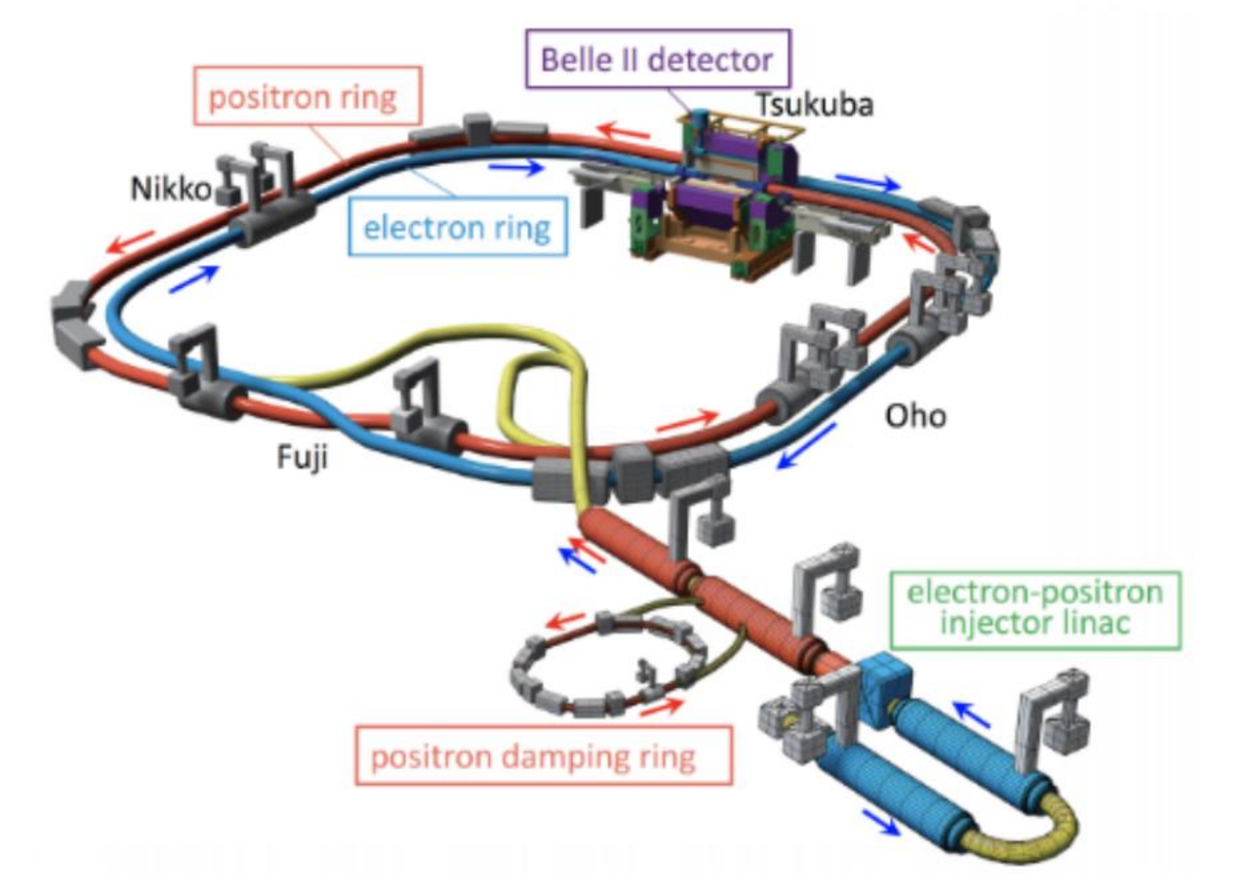
Experimental setup for high-precision laser polarisation determination

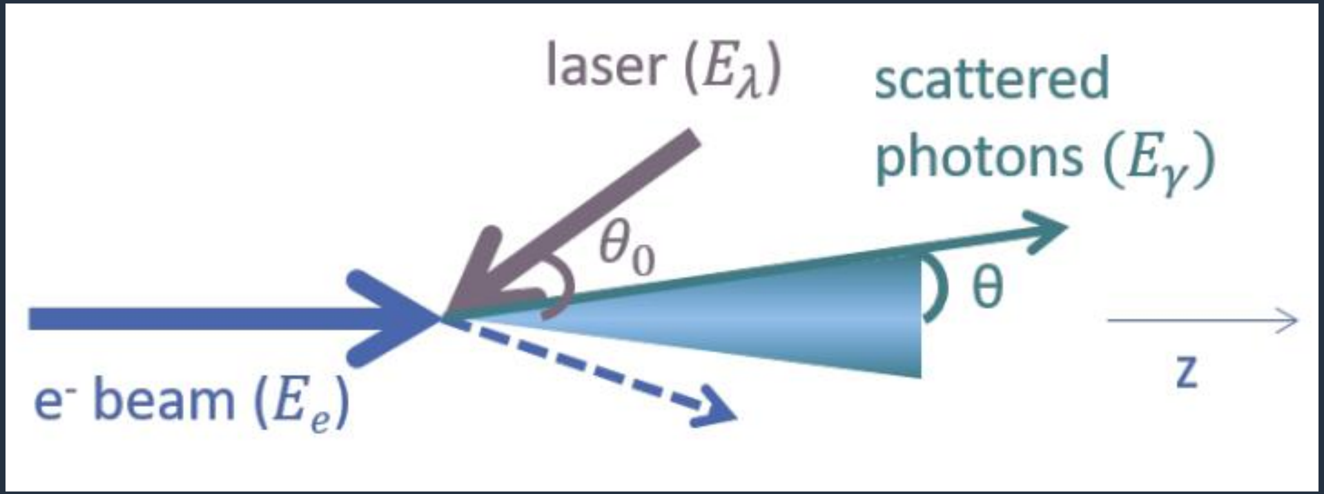
Santiago Rodríguez

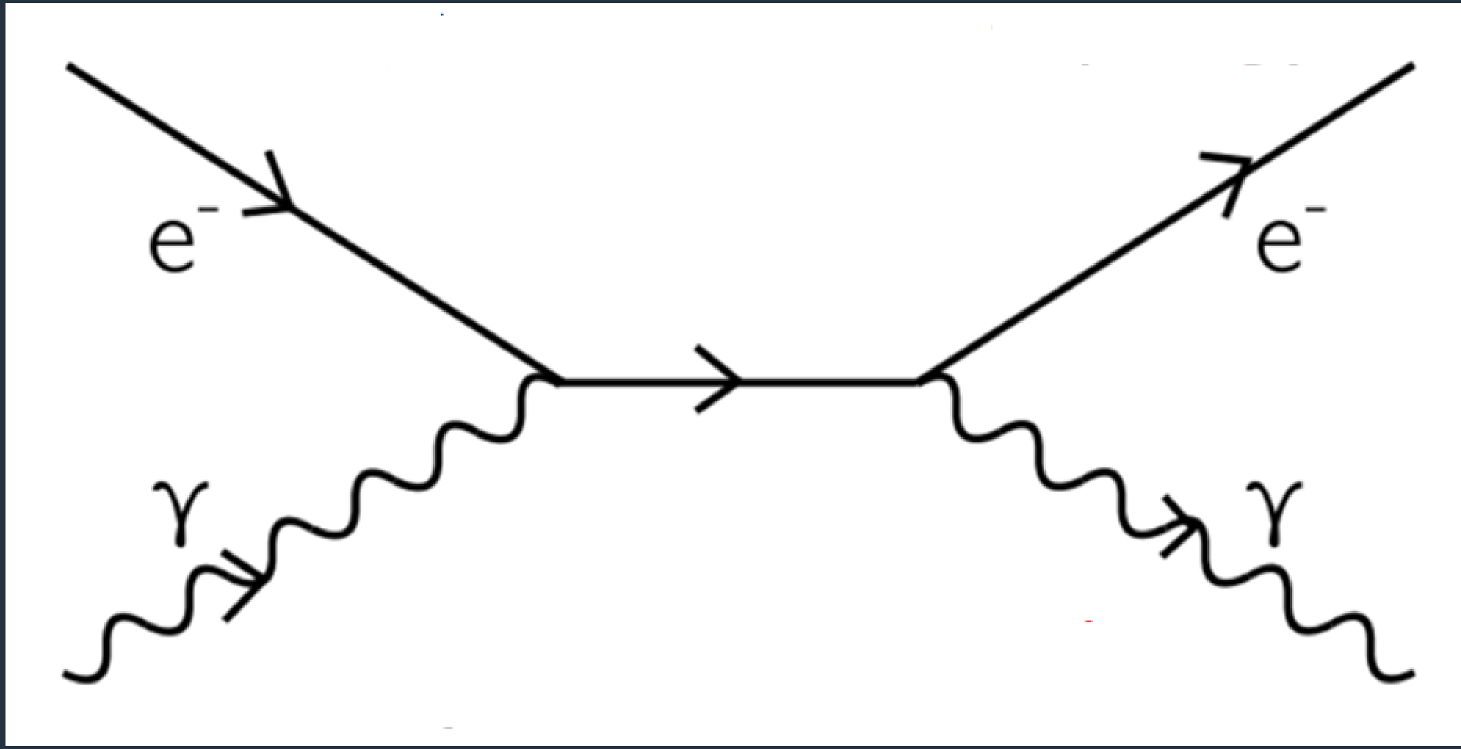
Aurélien Martens

MOTIVATION: We need to measure the polarization of high energy e- beams



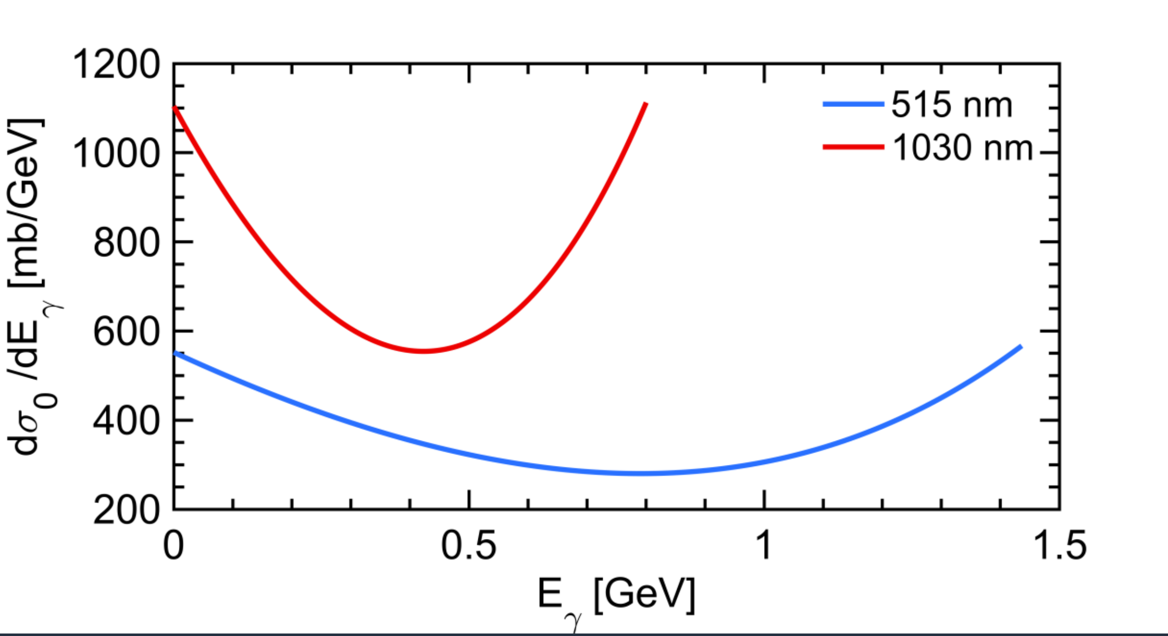
Inverse Compton Scattering

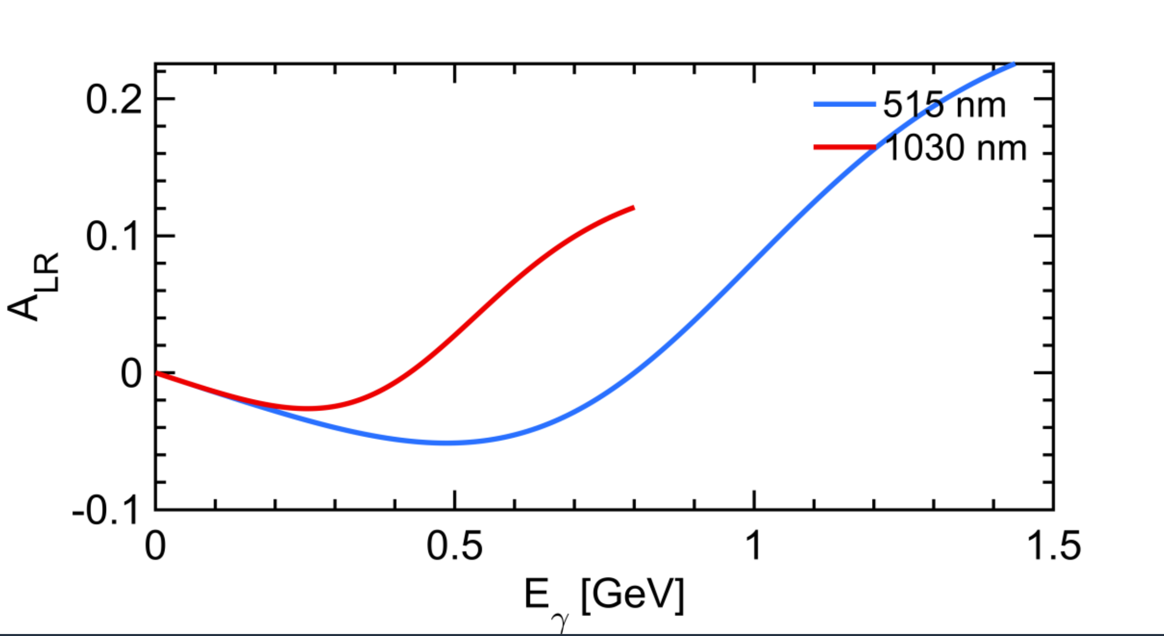




Differential cross section

$$\frac{d\sigma}{dE_\gamma}(E_\gamma) \approx \frac{d\sigma_0}{dE_\gamma}(1 + P_z P_c A_{LR})$$



