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Marco Calvi :: ID group :: Paul Scherrer Institute

Hall Probe Measurements in Insertion Device

Tutorial – IMMW20, Diamond Light Source, June 4, 2017

Overview

- Introduction to Light Sources: PSI examples
- Dipole Radiation
- Undulator fundamental relation
- Measurement bench:
  - Alignment
  - K-value
  - RMS phase error
  - Orbit distortion
- Optimisation
- An example of measurement & optimisation campaign
- The operation based on magnetic measurements
- Open for questions

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SLS – 2.4 GeV Light Source

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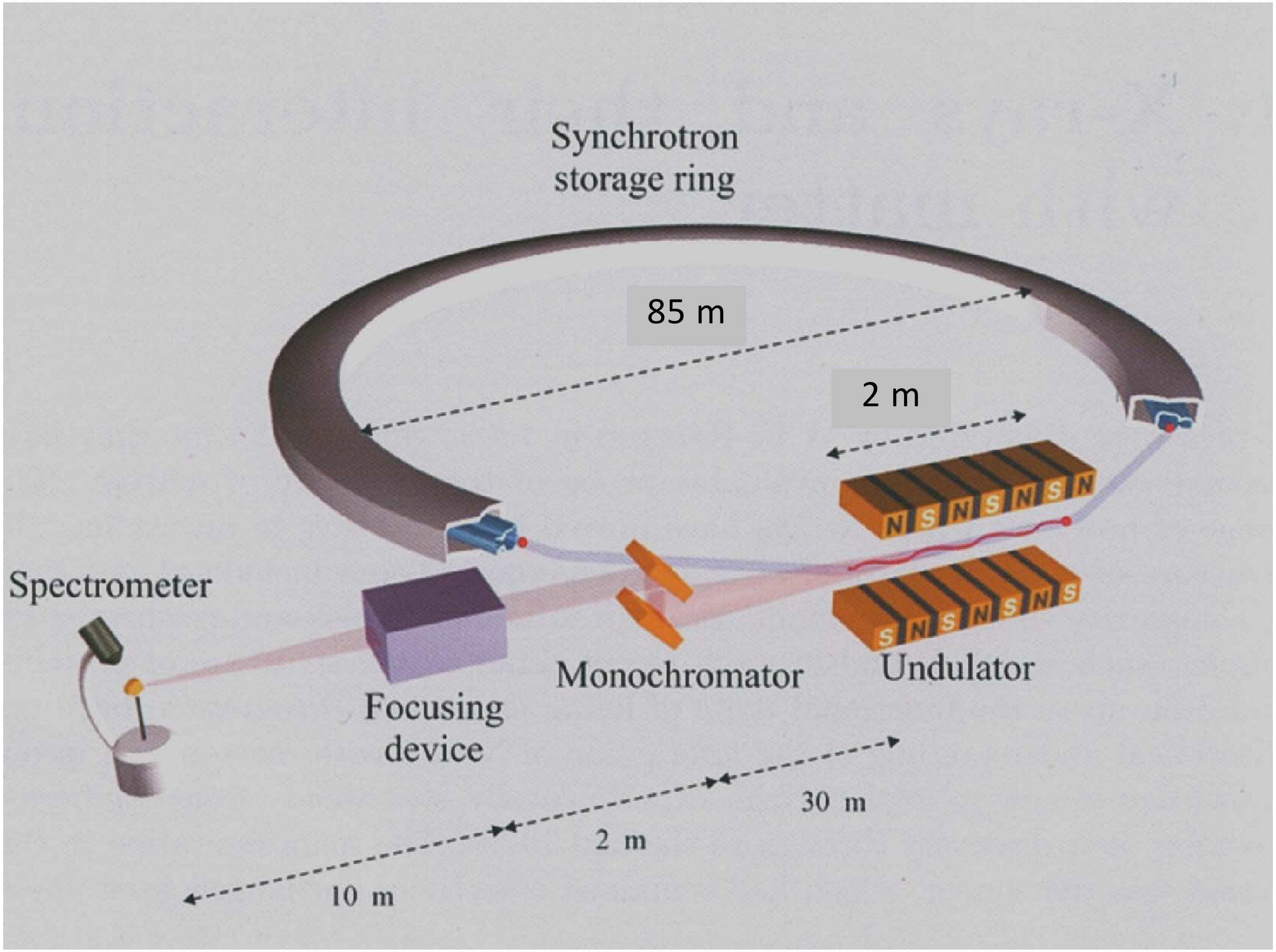
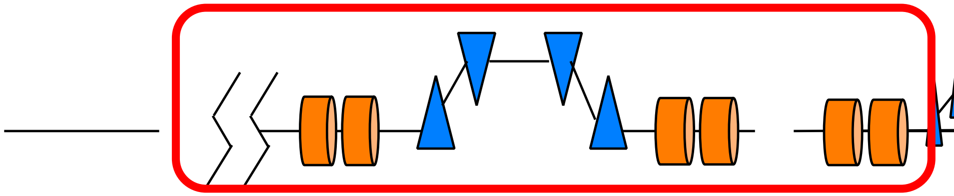


SwissFEL



SwissFEL

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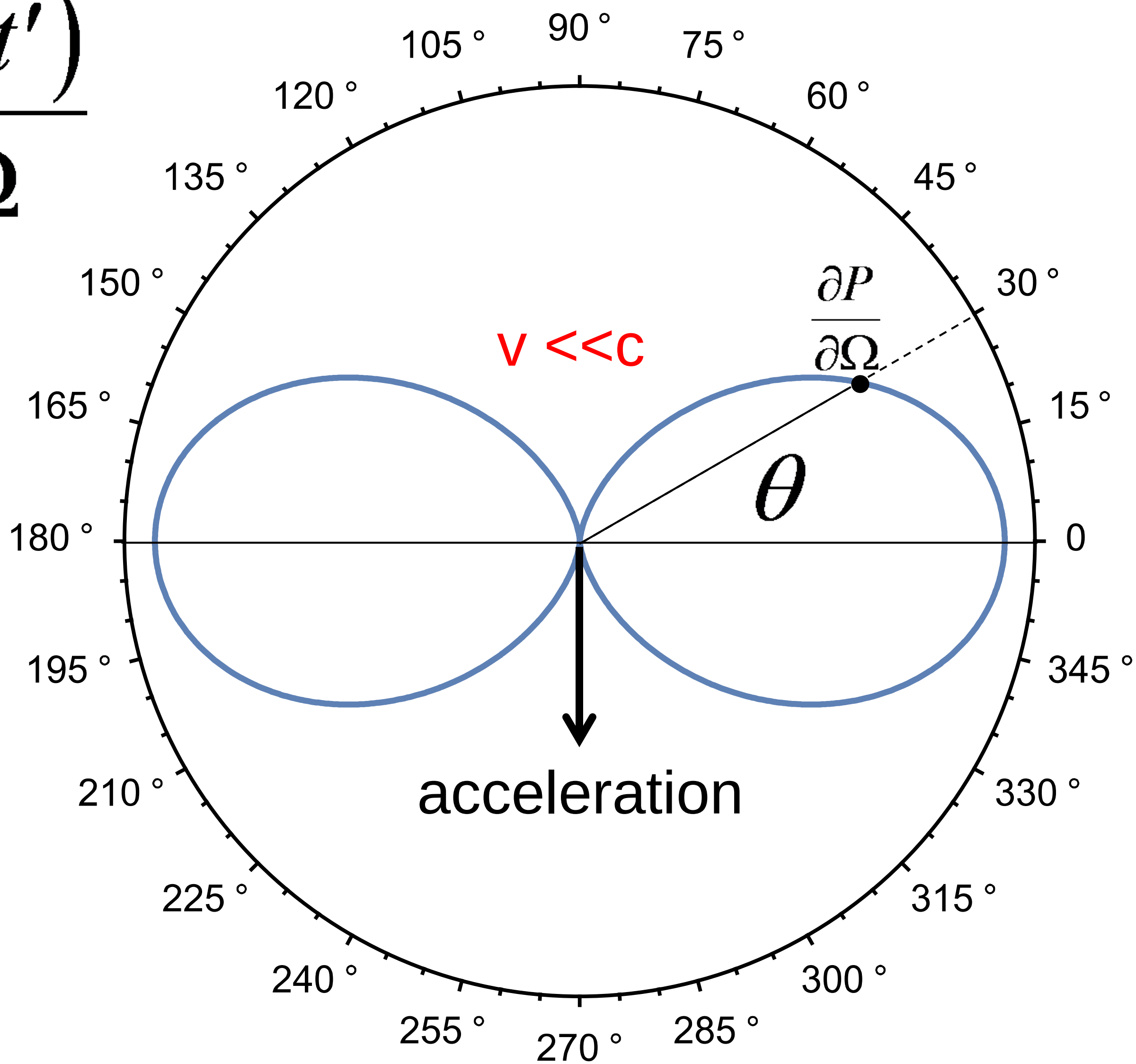
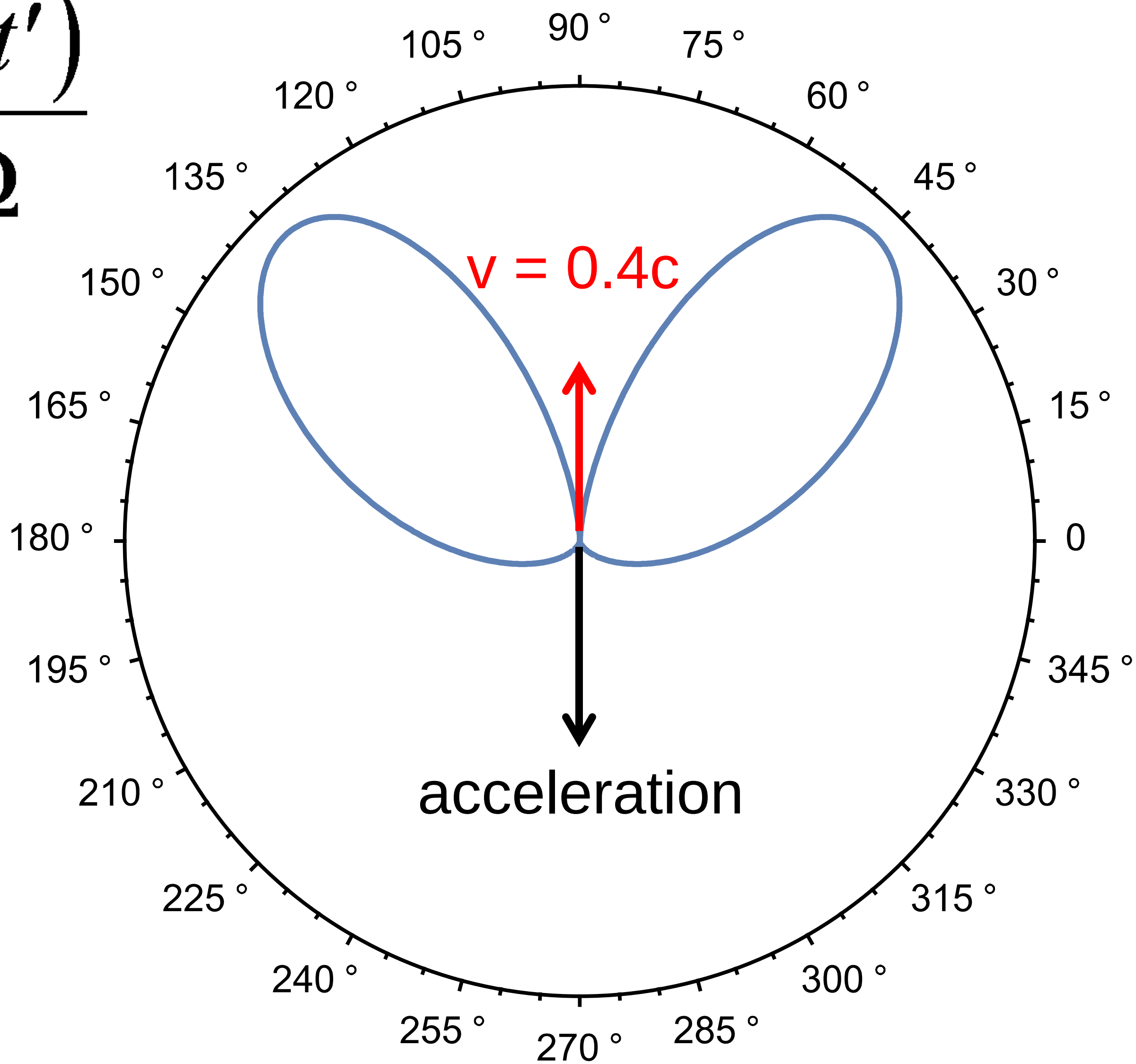
Dipole Radiation

$$\frac{\partial P(t')}{\partial \Omega}$$



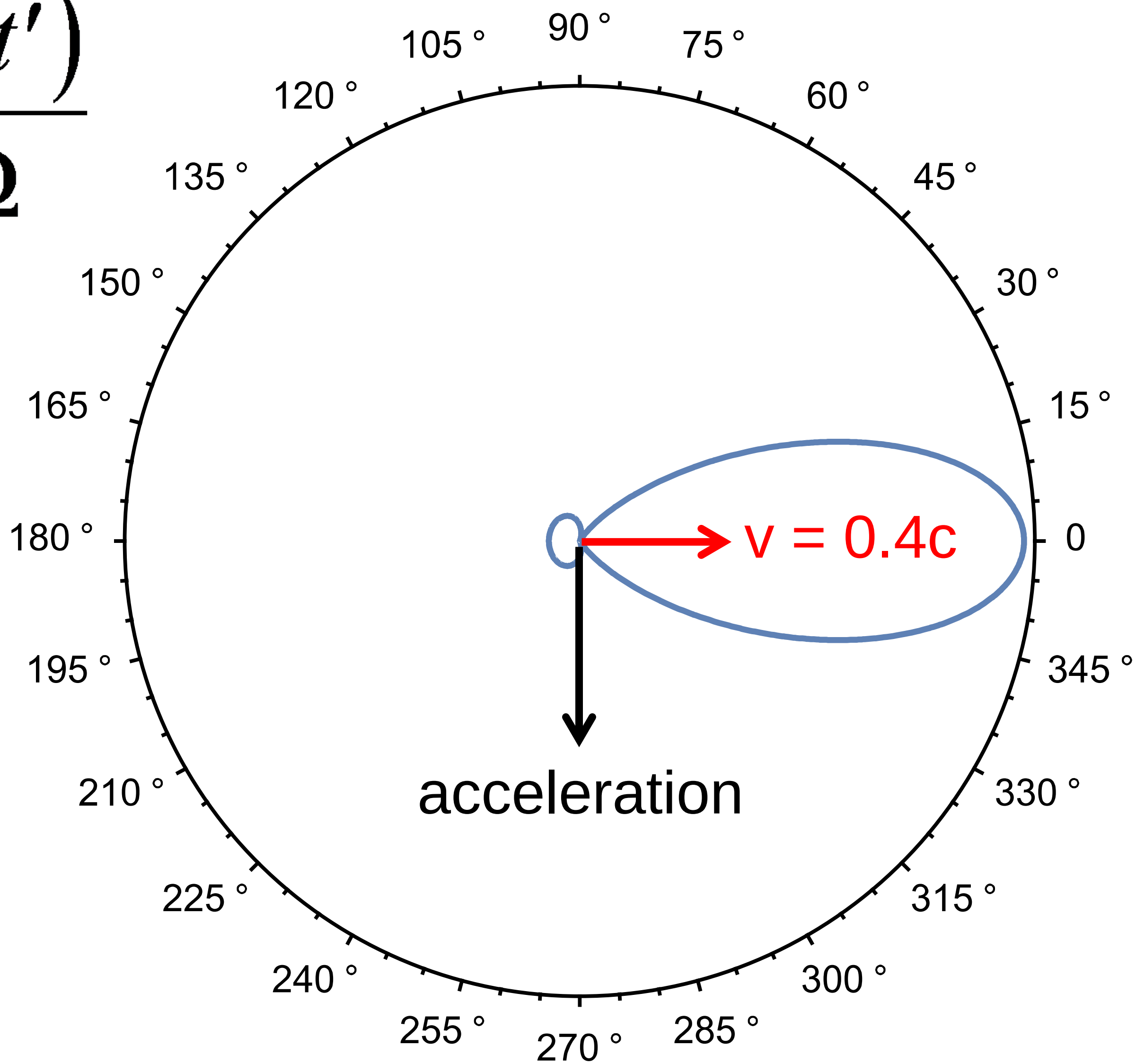
velocity // acceleration

$$\frac{\partial P(t')}{\partial \Omega}$$



velocity ⊥ acceleration

$$\frac{\partial P(t')}{\partial \Omega}$$



velocity ⊥ acceleration

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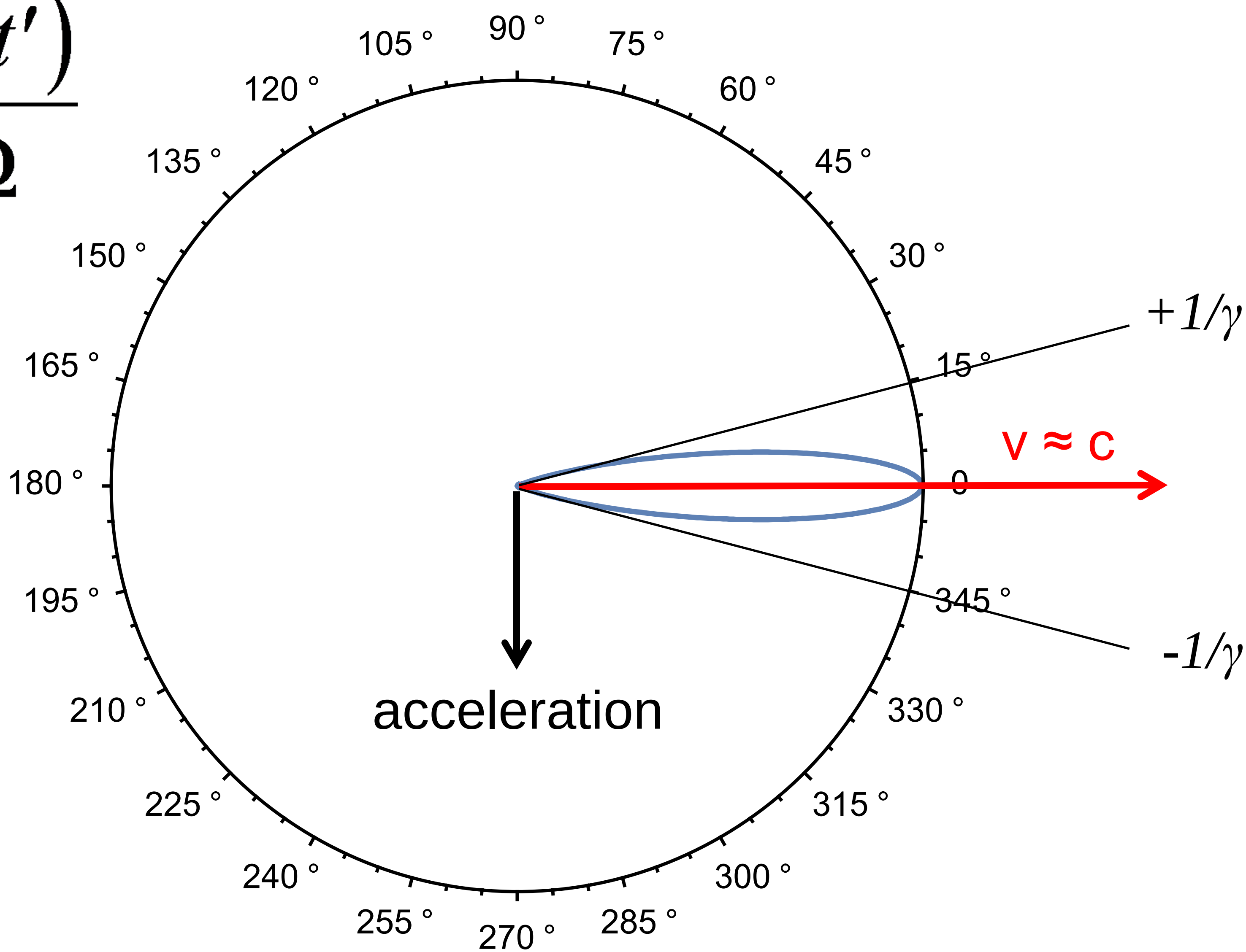

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Undulator Fundamental Relation

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

λ_u period length

γ Lorentz factor

$$K = \frac{e}{2\pi mc}\lambda_u B_e$$

$$\approx 0.9336 \cdot \lambda_u[cm] \cdot B_e[T]$$

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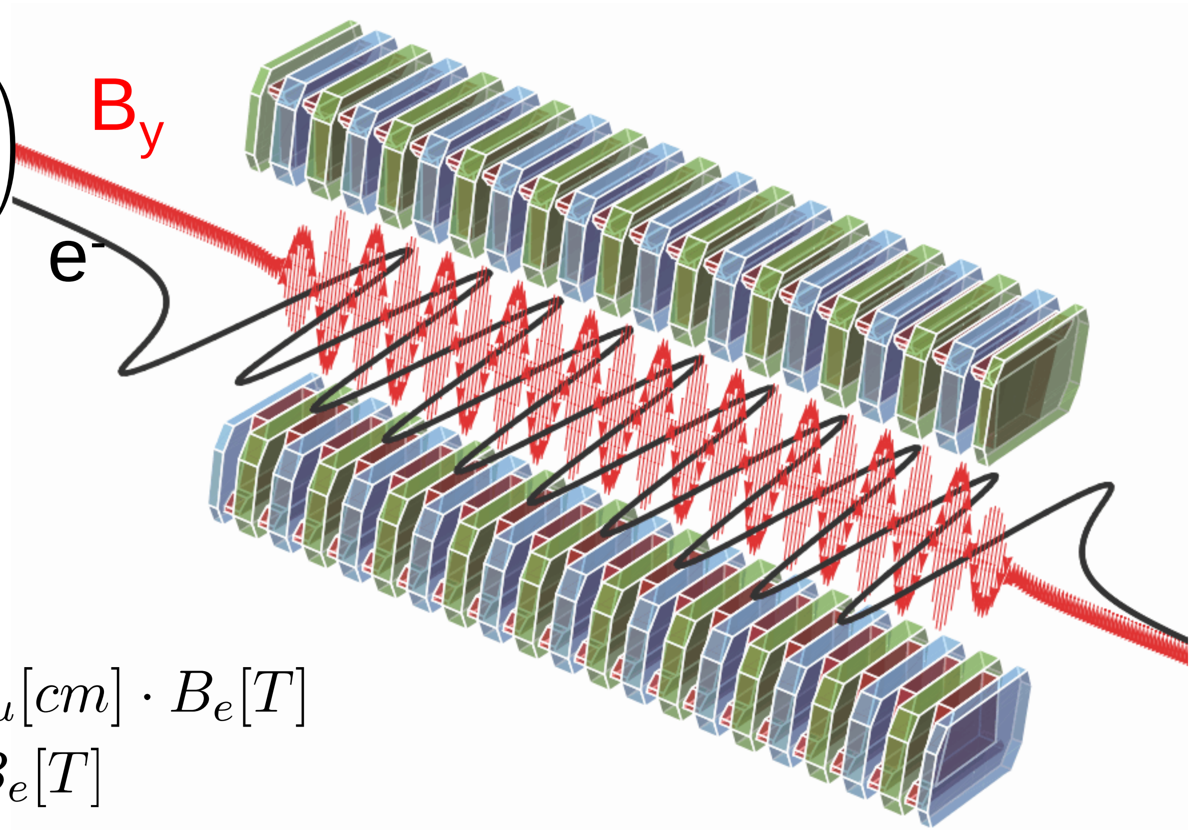
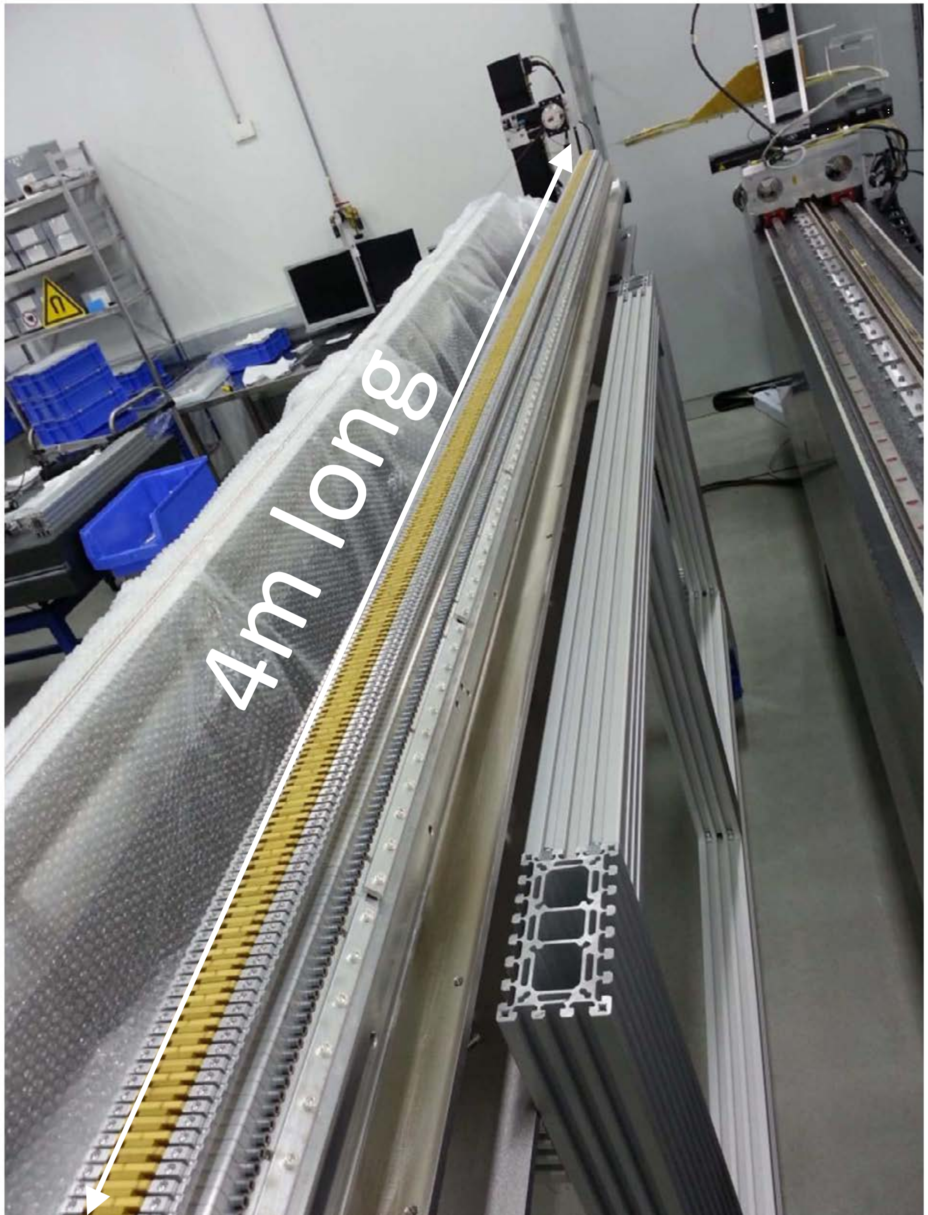
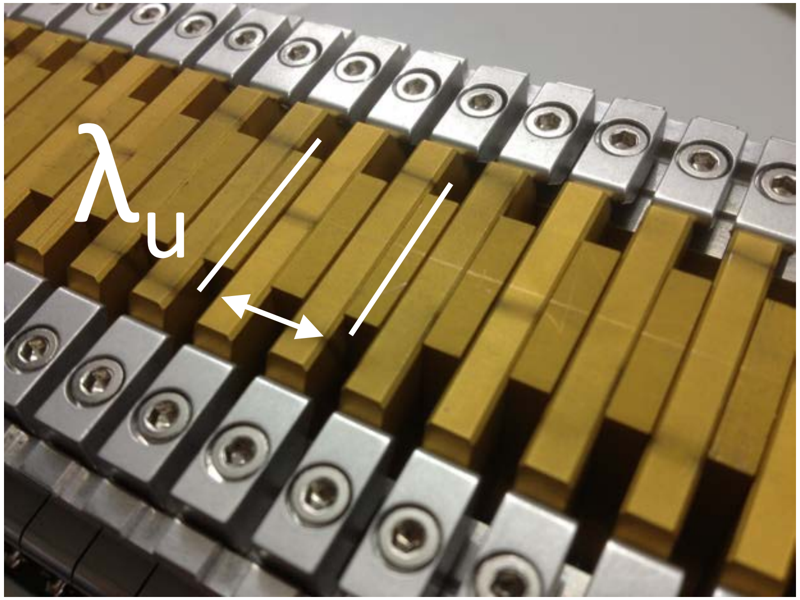
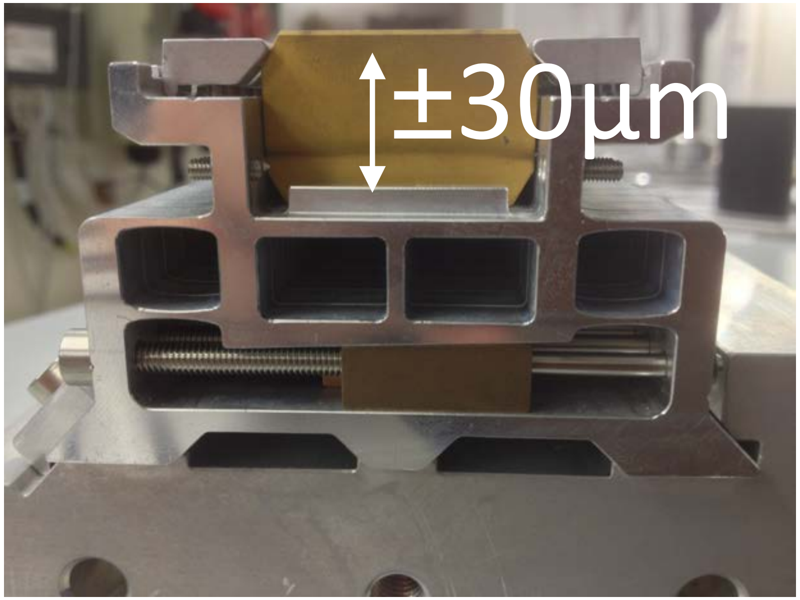


Aramis In-vacuum undulator







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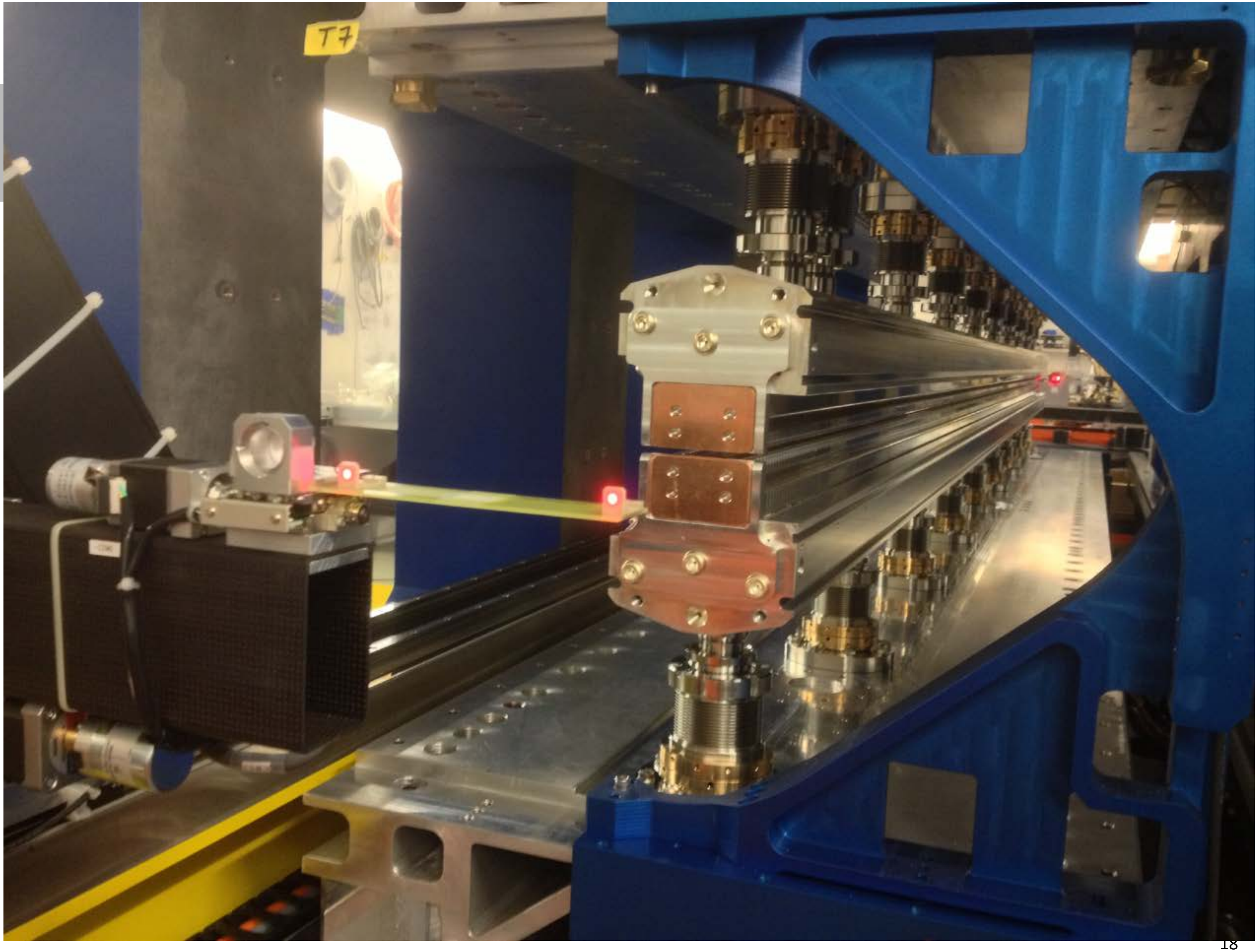

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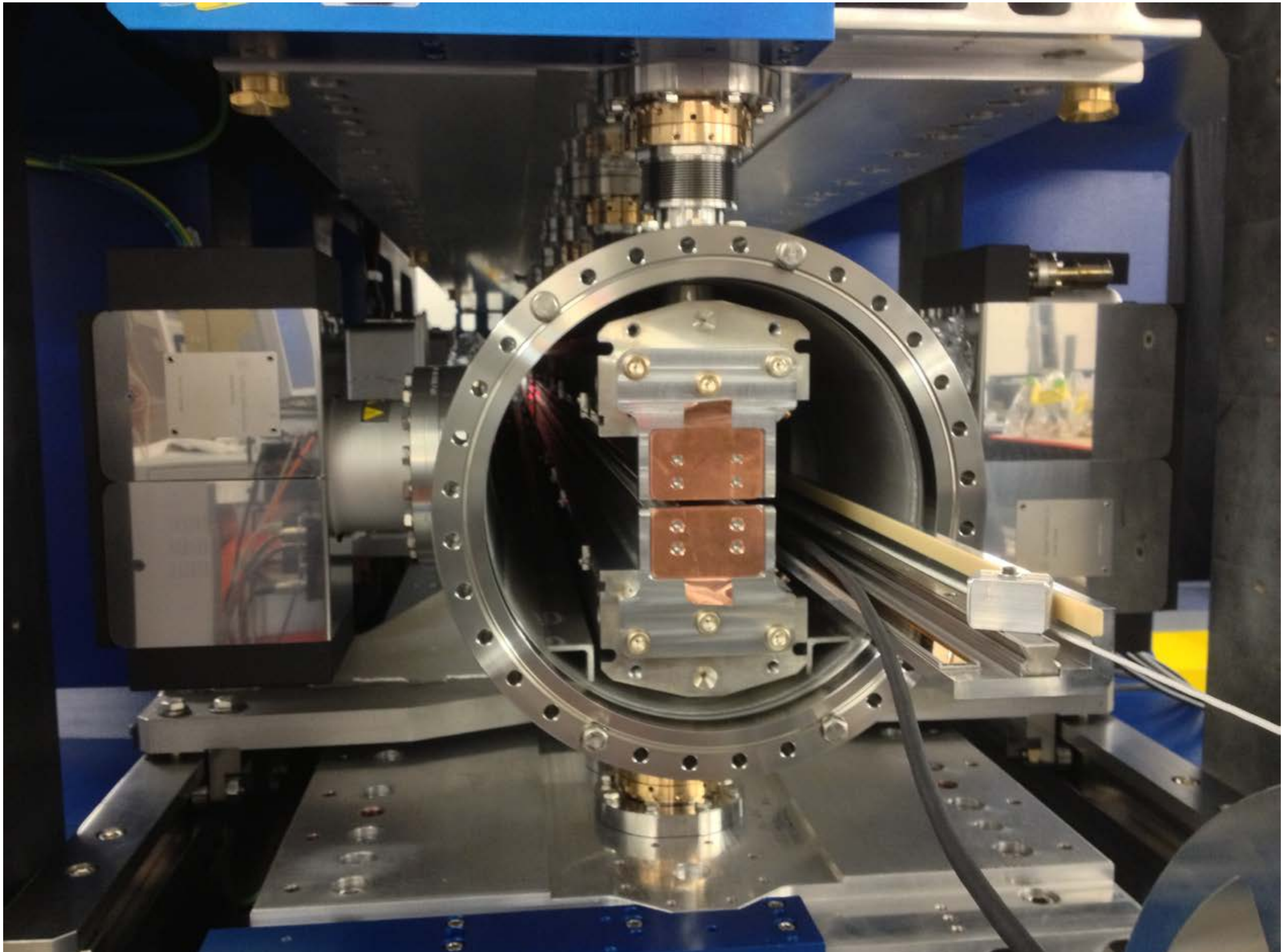


PUSH
EMERGENCY
STOP

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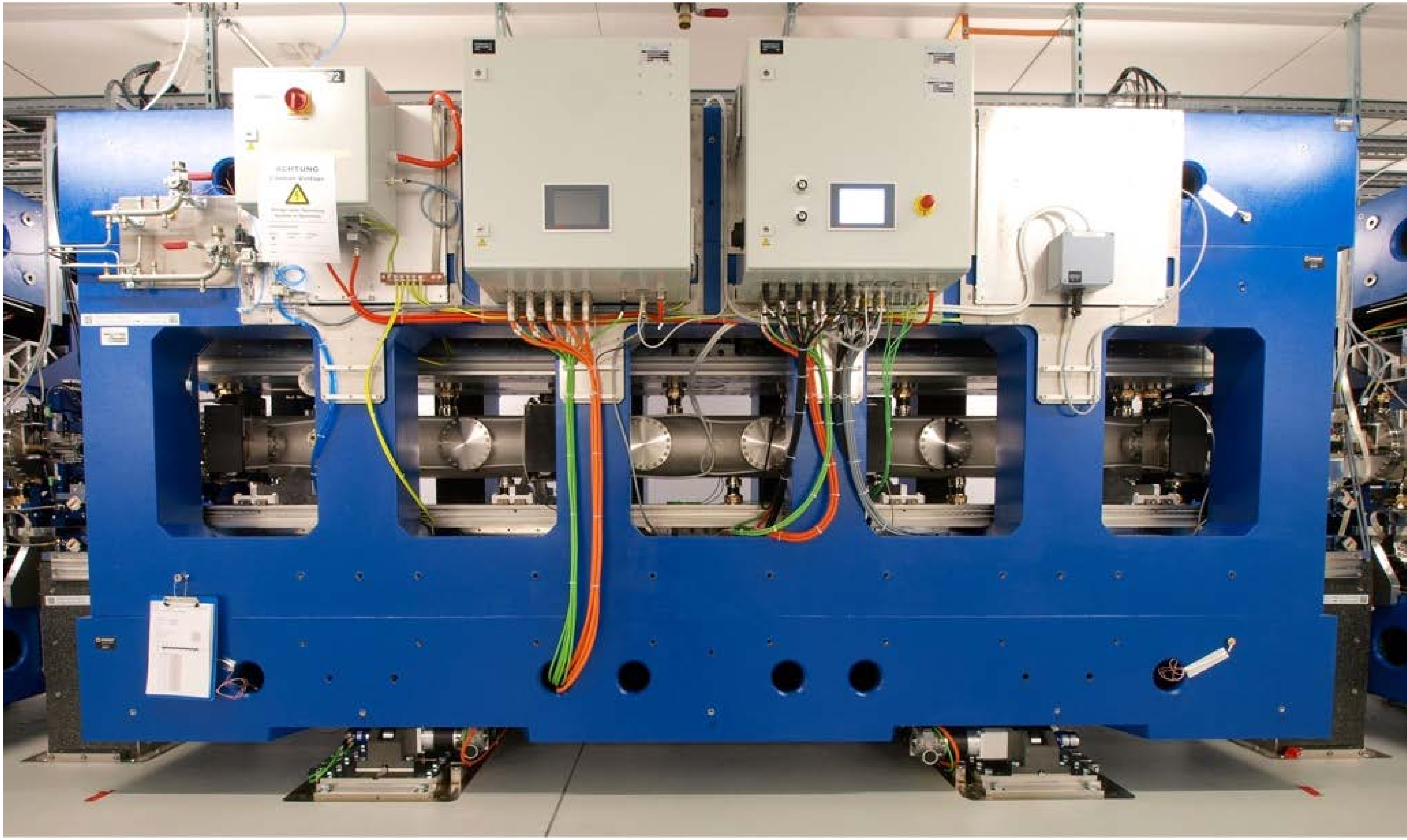
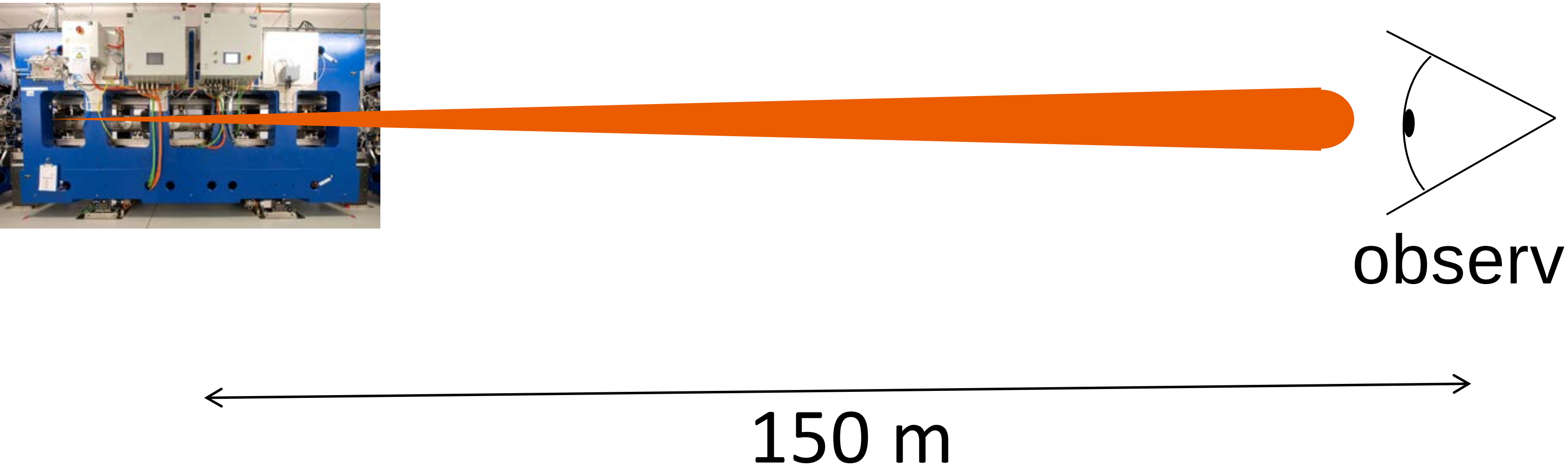
Aramis In-vacuum undulators





observer
150 m

Undulator Fundamental Relation

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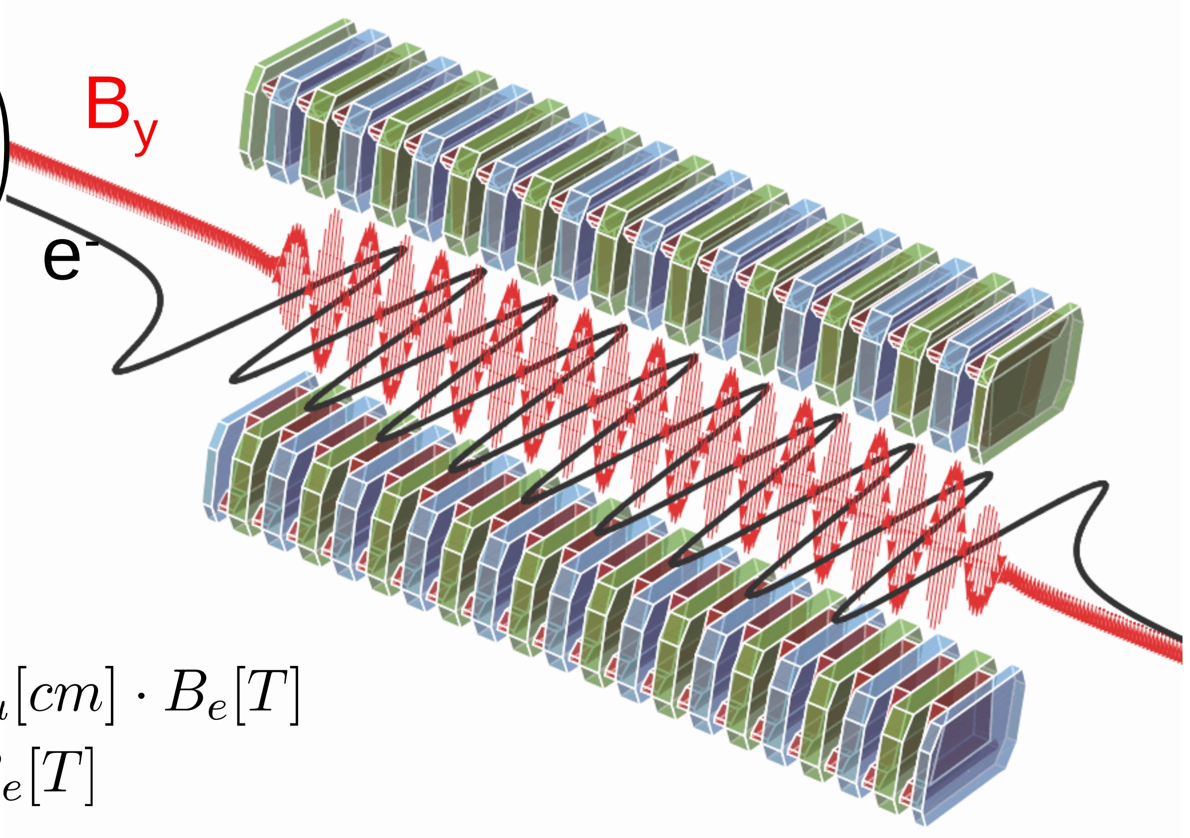

