Impact of bunch currents on optics measurements in SuperKEKB

JACQUELINE KEINTZEL

TU WIEN, VIENNA, AUSTRIA

CERN, GENEVA, SWITZERLAND

Acknowledgements:

T. Ishibashi, H. Koiso, A. Morita, G. Mitsuka, K. Ohmi, Y. Ohnishi, H. Sugimoto, S. Terui, R. Tomas, M. Tobiyama, R. Yang, D. Zhou, F. Zimmermann

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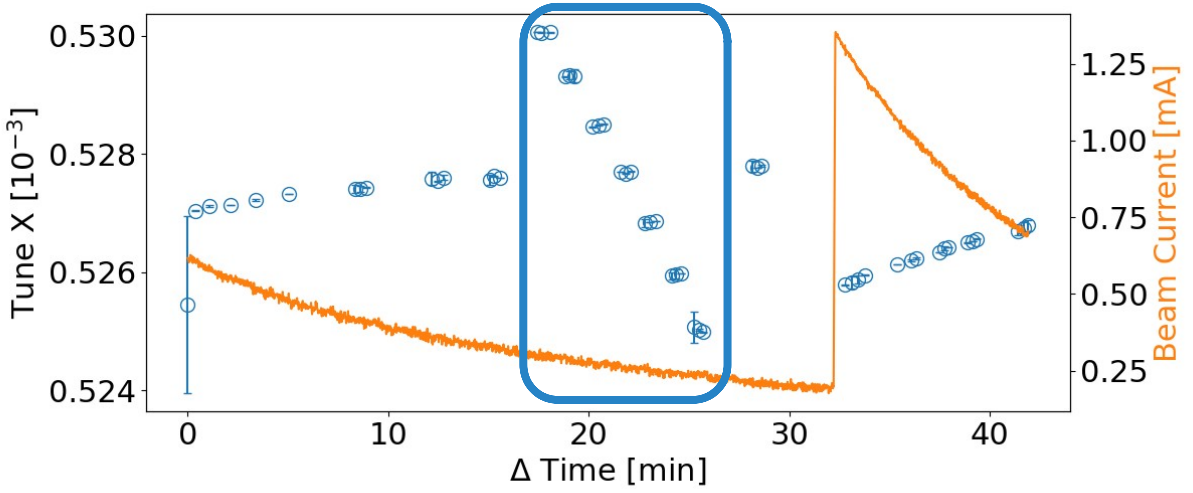
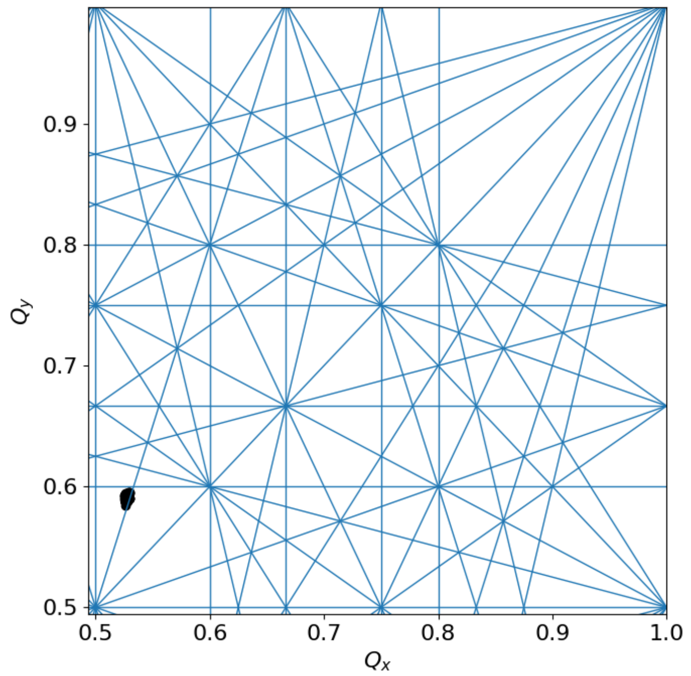
Optics Measurements I

