Hydrostatic Levelling Systems (HLS) on ILC

- general aspects and possible realization -

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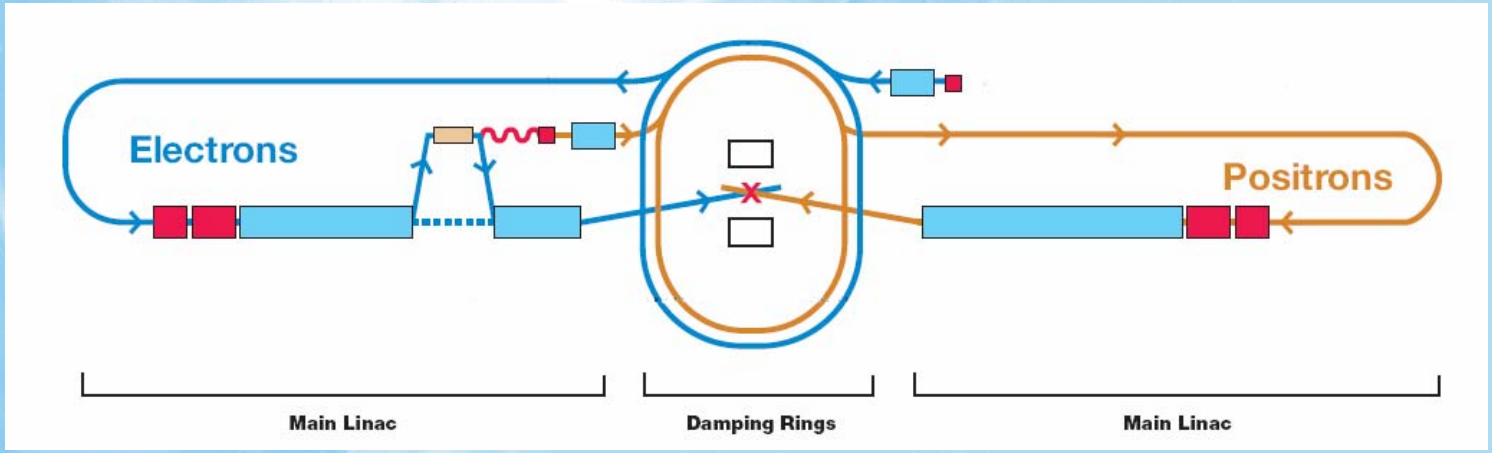
International Linear Collider ILC

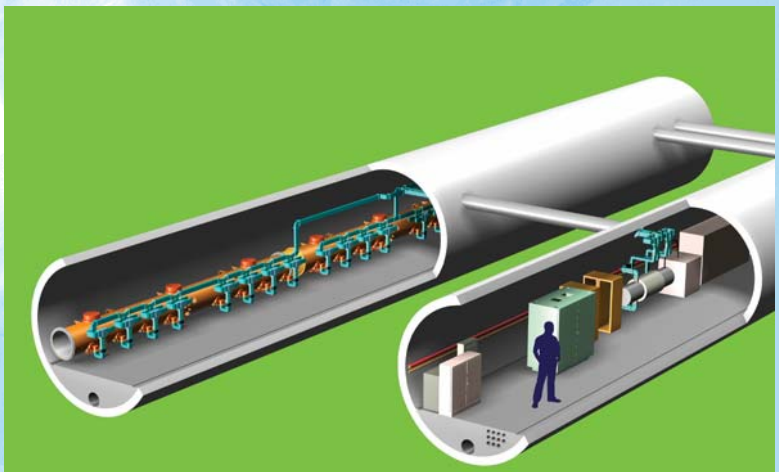
- International Linear Collider (ILC) […], a future $6.7 billion particle accelerator designed to recreate the conditions of the early universe. (New Scientist)
- colliding electrons (e^-) and positrons (e^+)
- approx. 30km in length, Interaction Point (IP) is in the middle



HLS on ILC

general idea of ILC tunnel layout

- tunnel laser straight or **following the curvature of the earth**
- ILC alignment could benefit from HLS, particularly (but not exclusively) if tunnel is following the curvature of the earth



www.linearcollider.org

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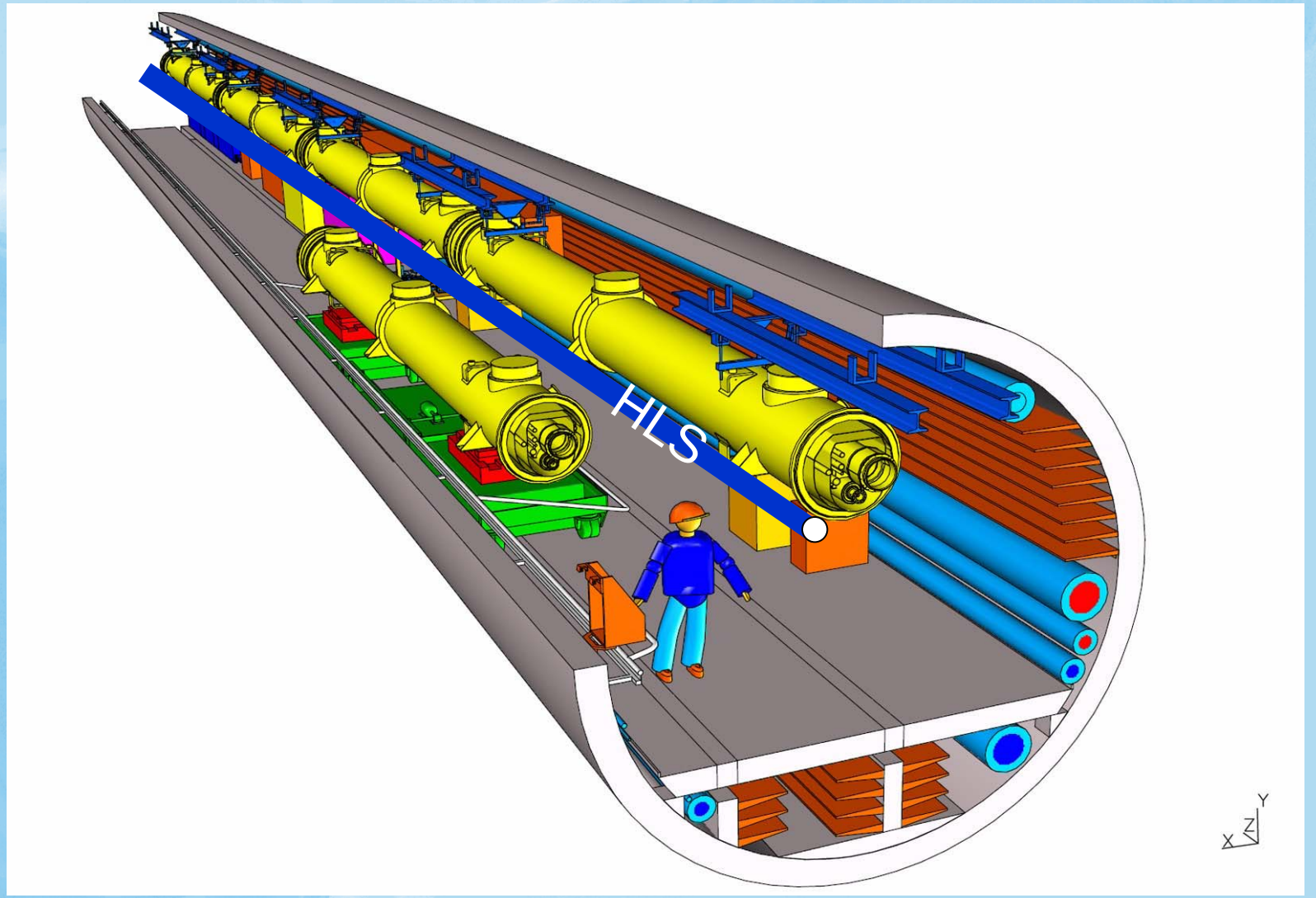
XFEL Layout (ML) with HLS



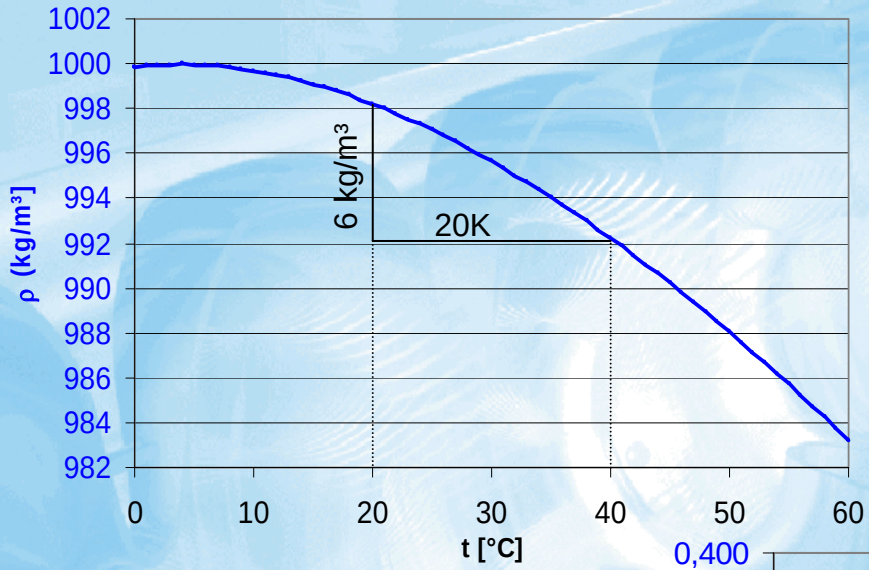
What is a HLS?

