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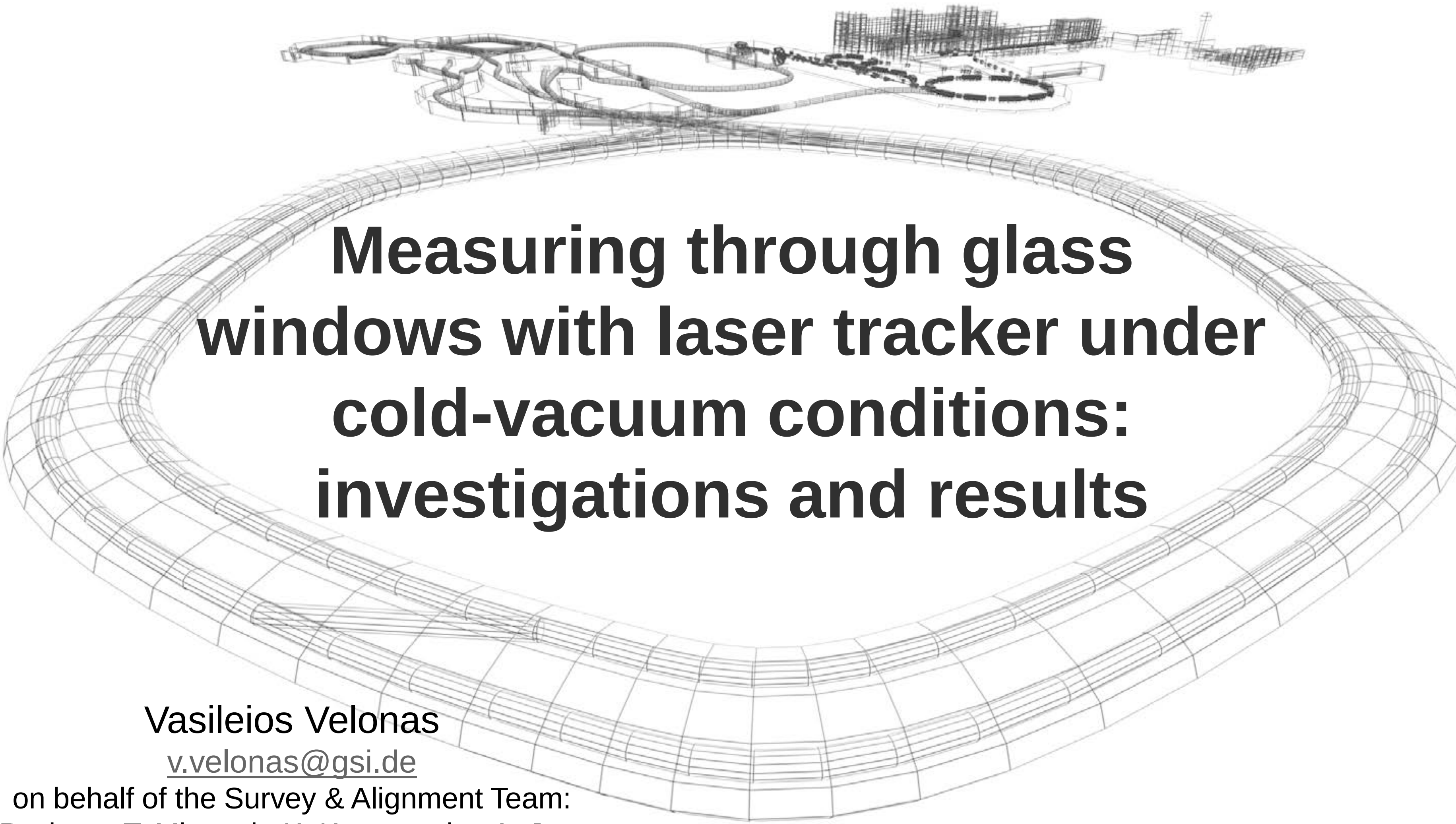

Measuring through glass windows with laser tracker under cold-vacuum conditions: investigations and results

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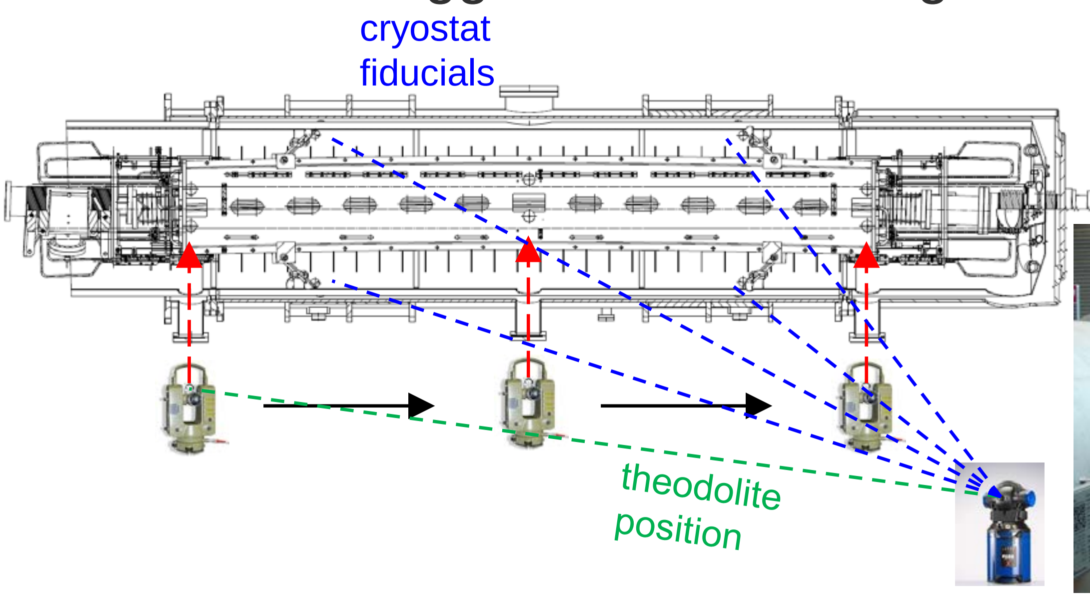
Outline

- Motivation
- Measuring through air-glass-air
- Measuring through air-glass-vacuum-cold
- Building a mathematical model (MM) to gain absolute coordinates in a given reference system
- Summary and outlook

Motivation

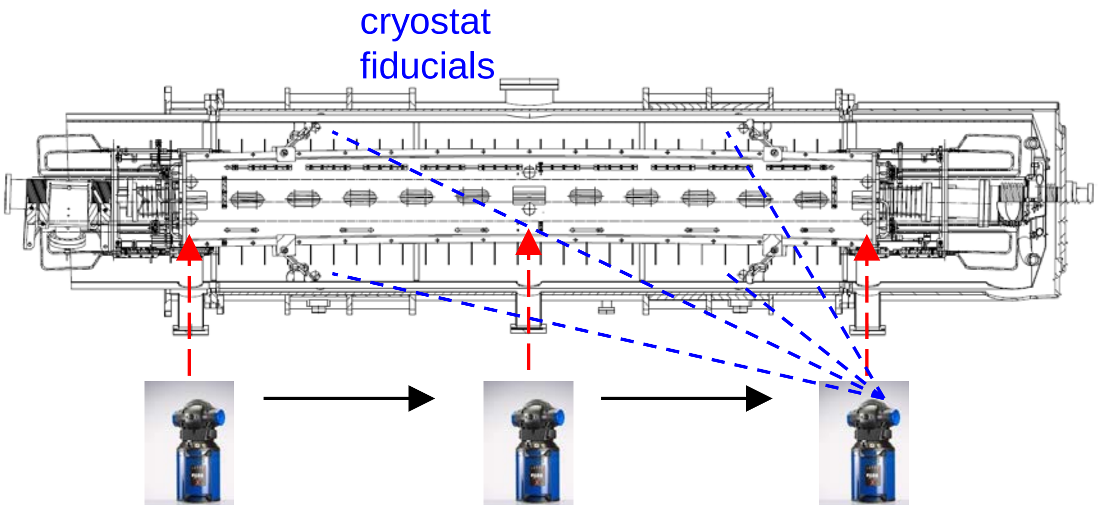
- What was the trigger for this investigation...



- ✓ Measuring through glass window in cold conditions up to 4K
- ✓ Observing targets which are positioned on the cold mass
- ✓ Combination of theodolite and laser tracker
- ✓ Only 2D information gained from this procedure

Motivation

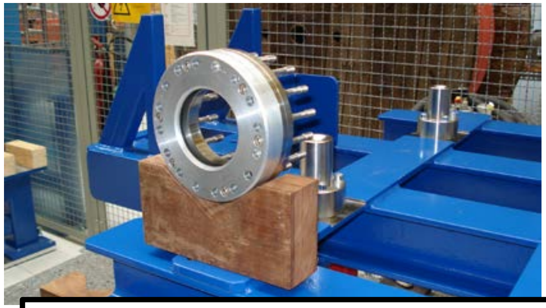
- ... and what we aim at, is ...

