Albert Einstein Institute

Max Planck Institute for Gravitational Physics and
Leibniz Universität Hannover

Optimising Test Mass Position for the LISA-Pathfinder Optical Metrology System

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German Aerospace Center

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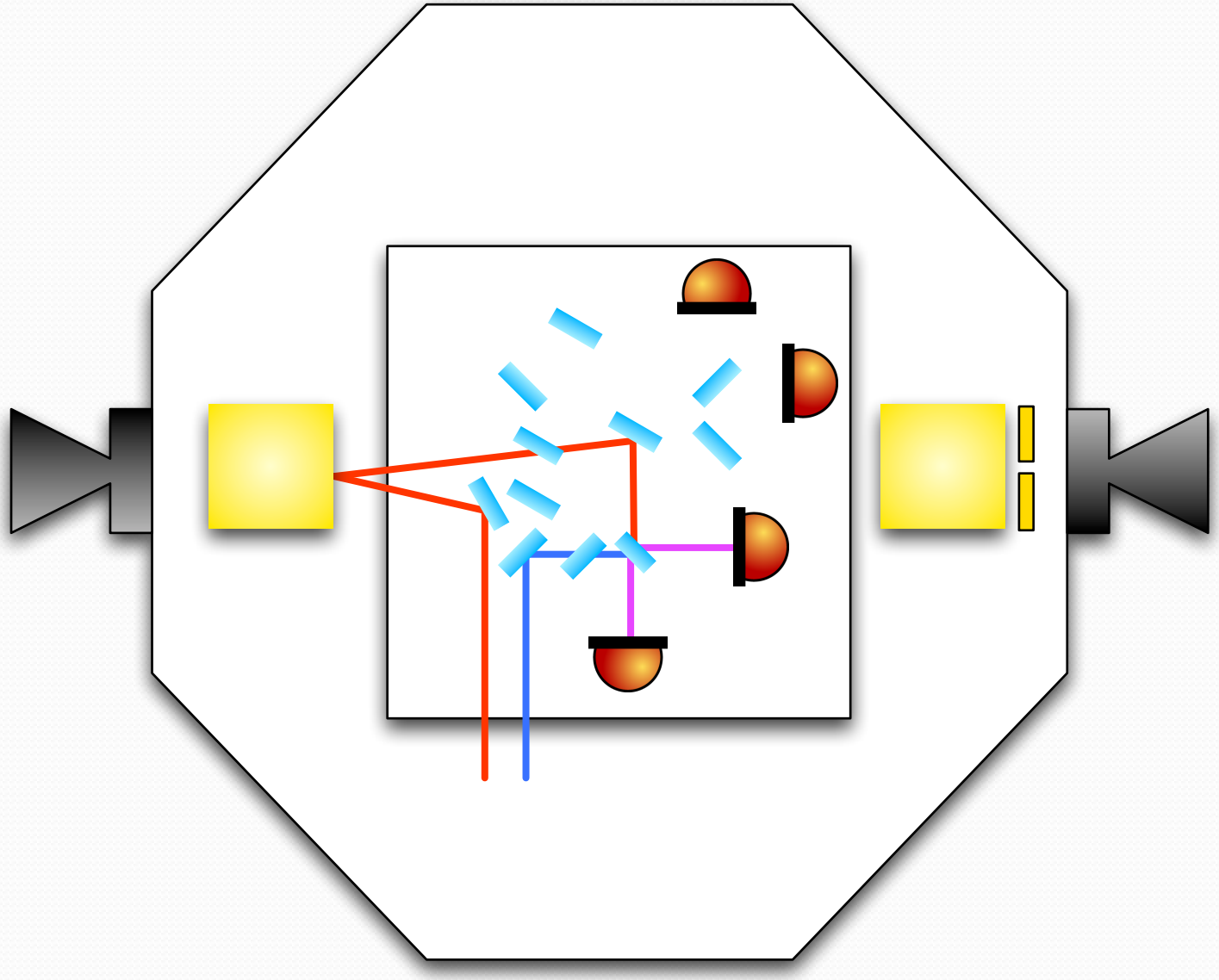
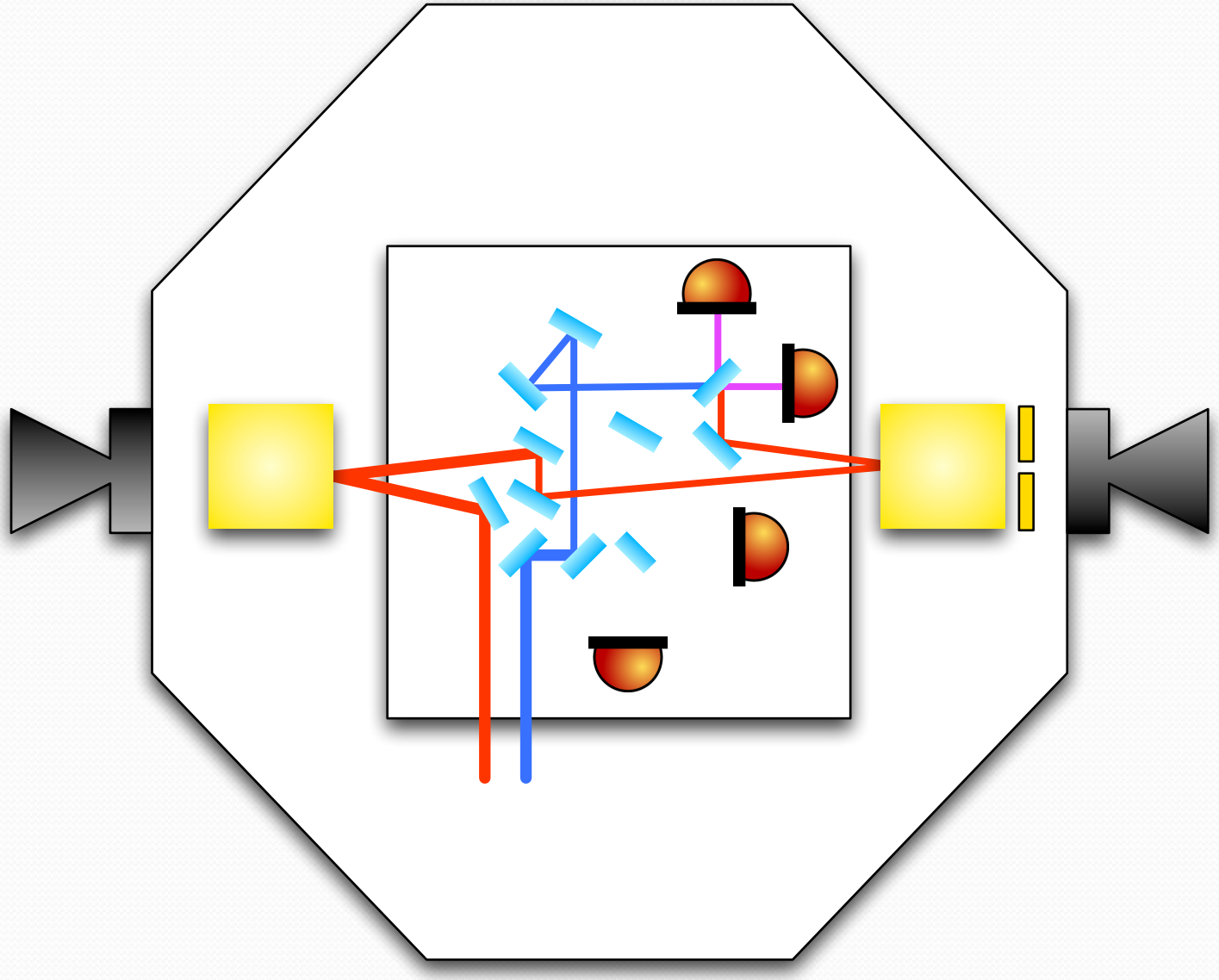
LPF x-Axis Measurement

