Beam optics and emittance measurement evaluations 2019 & 2020

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Beam dynamics meeting, December 15, 2020

Data

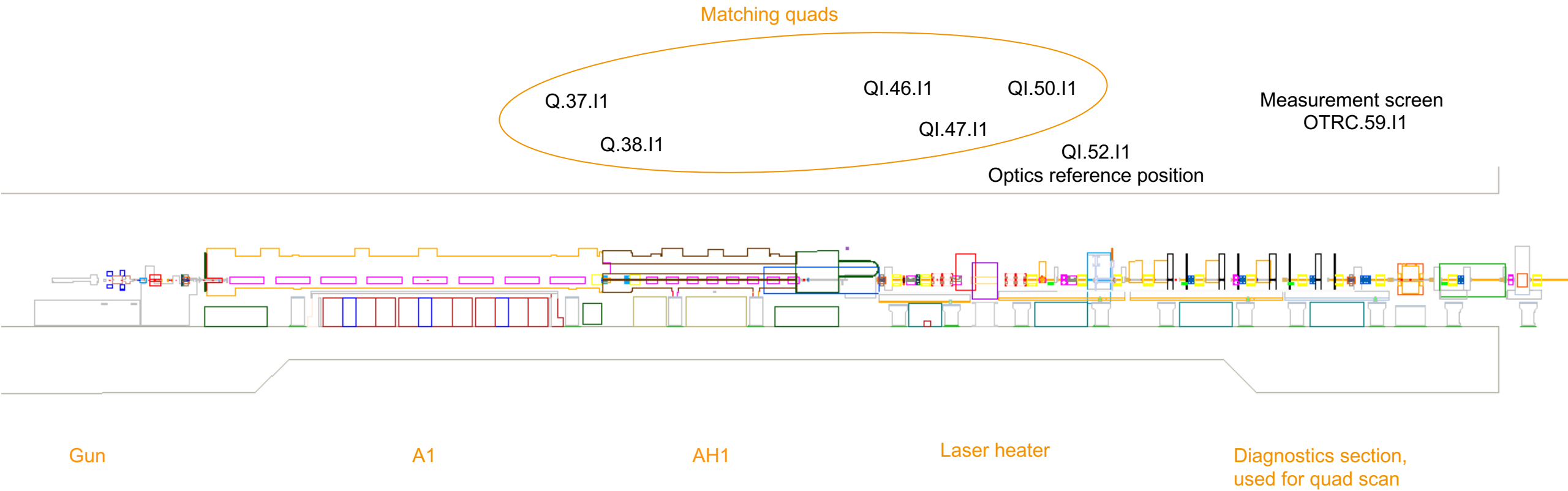
- The evalueated data is a subset of all results optained by multi quad scans carried out between January 2019 and June 2020.
  - The are no machine files saved for older scans.
  - Data taken between June and November 2020 could not be loaded yet. The reason is currently unclear.
- The minimum requirement on the measurement data was a mismatch amplitude of 1.5 or better.
  - In total 949 measurements were evaluated.
- The optics reference position of all measurements is the start of the quad QI.52.I2.
- All measured Twiss-parameters were tracked back with Elegant to the start of the first quadrupole (Q.37.I1)
  - The correct quad strength at the time of the measurement and the correct RF module setup (AH1) was considered.

- This allows us to study the Twiss parameters at the start of the lattice and the impact of the setup on the emittance.

- Uncertainties:
  - It was assumed that the beam energy in the diagnostics section was exactly 130 MeV.
  - The on-crest phases of the RF module could have been wrong at the time of the measurement leading to a wrong kick of the two cold quads and thus different results from the backtracking.

- Updates and more information can be found in Conflunece: https://confluence.desy.de/x/crxACw

Injector layout

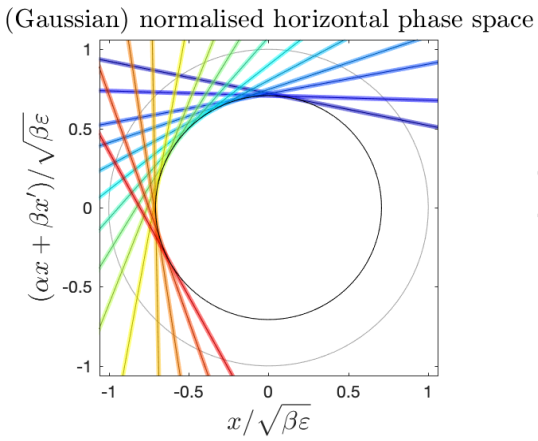


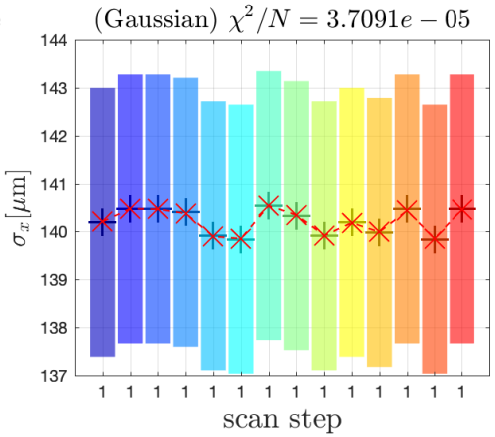
Example for a prepared scan in for projected beam optics and emittance measurements in I1

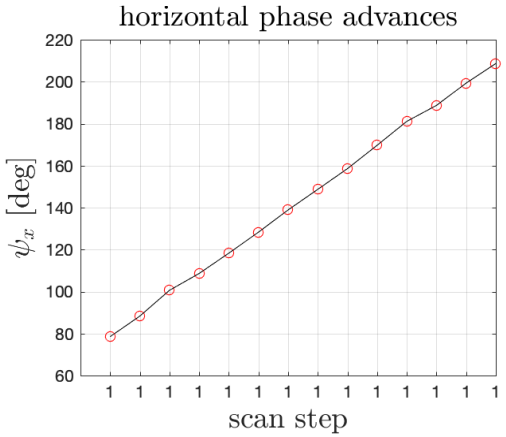
Multi quad scans

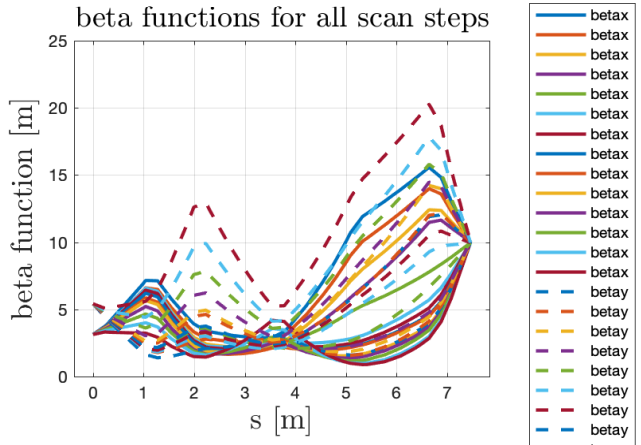
Multi quad scans are prepared for different locations and purposes and can be started with a Matlab client.