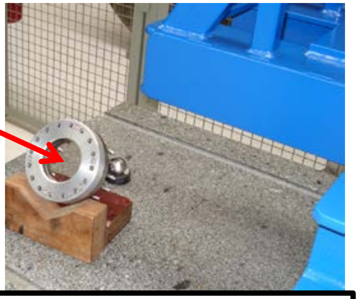


✓ The high precise monitoring regarding deformations of the cold mass along with movements vs. cryostat of superconducting components in 3D!!

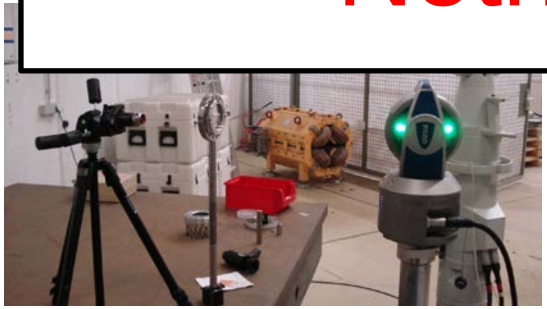
Step 1 - Measuring through glass windows in air-glass-air

- First phase measurements





Nothing did really work!



Measuring through other glass windows

Autocollimation of the laser beam

- Measurements were not always possible
- Reproducibility of the position behind the windows was chaotic
- Laser tracker head could not find the target by autocollimation
- No tracking was possible through the window
- The reflection of the glass window was too high

Step 2 – Coating of a glass window

Two main parameters are highly important to know before coating a glass window:

1. The max. allowed reflection from both planes of the glass (in our case 0.5 %)

2. What is the needed wavelength which is allowed to pass through? (in our case for all laser trackers)

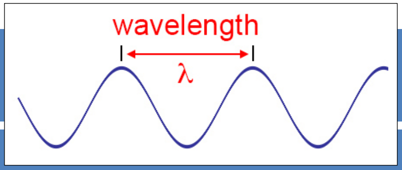
The glass window that we released to coat was a 15 mm thickness borosilicate (N-BK7) coplanar glass window

Step 3 - What is the wavelength of our instruments?

- Wavelengths of the laser trackers

Leica LTD 500 | Leica AT402 | FARO SI2 | FARO Vantage



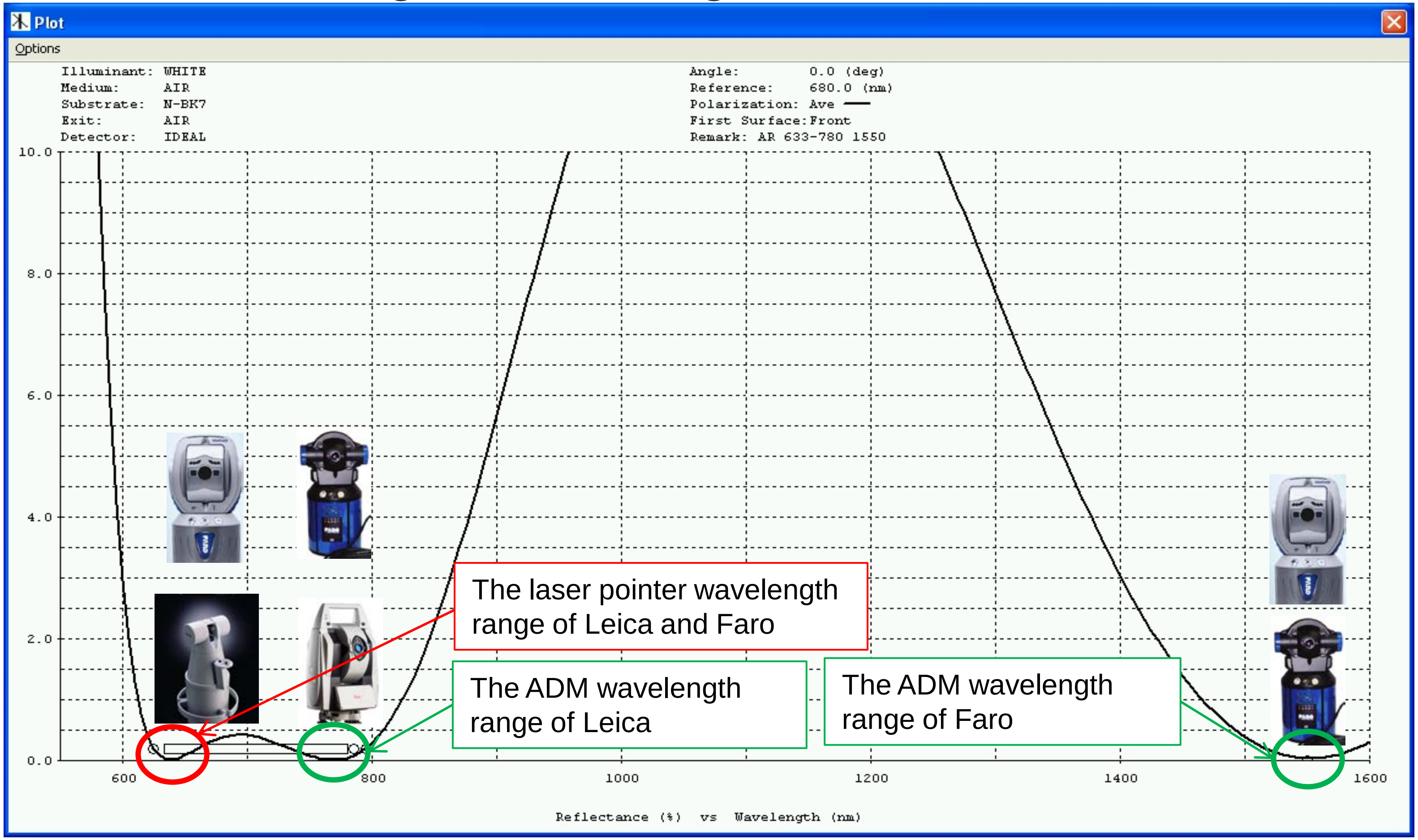



	Leica LTD 500	Leica AT402	FARO SI2	FARO Vantage
	[nm]	[nm]	[nm]	[nm]
Absolute Distance Measurement (ADM)	780	795	1550	1550
Laser Interferometer (IFM)	633	*	633	*
Automatically Target Recognition (ATR)	*	905	*	*
Laser-Pointer	633	635	633-635	653-663

Source: Leica and Faro

Step 3 - What is the wavelength of our instruments?

- Reflection diagram including all our laser trackers



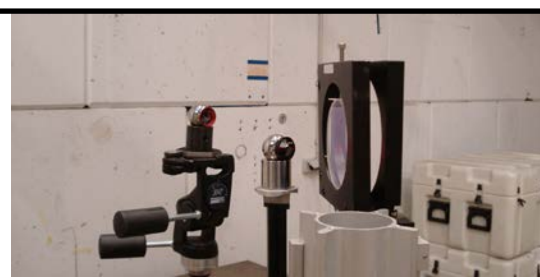
Source of the diagram: Prinz Optiks GmbH

Step 4 - Measuring through coated glass window in air-glass-air

- Second phase measurements

Coating the glass was successful!

