PHASE ALIGNMENT IN FERRITE AND FINEMET CAVITIES

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PROJECT DESCRIPTION

Goal:

To develop an algorithm for the beam-based relative phase alignment of RF cavities in the PSB.

MATHEMATICAL AND NUMERICAL ANALYSIS

SYNCHRONOUS PHASE

$$\sin(\varphi_{s0}) = \sin(\varphi_s) + \alpha \sin(n\varphi_s + \Phi_2)$$

$\frac{V_1}{V_2} = \alpha$, the voltage ratio between the cavities.

φ_{s0}, synchronous phase of the system with the second cavity switched off.

n, harmonic number. Frequency ratio between cavities.

Φ_2, phase difference between the cavities.

φ_s, resultant synchronous phase of the system.

Analyse $\varphi_s(\Phi_2)$

$\varphi_s(\Phi_2)$ CASE OF $n \in \{1,2\}$

Implicit equation $\xrightarrow{\text{change of variables}}$ polynomial equation

For $n = 1$ the equation is of order 2 } solvable

For $n = 2$ the equation is of order 4

For $n > 2$ the equation is of order > 4 } "unsolvable"

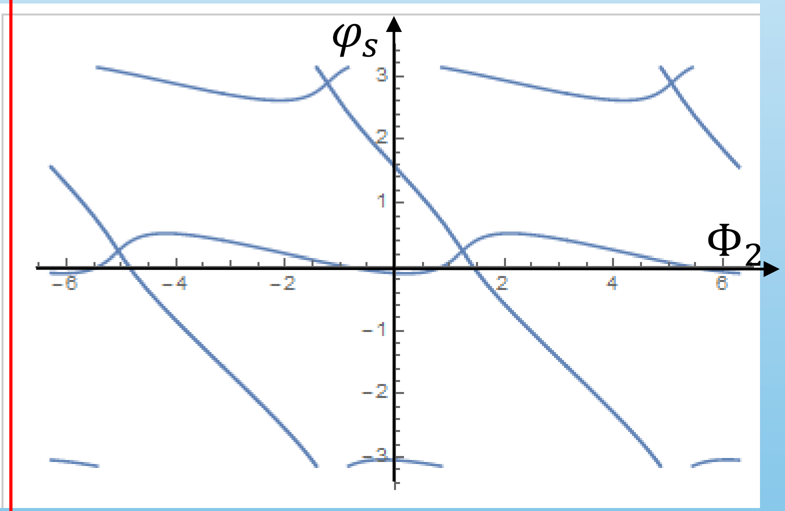
$$0 = \alpha z^{2n} e^{i\Phi_2} - i z^{n+1} - 2 z^n \sin(\phi_{s0}) + i z^{n-1} + \alpha e^{-i\Phi_2}$$

$$\phi_s = \arg(z_i)$$

$\varphi_s(\Phi_2)$ GENERAL CASE

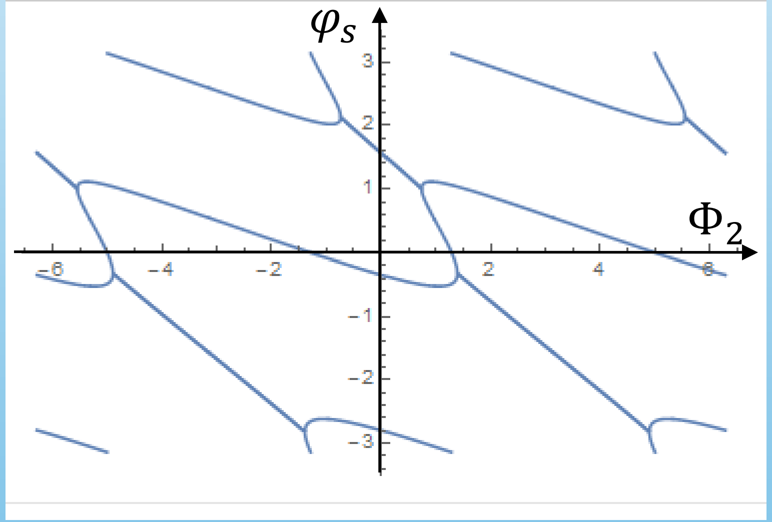
$$n = 2, \qquad \varphi_{s0=}0.2$$

$\alpha = 0.3$



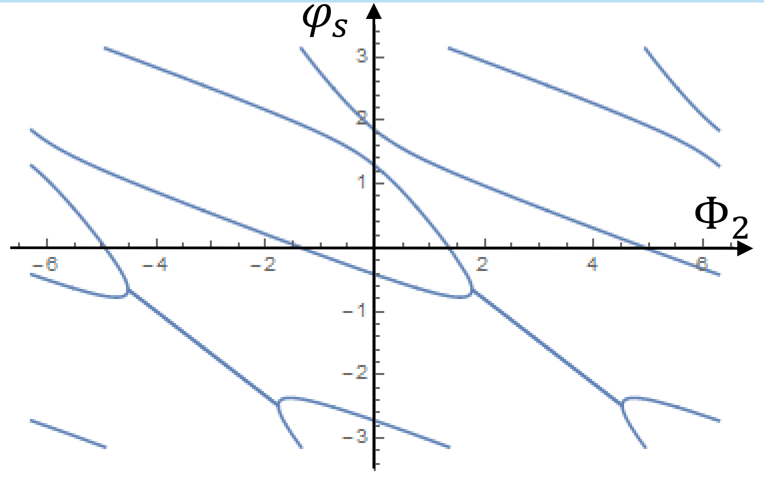
$$\alpha < \sqrt{\frac{\sin(\varphi_{s0})^2}{1-n^2} - \frac{1}{n^2}}$$

$\alpha = 0.7$



$$\sqrt{\frac{\sin(\varphi_{s0})^2}{1-n^2} - \frac{1}{n^2}} \leq \alpha \leq 1 - |\sin(\varphi_{s0})|$$

