# Orbit Correction in the XFEL
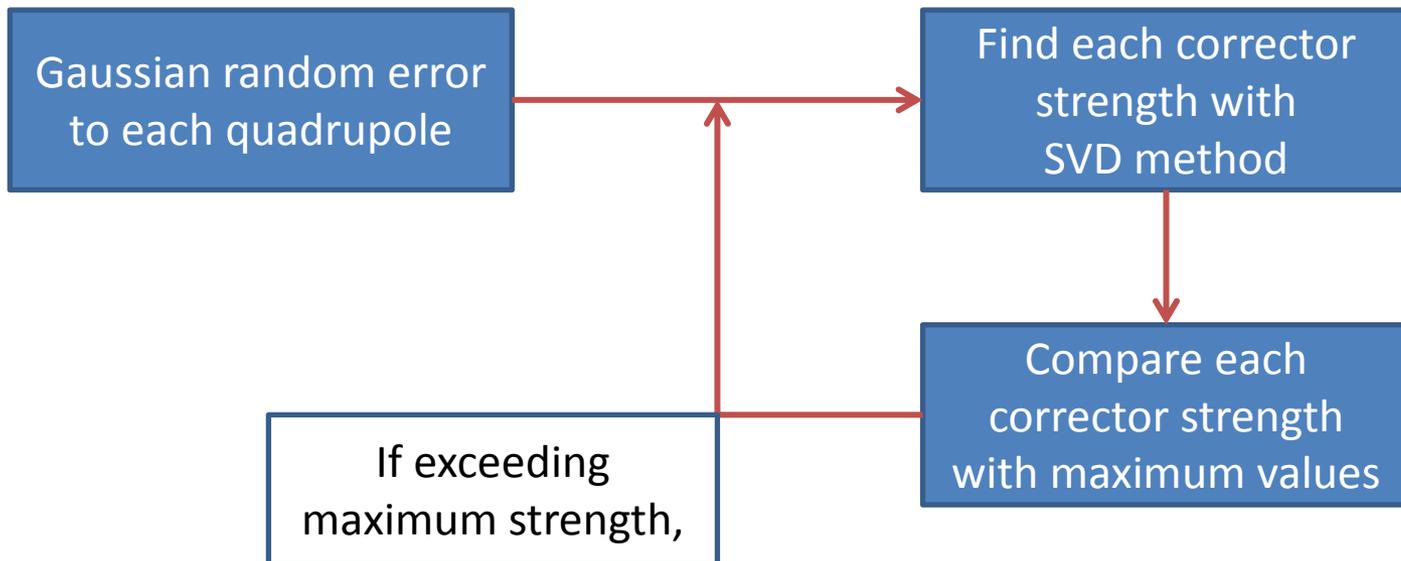
Hyunchang Jin, Winfred Decking, Torsten Limberg

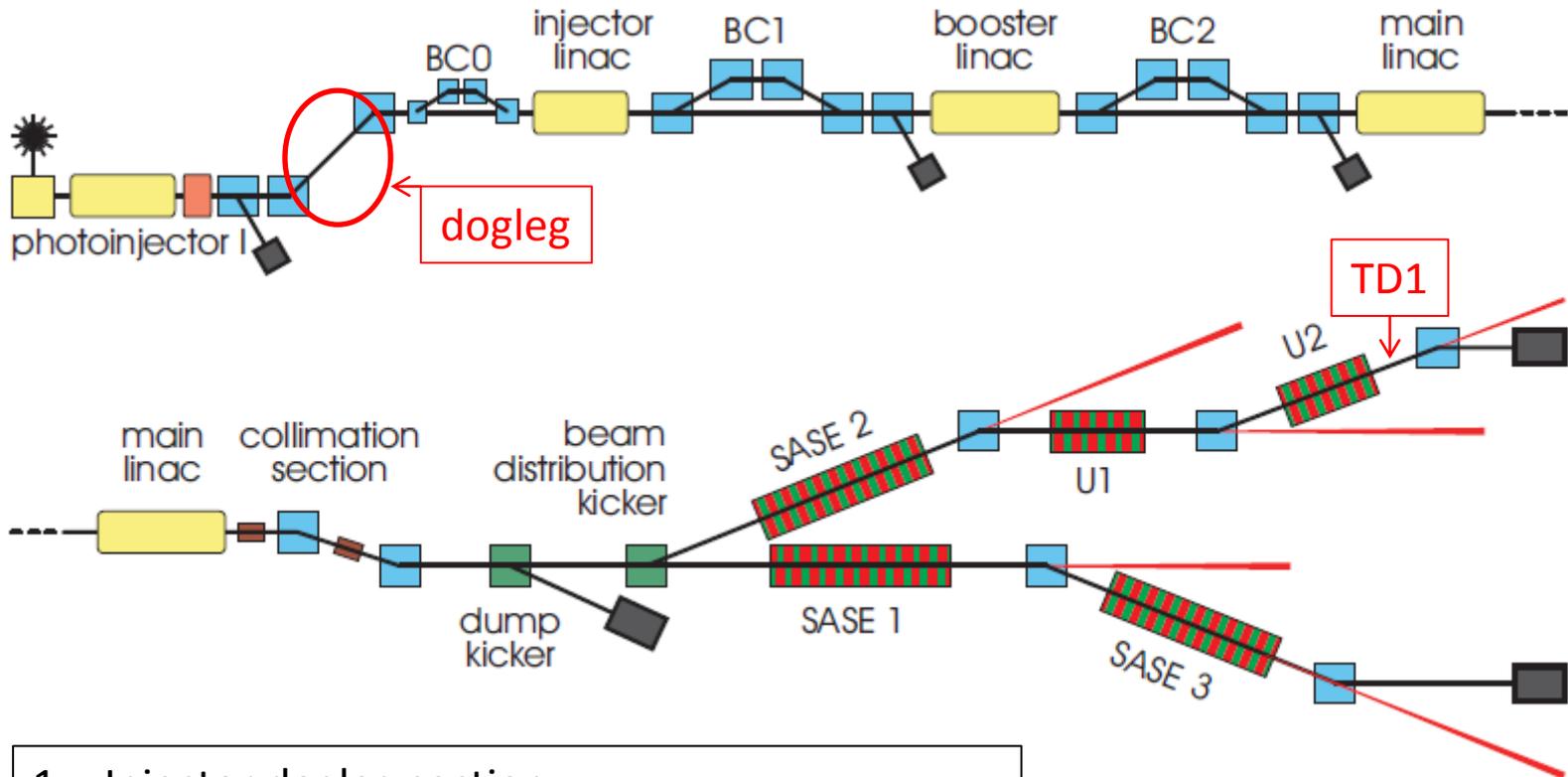Beam dynamics meeting (2012.02.20)

