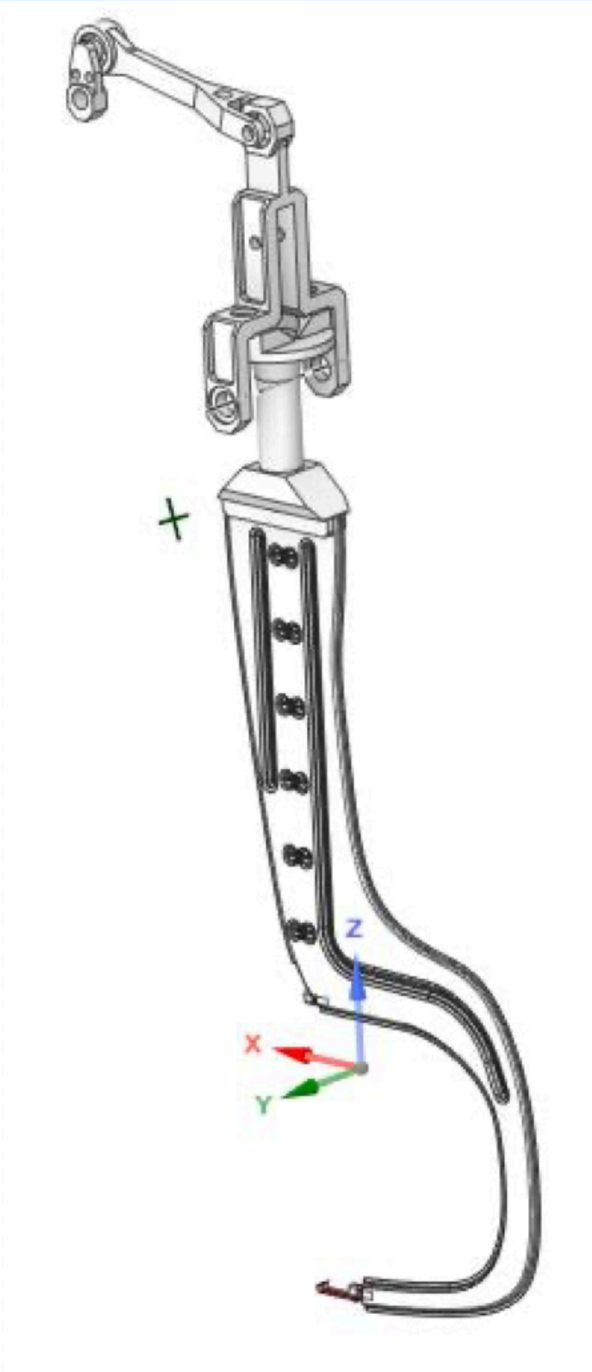
Vibration analysis of the New Wire Scanner, PSI

Project presentation



Marius LE CHENADEC

Project introduction

Goals

- Setup different experiments for each type of vibrations (camera, light, software)
- Record transversal vibration during motion and when it stops in vacuum, air, with and without wire
- Characterize the vibrations and dependence
- Check the longitudinal speed profile vs predicted speed profile + vibrations in that profile if possible (normally not possible except if there is play in-between pieces)

Project introduction

Wire scanner geometry and setup

- Vacuum: 50 μm diameter, Tungsten wire with 20g tension
- Air: 50 μm diameter, Molybdenum wire with 20g tension
- Air and no wire
- Fork in Stainless steel and Titanium

Methodology

Cameras and softwares

- **Cameras:**
- Smartphone Google Pixel 9a: record in slow motion (x4, x8), fps=120 or 240
- Fujifilm X-T50 with a macro lens *Super EBC f/2.4 with a focal length of 60mm*, recording in slow motion (x4), ISO=5000, fps=200
- PCO Dimax high speed CMOS camera, recording with fps=1201.44 and 2000, with a lens K2 DistaMax (Long-Distance Microscope) from Infinity Photo-Optical
- **Softwares:**
- Tracker
- Matlab

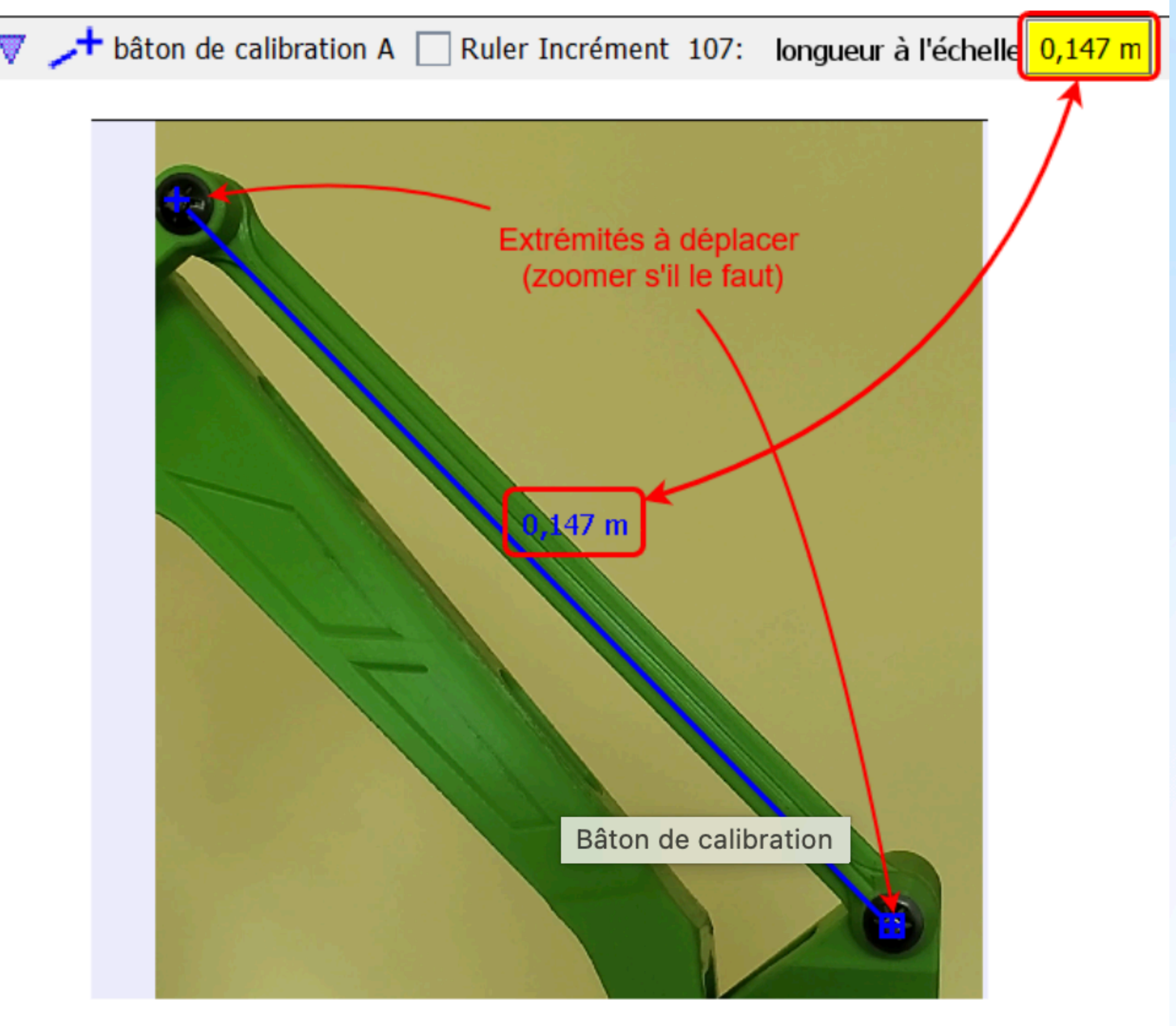
Methodology

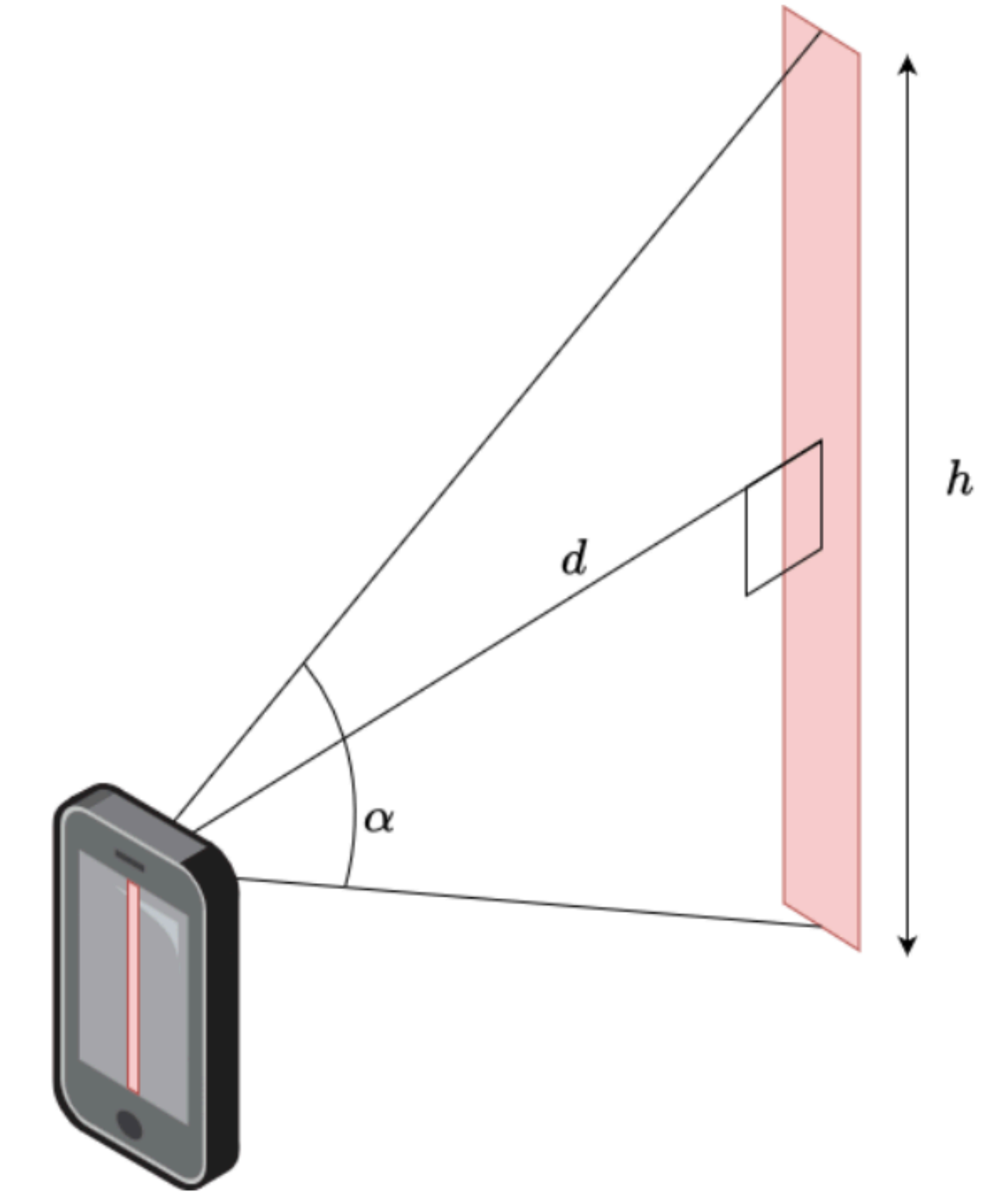
Tracker

- Allow for automatic tracking frame by frame
- Allow for geometry (opening) corrections and length assignments
- Allow filters, manual tracking, data analysis (position, speed, acceleration)
- Allow for fit and data extraction

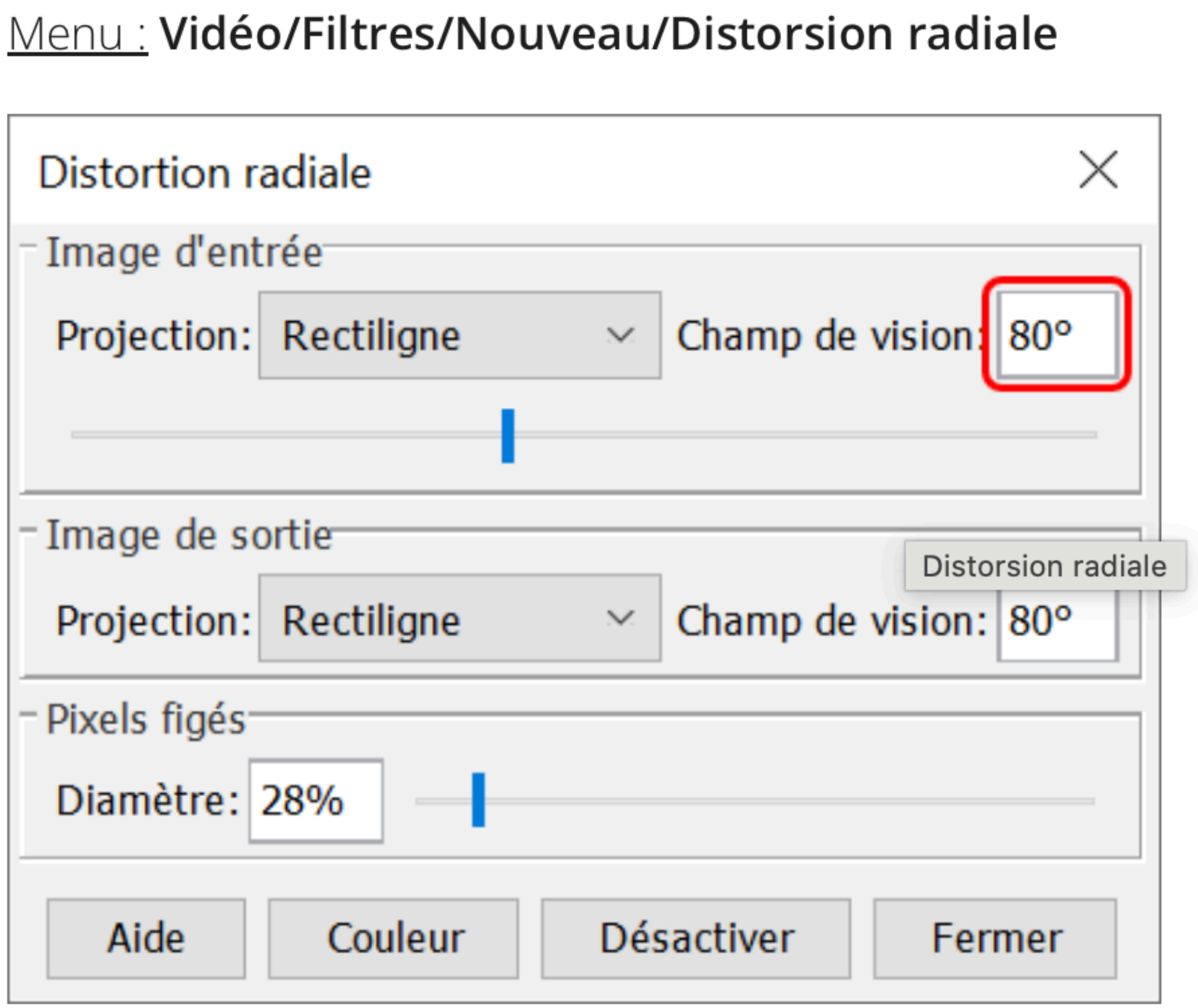
Methodology

Tracker, length and geometry





$$\alpha = \arctan \frac{h}{d}$$



Source: Tracker Video Analysis and Modeling Tool (Open Source Physics)

Methodology

Matlab

- Script that uses a .txt from Tracker of the position
- FFT analysis
- Amplitudes analysis
- Damping analysis
- Fitting and takes into account for uncertainties

Methodology

Matlab and uncertainty

- A0 corresponds to the initial vibration amplitude immediately after the scanner motion stops and the free damped oscillation begins.
- **Weighted exponential regression:**
- Considering only peaks of the trajectory: $|x(t)| \approx A_0 e^{-\gamma t}$ where γ is the damping constant
- $\Rightarrow \ln p_i = \ln A_0 - \gamma t_i$ and uncertainty propagation on $\ln(p_i)$is propagated on p_i: $\sigma_{\ln p_i} = \dfrac{\sigma_x}{p_i}$
- **Weighted least squares:** $\chi^2 = \sum_{i=1}^{N} \dfrac{\left(ln(p_i) - (-\gamma t_i + ln(A_0))\right)^2}{\sigma_{pi}^2}$
- $\Rightarrow \beta = \begin{bmatrix} -\gamma \\ \ln A_0 \end{bmatrix} = \left(X^\top W X\right)^{-1} X^\top W \ln \mathbf{p}, \quad X = \begin{bmatrix} t_i & 1 \end{bmatrix}, \quad W = \operatorname{diag}\left(\dfrac{1}{\sigma_{\ln p_i}^2}\right)$

