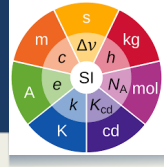

SI-traceable laboratory calibration of seismometers with or without a Laser

Thomas Bruns

Dr. rer.-nat., Head of Dept. 1.7 “Acoustics and Dynamics”
Physikalisch-Technische Bundesanstalt (PTB), Germany

Presentation Date: 10th September 2025

SI-traceable laboratory calibration of seismometers with or without a Laser

Dr. Thomas Bruns

Calibration …

Establish a relationship between a reference standard (Ref) representing **the quantity** and **the indication** of the instrument to be calibrated (DUT).

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Establish a relationship between a reference standard (Ref) representing **the quantity** and **the indication** of the instrument to be calibrated (DUT).

Velocity (Input) <-> Voltage (Output)

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Calibration …

Establish a relationship between a reference standard (Ref) representing **the quantity** and **the indication** of the instrument to be calibrated (DUT).

Velocity (Input) <-> Voltage (Output)

Primary Calibration: Reference is of a different kind than the Instrument to be calibrated. Usually the Reference is close(r) to the unit's definition.

Secondary Calibration: Reference is of the same kind as the DUT.

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Calibration …

Establish a relationship between a reference standard (Ref) representing **the quantity** and **the indication** of the instrument to be calibrated (DUT).

Velocity (Input) <-> Voltage (Output)

Primary Calibration: Reference is of a different kind than the Instrument to be calibrated. Usually the Reference is close(r) to the unit's definition.

Laser Interferometer <-> Seismometer

Secondary Calibration: Reference is of the same kind as the DUT.

Seismometer <-> Seismometer

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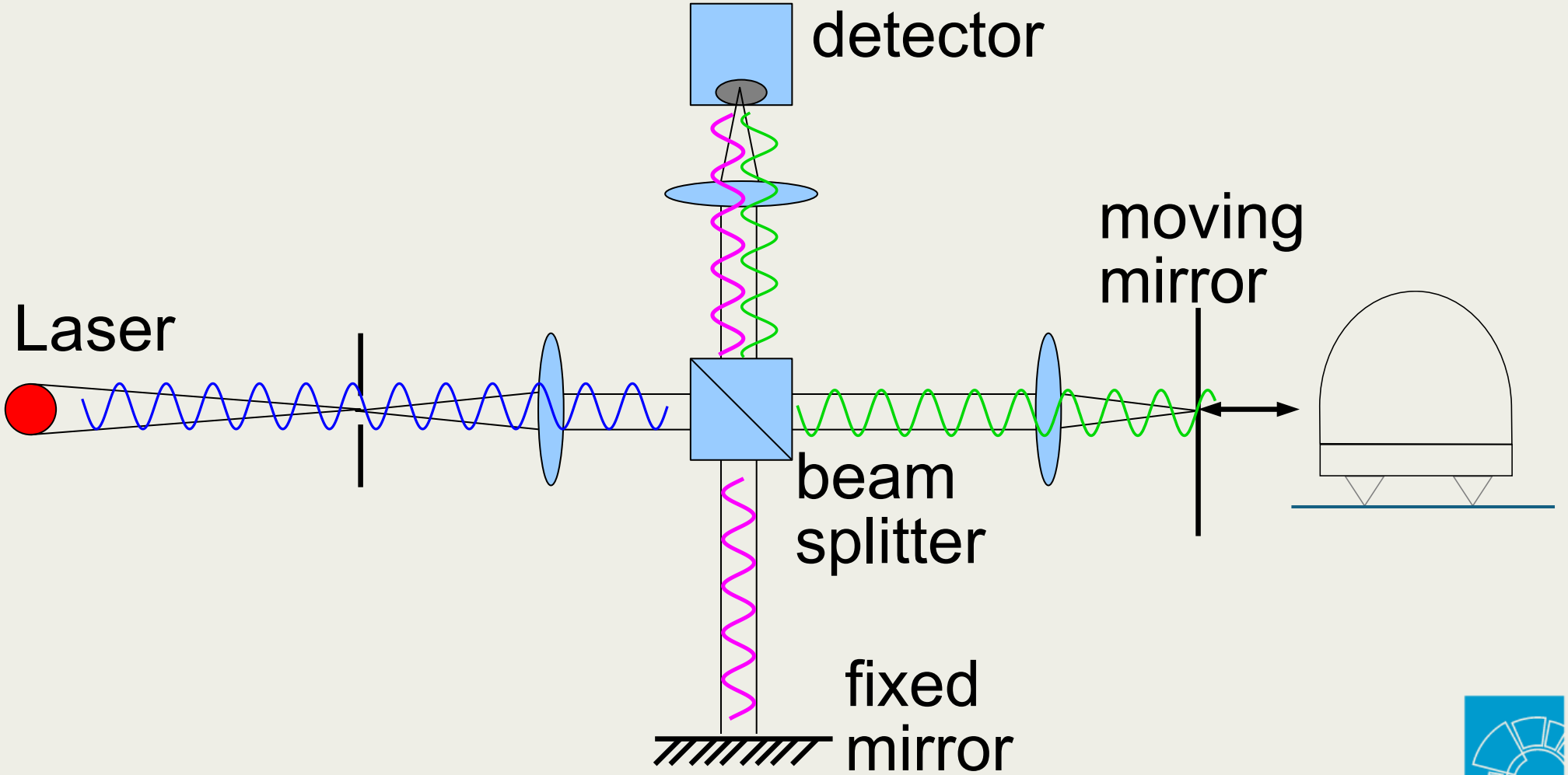
SI-traceable laboratory calibration of seismometers with or without a Laser

Dr. Thomas Bruns

Primary Calibration according to ISO 16063-11



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Primary Calibration according to ISO 16063-11

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Primary Calibration according to ISO 16063-11

- Direct SI-traceable via Laser-wave length, time (sample rate) and Voltage
- Very precise, stable, reproducible. …

