INFN
Istituto Nazionale di Fisica Nucleare

GINGER

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

IN SUPREMÆ DIGNITATIS · 1343 ·
UNIVERSITÀ DI PISA

Plenaria Napoli 2025

Giuseppe Di Somma

Deep Learning for fast signal reconstruction

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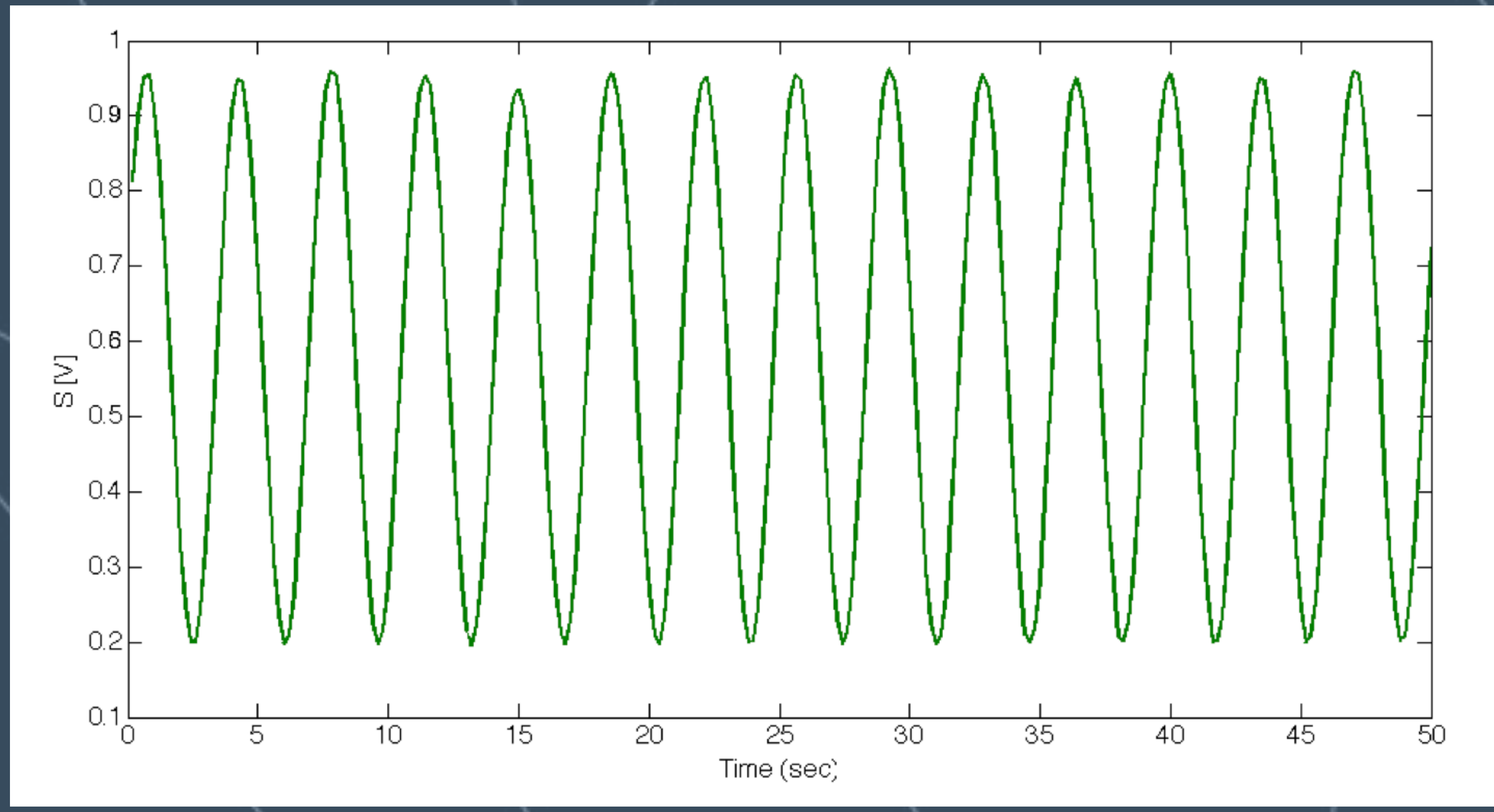
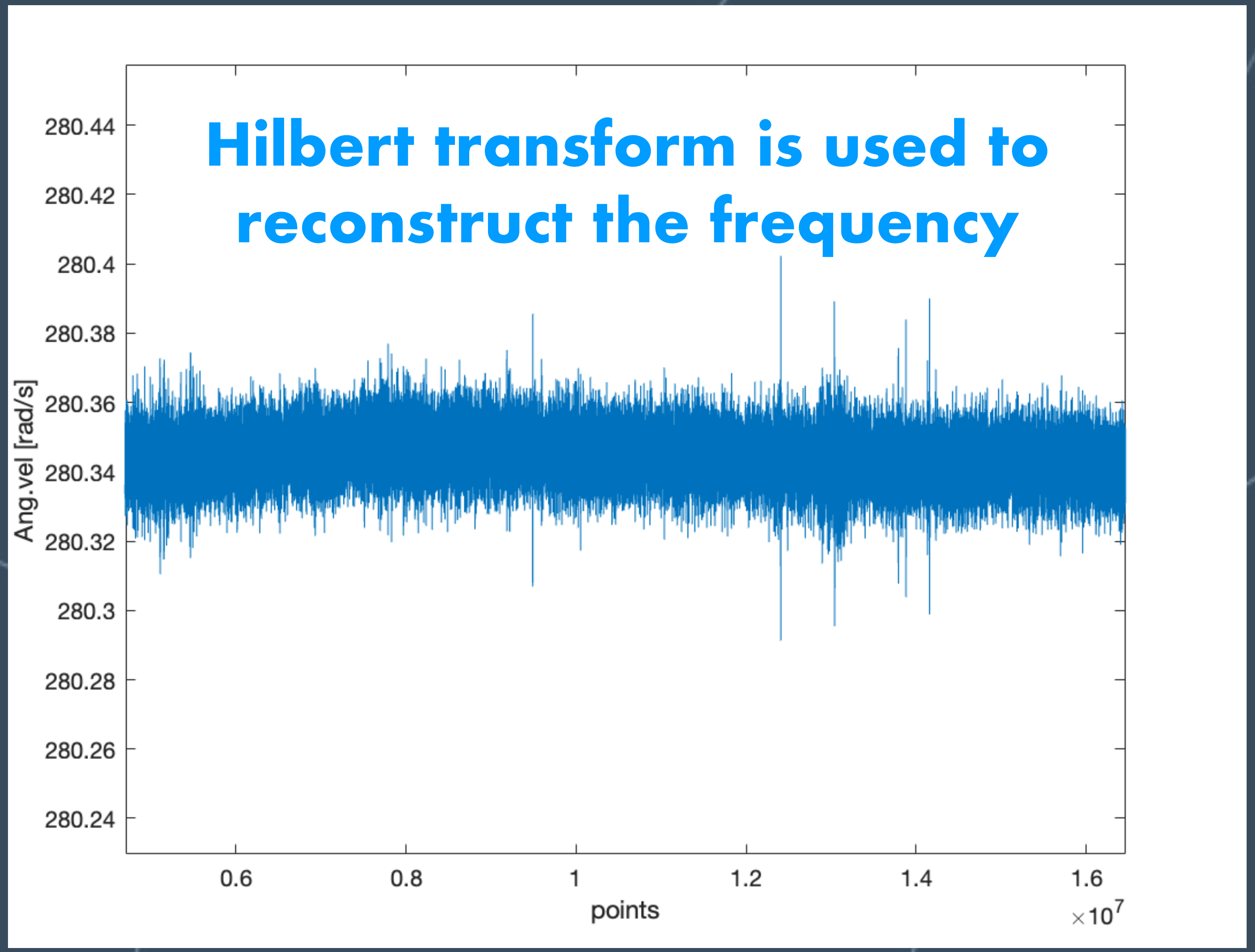
The beat note detected by GINGERINO in 50 secs

