Università degli Studi di Bari

DIPARTIMENTO INTERATENEO DI FISICA, 'MICHELANGELO MERLIN'

PhD course in Physics – XXXIV cycle

Study of the electro-thermal properties and acoustic coupling of quartz tuning forks

Tutors:
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Dott. Pietro Patimisco

PhD student:

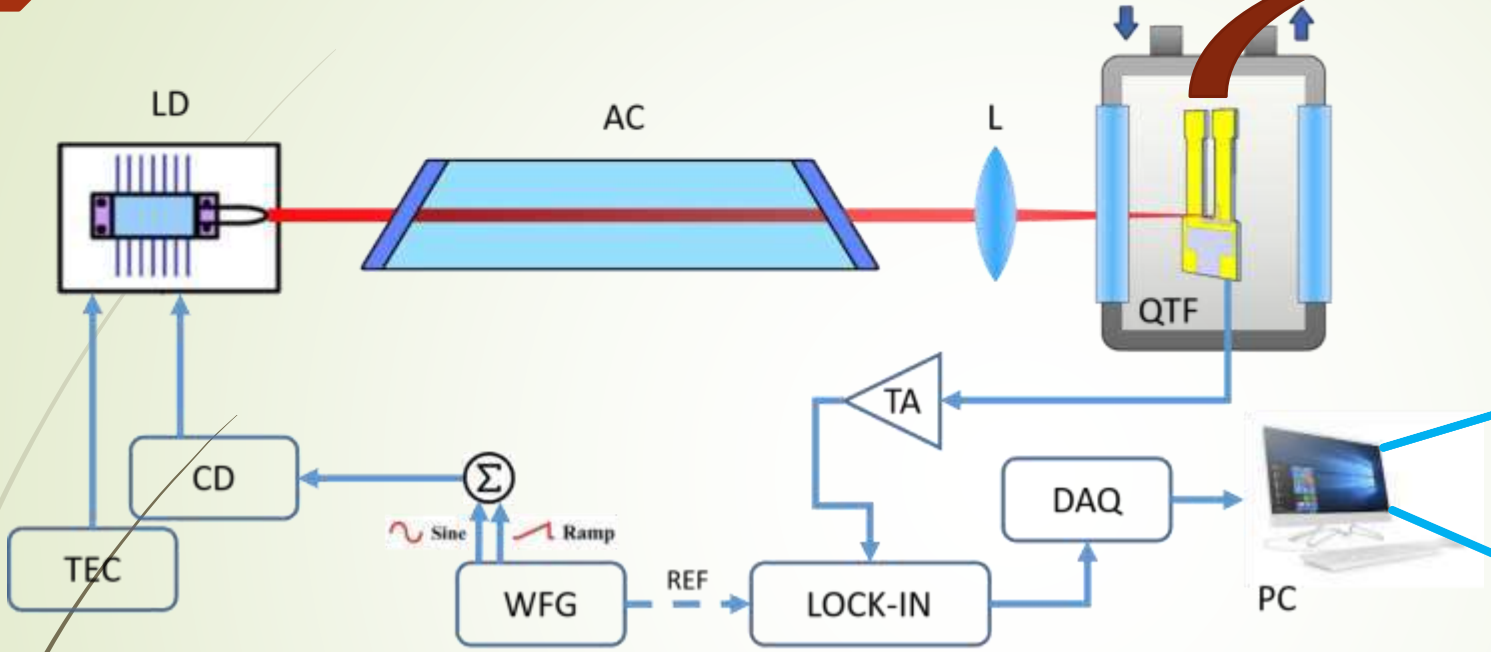
Stefano Dello Russo

Second year report

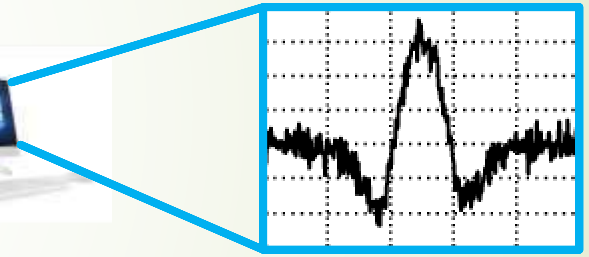
Outline

- **Light-induced thermo-elastic spectroscopy** (LITES)
- LITES **signal mapping** on QTF and maximization process
- **Comparison** between QTF and Near-IR photodetector
- **Low-pressure** and **Mid-IR** measurements
- **CH_4 – H_2O** QEPAS measurements near a **traffic light**

Light-induced thermo-elastic spectroscopy



QTF used as Photodetector



2f wavelength modulation spectroscopy

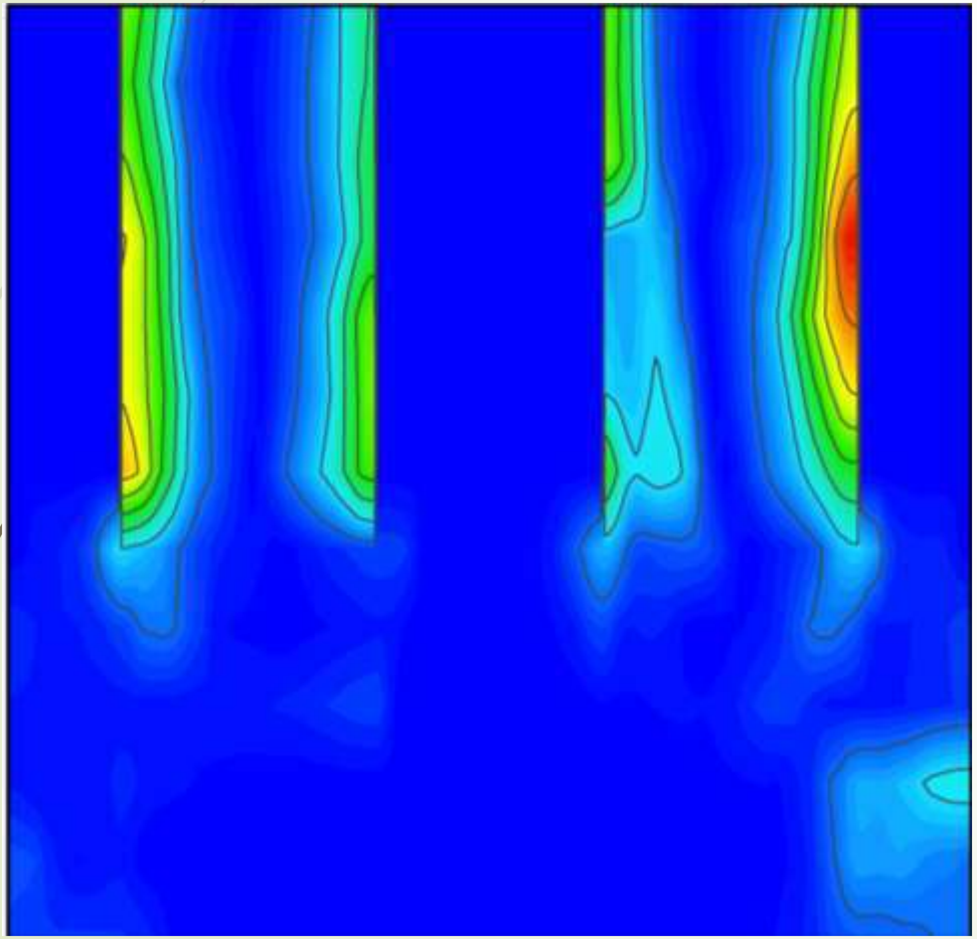
- Optical modulated LASER absorption
- Photothermal energy generation
- Thermo-elastic conversion
- Induced vibration
- Piezo-electric charge accumulation

