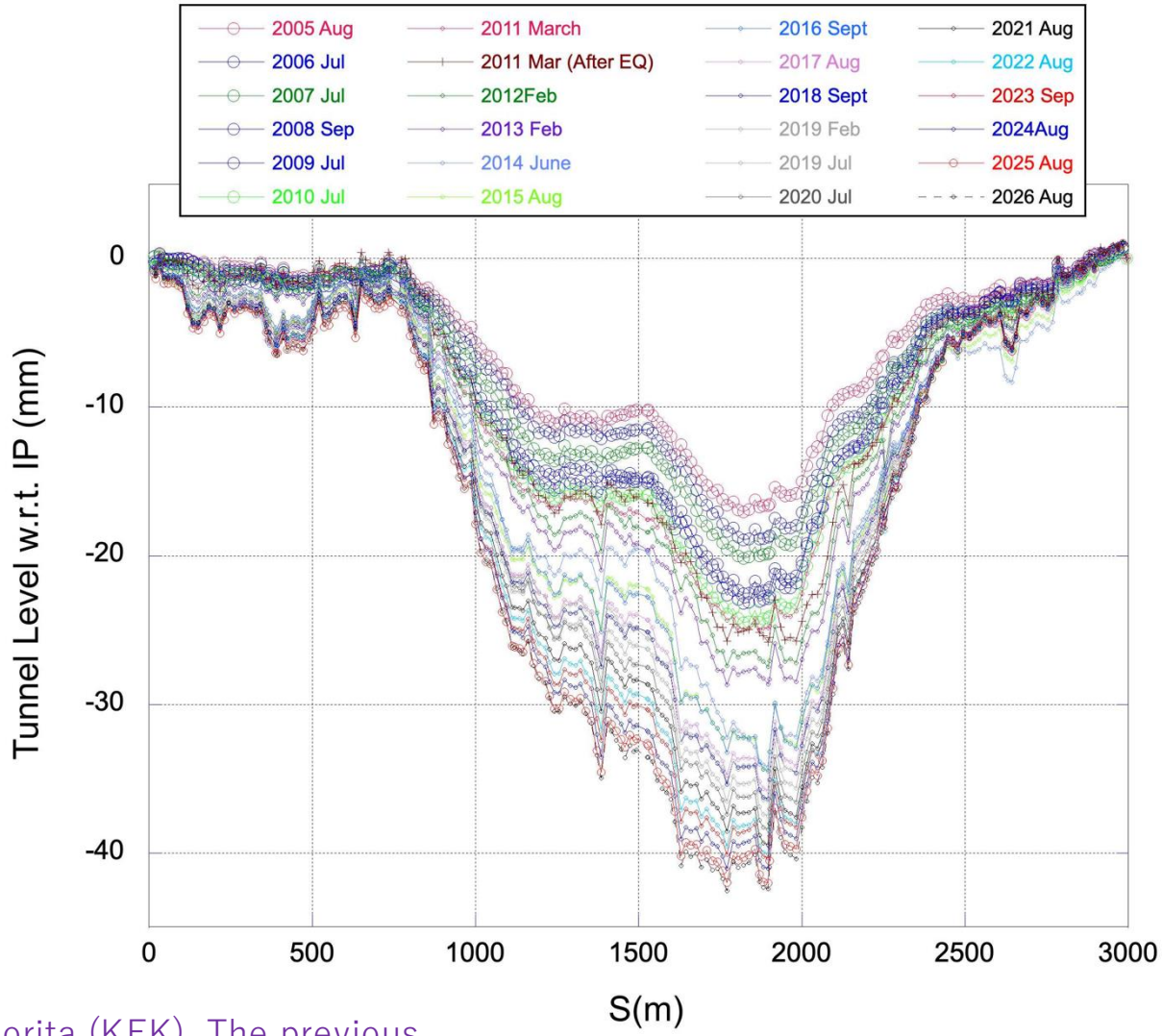
Simulation Study of Tunnel Settlement Effects on Beam Optics and Vertical Emittance in SuperKEKB