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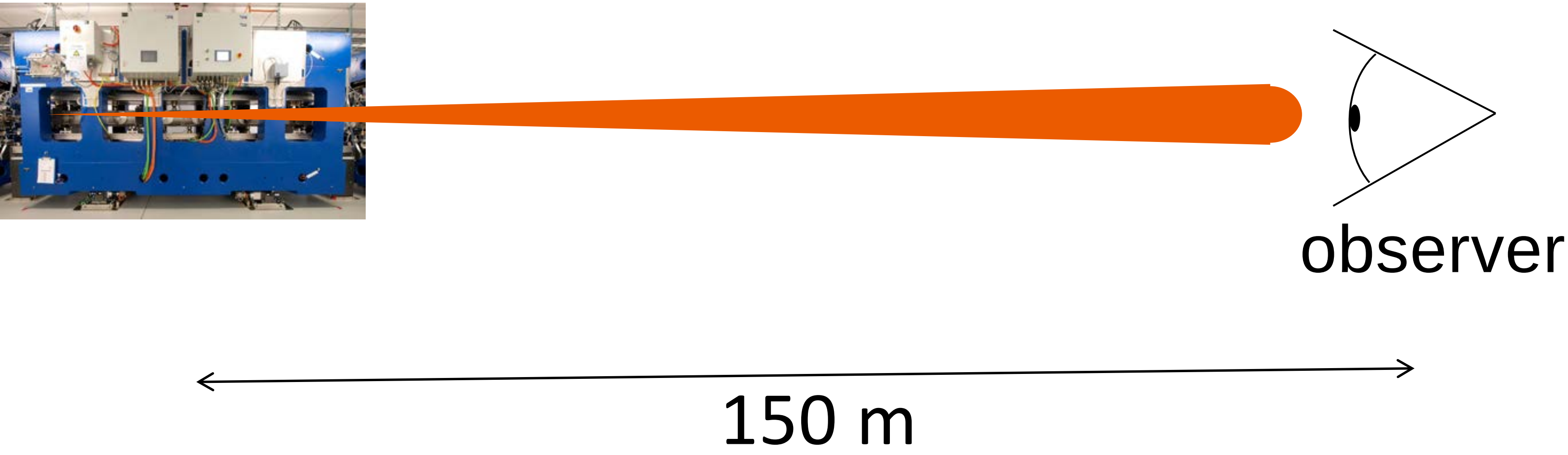
$$\approx \lambda_u[cm] \cdot B_e[T]$$

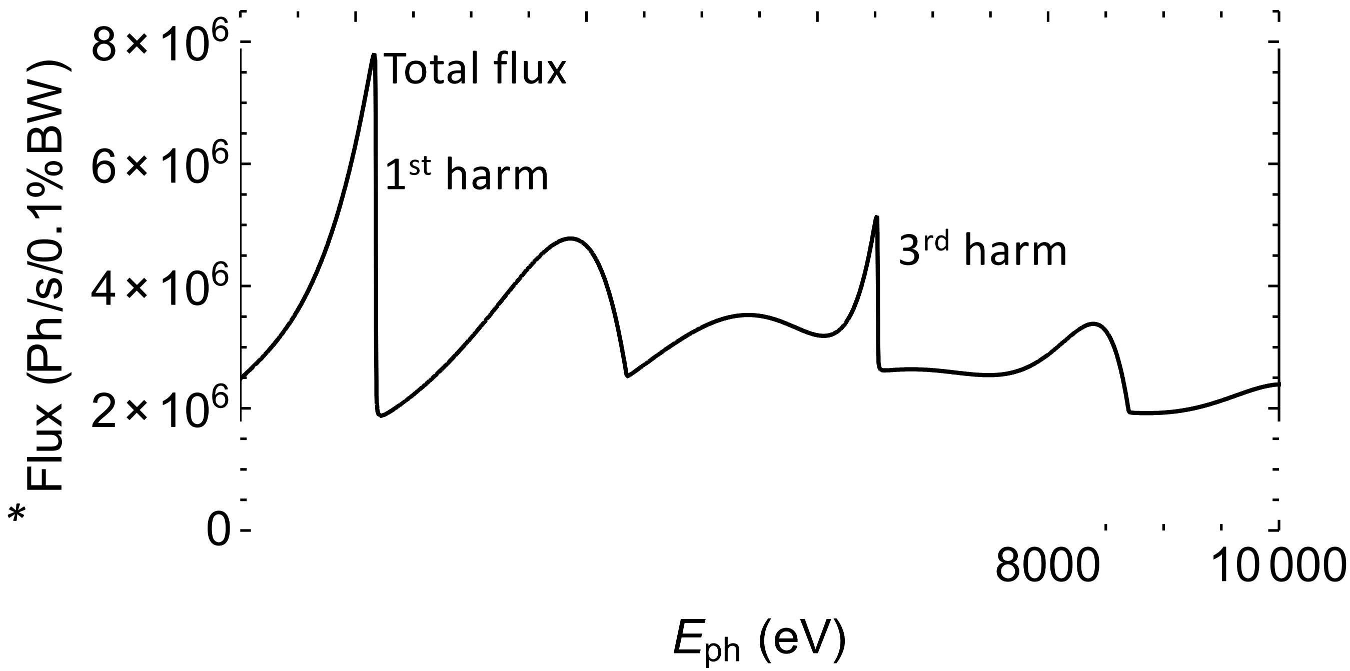
$$\lambda_n = \frac{\lambda_u}{2n\gamma}\left(1 + \frac{K^2}{2} + \theta^2\gamma^2\right)$$

θ Observation angle


observer
150 m

E=3.0GeV & K=1.8

$$\lambda_n = \frac{\lambda_u}{2n\gamma}\left(1 + \frac{K^2}{2} + \theta^2\gamma^2\right)$$

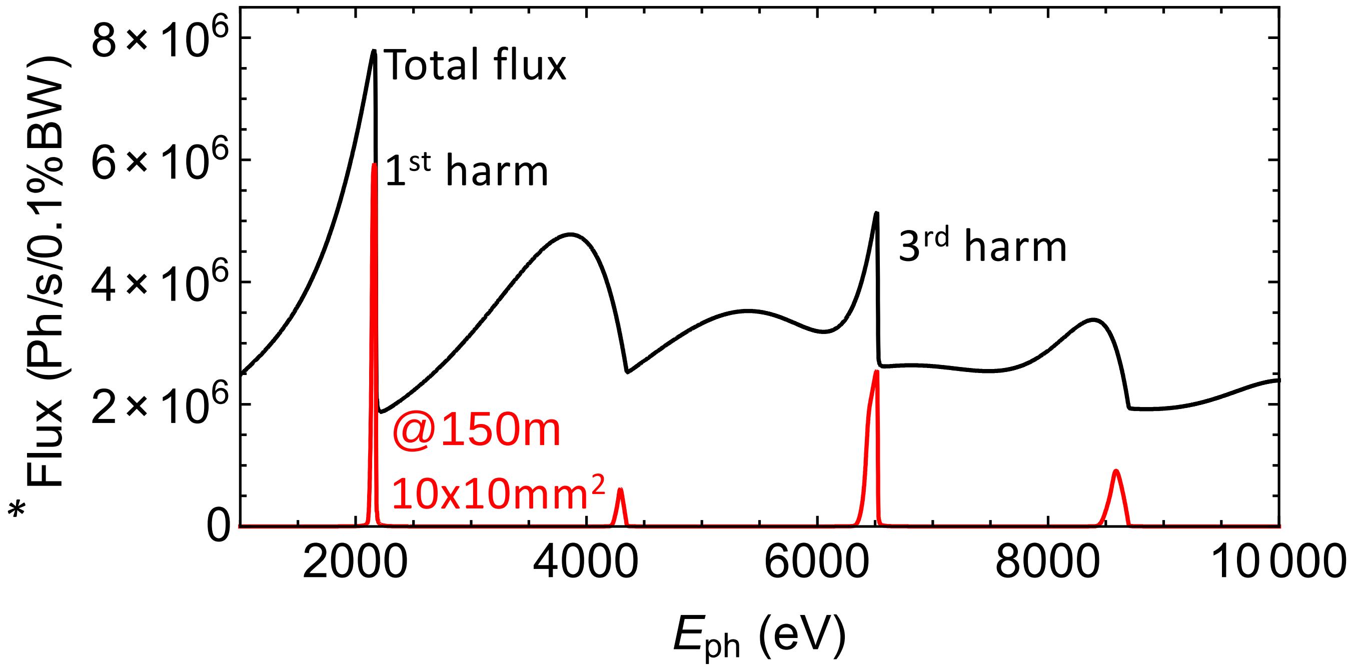


*All calculations made with 1Hz repetition rate → 1/s = per shot

Charge = 200pC

E=3.0GeV & K=1.8

$$\lambda_n = \frac{\lambda_u}{2n\gamma}\left(1 + \frac{K^2}{2} + \theta^2\gamma^2\right)$$



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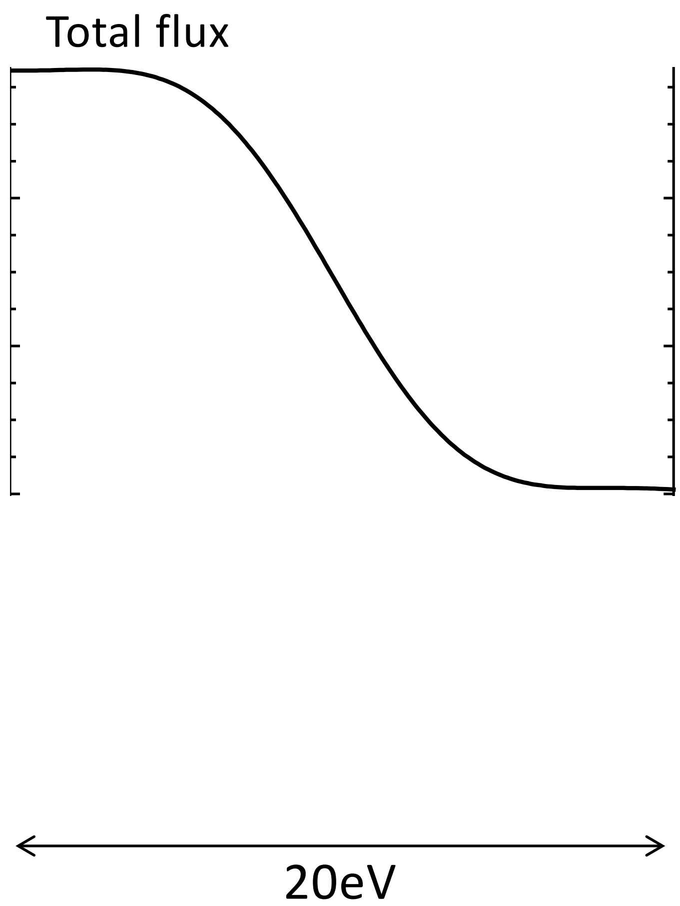
E=3.0GeV & K=1.8 – 1st harmonic

@150m



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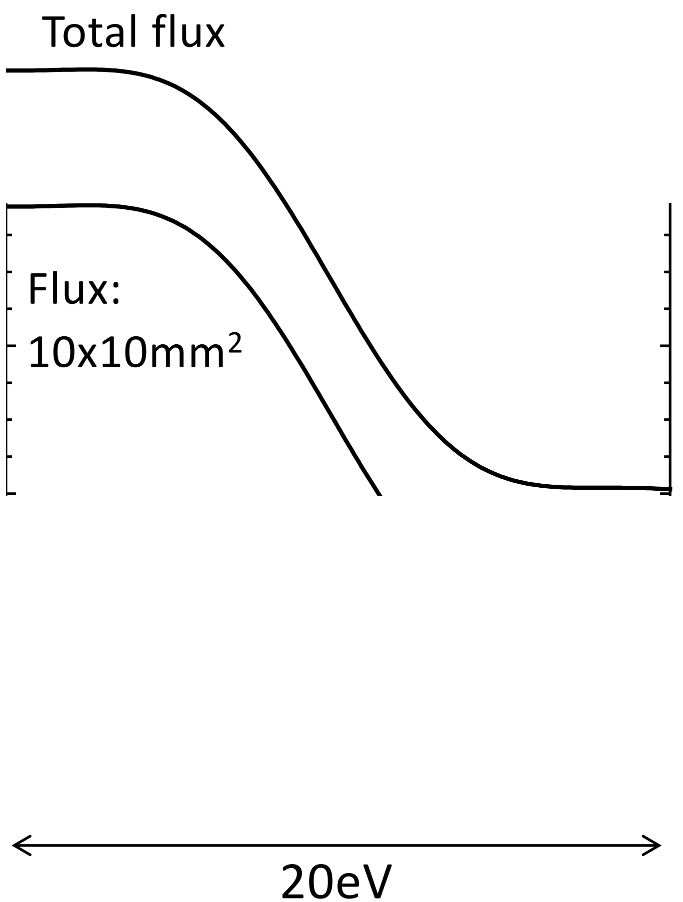

E=3.0GeV & K=1.8 – 1^{st} harmonic

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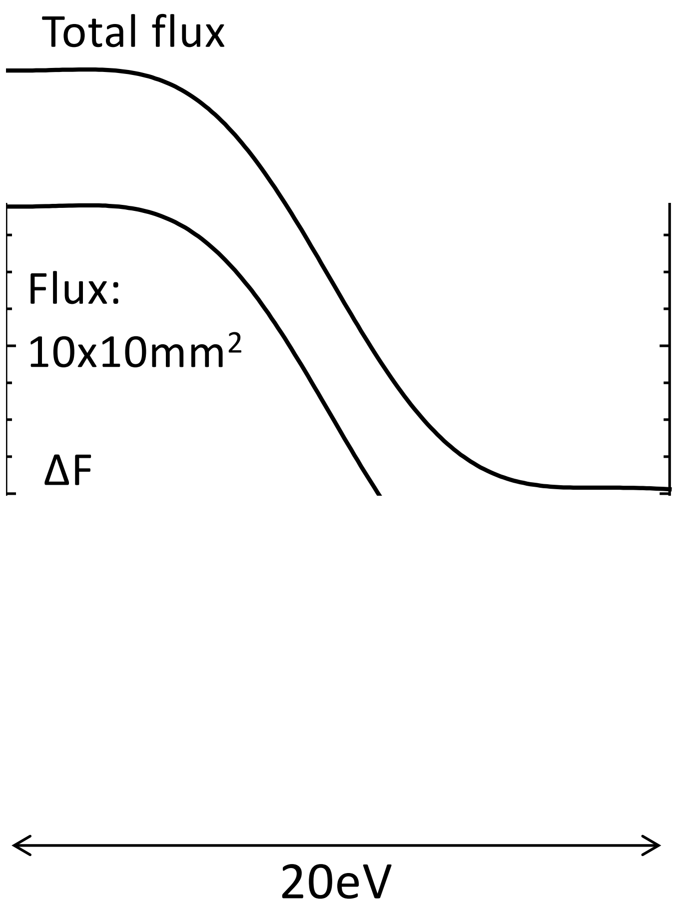
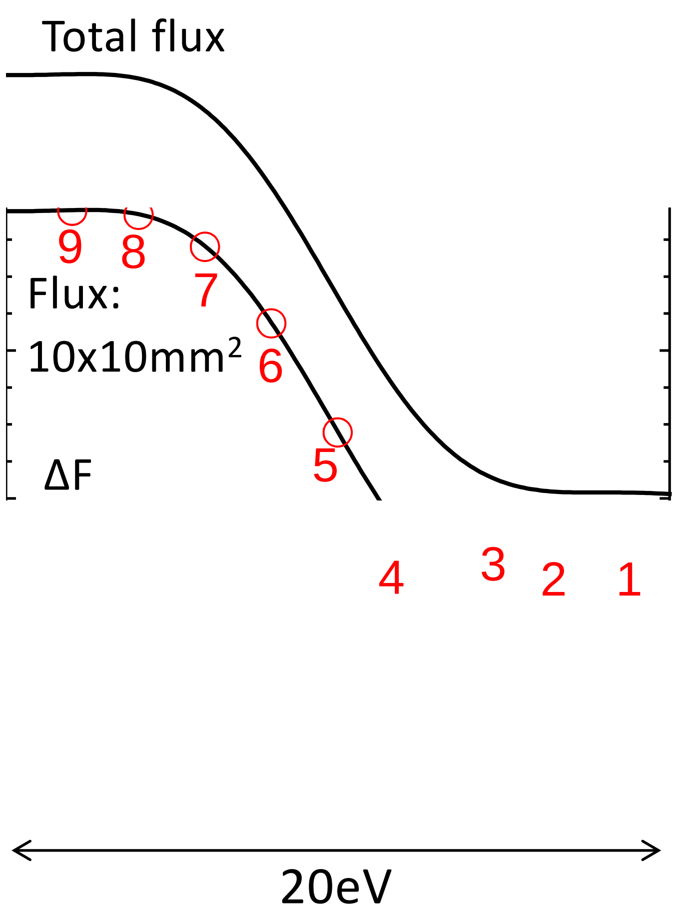


E=3.0GeV & K=1.8 – 1st harmonic

X (mm)

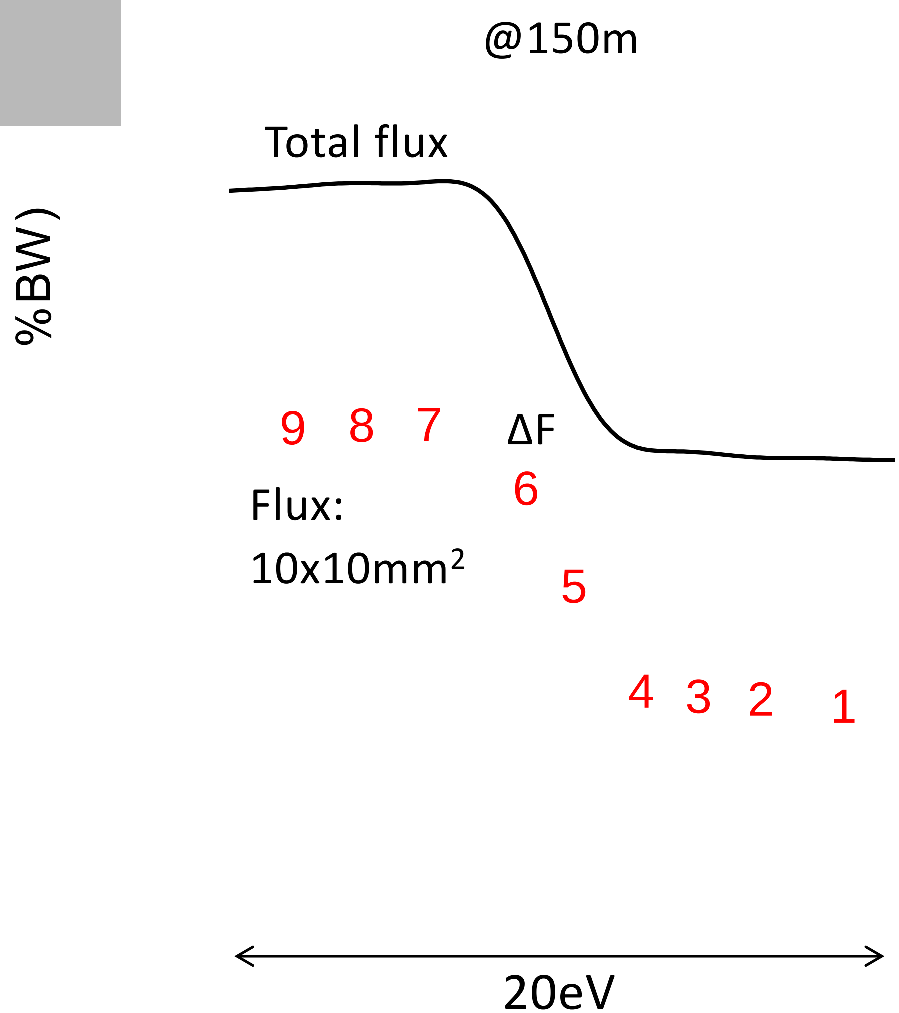
@150m

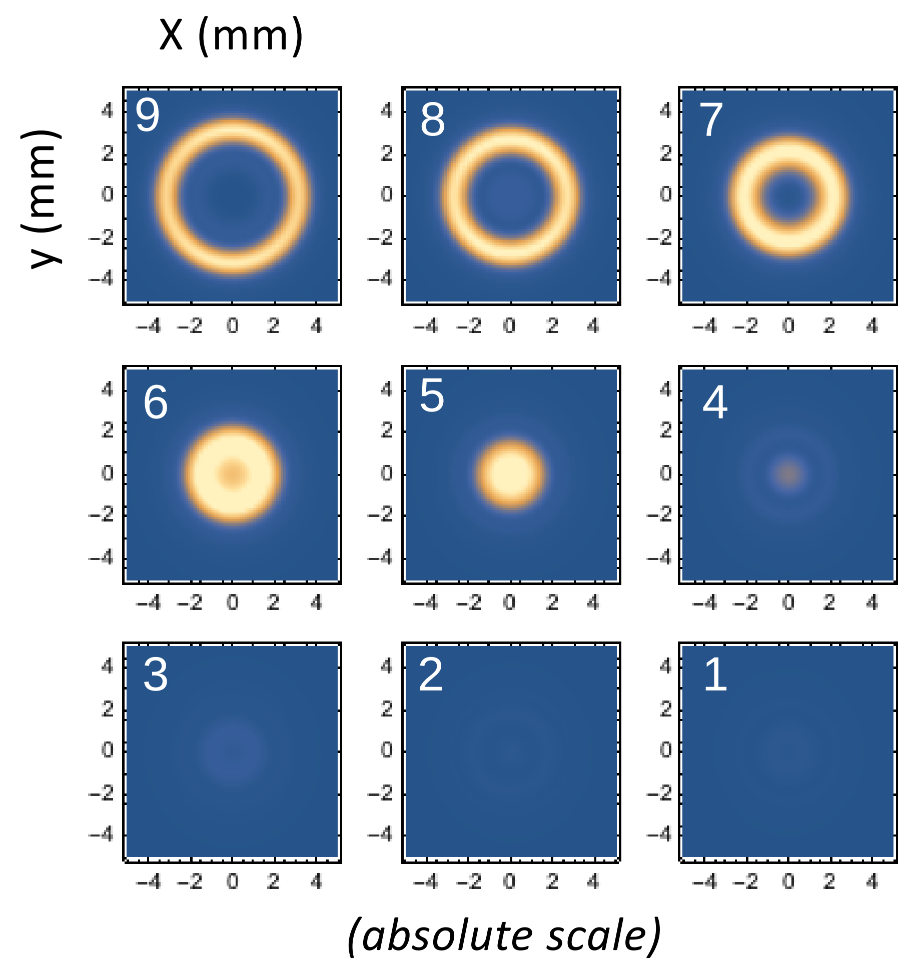


y (mm)

(absolute scale)

E=2.0GeV & K=1.8 – 3rd harmonic





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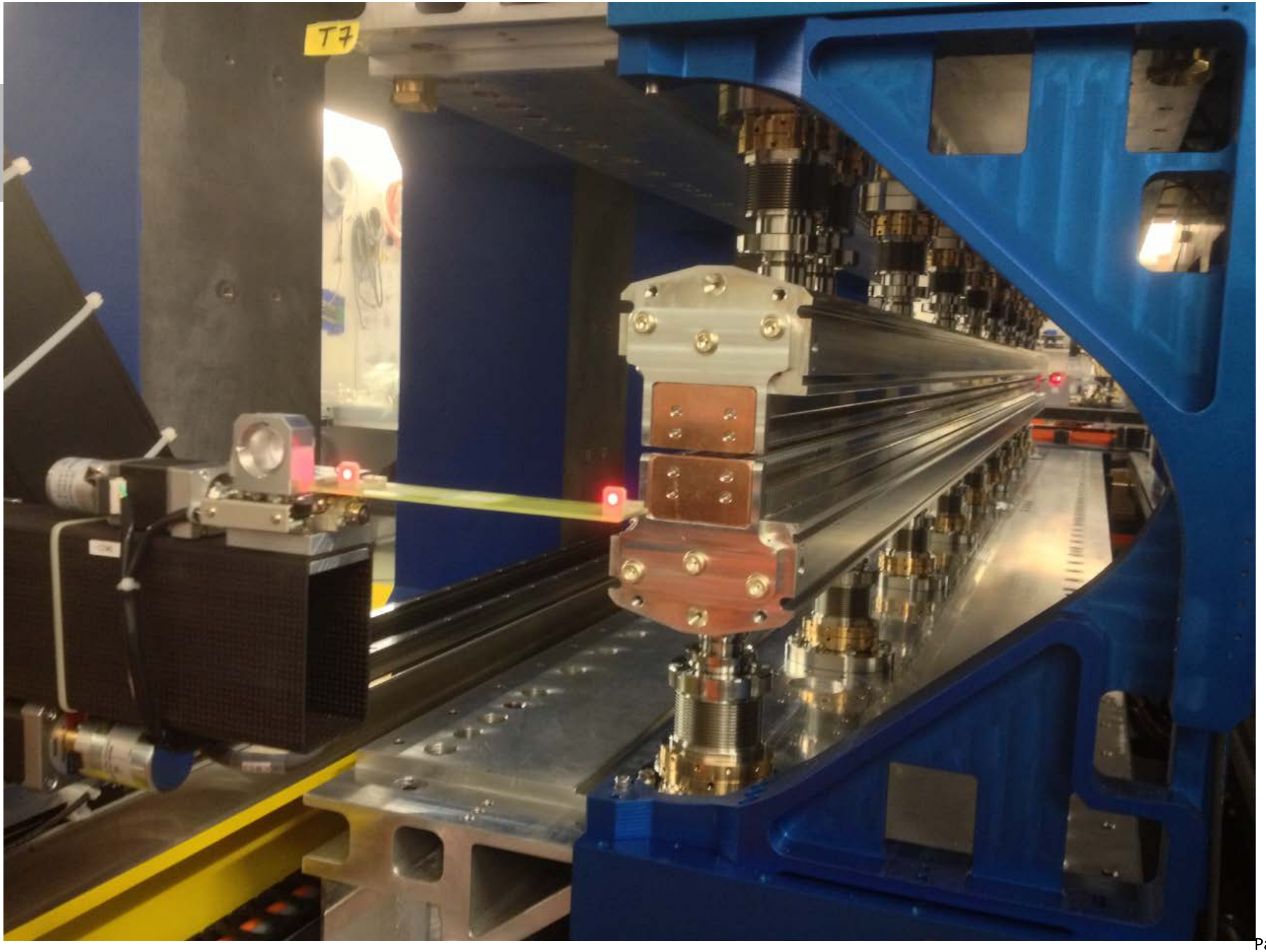
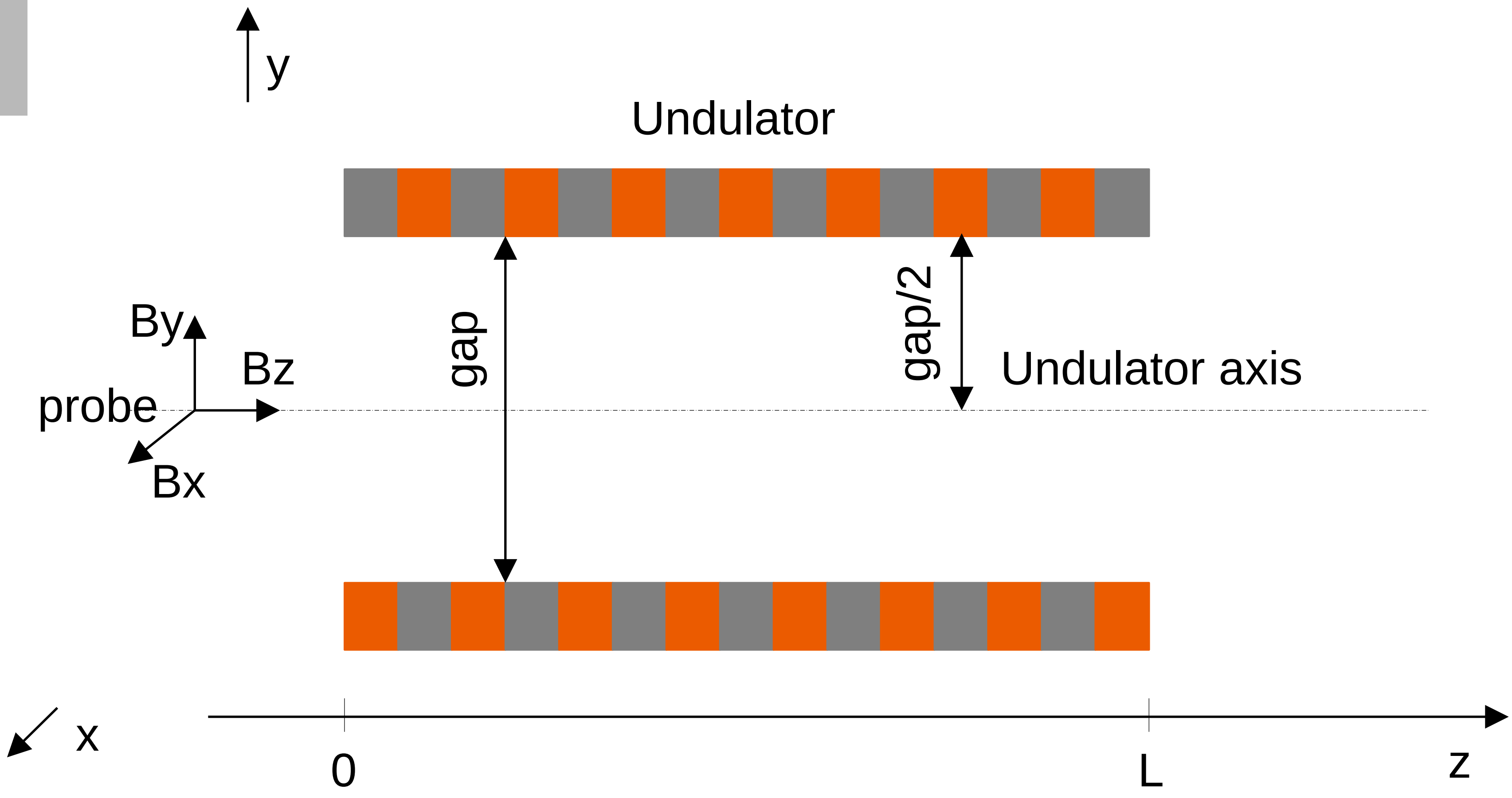
Measuring bench



Measuring bench



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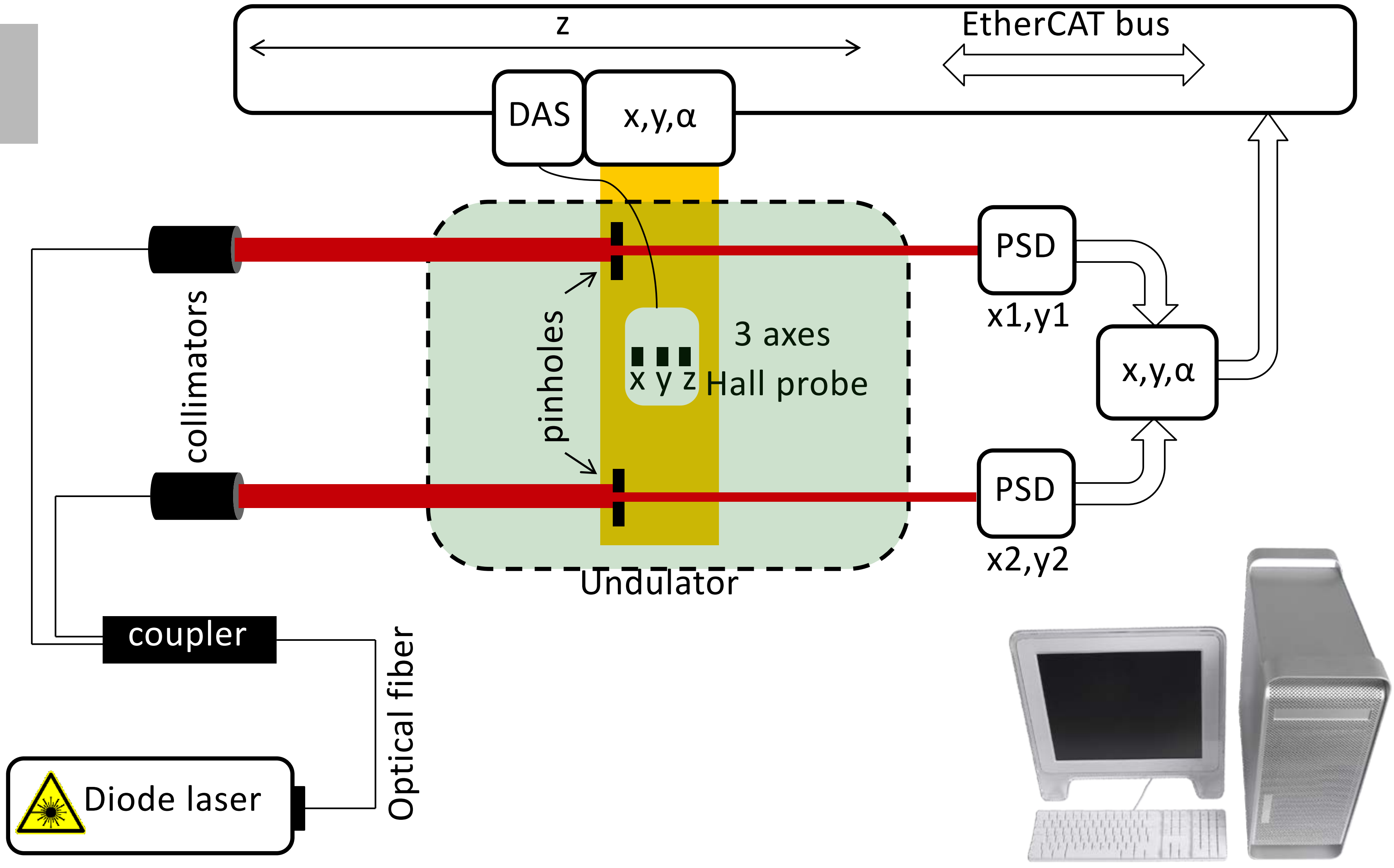

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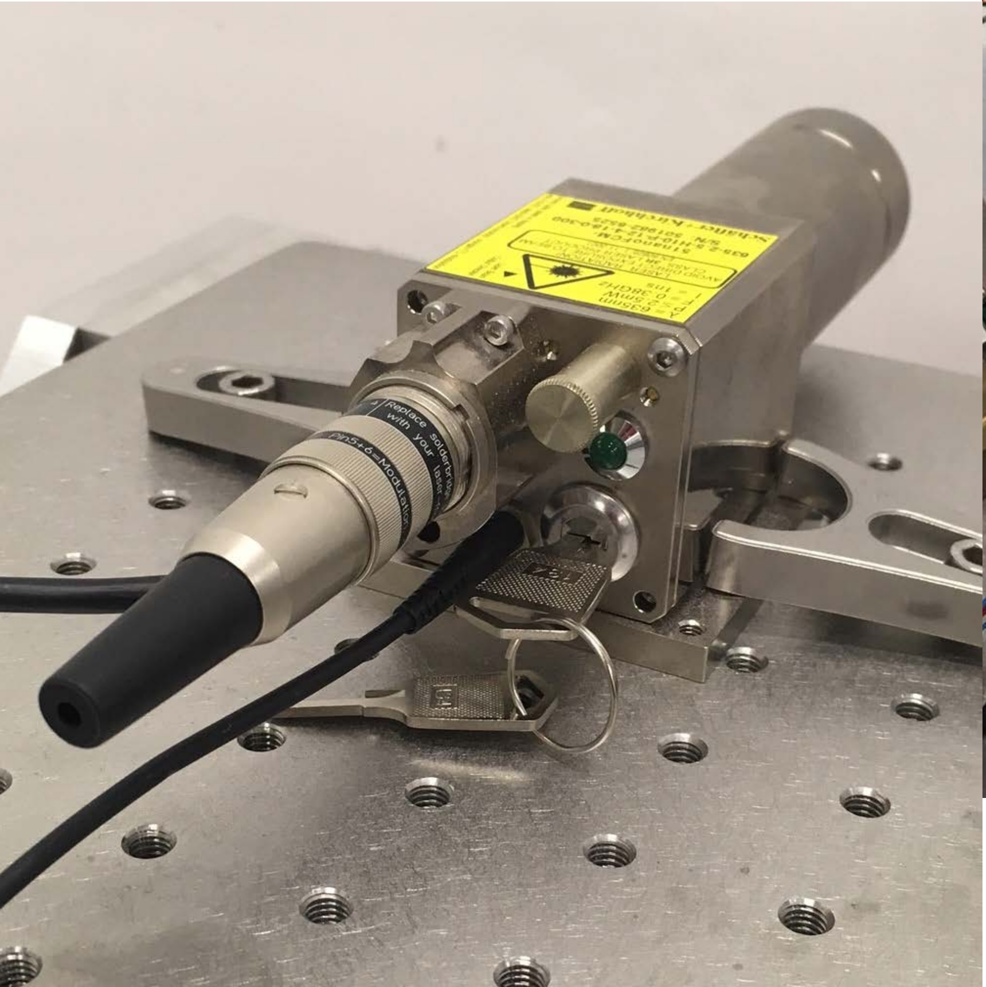

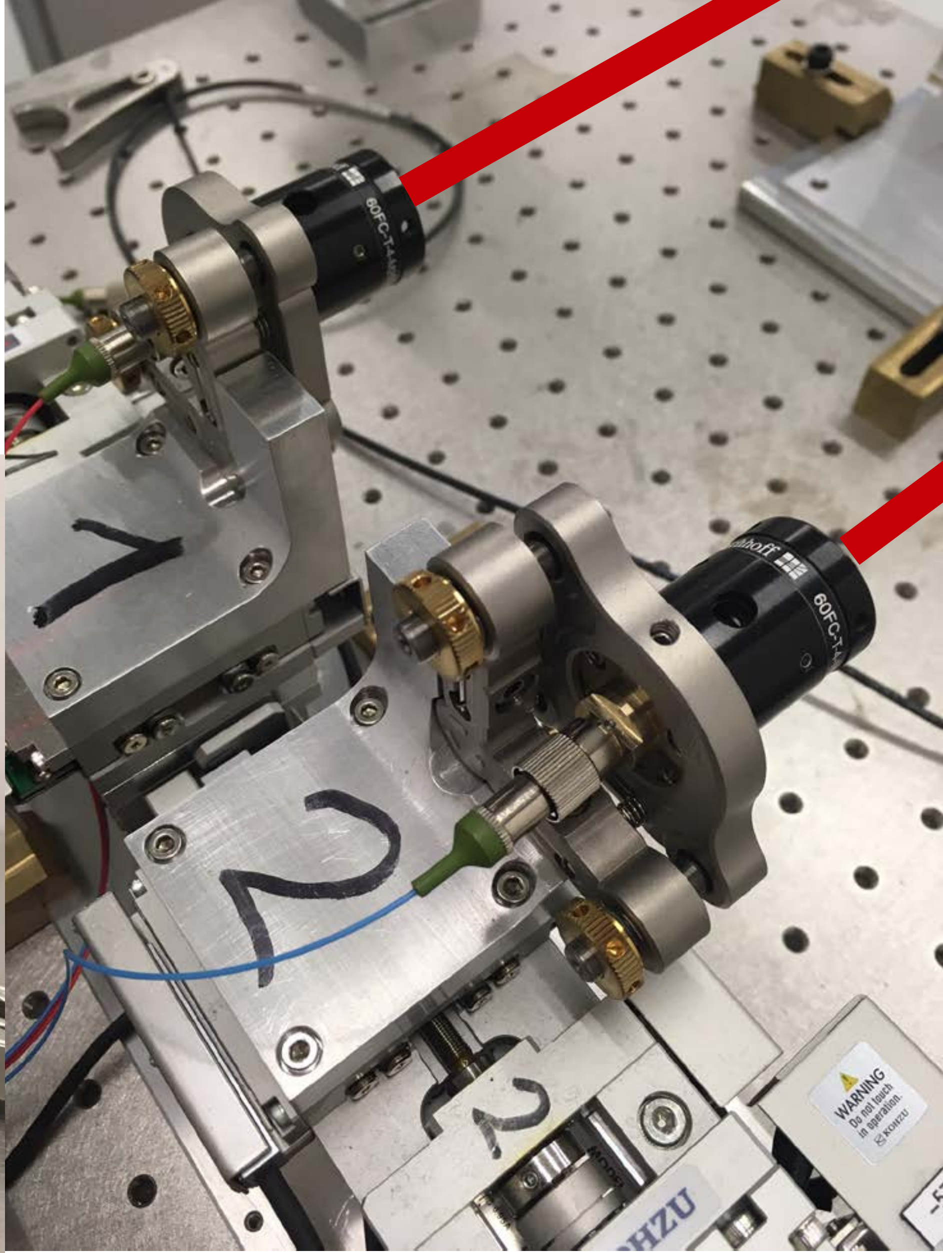

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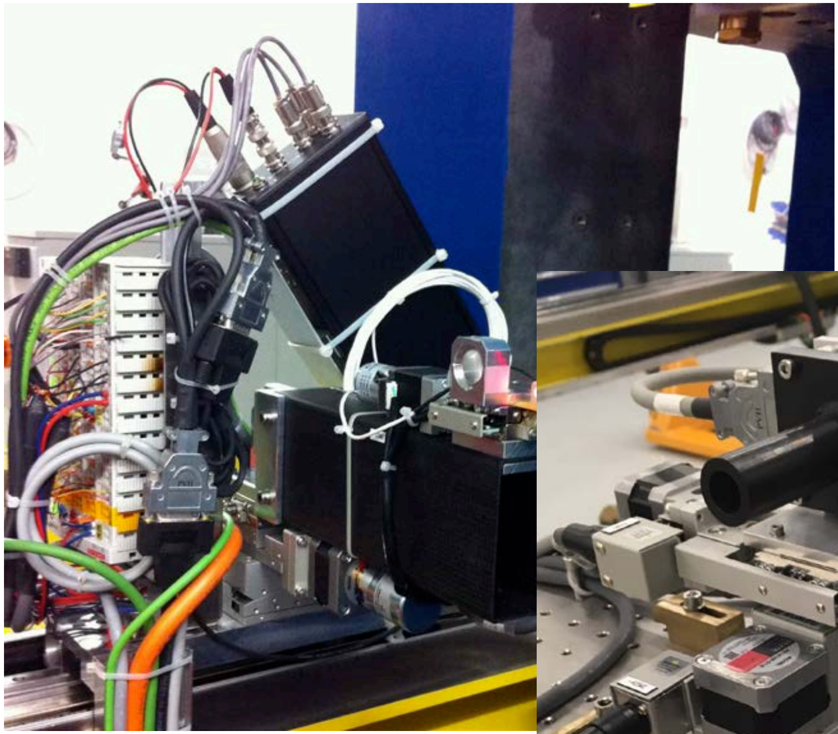
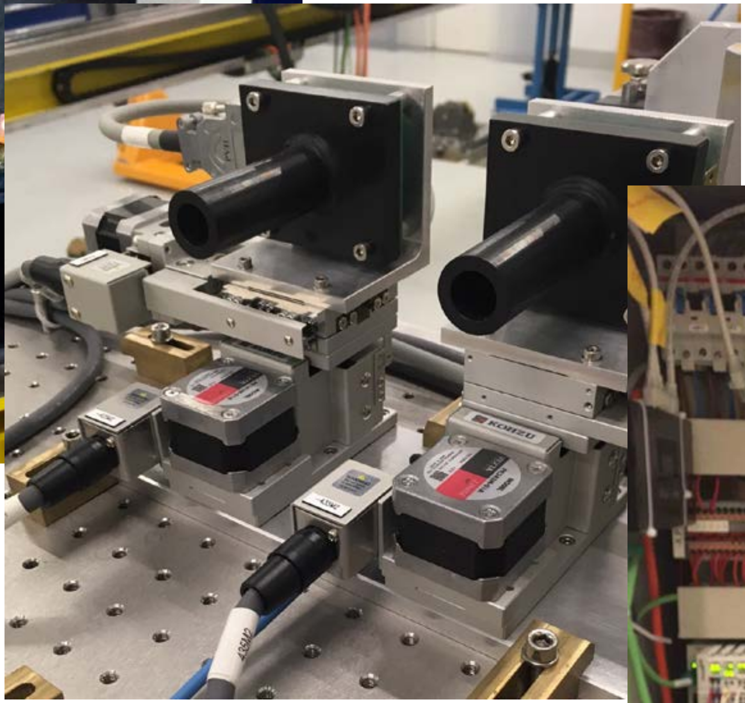
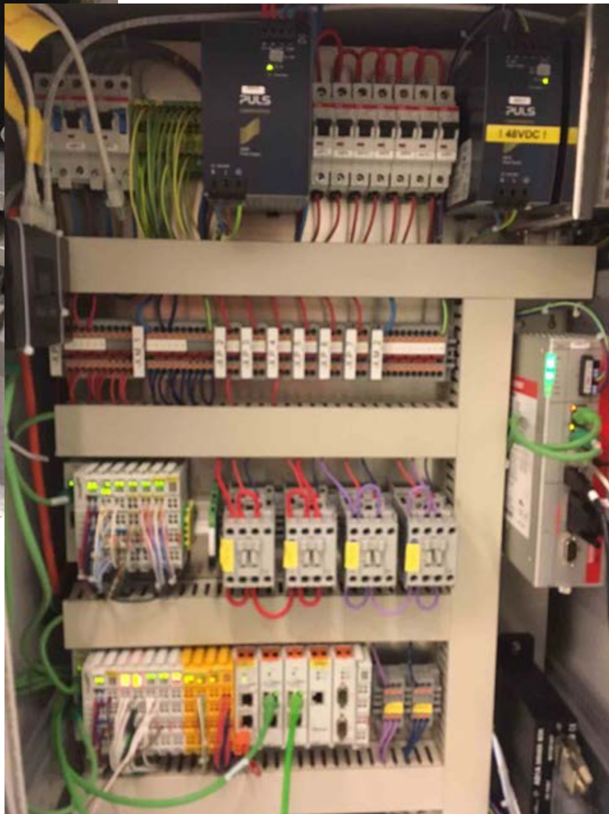
Measuring bench







