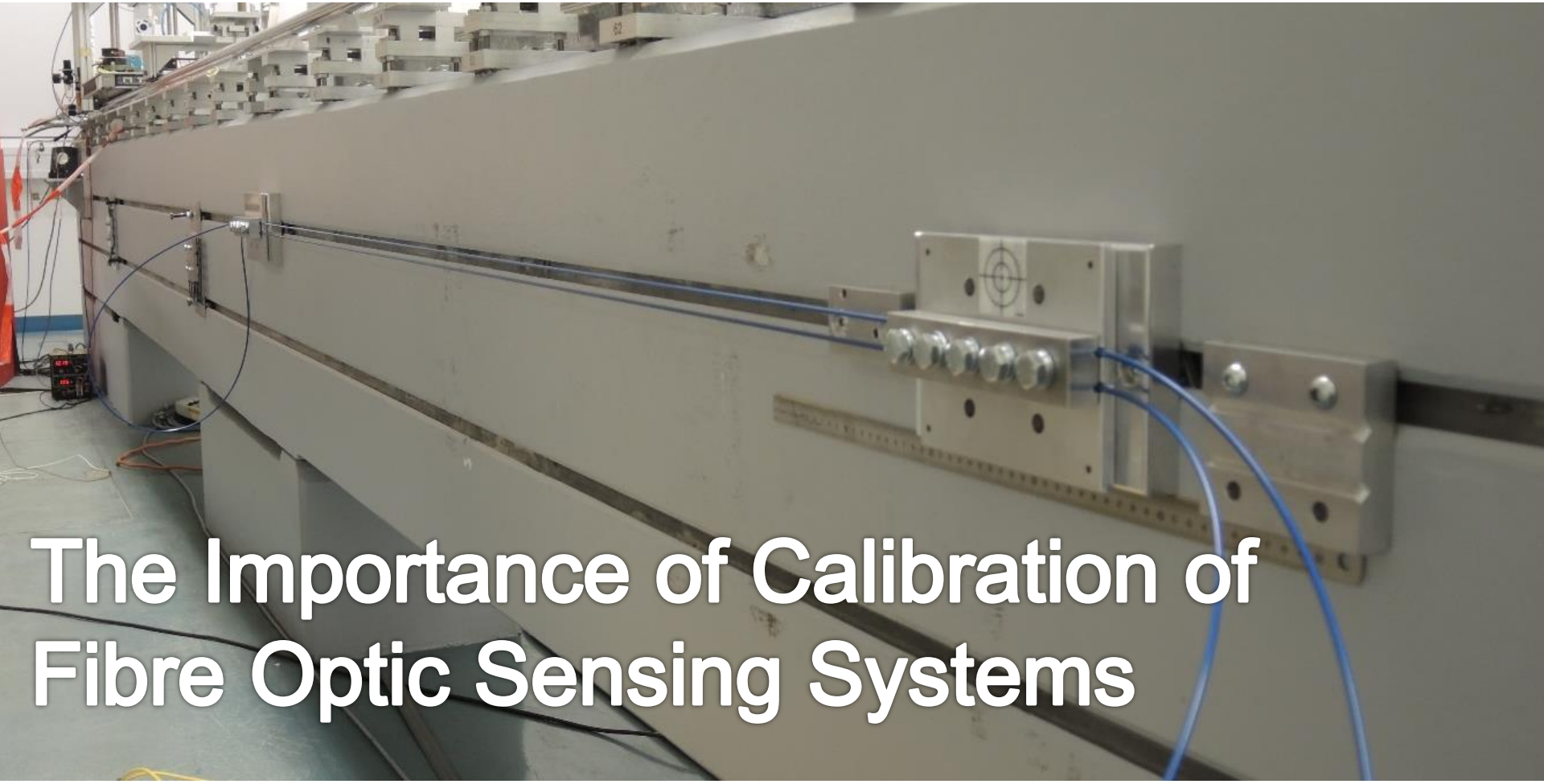
INSTITUTE OF ENGINEERING GEODESY
AND MEASUREMENT SYSTEMS



The Importance of Calibration of Fibre Optic Sensing Systems

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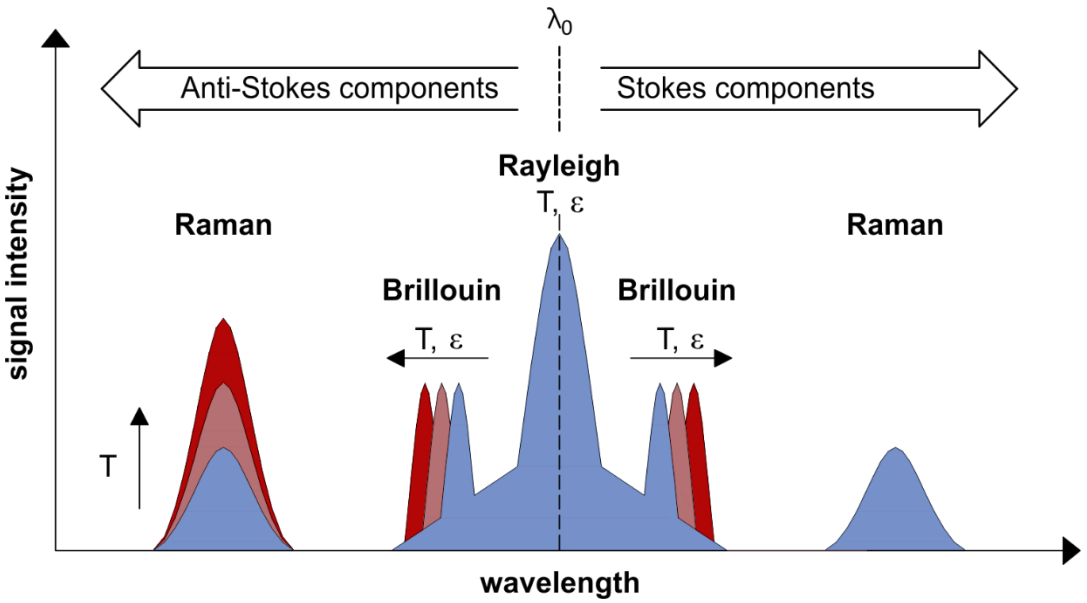
Measurements

Raw measurement

- Intensity
- Frequency/Wavelength
- Phase



Derived quantity

- Strain
- Strain rate
- Temperature

Relation between raw measurement and derived quantity has to be known!

Component Testing & Calibration

IGMS measurement lab

- Temperature controlled (20°C ± 0.5°C)
- Vibration isolated floor
- Static strain calibration
- Temperature calibration
- Dynamic testing
- Long term evaluation

Sound studio

- Zero noise environment
- Zero vibration environment

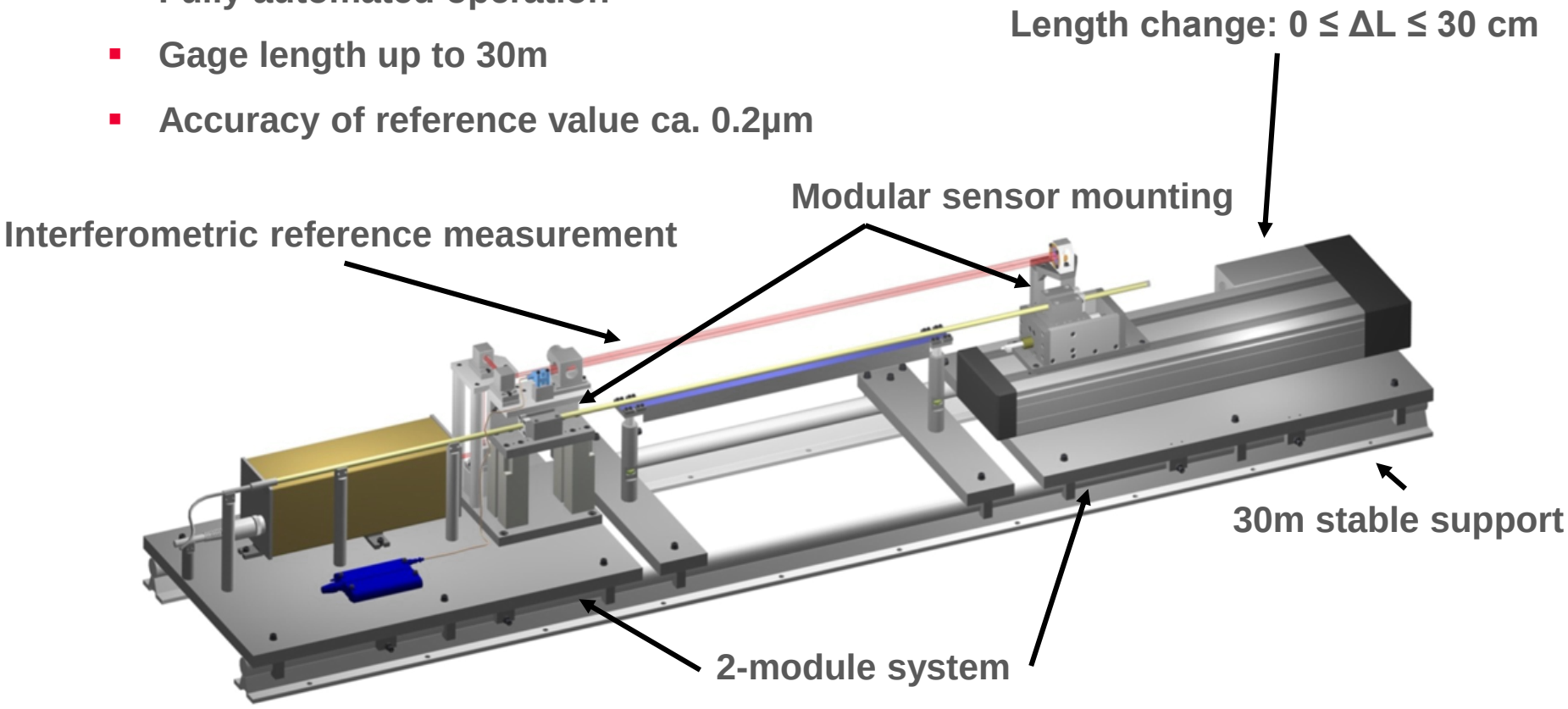
Fibre Optic Calibration

What is the achievable accuracy of a fibre optic measurement system?