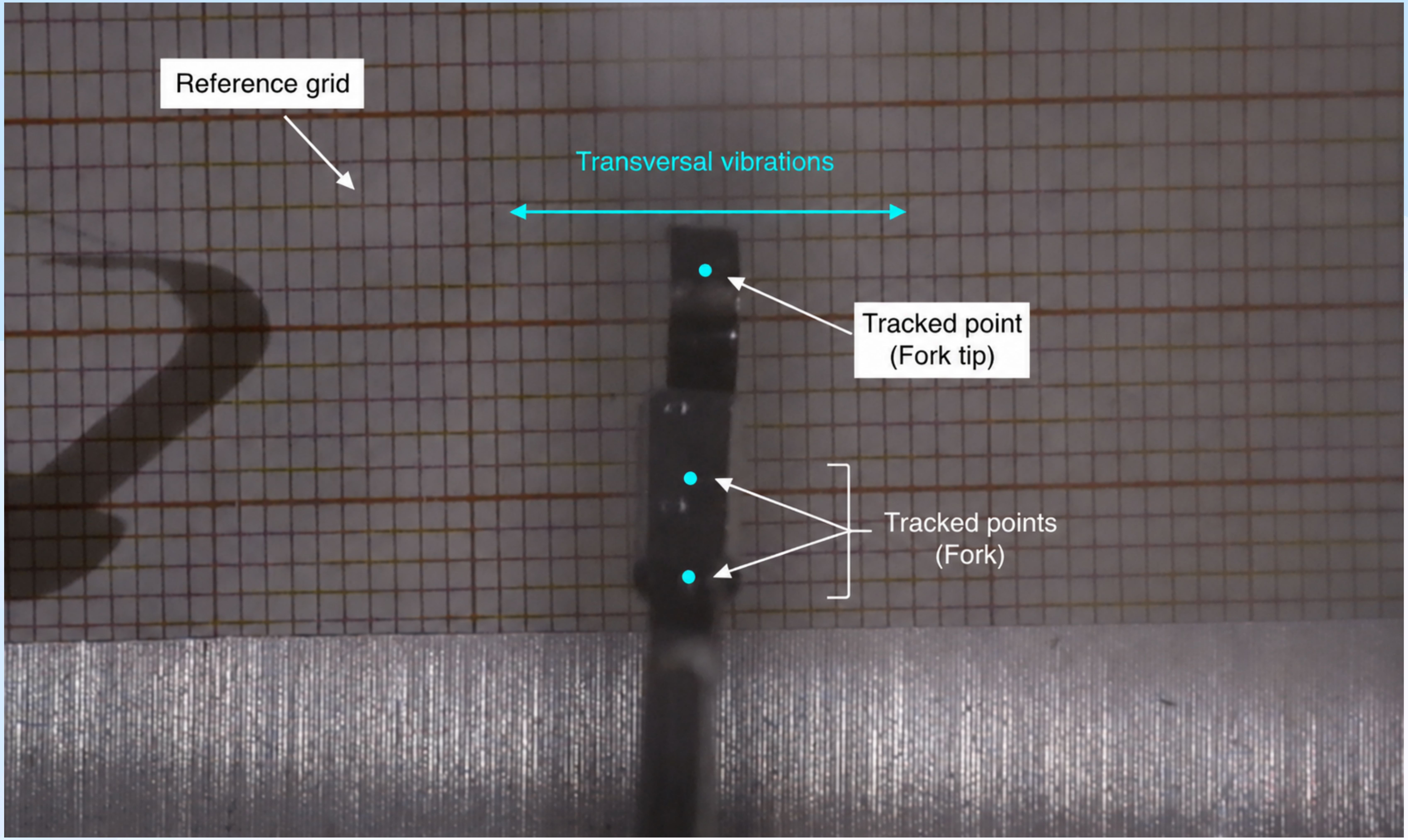
Methodology

Matlab and uncertainties

- **Monte Carlo method**: $\sigma_{pixel} = \pm 5 * p_{size}$ with p_{size} extracted from Tracker
- Implement 5000 iterations of $\vec{x} = \vec{x_0} \pm rand(0,1)\sigma_{pixel}$ for each point, same for $\vec{y}$
- Mean and standard deviation of f, τ and A for transversal vibration analysis
- Not fully implemented yet

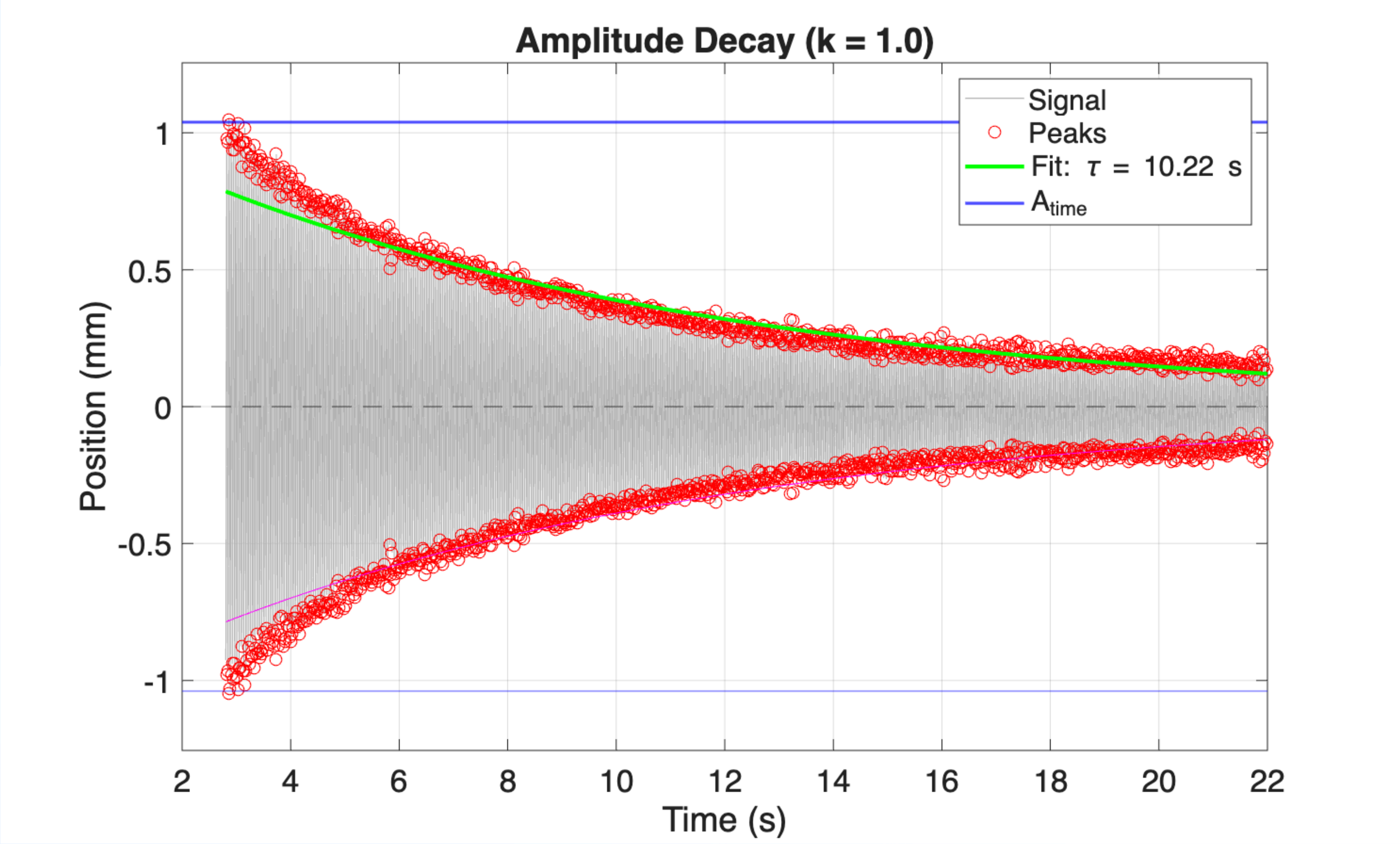
Recordings

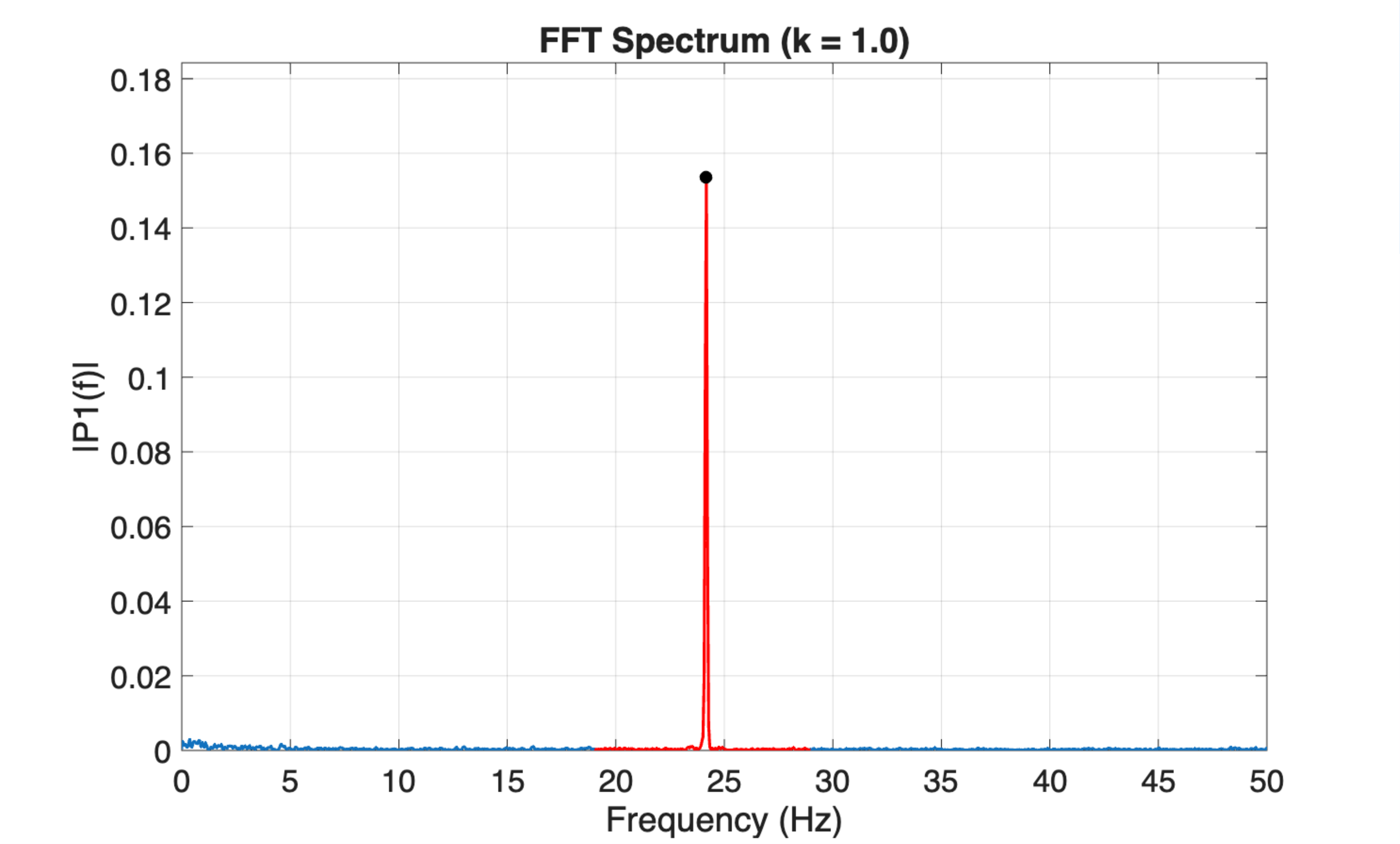
Fujifilm X-T50, slow motion (x4), 200 fps



Results

Transversal vibrations in vacuum with wire, one-way trip

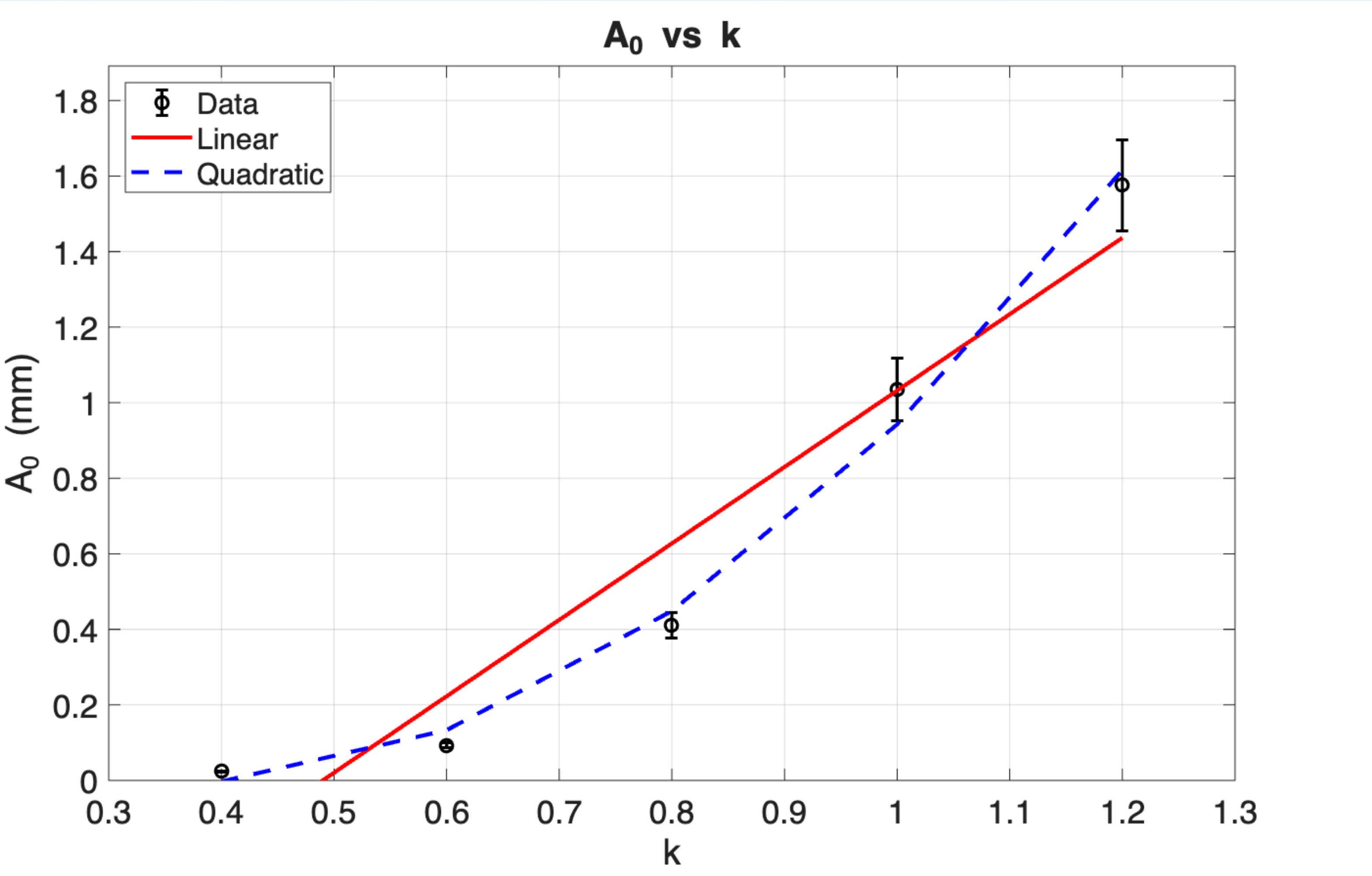




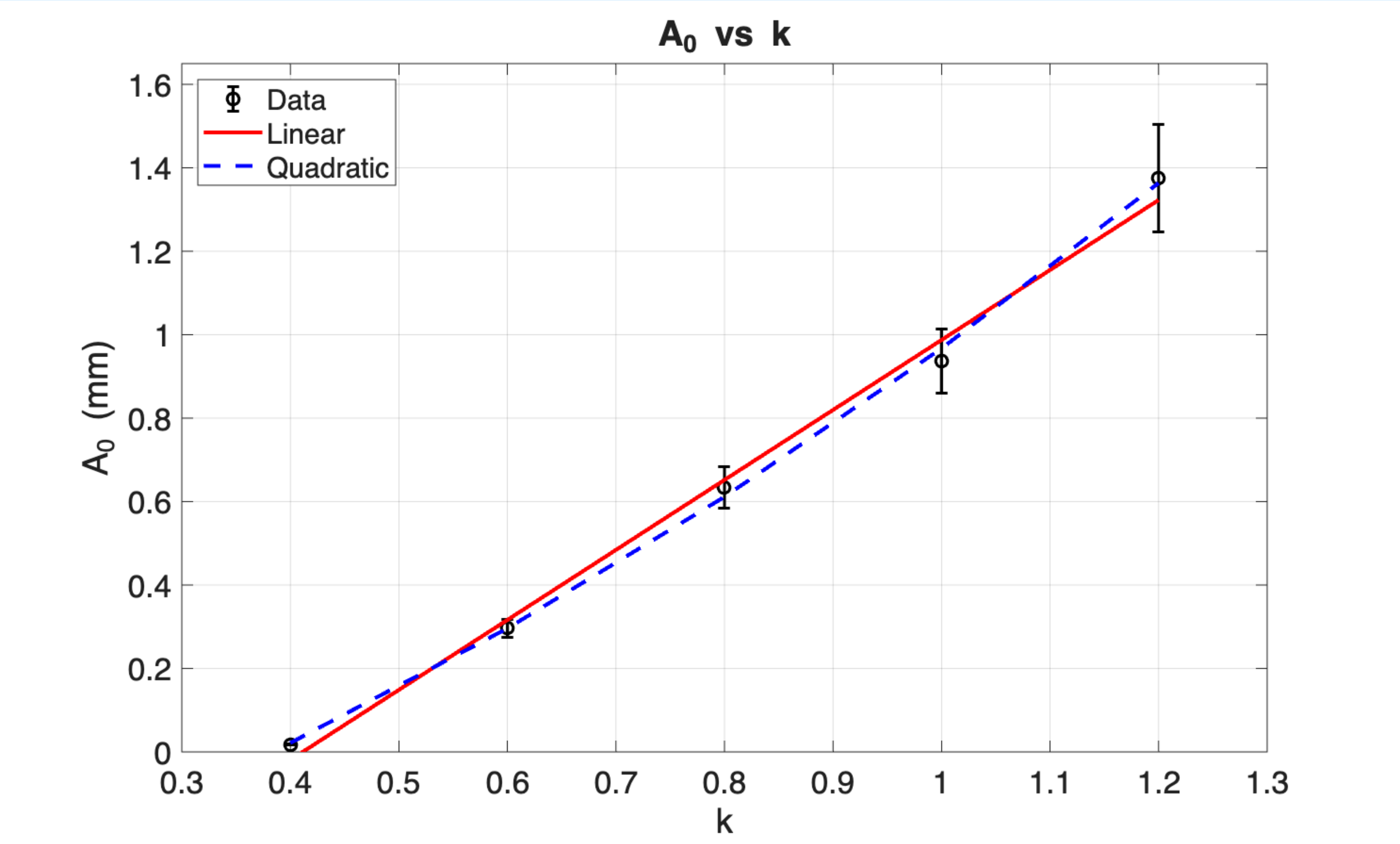
Result for k=1, titanium fork and wire in tungsten, one-way trip