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  - Injector dogleg section
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# Introduction

- Object : correcting the beam orbit distorted by quadrupole misalignment up to 500 μm with the technique of singular value decomposition (SVD).

- Method : MAD8 & MATLAB (100 random seeds)

```
┌──────────────────────┐              ┌──────────────────────┐
│ Gaussian random error│─────────────▶│ Find each corrector  │
│  to each quadrupole   │              │    strength with     │
│                      │              │     SVD method       │
└──────────────────────┘              └──────────────────────┘
                                                 │
                                                 ▼
           ┌──────────────────┐       ┌──────────────────────┐
           │   If exceeding   │       │   Compare each       │
           │ maximum strength,│       │  corrector strength  │
           │                  │       │ with maximum values  │
           └──────────────────┘       └──────────────────────┘
```

# XFEL layout



1. Injector dogleg section
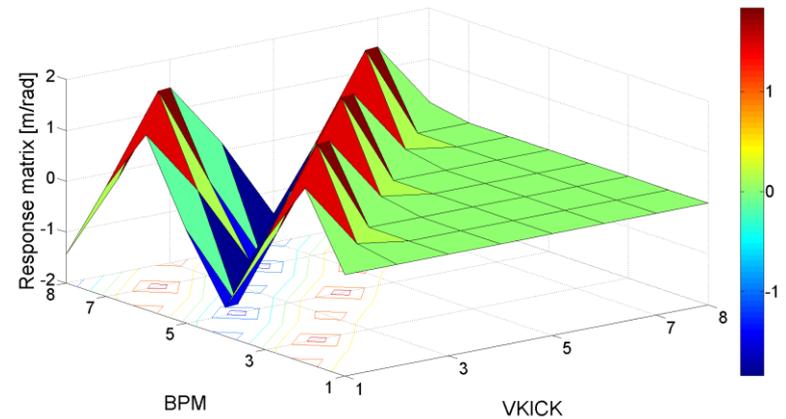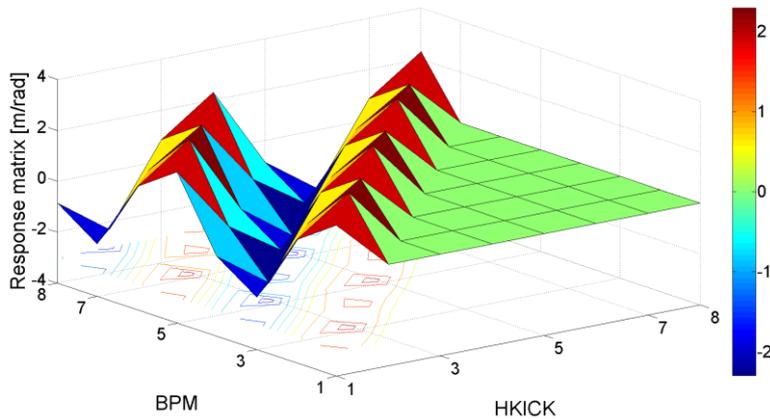2. From gun to the beamline TD1 (before dump)

# Orbit response matrix for SVD

- ## Orbit response matrix $M$

$$\Delta x_i = M_{ij}\Delta\theta_j$$
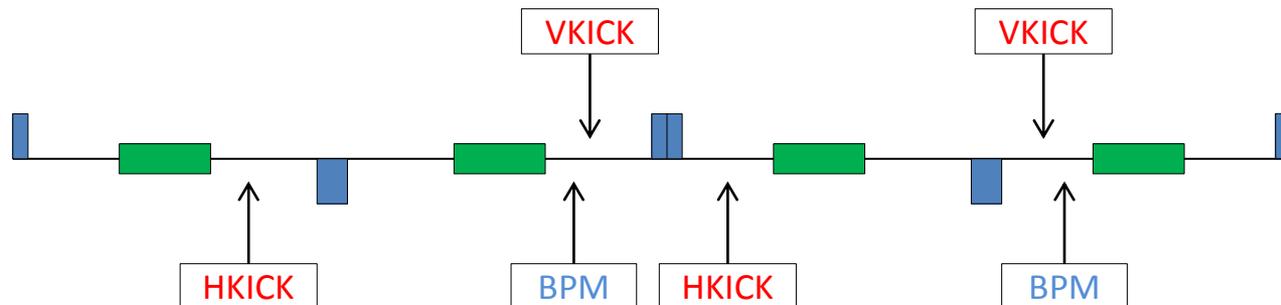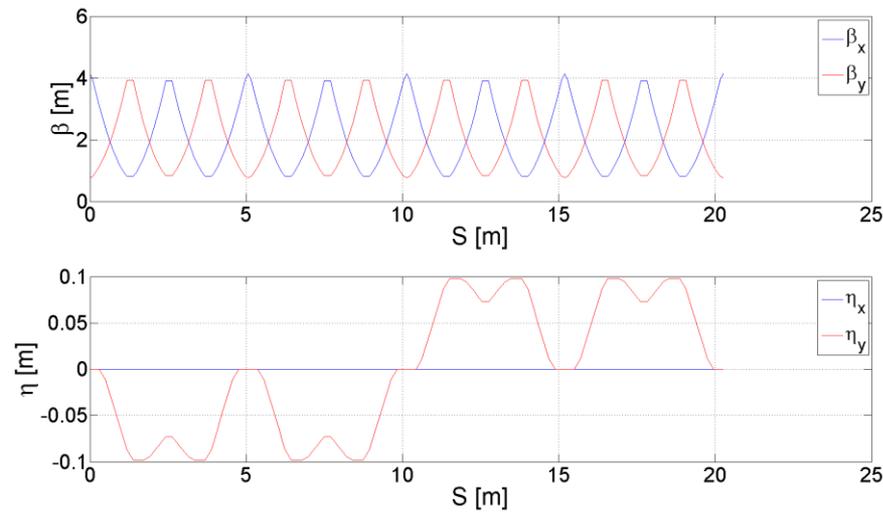
change of beam position at BPM $i$