- Measures only exactly straight motion (along line of Laser beam)
  - No accounting for **gravity disturbances** at low frequency (due to travel curvature)
  - No accounting for **dynamic tilt** at high frequencies (due to finite bearing stiffness)
  - No accounting for the position of the internal sensor (sensitive center)

SI-traceable laboratory calibration of seismometers with or without a Laser

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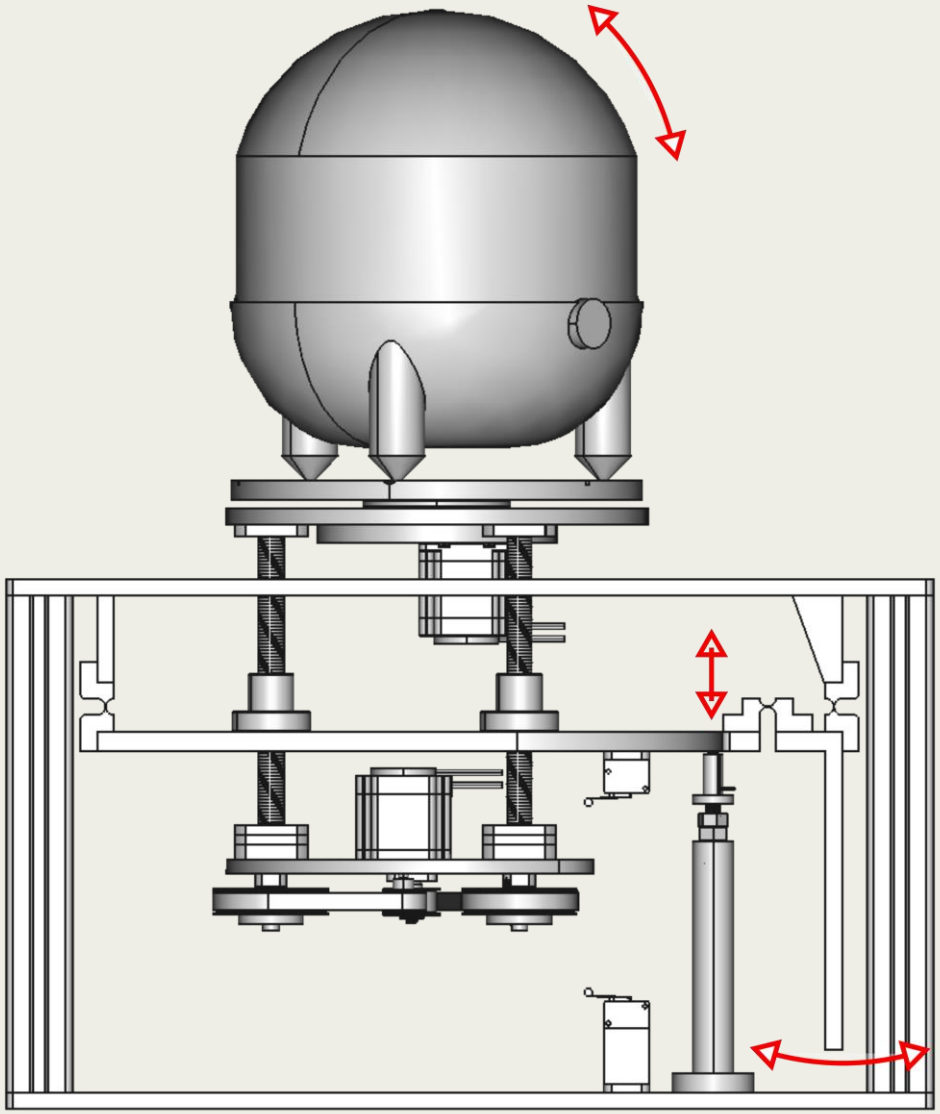
Primary Calibration “similar” to ISO 16063-42



- (horizontal) calibration by dynamic tilt in the
- gravitational field.

- Traceable via tilt amplitude, g_{local}, time (sample rate), voltage

- Works for very low frequencies below 2 Hz.

Bruns et al., Metrologia 61 (2024) 055012 (8pp)
https://doi.org/10.1088/1681-7575/ad795a

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Comparison calibration according to ISO 16063-21

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SI-traceable laboratory calibration of seismometers with or without a Laser