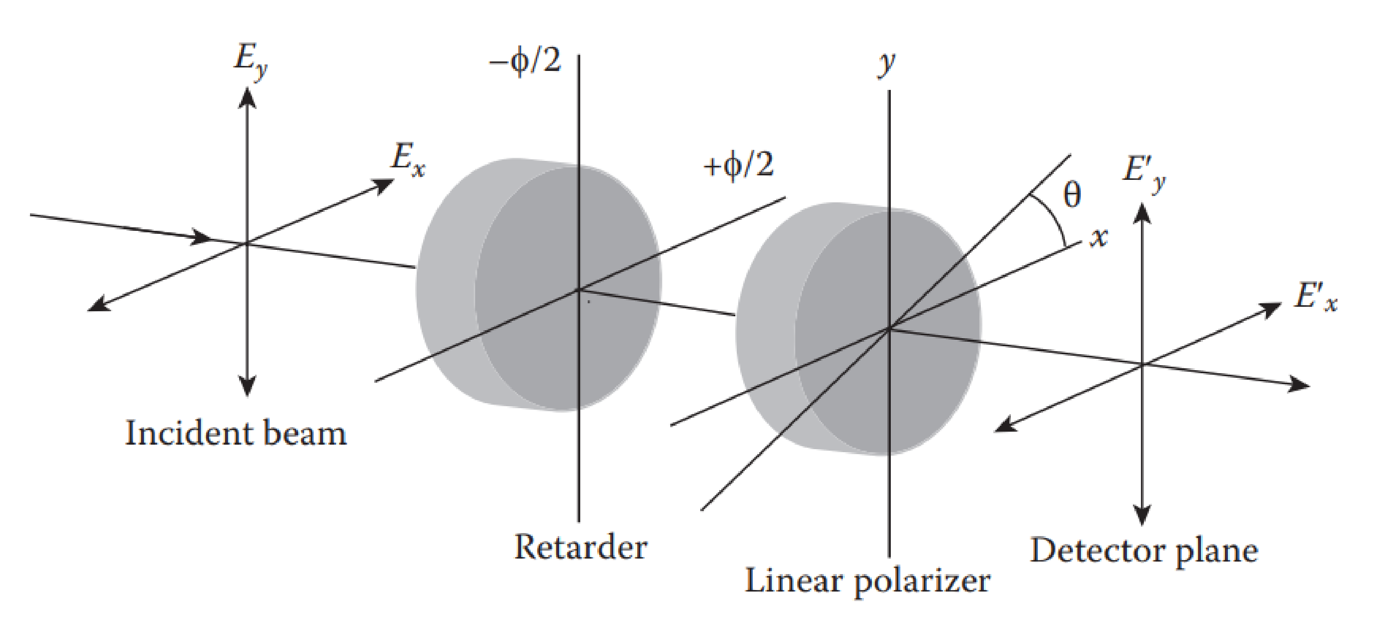


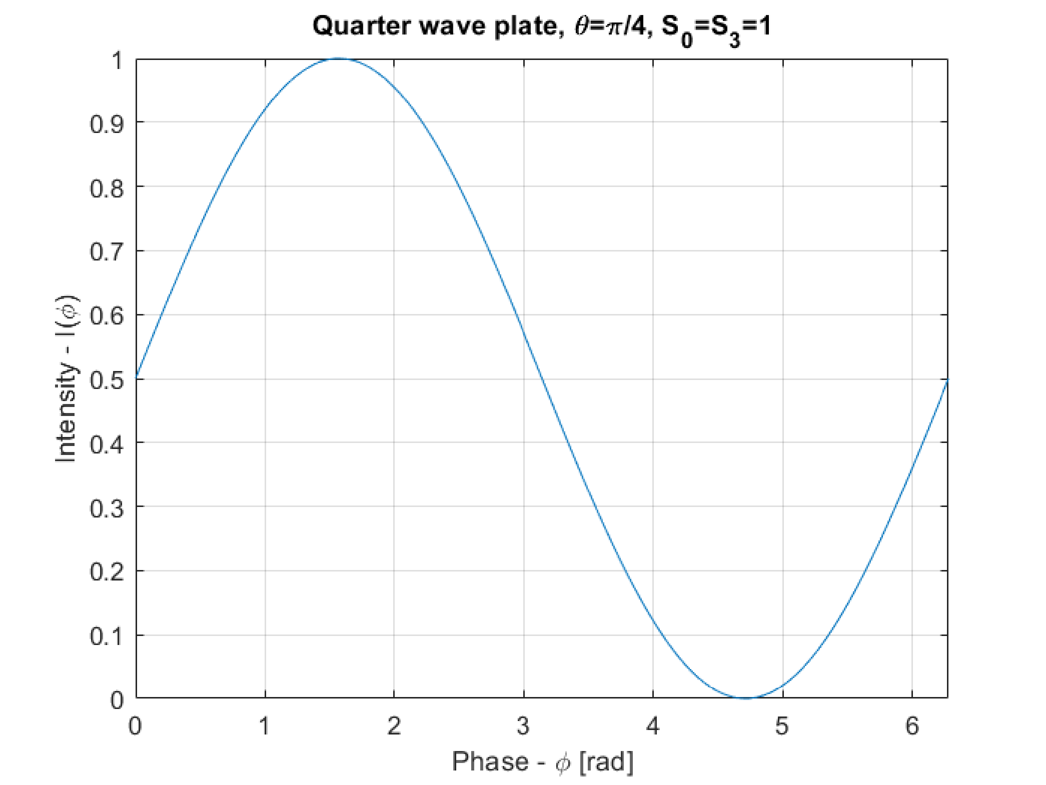
- **Asymmetric term is obtained through QED**
- **If we want 0.1% accuracy and precision of Pz**

=> we need 0.1% precision and accuracy of Pc

Classical measurement - Slow

$$I(\theta,\phi) = \frac{1}{2}[S_0 + S_1 \cos 2\theta + S_2 \sin 2\theta \cos\phi + S_3 \sin 2\theta \sin\phi].$$

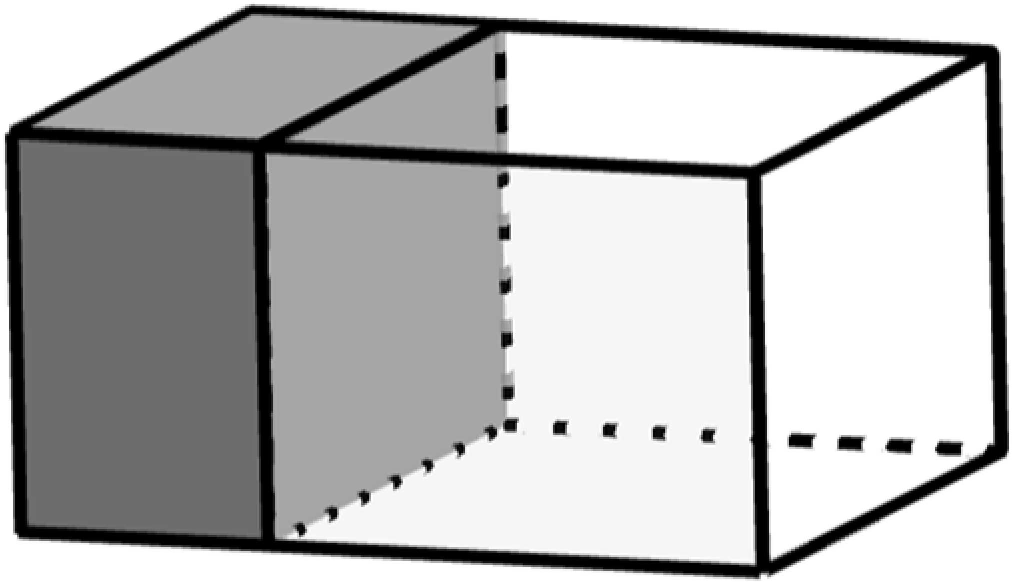




Dennis H Goldstein, Polarized Light - CRC Press Taylor & Francis Group

Photo-elastic modulator

Piezo-excited glass



$$n_x = n_0\left(1 - \frac{n_0^2 q_{11}}{2} P\right) \qquad n_y = n_0\left(1 - \frac{n_0^2 q_{12}}{2} P\right)$$

$$P = P(t) = P_m \sin(2\pi f t)$$

$$\phi(t) = \frac{2\pi\, e}{\lambda}(n_x - n_y) = \phi_0 \cos(2\pi f t)$$

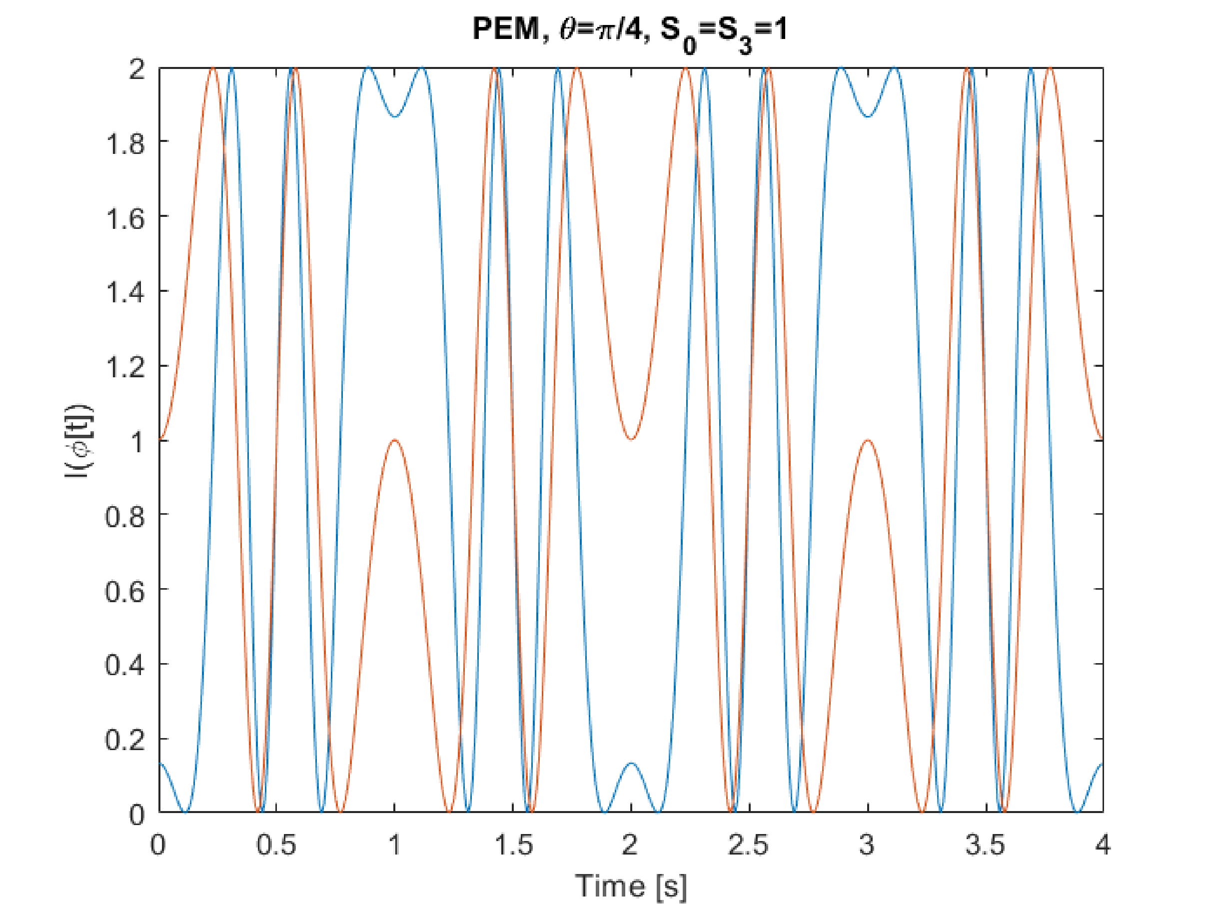
Modulated difference of refraction indices

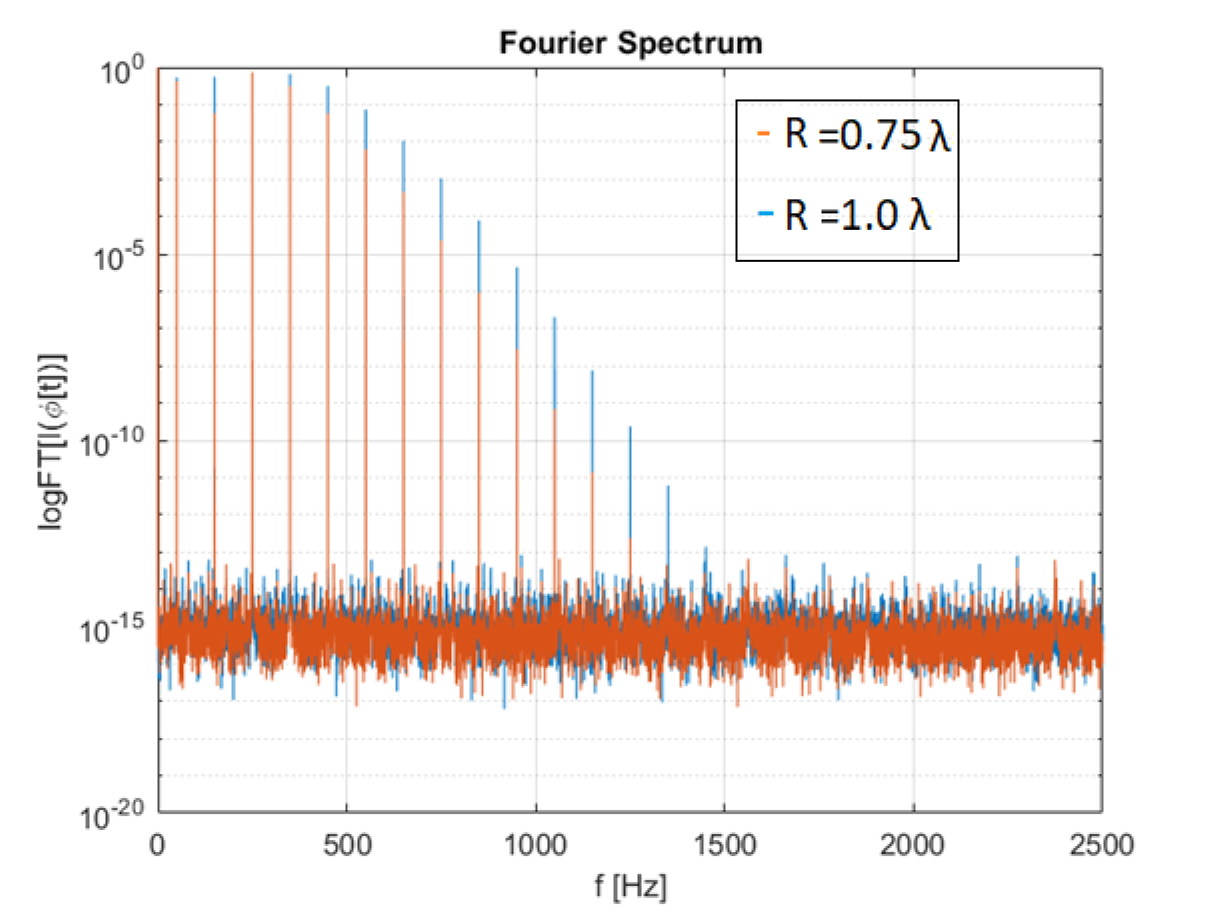
D. Yang, J. C. Canit, E. Gaignebet ; Photoelastic modulator – J. Optics (Paris)

Intensity measured with PEM

$$I(\theta,\phi[t]) = \frac{1}{2}[S_0 + S_1\cos(2\theta) + \sin(2\theta)(S_2\cos(\phi[t]) - S_3\sin(\phi[t])] \quad \Big| \quad \phi(t) = \phi_0\cos(2\pi f t)$$