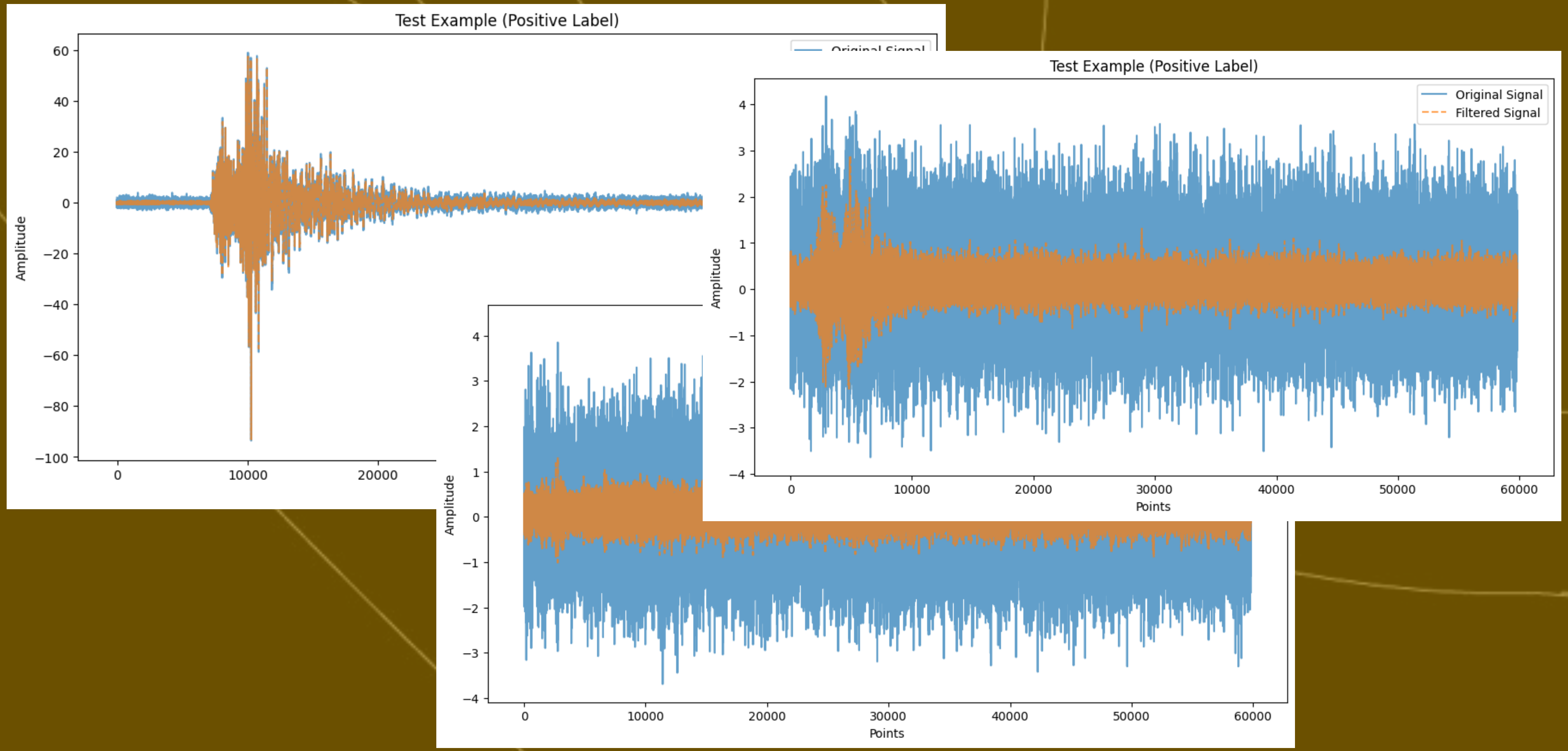


Interferogram of the two clockwise and counterclockwise beams



1° NN

Fast regressive Neural Network with linear activation

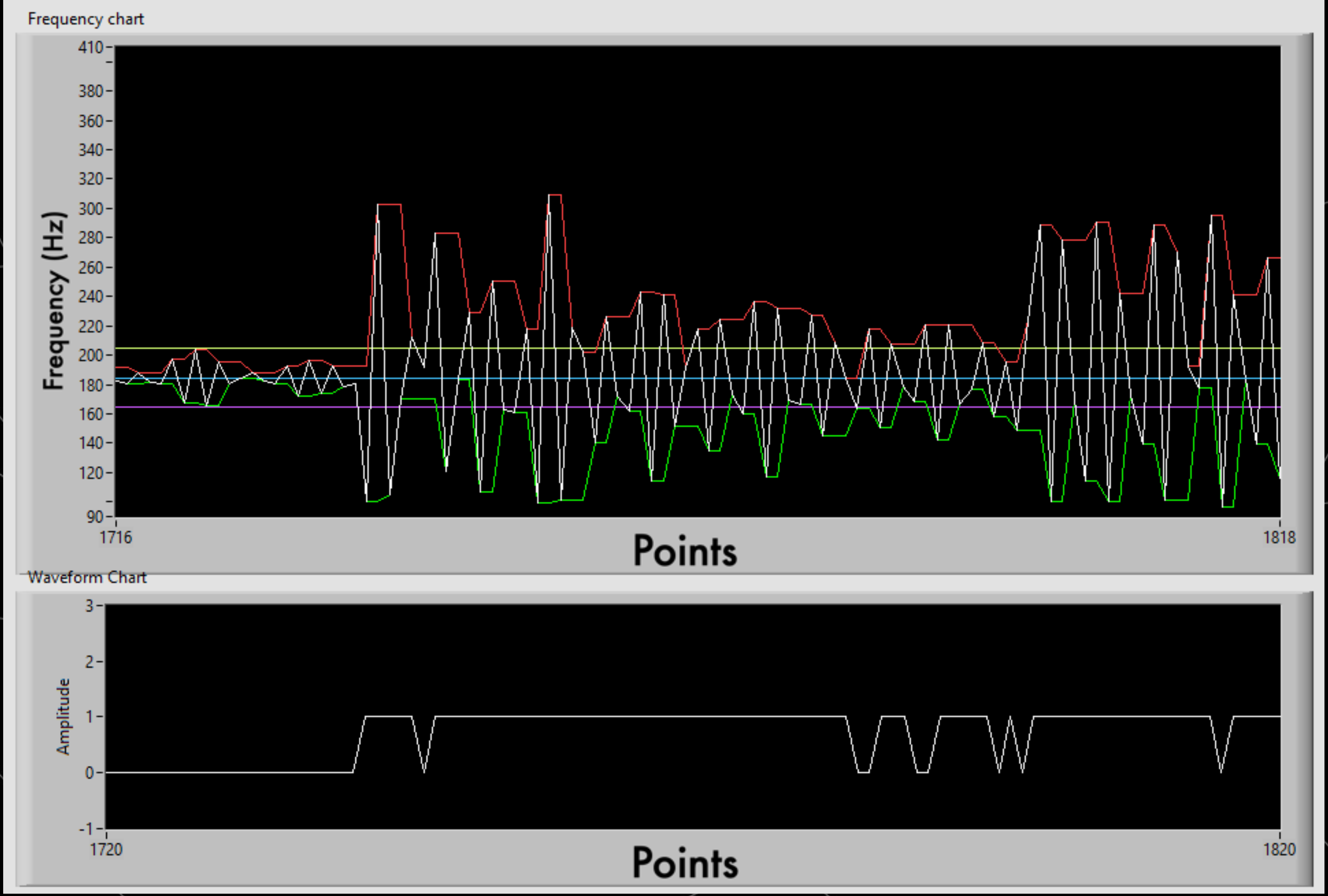


Earthquake yes or not?

2° NN

Neural network for classification with sigmoid activation

Implementation on GP2



Morphological closing

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(*Dilation* → *Erosion*, using the same structuring element)

Dilation expands "good" regions. At each position, the window performs a local logical test:"does this window contain at least one good sample?"

Erosion shrinks "good" regions. At each position, the window performs a local logical test: *"does this window contain only good samples?"*

Original mask (with holes):

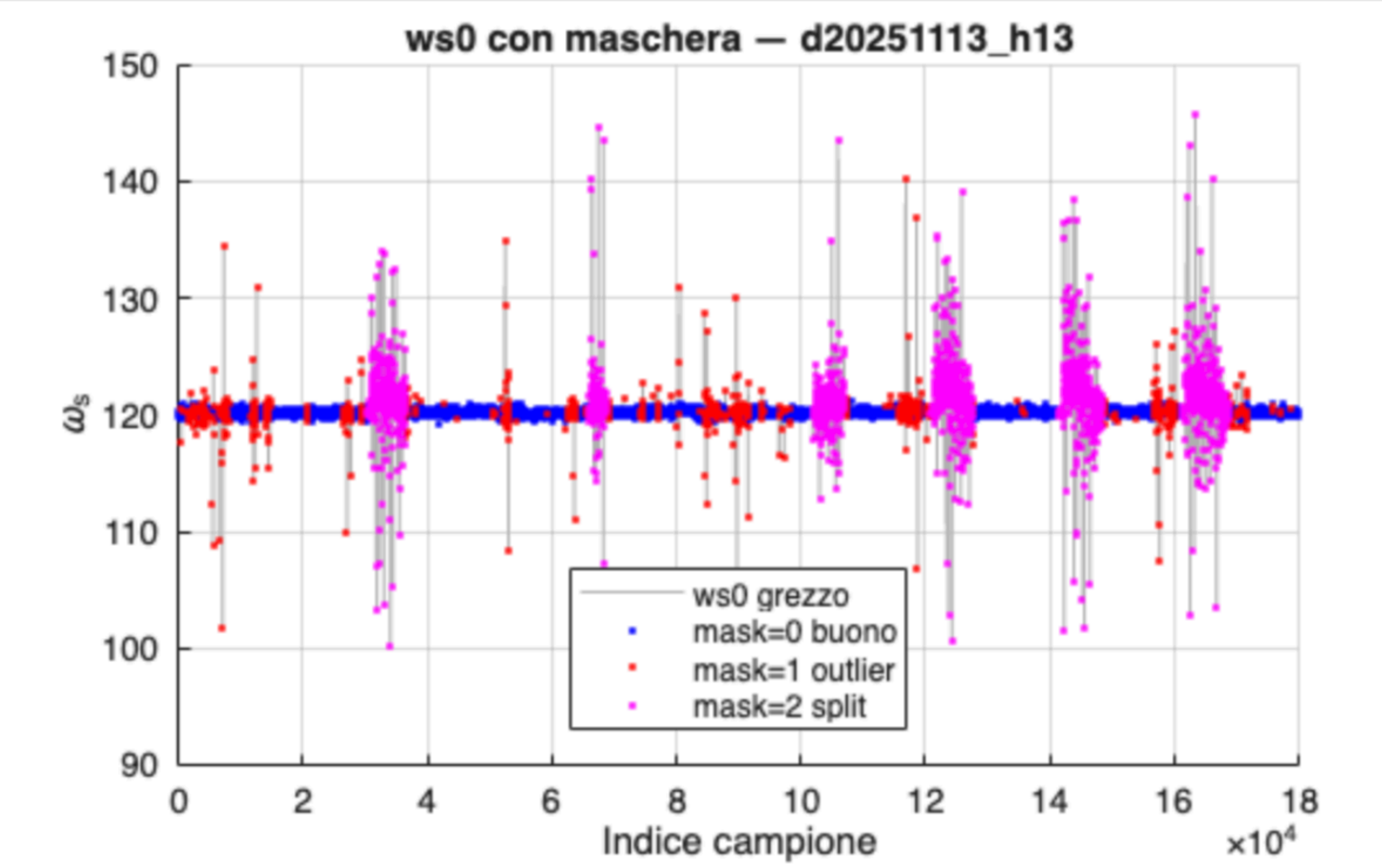
111011001111000111000011111000001111111

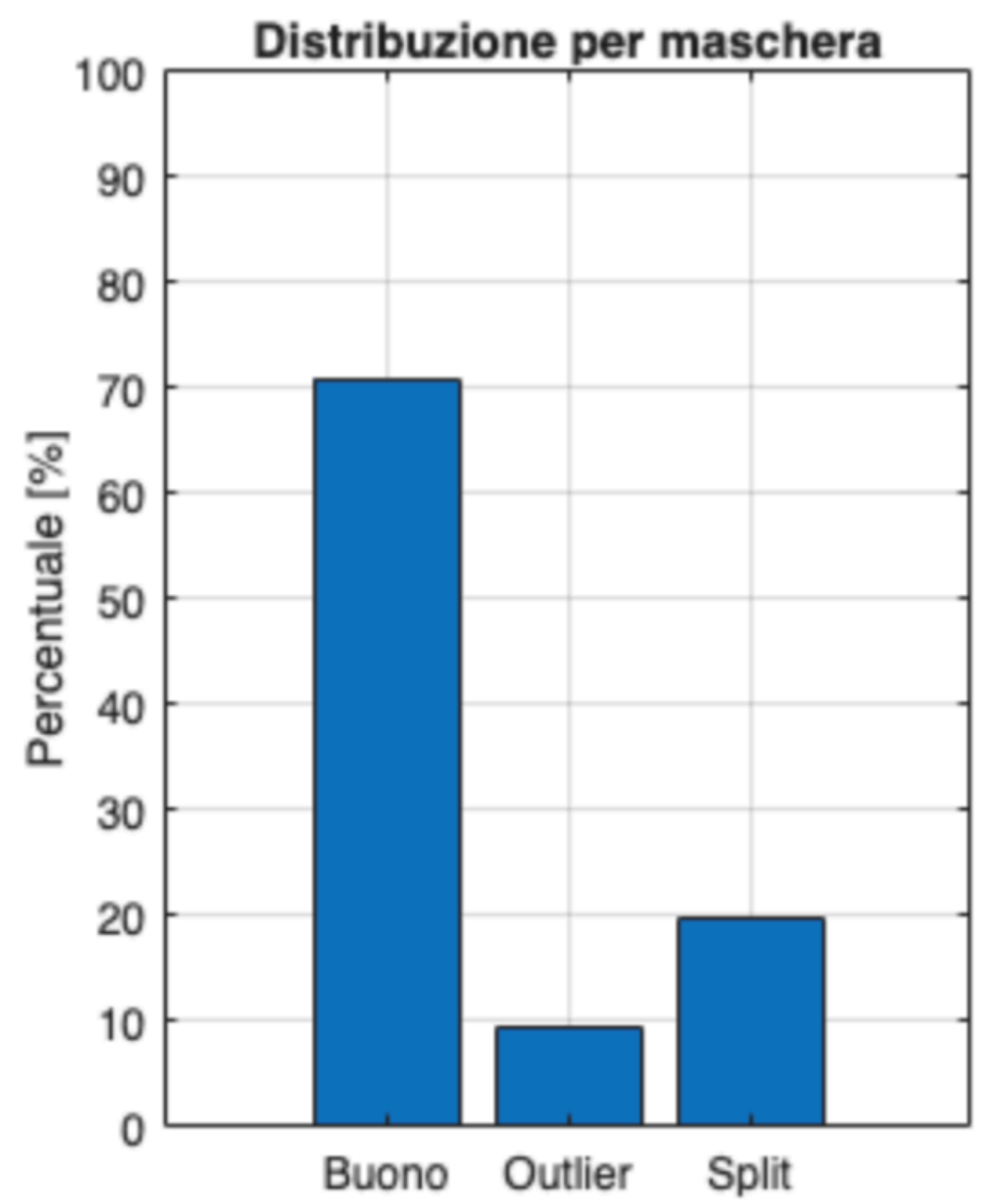
After dilation (window 4):

