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Machine Learning Applied to Automated Tunes Control at the 1.5 GeV Synchrotron Light Source DELTA

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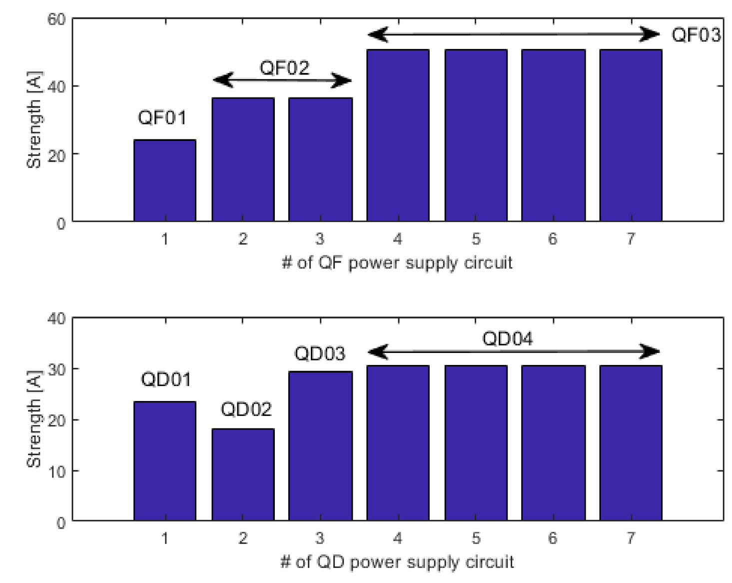
Introduction

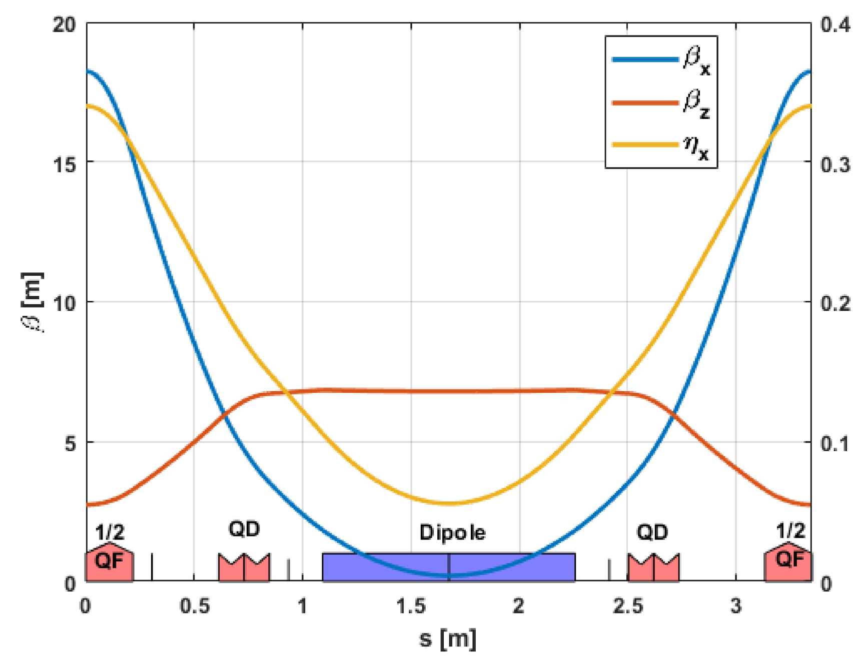
DELTA is a 1.5-GeV electron storage ring facility operated by the TU Dortmund University supplying radiation ranging from THz to the hard x-ray regime. Due to thermal orbit movements and magnetic current-dependent field changes, the betatron tunes may vary during machine operation. Therefore, automatic tunes correction is important, especially for the DELTA storage ring, as otherwise sudden beam losses can occur. For this purpose classical, shallow (non-deep), feed-forward neural networks (NNs) were investigated for automated adjusting the storage ring tunes. The NNs were trained with experimental machine data as well as with simulated data based on a detailed lattice model of the DELTA storage ring.