Wikipedia says:

- Havard Law School
- Homeland Security
- Historisches Lexikon der Schweiz
  (Encyclopedia on the history of Switzerland)
- hLs, an abbreviation for Hectolitres

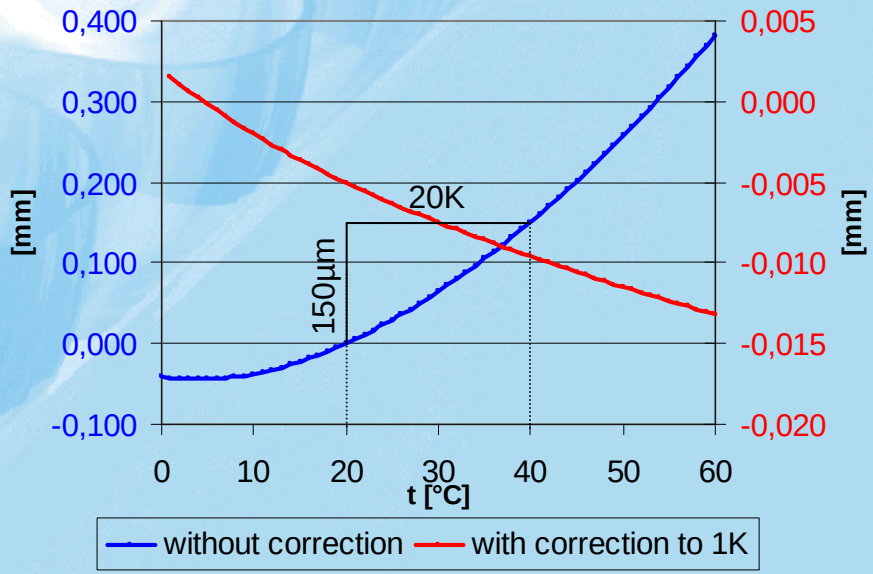
… but NO entry on Hydrostatic Levelling System

temperature effects

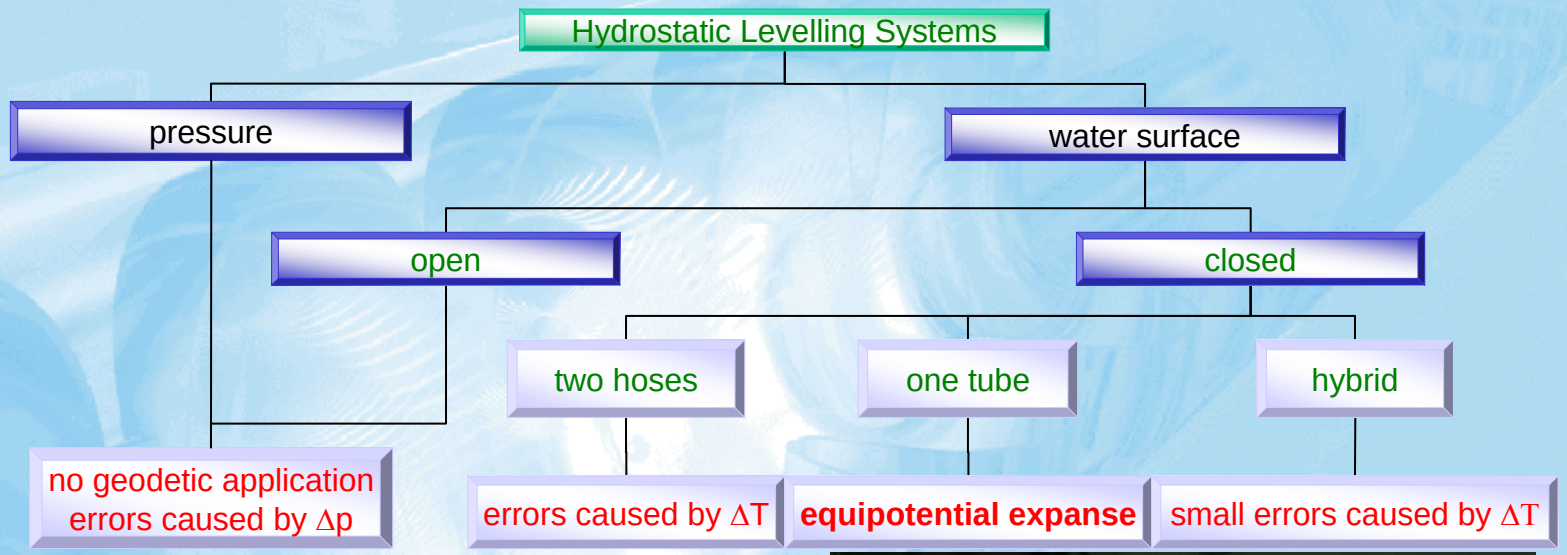


density of water vs. temperature

height change of a 25mm water calumn vs. temperature



Hydrostatic Levelling Systems



height change and water level change

With two-hoses HLS, the water level change in one measurement pot is

$$dW = \left(\frac{1}{i} - 1\right) dh$$

with

i : number of measurement pots

dh : true height change

dW : height change of water level

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height change and water level change

With single tube HLS the water level change in one measurement pot is

$$dW = \left(\frac{l}{l_{ges}} - 1 \right) dh$$

with

l	:	effective length of tube affected by height change
l_{ges}	:	total length of tube in system
dh	:	true height change
dW	:	change of water level

(strictly speaking only for rectangular tube)

geoid vs. ellipsoid

- one must always bear in mind that HLS represent the PHYSICAL geoid, but accelerator should follow a GEOMETRIC line, e.g. straight line on an ellipsoid.
- additional high resolution geoid information may be needed if HLS is used for alignment (and not just for monitoring vertical movements)
- for example in the mediterranean region (Cyprus) the gradient of the geoid undulation can be up to $d_N = 45\mu m/km$

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Geoid model by GfZ Potsdam

advantages of HLS in accelerators

- HLS is a permanent measuring system which requires only little maintenance.
- High accuracy (1µm or even better) is possible
- Could be operated during accelerator runs
- Electronics can be easily separated from sensor, that makes shielding easy
- Could be used to monitor height movement of all (or only critical) components.
- automatic feedback system is possible
- accuracy is NOT influenced by geometric distance (if certain requirements are met – closed system, free surface, etc.)

disadvantages of HLS in accelerators

can't think of any …

but wait …

ok, if i try really hard …

- allocates permanent space in tunnel
- costs money (not much, though)
- HLS detects only vertical movements – which is the main direction of movement for accelerator tunnels
- slow