1111111111111111111110111111110011111111

After erosion (closing):

1111111111111111110000111100000111111





Riepilogo

Ora: $d20251113_h13$

N tot: 180000

Buoni: 127754 (70.97%)

Outlier: 16740 (9.30%)

Split: 35506 (19.73%)

TRIO

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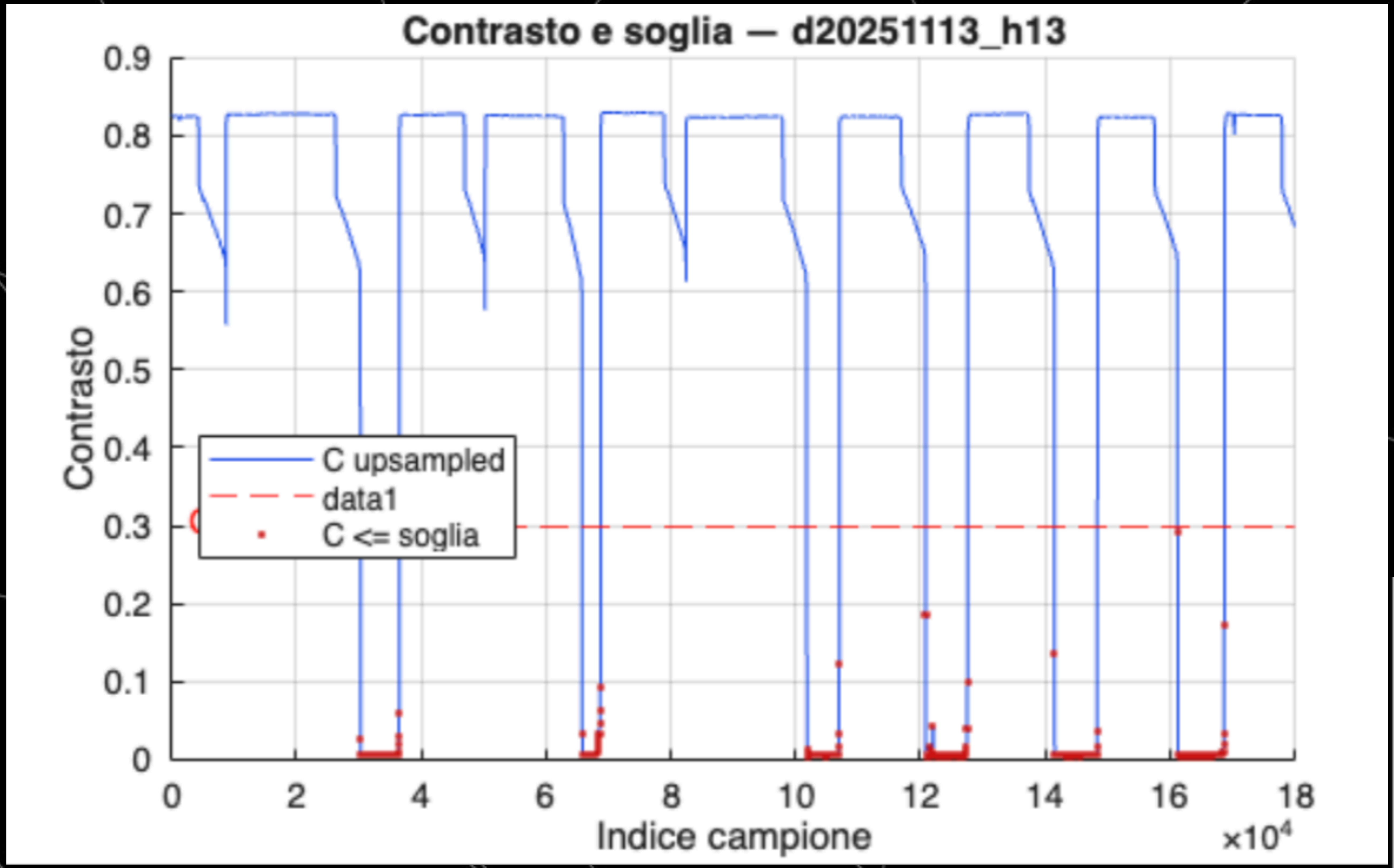
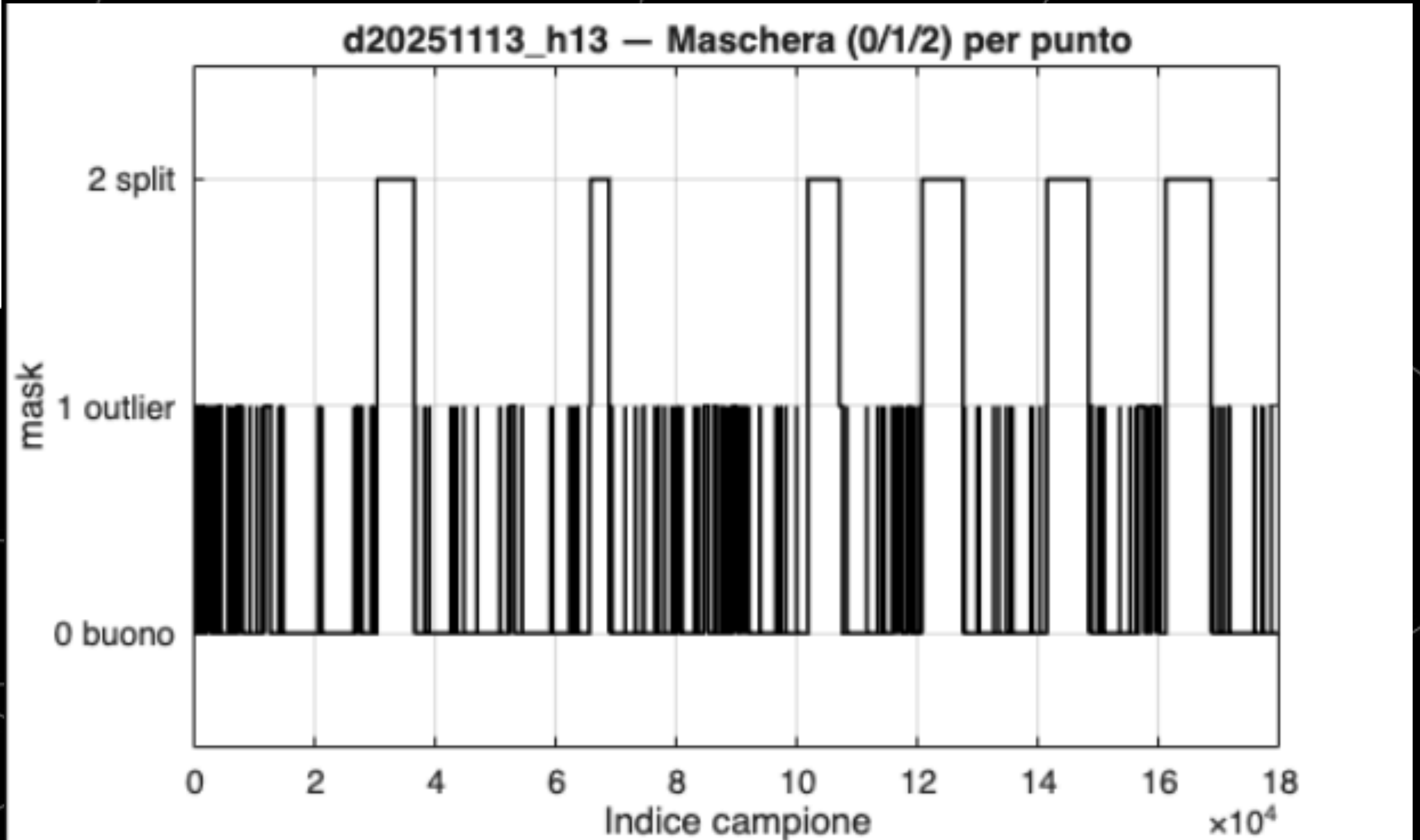
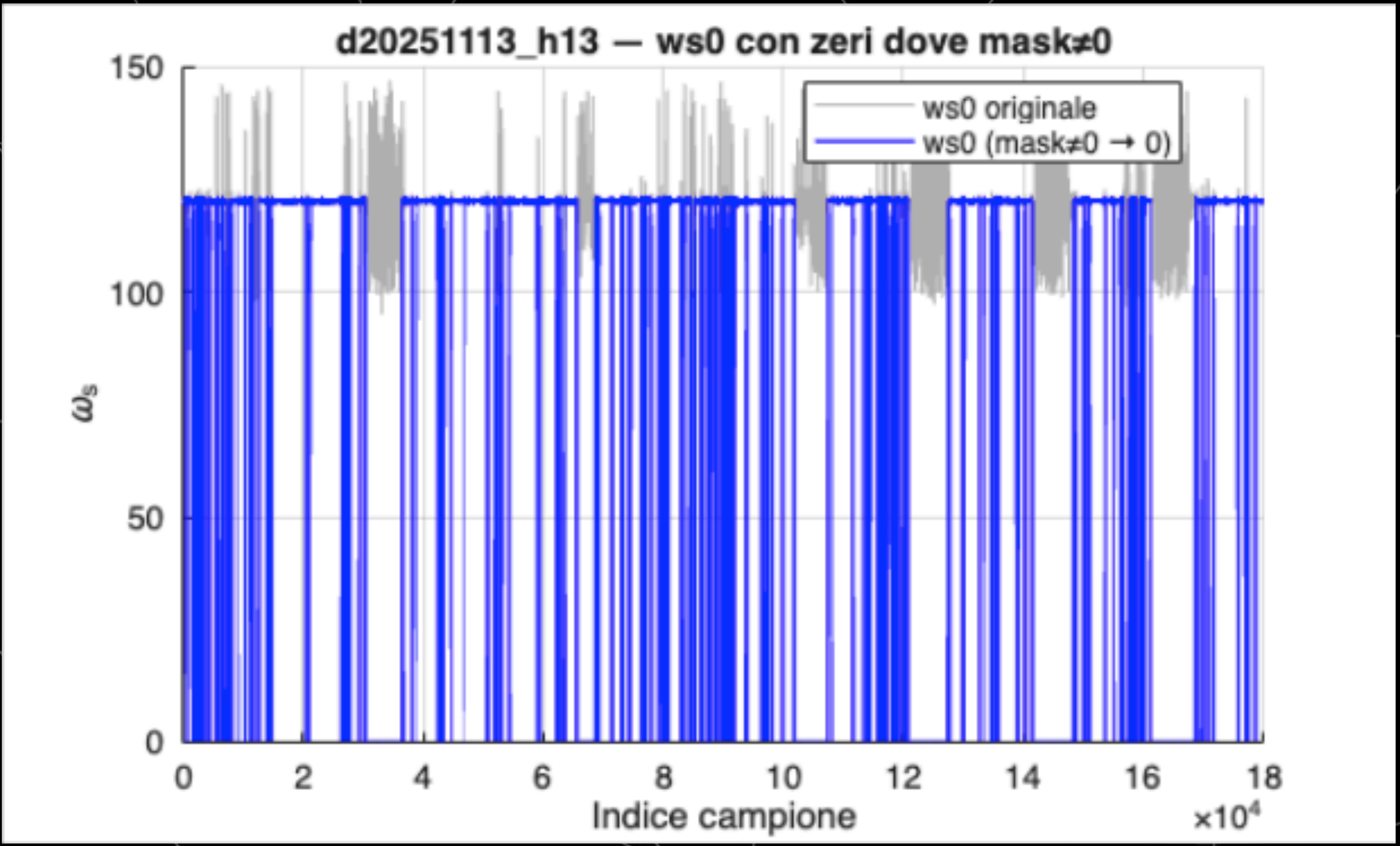
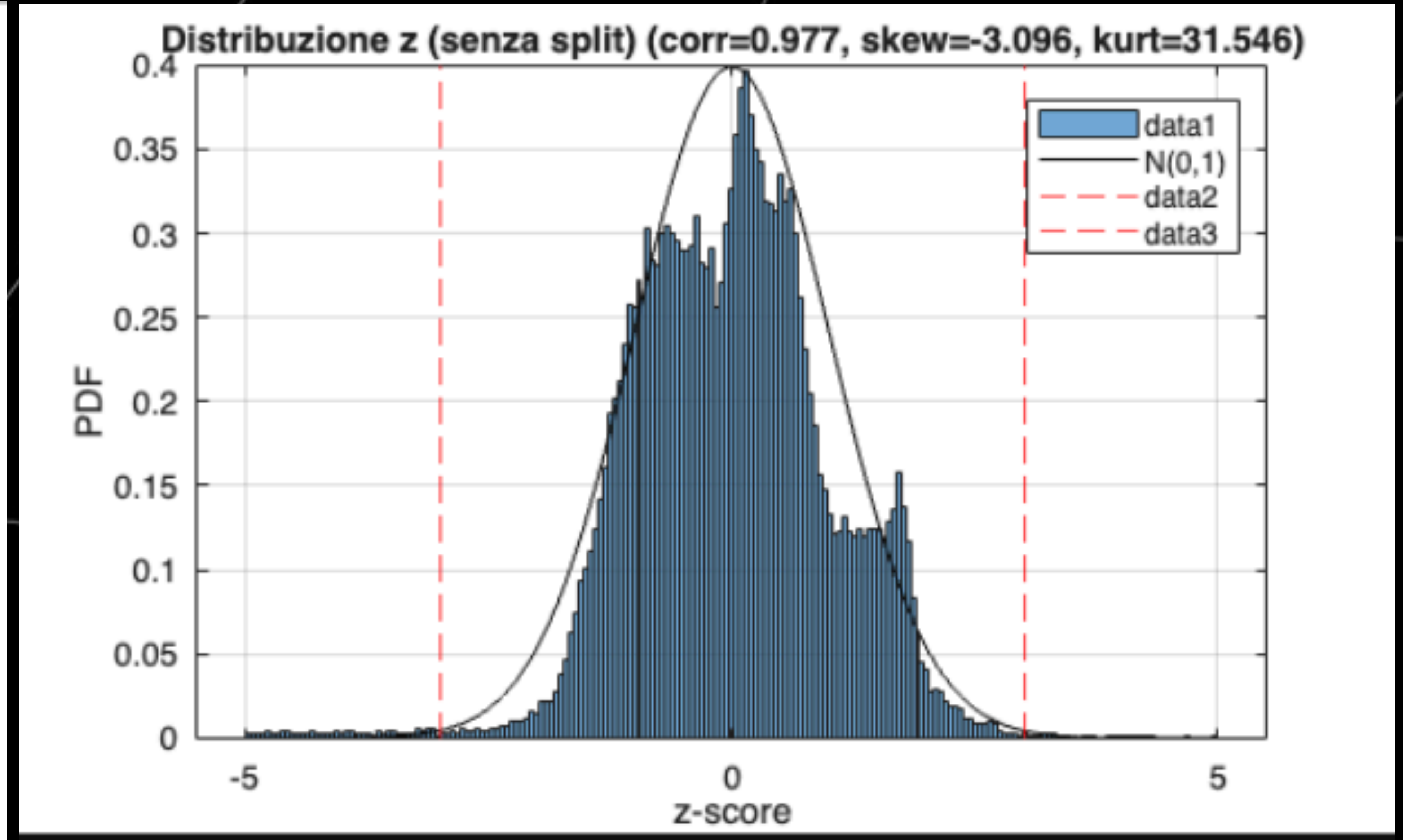


