HOM-based Cavity Alignment Measurement at FLASH

Thorsten Hellert, FEL-Seminar, 30.08.2016

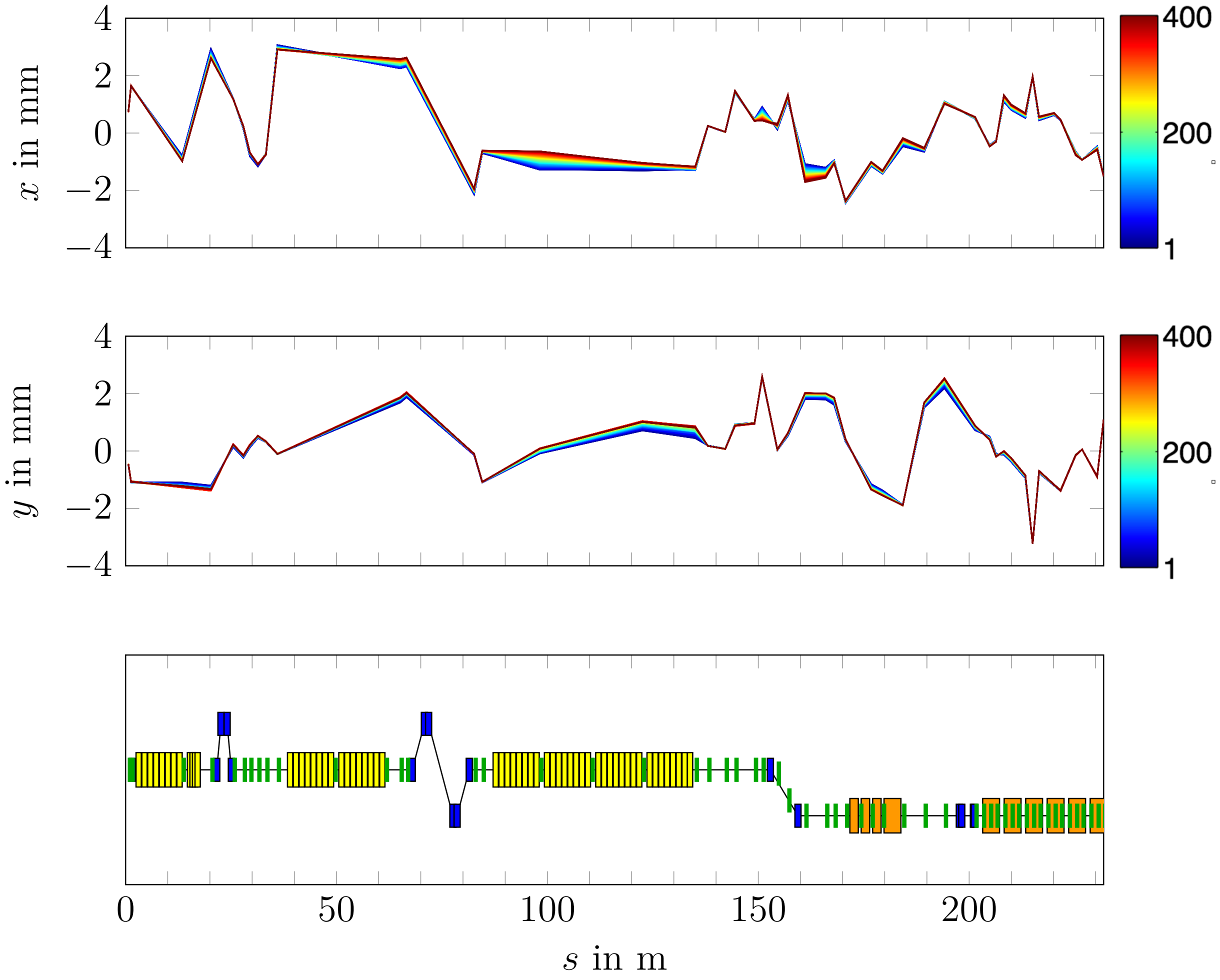
HELMHOLTZ | ASSOCIATION

DESY

outline

- motivation
- dipole mode characteristics
- experimental setup
- data evaluation
- outlook

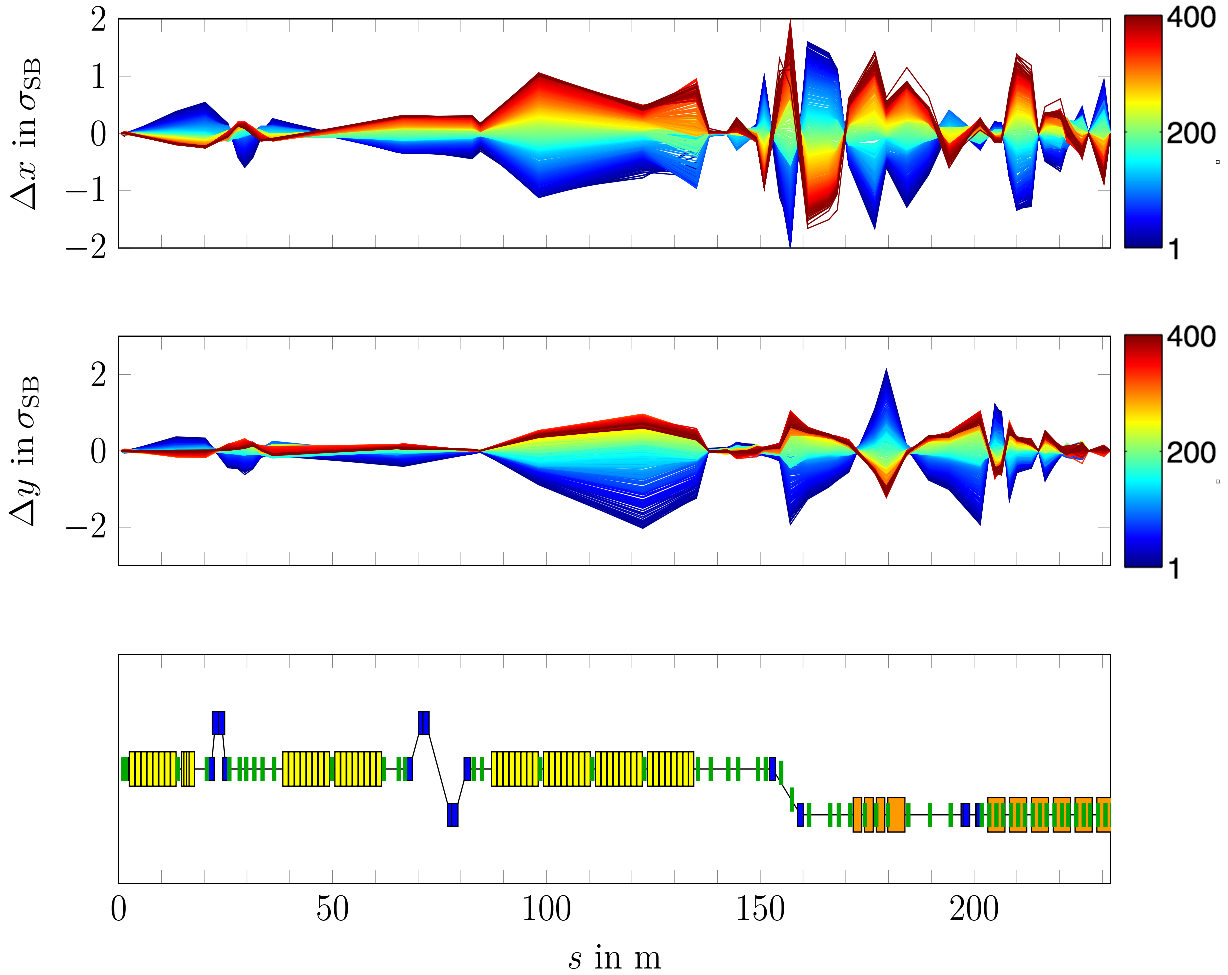
multi bunch orbit spread



- orbit for 400 bunches
- average over 92 pulses

> *data: user run with 400 bunches @ 28.01.15*

motivation — multi bunch orbit spread



- **orbit variations > 1kHz**
  - **no iron magnets**
  - **no vibrations**
  - **GUN**
  - **RF modules**
  - **non closed dispersion**
  - **wakefields, resonances …(?)**

- **difficulties**
  - **unknown sources**
  - **small number of BPMs**
  - **insufficient model**

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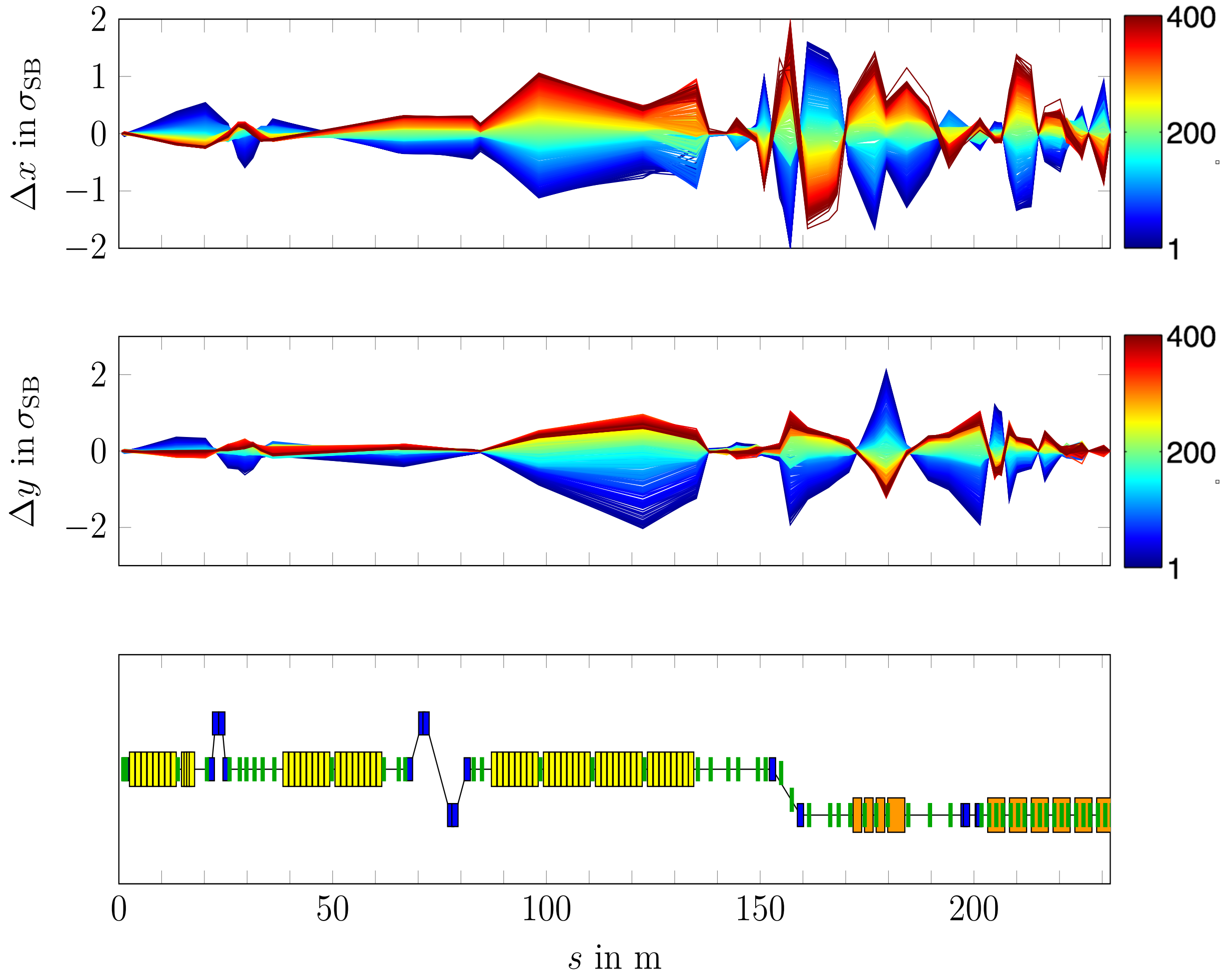
motivation

multi bunch orbit spread



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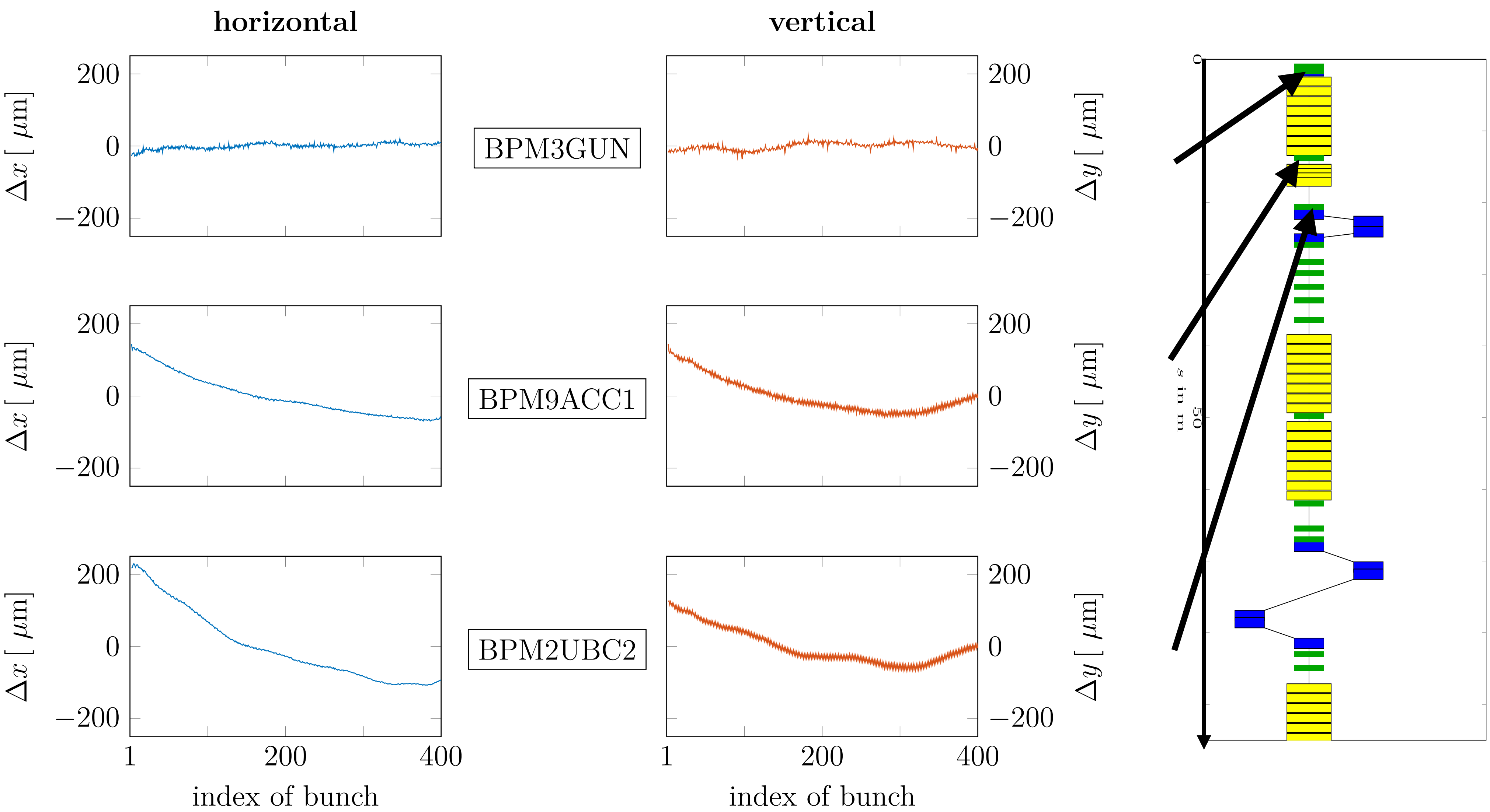

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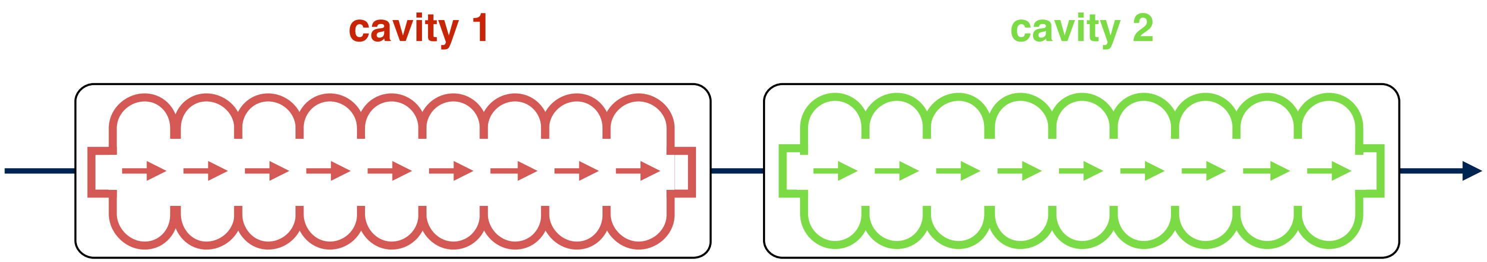
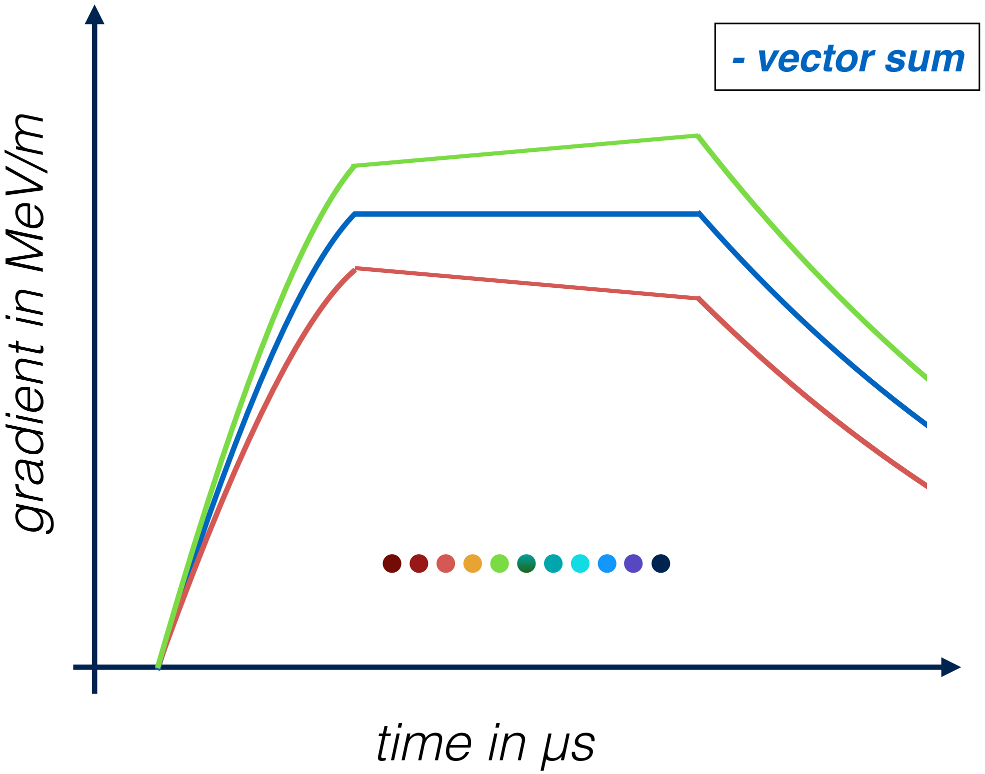
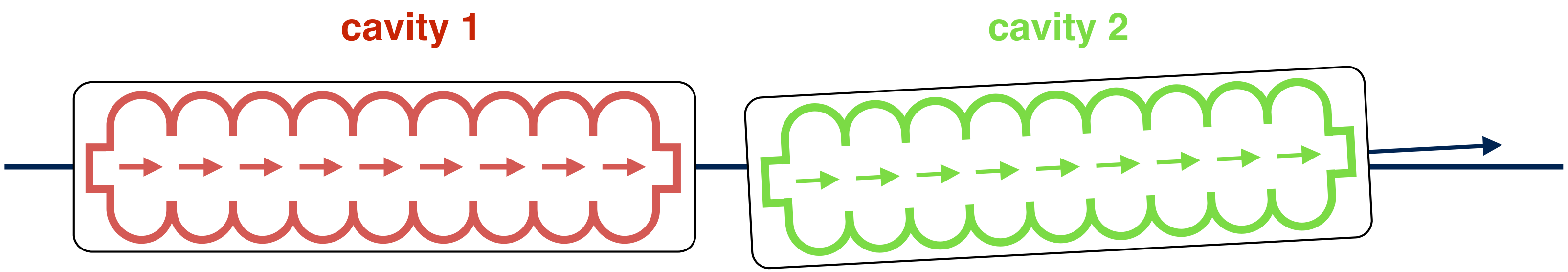
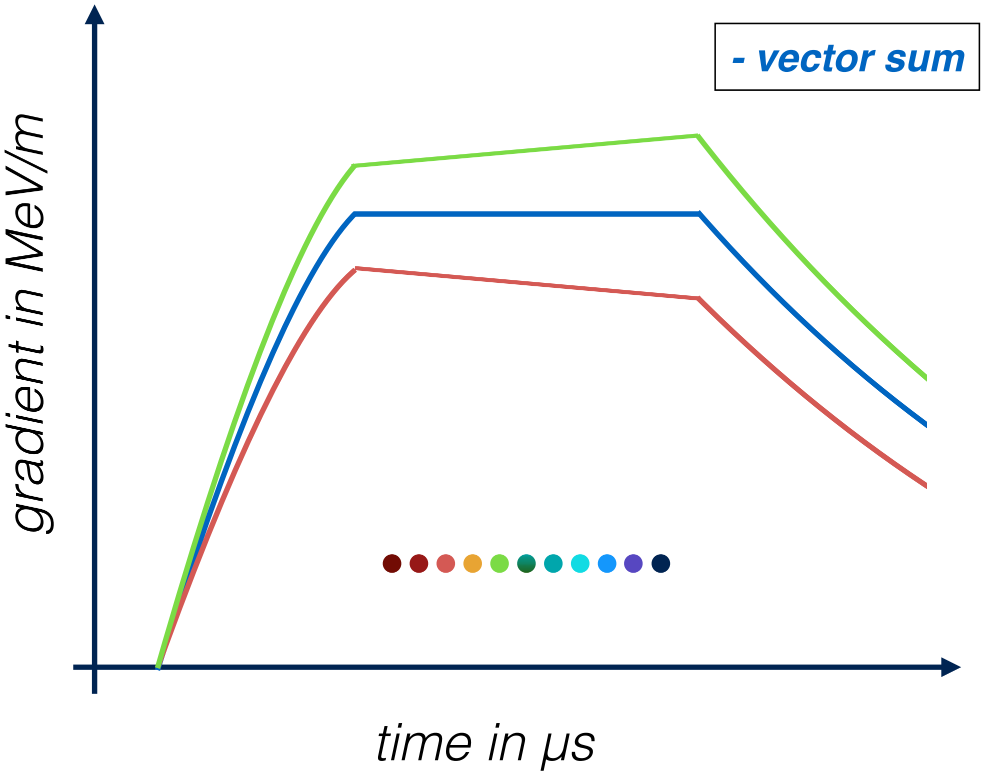