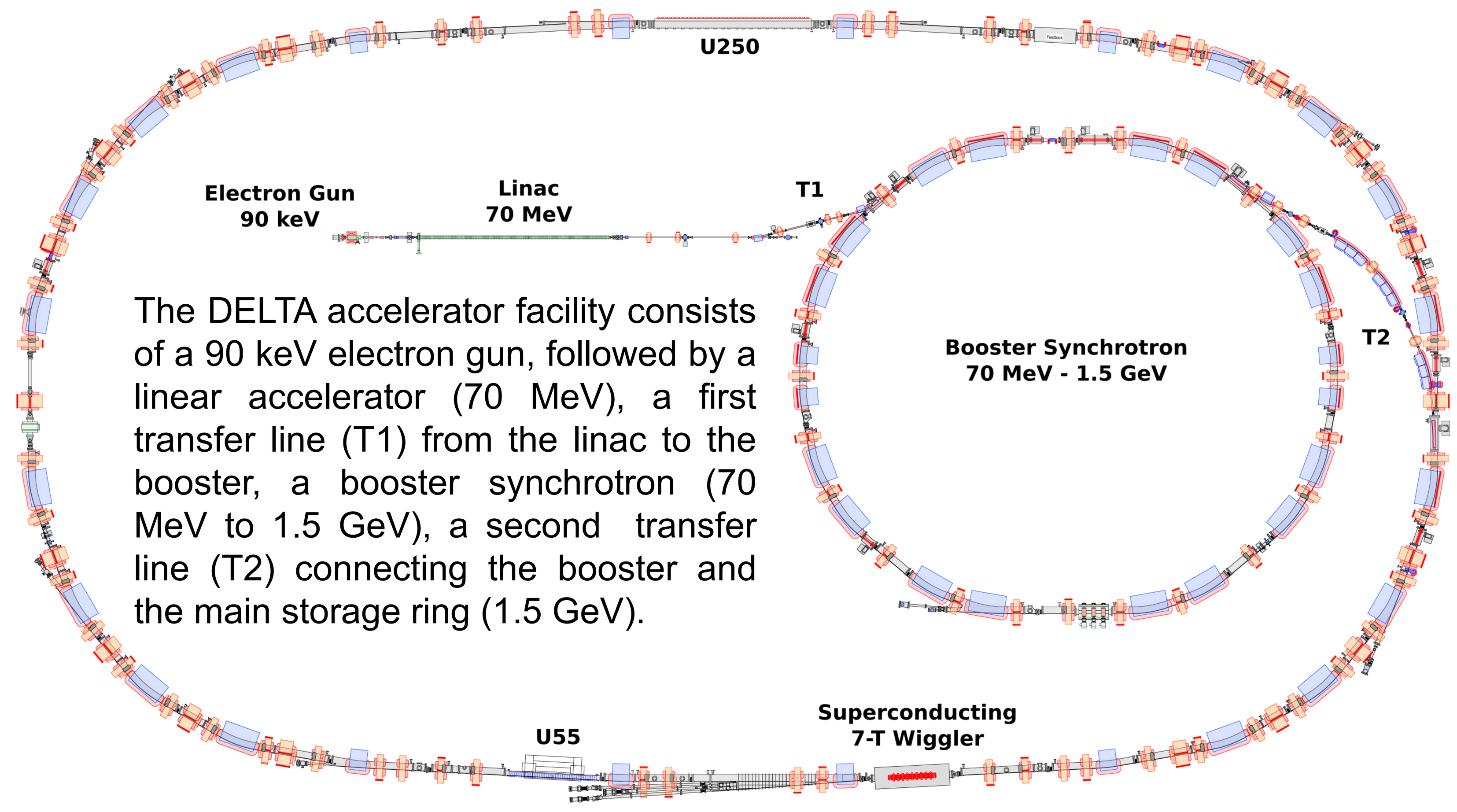
Tunes Control Setup

Quadrupole family settings in triplet cells



Triplet unit cell optics



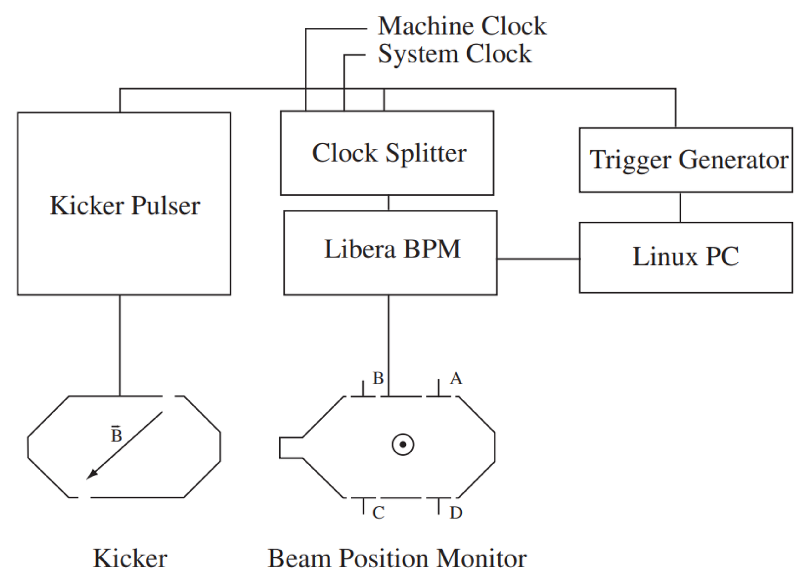


The DELTA accelerator facility consists of a 90 keV electron gun, followed by a linear accelerator (70 MeV), a first transfer line (T1) from the linac to the booster, a booster synchrotron (70 MeV to 1.5 GeV), a second transfer line (T2) connecting the booster and the main storage ring (1.5 GeV).

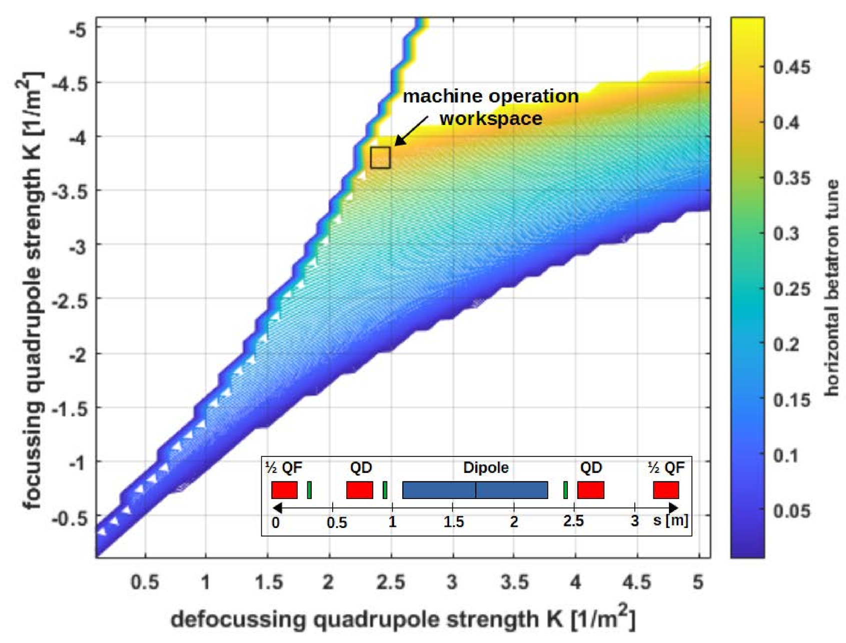
The tune measurement based on broadband beam excitation with an x,y-kicker magnet and determination of the relaxation betatron oscillations turn-by-turn via a Libera-BPM electronics. The betatron frequency detection utilized a classical numeric approach applying FFT and Levenberg-Marquardt algorithms for data fitting (Fig. top right) [1].
The linear optics of the DELTA storage ring can be flexibly adjusted with triplet cell quadrupoles (Fig. bottom left, right). In order not to change the optics in the straight sections, only 7 quadrupole families in the arcs are used for tunes control (Fig. top left) [2].

[1] P. Hartmann et al, "Kicker Based Tune Measurement for DELTA", in Proc. DIPAC'07, Venice, Italy, pp. 277-279.
[2] D. Schirmer and K. Wille, "DELTA Optics", in IEEE PAC, volume 5, pp 2859-2861, San Francisco, California, 1991 May 6-9.