Autocollimation of the laser beam



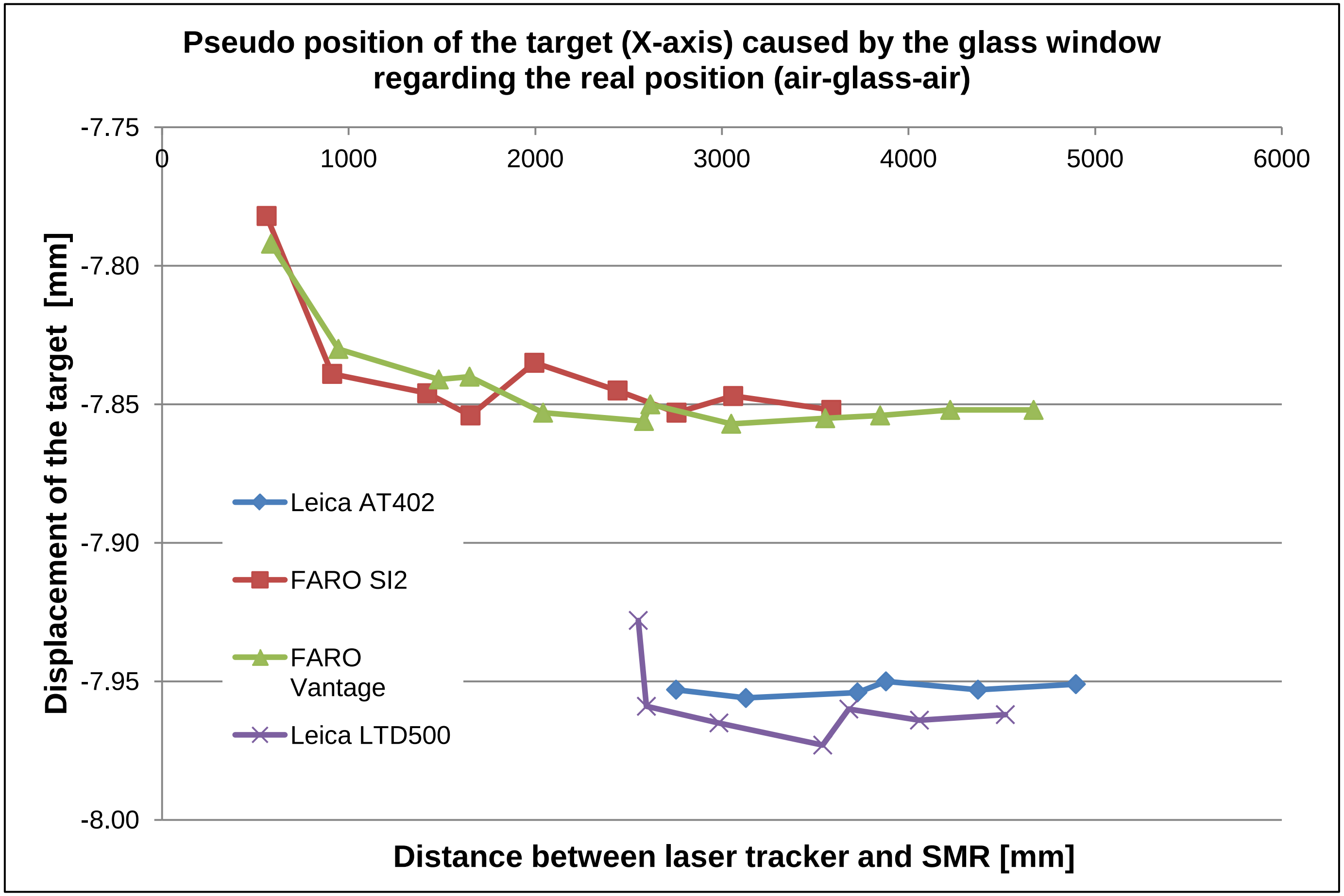
Extreme position (approx.60°) of the glass window regarding the laser beam

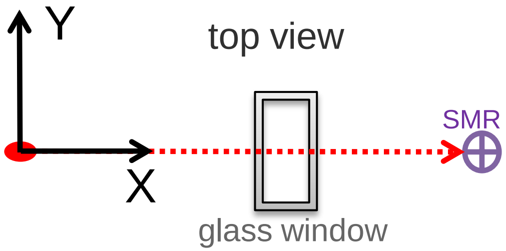
- Different setup of the instruments and the SMRs regarding the glass window
- Measuring the same position of the targets at least five times in two telescope positions
- All laser trackers could find the targets without any problem
- Tracking the laser beam behind the glass window was possible

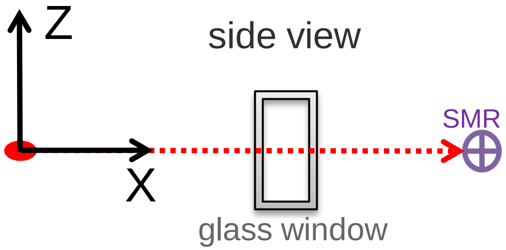
❖**The position of the points behind the glass window is highly reproducible for all instruments sd_{XYZ}= 5 µm (1σ)**

