BPM buttons

non linear beam response meets machine learning

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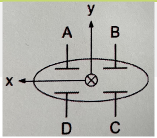
Introduction



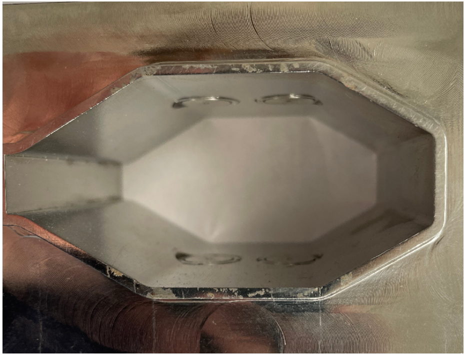


Figure: standard BPM implemented in BESSY II

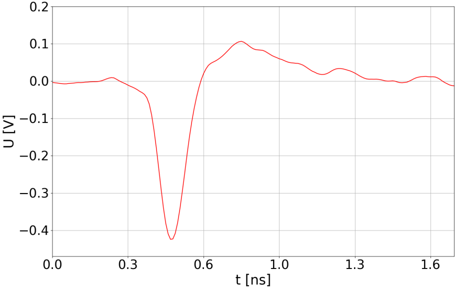
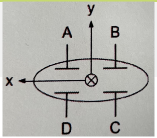


Figure: voltages over time, single bunch signal

Motivation



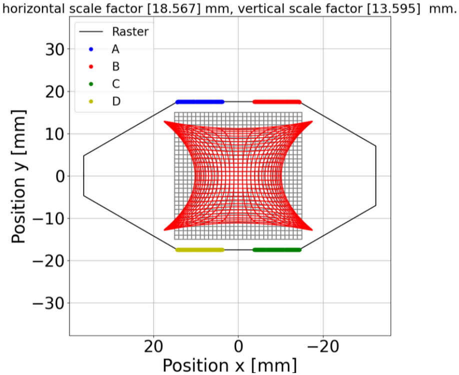


Figure: non-linearity in geometry of BESSY II

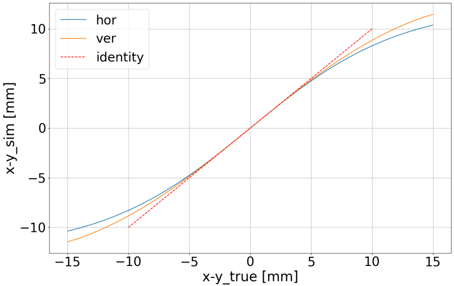


Figure: sensitivity and beam displacement

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Simulation

Principle

- parametrize **geometry** of BPMs & buttons
- simulate **beam positions** in geometry through raster
- calculate **induced charge** for beam positions on chamber wall of geometry
  $\Longrightarrow$ boundary element method (**BEM**) [1]
- calculate beam position **backwards** from induced charges on ABCD

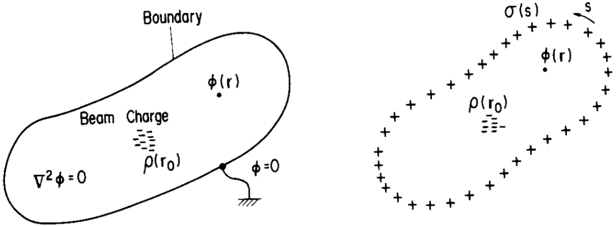
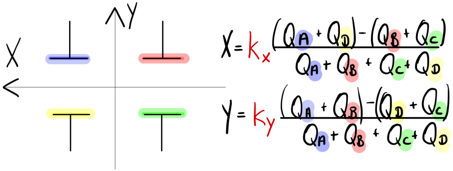


Figure: Reference [1]

Code Conversion



$$X = k_x \frac{(Q_A + Q_D) - (Q_B + Q_C)}{Q_A + Q_B + Q_C + Q_D}$$

$$Y = k_y \frac{(Q_A + Q_B) - (Q_D + Q_C)}{Q_A + Q_B + Q_C + Q_D}$$

Original Matlab code [2] $\Longrightarrow$ Python code

What's included?

- calculation of **induced charge**
  $\Longrightarrow$BEM method
- beam position raster & non linear solution
- Differences over Sum (**DoS**) method
  $\Longrightarrow$applied method to calculate XY-beam-position from ABCD-signals
- calculation of non linear **k-factor**
  $\Longrightarrow$ scale factor is change of beam position divided by change of x or y around centres, needs to be applied to DoS solution
- **Newton Raphson Algorithm**
  $\Longrightarrow$iteration method to find XY-position from ABCD signals !time consuming!