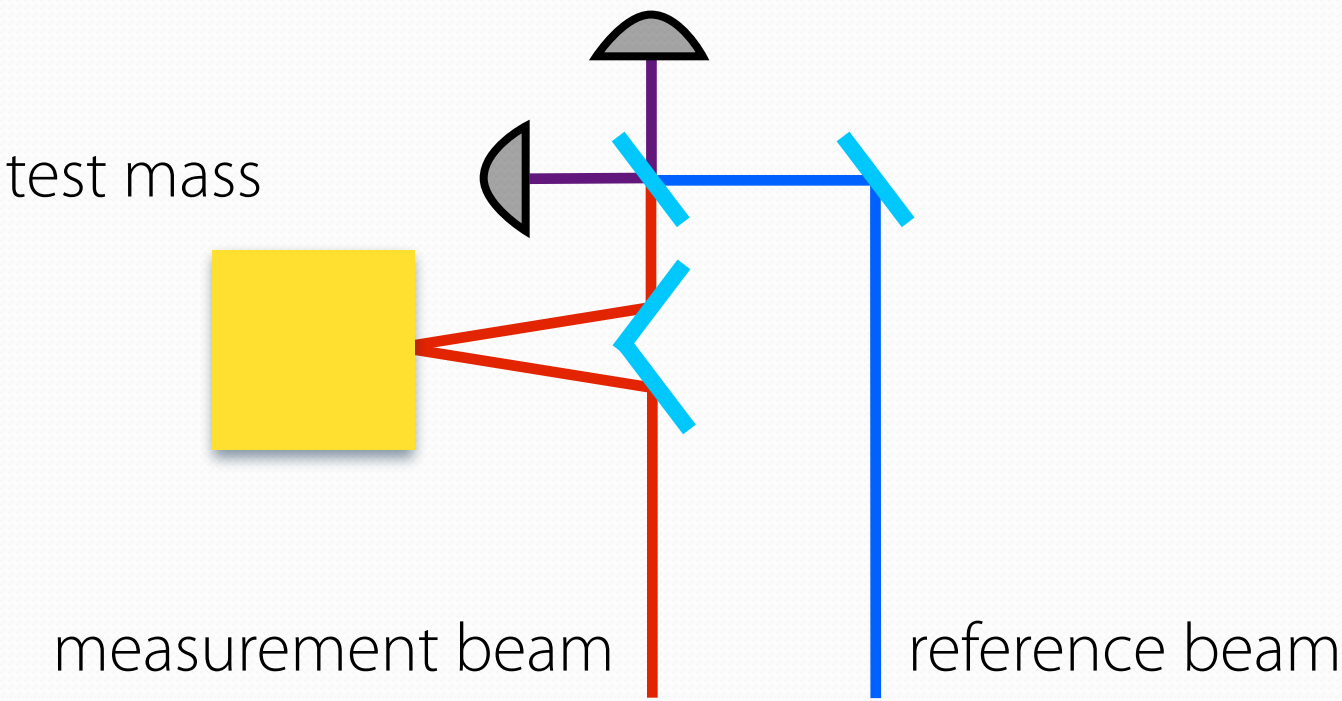


LPF x-Axis Measurement



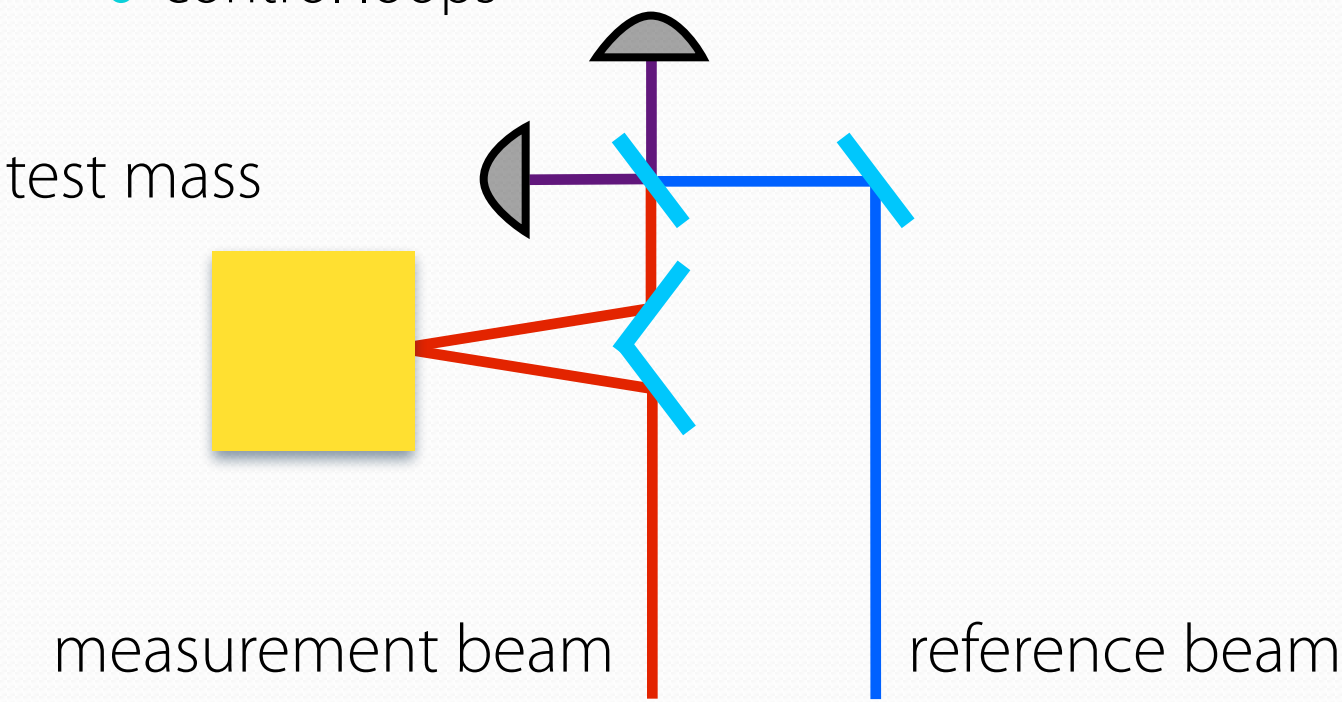
Interferometry

- interferometer signal
  - optical path length difference noise
  - amplitude noise
  - frequency noise



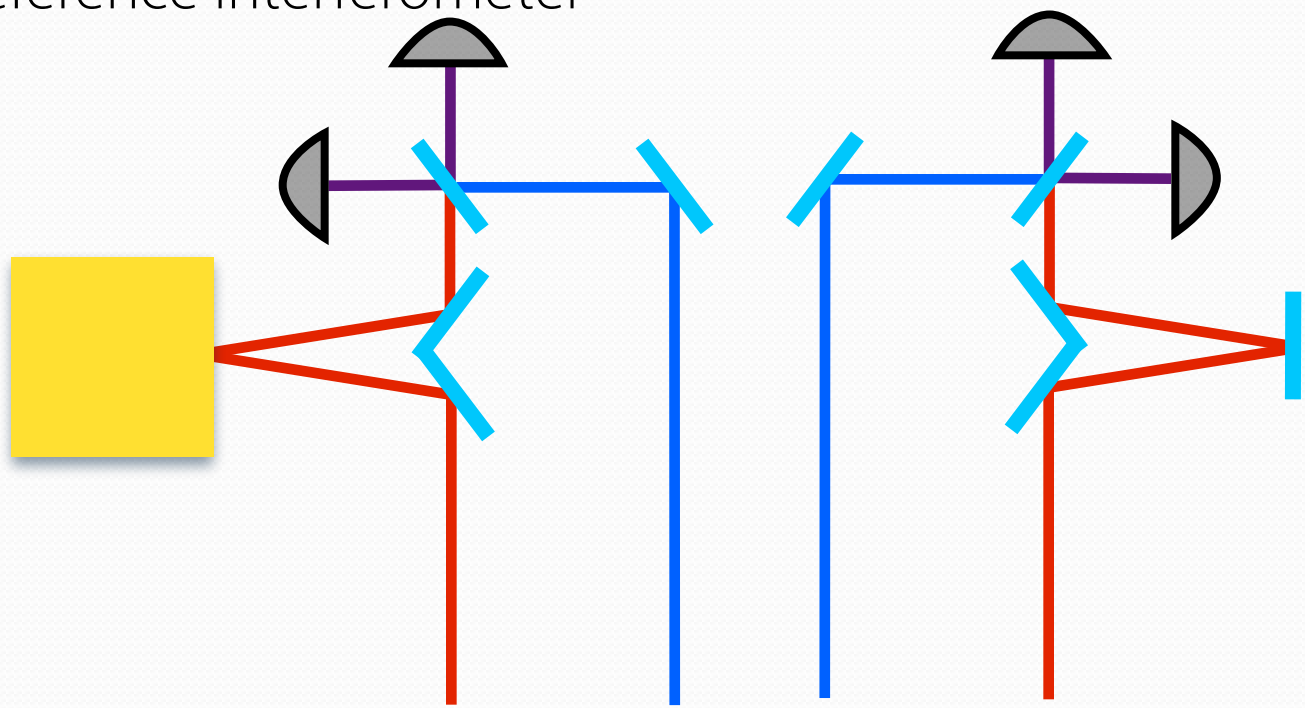
Interferometry

- interferometer signal
  - optical path length difference noise
  - amplitude noise
  - frequency noise
- control loops



Interferometry

- interferometer signal
  - optical path length difference noise
  - amplitude noise
  - frequency noise
- reference interferometer



Reference signal subtraction

Common mode noise rejection properties of amplitude and phase noise in a heterodyne interferometer

Gerald Hechenblaikner*

EADS Astrium, 88039 Friedrichshafen, Germany

compiled: March 8, 2013

High precision metrology systems based on heterodyne interferometry can measure position and attitude of objects to accuracies of picometer and nanorad, respectively. A frequently found feature of the general system design is the subtraction of a reference phase from the phase of the position interferometer, which suppresses low frequency common mode amplitude and phase fluctuations occurring in volatile optical path sections shared by both, the position and reference interferometer. Spectral components of the noise at frequencies higher than the heterodyne frequency, however, are generally transmitted into the measurement band and may limit the measurement accuracy. Detailed analytical calculations complemented with Monte Carlo simulations show that high frequency noise components may also be entirely suppressed, depending on the relative difference of measurement and reference phase, which may be exploited by corresponding design provisions. Whilst these results are applicable to any heterodyne interferometer with certain design characteristics, specific calculations and related discussions are given for the example of the optical metrology system of the LISA Pathfinder mission to space.

OCIS codes: 120.3940,120.3180,040.2840,100.5070

Interferometer signals

- Flight model uses both photodiodes
  - subtraction of common mode amplitude noise

$$F_{i,j} = \begin{cases} \frac{1}{2}\left(F_{i,j,A} + F_{i,j,B}\right) & \text{A and B OK} \\ F_{i,j,A} & \text{A OK, B failure} \\ F_{i,j,B} & \text{B OK, A failure} \\ \text{Non - computable} & \text{A and B failure} \end{cases}$$

source: s2-asd-rs-3018-phasemeter-processing-laser-control

Interferometer signals

- Flight model uses both photodiodes
  - one photodiode could fail
  - beamsplitter not 50/50
  - measure limiting noise source

Amplitude noise

$$\phi_n - \psi_n$$

$$\Delta n_{\mathrm{an}} = \Delta\phi_{\mathrm{an}} - \Delta\psi_{\mathrm{an}}$$

reference signal

measurement signal

remaining amplitude noise

Amplitude noise

$$\phi_n - \psi_n$$

$$\Delta n_{\mathrm{an}} = \Delta\phi_{\mathrm{an}} - \Delta\psi_{\mathrm{an}}$$

$$\langle \Delta n_{\mathrm{an}}^2 \rangle = \frac{2}{N A_{\mathrm{in}}^2} \langle n_k^2 \rangle 4 \sin^2 (\psi/2)$$

phase difference

injected amplitude noise

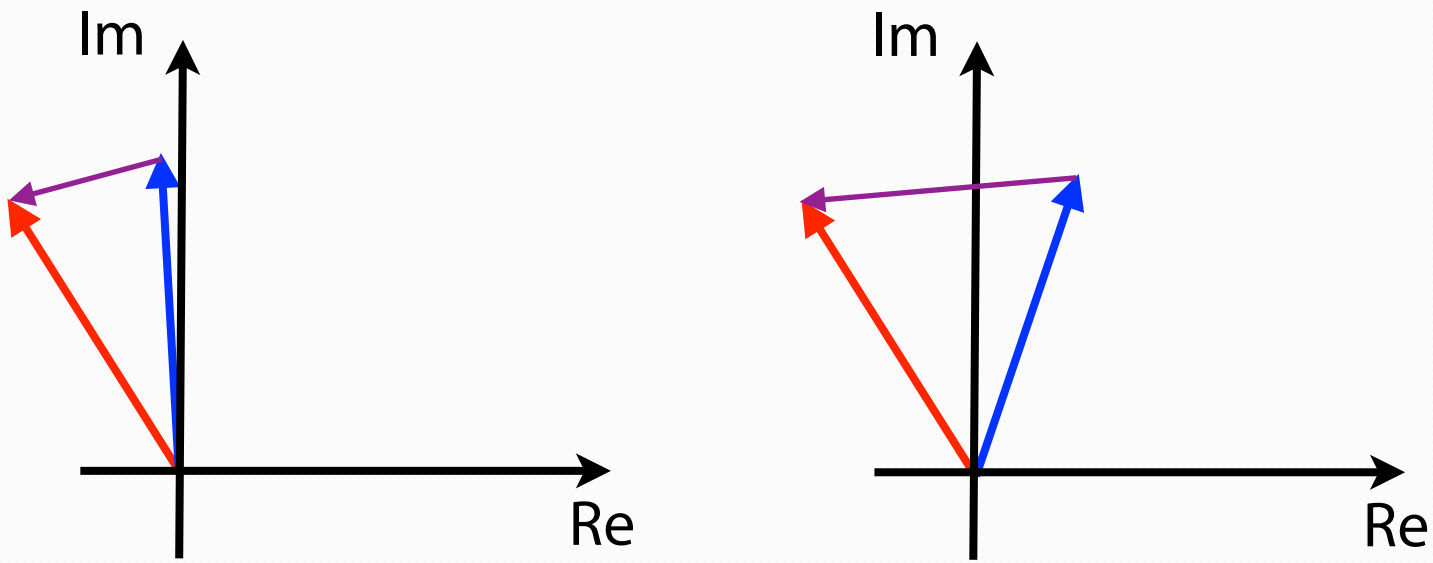
remaining amplitude noise

Amplitude noise

$$\phi_n - \psi_n$$

$$\Delta n_{\mathrm{an}} = \Delta\phi_{\mathrm{an}} - \Delta\psi_{\mathrm{an}}$$

$$\langle \Delta n_{\mathrm{an}}^2 \rangle = \frac{2}{N A_{\mathrm{in}}^2} \langle n_k^2 \rangle 4 \sin^2(\psi/2)$$



