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"

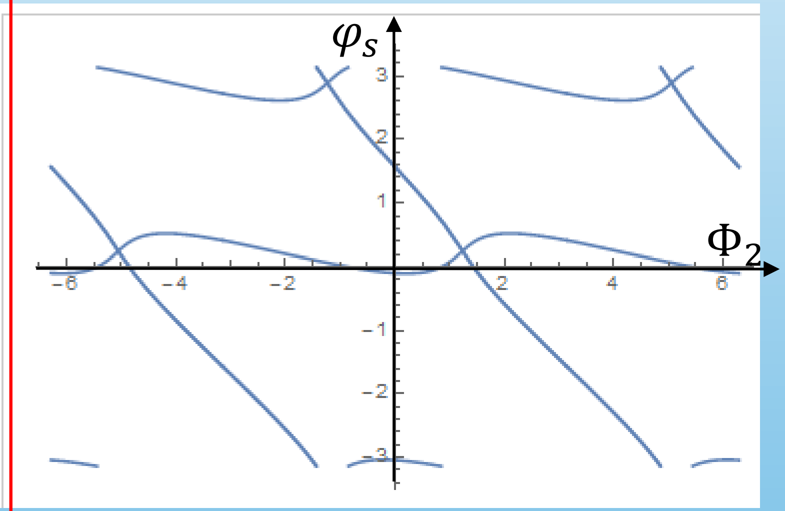
$$0 = \alpha z^{2n} e^{i\Phi_2} - i z^{n+1} - 2 z^n \sin(\phi_{s0}) + i z^{n-1} + \alpha e^{-i\Phi_2}$$

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

$\varphi_s(\Phi_2)$ GENERAL CASE

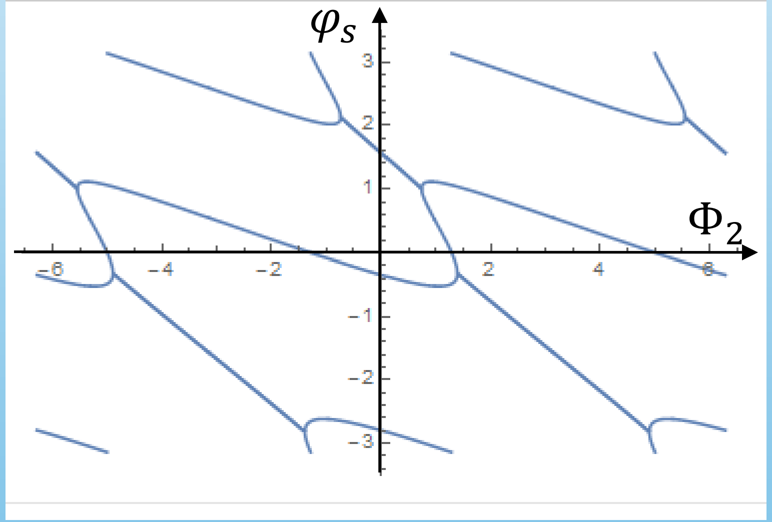
$$n = 2, \qquad \varphi_{s0=}0.2$$

$\alpha = 0.3$



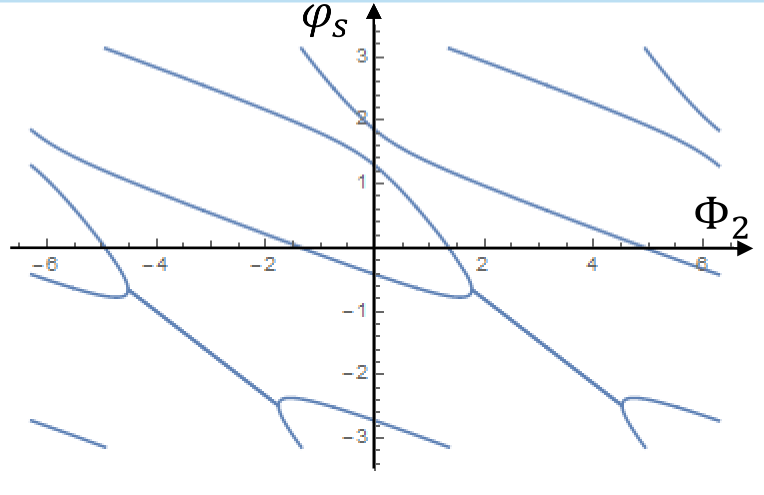
$$\alpha < \sqrt{\frac{\sin(\varphi_{s0})^2}{1-n^2} - \frac{1}{n^2}}$$