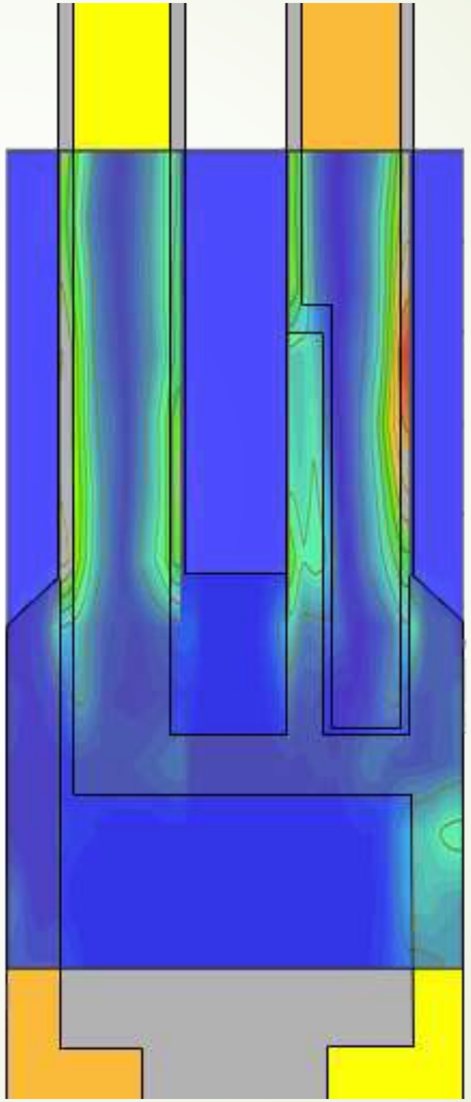
Custom QTFs can improve LITES performance with respect to standard QTF[1]

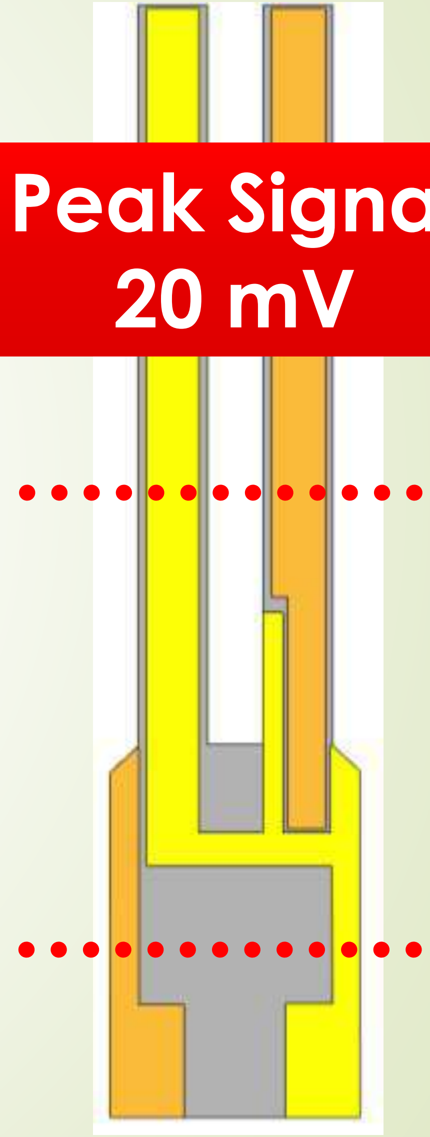
[1] Y. Ma , Y. He, P. Patimisco, A. Sampaolo, S. Qiao, X. Yu, F.K. Tittel, V. Spagnolo, "Ultra-high sensitive trace gas detection based on light-induced thermoelastic spectroscopy and a custom quartz tuning fork", Applied Physics Letters 116, 011103 (2020).

LITES signal mapping on QTF surface

7.2 kHz – Fundamental mode
0° degrees tilt



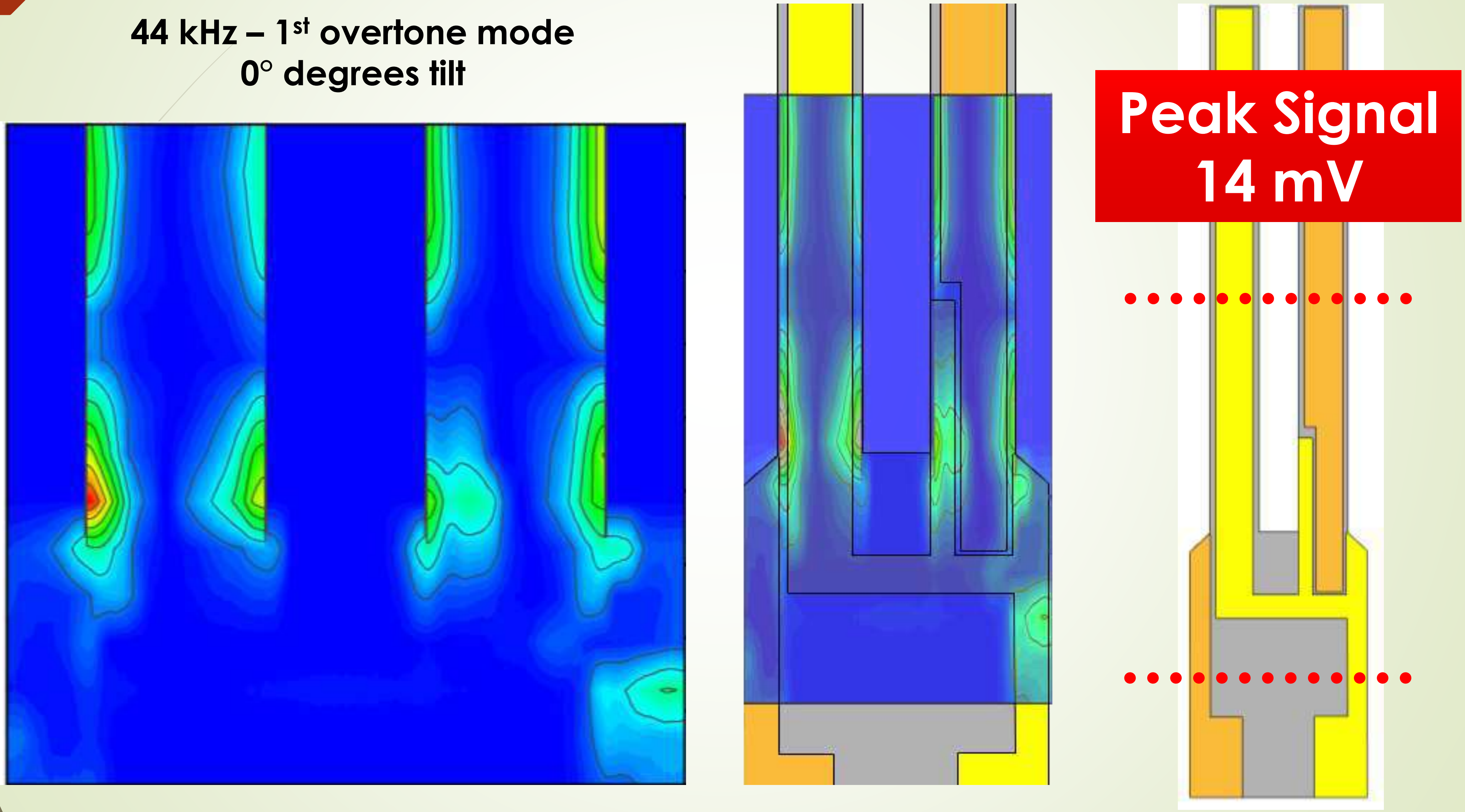




Peak Signal 20 mV

LITES signal mapping on QTF surface

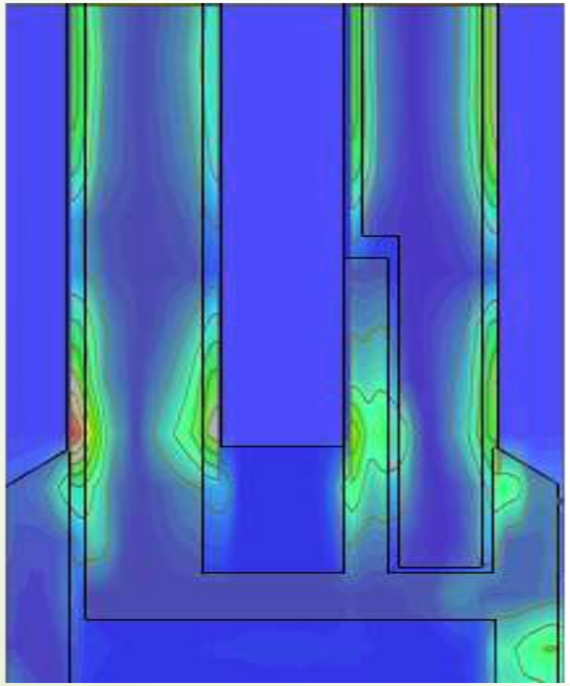
44 kHz – 1st overtone mode
0° degrees tilt