Step 4 - Measuring through coated glass window in air-glass-air

- Results

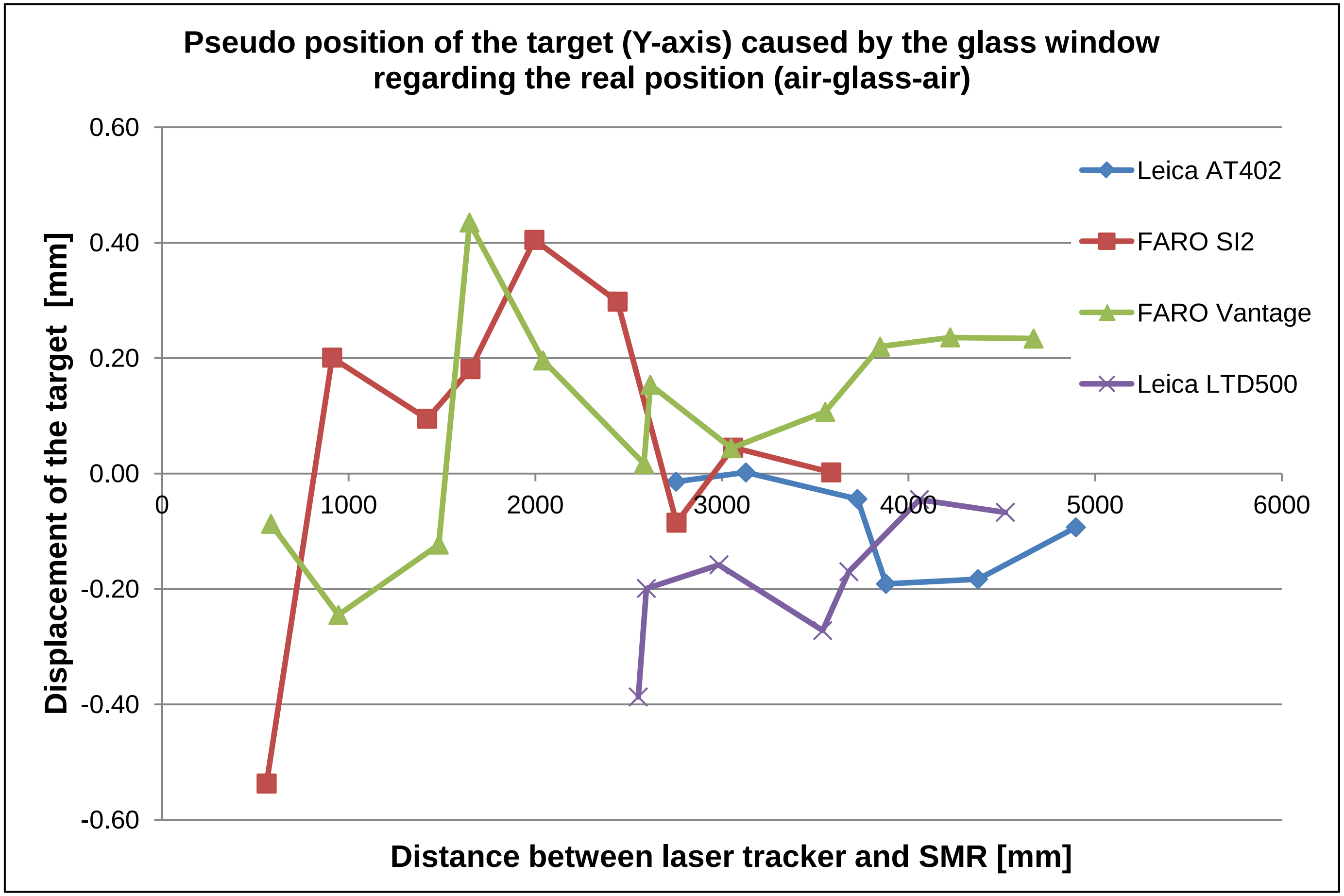


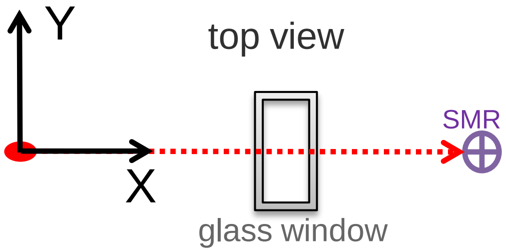


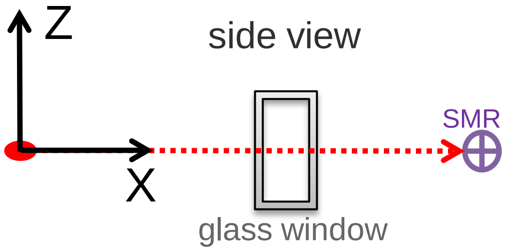


Step 4 - Measuring through coated glass window in air-glass-air

- Results

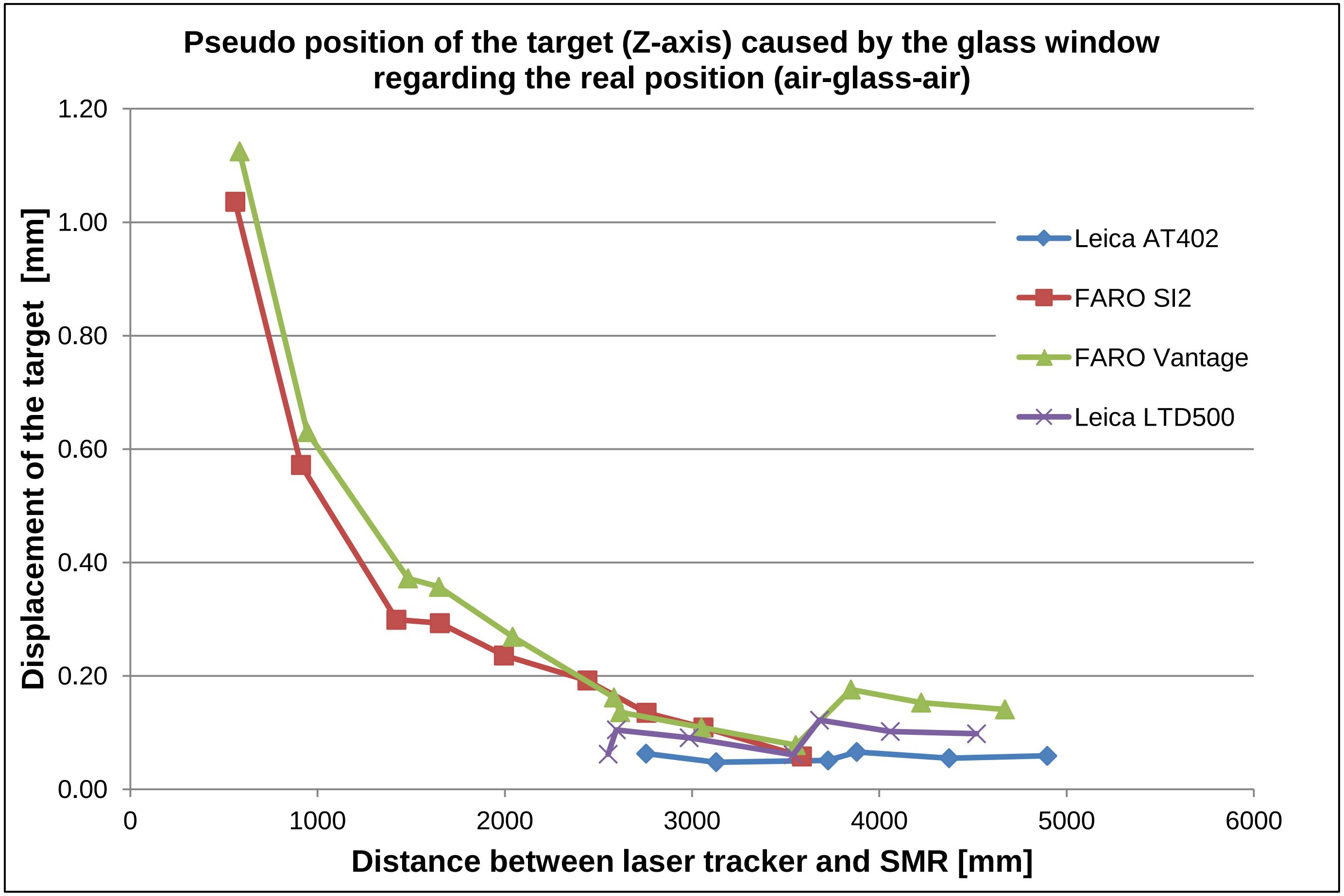


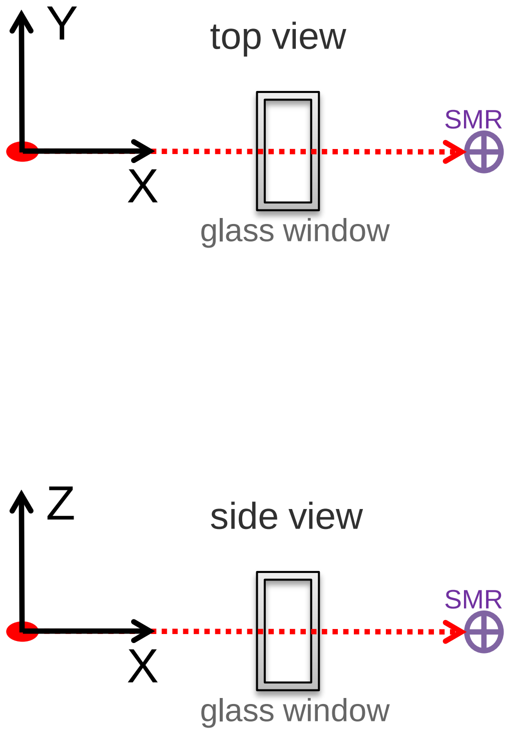




Step 4 - Measuring through coated glass window in air-glass-air

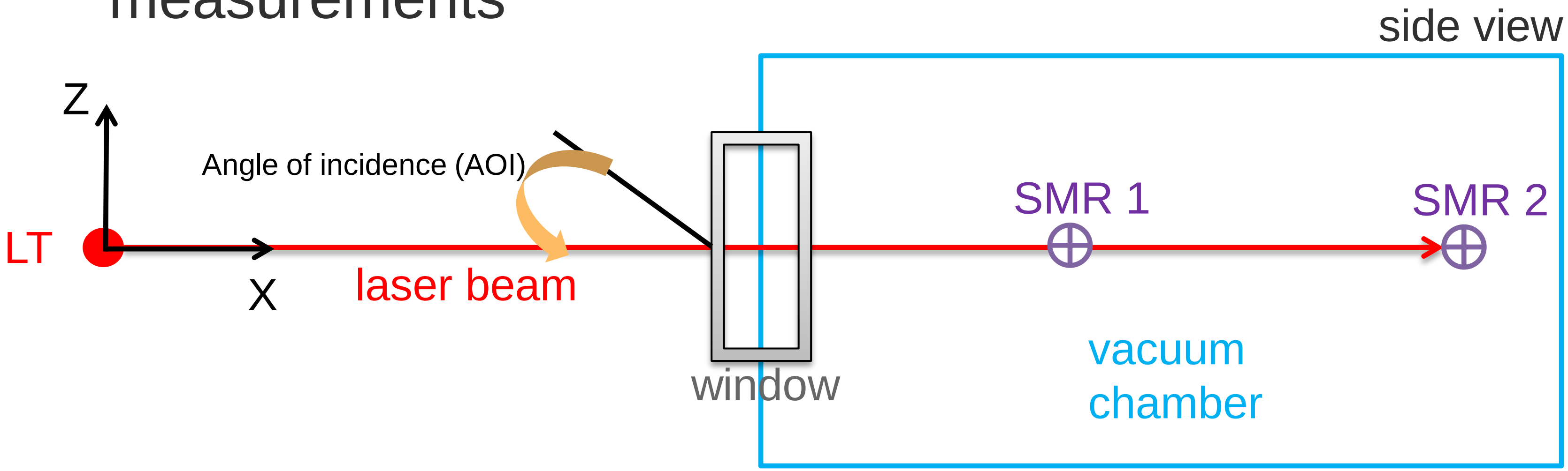
- Results



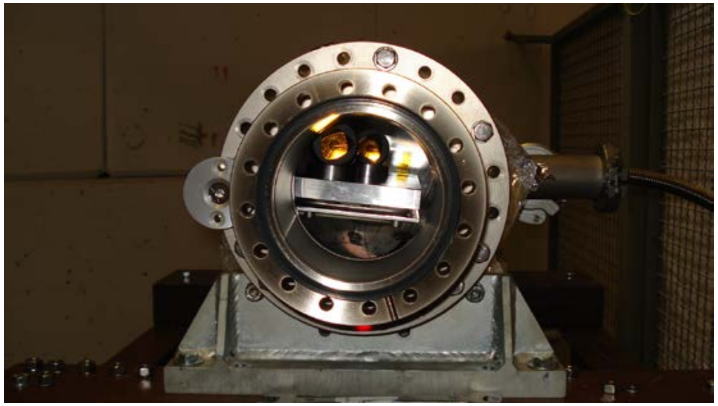


Step 5 – Measuring through coated glass window in air-glass-vacuum-cold

- Setup of the instruments and conditions for the measurements

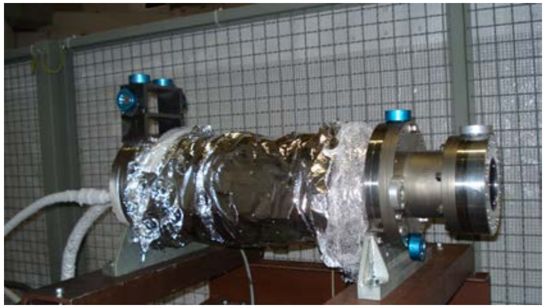


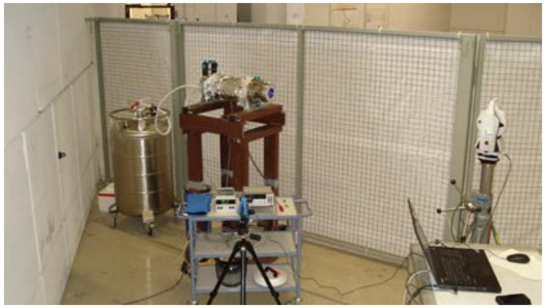
- ✓ Using of break resistant reflector (BRR)
- ✓ Vacuum in the chamber 10^{-3} mbar
- ✓ Cold conditions up to 90 K using liquid nitrogen
- ✓ The angle of incidence (AOI) is up to 5°