Horizontal plane

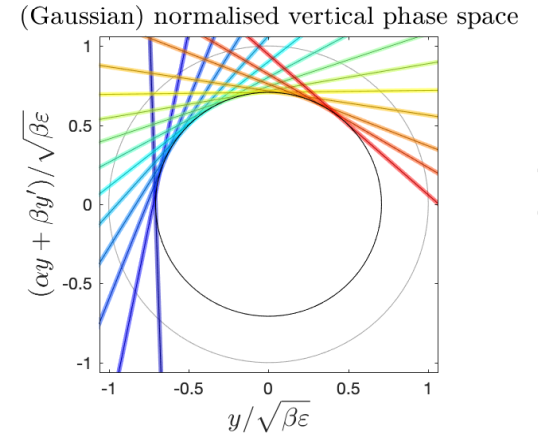


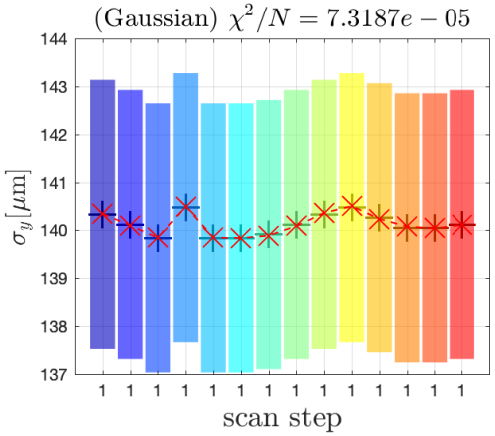


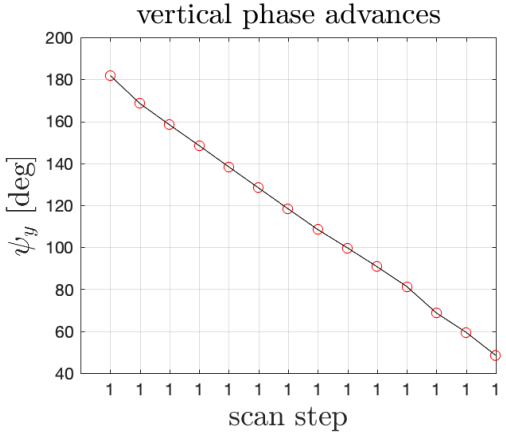




Vertical plane

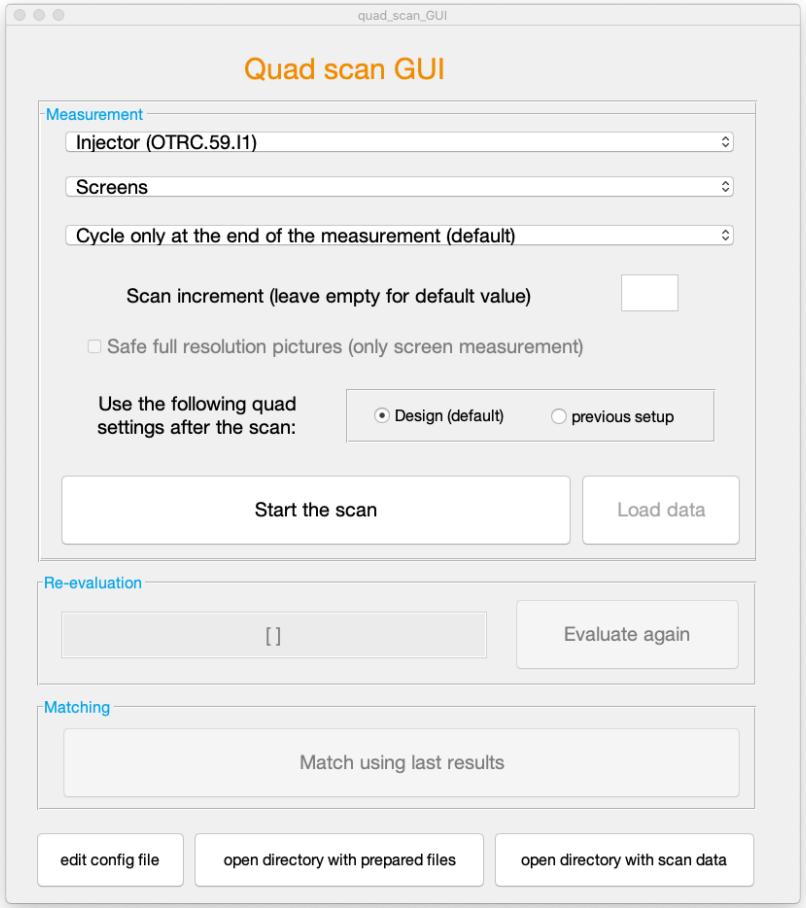


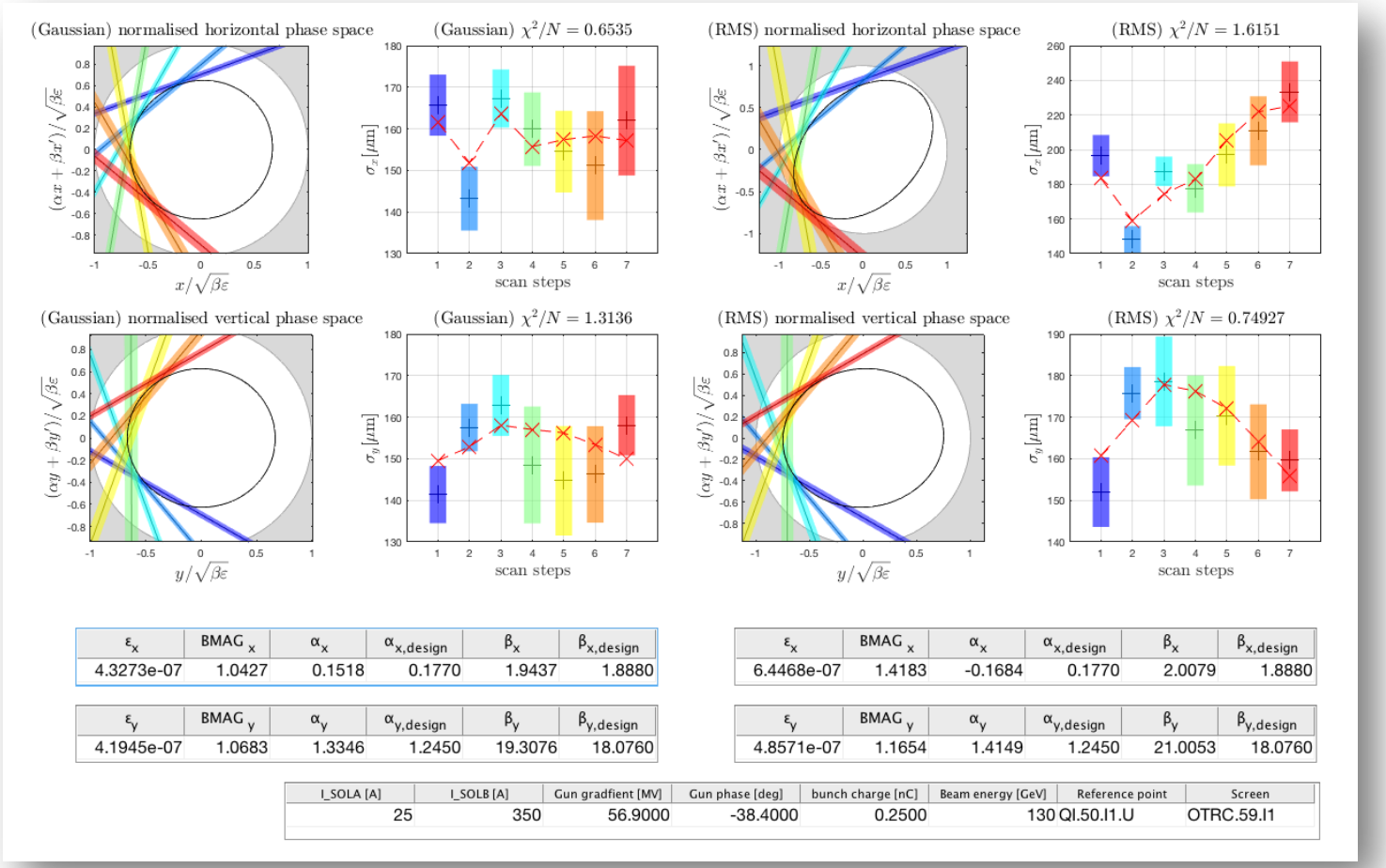




Example for a prepared scan for projected beam optics and emittance measurements in I1

Optics matching in the injector using screen stations and multi knob quad scans





ε_x	BMAG $_x$	α_x	$\alpha_{x,design}$	β_x	$\beta_{x,design}$
4.3273e-07	1.0427	0.1518	0.1770	1.9437	1.8880

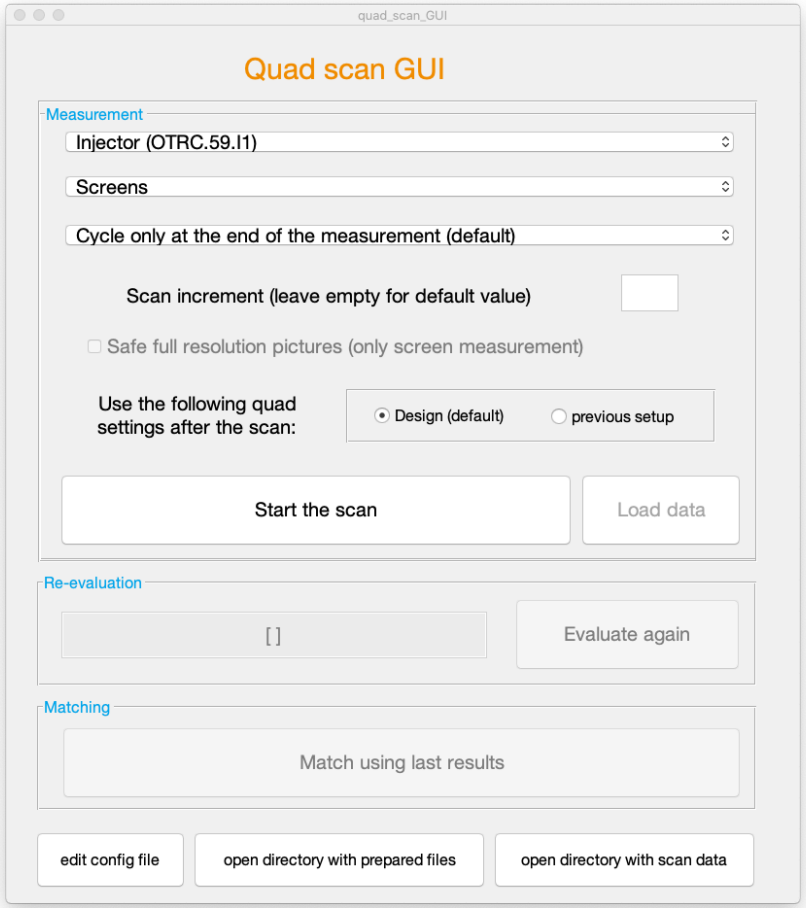
ε_x	BMAG $_x$	α_x	$\alpha_{x,design}$	β_x	$\beta_{x,design}$
6.4468e-07	1.4183	-0.1684	0.1770	2.0079	1.8880