- LER TbT measurements on 22th Feb 2021
- Used optics with $beta_{x,y}$* = 80,2 mm
- Single kicks performed with injection kicker
- Bunch currents from 0.2 – 1.2 mA

Off-momentum measurements

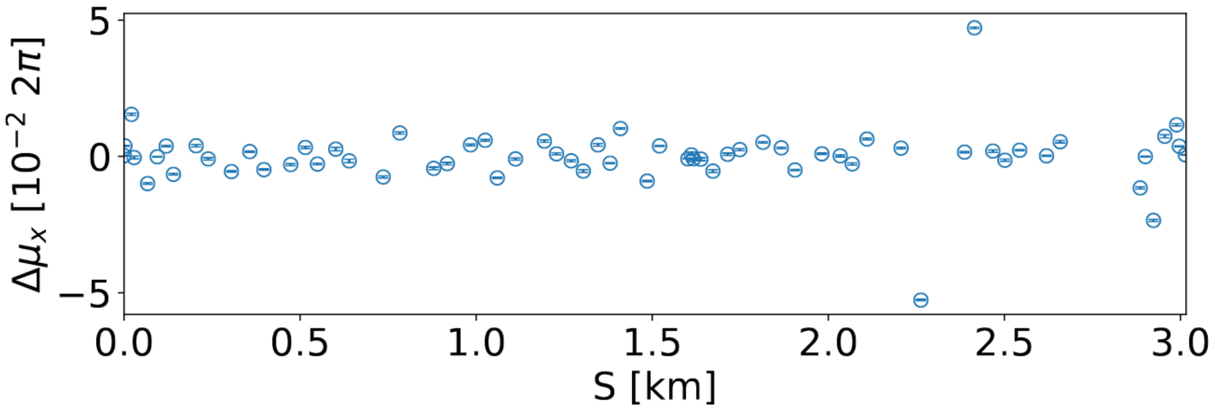


Working point close to octupole line

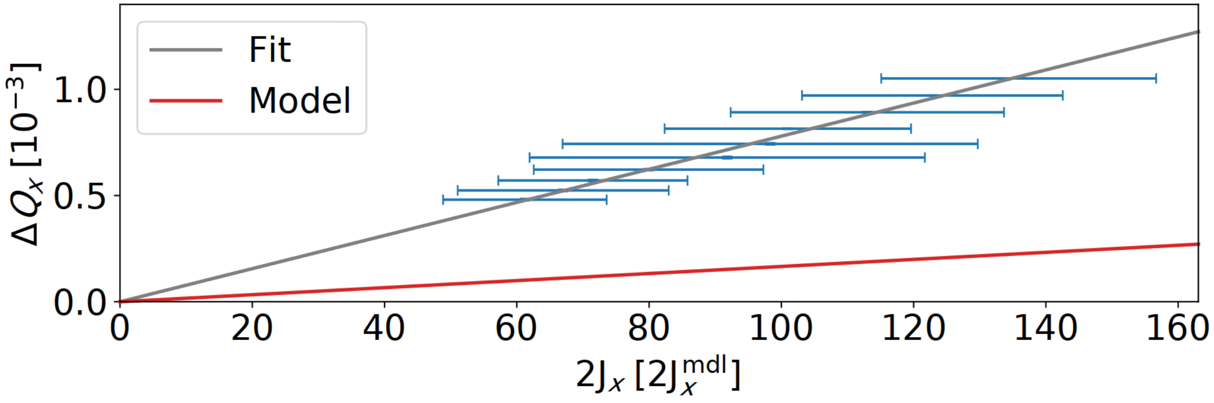


Optics Measurements II

- LER TbT measurements on 22th Feb 2021
- Used optics with $beta_{x,y}$* = 80,2 mm
- Single kicks performed with injection kicker
- Measured C_ = (3.3 ± 0.2) x 10^{-3}
- Bunch currents from 0.2 – 1.2 mA
- Chromaticity:
  - Q'x = 1.54 ± 0.01 (model -1)
  - Q'y = -2.4 ± 1.6 (model +3)



RMS phase advance error 1.1x10^{-2} (2π)
Resulting rms β-beating 4.1 %



Amplitude detuning (8.1±0.3)x10^{-3} m^{-1}
6.37x10^{-4} rms relative momentum spread

