Advancing Orbit Stability at the Electron Storage Ring at DELTA

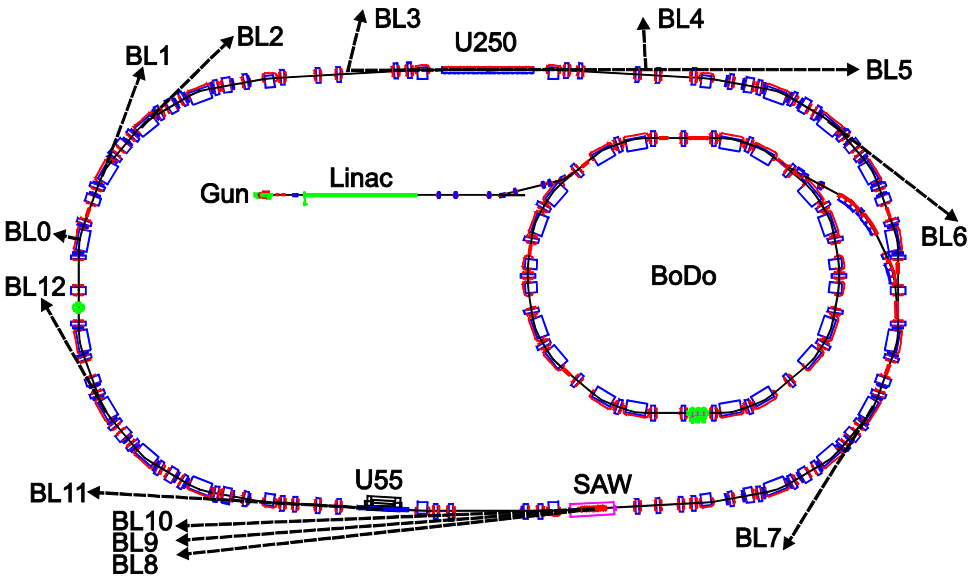
Stephan-Robert Kötter

TU Dortmund University, DELTA

28.11.2018

Gerald Schmidt, Tanja Schulte-Eickhoff,
Shaukat Khan, Thomas Weis

Recent Activities at DELTA



1.5 GeV synchrotron radiation light source in Dortmund, Germany

This presentation should give you an idea about a

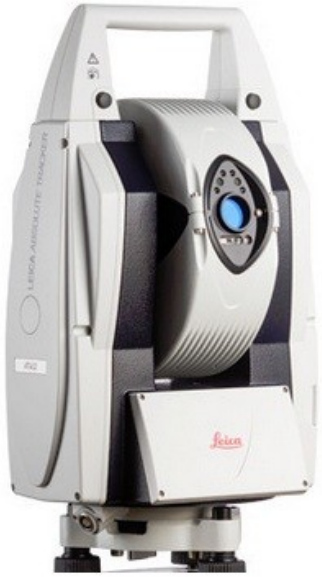
I) **horizontal lattice realignment**[1] and a

II) **software upgrade for our slow-orbit feedback**[2]**,**

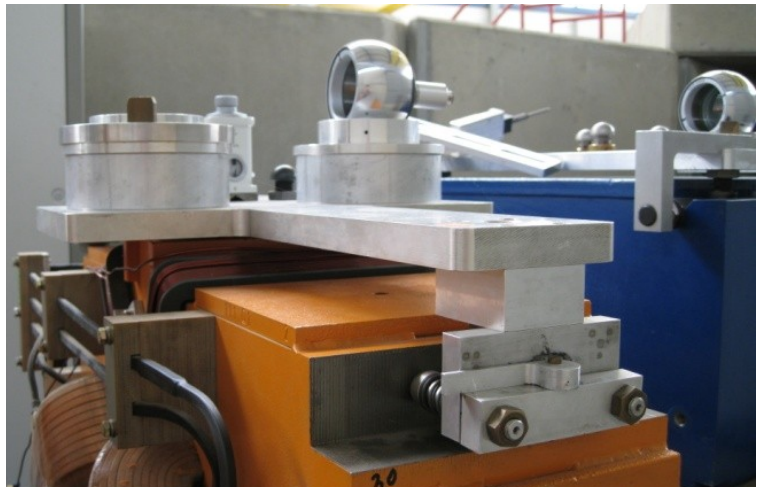
that were conducted in the recent past at DELTA to increase orbit accuracy and stability.

1) Tanja Schulte-Eickhoff, Gerald Schmidt
2) Stephan Kötter

Survey of Magnet Positions



Laser tracker
Leica AT402



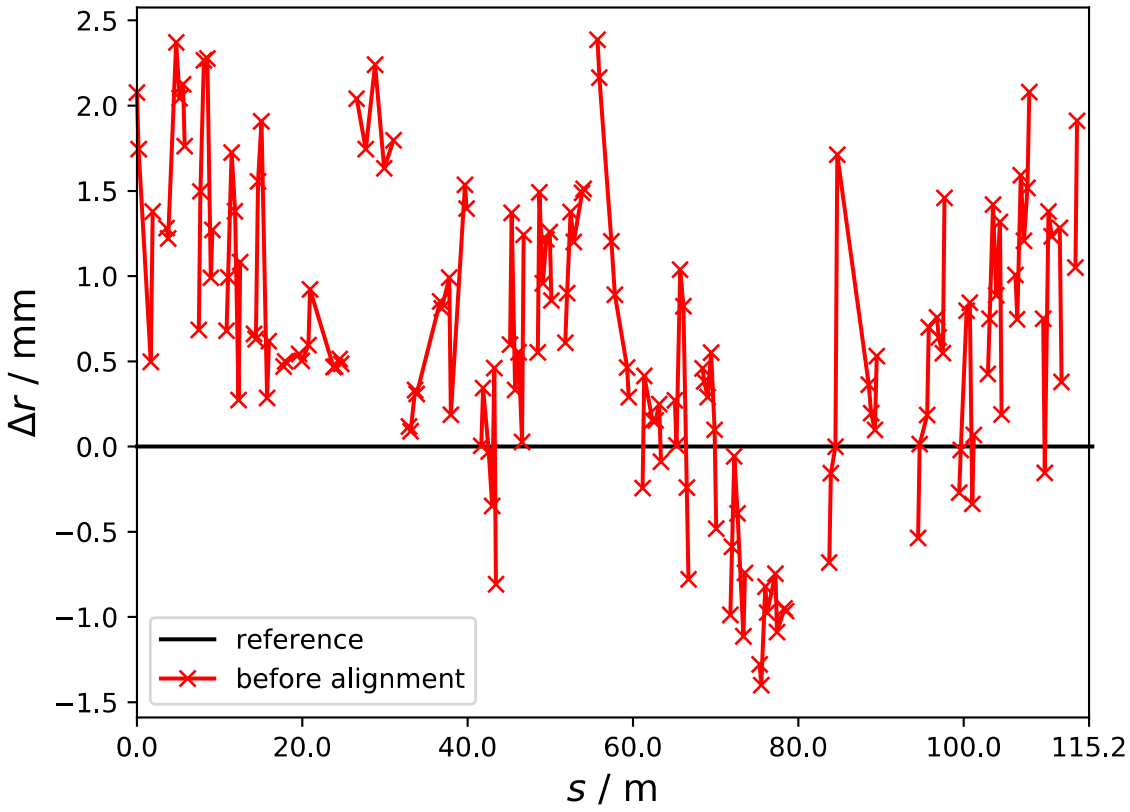
Reflector mounted on top
of a quadrupole