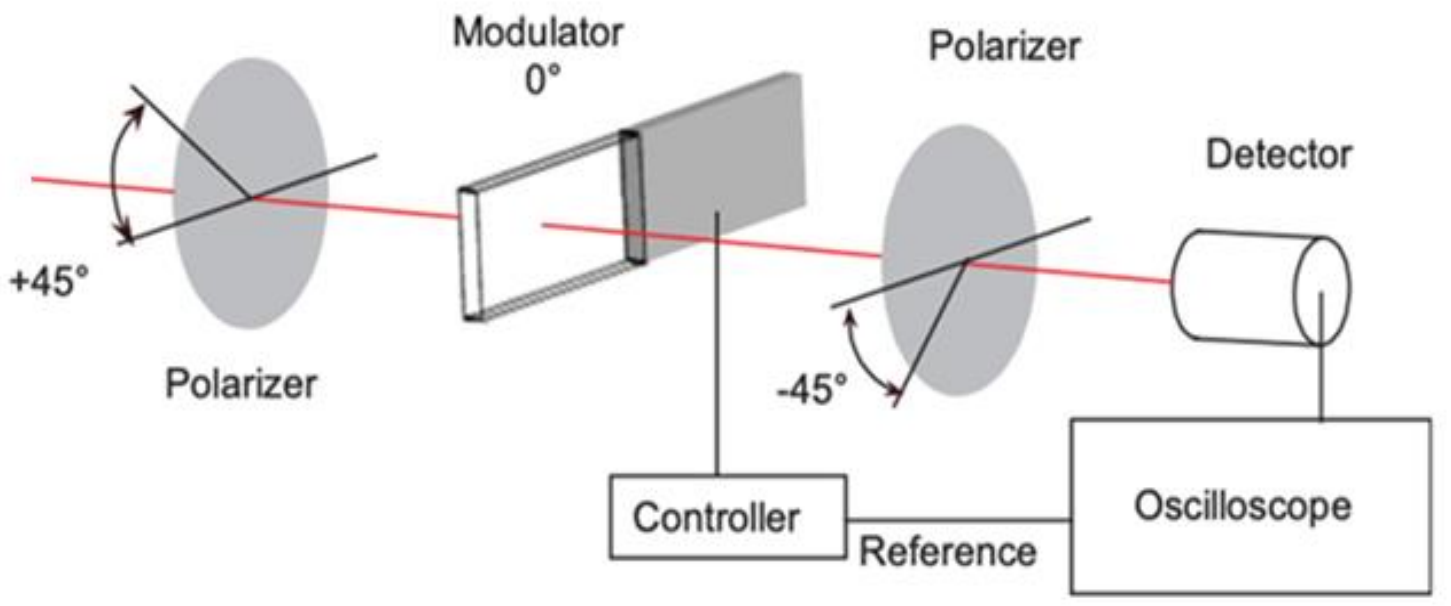
$$\phi_0 = \frac{2\pi R}{\lambda}$$

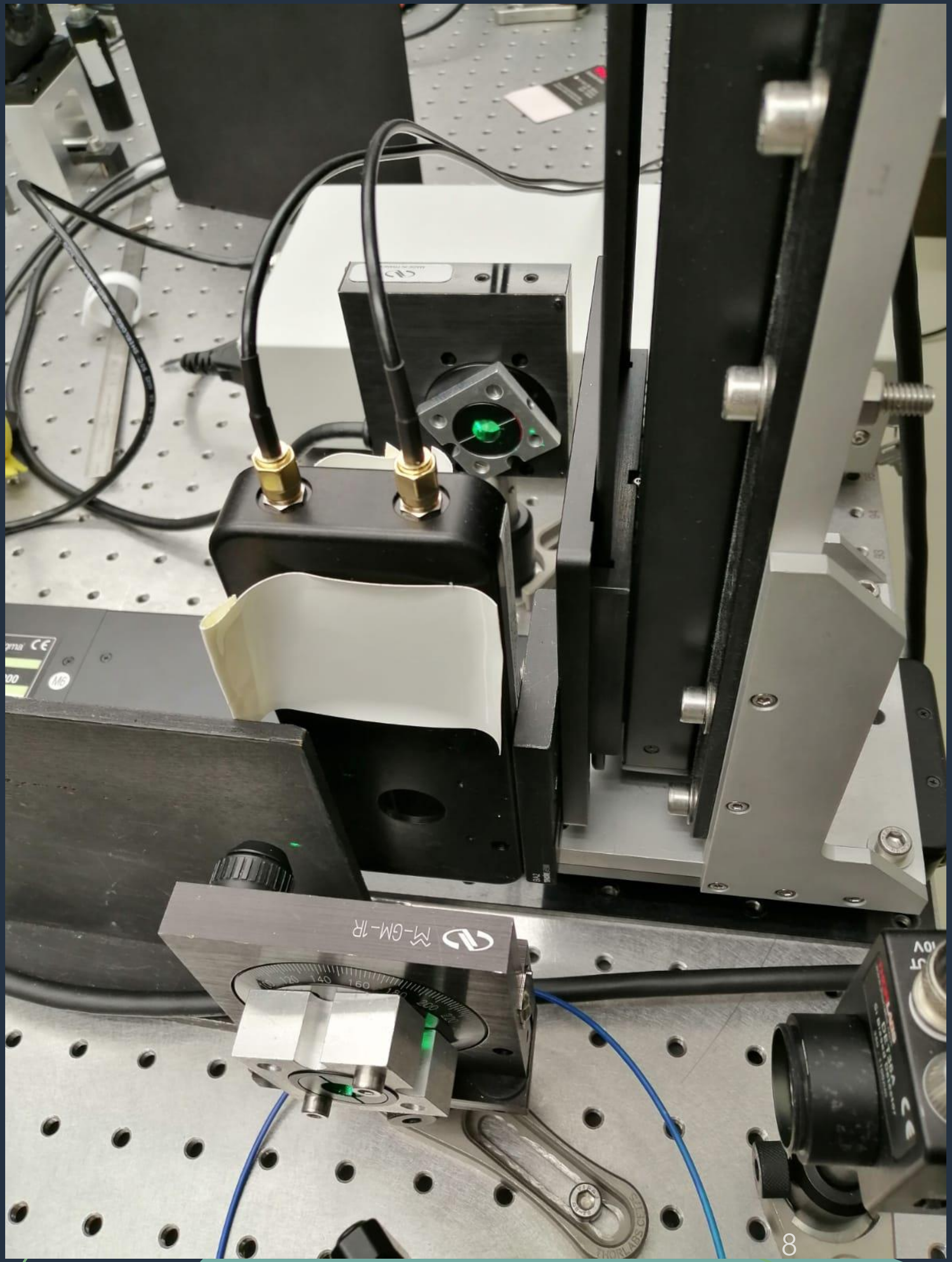




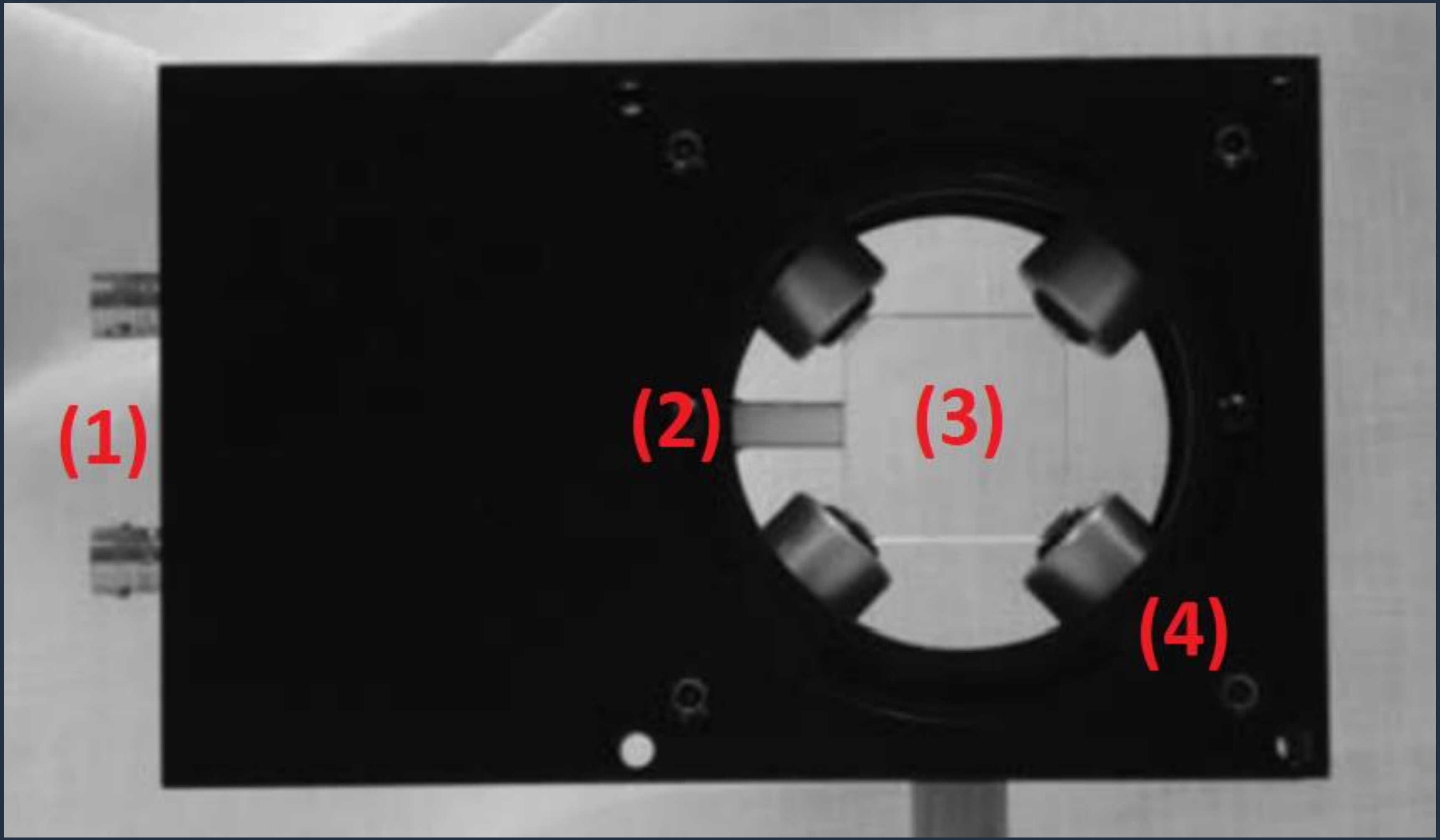
MATLAB simulation

PEM calibration setup





Example of a real PEM



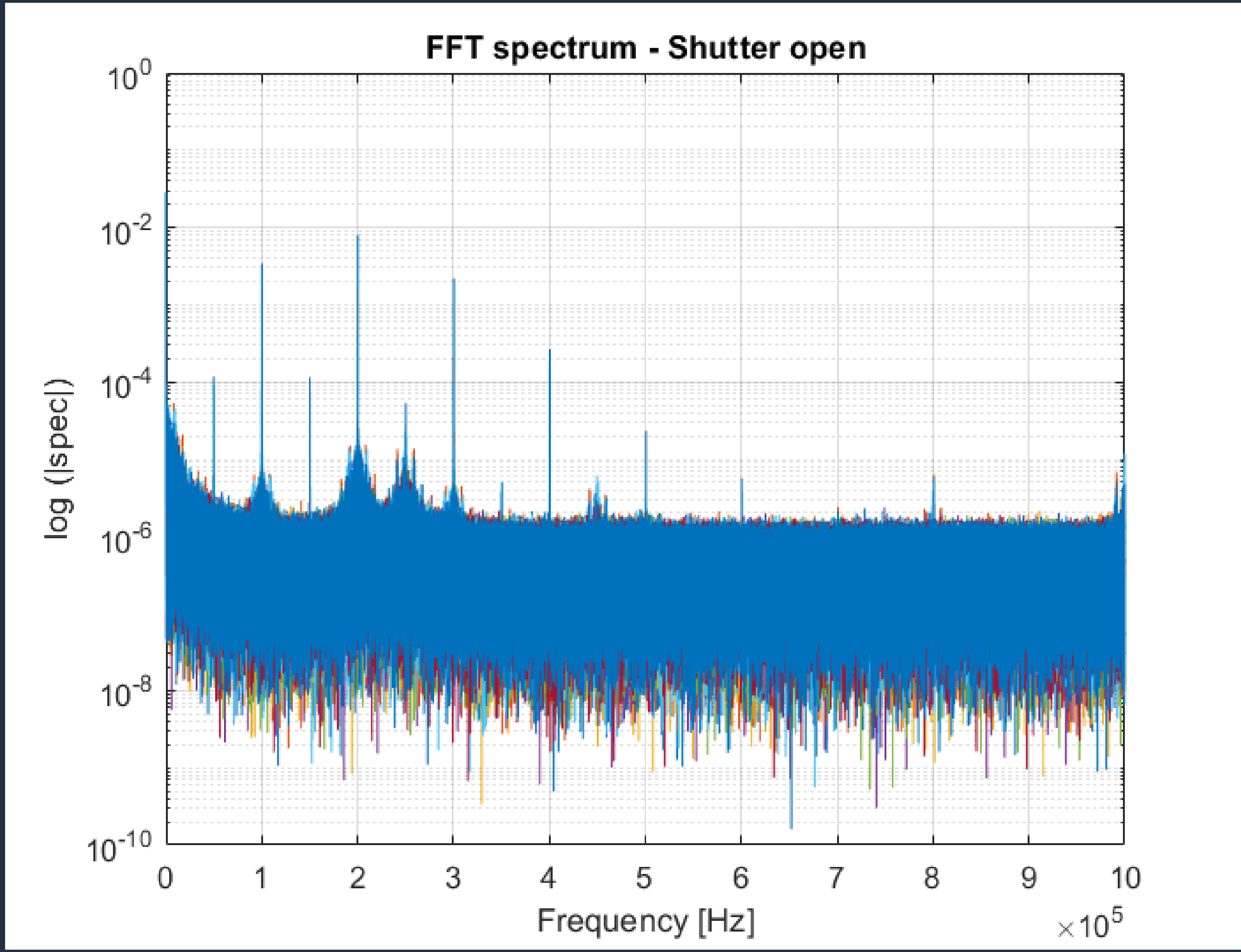
Dennis H Goldstein, Polarized Light - CRC Press Taylor & Francis Group

Non-linear approach

$$\boxed{\Phi = \delta_0 + \delta_1 cos(2\pi f t + \phi_1) + \delta_2 cos(4\pi f t + \phi_2)}$$

$$\begin{aligned}
I(\delta_0,\delta_1,\delta_2,t) = I_o\Big\{ & 1 - J_0(\delta_2)J_0(\delta_1) + 2\delta_0 J_0(\delta_2)J_1(\delta_1)cos(A) + 2\delta_0 J_1(\delta_2)J_0(\delta_1)cos(B) \\
& + 2J_1(\delta_2)J_1(\delta_1)\Big(cos(A+B) + cos(A-B)\Big) + 2\sum_{n=1}^{\infty}(-1)^n\Big[\delta_0 J_{2n+1}(\delta_2)J_0(\delta_1)cos((2n+1)B) \\
& + J_{2n+1}(\delta_2)J_1(\delta_1)\Big(cos(A+(2n+1)B) + cos(A-(2n+1)B)\Big) - J_{2n}(\delta_2)J_0(\delta_1)cos(2nB) \\
& + \delta_0 J_{2n}(\delta_2)J_1(\delta_1)\Big(cos(A+2nB) + cos(A-2nB)\Big) - J_0(\delta_2)J_{2n}(\delta_1)cos(2nA) \\
& + \delta_0 J_1(\delta_2)J_{2n}(\delta_1)\Big(cos(2nA+B) + cos(2nA-B)\Big) + \delta_0 J_0(\delta_2)J_{2n+1}(\delta_1)cos((2n+1)A) \\
& + J_1(\delta_2)J_{2n+1}(\delta_1)\Big(cos((2n+1)A+B) + cos((2n+1)A-B)\Big)\Big] + 2\sum_{k=1}^{\infty}\sum_{n=1}^{\infty}(-1)^k(-1)^n \\
& \cdot \Big[J_{2k+1}(\delta_2)J_{2n+1}(\delta_1)\Big(cos((2n+1)A+(2k+1)B) + cos((2n+1)A-(2k+1)B)\Big) \\
& + \delta_0 J_{2k+1}(\delta_2)J_{2n}(\delta_1)\Big(cos(2nA+(2k+1)B) + cos(2nA-(2k+1)B)\Big) \\
& - J_{2k}(\delta_2)J_{2n}(\delta_1)\Big(cos(2nA+2kB) + cos(2nA-2kB)\Big) \\
& + \delta_0 J_{2k}(\delta_2)J_{2n+1}(\delta_1)\Big(cos((2n+1)A+2kB) + cos((2n+1)A-2kB)\Big)\Big]\Big\}
\end{aligned}$$