Collimators and Kick Factor

- Kick factor k describes the magnitude of the intensity dependent centroid bunch deflection

$$\Delta x' = k_{\perp} Q x_0 / E$$

- Kick factor includes dipolar and quadrupolar contributions
- Treshold bunch current defined by dipolar kick factor by

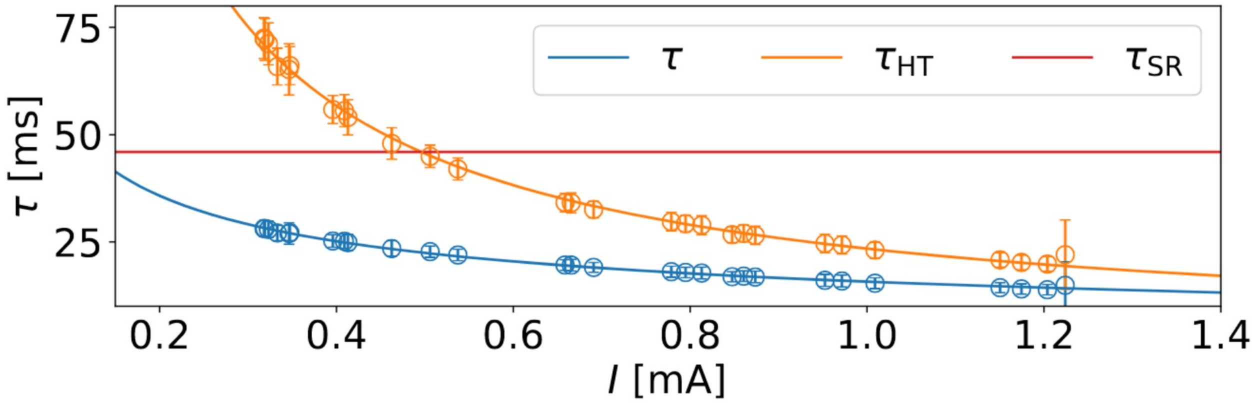
$$I_{\text{thr}} = \frac{C_1 f_s E / e}{\sum_n \beta_n k_{\perp,n}^{\text{dip}}}$$

Kick factor includes dipolar and quadrupolar terms
Computed for bunch length of 0.5 mm with GdfidL
Real bunch length about 5-6 mm

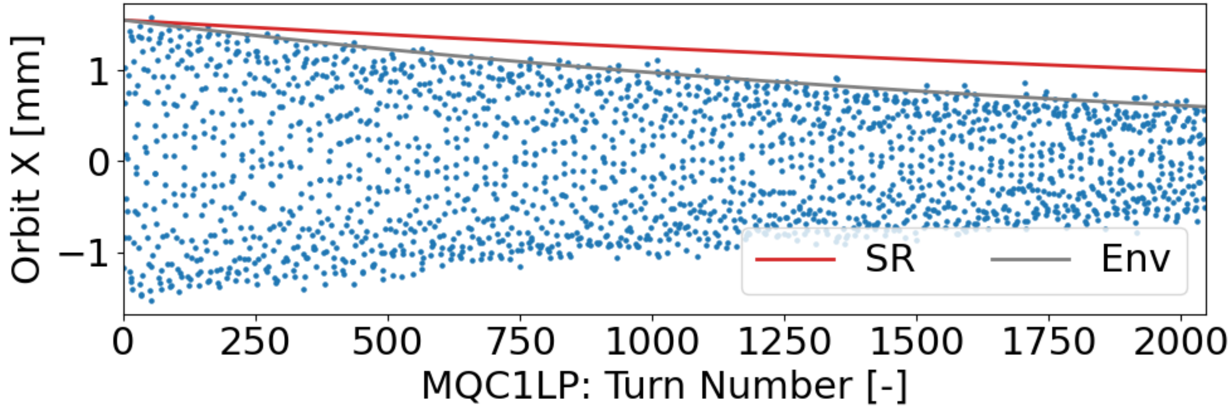
Name	Width [mm]	$\beta_{x,y}$ [m]	$k_{\perp}\beta_{x,y}$ [10^{15} V/C]
D06V1	2.74	61.4	15.2
D06V2	3.01	19.2	4.4
D03V1	8.02	17.0	0.9
D02V1	2.36	17.0	5.7
$\sum$V	–	–	26.2
D06H1	10.20	24.2	0.7
D06H3	12.05	24.2	0.5
D03H1	14.51	29.0	0.4
D02H1	8.99	17.7	0.7
D02H2	11.50	27.1	0.6
D02H3	18.00	51.5	0.4
D02H4	10.51	20.1	0.5
$\sum$H	–	–	3.9