$\alpha = 0.7$



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

$\alpha = 0.9$



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

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

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

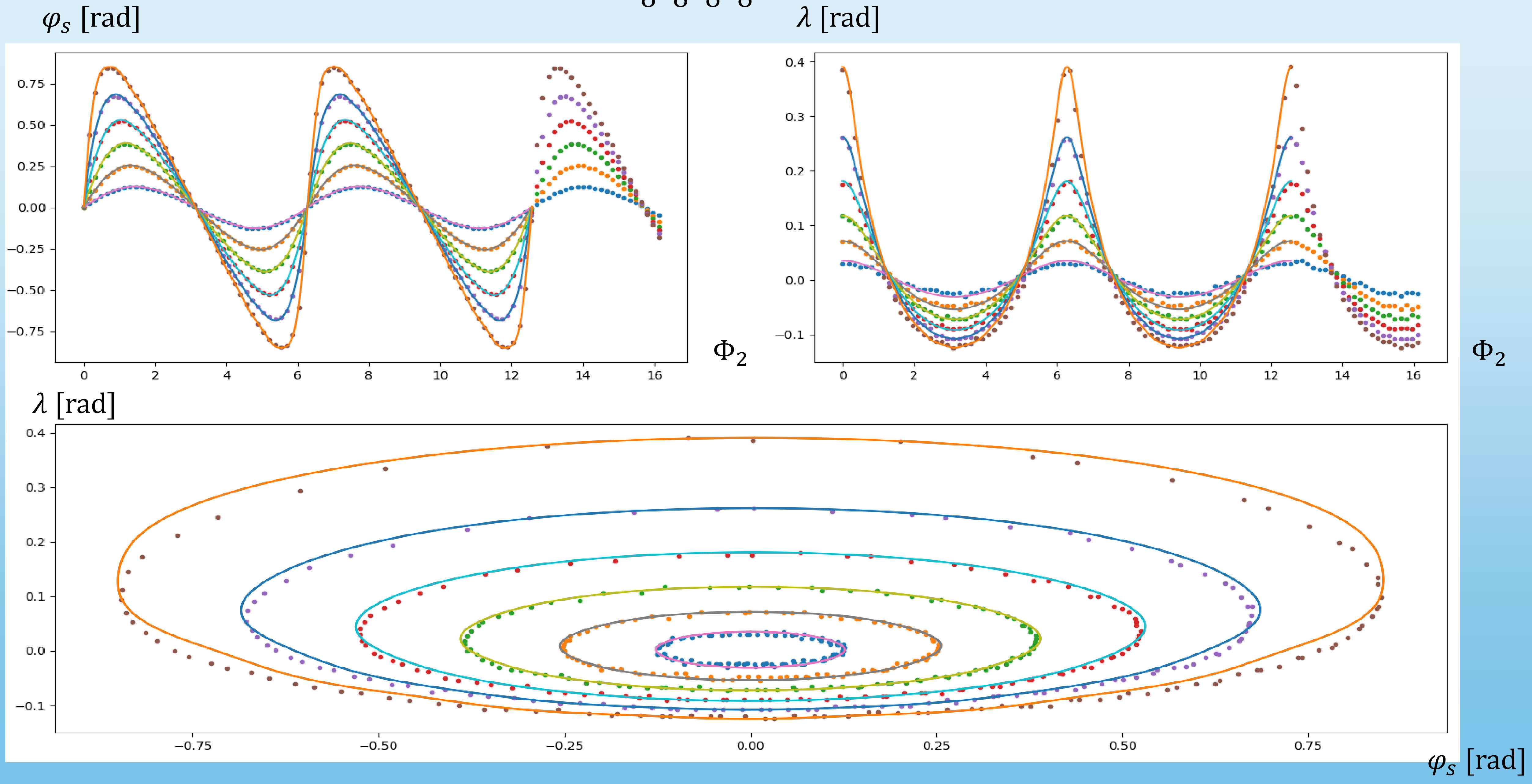