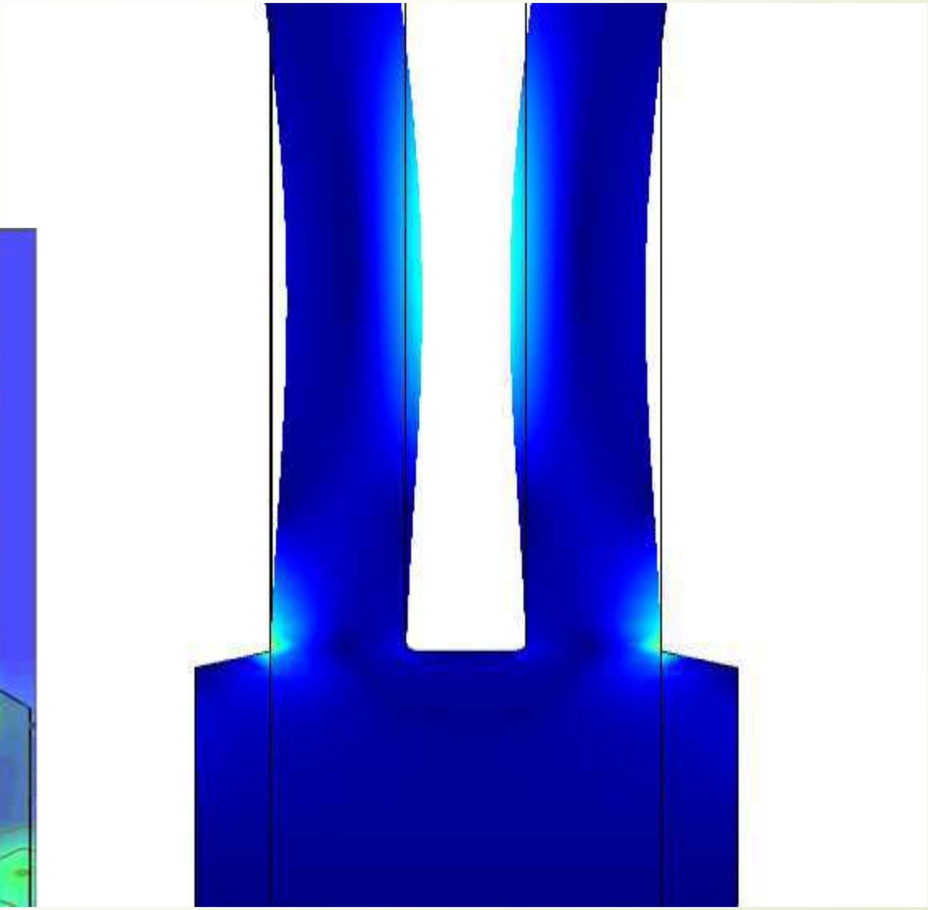


LITES signal mapping on QTF surface

The piezoelectric charges are proportional to the **strain intensity**

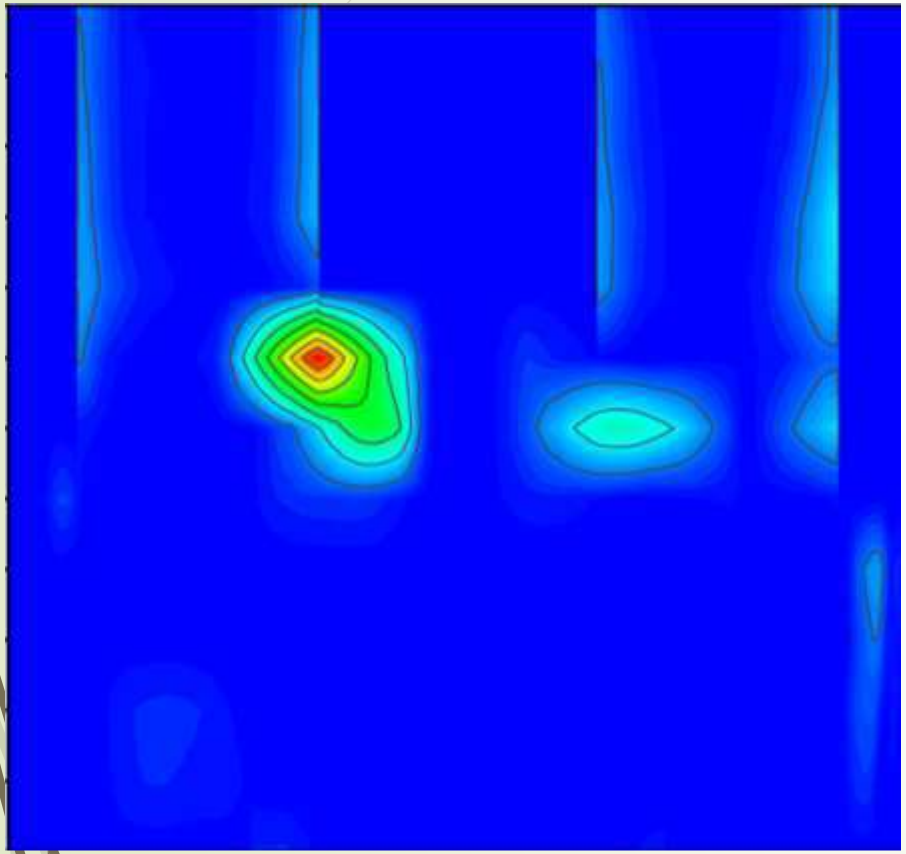
1st Overtone signal mapping and strain simulation