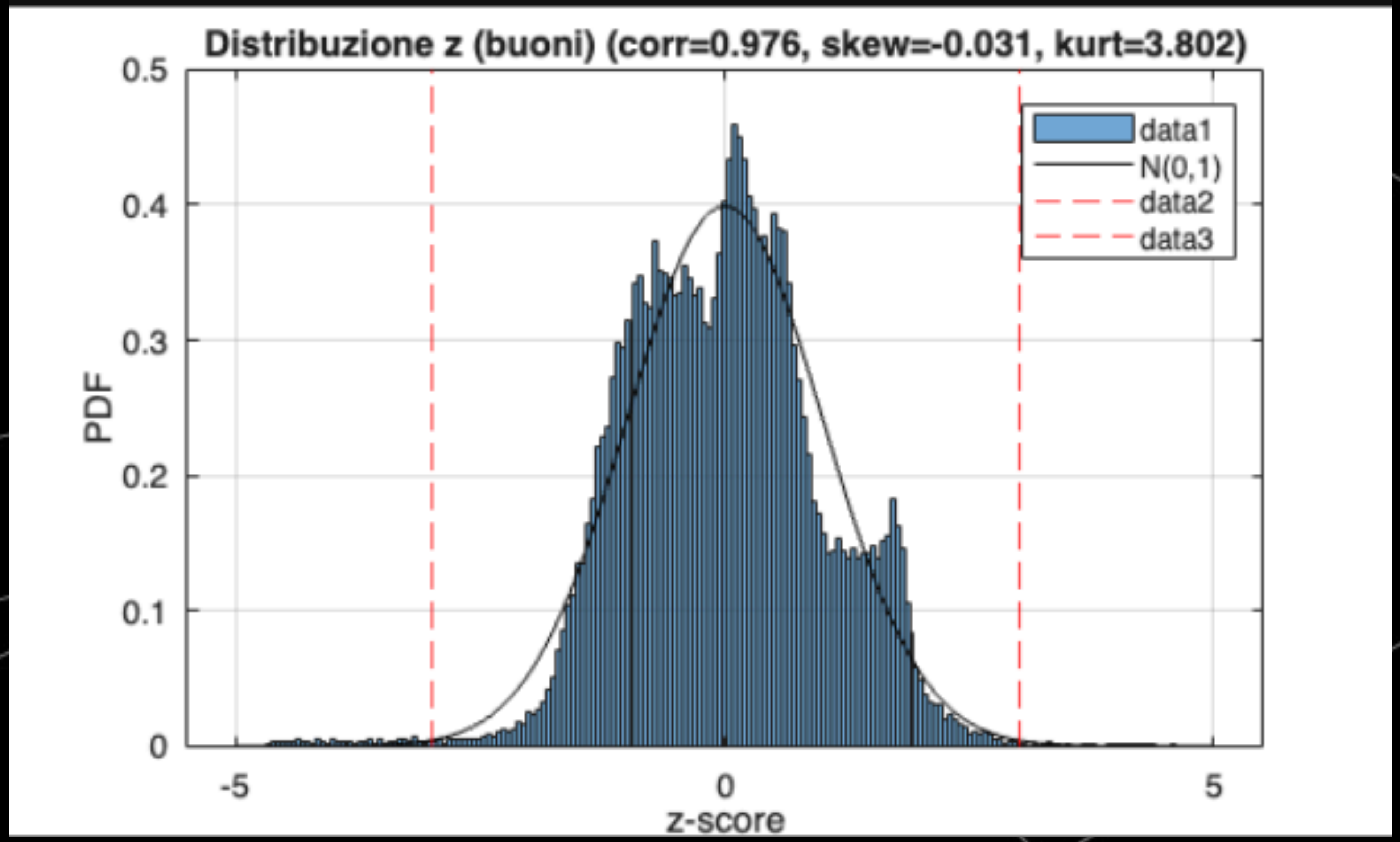
Contrasto e soglia — d20251113_h13
Contrasto
C upsampled
data1
C <= soglia
Indice campione
×10^4



d20251113_h13 — Maschera (0/1/2) per punto
mask
2 split
1 outlier
0 buono
Indice campione
×10^4


d20251113_h13 — ws0 con zeri dove mask≠0
ws0 originale
ws0 (mask≠0 → 0)
ω_s
Indice campione
×10^4
150
100
50
0
0 2 4 6 8 10 12 14 16 18


Distribuzione z (senza split) (corr=0.977, skew=-3.096, kurt=31.546)
data1
N(0,1)
data2
data3
PDF
z-score
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-5 0 5


Distribuzione z (buoni) (corr=0.976, skew=-0.031, kurt=3.802)
data1
N(0,1)
data2
data3
PDF
z-score
0.5
0.4
0.3
0.2
0.1
0
-5 0 5