measurement signal

reference signal

Amplitude noise

$$\phi_n - \psi_n$$

$$\Delta n_{\mathrm{an}} = \Delta\phi_{\mathrm{an}} - \Delta\psi_{\mathrm{an}}$$

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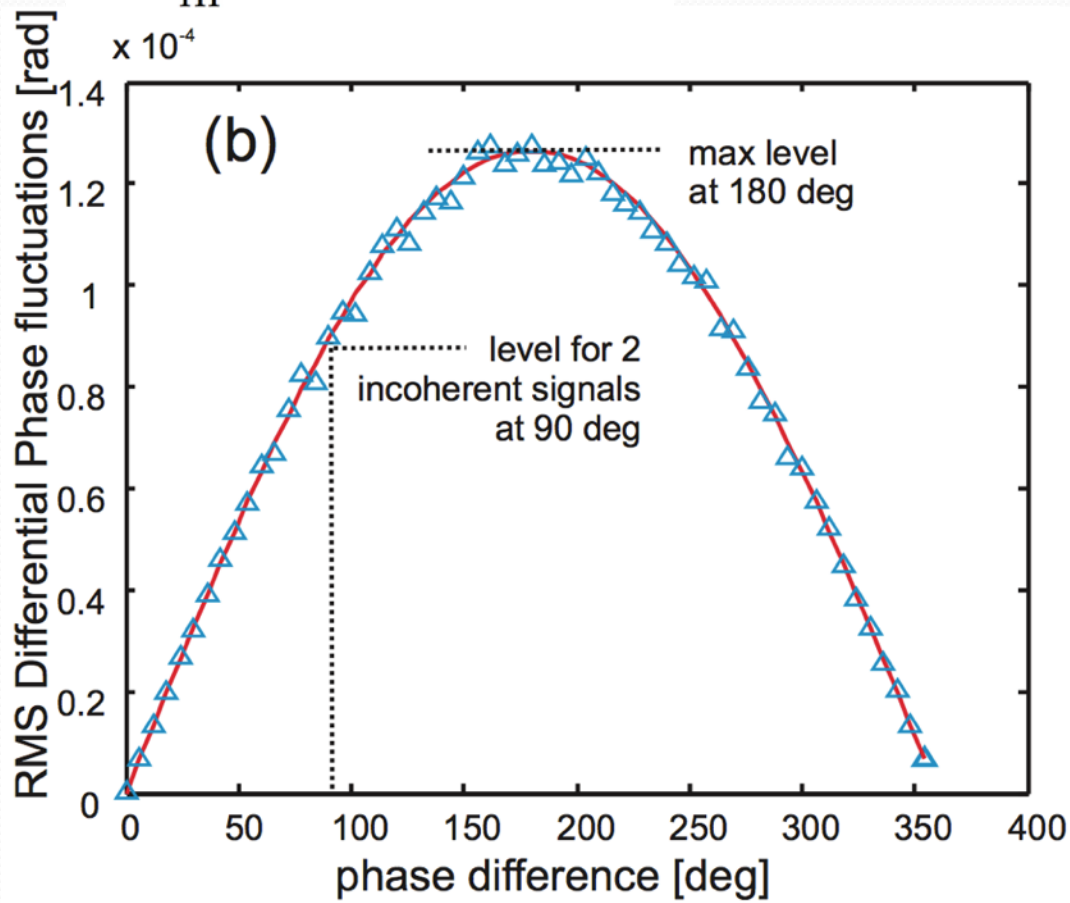
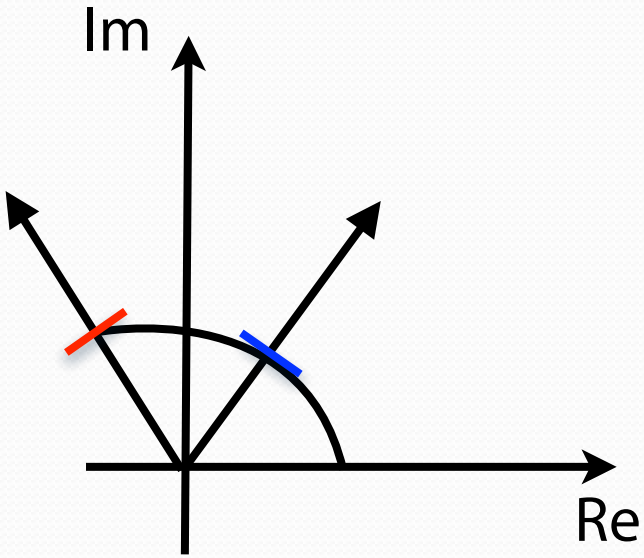


OPD noise

$$\phi_n - \psi_n$$

$$\Delta n_{\mathrm{pn}} = (\phi_{\mathrm{pn}} - \psi_{\mathrm{pn}}) - (\phi - \psi)$$

$$= \frac{2}{N}\langle n_k^2 \rangle \sin^2(\phi - \psi)$$



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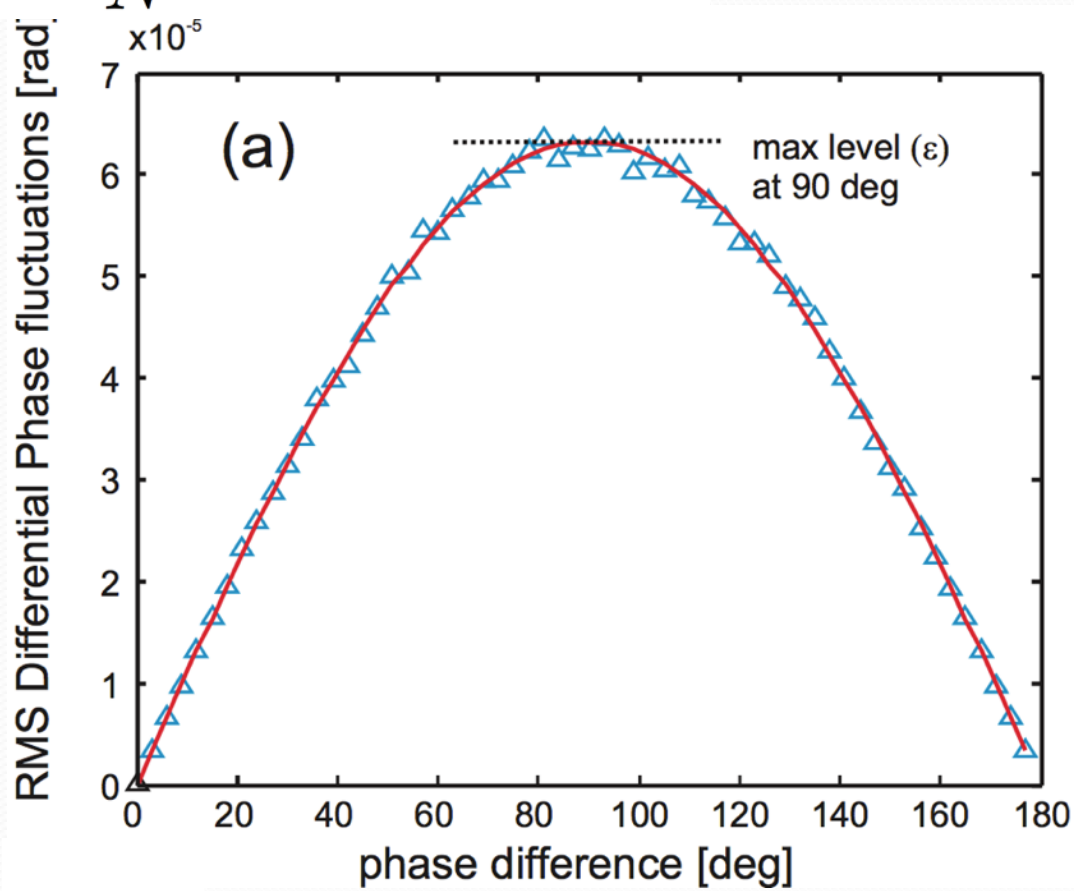
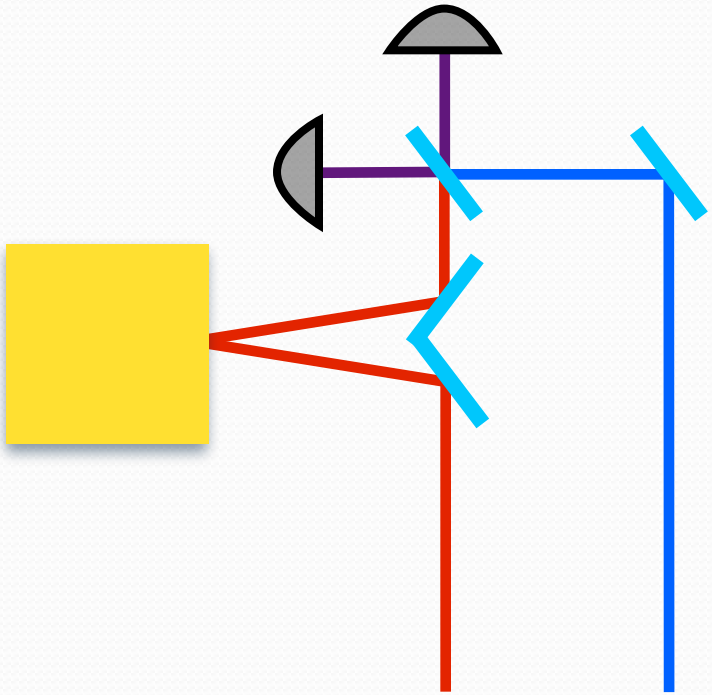
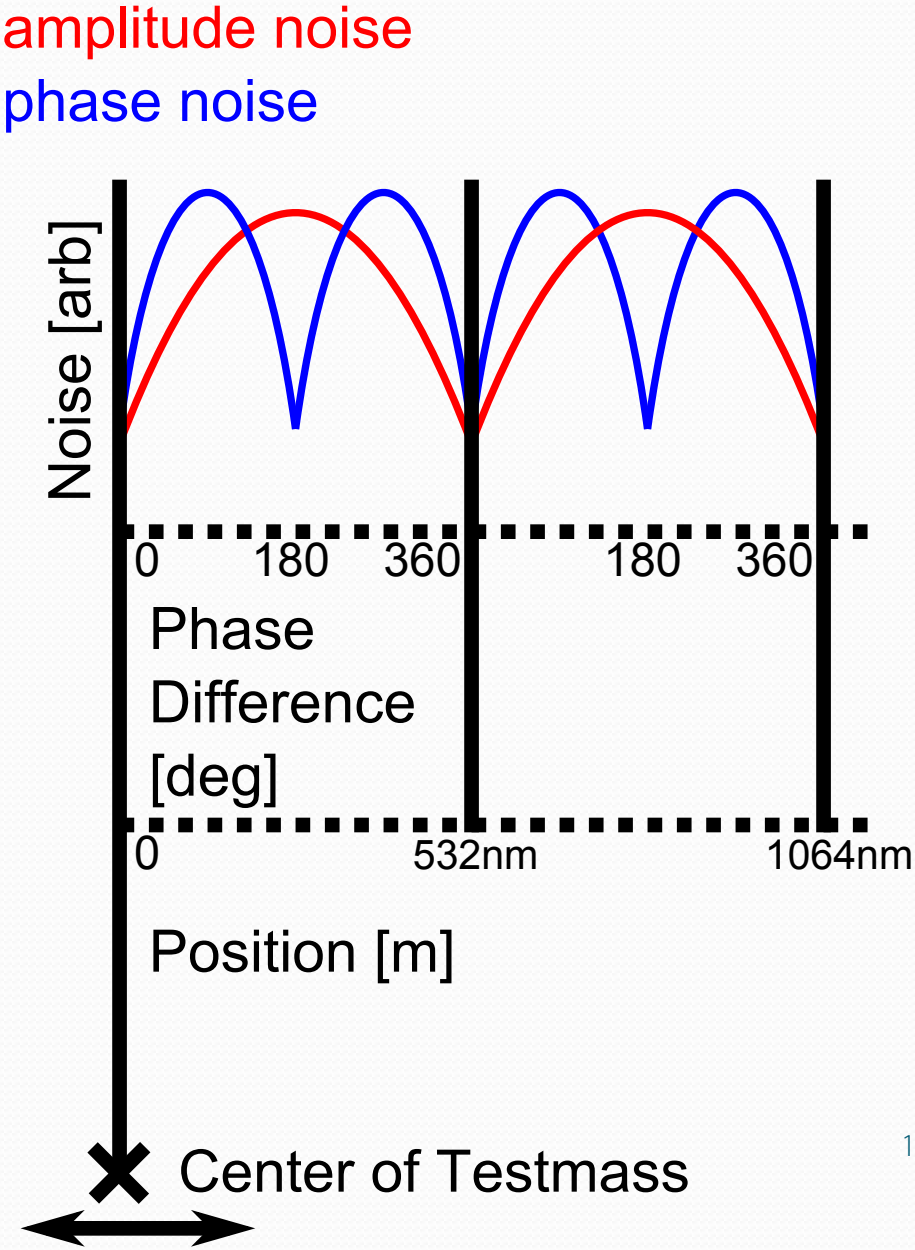
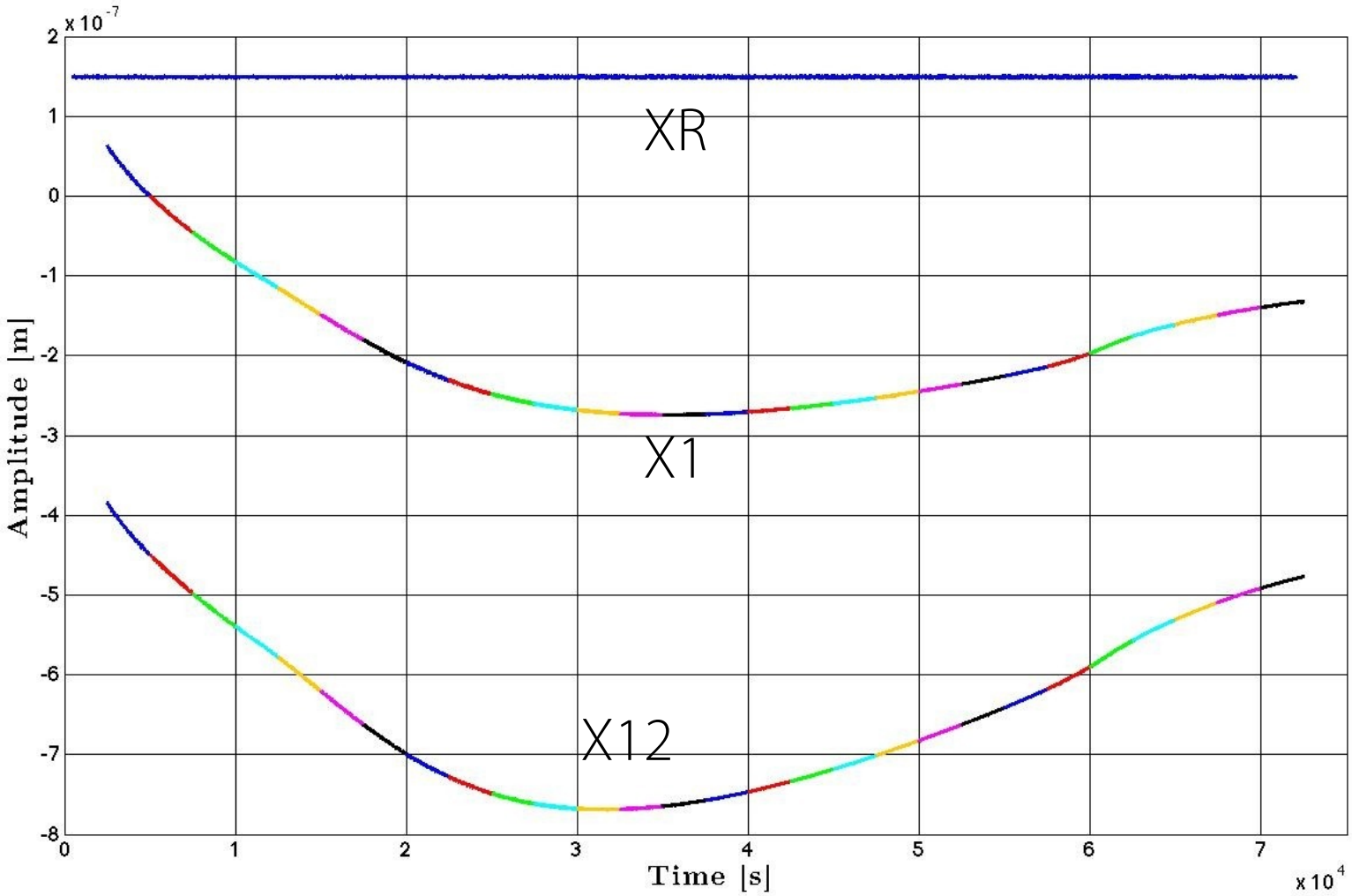