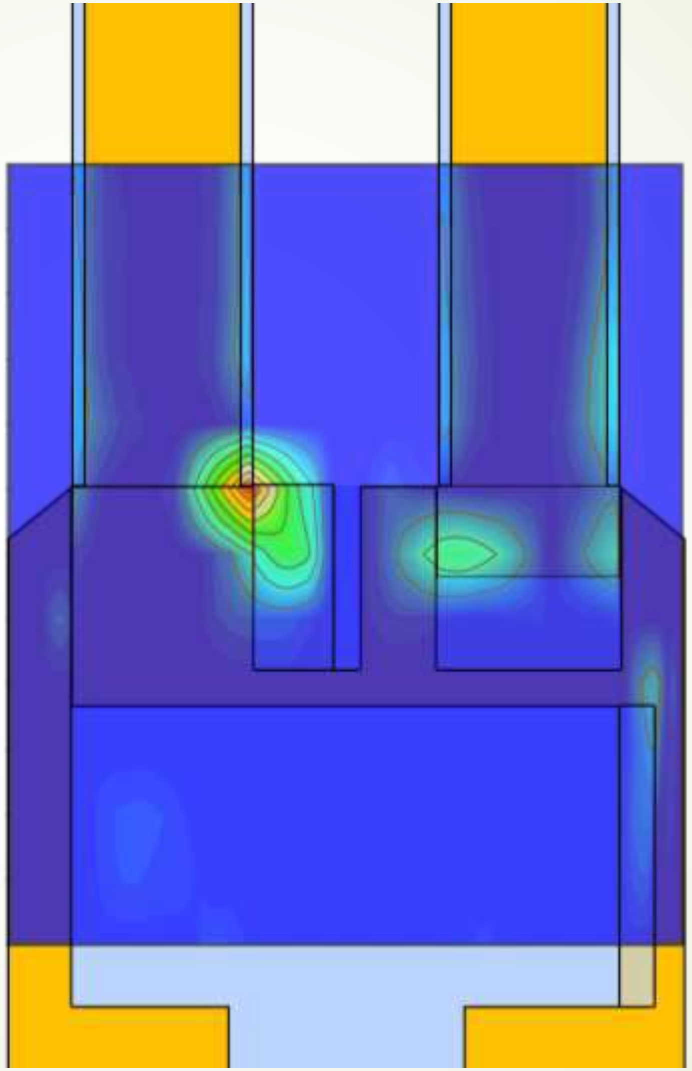


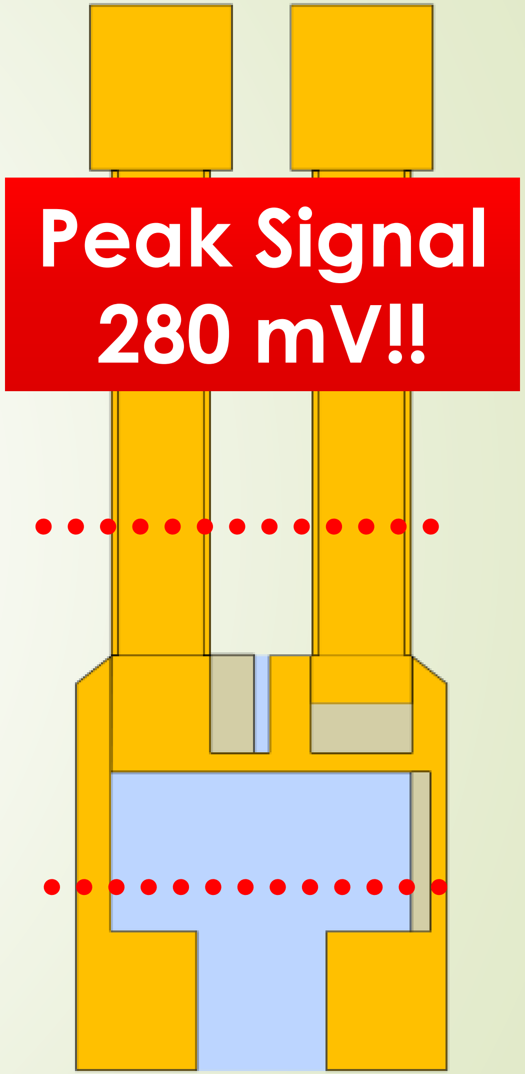


LITES signal mapping on QTF surface

9.5 kHz – Fundamental mode
0° degrees tilt

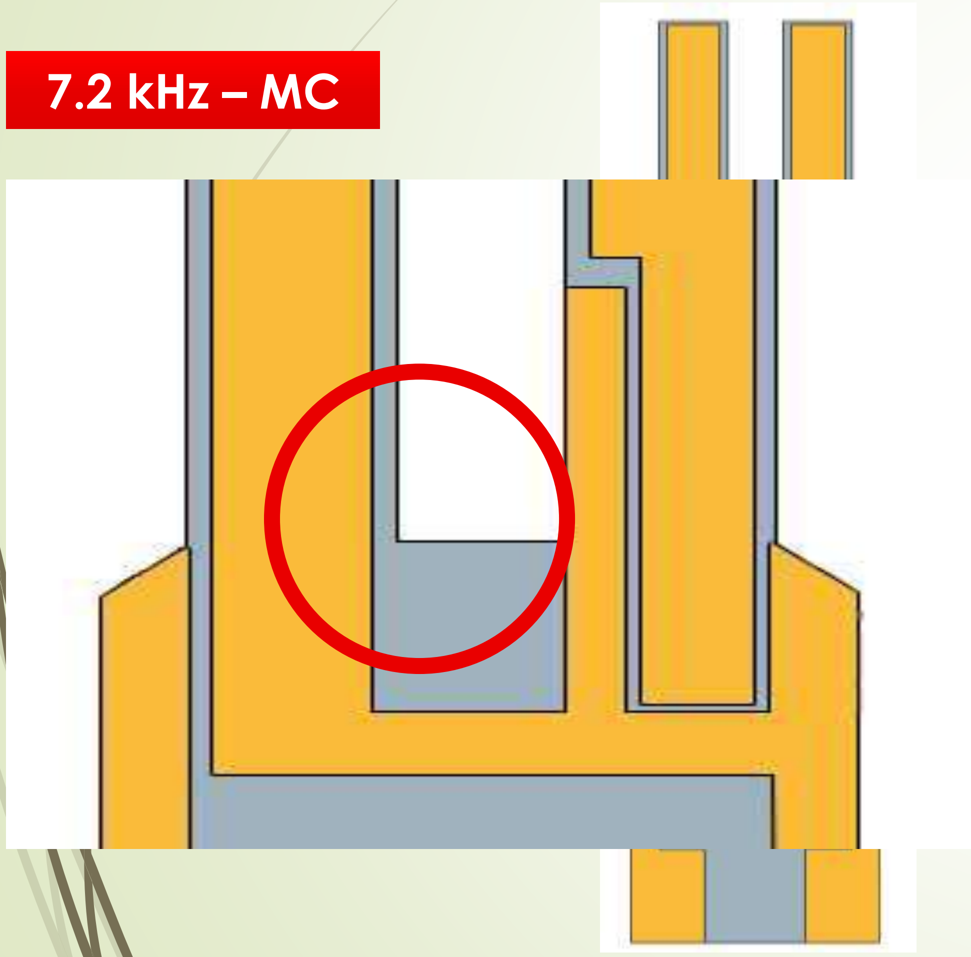


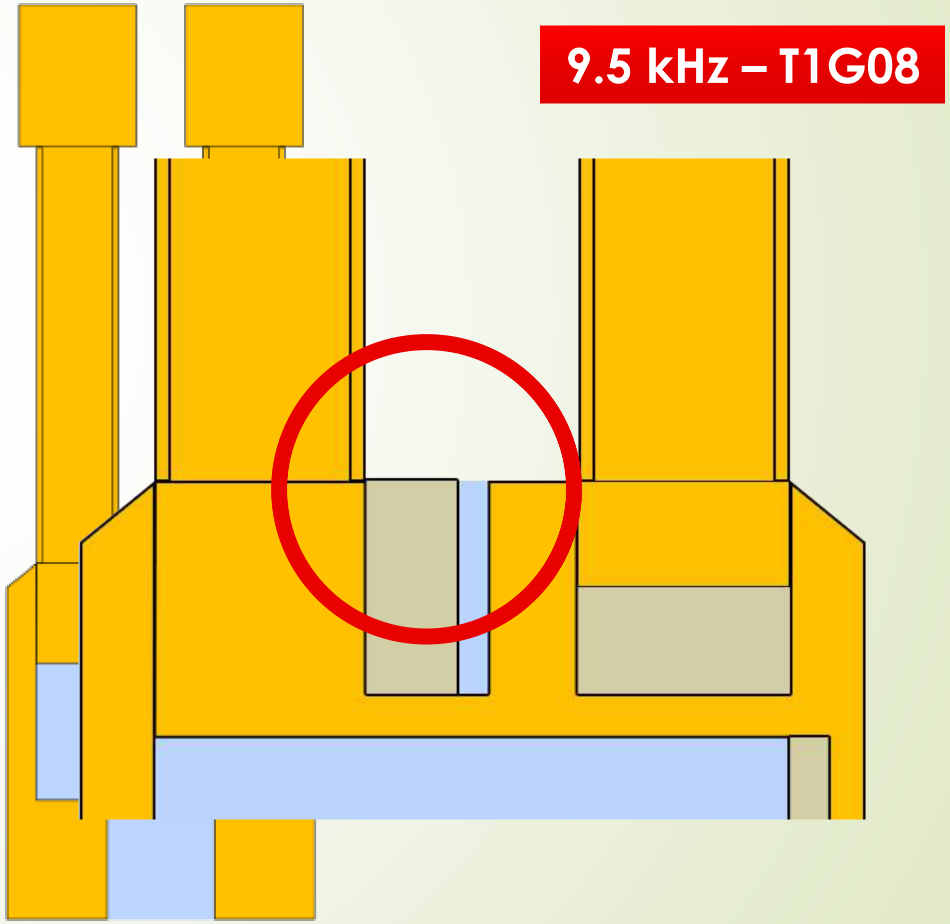




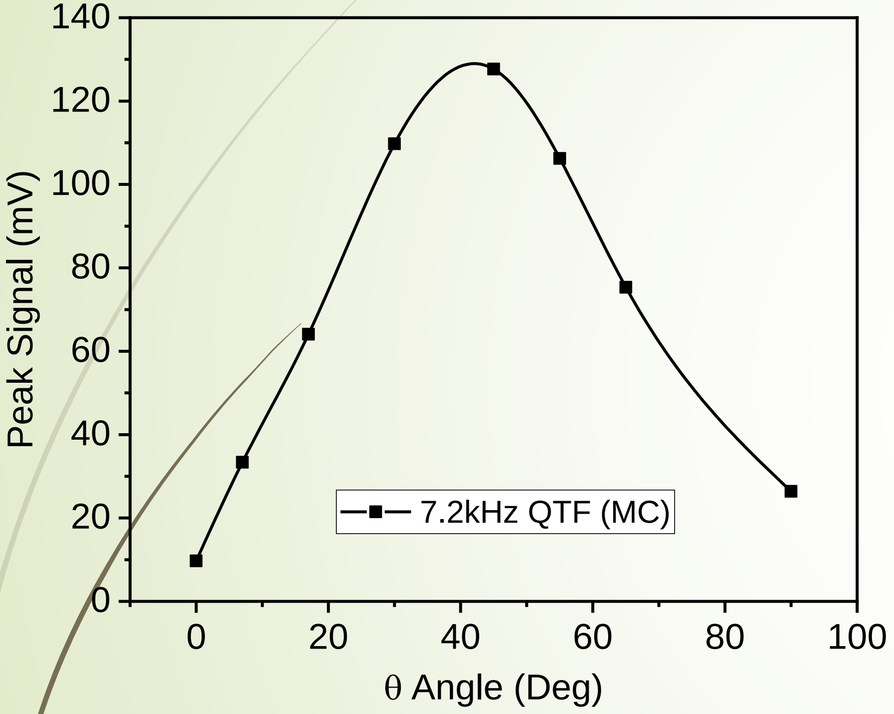
LITES signal mapping on QTF surface

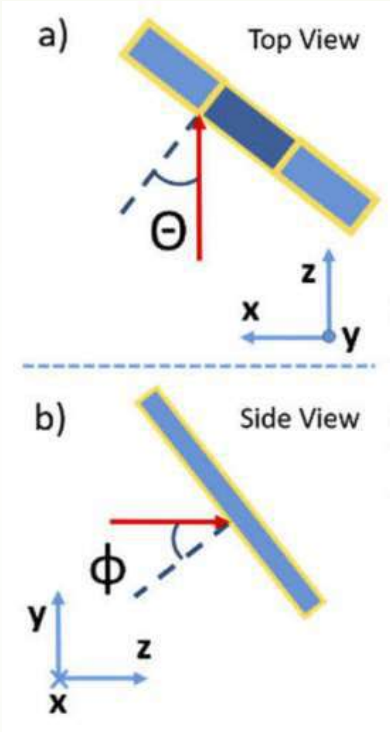
The QTF-T1G08 signal is 14 times better compare to the other QTF, but the strain is only 1.7 times higher. Are we hitting the right point?

