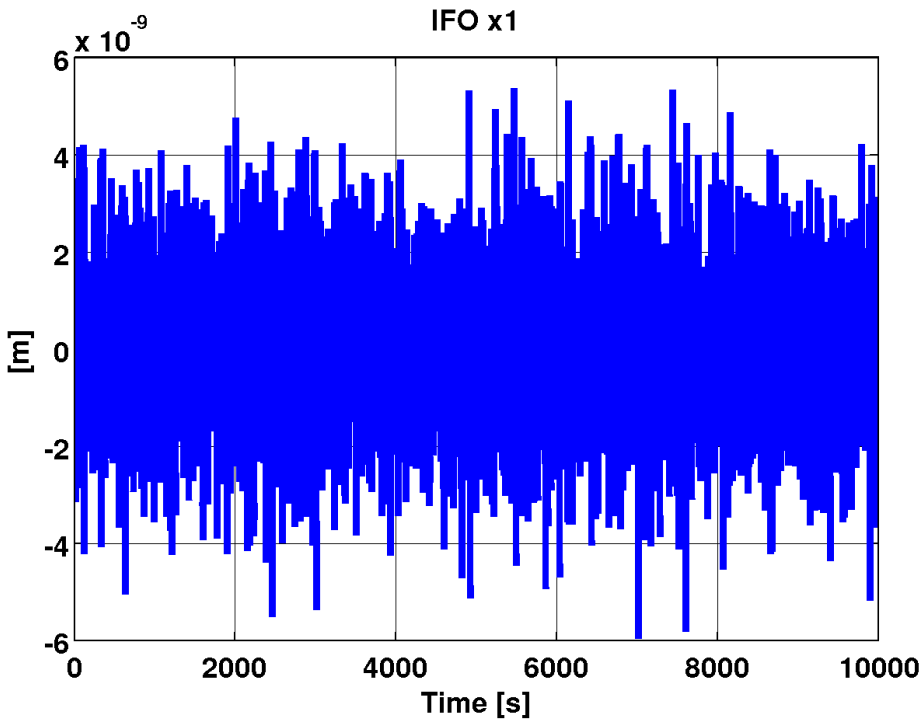
Typical input:
- 5 pulses simultaneously on H5 and H6
- Power: 1W
- Pulse frequency: 1mHz
- Pulse length: 50s (duty cycle: 5%)