DESY-HLS

temperature differences at different locations

-> use a half filled pipe system

drifts in electronics results in biased results

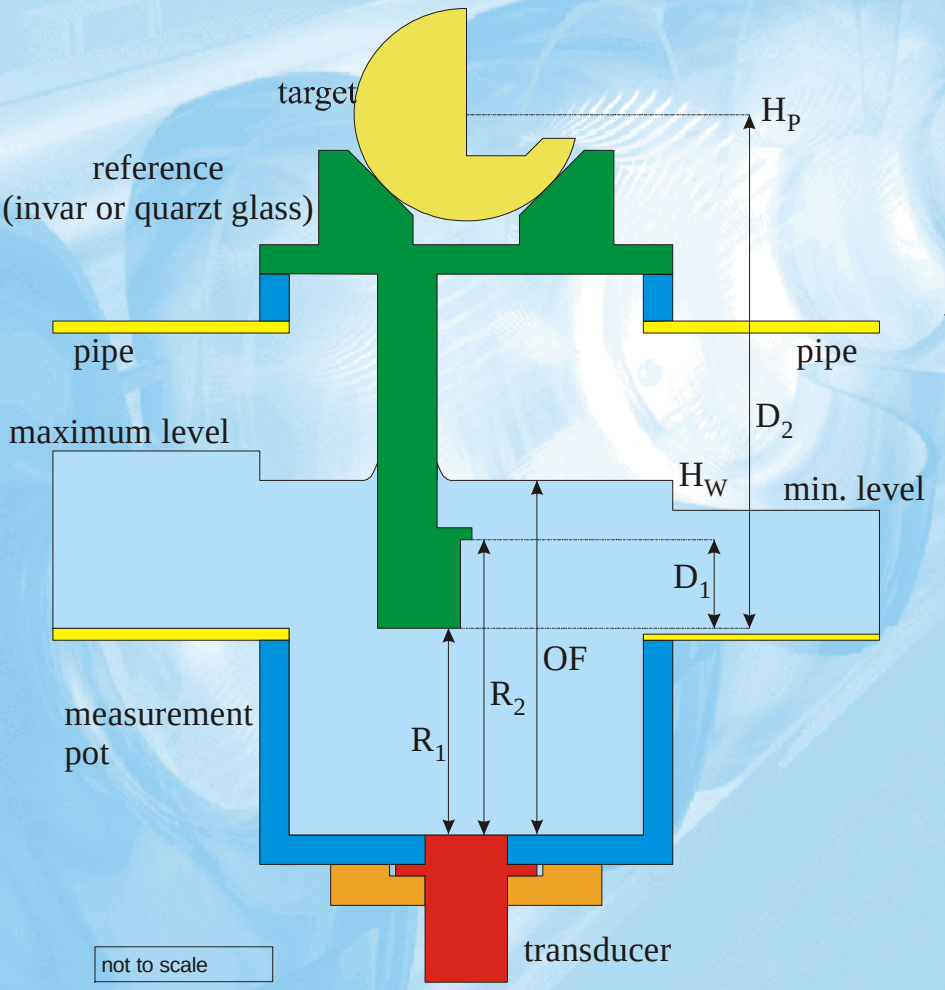
-> build a system which is drift-free

exchange of sensors is challenging

-> build a system with easy recalibration

DESY HLS

measurement pot with in-situ calibration



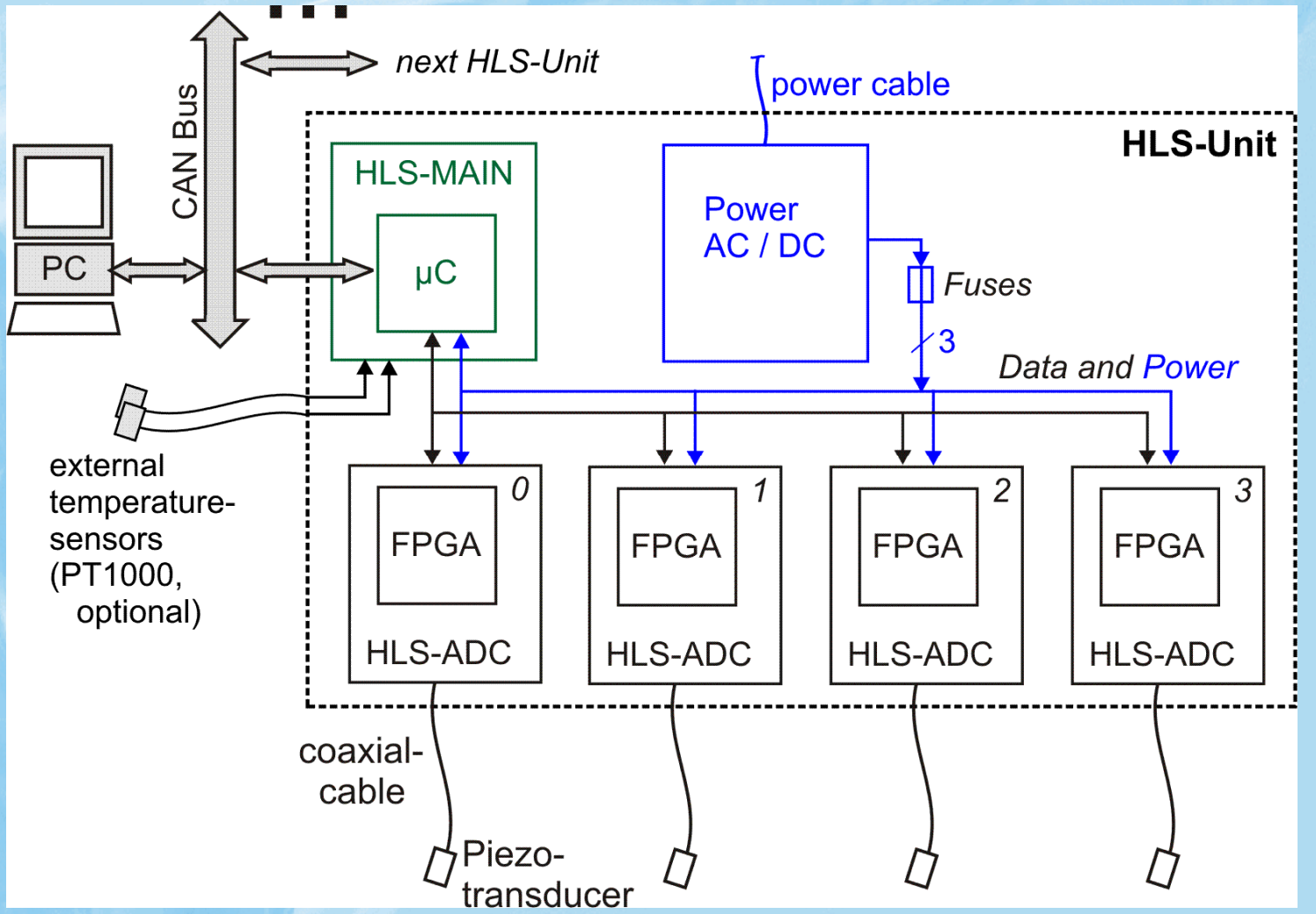
$$H_P = H_W + D_2 - D_1 \frac{OF - R_1}{R_2 - R_1}$$

- **position of transducer drops out**
- **scale drops out**

DESY HLS

- Because of the nonsatisfying Krautkrämer (GE) equipment which is build for non-destructive material testing, we decided to develop our own electronics
- Development time was from 2006 - 2007
- First charge of PETRA III electronics has been built, with approx. 150 measurement pots.

DESY HLS - Electronics Structure

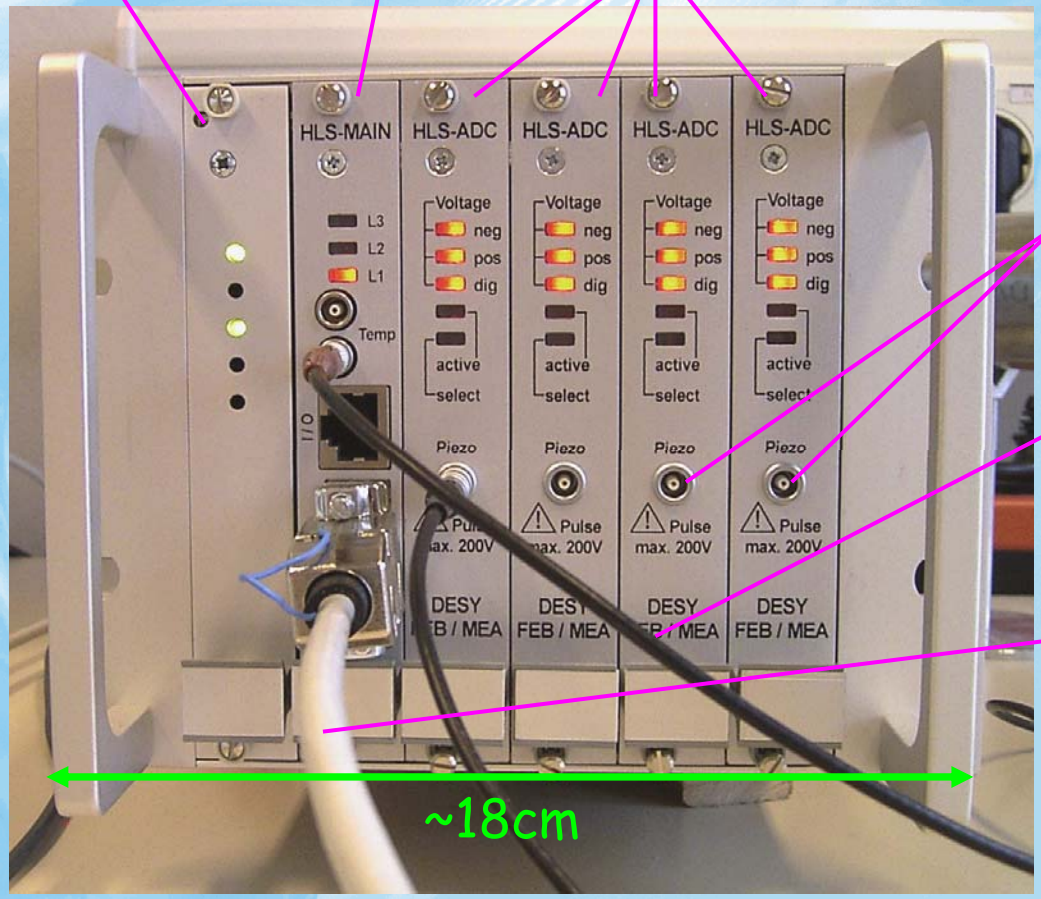


DESY HLS - New Electronics

Power (AC/DC)

Control Unit (HLS-MAIN)

Up to four metering points per unit (HLS-ADCs)



Operate Transducer (coaxial cable)

Temperature Sensors (PT1000)