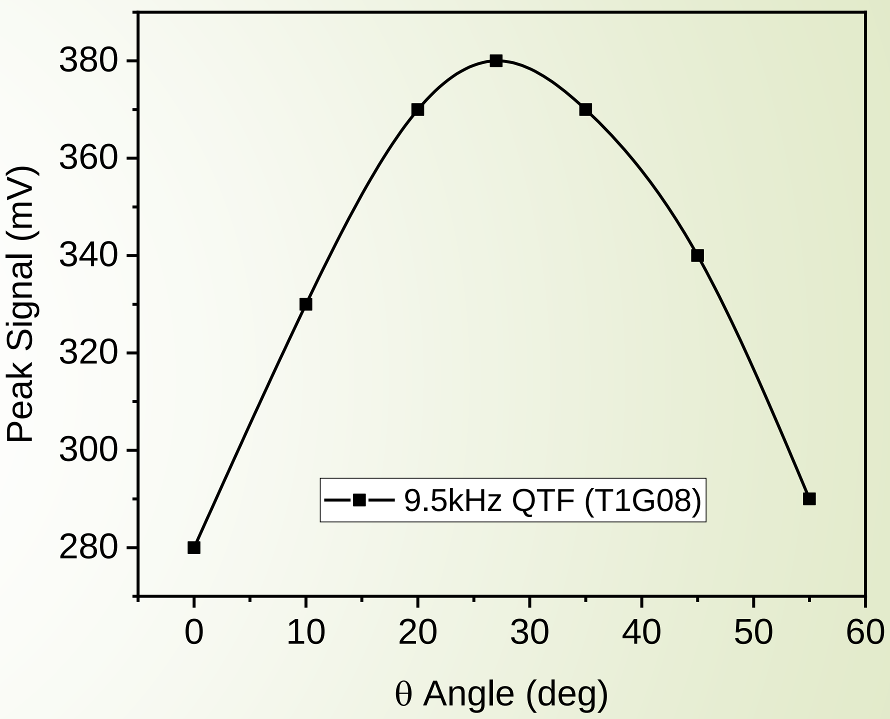




Best LITES signal by varying hitting angle





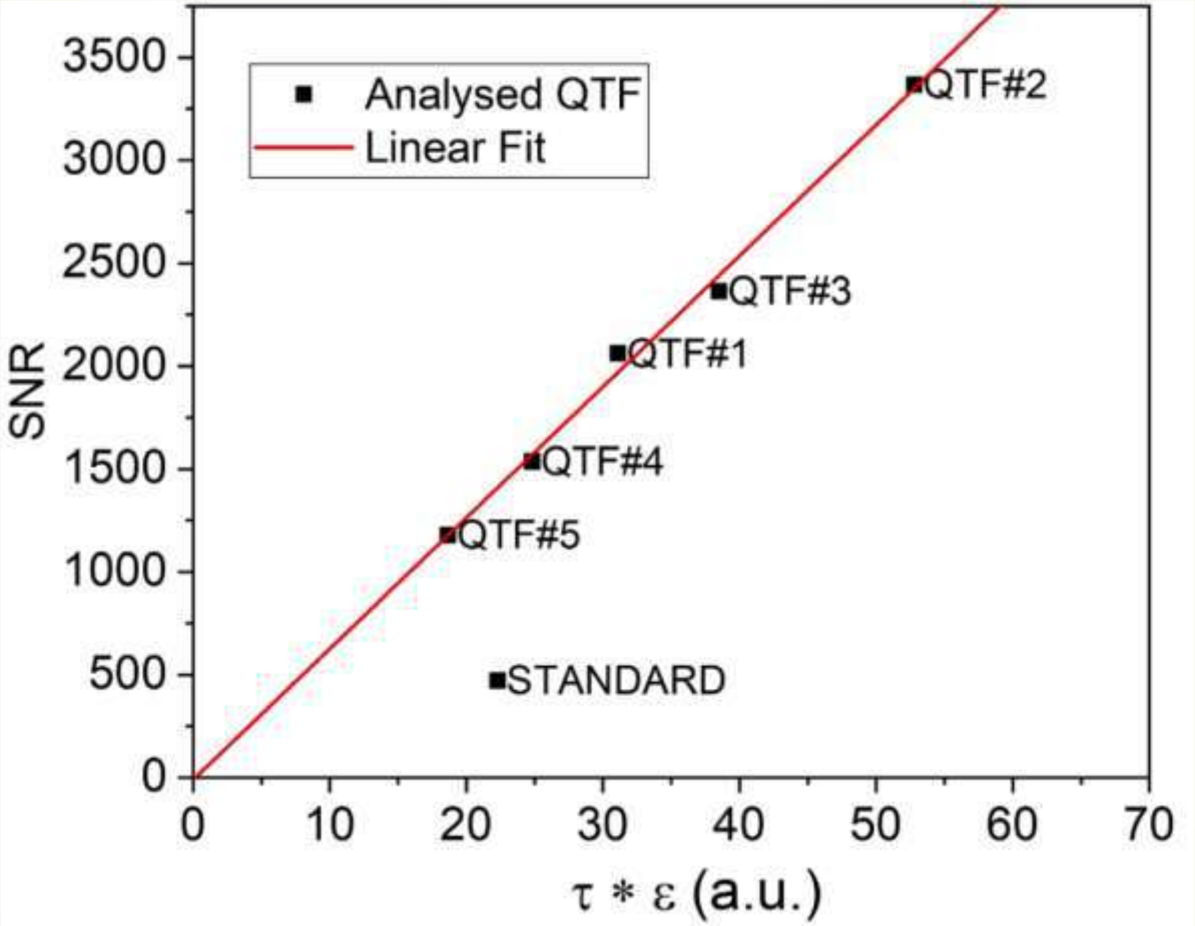


Enhancement ~ **6.5**

Enhancement ~ 1.4

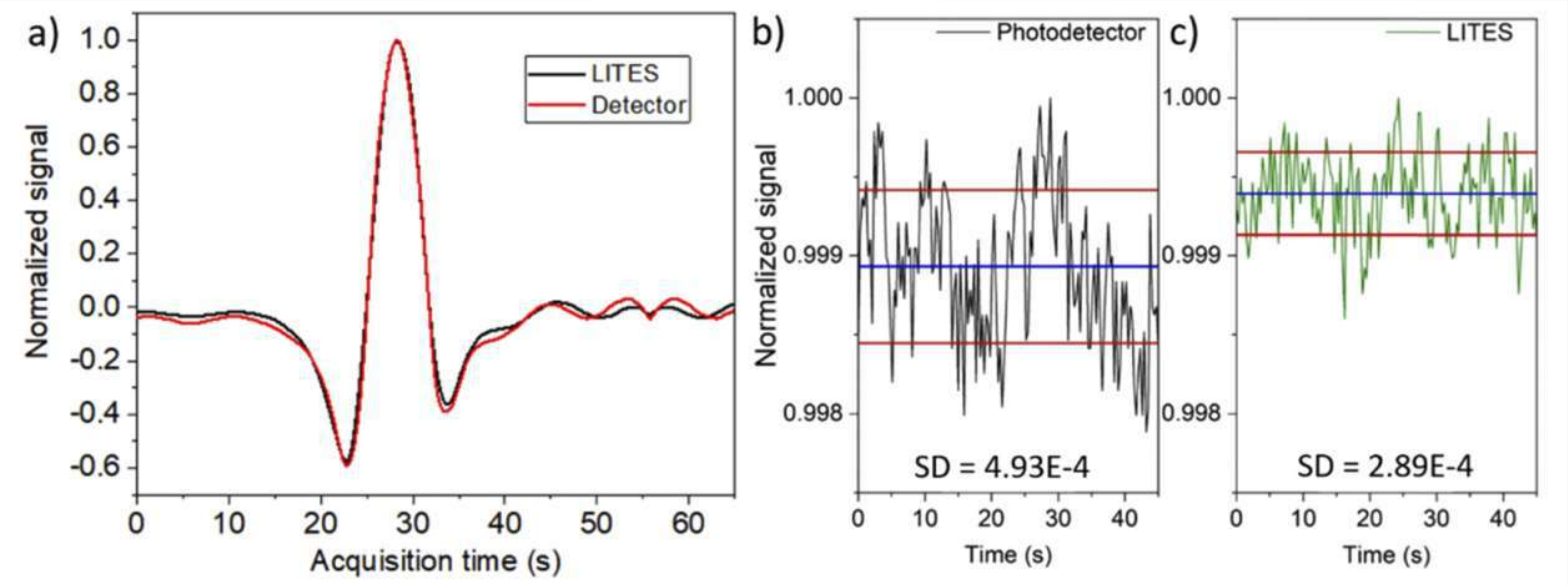
The effects due to the different gold pattern can be overcome by appropriately choosing the hitting angle

QTF SNR comparison and analysis



Apart from standard QTF, LITES SNR values follow a linear trend as a function of the product **τ·ε**

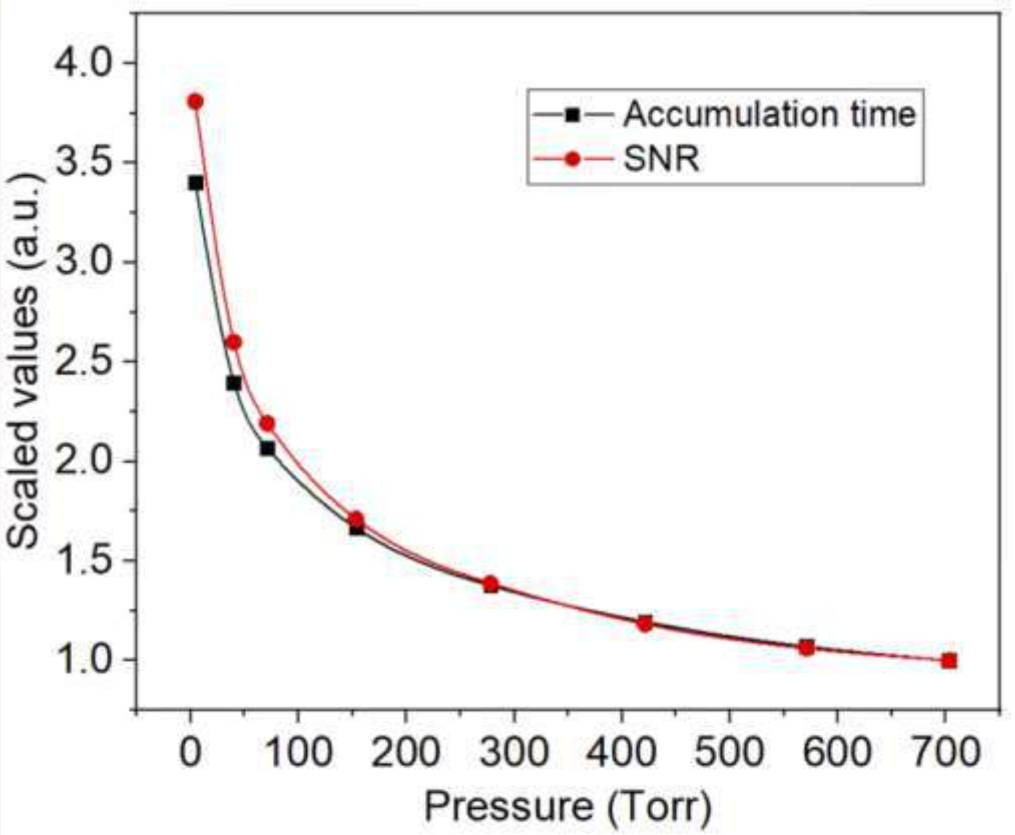
Comparison LITES - Photodetector



Best LITES SNR = **3500**
PDA10CF-EC SNR = 2030

→ Comparable performances in Near-IR range

Pressure analysis