Static Strain Calibration

Design

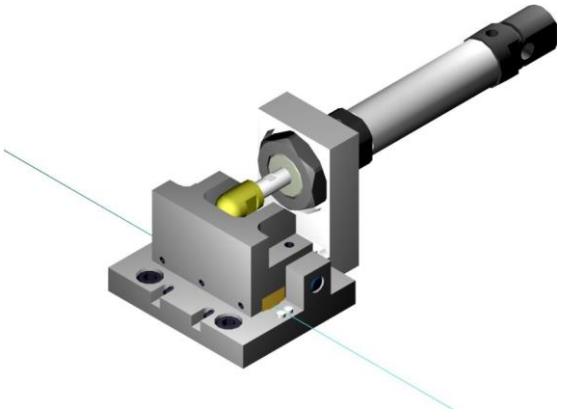
- Controlled length changes
- Reference values by laser interferometer
- Fully automated operation
- Gage length up to 30m
- Accuracy of reference value ca. 0.2µm



Static Strain Calibration

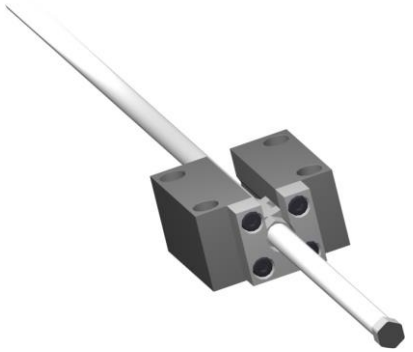
Test features

- Calibration of various sensor types (FBG, SOFO, DFOS cables, …)
- Calibration of bare fibres or sensors with housing
- System calibration
  - Calibration of complete system with instrument – sensor - adapter



Bare Fiber Adapter

FBG Sensor Adapter

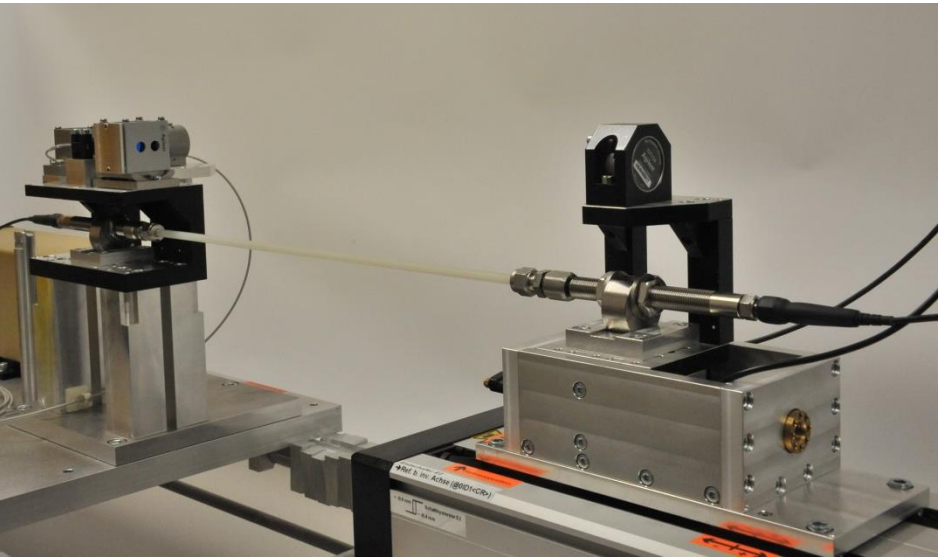


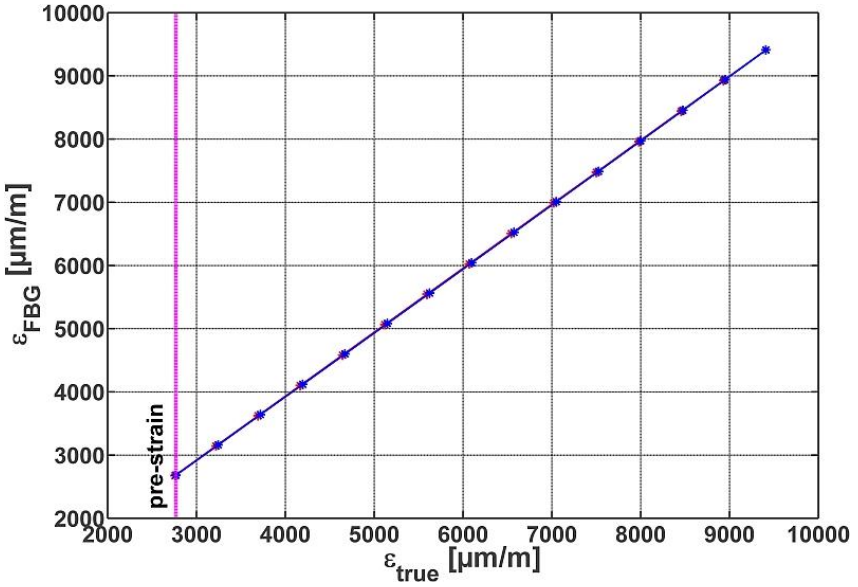
Point Sensor Adapter

Static Strain Calibration

Example

- Calibration of FBG sensor



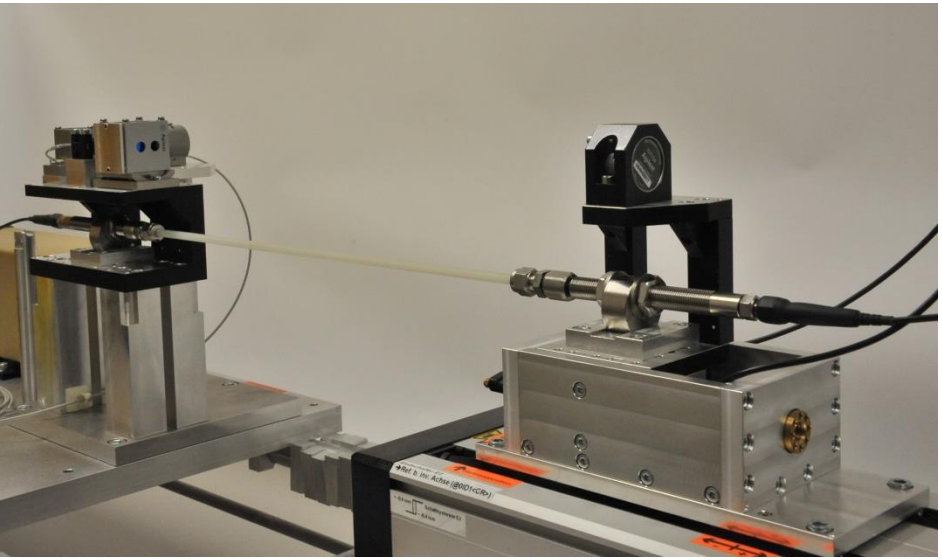


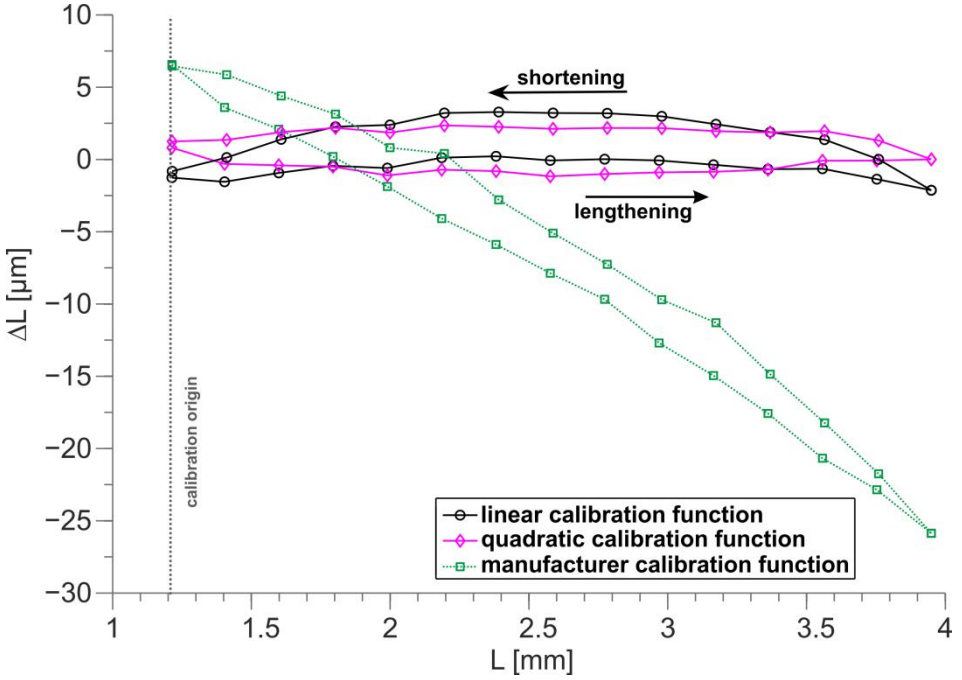
- Calibration function given by the manufacturer

Static Strain Calibration

Example

- Calibration of FBG sensor



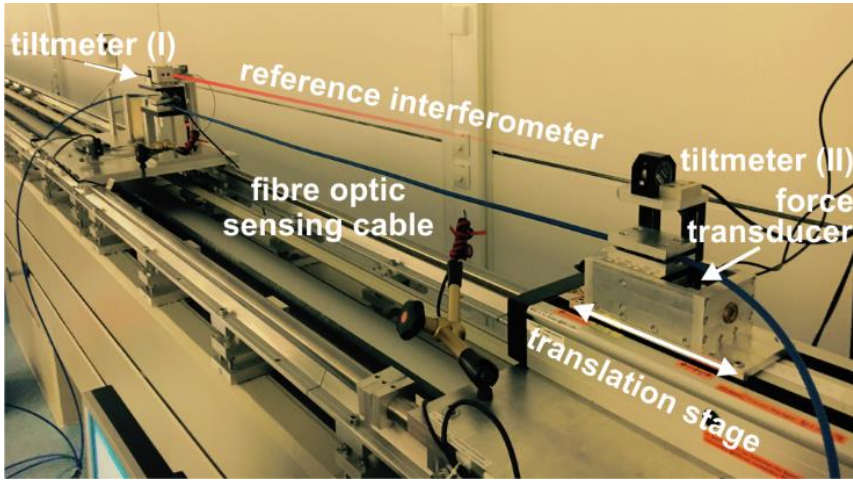


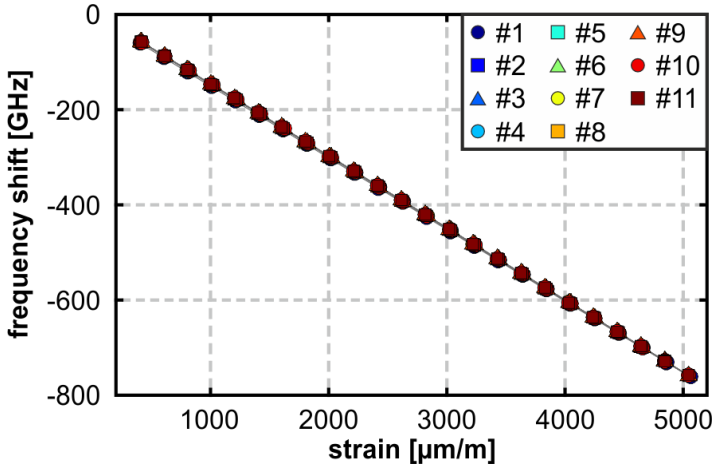
- Calibration function given by the manufacturer not sufficient for highest accuracy