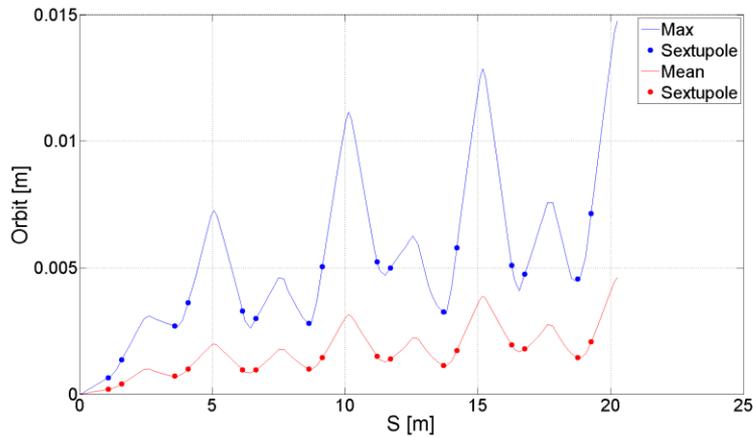change of the kick angle of the corrector $j$



Orbit response matrix at the injector dogleg section in XFEL

# Injector dogleg section
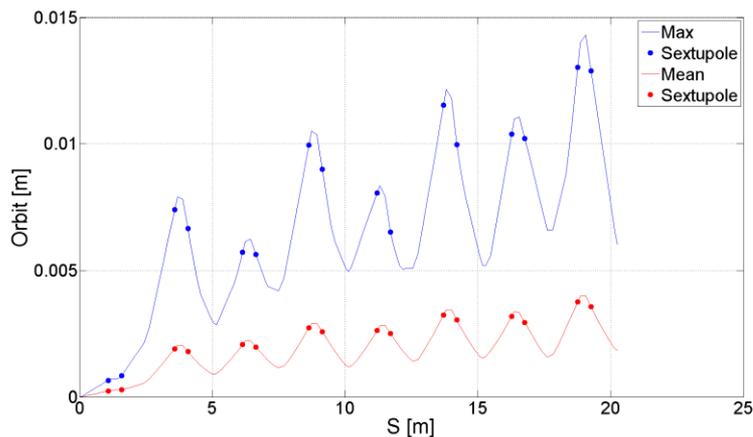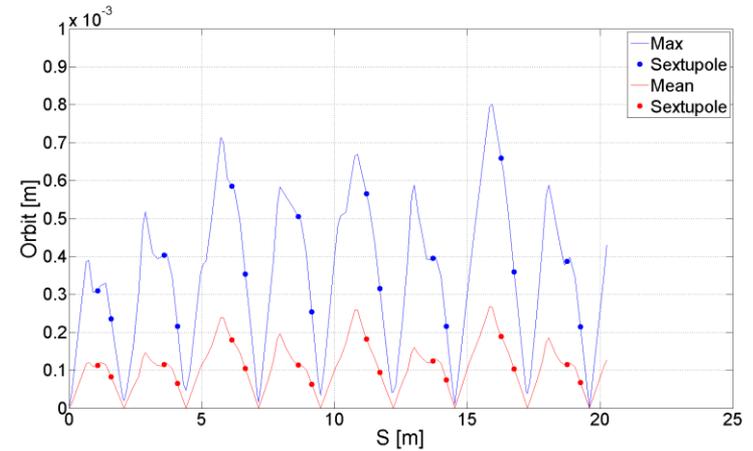
- 8 FODO cells in dogleg section