$\alpha = 0.9$



$$1 - |\sin(\varphi_{s0})| < \alpha$$

$\varphi_s(\Phi_2)$ AND $\lambda(\Phi_2)$ FOURIER SERIES

$$\varphi_s(\Phi_2) = \sum_{m=-\infty}^{\infty} a_m\, e^{im\Phi_2}$$

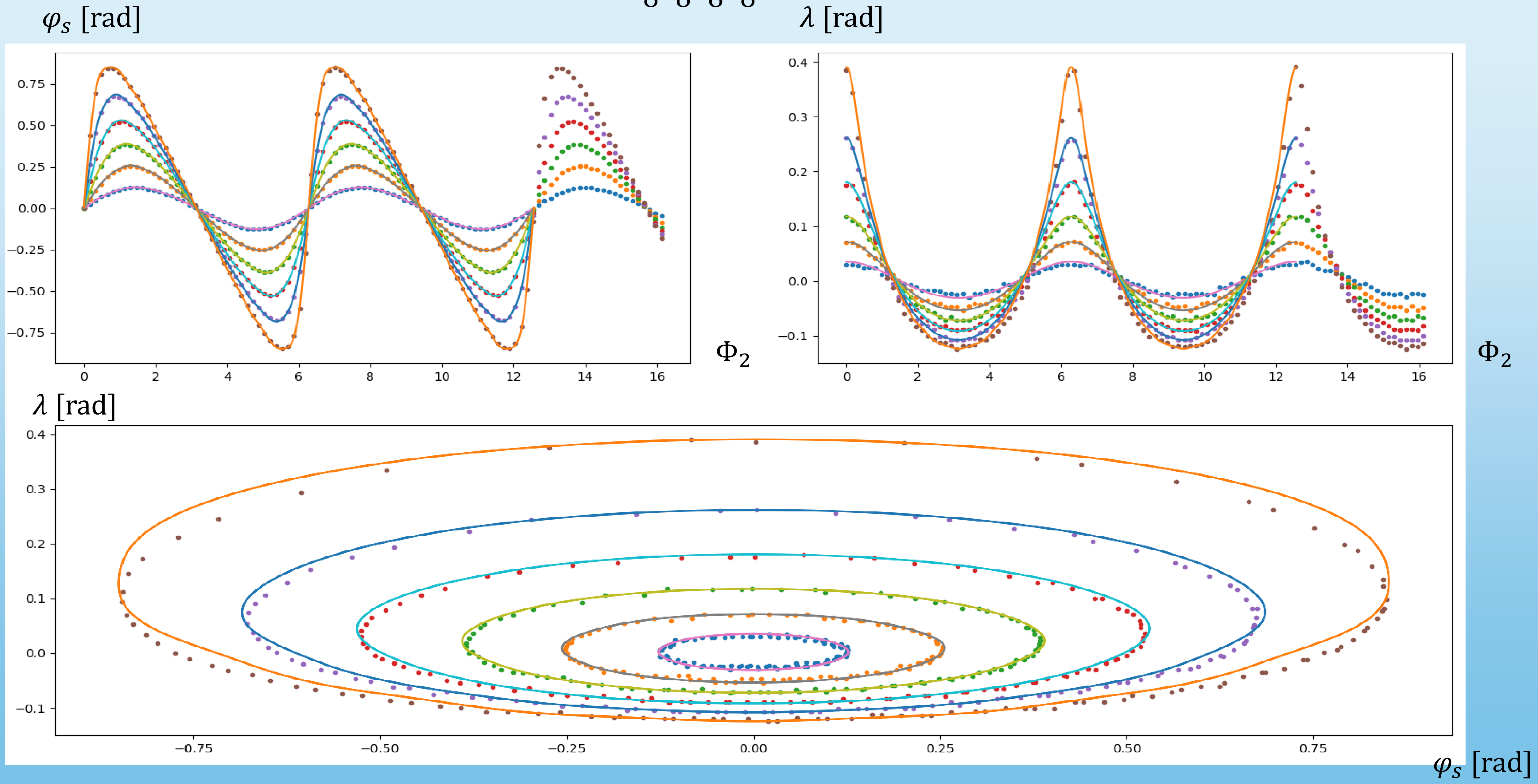
Guess $\lambda(\Phi_2)$ *such that the plot* $(\varphi_s(\Phi_2), \lambda(\Phi_2))$ *forms a closed path?*

Possible answer: Hilbert transform of φ_s.

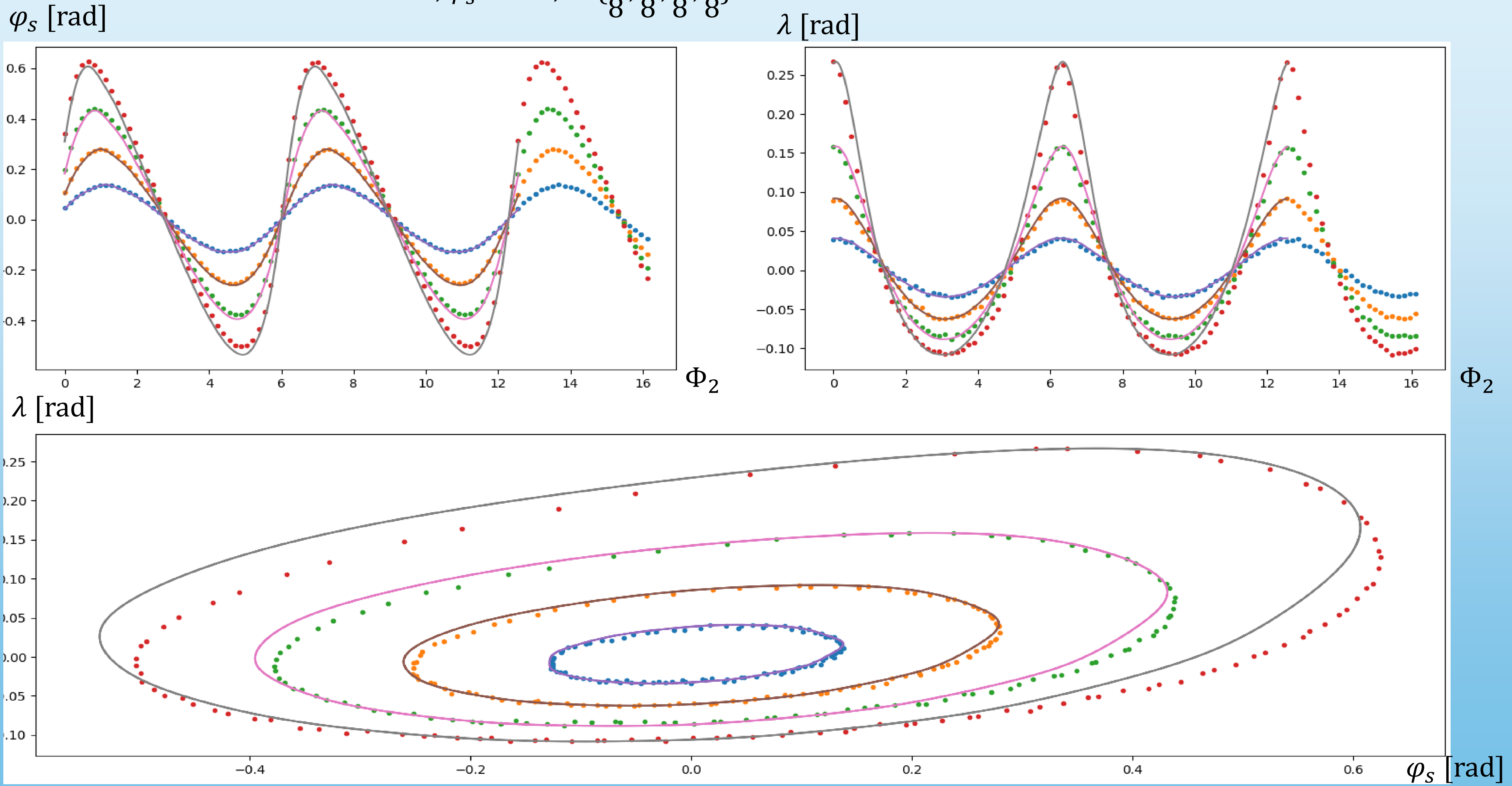
$$\widehat{\varphi_s}(\Phi_2) = -i \sum_{m=-\infty}^{\infty} \operatorname{sgn}(m)\, a_m\, e^{im\Phi_2}$$