Tune measurement setup



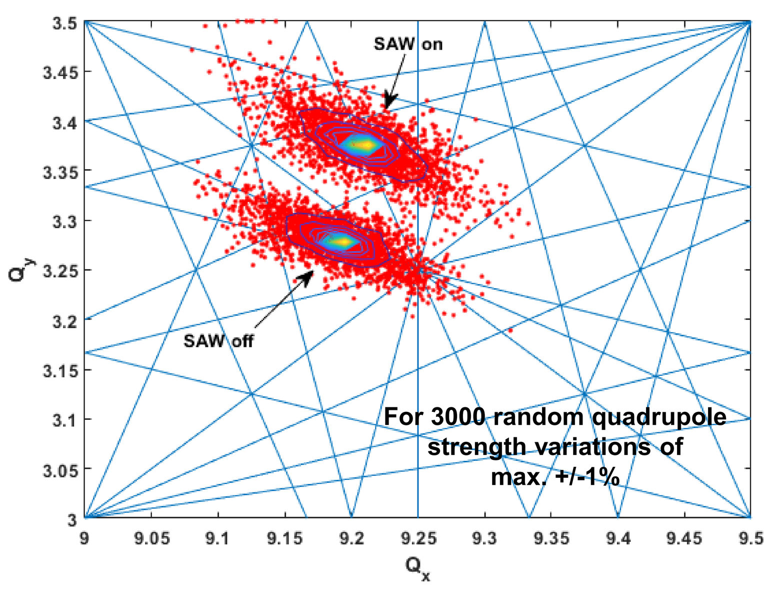
Tune shift per triplet unit cell



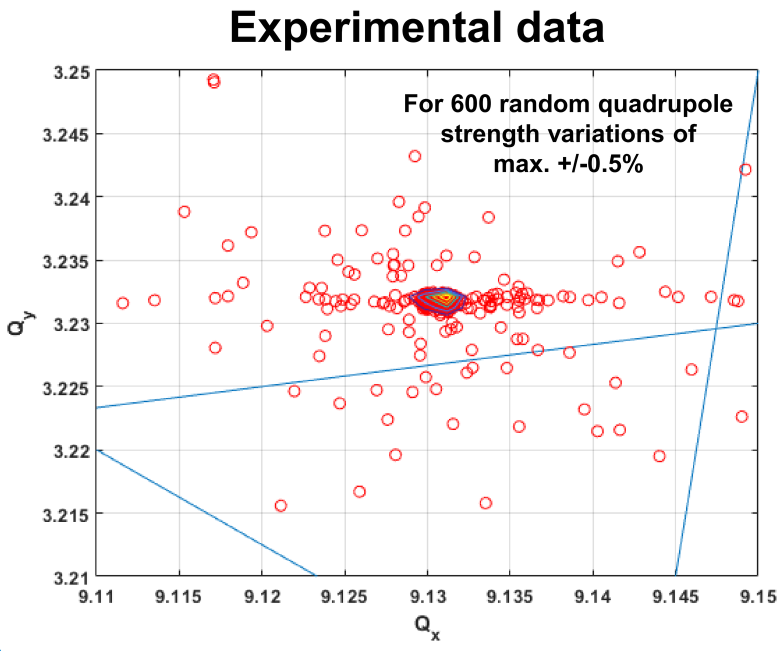
Tunes Control with Feed-Forward Neural Networks (FFNN)