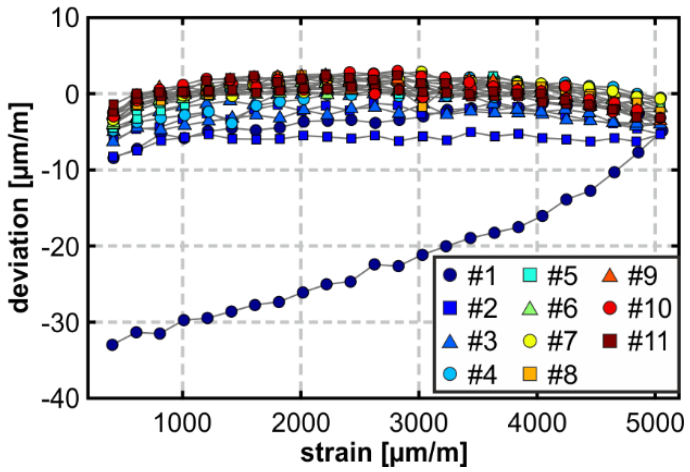
Static Strain Calibration

Example

- Calibration of DFOS Cable
- Measurement with Rayleigh instrument
- Linear relationship
- Run in effects can be observed
- Variations within ± 5 µm after 1st cycle



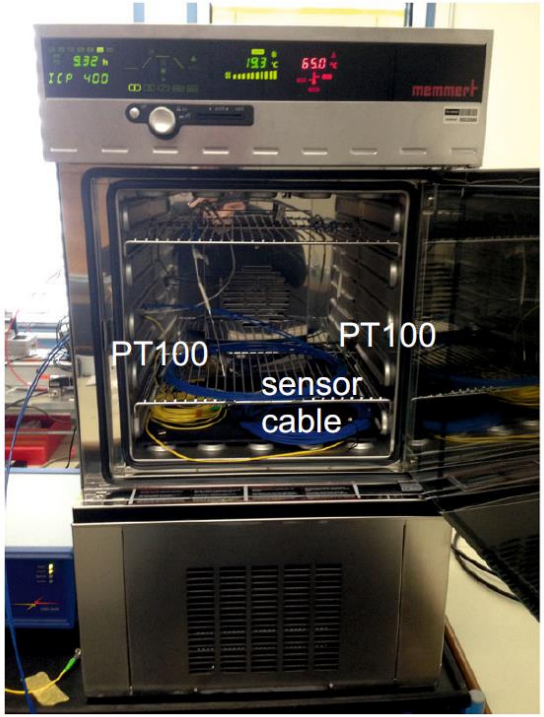


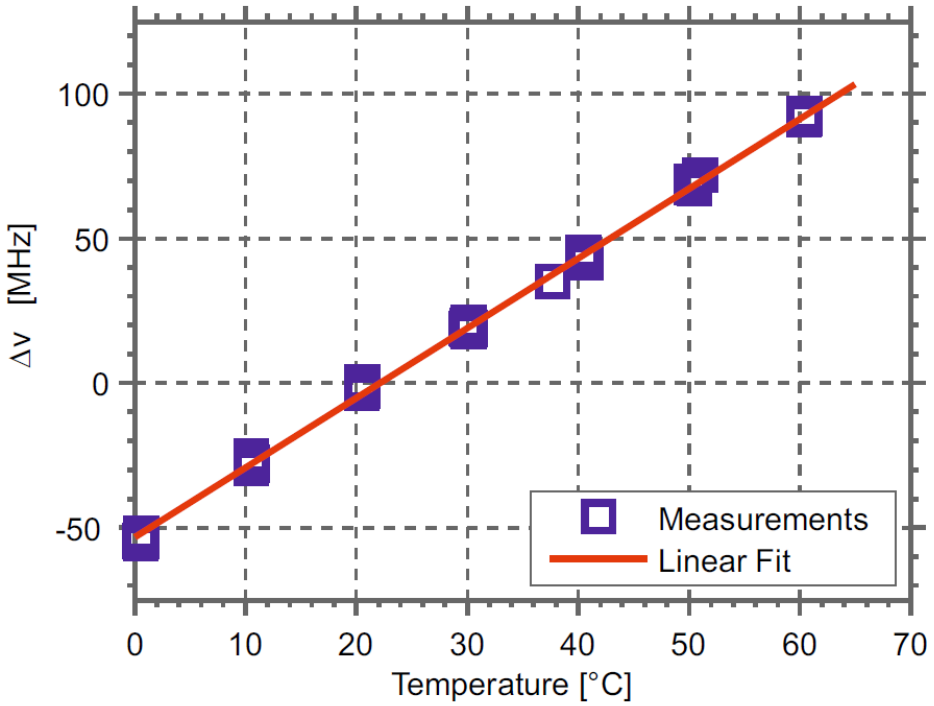


Temperature Calibration

Principle

- Sensing cable placed into water bath or climate chamber
- Temperature cycles





Fibre Optic Calibration

Does the measurement system drift?

What happens when the reading unit has to be changed?

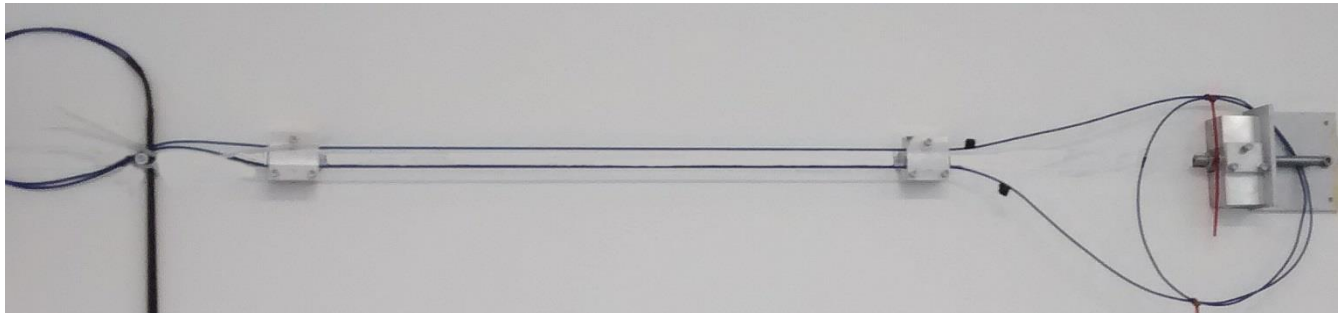
Is there an offset in the data?

Long term stability: Laboratory verification

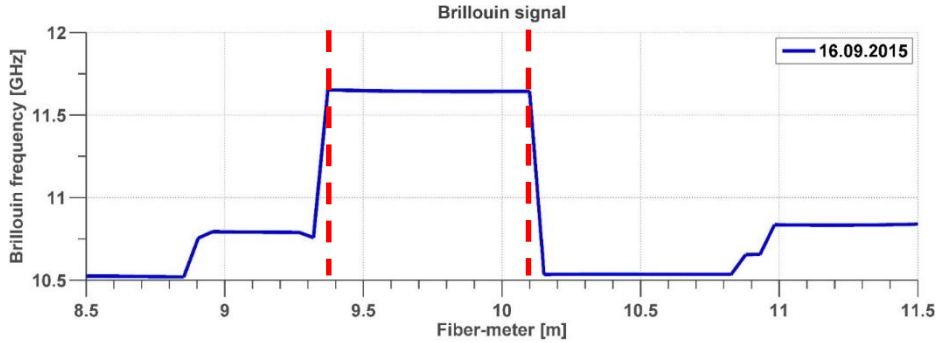
Test setup 1

- Standard sensor cable for distributed fibre optic sensing
- Sensor cable is pre-strained with ~3.5% (bare fibre limit for long term)

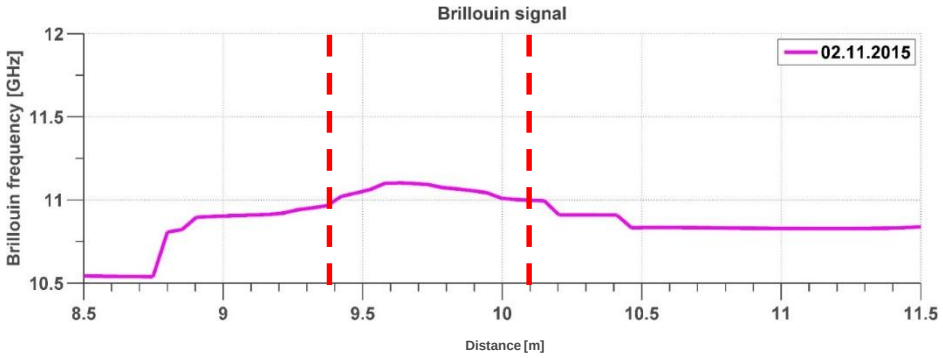
  (≙ 20 mm at 60 cm base)
- Regular measurements over several months



Long term stability: Laboratory verification

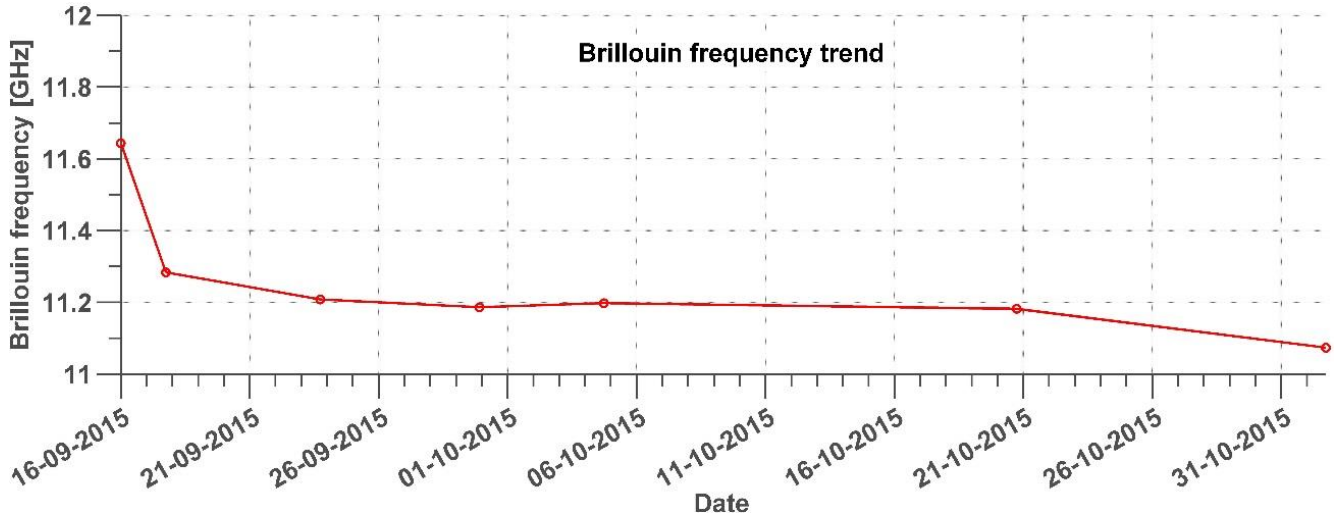


Initial signal



After 47 days

Long term stability: Laboratory verification



Reason for this behaviour?