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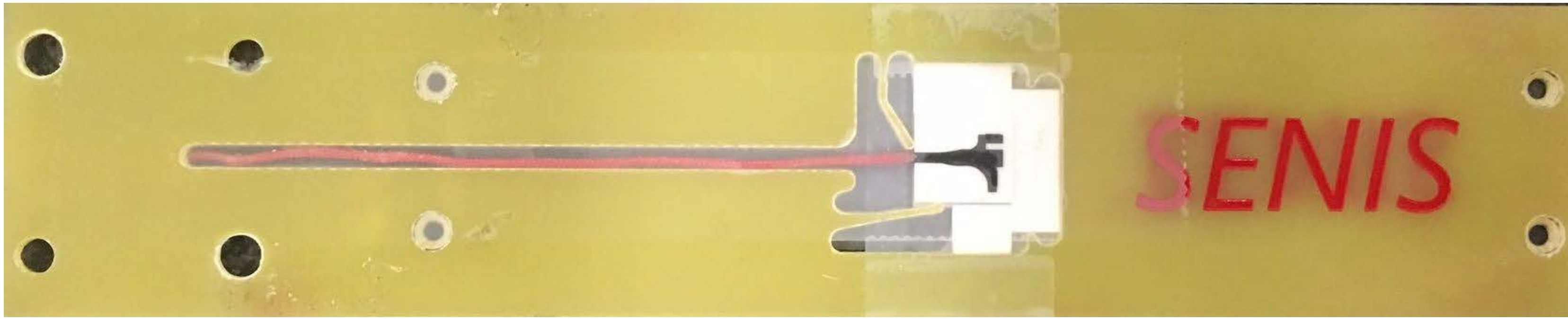
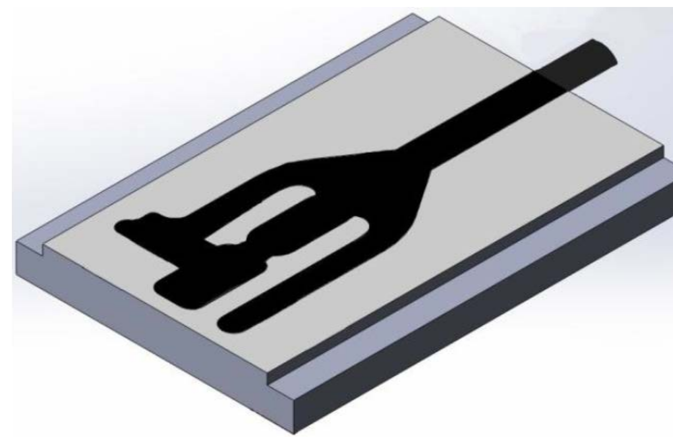




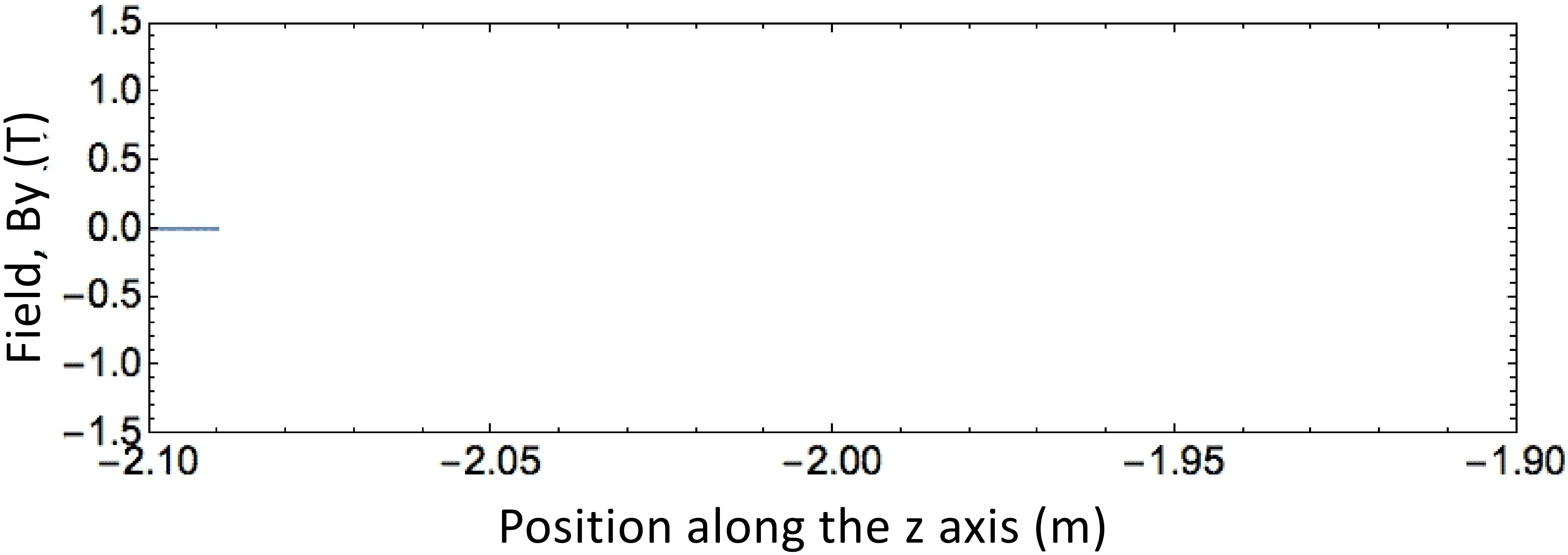
Dimensions: 1.4x10.5x15.0mm3

Mutual orthogonality: <2°

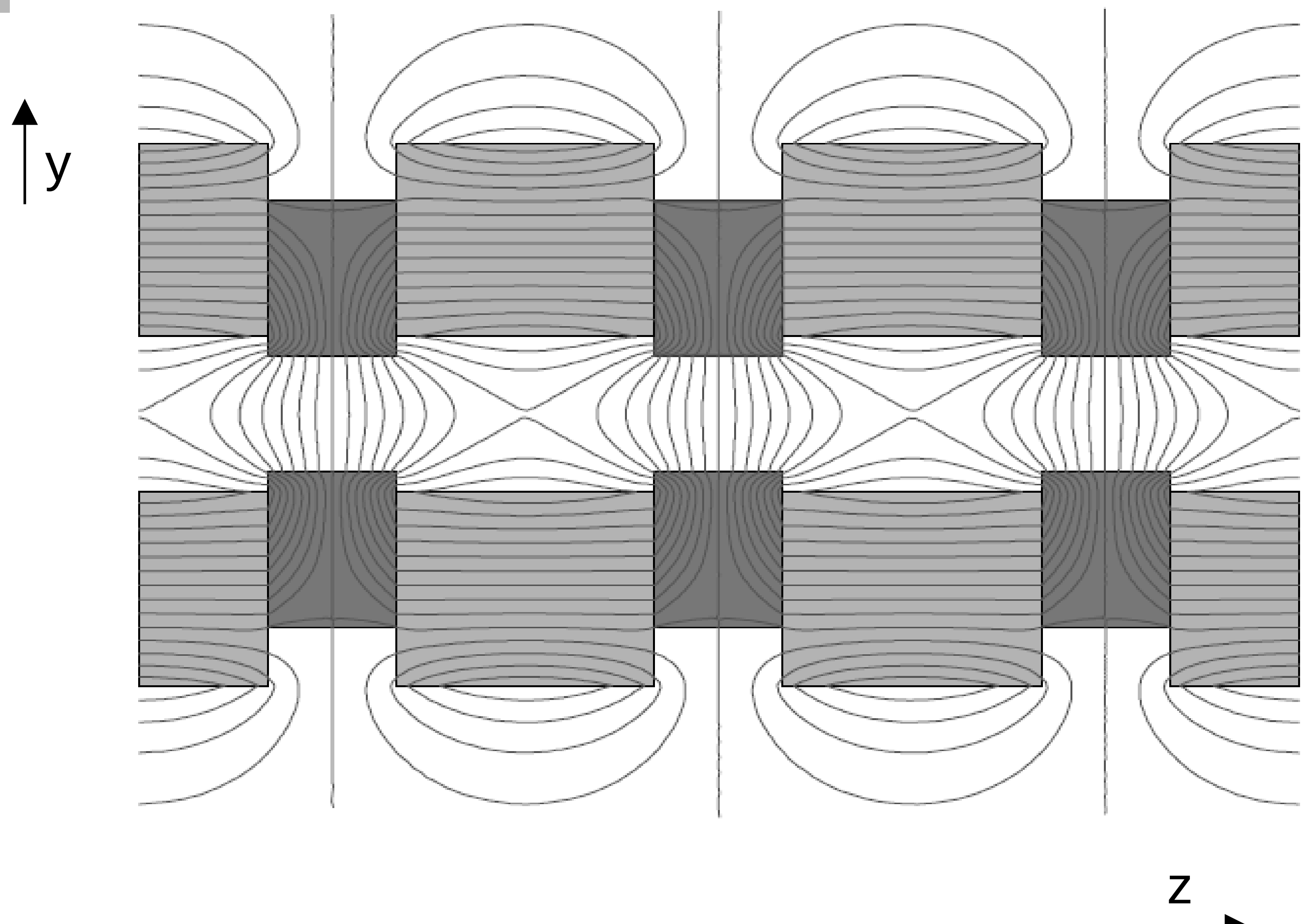
Angular accuracy with respect to the reference surface: ±2°

The three probes are all at the same height of 0.7 (middle of the probe) and horizontal position, while they are spaced longitudinally by 2mm

Measurement example – Raw data

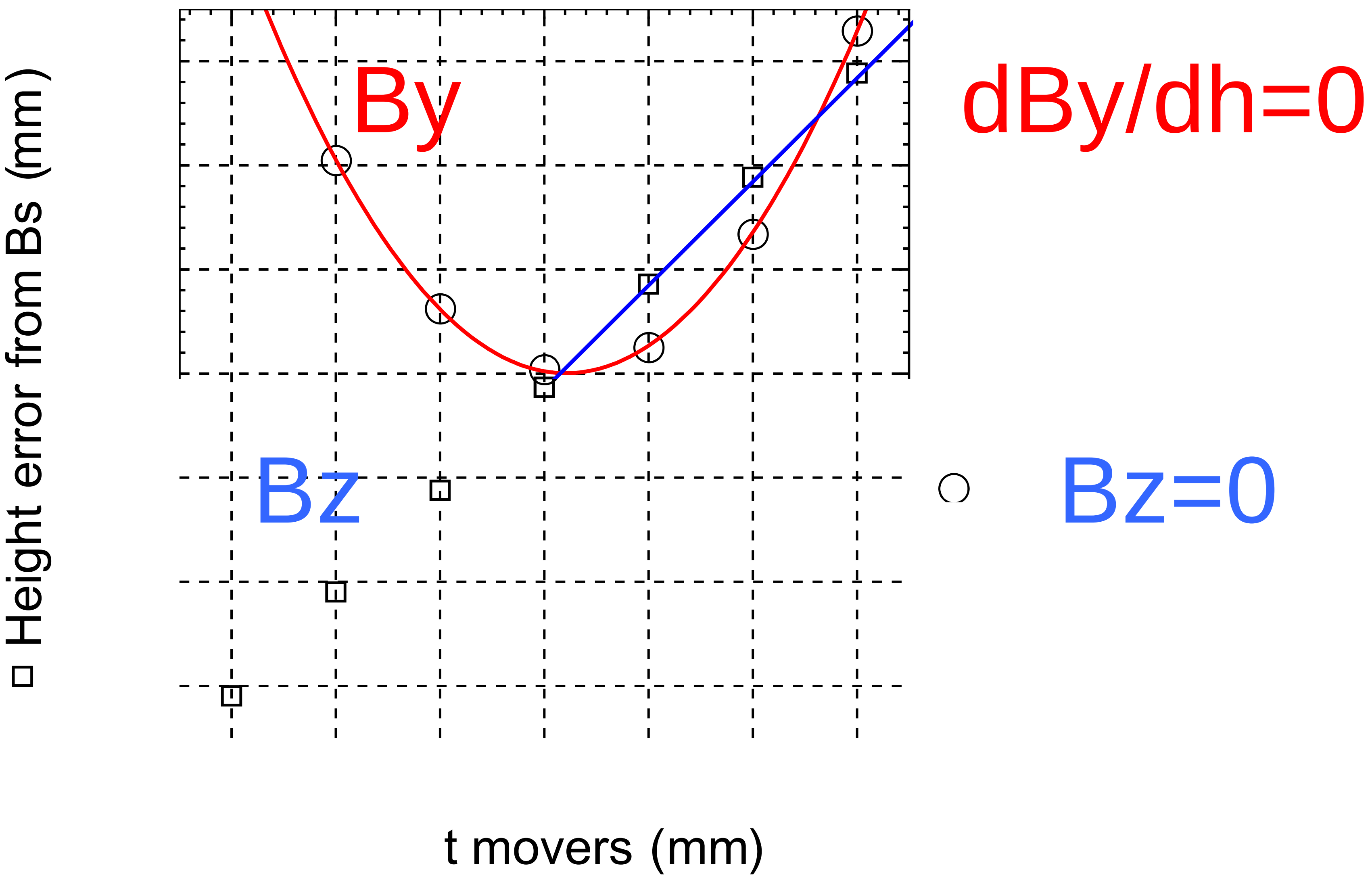


axis definition: $\frac{\partial B_y}{\partial y} = 0$ or $B_z = 0$

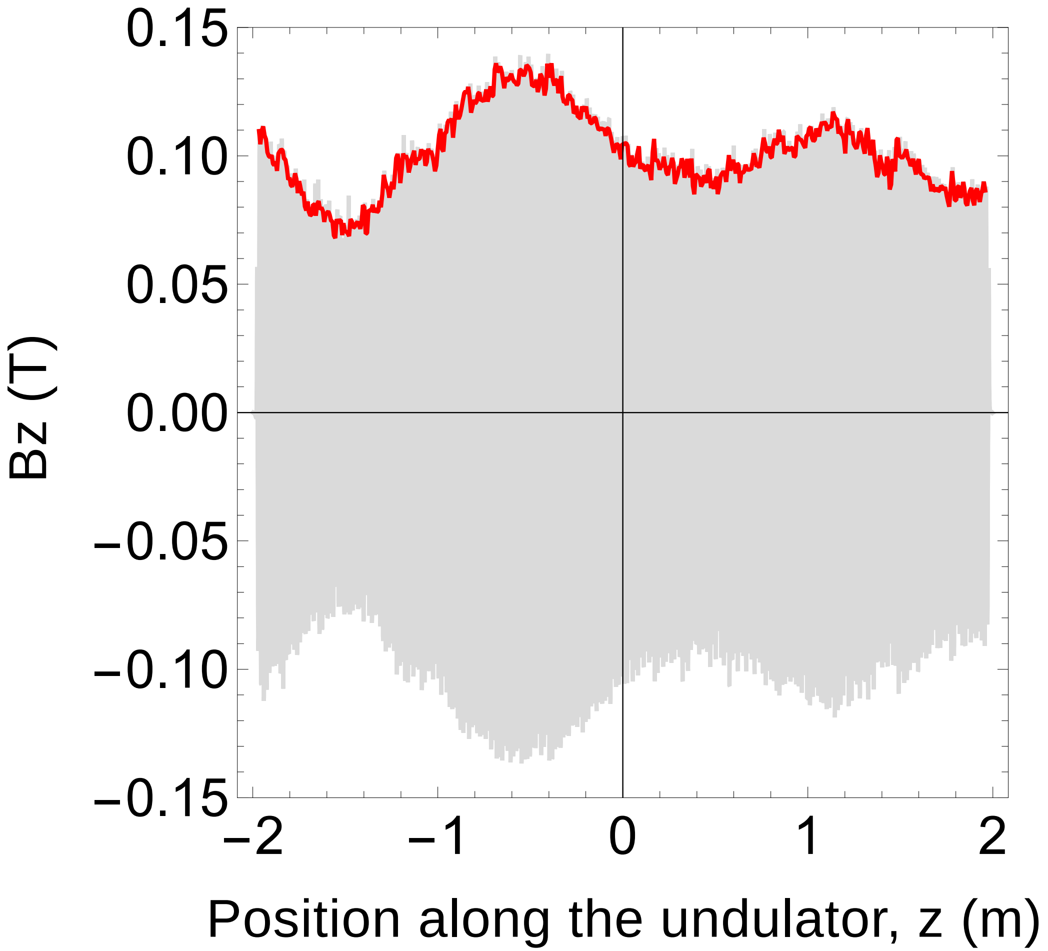


Alignment

Prototype

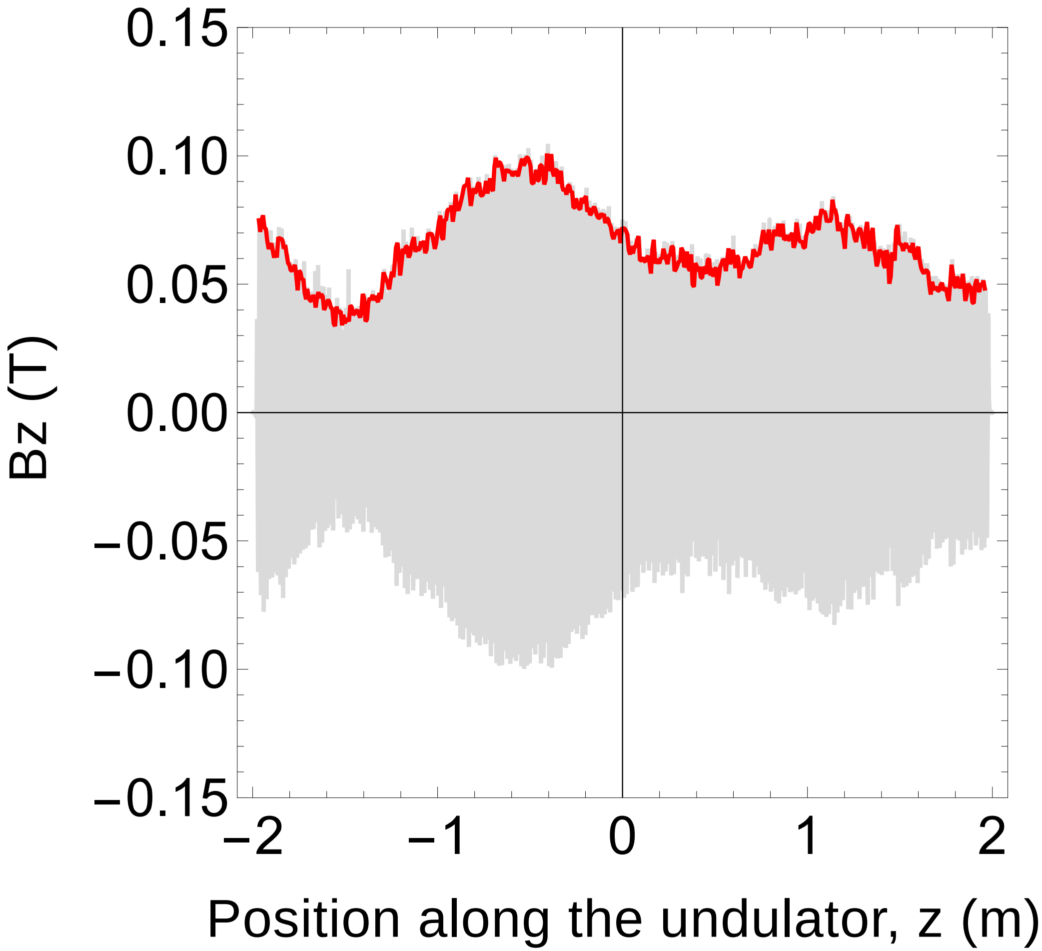


Alignment



0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
Bz (T)
−2
−1
0
1
2
Position along the undulator, z (m)

Alignment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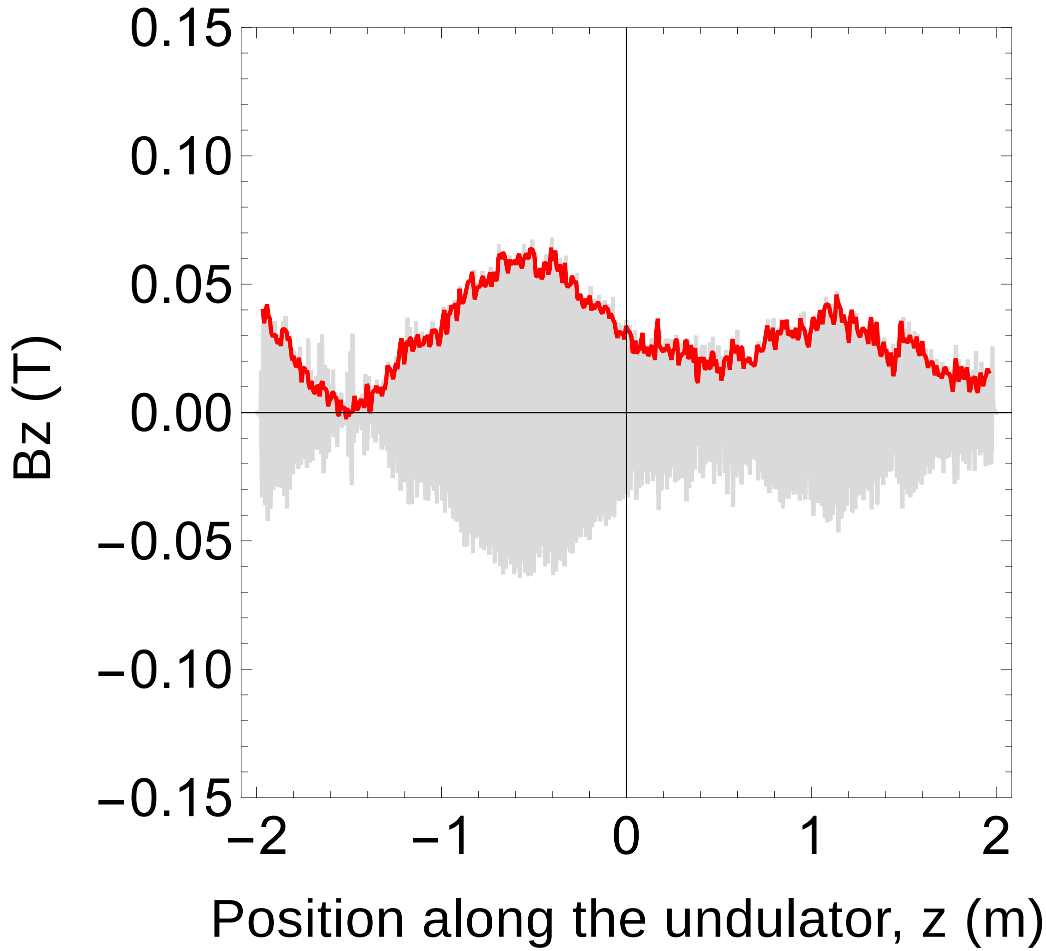
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0.10
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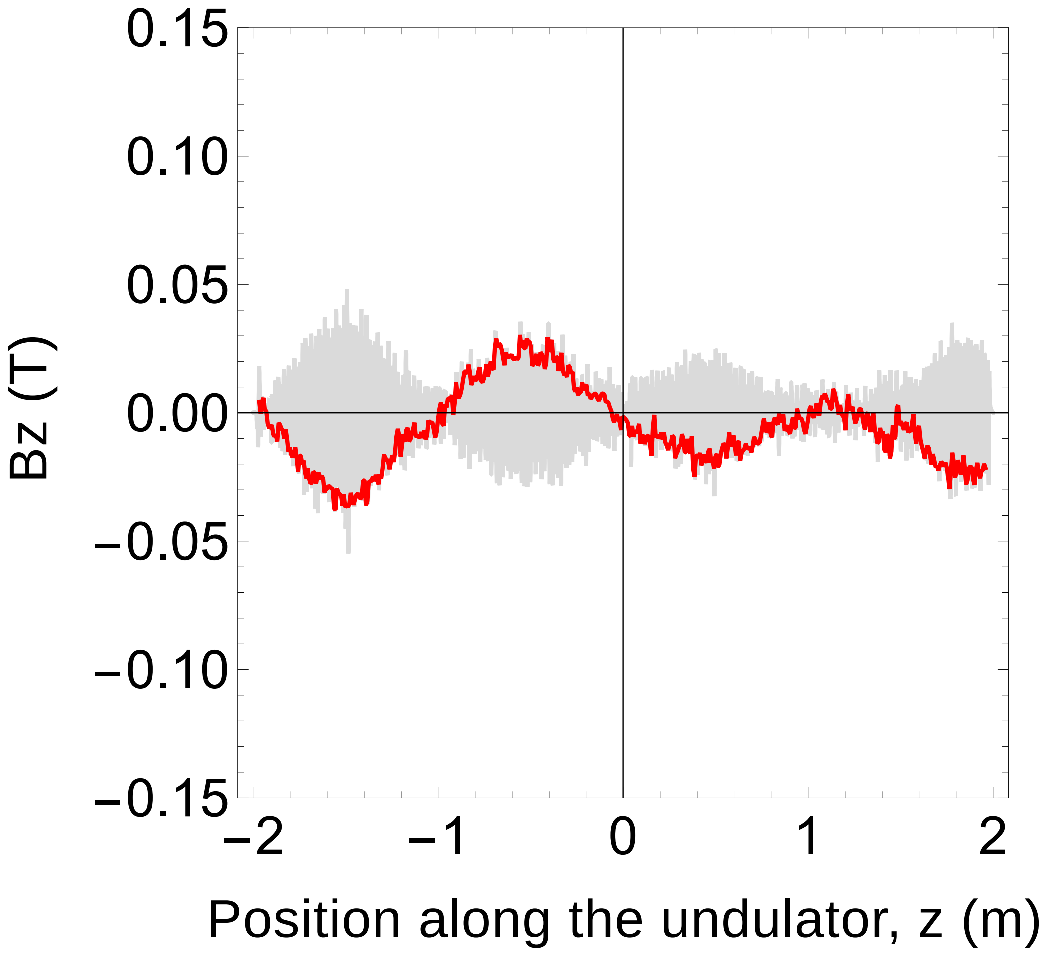
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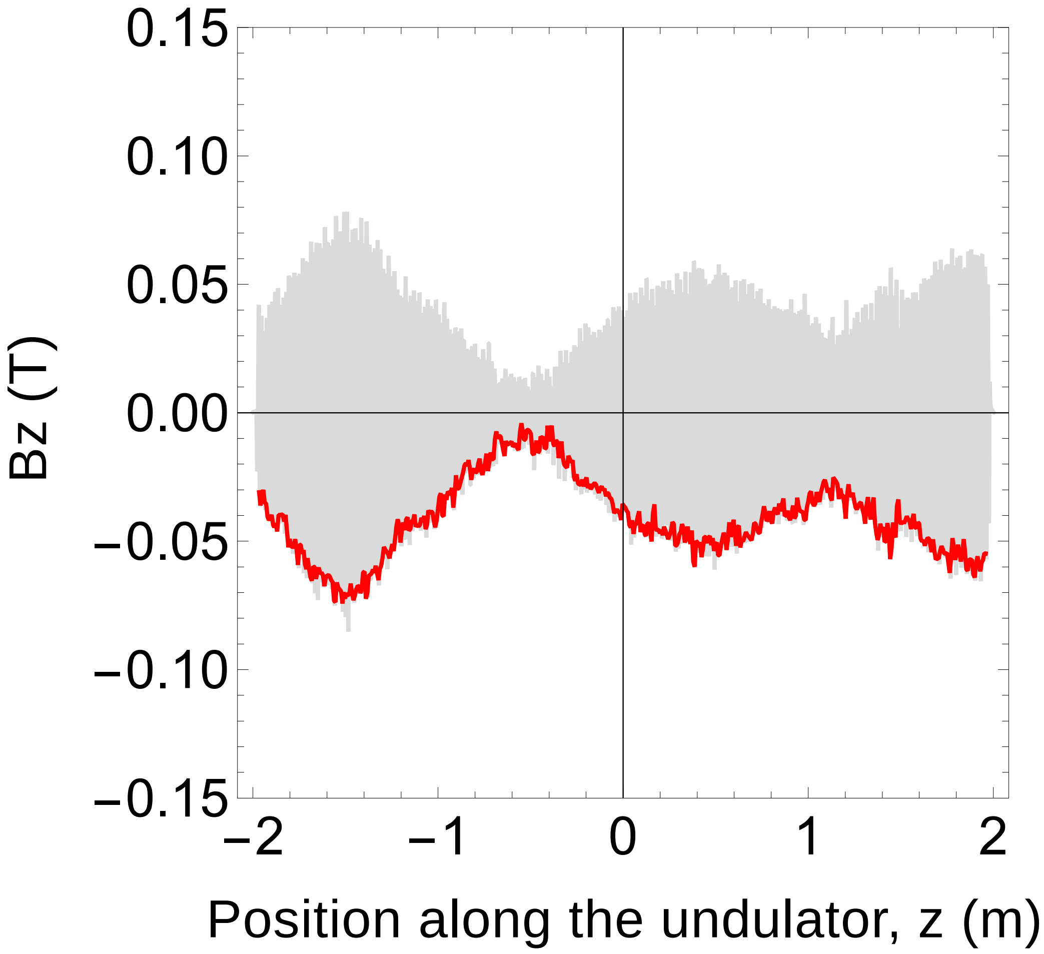
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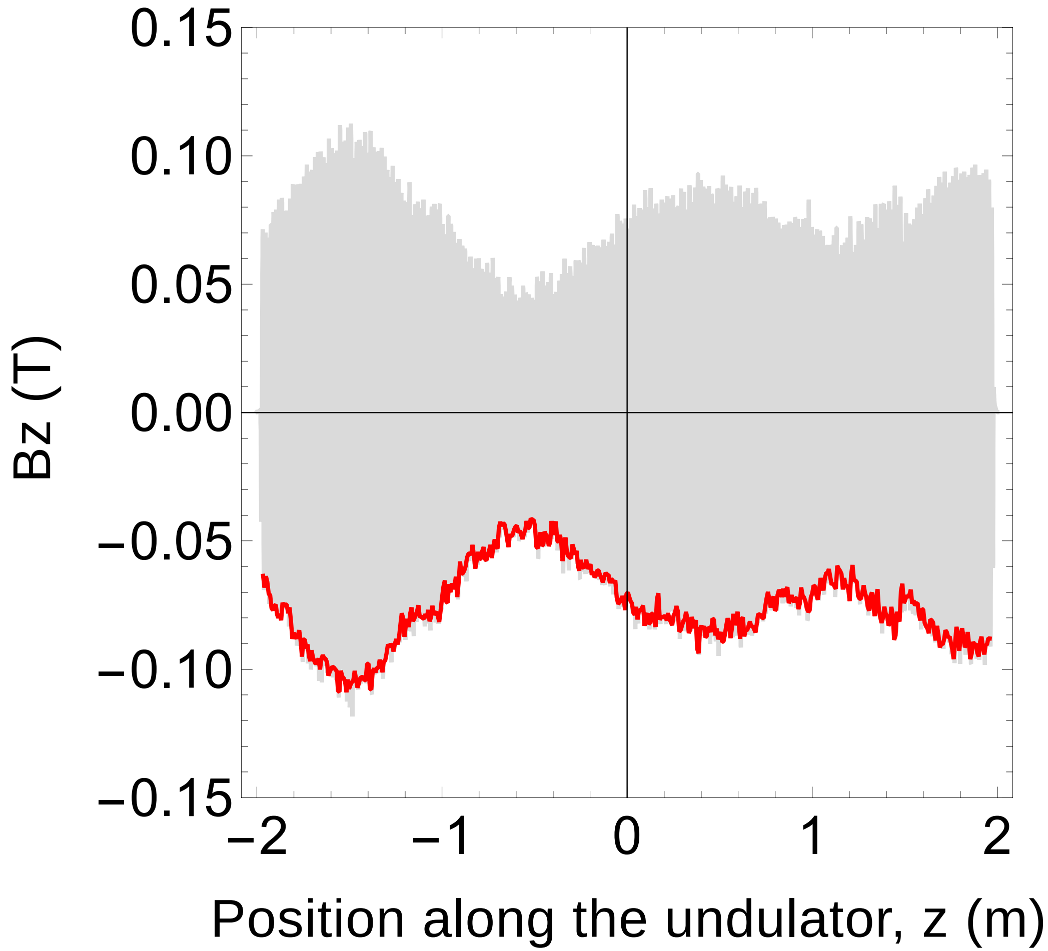
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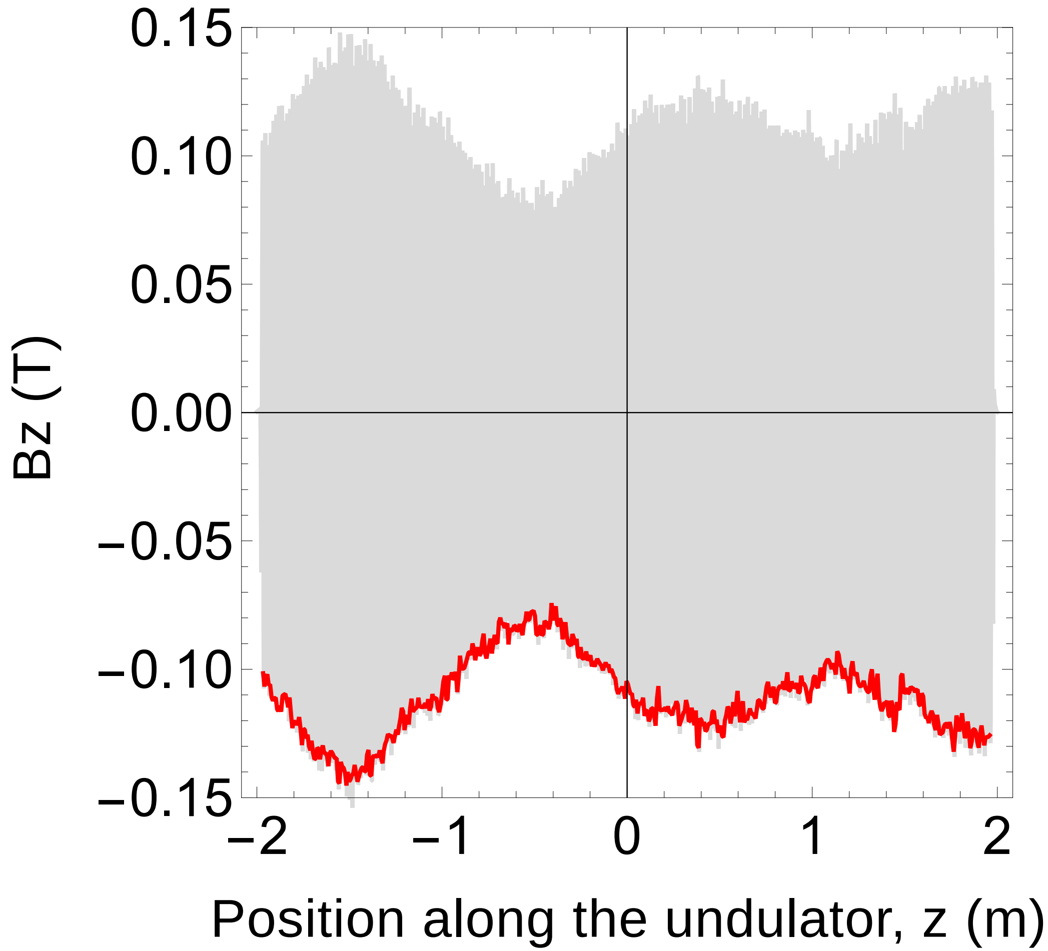
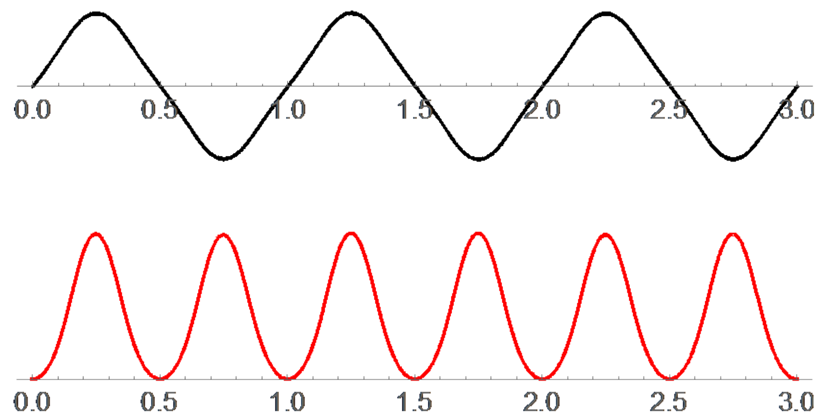


0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
Bz (T)
−2
−1
0
1
2
Position along the undulator, z (m)

Correction of the integrals

$\tilde{B}_\xi(z)$ the magnetic field component, x or y

$$B_\xi(z) = \tilde{B}_\xi(z) + \alpha_\xi \tilde{B}^2_\xi(z)$$



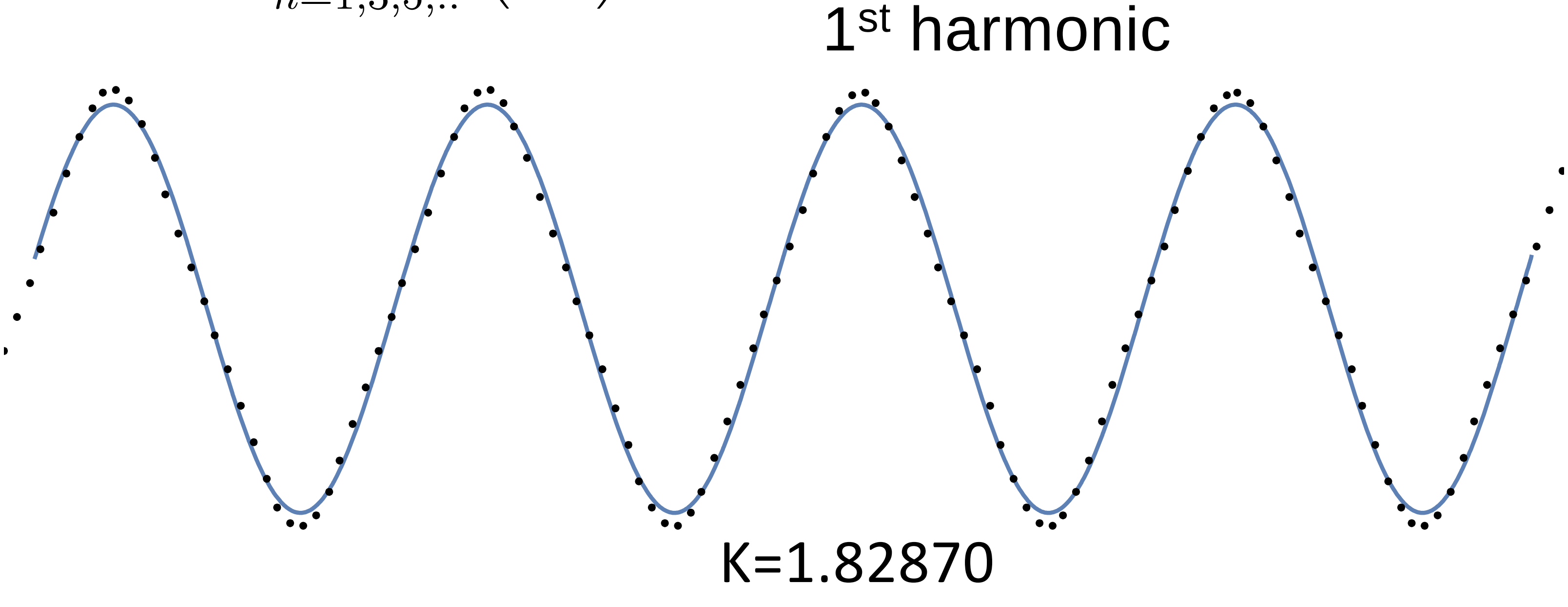
$$I_\xi = \int_{s_0}^{s_1} \tilde{B}_\xi(s)ds + \alpha \int_{s_0}^{s_1} \tilde{B}^2_\xi(s)ds$$

This is the field integral, in x or y, measured with an independent and more accurate system: *MOVING WIRE*

Measurement of the K

$$K = \frac{e}{2\pi mc}\lambda_u B_e$$

$$B_e^2 = \sum_{n=1,3,5,..}\left(\frac{\hat{B}_n}{n}\right)^2$$



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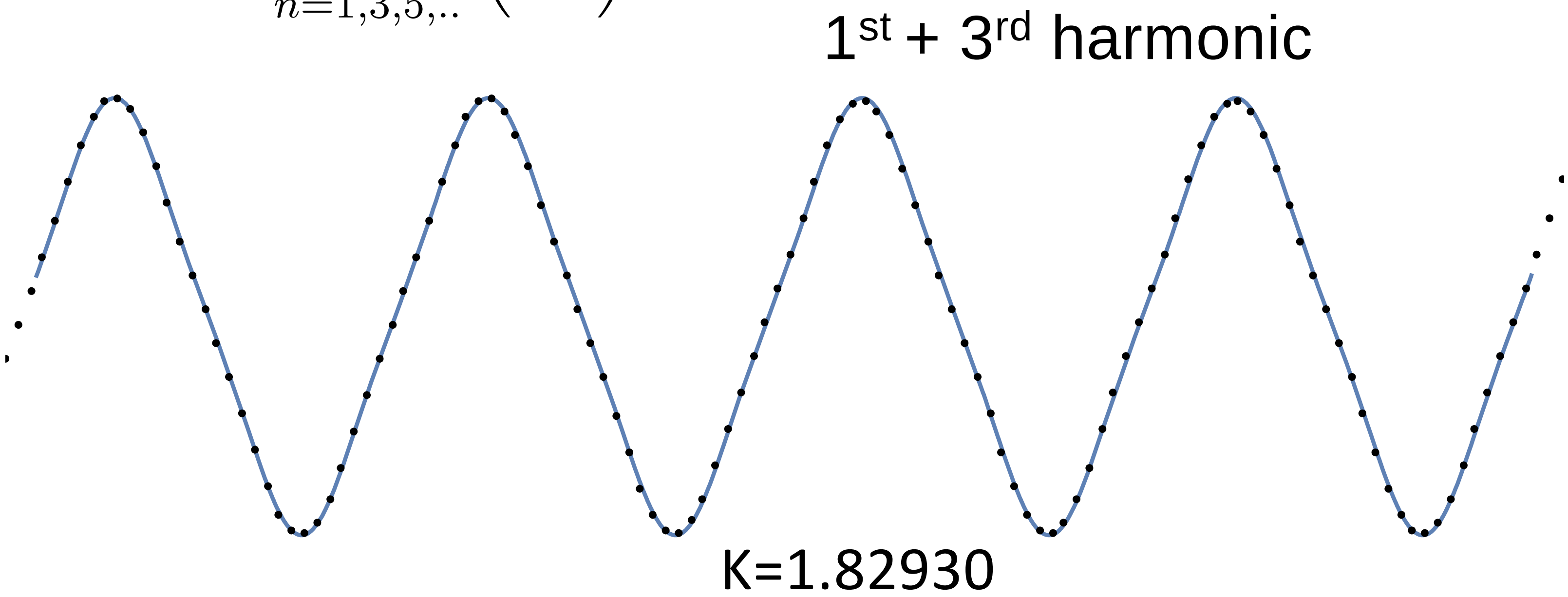

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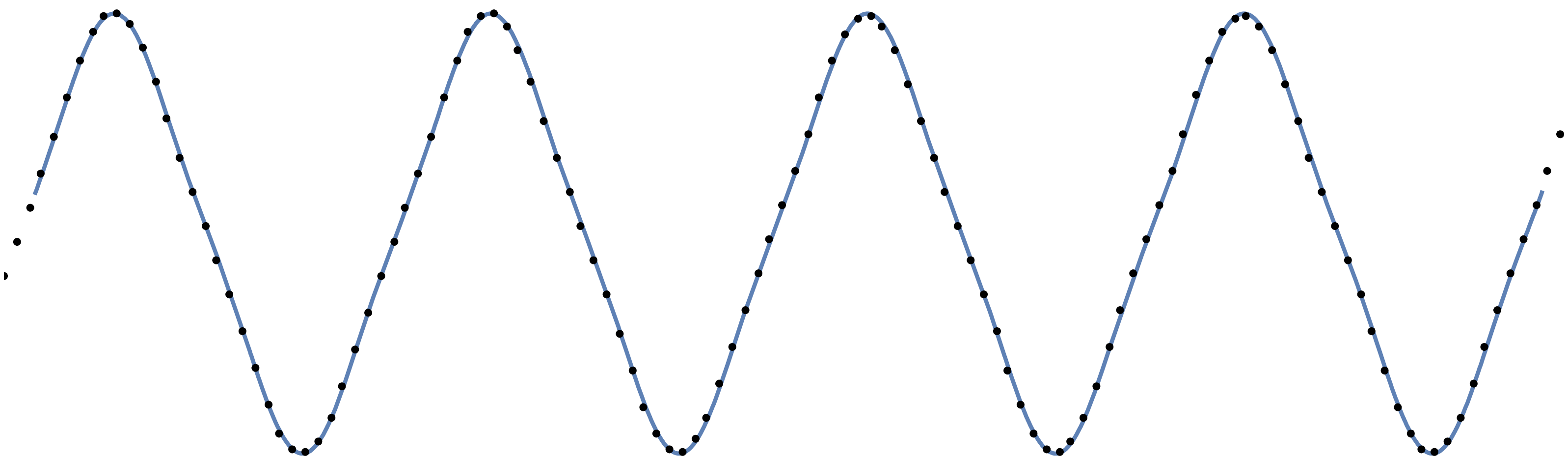
1st + 3rd + 5th harmonic



K=1.82930

Measurement of the Phase

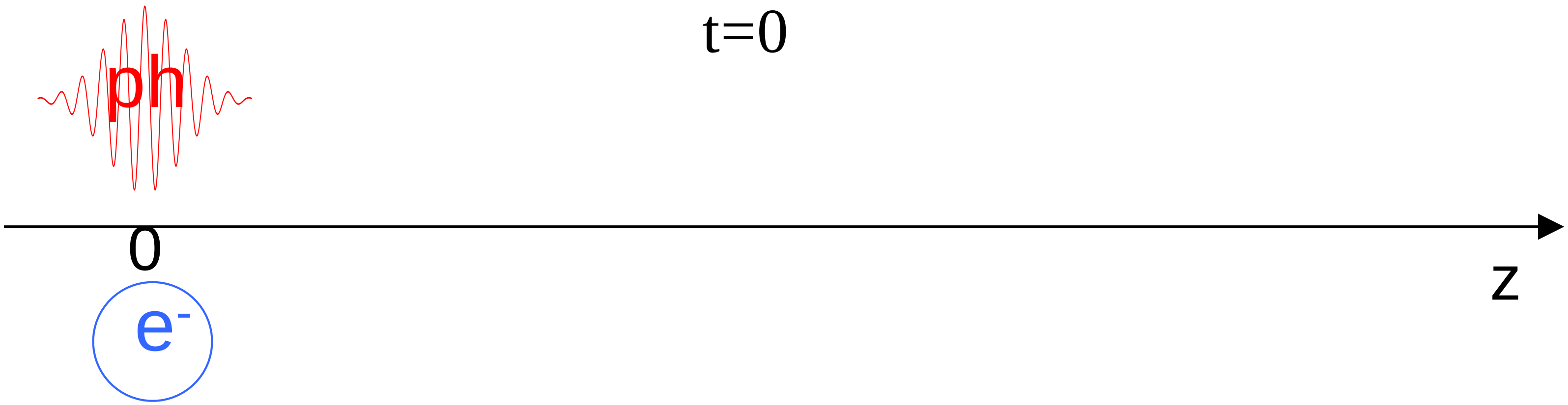
$$\phi(z) = \frac{1}{2\lambda}\left(\frac{z}{\gamma^2} + \int_0^z \dot{x}^2(z')dz'\right)$$

$$\dot{x}(z) = \frac{e}{\gamma mc}\int_0^z B(z')dz'$$

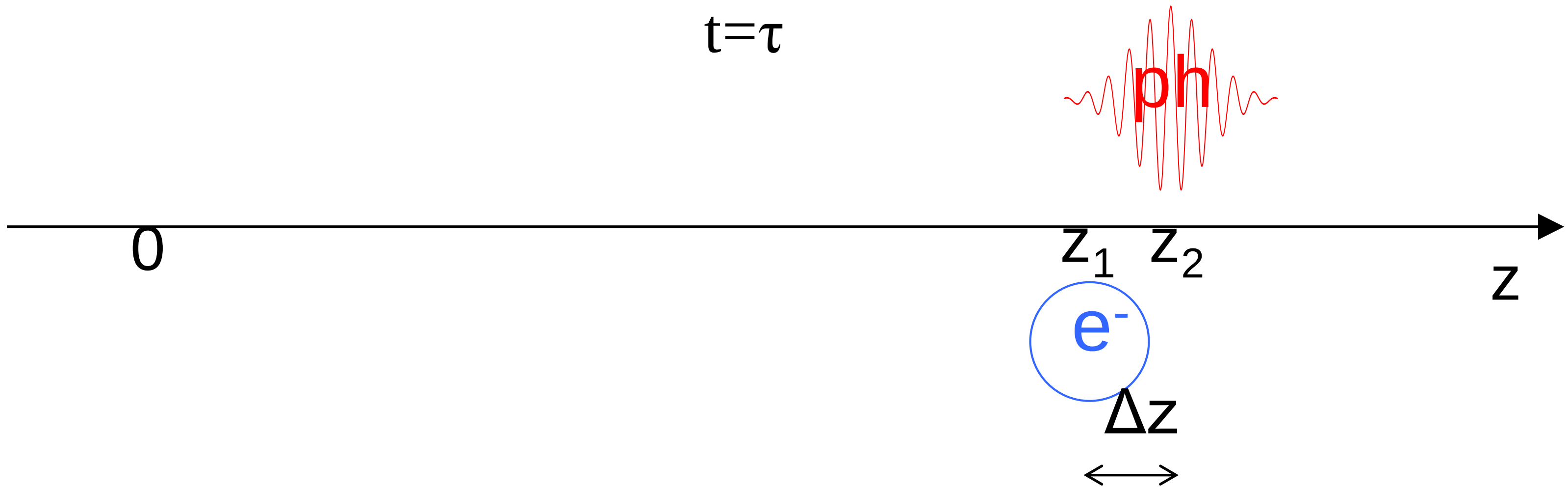
?