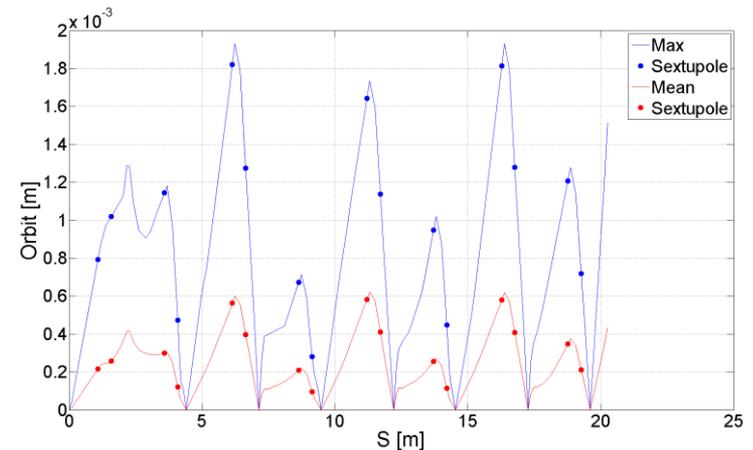# Orbit correction
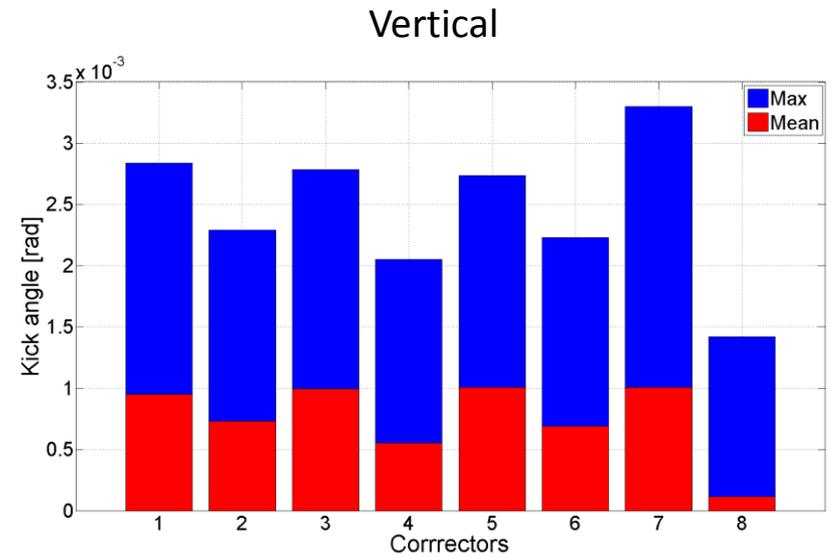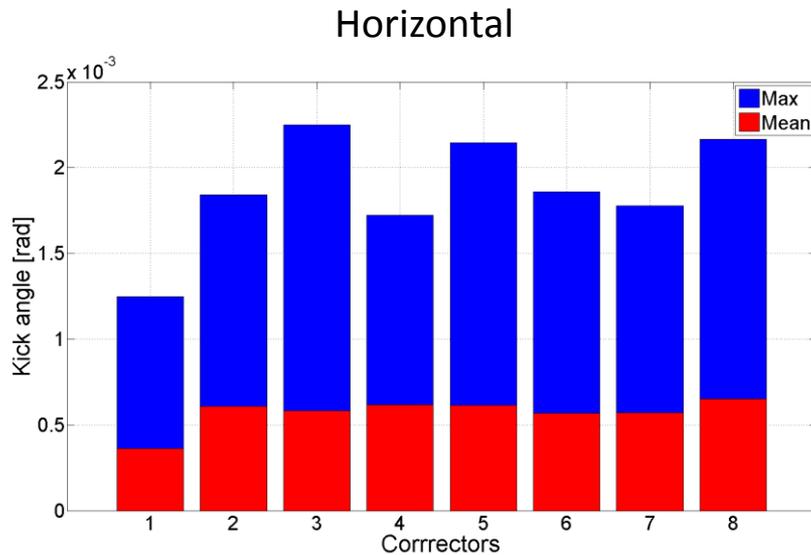# for quadrupole misalignment 500 μm



Correction

**Horizontal plane**

Correction

**Vertical plane**

# Corrector strength for orbit correction



Horizontal

Vertical

- Each corrector has the maximum kick angle as 3.3 mrad which restricted by magnet field strength and beam energy.
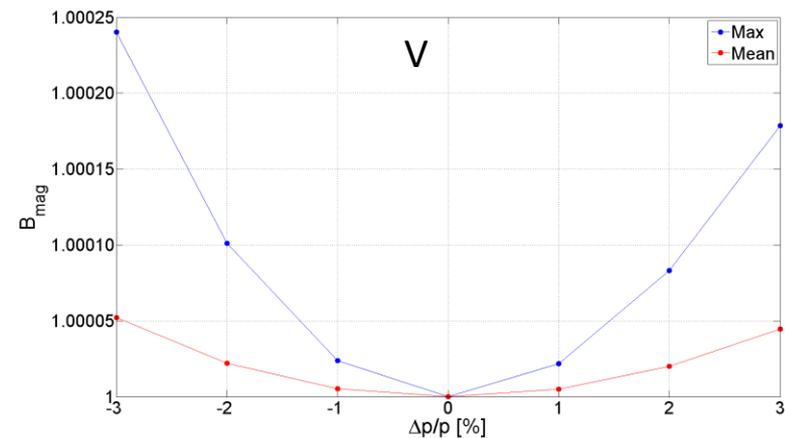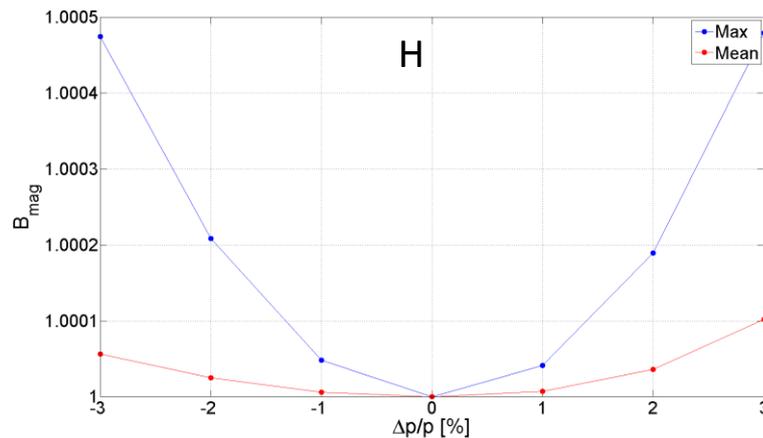
# Beta-mismatch parameter $B_{mag}$