- Composite sensor cable construction => fiber creeps at high strain
- After 3 months only 1.2% (≙ 7 mm at 60 cm base) are measured instead of 3.5%

Long term stability

Test setup 2

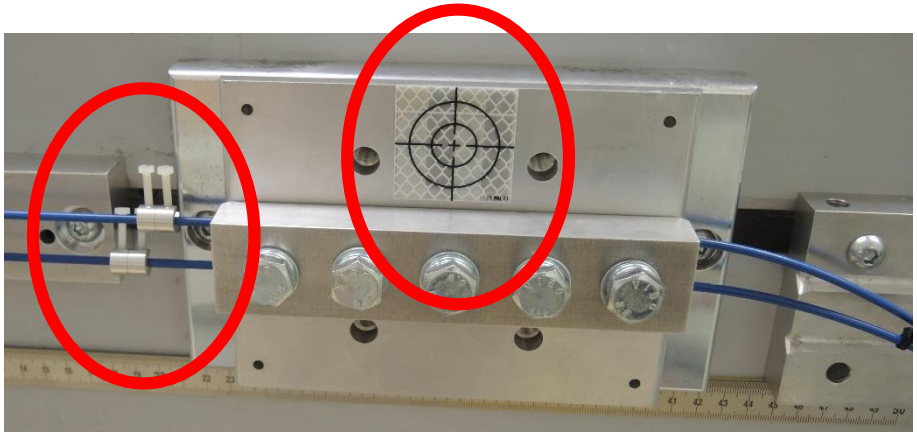
- Permanent laboratory installation with constant strain
- Investigation of long term behaviour

Long term stability

Test setup 2

- Marker to detect possible slip of anchors
- Marker to verify stability of anchors
- Measurement of markers with total station

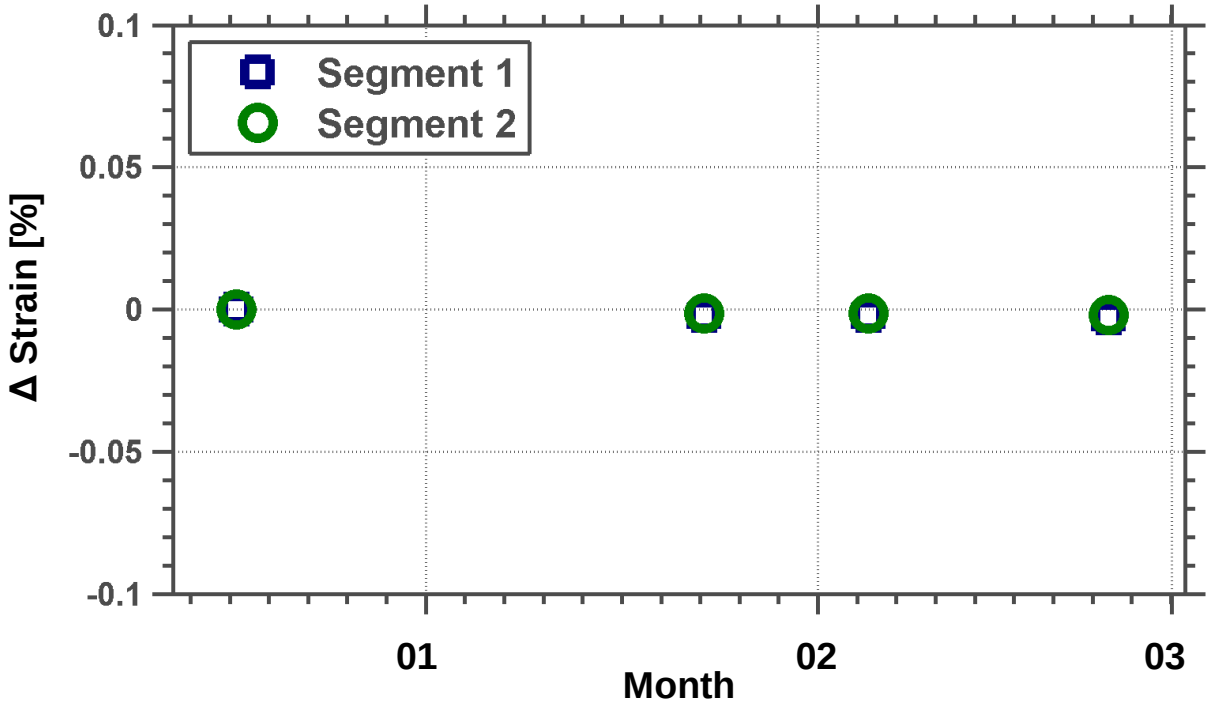
angle readings: σ_{HZ}=2.6cc → ca. 14µm @ 3,3m