Summary

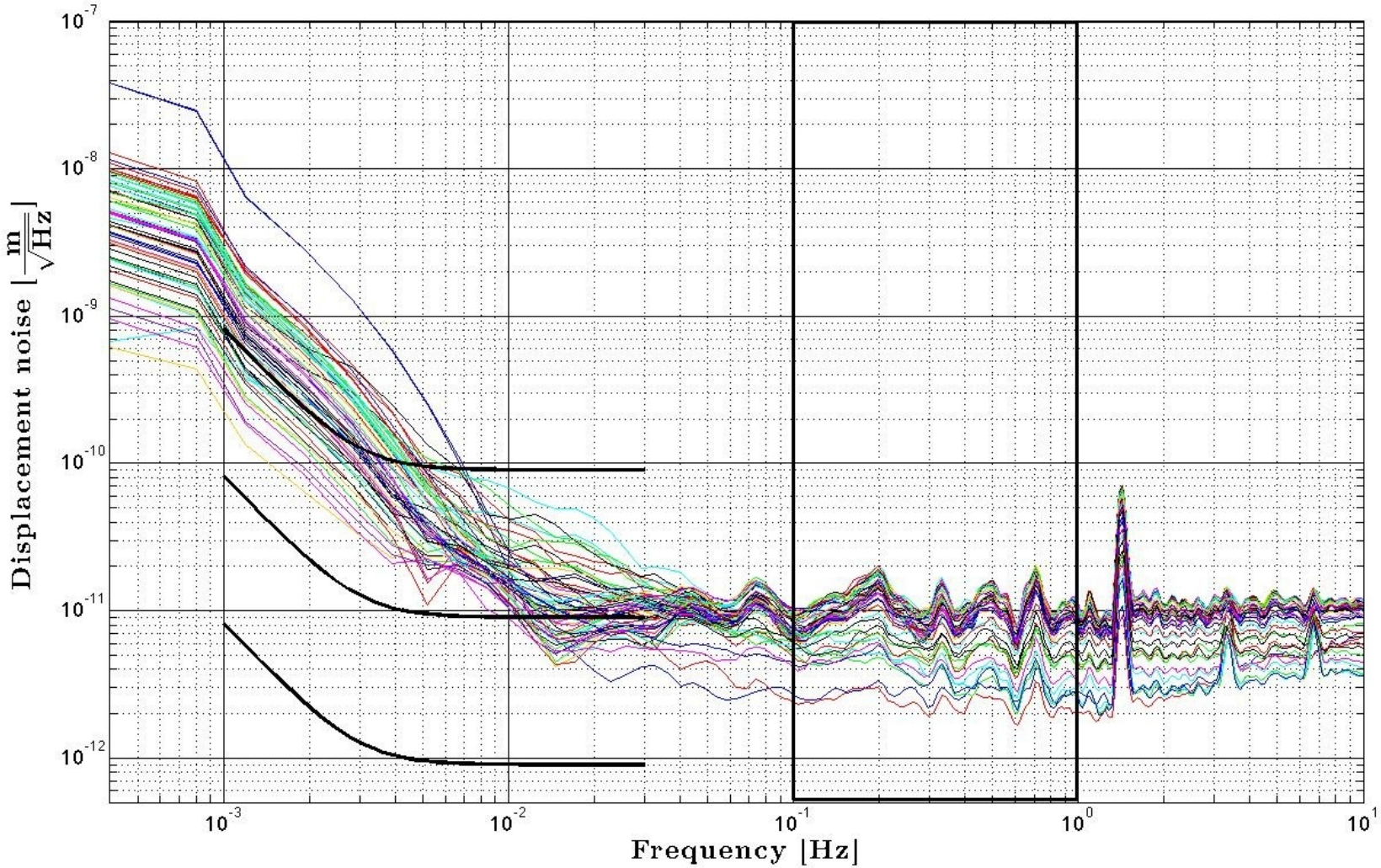



amplitude noise
phase noise
Noise [arb]
0
180
360
180
360
Phase
Difference
[deg]
0
532nm
1064nm
Position [m]
Center of Testmass

Experiment

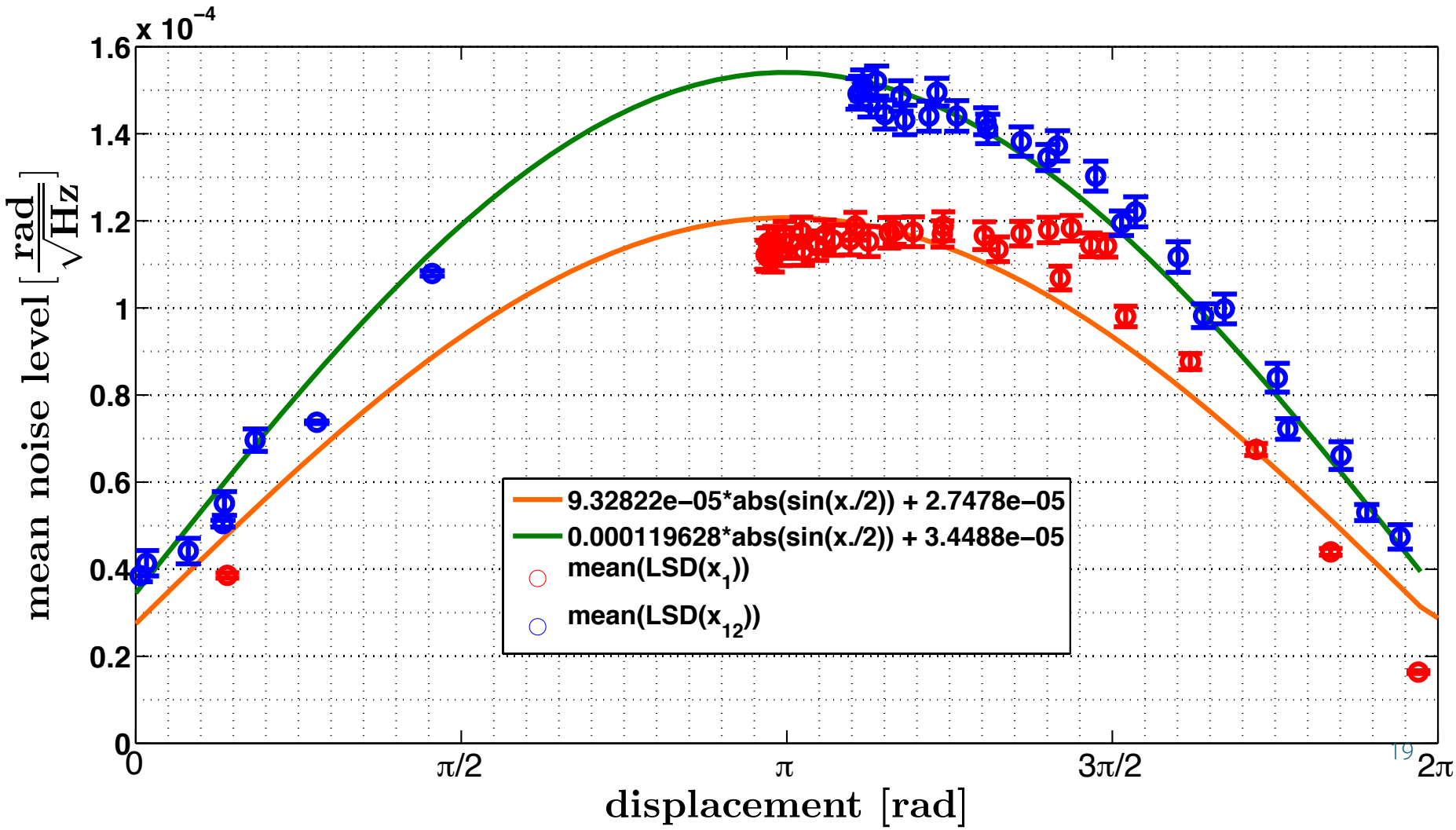


Experiment


Displacement noise $[\frac{m}{\sqrt{Hz}}]$
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Frequency [Hz]