- Beta-mismatch parameter

$$B_{mag} = \frac{1}{2}\left[\frac{\beta(E)}{\beta(E_0)} + \frac{\beta(E_0)}{\beta(E)} + \left(\alpha(E)\sqrt{\frac{\beta(E_0)}{\beta(E)}} - \alpha(E_0)\sqrt{\frac{\beta(E)}{\beta(E_0)}}\right)^2\right]$$
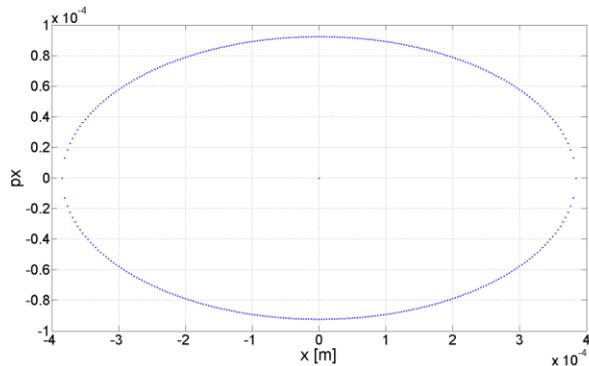
- Emittance growth by beta-mismatch
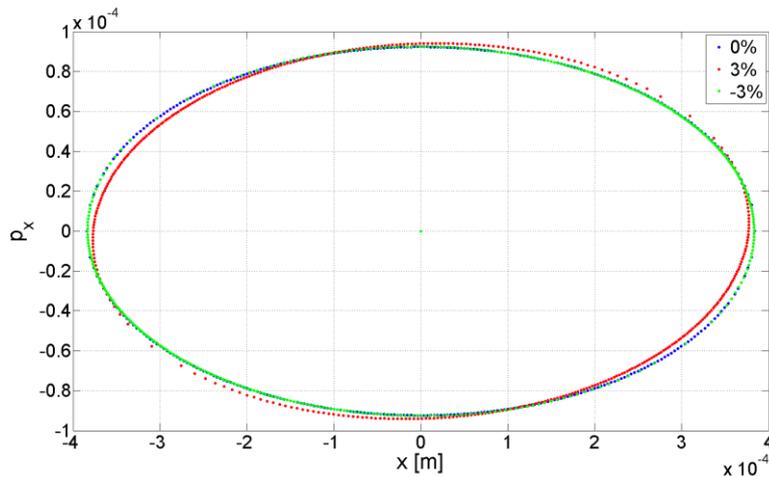
$$\Delta\epsilon = \epsilon(B_{mag} - 1)$$

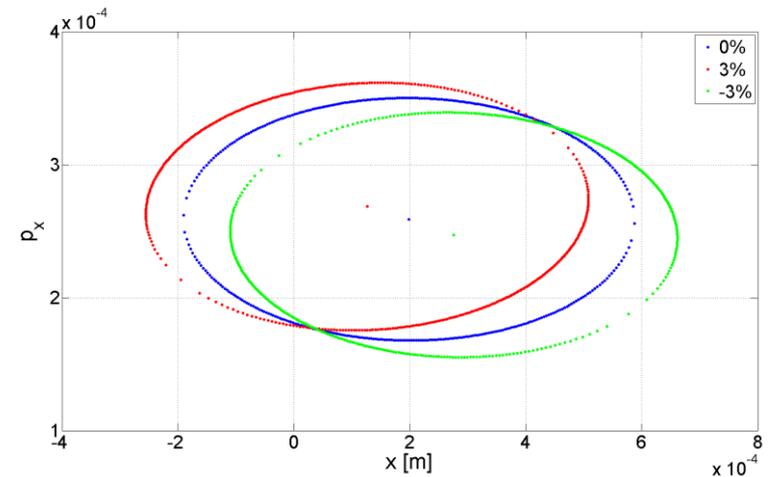# Horizontal beam transport

### Initial distribution



- Phase space portraits of monochromatic $3\sigma_x$ ellipse at the end of dogleg section without errors (lower left) and with errors after orbit correction (lower right).
- The relative energy deviations are equal to 0(blue), 3(red), and -3%(green).
- Sextupoles are switched on.
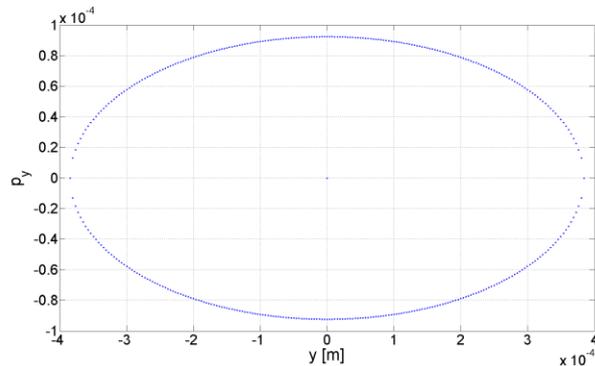- Normalized horizontal emittance is 1.0 μm.