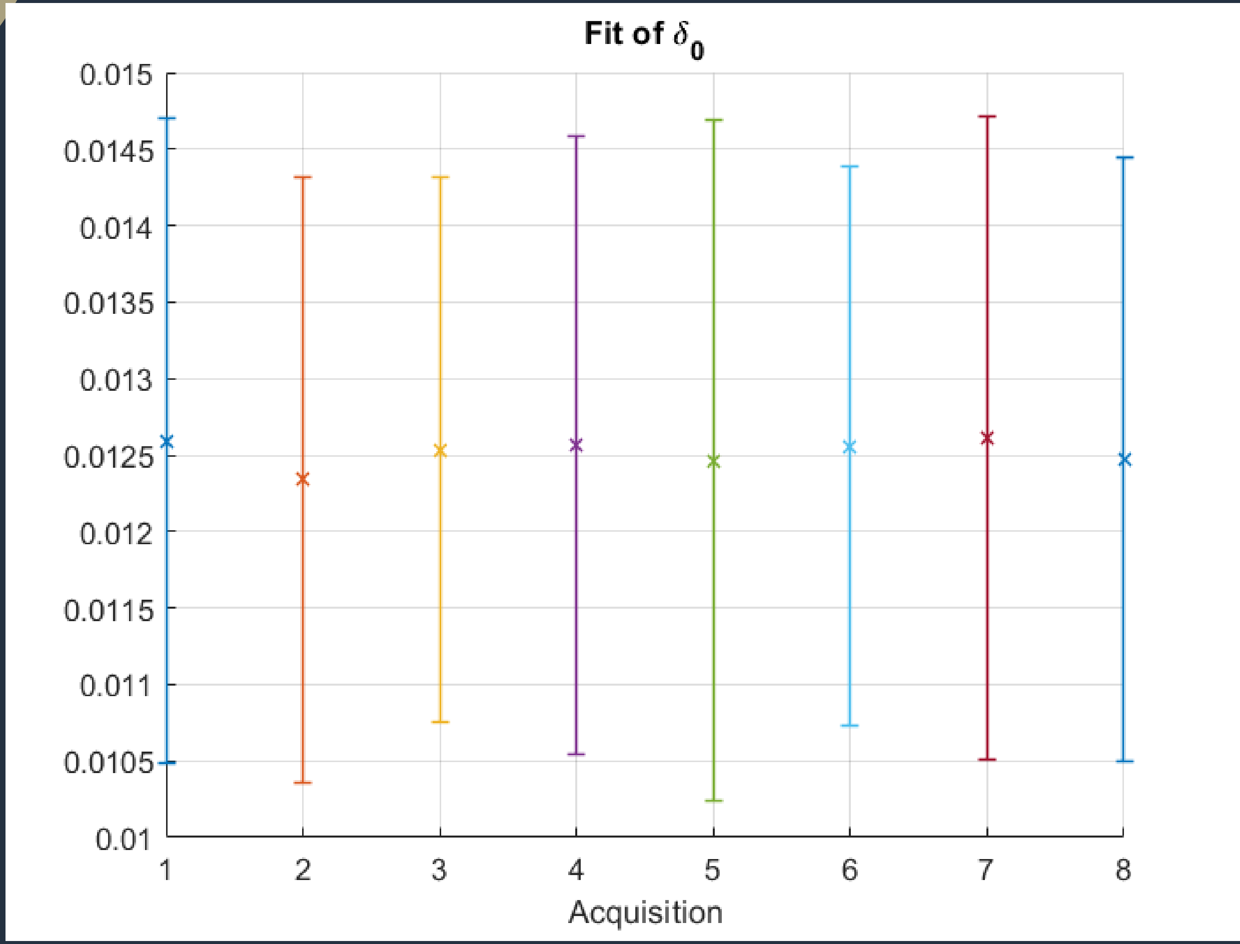
Frequency	Amplitude
n=0	$1 - J_0(\delta_2)J_0(\delta_1) + 2\Big[J_2(\delta_2)J_4(\delta_1) - J_4(\delta_2)J_8(\delta_1) + J_6(\delta_2)J_{12}(\delta_1) - J_8(\delta_2)J_{16}(\delta_1) + \delta_0\Big(J_3(\delta_2)J_6(\delta_1) - J_5(\delta_2)J_{10}(\delta_1) + J_7(\delta_2)J_{14}(\delta_1) - J_1(\delta_2)J_2(\delta_1)\Big)\Big]$
n=1	$2\Big[J_1(\delta_2)J_1(\delta_1) - J_1(\delta_2)J_3(\delta_1) - J_3(\delta_2)J_5(\delta_1) + J_3(\delta_2)J_7(\delta_1) + J_5(\delta_2)J_9(\delta_1) - J_5(\delta_2)J_{11}(\delta_1) - J_7(\delta_2)J_{13}(\delta_1) + J_7(\delta_2)J_{15}(\delta_1) + J_9(\delta_2)J_{17}(\delta_1) + \delta_0\Big(J_0(\delta_2)J_1(\delta_1) + J_2(\delta_2)J_3(\delta_1) - J_2(\delta_2)J_5(\delta_1) - J_4(\delta_2)J_7(\delta_1) + J_4(\delta_2)J_9(\delta_1) + J_6(\delta_2)J_{11}(\delta_1) - J_6(\delta_2)J_{13}(\delta_1) - J_8(\delta_2)J_{15}(\delta_1) + J_8(\delta_2)J_{17}(\delta_1)\Big)\Big]$
n=2	$2\Big[J_0(\delta_2)J_2(\delta_1) - J_2(\delta_2)J_2(\delta_1) - J_2(\delta_2)J_6(\delta_1) + J_4(\delta_2)J_6(\delta_1) + J_4(\delta_2)J_{10}(\delta_1) - J_6(\delta_2)J_{10}(\delta_1) - J_6(\delta_2)J_{14}(\delta_1) + J_8(\delta_2)J_{14}(\delta_1) + \delta_0\Big(J_1(\delta_2)J_0(\delta_1) + J_1(\delta_2)J_4(\delta_1) - J_3(\delta_2)J_4(\delta_1) - J_3(\delta_2)J_8(\delta_1) + J_5(\delta_2)J_8(\delta_1) + J_5(\delta_2)J_{12}(\delta_1) - J_7(\delta_2)J_{12}(\delta_1) - J_7(\delta_2)J_{16}(\delta_1) + J_9(\delta_2)J_{16}(\delta_1)\Big)\Big]$

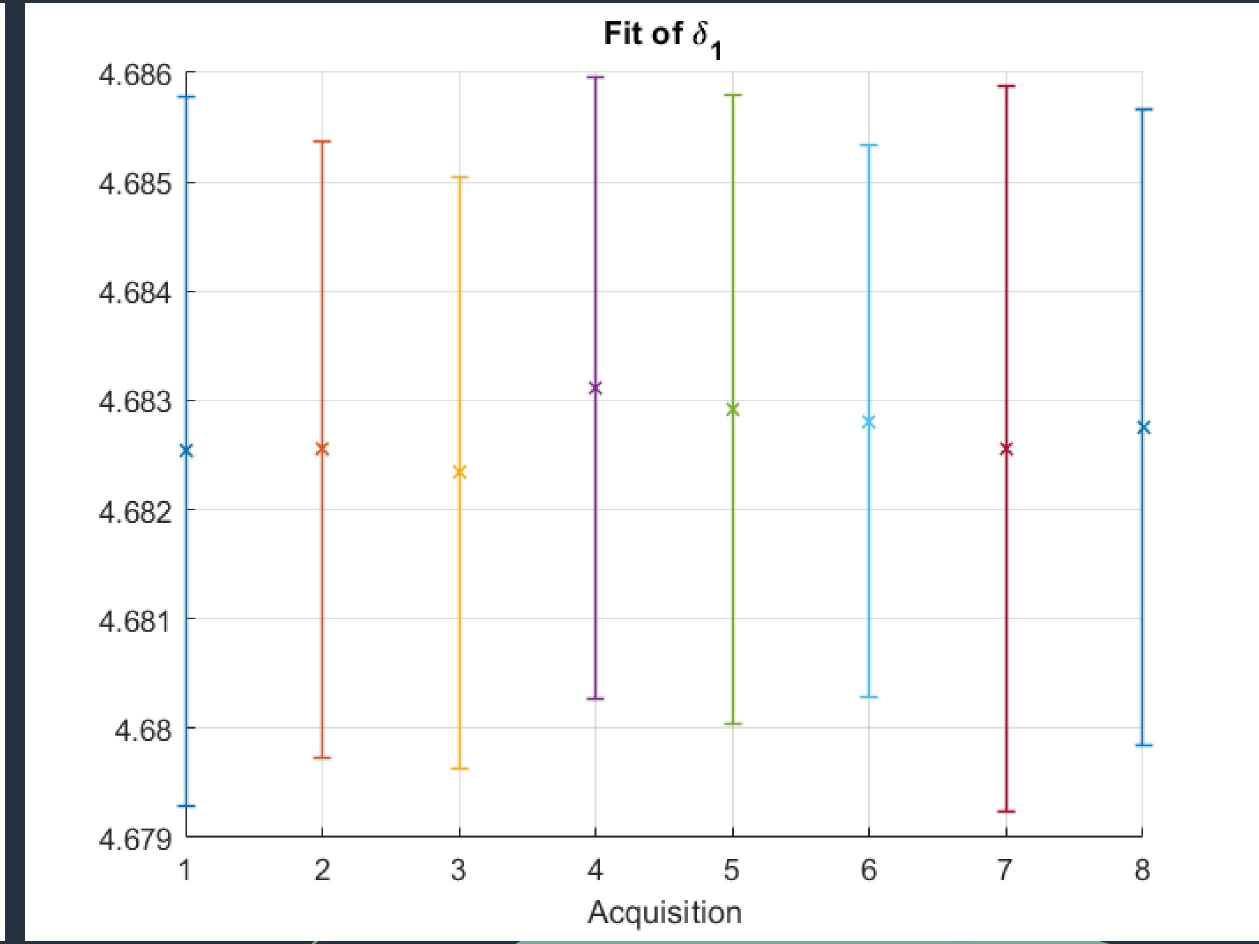


Experimental results

$$\delta_0 = \frac{2\pi}{\lambda}\Delta n \cdot e \;\; ; \;\; e(width) \rightarrow 10mm$$