- $Q_1 \neq Q_2$
- **beam loading effects**
- **detuning of cavities**
- **…**





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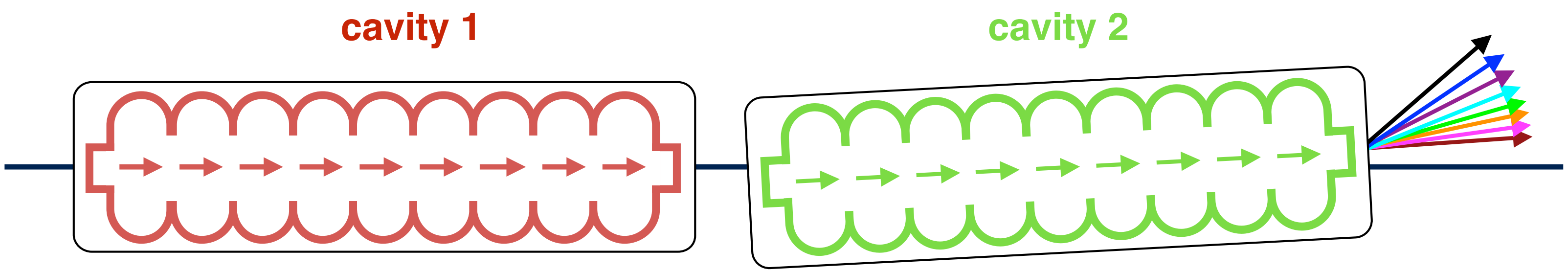
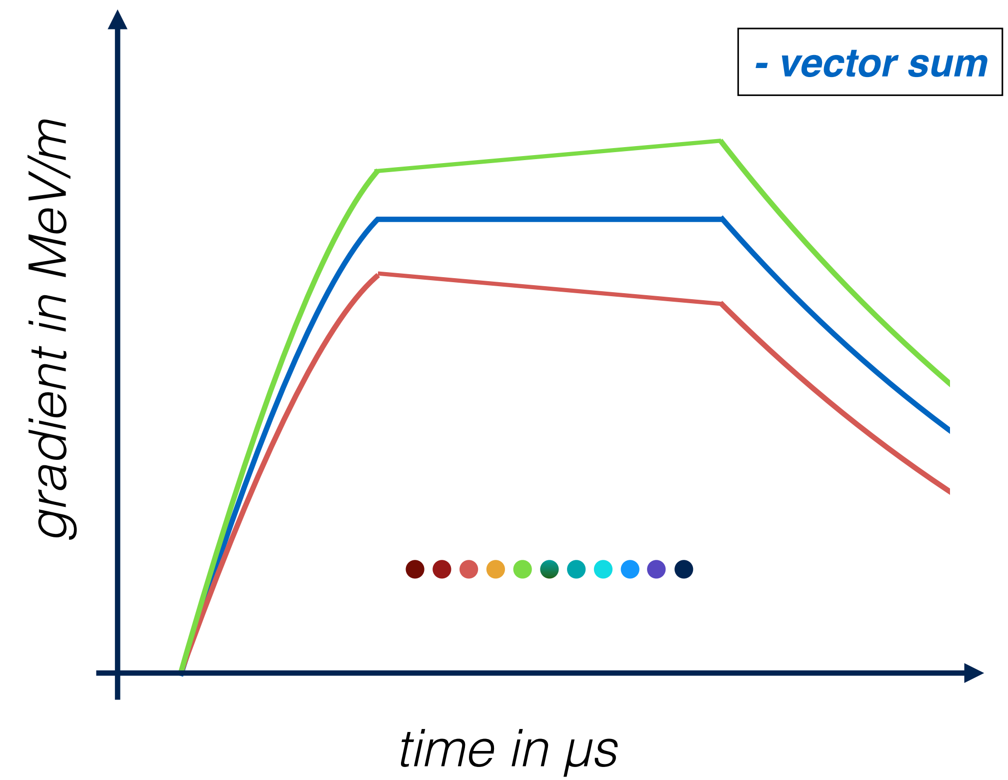
- …
- cavity misalignment





- $Q_1 \neq Q_2$
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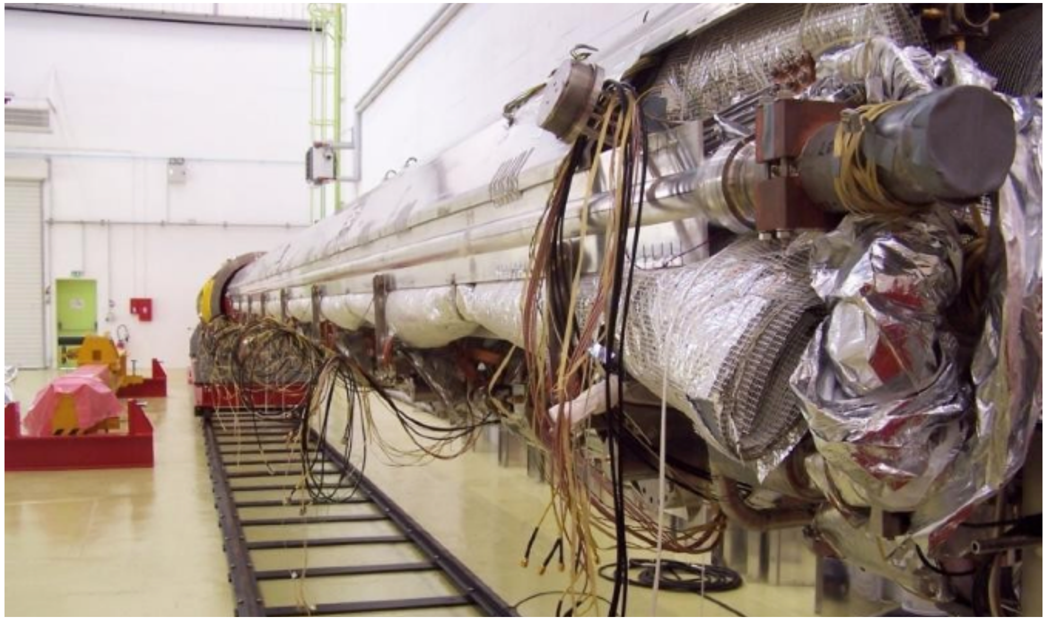
- **detuning of cavities**
- …
- **cavity misalignment**

> $k_i \neq k_j$

motivation

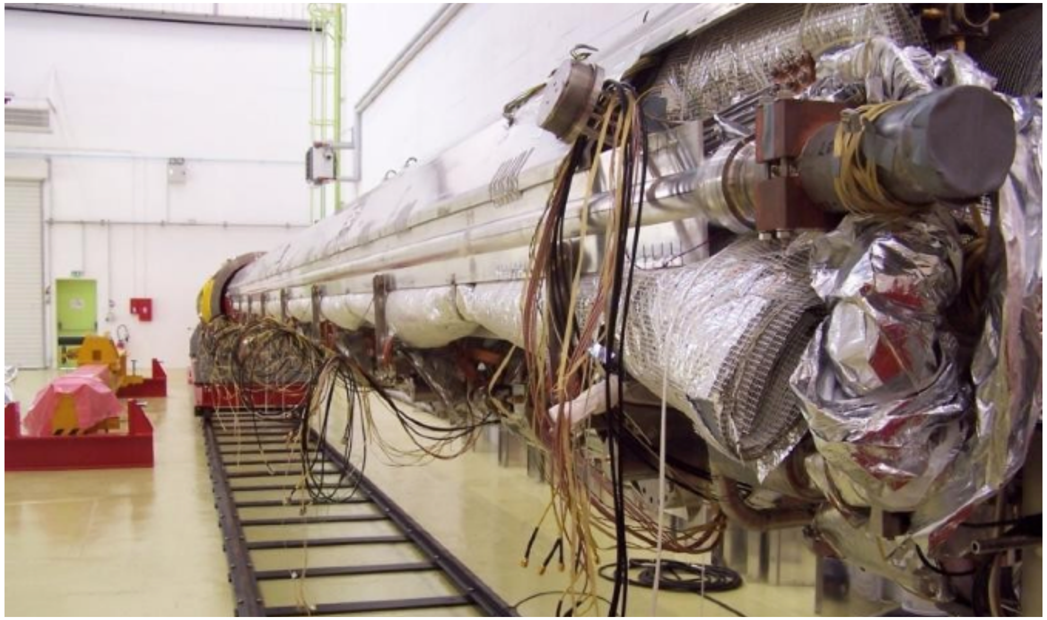
cavity alignment



- 8 cavities within one module
- cryogenic string
- thermal contraction
- no direct measurement

\> **beam based diagnostics**

  \> **multi-bunch**



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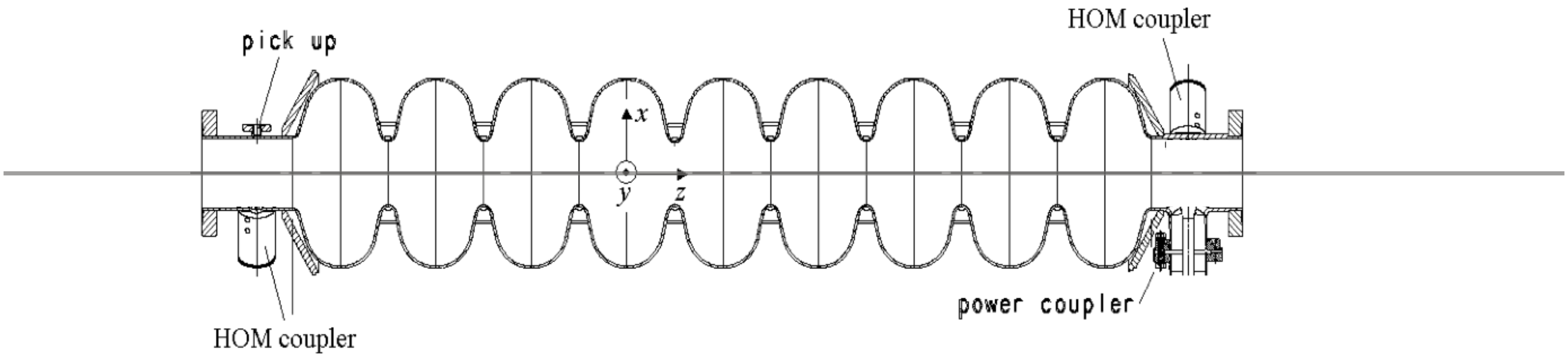
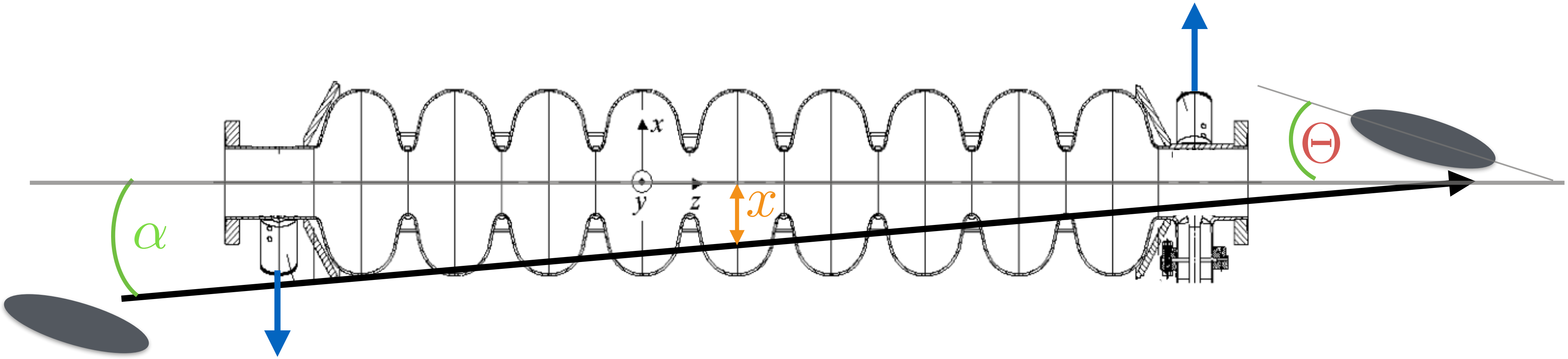
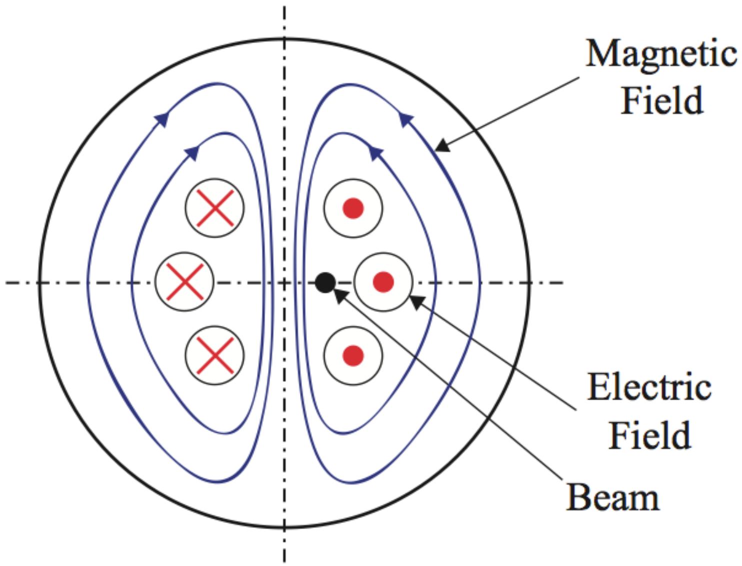
> **beam based diagnostics**
> - ~~multi-bunch~~
> - HOM


pick up
HOM coupler
x
y
z
HOM coupler
power coupler

dipole modes



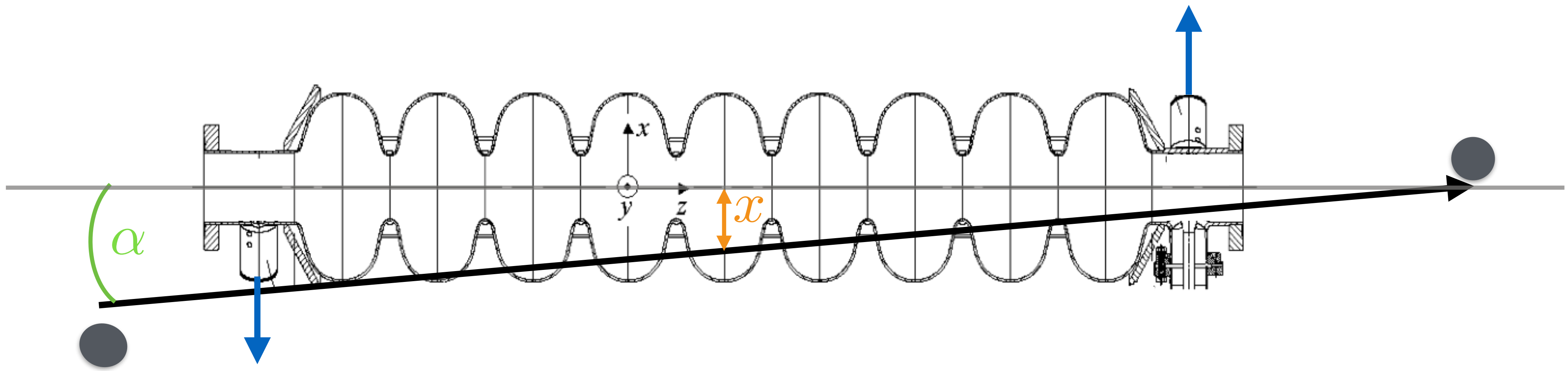


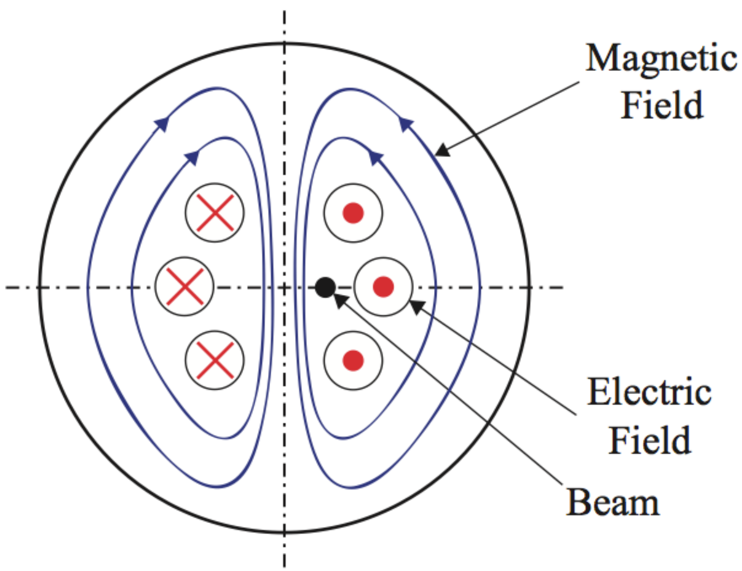
$$V_x(t) \propto x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t)$$

$$V_\alpha(t) \propto \alpha \cdot e^{-\frac{t}{2\tau}} \cos(\omega t)$$

$$V_\Theta(t) \propto \Theta \cdot e^{-\frac{t}{2\tau}} \cos(\omega t)$$

Sean Walston et al. Performance of a High Resolution Cavity Beam Position Monitor System. *Nucl. Instrum. Meth.*, A578:1–22, 2007.