$$\lambda(\Phi_2) \sim \widehat{\varphi_s}(\Phi_2 - \varphi_{s0})$$

$$n = 1, \varphi_s \approx 0, \alpha \epsilon \{\frac{1}{8}, \frac{2}{8}, \frac{3}{8}, \frac{4}{8}\}$$



$$n = 1, \varphi_s \approx 0.3, \alpha \epsilon \{\frac{1}{8}, \frac{2}{8}, \frac{3}{8}, \frac{4}{8}\}$$



EXPERIMENTAL WORK AND ALGORITHM DEVELOPMENT

ALGORITHMS FOR MEASURING φ_s AND λ

$$f(t) = Re\{f(t) + i\hat{f}(t)\} = Re\{r(t)e^{i\theta(t)}\} = r(t)\cos(\theta(t))$$

$\theta(t) = \arctan\left(\frac{\hat{f}(t)}{f(t)}\right)$ is called the instantaneous phase of $f(t)$

$r(t) = \sqrt{f(t)^2 + \hat{f}(t)^2}$ is called the analytic envelope of $f(t)$

$\theta(t) = \pm\frac{\pi}{2}$ implies $f(t) = 0$

$\theta(t) = 0$ implies $f(t) = r(t)$

For symmetric signals the maxima of $r(t)$ and $f(t)$ coincide.

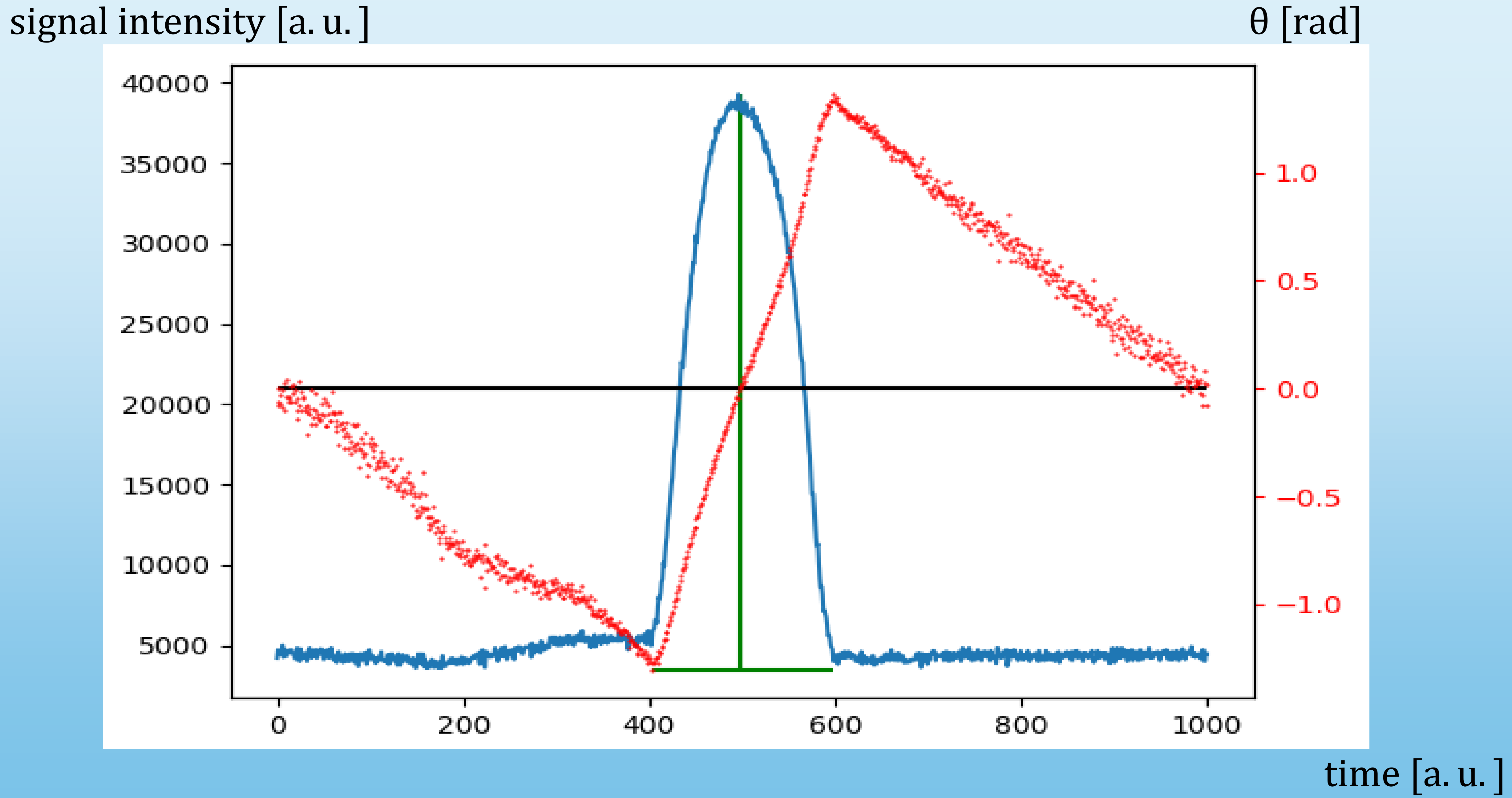
ALGORITHMS FOR MEASURING φ_s AND λ

General result:

Finding $f(t) = 0$ is the same as maximising $\theta(t)$

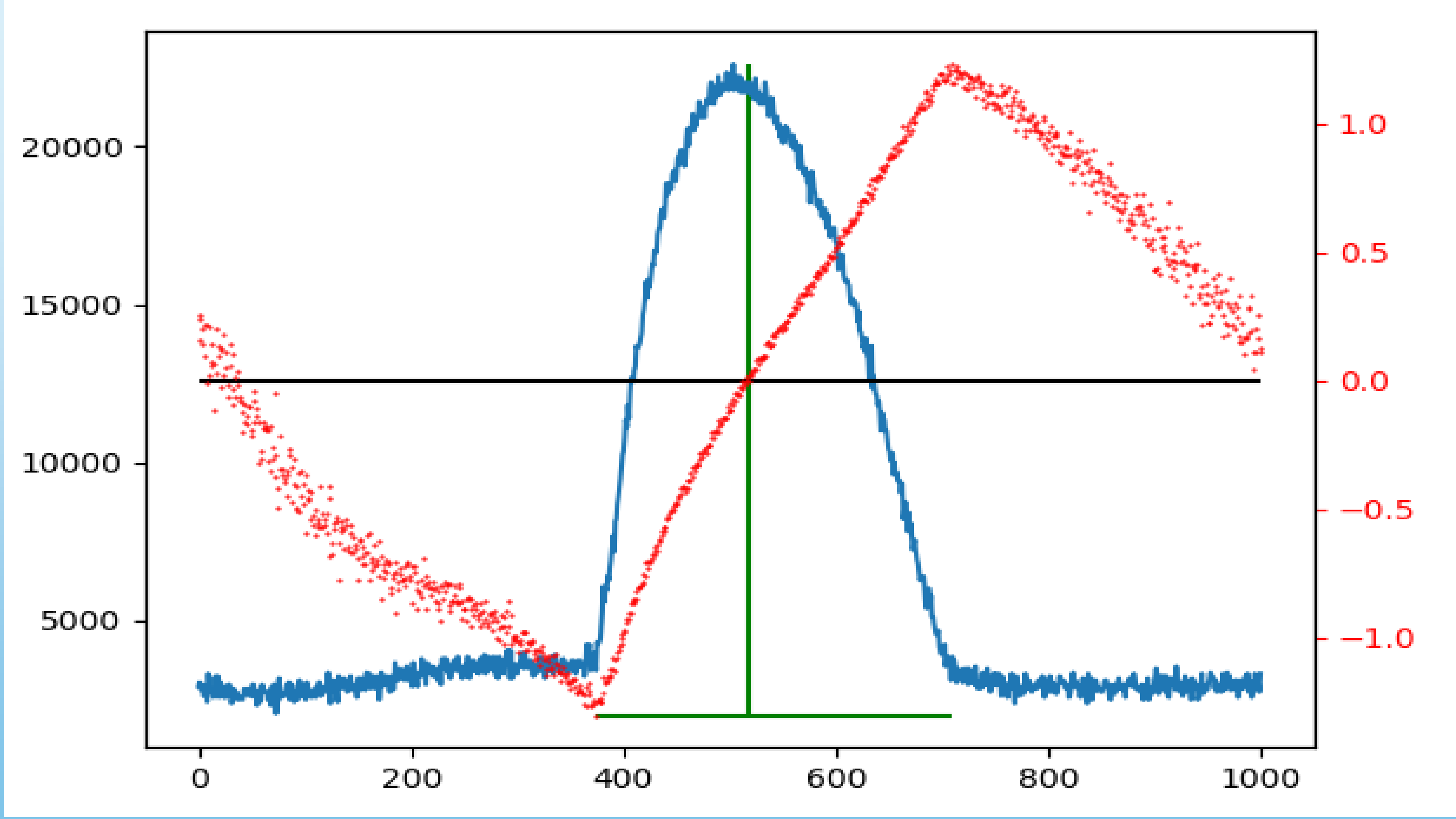
For symmetric signals:

Maximising $f(t)$ is the same as solving $\theta(t) = 0$

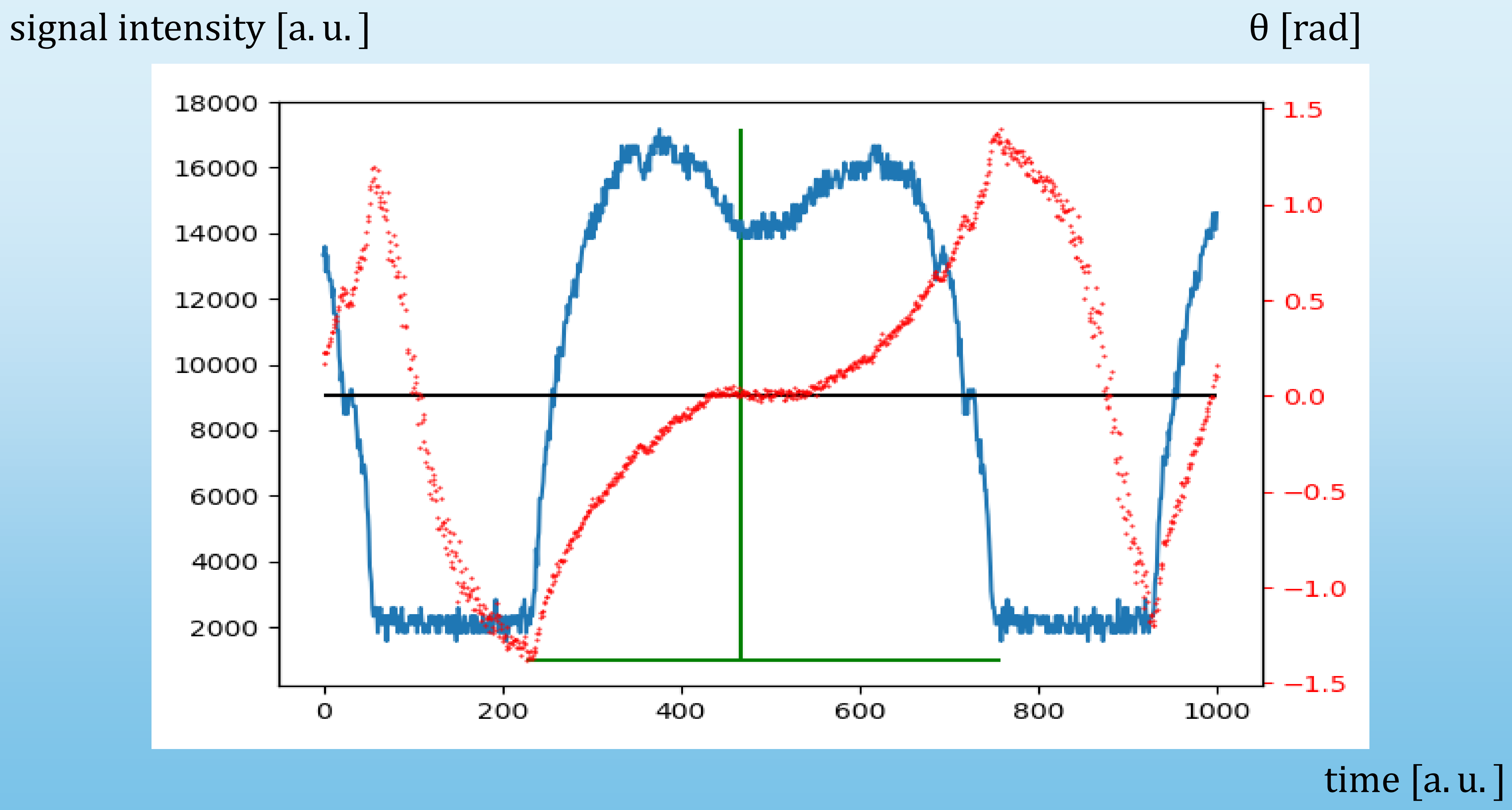

signal intensity [a. u.]
θ [rad]
40000
35000
30000
25000
20000
15000
10000
5000
1.0
0.5
0.0
−0.5
−1.0
0
200
400
600
800
1000
time [a. u.]

signal intensity [a. u.]

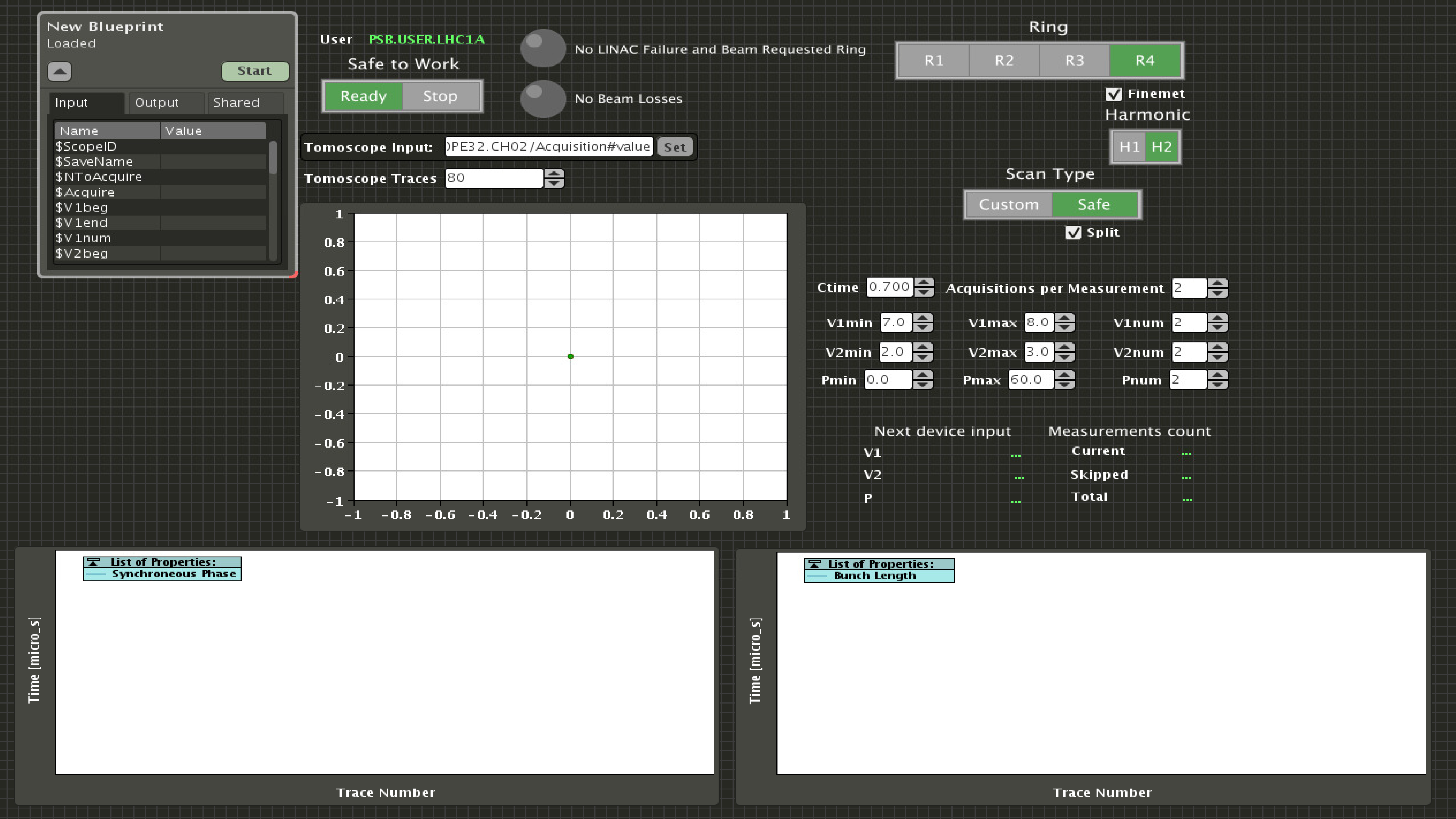
θ [rad]



time [a. u.]


signal intensity [a. u.]
θ [rad]
18000
16000
14000
12000
10000
8000
6000
4000
2000
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
200
400
600
800
1000
time [a. u.]