$$\delta_1 = \frac{2\pi\, R}{\lambda} \approx 4.712$$

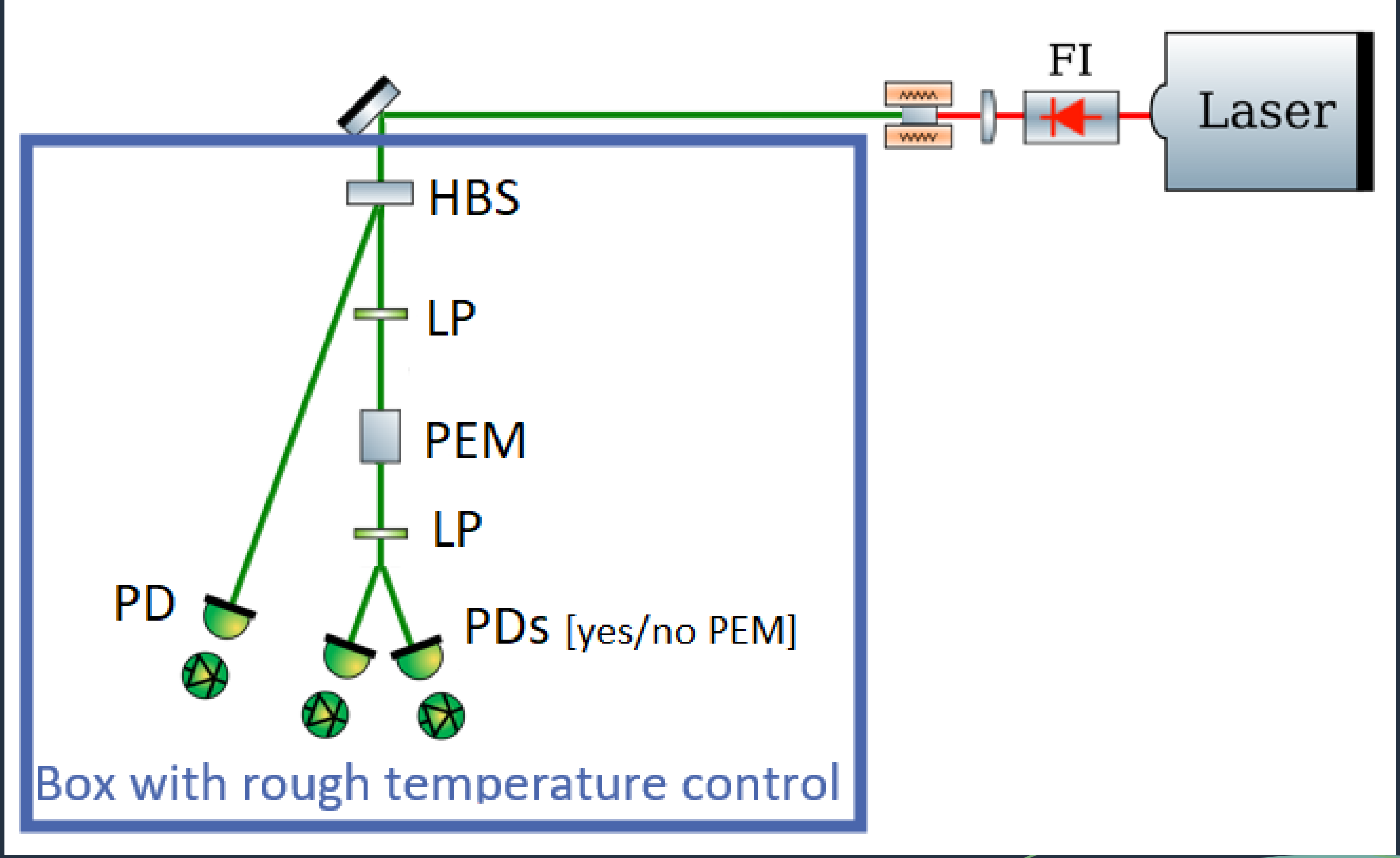


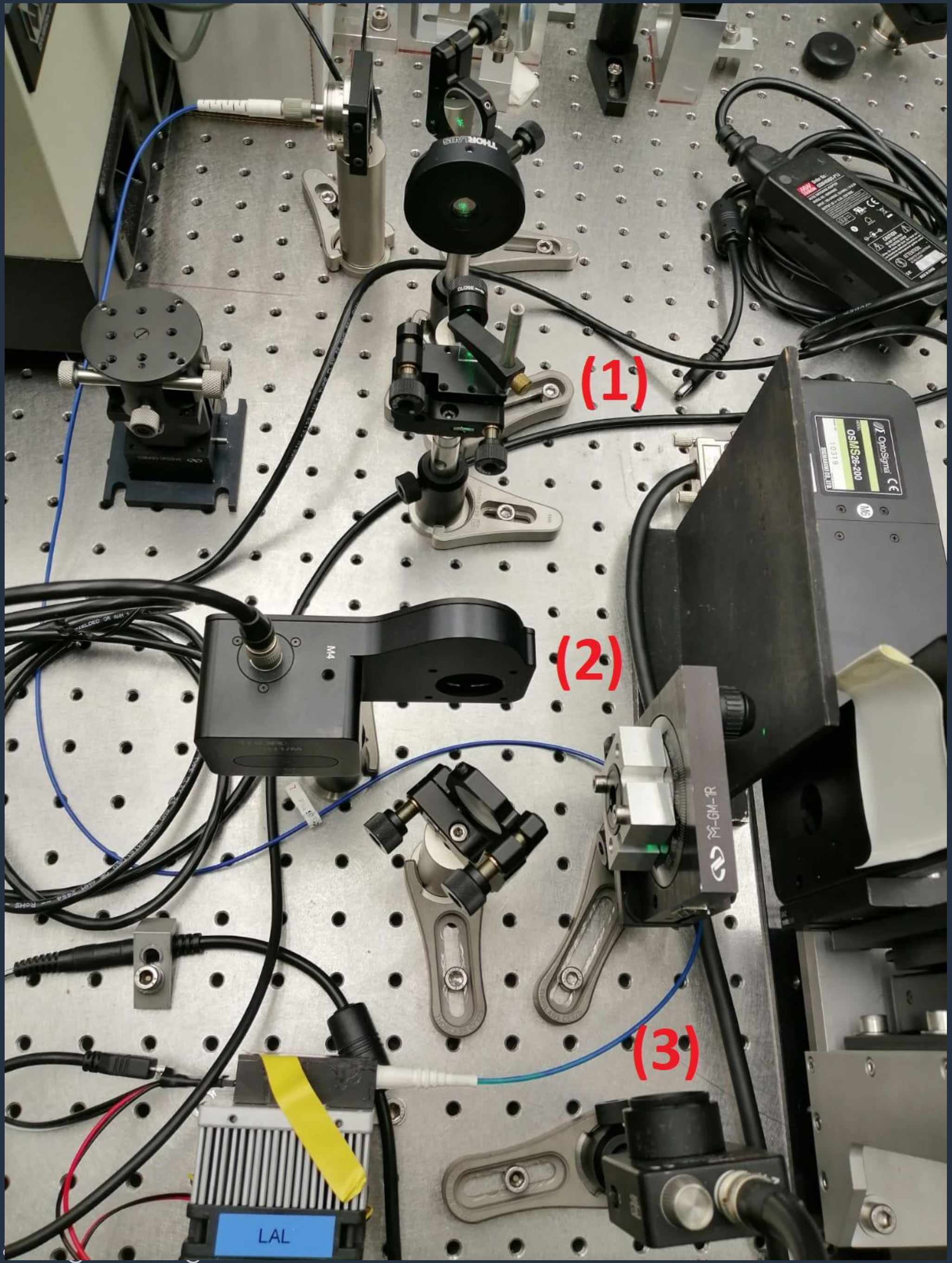


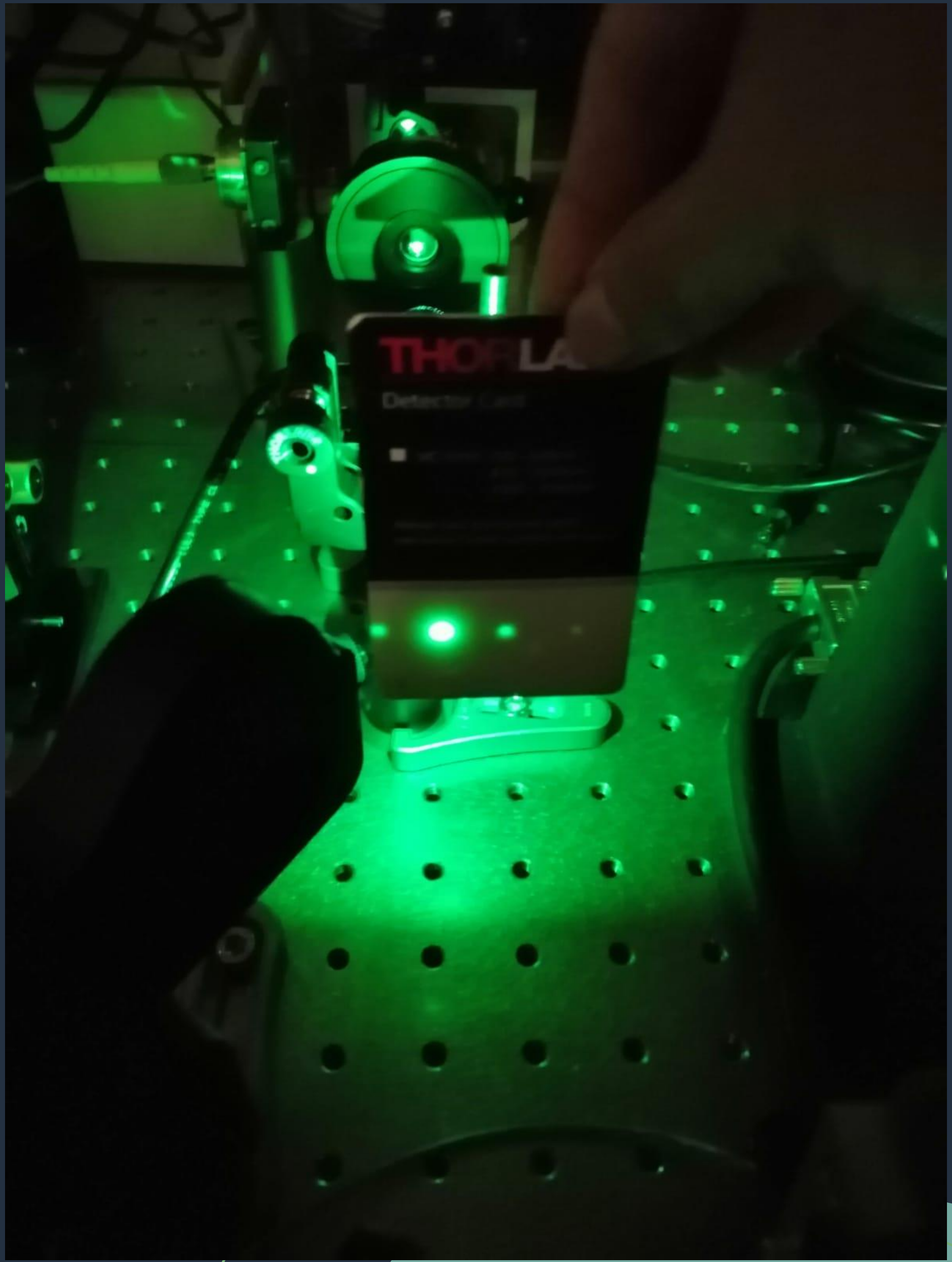
Conclusions and prospects

- The first order treatment gives stable and consistent results, especially for even harmonics.
- The use of the Fourier transform to analyze the signals represents a great advantage.
- For future work, higher order terms should be considered, keeping in mind the relative phase that is generated.