T. Asami (KEK)

Background / Objective

M. Masuzawa

- Tunnel settlement has been observed around the ring.
- This may lead to an increase in vertical emittance, making it crucial to evaluate its impact.
- Therefore, we investigated this effect for both HER and LER using the latest tunnel survey data.
- **Methodology:** Orbit, optics, and coupling corrections were performed with tunnel settlement included. **The vertical emittance arising from the residual errors after these corrections was then evaluated through simulations.**



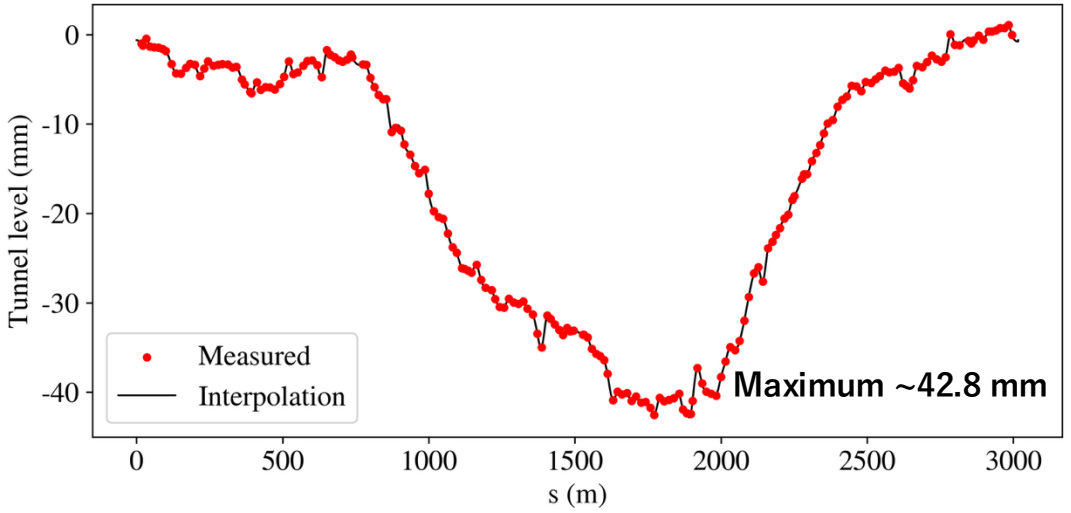
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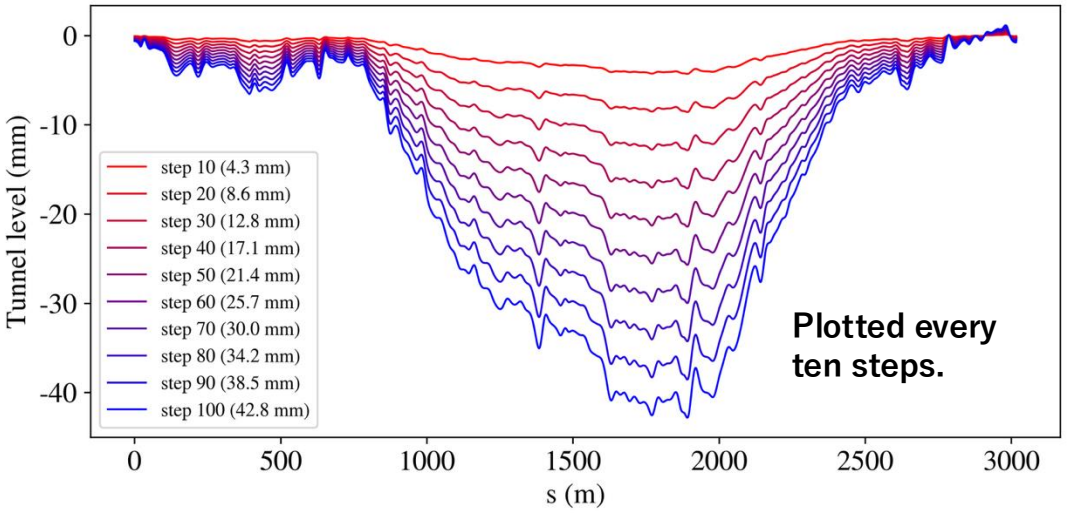
- A similar study for the LER was previously conducted by Prof. A. Morita (KEK). The previous study on LER serves as a valuable reference in developing our analysis strategy.
- Dr. H. Sugimoto (KEK) provided a list of currently available correction knobs.