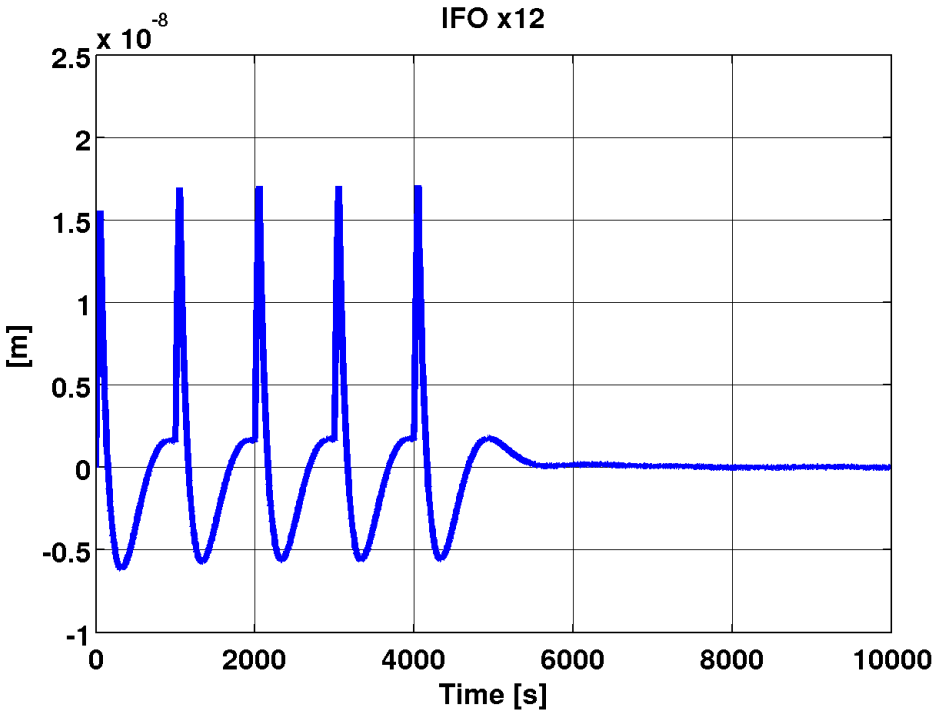
Example 2: OW experiment





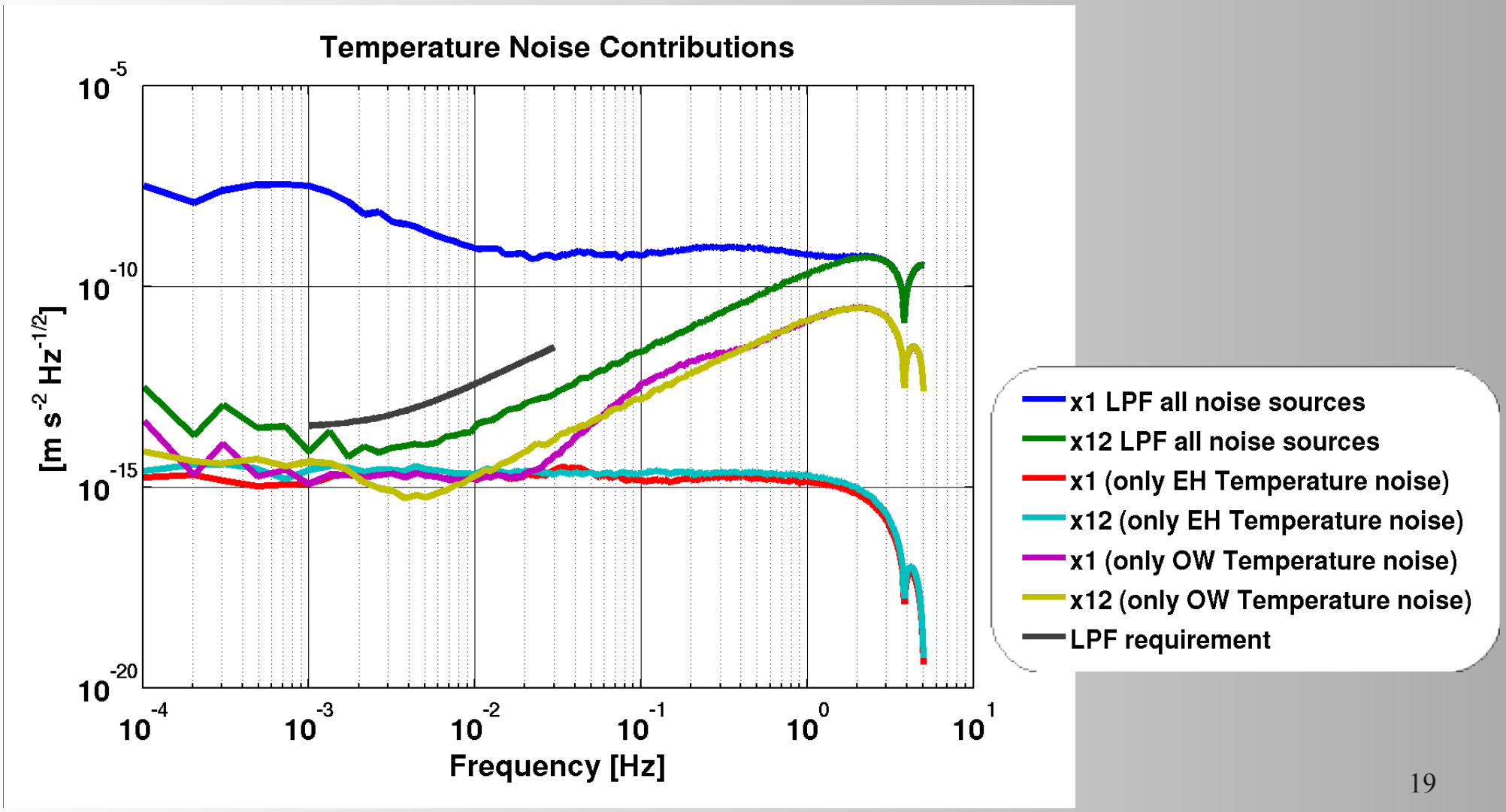
Example 2: OW experiment





Example 3: Injecting noise

Other experiment: injecting temperature white noise at inputs. (10^{-4} K/sqrt(Hz))



Summary & Future work

- Models for the simulation of the EH and OW experiments have been presented.
- ESATAN data from thermal model adapted to the LTPDA frame.
- Closed-loop simulations of the EH and OW Thermal Experiments ready.
- Different parameters need still to be adjusted.
- Analysis and model extraction from the TOQM data, required to model the thermal STR experiments.