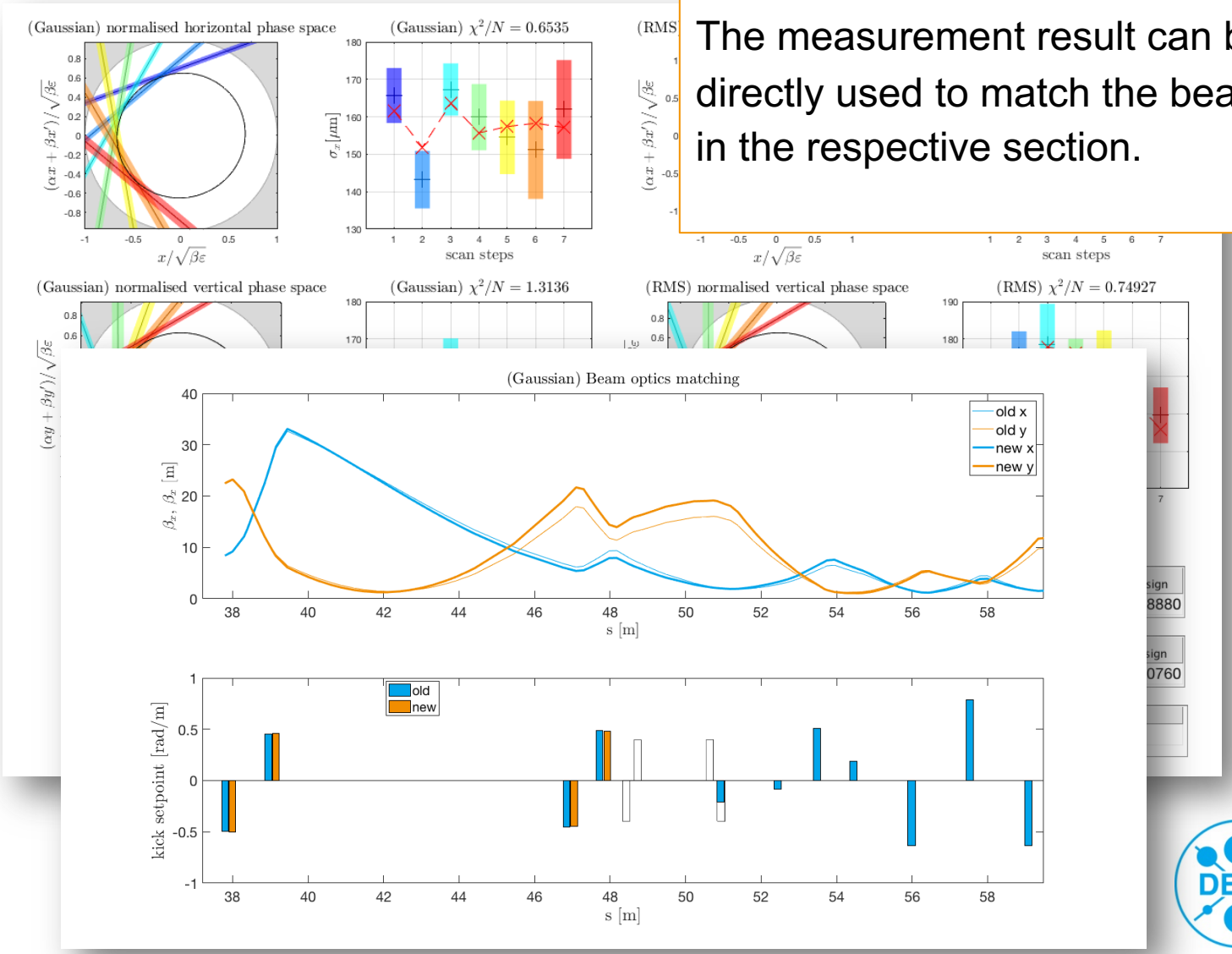
ε_y	BMAG $_y$	α_y	$\alpha_{y,design}$	β_y	$\beta_{y,design}$
4.1945e-07	1.0683	1.3346	1.2450	19.3076	18.0760

ε_y	BMAG $_y$	α_y	$\alpha_{y,design}$	β_y	$\beta_{y,design}$
4.8571e-07	1.1654	1.4149	1.2450	21.0053	18.0760

I_SOLA [A]	I_SOLB [A]	Gun gradfient [MV]	Gun phase [deg]	bunch charge [nC]	Beam energy [GeV]	Reference point	Screen
25	350	56.9000	-38.4000	0.2500	130	QI.50.I1.U	OTRC.59.I1

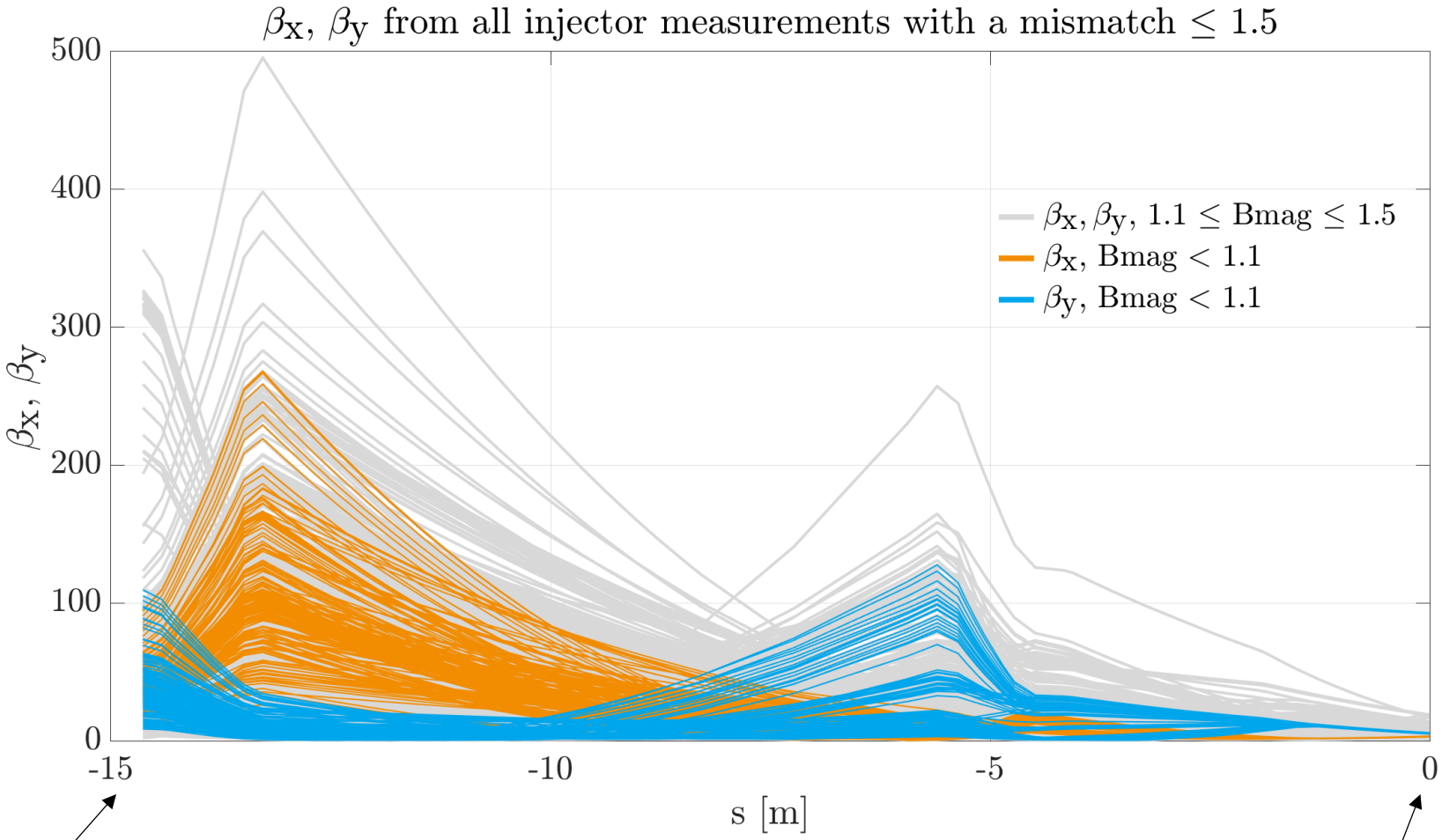
Optics matching in the injector using screen stations





The measurement result can be directly used to match the beam in the respective section.