Method

- The tunnel settlement data, $\Delta y_{\mathrm{sink}}(s)$ were interpolated.
- Directly applying the full settlement to SAD resulted in failure to find a closed orbit.
- Therefore, the following procedure was adopted:
  1. Apply the scaled settlement $\Delta y_{\mathrm{sink}}(s) \times n/100$ $(n = 1, 2, \ldots, 100)$ to each element.
  2. Adjust the RF frequency to account for the change in circumference caused by tunnel settlement.
  3. Correct the orbit, XY coupling, and optics (next slide). Readjust the RF frequency after each correction and repeat this procedure several times.
  4. Only beam-based measurable quantities are used for corrections, considering the BPM resolution (assumed to be 2 μm for all BPMs).
  5. Calculate the vertical emittance.
  6. Increment n by 1 and return to Step 1.

Interpolation of tunnel level data





s=0 : IP

Orbit, XY coupling, and Optics corrections

- **Correction Knobs:** All currently available K0, K1, and SK1 correction knobs (excluding AQ*).
- **Observables:**
  - Orbit displacements at all BPMs.
  - Orbit responses to a single kick for optics measurements.
  - Physical dispersions PEX and PEY.
- **Lattice errors:** Tunnel settlement and BPM jitter (2 μm).

Magnet misalignments and BBA accuracies will be considered in further simulation.

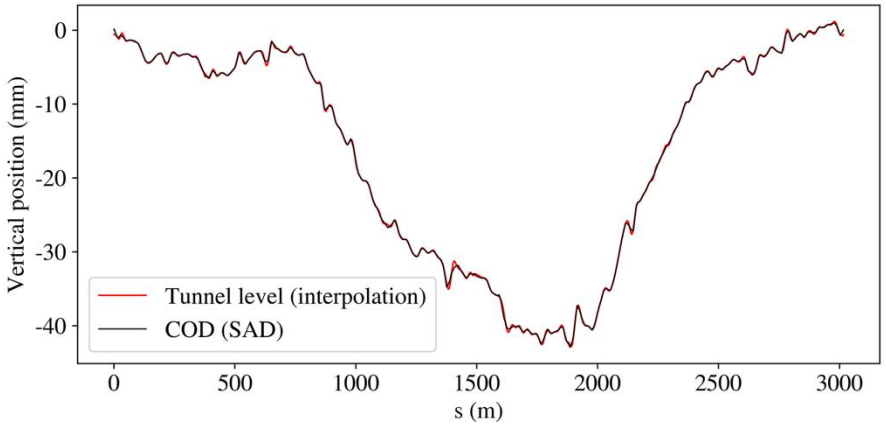
- **Correction Methods:**
  - **Closed Orbit Correction:** Correct the orbit to pass through the BPM centers.
  - **XY Coupling and Optics Correction:** Determine the required K1/SK1 knob adjustments using single-kick orbit responses and PEX/PEY measurements.