$$V_x(t) \propto x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t)$$

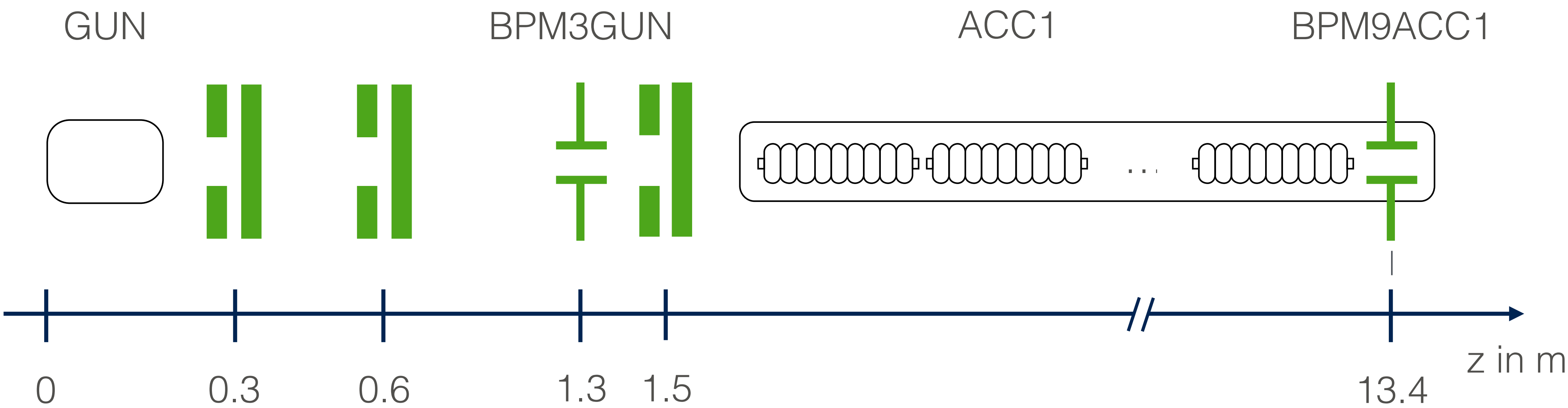
$$V_\alpha(t) \propto \alpha \cdot e^{-\frac{t}{2\tau}} \cos(\omega t)$$

$$V_\Theta(t) \approx 0$$

> **ultra short pulses**

Sean Walston et al. Performance of a High Resolution Cavity Beam Position Monitor System. *Nucl. Instrum. Meth.*, A578:1–22, 2007.

experimental setup: FLASH



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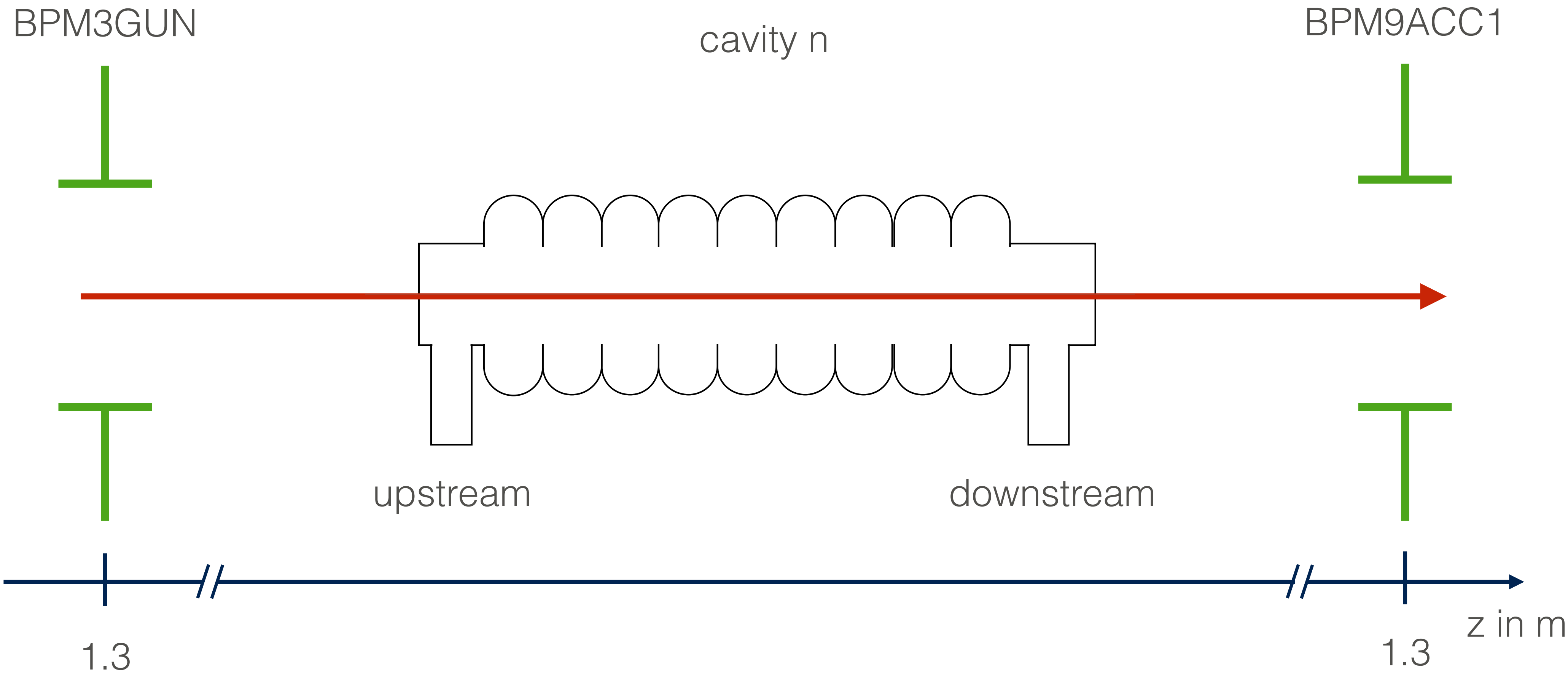

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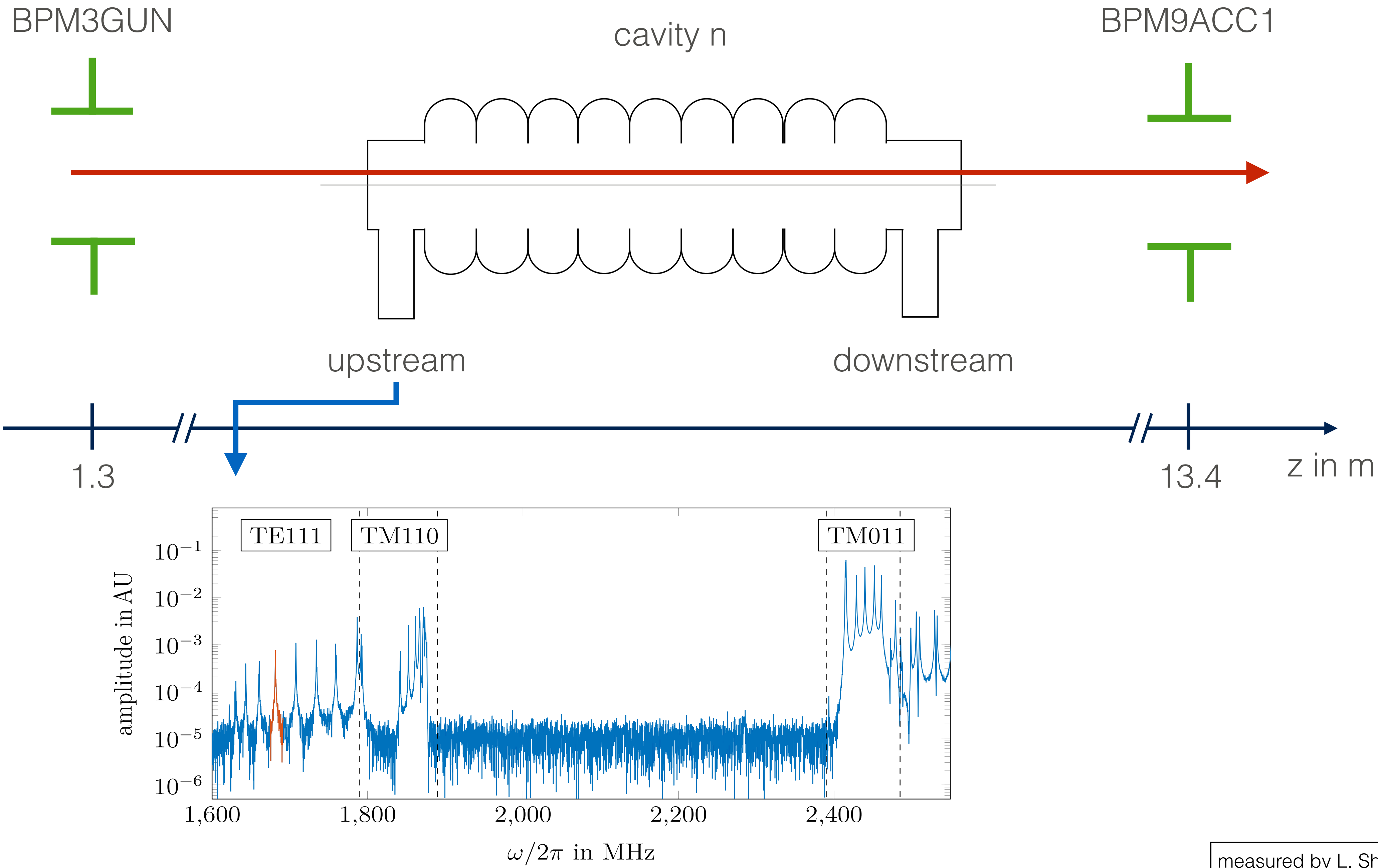
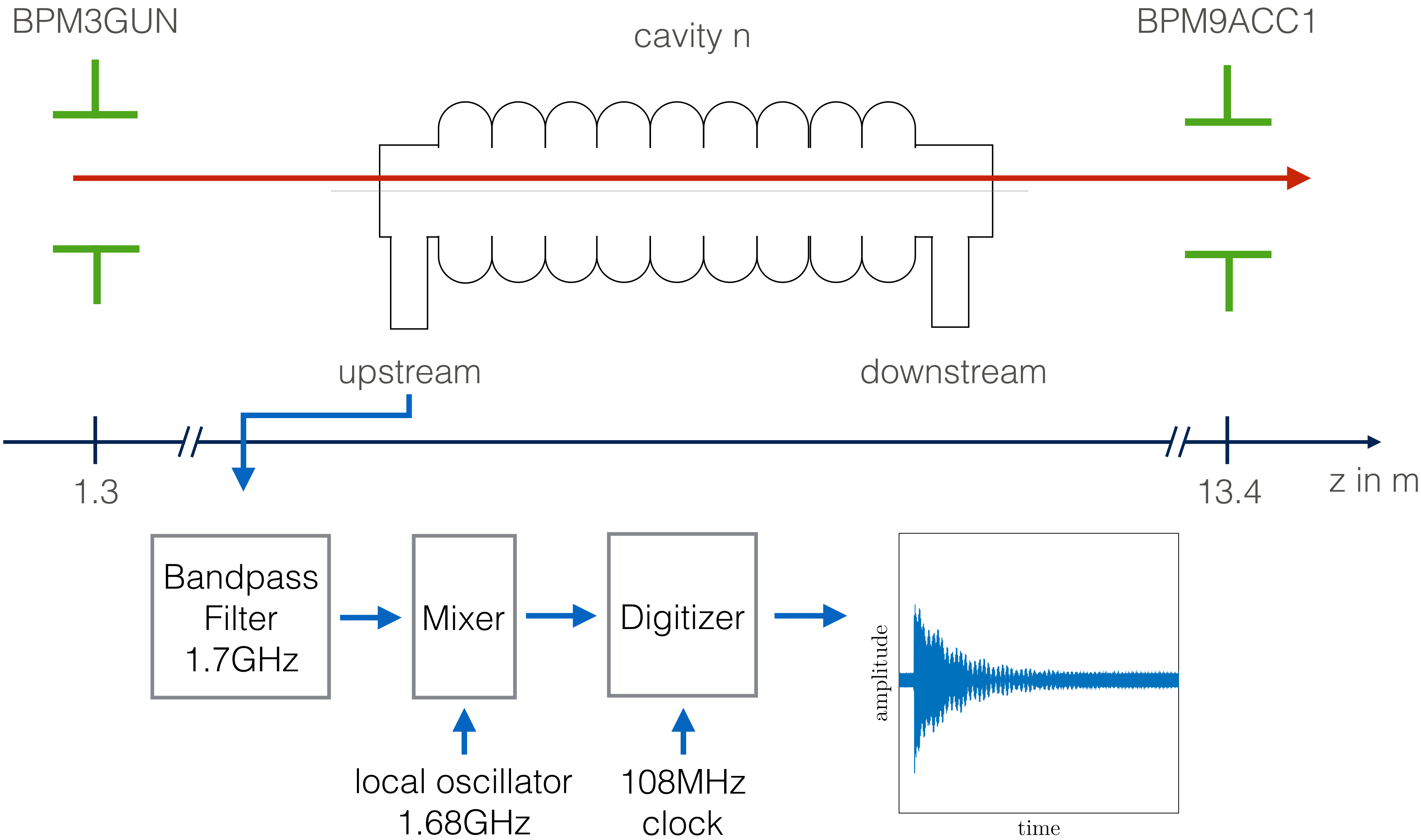
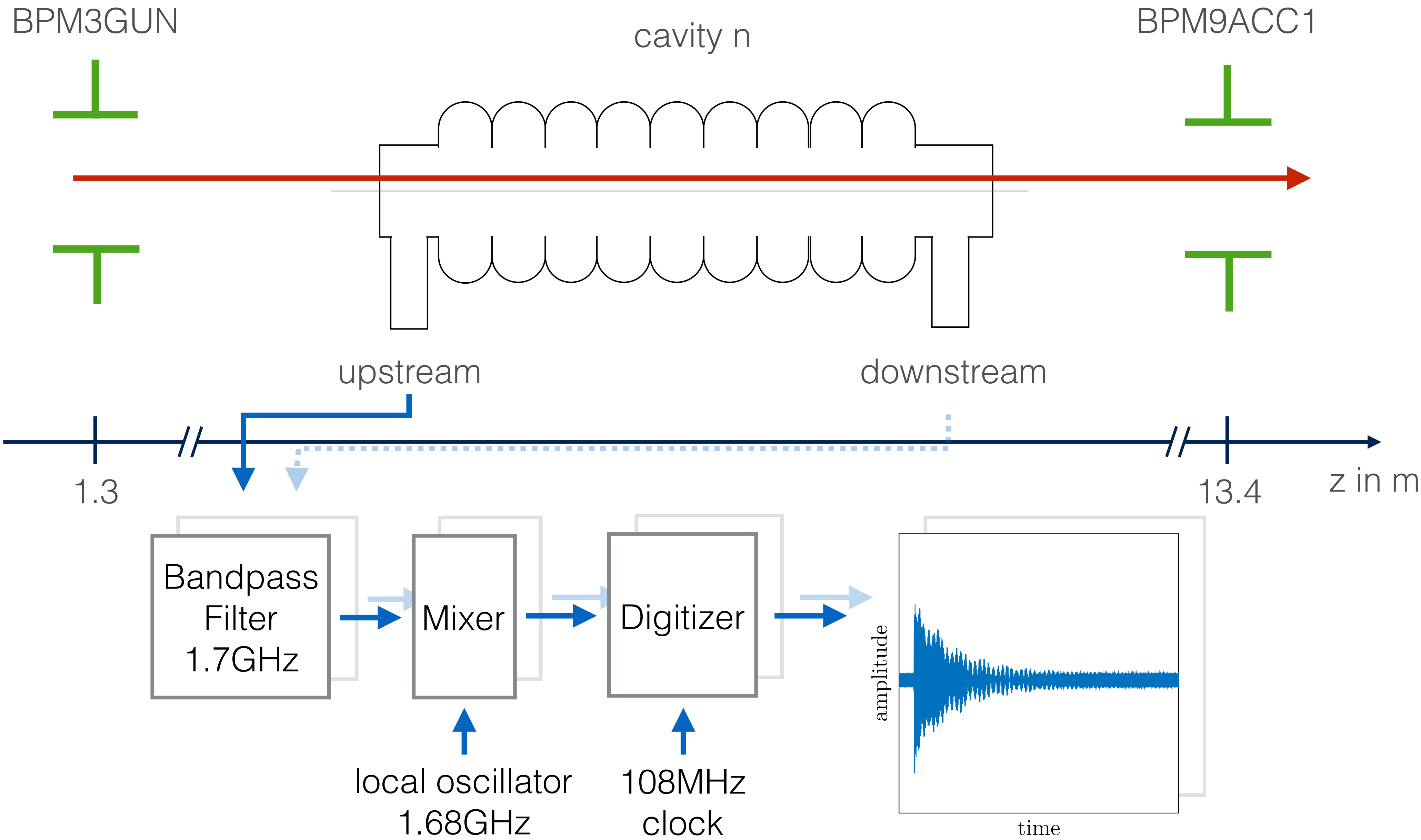