Measurement of the Phase

t=0



Measurement of the Phase



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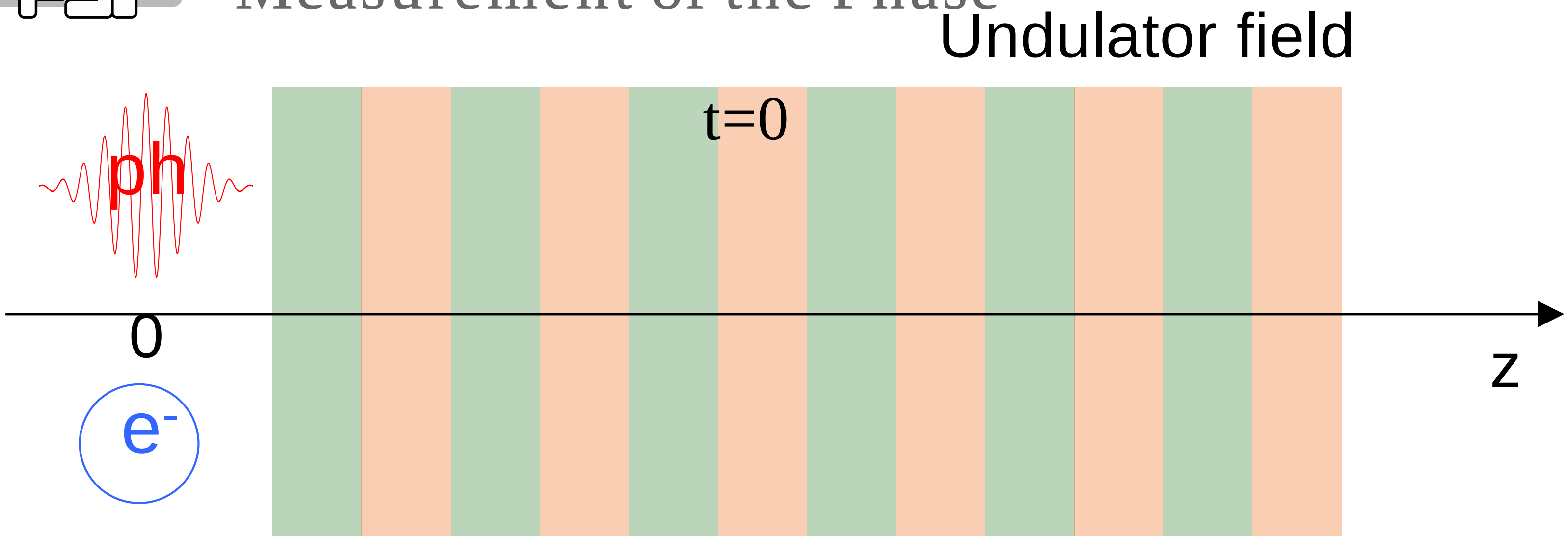

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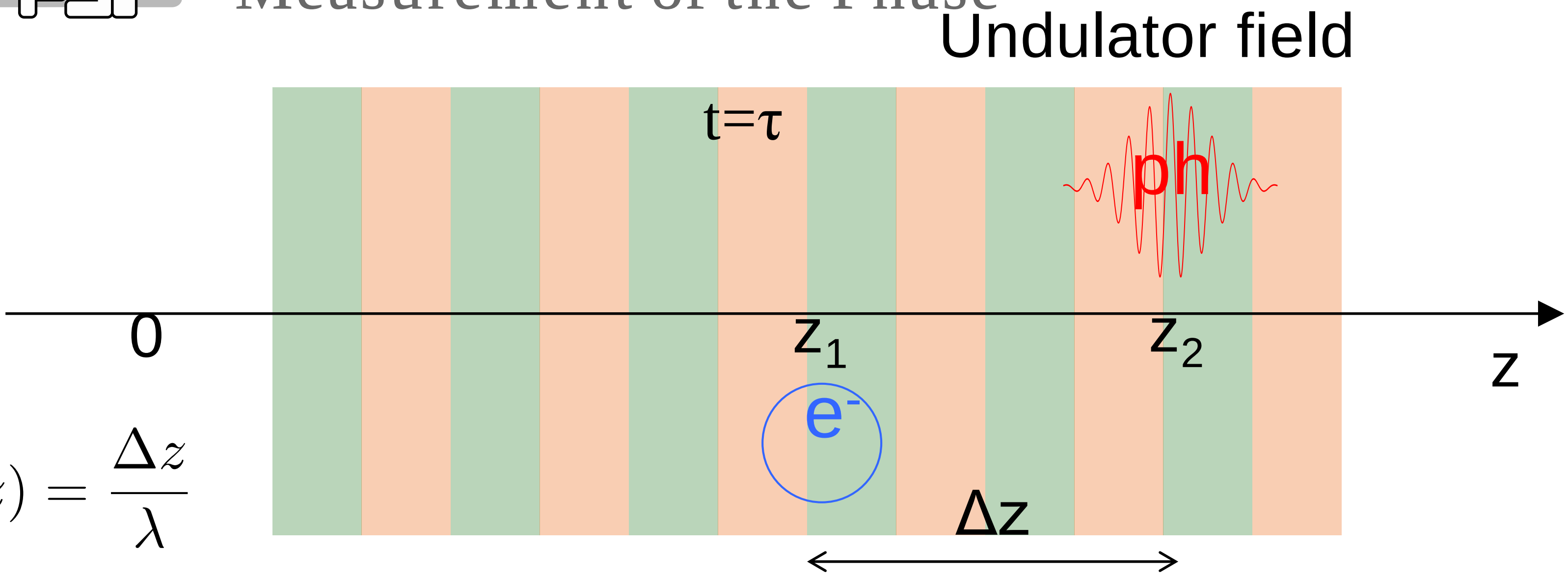

$$\phi(z) = \frac{\Delta z}{\lambda}$$

$$dt = \frac{dz}{v_z}$$

$$\tau = \int_0^{z_1} \frac{dz}{v}$$

$$\int_0^{z_1} \left(\frac{1}{v} - \frac{1}{c}\right) dz = \int_{z_1}^{z_1+\Delta z} \frac{dz}{c}$$

$$\Delta z = \int_0^{z_1} \frac{c}{v} dz - z_1$$

$$\Delta z = \int_0^{z} \frac{1}{\beta_z(z')} dz' - z$$

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Measurement of the Phase

$$\Delta z = \int_0^z \frac{1}{\beta_z(z')} dz' - z$$

$$\beta_z^2 = \beta^2 - \beta_x^2$$

$$\frac{1}{\beta_z} = \frac{1}{\beta}\left[1 - \left(\frac{\beta_x}{\beta}\right)^2\right]^{-\frac{1}{2}} \approx \frac{1}{\beta}\left[1 + \frac{1}{2}\left(\frac{\beta_x}{\beta}\right)^2\right]$$

$$\Delta z = \left(\frac{1}{\beta} - 1\right) z + \frac{1}{2}\frac{1}{\beta^3}\int_0^z \beta_x^2(z') dz'$$

(with $\left(\frac{1}{\beta} - 1\right) \rightarrow \frac{1}{2\gamma^2}$, and $\frac{1}{\beta^3}$ struck out)

$$\phi(z) = \frac{1}{2\lambda}\left(\frac{z}{\gamma^2} + \int_0^z \dot{x}^2(z') dz'\right)$$

$$\beta_x \approx \frac{dx}{dz} = \dot{x} = \frac{e}{\gamma m c}\int_0^z B_y(z') dz'$$

Measurement of the Phase

$$\phi(z) = \frac{1}{2\lambda}\left(\frac{z}{\gamma^2} + \int_0^z \dot{x}^2(z')dz'\right)$$

$$\dot{x}(z) = \frac{e}{\gamma mc}\int_0^z B(z')dz'$$

$$\phi(z) = \frac{1}{\lambda_u\left(1+\frac{1}{2}K^2\right)}\left(z + \left(\frac{e}{mc}\right)^2 \int_0^z I^2(z')dz'\right)$$

$$I(z) = \int_0^z B(z')dz'$$

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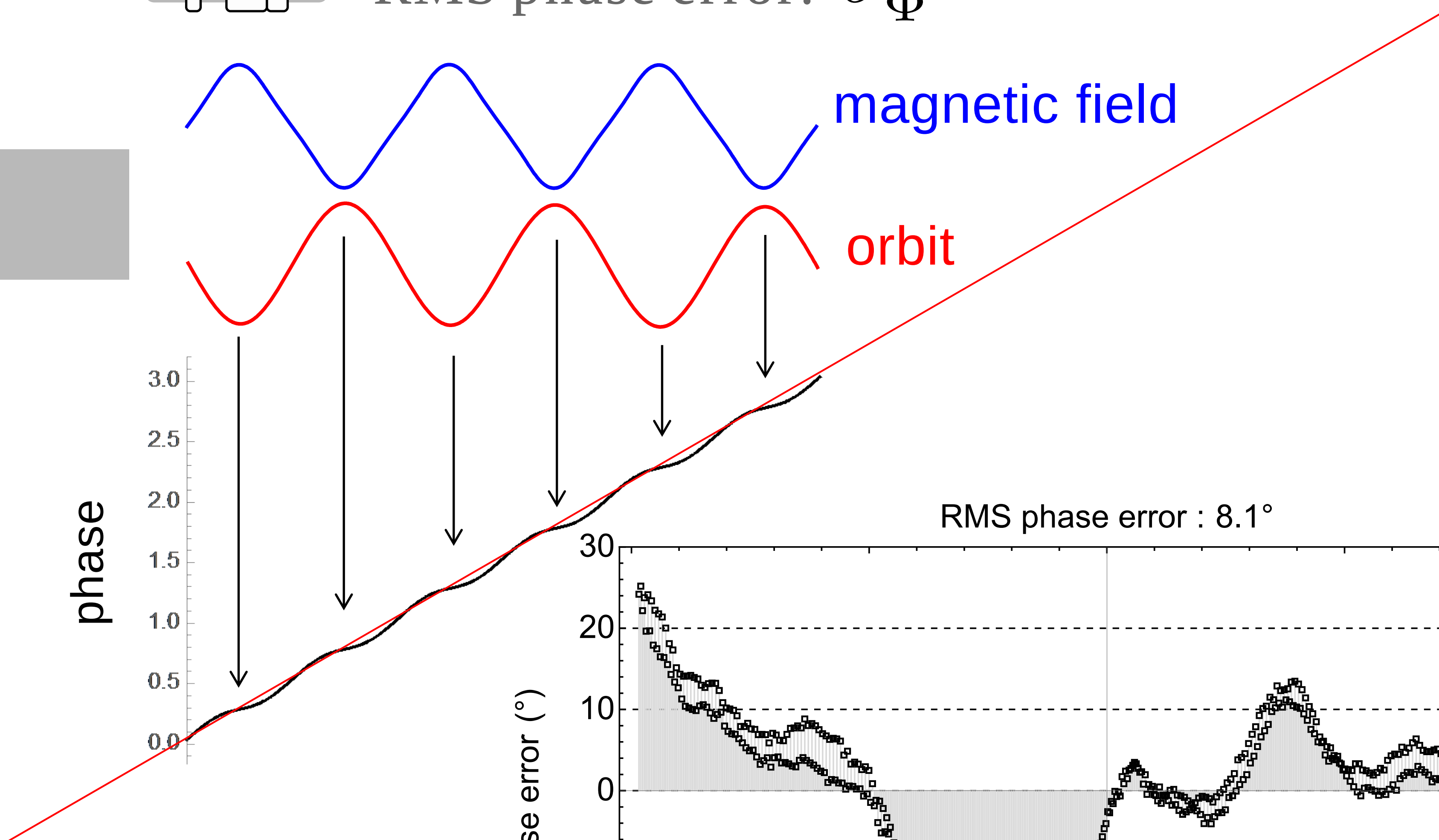
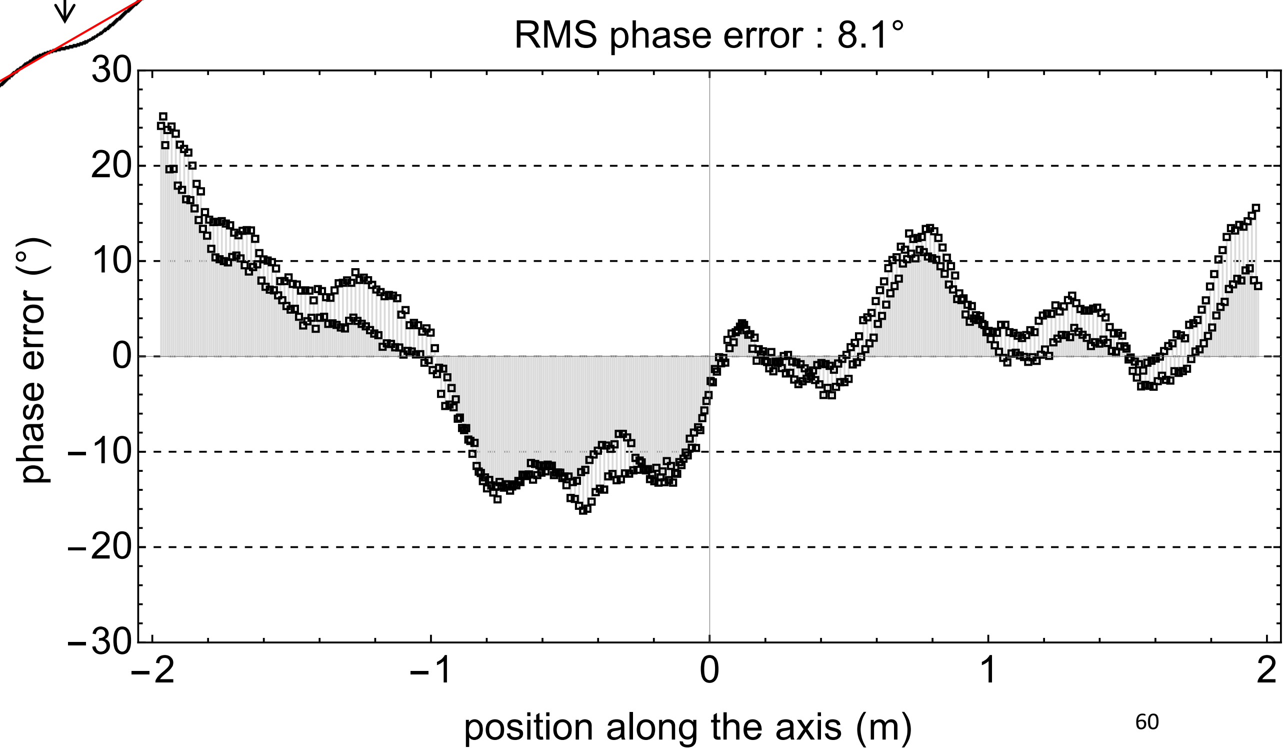
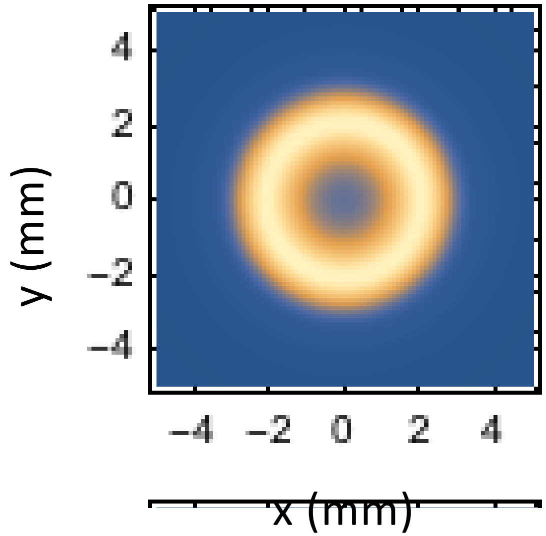
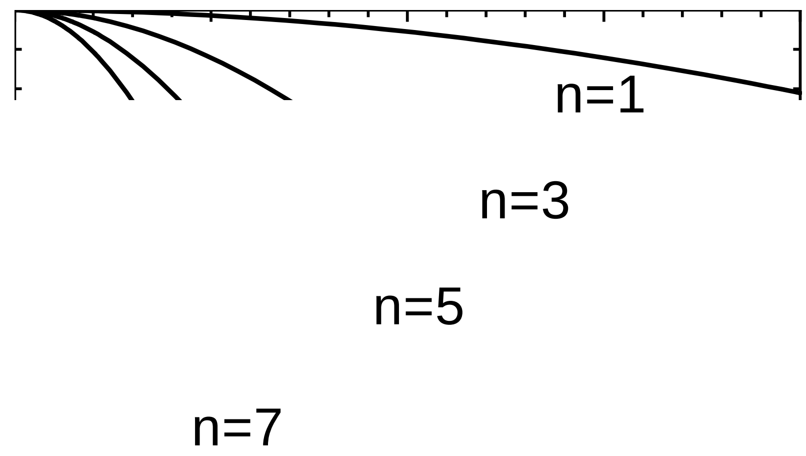
RMS phase error: σ_{Φ}^{2}





RMS phase error: σ_{Φ}^{2}





$$R \approx e^{-n^2 \sigma_{\Phi}^{2}}$$

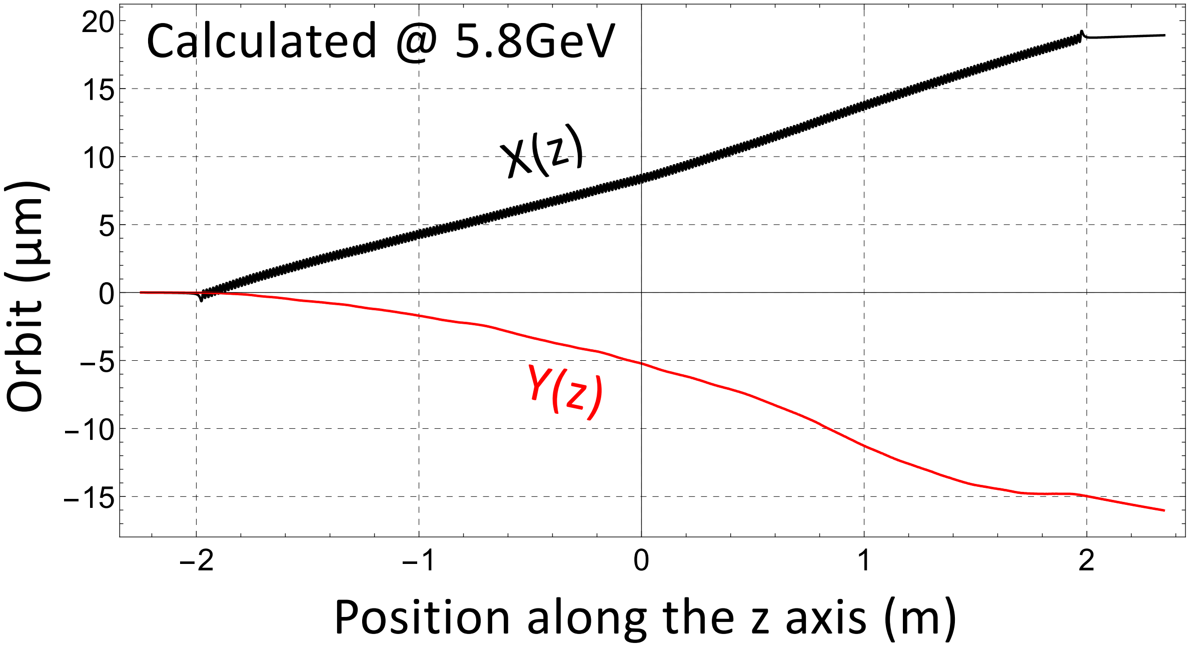
R is the relative intensity

n is the harmonic number

R.P.Walker, Nucl. Instrum. Methods 335 (1993) 328-337

Measurement of the Orbit distortion

$$x/y(z) = \frac{e}{\gamma mc} \int_{-\infty}^{z} \int_{-\infty}^{z'} B_{y/x}(z'')dz''dz'$$



$$\xi(z) = \begin{cases} 0 & z < z_i \\ \kappa_i(z - z_i) + \frac{1}{2}E_c(z - z_i)^2 & z_i < z < z_o \\ \kappa_i(z - z_i) + 4E_c z + \kappa_o(z - z_o) & z > z_o \end{cases}$$

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  - K-value
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  - Orbit distortion
- Optimisation
- An example of measurement & optimisation campaign
- The operation based on magnetic measurements
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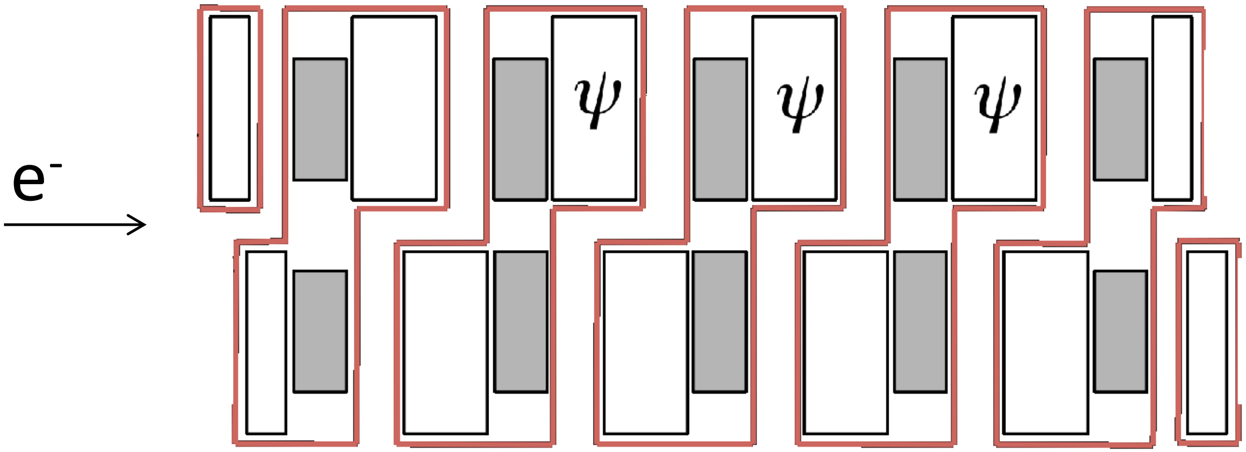
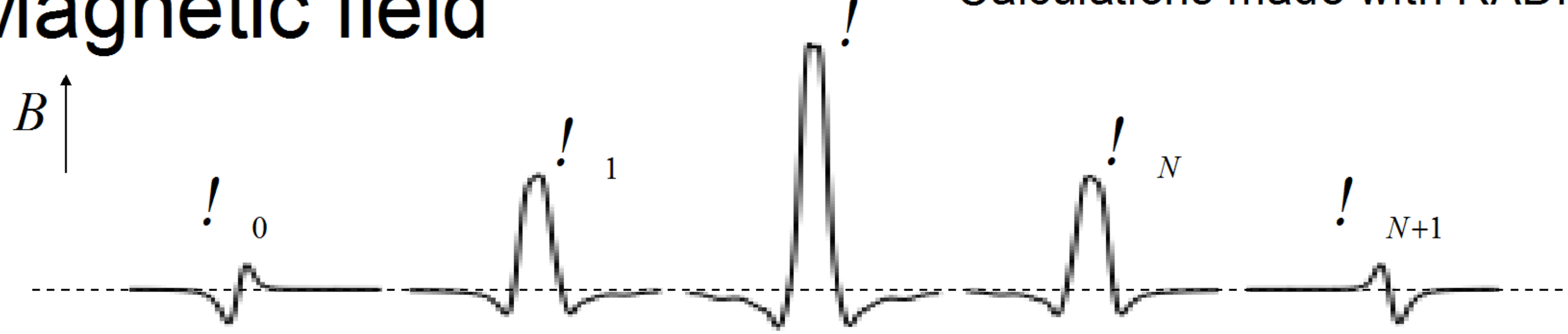
Optimization: field



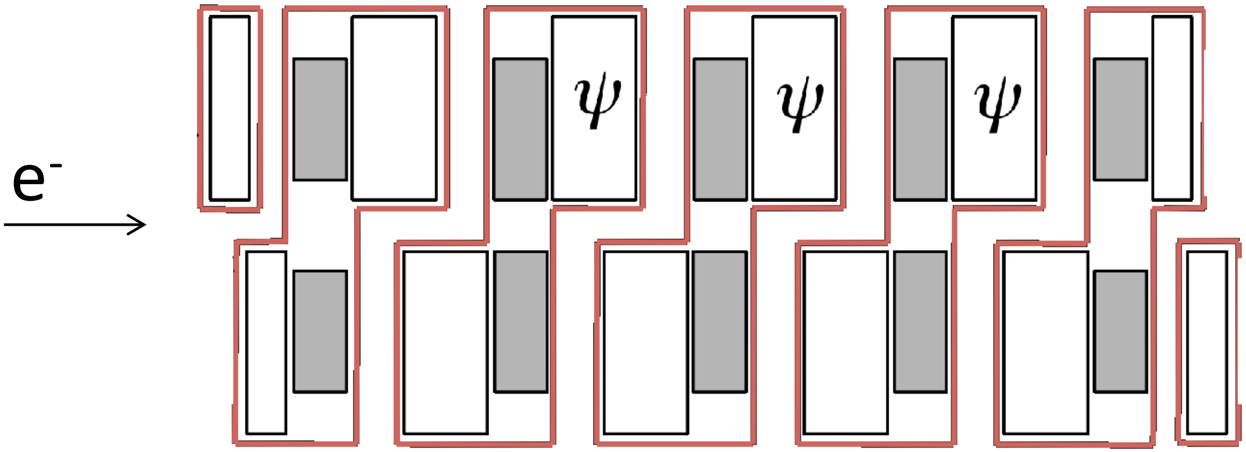
Magnetic field

Calculations made with RADIA



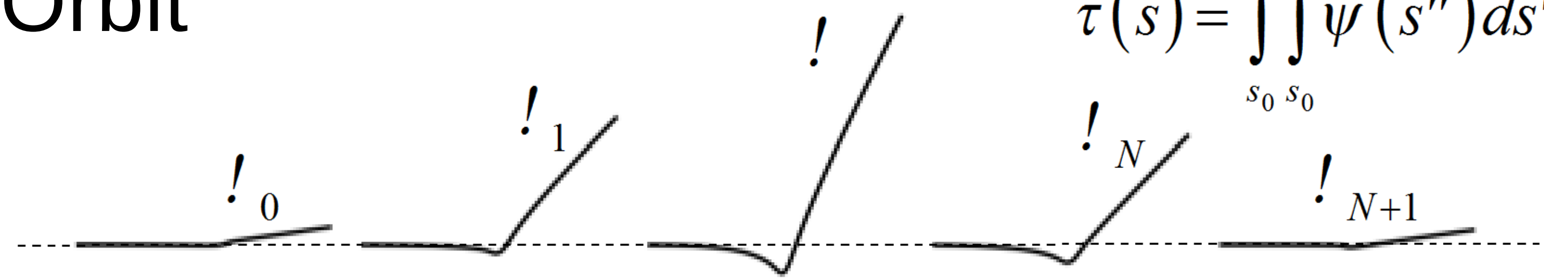
$$\Delta B(s) = \Psi_e(s) + \sum_{n=2}^{N-1} (-1)^n b_n \psi(s - s_n)$$

Optimization: Orbit



Orbit

$$\tau(s) = \int_{s_0}^{s} \int_{s_0}^{s'} \psi(s'')\, ds''$$



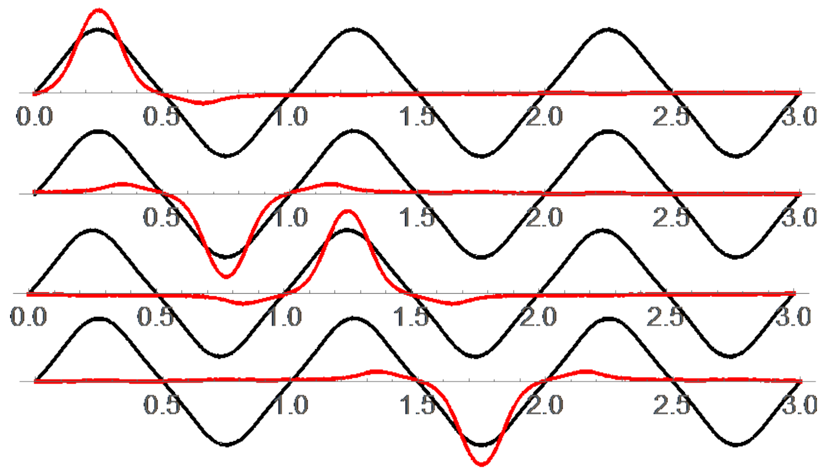
$$\Delta T(s) = \tau_e(s) + \sum_{n=2}^{N-1} (-1)^n b_n \tau(s - s_n)$$

Local-K Optimisation

Simulations

$$p_{n,m} = \frac{1}{\delta h} \int_{z_n}^{z_{n+1}} \delta B_y \left(z - \bar{z}_m\right) dz$$

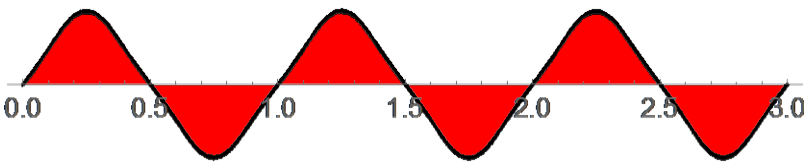
$$\bar{z}_m = \frac{1}{2} \left(z_m + z_{m+1}\right)$$



Measurements

$$k_n = \left| \int_{z_n}^{z_{n+1}} B_y(z) dz \right|$$

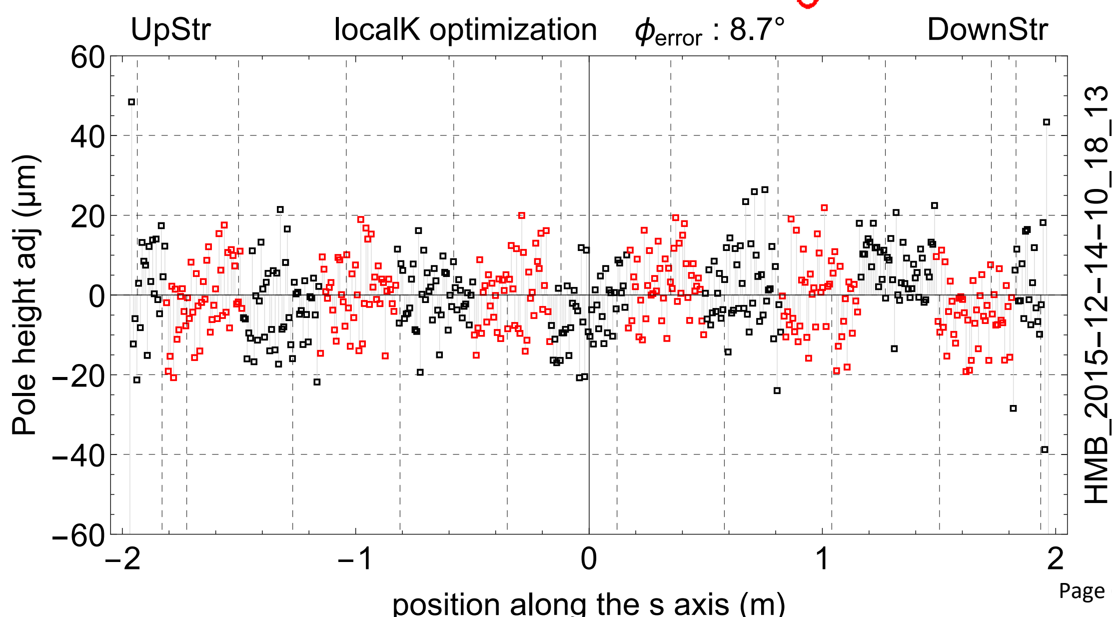
$$\delta k_n = k_n - \langle k_n \rangle$$



Optimisation

$$\delta \mathbf{k} - \mathbf{P}(g) \delta \mathbf{h} = 0$$

$$\boxed{\delta \mathbf{h} = \mathbf{P}^{-1} \delta \mathbf{k}}$$



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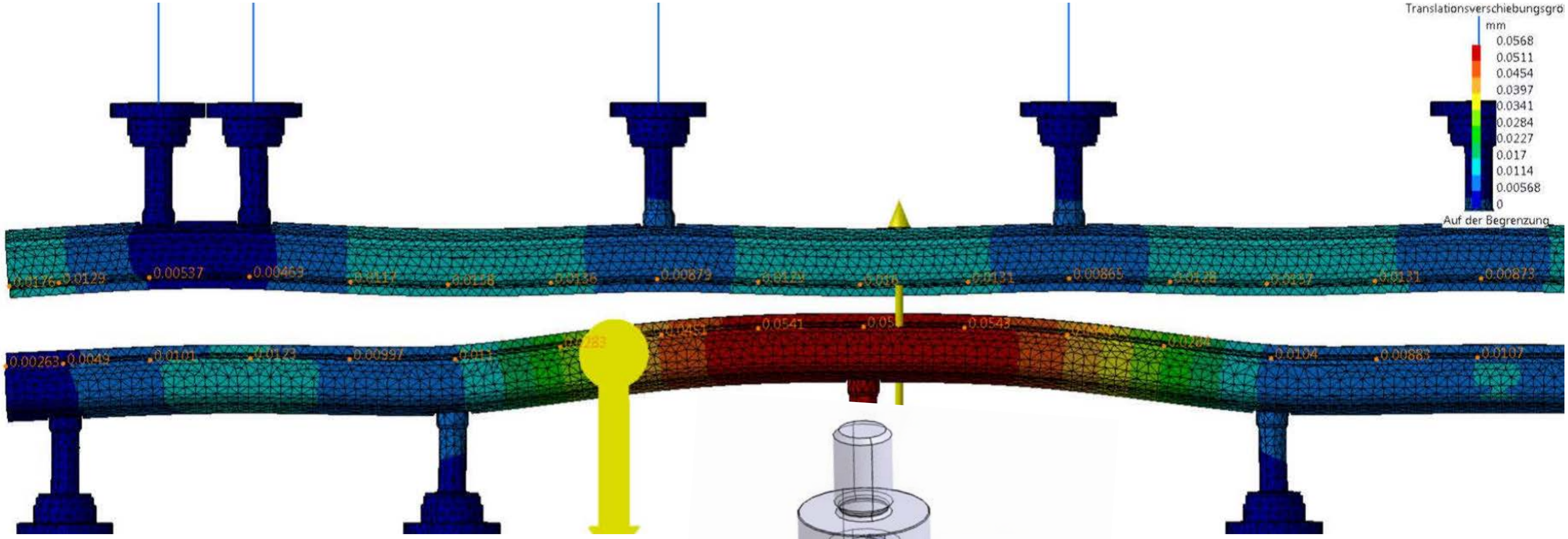
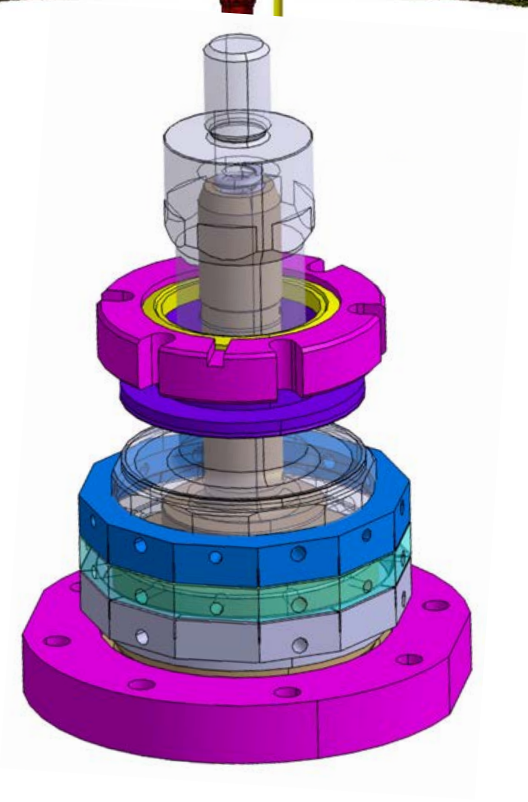
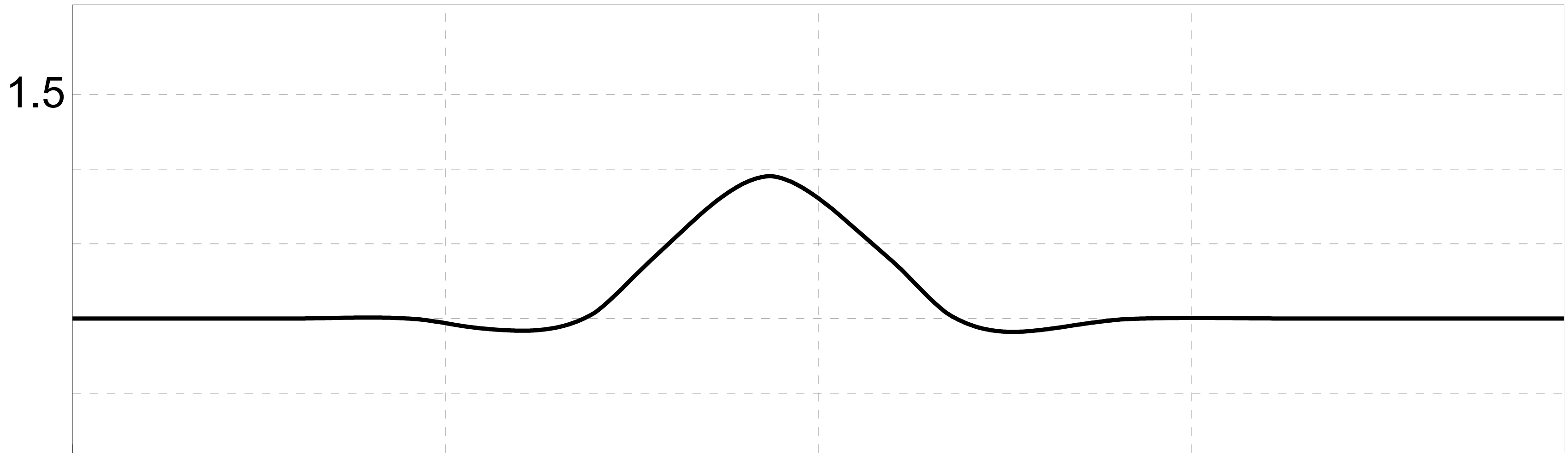
Columns optimisation