Guess $\lambda(\Phi_2)$ *such that the plot* $(\varphi_s(\Phi_2), \lambda(\Phi_2))$ *forms a closed path?*

Possible answer: Hilbert transform of φ_s.

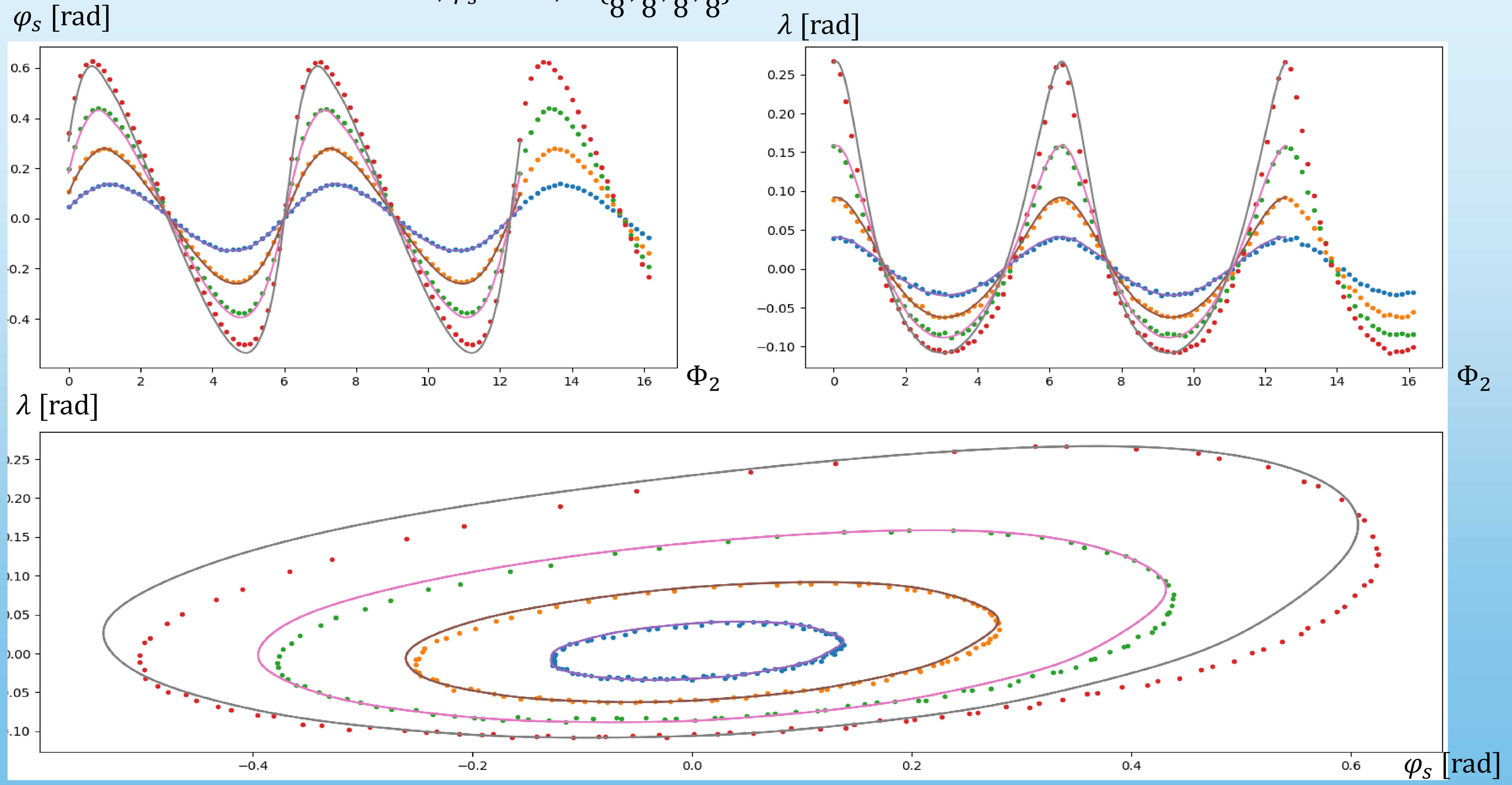
$$\widehat{\varphi_s}(\Phi_2) = -i \sum_{m=-\infty}^{\infty} \mathrm{sgn}(m) \, a_m \, e^{im\Phi_2}$$