Mounted reflector with
laser dot of tracker

Empty mounts on magnets

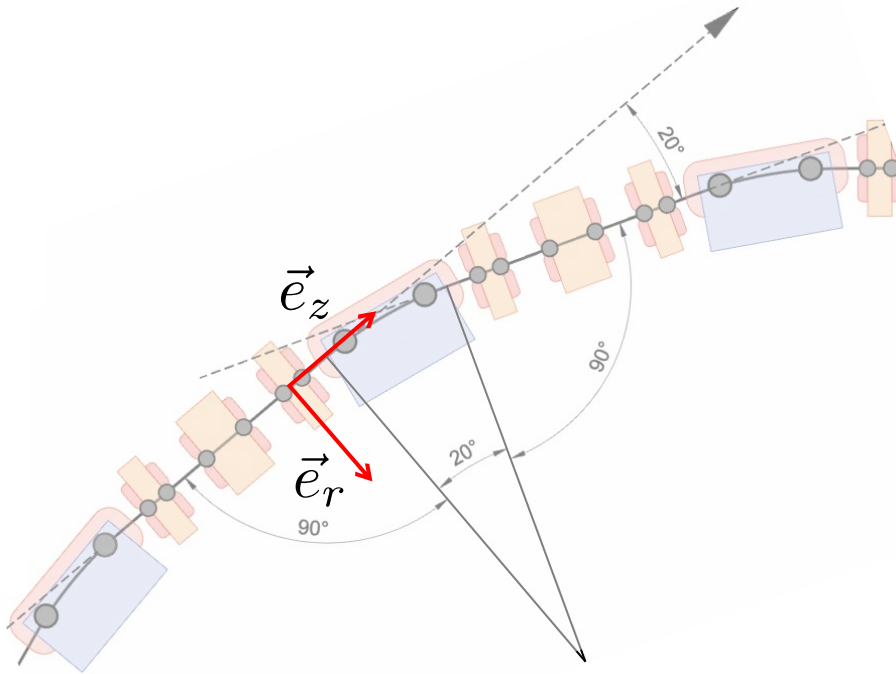
Combined point accuracy of tracker and mounts (structural and alignment) $< 300\,\mu\mathrm{m}$

Survey Results



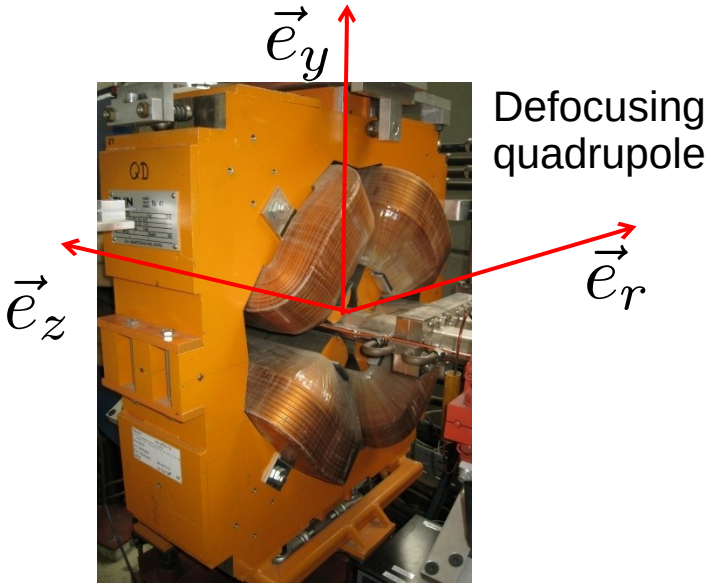
Radial displacement of all 78 quadrupoles before alignment

- Maximum displacement
  $$\approx 2.5\,\mathrm{mm}$$
- Magnets not aligned



Coordinate system for a defocusing quadrupole in a triplet

Alignment Process & Results

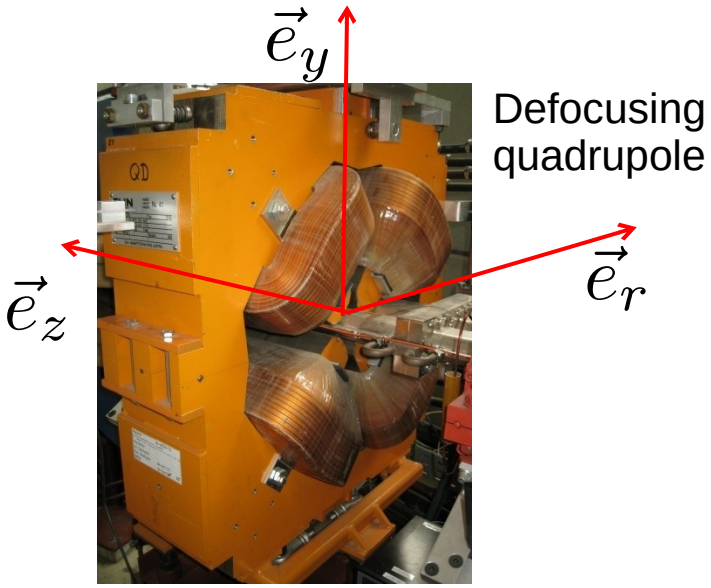


Defocusing quadrupole

Iteratively corrected position of all 78 quadrupoles in groups of up to five magnets from September 2017 to October 2018

- Radial displacement Δr
- Rotation around $\vec{e}_y$
- Rotation around $\vec{e}_z$