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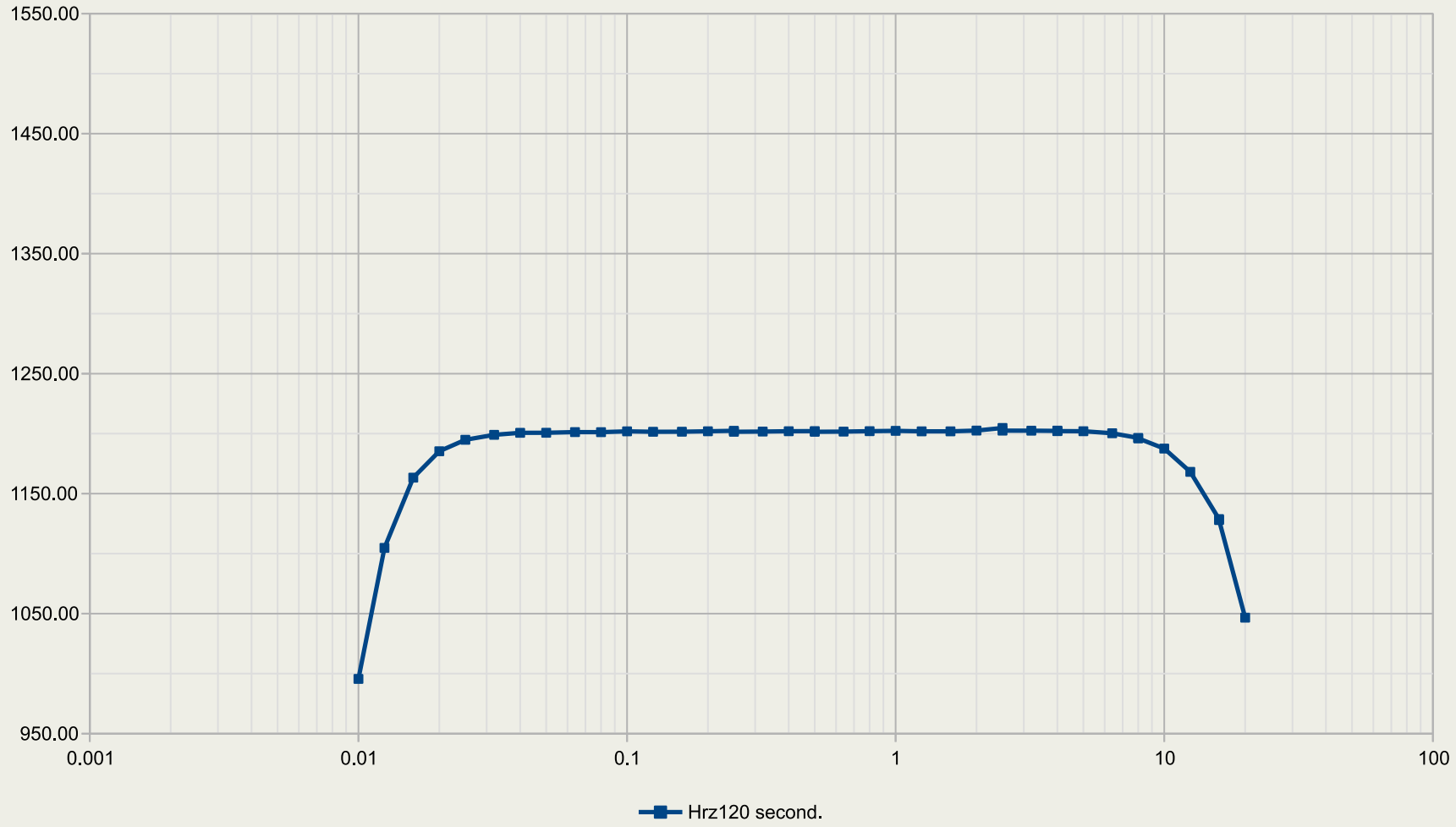
Comparison calibration simple approach

$$S_{\mathrm{DUT}} = S_{\mathrm{Ref}} \cdot \frac{\hat{U}_{\mathrm{DUT}}}{\hat{U}_{\mathrm{Ref}}}$$



SI-traceable laboratory calibration of seismometers with or without a Laser

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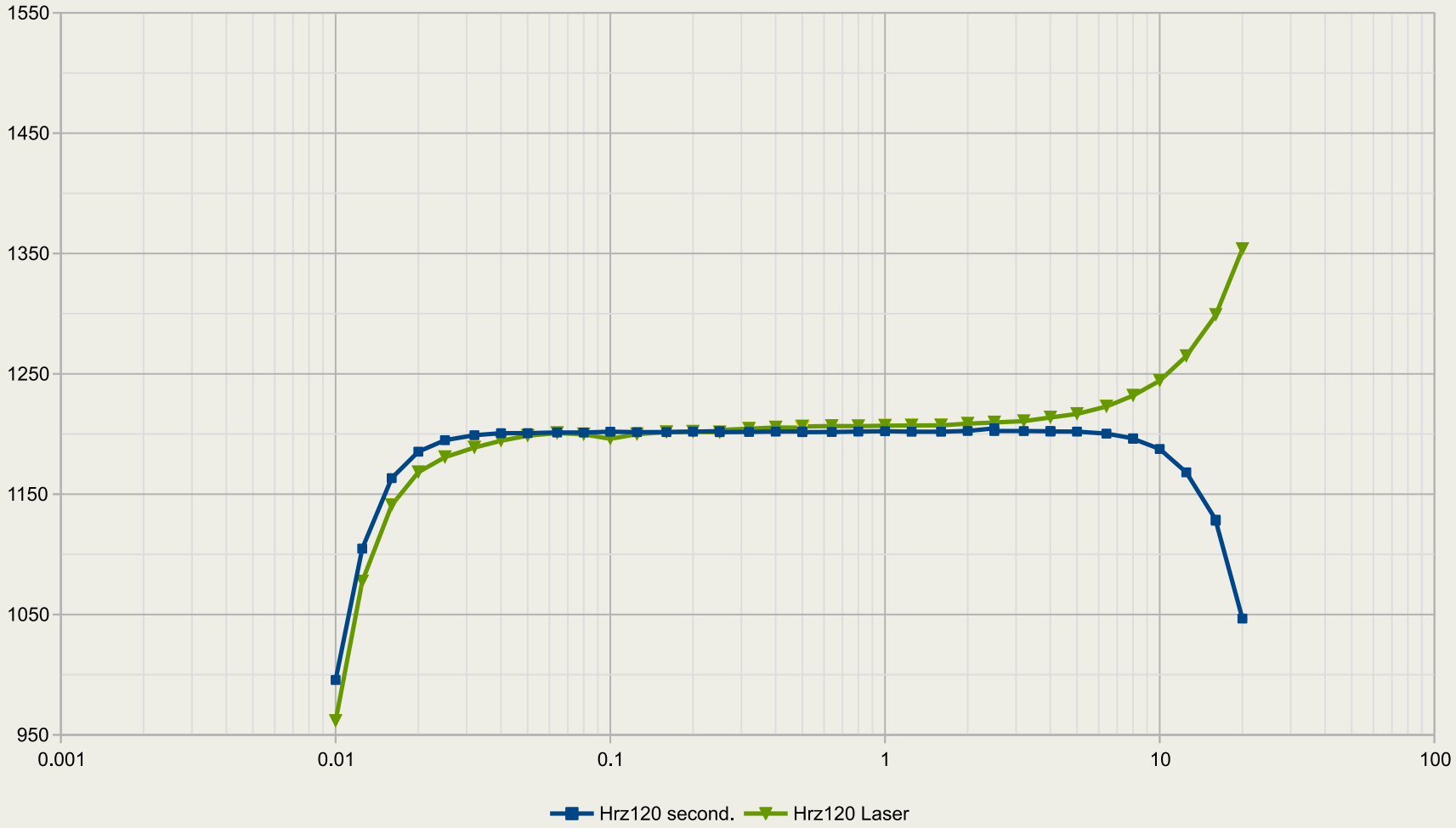
Comparison calibration simple approach