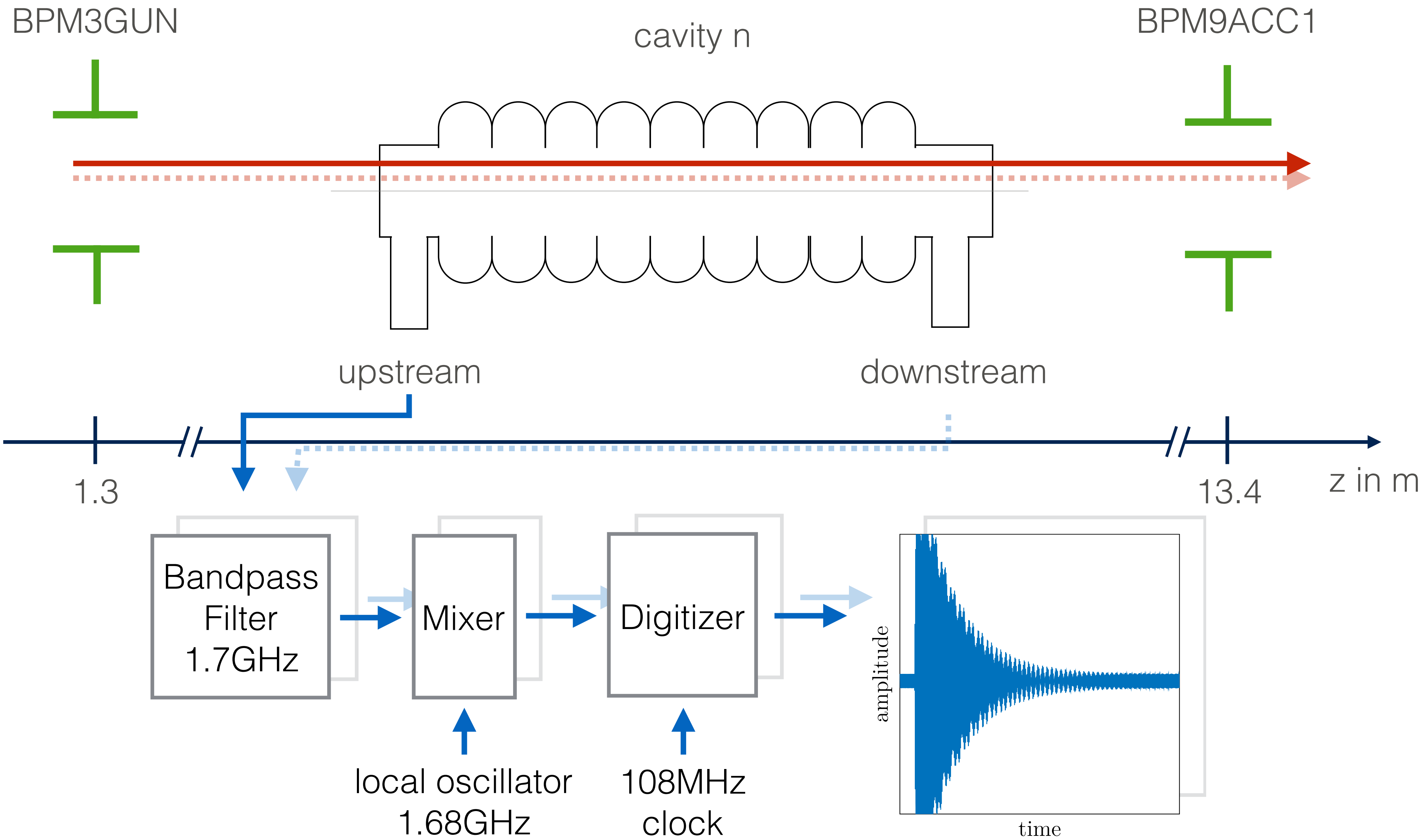
measured by L. Shi

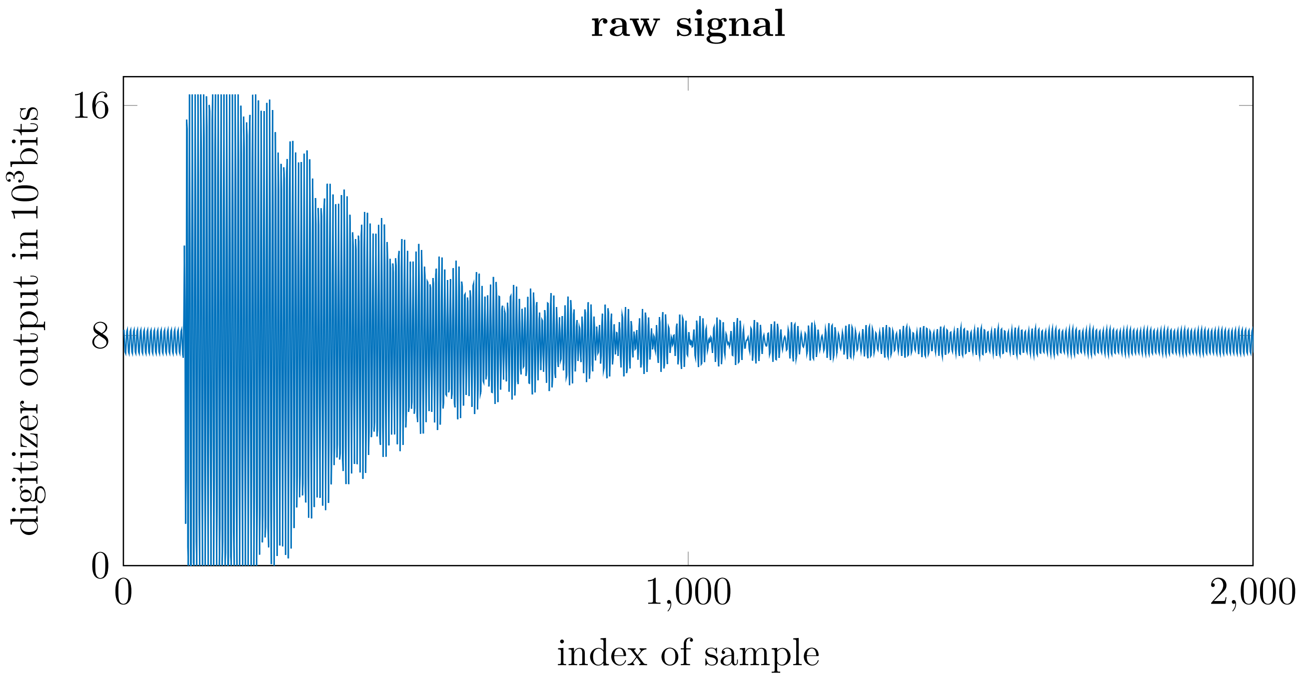
experimental setup: FLASH



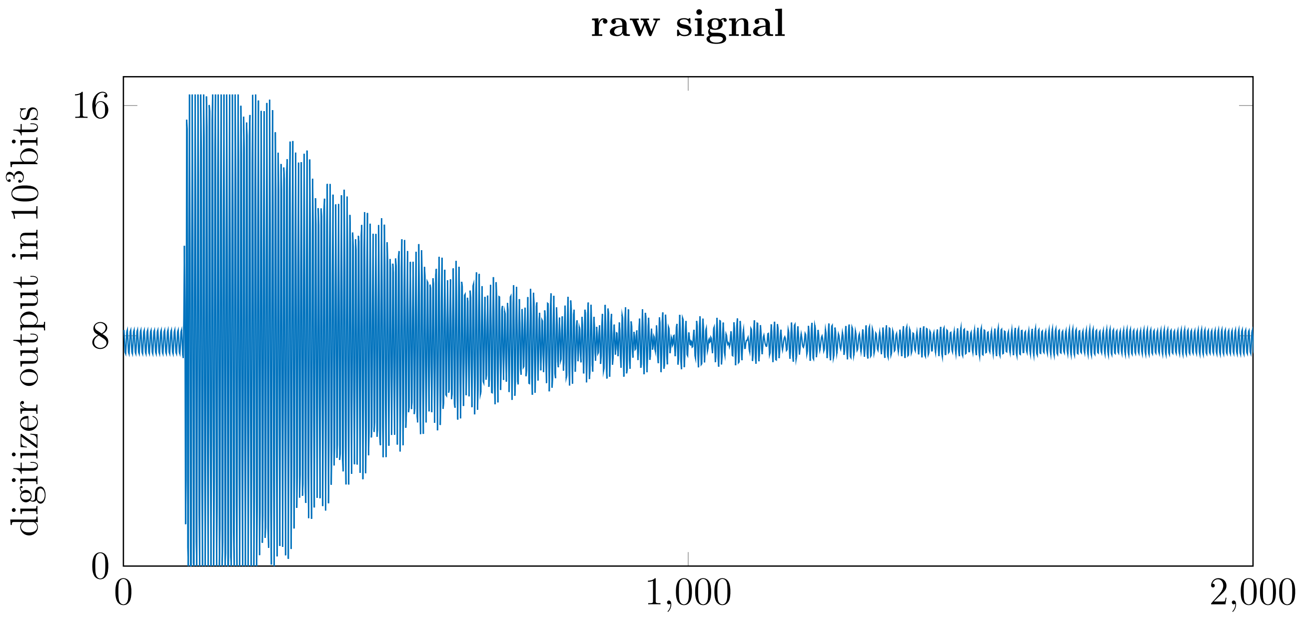

BPM3GUN
cavity n
BPM9ACC1
upstream
downstream
1.3
13.4
z in m
Bandpass Filter 1.7GHz
Mixer
Digitizer
local oscillator 1.68GHz
108MHz clock
amplitude
time