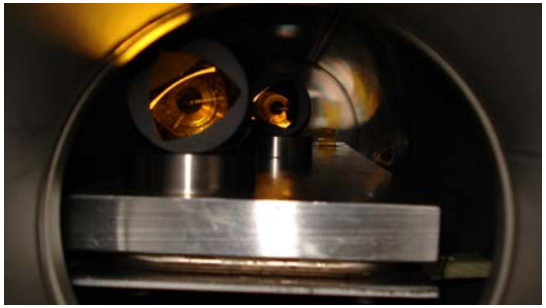

The chamber (front side)

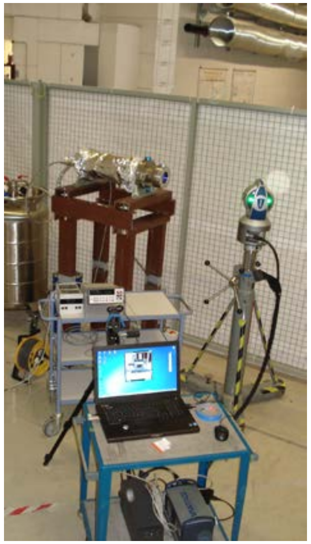
Step 5 – Measuring through coated glass window in air-glass-vacuum-cold

- Third phase measurements


The chamber


Set up in a long distance


The insight of the chamber

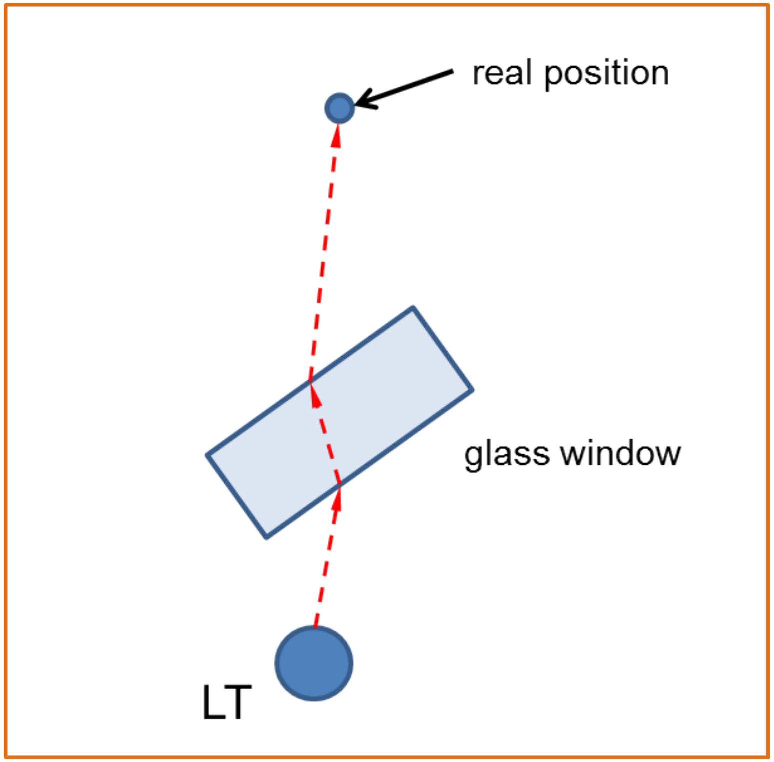

Set up in a short distance

- All laser trackers could find the target without any problem, in vacuum as well as in cold condition

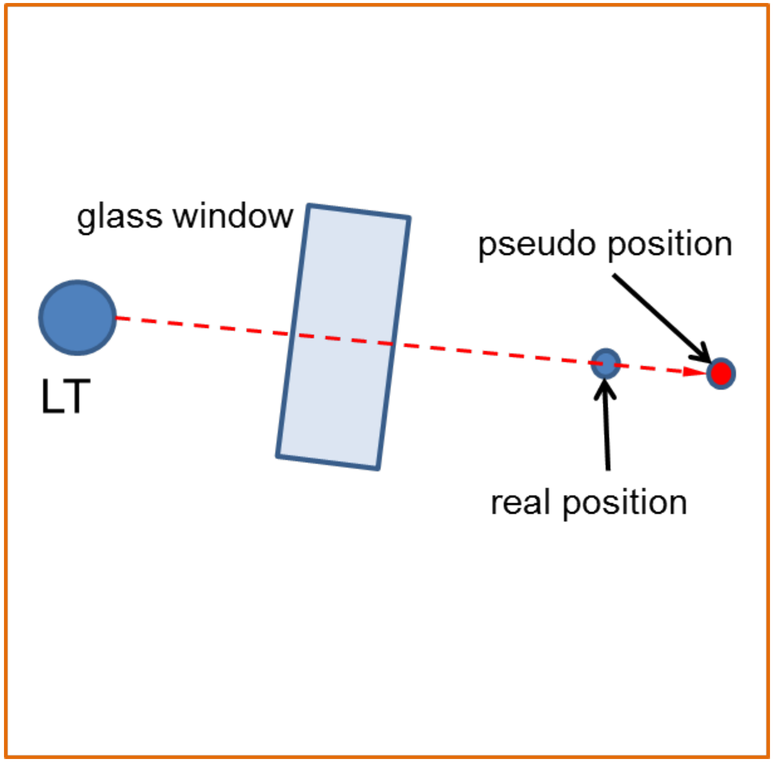
❖**The position of the points behind the glass window is <u>again</u> highly reproducible for all instruments sd_{XYZ}= 5 µm (1σ)**

Step 6 – Recognizing the problem measuring through different optical media by laser trackers. Definition of the absolute position

- Pointing error (top view)

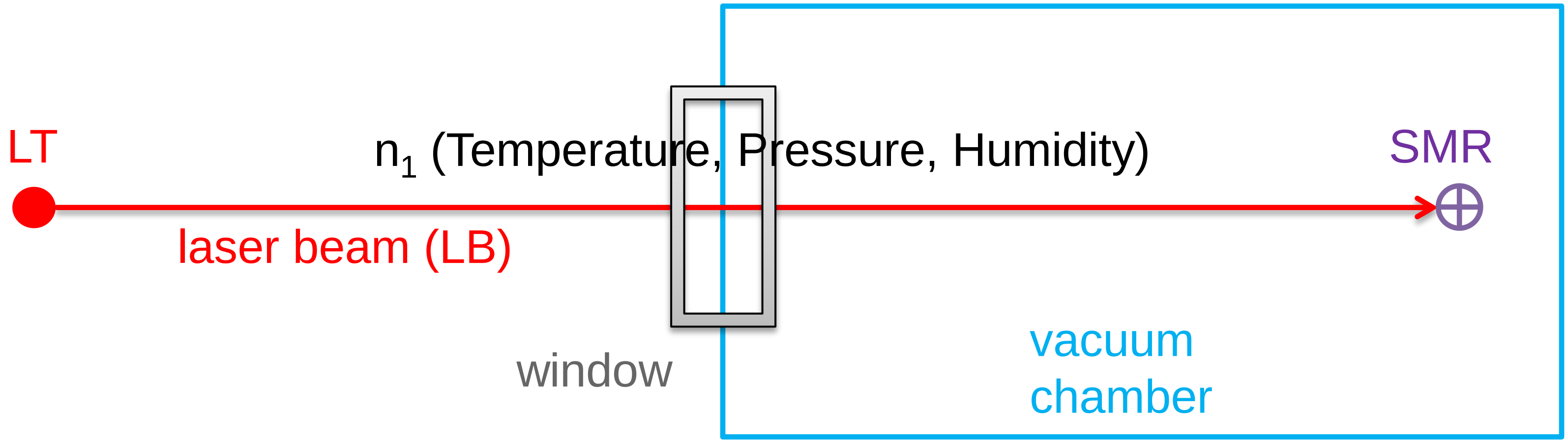


- Range error (side view)



Step 6 – Recognizing the problem measuring through different optical media by laser trackers. Definition of the absolute position

- The problem of the range error caused by different optical media which the laser tracker can not understand