Without errors



With errors
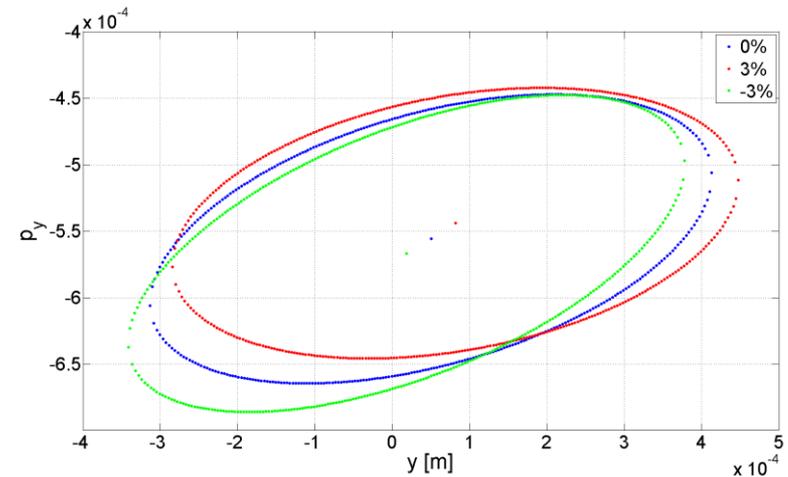
# Vertical beam transport

Initial distribution



- Phase space portraits of monochromatic $3\sigma_y$ ellipse at the end of dogleg section without errors (lower left) and with errors after orbit correction (lower right).
- The relative energy deviations are equal to 0(blue), 3(red), and -3%(green).
- Sextupoles are switched on.
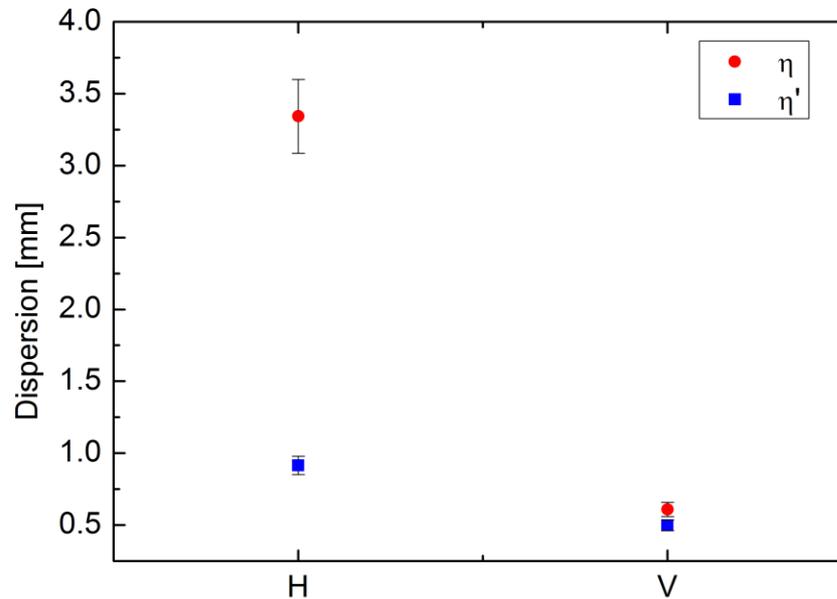- Normalized vertical emittance is 1.0 μm.
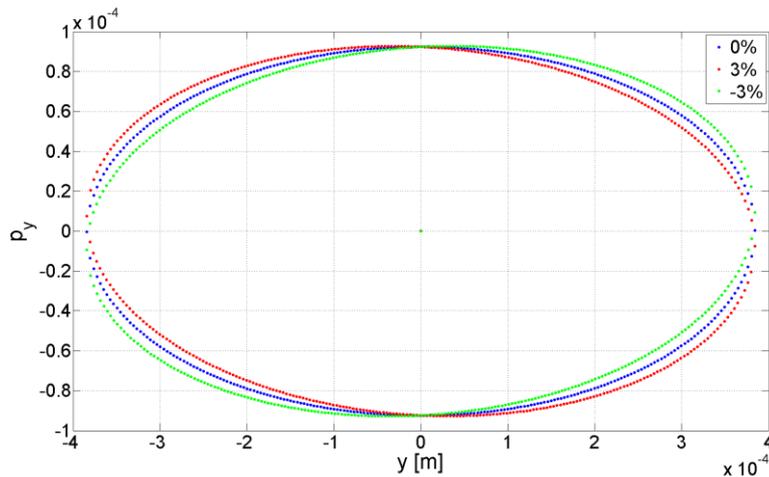


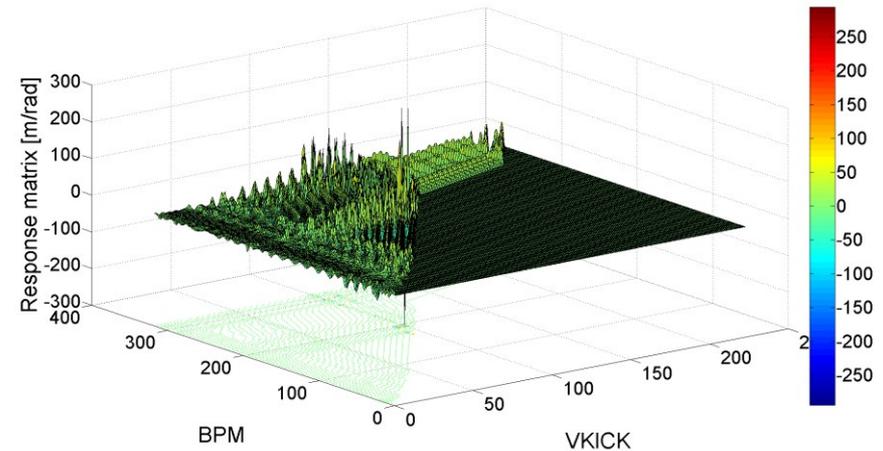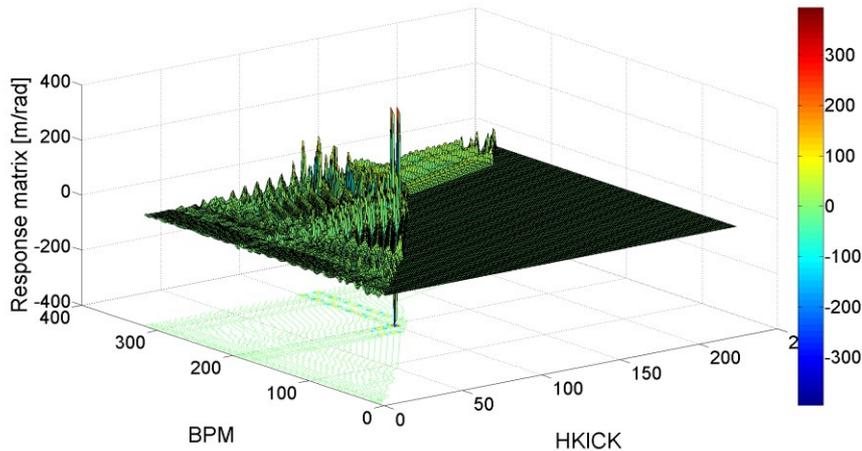Without errors