CAN Bus to PC (system master)

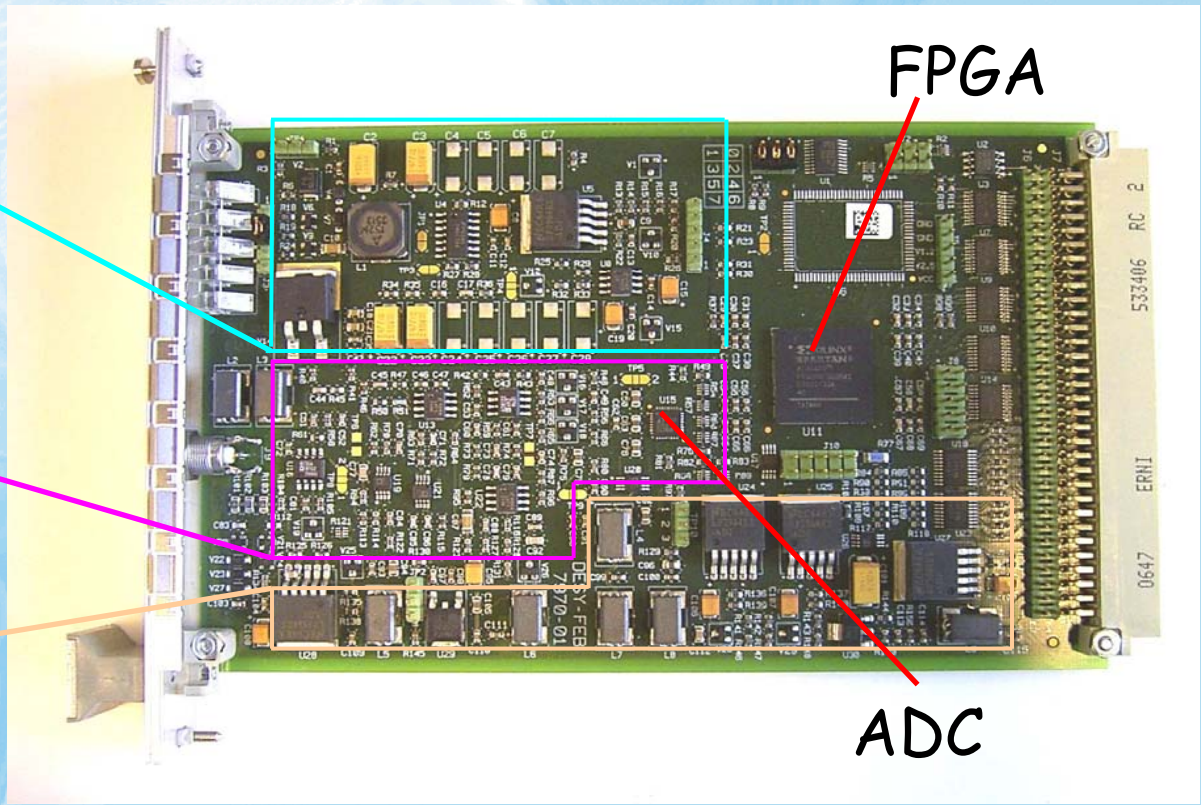
DESY HLS - New Electronics

Features:

- Up to 4 measuring units (HLS-ADC) per control unit (HLS-MAIN) => cost effective
- Measures with up to 1Hz (depending on readout speed and number of units per CAN bus)
- Fully controlled via CAN Bus (Ethernet possible)
- Provides Raw Data on request
- Firmware upgrade (software algorithm) possible
- Two external temperature sensors
- Compact housing: width-optimized EURO frame
- CE (safety, EMC) certified
- low power: ~30W/crate (~8W/channel)

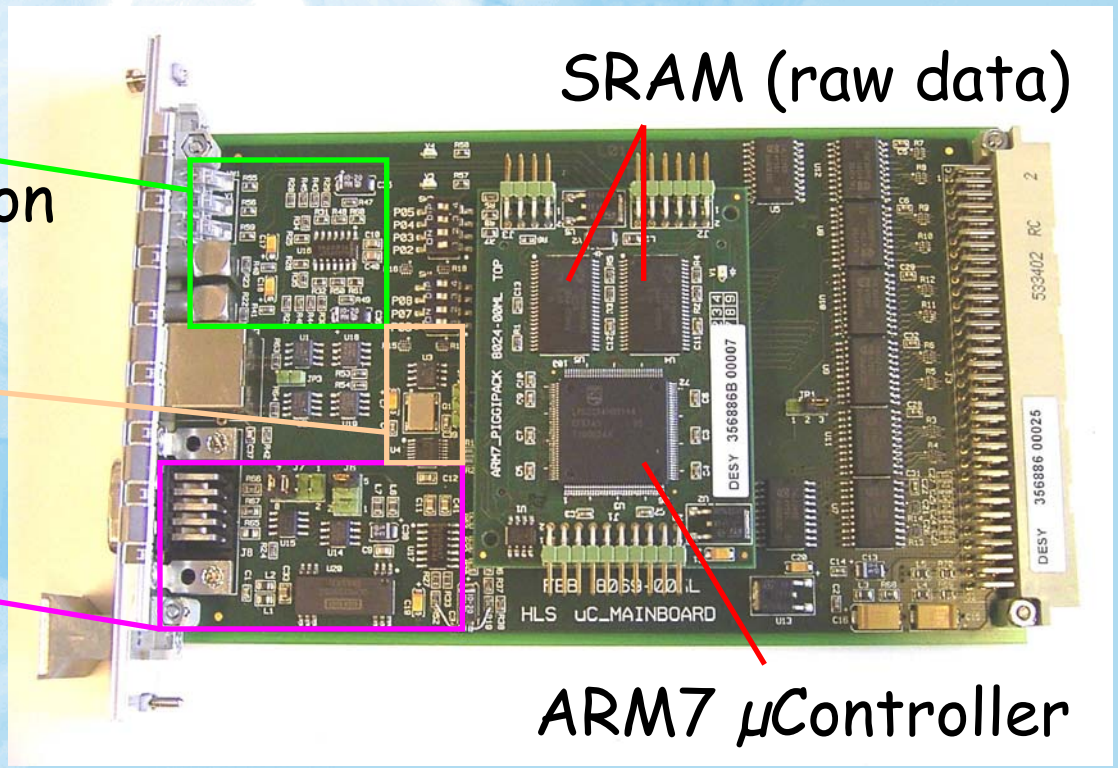
HLS-ADC: Metering Unit

- Pulse Generation (Piezo): 120V, 30ns, adjustable
- Receiver: 4th order Bessel filter, amplifier
- ADC: 12bit, 100MSamples/s
- FPGA for fast data handling



HLS-Main: Control Unit

- Communication with system's master (CAN bus)
- Readout of raw data from the four HLS-ADCs
- Calculation of the transit times R1, R2 and OF
- Operation of the temperature sensors