Alignment Process & Results



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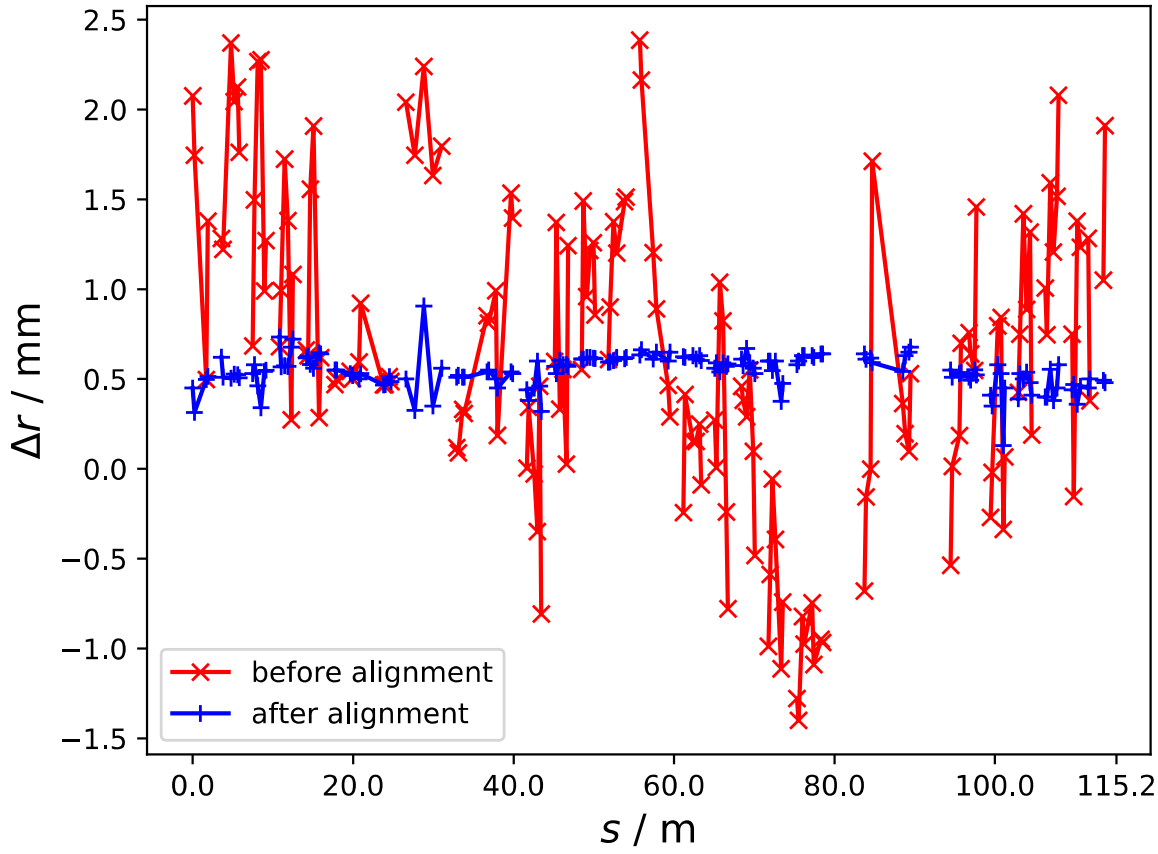
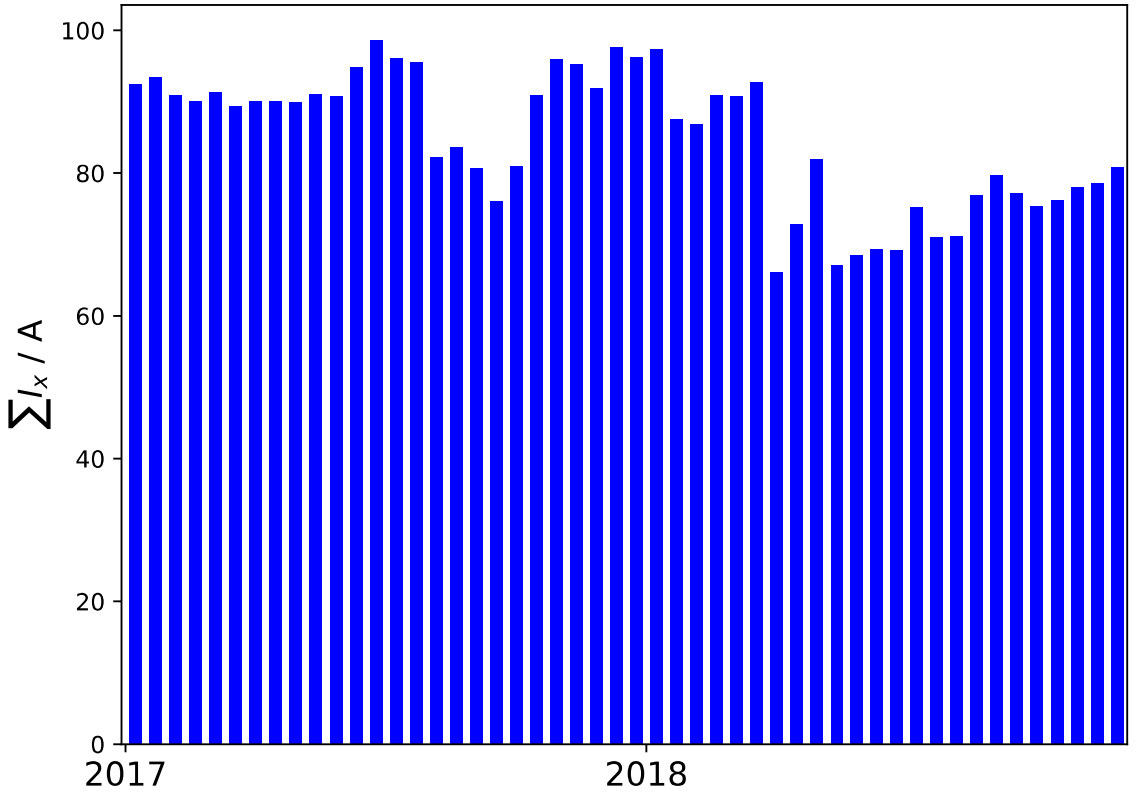