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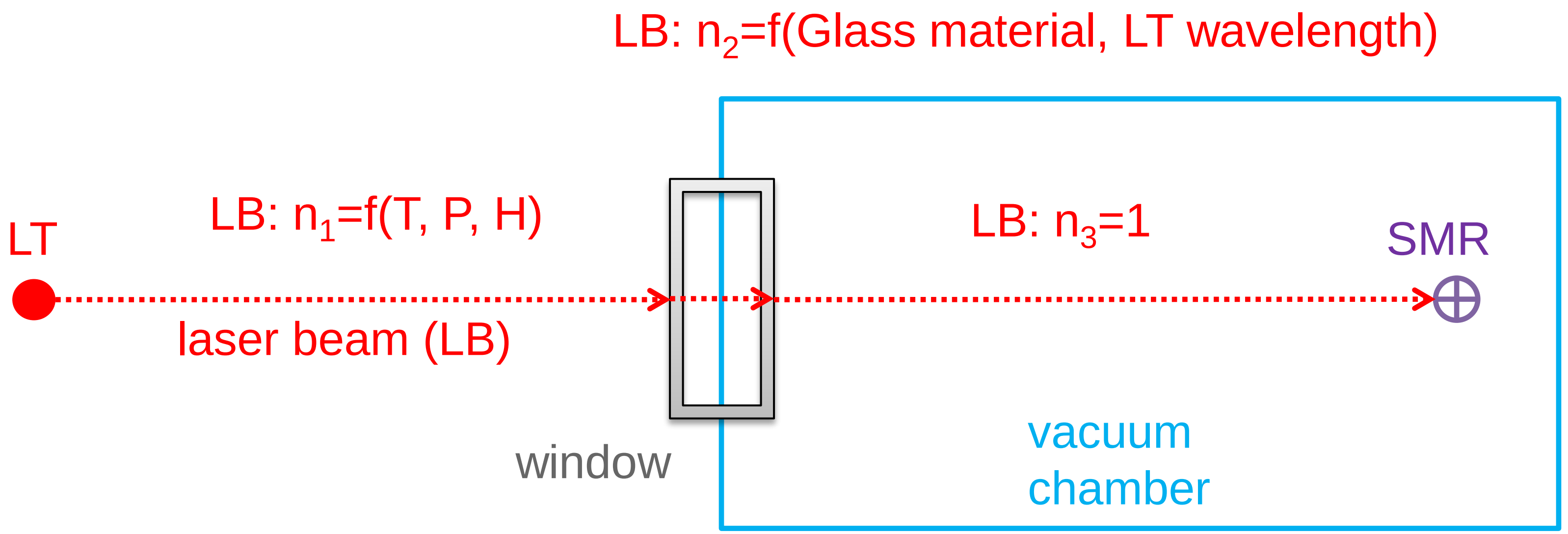
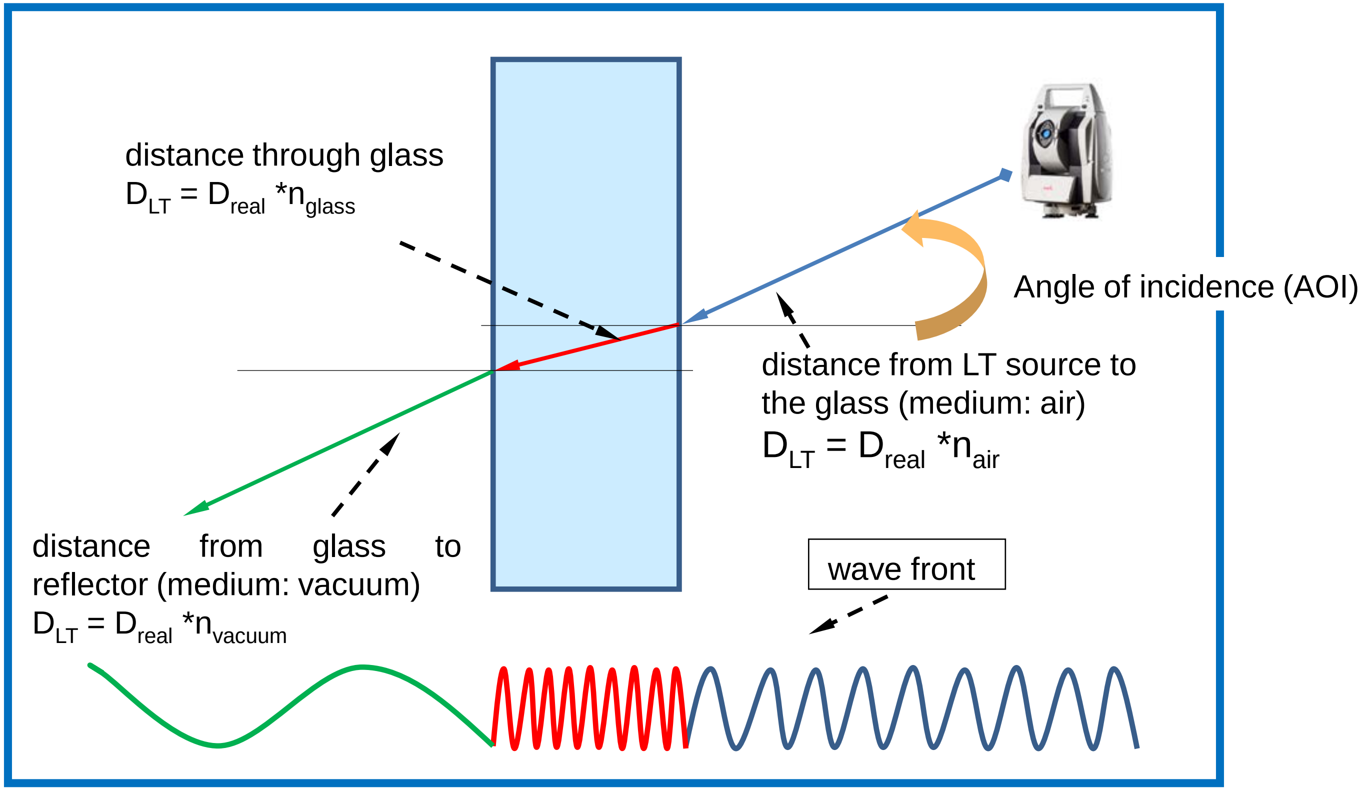


Step 6 – Recognizing the problem measuring through different optical media by laser trackers. Definition of the absolute position

- For the correction of the pointing error quaternions (mathematical tool) were used to manipulate the rotation in 3D in combination with Snell's law



Step 7 – Building a Mathematical Model (MM)

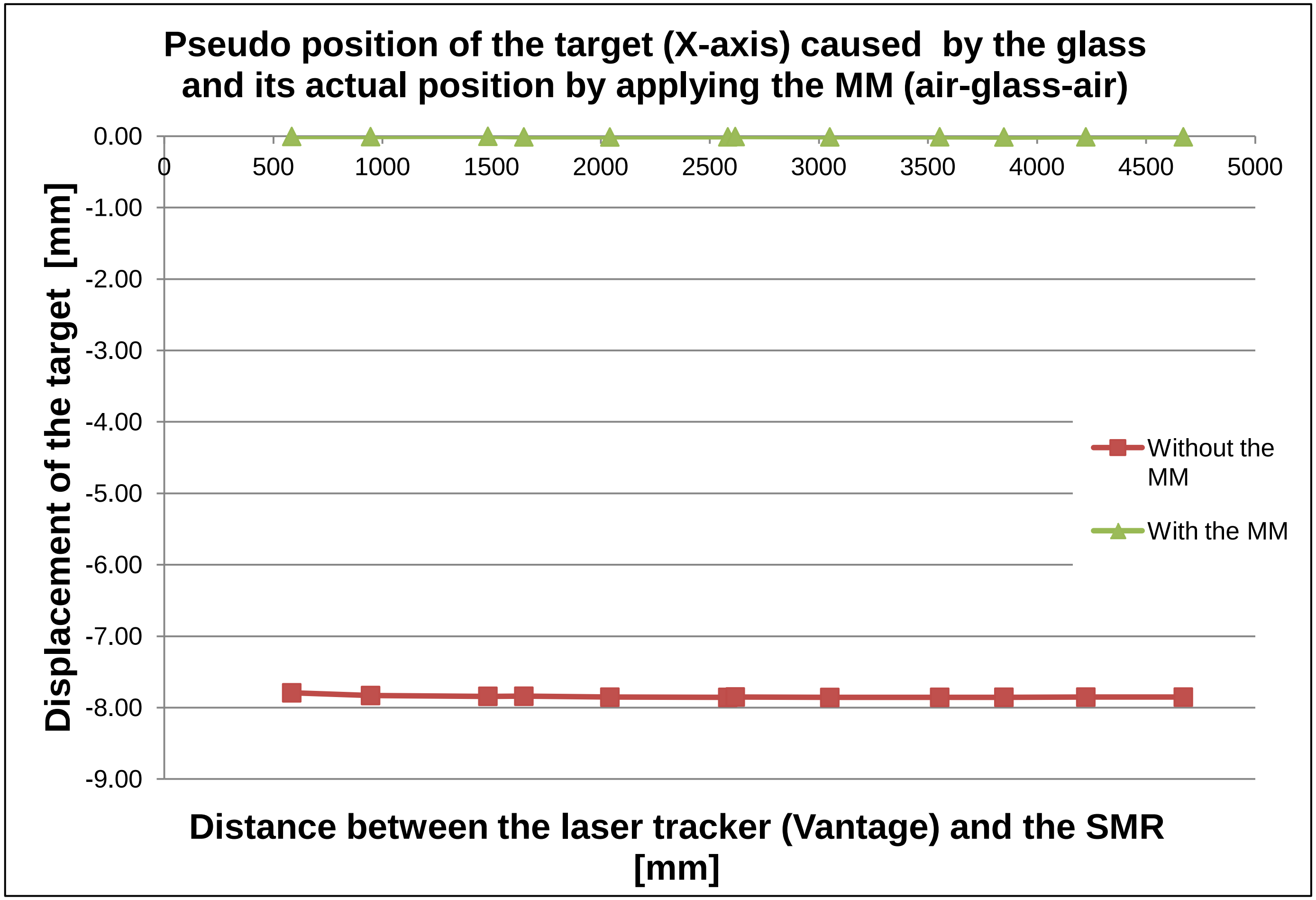
- To calculate **<u>absolute coordinates</u>** to a given reference system a MM is needed to correct the pointing and range errors
- The MM is a function of all parameters which are known and measureable:

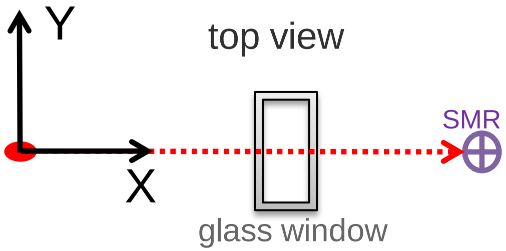
Geometry of the window
Position of the laser tracker
Angle of incidence
Material of the window
Wavelength of the laser tracker
Temperature
Pressure
Humidity
et al.

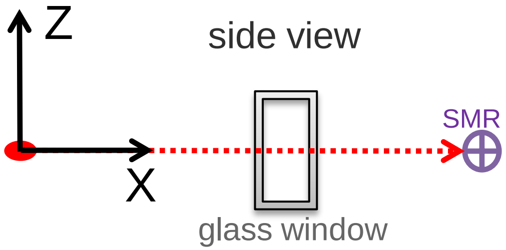
⇨ **MM**

Step 8 – Applying the Mathematical Model (MM)

- Results in air-glass-air (FARO Vantage)

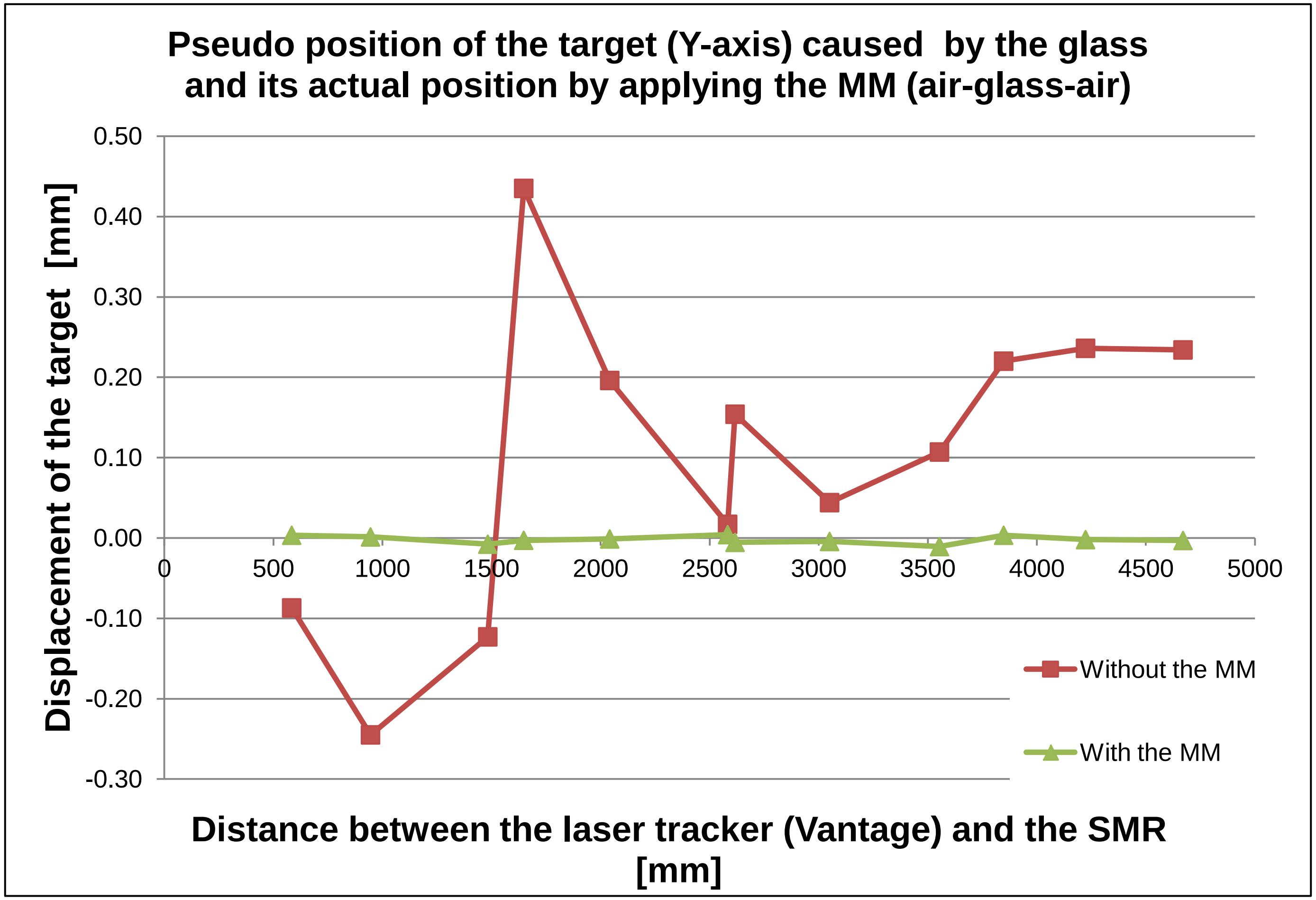


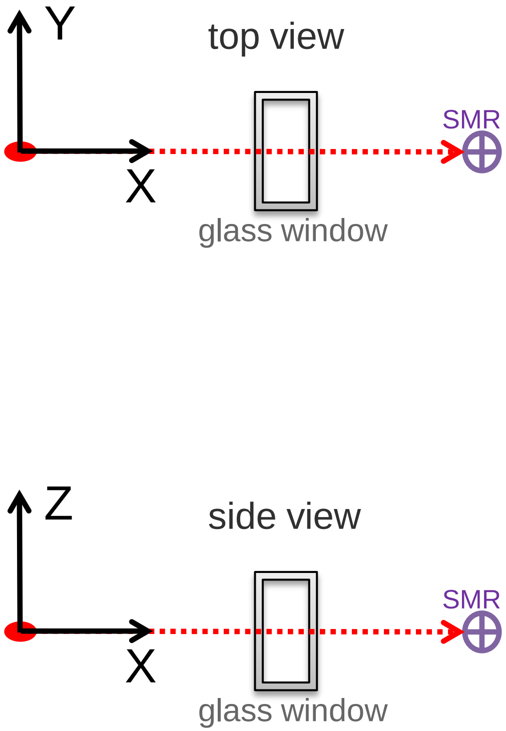




Step 8 – Applying the Mathematical Model (MM)