Long term stability

Result

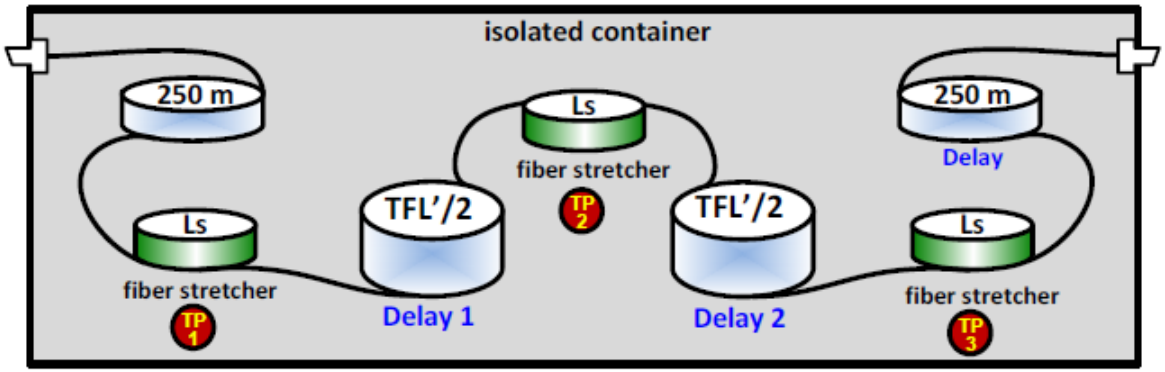
- No drift within 3 months



Dynamic Testing

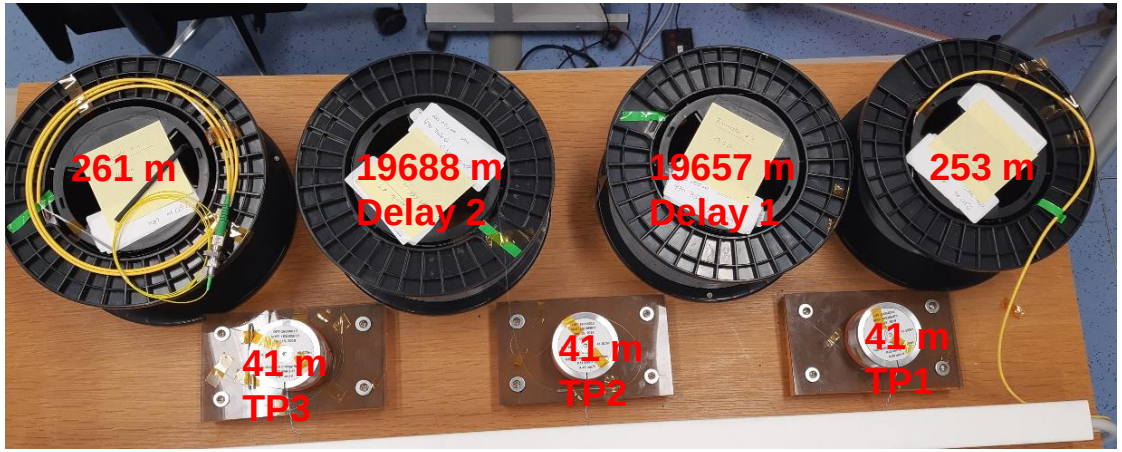
Seafom

- Measuring Sensor Performance (SEAFOM MSP-02)
- 3 stretcher



IGMS Setup

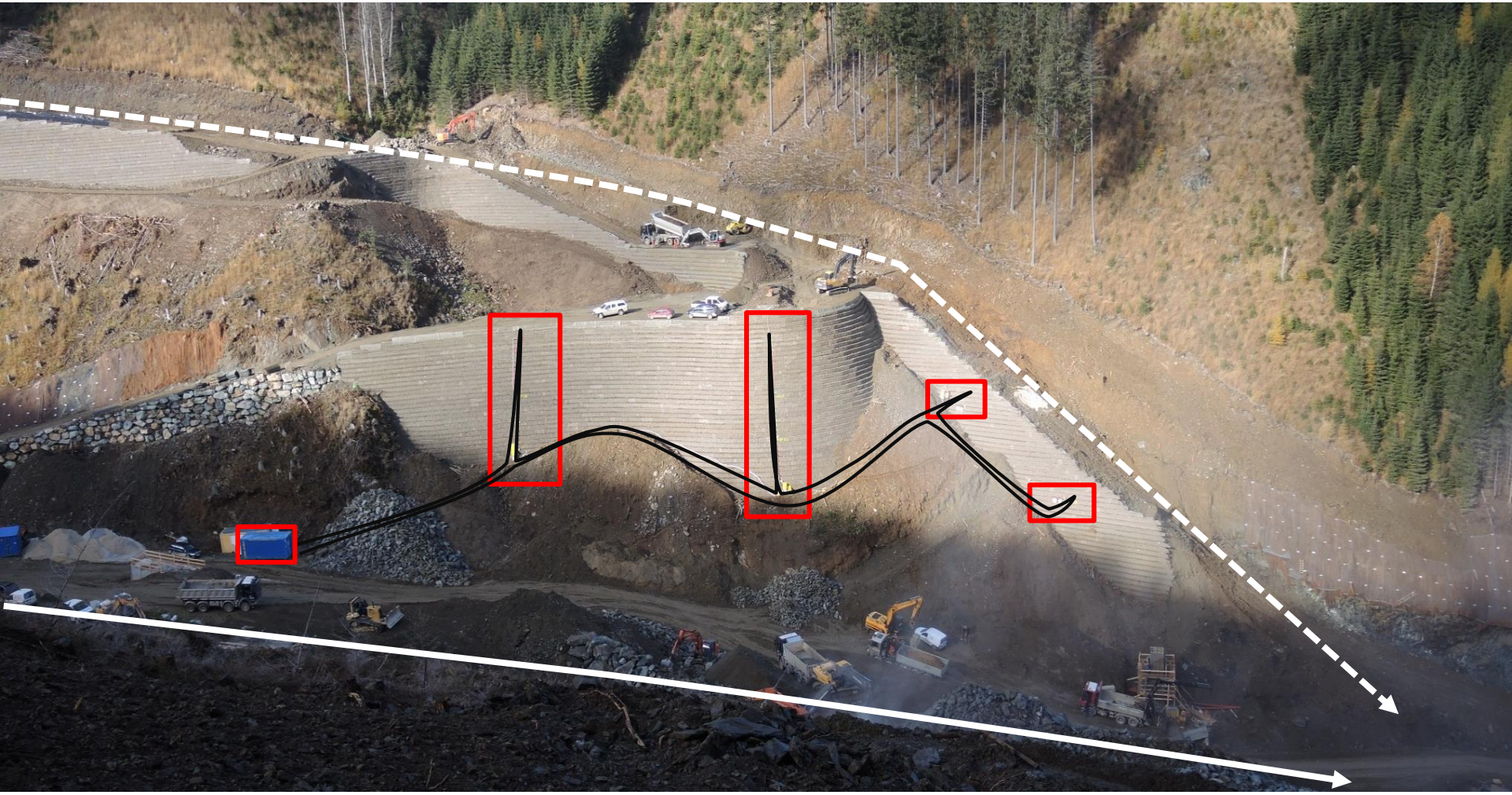
- 3 stretcher with 40 m
- Total length 40 km



Fibre Optic Calibration

Laboratory measurements are nice but what about the real world?