Measurement accuracy is $300\,\mu\mathrm{m}$

Alignment Conclusion & Outlook

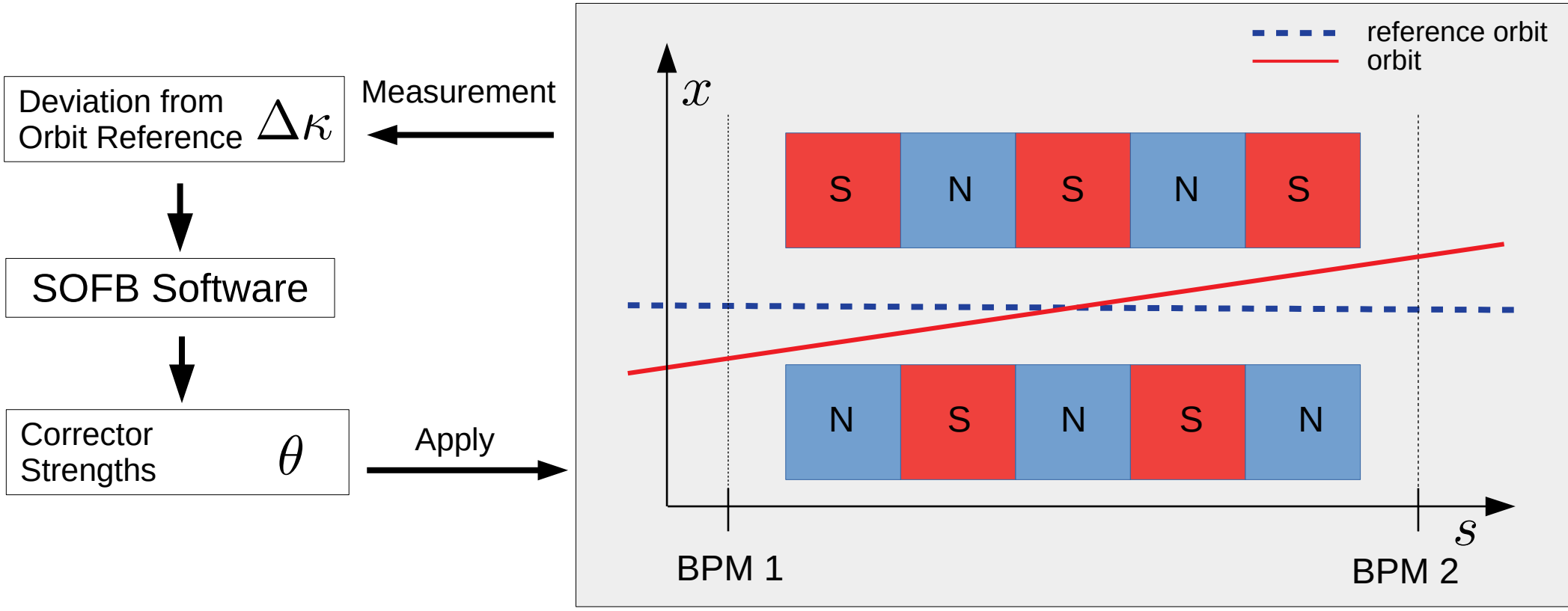
- Better machine handling
- Steerer currents have decreased

- SAW and U55 still have to be moved
- Beamlines need to be aligned
- Alignment process will be concluded with aligning all dipoles horizontally and longitudinally



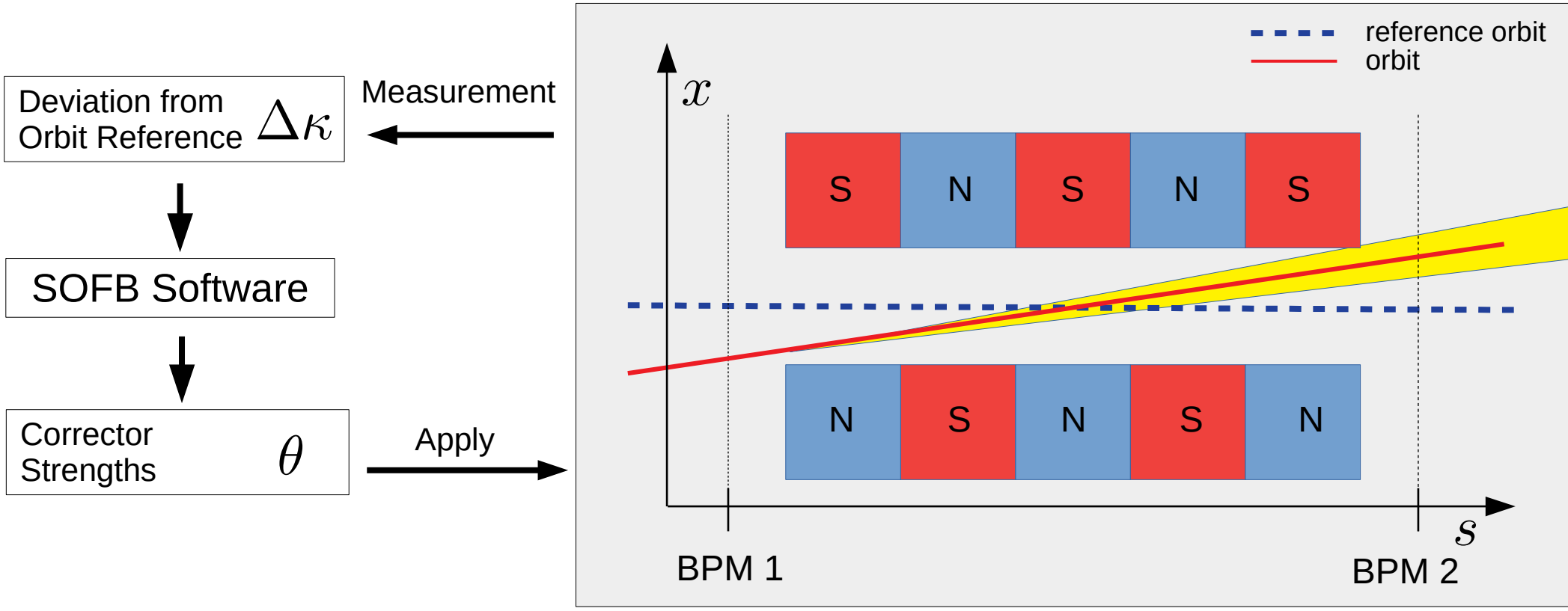
Averaged sum of horizontal steerer currents throughout 2017 and 2018

Upgrading the Slow-Orbit Feedback with new Software



Replace Software and improve reliability, versatility and performance!

Upgrading the Slow-Orbit Feedback with new Software



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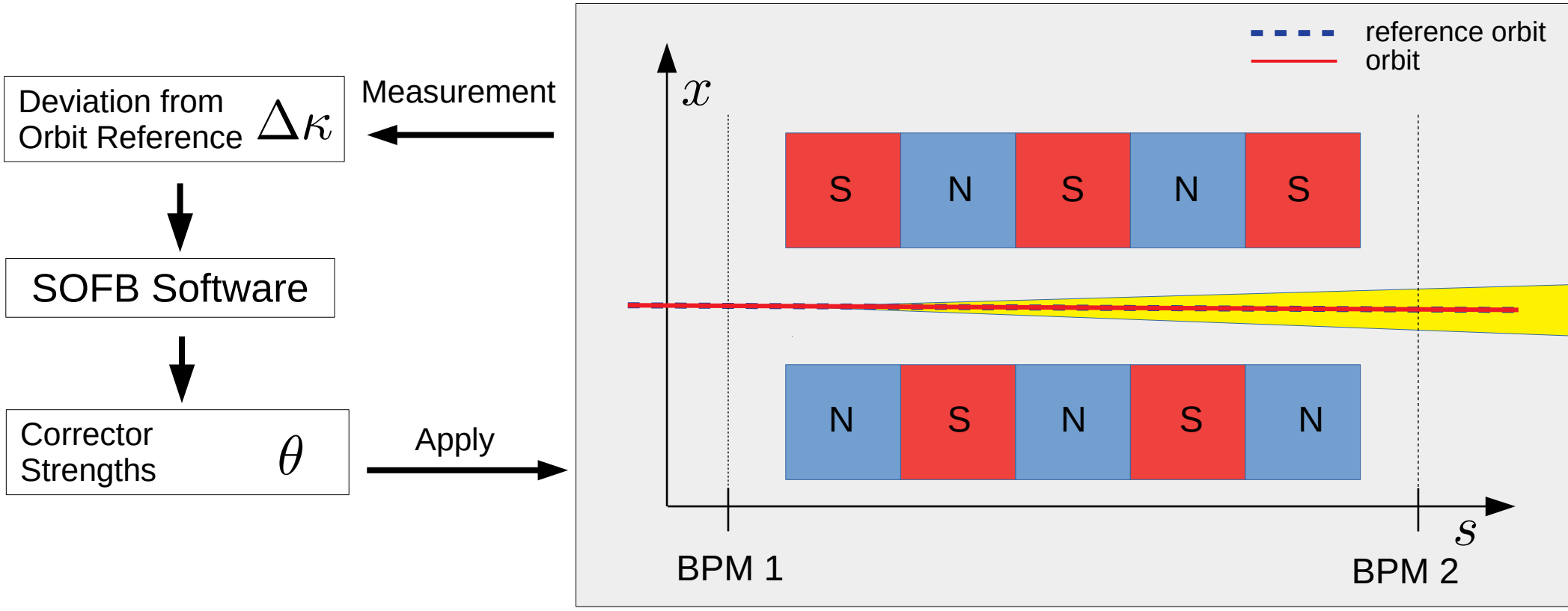