Hilbert's analytical function

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$$I(t) = I_1 + I_2 + 2\sqrt{I_1 I_2}\,\cos(\omega_m t + \Delta\phi)\,.$$

$$x(t) = I(t) - < I(t) >$$

$$z(t) = x(t) + i\,\mathscr{H}\{x(t)\}\,.$$

$$\mathscr{H}\{x(t)\} = \frac{1}{\pi}\,\mathrm{p.v.}\int_{-\infty}^{+\infty} \frac{x(\tau)}{t-\tau}\,d\tau\,.$$

$$x(t) = A(t)\cos(\psi(t)), \quad z(t) = A(t)\,e^{i\psi(t)}\,.$$

$$A(t) = |z(t)| = \sqrt{x(t)^2 + \left(\mathscr{H}\{x(t)\}\right)^2}\,.$$

$$\psi(t) = \arg(z(t)) = \arctan\left(\frac{\mathscr{H}\{x(t)\}}{x(t)}\right).$$

$$\omega_{\mathrm{m}}(t) = \frac{d\psi(t)}{dt}\,.$$

Analysis of ring laser gyroscopes including laser dynamics

https://doi.org/10.1140/epjc/s10052-019-7089-5

$$\dot{I}_1 = \frac{c}{L}\left(\alpha_1 I_1 - \beta_1 I_1^2 - \theta_{12} I_1 I_2 + 2 r_2 \sqrt{I_1 I_2}\,\cos(\psi + \varepsilon)\right)$$

$$\dot{I}_2 = \frac{c}{L}\left(\alpha_2 I_2 - \beta_2 I_2^2 - \theta_{21} I_1 I_2 + 2 r_1 \sqrt{I_1 I_2}\,\cos(\psi - \varepsilon)\right)$$

$$\dot{\psi} = \omega_s - \delta_{ns} - \frac{c}{L}\left(r_1\sqrt{\frac{I_1}{I_2}}\,\sin(\psi - \varepsilon) + r_2\sqrt{\frac{I_2}{I_1}}\,\sin(\psi + \varepsilon)\right)$$

$$\delta_{ns} = \sigma_2 - \sigma_1 + \tau_{21} I_2 - \tau_{12} I_1$$

$$K(t) = \sqrt{\frac{\alpha_1}{\alpha_2}}\,c r_1 \sin(\varepsilon - t\omega_s) - \sqrt{\frac{\alpha_2}{\alpha_1}}\,c r_2 \sin(t\omega_s + \varepsilon)$$

$$(\omega_m - \delta_{ns})\,\delta t \simeq \left(\omega_s + \frac{K(t)}{L} - \frac{2c^2 r_1 r_2 \cos(2\epsilon)}{L^2 \omega_s}\right)\delta t$$

$$I_1(t) \simeq \frac{\alpha_1}{\beta} + \frac{2\sqrt{\alpha_1\alpha_2}\,r_2\left(\frac{L\omega_s}{c}\sin(t\omega_s + \epsilon) + \alpha_1\cos(t\omega_s + \epsilon)\right)}{\beta\left(\alpha_1^2 + \frac{L^2\omega_s^2}{c^2}\right)} - \frac{2c r_1 r_2 \sin(2\epsilon)}{\beta L \omega_s}$$

$$I_2(t) \simeq \frac{\alpha_2}{\beta} + \frac{2\sqrt{\alpha_1\alpha_2}\,r_1\left(\alpha_2\cos(\epsilon - t\omega_s) - \frac{L\omega_s}{c}\sin(\epsilon - t\omega_s)\right)}{\beta\left(\alpha_1^2 + \frac{L^2\omega_s^2}{c^2}\right)} + \frac{2c r_2 r_1 \sin(2\epsilon)}{\beta L \omega_s}$$

$$\psi_0(t) \simeq \frac{c}{L\omega_s}\left(\sqrt{\frac{\alpha_1}{\alpha_2}}\,r_1\cos(\epsilon - t\omega_s) + \sqrt{\frac{\alpha_2}{\alpha_1}}\,r_2\cos(t\omega_s + \epsilon)\right) + t\left(\omega_s - \frac{2 r_1 r_2 \left(\frac{c}{L}\right)^2 \cos(2\epsilon)}{\omega_s}\right)$$

$$\omega_s = \frac{\omega_m}{2} + \sqrt{\frac{8c^2 r_1 r_2 \cos(2\epsilon) + \left(K - L(\omega_m + \delta_{ns})\right)^2}{4L^2}} - \frac{K}{2L} - \frac{\delta_{ns}}{2}$$

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$$\omega_s \simeq \omega_{s0} + \omega_{ns1} + \omega_{K1} + \mathcal{O}(2)$$

$$\delta_{ns} = \sigma_2 - \sigma_1 + \tau_{21} I_2 - \tau_{12} I_1$$

$$K(t) = \sqrt{\frac{\alpha_1}{\alpha_2}}\, c r_1 \sin(\varepsilon - t\omega_s) - \sqrt{\frac{\alpha_2}{\alpha_1}}\, c r_2 \sin(t\omega_s + \varepsilon)$$

$$r_1 = \frac{I_{S2}\,\omega_m\, L}{2c\sqrt{PH_1 PH_2}}, \qquad r_2 = \frac{I_{S1}\,\omega_m\, L}{2c\sqrt{PH_1 PH_2}}$$

$$\omega_{s0} = \left(\frac{1}{2}\sqrt{\frac{8c^2 r_1 r_2 \cos(2\epsilon)}{L^2} + \omega_m^2} + \frac{\omega_m}{2}\right)$$

$$\omega_{ns1} = -\,\delta_{ns}\left(\frac{\omega_m}{2\sqrt{\frac{8c^2 r_1 r_2 \cos(2\epsilon)}{L^2} + \omega_m^2}} + \frac{1}{2}\right)$$

$$\omega_{K1} = -\frac{K}{L}\left(\frac{\omega_m}{2\sqrt{\frac{8c^2 r_1 r_2 \cos(2\epsilon)}{L^2} + \omega_m^2}} + \frac{1}{2}\right)$$

https://doi.org/10.1140/epjc/s10052-020-7659-6

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$$\mu_{ab} = \sqrt{\pi\varepsilon_0 A_{ik}\left(\frac{\lambda}{2\pi}\right)^3 \frac{h}{2\pi}}$$

$$Z_i(\xi,\eta) = \sqrt{\pi}e^{-\xi^2} - 2\eta$$

$$Z_r(\xi,\eta) = -2\xi e^{-\xi^2}$$

$$Lor(\xi,\eta) = \frac{1}{1+(\xi/\eta)^2}$$

$$\beta_s(\xi,\eta,G) = G\frac{Z_i(\xi,\eta)}{Z_i(0,\eta)}$$

$$\alpha_s(\xi,\eta,G,\mu) = \beta_s(\xi,\eta,G) - \mu$$

$$\sigma_s(\xi,\eta,G) = G\frac{FSR}{2}\frac{Z_r(\xi,\eta)}{Z_i(0,\eta)}$$

$$\tau_s(\xi_X,\xi_Y,\eta,G) = G\frac{FSR}{2}\frac{\xi_X}{\eta}\frac{Z_i(\xi_Y,\eta)}{Z_i(0,\eta)}Lor(\xi_X,\eta)$$

$$\beta_d = k_{20}\beta_s(\xi_{20}) + k_{22}\beta_s(\xi_{22})$$

$$\alpha_d = k_{20}\alpha_s(\xi_{20}) + k_{22}\alpha_s(\xi_{22})$$

$$\sigma_d = k_{20}\sigma_s(\xi_{20}) + k_{22}\sigma_s(\xi_{22})$$

$$\tau_d = k_{20}\tau_s(\xi_{X20},\xi_{Y20}) + k_{22}\tau_s(\xi_{X22},\xi_{Y22})$$

$$B_1 = k_{20}\frac{Z_i(\xi_{120},\eta_{20})}{Z_i(0,\eta_{20})} + k_{22}\frac{Z_i(\xi_{122},\eta_{22})}{Z_i(0,\eta_{22})}$$

$$B_2 = k_{20}\frac{Z_i(\xi_{220},\eta_{20})}{Z_i(0,\eta_{20})} + k_{22}\frac{Z_i(\xi_{222},\eta_{22})}{Z_i(0,\eta_{22})}$$

$$G_1 = \frac{\mu}{(1-I_1)B_1}, \qquad G_2 = \frac{\mu}{(1-I_2)B_2}$$

$$\eta_{20} = \frac{\gamma_{ab}}{D_{20}}, \qquad \eta_{22} = \frac{\gamma_{ab}}{D_{22}}$$

$$\alpha_d = k_{20}\alpha_s(\xi_{20}) + k_{22}\alpha_s(\xi_{22})$$

$$\xi_{120} = \frac{+Sh/2}{D_{20}}, \qquad \xi_{122} = \frac{-Sh/2}{D_{22}}$$

$$\xi_{220} = \frac{f_s + Sh/2}{D_{20}}, \qquad \xi_{222} = \frac{f_s - Sh/2}{D_{22}}$$

$$D_{20} = \frac{1}{\lambda}\sqrt{\frac{2k_BT_p}{m_{20}}}, \qquad D_{22} = \frac{1}{\lambda}\sqrt{\frac{2k_BT_p}{m_{22}}}$$

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$$c_{I2P} = \frac{\pi^2 \mu_{ab}^2}{2h^2 \gamma_a \gamma_b} \frac{1}{2c\varepsilon_0 T_{\text{mir}} a} \qquad c_{I2V} = \frac{c_{I2P}}{GAmp\, a_{\text{eff}}} \qquad I_1 = c_{I2V} PH_1, \qquad I_2 = c_{I2V} PH_2$$