SOFTWARE DEVELOPMENT

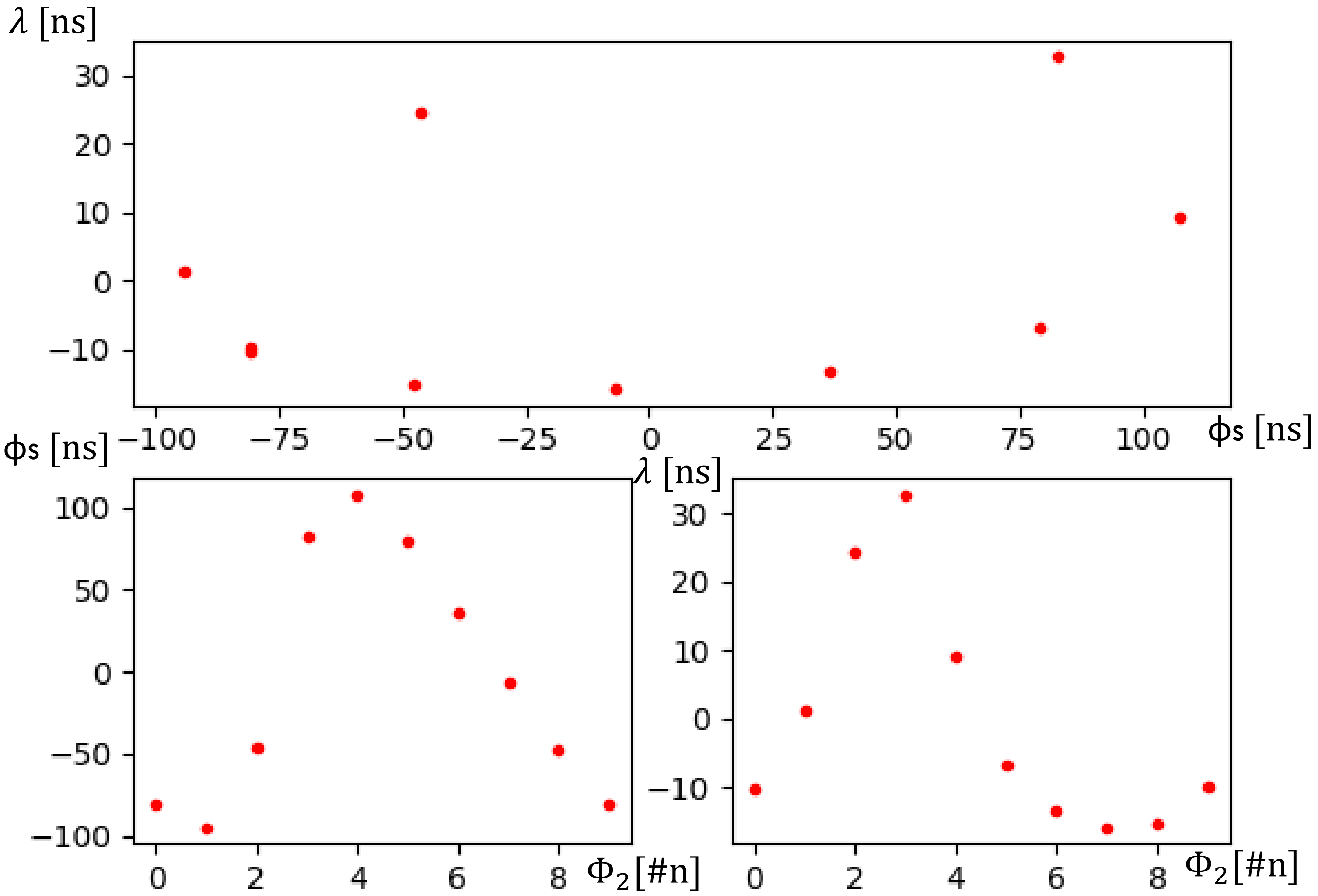

New Blueprint
Loaded
Start
Input
Output
Shared
Name
Value
$ScopeID
$SaveName
$NToAcquire
$Acquire
$V1beg
$V1end
$V1num
$V2beg
User
PSB.USER.LHC1A
Safe to Work
Ready
Stop
No LINAC Failure and Beam Requested Ring
No Beam Losses
Ring
R1
R2
R3
R4
Finemet
Harmonic
H1
H2
Scan Type
Custom
Safe
Split
Tomoscope Input:
)PE32.CH02/Acquisition#value
Set
Tomoscope Traces
80
Ctime
0.700
Acquisitions per Measurement
2
V1min
7.0
V1max
8.0
V1num
2
V2min
2.0
V2max
3.0
V2num
2
Pmin
0.0
Pmax
60.0
Pnum
2
Next device input
V1
V2
P
Measurements count
Current
Skipped
Total
List of Properties:
Synchroneous Phase
Time [micro_s]
Trace Number
List of Properties:
Bunch Length
Time [micro_s]
Trace Number

RESULTS

1. MEASURE DATA

$n = 1$
$V_1 = 8kV$
$V_2 = 5kV$
C time = $720\mu s$
φ_{s0} = ?

- Inputs: C time, V_1, V_2, range of Φ_2.
- Choose an algorithm for calculating φ_s and λ.
- Plot the data.