Damping Times

- After single kick amplitude decays
- Measured decay time obtained by fit of measured amplitude
- Faster than expected from synchrotron raditation damping
- Assumption: Additional damping solely from head-tail



$A(t) = Ae^{-t/\tau}$ τ_{SR} = 46 ms



- Total damping time given by sum of inverse damping times

$$\tau^{-1} = \sum_n \tau_n^{-1}$$

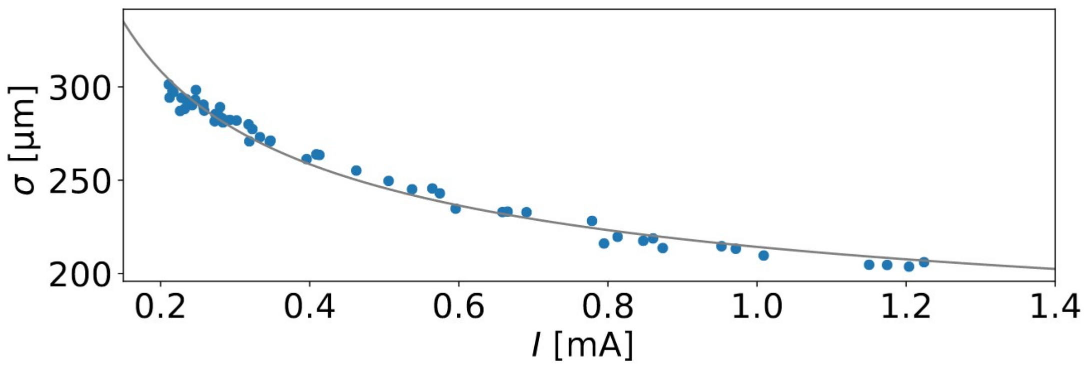
Below 0.5 mA synchrotron radiation main contribution
Above 0.5 mA head-tail damping main contribution

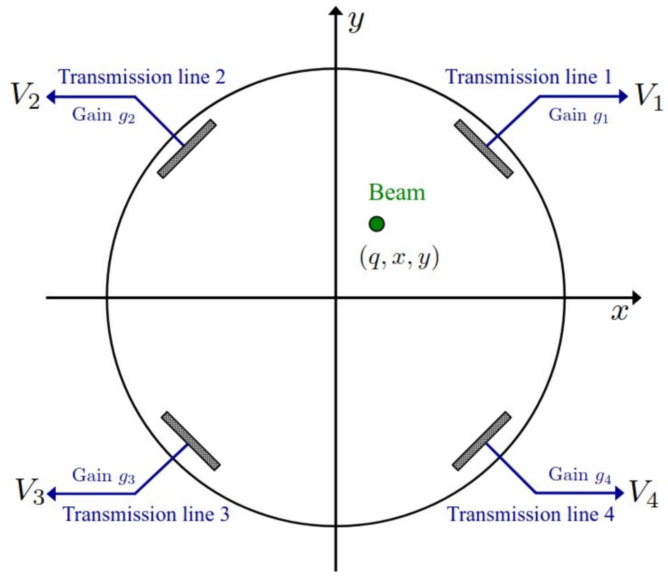
BPM Resolution

- BPM resolution
  - Decreases with increasing bunch current
  - Estimated by subtracting cleaned orbit from raw one and computing rms at each BPM
- Lowest resolution of 200 μm at 1.25 mA