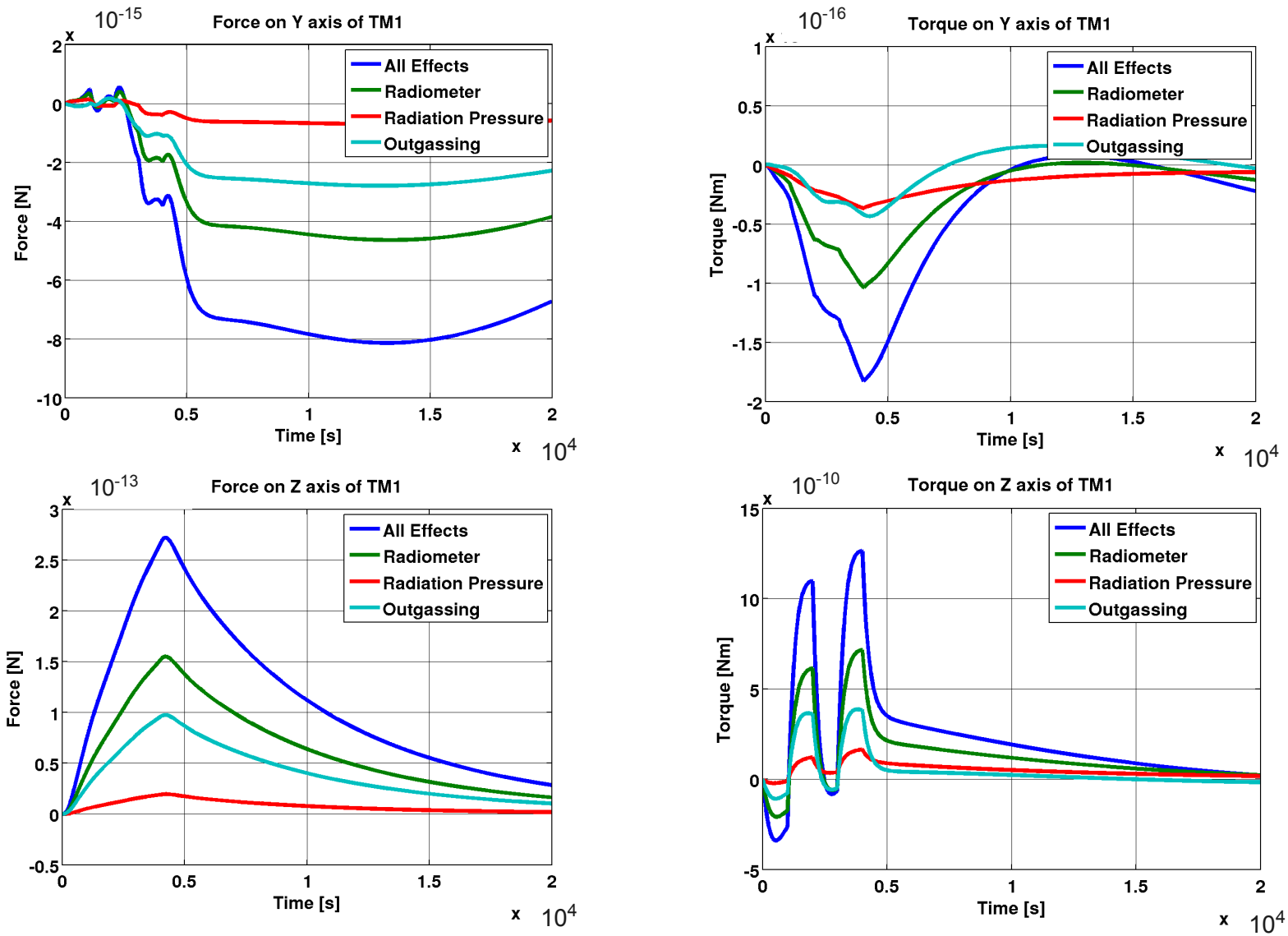
Thanks for your attention!