Columns optimisation





Columns optimisation



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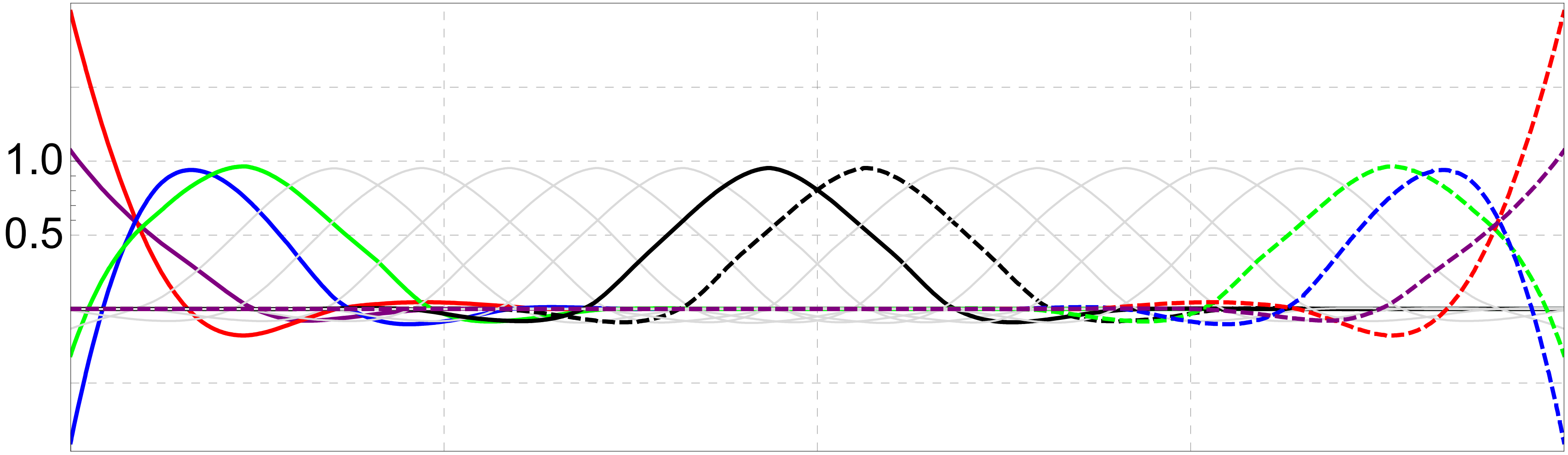
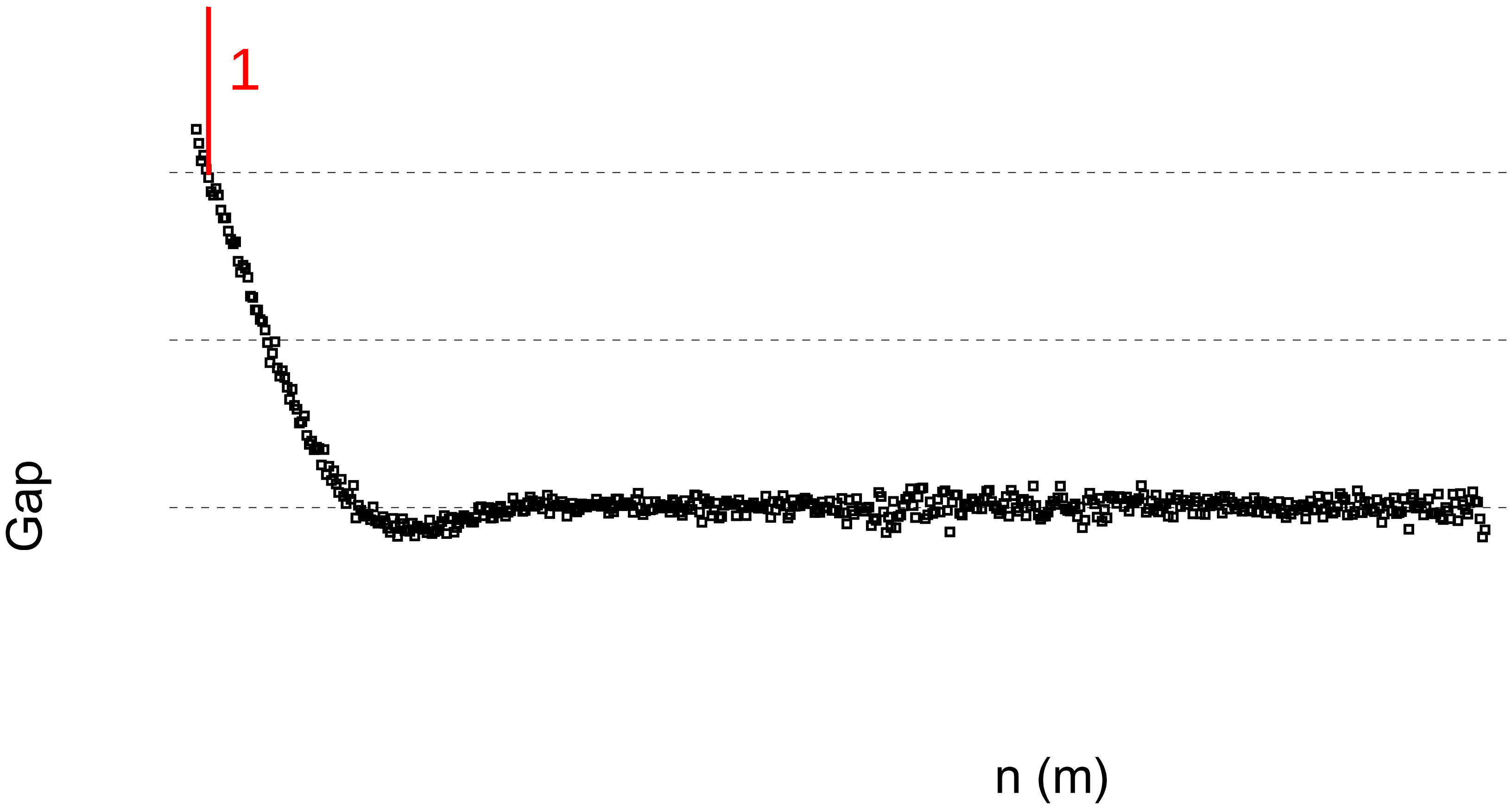
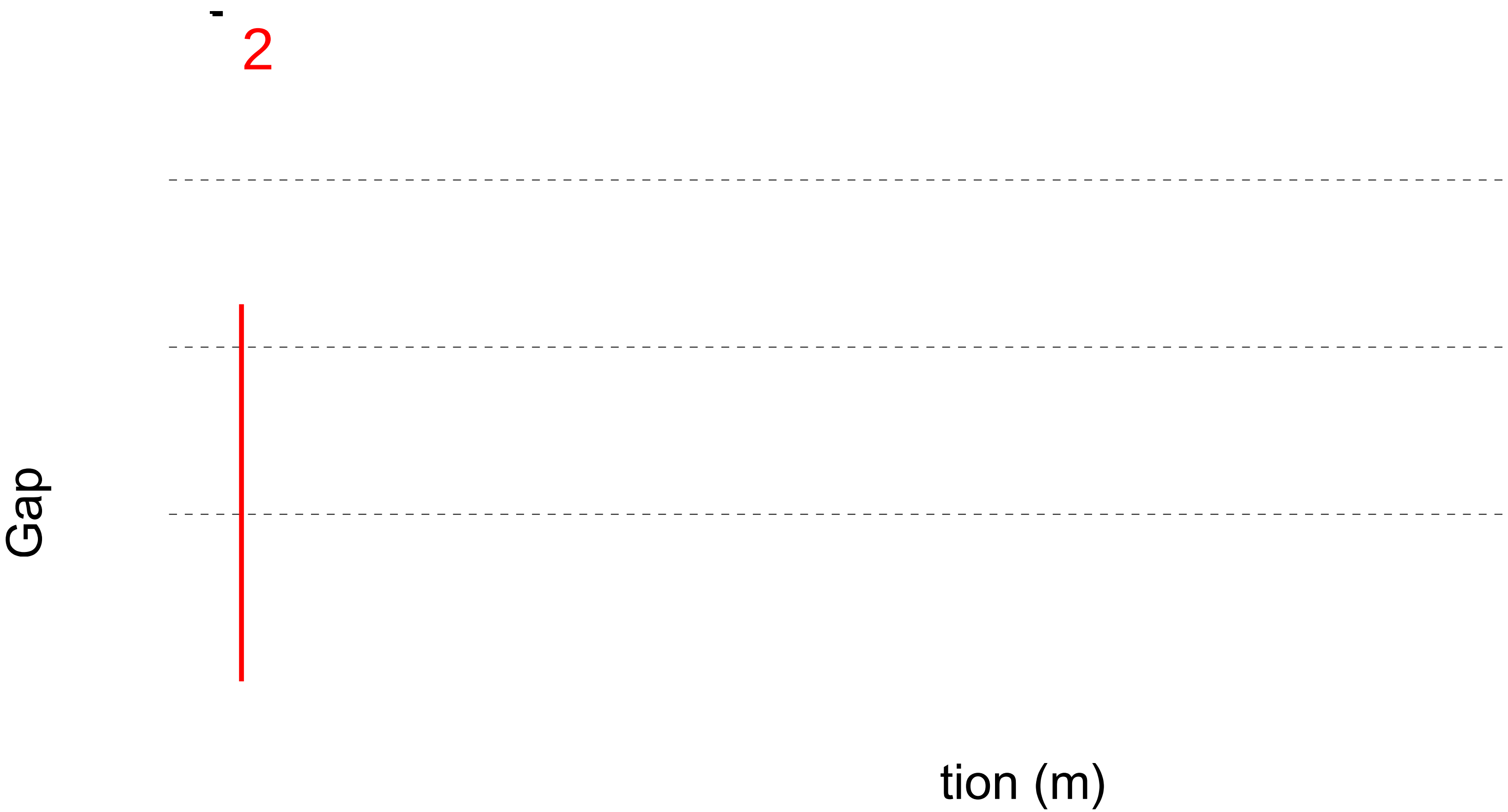


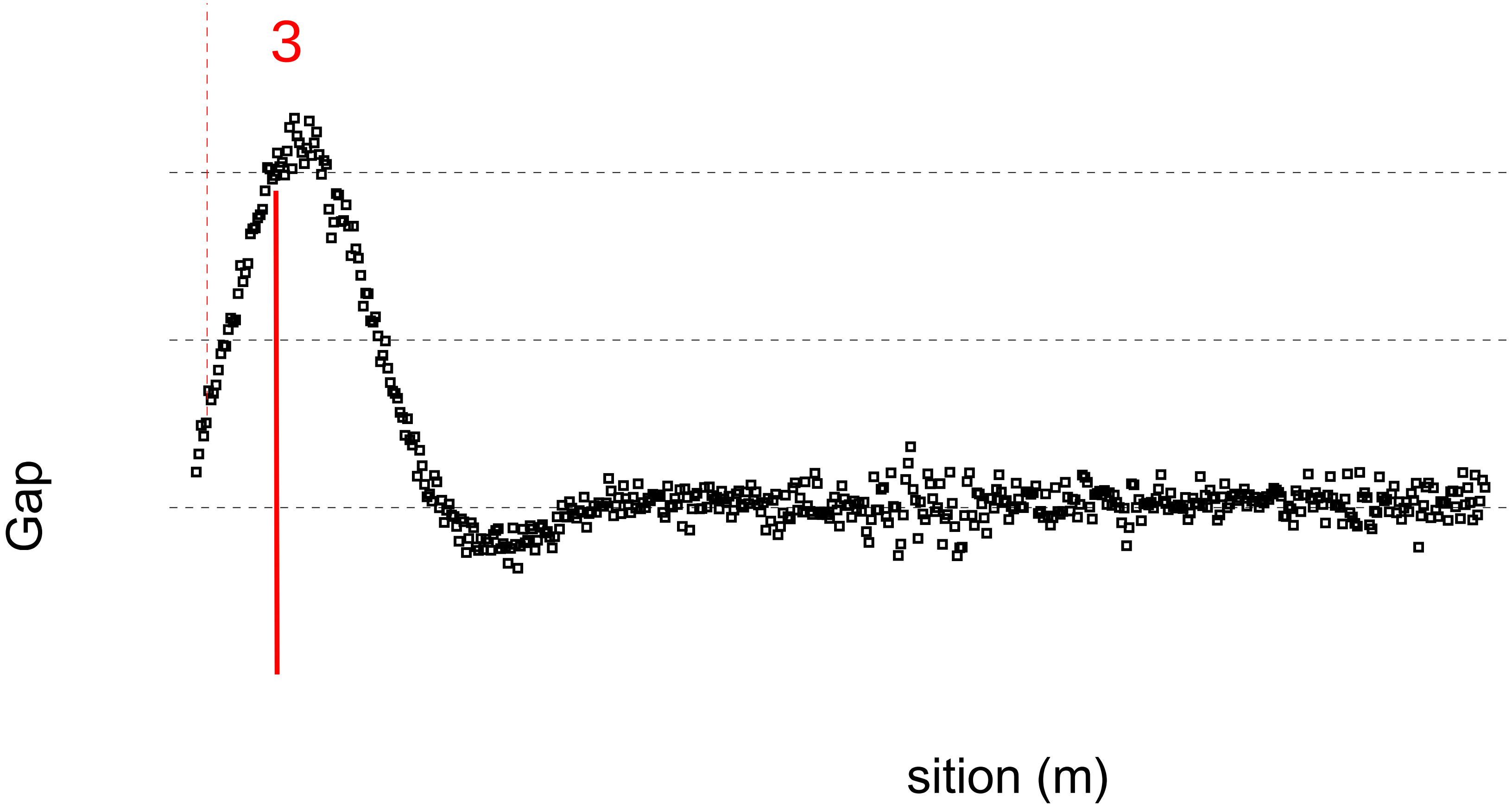
Columns optimisation



Columns optimisation



Columns optimisation



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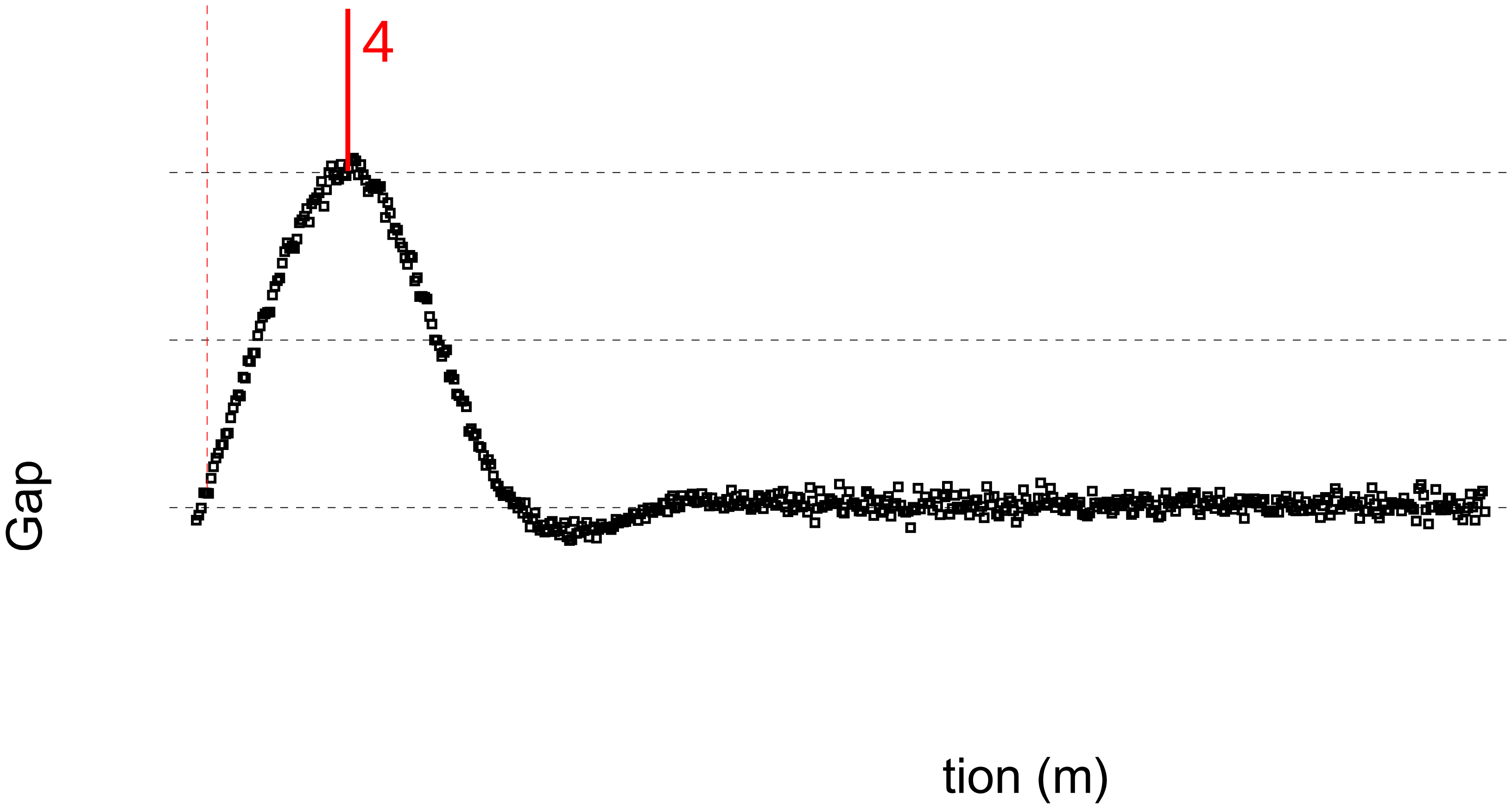
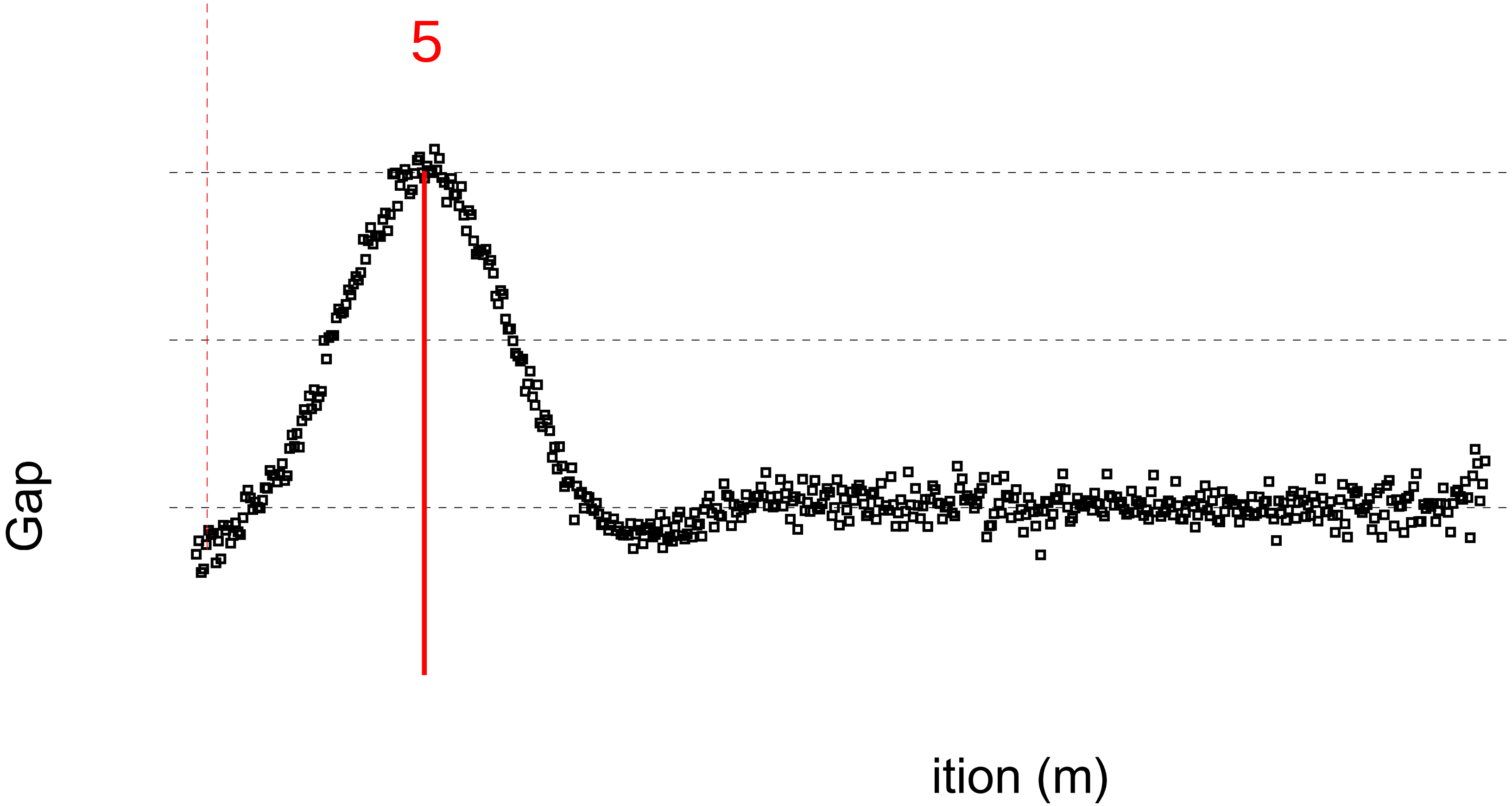
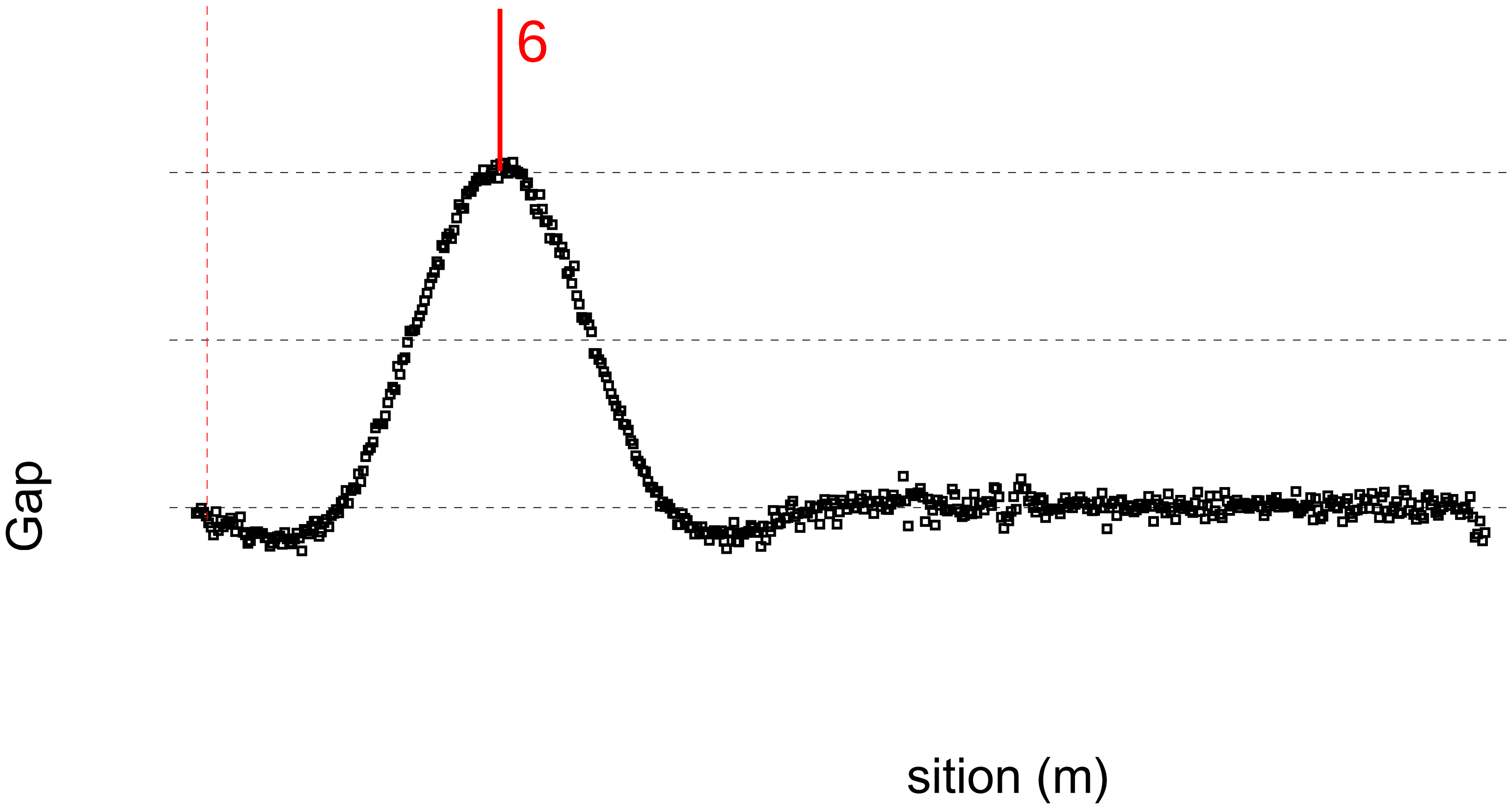


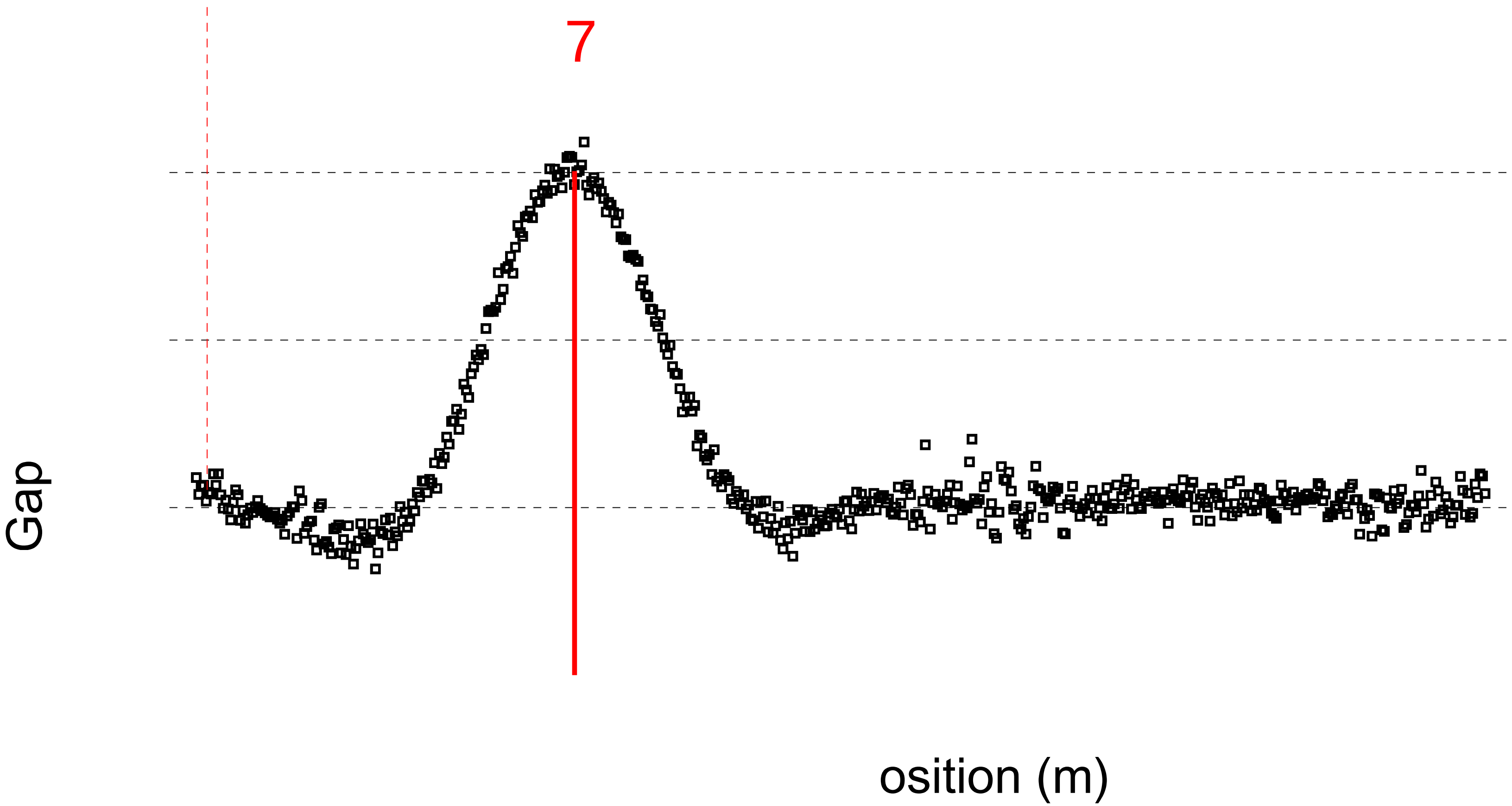
Columns optimisation



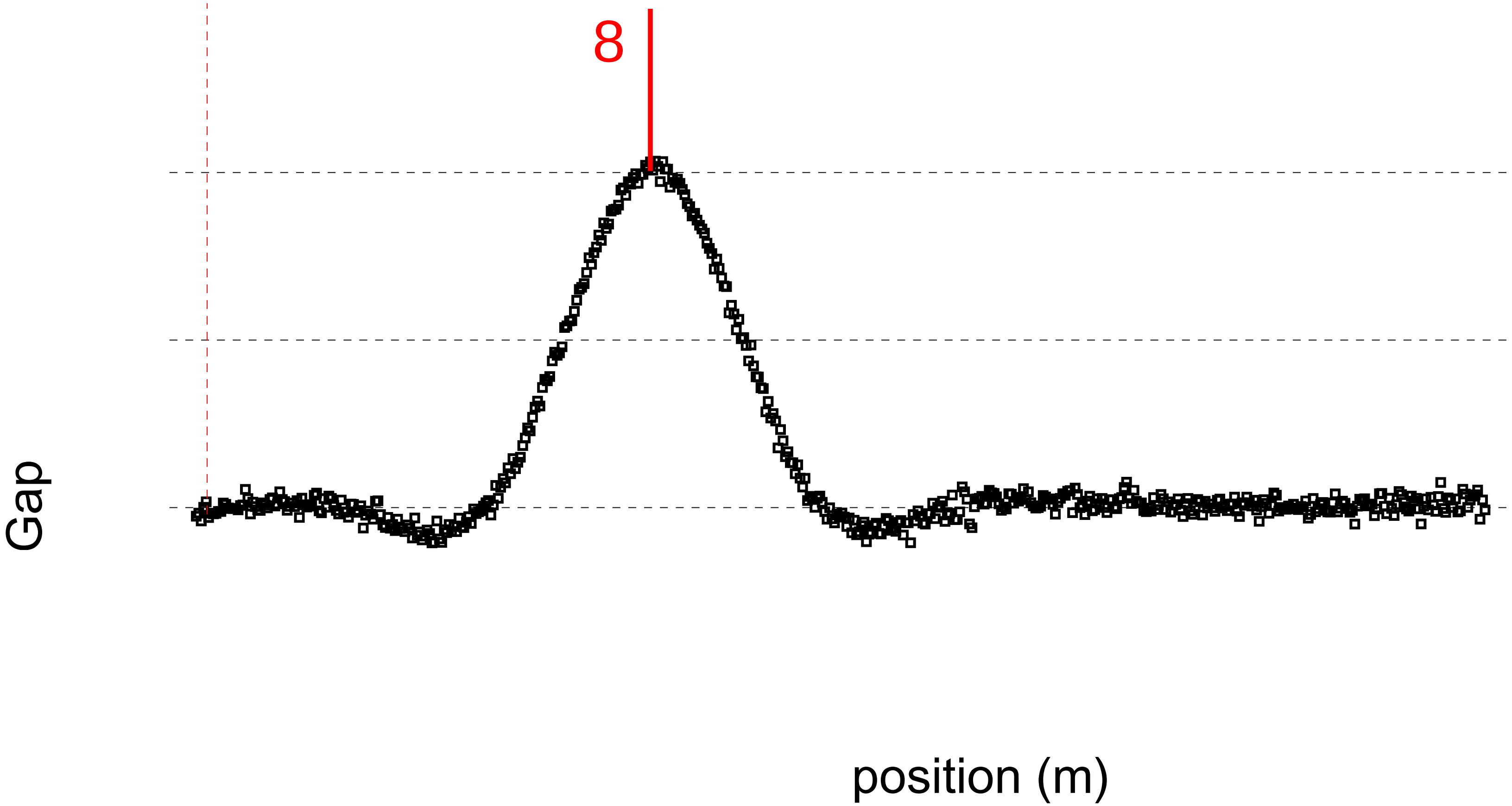
Columns optimisation



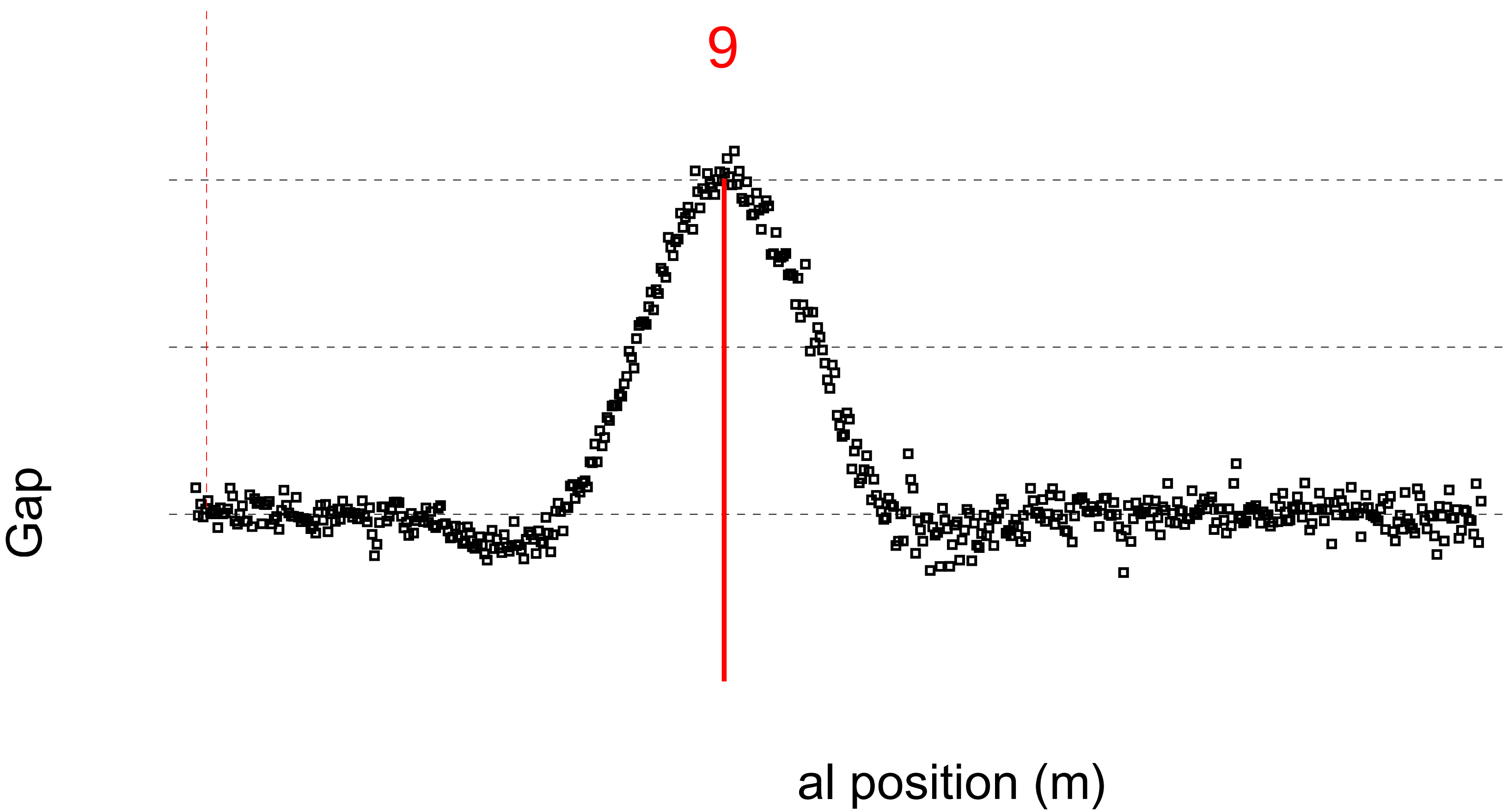
Columns optimisation



Columns optimisation



Columns optimisation



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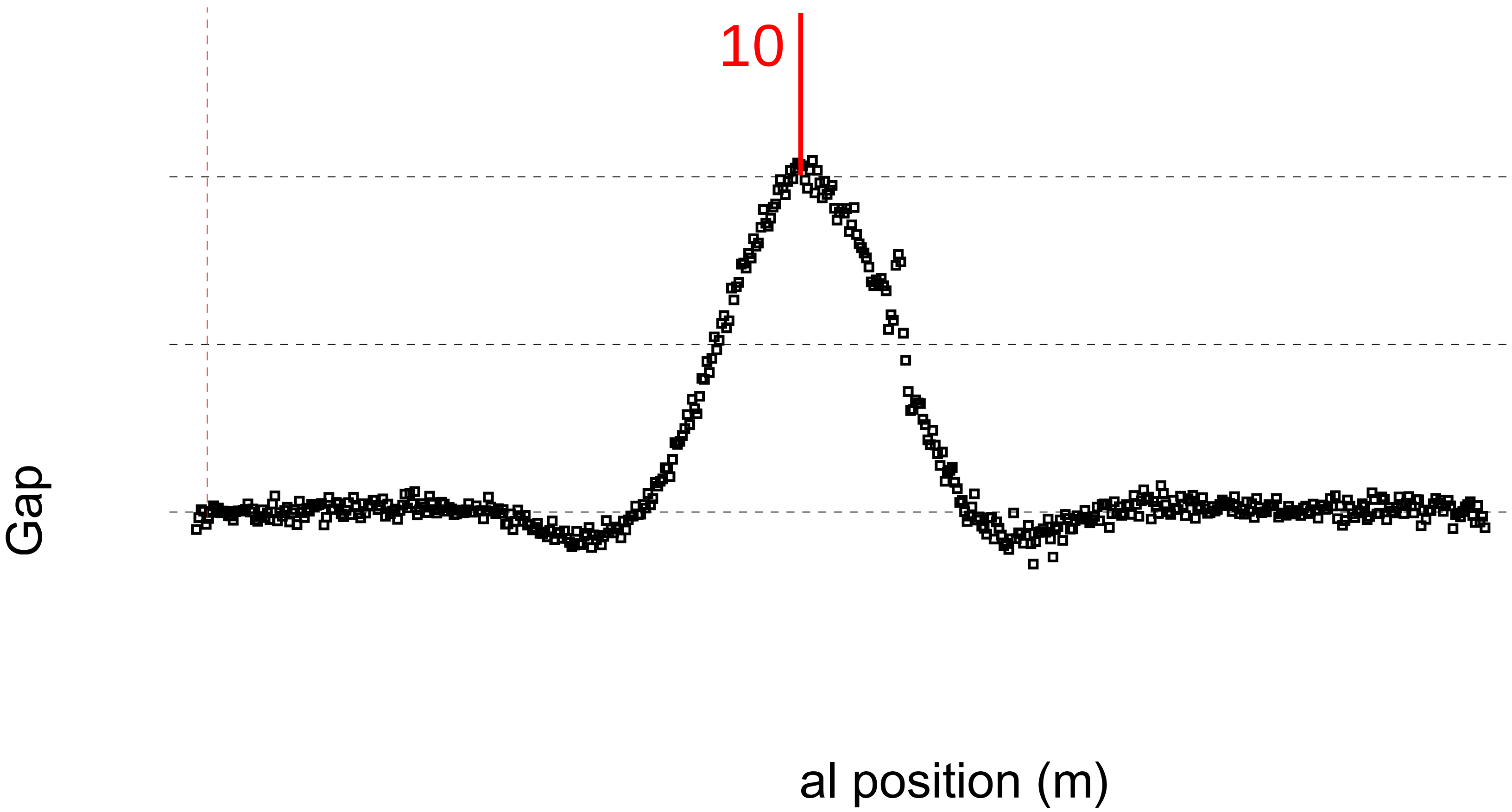

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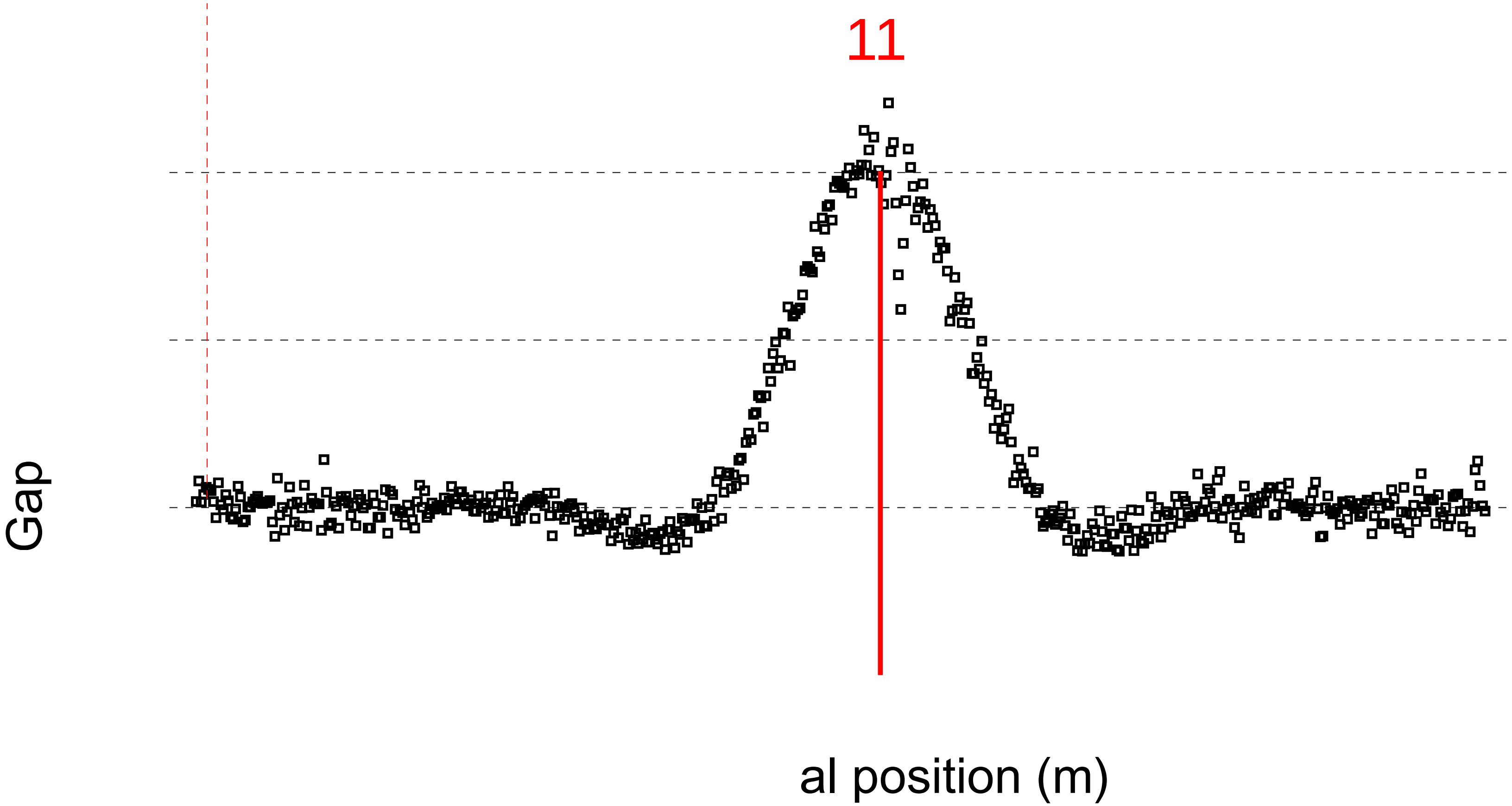

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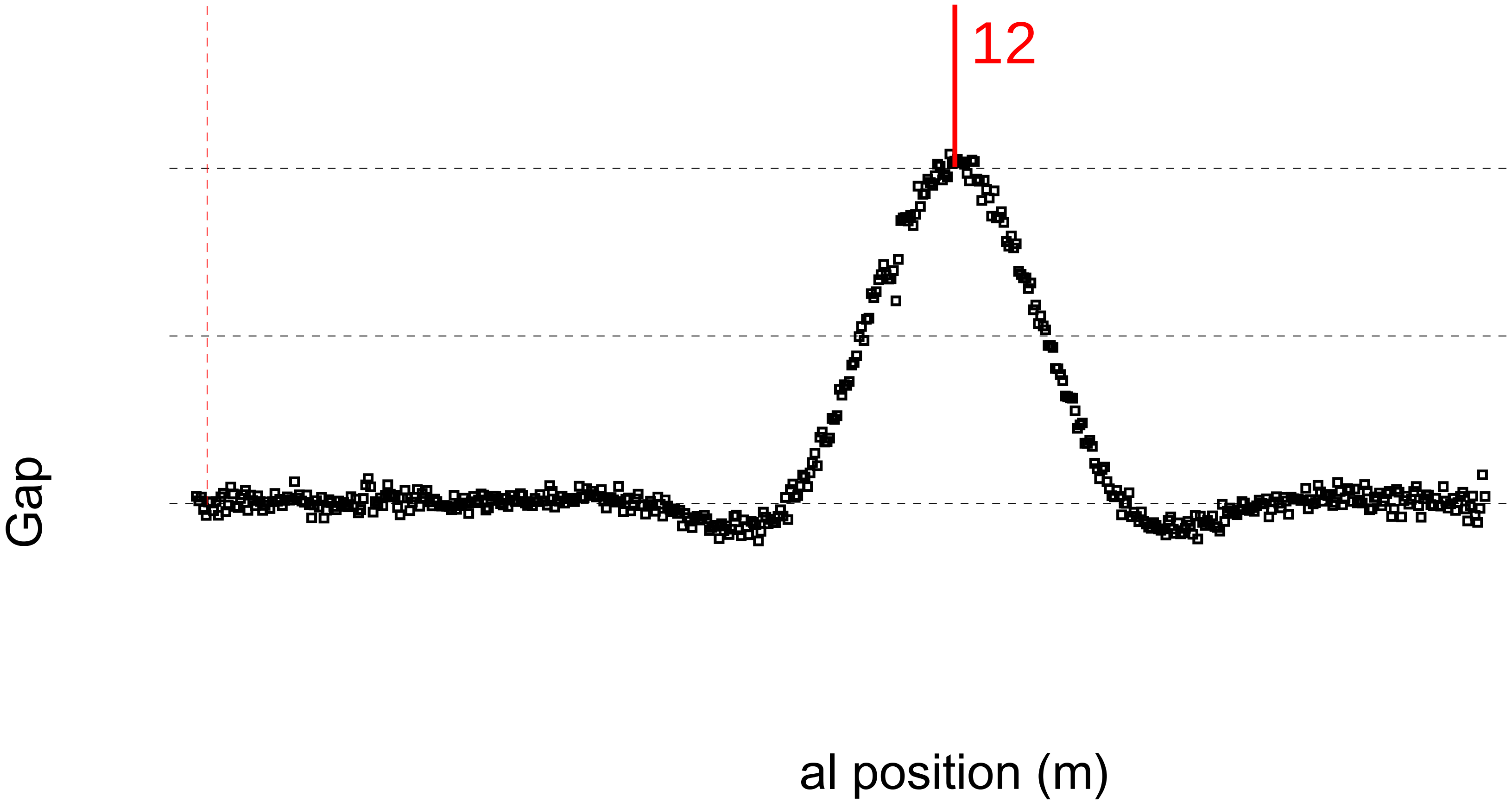

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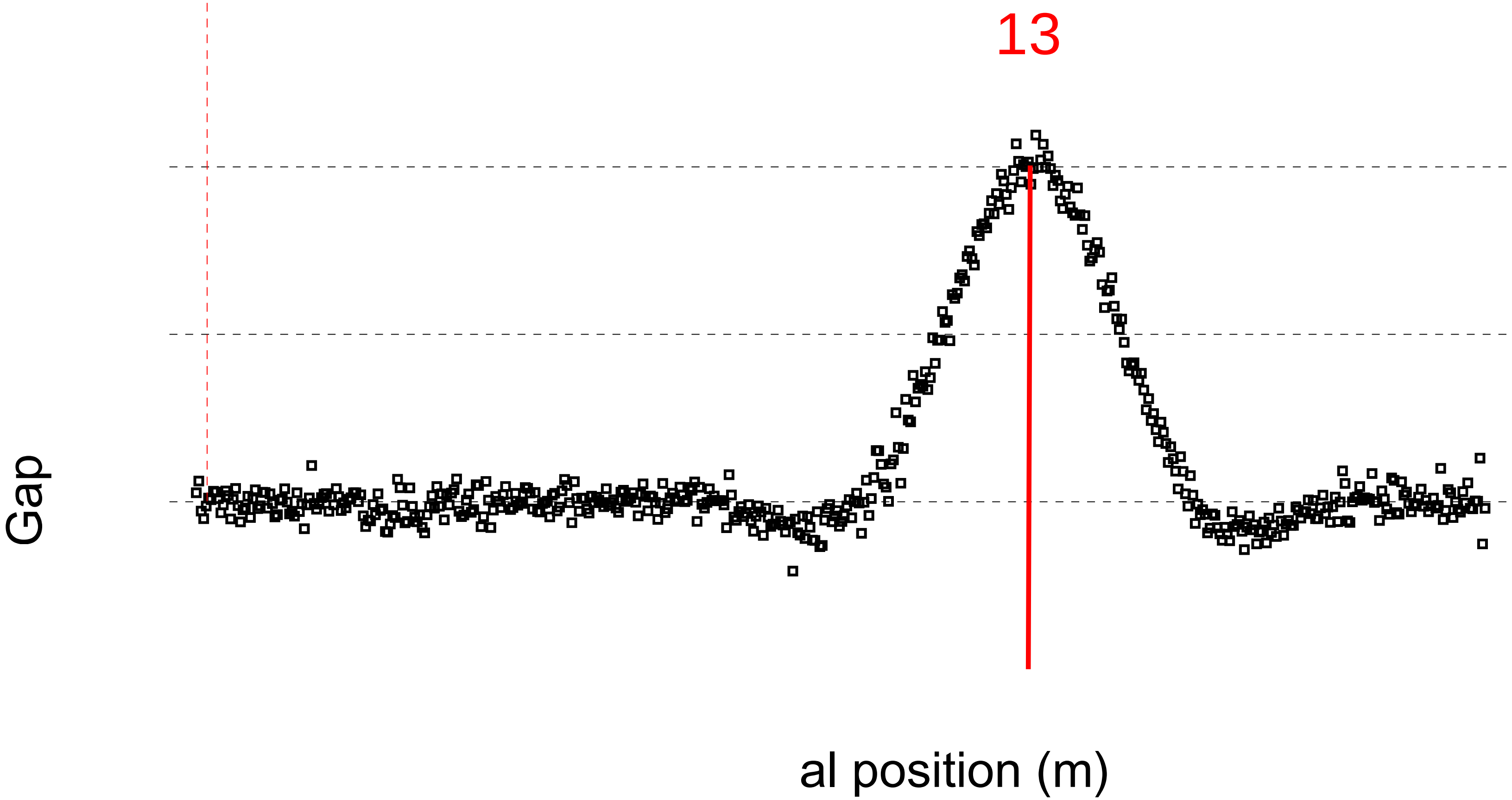