The LITES SNR follows almost the same trend as the QTF accumulation time

SNR @ 5 Torr = **13500**

Comparison LITES - Photodetector

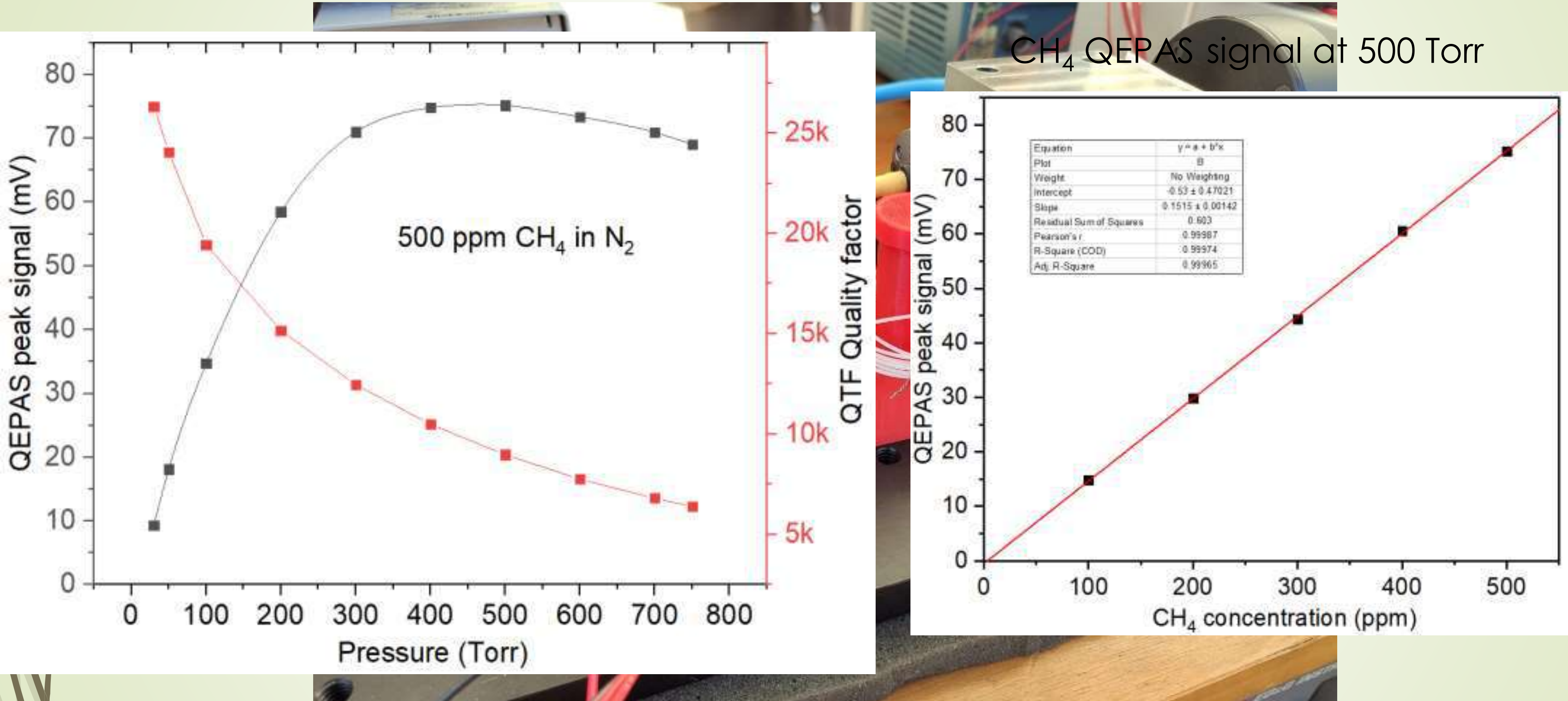
NEAR-IR and MID-IR spectral ranges

Laser type	Wavelength (µm)	Power (mW)	Gas target	Pathlength (cm)	Linestrength (cm/mol)	Detector	MDL (ppm)
LD	1.36	3.5	H_2O	60	$8.84 \cdot 10^{-21}$	QTF PDA10CF-EC	0.74 4.93
LD	1.65	1.13	CH_4	1000	$9.27 \cdot 10^{-22}$	QTF PDA10CF-EC	3.5 2.27
ICL	3.33	1.2	CH_4	15	$4.57 \cdot 10^{-20}$	QTF PVI-4TE-4	1.98 2.9
QCL	5.26	5.1	H_2O	60	$3.13 \cdot 10^{-22}$	QTF PVI-4TE-6	14.05 138.5
QCL	10.34	5.6	NH_3	15	$5.19 \cdot 10^{-19}$	QTF PVI-4TE-10.6	0.28 0.34