Results

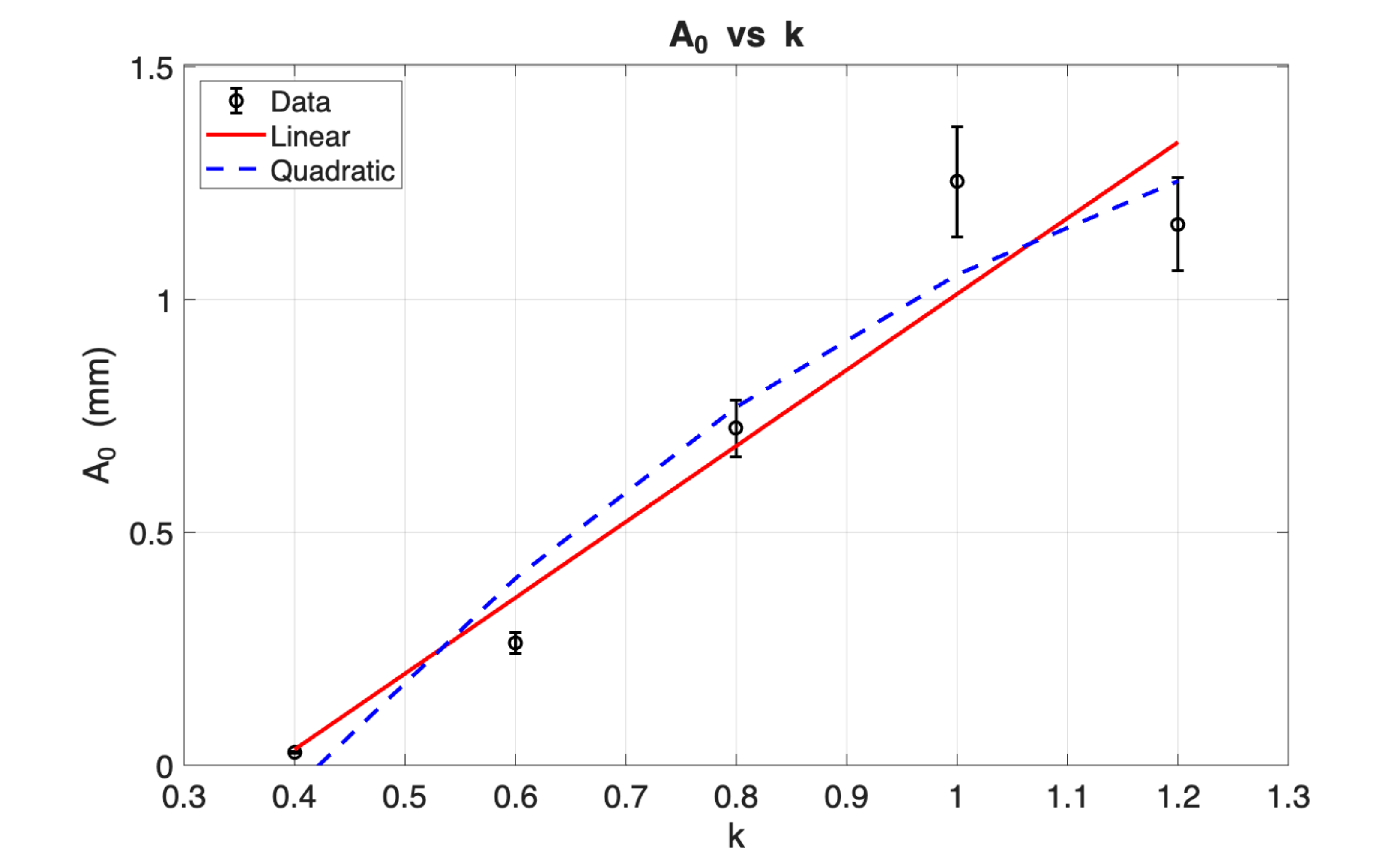
Comparison of one-way trip with different setup, k dependency/ A_0



Vacuum, Tungsten wire



Air, Molybdenum wire

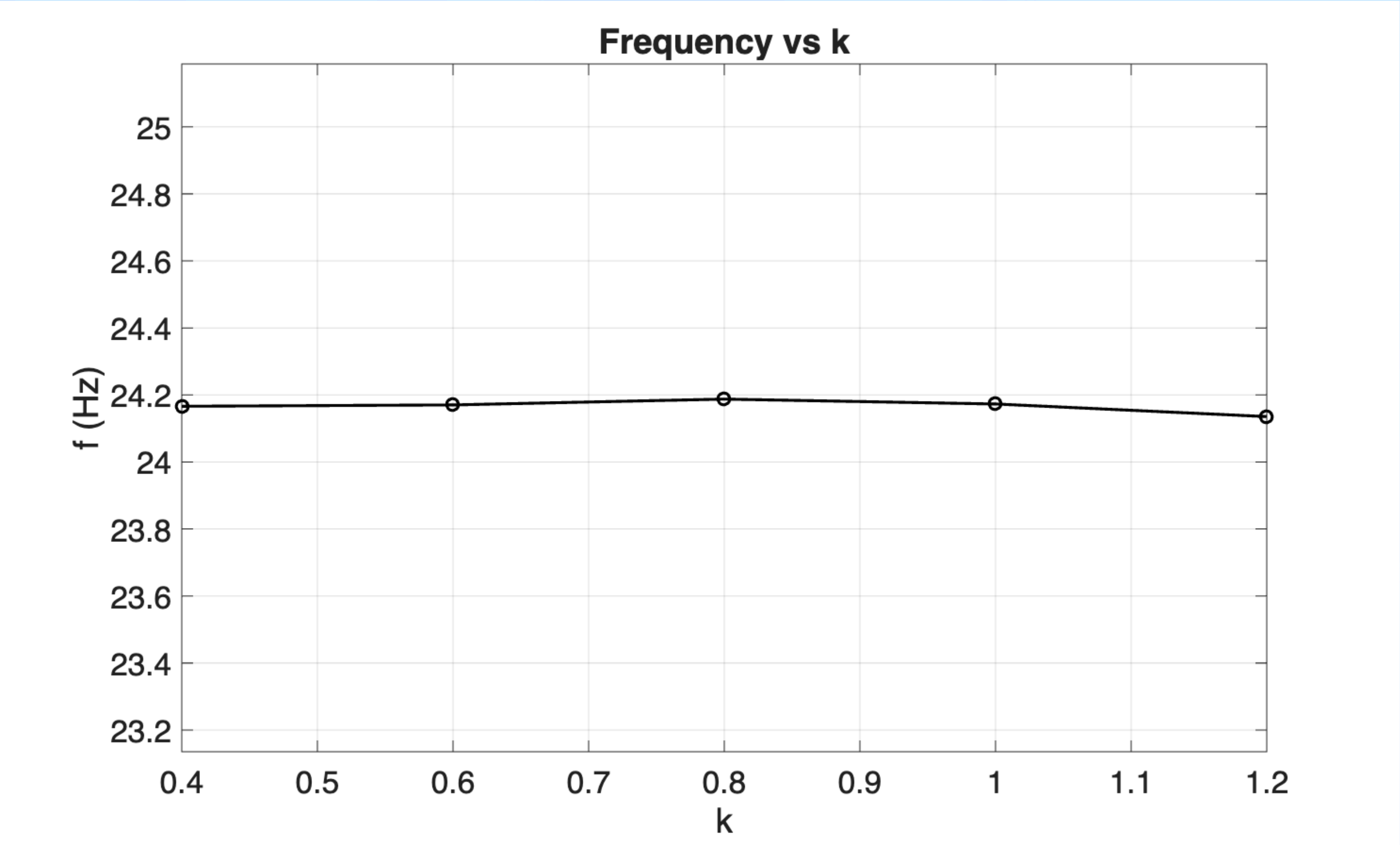


Air, no wire

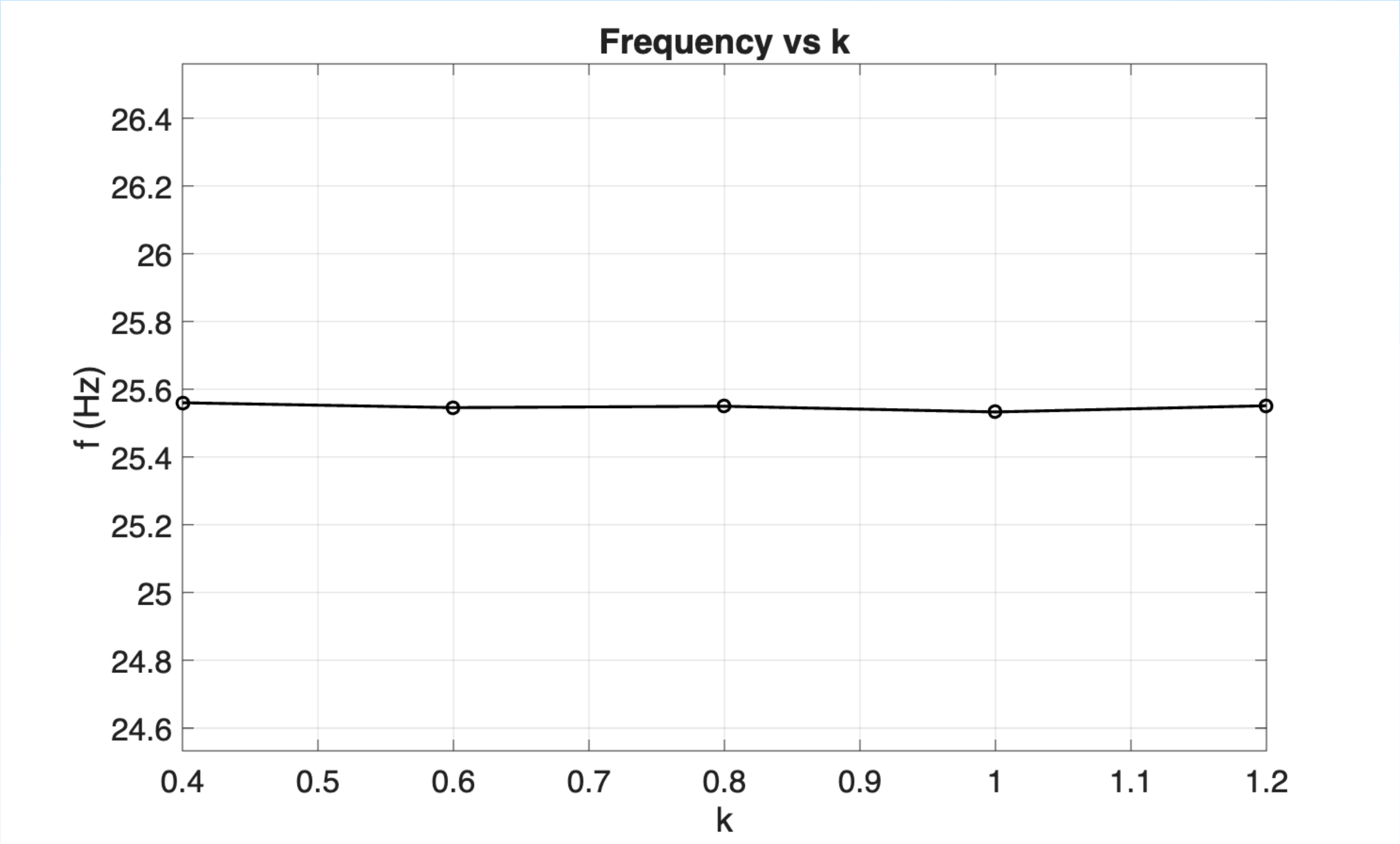
Each experimental point corresponds to the average value extracted from a complete recording sequence. Uncertainties are represented by error bars obtained from the fitting procedure and uncertainty propagation.

Results

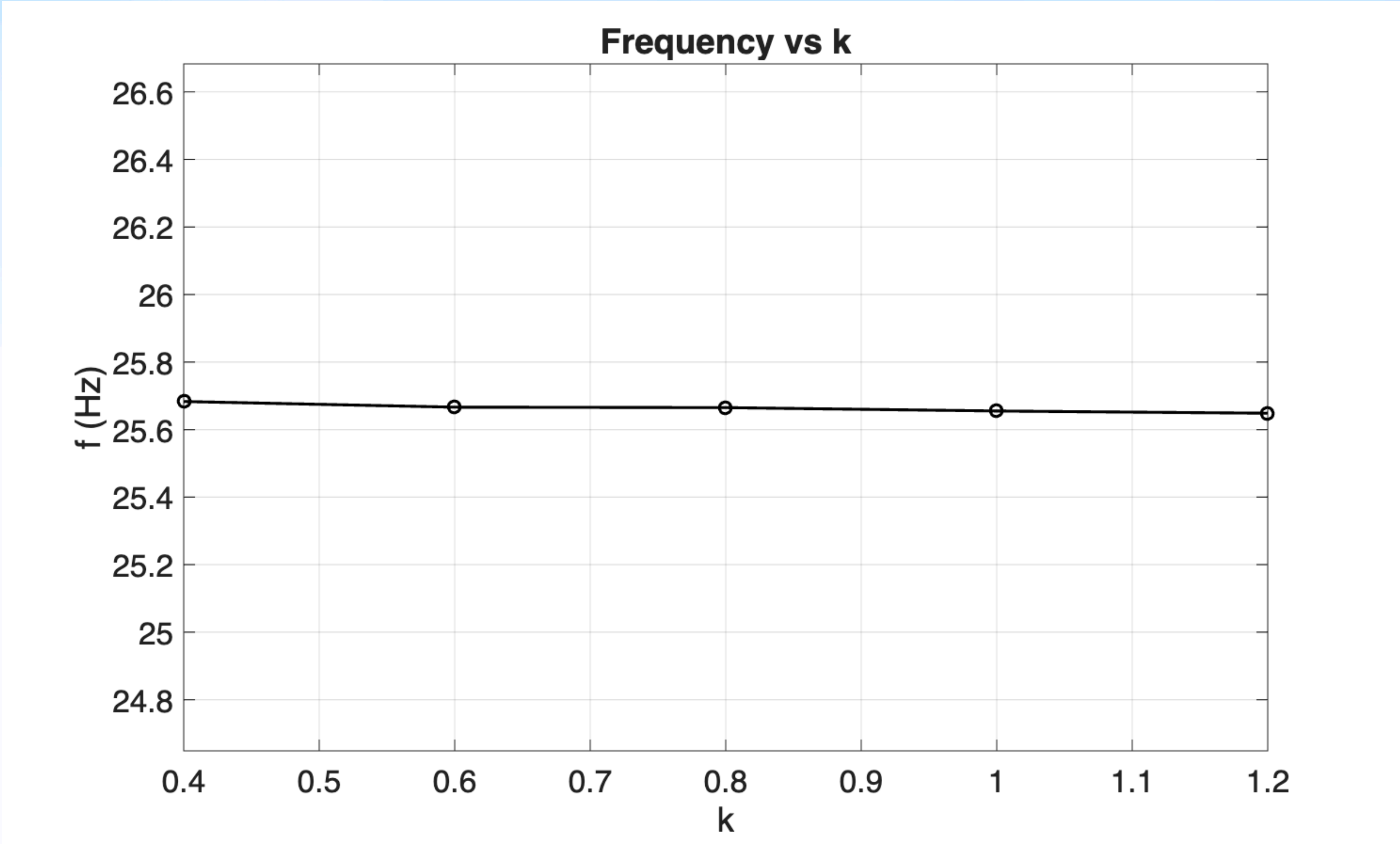
Comparison of one-way trip with different setup, k dependency/ f