Relocation of River Stream



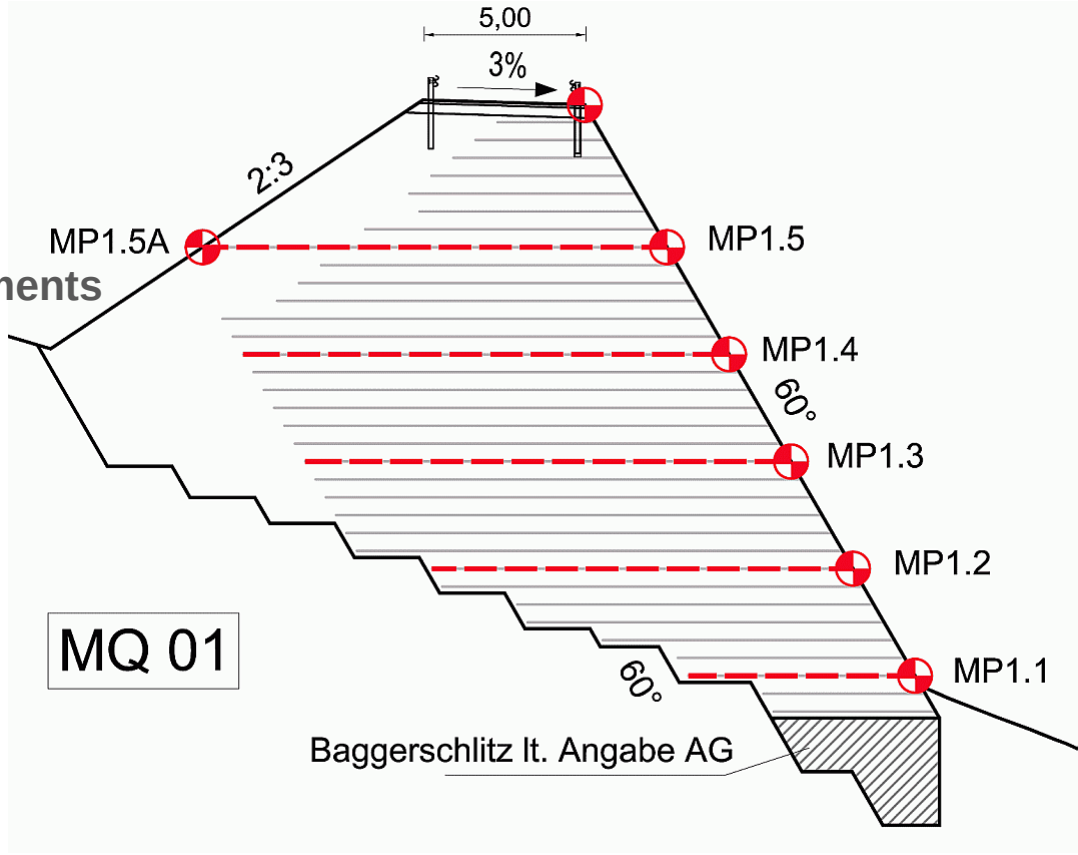
Measurement Concept

Dam Surface

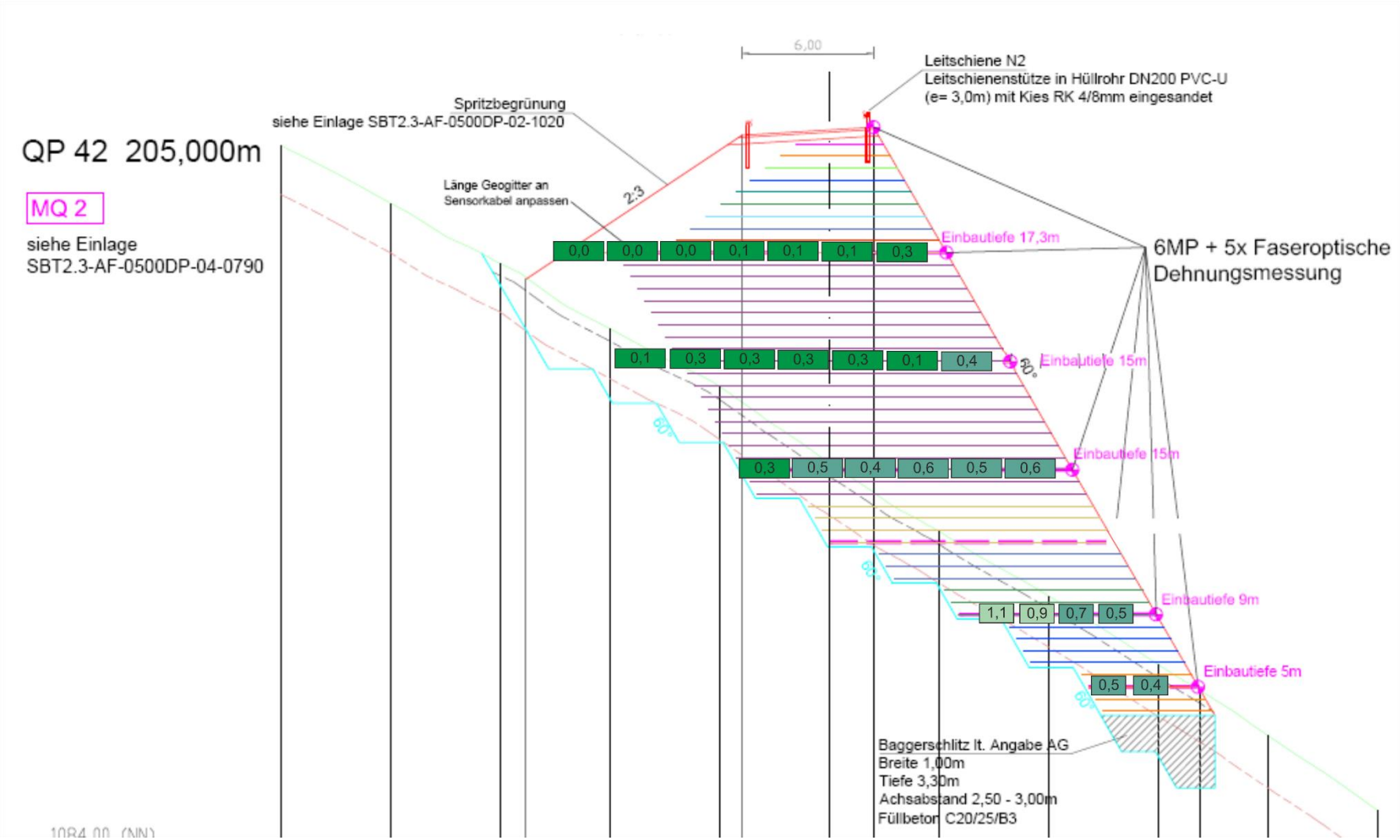
- Geodetic Prism Measurements

Geogrid

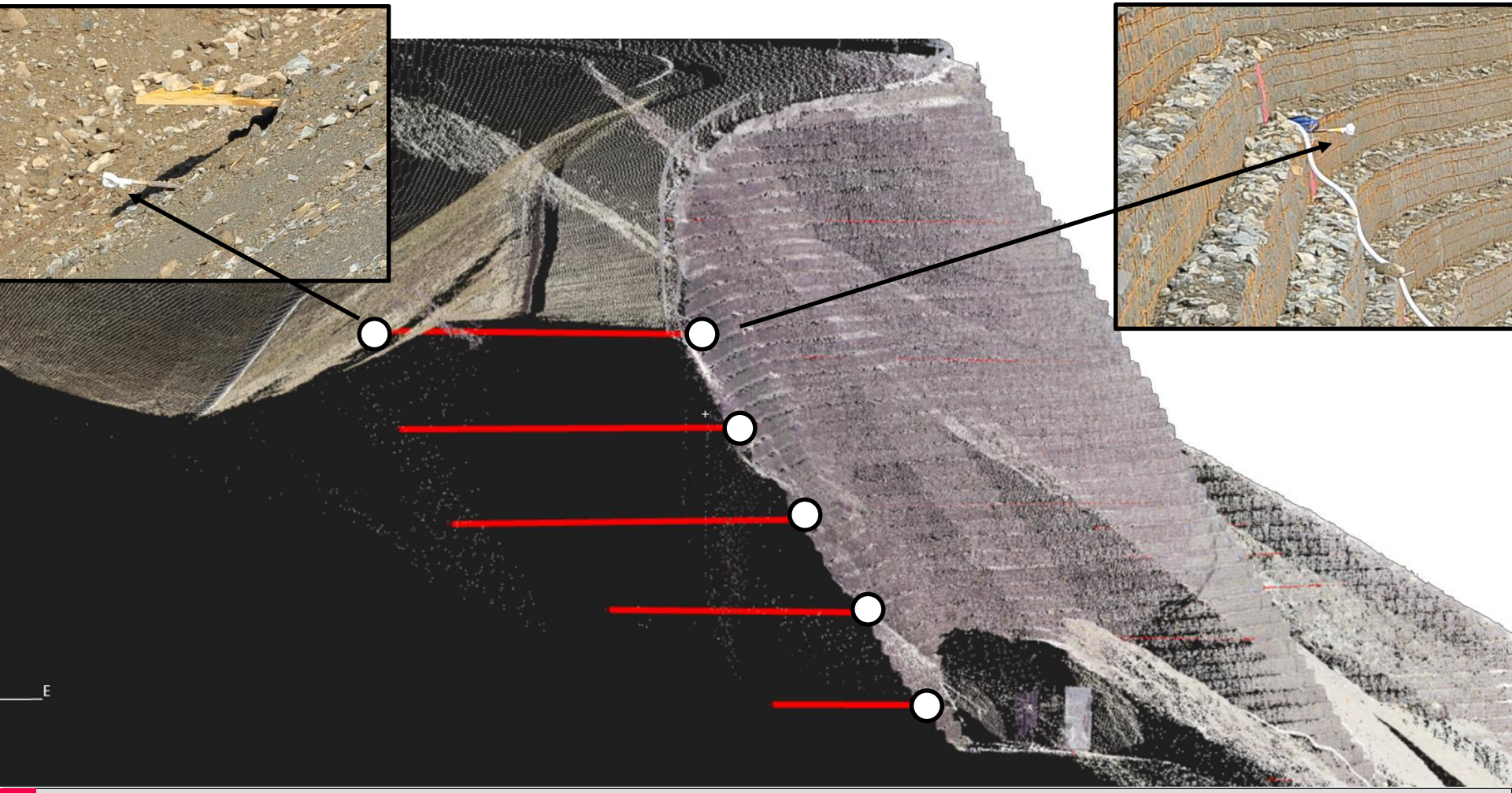
- Distributed fibre optic measurements
- 4 measurement profiles
- Up to 5 layers / profile
- More than 2km sensing cable



Strain [%]


QP 42 205,000m
MQ 2
siehe Einlage
SBT2.3-AF-0500DP-04-0790
6,00
Leitschiene N2
Leitschienenstütze in Hüllrohr DN200 PVC-U
(e= 3,0m) mit Kies RK 4/8mm eingesandet
Spritzbegrünung
siehe Einlage SBT2.3-AF-0500DP-02-1020
Länge Geogitter an
Sensorkabel anpassen
2:3
0,0 0,0 0,0 0,1 0,1 0,1 0,3
Einbautiefe 17,3m
6MP + 5x Faseroptische
Dehnungsmessung
0,1 0,3 0,3 0,3 0,3 0,1 0,4
Einbautiefe 15m
60°
0,3 0,5 0,4 0,6 0,5 0,6
Einbautiefe 15m
1,1 0,9 0,7 0,5
Einbautiefe 9m
0,5 0,4
Einbautiefe 5m
Baggerschlitz lt. Angabe AG
Breite 1,00m
Tiefe 3,30m
Achsabstand 2,50 - 3,00m
Füllbeton C20/25/B3

Long term stability: On-site verification



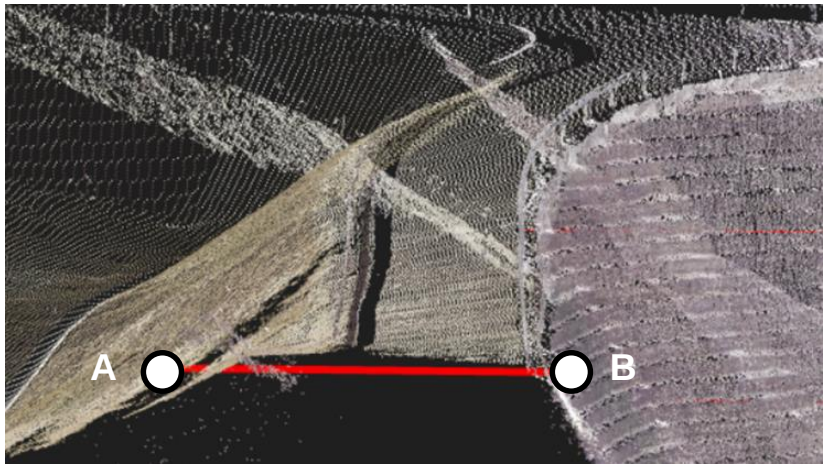
Long term stability: On-site verification

Total station measurements

- Length change from coordinates

$$\Delta l = l_{t2} - l_{t1}$$

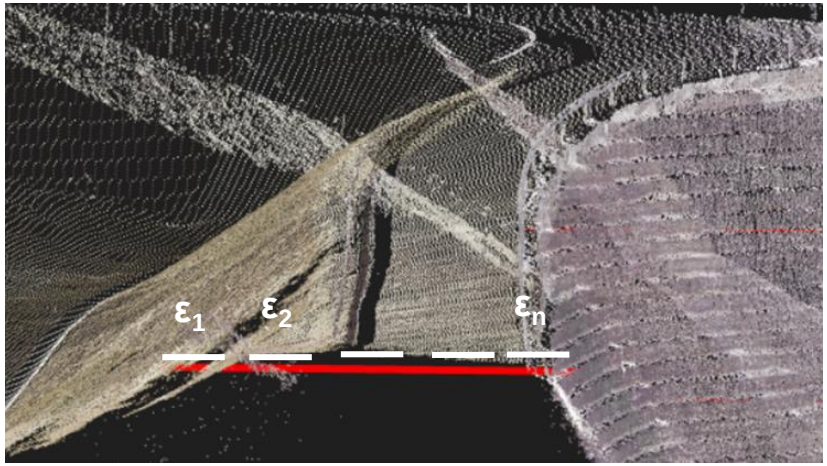
$$l_{ti} = \sqrt{(x_{E_{ti}} - x_{A_{ti}})^2 + (y_{E_{ti}} - y_{A_{ti}})^2 + (z_{E_{ti}} - z_{A_{ti}})^2}$$