$$S_{\mathrm{DUT}} = S_{\mathrm{Ref}} \cdot \frac{\hat{U}_{\mathrm{DUT}}}{\hat{U}_{\mathrm{Ref}}}$$



SI-traceable laboratory calibration of seismometers with or without a Laser

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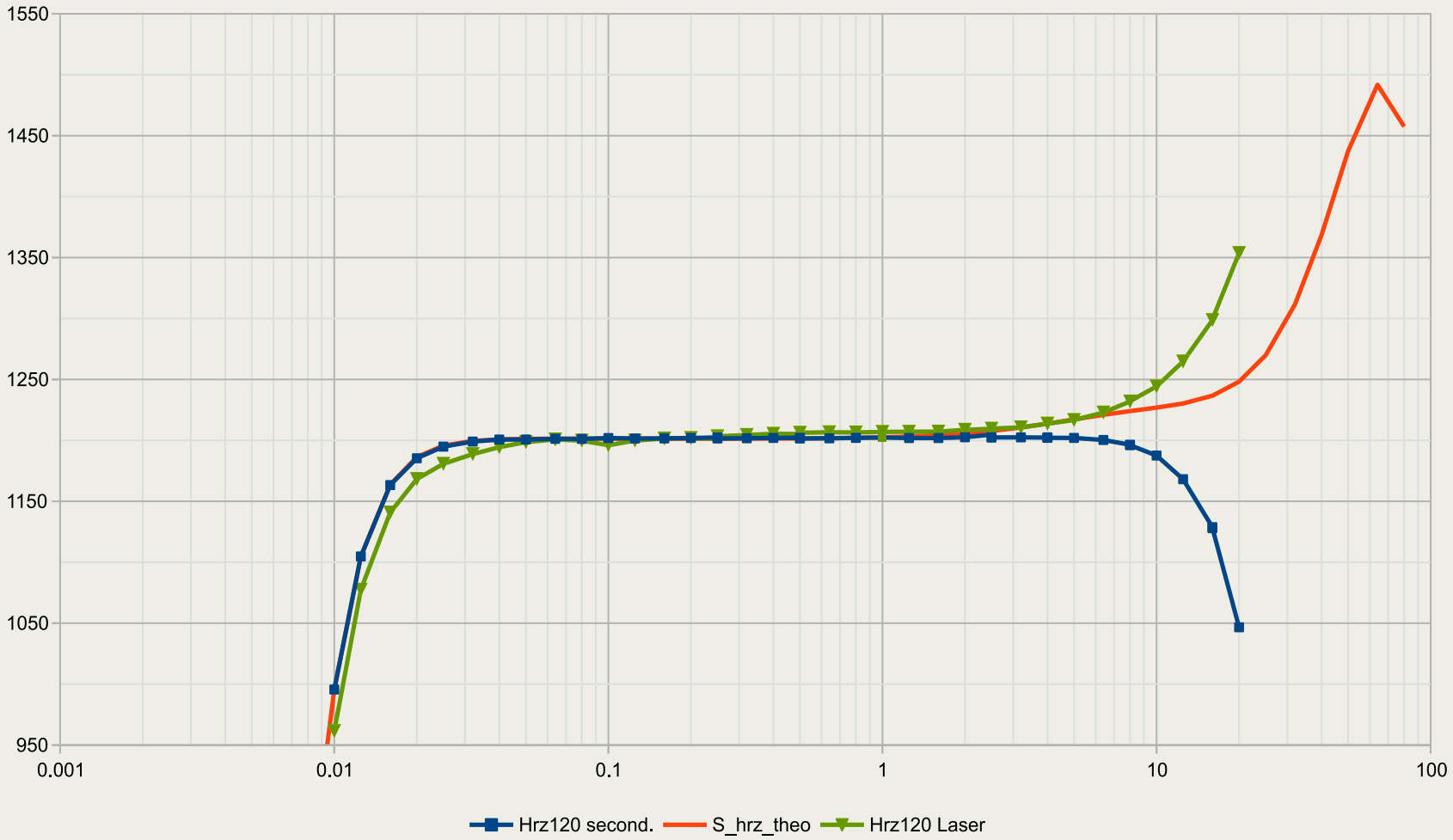
Comparison calibration simple approach

$$S_{\mathrm{DUT}} = S_{\mathrm{Ref}} \cdot \frac{\hat{U}_{\mathrm{DUT}}}{\hat{U}_{\mathrm{Ref}}} \quad ?$$



SI-traceable laboratory calibration of seismometers with or without a Laser

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What happens here ?