Code Conversion: Matlab to Python

Most important changes

- conversion to **SI** units
  $\Longrightarrow$mm $\longrightarrow$ m
- 18 **geometries** included
  $\Longrightarrow$e.g. round, rectangular, two buttoned
- **axis** transformation
  $\Longrightarrow$according to BESSY II convention

Small Bug

- BEM method $\longrightarrow$ calculation of induced charge
  $\Longrightarrow$matrix of Green's functions solving the 2D electrostatic Laplace equation:

$$G_{ii} = \int_{\Gamma_i} \ln\left(\frac{1}{|r_i - r_i|}\right) dr_i = s \cdot \left(1 - \ln\left(\frac{s}{2}\right)\right);\ s = segments\ width$$

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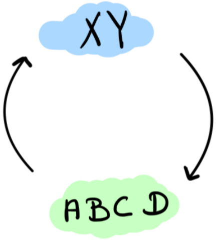
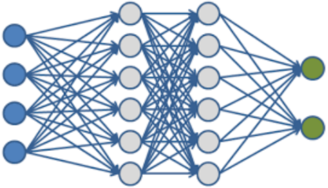
Idea

- train **neural network** how to solve XY-beam-position to ABCD-button-signal
  $\Longrightarrow$ well known & easy calculation
- generate **training data** with simulation code
- goal: neuronal network learns **inverse** problem
  $\Longrightarrow$ the inversion we use is a good **approximation** for **small** beam displacements
  $\Longrightarrow$ we want a **fast** solution for small & large amplitudes



Some Numbers



Example model:

- time of training : *57265.4s* $\approx$ *7h* on CPU
- training data size : *5.2GB*
- model size : *4.6MB* (not minimized)
- model architecture : 4 layers : [1000, 700, 500, 300]
- CPU * times for ML prediction : $\approx$ *80ms* for measured dataset **

  $\Longrightarrow$ CPU * times for Newton Raphson : $\approx$ *7s* for measured dataset **

  * *13th Gen Intel(R) Core(TM) i7-1365U, 12 threads, 5.2 GHz*

  ** $\approx$ *7800 ABCD signals*

Outcomes

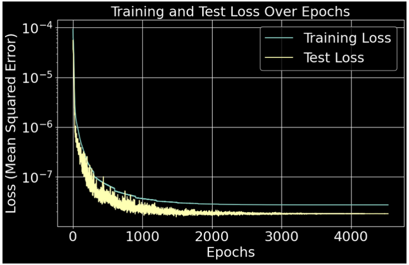
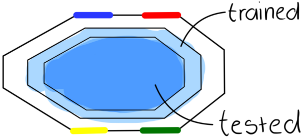


Figure: behaviour of training and testing data during model development



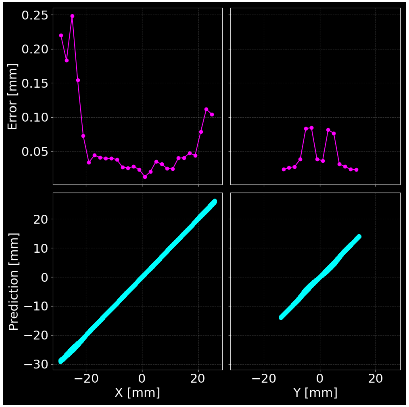


Figure: performance

Outcomes

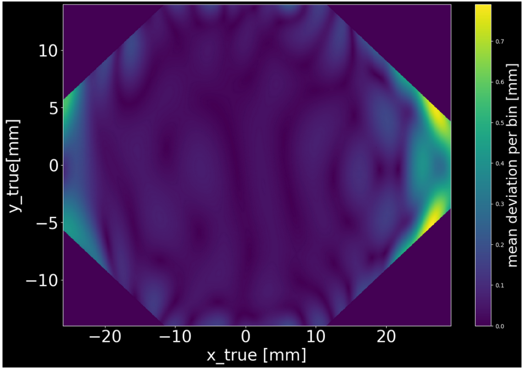


Figure: 2D model performance

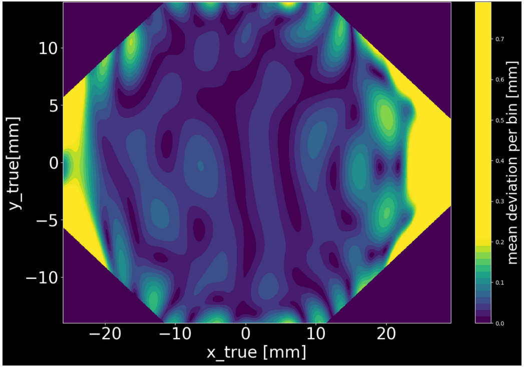


Figure: 2D performance (dicrete area)

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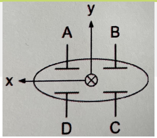
Measurement



measured data of huge beam position shifts by changing masterclock frequency
$\alpha \approx 7 \cdot 10^{-4}$, dispersion ≈ 0.5m