Vacuum, Tungsten wire



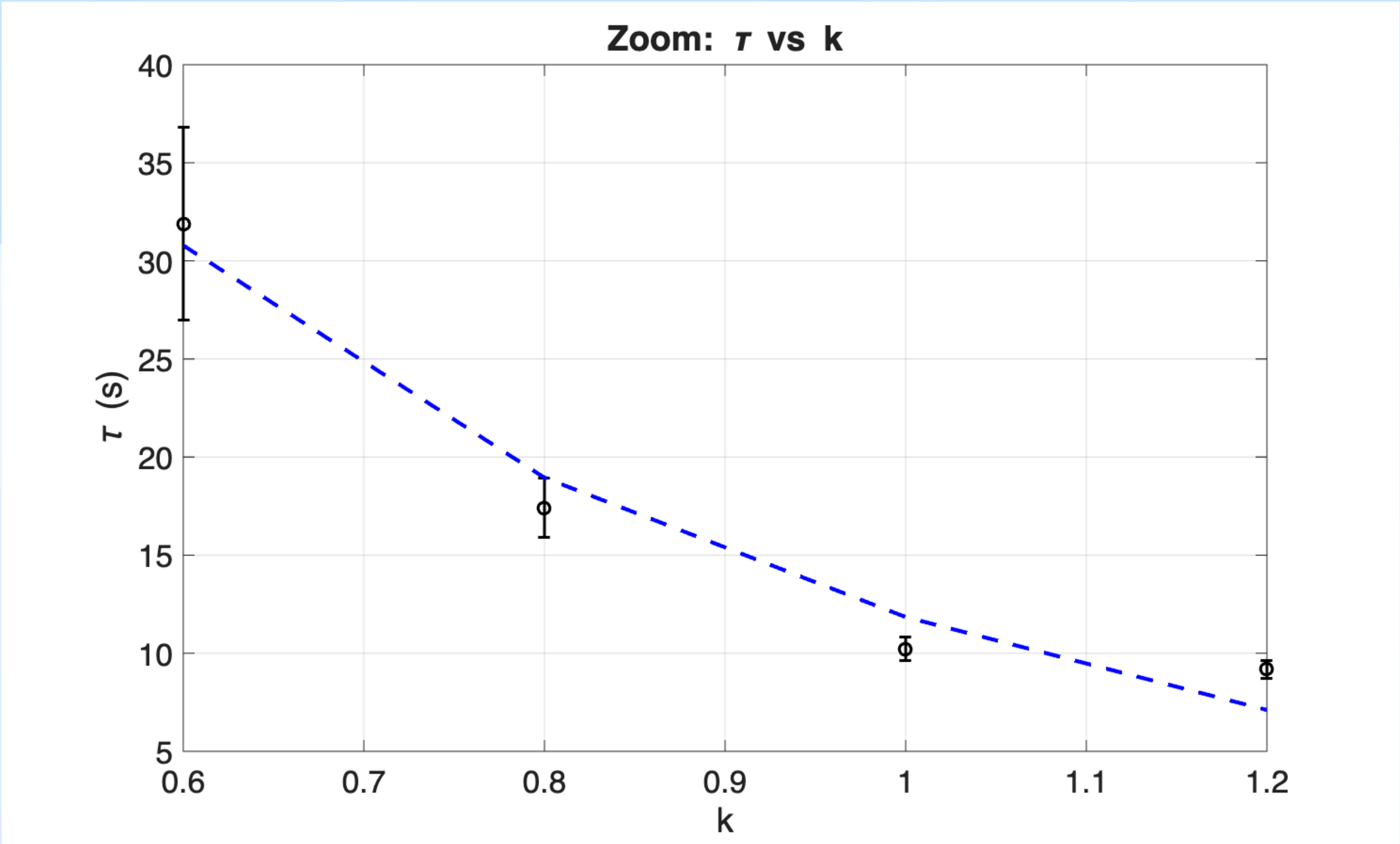
Air, Molybdenum wire



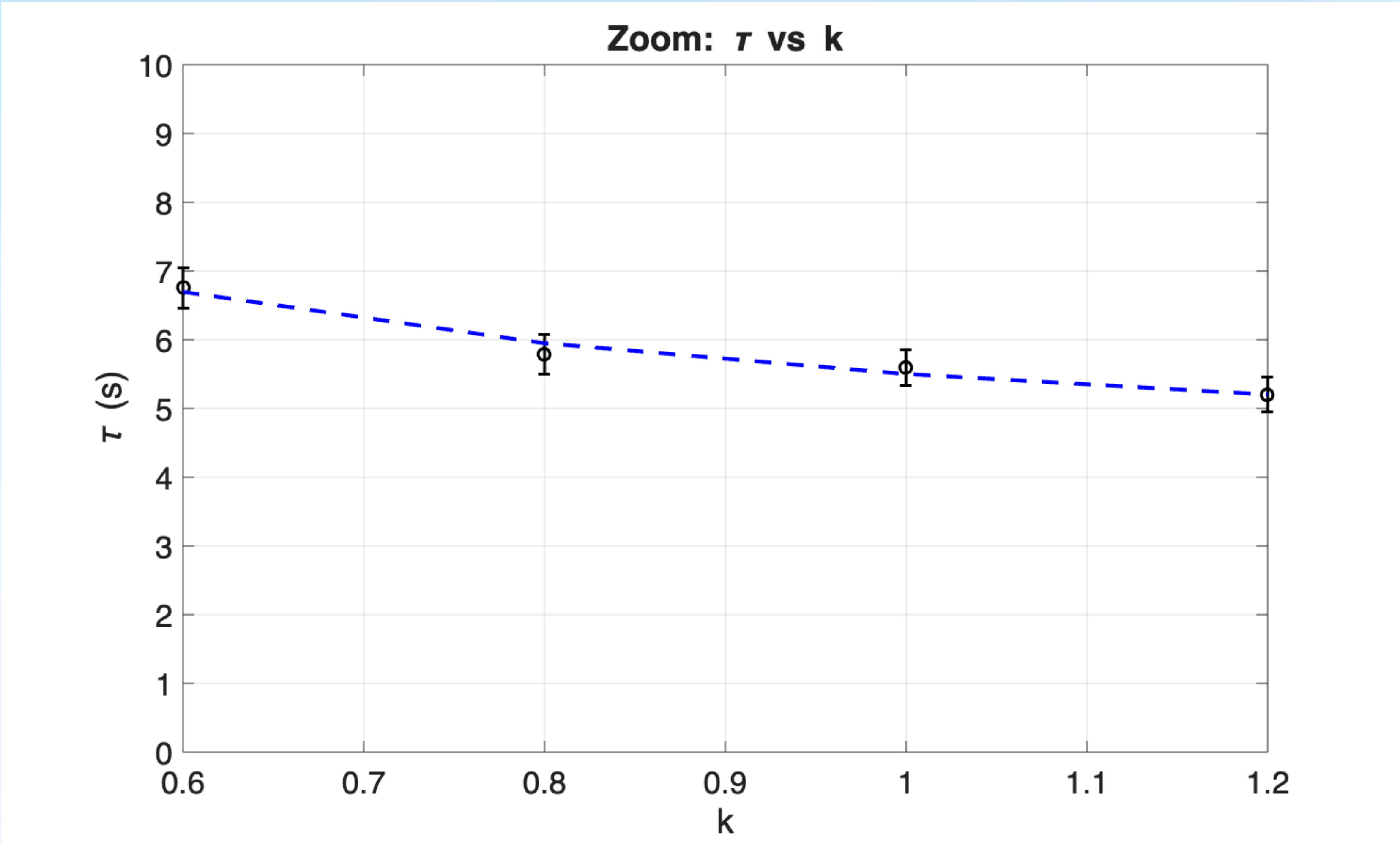
Air, no wire

Results

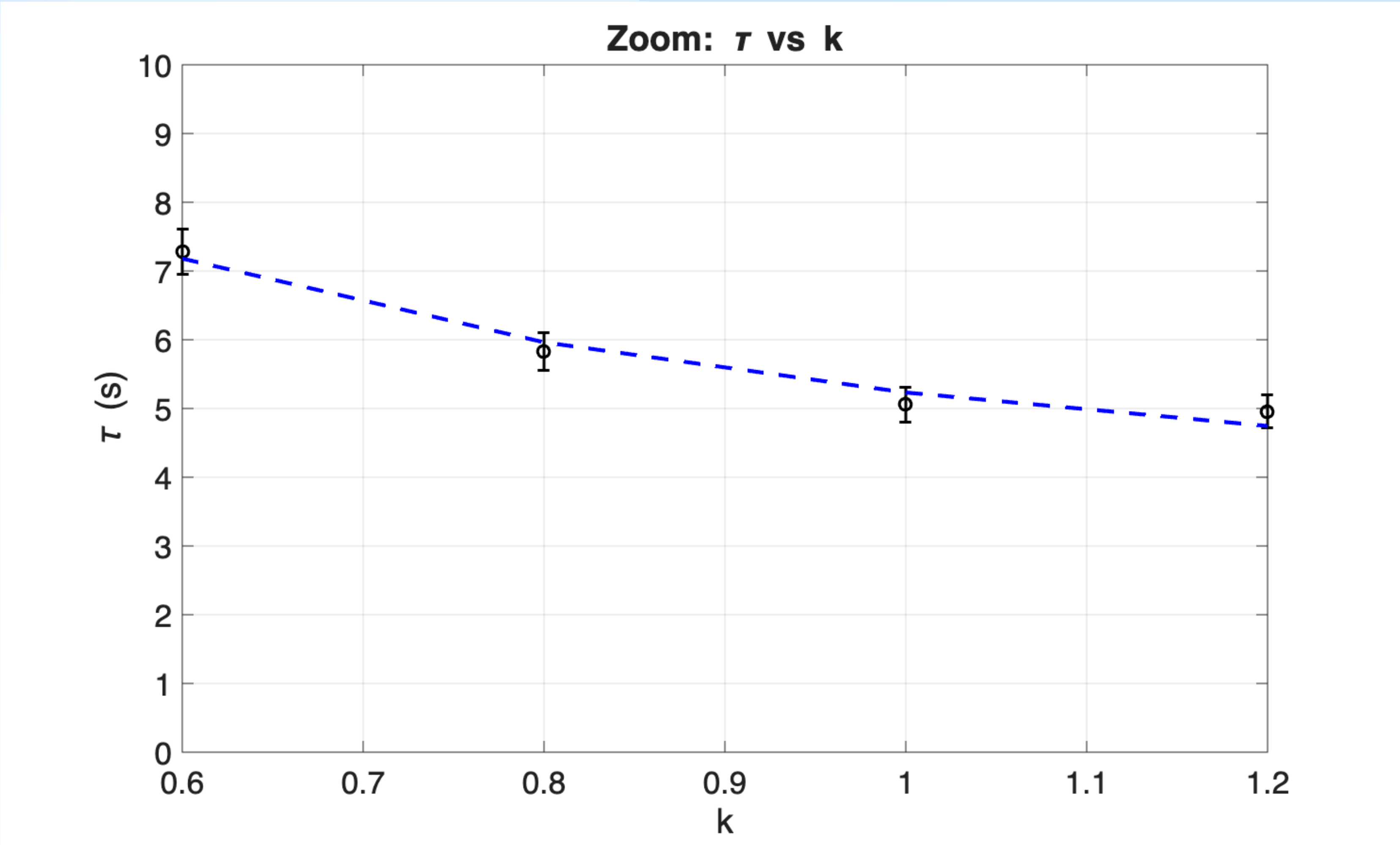
Comparison of one-way trip with different setup, k dependency/ τ