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

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



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



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.

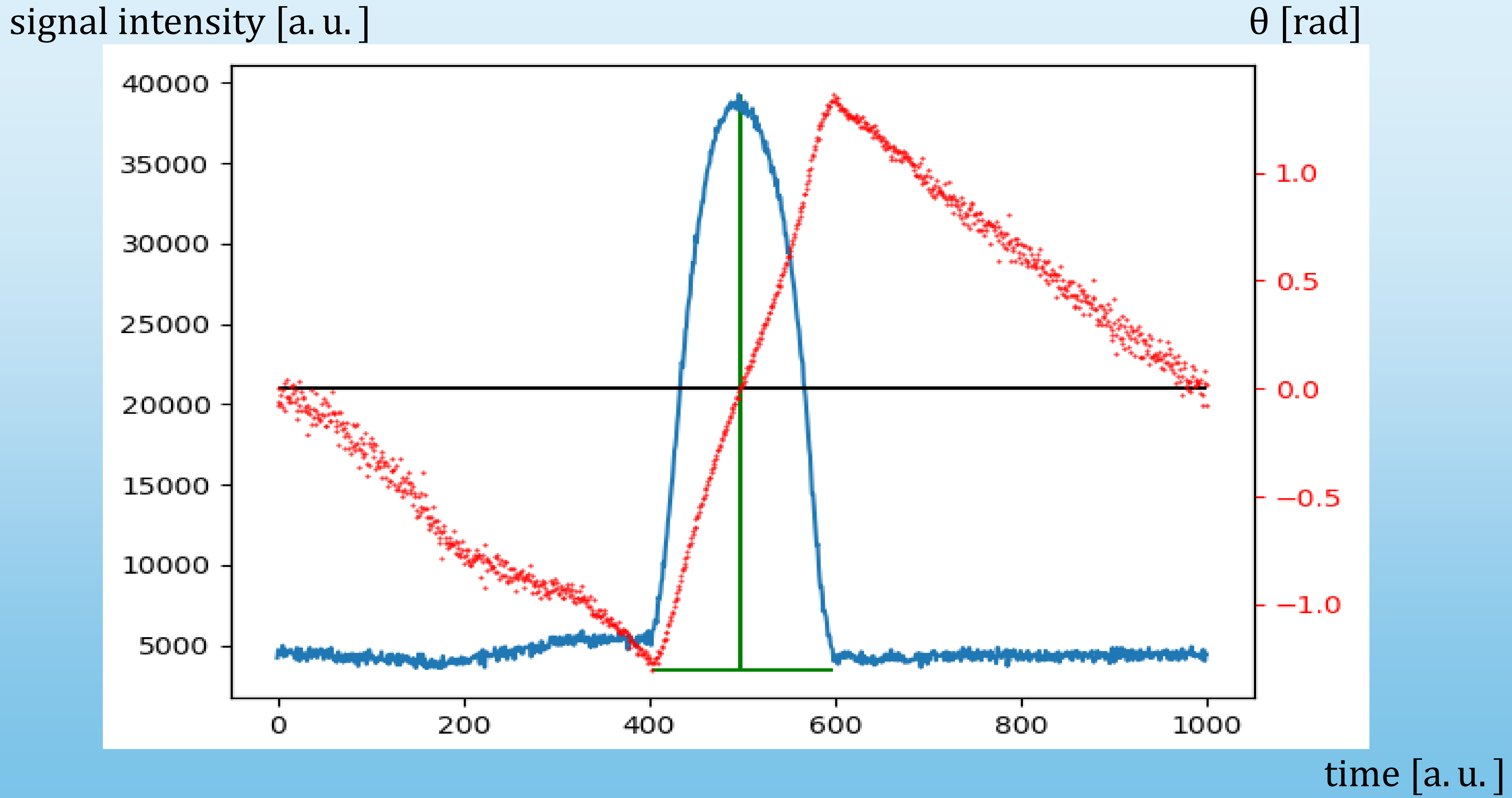
ALGORITHMS FOR MEASURING φ_s AND λ

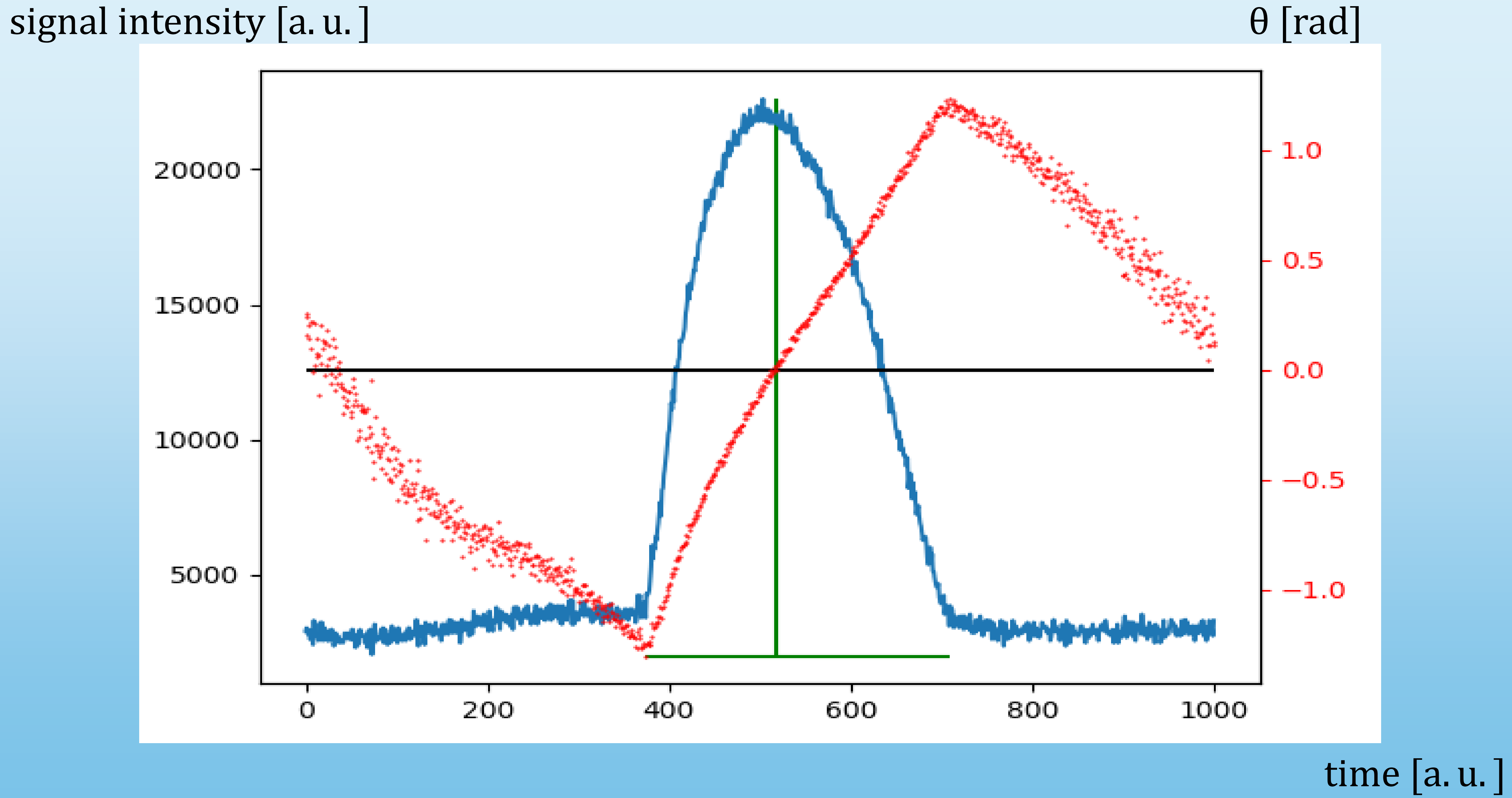
General result:

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.]
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0
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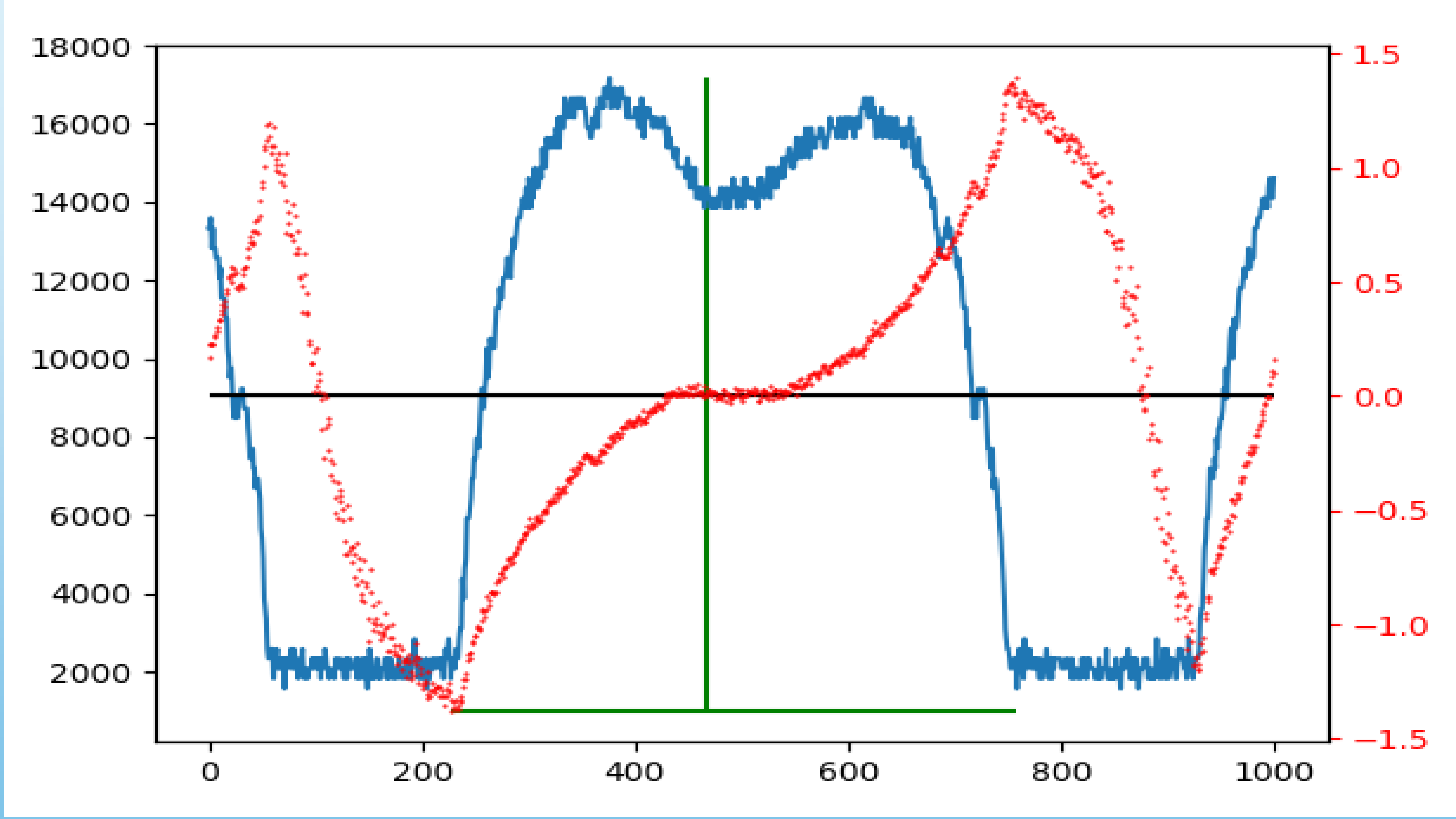
400
600
800
1000
time [a. u.]

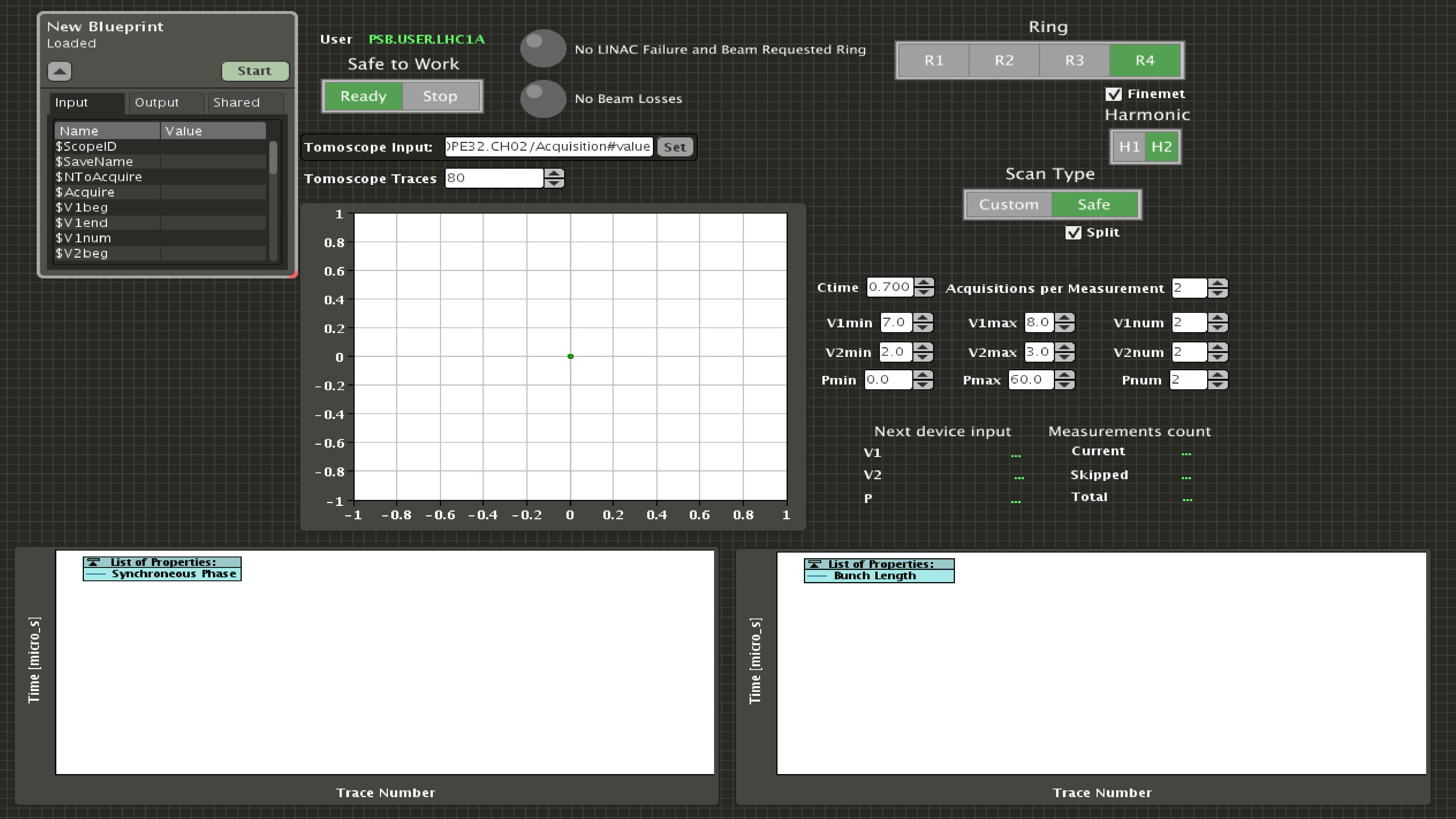
signal intensity [a. u.]