$$\delta_{ns} = \sigma_2 - \sigma_1 + \tau_{21} I_2 - \tau_{12} I_1$$

$$\left| \frac{\delta_{nsa}}{\omega_m} \right| \leq 0.01$$

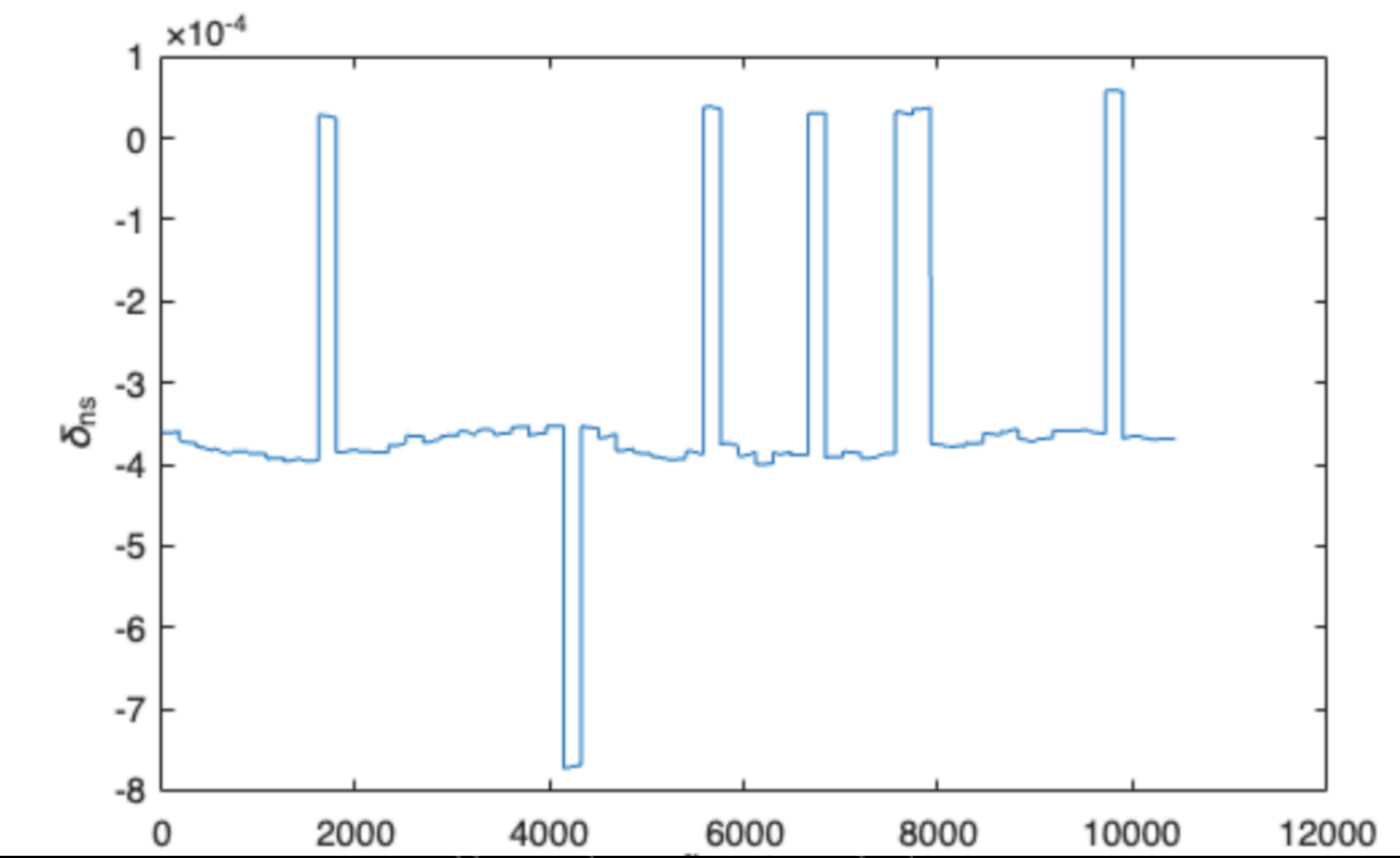
$$\sigma_d = k_{20} \sigma_s(\xi_{20}) + k_{22} \sigma_s(\xi_{22})$$

$$\tau_{12} = \tau_d(\xi_{X20}, \xi_{Y20}) I_1 + \tau_d(\xi_{X22}, \xi_{Y22}) I_1$$

$$\tau_{21} = \tau_d(\xi_{Y20}, \xi_{X20}) I_2 + \tau_d(\xi_{Y22}, \xi_{X22}) I_2$$

$$\tau_{12a} \simeq \frac{\alpha_{1a}}{I_2} + 2r_2 \sqrt{\frac{1}{I_1 I_2}} \cos(t\omega_s + \varepsilon)$$

$$\tau_{21a} \simeq \frac{\alpha_{2a}}{I_1} + 2r_1 \sqrt{\frac{1}{I_1 I_2}} \cos(t\omega_s + \varepsilon)$$



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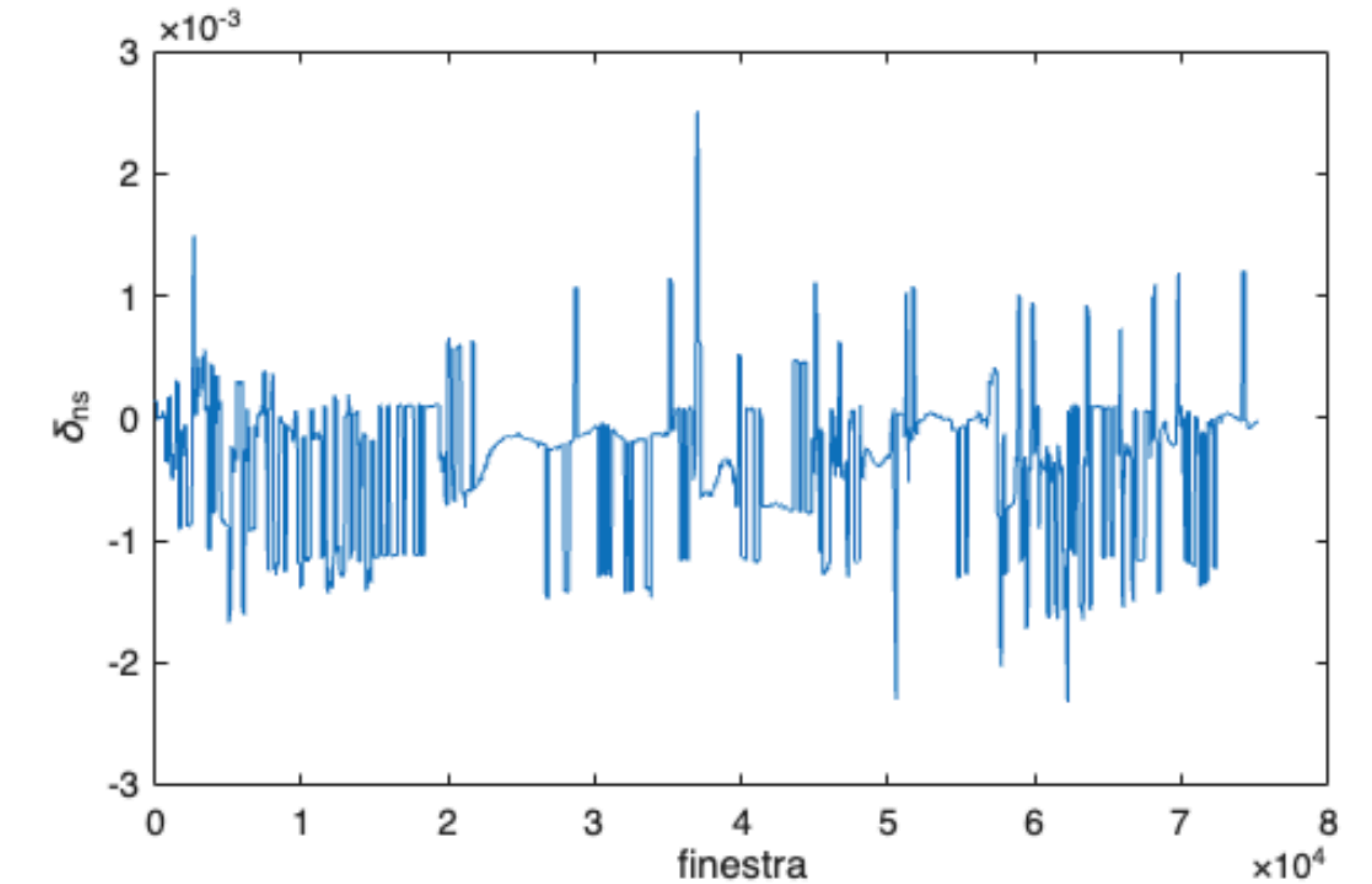

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$$\alpha_1 = \beta_1\left(I_1 + \frac{IS_1^2}{4PH_1}\right) + \frac{IS_1 IS_2\,\omega_m \sin 2\varepsilon}{4PH_2}\frac{L}{c} \qquad \alpha_2 = \beta_2\left(I_2 + \frac{IS_2^2}{4PH_2}\right) - \frac{IS_1 IS_2\,\omega_m \sin 2\varepsilon}{4PH_1}\frac{L}{c}$$

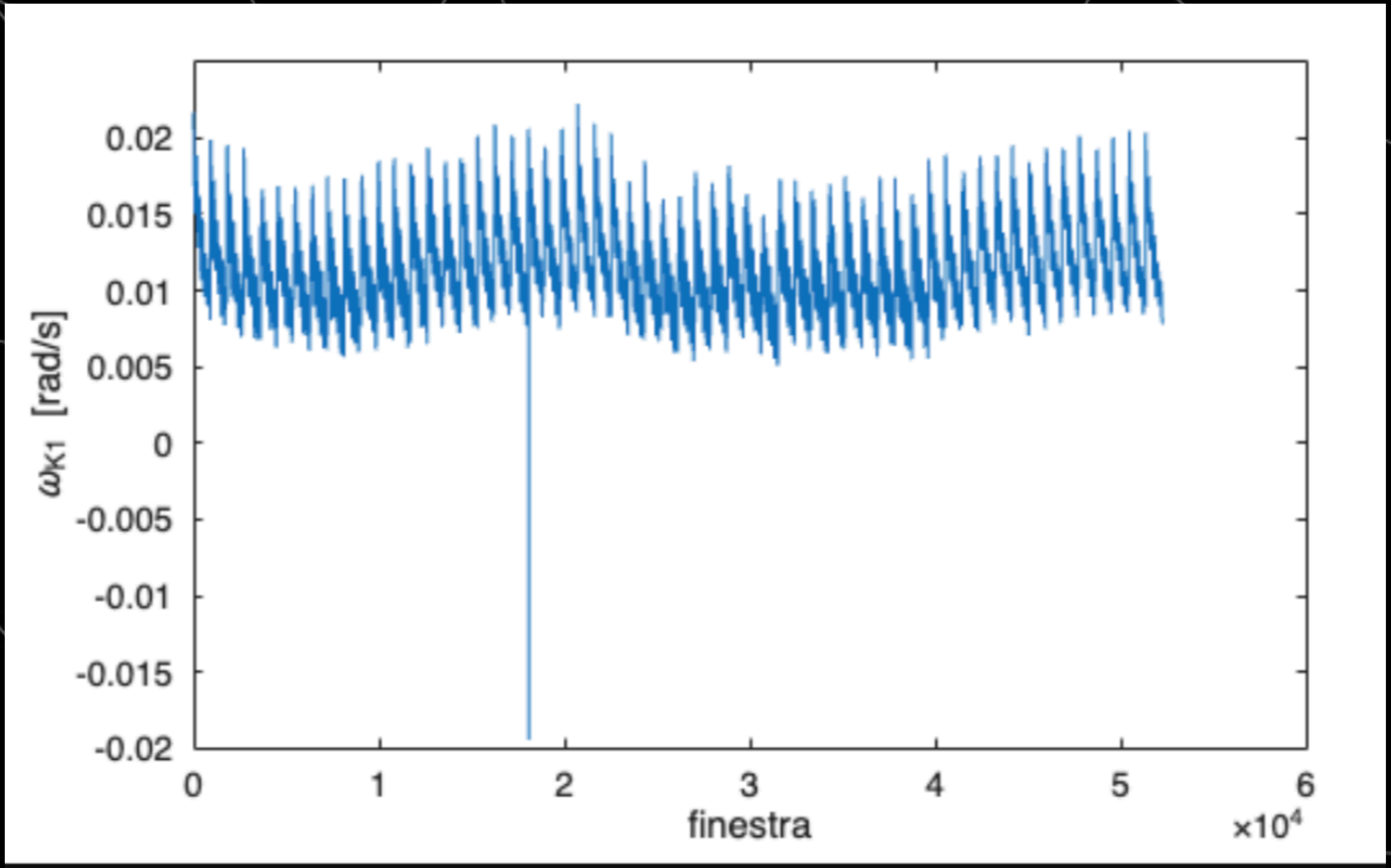
$$K_{eff} = \sqrt{\frac{\alpha_1}{\alpha_2}}\frac{IS_2 L\omega_m}{4\sqrt{PH_1 PH_2}}(-\cos\varepsilon + \sin\varepsilon) - \sqrt{\frac{\alpha_2}{\alpha_1}}\frac{IS_1 L\omega_m}{4\sqrt{PH_1 PH_2}}(\cos\varepsilon + \sin\varepsilon)$$