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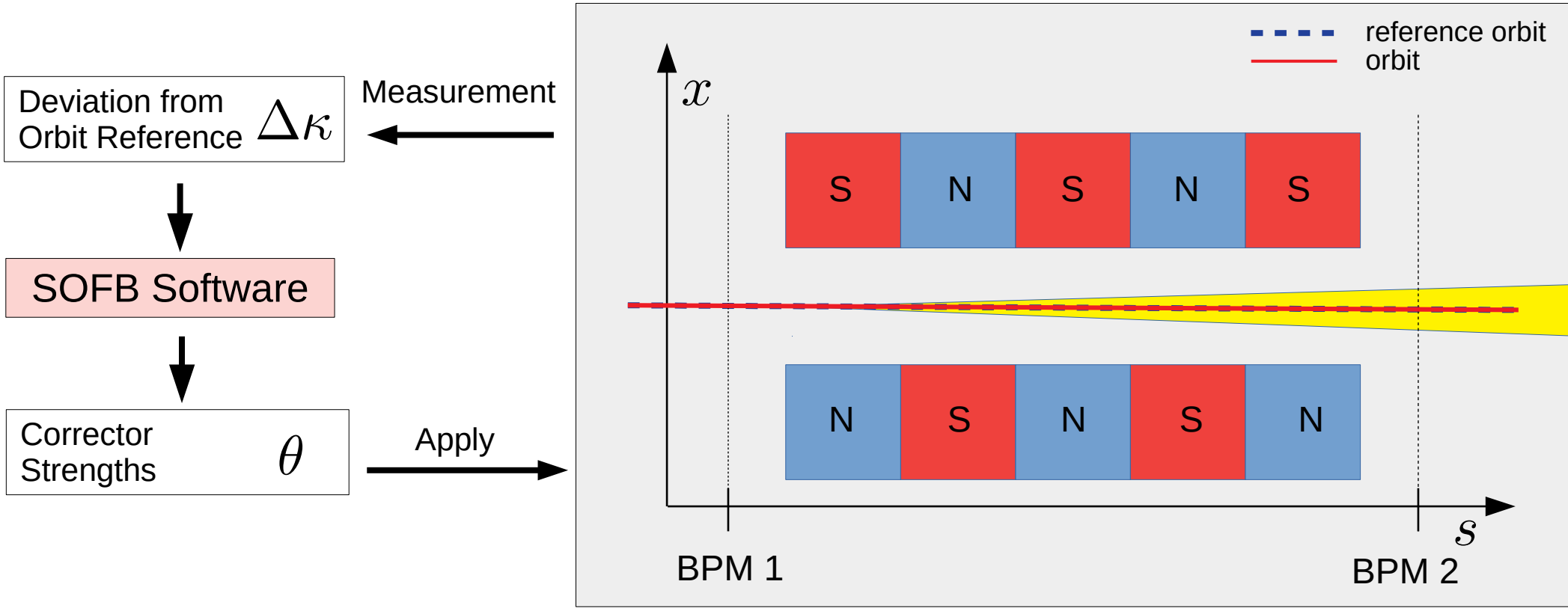
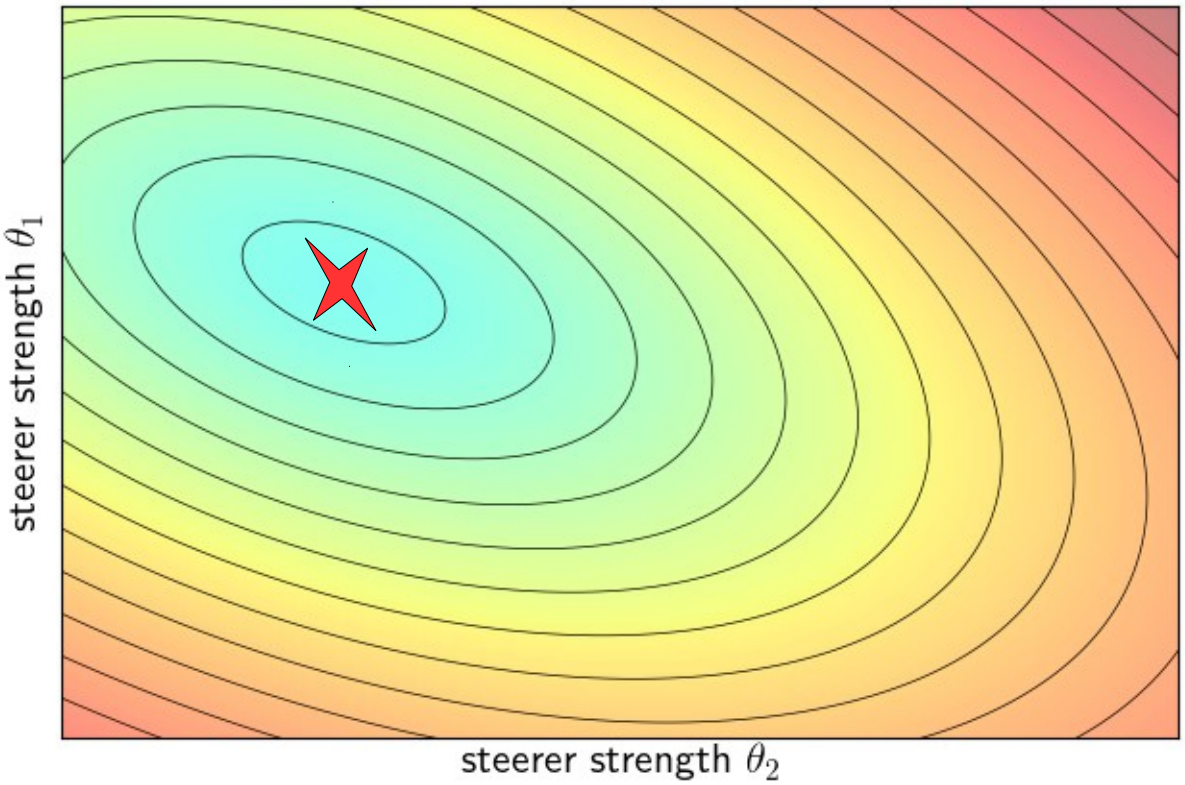


Replace Software and improve reliability, versatility and performance!