Vacuum, Tungsten wire



Air, Molybdenum wire

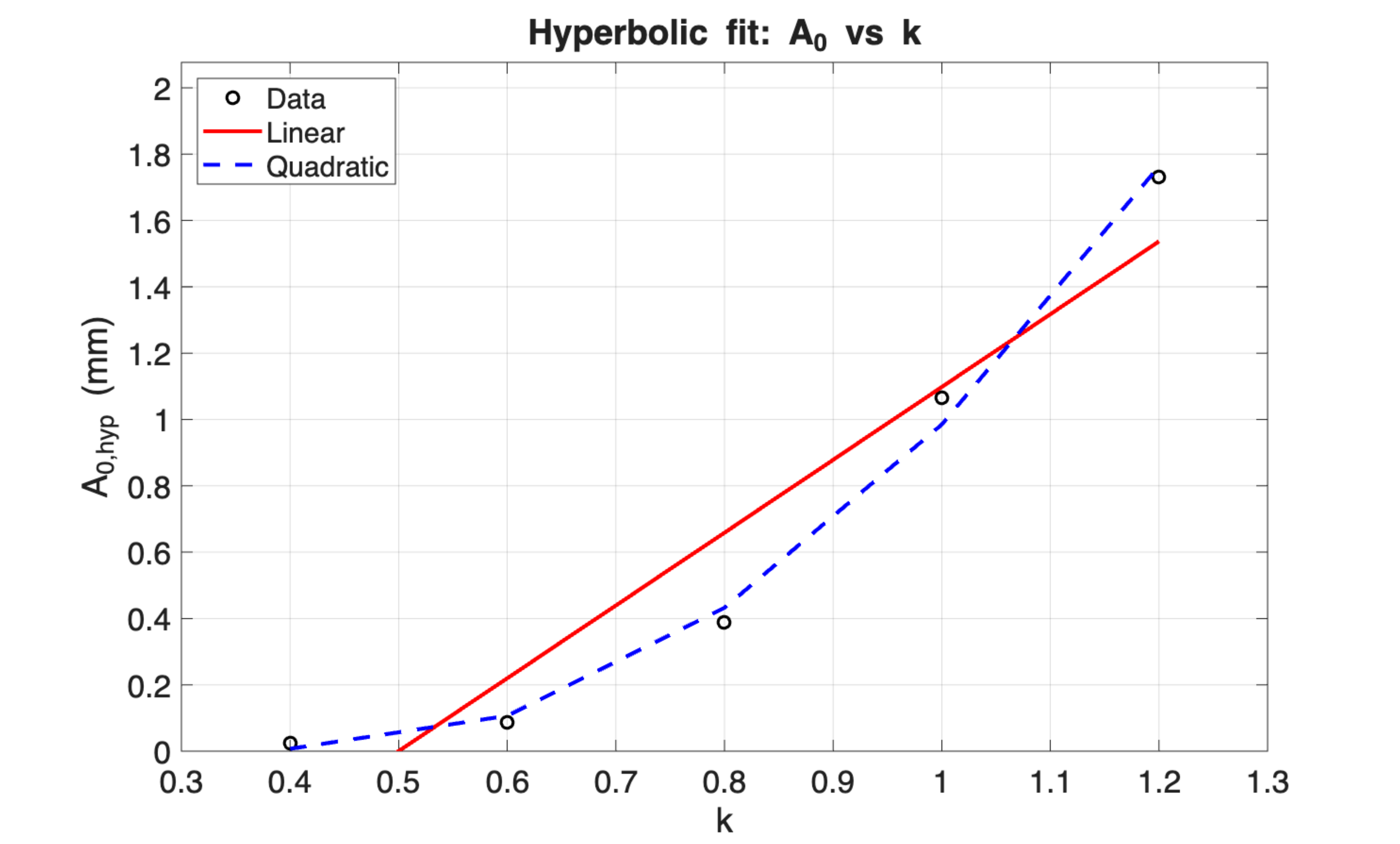


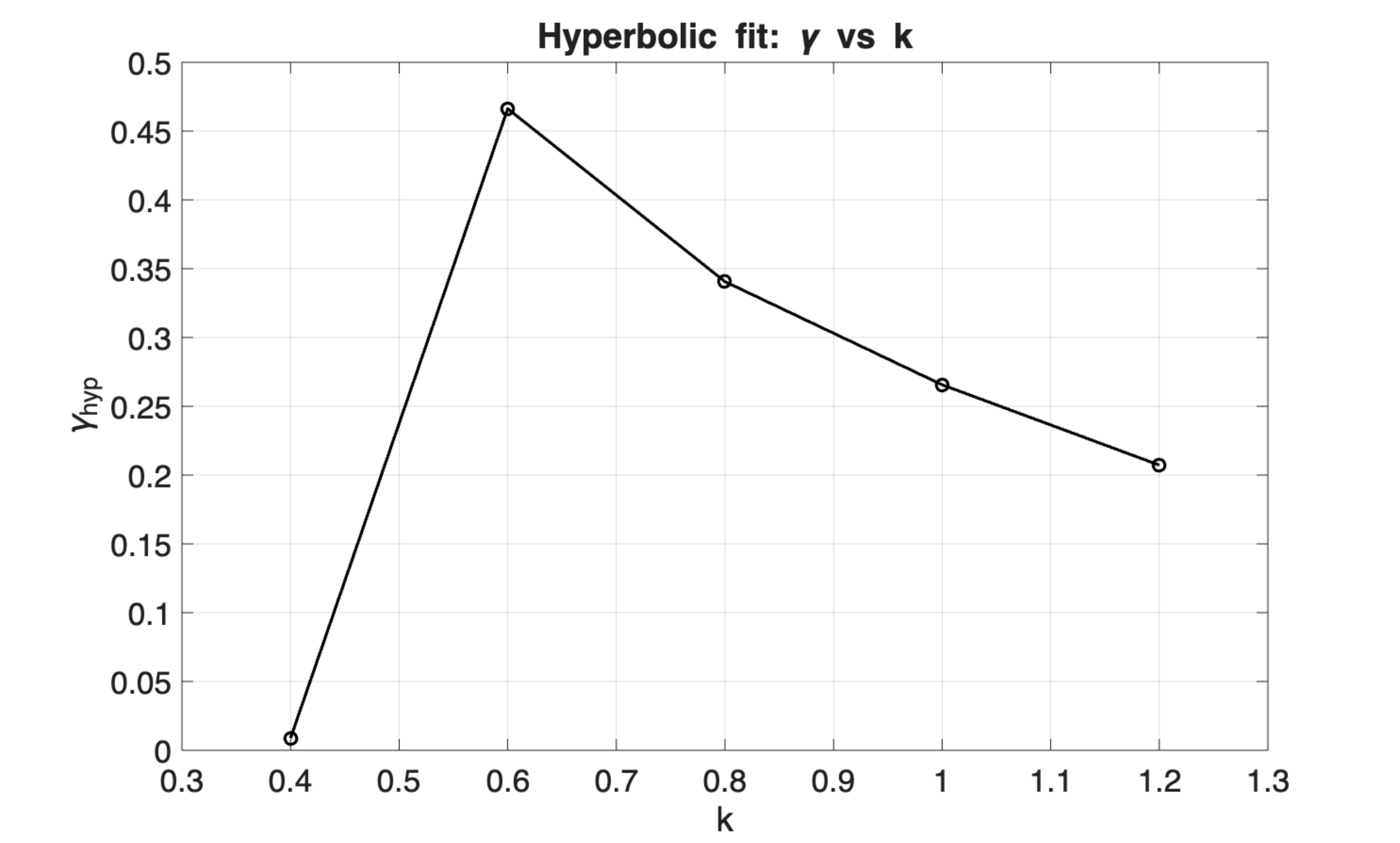
Air, no wire

Results

Hyperbolic fit in vacuum with a wire

$$A(t) = \frac{A_0}{1 + A_0 * \lambda * t} \text{ with } \lambda[mm^{-1}s^{-1}]$$

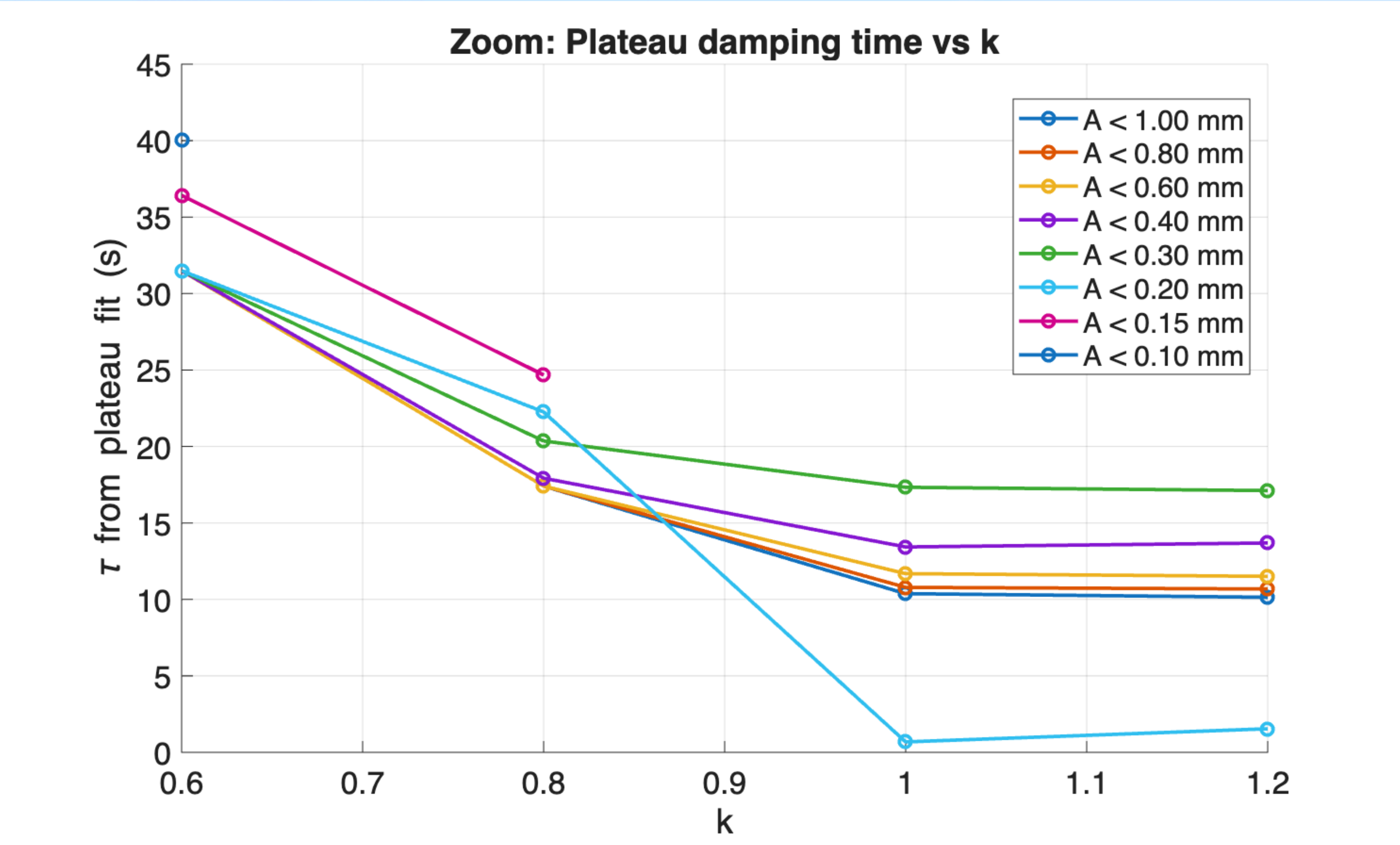


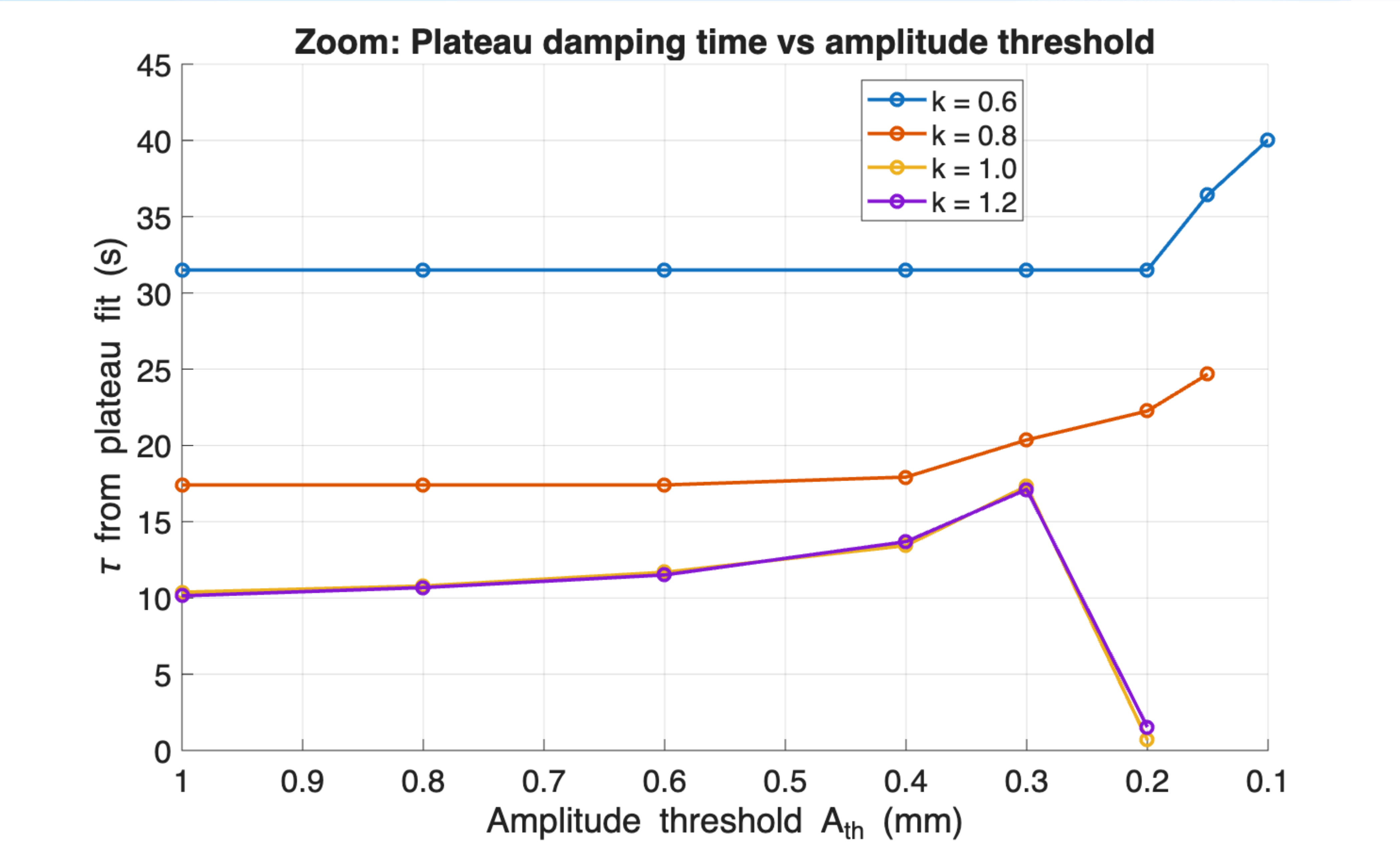


Results

Moving threshold

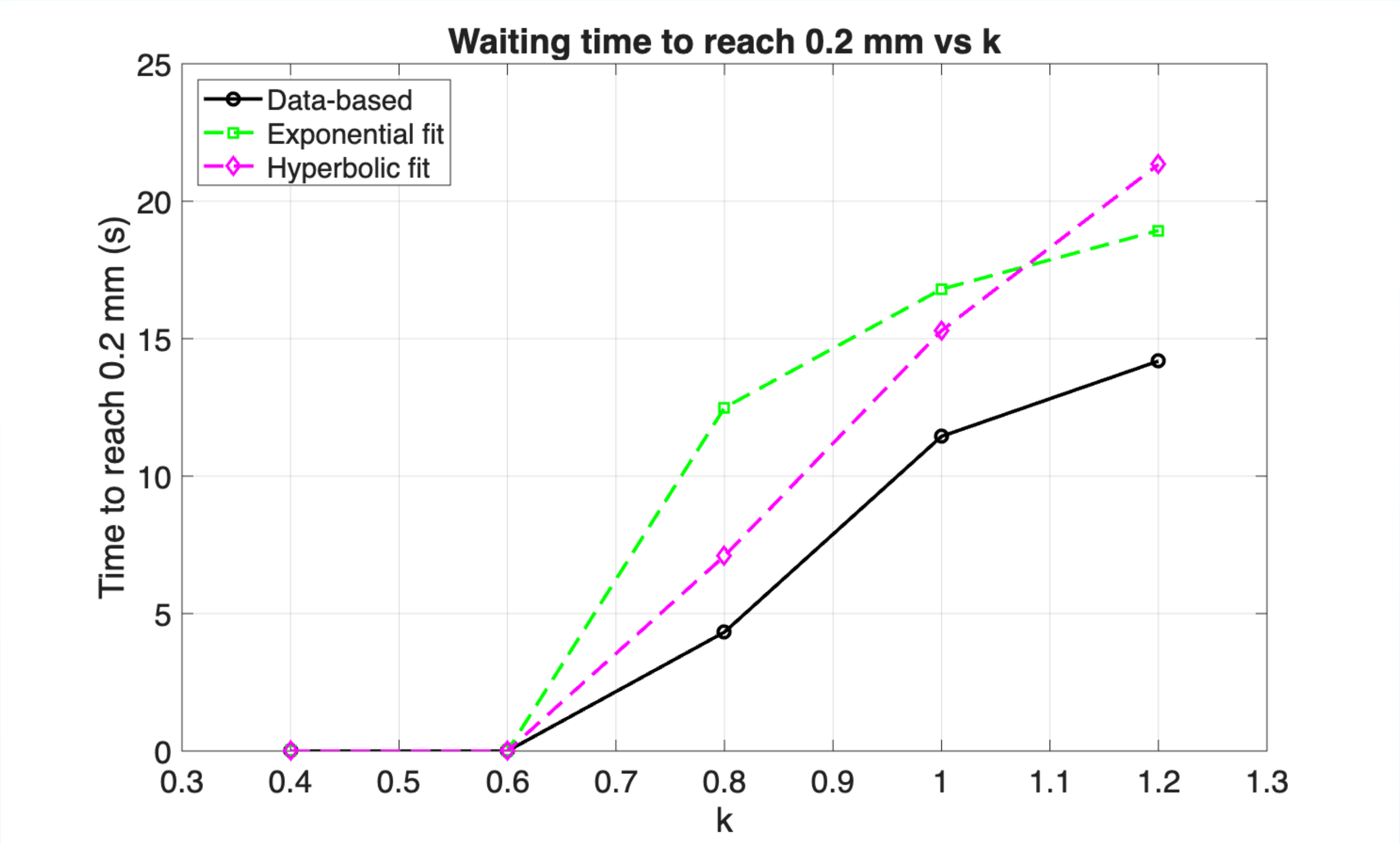
- Moving threshold that select a time where all $A(t) < A_{threshold}$ to fit multiple τ and look its amplitude and k dependency:





Results

Find a characteristic time for the amplitudes to reach a certain amplitude A=0.2 mm



Results

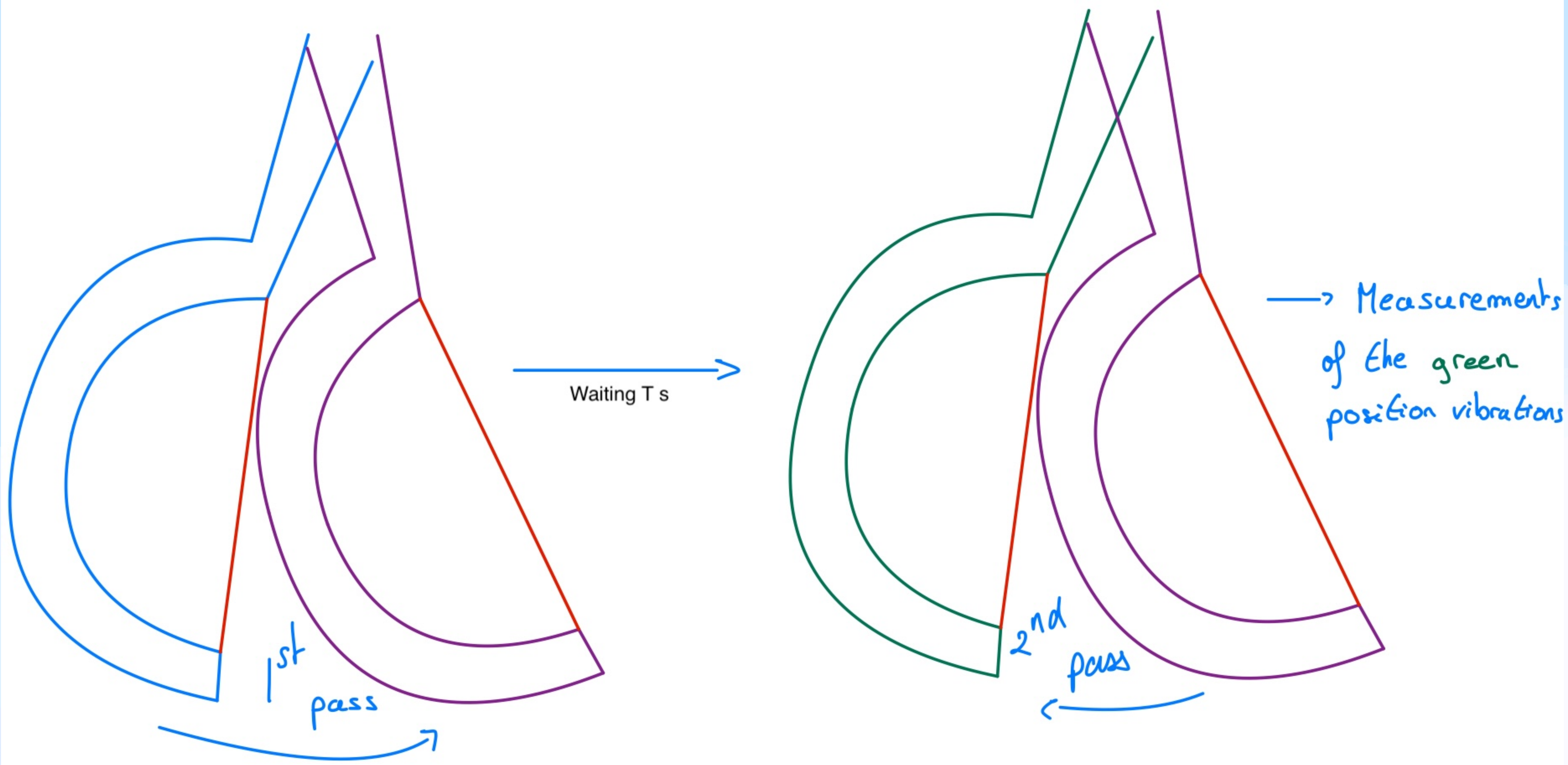
Conclusion of all one-way cases

	Vacuum + wire			Air no wire			Air + wire		
k	A_0	τ	f	A_0	τ	f	A_0	τ	f
0.4	0.024	159	24.2	0.028	8.04	25.7	0.018	9.58	25.6
0.6	0.093	31.9	24.2	0.262	7.29	25.7	0.296	6.75	25.5
0.8	0.410	17.4	24.2	0.724	5.82	25.7	0.634	5.79	25.5
1.0	1.034	10.2	24.2	1.25	5.06	25.7	0.937	5.59	25.5
1.2	1.576	9.17	24.1	1.16	4.96	25.6	1.37	5.21	25.6