θ [rad]



time [a. u.]

SOFTWARE DEVELOPMENT



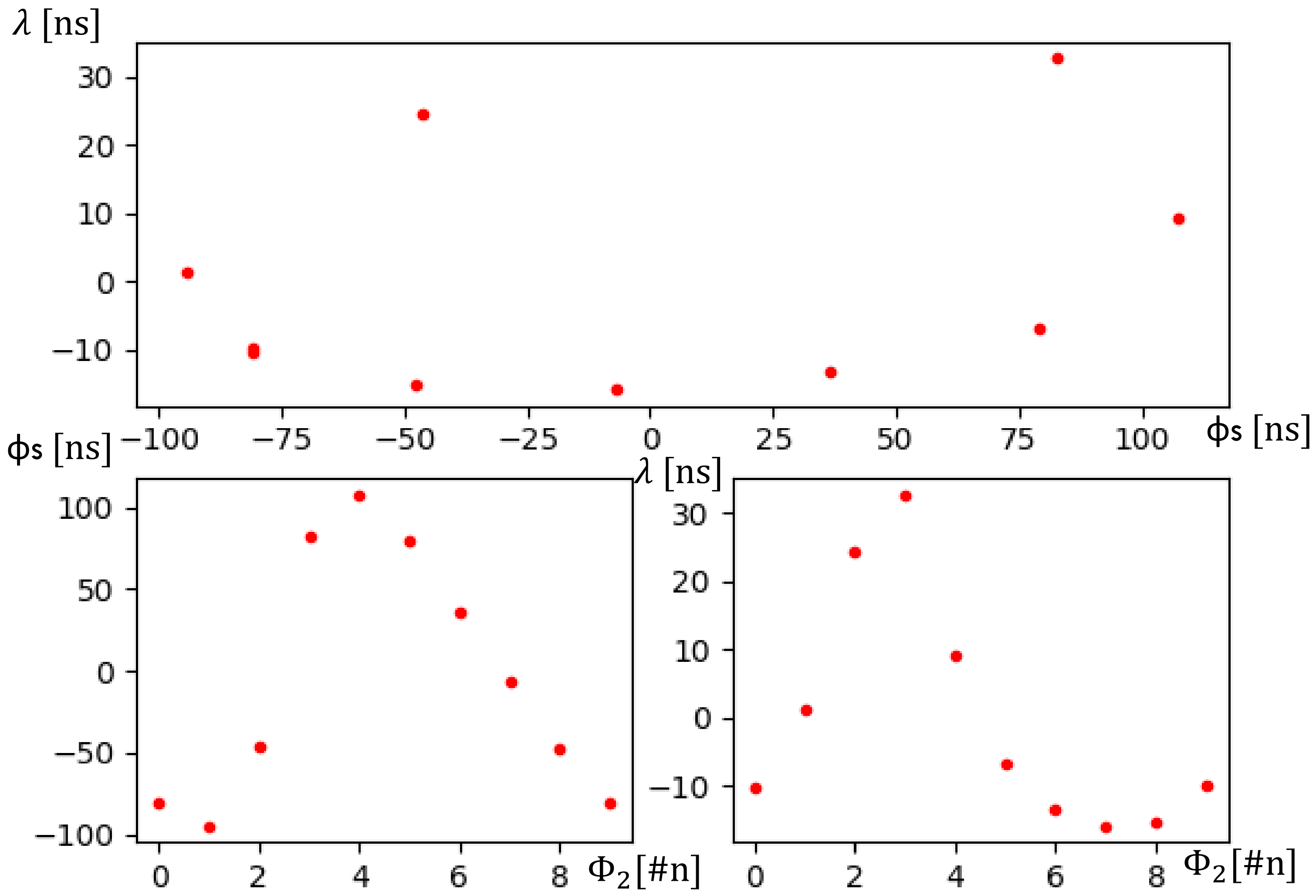
New Blueprint
Loaded
Start
Input
Output
Shared
Name
Value
$ScopeID
$SaveName
$NToAcquire
$Acquire
$V1beg
$V1end
$V1num
$V2beg
User
PSB.USER.LHC1A
Safe to Work
Ready
Stop
No LINAC Failure and Beam Requested Ring
No Beam Losses
Ring
R1
R2
R3
R4
Finemet
Harmonic
H1
H2
Tomoscope Input:
)PE32.CH02/Acquisition#value
Set
Tomoscope Traces
80
Scan Type
Custom
Safe
Split
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.