Hardware Limitations at DELTA

1. Less steerer magnets than beam position monitors

2. Corrector magnets are sometimes out of range

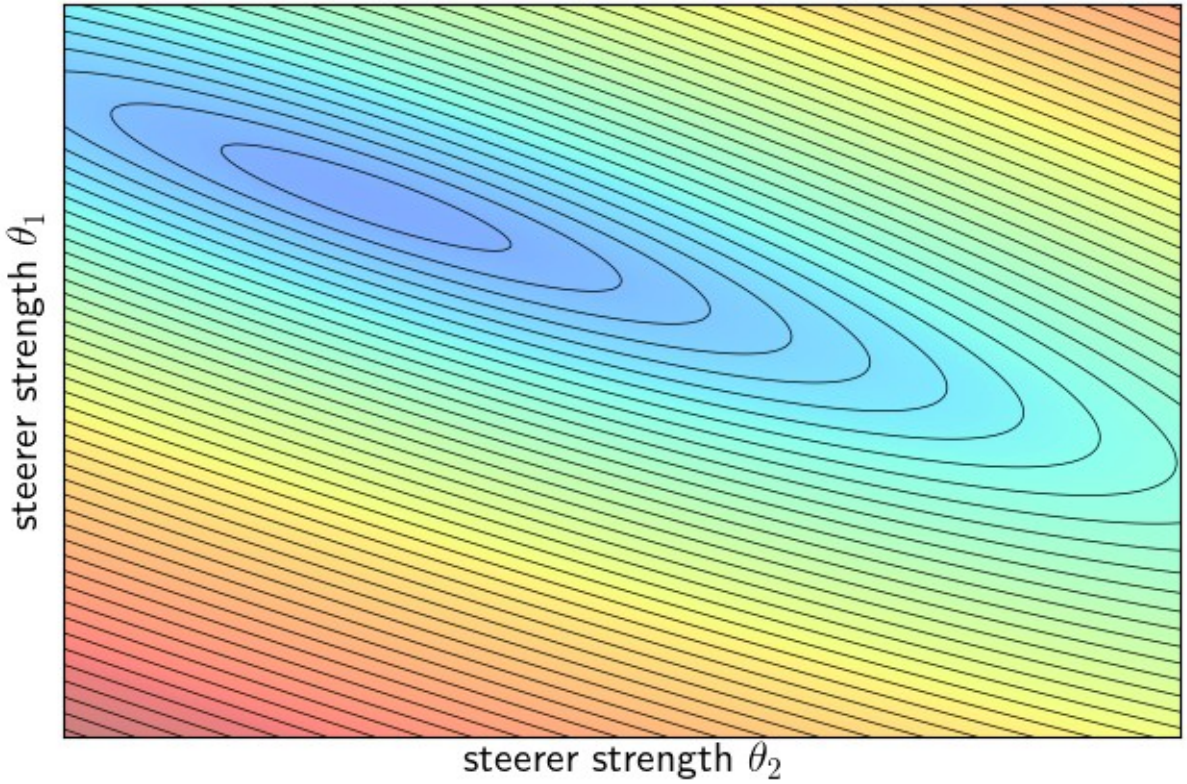


$$\min_{\theta}\{||\Delta\kappa + R\theta||^2\} \quad = \quad \textbf{“ Find minimum of a multi-dimensional parabola! ”}$$

Hardware Limitations at DELTA

1. Less steerer magnets than beam position monitors
   => Add weights!

2. Corrector magnets are sometimes out of range

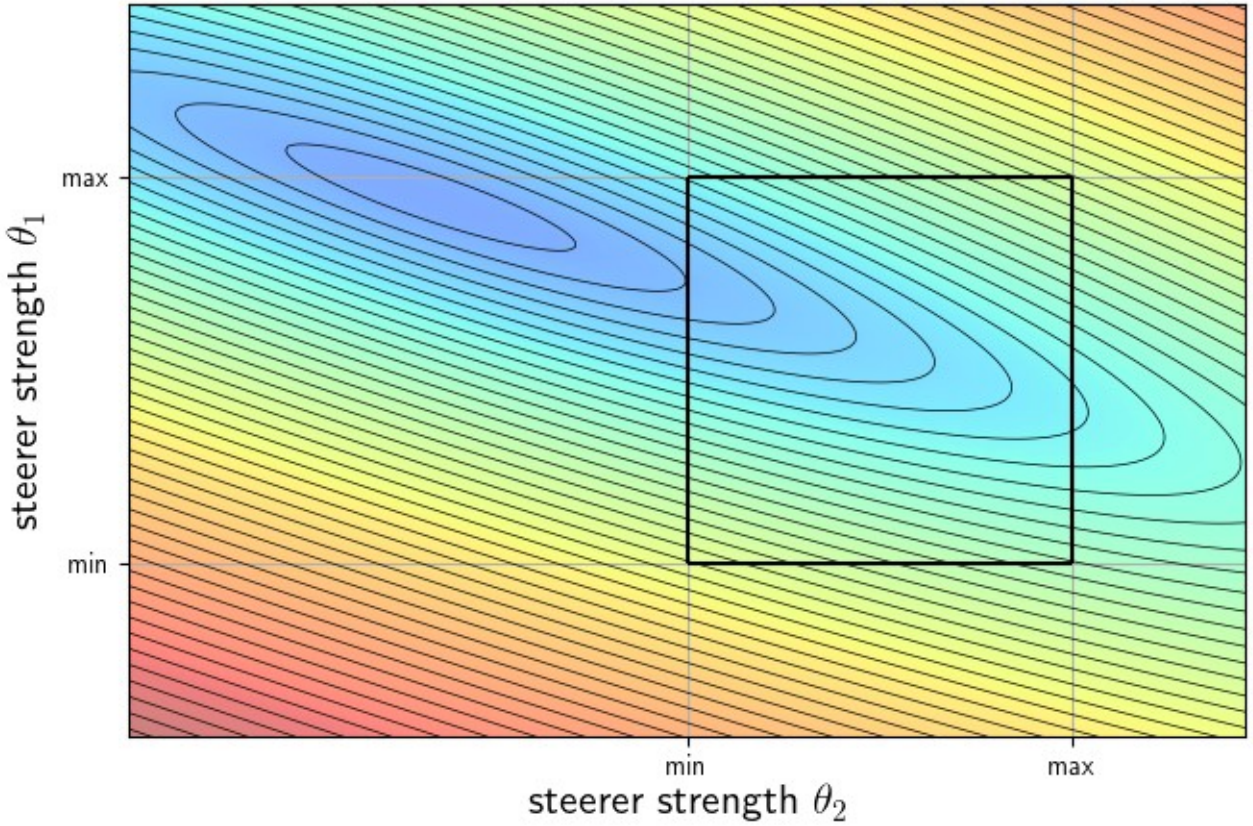


$$\min_{\theta}\{||W(\Delta\kappa + R\theta)||^2\}$$ **=** **“ Find minimum of a bad-conditioned, multi-dimensional parabola! ”**