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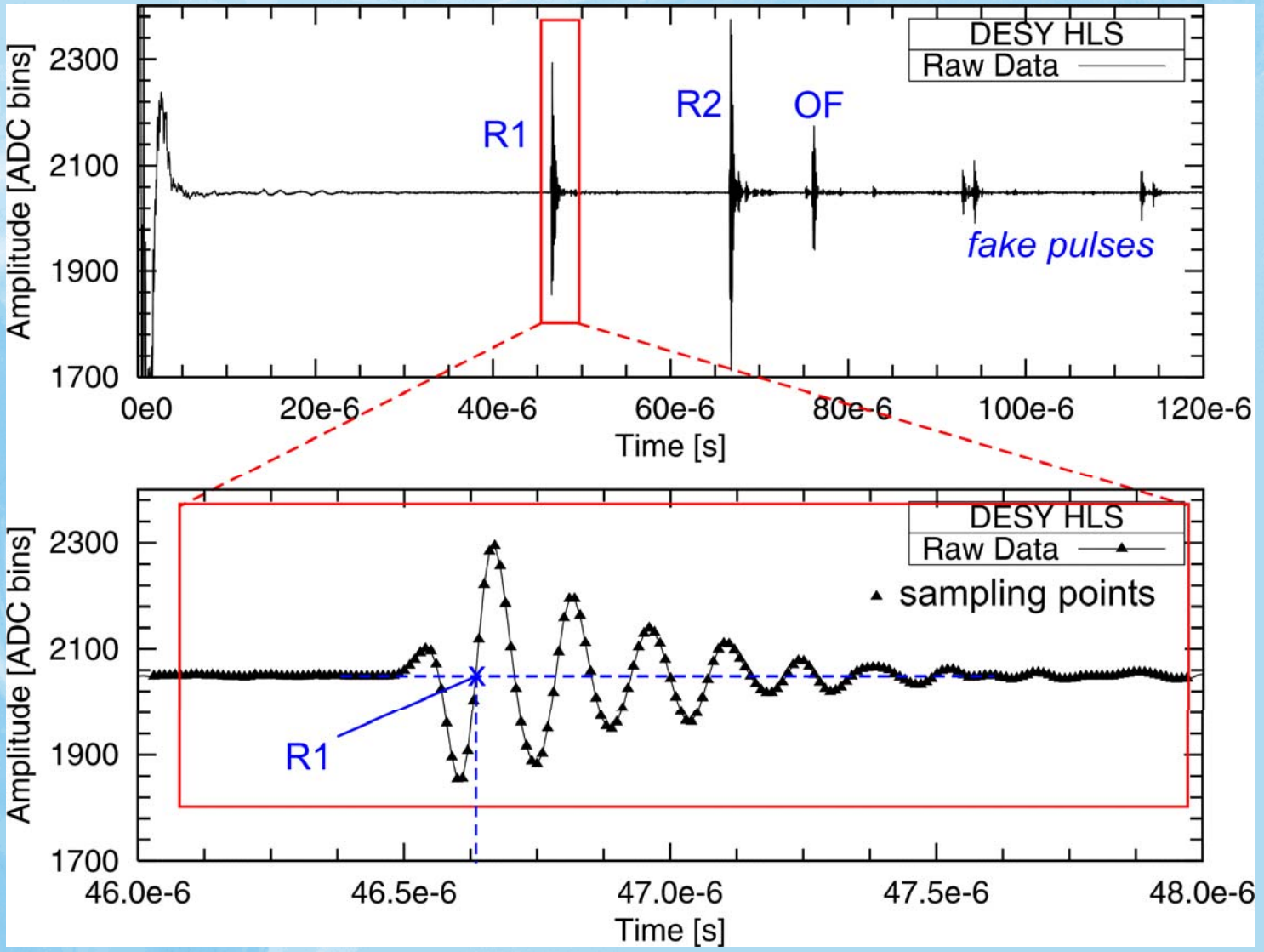
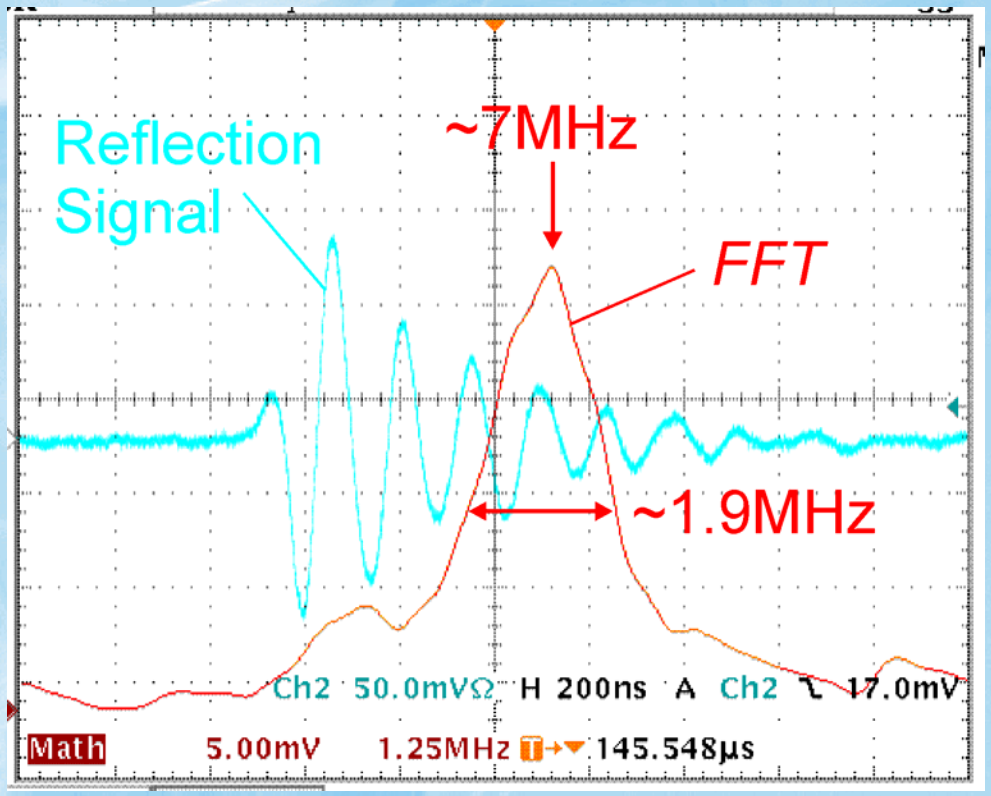
DESY HLS - Raw Data



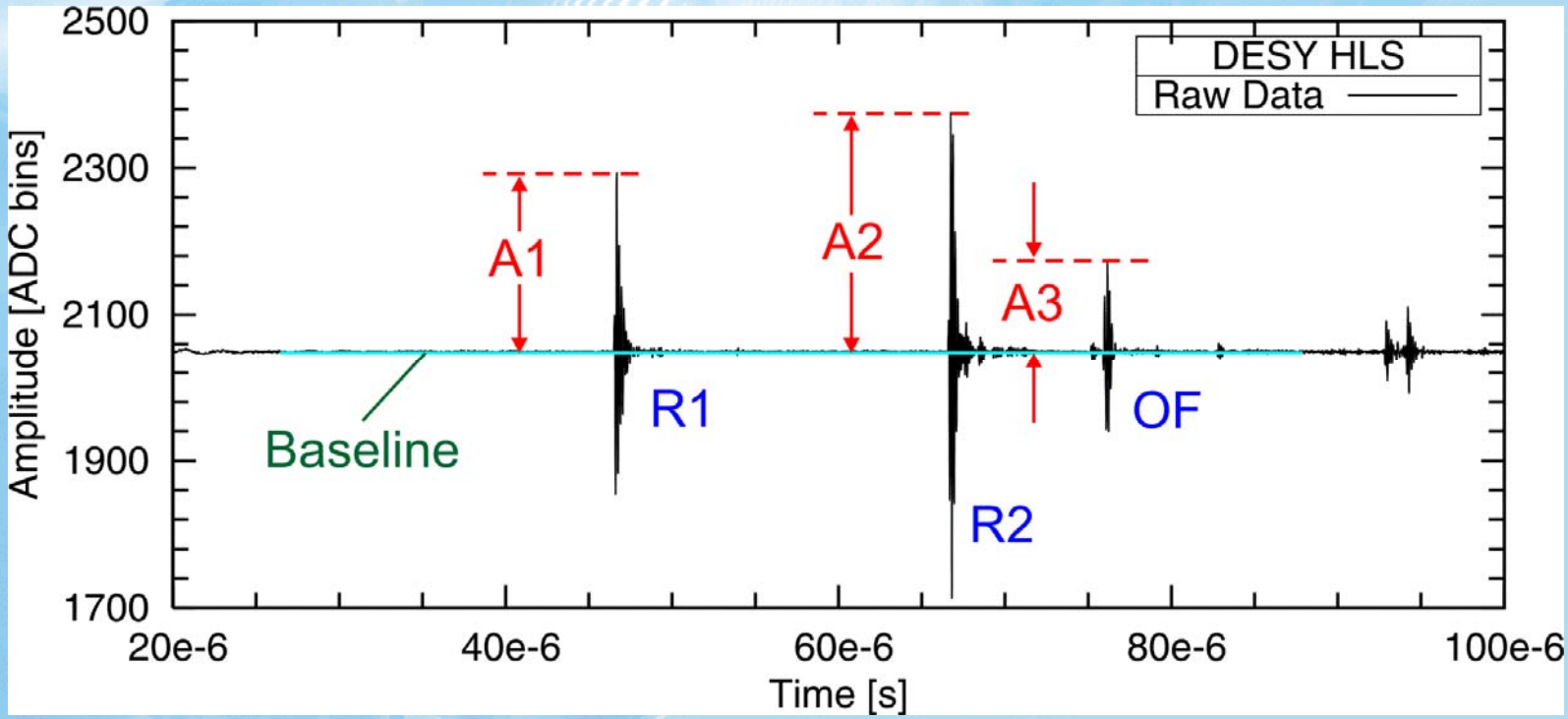
DESY HLS - Transducer



Measured frequency spectrum (red) of a reflection signal (light blue)