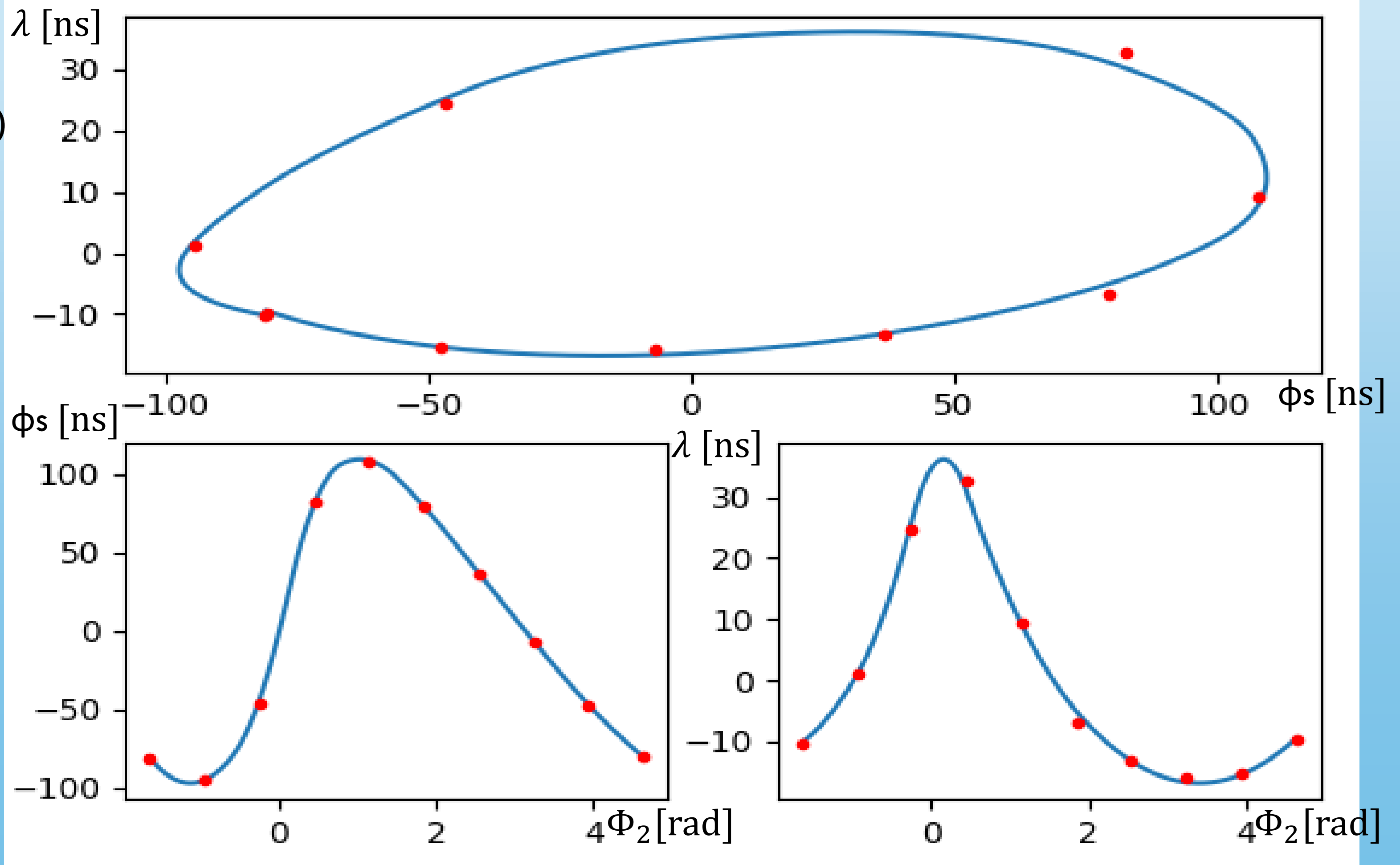


2. INTERPOLATE AND SHIFT THE DATA

$n = 1$
$V_1 = 8kV$
$V_2 = 5kV$
C time $= 720\mu s$
$\varphi_{s0} = 0.05$

- Only for n=1: calculate the phase misalignment ψ such that the steepest gradient point of Φ_2 is at (0,0)
- Calculate φ_{s0} by

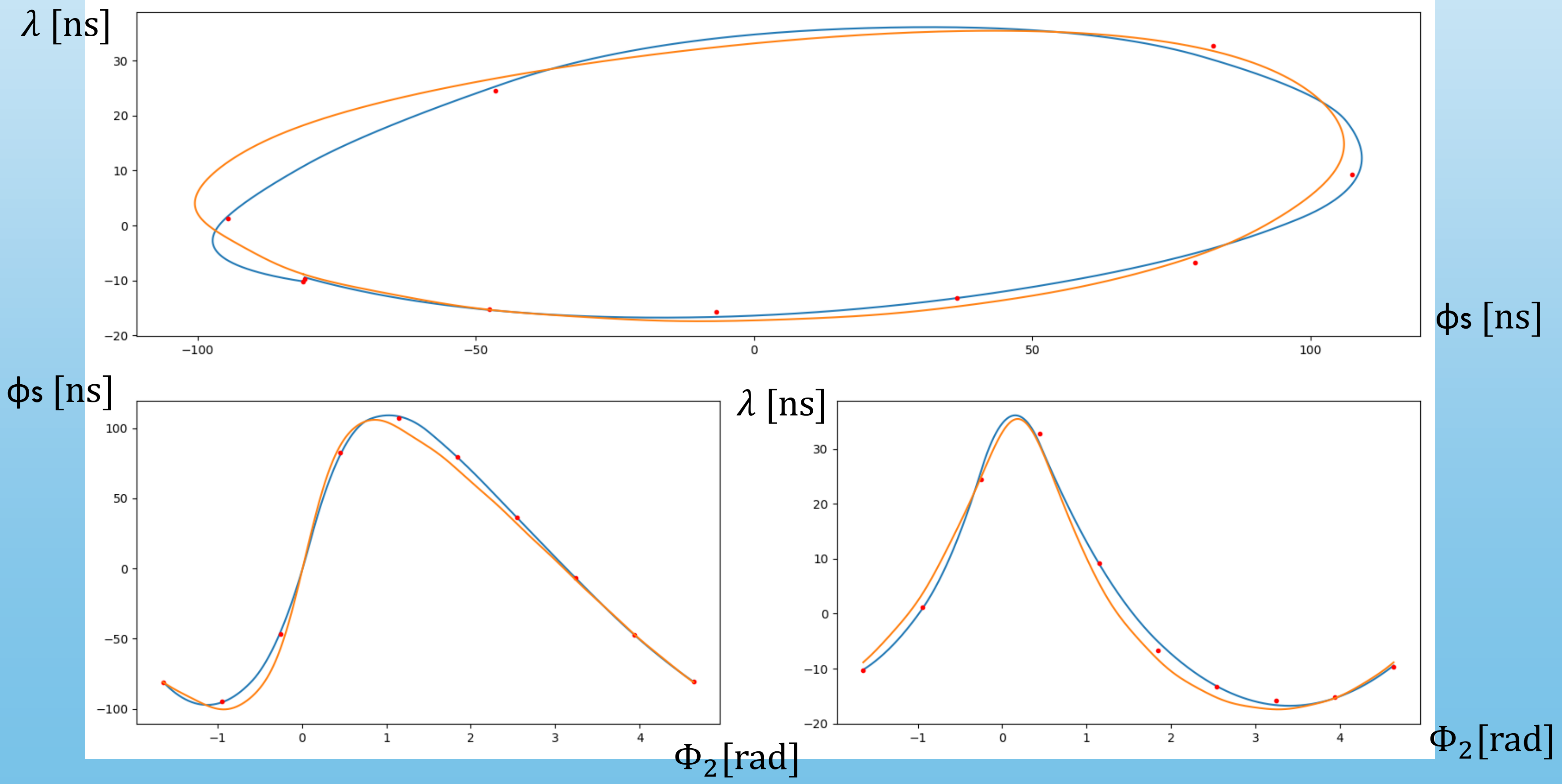
$\varphi_{s0} = \arcsin(\sin(\mathrm{argmax}(\varphi_s)) - \alpha)$