Storage ring tunes

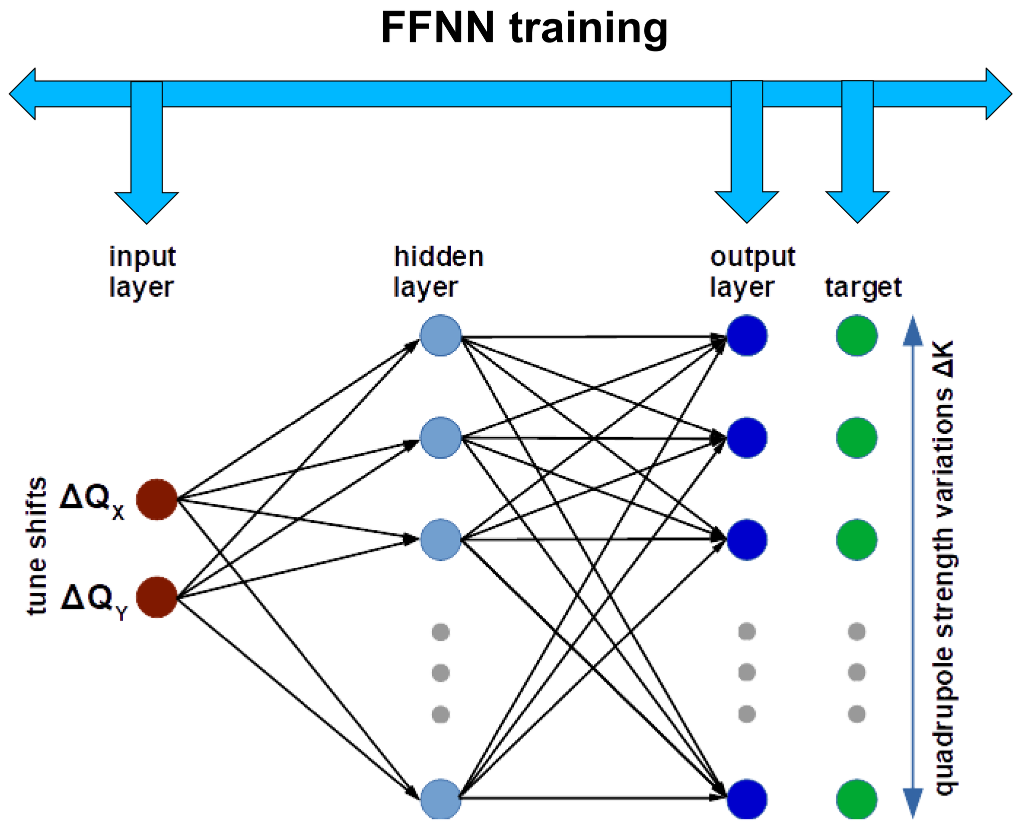
Optics simulations



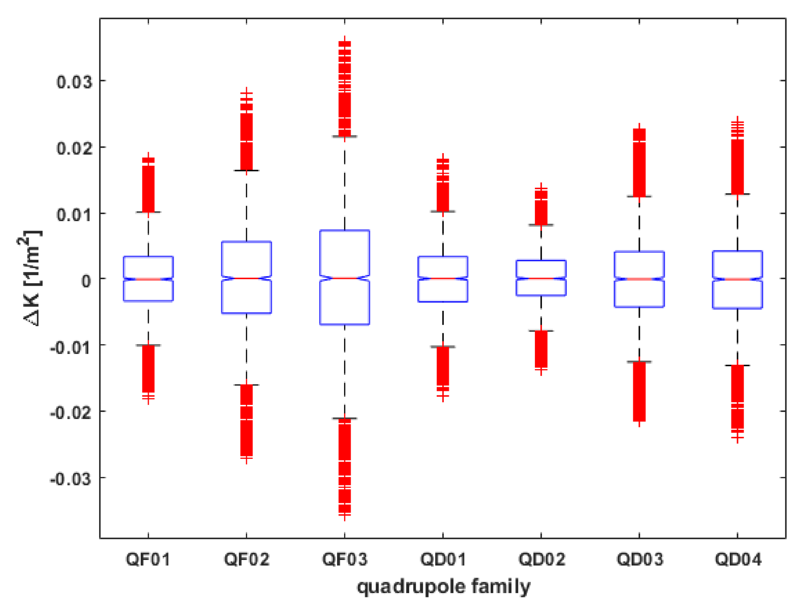
Experimental data



FFNN training



Random quadrupole strength variations (+/-0.1% - +/-2%)