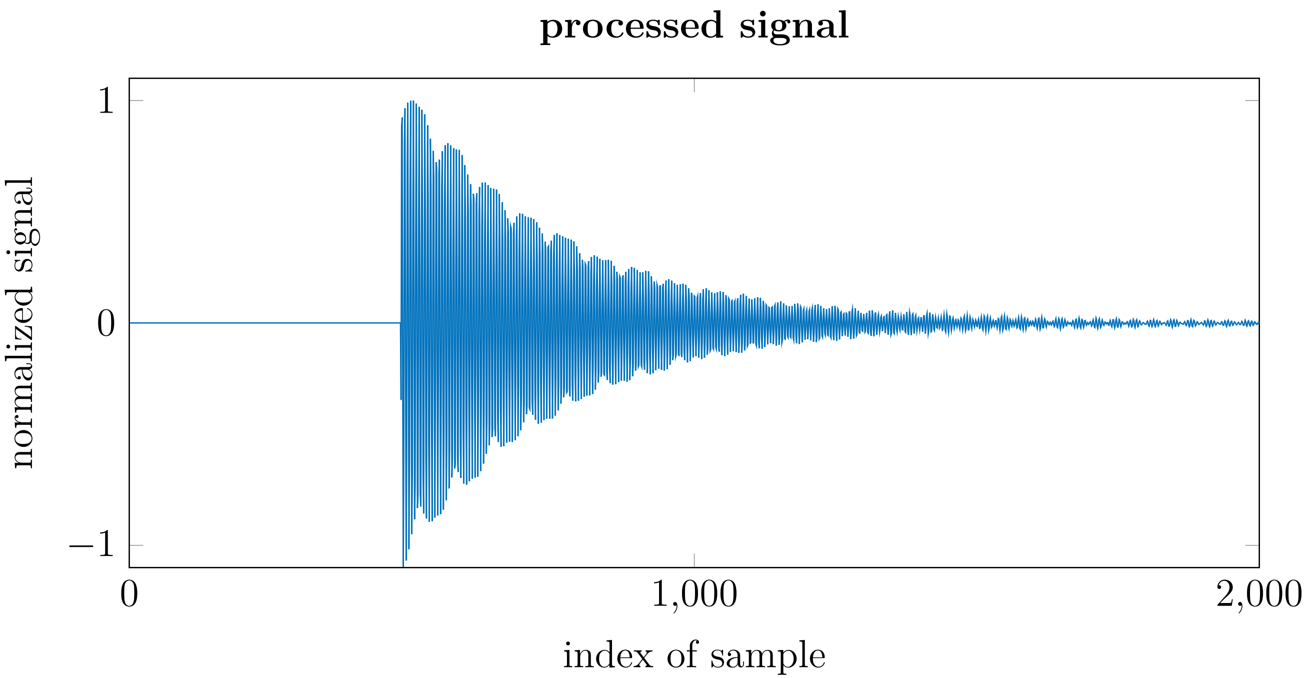
experimental setup: FLASH





- charge threshold
- electronic artifact
- transient signal
- signal saturation

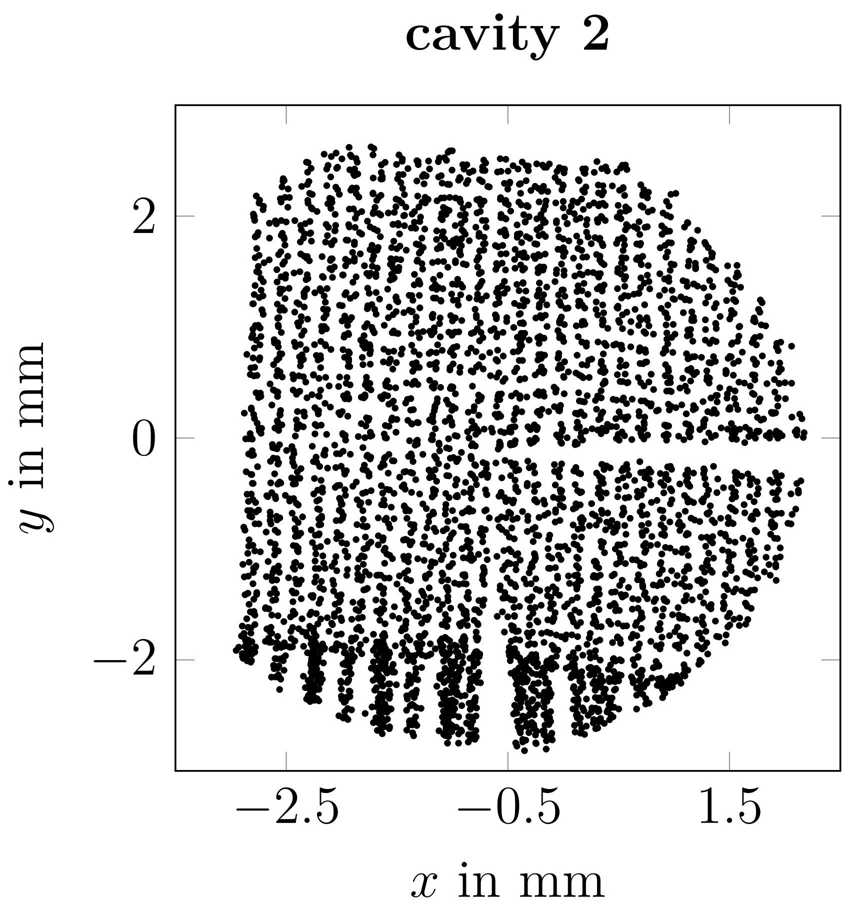


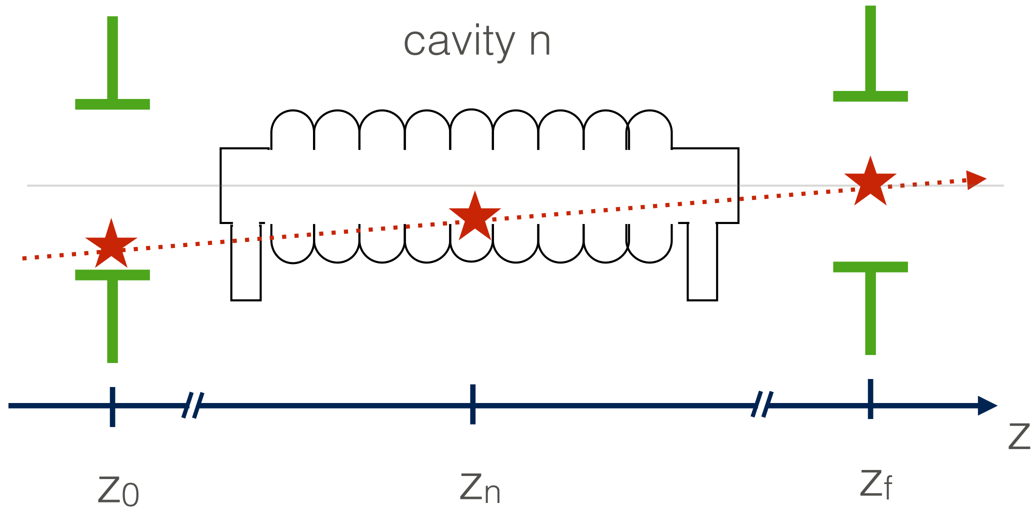


- charge threshold
- electronic artifact
- transient signal
- signal saturation

> **final signal**

data evaluation

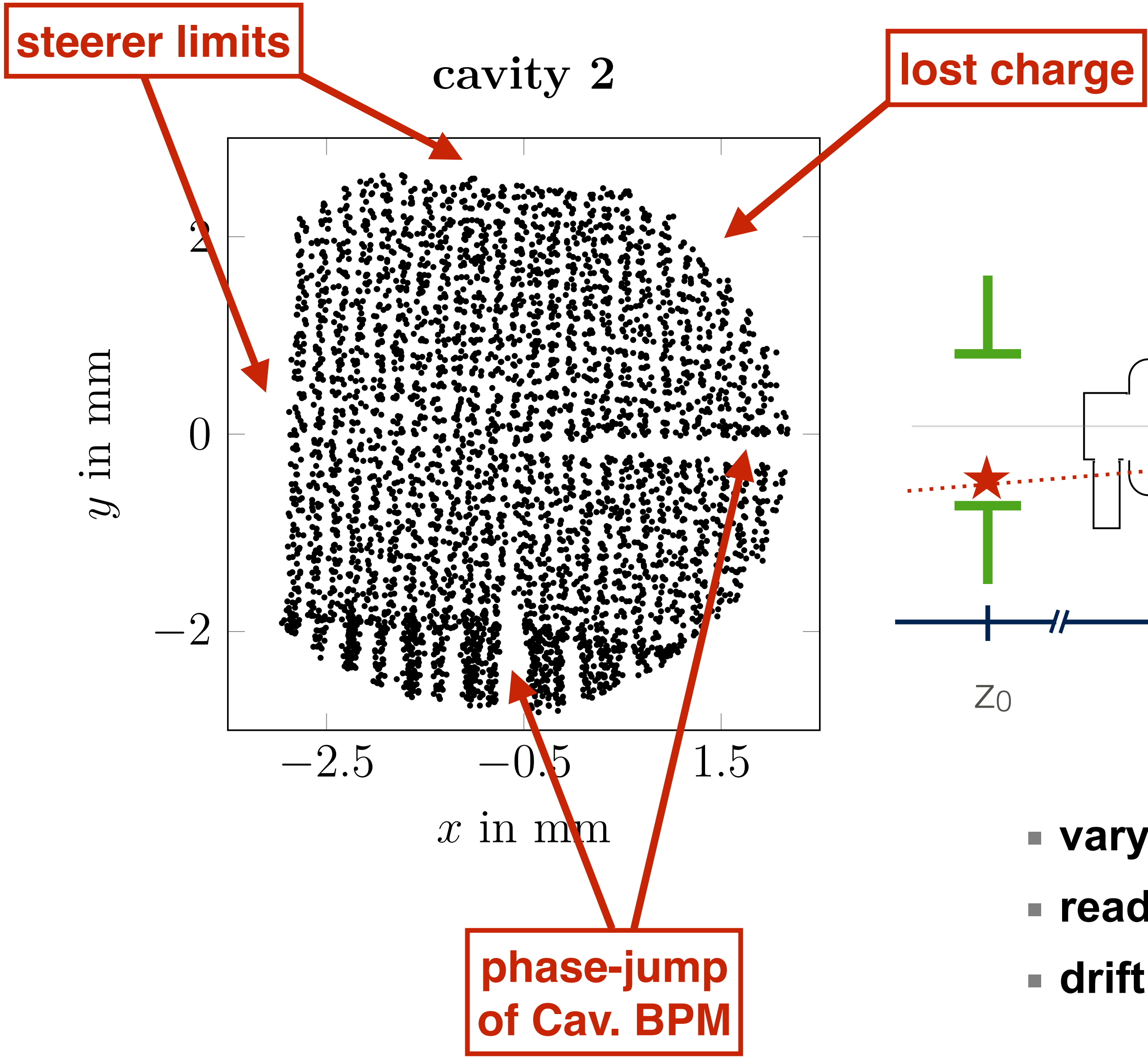


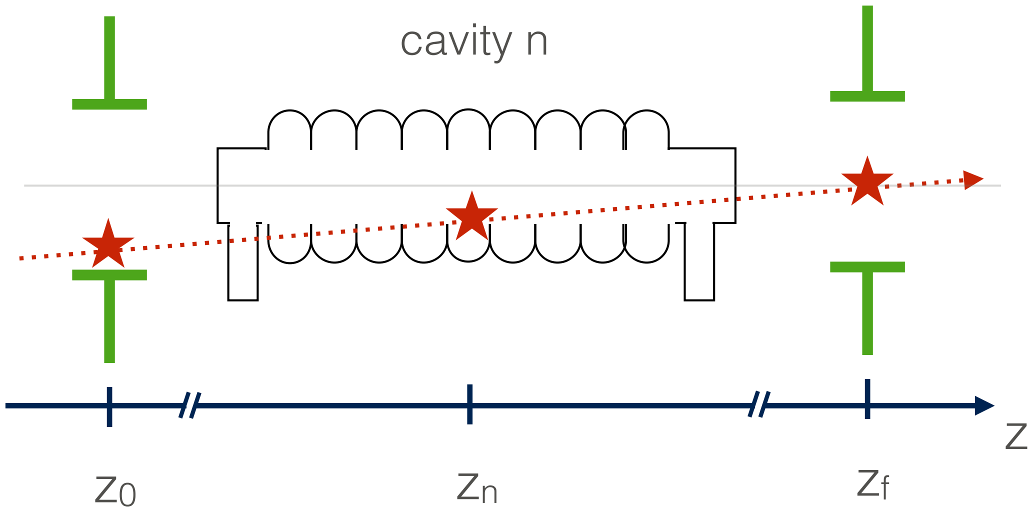


- vary beam trajectory
- read BPM values
- drift space

> **beam position at cavity**

interpolate beam trajectory





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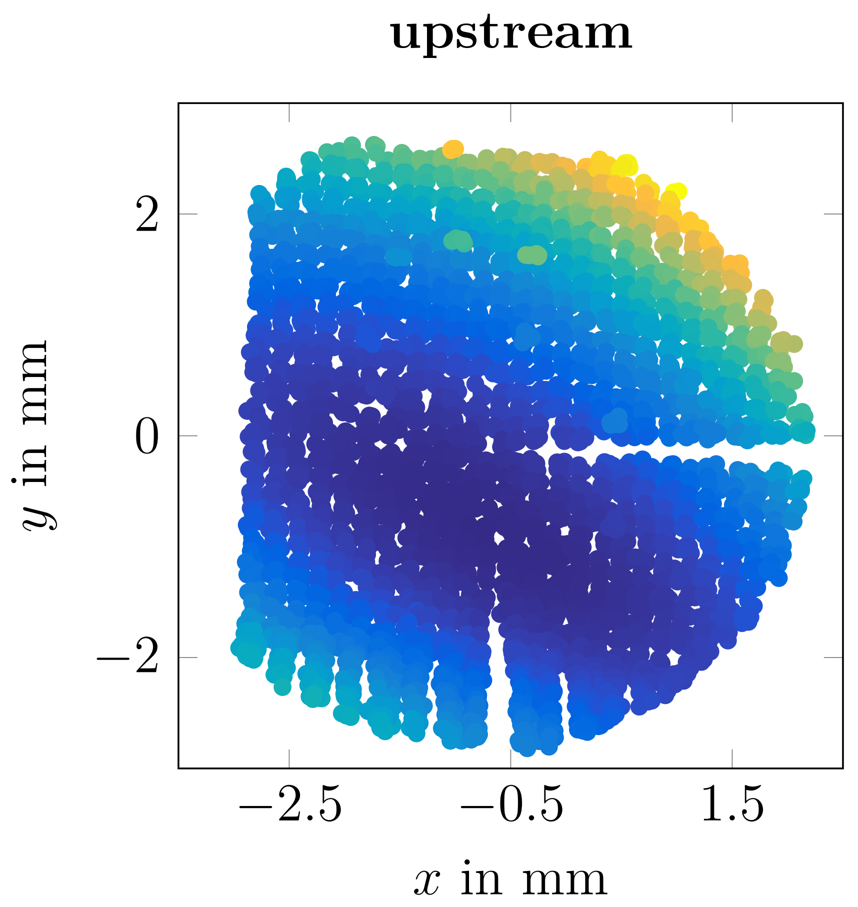
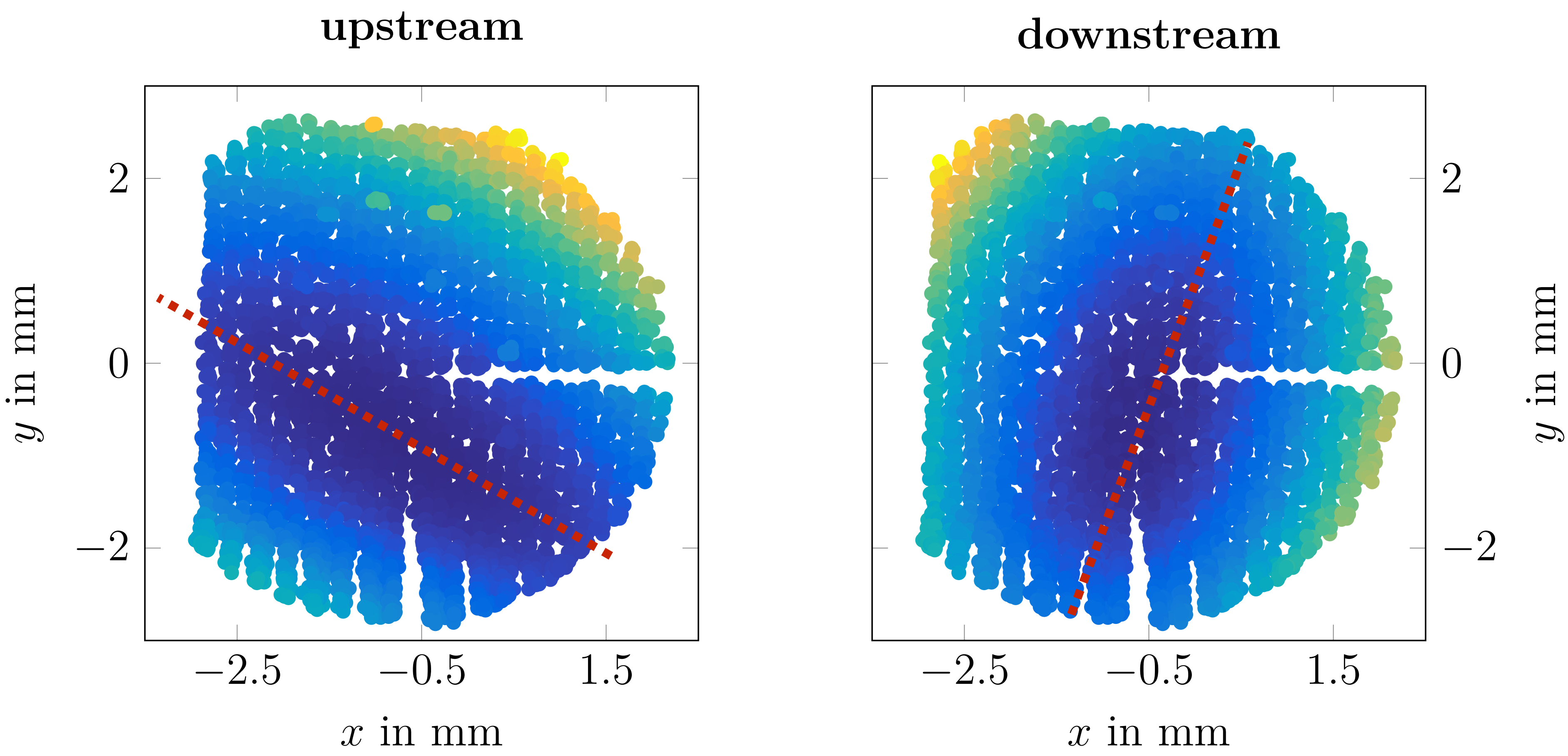


$$P_{out,x} = \frac{\omega^2}{4Q_{\text{ext}}}\left[\frac{R}{Q}\right]_0 \frac{x^2}{x_0^2} q^2 \exp\left(-\frac{\omega^2\sigma_z^2}{c^2}\right)$$



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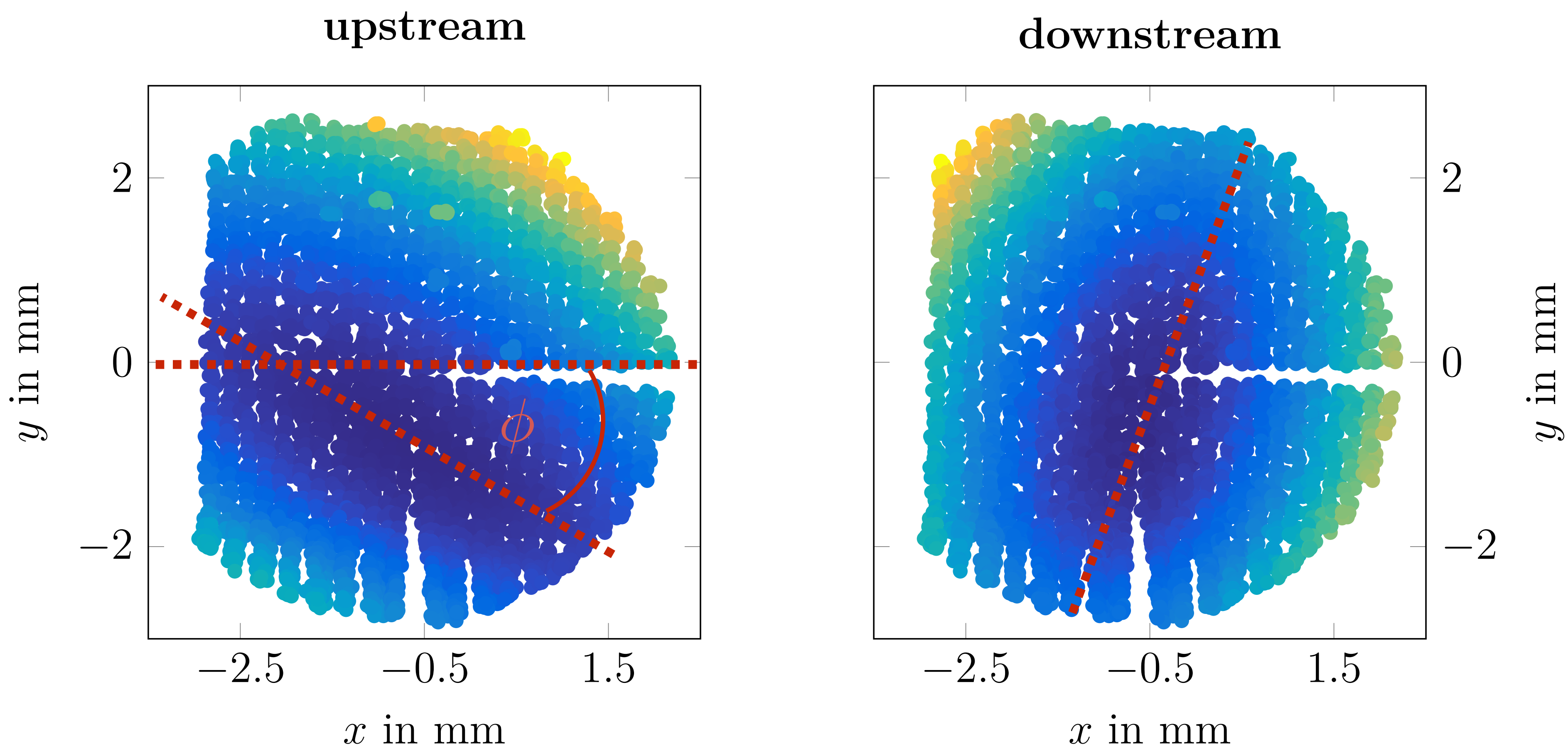
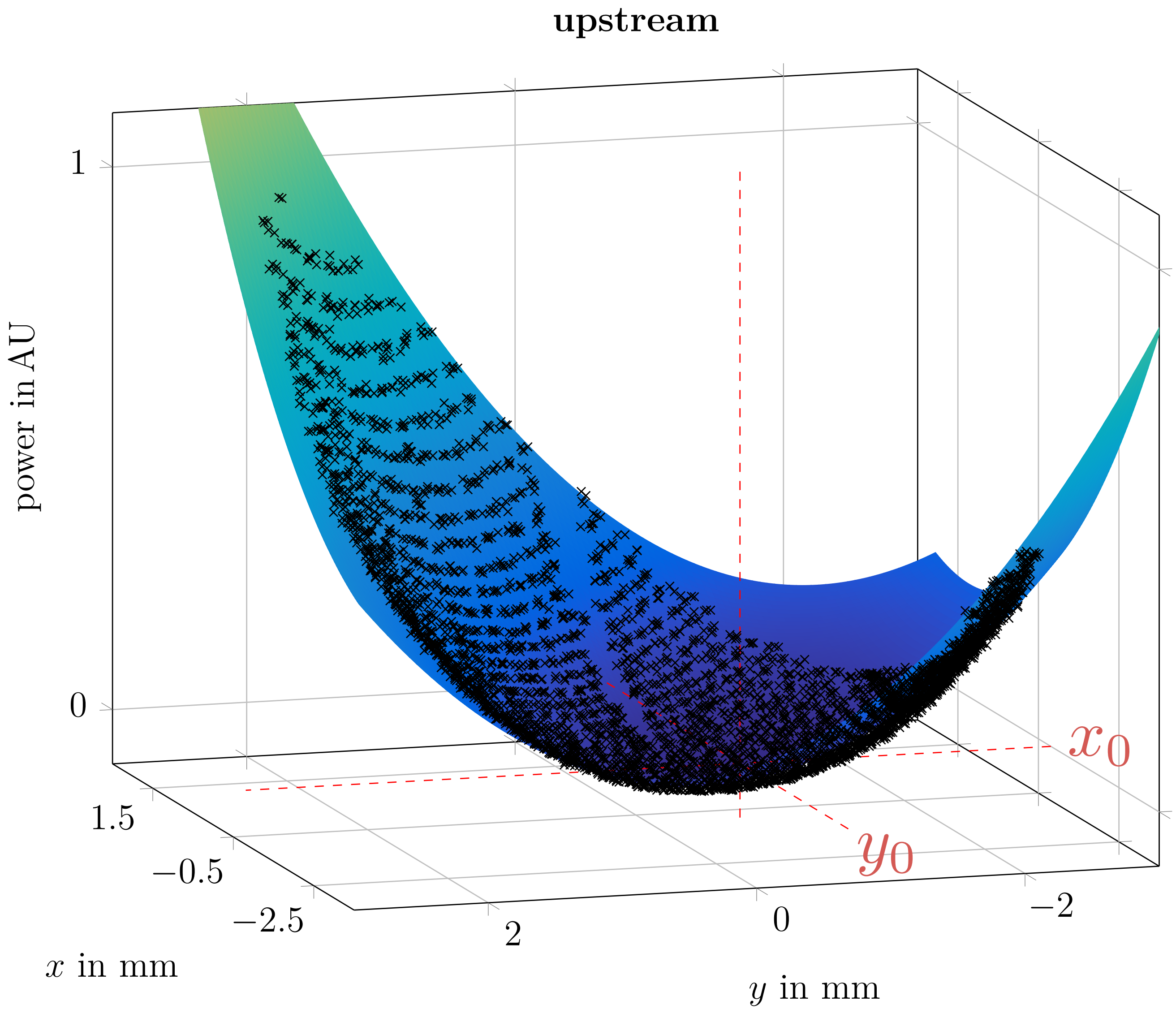


$$\tilde{x} = x\cos\phi + y\sin\phi$$
$$\tilde{y} = y\cos\phi - x\sin\phi$$

$$f\left(\tilde{x},\tilde{y}\right) = A_x\left(\tilde{x}-\tilde{x}_0\right)^2 + A_y\left(\tilde{y}-\tilde{y}_0\right)^2 + c$$

$$\underset{\tilde{x}_0,\tilde{x}_0,\phi}{\arg\min}\left(\sum_i f\left(\tilde{x}_i,\tilde{y}_i\right) - P_i\right)$$

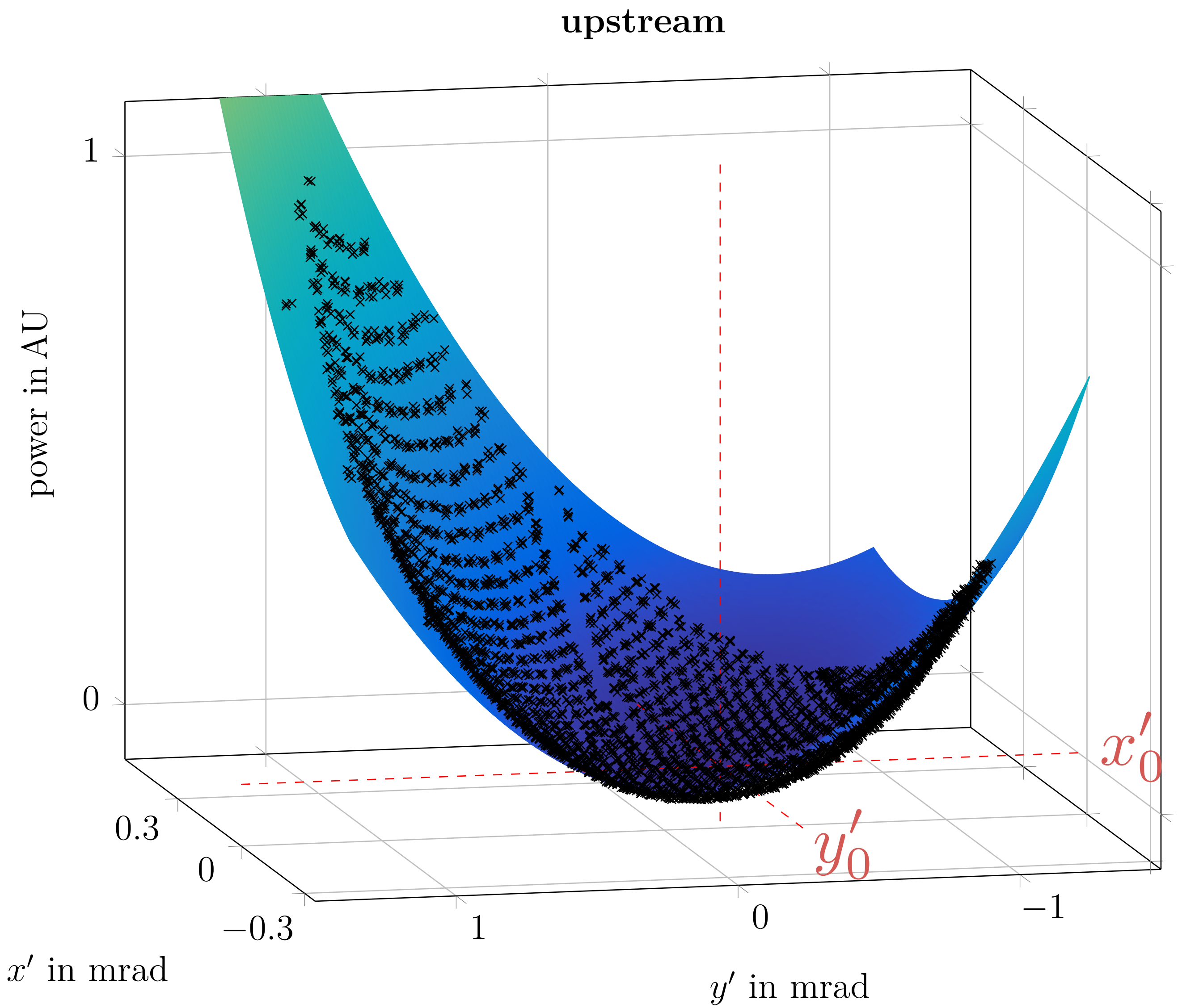
$$P_{out,x} = \frac{\omega^2}{4Q_{\text{ext}}}\left[\frac{R}{Q}\right]_0 \frac{x^2}{{x_0}^2} q^2 \exp\left(-\frac{\omega^2\sigma_z^2}{c^2}\right)$$



- assume <P(x',y')> = const.
- sort P by (x,y)
- fit 2D parabola

> **cavity x-y-center**

$$P_{out,x'} = \frac{\omega^2}{4Q_{\text{ext}}}\left[\frac{R}{Q}\right]_0 \frac{x'^2}{x_0'^2} q^2 \exp\left(-\frac{\omega^2\sigma_z^2}{c^2}\right)$$



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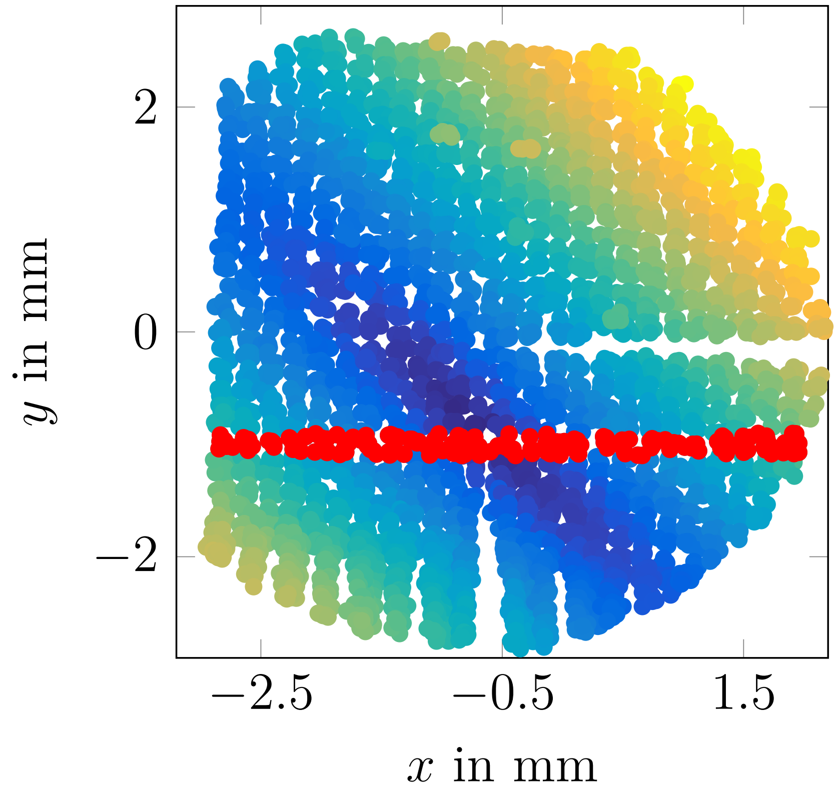