Table: Comparison of each vibration parameters vs k

Results

2-way measurements with interval T in s

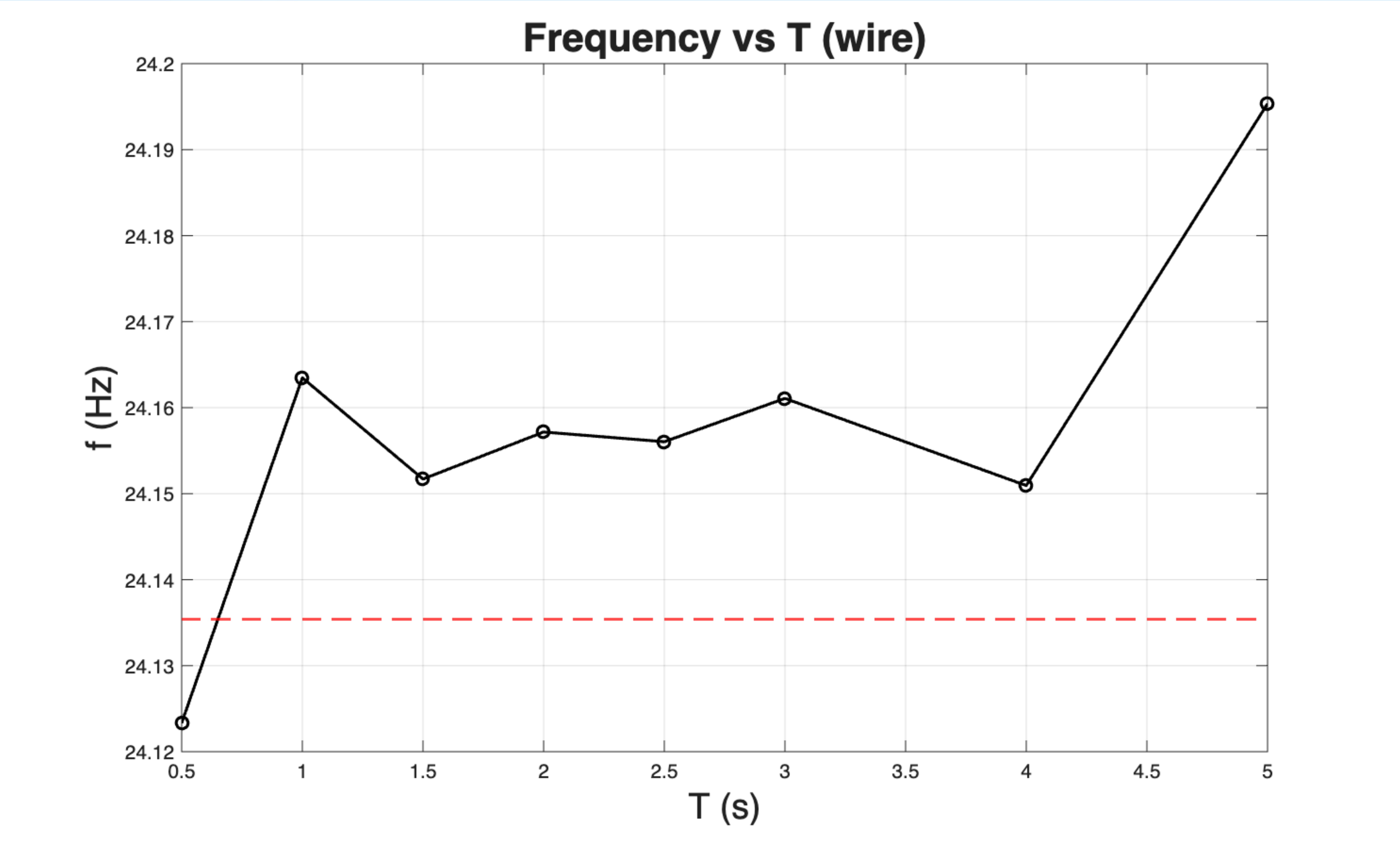


T represents the waiting time between the first scanner pass and the start of the return motion.

The same tracking point was used for all configurations to ensure consistency between measurements.
Recordings were obtained with the Fujifilm X-T50 camera operating at 200 fps.

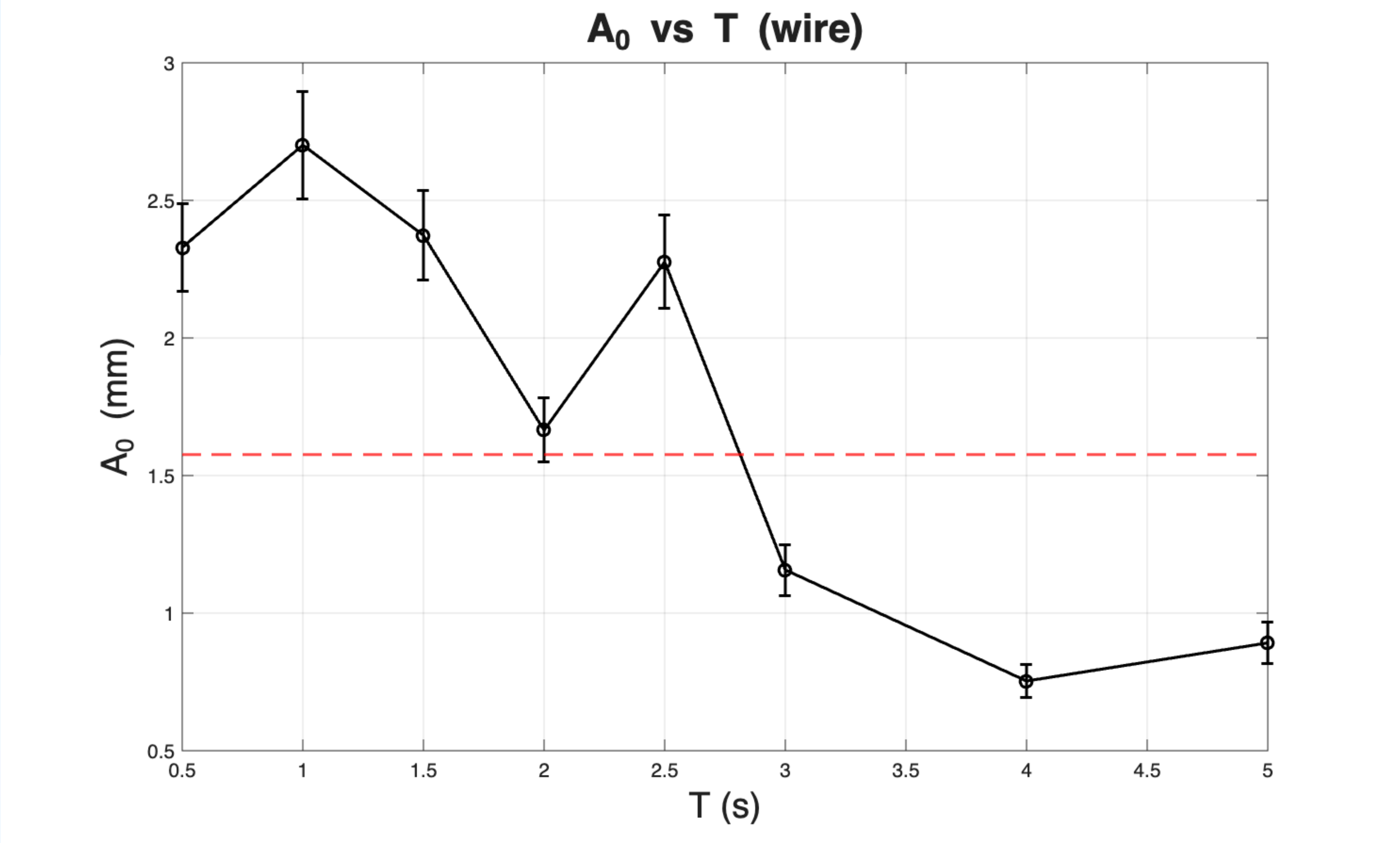
Results

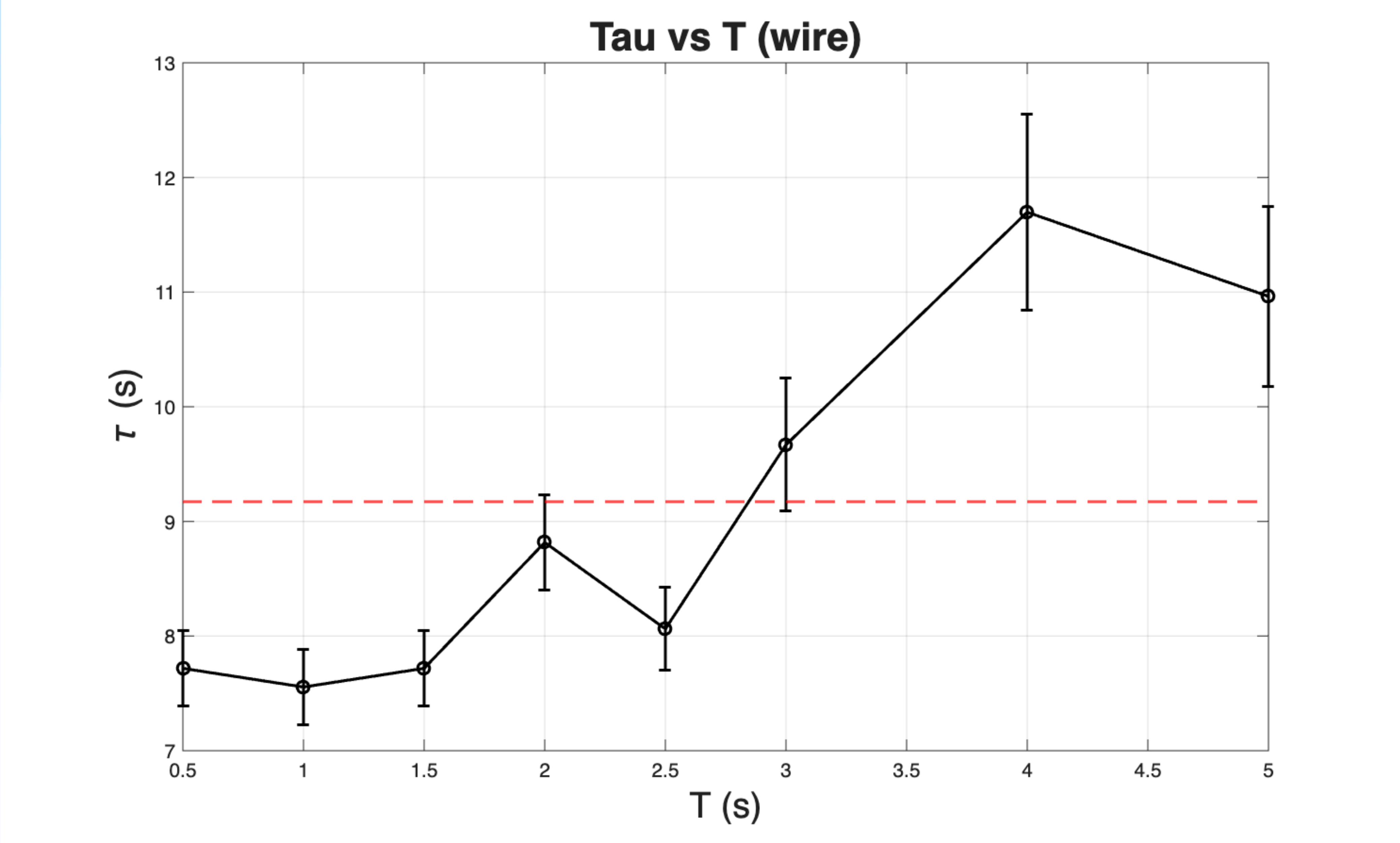
2-way with intervals T going from 0.5s to 5s, k=1.2/ f