Injector beta functions Q.37.I1_start -> QI.52.I1_start

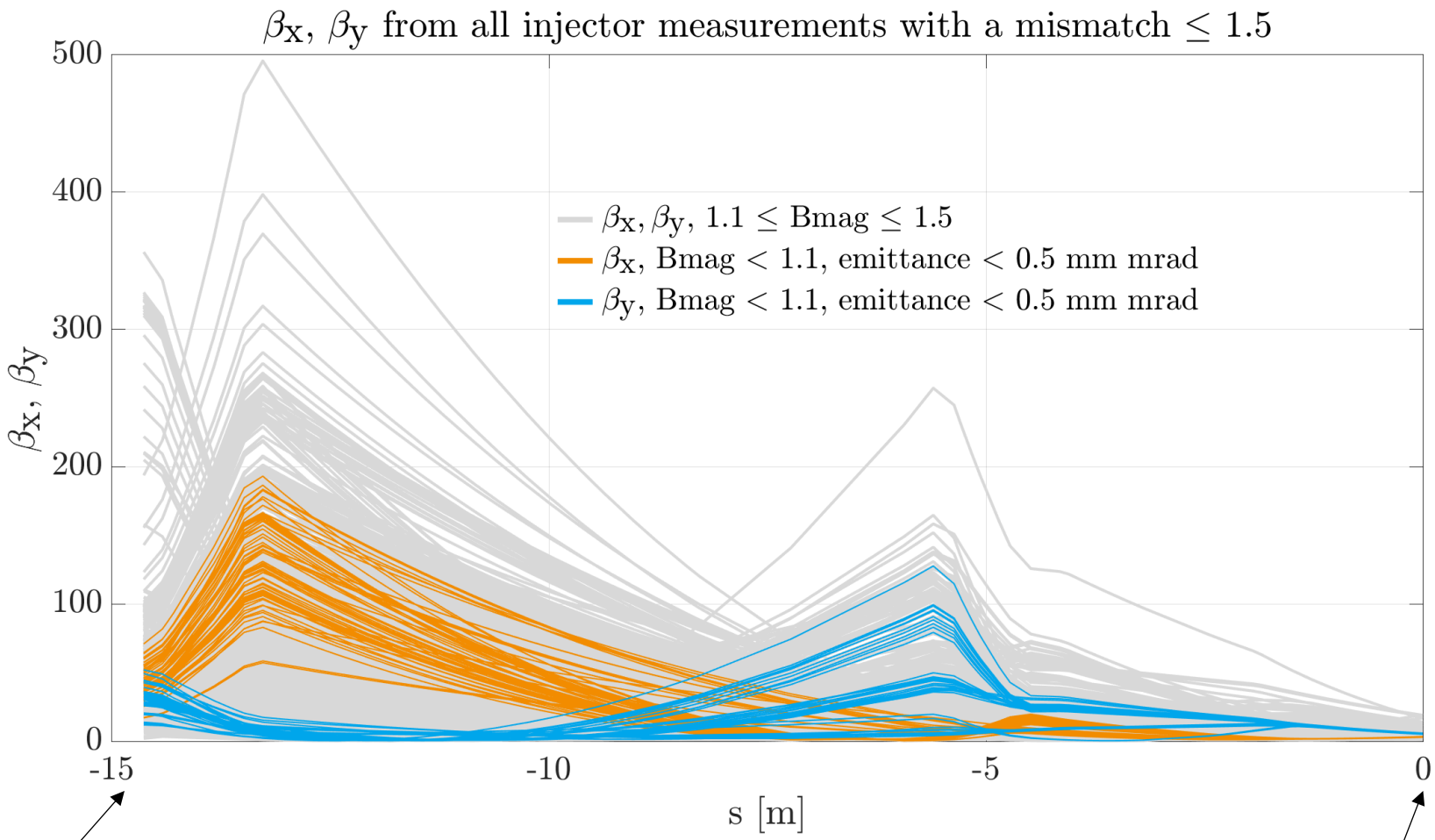


Q.37.I1_start AH1 Laser heater QI.52.I1_start

Additional data constrains:

- 250 pC bunch charge
- No emittance thresholds
- Results from backtracking
- Very large beta functions at the start or in the second quad lead always to large mismatch -> grey lines
- It looks like there are 3 matching solutions at least in the vertical plane -> blue lines.

Injector beta functions Q.37.I1_start -> QI.52.I1_start

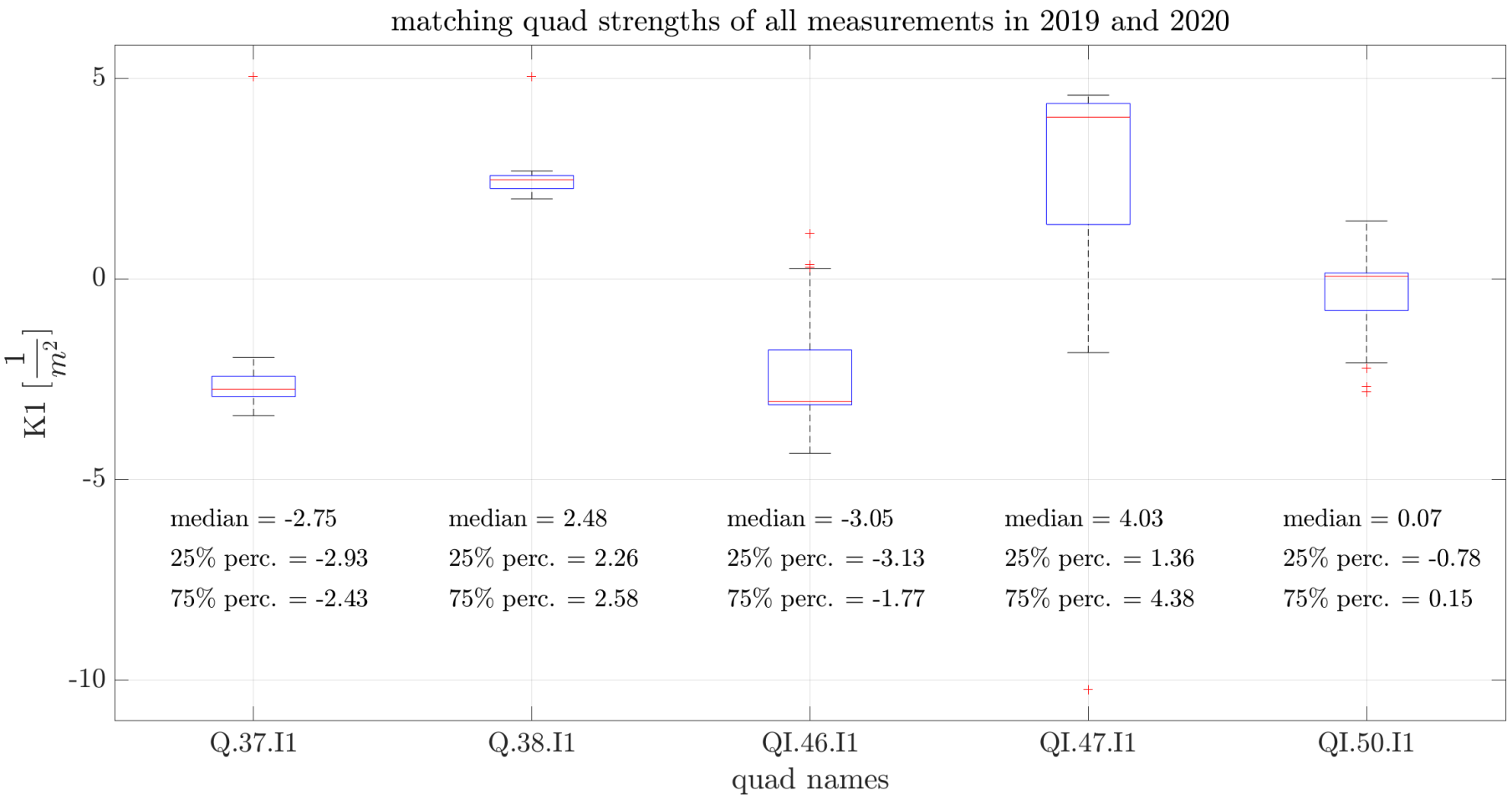


Q.37.I1_start AH1 Laser heater QI.52.I1_start

Additional data constrains:

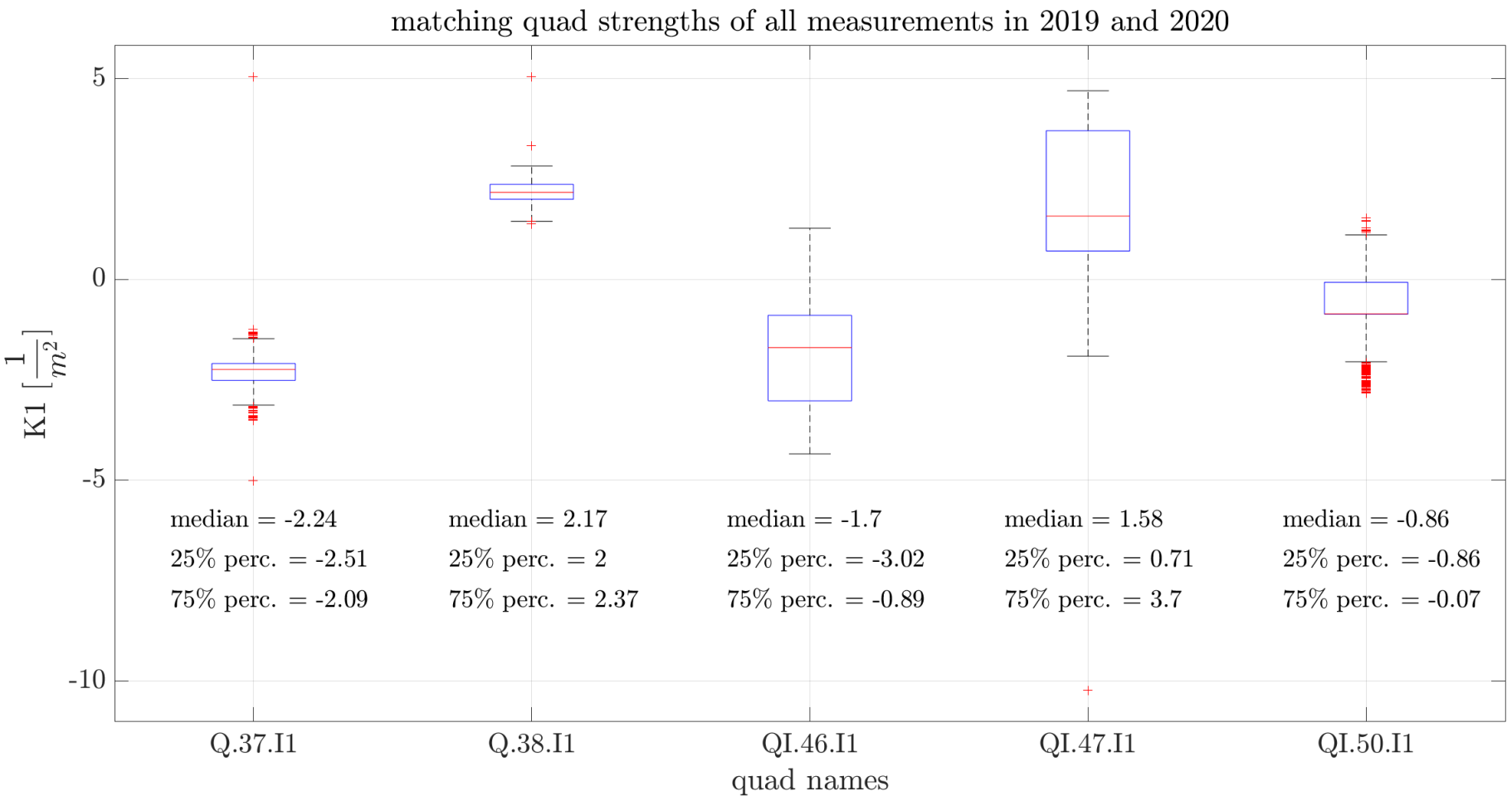
- 250 pC bunch charge
- Emittances smaller than 0.5 mm mrad
- Results from backtracking
- Only a few beta function trajectories are sufficient for good matching and small emittances.
- These results should/will be used as presets for future matching attempts.

Quad kick strength of all considered measurements



No additional constrains on the data

Quad kick strength of the good measurements

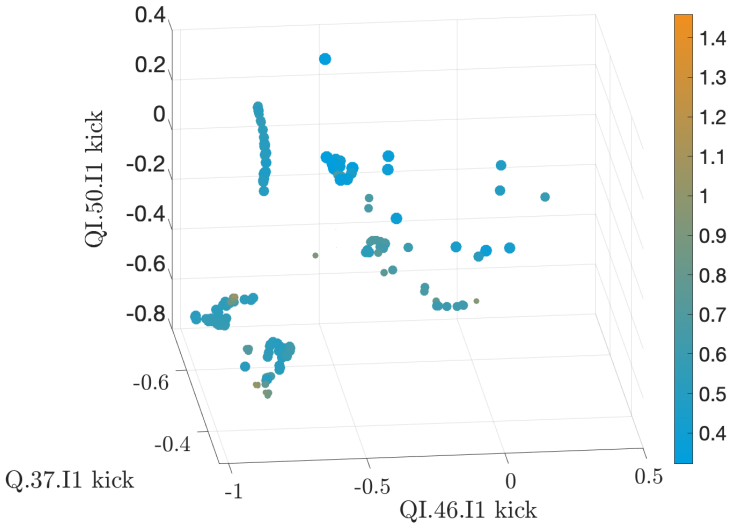


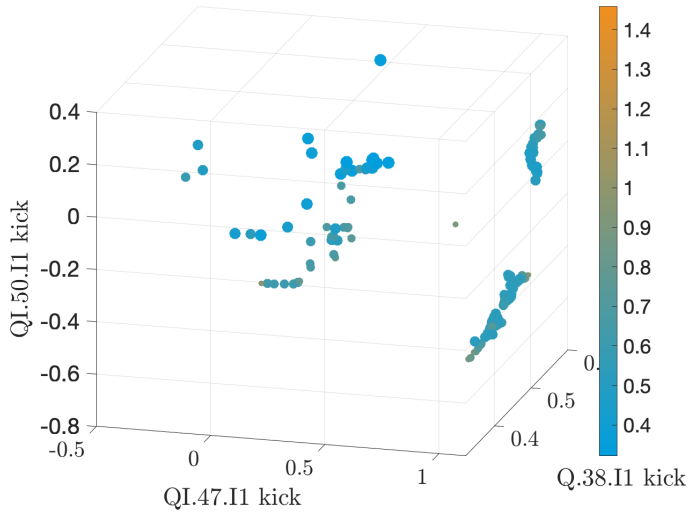
Additional data constrains:

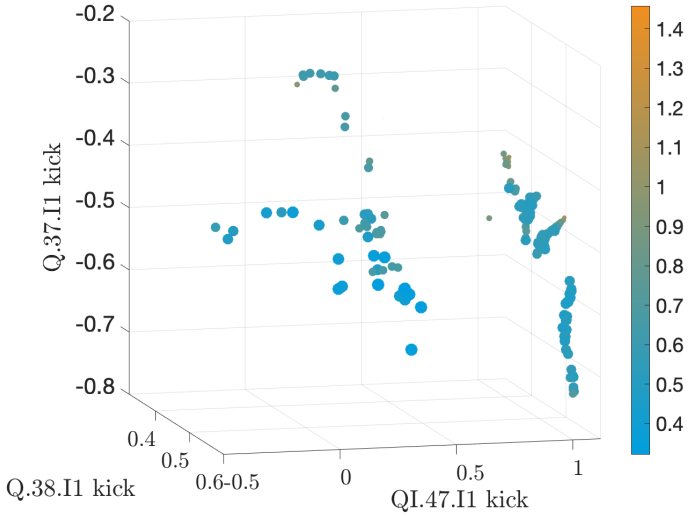
- 250 pC bunch charge
- Mismatch < 1.2 in both planes at the same time.
- Emittance < 0. 6mm mrad in both planes at the same time.
- On-crest measurements only
- 59 measurements in total
- Median kick strengths:

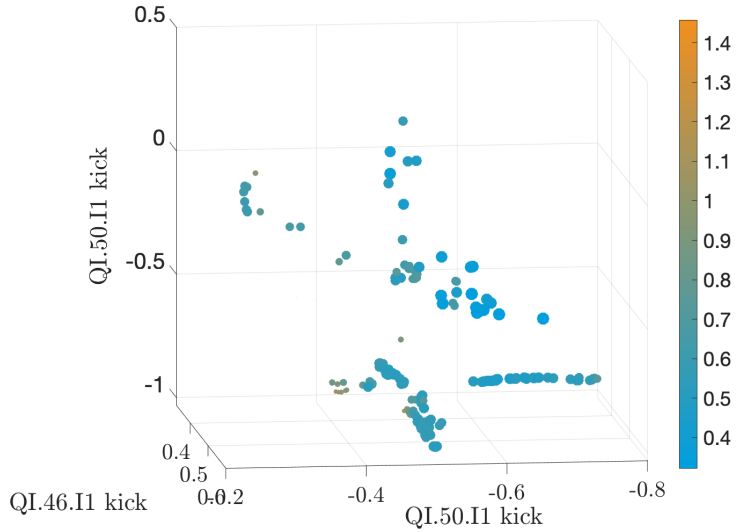
Q.37.I1: K1 = -2.75 1/m^2
Q.38.I1: K1 = 2.48 1/m^2
QI.46.I1. K1 = -3.05 1/m^2
QI.47.I1 K1 = 4.03 1/m^2
QI.50.I1 K1 = 0.07 1/m^2

Quad strengths of different matching solutions









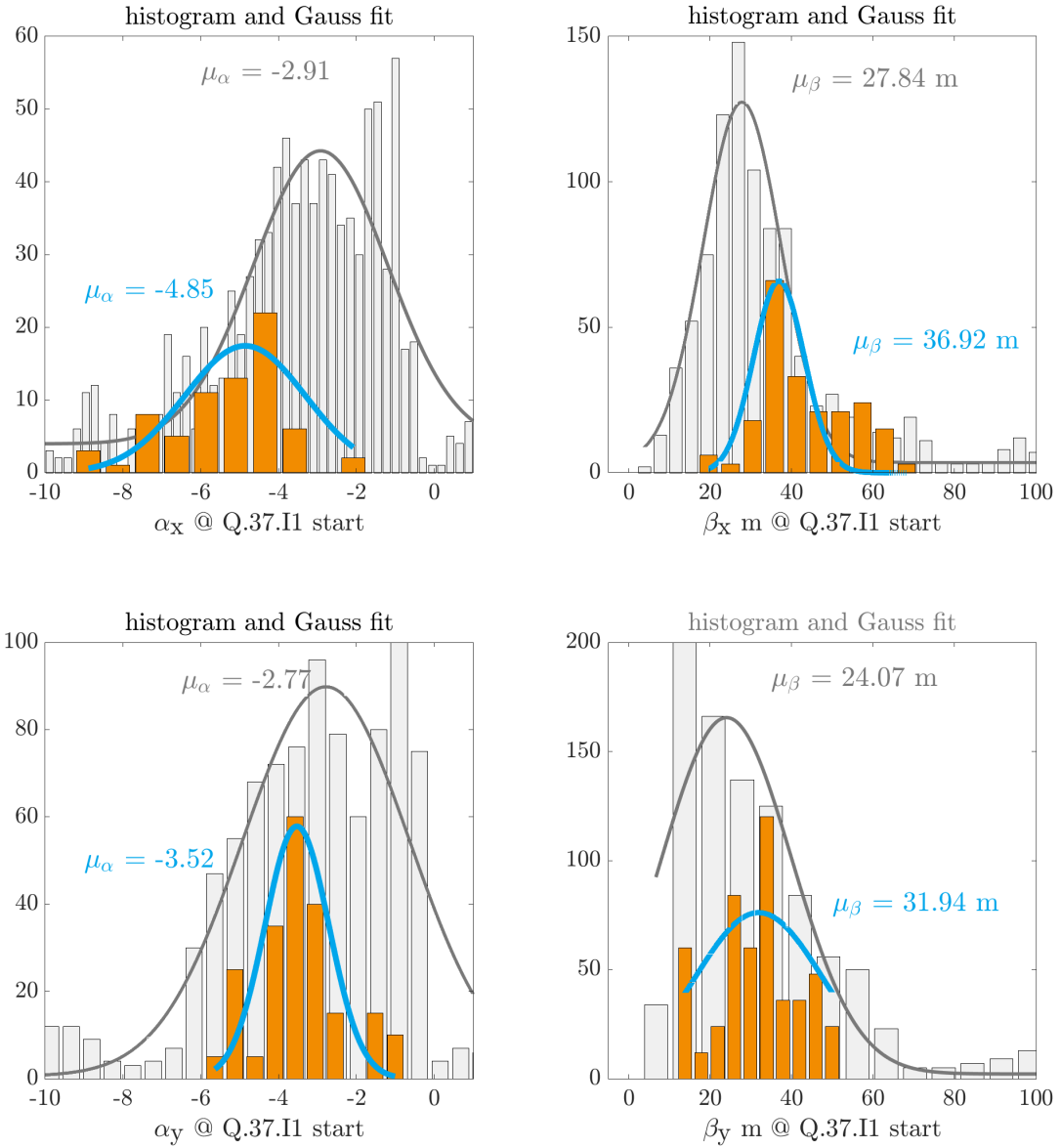
Additional data constrains:

- 250 pC bunch charge
- Mismatch < 1.2

- The color scale shows the mismatch of the respective measurement. The spot size transports the same information (bigger dot, better visible -> smaller mismatch)

- Some visible clusters/grouping of k-values. But less clear than I hoped.

Evaluation of Twiss parameters at Q.37.I1_start



Histograms of all Twiss parameters at the start of Q.37.I1

Additional data constrains:

- 250 pC bunch charge

- Grey bars: All considered measurements
- Orange bars: Bmag < 1.1 and emittance smaller than 0.45 mm mrad.
- Grey and blue lines: Gaussian fits

- Twiss parameters of the good measurements (orange bars, blue fits)
  - alpha_x = -2.91
  - beta_x = 27.84 m
  - alpha_y = -2.77
  - beta_y. = 24.07 m

- -> not perfectly symmetric but close.

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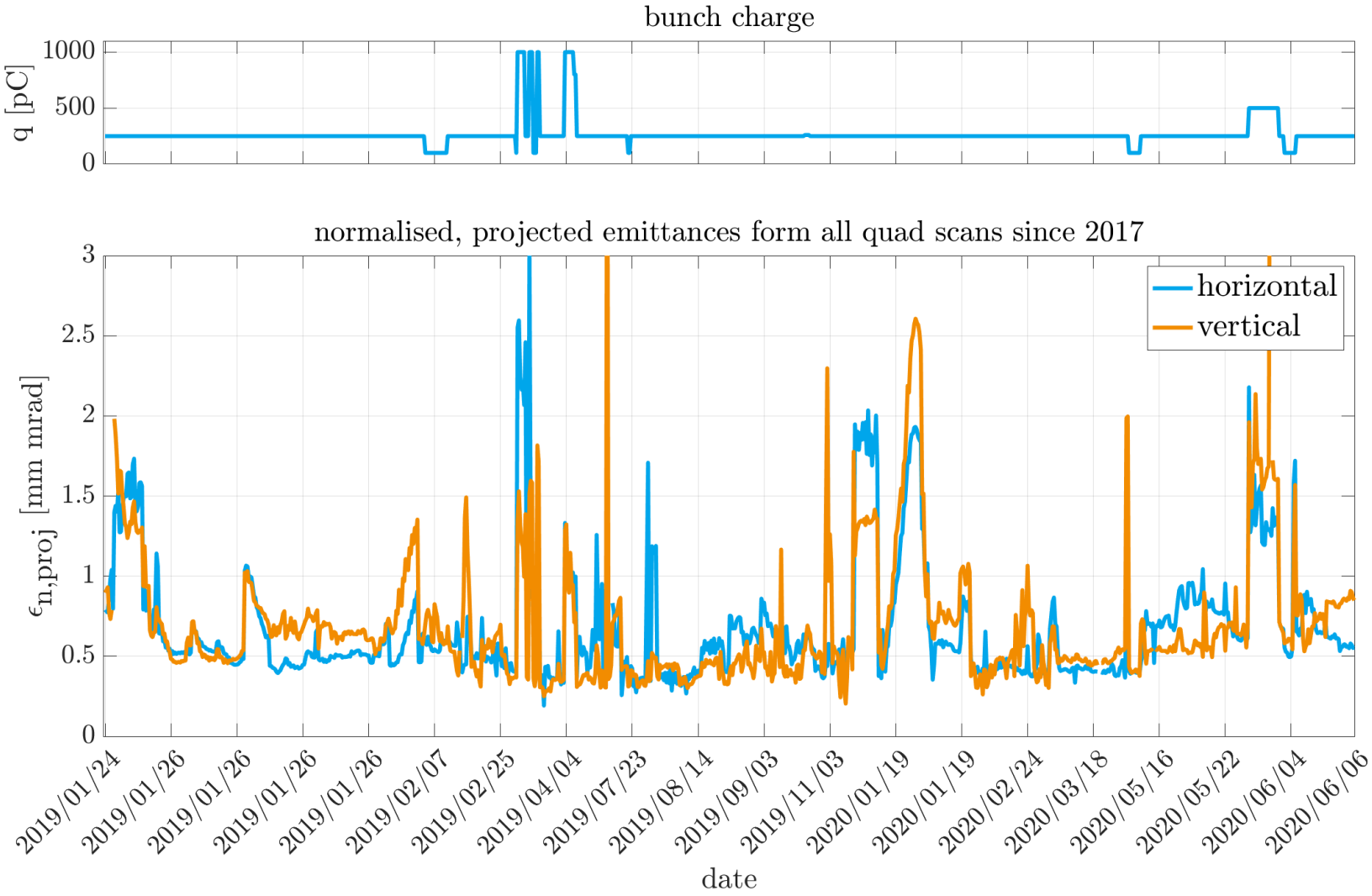
DESY