(The latter employs some methods discussed in *T. Asami et al., PRAB 28, 012801 (2025).*)

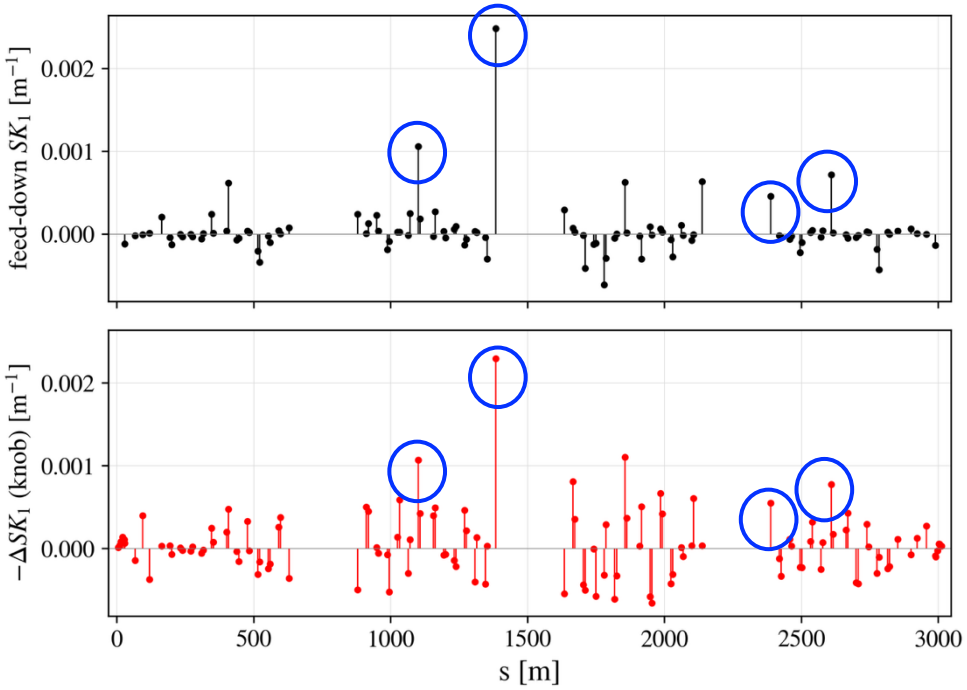
LER results

	LER
Vertical emittance [pm]	**4.9**
BX RMS residual [%]	0.13
BY RMS residual [%]	0.56
EY RMS residual [mm]	4.4
Ver COD RMS residual [mm]	0.16

Interpolation of tunnel level data and SAD COD



Sextupole Feed-Down and Skew Quadrupole Knobs



Agreement is achieved at the order-of-magnitude level, but suppressing the effects of small singular values appears necessary to reproduce the magnetic field error distribution itself.

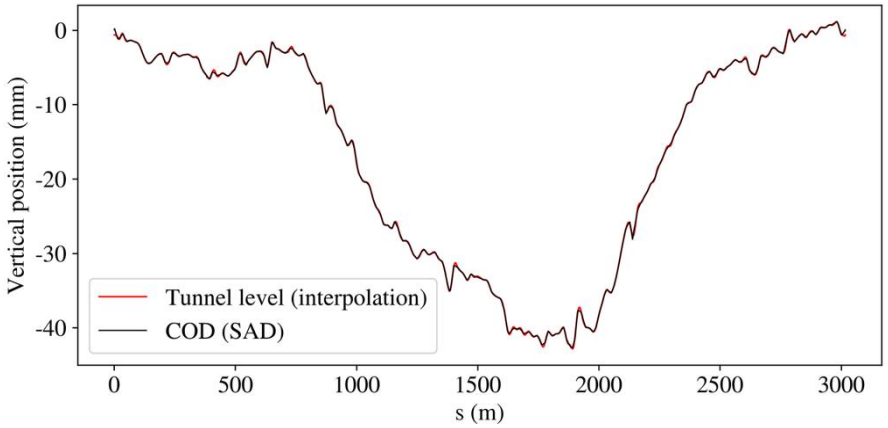
Knob RMS (K value)
K0 6.8e-05 rad; K1 7.5e-5 /m; SK1 4.2 e-4 /m

Assuming a BPM jitter of 2 μm and ideal orbit and optics corrections based on measurable observables,
the simulations suggest that a vertical emittance of ~5 pm is achievable in principle, even with tunnel settlement.