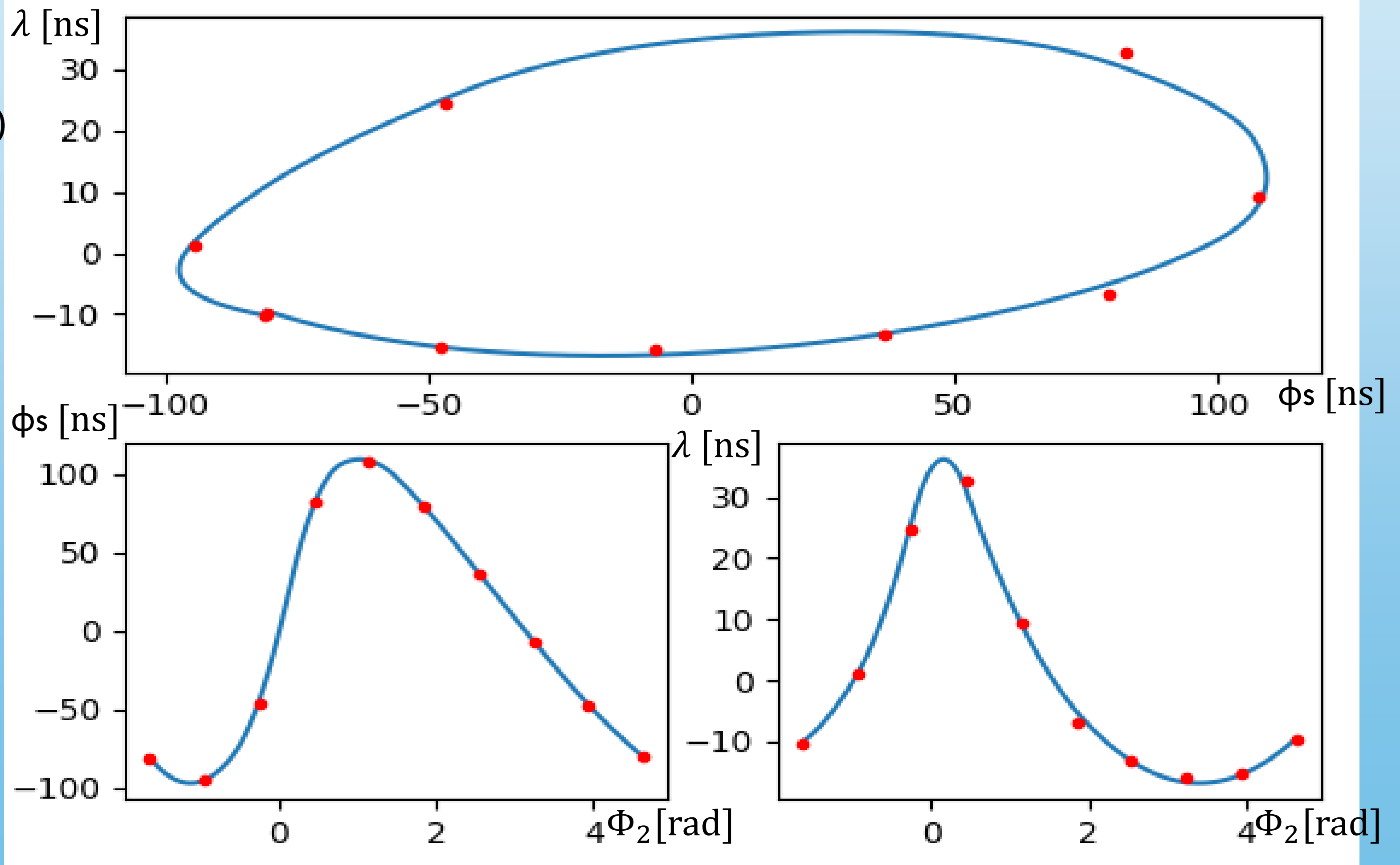


2. INTERPOLATE AND SHIFT THE DATA

$n = 1$
$V_1 = 8kV$
$V_2 = 5kV$
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

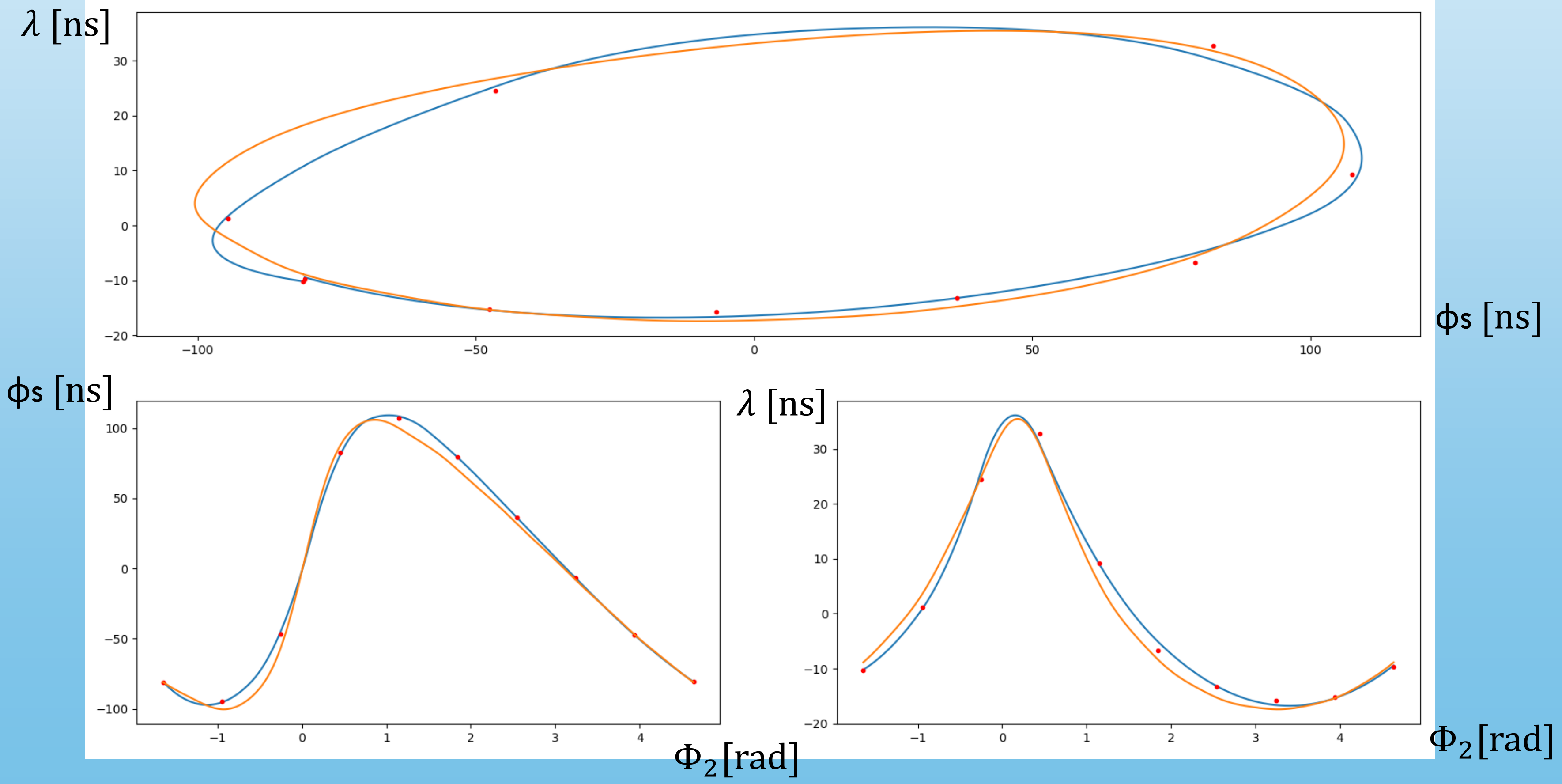
$$\varphi_{s0} = \arcsin(\sin(\text{argmax}(\varphi_s)) - \alpha)$$