Hardware Limitations at DELTA

1. Less steerer magnets than beam position monitors
   => Add weights!

2. Corrector magnets are sometimes out of range
   => Add constraints!



$$\min_{\theta}\{||W(\Delta\kappa + R\theta)||^2\}$$
subject to $\theta_{\min} \leq \theta \leq \theta_{\max}$

=

“ Find minimimum of a bad-conditioned, multi-dimensional parabola subject to constant, inequality constraints! ”

Best Algorithm for the Job

- **Primal-dual interior-point method on a second-order cone**[1] from the cvxopt python package[2]
  - Finds solution to minimization problem if there is any[1]
  - Short and predictable runtime[1] (< 25 ms for typical correction problem at DELTA)
  - Handles arbitrary linear constraints[1][2]

Can be exploited for orbit constraints ...

1) A. Ben-Tal etal. *Lectures on Modern Convex Optimization: Analysis, Algorithms, Engineering Applications*. MOS-SIAM Series on Optimization (2001).
2) M. S. Andersen et al. *CVXOPT: A Python package for convex optimization*. cvxopt.org (2013).

Orbit Constraints

- Equality orbit constraints[1] have a similar effect as big weights
- Inequality orbit constraints keep the orbit at specified BPMs within a defined range

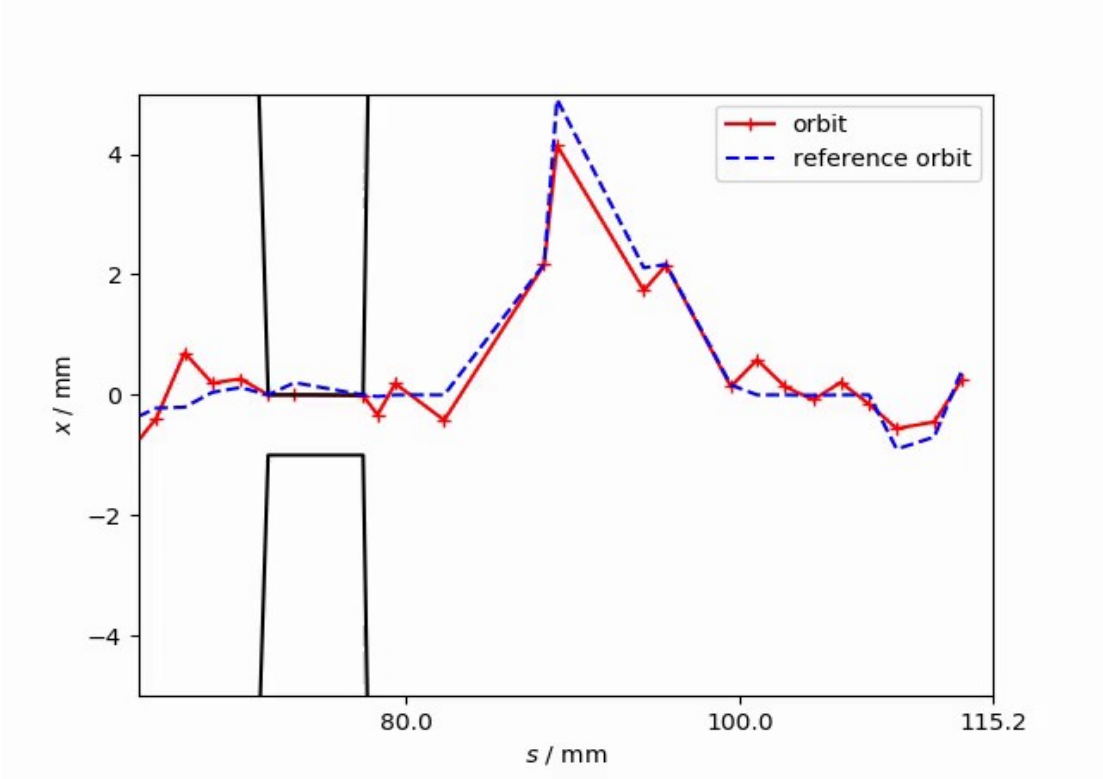
1) N. Nakamura et al. *New Orbit Correction Method Uniting Global and Local Orbit Corrections.* Nuclear Instruments and Methods in Physics Research. volume 556 (2006).

Orbit Constraints

- Equality orbit constraints[1] have a similar effect as big weights
- Inequality constraints keep the orbit at specified BPMs within a defined range

Inequality orbit constraints may offer an advantage over equality orbit constraints in locking the orbit in place

May be used in the future to replace/modify the weights used at DELTA



Corrected orbit for a given reference orbit and orbit constraints. Simulation based on real data.

1) N. Nakamura et al. *New Orbit Correction Method Uniting Global and Local Orbit Corrections.* Nuclear Instruments and Methods in Physics Research. volume 556 (2006).