Extra slides

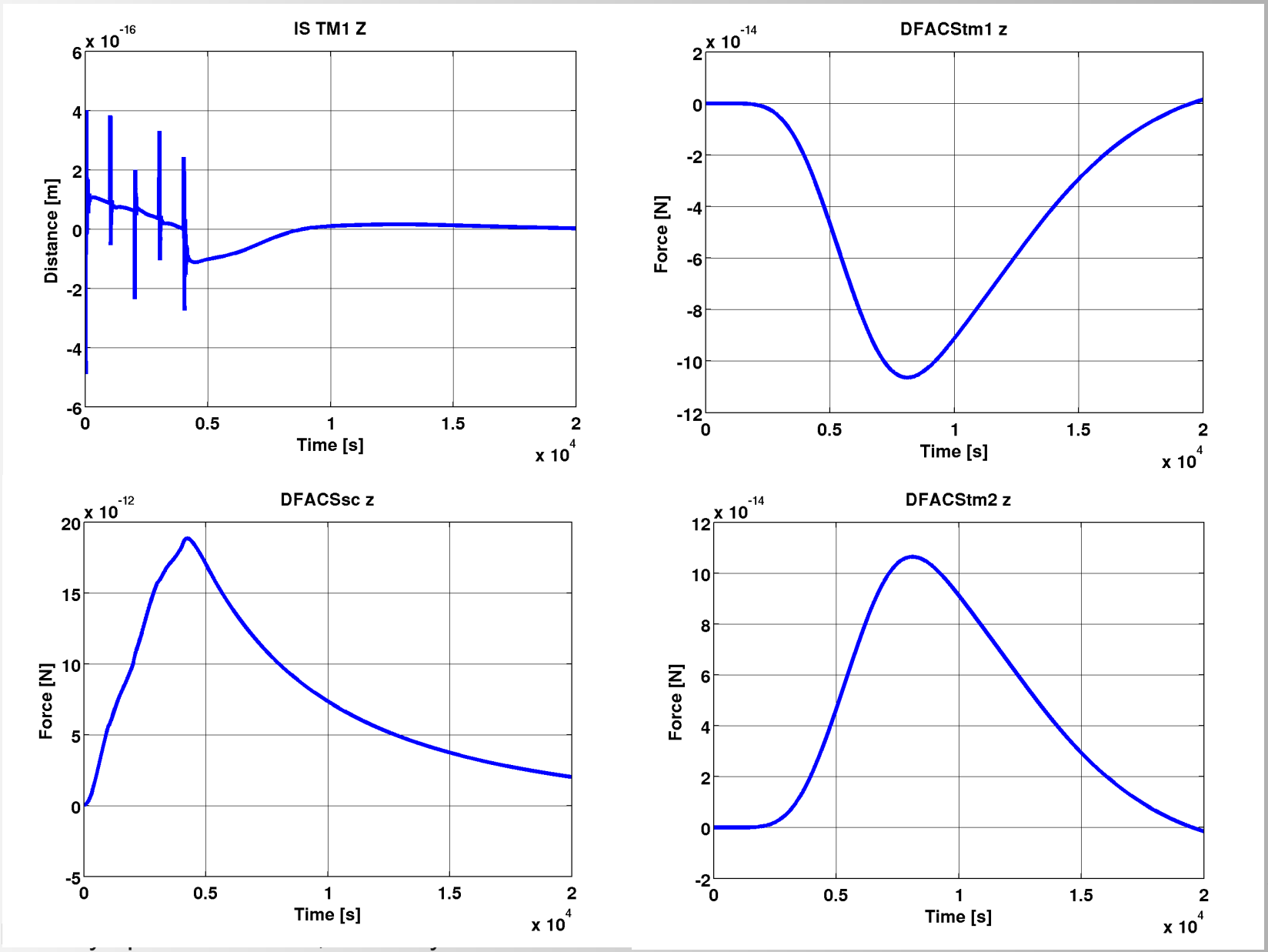
Example 1: EH experiment

Y axis:
(eta)

Z axis:
(phi)



EH experiment: Z axis displacement



EH experiment: eta rotation (Y axis)