$$x = \frac{V_1 + V_4 - (V_2 + V_3)}{V_1 + V_2 + V_3 + V_4}$$

$$y = \frac{V_1 + V_2 - (V_3 + V_4)}{V_1 + V_2 + V_3 + V_4}$$





Intensity Dependent Tune

- Tune decreases with bunch current

$$\Delta Q = \frac{I}{4\pi E/e f_0} \sum_n \beta_n k_{\perp,n}$$

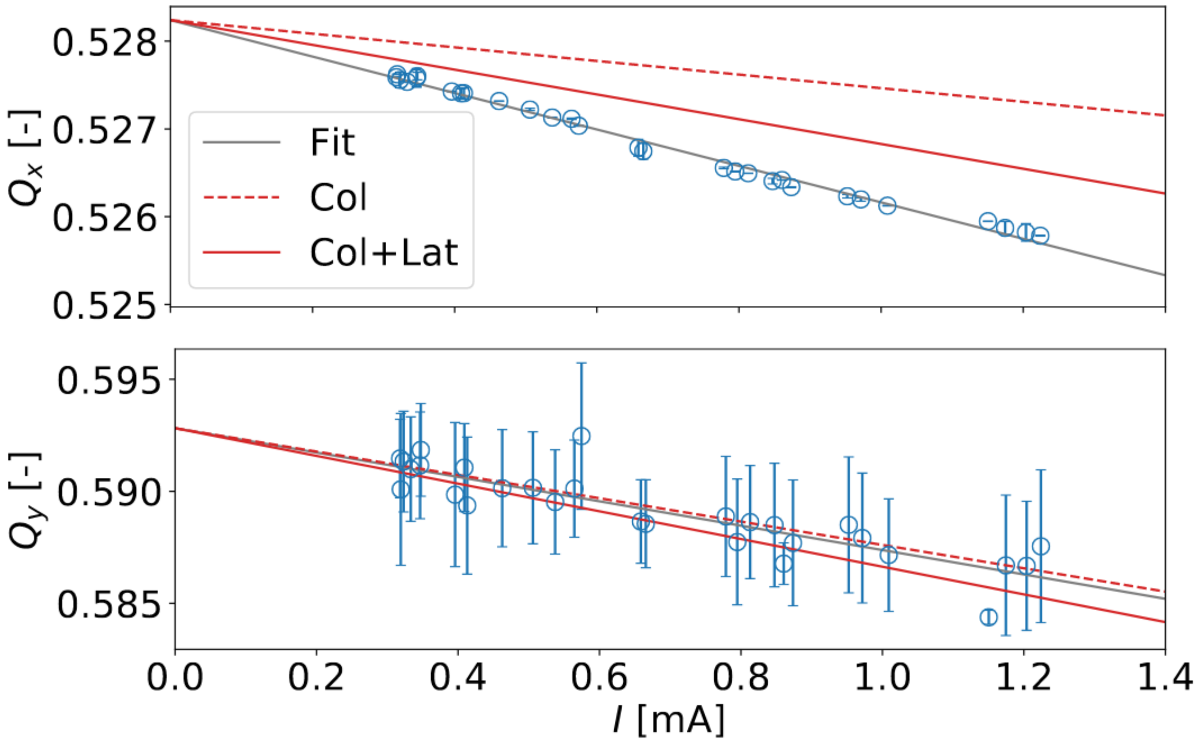
- Transverse impedance estimated

$$\mathrm{Im}(Z_{\mathrm{eff}}) = \frac{8\pi^{3/2}\sigma_z E/e}{\langle\beta\rangle C} \frac{\mathrm{d}Q}{\mathrm{d}I}$$

- 32.7 ± 1.3 kΩ/m horizontally
- 67 ± 20 kΩ/m vertically

Take away:
✔ Known sources explain 68 % and 100 % of the measured horizontal and vertical tune shift