DESY HLS - Software Algorithm I

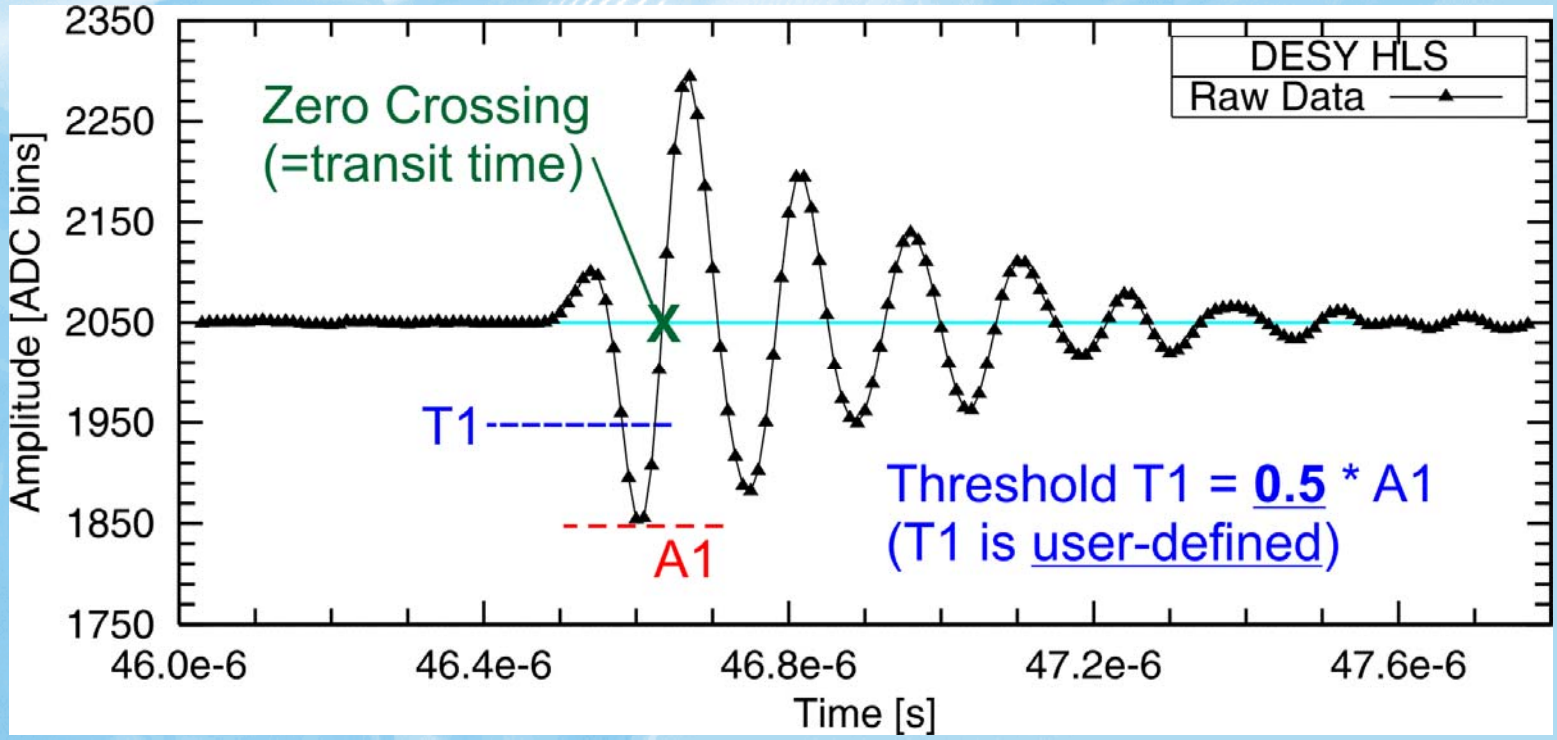
Step 1: Calculate the baseline and **for each** reflection_signal the amplitudes A1, A2 and A3.



=> Signal (amplitude) fading is compensated.

DESY HLS - Software Algorithm II

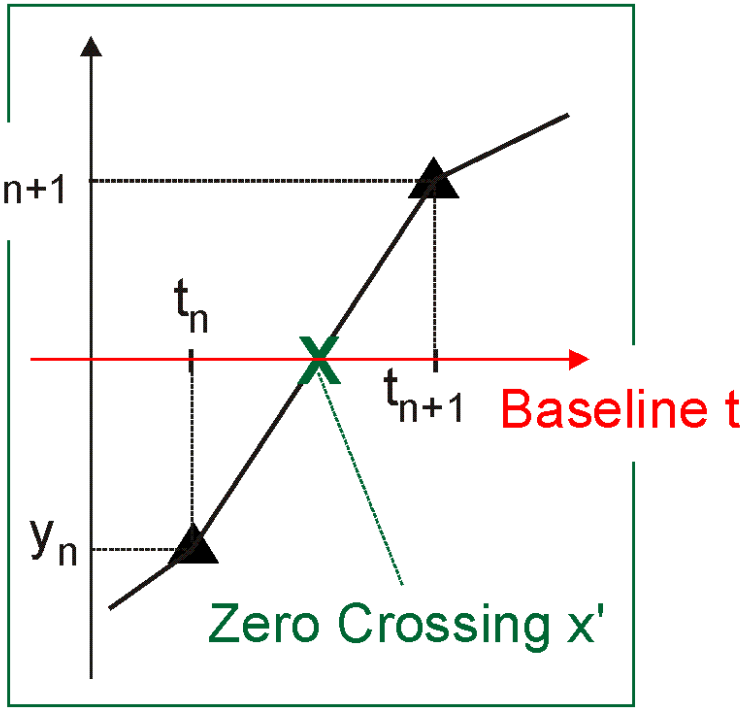
Step 2: Read user setting for **threshold** and analyze the following **zero crossing** in the raw data.



The **threshold** defines which **zero crossing** in the reflection signal is **THE** transit time (R1, R2 or OF)

DESY HLS - Software Algorithm III

Step 3: Optimize the result by interpolating between the sampling points before and after the actual zero Crossing.



▲ ADC sampling point

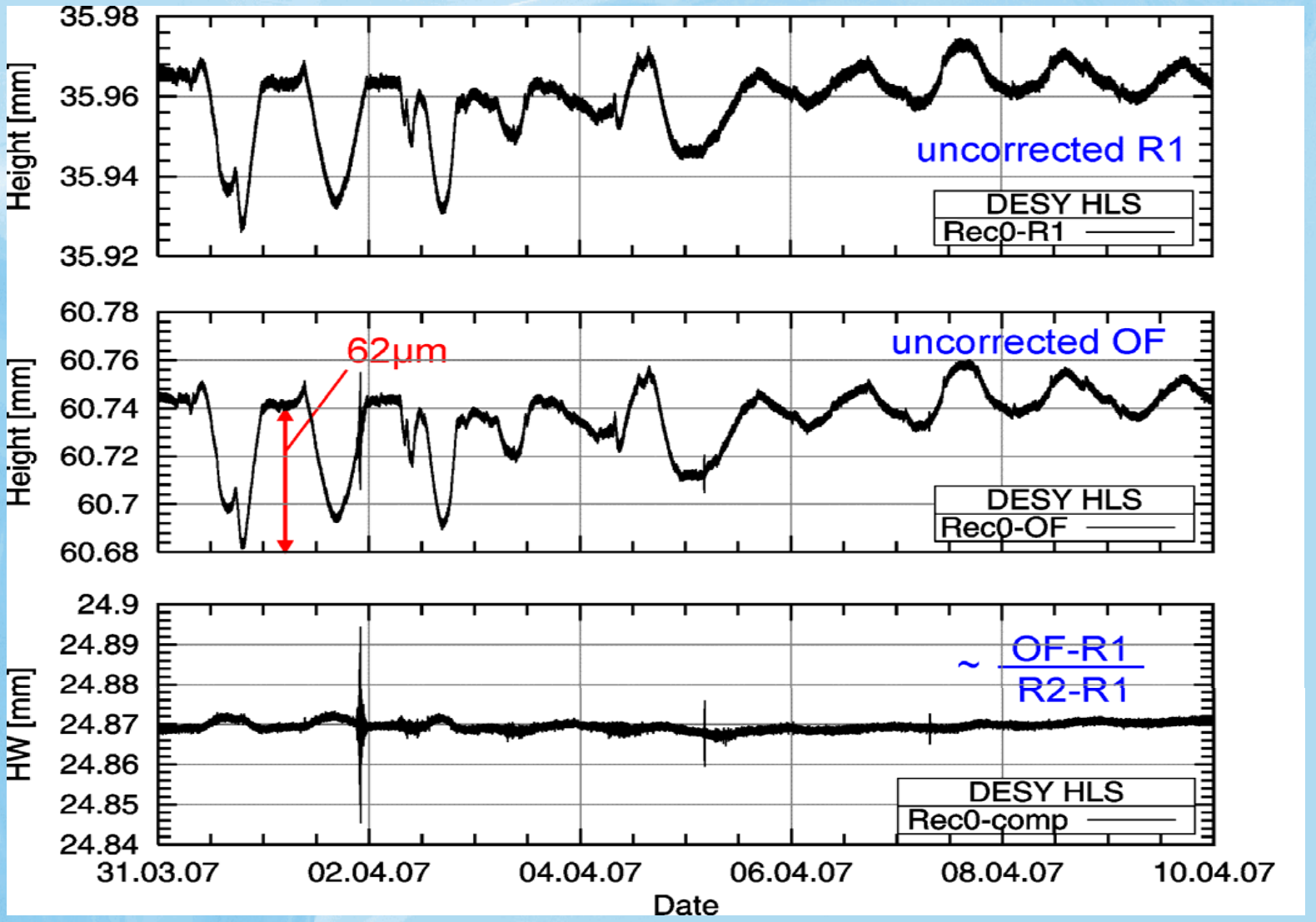
$t_{n+1} - t_n = 10ns$ (=clock)