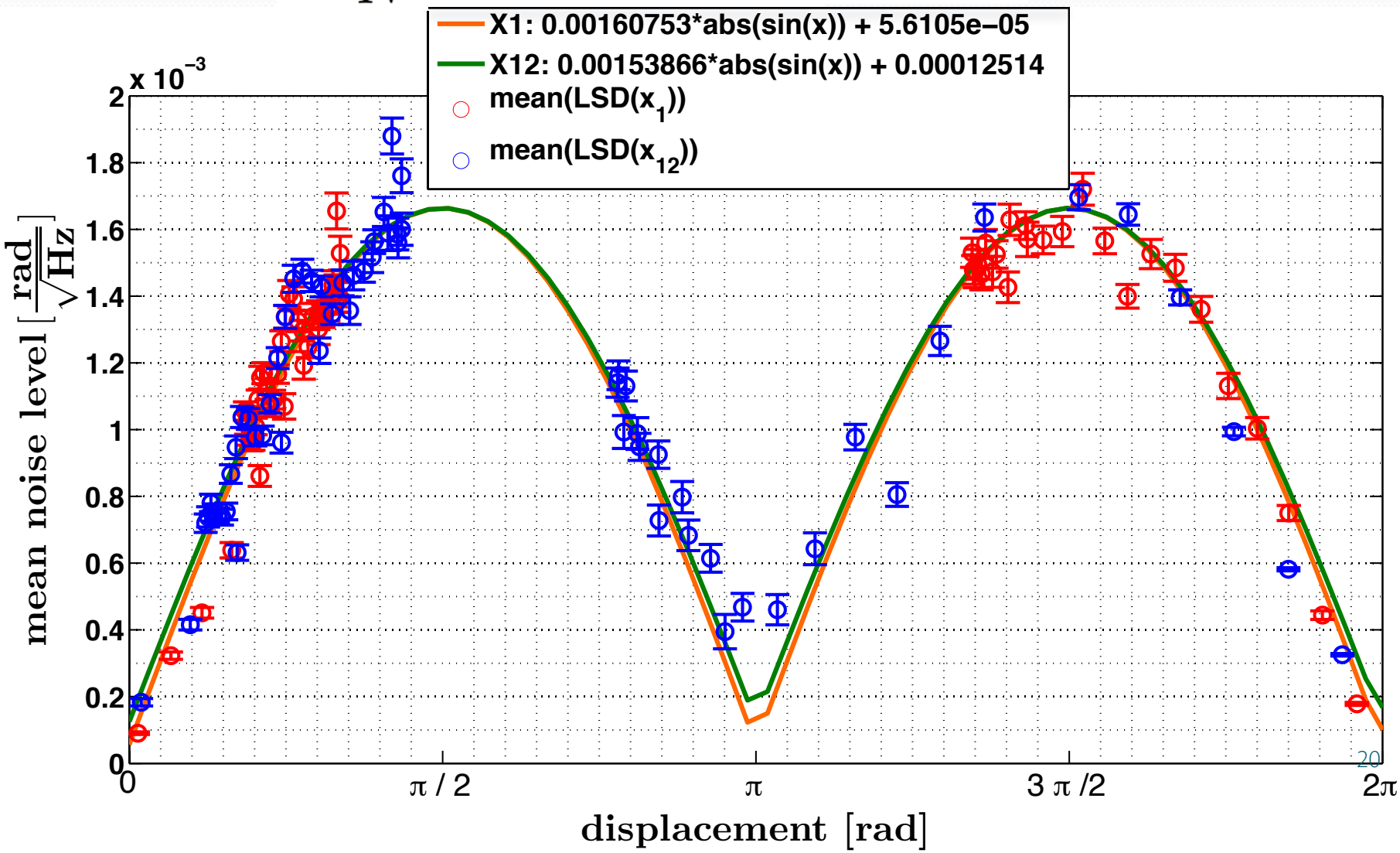
Measurements - amplitude noise

$$\langle \Delta n_{\mathrm{an}}^2 \rangle = \frac{2}{N A_{\mathrm{in}}^2} \langle n_k^2 \rangle 4 \sin^2(\psi/2)$$



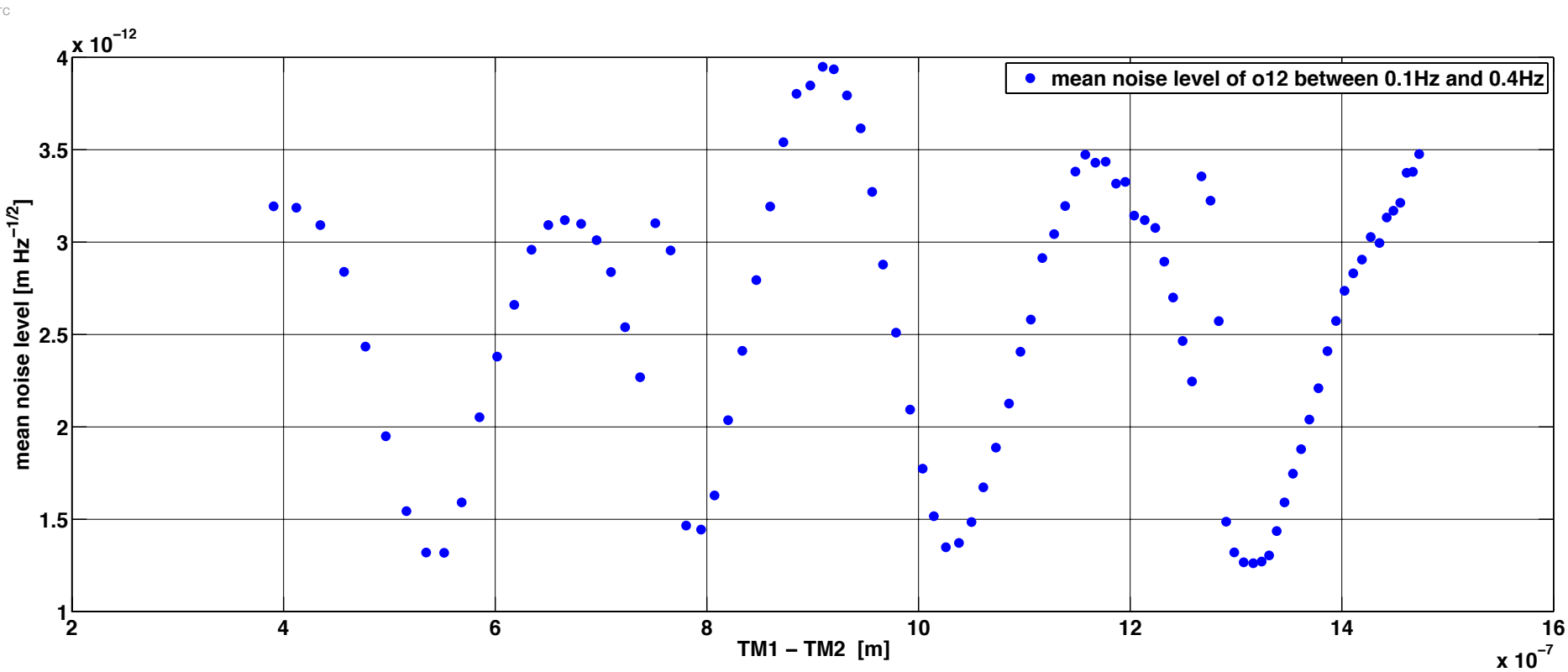
Measurements - phase noise

$$\Delta n_{\mathrm{pn}} = \frac{2}{N}\langle n_k^2\rangle \sin^2(\phi - \psi)$$



Measurements - phase noise

- LPF STOC SIM4

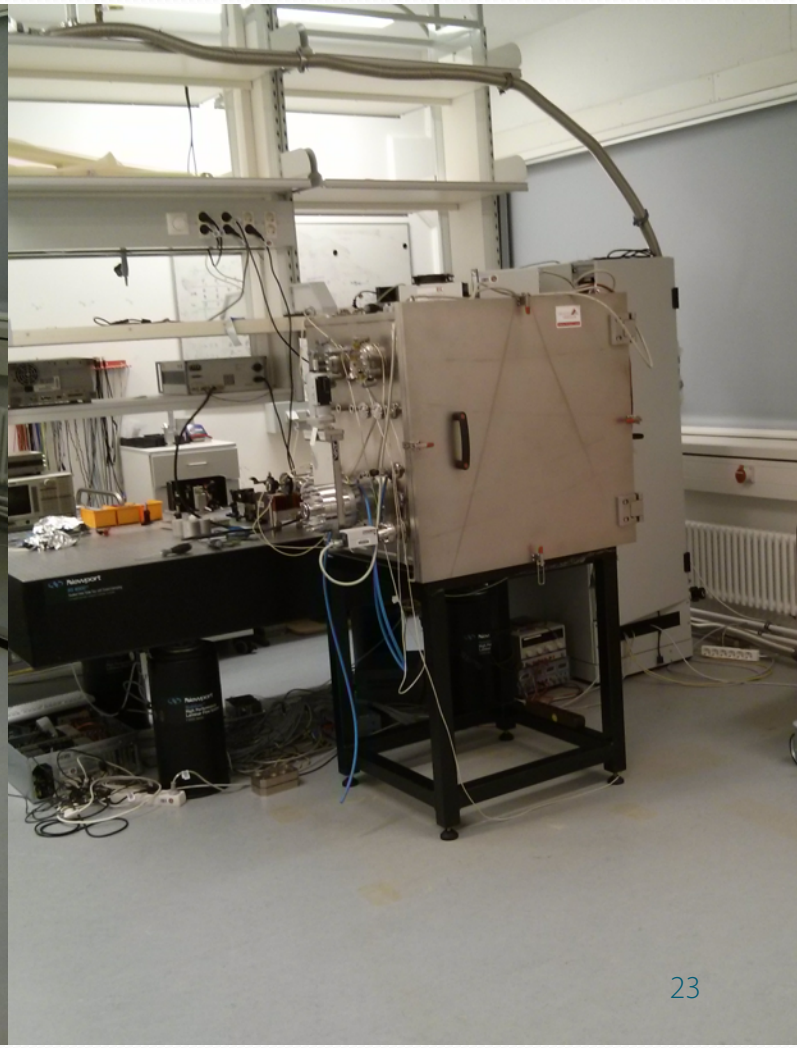


Outlook

- new vacuum tank

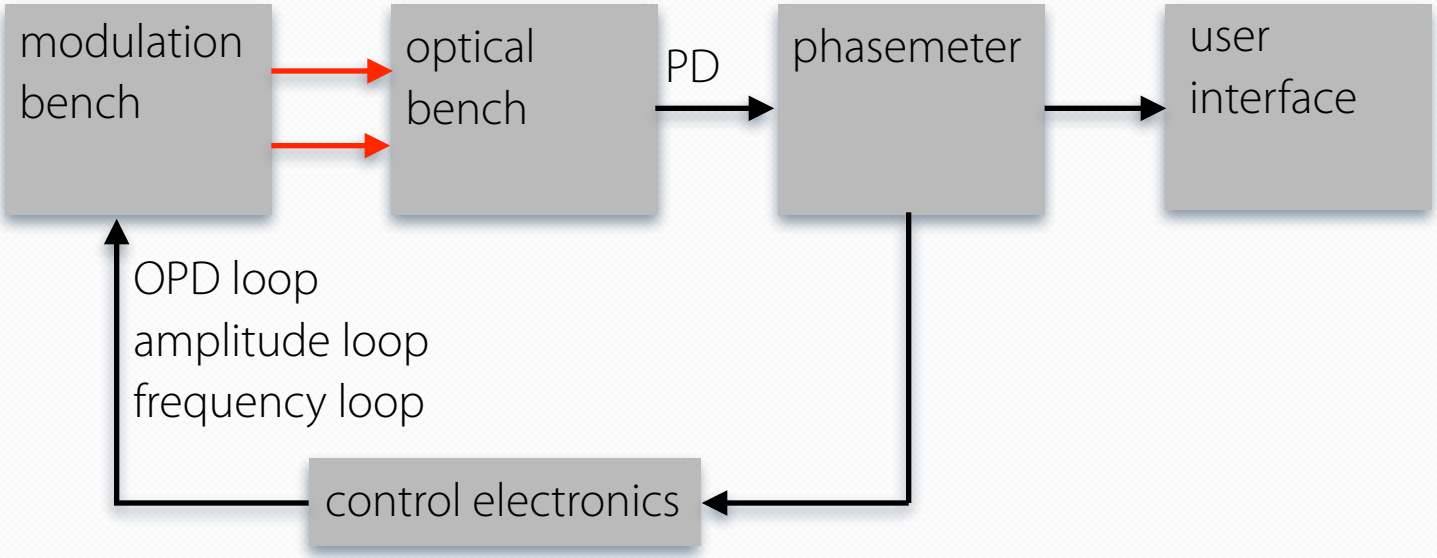
Outlook

- new vacuum tank



Outlook

- new vacuum tank
- CDS system for phasemeter readout
- digital control and/or monitoring of control loops