Zero bunch tune: Q_x = 0.5282, Q_y = 0.5928



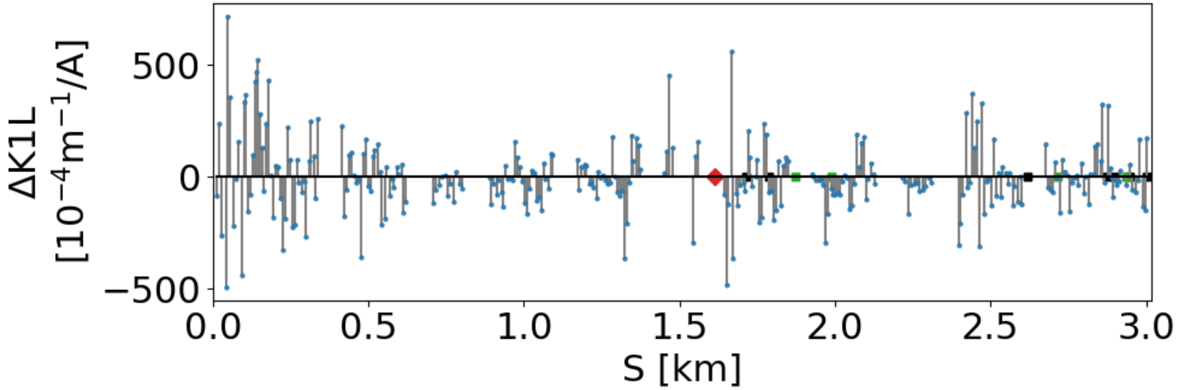
ΔQ/mA [10^{-3}]	Meas.	Coll.	Coll.+Lat.
Hor.	-2.08 ± 0.04	-0.78 (40%)	-1.41 **(68%)**
Ver.	-5.33 ± 0.59	-5.21 (~100%)	-6.19 **(~100%)**

Impedance Localization I

- Transverse impedance sources lead to quadrupolar kick
- Aim to localize sources using phase advance shift from bunch current
- Response matrix approach

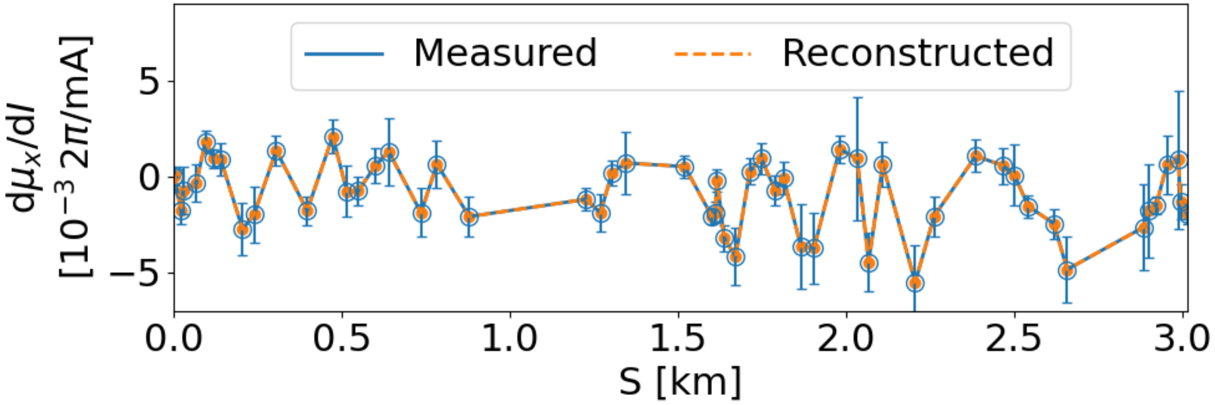
Find quadrupole strengths ΔK for measured change in phase advance

$$\mathbf{R}\,\overrightarrow{\Delta K} = \overrightarrow{\Delta\mu}$$



Red diamond: injection kicker
Black: horizontal collimator, green: vertical collimator