Reproducing and Minimizing Steerer Settings

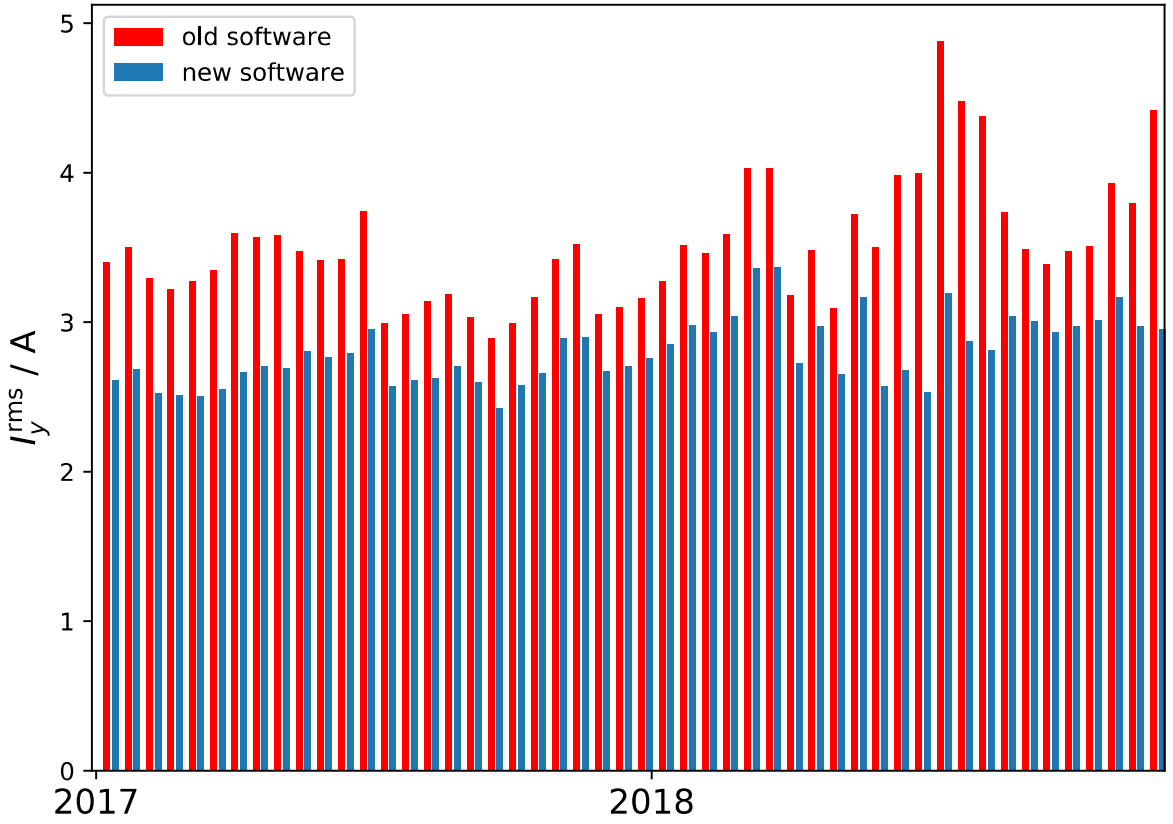
Linear dependent steerer magnets due to lattice symmetry and regularization (cutting of singular values)

=> Add second optimization problem

$$\min\{||\theta||\}$$

subject to $R\theta = \text{const}$

- Reduce corrector currents
- Reproduce corrector currents
- Do not loose range
- No maintainance required



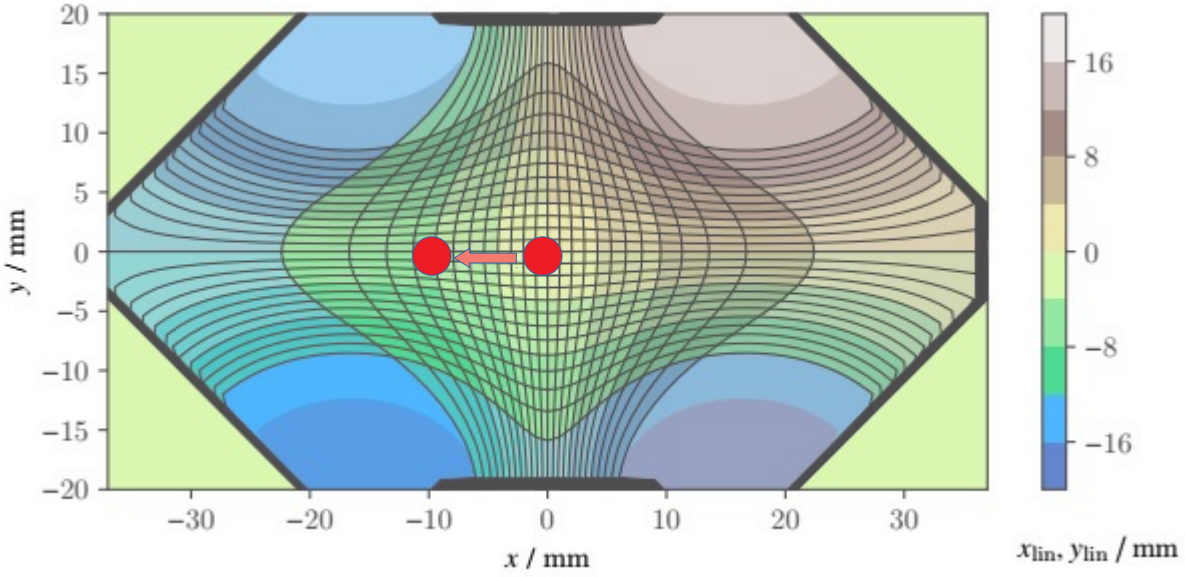
Average RMS current throughout 2017 and 2018.
Analysis based on logged data.

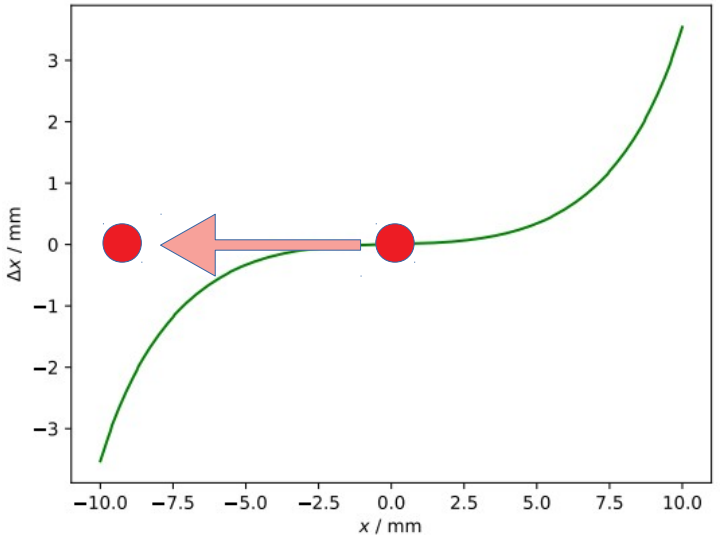
Status & Summary & Conclusion

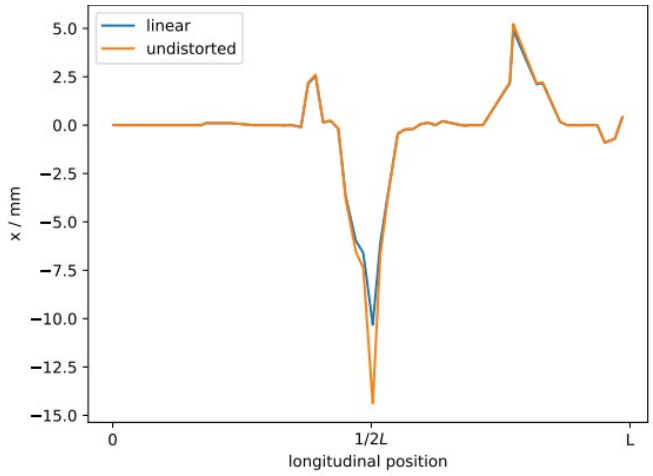
- New slow-orbit-feedback software deploys
  primal-dual interior-point method on a second-order cone
- Achieved correction quality mainly limited by BPMs => Ready for commissioning
- Program uses weights and/or orbit constraints
- Work on degree elevation for MICADO and pincushion distortion

Thank you for your Attention!

Removing Pincushion Distortion







- Remove nonlinearities to better align the real machine with the linear orbit-response model
- Implemented but not tested

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