All emittances measured in the period



No additional thresholds

- In general, better emittances in 2019 compared to 2020 (new screens?).
- 100 pC emittances are not clearly smaller than the 250 pC emittances (Experience?). There seems to be improvement possible.

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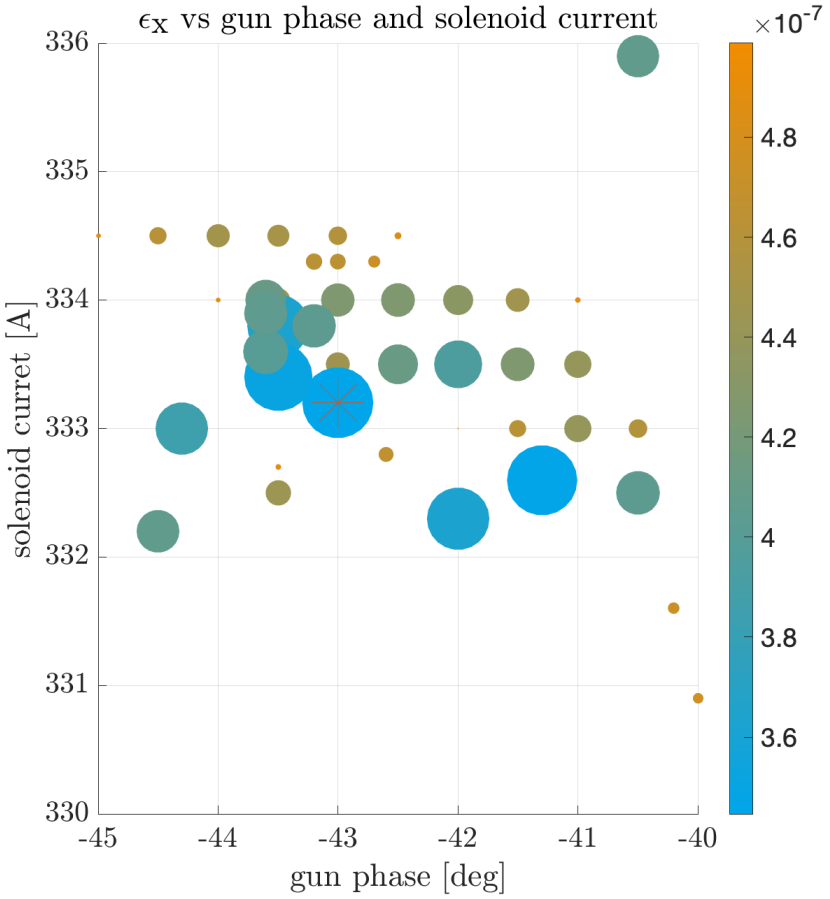
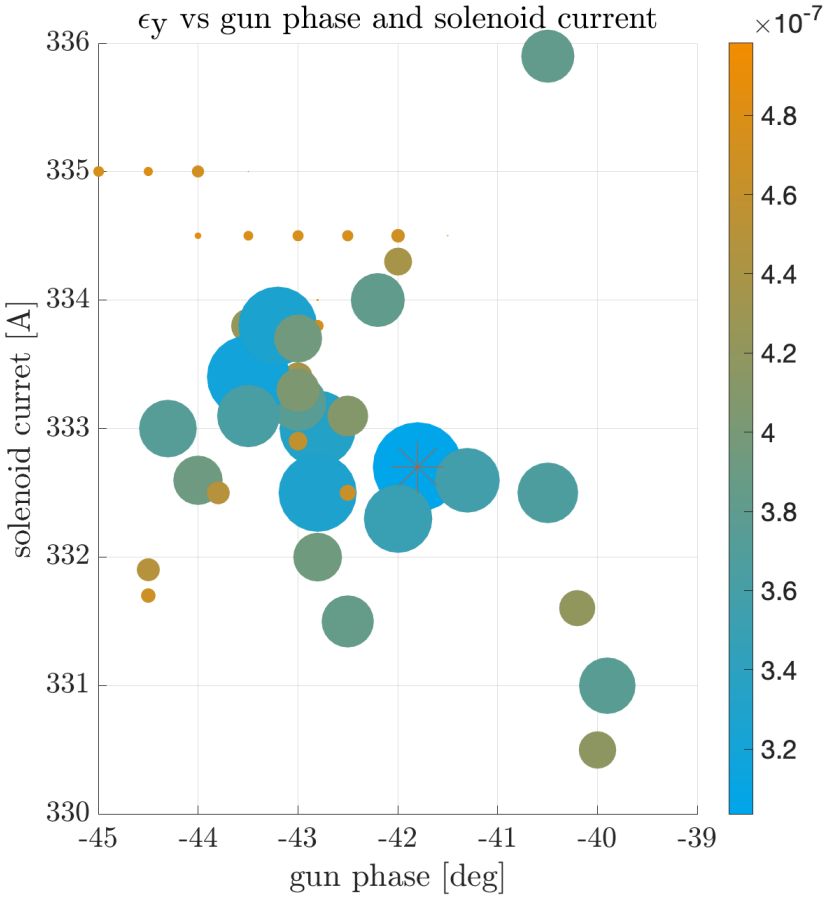
DESY

Emittance dependence on gun phase and main solenoid current





Additional data constrains:

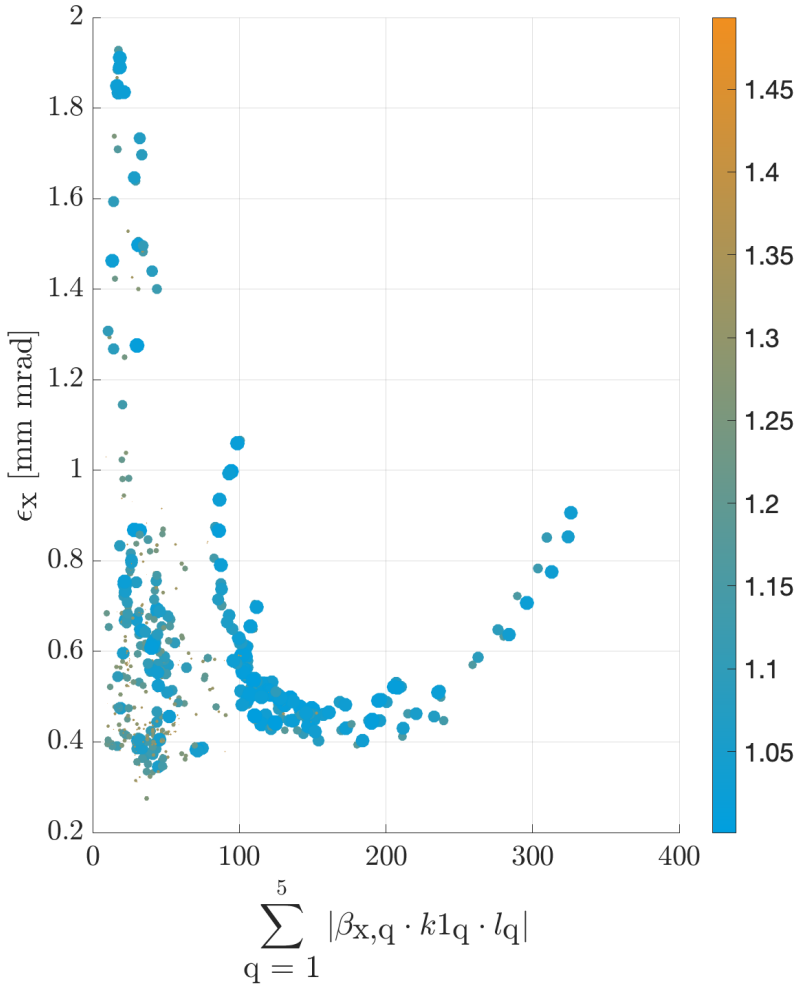
- 250 pC bunch charge
- Mismatch smaller than 1.2
- RF stations on-crest