Phase advance 100 % reconstructed using all quads



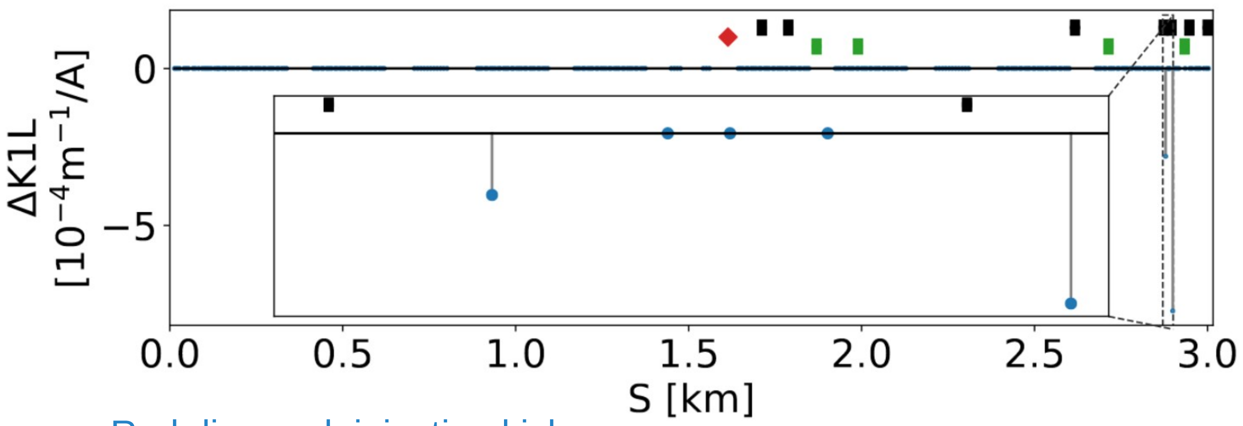
Unconstraint response matrix solves problem exactly
Result in very large kicker strengths

Impedance Localization II

- Transverse impedance sources lead to **negative** quadrupolar kick
- Aim to localize sources using phase advance shift from bunch current
- Response matrix approach

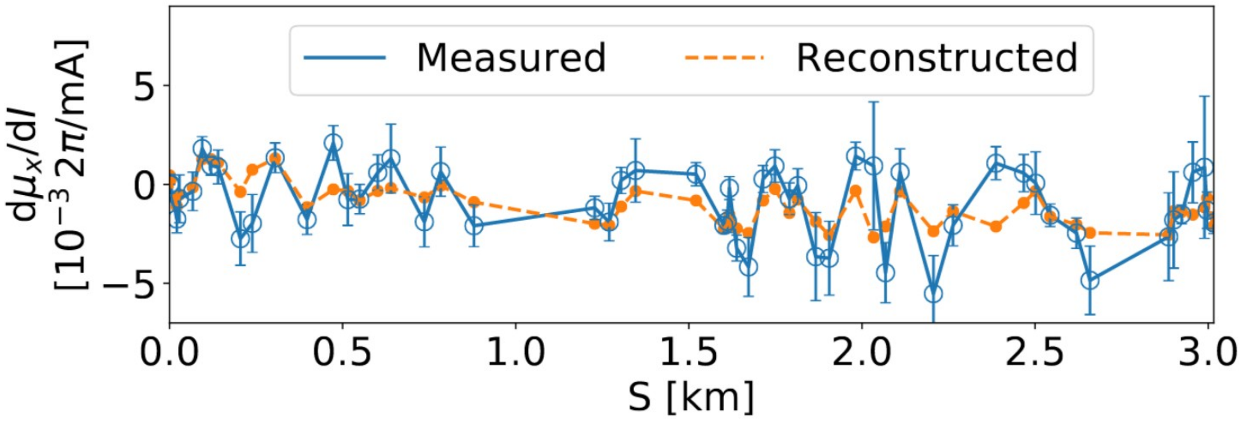
Find **negative** quadrupole strengths ΔK for measured change in phase advance

$$\mathbf{R}\,\overrightarrow{\Delta K} = \overrightarrow{\Delta \mu}$$



Red diamond: injection kicker
Black: horizontal collimator, green: vertical collimator