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SI-traceable laboratory calibration of seismometers with or without a Laser

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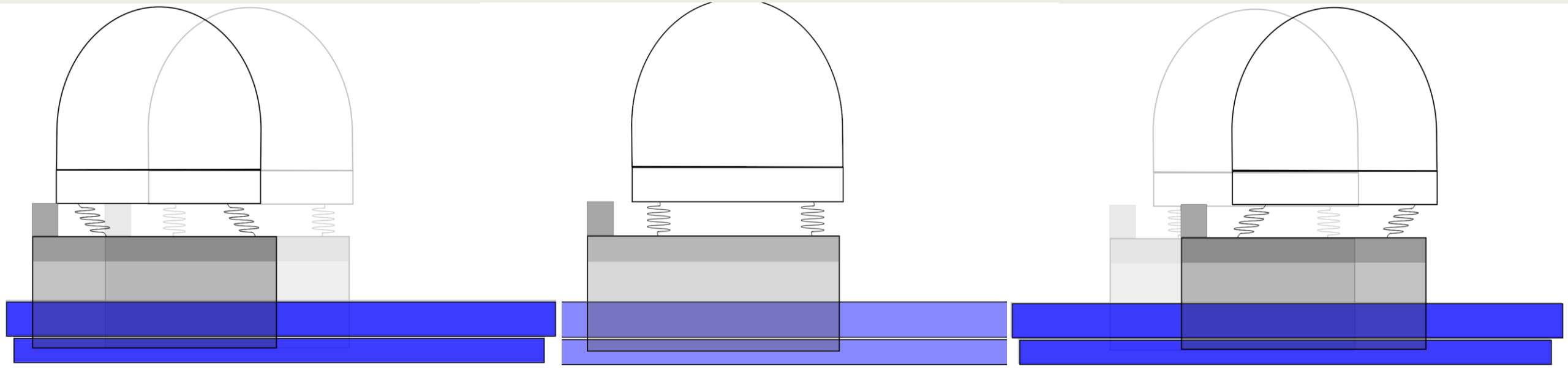
What happens here ?

Sheering of seismometer feet (inertia driven)



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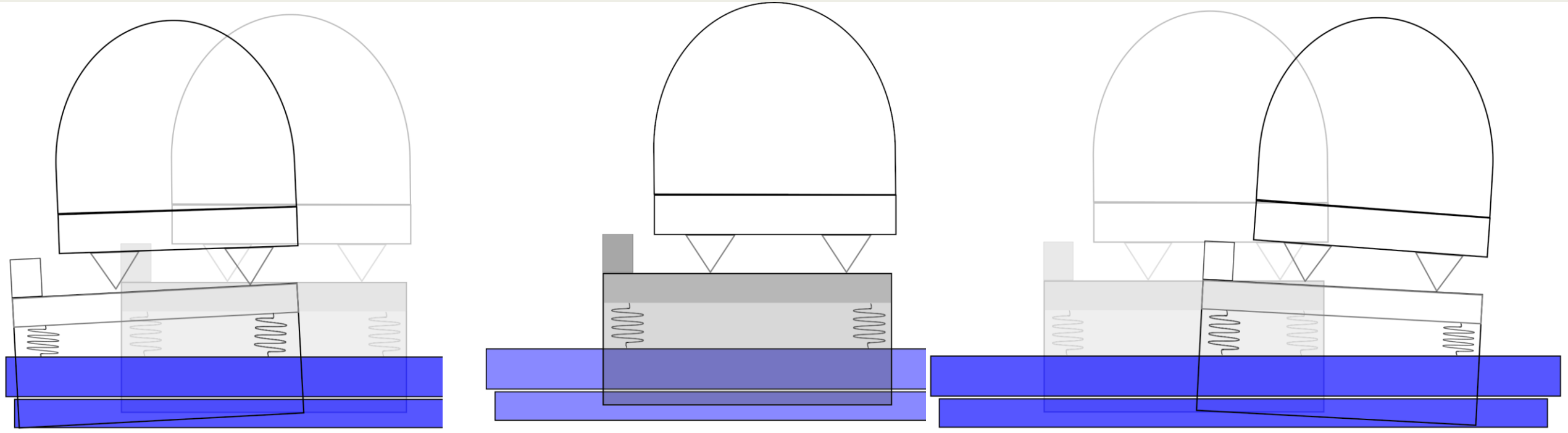
What happens here ?

Air bearing tilt (inertia driven)



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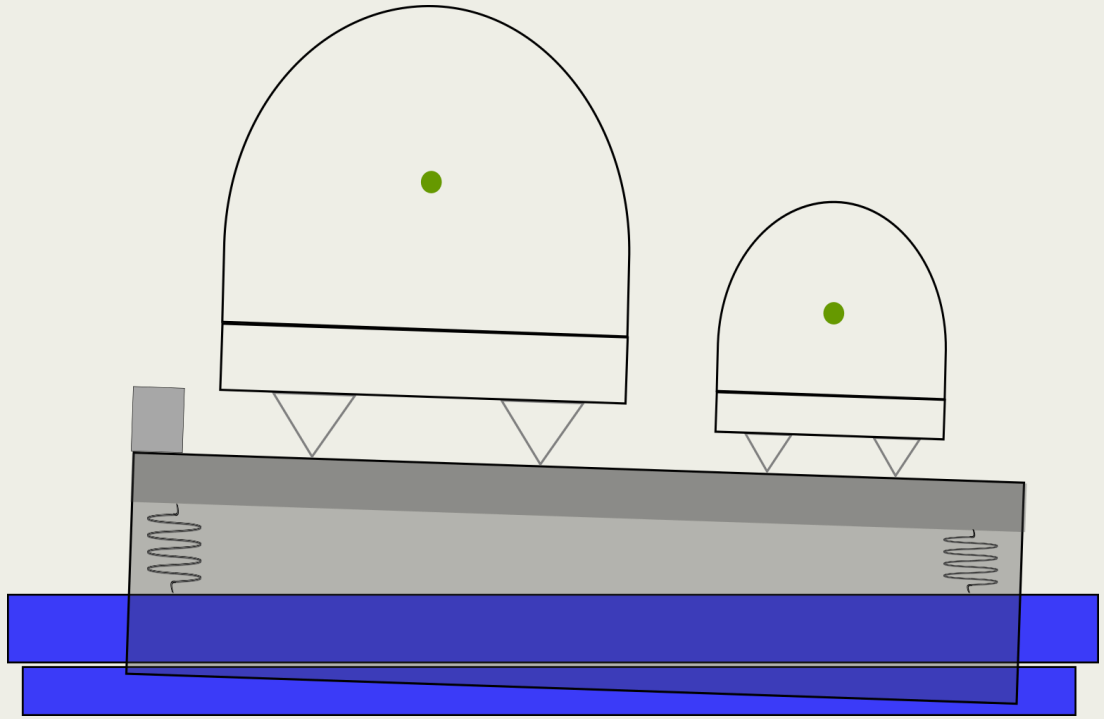
What happens here ?