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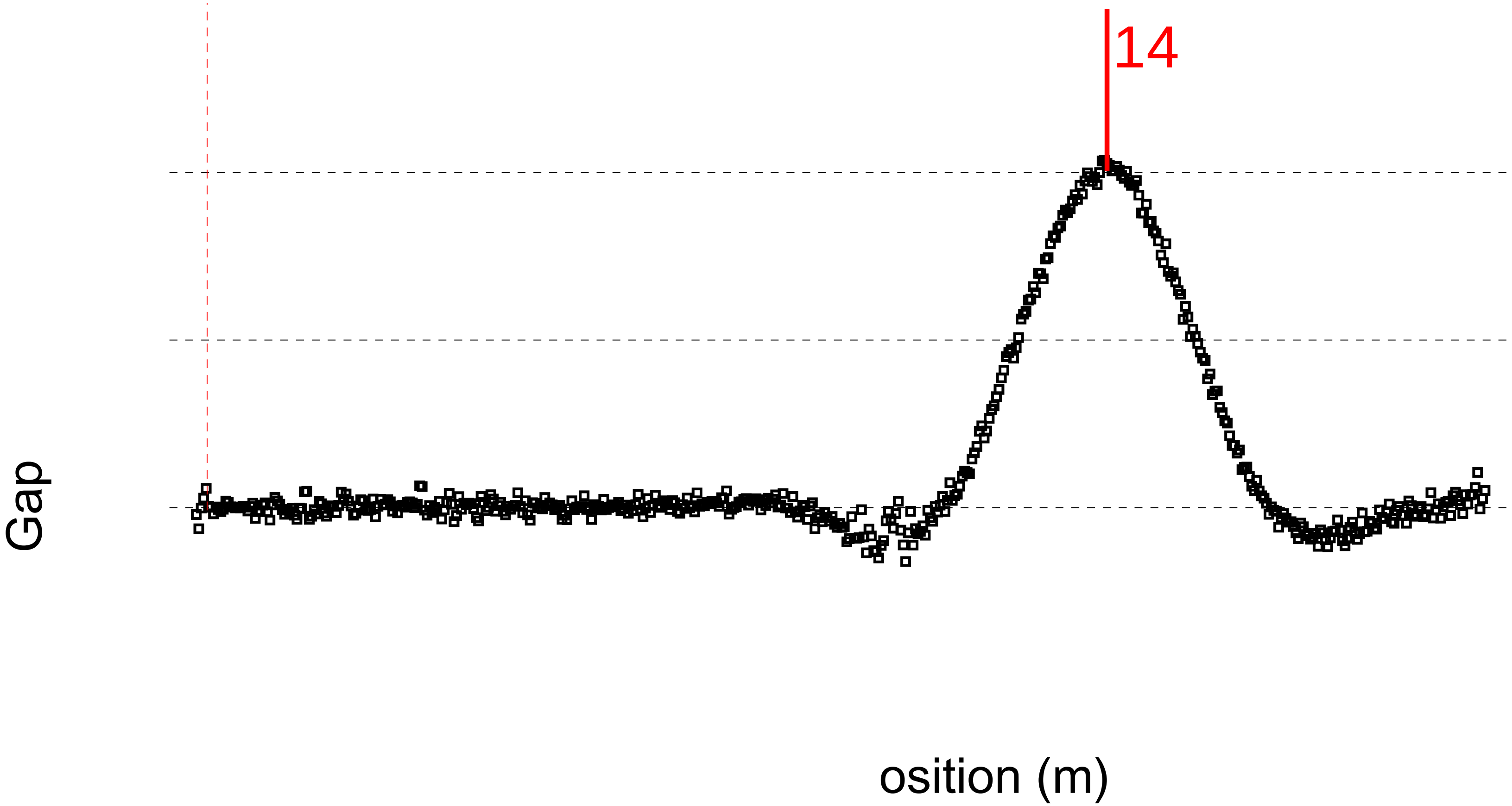

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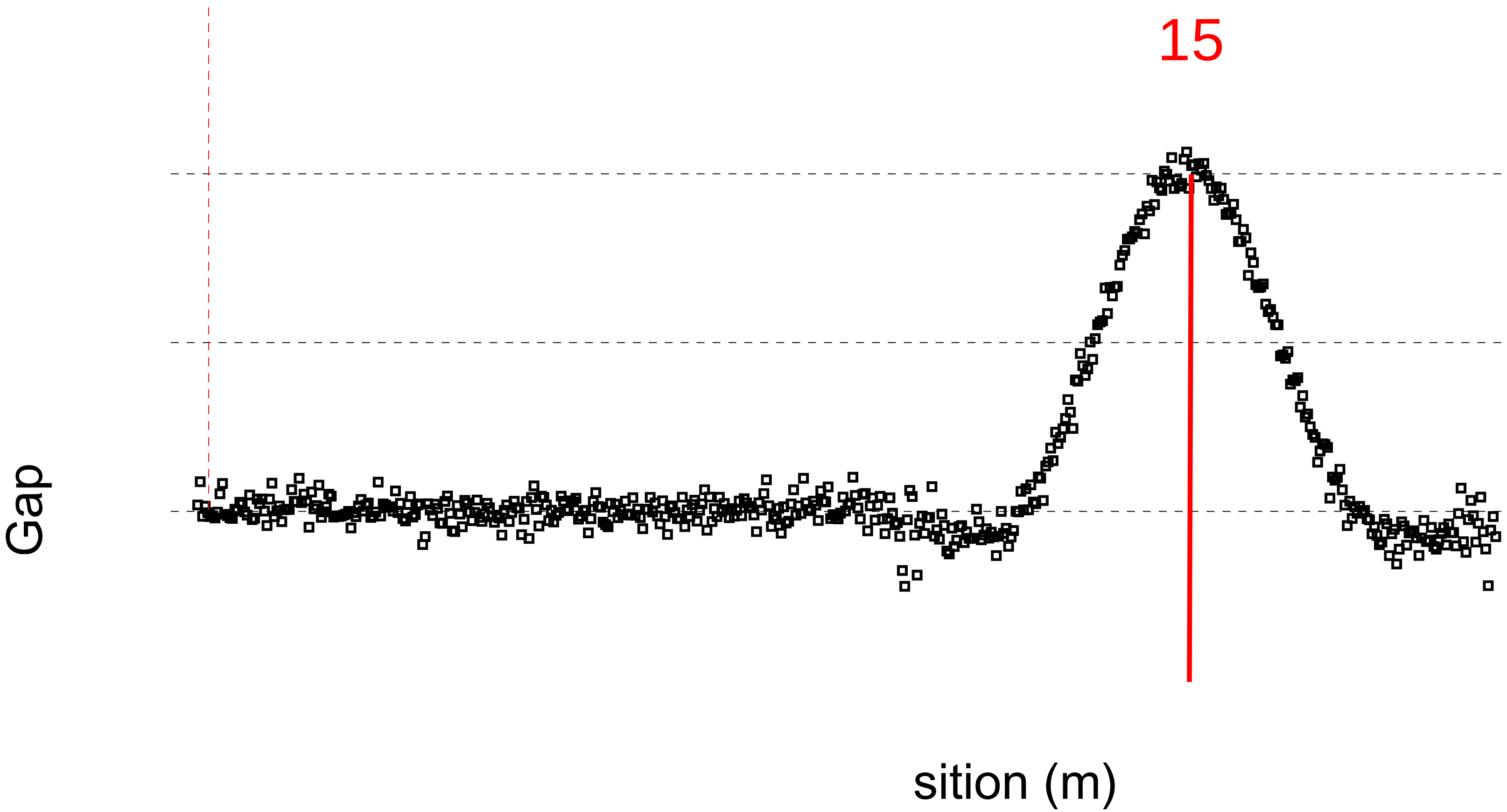
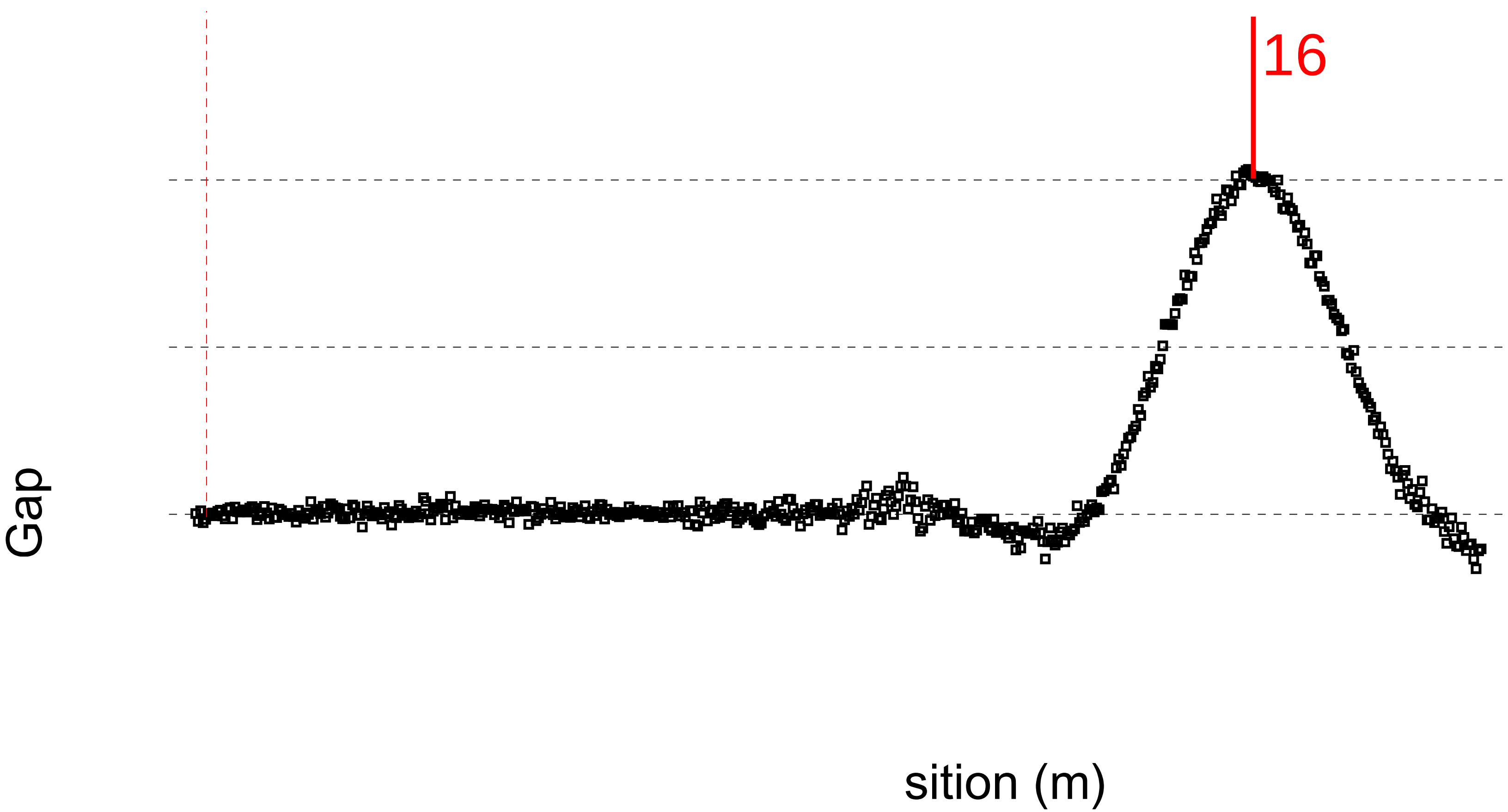
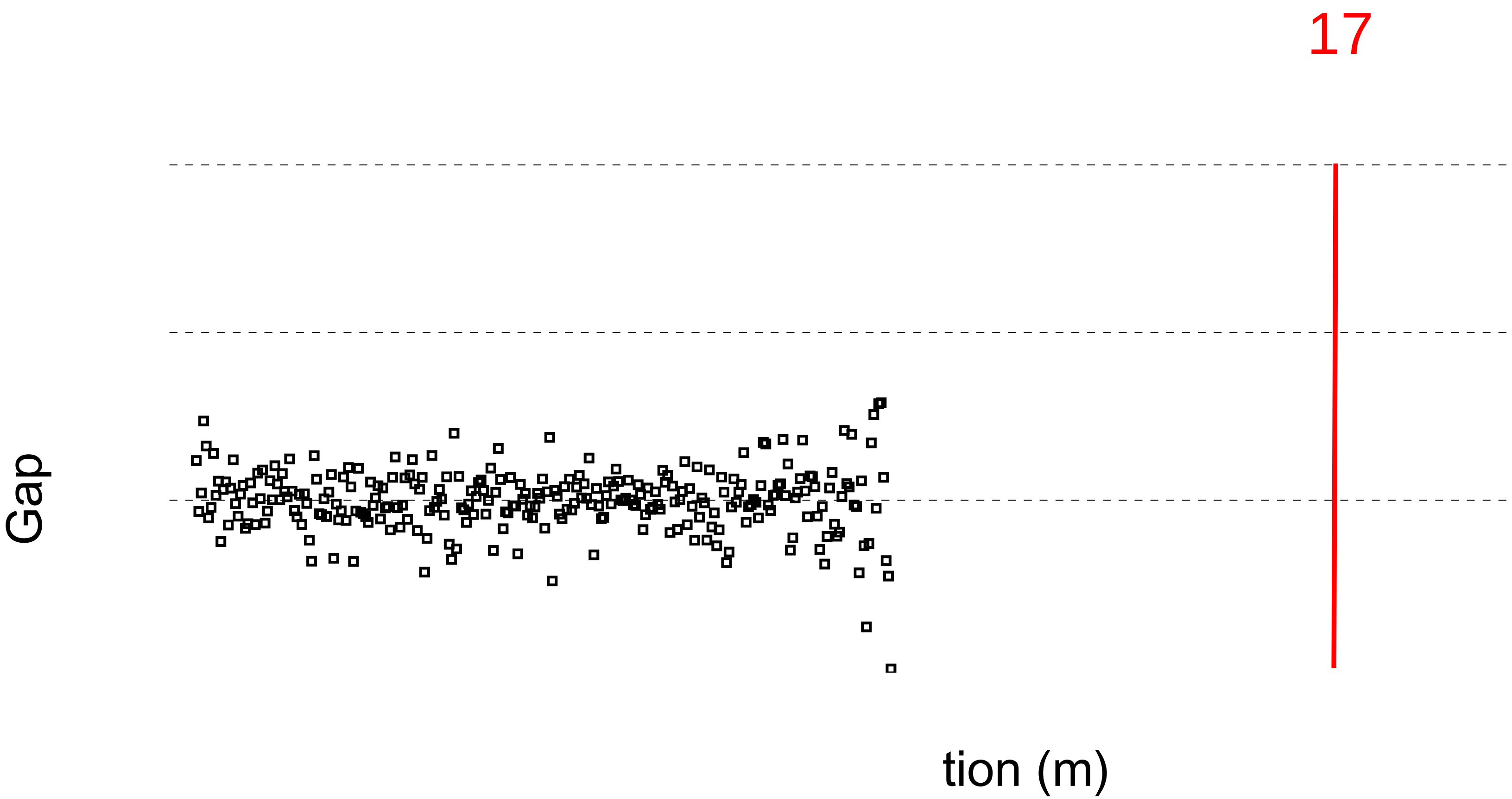


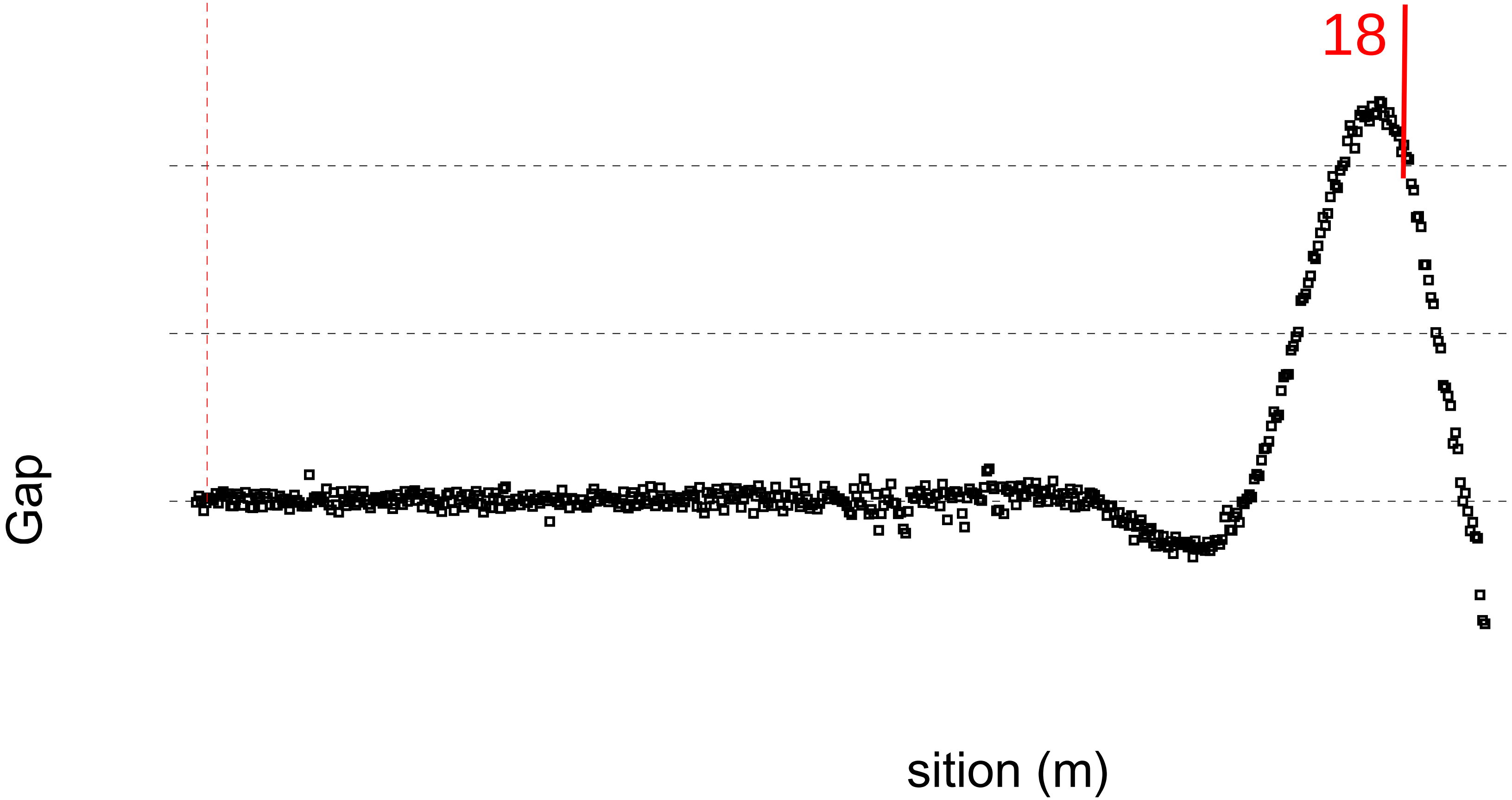
Columns optimisation



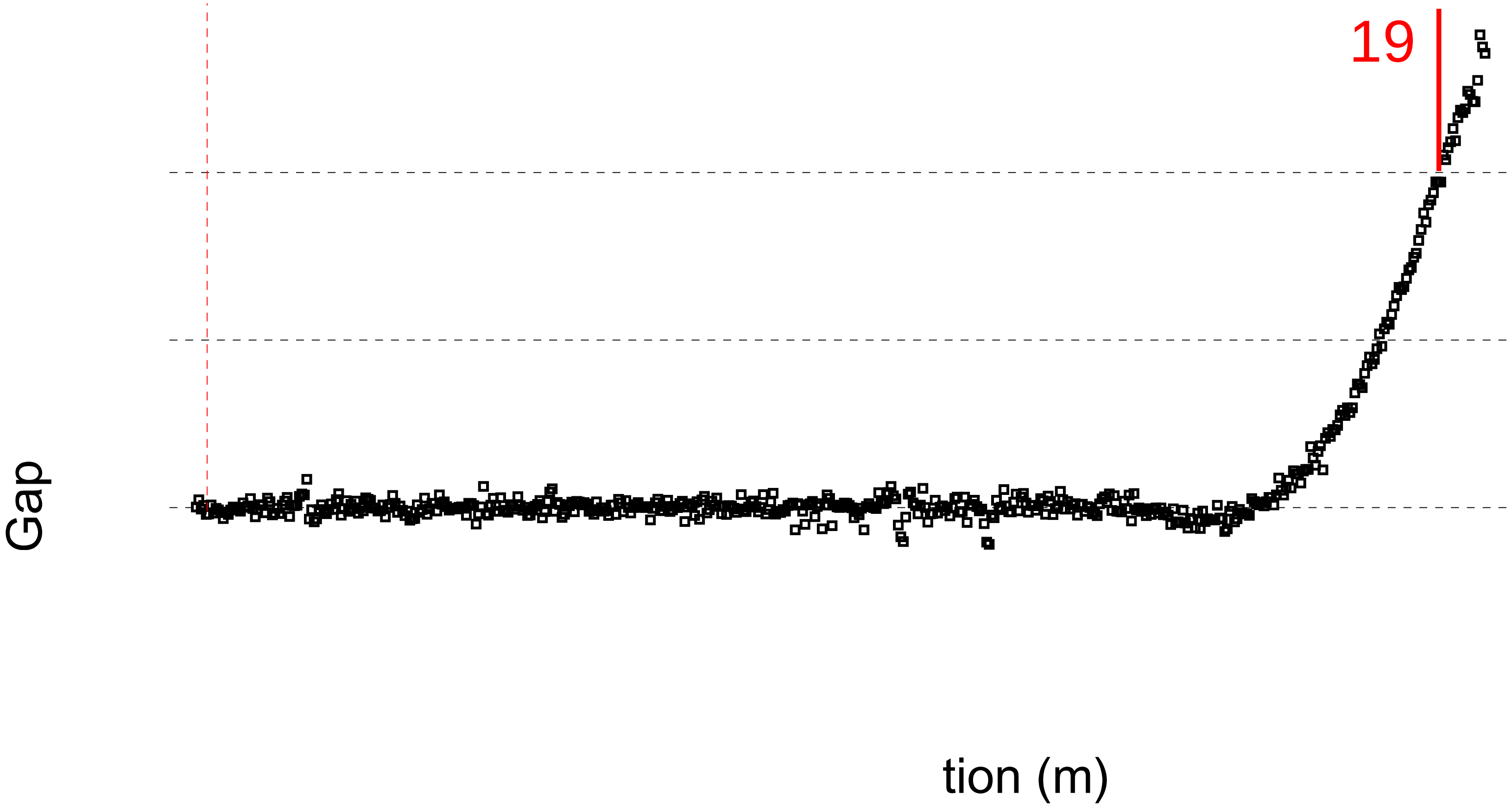
Columns optimisation



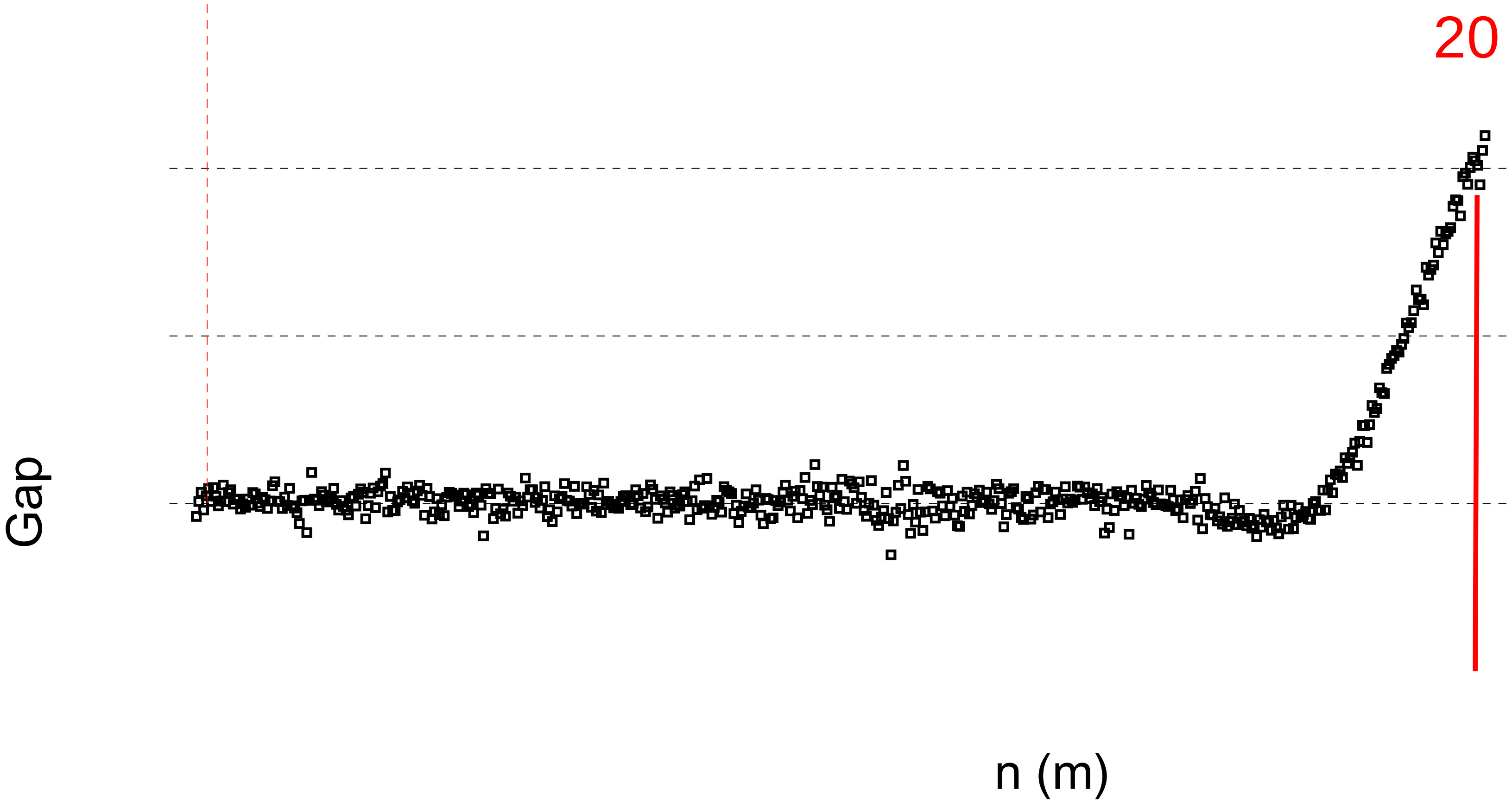
Columns optimisation



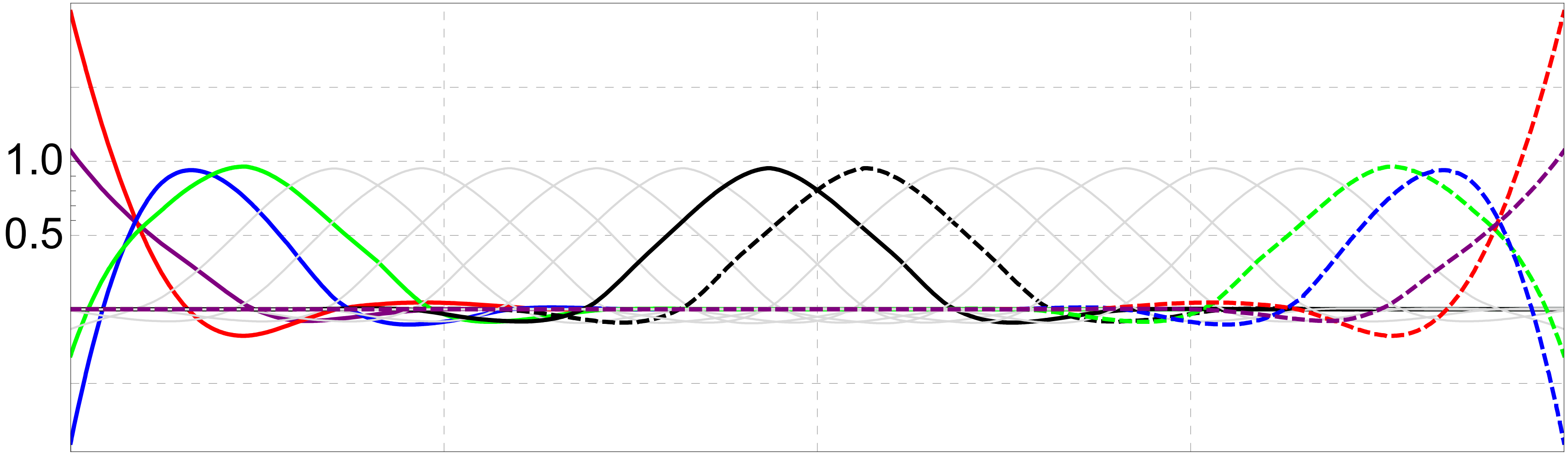
Columns optimisation

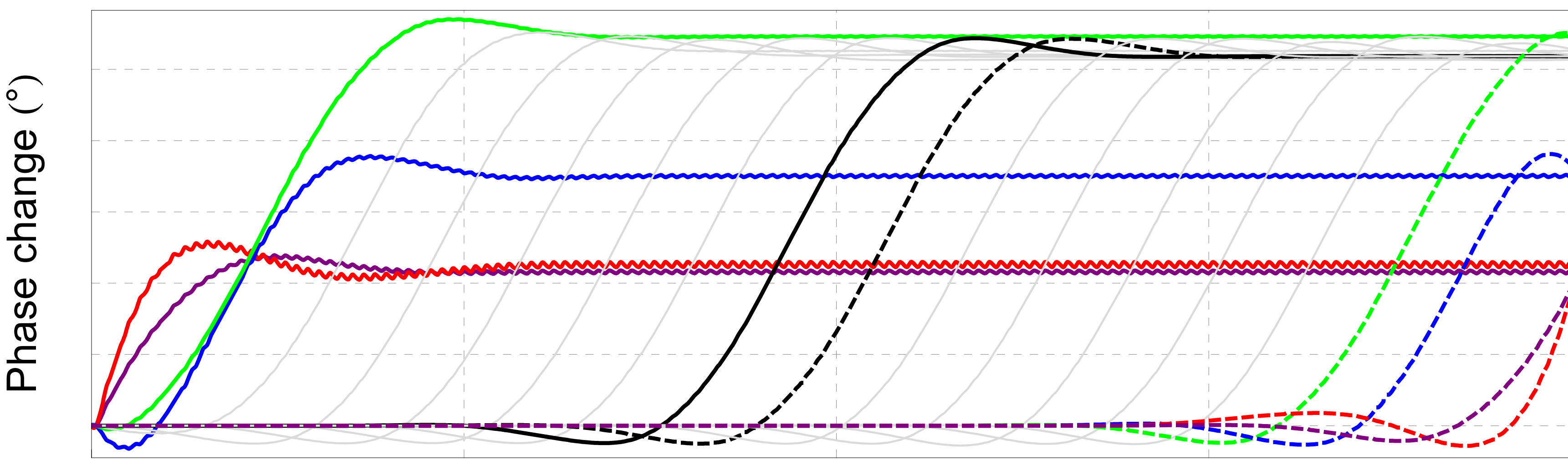


Columns optimisation



Columns optimisation





ng the inner I–beam (m)

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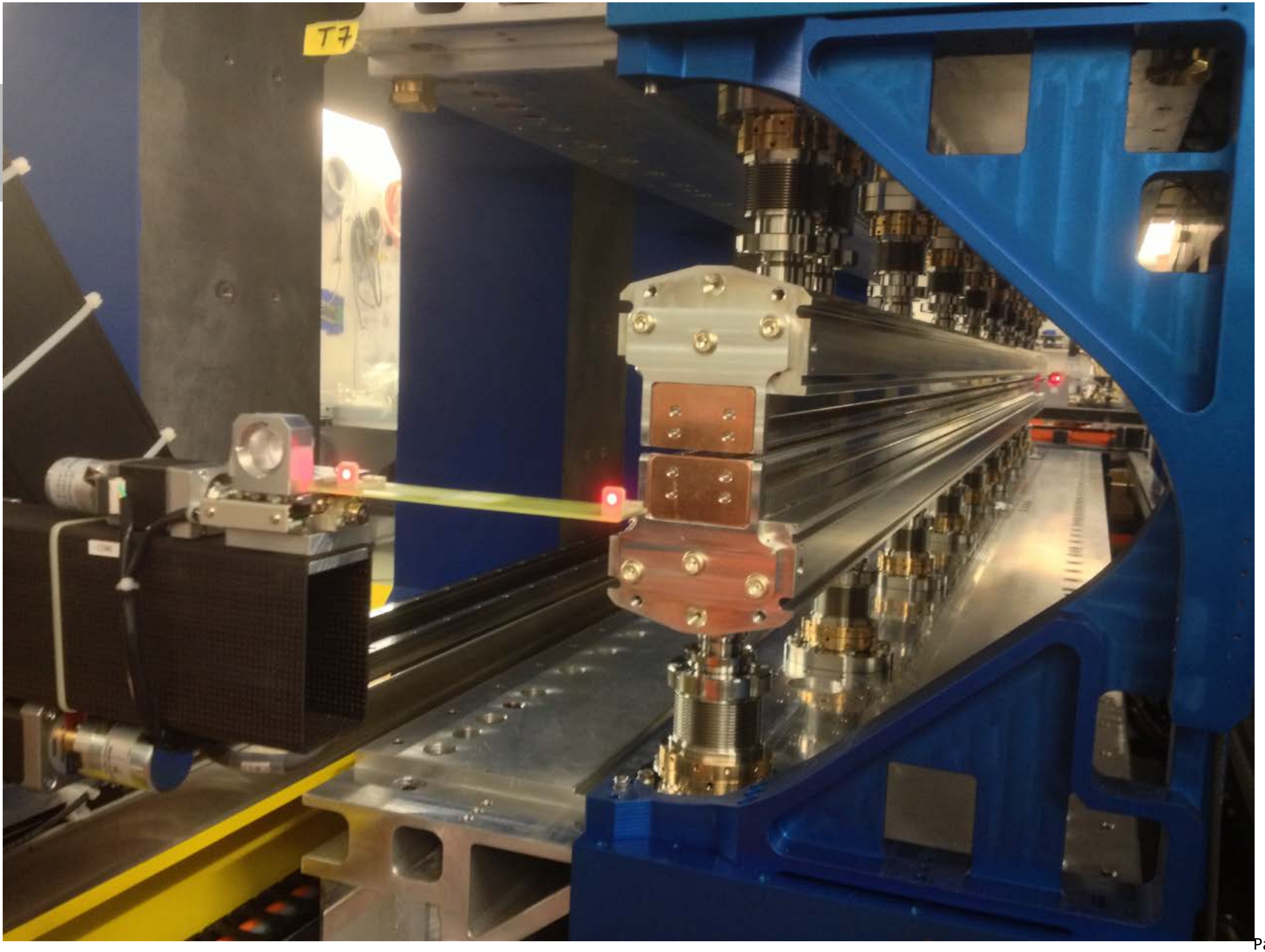
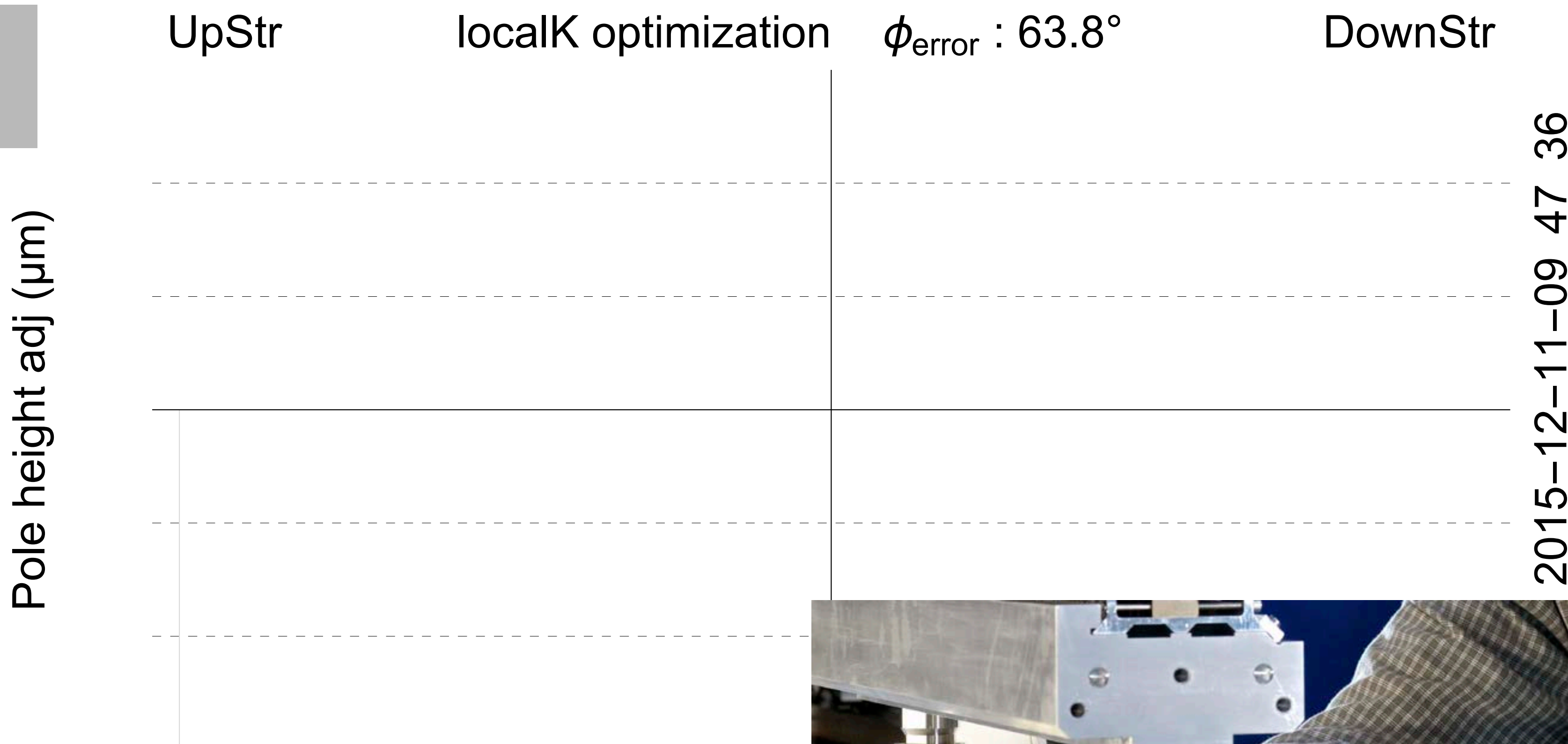
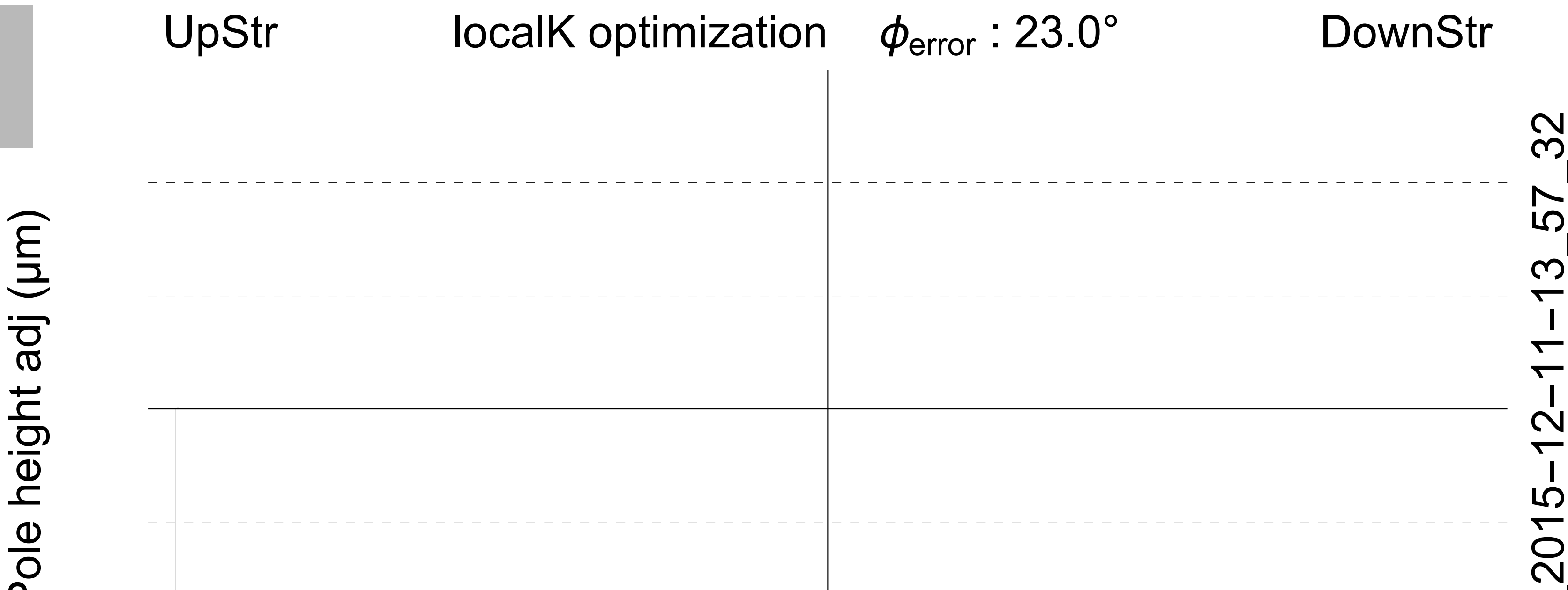
Ex-Vacuum Bench