$s = \frac{y_{n+1} - y_n}{10ns}$ (slope)

$0 = y_n + s\,(t - t_n)$

$\Rightarrow \boxed{t' = t_n - y_n/s}$

Temperature Compensation



DESY HLS - Costs

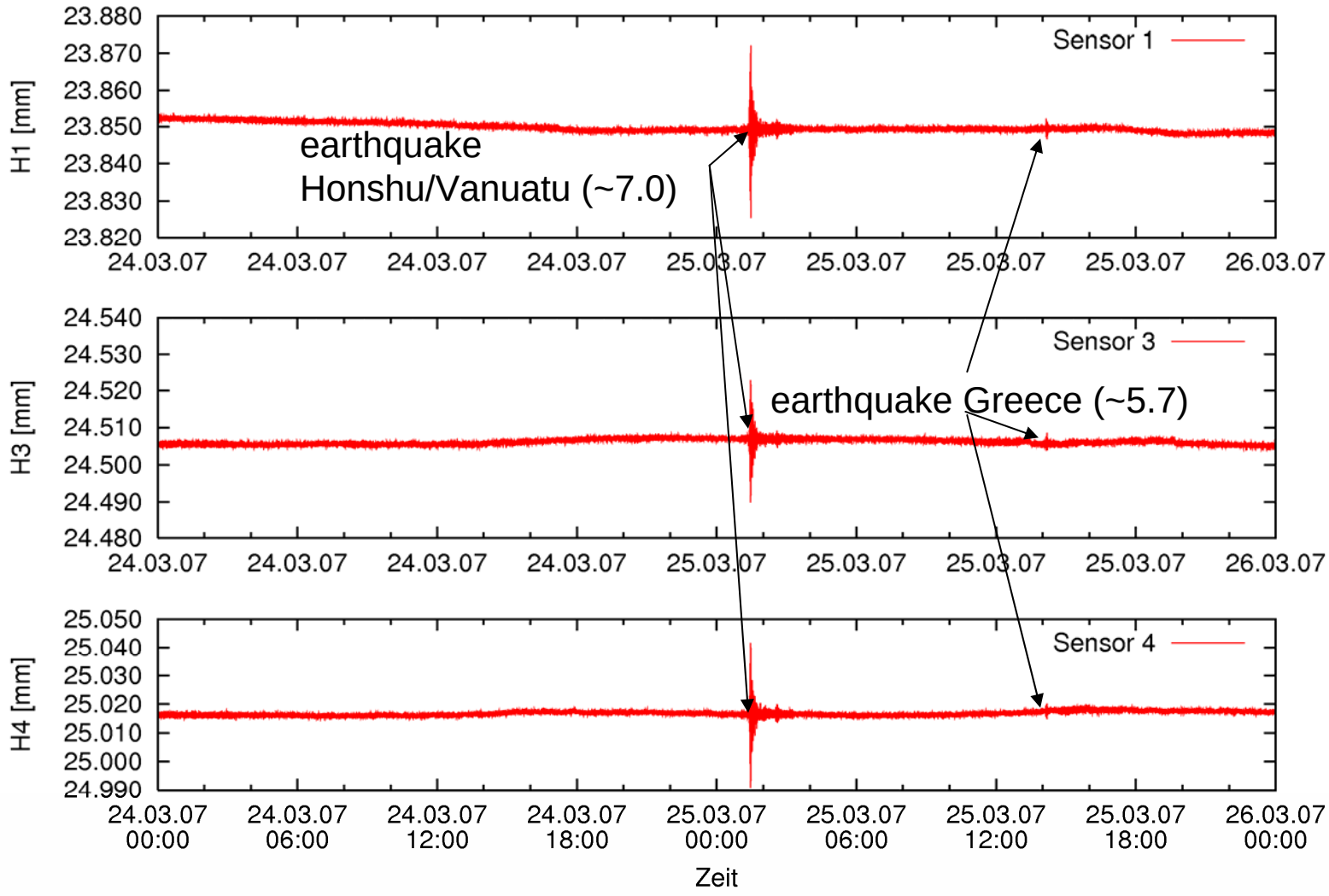
Approx. component costs, including PCBs:

1. HLS-MAIN (1 per unit): 170€
2. HLS-ADC (up to 4 per unit): 200€
3. Mechanics + AC/DC conv. (1 per unit): 340€
4. Piezo-Transducer (1 per HLS-ADC): 800€

Costs per channel without Piezo-Transducer:

700€ (1 channel in unit)
330€ (4 channels in unit)

eathquake monitoring



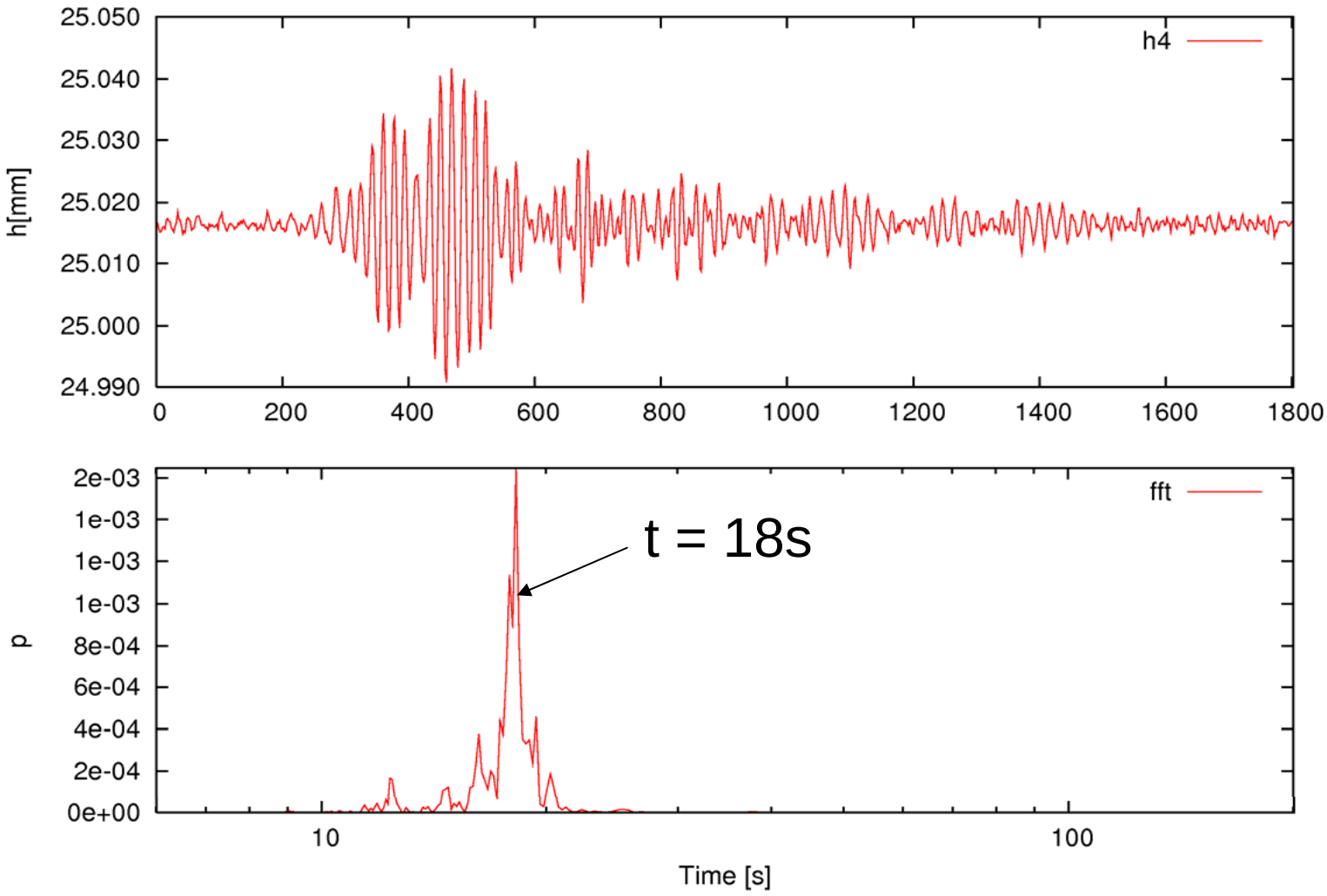
eathquake monitoring

- two earthquakes within a short time
  -> Honshu, Japan Mag 6,7 00:41:57
  -> Vanuatu Mag 7,2 00:40:03
  (Quelle: USGS)