Results

2-way with intervals T going from 0.5s to 5s, k=1.2/ τ and A_0



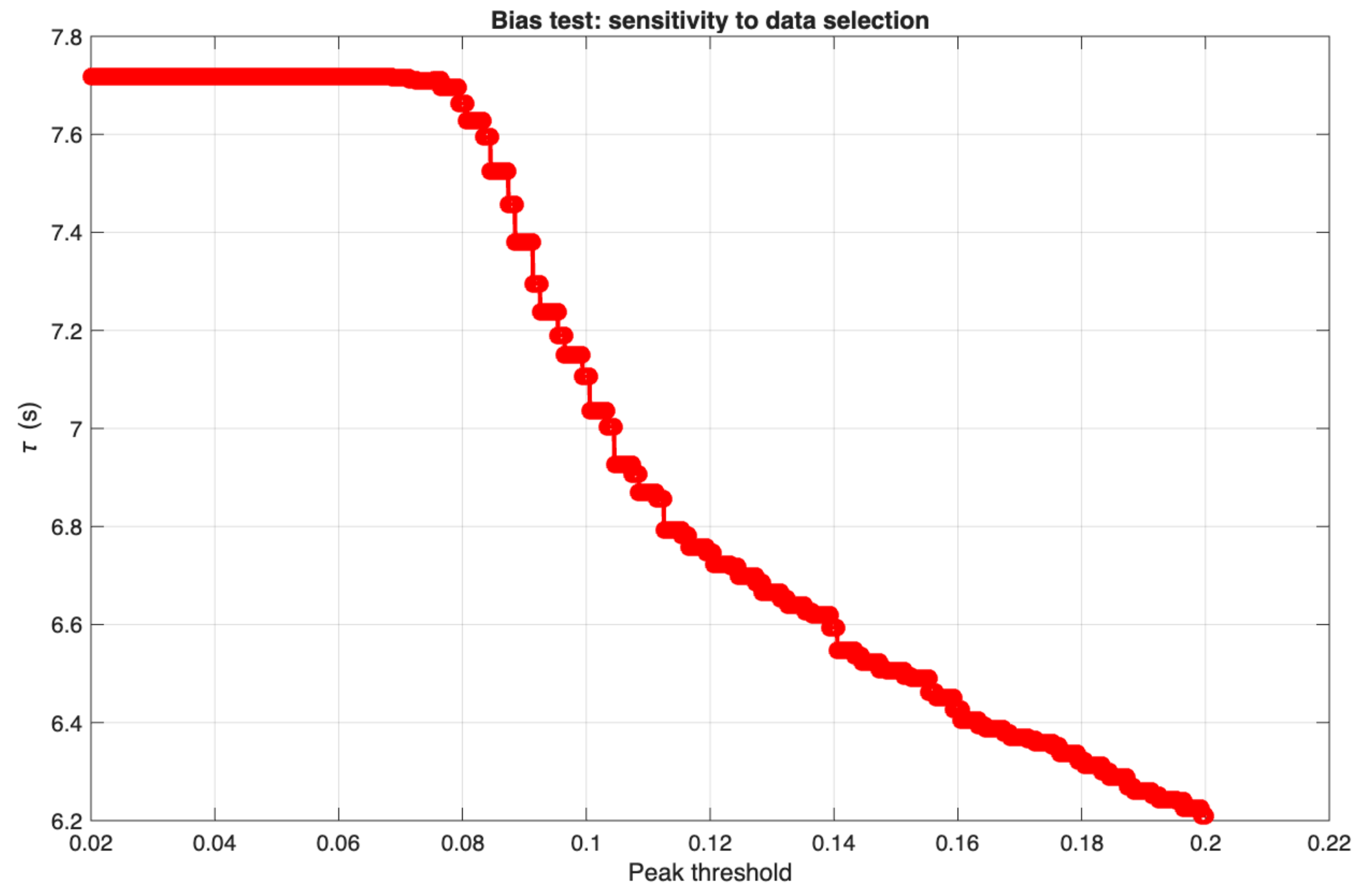


Perturbed at T=3s

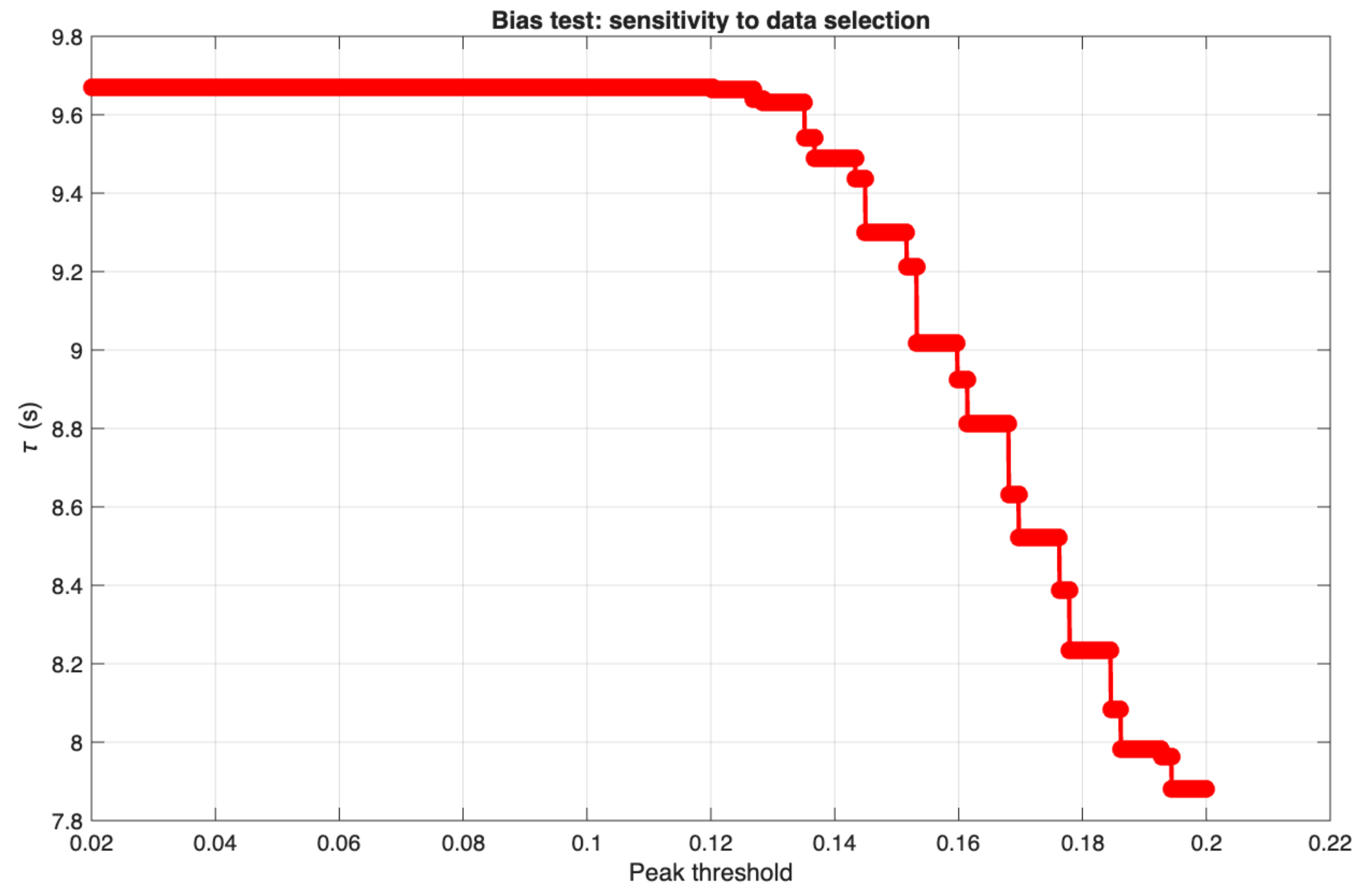
Results

Dependency on the quality of the data

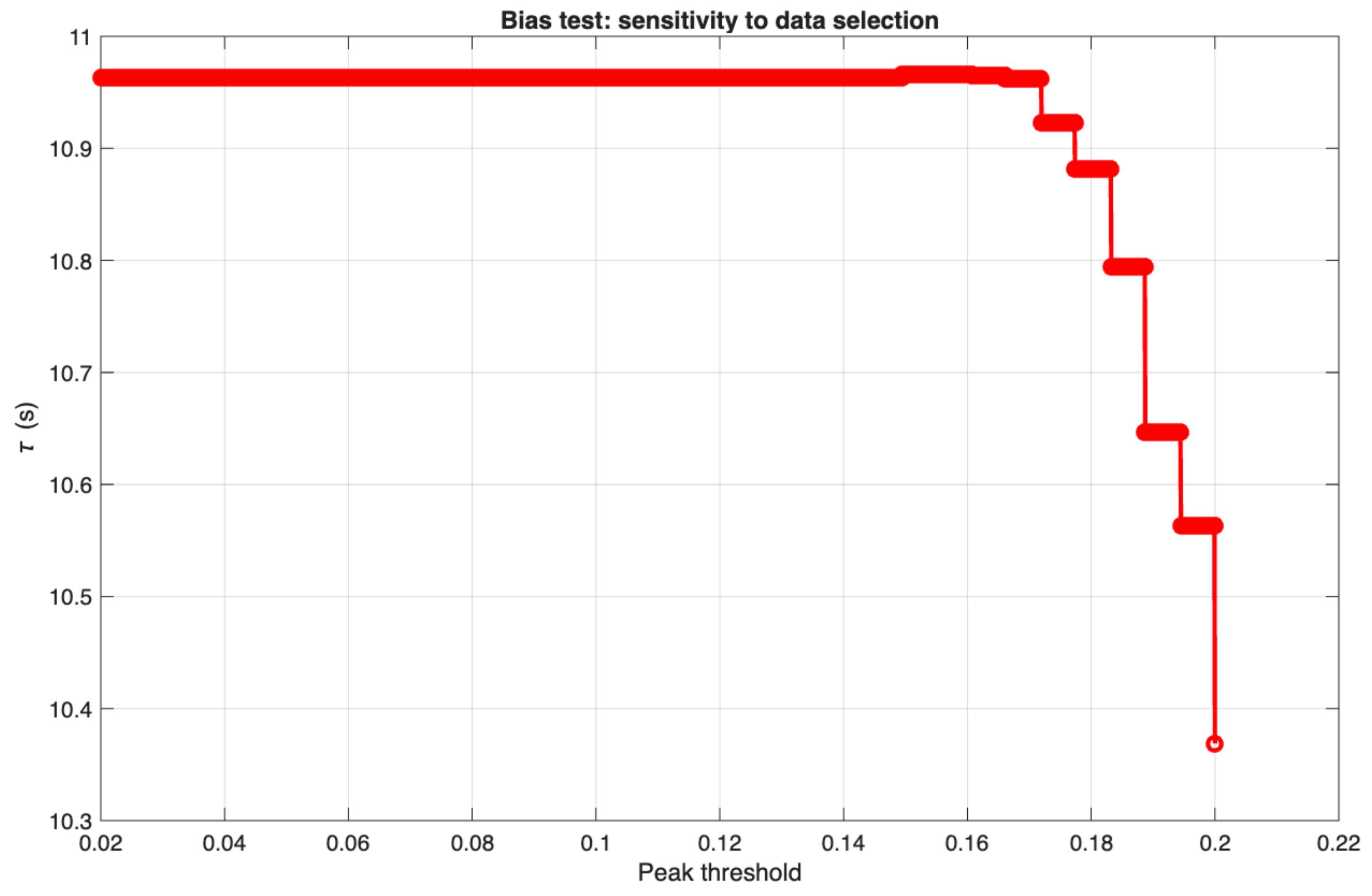
- The goal of using a moving threshold for peak selection ($p_k = A_0\alpha$ with α the relative threshold) was to determine whether high amplitudes have a higher weight and bring noise into the determination of τ (the red dashed line represents the reference threshold used for peak selection) :



T=0.5s



T=3s

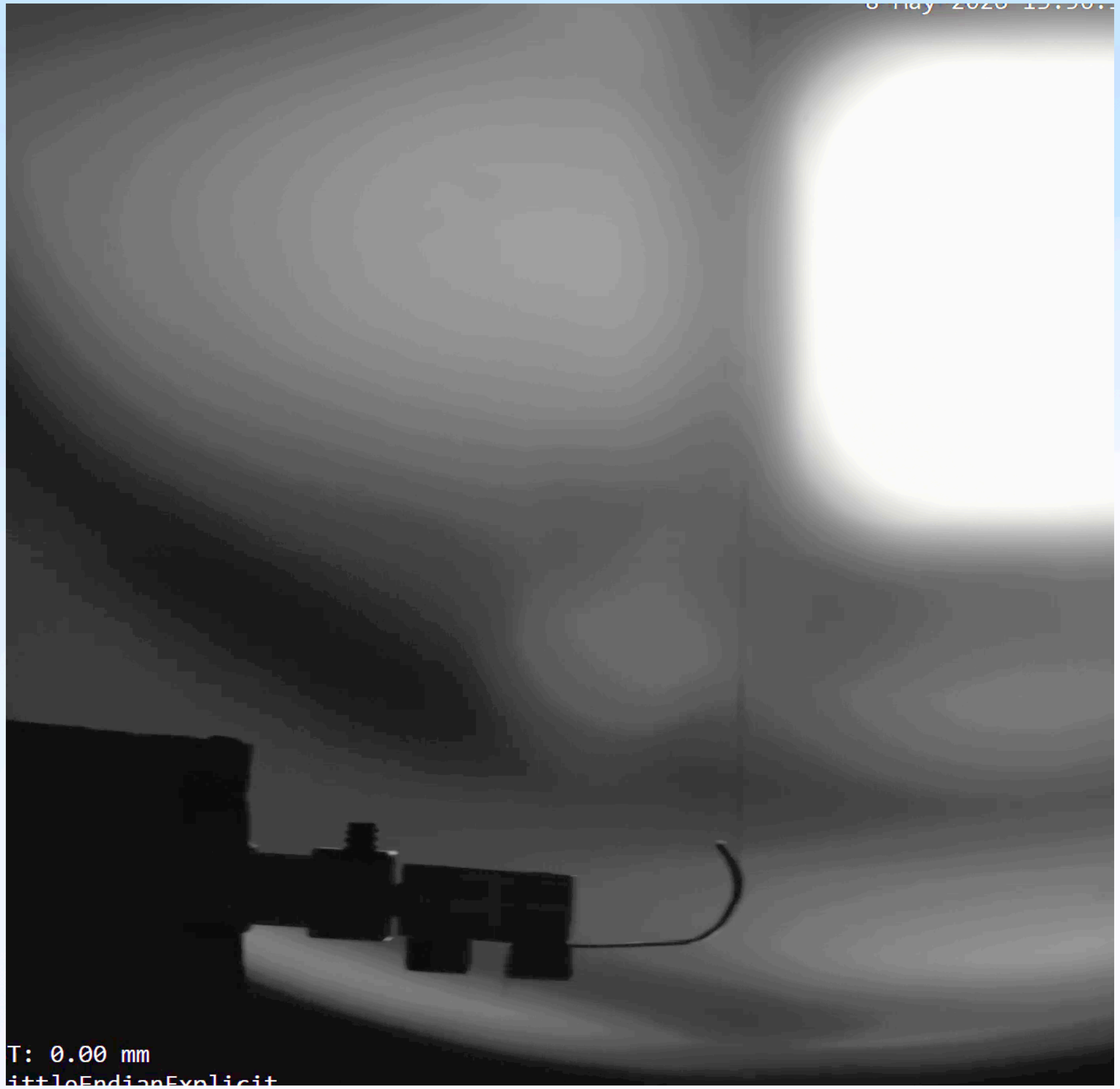


T=5s

At high thresholds, τ decreases significantly due to the selection of only early-time peaks, which are more sensitive to fitting errors and transient effects.