Phase advance 72 % reconstructed using only 2 quads



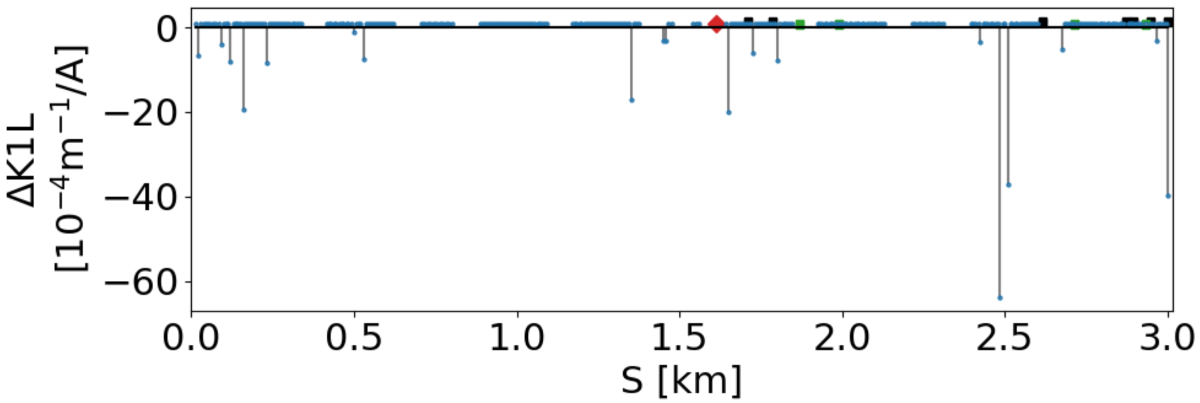
Take away:
✔ 72% measured phase advance reconstructed using only 2 negative quadrupole kicks

Impedance Localization III

- Transverse impedance sources lead to negative quadrupolar kick
- Aim to localize sources using phase advance shift from bunch current
- Response matrix approach

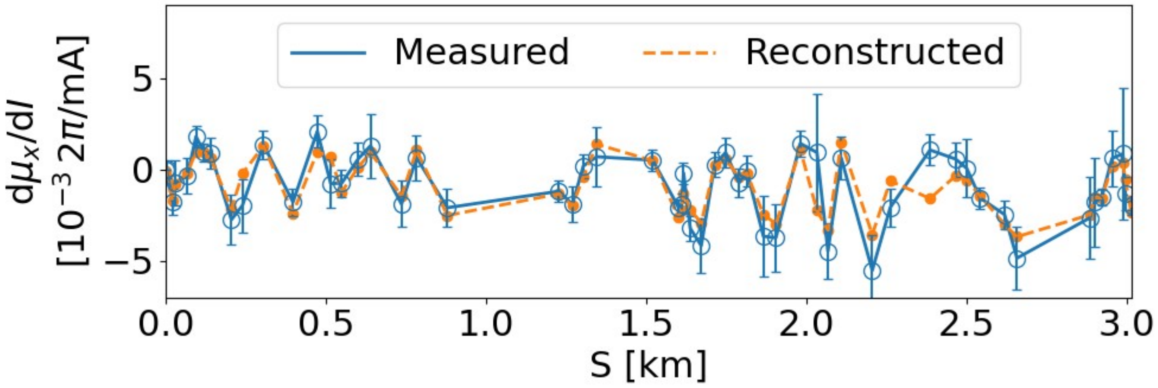
Find quadrupole strengths ΔK for measured change in phase advance

$$\mathbf{R}\,\overrightarrow{\Delta K} = \overrightarrow{\Delta\mu}$$



Red diamond: injection kicker
Black: horizontal collimator, green: vertical collimator

Constraints: $K1L_{max}$ = 2e-4
Phase advance 85 % reconstructed using ~20 quads



Using 20 negative kickers and the rest slightly positive
Result in large kicker strengths
Result changes with different max constraint

Conclusion and Outlook

- Conclusion:
- BPM resolution decreases with increasing bunch current
- Below 0.5 mA damping dominated by SR, above 0.5 by head-tail
- Sources of vertical tune shift known, horizontally about 70 %
- Correction of dμ/dI suggest 4th and 5th collimators as major impedance sources

- Outlook:
- Improve impedance localization by adding quadrupoles next to elements

  → Might help to identify new sources to explain tune shift (ongoing)
- Chromaticity scans can help to understand contribution of head-tail and might help to distinguish between head-tail and possible decoherence

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