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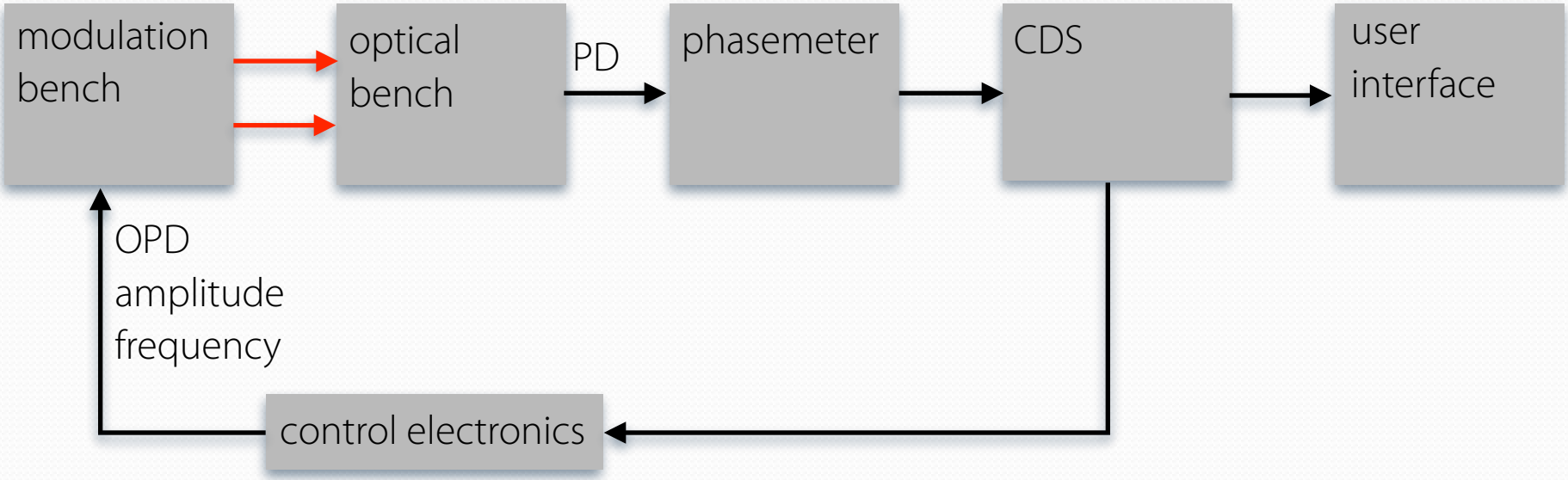

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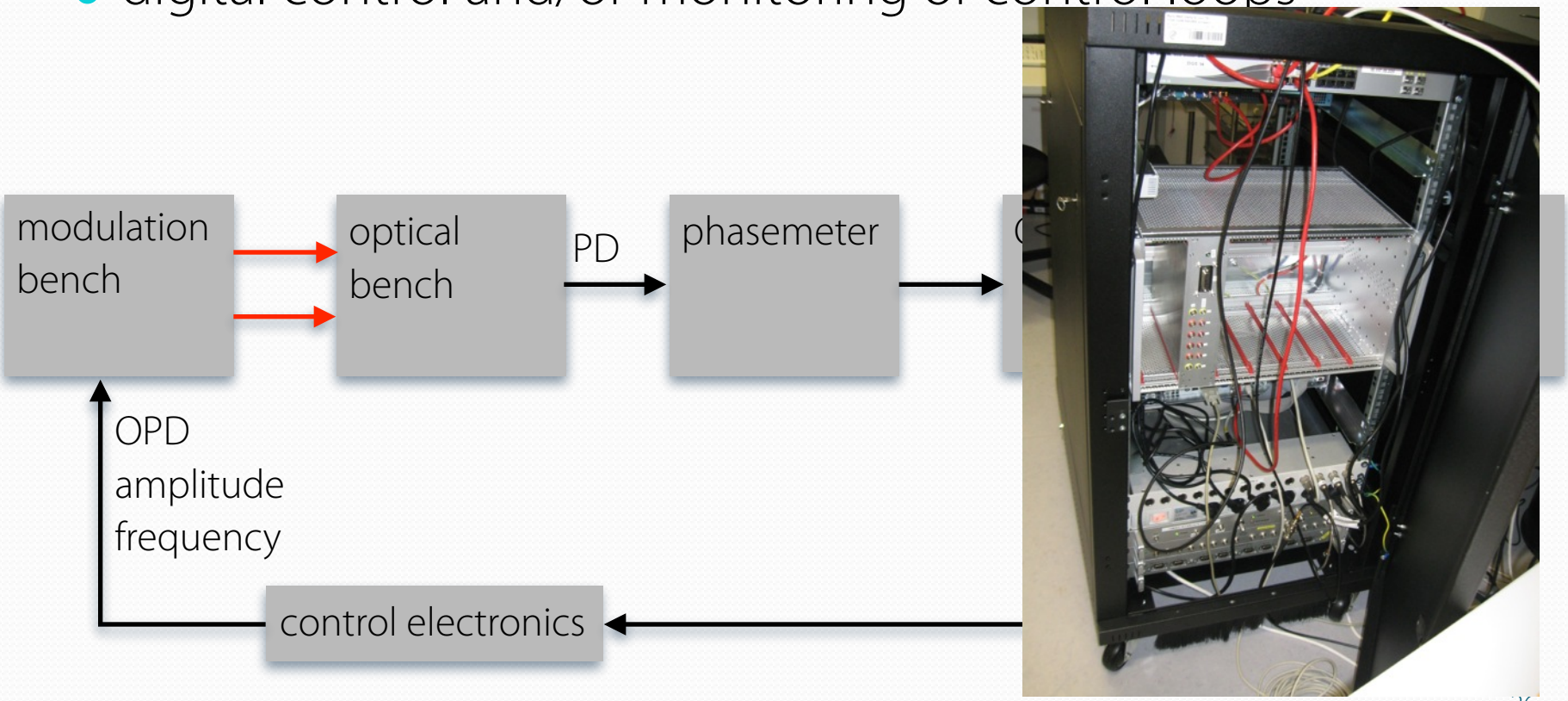
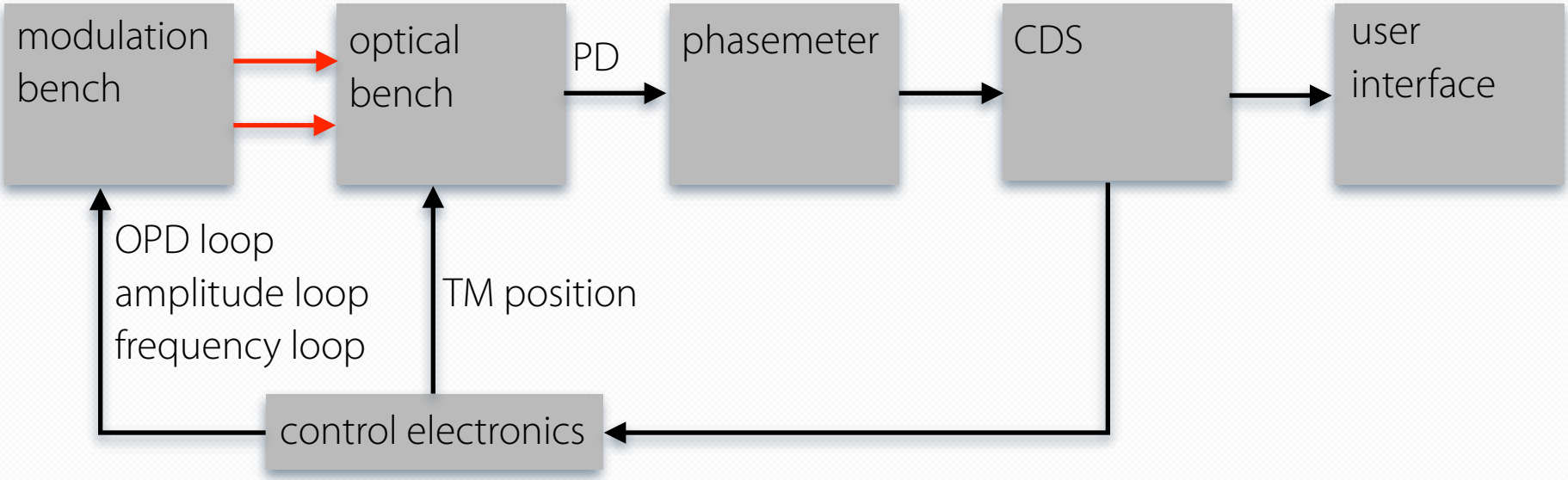


Outlook

- new vacuum tank
- CDS system for phasemeter readout
- digital control and/or monitoring of control loops
- digital control of test mass mirror piezos