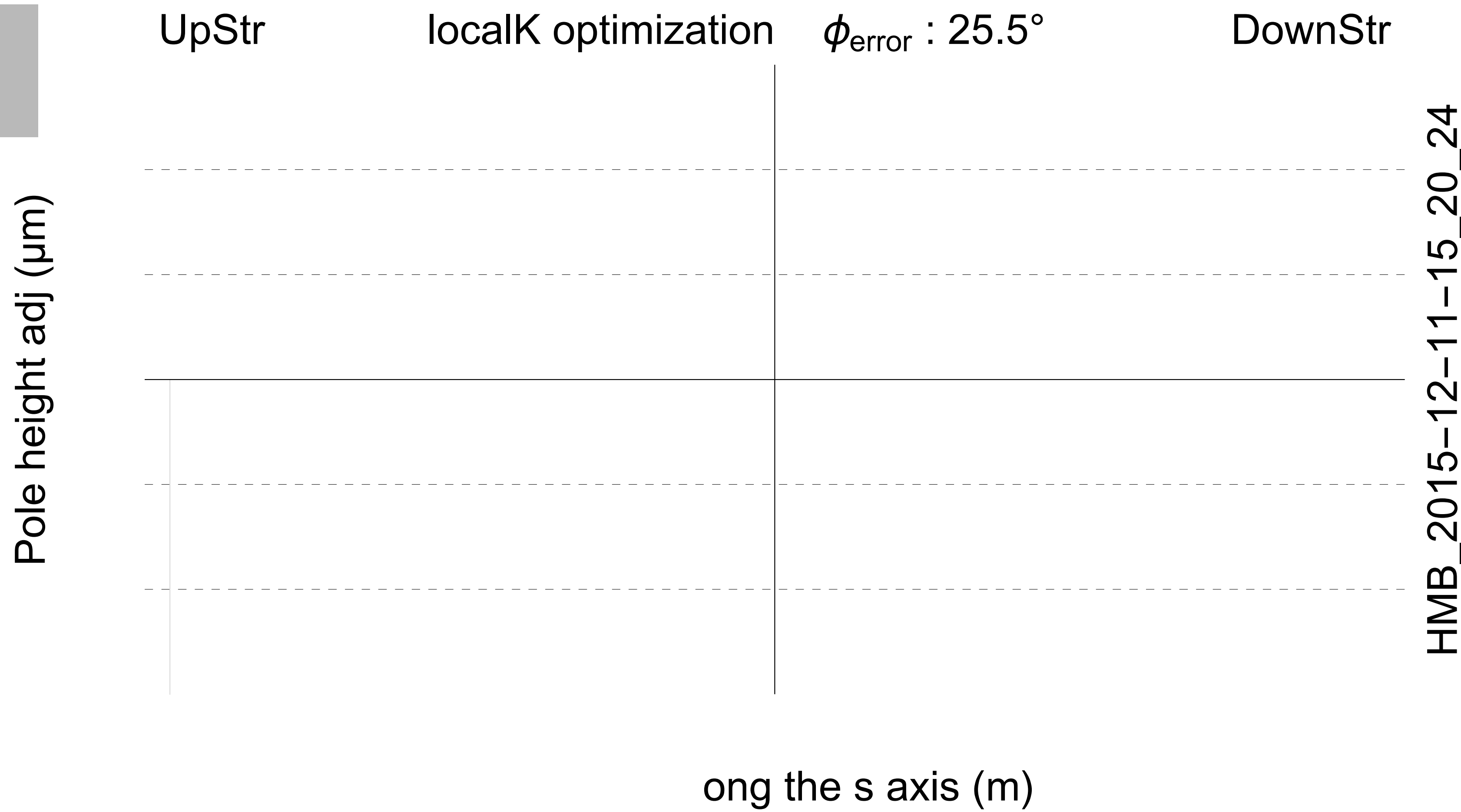
Ex-Vacuum Bench

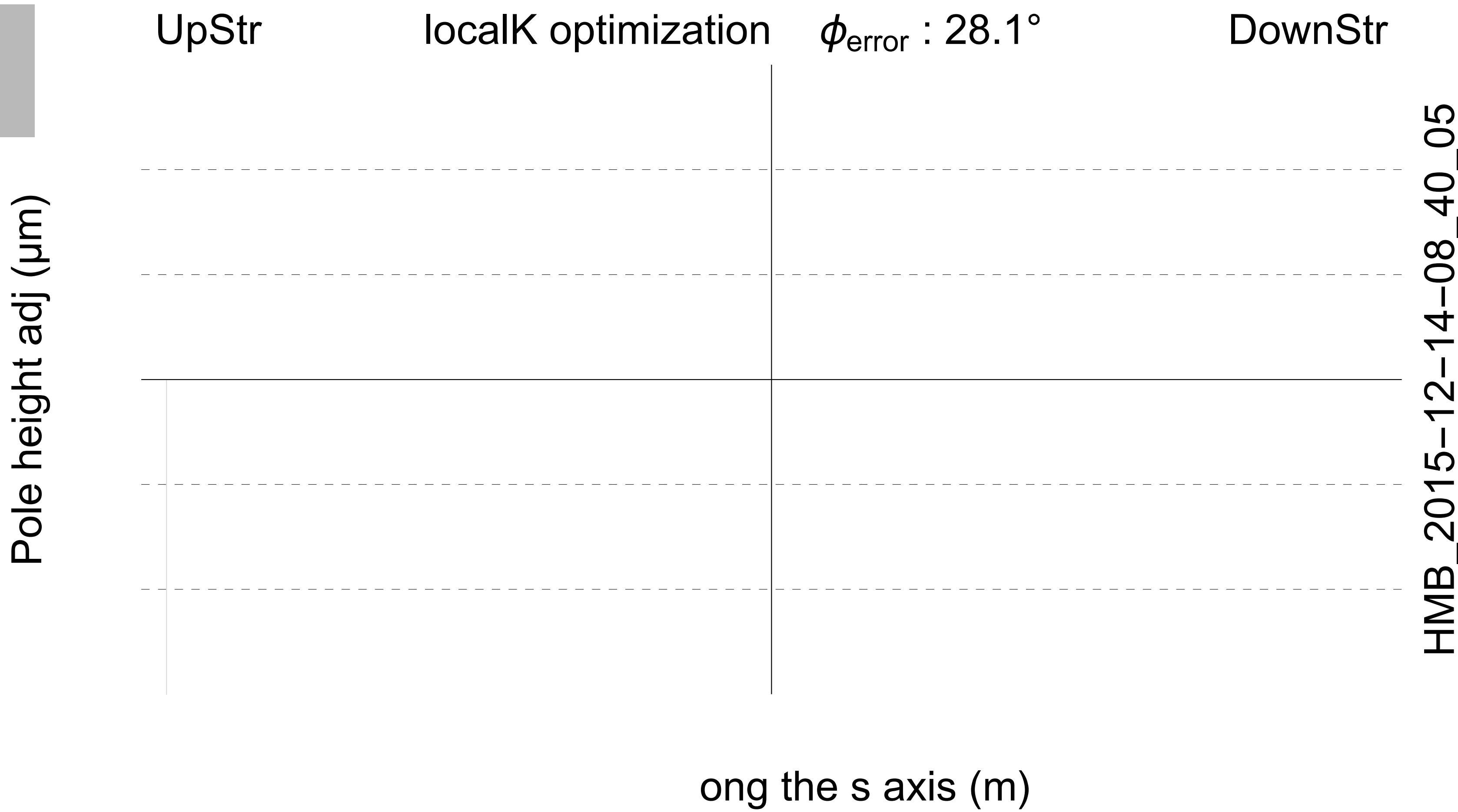
09:37 11-12-2015



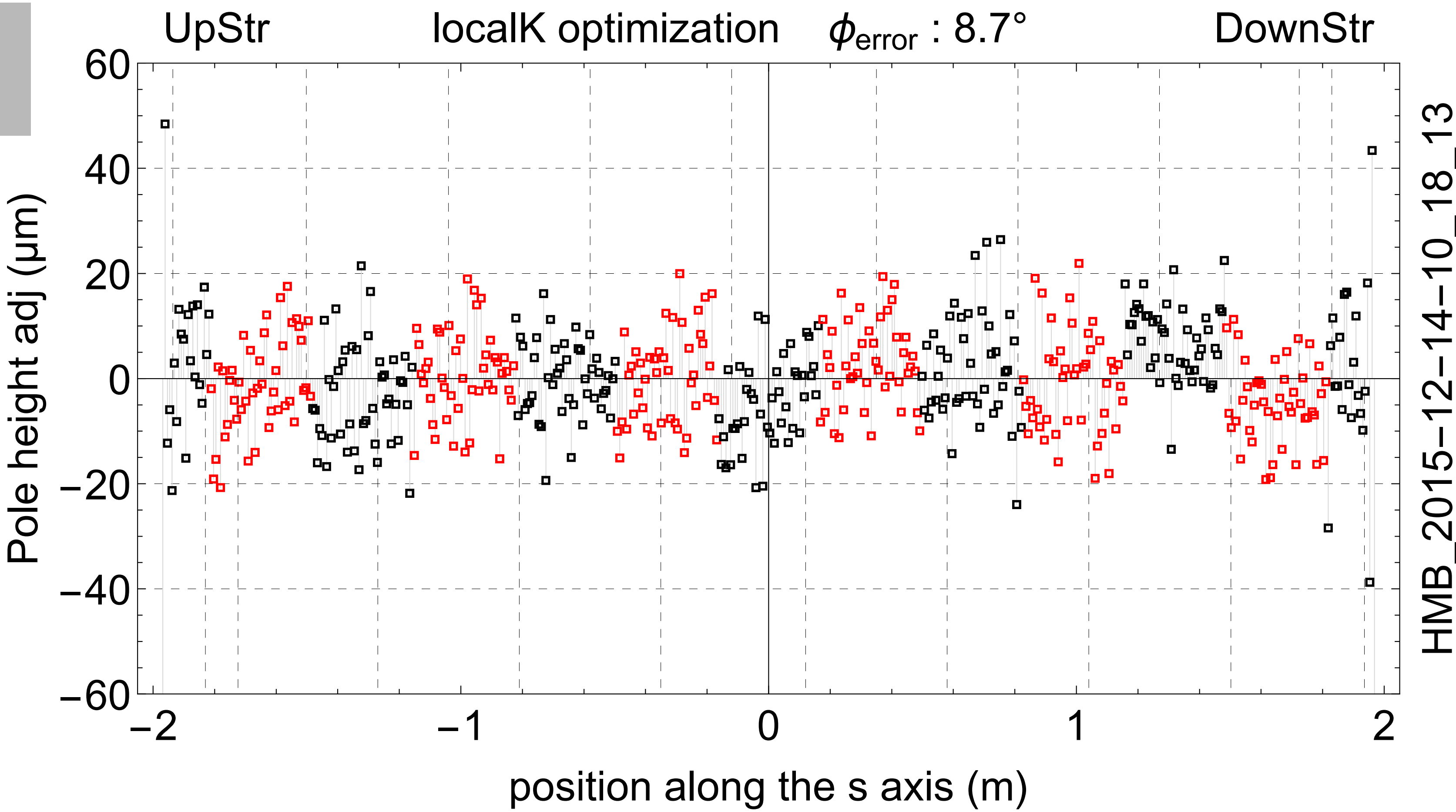

UpStr
localK optimization
ϕ_{error} : 23.0°
DownStr
Pole height adj (µm)
2015–12–11–13_57_32
along

PAUL SCHERRER INSTITUT PSI 15:20 11-12-2015



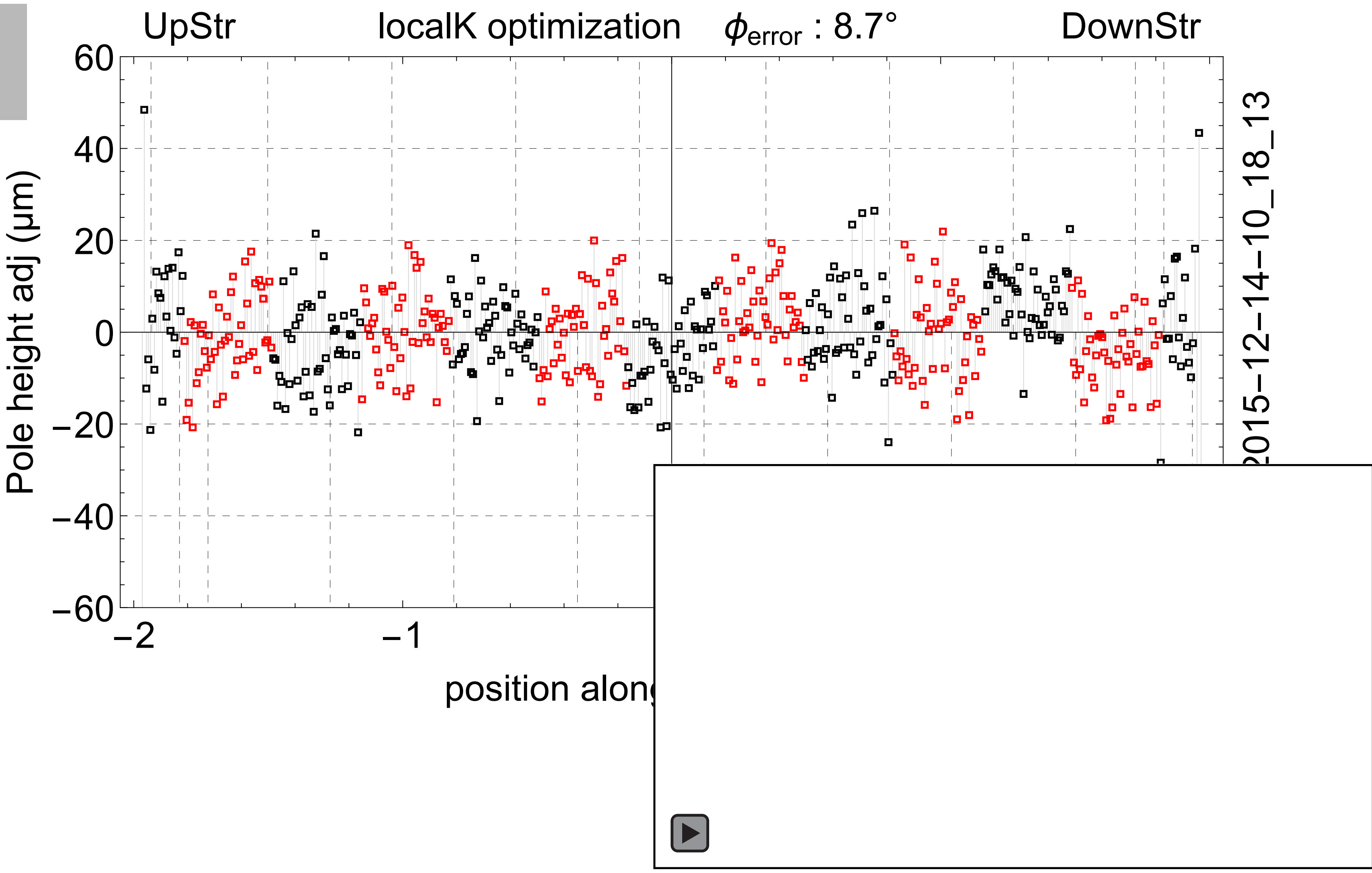

UpStr
localK optimization
ϕ_{error} : 28.1°
DownStr
Pole height adj (µm)
HMB_2015–12–14–08_40_05
ong the s axis (m)

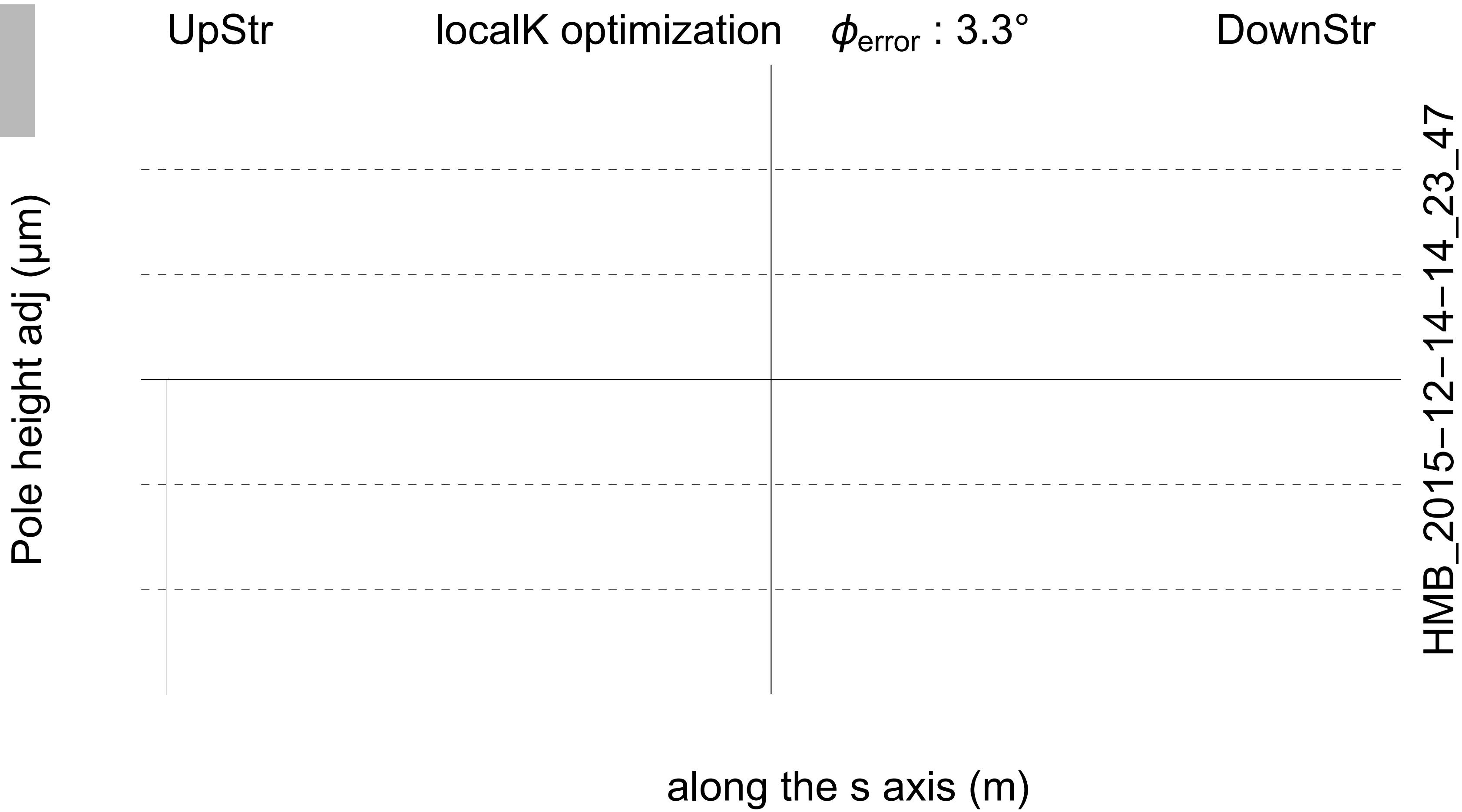
Ex-Vacuum Bench

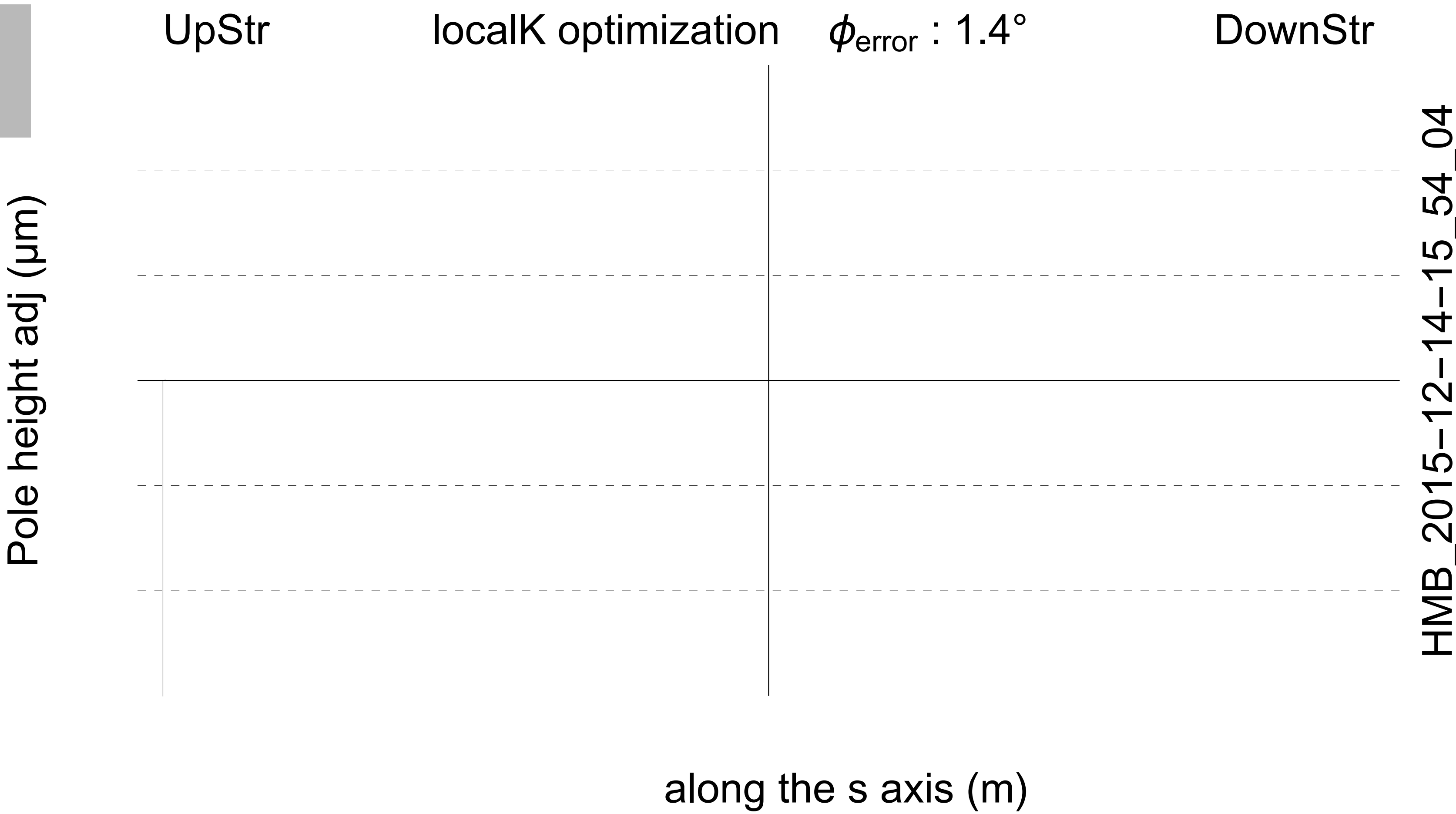


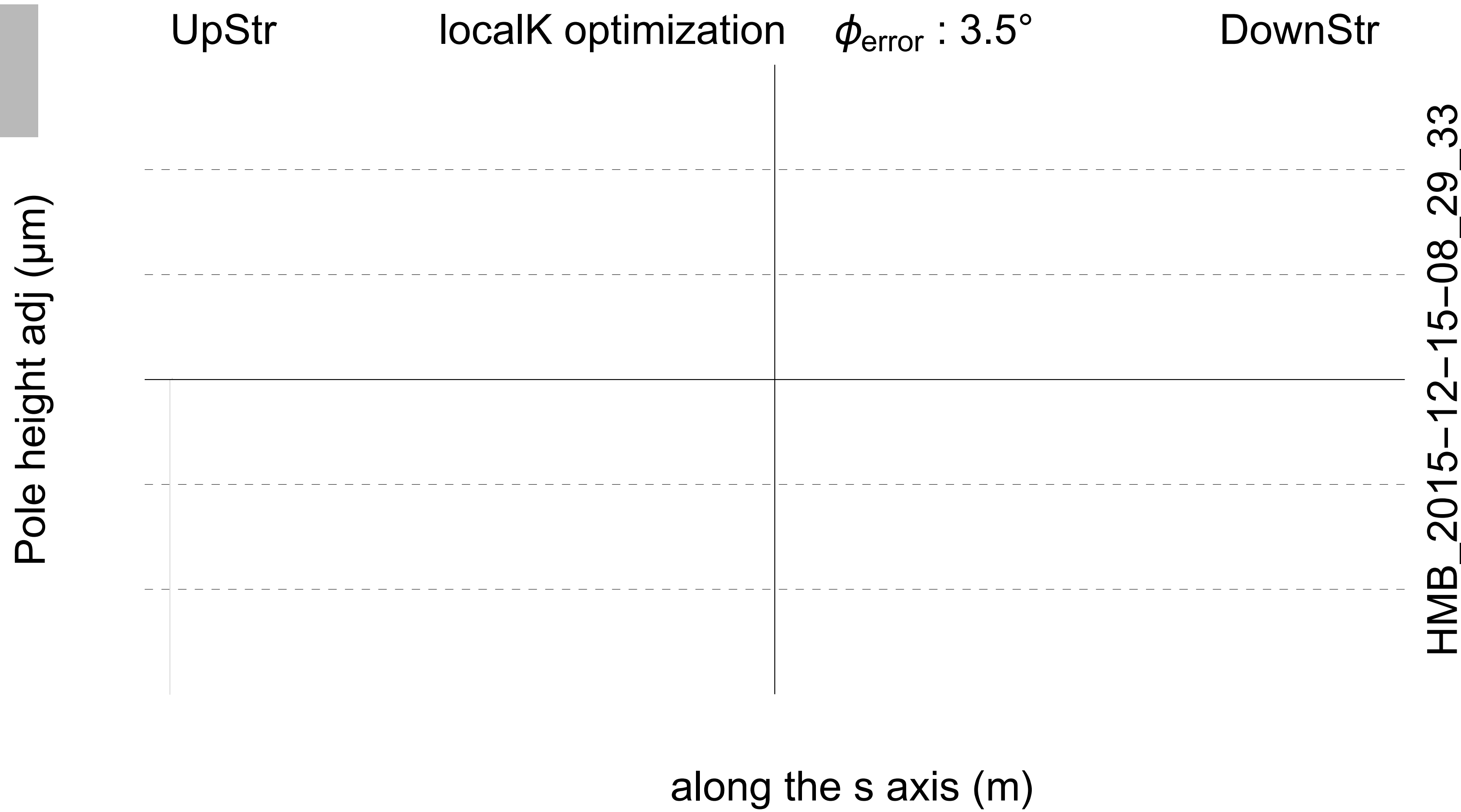
10:18 14-12-2015

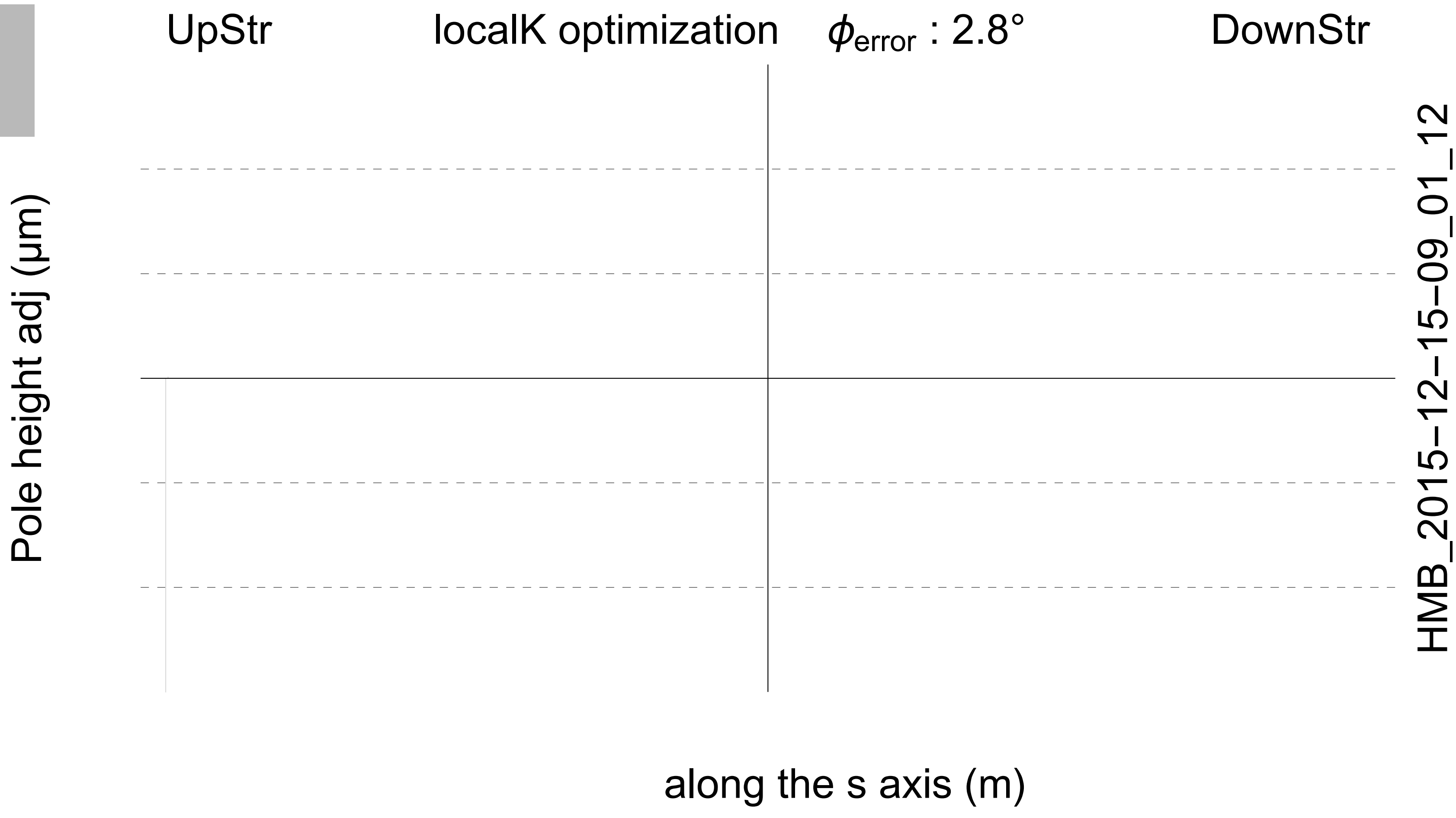
Ex-Vacuum Bench

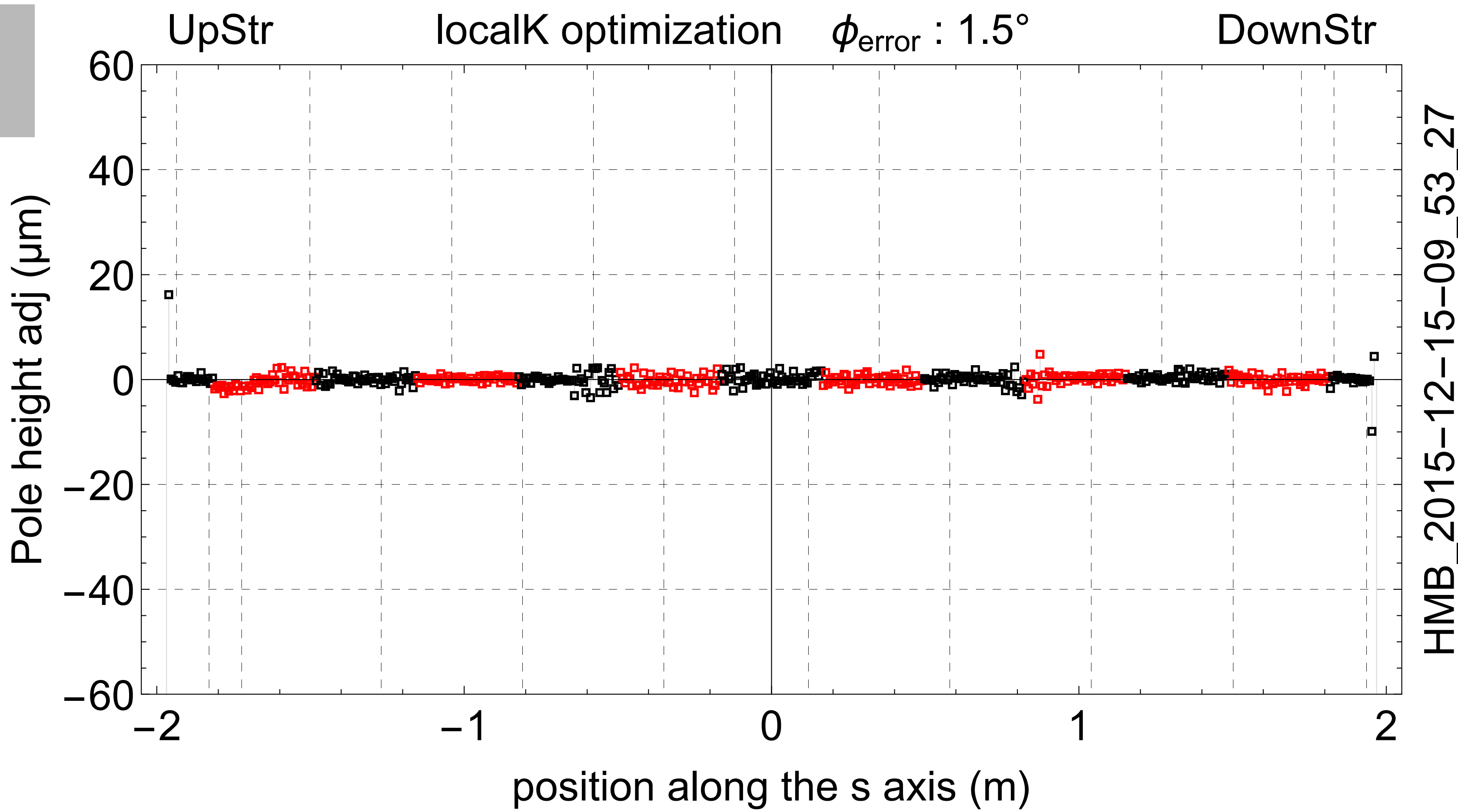



UpStr
localK optimization
ϕ_{error} : 3.3°
DownStr
Pole height adj (µm)
HMB_2015–12–14–14_23_47
along the s axis (m)


UpStr
localK optimization
ϕ_{error} : 1.4°
DownStr
Pole height adj (µm)
along the s axis (m)
HMB_2015−12−14−15_54_04


UpStr
localK optimization
ϕ_{error} : 3.5°
DownStr
Pole height adj (µm)
HMB_2015–12–15–08_29_33
along the s axis (m)


UpStr
localK optimization
ϕ_{error} : 2.8°
DownStr
Pole height adj (µm)
HMB_2015–12–15–09_01_12
along the s axis (m)


UpStr
localK optimization
ϕ_{error} : 1.5°
DownStr
60
40
20
0
−20
−40
−60
Pole height adj (μm)
−2
−1
0
1
2
position along the s axis (m)
HMB_2015−12−15−09_53_27

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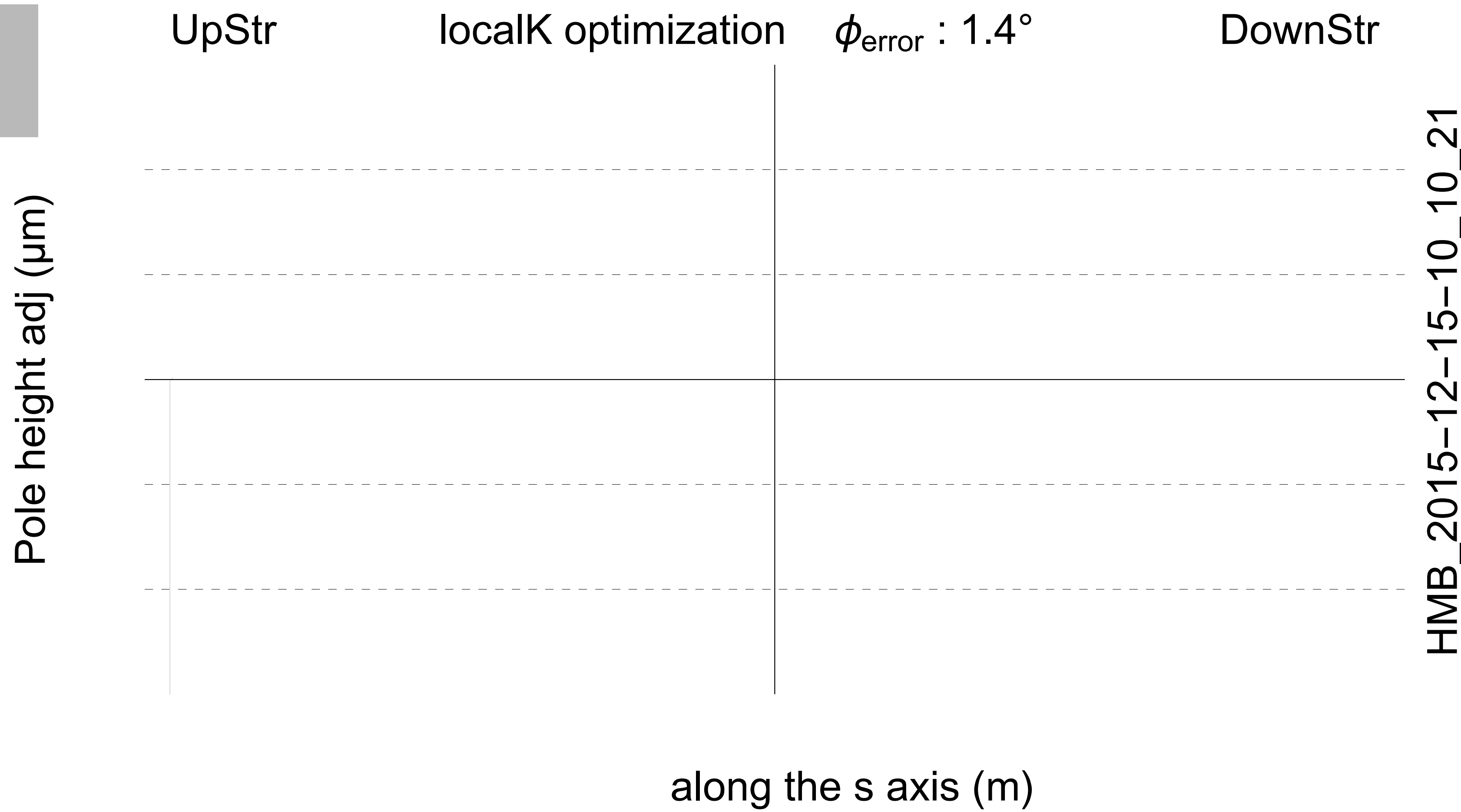
10:10 15-12-2015



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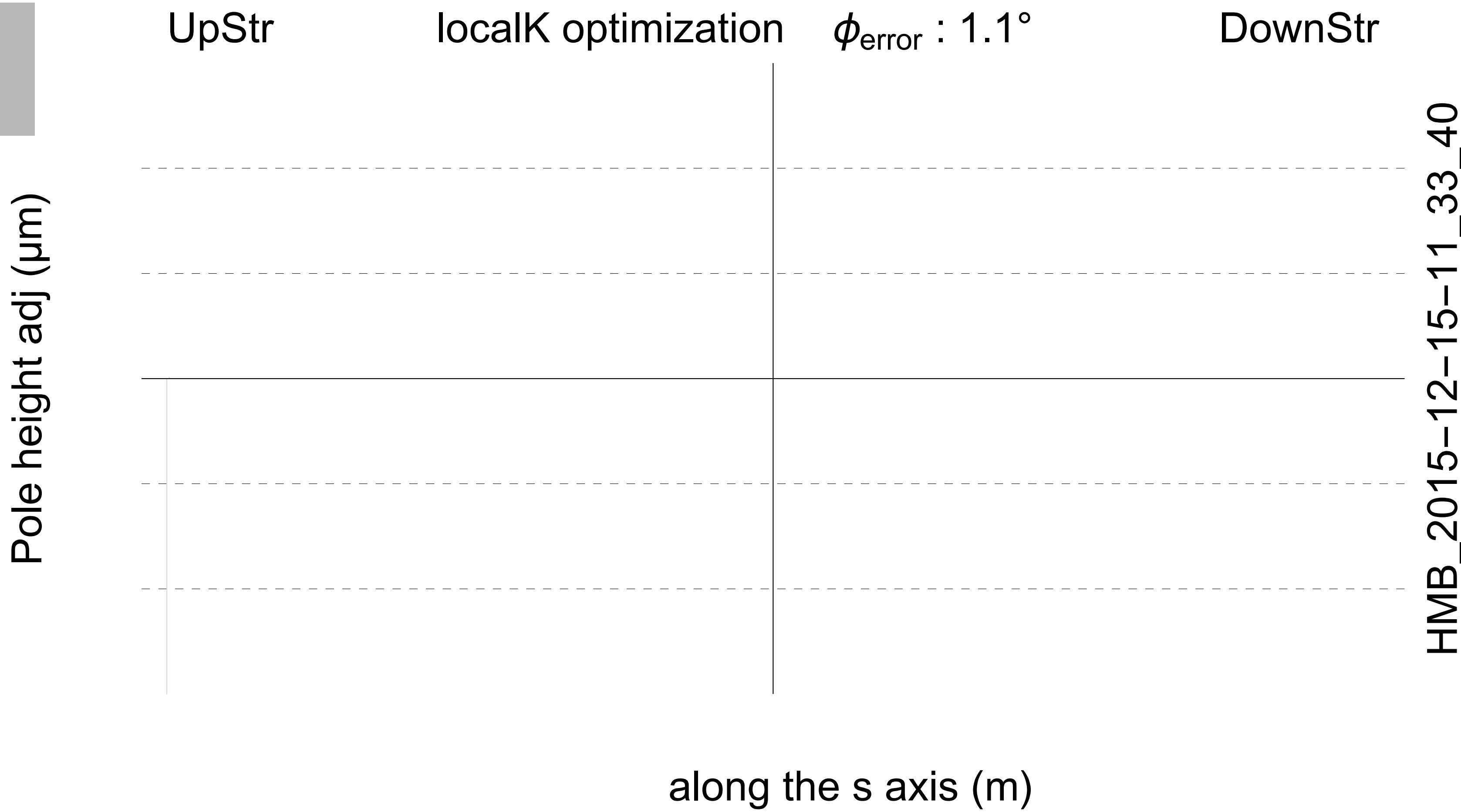
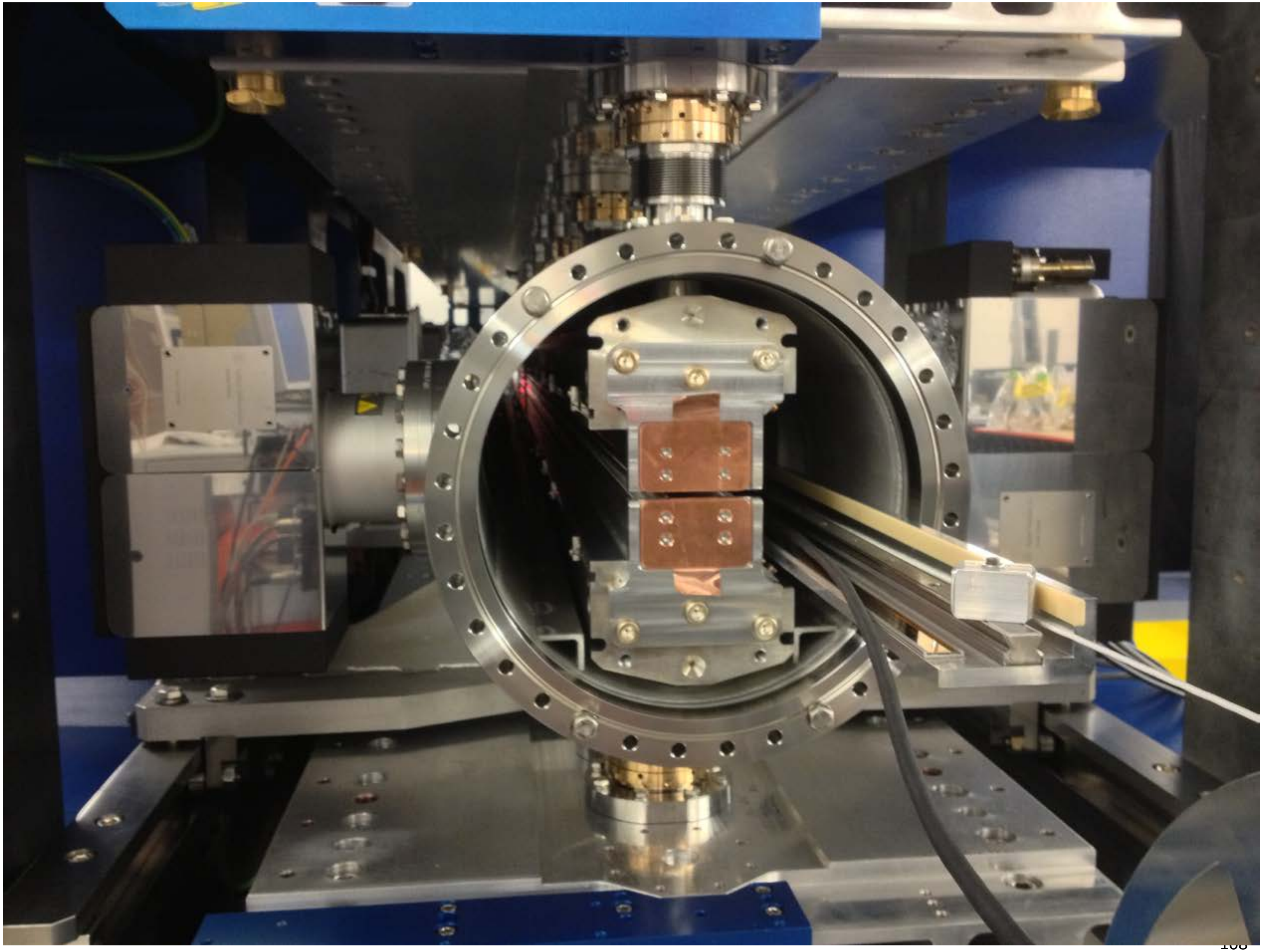
11:33 15-12-2015



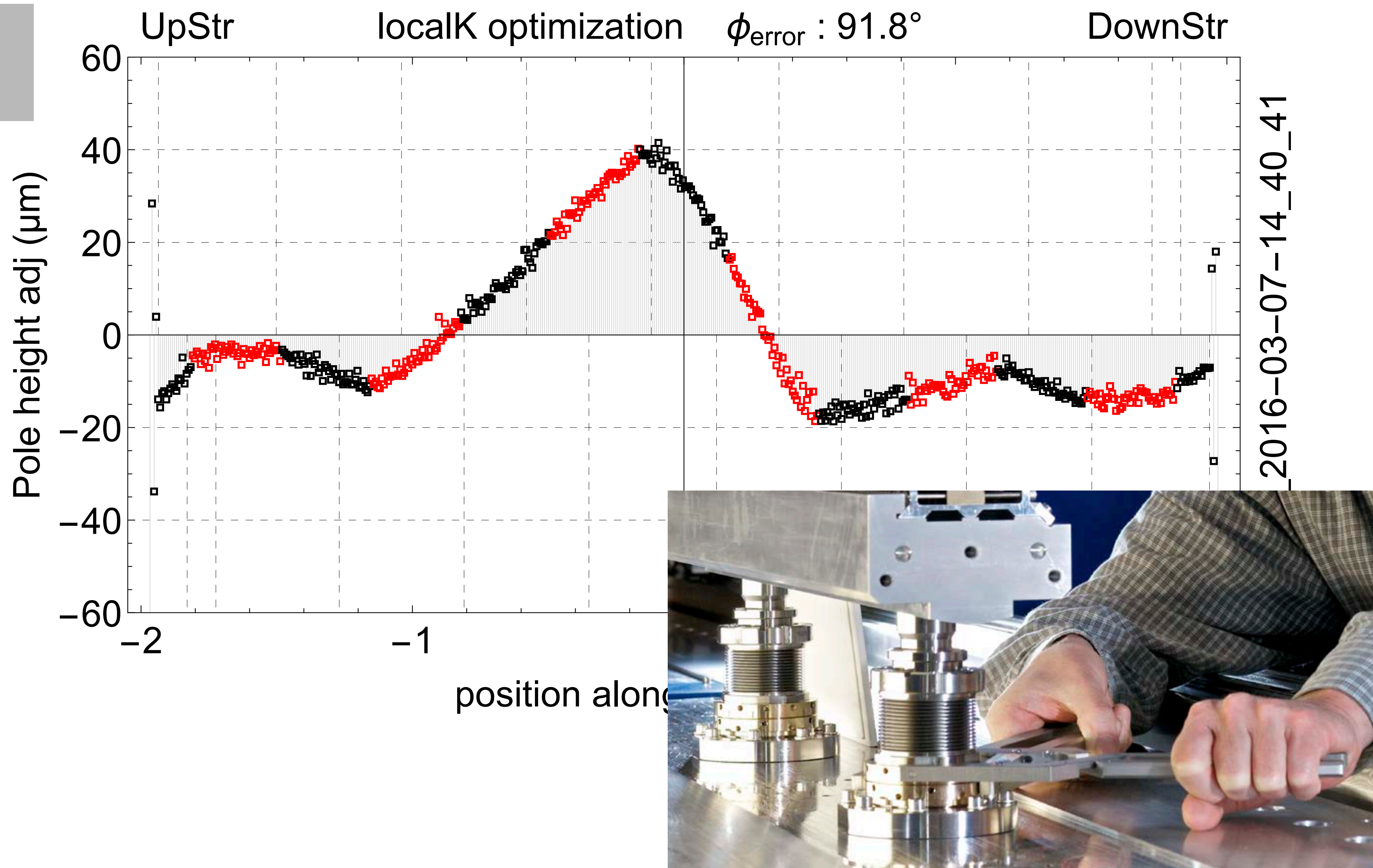
Moving to Bench B

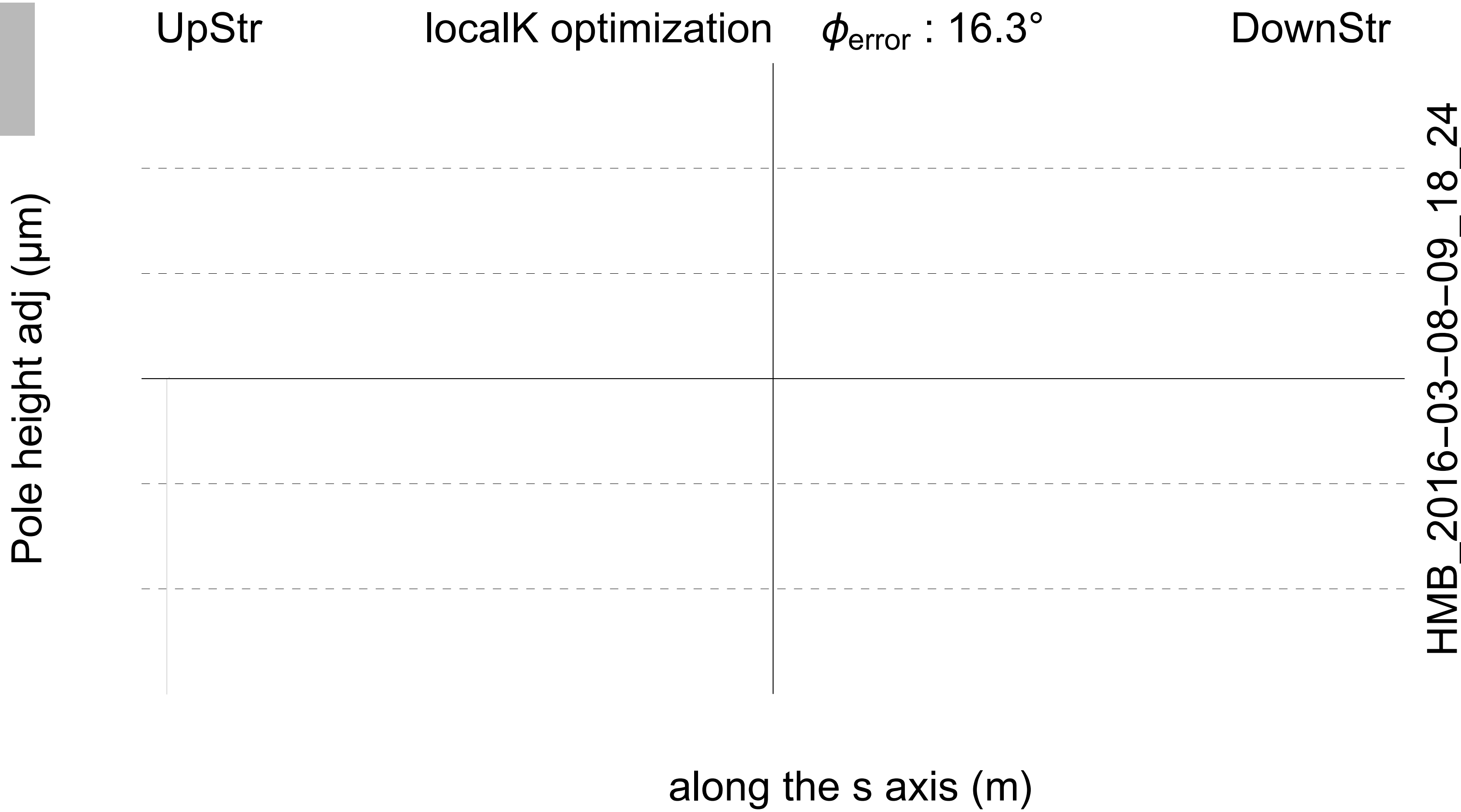
In-vacuum bench



14:40 07-03-2016

In-Vacuum Bench




UpStr
localK optimization
ϕ_{error} : 16.3°
DownStr
Pole height adj (µm)
HMB_2016−03−08−09_18_24
along the s axis (m)