The QTF performances are **comparable** with respect to those obtained for **commercial detectors**

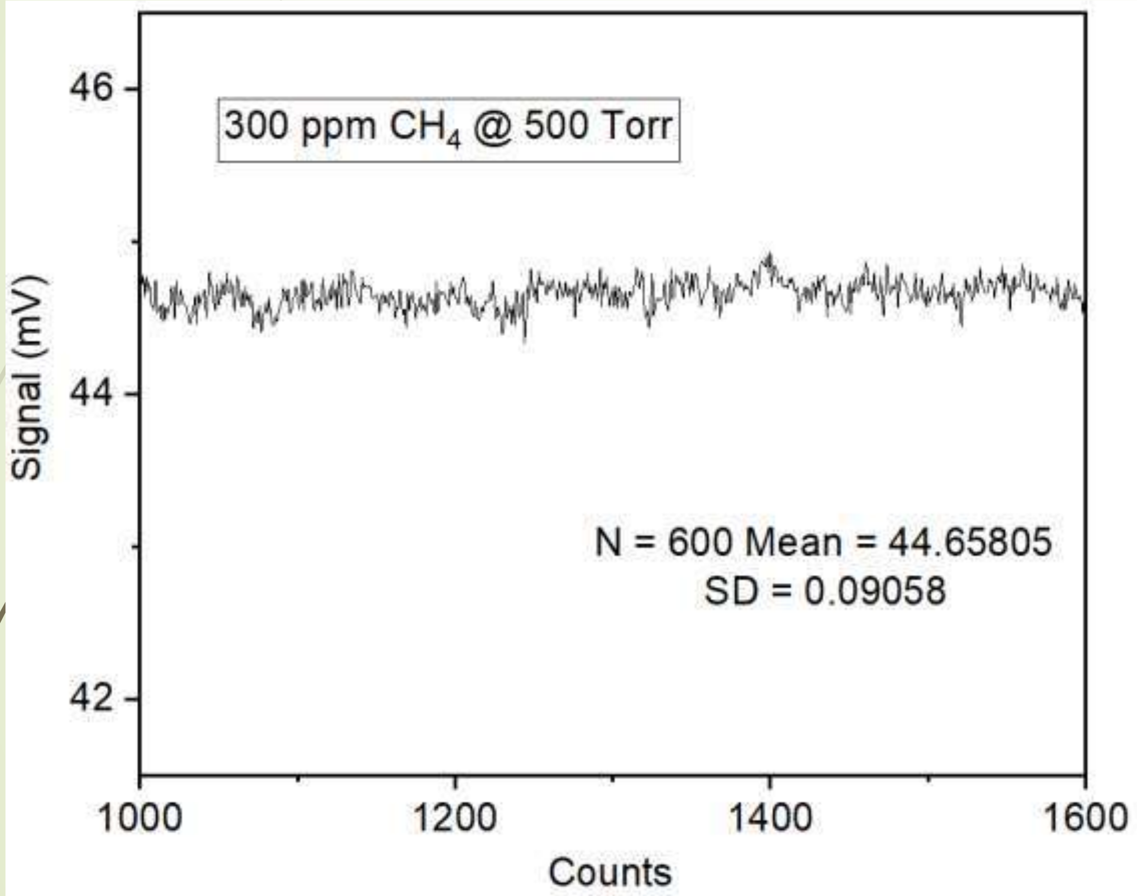
CH_4 – H_2O QEPAS concentration measurement near a traffic light

CH_4 sensor calibration



Slope = **152 µV/ppm**
Intercept ≈ 0

CH_4 peak signal stability



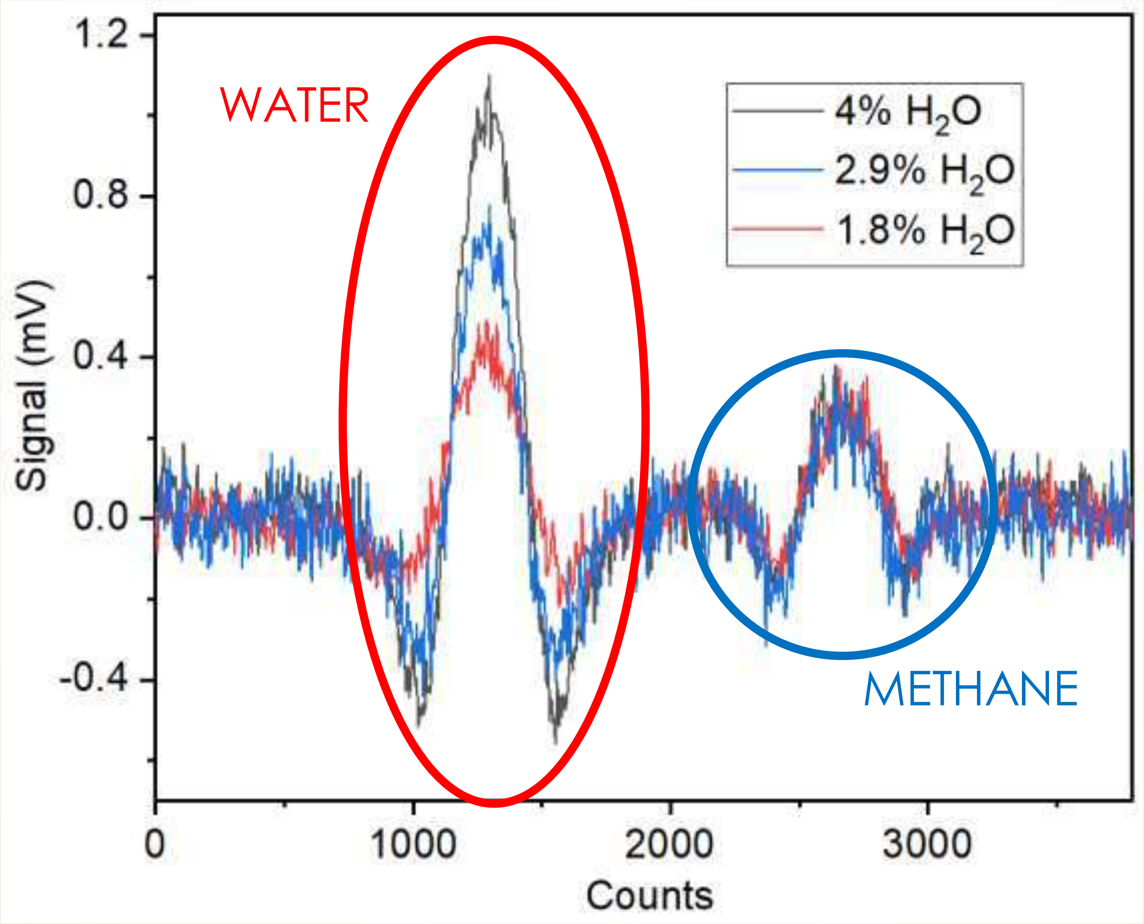
2 s integration time
6 s acquisition time