3. FIT THE FOURIER SERIES

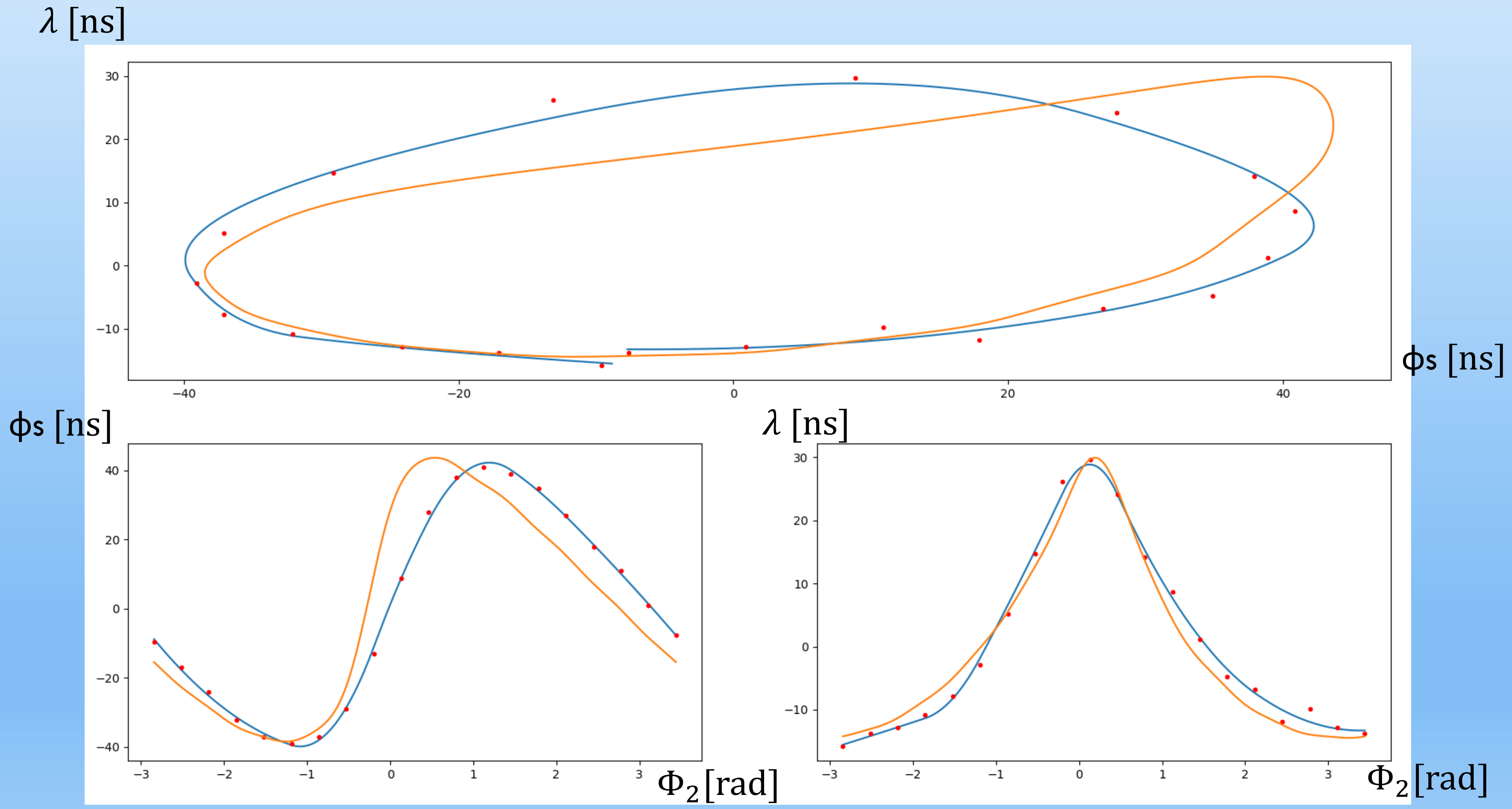
$n = 1$
$V_1 = 8kV$
$V_2 = 5kV$
C time $= 720\mu s$
$\varphi_{s0} = 0.05$

- 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.