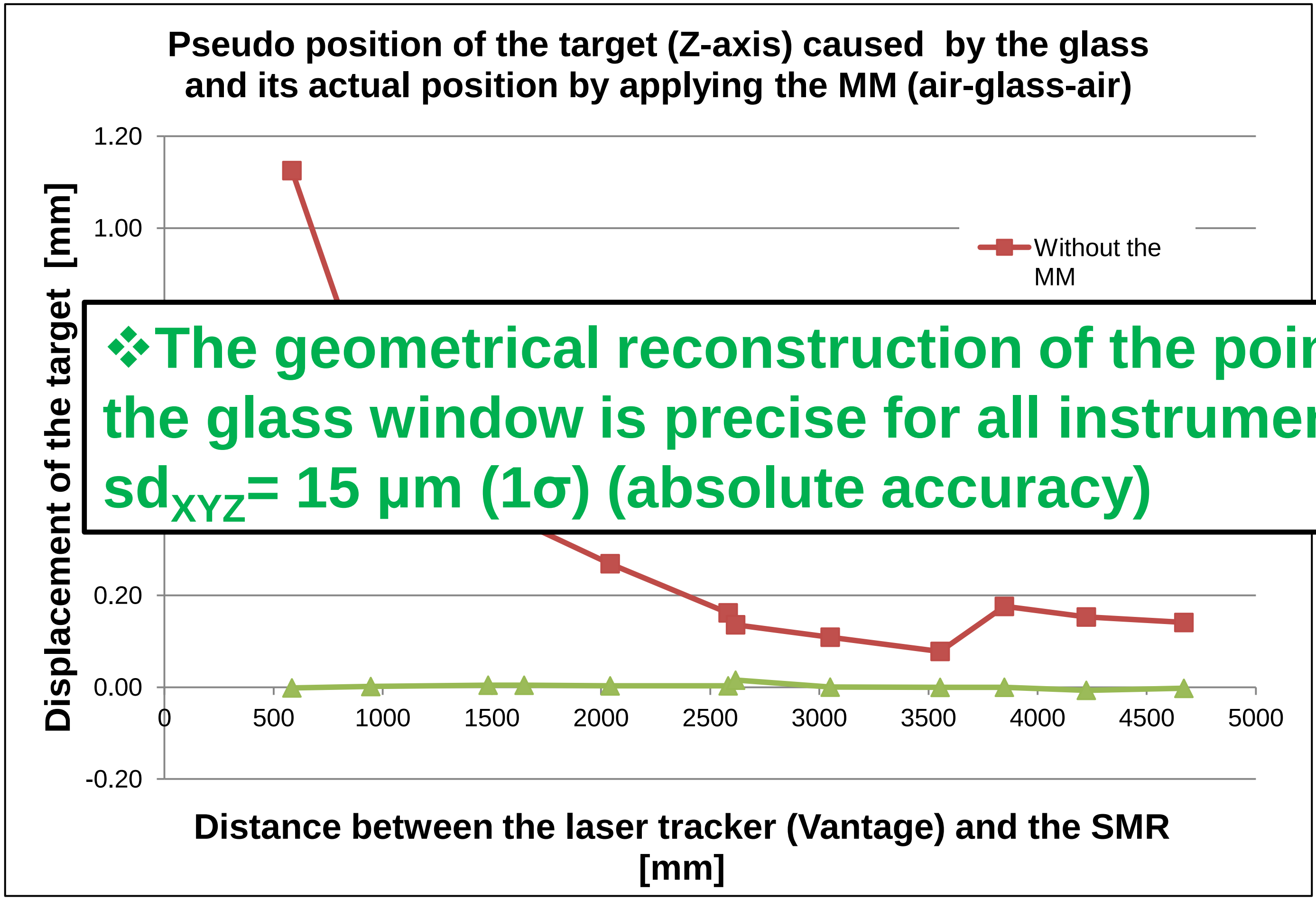
- Results in air-glass-air (FARO Vantage)

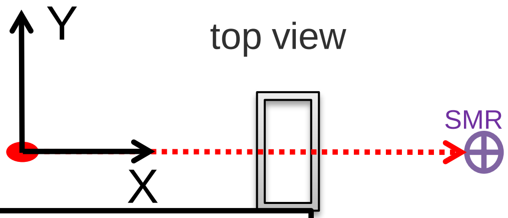


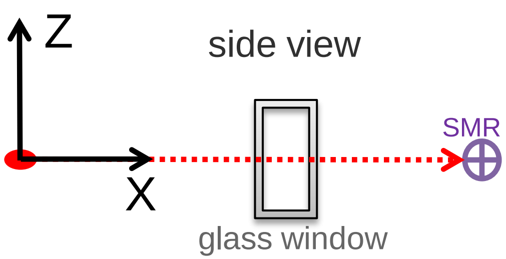


Step 8 – Applying the Mathematical Model (MM)

- Results in air-glass-air (FARO Vantage)



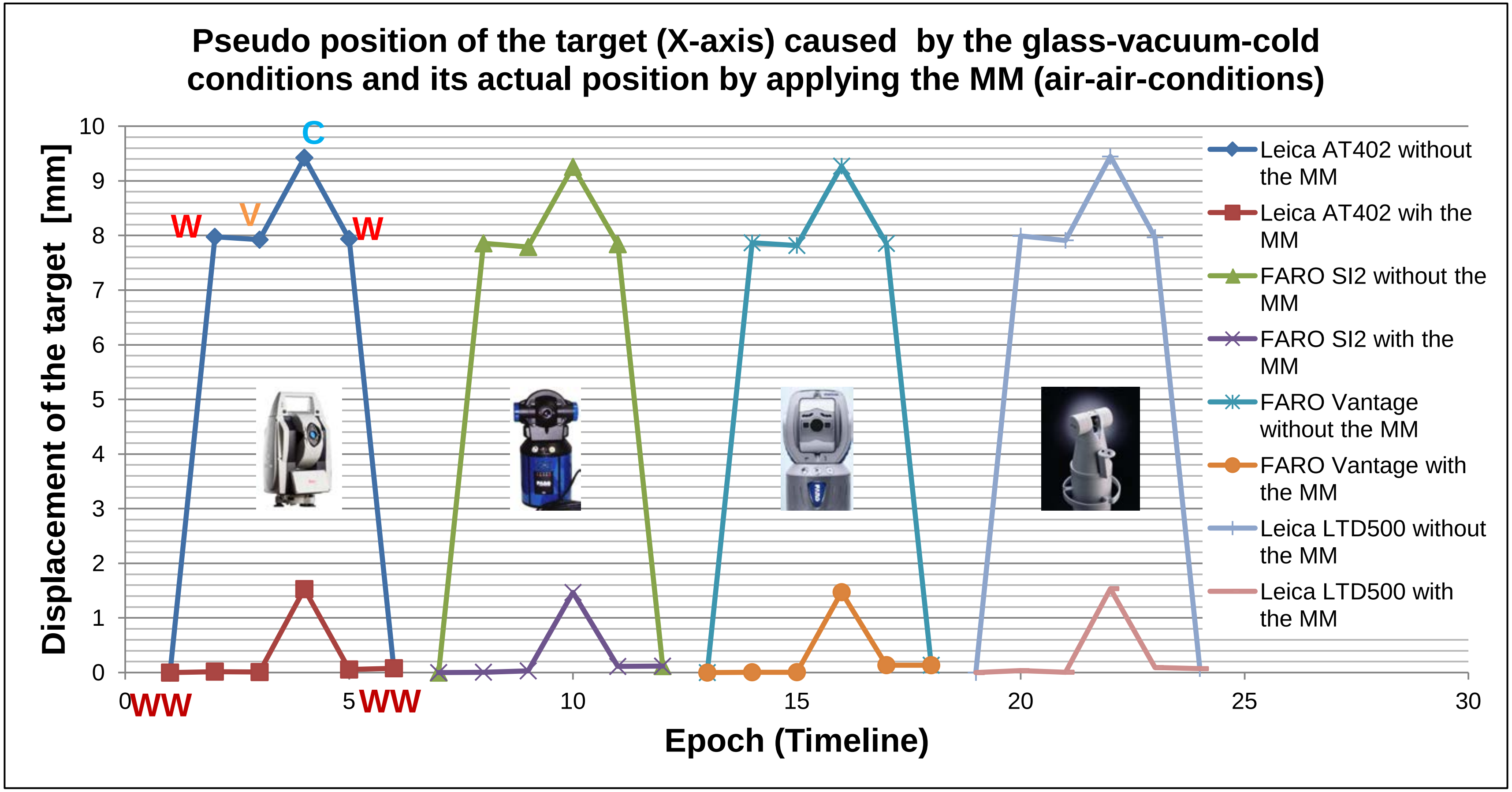




❖**The geometrical reconstruction of the points behind the glass window is precise for all instruments sd_{XYZ}= 15 µm (1σ) (absolute accuracy)**

Step 8 – Applying the Mathematical Model (MM)

- Results in air-glass-vacuum-cold (all instruments)



WW: Without Window **W: Warm** **V:Vacuum** **C:Cold**

Conclusion and outlook

- The reproducibility of the points behind the glass window is highly accurate in air-glass-air as well as in air-glass-vacuum-cold condition (sd_{XZY}= 5 µm).

- Comparing relative coordinates behind the glass window requires a position of the instrument more than 3 m in order to avoid disturbance. Combining the instruments in this case is fatal, <u>do not do this!</u>

- Using the mathematical model absolute coordinates can be calculated. The pointing and range errors can be eliminated which are caused by the glass window (sd_{XZY}= 15 µm).

- The material of the glass window in combination with the wavelength of the instrument defines the refractive index of the glass window, thus the material of the glass window has to be chosen wisely.

Conclusion and outlook

- The mechanical properties of the window (size of the glass surface, thickness) has to be taken in account in order to reduce or eliminate the bulge of the window, caused by the vacuum in the chamber, which can produce an error in the mathematical model. Also, as smaller the angle of incidence is, as more negligible this error can be.

- Cross checking and optimization of the mathematical model by a practical approach is in progress.

- The movement of the SMR center point because of the contraction in cold environment has to be taken in account in order to distinguish it from the displacement of the cold mass.

Thank you for your attention!