The QEPAS peak signal is constant over **1 hour** measurement

MDL ≈ **600 ppb**

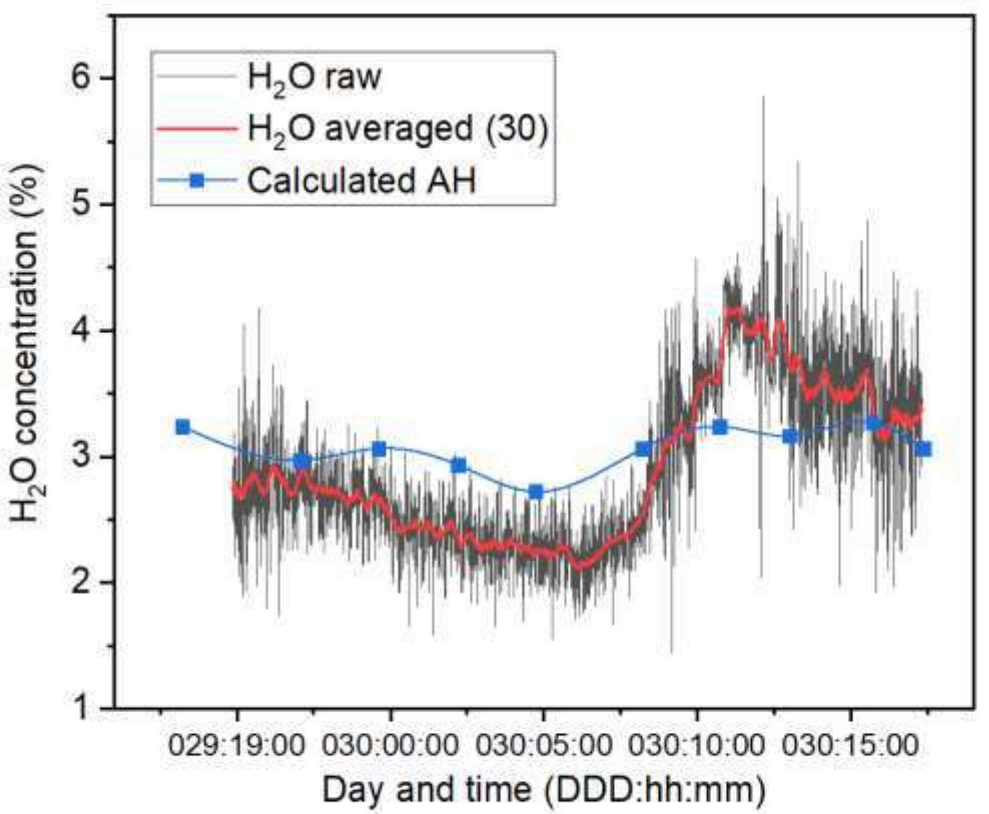
The sensor calibration shows the possibility of measuring the CH_4 atmospheric concentration

H_2O-CH_4 spectral scan



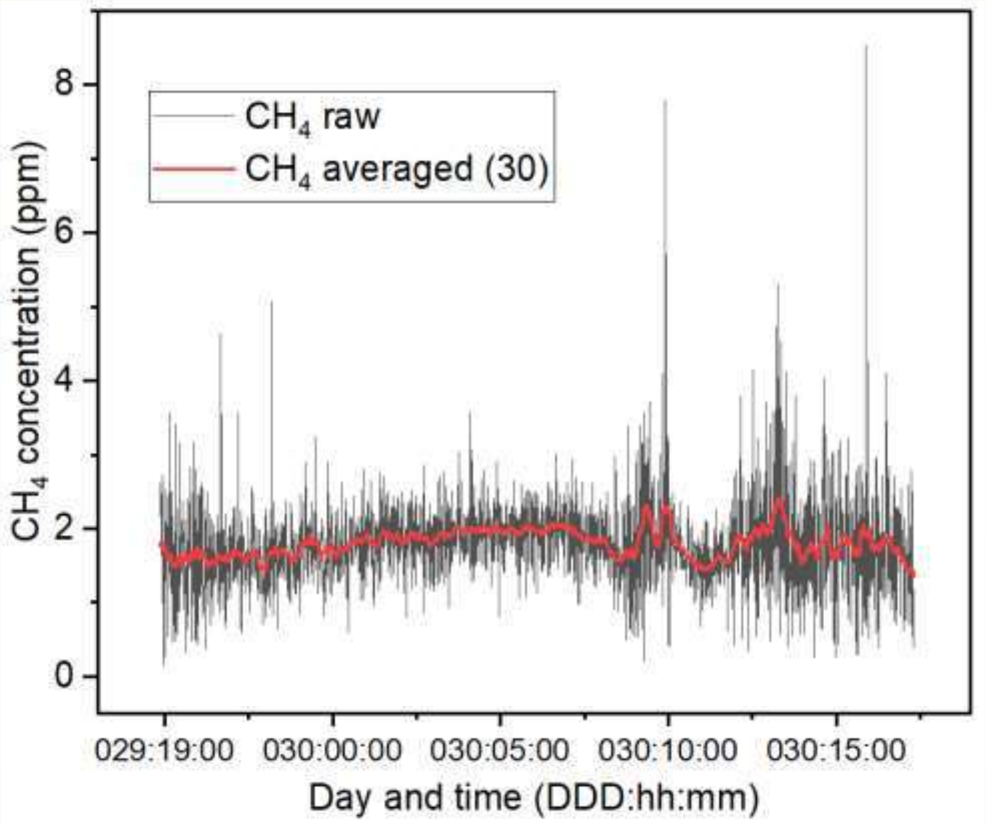
The CH_4 QEPAS peak value was almost unchanged

CH_4-H_2O concentration near a traffic light



Good agreement between values measured by the QEPAS sensor-head and those calculated from the measurements provided by the weather station

CH_4-H_2O concentration near a traffic light



During rush hours, the methane concentration reaches peak values up to 8.5 ppm
Average values of 2.4 ppm were measured during two rush periods

Third year goals

- LITES with **multipass cells**

Improvement of detection sensitivities

- QEPAS sensors for **environmental monitoring**

NO, N_2O, NO_2, SO_2, NH_3 → **PM2.5** creation
CO, CO_2 → **Coal, gas & oil** consumption
CH_4, CO_2, N_2O, H_2O → **Greenhouse gases**

List of publications

- **S. Dello Russo**, S. Zhou, A. Zifarelli, P. Patimisco, A. Sampaolo, M. Giglio, D. Iannuzzi, V. Spagnolo, “Photoacoustic spectroscopy for gas sensing: a comparison between piezoelectric and interferometric readout in custom quartz tuning forks”, Photoacoustics **2020**, 17, 100155.
- F. Sgobba, G. Menduni, **S. Dello Russo**, A. Sampaolo, P. Patimisco, M. Giglio, E. Ranieri, V. M. N. Passaro, F. K. Tittel, V. Spagnolo, “Quartz-Enhanced Photoacoustic Detection of Ethane in the Near-IR Exploiting a Highly Performant Spectrophone”, Appl. Sci. **2020**, 10(7), 2447.
- G. Menduni, A. Sampaolo, P. Patimisco, M. Giglio, **S. Dello Russo**, A. Zifarelli, A. Elefante, P.Z. Wieczorek, T. Starecki, V.M.N. Passaro, F.K. Tittel, V. Spagnolo, “Front-End Amplifiers for Tuning Forks in Quartz Enhanced PhotoAcoustic Spectroscopy”, Appl. Sci. **2020**, 10(8), 2947.
- **S. Dello Russo**, A. Zifarelli, P. Patimisco, A. Sampaolo, T. Wei, H. Wu, L. Dong, V. Spagnolo, “Light-induced thermo-elastic effect in quartz tuning forks exploited as a photodetector in gas absorption spectroscopy”, Optics Express **2020**, 28, 19074.
- B. Sun, A. Zifarelli, H. Wu, **S. Dello Russo**, S. Li, P. Patimisco, L. Dong and V. Spagnolo, “Mid-infrared quartz-enhanced photoacoustic sensor for ppb-level CO detection in SF_6 gas matrix exploiting a T-grooved quartz tuning fork”, Analytical Chemistry **2020**, 92, 13922-13929.

Conference proceedings

- **S. Dello Russo**, P. Patimisco, A. Sampaolo, M. Giglio, G. Menduni, A. Elefante, V.M.N. Passaro, F.K. Tittel, V. Spagnolo, “Measurement of non-radiative gas molecules relaxation rates by using quartz-enhanced photoacoustic spectroscopy”, Proc. SPIE, Quantum Sensing and Nano Electronics and Photonics XVII, **2020**.
- P. Patimisco, S. Zhou, **S. Dello Russo**, A. Zifarelli, A. Sampaolo, M. Giglio, H. Rossmadl, V. Mackowiak, A. Cable, D. Iannuzzi, V. Spagnolo, “Comparison between interferometric and piezoelectric readout of tuning fork vibrations in quartz-enhanced photoacoustic spectroscopy”, Proc. SPIE, Quantum Sensing and Nano Electronics and Photonics XVII, **2020**.

Thank you for your attention

PolySenSe