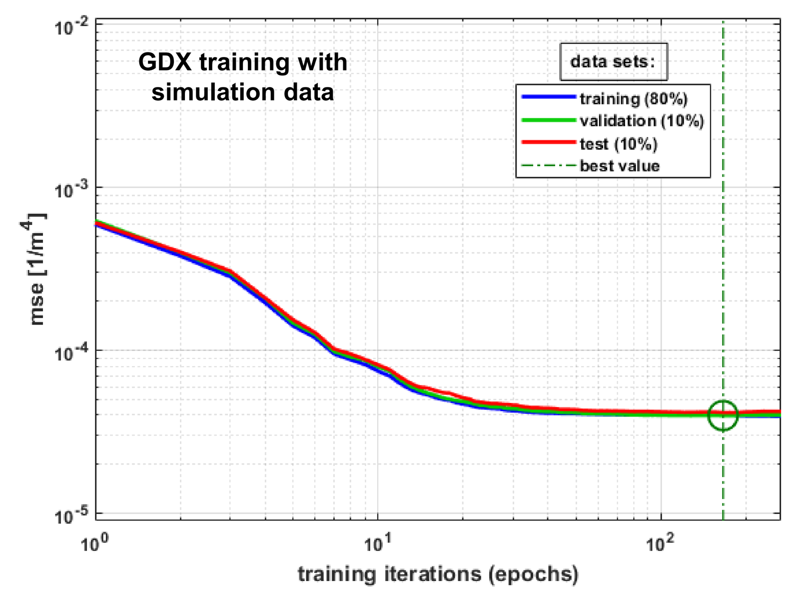


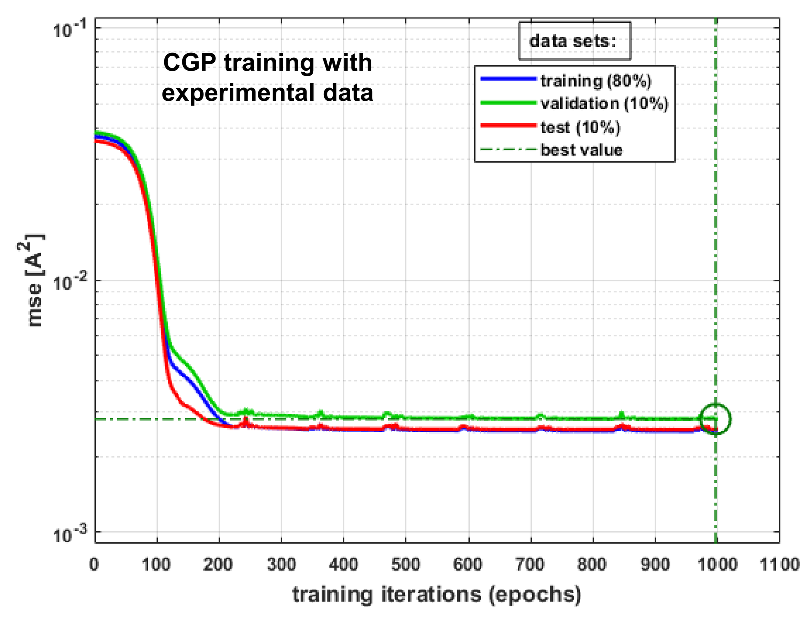
Classical fully connected feed-forward NNs were trained by supervised learning with experimental machine and simulated model data sets (Fig. left, center: $\Delta Q_{x,y}$,ΔK) [3,5]. The training was performed with conjugate gradient (CGP) and gradient descent with momentum and adaptive learning rate (GDX) back-propagation algorithms [4,5]. The mean square NN output error (mse) scores the training performance (Fig. right) [5].

[3] A. Terebilo, "Accelerator Modeling with Matlab AcceleratorToolbox", in Proc. PAC'01, Chicago, USA, pp. 3203-3205.
[4] M.F. Moller, "A scaled conjugate gradient algorithm for fast supervised learning", Neural Networks, Vol. 6, 1993, pp. 525–533.
[5] MATLAB/SIMULINK, Release 2017b, The MathWorks, Inc., Natick, Massachusetts, United States.

FFNN mse training performance

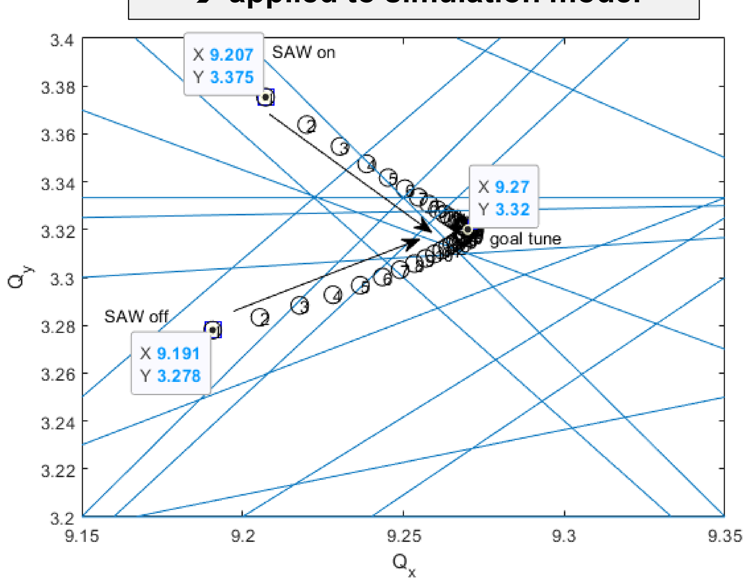
$$mse = \frac{1}{P}\sum_{p=1}^{P}\frac{1}{N}\sum_{n=1}^{N}(o_{pn}-t_{pn})^2$$