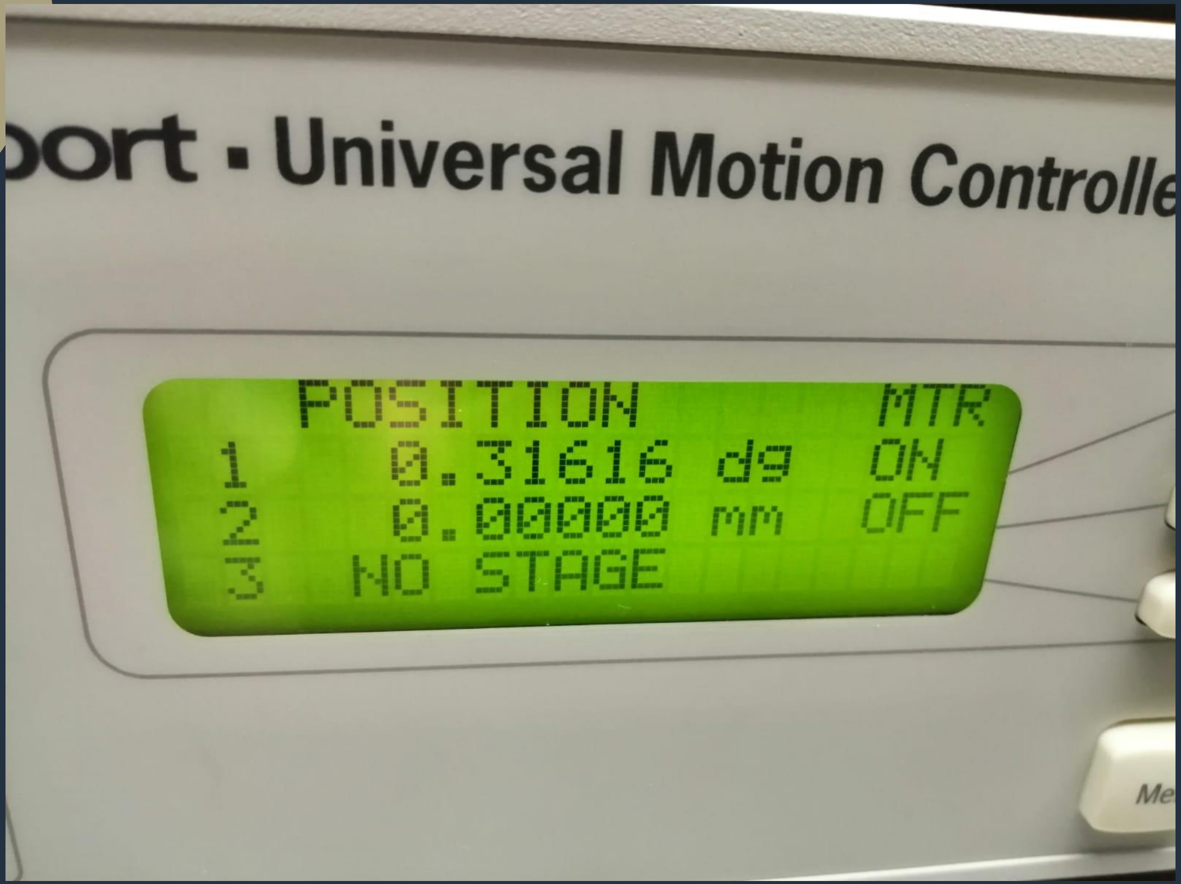
BACKUP – Optical setup



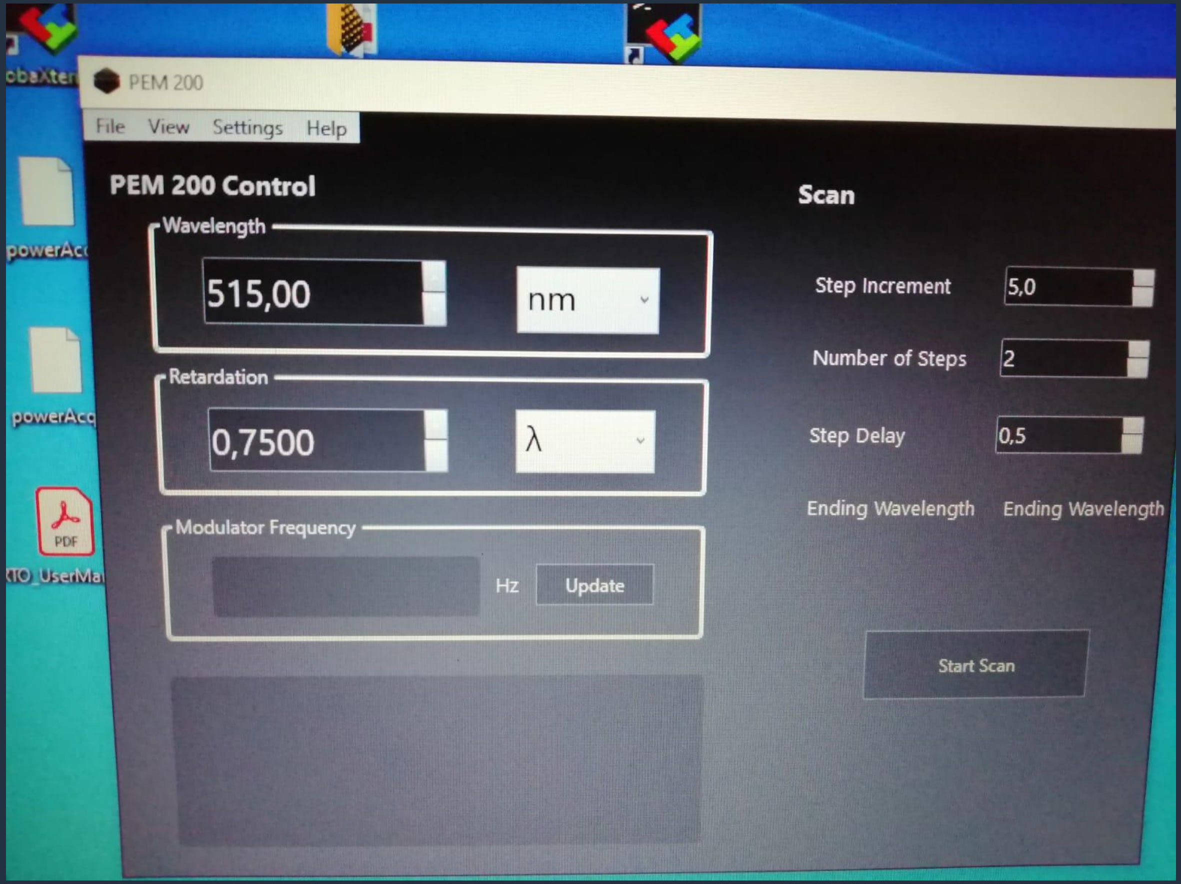

(1)
(2)
(3)
M4
LAL



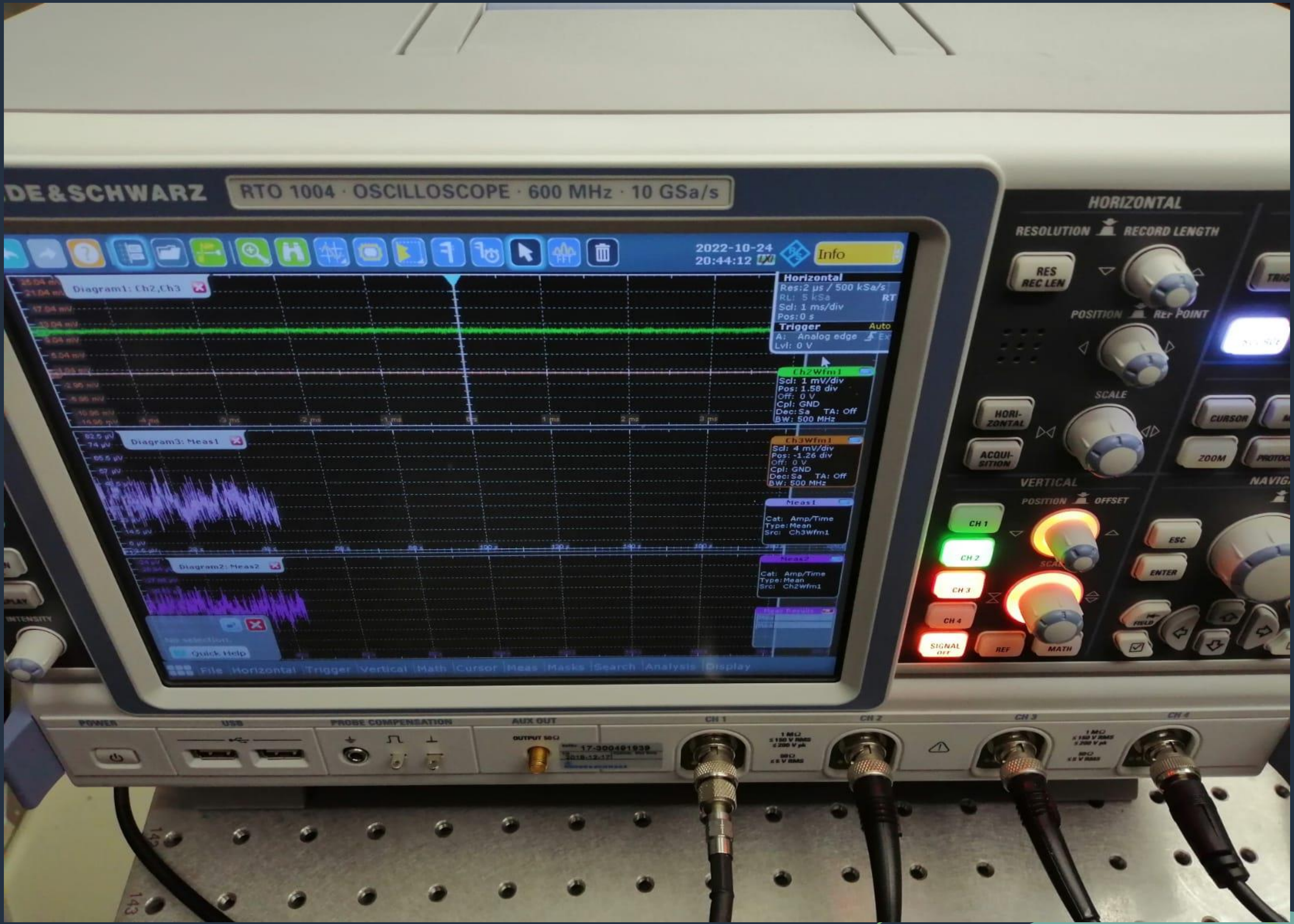
Drivers used in the optical room



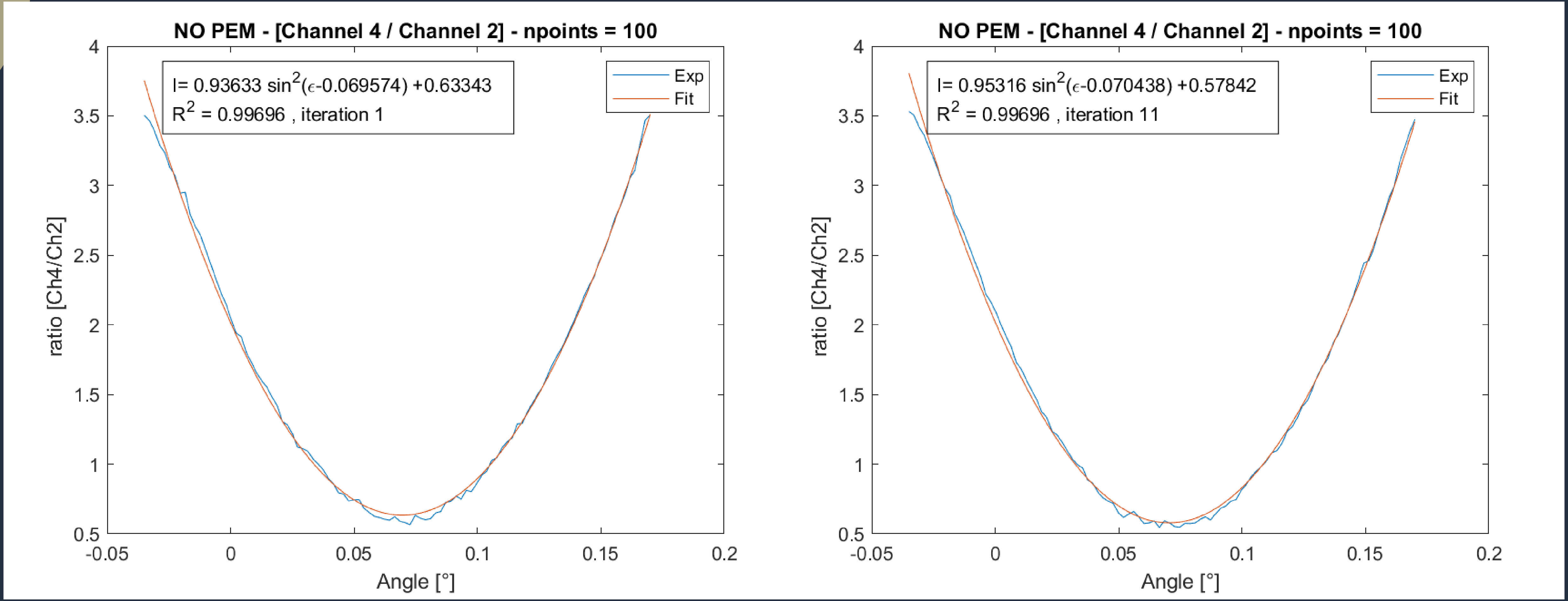
Second polarizer rotator



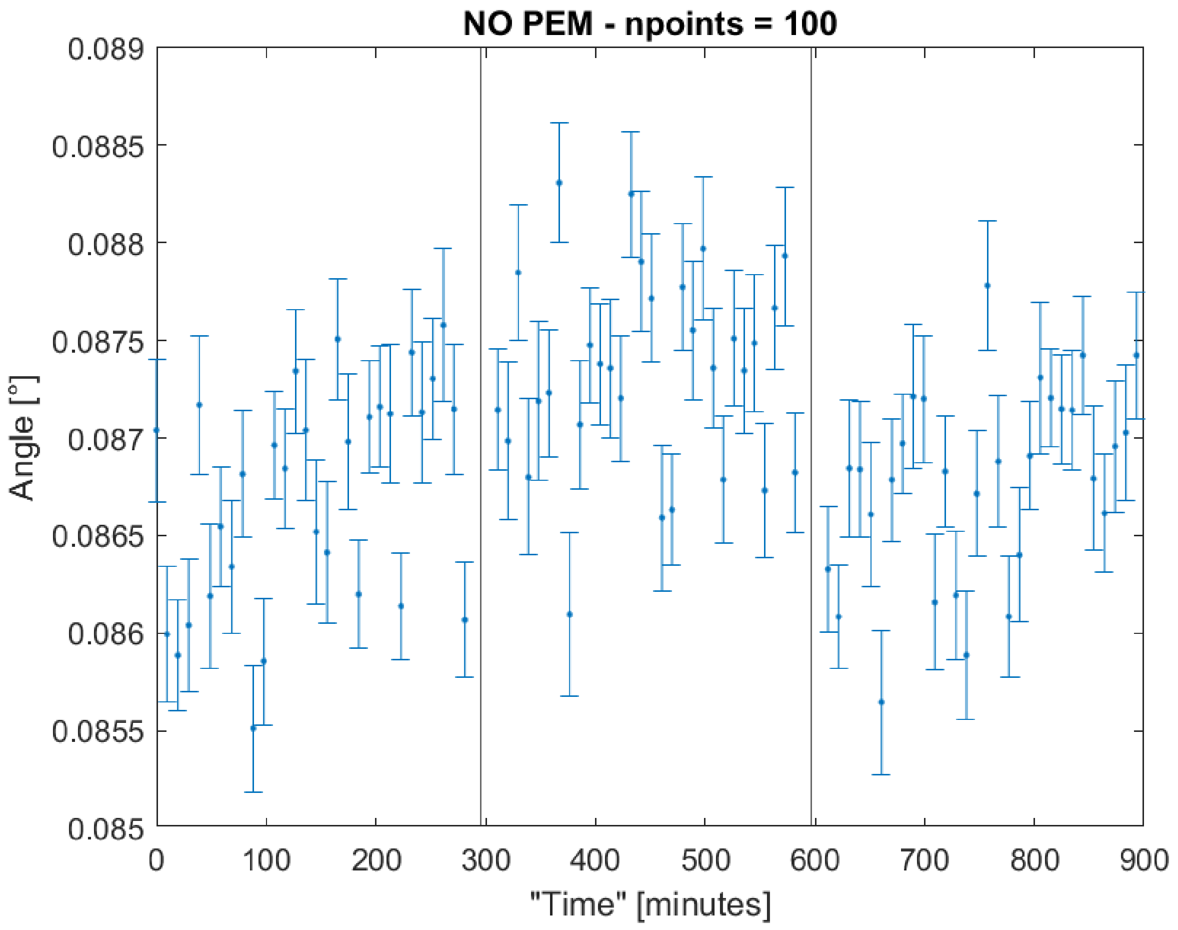
Photoelastic modulator controller

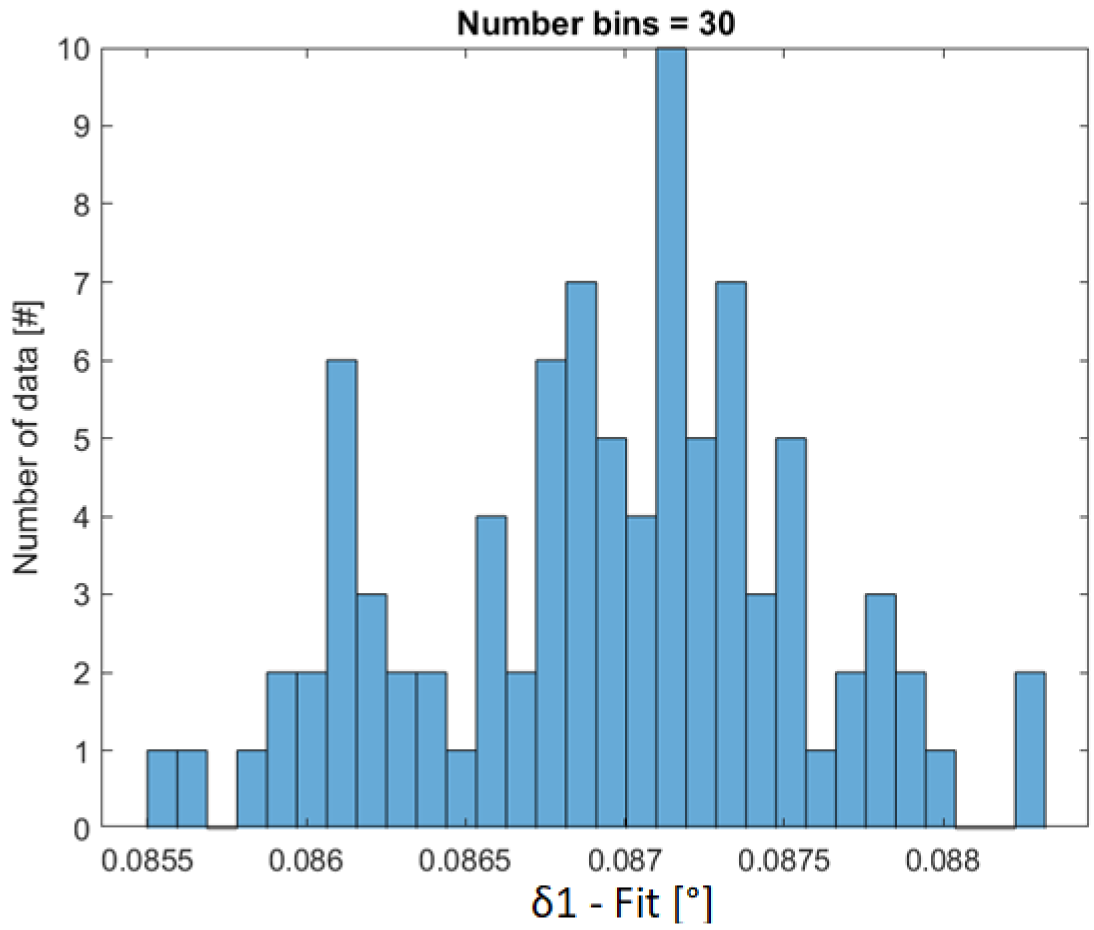

DE&SCHWARZ
RTO 1004 · OSCILLOSCOPE · 600 MHz · 10 GSa/s
2022-10-24
20:44:12
Info
HORIZONTAL
RESOLUTION
RECORD LENGTH
VERTICAL

Looking for the cross angle



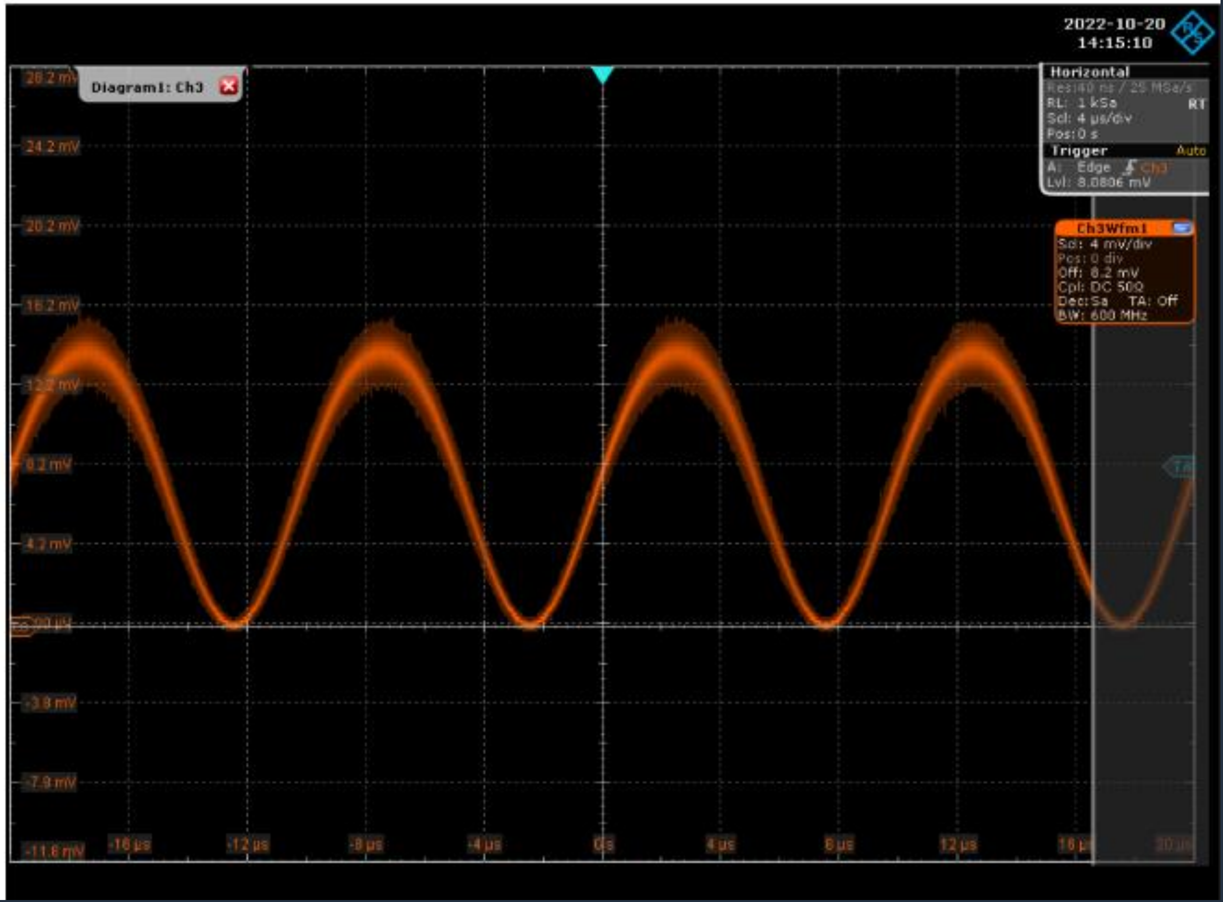
Collecting the data of three days



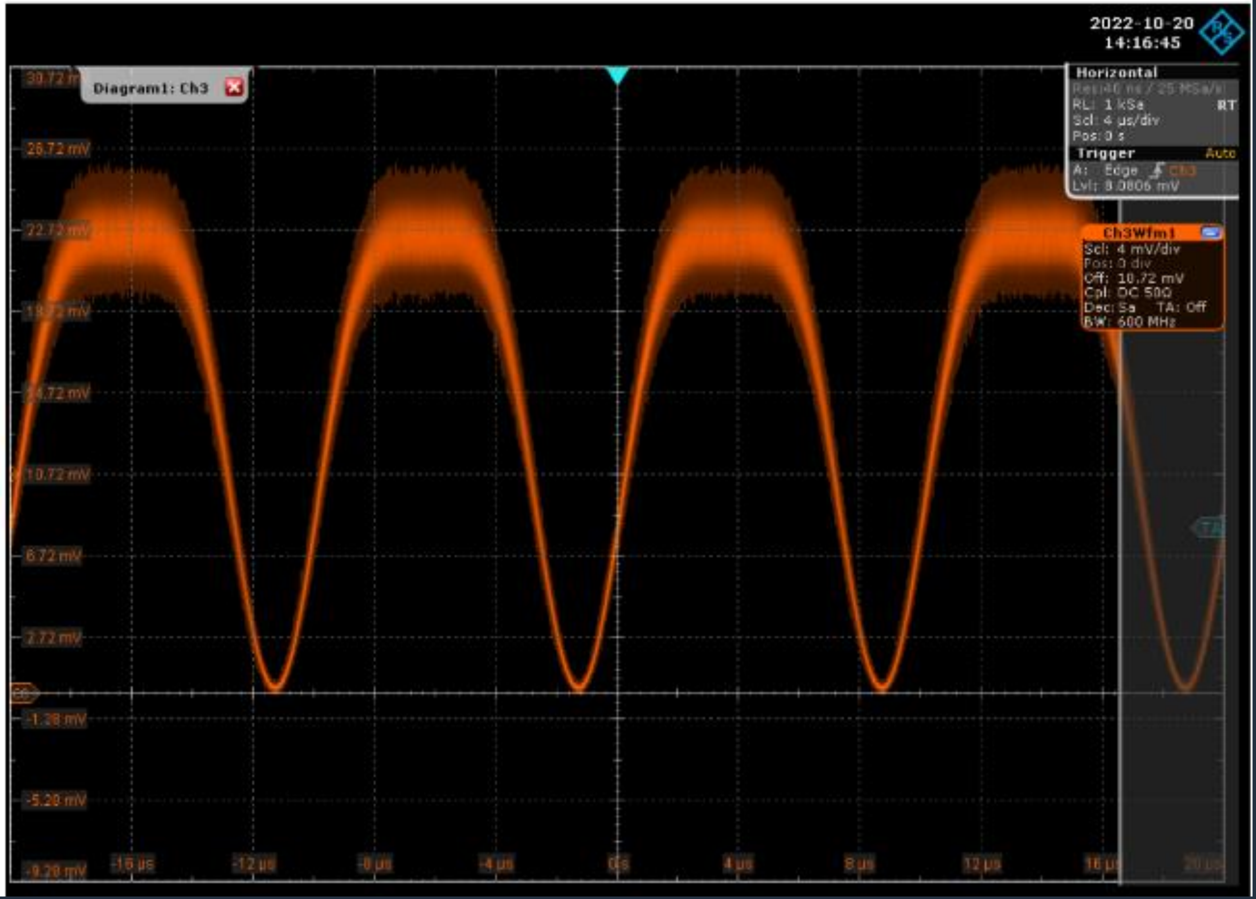


Using the PEM driver

$\lambda = 0.25$:

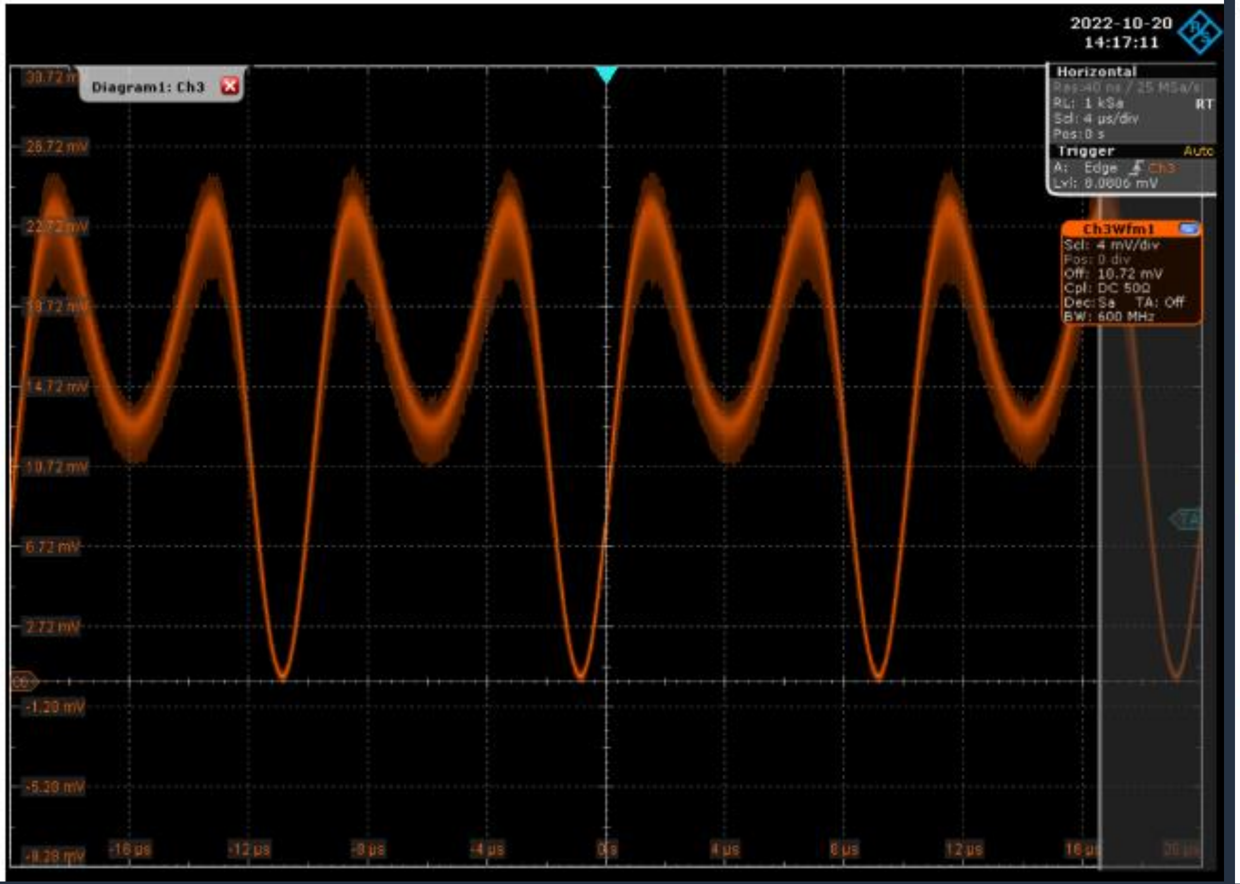


$\lambda = 0.5$:

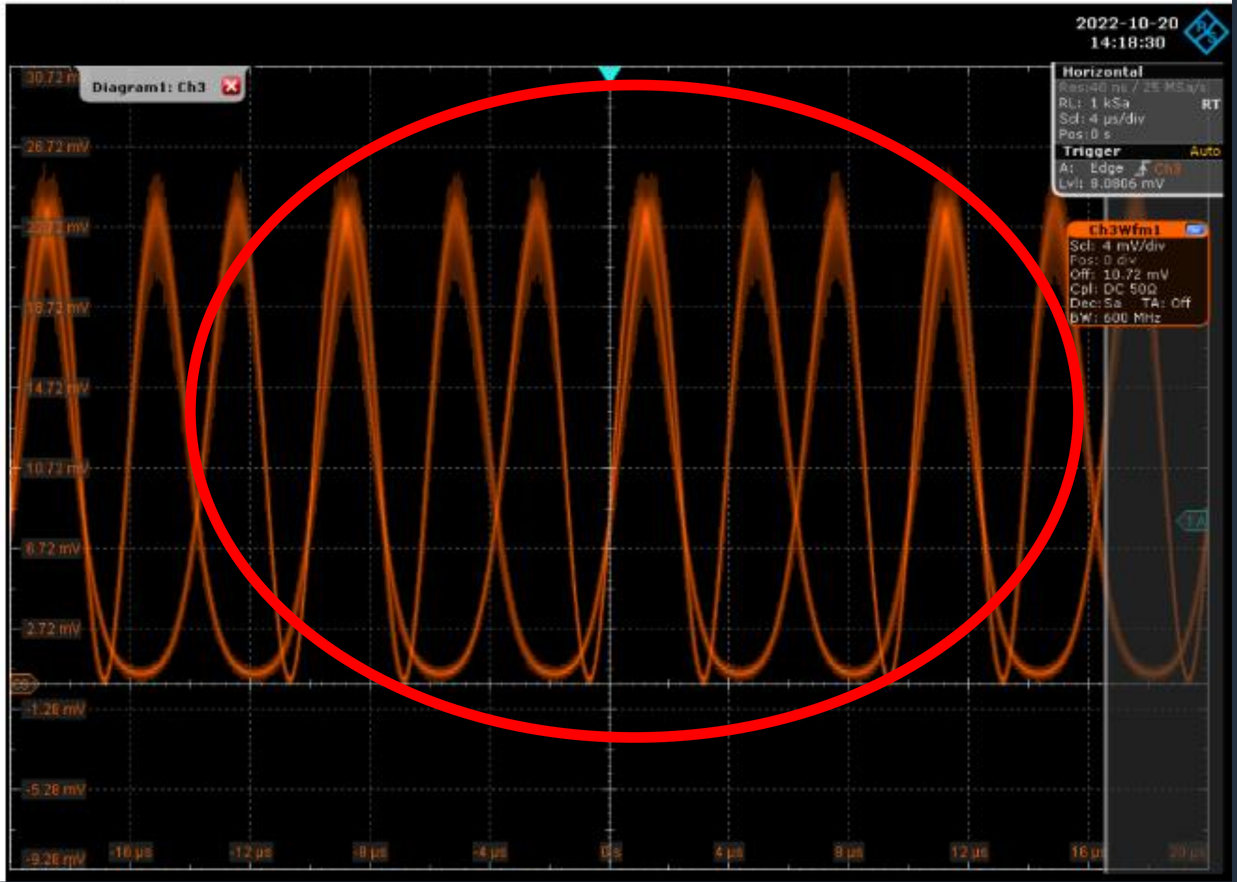


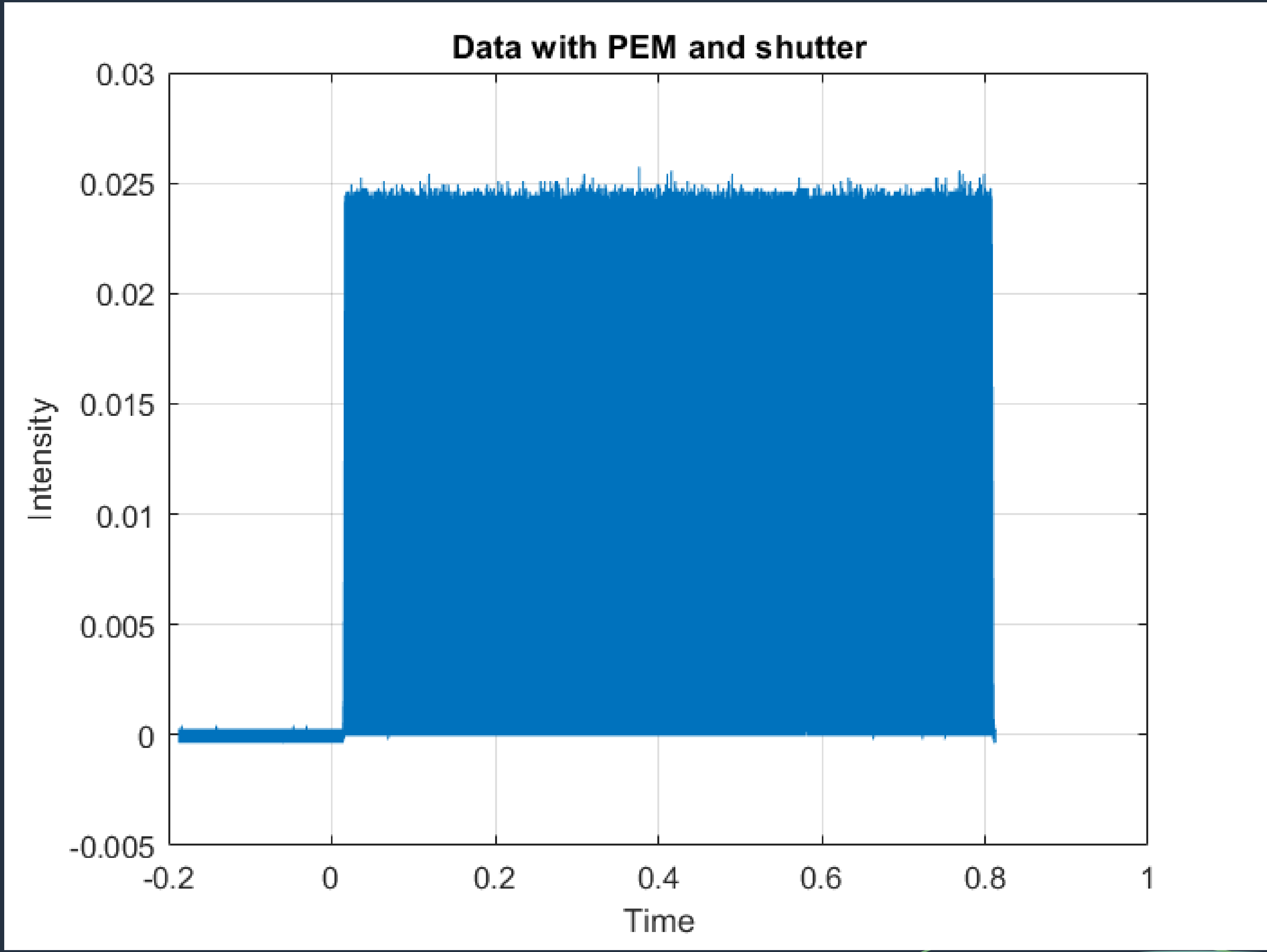
Relevance of trigger position !!!

$\lambda = 0.75$:

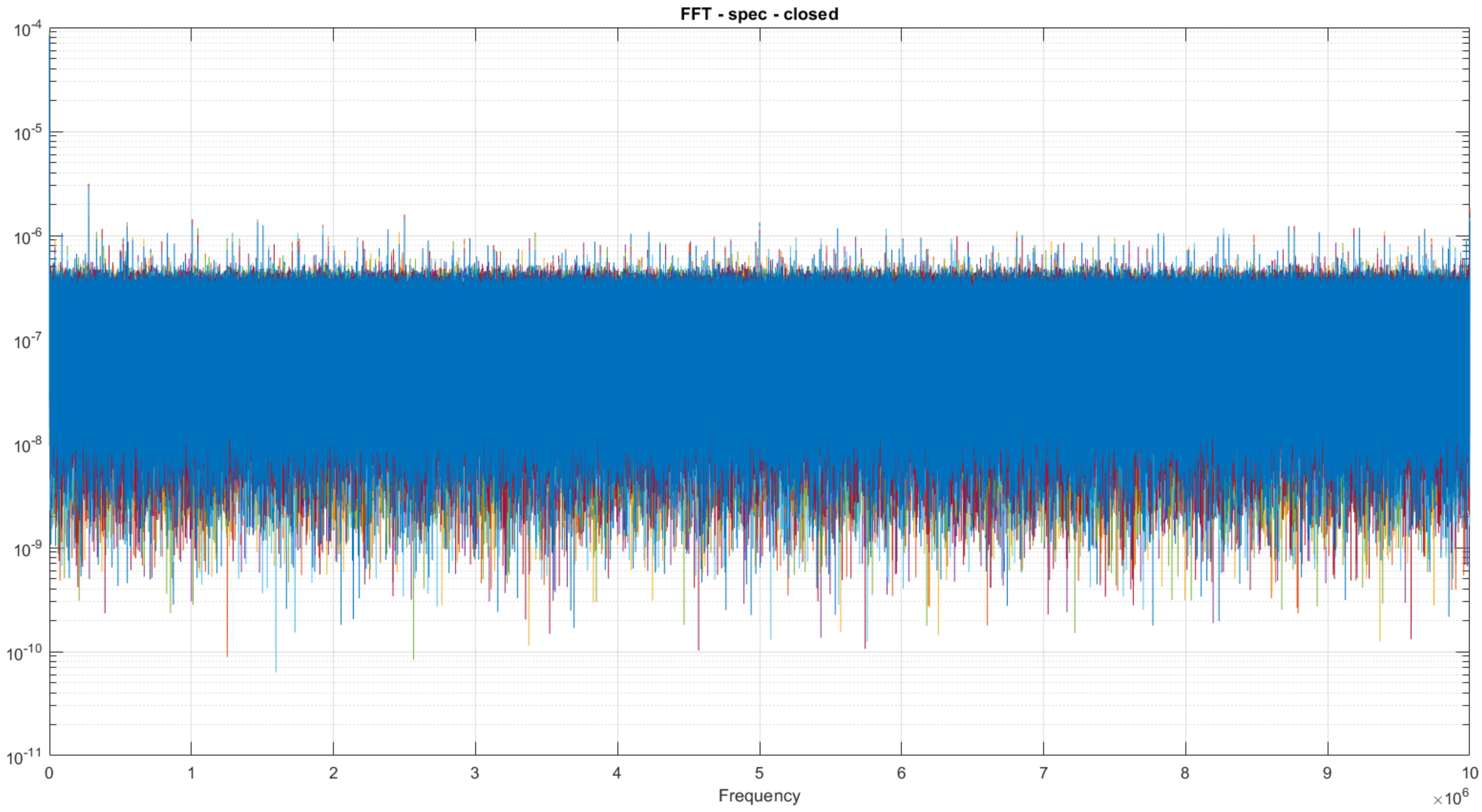


$\lambda = 1$:

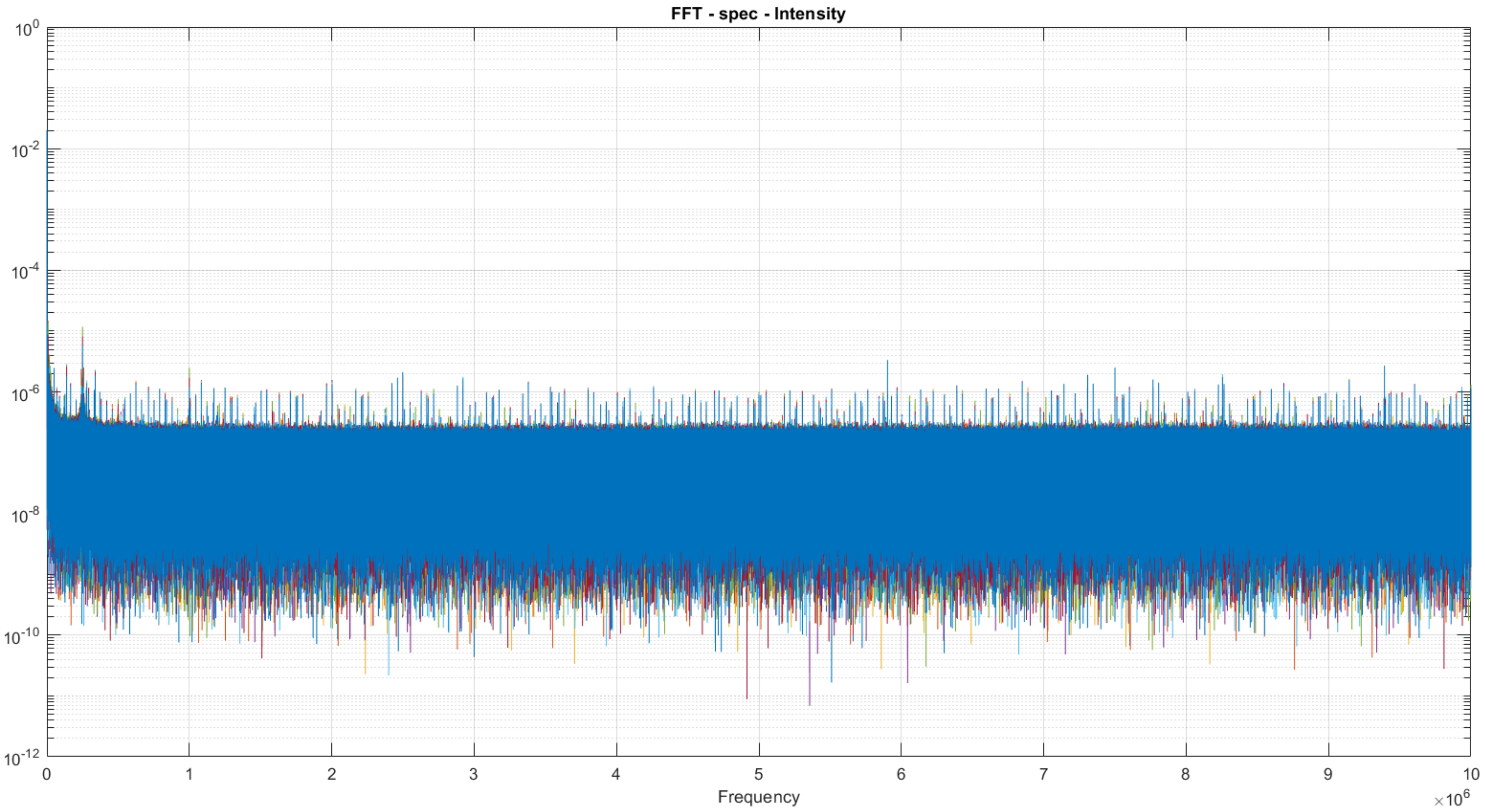




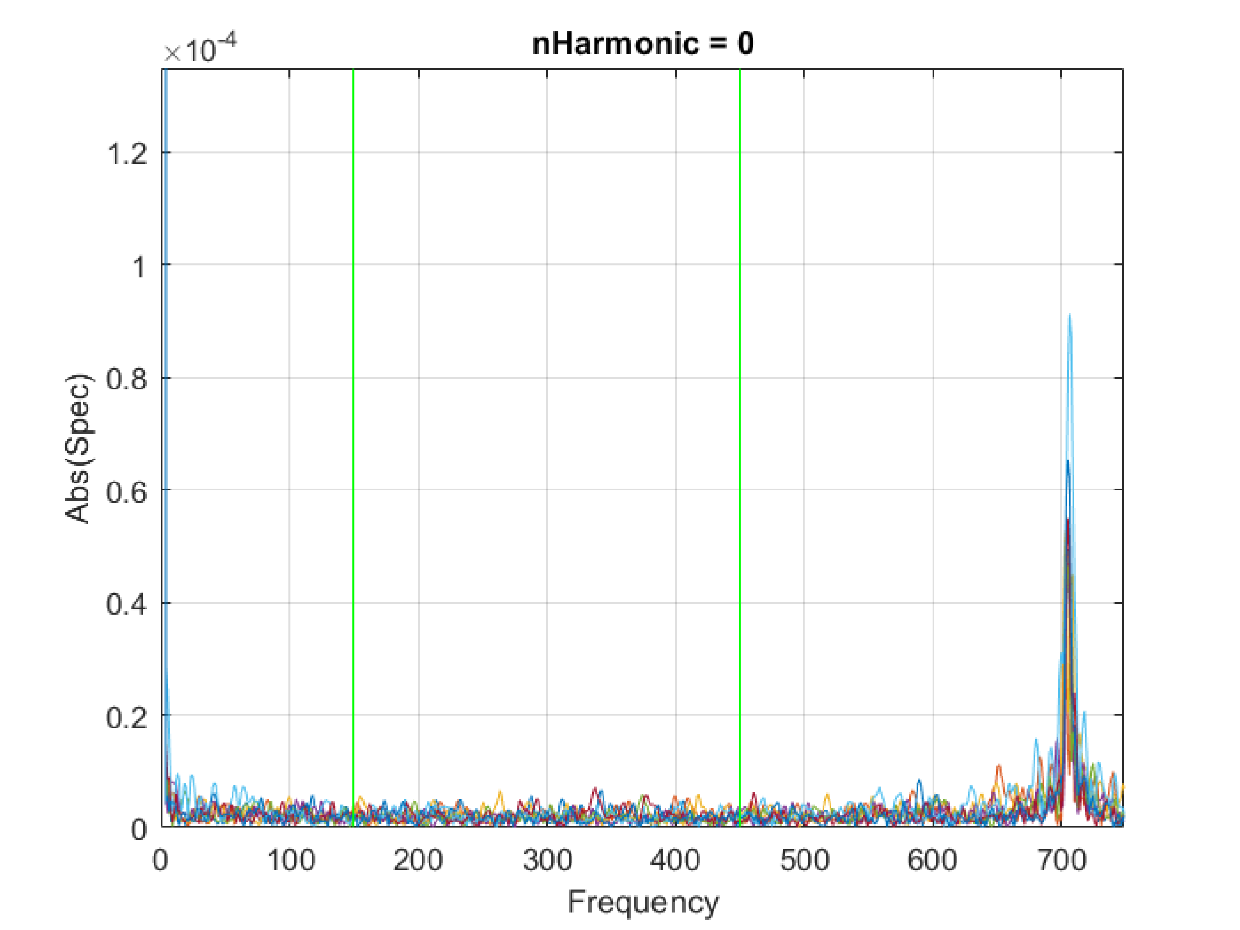
Data with PEM and shutter
Intensity
Time
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.2
0
0.2
0.4
0.6
0.8
1

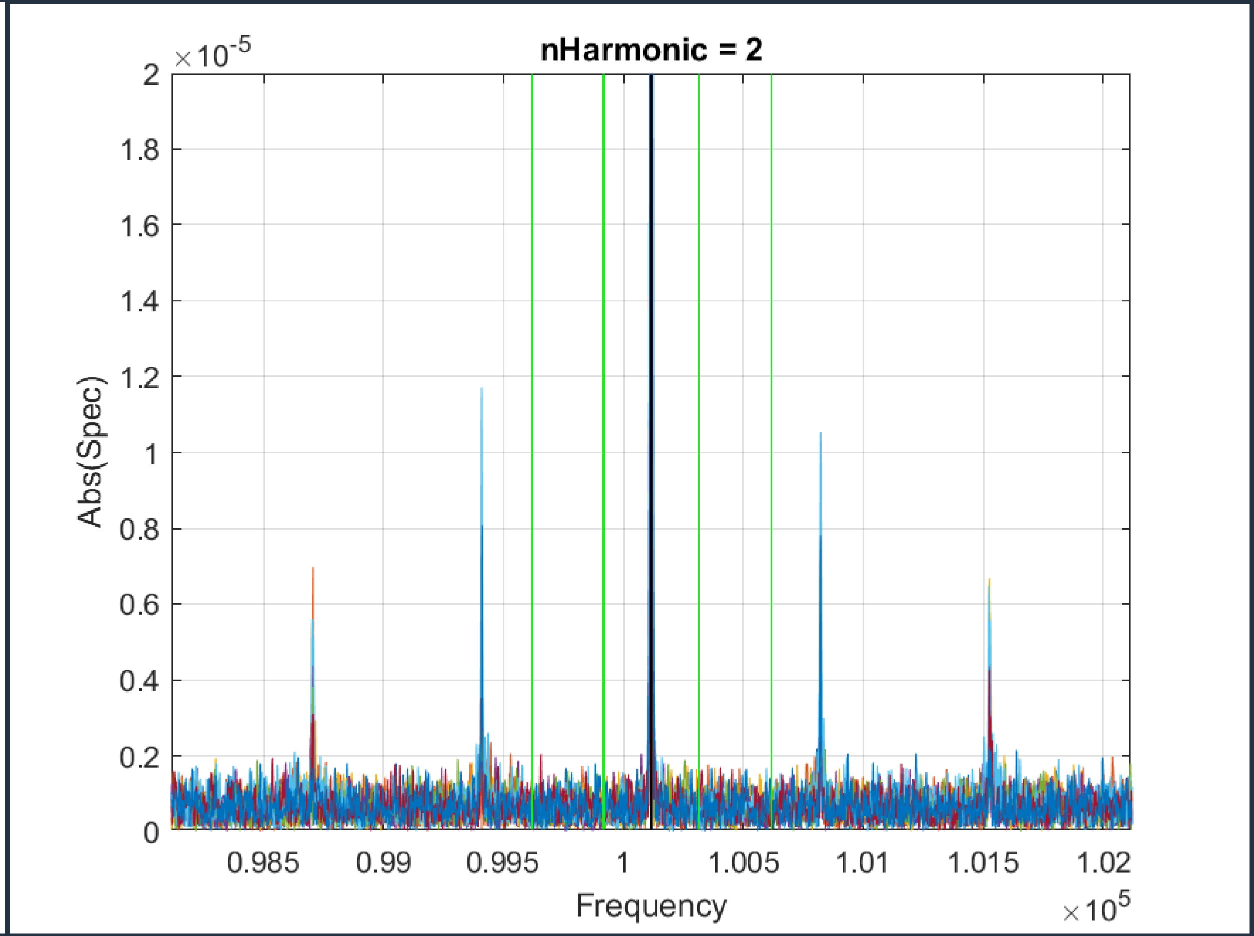


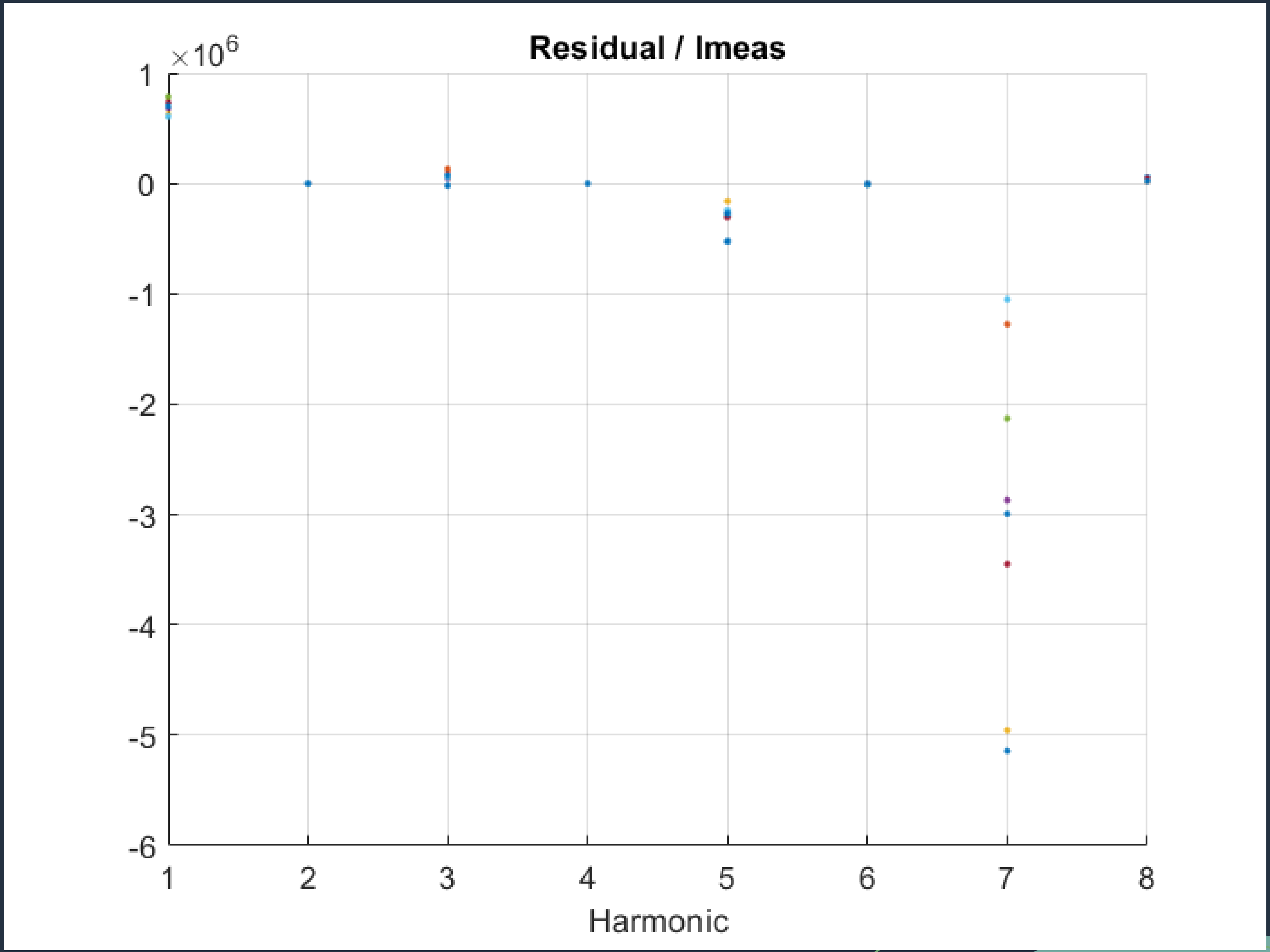
FFT - spec - closed
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
0
1
2
3
4
5
6
7
8
9
10
Frequency
$\times 10^{6}$


FFT - spec - Intensity
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
0
1
2
3
4
5
6
7
8
9
10
Frequency
$\times 10^{6}$

Harmonic peaks and background zones






Residual / Imeas
×10^6
1
0
-1
-2
-3
-4
-5
-6
1
2
3
4
5
6
7
8
Harmonic