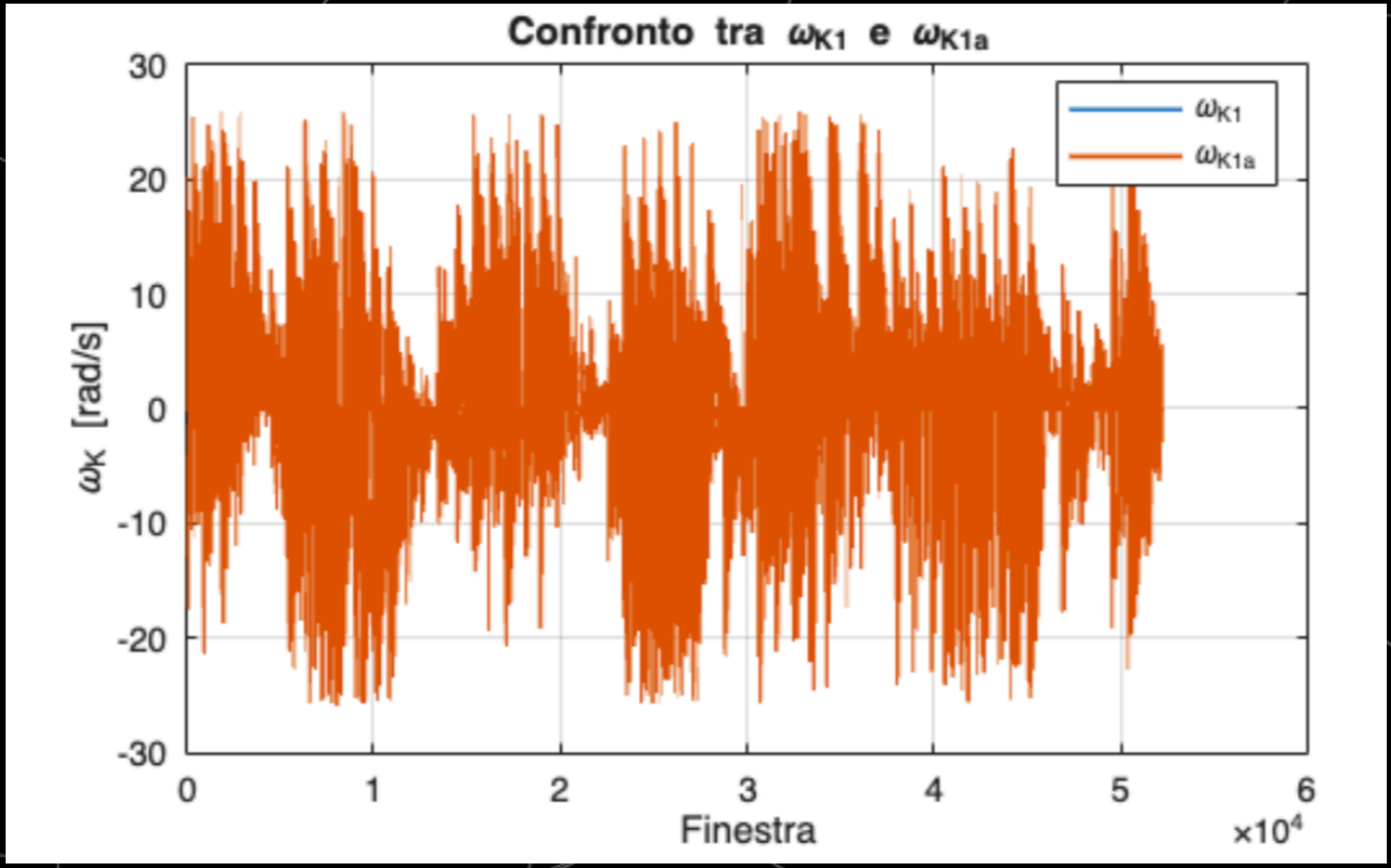
$$\alpha_{1a} \simeq -2r_2\sqrt{\frac{I_2}{I_1}}\cos(t\omega_S + \varepsilon) \qquad \alpha_{2a} \simeq -2r_1\sqrt{\frac{I_1}{I_2}}\cos(t\omega_S - \varepsilon)$$

$$K_{eff1a} = \sqrt{\frac{\alpha_{1a}}{\alpha_{2a}}}\,cr_1\sin(\varepsilon - t\omega^{(n)}) - \sqrt{\frac{\alpha_{2a}}{\alpha_{1a}}}\,cr_2\sin(t\omega^{(n)} + \varepsilon)$$

$$\omega^{(n+1)} = \omega^{(n)} + \omega^{(n)}_{K1a} \qquad \left|\frac{K_{eff1a}}{\omega_{S0}}\right| \leq 0.01$$

$$K_{eff} = \sqrt{\frac{\alpha_1}{\alpha_2}}\frac{IS_2L\omega_m}{4\sqrt{PH_1PH_2}}(-\cos\varepsilon + \sin\varepsilon) - \sqrt{\frac{\alpha_2}{\alpha_1}}\frac{IS_1L\omega_m}{4\sqrt{PH_1PH_2}}(\cos\varepsilon + \sin\varepsilon)$$





$$K_{eff1a} = \sqrt{\frac{\alpha_{1a}}{\alpha_{2a}}}cr_1\sin(\varepsilon - t\omega^{(n)}) - \sqrt{\frac{\alpha_{2a}}{\alpha_{1a}}}cr_2\sin(t\omega^{(n)} + \varepsilon)$$

$$\omega_S = S\vec{\Omega} \cdot \hat{n}$$

$$\omega_S = S\Omega cos\theta$$

$$\omega_S \simeq S(t)\Omega(t)\left(cos\theta + \delta\theta(t)sen\theta\right)$$

$$S(t) \approx S_0\left[1 + k_1\,\Delta T(t) + k_2\,\Delta T^2(t)\right]$$

$$\Omega(t) \simeq \Omega_{IERS} + \Omega_{TIDALS} + \Omega_{LOC} + \Omega_{GR}$$

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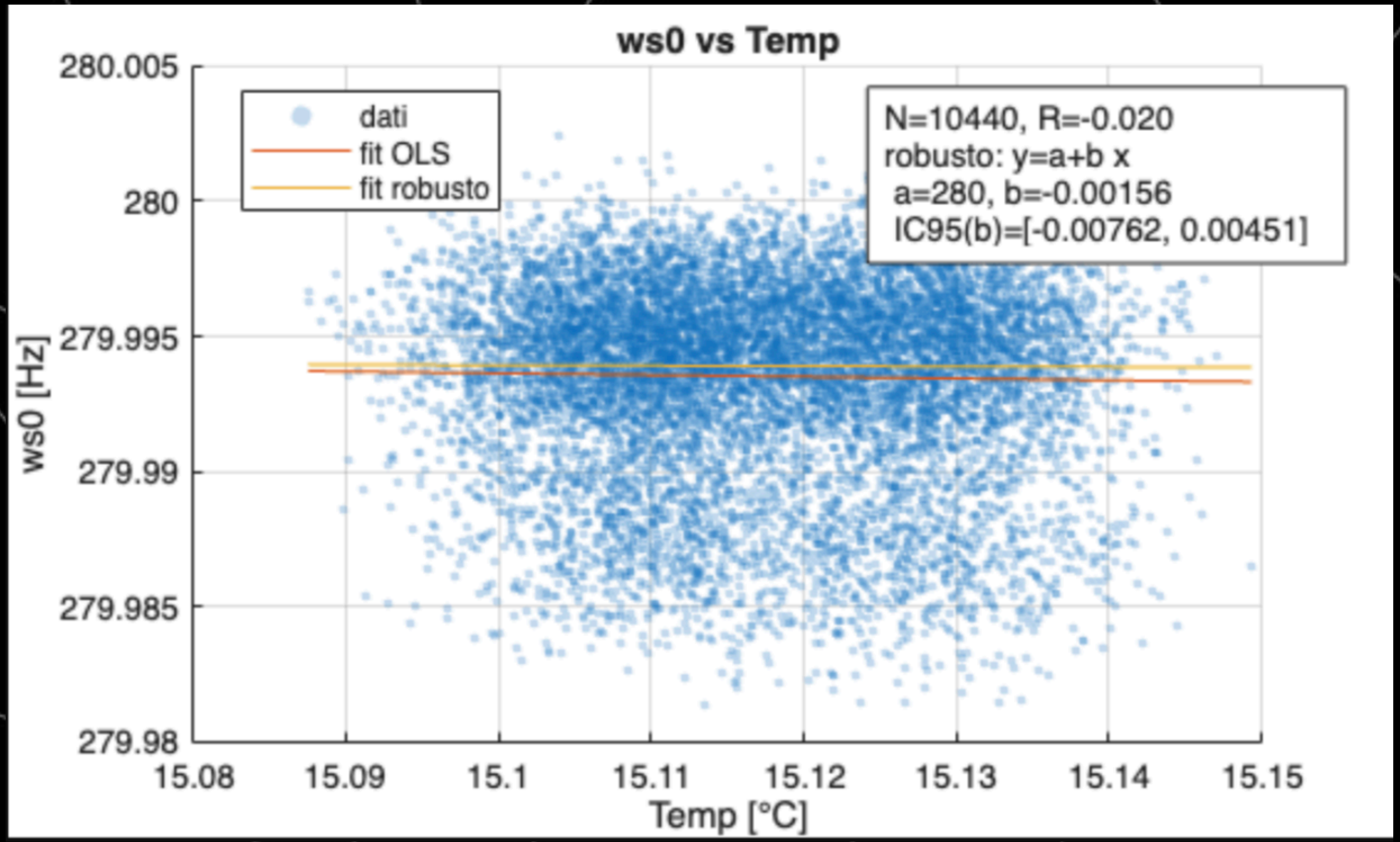