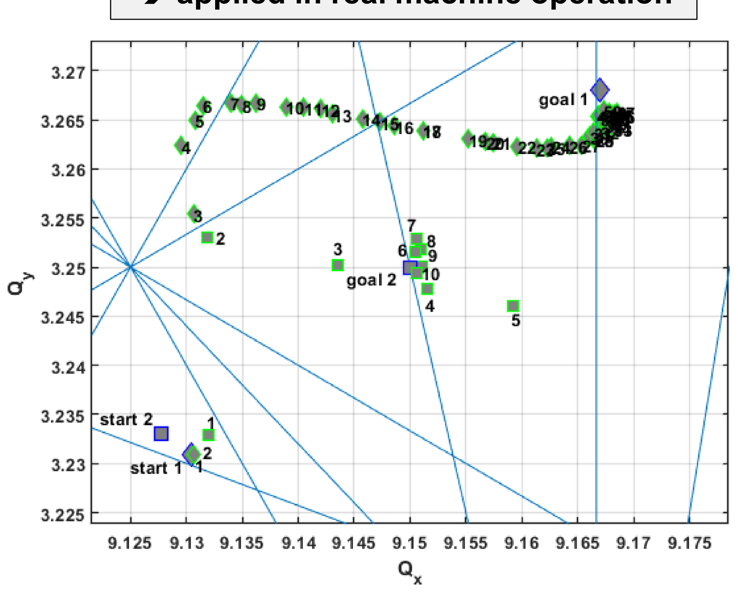


Tunes Control Examples

NNs trained by simulation data → applied to simulation model

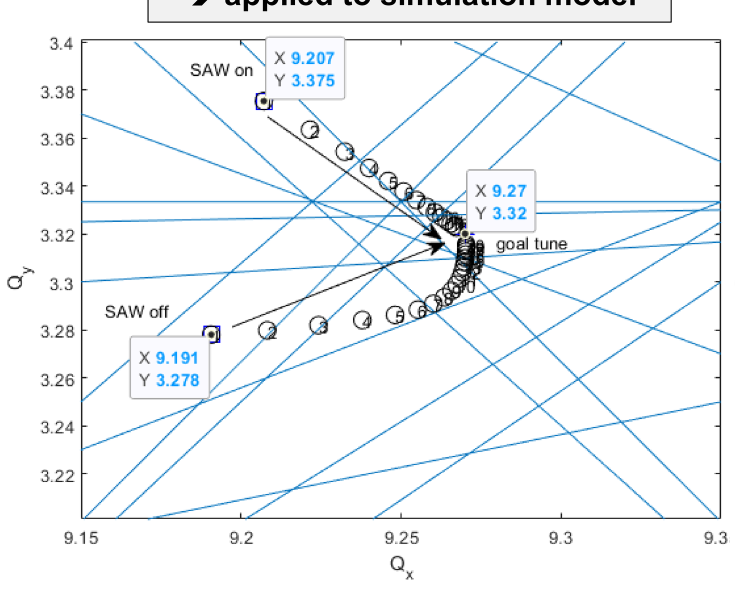


NNs trained by experimental data → applied in real machine operation



Since the power supplies of the quadrupole magnets cannot be controlled synchronously in real time, the new quadrupole set values must be approached in several smaller current steps. After each single step the tunes have been determined again (see numbered actual tunes in adjacent plots) and the NNs calculate the next quadrupole settings until the desired goal tunes are reached iteratively.

NNs trained experimental data → applied to simulation model



NNs trained by simulation data → applied in real machine operation