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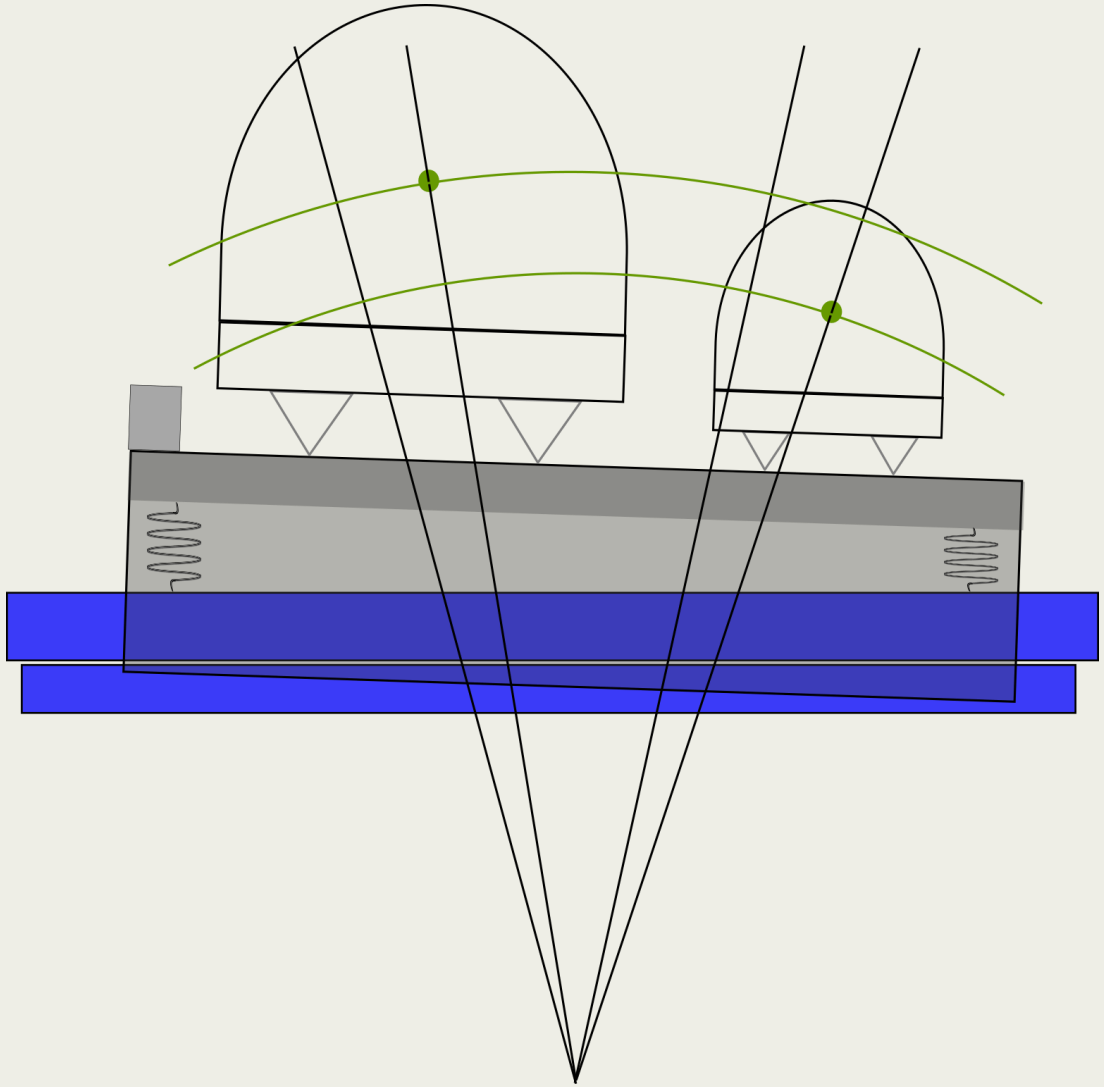
What happens here ?



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Comparison calibration complex approach