Results

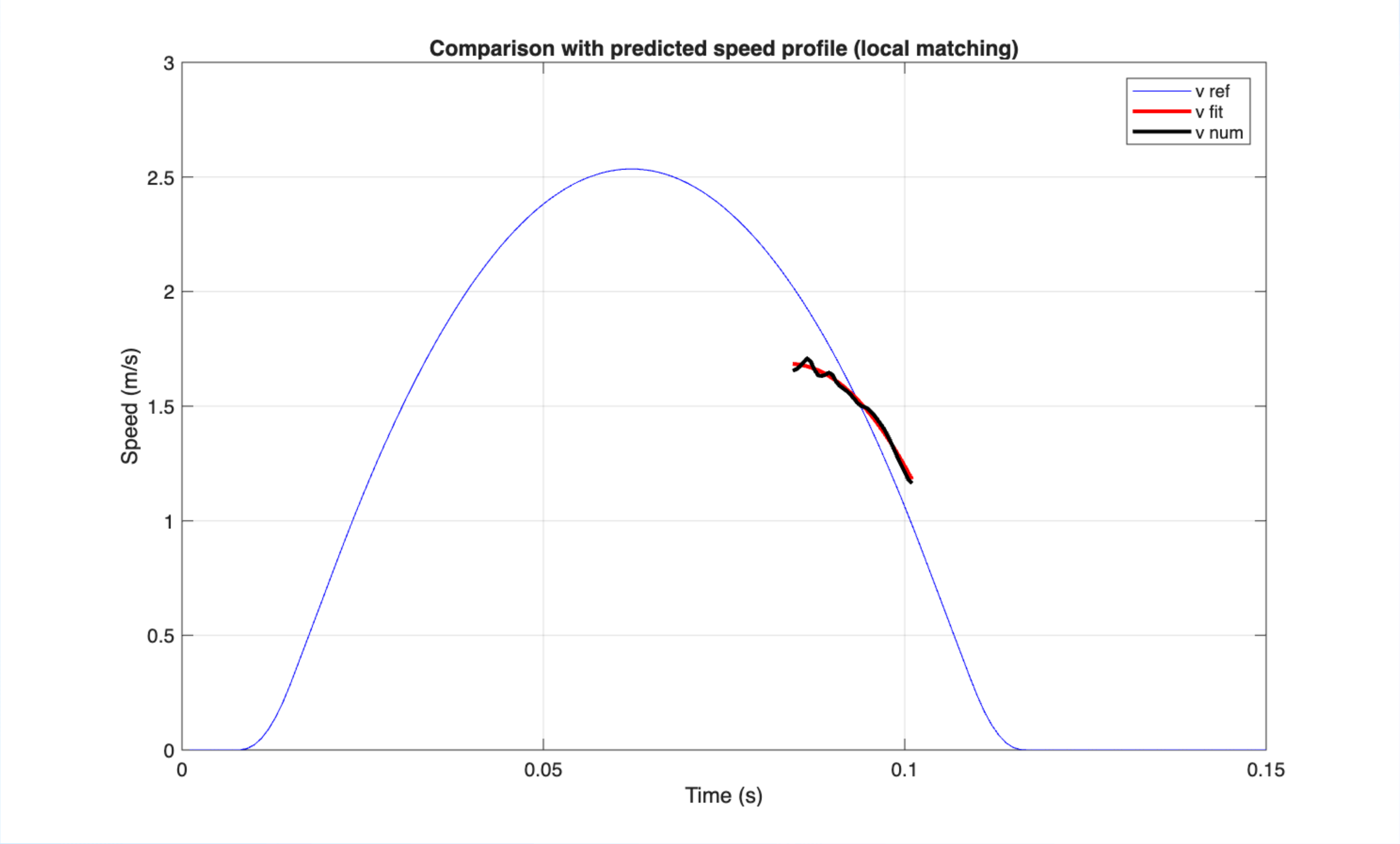
Speed profile recordings



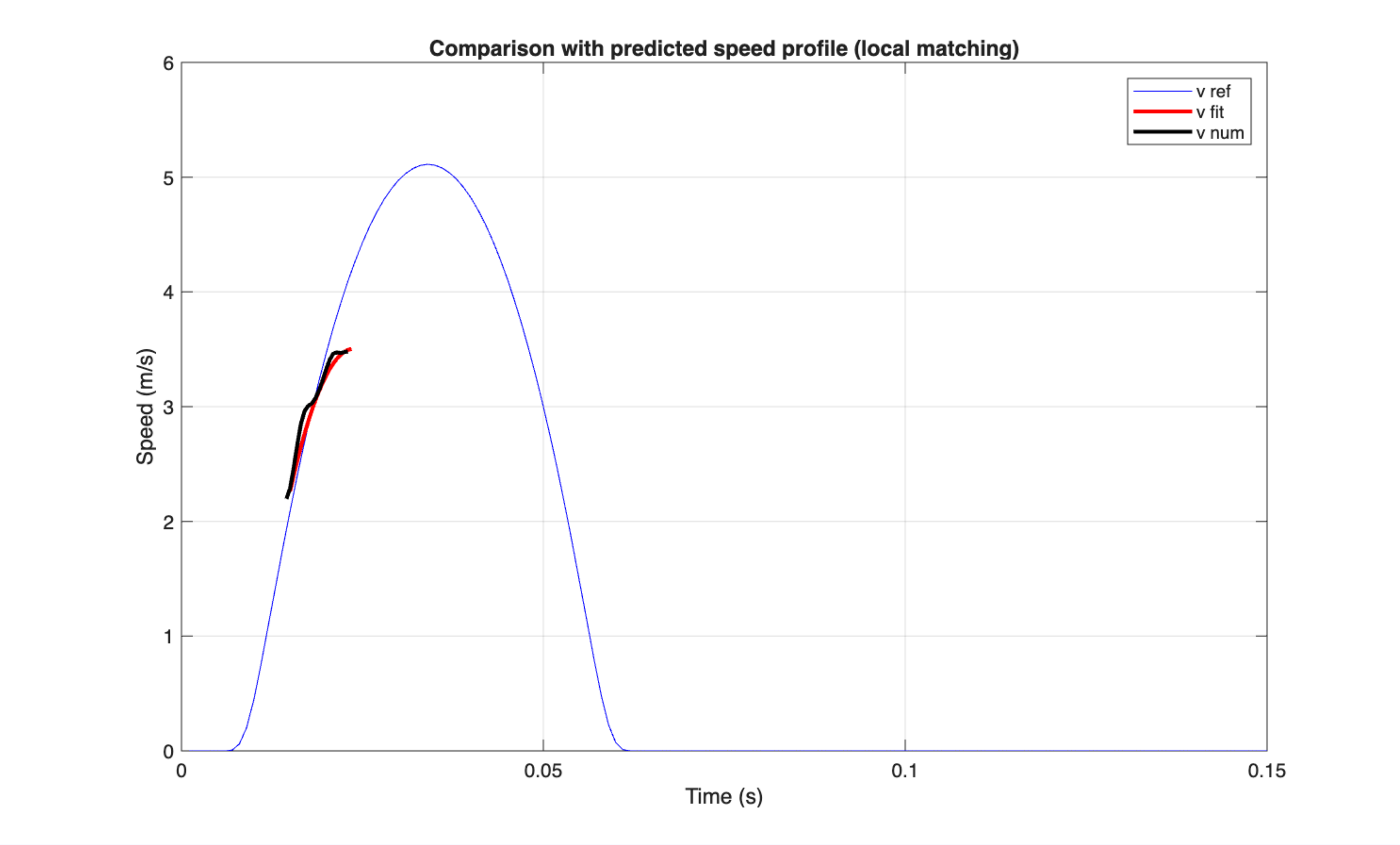
Results

Speed profile measurements

- We did the tracking using Tracker, with the $\vec{x}$ and $\vec{y}$, we can either fit the trajectory and extract the speed or stepwise calculate the speed, and combine both components using the Euclidean norm. Lastly, we define a score that represents the best alignment position of the measured tracking window relative to the predicted speed profile. The score function is used to determine the temporal shift producing the best agreement between the measured and predicted speed profiles: $S - score = \overrightarrow{v_{meas}} - \overrightarrow{v_{ref}}(\tau)$ where $\overrightarrow{v_{ref}}(\tau)$ is a portion of the predicted speed profile of the length as $\overrightarrow{v_{meas}}$ and with τ going from $t = 0$ to $t = t_f - dt * length(\overrightarrow{v_{meas}})$



k=0.6



k=1.2

Conclusion

- Successful characterization of transversal vibrations of the wire scanner
- Frequency remains approximately constant around 25 Hz for all configurations
- Damping strongly depends on the environment (vacuum, air, wire)
- Higher $\mathbf{k}$ values increase the vibration amplitude and reduce damping time
- Tracker and Matlab methods provided consistent vibration analysis results
- 2-way measurements show that waiting time influences residual vibrations
- Further work: improve uncertainty analysis and complete speed profile measurements

Thanks for your attention, let me know your questions or remarks.

References

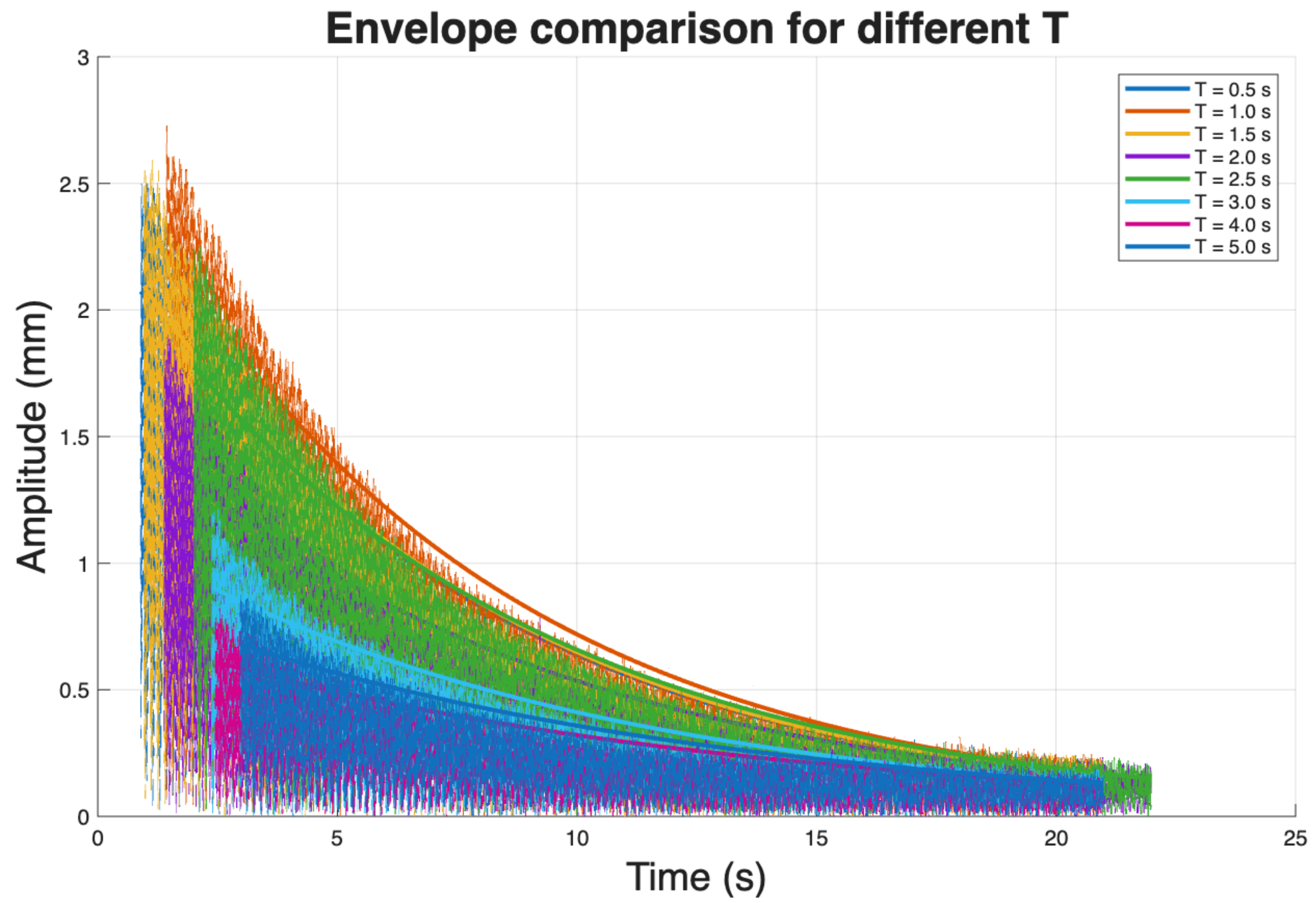
- Herranz, J., Dehning, B., Effinger, E., Emery, J., Guerrero, A., Pereira, C., and Barjau, A., *Wire Scanners and Vibrations – Models and Measurements*, Proceedings of IBIC2015, Melbourne, Australia, 2015.
- Herranz, J., Barjau, A., Dehning, B., et al., *Vibration measurements of a wire scanner – Experimental setup and models*, Mechanical Systems and Signal Processing, Vol. 70–71, pp. 974–994, 2016.
- Arutunian, S. G., Dobrovolski, N. M., Mailian, M. R., Sinenko, I. G., and Vasiniuk, I. E., *Vibrating Wire Scanner for Beam Profile Monitoring*, Proceedings of the 1999 Particle Accelerator Conference, New York, USA, 1999.
- Open Source Physics Project, *Tracker Video Analysis and Modeling Tool*, https://si.blaisepascal.fr/tracker/

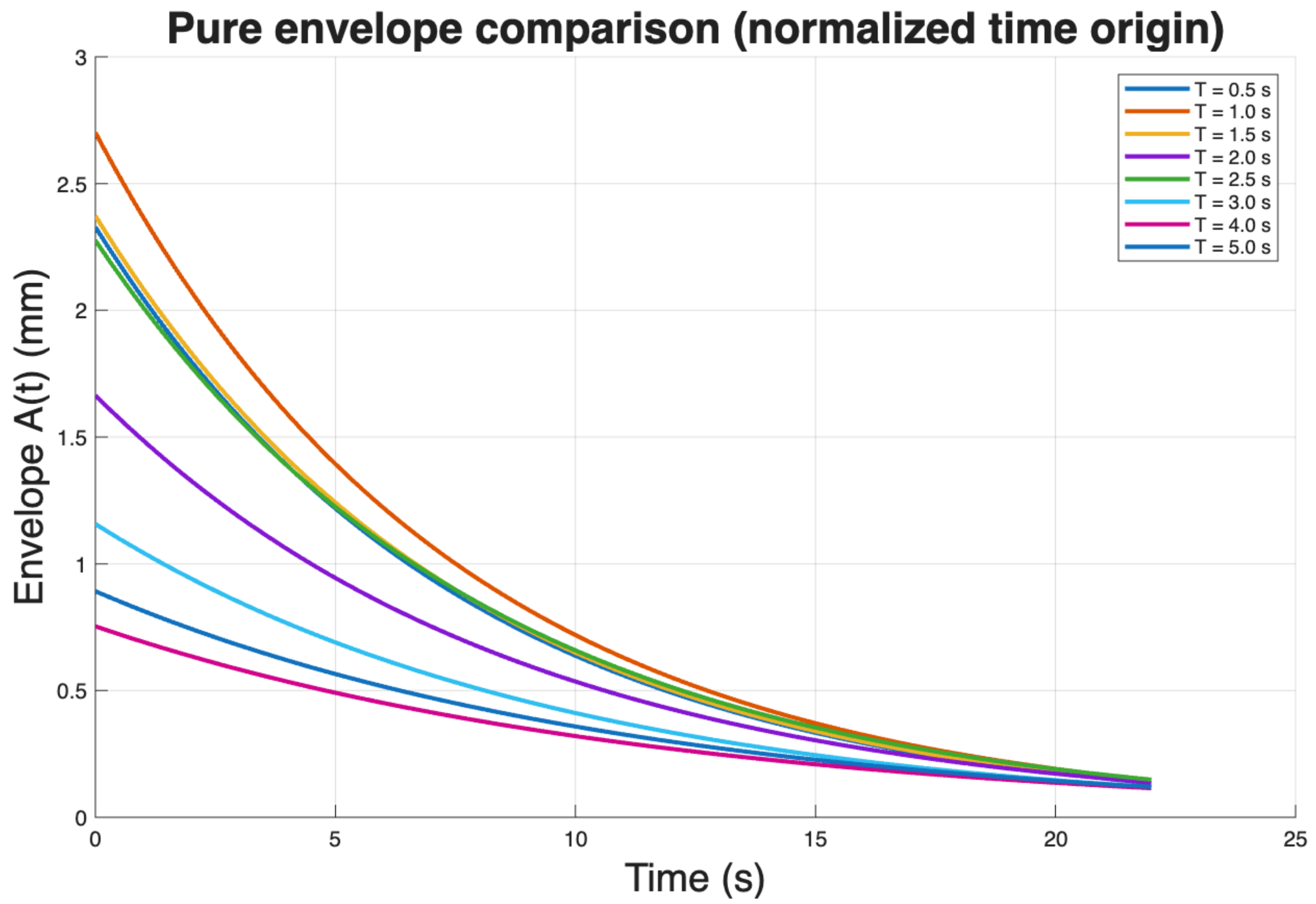
Additional slides

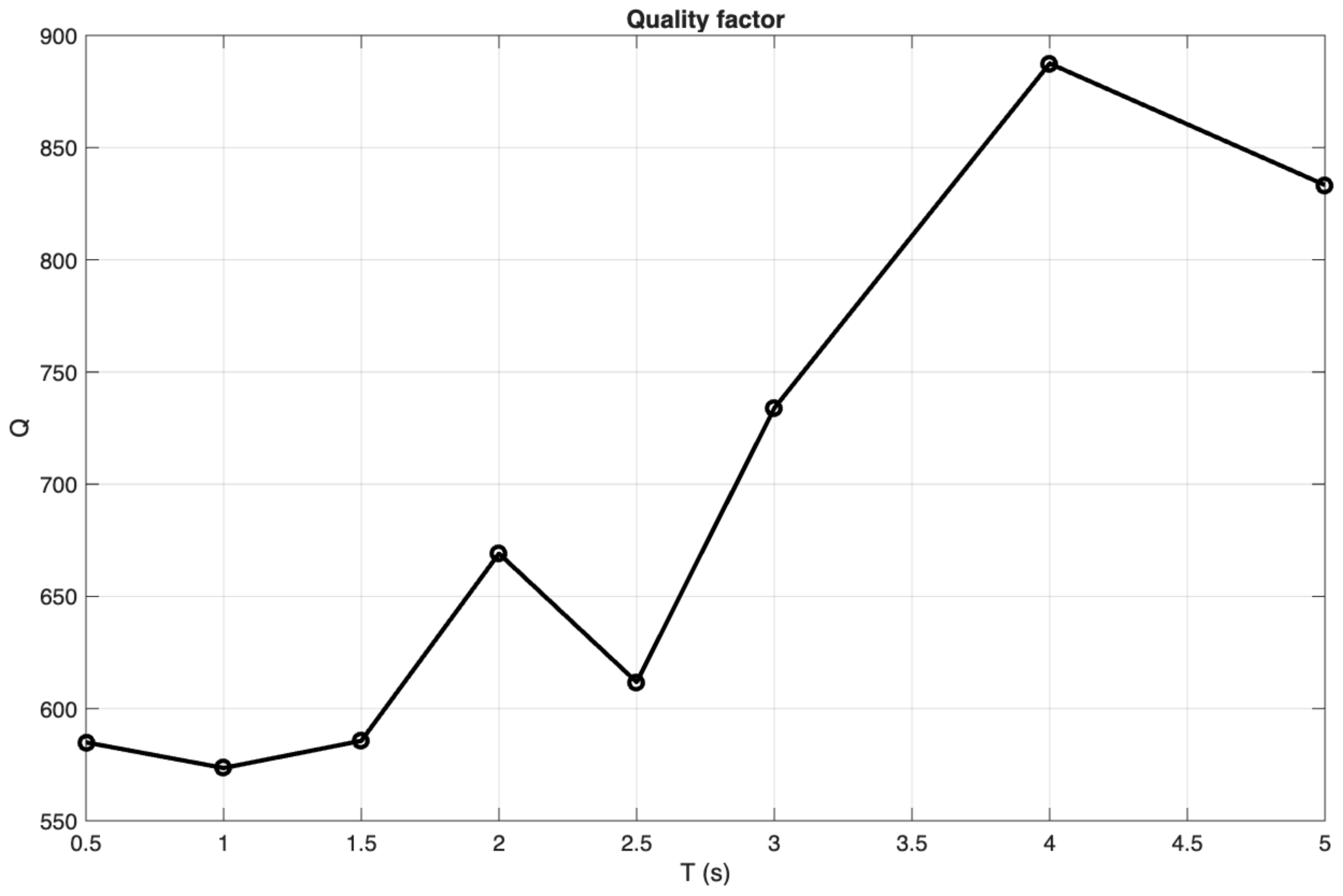
Results

Estimate the best waiting time for a 2-way trip, comparison of envelopes

- From classical mechanics: $\ddot{x} + 2\zeta\omega\dot{x} + \omega^2 x = 0$, we have $\omega = 2\pi f$, $\lambda = 1/\tau$ and $\zeta = \lambda/\sqrt{\lambda^2 + \omega^2}$, therefore, to characterize the amount of damping, we define the Q-factor as $Q = 1/2\zeta$:







Results

Speed profile, k=0.6 and k=1.2