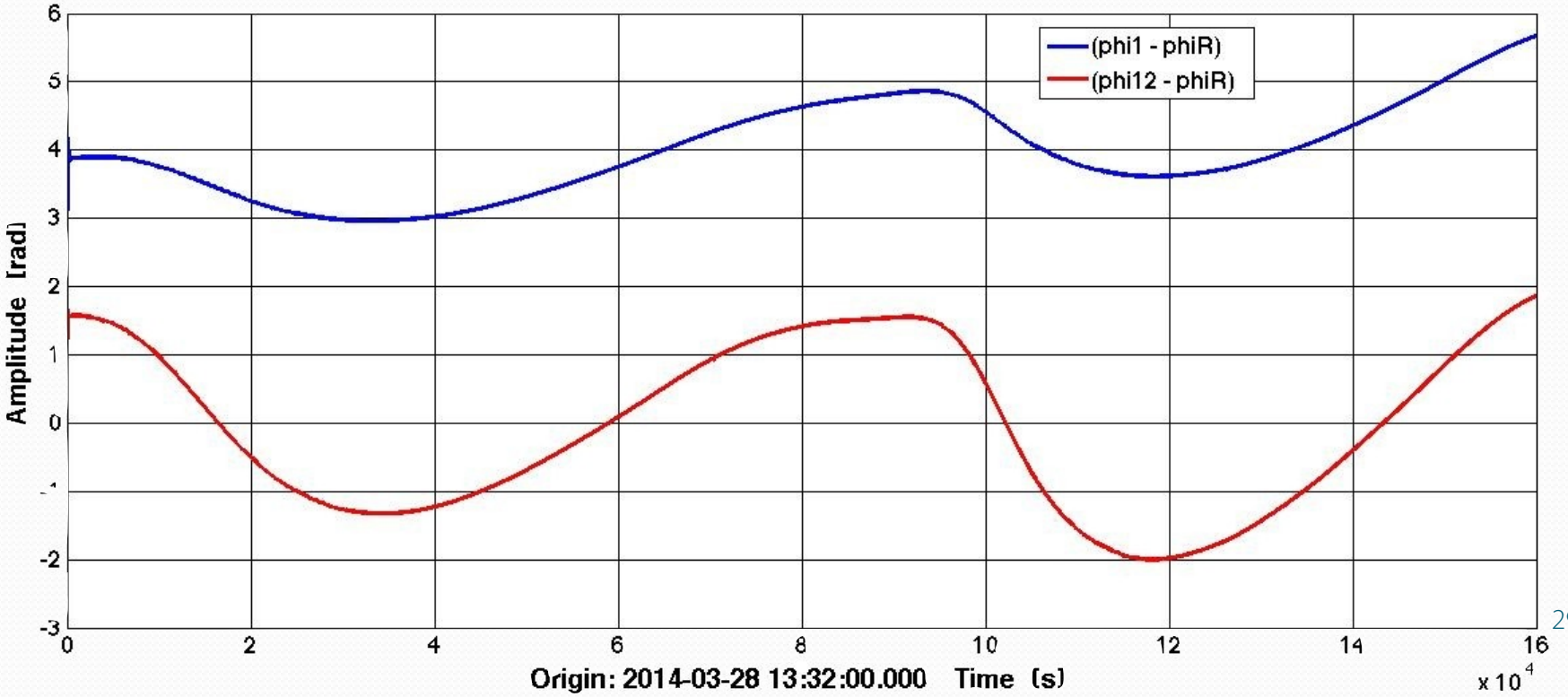


Outlook

- new vacuum tank
- CDS system for phasemeter readout
- digital control and/or monitoring of control loops
- digital control of test mass mirror piezos
  - adjustment of test masses while the tank is closed
  - low frequency test mass drift stabilisation

Outlook

- new vacuum tank
- CDS system for phasemeter readout
- digital control and/or monitoring of control loops
- digital control of test mass mirror piezos



Outlook

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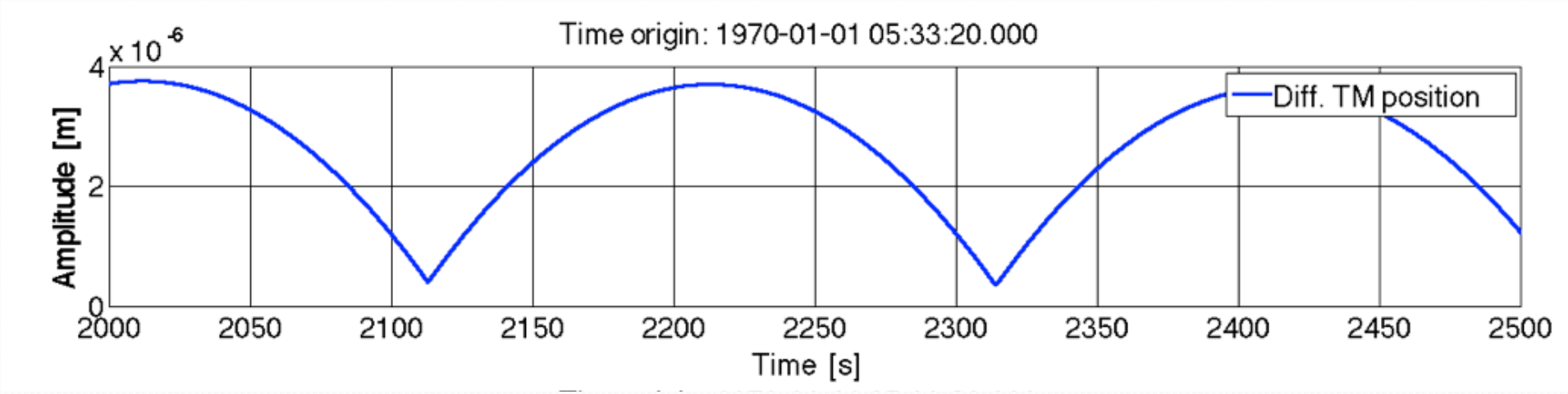

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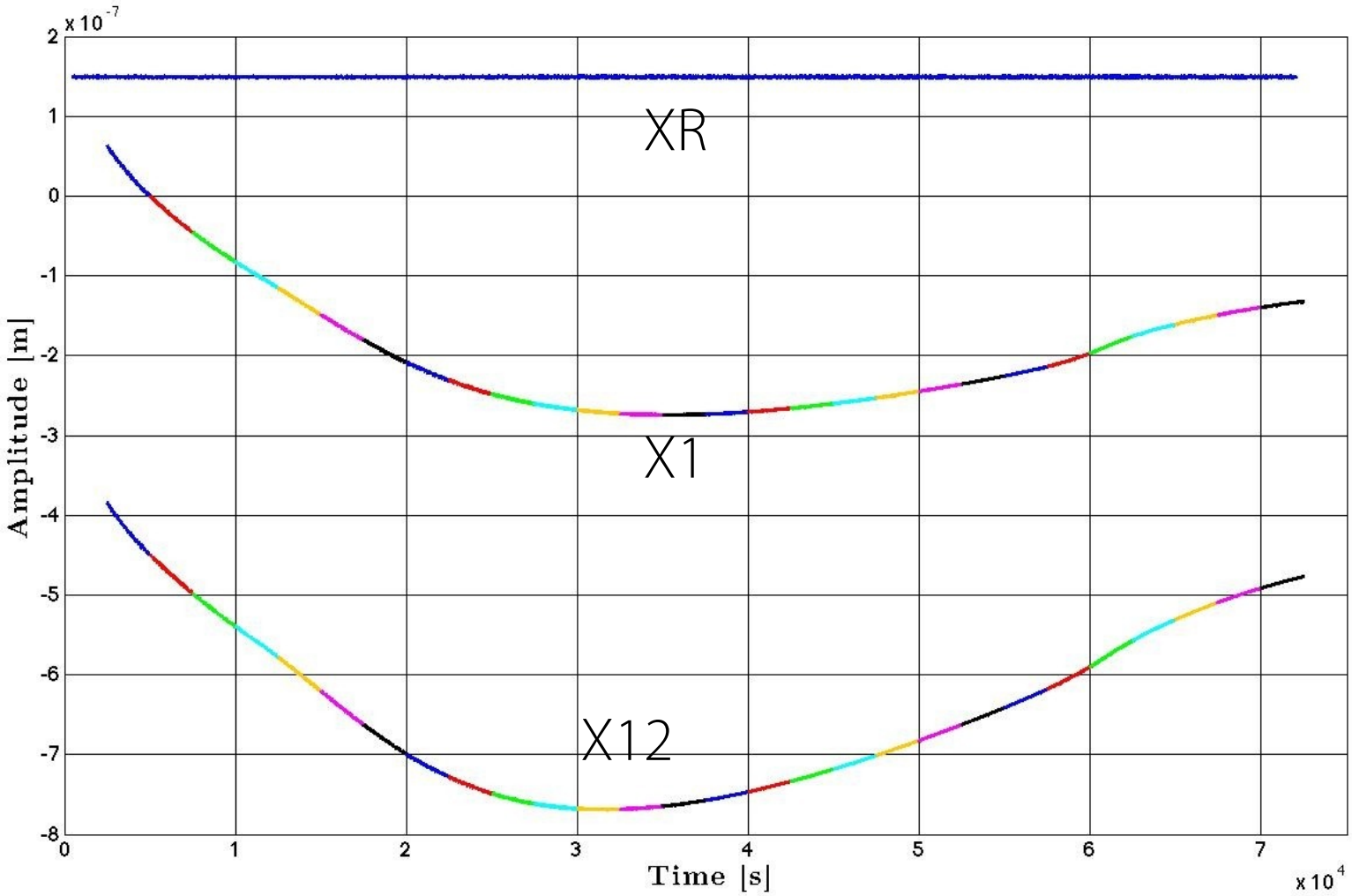
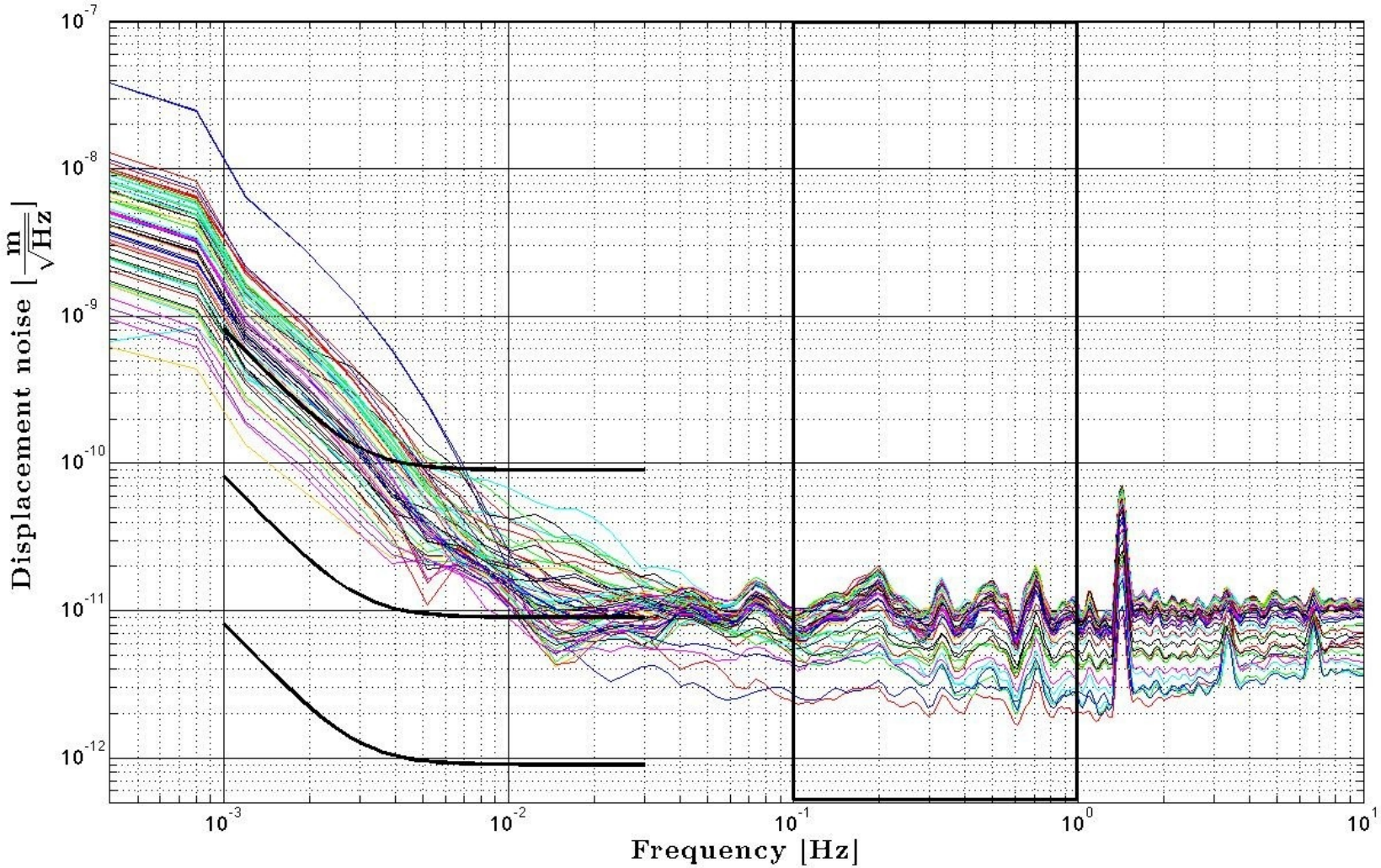
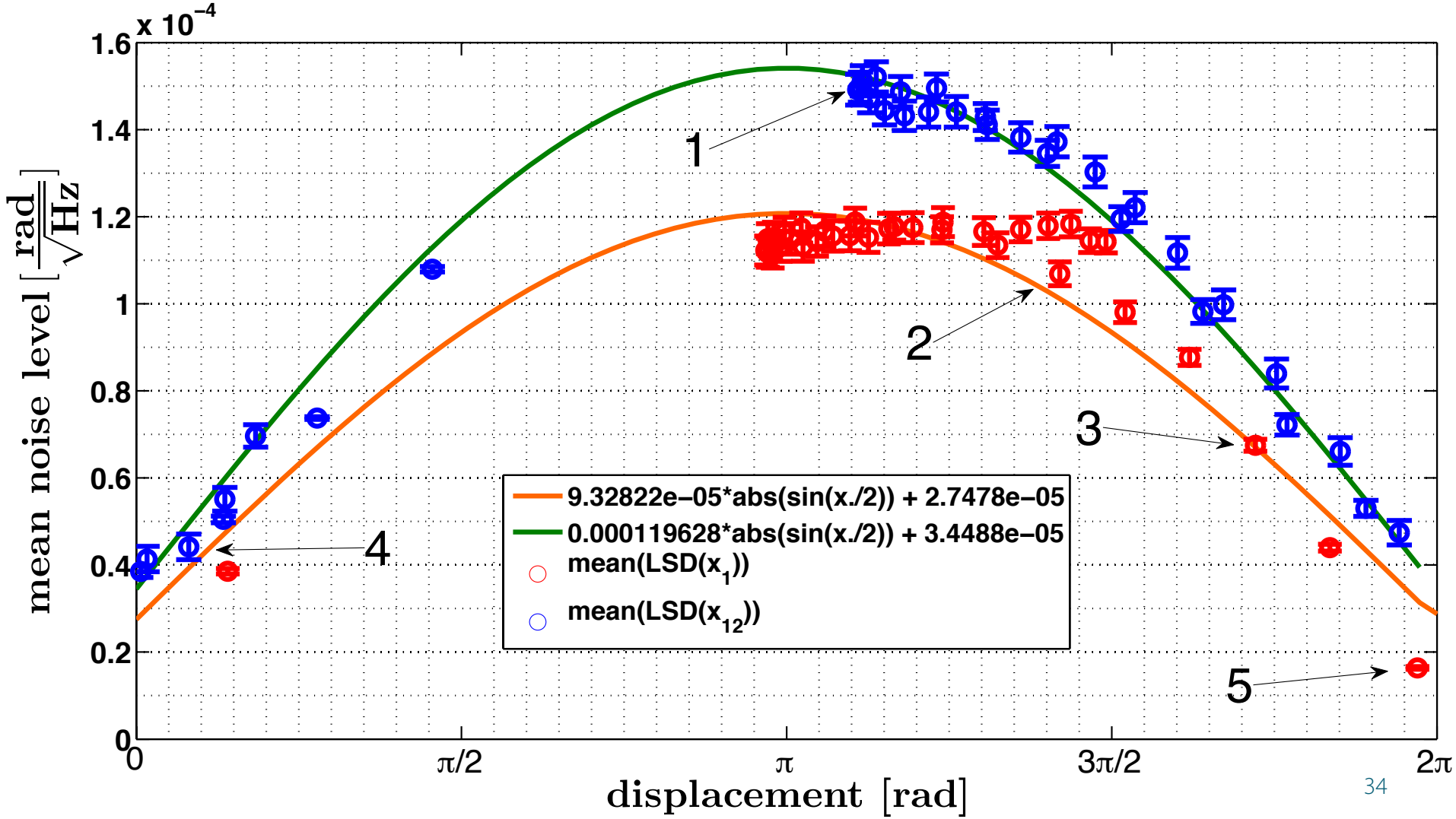
extra - data analysis