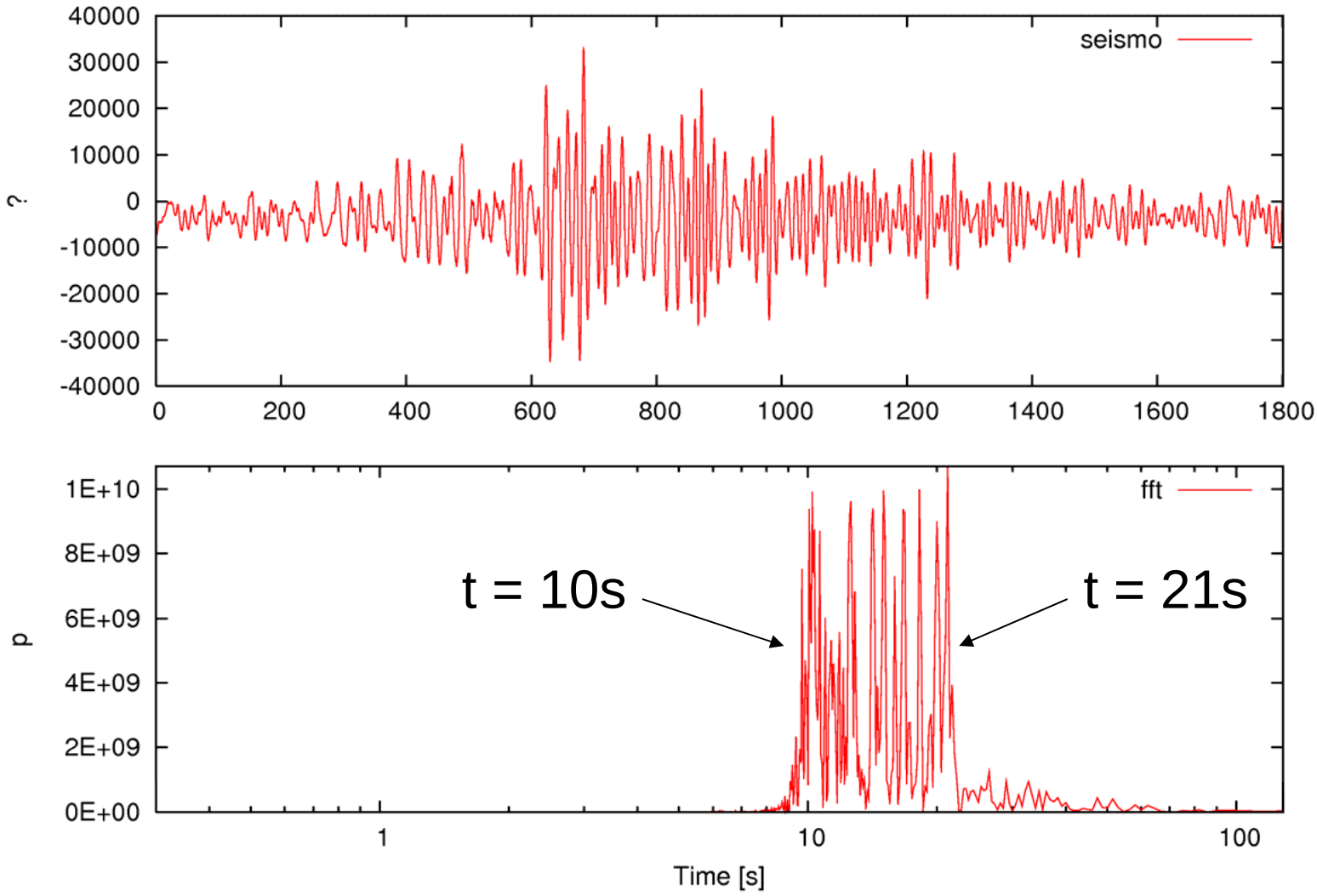
- one earthquake in Europe
  -> Greece Mag 4,5 13:58:00

- The earthquake in Greece is considerably smaller, but can be seen in Hamburg due to the much shorter distance

fft of HLS-Signal



fft of seismometer signal „bseg“



accuracy of HLS

σ_{US} : accuracy of ultrasonic measurement

σ_D : accuracy of calibration measurement

$$\sigma_{\Delta H}^{\ 2} = 2\sigma_M^{\ 2}$$

$\sigma_{\Delta H}$ = 1.2µm

$$\sigma_M^{\ 2} = 5\sigma_D^{\ 2} + 6\sigma_{US}^{\ 2}$$

σ_M = 0.86µm

σ_{US} = 0.3µm

σ_D = 0.2µm

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corrosion

problems with corrosion at two parts of the measurement system

1. Ultrasonic transducer
2. reference reflector

corrosion of transducer

no corrosion during lifetime of old systems (~5 years)

heavy corrosion with new systems (within 5 weeks)

corrosion of transducer

sensors after ~ 4 weeks in system

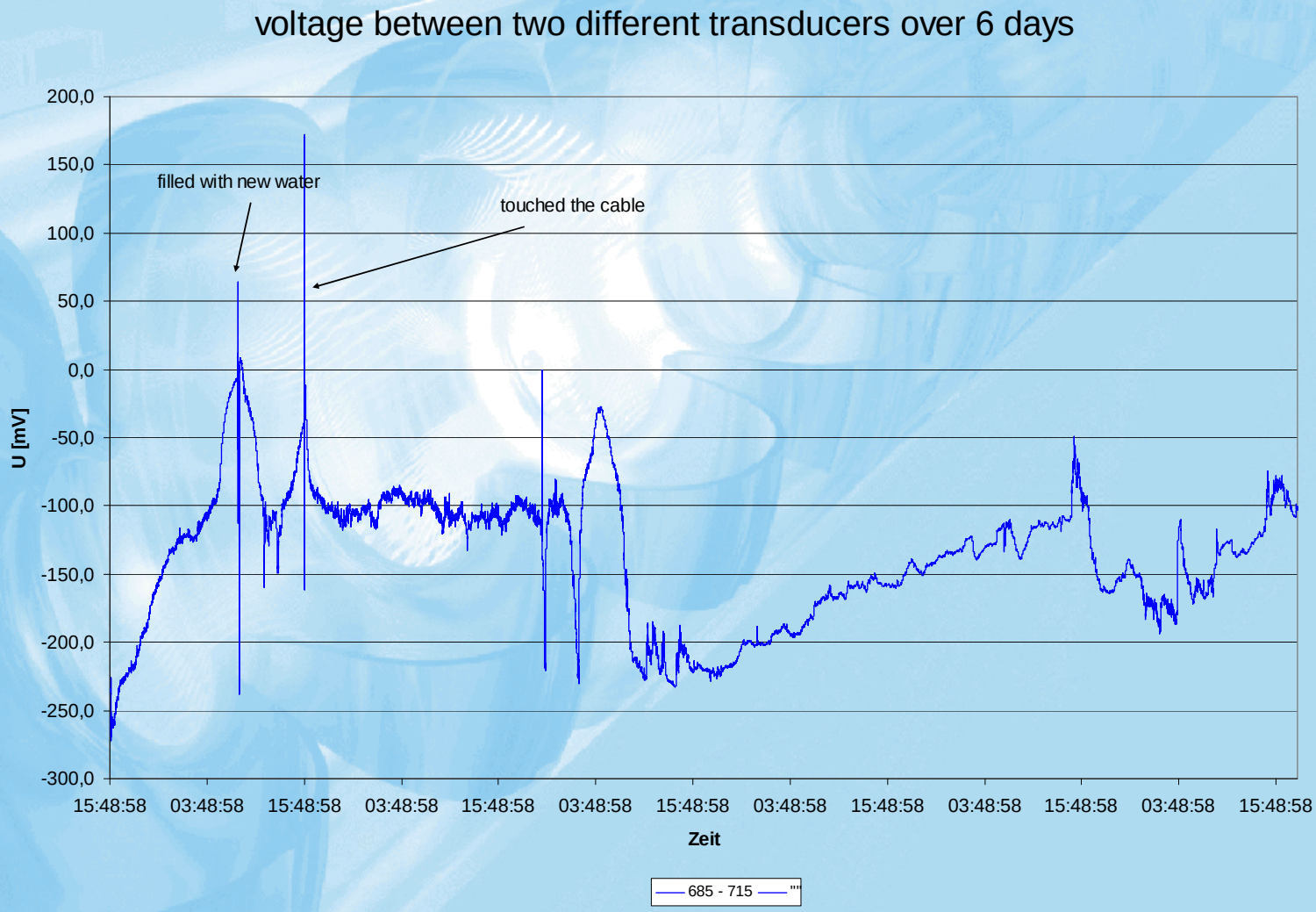
corrosion of transducer

various models for this ultra-fast corrosion

- chemical (influence of synchrotron radiation & o-ring
- electro-chemical
- cavitation

two different sensors in water give a voltage of up to 200mV

building a battery



reason & solution

- Krautkramer (GE) changed the solder to a non-lead one
- transducers were produced with different solders
- solder is replaced with an o-ring, lid is screwed
- prototypes ready, tests to come

corrosion of invar reference

- invar is rusting, so the invar references were coated with nickel
- ~ 1 of 10 references rusted anyway starting at the edges
- this could not be avoided by thicker coating

solution

make the reference from quartz glass

$\alpha = 0.5\ 10^{-6}$

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conclusion

- ILC alignment could benefit from HLS
- geoid undulations have to be measured for alignment
- HLS is cheap and provides high accuracy
- some problems with the mechanics of the DESY-HLS have been solved