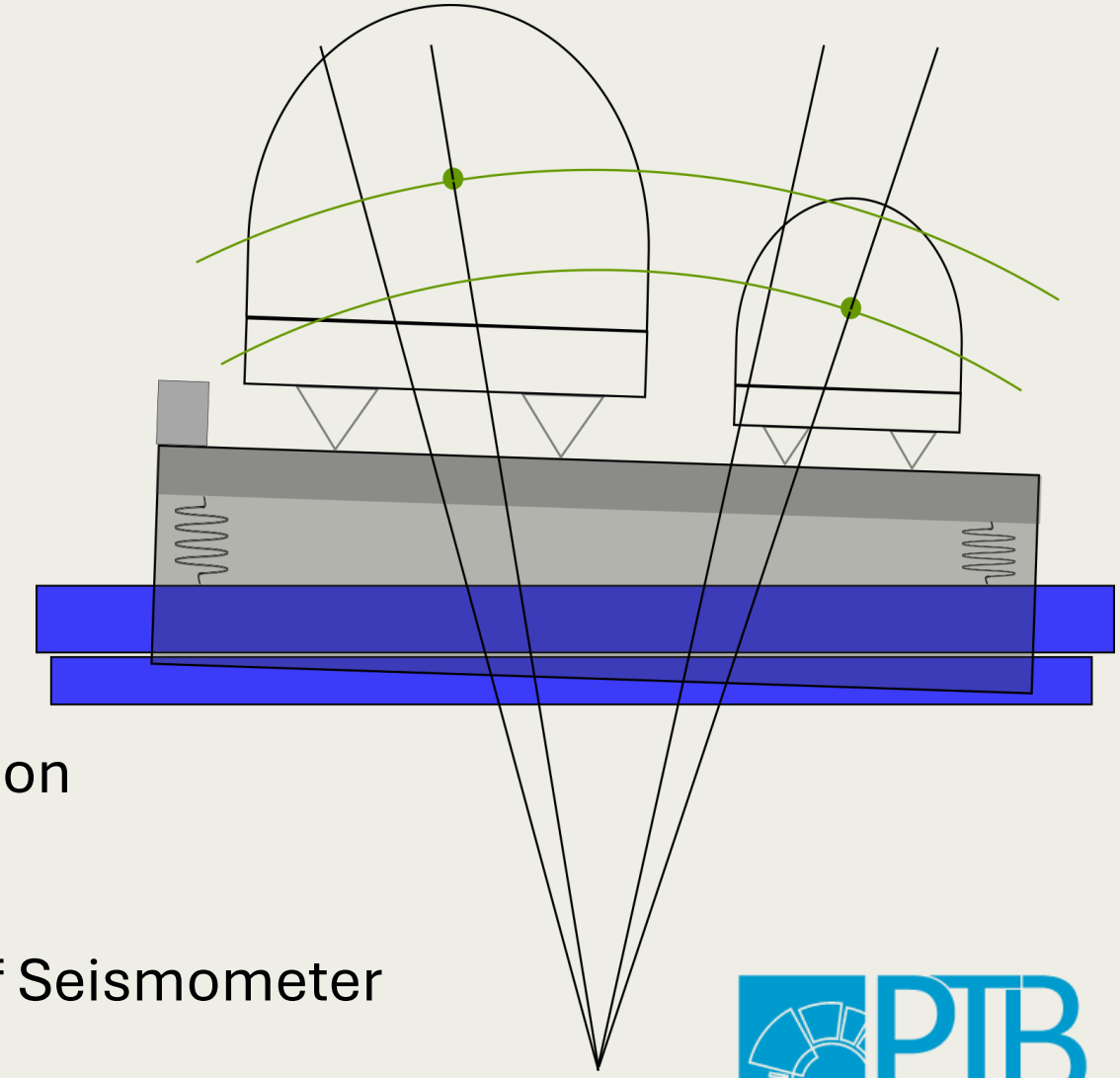
$$S_{\mathrm{DUT}} = S_{\mathrm{Ref}} \cdot \frac{\hat{U}_{\mathrm{DUT}}}{\hat{U}_{\mathrm{Ref}}} \cdot \frac{1+\omega^2 k\, h_{\mathrm{Ref}}}{1+\omega^2 k\, h_{\mathrm{DUT}}}$$

with *k* as the „Tilt-Stiffness“

$$\alpha = k \cdot a_{\mathrm{Grd}}$$

Tilt angle

ground acceleration



h_{Ref} , h_{DUT} height of the sensitive center of Seismometer

SI-traceable laboratory calibration of seismometers with or without a Laser

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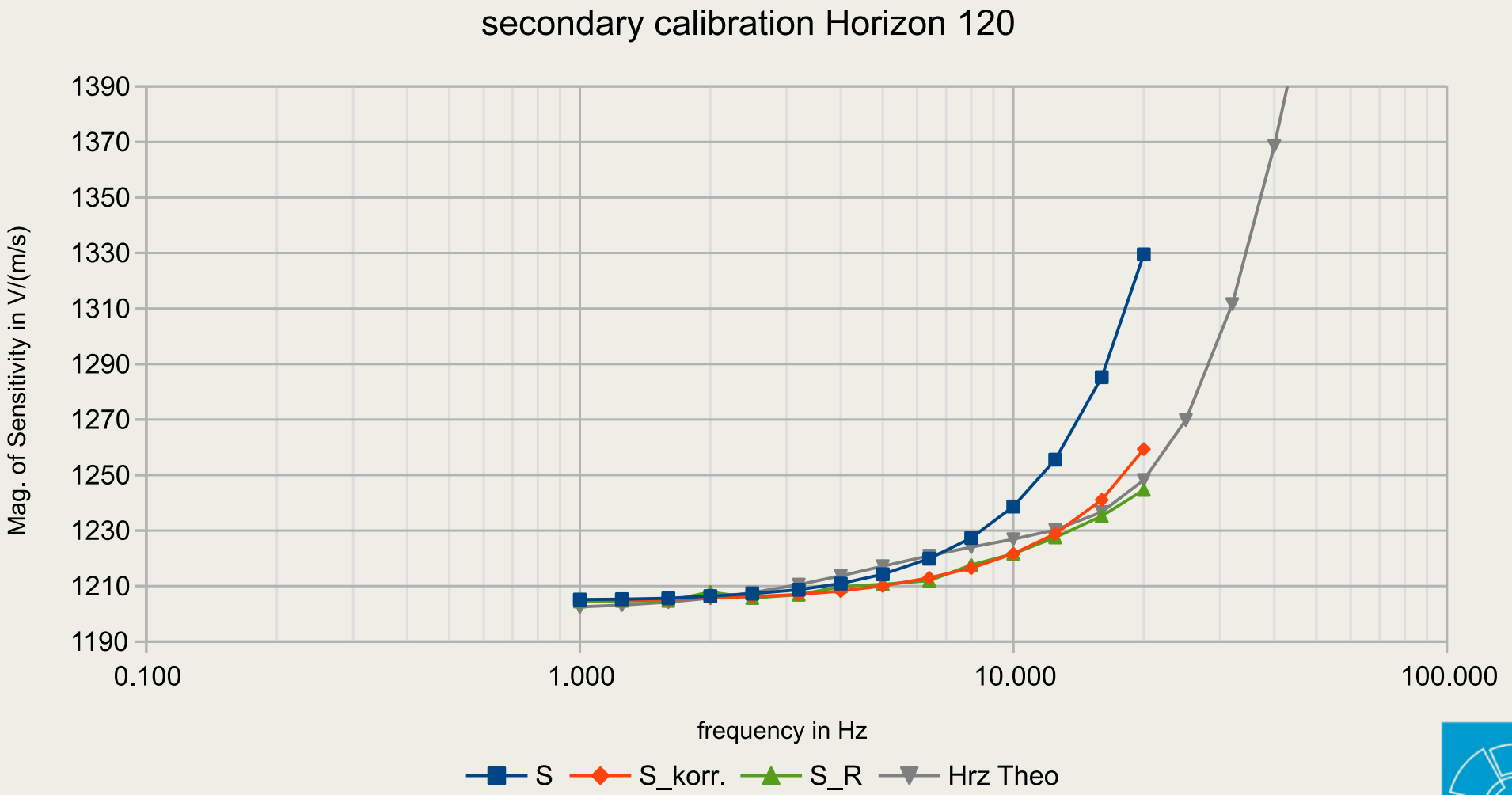
Does this help …