With errors

# Dispersion after orbit correction



- The first and second-order horizontal and vertical dispersions can be obtained from the previous phase space portraits. 100 random seeds are examined.
- First and second-order dispersions (absolute values in figure) :
  - H : $|\eta_x| \approx 3.3$ mm & $|\eta'_x| \approx 9.2\times10^{-4}$
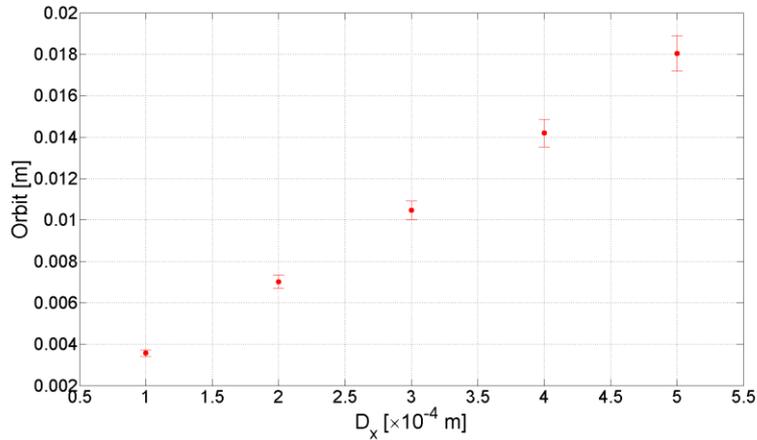  - V : $|\eta_y| \approx 0.6$ mm & $|\eta'_y| \approx 5.0\times10^{-4}$

# Gun → TD1

- Correctors : 224(H), 223(V)
- BPMs : 320



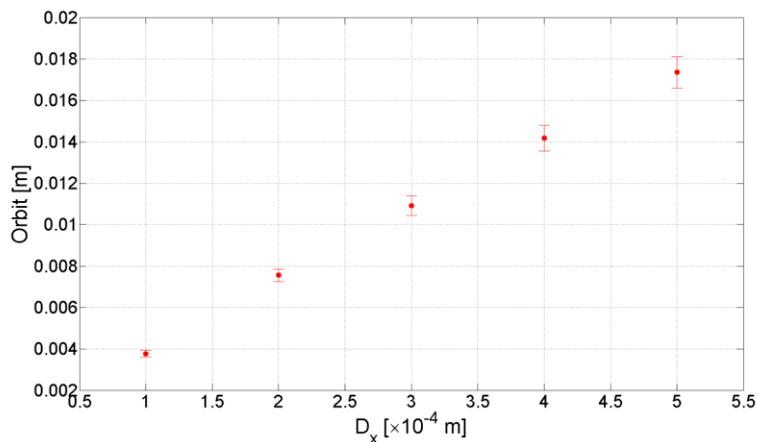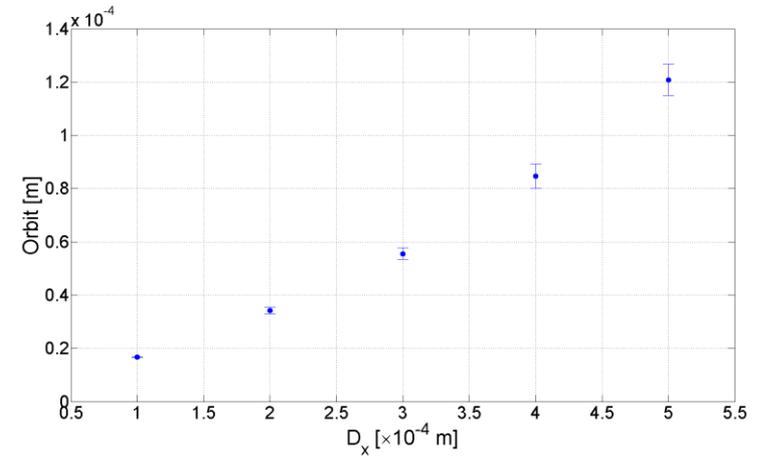Orbit response matrix in XFEL

# Orbit correction
# for quadrupole misalignment($D_x$) 100-500 $\mu$m
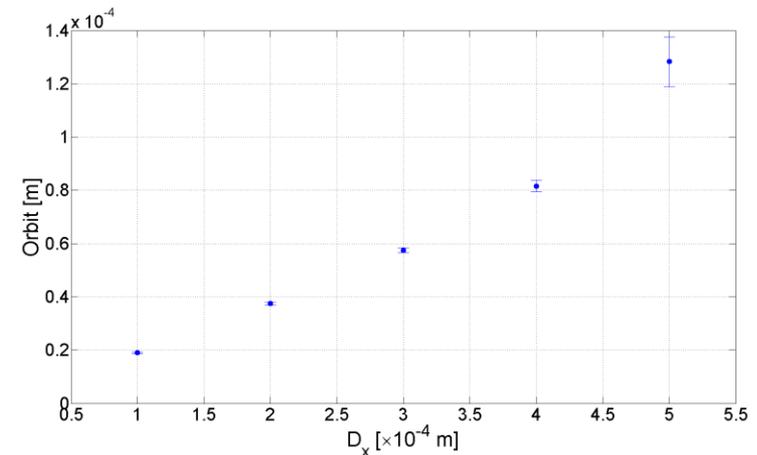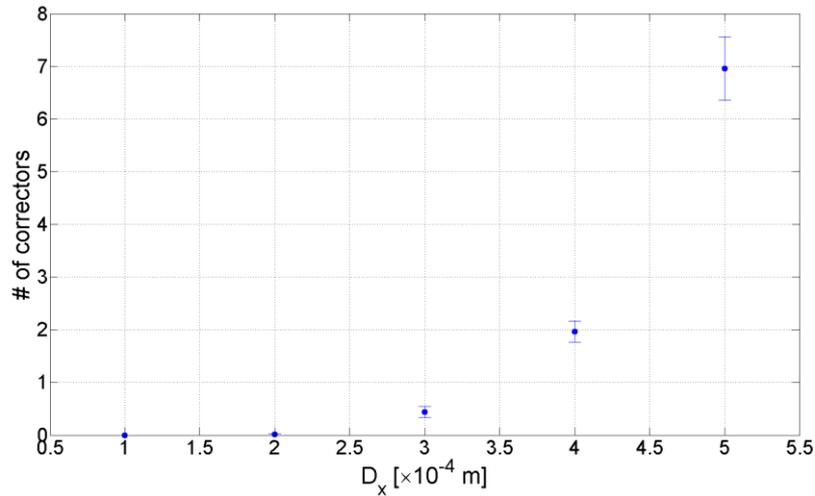