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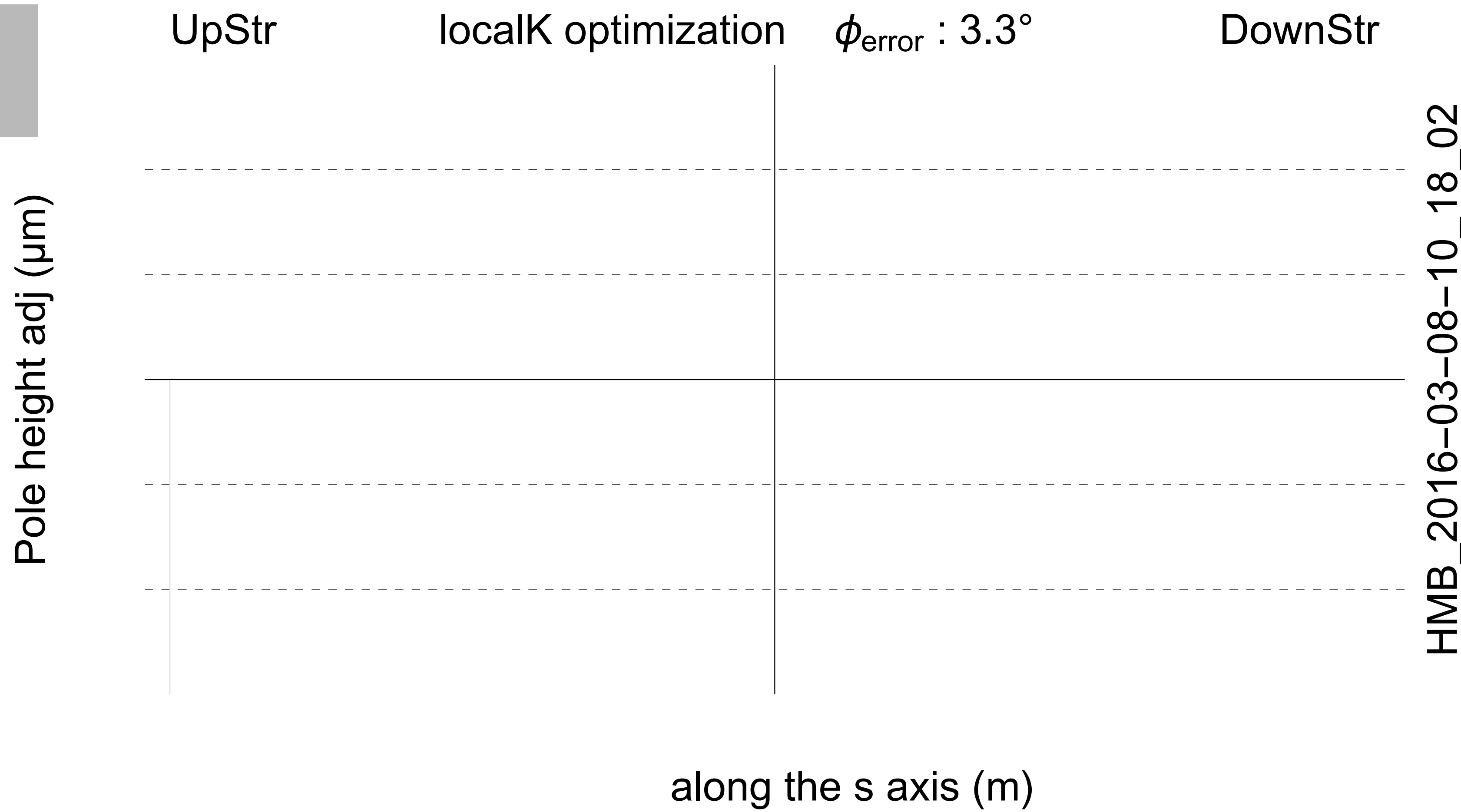
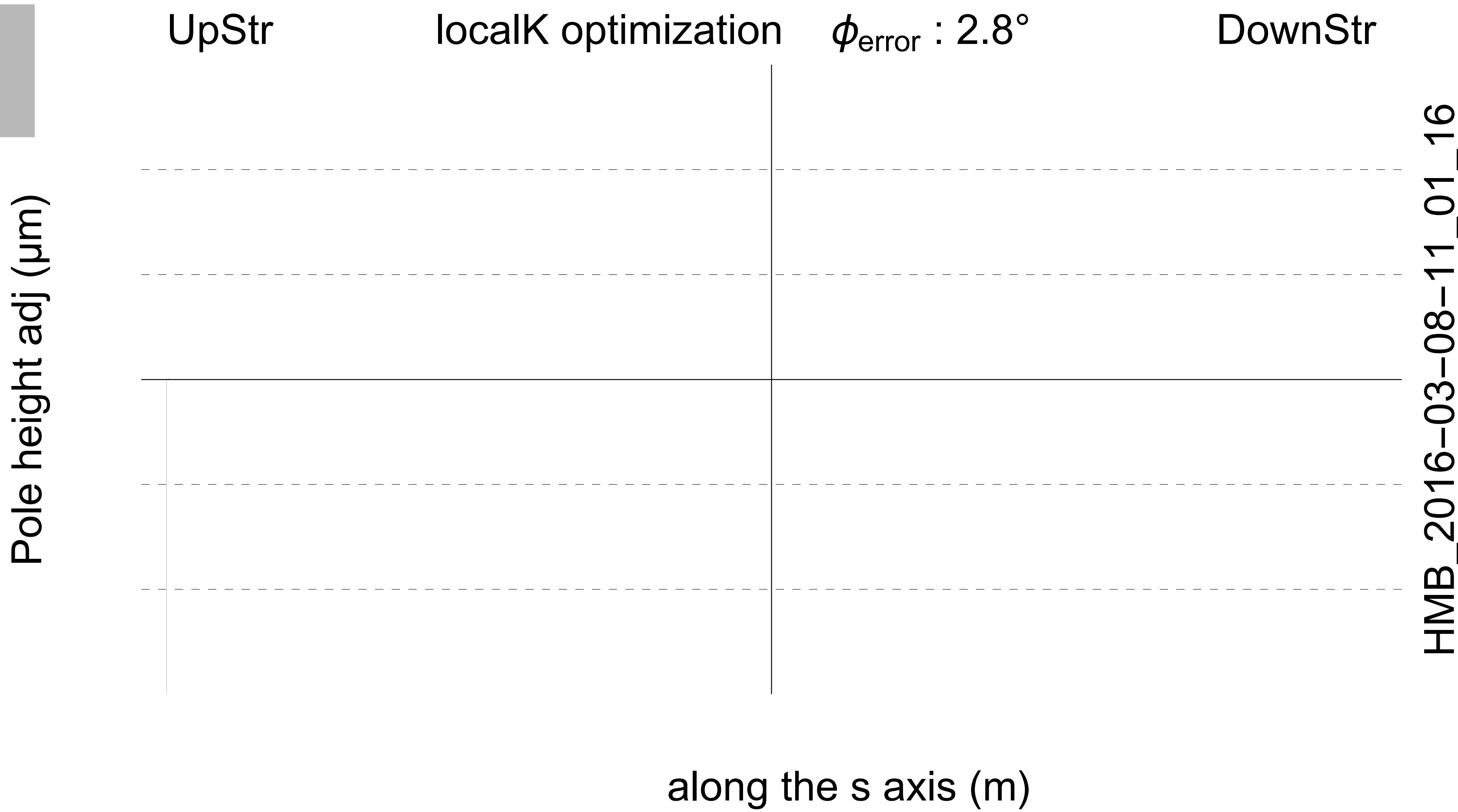
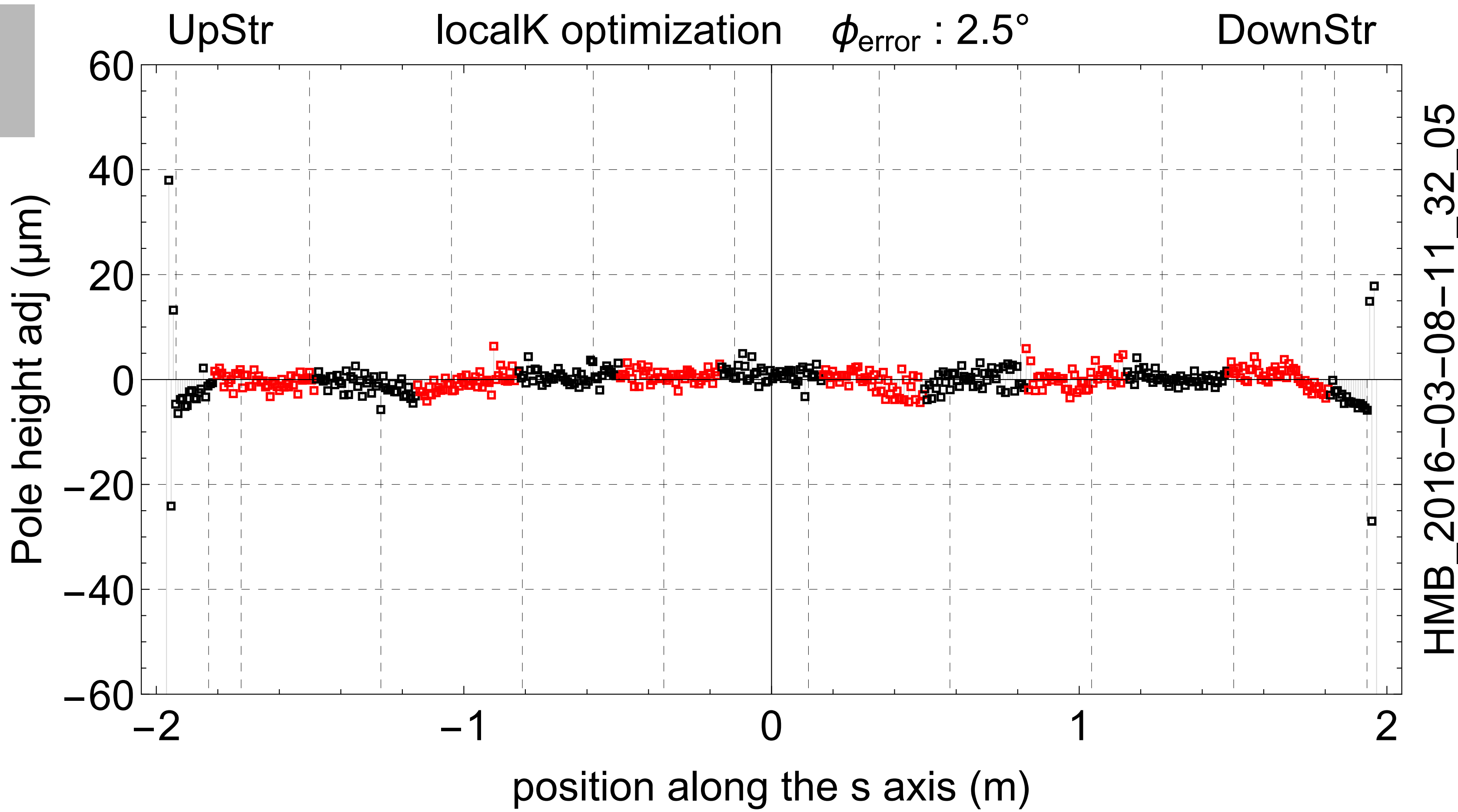
10:18 08-03-2016

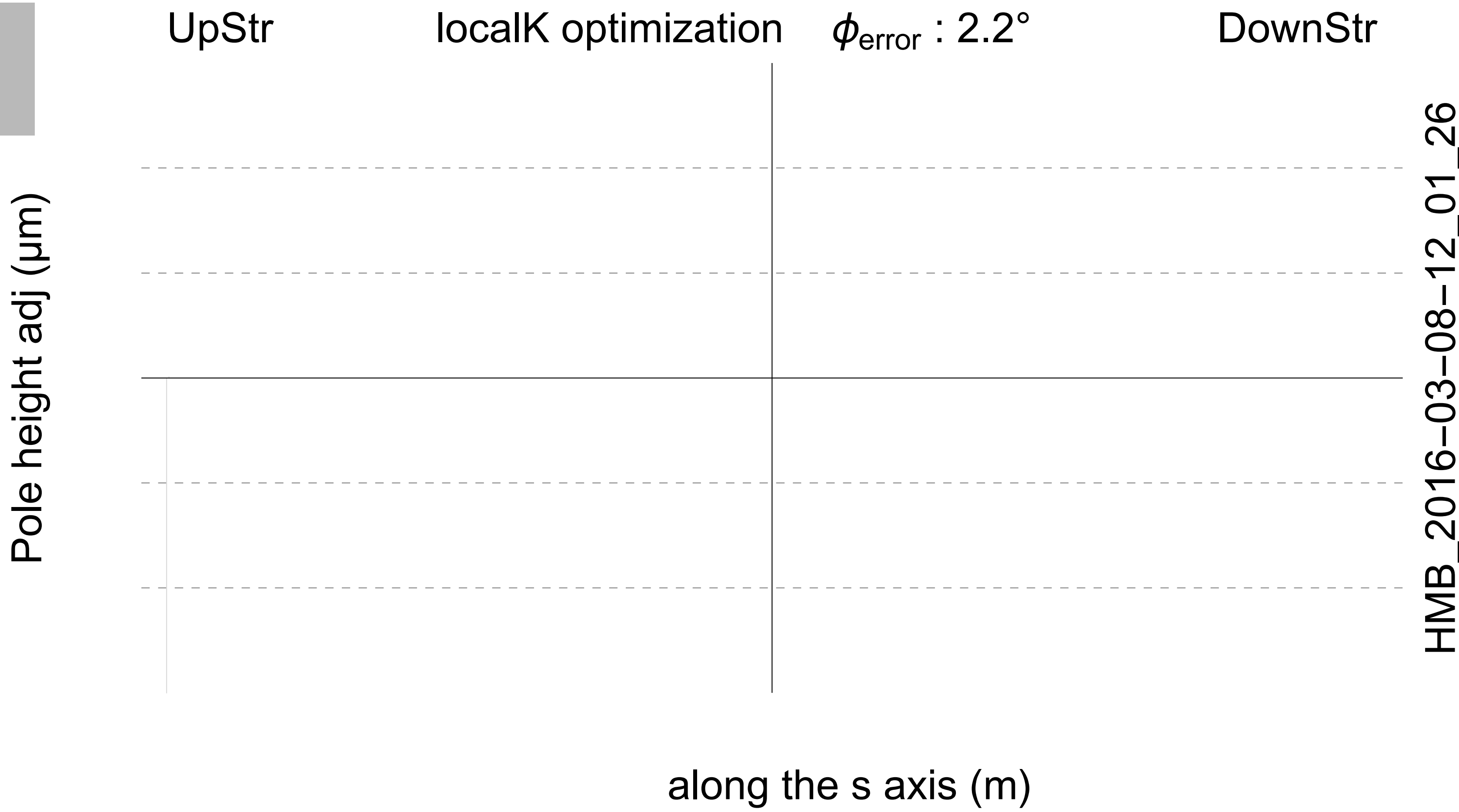



UpStr
localK optimization
ϕ_{error} : 2.8°
DownStr
Pole height adj (µm)
HMB_2016–03–08–11_01_16
along the s axis (m)

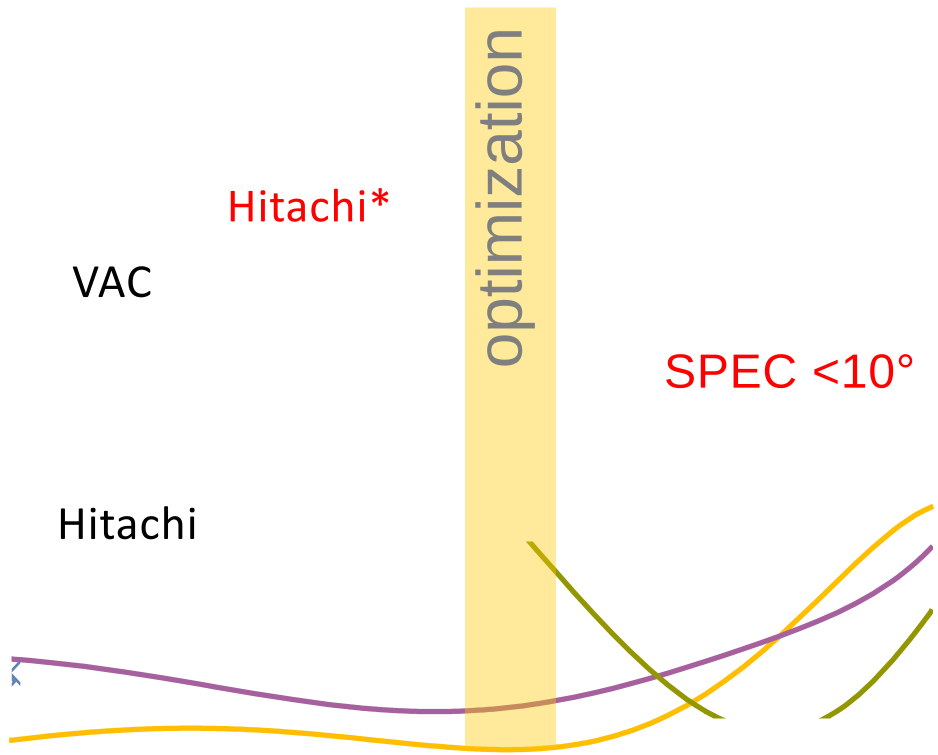

UpStr
localK optimization
ϕ_{error} : 2.5°
DownStr
Pole height adj (μm)
position along the s axis (m)
HMB_2016–03–08–11_32_05
60
40
20
0
−20
−40
−60
−2
−1
0
1
2

PAUL SCHERRER INSTITUT PSI

12:01 08-03-2016



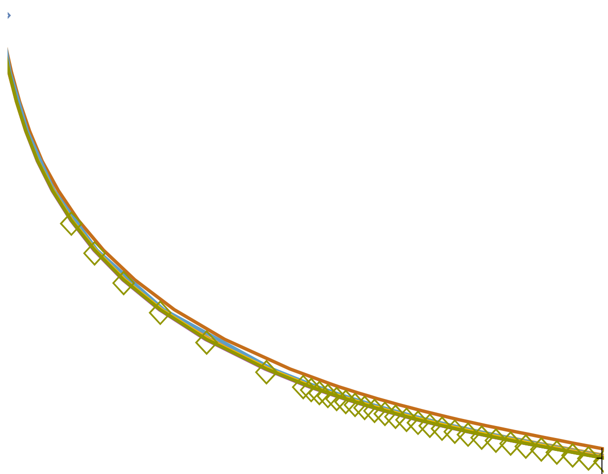
Summary of the 13 undulator of Aramis line

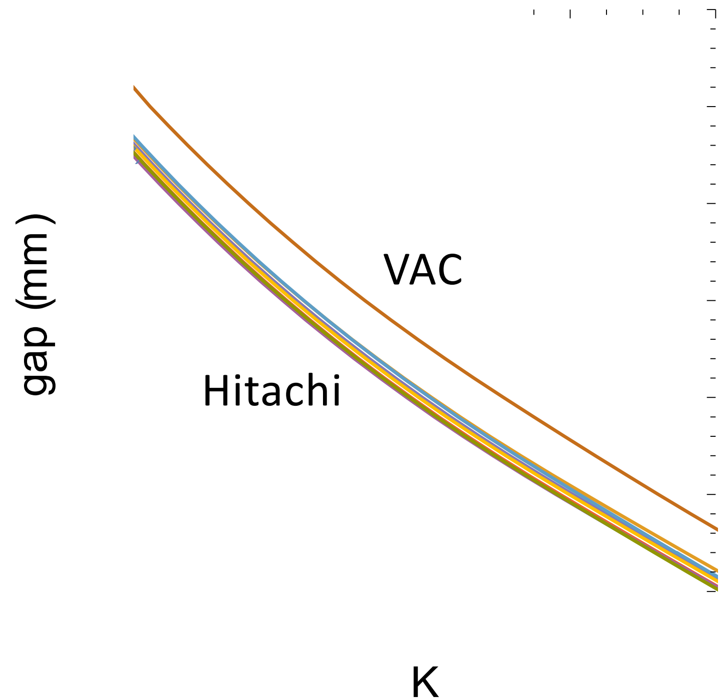


Overview

- Introduction to Light Sources: PSI examples
- Dipole Radiation
- Undulator fundamental relation
- Measurement bench:
  - Alignment
  - K-value
  - RMS phase error
  - Orbit distortion
- Optimisation
- An example of measurement & optimisation campaign
- The operation based on magnetic measurements
- Open for questions

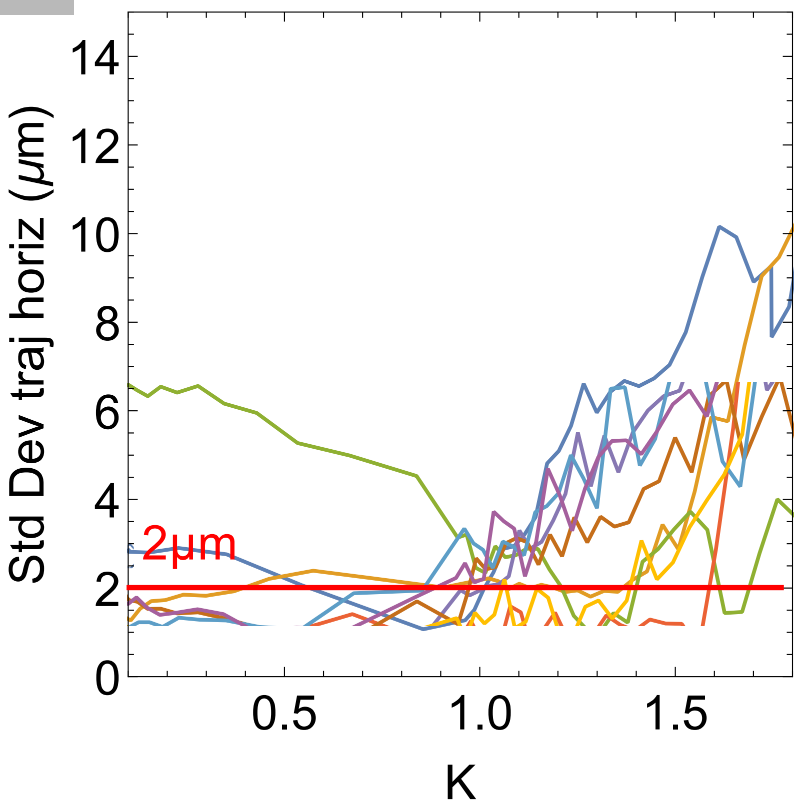
Setting the gap

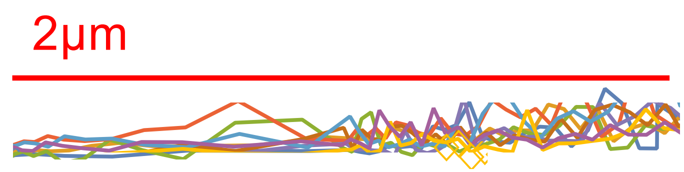




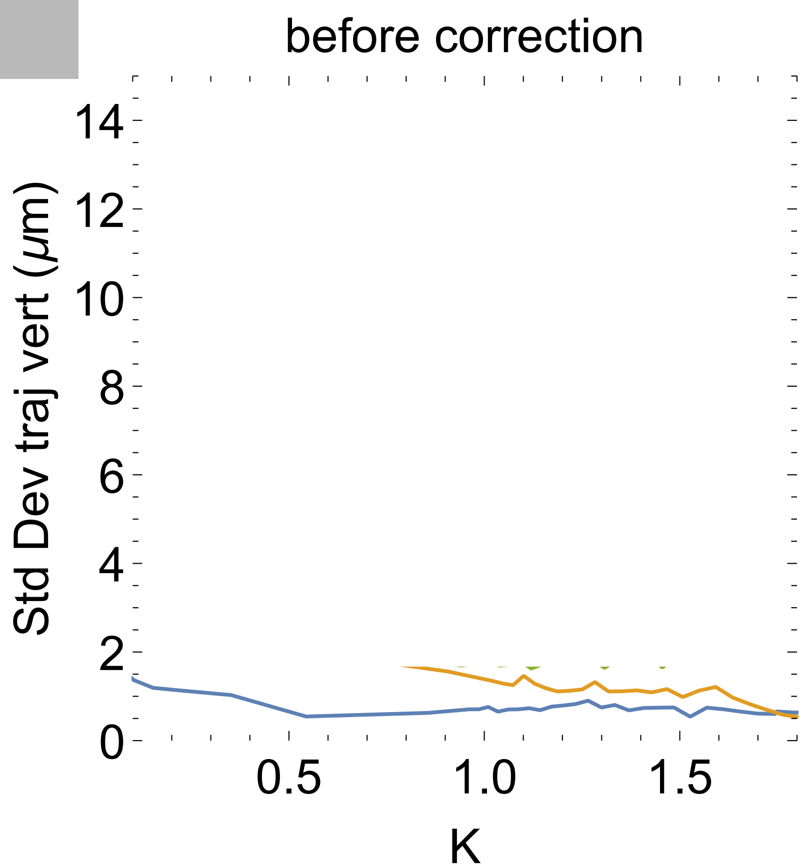
Orbit correction

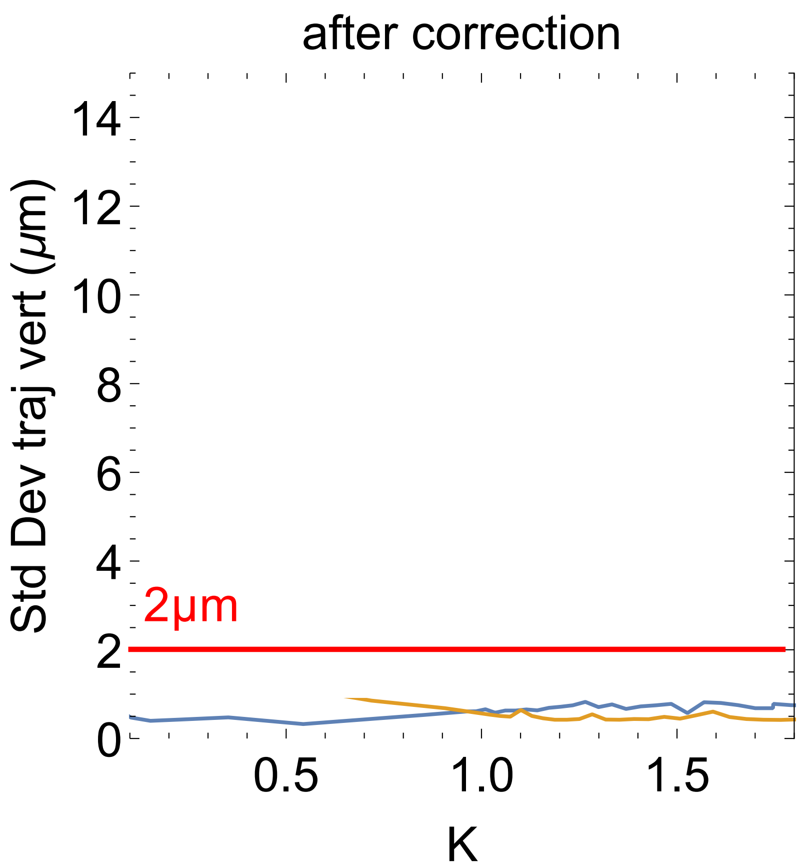
before correction



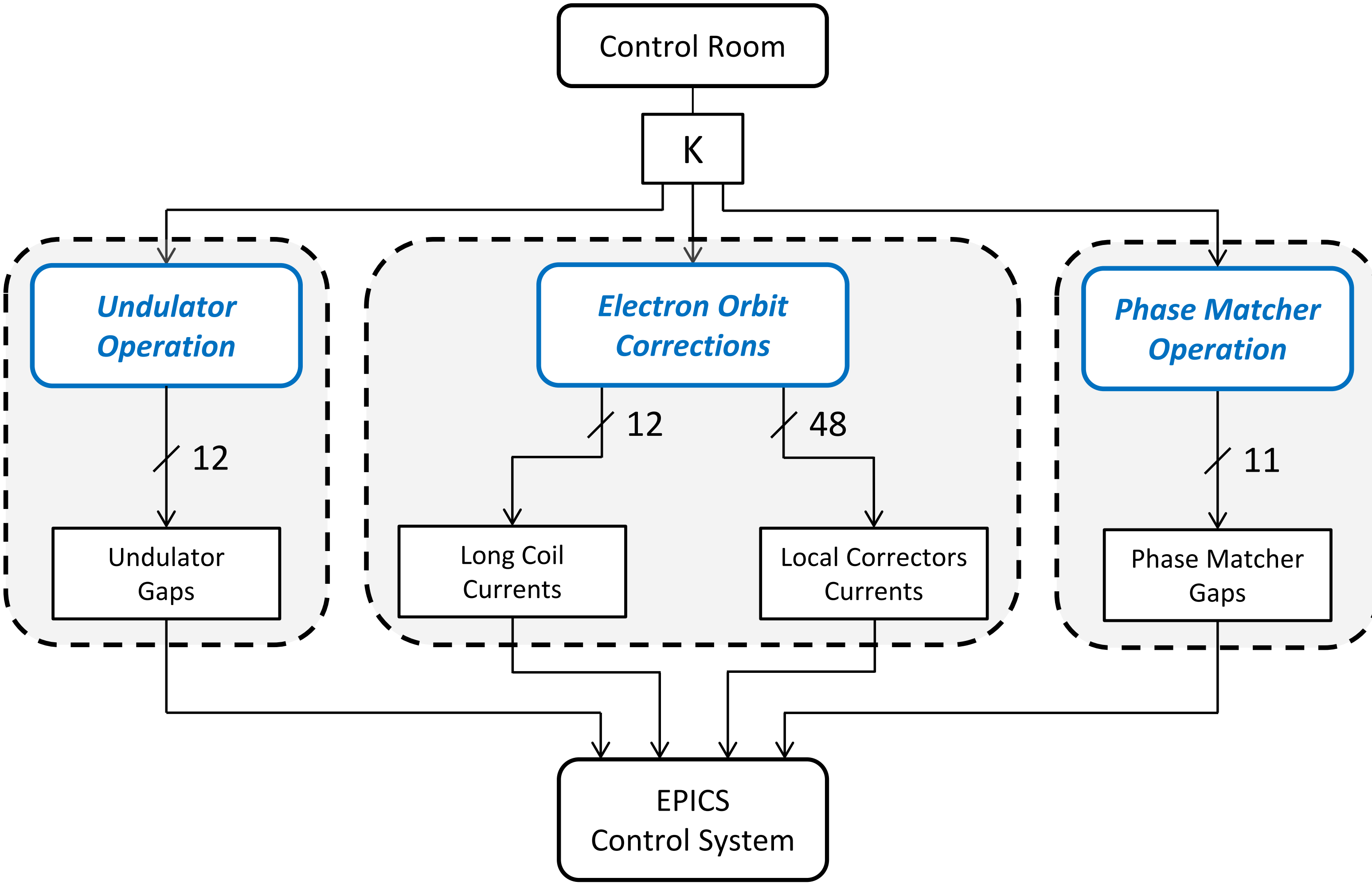


Orbit Corrections



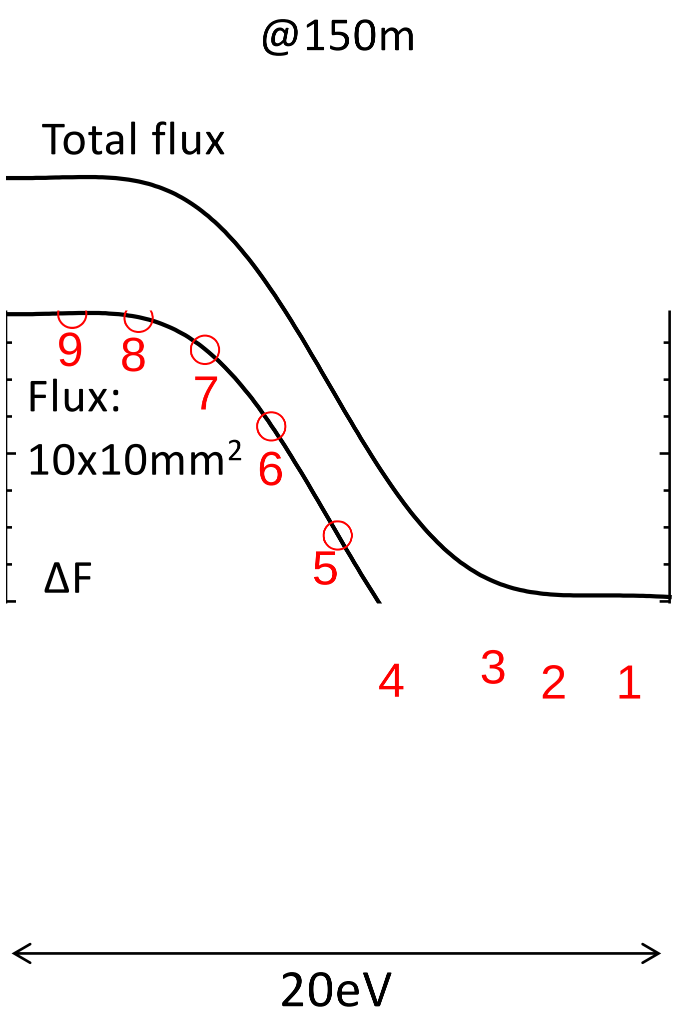


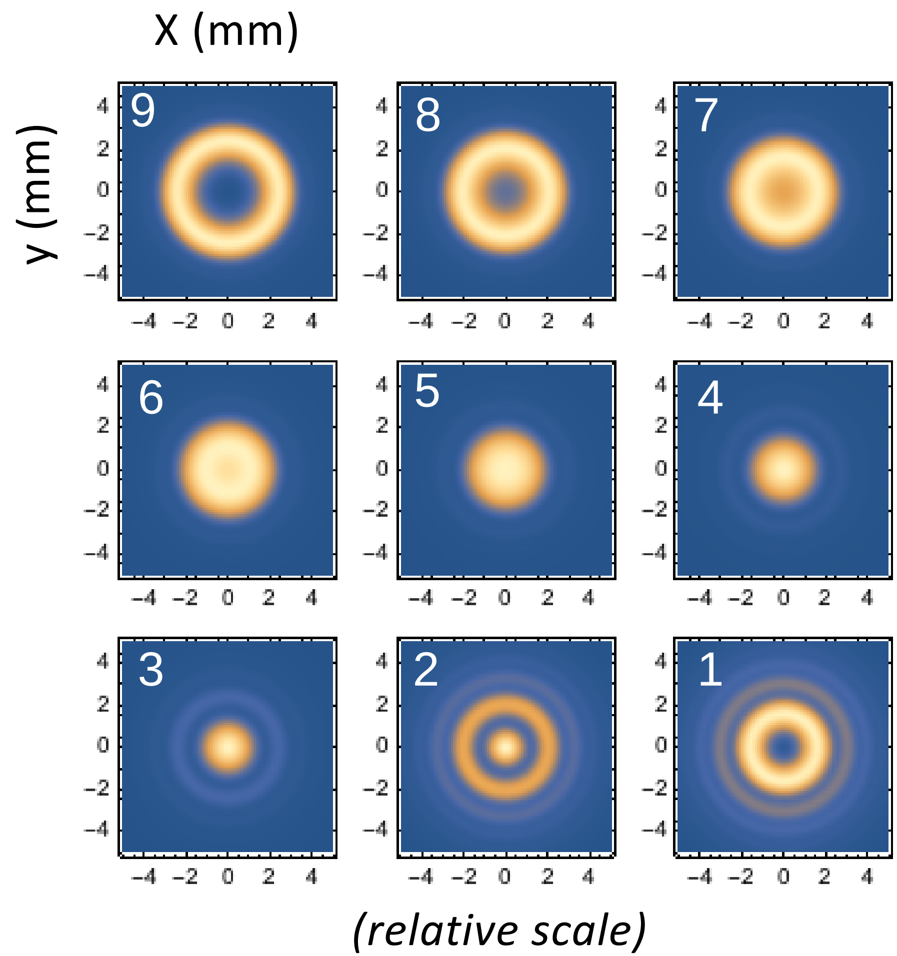
Aramis Beamline



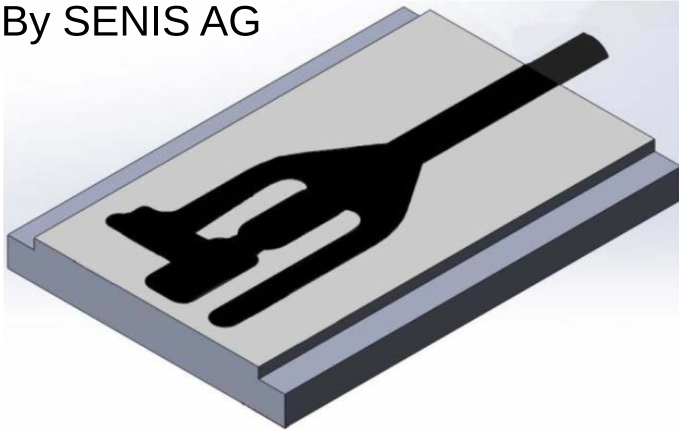
OPEN FOR QUESTIONS

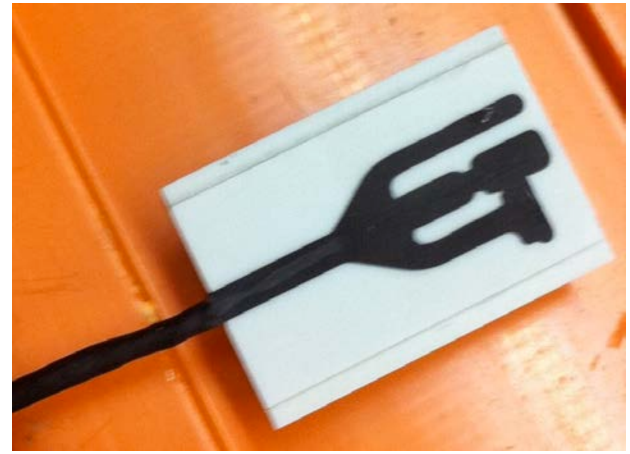
E=3.0GeV & K=1.8 – 1st harmonic





By SENIS AG



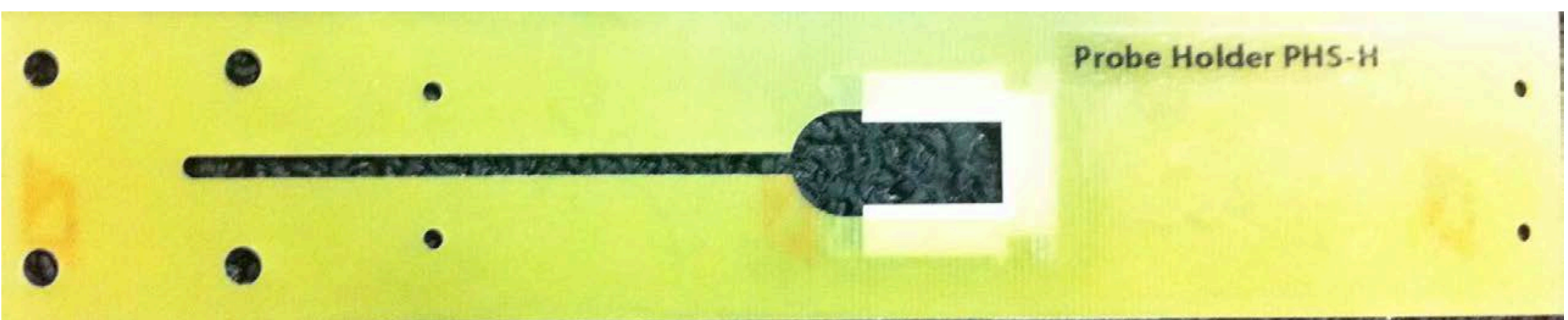


Dimensions: 1.5x10.5x15.0mm3

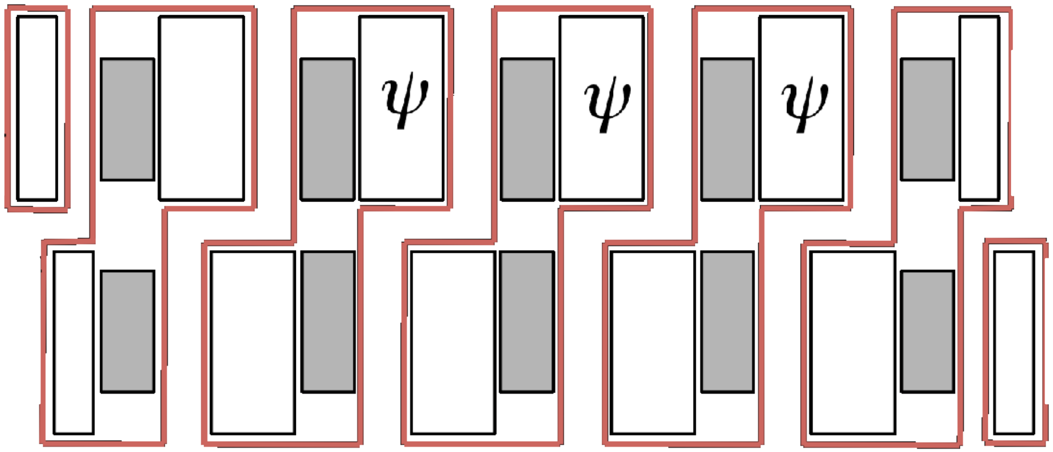
Mutual orthogonality: <2°

Angular accuracy with respect to the reference surface: ±2°

The three probes are all at the same height of 0.75 (middle of the probe) and horizontal position, while they are spaced longitudinally by 2mm



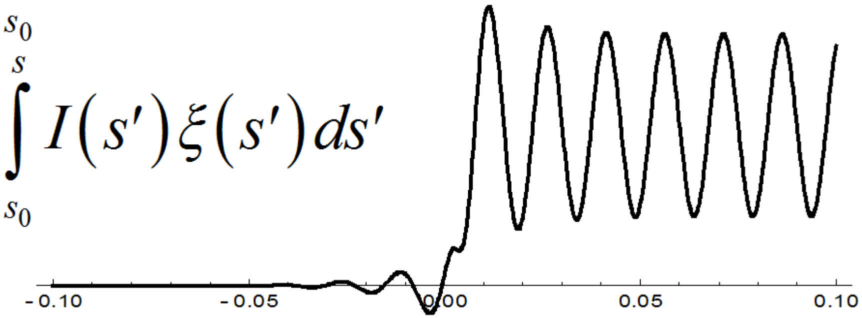
Optimization: Phase



Phase

$$\xi(s) = \int_{s_0}^{s} \psi(s')\,ds'$$

$$\chi(s) = \int_{s_0}^{s} I(s')\,\xi(s')\,ds'$$



$$\Delta\varphi(s) = 2\alpha \sum_{n} b_n \chi(s - s_n)$$

Aramis Beamline