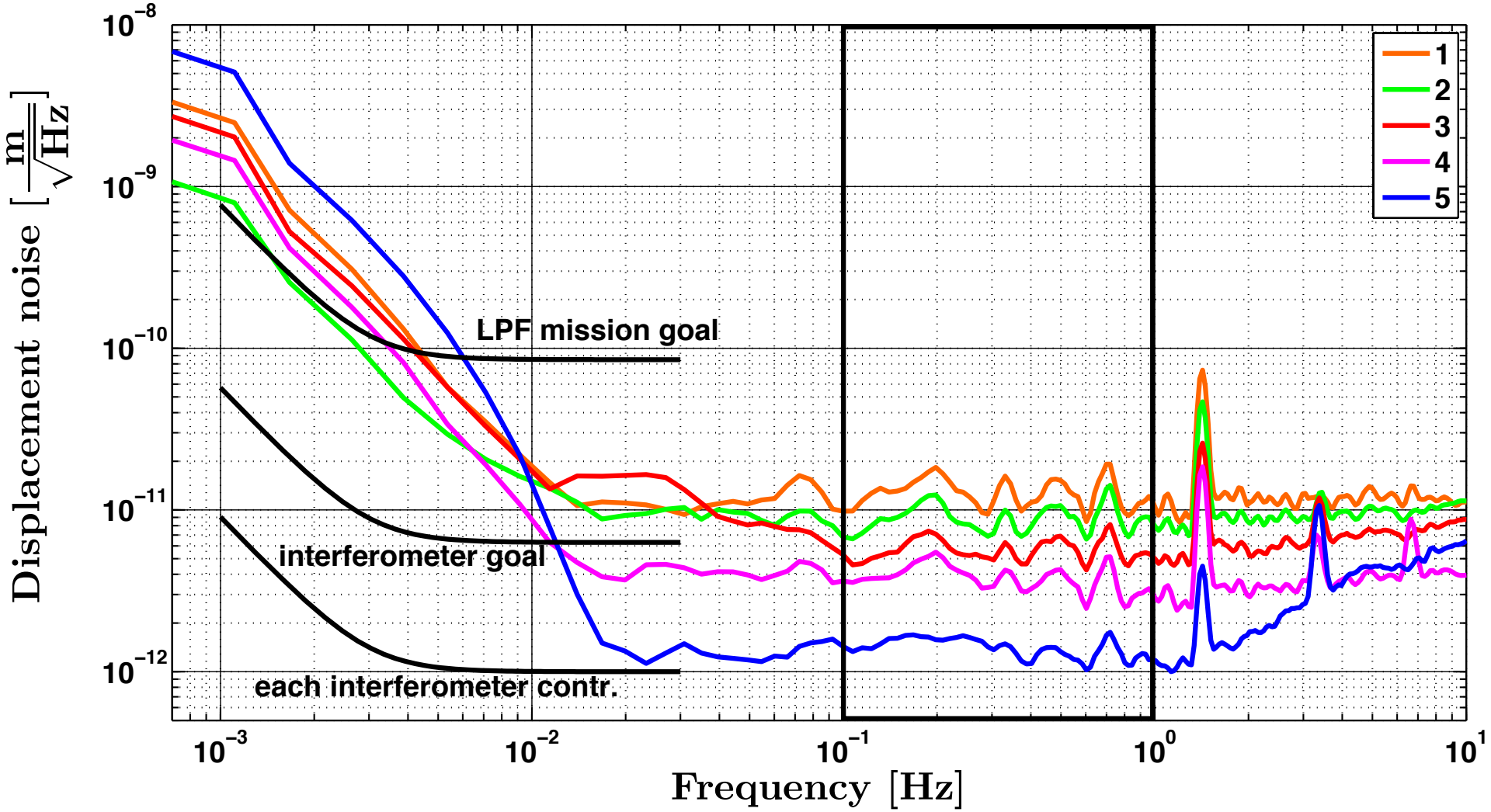
extra - data analysis



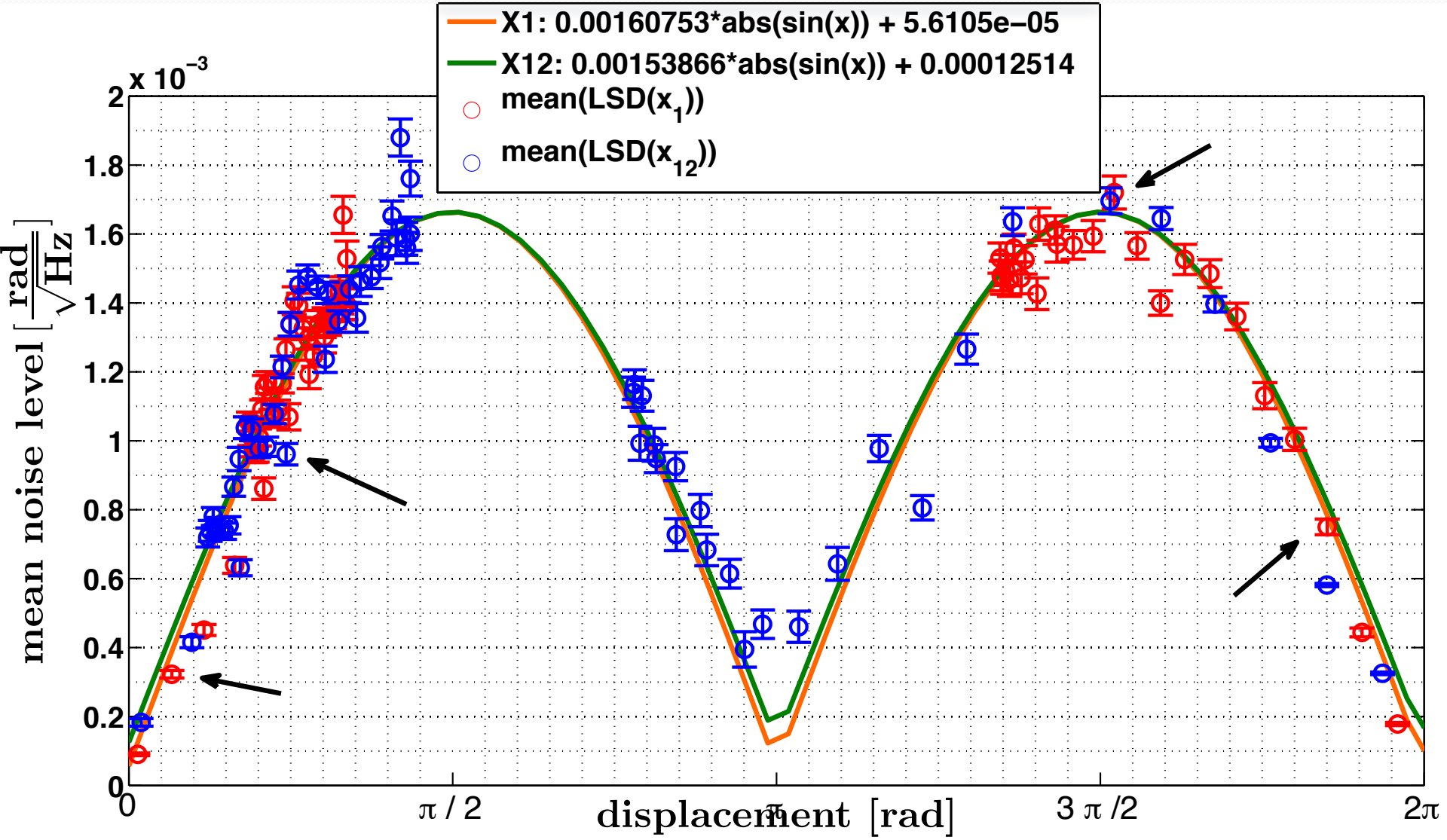
extra - amplitude noise



extra - amplitude noise



extra - OPD noise



extra - OPD noise