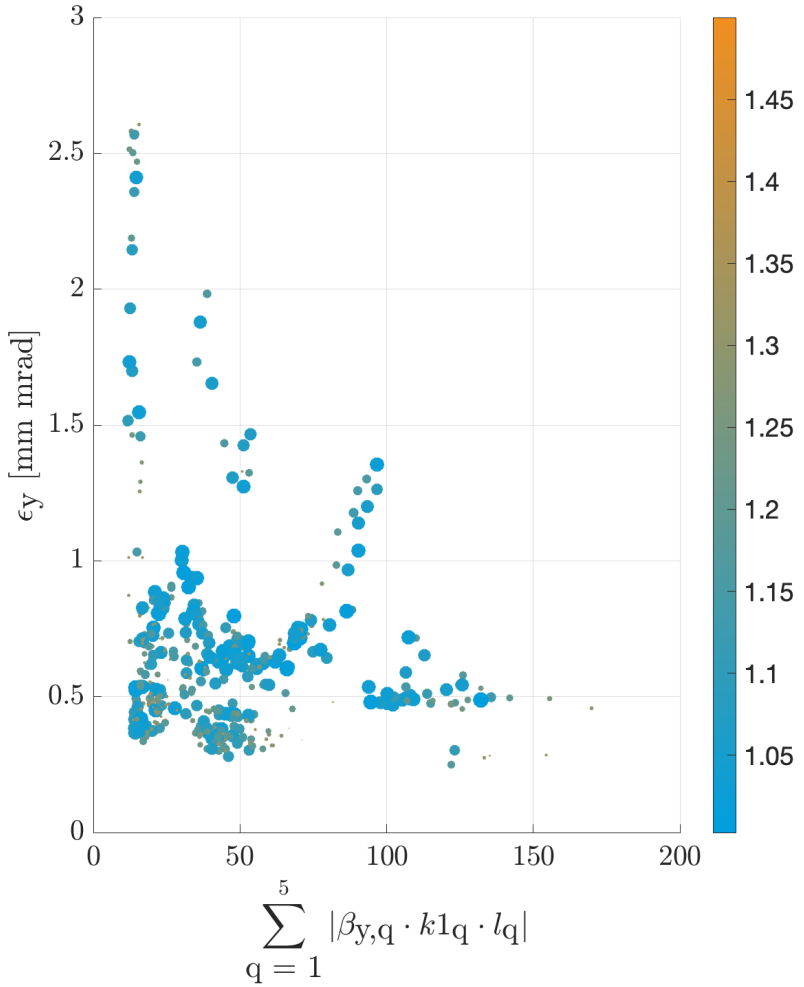
- Rounding of gun phase and solenoid current to one decimal point (data grouping).
- Selection of the best emittance of each pair (gun phase and solenoid current) individually for both planes.

- The color code as well as the dot sizes show the emittance size (bigger dot, better visible -> smaller emittance).

- No big surprises in this evaluation. Gun phase -43 degree and solenoid current 333 A.

Emittance dependence on large beta functions in strong quads

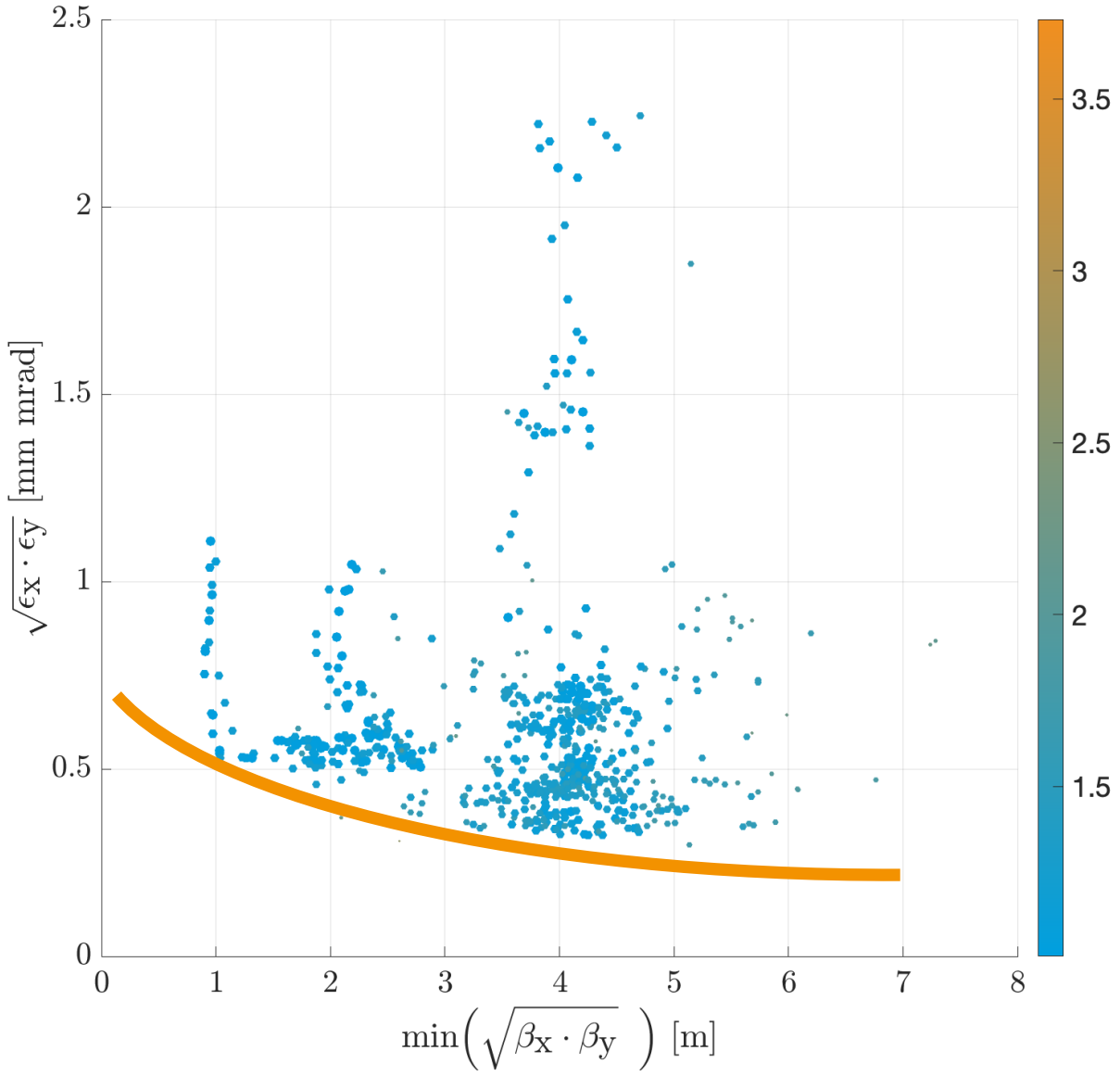




Additional data constrains:

- 250 pC bunch charge
- The color scale shows the mismatch of the respective measurement. The spot size transports the same information (bigger dot, better visible -> smaller mismatch)
- Hypothesis
  - Large sums -> chromatic effects
  - Small sums -> space charge
- Lets take out the quads in the next evaluation setp.

Emittance dependence on maximum charge density



Additional data constrains:

- 250 pC bunch charge
- The color scale shows the mismatch of the respective measurement. The spot size transports the same information (bigger dot, better visible -> smaller mismatch)
- On the horizontal axes we see minimum of the product of both beta functions between the first quad and the optics reference position.
- It looks like we get increasing emittances for beams with too small diameters.

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DESY

Summary

- Data evaluation is ongoing. Next step -> evaluate data from the end of 2020.
- The scripts can be used in the future to redo the same evaluations again for new measurements.

- We found restrictions for max and min beta functions that have to be considered if small emittances should be achieved.
- The findings will be used in an updated matching routine.
- A set of Twiss parameters at the start of the XFEL lattice could be determined that can be used in future simulations.

- Further suggestion for additional evaluations?

Thanks for you attention!

Quad's momentum set point correction