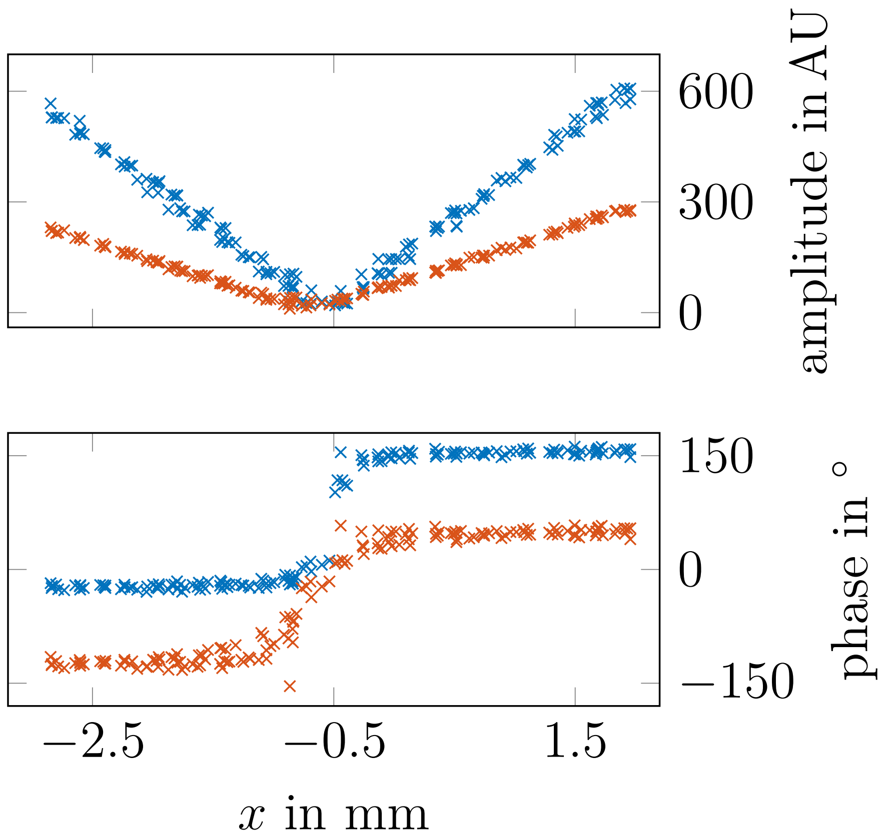

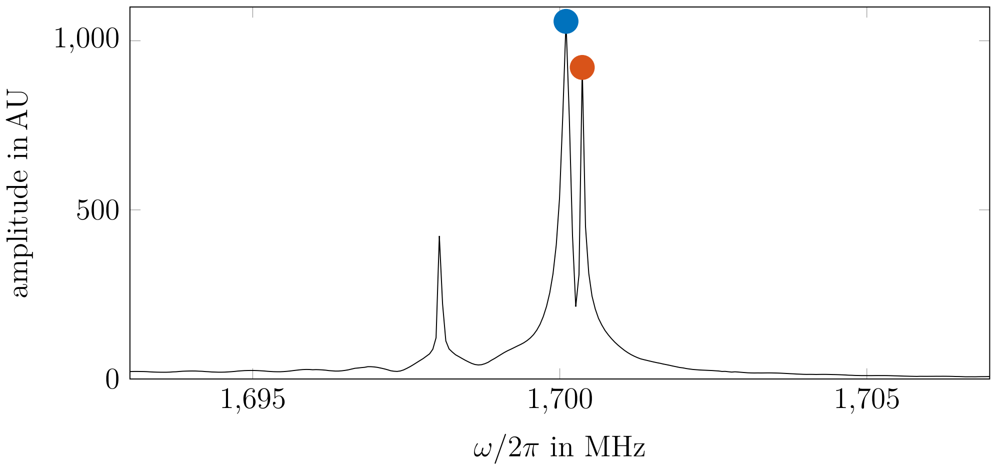

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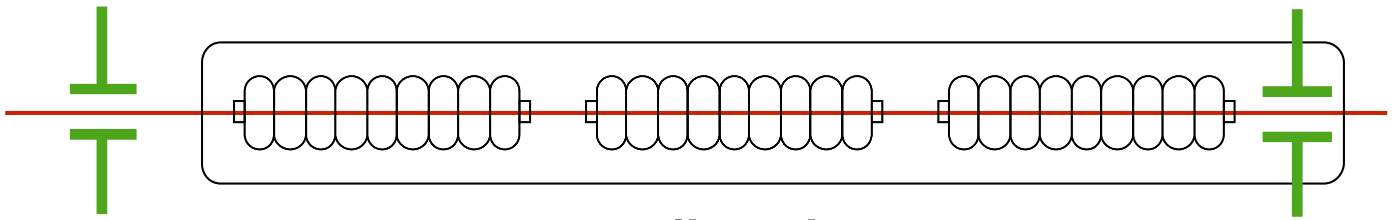
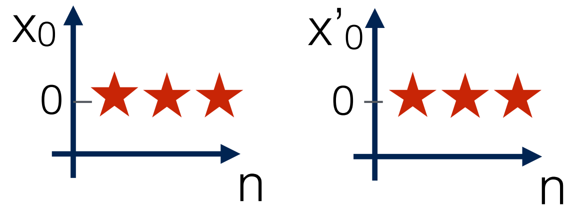
data evaluation

expected results



aligned



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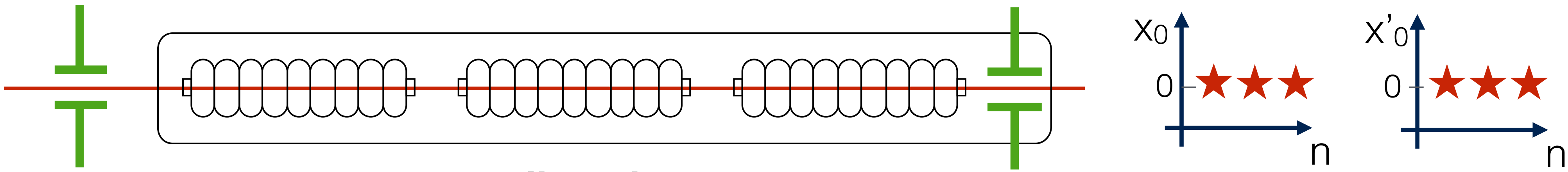
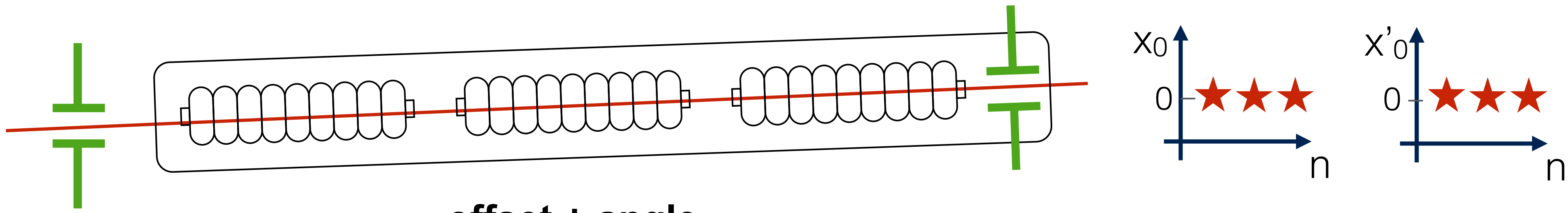