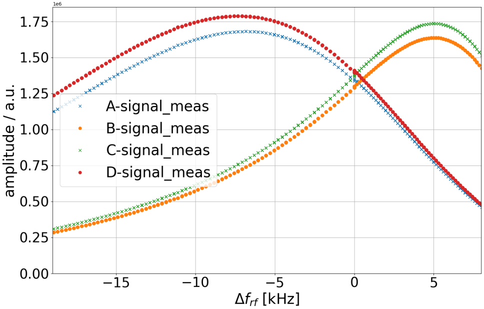


Figure: signals on BPM buttons

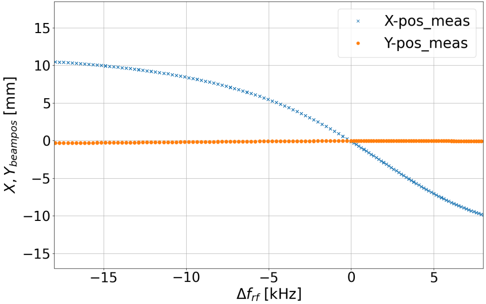
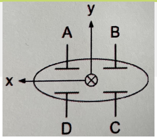


Figure: XY positions

Evaluate model



evaluation in BESSY II model [3] in comparison to measurement results:

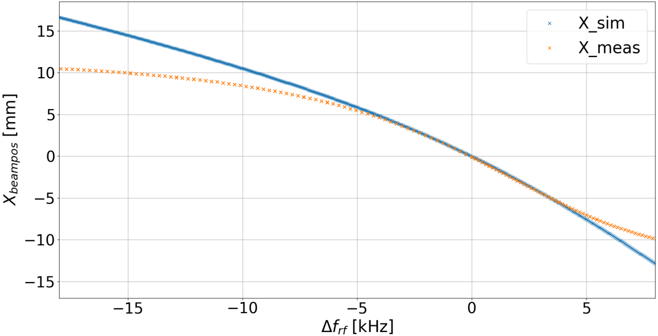
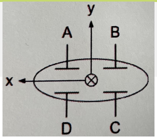


Figure: X positions comparison

Comparison to Newton Raphson



application of measurement data on Newton Raphson algorithm:

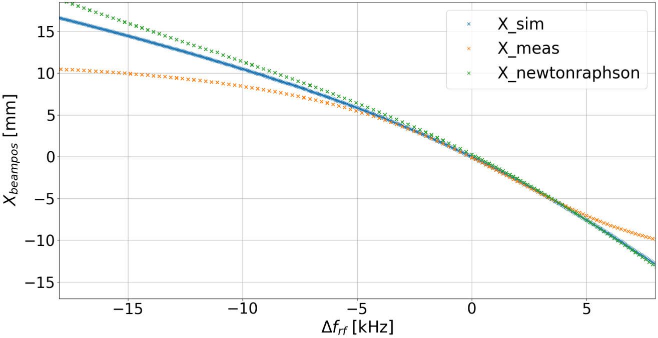
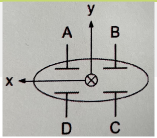


Figure: X positions comparison

Comparison to ML model



application of measurement data on ML model:

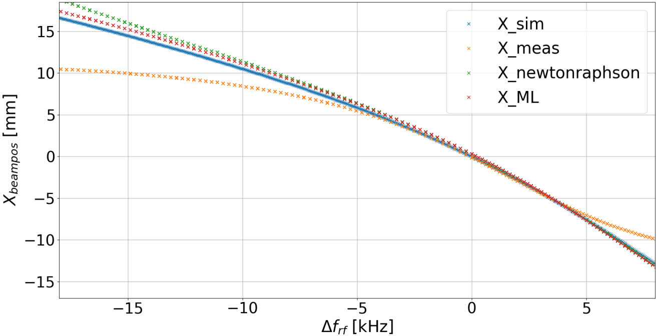


Figure: X positions comparison

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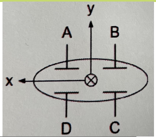
- convert python code into **python package**
  ⟹ loadable & easy to apply
- implementation of different **BPM button** geometries
- apply **beam current** to ML model
  ⟹ atm needs to be fixed by **norm factor** on ABCD
- apply ML model to **FPGA system**



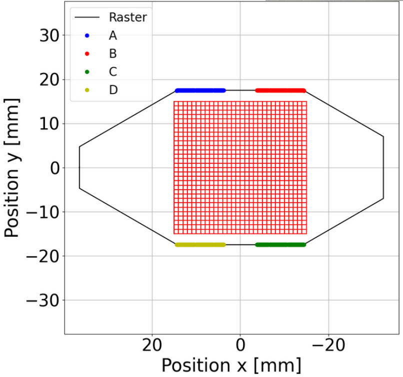


Figure: HZB, BESSY II [4]

References

[1] Shintake et al., " Sensitivity calculation of beam position monitor using boundary element method " , 1987, journal NIM-A, volume 254, pp. 146-150

[2] A. Olmos, F. Perez, and G. Rehm, “Matlab Code for BPM Button Geometry Computation”, in Proc. DIPAC’07, Venice, Italy, May 2007, paper TUPC19, pp. 186-188

[3] Pyat documentation: $https://atcollab.github.io/at/p/index.html$

[4] Dirk Laubner $https://www.helmholtz-berlin.de/forschung/quellen/bessy/index_de.html$

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