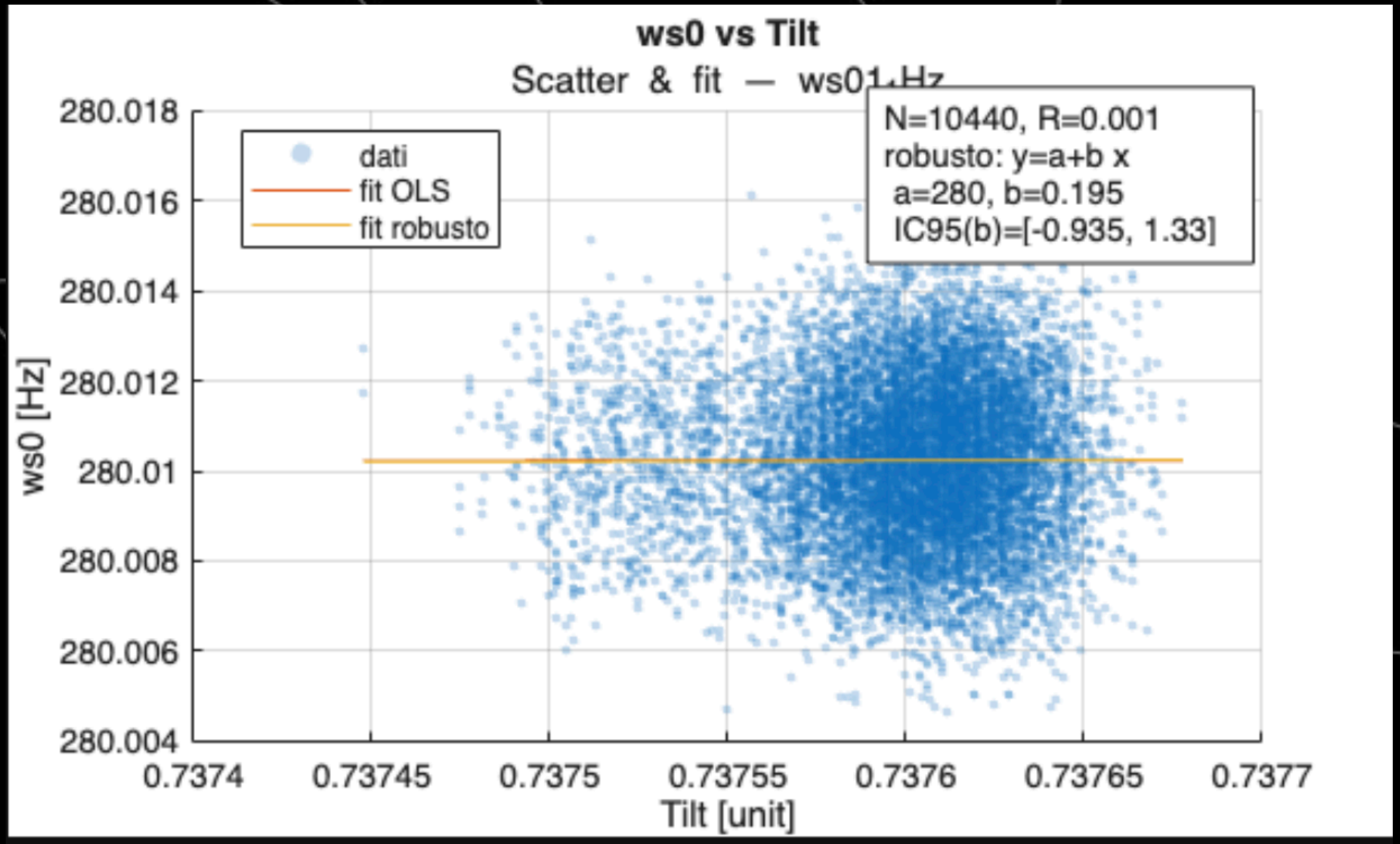

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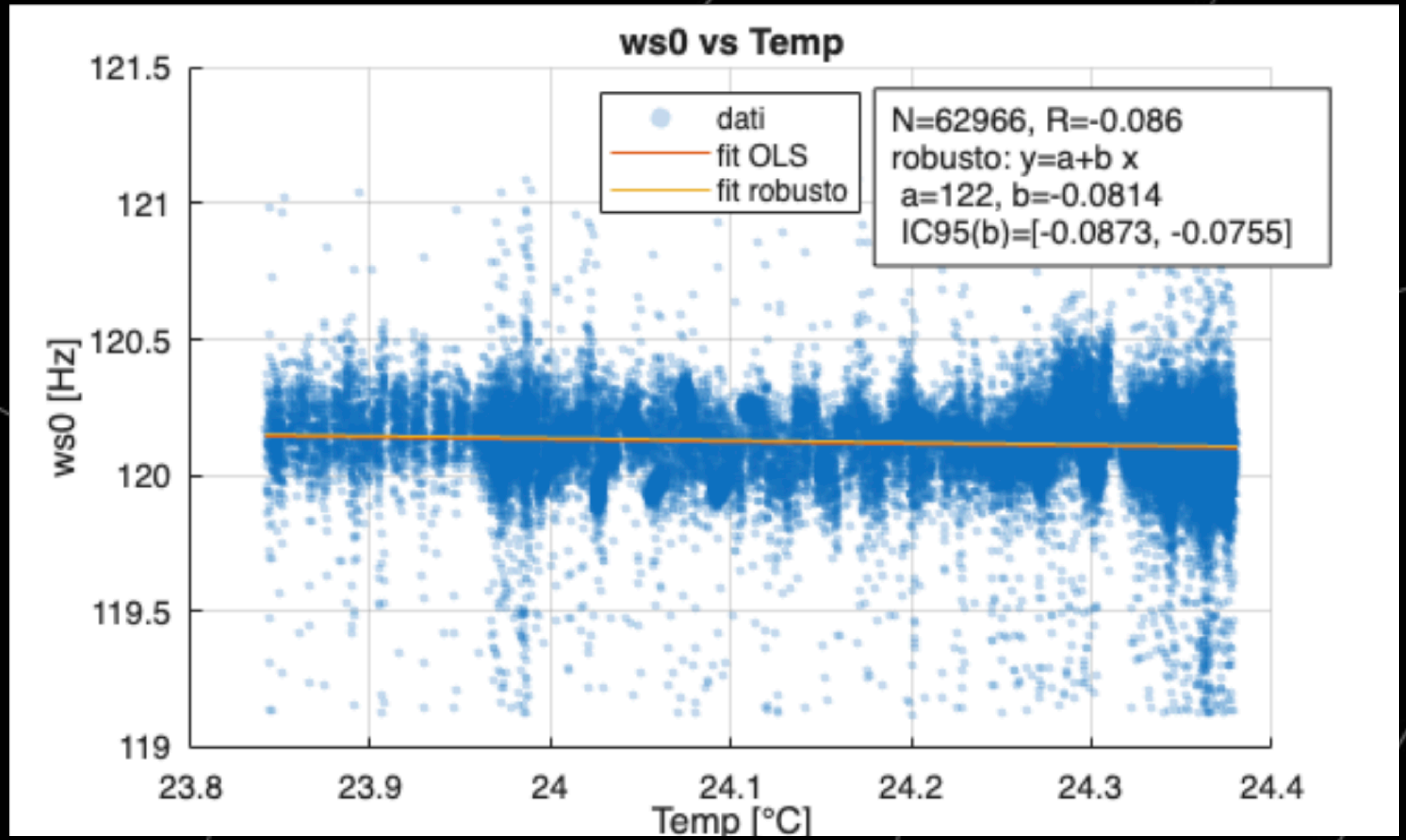

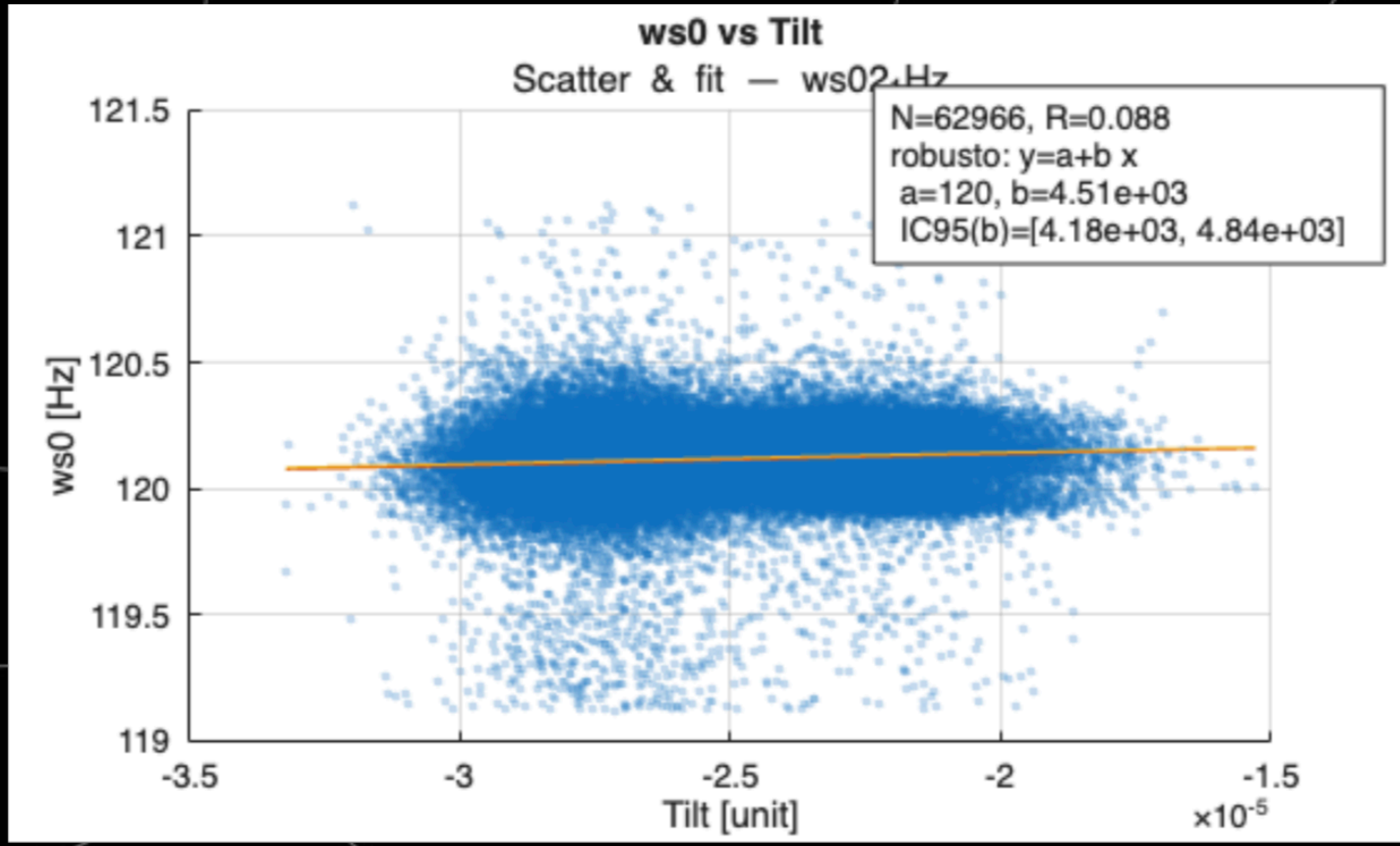

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