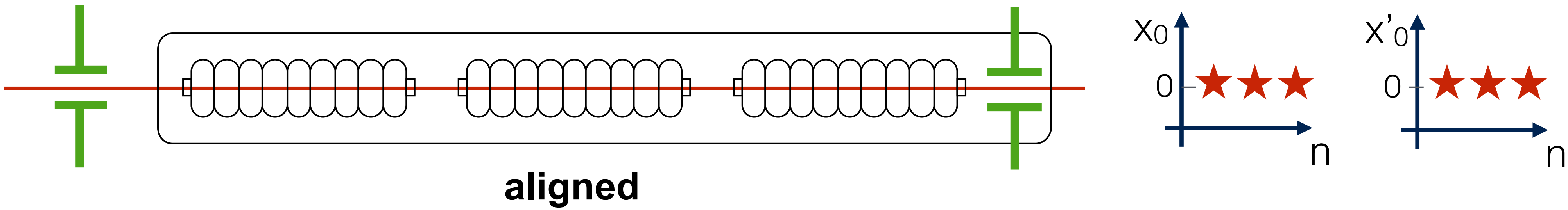
aligned

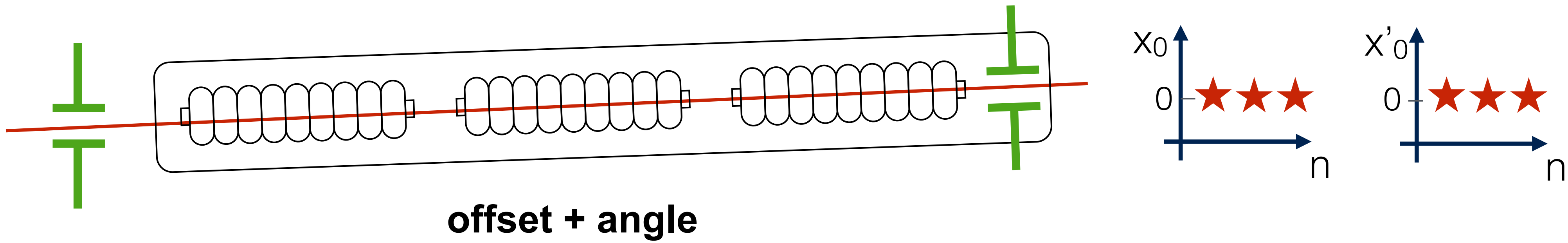


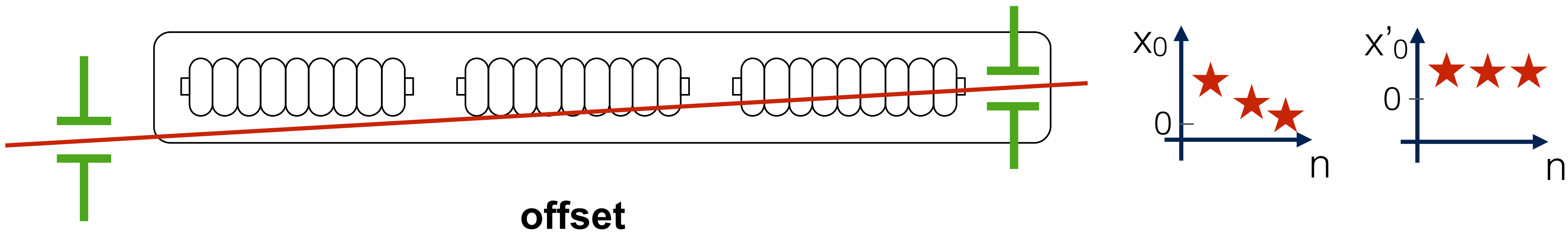
offset + angle

data evaluation

expected results

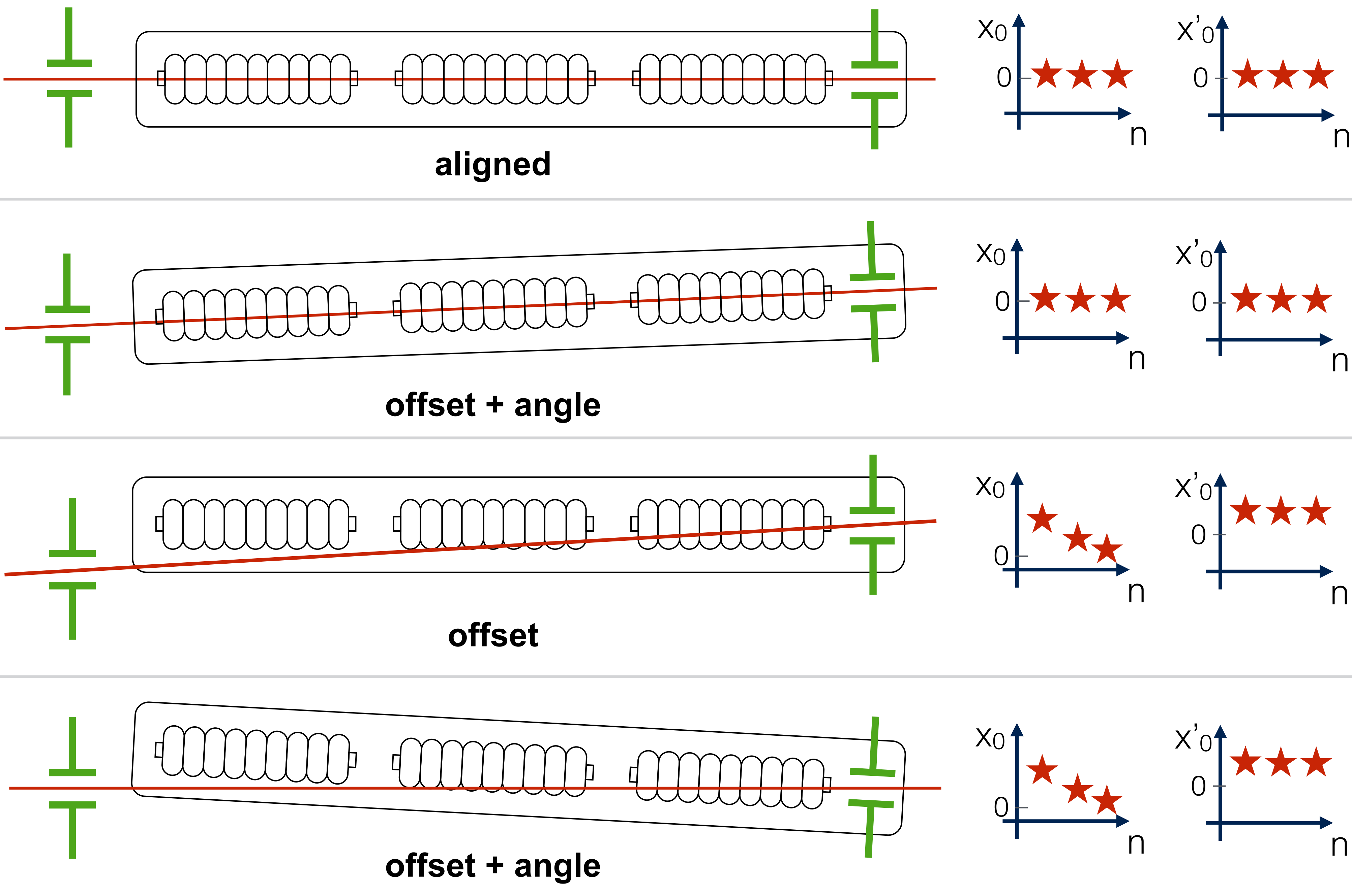


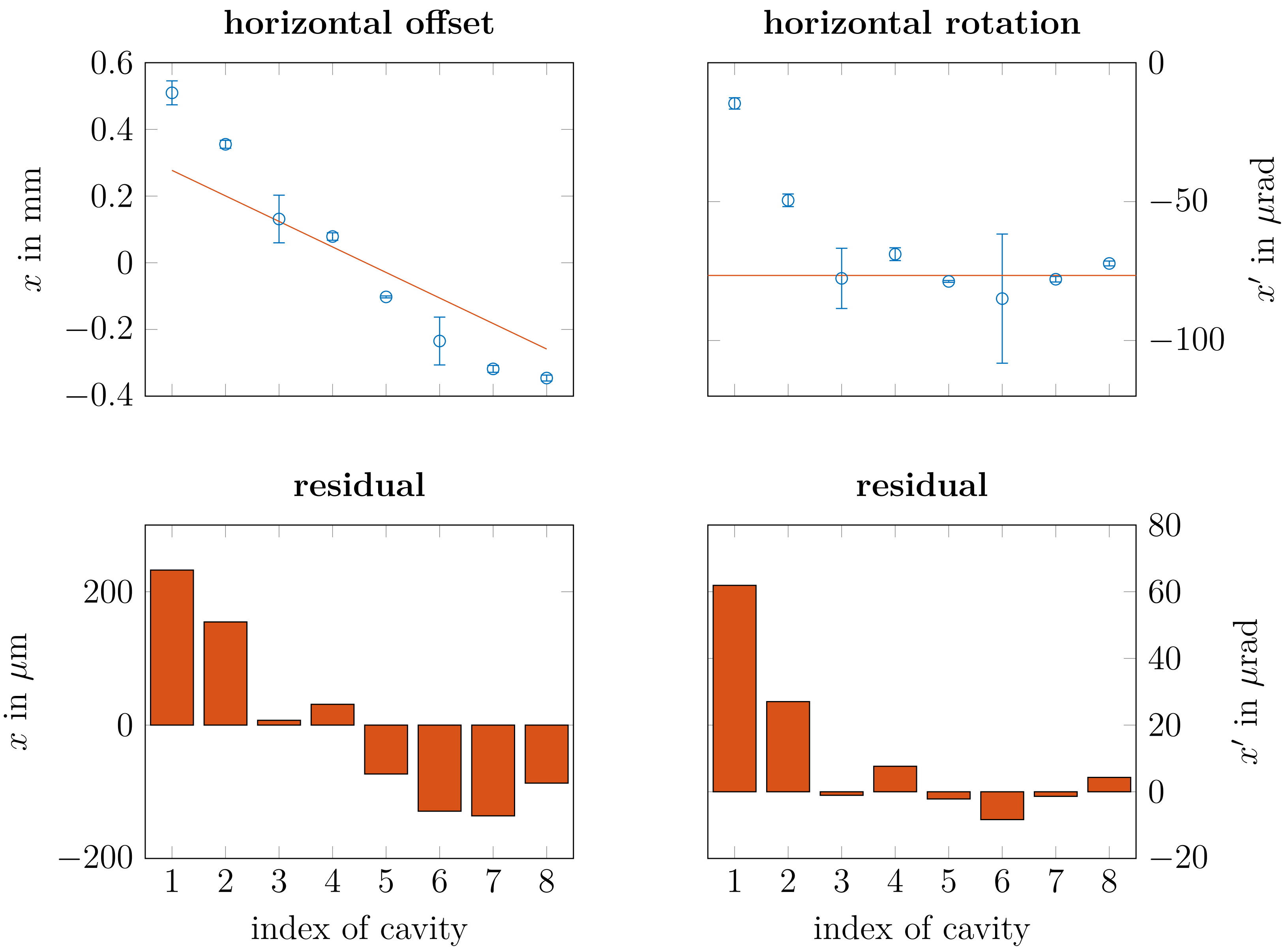


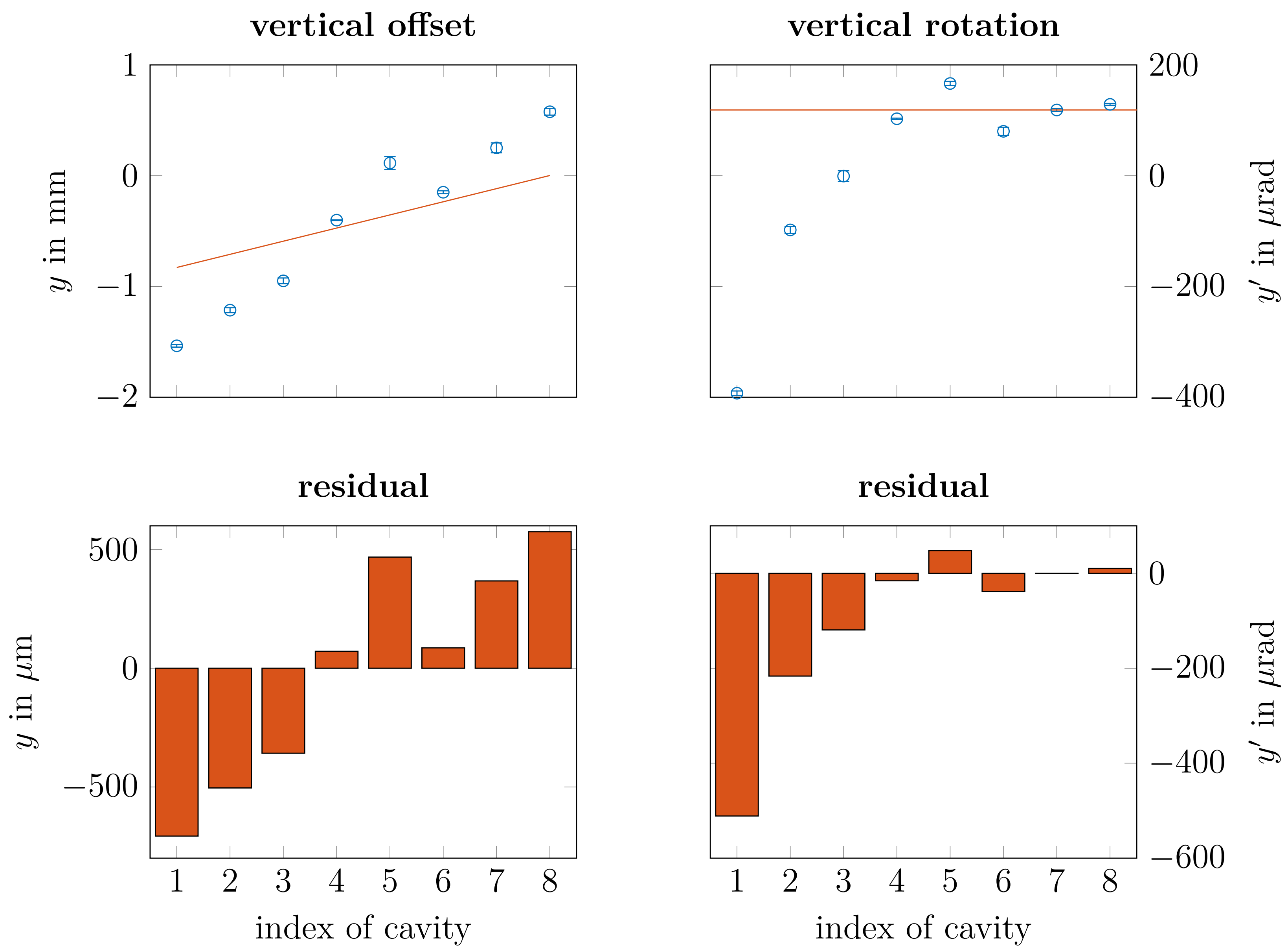


data evaluation

expected results

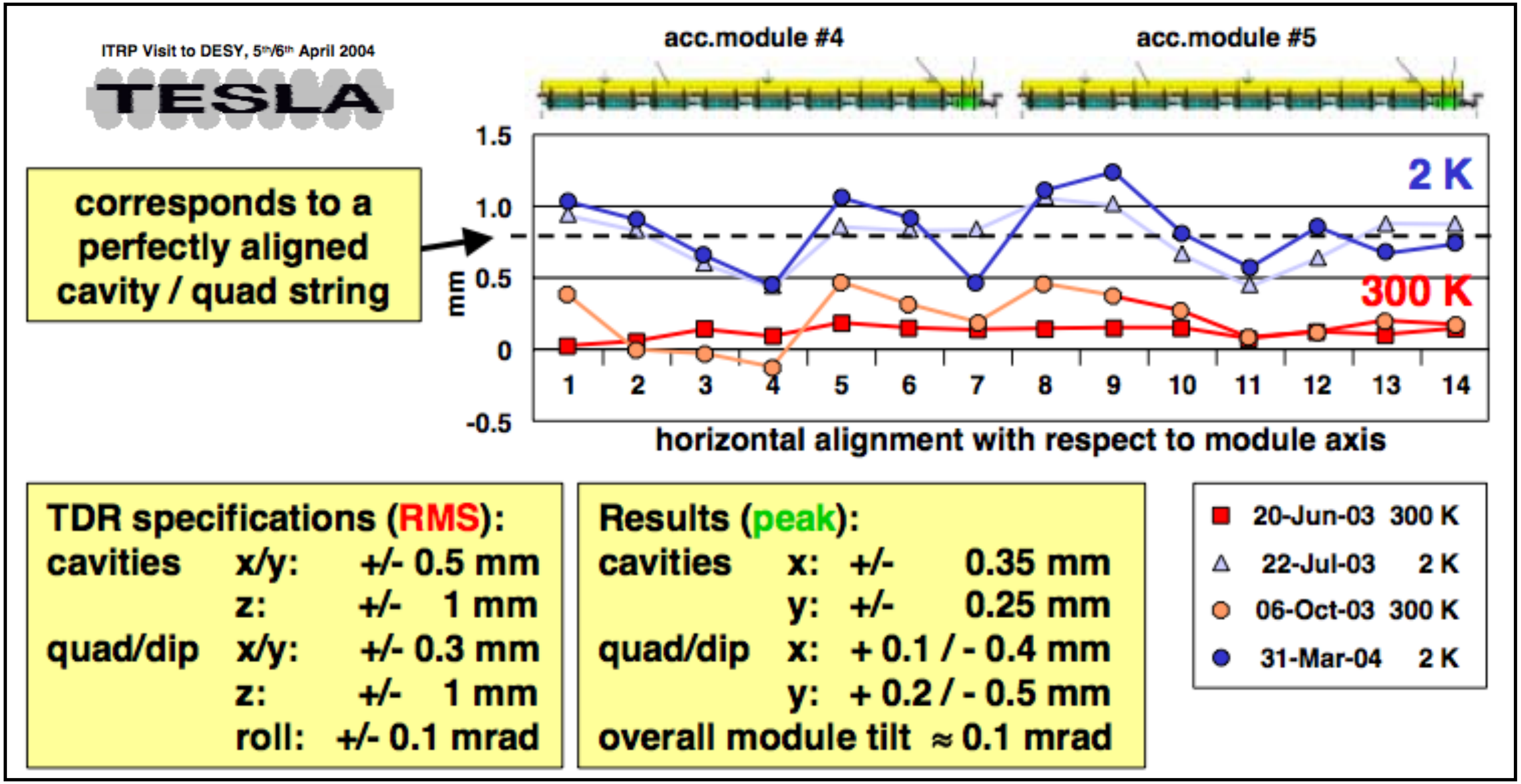



horizontal offset
0.6
0.4
0.2
0
−0.2
−0.4
x in mm
horizontal rotation
0
−50
−100
x' in μrad
residual
200
0
−200
x in μm
residual
80
60
40
20
0
−20
x' in μrad
1 2 3 4 5 6 7 8
index of cavity
1 2 3 4 5 6 7 8
index of cavity


vertical offset
vertical rotation
residual
residual
y in mm
y' in μrad
y in μm
y' in μrad
1
0
−1
−2
200
0
−200
−400
500
0
−500
0
−200
−400
−600
1 2 3 4 5 6 7 8
index of cavity
1 2 3 4 5 6 7 8
index of cavity

data evaluation

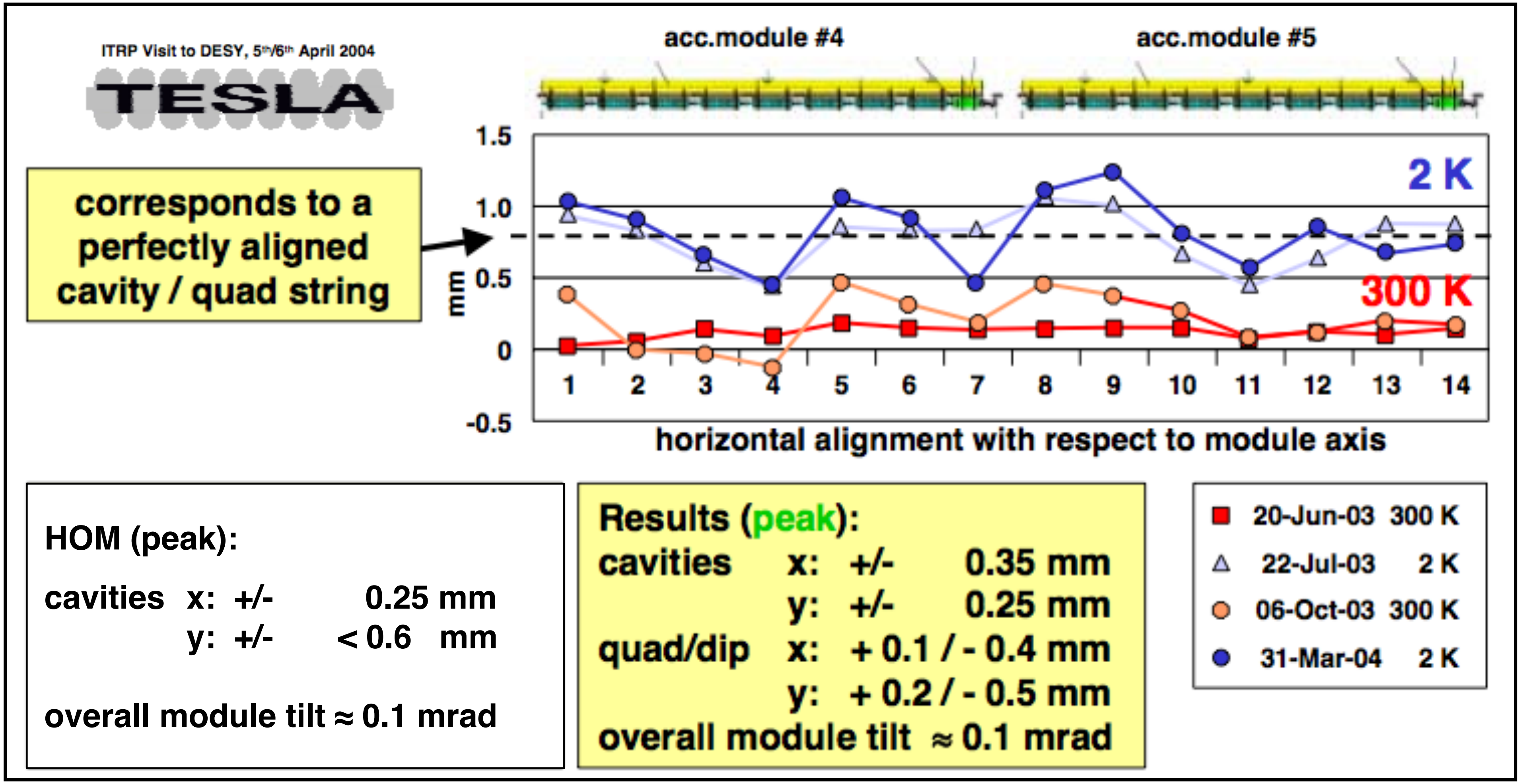
stretched wire system



https://labcit.ligo.caltech.edu/~BCBAct/PDF%20files/ITRP_Weise_TTF.pdf

- measurement till 2004
- results within TDR limits

> not reproducible!



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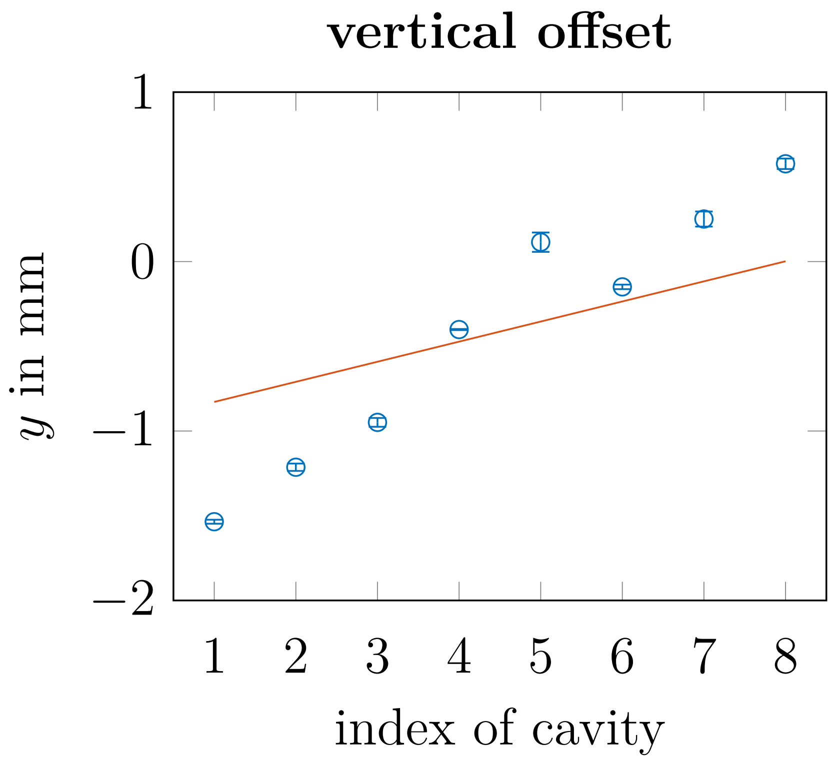
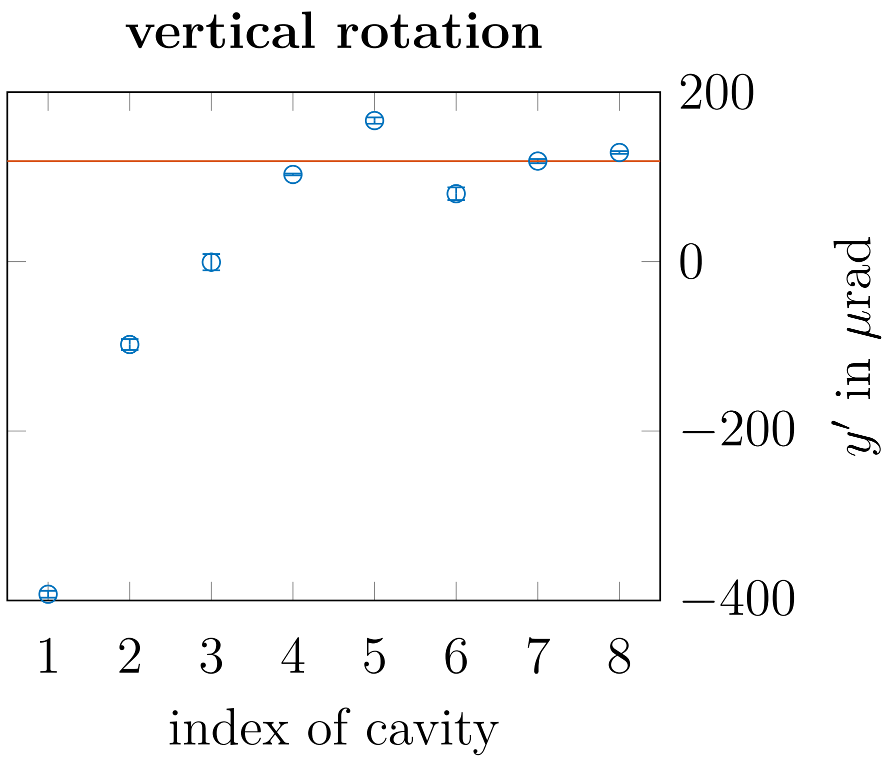




HOM (peak):

cavities x: +/- 0.25 mm
y: +/- < 0.6 mm

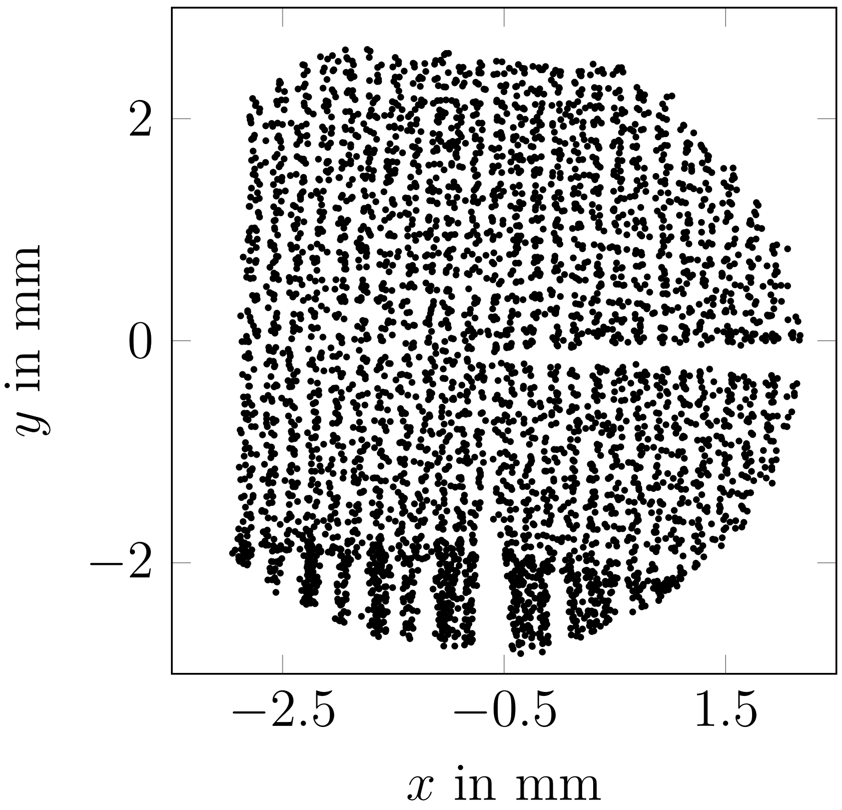
overall module tilt ≈ 0.1 mrad

wire (peak):

cavities x: +/- 0.35 mm
y: +/- 0.25 mm

overall module tilt ≈ 0.1 mrad

cavity 2



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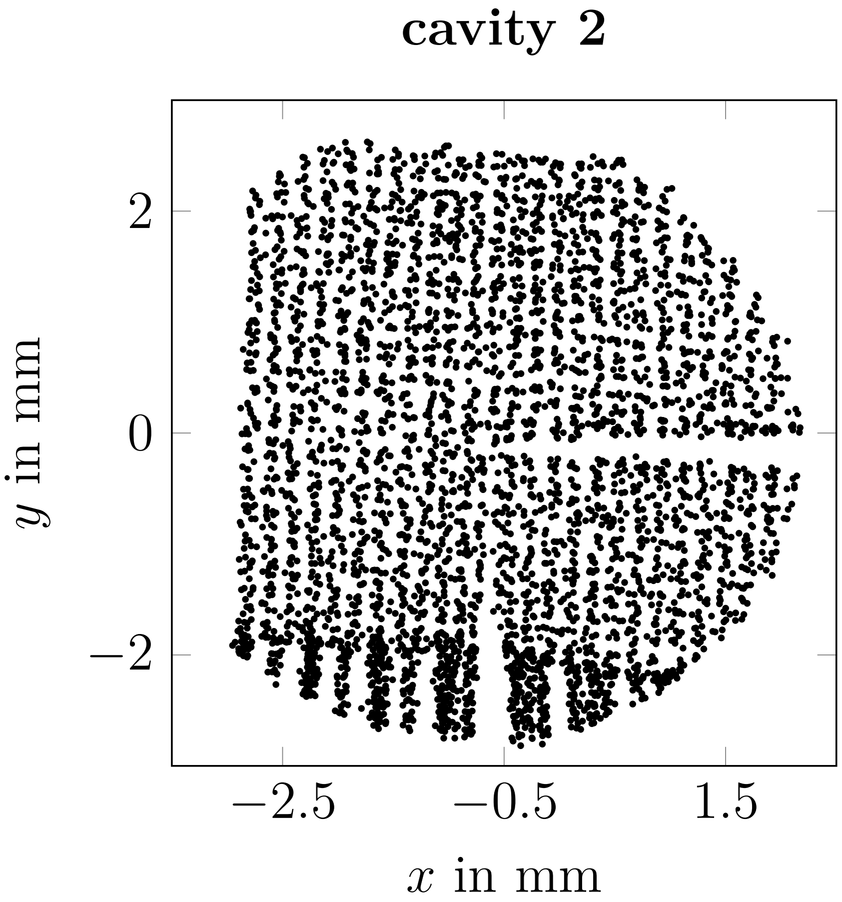
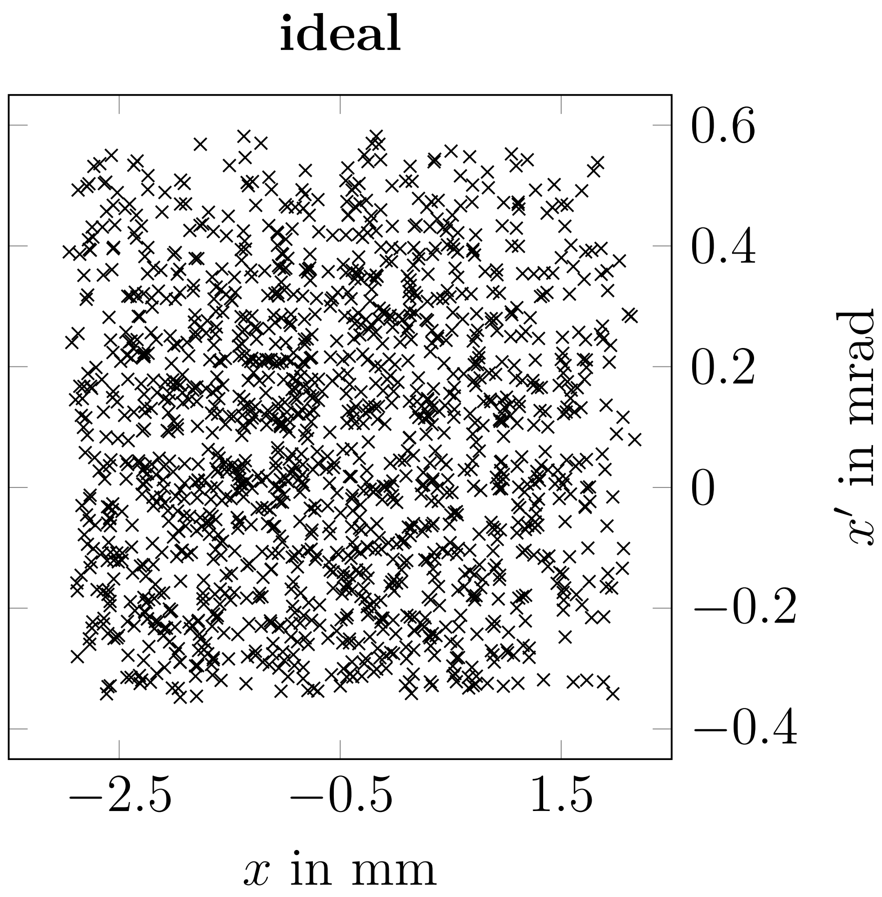
- sort P by (x,y)
- fit 2D parabola

> cavity x-y-center

$$V_x(t) = A_x\,\Delta x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) + A_{x'}\,\Delta x' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) + c$$