SI-traceable laboratory calibration of seismometers with or without a Laser

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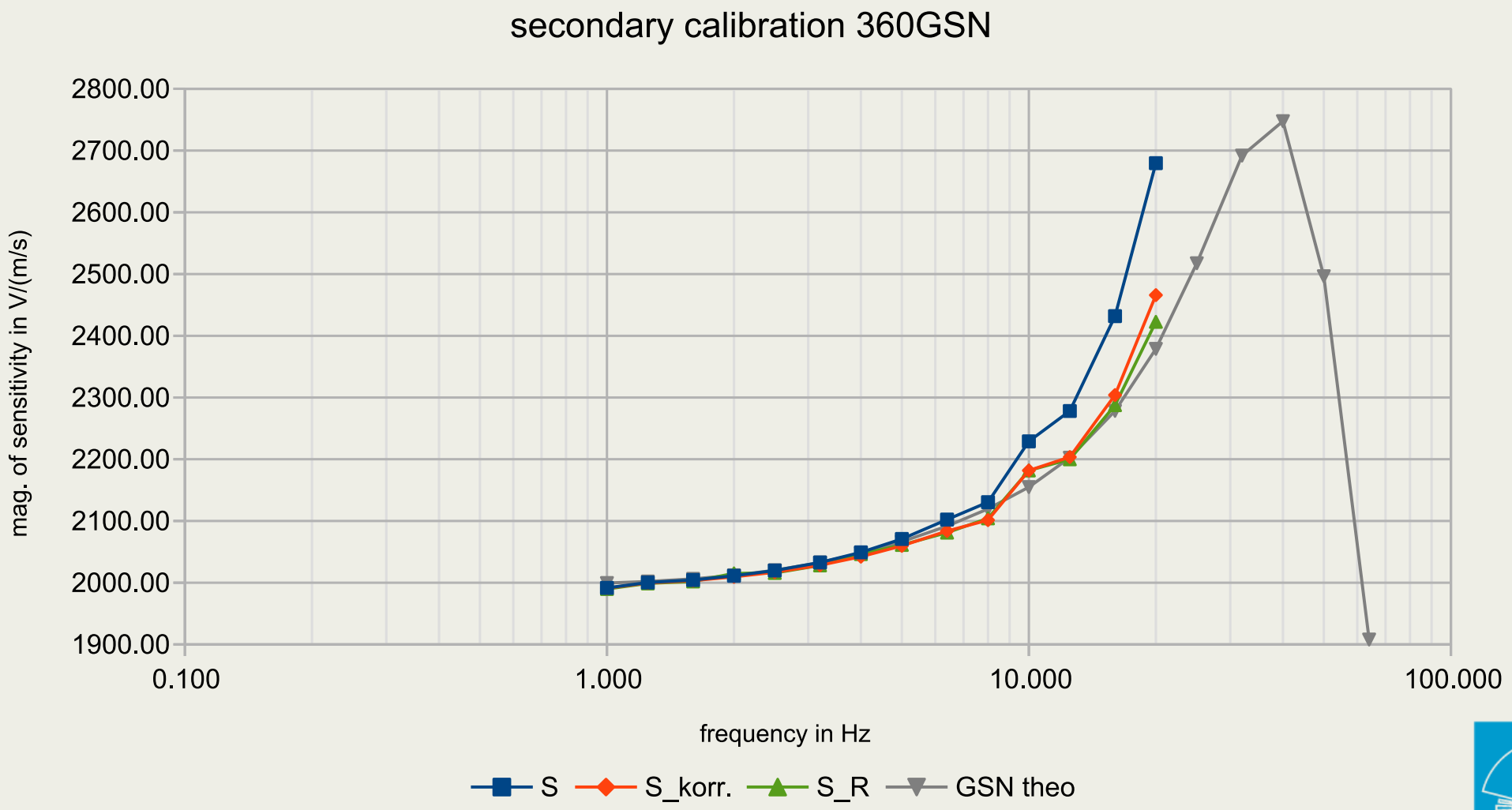
Does this help …



SI-traceable laboratory calibration of seismometers with or without a Laser

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Summary

- **Primary calibration** with Laser-Doppler-interferometry works well from 0.1 Hz to 20 Hz (or more) if
  - the sensitive center location is known
  - dynamic tilt components are taken into account

- **Primary calibration** using tilt in the gravitational field works well from 1 mHz to 2 Hz if
  - the sensitive center location is known
  - or two measurements at different heights deliver the s.c.l, additionally

- **Secondary calibration** using a reference seismometer works from 10 mHz to 20 Hz if
  - the sensitive center location is known
  - dynamic tilt components are taken into account
  - a traceable calibrated reference seismometer is available (with suitable frequency range)

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