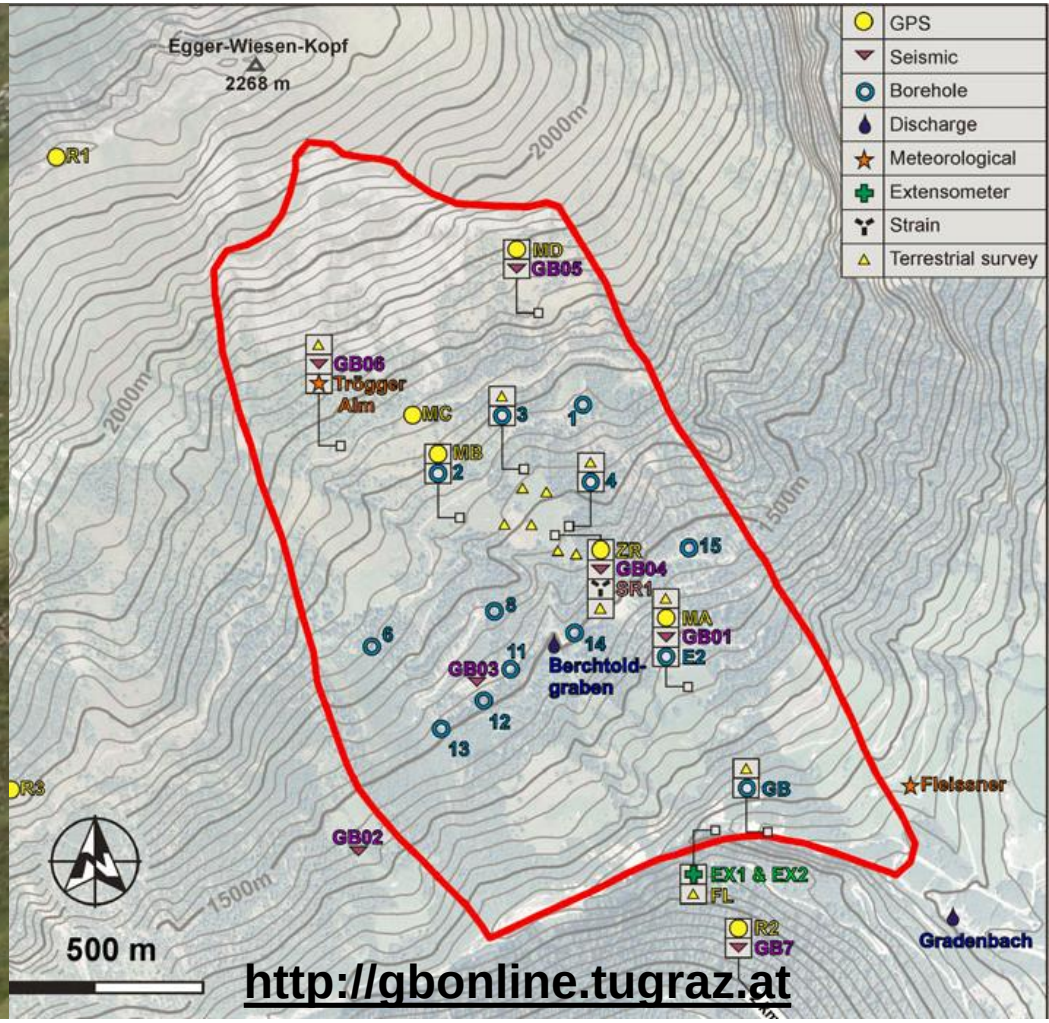
DFOS measurements

- Length change from integrated strain measurements

$$\Delta l = l_{Gauge} \sum_{i=1}^{n} \epsilon_i$$



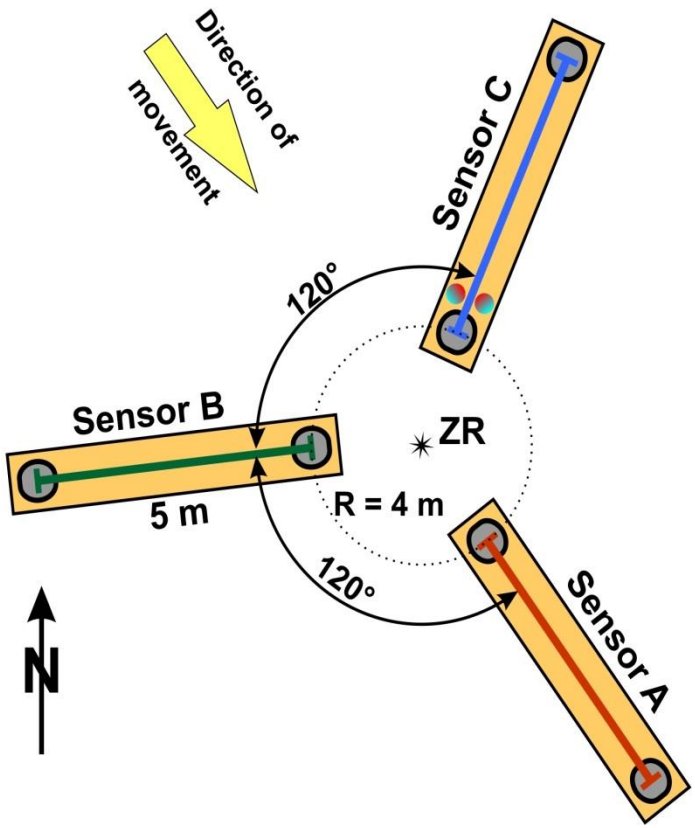
The Gradenbach Observatory

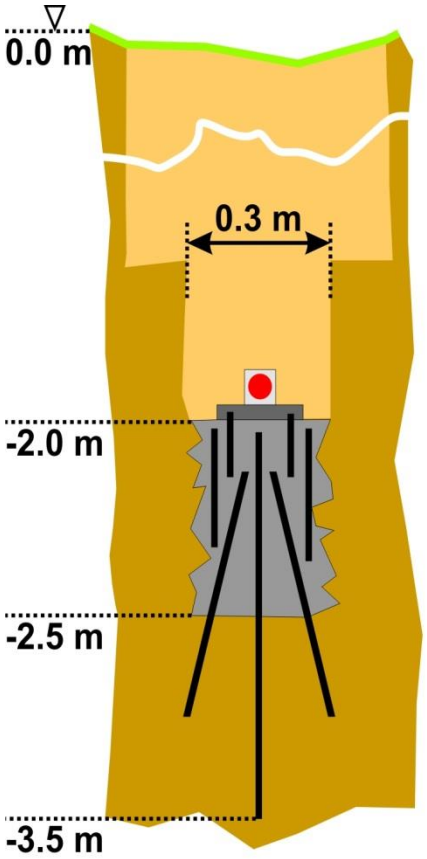


Strain Rosette

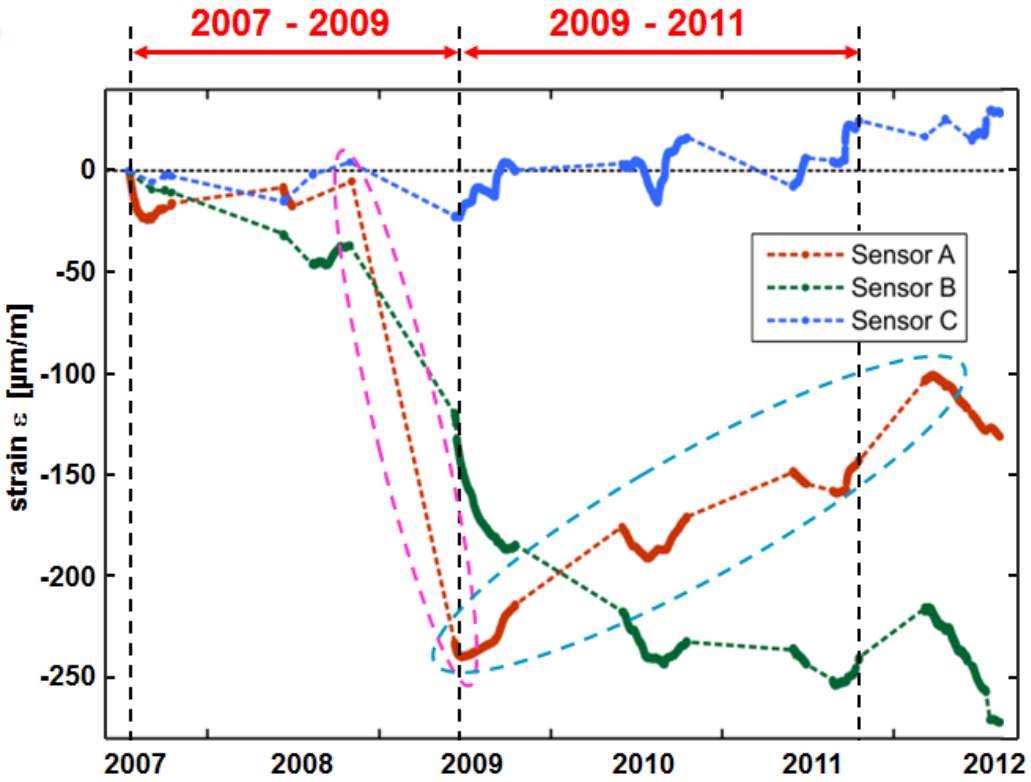
Installation

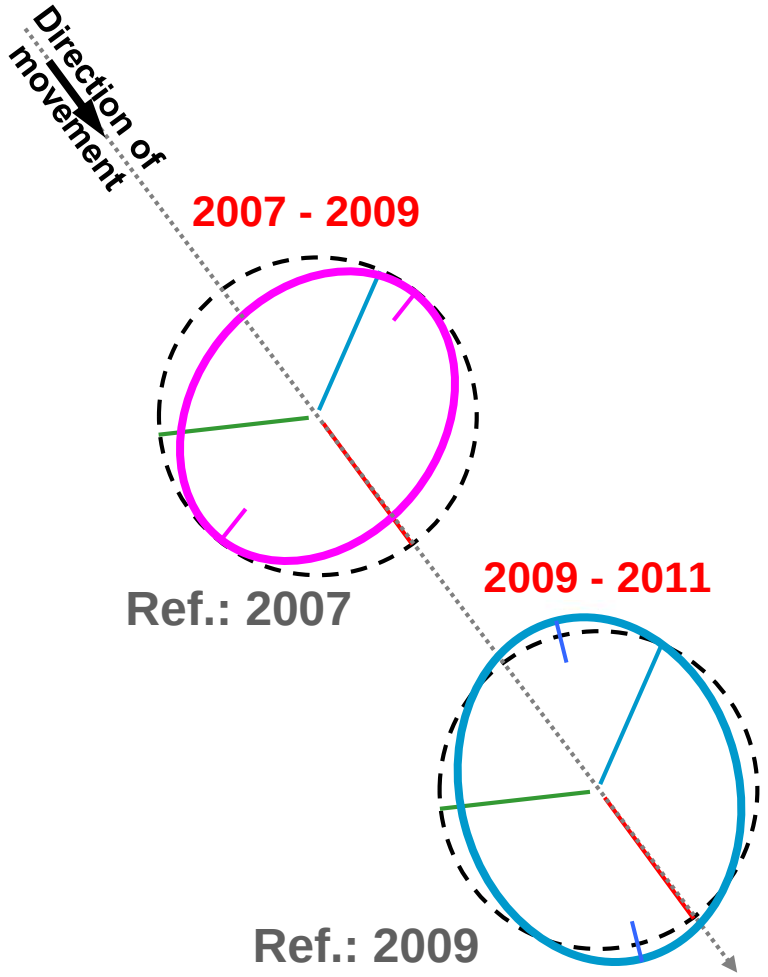
- 2007





Acceleration and Deceleration Phases

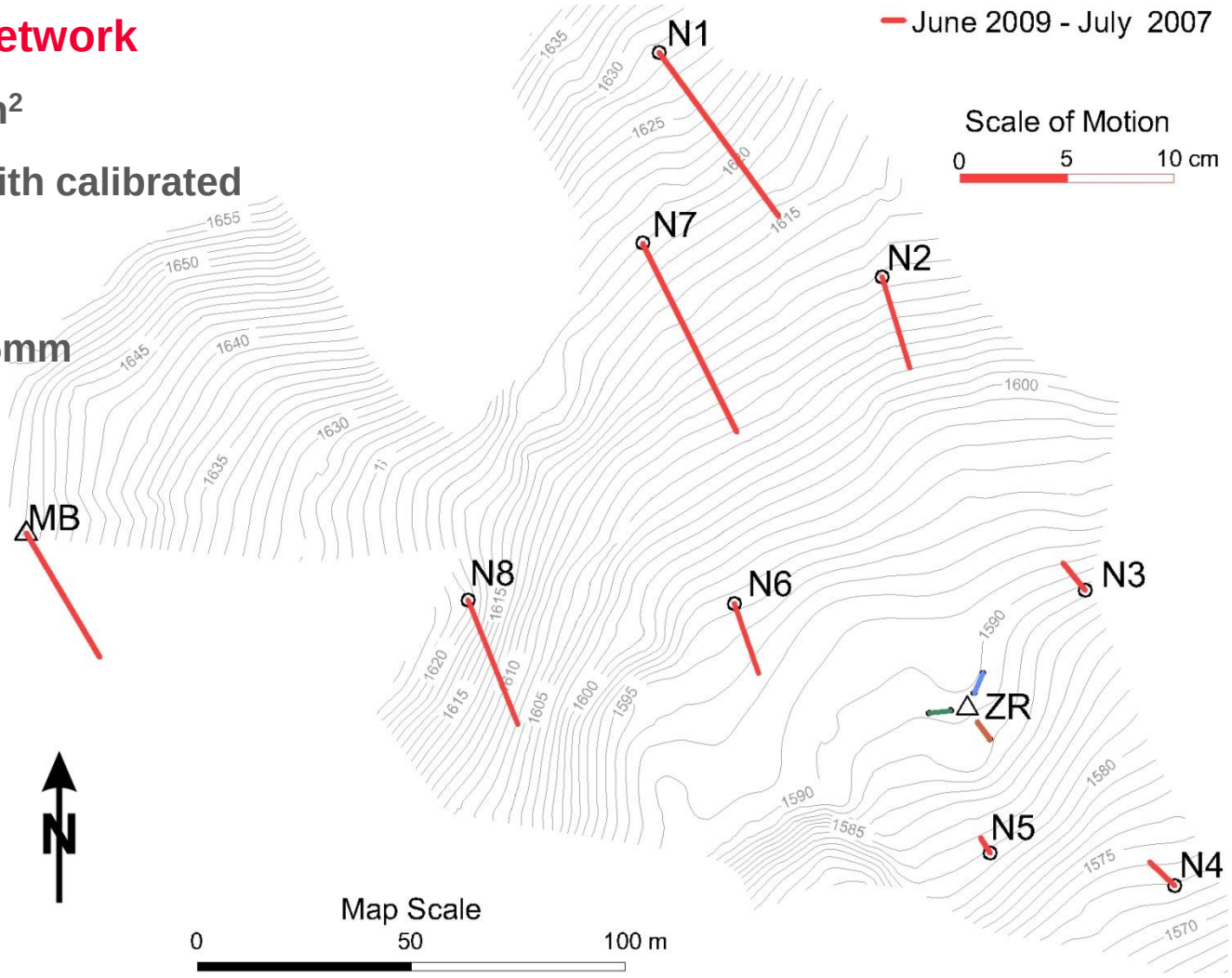




Verification

Local geodetic network

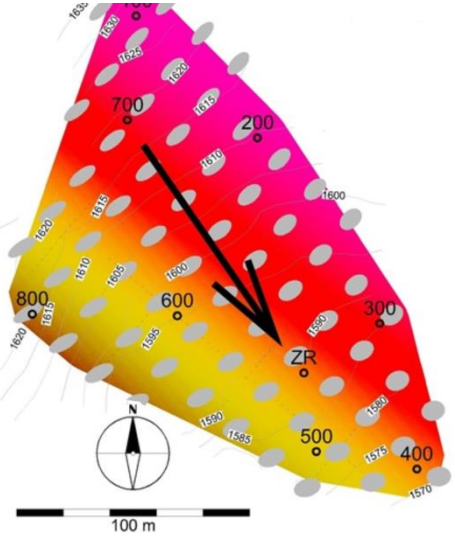
- Area 270 x 200m²
- Measurement with calibrated total station
- Precision of coordinates: 0.5mm