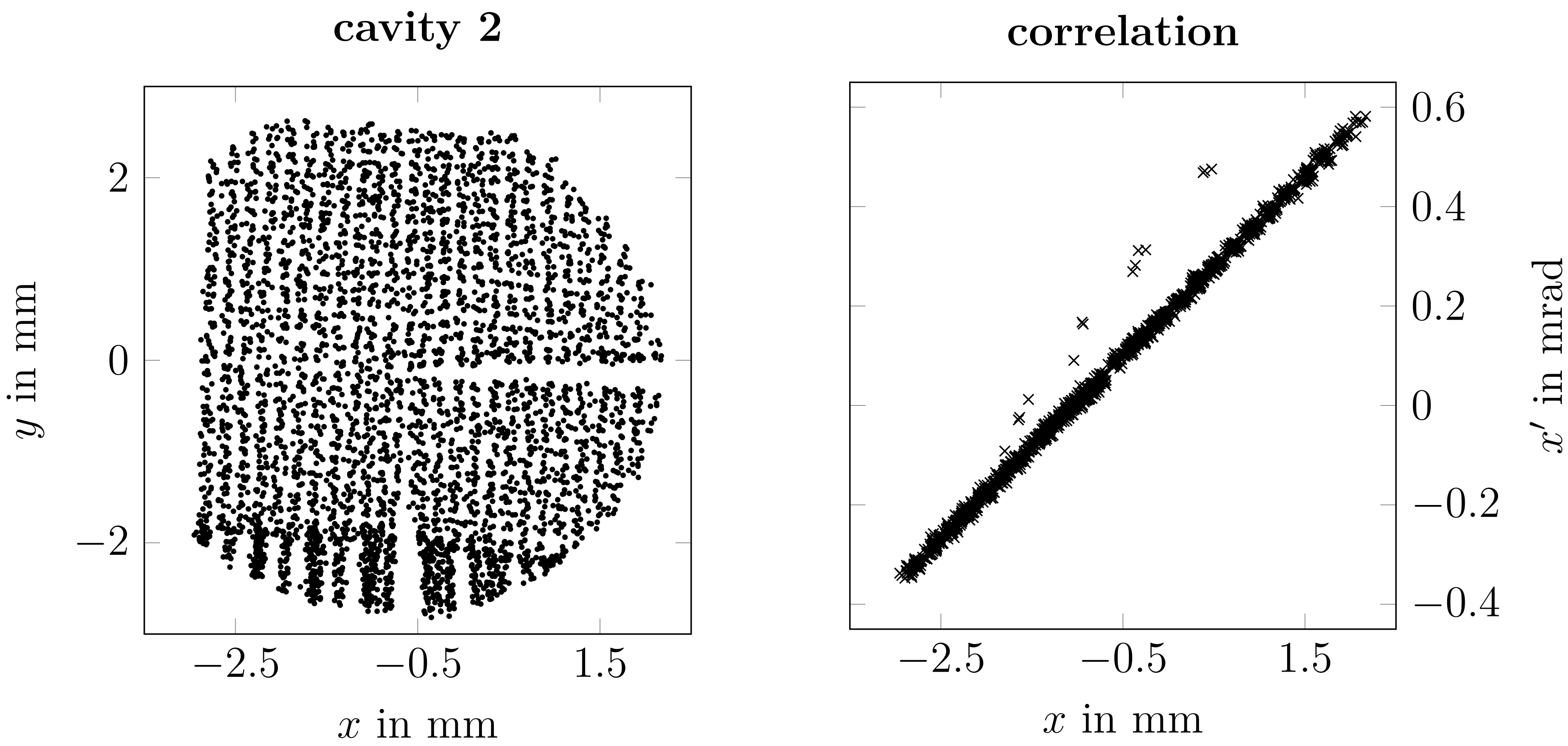
$$V_y(t) = A_y\,\Delta y \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) + A_{y'}\,\Delta y' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) + c$$





$$V_x(t) = A_x \,\Delta x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) + A_{x'} \,\Delta x' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) + c$$

$$V_y(t) = A_y \,\Delta y \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) + A_{y'} \,\Delta y' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) + c$$



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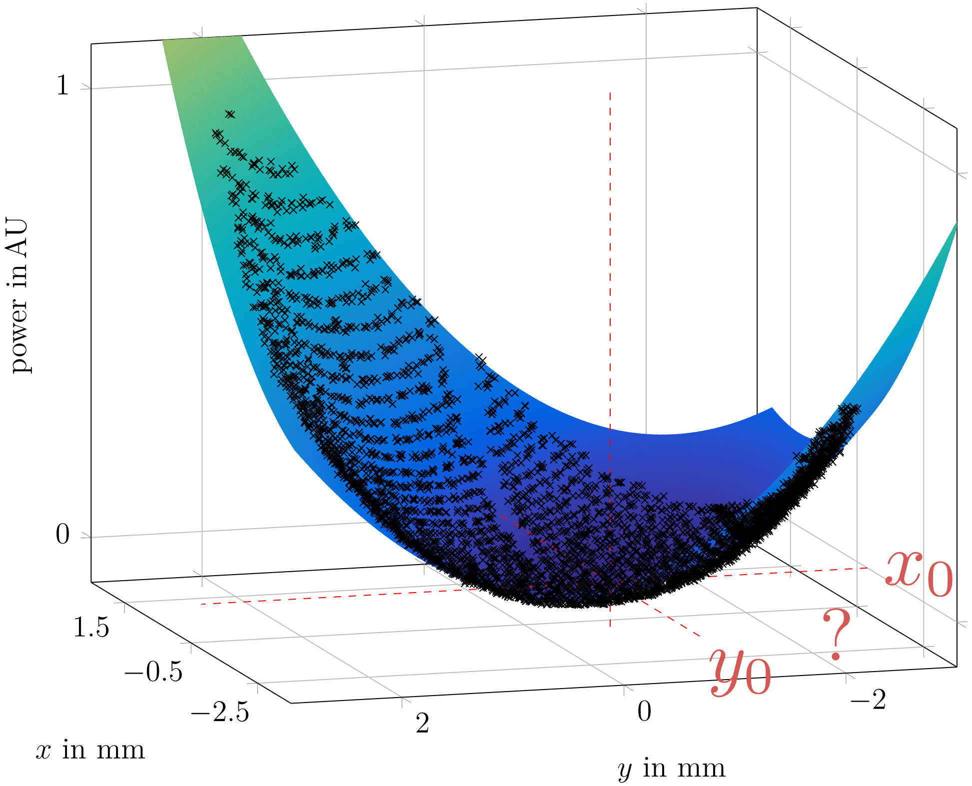

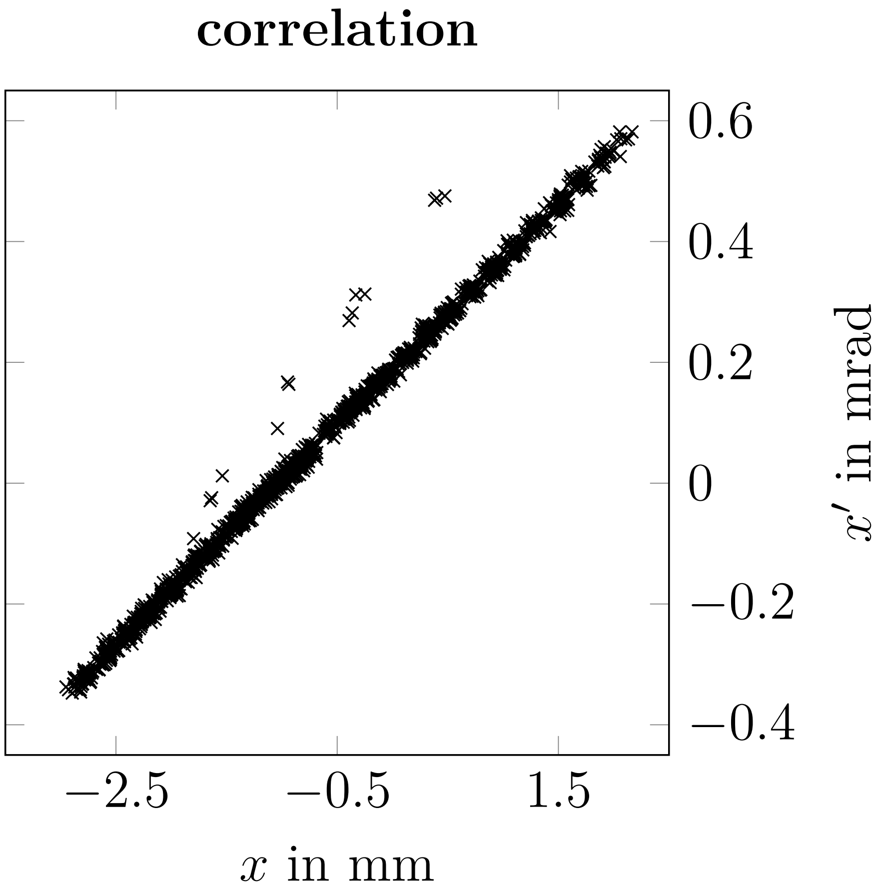

$$V_x(t) = A_x \, \Delta x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t) + A_{x'} \, \Delta x' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t) + c$$

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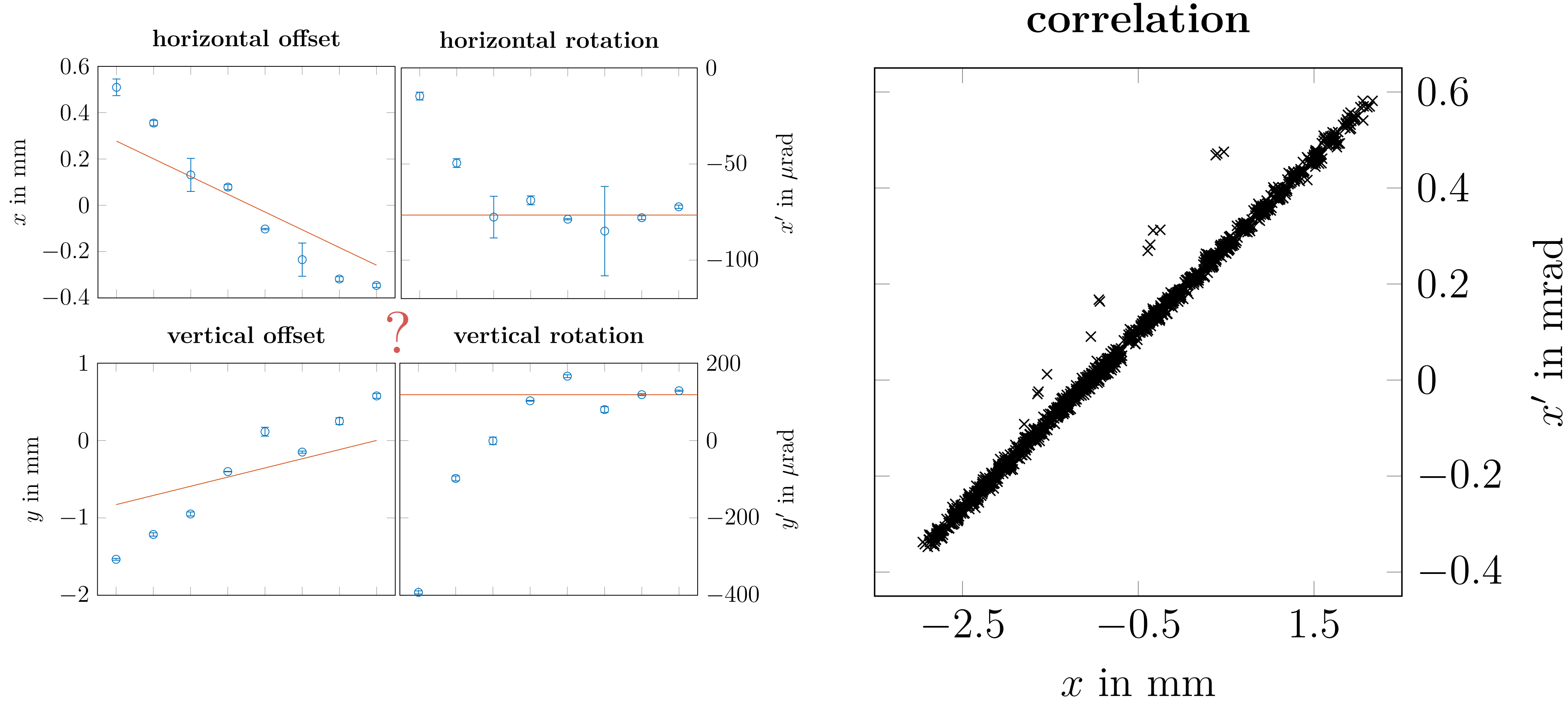

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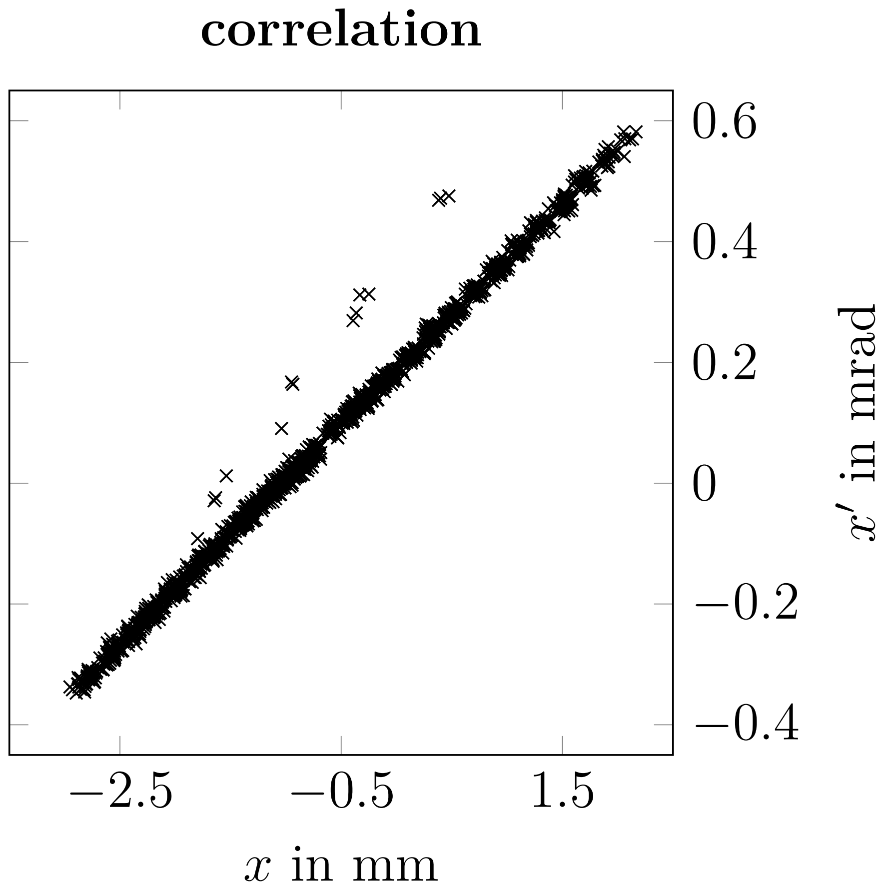
conclusion

- measurement & data evaluation scripts developed
- experimental experience gained

> **data unreliable(?)**



conclusion

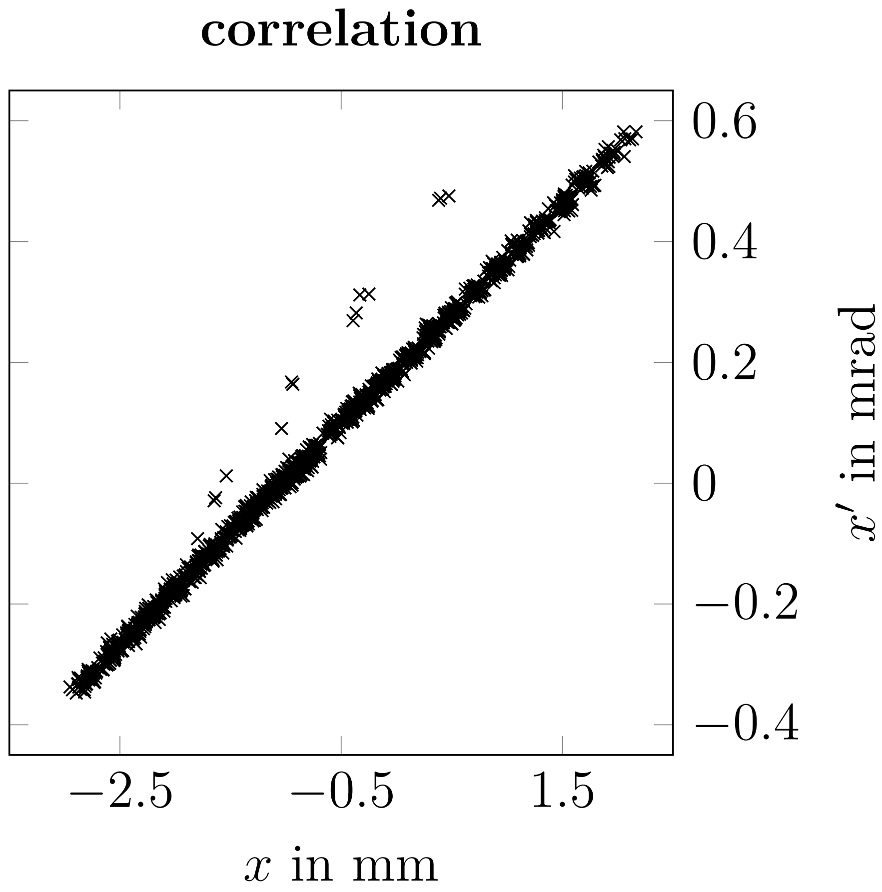
- measurement & data evaluation scripts developed
- experimental experience gained

> data unreliable(?)

next steps:

- HOM shifts in octobre 2016
- focus on uncorrelated beam trajectories
- get reliable data

> realign GUN section(?)



conclusion

- measurement & data evaluation scripts developed
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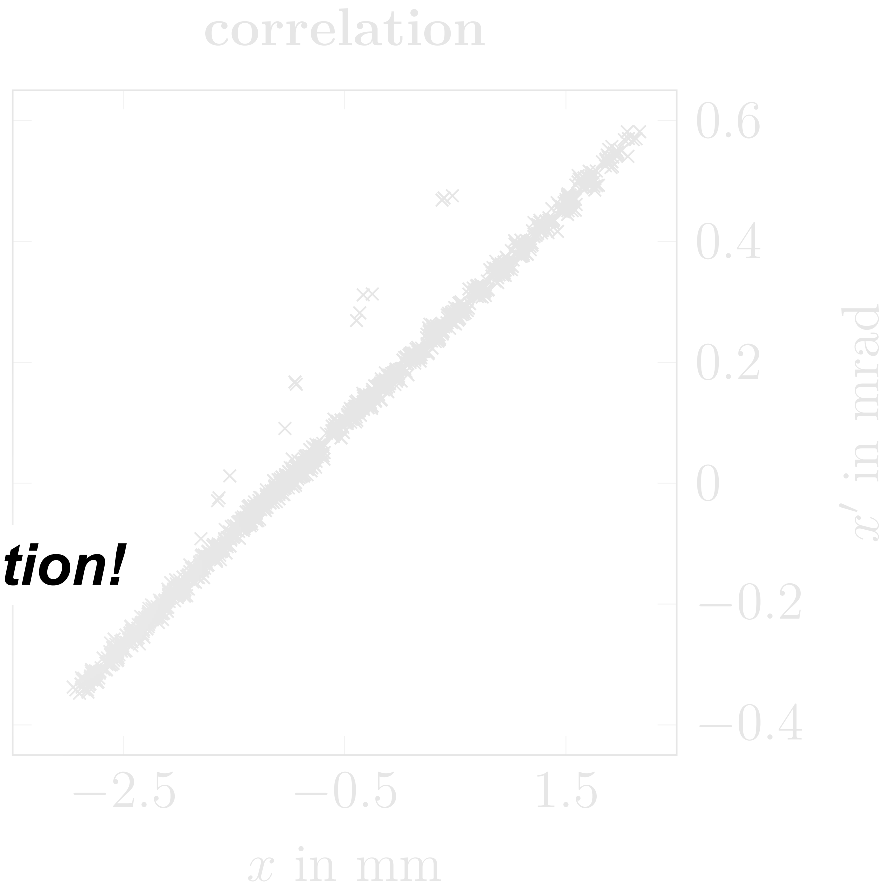

> ***thanks for your attention!***

next steps:

- HOM shift at octobre, 17th
- focus on uncorrelated beam trajectories
- get reliable data

> move GUN section