3. FIT THE FOURIER SERIES

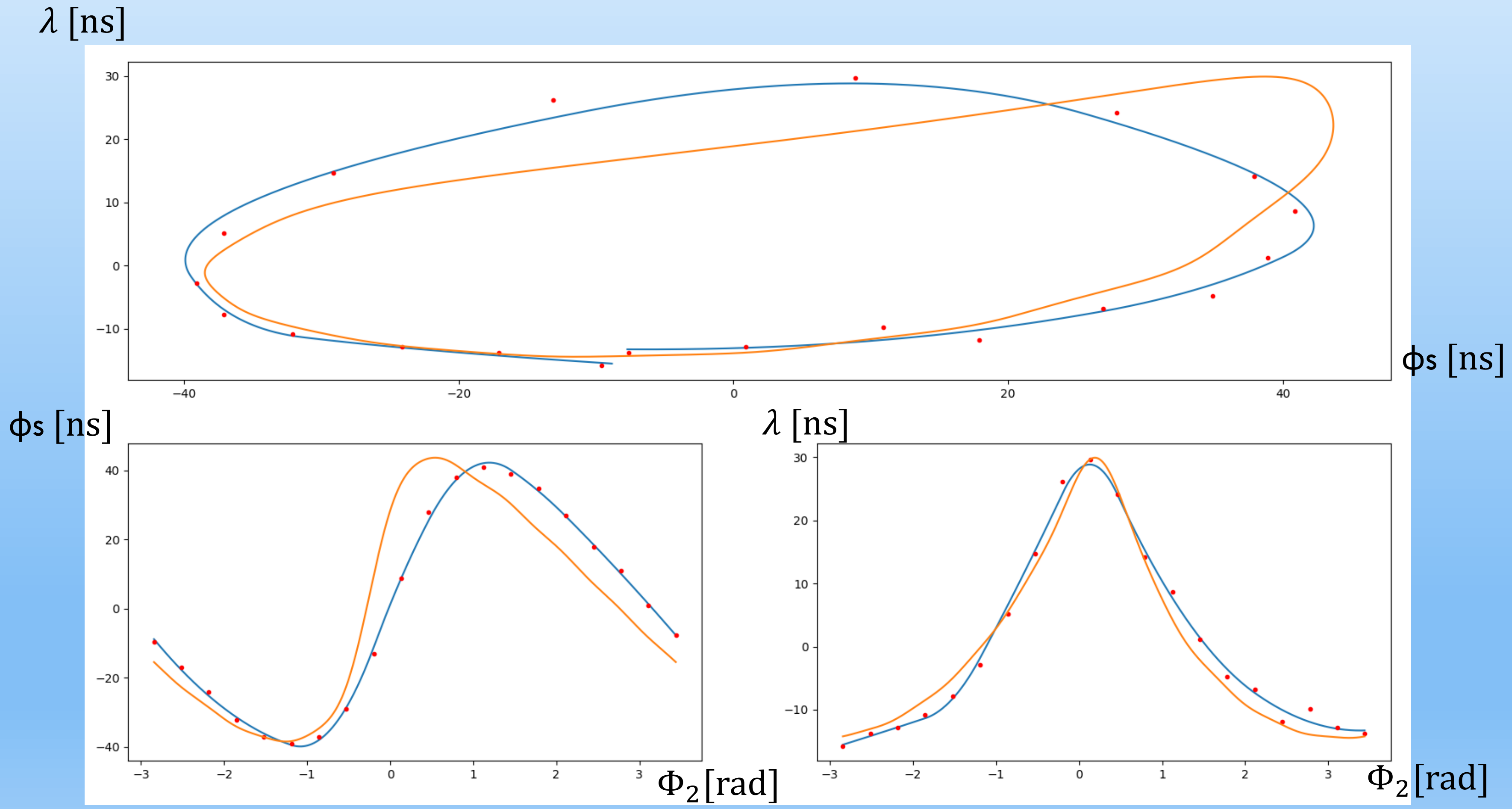
$n = 1$
$V_1 = 8kV$
$V_2 = 5kV$
C time $= 720\mu s$
$\varphi_{s0} = 0.05$

- Calculate the Fourier series using the input α.
- Scale using the input C time.



PROBLEMS

$n = 2$
$V_1 = 7kV$
$V_2 = 2kV$
C time $= 675\mu s$
$\varphi_{s0} = 0.50$???



OUTLOOK

- Change the measurement technique for the synchronous phase.
- Create map between $(\alpha, \varphi_{s0}, \Phi_2) \rightarrow (\varphi_s, \lambda)$
- Take better measurements to evaluate the azimuth and delay compensation for the low level RF.