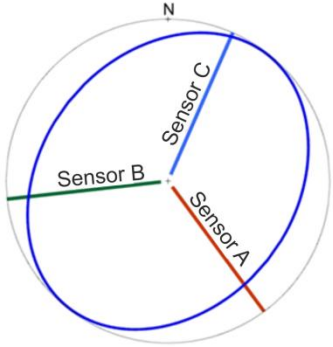


Comparison Geodetic and Fibre Optic Measurements

2007-2009

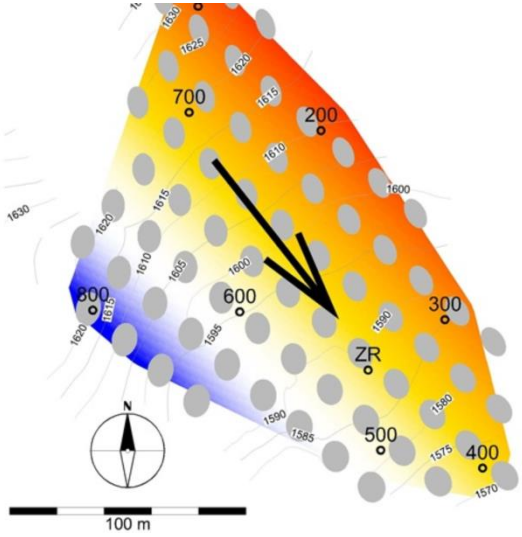
- Compression phase

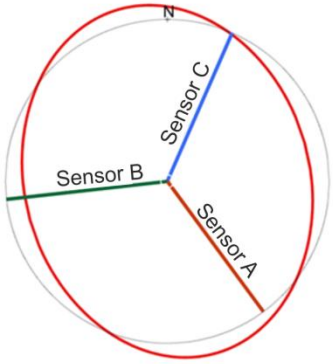




2009-2011

- Decompression phase

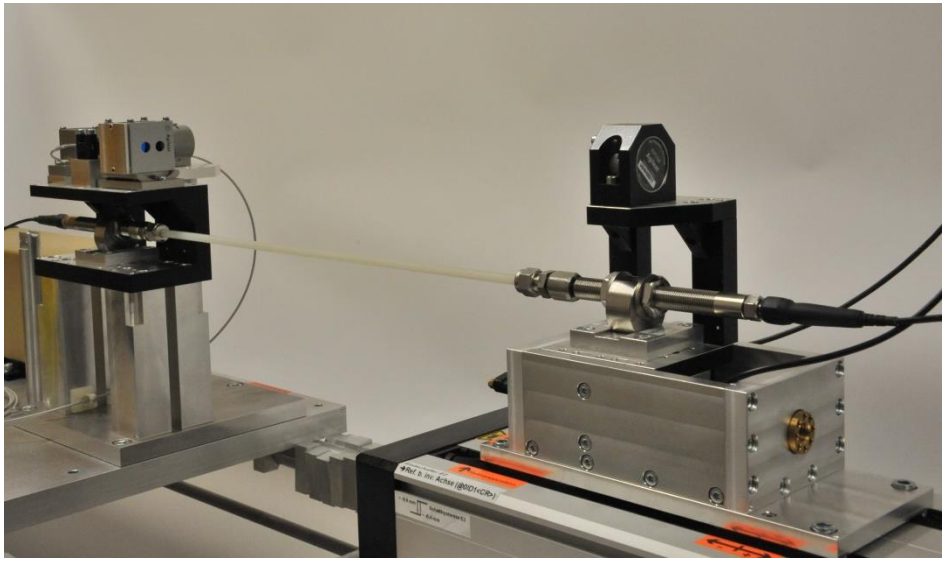




Conclusion

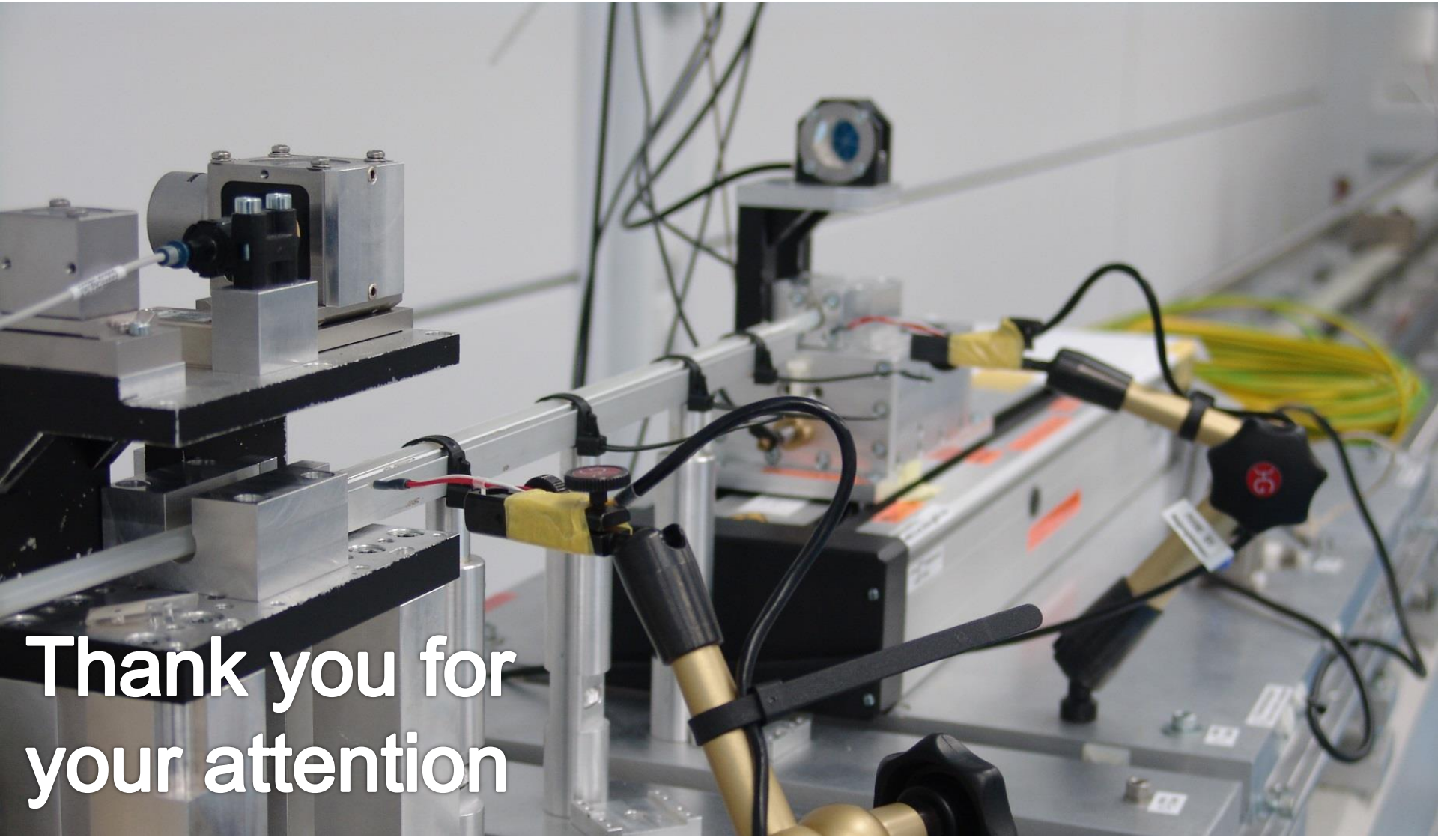
Laboratory calibration

- Special infrastructure needed due to high resolution of FOS measurements
- Some sensor cables show drifts
- Errors up to 10% without calibration



Field validation

- External geodetic measurements can independently verify FOS
- Other internal point wise measurements e.g. VWS can verify FOS


Thank you for
your attention