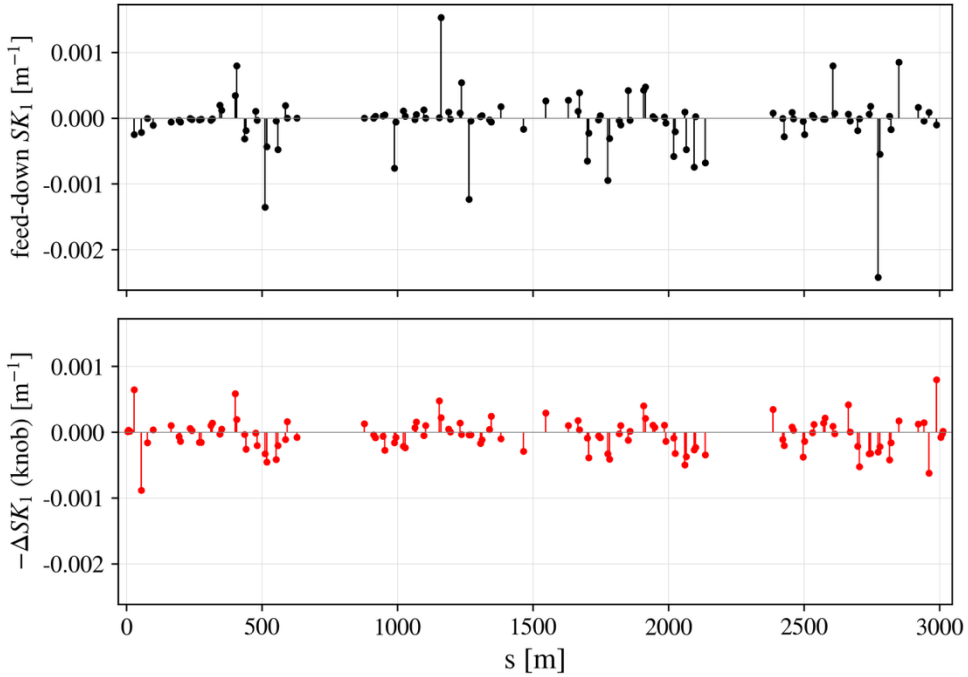
HER results

	HER
Vertical emittance [pm]	**1.8**
BX RMS residual [%]	0.19
BY RMS residual [%]	0.70
EY RMS residual [mm]	3.9
Ver COD RMS residual [mm]	0.11

Interpolation of tunnel level data and SAD COD



Sextupole Feed-Down and Skew Quadrupole Knobs



Agreement is achieved at the order-of-magnitude level, but suppressing the effects of small singular values appears necessary to reproduce the magnetic field error distribution itself.

Knob RMS (K value)
K0 7.6e-05 rad; K1 9.2e-5 /m; SK1 8.8 e-4 /m

Assuming a BPM jitter of 2 μm and ideal orbit and optics corrections based on measurable observables,
the simulations suggest that a vertical emittance of ~2 pm is achievable in principle, even with tunnel settlement.

Summary

- We evaluated the effects of the latest tunnel settlement data on optics distortions and vertical emittance in both the LER and HER.
- The simulations confirmed that the vertical emittance can be reduced to **~5 pm in the LER and ~2 pm in the HER under the following assumptions:**
  - Ideal orbit/optics corrections can be performed using measured orbit displacements, orbit response and physical dispersions.
  - No lattice errors other than tunnel settlement and BPM jitter (2 μm) are considered.
- However, these results **do not necessarily imply that tunnel settlement is not a source of vertical emittance growth in the actual machine.**
- Rather, the conclusion is that, **in principle, there is no fundamental limitation arising from an insufficient number of measurable observables or available correction knobs** for orbit and optics corrections in the presence of tunnel settlement.