Correction

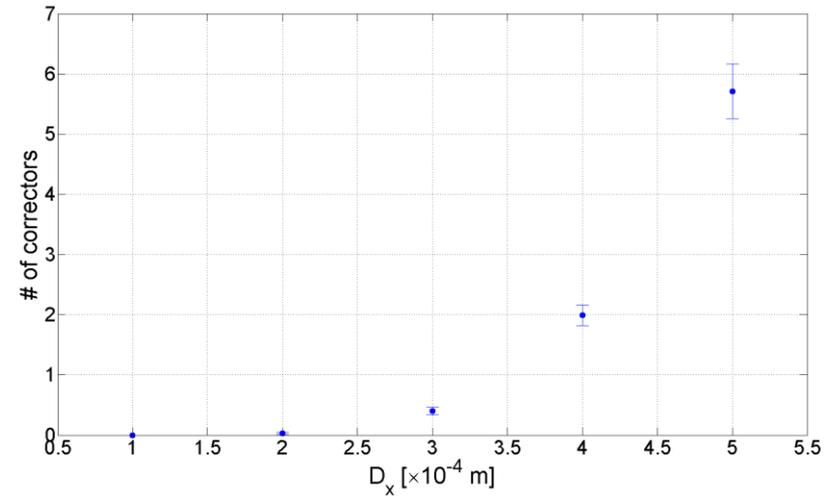Horizontal plane

Correction

Vertical plane

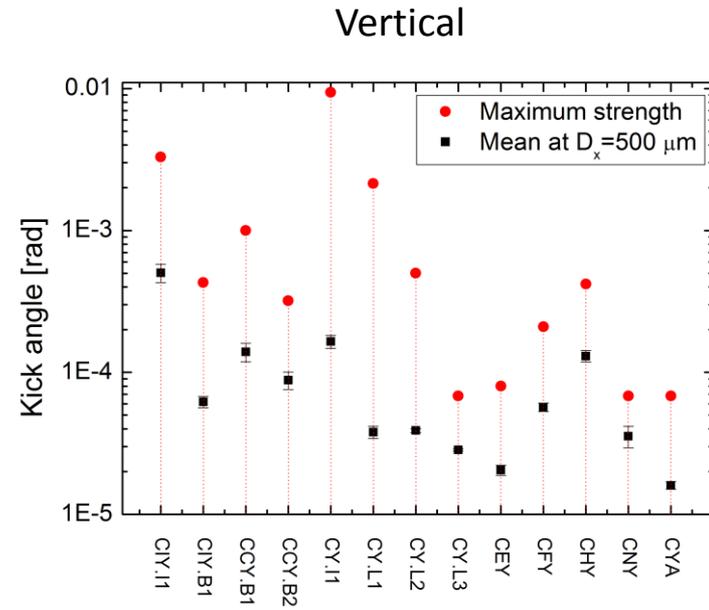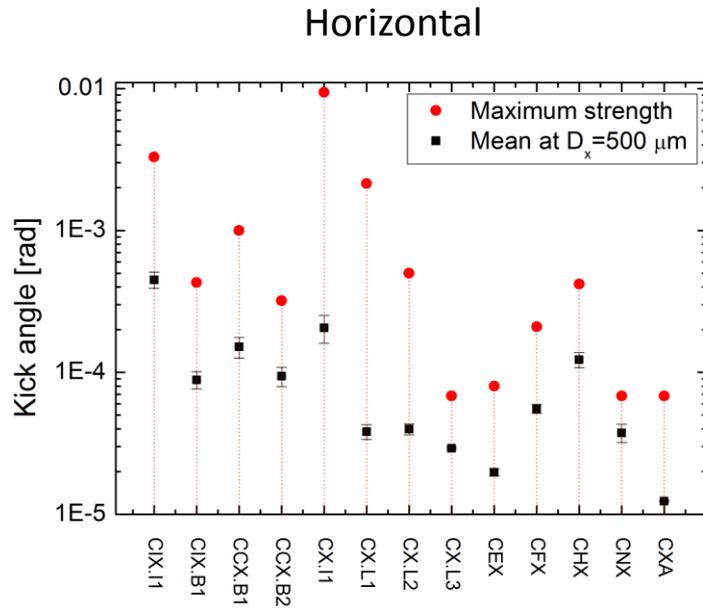# Number of correctors exceeding maximum strength

Horizontal

Vertical



- Each corrector has the maximum kick angle which restricted by magnet field strength and beam energy.

# Average strength of correctors



Horizontal

Vertical

- Figure shows the average strength of corrector families which have same maximum strength for the quadrupole misalignment ($D_x$) 500 $\mu$m.

# Summary

- ## Injector dogleg section
  - Maximum orbit size for quad-misalignment 500 μm
    - H : 1.5 cm → 0.8 mm
    - V : 1.5 cm → 2.0 mm
  - Weak chromatic effects after orbit correction
    - H : $B_{mag\_max}$ ≈ 1.0005 (±3%), $|\eta_x|$ ≈ 3.3 mm
    - V : $B_{mag\_max}$ ≈ 1.0002 (±3%), $|\eta_y|$ ≈ 0.6 mm
- ## Gun to TD1
  - Rms orbit size for quad-misalignment 500 μm
    - H : 1.8 cm → 0.12 mm
    - V : 1.8 cm → 0.13 mm
  - The correctors to be installed in XFEL are enough for correcting the orbit distorted by quadrupole misalignment up to 500 μm.

**Thank you for your attention!**